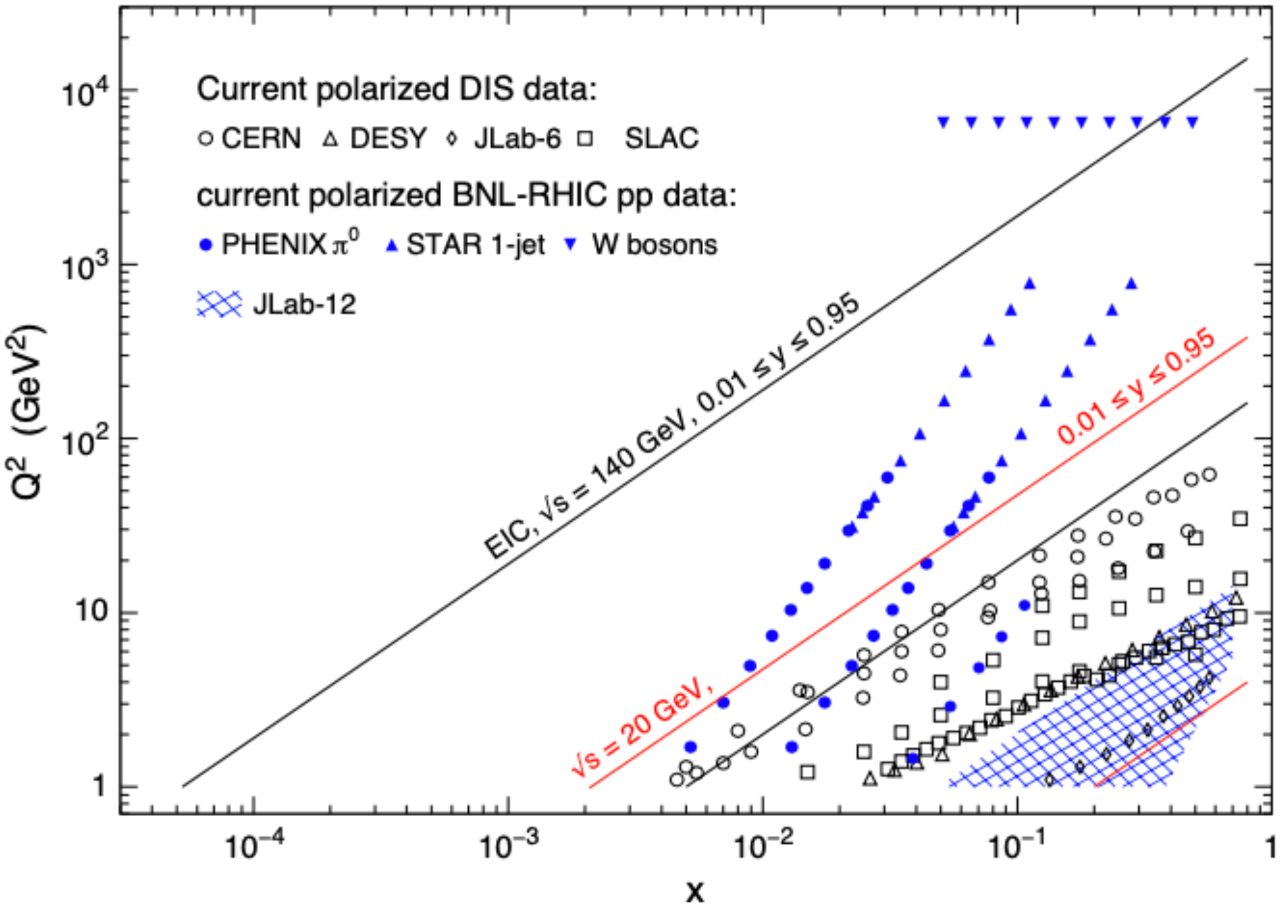
Perspectives of polarized internal target experiments using EIC beams

Bogdan Wojtsekhowski, Jefferson Lab

- Physics motivation
- Internal target proposals and experiments
- Parameters of the setup with EIC beams

Kinematical reach



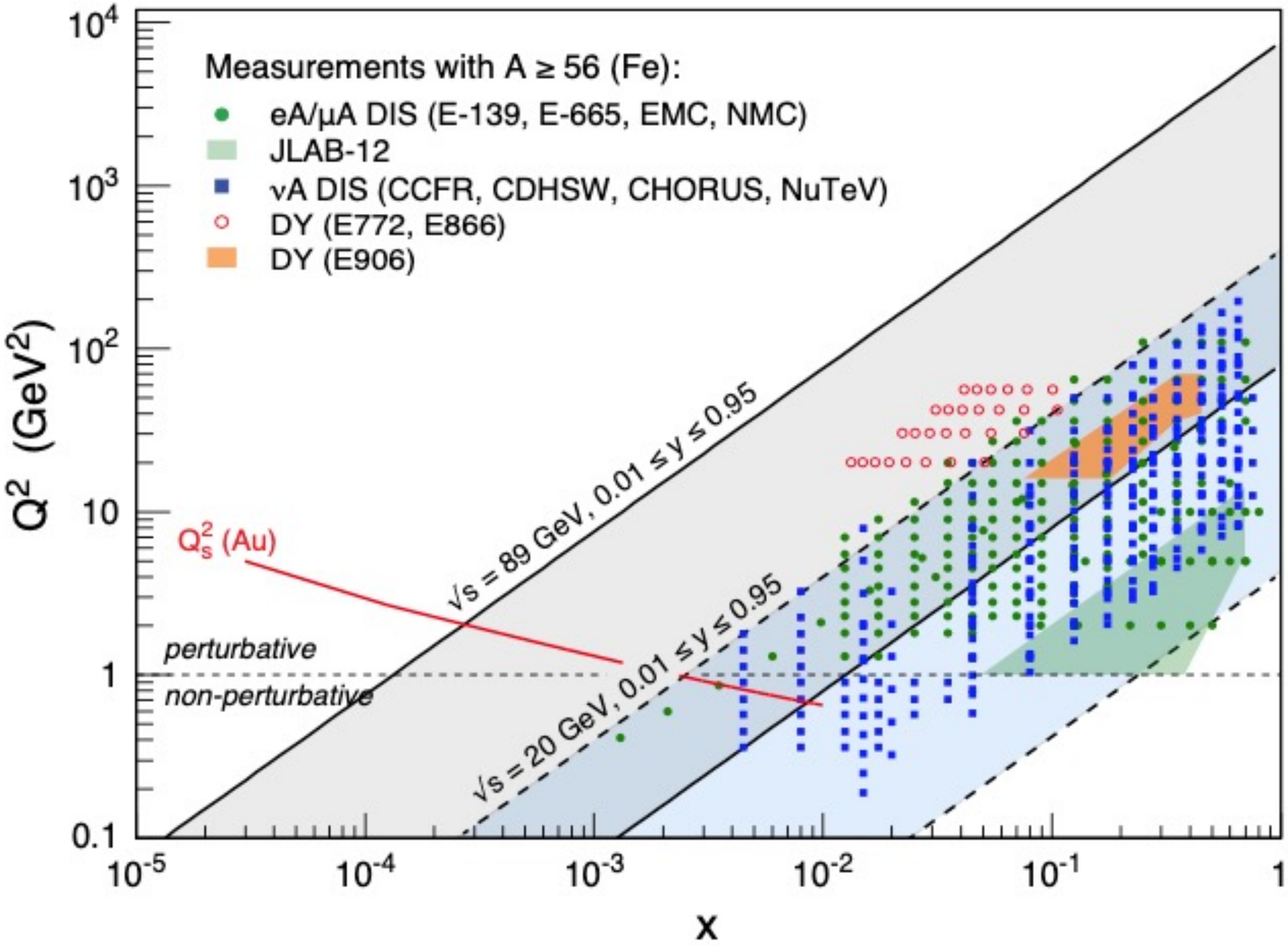


Figure 6.4: The kinematic coverage of the EIC for DIS on nuclei compared to that of previous experiments. The expected "saturation scale" $Q_s^2(x)$ for non-linear gluon dynamics in a large nucleus is indicated by a red line [40–42].

