3D Structure of the Nucleon: GPDs and Form Factors

<u>Conveners</u>: *Cédric Lorcé* & *Silvia Niccolai*

ÉCOLE POLYTECHNIQUE UNIVERSITÉ PARIS-SACLAY

UNIVERSITÉ PARIS SUD université PARIS-SACLAY

Sep 14, Ferrara, Italy

Contributions

14 presentations in 5 parallel sessions + 1 plenary talk

Simonetta Liuti (University of Virginia, USA)

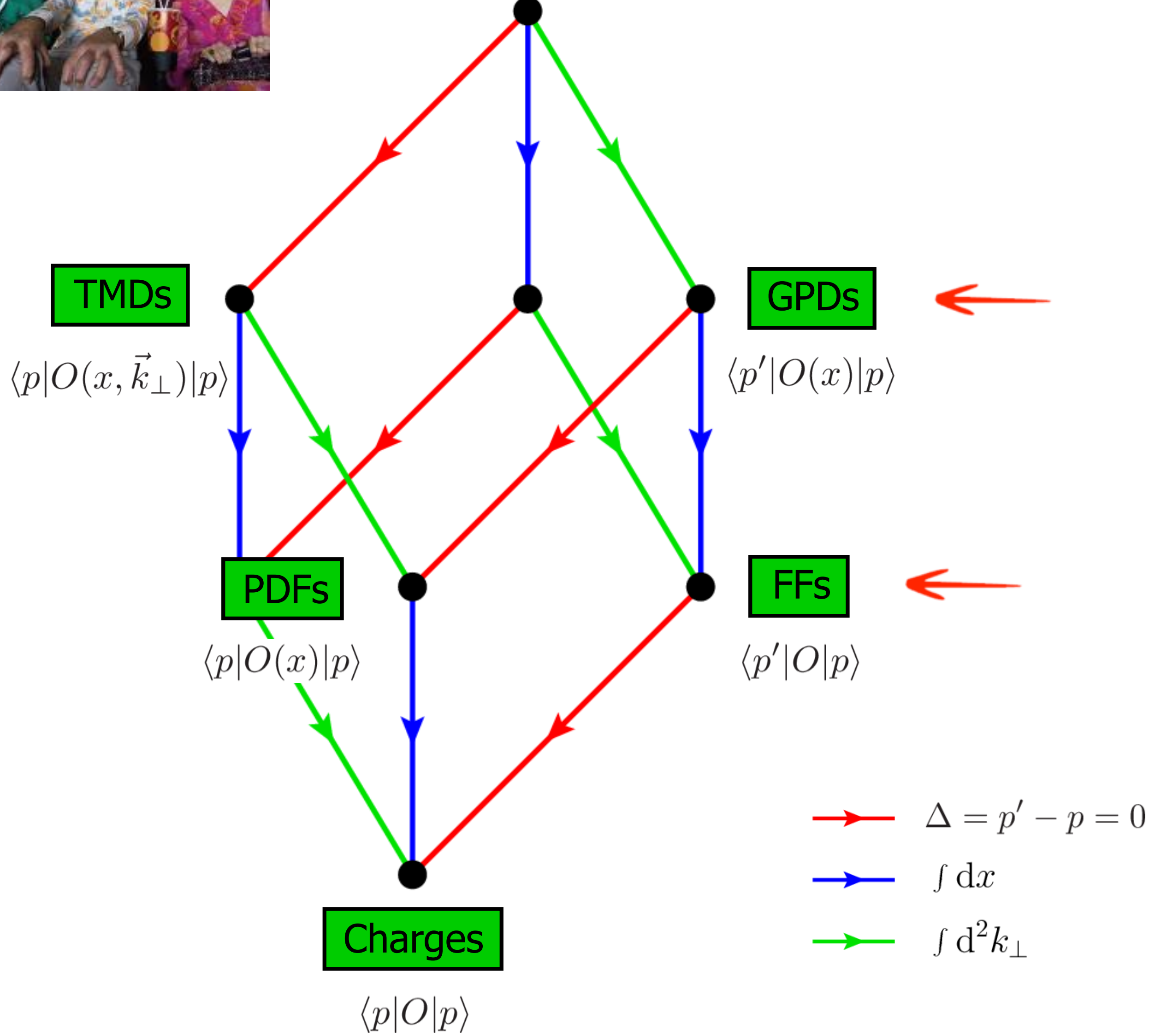
4 theory talks

Maxim Polyakov (Ruhr Universität Bochum, Germany)
Tanmay Maji (IIT Bombay, India) **Canceled**
Barbara Pasquini (Università di Pavia, Italy)
Oleg Teryaev (JINR, Russia)

10 experimental talks

Andrea Ferrero (CEA-Saclay/IRFU/DPhN, France)
Shengying Zhao (IPNO, France)
Meriem Benali (LPC Caen, France)
Nikos Sparveris (Temple University, USA)
Qin-Tao Song (Sokendai/KEK, Japan)
Frédéric Georges (IPNO, France)
Bohdan Marianski (National Center for Nuclear Research, Poland)
Valery Kubarovsky (Jlab, USA)
Gunar Schnell (University of the Basque Country UPV/EHU, Spain)
Eric Fuchey (University of Connecticut, USA)

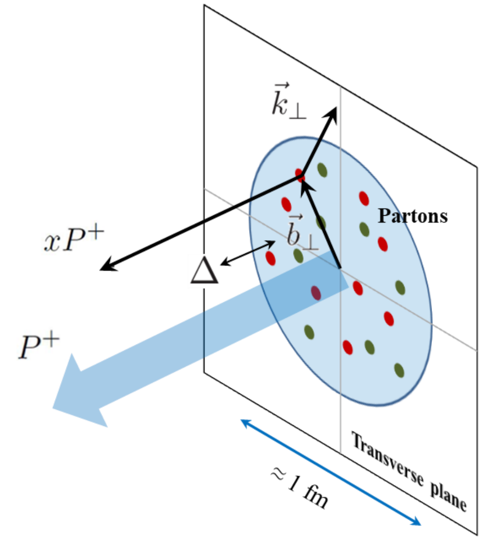
Hadron imaging



Impact-parameter distributions

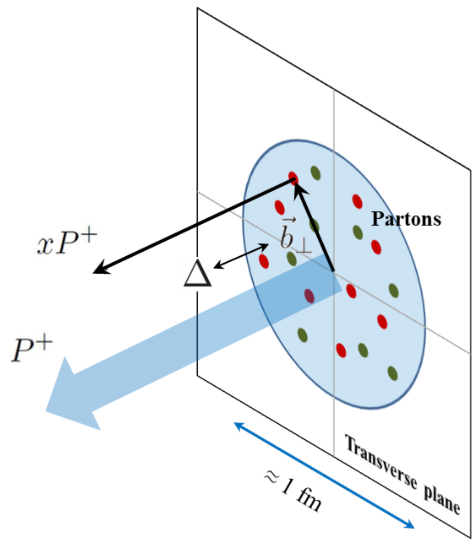
GTMDs

Complicated hard exclusive processes ?



