Timelike Compton Scattering with CLAS12 at Jefferson Lab

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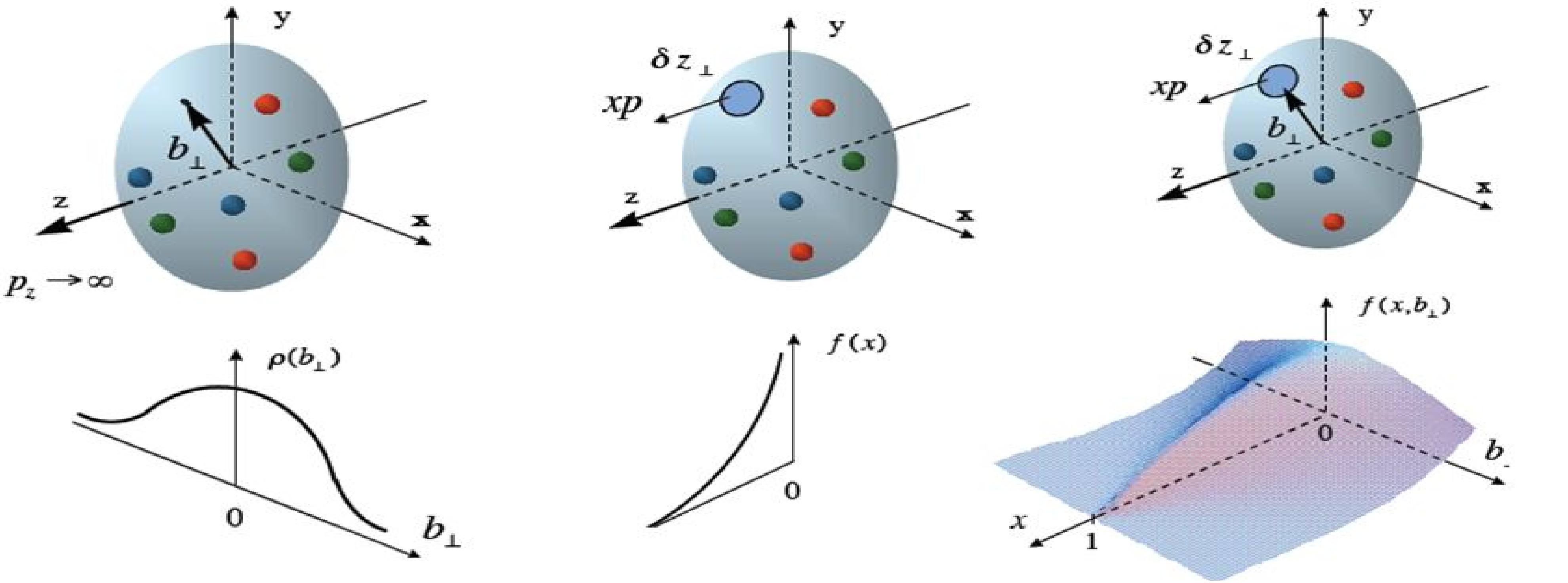
For the CLAS Collaboration

DNP Talk Review 06/28/18

Nucleon structure functions



Form Factors
F_1, F_2

Elastic scattering
ep→ep

Parton Distribution Functions (PDF)

Inelastic scattering
ep→eX

Generalised Parton Distributions (GPD)
$H, E, \tilde{H}, \tilde{E}$

Exclusive processes
ep→epɣ

Properties of GPDs

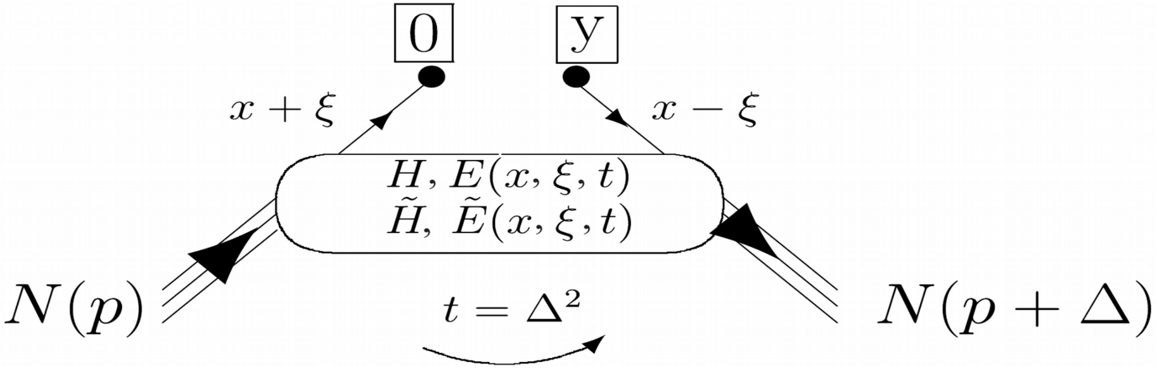
Model independent limits :

$$H^q(x,0,0) = \begin{cases} q(x), & x > 0 \\ -\bar{q}(-x), & x > 0 \end{cases}$$

$$\tilde{H}^q(x,0,0) = \begin{cases} \Delta q(x), & x > 0 \\ -\Delta\bar{q}(-x), & x > 0 \end{cases}$$

$$\int_{-1}^{1} dx H^q(x,\xi,t) = F_1^q(t)$$

$$\int_{-1}^{1} dx E^q(x,\xi,t) = F_2^q(t)$$

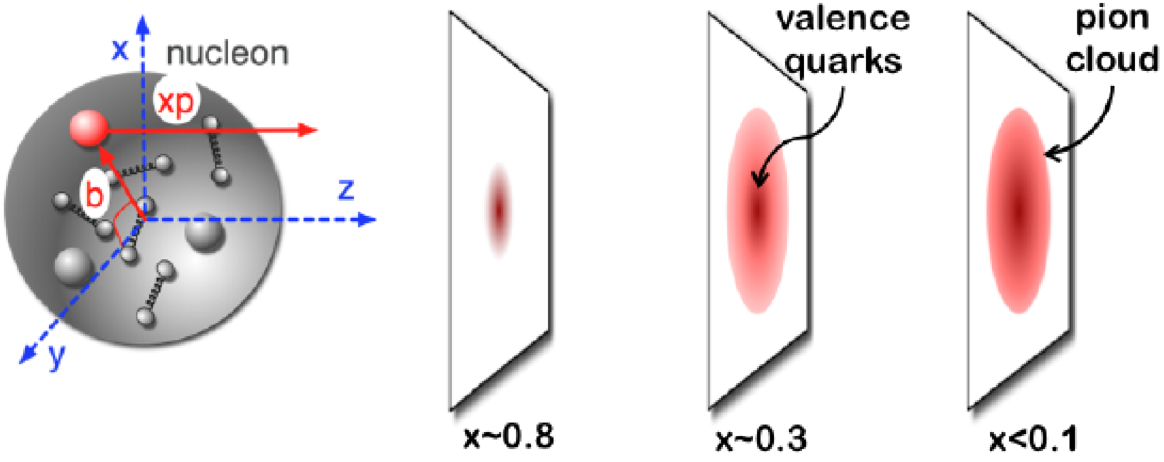


Compton Form Factors (CFF) :

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

Why are GPDs interesting ?