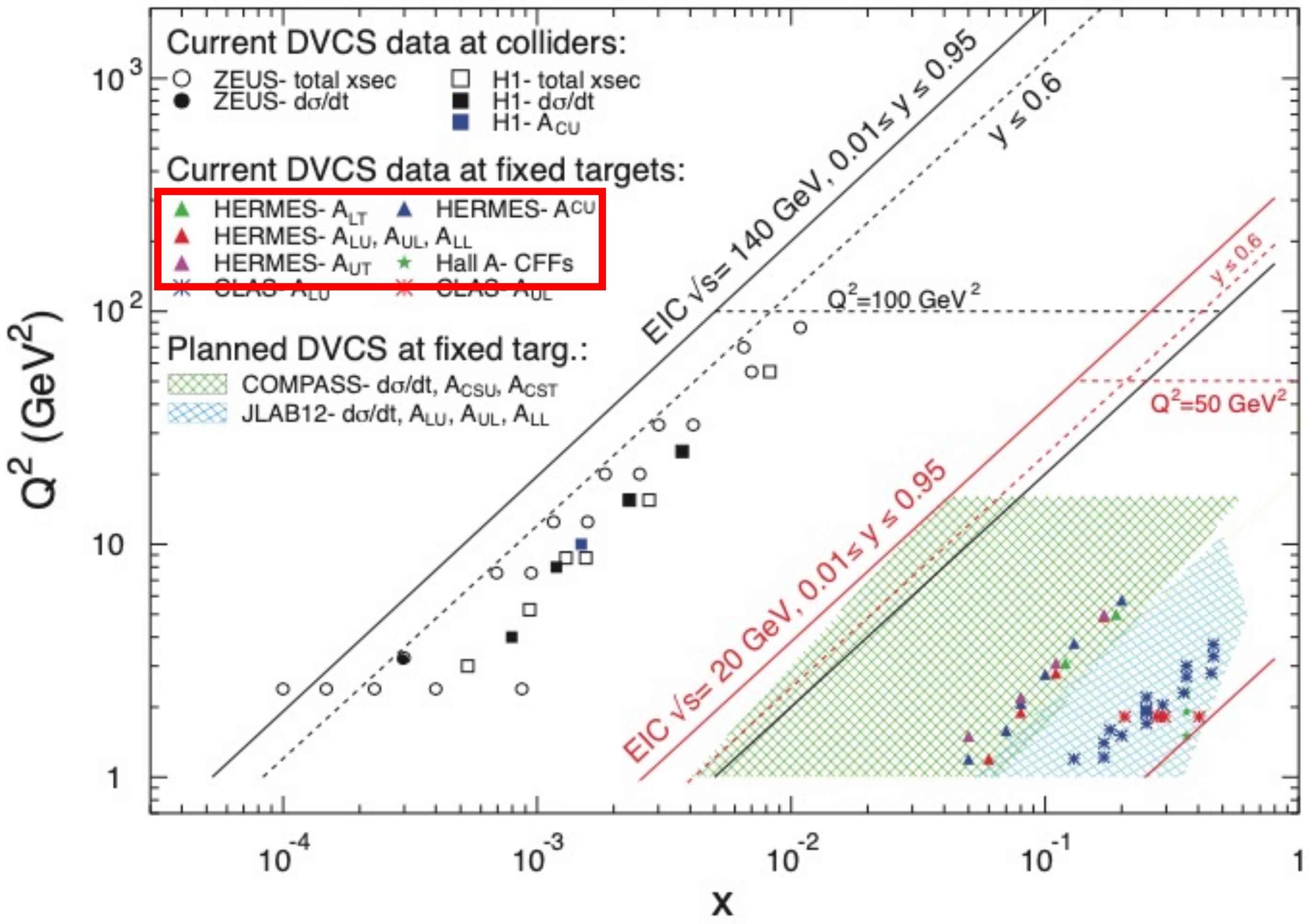
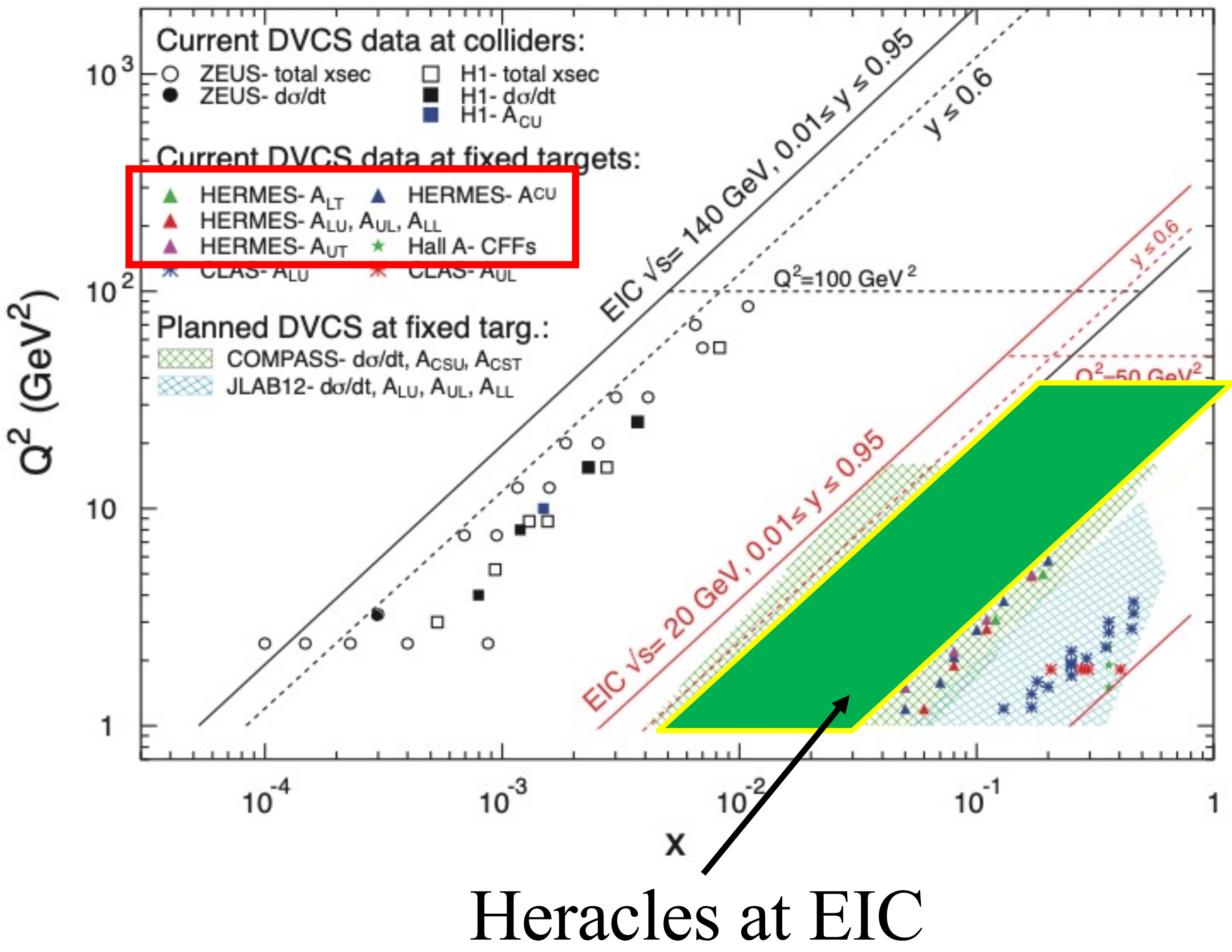
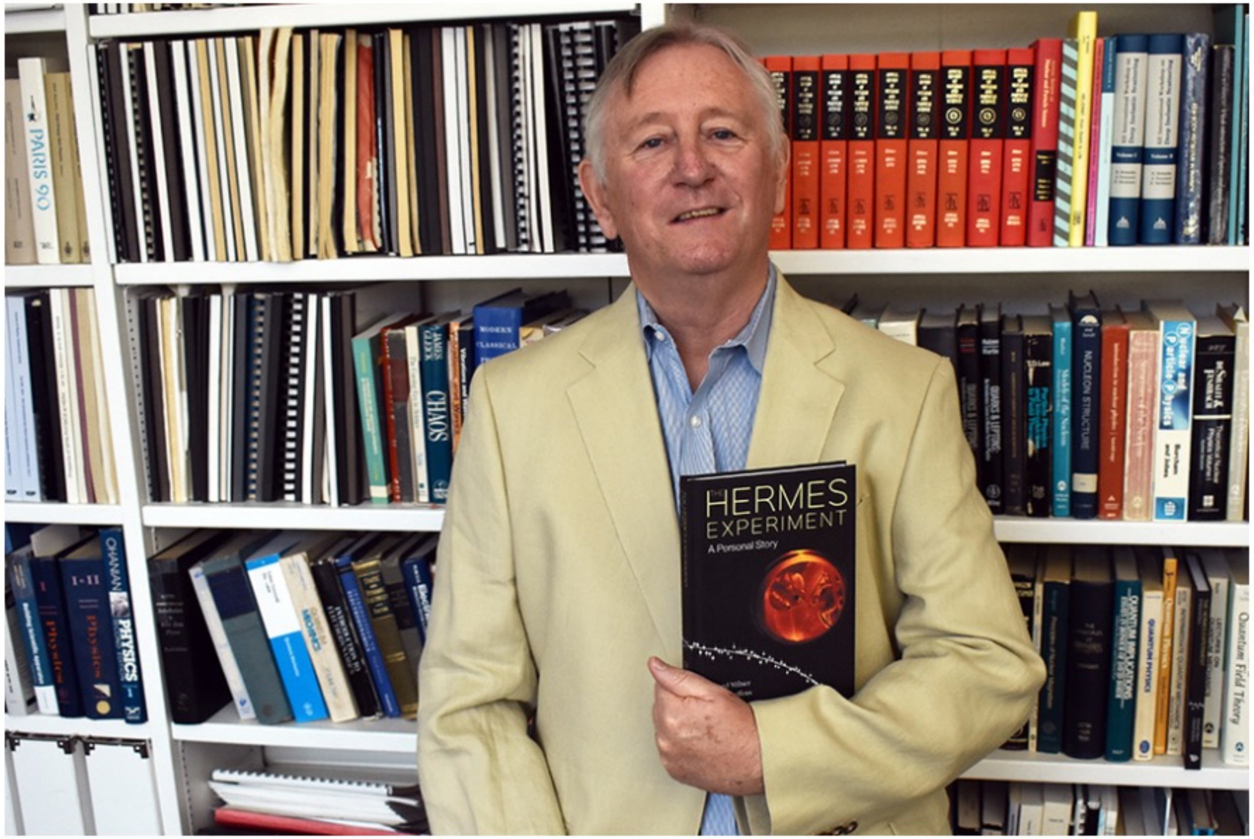


Figure 6.2: The kinematic coverage of the EIC for the DVCS process compared to other DVCS experiments.

