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Timelike Compton Scattering with CLAS12 at 11 GeV

Deeply Virtual Compton Scattering: From Observables to GPDs

Ruhr-Universität Bochum, February 10-12, 2014

Outline

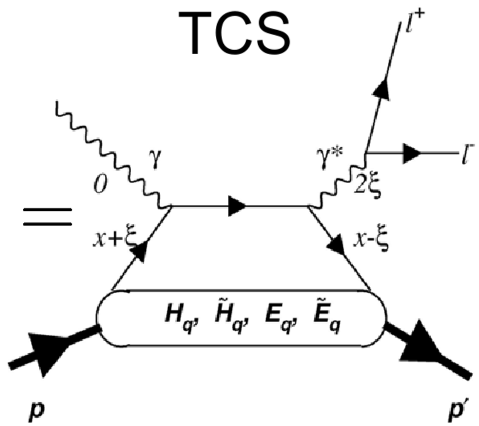
- Accessing GPDs experimentally through TCS
- TCS analysis from CLAS electroproduction data
- How to extract M^{--}
- Kinematic coverage of TCS
- Estimates of errors on M^{--} extraction

Accessing GPDs experimentally - TCS

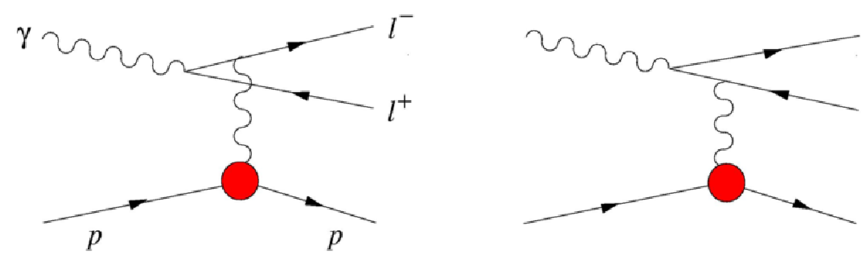
TCS

Bethe-Heitler (BH)

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

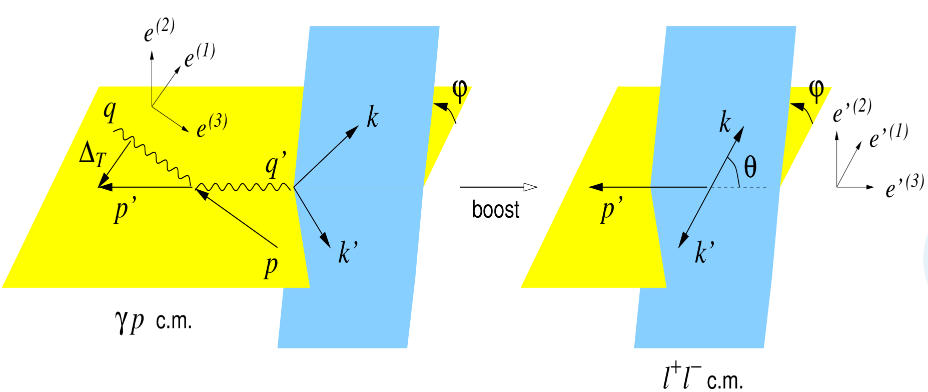


$+$



$$\sigma(\gamma p \rightarrow e^- e^+ p) = \underbrace{\sigma_{TCS} + \sigma_{BH}}_{\text{Symmetric}} + \underbrace{\sigma_{Int}}_{\text{Antisymmetric}}$$

$$k \leftrightarrow k'$$



$$\frac{d\sigma_{INT}}{dQ'^2 dt dcos(\theta) d\phi} \propto A[cos\phi Re\tilde{M}^{--} + ...]$$

Incoming photon polarization

$$\nu B[sin\phi Im\tilde{M}^{--} + ...]$$

$$\tilde{M}^{--} = \frac{2\sqrt{t_0 - t}}{M} \frac{1-\eta}{1+\eta} \left[F_1 \mathcal{H}_1 - \eta (F_1 + F_2) \tilde{\mathcal{H}}_1 - \frac{t}{4M^2} F_2 \mathcal{E}_1 \right]$$

TCS analysis from CLAS Data

Quasi-real photoproduction events, when incoming electron scatters at ~ 0 degree, have been selected from high energy electroproduction data on hydrogen

In the production of e^-e^+ pair there are two electrons in the final state

scattered electron

$$ep \rightarrow e' \underbrace{e^- e^+}_{\text{pair production}} p'$$

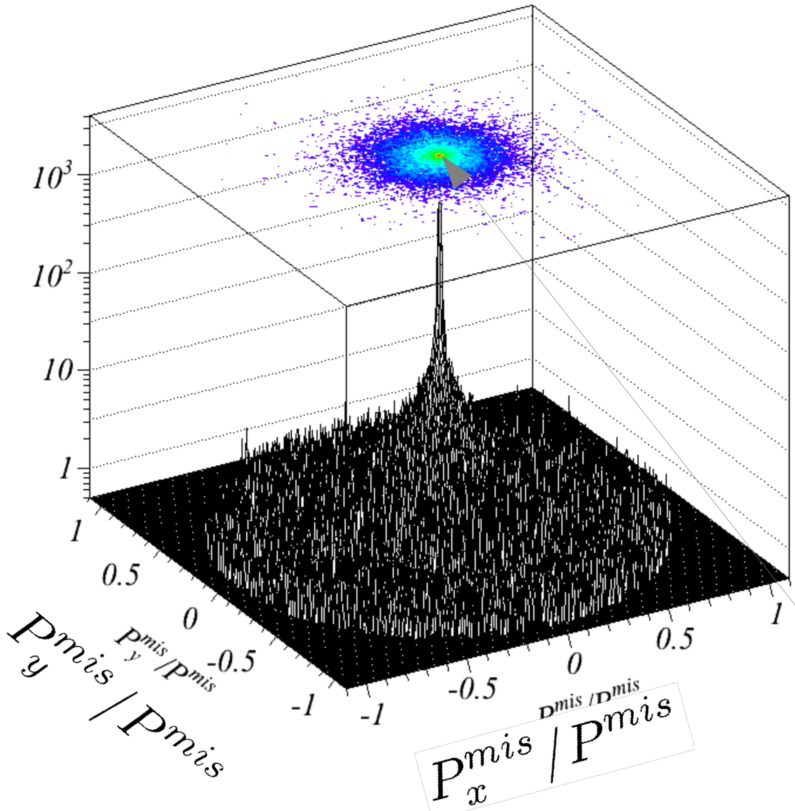
Final state to be analyzed

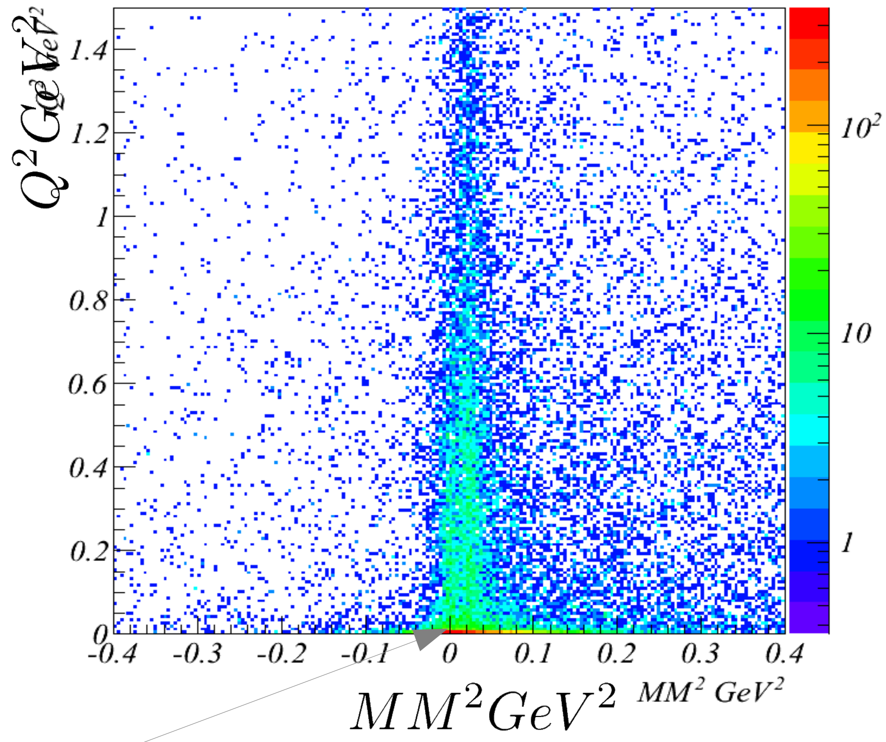
$$ep \rightarrow e^- e^+ pX$$

The scattered electron momentum is deduced from the missing momentum analysis

Quasi-real photo-production of e⁻e⁺ pair with CLAS

The final state to be analyzed $ep \to e^- e^+ pX$





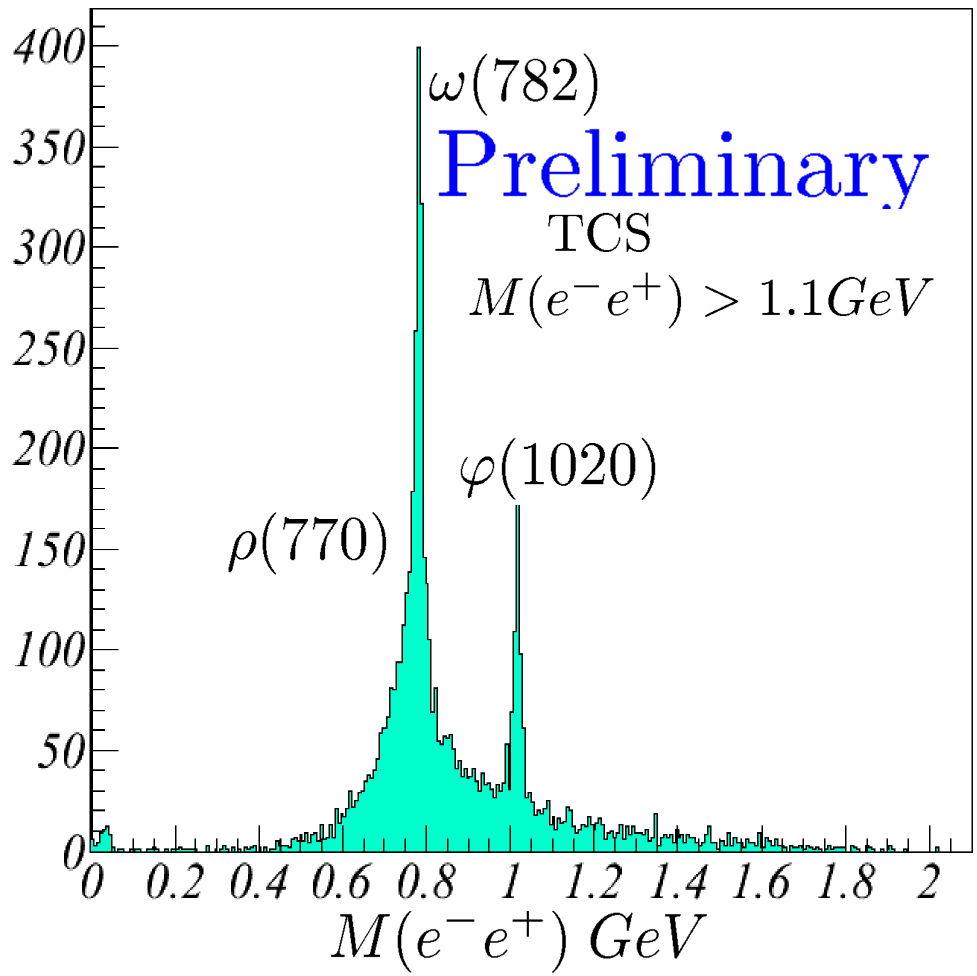
X is identified as a beam electron scattered at 0 degree

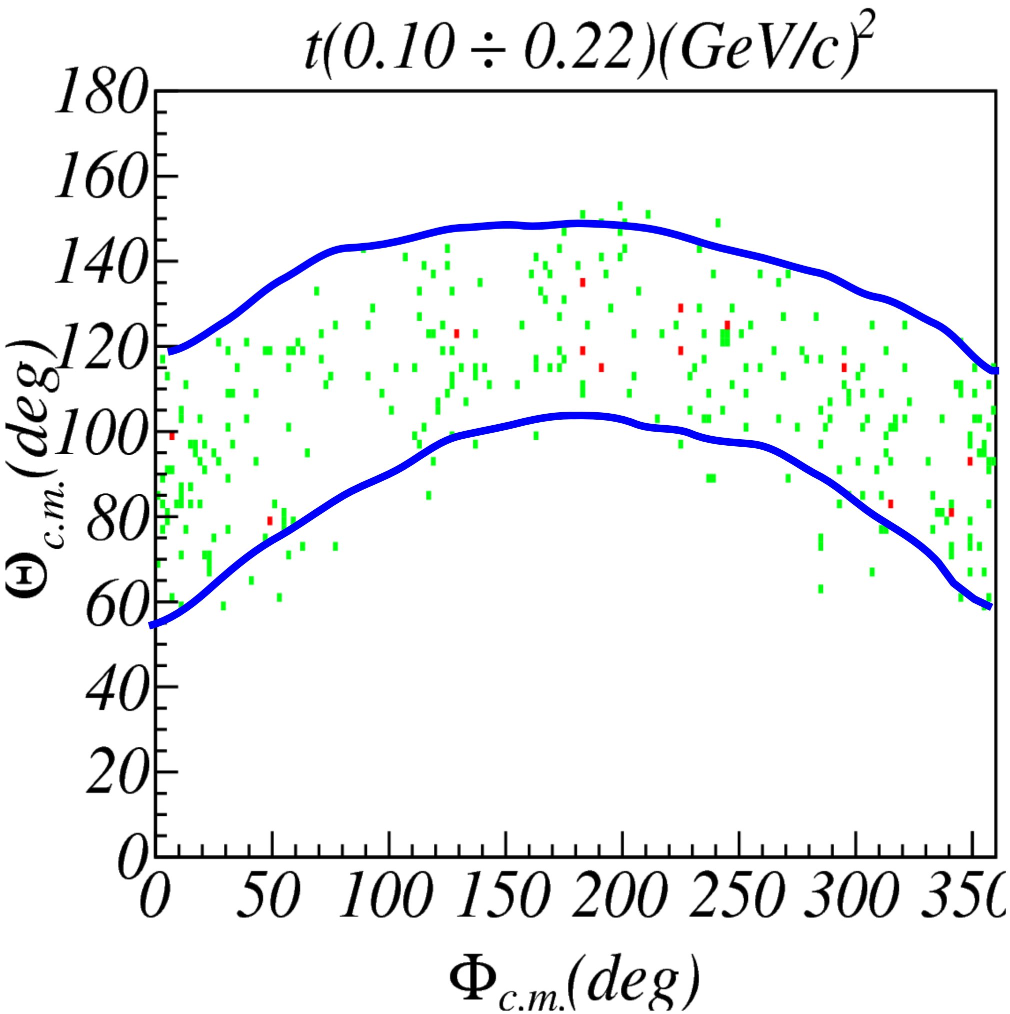
$Q^2 < 0.01 GeV^2 \quad |M_x|^2 < 0.1 GeV^2$

Photoproduction of lepton pairs

Region where TCS can be studied: M>1.1 GeV

CLAS acceptance





Theoretical R

$$R_{Theory} = \frac{2\int_0^{2\pi} d\phi cos(\phi) \frac{dS}{dQ^2 dt d\phi}}{\int_0^{2\pi} d\phi \frac{dS}{dQ^2 dt d\phi}}$$

$$\frac{dS}{dQ^2 dt d\phi} = \int_{\pi/2-\Delta}^{\pi/2+\Delta} \frac{L(\theta,\phi)}{L_0(\theta)} \frac{d\sigma}{dQ^2 dt d\theta d\phi}$$

E. R. Berger, M. Diehl, B. Pire arXiv:hep-ph/0110062

$$R_{Theory} \propto M^{--}$$

CLAS/CLAS12 acceptance doesn't allow to measure it directly, there is substantial φ dependence in θ acceptance.

