Global GPD analysis of data

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

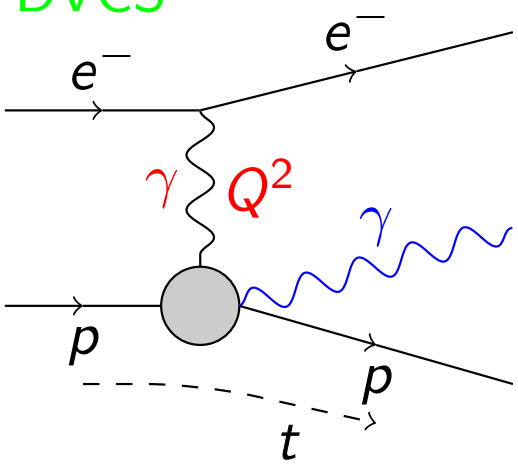
Irfu/SPhN, CEA-Saclay

CLAS12 2nd European Workshop - 03 / 07 / 2011

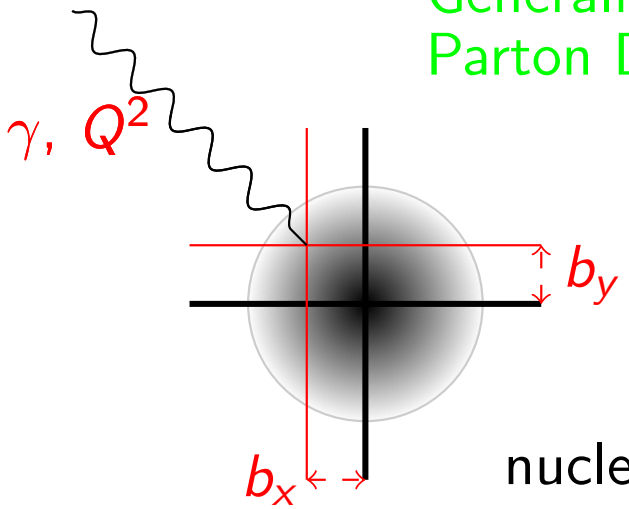
Generalized Parton Distributions.

Viewing nucleon structure in 3d.

DVCS



Generalized Parton Distributions

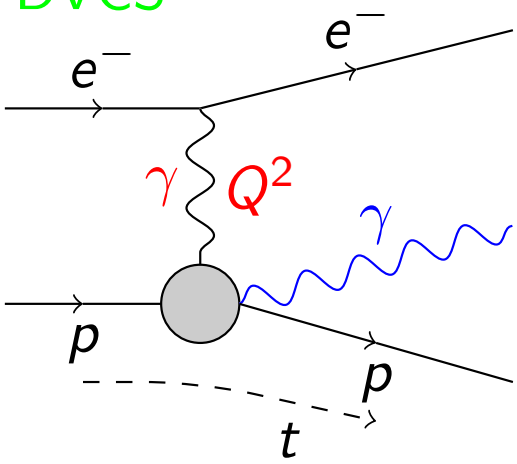


- Correlation of the **longitudinal momentum** and the **transverse position** of the struck quark.

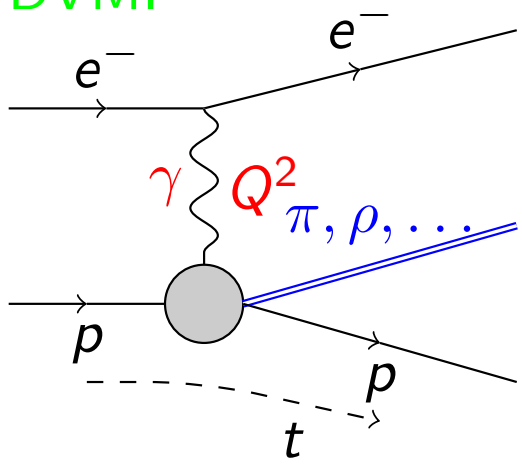
Generalized Parton Distributions.

Viewing nucleon structure in 3d.

DVCS



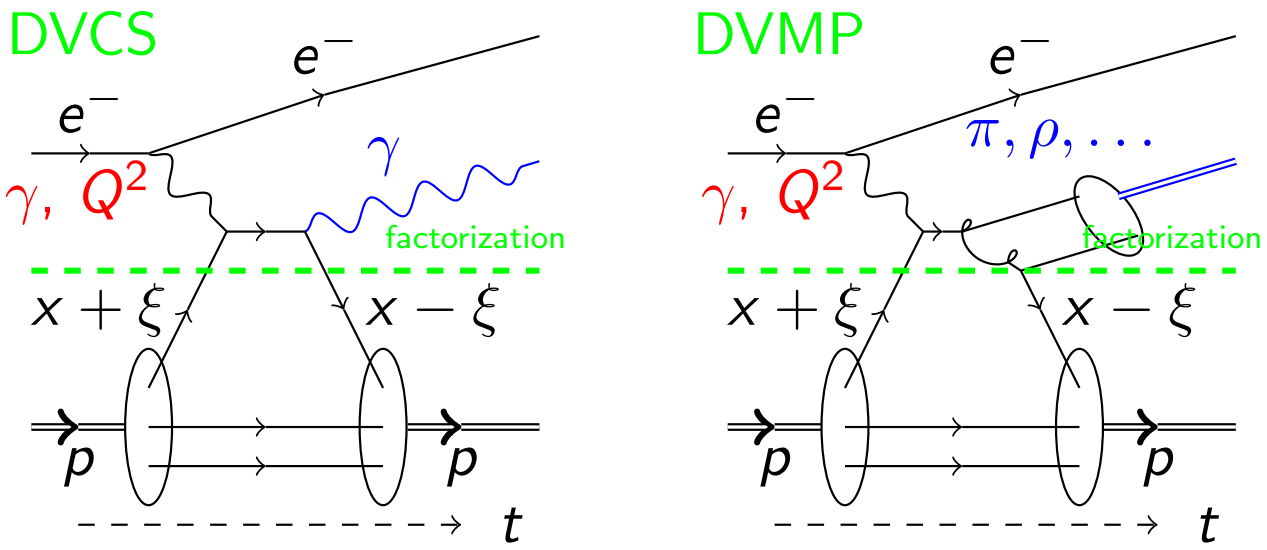
DVMP



- 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.

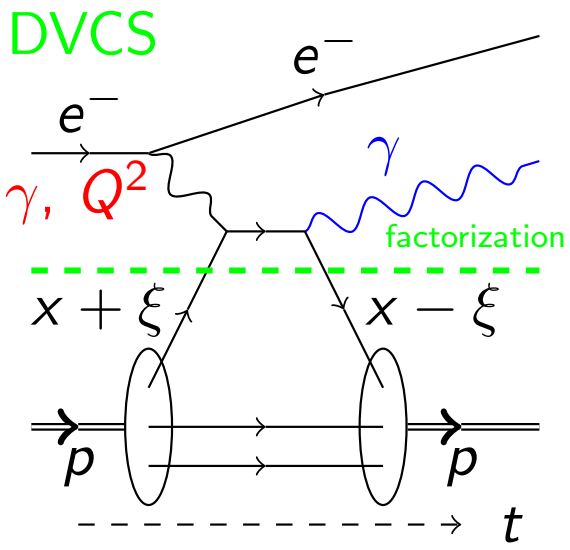
Viewing nucleon structure in 3d.

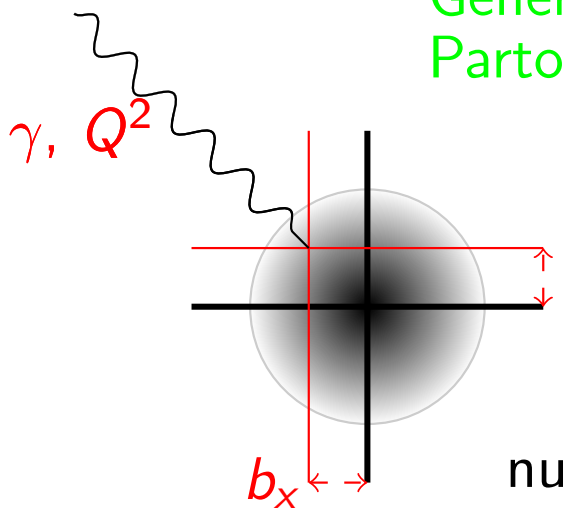


- Correlation of the **longitudinal momentum** and the **transverse position** of the struck quark.
- **3-dimensional** description of the nucleon.
- Insights on :
  - spin structure,
  - energy-momentum structure.

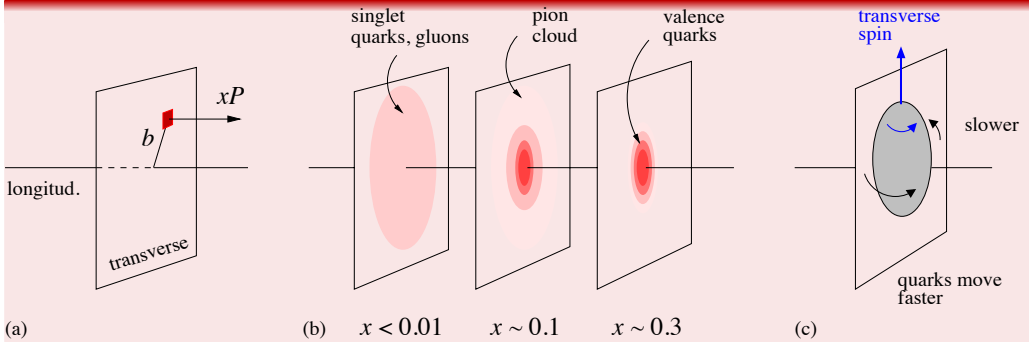
Generalized Parton Distributions.

Viewing nucleon structure in 3d.





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.

- Example : GPD H

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

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

Compton Form Factor at Leading Order

$$\begin{aligned} Re\mathcal{H} &= \mathcal{P} \int_{-1}^{+1} dx\, H(x,\xi,t) \left(\frac{1}{\xi - x} - \frac{1}{\xi + x} \right) \\ Im\mathcal{H} &= \pi \Big(H(\xi,\xi,t) - H(-\xi,\xi,t) \Big) \end{aligned}$$

- Similar relations for $Re\mathcal{E}$, $Im\mathcal{E}$, $Re\tilde{\mathcal{H}}$, $Im\tilde{\mathcal{H}}$, $Re\tilde{\mathcal{E}}$ and $Im\tilde{\mathcal{H}}$.

Current extraction methods on the market.

Problems : Model dependence ? Degrees of freedom ?