Kinematical reach of the experiments

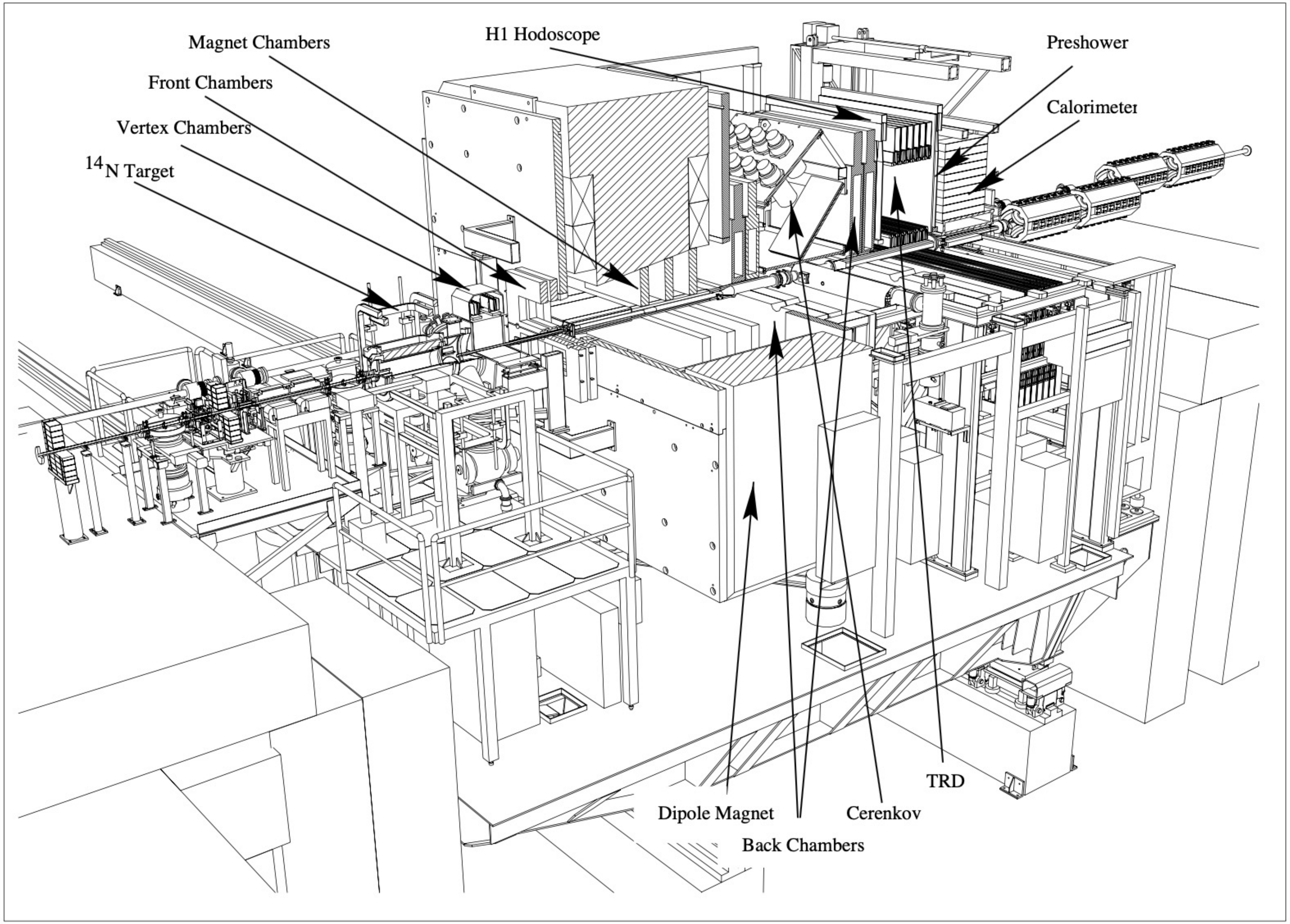


The HERMES book

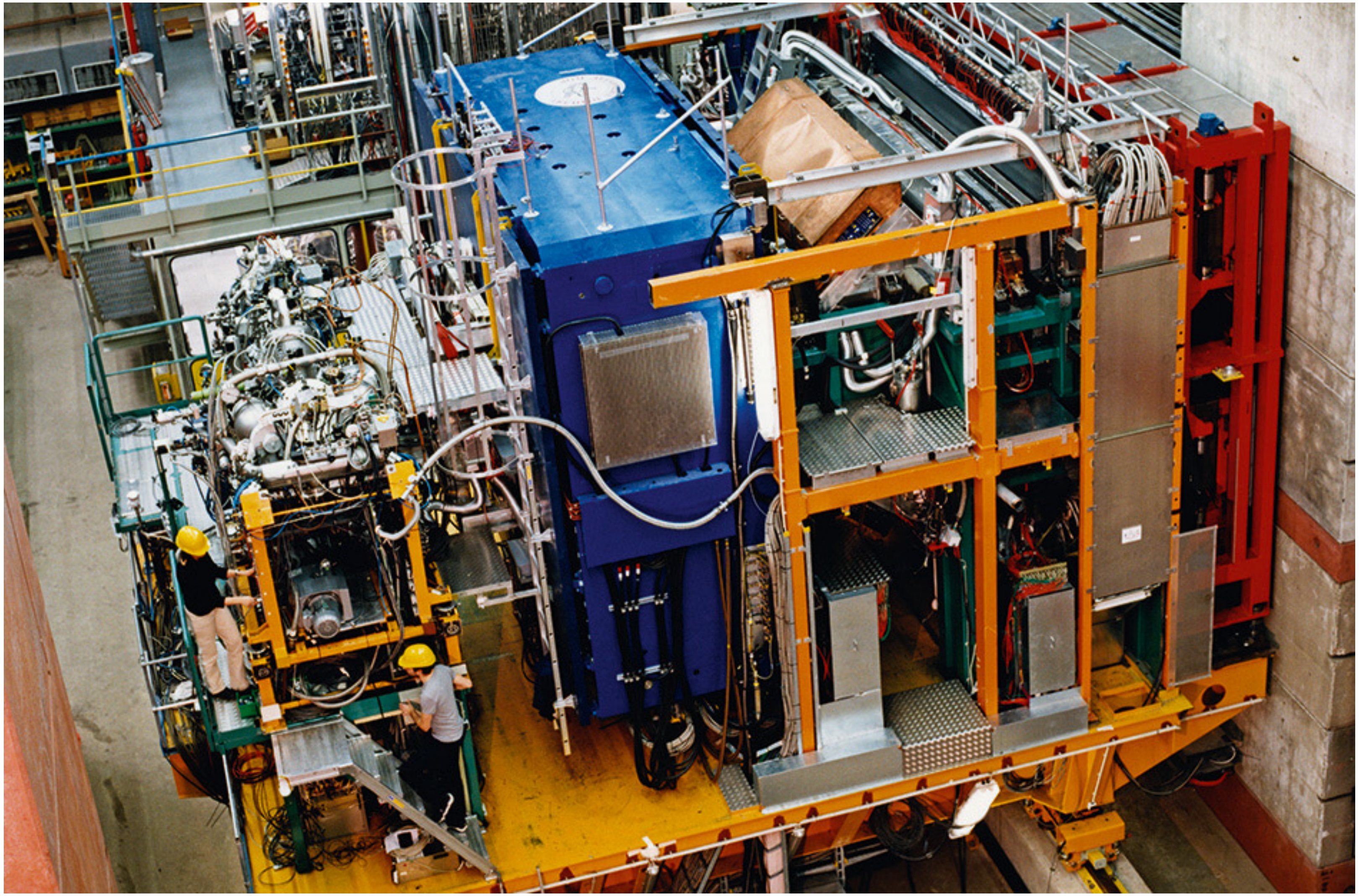


"The Hermes Experiment," a new book by MIT physics Professor Richard Milner and FAU Erlangen-Nurnberg Professor Erhard Steffens, tells the story of how several hundred physicists

