DVCS predictions + fits based on H1/ZEUS + EIC mock data

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KMP-K, 0807.0159 [hep-ph]; **KM 0904.0458 [hep-ph]**
flexible GPD model for small *x* and fits of H1/ZEUS data
two codes in Phyton (+ Minuit + GeParD) & Mathematica + GeParD

S. Fazio in 1108.1713 [hep-ph]
EIC mock data 20 x 250 from a modified NLO Freund/McDermott code, exponential t-dependence
statistical errors, smeared kinematical variables + 5% systematic error added by hand

Model based on SL(2,R) and SO(3) PWE

- SL(2,R) GPD moments: $$F_j(\eta,t) = \sum_{J=J^{\min}}^{j+1} f_j^J(t)\,\eta^{j+1-J}\,\hat{d}_J(\eta)$$

partial wave amplitudes depending on j and J

reduced Wigner rotation matrices

- taking 2 better 3 SO(3) PWs:
  (two parameters s_2 and s_4)

$$f_j^{j-1}(t) = s_2 f_j^{j+1}(t)\,,$$
$$f_j^{j-3}(t) = s_4 f_j^{j+1}(t)\,,$$

- resulting CFF easy to handle:

$$\mathcal{F} = \frac{1}{2i}\sum_{\substack{k=0\\ \text{even}}}^{4}\int_{c-i\infty}^{c+i\infty} dj\,\xi^{-j-1}\frac{2^{j+1+k}\Gamma(5/2+j+k)}{\Gamma(3/2)\Gamma(3+j+k)}\left(i-\frac{\cos(\pi j)\mp 1}{\sin(\pi j)}\right)$$
$$\times s_k E_{j+k}(\mathcal{Q}^2) f_j^{j+1}(t)\hat{d}_j(\xi), \quad s_0 = 1$$

- zero-skewness GPD: $$h_j^{j+1} = q_j\frac{j+1-\alpha(0)}{j+1-\alpha(0)-\alpha' t}\left(1-\frac{t}{M_j^2}\right)^{-p}$$

PDF

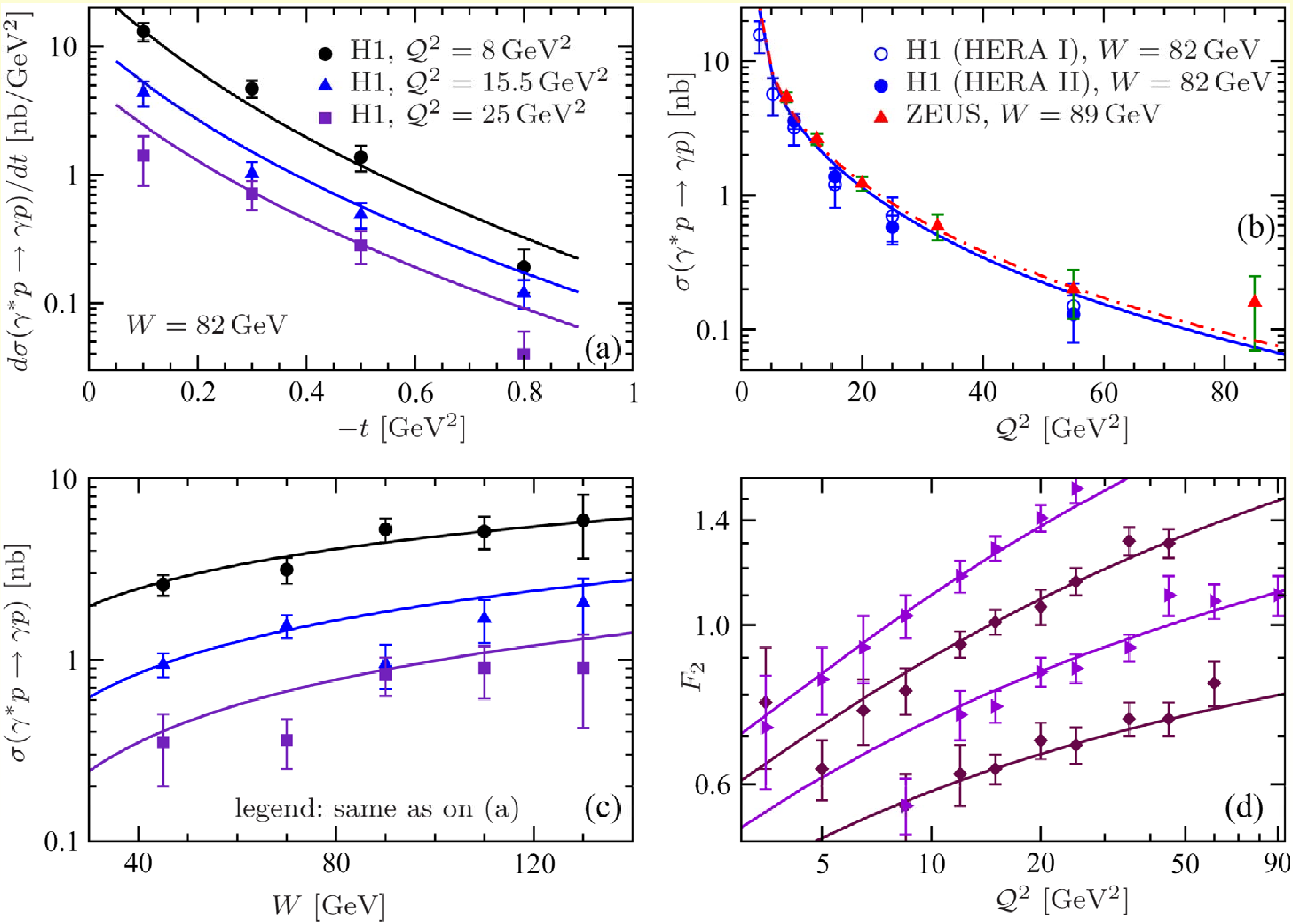
\`pomeron intercept' (biuld in PDF) + Regge slope

residual t dependence

2x(2, 3, or 4) parameters:

***s_2, s_4, M or b*, (perhaps α')**

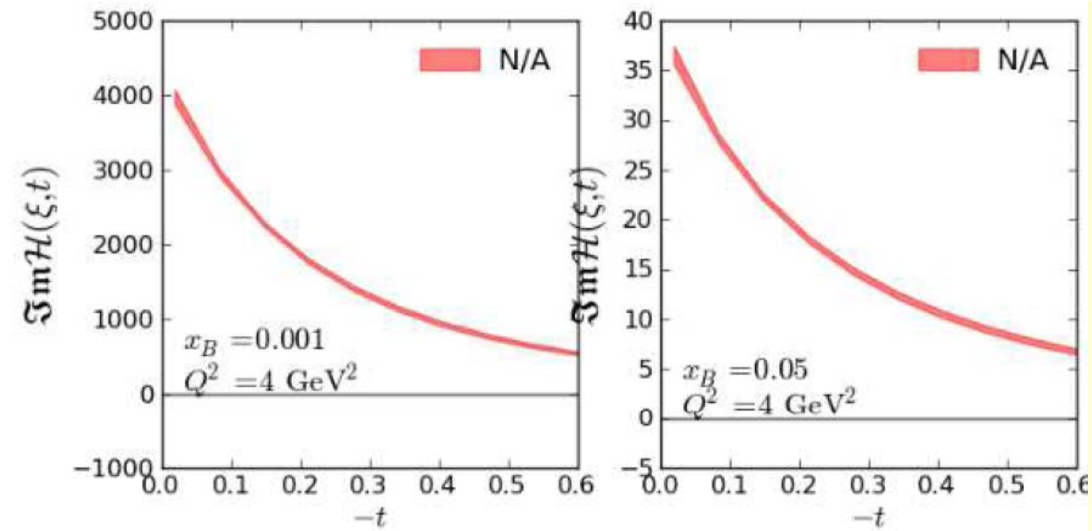
good DVCS fits at LO, NLO, and NNLO with flexible GPD ansatz



H1/ZEUS data

~ 180 data points H1/ZEUS, not statistically independent

four parameter H1/ZEUS fit (s_2^Q, M_2^Q, s_2^G, M_2^G) provides small error bands



Note: PDF is considered as known (another uncertainty)
(n^{sea},α^{sea}, α^{sea}, are fixed and $n^{sea}+n^{val}+n^{G}=1$)

art of error propagation

increasing amount of (compatible) data will reduce error bands
increasing parameter set might result in bigger error bands
taking strongly correlated parameters s^2,s^4 might induce very big error bands
error bands depend on model assumptions and hypotheses

4 parameter fit with fixed PDFs

~ 30-50 H1/ZEUS points might be considered as independent
b=5/GeV^2 is a bit incompatible with H1/ZEUS data
new mock data from Salvatore with b ~ 5.6/GeV^2 are better
(not entirely consistent with HERA data, statistically inconsistent)

Observables for $e^-p \to e^-p\gamma$ at small x_B

DVCS cross section (dominated by *H* and slightly dependent on *E*)

$$\frac{d\sigma^{\mathrm{DVCS}}}{dt}(W,t,\mathcal{Q}^2) \approx \frac{\pi\alpha^2}{\mathcal{Q}^4}\frac{W^2 x_{\mathrm{Bj}}^2}{W^2+\mathcal{Q}^2}\left[|\mathcal{H}|^2 - \frac{t}{4M_p^2}|\mathcal{E}|^2\right](x_{\mathrm{Bj}},t,\mathcal{Q}^2)\Big|_{x_{\mathrm{Bj}}\approx\frac{\mathcal{Q}^2}{W^2+\mathcal{Q}^2}}$$

(electron) beam spin asymmetry (dominated by *H* and slightly dependent on *E*)

$$A_{\mathrm{BS}}^{(1)} \propto y\left[F_1(t)H(\xi,\xi,t,\mathcal{Q}^2) - \frac{t}{4M^2}F_2(t)E(\xi,\xi,t,\mathcal{Q}^2) + \cdots\right]$$

sin(ψ) transverse target spin asymmetry (governed by *E* and *H*)

$$A_{\mathrm{TS}}^{\Uparrow(1)} \propto \frac{t}{4M^2}\left[F_2(t)H(\xi,\xi,t,\mathcal{Q}^2) - F_1(t)E(\xi,\xi,t,\mathcal{Q}^2) + \cdots\right]$$

cos(ψ) transverse and longitudinal target spin asymmetries are sensitive to parity odd GPDs – expected to be suppressed at small x_B

$$A_{\mathrm{TS}}^{\Downarrow(1)} \propto \frac{t}{4M^2}\left[F_2(t)\widetilde{H}(\xi,\xi,t,\mathcal{Q}^2) - F_1(t)\xi\widetilde{E}(\xi,\xi,t,\mathcal{Q}^2) + \cdots\right]$$

$$A_{\mathrm{TS}}^{\Rightarrow(1)} \propto \left[F_1(t)\widetilde{H}(\xi,\xi,t,\mathcal{Q}^2) - \frac{t}{4M^2}F_2(t)\xi\widetilde{E}(\xi,\xi,t,\mathcal{Q}^2) + \cdots\right]$$

effective model parameterization (small x)

PDF: $$q^{\rm sea}(\xi, \mathcal{Q}_0) = n\xi^{-\alpha}, \quad \alpha \gtrsim 1, \quad F_1^{\rm sea}(0) = 1$$

GPD *H*: $$H^{\rm sea}(\xi, \xi, t, \mathcal{Q}_0) = r(\eta/x = 1|s_2, s_4) F_1^{\rm sea}(t) \xi^{\alpha'(t)} q^{\rm sea}(\xi)$$

- PDF is assumed to be known (from some fit with to "stone age" HERA data)
- *t*-dependence of residue is taken to be exponential with slope *B*
- free parameters: two sets $\{\alpha', B, s_2, s_4\}$ for sea quarks and gluons
- momentum sum rule is implemented

GPD *E*:

$$E^{\rm sea}(\xi, \mathcal{Q}_0) = n\xi^{-\alpha}, \quad \alpha \gtrsim 1, \quad F_2^{\rm sea}(0) = \kappa^{\rm sea}$$

$$E^{\rm sea}(\xi, \xi, t, \mathcal{Q}_0) = r(\eta/x = 1|s_2, s_4) F_2^{\rm sea}(t) \xi^{\alpha'(t)} E^{\rm sea}(\xi, \eta = 0)$$

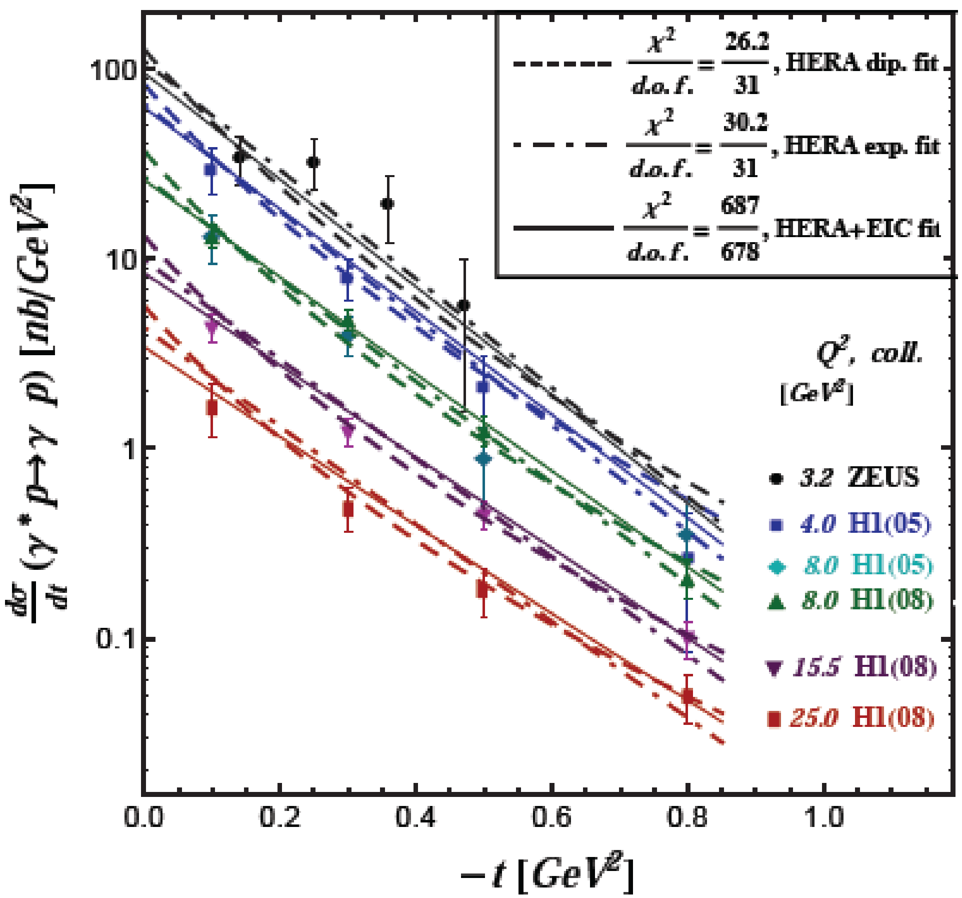
- PDF analog is unknown
- *t*-dependence of residue is taken to be exponential with slope *B*
- free parameters: κ^{sea} + two sets $\{\alpha, \alpha', B, s_2, s_4\}$ for sea quarks and gluons
- κ^G *is constrained by Ji`s* sum rule

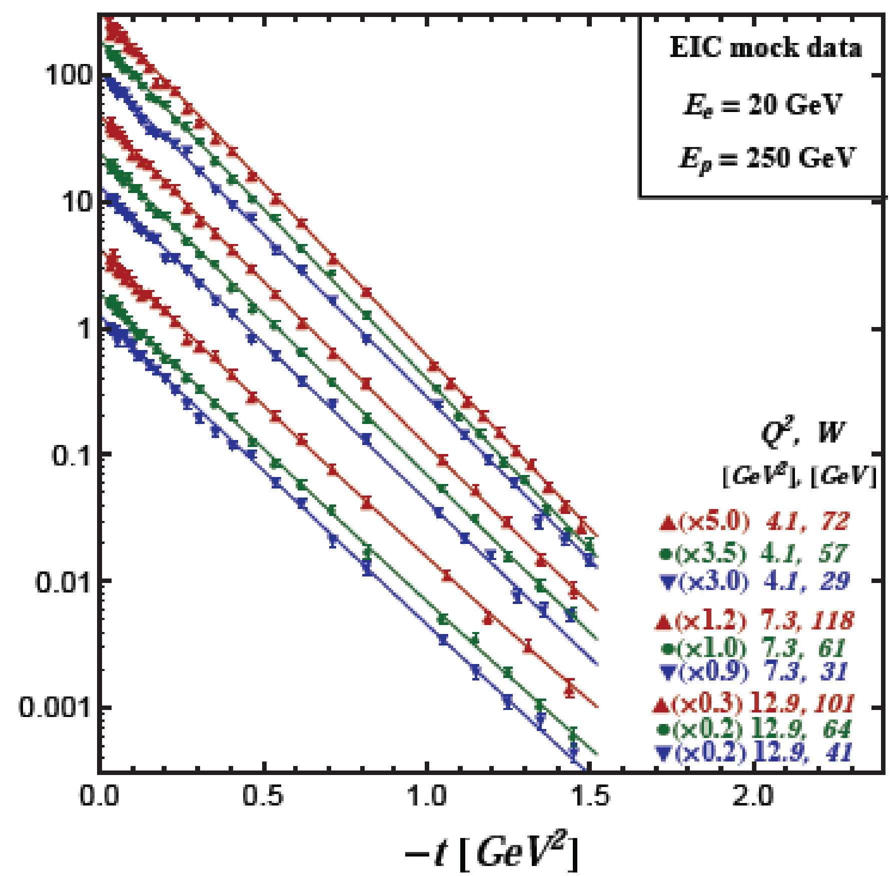
real part of Compton form factors is determined by their imaginary parts

Impact of EIC data to extract GPD H

two simulations from Salvatore for DVCS cross section ~ 650 data points
$-t <$ ~0.8 GeV^2 for ~ 10/pb
1 GeV^2 $< -t <$ 2 GeV^2 for ~ 100/pb (cut: $-t < 1.5$ GeV^2 , 4 GeV^2 $< Q2$ to ensure $-t < Q^2$)

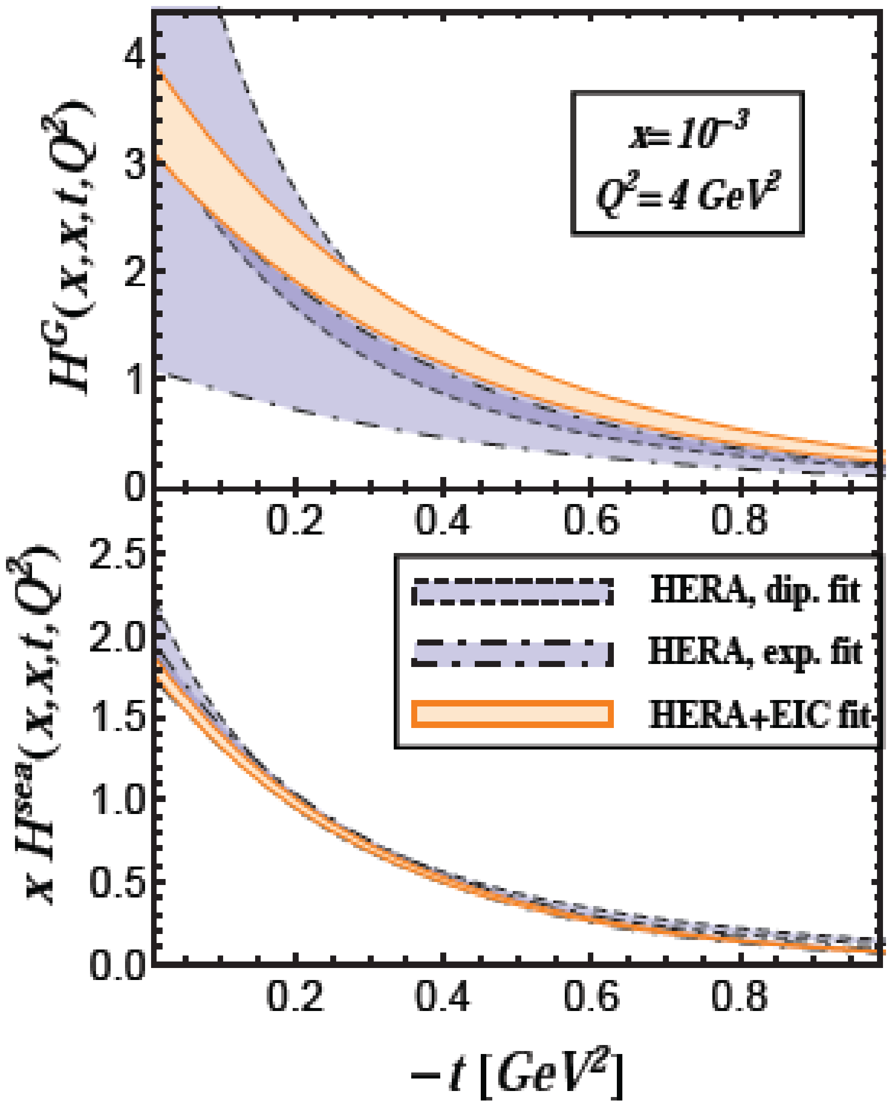
mock data are re-generated with GeParD
statistical errors rescaled
5% systematical errors added in quadrature





Imaging (probabilistic interpretation)

$$q(x,\vec{b},\mu^2) = \frac{1}{\pi}\int_0^\infty d|t|\, J_0(|\vec{b}|\sqrt{|t|})H(x,\eta=0,t,\mu^2)$$



FT

skewness effect vanishes (s_2 , $s_4 \rightarrow 0$)

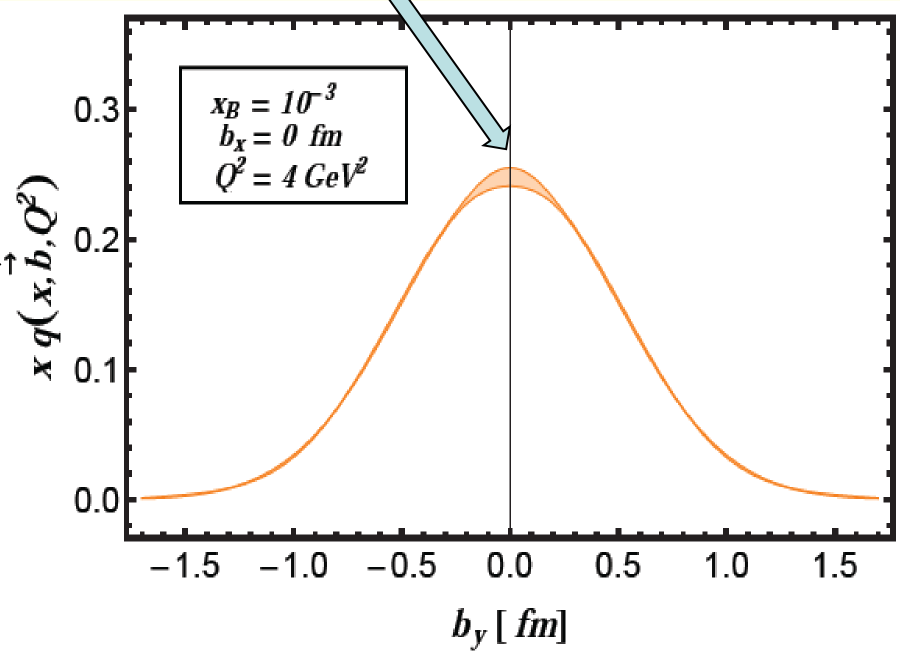
- reduce fit uncertainties
- increase model uncertainties

extrapolation errors for $-t \rightarrow 0$

(large b uncertainties – small effect)

extrapolation errors into $-t > 1.5$ GeV^2

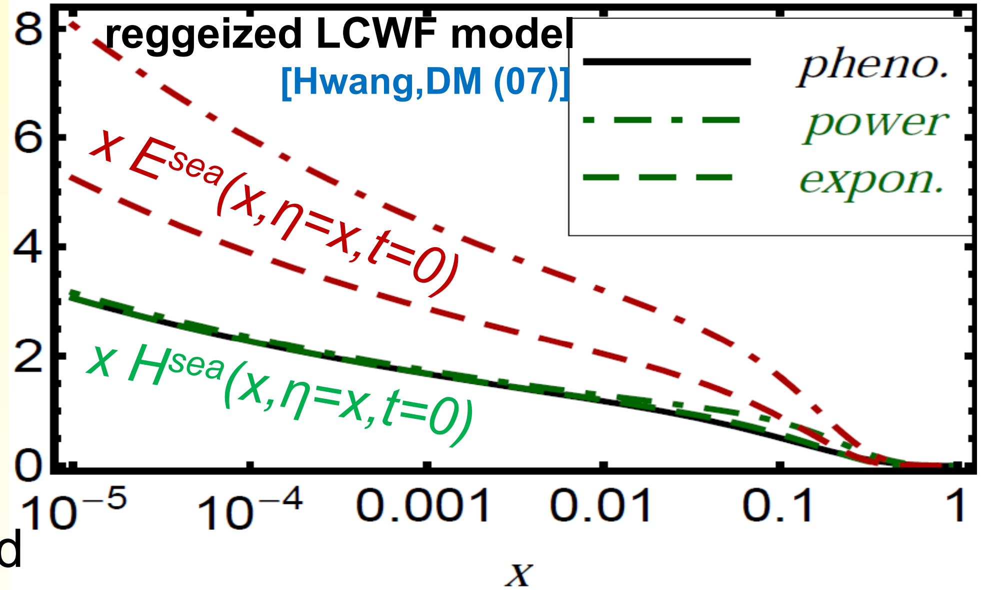
(small b uncertainties)



$? \quad E^{\mathrm{sea}}(\xi,\xi,t,\mathcal{Q}), \quad E^{\mathrm{G}}(\xi,\xi,t,\mathcal{Q})$

? exist a helicity flip "pomeron"-proton coupling

- not seen in Regge phenomenology
- might be sizeable in instanton models
- reggeized spectator quark models
- pQCD suggests `pomeron' intercept
- large N_c states $E \sim H$ (isosinglet)



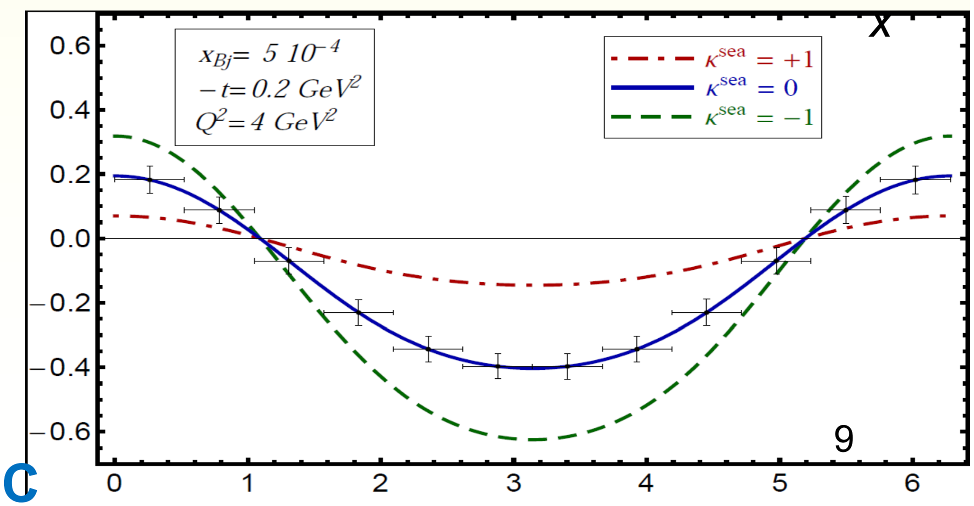
qualitative understanding of *E* is needed
(not only forJi`s spin sum rule)

$$B = \int_0^1 dx\, x E(x,\eta,t,\mathcal{Q})$$

$$\sum_q B^q + B^G = 0$$

$$\lim_{\mathcal{Q}\to\infty} \sum_q B^q(\mathcal{Q}) = \lim_{\mathcal{Q}\to\infty} B^G(\mathcal{Q}) = 0$$

transverse target spin asymmetry is
is **sensitive to *E and accessible* at EIC**

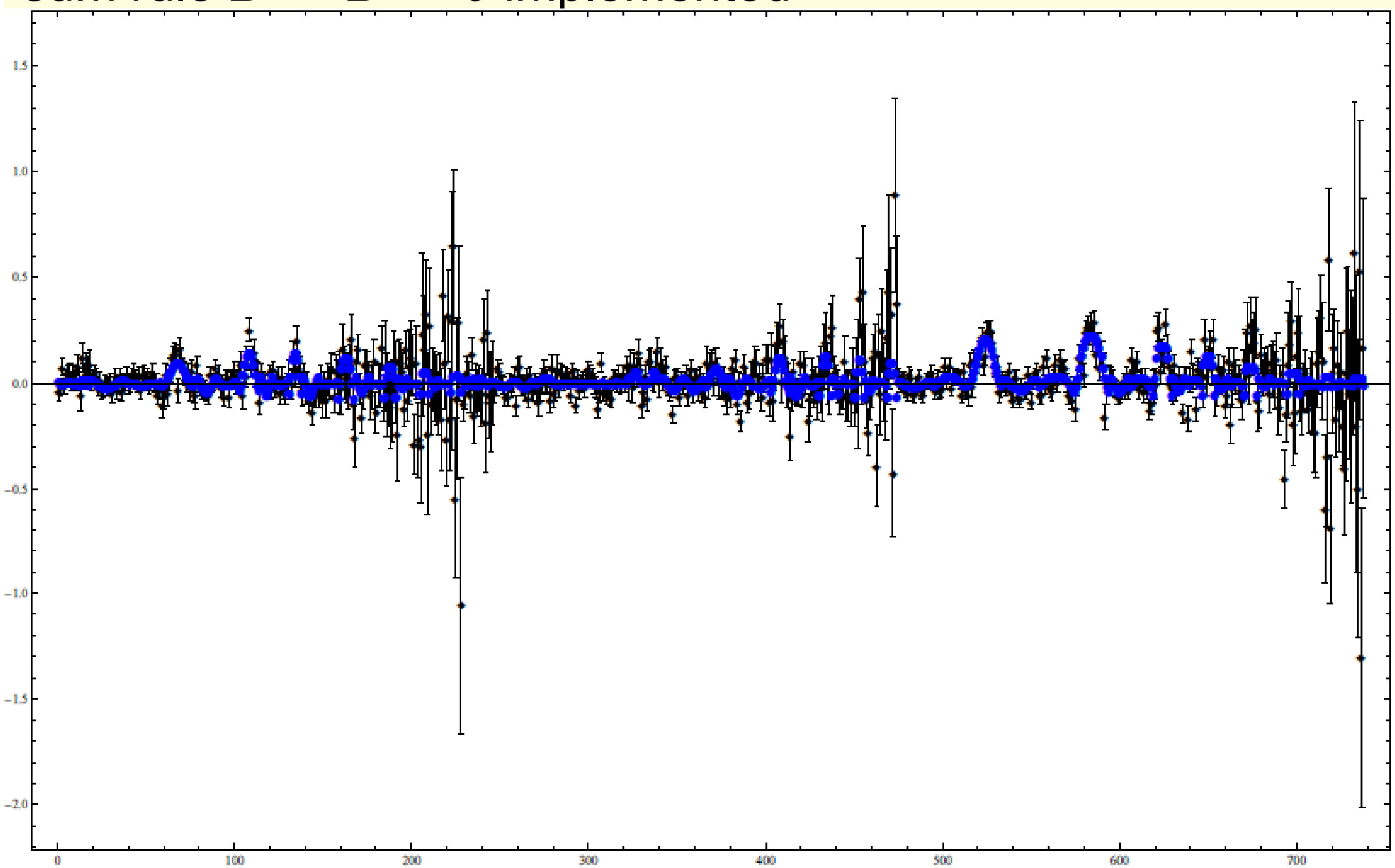


Salvatore: statistical errors with 11/pb for 738 data points [72 bins in (x_B,t, Q^2)]

1.5 $10^{-4} < x_B < 10^{-2}$, $-t \in \{0.08, 0.28, 0.65\}$ GeV^2, $Q^2 \in$ {4.4, 7.8, 13. 9} GeV^2

5% systematical error added to cross section → asymmetry error 0.035
5 % polarization error added

so far fit to transverse TSA done with fixed GPD *H* and fully flexible GPD *E*
sum rule $B^Q + B^G = 0$ implemented



paramerters for CFF model "DR" from a χ^2/d.o.f. = 1.04 fit (obtained in 550. s):

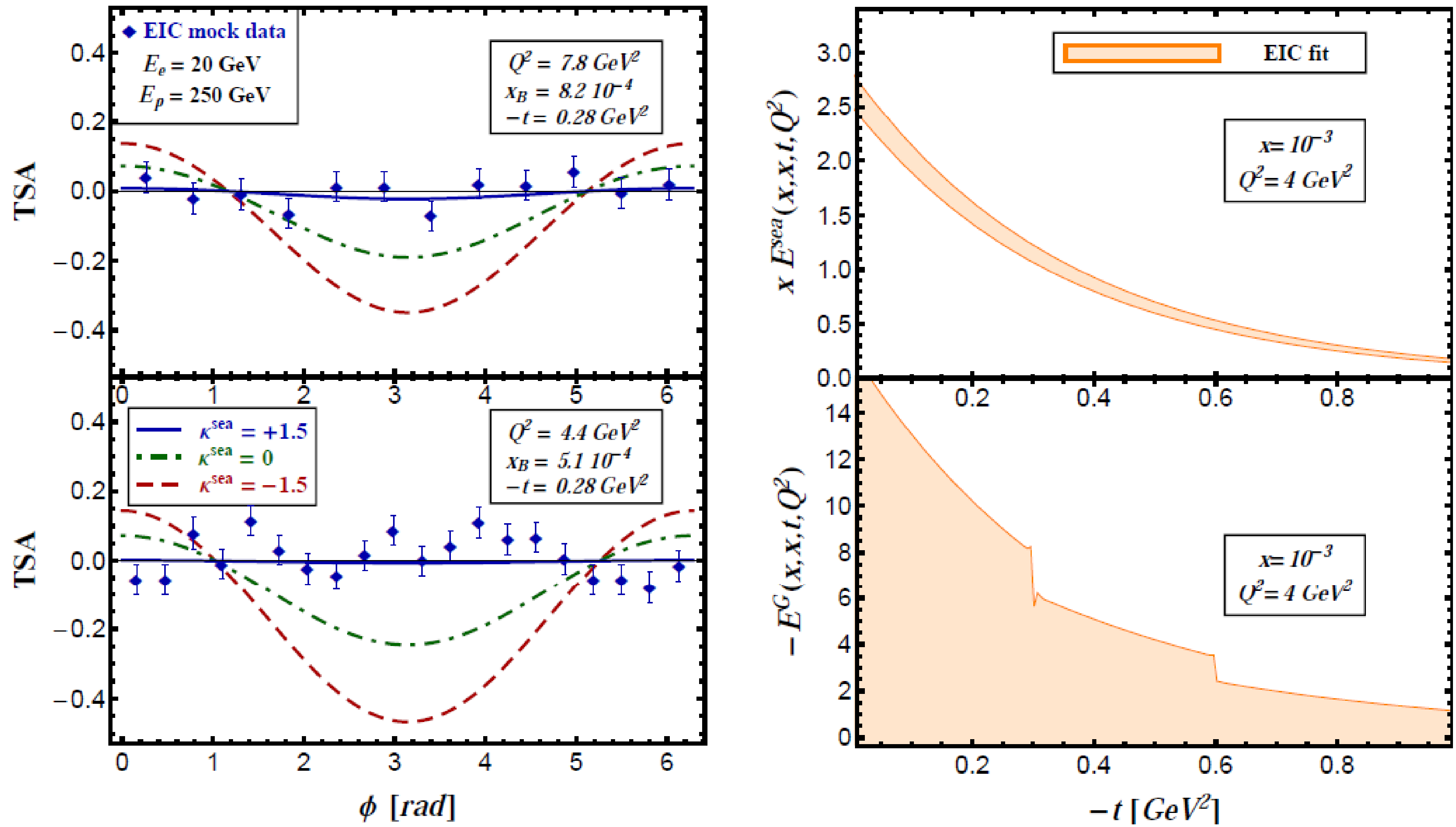
χ^2/d.o.f. ~ 1.04

correlations:

$B \leftrightarrow \alpha'$

$\kappa^{sea} \leftrightarrow s_2 \leftrightarrow s_4$

normalization (and *t*-depency) of E^{sea} is reasonable constraint
E^{G} is essentially unconstraint



Imaging (probabilistic interpretation)

density for a transverse polarized proton in impact spce

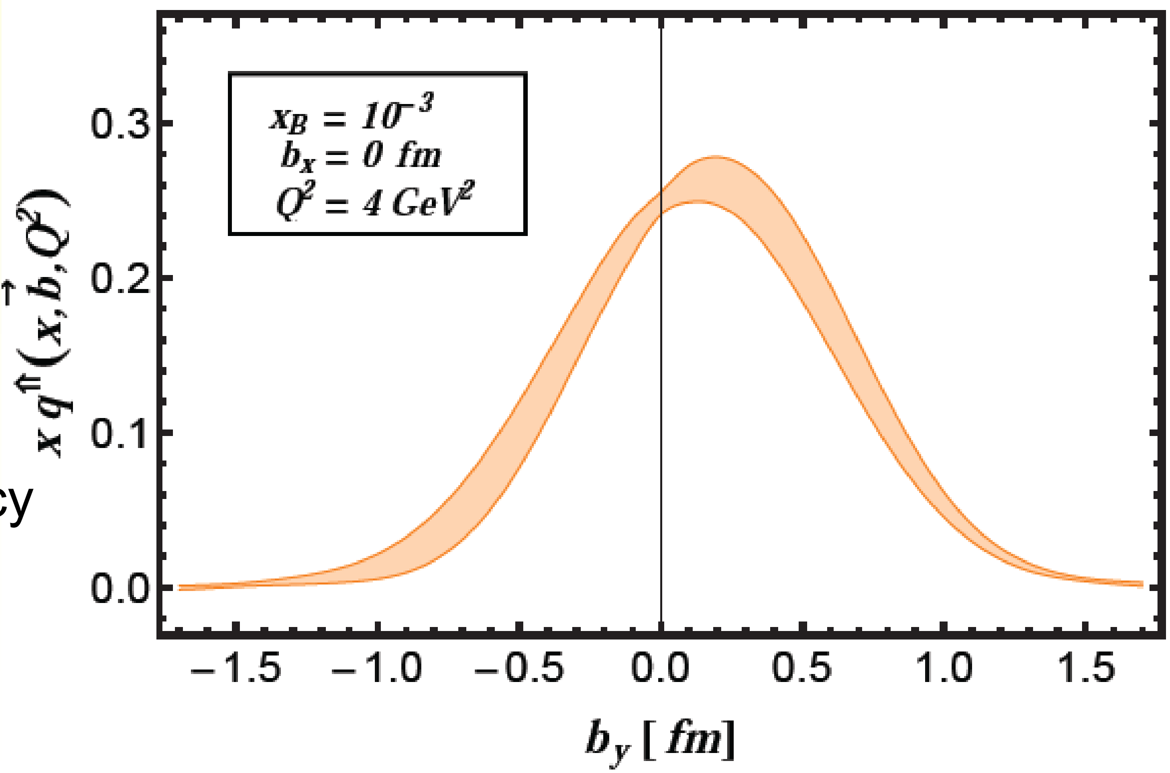
$$q^{\Uparrow}(x,\vec{b},\mu^2) \;=\; q(x,\vec{b},\mu^2) - \frac{1}{2M}\frac{\partial}{\partial b_y}E(x,\vec{b},\mu^2)$$

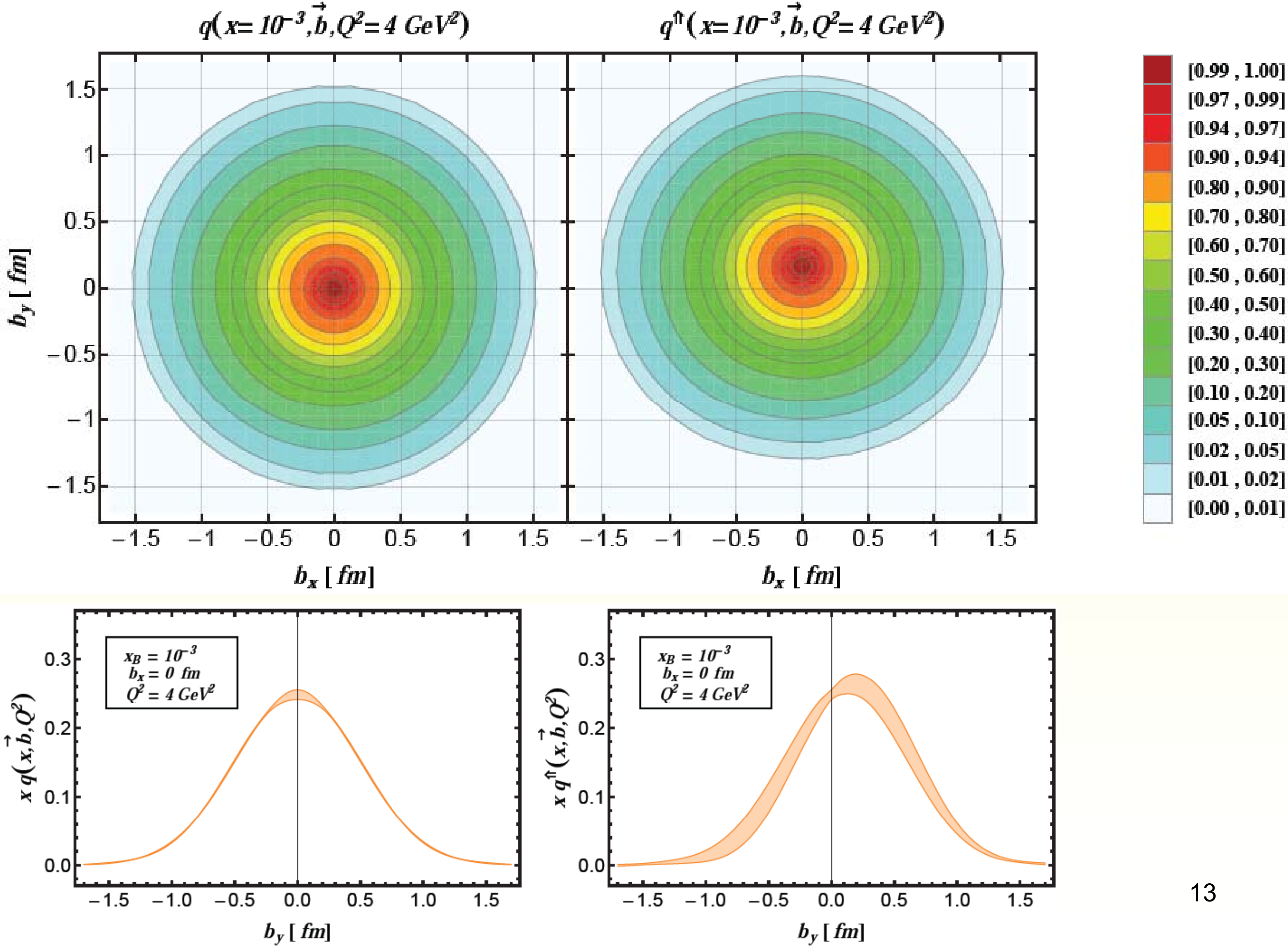
$$= \frac{1}{\pi}\int_0^{\infty} d|t| \left[J_0(|\vec{b}|\sqrt{|t|})H + \frac{b_y\sqrt{|t|}}{|\vec{b}|2M} J_1(|\vec{b}|\sqrt{|t|})E \right](x,\eta=0,t,\mu^2)$$

already assumed that E is constrained for -t < 1.5 GeV²

extrapolation errors into *-t > 1.5* GeV² are taken

NOTE:
normalization and t-dependency of E are now extracted while normalization of H is fixed by unpolarized PDF





$q(x=10^{-3},\vec{b},Q^2=4\ GeV^2)$
$q^{\Uparrow}(x=10^{-3},\vec{b},Q^2=4\ GeV^2)$
b_y [fm]
b_x [fm]
[0.99 , 1.00]
[0.97 , 0.99]
[0.94 , 0.97]
[0.90 , 0.94]
[0.80 , 0.90]
[0.70 , 0.80]
[0.60 , 0.70]
[0.50 , 0.60]
[0.40 , 0.50]
[0.30 , 0.40]
[0.20 , 0.30]
[0.10 , 0.20]
[0.05 , 0.10]
[0.02 , 0.05]
[0.01 , 0.02]
[0.00 , 0.01]
$x_B = 10^{-3}$
$b_x = 0$ fm
$Q^2 = 4\ GeV^2$
$x\, q(x,\vec{b},Q^2)$
$x\, q^{\Uparrow}(x,\vec{b},Q^2)$
b_y [fm]

(optional) upgrades (perhaps for a paper)

simulation

? more *t*-bins for asymmetries (20 x 250)
including 5 x100 data
generating mock data for BSA

fits and observables

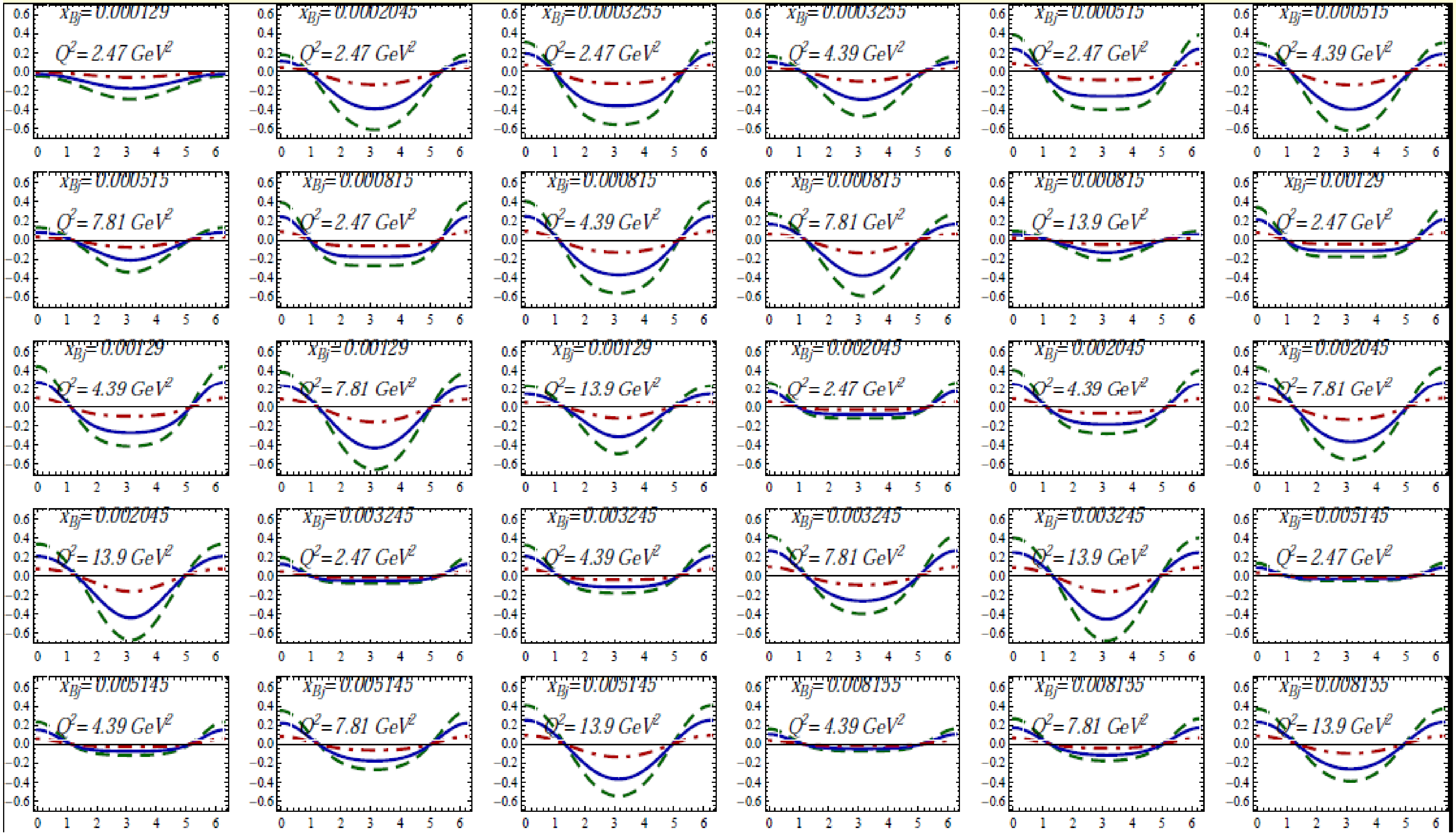
cross check with MINUIT
simultaneous fit to X, transverse TSA , and perhaps BSA
discussing longitudinal TSA
dipole ansatz versus exponential *t*-dependency

errors /presentation

separating statistical and systematical errors
separating errors related to *t*-dependency and normalization (skewness)

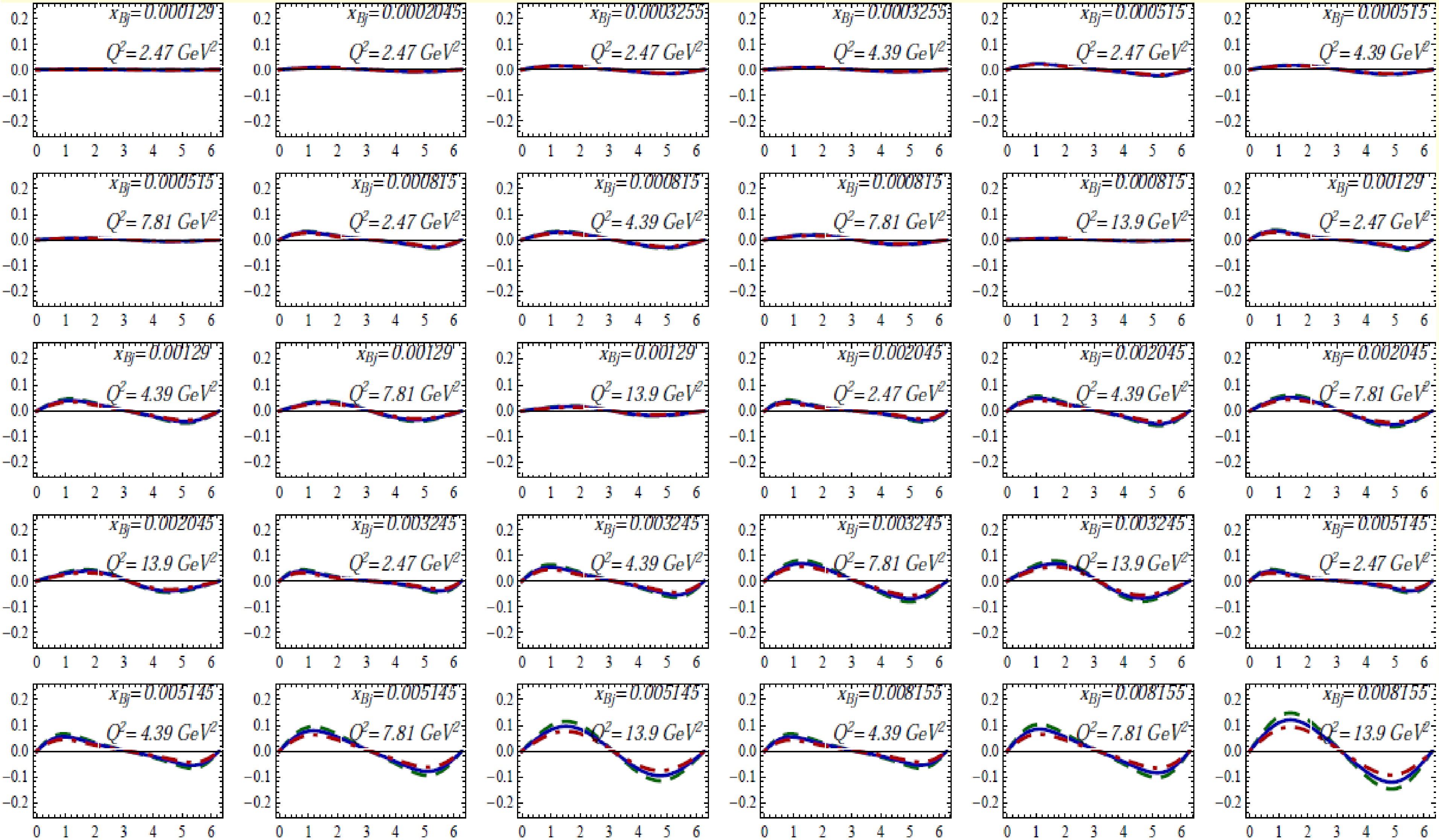
y-Transverse target spin asymmetry TSA

20x250 bins three models ***E* = 0** , ***E*= -*H***, ***E* = +*H***, sensitive to Im E



Longitudinal and x-transverse TSA

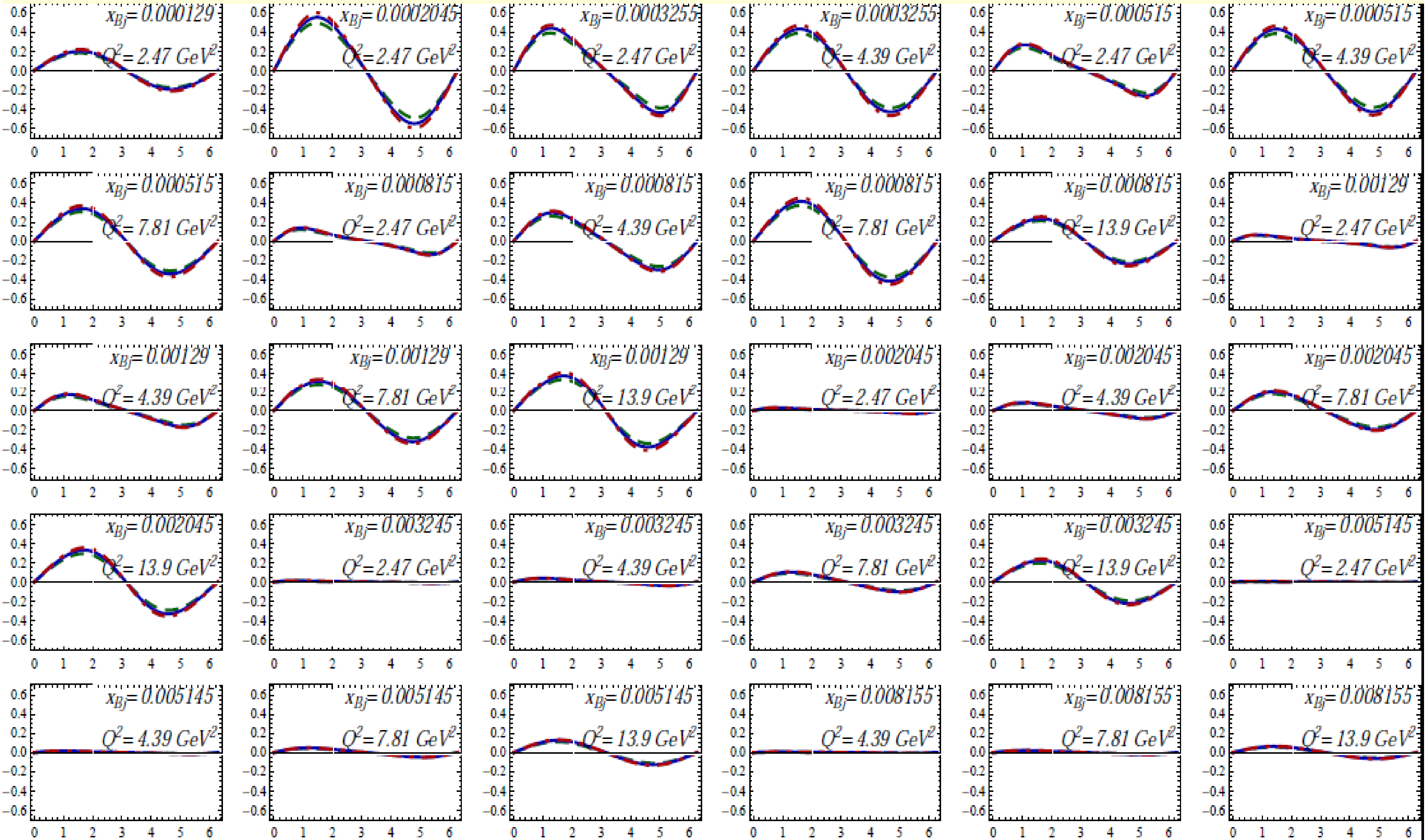
20x250 bins three models $\hat{H} = 0$, $\hat{H} = -H/2$, $\hat{H} = +H/2$, (in principle) sensitive to Im $\hat{H}$
non-zero values expected for larger x



Beam spin asymmetry BSA

20x250 bins three models ***E = 0*** , ***E= -H***, ***E = +H***

BSA requires large y values, not sensitive to E, however, to Im H



The first DVCS+DVMP fit to H1/ZEUS data

a global GPD fit to LO works surprisingly well $\chi^2/d.o.f. \sim 2$