Spin physics and more with HERMES

bmb+f - Förderschwerpunkt
HERMES
Großgeräte der physikalischen Grundlagenforschung

Electron Nucleus Scattering VII
Elba International Physics Center
June/25 2002

From inclusive scattering ...

... to exclusive reactions

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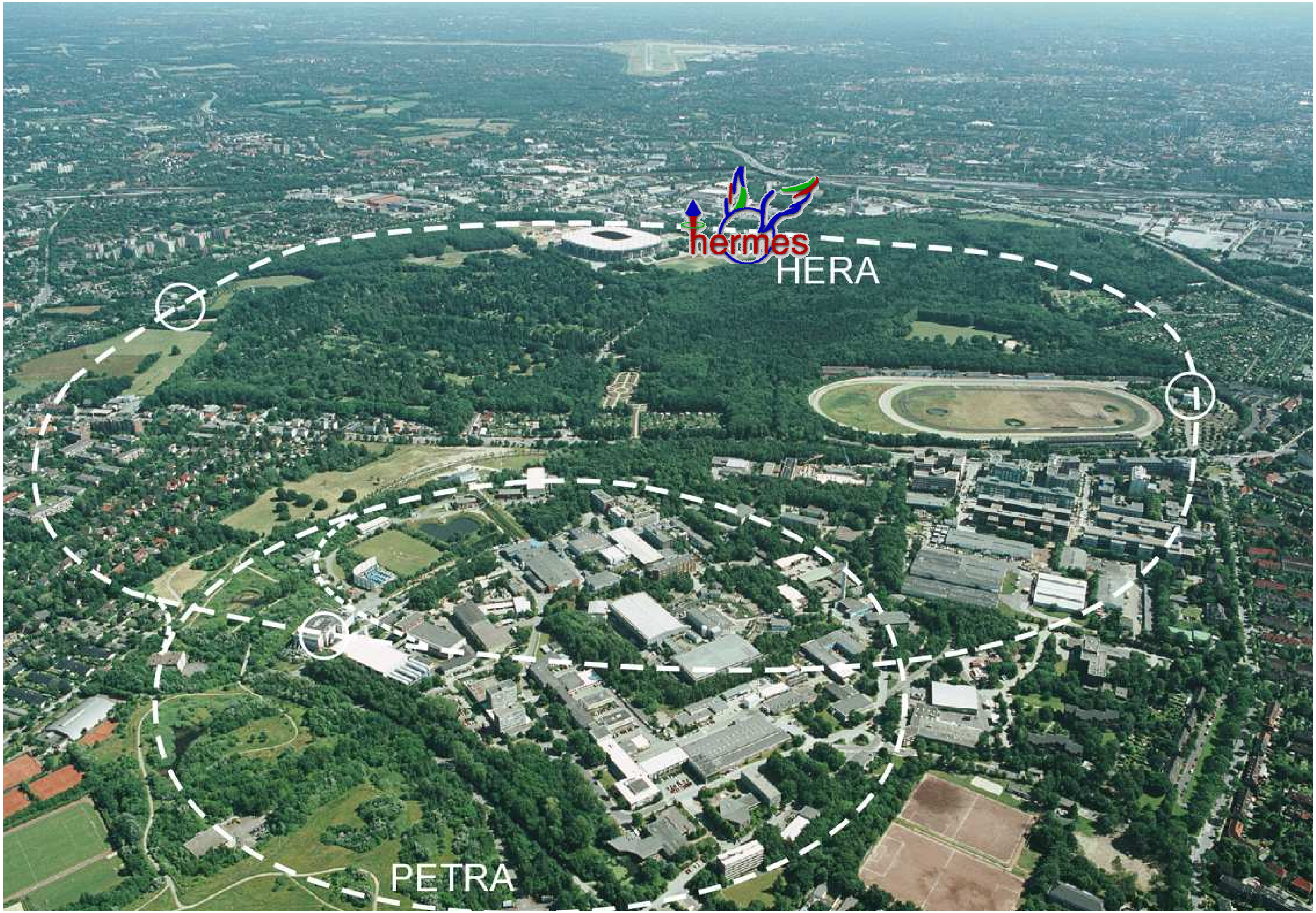
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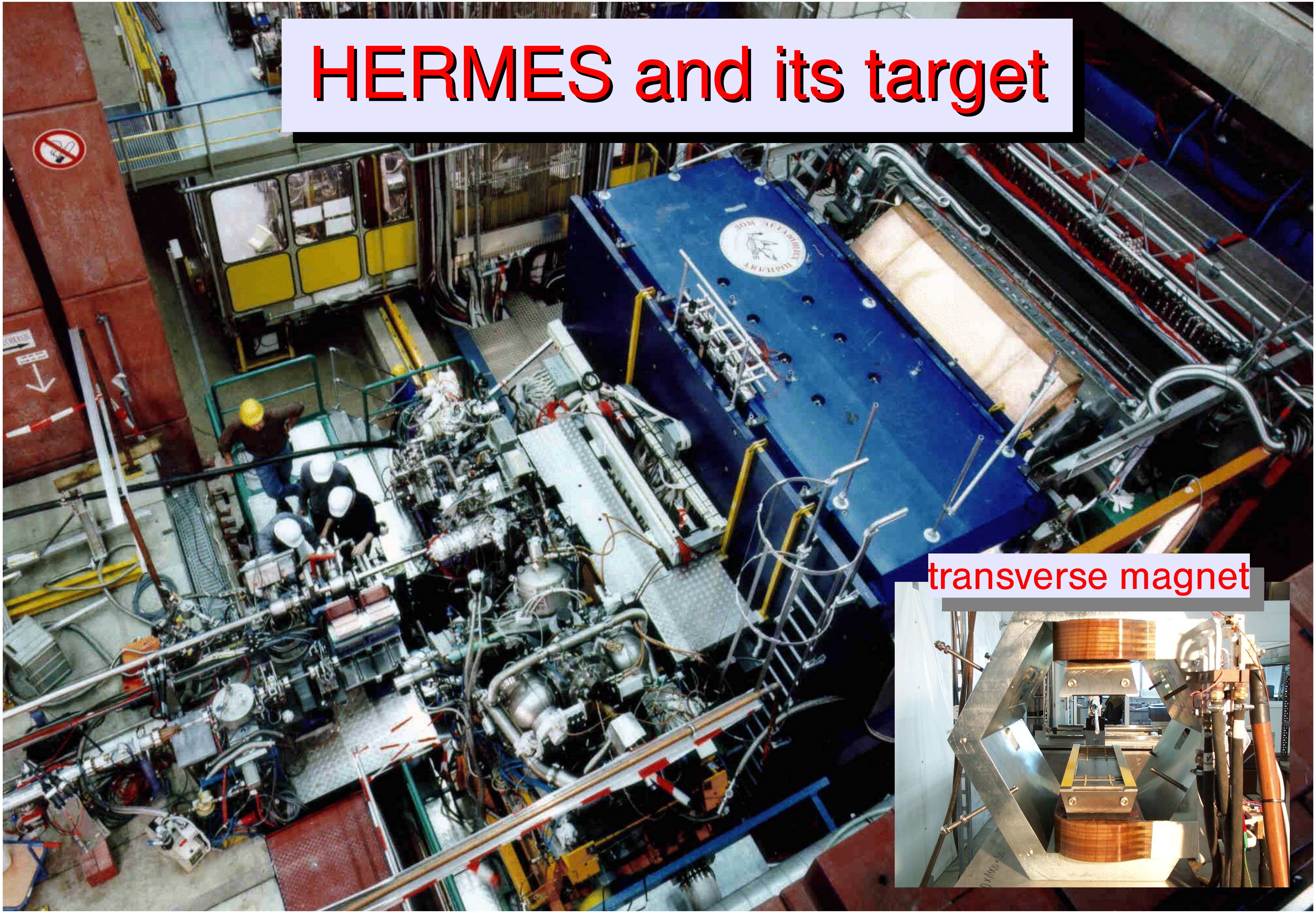
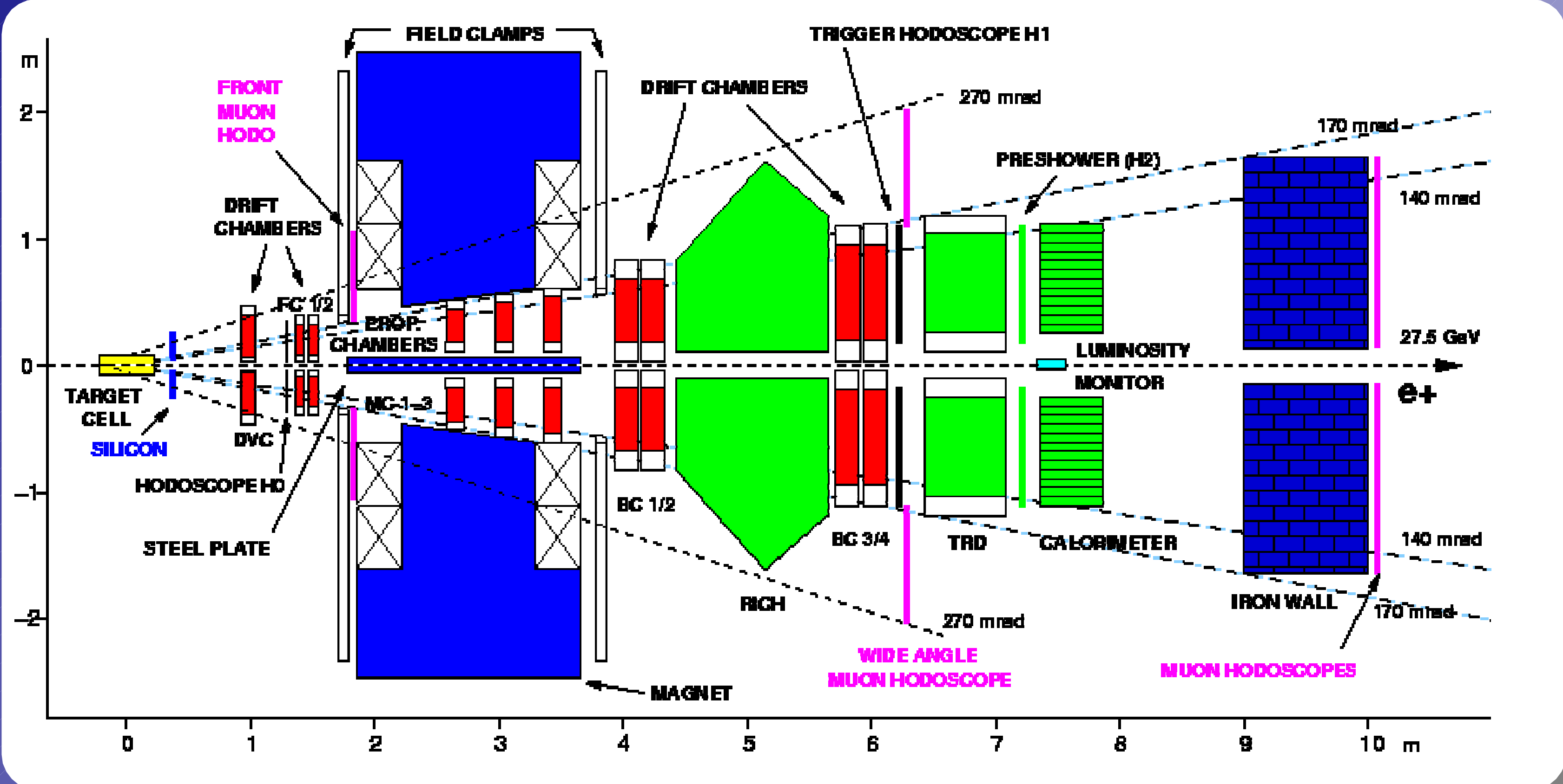
HERA
PETRA

HERMES and its target



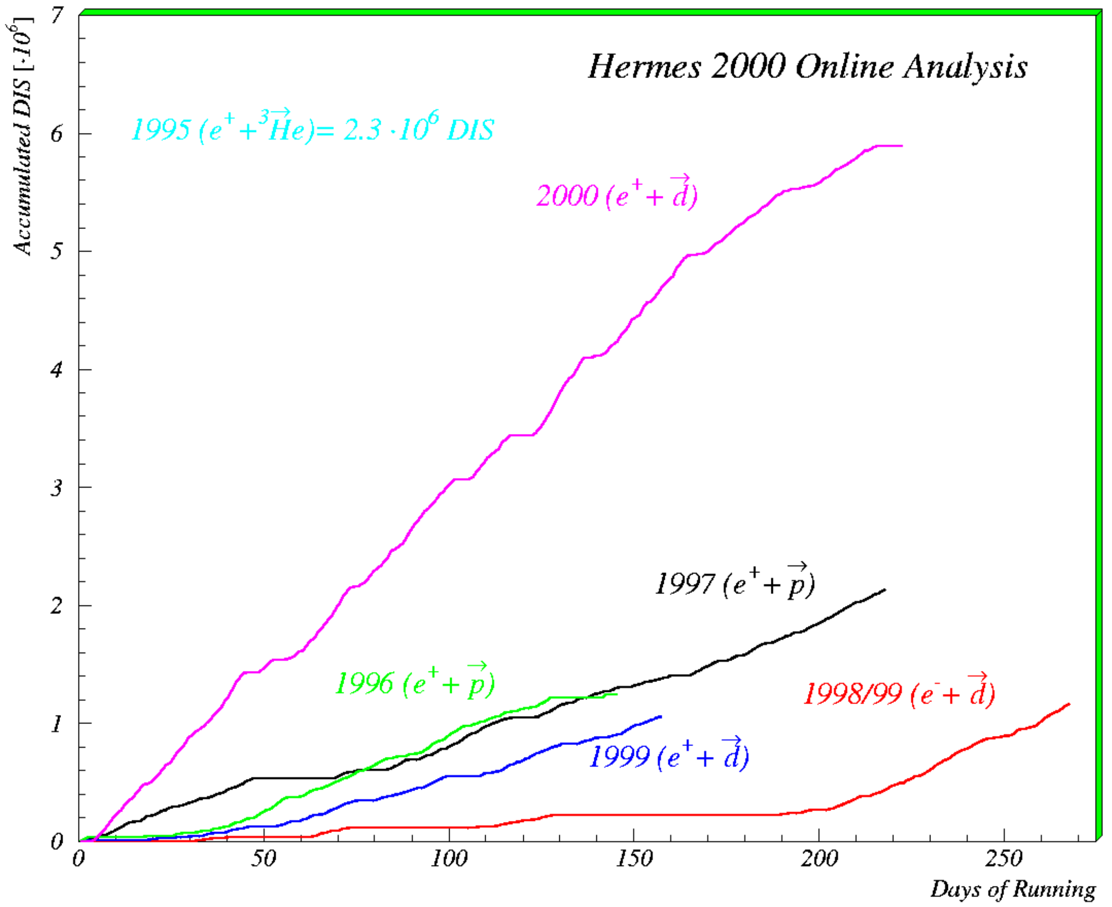
transverse magnet

HERMES spectrometer



- 57 tracking planes ($\delta P/P < 1.6\%$)
- PID using RICH, TRD, CALO (ε_e>0.98, π,K,p separation)
- $0.8 < Q^2 < 12$ GeV^2, $0.02 < x < 0.7$, $1 < W^2 < 45$ GeV^2

HERMES past performance



In 2000 alone

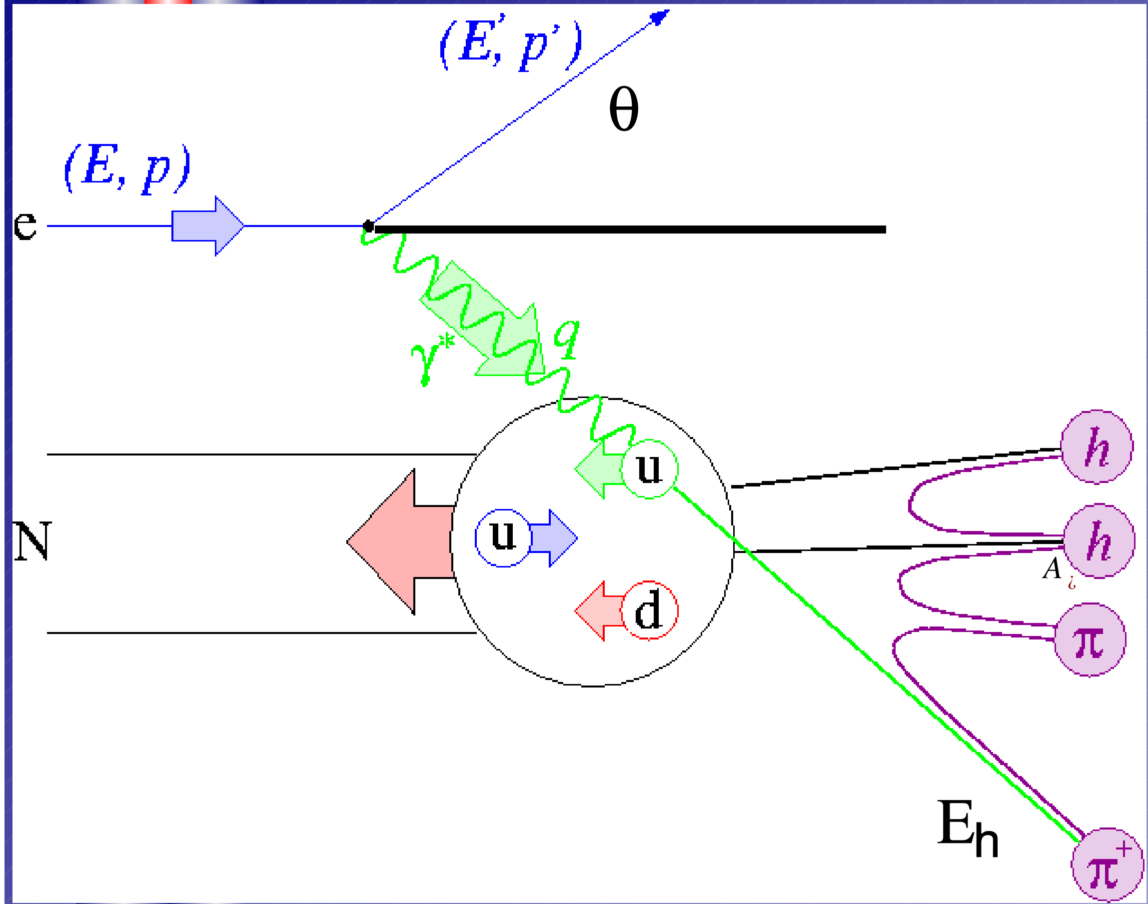
polarised
D: 6.8 Million DIS

unpolarised (End-of-Fill running)
H: 6.6 Million DIS
D: 2.0 Million DIS
Ne: 3.9 Million DIS
^{4}He: 1.1Million DIS

In addition: data on N, Kr from 1998/1999

high quality sample of polarised data plus a lot of data on heavy nuclei

Polarised DIS: kinematics



$$Q^2 = -q^2 \approx 4EE' \sin^2\left(\frac{\theta}{2}\right)$$

$$x = \frac{Q^2}{2M \cdot \nu}$$ incl. DIS

$$\nu = E - E'$$

semi-incl. DIS

$$z = \frac{E_h}{\nu} \qquad x_F = \frac{2p_\parallel}{W}$$

$$A_\parallel = D\,(A_1 + \eta A_2) \qquad A_1 = \frac{g_1 - \gamma^2 g_2}{F_1}$$

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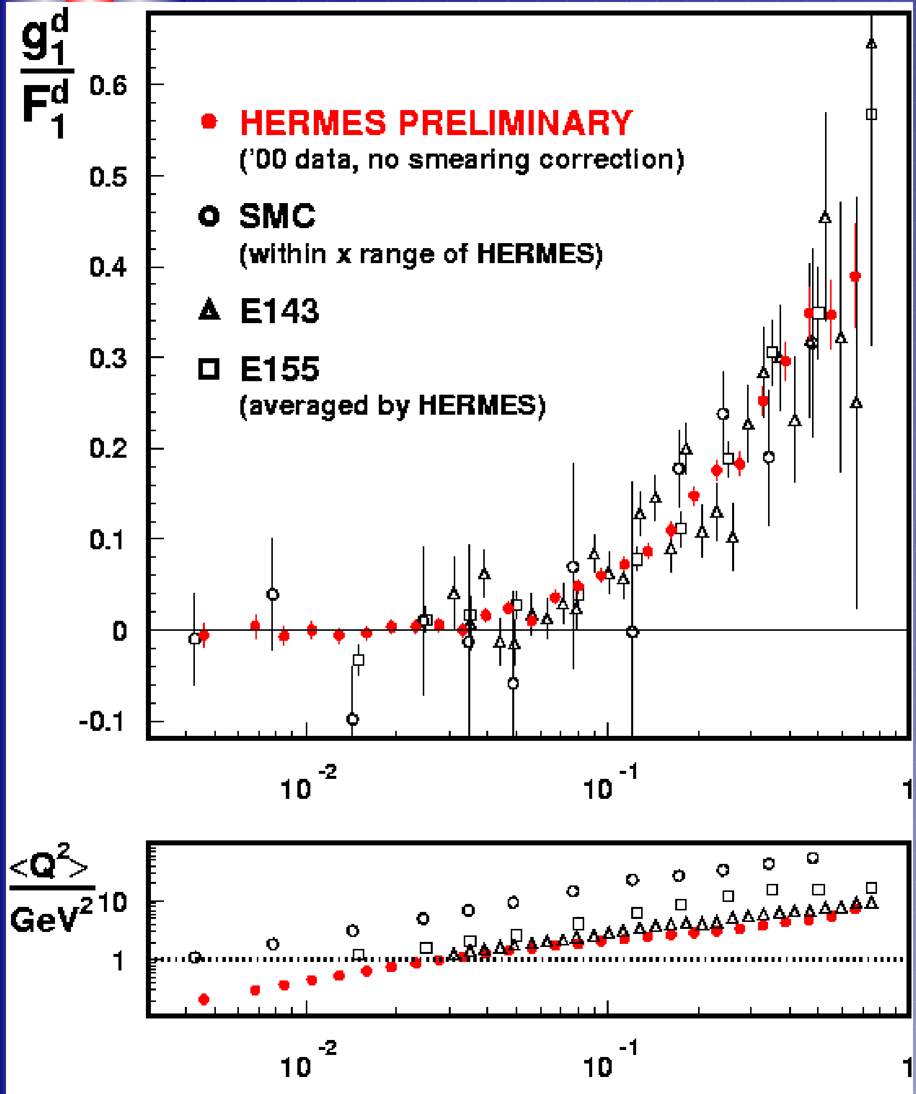
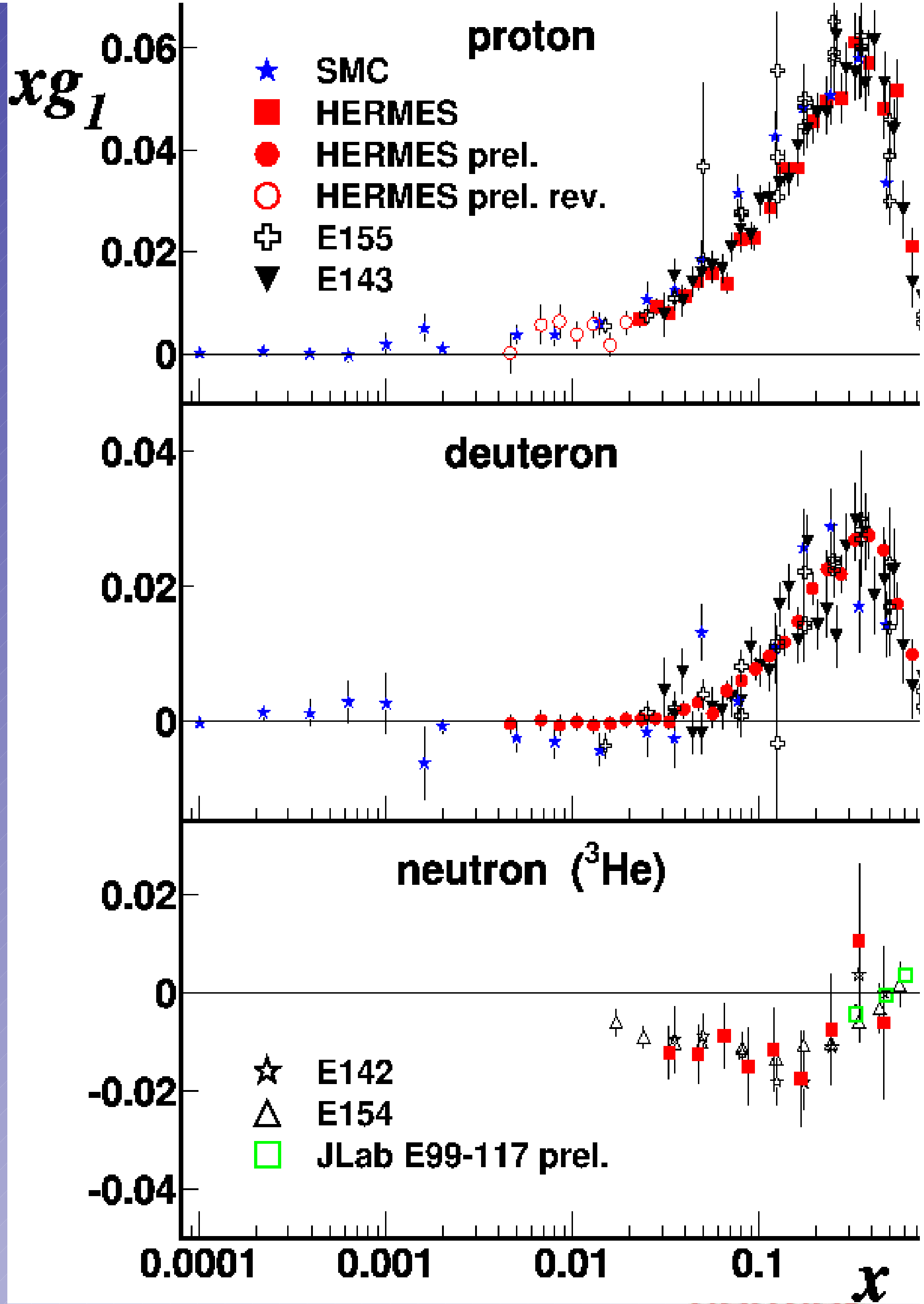
A1 and g1(x)





- excellent statistical precision
- no significant Q^2-dependence
- tensor polarised d data -> analyse b_1

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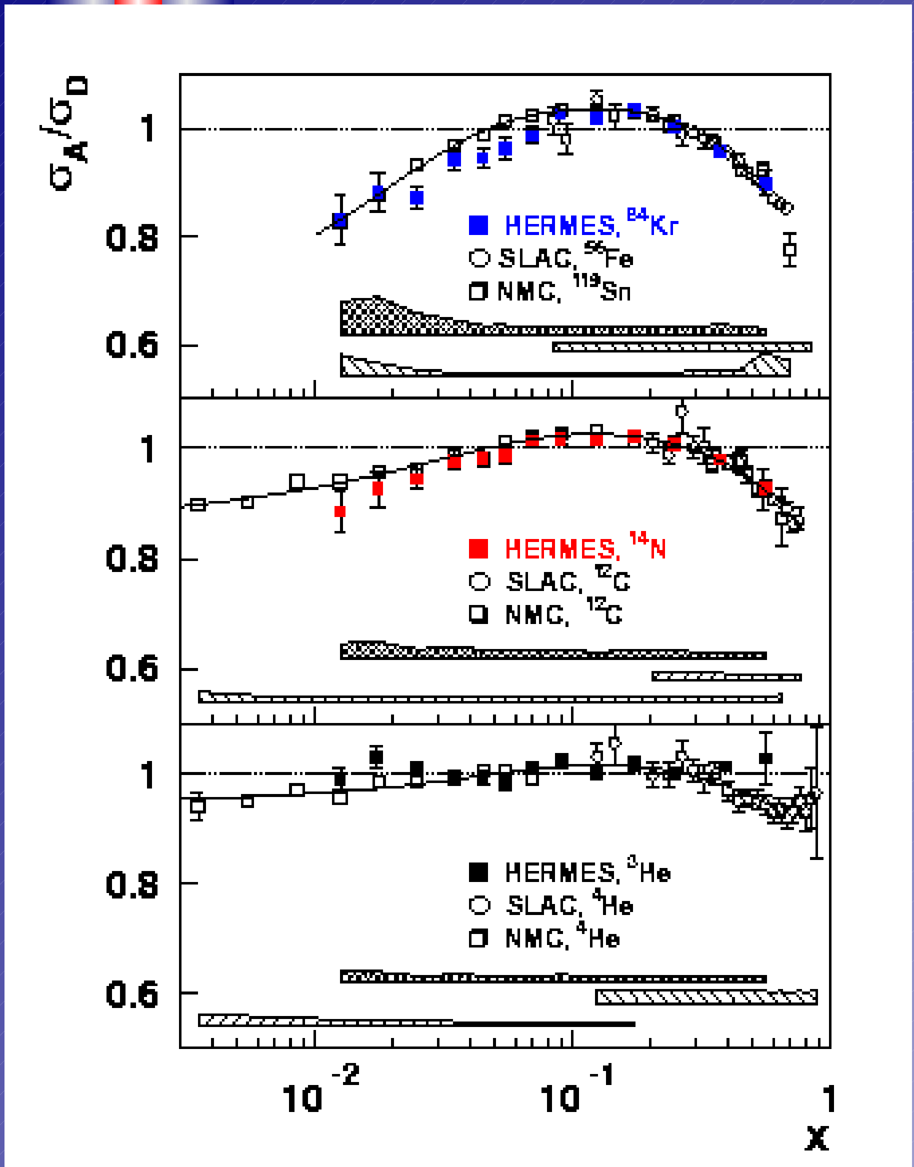
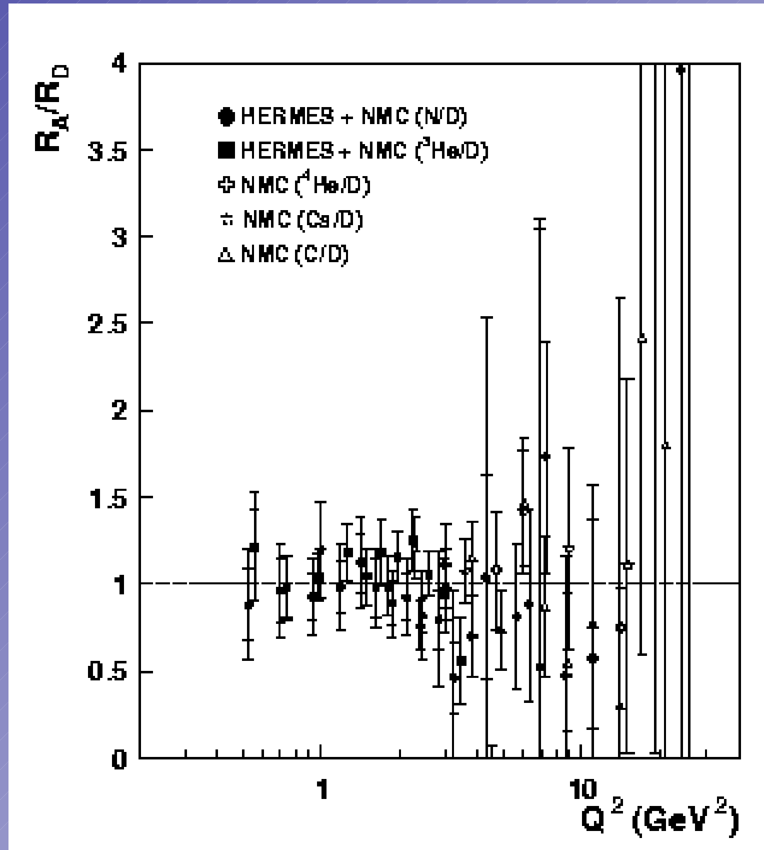
Getting big: heavy nuclei





- agreement with previous measurements
- no significant Q^2 dependence
- R_A/R_D consistent with 1

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1^{st} break: inclusive measurements

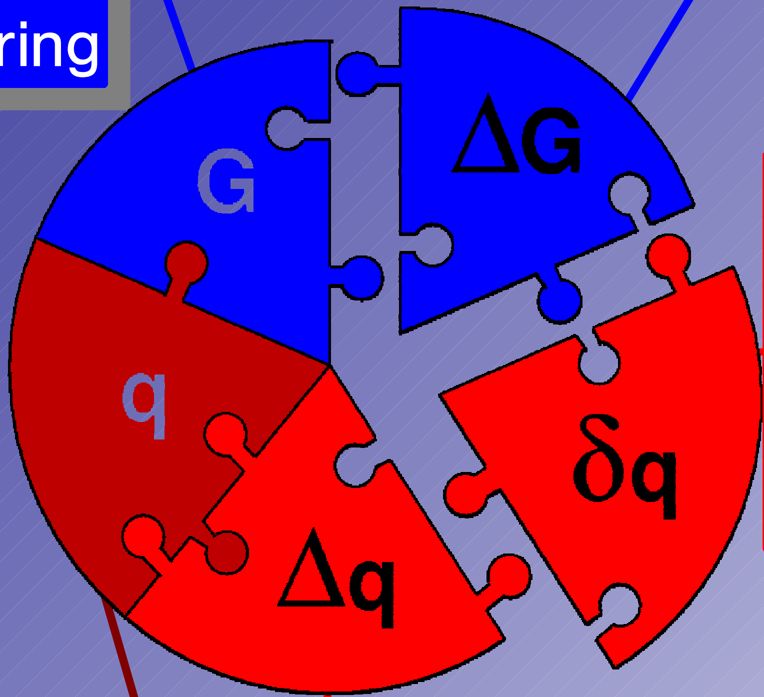
- HERMES offers a large variety of polarised and unpolarised targets
- high precision data on g_1^d
- high precision data on g_1^p
- no significant Q^2-dependence observed in the asymmetry
- cross section ratios measured for p,d,^{14}N,^{84}Kr
- also data with 12 GeV beam energy on nuclear targets on tape -> explore different kinematic ranges

Integral measurement of spin structure functions:
➔ study generalized GDH integral and duality
➔ cf. Talk by Alessandra Fantoni (after coffee)

Nucleon structure at leading twist

Measured in unpolarised Deep Inelastic Scattering

Measured in polarised Photon Gluon Fusion



Measured in transversity dependent, semi- inclusive Deep Inelastic Scattering

Measured in unpolarised Deep Inelastic Scattering

Measured in helicity dependent, semi-inclusive Deep Inelastic Scattering

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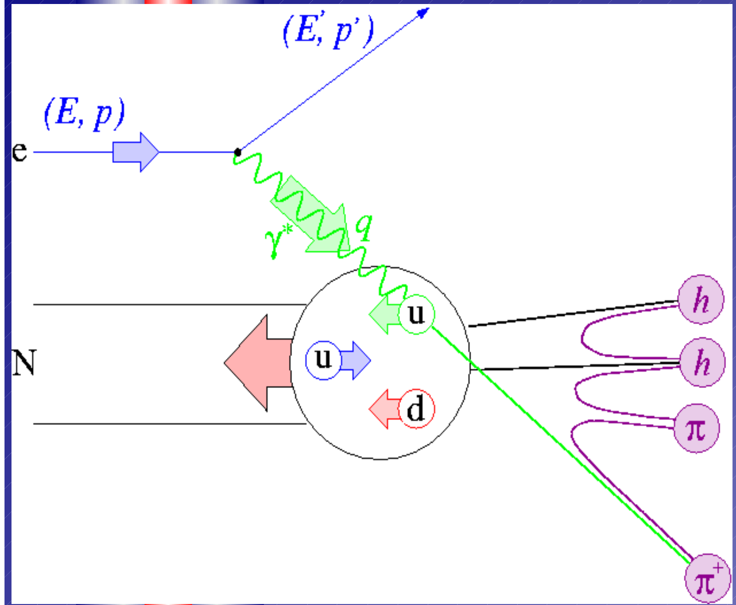
Getting the flavour of it ...



$$A_1^h \approx \frac{g_1^h}{F_1^h}(x,Q^2) = \frac{\int dz\, \Sigma_q e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)}{\int dz\, \Sigma_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}$$

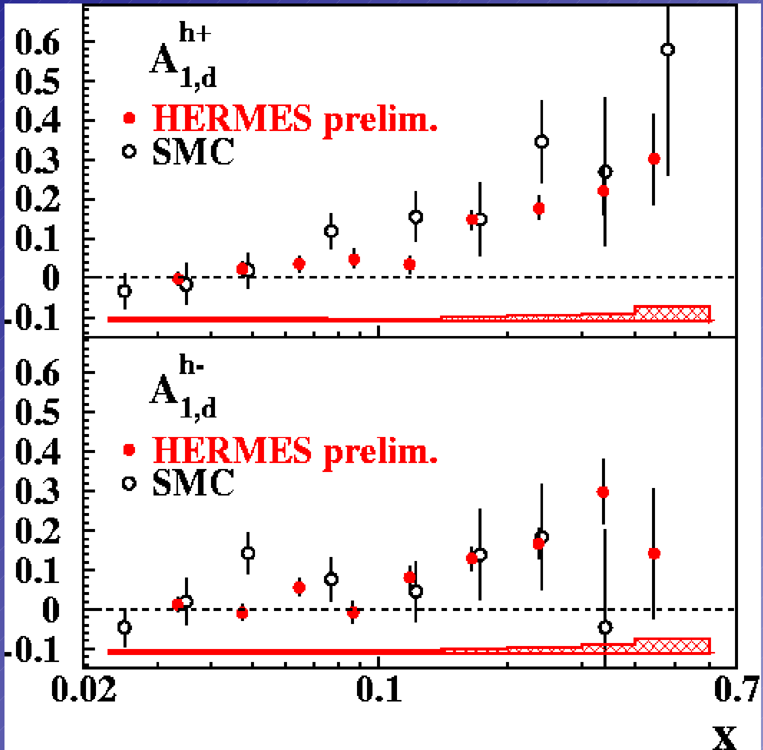
flavour of struck quark related to observed hadron via fragmentation functions D_q^h

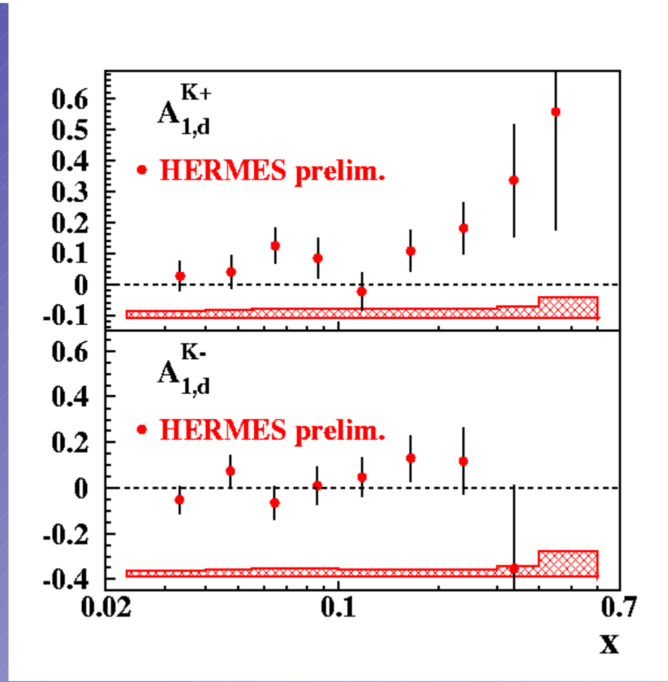
can be rewritten in terms of a purity matrix

$$A_1^h(x,z) = \sum_q P_q^h(x,z) \frac{\Delta q(x)}{q(x)}$$

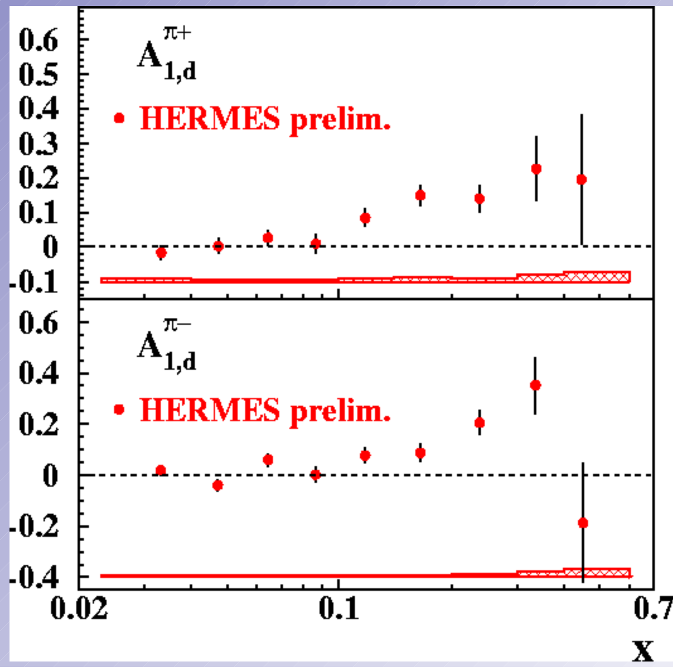
purities are spin-independent quantities to be derived by Monte Carlo

Semi–inclusive Asymmetries





with hadron identification



in addition: A_1^h from p and ^{3}He
(only pion identification possible)

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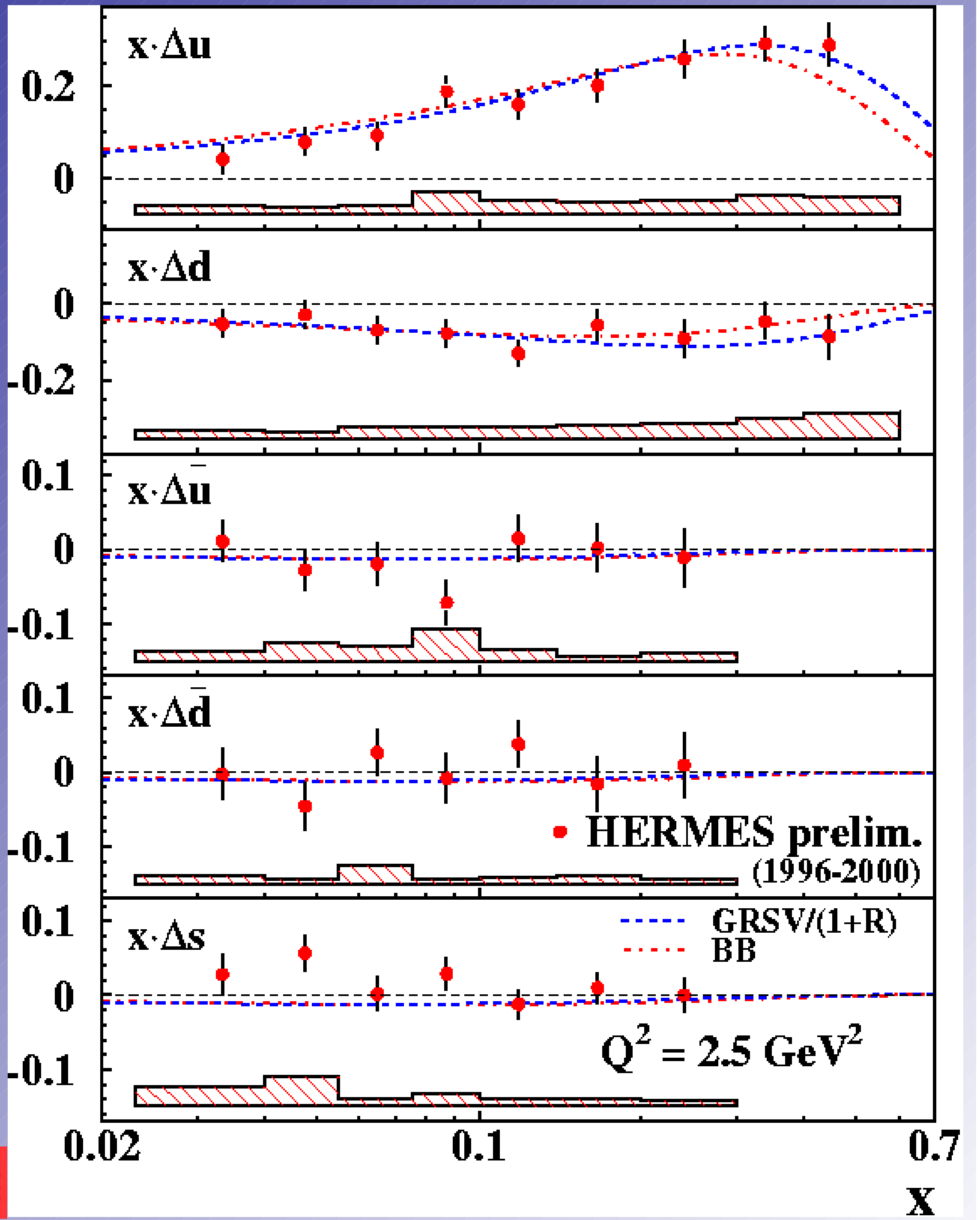
Quark polarisations

using CTEQ 5 LO
@ Q^2=2.5GeV^2
as unpol. PDF (input)

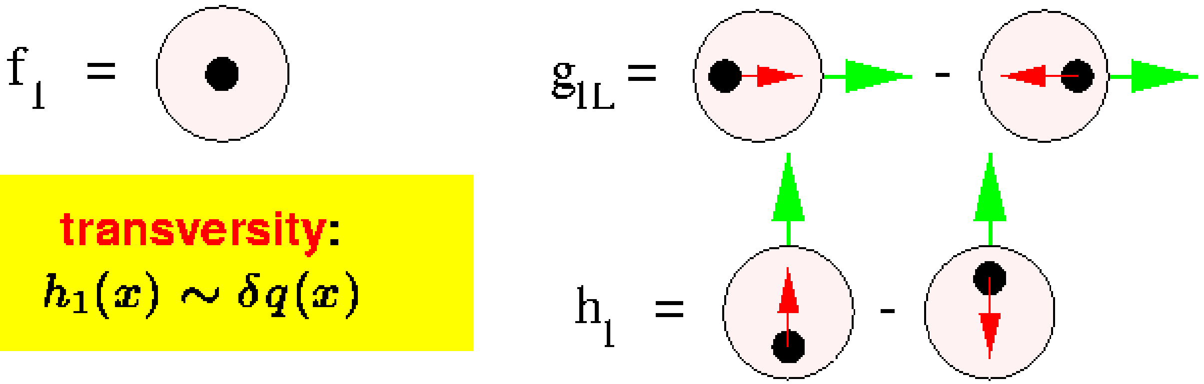
p: A_1^h dominated by Δu
n: A_1^h dominated by Δd
no indication for negative Δs

systematics dominated by limited knowledge of fragmentation functions and unpol. PDF



polarised quark sea separated

The last twist–2 distribution function: Transversity



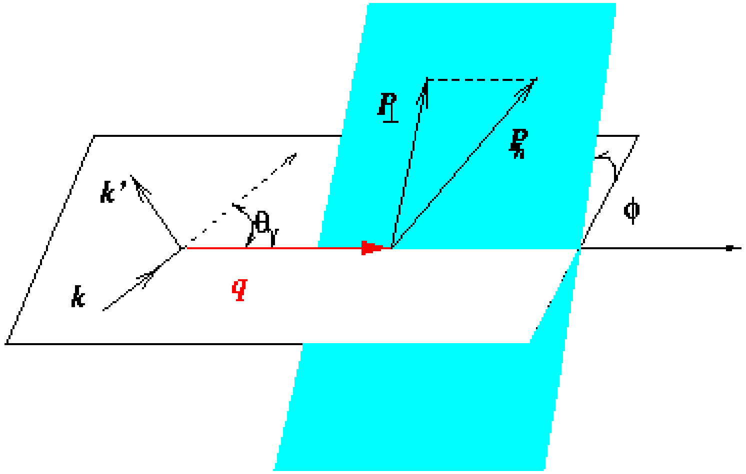
transversity:
$h_1(x) \sim \delta q(x)$

complete description of momentum and spin structure at leading twist needs new PDF: δq

- in absence of relativistic and spin orbit effects: $\delta q = \Delta q$
- quark and gluon polarization don‘t mix in QCD evolution of h_1
- h_1 predominantly sensitive to valence quark polarization
- h_1 is a chiral-odd distribution function, related to spin flip of transversly polarized quarks

Transversity inaccessible in incl. DIS, but can be probed via azimuthal distributions in polarized semi-inclusive DIS (esp. with transversly polarized target)

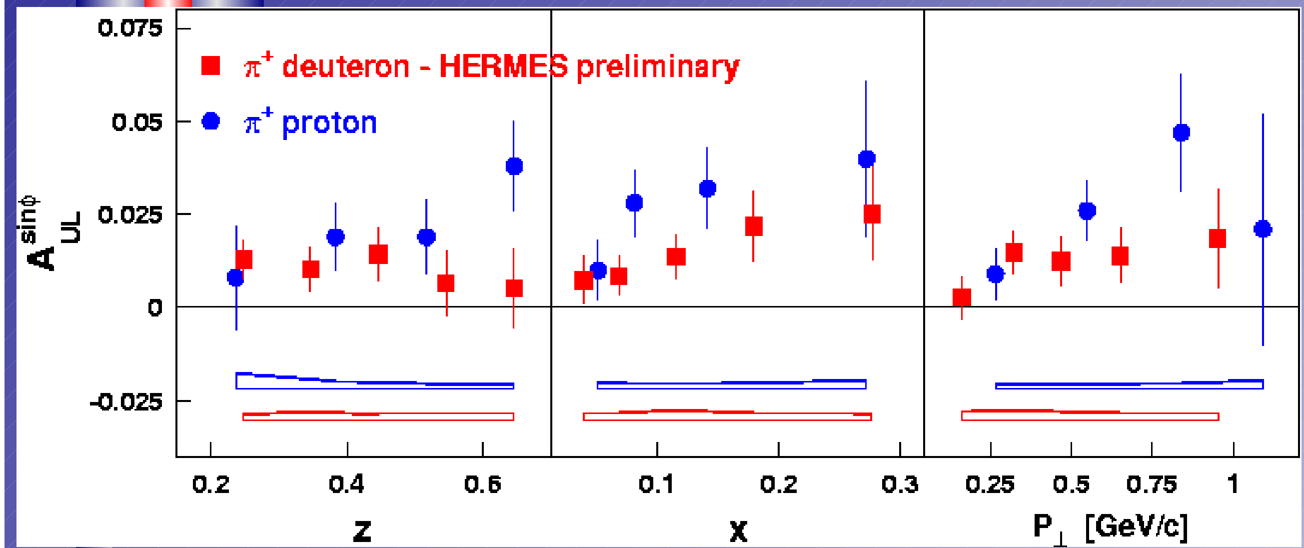
Single Spin Asymmetries



Longitudinal target single-spin asymmetry:

$$A_{UL}(\phi) = \frac{1}{P}\frac{N^+(\phi) - N^-(\phi)}{N^+(\phi) + N^-(\phi)}$$

$A_{UL}(\Phi)$ related to product of $h_1(x)$ and chiral odd FF $H_1^{\perp}(z)$

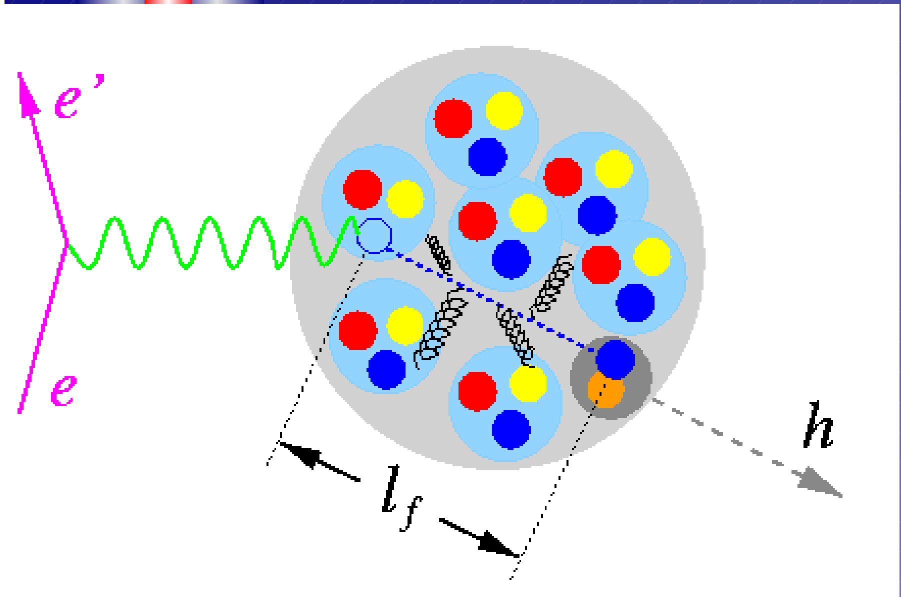


Predictions by Collins:

- should peak at x = 0.3
- dominant for π^+ (u-Quark)
- should grow with p_T and peak at p_T=1 GeV

$A_{UL}(\Phi) \neq 0$ means $h_1(x)$ and $H_1^{\perp}(z)$ both non-zero

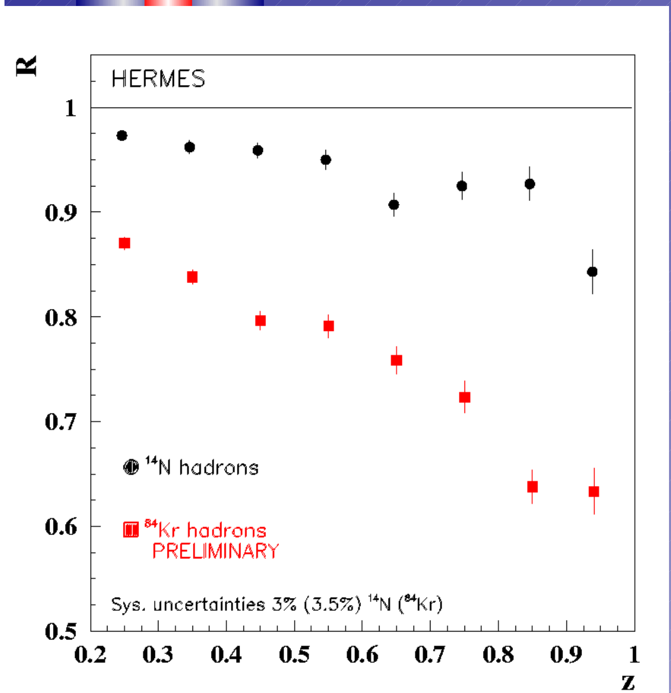
Nuclei as femto–laboratory



Nucleus acts as an ensemble of targets: reduction of multiplicity of fast hadron due to both hard partonic and soft hadronic interactions

Aim: understand space-time evolution:

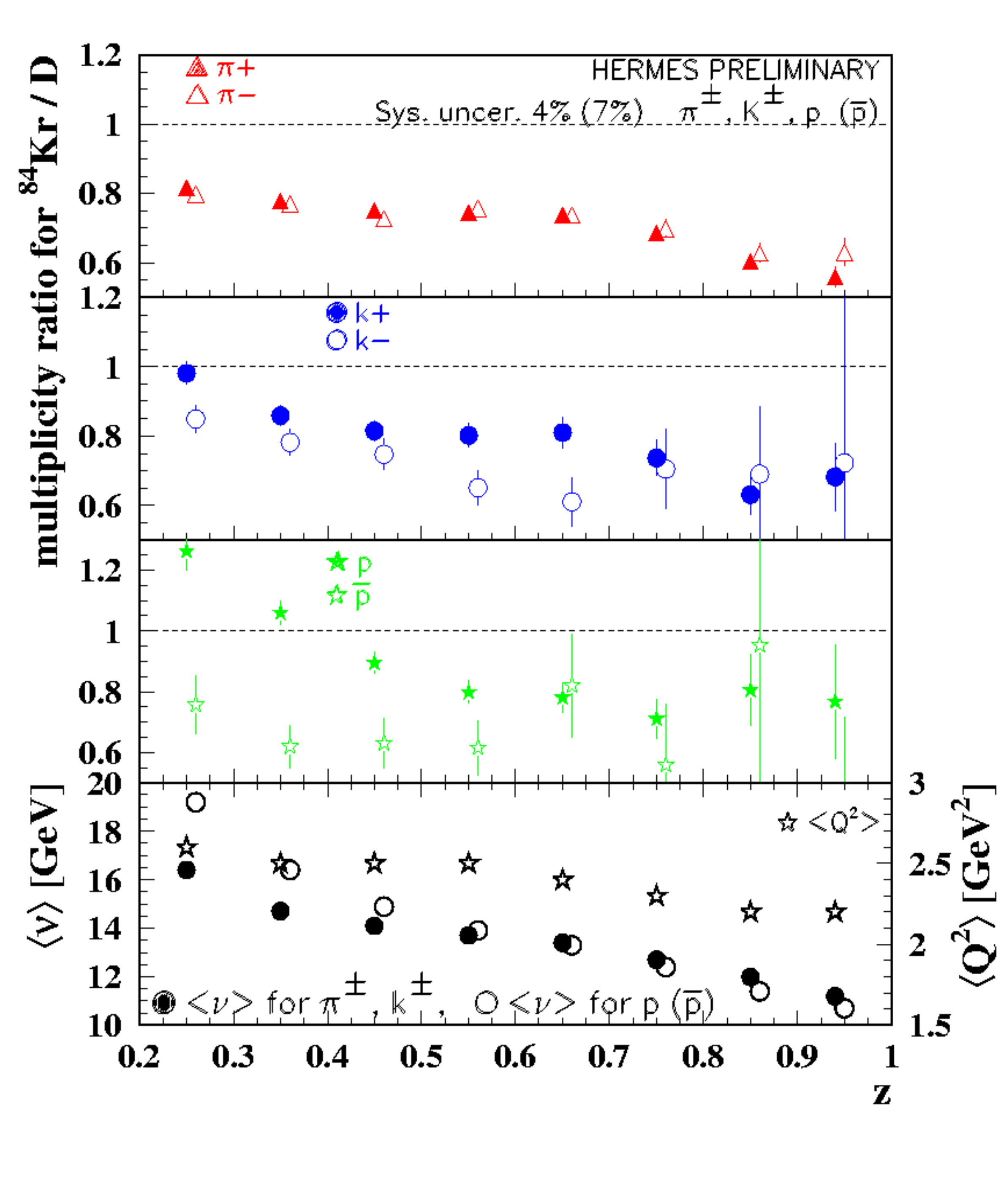
- $\tau_f = l_f/c$ formation time
- FF modification in nuclear medium
- HERMES in ideal kinematic range



$$R_M^h(z,\nu) = \frac{N_h^A(\nu)}{N_e^A(\nu)} \Big/ \frac{N_h^D(\nu)}{N_e^D(\nu)}$$

- HERMES data improve statistical accuracy of SLAC and EMC measurements
- HERMES data provide information in the unexplored region z > 0.8

Identifying the culprits ...

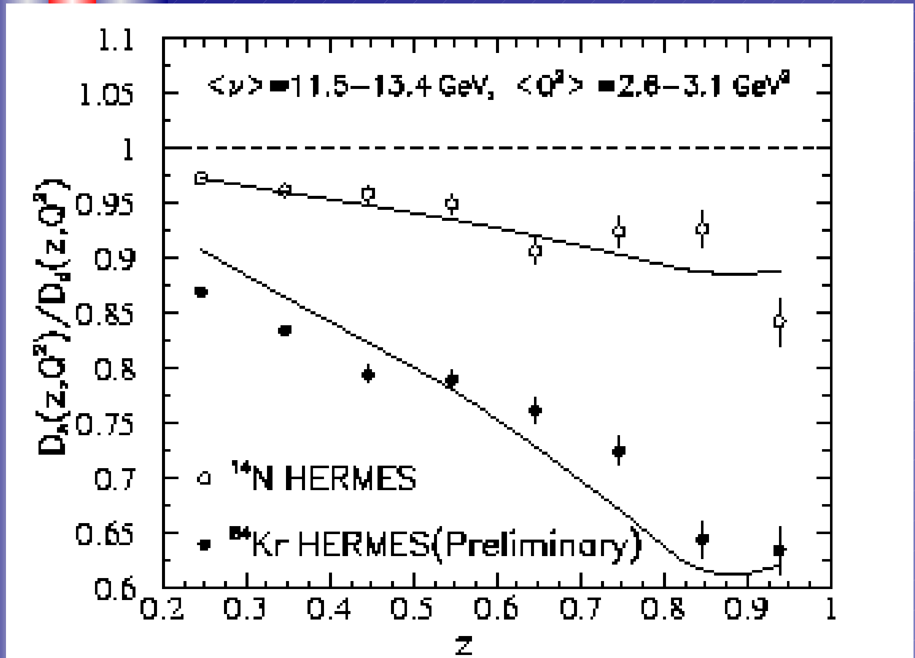


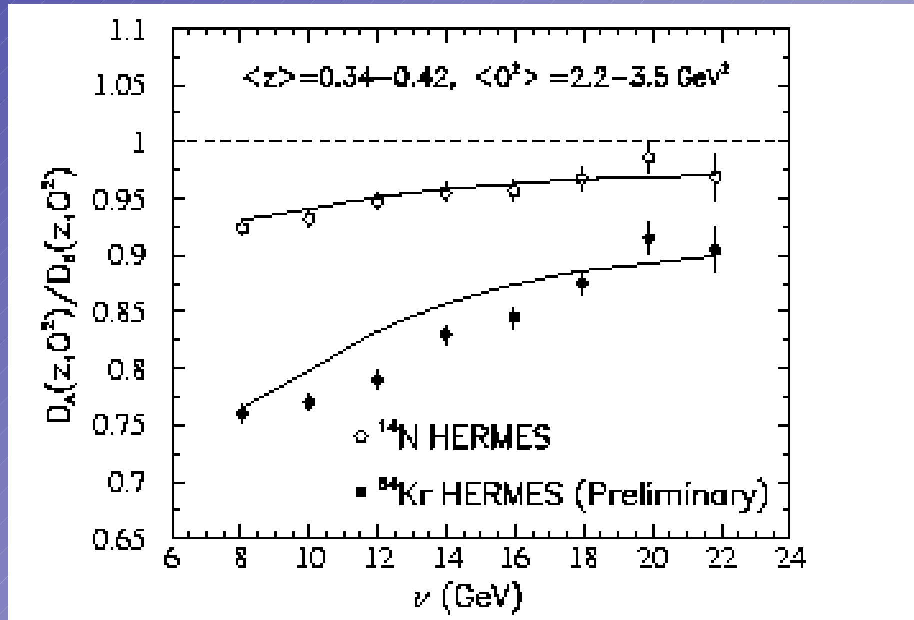
RICH data allow separation into different hadron types

- no significant difference between π^+ and π^-
- marginal difference between K^+ and K^-
- significant difference between p and $\bar{p}$

different formation times and different FF modifications for different hadrons

attenuation vs FF modification





Data are consistent with FF modification due to parton scattering and induced energy loss (without hadron rescattering) (hep-ph/0202105)

- Scaling law: $R_{kr}/R_N = 3.7$ -> Theorie $A^{2/3} = 3.3$
- one free parameter: q-g correlation strength (fit to N)
- q energy loss = energy of radiated gluons
- dE/dx = 0.3 GeV/fm for HERMES Kr data

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2^{nd} break: semi–inclusive results

Polarized semi-inclusive DIS:
- determination of quark polarisations via flavour tagging
- flavour decomposition of light quark sea
- no significant flavour asymmetry $\Delta\bar{u}$ - $\Delta\bar{d}$
- Δs compatible with 0

Single Spin Asymmetries:
- first glimpse on transversity (inaccessible in incl. DIS)
- non-zero SSA shows both h_1 and Collins FF are not zero

hadron formation in nuclei:
- attenuation observed at high z
- charge independet, but particle type dependent
- consistent with modified fragmentation functions in nuclear medium

semi-inclusive scattering offers unique possibilities

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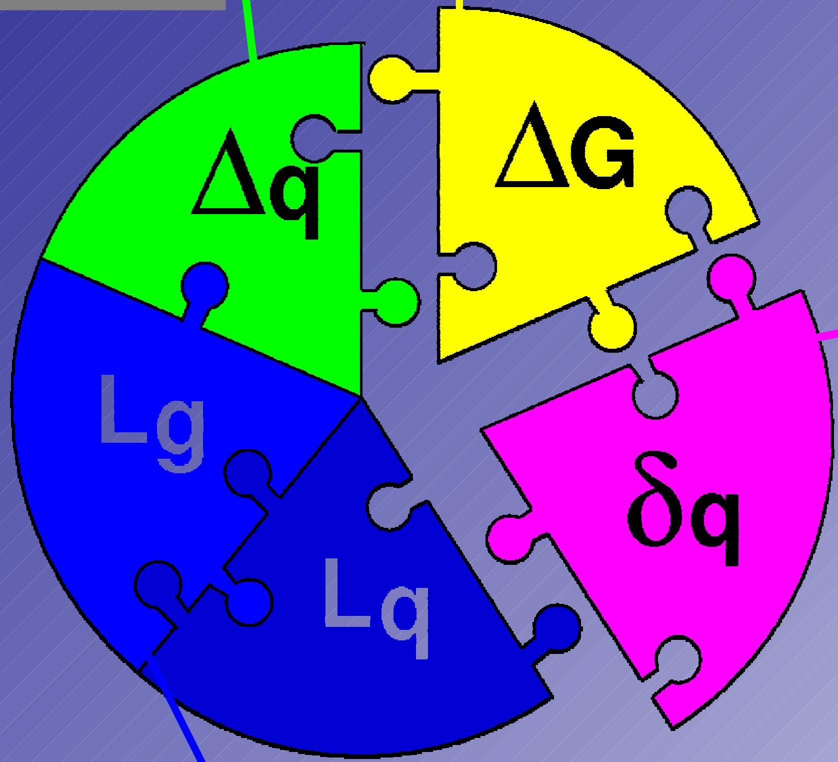
Solving the spin puzzle

Semi-inclusive DIS
(HERMES,
SMC, COMPASS)

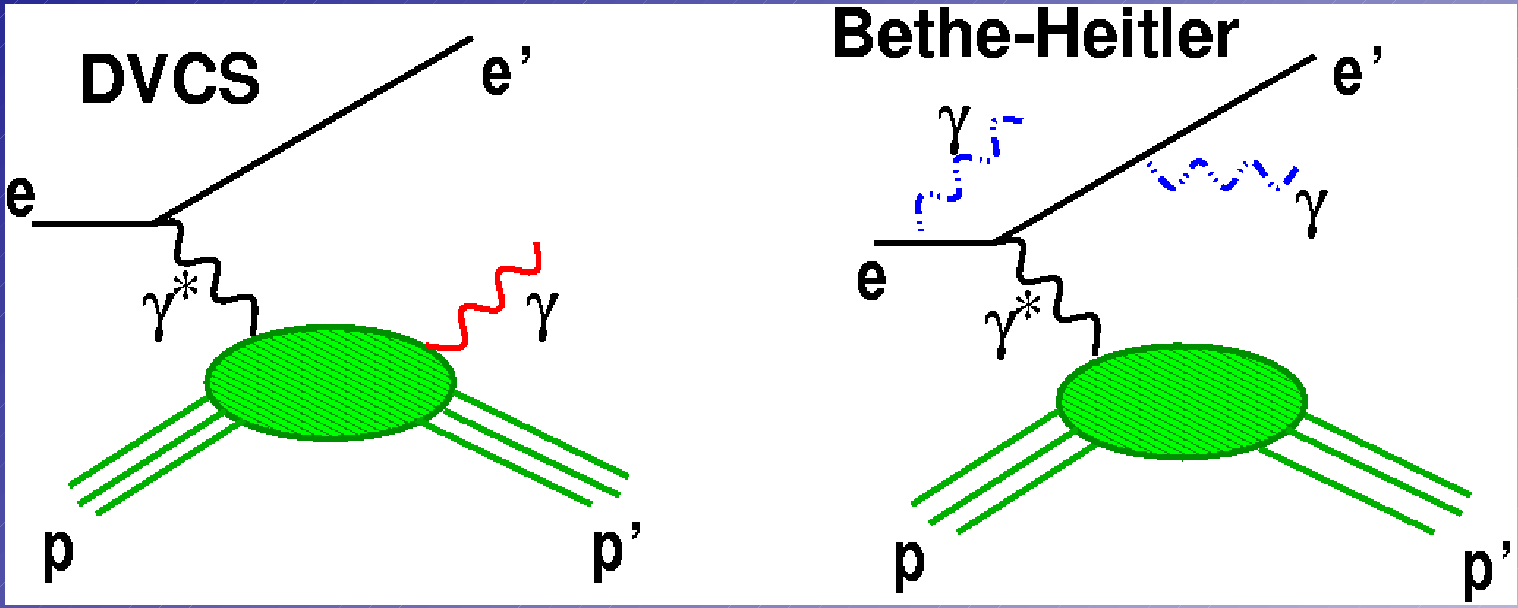
Photon- Gluon Fusion (HERMES, COMPASS)
pol. pp scattering (Spin RHIC)



Semi-inclusive DIS
with transversly
polarised target
(HERMES, TESLA-N)

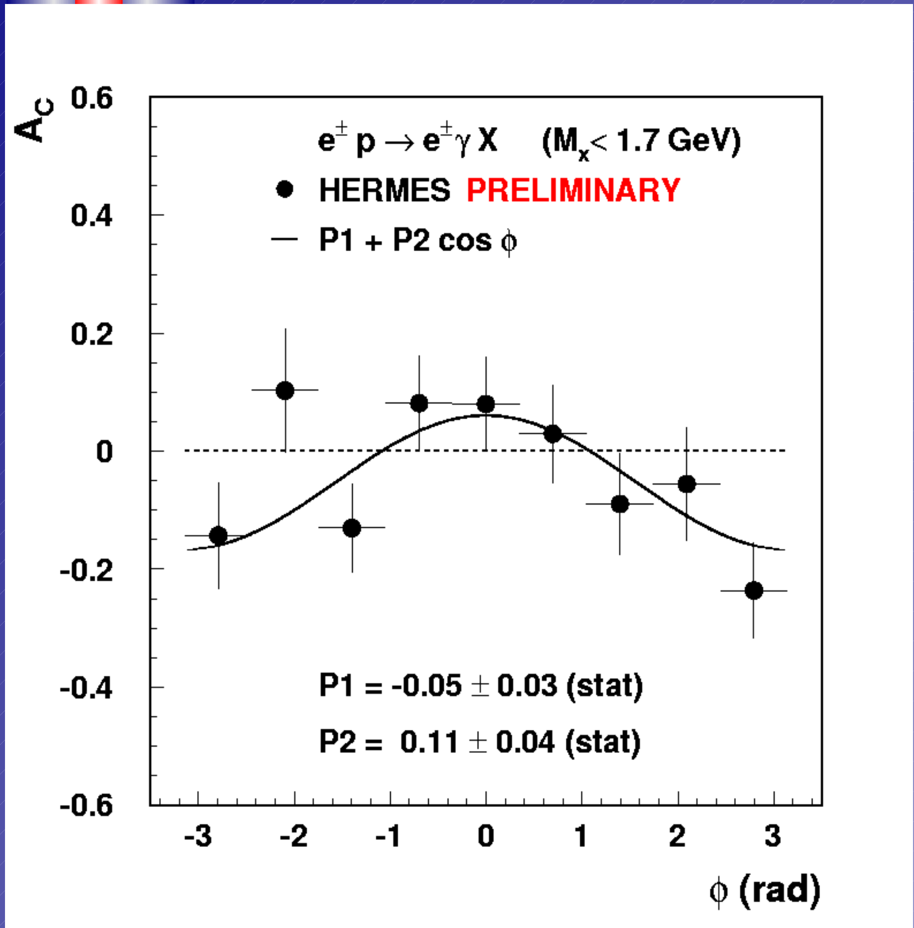
Hard Exclusive Reactions (e.g. DVCS)
Program @ HERMES, COMPASS, Jlab

Aiming for the amplitudes: DVCS–BH



- measure interference of different wave functions p, p'
- cleanest process: DVCS
- same final state: quantummechanical interference
- large BH serves as lever arm for DVCS
- interference on amplitude level -> direct access to amplitudes
- spin/flavour filter: Hard Exclusive Meson production

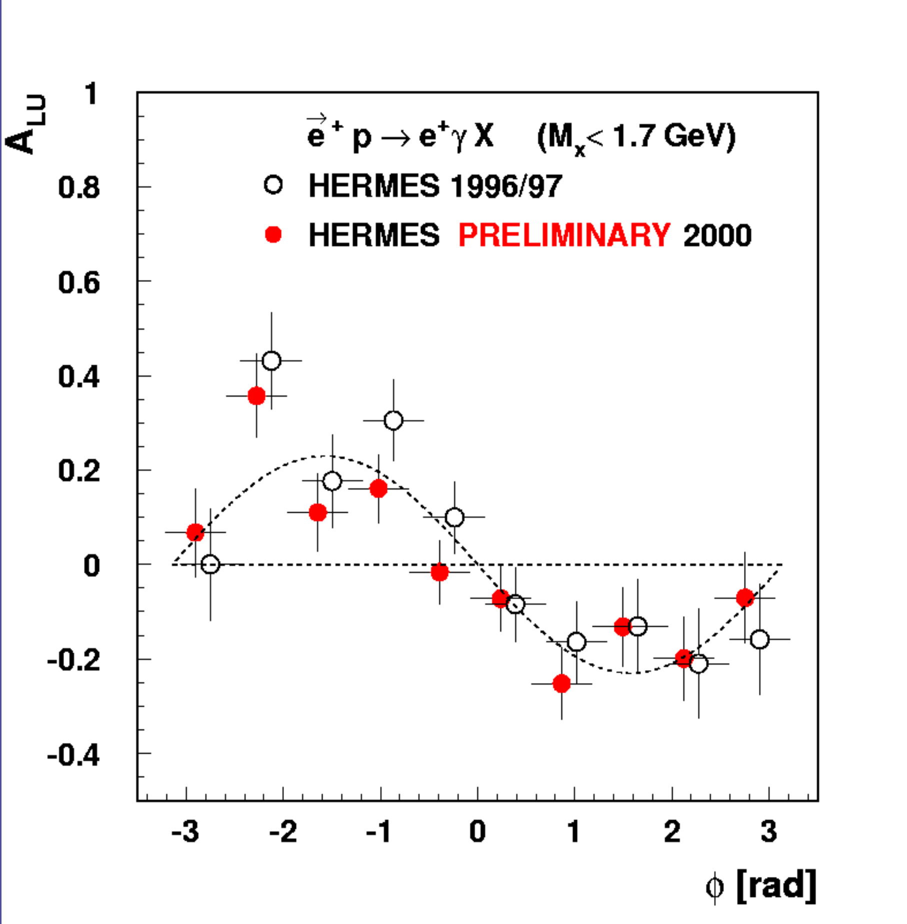
Getting real: Beam Charge Asymmetry



- proportional to cos ϕ
- proportional to real part of DVCS amplitude
- unique feature at HERMES (different beam charges possible)
- precision limited by e^- data
- very sensitive to details of GPD models (Polyakov–Weiss D–Term)

$$d\,\Delta\sigma_{ch} \equiv d\,\sigma(e^{+}\,p) - d\,\sigma(e^{-}\,p) \sim \cos\phi \times \Re(A)$$

Only imaginary: Beam Spin Asymmetry

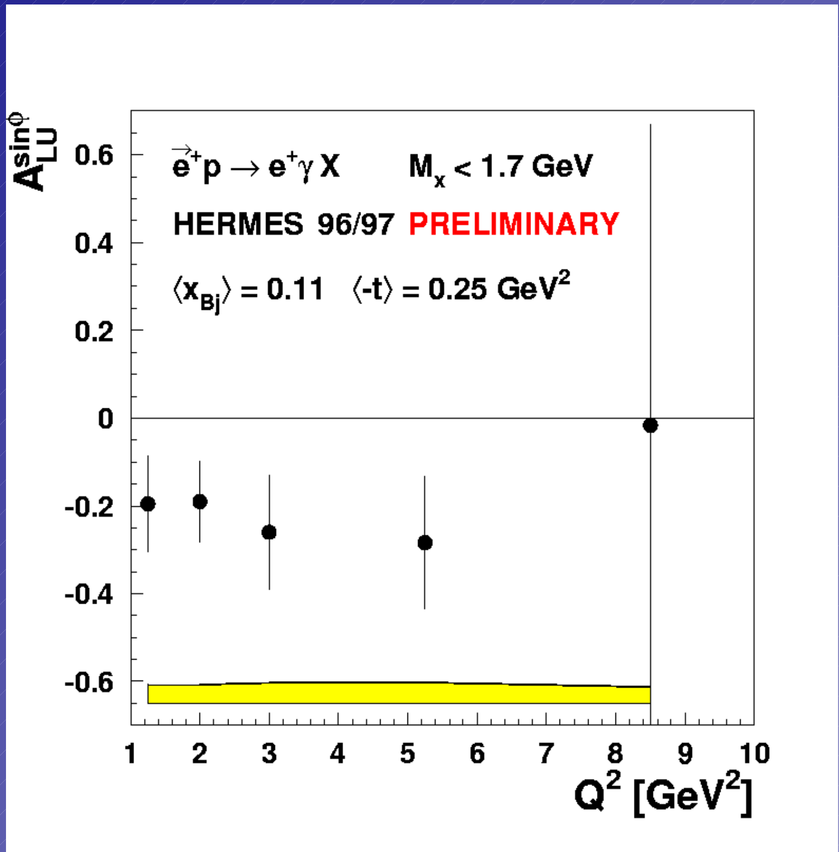


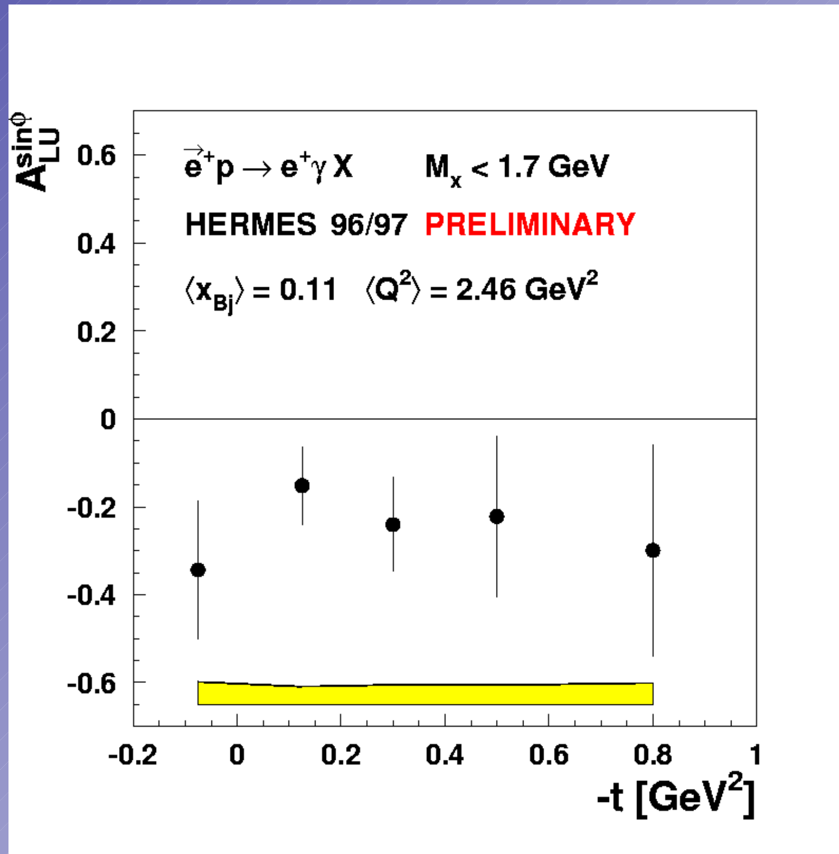
- proportional to sin ϕ
- direct access to imaginary part of DVCS amplitude
- directly proportional to a linear combination of GPDs
- independent of beam charge

BCA + BSA:
real and imaginary part of DVCS amplitude thanks to interference with BH

$$d\,\Delta\sigma_{LU} \equiv d\,\sigma_{\leftarrow}(ep) - d\,\sigma_{\rightarrow}(eq) \sim \sin(\phi) \times \Im(A)$$

DVCS:BSA kinematical dependence





- combined statistics of 1997/2000 Hydrogen running
- no significant t, x or Q^2 dependence observed
- t dependence limited by resolution
  -> detector upgrade with improved resolution

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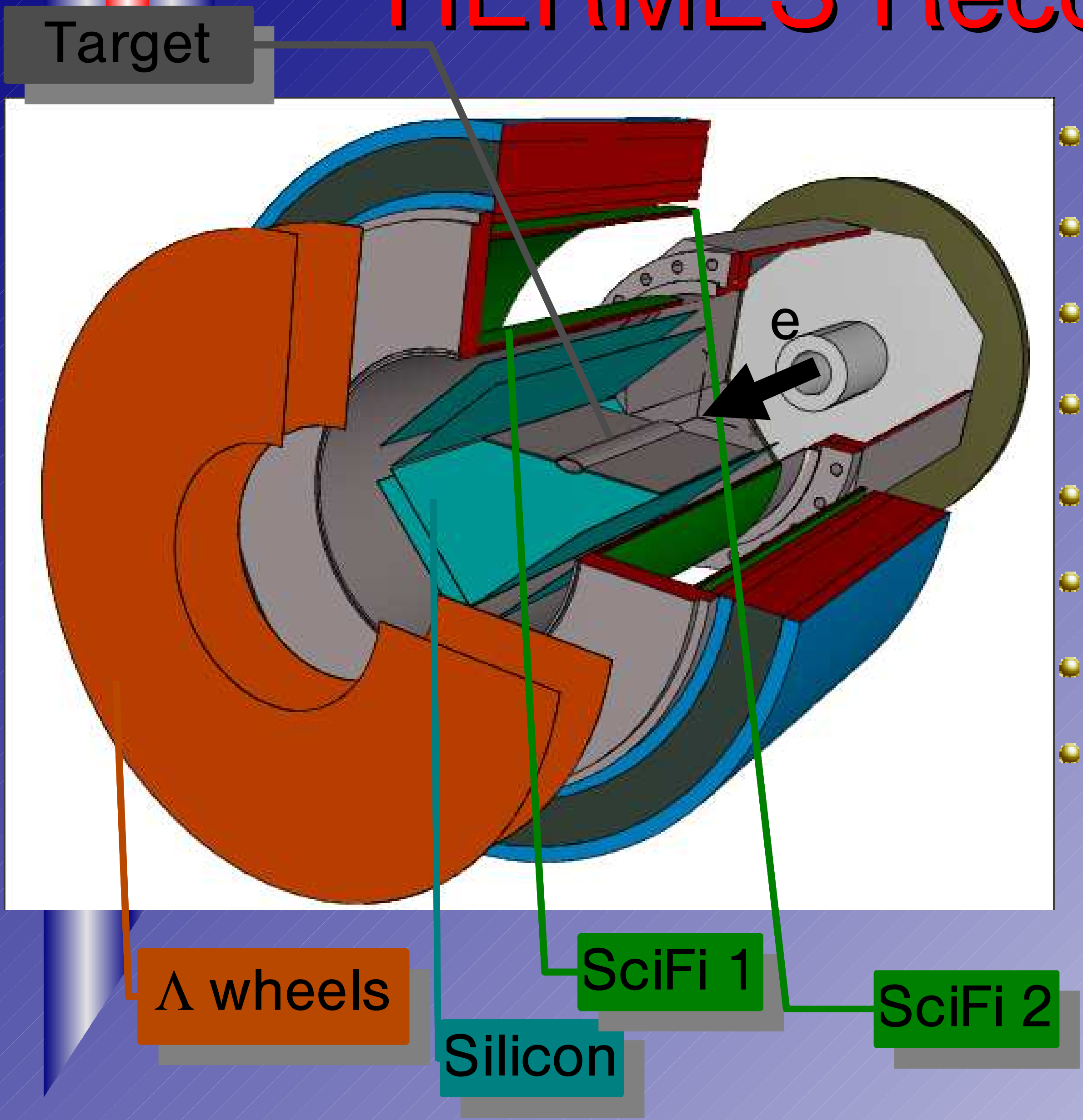
HERMES Recoil Project



- detect recoil p and $\pi^{\pm}$
- 2 layers of silicon
- 2 scintillating fiber barrels
- γ–detector for π^0
- 2 years Hydrogen running
- focus on exclusive reactions
- tagged structure functions
- Hyperon physics possible

HERMES will make
very interesting
pioneering experiments
to study GPDs
(DESY-PRC, May 2002)

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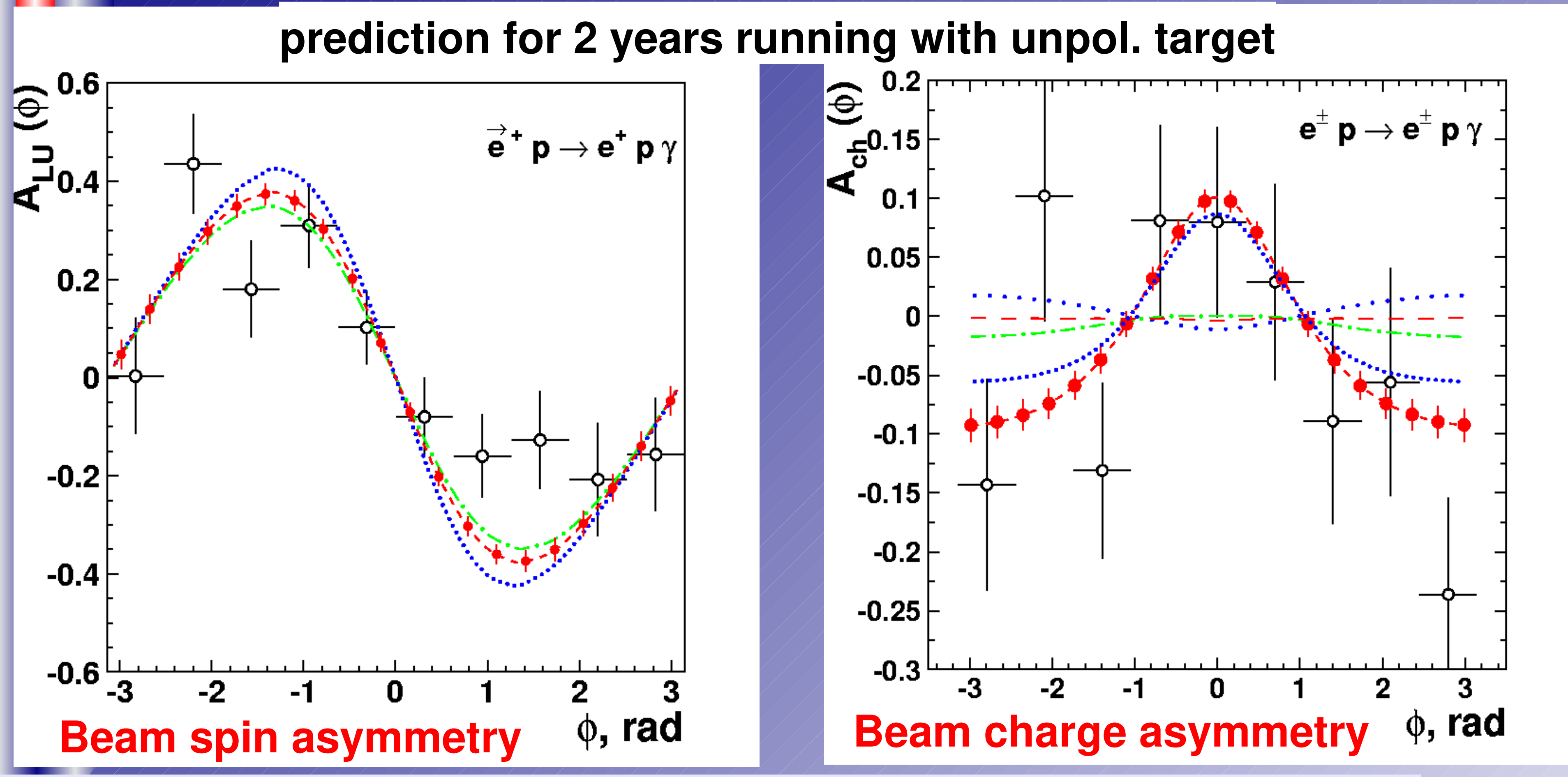
HERMES projections for the future



- sensitive to models and different linear combinations of GPDs
- large statistics allows fine binning in Q^2,t,x
- t–dependence accessible due to much improved resolution
- Δ rejection > 90 %, i.e. Δ contribution to asymmetry < 0.5 %
- systematic accuracy comparable to statistical precision

3^{rd} break: exclusive reactions

- Beam Spin Asymmetry in DVCS measured together with kinematical dependencies
- first measurement on Beam Charge Asymmetry in DVCS
- Beam Spin Asymmetry for DVCS on the Deuteron under investigation
- Target Spin Asymmetries for DVCS on the Deuteron as well

- target Single Spin Asymmetry in $\gamma p \to n\pi^+$ measured for the first time
- no theoretical description available, but kinematics as expected from GPD framework
- data on ρ production in agreement with GPD predictions

2002 - 2004: important data from transverse target expected
2004 + installation and data taking with dedicated Recoil Detector

HERMES so far ...

HERMES Run 1: 5 years successful data taking
- both beam charges (e+ and e-) @ 27.5 GeV and @ 12.1 GeV
- targets: pol. H,D,^{3}He; unpol. H_2,D_2,^{4}He,^{14}N,^{20}Ne,^{84}Kr

inclusive measurements:
- spin structure functions g_1^p, g_1^d,g_1^n
- integrals of spin structure functions (GDH, Bjorken SR, duality)
- cross section ratios of heavy nuclei

semi-inclusive measurements:
- quark contributions to nucleon spin: Δu,Δd,Δq_{sea},Δs
- formation of hadrons in nuclear environement
- SSA giving first glimpse on Collins fragmentation and transversity

exclusive reactions:
- BSA and BCA for DVCS from the proton
- SSA for excl. π^+ on the proton
- σ_L for excl. ρ production

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... HERMES in the future

continue analysis with data on tape: still a lot to discover in all fields

Transverse target (till 2004)

- first measurement of δq
- important data for exclusive reactions expected in all accessible excl. channels
- high density end of fill running with different gases will continue for studiying nuclear effects

Recoildetector (2004 +)

- focus on excl. reactions
- improved resolution
- improved exclusivity for γ,ρ^0,π^0,..
- both beam charges
- high density targets
- tagged structure functions
- Hyperons in the target region

additional data taking with long.pol. H and RICH detector envisaged
Hadron separation on p (flavour tag) to improve present data on Δq

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