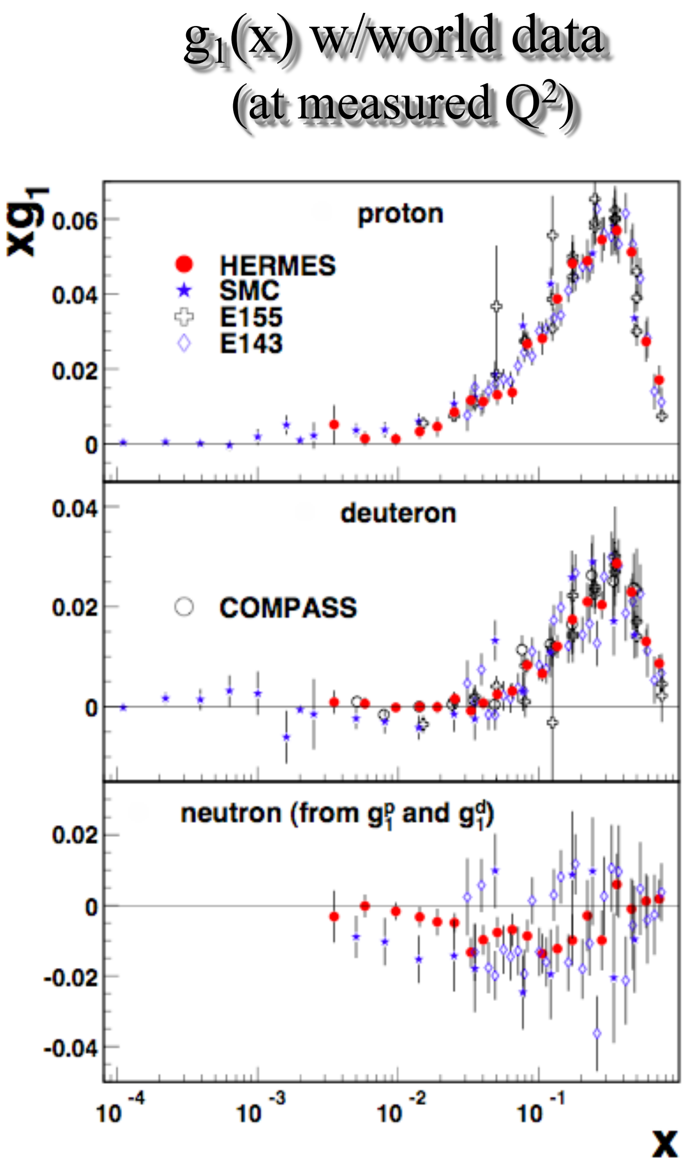
The HERMES spectrometer

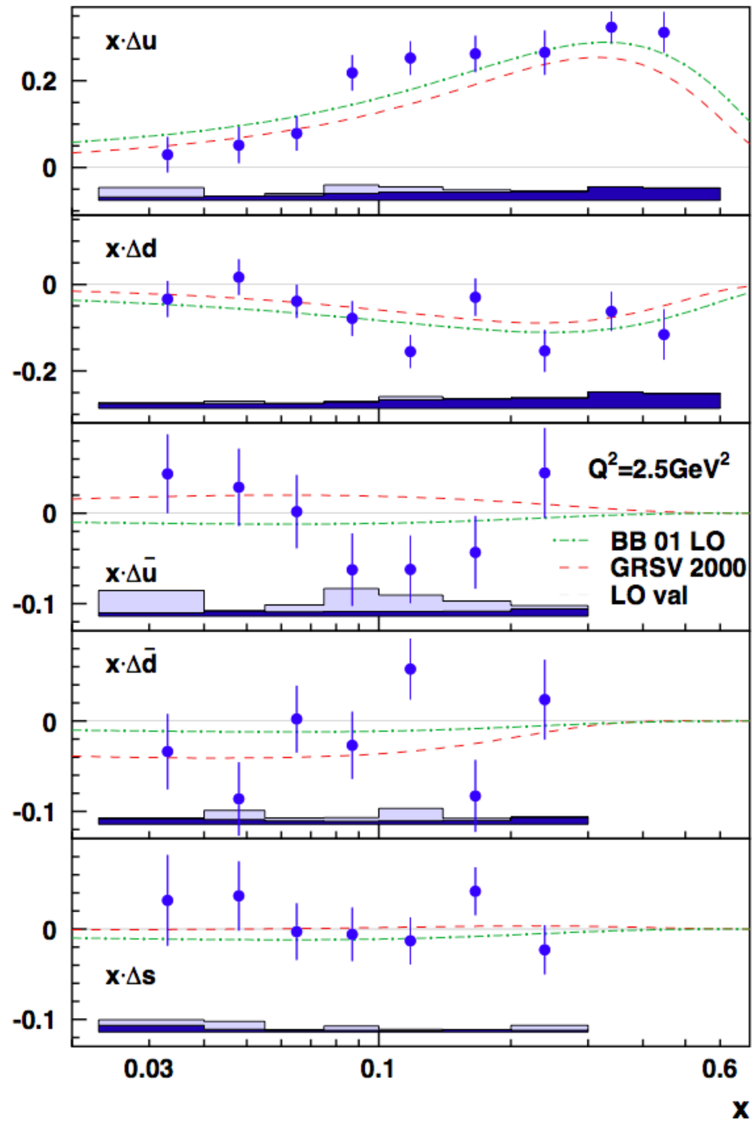


The HERMES spectrometer

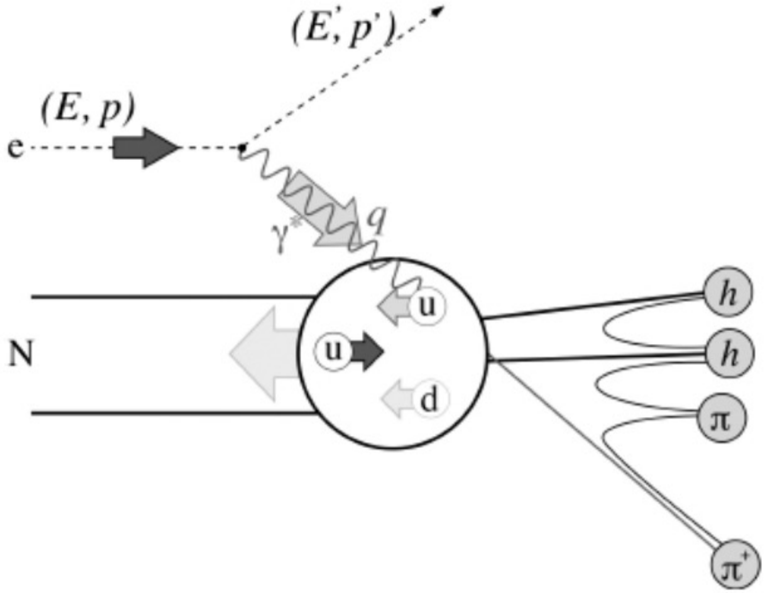


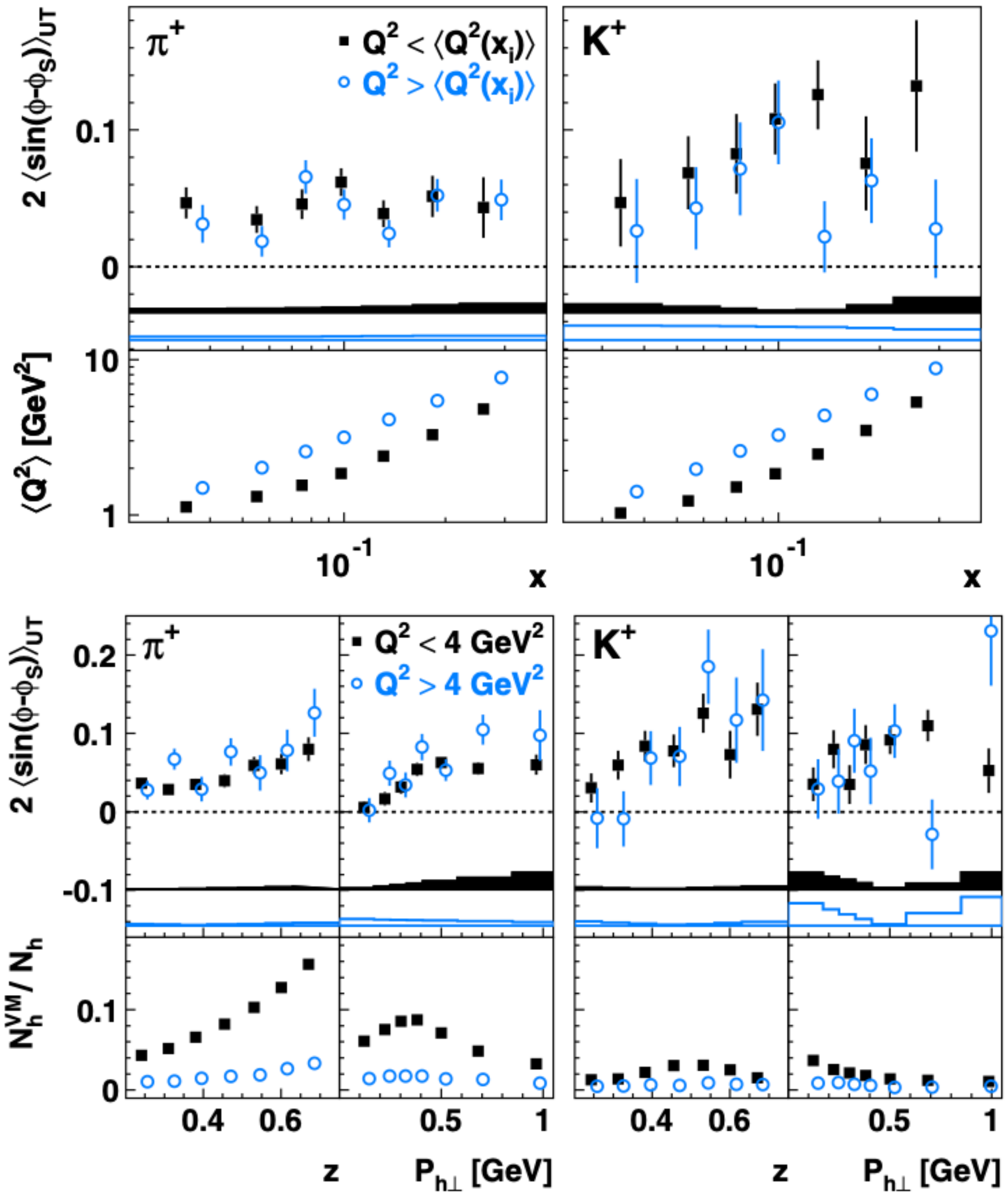
The HERMES physics results





The HERMES physics results





PEGASYS/Mark II:
A Program of Internal Target Physics
Using the Mark II Detector
at the PEP Storage Ring

III. PHYSICS EXPERIMENTS

III.A Quark Hadronization in Deep Inelastic Scattering

III.B Nuclear Transparency in Exclusive Electroproduction Reactions

III.C Azimuthal Distributions of Leading Hadrons from the Nucleon

III.D Cumulative Production; Tagged Structure Functions

III.E Study of Inelastic and Quasi-elastic Scattering at Large x_{Bj}

III.F Nuclear Response to Deep Inelastic Scattering

III.G Inclusive Virtual Compton Scattering

III.H Exclusive Virtual Compton Scattering

III.J Precision Measurement of Internal Bremsstrahlung

III.K J/ψ Production

III.L Open Charm Production

III.M Exclusive Kaon Production from the Proton and Deuteron

III.N Search for New Particles Coupling only to Leptons

III.O Bose-Einstein Correlations in $eA \to e'\pi^\pm\pi^\pm X$

PEGASYS – A PROPOSED INTERNAL TARGET SPECTROMETER FACILITY FOR THE PEP STORAGE RING

Karl VAN BIBBER

Department of Physics, Lawrence Livermore National Laboratory, PO Box 808, L-405, Livermore, CA 94550, USA

A proposal for an internal gas-jet target and forward spectrometer for the PEP storage ring is described. The beam structure, allowable luminosity ($\mathscr{L} = 10^{33}$ cm^{-2} s^{-1} for H_2, D_2 decreasing as $Z^{-1.75}$ for nuclear targets) and energy ($E_e \leq 15$ GeV) make the ring ideal for multiparticle coincidence studies in the scaling regime, where perturbative QCD may be an apt description of some exclusive and semi-inclusive reactions.

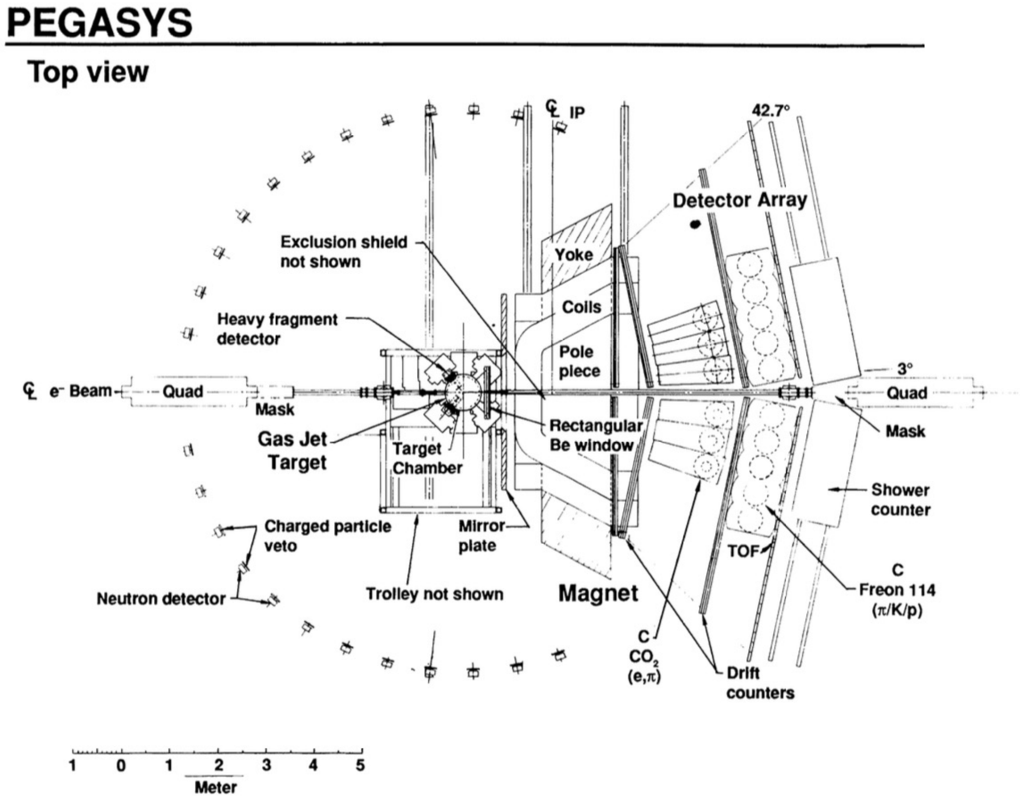
1. Introduction

The utility of storage rings for coincidence measurements, and for applications where ultrathin targets are required or are the only targets available, is well known and will not be elaborated on further [1]. An internal target facility at the PEP storage ring, PEGASYS (*PE*P *ga*s jet *s*pectrometer *sys*tem), would provide unique opportunities in the Bjorken scaling regime, and complement the programs at SLAC End Station A, the Tevatron muon facility and CEBAF in the future.

the desired storage lifetime. Fig. 1 shows that the luminosity of H_2 and D_2 may be 10^{33} cm^{-2} s^{-1} for target thicknesses of 10–20 ng/cm^2; the luminosity (in terms of *nuclear* scattering centers) decreases roughly as $Z^{-1.75}$. This luminosity results from, e.g., a 20 mA current and a 2 h beam lifetime. In practice, the time in between fills with probably be 4–12 h, but the current can be higher if running at less than full energy.

The PEP ring will continue to operate for high-energy physics (the TPC collaboration) in the intermediate term. A synchrotron radiation physics program has begun at PEP and promises long term stability for the machine.

