HERA, lepton-beam polarization and HERMES

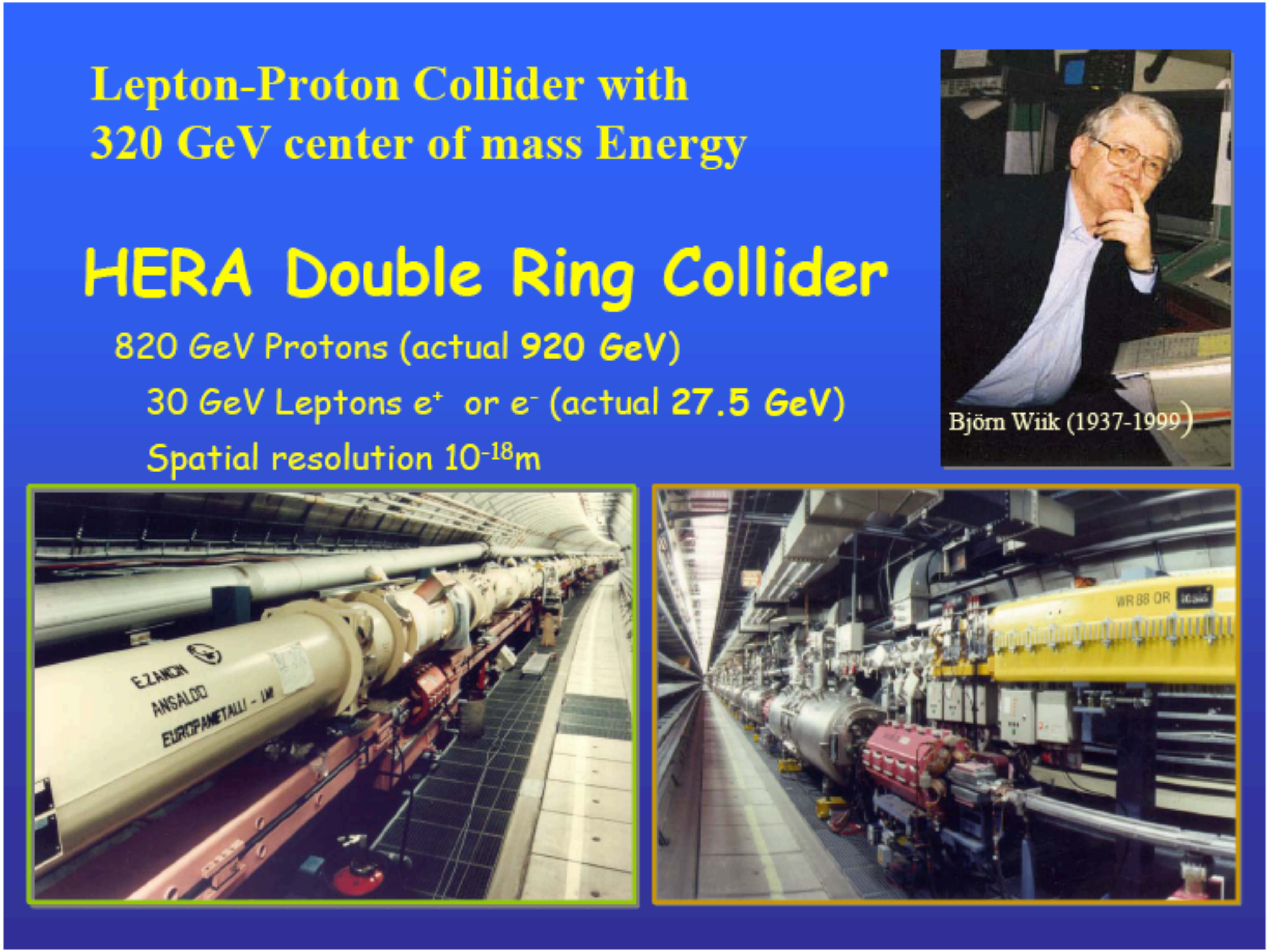
"“HERA Event” October 25, 2012

Caroline Riedl


HERA @ DESY retired 30.6.2007
e
p
O
N
S
W
HERA
hermes
ZEUS
H1
HERA B
you are here
PETRA

HERA: Hadron-Elektron Ring Anlage

- So far unique machine – clean tool to study hadron structure (e = pointlike)
- **Two lepton-beam charges**
  - Usually cross section $\propto |\mathbf{T}|^2 \Rightarrow$ beam-charge dependence squared out
  - Need interference process with odd number of couplings to beam:
    - Example 1: Deeply Virtual Compton Scattering and Bethe-Heitler interference
    - Example 2: interference structure function $F_2^{\gamma Z}$ from interference of γ and Z exchange
  - Beam charge generates sensitiveness to quark flavor (W^{+-} carry charge)
- **Polarized lepton beam** with regular helicity switch
  - Essential for HERMES and considerable enhancement of physics potential for collider experiments
  - No need to rely on polarized source



Courtesy F. Willeke

HERA Milestones
adapted from Willeke 2004 [8]

1981 Proposal

1984 Start Construction

1991 Commissioning, first collisions

1992 Start Operations for **H1 and ZEUS**, 1st Exciting Results with low Luminosity

1994 Install **East spin rotators** → longitudinally polarized leptons for **HERMES**

1996 Install 4th Interaction region for **HERA-B**

1998 Install NEG pumps against dust problem (**electron life time problem**),
Reliability Upgrade

2000 High efficient luminosity production rate: 100 $pb^{-1}y^{-1}$
180 pb^{-1} $e^{+}p$ → Precision measurement on proton structure

2001 Install HERA **Luminosity Upgrade, spin rotators** for H1 and ZEUS

2001-2002 Recommissioning, HERA-B physics run

2003 1st longitudinal polarization in high energy ep collisions
Start-up of the HERA II Run

