HFS and QCD working group summary

Alberto Accardi, Sabine Lammers, Daniel Traynor

Our preferences and my understanding.
errors and omissions excepted.

Overview

- 49 talks, 13 different experiments and 13 theory talks.
- Several themed sessions:
  - Tuesday - jets cross sections, tests of QCD and extraction of α_s.
  - Wednesday - simi inclusive particle production with protons and neutrons and strangeness production.
  - Thursday morning - physics with photons and bosons.
  - Thursday afternoon - low x and parton dynamics.
- Several interesting talks beyond the standard topics.

+wide variety of

Theory

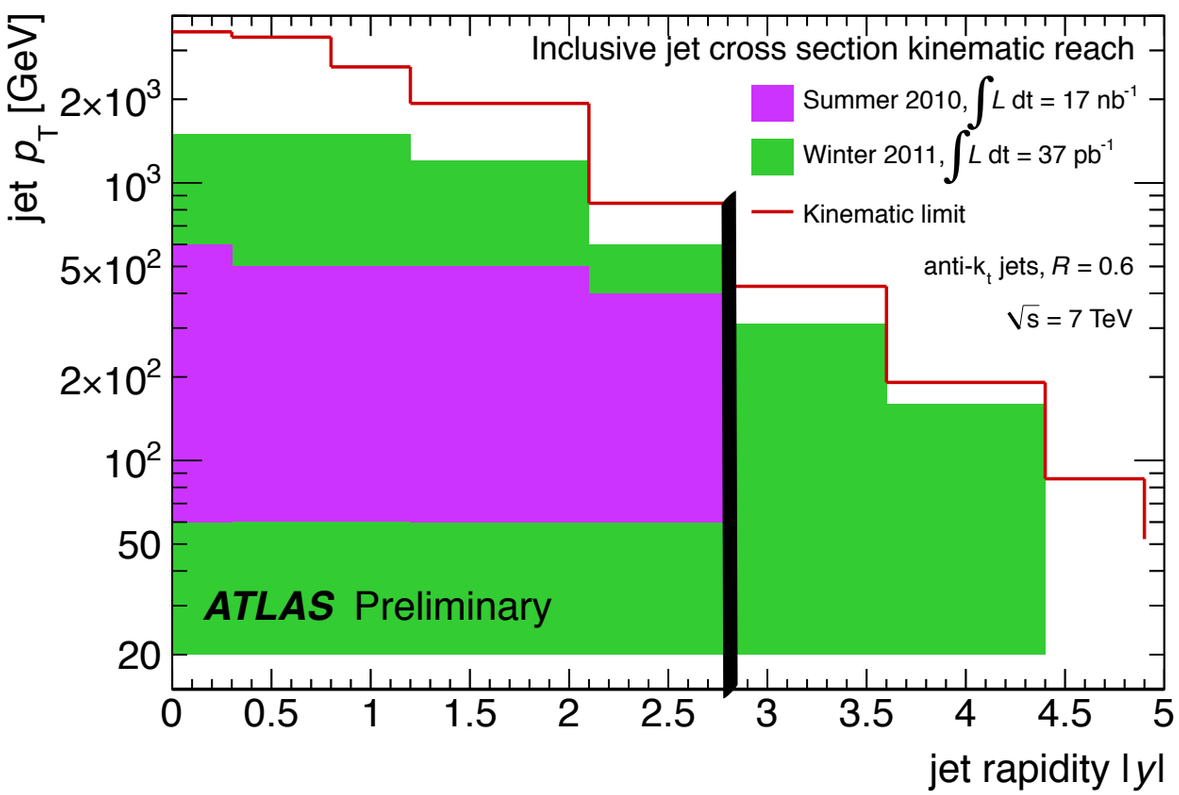
CLAS@ Jefferson Lab

Jets

Measurement of jet cross sections in ATLAS

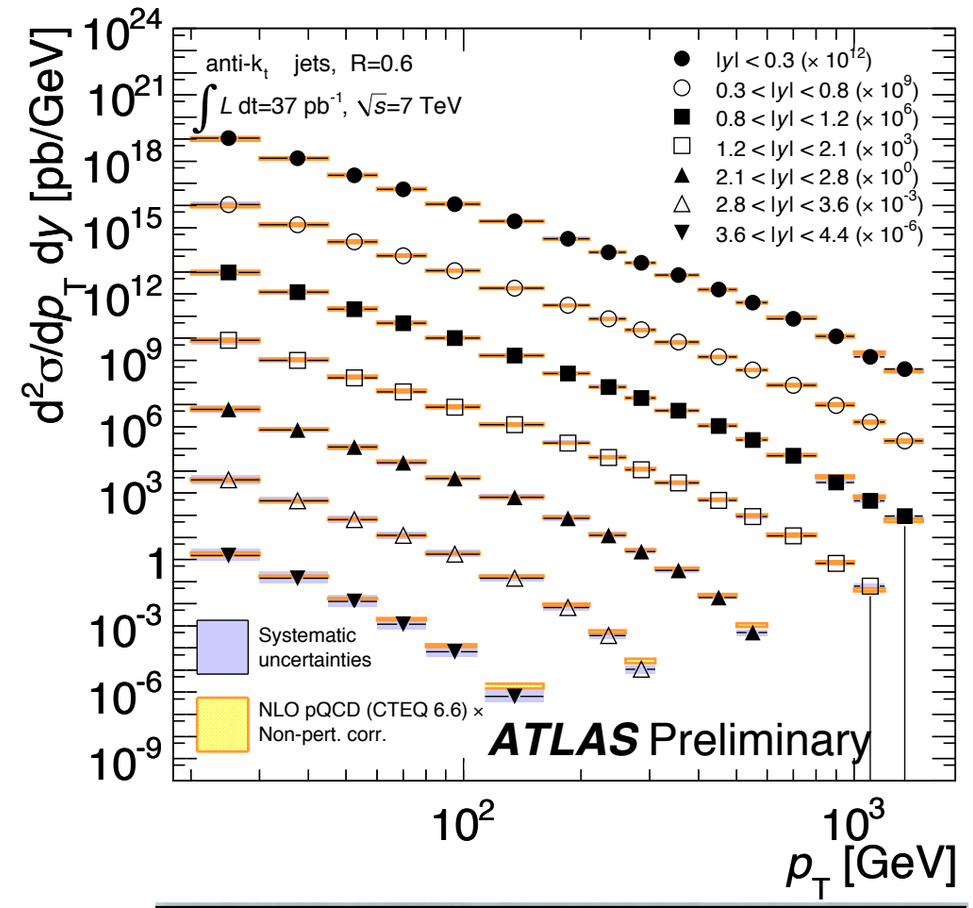
J. Poveda (University of Wisconsin-Madison)
on behalf of the ATLAS Collaboration

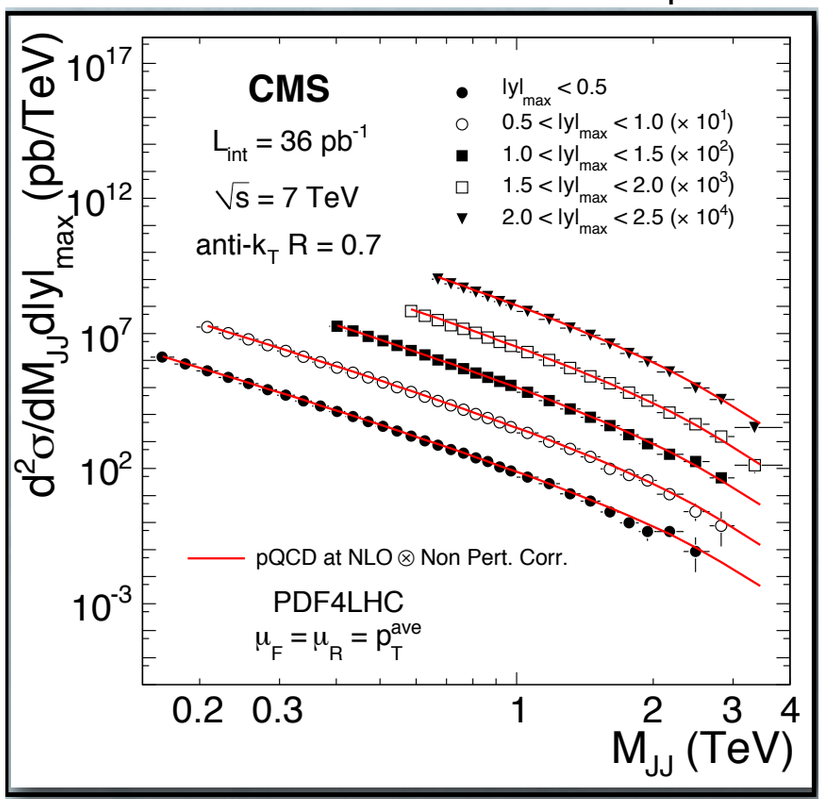
- Important extension from the previous published results:
  - Inclusive jet p_T measurement extended to 1.5 TeV
  - Dijet mass extended to 4.1 TeV
  - Extended coverage to low-p_T and high-rapidity regions



- Large rapidity region is sensitive to the choice of PDF
- CTEQ6.6 is disfavored; MSTW, NNPDF2.1 and HERAPDF 1.5 agree better with data

Anti-k_T $R = 0.6$





$8 \cdot 10^{-4} \leq x_1 \cdot x_2 \leq 0.25$

Jet Results from CMS

Cosmin Dragoiu

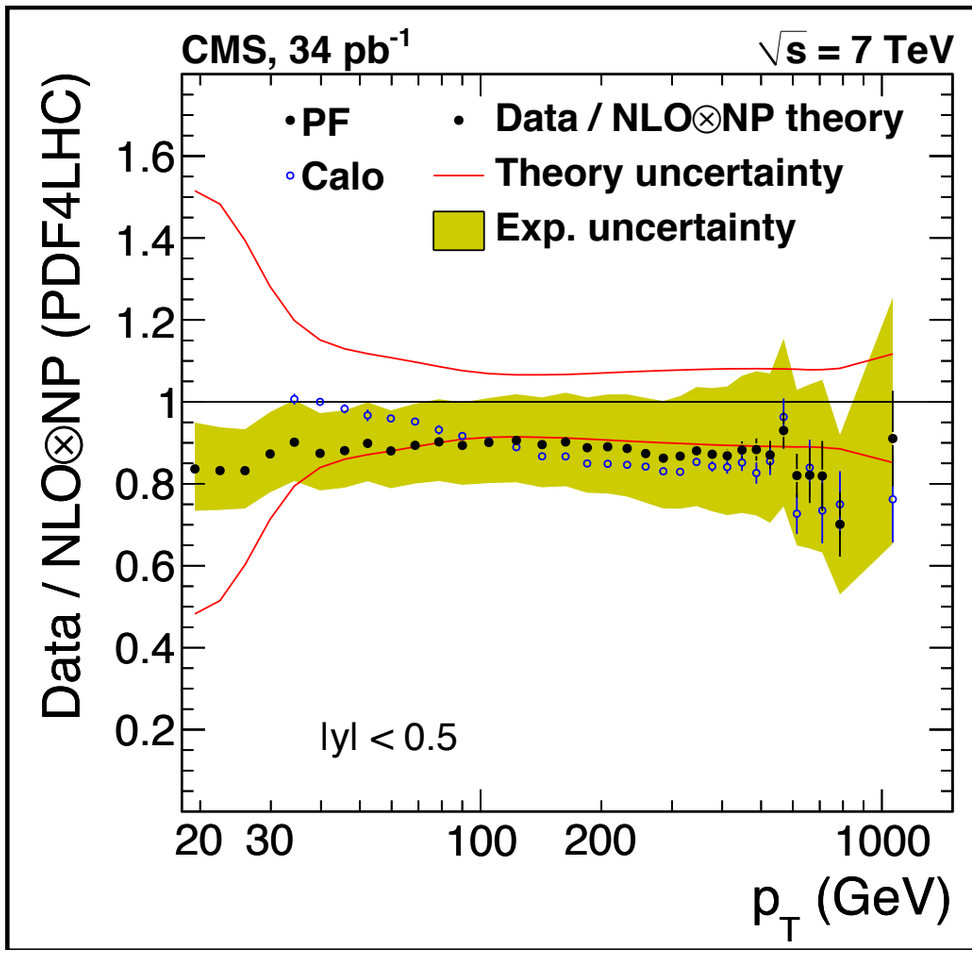
University of Illinois at Chicago

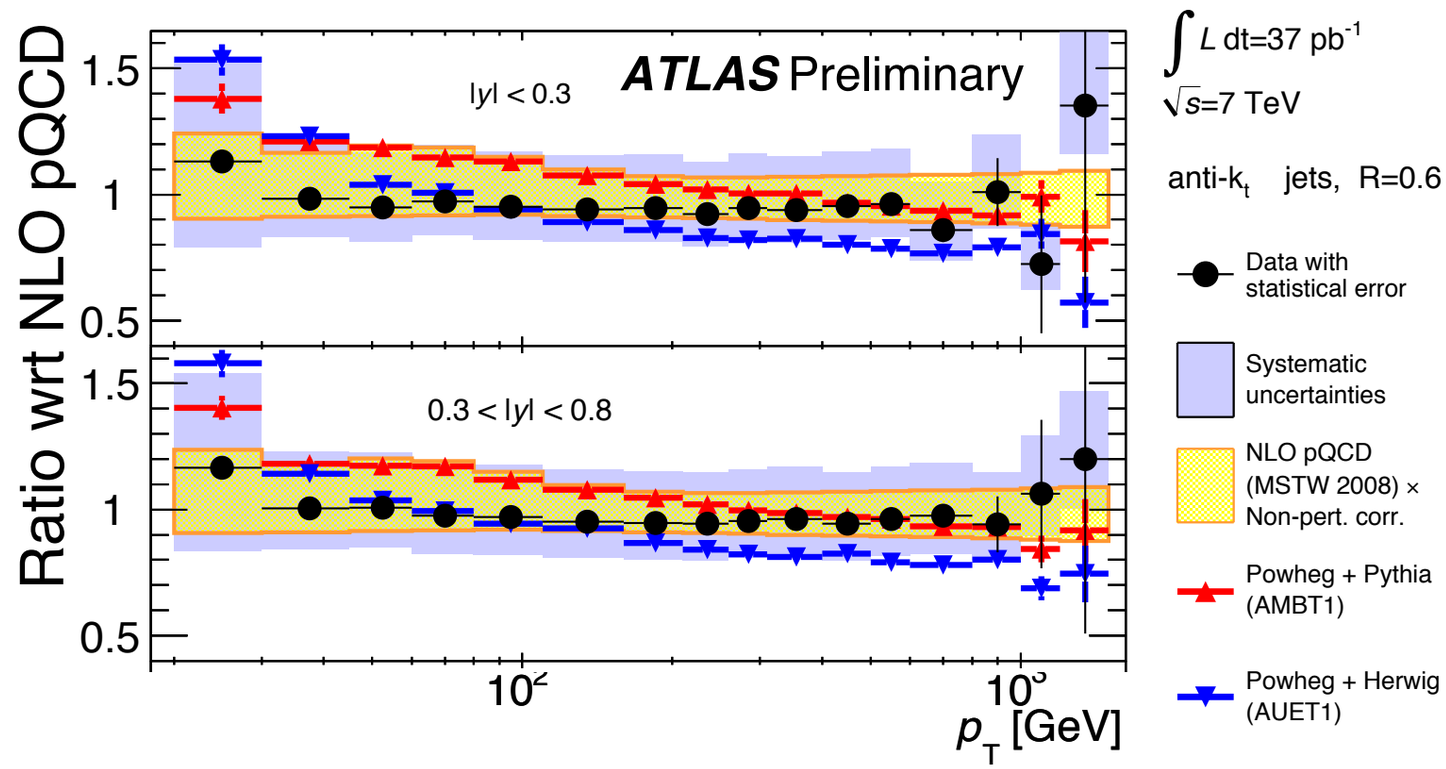
Multi jet measurements with the CMS detector at $\sqrt{s}$ =7 TeV

Joanna Weng

(ETH Zurich)

CMS vs ATLAS





Different cross section definition - pt, eta, R.

Different theory - PDFs, α_s, (scale)

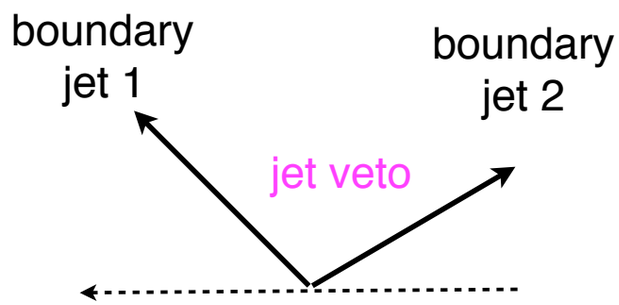
Dijet and Multi-jet Cross Sections Measurements in ATLAS Long Zhao (NYU)

The dijet cross-section with a jet veto

Simone Marzani
University of Manchester

Motivation :

- BFKL-like dynamics for large jet rapidity separation.
- Effect of wide-angle soft-gluon radiation in the limit that the average dijet transverse momentum is much larger than the scale used to veto on additional jet.
- Background for Higgs production via vector boson fusion.



Dijet production with a veto on additional radiation (with a scale) in the rapidity interval

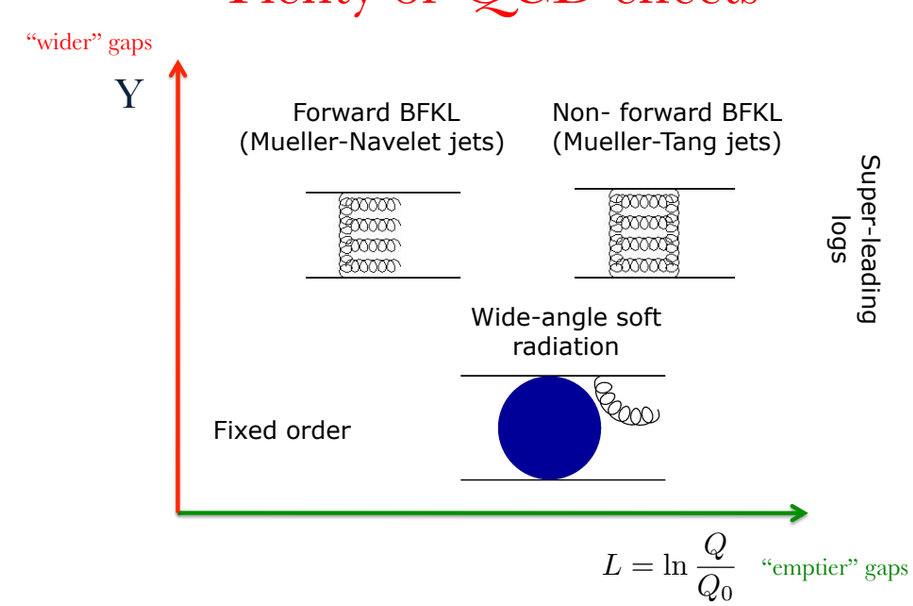
Boundary jets:

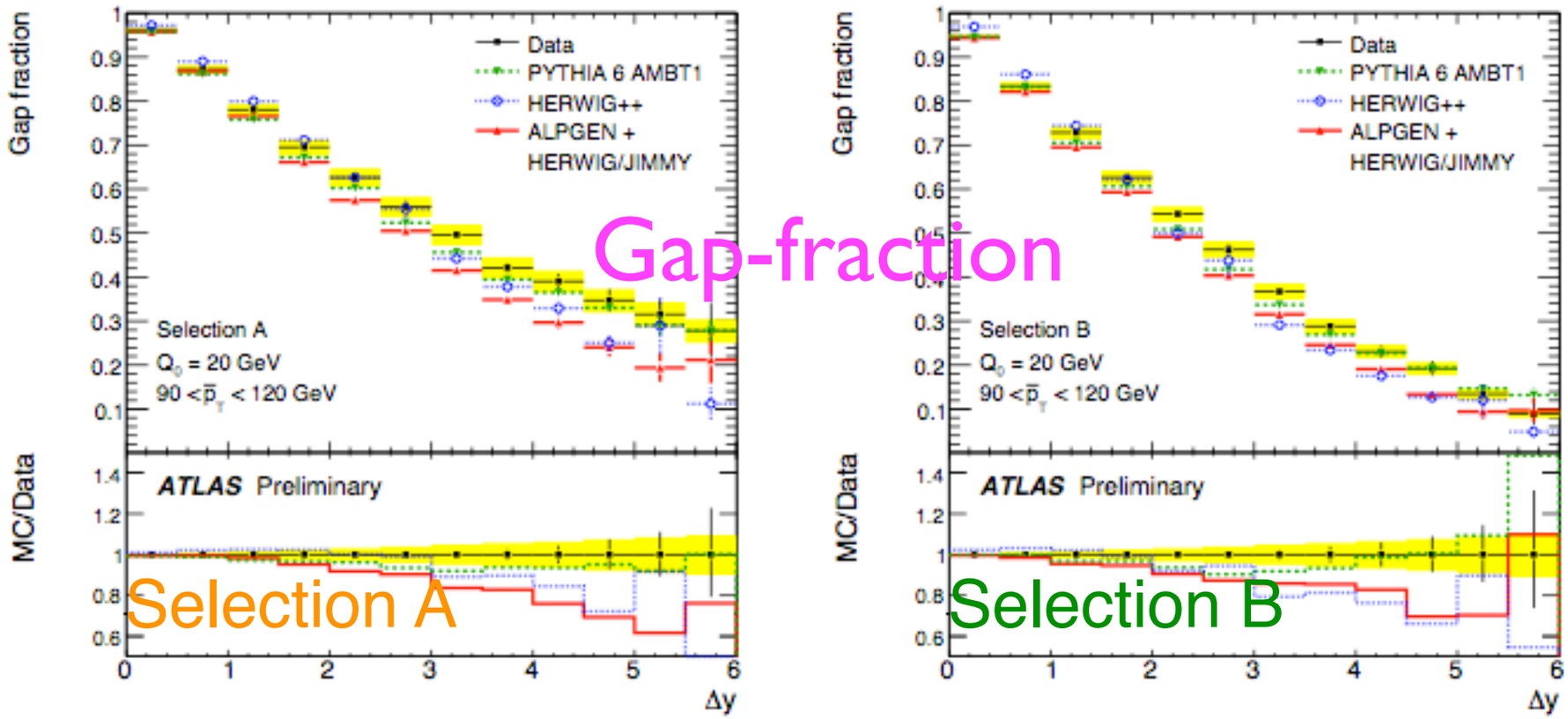
Selection A Use the two leading jets ⟶ wide-angle gluon radiation

Selection B Use the two jets with largest absolute rapidity ⟶ BFKL-like dynamics

physics:

Plenty of QCD effects



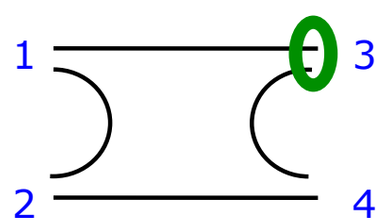


Gap-fraction

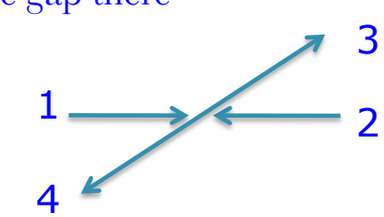
Selection A

Selection B

Colour radiation in Herwig++



- The colour partner of gluon 3 is chosen in each event between 1 and 4 with equal probability
- If the partner is on the same side of the gap there is very little radiation



- Inclusive interjet radiation

$$\text{jets}\ 4 \times \frac{1}{2} \times \frac{1}{2} \times N_c = N_c$$

dipole

partner across the gap

- Suppression factor for radiation in the gap

$$e^{-N_c \rho \xi} \left[\frac{1}{2} + \frac{1}{2} e^{-N_c Y \xi} \right]^4 \simeq \frac{1}{16} e^{-N_c \rho \xi}$$

- This vanishes slower than the soft gluon exponential

$$\sim \sum_i e^{-N_c(\rho + A_i Y)\xi}, \quad A_i > 0$$

- This led to a modification of the Herwig++ parton shower

Schofield and Seymour
arXiv:1103.4811

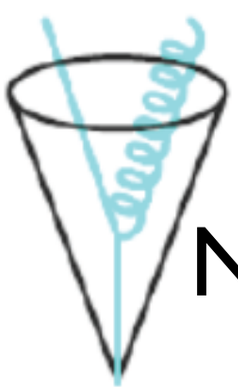
Zhao Li
Michigan State University

Event shapes

To discriminate QCD jets from boosted top jet or New Physics signal, we need to study jet substructure

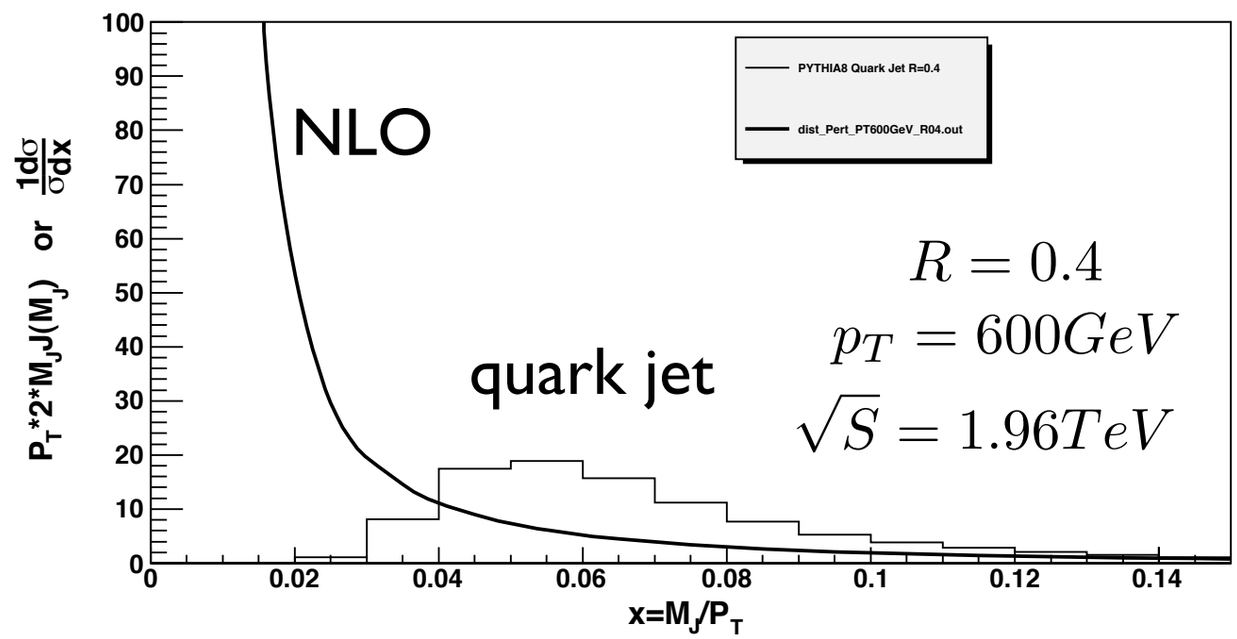
Various Theoretical Predictions

- **Event Generators**: leading log radiations, hadronization, underlying events, etc.
- **Fixed order QCD calculation**: finite number of soft/collinear radiations
- **Resummation**: all order soft/collinear radiations

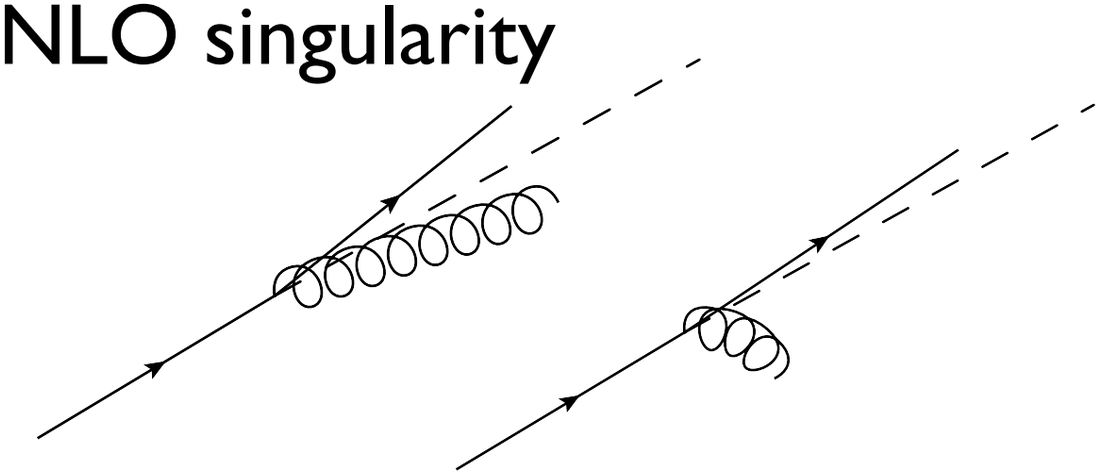


NLO

Fixed order prediction has singularity at MJ->0



NLO singularity



Resummation for Jet function (jet mass distribution)

