Deeply Virtual Compton Scattering

– continued –

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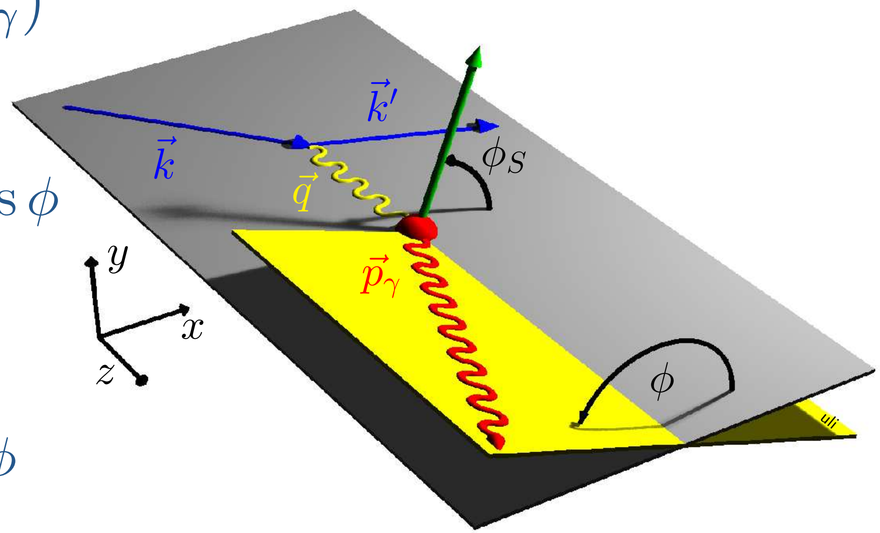
- Physics background
  - Quark-gluon structure of the nucleon
  - Generalized Parton Distributions
  - Deeply Virtual Compton Scattering
- How to perform a DVCS analysis
  - Knowledge about HERMES
  - An example – TTSA extraction
  - My analysis code ...

Azimuthal Asymmetries

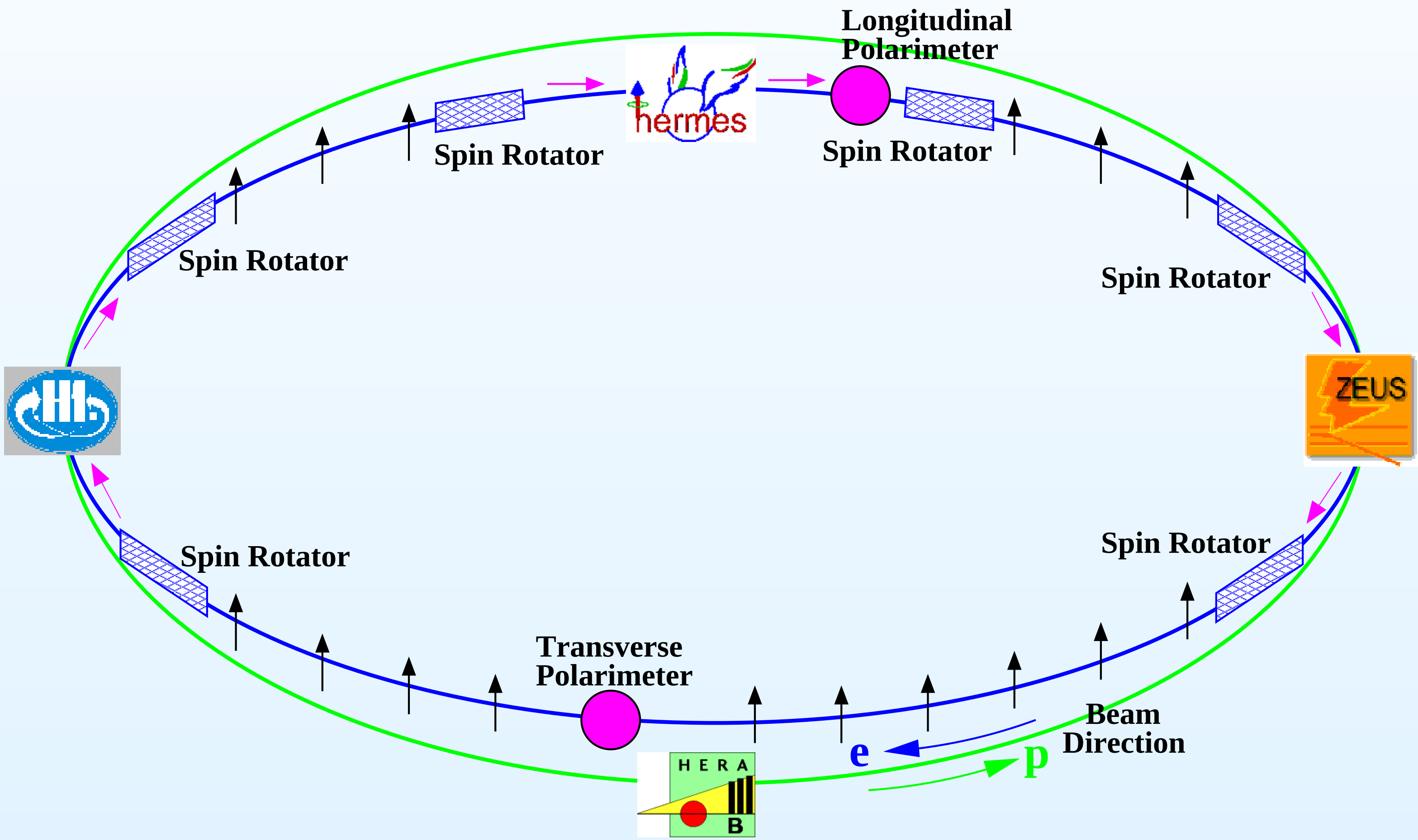
$$e(k) + p(P) \to e'(k') + p'(P') + \gamma(p_\gamma)$$



- Beam-charge asymmetry $A_C(\phi)$:
  $d\sigma(e^+,\phi) - d\sigma(e^-,\phi) \propto \mathrm{Re}[F_1\mathcal{H}] \cdot \cos\phi$
- Beam-spin asymmetry $A_{LU}(\phi)$:
  $d\sigma(\overrightarrow{e},\phi) - d\sigma(\overleftarrow{e},\phi) \propto \mathrm{Im}[F_1\mathcal{H}] \cdot \sin\phi$
- Longitudinal target-spin asymmetry $A_{UL}(\phi)$:
  $d\sigma(\overset{\Leftarrow}{P},\phi) - d\sigma(\overset{\Rightarrow}{P},\phi) \propto \mathrm{Im}[F_1\widetilde{\mathcal{H}}] \cdot \sin\phi$
- Transverse target-spin asymmetry $A_{UT}(\phi,\phi_s)$:
  $$d\sigma(\phi,\phi_S) - d\sigma(\phi,\phi_S+\pi) \propto \mathrm{Im}[F_2\mathcal{H} - F_1\mathcal{E}] \cdot \sin(\phi-\phi_S)\cos\phi$$
  $$+\mathrm{Im}[F_2\widetilde{\mathcal{H}} - F_1\xi\widetilde{\mathcal{E}}] \cdot \cos(\phi-\phi_S)\sin\phi$$

HERMES Experiment

- HERMES is a fixed target experiment.
  - long. polarized HERA 27.6 GeV $e^{\pm}$ beams $\Rightarrow$ BSA + BCA