PEGASYS project



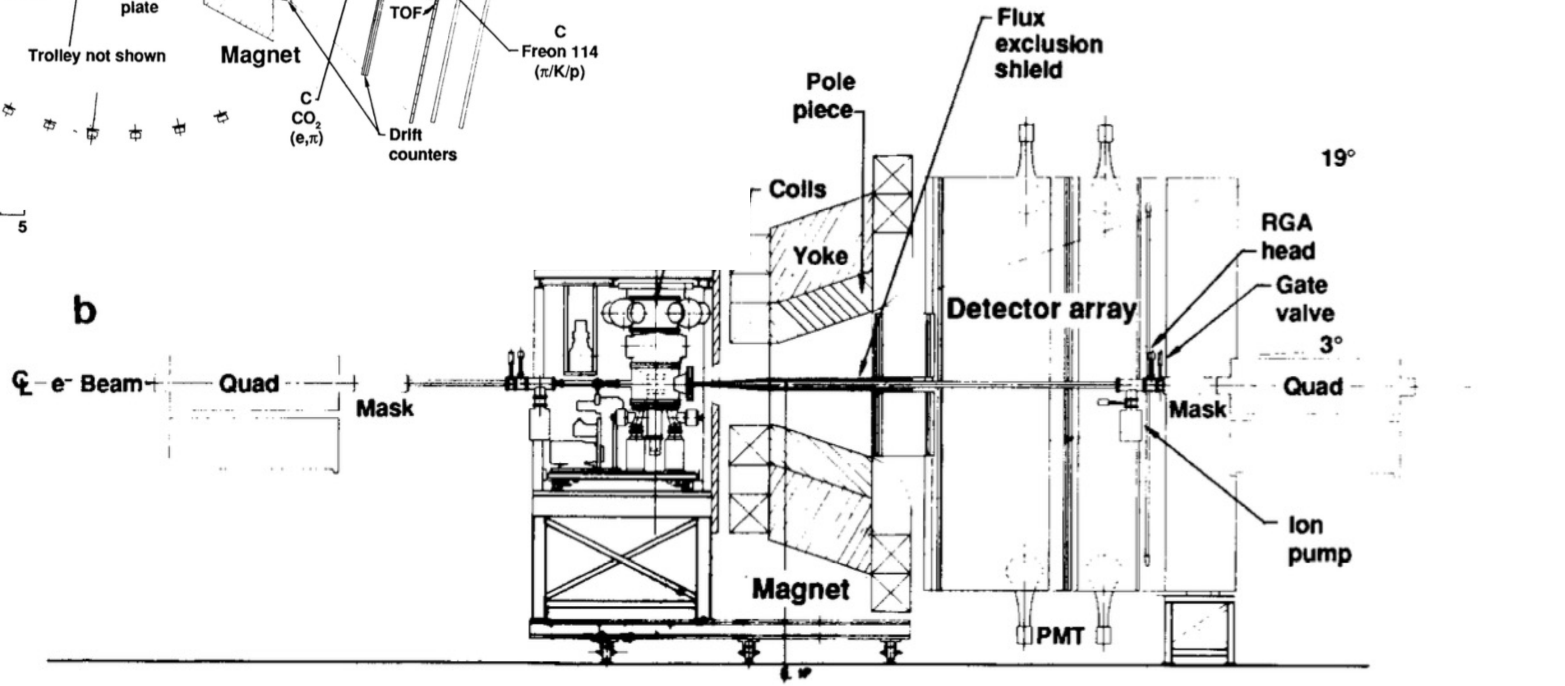
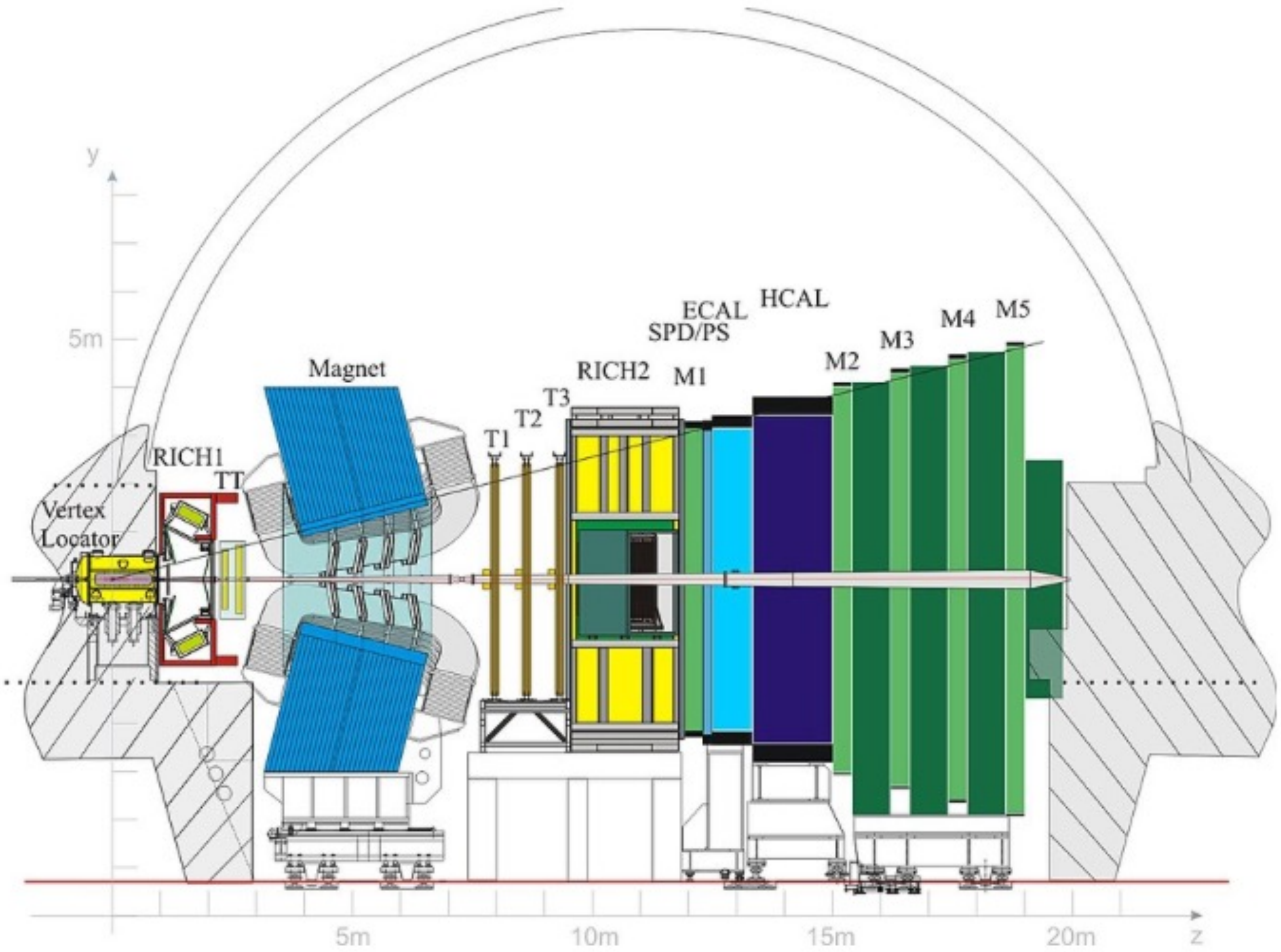


Fig. 2. Schematic top (a) and side (b) views of the proposed spectrometer and gas jet target. A shaped iron plate with a concentric soft iron pipe in its bore will occupy the spectrometer mid-plane to exclude flux from the beam path.

LHCb detector



PEGASYS cost

Project Overview

Original Proposal

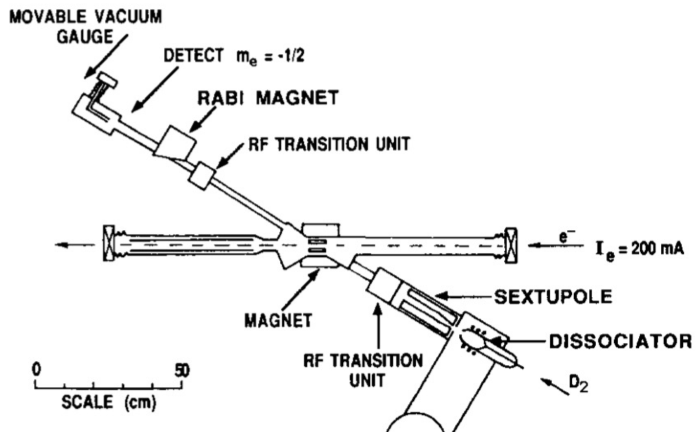
The PEGASYS Collaboration, which formed in November, 1986, proposed an experimental program to study multiparticle final states in electron deep inelastic scattering from nucleon and nuclear targets, using electrons of up to 15 GeV in the PEP storage ring. The Collaboration developed a detailed design for a facility consisting of a large-aperture forward spectrometer, a cryogenic gas jet target, and some particle detection capability at backward angles.

The capital construction costs of this facility were estimated to be approximately $15M, and would have been borne by the DOE Office of Nuclear Physics, SLAC, and the Institute for Theoretical and Experimental Physics in Moscow who would have provided the 600-ton magnet. Construction was estimated to take approximately 3 years after funding.

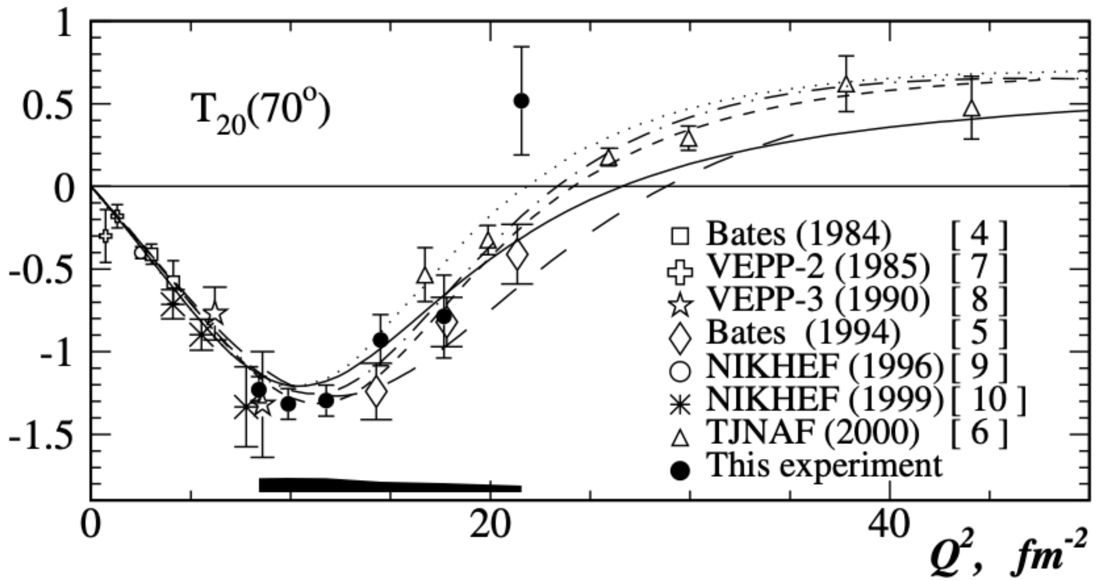
40 years later the cost could be $60M

Polarized internal target experiments at BINP

T20 team in 1986

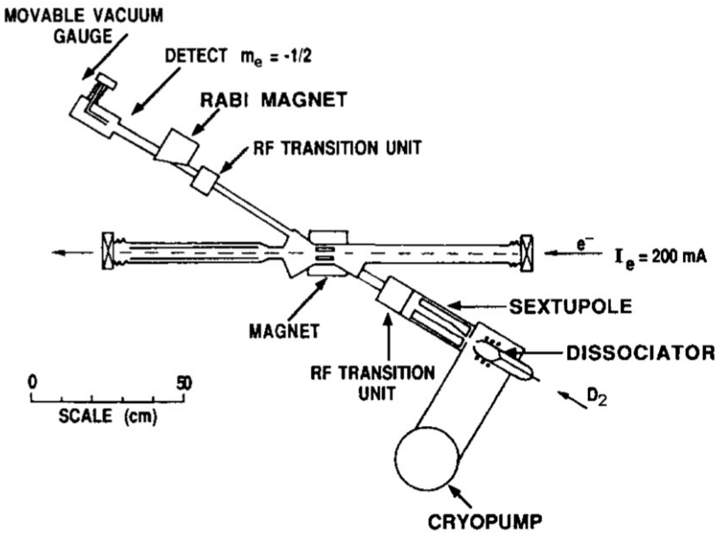


Modern developments in nuclear physics
at Novosibirsk, 1987



T20 results in 2003

Polarized internal target experiments at BINP

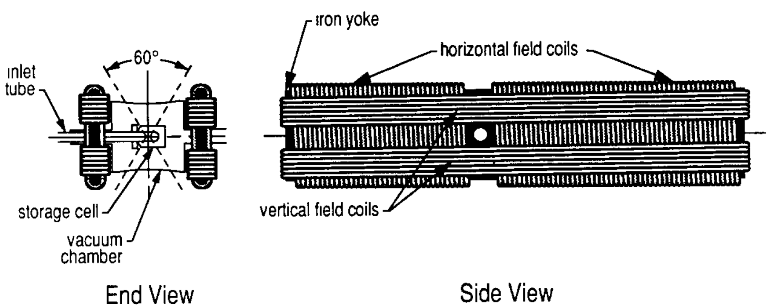


The Hamiltonian $\hat{H}$ of the interaction between the electron and nuclear magnetic moments μ_e and μ_d and the external magnetic field can be written as follows:

$$\hat{H} = \hat{H}_0 + \hat{H}_B,$$

with

$$\hat{H}_0 = A\boldsymbol{I}\cdot\boldsymbol{J} - \left(\frac{\mu_e \boldsymbol{J}}{J} + \frac{\mu_d \boldsymbol{I}}{I}\right)\cdot\boldsymbol{B}_0,$$



