A pivotal year for Generalized Parton Distributions

J. Ball, G. Charles, B. Moreno, H. Moutarde, F. Sabatié, S. Procureur

Irfu/SPhN, CEA-Saclay

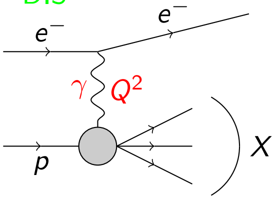
GdR PH-QCD - 21 / 10 / 2011

1. 2011 situation
2. Status of GPD analysis of data
3. Future orientations

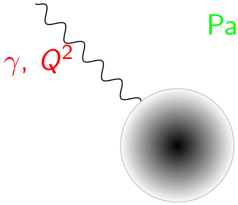
Generalized Parton Distributions.

Viewing nucleon structure in 3d.

DIS



Parton Distributions



nucleon

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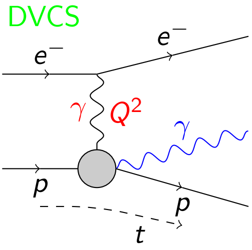

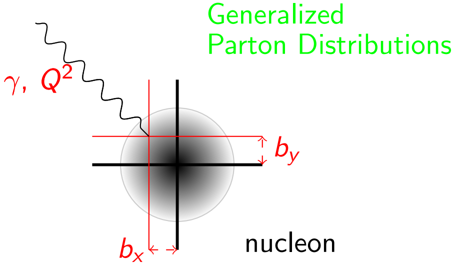

- Correlation of the **longitudinal momentum** and the **transverse position** of the struck quark.

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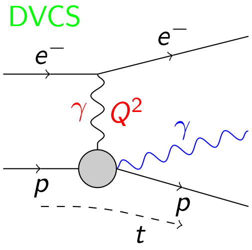

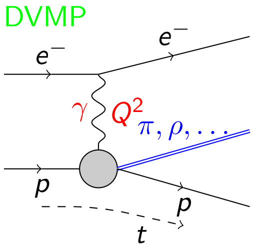

- Correlation of the **longitudinal momentum** and the **transverse position** of the struck quark.
- **3-dimensional** description of the nucleon.
- Insights on :
  - spin structure,
  - energy-momentum structure.

Generalized Parton Distributions.

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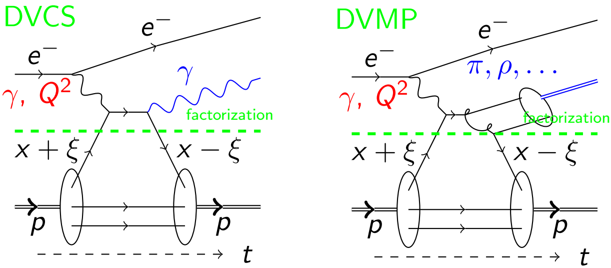

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Generalized Parton Distributions.

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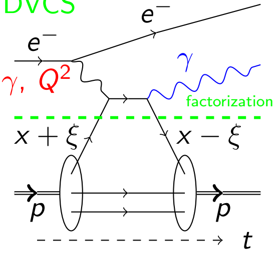
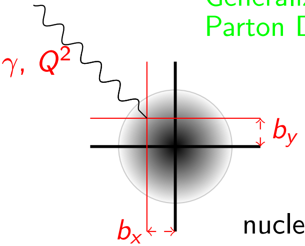
DVCS

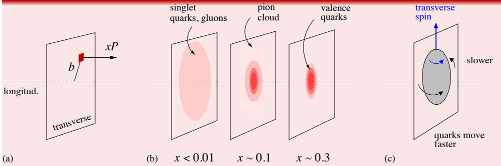


Generalized Parton Distributions

$H(x,\xi,t)$
$E(x,\xi,t)$
$\tilde{H}(x,\xi,t)$
$\tilde{E}(x,\xi,t)$



Obtain this 3d picture from DVCS / DVMP measurements ?



C. Weiss, AIP Conf. Proc. 1149, 150 (2009)

DVCS described by 4 Compton Form Factors.

Approximations : quark sector, leading twist and leading order.