HERMES Experiment

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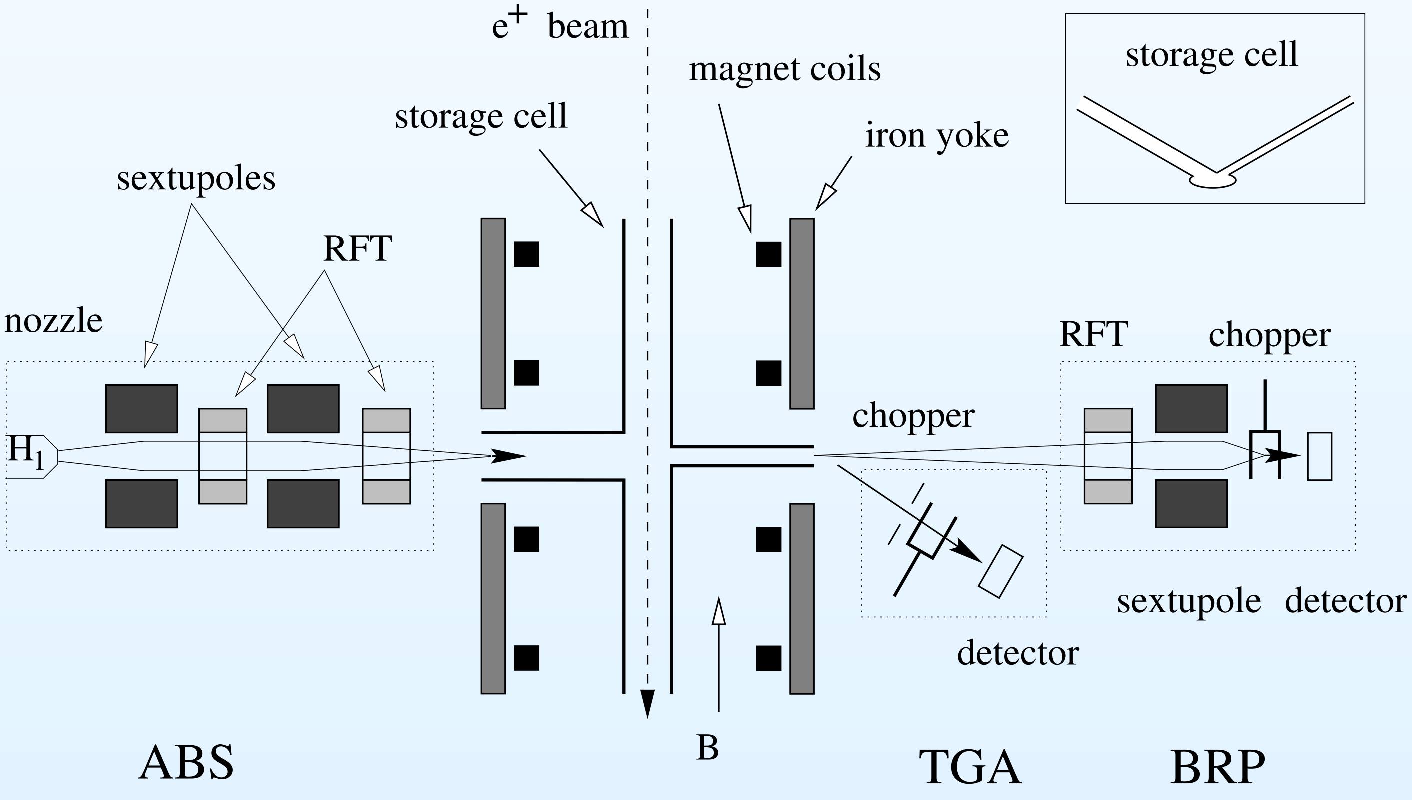
  - long. polarized HERA 27.6 GeV $e^{\pm}$ beams $\Rightarrow$ BSA + BCA
  - long. polarized H and D targets in 1996–2000 $\Rightarrow$ LTSA
    trans. polarized H target in 2002–05 $\Rightarrow$ TTSA



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  - long. polarized HERA 27.6 GeV $e^{\pm}$ beams $\Rightarrow$ BSA + BCA
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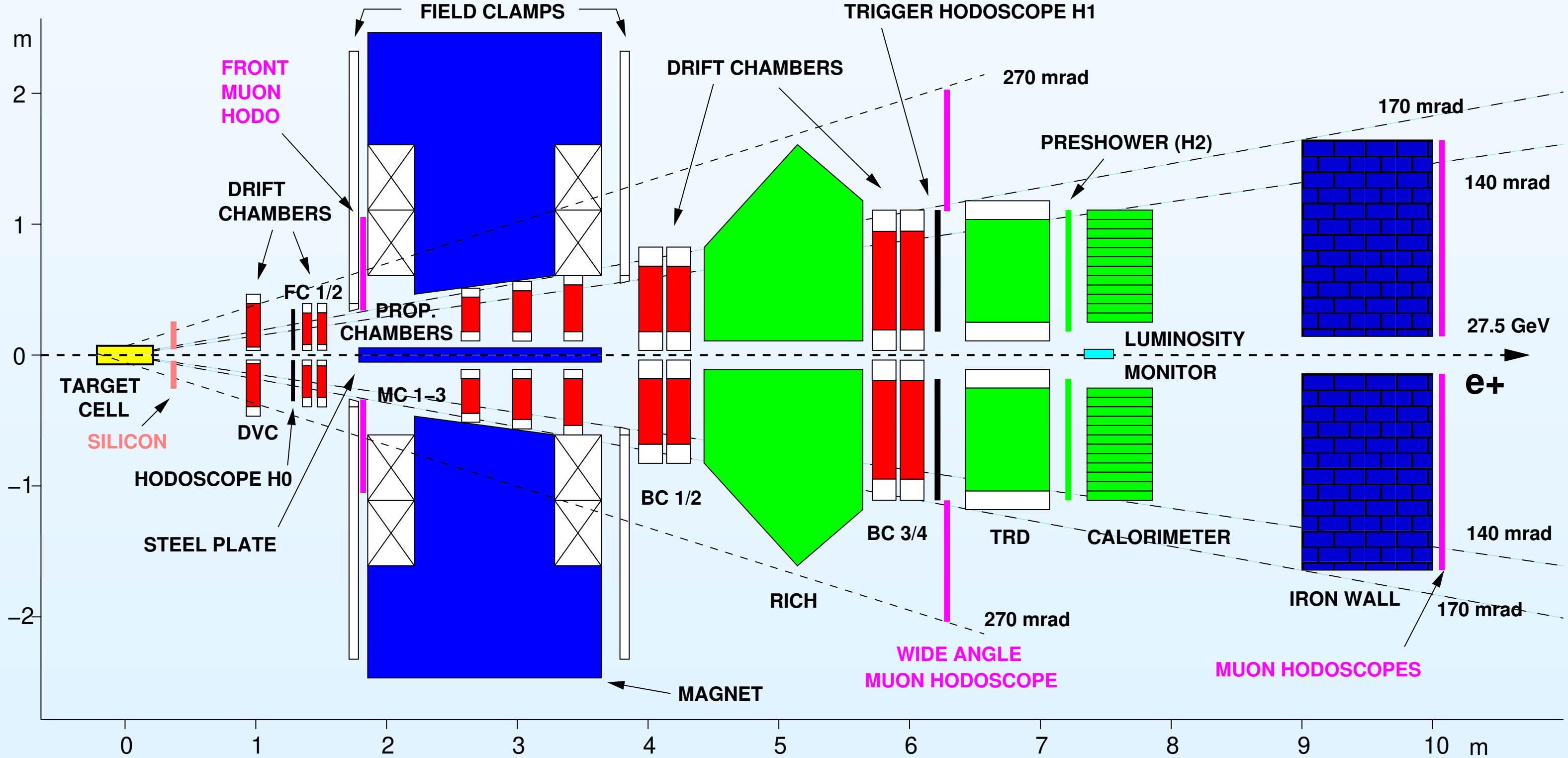
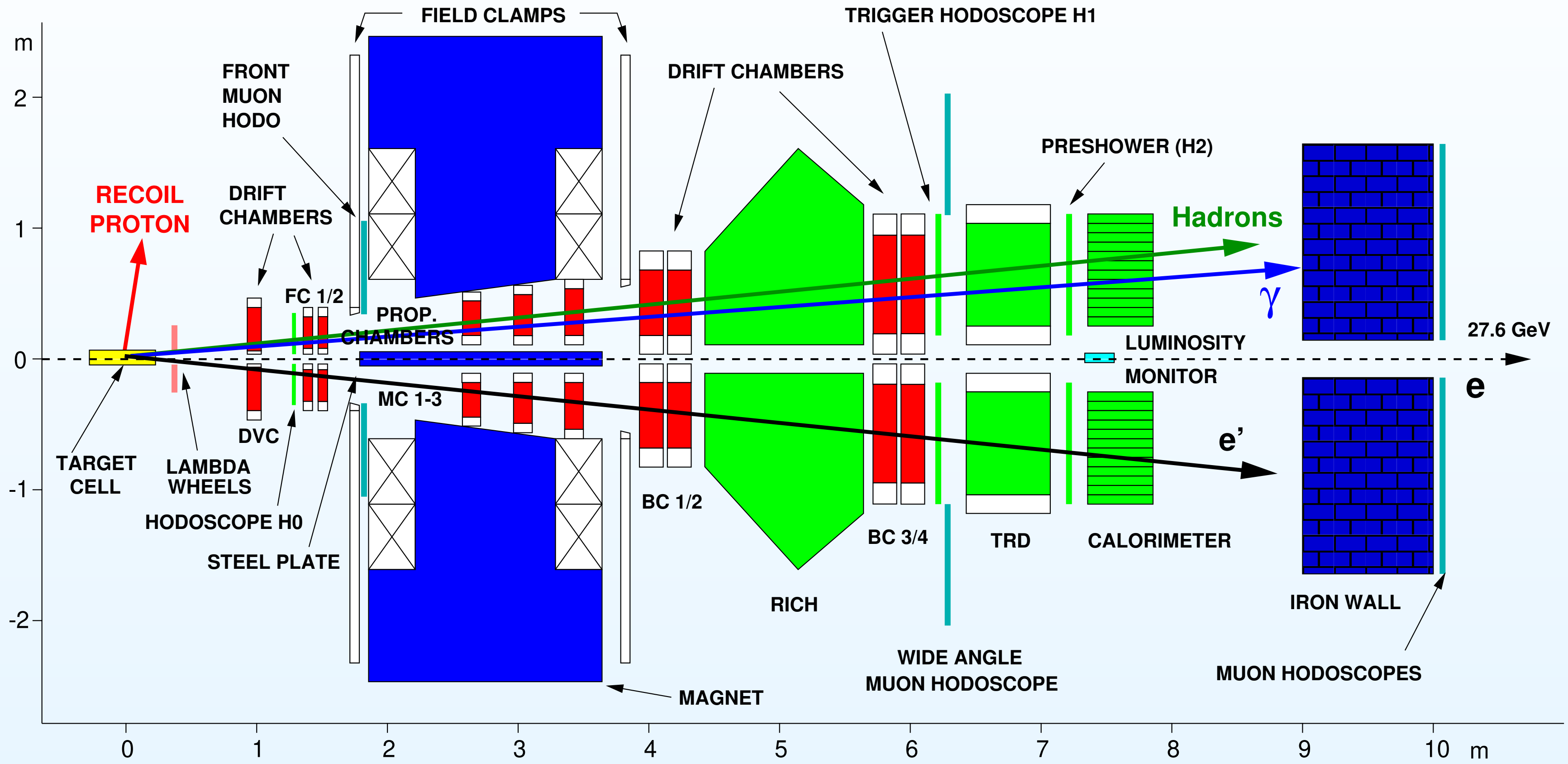
  - final state particles detected by the forward spectrometer



