DIS 2011

XIX International Workshop on Deep Inelastic Scattering and Related Subjects

April 11-15th 2011
Marriott at City Center
Newport News, Virginia

TOPICS:

- Structure Functions and Parton Densities
- Small-x, Diffraction and Vector Mesons
- Electroweak Physics and Beyond the Standard Model
- QCD and Hadronic Final States
- Heavy Flavours
- Spin Physics
- Future of DIS

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http://conferences.jlab.org/dis2011

WG5: Heavy Flavours

Olaf Behnke (DESY)
Alan Dion (BNL)
Fred Olness (SMU)

XIX International Workshop on Deep-Inelastic Scattering and Related Subjects (DIS 2011)

April 11-15, 2011

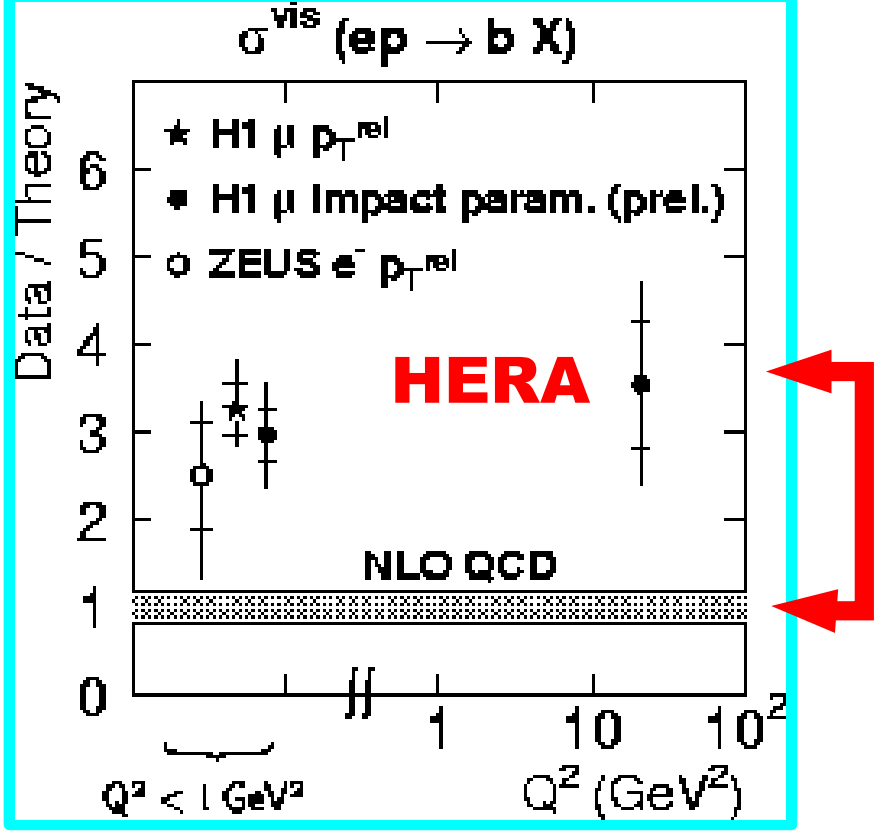
Jefferson Lab

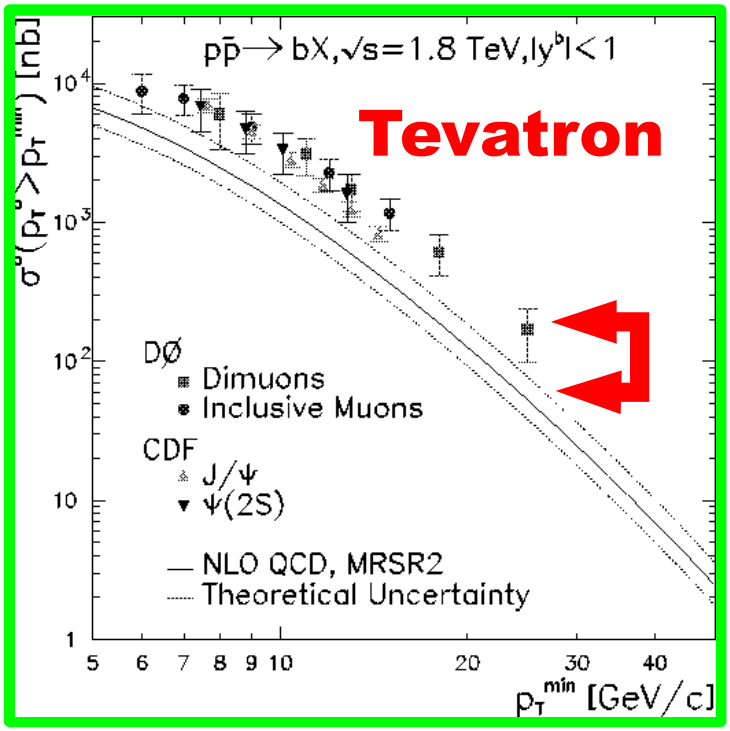
Newport News, VA USA

Busch GARDENS.
WILLIAMSBURG, VA

A few years later ...

Problems with Gangsters
& Heavy Quark Production





Progress Report

How have we done
over the last decade???

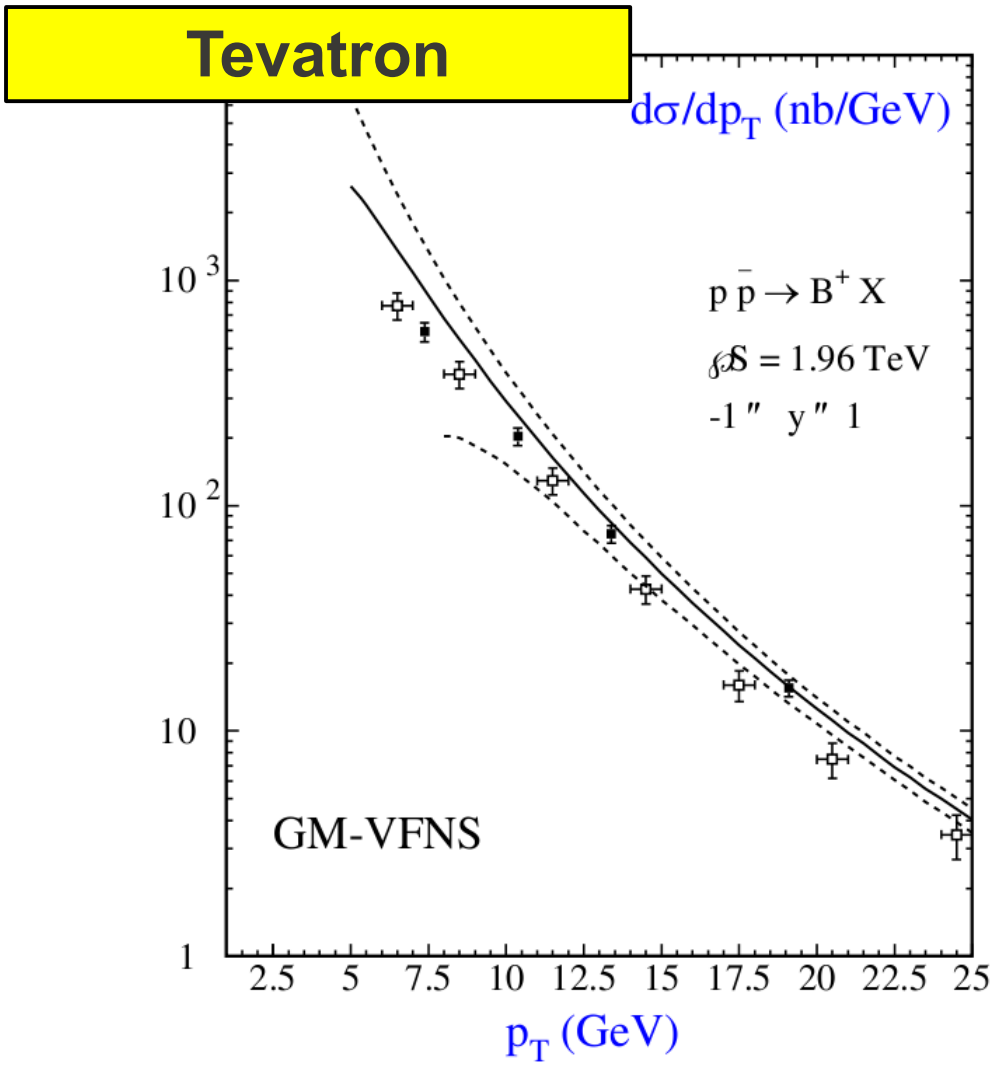
Selected Results:

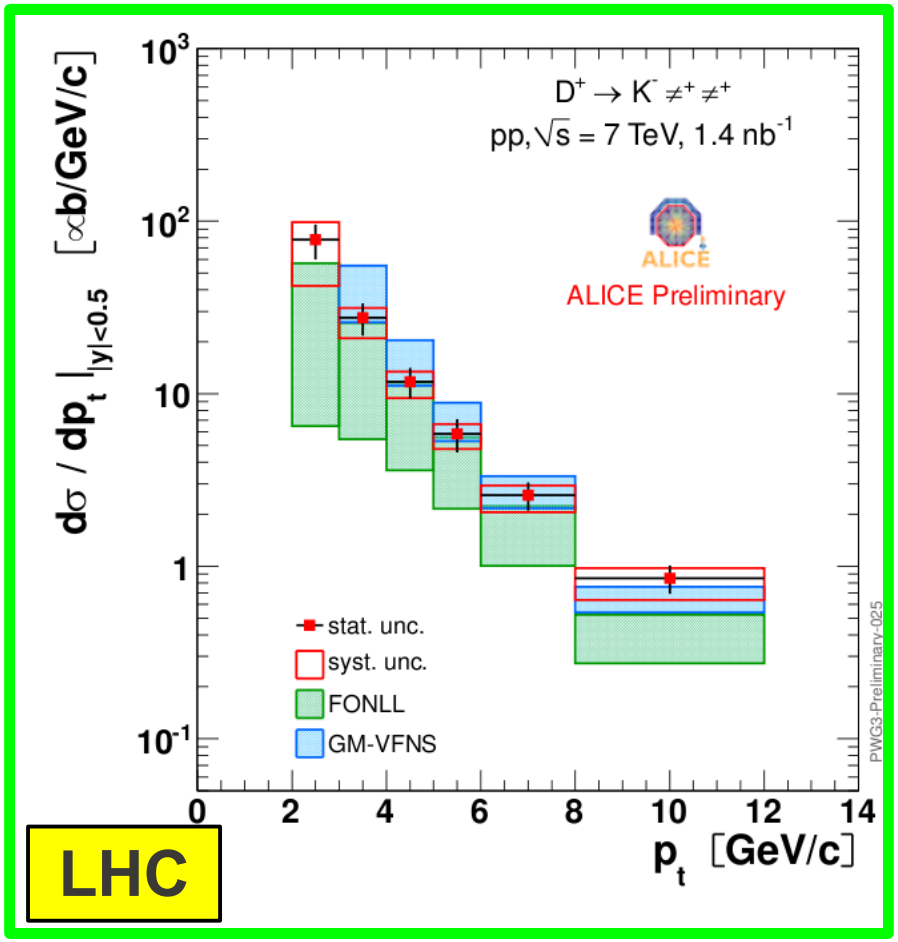
This cannot possibly be a comprehensive summary

GM-VFNS PREDICTION VS. CDF II [1,2]

Bernd Kniehl

Tevatron



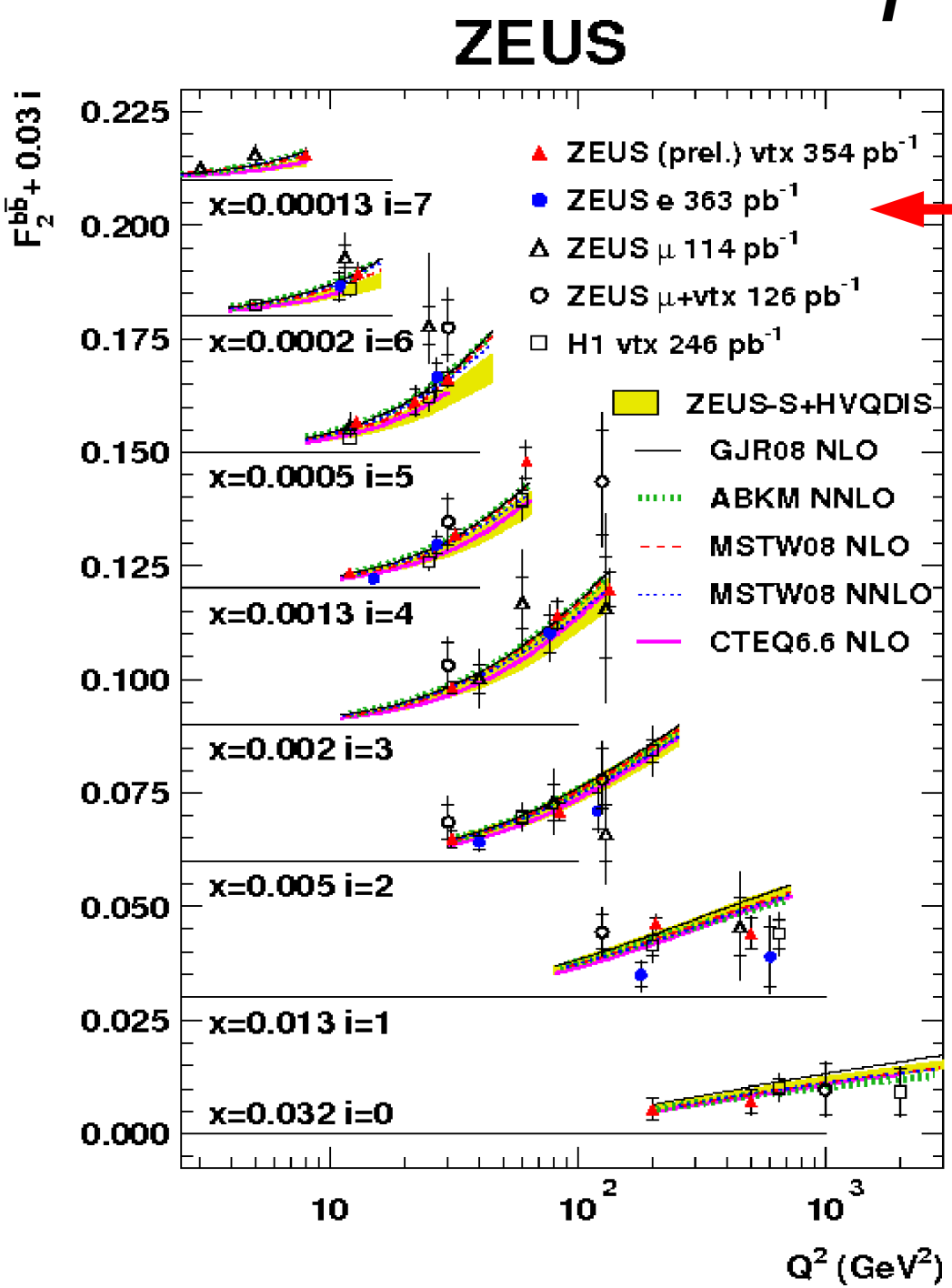


GM-VFNS
-Reduces to MS-bar
- No "parameters"
- Good agreement w/ C & B

[1] CDF, PRD71(2005)032001

[2] CDF, PRD75(2007)012010

$F_2^{b\bar{b}}$



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Ramoona Shehzadi

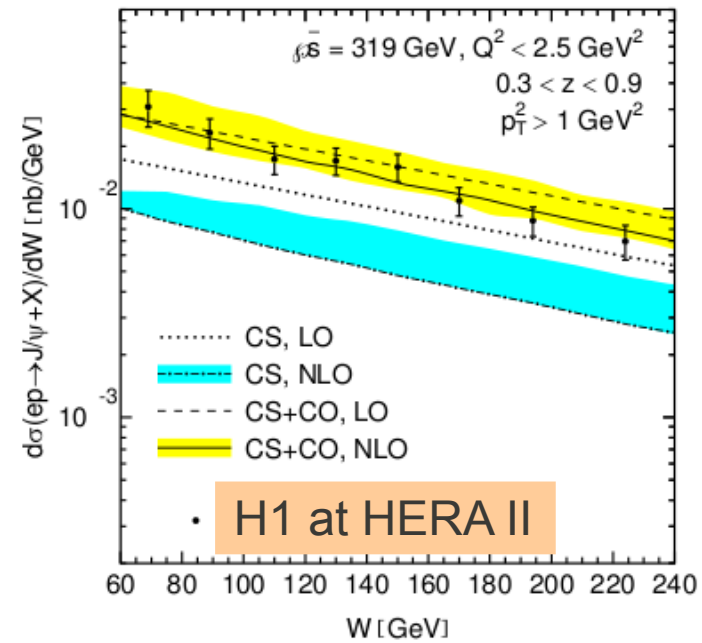
HF prod in DIS
electron channel

Vladyslav Libov

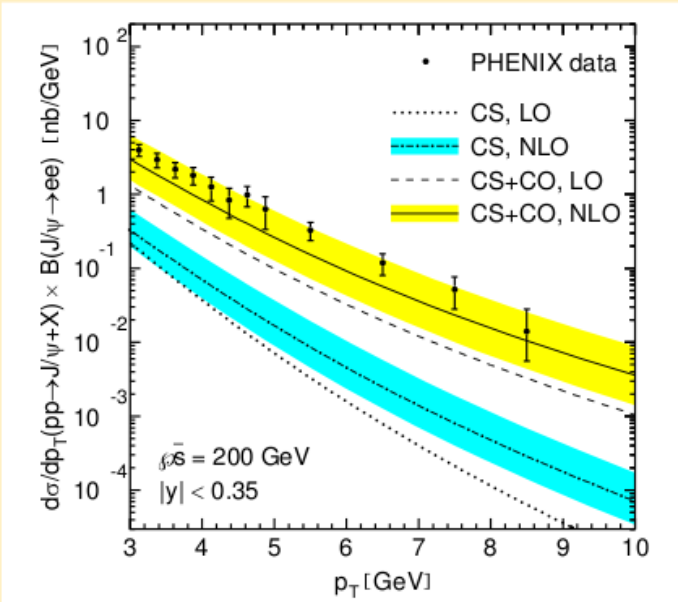
HF prod in DIS w/ inclusive
secondary vertex

Bernd Kniehl

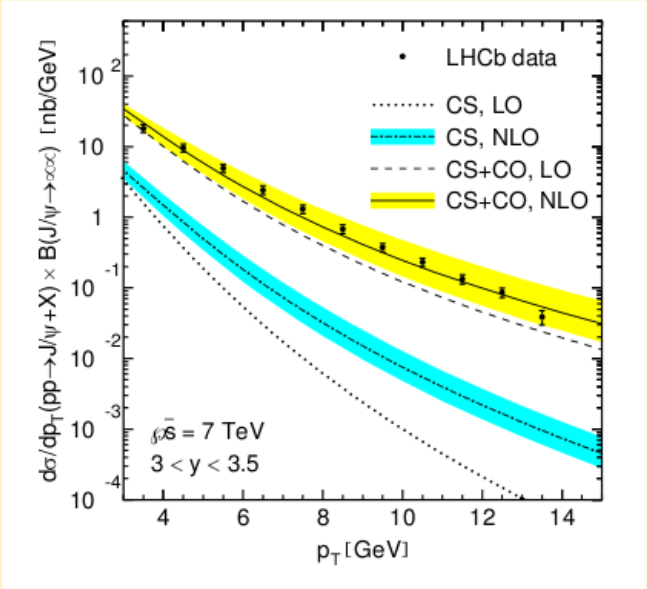
New global analysis of unpolarized J/Psi at NLO in NRQCD



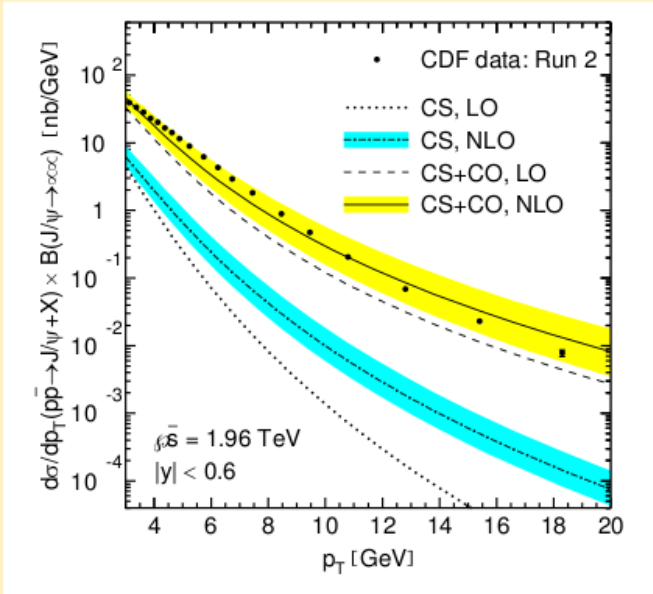
RHIC
PHENIX



LHCb
$3.0 < y < 3.5$



Tevatron II
CDF



Nikolai Zotov

B-quark, B-jet, & quarkonia production at the LHC

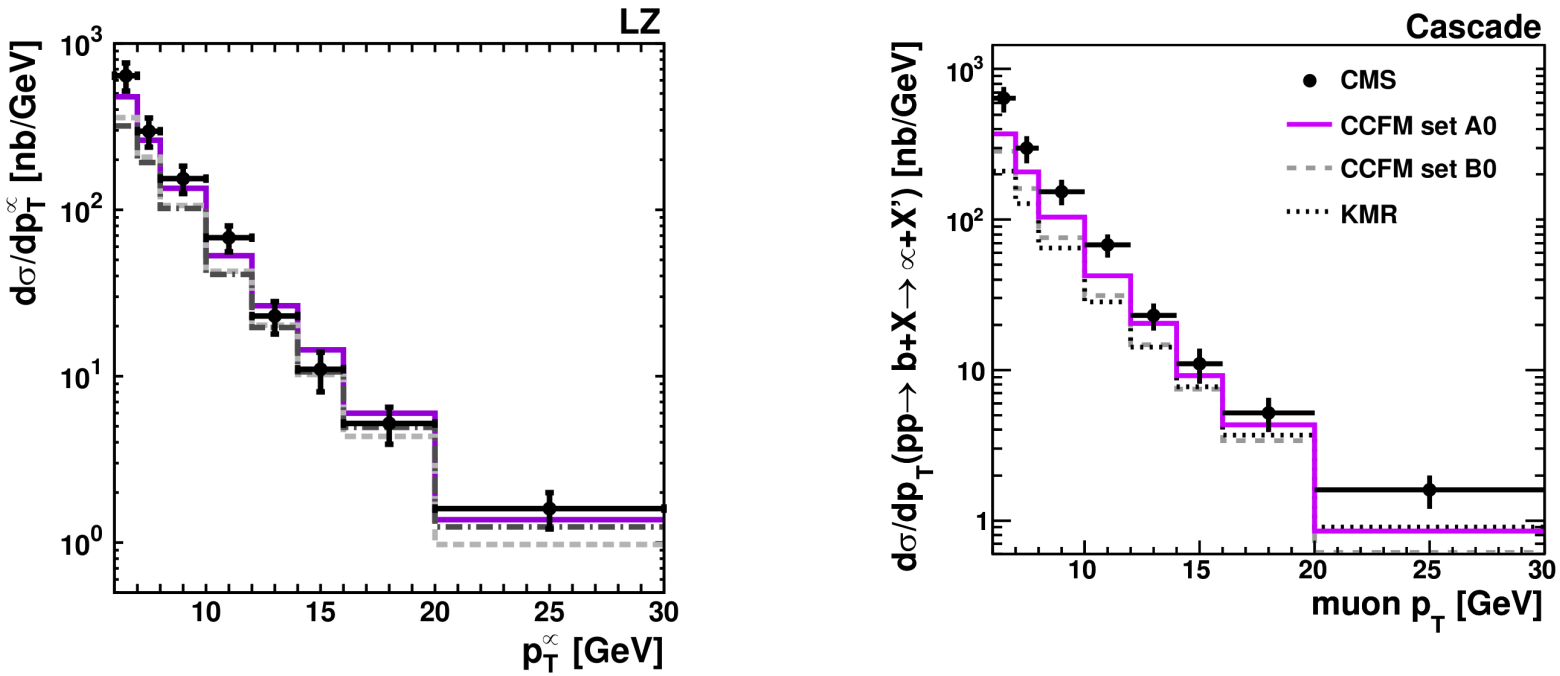


Figure 2: The transverse momentum distributions of muons arising from the semileptonic decays of beauty quarks. The first column shows the LZ numerical results while the second one depicts the CASCADE predictions. Notation of all histograms is the same as in Fig. 2. The experimental data are from CMS.

