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nuclear DVCS from HERMES

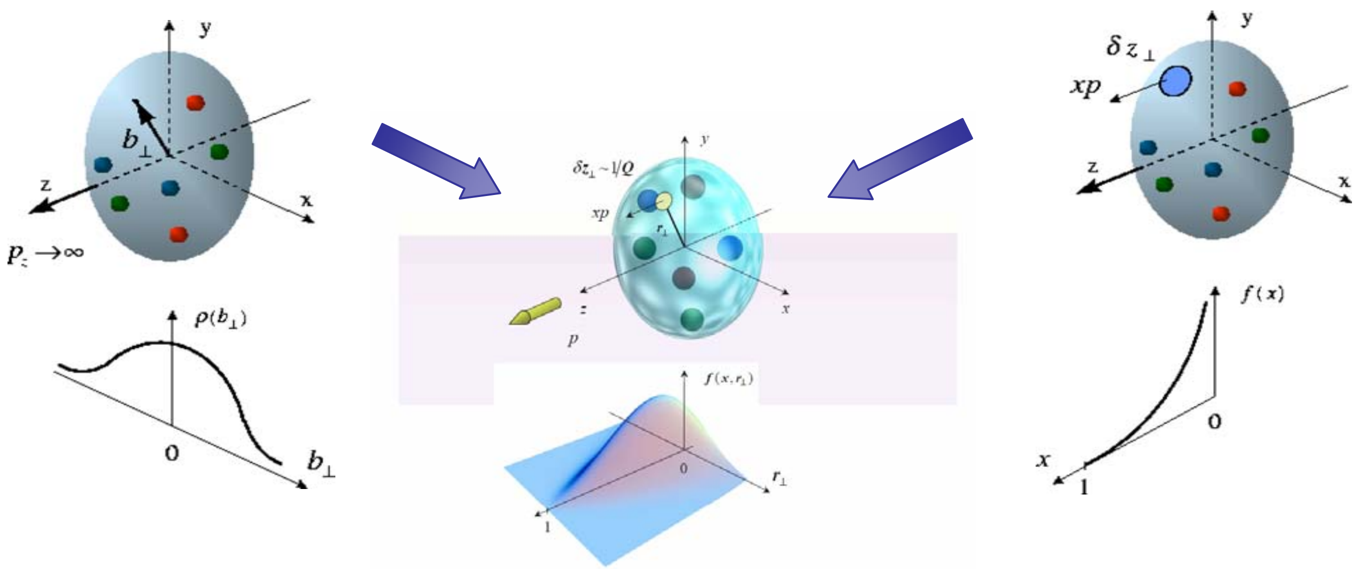
- a brief introduction
- some specific issues of the analysis
- results for beam- and charge asymmetries

ECT* workshop on "nuclear medium effects on the quark and gluon structure of hadrons", Trento, July 02-06 2008

nucleon studied for decades:

form factors
location of partons in nucleon

parton distributions
longitudinal momentum fraction x



generalised parton distributions (GPDs)
longitudinal momentum fraction x at transverse location $b_\perp$

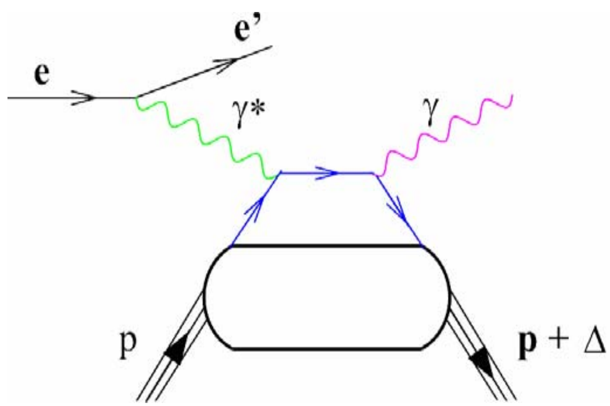
only known framework to gain information on 3D picture of hadrons

→ use nuclei as laboratories to 'trigger' *modifications* of transverse d.o.f.

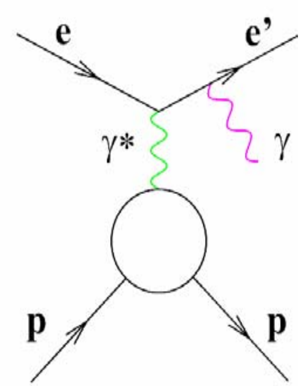
Deeply Virtual Compton Scattering DVCS

→ $H, \widetilde{H}, E, \widetilde{E}$ most clean channel for interpretation in terms of GPDs

DVCS



Bethe-Heitler



@HERMES/JLab:

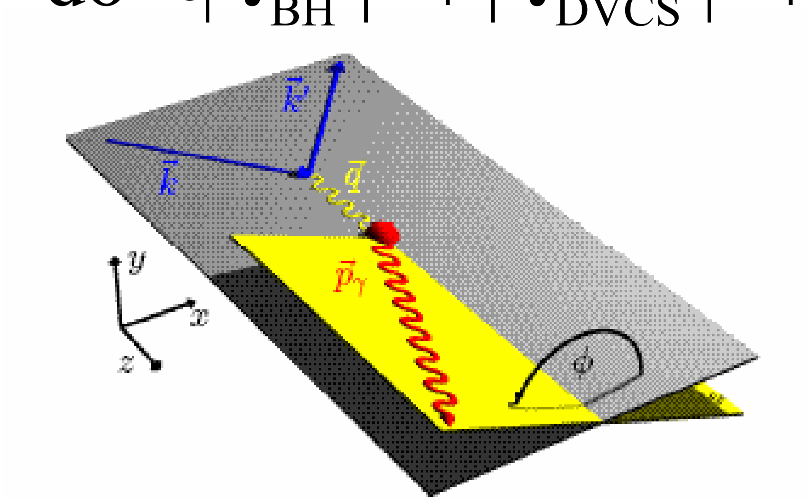
DVCS << Bethe-Heitler

$$\frac{d^4\sigma}{dx_B\, dQ^2\, d|t|\, d\phi} \propto |T_{DVCS} + T_{BH}|^2 = |T_{DVCS}|^2 + |T_{BH}|^2 + \underbrace{T_{DVCS}T^*_{BH} + T^*_{DVCS}T_{BH}}_{I}$$

→ leads to non-zero azimuthal asymmetries:

DVCS @amplitude level

$$d\sigma \propto |\tau_{BH}|^2 + |\tau_{DVCS}|^2 + (\tau^*_{BH}\tau_{DVCS} + \tau^*_{DVCS}\tau_{BH})$$



DVCS-BH interference leads to non-zero *azimuthal* asymmetry

$I \sim \Delta\sigma$

@HERMES:

→ different charges: e^+ e^- *(only @HERA!)*: $\Delta\sigma_C$

→polarisation observables: $\Delta\sigma_{UL}$, $\Delta\sigma_{UT}$, $\Delta\sigma_{LU}$

beam target

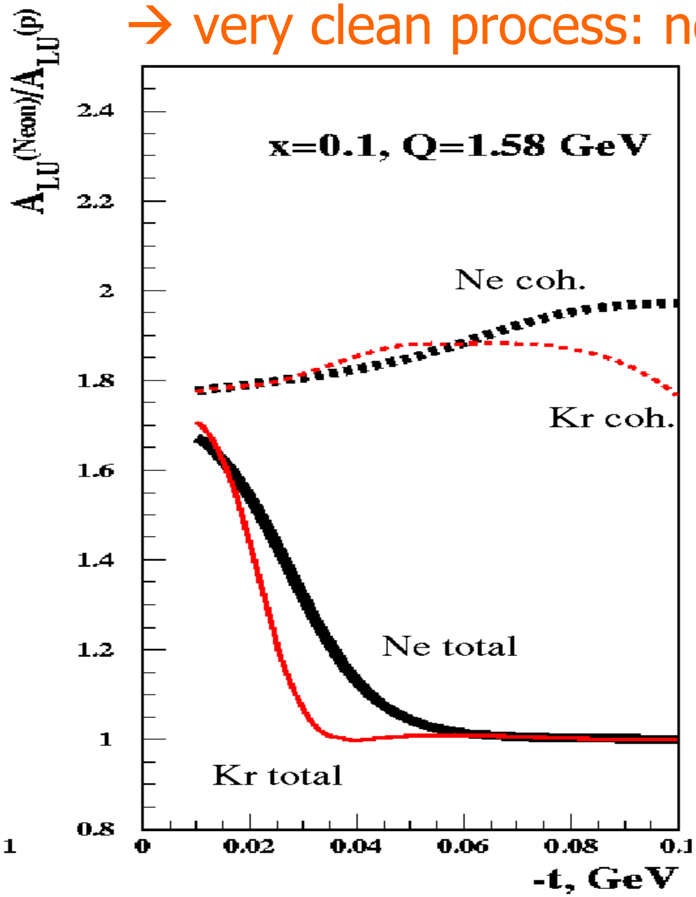
@nuclear targets

why nuclear DVCS ?