- GPD $F = H, E$ $(-)$ or $\tilde{H}, \tilde{E}$ $(+)$.

$$\mathcal{F} = \int_{-1}^{+1} dx\, F(x, \xi, t) \left(\frac{1}{\xi - x - i\epsilon} \mp \frac{1}{\xi + x - i\epsilon} \right)$$

- Integration yields **real** and **imaginary** parts to $\mathcal{F}$:

Compton Form Factor at Leading Order

$$Re\mathcal{F} = \mathcal{P} \int_{-1}^{+1} dx\, F(x, \xi, t) \left(\frac{1}{\xi - x} \mp \frac{1}{\xi + x} \right)$$

$$Im\mathcal{F} = \pi \Big(F(\xi, \xi, t) \mp F(-\xi, \xi, t) \Big)$$

- Existence of dispersion relations at fixed t.

(Part of) Selected DVCS measurements.

Fine kinematic binning, large kinematic coverage, several observables.

JLab Hall A : helicity-dependent and independent cross sections

C. Muñoz Camacho *et al.*, Phys. Rev. Lett. **97**, 262002 (2006)
Restricted kinematic range, highly-precise helicity-dependent cross sections.

JLab Hall B : Beam Spin Asymmetries

F.-X. Girod *et al.*, Phys. Rev. Lett. **100**, 162002 (2008)
Wide kinematic range, precise BSAs.

Hermes : BSAs, BCAs, TSAs

A. Airapetian *et al.*, JHEP **0806**, 017 (2008)
D. Zeiler *et al.*, arXiv:0810.5007 [hep-ex]
Restricted kinematic range, several different observables.

Irfu cea saclay

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Overview of current extraction methods.

Problems : Model dependence ? Degrees of freedom ? Extrapolations ?

Local fits

Take each kinematic bin independantly of the others.
Extraction of $Re\mathcal{H}$, $Im\mathcal{H}$, ... as independent parameters.

Global fit

Take all kinematic bins at the same time. Use a parametrization of GPDs or CFFs.

Hybrid : Local / global fit

Combine two previous methods to estimate model dependence.

Neural networks

Already used ofr PDF fits. In progress for GPDs.

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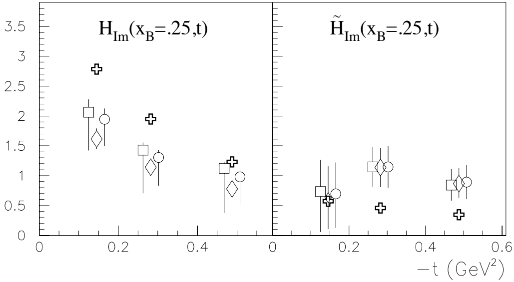

- □ or ○ : "7-CFF" fit results.
- ◇ : "$\mathcal{H}-\tilde{\mathcal{H}}$" fit results.
- $+$: VGG.

M. Guidal, Phys. Lett. B689 (2010) 156

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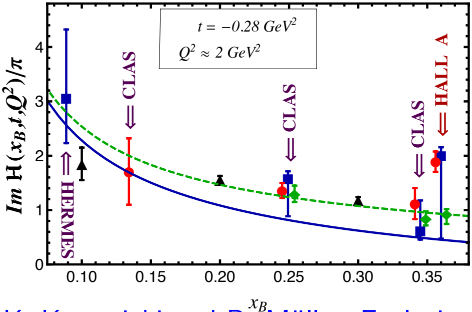

K. Kumericki and D. Müller, Exclusive 2010

- Without Hall A data.
- With Hall A data.
- △ : neural network.
- □ : "7-CFF" fit results.
- ◇ : "$\mathcal{H} - \tilde{\mathcal{H}}$".
- ○ : hybrid fits.

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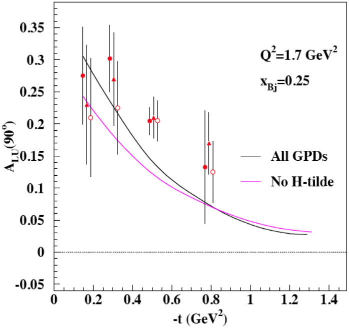

- BSA at 90°.
- Test of $\tilde{H}$ contribution.
- Negligible E contribution.

G. Goldstein *et al*, Phys. Rev. D84 (2011) 034007

Overview of current extraction methods.