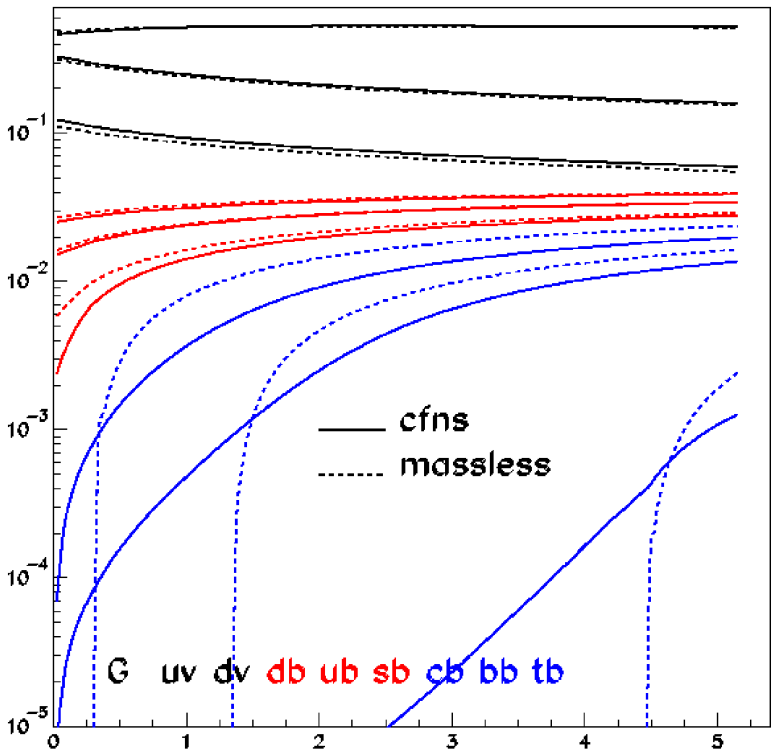
KT Factorization
Un-integrated PDFs
CASCADE code

Sample comparison shown for Beauty w/ CMS data

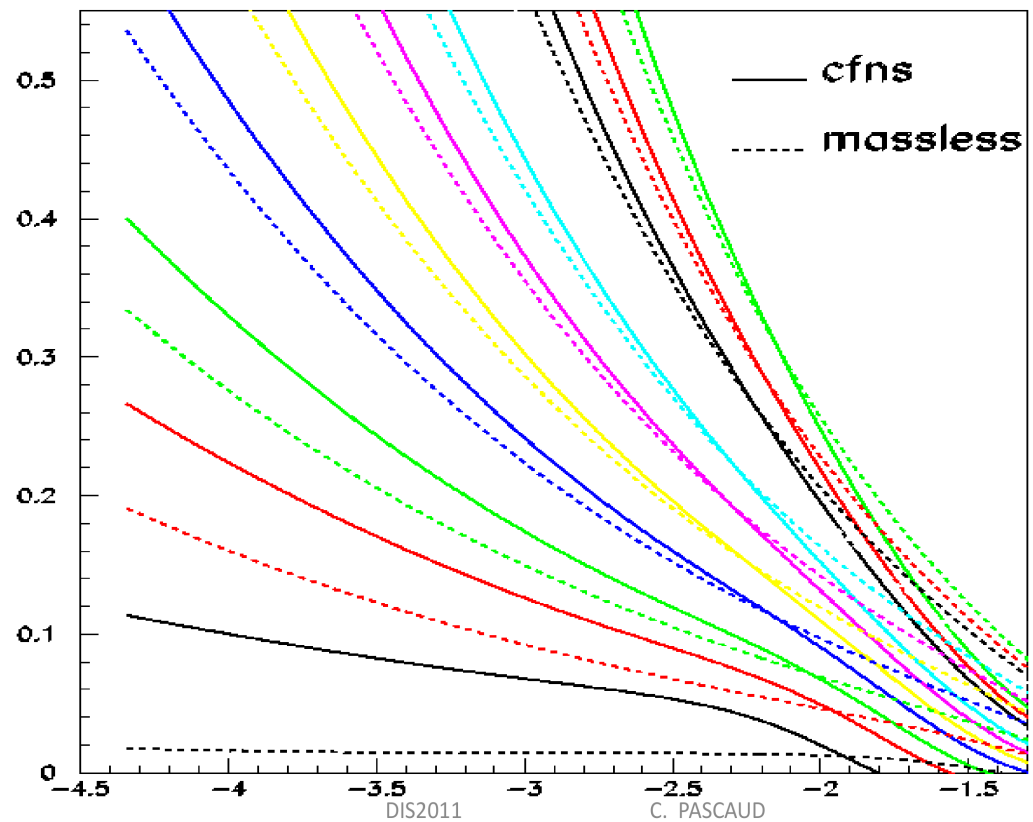
New Theoretical Developments

New scheme: HQ in DIS

Parton momemtum fractions



F2cc for 2 4 6.5 12 20 35 60 ...G

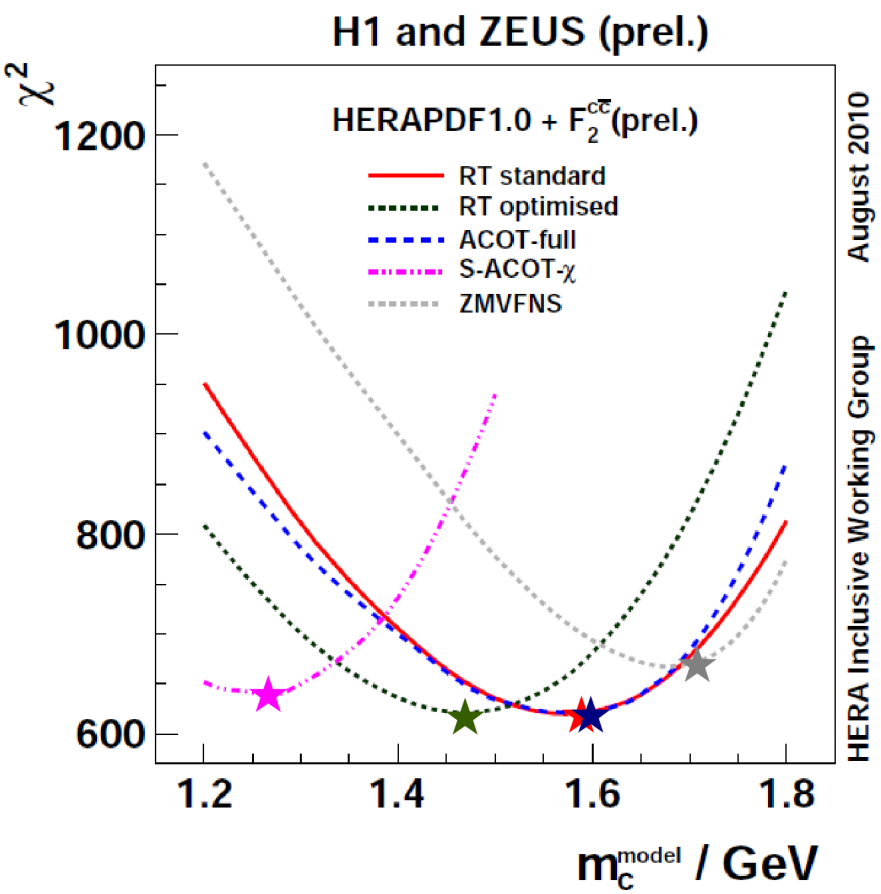


The role of the quark masses

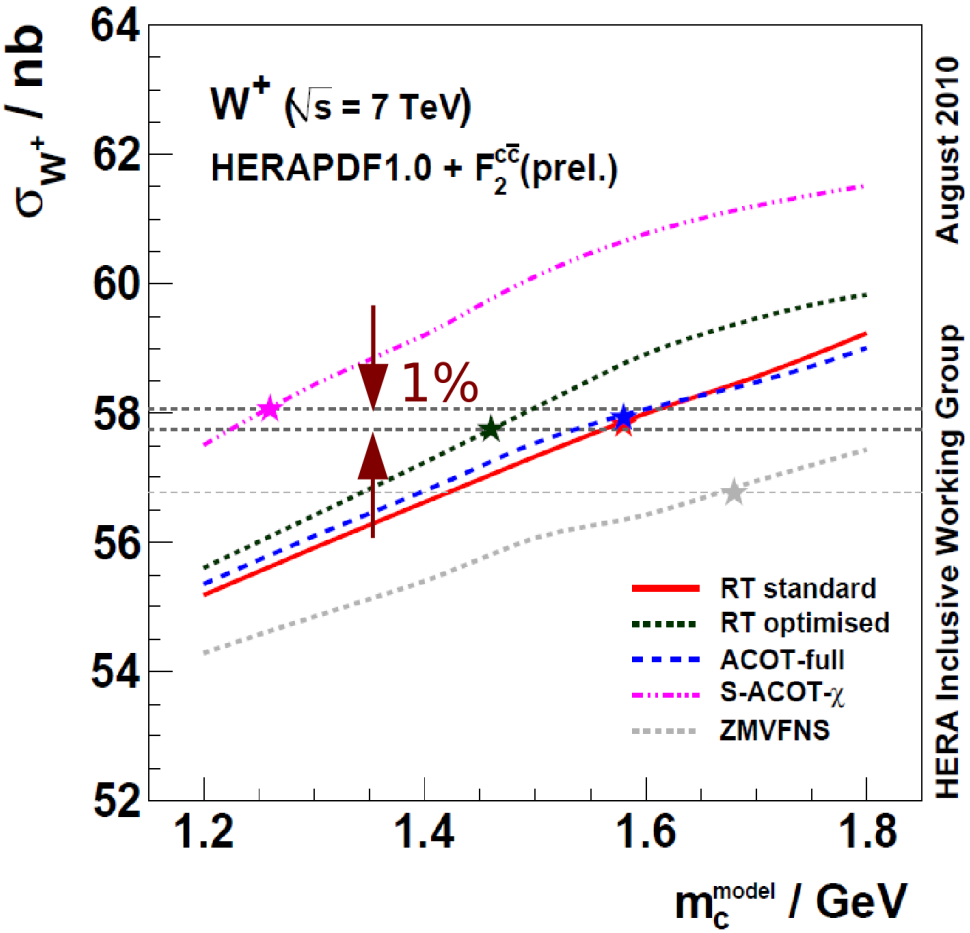
Constraints on PDFs from HERA Charm Data

Ringaile Placakyte

Inclusive ep data + F_2^{cc} for different HQ schemes



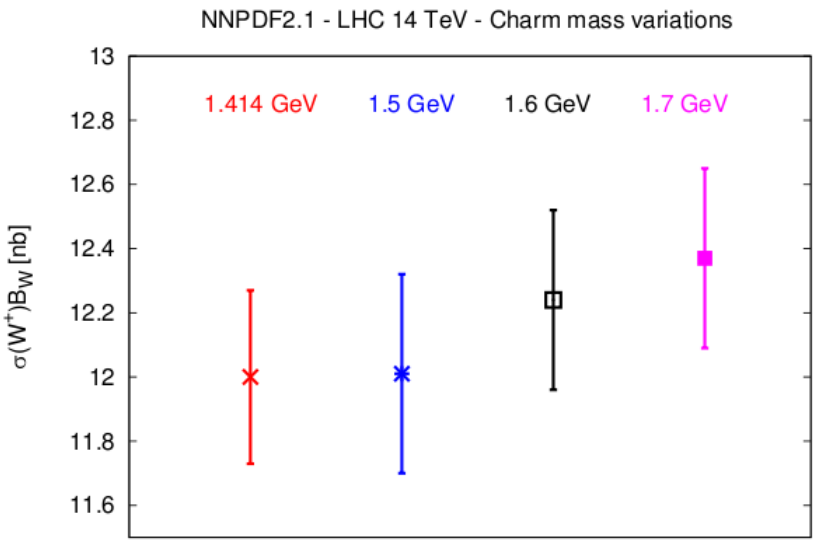
Impact of mc on W σ at LHC

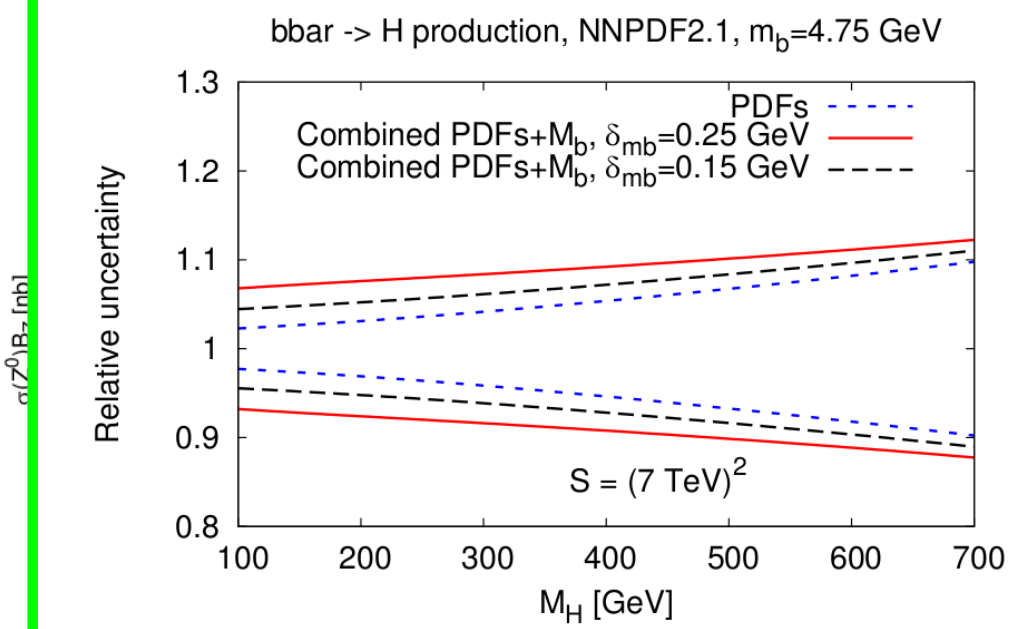


Different HQ schemes have different optimal m_c^{model}

Impact of HQ Masses on PDFs and LHC Phenomenology

Dependence on m_c





- The W/Z cross sections increase with the m_c used in the PDF fit
  δ_{m_c} is an intrinsic parametric uncertainty of the theory
- At 7 TeV, variations in range $m_c \in [1.4, 1.7]$ GeV at most $\lesssim$ 1–sigma shift
- At 14 TeV somewhat larger effects
- With the m_c varying NNPDF2.1 sets $\rightarrow$ Compute exact PDF+m_c uncertainty

At NLO pole and MSbar defitions equivalent
At NNLO theo uncertainties reduced using MSbar mass in GM-VFN structure functions

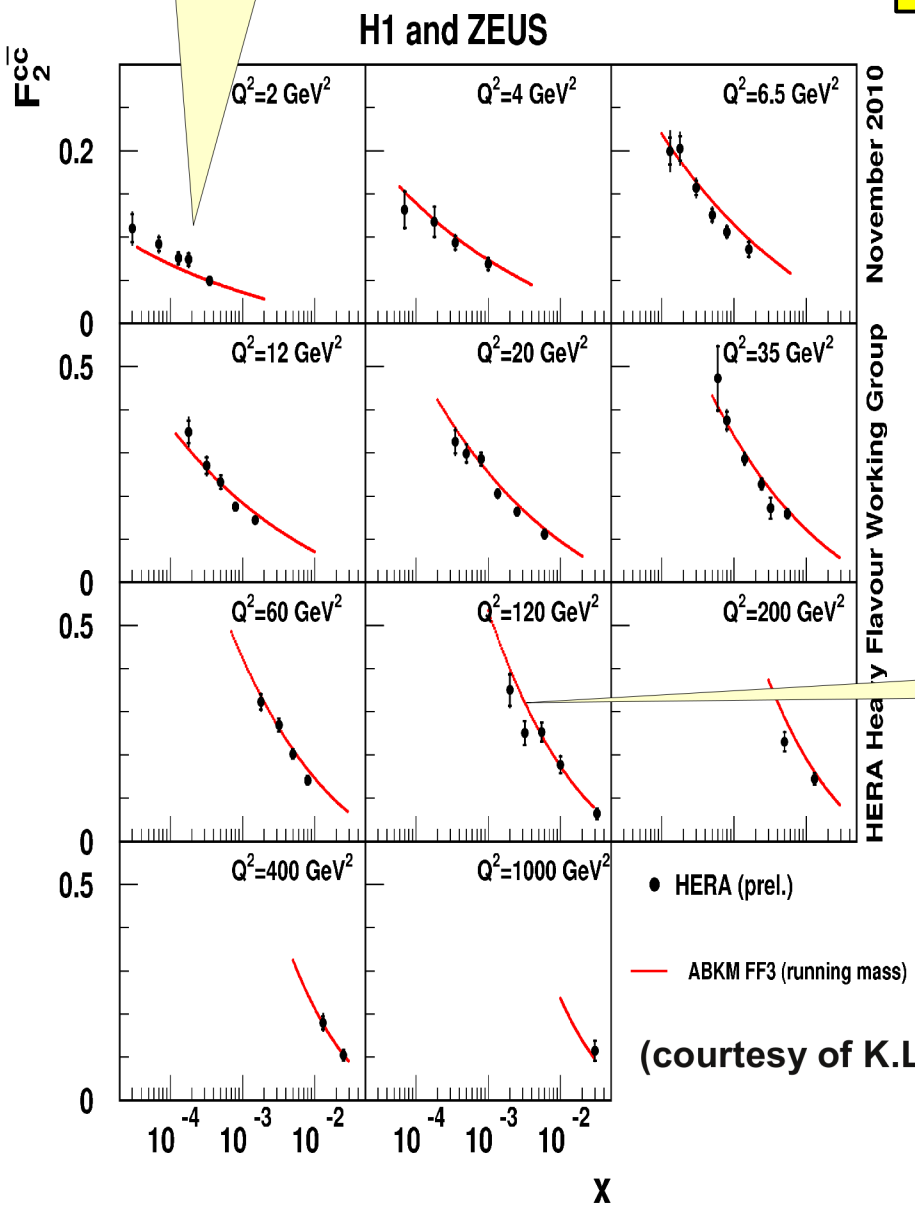
(Alekhin and Moch, arXiv:1011.5790)

Sergey Alekhin

c-quark production

The NNLO(approx.) FFNS ABM ***predictions*** based on the running mass definition are In nice agreement with the new HERA data

N^{3}LO corrections?



(courtesy of K.Lipka)

Impact of running quark mass for DIS

$m_c(m_c)$=1.18±0.06 GeV (incl.F_2 +PDG)

The HERA data prefer $m_c(m_c)$ close to the PDG value

Improved accuracy due to correlation between quark and gluon PDFs must be reduced

No need for the VFN scheme

At $Q >> m_c$ first Mellin NNLO moments are known

Ablinger at al. NPB 844, 26 (2011)

Bierenbaum, Blümlein, Klein NPB 829, 417 (2009)

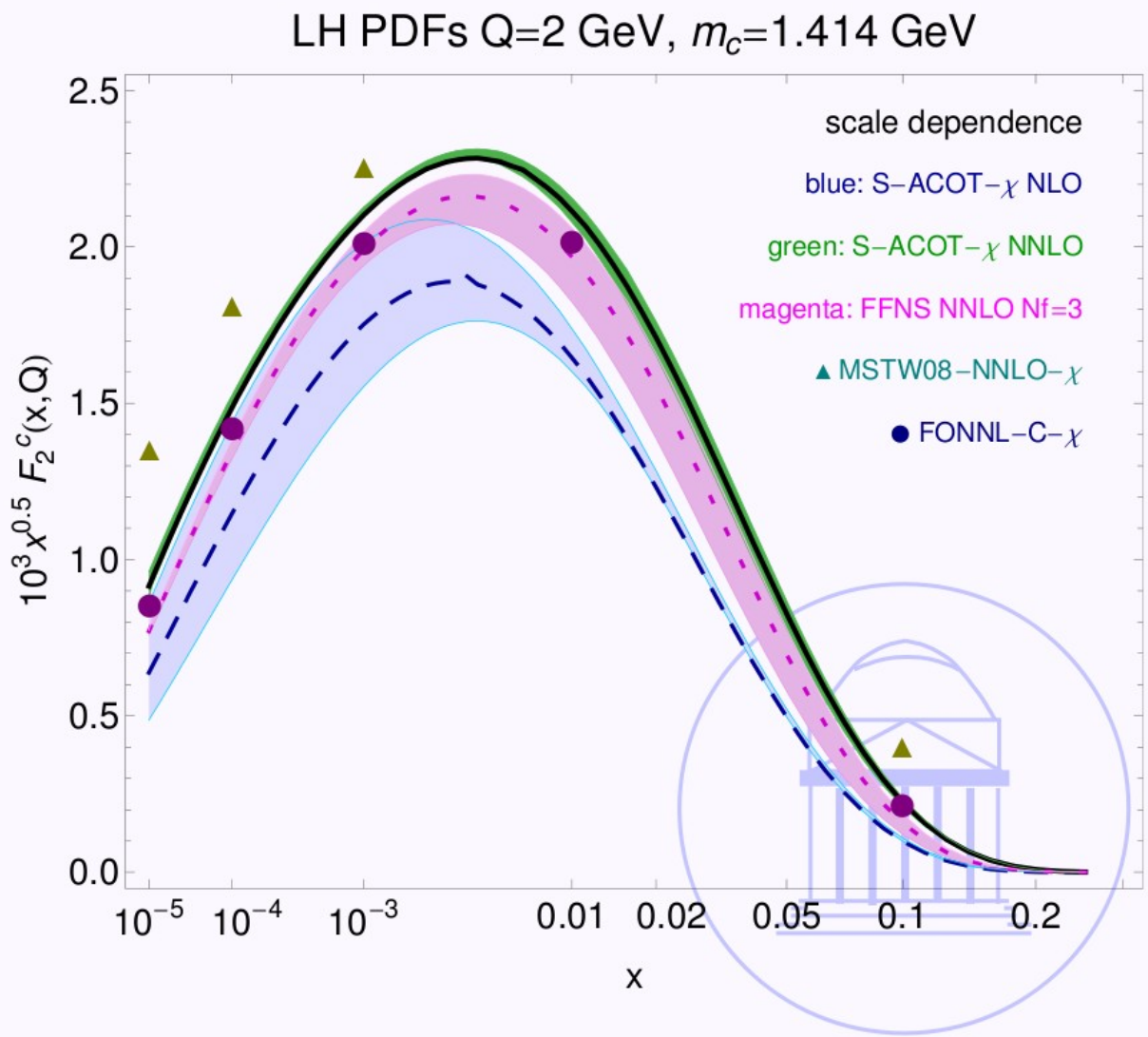
On to higher orders ...