explore nuclear structure in terms of quarks and gluons; EMC effect, (anti) shadowing, color transparency

GPDs modification in nuclear matter: spatial distribution of energy, angular momentum and shear forces inside the nuclei

→ very clean process: no initial/final state rescattering



$$\frac{A^{\sin\varphi}_{LU,\,nucleus}}{A^{\sin\varphi}_{LU,\,proton}} \propto \frac{A}{Z}$$

[Guzey,Siddikov,J.Phys.G32(2006)]

→ R_{coh} = 1.8–2.0 for A=12…90

→ R_{coh} = 1.0–1.1 for ^{4}He

[Liuti, Taneja PRC(2005)]

[Guzey, Strikmann Phys.Rev.C68(2003)]

accessing GPDs: caveats

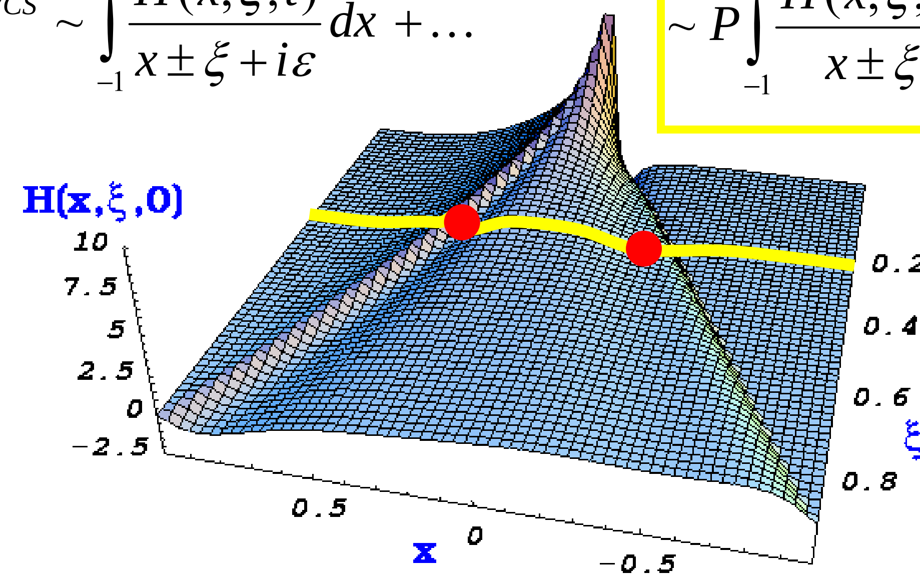
- $H(x,\xi,t)$ but only ξ and t accessible experimentally; $\xi \sim x_B$
- x is mute variable (integrated over):

→ apart from cross-over trajectory (ξ=x) GPDs not directly accessible: deconvolution needed ! (model dependent)

→ GPD moments cannot be directly revealed, extrapolations t → 0 are model dependent

e.g.

$$T^{DVCS} \sim \int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi + i\varepsilon} dx + \ldots \sim P\int_{-1}^{+1} \frac{H(x,\xi,t)}{x \pm \xi} dx - i\pi H(\pm\xi,\xi,t) + \ldots$$



cross sections & beam-charge asymmetry ~ Re(T^{DVCS})

beam or target-spin asymmetries ~ Im(T^{DVCS})

new ‘combined’ analysis

combined analysis of charge & polarisation dependent data

→ **separation of interference term + DVCS²**

$$\sigma_{LU} = \sigma^0_{UU}(\phi)\left[1 + e_l A_C(\phi) + P_b A_{LU}^{DVCS}(\phi) + e_l P_b A_{LU}^{\mathcal{I}}(\phi)\right]$$

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$$\sigma_{LU} = \sigma^0_{UU}(\phi)\left[1 + e_l A_C(\phi) + P_b A_{LU}^{DVCS}(\phi) + e_l P_b A_{LU}^{\mathcal{I}}(\phi)\right]$$

$$A_C(\phi) \rightarrow \sum_{n=0}^{3} c_n^I cos(n\phi)$$

$$A_{LU}^{\mathcal{I}}(\phi) \rightarrow \sum_{n=1}^{2} s_n^{\mathrm{I}} sin(n\phi)$$

- charge & polarisation dependent asymmetries:

$$A_C(\phi) = \frac{\sigma^{+\rightarrow} - \sigma^{-\rightarrow} + \sigma^{+\leftarrow} - \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{-\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\leftarrow}}$$

$$A_{LU}^{DVCS}(\phi) = \frac{\sigma^{+\rightarrow} + \sigma^{-\rightarrow} - \sigma^{+\leftarrow} - \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{-\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\leftarrow}}$$

$$A_{LU}^{\mathcal{I}}(\phi) = \frac{\sigma^{+\rightarrow} - \sigma^{-\rightarrow} - \sigma^{+\leftarrow} + \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{-\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\leftarrow}}$$

- only polarisation dependent asymmetries:

$$A_{LU}(\phi) = \frac{\sigma^{\rightarrow} - \sigma^{\rightarrow}}{\sigma^{\rightarrow} + \sigma^{\rightarrow}}$$

