

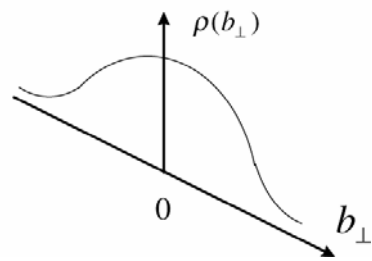
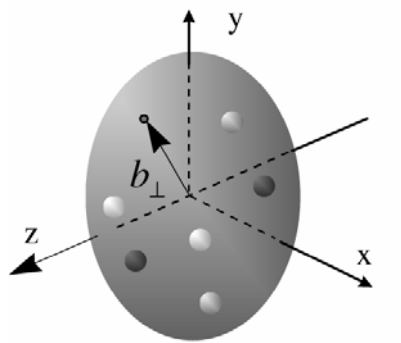
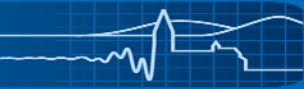


Study of Generalized Parton Distributions at Electron-Nucleon Collider (ENC) / GSI

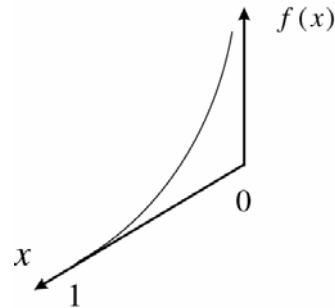
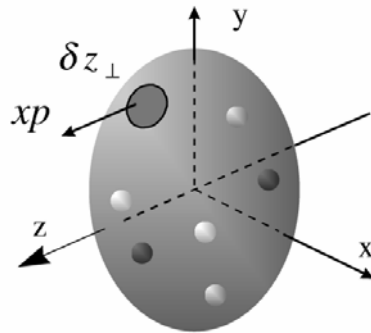
D. Kang (Universität Mainz)

- Introduction of GPDs
- Monte Carlo simulation for DVCS & BH
- Summary and Outlook

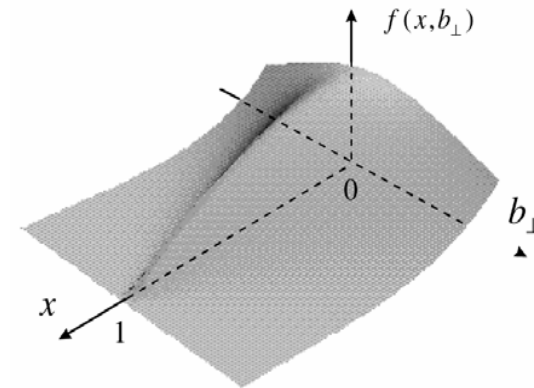
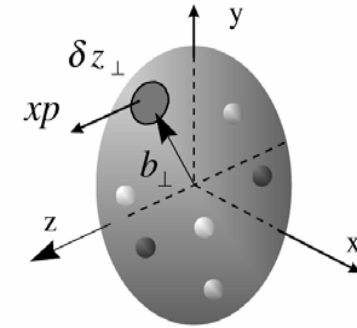
Generalized Parton Distributions



Form Factors via
Elastic scattering



Parton distribution via
Deep inelastic scattering



Generalized parton distribution
via Deeply exclusive scattering

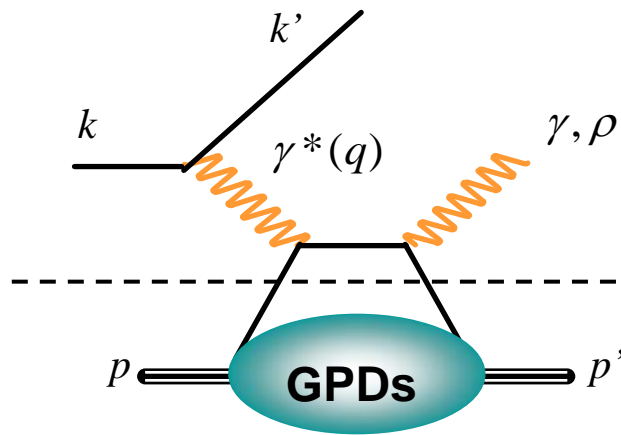
Two independent informations (b & x)
about the nucleon structure



a 3-dimensional picture
of the nucleon structure

How to access GPDs : DVCS

$ep \rightarrow ep\gamma(\rho)$: simplest hard exclusive process such as DVCS & HEMP



Perturbative description
(High Q^2 virtual photon)

Non perturbative can be described
by Generalized Parton Distributions
using pQCD factorization theorem,
factorization is valid only in Bjorken
regime i.e.,

4 GPDs :

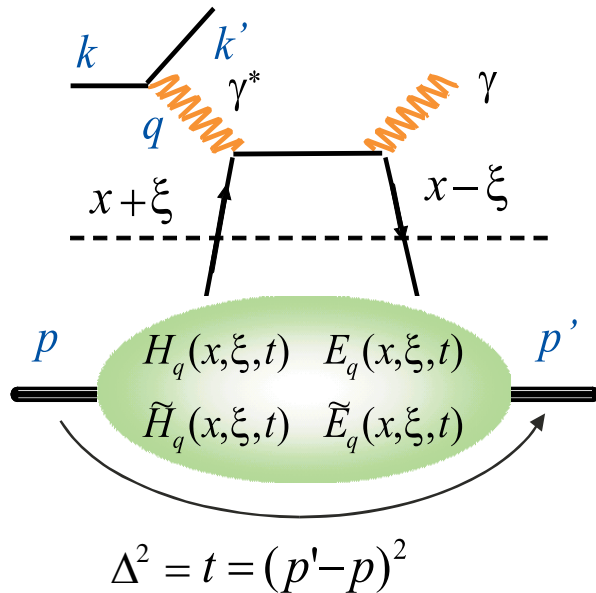
$$H^q, E^q, \tilde{H}^q, \tilde{E}^q(x, \xi, t)$$

For each quark flavor but
for gluon only in NLO or ρ

$$Q^2 = -(k - k')^2 \gg M^2$$
$$t = (p - p')^2 \ll Q^2$$

GPDs : coherent description of the nucleon

GPDs measure the **Coherence** $\Psi^*(x+\xi) \Psi(x-\xi)$ between a initial state with a quark carrying a fraction $x+\xi$ of the nucleon momentum and a final state with carrying $x-\xi$



- x : longitudinal momentum fraction of active quark, $x \neq x_{Bj}$
- ξ : longitudinal momentum fraction of the transfer Δ , $\xi = x_{Bj} / (2 - x_{Bj})$
- t : momentum transfer squared to the nucleon (fourier conjugate to the transverse impact parameter b)

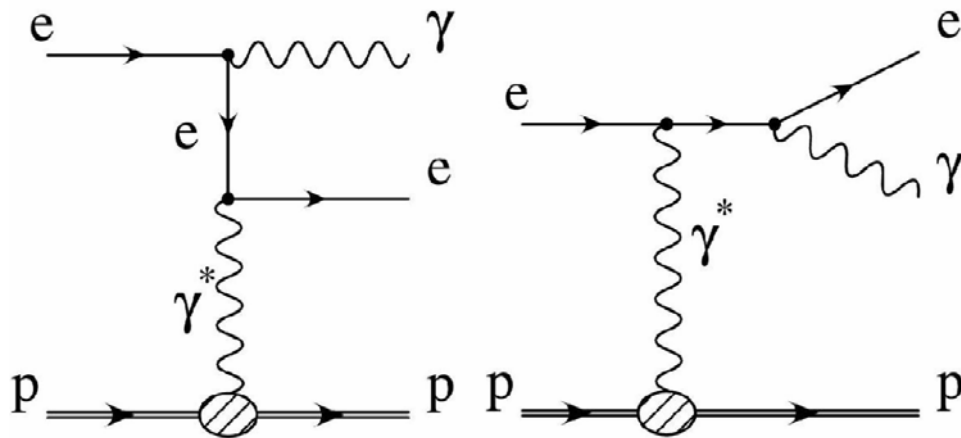
only ξ and t accessible experimentally: $\xi \sim x_{Bj}$

	proton helicity conserved	allowed helicity flip	E_q related to the angular momentum J_q (Ji's sum rule)
Unpolarised	H_q ,	E_q	
Polarised	\tilde{H}_q ,	\tilde{E}_q	

X. Ji, Phy.Rev.Lett.78,610(1997)

Experimental observables

Interference between QCD and QED gives access to the amplitude of DVCS via ϕ_γ asymmetry of differential cross section :



DVCS final state is indistinguishable from the Bethe-Heitler QED process

@ Manuel, COMPASS

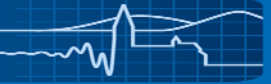
$$|T_{DVCS}|^2 \ll |T_{BH}|^2$$

$$\frac{d^4\sigma_{(ep \rightarrow ep\gamma)}}{dx_{Bj} dQ^2 dt d\phi} \propto |T_{DVCS} + T_{BH}|^2 = |T_{DVCS}|^2 + |T_{BH}|^2 + \boxed{T_{DVCS} T_{BH}^* + T_{DVCS}^* T_{BH}}$$

GPDs accessible through *cross-section differences* via interference

T_{Int} leads to non-zero ϕ_γ asymmetry

DVCS @ amplitude level



The GPDs enter the DVCS amplitude as an integral over x :

$$T_{(ep \rightarrow ep\gamma)}^{DVCS} = \int_{-1}^1 dx \frac{GPD(x, \xi, t)}{x - \xi + i\varepsilon} = P \int_{-1}^1 dx \frac{GPD(x, \xi, t)}{x - \xi} - i\pi GPD(x = \xi, \xi, t)$$

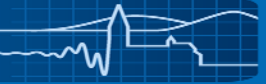
The real part of amplitude T depends on the integral of GPD over x

The imaginary part of amplitude T probes GPD at $x = \xi$

The parameterization of GPD will be determined by a fit to the data

Structure of differential cross section including lepton polarization (unpolarized proton) :

$$d\sigma_{ep \rightarrow ep\gamma} = d\sigma_{BH} + d\sigma_{DVCS}^{unpol} + P_l d\sigma_{DVCS}^{pol} + e_l \underline{d\sigma_{INT}^{even}} + P_l e_l \underline{d\sigma_{INT}^{odd}}$$
$$\propto \text{Re}T \cdot \cos\phi \quad \propto \text{Im}T \cdot \sin\phi$$



To separate interference and DVCS need combined analysis of charge & polarization dependent data :

Beam-Charge Asymmetry (BCA)

$$d\sigma_{e^+} - d\sigma_{e^-} \propto \text{Re}T \cos \phi \longrightarrow H$$

Beam-Spin Asymmetry (BSA)

$$d\sigma_{e \rightarrow} - d\sigma_{e \leftarrow} \propto \sigma_{DVCS}^{pol} - \text{Im}T \sin \phi \longrightarrow H$$


Need e+ and e- to separate $\text{Im}T \sin \phi$ from σ_{DVCS}^{pol}

Longitudinal and Transverse Proton Spin Asymmetries are also needed to get a complete information about all other GPD components :

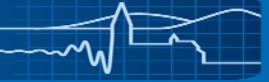
Transverse Proton Spin Asymmetry (TPSA)

$$d\sigma_{p \uparrow} - d\sigma_{p \downarrow} \propto \text{Im}[F_2 H - F_1 E] \sin(\phi - \phi_s) \cos \phi \longrightarrow E$$