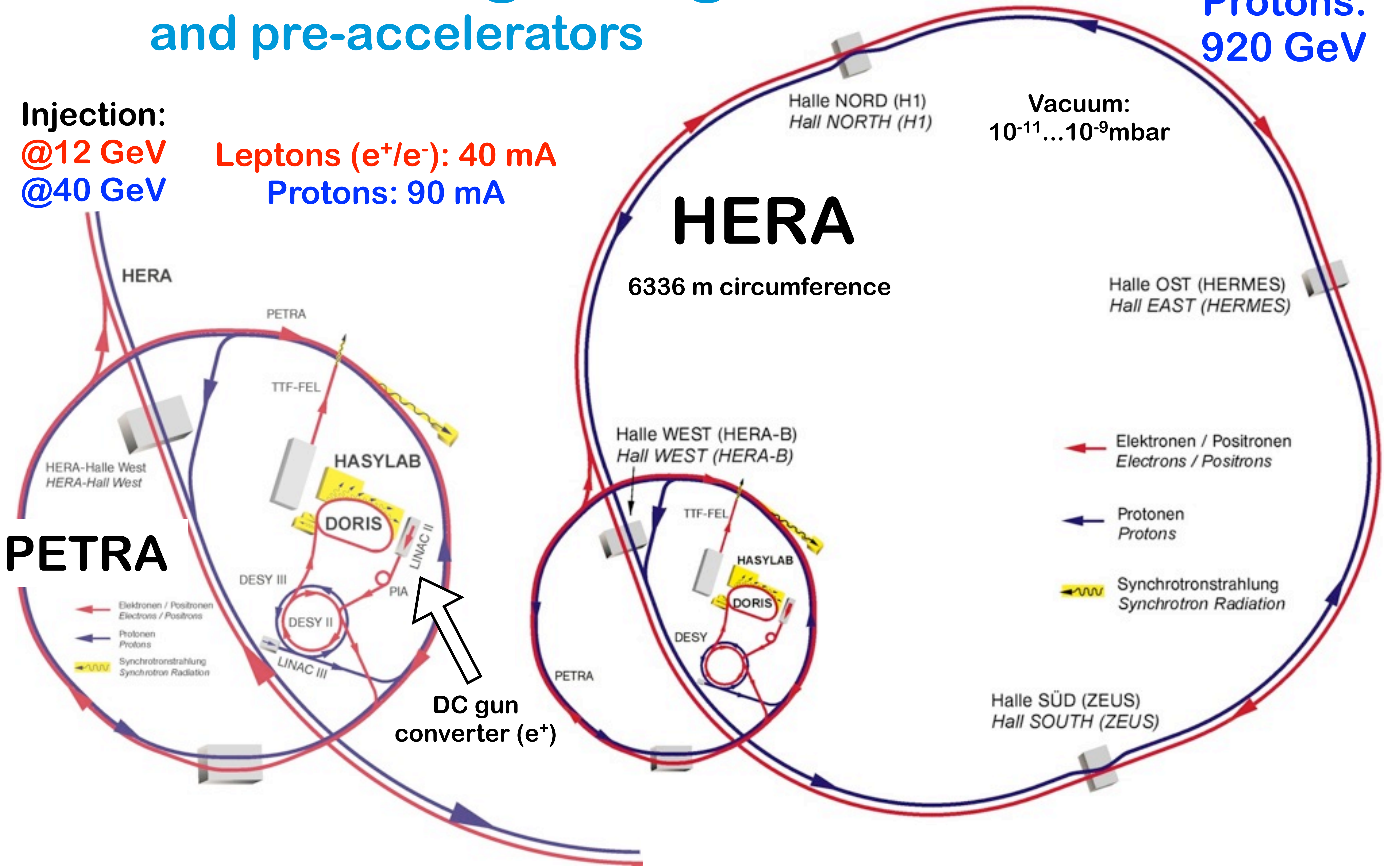
2007 End of HERA II Run

HERA storage ring
and pre-accelerators

Electrons: 27.6 GeV
Protons: 920 GeV

Injection:
@12 GeV
@40 GeV

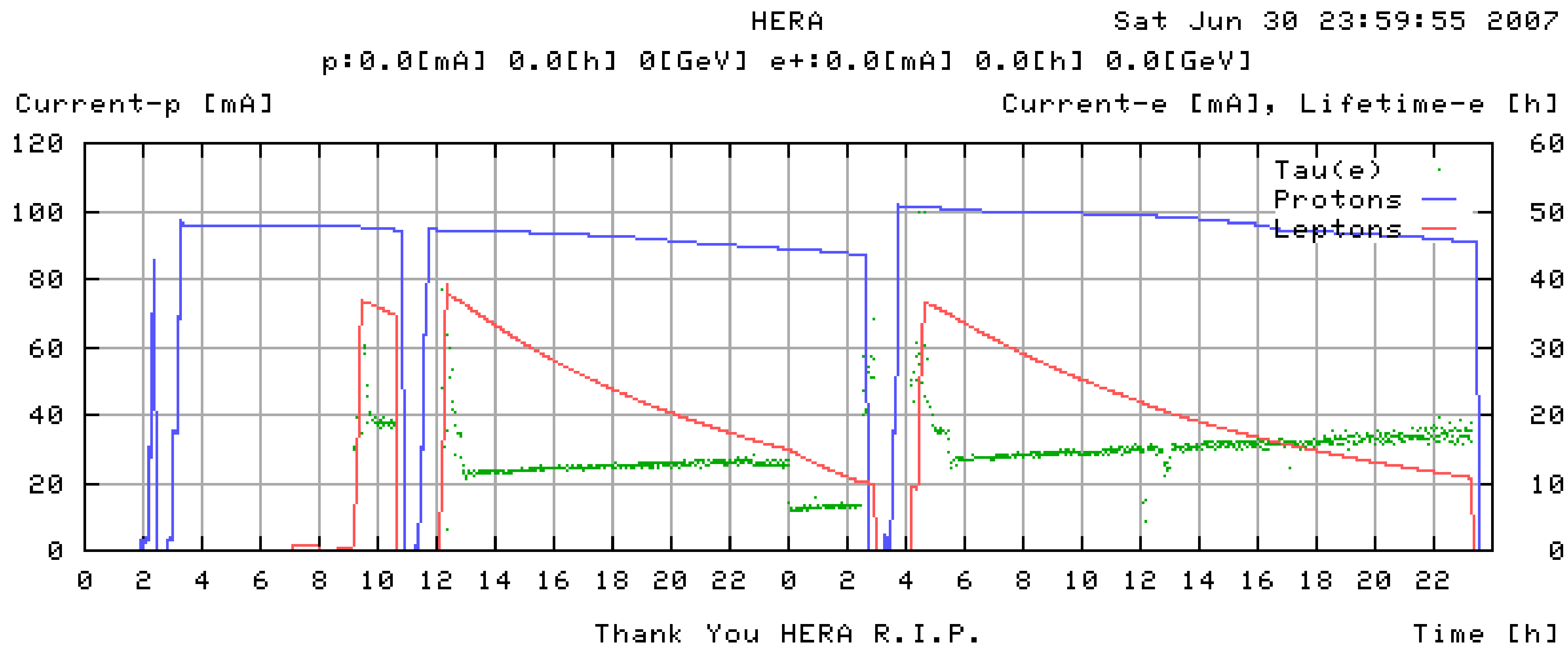
Leptons (e^+/e^-): 40 mA
Protons: 90 mA

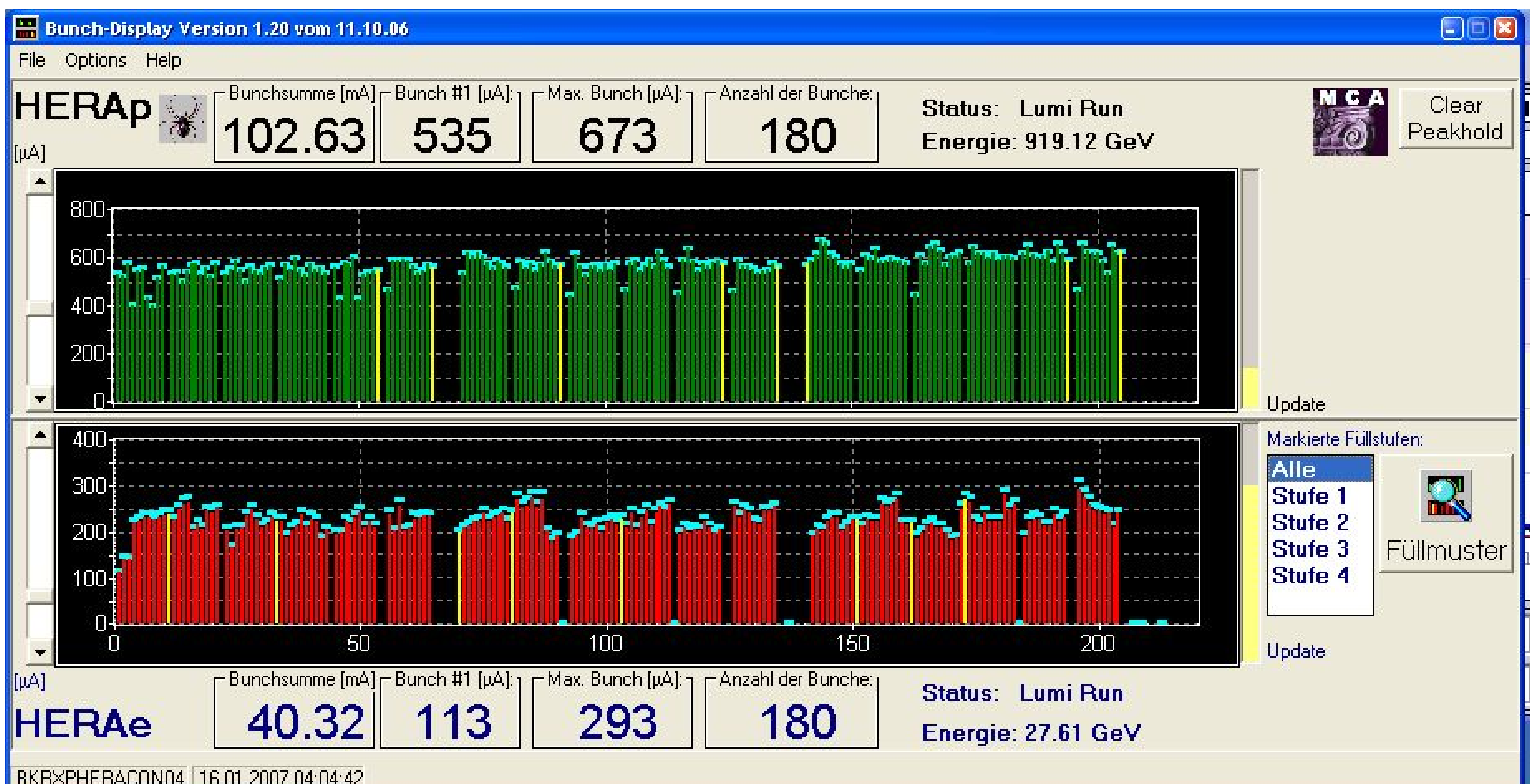


HERA fills and bunch structure

Positrons [mA]
Protons [mA]
Life time [h]