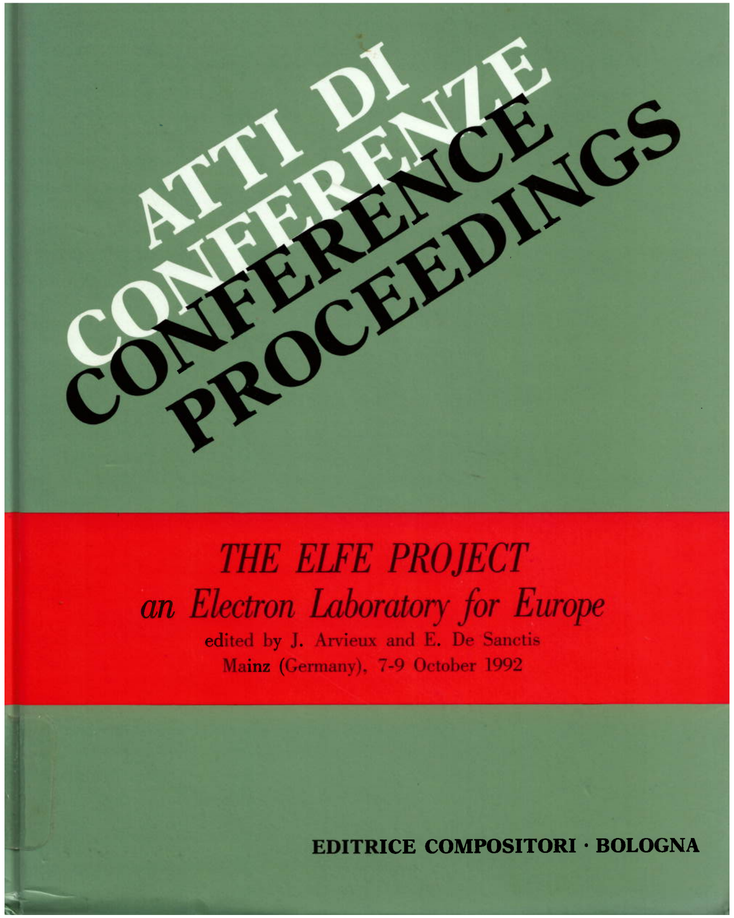
Characteristic parameters of the VEPP-3 storage ring and the BINP polarized deuterium source

VEPP-3	
Electron energy	up to 2 GeV
Bunch length	30 cm
Bunch cross section	5×1 mm
Circulation frequency	4.03 MHz
Number of bunches	1 or 2
BINP atomic beam source [a]	
Total polarized flux	1.5×10^{16} atom/s
Jet width	6 mm
Jet thickness	2×10^{11} atom/cm^2
p_{zz} for ($3\rightarrow5$ transition)	-1.07 ± 0.07
p_{zz} for ($2\rightarrow6$ transition)	1.08 ± 0.07

4.1. Depolarization by the magnetic field of bunches of electrons

The short bunches or pulses of electrons which circulate in the storage ring give rise to intense magnetic fields which are strong enough to depolarize the deuterium. The distribution of electrons in a single bunch along the direction of motion is assumed to be Gaussian in shape, with a standard deviation of 15 cm, corresponding to a pulse in time with a width of 0.5 ns, occurring at the revolution frequency of the storage ring (for 2 GeV beam energy). In the transverse directions, the bunch is approximately 5 mm (FWHM) in horizontal extent and 1 mm in vertical extent. For a typical average current of 200 mA (encountered just after the ring is filled), the corresponding current density is approximately 700 A/cm^2, and local magnetic fields as high as 50 to 100 G may be produced.

ELFE project in 1992



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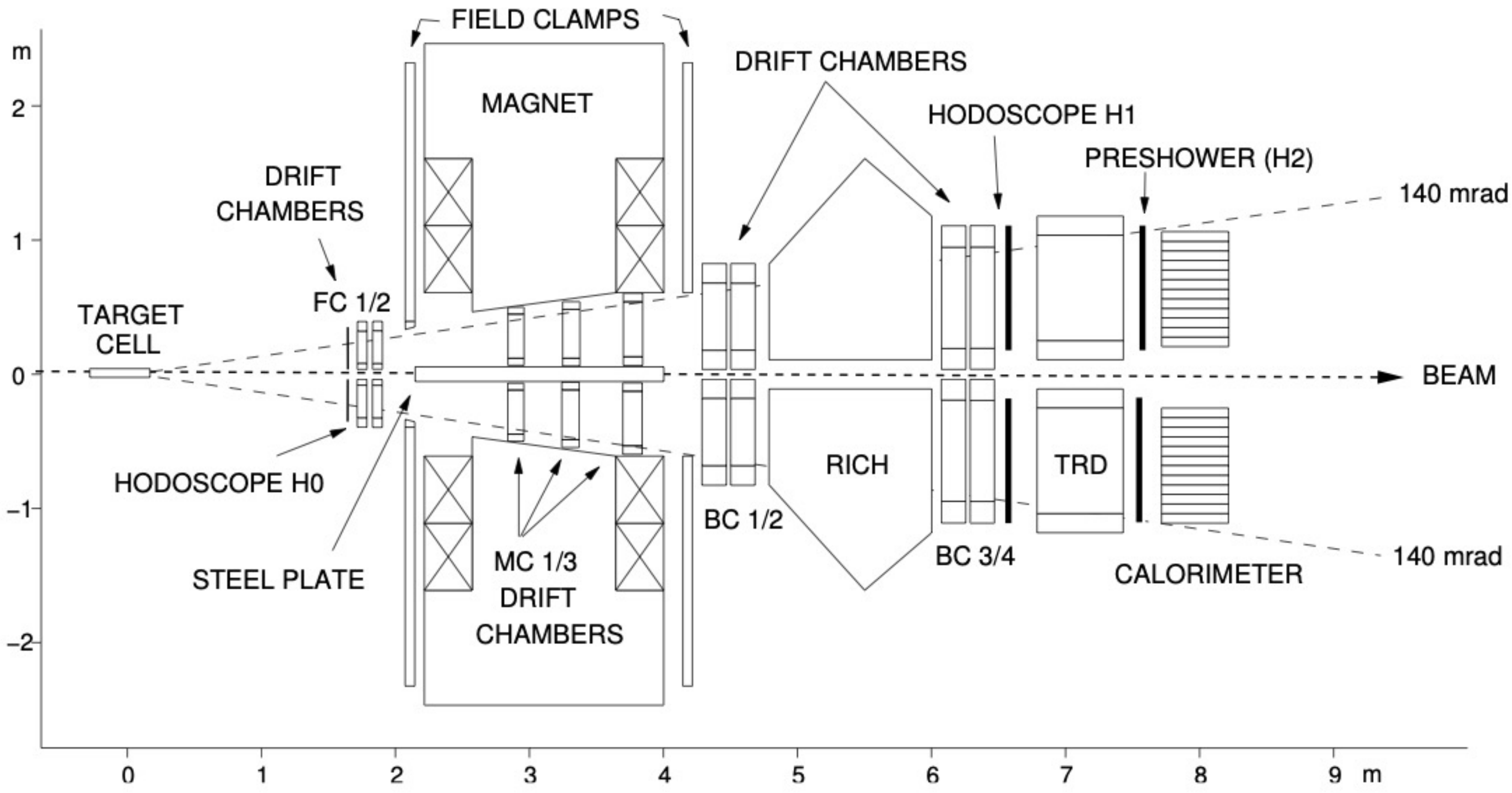
PAX detector



The Electron-Ion Collider – Accelerator Design Overview

Andrei Seryi
Associate Director for Accelerator Systems and International Partnership

2021 EIC UG Meeting Early Career Workshop

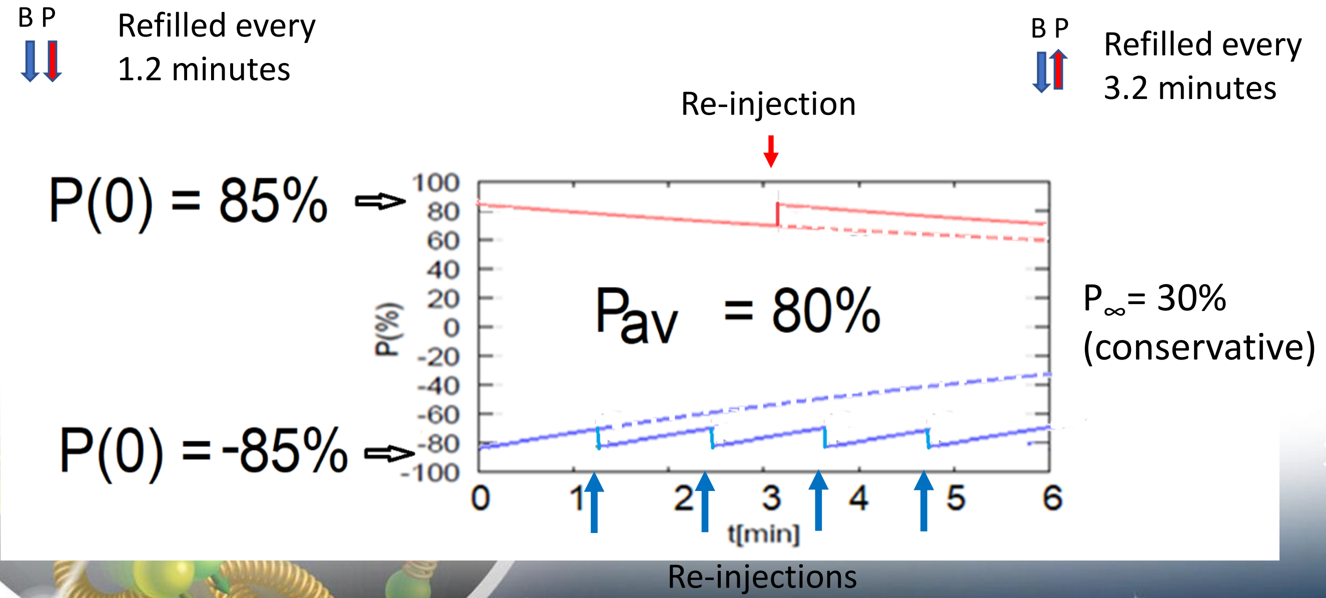
29 July 2021

Electron-Ion Collider

BROOKHAVEN NATIONAL LABORATORY · Jefferson Lab · U.S. DEPARTMENT OF ENERGY | Office of Science

High average polarization at electron storage ring of 80% by

- Frequent injection of bunches on energy with high initial polarization of 85%
- Initial polarization decays towards P_∞ < ~50%
  (equilibrium of self-polarization and stochastic excitation)
- At 18 GeV, every bunch is refreshed within minutes with RCS cycling rate of 2Hz
- Need both polarization directions present at the same time



Electron-Ion Collider

The HERMES at EIC (Heracles)

Physics: polarized TDIS, SIDIS, and DVCS, and more

Detector like HERMES with GEM-based trackers +

Luminosity will be up to a few 10^{35} /cm^2/s

Highly polarized proton, deuteron and He-3 atoms,
including transverse polarized and unique case
of tensor polarized deuteron

Heracles parameters vs. HERMES

EIC beam energy: E:	18 GeV vs. 27.5 GeV
EIC beam intensity, I_b:	2500 mA (at 10 GeV) vs. 25 mA
	227 mA (at 18 GeV)
EIC beam polarization, P_b:	80% vs. 40%
Target thickness, t_t :	25 larger than at HERA (thanks to pol. e- injection)
Target polarization, P_t:	the same high as at HERMES

Internal target will have luminosity $L_{at\ EIC} \sim 3 \times 10^{35}\ /cm^2/s$