Results for $F_2^c(x, Q^2)$ at NLO/NNLO - Preliminary

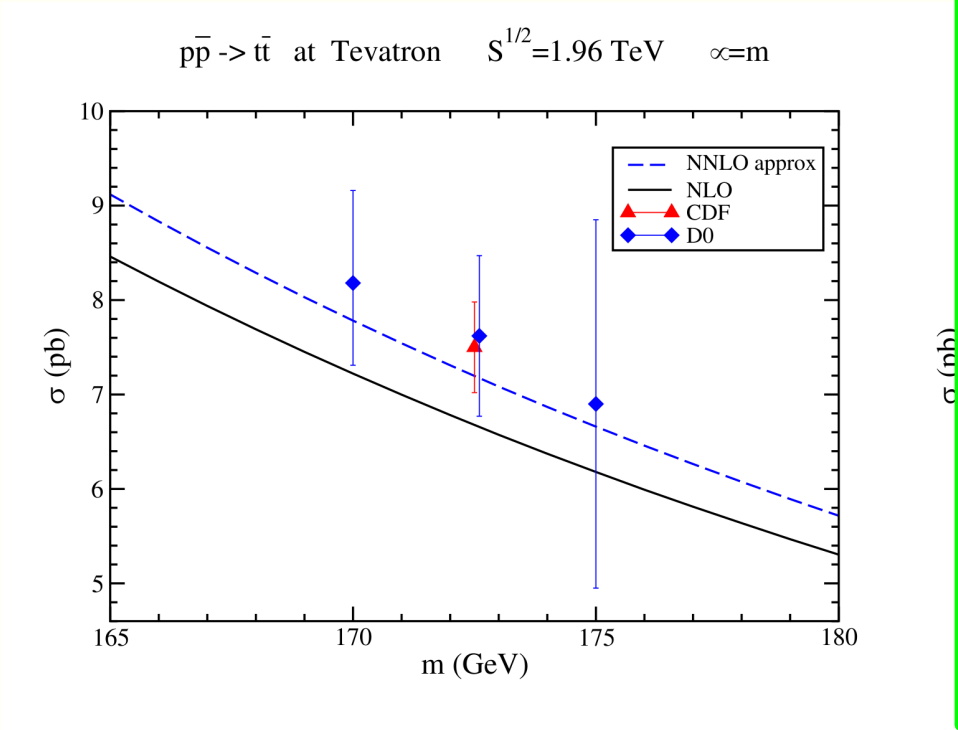
NNLO contributions to HF in S-ACOT Scheme

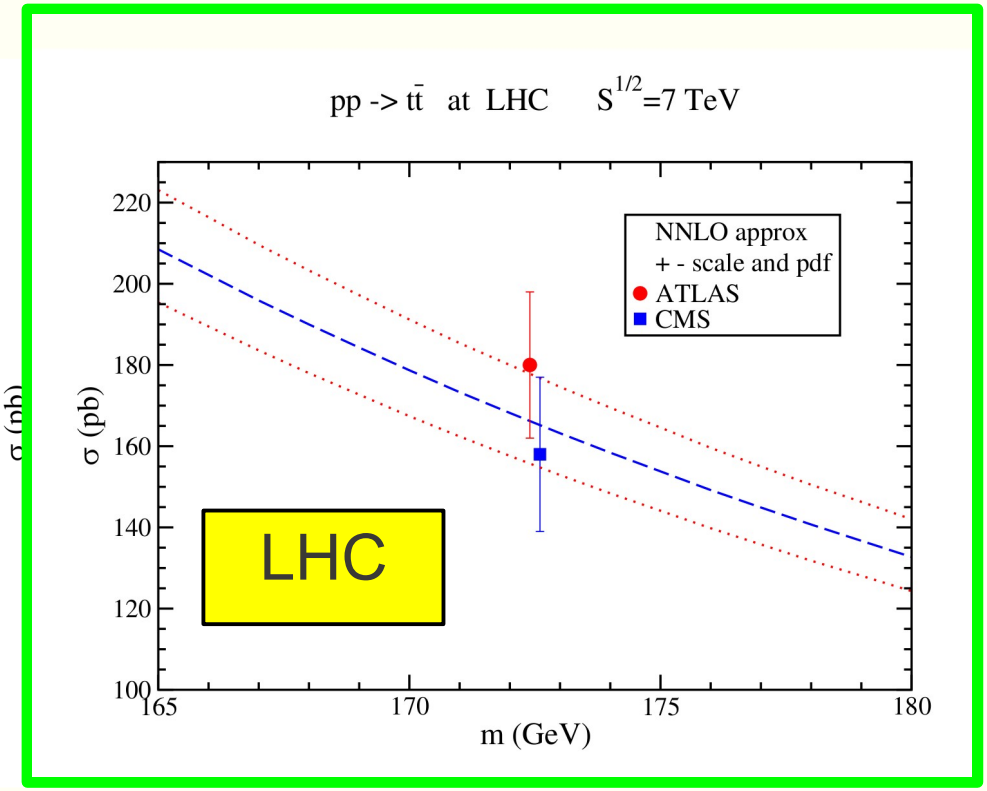
At NNLO and $Q \approx m_c$:

- S-ACOT-$\chi \approx$ FFN$(N_f = 3)$ without tuning
- It is close to other NNLO schemes
- S-ACOT-χ predictions are for a physically motivated rescaling variable $\zeta = x(1 + 4m_c^2/Q^2)$. Dependence on the form of ζ is also reduced



$t\bar{t}$ cross section at the Tevatron





$$\sigma_{t\bar{t}}^{\mathrm{NNLOapprox}}(m_t = 173\,\mathrm{GeV},\, 1.96\,\mathrm{TeV}) \quad = \quad 7.08^{+0.00\,+0.36}_{-0.24\,-0.27}\ \mathrm{pb}$$

scale pdf

NNLO approx: 7.8% enhancement over NLO

used MSTW 2008 NNLO pdf

Fabian Wissbrock

3-loop Corrections for F2CC

Beispiel-Diagramm D_{872}

$$
\begin{aligned}
D_{872} \;=\; & C_A T_F^2 \Bigg[\Bigg\{ \delta(N-2)\,[\cdots] + \delta(N-3)\,[\cdots] + \delta(N-4)\,[\cdots] \\
& + \theta(N-5) \Bigg[\frac{1}{\varepsilon^3} \frac{256(N-3)(2N^2+N-4)}{9N^2(N+1)^2} - \frac{1}{\varepsilon^2} \Bigg\{ \frac{64(2N^5+33N^4-13N^3+87N^2-28}{(N-1)N^2(N+1)^2(N+2)} \\
& + \frac{64(N-3)(2N^2+N-4)}{3N^2(N+1)^2} \ln(x) \Bigg\} + \frac{1}{\varepsilon} \Bigg\{ \frac{32Q_1}{81(N-1)^2N^4(N+1)^4(2+N)^2} \\
& + \frac{32(N-3)(2N^2+N-4)}{3N^2(N+1)^2} \left(\zeta_2 + S_2 + \ln^2(x)\right) \Bigg\} + \frac{8Q_2}{243(N-1)^3N^4(N+1)^5(N+2)^3} \\
& - \frac{8(2N^5+33N^4-13N^3+87N^2-283N+354)}{9(N-1)N^2(N+1)^2(N+2)} \zeta_2 \\
& - \frac{8(N-3)(2N^2+N-4)}{9N^2(N+1)^2} (4\zeta_3 + 9\zeta_2 + 6S_2 + 12S_3) \\
& + \frac{4Q_3}{225(N-2)(N-1)^2N^3(N+1)^3(N+2)(N+3)^2(N+4)^2} x \\
& + \frac{Q_4}{7350(N-3)^2(N-2)^2(N-1)N(N+1)^3(N+2)^3(N+3)^3(N+4)^3(N+5)^3(N+6)} \\
& + \frac{2Q_5}{893025(N-4)^2(N-3)(N-2)(N-1)N(N+1)^2(N+2)^2(N+3)^3(N+4)^3(N+5)} \\
& - \frac{8(2N^5+33N^4-13N^3+87N^2-283N+354)}{9(N-1)N^2(N+1)^2(N+2)} \ln^2(x) \\
& + \frac{4Q_6}{(N+1)(N+2)(N+3)(N+4)(N+5)(N+6)} x^2 \ln^2(x) + \frac{32Q}{9(N+3)(N+4)(N+5)(} \\
& + \frac{32(N-3)(2N^2+N-4)}{9N^2(N+1)^2} \ln^3(x) - \frac{8Q_8}{9(N-1)N^3(N+1)^3(N+2)} S_2 \\
& + \frac{8Q_6}{(N+1)(N+2)(N+3)(N+4)(N+5)(N+6)} S_2 x^2 + \frac{64Q_7}{9(N+3)(N+4)(N+5)(N+6)(N+7)(N+8)}
\end{aligned}
$$

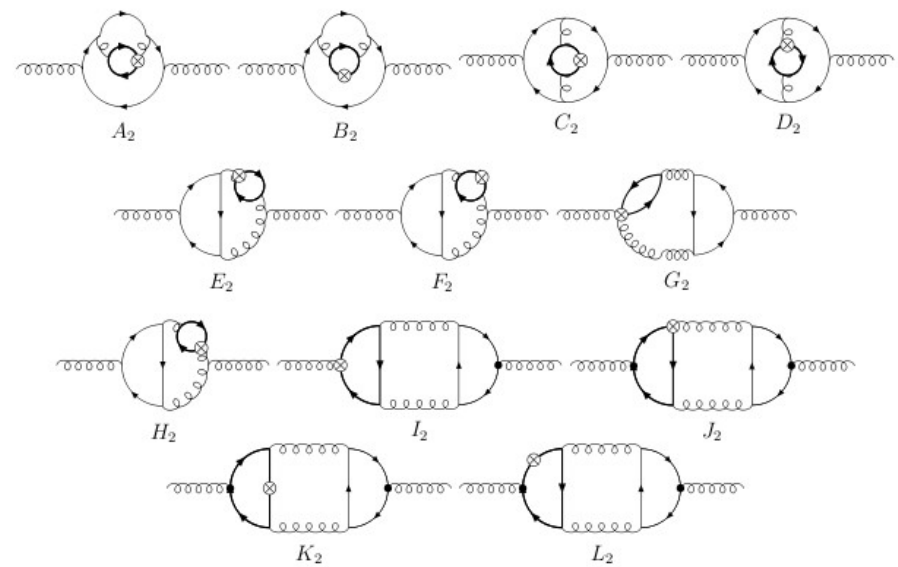


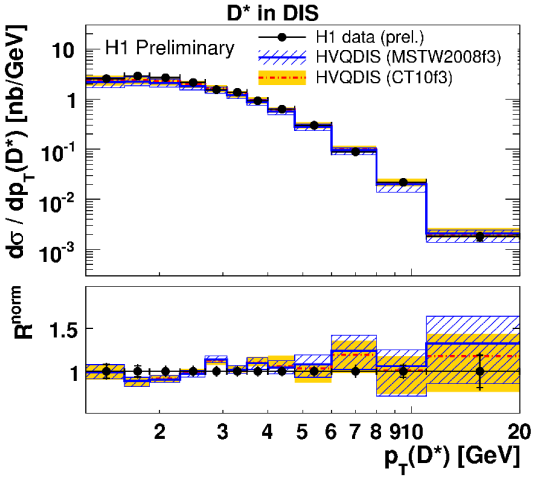
Figure: Further diagrams

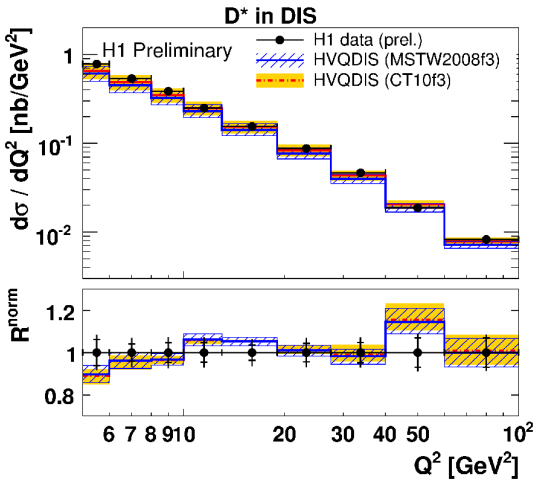
First complete expression for two color factors to HF Wilson coeffs for F2 at O(as^3)

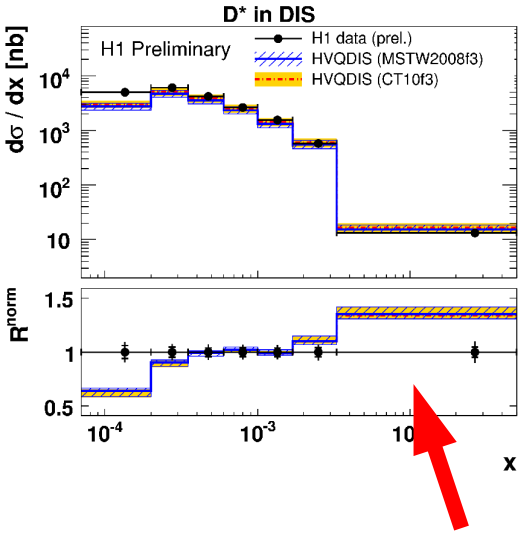
Still some work to do

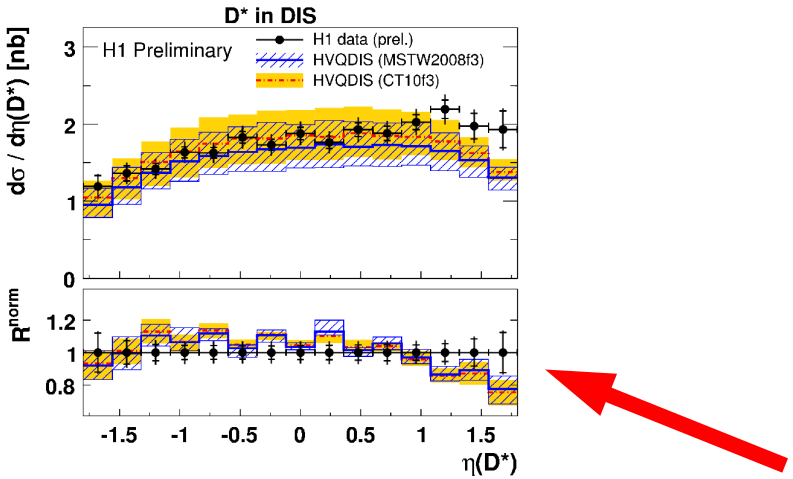
Conclusions

- Full H1 HERA II data sample analyzed for low Q^2 D* production:
  - Increased phase space in η and p_T
  - HVQDIS describes data quite reasonable
  - ZM calculation fails to describe x (and y)
  - The final word on D* in DIS from HERAII



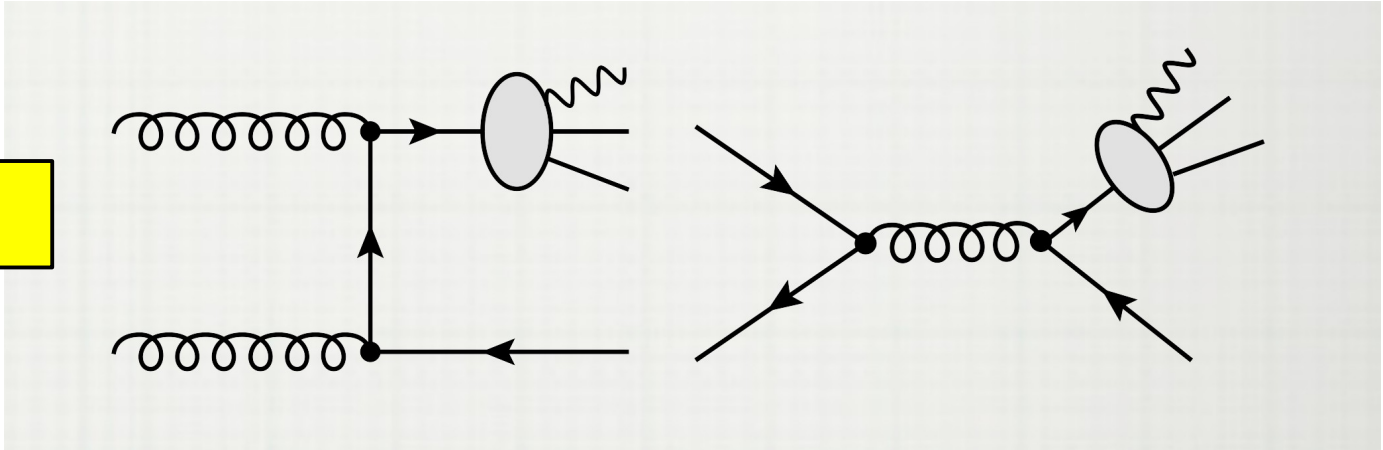


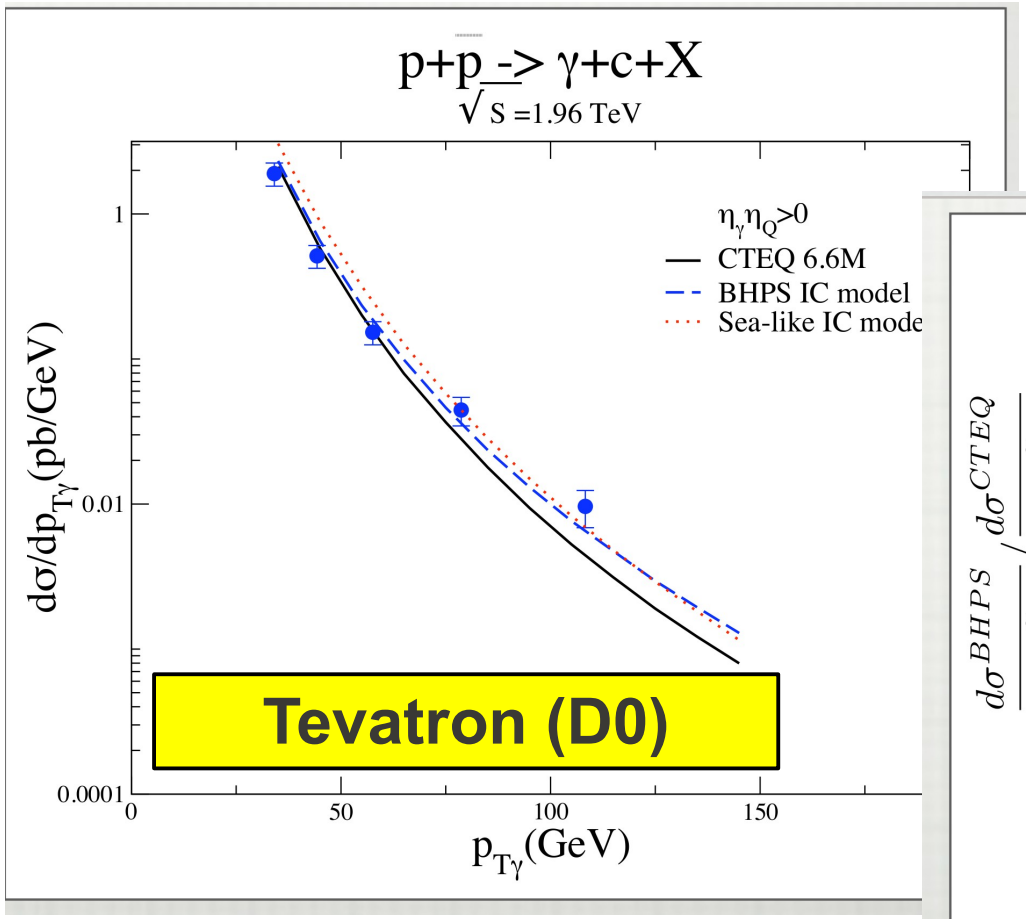




Karol Kovarik

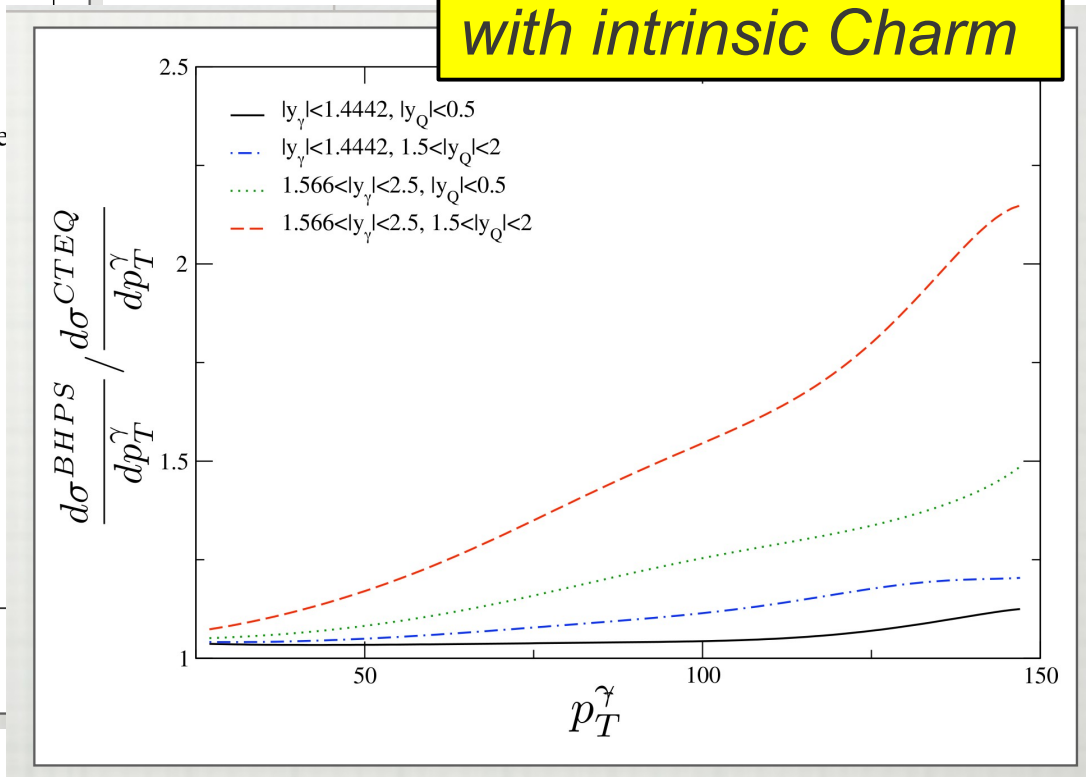
γ+HQ prod. in pp & pA





Tevatron (D0)

LHC (CMS)
with intrinsic Charm



Progress Report

How have we done
over the last decade???

Impressive progress!!!!!!!!!!

HFL session summary part I

1) Open c and b production

2) Quarkonia production

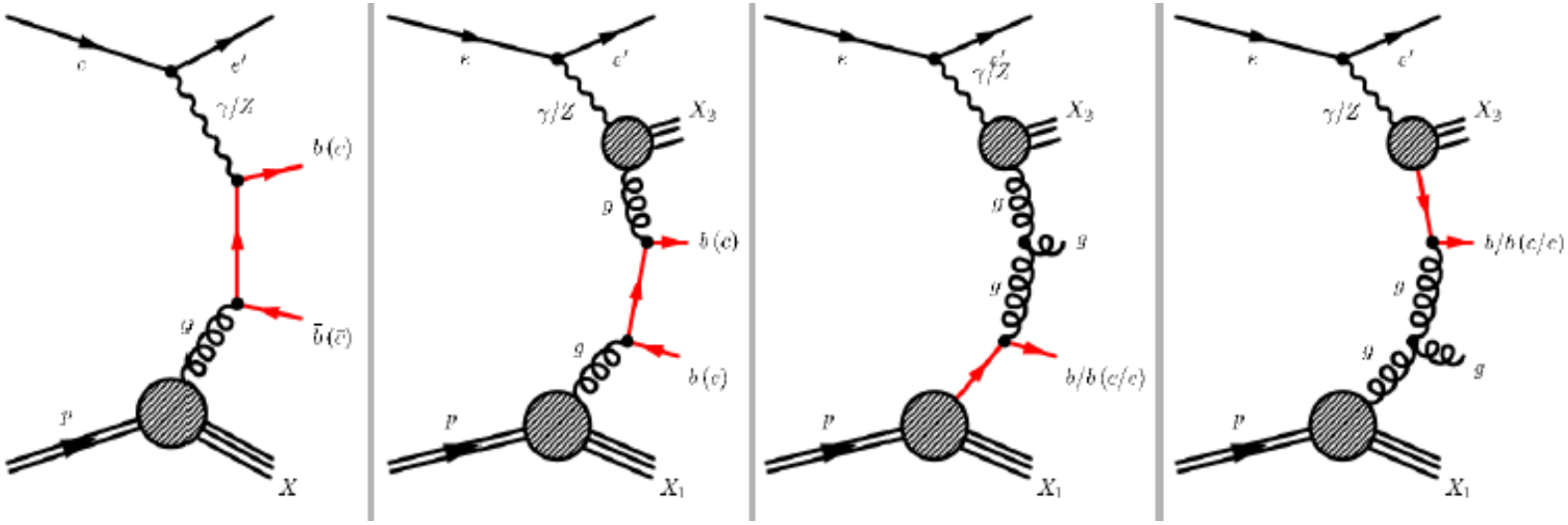
3) c and b spectroscopy

April 15th 2011, DIS 2011, Newport News, VA, USA

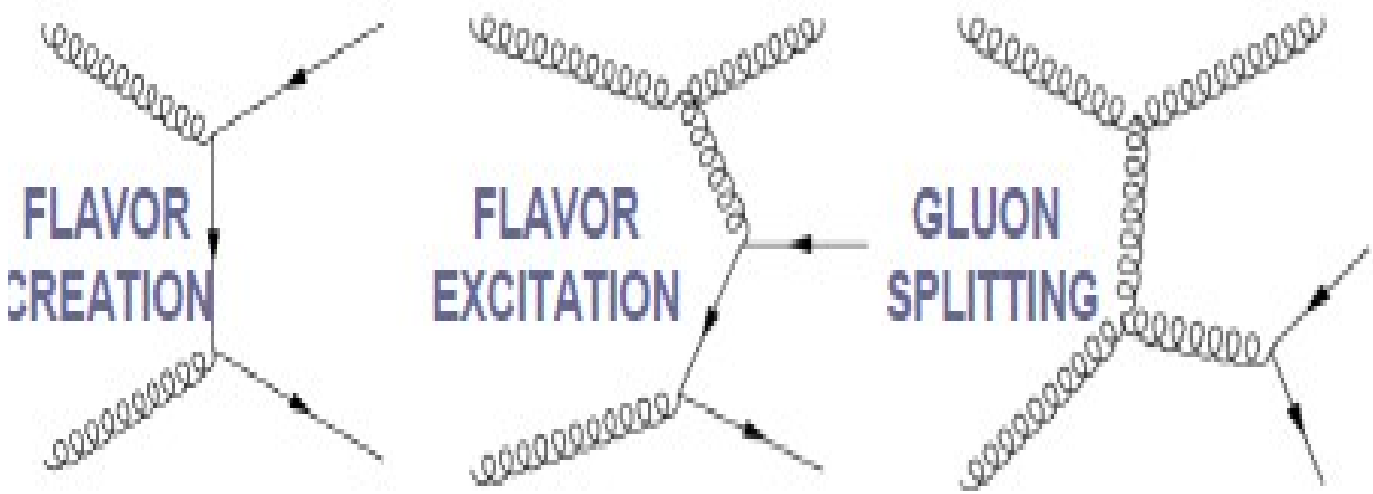
Olaf Behnke (DESY)

Open heavy flavour production diagrams

HERA γp and DIS



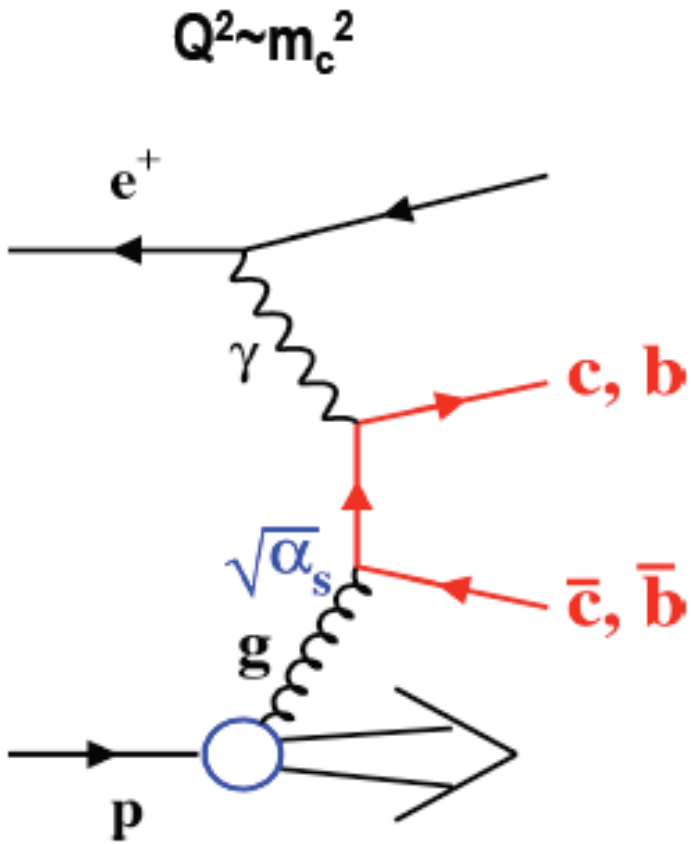
LHC, TEVATRON pp



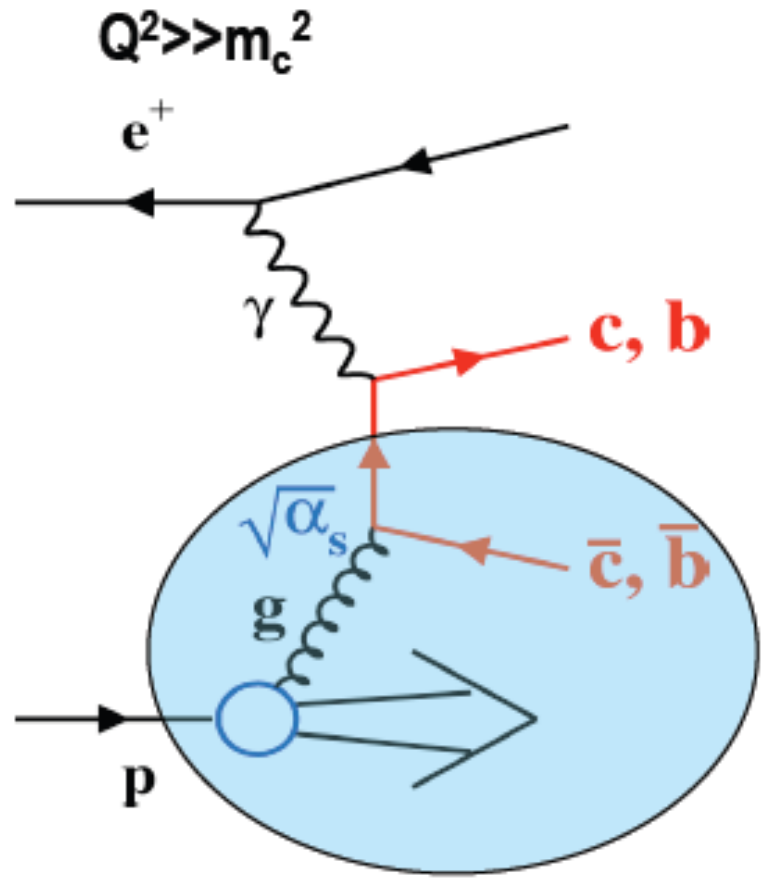
Seizable NLO k-factors

Measurements test pQCD

Subtle topic: correct treatment of heavy flavour masses in pQCD



Massive HQ



Massless Sea quark like c,b

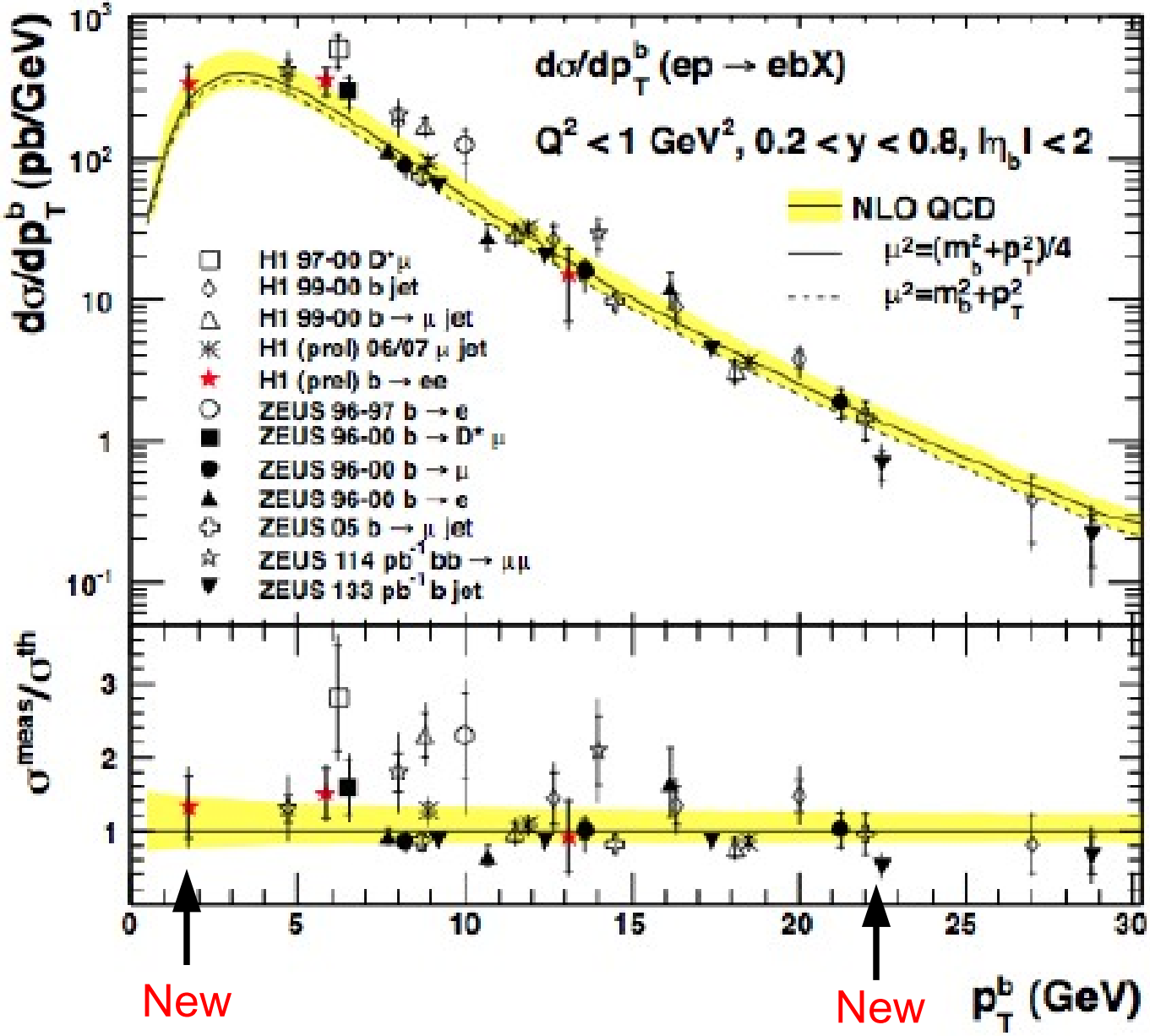
How to make properly the transition from left to right picture is a longstanding problem

Open heavy flavour calculation programs

State of the art

ep photoproduction	FMNR: Massive NLO
ep DIS	HVQDIS: Massive NLO
pp	MC@NLO, POWHEG: Massive NLO+PS
	GM-VFNS, FONLL: Mixed/improved massive-massless NLO schemes

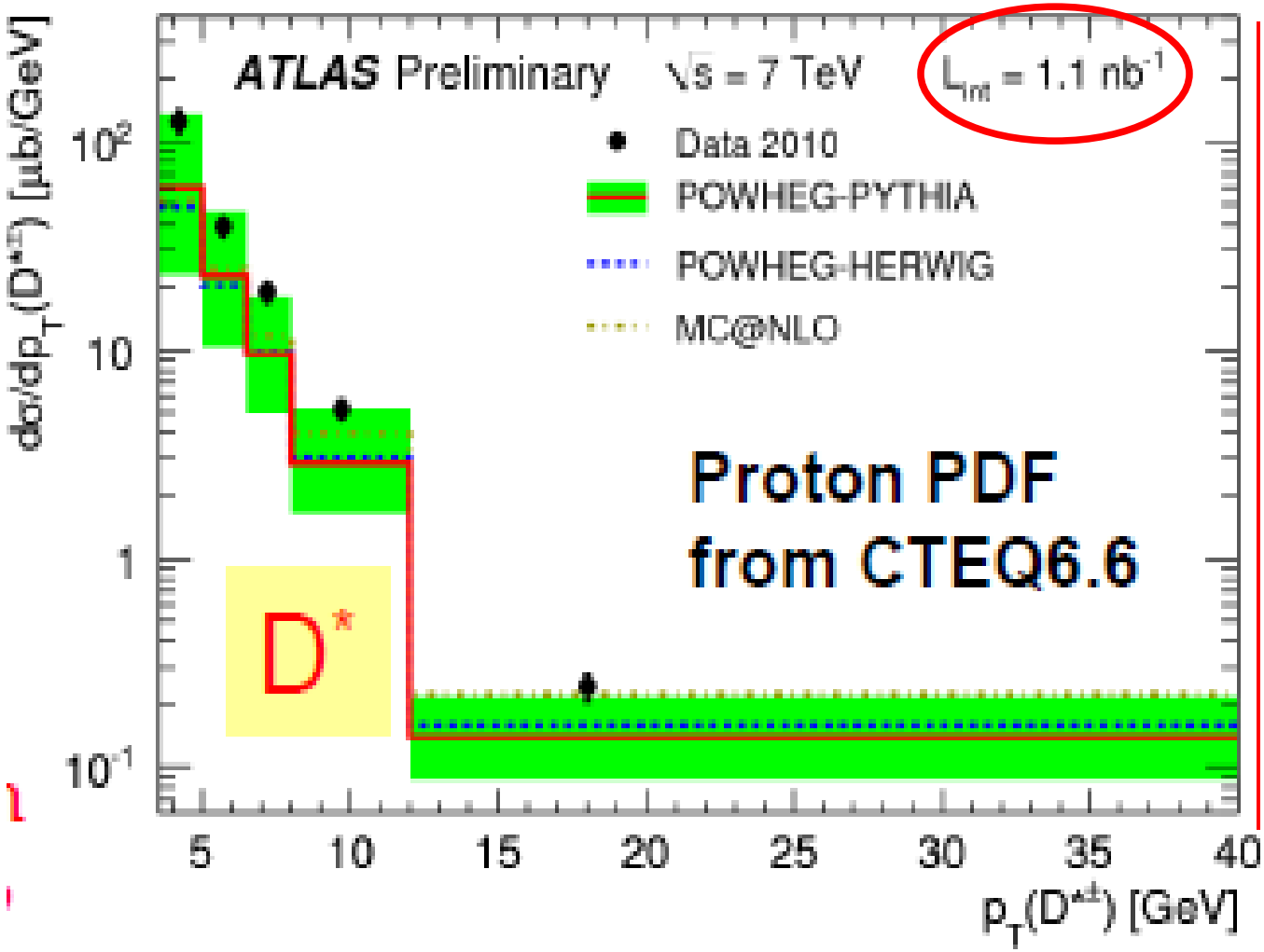
Beauty photoproduction at HERA vs $p_T(b)$



M. Sauter,
I. Brock

Good description by massive NLO over whole pT range

D* production in ATLAS vs $p_T(D^*)$

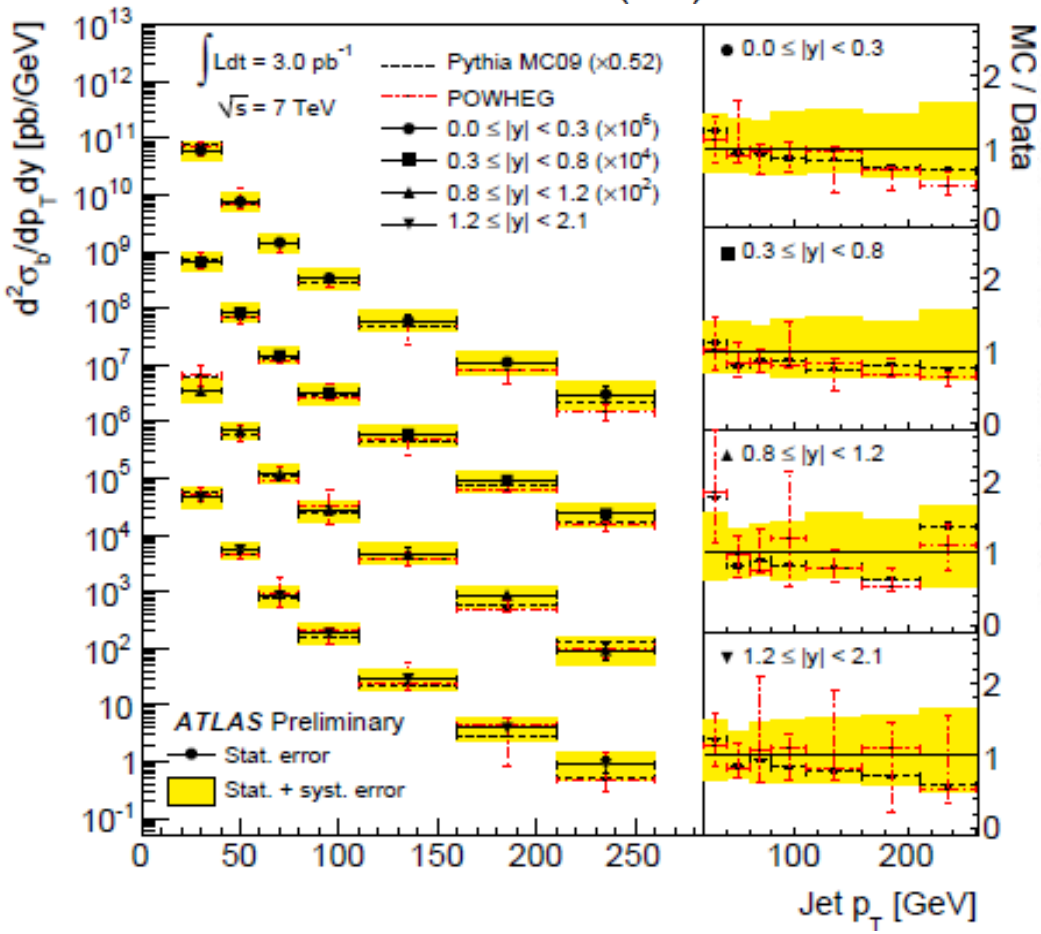


G. Chiodini: Exclusive HF production in ATLAS

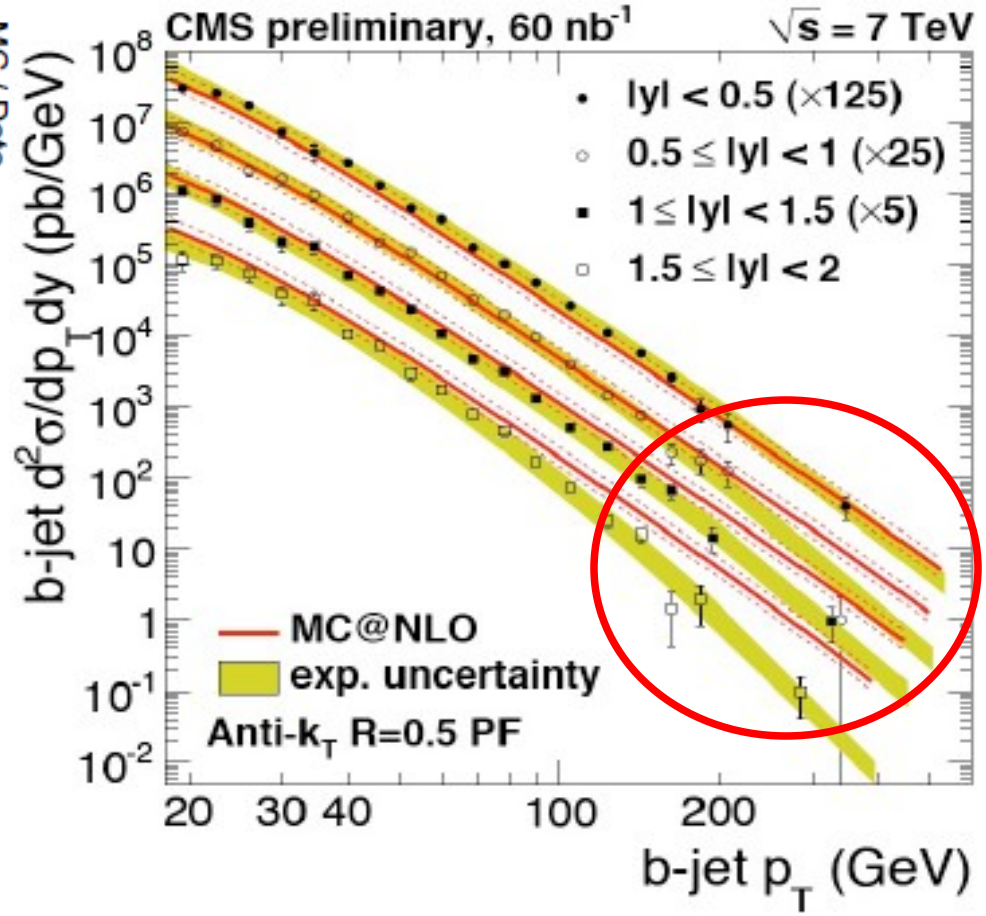
Reasonable description by massive NLO+PS,
To be extended to higher p_T

Beauty jets in ATLAS and CMS vs p_T

Arantxa Ruiz Martínez (ISU)



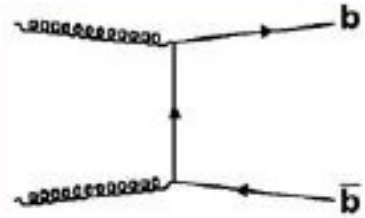
Alexander Schmidt

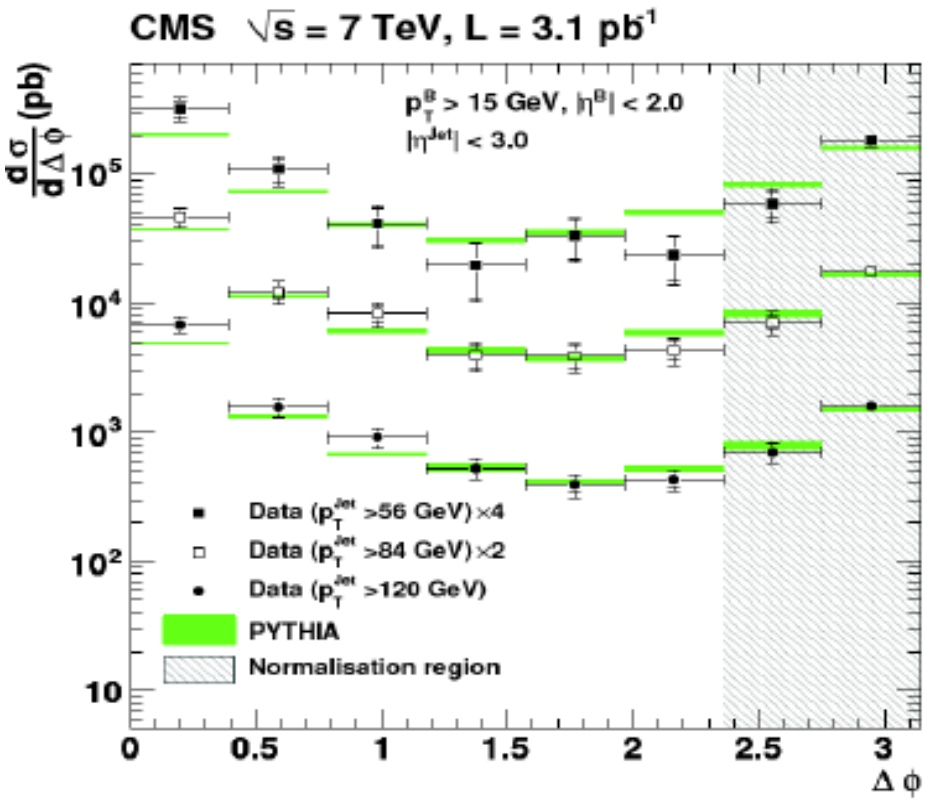


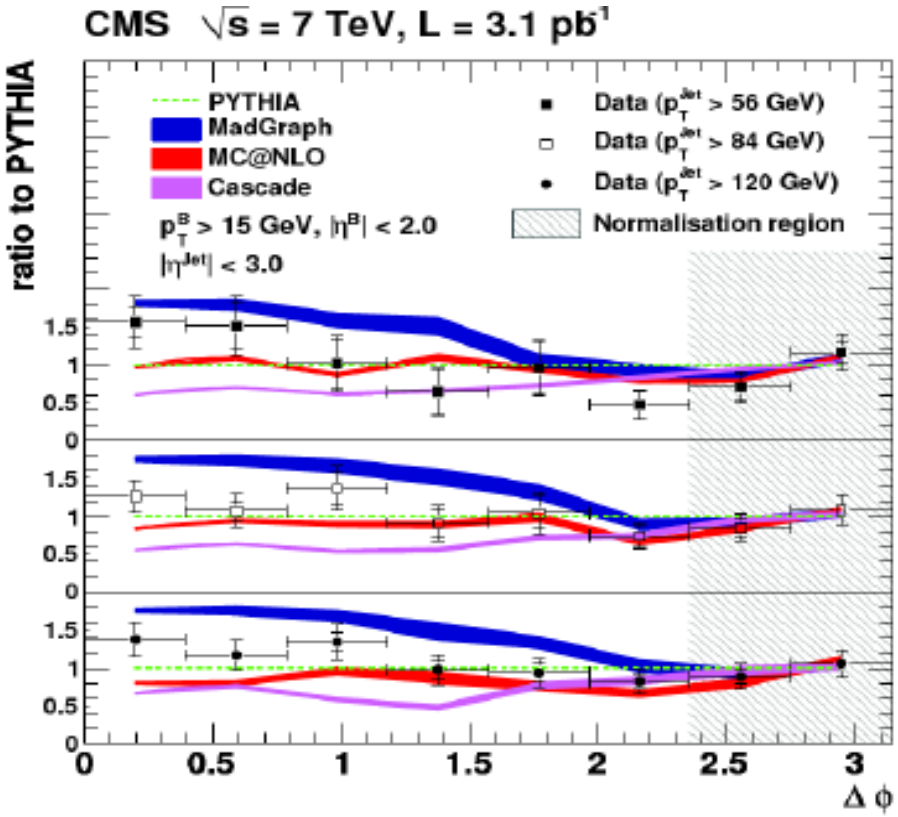
~reasonable description, MC@NLO Overshoots CMS data at high p_T

BB angular correlations at CMS

A.Rizzi







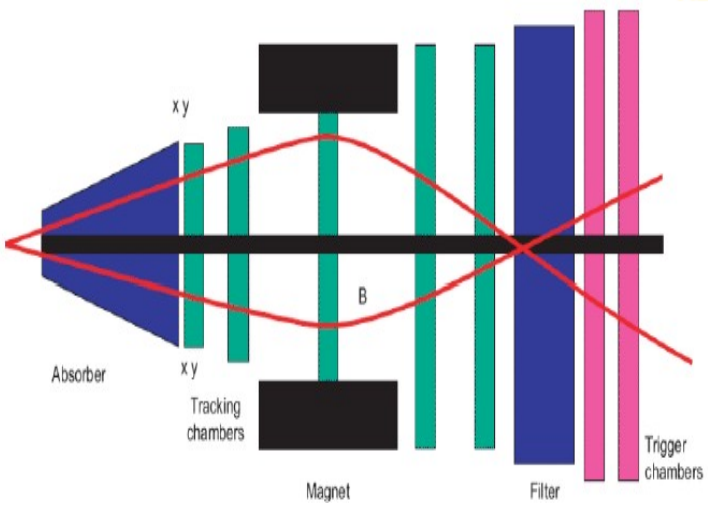
~gluon splitting dominates, description by calculations not perfect