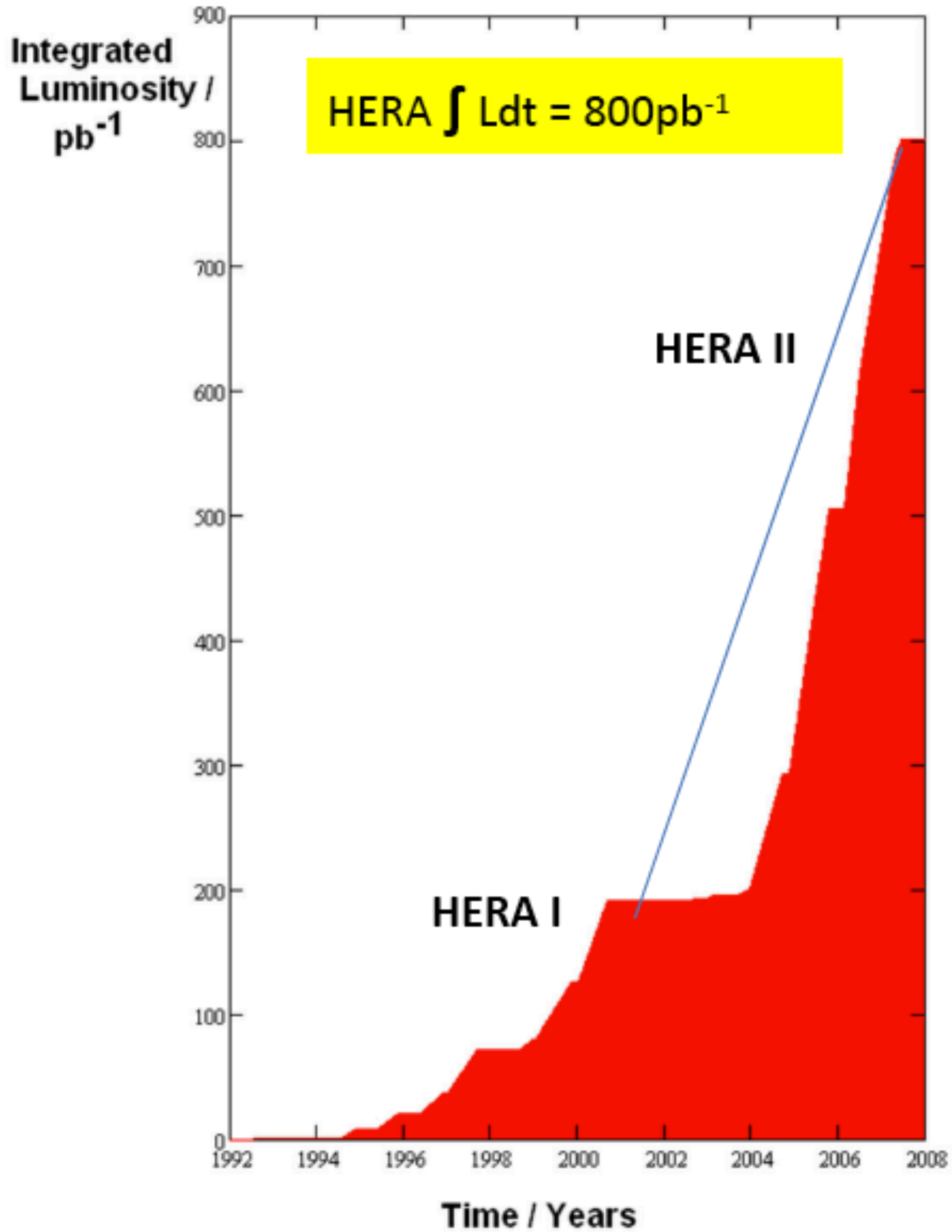
e-life time:
better for e^+
(push out residual gas cores)





180 bunches (max.220)
bunch length 27 ps
separated by 96 ns

HERA collider lumi



600 /pb

$L_{peak} = 5 \cdot 10^{31}\ cm^{-2}s^{-1}$

Lumi upgrade

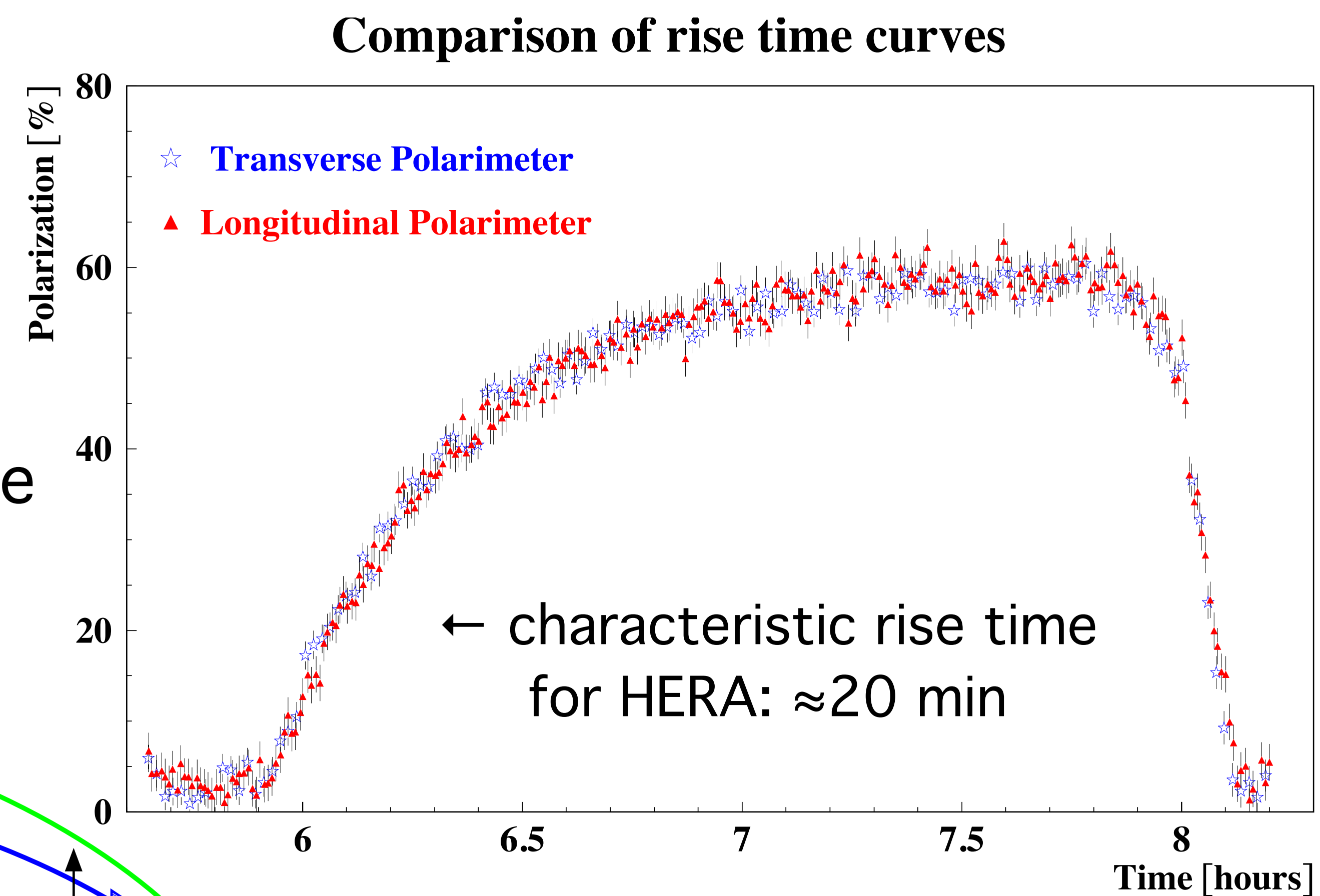
200 /pb

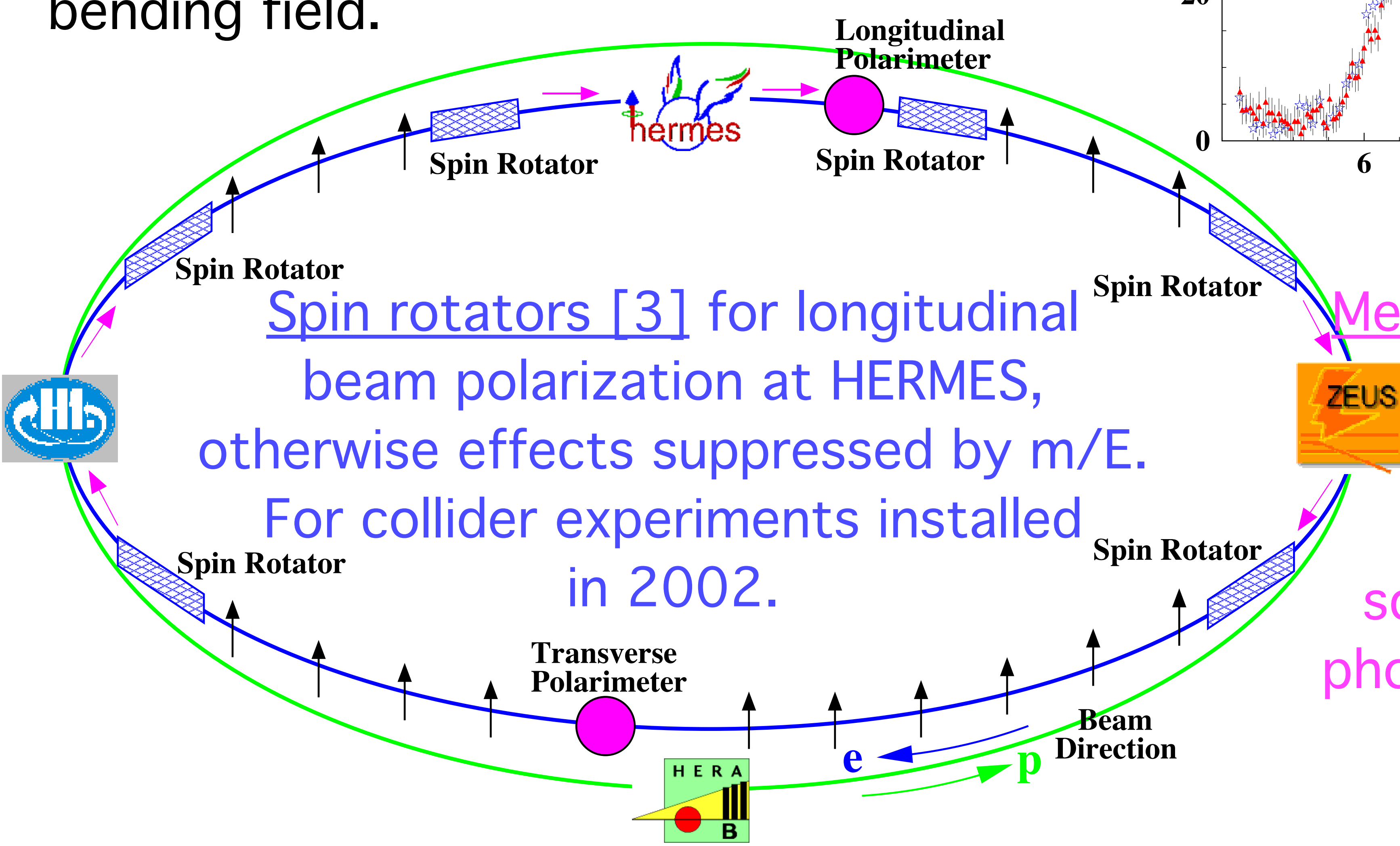
$L_{peak} = 2 \cdot 10^{31}\ cm^{-2}s^{-1}$

HERA lepton-beam polarization

Sokolov-Ternov effect [2]: e can become transversely self-polarized through the emission of spin-flip synchrotron radiation.