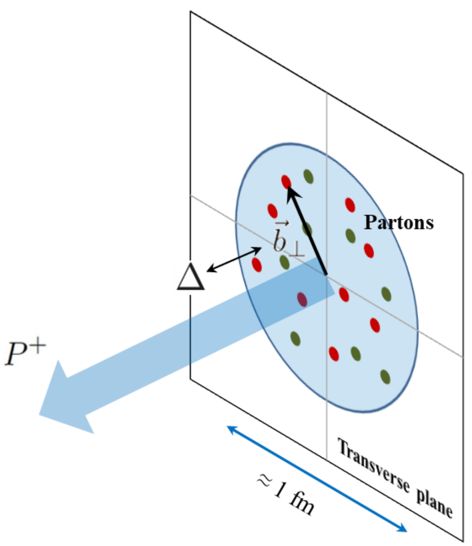
GPDs

Hard exclusive processes



FFs

Elastic scattering

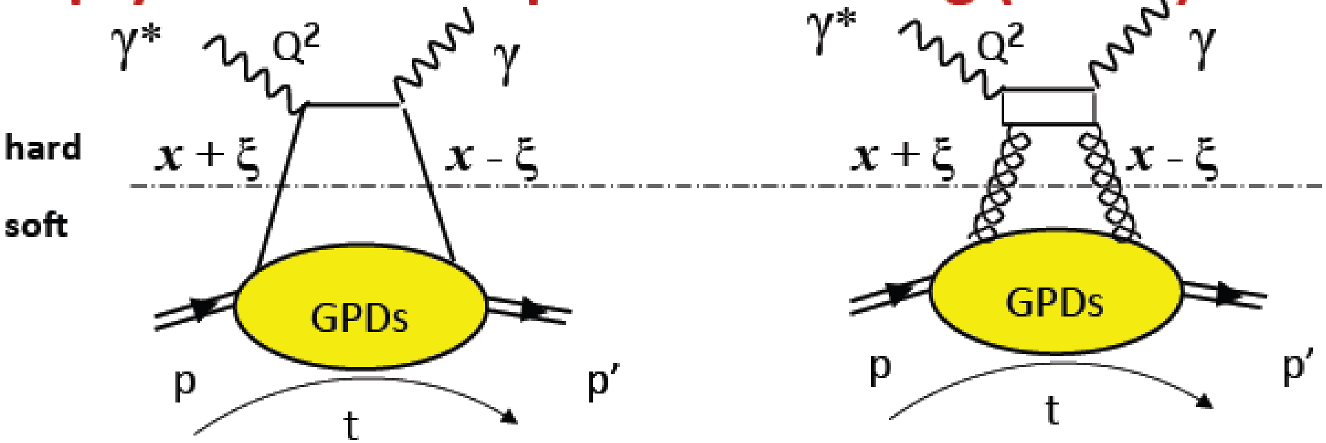


Andrea Ferrero

Exclusive Reactions: DVCS and HEMP

Deeply Virtual Compton Scattering (DVCS):

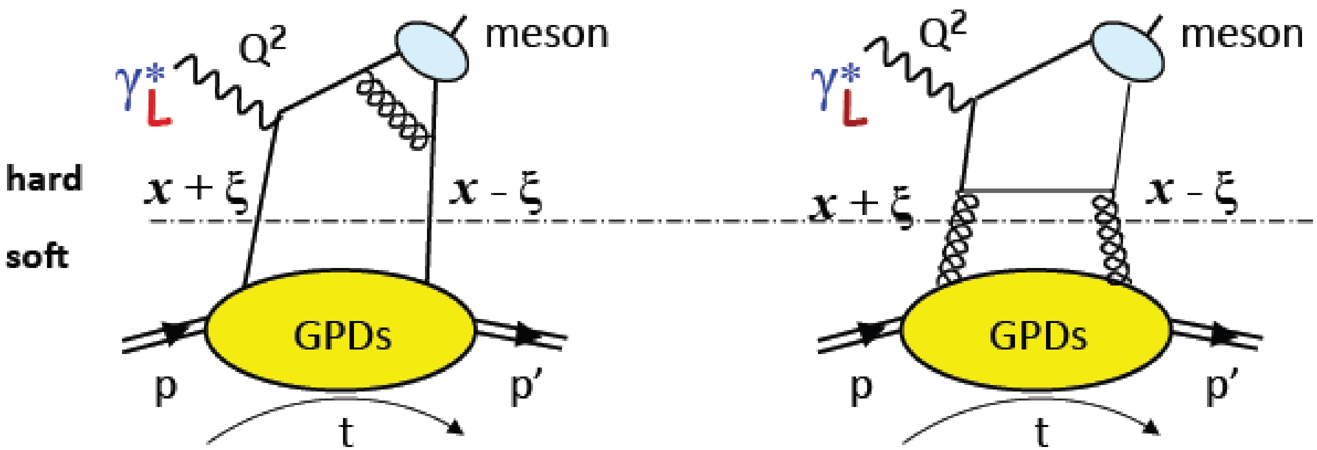
Factorisation:
Collins *et al.*



Q^2 large

$t << Q^2$

Hard Exclusive Meson Production (HEMP):