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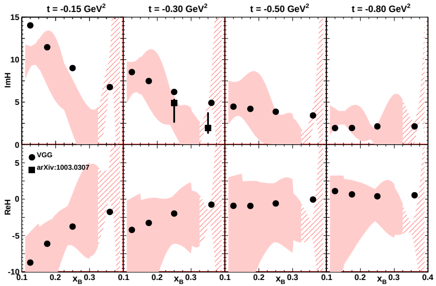
Combine two previous methods to estimate model dependence.



- Comparison to VGG model on JLab Hall B kinematics.
- Loss of information during the extraction.

H. Moutarde, Phys. Rev. D79 (2009) 094021

Overview of current extraction methods.

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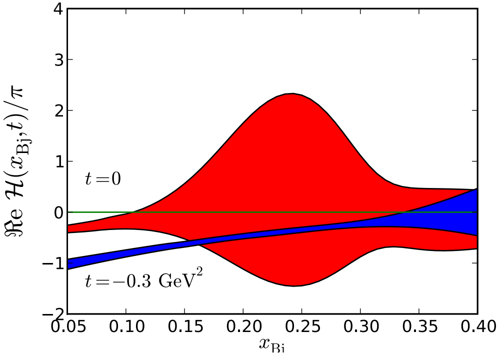
Neural networks

Already used ofr PDF fits. In progress for GPDs.



- HERMES BCAs and CLAS BSAs.
- Extrapolation $t \to 0$.

K. Kumericki and D. Müller, Exclusive 2010

Universality.

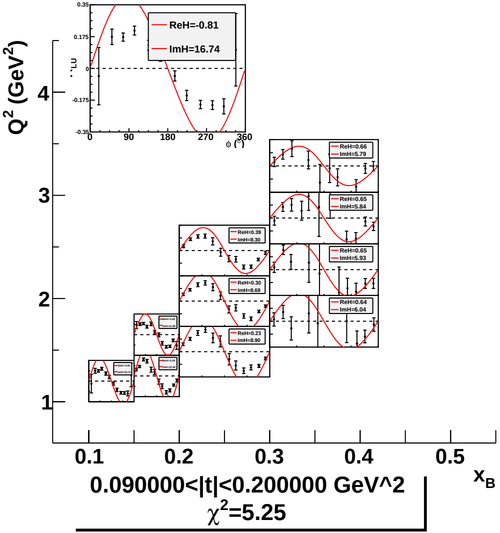
Same GPDs extracted in DVCS and DVMP ?

- DVCS and DVMP measurements since the early 2000's.
- Extractions of GPDs from DVCS and DVMP since $\simeq$ 2008.
- Current DVCS kinematics **suitable for GPD analysis**. Situation **less clear for DVMP**.
- **First step** : Compare GPDs extracted from DVCS and DVMP measurements.
- Input : S. Goloskokov and P. Kroll (GK) GPD model.
  S. Goloskokov and P. Kroll, Eur. Phys. J. C42 (2005) 281
  S. Goloskokov and P. Kroll, Eur. Phys. J. C53 (2008) 367
- **Designed for DVMP** analysis.
- Double Distribution model.

Universality.

Same GPDs extracted in DVCS and DVMP ?

- JLab Hall B.
- Data with $\frac{|t|}{Q^2} < \frac{1}{2}$.
- Data with $\frac{|t|}{Q^2} \geq \frac{1}{2}$.



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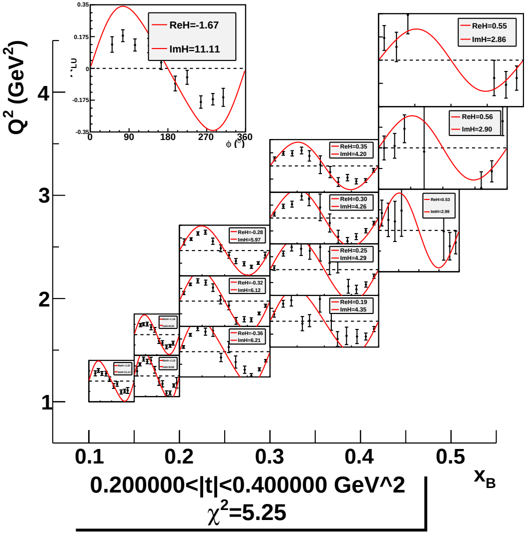

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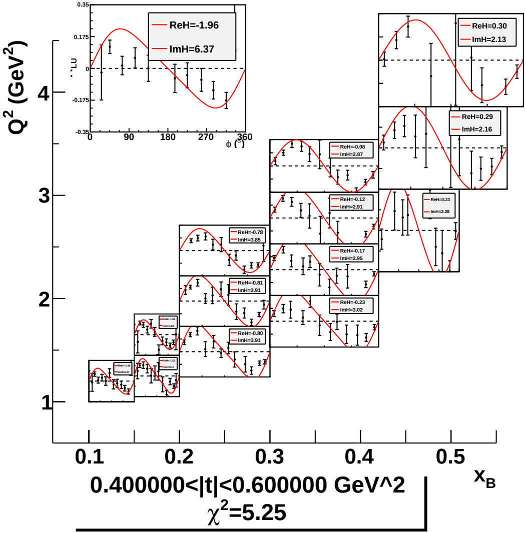

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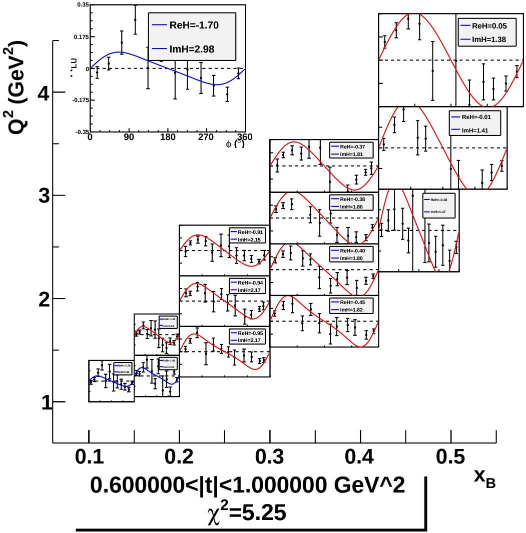

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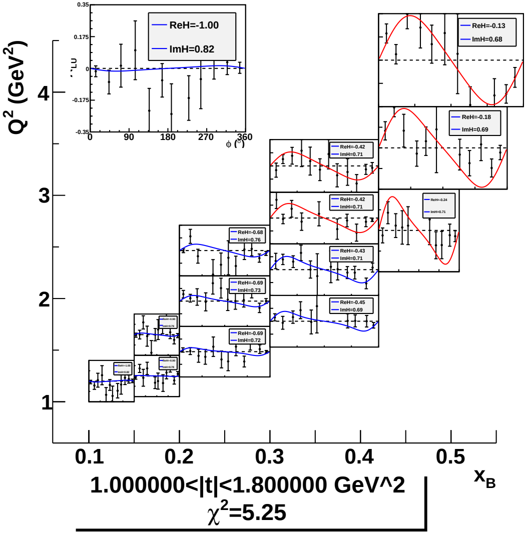

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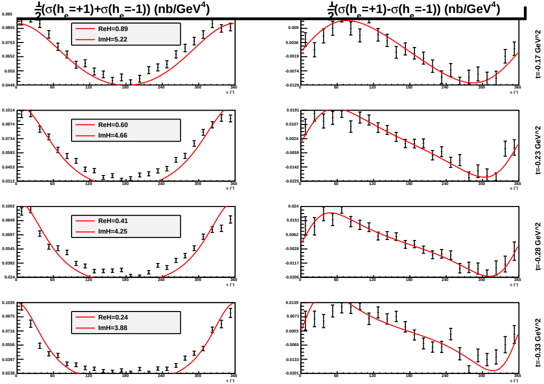

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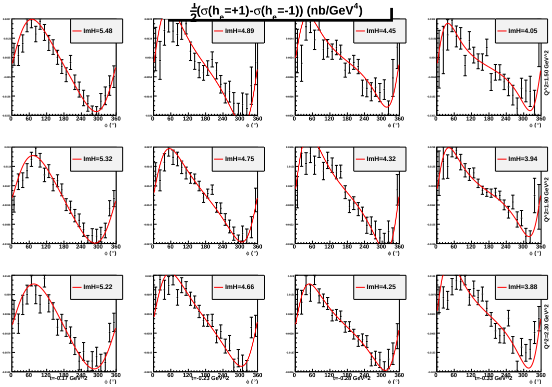


Universality.

Same GPDs extracted in DVCS and DVMP ?

- Similar VGG results ($\chi^2/\mathrm{dof} \simeq 5.86$).

  M. Vanderhaeghen, P. Guichon and M. Guidal Phys. Rev. D60 (1999) 094017 K. Goeke, M.V. Polyakov and M. Vanderhaeghen Prog. Part. Nucl. Phys. 47 (2001) 401

- **Fair agreement** between GK model and extractions for $\mathcal{H}$.
- **Further studies needed** to clarify the situation (and optimize GPD extractions !).
- Work in progress.

Key results.

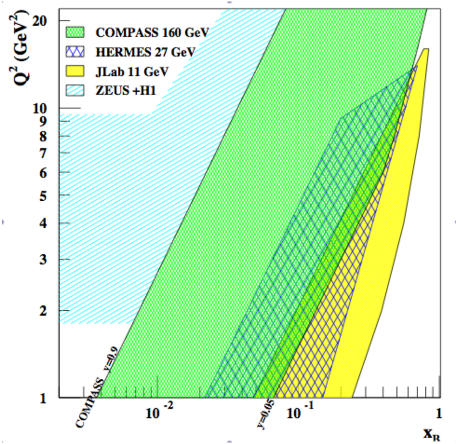
Common features of different extractions.

- **Dominance** of twist 2 and **validity** of a GPD analysis of DVCS data.
- $Im\mathcal{H}$ **best determined**. Large uncertainties on $Re\mathcal{H}$.
- However sizeable **higher twist contamination** for DVCS measurements.
- Already some indications about the invalidity of the H-dominance hypothesis.
- Today cross-sections seem a bigger constraint to phenomenology than BSAs.
- Question : What **observable** should be measured ? **Accuracy** ?

COMPASS-II.

Kinematic domain in between collider and fixed-target experiments.

- Access to several observables with **beam spin and charge** differences.

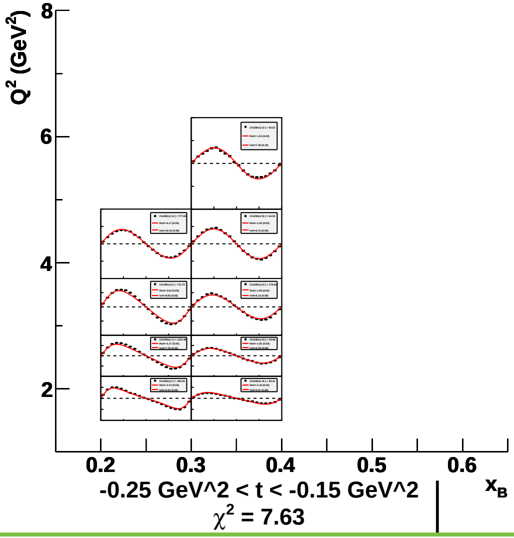


Proposal COMPASS-II (2010)

JLab's 12 GeV upgrade.

Dealing with 1 % statistical accuracy.

- Projection : CLAS12 data.
- Tentative fit.
- Preliminary !



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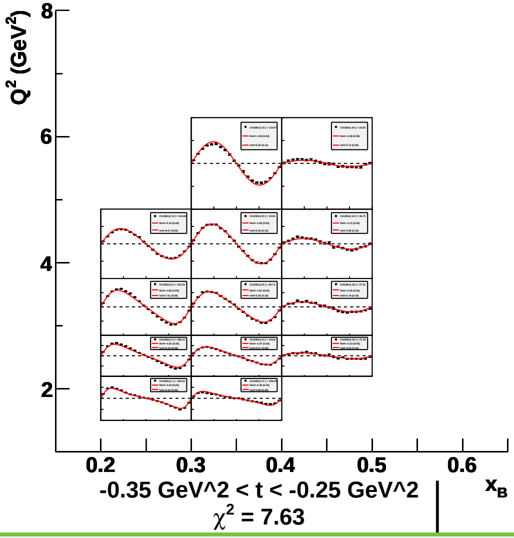

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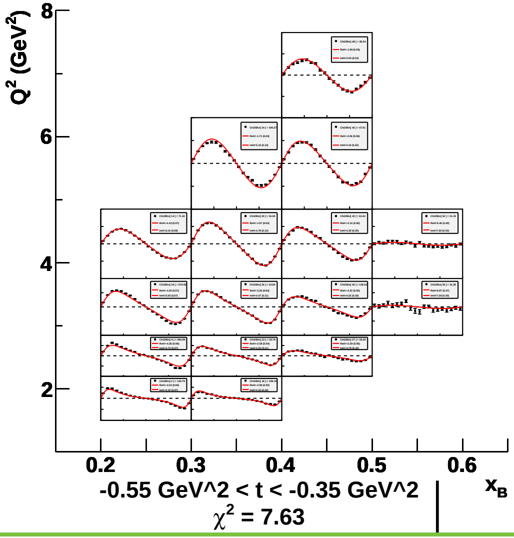

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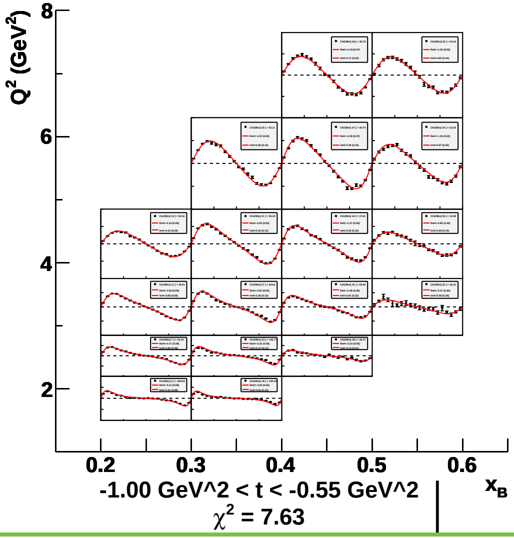


JLab's 12 GeV upgrade.

Dealing with 1 % statistical accuracy.

- $\chi^2/\mathrm{dof} \simeq$ 7.63 goes to 6.91 assuming more realistic 5 % uncertainty (statistical + systematic).
- Despite high χ^2, **fair agreement** with previous extractions of H at 6 GeV.
- Need careful analysis to see the (low) quality of the fit !
- Current hypothesis (H-dominance, ...) **no longer useable**.
- What observable should be measured ? **High precision asymmetries** seem a big constraint !

Local fits.

Is the accuracy sufficient for model-independent fitting ?

- Structure of BSA at twist 2 (Guichon-Vanderhaeghen formalism) :

$$\mathrm{BSA} = \frac{a \sin\phi + b \sin 2\phi}{1 + c\cos\phi + d\cos 2\phi + e\cos 3\phi}$$

where

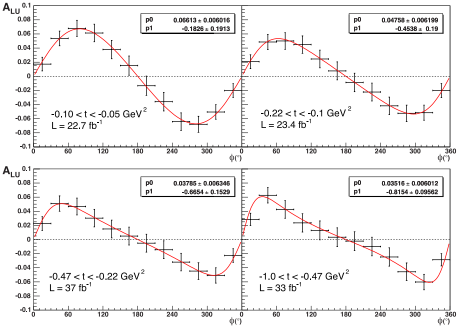
$$\begin{array}{ll} a = \mathcal{O}(Q^{-1}) & d = \mathcal{O}(Q^{-2}) \\ b = \mathcal{O}(Q^{-4}) & e = \mathcal{O}(Q^{-5}) \\ c = \mathcal{O}(Q^{-1}) & \end{array}$$

- **Underconstrained** problem (8 fit parameters : real and imaginary parts of 4 CFFs $\mathcal{H}$, $\mathcal{E}$, $\tilde{\mathcal{H}}$ and $\tilde{\mathcal{E}}$).
- Need other asymmetries on **same** kinematic bin (or **add** $\simeq$ 5-10 % **systematic uncertainty**).

Electron Ion Collider.

Spin observables : both polarized ions and electrons.

- Luminosity : $\simeq 10^{34}\ \mathrm{cm}^{-2}.s^{-1}$.
- Configuration : 20 GeV $\times$ 250 GeV.
- 3 months beam time.
- x_B range : $1.6.10^{-3} \rightarrow 2.5.10^{-3}$.
- Q^2 range : $3.2 \rightarrow 5.6$ GeV^2.
- t range : $-1. \rightarrow -0.05$ GeV^2.



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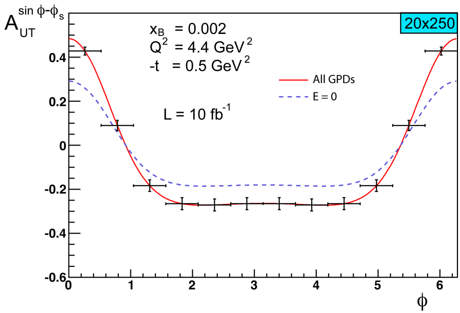


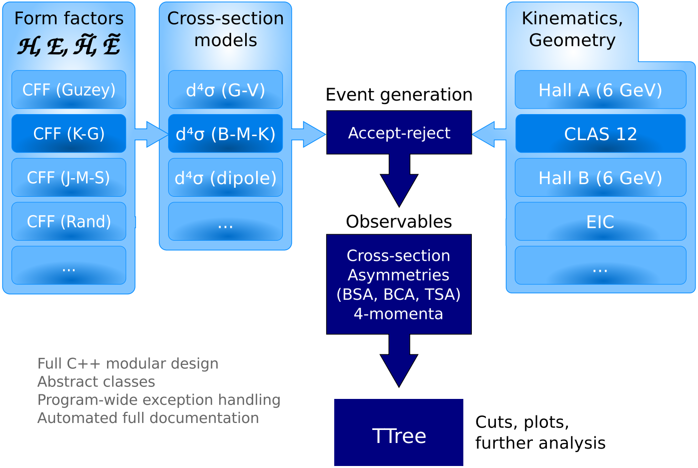
A software platform for GPD phenomenology.

The path between models and data.

1. Comprehensive **database of experimental results**.
2. Comprehensive **database of theoretical predictions**.
3. **Fitting engine**.
4. **Propagation** of statistic and systematic **uncertainties**.
5. **Visualizing software** to compare experimental results and model expectations.
6. Connection to **experimental set-up descriptions** to design new experiments.
7. **Interactive website** providing free access to model and experimental values.

A software platform for GPD phenomenology.

First components already used in fits or event generators.

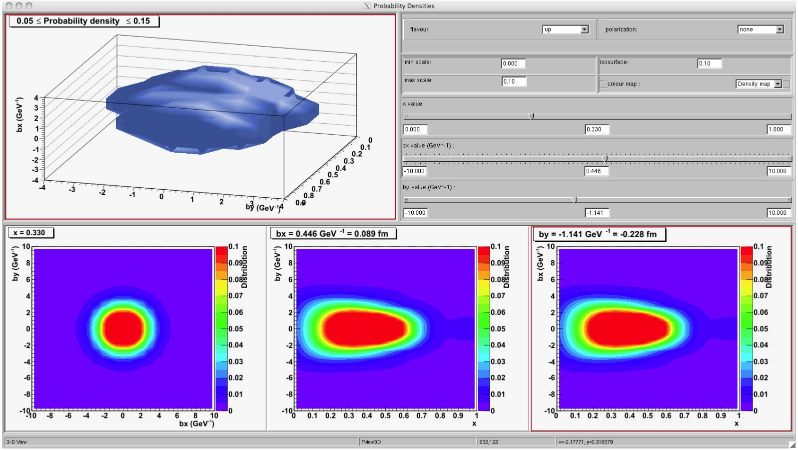


Full C++ modular design
Abstract classes
Program-wide exception handling
Automated full documentation

A software platform for GPD phenomenology.

Tentative design of a visualizing software.

- Bag model, up quark in unpolarized proton.



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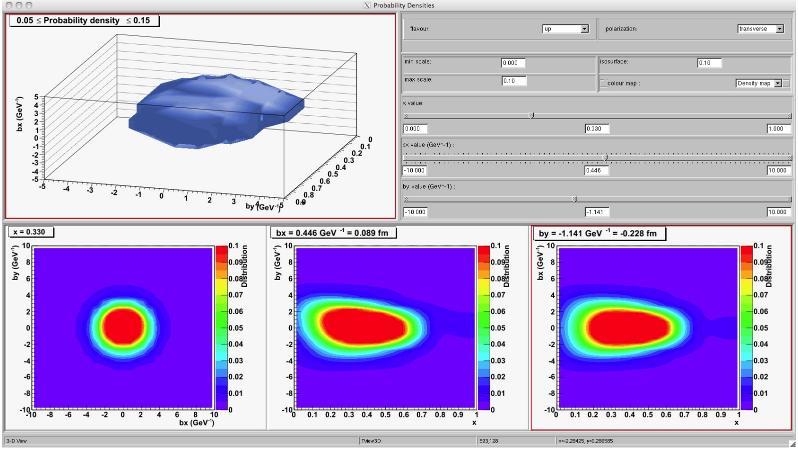

A software platform for GPD phenomenology.

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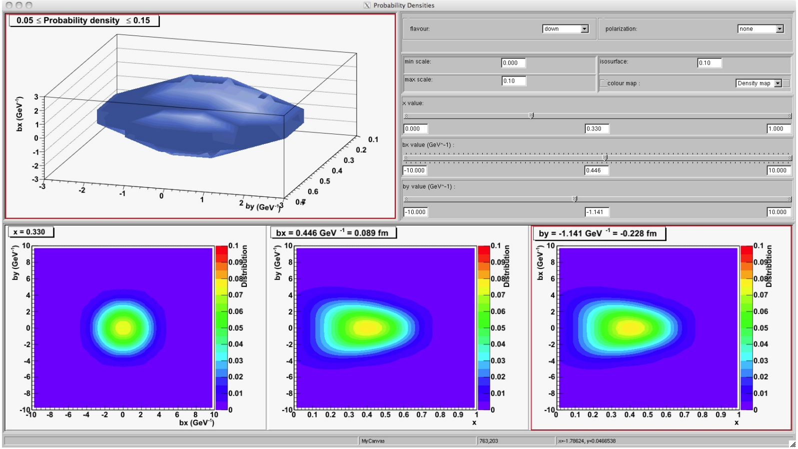

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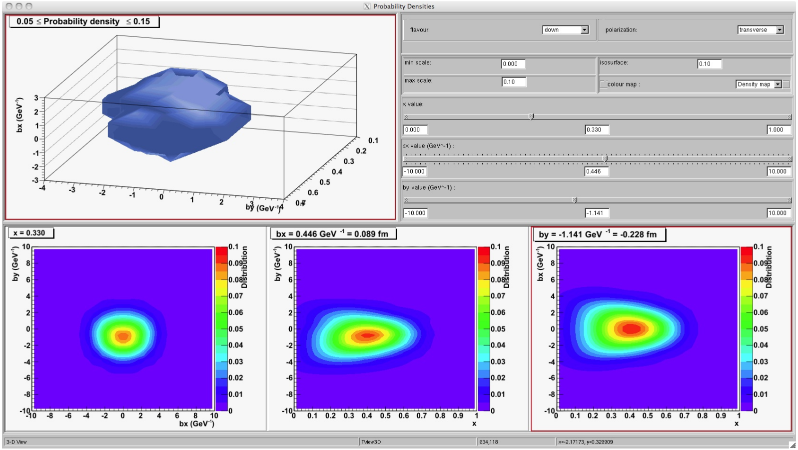

Conclusions.

Facing very exciting times for GPDs !

- Important experimental results during the last decade.
- **Encouraging first results** on extraction of GPDs.
- Several points still need to be clarified :
  - **Universality**.
  - Precise impact of subdominant GPDs and their hierarchy.
- **New facilities** will explore new kinematic ranges or provide challenging constraints for phenomenology.
- Need of a robust and efficient **fitting strategy** for DVCS and DVMP. Extension to TCS.
- First steps in the development of a **platform dedicated to global GPD analysis**.

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- P. Kroll
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- D. Müller
- C. Muñoz Camacho
- K. Passek-Kumericki
- B. Pire
- K. Semenov
- M. Vanderhaeghen