Involves small asymmetry in spin-flip amplitudes, enhancing the population of the spin state anti-parallel to the magnetic bending field.





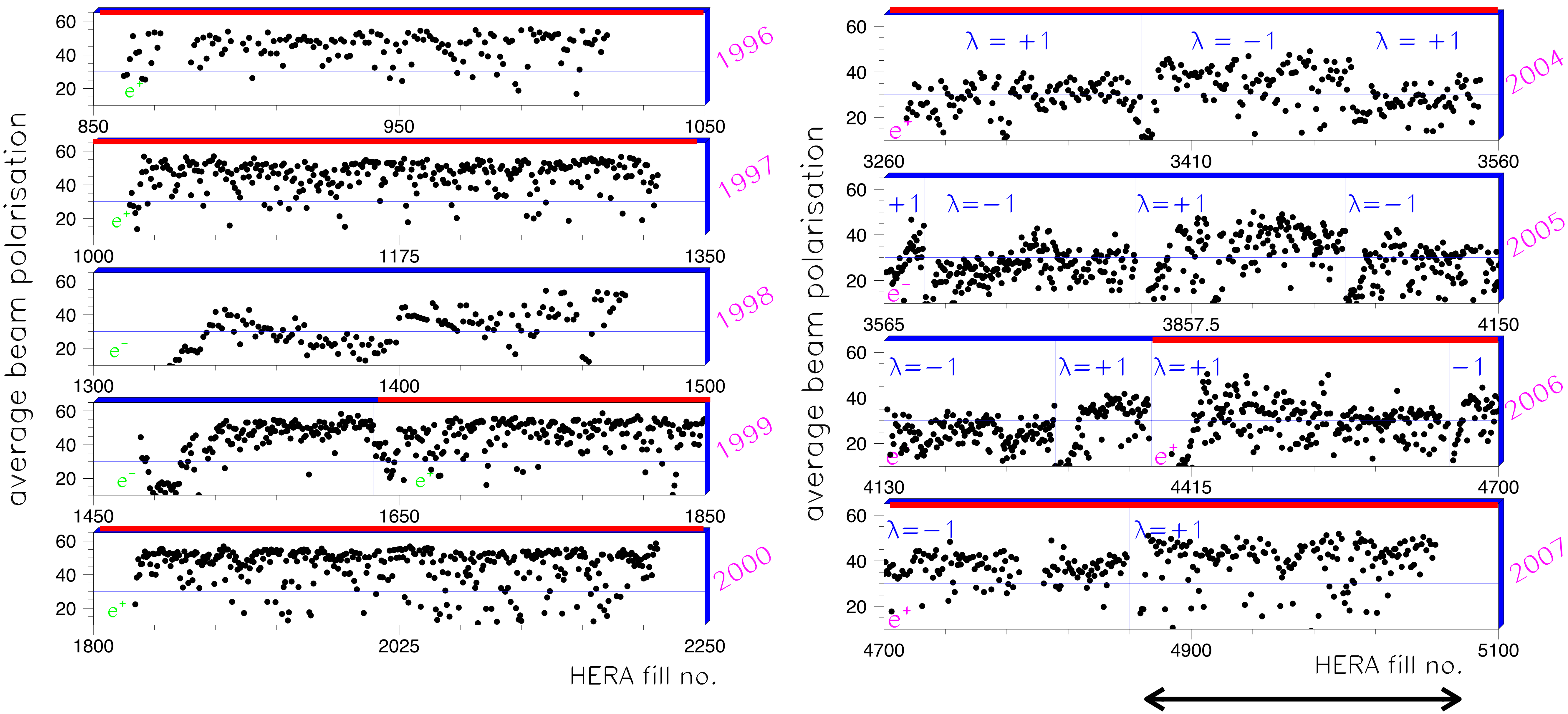
Spin rotators [3] for longitudinal beam polarization at HERMES, otherwise effects suppressed by m/E. For collider experiments installed in 2002.

Measurement of beam polarization

Exploit spin-dependent cross section for Compton scattering of circularly polarized photons off charged leptons [4], [5]. Accuracy: 2% (sys) [6].

HERA e+- polarization over the years

HERA I ➜ lumi upgrade ➜ HERA II



low-energy proton run with higher polarization

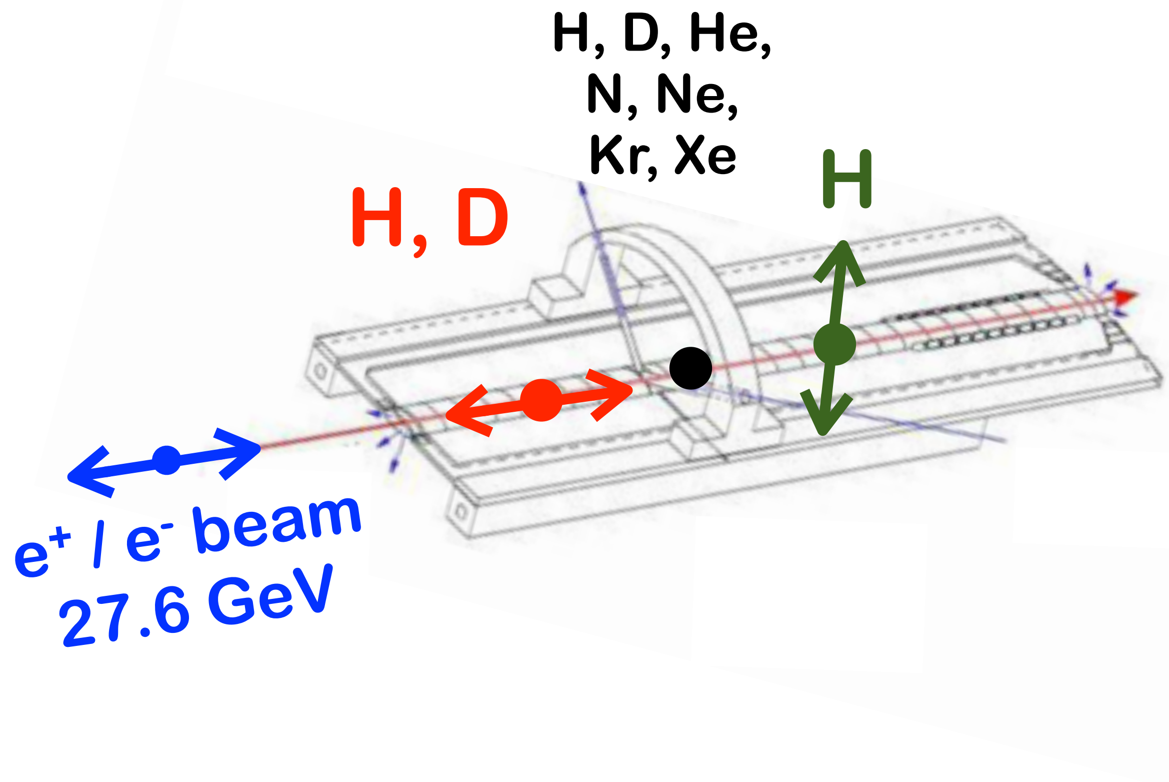
- Beam-beam effects can have effect on polarization. (e^-p) beam focussing, (e^+p) defocussing.
- Polarization lower after HERA lumi upgrade: tune optimized for luminosity and not lepton polarization.