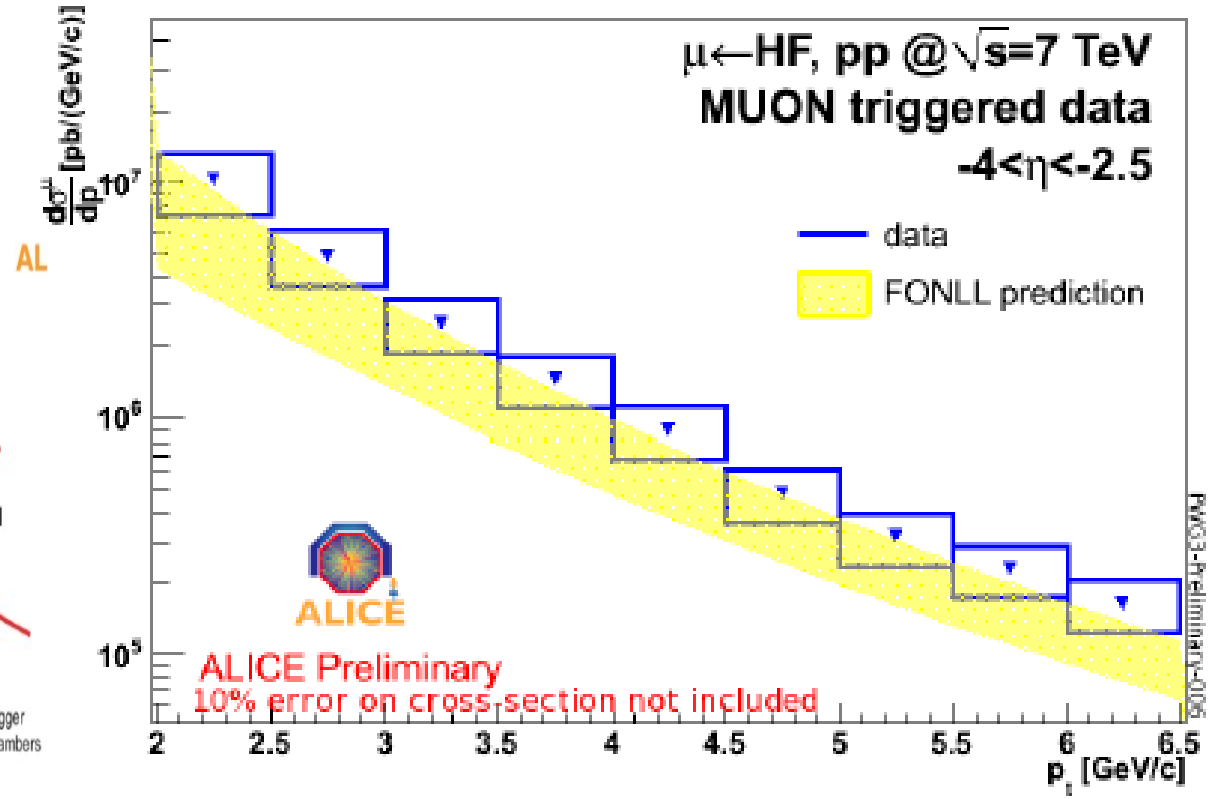
ALICE:

$c/b \rightarrow$ single-μ cross section in p-p

Chiara Bianchin

ALICE forward muon spectrometer

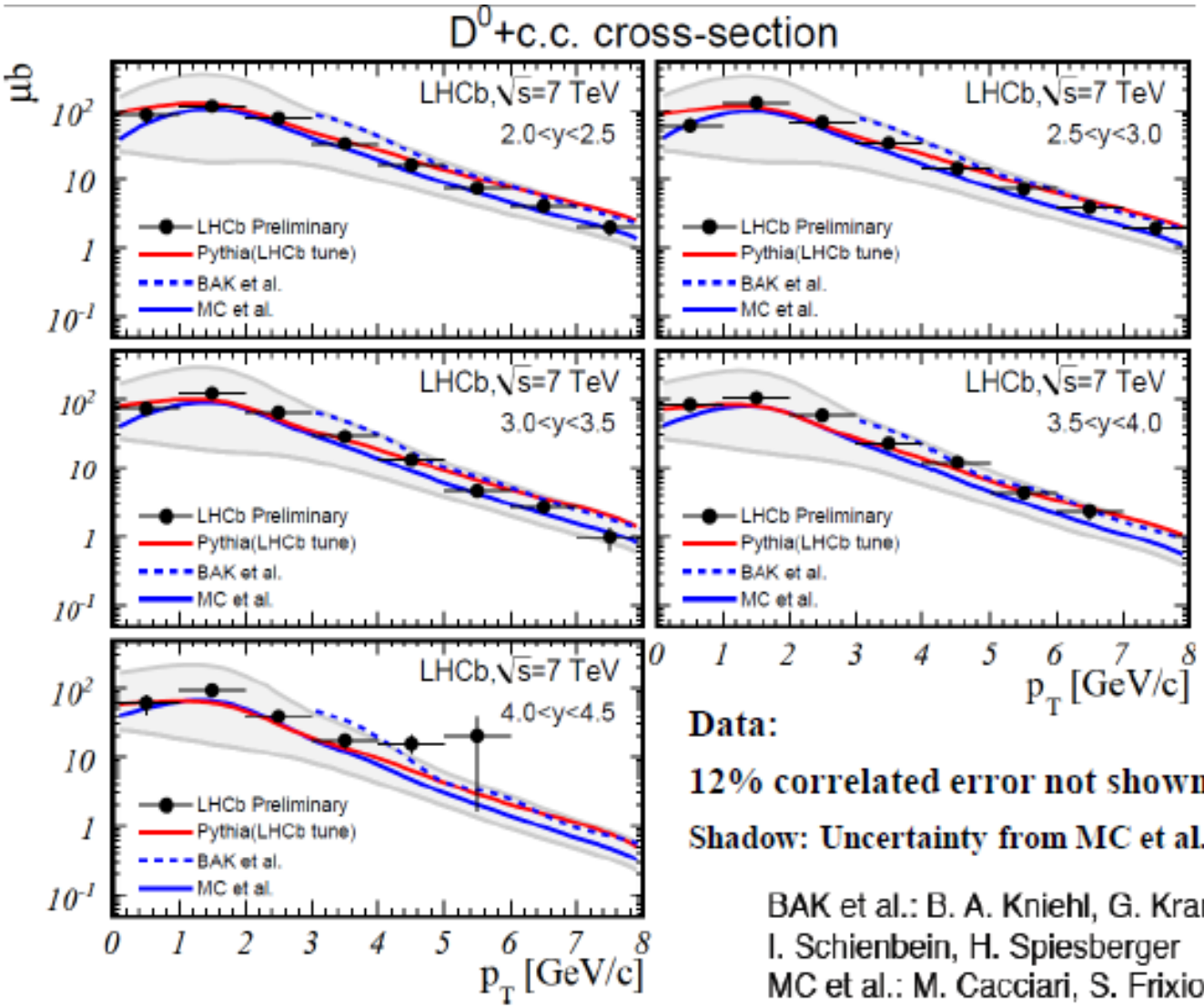




FONLL in agreement with the data, analysis will be extended soon to larger p_T

D^0 cross sections at LHCb

Liming Zhang



Covering forward rapidities 2<y<5

Data:

12% correlated error not shown

Shadow: Uncertainty from MC et al.

BAK et al.: B. A. Kniehl, G. Kramer, I. Schienbein, H. Spiesberger
MC et al.: M. Cacciari, S. Frixione, M. Mangano, P. Nason, G. Ridolfi.

Good/reasonable description by the various calculations

The future of open c and b production: LHC measurements can easily further add statistics & extend the kinematic phasespace: higher pt, rapidities, correlation measurements, etc.

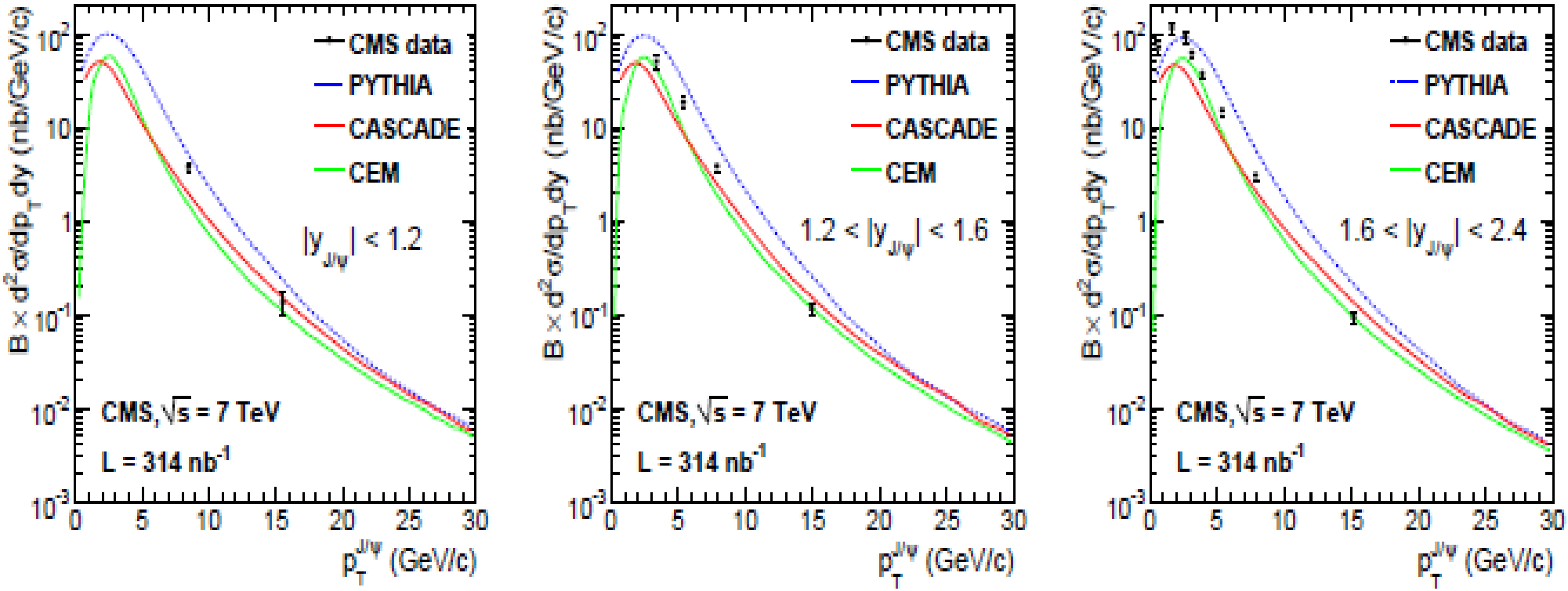
but how much can the theory still improve? Scale uncertainties are seizable

Quarkonia production

- Quarkonia production at a hadron collider is not theoretically settled.
- Most models fail to simultaneously explain experimental measurements of both cross section and polarization.

Prompt J/Psi cross sections at CMS

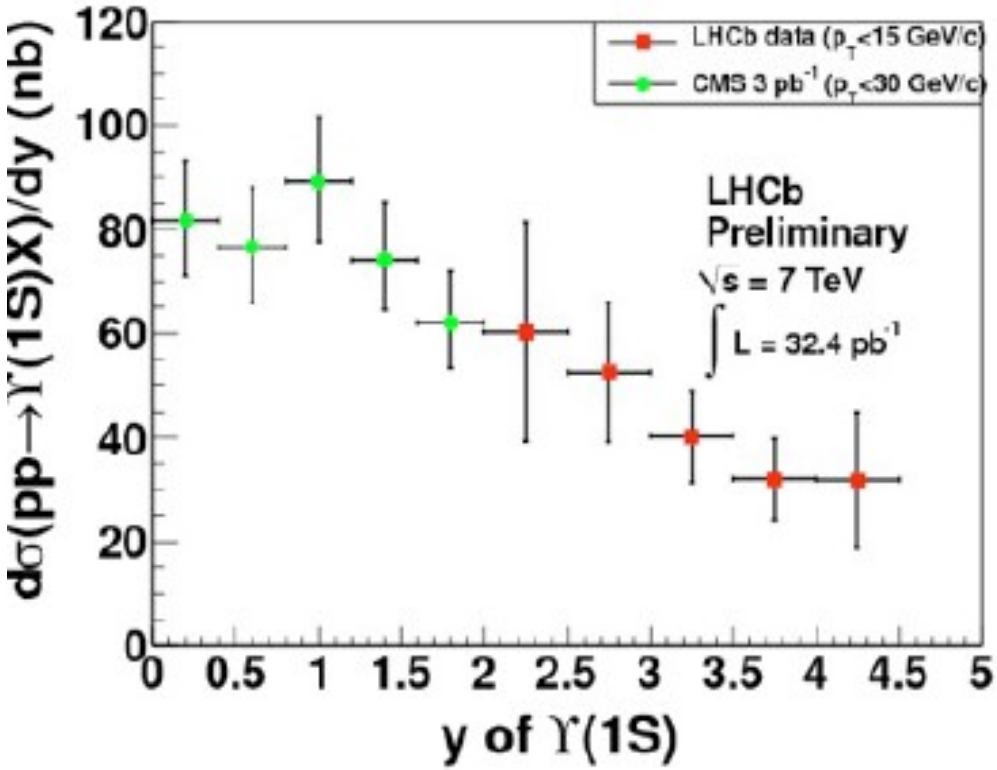
P. Ronchese

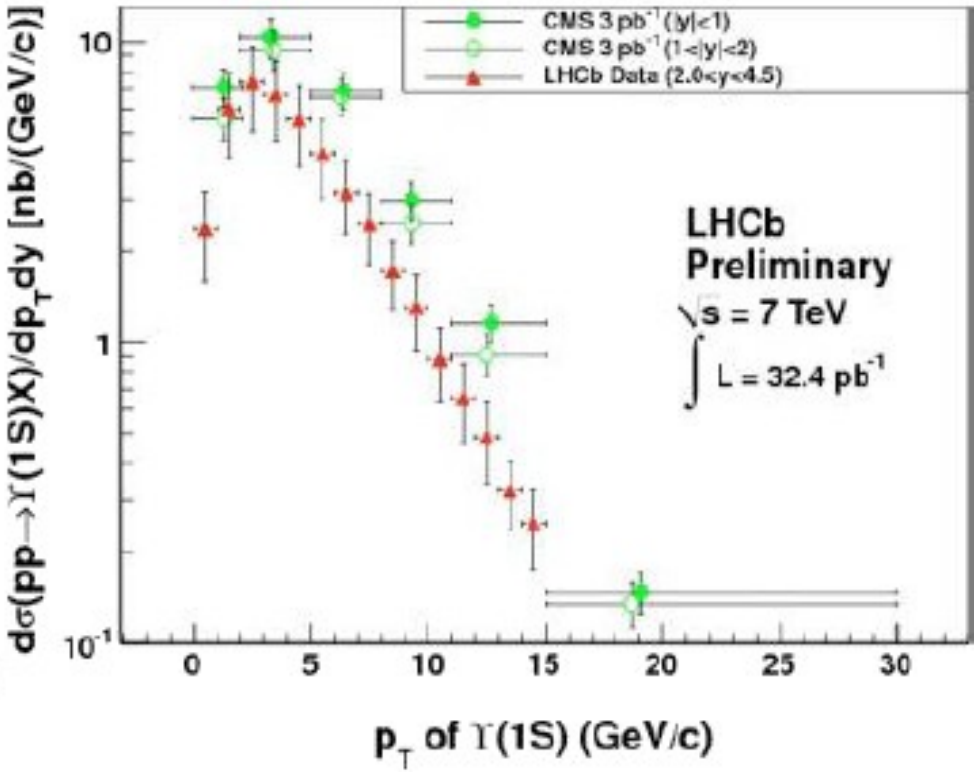


- Calculations include contributions from heavier states decays (χ_c , $\psi(2S)$)

Cross section exceeding expectations in the forward region at low pT

Upsilon(1s) cross sections at LHCb and CMS





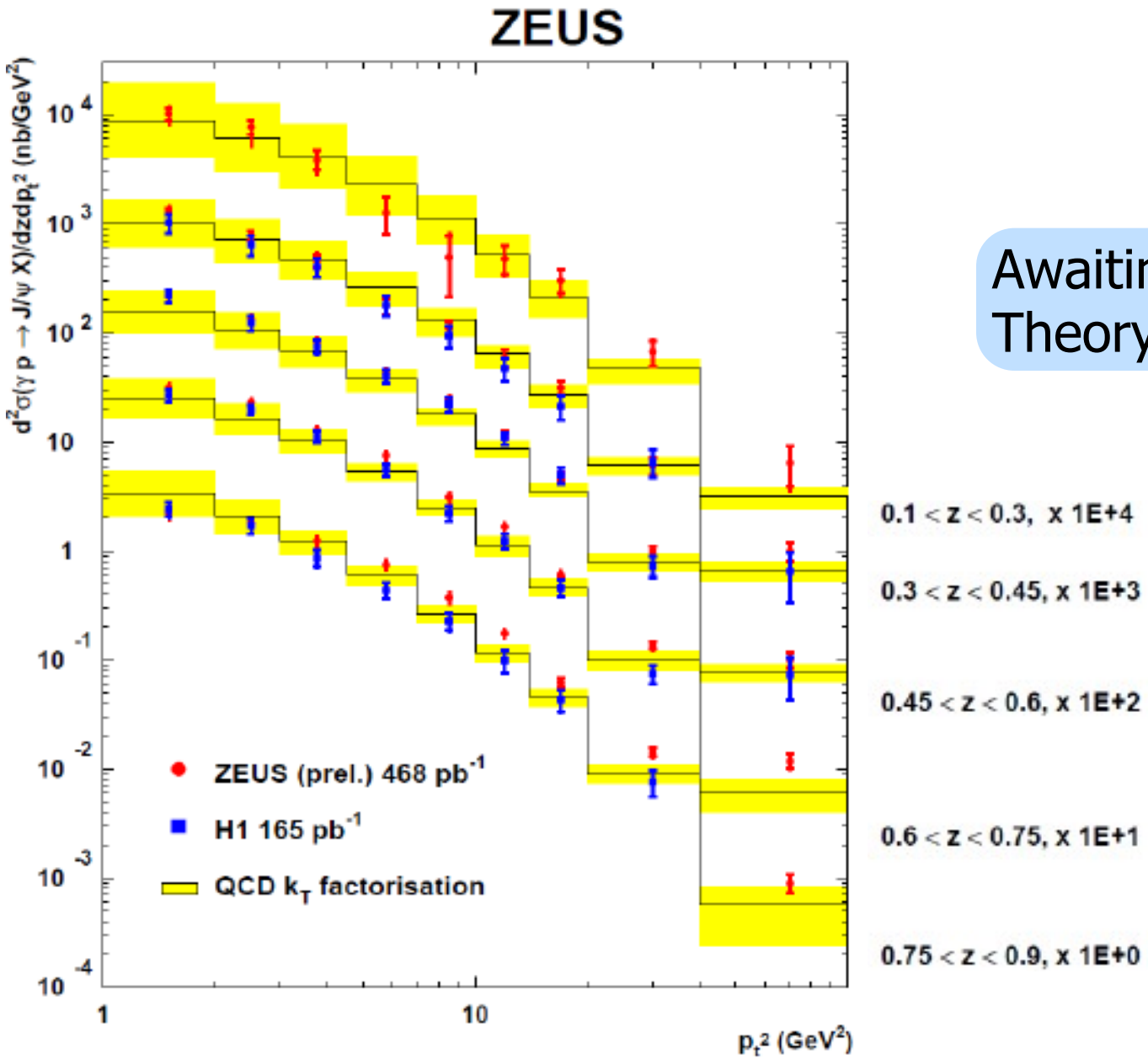
J. Anderson, U. Kerzel

Nice continuation of cross sections

Good agreement of CMS cross sections at large pt with NRQCD (not shown)

J/psi photoproduction cross sections at HERA

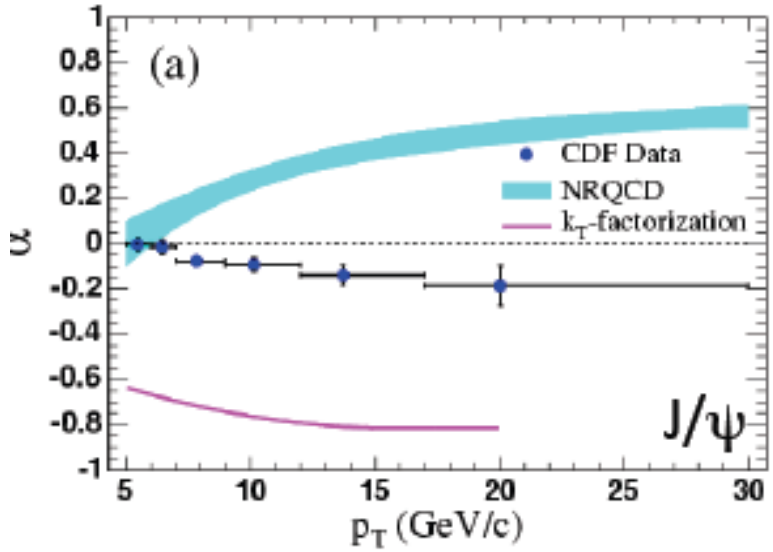
A. Bertolin

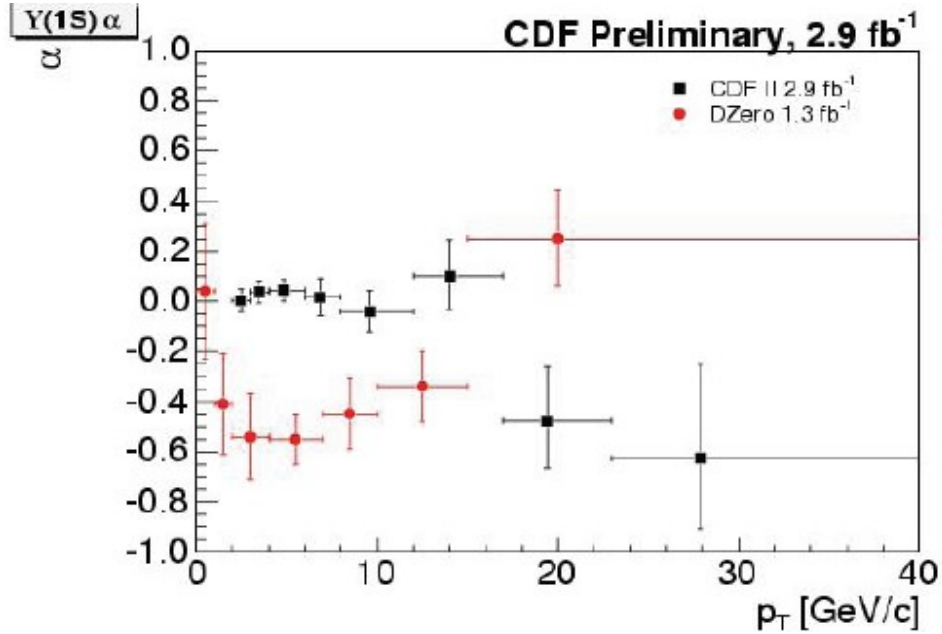


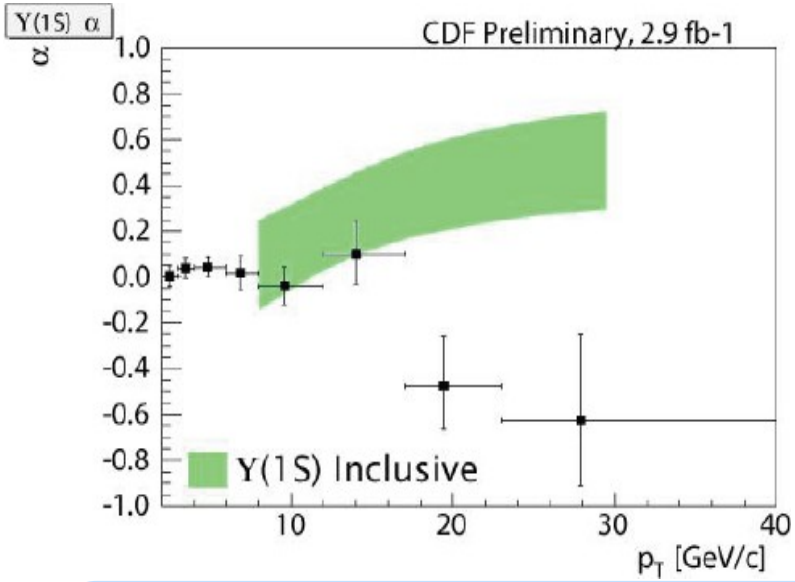
Awaiting comparisons with Theory (NRQCD, kT)