An example – TTSA

- DVCS@HERMES
- Asymmetry Extraction Methods
- Fit Function
- Smearing and Acceptance
- Background Correction
- Results

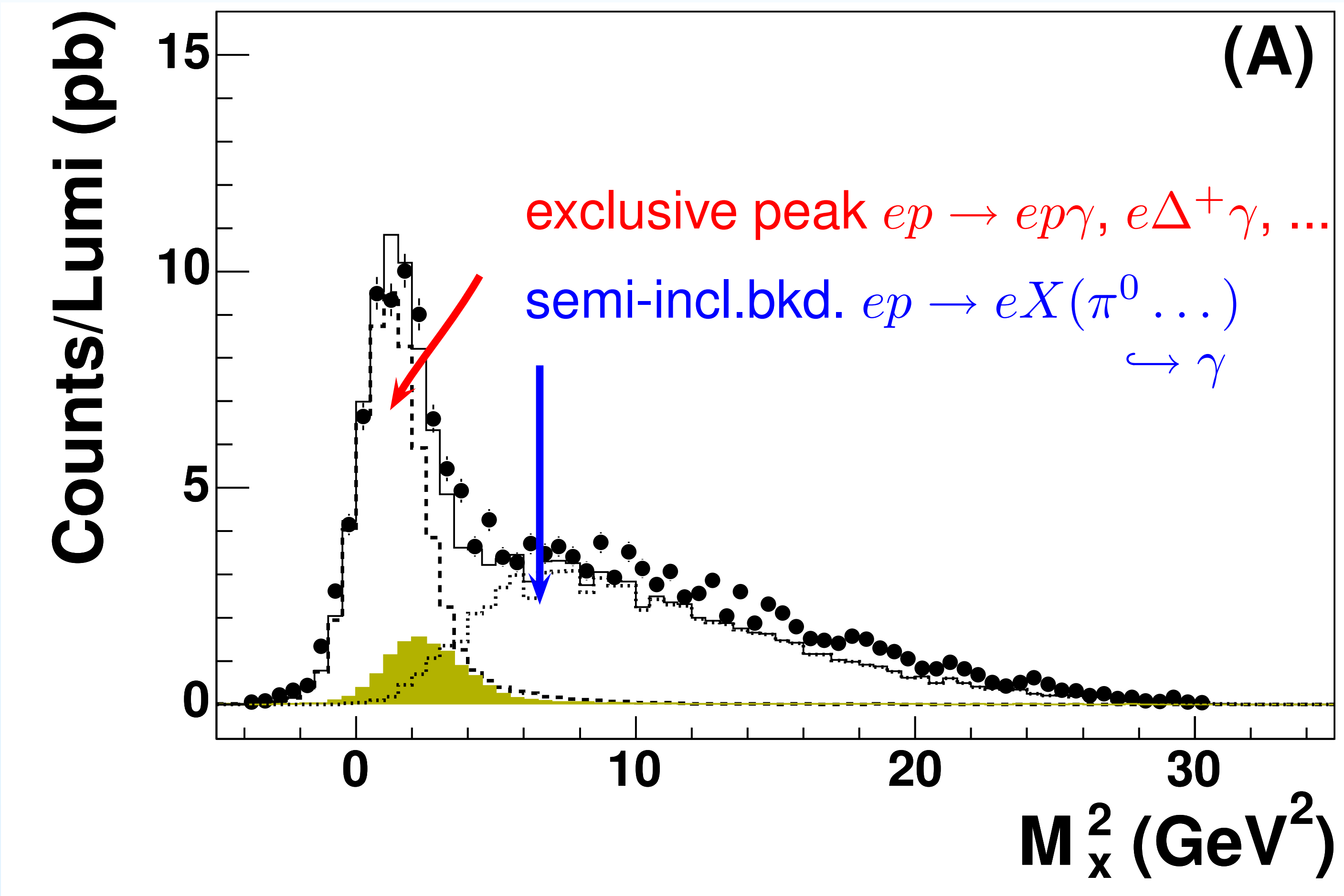
DVCS@HERMES



- Tracking: $\delta P_e/P_e < 2\%$, $\delta\theta_e < 1$ mrad
- Particle identification: $\epsilon_e > 99\%$, hadron contamination $< 1\%$
- Photon detection: calorimeter $\delta E_\gamma/E_\gamma \sim 5\%$, $\delta x(y) \sim 0.5$ cm

DVCS@HERMES

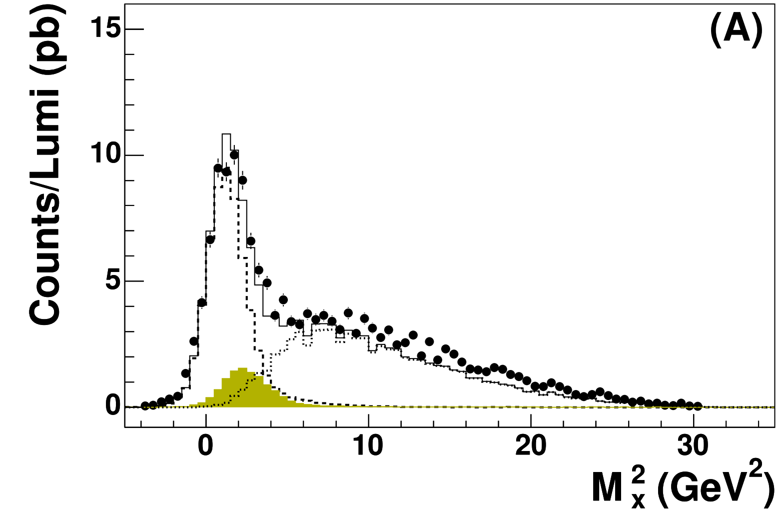
- Recoiling protons were not detected $\Rightarrow$ maitain exclusivity through missing mass $\mathrm{M_x^2} = (P_e + P_p - P_{e'} - P_\gamma)^2$.

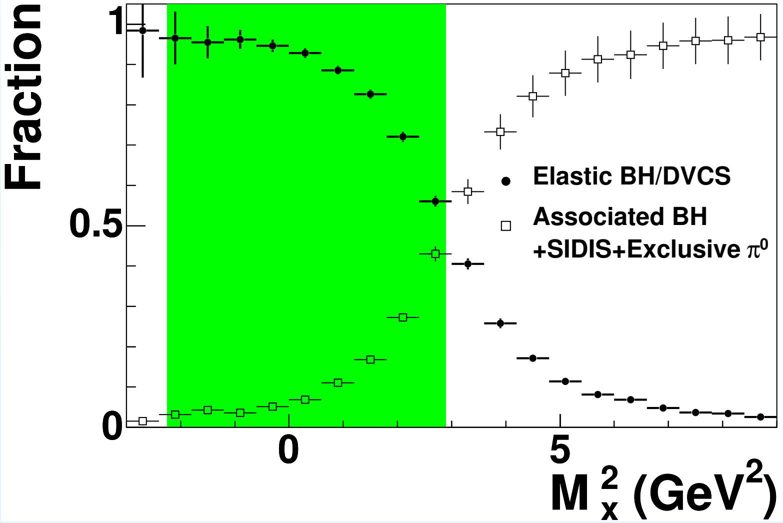


DVCS@HERMES

- Recoiling protons were not detected $\Rightarrow$ maitain exclusivity through missing mass cut $-(1.5)^2 < \mathrm{M_x^2} < (1.7)^2$ GeV^2.
- MC: generator $\rightarrow$ detector (HMC) $\rightarrow$ reconstruction (HRC).

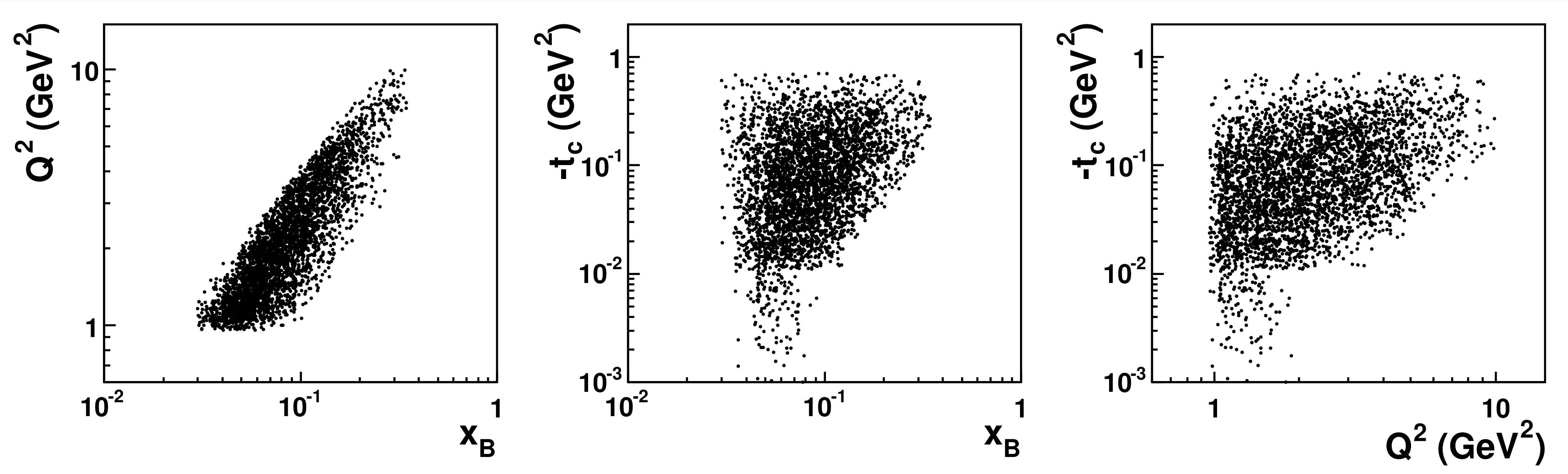
generator	processes simulated	
gmc_dvcs	elastic BH+DVCS	$ep\gamma$
	associated	$e\Delta^+\gamma$, $ep\pi^0\gamma$, ...
gmc_disNG	semi-inclusive	$ep \rightarrow e\pi^0 X$, $ep \rightarrow e\eta X$, ...
gmc_exclpion	exclusive π^0	$ep \rightarrow ep\pi^0$



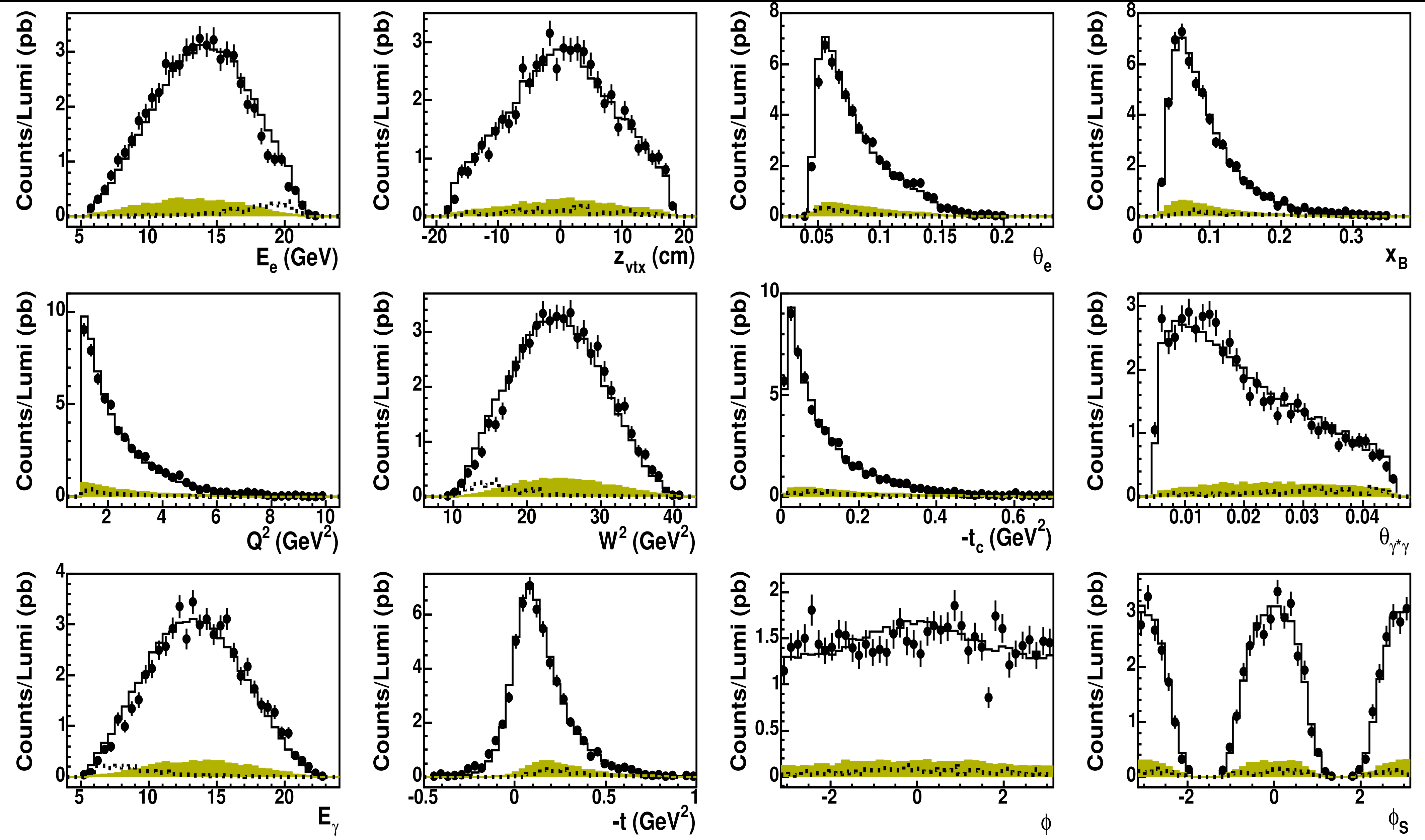


DVCS@HERMES

- Recoiling protons were not detected $\Rightarrow$ maitain exclusivity through missing mass cut $-(1.5)^2 < \mathrm{M}_\mathrm{x}^2 < (1.7)^2$ GeV^2.
- MC: generator $\rightarrow$ detector (HMC) $\rightarrow$ reconstruction (HRC).
- 3,813 candidates of exclusive BH+DVCS events from the 02-04 data after applying data quality and event selection cuts.



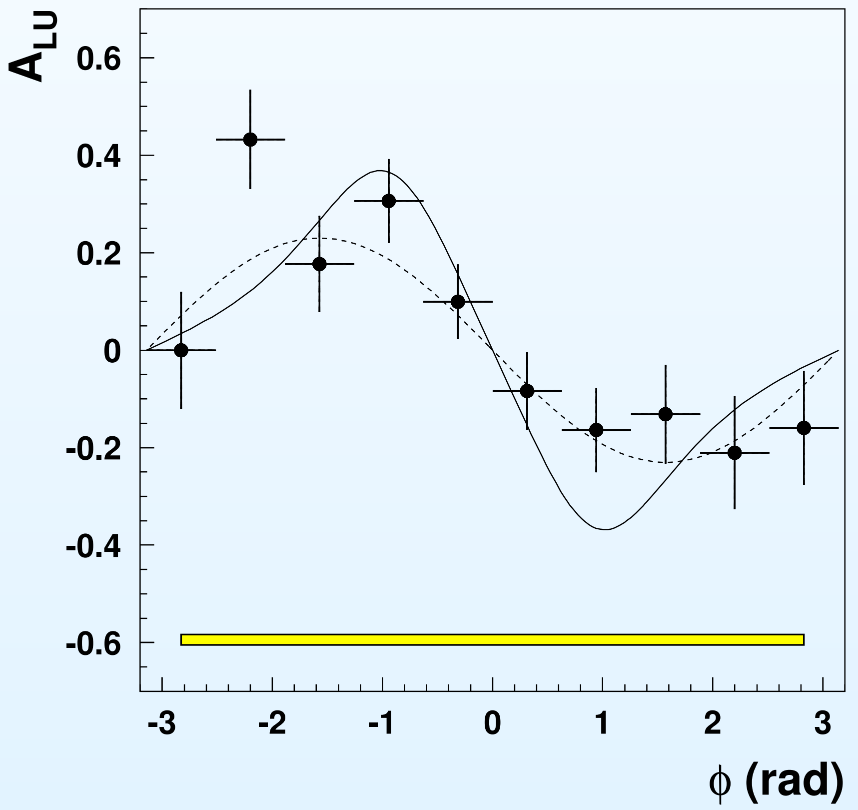
$$-(1.5)^2 < \mathrm{M}_{\mathrm{x}}^2 < (1.7)^2 \text{ GeV}^2,\ |t| < 0.7 \text{ GeV}^2,\ 0.03 < x_B < 0.35,\ 1 < Q^2 < 10 \text{ GeV}^2$$



Extraction Methods

- Least Square Method:

$$\text{BSA} \qquad A_{LU}(\phi) = \frac{1}{\langle |P_B| \rangle} \frac{N_+(\phi)/\mathbb{L}_+ - N_-(\phi)/\mathbb{L}_-}{N_+(\phi)/\mathbb{L}_+ + N_-(\phi)/\mathbb{L}_-}$$



Extraction Methods

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$$\text{BSA} \qquad A_{LU}(\phi) = \frac{1}{\langle|P_B|\rangle} \frac{N_+(\phi)/\mathbb{L}_+ - N_-(\phi)/\mathbb{L}_-}{N_+(\phi)/\mathbb{L}_+ + N_-(\phi)/\mathbb{L}_-}$$

$$\text{TTSA} \qquad A_{UT}(\phi, \phi_S) = \frac{1}{\langle|P_T|\rangle} \frac{N_+(\phi, \phi_S)/\mathbb{L}_+ - N_-(\phi, \phi_S)/\mathbb{L}_-}{N_+(\phi, \phi_S)/\mathbb{L}_+ + N_-(\phi, \phi_S)/\mathbb{L}_-}$$

Extraction Methods

- Maximum Likelihood Method:

$\sigma_U(\phi)$	unpolarized cross section
$A_{UT}(\phi, \phi_S; \boldsymbol{\theta})$	transverse target-spin asymmetry
$\epsilon(\phi, \phi_S) = \epsilon^{\pm}$	detection efficiency
$f^{\pm} \sim \epsilon \cdot \sigma_U \cdot (1 \pm P_T \cdot A_{UT})$	probability distribution function

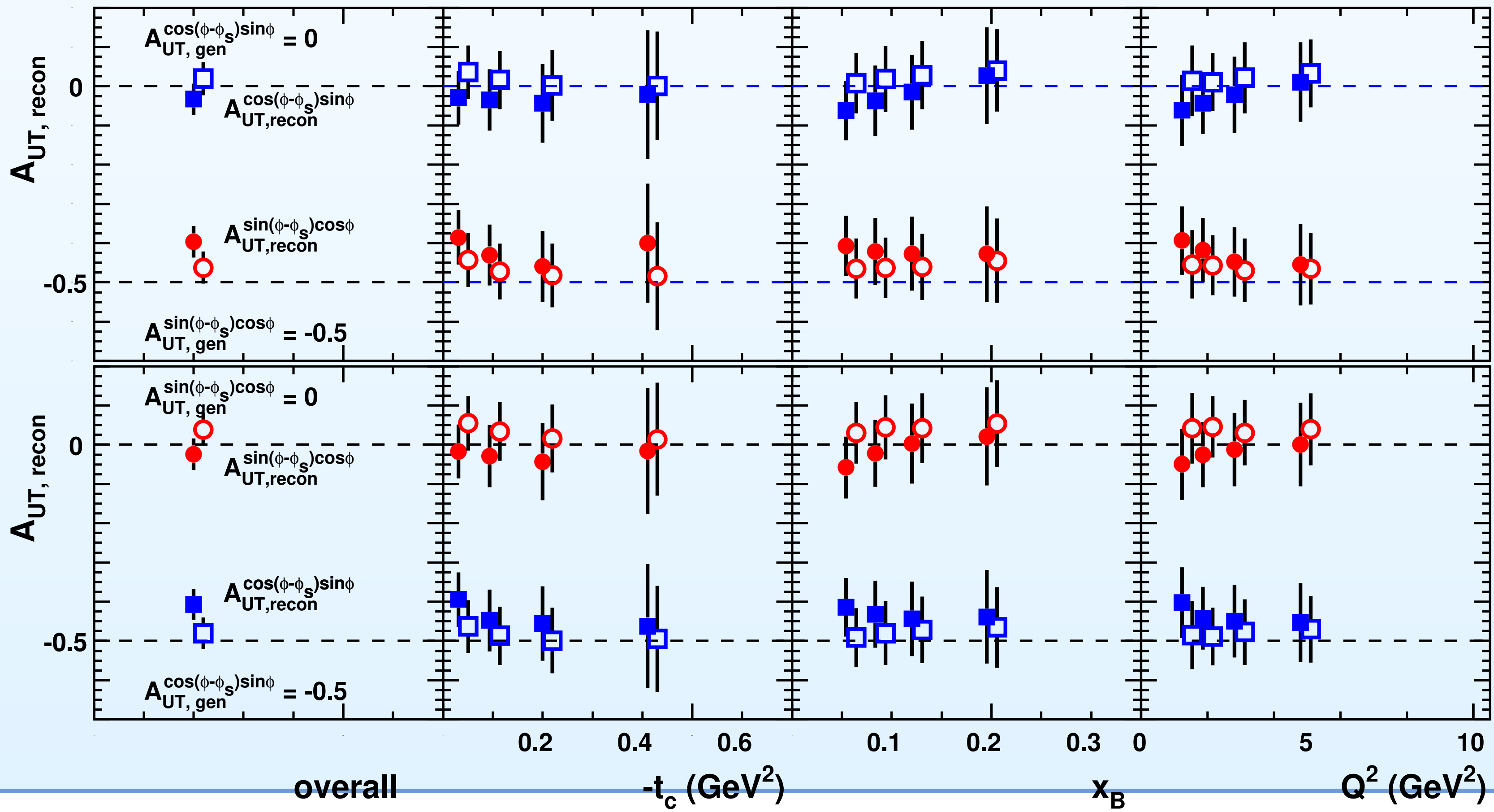
$$\begin{aligned}
-\ln L^{\pm}(\boldsymbol{\theta}) &= -\sum_{i=1}^{n^{\pm}} \ln f(\phi^i, \phi_S^i, \pm P_T; \boldsymbol{\theta}) = -\sum_{i=1}^{n^{\pm}} \ln \frac{1 \pm P_T A_{UT}(\phi^i, \phi_S^i; \boldsymbol{\theta})}{\mathbb{N}^{\pm}(\boldsymbol{\theta})} \\
\mathbb{N}^{\pm}(\boldsymbol{\theta}) &= \iint \epsilon(\phi, \phi_S) \cdot \sigma_U(\phi) \cdot L \cdot \left[1 \pm P_T \cdot A_{UT}(\phi, \phi_S; \boldsymbol{\theta})\right] \\
&\approx \sum_{i=1}^{\langle P_T \rangle = 0} \left[1 \pm P_T \cdot A_{UT}(\phi^i, \phi_S^i; \boldsymbol{\theta})\right]
\end{aligned}$$

Extraction Methods

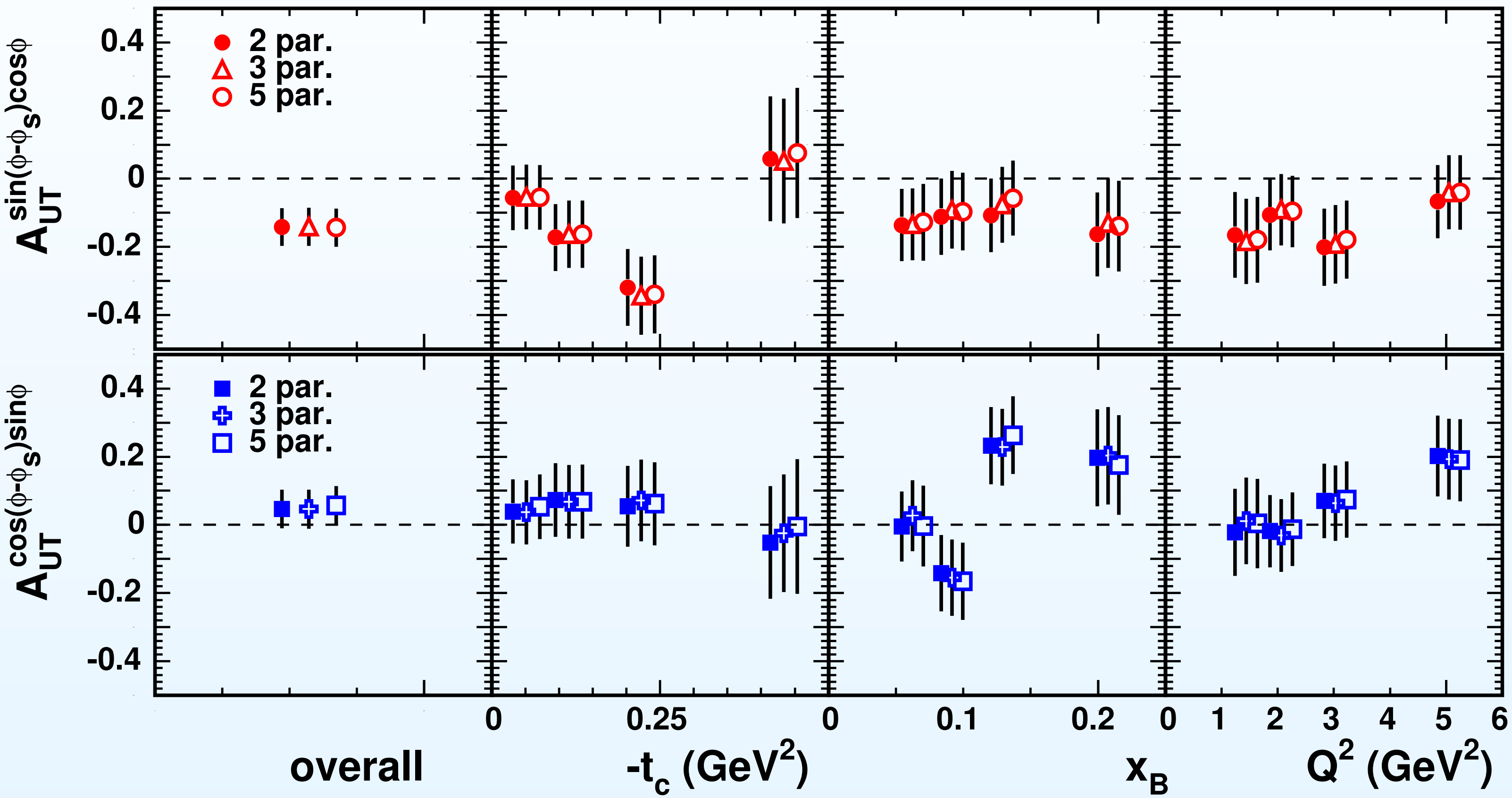
- Testing the methods in MC with known input asymmetries:

  results of 1000 MC tests

  ⇒ the ML method (open) is better than the LS method (filled)



Fit Function



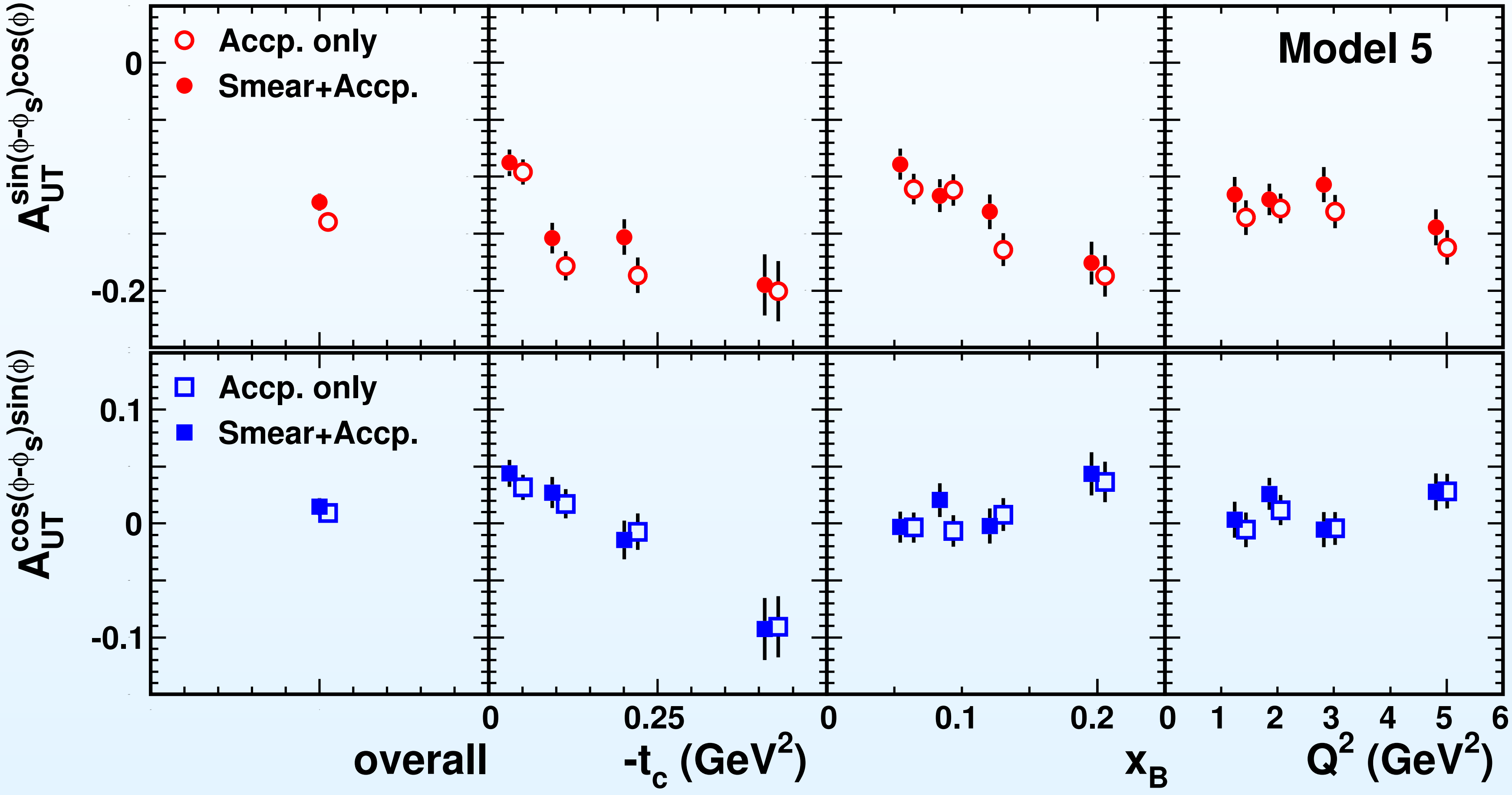
2 parameters : $$A_{UT}(\phi,\phi_S) = c_1 \cos\phi \cdot \sin(\phi-\phi_S) + s_1 \sin\phi \cdot \cos(\phi-\phi_S)$$

3 parameters : $$A_{UT}(\phi,\phi_S) = (c_0 + c_1 \cos\phi) \cdot \sin(\phi-\phi_S) + s_1 \sin\phi \cdot \cos(\phi-\phi_S)$$

5 parameters : $$A_{UT}(\phi,\phi_S) = (c_0 + c_1 \cos\phi + c_2 \cos 2\phi) \cdot \sin(\phi-\phi_S) + (s_1 \sin\phi + s_2 \sin 2\phi) \cdot \cos(\phi-\phi_S)$$

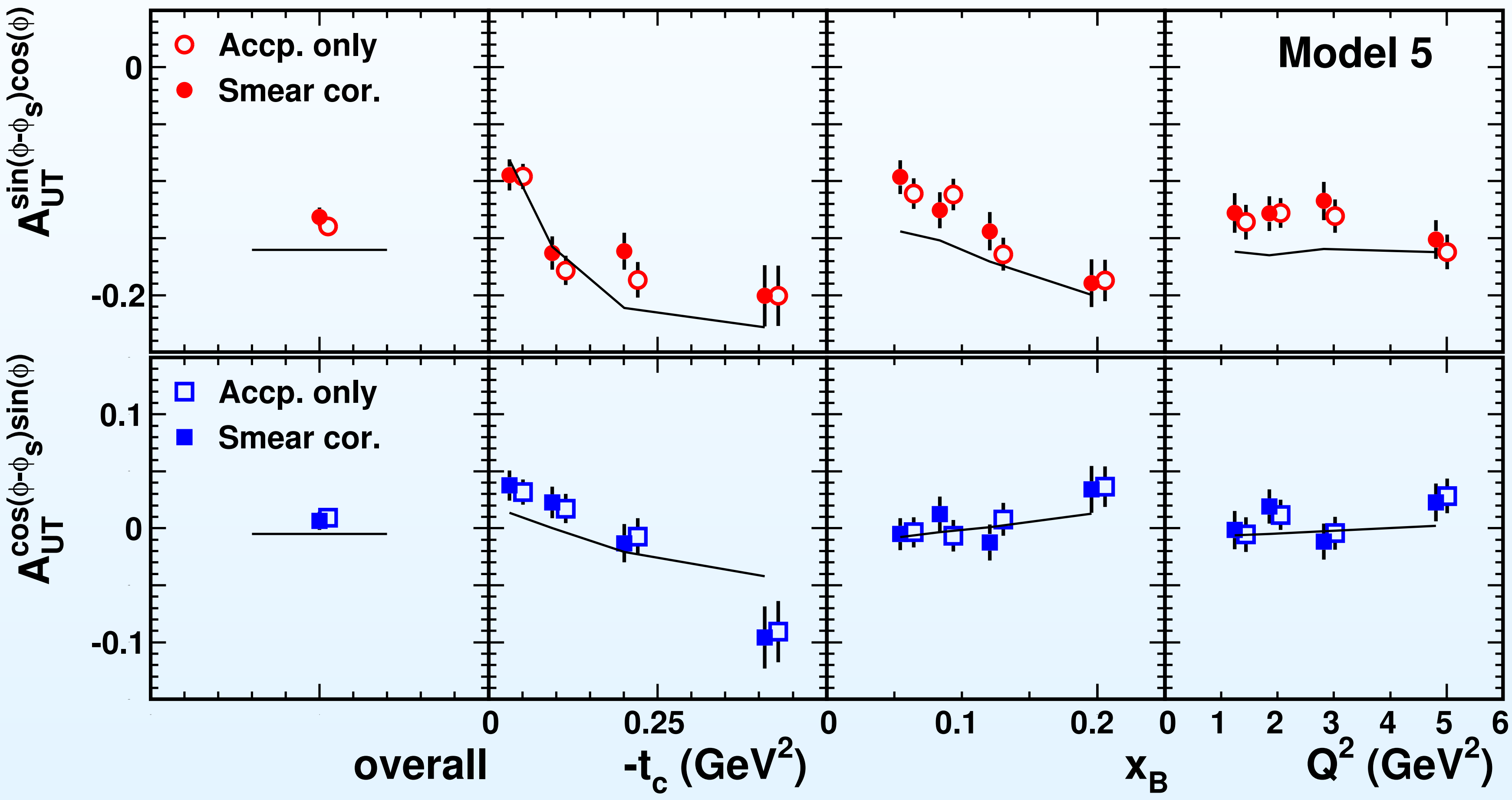
Smearing Effects

- Acceptance only (open) vs smear+acceptance (filled) in MC



Acceptance Effects

- acceptance only (open) vs input (lines) in MC



Background Correction

If all background contributions and asymmetries are known, they can be corrected for from the measured asymmetry A_m

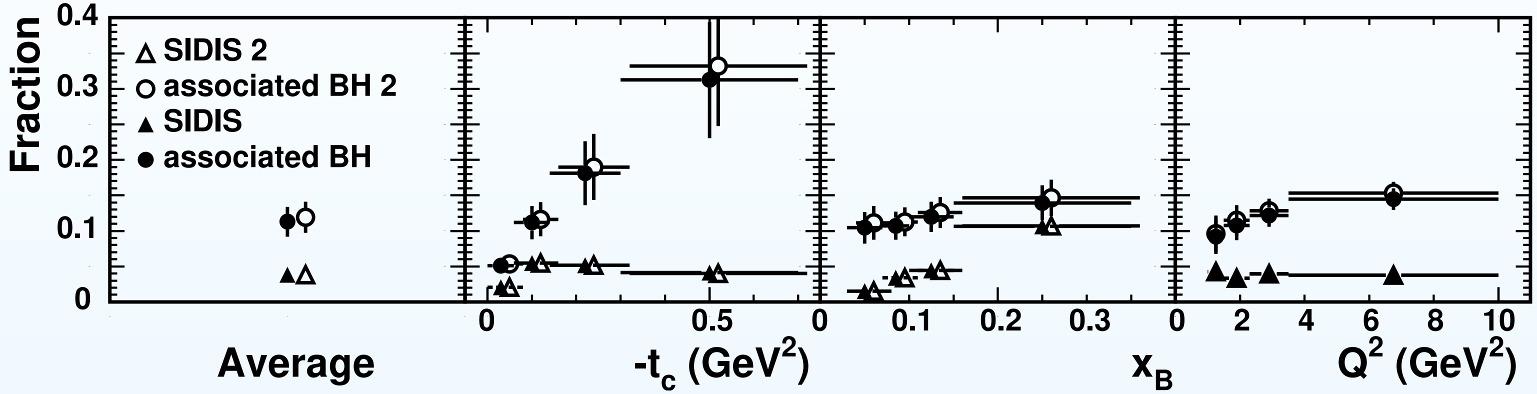
$$A_{ela} = \frac{A_m - f_{res}A_{res} - f_{semi}A_{semi} - f_{excl}A_{excl}}{1 - f_{res} - f_{semi} - f_{excl}},$$

where f (A) denotes the relative contribution (asymmetry) of the individual processes:

- elastic: $ep \to ep\gamma$
- associated (resonance): $ep \to e\Delta^+\gamma$, $ep \to ep\pi^0\gamma$, ...
- semi-inclusive: $ep \to e\pi^0 X$, $ep \to e\eta X$, ...
- exclusive: $ep \to ep\pi^0$.

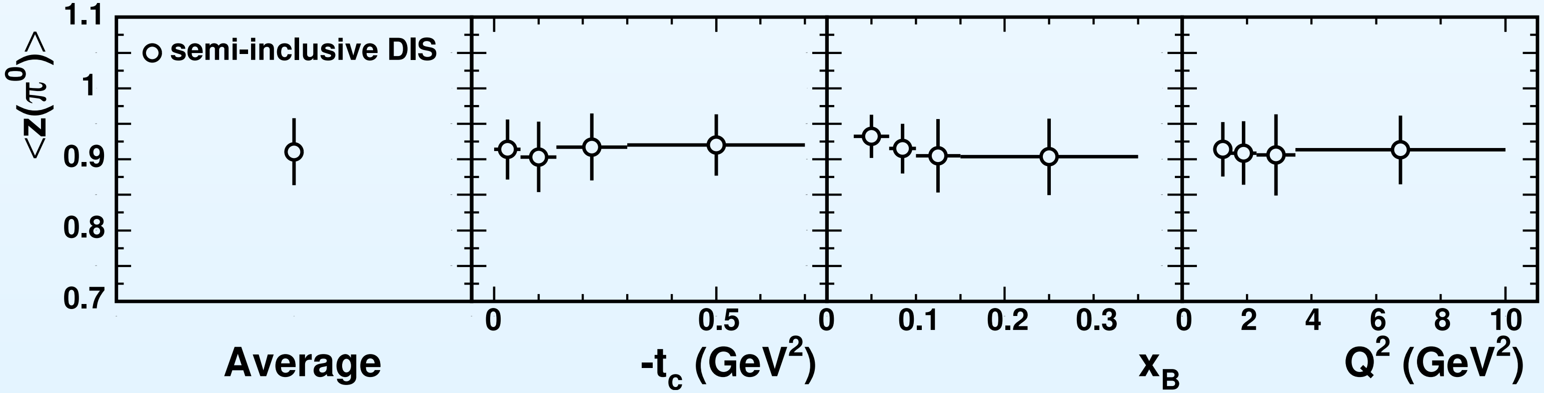
Background Correction

- Background contributions estimated in MC:



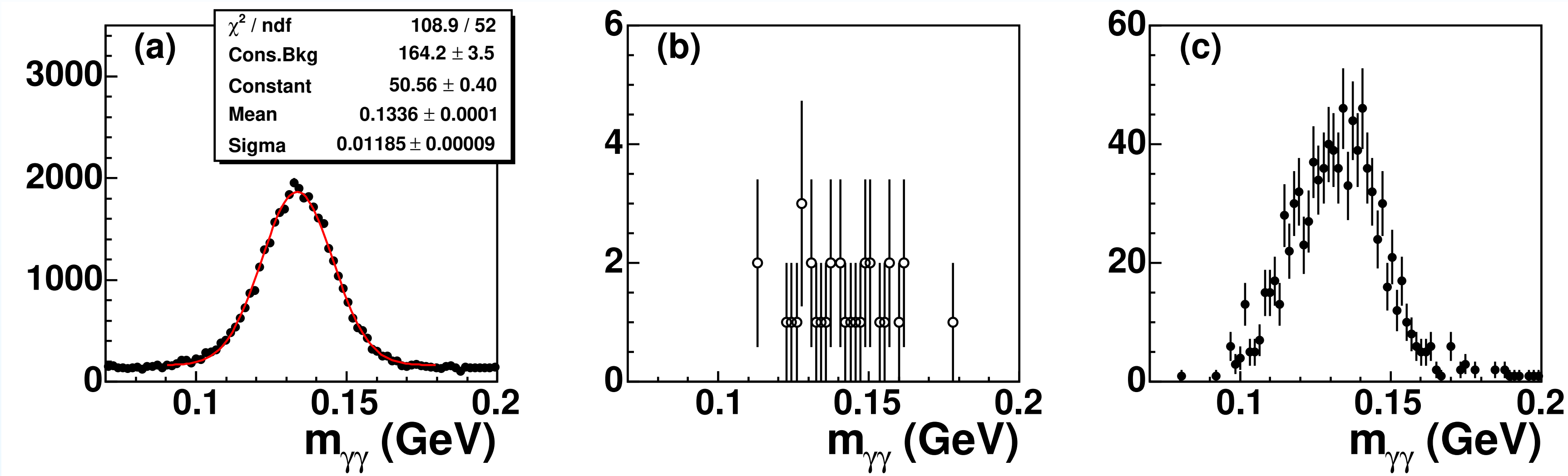
$\Rightarrow$ associated $(e\Delta^+\gamma) \sim$ 12%

$\Rightarrow$ SIDIS $(e\pi^0 X$, $e\eta X$ ...$) \sim$ 4%, $z = E_{\pi^0}/(E - E_e) \sim 0.8$



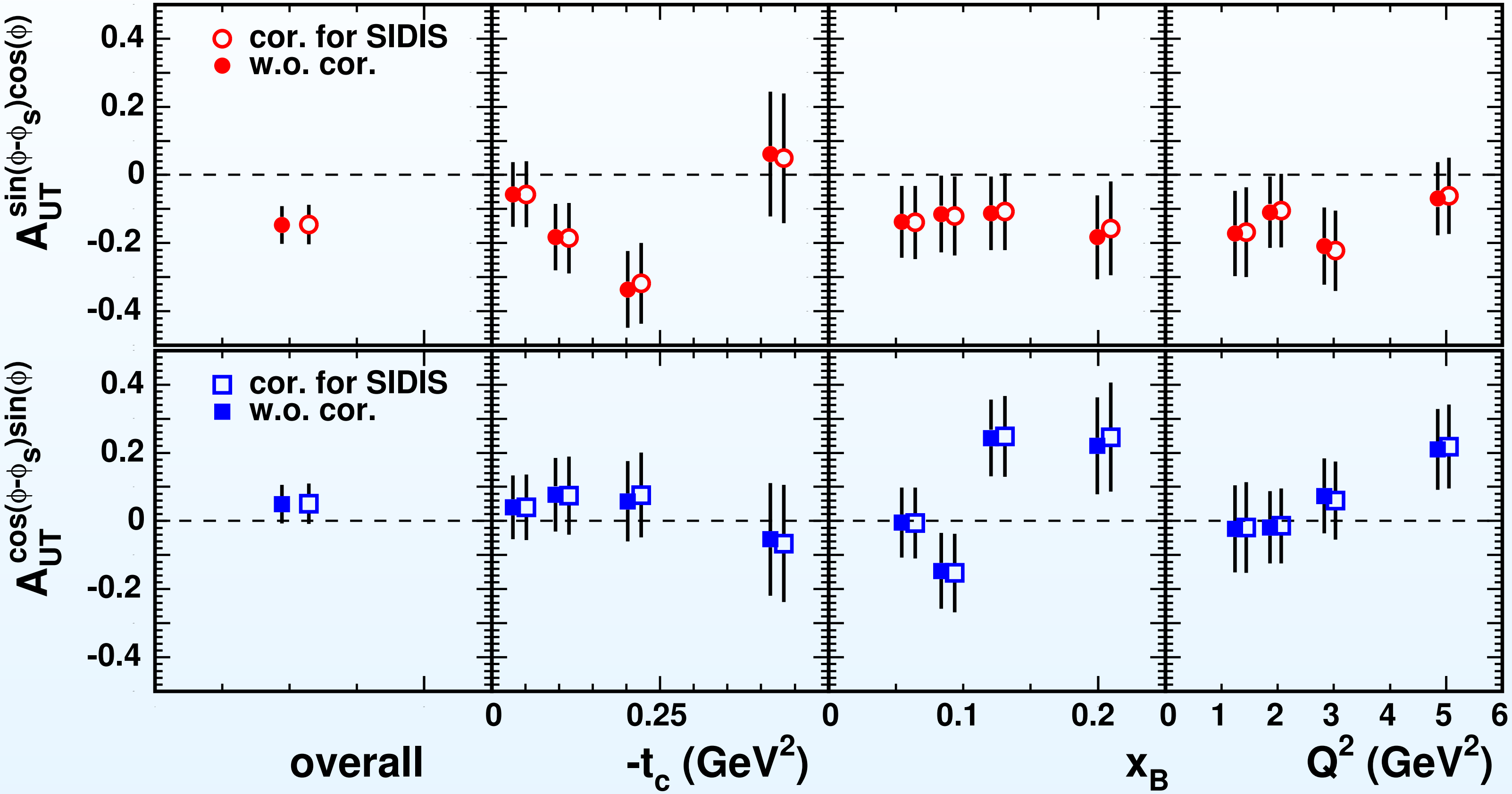
$\Rightarrow$ Exclusive $(ep\pi^0) \sim$ 0.4%,

Background Correction



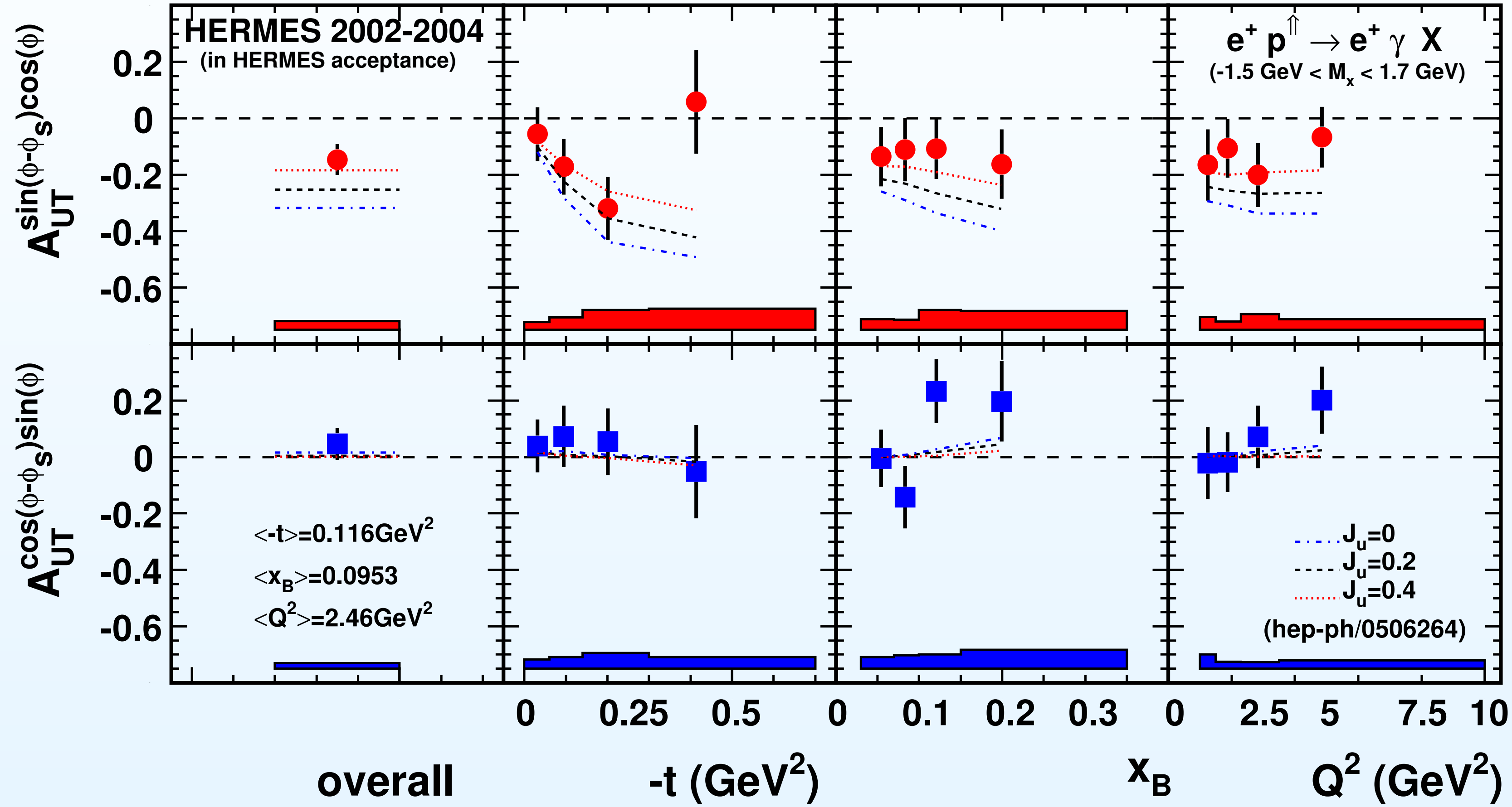
- Instead of one trackless cluster, two are required in the real data.
  - (a) all events with two trackless clusters
  - (b) those fullfil $-(1.5)^2 < M_x^2 < (1.7)^2$ GeV^2
  - (c) those fullfil $z > 0.8 \Rightarrow$ SIDIS background asymmetry

Background Correction



- The difference between with/w.o correction for the SIDIS and exclusive background is assigned as a systematic uncertainty.
- The results need to be understood as the combined effect of the elastic ($ep \to ep\gamma$) and associated ($ep \to e\Delta^+\gamma$, 12%) processes.

Results on TTSA



Systematic uncertainties:

- target pol≈ 0.01; fit function ≈ 0.01; background ≈ 0.02;
- misalign+cali≈ -; smearing≈ 0.02; (accptance) ≈ 0.03.

My Analysis Code

- worf.desy.de:/user/yezhenyu/codes/analysis/bsa:
  Event selection of 2000 unpolarized H data
- worf.desy.de:/user/yezhenyu/codes/analysis/final:
  Extraction of BSA amplitudes using Least Square method
- worf.desy.de:/user/yezhenyu/codes/mc-analysis/dvcs-trans:
  Event selection of MC data
- worf.desy.de:/user/yezhenyu/codes/mc-analysis/final:
  Extraction of BSA amplitudes using Least Square method
- Analysis based on ROOT (recompile by yourself)
- Source codes to be looked at: ***/inc ***/lib (***/src),
- scripts to play with: ***/script