prerequisites

polarised and unpolarised gas targets → **H, D**, He, N, Ne, Kr, Xe

27 GeV

e^+ , e^-

prerequisites

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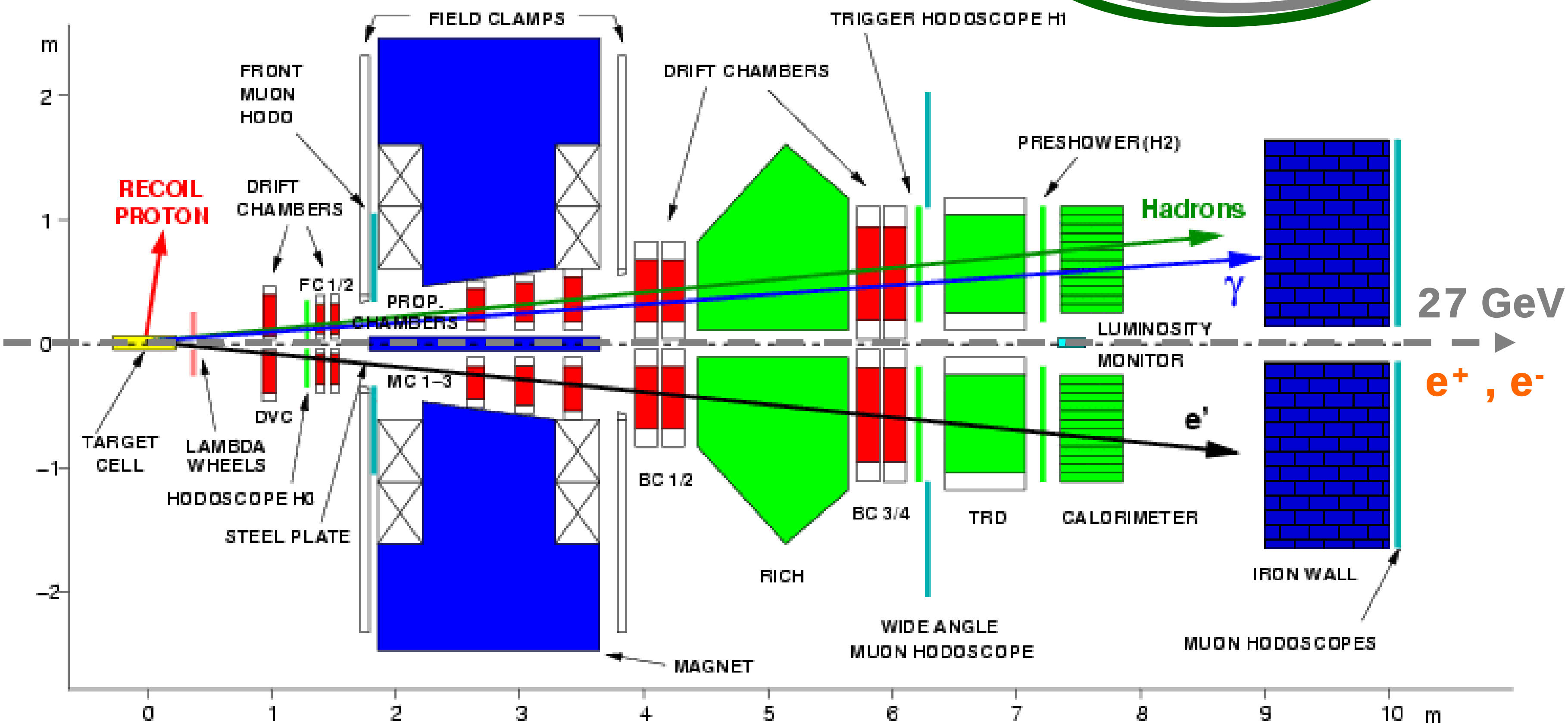
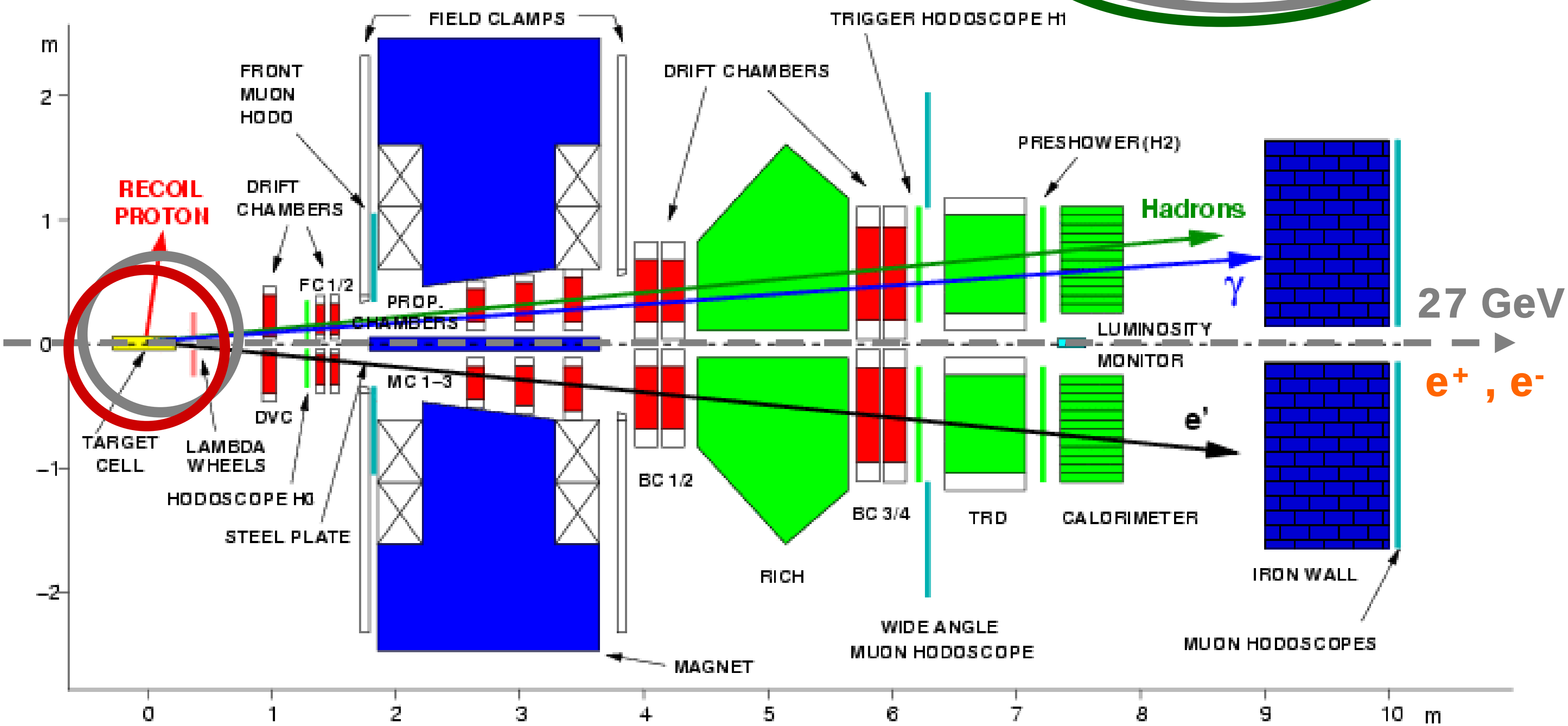


prerequisites

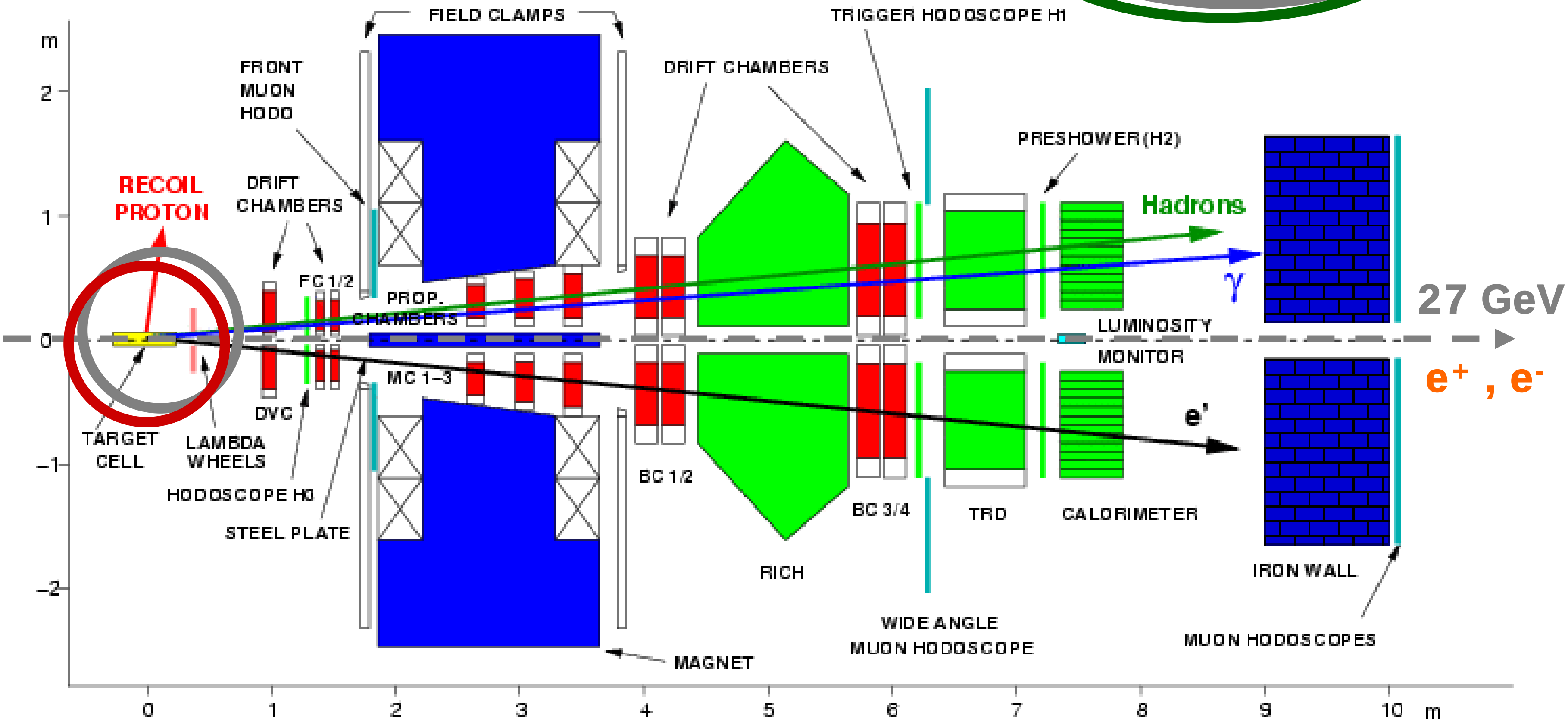
polarised and unpolarised gas targets → **H, D**, He, N, Ne, Kr, Xe



all data in the following taken before installation of recoil detector in Feb 2006 !