In fixed order calculations, there are large logarithmic terms of the ratio of jet pT to jet mass,

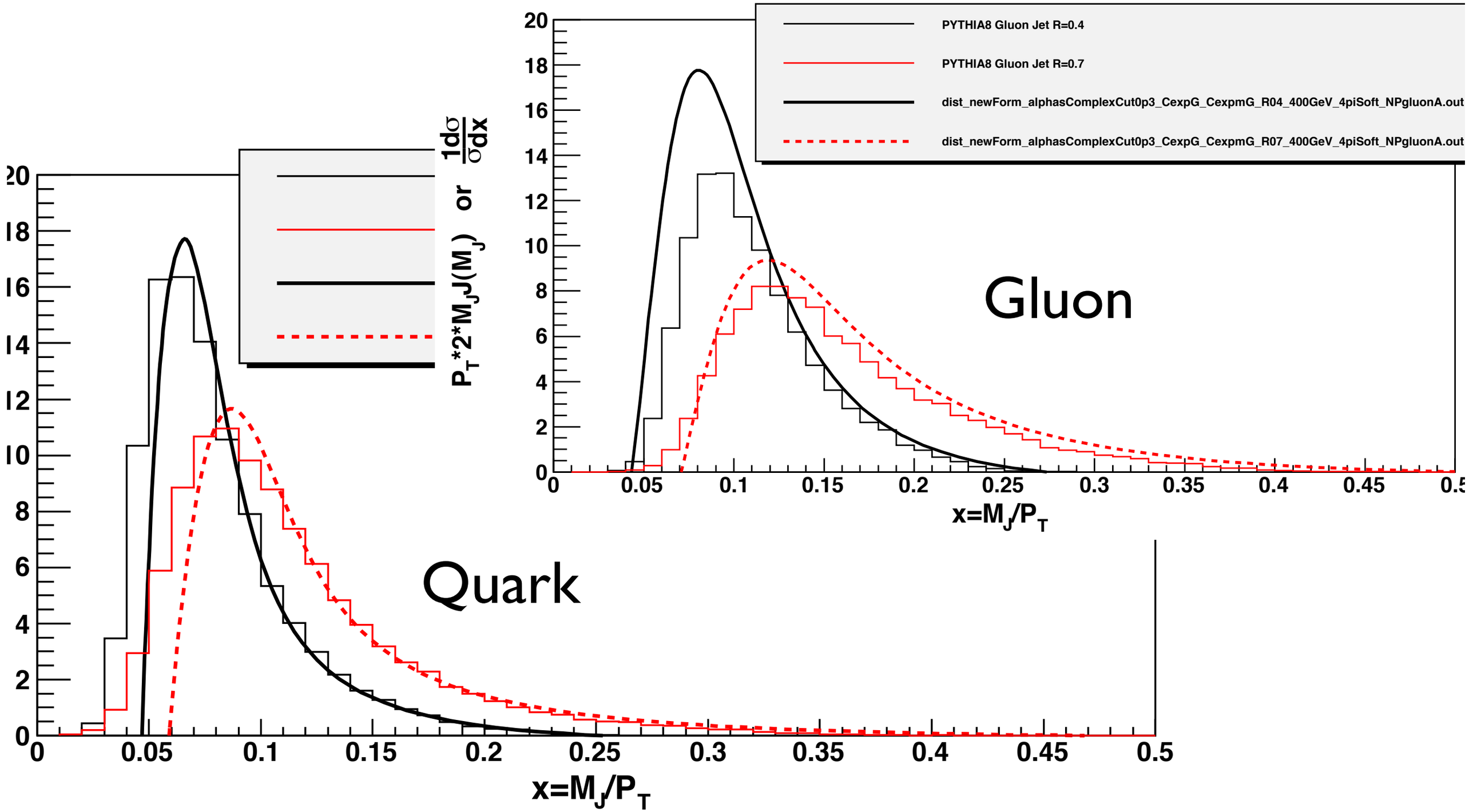
$$\ln\left(\frac{M_J}{RP_T}\right)$$

which can be resummed by applying renormalization group (RG) technique.

The key idea of resummation technique is to vary Wilson line direction to arbitrary gauge vector n, since collinear dynamics is independent of n.

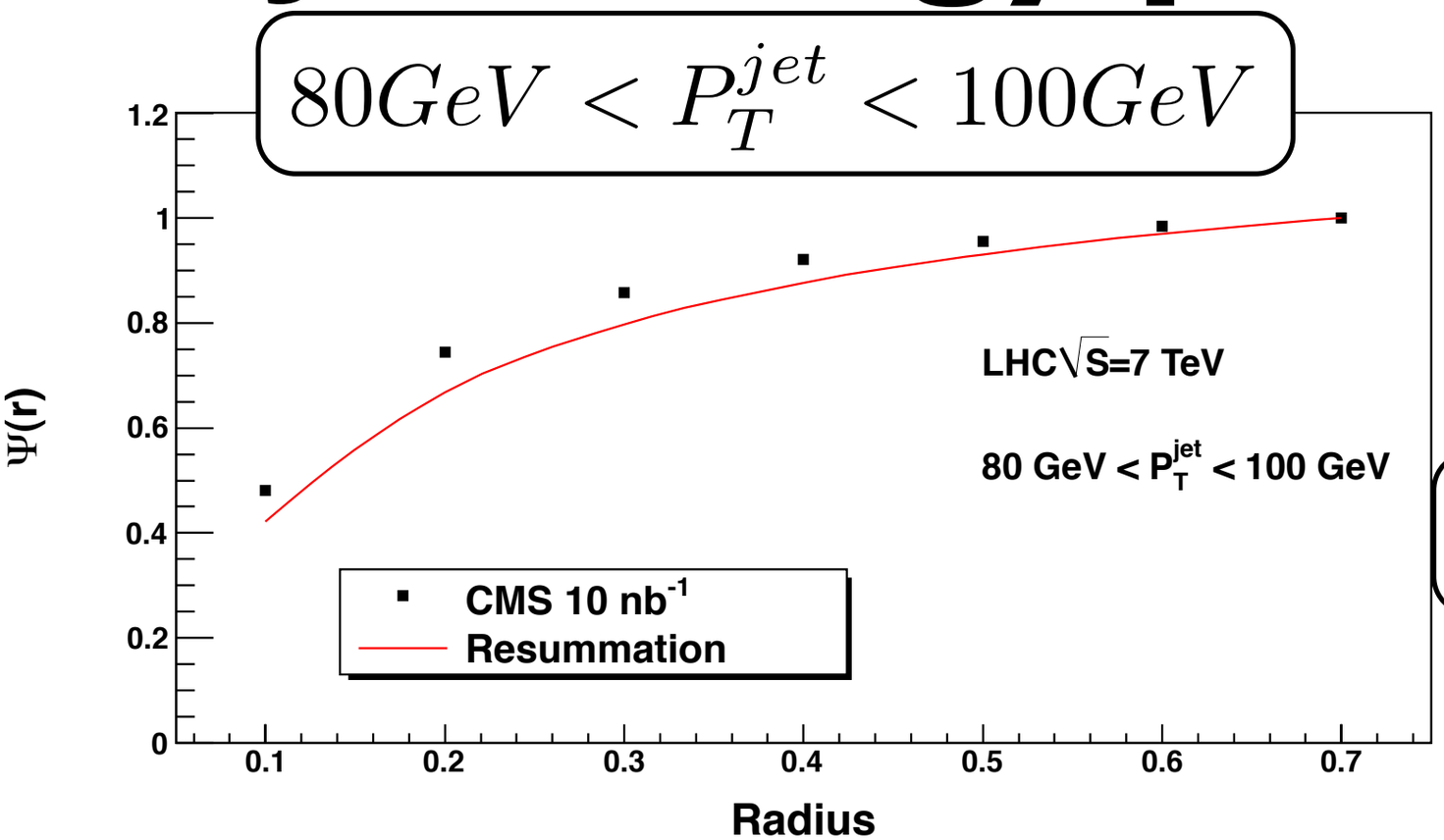
Zhao Li
Michigan State University

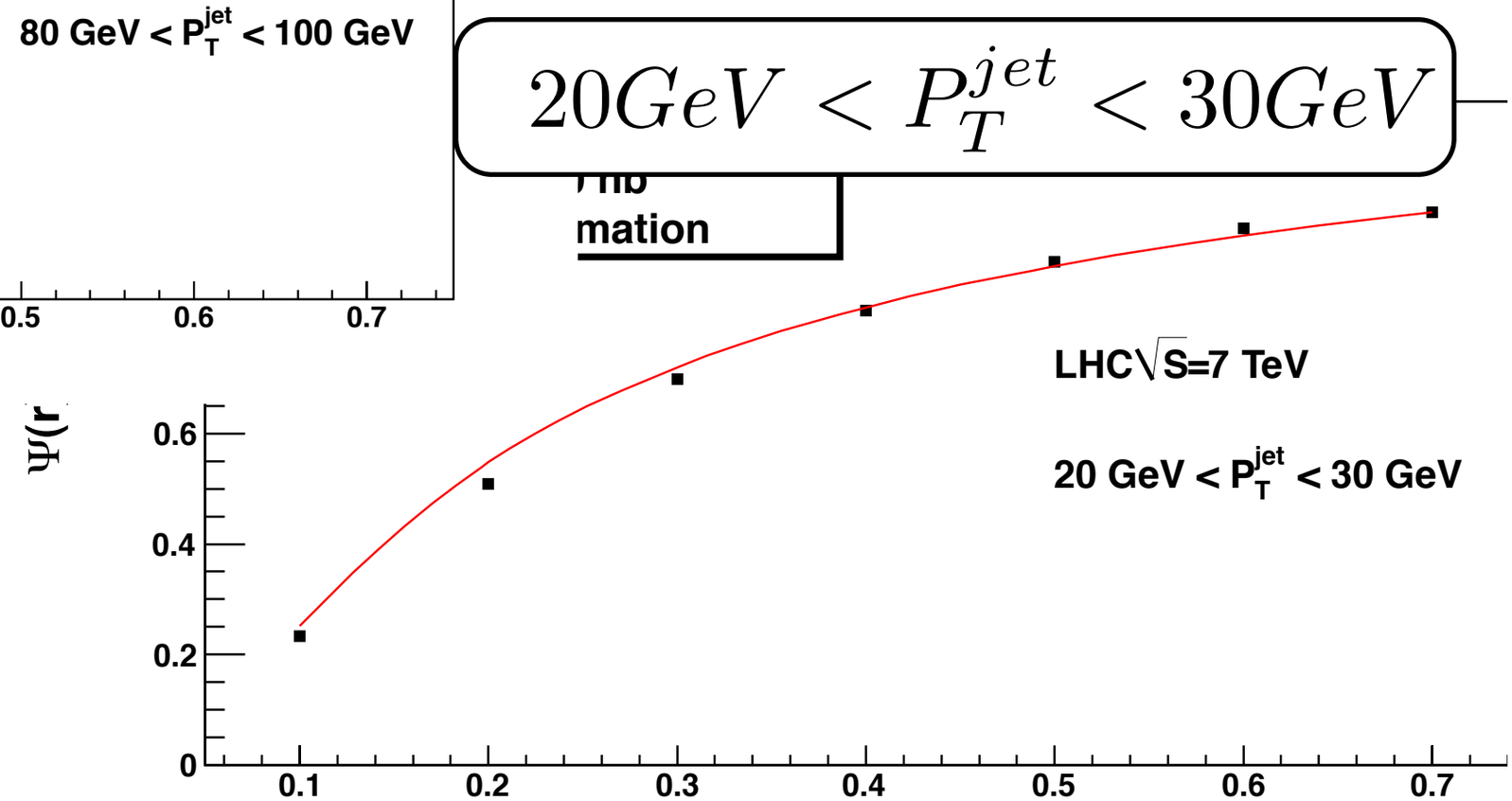
Quark and gluon jets at pT=400GeV



Non-perturbative parameters were fit at pT=600GeV with R=0.7.

Jet energy profile @ CMS





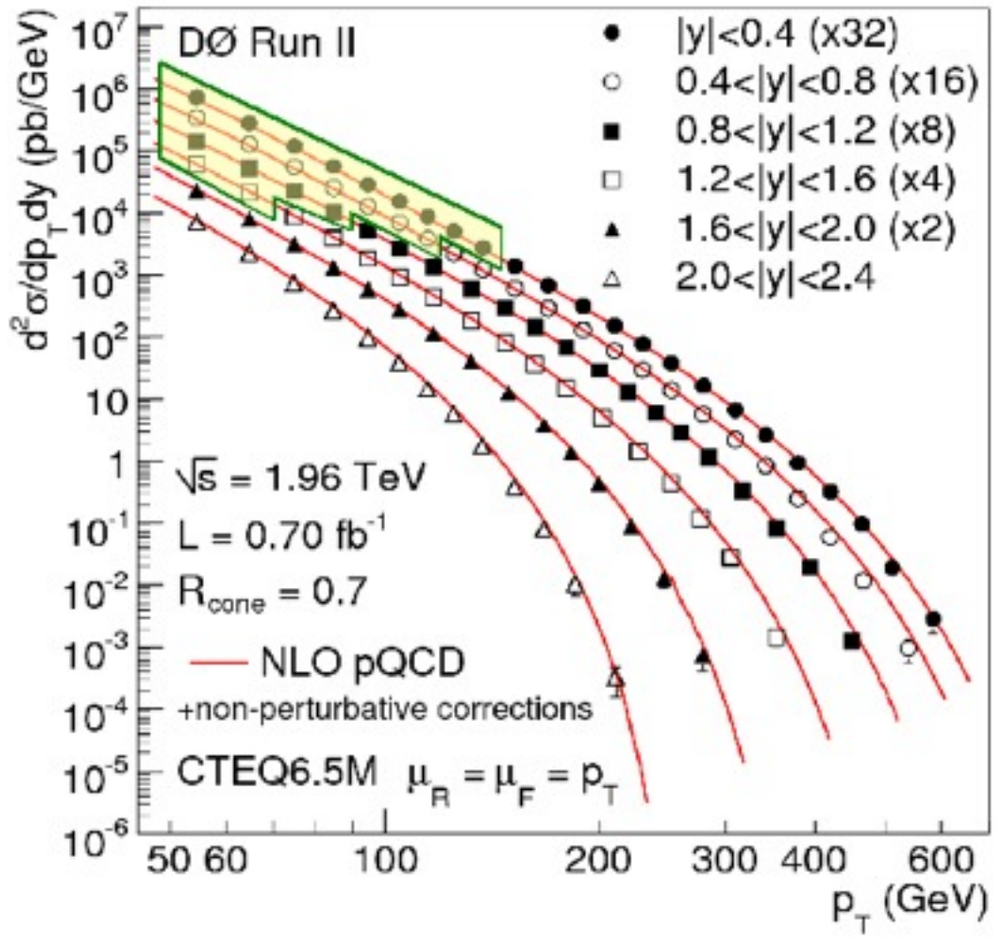
- Resummation predictions for jet energy profile agree with CDF and CMS data.
- Our formalism can be extended for heavy quark jet, e.g., a boosted top quark jet. (in progress)
- Same formalism can be used in jet study at HERA and RHIC.

Multi-jet measurements at DØ

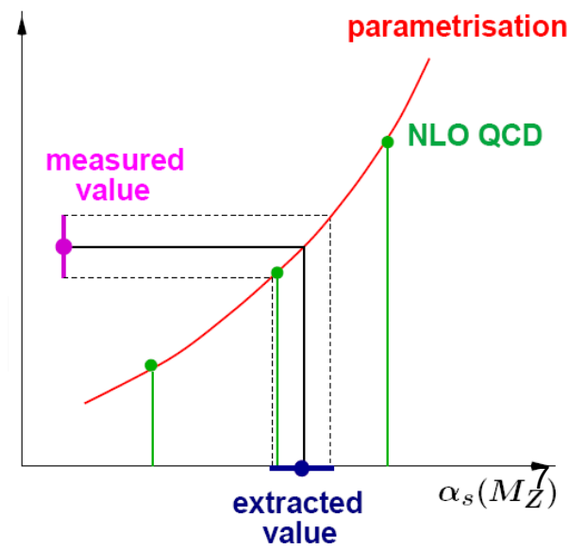
Zdenek Hubacek
CEA Saclay, Irfu, SPP

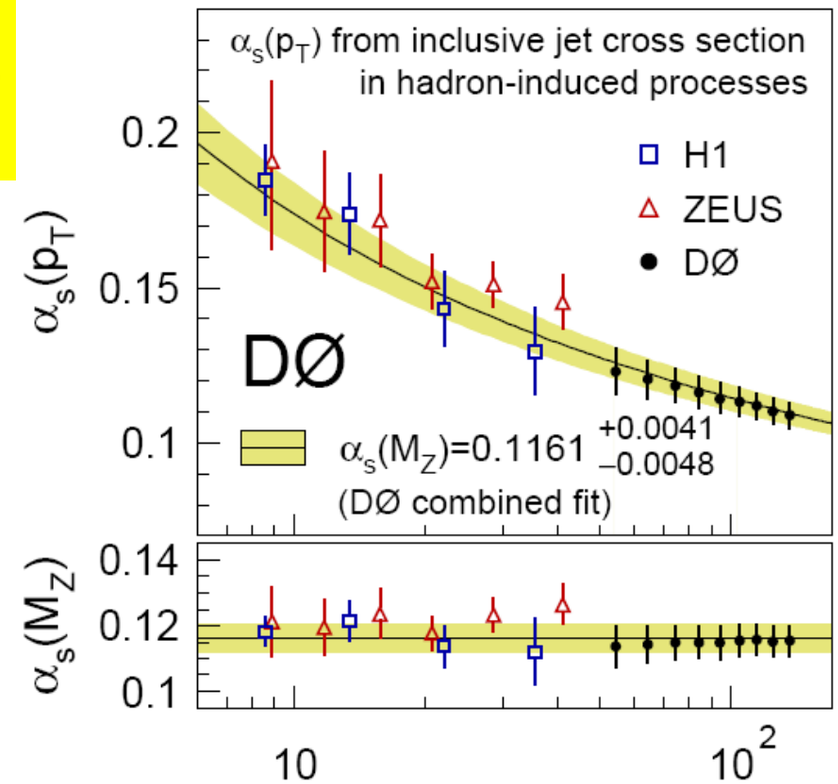
(Multi-) Jet Production and Determination of the Strong Coupling Constant

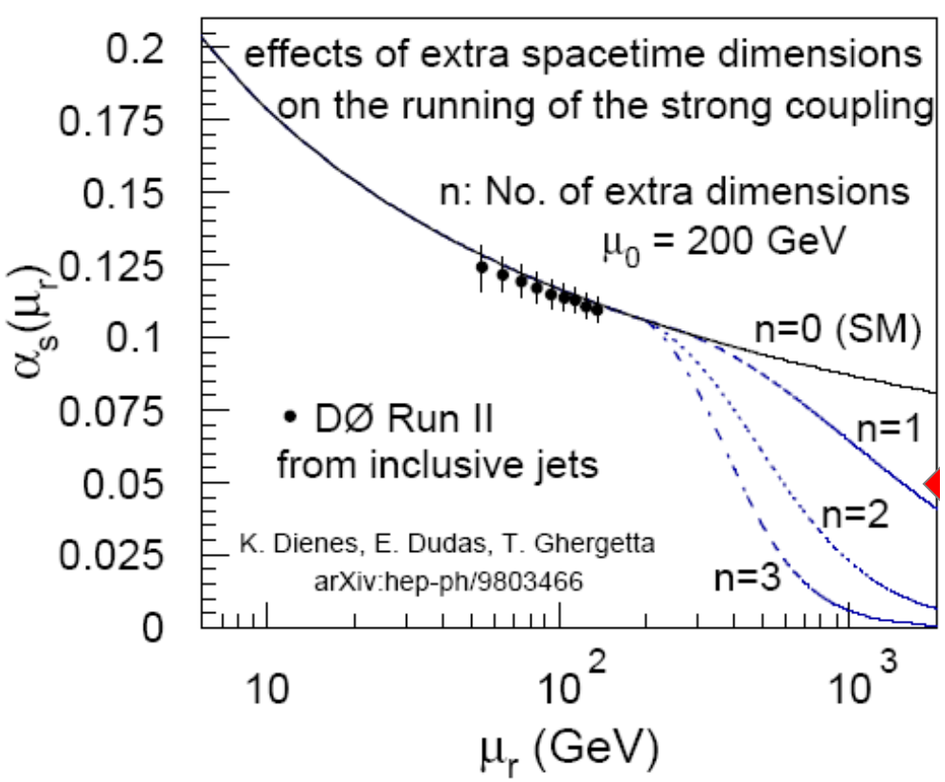
Markus Wobisch
Louisiana Tech University

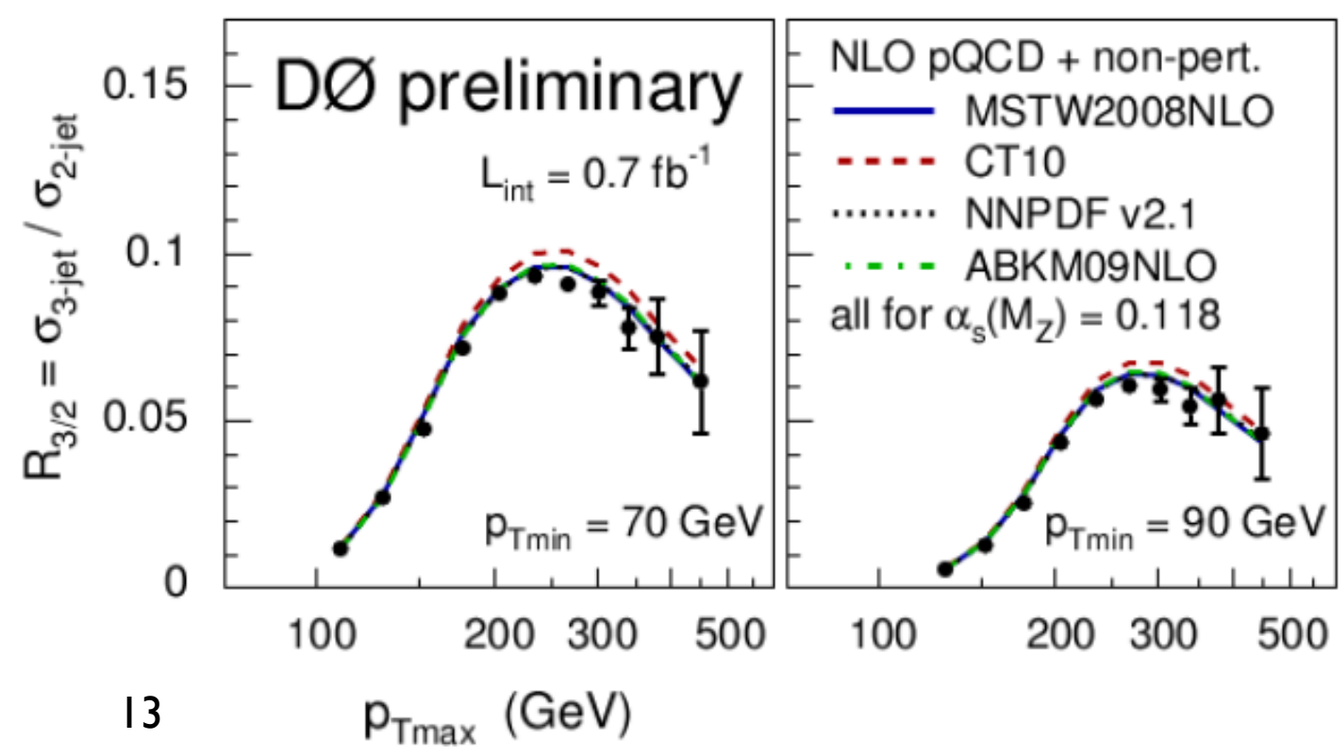


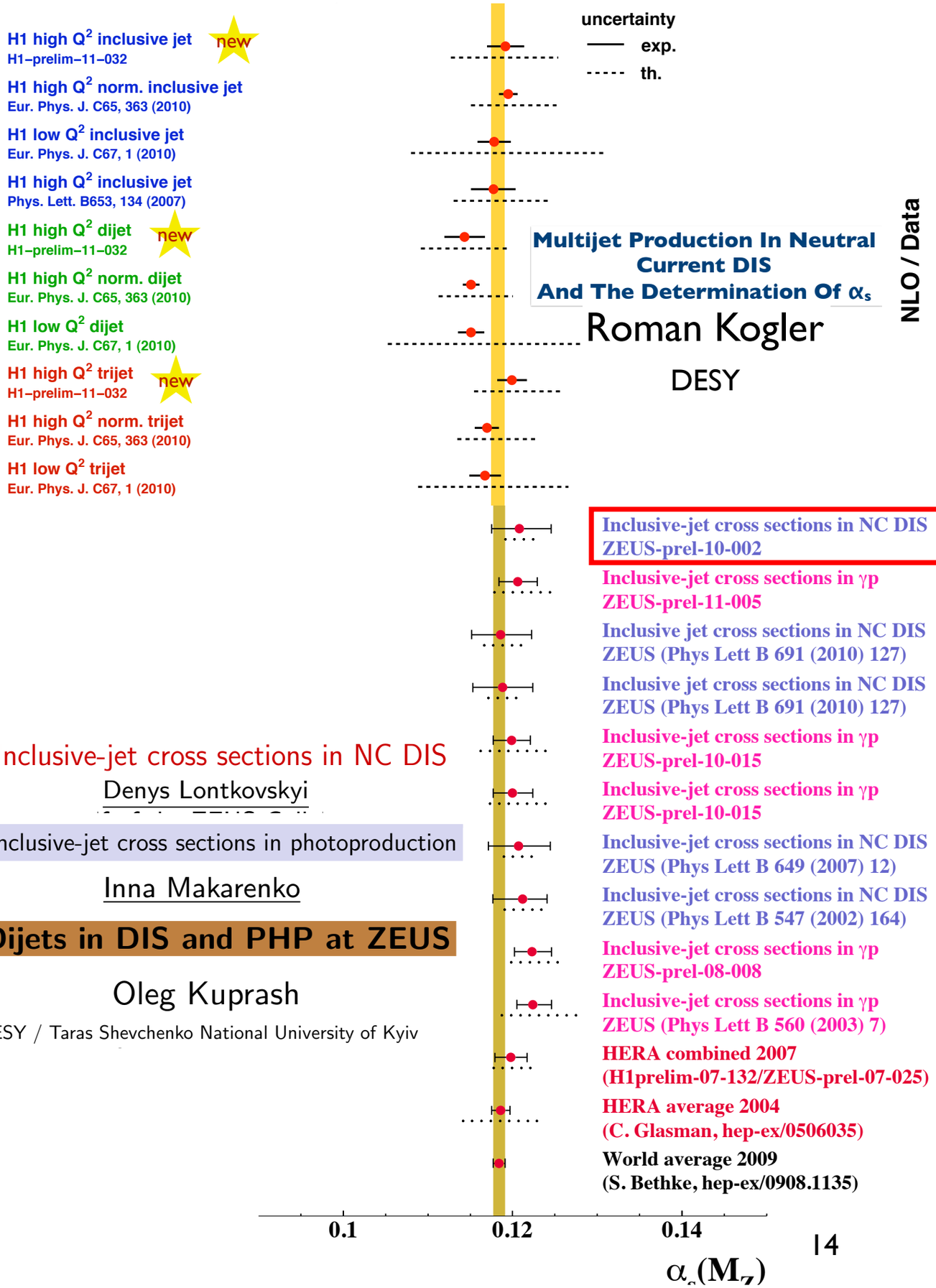
→ Restrict α_s analysis to kinematic regions where impact of Tevatron data for PDFs is small.











Multijet Production In Neutral Current DIS And The Determination Of α_s

Roman Kogler

DESY

Inclusive-jet cross sections in NC DIS

Denys Lontkovskyi

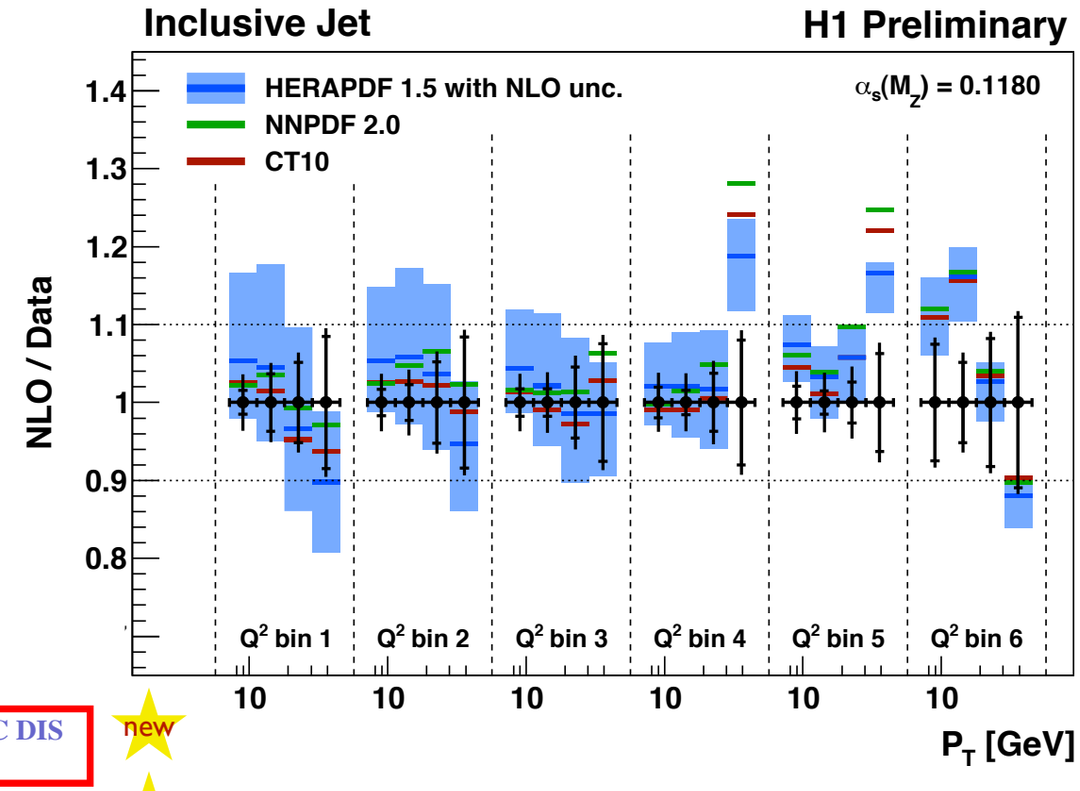
Inclusive-jet cross sections in photoproduction

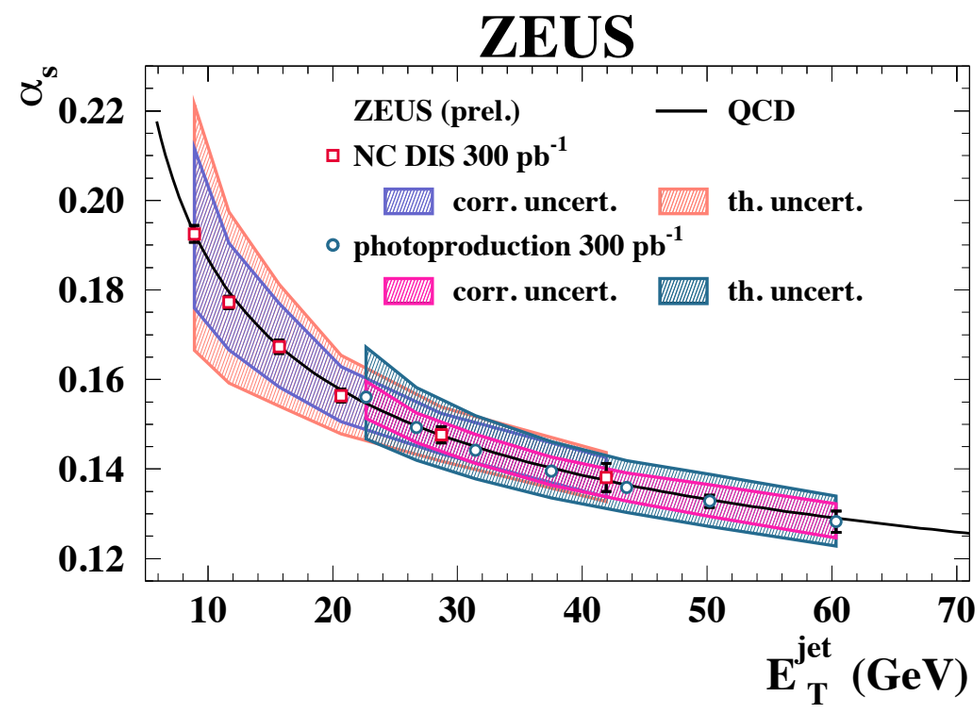
Inna Makarenko

Dijets in DIS and PHP at ZEUS

Oleg Kuprash

DESY / Taras Shevchenko National University of Kyiv

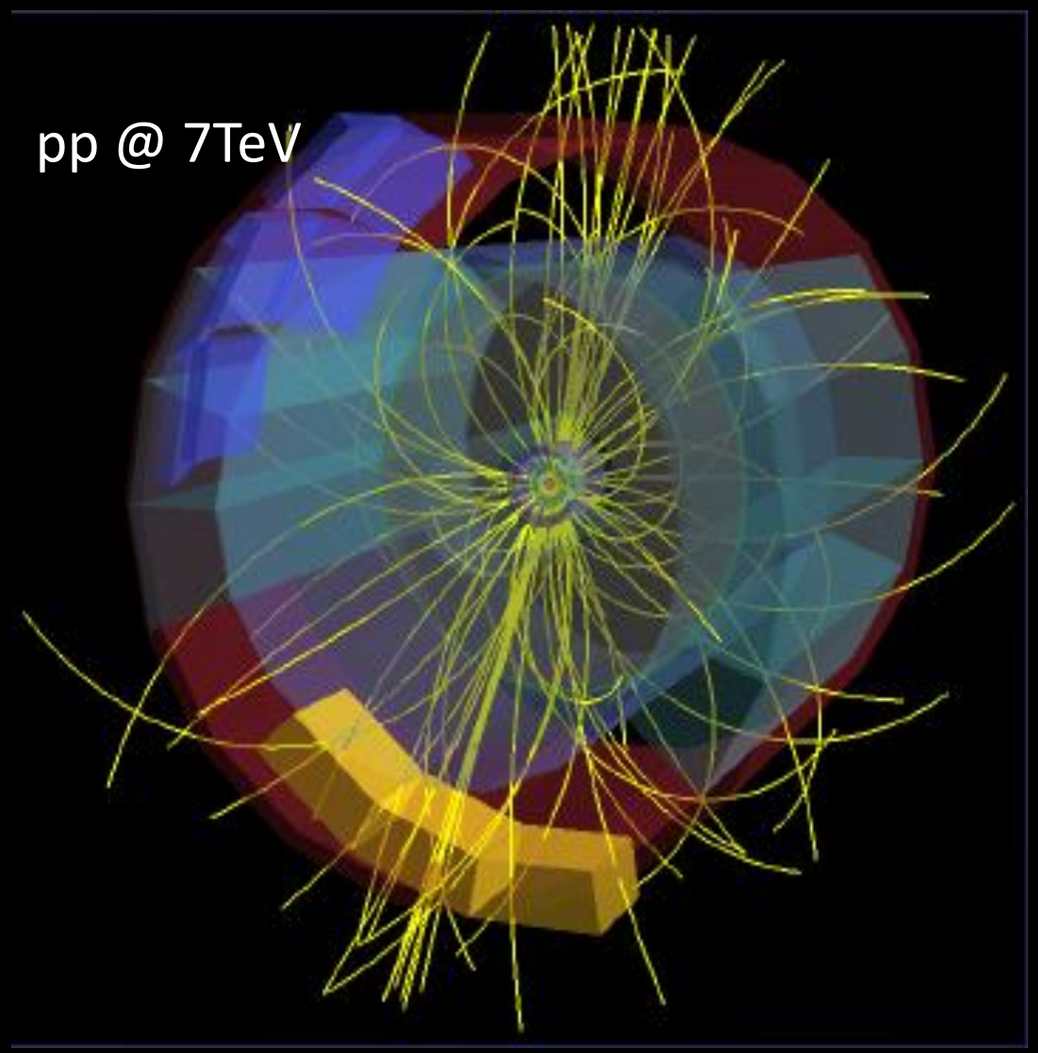


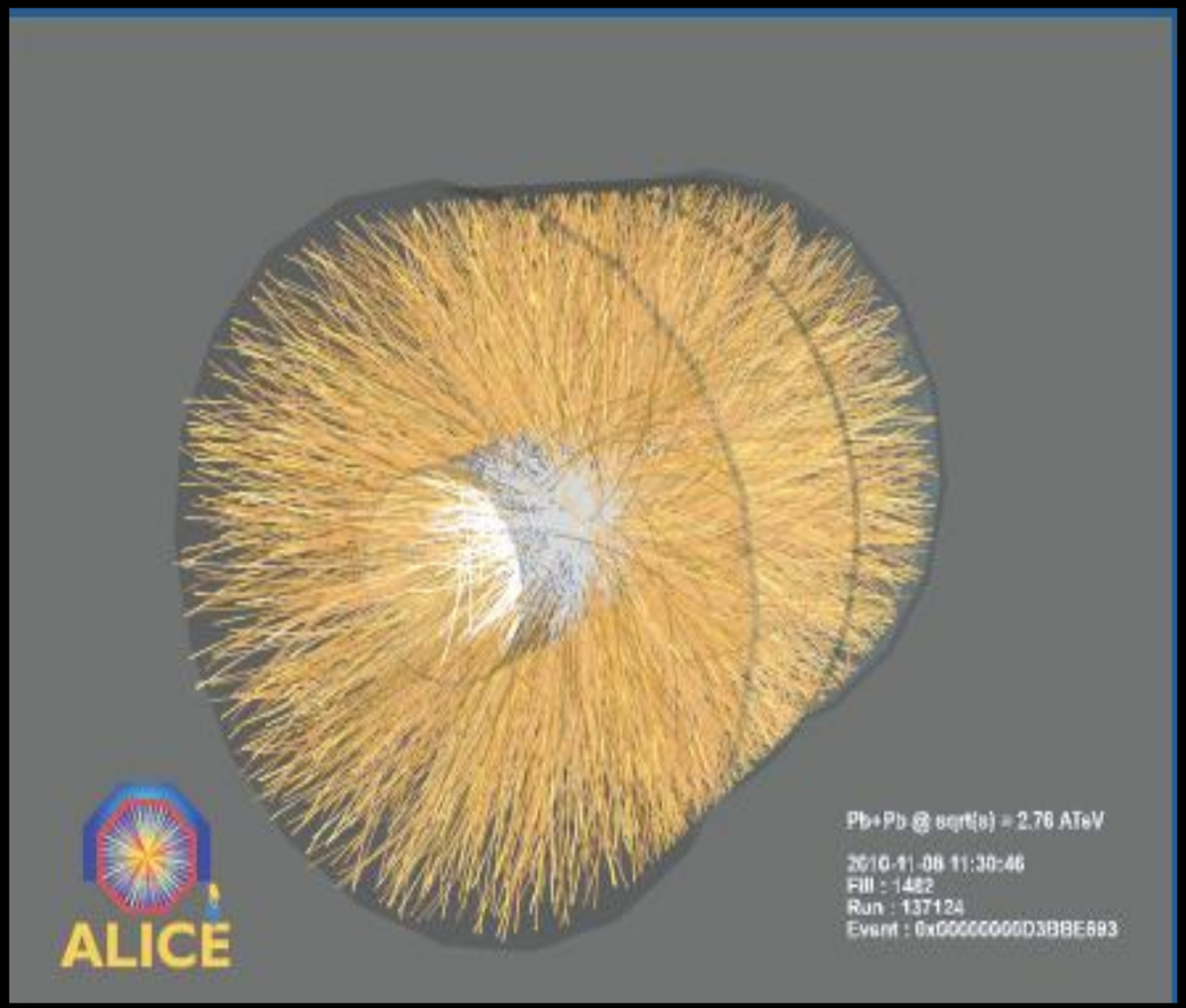


14

Friday, 15 April 2011

Jet physics with ALICE



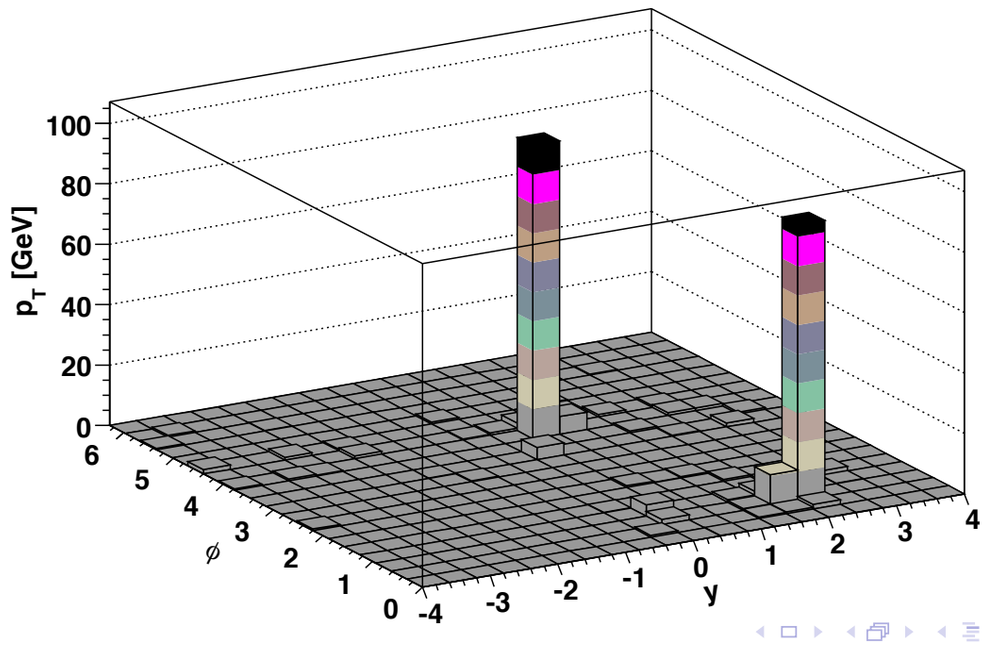


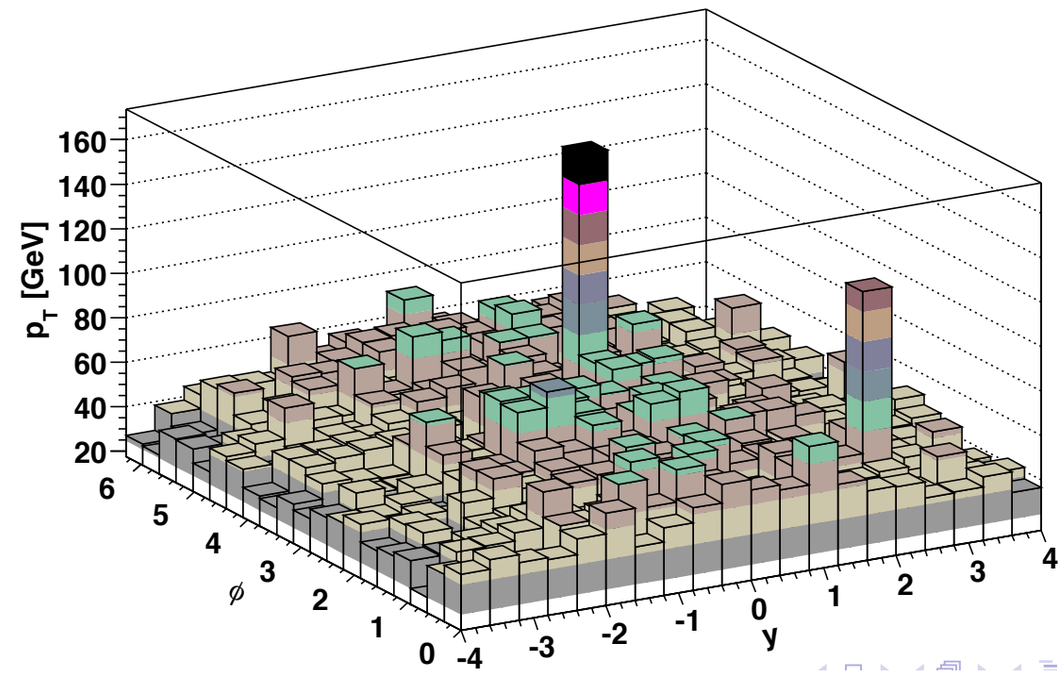
Leticia Cunqueiro
INFN FRASCATI

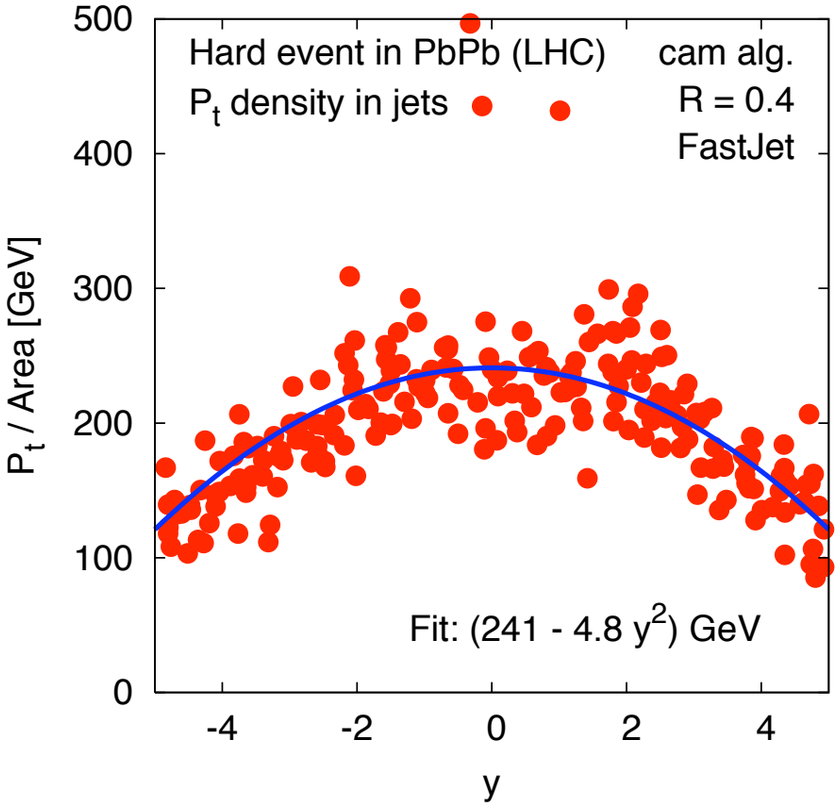
And full jet reconstruction is a challenge in HIC

Jets in HIC → A messy environment!

Distribution of jets in $pp \to gg$ events with $p_T^{\rm jet} \sim 100$ GeV and $R = 0.4$ embedded in PbPb high multiplicity

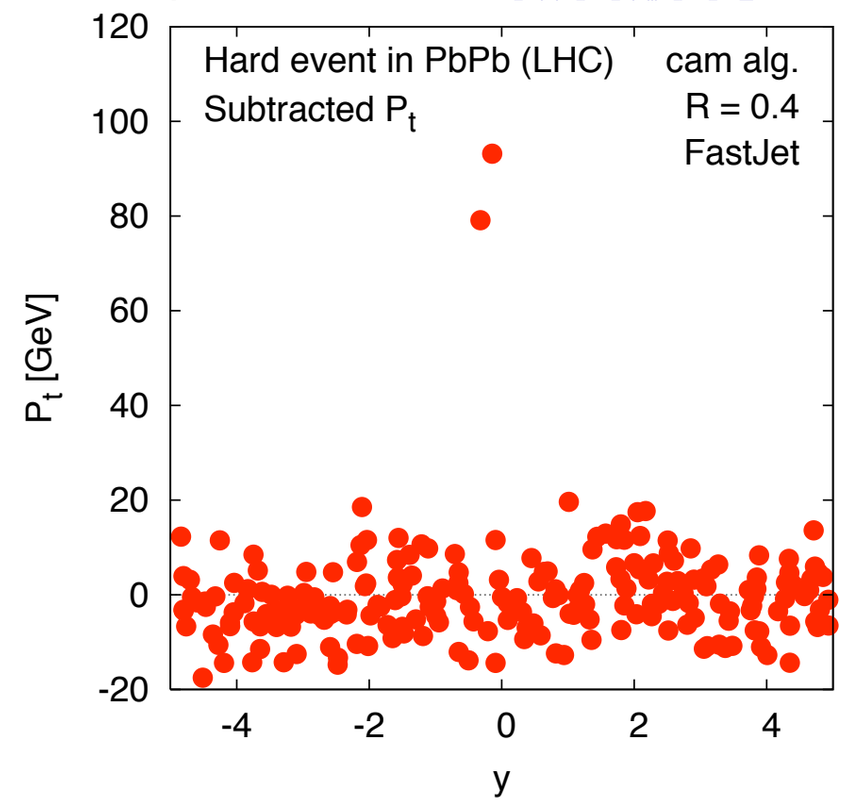




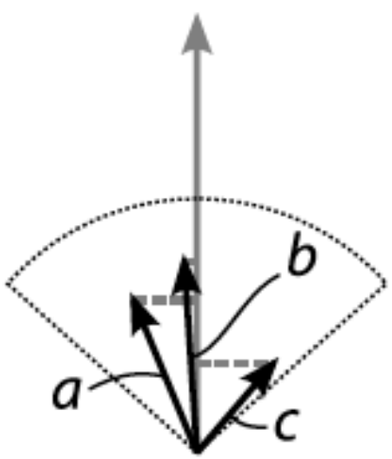


1.- Measure the p_T of all jets in event
2.- Normalize by the jet area A_j
Key observation → For UE jets, $p_T^{\rm jet} \sim \rho(y,\phi) A_{\rm jet}$
3.- Determine $\rho(y,\phi)$
(No unique strategy, HIC background very complex structure)
4.- Subtract $\rho(y,\phi)$ from the all jets using its area A_j

$$p_{\mu j}^{(\rm sub)} = p_{\mu j} - A_{\mu j}\, \rho(y,\phi) \qquad (1)$$



Gaussian filter algorithm



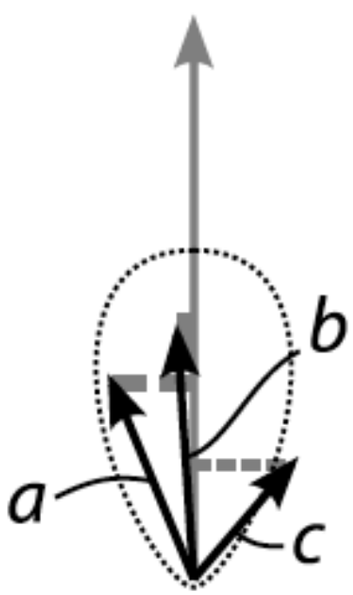
Cone

- Construct the p_T density for the event

$$p_T(\eta,\phi) = \sum_{i \in \text{particles}} p_{T,i}\,\delta(\eta-\eta_i)\,\delta(\phi-\phi_i)$$

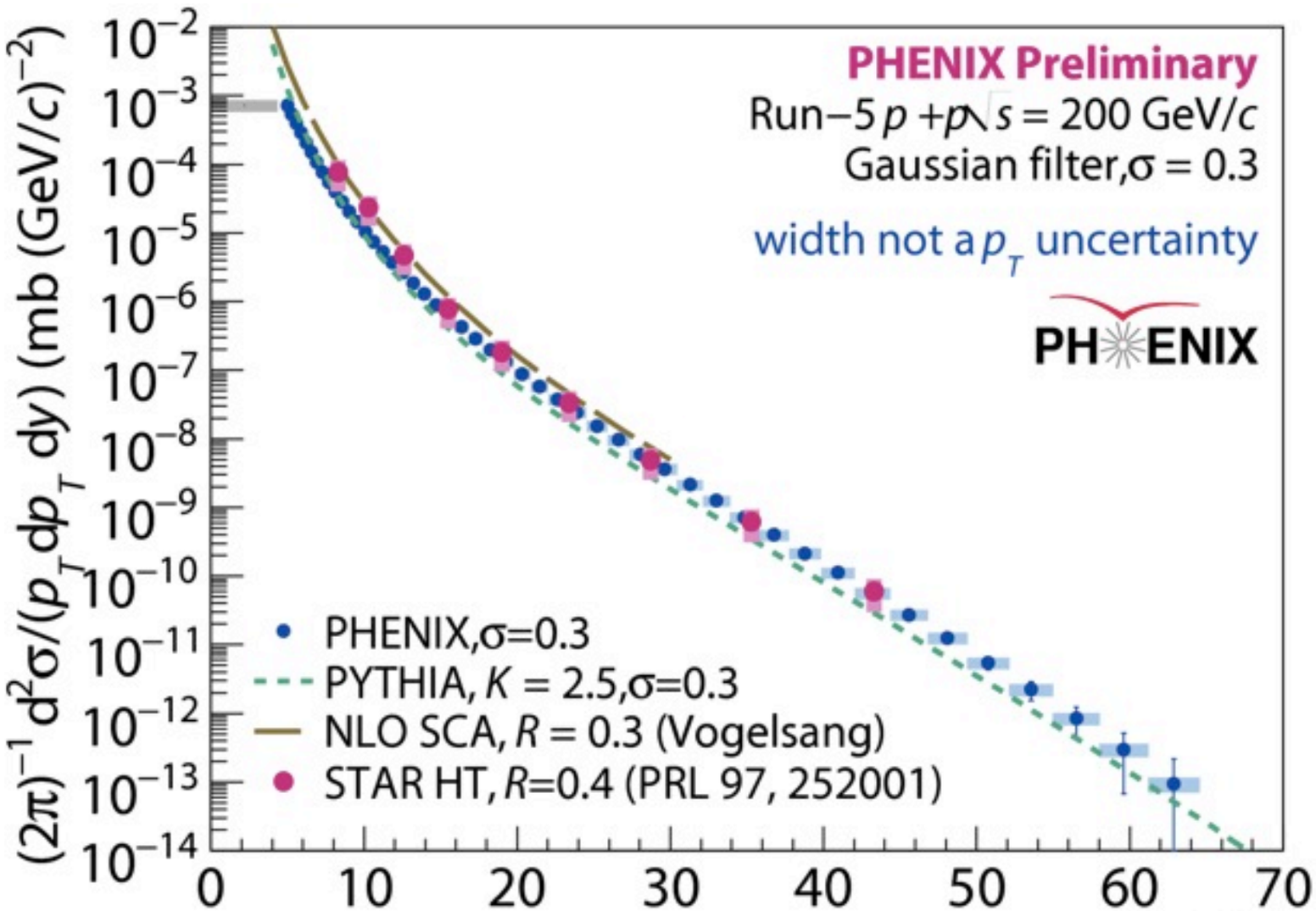
- Determine weighted density at each point convolving the p_T density with a Gaussian filter function

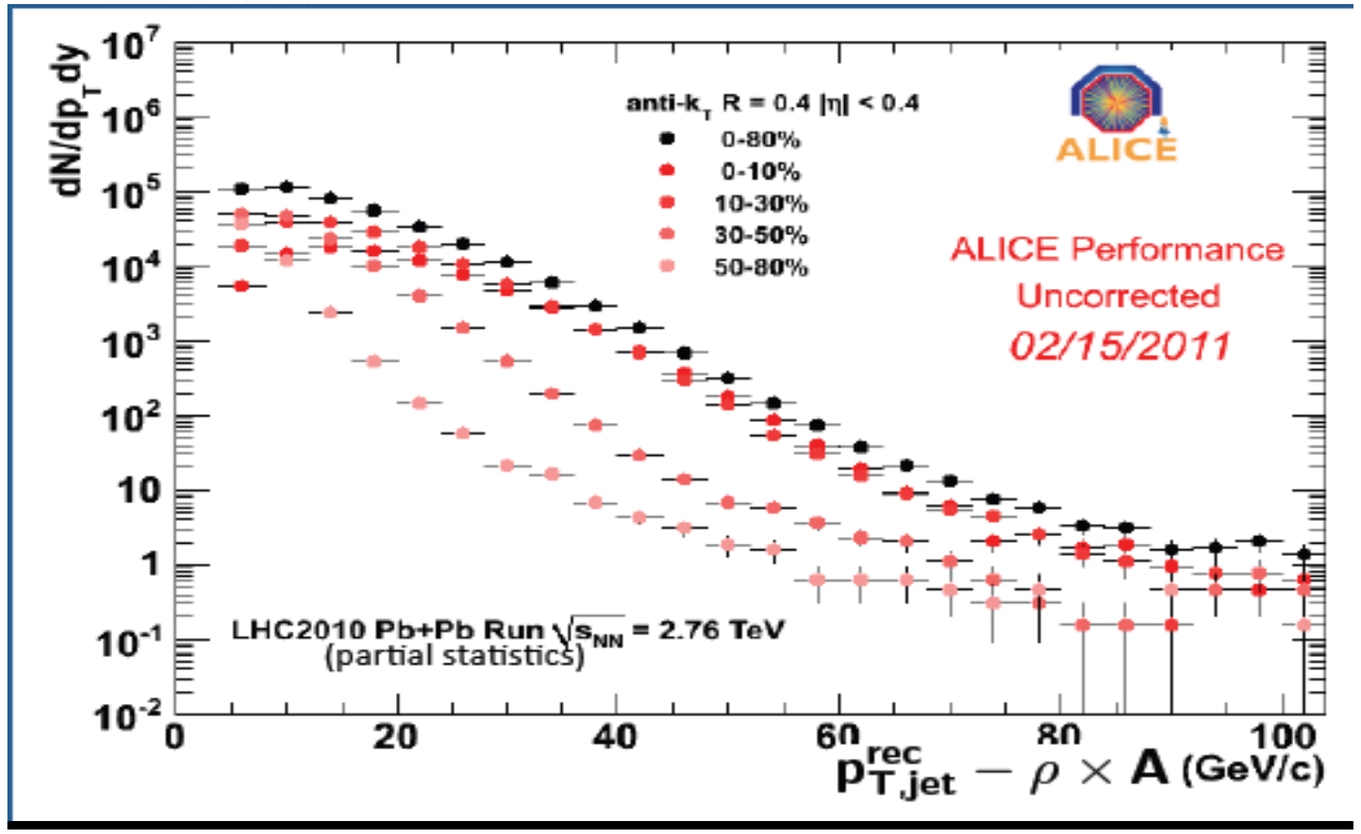
$$p_T^{\text{filt}}(\eta,\phi) = \iint d\eta' d\phi' p_T(\eta',\phi') \exp\left(-\frac{(\eta-\eta')^2+(\phi-\phi')^2}{2\sigma_{\text{filter}}}\right)$$



Filter

- Local maxima correspond to reconstructed jets
- Similar to seedless cone algorithm BUT
- No hard angular cut-off
  - naturally infrared and collinear safe
- Gaussian shape:
  - focuses on core of jet: optimizes signal to background and stabilizes jet axis in large background environment
  - reduces impact of limited acceptance


PHENIX Preliminary
Run−5 p + p √s = 200 GeV/c
Gaussian filter, σ = 0.3
width not a p_T uncertainty
PHENIX
PHENIX, σ=0.3
PYTHIA, K = 2.5, σ=0.3
NLO SCA, R = 0.3 (Vogelsang)
STAR HT, R=0.4 (PRL 97, 252001)
(2π)^-1 d²σ/(p_T dp_T dy) (mb (GeV/c)^-2)


anti-k_T R = 0.4 |η| < 0.4
0-80%
0-10%
10-30%
30-50%
50-80%
ALICE
ALICE Performance
Uncorrected
02/15/2011
LHC2010 Pb+Pb Run √s_NN = 2.76 TeV
(partial statistics)
dN/dp_T dy
p^rec_T,jet − ρ × A (GeV/c)

Hua Pei
UIC UNIVERSITY OF ILLINOIS AT CHICAGO

Jet studies in STAR via 2+1 correlations

- The 2+1 correlation are used as proxy of dijets to study parton-medium interaction.
- When two back-to-back high-p_T particles are triggered, the whole associated particles sustain jet-like structures, at a close shape and magnitude, on both correlation functions and spectra, at Au+Au to d+Au.
- Theory models are tested primarily:
  - Surface emission model (core/corona) agrees with data.
  - Path-length dependent energy loss mode are expected to:
    - Show a relative difference between near- and away-side Au+Au/d+Au (double ratio),
    - It is not observed in either symmetric or asymmetric trigger case.
- Detailed study is going on.

NNLO theory progress reported by **Radja Boughezal**
Antennae subtraction method used to remove IR singularities in hadron-hadron processes - next step physical predictions.

Michal Deák present a study of MPI pythia vs unordered pt emissions CASCADE in forward - central jet correlation's at the LHC. Difference in predictions which may be observable in experiments.

A review of work about the transverse nucleon structure and its implications for finals states at the LHC was presented by **Christian Weiss**. Implications for underlying event, muliparton processes, and rapidity gap survival.

Aharon Levy* showed how ZEUS have been able to determine the W dependence of $\sigma_{tot}(\gamma P)$ from a single experiment. Possible implications for the total hadron hadron cross section.

Christophe Royon presented results on gaps between Jets at the Tevatron and LHC. Use a BFKL approach which is able to predict forward jets at H1 and gaps between jets at Tevatron and have made predictions for the LHC which are actively being analysed.

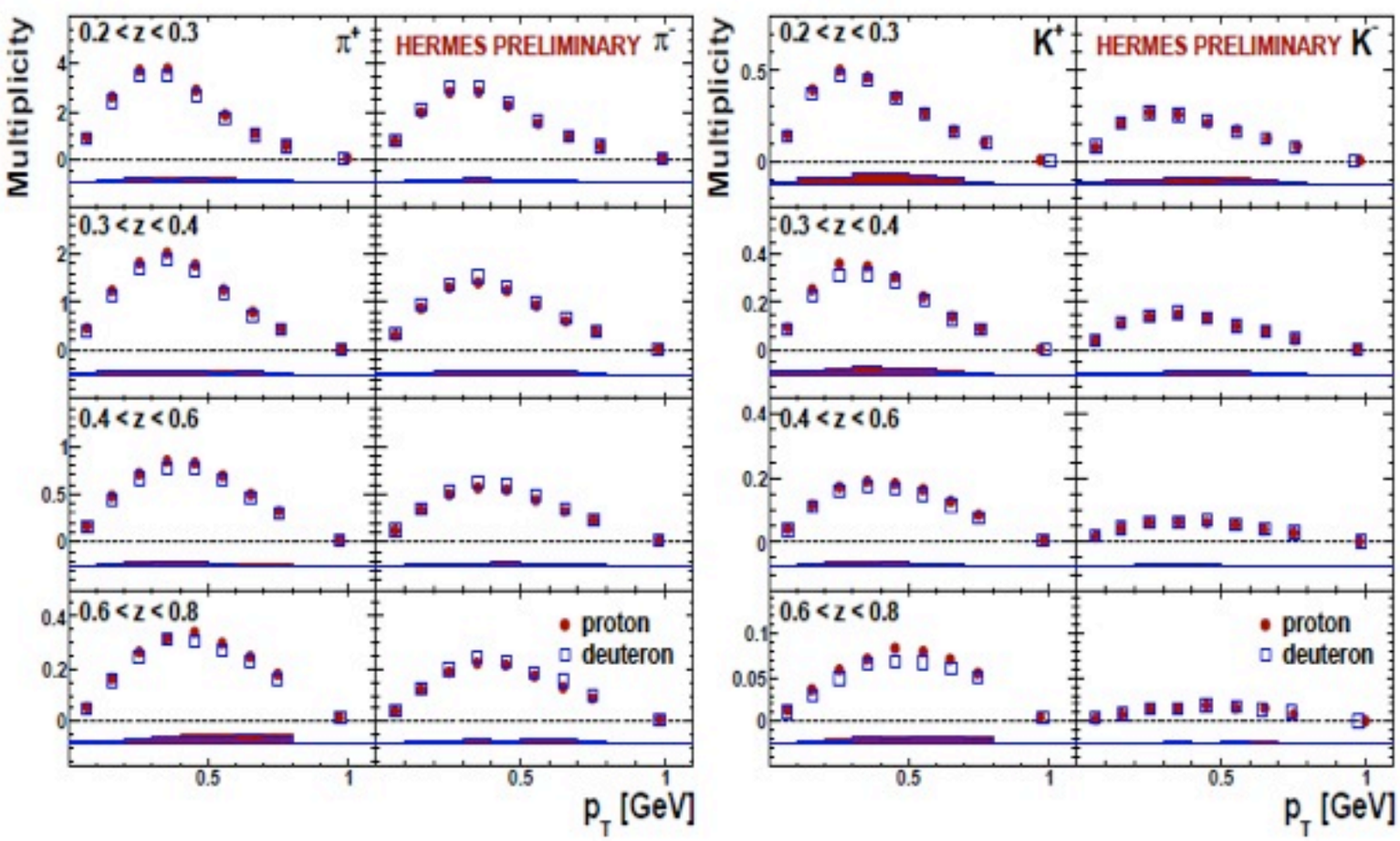
*on behalf of Vladimir Drugakov

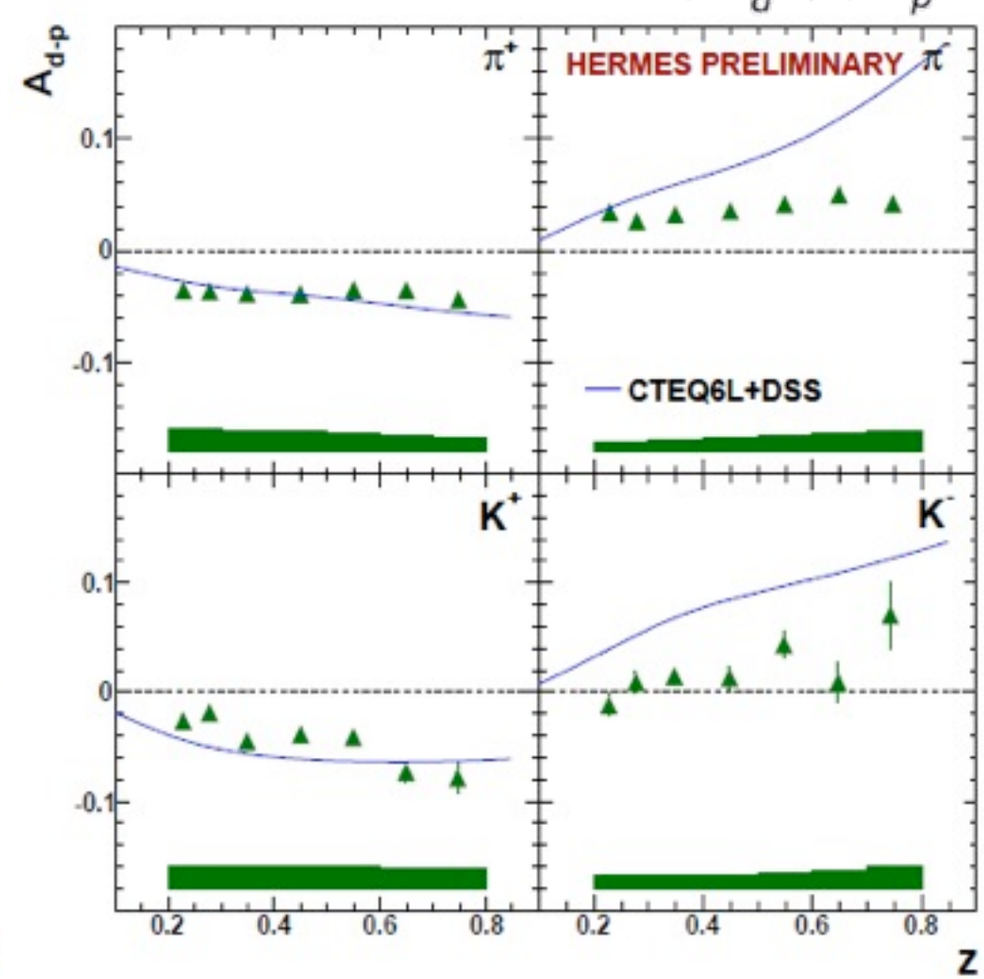
particle production

Hadron spectra: proton, deuterium

- **Charged separated $\pi^{\pm}$, $K^{\pm}$ @ HERMES:** [S. J. Joosten]
  - Unique set of 3D high-precision SIDIS multiplicities
  - p-d asymmetries: even higher precision
  - Great input for Fragmentation Functions fits
    - negative correlated errors - to be accounted for
    - problems with negative charges?

$$A^h_{d-p} \equiv \frac{\mathcal{M}^h_d - \mathcal{M}^h_p}{\mathcal{M}^h_d + \mathcal{M}^h_p}$$





Hadron spectra: proton

- **Strangeness production**

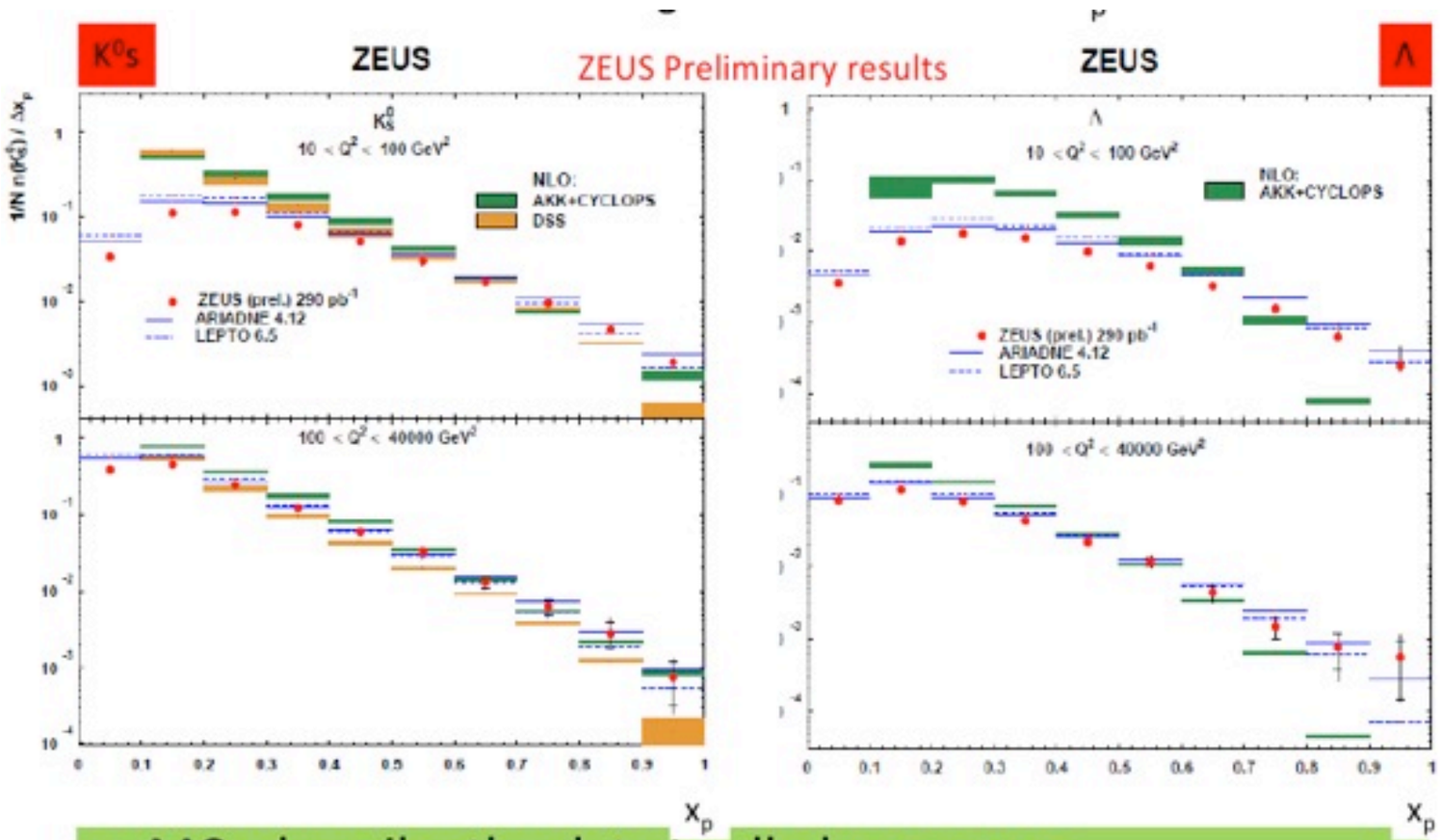
@ ZEUS [R. Hori]

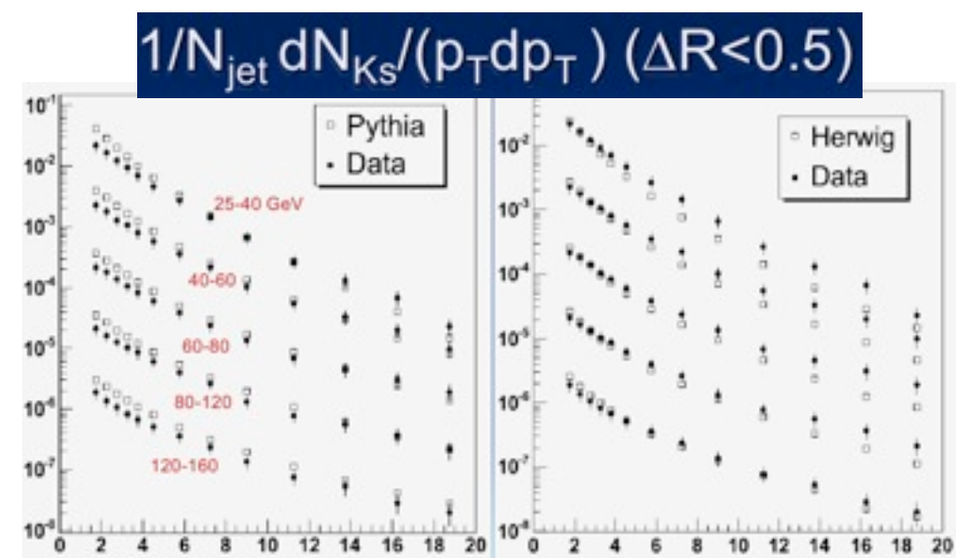
- K_s^0, Λ $\quad 10 < Q^2 < 40{,}000$

@ CDF [S. Oh]

Λ, Ξ, Ω, K_s^0, K^*, $K^{+/-}$, φ^0

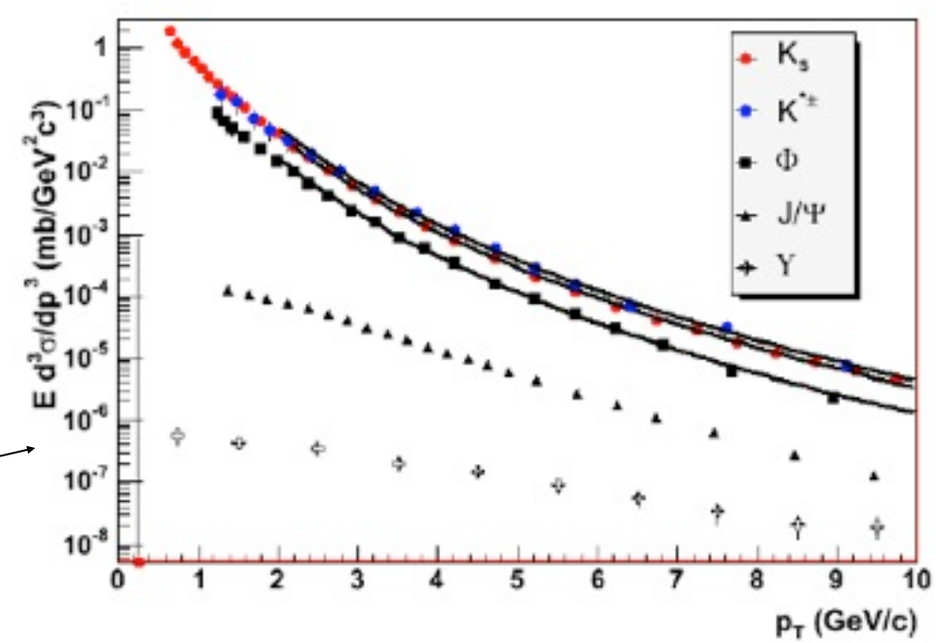
min bias, in jet (1st time at h coll)





- MCs describe the data in all phase space.
- Description of NLO QCD calculations(AKK+CYCLOPS, DSS) become better at high Q^2 and high x_p.

More food for FF fitters

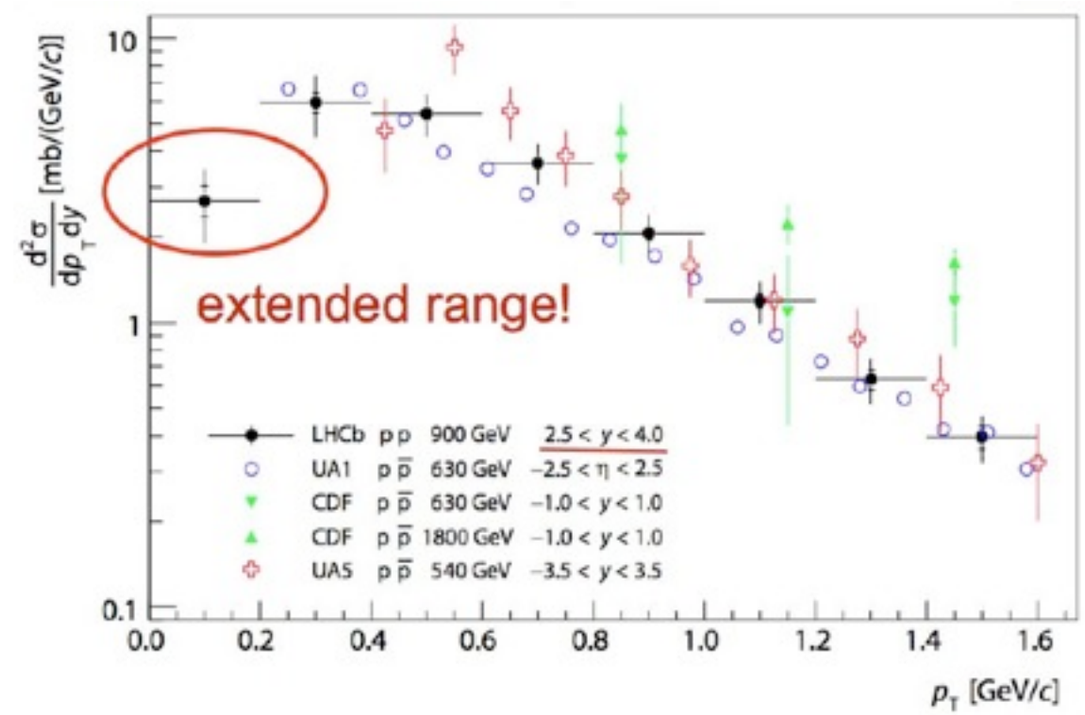


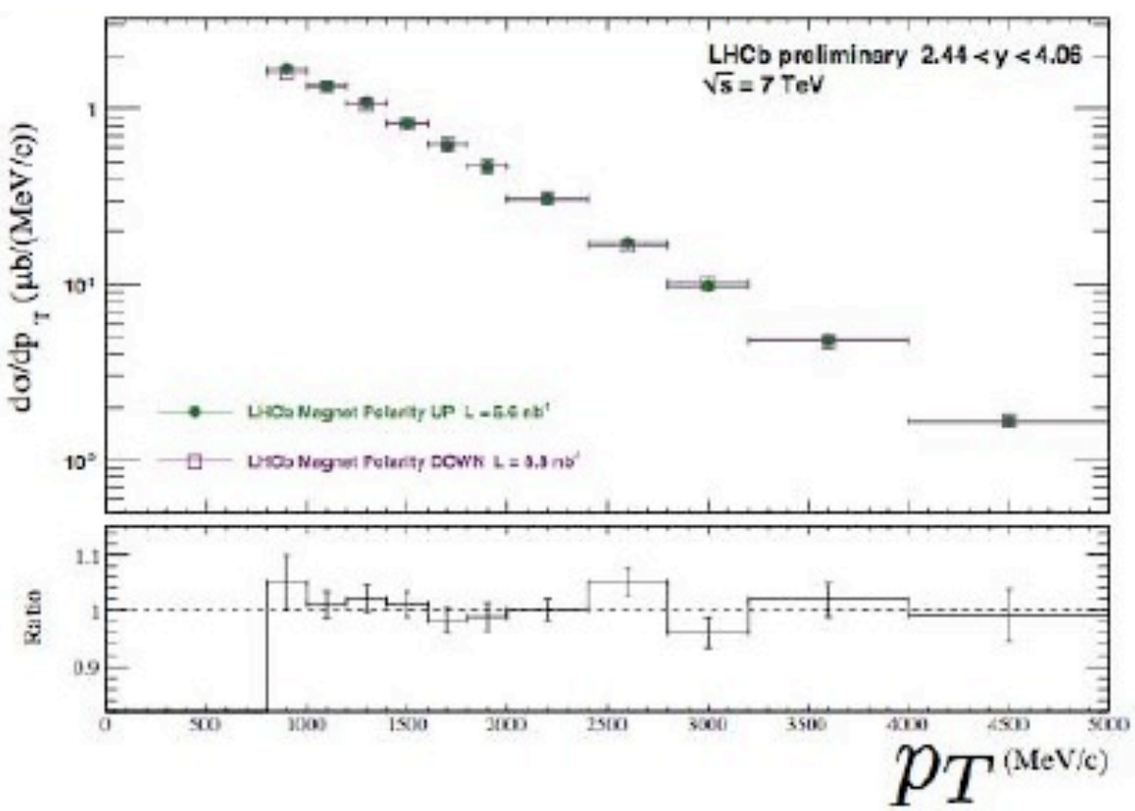
Hadron spectra: proton

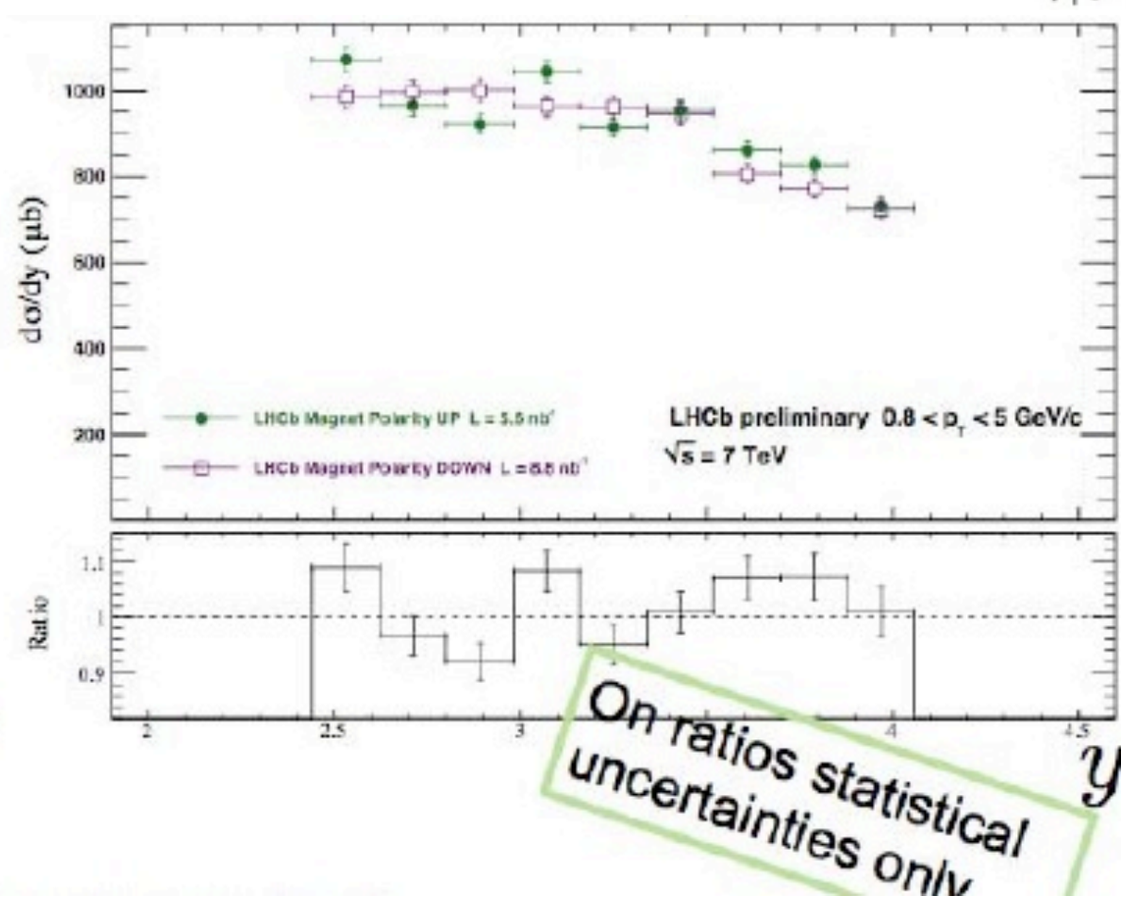
- **Strangeness production**

@ LHCb [M.Adinolfi / J.Merkel]

- soft K_s @ 0.9 TeV
- soft and hard φ @ 7 TeV

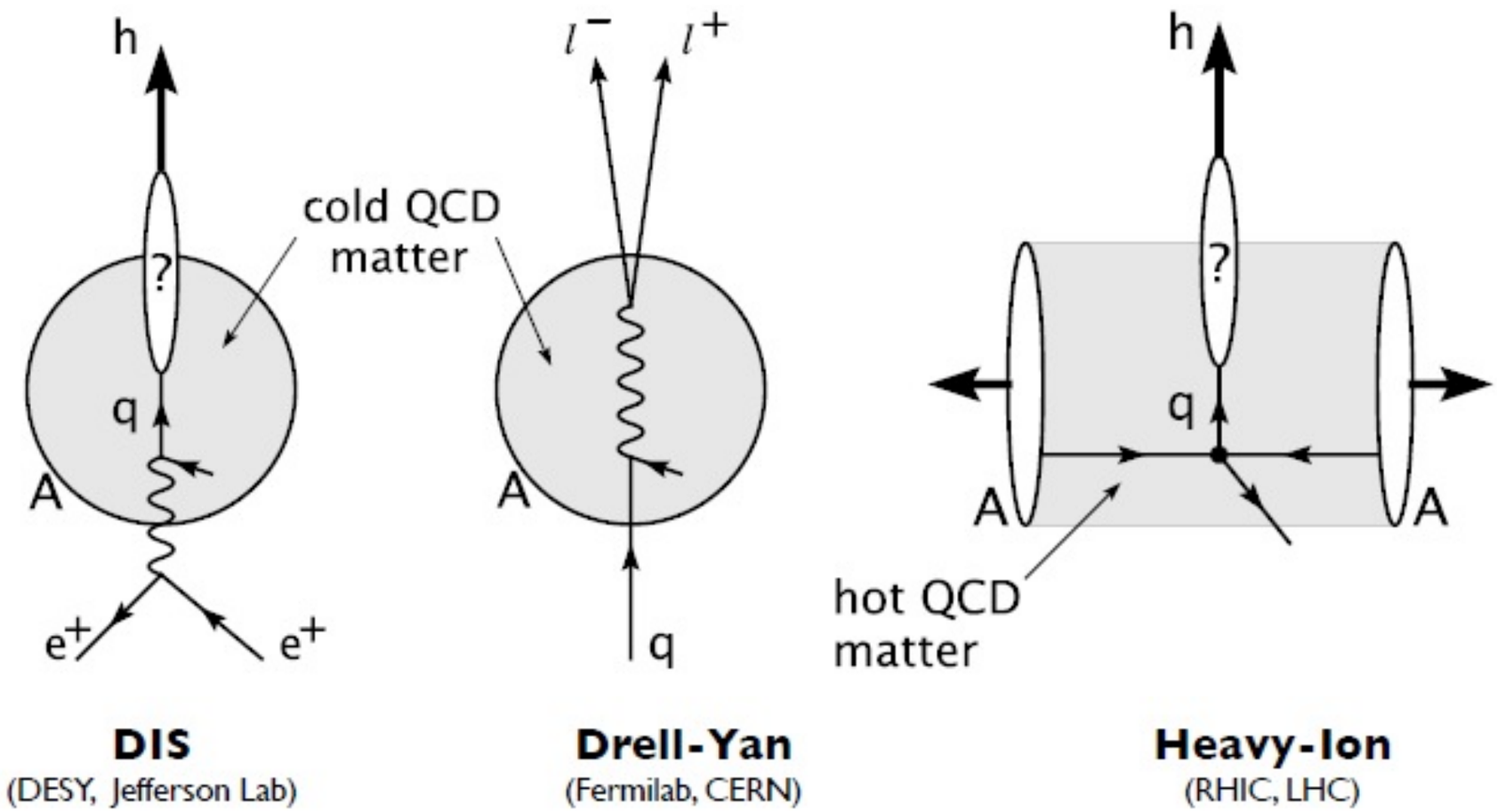






Hadron spectra: nuclear targets

- **Nucleus as femtometer detector of hadronization**
  - Dynamics of color confinement: hadronization timescales
- **Partons as probes of nuclear medium**
  - p_T-broadening sensitive to soft nuclear gluons, saturation scale Q_{sat}
  - Calibrated tomography of Quark-Gluon Plasma

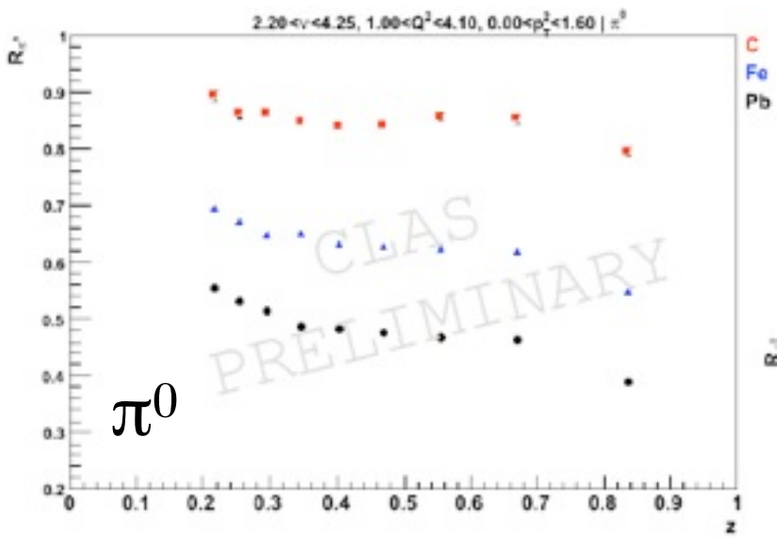


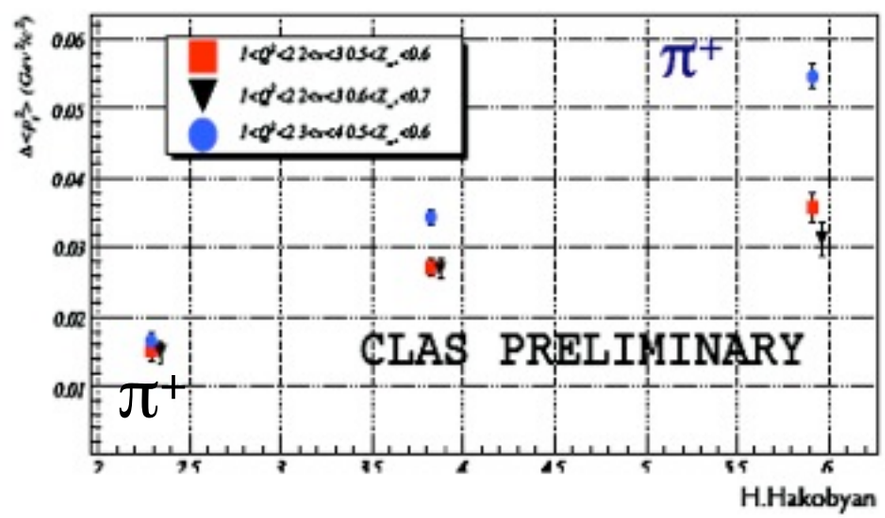
Hadron spectra: nuclear targets

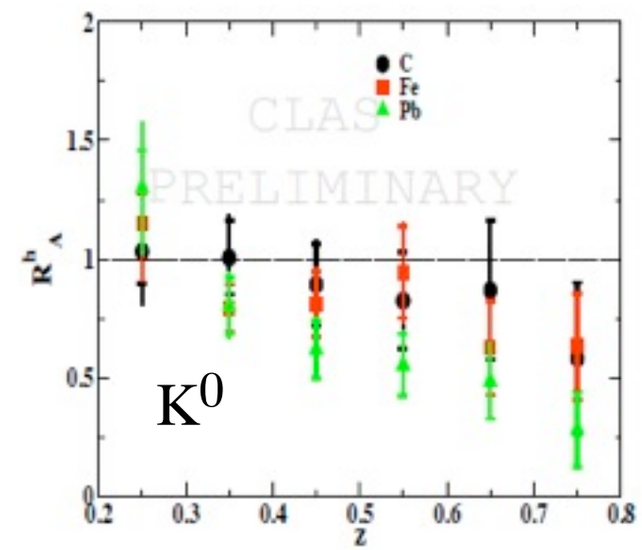
- **Preliminary CLAS data** [T. Mineeva]
  - Hadron attenuation, p_T–broadening:
  - multi–D $\pi^{\pm}$, π^0; first data on K^0; will do η and more...; 12 GeV upgrade

Connects to partonic phase

- in-medium partonic multiple scattering
- medium stimulated gluon emission
- quark energy loss
- average transport coefficient
- hadron formation times and mechanisms
- in-medium cross sections





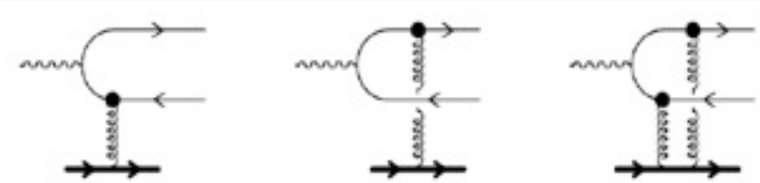


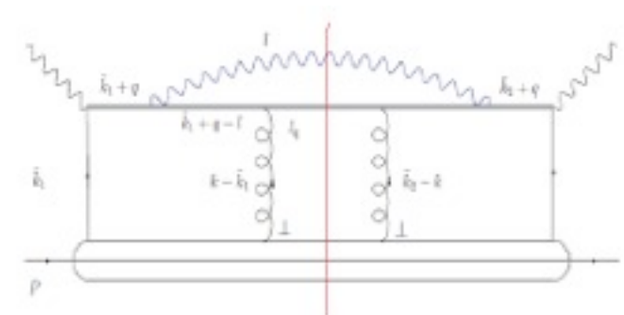
- **Cos ϕ asymmetry** [J. Zhou]

small x<0.01: test gluon saturation

large x and pT–broadening:
new handle on energy loss, Qsat

sin ϕ also possible (easier on exp.)



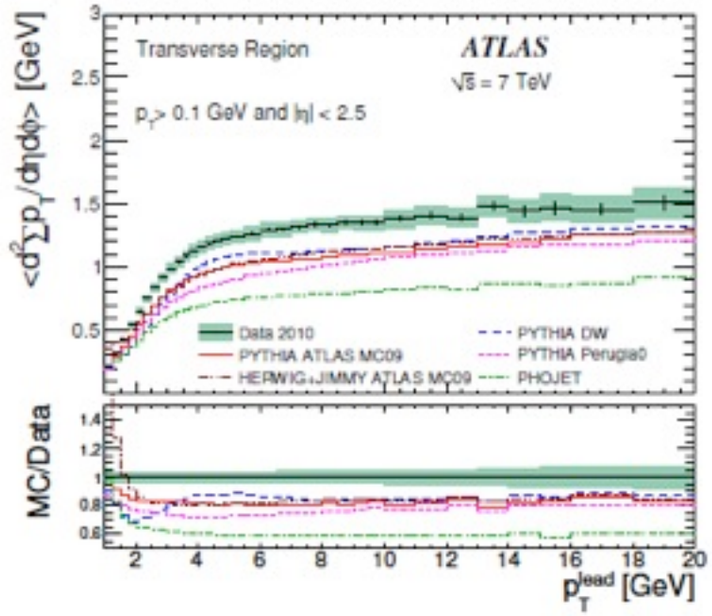


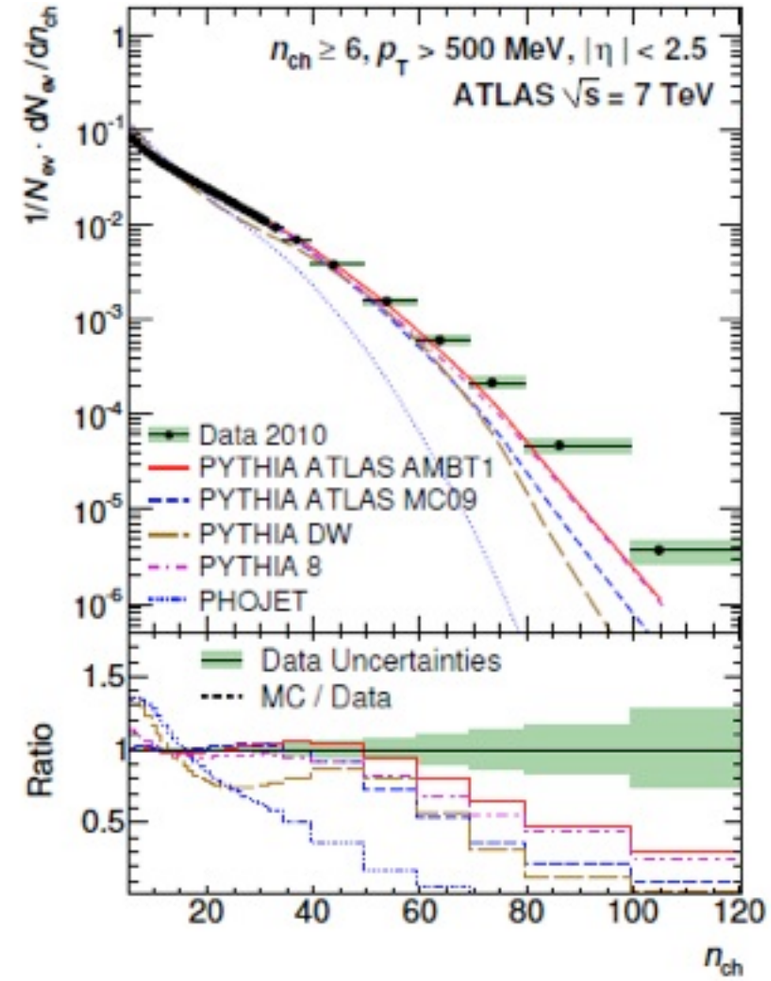
Multiple scattering leads to the nuclear dependent CosΦ asymmetry in SIDIS off large nuclei in both small x and intermediate x region.

$$\frac{d\sigma}{d\phi} = A + B\cos\phi + C\cos 2\phi$$

Minimum bias production & underlying event

- **Too much activity at large n_{ch}, large p_T**
  [H. Schulz]
  - even when data included in tuning
  - See multiple parton interaction talks

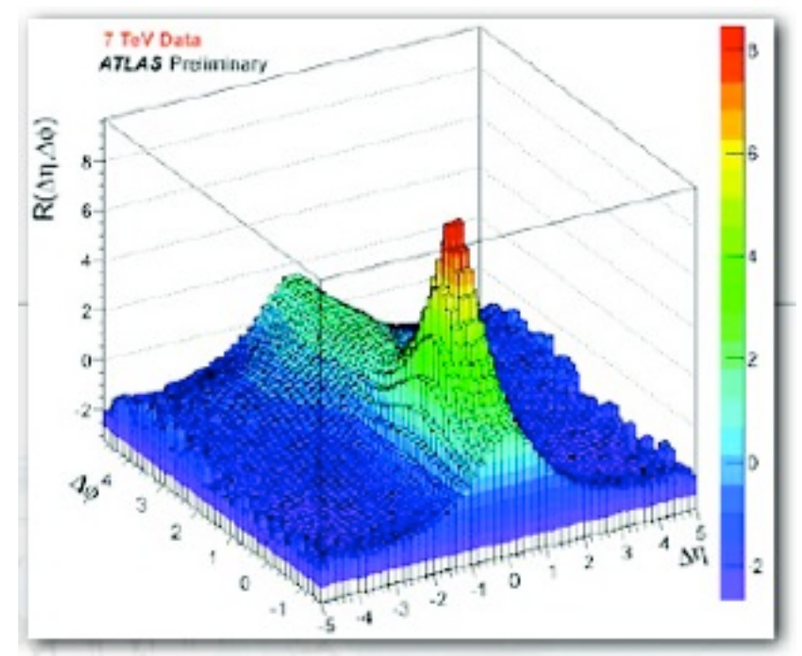




- **2 particle correlation in min bias**
  [C. Oropeza Barrera]

complex structure @ 0.9 and 7 TeV

No models reproduce strength

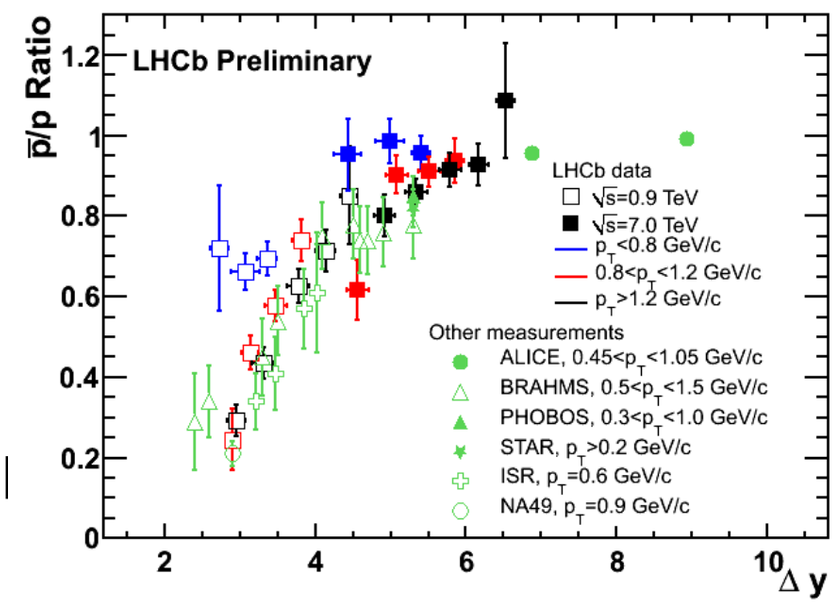


Exciting times! Many more measurements to come!

Other hadronic final states

- **On $k_\perp$-dependent PDFs in studies of hadronic data** [E. Avsar]
  - Better treatment of kinematics, high-energy evolution, needed at LHC
  - Lack of operator definition a limitation in many approaches (CCFM, CCH, ...)
  - "Before trying to interpret implications of small-x evolution on observables, establish factorization and associated PDFs!"

- **Baryon number transport @ LHCb** [M. Adinolfi]
  - Λbar/Λ , Λbar/K_S , pbar/p ratios
  - Tuning of Monte Carlos



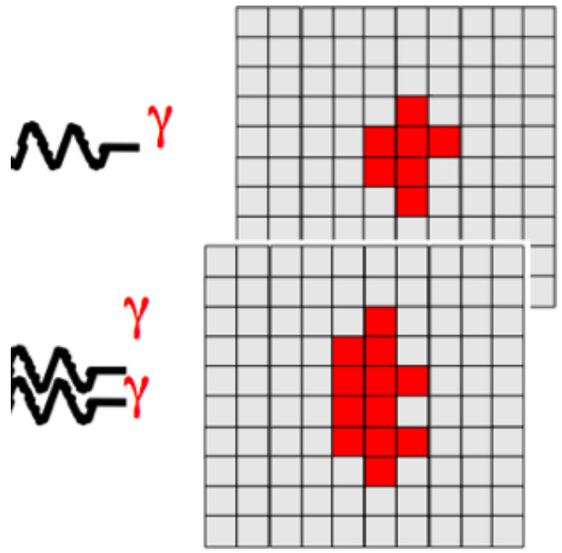
- **Hyperon production and polarization with CLAS at Jla**
  [S. Anefalos Pereira]
  - photoproduction: study baryon resonances
  - hyperons: complete recoil polarization measurements
  - New results on deuterium
    - quasi-free neutrons
    - bound proton vs. free proton

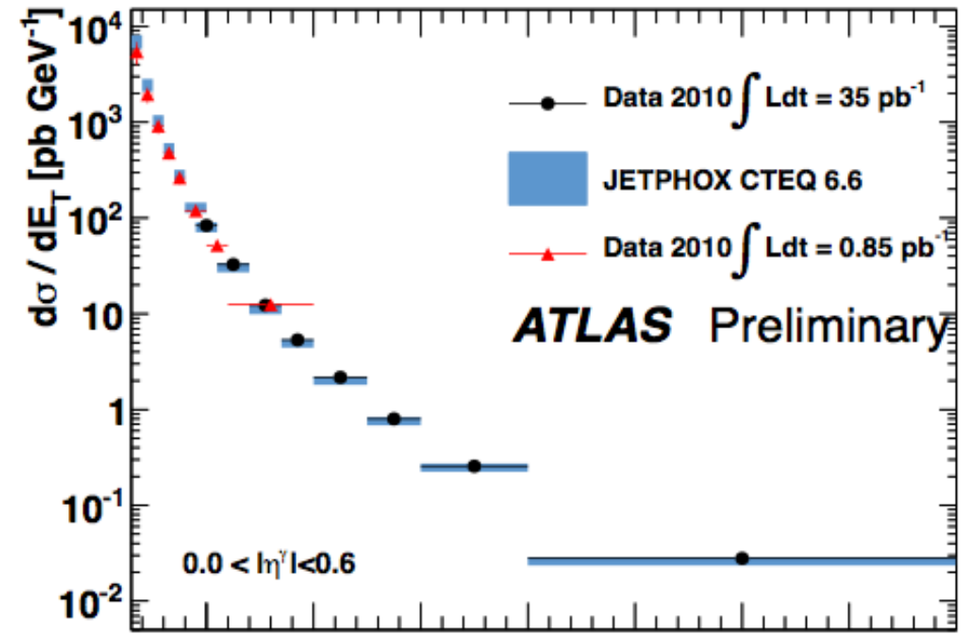
physics with bosons

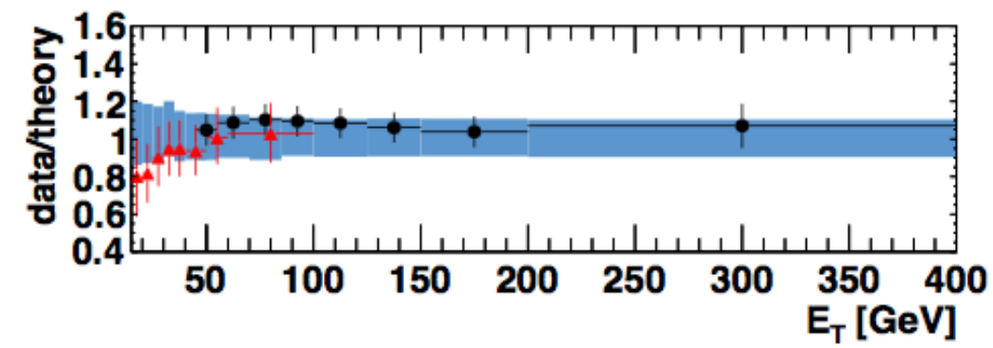
Prompt photons at the LHC

Giovanni Marchiori Andre David

Photons distinguished from pions by shower shape

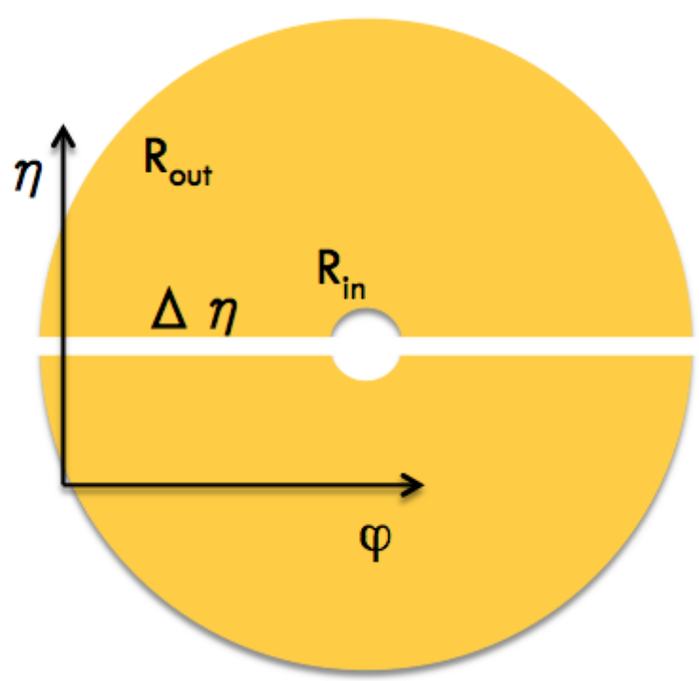


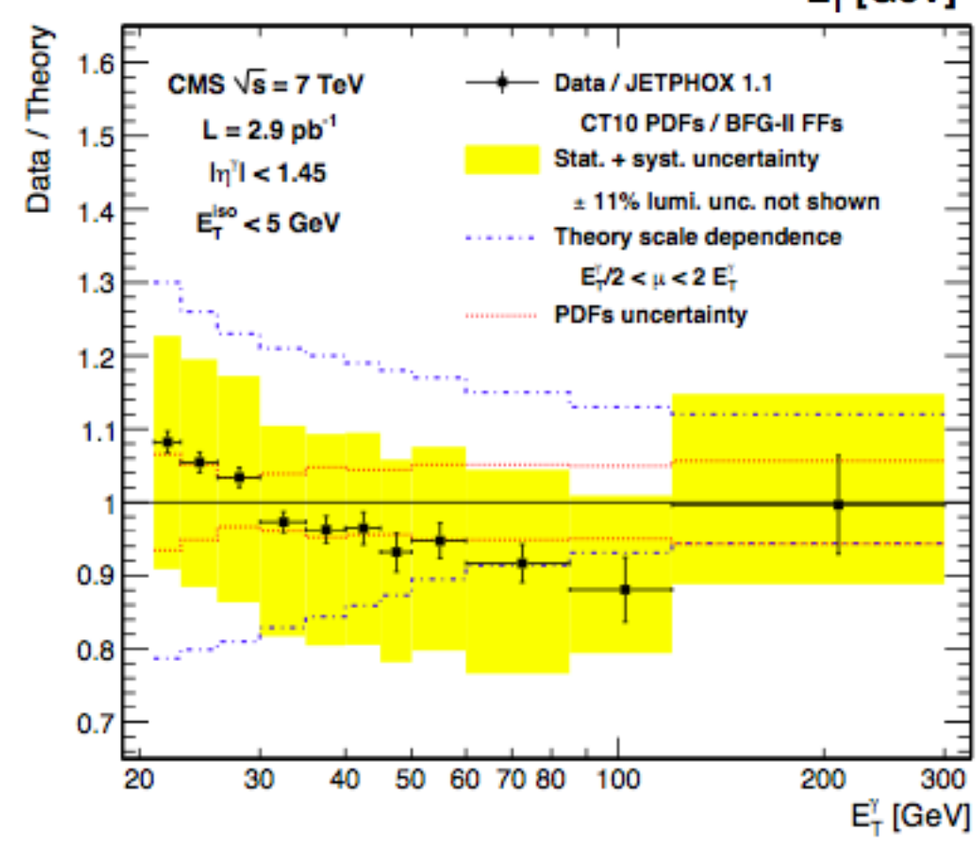




- Prompt photon production clearly observed in ATLAS and CMS
- High efficiency, purity samples using isolation discriminant
- Creative use of Z→ee control samples

Modified isolation inner cone: Identifies electrons with Bremsstrahlung

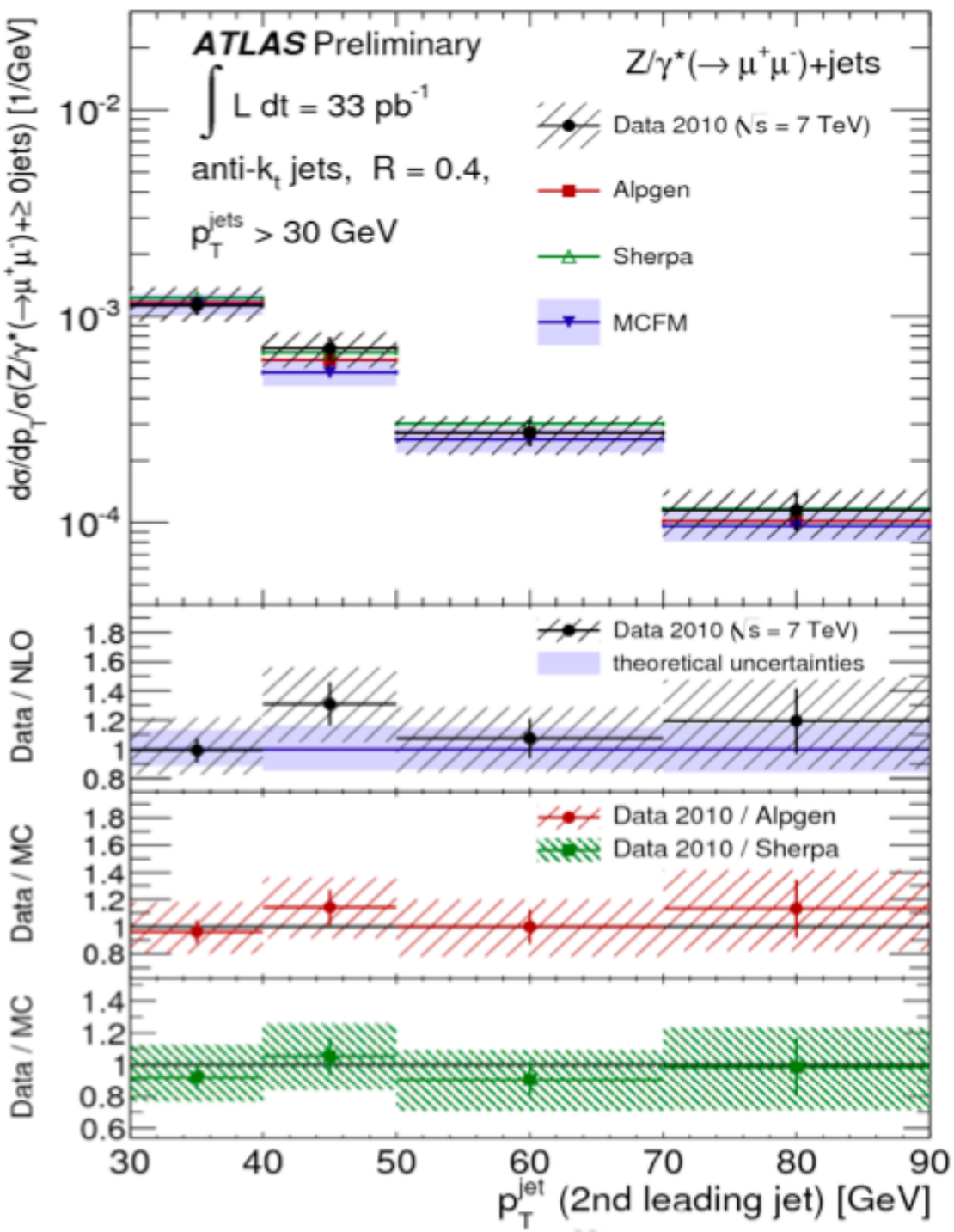




W/Z+jets production at Tevatron

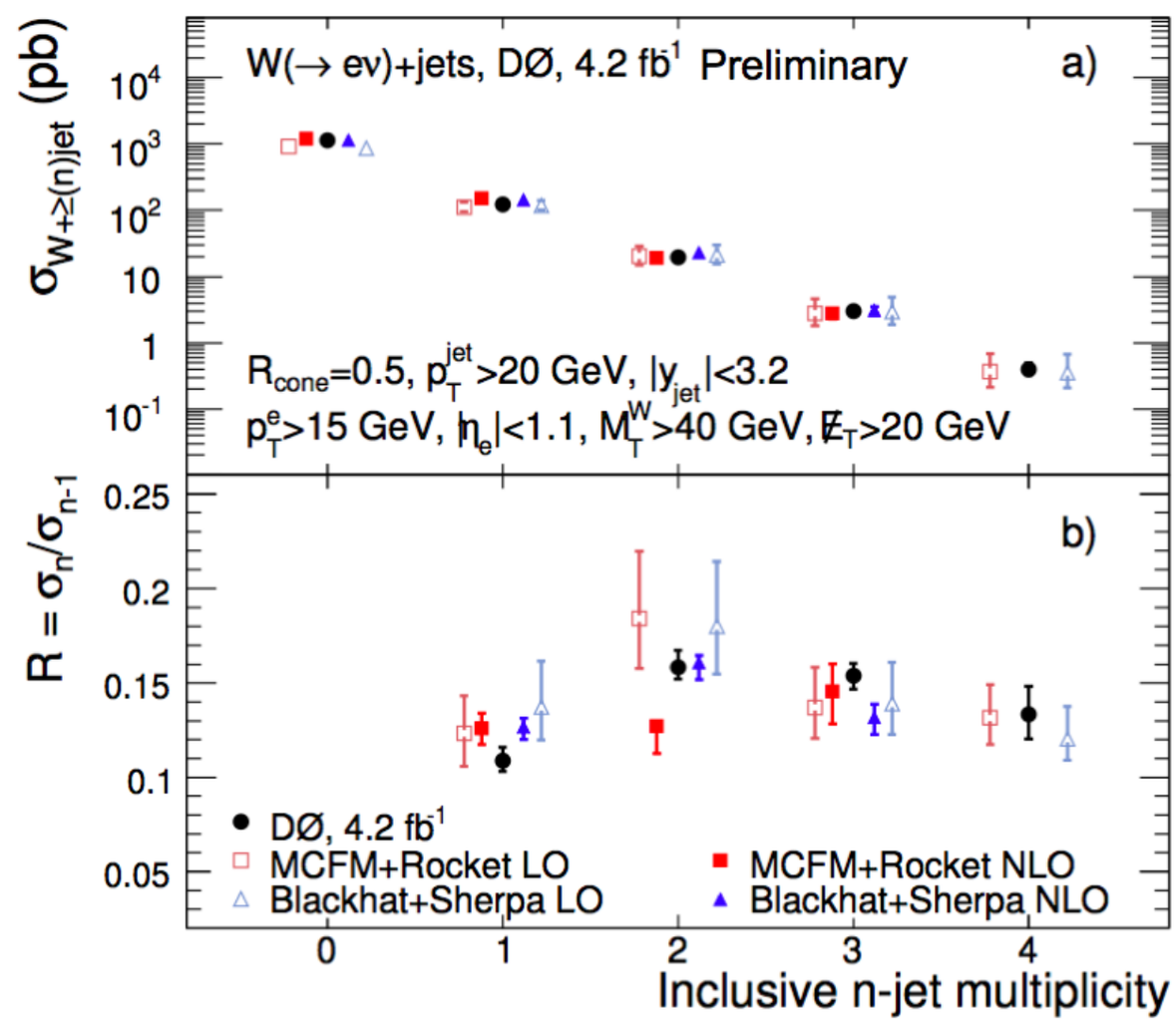
Stefan Ask
Darren Price

- Cross sections comapared with NLO and MC theory as a function of many variables



Brand new results for DIS2011

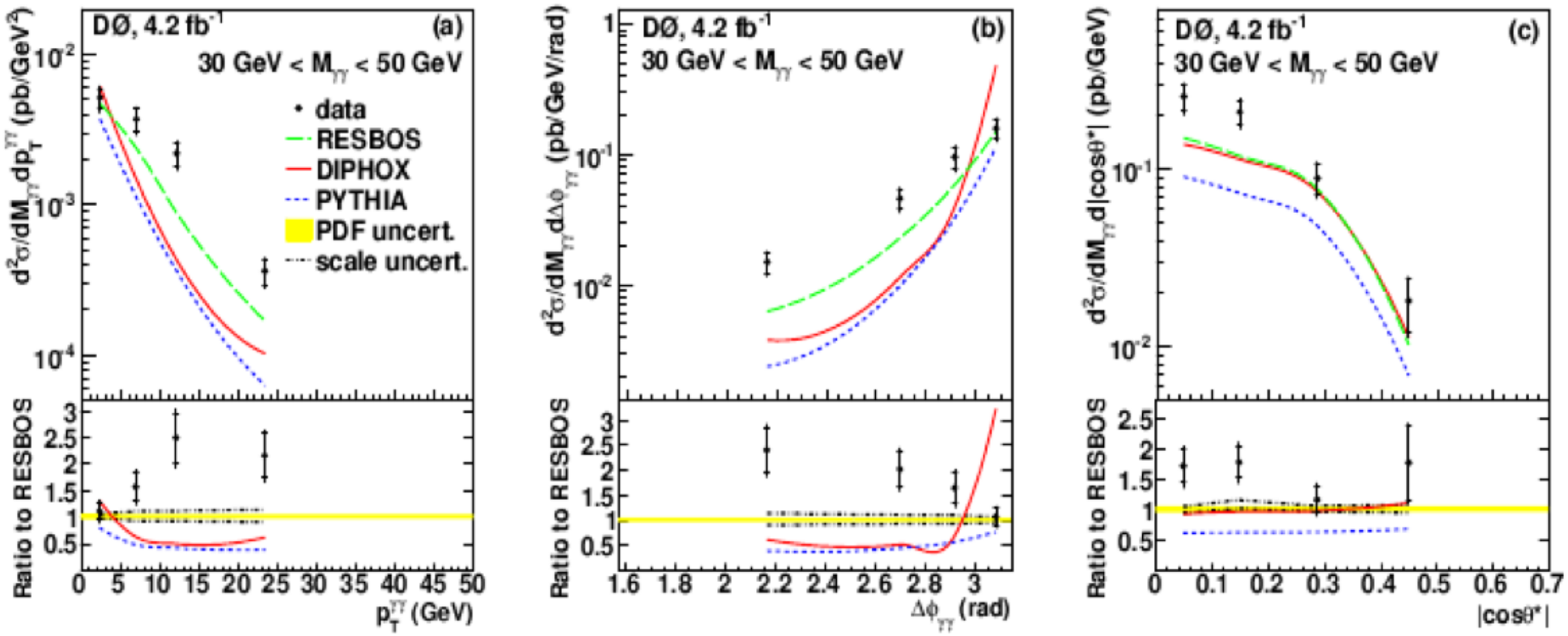
- Precise measurement of W+njet inclusive cross sections and differentially as function of jet pT
- Small data uncertainties allow detailed studies of NLO theory



Diphotons

Dmitry Bandurin

- Motivation: test pQCD and distinguish prompt diphoton kinematics from H→γγ



- Measurements are compared with latest theory predictions using RESBOS, DIPHOX and PYTHIA. None of the packages is able to describe data in the whole kinematic region. Most problematic are regions of small masses, large $p_T^{\gamma\gamma}$ and small $\Delta\Phi_{\gamma\gamma}$.

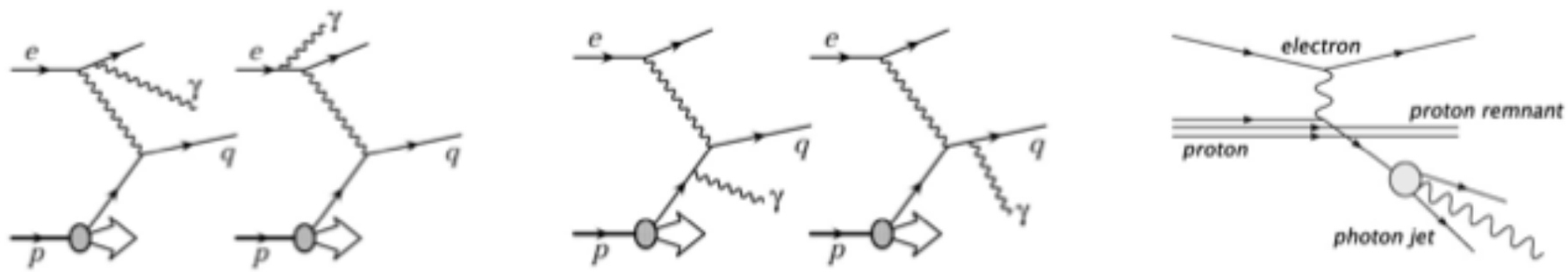
- RESBOS predictions are closest to data, with excellent agreement at M>80 GeV. Resummation works well at low $p_T^{\gamma\gamma}$ and large $\Delta\Phi_{\gamma\gamma}$.

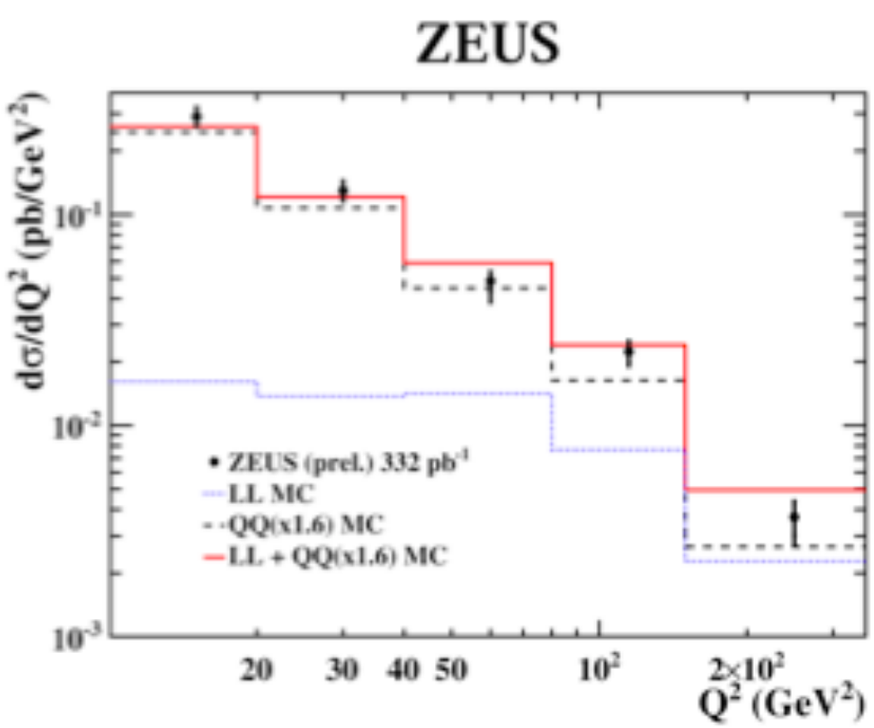
- The measurements should allow further improvements/tuning of QCD theory predictions.

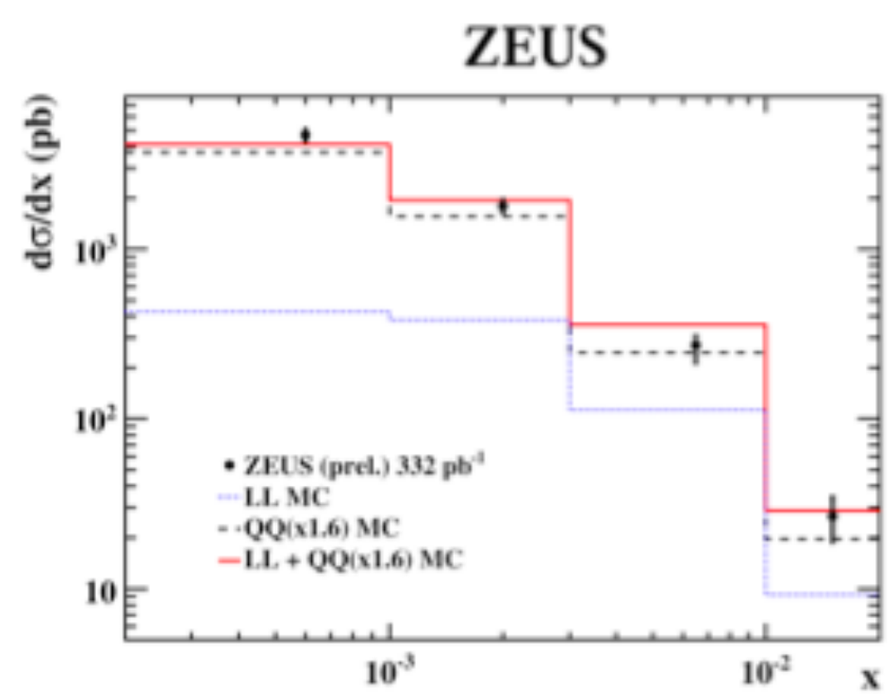
Prompt Photon + jets in DIS

Nataliia Zhmak

- Motivation: final state that is sensitive to underlying partonic process





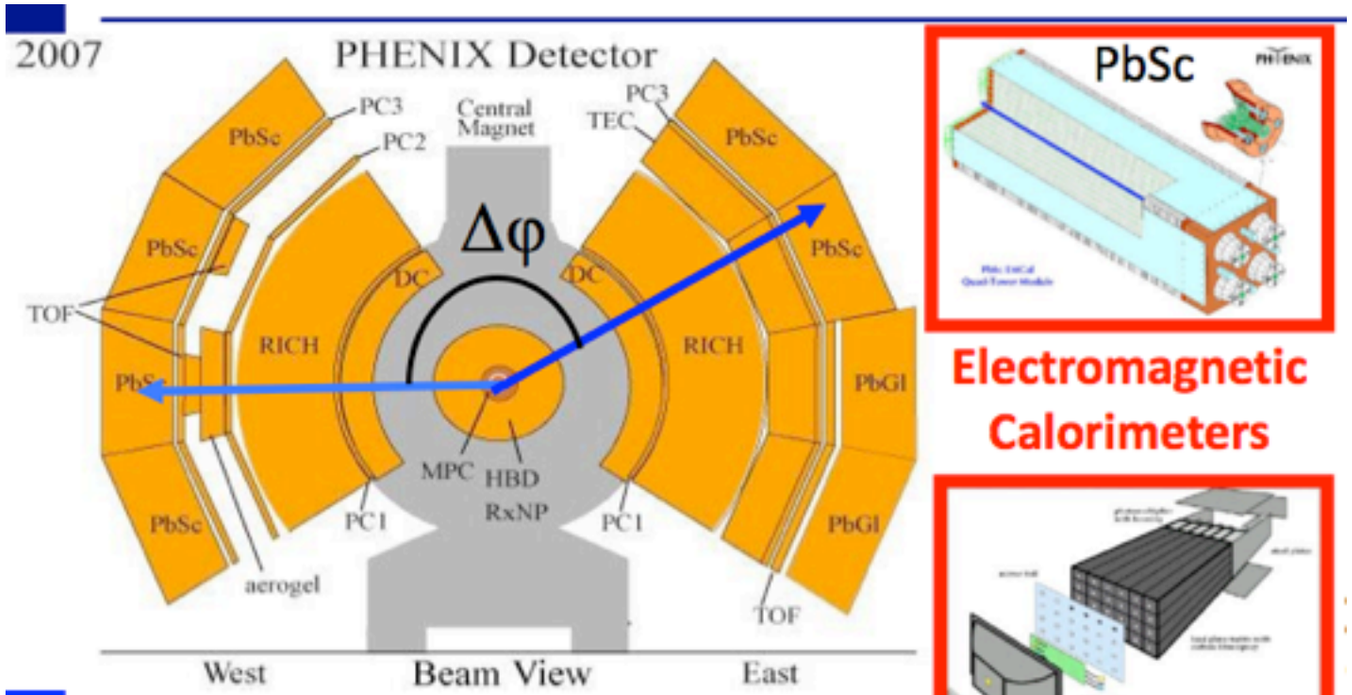


- Prompt photon + jets cross sections in DIS have been measured differentially in η_γ, $E_{T,\gamma}$, x, Q^2, η_{jet} and $E_{T,jet}$ at HERA using ZEUS detector in restricted phase spase

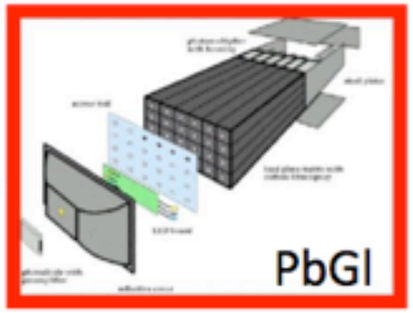
Outlook:
compare with theory

Photon-hadron correlations with PHENIX

Megan Connors



Electromagnetic Calorimeters

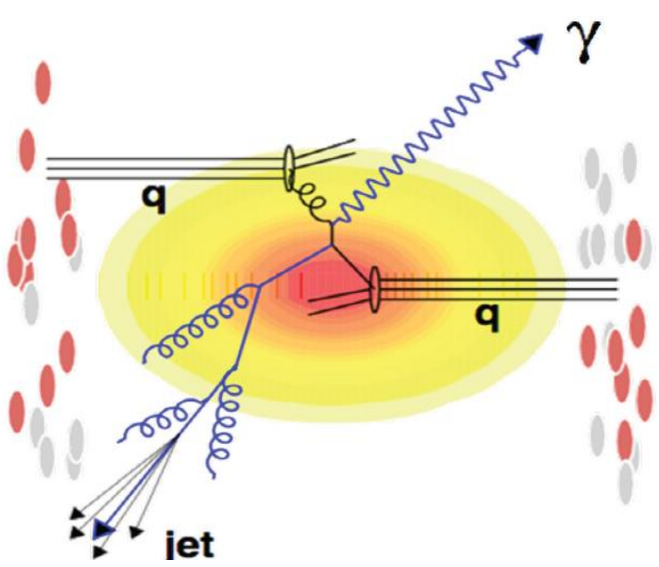


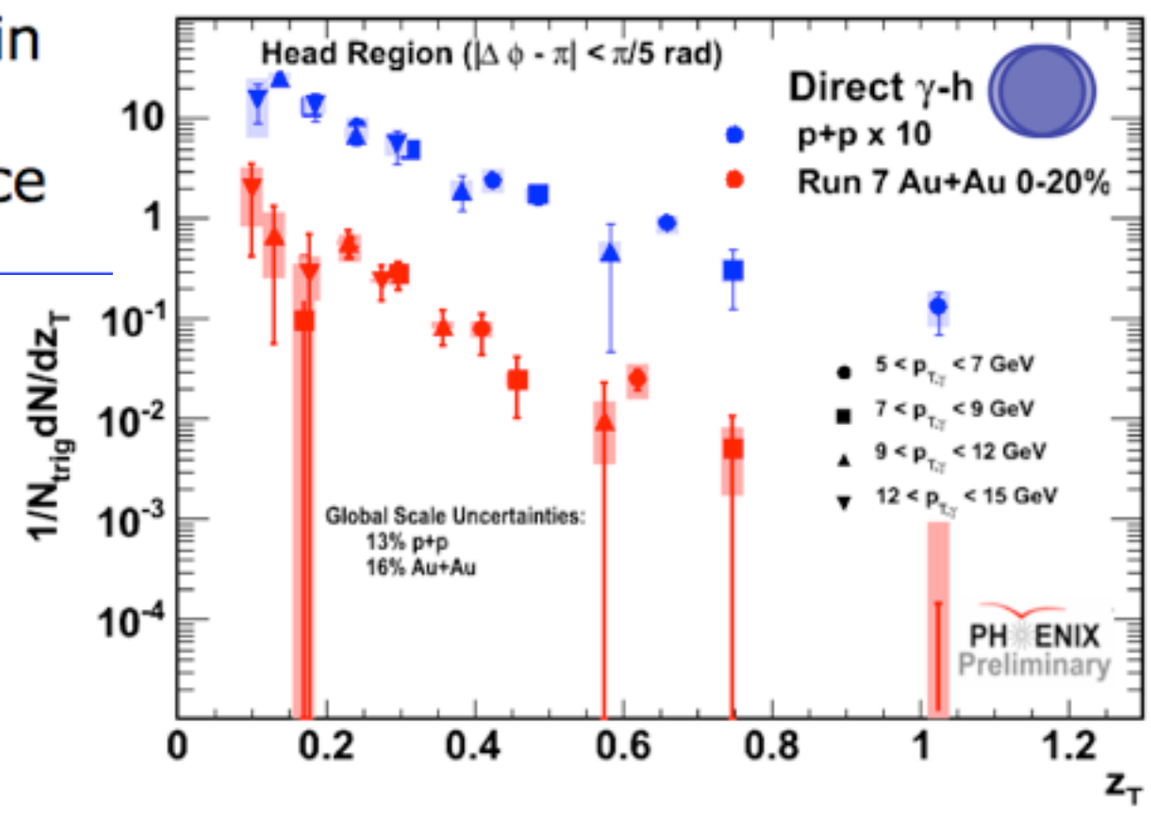
- Trigger on a high p_T (>5GeV/c) inclusive photon
- Measure $\Delta\phi$ between photon and all hadrons in the event within a certain p_T range
- Event mixing corrects for acceptance and combinatorial pairs

- Measurement of modified FF in Au+Au compared to p+p

$$z_T = \frac{p_T^h}{p_T^\gamma}$$

$$p_T^\gamma \approx p_T^{jet}$$





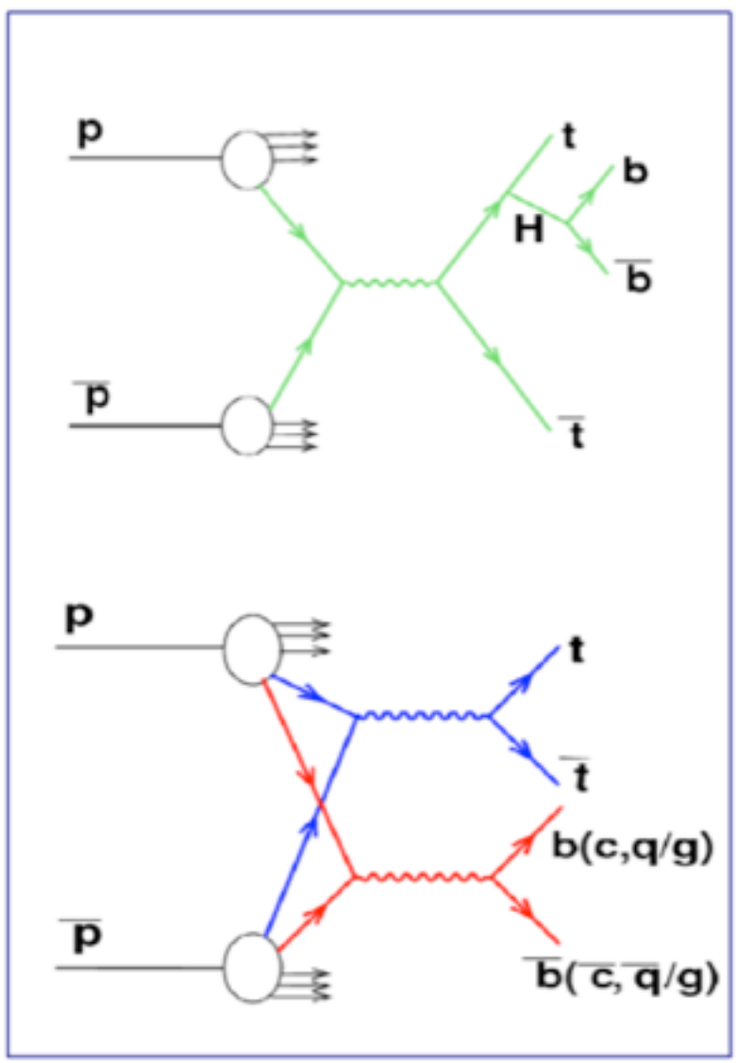
Multiparton interactions in photon+jets

Alexander Verkheev

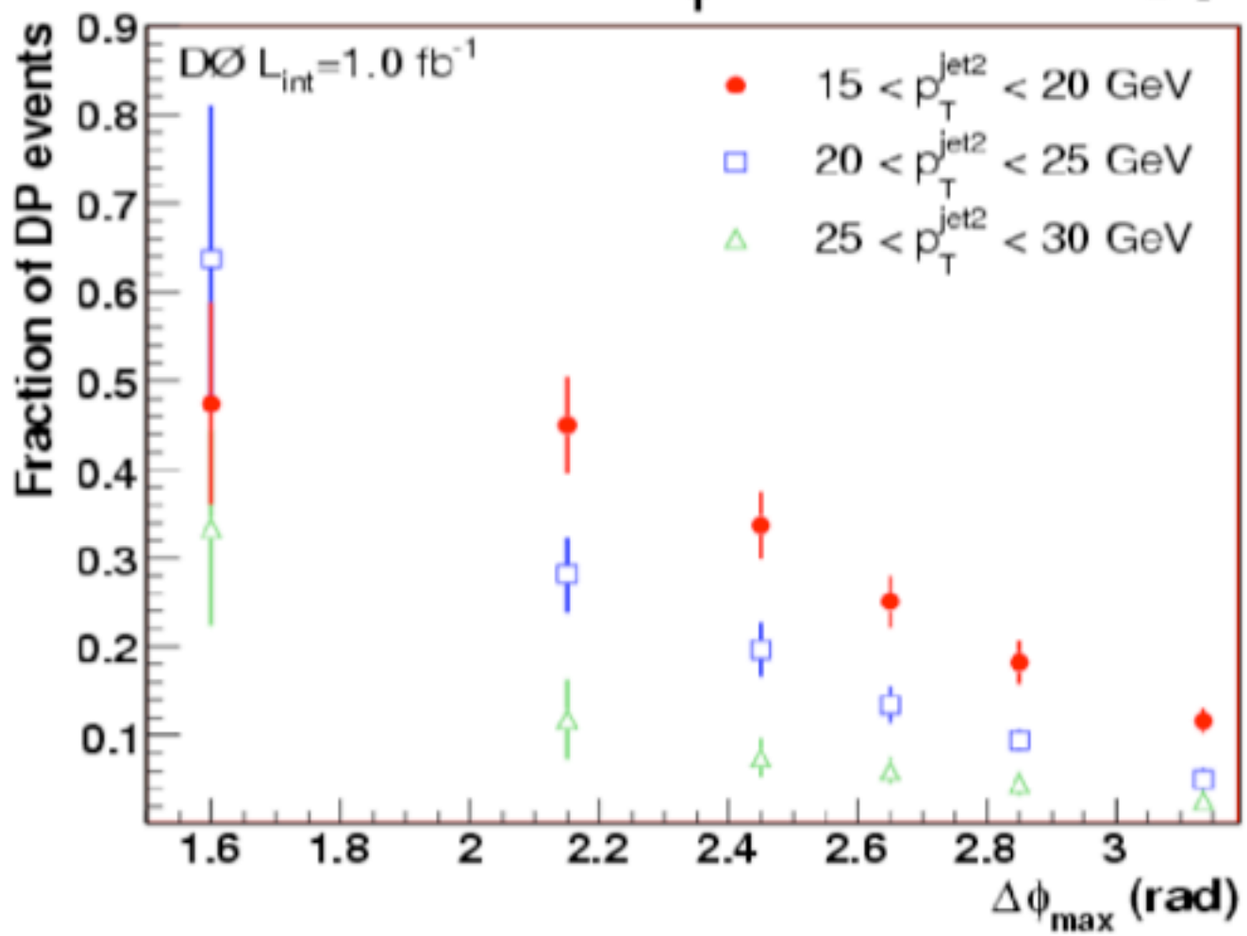
- New and complementary information about proton structure:
  - spatial distribution of the partons within proton;
  - possible parton-parton correlations.
- Needed for an understanding of nature of signal events and correct estimation of background to many rare processes especially with multi-jet final state, for example SM Higgs and SUSY productions.

Higgs signal

DP bkgd.



DP fractions as a function of the upper limit on $\Delta\phi$ for 3 bins of p_T^{jet2}



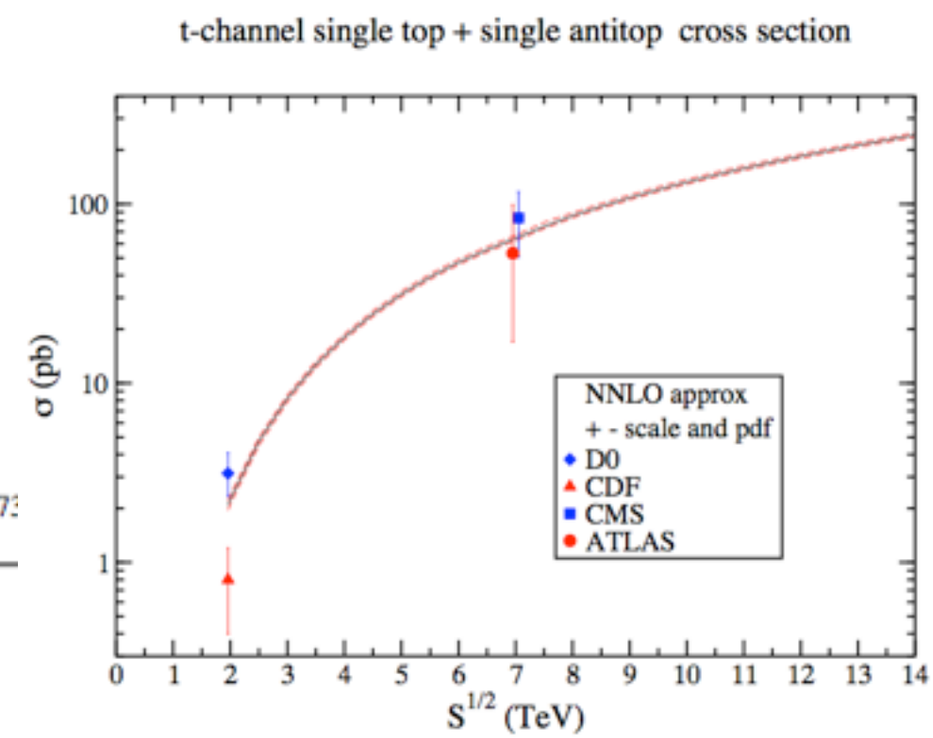
$\Delta\phi$ (γ+jet1, jet2)

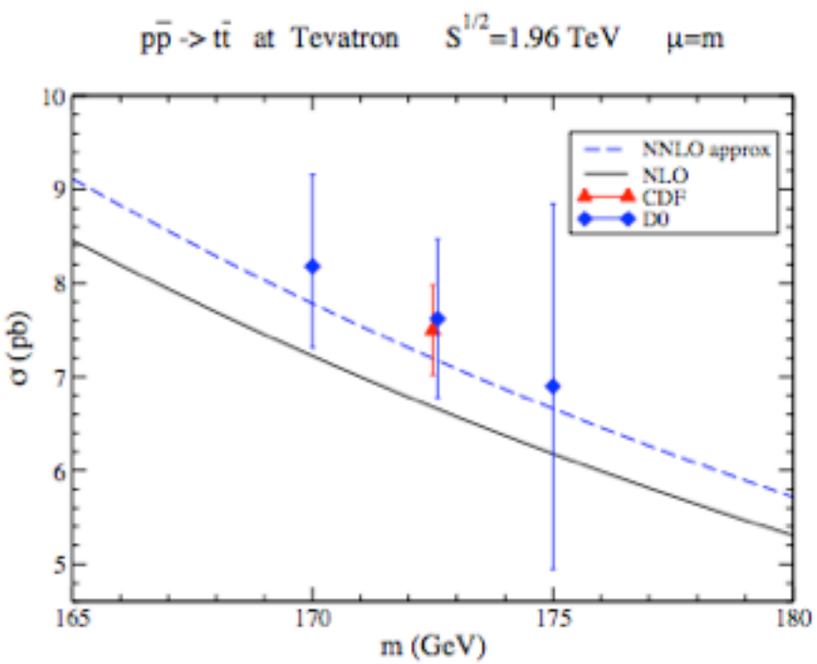
- Fractions increase toward smaller pT and smaller angles

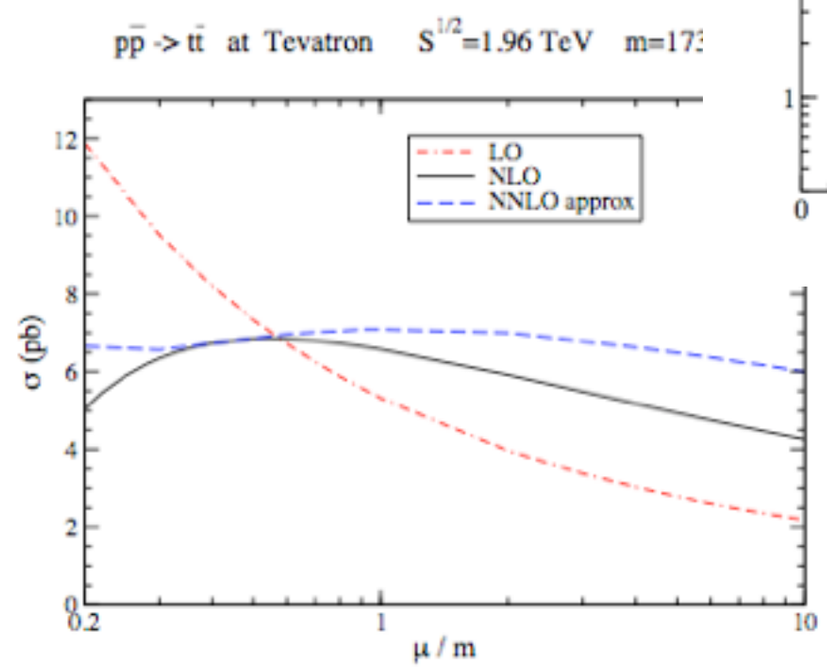
Nikolaos Kidonakis

Renormalization group evolution of collinear and infrared divergencies

- Recent results of NNLL predictions for ttbar, single top, H^-, W^-, γ
  - two-loop calculations completed
- Approximate NNLO cross section from expansion of resummed cross section
  - NNLO corrections move in direction of data
  - flat dependence on scale
- Essential ingredient: two-loop soft anomalous dimension







Tevatron and LHC results consistent with theory

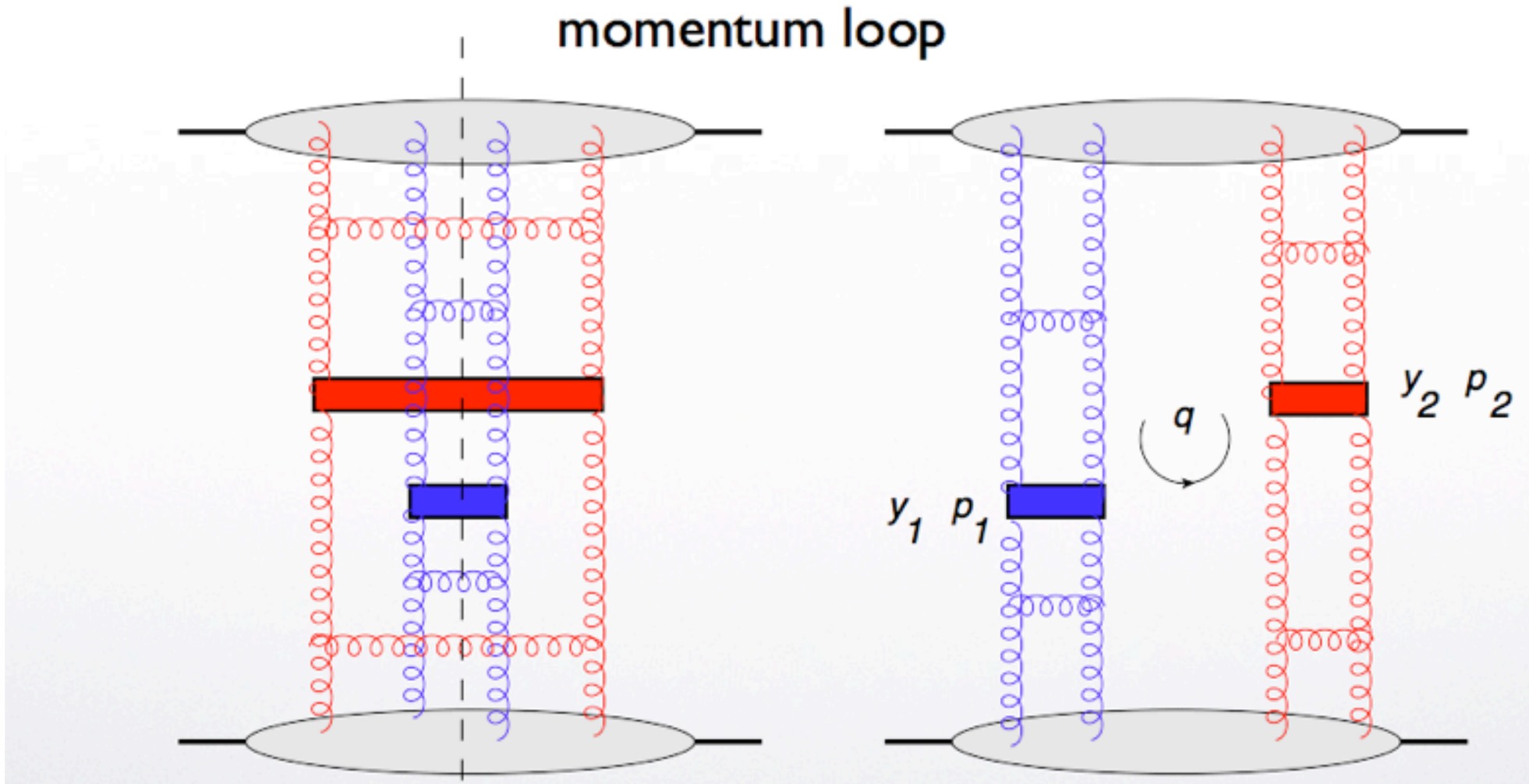
Multiparton Evolution: recombination

Jochen Bartels

Questions:

- evolution equations : in x or in momentum scale ?
  (BFKL-type vs higher twist B'F'KL)
- consistency requirements - AGK cutting rules
- detailed form of evolution equations
- in course of evolution, change the number of parton chains (triple vertex)

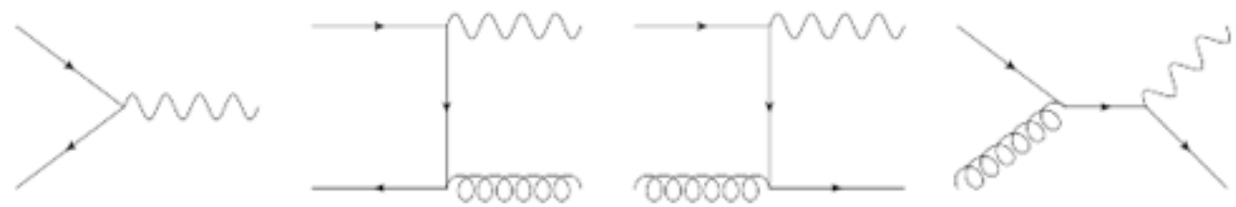
Production of two pairs of jets from two noninteracting chains:



Drell-Yan at forward rapidity

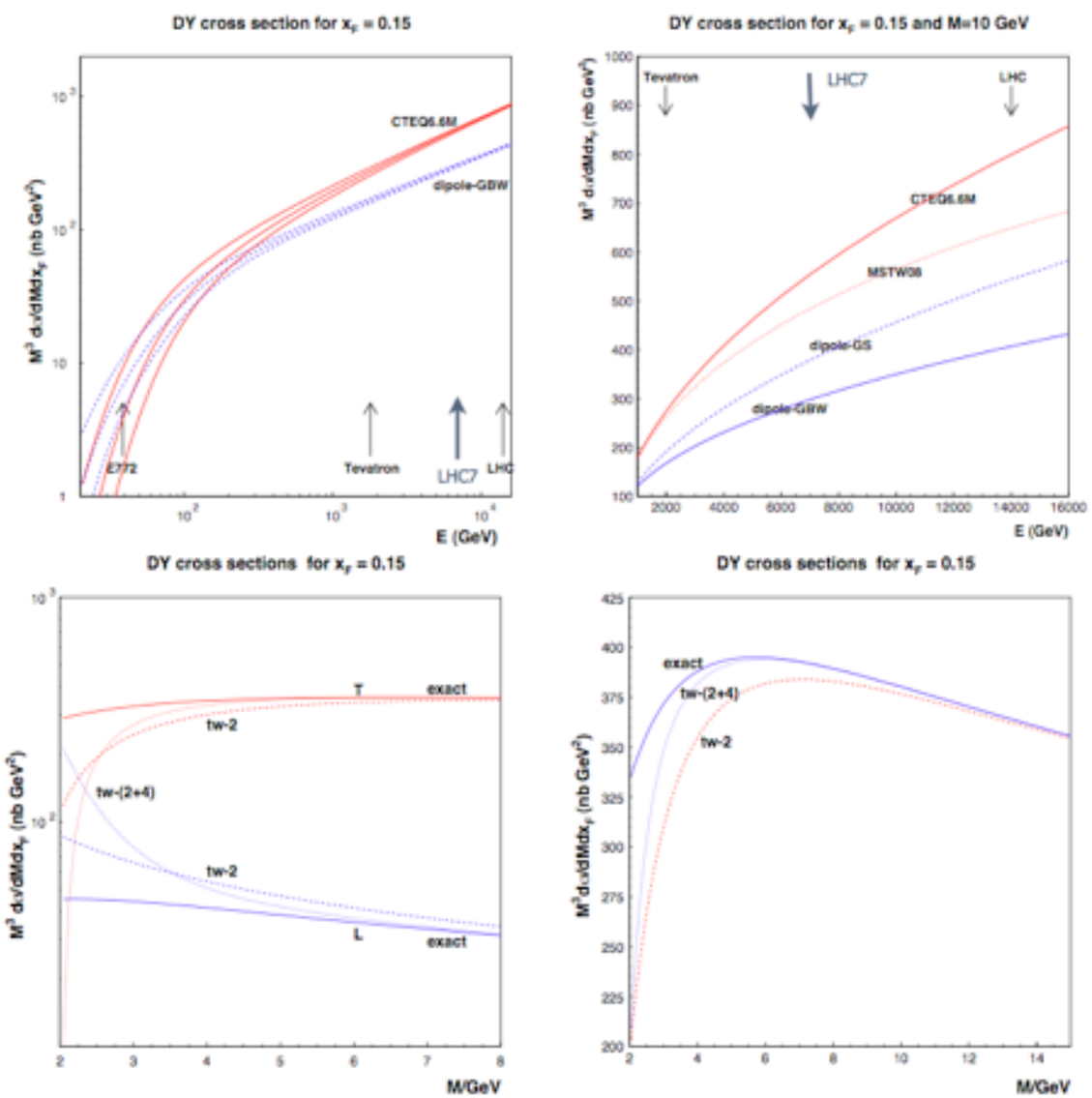
Anna Stasto

In the standard collinear factorization approach Drell-Yan process described by the fusion of the quark-antiquark and the production of the massive photon with subsequent decay. Higher orders involve gluon corrections.



M : invariant mass of the lepton pair

$$x_1 x_2 = M^2/s \equiv \tau$$



$\sqrt{s} = 14$ TeV

- Large differences between collinear approaches
- Dipole predictions systematically lower than collinear calculations
- Twist expansions calculated for Drell-Yan
  - twist expansion divergent for M<4
  - for higher masses M>6 twist 2 sufficient
  - sum of longitudinal and transverse parts better approximated by twist expansion

Angular coefficients of Drell-Yan pairs

Arie Bodek

- First measurement of angular coefficients in production of γ*/Z bosons at large transverse momentum

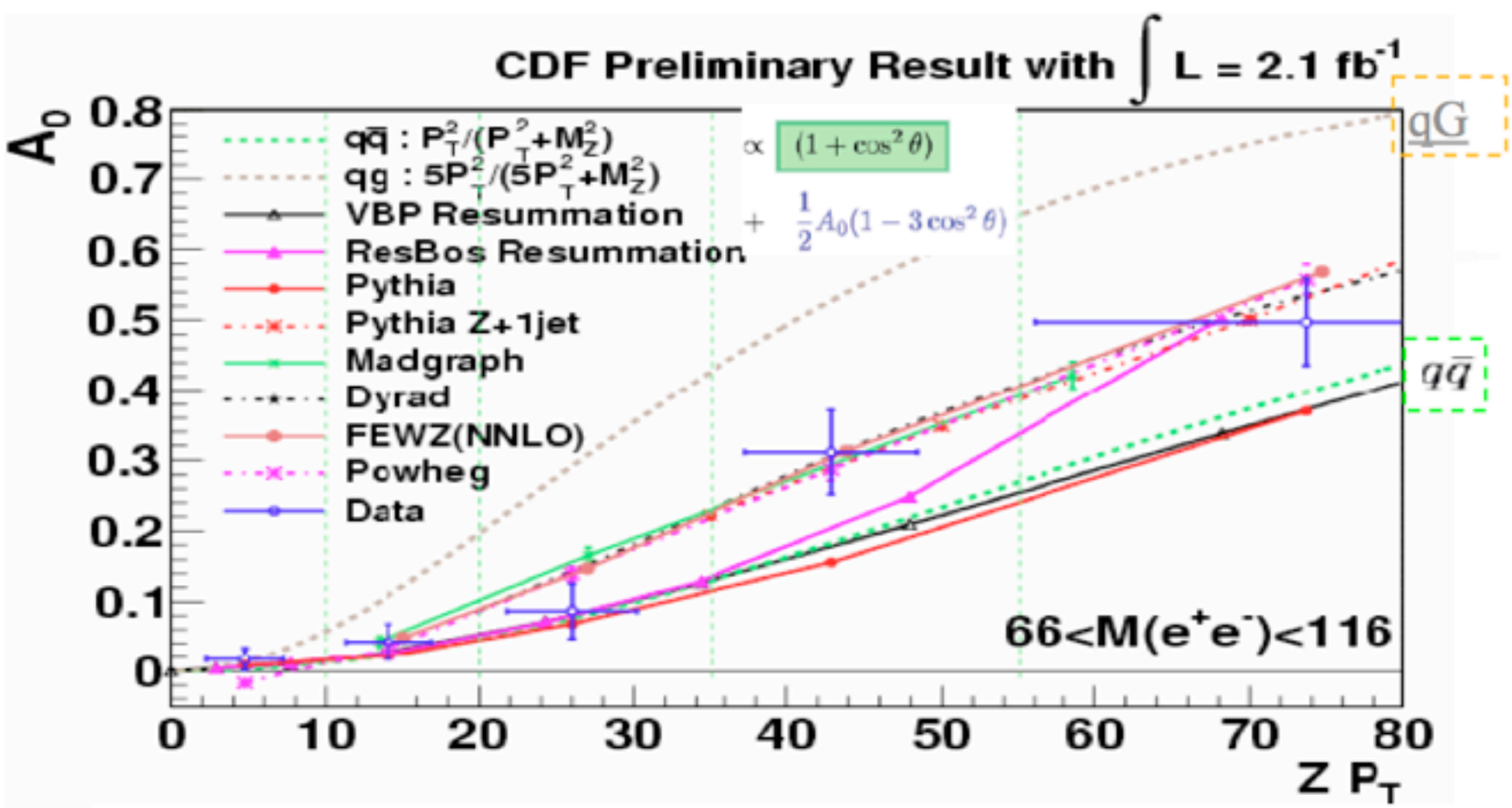
$$\frac{d\sigma}{dP_T^2 dy d\cos\theta d\phi} \propto (1+\cos^2\theta) \longrightarrow \textit{LO term}$$

$$+ \frac{1}{2}A_0(1-3\cos^2\theta) \longrightarrow \cos^2\theta : \textit{higher order term}$$

$$+ A_1 \sin 2\theta \cos\phi + \frac{1}{2}A_2 \sin^2\theta \cos 2\phi + A_3 \sin\theta \cos\phi \rightarrow (\theta, \phi)\ \textit{terms}$$

$$+ A_4 \cos\theta \longrightarrow \textit{LO term : determine } A_{fb}$$

$$+ A_5 \sin^2\theta \sin 2\phi + A_6 \sin 2\theta \sin\phi + A_7 \sin\theta \sin\phi \rightarrow \textit{very small terms}$$



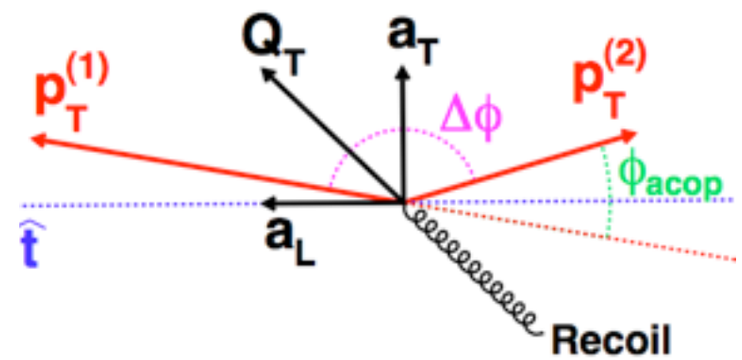
Results are in agreement with fixed order perturbation theory predictions

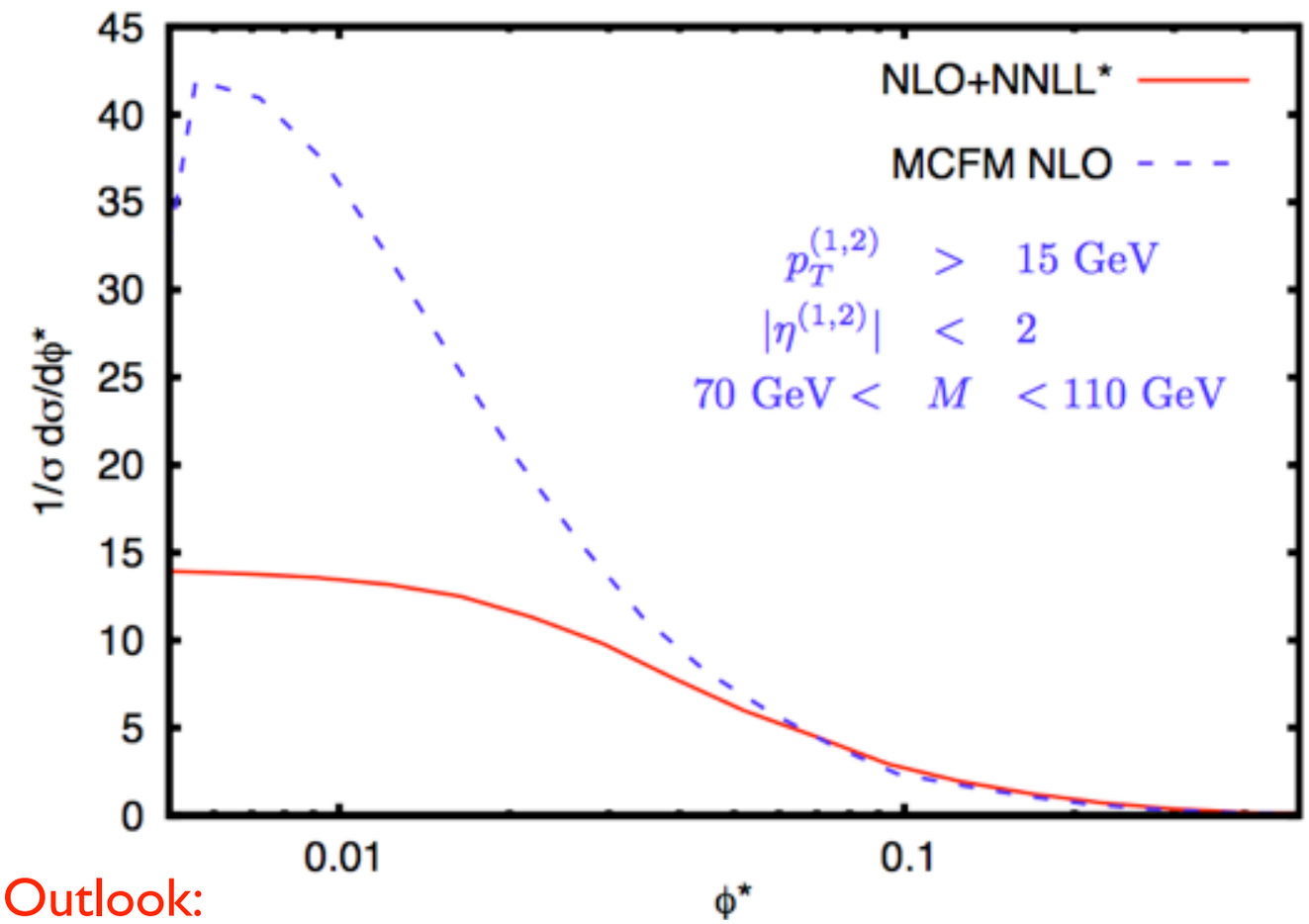
QCD resummation for new dilepton variables

Simone Marzani

- New initiative: phenomenology of D0 ϕ^* variable, introduced to study p_T of Z boson

$$\left(\frac{d\sigma}{d\phi^*}\right)_{\text{matched}} = \left(\frac{d\sigma}{d\phi^*}\right)_{\text{resummed}} + \left(\frac{d\sigma}{d\phi^*}\right)_{\text{MCFM}} - \left(\frac{d\sigma}{d\phi^*}\right)_{\text{expanded}}$$

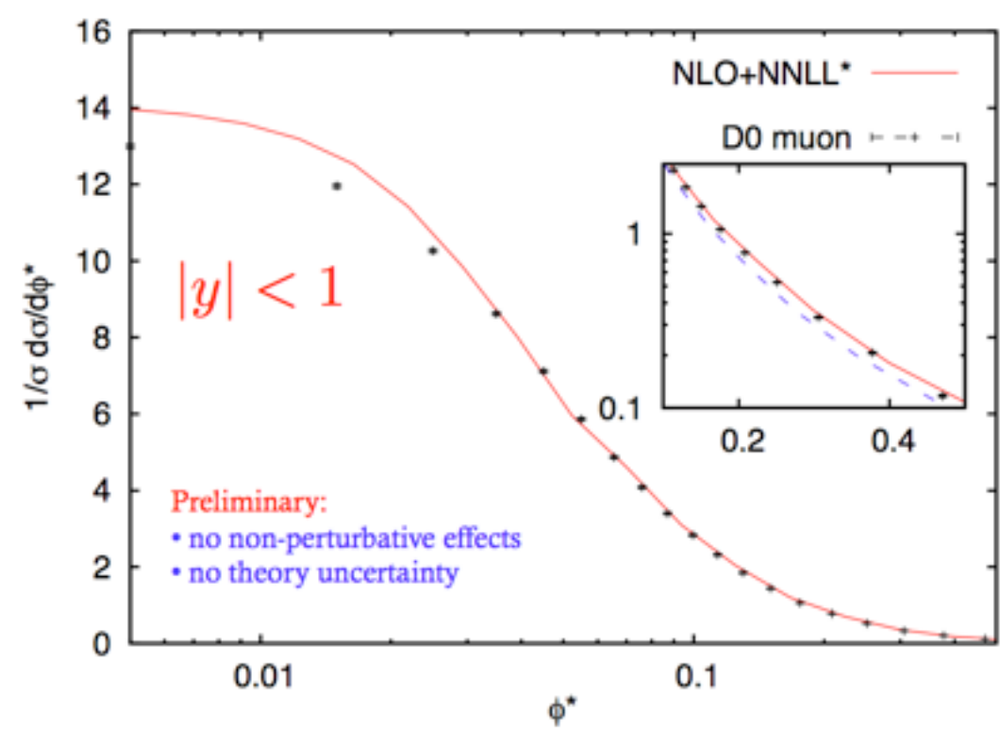




- Smooth matching procedure: no need to switch off terms
- The matched curve and fixed order agree at large ϕ^*
- But they very much differ in a large region

$$\phi^* = \tan\left(\phi_{\text{acop}}/2\right)\sin\theta^*$$

Comparison to D0 data



Outlook:

- We need to implement full NNLL
- We have to estimate the theoretical uncertainty:
  - missing higher orders in the fixed-order part (estimating by varying renormalization and factorization scales)
  - missing higher orders in the resummation (estimating by varying the argument of the logs we resum)
  - different procedures to regularize the b-integral (cut-off, minimal prescription etc.)