TPSA is only asymmetry where GPD E is not suppressed



2. Monte Carlo simulation for
DVCS, BH and Interference
with panda detector



Generator of $ep \rightarrow ep\gamma$: HEPGEN using in COMPASS

DVCS + BH + Int

by Frankfurt, Freund and Strikman model (hep-ph/9710356) based on two gluon exchange

$d\sigma_{DVCS}$ is parameterized in terms of DIS differential cross section, for t distribution slope $b = 5.0 \text{ GeV}^{-2}$

Events are generated with $E_e = 96 \text{ GeV}$ in fixed target mode, then final state are translated into the collider mode

Event weights is proportional to the differential cross section

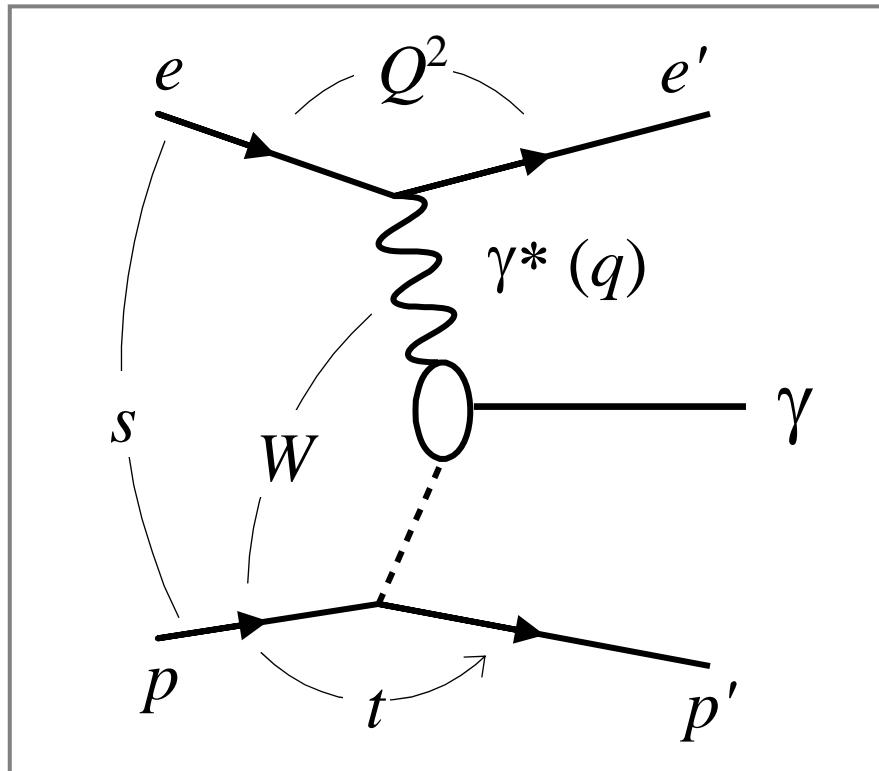
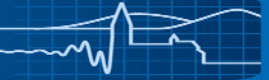
$$\frac{d\sigma^{\text{DVCS}}}{dx dy dt d\phi_r} \sim \frac{1}{Q^6} e^{-b|t|} F_2^2(x, Q^2) (1 + \eta^2)$$

$$\eta = \frac{\text{Re}(A(\gamma^* p \rightarrow \gamma p))}{\text{Im}(A(\gamma^* p \rightarrow \gamma p))}$$

$$\frac{d\sigma^{\text{BH}}}{dx dy dt d\phi_r} \sim \frac{1}{Q^4} \frac{1}{|t|}$$

$$\frac{d\sigma^{\text{INT}}}{dx dy dt d\phi_r} \sim \pm \frac{1}{Q^{5/2}} \eta \frac{e^{-b|t|/2}}{\sqrt{|t|}} \cos \phi_r$$

$$\phi_r = \phi'_e - \phi'_p$$



Kinematic variables

$$s = (k + p)^2$$

$$W^2 = (q + p)^2 = Q^2(1-x)/x$$

$$Q^2 = (-q^2) = -(k - k')^2 = sxy$$

$$x_{Bj} = Q^2 / p \cdot q$$

$$y = p \cdot q / p \cdot k$$

$$t = (p - p')^2$$

$$E_p = 15 \text{ GeV}, E_e = 3 \text{ GeV}$$

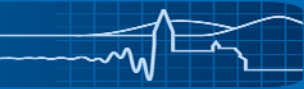
$$s = 2(E_e E_p + |\vec{p}_e \parallel \vec{p}_p|) + m_e^2 + m_p^2$$

$$\approx 180 (\text{GeV}/c^2)^2$$

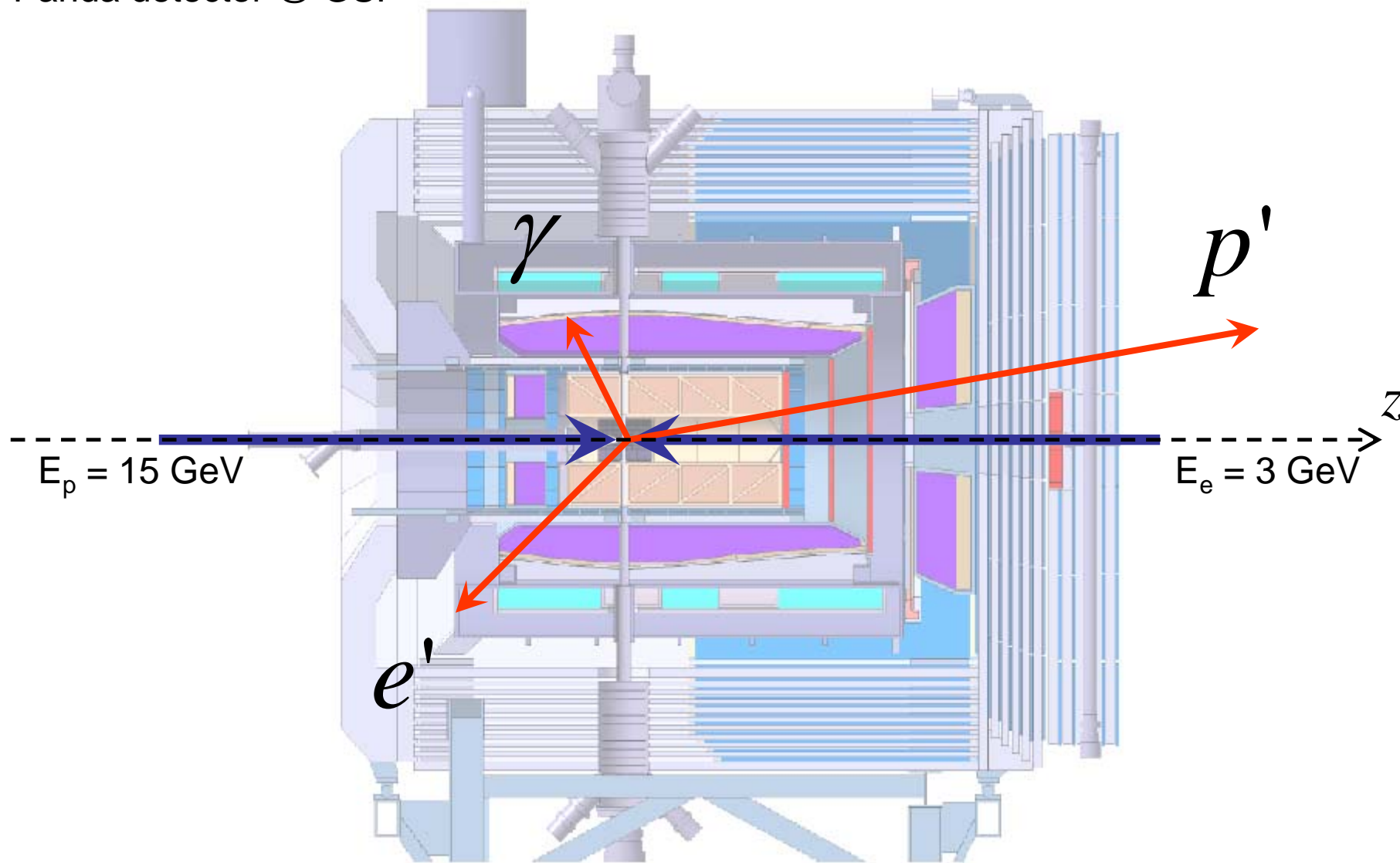
Kinematic cuts

- $Q^2 > 1 (\text{GeV}/c^2)^2$
- $0.001 < x_{Bj} < 0.999$
- $0.001 < y < 0.999$
- $0.001 < |t| < 2.0 (\text{GeV}/c^2)^2$

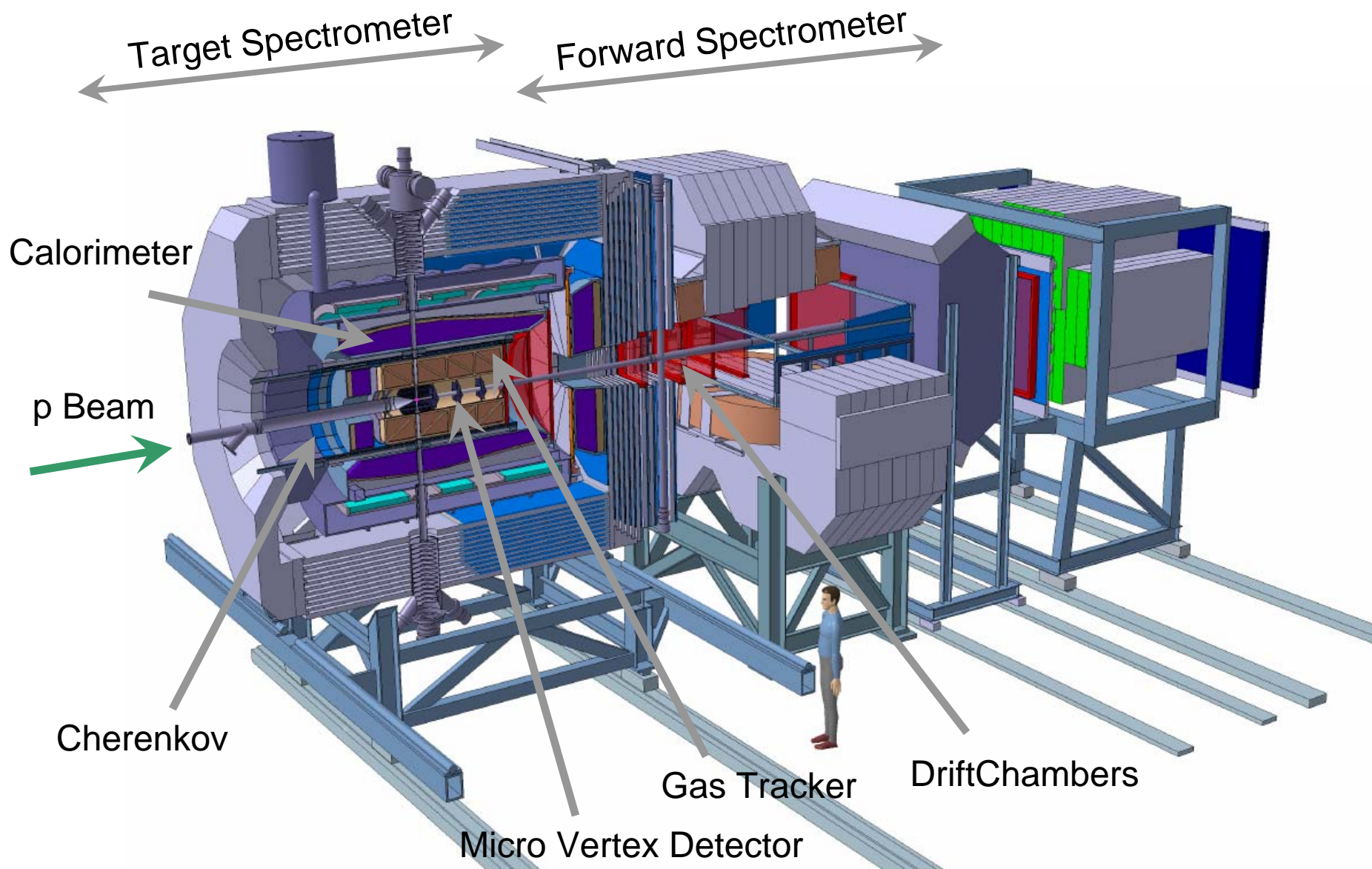
Panda spectrometer

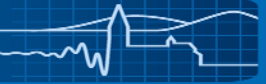


Panda detector @ GSI



Panda spectrometer





Detector setup

Target Spectrometer :

EMC-Barrel	: $22^\circ < \theta < 140^\circ$
EMC-Forward	: $5^\circ < \theta < 22^\circ$
EMC-Backward	: $140^\circ < \theta < 170^\circ$
Micro Vertex	: $10^\circ < \theta < 170^\circ$
Drift Chamber	: $0.5^\circ < \theta < 22.0^\circ$
TPC	: $7.8^\circ < \theta < 160^\circ$
Chrenkov-Barrel	: $22^\circ < \theta < 140^\circ$
Chrenkov-Disc	: $5^\circ < \theta < 22$
ToF	: $22^\circ < \theta < 140^\circ$

Forward Spectrometer :

EMC-Forward	: $0.05^\circ < \theta < 5.0^\circ$
Muon Detector	: $0.5^\circ < \theta < 10.0^\circ$

Dedicated detection of 3 particles

Each detector have a
arbitrary resolution :

$$\Delta p/p \sim 0.01$$

$$\Delta \phi/\phi \sim 0.01$$

$$\Delta \theta/\theta \sim 0.01$$

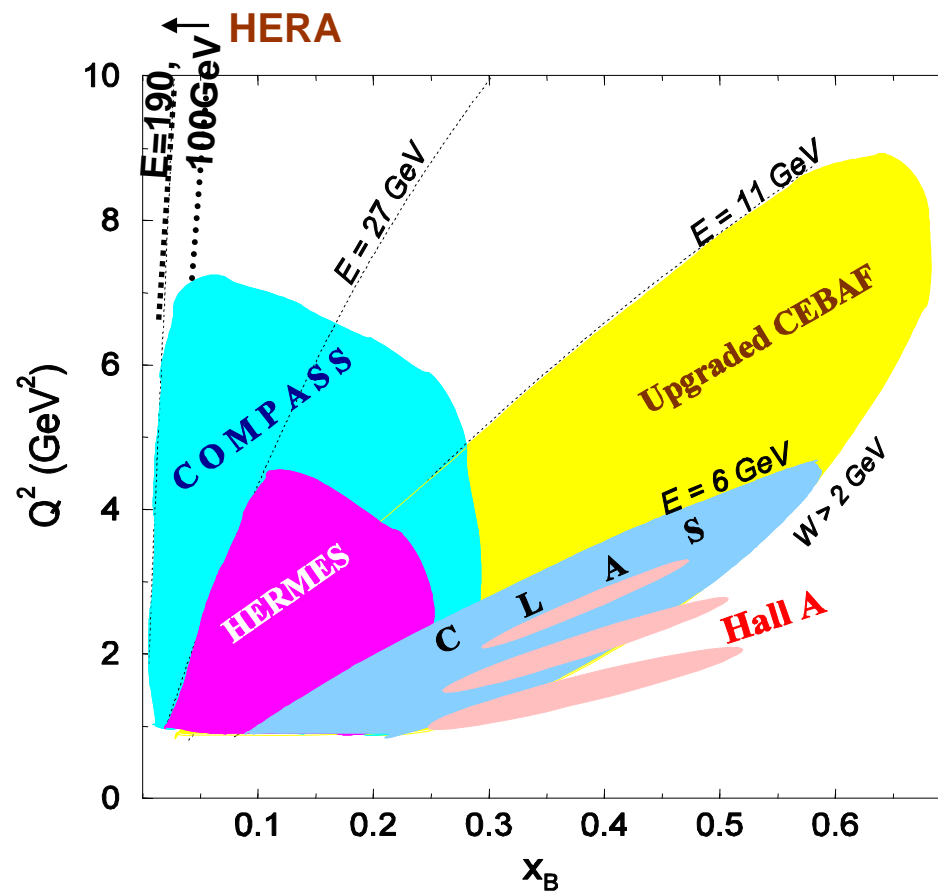
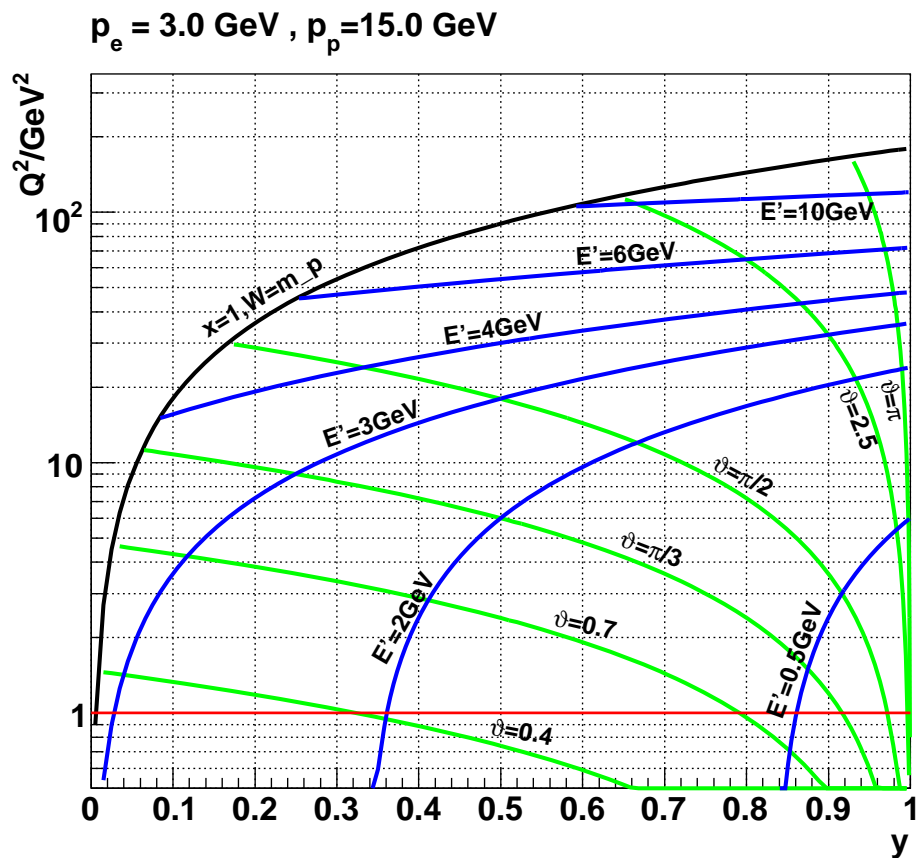
$$\Delta dE/dx \sim 0.25$$

photon to be seen
in ECALs, $E_\gamma > 0.01$ GeV

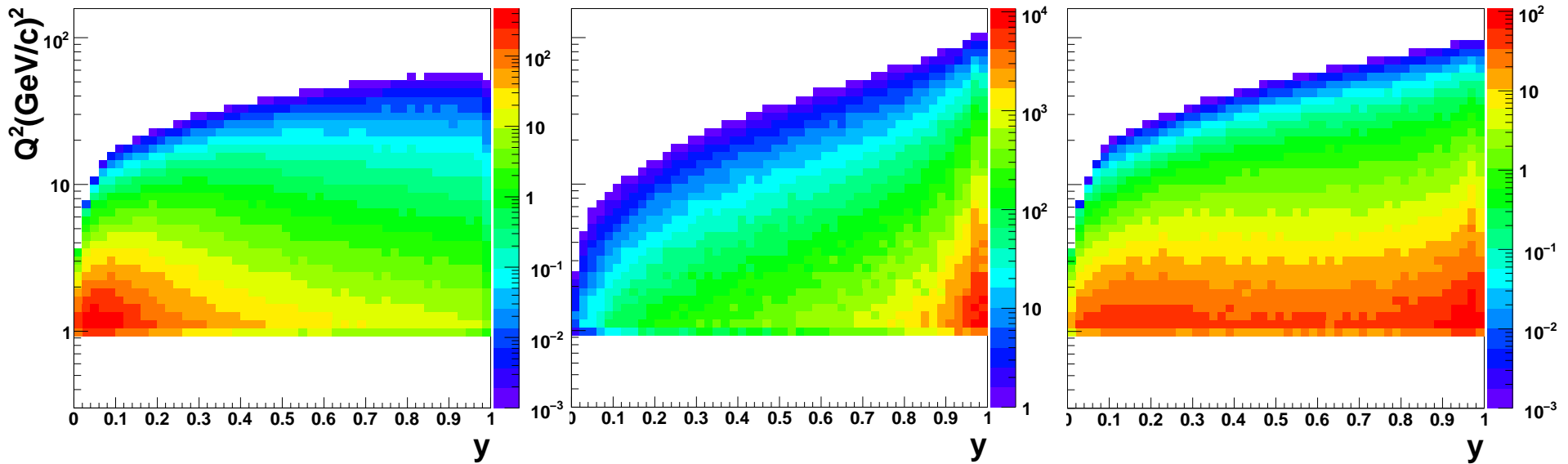
scattered electron and proton
pass through tracking and PID
detectors

no magnet field in the fast
simulation for the moment

Kinematic coverage



Kinematics for DVCS & BH



DVCS ~ 20,000

BH ~ 446,000

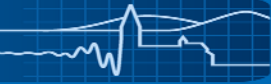
Int ~ 16,000

Kinematic domains are completely different

$N_{\text{Bethe-Heitler}} \gg N_{\text{DVCS}} : \text{Ratio}(N_{\text{BH}}/N_{\text{DVCS}}) \sim 22$

Interference term is plotted by $|d\sigma_{\text{INT}}(\cos\phi)|$

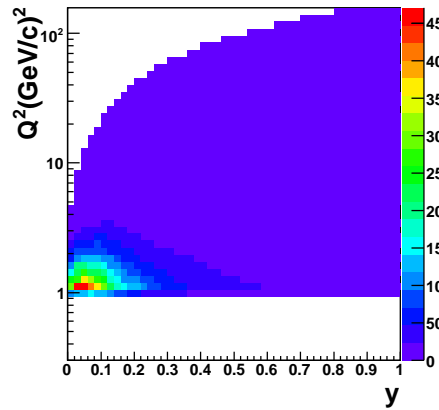
Kinematics for DVCS & BH



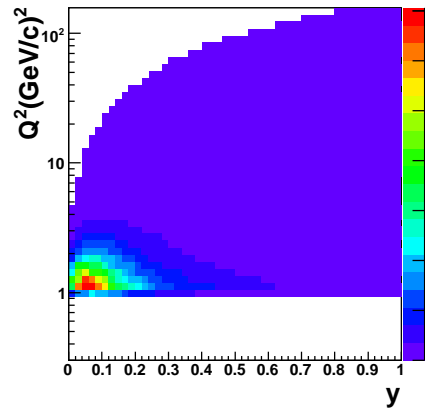
DVCS

Bethe-Heitler

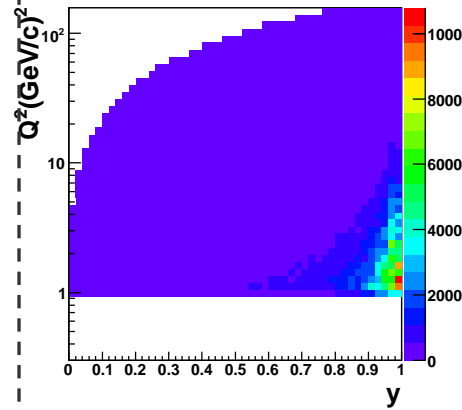
Generated



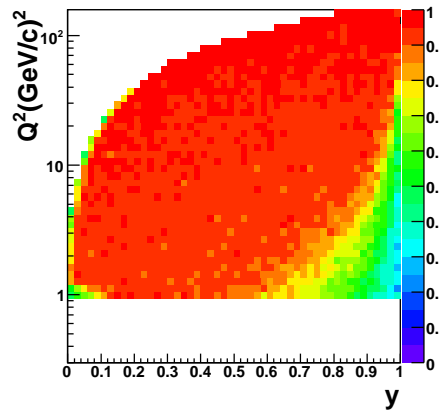
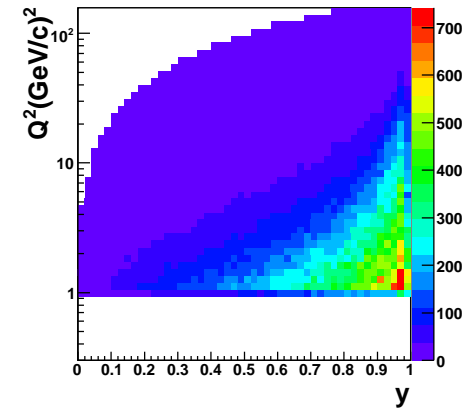
Reconstructed



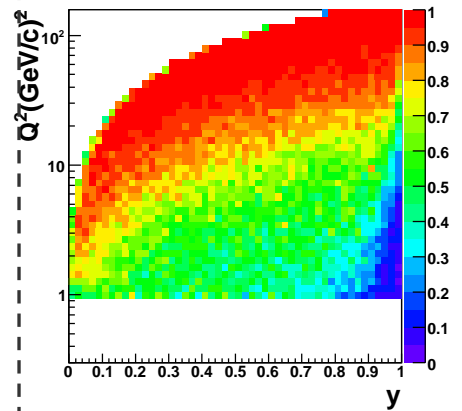
Generated



Reconstructed

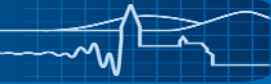


Acc(Rec/Gen)



Acc(Rec/Gen)

Kinematics for DVCS & BH



DVCS

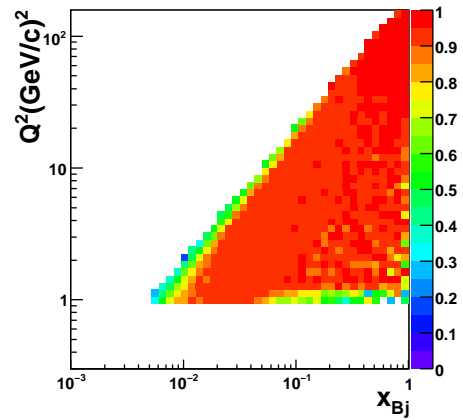
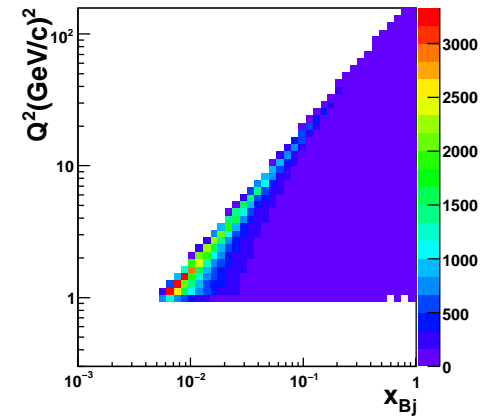
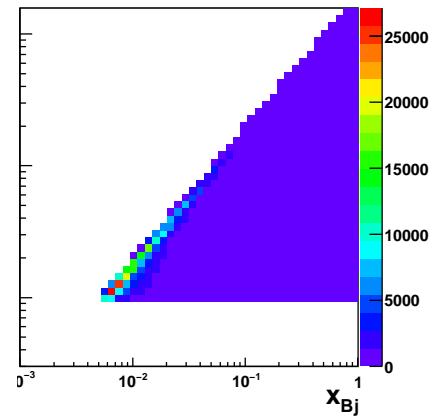
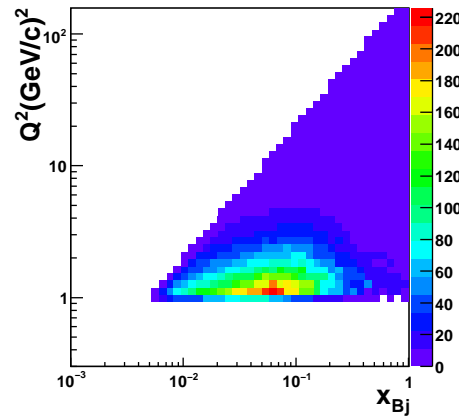
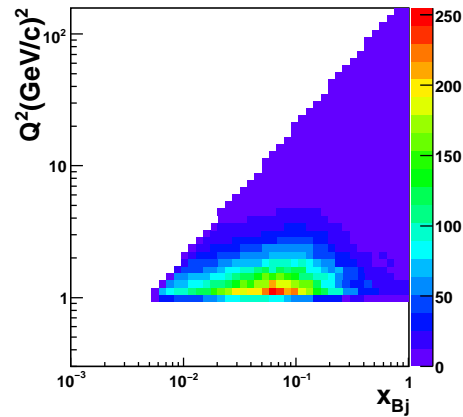
Bethe-Heitler

Generated

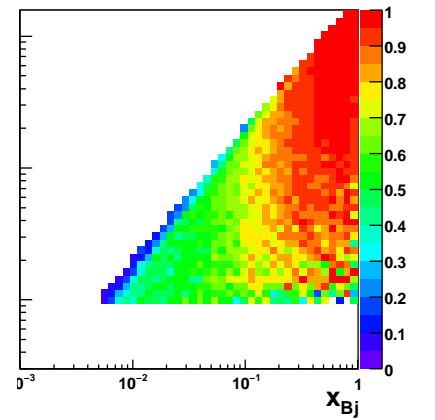
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Generated

Reconstructed

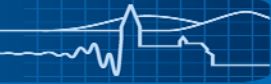


Acc(Rec/Gen)



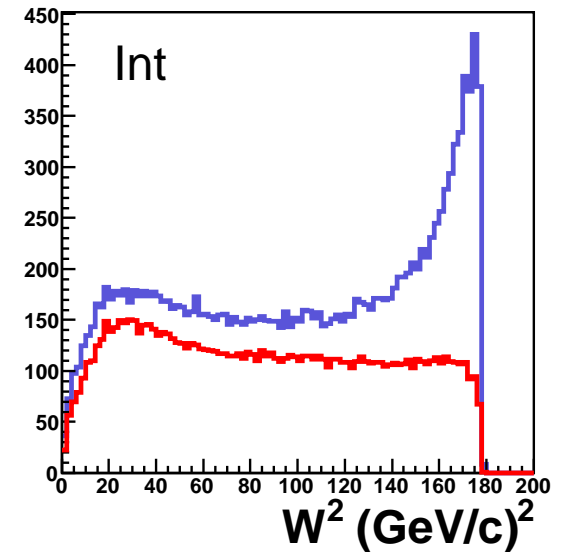
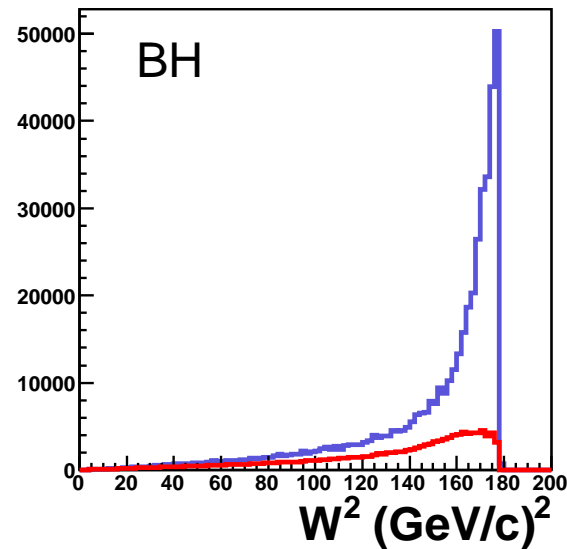
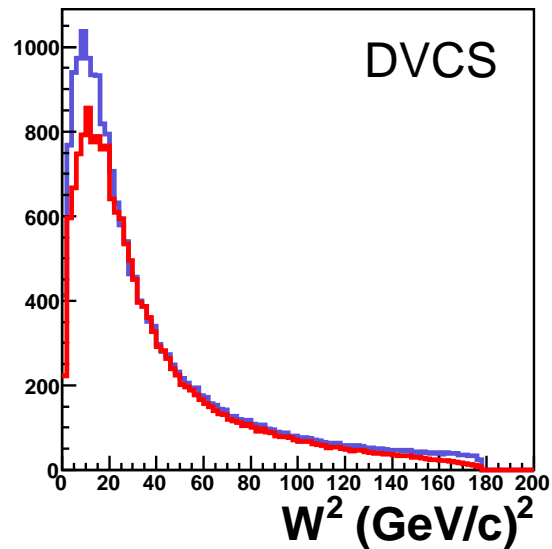
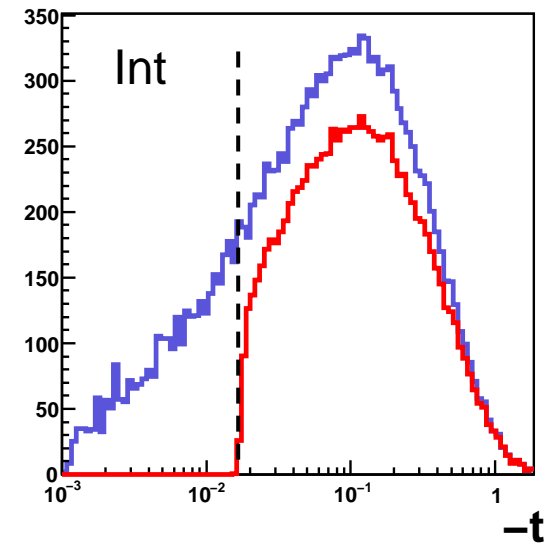
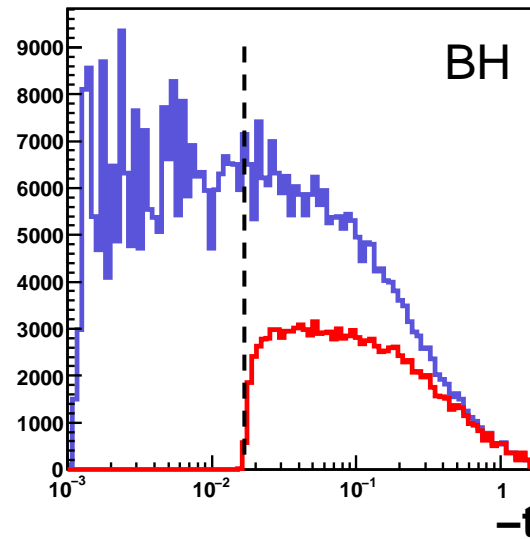
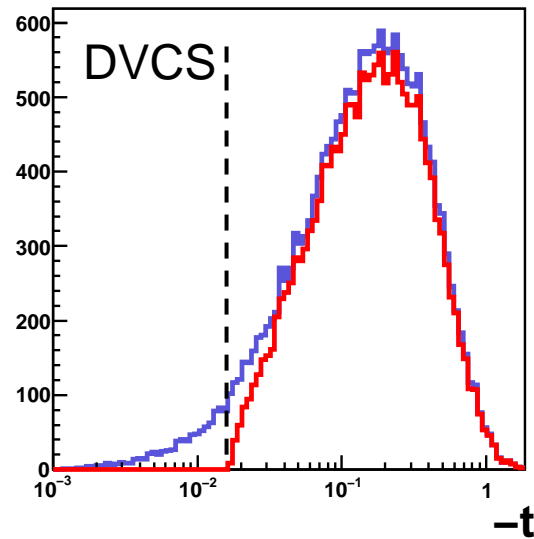
Acc(Rec/Gen)

Kinematics for DVCS & BH



$-|t|$ and W^2 distributions

— Gen.
— Rec.

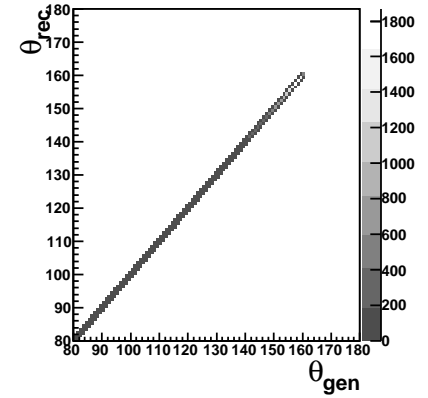
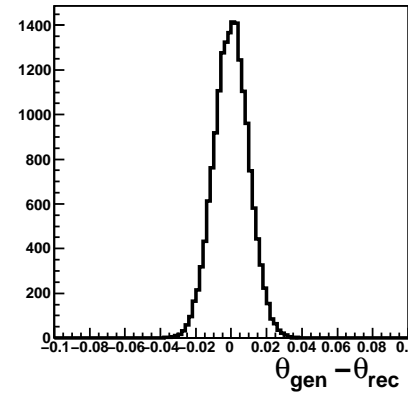
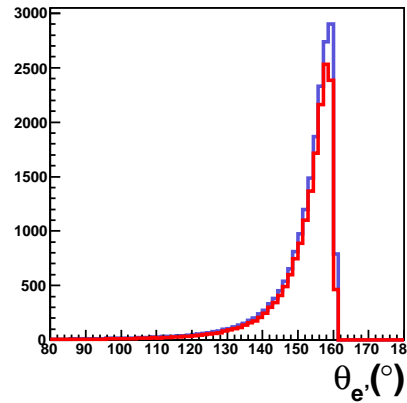


Particle Information for DVCS & BH

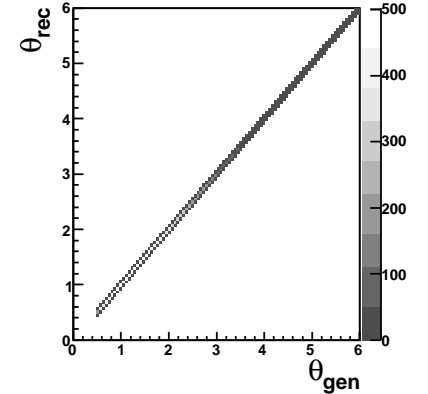
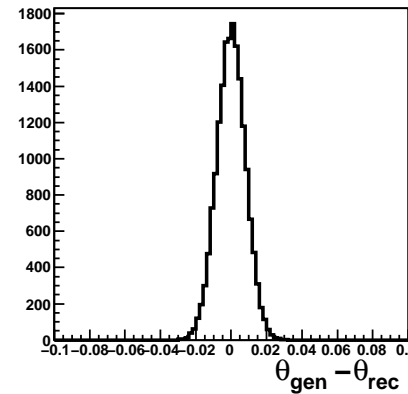
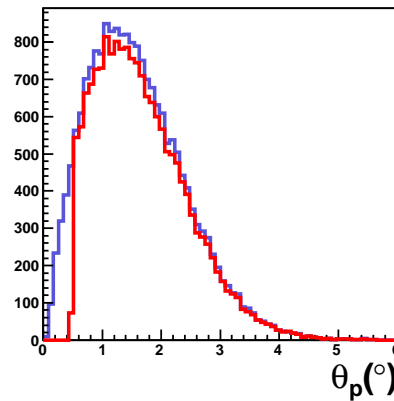
DVCS : θ_{Lab} distributions

— Gen.
— Rec.

e



p



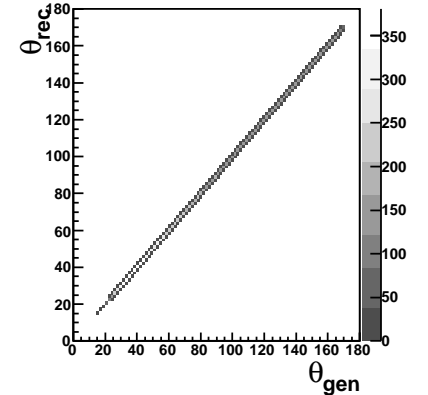
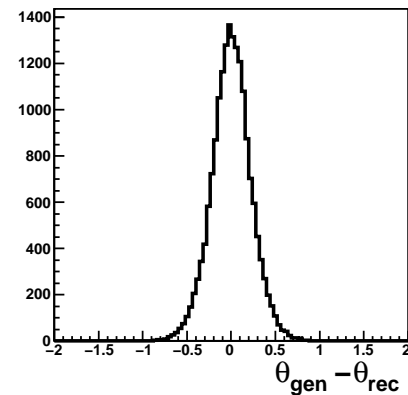
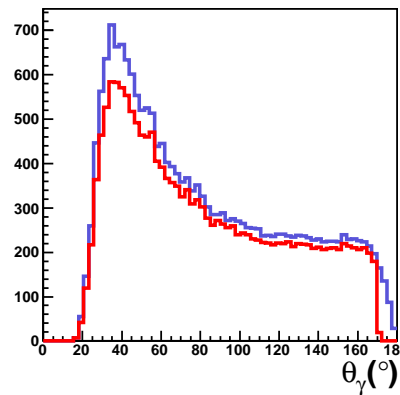
Resolution :

$$\Delta\theta_{e'} / \theta_{e'} \sim 0.01$$

$$\Delta\theta_p / \theta_p \sim 0.01$$

$$\Delta\theta_\gamma / \theta_\gamma \sim 0.01$$

γ

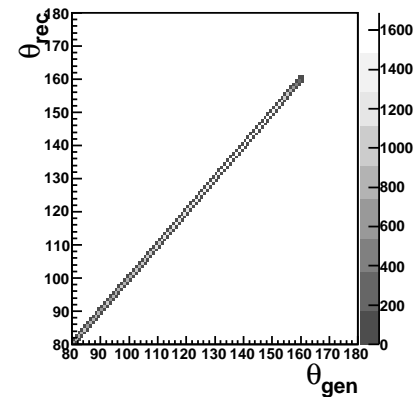
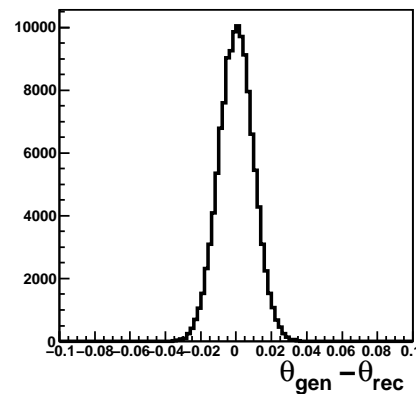
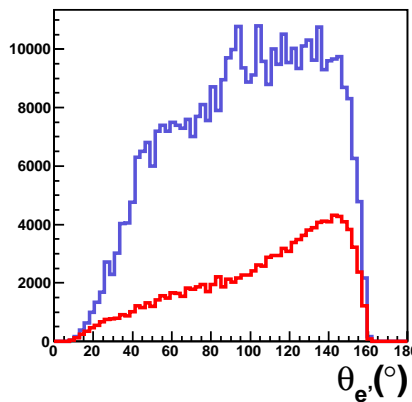


Particle Information for DVCS & BH

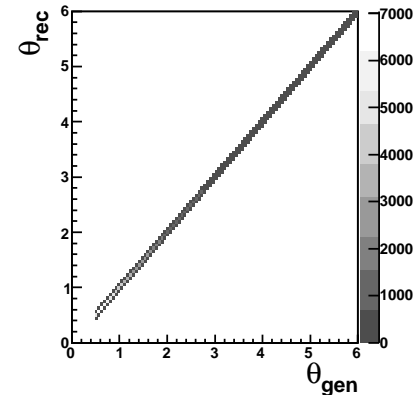
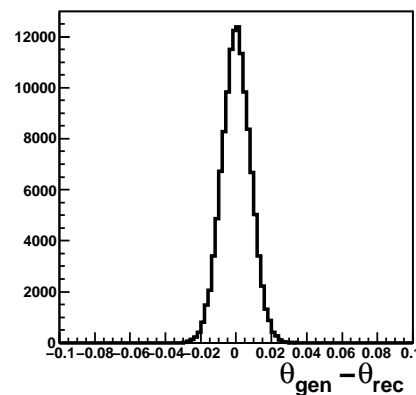
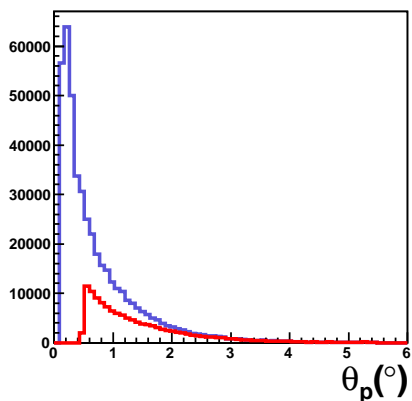
BH : θ_{Lab} distributions

— Gen.
— Rec.

e



p



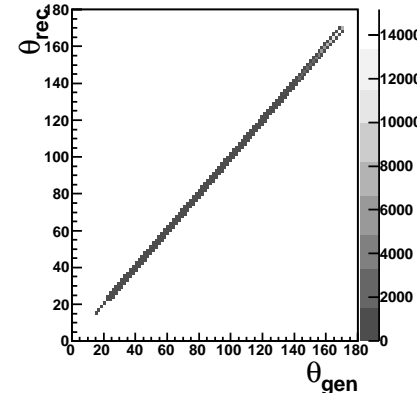
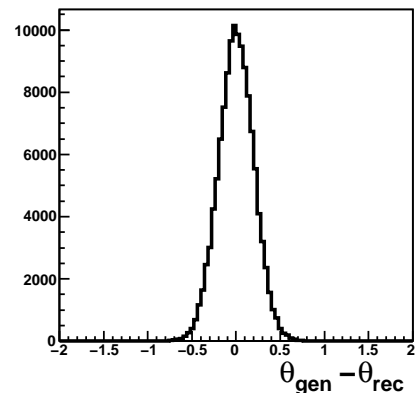
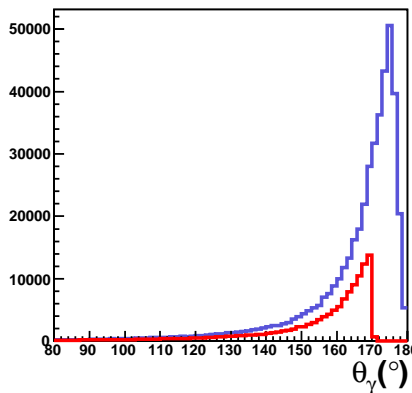
Resolution :

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$$\Delta\theta_\gamma / \theta_\gamma \sim 0.01$$

γ

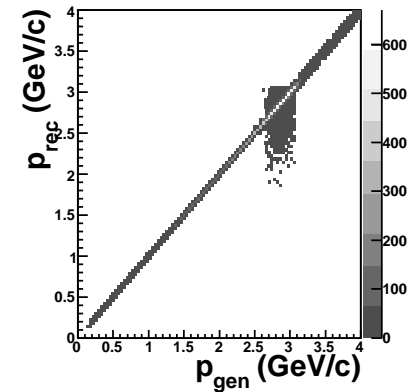
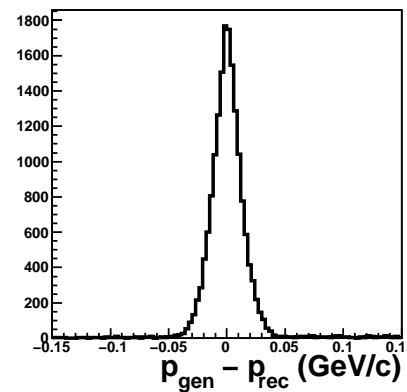
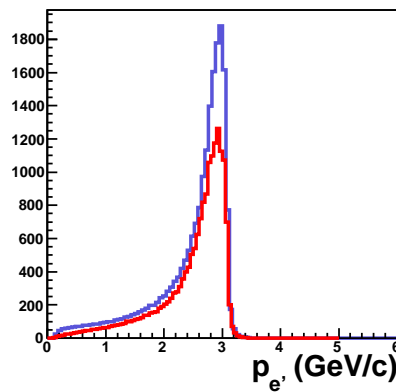


Particle Information for DVCS & BH

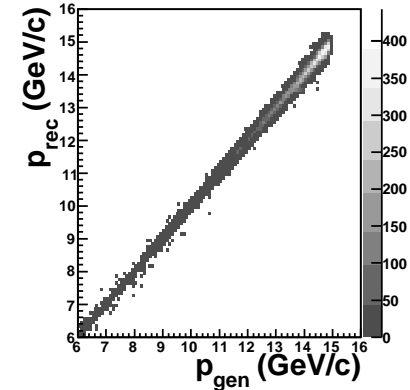
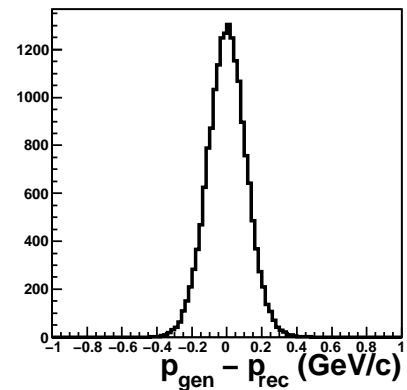
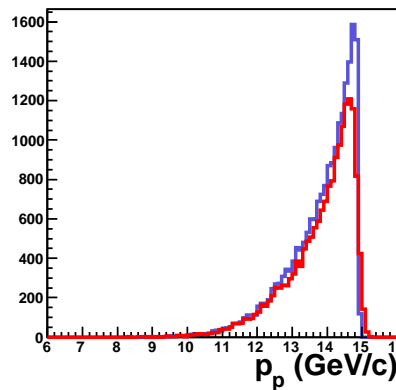
DVCS : p distributions

— Gen.
— Rec.

e



p



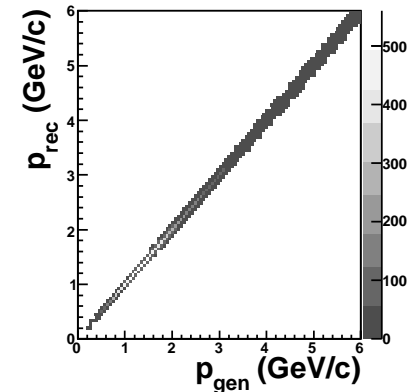
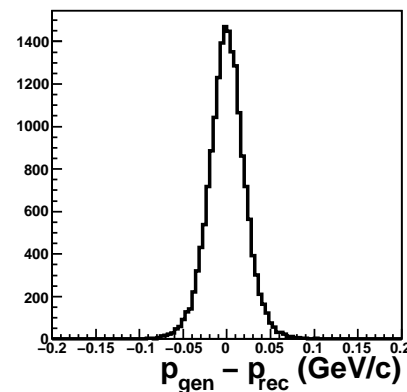
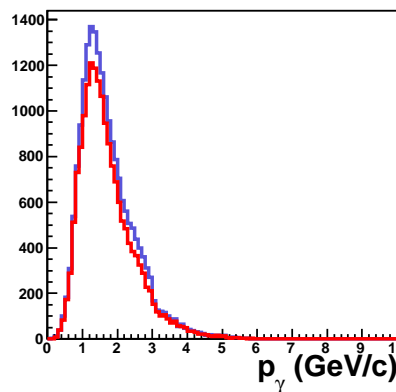
Resolution :

$$\Delta p_{e'} / p_{e'} \sim 0.01$$

$$\Delta p_p / p_p \sim 0.01$$

$$\Delta p_\gamma / p_\gamma \sim 0.01$$

γ

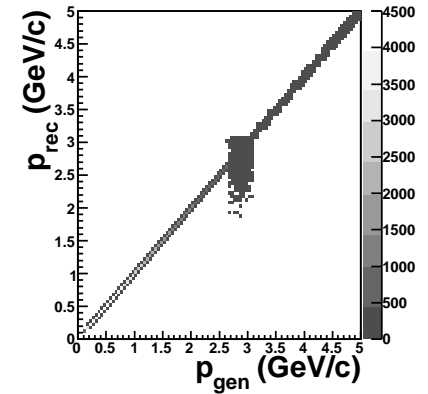
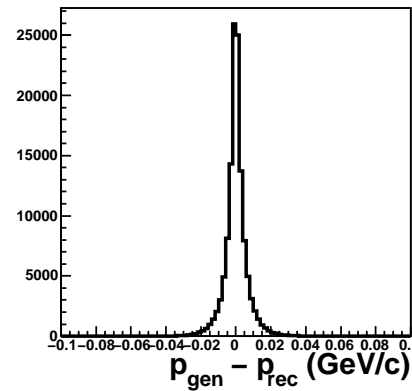
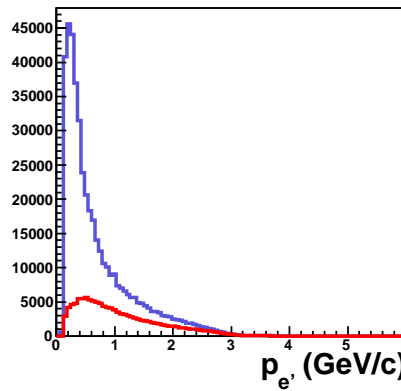


Particle Information for DVCS & BH

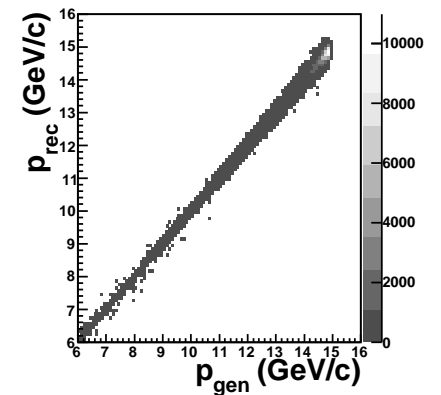
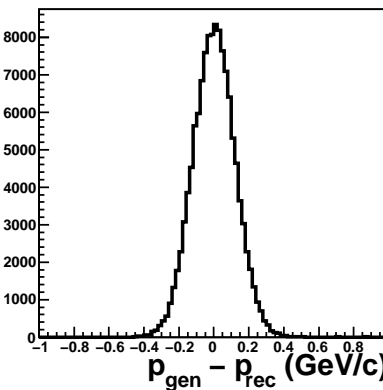
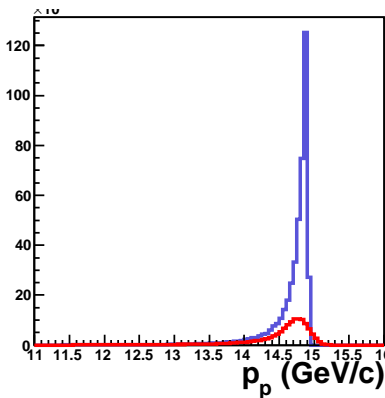
BH : p distributions

— Gen.
— Rec.

e



p



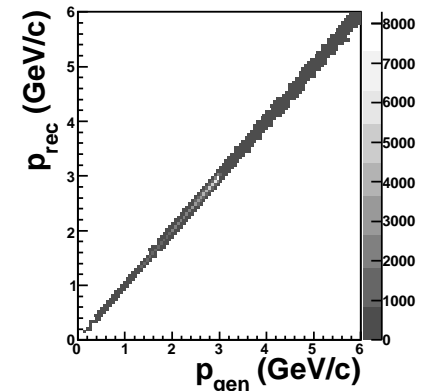
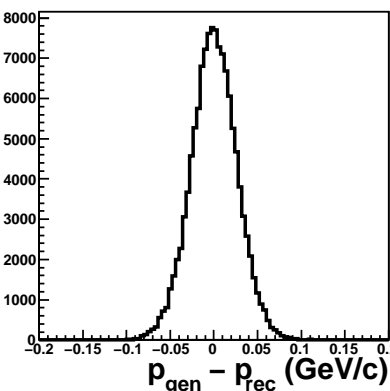
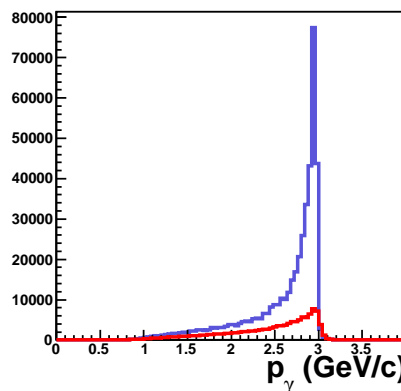
Resolution :

$$\Delta p_{e'} / p_{e'} \sim 0.01$$

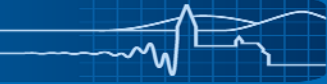
$$\Delta p_p / p_p \sim 0.01$$

$$\Delta p_\gamma / p_\gamma \sim 0.01$$

\gamma



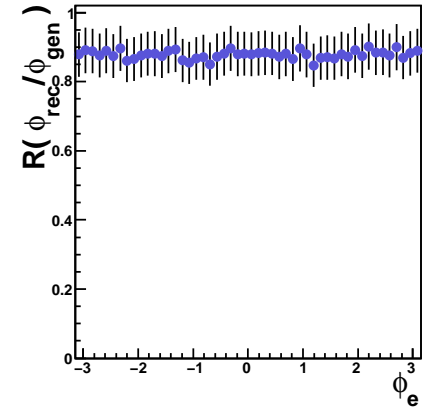
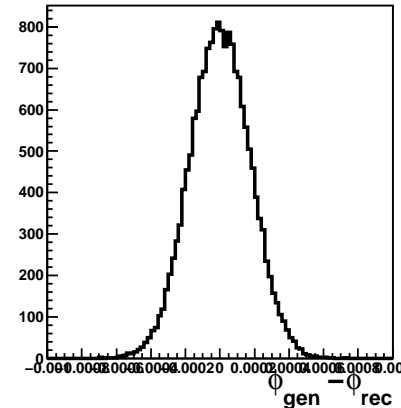
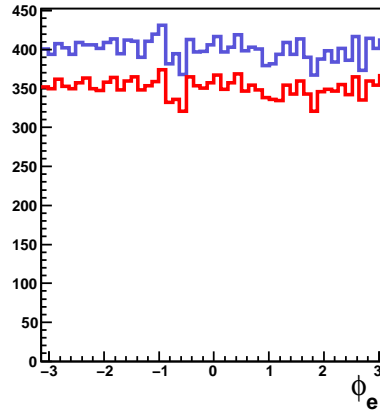
Particle Information for DVCS & BH



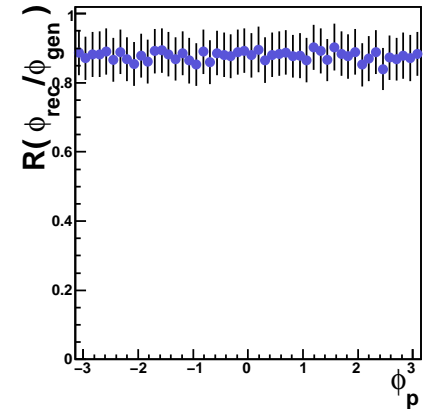
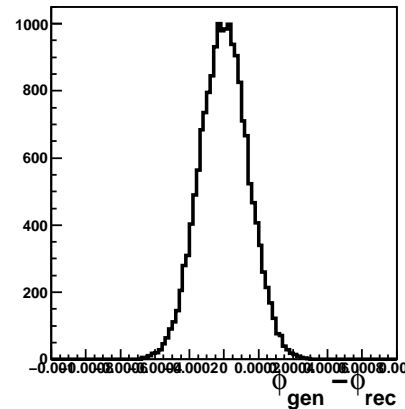
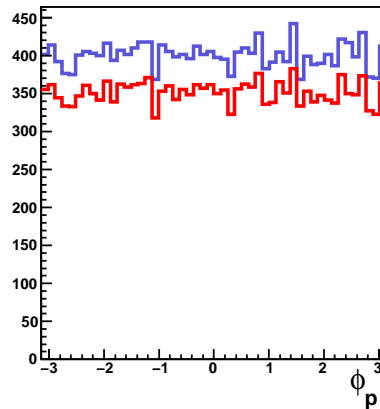
DVCS : ϕ_{Lab} distributions

— Gen.
— Rec.

e



p



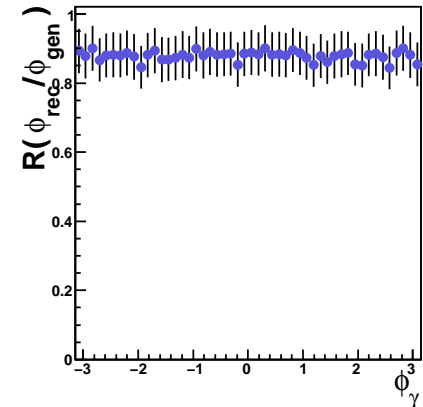
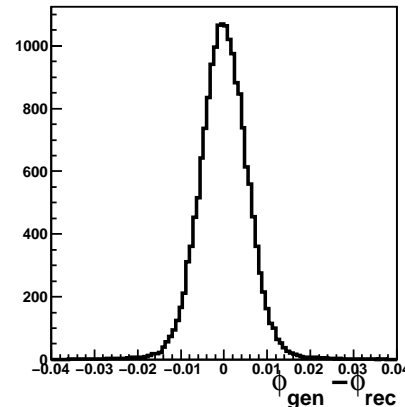
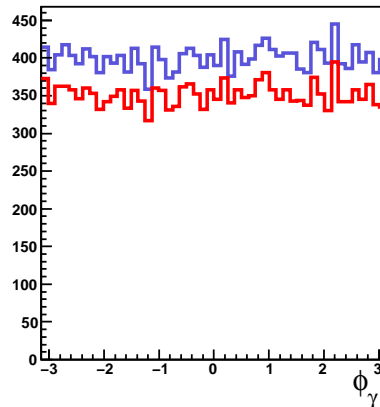
Resolution :

$$\Delta\phi_{e'} / \phi_{e'} \sim 0.01$$

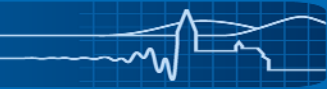
$$\Delta\phi_p / \phi_p \sim 0.01$$

$$\Delta\phi_\gamma / \phi_\gamma \sim 0.01$$

γ



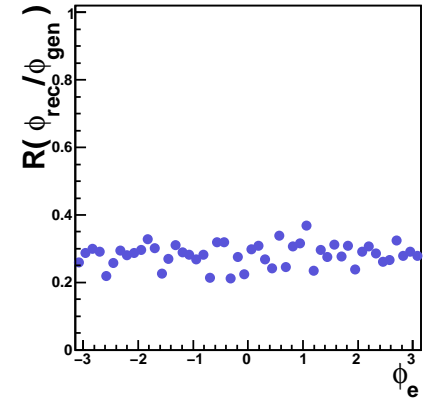
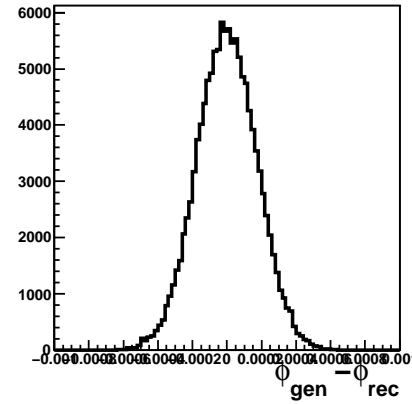
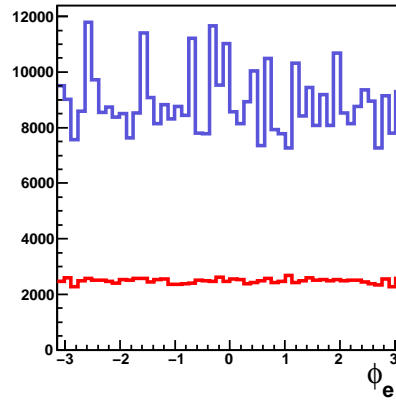
Particle Information for DVCS & BH



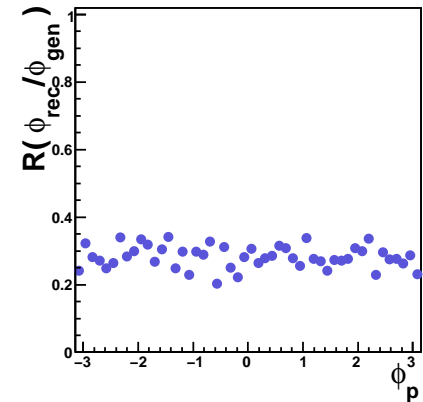
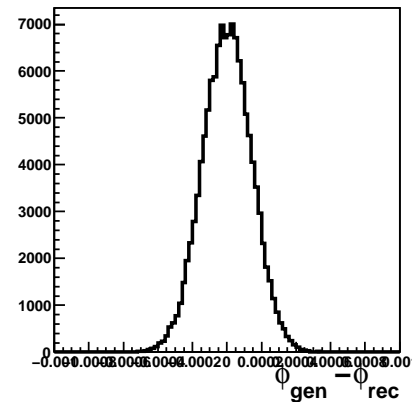
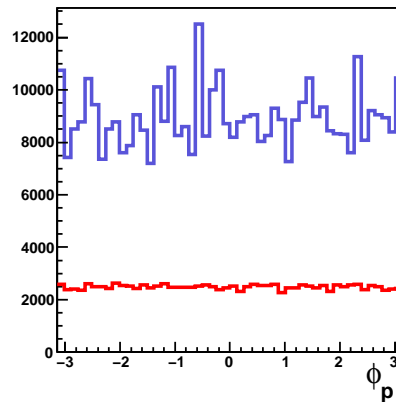
BH : ϕ_{Lab} distributions

— Gen.
— Rec.