prerequisites

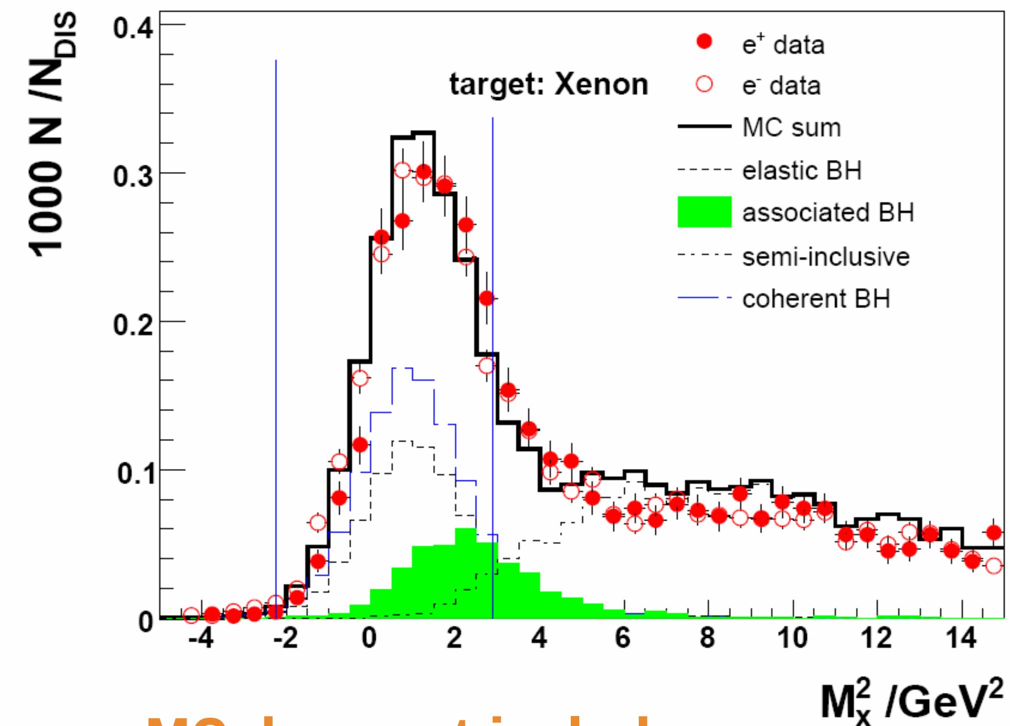
polarised and unpolarised gas targets → **H, D,** He, N, Ne, Kr, Xe



- exactly one charged track identified as lepton
- one neutral cluster in calorimeter w/o associated track

exclusivity via missing mass

DVCS: $M_x^2 = (P_p + P_e - P_{e'} - P_\gamma)^2$



MC:

elastic BH

associated BH

(cannot be resolved or simulated → defined to be part of experimental signal)

semi-inclusive: mainly π^0

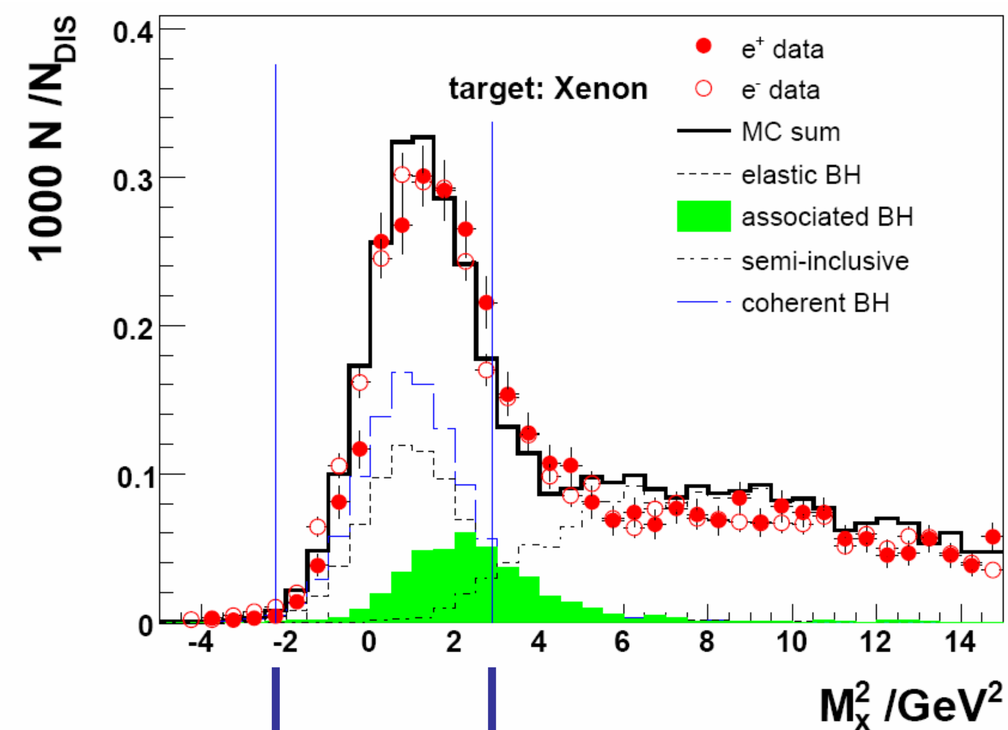
(~5% corrected for)

MC does not include:

- exclusive π^0 : appears to be negligible as no 2γ signal could be found
- DVCS : from dual-model [Guzey, Treckentrupp PRD74(2006)]
- radiative corrections to BH (shifts events to higher Mx)

exclusivity via missing mass

DVCS: $M_x^2 = (P_p + P_e - P_{e'} - P_\gamma)^2$



MC:

elastic BH

associated BH

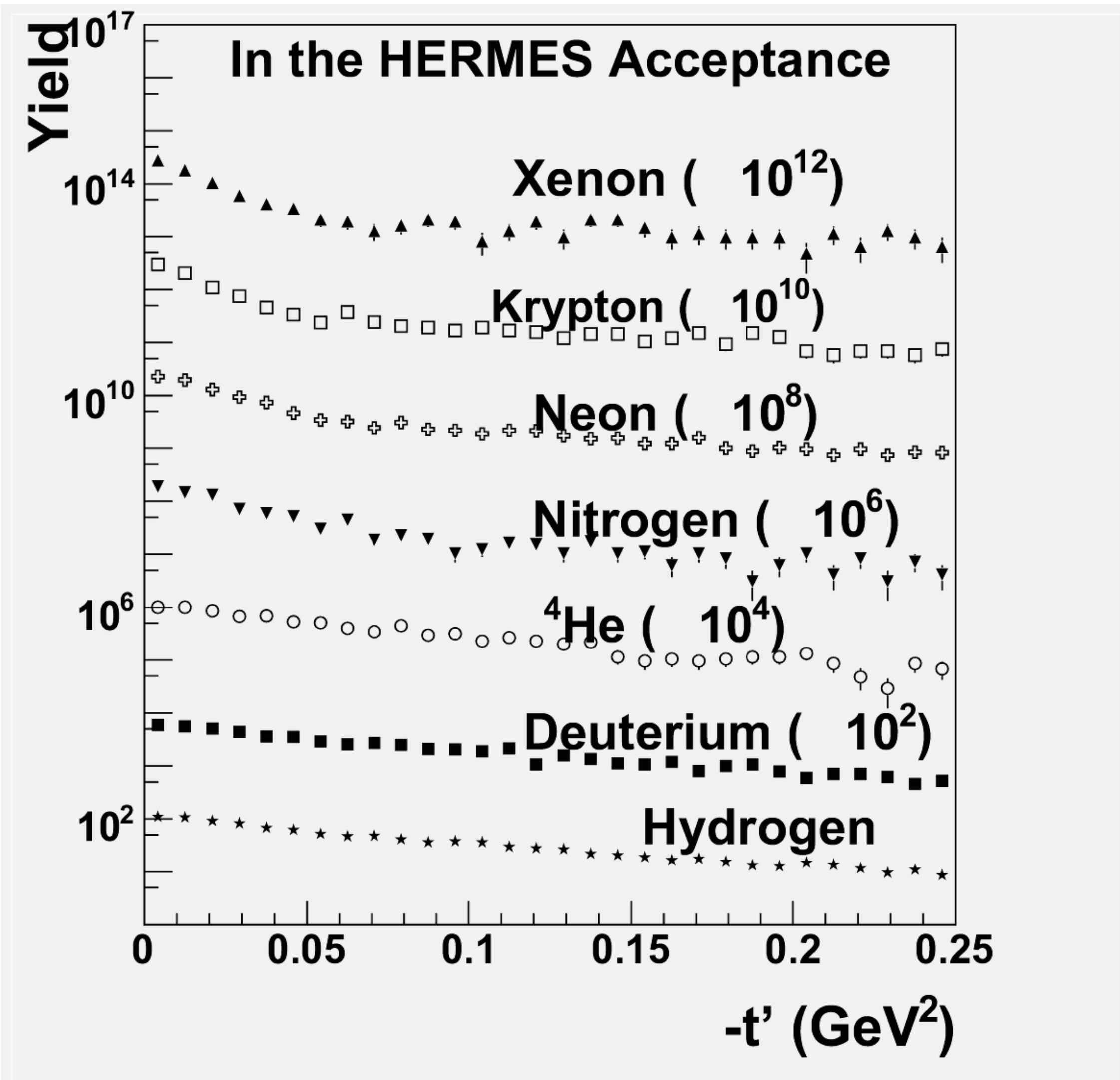
(cannot be resolved or simulated → defined to be part of experimental signal)

semi-inclusive: mainly π^0

(~5% corrected for)

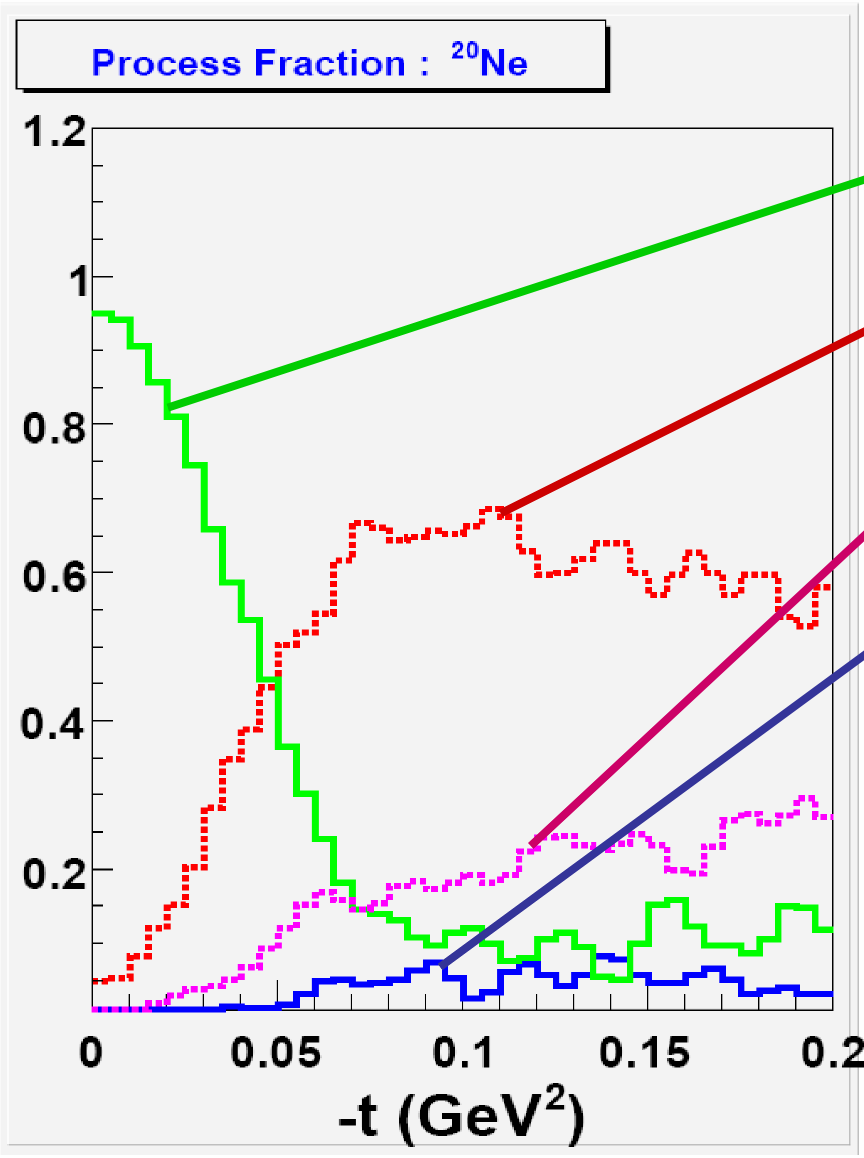
$M_p^2 - 3\sigma(M_x^2)$ **signal=background** → selected 'exclusive region': $(-1.5 < M_x < 1.7)^2\ \mathrm{GeV}^2$

coherent/incoherent contributions



- small –t: coherent production
- large –t: incoherent production

coherent/incoherent contributions



MC:

coherent BH contribution

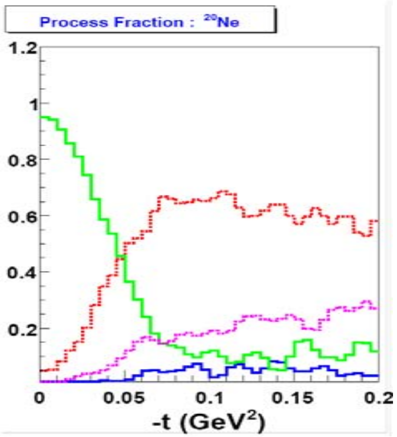
incoherent BH contribution

semi-inlusive π^0

resonances

DVCS not simulated

coherent/incoherent contributions



task: find upper (lower) –t cut for each target in order to compare the asymmetries for coherent (incoherent) production at similar average values of –t, x_B and Q^2