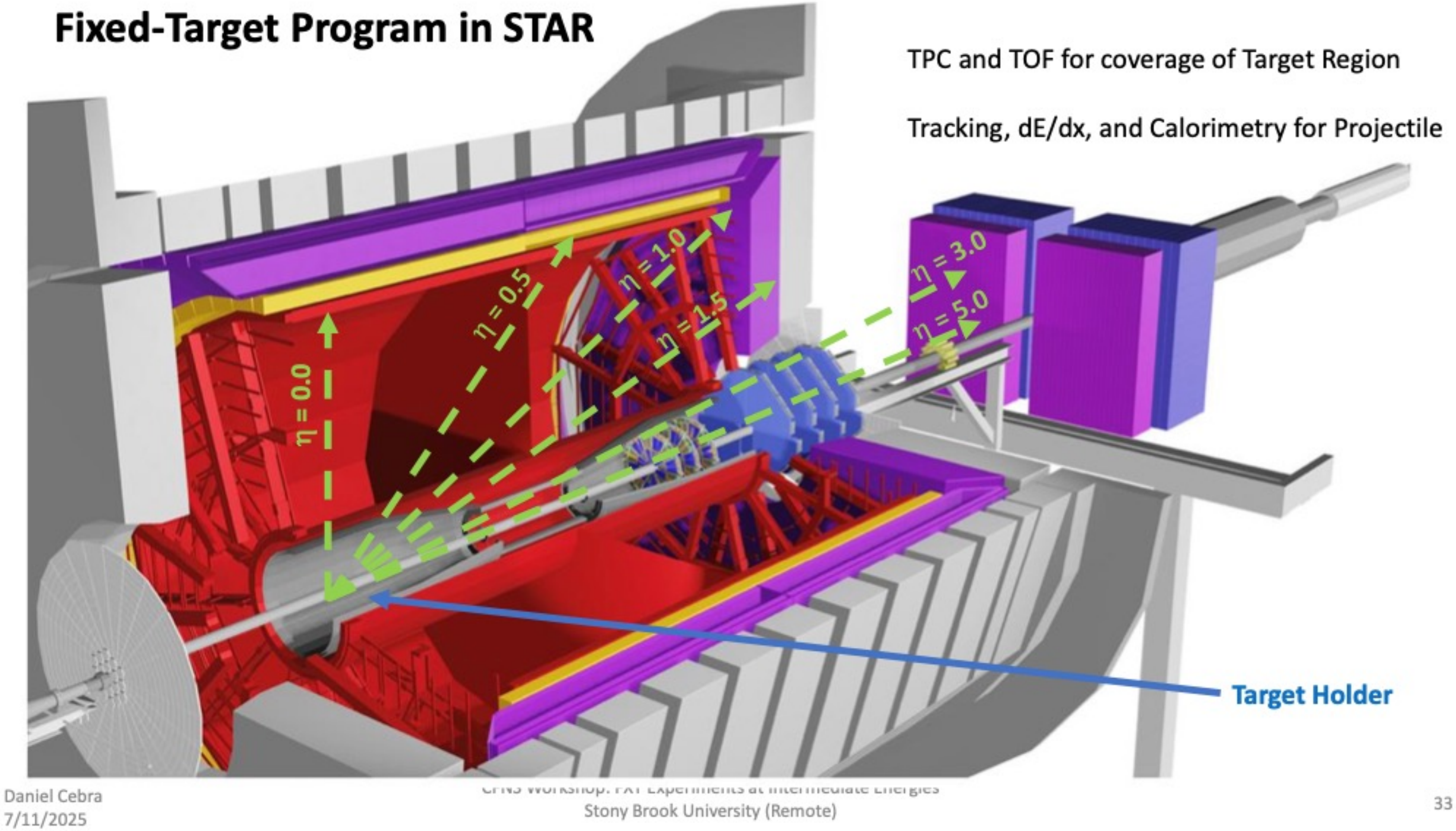
The experiment FOM gain: ($I_b \times t_t \times P_b{}^2 \times P_t{}^2$): ~ (10-100) x 25 x 4 x 1

A factor of 500+ larger FOM opens a field for many advances in hadron physics

Comparison of Luminosity / FOM

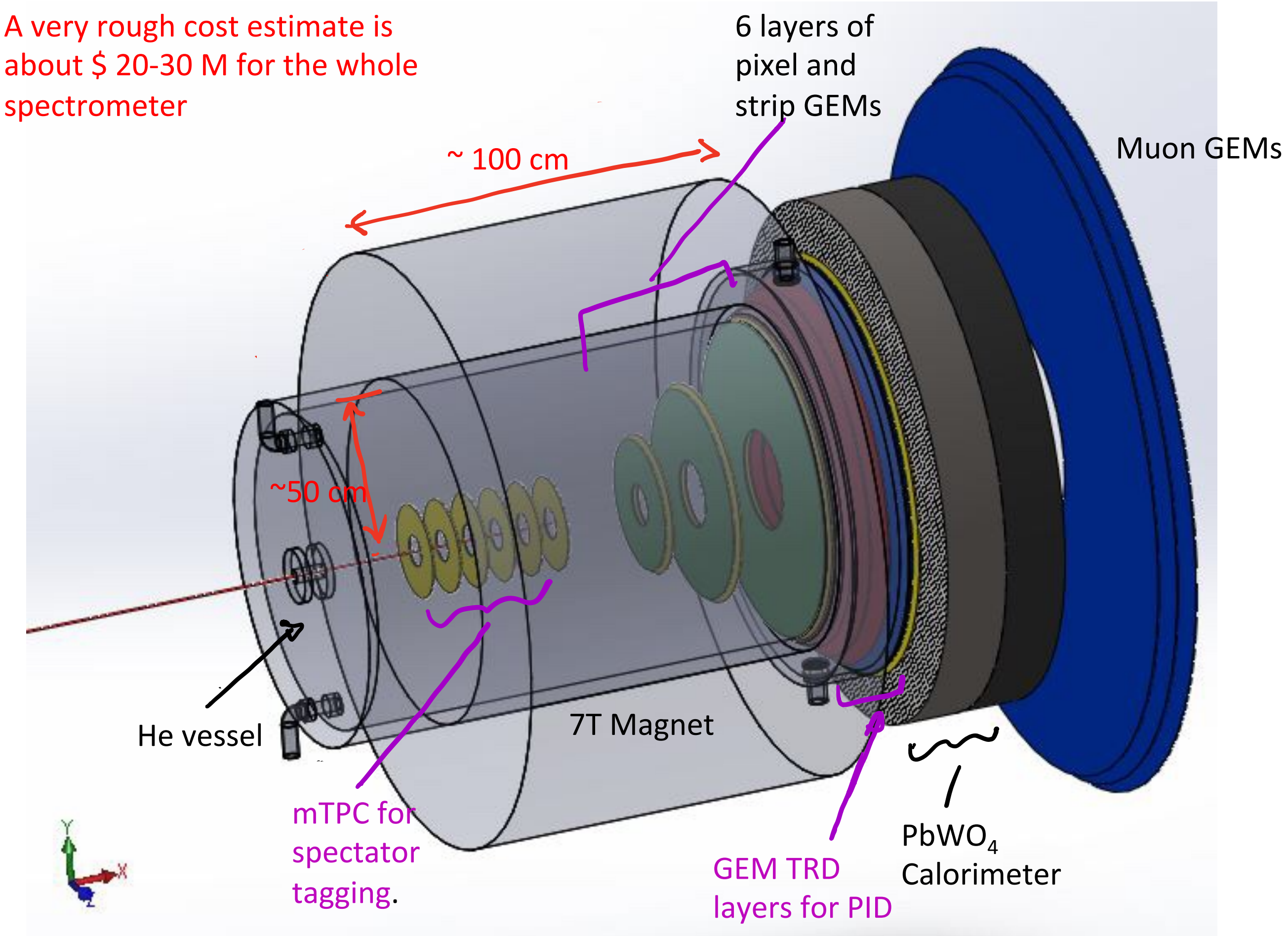
	HERMES, 22 GeV	EIC, 10 /18 GeV	JLab, 12 GeV
Beam current	25 mA	2500 / 227 mA	External target
Luminosity He-3	3×10^{32}	3×10^{35} (18 GeV)	3×10^{36}
Luminosity H,D photo-chem. CH	3×10^{31}	3×10^{33} (18 GeV) 3×10^{34}	5×10^{33} (FOM)