HERMES

HERa MEasurement of Spin

@ HERA East Hall

Gas target
internal to lepton ring



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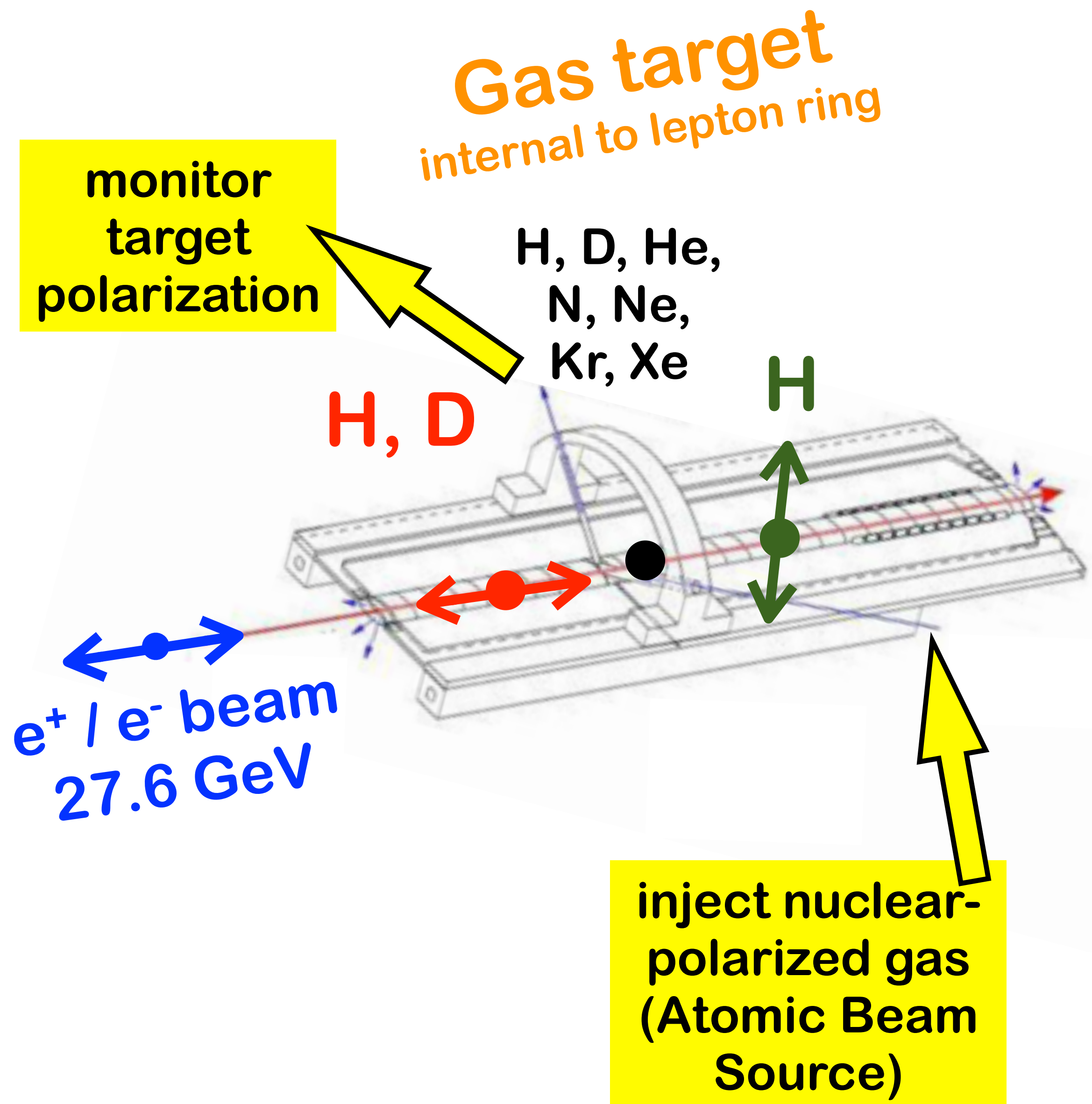
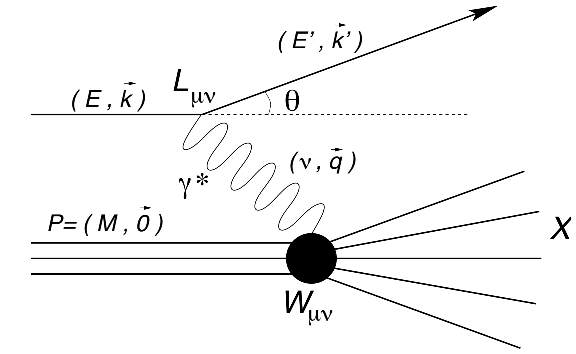


Spin structure function in DIS



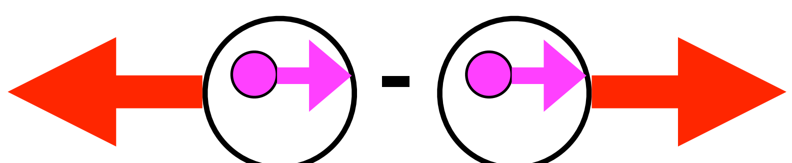
$$\left.\frac{d^2\sigma}{dE'd\Omega}\right|_{1\gamma^*} = \frac{\alpha^2}{2MQ^4}\frac{E'}{E}L_{\mu\nu}W^{\mu\nu}$$

leptonic tensor (QED)

hadronic tensor (QCD)

$W^{\mu\nu}$ parameterized by 4 structure functions (spin-½):

spin-independent: $F_1, F_2,$ spin-dependent: g_1, g_2

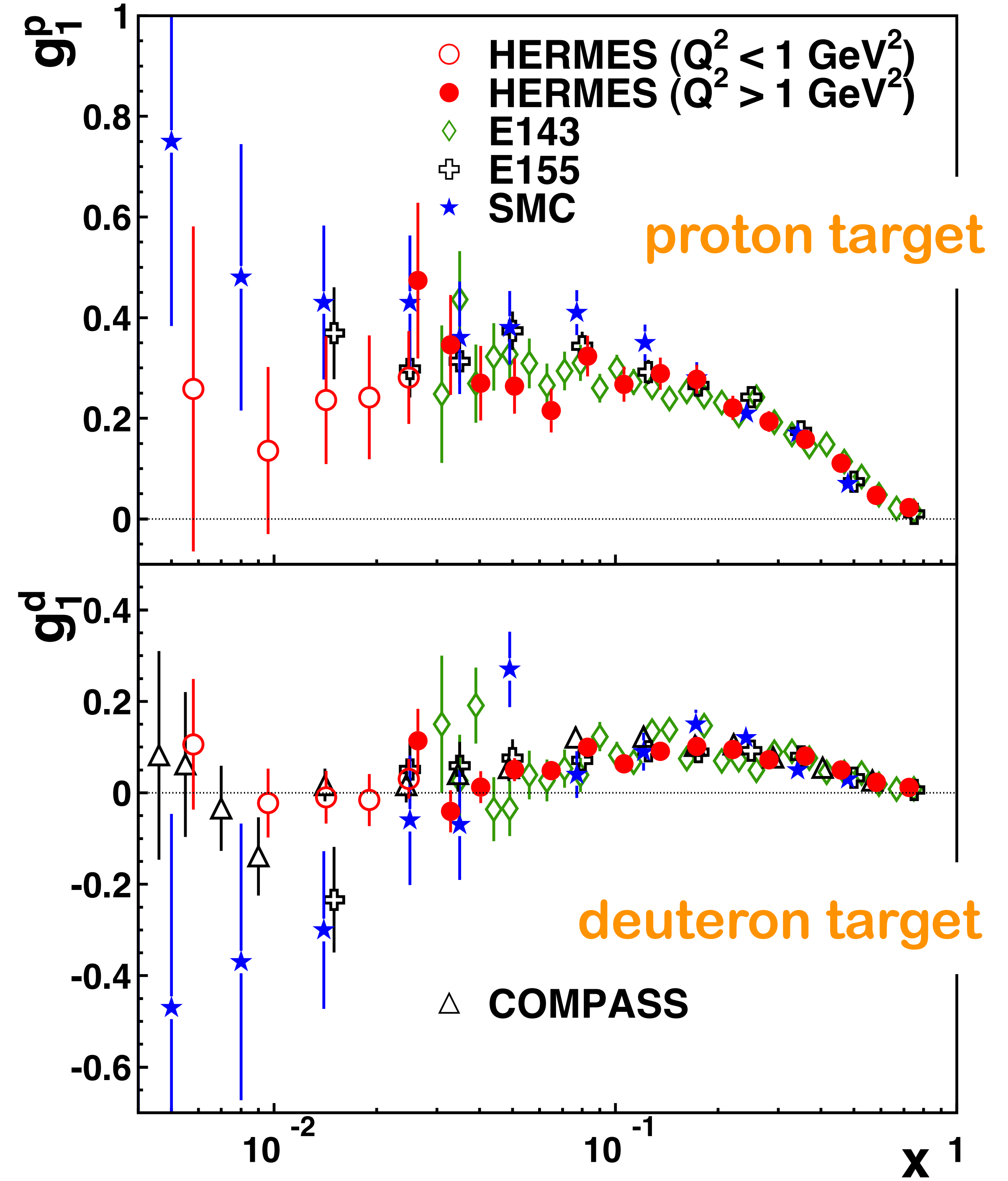


$$g_1 = \frac{1}{2}\sum_q e_q^2 (q^+ - q^-)$$

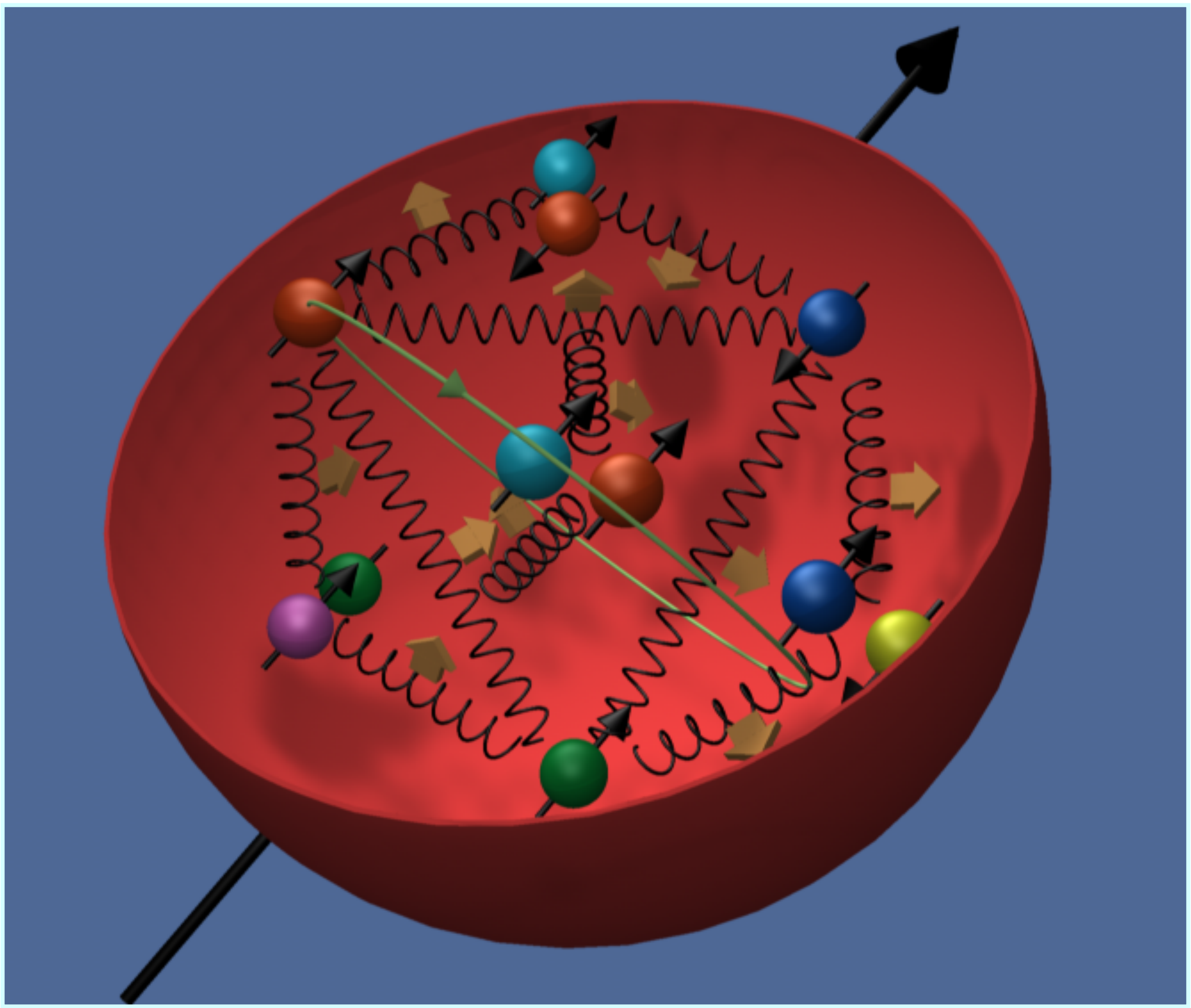
Probabilistic interpretation in Quark Parton Model

$q^{+[-]}(x,Q^2)$ =
probability of finding a quark with **longitudinal momentum fraction x** and with same [opposite] spin orientation as the parent nucleon

Phys. Rev. D 75 (2007) 012007



The Spin of the Nucleon



"Spin Puzzle"

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + J_g$$

quark spin

$\Delta\Sigma \approx \frac{1}{3}$

quark orbital angular momentum

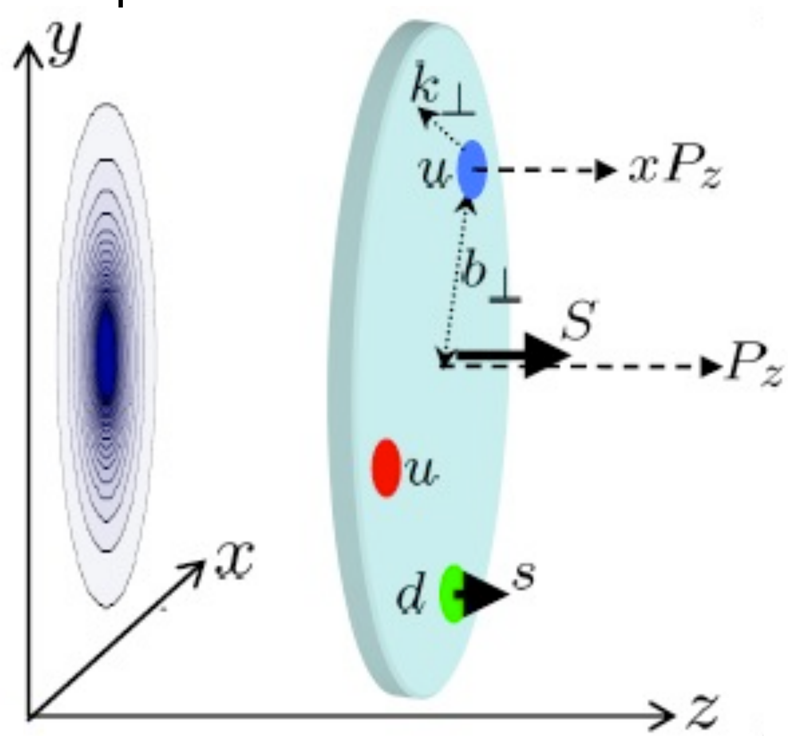
gluon spin [very small] and orbital angular momentum

?!

Dynamic Hologram of the Nucleon

$W(x, b_\perp, k_\perp)$

probability of finding a quark
with certain polarization,
position and momentum



Wigner phase-space distributions, “mother distributions” [7]

Dynamic Hologram of the Nucleon

W(x,b⊥,k⊥)

probability of finding a quark with certain polarization, position and momentum

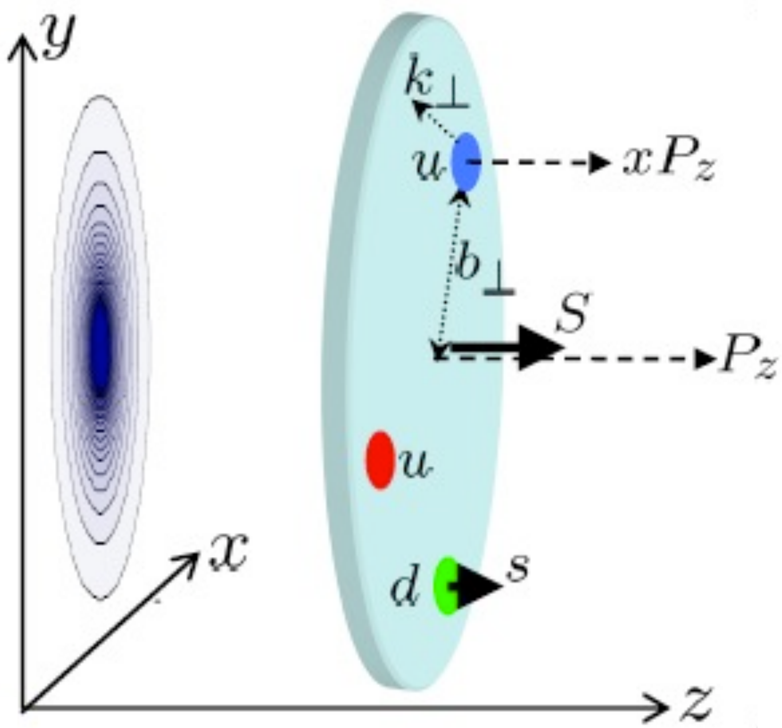
Correlation between **spin** and **transverse momentum** ?

TMDs:

Transverse Momentum dependent PDFs

f(x,k⊥)

3D in momentum space



semi-inclusive measurements

Wigner phase-space distributions, “mother distributions” [7]

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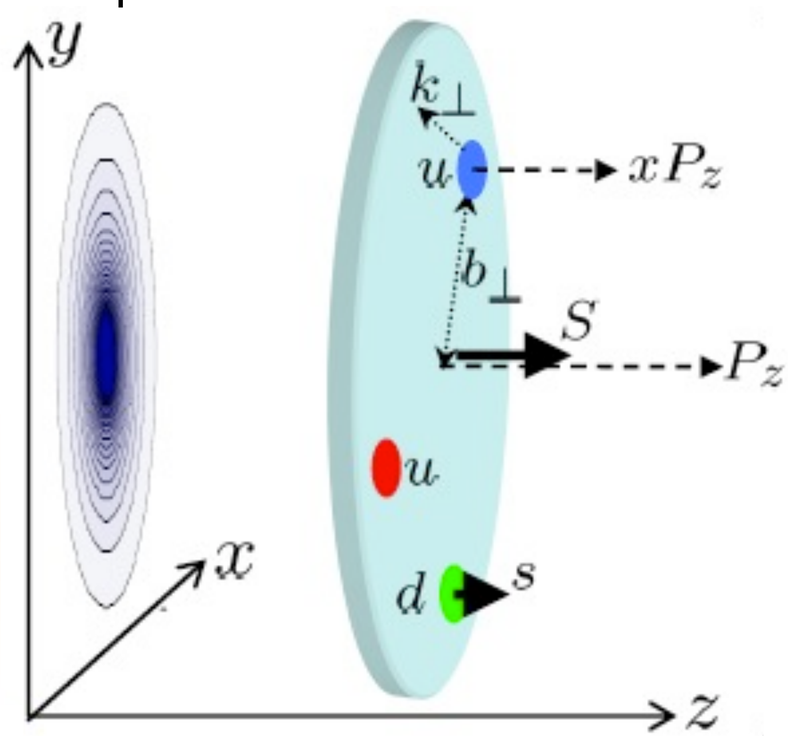

Correlation between **longitudinal momentum** and **transverse position** ?

GPDs:

Generalized Parton Distributions

3D in coordinate space

$H(x, b_\perp)$

↕ FT

$H(x, \xi, t)$

semi-inclusive measurements

exclusive measurements

Wigner phase-space distributions, “mother distributions” [7]

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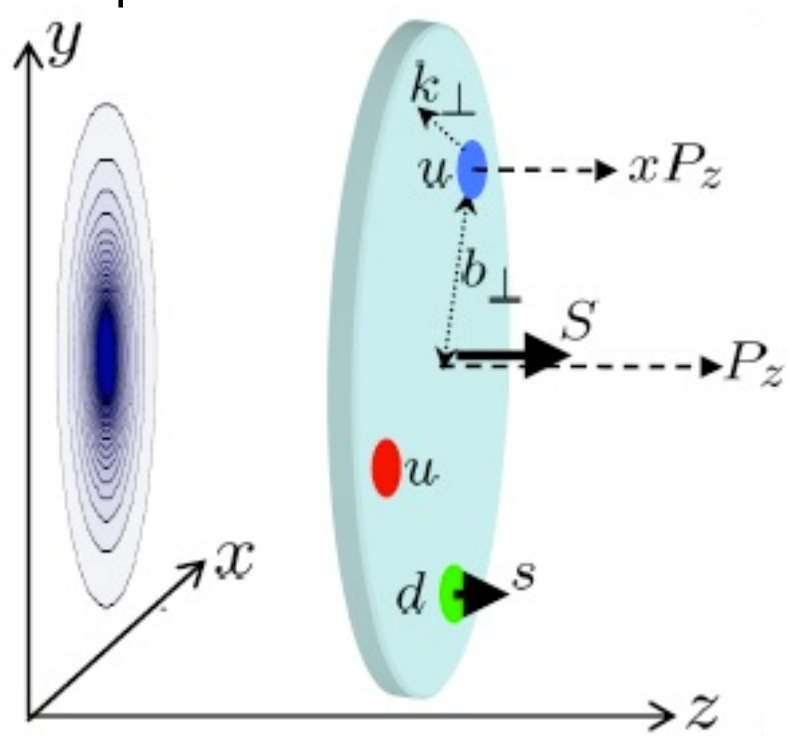


$k_\perp$-integration

ξ=0, t=0

PDFs q(x):

Parton Distribution Functions

1D

semi-inclusive measurements

inclusive measurements

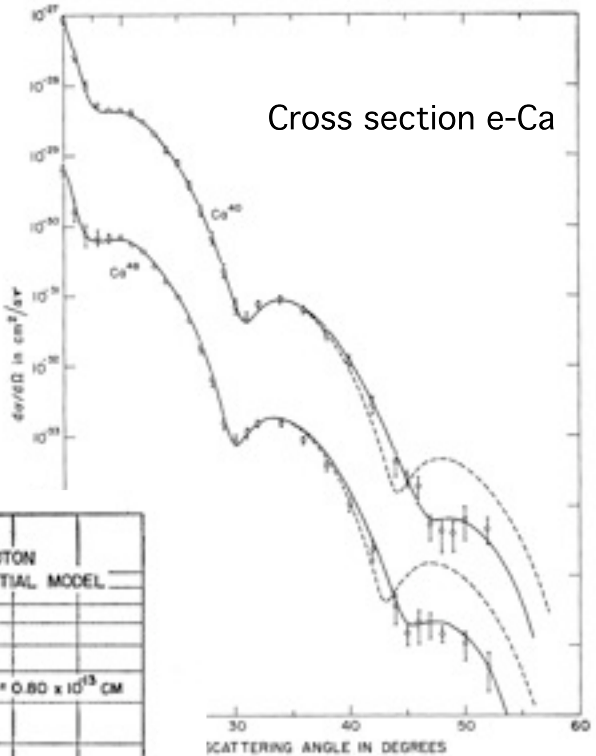
exclusive measurements

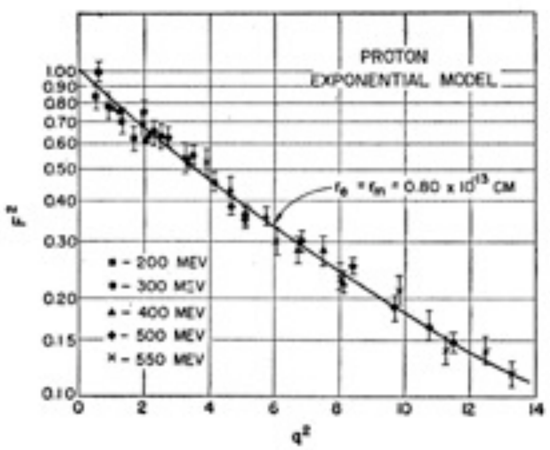
Wigner phase-space distributions, "mother distributions" [7]

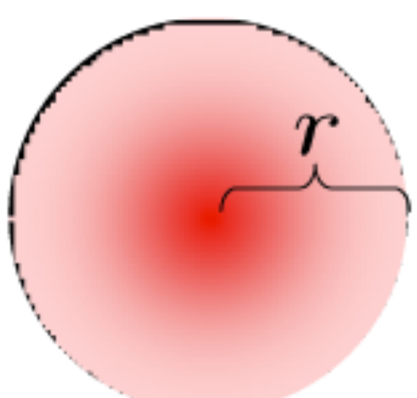
Nucleon Tomography

Form Factors

from elastic scattering

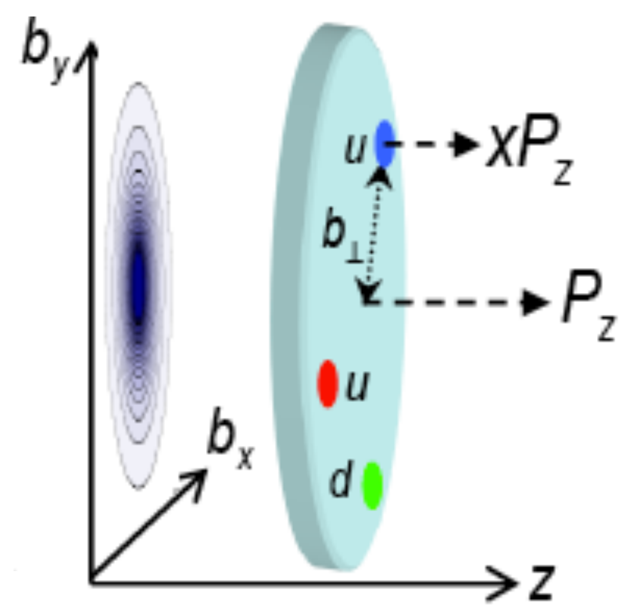


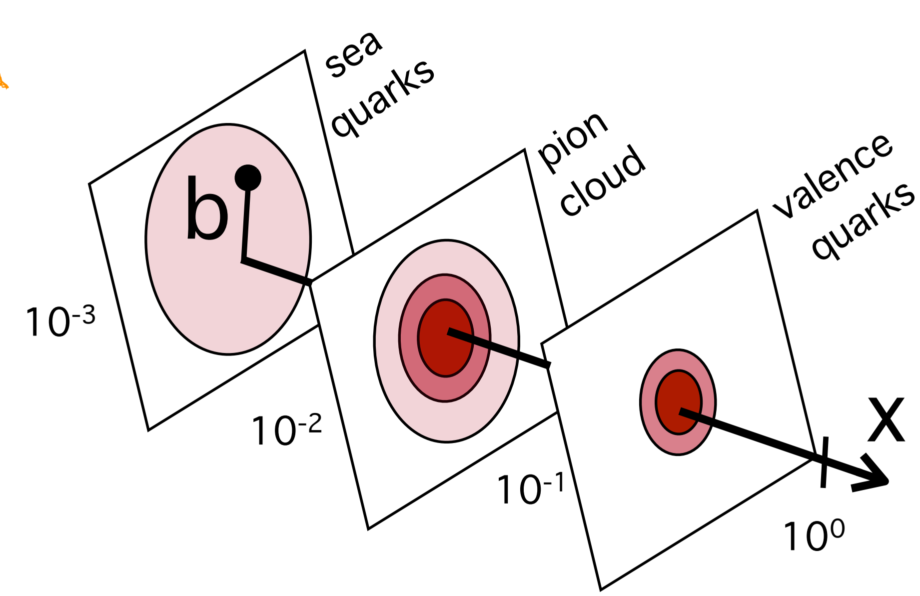




transverse position

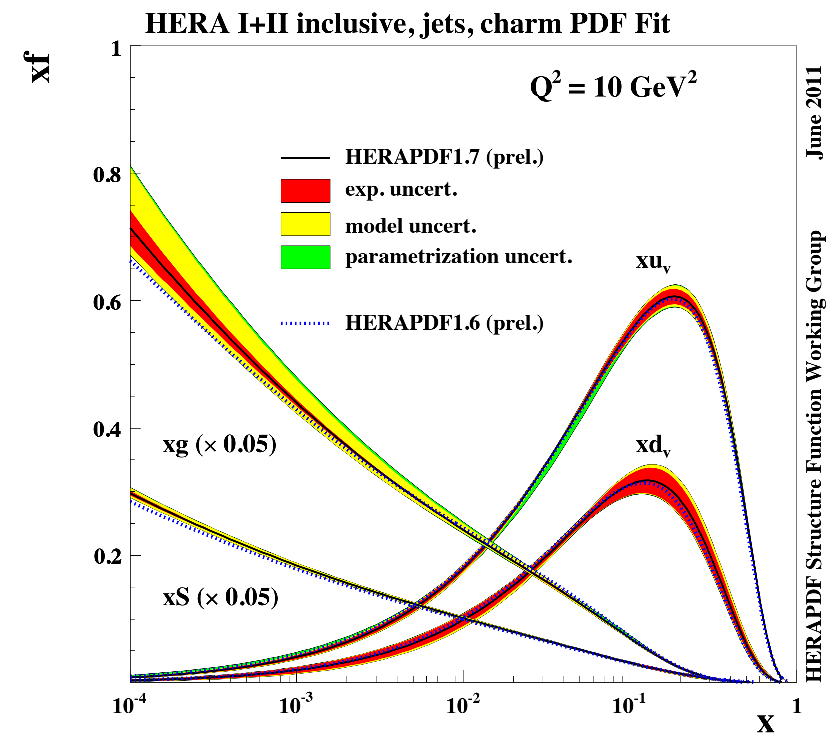
Generalized Parton Distributions



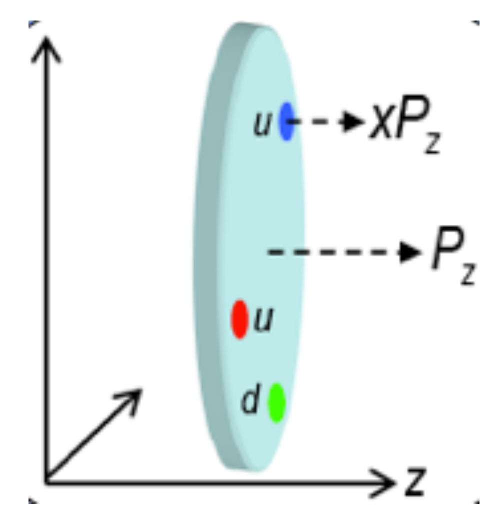


Parton Distribution Functions

from inclusive deep-inelastic scattering



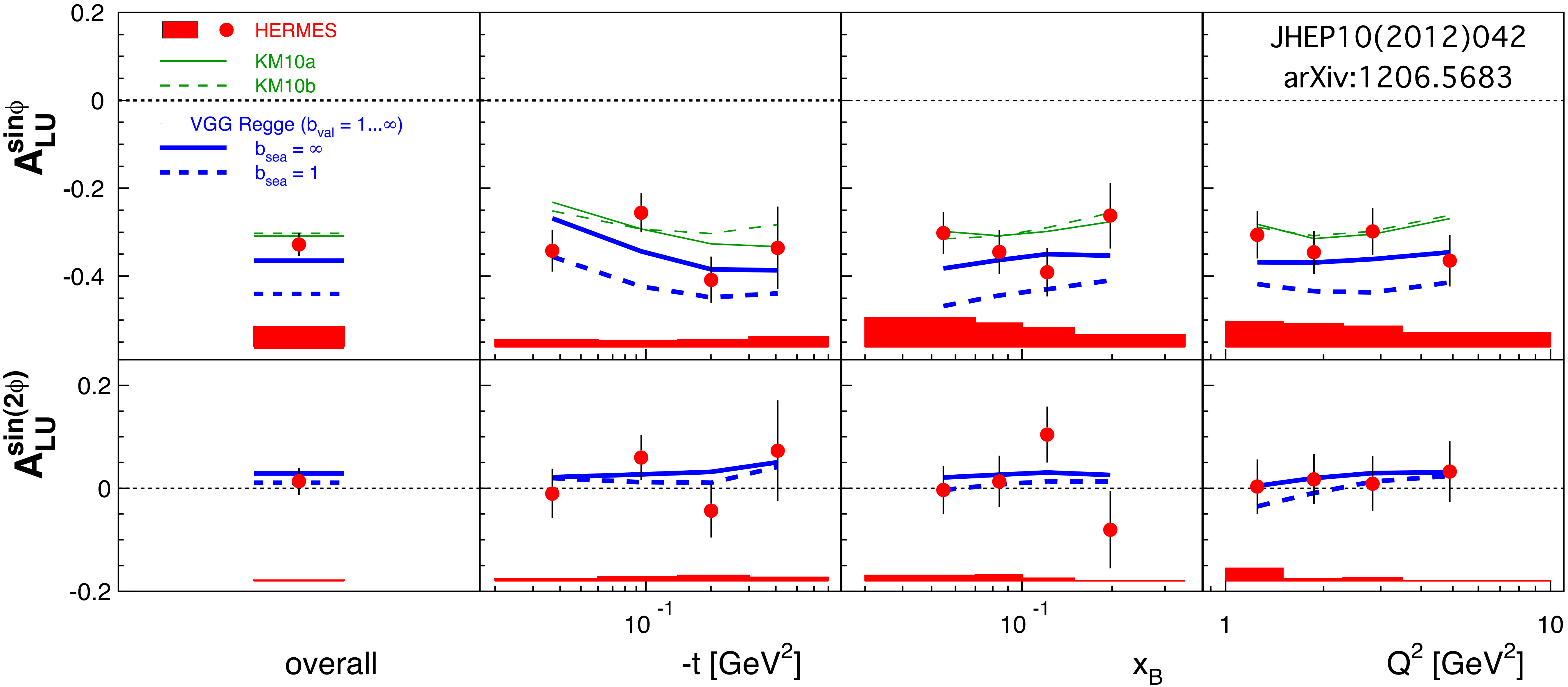
longitudinal momentum



HERAPDF1.7 NLO (Preliminary): H1prelim-11-143,ZEUS-prel-11-010

Illustrations: Ph. Hägler (TUM)

Beam-spin asymmetry in Deeply Virtual Compton Scattering



Global fit of world data

JLab, HERMES and HERA,

dashed excludes JLab Hall A cross section

K. Kumericki and D. Müller, Nucl. Phys. B 841 (2010) 1

GPD model calculation "VGG Regge"

Phys.Rev. D60 (1999) 094017 and Prog.Nucl.Phys. 47 (2001) 401

Your access card to the HERA area

Everybody entering the hall and the tunnel needs one!

Sign in @beginning
Sign out @end

Please return to me afterwards!

Selected Literature I

[1] HERA brochure: "POINTING THE WAY"

[2] Sokolov-Ternov effect: A. Sokolov and I. Ternov, On polarization and spin effects in the theory of synchrotron radiation, Sov. Phys. Doklady 8 (1964) 1203.

[3] Spin rotators: J. Buon and K. Steffen, HERA Variable Energy 'Mini' Spin Rotator and head-on ep Collision scheme with Choice of Electron Helicity, Nucl. Instrum. and Meth. A 245 (1986) 248.

[4] TPOL: D.P. Barber et al., High Spin Polarisation at the HERA Electron Storage Ring, Nucl. Instrum. and Meth. A 338 (1994) 166.

[5] LPOL: M. Beckmann et al., The Longitudinal Polarimeter at HERA, Nucl. Instrum. and Meth. A 479 (2002) 334 [arXiv:physics/0009047].

[6] HERA polarization: B. Sobloher, R. Fabbri, T. Behnke, J. Olsson, D. Pitzl, S. Schmitt, J. Tomaszewska, Polarisation at HERA – Reanalysis of the HERA II Polarimeter Data [http://arxiv.org/abs/1201.2894]

[7] Wigner phase-space distributions [X. Ji, PRL 2003; A. Belitsky, X. Ji, F. Yuan, PRD 2004]
“Mother Distributions” [Meissner, Metz, Schlegel, JHEP 0908:056, 2009]

Selected Literature II

[8] F. Willeke, DESY seminar November 2004: HERA operations and prospects
http://www.desy.de/f/seminar/willeke.pdf

[9] D. Trines, HERA symposium 2012: Technical challenges / problems during operation
https://indico.desy.de/getFile.py/access?resId=0&materialId=6&confId=5719