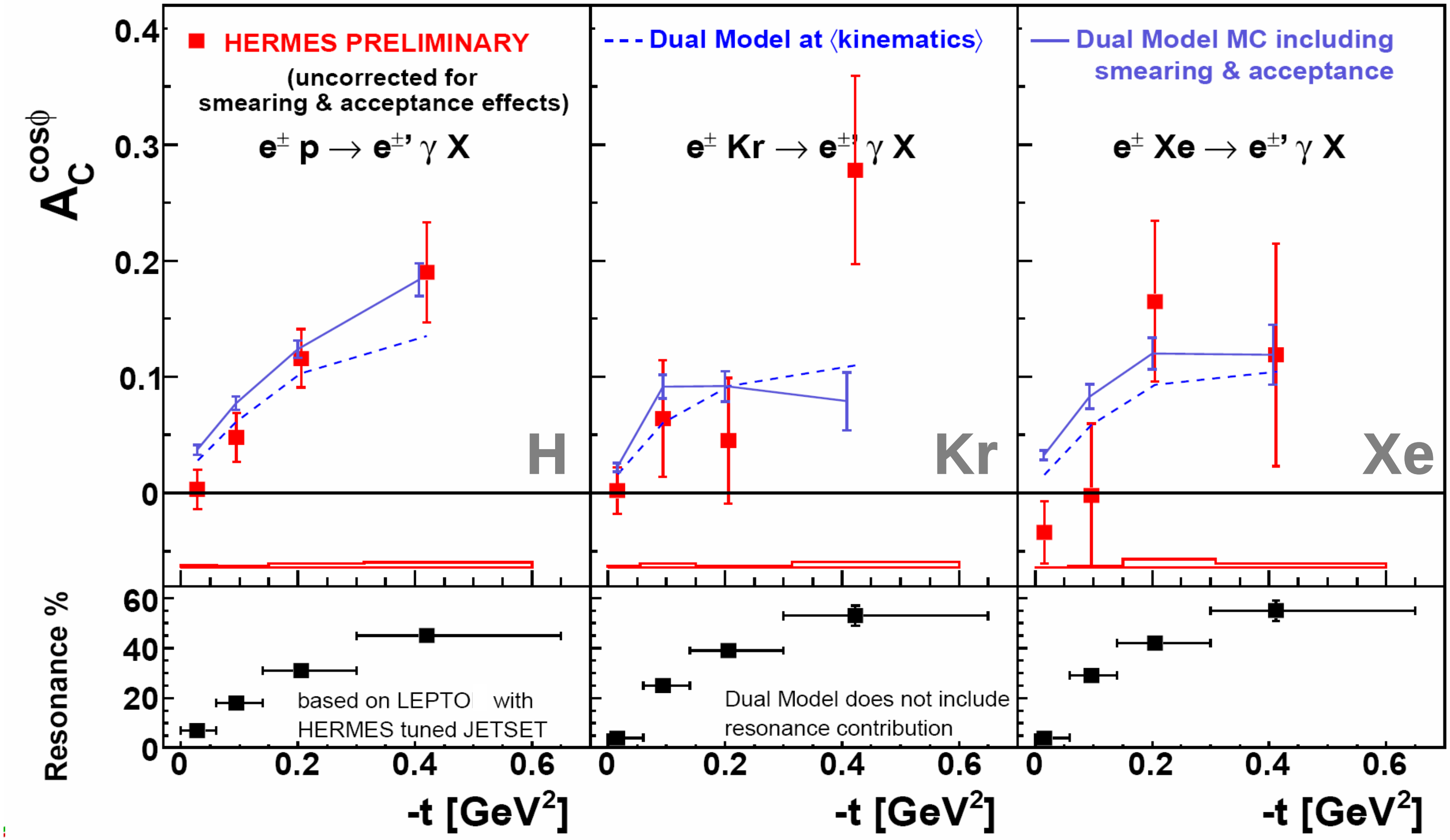
→ coherent: $<-t>$ = 0.018 GeV^2

→ incoherent: $<-t>$ = 0.20 GeV^2

Target	t cutoff	estimated %elas. coh. incoh. (by MC)	$\langle t \rangle$ (RMS)	$\langle x_B \rangle$ (RMS)	$\langle Q^2 \rangle$ (RMS)
H	$-t < -t_{coh.}$	–	-0.018(0.008)	0.070(0.023)	1.81(0.75)
	$-t > -t_{incoh.}$	–	-0.200(0.120)	0.109(0.059)	2.89(1.62)
Kr	$-t < -t_{coh.}$	70	-0.018(0.015)	0.064(0.023)	1.63(0.68)
	$-t > -t_{incoh.}$	58	-0.200(0.125)	0.108(0.058)	2.84(1.61)
Xenon	$-t < -t_{coh.}$	66	-0.018(0.017)	0.062(0.023)	1.60(0.66)
	$-t > -t_{incoh.}$	56	-0.200(0.126)	0.107(0.058)	2.86(1.63)

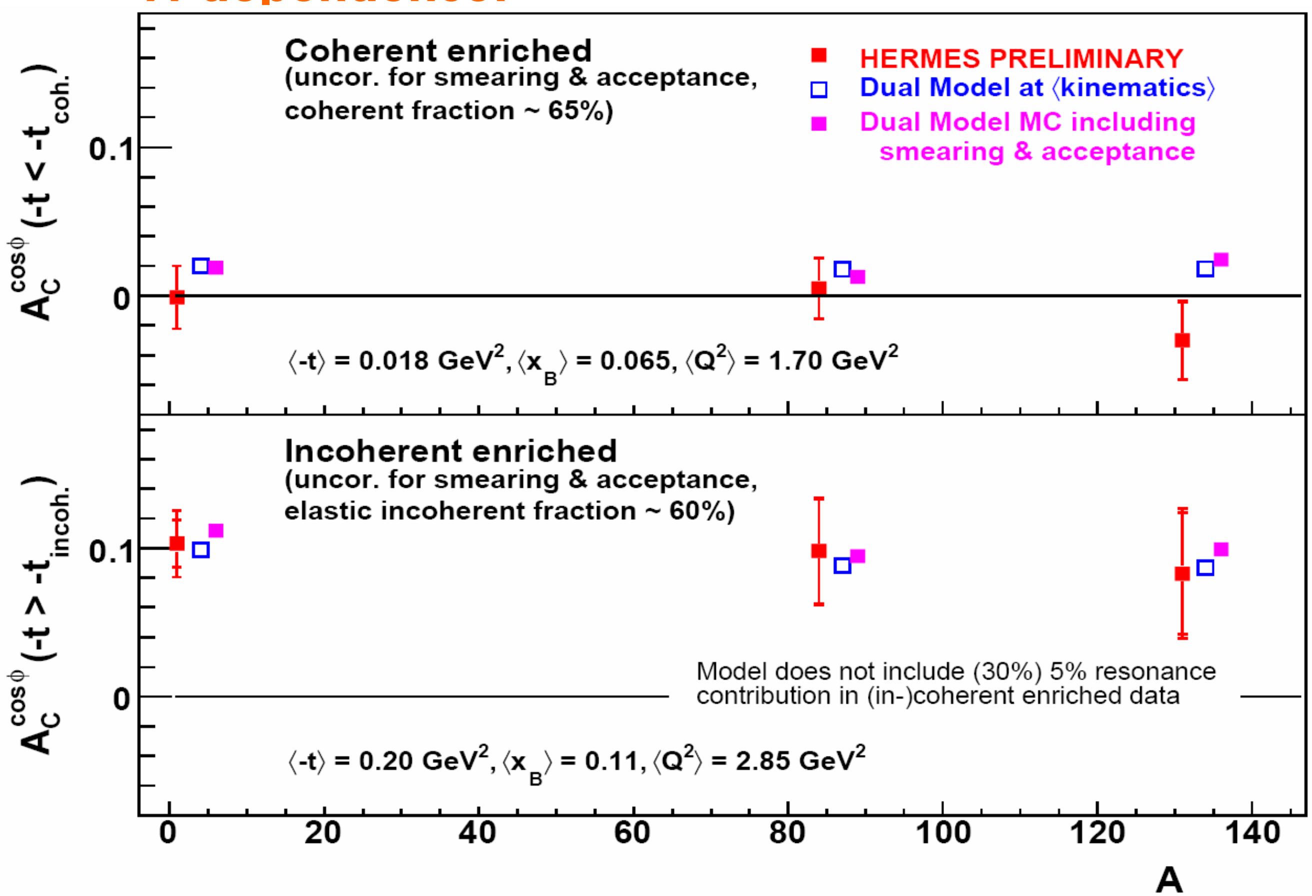
beam-charge asymmetry

$$A_C(\phi) = \frac{\sigma^{+\rightarrow} - \sigma^{-\rightarrow} + \sigma^{+\leftarrow} - \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{-\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\leftarrow}}$$



beam-charge asymmetry

A-dependence:



→ A_C for coherent production consistent with zero

→ A_C for incoherent production: no A-dependence observed

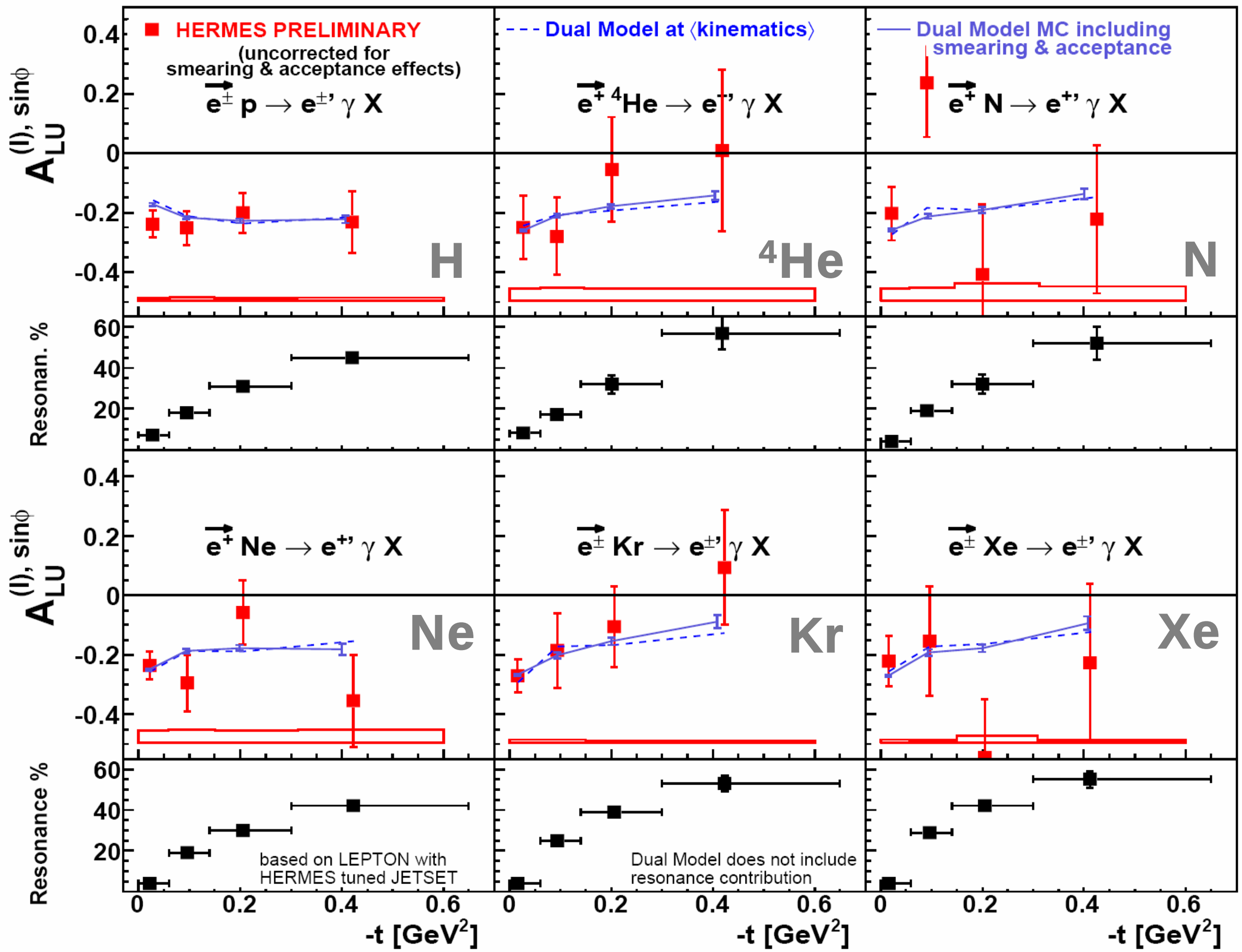
beam-spin asymmetry

H, Kr, Xe:

$$A^{\mathcal{I}}_{LU}(\phi) = \frac{\sigma^{+\rightarrow} - \sigma^{-\rightarrow} - \sigma^{+\leftarrow} + \sigma^{-\leftarrow}}{\sigma^{+\rightarrow} + \sigma^{-\rightarrow} + \sigma^{+\leftarrow} + \sigma^{-\leftarrow}}$$

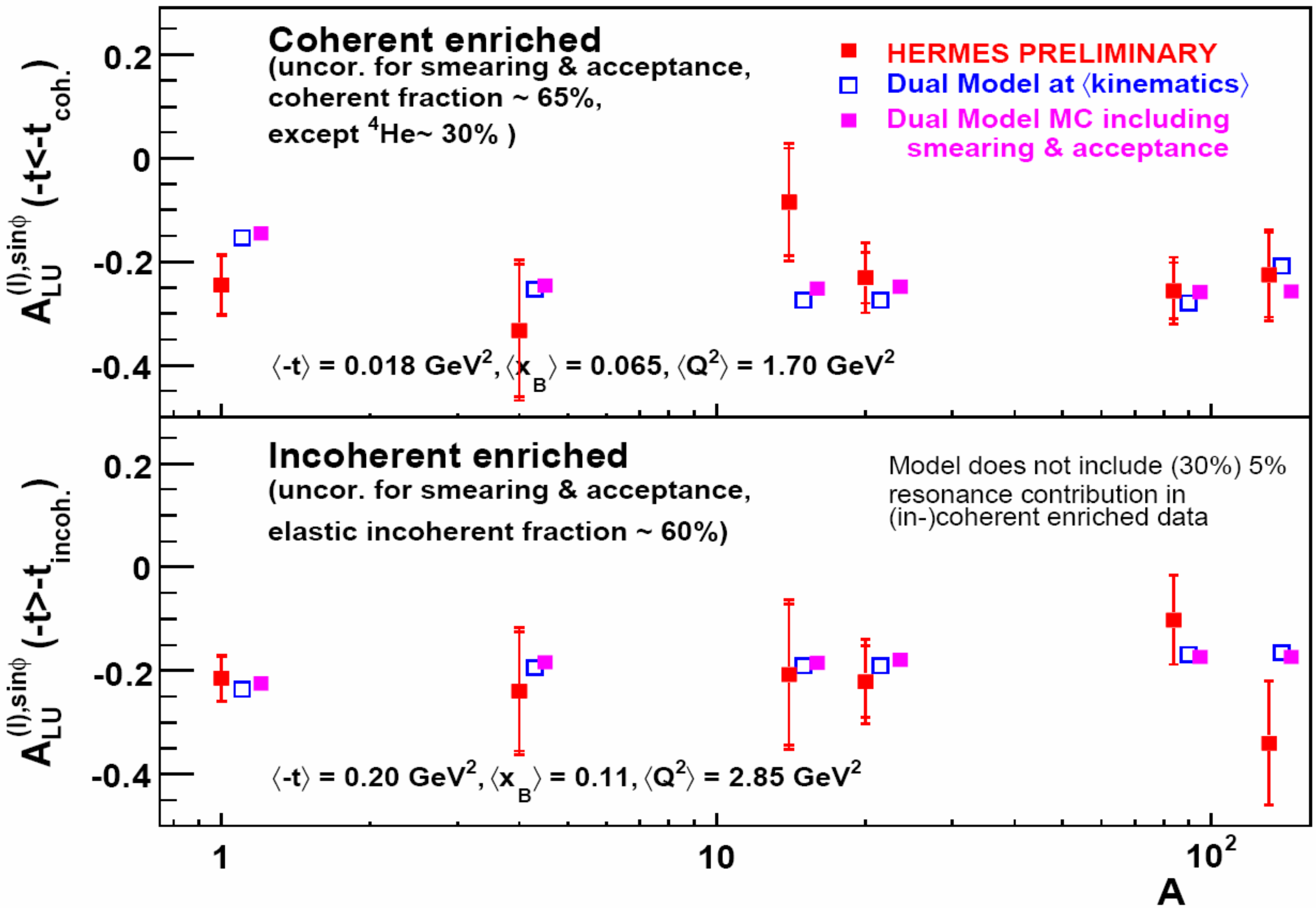
^{4}He, N, Ne:

$$A_{LU}(\phi) = \frac{\sigma^{\rightarrow} - \sigma^{\rightarrow}}{\sigma^{\rightarrow} + \sigma^{\rightarrow}}$$