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

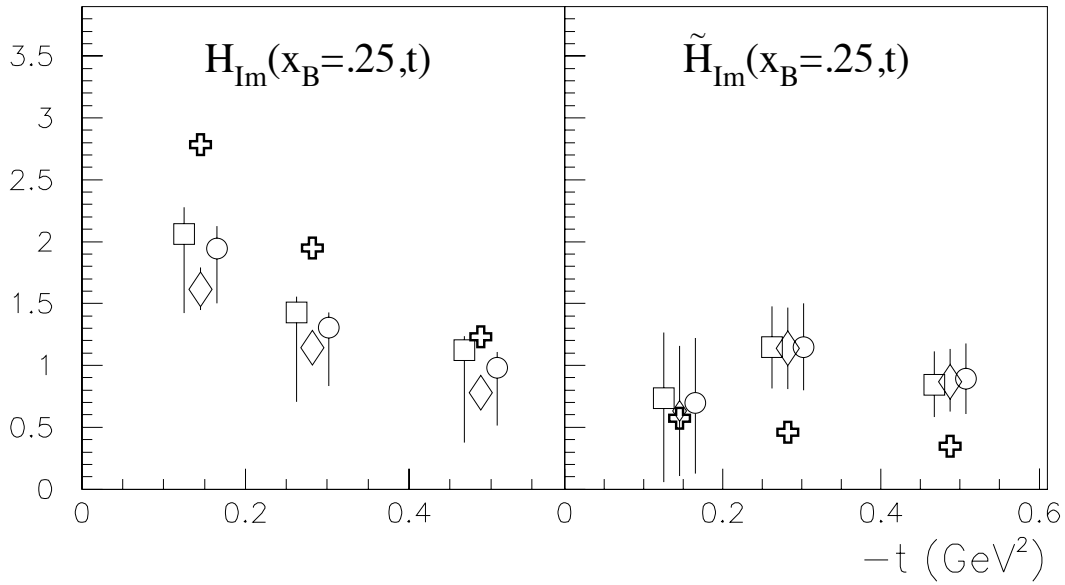
Already used ofr PDF fits. In progress for GPDs.

Current extraction methods on the market.

Problems : Model dependence ? Degrees of freedom ?

Local fits

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



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

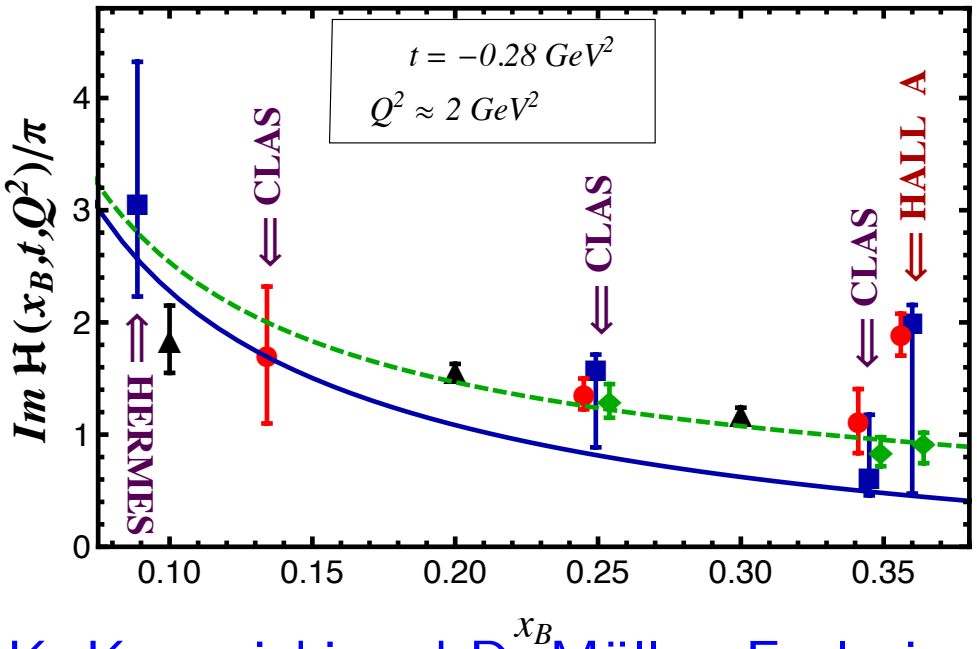
M. Guidal, Phys. Lett. B689 (2010) 156

Current extraction methods on the market.

Problems : Model dependence ? Degrees of freedom ?

Global fit

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



K. Kumericki and D. Müller, Exclusive 2010

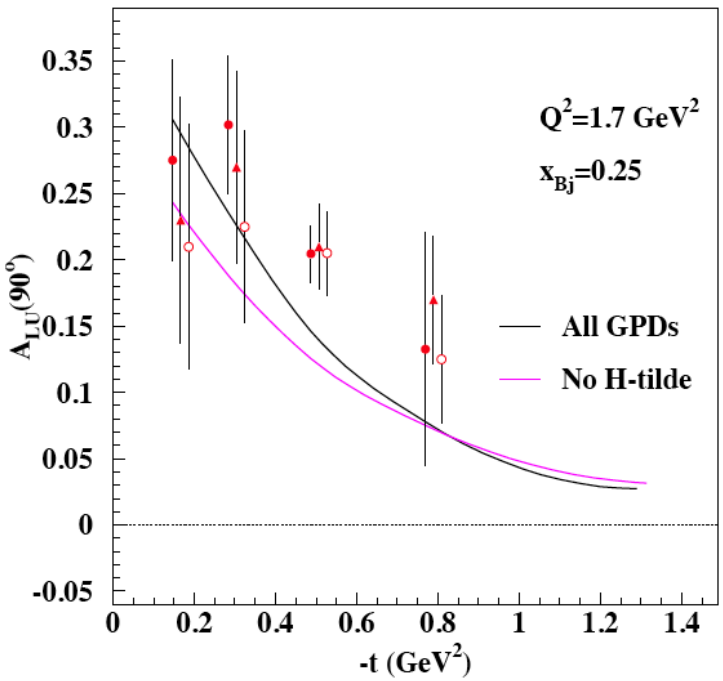
- Without Hall A data.
- With Hall A data.
- △ : neural network.
- □ : "7-CFF" fit results.
- ◇ : "$\mathcal{H} - \tilde{\mathcal{H}}$".
- ○ : hybrid fits.

Current extraction methods on the market.

Problems : Model dependence ? Degrees of freedom ?

Global fit

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



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

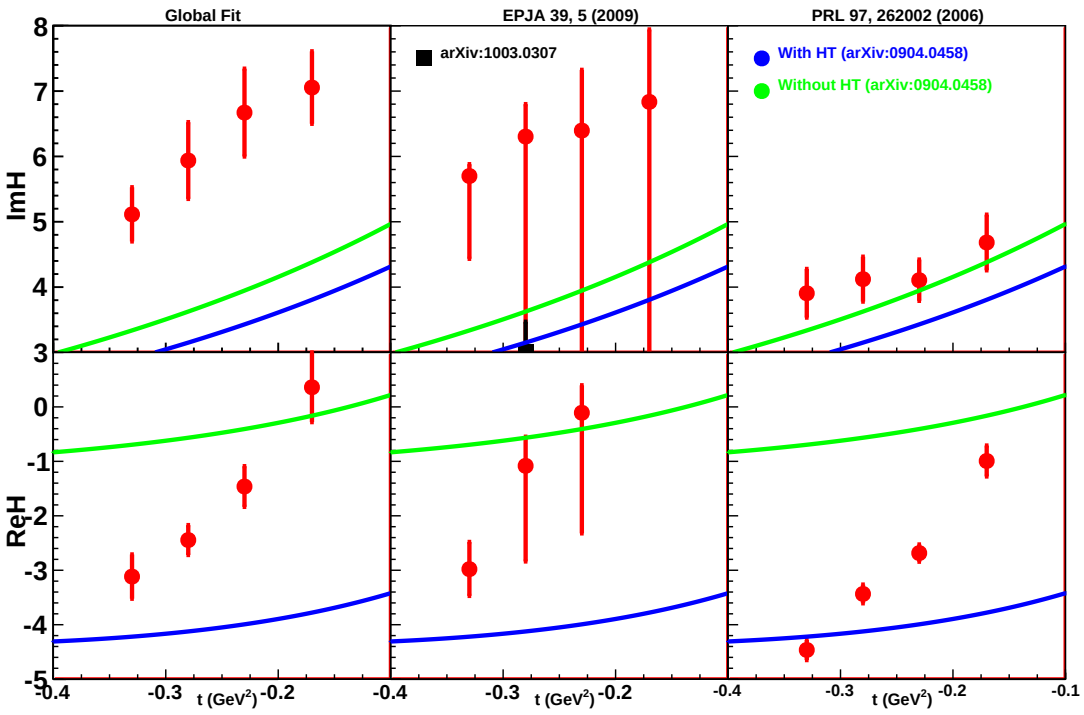
G. Goldstein *et al*, arXiv:1012.3776

Current extraction methods on the market.

Problems : Model dependence ? Degrees of freedom ?

Hybrid : Local / global fit

Combine two previous methods to estimate model dependence.



- Hybrid fit.
- Without Hall A data.
- With Hall A data.
- △ : neural network.
- □ : "7-CFF" fit results.

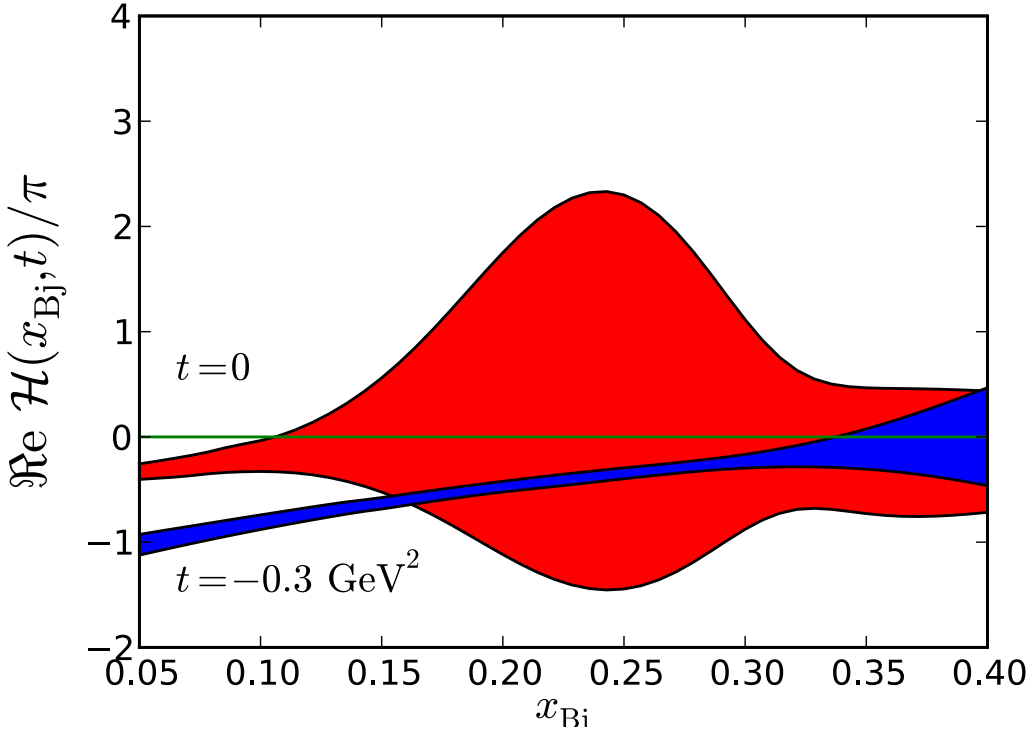
H. Moutarde, Phys. Rev. D79 (2009) 094021

Current extraction methods on the market.

Problems : Model dependence ? Degrees of freedom ?

Neural networks

Already used ofr PDF fits. In progress for GPDs.

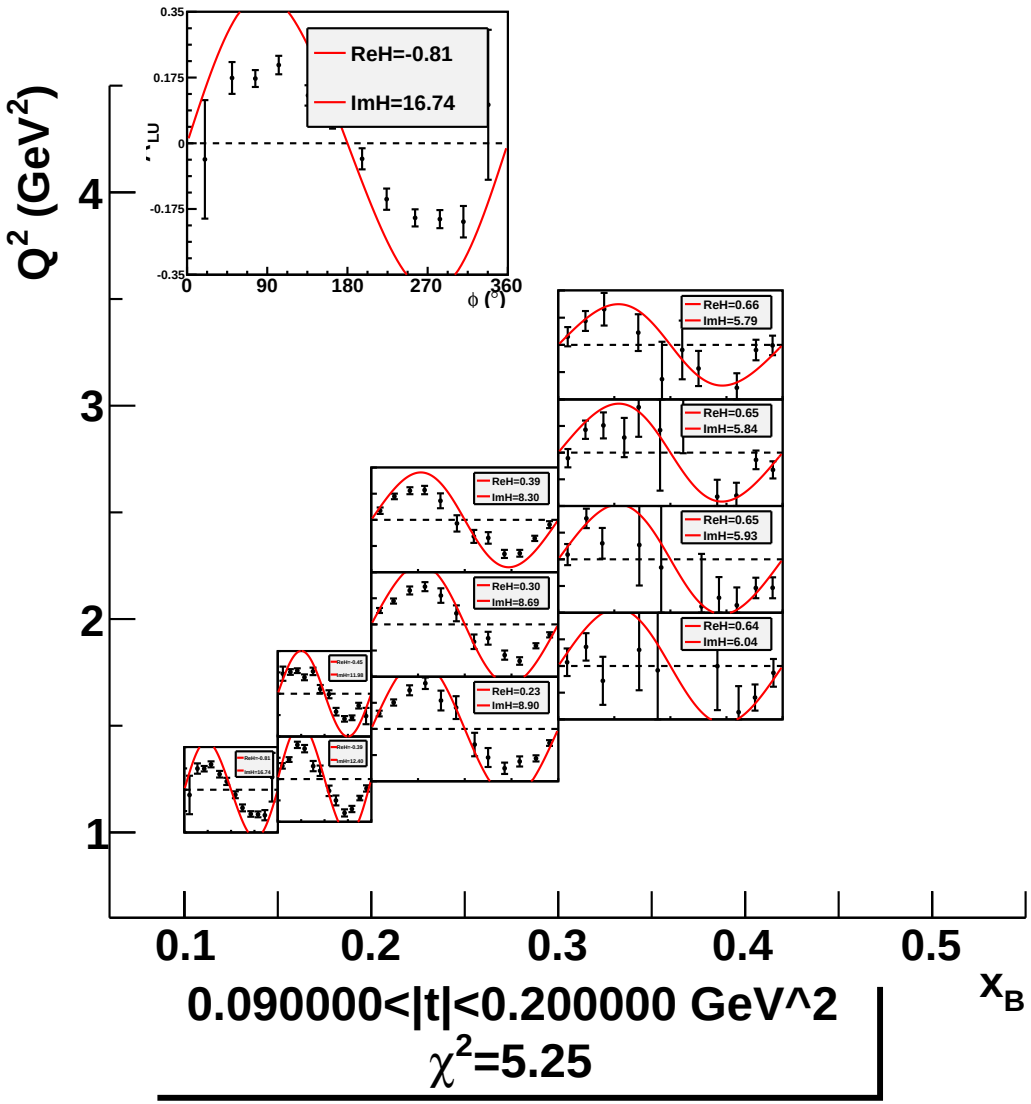


- HERMES BCAs and CLAS BSAs.
- Extrapolation $t \longrightarrow 0$.

K. Kumericki and D. Müller, Exclusive 2010

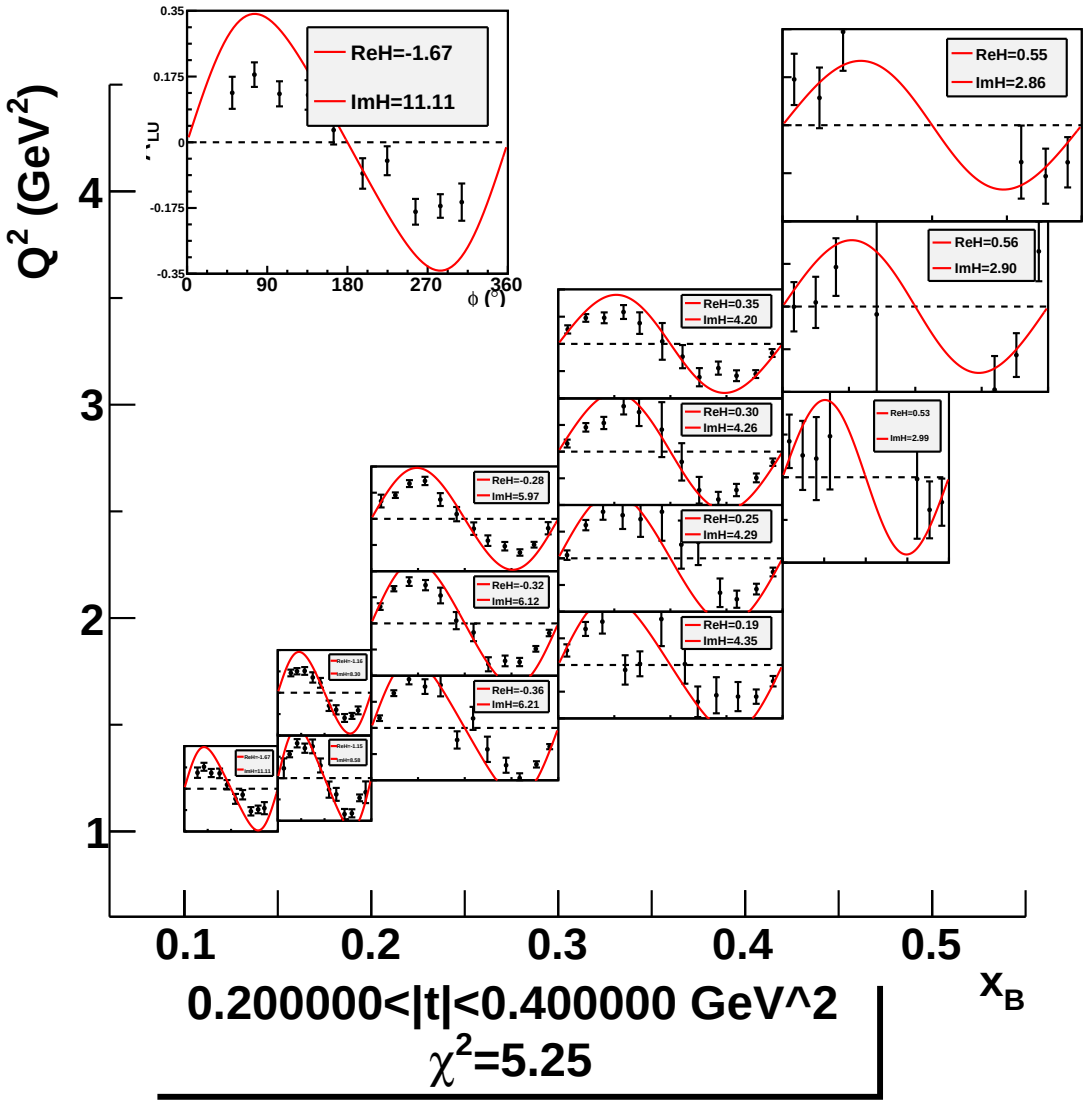
Universality

Same GPDs extracted in DVCS and DVMP ?



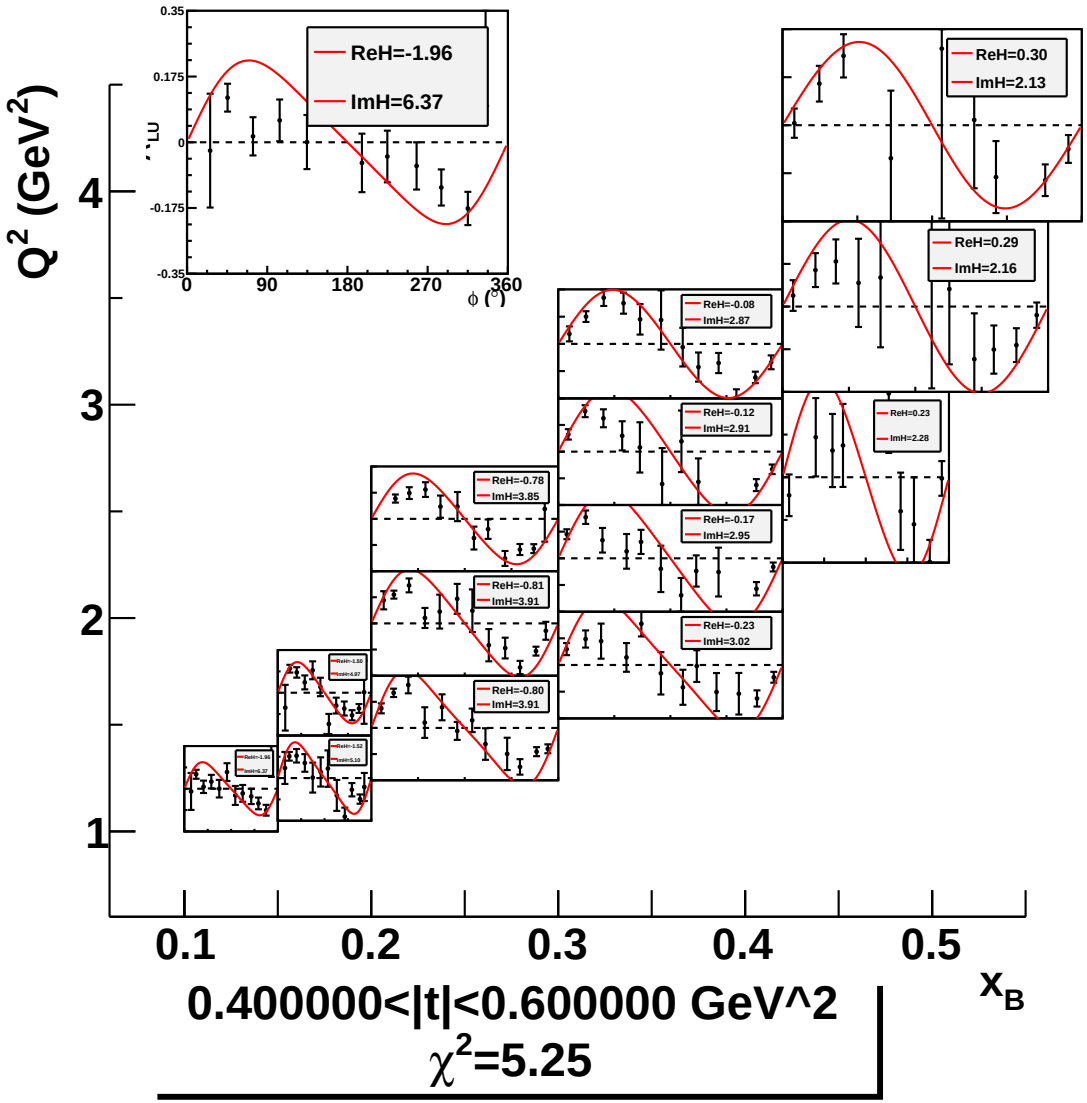
Universality

Same GPDs extracted in DVCS and DVMP ?



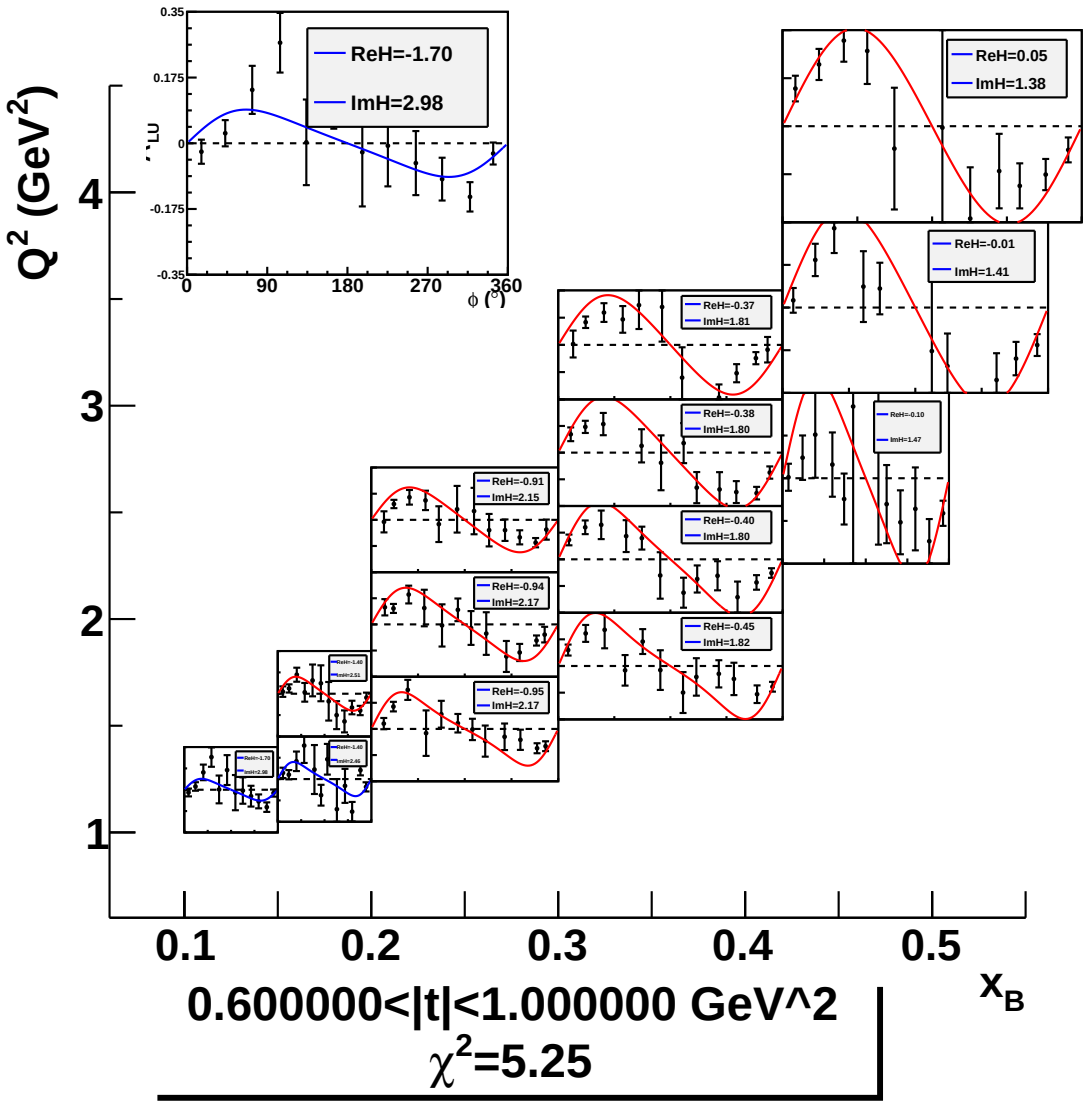
Universality

Same GPDs extracted in DVCS and DVMP ?



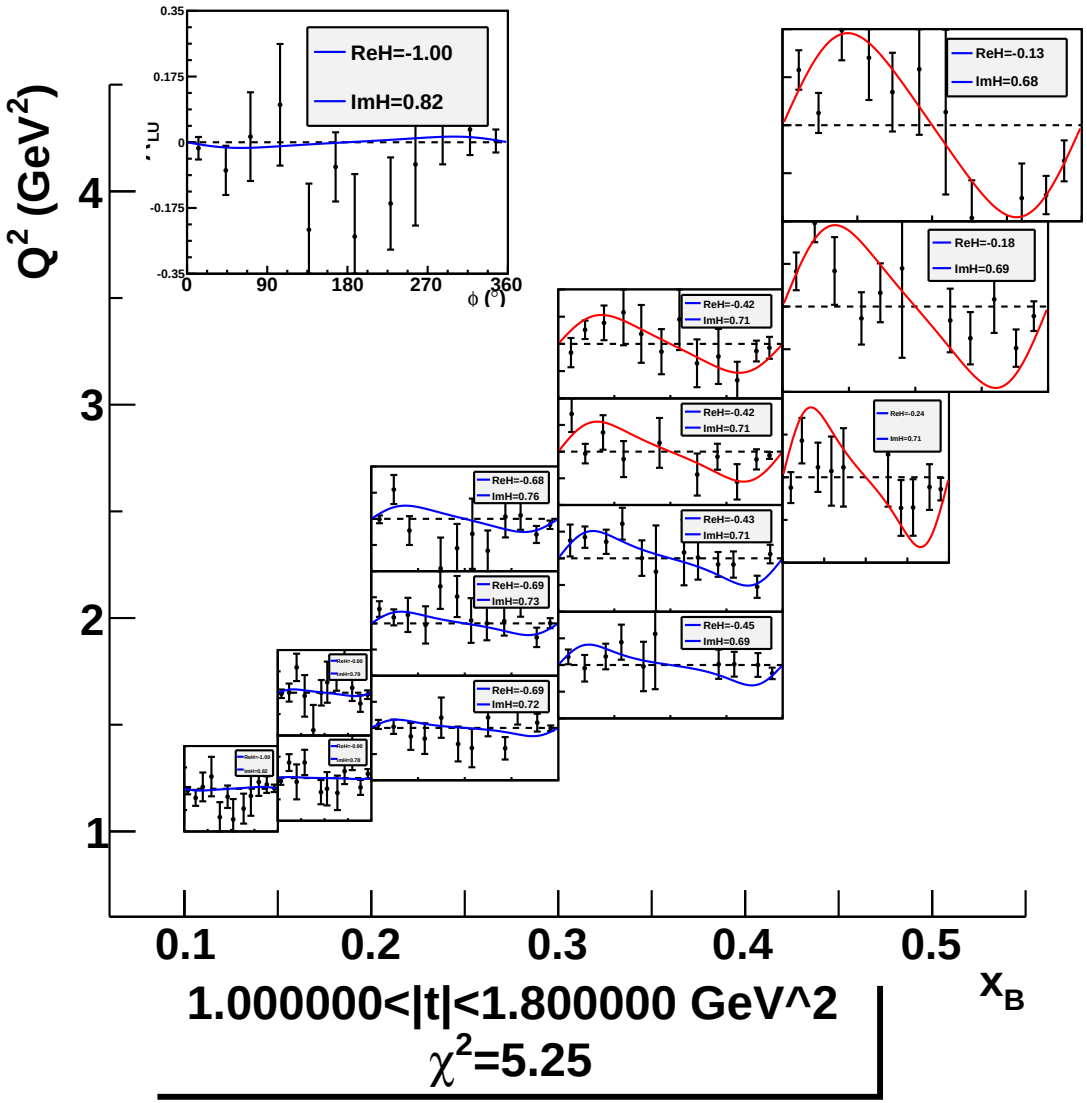
Universality

Same GPDs extracted in DVCS and DVMP ?



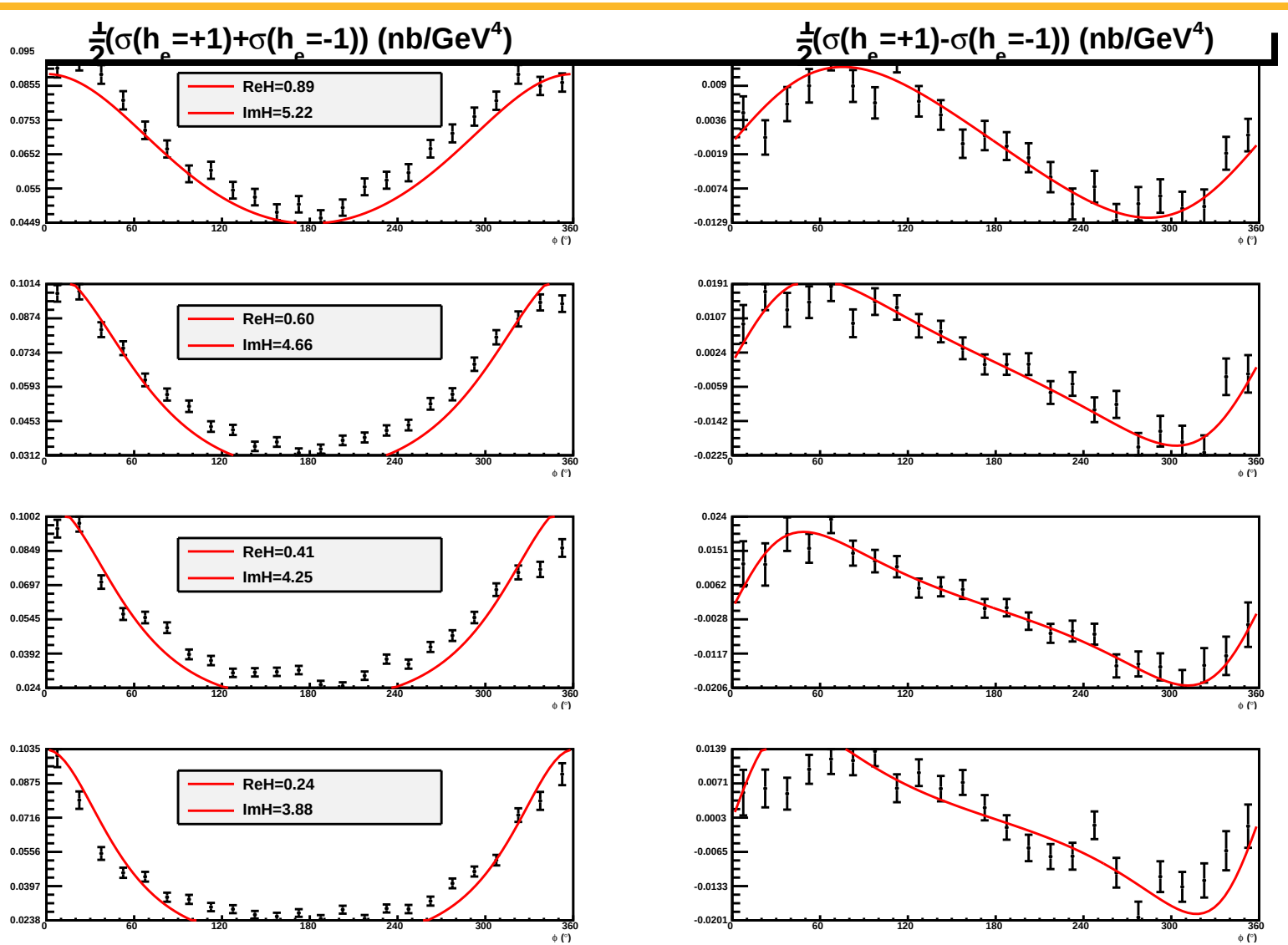
Universality

Same GPDs extracted in DVCS and DVMP ?



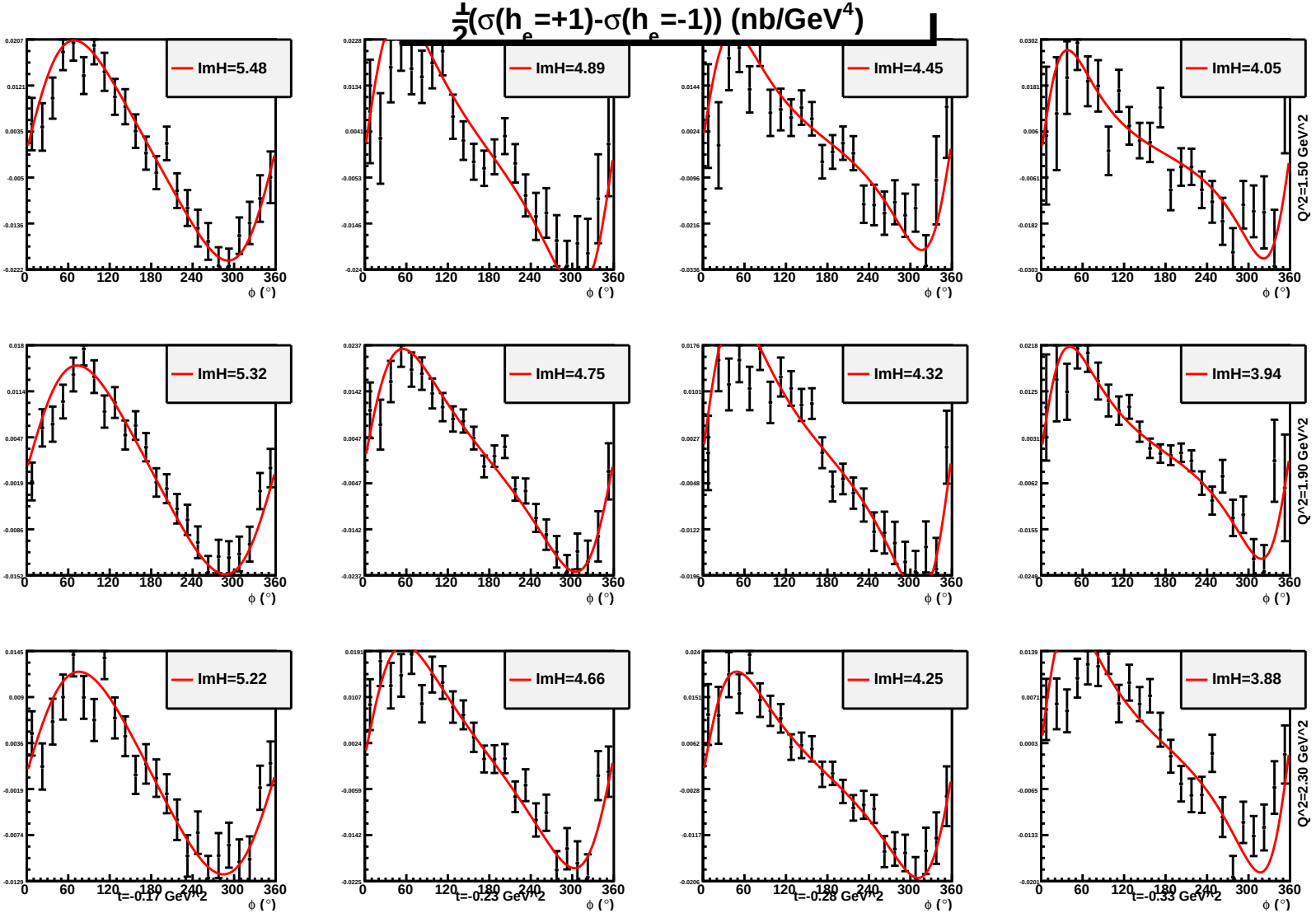
Universality

Same GPDs extracted in DVCS and DVMP ?



Universality

Same GPDs extracted in DVCS and DVMP ?



Universality

Same GPDs extracted in DVCS and DVMP ?

- 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.

- 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 $\mathcal{H}$.

Key results.

Common features of different extractions.

- **Dominance** of twist 2 and **validity** of a GPD analysis of DVCS data.
- However a small **twist 3** contribution presumably exists.
- Already some indications about the validity of the H-dominance hypothesis.
- Cross-sections seem a bigger constraint to phenomenology than BSAs, looking forward to Hall B results.
- Question : What observable should be measured ? Accuracy ?

Hybrid fit method.

Smooth parametrization for the global fit.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x,\xi,t,Q^2) = H(x,\xi,t,Q^2) - H(-x,\xi,t,Q^2)$$

- Smooth parametrization of H_+ :

$$2\sum_{n=0}^{\infty}\sum_{l=0}^{n+1} B_{nl}(t,Q^2)\,\theta\left(1-\frac{x^2}{\xi^2}\right)\left(1-\frac{x^2}{\xi^2}\right)\; C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right)\quad P_{2l}\left(\frac{1}{\xi}\right)$$

Hybrid fit method.

Smooth parametrization for the global fit.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x,\xi,t,Q^2) = H(x,\xi,t,Q^2) - H(-x,\xi,t,Q^2)$$

- Smooth parametrization of H_+ :

$$2\sum_{n=0}^{\infty}\sum_{l=0}^{n+1} B_{nl}(t,Q^2)\,\theta\left(1-\frac{x^2}{\xi^2}\right)\left(1-\frac{x^2}{\xi^2}\right)\; C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right)\; \underbrace{P_{2l}\left(\frac{1}{\xi}\right)}$$

Legendre polynomial

Hybrid fit method.

Smooth parametrization for the global fit.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x,\xi,t,Q^2) = H(x,\xi,t,Q^2) - H(-x,\xi,t,Q^2)$$

- Smooth parametrization of H_+ :

$$2\sum_{n=0}^{\infty}\sum_{l=0}^{n+1} B_{nl}(t,Q^2)\,\theta\left(1-\frac{x^2}{\xi^2}\right)\left(1-\frac{x^2}{\xi^2}\right)\underbrace{C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right)}_{\text{Gegenbauer polynomial}}\quad P_{2l}\left(\frac{1}{\xi}\right)$$

Hybrid fit method.

Smooth parametrization for the global fit.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x,\xi,t,Q^2) = H(x,\xi,t,Q^2) - H(-x,\xi,t,Q^2)$$

- Smooth parametrization of H_+ :

$$2\sum_{n=0}^{\infty}\sum_{l=0}^{n+1} B_{nl}(t,Q^2)\underbrace{\theta\left(1-\frac{x^2}{\xi^2}\right)}\left(1-\frac{x^2}{\xi^2}\right) \quad C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right) \quad P_{2l}\left(\frac{1}{\xi}\right)$$

Support :
Smeared

Hybrid fit method.

Smooth parametrization for the global fit.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x,\xi,t,Q^2) = H(x,\xi,t,Q^2) - H(-x,\xi,t,Q^2)$$

- Smooth parametrization of H_+ :

$$2\sum_{n=0}^{\infty}\sum_{l=0}^{n+1} \underbrace{B_{nl}(t,Q^2)}_{\substack{\text{Model} \\ \text{t-dep.}}} \theta\left(1-\frac{x^2}{\xi^2}\right)\left(1-\frac{x^2}{\xi^2}\right) C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right) \quad P_{2l}\left(\frac{1}{\xi}\right)$$

with $B_{nl}(t,Q^2) = \left(\ln\frac{Q_0^2}{\Lambda^2}\Big/\ln\frac{Q^2}{\Lambda^2}\right)^{\frac{\gamma_p}{\beta_0}} B_{nl}(t,Q_0^2)$.

Hybrid fit method.

Smooth parametrization for the global fit.

- DVCS cross sections depend on singlet combination H_+ :

$$H_+(x,\xi,t,Q^2) = H(x,\xi,t,Q^2) - H(-x,\xi,t,Q^2)$$

- Smooth parametrization of H_+ :

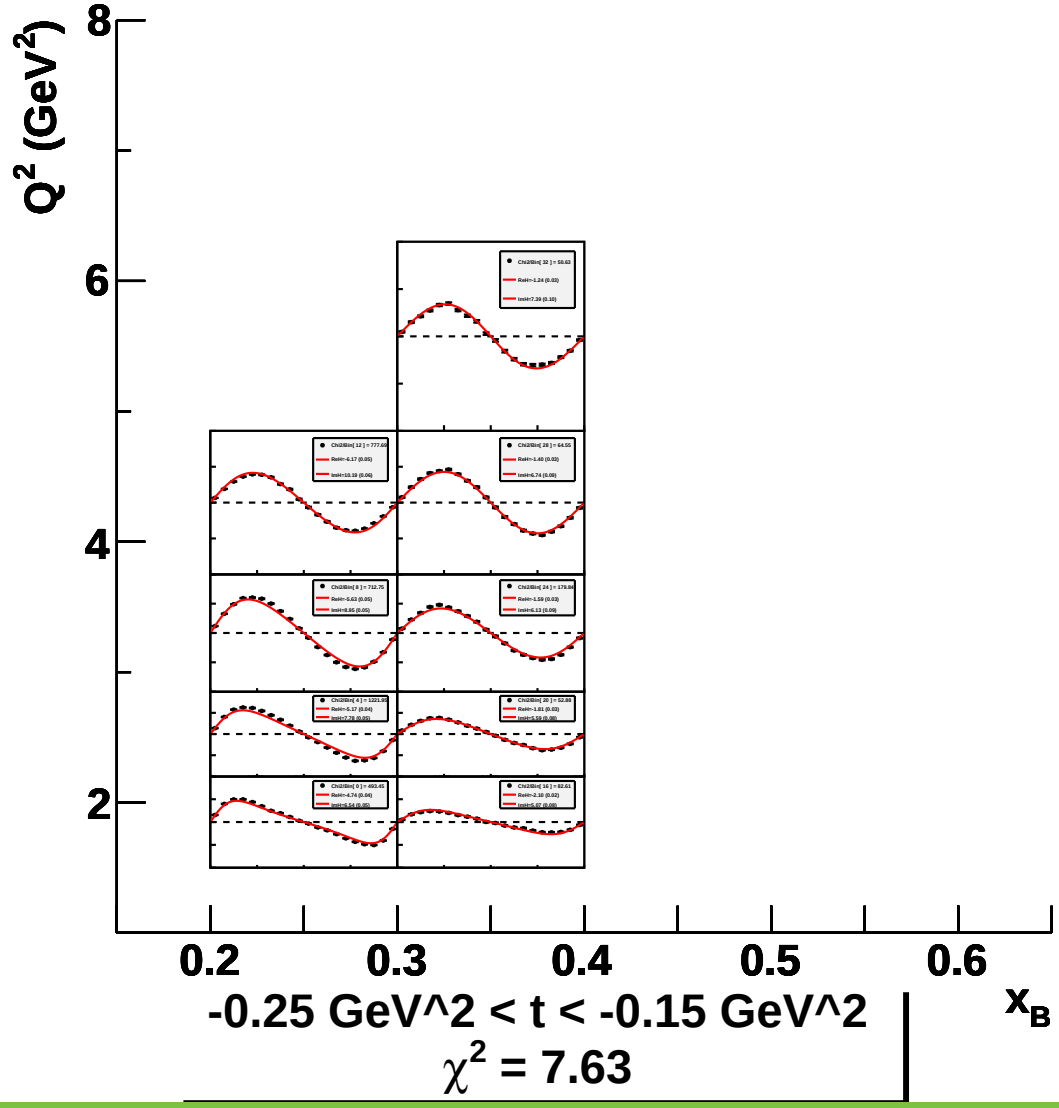
$$2\sum_{n=0}^{N}\sum_{l=0}^{n+1} \underbrace{B_{nl}(t,Q^2)}_{\substack{\text{Model} \\ \text{t-dep.}}} \theta\left(1-\frac{x^2}{\xi^2}\right)\left(1-\frac{x^2}{\xi^2}\right) C_{2n+1}^{\frac{3}{2}}\left(\frac{x}{\xi}\right) \quad P_{2l}\left(\frac{1}{\xi}\right)$$

with $B_{nl}(t,Q^2) = \left(\ln\frac{Q_0^2}{\Lambda^2}\Big/\ln\frac{Q^2}{\Lambda^2}\right)^{\frac{\gamma_p}{\beta_0}} \quad \frac{a_{nl}}{1+b_{nl}(t-t_0)^2}$.

- Non-trivial correlation between x and t.
- a_{nl} and b_{nl} are fitted. t_0 is chosen prior to the fits.

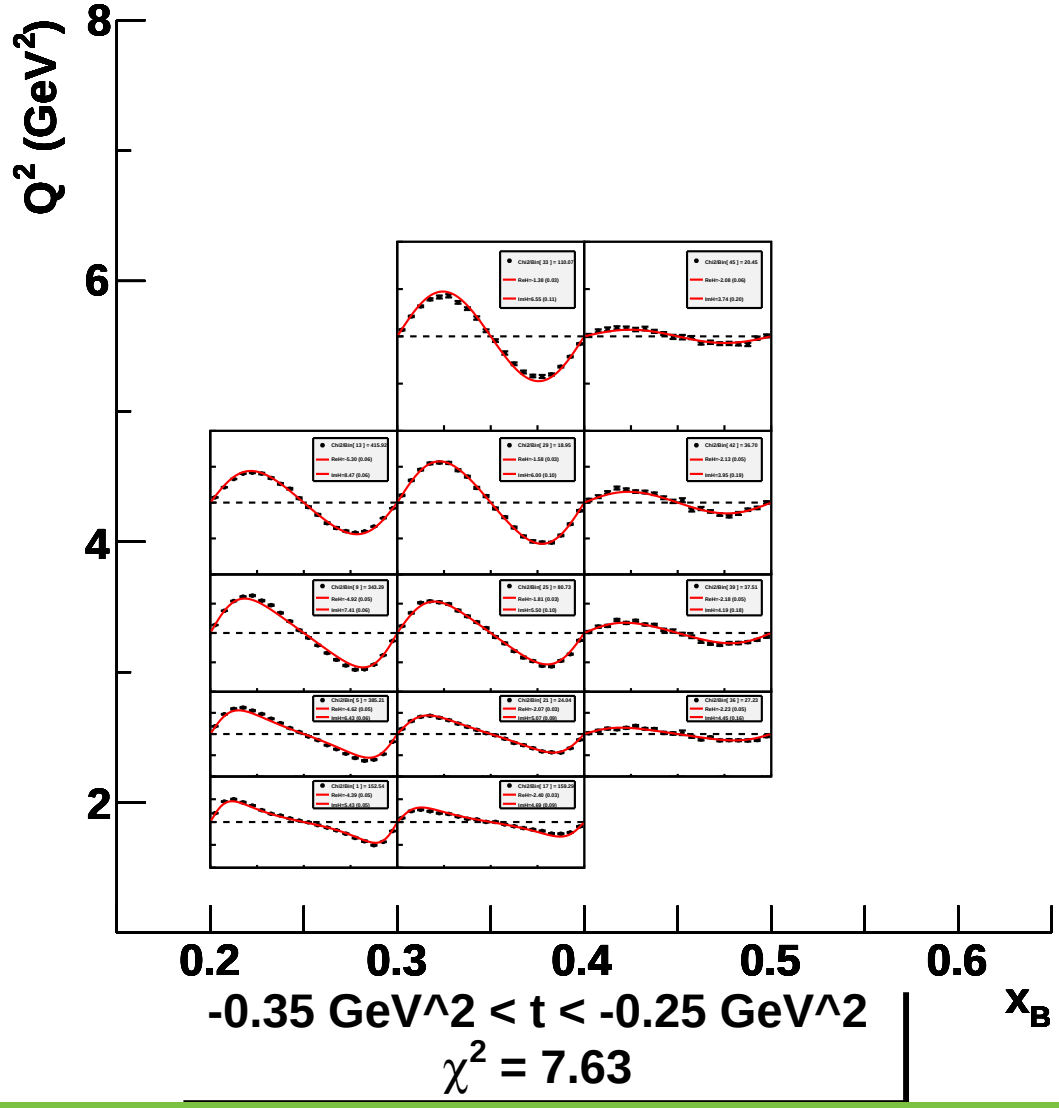
Hybrid fit method.

Dealing with 1 % statistical accuracy.



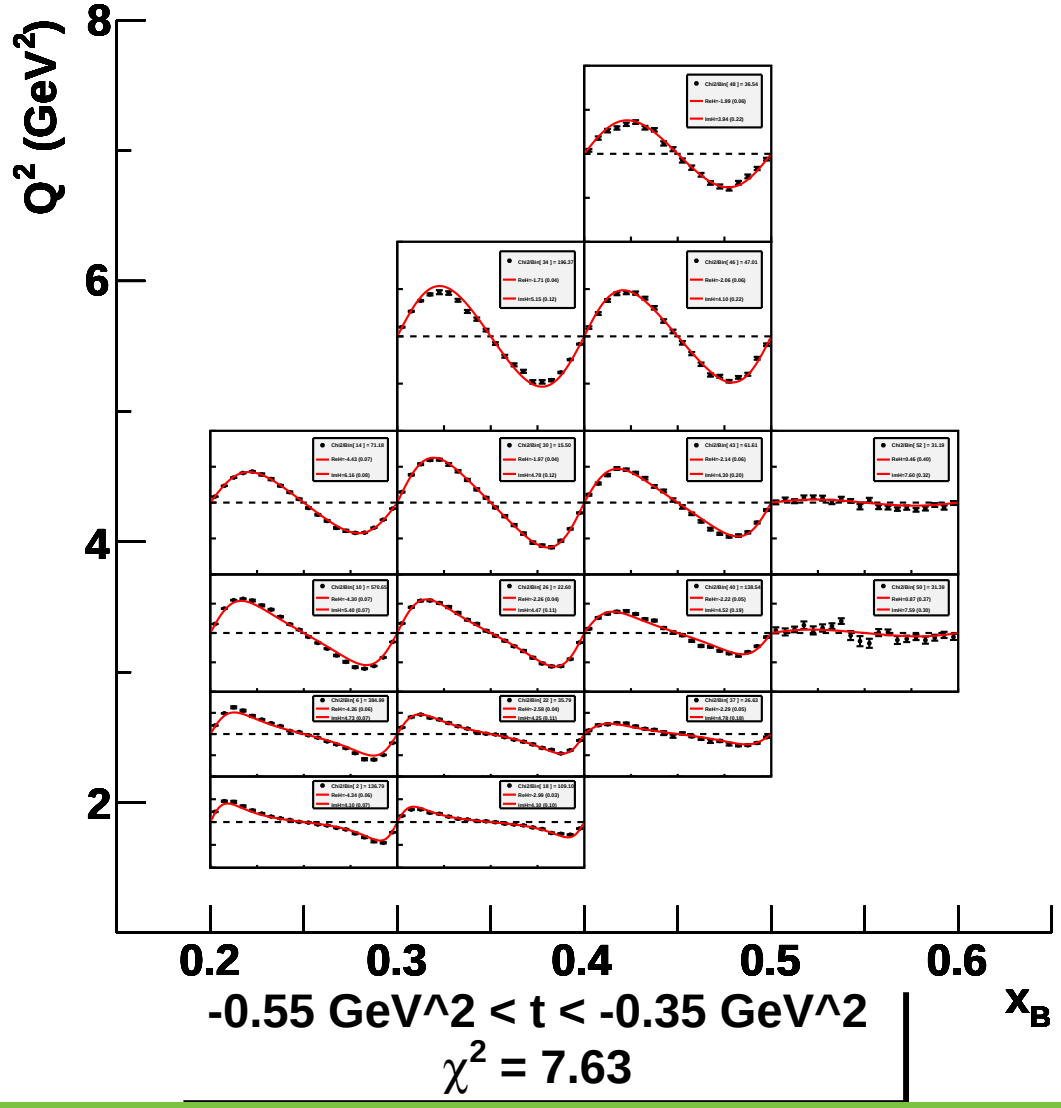
Hybrid fit method.

Dealing with 1 % statistical accuracy.



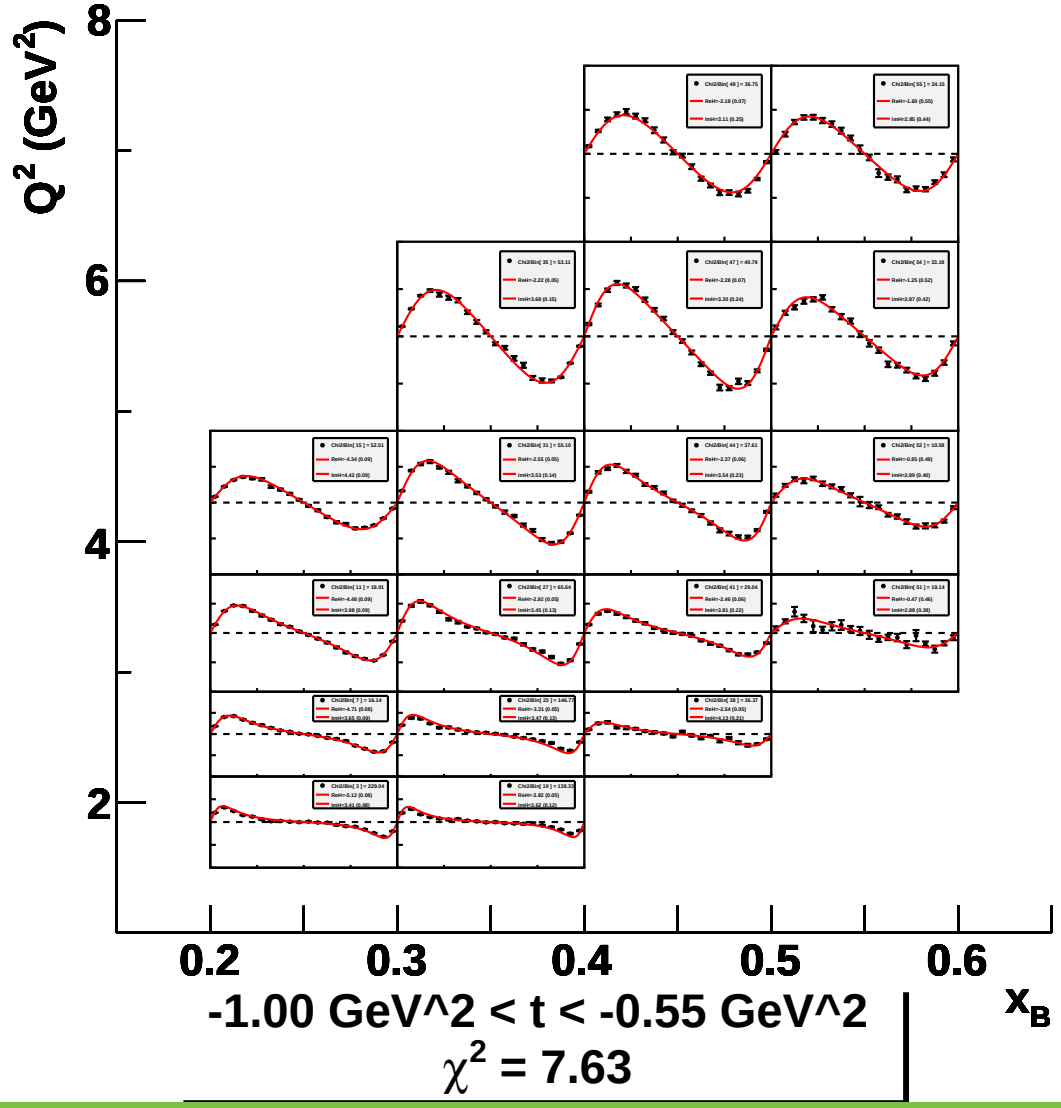
Hybrid fit method.

Dealing with 1 % statistical accuracy.



Hybrid fit method.

Dealing with 1 % statistical accuracy.



Hybrid fit method.

Dealing with 1 % statistical accuracy.

- $\chi^2/\mathrm{dof} \simeq 7.63$ goes to 6.91 assuming more realistic 5 % uncertainty (statistical + systematic).
- **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 in 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

$$a = \mathcal{O}(Q^{-1}) \quad d = \mathcal{O}(Q^{-2})$$
$$b = \mathcal{O}(Q^{-4}) \quad e = \mathcal{O}(Q^{-5})$$
$$c = \mathcal{O}(Q^{-1})$$

- **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**).

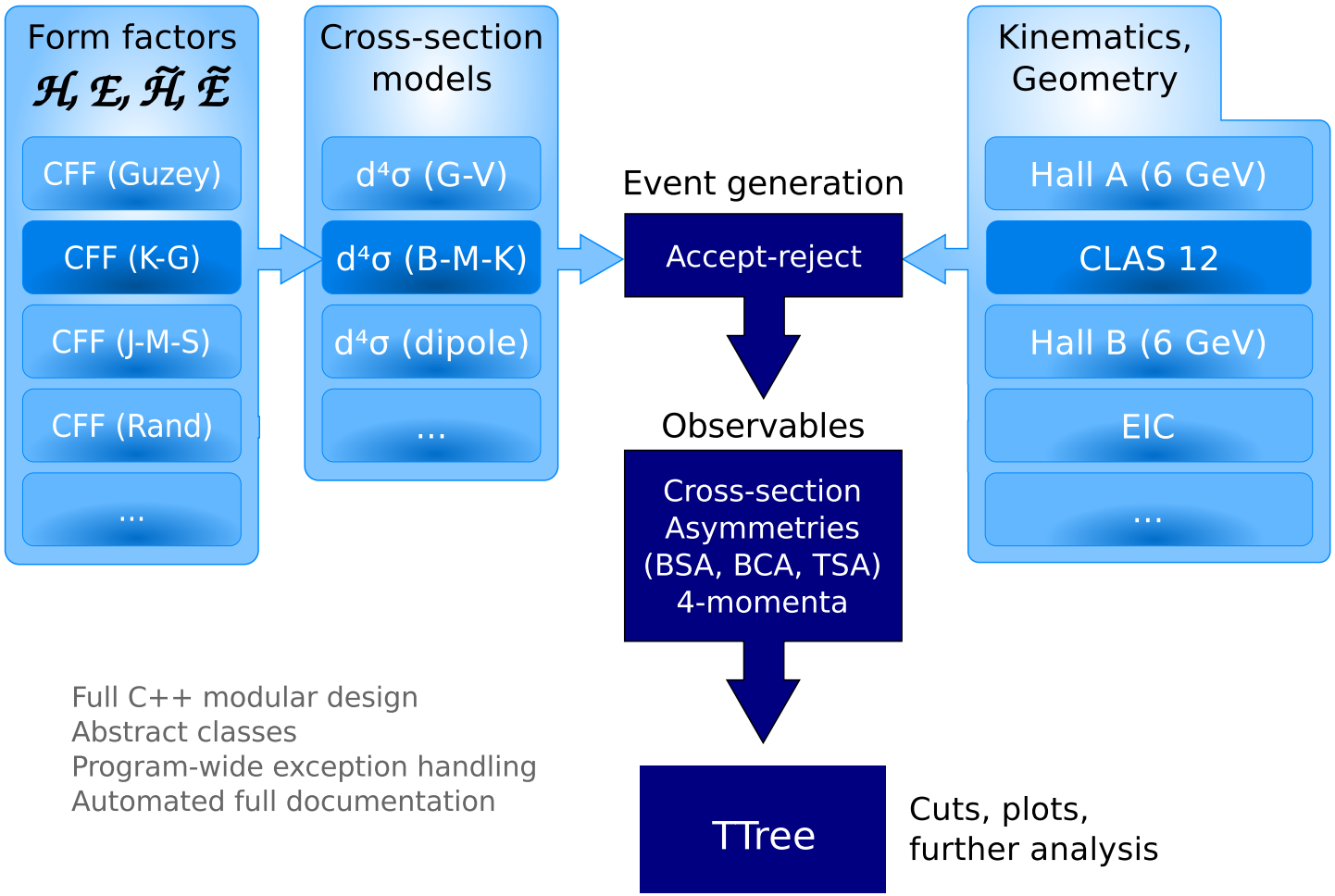
PROPHET

Platform for **R**epresenting the **O**rganization of **P**artons inside **H**adrons and **E**xperimental **T**omographies.

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.

PROPHET

First components already used in fits or event generators.

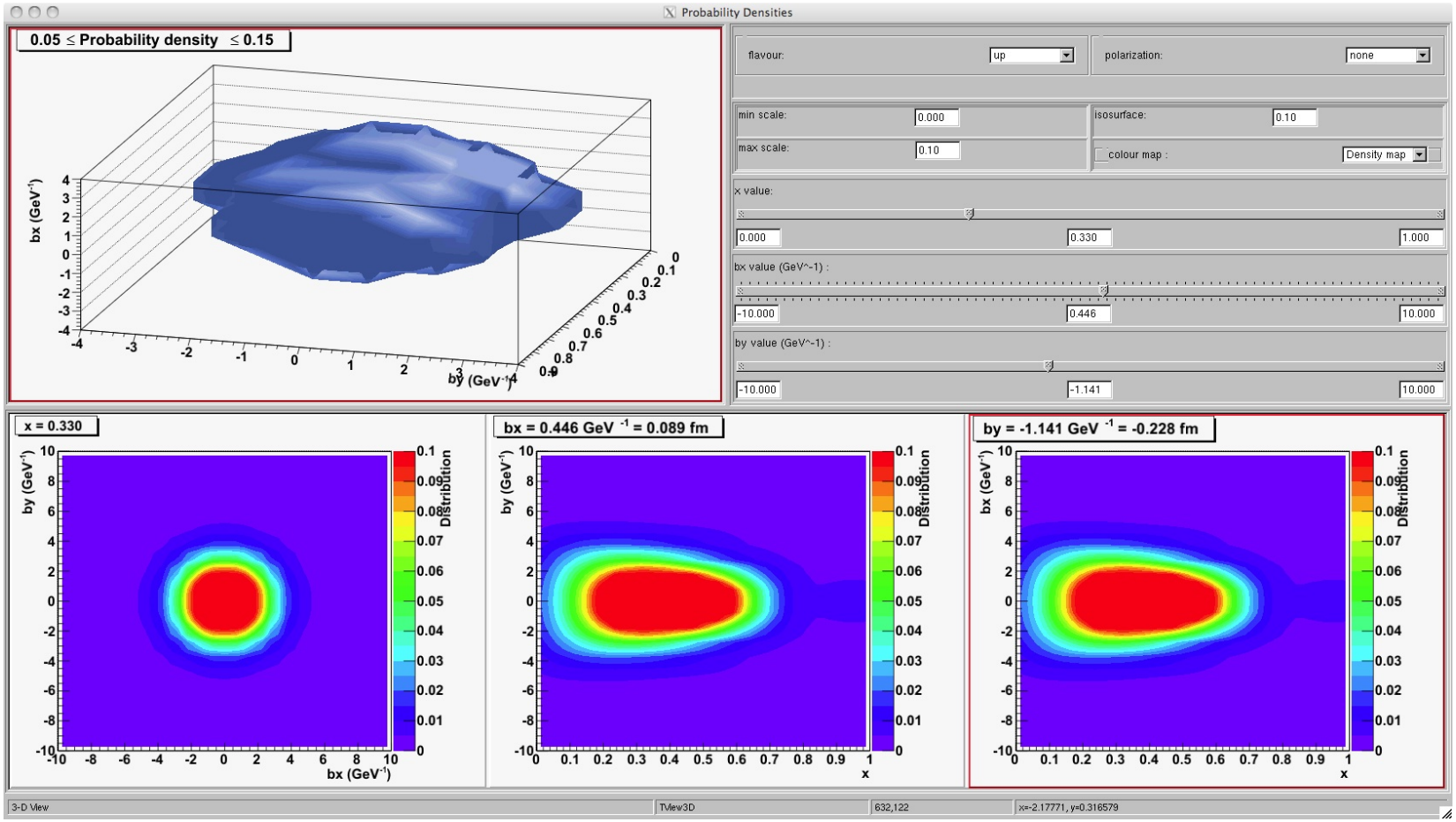


Full C++ modular design
Abstract classes
Program-wide exception handling
Automated full documentation

PROPHET

Tentative design of a visualizing software.

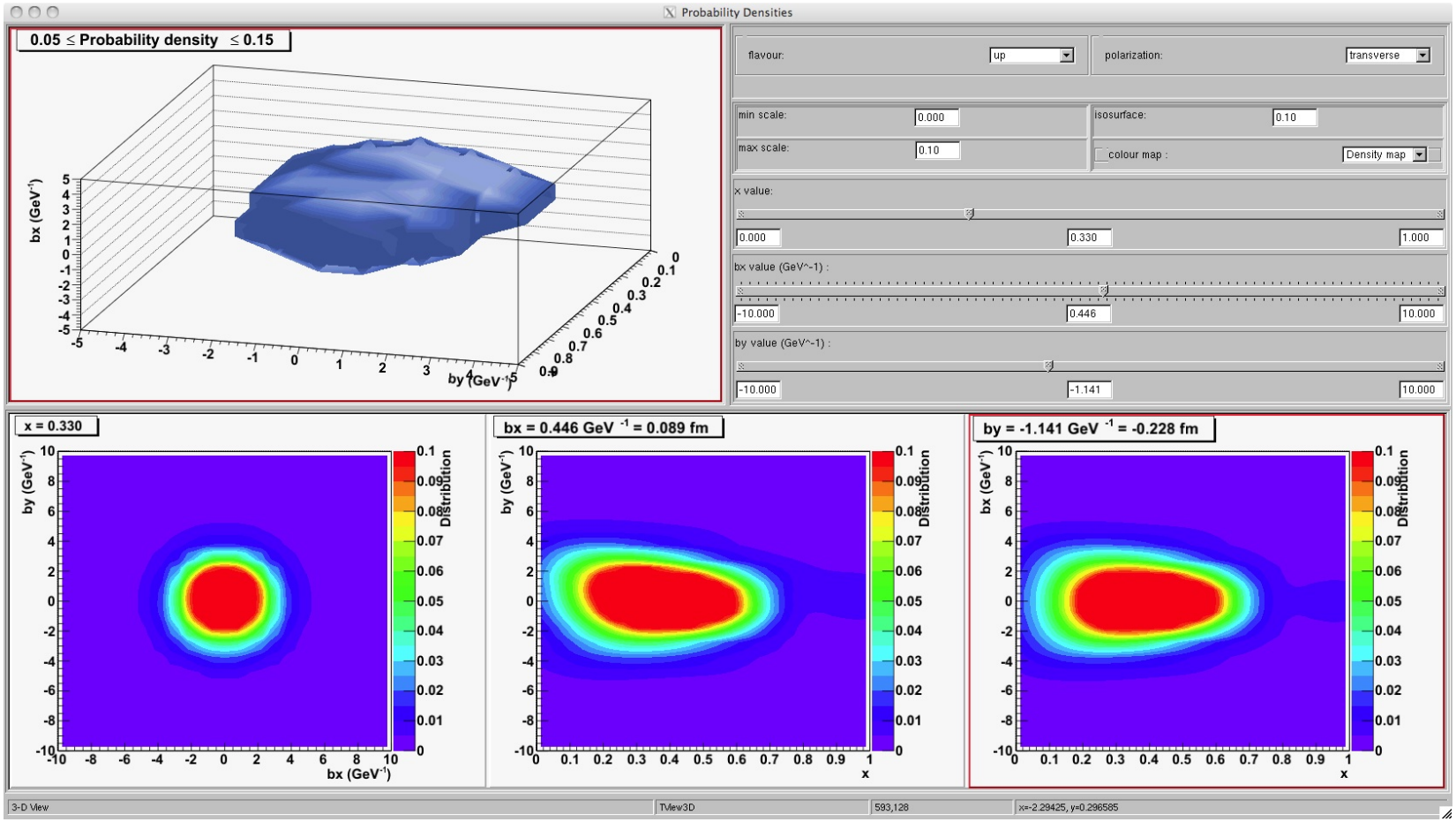
- Bag model, up quark in unpolarized proton.



PROPHET

Tentative design of a visualizing software.

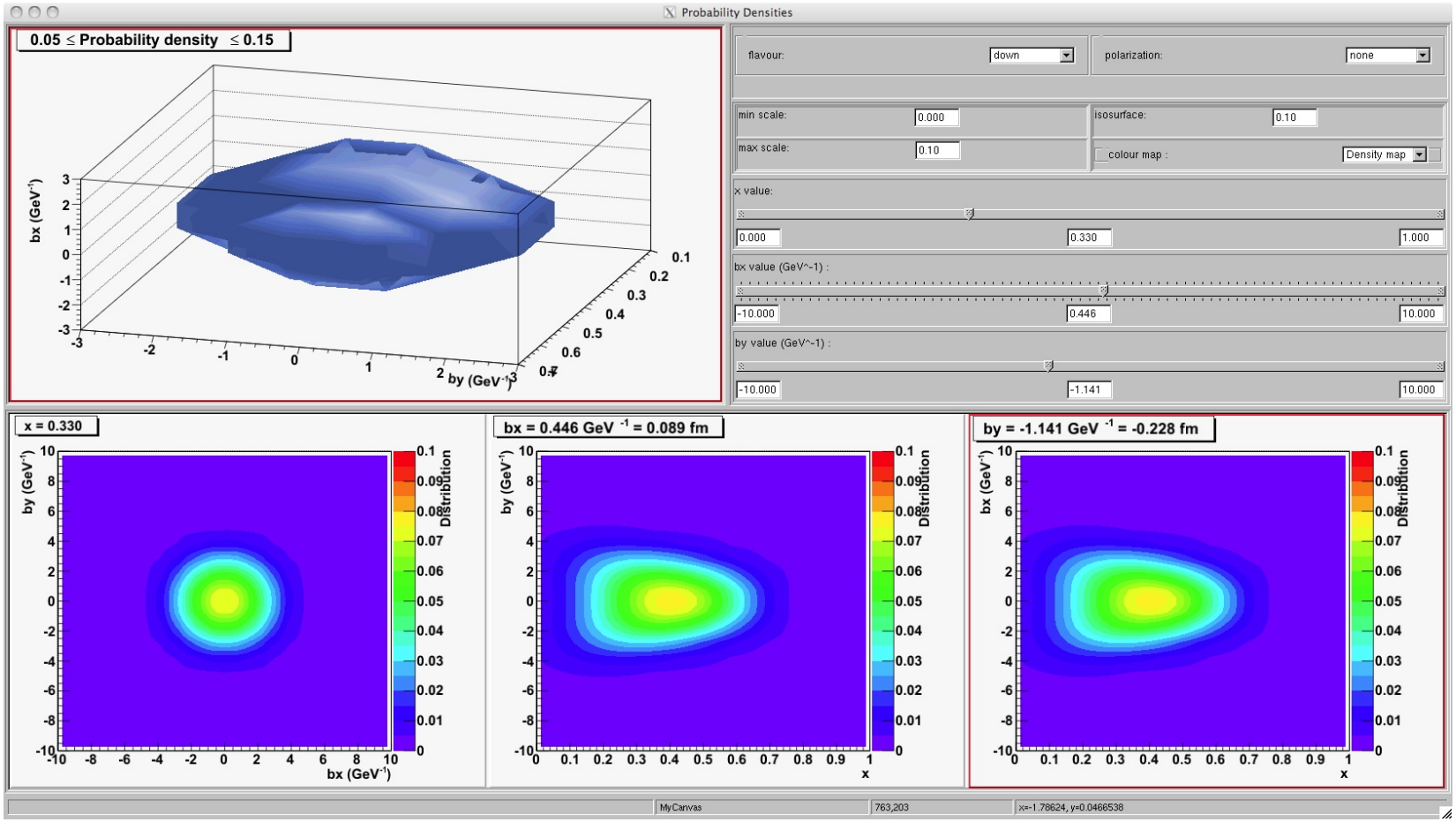
- Bag model, up quark in transversely polarized proton.



PROPHET

Tentative design of a visualizing software.

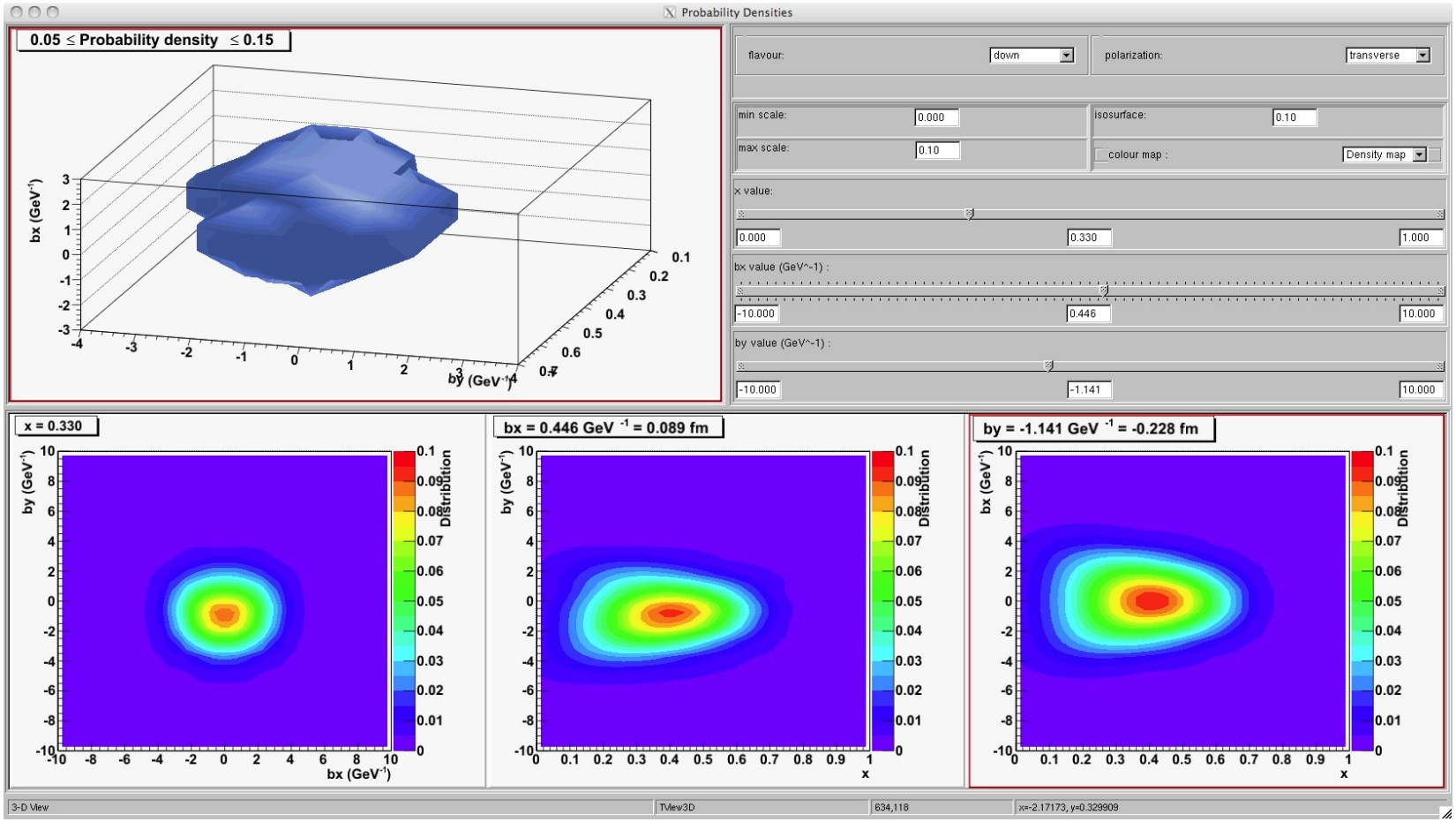
- Bag model, down quark in unpolarized proton.



PROPHET

Tentative design of a visualizing software.

- Bag model, down quark in transversely polarized proton.



Conclusions.

Waiting for the 12 GeV upgrade.

- **Encouraging first results** on extraction of GPDs from JLab measurements.
- Several points still need to be clarified :
  - **Universality**.
  - Precise impact of subdominant GPDs.
- The **12 GeV upgrade** will be more challenging and will put great constraints on phenomenology.
- Need of a robust and efficient **fitting strategy**.
- First steps in the development of a **platform dedicated to global GPD analysis**.

Acknowledgments.

- F.-X. Girod
- S. Goloskokov
- P. Guichon
- M. Guidal
- P. Kroll
- K. Kumericki
- D. Müller
- C. Muñoz Camacho
- K. Passek-Kumericki
- K. Semenov
- M. Vanderhaeghen