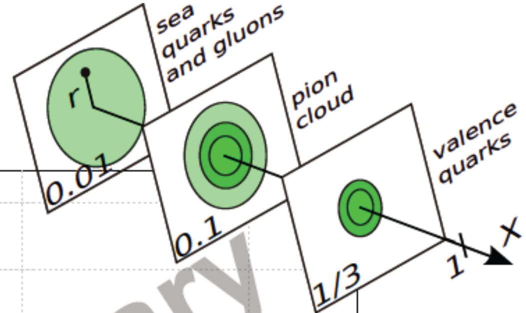
Quark contribution

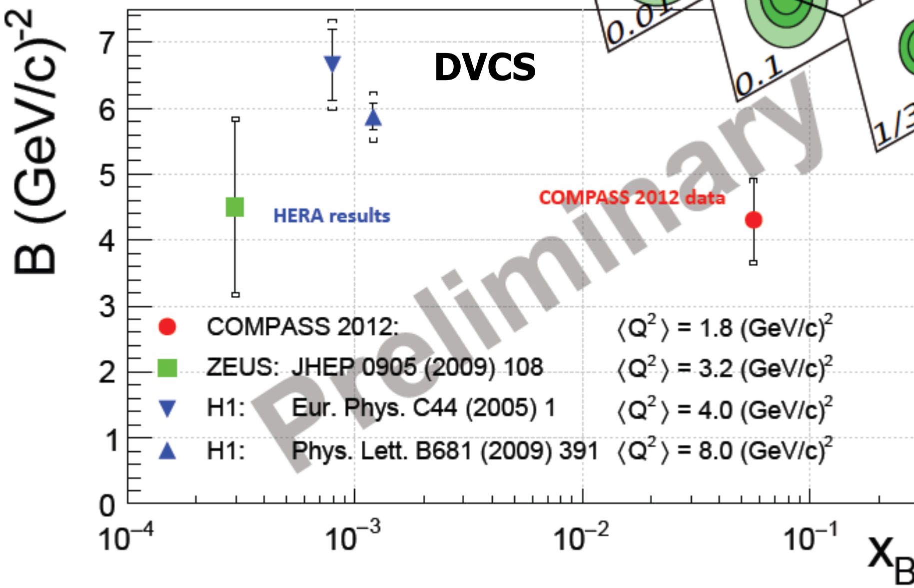
Gluon contribution

+ γ^*_L

Meson w.f.
Large power & NLO
Very slow scaling

x_B dependence of *t*-slope



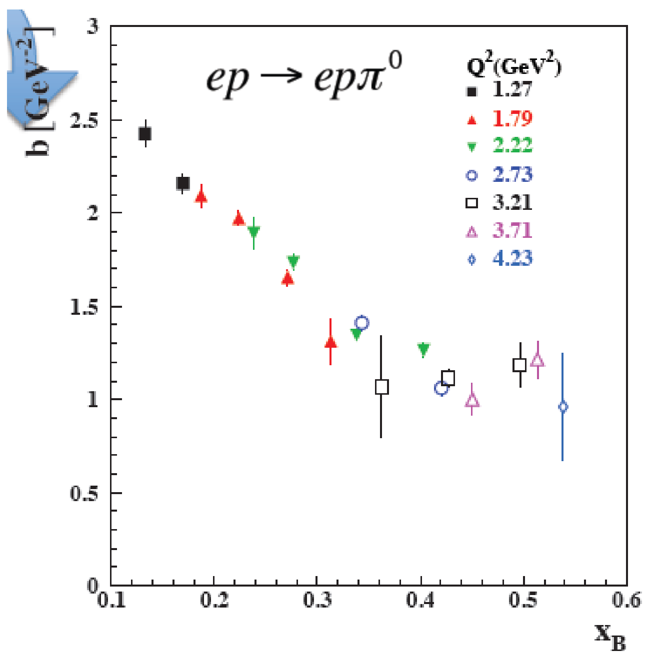


Andrea Ferrero

COMPASS 2012 data

10x more statistics expected from 2016-17 data taking

$$\frac{d\sigma}{dt} \propto e^{bt}$$



Valery Kubarovsky

CLAS data

New CLAS12 detector just began to take data with 10.6 GeV *e* beam

First DVCS experiment at 11 GeV

Jefferson Lab   **Hall A**   *Frédéric Georges*

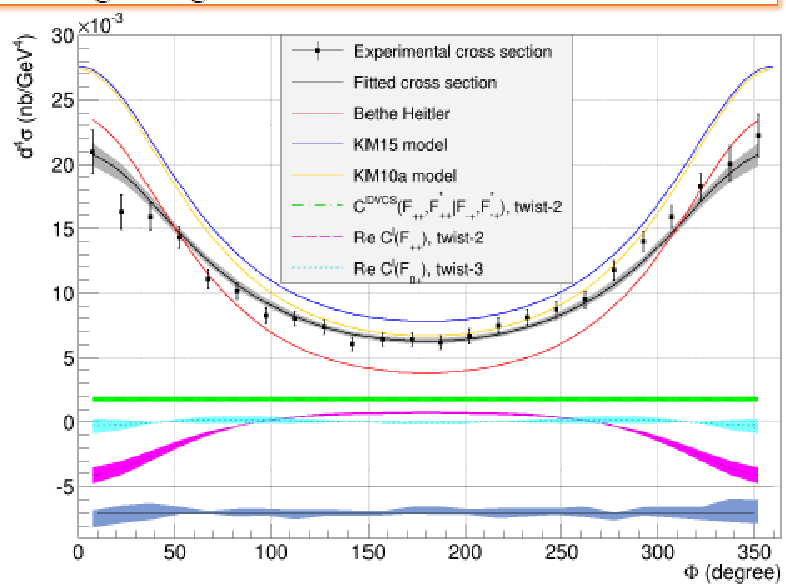
Preliminary results

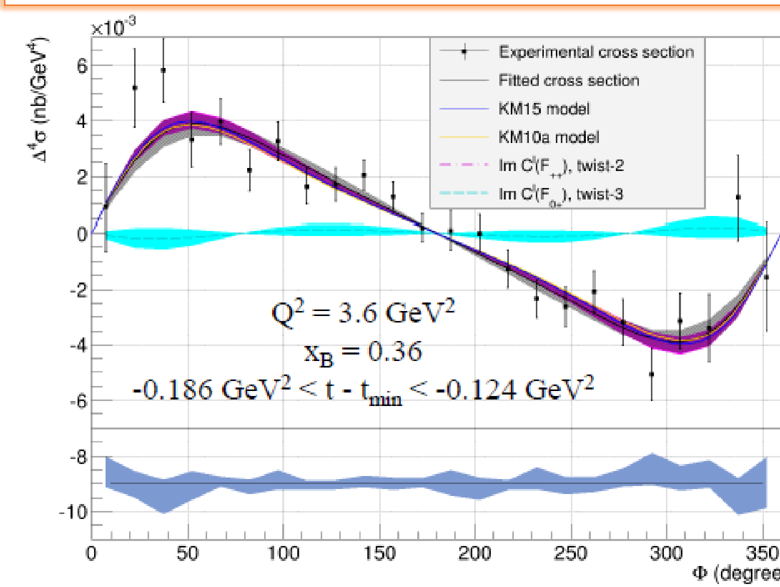
- Unpolarized: DVCS term dominant at $\phi = 180°$, interference increases at $\phi = 0°$ and $\phi = 360°$.
- Twist-2 dominant, Twist-3 compatible with 0.
- Unpolarized: models overshoot data, better agreement with model KM10a than KM15.
- Polarized: good agreement of both models with data.

- KM10a & KM15: global fits to DVCS data. http://calculon.phy.hr/gpd/
- KM10a: does not use Hall A data.
- KM15: use Hall A and CLAS data up to 2015.

K. Kumerički, S. Liuti, and H. Moutarde. GPD phenomenology and DVCS fitting. *Eur. Phys. J. A. 52, 157*, 2016. arXiv:1602.02763.

K. Kumerički and D. Müller. Description and interpretation of DVCS measurements. *EPJ Web of Conferences 112, 01012*, 2015. arXiv:1512.09014.



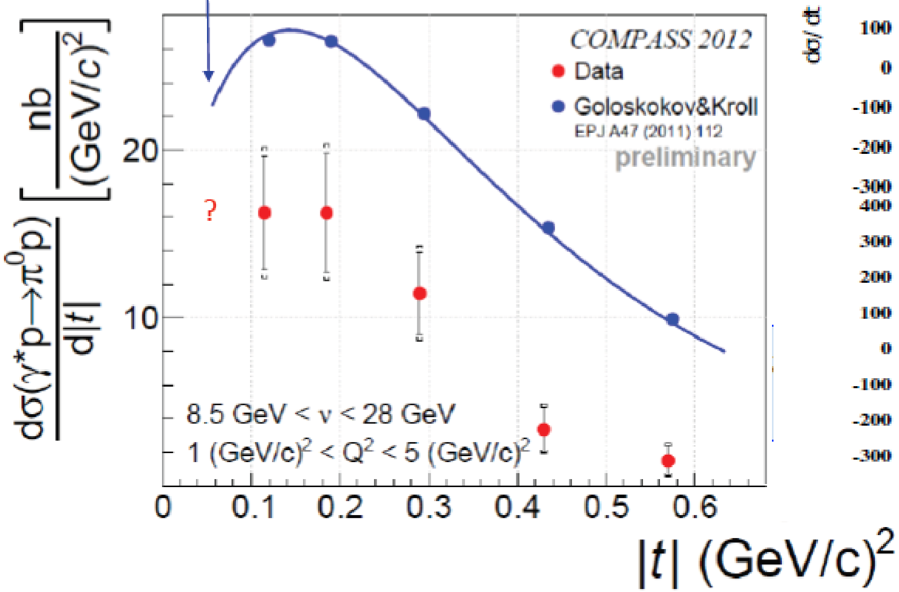


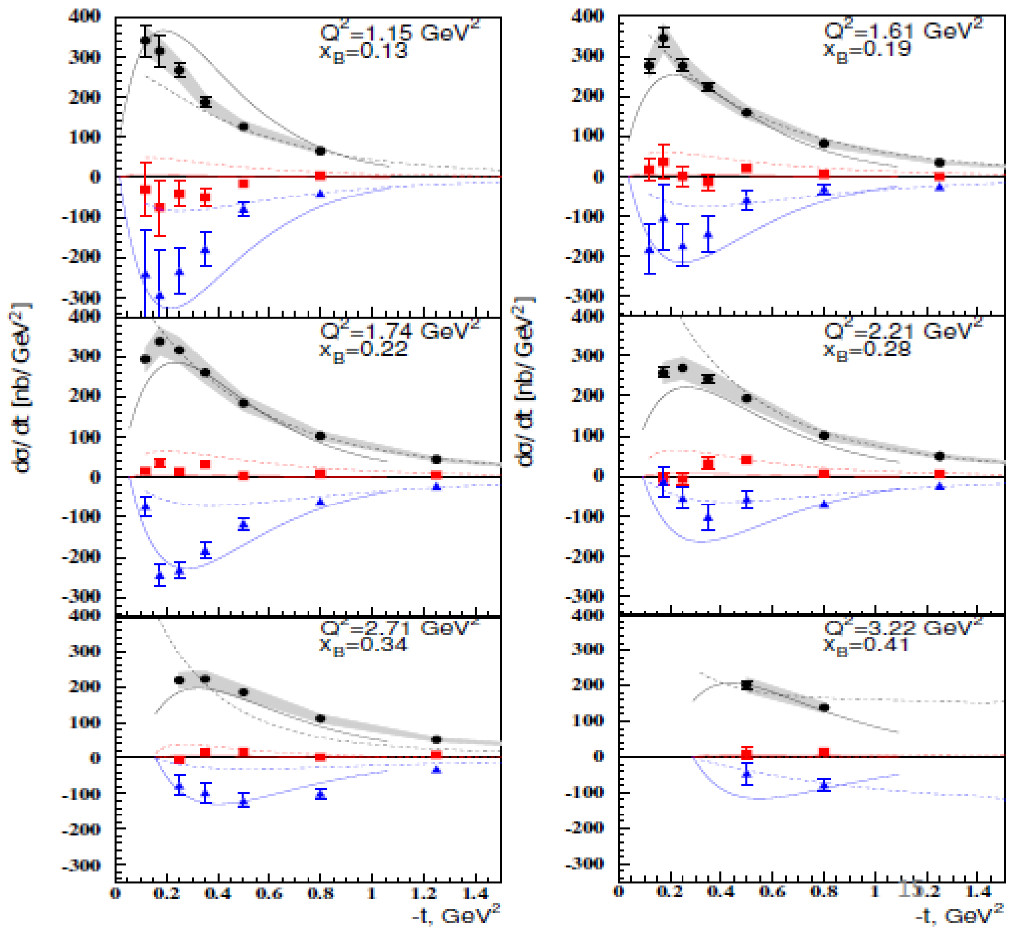
t dependence of π^0 production + comparison with GPD models

Andrea Ferrero

Valery Kubarovsky

The dip at small t
indicates the large impact of ETbar





Flavor dependence of Compton FFs

Hall A

Jefferson Lab

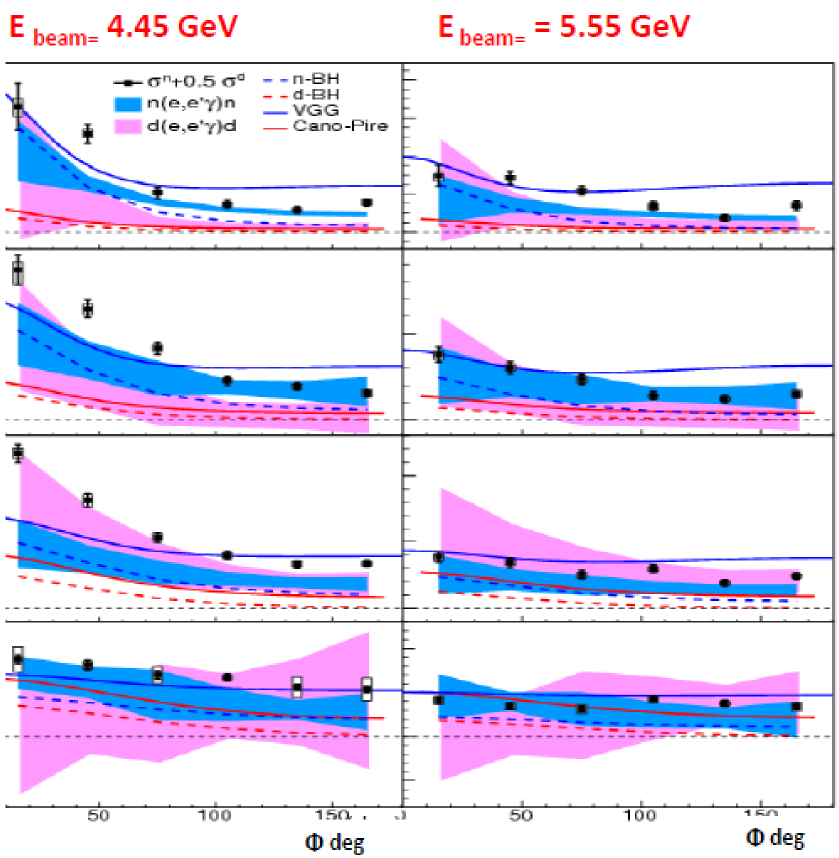
Hall B

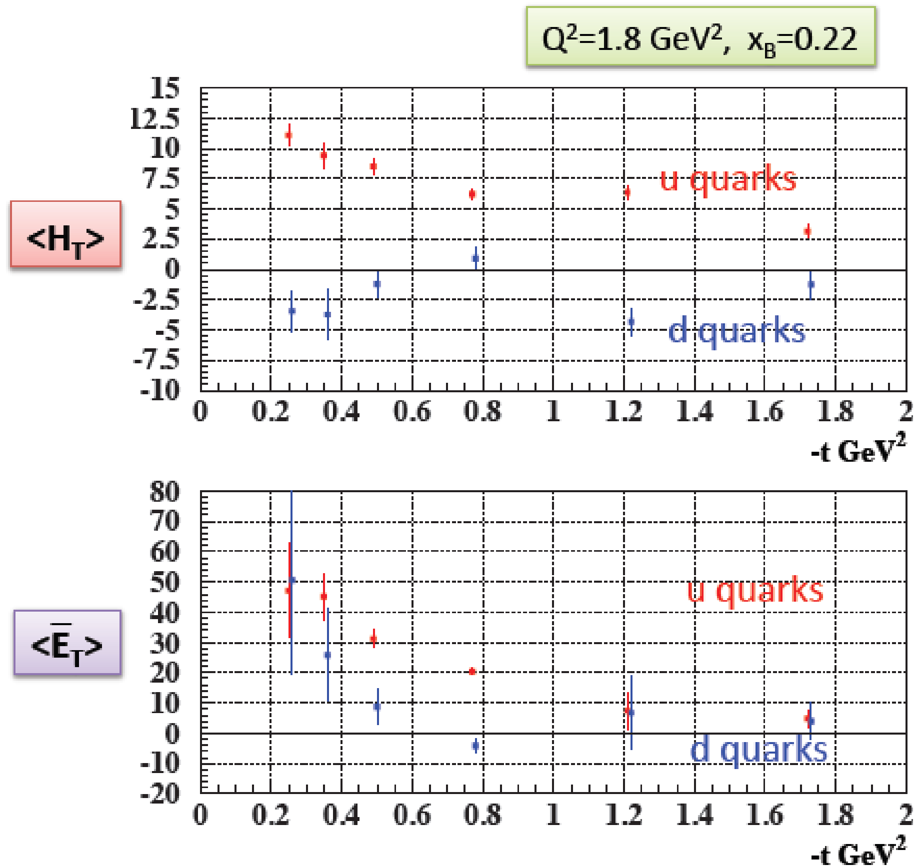
***n* and *d* DVCS** *Meriem Benali*

w/ *p* tagging @11 GeV *Eric Fuchey*

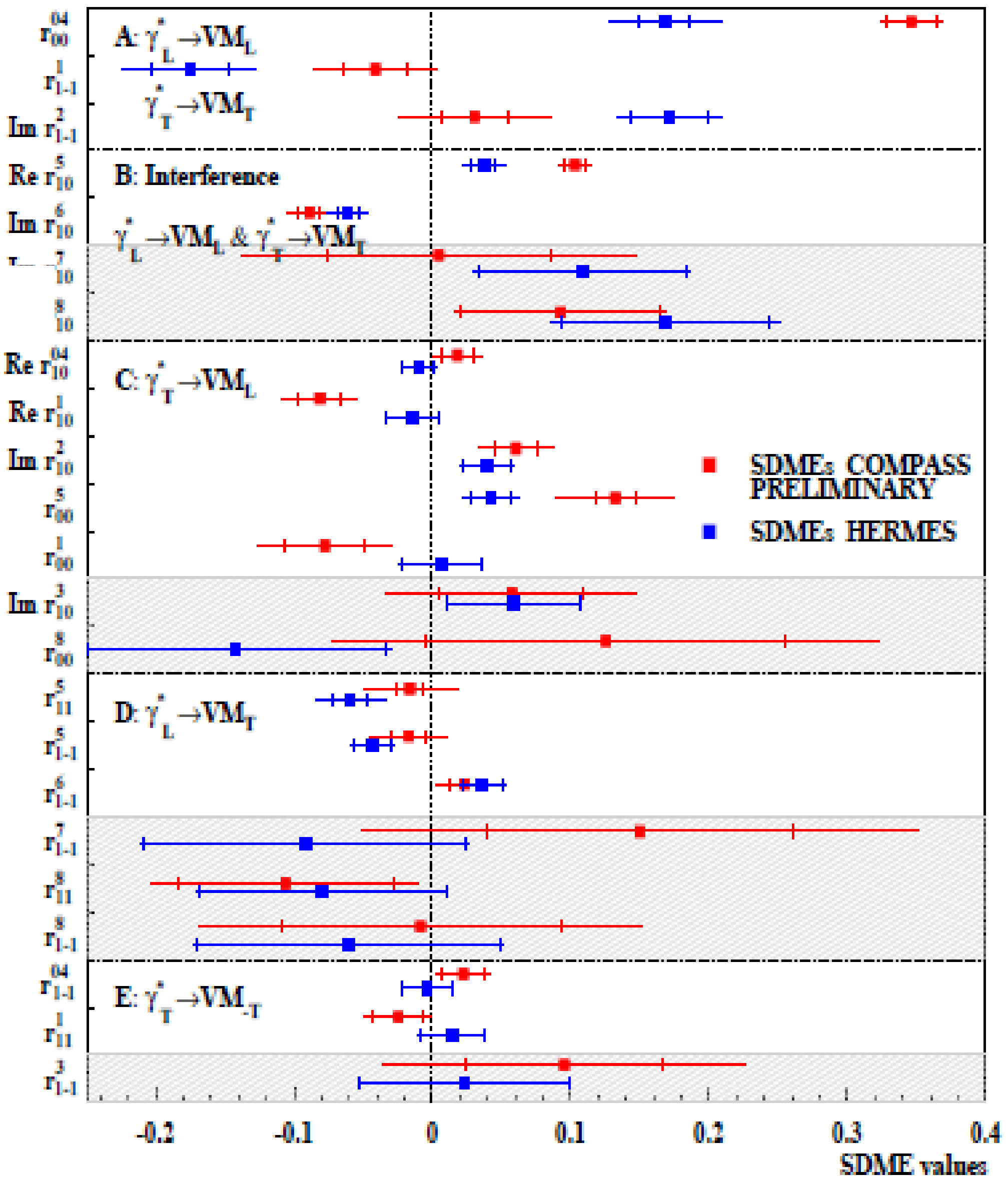
Valery Kubarovsky

π^0 and η production





Comparison of Spin Density Matrix Elements for vector mesons



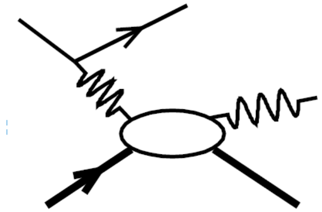
Gunar Schnell

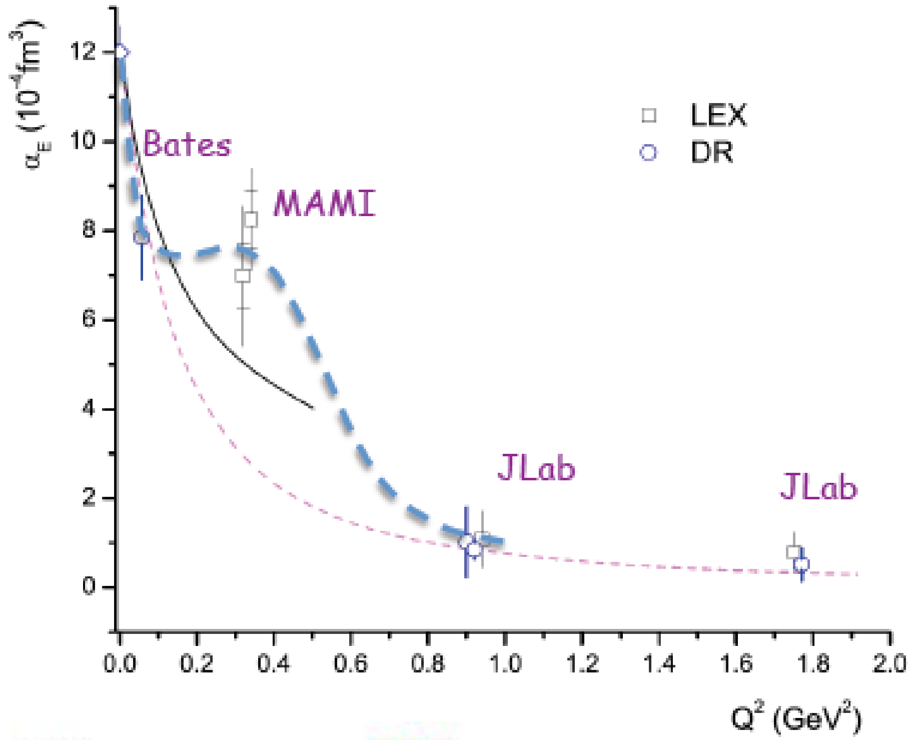
Bohdan Marianski

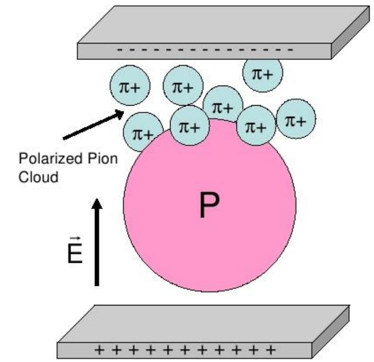
Unnatural parity exchange dominates for ω

-> important role of pion pole

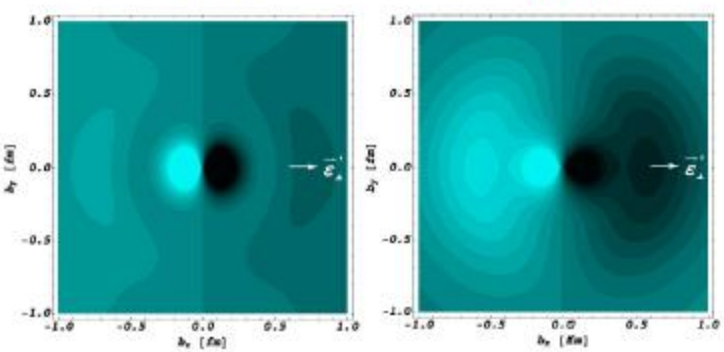
Puzzle with proton electric polarizability from VCS





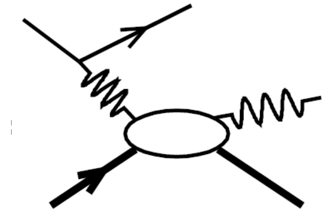


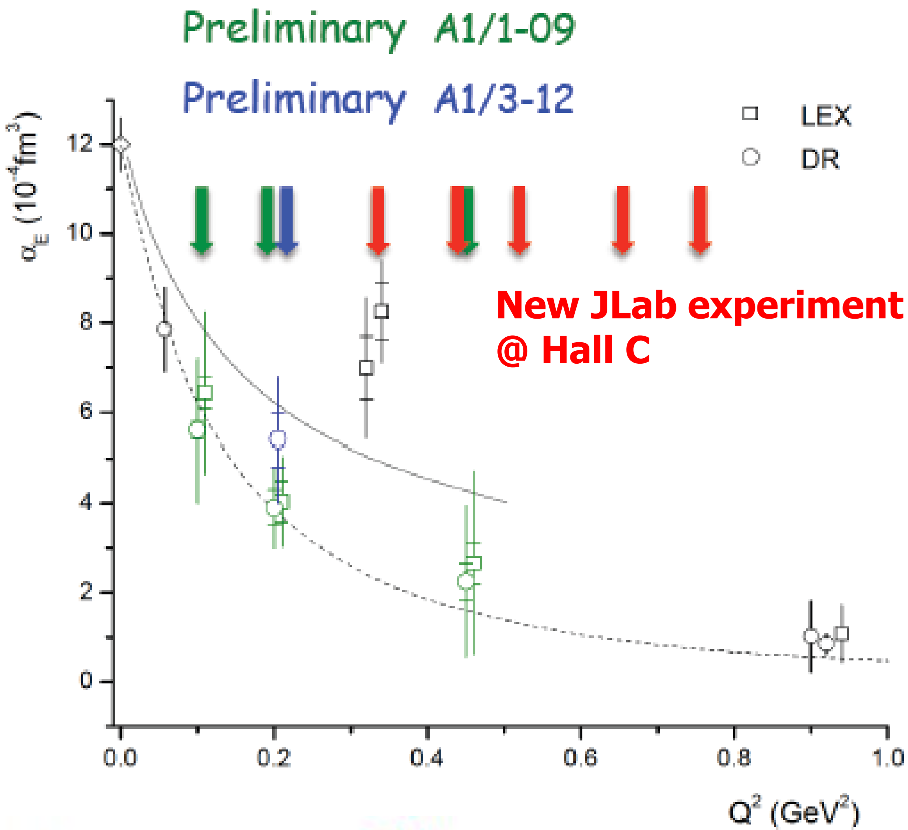
GP I GP II

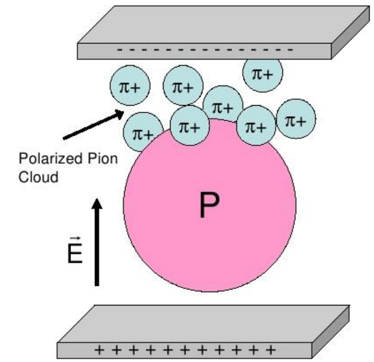


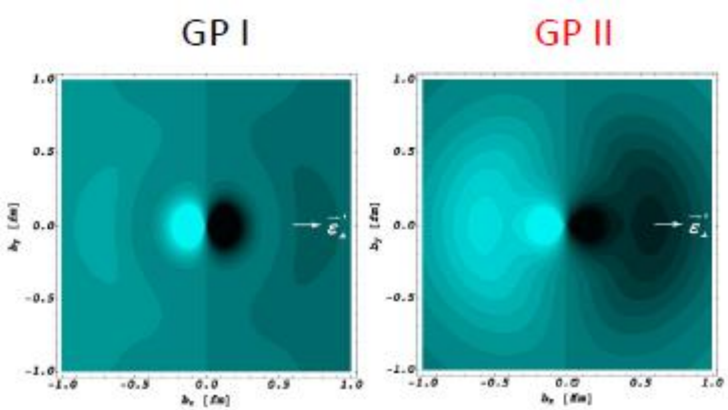
Nikos Sparveris

Puzzle with proton electric polarizability from VCS



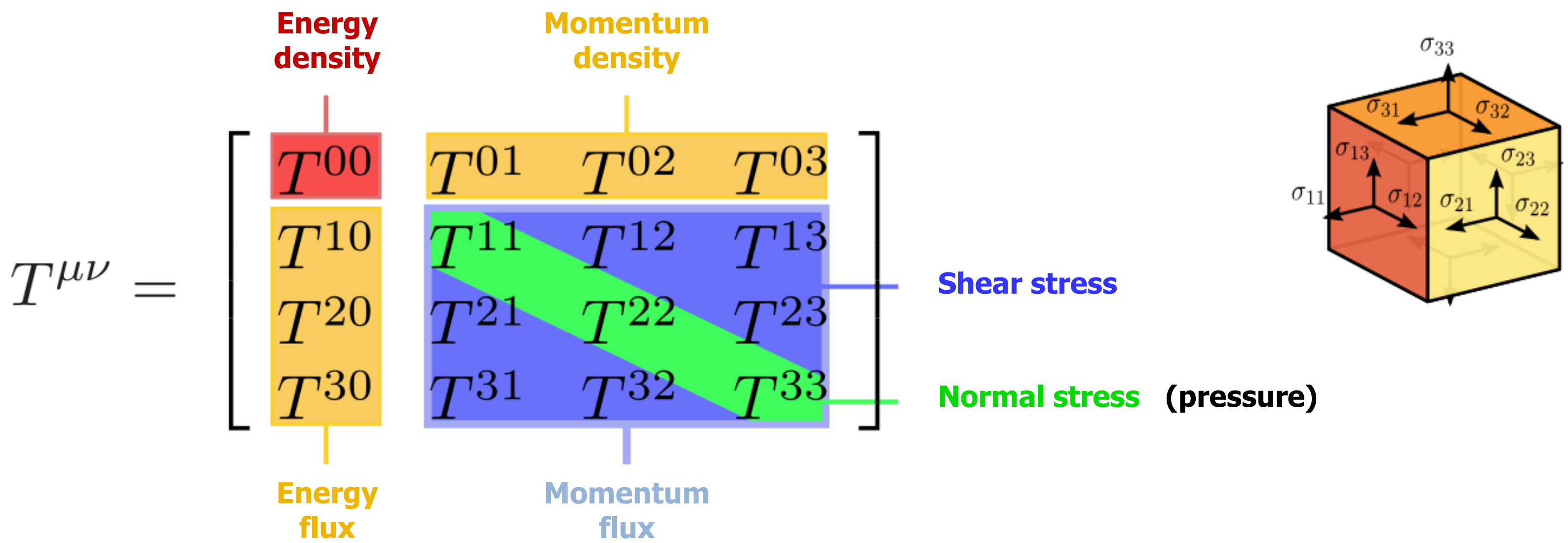






Nikos Sparveris

Mechanical properties



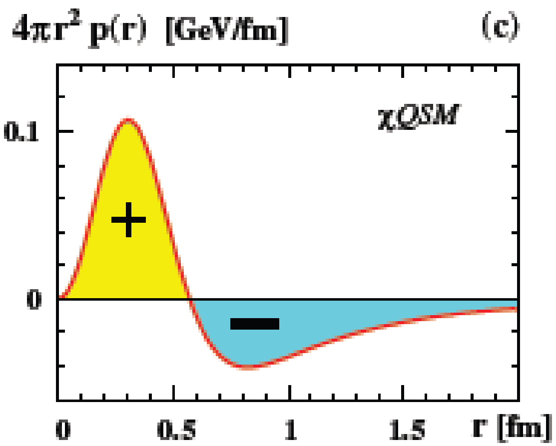
$$\langle p'|T^a_{\mu\nu}(0)|p\rangle = \bar{u}'\left[A^a(t)\,\frac{P_\mu P_\nu}{M_N} + J^a(t)\,\frac{i\,P_{\{\mu}\sigma_{\nu\}\rho}\Delta^\rho}{2M_N} + D^a(t)\,\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{4M_N} + M_N\,\bar{c}^a(t)g_{\mu\nu}\right]u$$

- $A^a(t)$ ↔ δg^{00} → Mass: $\sum_a A^a(0) = 1$
- $J^a(t)$ ↔ δg^{0i} → Spin: $\sum_a J^a(0) = \frac{1}{2}$
- $D^a(t)$ ↔ δg^{ij} → deformation of space = elastic properties of N
- $\bar{c}^a(t)$ ↔ non – conservation of EMT pieces → $\sum_a \bar{c}^a(t) = 0$

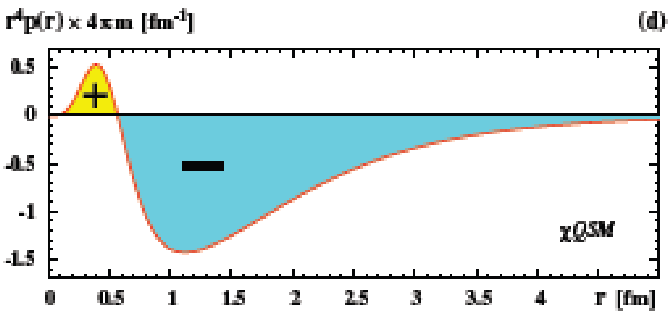
Pressure force distributions

Maxim Polyakov

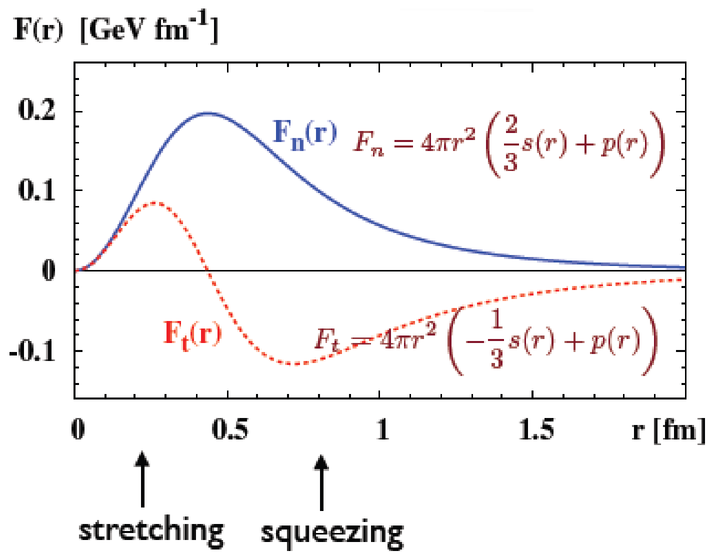
Equilibrium



Stability



Radial and tangential forces



Gravitation FFs and equivalence principle

Oleg Teryaev

Gravitomagnetism

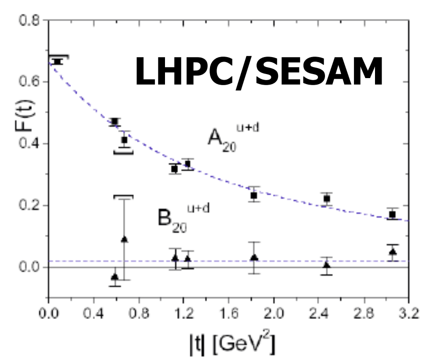
- Gravitomagnetic field (weak, except in gravity waves) – action on spin from $M = \frac{1}{2}\sum_{q,G}\langle P'|T^{\mu\nu}_{q,G}|P\rangle h_{\mu\nu}(q)$

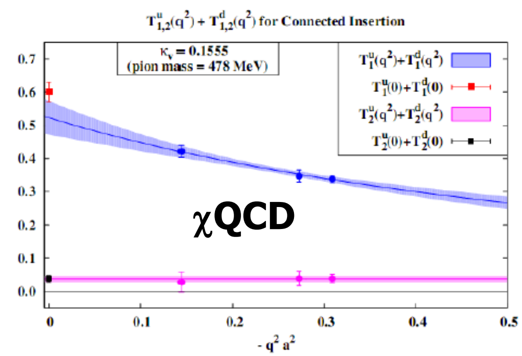
  $\vec{H}_J = \frac{1}{2} rot\vec{g};\ \vec{g}_i \equiv g_{0i}$ spin dragging twice smaller than EM
- Lorentz force – similar to EM case: factor ½ cancelled with 2 from $h_{00} = 2\phi(x)$ Larmor frequency same as EM

  $\omega_J = \frac{\mu_G}{J} H_J = \frac{H_L}{2} = \omega_L \quad \vec{H}_L = rot\vec{g}$
- Orbital and Spin momenta dragging – the same - Equivalence principle
- Gravitomagnetic g=2 for any spin
- Special role of g=2 for ANY spin (asymptotic freedom for vector bosons)
- Should Einstein know about PNEP, the outcome of his and de Haas experiment would not be so surprising
- Recall also g=2 for Black Holes. Indication of "quantum" nature?!

Extended Equivalence Principle=Exact EquiPartition

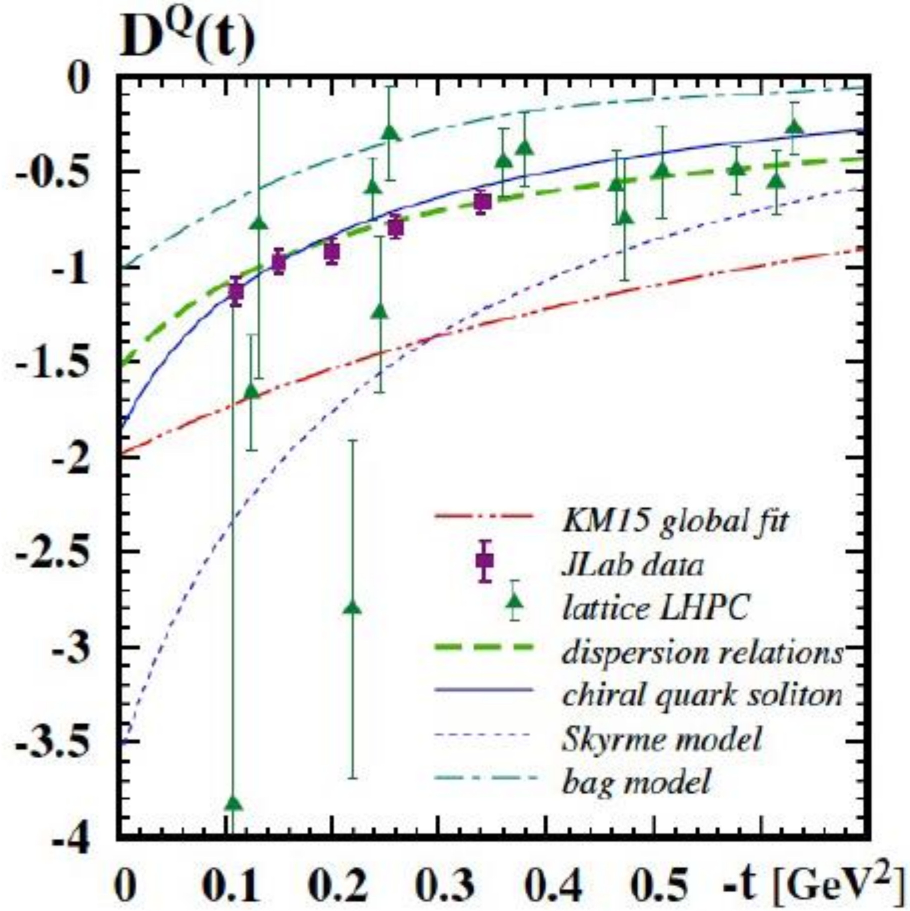
- In pQCD – violated
- Reason – in the case of ExEP- no smooth transition for zero fermion mass limit (Milton, 73)
- Conjecture (O.T., 2001 – prior to lattice data) – valid in NP QCD – zero quark mass limit is safe due to chiral symmetry breaking
- Gravityproof confinement? Nucleons do not break even by black holes?
- Support by recent observation of smalness of Cbar (talk of Maxim Polyakov)





Prediction from Dispersion Relations for nucleon target

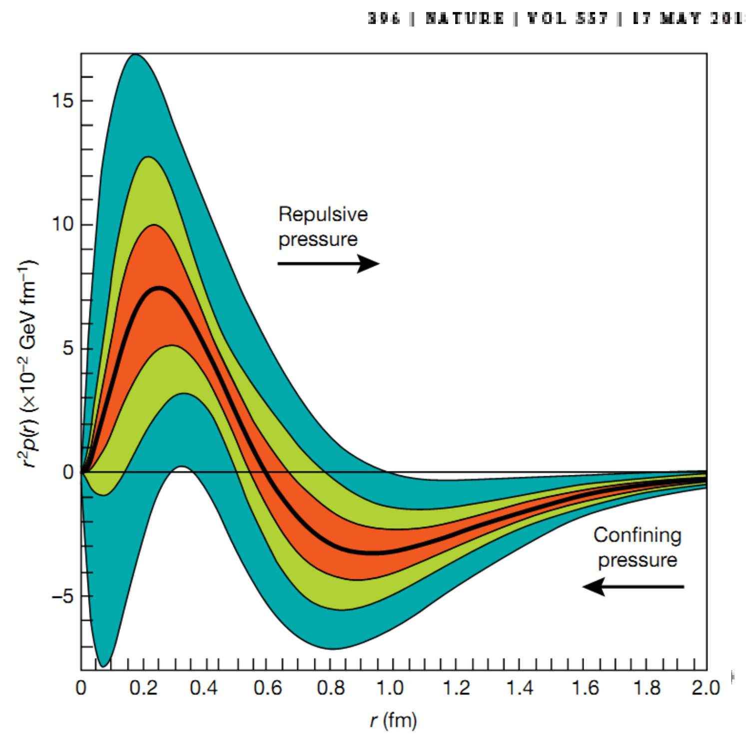
Barbara Pasquini



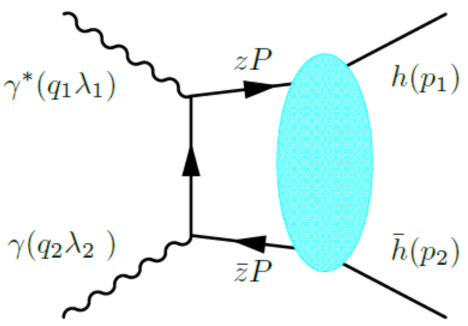
Polyakov and Schweitzer, arXiv:1805:06596

Girod, Elouadrhiri,Burkert, Nature 557 (2018) 7705

Recent experimental extraction

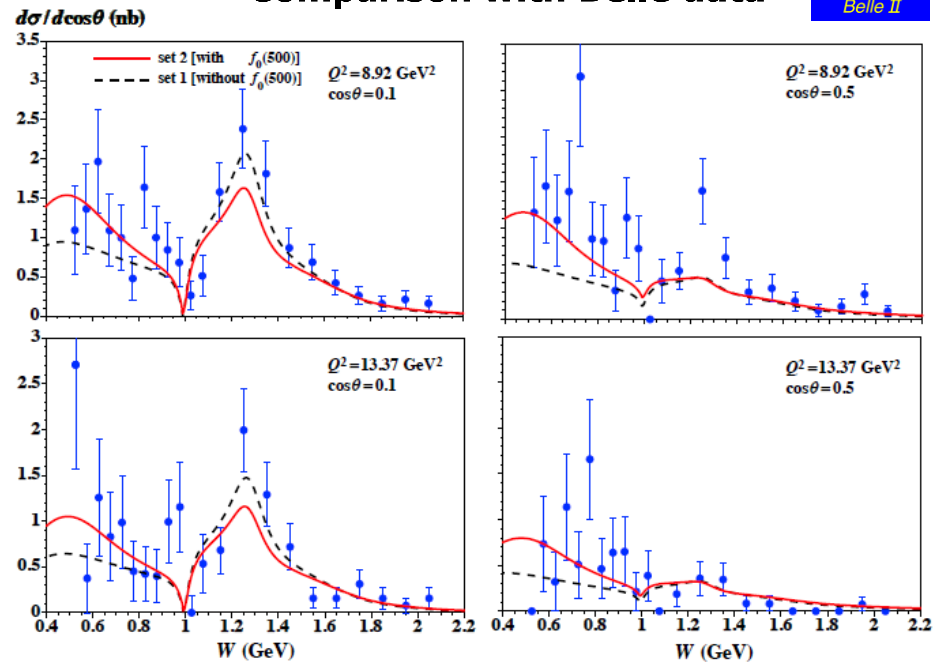


GDA model for pion target

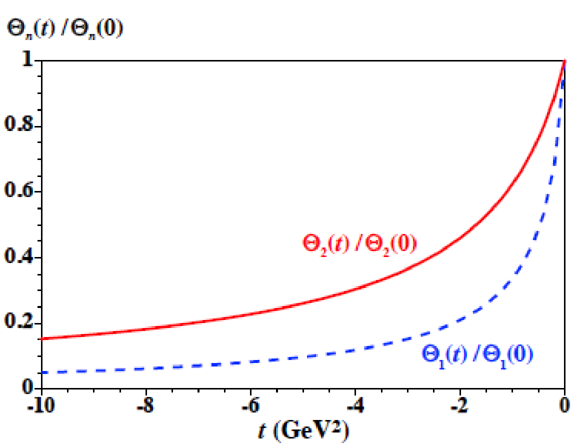


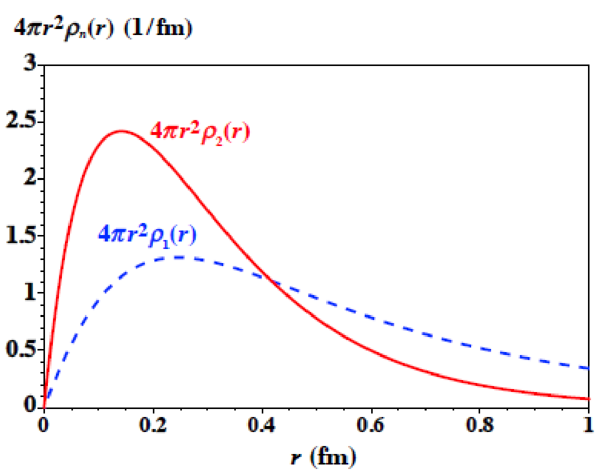
Qin-Tao Song

Comparison with Belle data



Pion gravitational FFs

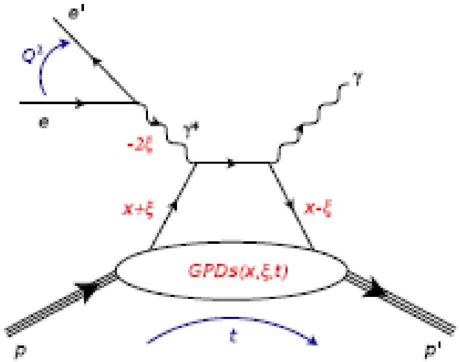




Gravitational FFs requires *x* dependence of GPDs

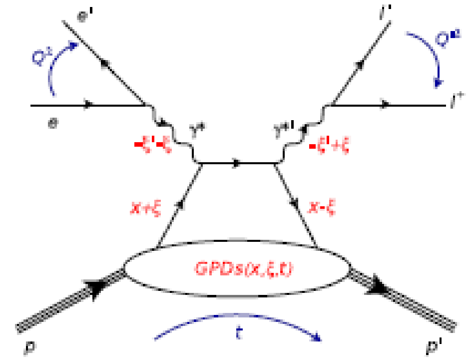
DVCS and DDVCS [4-6] are two golden processes for direct measurements of GPDs

$ep \rightarrow ep\gamma$



Deeply Virtual Compton Scattering (DVCS)

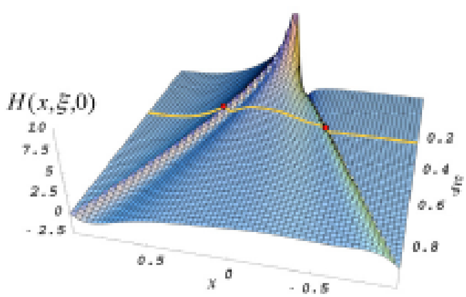
$ep \rightarrow epl^- l^+$



Double DVCS (DDVCS)

$$\mathcal{H}(\xi,\xi,t) = \sum_q e_q^2 \Big\{ \mathcal{P} \int_{-1}^{1} dx\, H^q(x,\xi,t) \left[\frac{1}{x-\xi} + \frac{1}{x+\xi} \right] - i\pi \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t) \right] \Big\}$$

$$\mathcal{H}(\xi',\xi,t) = \sum_q e_q^2 \Big\{ \mathcal{P} \int_{-1}^{1} dx\, H^q(x,\xi,t) \left[\frac{1}{x-\xi'} + \frac{1}{x+\xi'} \right] - i\pi \left[H^q(\xi',\xi,t) - H^q(-\xi',\xi,t) \right] \Big\}$$



- DVCS can access GPDs only at $x = \pm\xi$;
- DDVCS allows one to measure the GPDs for each x, ξ, t values independently ($|\xi'| < \xi$).

Shengying Zhao

Feasability studies @ JLab 12GeV

- **Challenging luminosity (10^{37} cm^{-2} s^{-1})**
- **Sign change predicted for beam spin asymmetry $\Delta\sigma_{LU}$ when $Q'^2 > Q^2$**


INVITATION
With joyful hearts,
we ask you to be present
at the ceremony.

Save the date!