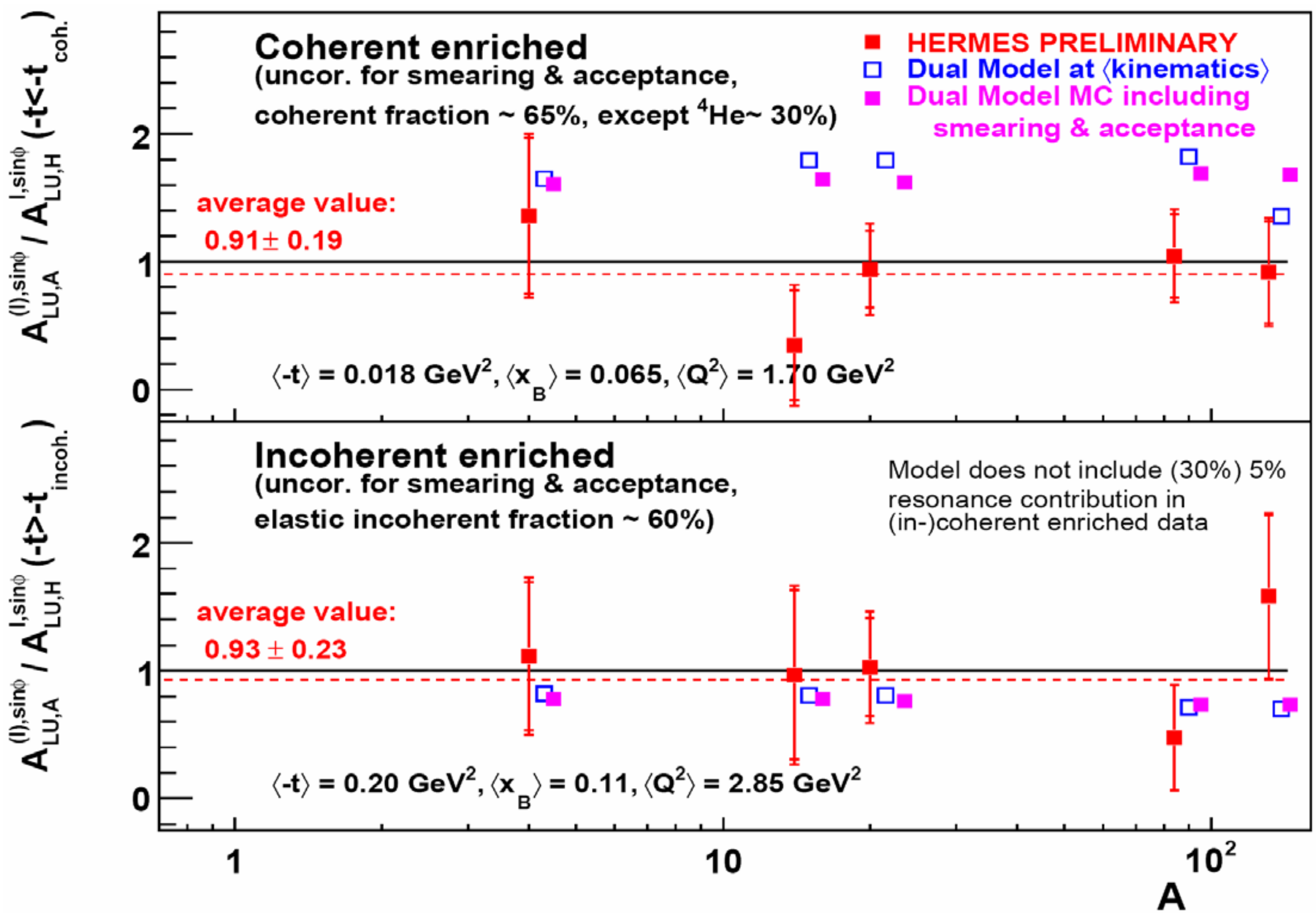
beam-spin asymmetry

A-dependence:



beam-spin asymmetry

ratio of leading BSA amplitudes: $A_{LU,A}^{(I),\sin\phi} \,/\, A_{LU,H}^{I,\sin\phi}$



→ ≈1 in *contrast* to predictions from dual model: R≈2 !
[Guzey etal]

→ R=1-1.1 for ^{4}He
[Liuti, Taneja PRC(2005)]

→ ≈1 as naively expected:
any deviation from unity is due to neutron contribution

conclusions

GPDs

contain a wealth of new information on hadron structure at parton level

→ new insides in nuclear forces from nuclear DVCS ←

- *beam-charge* asymmetry does not exhibit an A-dependence
- ratio of leading *beam-spin* amplitudes comparable with unity for both coherent and incoherent samples

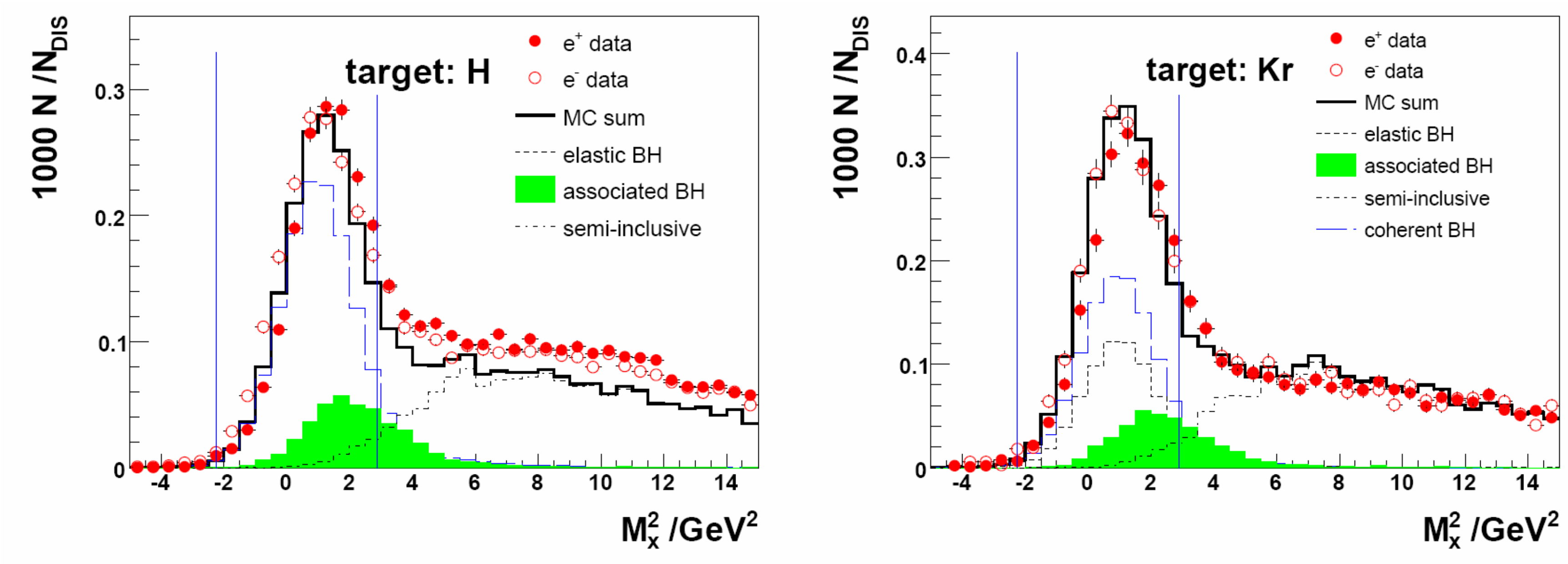
  → in contrast to predictions from 'dual model' (Guzey) ← might be due to its assumption of same neutron and proton matter distribution in nuclei

  → in agreement with predictions for ^{4}He from 'Mellin moment model' (Liuti+Taneja)
- **coming soon:** data from deuterium → possible contribution of quasi-free neutron

➡ looking forward to more model calculations for DVCS from nuclear targets

back-up slides

DVCS candidates: missing mass



systematic uncertainties

- Systematic uncertainty due to shifted exclusive M_x peak positions for different beam charges.

- Background correction for semi-inclusive π^0 production. Fractional contributions are obtained from MC. Asymmetries are taken from data.

$$A_{\mathrm{excl.}} = \frac{1}{1 - f_{\mathrm{i}}} \left[A_{\mathrm{meas.}} - f_{\mathrm{i}} A_{\mathrm{i}} \right]$$

- MC study for bin-width, acceptance, smearing and mis-alignment effect using various input models.

beam-spin asymmetry

DVCS² term: