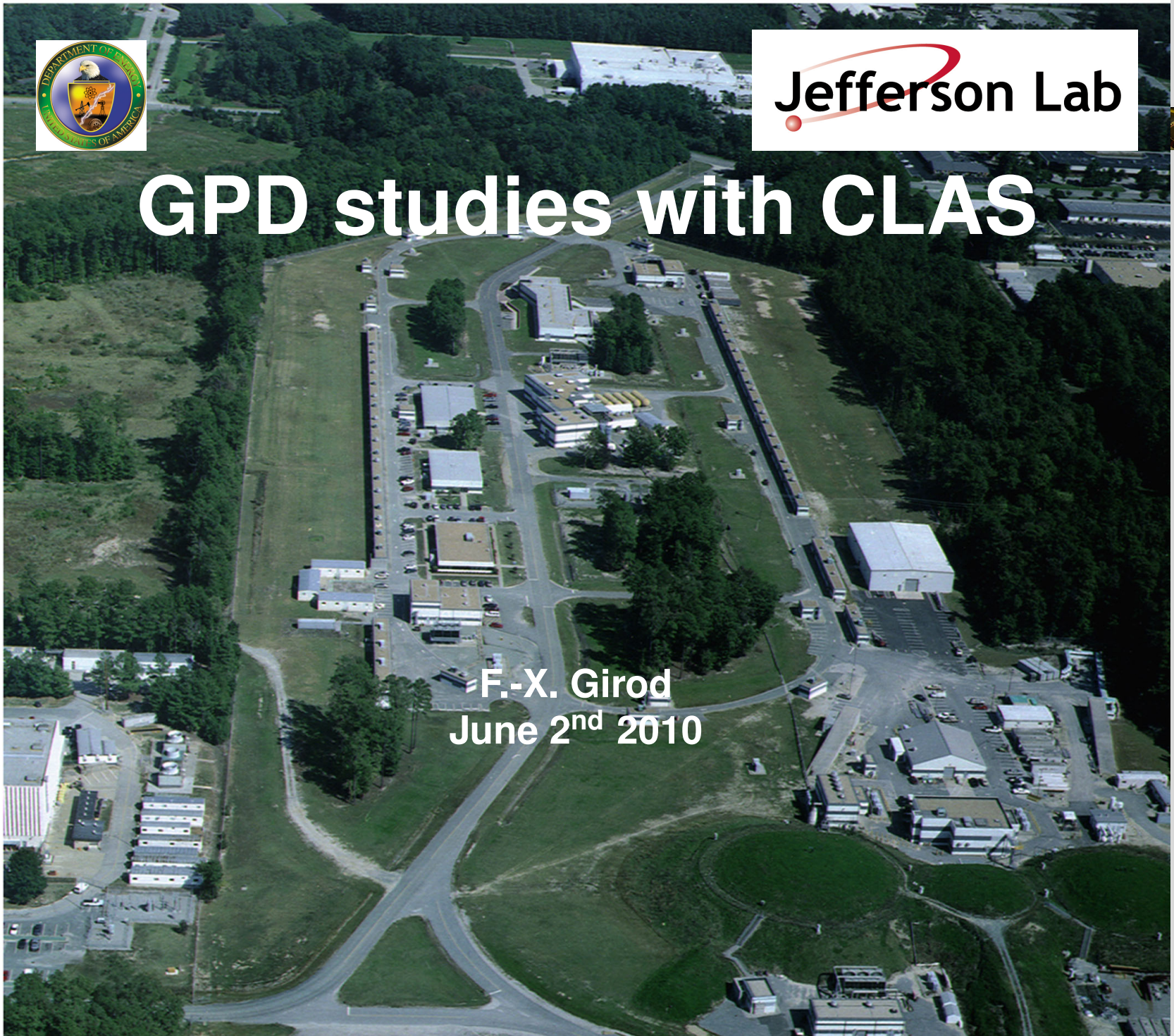

GPD studies with CLAS

F.-X. Girod

June 2nd 2010

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$A_{LU} \propto F_1 \mathcal{H}$

Towards GPDs extraction

$A_{UL} \propto F_1 \tilde{\mathcal{H}}$

σ

A_{UT} and A_{LT} (projected)

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   - $A_{UL} \propto F_1\tilde{\mathcal{H}}$
   - σ
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Physical content of GPDs

Momentum distributions in the transverse plane

$$q_X(x,\vec{b}_\perp) = \int \frac{\mathrm{d}^2\vec{\Delta}_\perp}{(2\pi)^2} H(x,0,t)\mathrm{e}^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp} - \frac{1}{2M}\frac{\partial}{\partial b_y}\int \frac{\mathrm{d}^2\vec{\Delta}_\perp}{(2\pi)^2} E(x,0,t)\mathrm{e}^{-i\vec{\Delta}_\perp\cdot\vec{b}_\perp}$$

M. Burkardt, Phys. Rev. **D62**, (2000) 071503
$\xi \neq 0$ in M. Diehl, Eur. Phys. J. **C25** (2002) 223

Energy-momentum tensor of q flavored quarks

$$\langle p_2|\hat{T}^q_{\mu\nu}|p_1\rangle = \bar{U}(p_2)\left[M_2^q(t)\,\frac{P_\mu P_\nu}{M} + J^q(t)\,\frac{i(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M} + d_1^q(t)\,\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M}\right]U(p_1)$$

To measure gravitational FFs : graviton scattering or GPDs identities :

$$J^q(t) = \frac{1}{2}\int_{-1}^{1}\mathrm{d}x\, x\left[H^q(x,\xi,t)+E^q(x,\xi,t)\right]\ , \quad M_2^q(t)+\frac{4}{5}d_1(t)\xi^2 = \frac{1}{2}\int_{-1}^{1}\mathrm{d}x\, xH^q(x,\xi,t)$$

(Ji's sum rule)

Access to GPDs : the DVCS process

Observables in the Bjorken limit

$$\gamma^* p \to \gamma p' \qquad ep \to ep\gamma$$

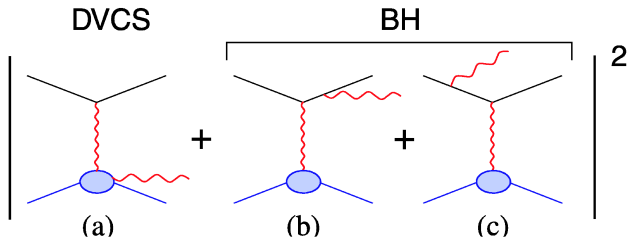
Bjorken regime :

$Q^2 \to \infty,$

$\nu \to \infty,$

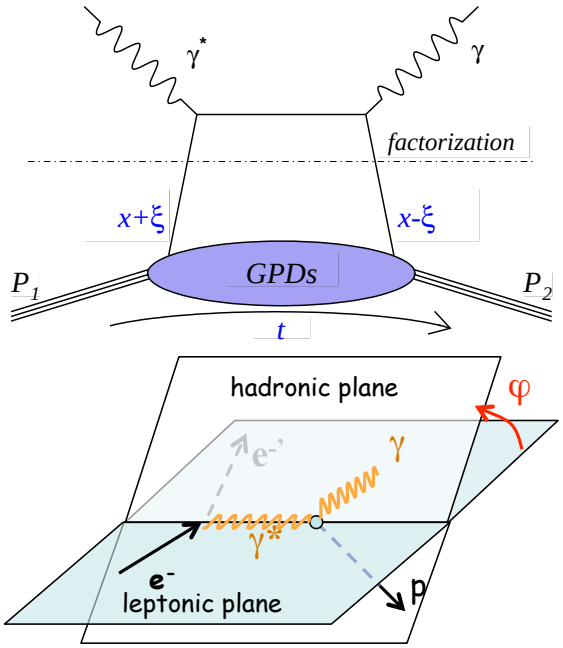
$x_B = Q^2/2M\nu$ fixed

$\left(\xi \to \frac{x_B}{2-x_B}\right)$

$\sigma(ep \to ep\gamma) \propto$ 

Diehl, Gousset, Pire, Ralston (1997)

Belitsky, Müller, Kirchner (2002, 2010)



$$A_{LU} = \frac{d^4\sigma^{\rightarrow} - d^4\sigma^{\leftarrow}}{d^4\sigma^{\rightarrow} + d^4\sigma^{\leftarrow}} \overset{\text{twist-2}}{\approx} \frac{\alpha \sin\phi}{1+\beta\cos\phi}$$

$$\alpha \propto \left(F_1\mathcal{H} + \xi G_M\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right)$$

$$\mathcal{H}(\xi,t) = \pi\sum_q Q_q^2\left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right]$$

$$A_{UL} \propto \left(F_1\tilde{\mathcal{H}} + \xi G_M\mathcal{H} + G_M\frac{\xi}{1+\xi}\mathcal{E} + \cdots\right)\sin\phi$$

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Observables and GPD CFFs

Only a global analysis of all observables can disentangle GPDs

	$\mathcal{I}$m	$\mathcal{R}$e
$\mathcal{H}$	A_{LU}	σ , A_{LL}
$\tilde{\mathcal{H}}$	A_{UL}	
$\mathcal{E}$	A_{UT} , A_{LT}	

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Detector overview

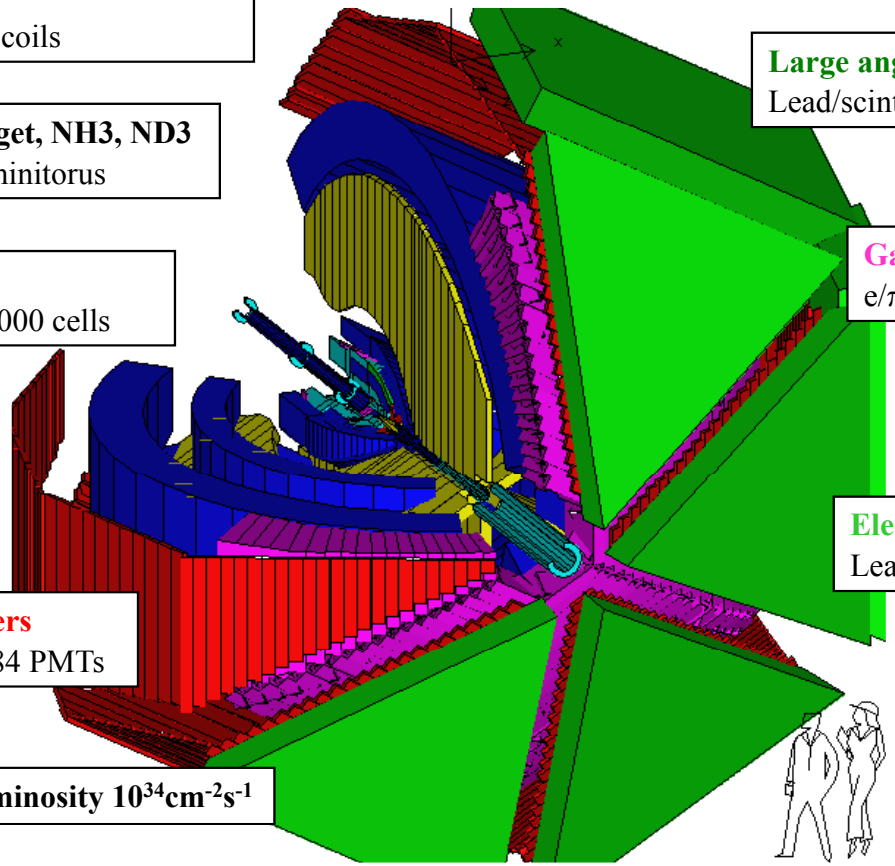
Torus magnet
6 superconducting coils

Liquid D_2 (H_2)target, NH3, ND3
γ start counter; e^- minitorus

Drift chambers
argon/CO_2 gas, 35,000 cells

Time-of-flight counters
plastic scintillators, 684 PMTs

Operating luminosity $10^{34}cm^{-2}s^{-1}$



Large angle calorimeters
Lead/scintillator, 512 PMTs

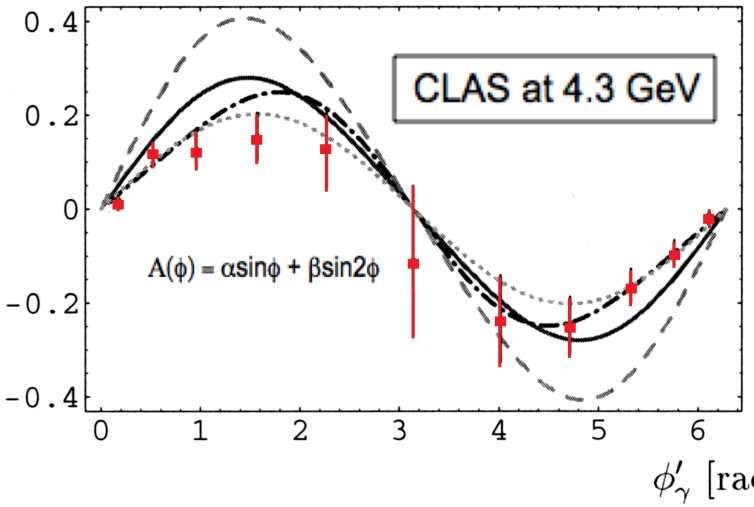
Gas Cherenkov counters
e/π separation, 216 PMTs

Electromagnetic calorimeters
Lead/scintillator, 1296 PMTs

Pioneering observations

First DVCS BSA and TSA observations

$$A_{LU} \propto F_1\mathcal{H} + \xi G_M\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}$$



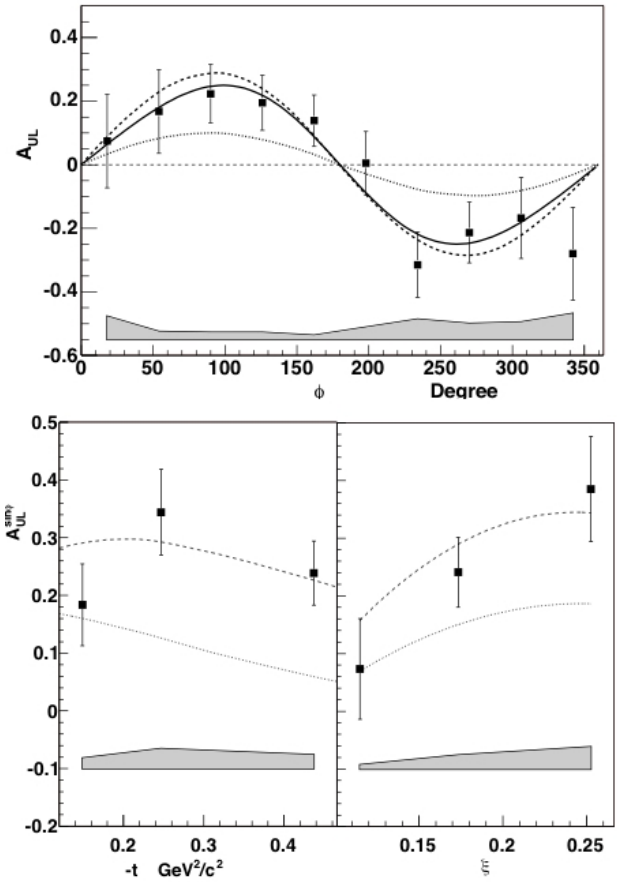
$Q^2 = 1.3\ \text{GeV}^2$, $x_B = 0.2$, $-t = 0.2\ \text{GeV}^2$

$$\begin{aligned} A(\phi) &= \alpha \sin\phi + \beta \cos(2\phi) \\ \alpha &= 0.202 \pm 0.028^{\text{stat}} \pm 0.013^{\text{syst}} \\ \beta &= -0.024 \pm 0.021^{\text{stat}} \pm 0.009^{\text{syst}} \end{aligned}$$

S. Stepanyan *at al.*,

PRL **87** (2001) 182002

$$A_{UL} \propto F_1\tilde{\mathcal{H}} + \xi G_M\left(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}\right) - \cdots$$

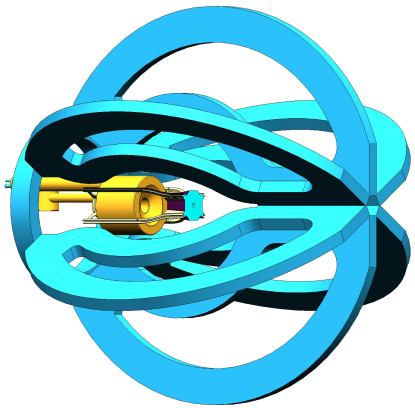


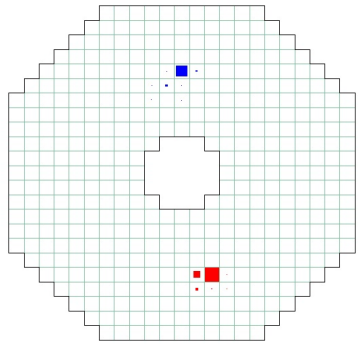
S. Chen *et al.*,

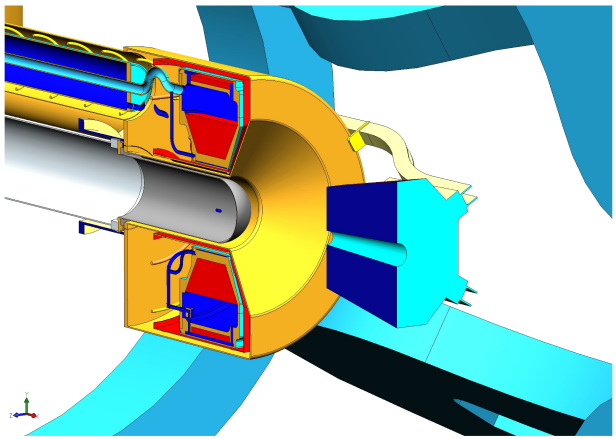
PRL **97** (2006) 072002

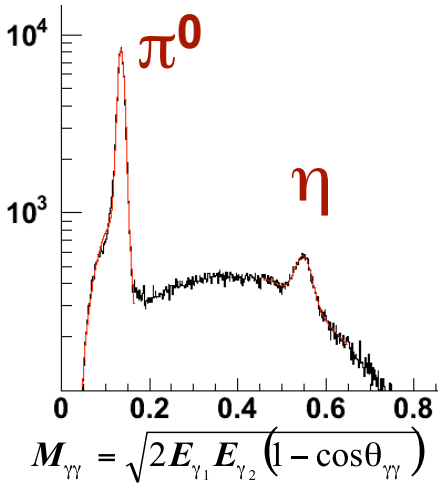
Solenoid and Inner Calorimeter

Hydrogen target, beam polarisation $\approx 80\%$, $\int \mathcal{L} \approx 45$ fb^{-1}









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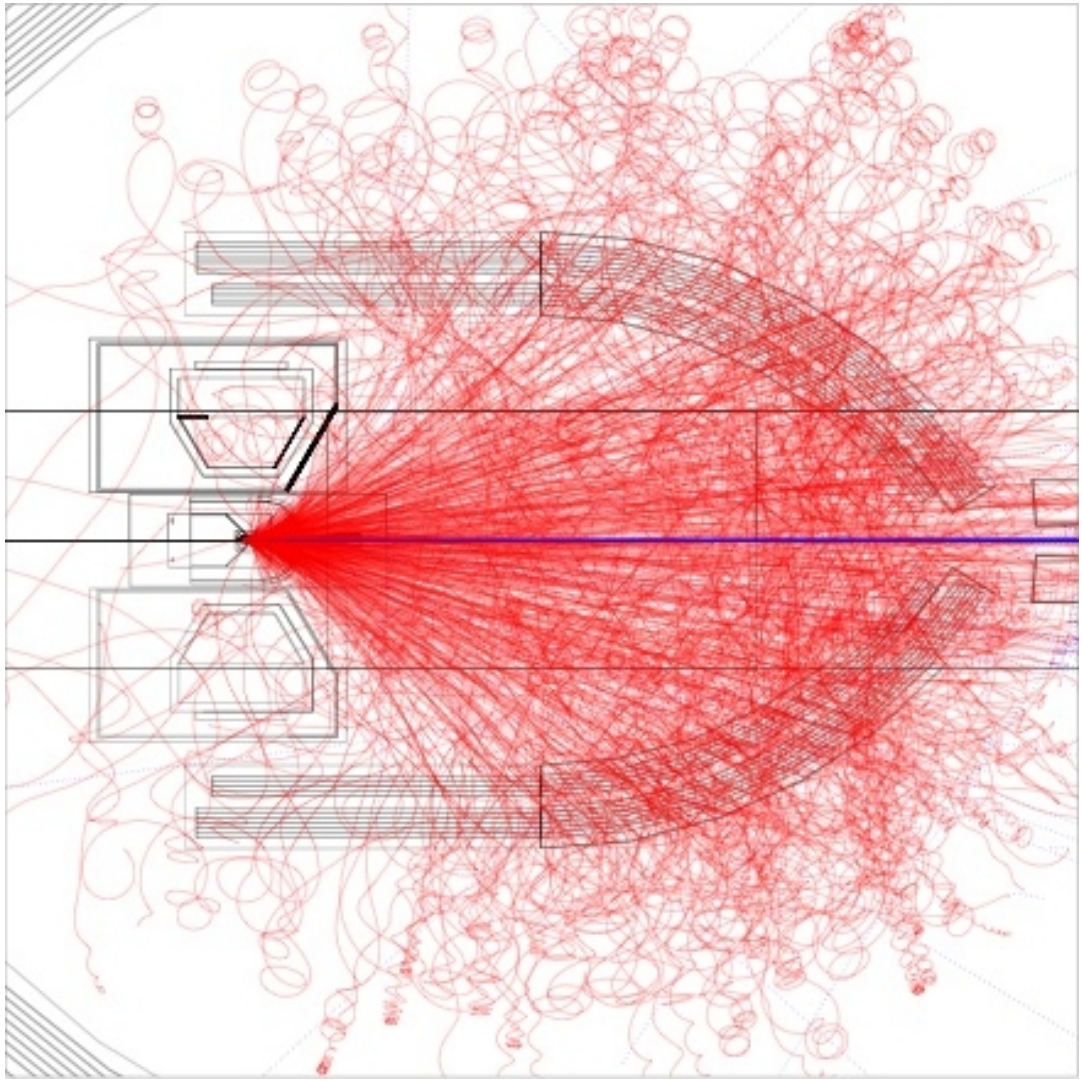
Solenoid and Inner Calorimeter



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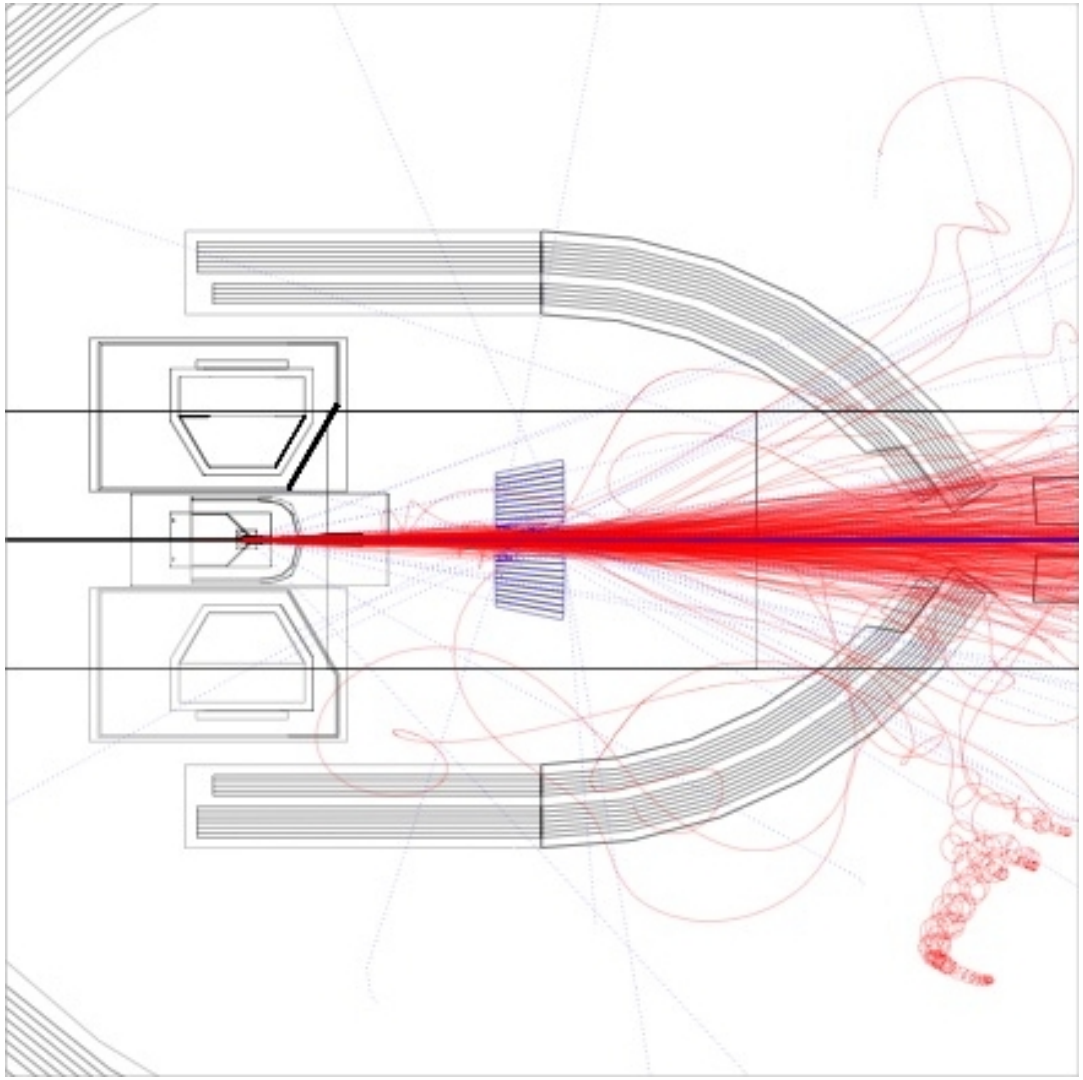

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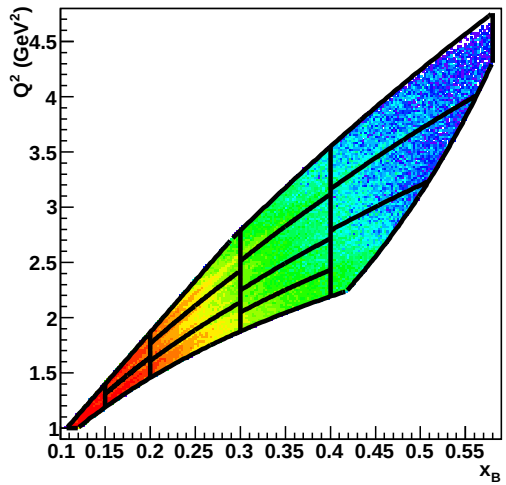
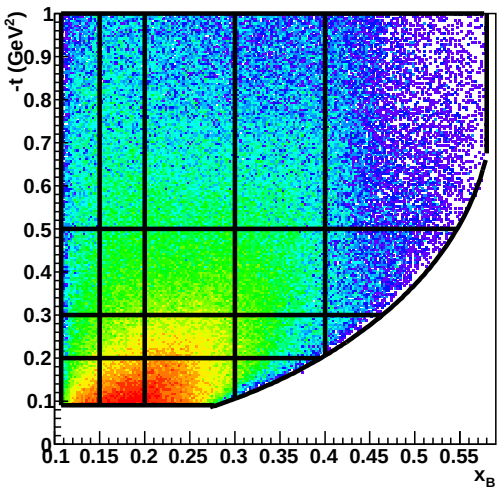
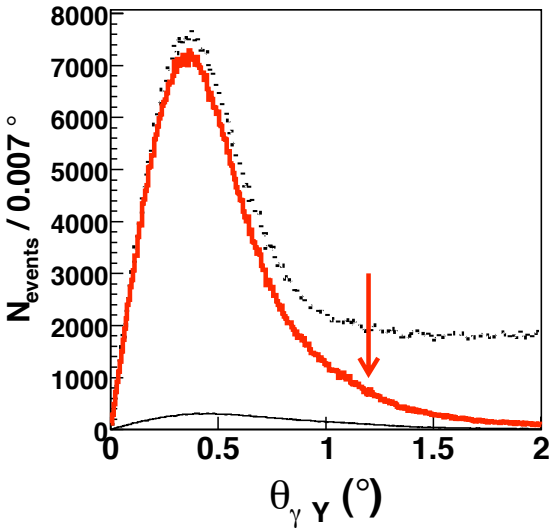
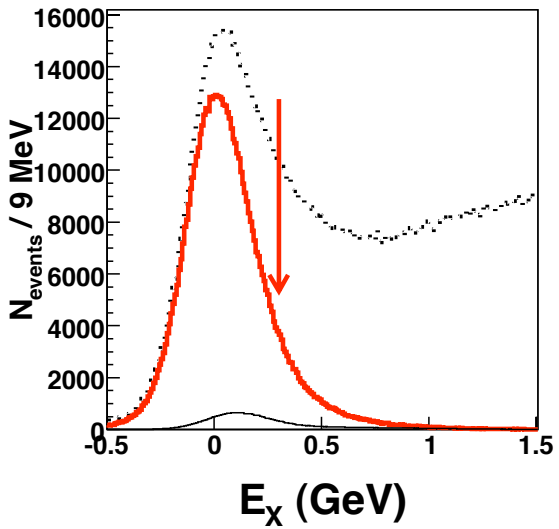
Flavor of analysis

- kinematical coverage
- exclusivity cuts
- π^0 subtraction









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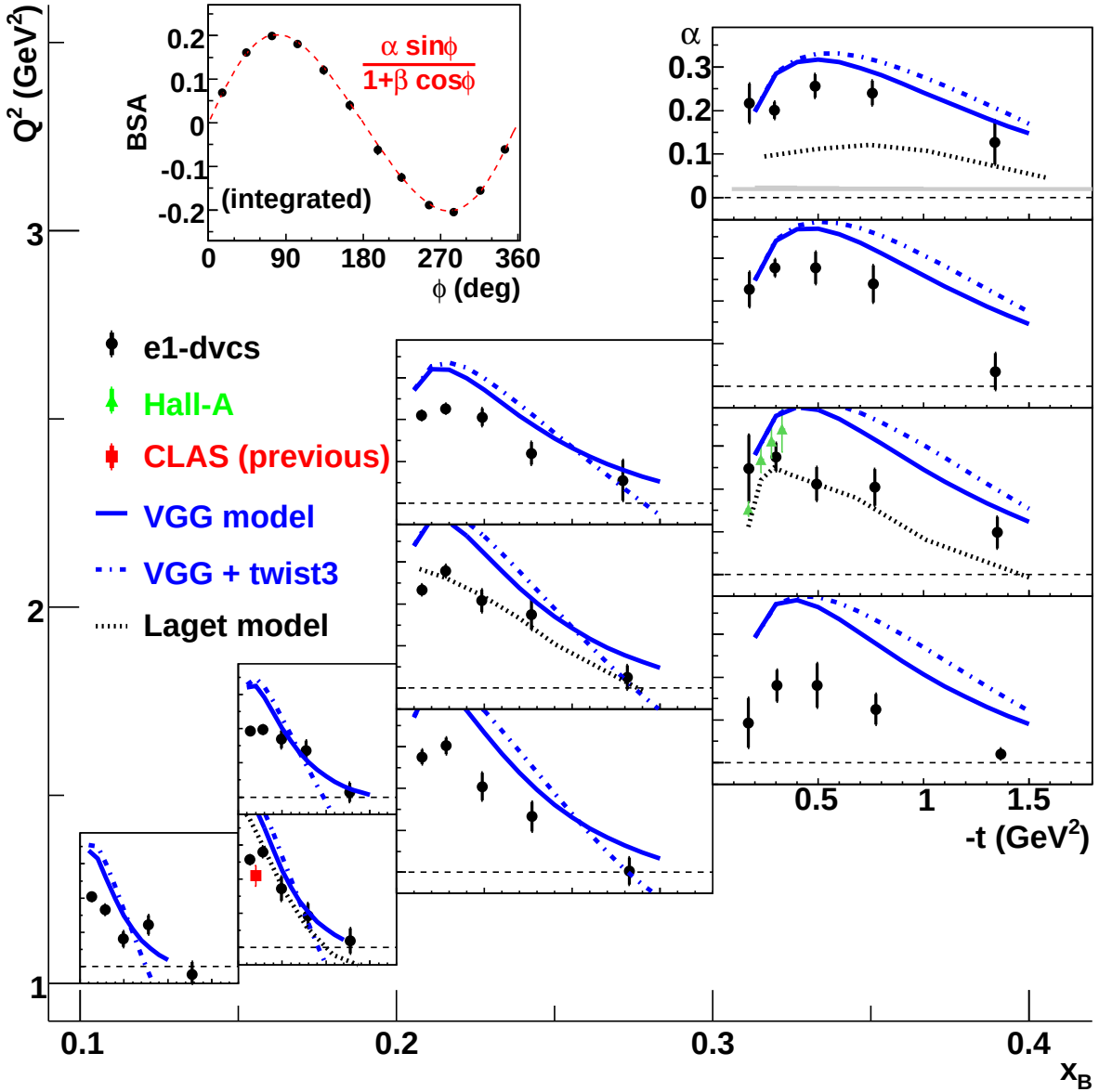
Selected results

Proton BSA

$$F_1\mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}$$



F.-X. G. *et al.*, PRL **100** (2008) 162002

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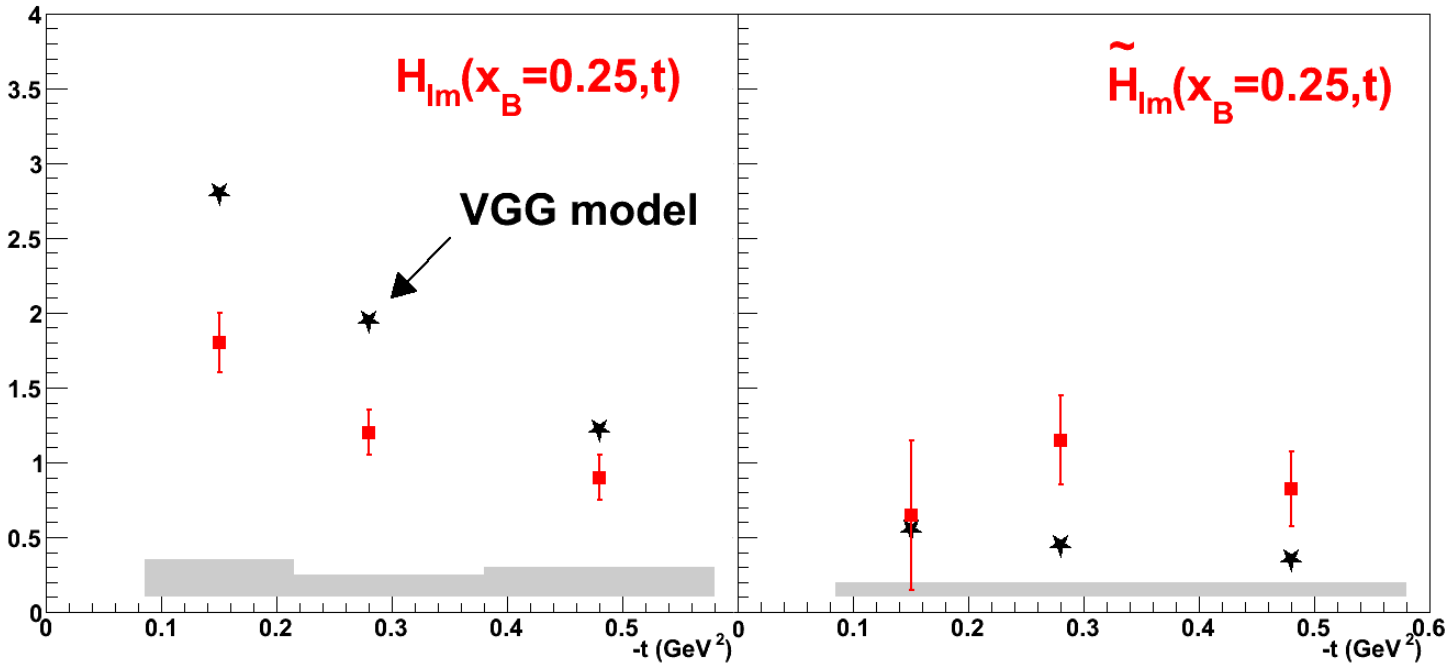
Model independent extraction

Using only A_{LU} and A_{UL} with sensitivity to $\mathcal{H}$ and $\tilde{\mathcal{H}}$

- CFFs varied within VGG model range
- Independence on Q^2
- $\tilde{\mathcal{H}}(t)$ more flat than $\mathcal{H}(t)$
- Stable results
- Large uncertainties



M. Guidal, arXiv:1003.0307

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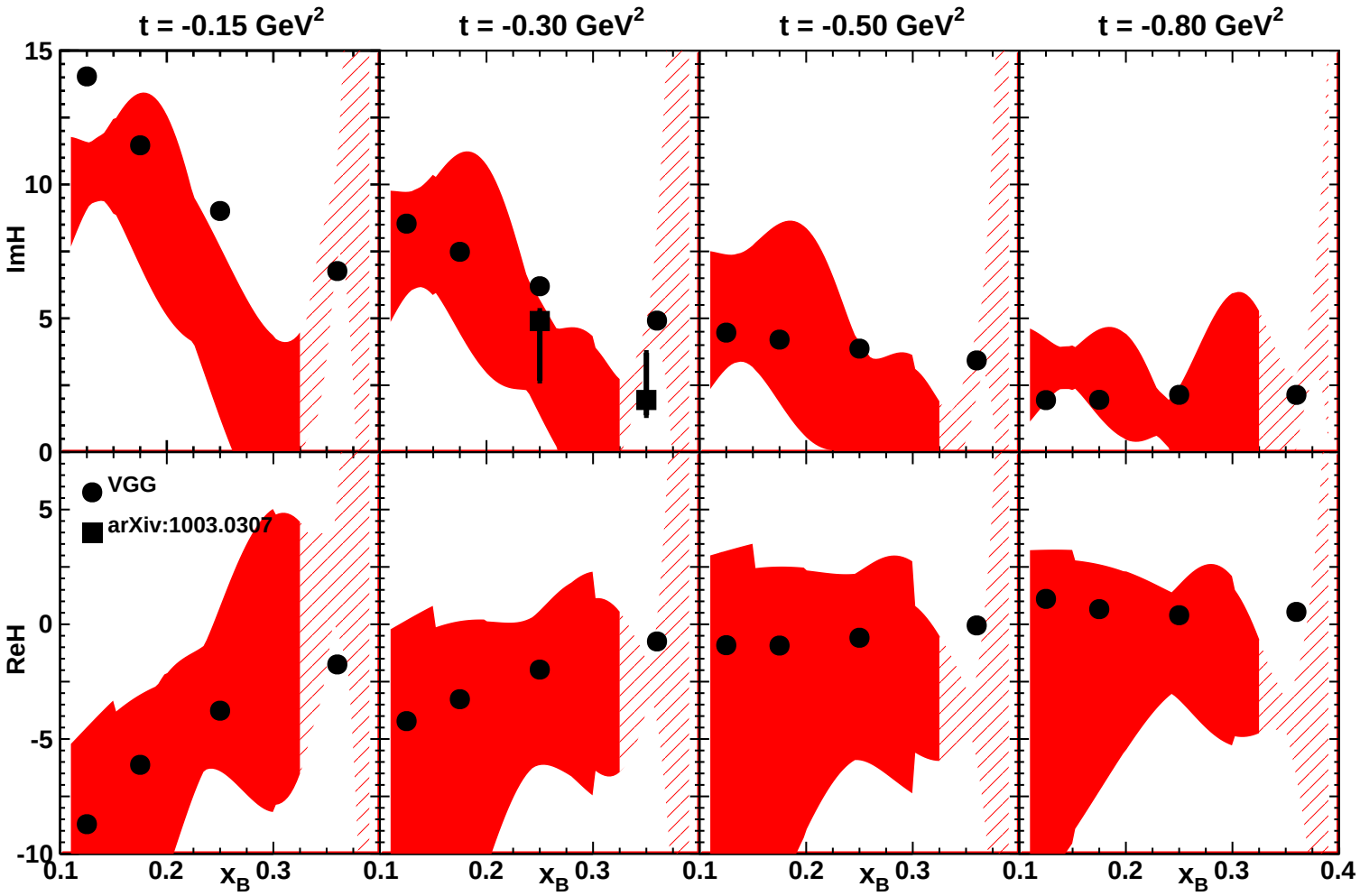
Global analysis of CFFs



H. Moutarde, PR **D79** (2009) 094021

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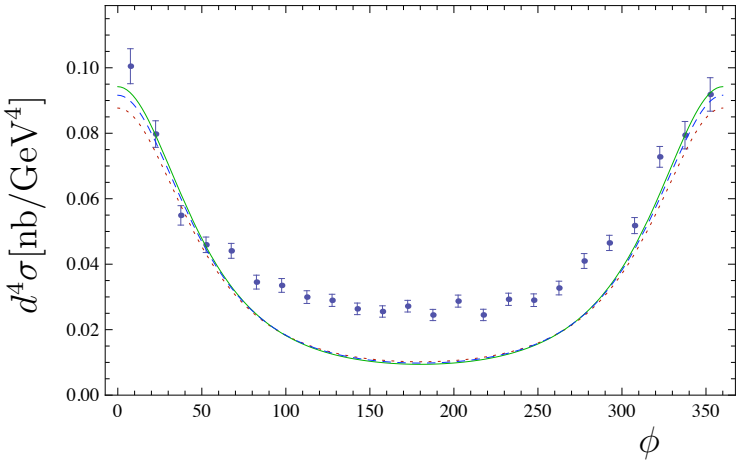
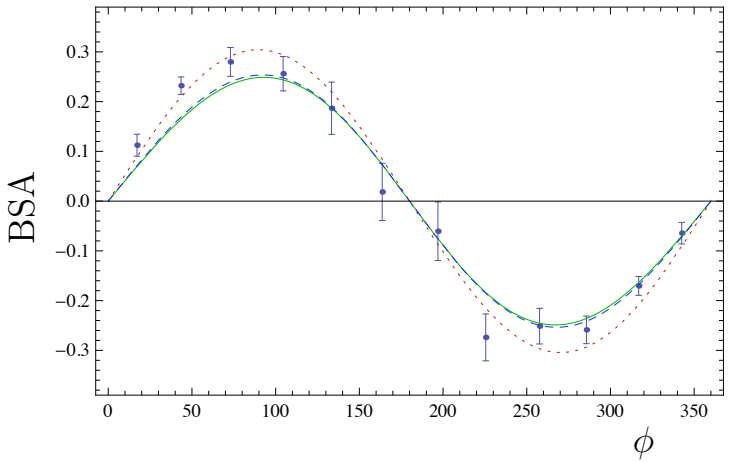
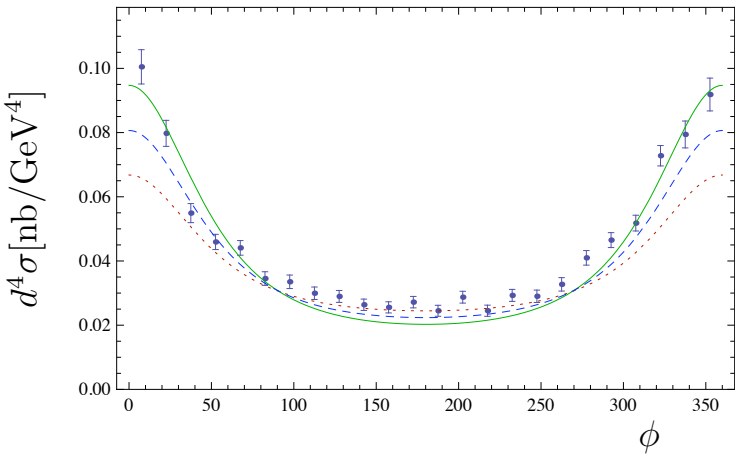
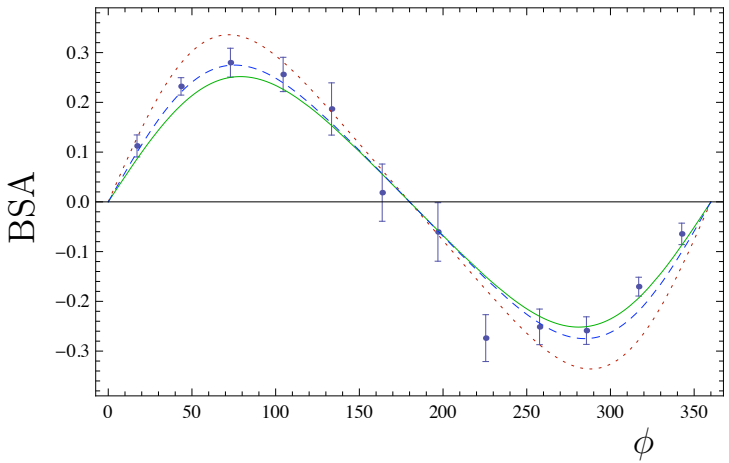
Systematic errors









A.V. Belitsky, D. Müller, arXiv:1005.5209

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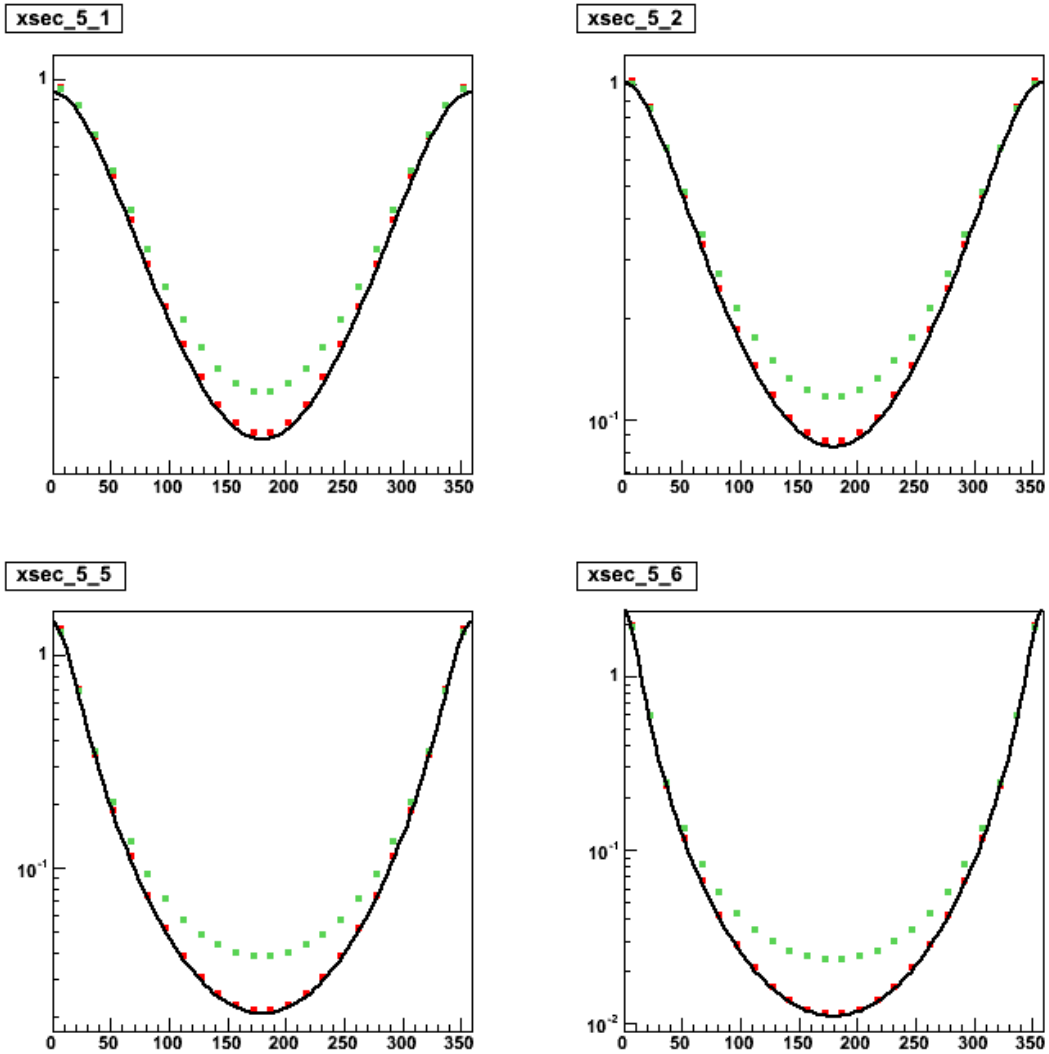
Where does BH dominate ?

Fast variation of the BH cross-section



VGG model

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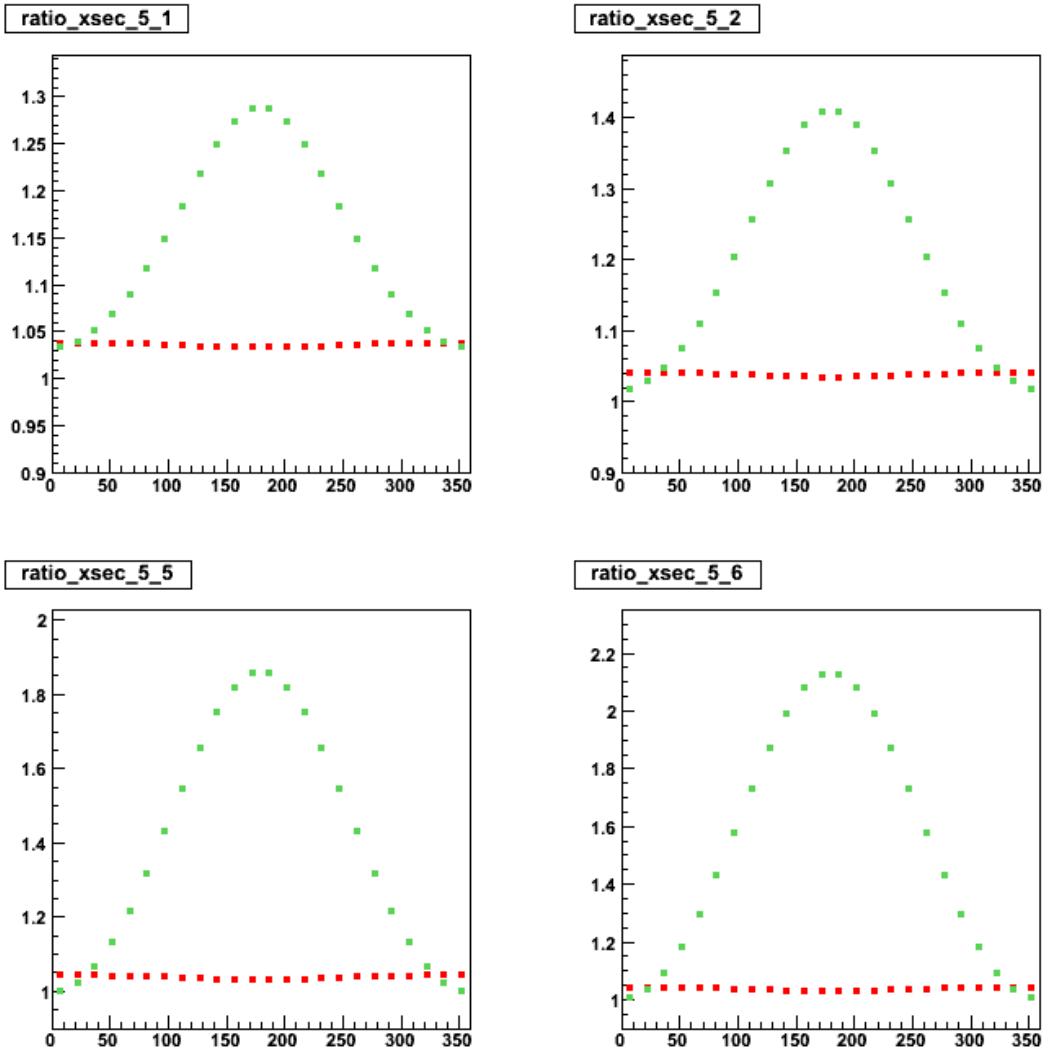
Where does BH dominate ?

Fast variation of the (ratio of total cross-section to) BH cross-section



VGG model

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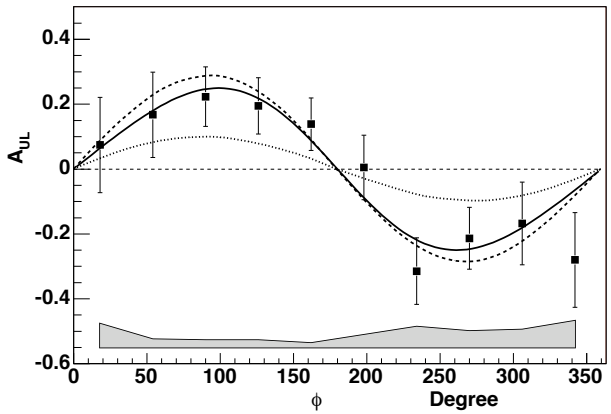
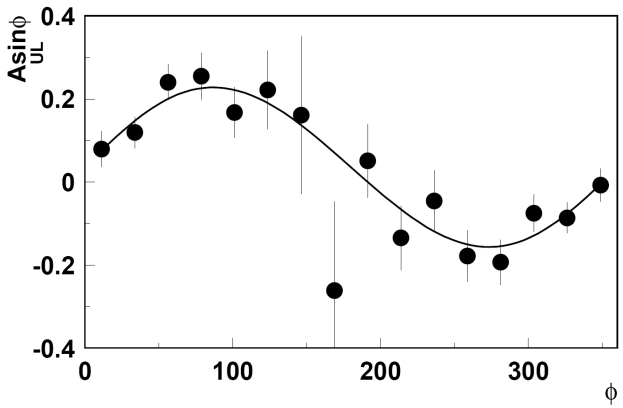
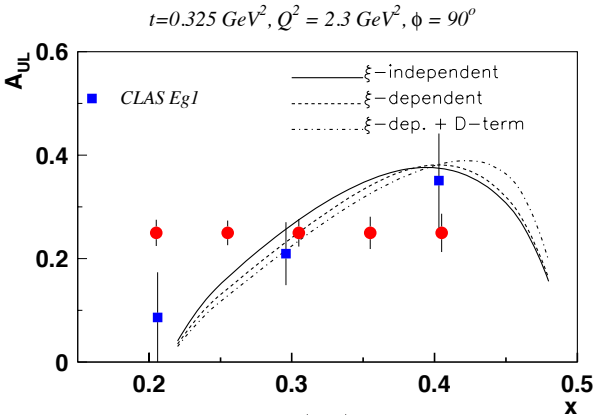
$A_{UL} \propto F_1 \tilde{\mathcal{H}}$

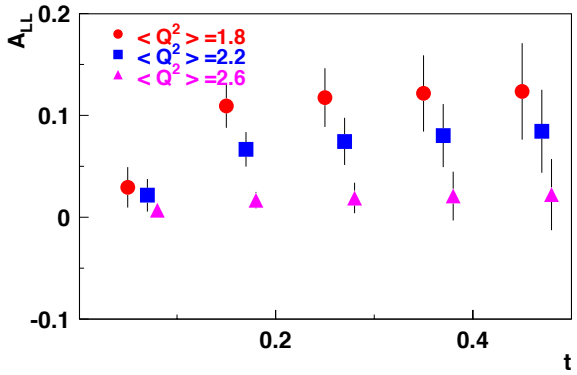
- Increase statistics with
  - better background conditions for σ and BSA
  - charged particle tagging in the Inner Calorimeter
- Dedicated experiment for $TSA_{||}$ with IC

$$A_{UL} \propto F_1 \tilde{\mathcal{H}} + \xi G_M \left(\mathcal{H} + \frac{\xi}{1+\xi} \mathcal{E} \right) - \cdots$$









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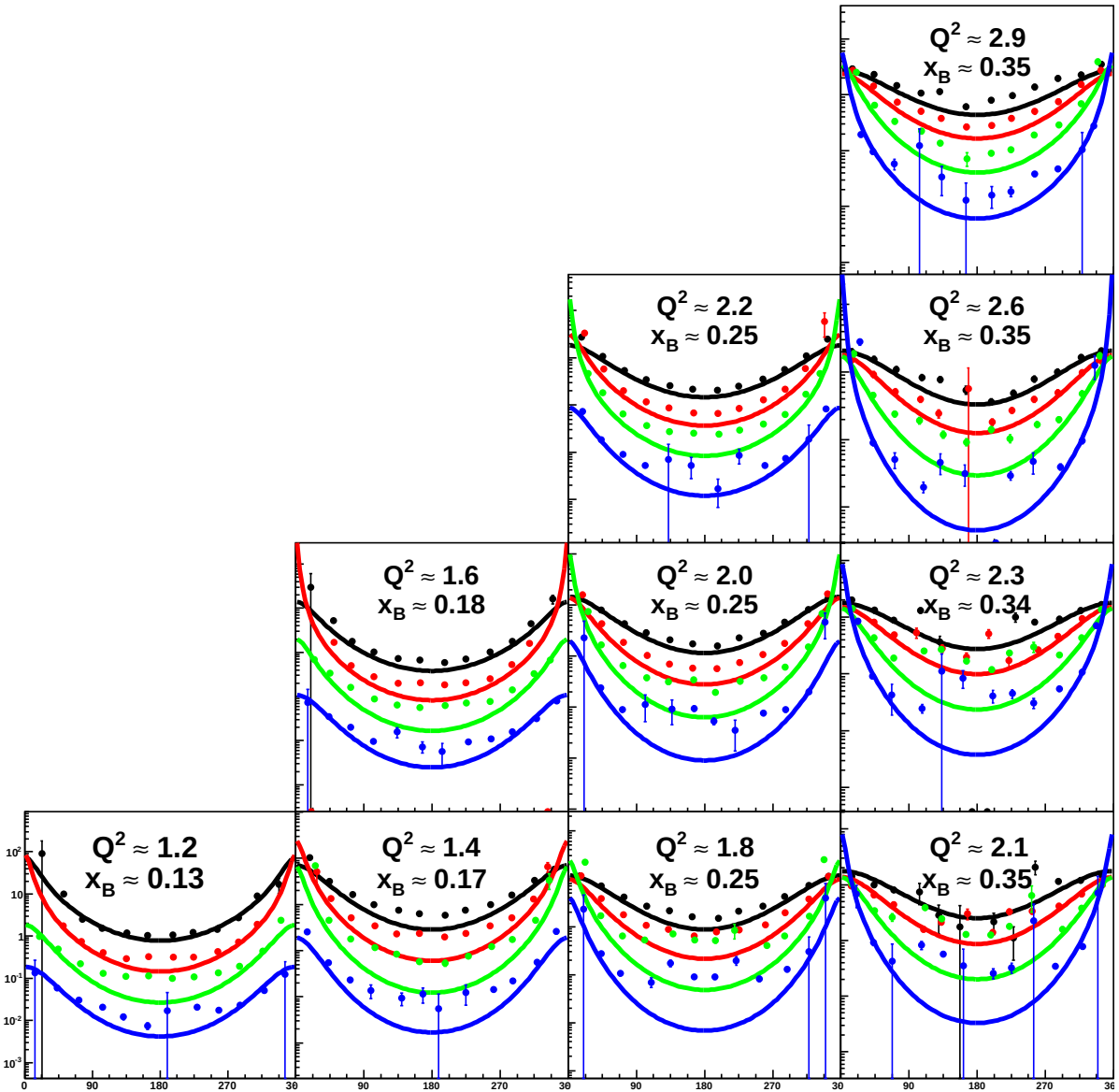
Proton cross-section (preliminary) $F_1\mathcal{H} + \xi G_M\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}$



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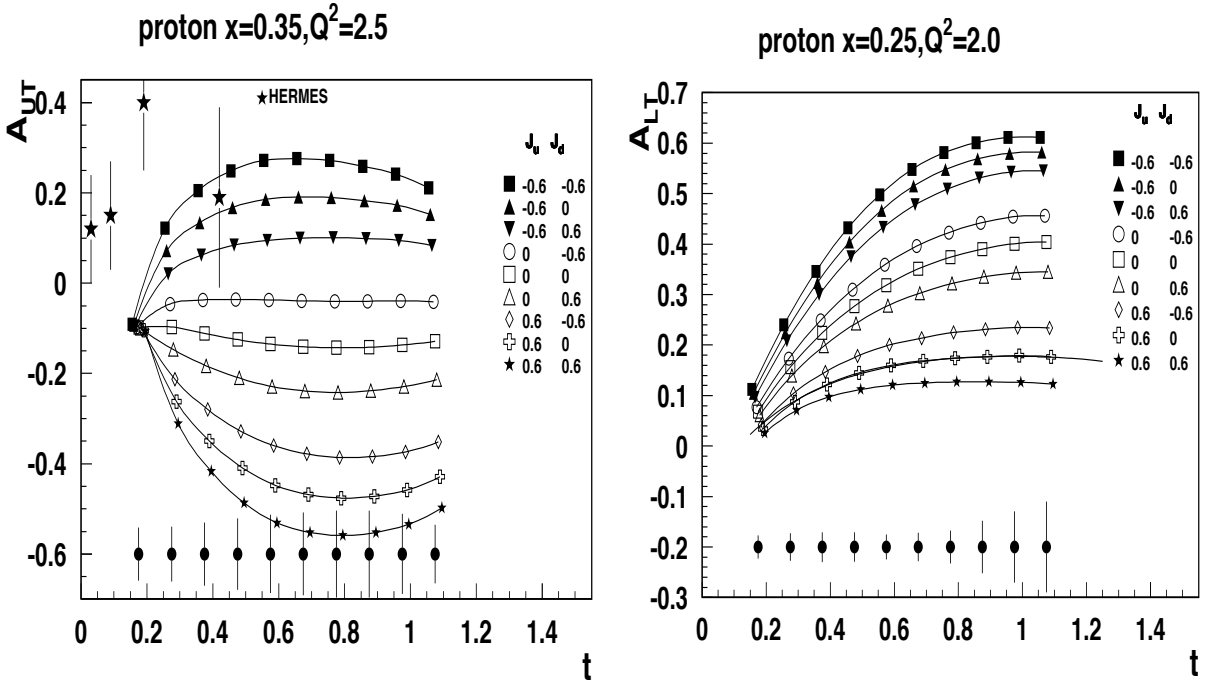
A_{UT} and A_{LT}

Conditionally approved experiment with HD-Ice target (2012)

$\frac{t}{4M^2}(F_2\mathcal{H} - F_1\mathcal{E})$



Model-dependent extraction of J_u and J_d

Combined fit to all data will allow separation of $\mathcal{H}$, $\mathcal{E}$ and $\tilde{\mathcal{H}}$

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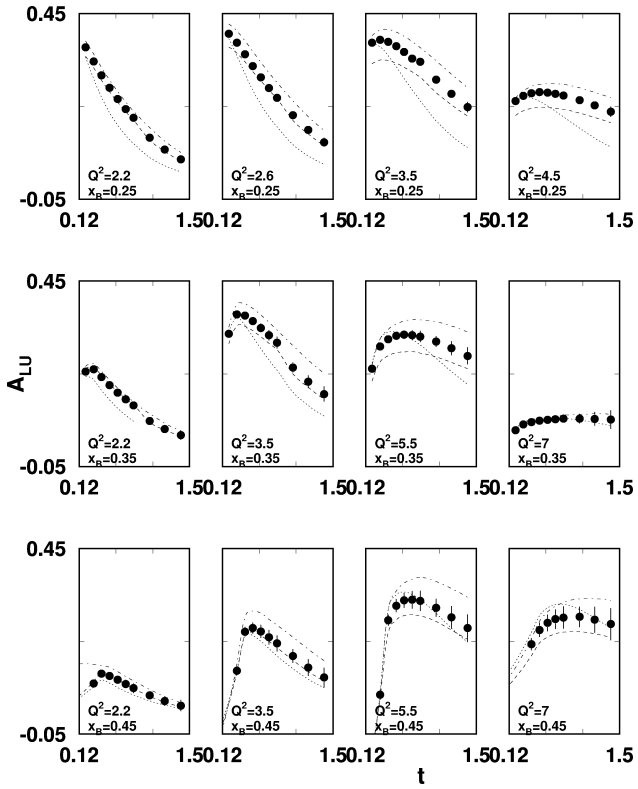
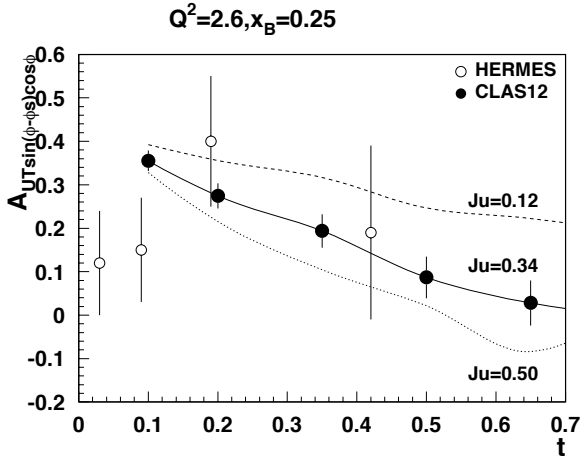
Proton DVCS with 12 GeV

V. Burkert, arXiv:0711.4741

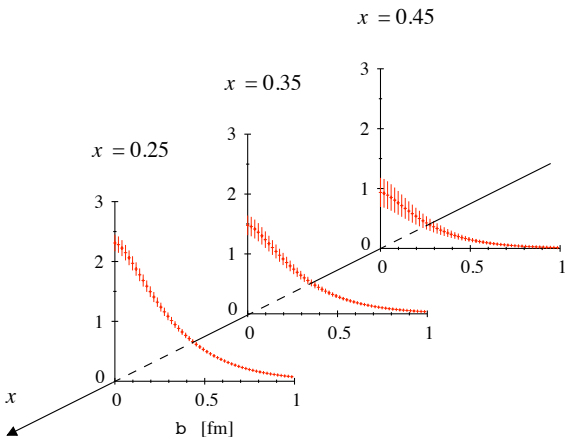
A_{LU}



A_{UT}



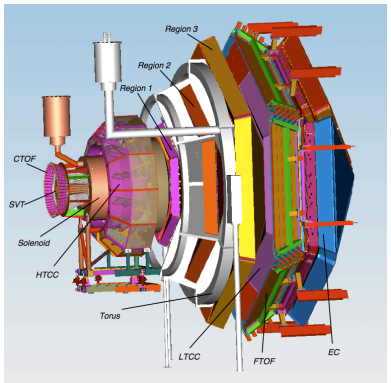
Projected extraction of u-quark distribution in the transverse plane



Conclusion

Summary

- 3-D imaging and spin structure of the nucleon *via* GPDs
- Aiming at a common framework for a global analysis, with different approaches
- Complementary channels for flavor separation from meson production
- Compton scattering in the Timelike region sensitive to the real part of CFFs
- Double DVCS maps separately x and ξ dependences
- Also DVCS on nuclei (^{4}He)
- CLAS12 will participate crucially in this program



Overview
Introduction
CLAS
Pioneering observations
Dedicated experiments
$A_{LU} \propto F_1 \mathcal{H}$
Towards GPDs extraction
$A_{UL} \propto F_1 \tilde{\mathcal{H}}$
σ
A_{UT} and A_{LT} (projected)
DVCS 12 GeV
Conclusion