Quarkonia Polarisation

$dN/d(\cos\theta^*) \propto 1 + \alpha \cos^2\theta^*$







CDF and DØ results largely inconsistent

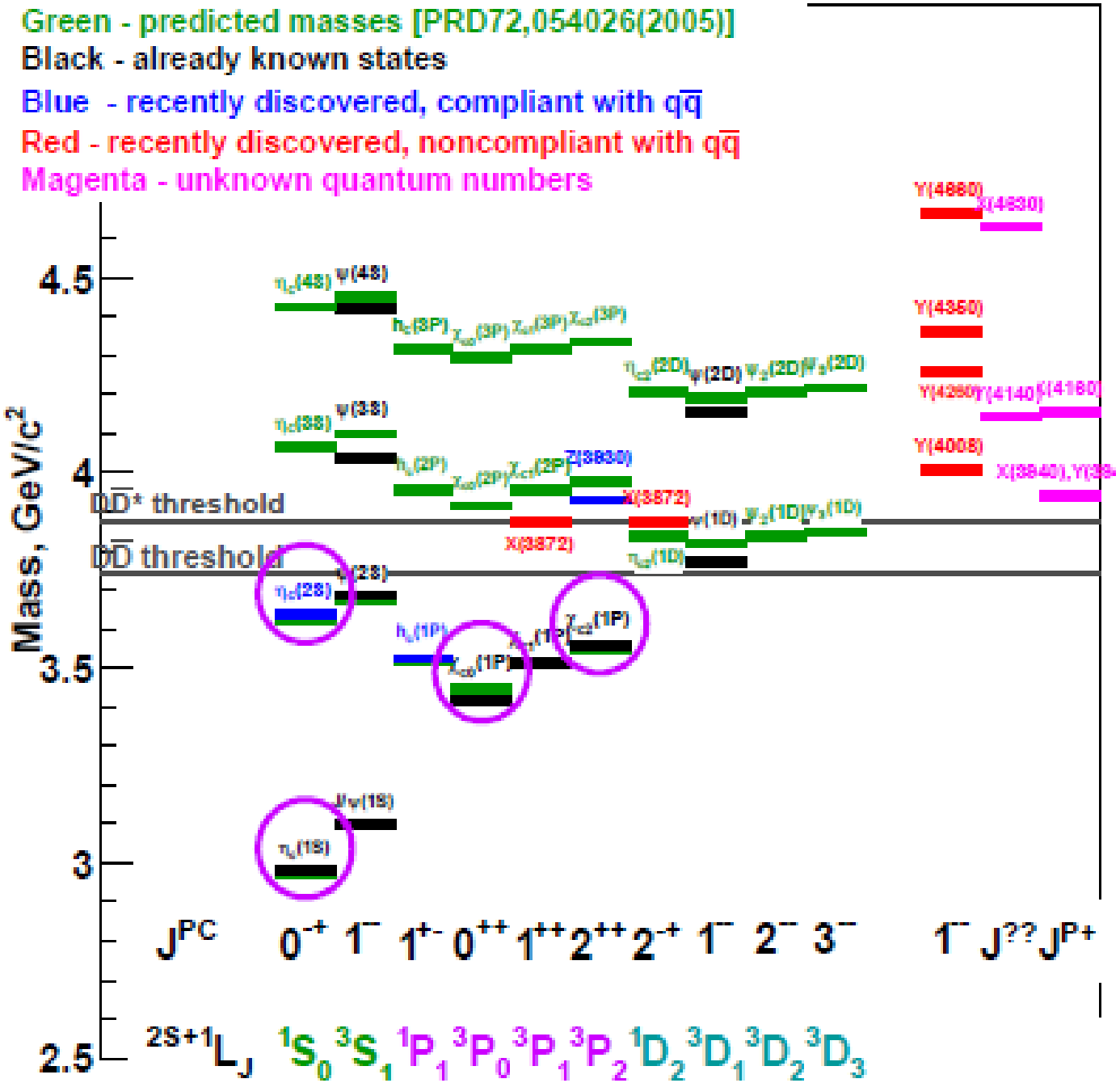
- Different rapidity regions
  - CDF: $|y|<0.6$ DØ: $|y|<1.8$

Heather Kay Gerberich

Experimental and theoretical puzzles still to be understood

Charmonium spectroscopy

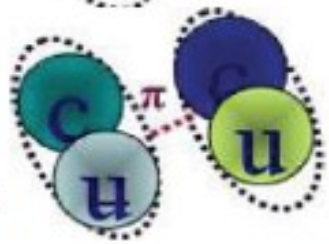
A. Rakitin



Exotic charmonium-like states

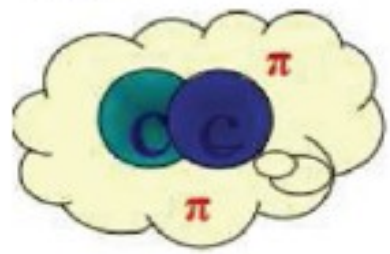
Tetraquark:
four tightly bound quarks

Molecular state:
two loosely bound mesons



Hybrid: states with
excited gluonic degrees of freedom

Hadrocharmonium: charmonium state,
"coated" by excited light-hadron matter

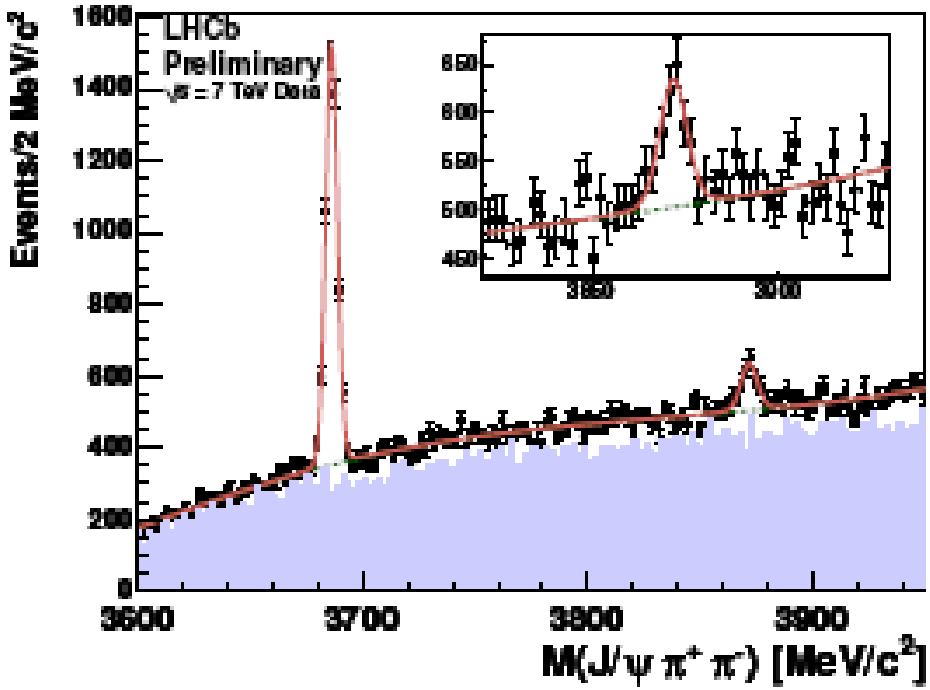


Exotics signature:
- J^{PC}, forbidden for charmonium
- Extremely narrow width for a state above $D\bar{D}$
- Non-zero charge, strangeness

X(3872) at LHCb

Michel De Cian

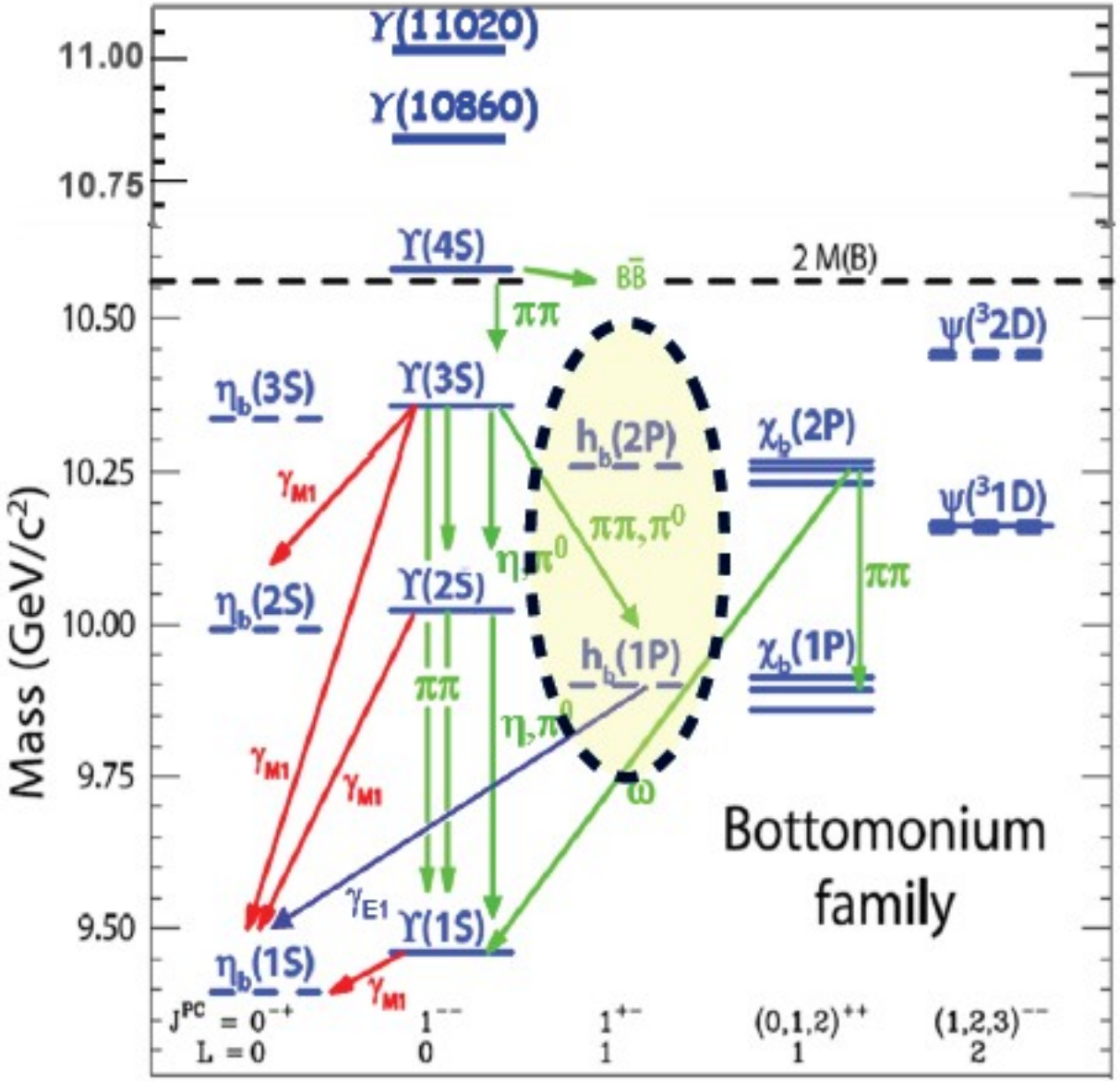
X(3872) Selection



Summary of De Cian:

- Showed mass measurements for $B_u, B_d, B_s, B_c, \Lambda_b$ and $X(3872)$.
- World best measurements for B_u, B_d, B_s and Λ_b after one year of data taking.
- 2011 will bring us the Ω_b, precise measurements of the $X(3872)$, and maybe some tetraquarks.

Expectations for the h_b and $h_b(2P)$ masses

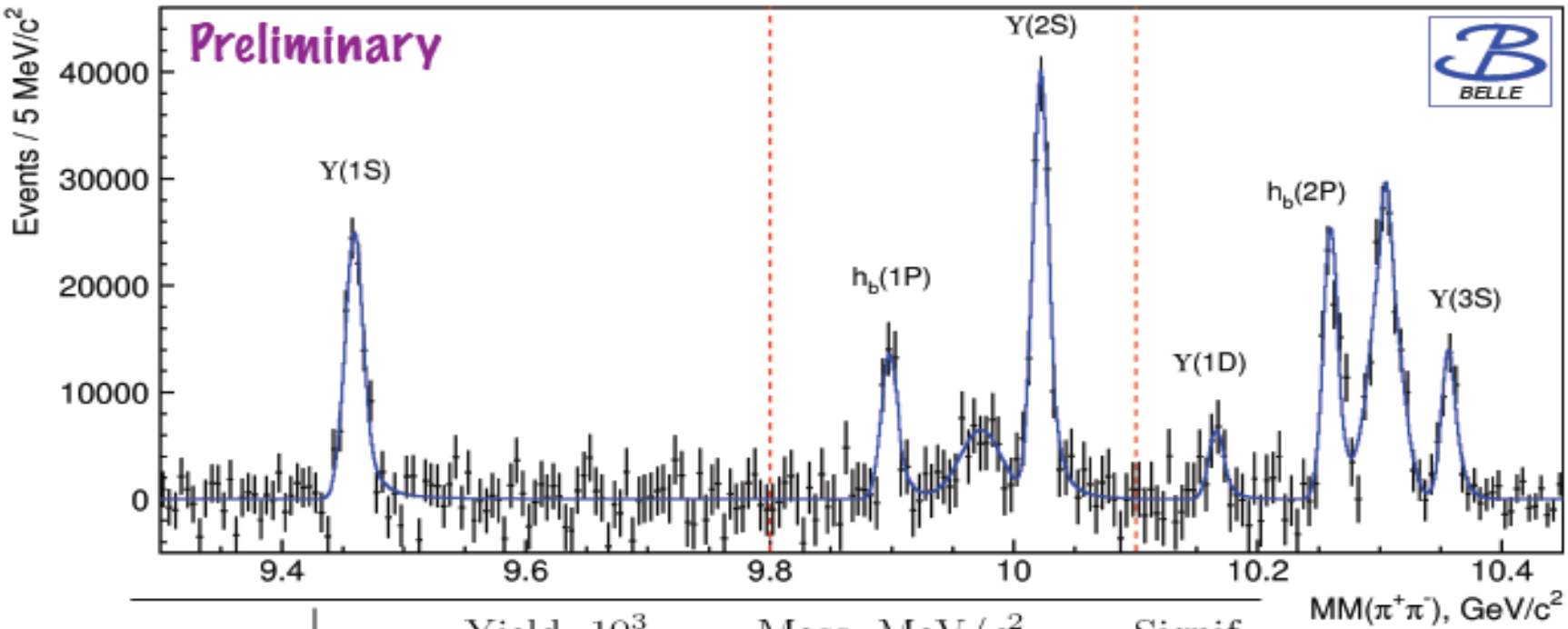


Search for the h_b family

$h_b(1p)$ and $h_b(2p)$ results from Belle

Leo Piilonen

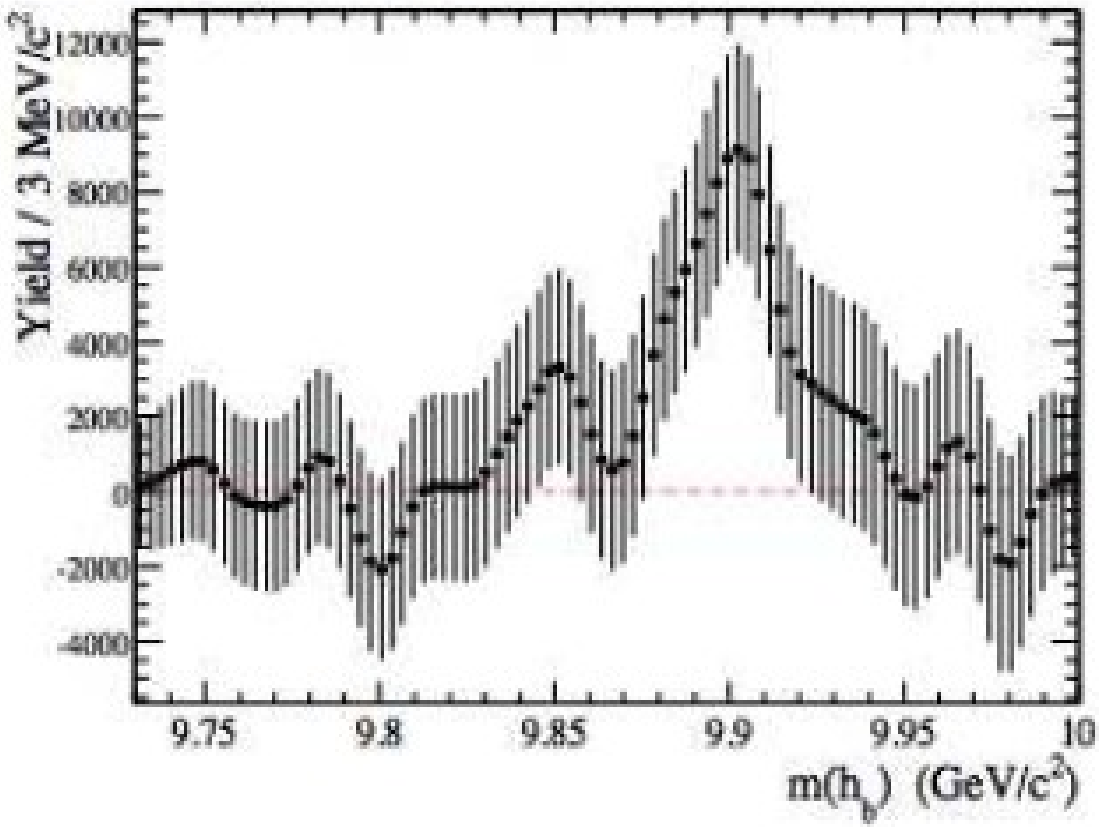
Use the missing-mass technique to find h_b and $h_b(2P)$



	Yield, 10^3	Mass, MeV/c^2	Signif.
$\Upsilon(1S)$	$105.2 \pm 5.8 \pm 3.0$	$9459.42 \pm 0.53 \pm 1.02$	$18.2\,\sigma$
$h_b(1P)$	$50.4 \pm 7.8^{+4.5}_{-9.1}$	$9898.25 \pm 1.06^{+1.03}_{-1.07}$	$6.2\,\sigma$
$3S \to 1S$	55 ± 19	9973.01	$2.9\,\sigma$
$\Upsilon(2S)$	$143.4 \pm 8.7 \pm 6.8$	$10022.25 \pm 0.41 \pm 1.01$	$16.6\,\sigma$
$\Upsilon(1D)$	22.1 ± 7.8	10166.2 ± 2.4	$2.4\,\sigma$
$h_b(2P)$	$84.4 \pm 6.8^{+23.}_{-10.}$	$10259.76 \pm 0.64^{+1.43}_{-1.03}$	$12.4\,\sigma$

Search for $\Upsilon(3S) \to \pi^0 h_b(1P)$

Fitted yield as a function of fixed $h_b(1P)$ mass:



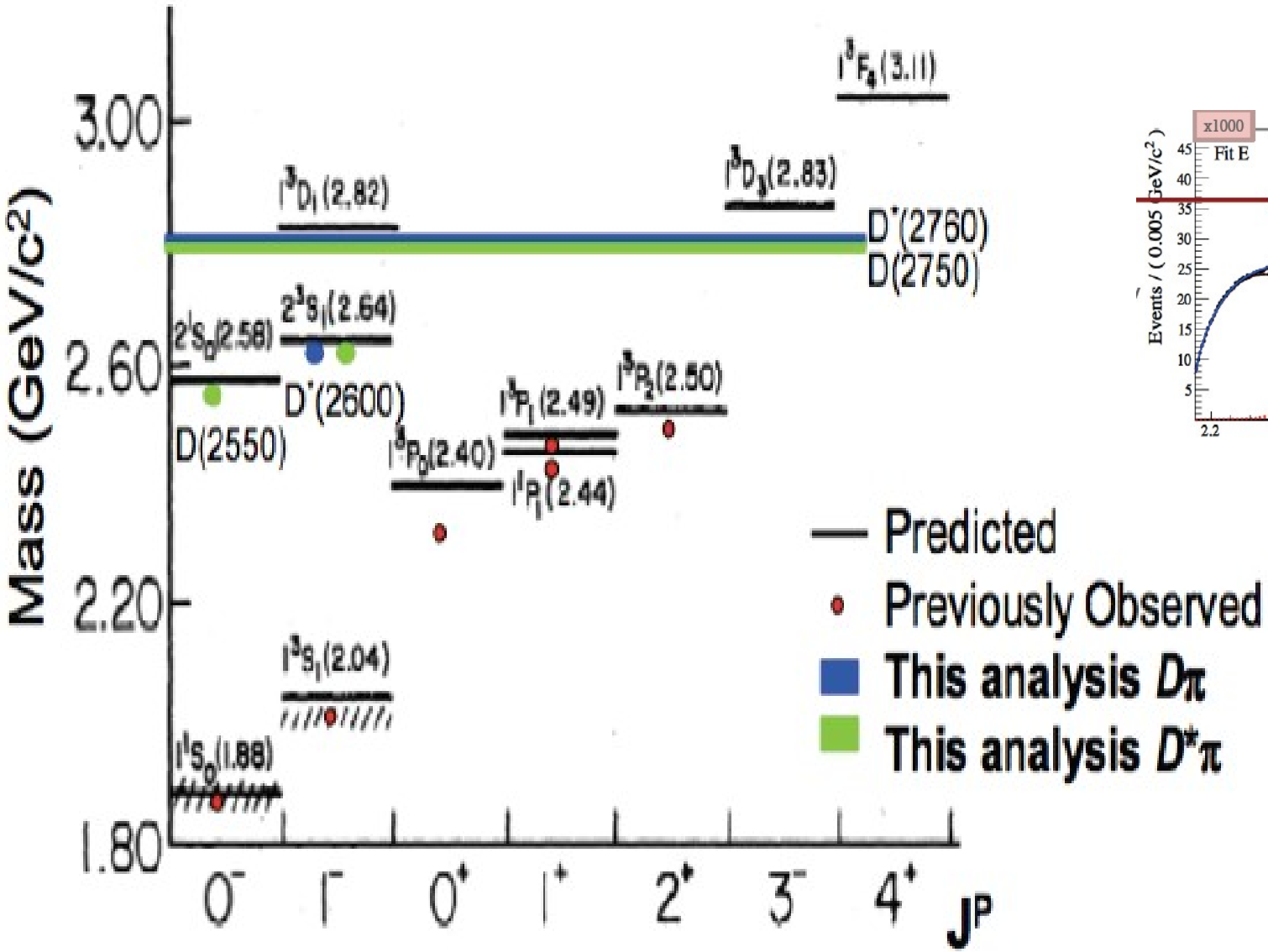
A. Rakitin

$m(h_b(1P)) = 9902 \pm 4(\text{stat.}) \pm 1(\text{syst.})\ \text{MeV}/c^2$

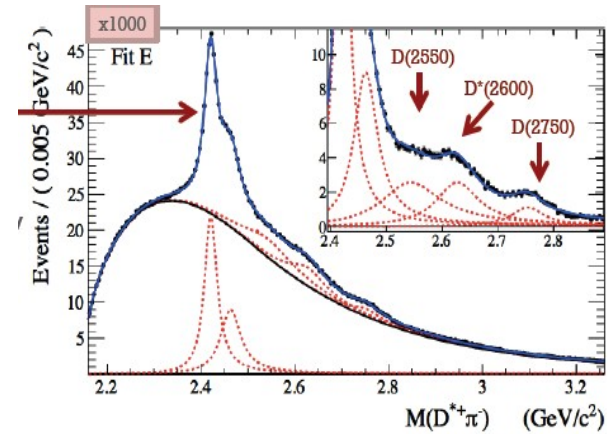
Summarising comment from Leo Piilonen

B factories have made surprising studies of new states in charmonia / bottomonia, but more studies and more data are needed to reveal their true nature.

D-meson spectroscopy – new states found at BABAR



G. Cibinetto



Further interesting results/talks in the parallel sessions

- P. Thompson: c/b jets in DIS (good description by massive NLO calculations)
- U. Kerzel: chic production at LHCb (problem with talk PDF file)
- U. Kerzel: quarkonium to production at LHCb (problem with talk PDF file)
- Andrii Verbitskyi: excited charm mesons at HERA (confirm BABAR results for D(2420) width)

Motivation for Studying Open Heavy Flavor

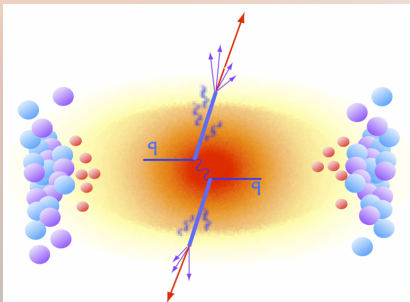
Why open heavy flavor?

•Heavy quarks produced early in collision, good probe of full evolution.

•Measurement in p+p serves as a baseline for heavy ion. Also helps us understand heavy production mechanisms, compare to NLO.

•In heavy ion understand heavy flavor thermalization, energy loss.

•Help to interpret charmonium suppression/recombination effects



2

Motivation for Studying Open Heavy Flavor

High p_T heavy quarks probe jet quenching, lower p_T heavy quarks probe collective flow.

Jet quenching quantified by:

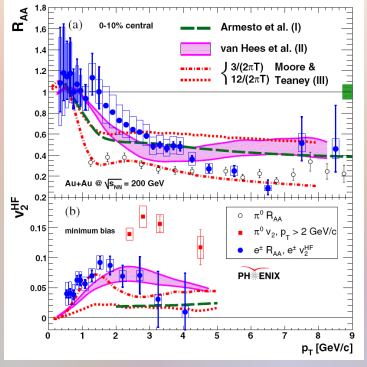
$$R_{AB} = \frac{dN^P_{AB}}{\langle T_{AB}\rangle_f \times d\sigma^P_{NN}} = \frac{dN^P_{AB}}{\langle N_{coll}\rangle_f \times dN^P_{NN}}$$

Elliptic flow quantified by v_2, where:

$$\frac{d^2N}{d\phi dp_T} = N_0(1 + 2v_2(p_T)\cos(2\phi))$$

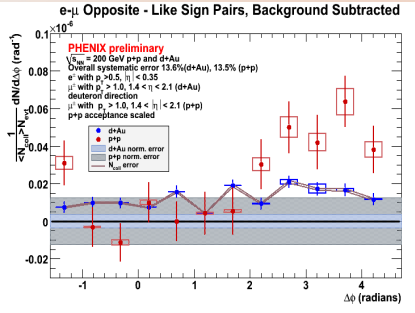
Single particle measurements provide yields, R_{AA} and v_2 values.

Correlations probe heavy flavor jet structure modified by medium



3

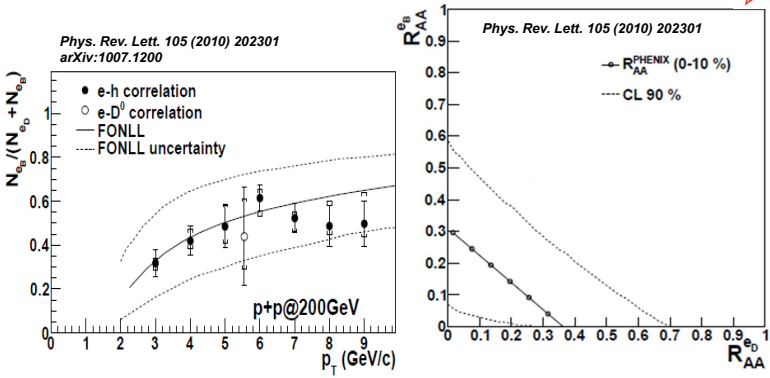
e - μ Correlations in p+p and d+Au



- Signal: opposite sign e-μ pairs with Δφ ≈ π. Product of back-to-back charm pairs produced via gluon fusion and higher order processes.
- Pure signal, few sources of physics background
  - No contribution from Drell-Yan, thermal production, resonance decays.
  - Like-sign subtraction removes combinatoric background, e-μ pairs from dijets.
- Measurement in p+p proves method, found consistent with predicted NLO charm jet shape.
- d+Au measurement shows suppression/decorrelation relative to p+p.

10

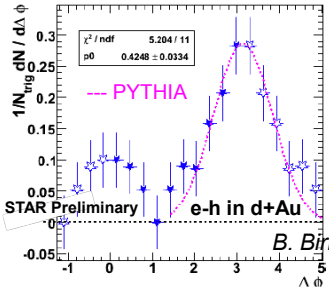
B Meson is Suppressed in 200GeV Au+Au Collisions

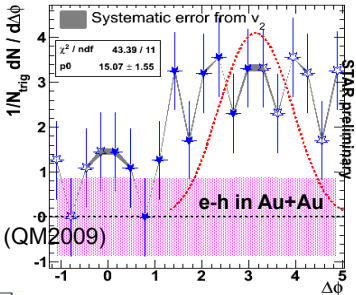


- ~30-60% of non-photonic electron come from B meson in 200GeV p+p collisions.
- Assume the same fraction in Au+Au collisions, results indicate B meson is suppressed

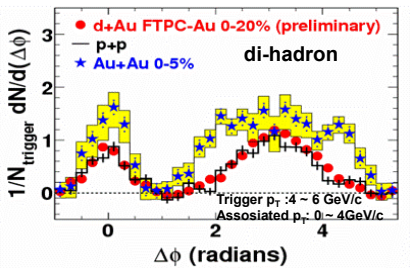
9

Broadened Away-side in the NPE and Hadron Correlations





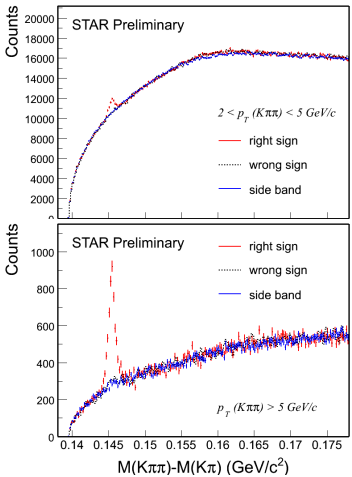
B. Biritz (QM2009)

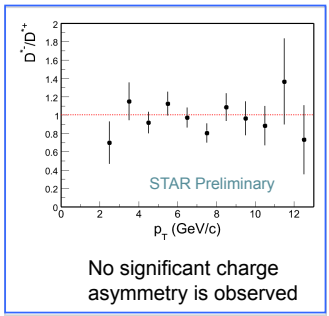


Result indicates the broadening of the awayside peak in both di-hadron and e-h correlation in Au+Au central collisions

11

D* reconstruction in p+p 200GeV





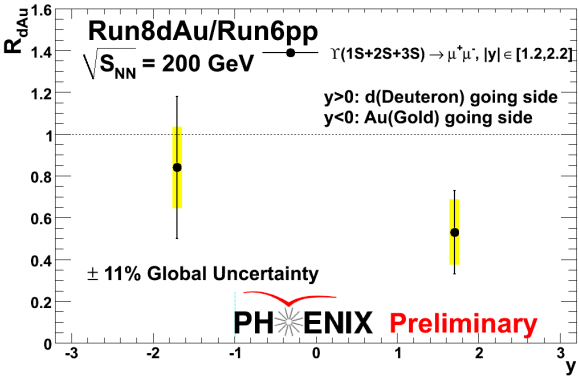
$D^{*+} \rightarrow D^0\pi^+$ (BR = 68%)
$\hookrightarrow K^-\pi^+$

More than 4σ signal at low p_T and very significant at high p_T - mostly from EMC-based high neutral energy triggers.

Both wrong sign and side-band methods reproduce background well.

14

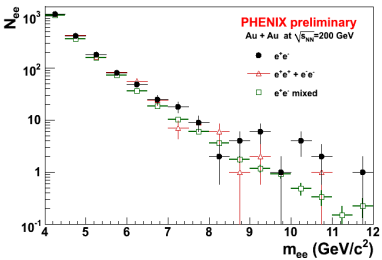
ϒ in d+Au



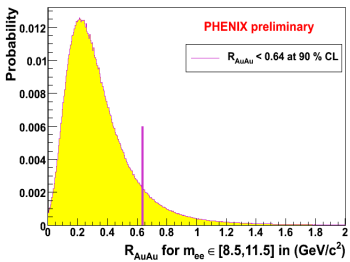
• Shows suppression at low x region

11

ϒ (or rather: high mass di-leptons) R_{AA} in A+A



-0.35 < y < 0.35



R_{AuAu} [8.5,11.5] < 0.64 at 90% C.L.

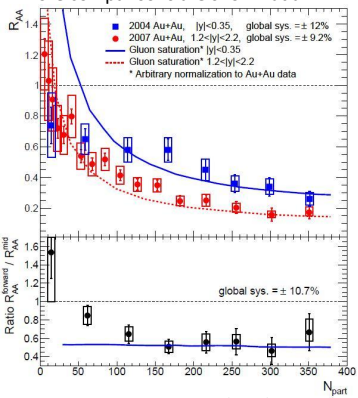
- Derived a 90% C.L. for high-mass dileptons R_{AA}

14

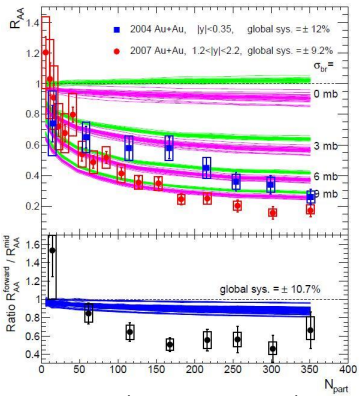
J/ψ R_{AA} vs N_{part} in A+A

New 2007 data

More comparisons are shown at arXiv:1103.6269



Color Glass Condensate(CGC)
Arbitrary normalization by mid rapidity



Shadowing/Nuclear absorption/Initial state parton energy loss

13

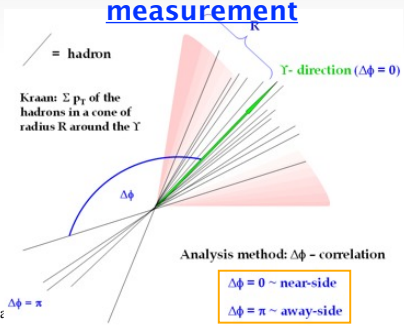
Upsilon + Hadron Correlations

- **Hadronic activity directly around the heavy quarkonium has been suggested as an experimental observable to measure the radiation emitted off the colored heavy quark pair during production.** (Kraan, A. C., arXiv:0807.3123v1 [hep-ex] 19 Jul 2008)

$\Delta\phi$ – correlation measurement

* Observation of this effect in simulation (PYTHIA).

* We search for the increase in hadronic activity coming from the radiated gluons using the similar but alternative method of "azimuthal correlations".

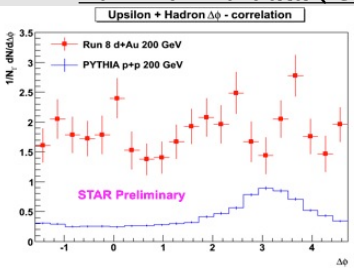


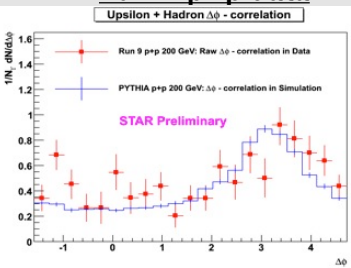
April 12, 2011 Deep Inelastic Sca

Friday, April 15, 2011

$\Delta\phi$ – correlation (*RAW): Data vs. PYTHIA

Run 8 d+Au data (left) **Run 9 p+p data**





- In d+Au data, correlation is not significant relative to the underlying-event.
- In p+p data, PYTHIA has a similar underlying-event.
- *RAW: $\Delta\phi$ – correlation is not corrected for efficiency and acceptance.

April 12, 2011 Deep Inelastic Scattering, Newport News, Virginia 13

Friday, April 15, 2011

J/ψ –> e^+e^-: results and systematic uncertainties

Luminosity normalisation

- Reference process: coincidence of V0 hits on both sides of the IP (V0and)
- Measured in van der Meer scans

Sources of systematic uncertainty

Kinematics	<1%
Track quality, #clusters TPC	10%
PID cuts	10%
Signal extraction range	4%
Luminosity normalisation	10 %
Total systematic error	**18 %**

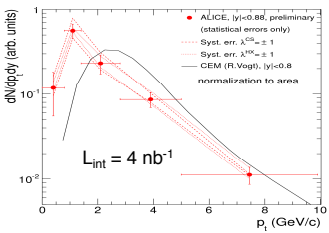
Inclusive J/ψ cross section in |y| < 0.88

Using best calibrated subset of data (L_{int} = 1.5 nb^{-1}):

$d\sigma_{J/\psi}/dy = 7.36 \pm 1.22 \pm 1.32 - 1.84 + 0.88\ \mu b$

stat. syst. syst. pol.

p_T spectrum



Systematics evaluation and normalisation of the full data set ongoing -> $d\sigma/dp_T$

J/ψ –> $\mu^+\mu^-$: results and systematic uncertainties

Luminosity normalisation

- Single muon cross section relative to minimum-bias (using V0and for absolute normalisation)

Sources of systematic uncertainty

Signal extraction	7.5 %
p_T and y shapes used in the MC	p_T: +2 -1.3%, y: +1.4 -1.3%
Trigger efficiency	4%
Tracking efficiency	2%
Luminosity normalization	10 %
Total systematic error	**13.5 %**

Integrated J/ψ cross section in -4 < y < -2.5:

$$7.25 \pm 0.29 \pm 0.98 ^{-1.50}_{+0.87}\ \mu b$$

stat. syst. syst. pol.

- Obtained with L_{int} = 13.6 nb^{-1}
- Good agreement with **LHCb result** in the same rapidity window:

  $$7.65 \pm 0.19 \pm 1.10 ^{-1.27}_{+0.87}\ \mu b$$

  (preliminary, ICHEP 2010)
- p_T and rapidity differential cross sections have also been measured (next slide)

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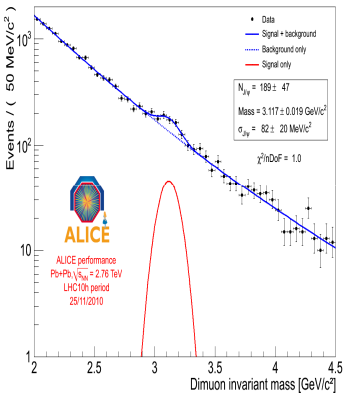
Status of J/ψ analysis in Pb-Pb collisions



First J/ψ –> $\mu^+\mu^-$ signal

2.6 M minimum-bias events

- Analysis focuses on the muon channel
- Low luminosity (~10^{25} Hz/cm²)
  -> no dedicated muon trigger needed
- About 30 M minimum-bias events on tape
- Analysis of pt-integrated (p_T>0) nuclear modification factor in progress
- Need p-p reference at $\sqrt{s}$ = 2.76 TeV
  Two strategies:
  - direct measurement in p-p collisions at 2.76 TeV in March 2011:
    34h data-taking - 9M muon triggers
  - energy interpolation
    (arXiV:1103.2394)

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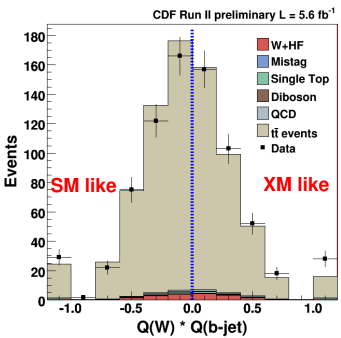
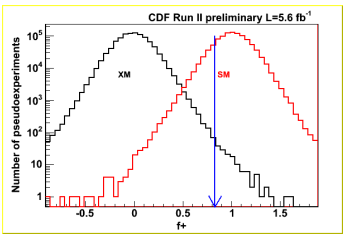
Top quark charge

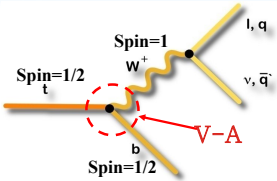
- Lepton + jets events with two b tags
- Use kinematic fit in to choose best combination of W^+b and W^-b
- Flavor tag b jets using soft leptons or jet charge
- Compare probabilities for Q=+2/3 vs. -4/3 solutions

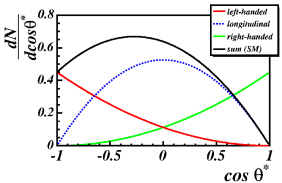




- Compare to MC trials
- Consistent with SM at 13% CL
- Exclude Q=-4/3 @95% CL

W boson polarization in top decay

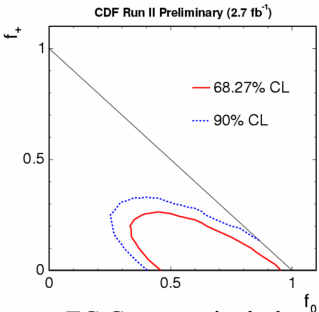




- *The SM top decays via EW interaction: Br(t→bW)~100%*
  - *Top decays as a bare quark ⇒ spin info transferred to final states*
- *V-A coupling in the SM ⇒* $F_0 \equiv BR(t \to W_0 b) \approx \frac{m_t^2}{m_t^2 + 2M_W^2} \approx 70\%, \quad F_- \approx 30\%, \quad F_+ \approx 0\%$
  - *longitudinal fraction f_0 ~70%*
  - *left-handed fraction f_- ~30%*
  - *right-handed fraction f_+ ~0%*
- *The SM prediction modified in various new physics models*
- *W polarization fractions are sensitive to non-SM tWb couplings*
- *Use cos θ* : Angle between lepton (down-type quark) in W rest frame and the momentum of the W in the top-quark rest frame*

Result from lepton+jets events

- *Simultaneous measurement:*
  - $f_0 = 0.88 \pm 0.11$ (stat) ± 0.06 (sys)
  - $f_+ = -0.15 \pm 0.07$ (stat) ± 0.06 (syst)
  - *Correlation coefficient of -0.59*
  - *As measured central values are unphysical use Feldman Cousins (FC) method to obtain confidence level intervals*
- *Model dependent measurements:*
  - $f_0 = 0.70 \pm 0.07$ (stat) ± 0.04 (syst) *constraining* $f_+=0.0$
  - $f_+ = -0.01 \pm 0.02$ (stat) ± 0.05 (syst) *constraining* $f_0=0.7$
    - *Upper limit at 95% CL :* $f_+<0.12$



FC Contours include stat+syst uncertainties

Published for PRL publication FERMILAB-PUB-10-041-E,
Phys. Rev. Lett. **105**, 042002 (2010)

NEW

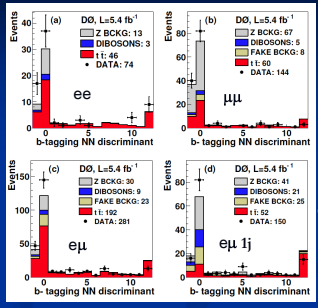
Dilepton Results

- Measured by simultaneously fitting the b-tagging NN discriminant and maximizing a binned likelihood function over all analysis channels

$\sigma_{tt}(ll) = 7.4^{+0.9}_{-0.8}$ (stat+syst) pb

m_t=172.5GeV $\delta\sigma/\sigma = 11\%$

Most precise dilepton result to-date



Preliminary

Dilepton and l+jets Combination

- Lepton + Jets and Dilepton disjoint samples are combined
  - Largest uncertainties are luminosity, b-tagging and signal modeling.

$\sigma_{tt}(ll+lj) = 7.6 \pm 0.6$ (stat+syst) pb

$\delta\sigma/\sigma = 8\%$

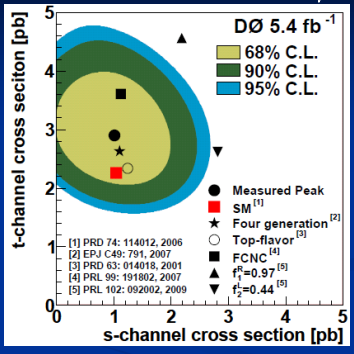
NEW

t-channel Cross Section

NEW

- MVAs optimized to maximize sensitivity to tqb (tb treated as background).
- (2D) posterior probability density as a function of tqb and tb x-sections
  - Sensitive to new physics
- tqb cross section extracted from a 1D posterior obtained by integrating over the tb axis
  - no assumptions on the s-channel x-sec or the s:t relative rate.

m_t (GeV)	cross section (pb)	
	t channel (tqb)	s channel (tb)
170	2.80+0.57-0.61	1.31+0.77-0.74
172.5	2.90±0.59	0.98+0.62-0.63
175	2.53+0.58-0.57	0.65+0.51-0.50



- $\delta\sigma/\sigma$ = 20%, 11% Systematics
  - Dominant systematics: JES, JER, b-tag eff and W_{HF} normalization

Observed significance > 5SD

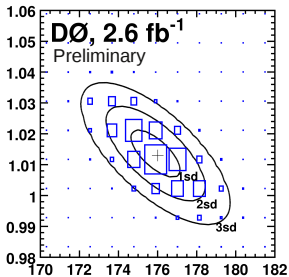
Mass of the Top Quark

NEW, Precision

- Matrix Element method (ME) calculates event probability densities (PD) from differential cross sections and detector resolutions:

$$P(x, m_t) = \frac{1}{\sigma(m_t)} \int \sum \underbrace{d\sigma(y, m_t)}_{\text{LO ME}} \, dq_1 dq_2 \, \underbrace{f(q_1) f(q_2)}_{\text{PDFs}} \, \underbrace{W(y, x, k_{\text{JES}})}_{\text{Transferfunction}}$$

- The Transferfunction relates the PD of measured set x to the partonic set y
- k_{JES} is a global factor for the Jet Energy Scale
- Selection of l+jets events, use b-tagging to increase purity of the sample
- Measurement is dominated by systematic uncertainty



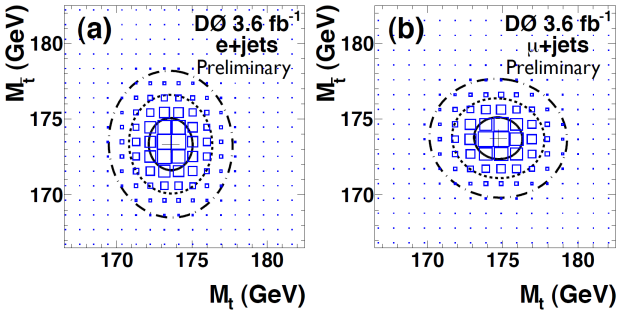
→ Most precise DØ mass measurement (3.6 fb^{-1}):

m_t = 174.9 ± 0.8 (stat.) ± 1.2 (sys.+JES) GeV

Mass of the Top Quark

NEW

- Very short lifetime of the top quark, top decays before hadronization
- Allows to test CPT invariance at the quark level



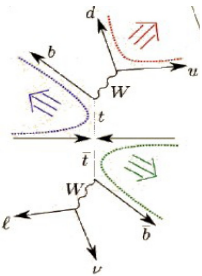
→ Measurement uses 3.6 fb^{-1}:

$\Delta M_t = 0.8 \pm 1.8$ (stat.) ± 0.8 (sys.) GeV

Colorflow in $t\bar{t}$ events

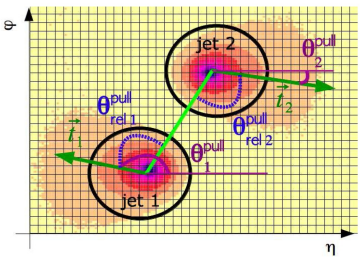
NEW

- Partons are carrying color charge, that provides additional information:
  - Singlet: $H^0 \rightarrow b\bar{b}$ or Octet: $g \rightarrow b\bar{b}$
- Choose $t\bar{t}$ decay channel as an optimal playground:



$W \rightarrow q\bar{q}$ (singlet)

b-jet (octet), color connected to the beam



- Fraction of events with light jets coming from singlet W: $f_{Singlet}$ (=1 in SM)
- Total systematic uncertainty is 0.22, statistically limited

→ $f_{Singlet}$ = 0.56 ± 0.38 (stat.+sys.) ± 0.19 (MC stat.)

http://arxiv.org/abs/1101.0648

Cross section estimation **1-lepton with b-tag**

- Systematic uncertainties: Total=**11%**
  - Jet reconstruction (Energy Scale) : 6%
  - Heavy flavor fraction in W+jets : 7%
  - B-tagging efficiency : 7%
  - Initial & Final state radiation : 4%

- Cross section estimation

$$186 \pm 10\ ^{+21}/_{-20} \pm 6\ \text{pb}$$

* **Statistical error**, * **Systematic error**, * **Luminosity uncertainty**

  - $\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ =**13%**

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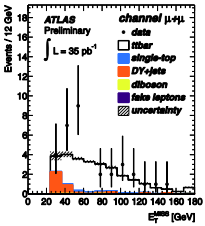
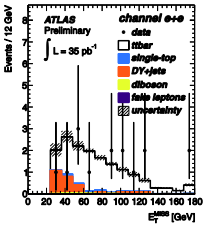
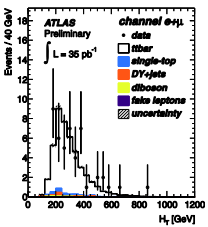
Cross section estimation 2-lepton with b-tag

- Selection criteria
  - Require at least 1 b-jet loosen other selections
    - B-tagging algorithm with respect to transverse impact parameter are used.
- Systematic Uncertainty
  - B-tagging efficiency 7%
  - Jet reconstruction 5%







$$171 \pm 22\ ^{+21}/_{-16}\ ^{+7}/_{-6}\ \text{pb}$$

Statistical error, **Systematic error**, **Luminosity uncertainty**

$\delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}}$ **=17%**

- In agreement with pre-tag results
- Large fraction of $t\bar{t}$ signal

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Dileptonic: results 1/2

Systematic uncertainties :

- For signal selection: cf. table
  (given in percent, the sources are uncorrelated, the channels are 100% (anti)correlated)
- For backgrounds:
  - extracted from the data-driven methods
  - assigned conservatively from the MC simulation
- For luminosity uncertainty: 4%

	$N_{jet} = 1$		$N_{jet} \geq 2$	
Source	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$	$e^+e^- + \mu^+\mu^-$	$e^\pm\mu^\mp$
Lepton selection	1.91/1.30	1.11	1.91/1.30	1.11
Energy scale	−3.0	−5.5	3.8	2.8
Lepton selection model	4.0	4.0	4.0	4.0
Branching ratio	1.7	1.7	1.7	1.7
Decay model	2.0	2.0	2.0	2.0
Event Q^2 scale	8.2	10	−2.3	−1.7
Top-quark mass	−2.9	−1.0	2.6	1.5
Jet and $\not{E}_T$ model	−3.0	−1.0	3.2	0.4
Shower model	1.0	3.3	−0.7	−0.7
Pileup	−2.0	−2.0	0.8	0.8
Subtotal (before tags)	11.2/11.1	13.1	8.0/7.9	6.2
b tagging ($\geq$ 1 b tag)			5.0	5.0
Subtotal with tags			9.5/9.4	8.0
Luminosity	4	4	4	4

Final state	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
At least two jets, no b-tagging requirement			
Events in data	23	28	60
All backgrounds	5.5 ± 2.3	9.5 ± 4.3	6.7 ± 2.0
Cross section, pb	$189 \pm 52 \pm 29 \pm 8$	$159 \pm 45 \pm 39 \pm 6$	$160 \pm 23 \pm 12 \pm 6$
At least two jets, at least one b-jet			
Events in data	15	24	51
All backgrounds	2.3 ± 1.4	3.8 ± 2.0	3.0 ± 1.4
Cross section, pb	$150 \pm 46 \pm 22 \pm 6$	$186 \pm 45 \pm 25 \pm 7$	$156 \pm 23 \pm 13 \pm 6$
One jet, no b-tagging requirement			
Events in data	8	10	18
All backgrounds	2.1 ± 0.7	7.1 ± 4.3	4.9 ± 1.5
Cross section, pb	$282 \pm 135 \pm 45 \pm 11$	$107 \pm 119 \pm 163 \pm 4$	$200 \pm 65 \pm 35 \pm 8$

Results:

9 cross sections are obtained

2 jets 1 b-tag: more precise than without b-tag for the ee and μμ channels (but not for the eμ channel)

1 jet no b-tags: less precise but improves the combined result

Combination

Combining the results, using the BLUE technique:

- dileptonic : 168 ± 18 (stat) ± 14 (syst) ± 7 (lumi) pb
- semi-leptonic : 150 ± 9 (stat) ± 17 (syst) ± 6 (lumi) pb

→ $\sigma_{t\bar{t}}$(CMS) =
158 ± 10 (unc.) ± 15 (cor.) ± 6 (lumi) pb

where unc. : statistical uncertainties + background modelling in the dileptonic analysis

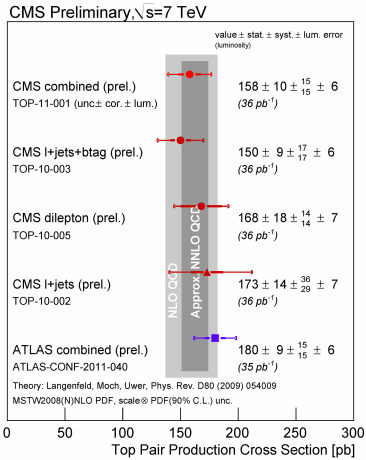
cor.: all the other uncertainties

This result is consistent with the theoretical $t\bar{t}$ cross section at approximate NNLO :

$\sigma_{t\bar{t}}$(HATHOR)= 164^{+5}_{-9} (scale) $^{+9}_{-9}$ (pdf) pb

$\sigma_{t\bar{t}}$(Kidonakis)= 163^{+7}_{-5} (scale)$^{+9}_{-9}$ (pdf) pb

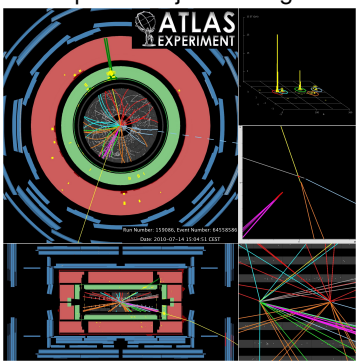
and more precise than the NLO theory uncertainty



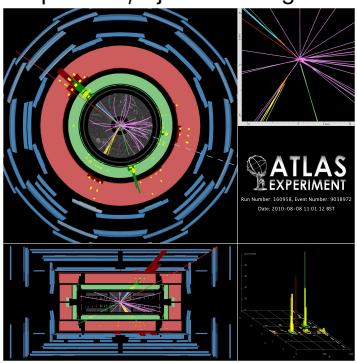
$t\bar{t}$ semi and dileptonic events

☞ top candidates seen in ATLAS:

semileptonic e+jets w/btag



dileptonic $e\mu$+jets w/2 btag

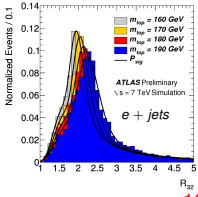


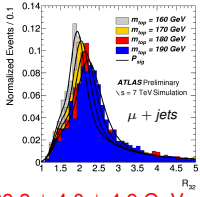
6 / 20

Top quark mass

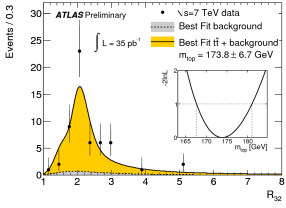
- 3 complementary methods developed to reduce JES uncertainty on top mass measurement.
- The 1D template analysis to measure the top quark mass is based on the ratio:

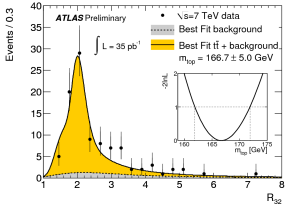
$$R_{32} = \frac{m_{top}^{reco}}{m_W^{reco}} = \frac{m_{jjb}}{m_{jj}} \text{ (low sensitivity to JES)}$$





$m_{top} = 169.3 \pm 4.0 \pm 4.9$ GeV



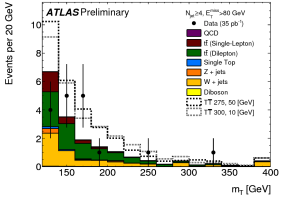


Dominant systematics

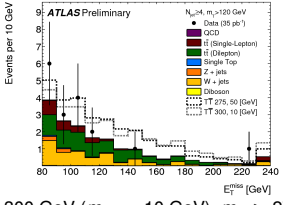
	Uncertainty [GeV]	
	Electron channel	Muon channel
Statistical uncertainty	6.7	5.0
ISR and FSR (signal only)	2.2	2.6
Jet energy scale ($\pm 1\sigma$) plus 5% for close by jets	2.3	1.9
b-jet energy scale ($\pm 2.5\%$)	2.5	2.5
Total systematic uncertainty	4.8	5.0

$t\bar{t}$ + anomalous E_T^{miss}

- No disagreement between data and SM expectation:



Source	Yield
Single-Lepton $t\bar{t}/W$	8.4 ± 1.6
Dilepton $t\bar{t}$	7.6 ± 2.0
Z+jets	0.4 ± 0.1
Dibosons	$0.2 \pm <0.1$
Single Top	0.4 ± 0.1
QCD	0.2 ± 0.6
Total Background	17.2 ± 2.6
Data	17



Systematics	Relative Error
Dilepton $t\bar{t}$, Single Top, Dibosons, Z+jets	
Cross Section	15%
Dilepton Veto	15%
Jet Energy Scale & Resolution	11%
Luminosity	3.4%
Lepton ID	3%
Monte Carlo Statistics	1%
Total	25% (2.1 events)
Single Lepton Backgrounds	
Spread in $S(m_T)$	15%
Normalization	10%
b-Tag Veto	3%
QCD Shape	1%
Total	18% (1.6 events)
QCD	
Normalization in Control Regions	100%
Muon Statistics	0.6 events
Total	0.6 events

- $m_T > 300$ GeV ($m_{A_0} = 10$ GeV), $m_T > 275$ GeV ($m_{A_0} = 50$ GeV) exclusion at 95% CL

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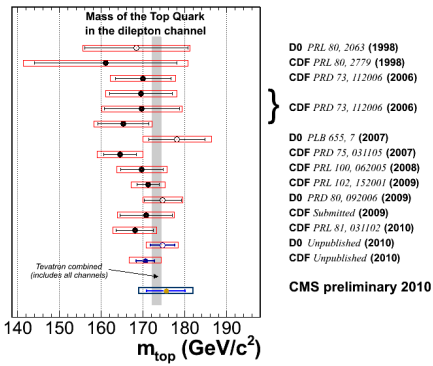
Conclusions

- **First top quark mass measurement which was not performed at the Tevatron**
- The **dilepton channel** is used
  - **Lower background** contamination
  - **Underconstrained system**
- Two different **template-based methods** compared: KINb and AMWT
  - Similar uncertainties (stat. and syst.) expected in both cases
  - Use of b-tagging information and combination of fits improves resolution



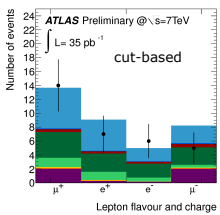
Measurement is the outcome of the first year of data taking/analysis in CMS

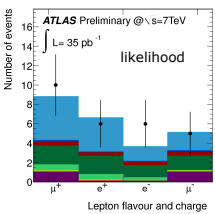
All details in CMS-PAS-TOP-10-006

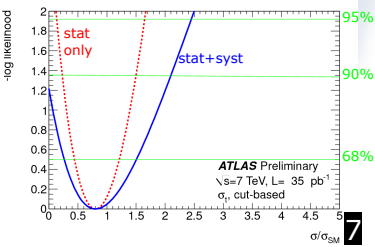
t-channel Results

- Combine e+μ, then separate into +/- charge samples to improve sensitivity
- Performance of the cut-based and likelihood analyses is very similar, use cut-based as baseline

- Cross-section/limit extraction based on profile likelihood ratio
- Find $\sigma_t = 53^{+27}_{-24}$ **(stat)**$^{+38}_{-27}$ **(syst) pb** [1.6σ obs 1.9σ exp]
  - Translates to σ_t < 182 pb @ 95% CL
  - Dominant uncertainties: jet energy scale, b-tagging, W+jets normalization





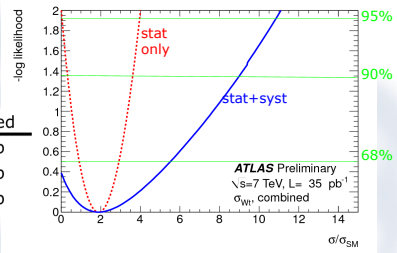


Combined Wt-channel Result

Total of **9** orthogonal final states (e/μ+2/3/4 jets, ee/eμ/μμ+1 jet)

- Set limits using profile likelihood ratio:

95% CL Upper Limit	Expected	Observed
Lepton+jets	123 pb	198 pb
Dilepton	112 pb	110 pb
Combined	94 pb	158 pb



- Expected (observed) limit on σ_{Wt} corresponds to 6.3 (10.5) times the SM expectation
- Dominant sources of uncertainty
  - Lepton+jets: jet energy scale, b-tagging
  - Dilepton: jet energy scale, initial/final state radiation modeling
  - Signal statistics also quite important for both analyses

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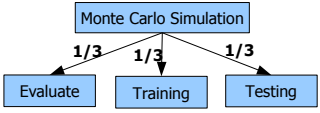
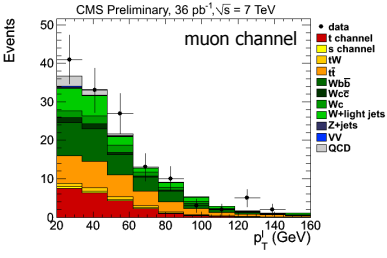
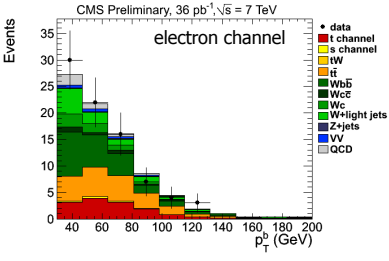
BDT Analysis

- 37 well-modelled input variables in 5 categories:
  - **Kinematics** of final-state objects
  - **Correlations** of final-state objects
  - Properties of **reconstructed W, t, t+q**
  - **Angular distributions** of l,j wrt W,t,t+q
  - **Global event properties**



- **Performed Kolmogorov-Smirnov-Test on W-enriched control sample for each variable: obtained good description of all input variables**





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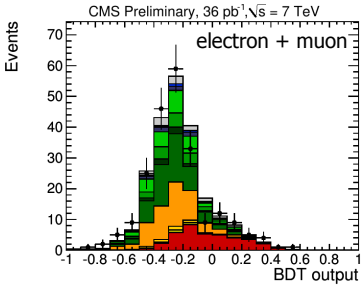
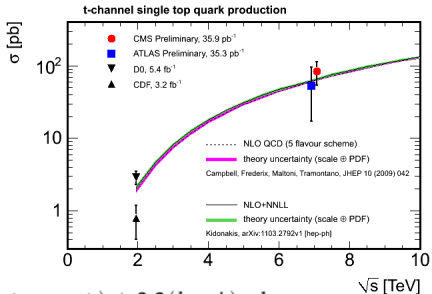
Conclusion





$$\sigma = 83.6 \pm 29.8(stat. + syst.) \pm 3.3(lumi.)\ \text{pb}$$

Observed significance: 3.5σ (BDT) and 3.7σ (2D)

- **First measurement of single top quark t-channel production at 7 TeV**
- **First measurement of single top quark t-channel without MVA**
- **Consistent with Standard Model**
- **36% precision with 2010 data**

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W'→tb : results

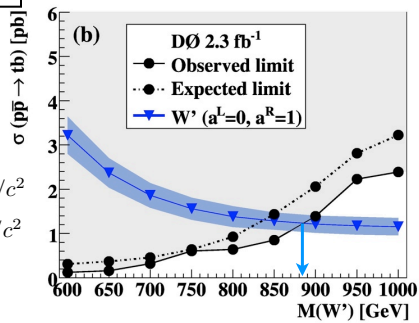
- Couplings to first and third generation quarks taken as equal
- for each W' mass, construct signal templates varying left/right-handed couplings between 0 and 1 in step of 0.1

Pure right-handed couplings of W'

$M(W')>M(\nu_R)$: $M(W')>885$ GeV/c^2

$M(W')<M(\nu_R)$: $M(W')>890$ GeV/c^2

at 95 % C.L.



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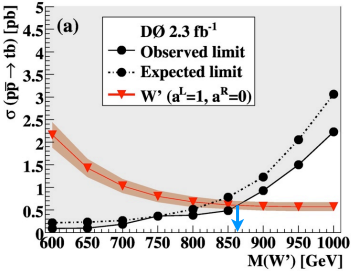
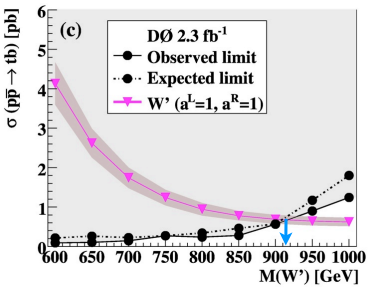
W'→tb : results

Pure left-handed W'



Mixed couplings W'



$M(W')>863\ \mathrm{GeV}/c^2$ $M(W')>916\ \mathrm{GeV}/c^2$

at 95 % C.L.

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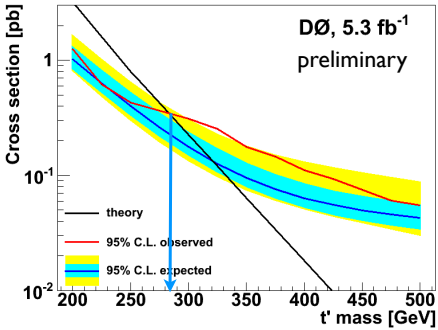
4th generation t' quark : limits



$$M(t') \leq 285\mathrm{GeV}/c^2 \text{ @ } 95\% \text{ C.L.}$$

- we achieve the best fit to the data with a t't' production cross section of 1.1+/-0.5 times the theoretical cross section for $m_{t'}$ = 325 GeV (2.2 standard deviations)

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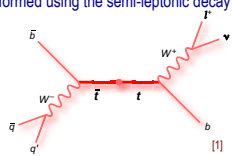
Introduction

Many extensions of the Standard Model predict gauge interactions whose couplings with the top quark are enhanced. The resulting new particles could show up as resonances in the $t\bar{t}$ mass distribution and not in other channels.

The search for such resonances is performed using the semi-leptonic decay of the $t\bar{t}$ pair.



BR(t→Wb) ≈ 0.99
$t\bar{t}$ semileptonic (e,μ) BR ≈ 0.34

Signature and backgrounds

Energetic and isolated muon/electron in an energetic hadronic environment with two heavy flavour jets.

Main backgrounds:

- SM $t\bar{t}$ production
- W bosons plus jets
- Single t quark production
- QCD

QCD and W plus jets can be suppressed by requiring the lepton isolation and at least three energetic jets respectively.

[1] http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_feynman_diagrams.html

Measurement of the top pair invariant mass distribution at 7 TeV and search for new physics with the CMS experiment

Comparison data and MC – muon case

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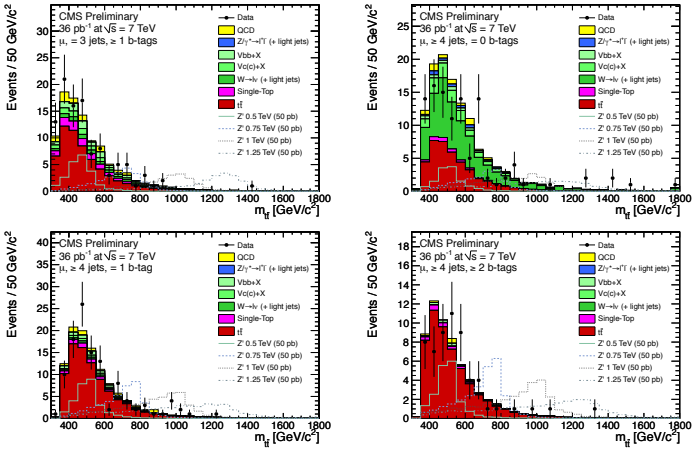

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Measurement of the top pair invariant mass distribution at 7 TeV and search for new physics with the CMS experiment

Statistical description – limit setting on Z' production

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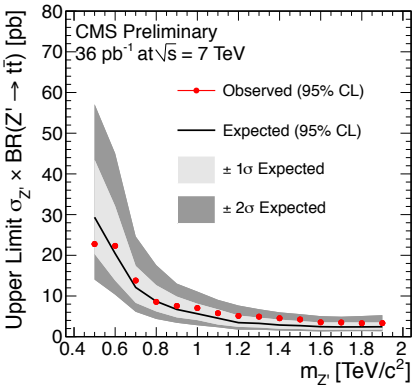

Expected limits range

- ~30 pb ($M_{Z'}$ = 0.5 TeV)
- ~3 pb ($M_{Z'}$ > 1.5 TeV)

Observed and expected limits are compatible within one standard deviation except for the 1.5 TeV region where the observed limits are slightly higher than the one sigma band.

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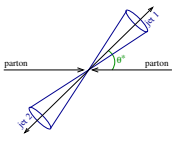
Di-Jet Mass and Angular Distributions

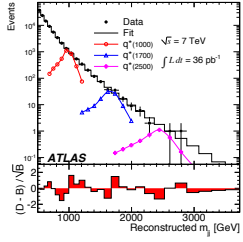
- consider events with two high energy jets recoiling back-to-back



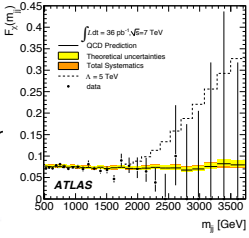
$$y^* = \frac{1}{2}(y_1 - y_2) = \frac{1}{2}\ln\frac{1+|cos\theta^*|}{1-|cos\theta^*|}$$

$$F_\chi = \frac{N_{events}(|y^*| < 0.6)}{N_{events}(|y^*| < 1.7)}$$

→ bump search: invariant mass $\mathbf{m_{jj}}$
→ non-resonance: angular dist., e.g. $\mathbf{F_\chi(m_{jj})}$

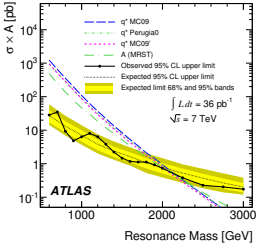


- no evidence for a bump in the m_{jj} distribution, no any deviation in the angular dist. (χ^2-test, p-value 0.88)
  ⇒ exclusion limits

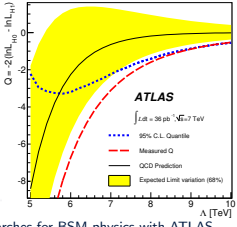


Di-Jet Exclusion Limits

observable	M_X,TeV upper limit @ 95% C.L. expected	observed
	excited quark q^*	
m_{jj}	2.07	2.15
$F_\chi(m_{jj})$	**2.12**	**2.64**
Randall-Meade quantum black hole for n=6		
m_{jj}	**3.64**	**3.67**
$F_\chi(m_{jj})$	3.49	3.78
	axigluon	
m_{jj}	**2.01**	**2.10**
	contact interaction Λ	
$F_\chi(m_{jj})$	**5.72**	**9.51(6.7)***



- * 9.51 TeV: CL_{s+b}, within 2σ, 6.7 TeV: Bayesian as a check
- excited quark: M > 870 GeV (CDF, Phys.Rev. D79 112002, 2009)
- axigluon: M > 1250 GeV (CDF, Phys.Rev. D79 112002, 2009)
- contact interaction: Λ > 2.9 TeV (DØ, Phys.Rev.Lett. 103:191803, 2009)



Search with Di-Lepton + Di-Jets

- **leptoquark** carries lepton & quark quantum numbers
- β = branching fraction of a leptoquark to a charged lepton
  $\rightarrow \ell\ell$jj, $\ell\nu$jj final states
- observables:

$\rightarrow$ leptoquark (trans.) inv. mass

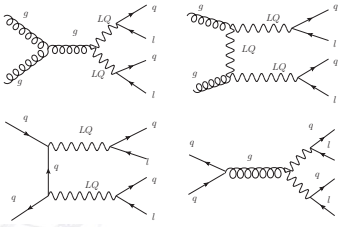
$\rightarrow$ $S_T^{\nu} = p_T{}^{\ell_1} + E_T^{miss} + p_T{}^{j_1} + p_T{}^{j_2}$

$\rightarrow$ $S_T^{\ell} = p_T{}^{\ell_1} + p_T{}^{\ell_2} + p_T{}^{j_1} + p_T{}^{j_2}$

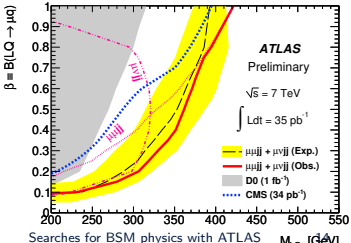
- upper limits @ 95% C.L.:

β	$M_{1.gen}$	$M_{2.gen}$
0.5	319 GeV	362 GeV
1.0	376 GeV	422 GeV

- DØ: Phys Lett B 671 224, 2009

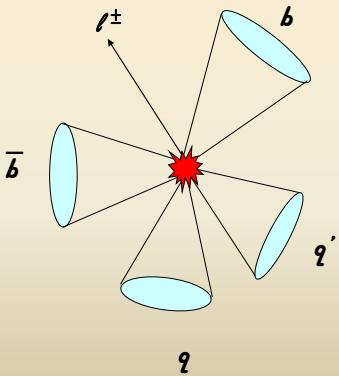


2nd generation

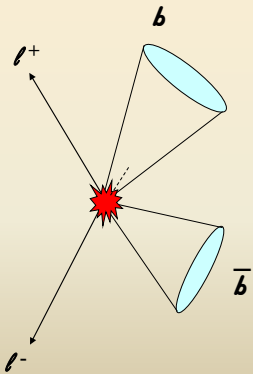


$t\bar{t}$ decay channels used

Lepton + Jets, LJ



Di-lepton, DIL



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tt rest frame asymmetry

Δy_{tt}

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

$$= \frac{N(y_t^{t\bar{t}} > 0) - N(y_t^{t\bar{t}} < 0)}{N(y_t^{t\bar{t}} > 0) + N(y_t^{t\bar{t}} < 0)}$$

A_{fb} summary, LJ

- Inclusive A in lab and tt frames in 2 sigma excess over SM
- Consistent with CP conservation
  - consistency between positive and negative lepton samples
- A^{tt} has a strong dependence on Δy, M_{tt}
- For $M_{tt} > 450$ GeV/c^2

$$A^{tt}_{reco} = 0.210 \pm 0.049, \quad A^{tt}_{parton} = 0.475 \pm 0.112$$

$$A^{tt}_{NLO\ reco} = 0.043 \pm 0.006, \quad A^{tt}_{MCFM} = 0.088 \pm 0.013$$

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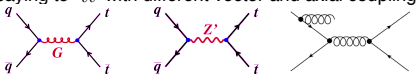
Charge Asymmetry

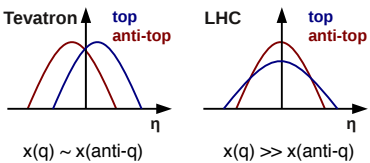
- The charge asymmetry provides the possibility to search for the unknown top quark production mechanisms
- Sources of asymmetry: new particles decaying to $t\bar{t}$ with different vector and axial couplings, interference with SM processes



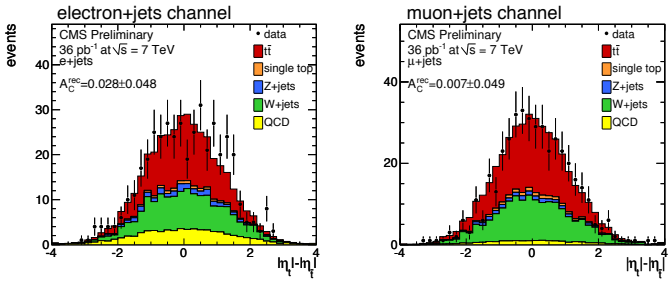
  - top (anti-top) quarks preferably emitted in quark (anti-quark) direction

- The asymmetry appears only for asymmetric initial states - at LHC, the asymmetric initial states like $q\bar{q}$ are still possible, with the anti-quark coming from the sea quarks, but these events have a much smaller probability

- Proton-antiproton (Tevatron) - quark (anti-quark) are mainly from proton (antiproton).
  - the measured forward-backward asymmetry shows 2-3 σ deviation from the SM prediction



Uncorrected A_C



- By combining the electron+jets and muon+jets channels: **A_C^{rec}=0.018±0.034(stat)**

- The measured value may be distorted by several effects:
  - the **amount of background .** When subtracted, **$A_C^{bkg\text{-}subtr}$=0.035±0.070(stat)**
  - **smearing**: reconstructed $|\eta_t| - |\eta_{\bar{t}}|$ does not directly correspond to true value
  - **lepton efficiency**

Systematics Results

- Only systematics influencing the direction of the reconstructed top quark momenta can change the charge asymmetry value.
- Systematics are evaluated by drawing pseudo-experiments from systematically shifted templates

source of systematic	positive shift in A_C	negative shift in A_C
jet energy scale	0.017	-
jet energy resolution	0.007	-0.006
Q^2 scale	0.003	-0.007
ISR/FSR	0.005	-0.0006
matching threshold	0.004	-0.006
PDF	0.004	-0.011
b tagging	0.007	-
lepton efficiency	0.017	-0.018
QCD model	0.005	-0.005
overall	± 0.026	

$$A_C = 0.060 \pm 0.134(\text{stat})^{+0.028}_{-0.025}(\text{syst})$$

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