Ke4 decays at NA48

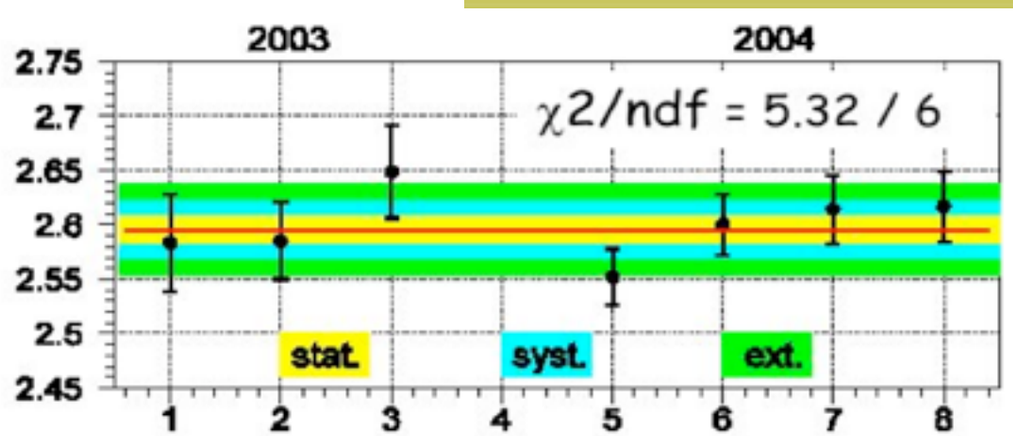
Sergio Giudici

- First analysis of 2003 and 2004 data for these decays:

label	decay	BR prediction	BR PDG	#events
Ke4 +-	$K^+ \to e^+ \nu \pi^+ \pi^-$	$(3.91 \pm 0.17)\ 10^{-5}$	$(4.09 \pm 0.10)\ 10^{-5}$	418000
Ke4 00	$K^+ \to e^+ \nu \pi^0 \pi^0$	$(2.01 \pm 0.11)\ 10^{-5}$	$(2.20 \pm 0.40)\ 10^{-5}$	37
Ke4 0-	$K^0 \to e^+ \nu \pi^0 \pi^-$	$(4.69 \pm 0.87)\ 10^{-5}$	$(5.20 \pm 0.11)\ 10^{-5}$	6131

- Measurements allow for precise determination of form factors
- First approach to FF shows consistency between (+-) and (00) modes
- Extremely precise measurements of branching ratios

BR Ke4 (+-) 0.8% rel. (factor 3 improvements /PDG)
BR Ke4 (00) 1.6% rel. (factor 10 improvements /PDG)

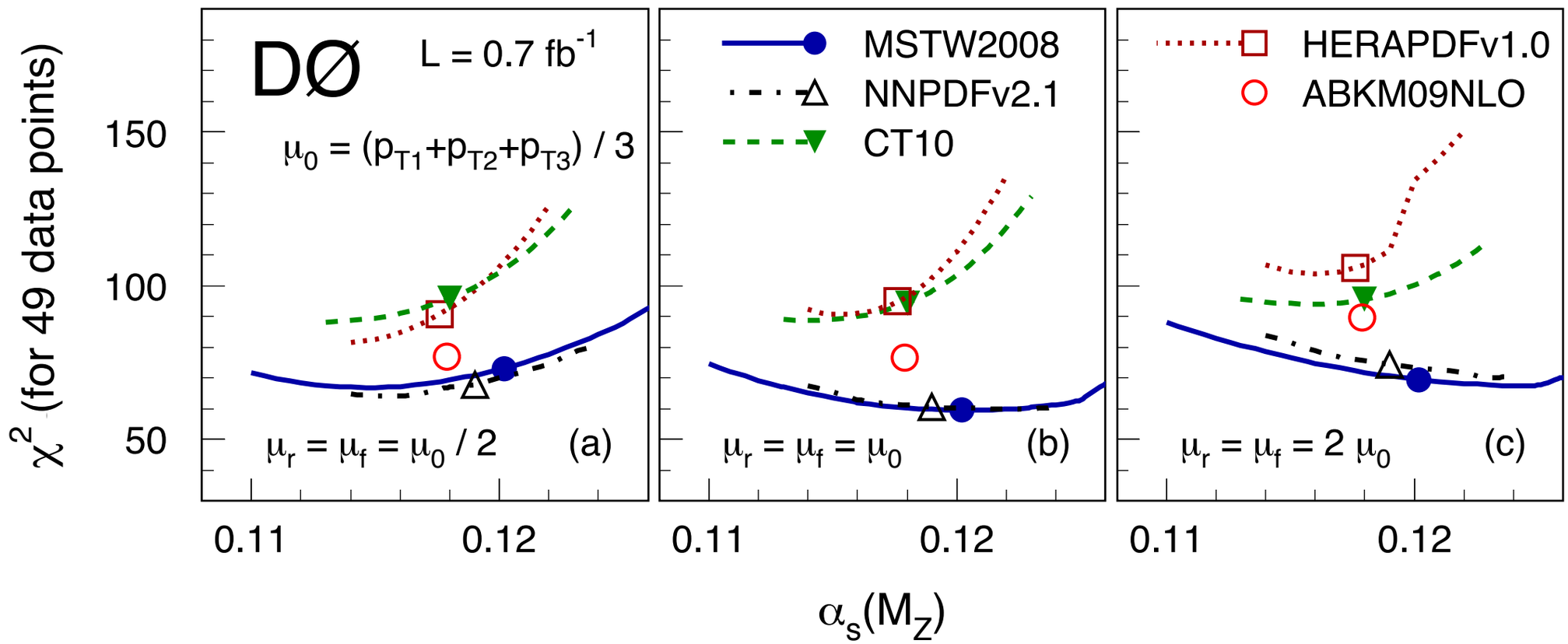


measurements show
nice stability over time

backup

PDF TESTS

- Cross section depends on the choice of PDF, α_S, scales
- Calculate χ^2 for all data points including all correlated uncertainties except PDF uncert. (test of central PDF)



- for α_S close to the world average, observed lowest χ^2 for the default scales
- lowest χ^2 for MSTW2008 and NNPDFv2.1

Integrated Subtracted Terms for Two Unresolved Partons

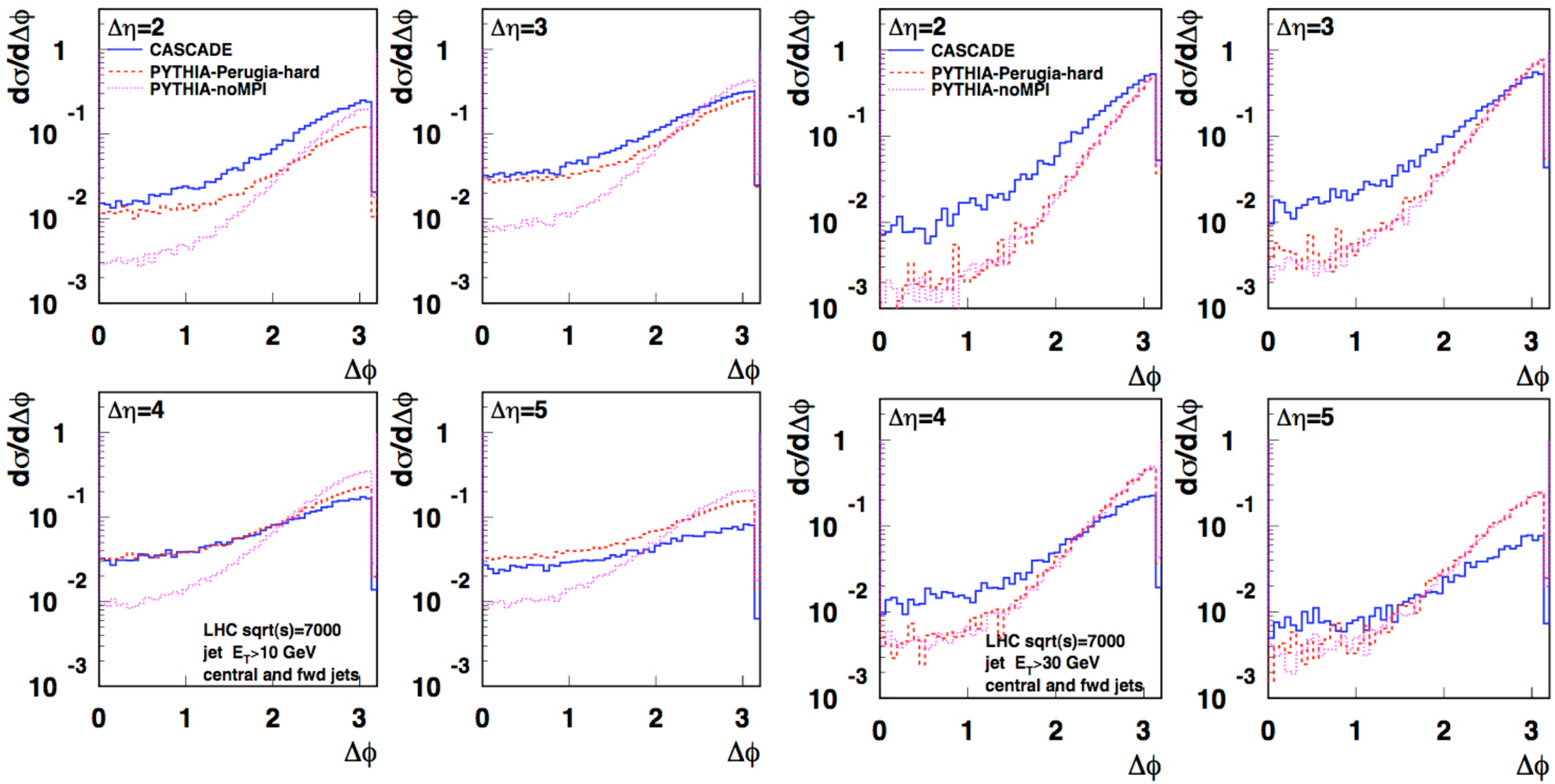
- Final-final antennae:
  - needed for lepton-lepton collider observables
  - applied already to ee → 3jets A. Gehrmann, T. Gehrmann, N. Glover, G. Heinrich; S. Weinzierl
  - all unintegrated and integrated f-f antennae are known
- Initial-final antennae: A. Daleo, A.. Gehrmann, T. Gehrmann, G. Luisoni
  - needed for lepton-hadron collider observables (eg. DIS (2+1)-jet production)
  - known in the unintegrated and integrated form

- Initial-initial antennae: R. B., A. Gehrmann-De Ridder, M. Ritzmann
  - Required for any process with two hadronic initial states,

    eg. V+j, pp → 2jets, W-pair production
  - were missing until this work

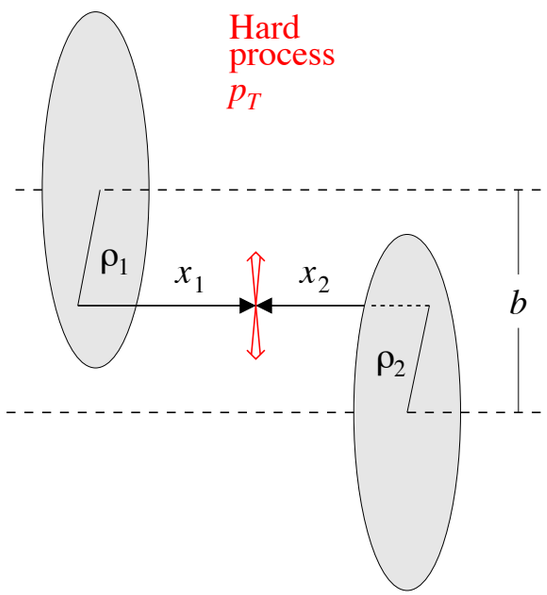
This talk

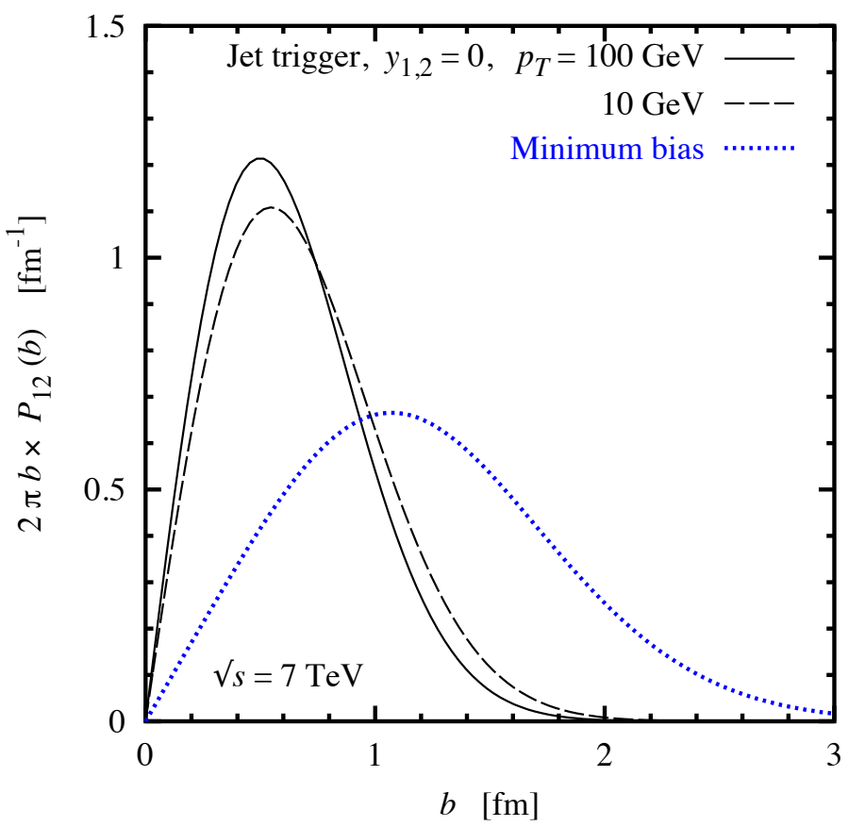
Azimuthal dependence



- flattening dependent on $\Delta\eta$

Proton–proton: Impact parameter dependence





- Hard process from parton–parton collision

  Local in transverse space $p_T^2 \gg$ (transv. size)$^{-2}$

- Cross section as function of pp impact parameter b

$$\sigma_{12}(b) \;=\; \int d^2\rho_1\, d^2\rho_2\, \delta(\boldsymbol{b} - \boldsymbol{\rho}_1 + \boldsymbol{\rho}_2) \times G(x_1, \rho_1)\, G(x_2, \rho_2)\, \sigma_{\rm parton}$$

  Calculable from known transverse distributions
  Integral $\int d^2b$ reproduces inclusive formula

  Normalized distribn $P_{12}(b) = \sigma_{12}(b)/[\int \sigma_{12}]$
  FSW, PRD83 (2011) 054012

- New information!

  Spectator interactions and underlying event

  Multiple hard processes

  Gap survival in diffraction

Results

The γp cross sections ratio

$$R = \frac{\sigma_i^{\gamma p}}{\sigma_{HER}^{\gamma p}} = \frac{N_i}{N_{HER}} \cdot \cancel{\frac{A_{HER}}{A_i}} \cdot \frac{\mathcal{L}_{HER}}{\mathcal{L}_i} \cdot \frac{f_{HER}}{f_i}$$

$\mathcal{L}_{LER}$=912 nb^{-1}

$\mathcal{L}_{MER}$=949 nb^{-1}

$\mathcal{L}_{HER}$=567 nb^{-1}

f_{LER}=0.877*10^{-3}

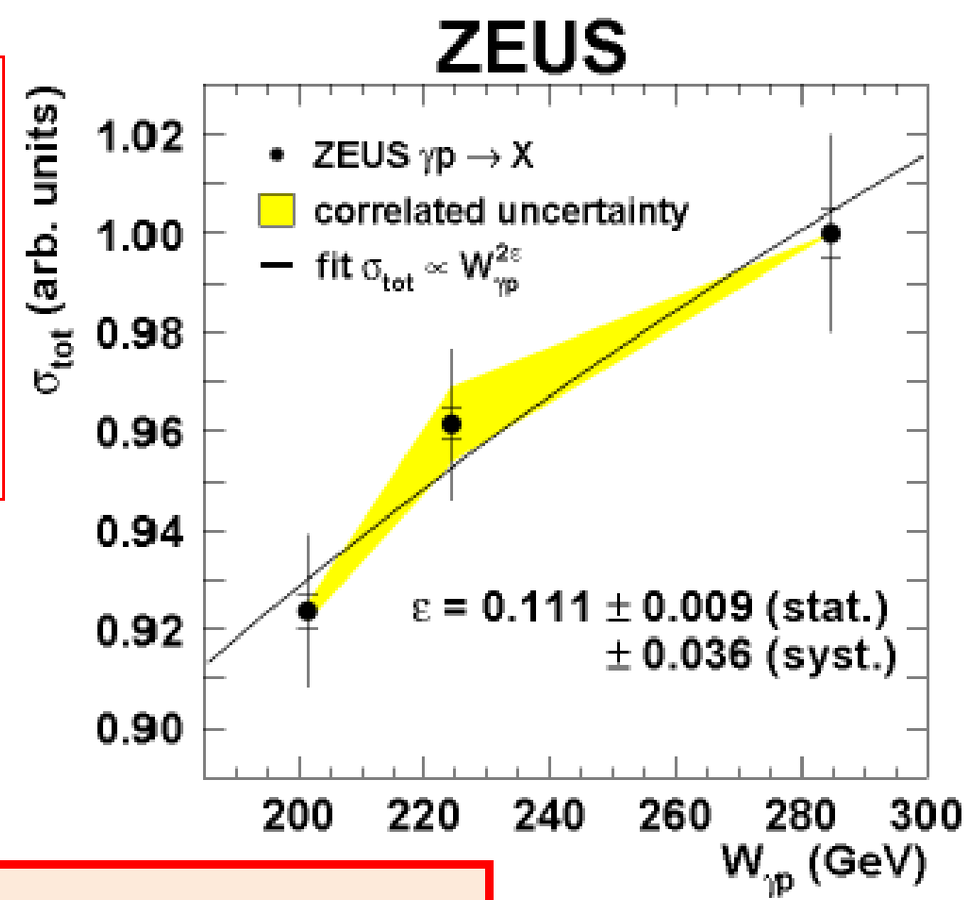
f_{MER}=0.895*10^{-3}

f_{HER}=0.852*10^{-3}

N_{LER}=116740

N_{MER}=128954

N_{HER}=76310



$$\varepsilon = 0.111 \pm 0.009(\text{stat.}) \pm 0.036(\text{sys.})$$

General Strategy

Systematic comparison of jet algs performance in HIC

Embed *pp* events (with and wo quenching) into minbias PbPb events

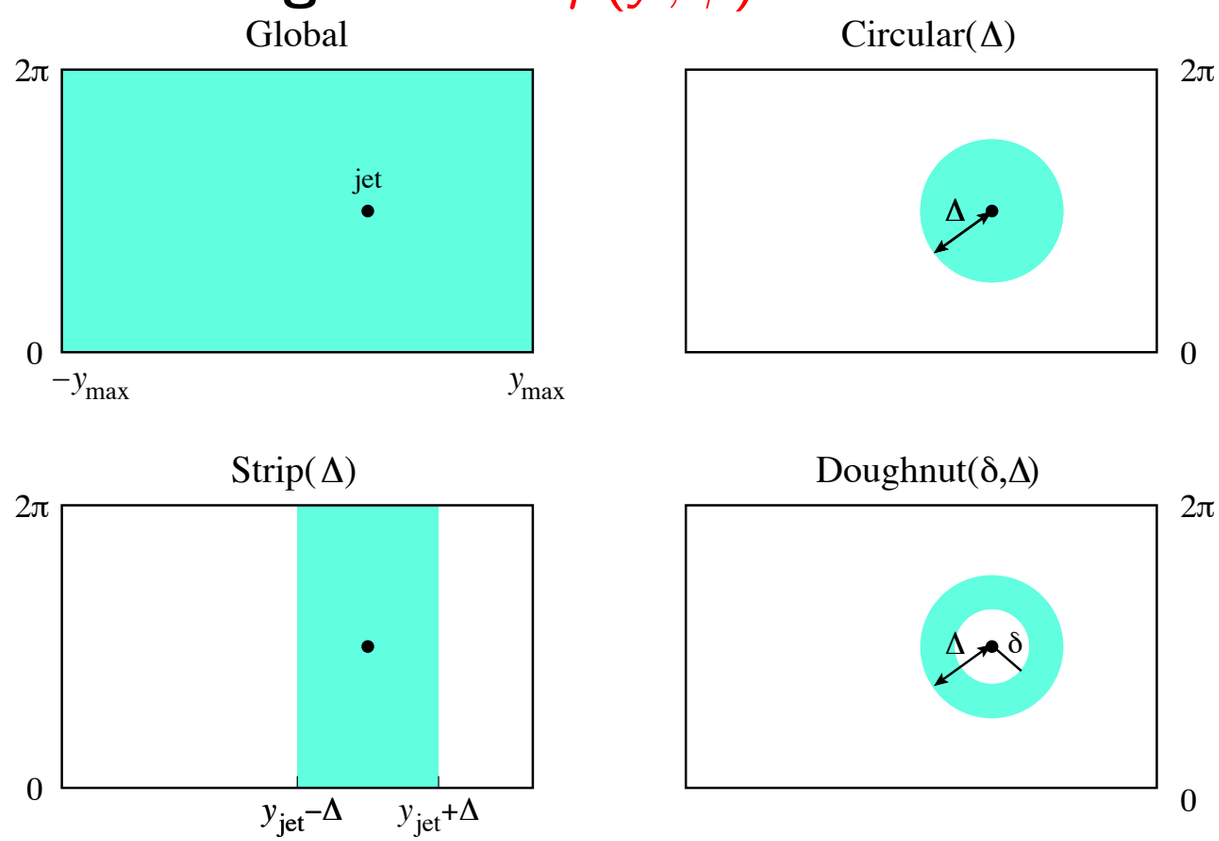
- p_t **offset**: $\Delta p_t \equiv p_t^{AA,\mathrm{sub}} - p_t^{pp,\mathrm{sub}}$
- p_t **dispersion**: $\sigma_{\Delta p_t} \equiv \sqrt{\langle \Delta p_t^2 \rangle - \langle \Delta p_t \rangle^2}$

Jet algorithms

- kt
- Cambridge/Aachen
- Anti-kt
- Cam/Aa with filtering

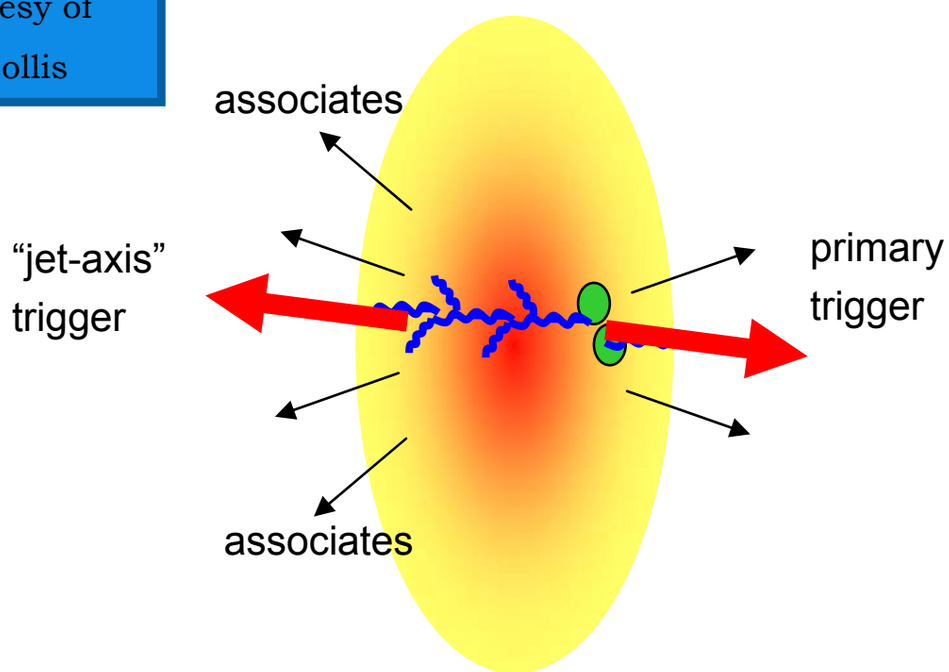
with $\mathbf{R = 0.4}$, $\mathbf{R_\rho = 0.3 - 0.5}$

Range where $\rho(y, \phi)$ estimated



The “2+1” correlation

Courtesy of
R .Hollis



- **Use two back-to-back high-p_T triggers as proxy of dijets**
  - **“pin” the ‘jet axis’ selecting back-to-back high-p_T triggers**
  - **Study all low-p_T particles correlation in the events, w.r.t. this axis**