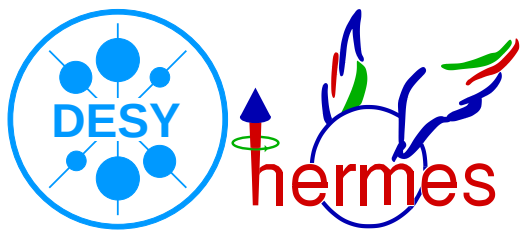
Эксклюзивное рождение π^+ в эксперименте на установке ГЕРМЕС

А.Иванилов (ИФВЭ)
от коллаборации ГЕРМЕС



Сессия-конференция секции ядерной физики ОФН РАН
Протвино, 22-25 декабря, 2008

- Generalised Parton Distributions
- Exclusive π^+ production at HERMES
  - Cross section measurements and results
  - Preliminary study of transverse spin asymmetry

Generalised Parton Distributions

- in the limit of $Q^2 \gg$ at x_B, t fixed, $\gamma^* p$ amplitude factorises

- contributions to the cross section

γ^*_L	leading-twist, QCD factorisation theorem
γ^*_L-γ^*_T	$\frac{1}{Q}$ suppressed
γ^*_T	$\frac{1}{Q^2}$ suppressed

- for exclusive π^+ production $\gamma^* p \longrightarrow \pi^+ n$

$$\sigma_L \propto (1-\xi^2)|\widetilde{H}|^2 - \xi^2\, t|\widetilde{E}|^2 - \xi^2 \mathrm{Re}(\widetilde{E}^*\widetilde{H})$$

ξ: skewness

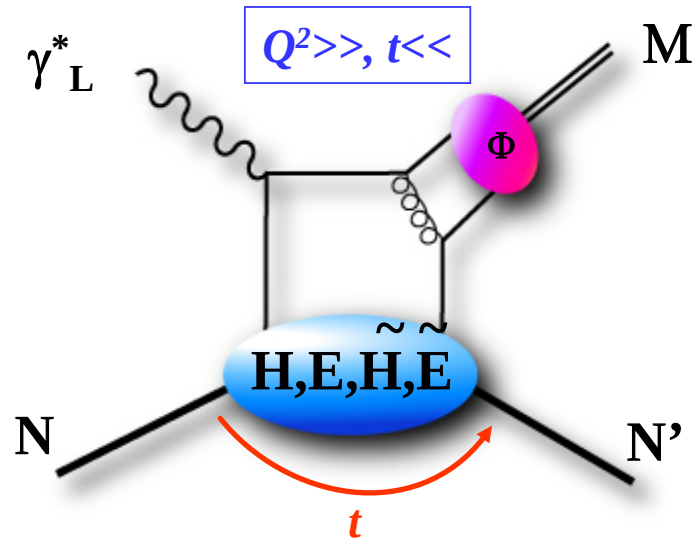
- relation to PDFs and FFs

$\widetilde{H}(x,0,0) = \Delta q(x)$ for $t \to 0$

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

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

- how to access GPDs?

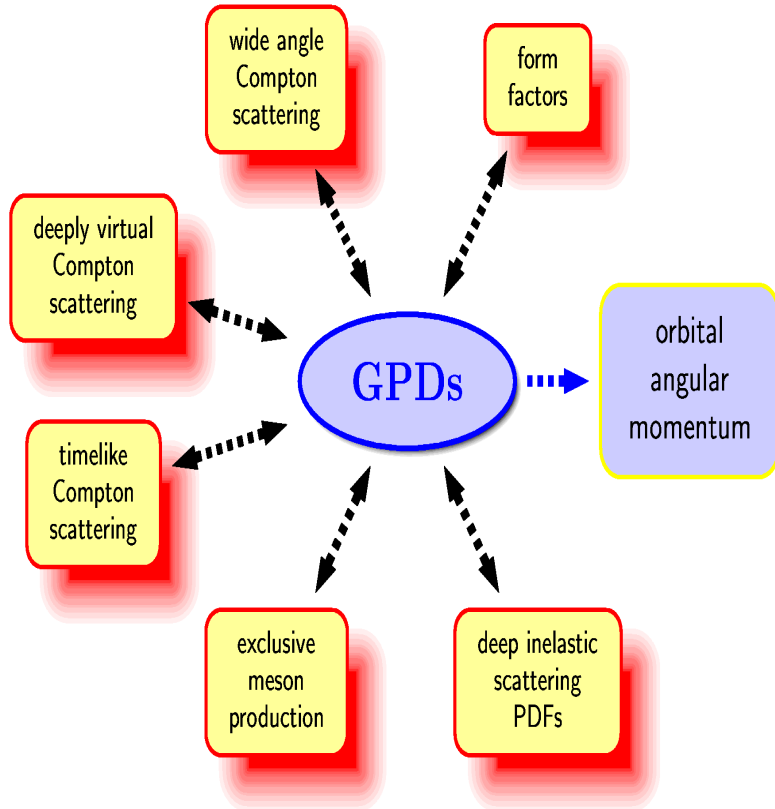


- exclusive production of

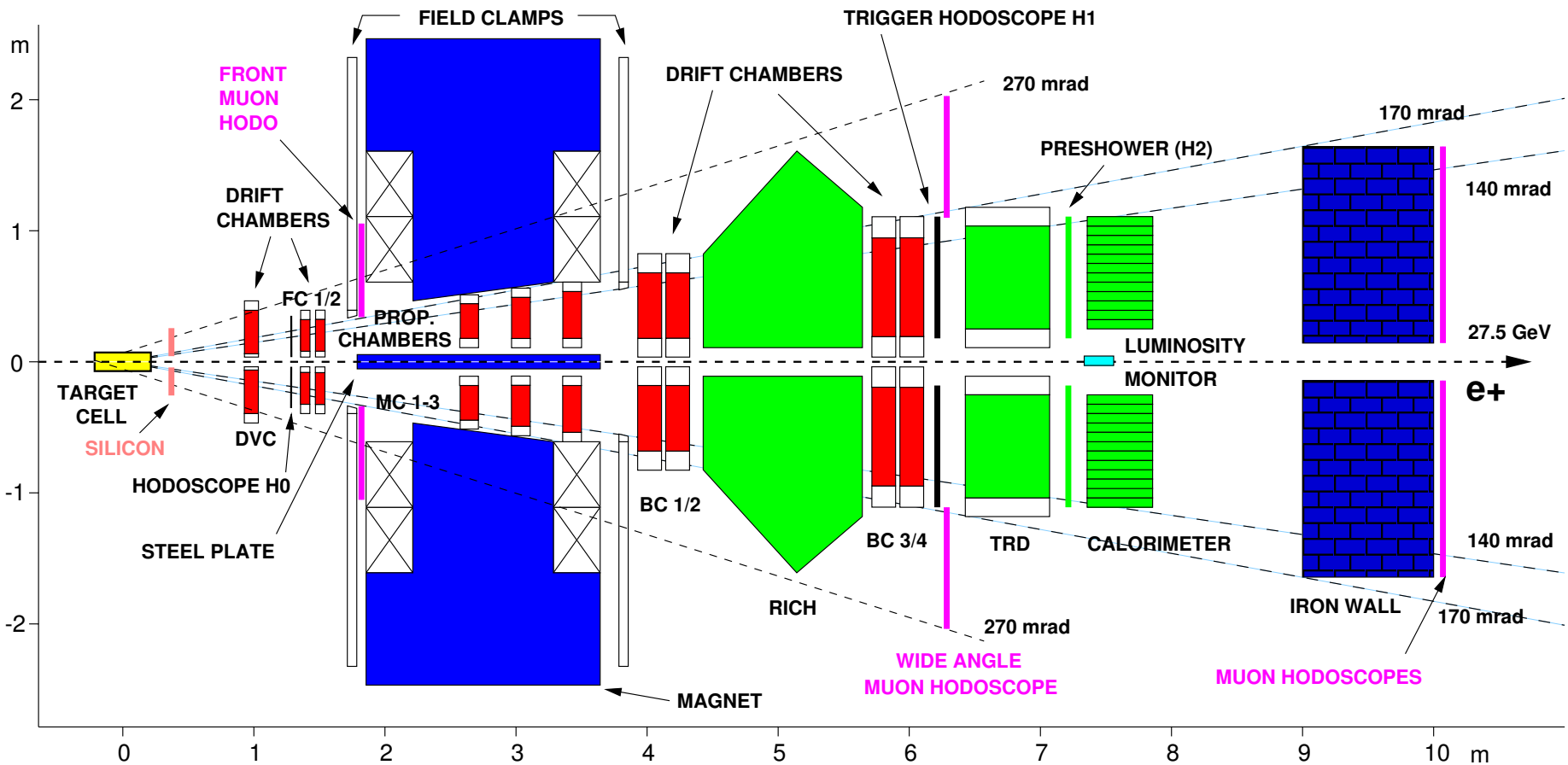
γ	$\longrightarrow$	$H, E, \widetilde{H}, \widetilde{E}$
ρ, ω, ϕ	$\longrightarrow$	H, E
π, η	$\longrightarrow$	$\widetilde{H}, \widetilde{E}$

! no precocious scaling at $Q^2 \geq 1\,\mathrm{GeV}^2$ for hard exclusive meson production

GPD


wide angle Compton scattering
form factors
deeply virtual Compton scattering
GPDs
orbital angular momentum
timelike Compton scattering
exclusive meson production
deep inelastic scattering PDFs

The HERMES experiment at DESY



- internal (polarised) hydrogen fixed target, $27.6\,\mathrm{GeV}$ (polarised) $e^{\pm}$ beam
- tracking system: drift chambers $\Delta\Theta = 0.6\,\mathrm{mrad}$, vertical dipole magnet $1.5\,\mathrm{T\,m}$, $\frac{\Delta p}{p} = 0.5\%$
- lepton-hadron separation: $> 99\%$ efficiency; particle identification: π, $p_\pi = 1\text{-}15\,\mathrm{GeV}$

Exclusivity for $ep \to e'\pi^+ n$ at HERMES

- no recoil detection

$\Rightarrow$ missing mass technique:

$M_X^2 = (q_e + q_p - q_{e'} - q_{\pi^+})^2$

for $(N_{\pi^+} - N_{\pi^-})^{\text{data}}$

for $(N_{\pi^+} - N_{\pi^-})^{\text{PYTHIA}}$

$\Rightarrow$ $N_{\pi^+}^{excl}$ obtained as a double difference

PYTHIA Monte Carlo generator:
-no nucl.res. and excl.π^+ processes
-tuned to HERMES SIDIS and VM prod.

- kinematic requirements

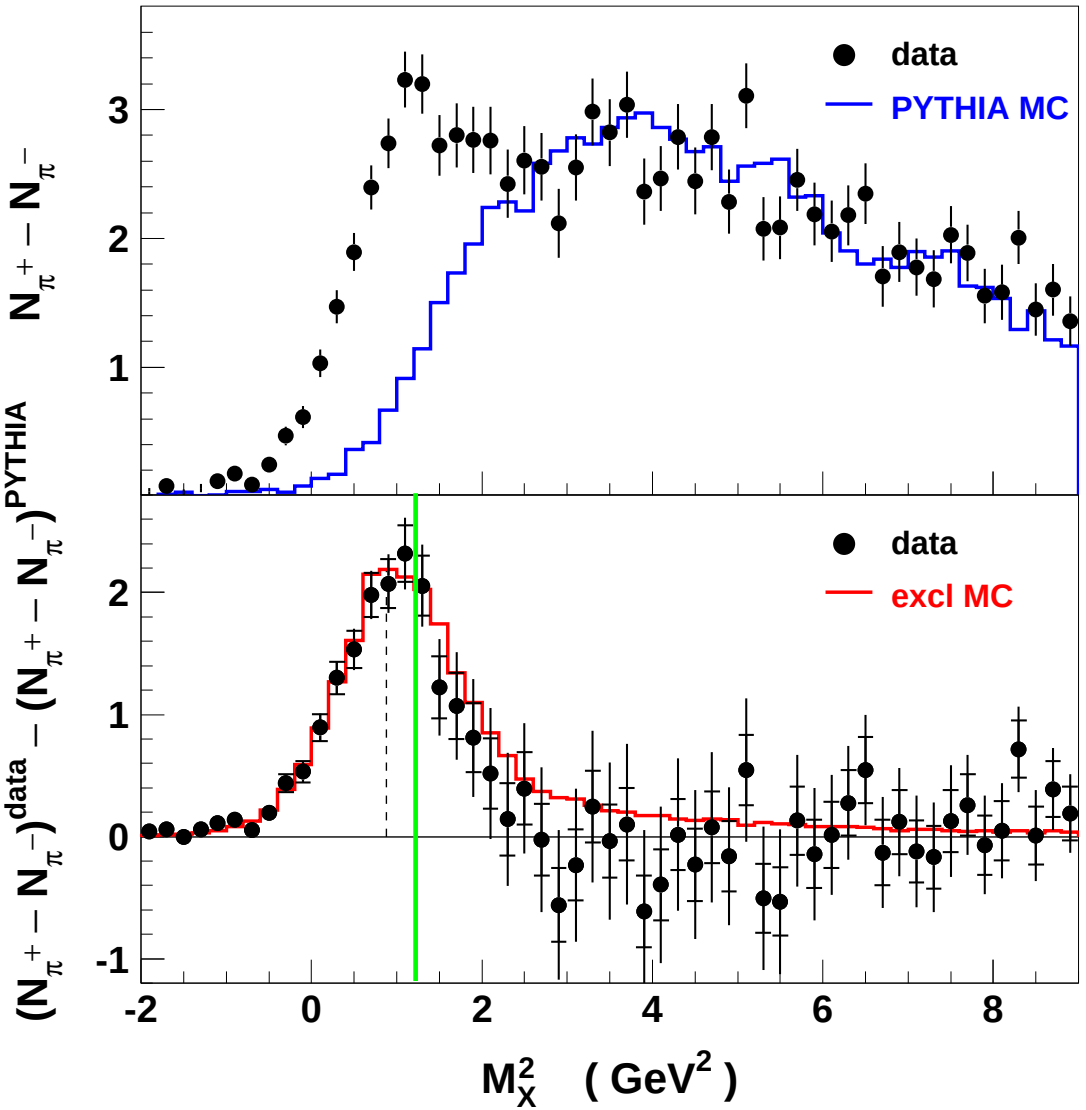
$Q^2 > 1\,\text{GeV}^2$

$W^2 > 10\,\text{GeV}^2$

$y < 0.85$

$p_\pi > 7\,\text{GeV}$

- $M_X^2 < 1.2\,\text{GeV}^2$
- $t' = t - t_0$



Exclusive peak clearly centred at the neutron mass

Mean and width in agreement with exclusive MC

Cross section determination

- $ep \leftrightarrow \gamma^* p$: $\frac{d\sigma^{\gamma^* p \to \pi^+ n}(x_B, Q^2, t', \phi)}{dt'\, d\phi} = \frac{1}{\Gamma_V(x_B, Q^2)} \frac{d\sigma^{ep \to e' \pi^+ n}(x_B, Q^2, t', \phi)}{dx_B\, dQ^2\, dt'\, d\phi}$
- Hand convention: $\Gamma_V(x_B, Q^2) = \frac{\alpha}{8\pi} \frac{1}{M_p^2 E^2} \frac{Q^2}{x_B^3} \frac{1-x_B}{1-\epsilon}$, ϵ: γ^* polarisation parameter

$N_{\pi^+}^{excl}$	π^+ events after background subtr.	κ	detection probability
Γ_V	virtual-photon flux factor	η	radiative correction factor
$\mathcal{L}$	integrated luminosity	Δ	bin size

For the data sample 1996-2005:

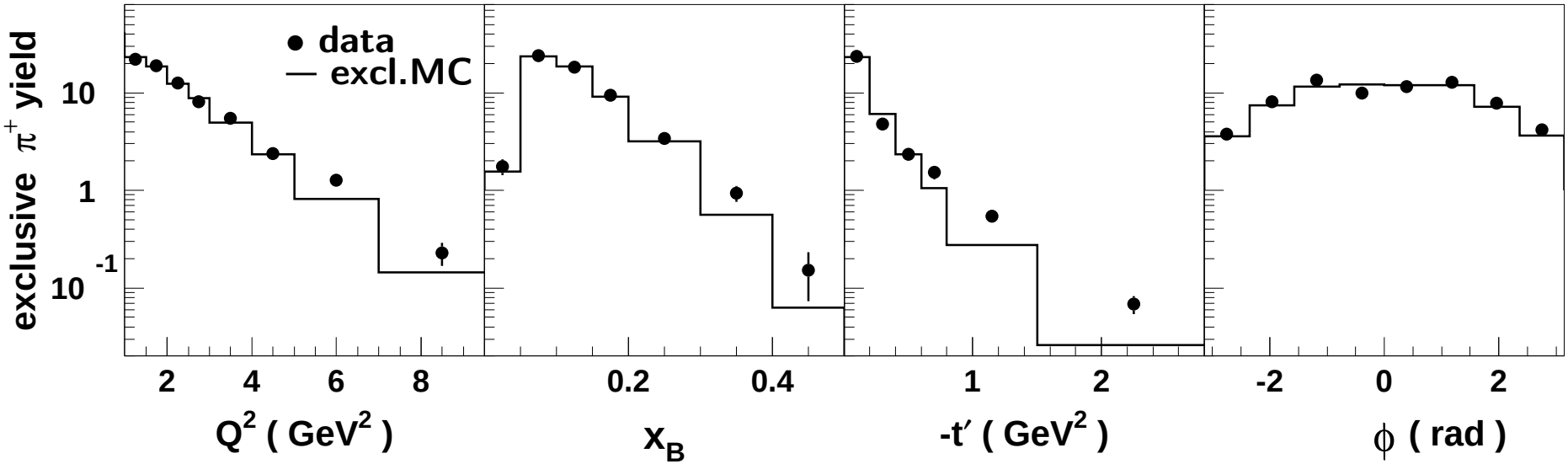
- $N_{\pi^+}^{excl} = 4510$ events, $[2-20\%]_{syst}$ $\mathcal{L} = 0.4\,\mathrm{fb}^{-1}$ $[5\%]_{syst}$
- kinematic range

$1 < Q^2 < 11\,\mathrm{GeV}^2 \quad \to \quad$ four Q^2 bins

$0.02 < x_B < 0.55 \quad \to \quad$ three x_B bins

$0 < -t' < 3\,\mathrm{GeV}^2 \quad \to \quad$ six $-t'$ bins

Exclusive distributions: Monte Carlo comparison



exclusive MC (GPD models):

- Vanderhaeghen,Guichon,Guidal PRD60(1999)094(

or

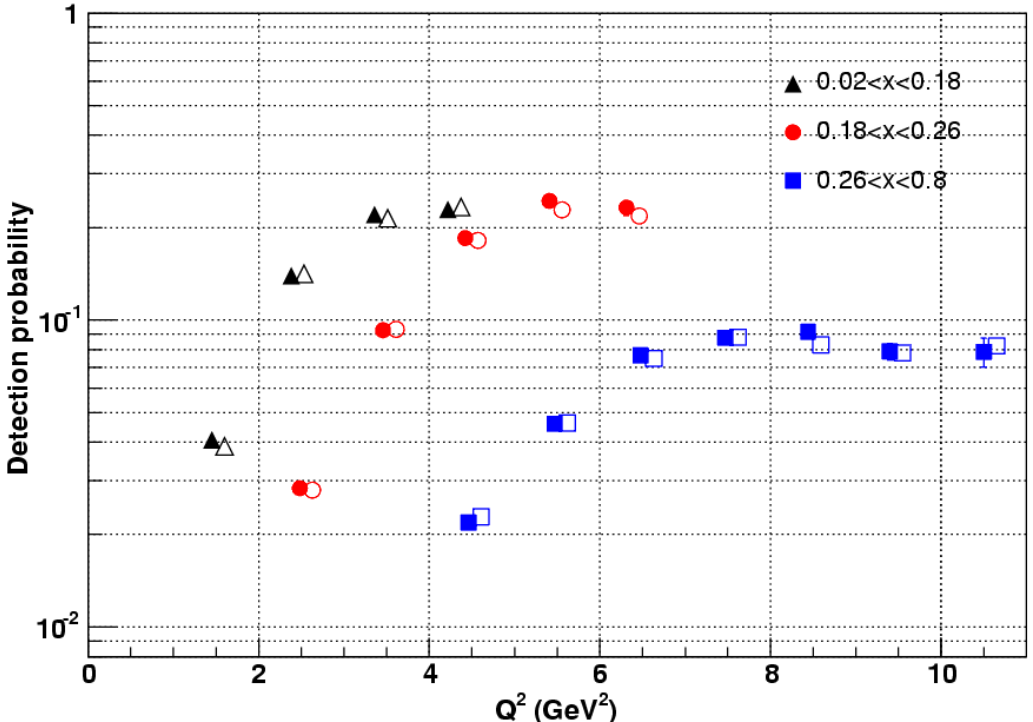
- Mankiewicz,Piller,Radyushkin EPJC10(1999)307

$$\kappa = \frac{N^{rec}_{\pi^+}}{N^{gen}_{\pi^+}} = [0.04 - 0.28]$$ acc. [0.1-0.7] cuts [0.4-0.5]

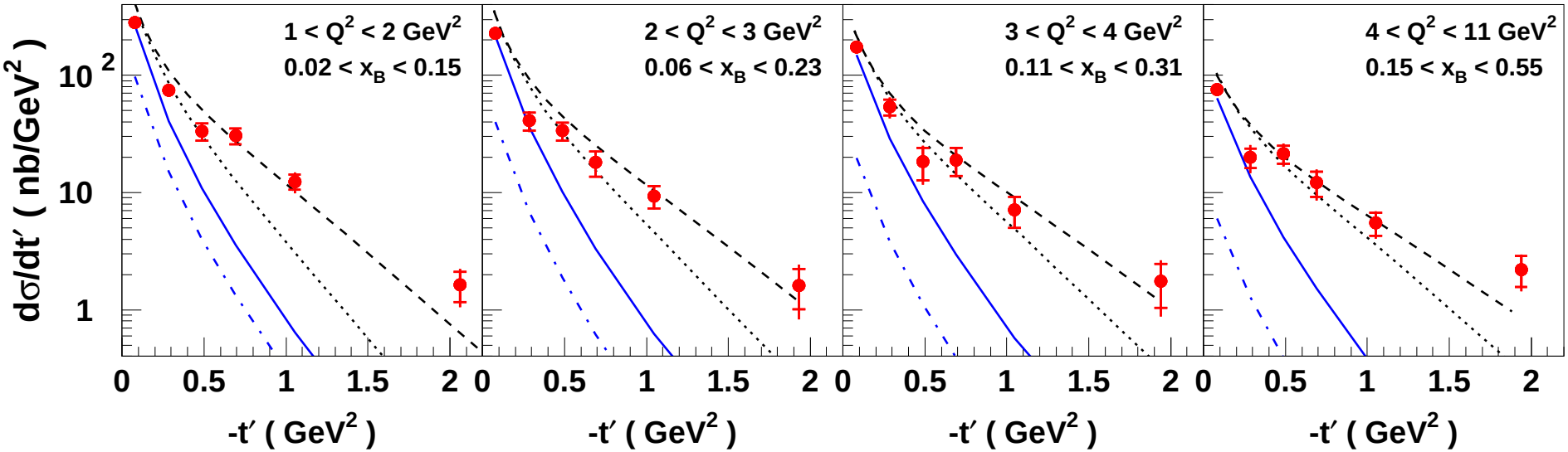
κ: probability to detect e' and π^+ (generated in 4π) in the HERMES spectrometer; $[\sim 15\%]_{syst}$

$$\eta = \frac{\sigma^{obs}}{\sigma^{Born}} = 0.77, \text{ at } M_X^2 < 1.2\,\mathrm{GeV}^2$$

-dominated by vertex&loop corrections
-independent of kinematics

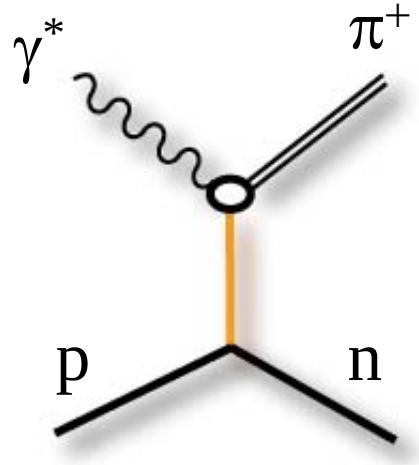


Results: the differential cross sections PLB659(2008)486



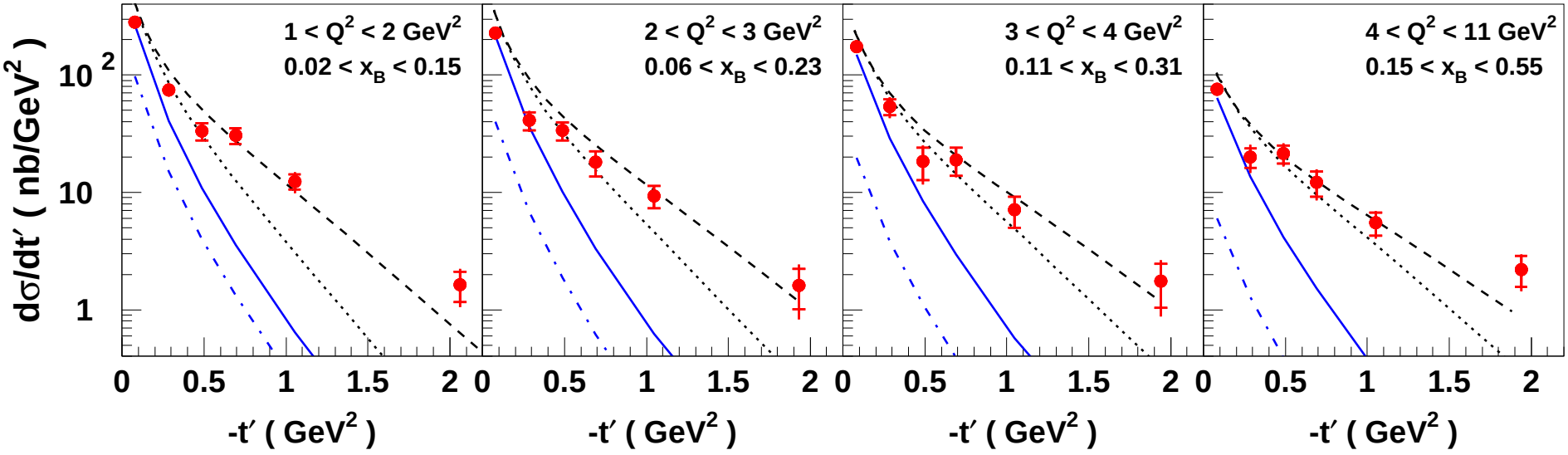
Regge model J.M.Laget PRD70(2004)054023 — — — $\frac{d\sigma}{dt}$ ..... $\frac{d\sigma_L}{dt}$

- π^+ production described by exchange of π and ρ Regge trajectories
- Q^2- and $-t'$-dependent FFs for $\pi\pi\gamma$ and $\pi\rho\gamma$
- σ_T predicted to be 15-25% of σ (about 6% at low $-t'$)



good description of the magnitude, and $-t'$, Q^2 dependences of the data

Comparison with theory PLB659(2008)486

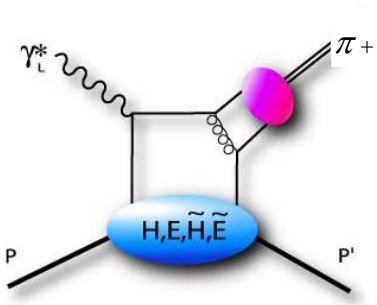


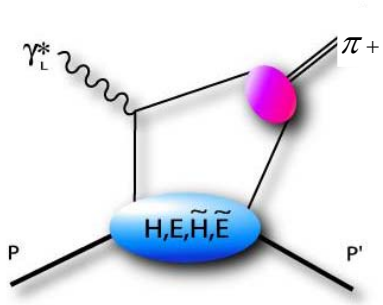
GPD model for $\frac{d\sigma_L}{dt'}$ — · — leading-order calculations

——— with power corrections

Vanderhaeghen,Guichon,Guidal PRD60(1999)094017

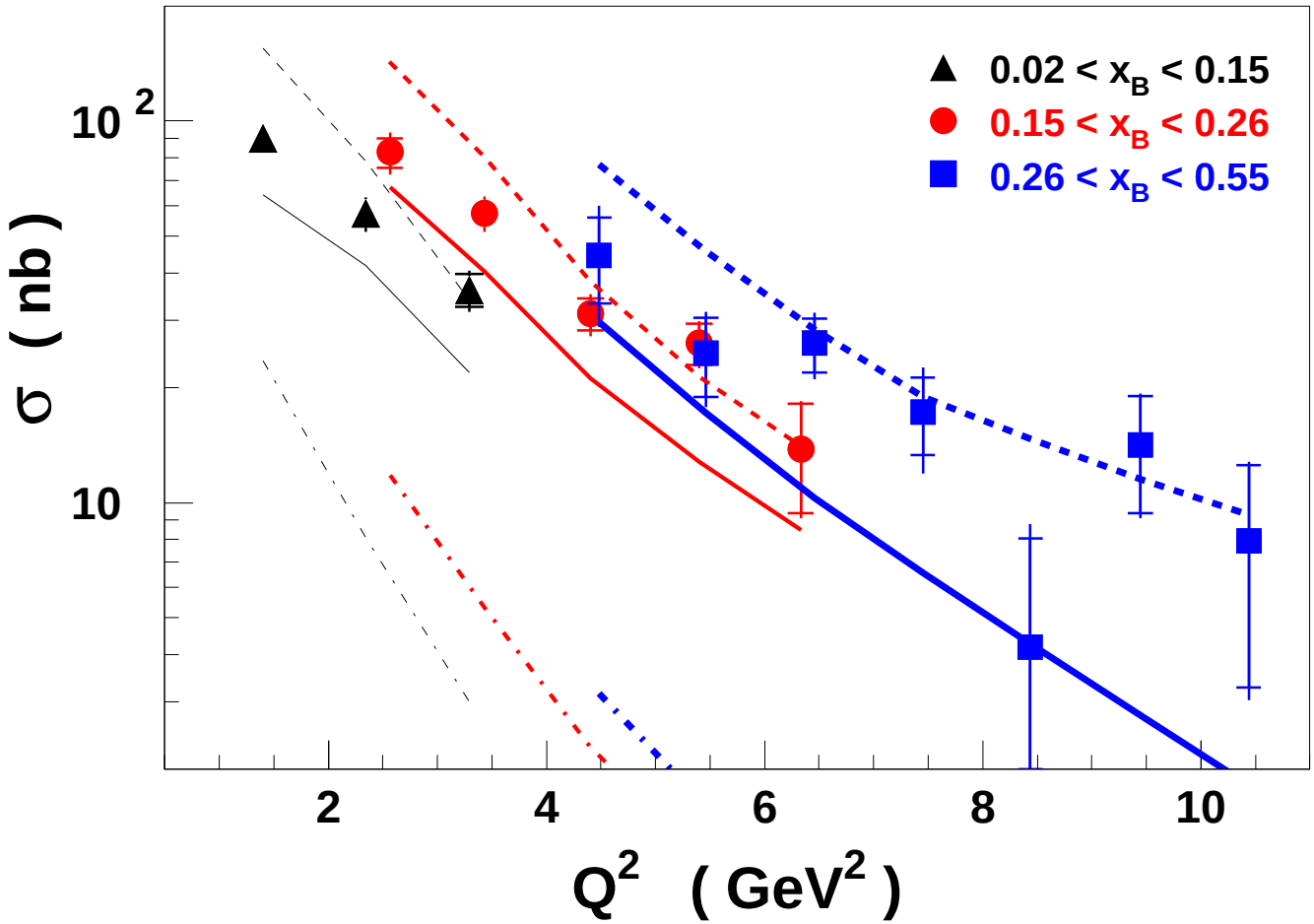
- $\widetilde{E}$ dominated by pion-pole, F_π
- $\widetilde{H}$ neglected
- Regge-inspired t dependence for $\widetilde{E}$
- power corrections due to intrinsic k_T and soft-overlap contribution





fair agreement with data at lower $-t'$ if power corrections are included

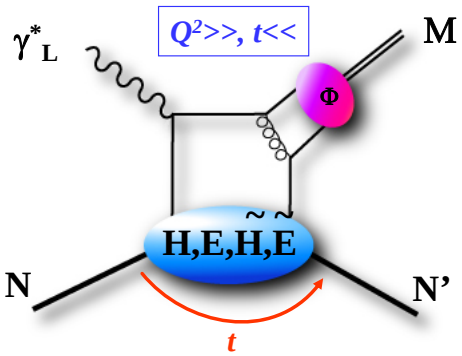
Results: the total cross section PLB659(2008)486



GPD model	— · —	leading-order calculations
	———	with power corrections
Regge model	— — —	Regge model for σ

GPD model: fair agreement, Regge model: good description of data

Transverse spin asymmetry

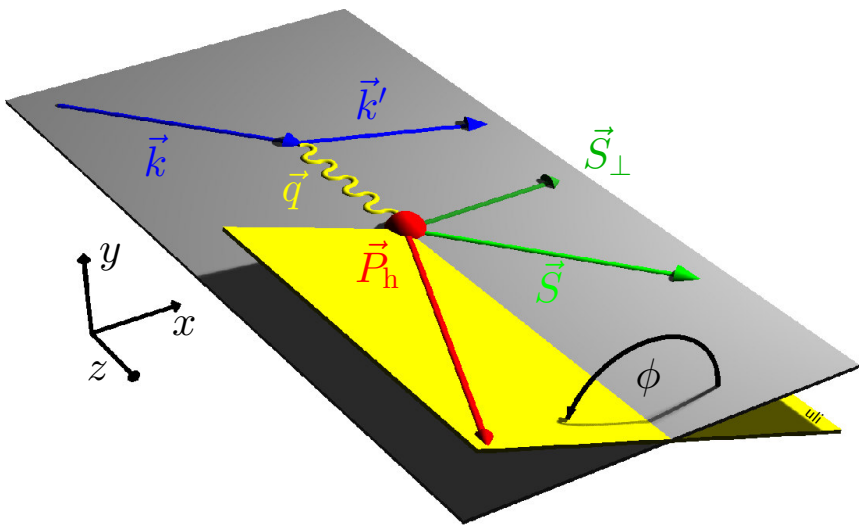


unp. cross section $\sigma_{UU} \propto |\widetilde{H}|^2 - t|\widetilde{E}|^2 - \mathrm{Re}(\widetilde{E}^*\widetilde{H})$

spin asymmetry $\propto \mathrm{Im}(\widetilde{E}^*\widetilde{H})/\sigma_{UU}$

higher order corrections cancel

scaling reached at lower Q^2



For transversely polarised target:

$\sigma_{UT} \propto |\vec{S}_T| \sin(\phi - \phi_S)\, \mathrm{Im}(\widetilde{E}^*\widetilde{H}) + \ldots$

$\Rightarrow$ extract $A_{UT}^{\sin(\phi-\phi_S)}$ plus additional five sine amplitudes

M. Diehl, S. Sapeta EPJC41(2005)515

Transverse spin asymmetry

$$\mathcal{A}_{\mathbf{UT}} = \frac{\mathbf{1}}{|\mathbf{P_T}|} \frac{\mathbf{d}\boldsymbol{\sigma}(\boldsymbol{\phi}, \boldsymbol{\phi_S}) - \mathbf{d}\boldsymbol{\sigma}(\boldsymbol{\phi}, \boldsymbol{\phi_S}+\boldsymbol{\pi})}{\mathbf{d}\boldsymbol{\sigma}(\boldsymbol{\phi}, \boldsymbol{\phi_S}) + \mathbf{d}\boldsymbol{\sigma}(\boldsymbol{\phi}, \boldsymbol{\phi_S}+\boldsymbol{\pi})}$$

M. Diel and S. Sapeta, Eur. Phys. J. C 41 (2005) 515 :

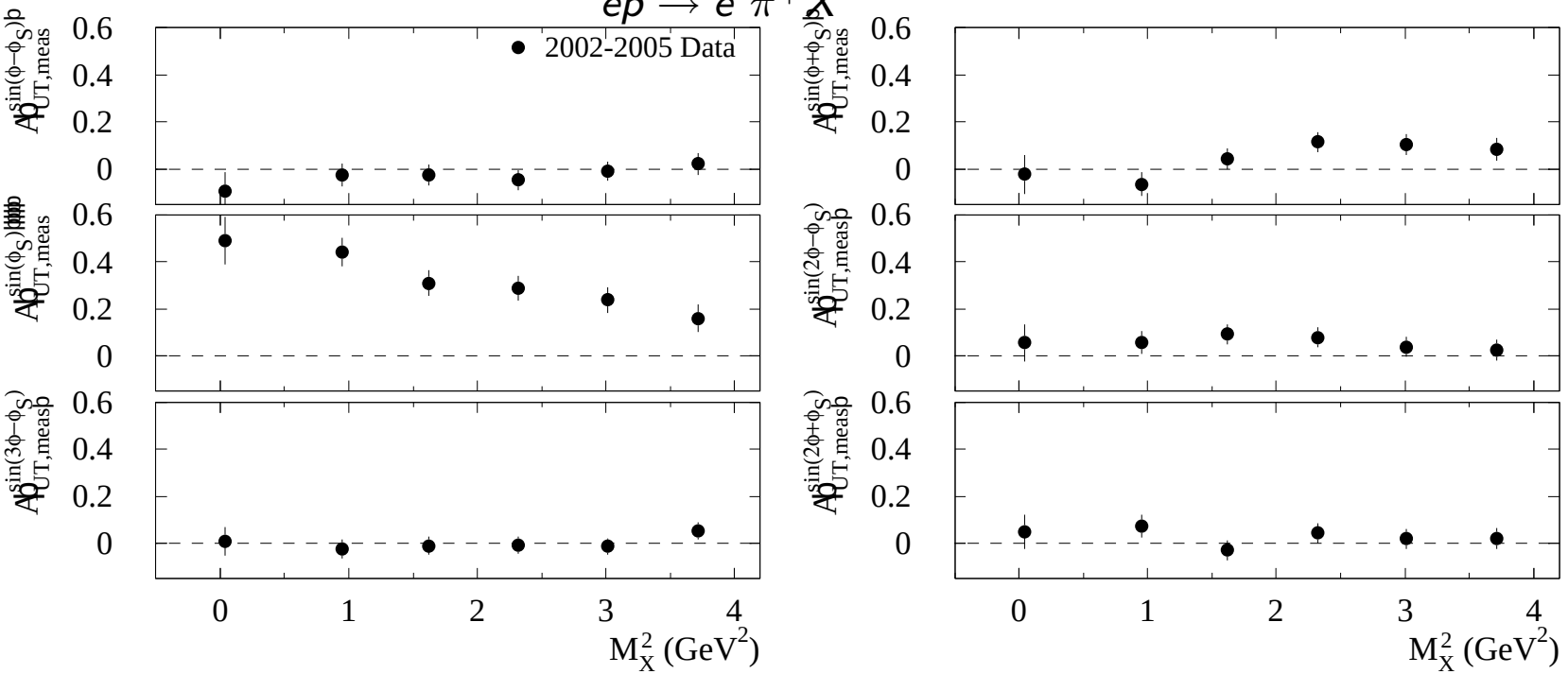
$$\begin{aligned}
&\mathcal{A}_{UT}(\phi, \phi_S; \eta_{UT}) \\
&= \quad A_{UT}^{\mathbf{sin}(\phi-\phi_S)} \mathbf{sin}(\phi - \phi_S) \quad + \quad A_{UT}^{\mathbf{sin}(\phi+\phi_S)} \mathbf{sin}(\phi + \phi_S) \\
&+ \quad A_{UT}^{\mathbf{sin}\phi_S} \mathbf{sin}\phi_S \quad + \quad A_{UT}^{\mathbf{sin}(2\phi-\phi_S)} \mathbf{sin}(2\phi - \phi_S) \\
&+ \quad A_{UT}^{\mathbf{sin}(3\phi-\phi_S)} \mathbf{sin}(3\phi - \phi_S) \quad + \quad A_{UT}^{\mathbf{sin}(2\phi+\phi_S)} \mathbf{sin}(2\phi + \phi_S)
\end{aligned}$$

Measured asymmetry A_{UT} vs. squared missing mass

measured = exclusive signal $f^{excl}_{\pi^+} = \frac{N^{excl}_{\pi^+}}{N^{data}_{\pi^+}} \approx \frac{1}{2}$ A_{UT} in $M_X^2 = [0.5 - 1.2]\,\mathrm{GeV}^2$

plus background $1 - f^{excl}_{\pi^+}$ $A_{UT,bg}$ in $M_X^2 = [1.9 - 3.3]\,\mathrm{GeV}^2$

$ep \longrightarrow e'\pi^+X$



- background correction $\longrightarrow$ extract exclusive asymmetry

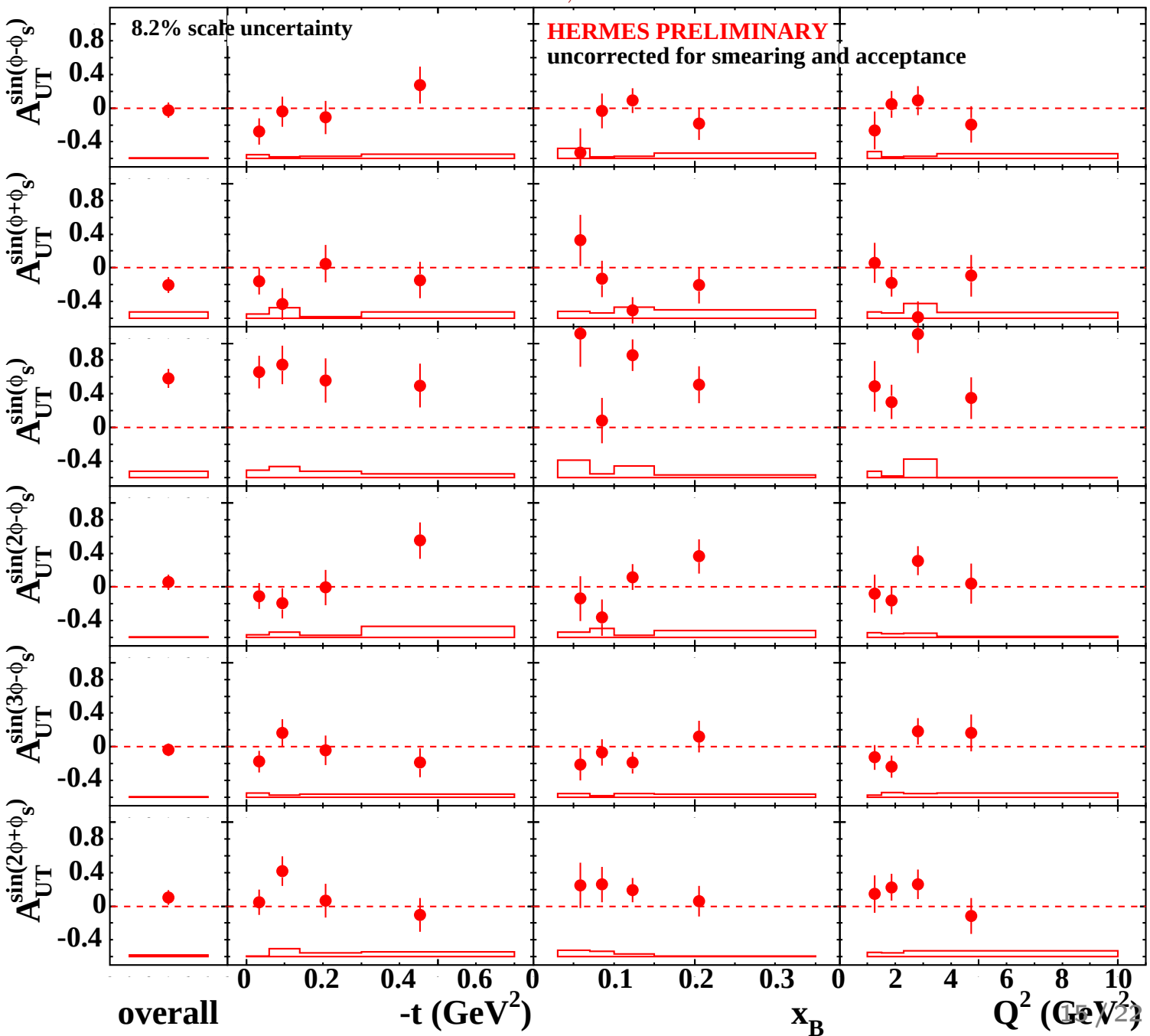
$$A^{excl}_{UT,\pi^+} \equiv A_{UT,bg.corr} = \frac{1}{f^{excl}_{\pi^+}} A_{UT} - \frac{1 - f^{excl}_{\pi^+}}{f^{excl}_{\pi^+}} A_{UT,bg}$$

Kinematic dependences of A_{UT,π^+}^{excl}

$ep \rightarrow e'\pi^+ n$

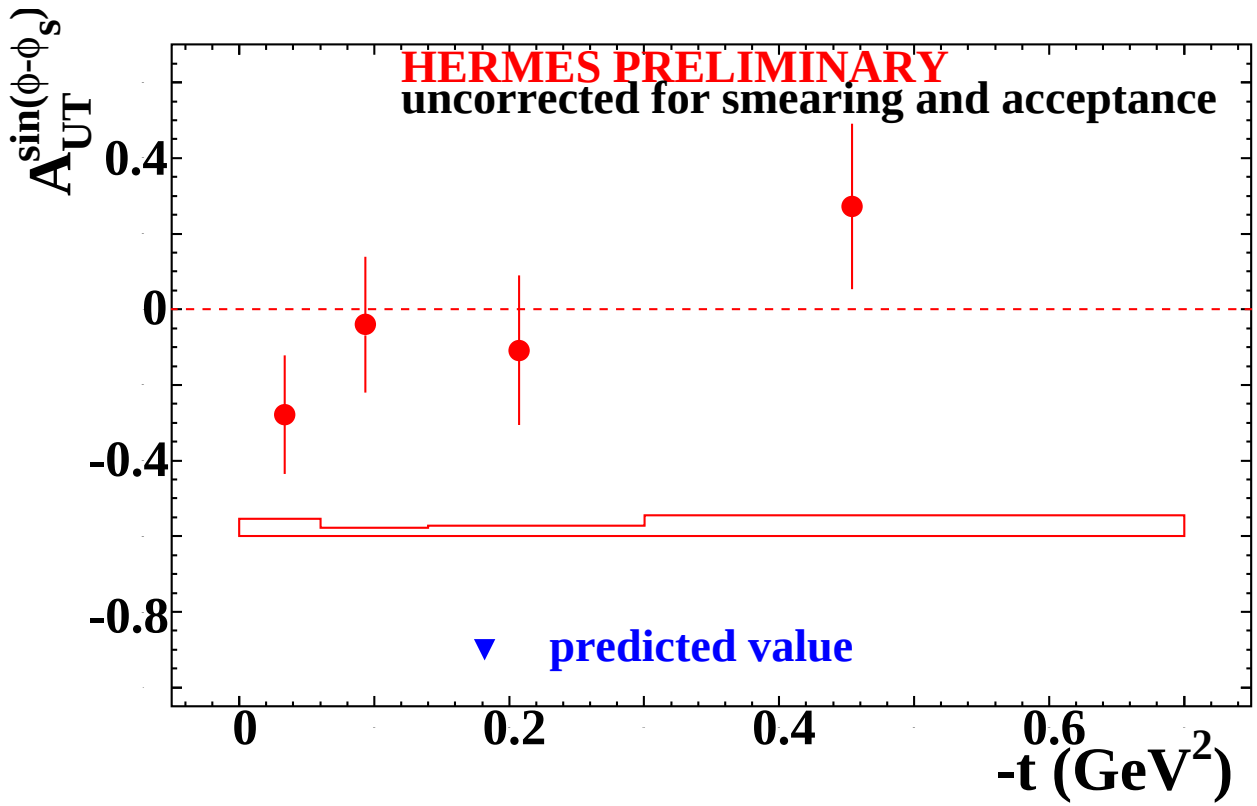
$-t \equiv -t'$

$\langle -t \rangle = 0.182\,\mathrm{GeV}^2$
$\langle x \rangle = 0.126$
$\langle Q^2 \rangle = 2.38\,\mathrm{GeV}^2$



Leading asymmetry amplitude $A_{UT}^{\sin(\phi-\phi_S)}$ vs. $-t$

- measurement indicates a sign change over $-t$ or consistency with zero
- cross section results indicate power corrections to $\widetilde{E}$ are important
  - therefore $\widetilde{E}$ increases substantially
  - but $\widetilde{H}$ remains small



$\Rightarrow A_{UT}^{\sin(\phi-\phi_S)}$ measurement consistent with cross section result

Summary and conclusions

Exclusive π^+ cross section

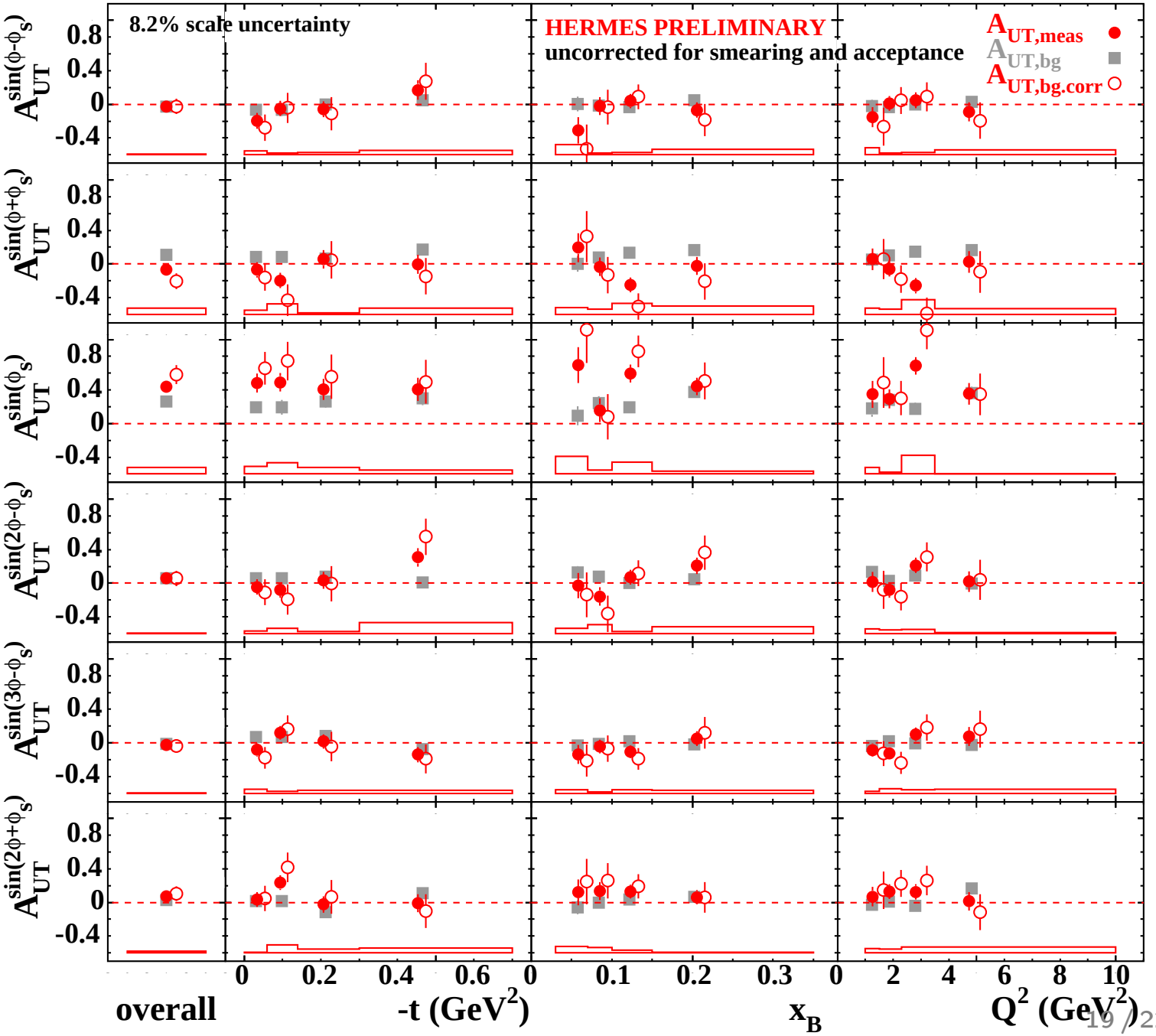
- results from recent paper PLB 659 (2008) 486
- cross section result indicates small σ_T contribution
- GPD model in fair agreement with data at low values of $-t$; data support the order of magnitude of power corrections
- Regge model provides good description of the kinematic dependences

Transverse spin asymmetry

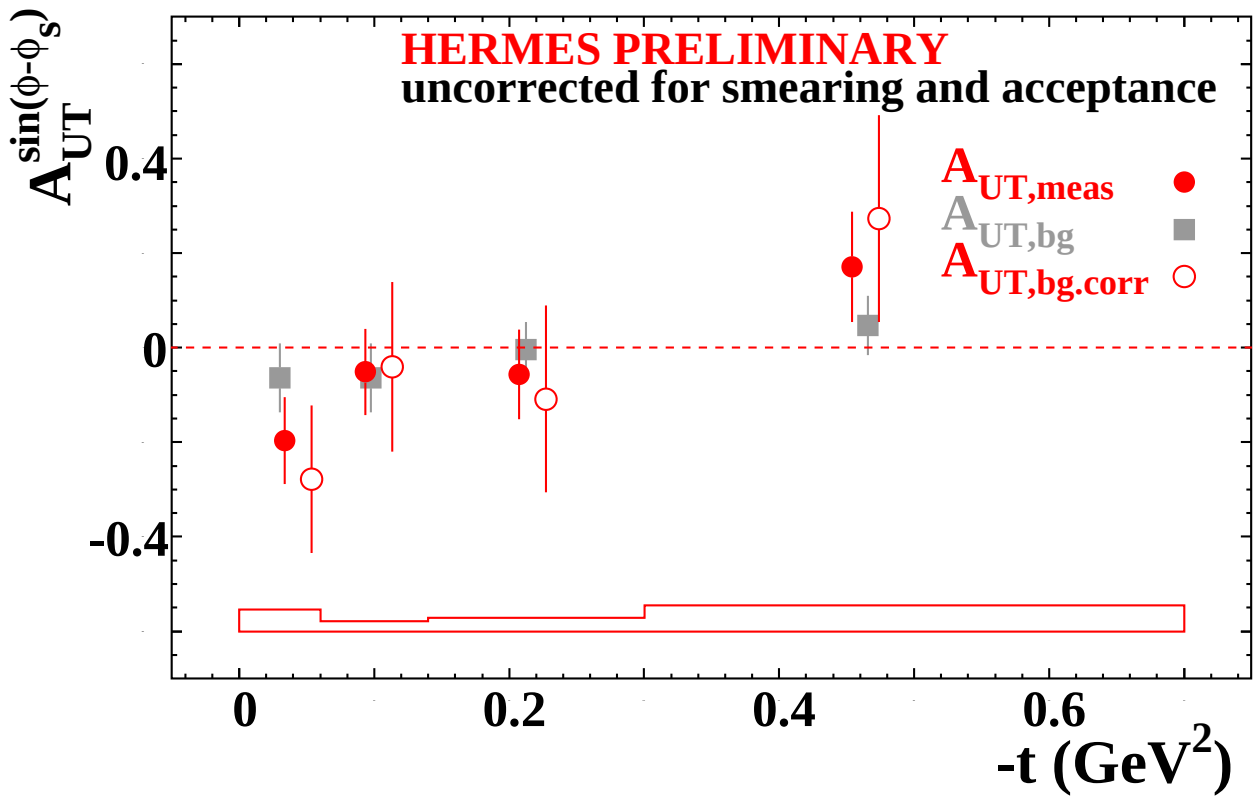
- preliminary results
- first experimental attempt to study this observable
- the leading asymmetry amplitude is compared to theoretical calculations: smaller asymmetry than predicted by theory
- supposedly $\tilde{E} \gg \tilde{H}$
- larger statistics required for more detailed studies of the kinematic dependences, for example @ JLab

Backup slides

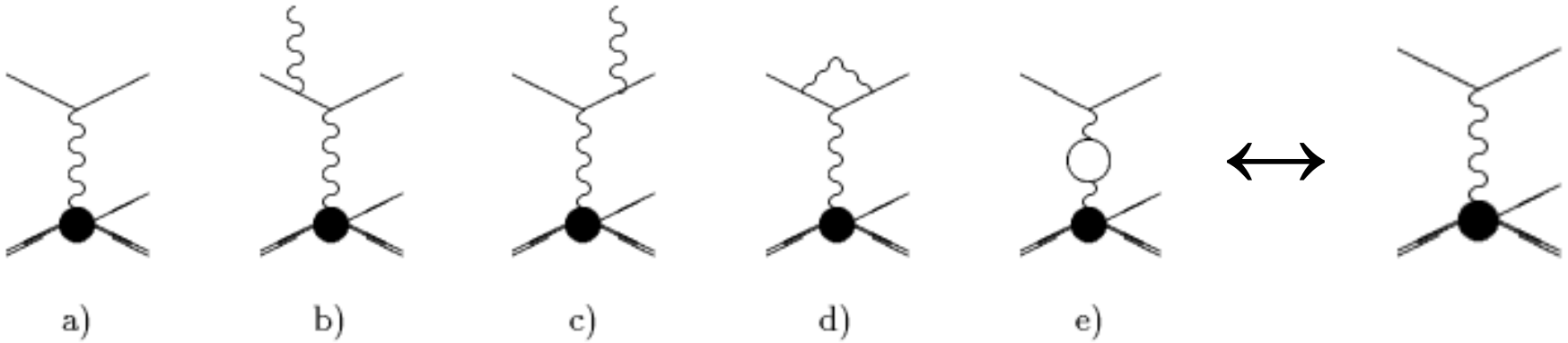
Kinematic dependences of A_{UT}



$A_{UT}^{\sin(\phi-\phi_S)}$ vs. $-t$



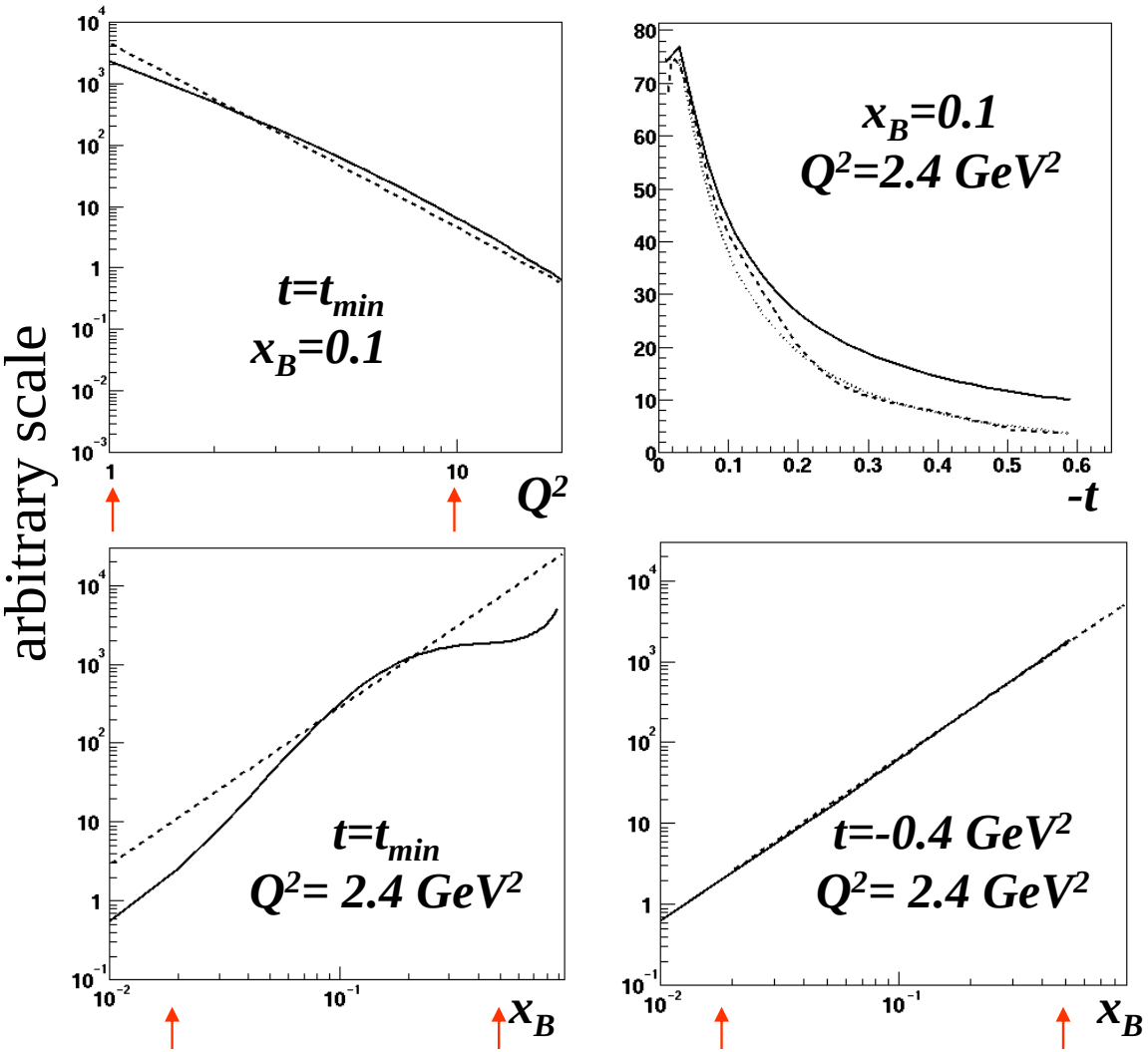
Radiative effects for exclusive π^+ production



- correct the measured cross section by $\eta = \dfrac{\sigma^{obs}}{\sigma^{Born}} = 0.77$
- RADGEN adapted to exclusive processes with VGG GPD model as input

  Akushevich,Böttcher,Ryckbosch hep-ph/9906408, A. Ilyichev
- little variation of η ($< 3\%$) as a function of x_B, Q^2, or t' for $M_X^2 < 1.2\,\mathrm{GeV}^2$
- compute at Born level $\langle x_B \rangle$, $\langle Q^2 \rangle$, $\langle t' \rangle$, $\Gamma_V(\langle x_B \rangle, \langle Q^2 \rangle)$
- corrections applied for smearing $12/15\%(< 25/35\%)$, bin size $\delta = 1.08(< 1.2)$

GPD models



— VGG model

..... Tuned VGG ($\tilde{E}^*e^t$)

- - Piller model

↑↑ Hermes kinematics

→ different dependence for VGG and Piller

- VGG model: Vanderhaeghen, Guichon, Guidal PRD 60 (1999) 094017
- Piller model: Mankiewicz, Piller, Radyushkin EPJC 10 (1999) 307