e



p



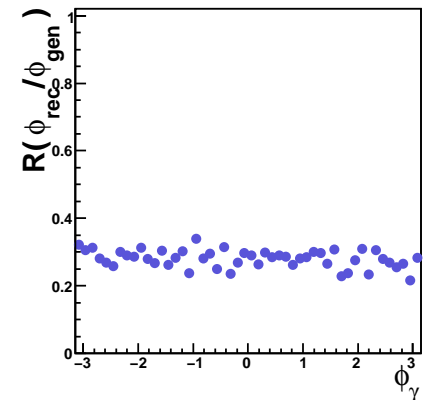
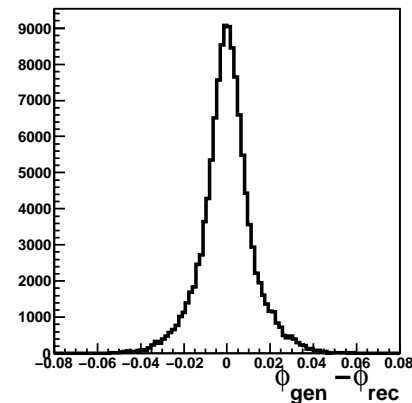
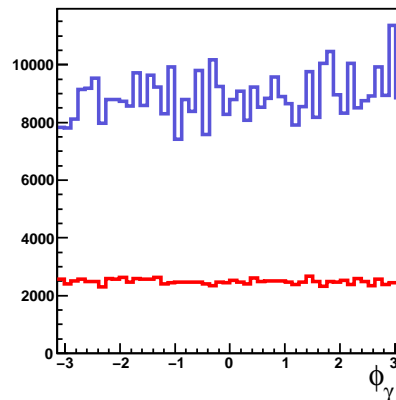
Resolution :

$$\Delta\phi_e / \phi_e \sim 0.01$$

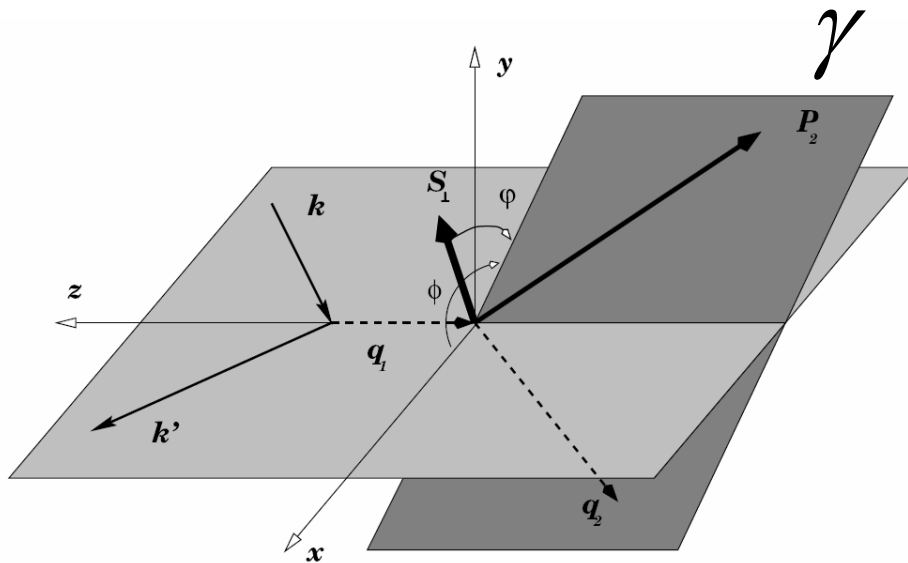
$$\Delta\phi_p / \phi_p \sim 0.01$$

$$\Delta\phi_\gamma / \phi_\gamma \sim 0.01$$

γ



ϕ_γ distribution

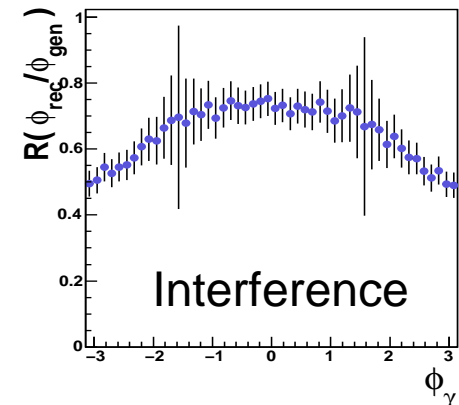
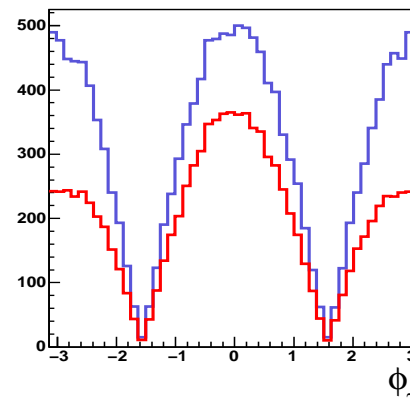
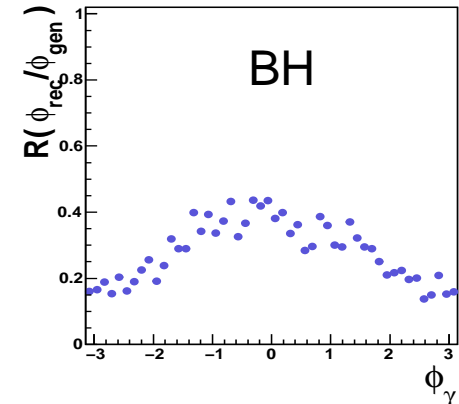
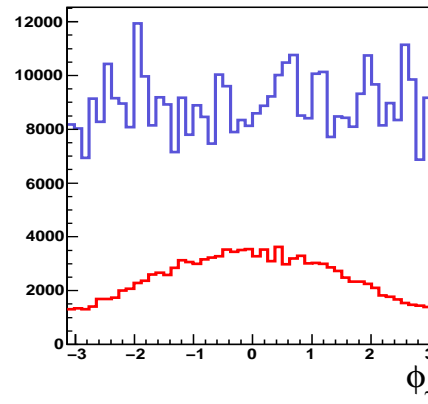
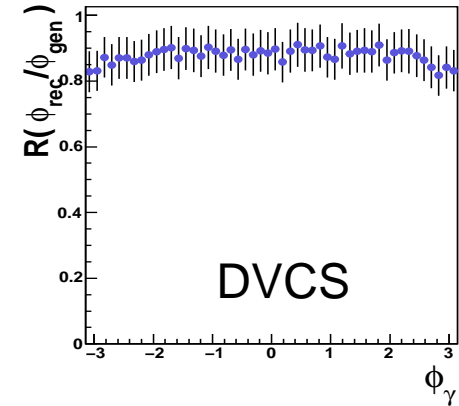
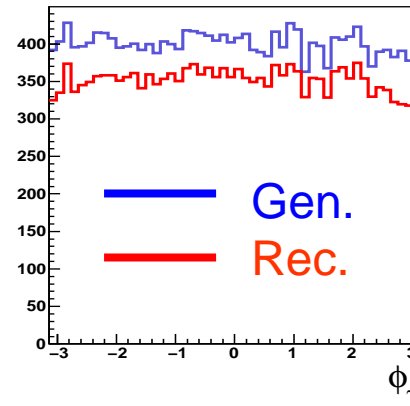


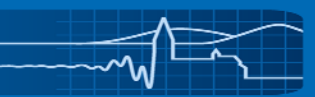
Lorentz-trans. in the γ^* -proton rest frame

Compute ϕ_γ in the Belitsky-Müller- Kirchner frame [hep-ph/01121108]:

$$\vec{z} = -\vec{\gamma}^*, \quad \vec{y} = \vec{k} \times \vec{k}', \quad \vec{x} = \vec{y} \times \vec{z}$$

Differ from the experimental ϕ'_γ
 Need to rotate the axis system to have the z axis along the γ^* , is related by $\phi'_\gamma = \pi - \phi_\gamma$





Interference term :

$$\pm d\sigma_{INT}(\cos\phi) =$$

$$d\sigma_{ep \rightarrow ep\gamma} - d\sigma_{BH} - d\sigma_{DVCS}$$

Fit : $f(\phi_\gamma) = a_0 \cos(a_1\phi_\gamma)$

$$a_0 = -500.0 \pm 4.0$$

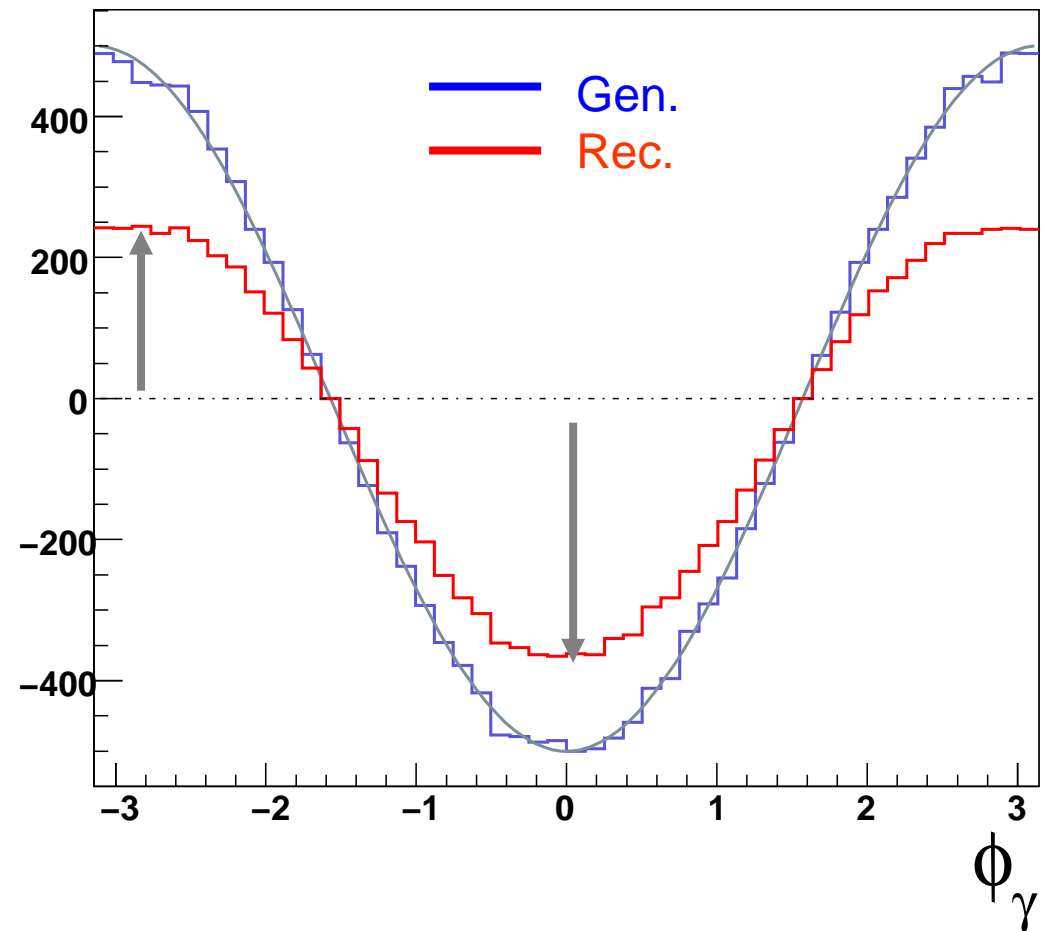
$$a_1 = 1.000 \pm 0.000$$

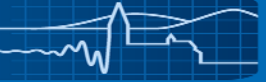
Different acceptance at

$$\phi_\gamma = \phi_{e'}^{Lab} - \phi_{p'}^{Lab} \approx 0,$$

$$\phi_\gamma = \phi_{e'}^{Lab} - \phi_{p'}^{Lab} \approx -\pi, \pi$$

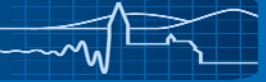
ϕ_γ of Interference





Fast simulations have been performed with FFS model for DVCS and panda detector for acceptance

- Significant effect of track reconstruction at small θ_γ and large y on total acceptance
- The panda geometrical setup optimized for DVCS, the acceptance for BH suppressed
- A complete and flat acceptance in ϕ_{Lab} can be expected, but some distortion for ϕ_γ



Generator for DVCS : What is more suited for intermediated x_{Bj} ?

- FFS model is suited for small x_{Bj}
- VGG (Vanderhaeghen, Guichon, Guidal) model based on Regge traject. is suited for large x_{Bj}

Full chain MC including magnetic field have to be simulated

- Works in progress
- Realistic estimate of expected statistics will be made soon

Background simulation

- Physics background can be provided Lepto or Pythia for the SIDIS contribution
- Diffractive dissociation can be included