Experimental R'

$$R' = \frac{2\sum_{\phi_i} \frac{Y_i}{\Delta Q^2 \Delta t \Delta \phi} cos(\phi)}{\sum_{\phi_i} \frac{Y_i}{\Delta Q^2 \Delta t \Delta \phi}}$$

$$\frac{Y_i}{\Delta Q^2 \Delta t \Delta \Phi} = \sum_{a(\phi)}^{b(\phi)} \frac{L(\theta,\phi)}{L_0(\theta)} N_\theta^\phi \frac{1}{Acc}$$

For comparison with theory, theoretical calculation can be done using ϕ dependent θ integration (R' instead of R)

However, R' doesn't reflect the scattering amplitude, and it is hard to tell how much one model is better than the other

Model independent extrapolation of data

BH: Well known (1-2%) $\quad INT = a \cdot M^{--} \cdot \frac{L_0(\theta)}{L(\phi,\theta)} cos(\phi)$

BH propagators

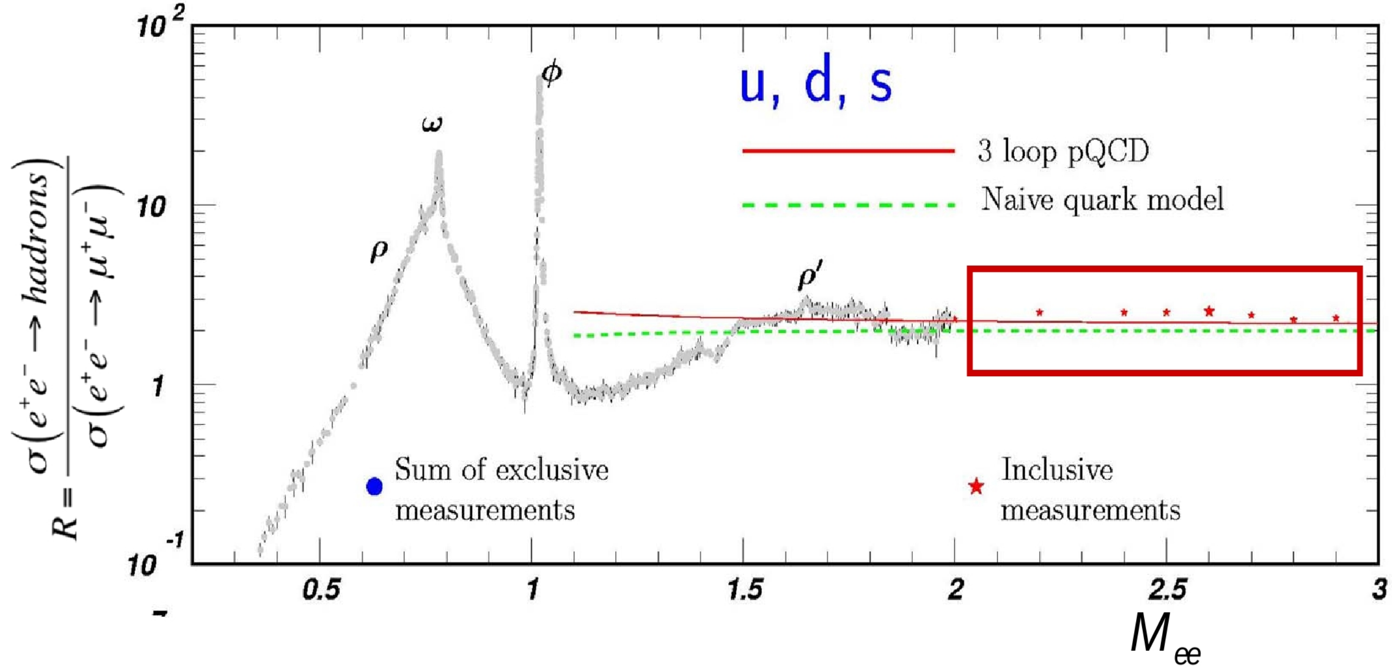
Weighted cross-section $\frac{dS}{dQ'^2 dt d\phi}\Big|_{\pi/4}^{3\pi/4} = \int_{\pi/4}^{3\pi/4} \frac{L(\theta,\phi)}{L_0(\theta)} \frac{d\sigma}{dQ'^2 dt d\theta d\phi} d\theta = B + A \cdot M^{--} cos(\phi)$

$$\Big|_{a(\phi)}^{b(\phi)} S_{Exp} - \Big|_{a(\phi)}^{b(\phi)} S_{BH} = \Big|_{a(\phi)}^{b(\phi)} S_{INT} = M^{--} \cdot cos(\phi) \cdot \int_{a(\phi)}^{b(\phi)} K(\theta) \cdot d\theta$$

$$\Big|_{\pi/4}^{3\pi/4} S_{INT} = \Big|_{a(\phi)}^{b(\phi)} S_{INT} \frac{\int_{\pi/4}^{3\pi/4} K(\theta) d\theta}{\int_{a(\phi)}^{b(\phi)} K(\theta) d\theta} = A \cdot M^{--} cos(\phi)$$

Prospects with CLAS12 upgrade

- Luminosity increases by one order of magnitude 10^{35} cm^{-2} s^{-1}
- With 11 GeV electron beam $M(e^-e^+)$ < 3.7GeV is accessible
- The $M(e^-e^+) \subset (2\text{-}3)$GeV resonance free region can be used for TCS studies



- J/ψ photo-production can be studied in energy range from threshold to 11 GeV

A proposal is approved for studying TCS and J/ψ photo-production using lepton pair photo-production with 120 days of beam time

Event generation

TCS: $\gamma p \to \gamma^\star p$

Experimentally: photoproduction of lepton pairs: $\gamma p \to l^- l^+ p$

2 steps: $\gamma p \to \gamma^\star p$ then $\gamma^\star \to e^- e^+$

$Q'^2 (4 - Q^2_{max}) GeV^2$ Resonance free region

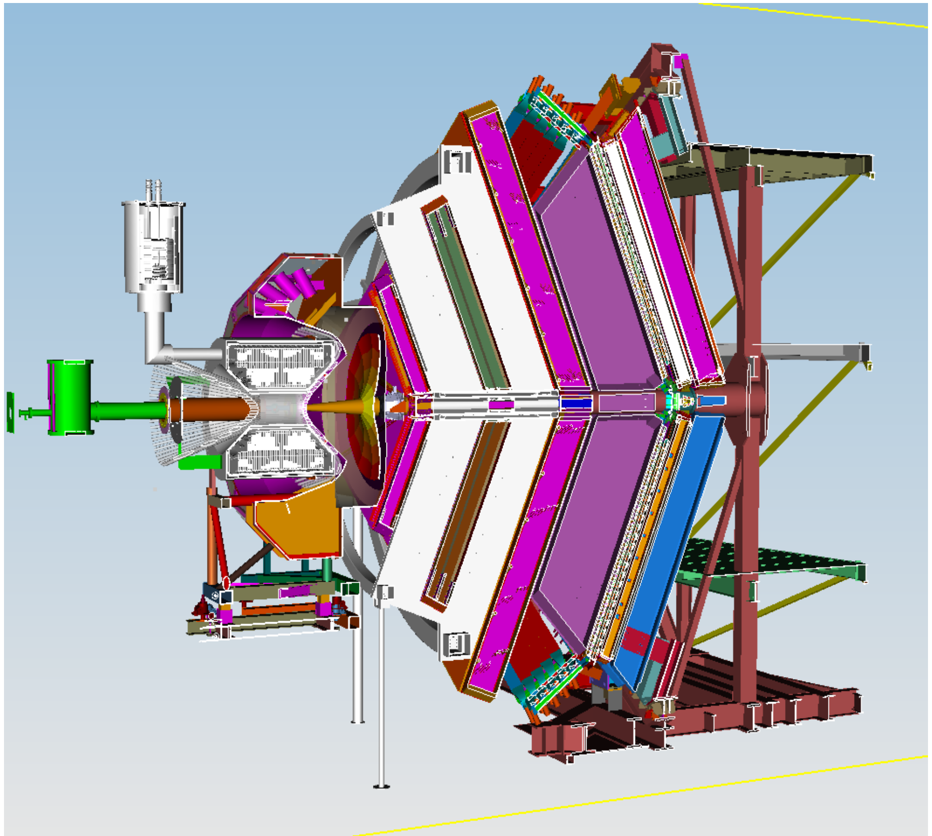
$E_\gamma (4 - 11) GeV$

$-t (t_{min} - 1.2) GeV^2$

Rates were estimated through CLAS12 fastmc

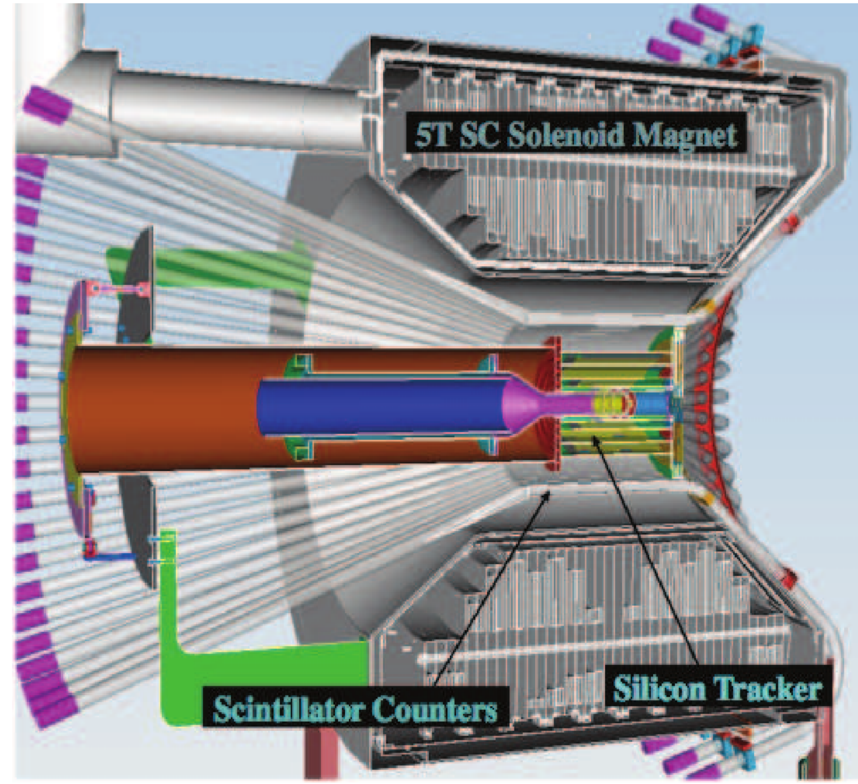
Torus current: maximal designed CLAS12 current

Forward Detector



e^- and e^+	e/π suppression
Forward EC	≈ 100
HTCC	≈ 1000 ($P < 4.9$ GeV)

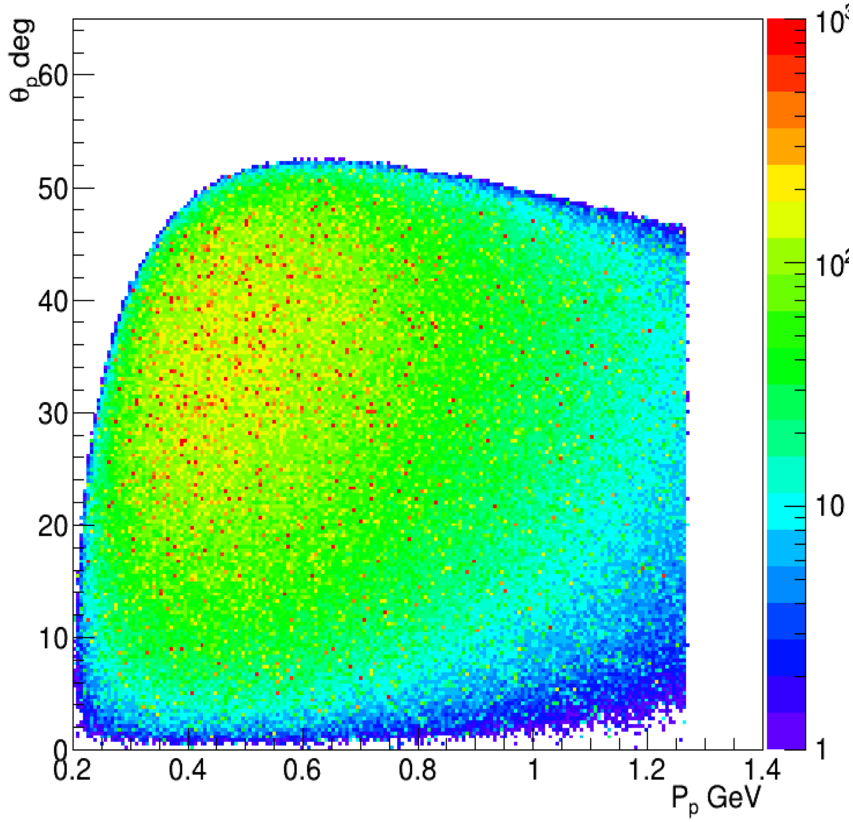
Central Detector



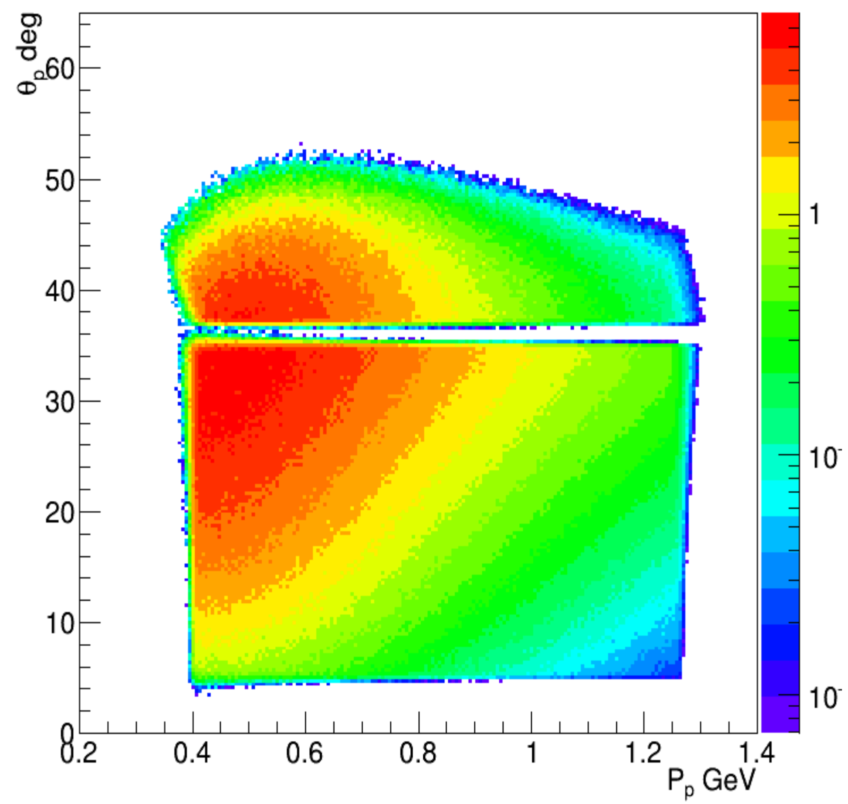
Protons ($P < 1.25$ GeV/c)	
Forward	Central
$5° < \theta < 35°$	$37° < \theta < 125°$
p/K, p/π^+ separation	
$> 10\sigma$	$> 3\sigma$

Proton acceptance

Generated

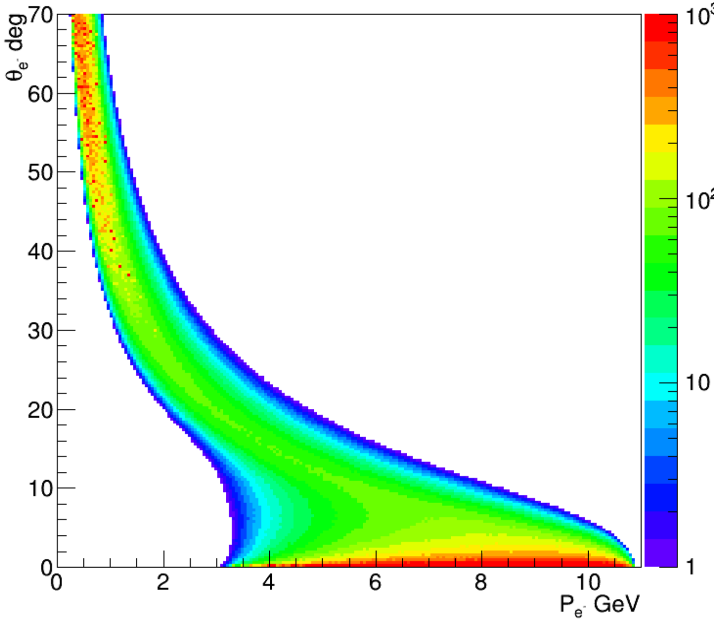


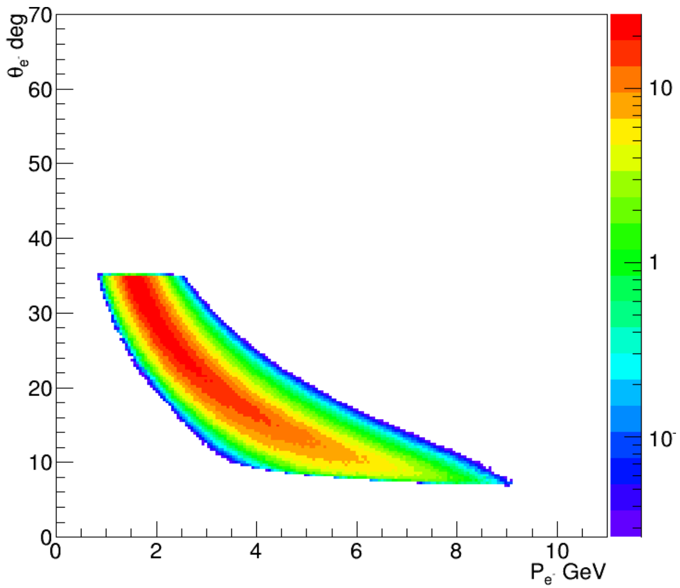
Accepted e-e+p in CLAS12



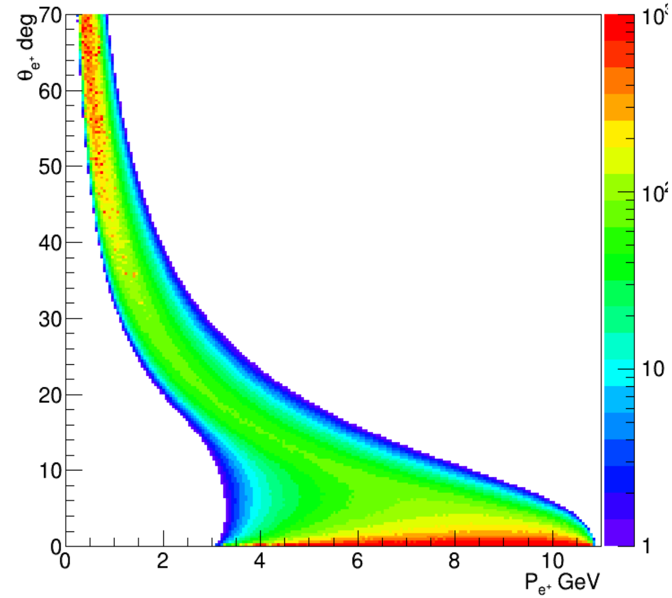
e- and e+ acceptances

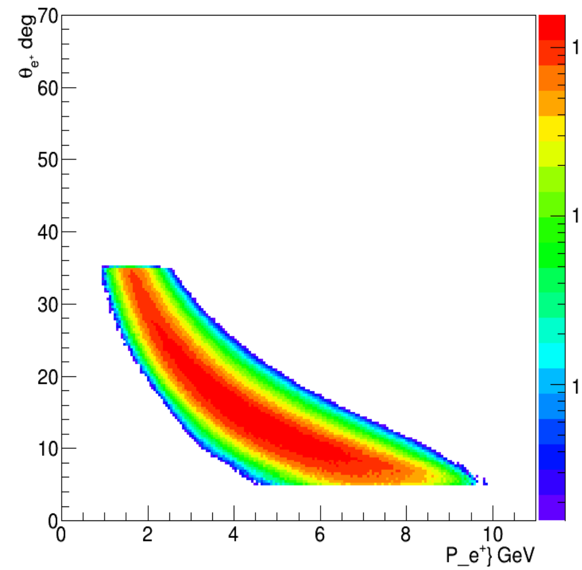
Electrons





Positrons





Contamination from $\pi^{-}\pi^{+}$ pairs

Both leptons have $P < 4.9\ GeV/c$

Suppression $\approx 10^{-10}$

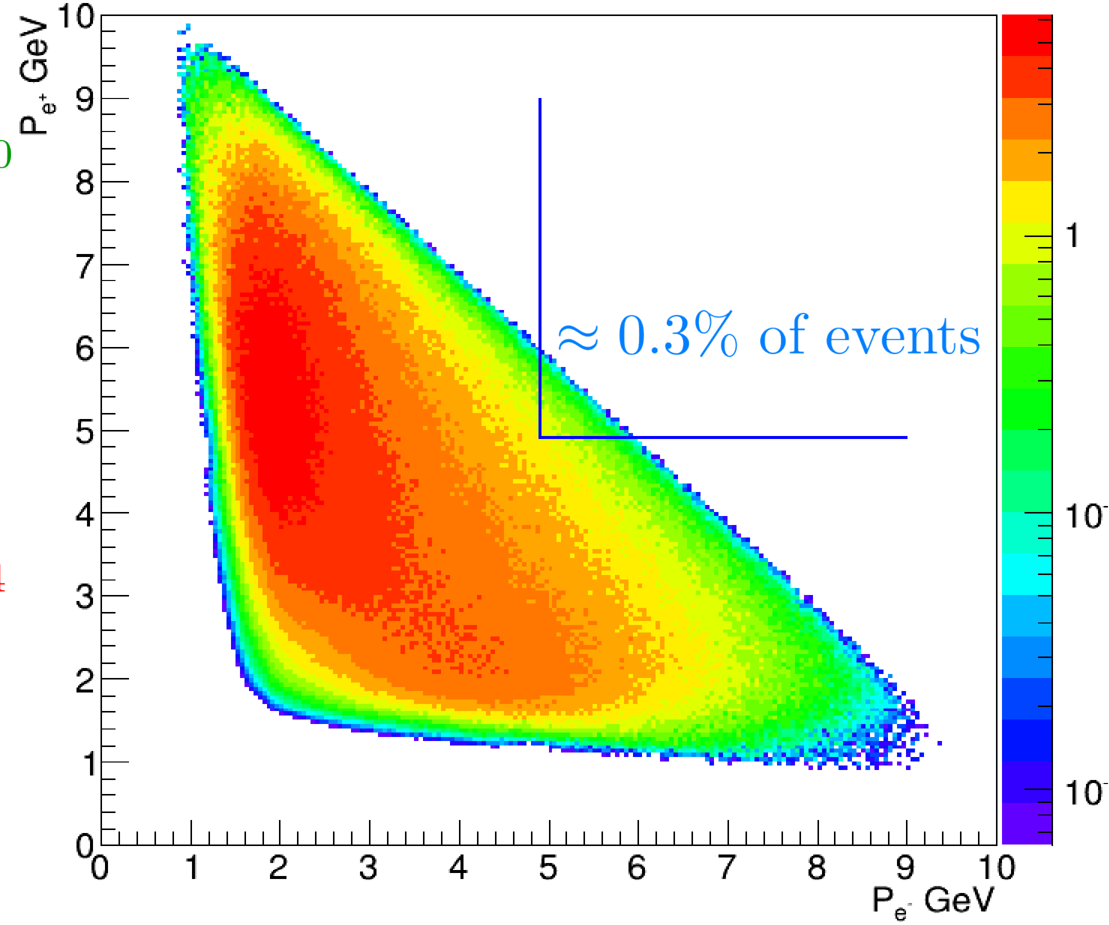
One of leptons has $P > 4.9\ GeV/c$

Suppression $\approx 10^{-7}$

Both leptons have $P > 4.9\ GeV/c$

Suppression $\approx 10^{-4}$

≈0.3% of events



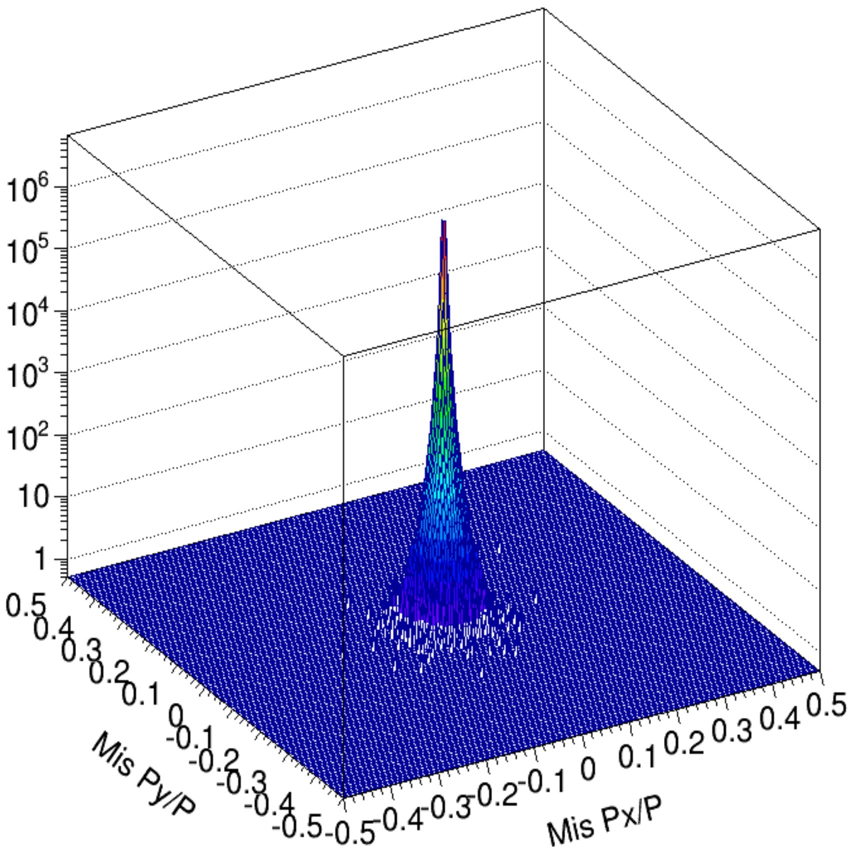
In CLAS12 energies $\pi^{-}\pi^{+}$ production cross section $\approx 0.1 mb$.

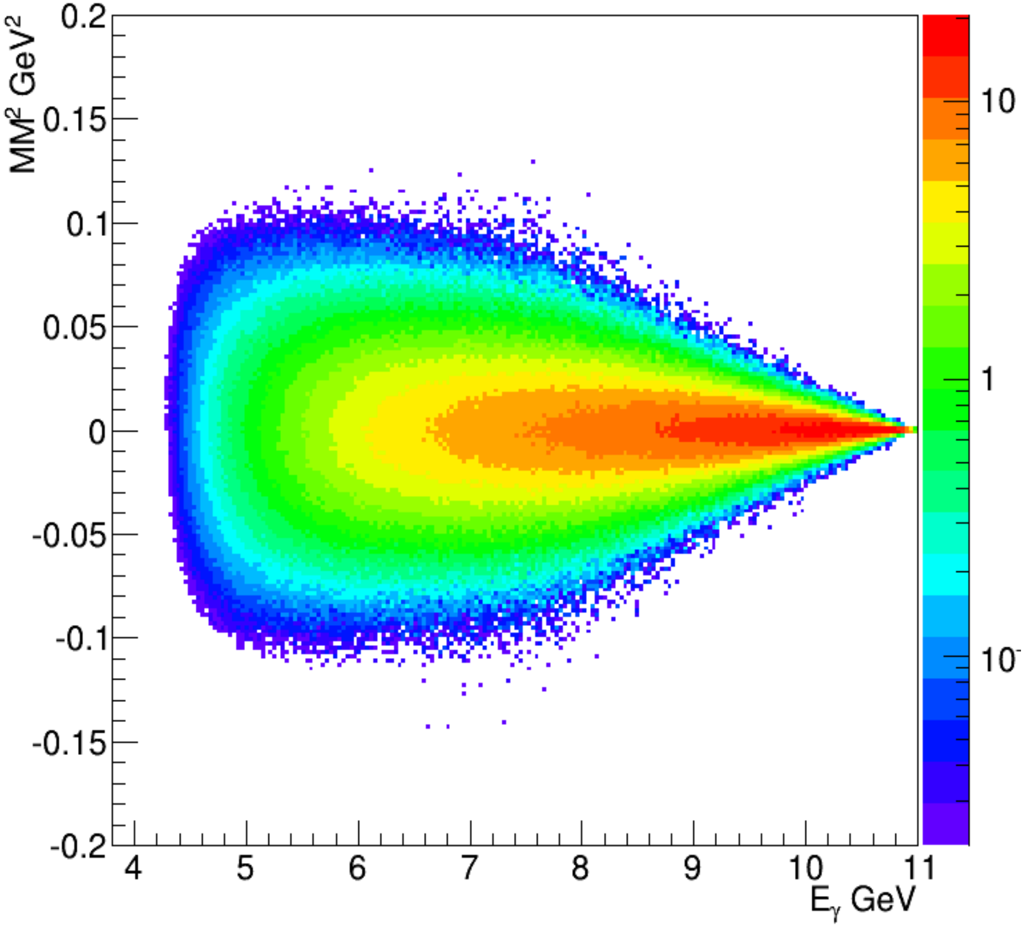
Total BH cross section $\approx 13\ nb$.

$Q^2 (4-9)\ GeV^2,\ -t < 1.2\ GeV^2,\ E_{\gamma} = 11\ GeV$

4 order of magnitude

CLAS12 mom. and angular resolution





CLAS12 momentum and angular resolution is enough for clean selection of Quasi-real photoproduction events from electroproduction.

Kinematic selection

DVCS

$$x_B = \frac{Q^2}{2pq}$$

Related to η

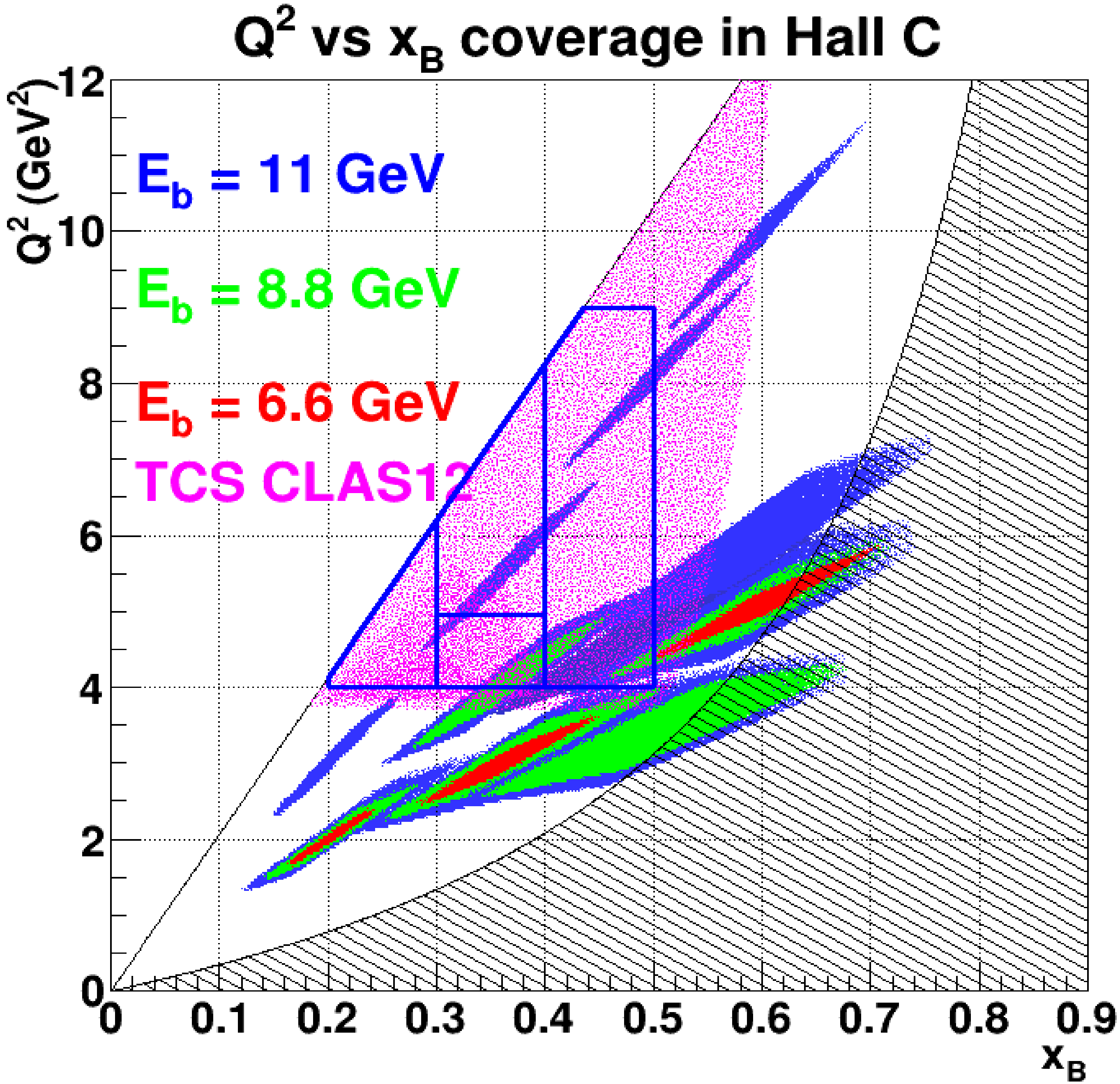
$$x_B \approx \frac{\eta}{2-\eta}$$

TCS

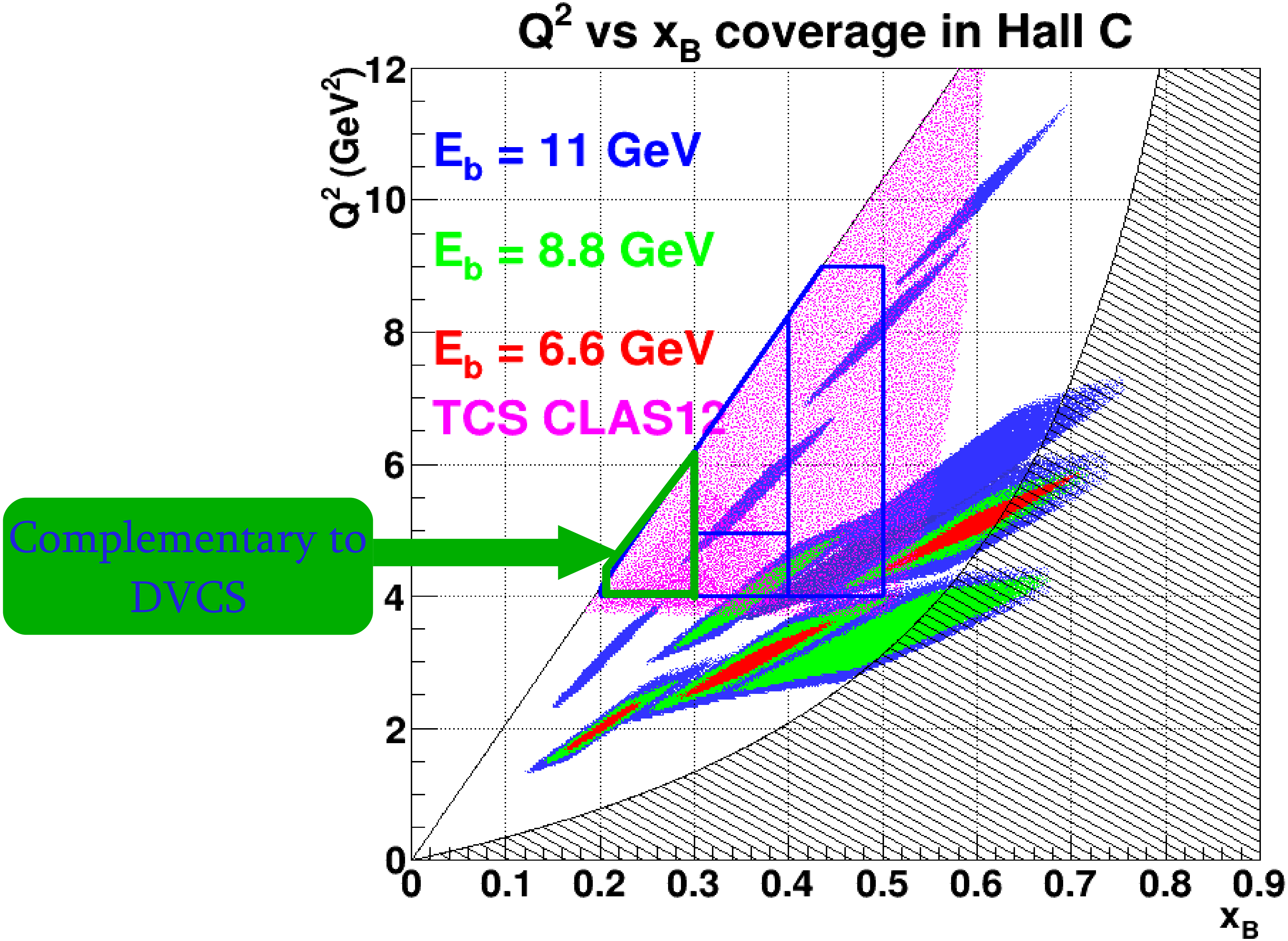
$$\tau = \frac{Q'^2}{2pq}$$

Related to η

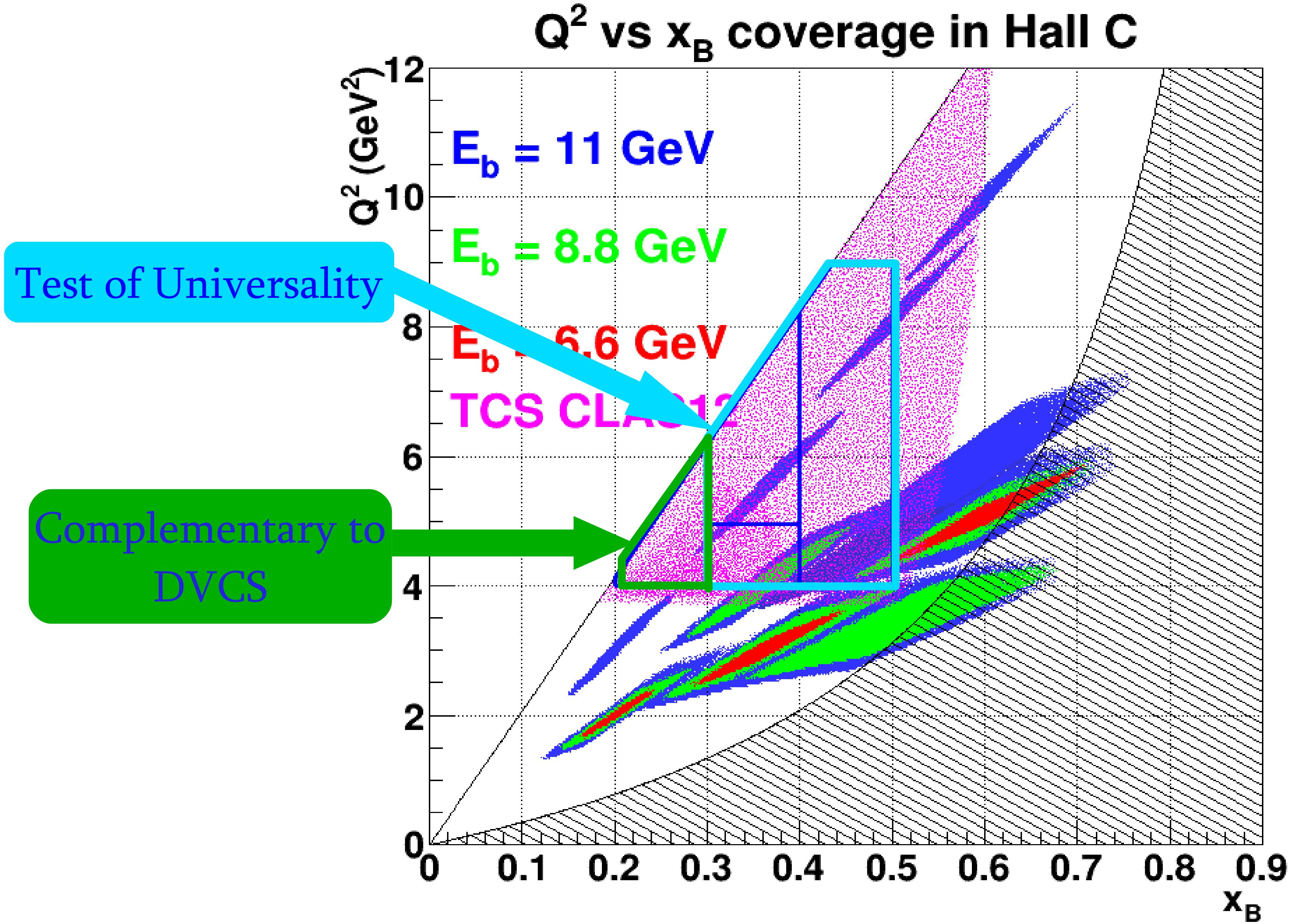
$$\tau \approx \frac{\eta}{2-\eta}$$



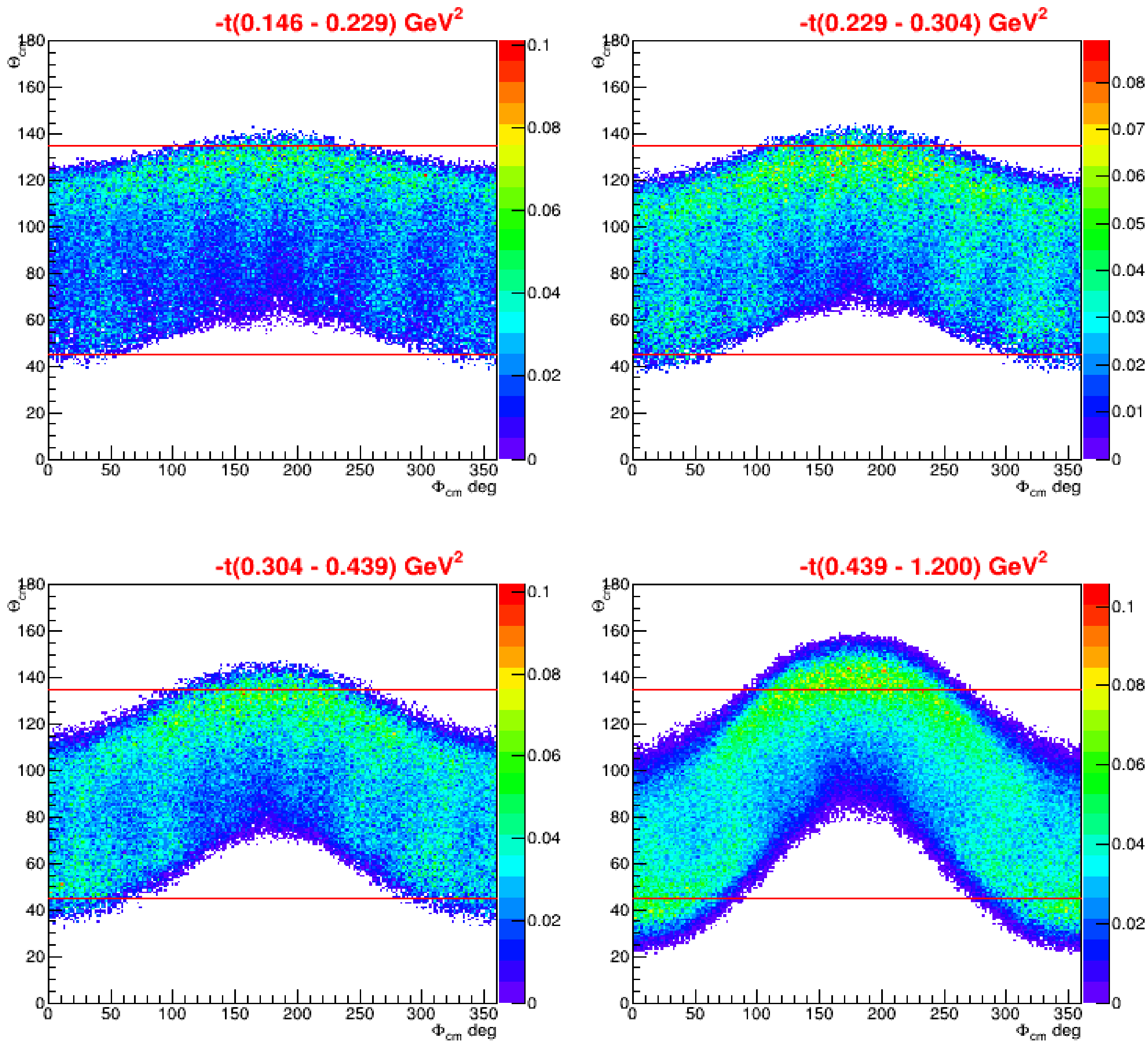
Kinematic selection



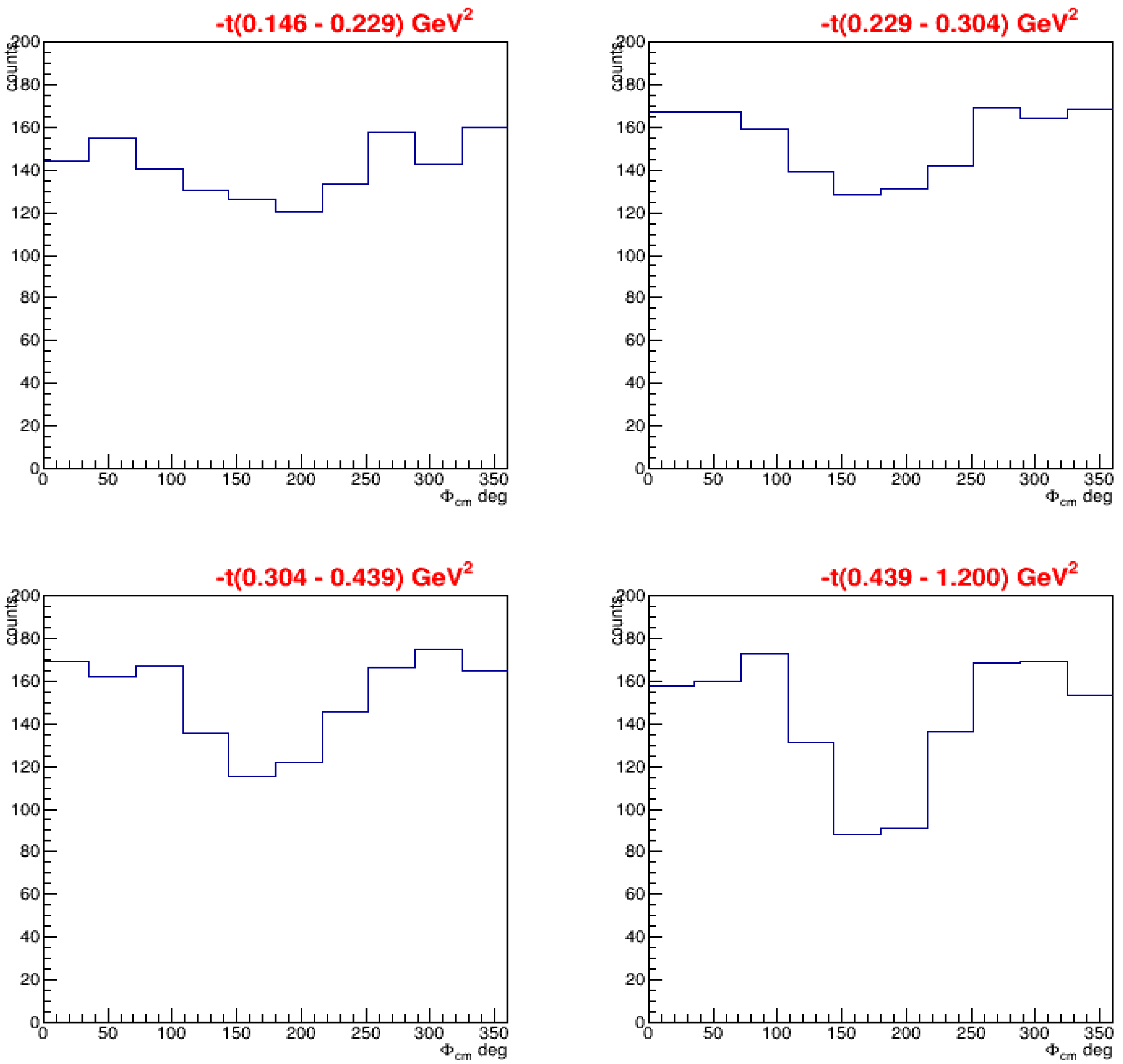
Kinematic selection



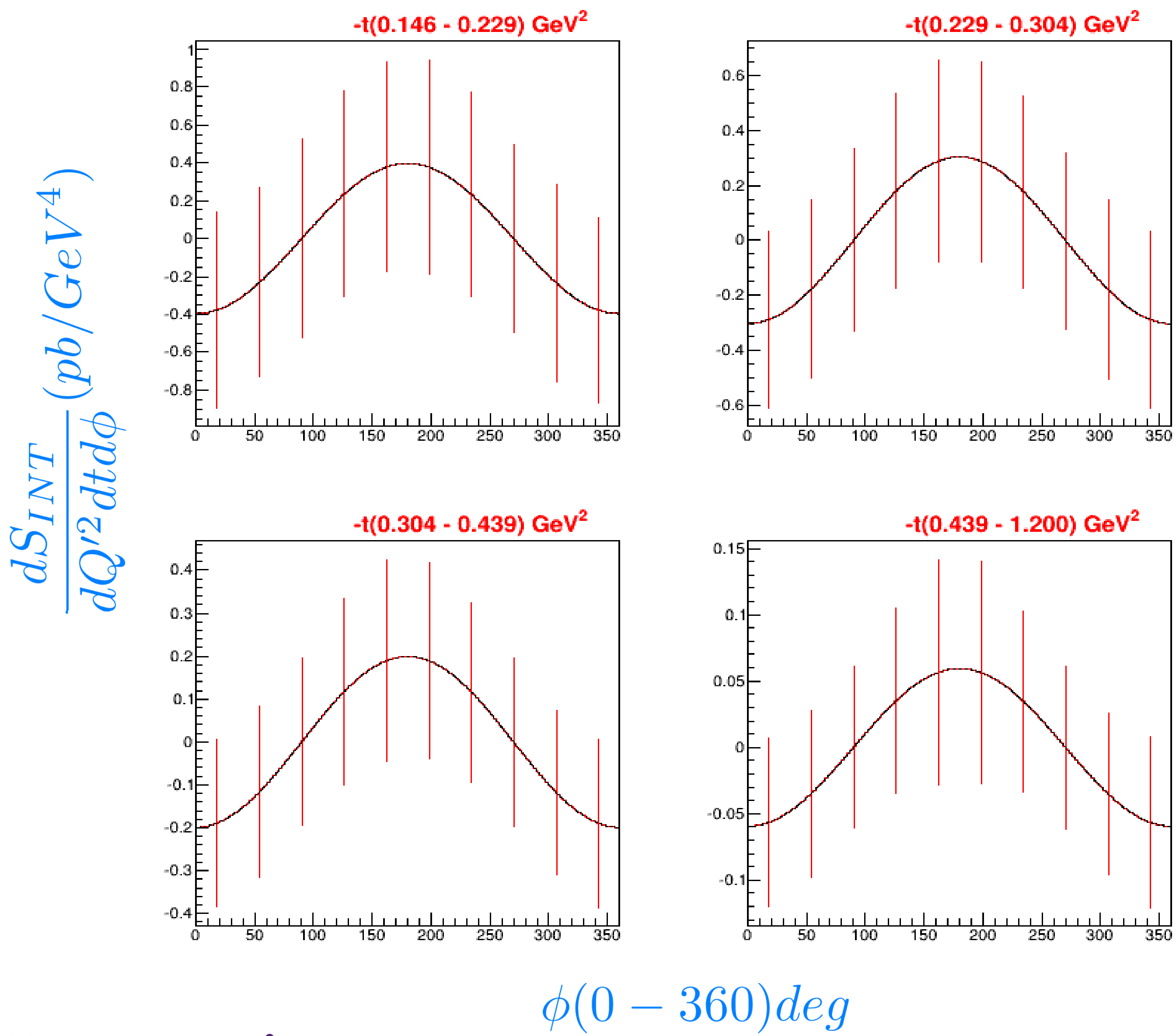
Theta vs Phi


-t(0.146 - 0.229) GeV^2
-t(0.229 - 0.304) GeV^2
-t(0.304 - 0.439) GeV^2
-t(0.439 - 1.200) GeV^2
Θ_{cm}
Φ_{cm} deg

Rates


-t(0.146 - 0.229) GeV2
-t(0.229 - 0.304) GeV2
-t(0.304 - 0.439) GeV2
-t(0.439 - 1.200) GeV2
counts
Φcm deg
0 20 40 60 80 100 120 140 160 180 200
0 50 100 150 200 250 300 350

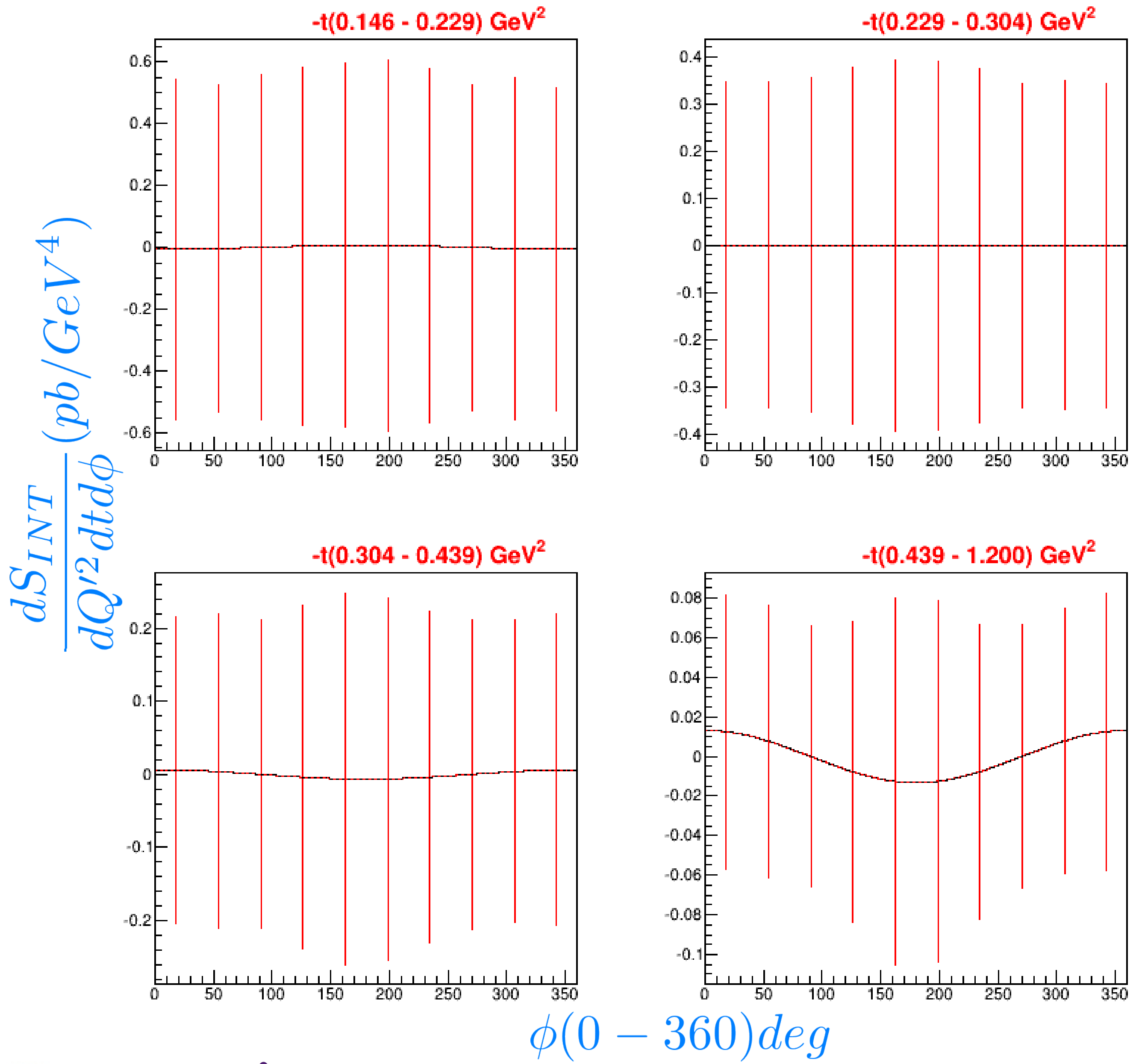
Errors on weighted cross section



$$\left.\frac{dS_{INT}}{dQ'^2dtd\phi}\right|_{\pi/4}^{3\pi/4} = P \cdot cos\phi$$

sc_D = 0

Errors on weighted cross section

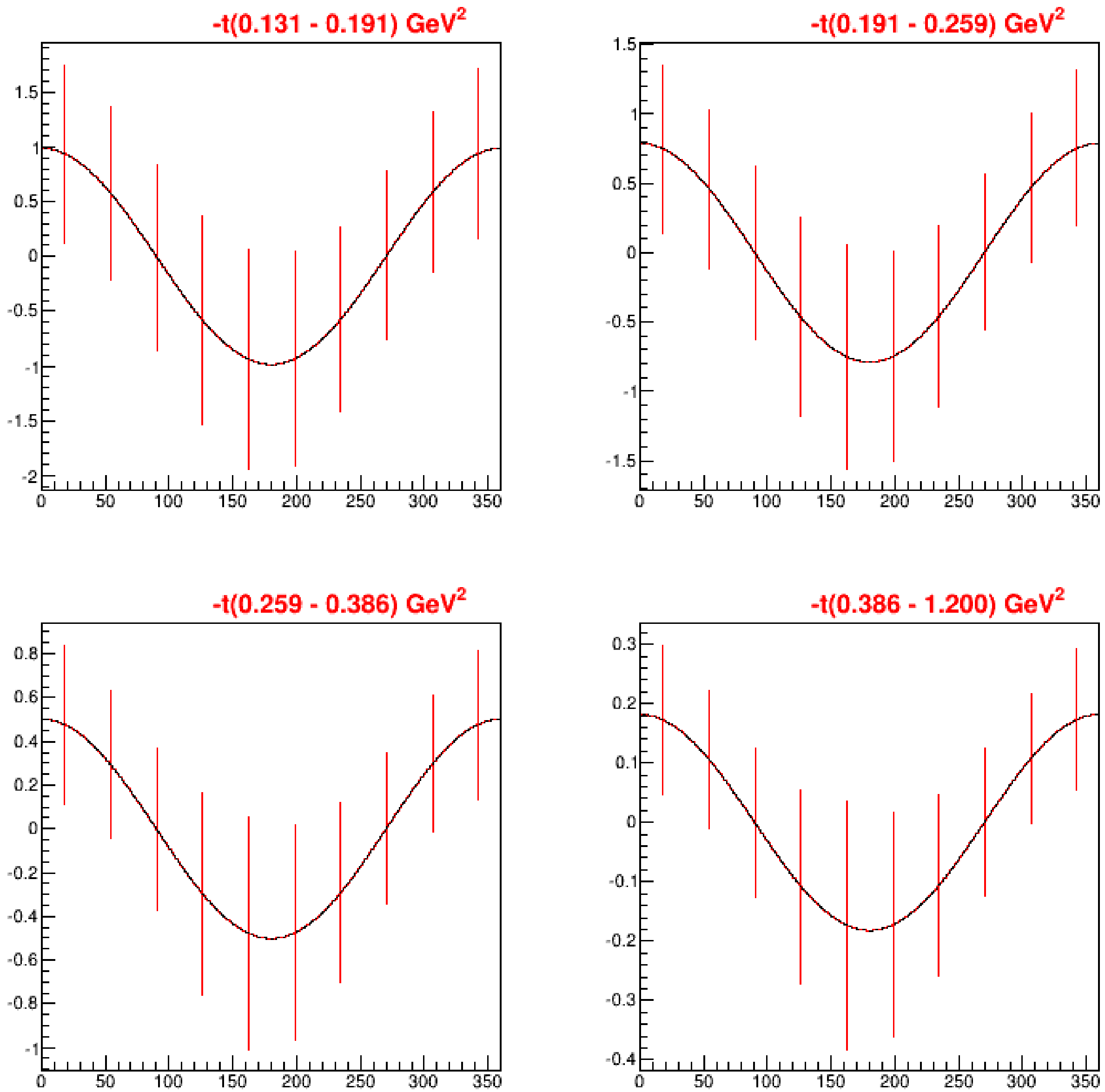


$$\left.\frac{dS_{INT}}{dQ'^2 dt d\phi}\right|_{\pi/4}^{3\pi/4} = P \cdot cos\phi$$

sc_D = 1

Errors on weighted cross section

$$\frac{dS_{INT}}{dQ'^2dtd\phi}(pb/GeV^4)$$



$$\phi(0-360)deg$$

$$\frac{dS_{INT}}{dQ'^2dtd\phi}\Big|_{\pi/4}^{3\pi/4} = P \cdot cos\phi$$

sc_D = 3

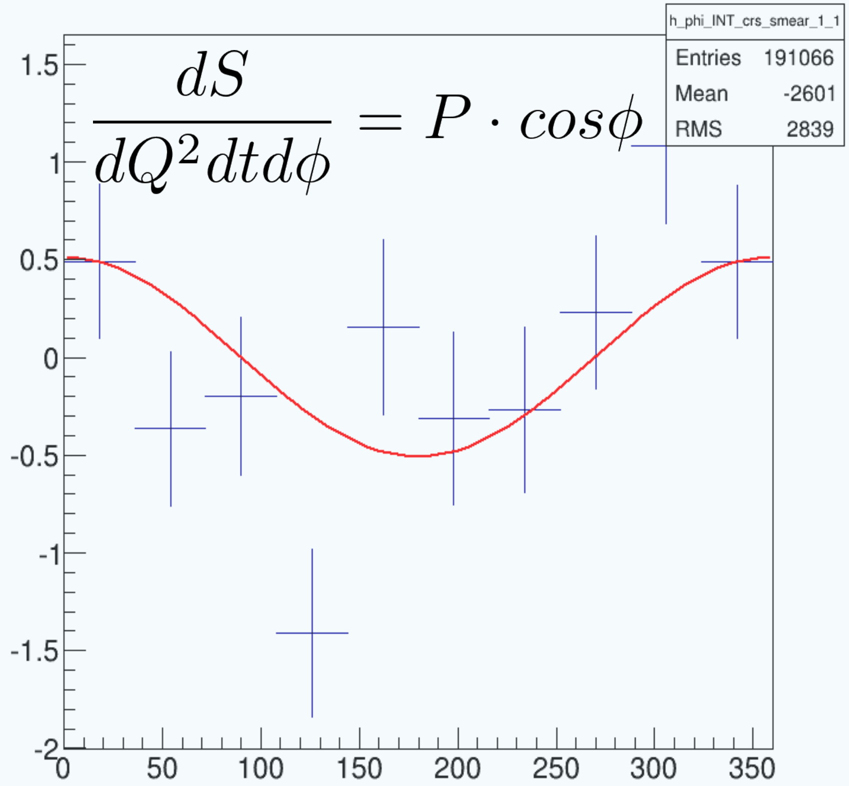
Estimation of errors on M^{--}

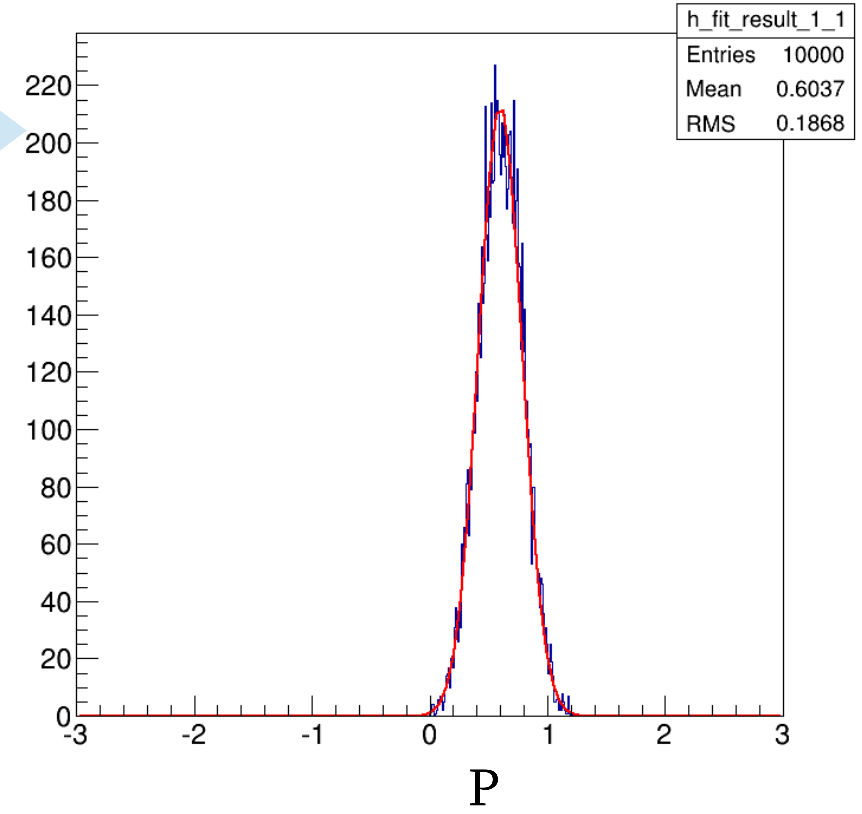
$$\frac{d\sigma_{INT}}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\left[\cos\varphi\frac{1+\cos^2\theta}{\sin\theta}\mathrm{Re}\,\tilde{M}^{--}\right.$$

Fit by Gaussian

Repeat many times!

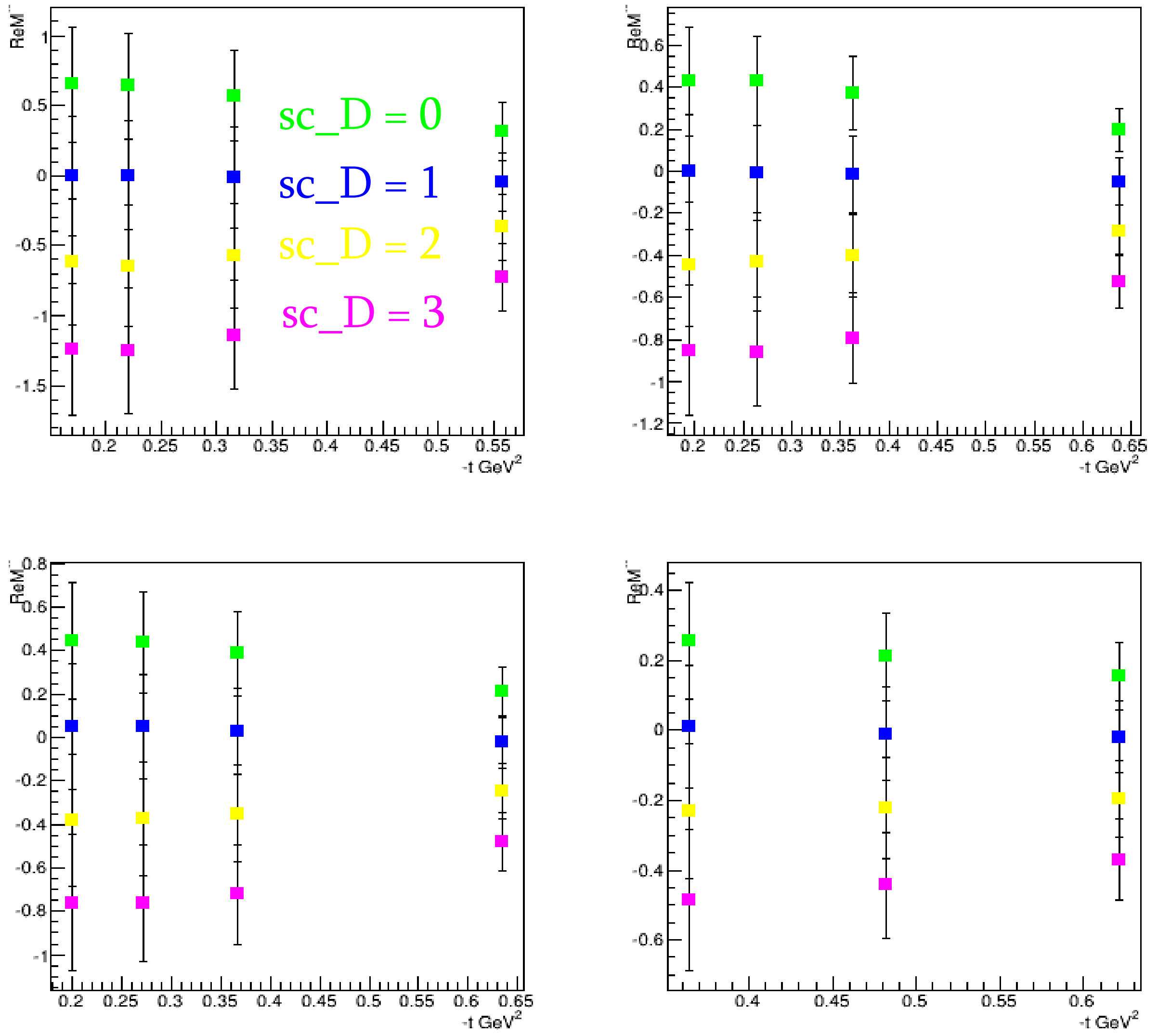
Smearing according stat errors





$$ReM^{--} = -\frac{P}{\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\cdot\int_{\pi/4}^{3\pi/4}(1+cos^2\theta)d\theta}$$

Expected errors on M^{--}



Summary

- CLAS data analysis showed that Time-like Compton Scattering can be studied using electroproduciton data

- CLAS12 offers higher beam energy and higher luminosity that allows TCS studies in resonance free region

- While both CLAS and CLAS12 have complicated acceptances, good theoretical knowledge of the interfering Bethe-Heitler process allows model independent extraction of relevant Compton amplitudes

- TCS provides complementary to DVCS information on GPDs and can test universality of GPDs

- With 11 GeV electron beam, in parallel to TCS, J/Psi photoproduction close to threshold can be studied using the same final state

Backups

General expression for the cross section

Total cross section — BH cross section — INT cross section

$$\frac{d\sigma_{TOT}}{dQ'^2dtd(cos\theta)d\phi} = \frac{d\sigma_{BH}}{dQ'^2dtd(cos\theta)d\phi} + \frac{d\sigma_{INT}}{dQ'^2dtd(cos\theta)d\phi}$$

Definition of the weighted cross section

Weighted total cross section — Weighted BH cross section — Weighted INT cross section

$$\frac{dS_{TOT}}{dQ'^2dtd\phi}\Bigg|_{\pi/4}^{3\pi/4} = \int_{\pi/4}^{3\pi/4} \frac{L(\theta,\phi)}{L_0(\theta)} \frac{d\sigma_{BH}}{dQ'^2dtd\theta d\phi} d\theta + \int_{\pi/4}^{3\pi/4} \frac{L(\theta,\phi)}{L_0(\theta)} \frac{d\sigma_{INT}}{dQ'^2dtd\theta d\phi} d\theta$$

Experimentally total weighted cross section is calculated by

$$\left.\frac{dS^{tot}_{EXP}}{dQ'^2 dt d\phi}\right|_a^b = \frac{1}{\mathcal{L}} \frac{1}{Acc} \frac{1}{\Delta Q'^2 \Delta t \Delta\phi} \cdot \sum_{i=1}^{n_{exp}} \frac{L(\theta,\phi)}{L_0(\theta)}$$

Experimentally INT weighted cross section θ(a-b) is calculated by

$$\left.\frac{dS^{int}_{EXP}}{dQ'^2 dt d\phi}\right|_a^b = \frac{1}{\mathcal{L}} \frac{1}{Acc} \frac{1}{\Delta Q'^2 \Delta t \Delta\phi} \cdot \sum_{i=1}^{n_{exp}} \frac{L(\theta,\phi)}{L_0(\theta)} - \left.\frac{dS_{BH}}{dQ'^2 dt d\phi}\right|_a^b$$

Extrapolation!

$$\left.\frac{dS^{int}_{EXP}}{dQ'^2 dt d\phi}\right|_{\pi/4}^{3\pi/4} = \left[\frac{1}{\mathcal{L}} \frac{1}{Acc} \frac{1}{\Delta Q'^2 \Delta t \Delta\phi} \cdot \sum_{i=1}^{n_{exp}} \frac{L(\theta,\phi)}{L_0(\theta)} - \left.\frac{dS_{BH}}{dQ'^2 dt d\phi}\right|_a^b\right] \cdot \frac{\int_{\pi/4}^{3\pi/4}(1+cos^2\theta)d\theta}{\int_a^b(1+cos^2\theta)d\theta}$$

By the above formula we should be able to measure weighted INT cross section as a function of Φ in a θ(π/4-3π/4) range, and the errors are calculated by the following formula

$$err_{\pi/4}^{3\pi/4} = \frac{1}{n_{exp}}\left[\frac{1}{\mathcal{L}} \frac{1}{Acc} \frac{1}{\Delta Q'^2 \Delta t \Delta\phi} \cdot \sum_{i=1}^{n_{exp}} \frac{L(\theta,\phi)}{L_0(\theta)}\right] \cdot \frac{\int_{\pi/4}^{3\pi/4}(1+cos^2\theta)d\theta}{\int_a^b(1+cos^2\theta)d\theta}$$

By putting Expression (30) into formula (43) from Berger's paper, we will get theoretical expression for the weighted INT cross section in the θ(π/4 – 3π/4)

$$\frac{dS}{dQ'^2 dt d\phi}\Bigg|_{\pi/4}^{3\pi/4} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}} ReM^{--} \cdot \int_{\pi/4}^{3\pi/4}(1+cos^2\theta)d\theta \cdot cos\phi$$

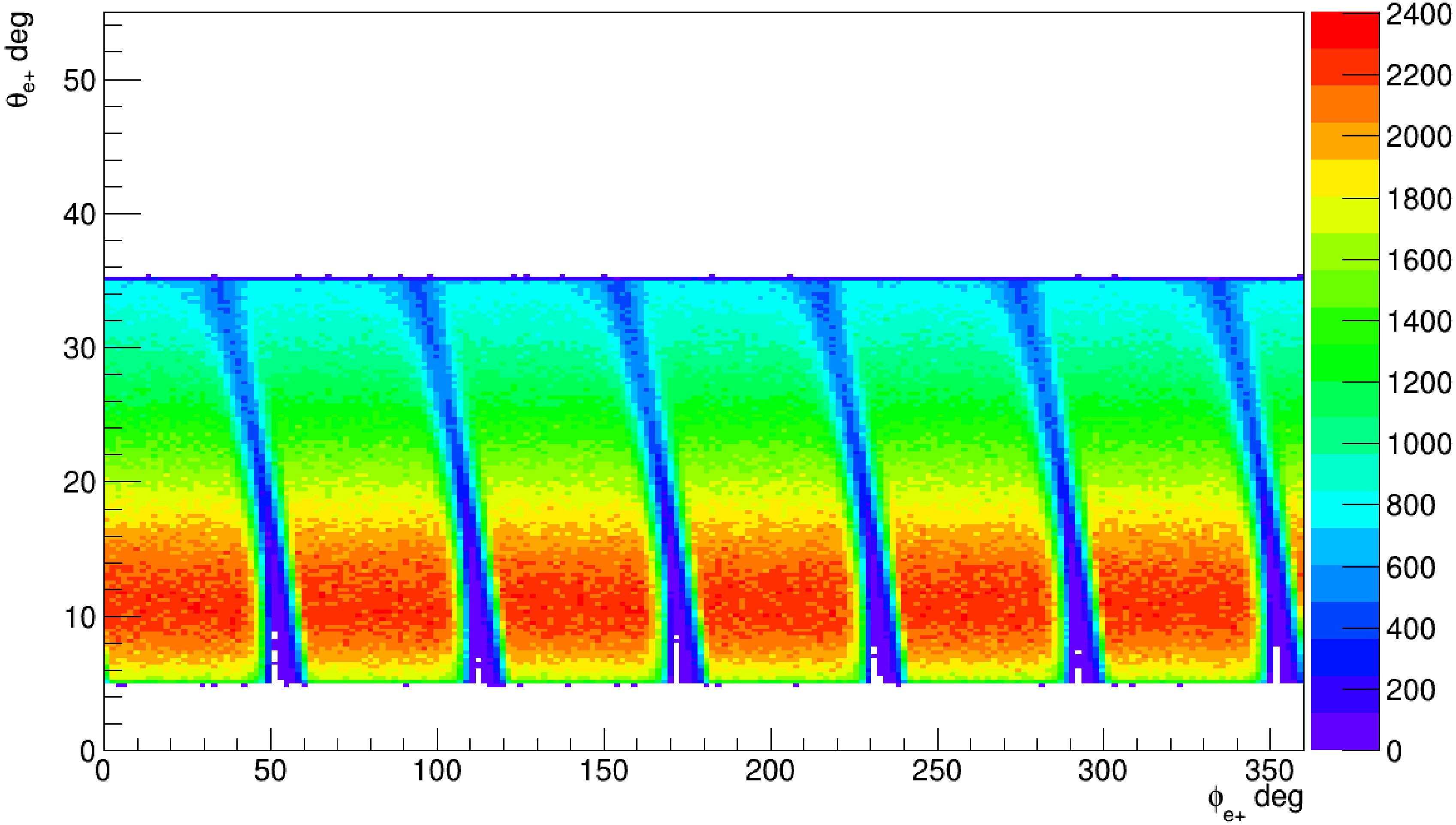
This is the formula, that we want to fit the experimental data, measured by the middle formula of previous slide. In a short notation it has f=P cos(φ) shape.

Where $P = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}} ReM^{--} \cdot \int_{\pi/4}^{3\pi/4}(1+cos^2\theta)d\theta$

From fit we get P, and M^{--} is obtained by

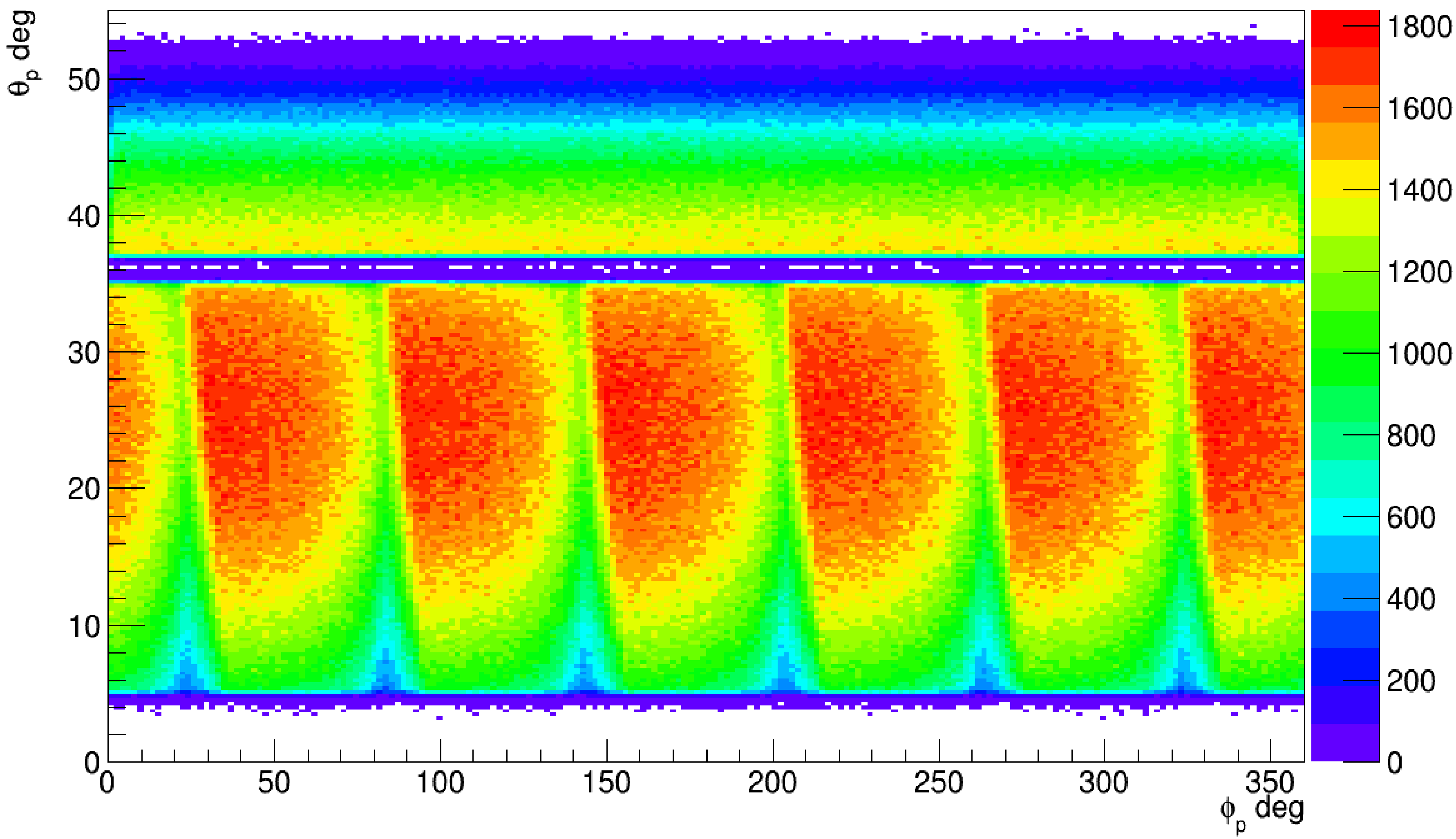
$$ReM^{--} = -\frac{P}{\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}} \cdot \int_{\pi/4}^{3\pi/4}(1+cos^2\theta)d\theta}$$

Positrons



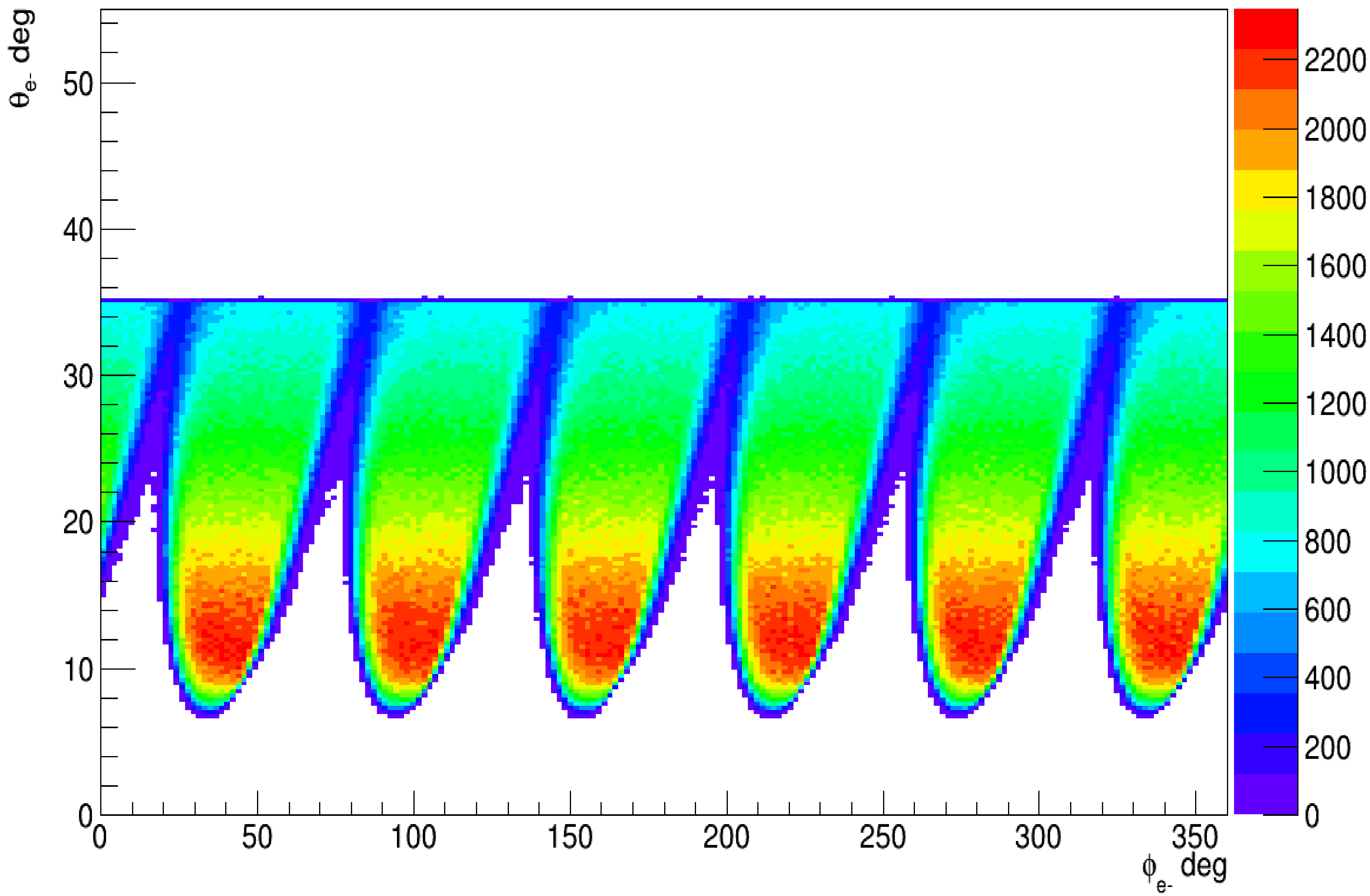
θ_{e+} deg
50
40
30
20
10
0
0
50
100
150
200
250
300
350
ϕ_{e+} deg
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0

Protons



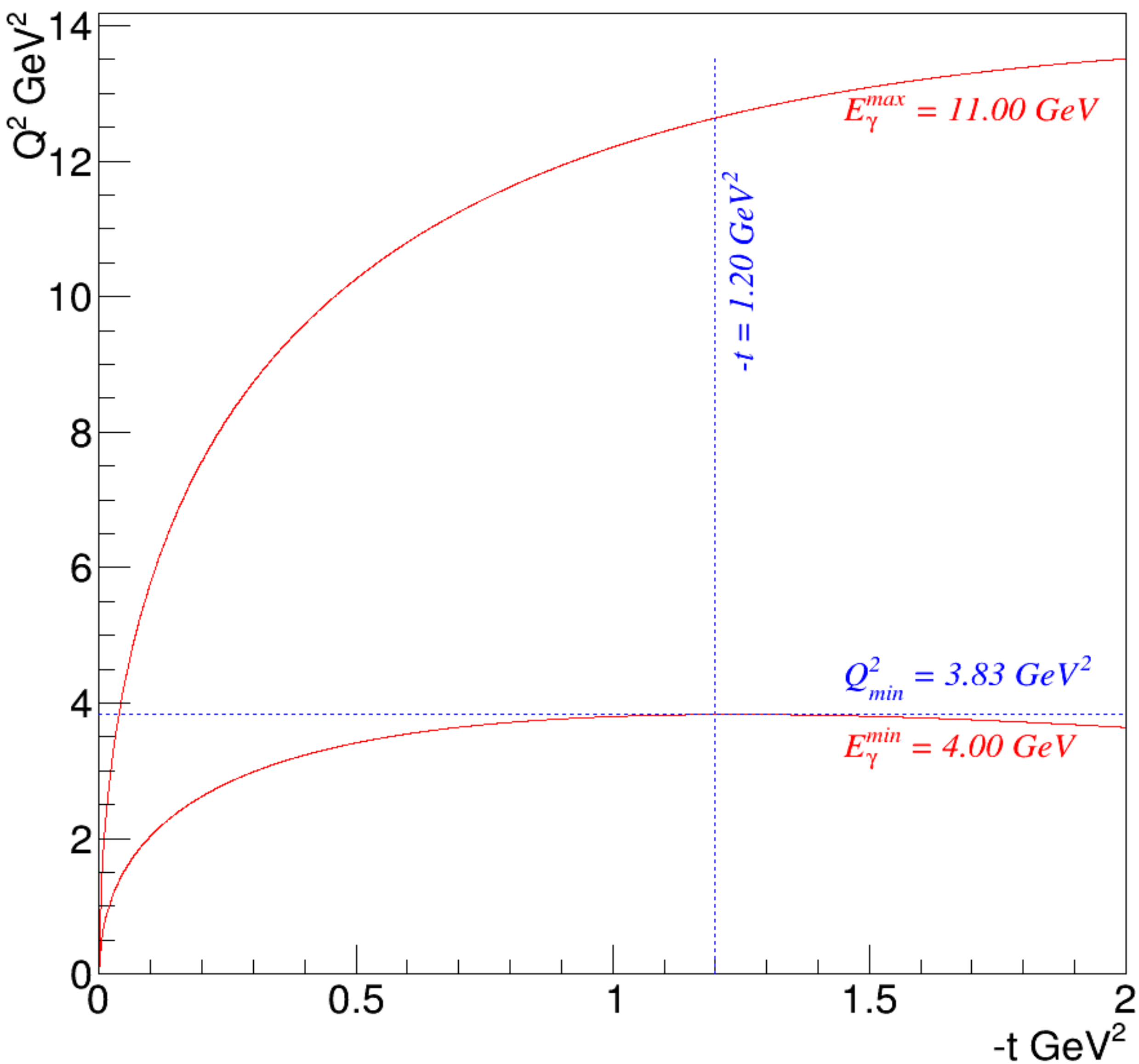
θ_p deg
0
10
20
30
40
50
0
50
100
150
200
250
300
350
ϕ_p deg
0
200
400
600
800
1000
1200
1400
1600
1800

Electrons



θ_{e-} deg
50
40
30
20
10
0
0
50
100
150
200
250
300
350
ϕ_{e-} deg
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0

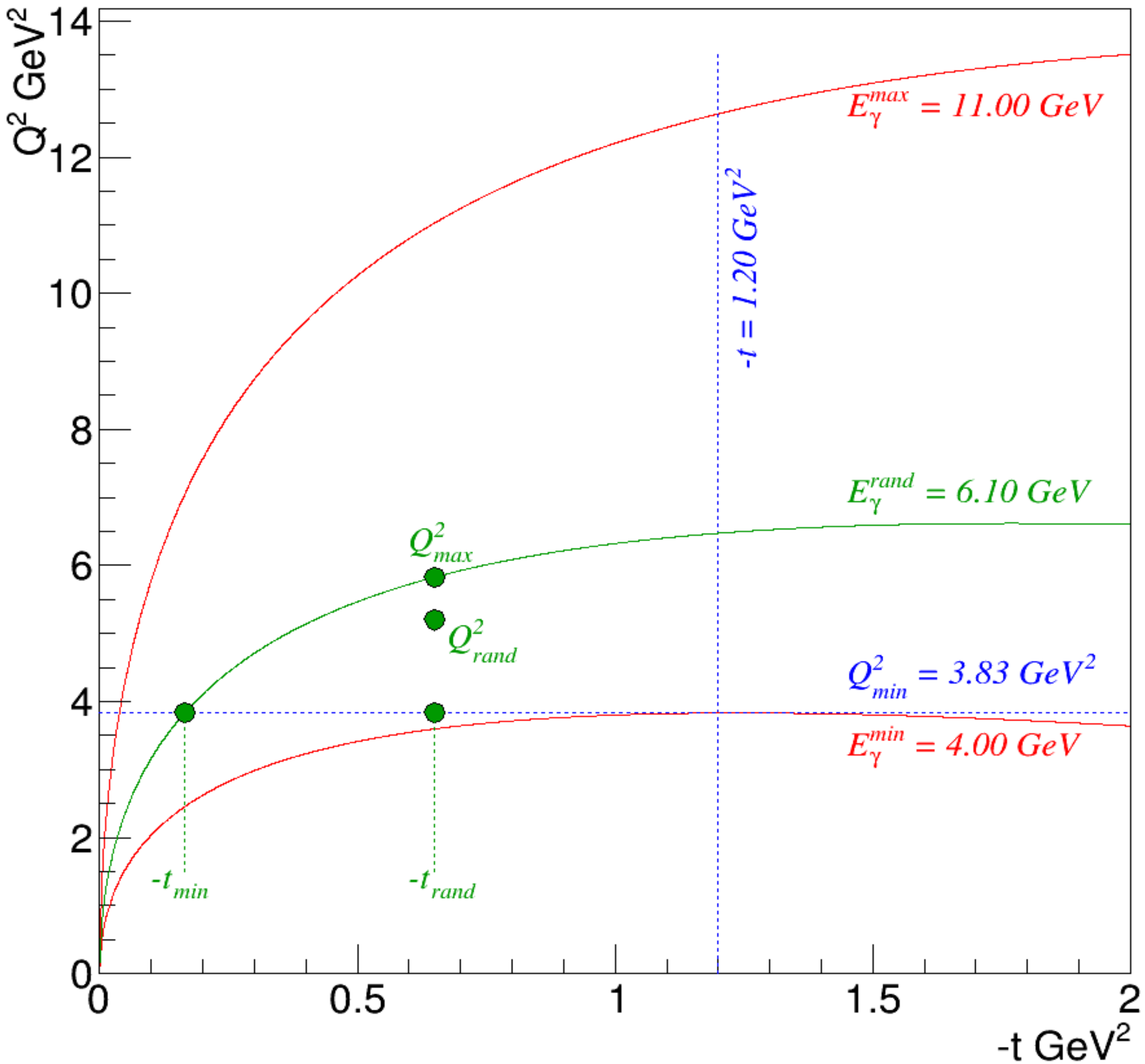
The plan is to generate $\gamma p \to \gamma^\star(\to e^- e^+)p$ reaction



2 steps

$$\gamma p \to \gamma^\star p$$

$$\gamma^\star \to e^- e^+$$



$$\gamma p \to \gamma^\star p$$

1) $E_\gamma \bullet (E_\gamma^{min} : E_\gamma^{max})$

2) $-t \bullet (-t_{min} : t_{lim})$

3) $Q^2 \bullet (Q^2_{min} : Q^2_{max})$

Having E_γ^{rand}, $-t_{rand}$ and Q^2_{rand}
$\gamma p \to \gamma^\star p$ is determined!

$\gamma^\star \to e^- e^+$ is trivial

1) $E^{CM}_{e^\pm} = \sqrt{Q^2}/2$

2) $\Phi^{CM} \bullet (0 : 2\pi)$

2) $cos(\Theta^{CM}) \bullet (-1 : 1)$

Boost all 4vectors
to the lab frame