- A 3D picture of the nucleon :



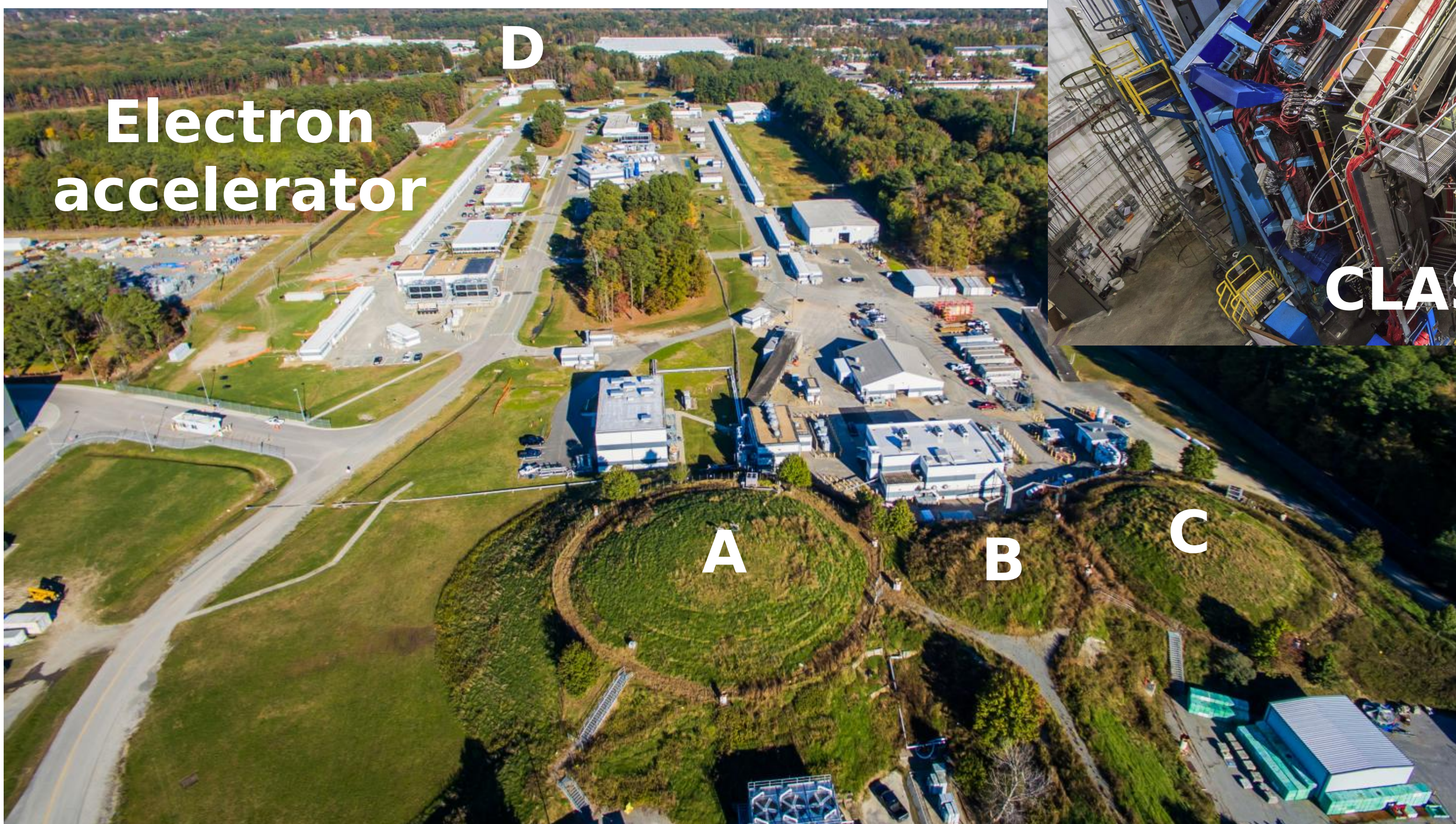
$$H^q(x, b_\perp) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{-ib_\perp \Delta_\perp} H^q(x, 0, -\Delta_\perp^2)$$

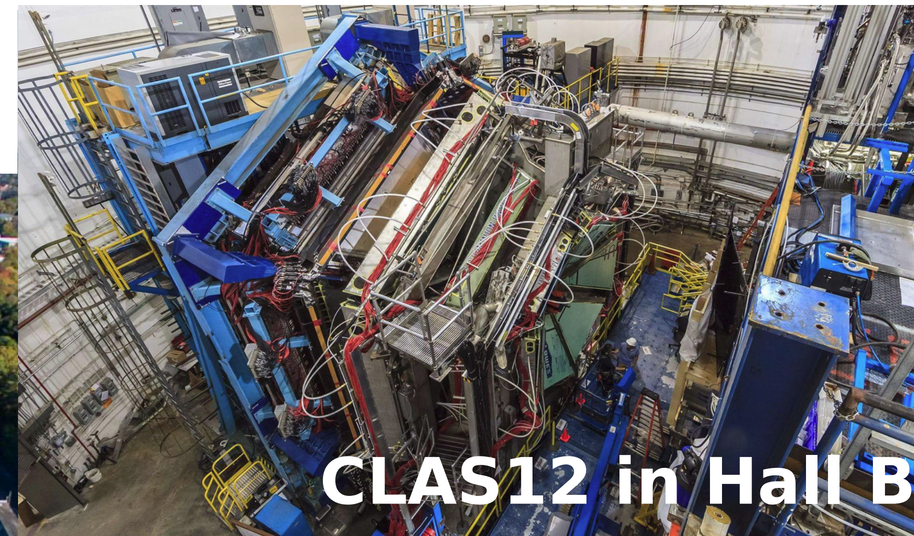
- A solution to the proton spin puzzle :
GPDs allow to measure the contribution of the quark angular momentum

$$\frac{1}{2} = J_q + J_g \qquad J_q = \frac{1}{2} \int_{-1}^{+1} \mathrm{d}x \, x \left[H^q(x, \xi, t=0) + E^q(x, \xi, t=0) \right]$$

Where do we measure GPDs ?

Jefferson Lab
Thomas Jefferson National Accelerator Facility





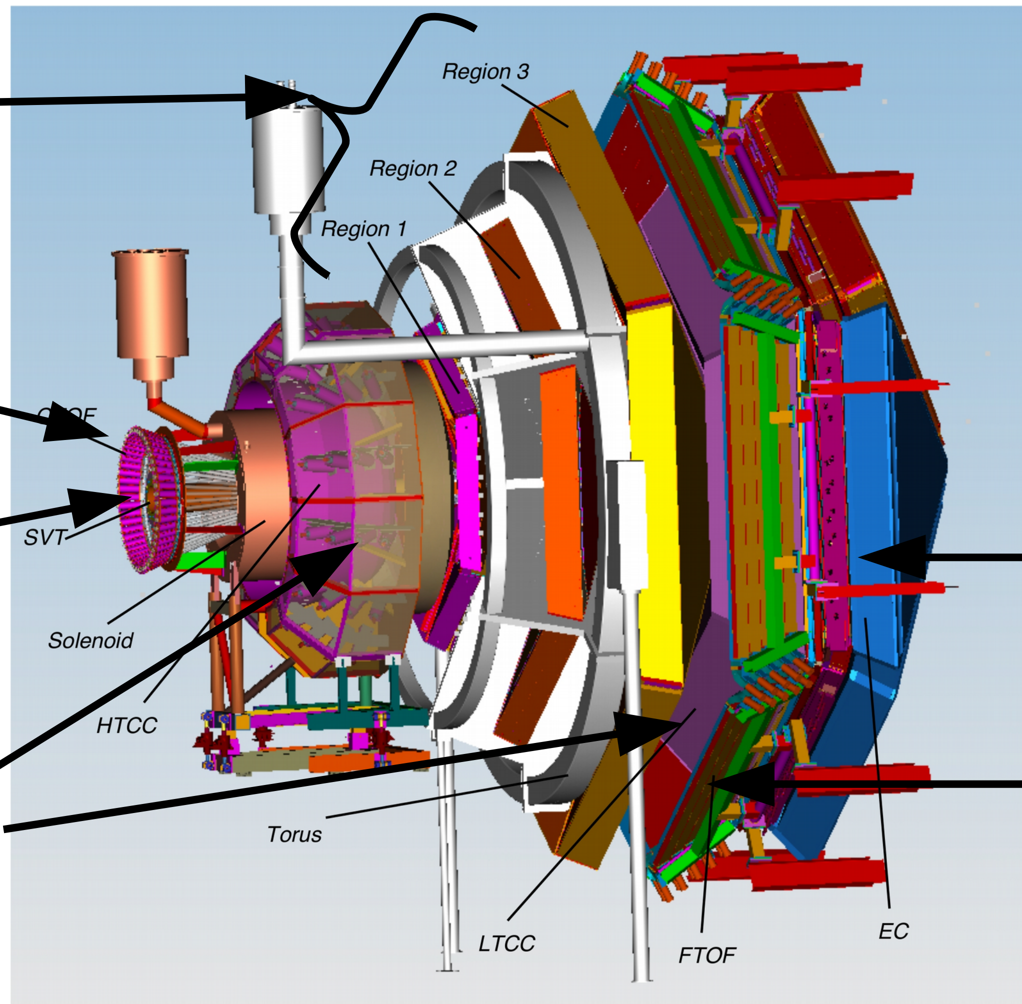
CLAS12 in Hall B

Drift Chambers
→ p and q

Time-of-Flight
→ β

Vertex Tracker
→ p and q

Cherenkov Counters
→ e,π,K identification



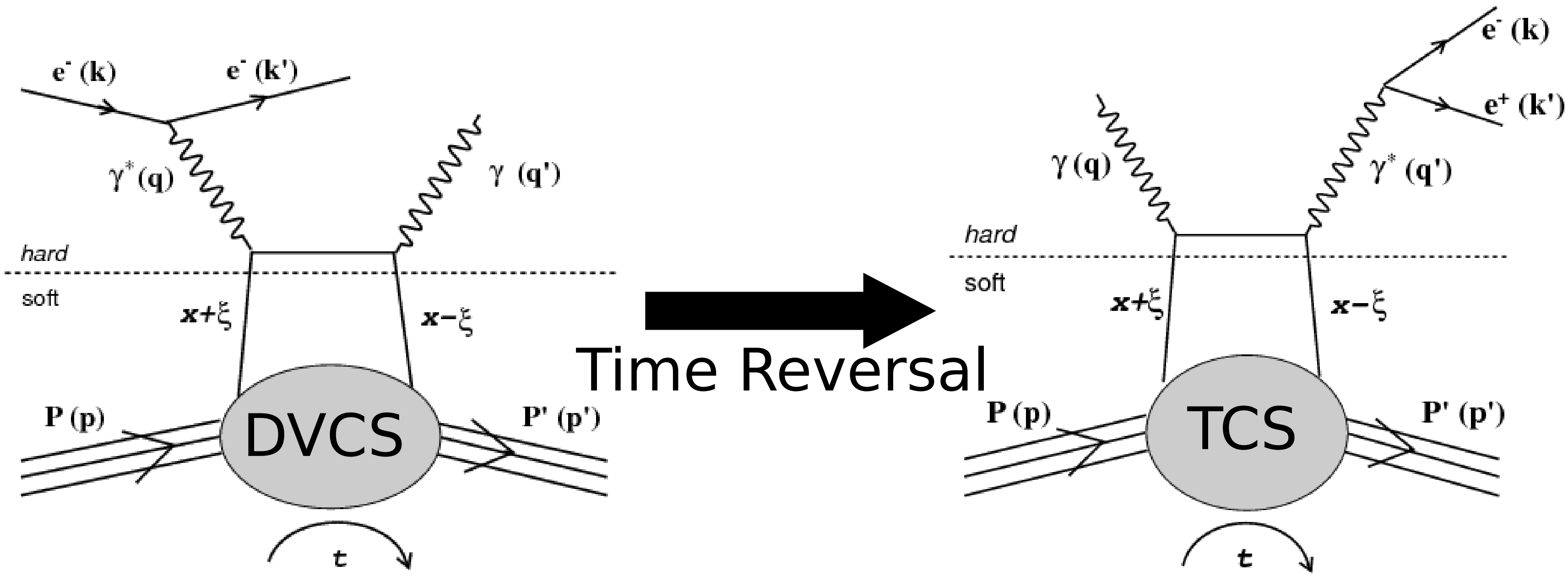
Calorimeter
→ E and particle id

Time-of-Flight
→ β and trigger

Timelike Compton Scattering

$e\,p \rightarrow e\,p\,\gamma^* \rightarrow e\,p\,\gamma$

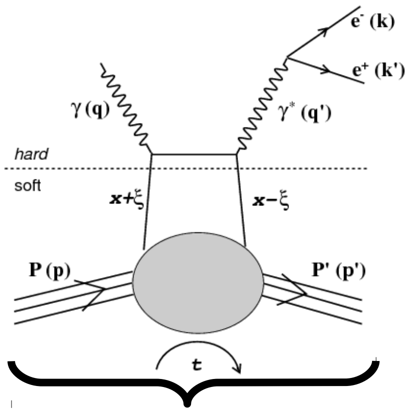
$(e)\,\gamma\,p \rightarrow (e)\,\gamma^*\,p \rightarrow e^+\,e^-\,p\,(e)$



→ Test universality of GPDs
→ Sensible to Real parts of CFF

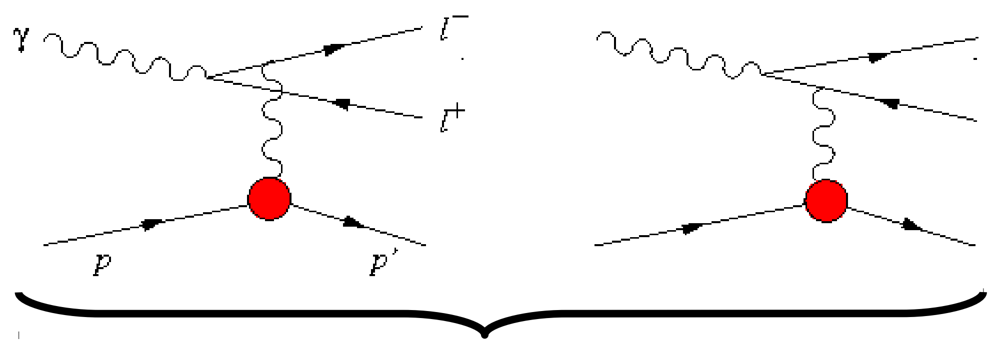
Measuring TCS

$\gamma p \to e^+ e^- p$ =

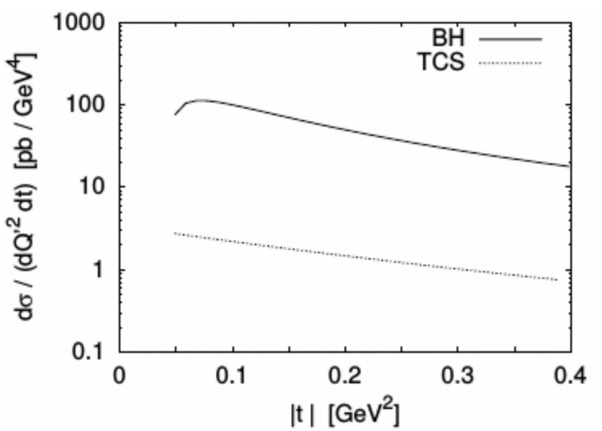


TCS

+



Bethe-Heitler



Integrated cross section

(E. Berger,M.Diehl,B.Pire)

$$\frac{d^4\sigma}{dQ'^2 dt d\Omega}(\gamma p \to p e^+ e^-) = \sigma_{TCS} + \sigma_{BH} + \sigma_{INT}$$

Not directly measurable

CFFs accessible throught interference term

$$\frac{d^4\sigma_{INT}}{dQ'^2 dt d\Omega} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{m_p}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}[cos\phi\frac{1+cos^2\theta}{sin\theta}Re\tilde{M}^{--} + \ldots$$

$$\tilde{M}^{--} = \frac{2\sqrt{t_0 - t}}{m_p}\frac{1-\xi}{1+\xi}\left[F_1\mathcal{H} - \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4m_p^2}F_2\mathcal{E}\right]$$

TCS Observables

Access TCS through interference

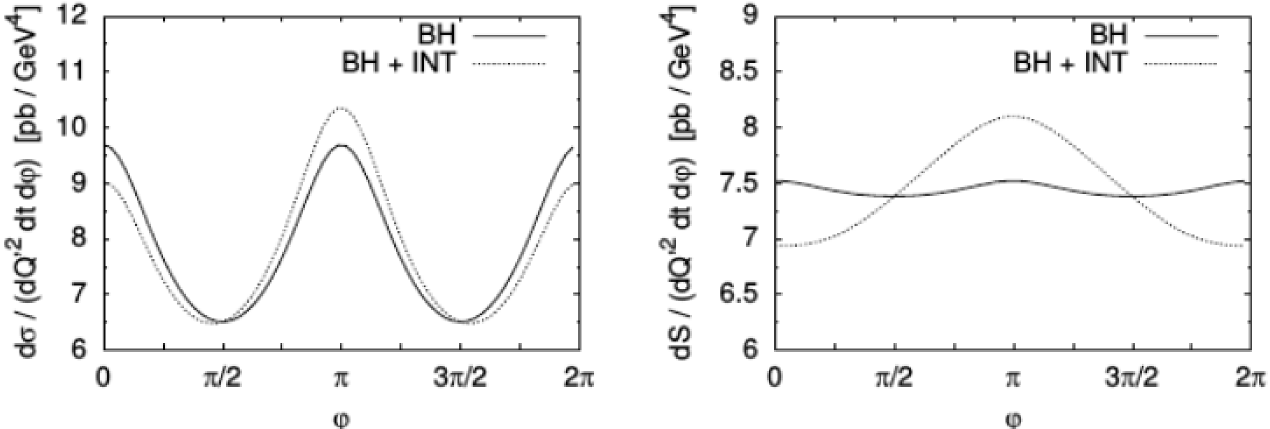
$$\frac{d^4\sigma_{INT}}{dQ'^2dtd\Omega} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{m_p}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}[cos\phi\frac{1+cos^2\theta}{sin\theta}Re\tilde{M}^{--}+\ldots$$

$$\tilde{M}^{--} = \frac{2\sqrt{t_0-t}}{m_p}\frac{1-\xi}{1+\xi}\left[F_1\mathcal{H}-\xi(F_1+F_2)\tilde{\mathcal{H}}-\frac{t}{4m_p^2}F_2\mathcal{E}\right]$$

Extract CFFs

$$R(\sqrt{s},Q'^2,t) = \frac{\int_0^{2\pi}d\phi cos\phi\frac{dS}{dQ'^2dtd\phi}}{\int_0^{2\pi}d\phi\frac{dS}{dQ'^2dtd\phi}} \qquad \frac{dS}{dQ'^2dtd\phi} = \int_{\pi/4}^{3\pi/4}d\theta\frac{L}{L_0}\frac{d\sigma}{dQ'^2dtd\phi d\theta}$$

$$L_0 = \frac{Q'^4sin^2\theta}{4} \qquad L = \frac{(Q'^2-t)^2-b^2}{4} \qquad b = 2(k-k')(p-p')$$



(E. Berger,M.Diehl,B.Pire)

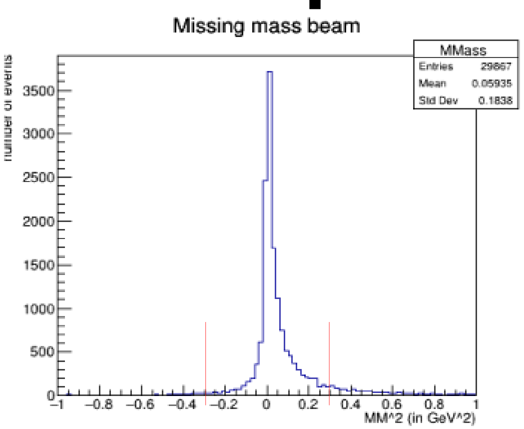
TCS Event Selection

$e\ p \rightarrow e\ \gamma\ p \rightarrow e^+ e^- p\ (e)$

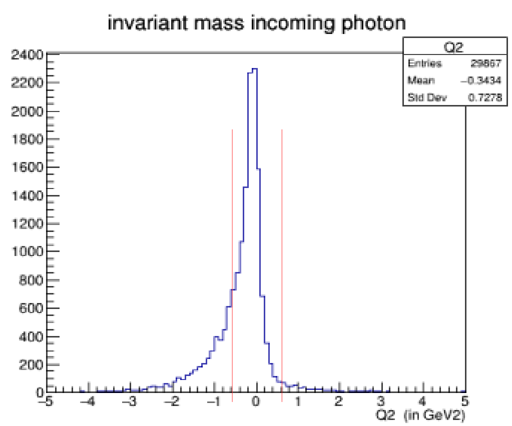
Not detected

Step 1 : Final state selection
e^+, e^-, p, X

Step 2 : Kinematics cuts



$X\ p \rightarrow e^+ e^- p\ (e)$



$e\ X\ p \rightarrow e^+ e^- p\ (e)$

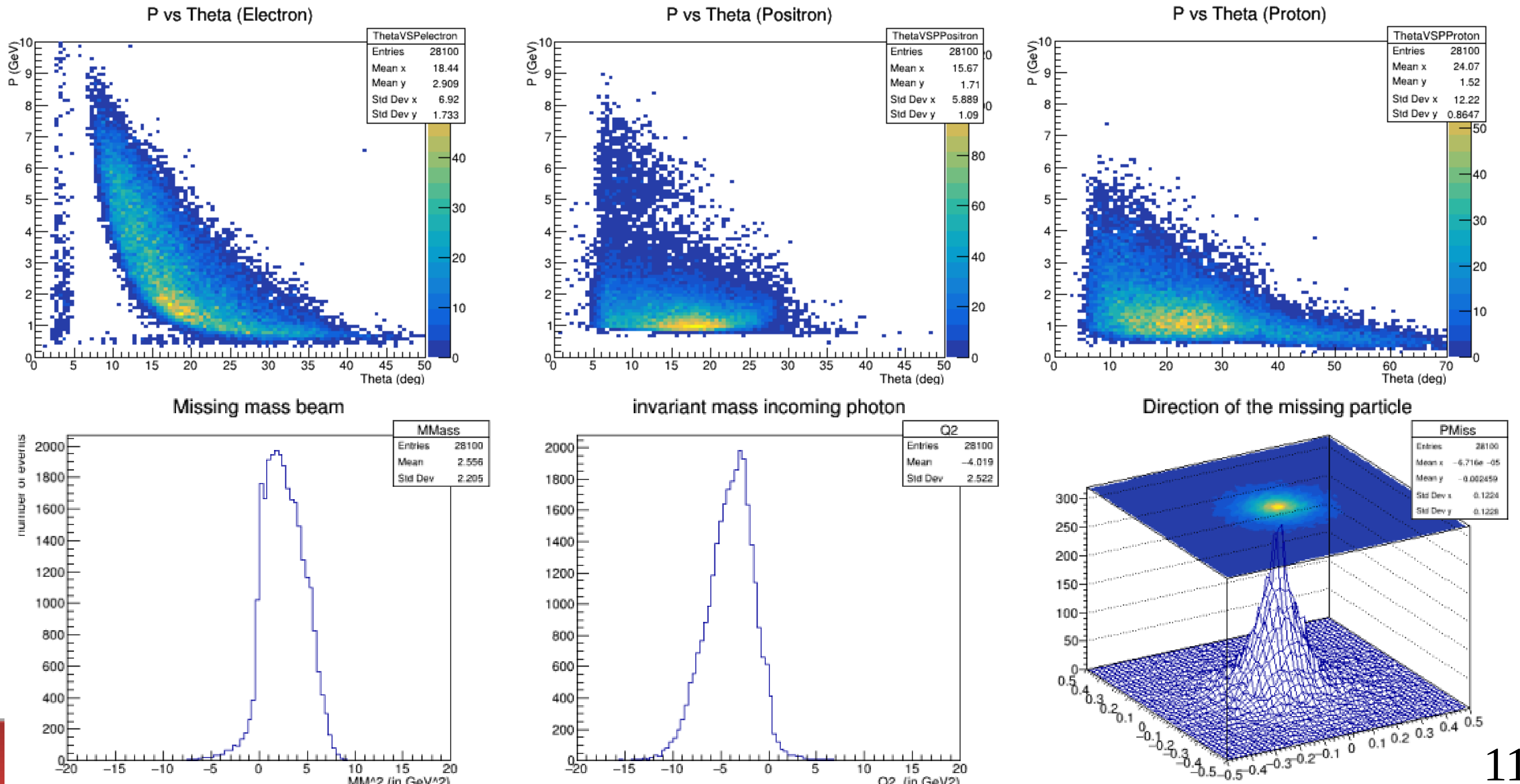
Proton :
- match p and β
- if p>3GeV require no LTCC signal

Electron/Positron :
- HTCC signal
- Energy in PCal
- Sampling fraction

First look at CLAS12 Data

Data set: 5 runs from Spring 2018, ~3,5M events, 10 hours of beam

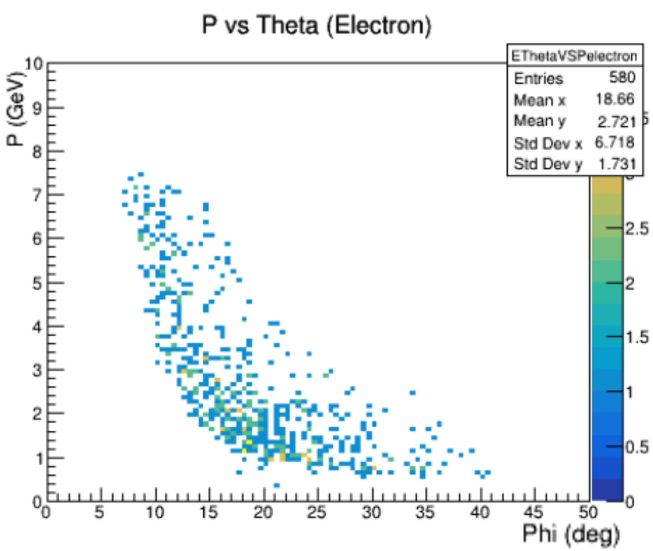
1st Selection : ask for at least 1 e+, 1e- and 1 proton
→ Only 28100 events left (~1% of total number of events)

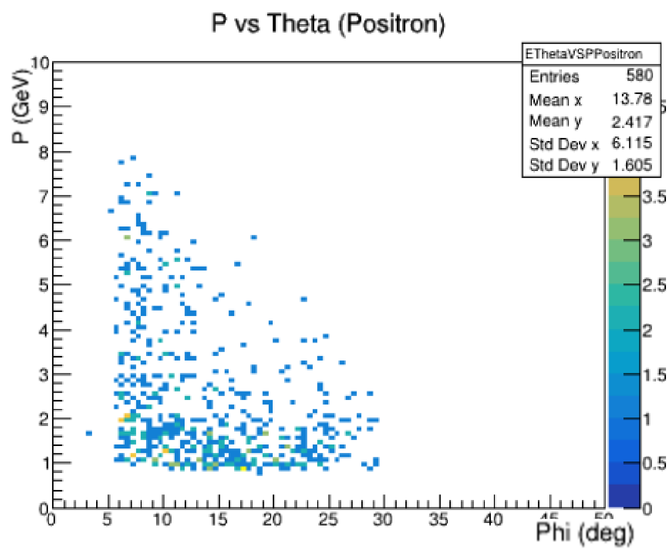


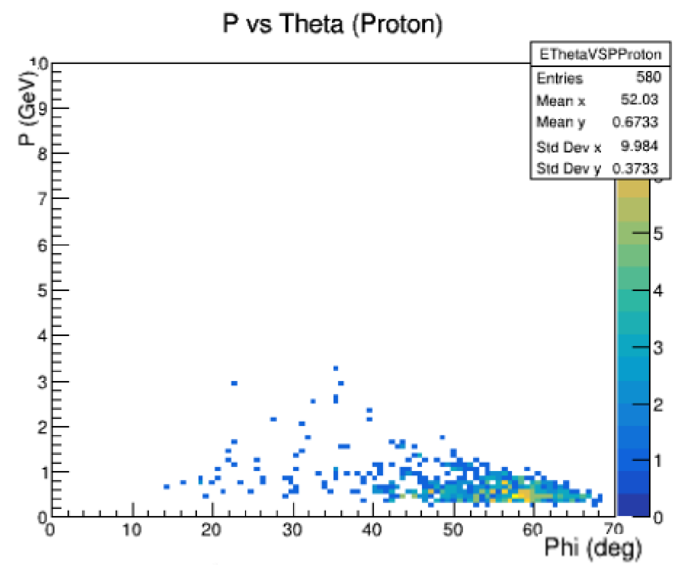
First look at CLAS12 Data

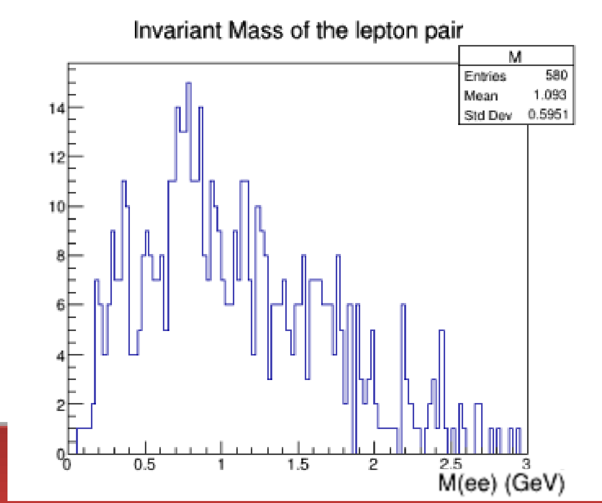
2nd Selection : Missing mass beam^2<0,3GeV^2, Q^2<0,5 GeV^2, Pt/P < 0,2

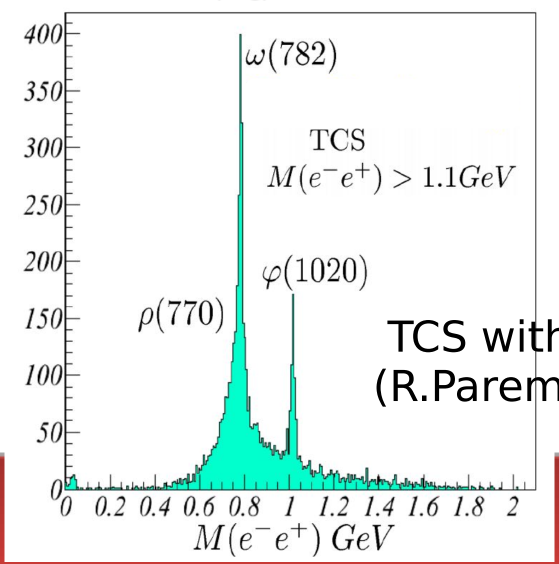
→ 580 events left (~0,016% of total number of events)











TCS with CLAS
(R.Paremuzyan)

TCS Simulations

Simulations

- Event Generator written by M.Boer (https://hallaweb.jlab.org/wiki/index.php/DDVCS_and_TCS_event_generator)

-Kinematic limits of the Generator :
LH2 target, no primary electron,
40° < ThetaCM <140° ;
$0,04 < -t(GeV^2) < 1,04$;
$3,8 < Q'^2(GeV^2) < 9,2$

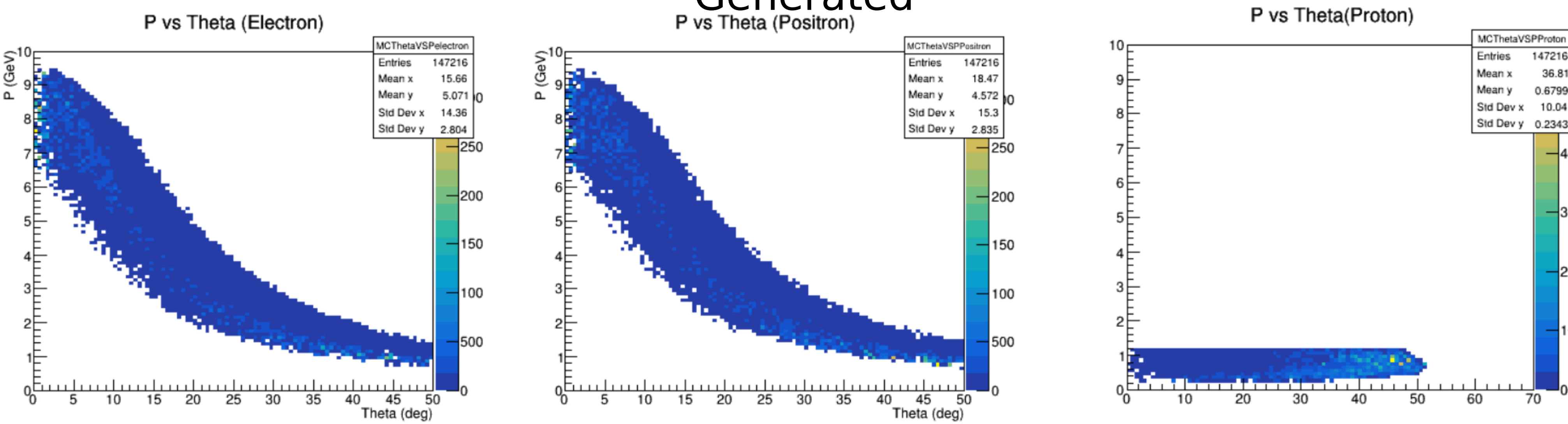
-Event Weighted with BH+Interference cross section

-150000 events were generated
-GEMC 4a.2.3 with clas12.gcard, no background, magnetic fields torus -1 solenoid 1
-Reconstruction with CoatJava 5b.3.3

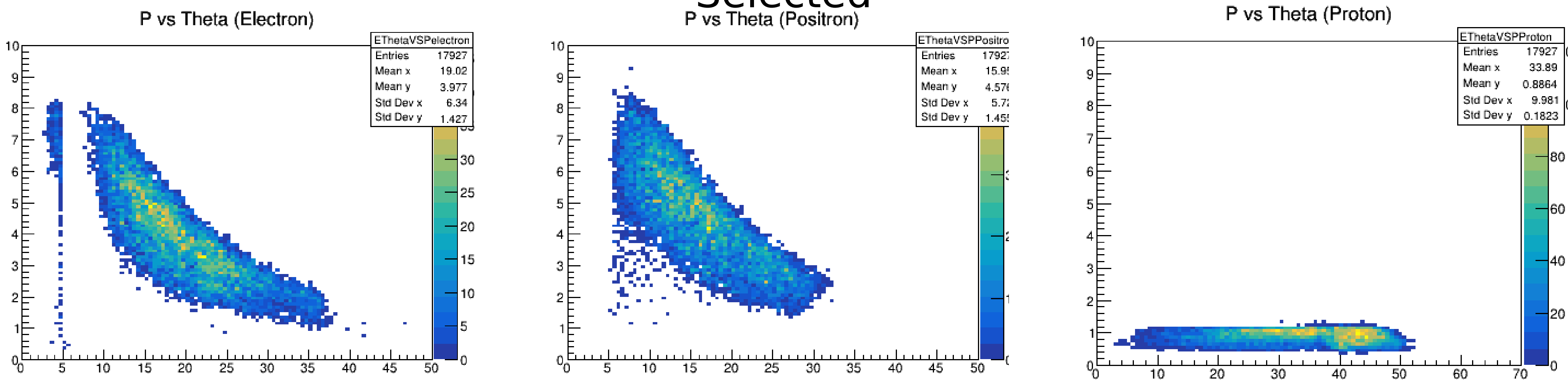
The full simulation chain is implemented and tested.

TCS Simulations

Generated



Selected



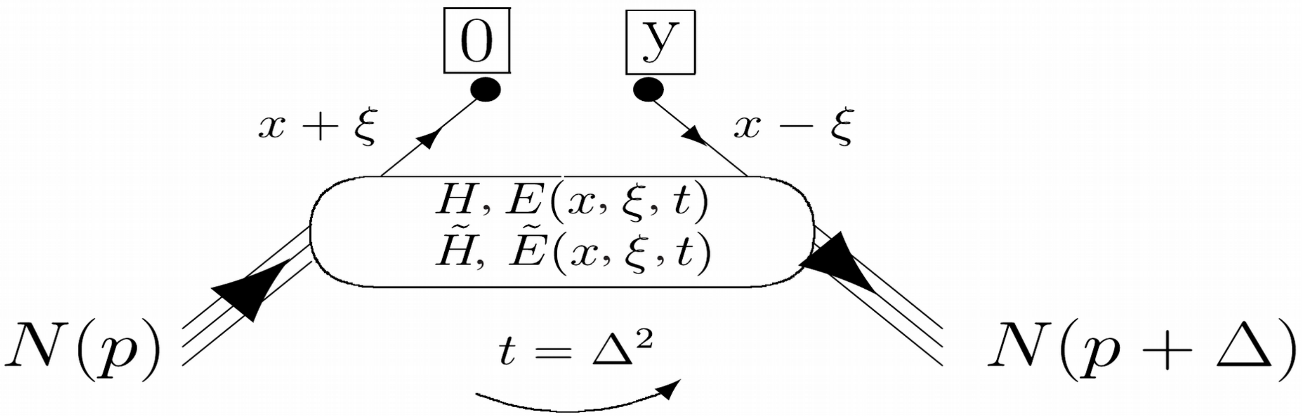
What's next ?

- Refine the particle ID algorithm
- Establish fiducial cuts
- Estimate CLAS12 acceptance from simulations

Thank you !

Backup slides

Formal Definition of GPDs



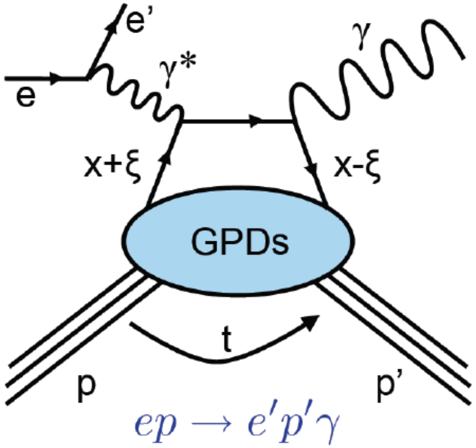
$$\frac{P^+}{2\pi}\int \mathrm{d}y^- \mathrm{e}^{\mathrm{i}xP^+y^-}\langle p'|\bar{\psi}_q(0)\gamma^+\psi_q(y)|p\rangle\Big|_{y^+=\vec{y}_\perp=0}$$
$$= H^q(x,\xi,t)\,\bar{N}(p')\gamma^+N(p)$$
$$+ E^q(x,\xi,t)\,\bar{N}(p')\mathrm{i}\sigma^{+\nu}\frac{\Delta_\nu}{2m_N}N(p),$$

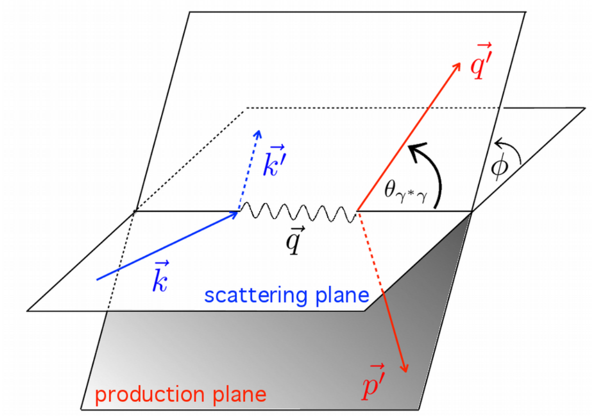
$$\frac{P^+}{2\pi}\int \mathrm{d}y^- \mathrm{e}^{\mathrm{i}xP^+y^-}\langle p'|\bar{\psi}_q(0)\gamma^+\gamma^5\psi_q(y)|p\rangle\Big|_{y^+=\vec{y}_\perp=0}$$
$$= \tilde{H}^q(x,\xi,t)\,\bar{N}(p')\gamma^+\gamma_5N(p)$$
$$+ \tilde{E}^q(x,\xi,t)\,\bar{N}(p')\gamma_5\frac{\Delta^+}{2m_N}N(p),$$

DVCS

The Golden Process : Deeply Virtual Compton Scattering

$e\ p \rightarrow \gamma^{*}\ p \rightarrow e\ p\ \gamma$





Measured asymmetries :

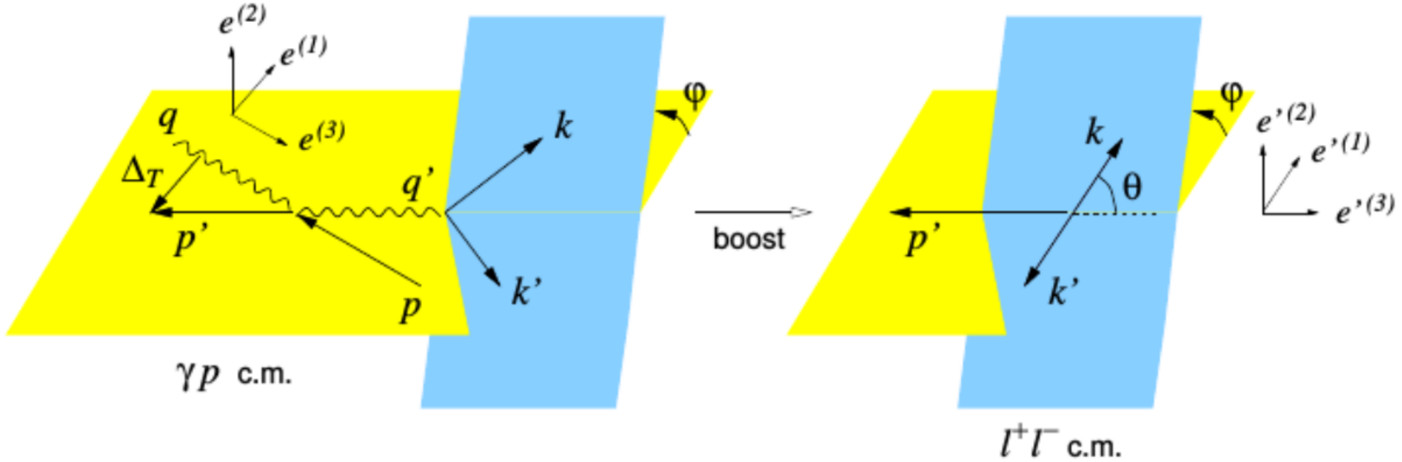
$$\Delta\sigma_{LU} \propto sin\phi Im\left\{(F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E} + ...\right\},$$

$$\Delta\sigma_{UL} \propto sin\phi Im\left\{(F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\tilde{\mathcal{H}} + \frac{x_B}{2}\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}} + ...\right\}$$

$$\Delta\sigma_{LL} \propto (A + Bcos\phi)Re\left\{(F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + \frac{x_B}{2}\mathcal{E}) + ...\right\}$$

$$\Delta\sigma_{Ux} \propto sin\phi Im\left\{k(F_2\mathcal{H} - F_1\mathcal{E}) + ...\right\},$$

Kinematic variables for TCS



Lepton center of mass frame angles

$$t = (p' - p)^2 \qquad Q'^2 = (k + k')^2$$