BNL detector with the internal target

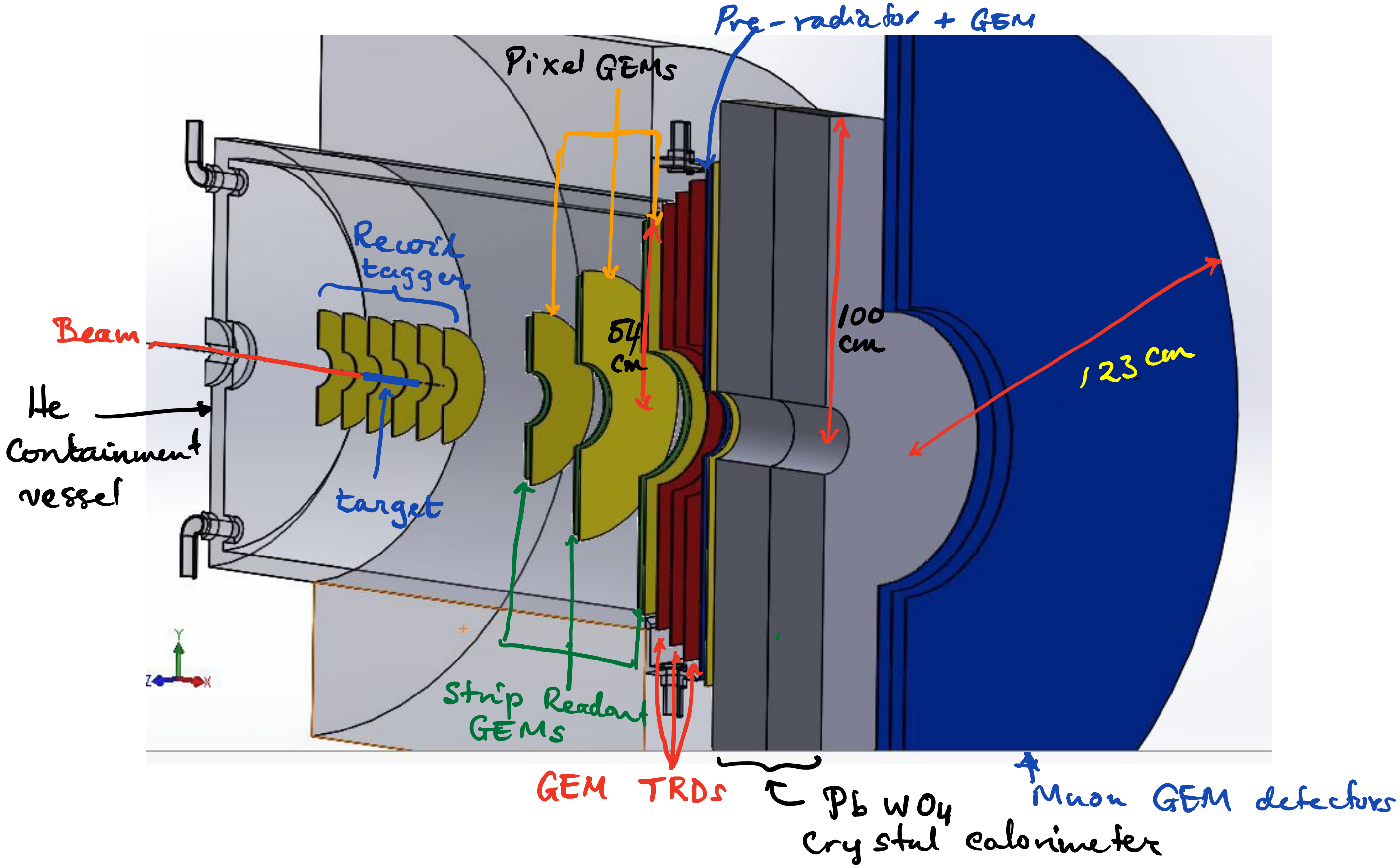


The concept of a new spectrometer

Nilanga Liyanage, Paul Souder, Weizhi Xiong

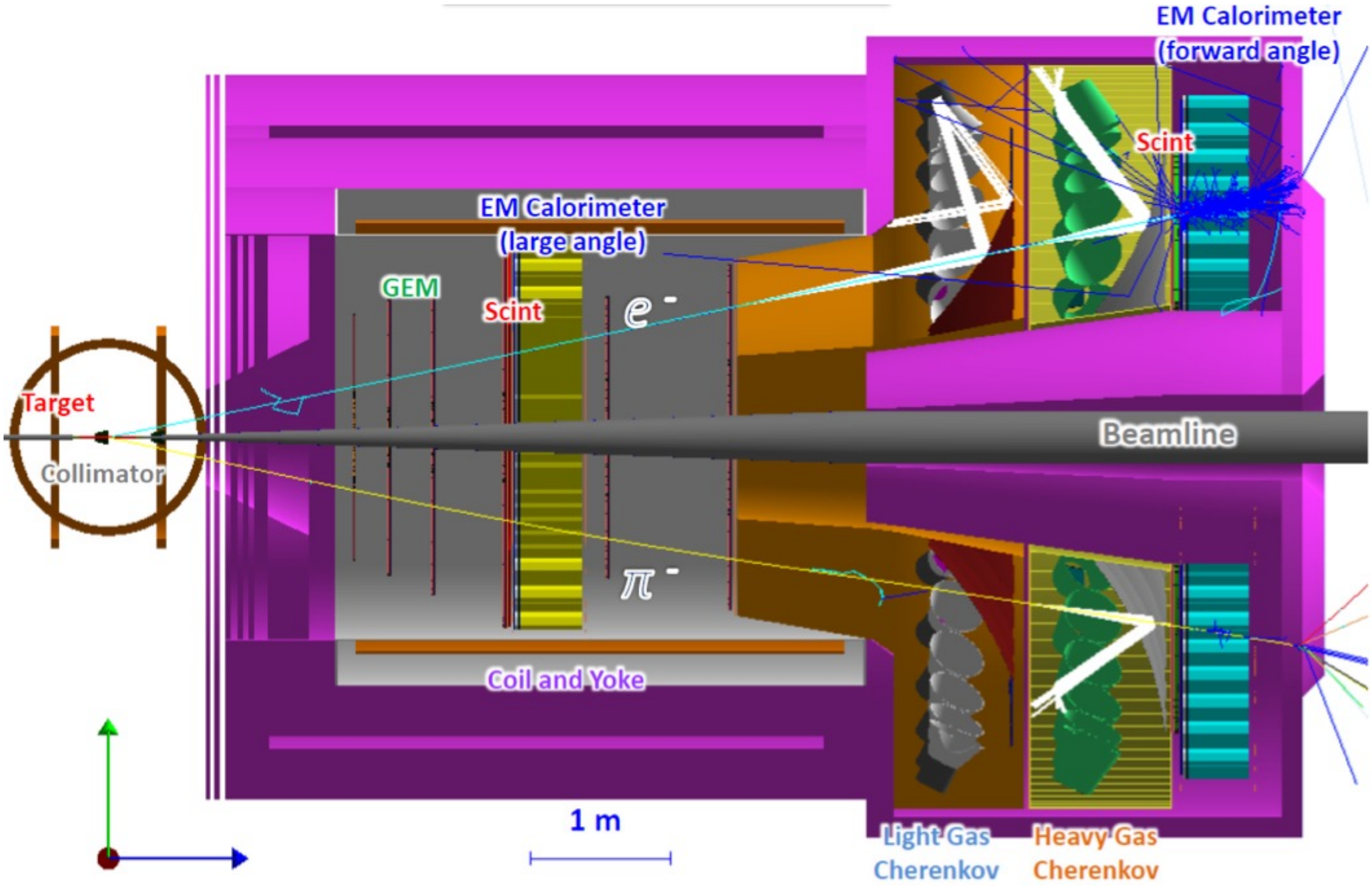


The concept of a new spectrometer



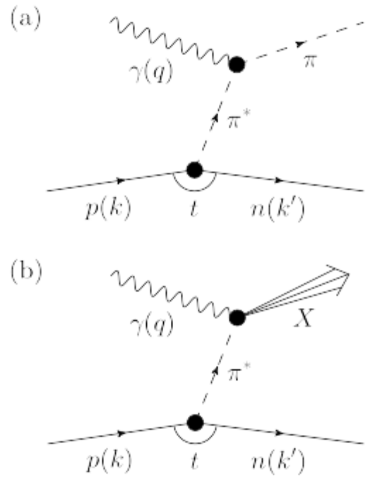
- Charged particle coverage from 12° to 36°.
- E/M calorimeter coverage from 5° to 36°.
- Pixel GEM and strip GEM layer pairs: Pixel GEM for detecting the track, strip GEM for high precision coordinate determination
- High time res. electronics to match the hits from the two layers.

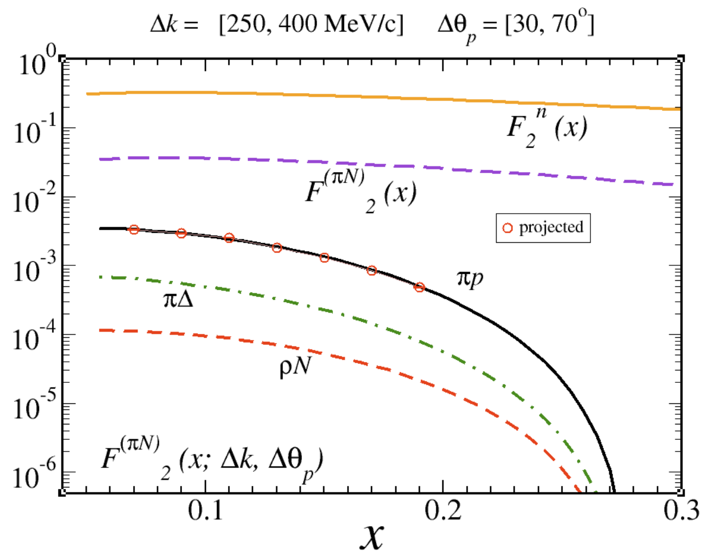
SoLID - spectrometer for JLab

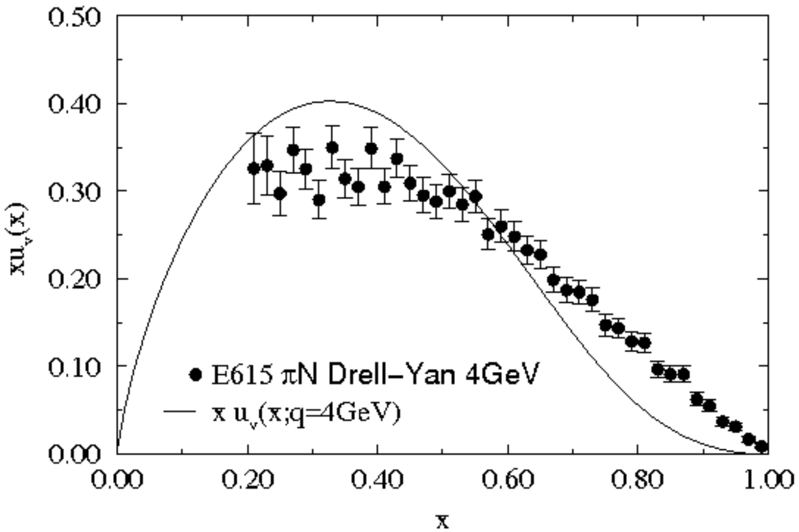


The HERMES at EIC (Heracles)

Physics: polarized T(aged)DIS,
Plots: JLab experiment C12-15-006
and C. Roberts' papers







The high energy photon beam for the external polarized target

- Laser back-scattering (like LEGS, GRALL, LEPS)
  tagged, polarized photons up to ~ 8 GeV

- Radiation from a thin internal target
  tagged, circular polarized photons, up to 18 GeV

- Apollon proposal at DESY

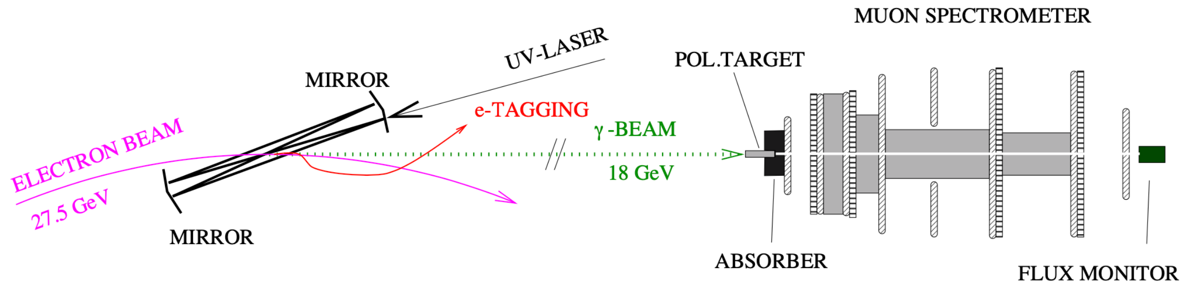


Figure 4: The basic layout of the APOLLON experiment. A laser beam is brought into collision with the HERA electron beam. The Compton backscattered high energy photons produce J/ψ mesons in a polarized target. The energy of the photons is selected by tagging the recoil electrons.

The double polarized proton-proton interaction

EIC project requirements

The EIC is a Nuclear Physics Collider Designed to meet NSAC and NAS requirements

- Collide polarized electrons and wide range of hadrons
  - Polarized protons and deuterons, otherwise unpolarized
  - In long term, possibly polarized positrons, ^{3}He
- Center of Mass Energies — 20 GeV – 140 GeV
- Maximum Luminosity — 10^{34} cm^{-2} s^{-1}
- Hadron Beam Polarization — >70%
- Electron Beam Polarization — >70%
- Ion Species Range — p to Uranium
- Number of interaction regions — up to two

Beam current 0.69 Ampere,
Luminosity is on the level of a few 10^{35}

NSAC – U.S. Department of Energy Nuclear Science Advisory Committee
NAS – U.S. National Academies of Sciences, Engineering, and Medicine

10

Electron-Ion Collider

Summary

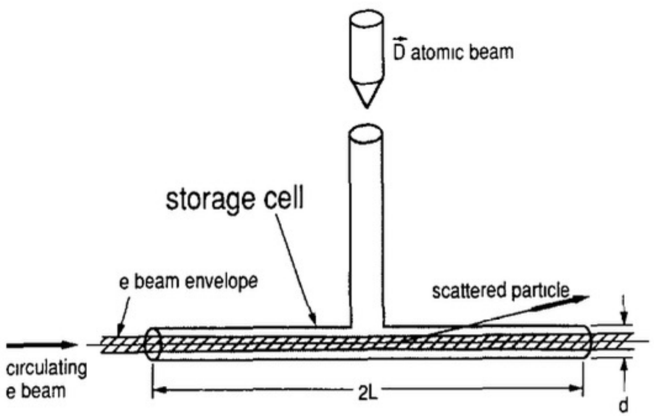
The beams of EIC provide excellent opportunities for double polarized hadron physics experiments, e.g. with high intensity 18 GeV polarized electron beam.

They could be used for the fixed target experiments similar to HERMES with 500x higher productivity, also for the tagged photon beam and more.

Heracles target impact on beam life time

Target areal density ~ 10^{14} protons/cm^2 should be compared with one due to overall vacuum 10^{-8} Torr in 3 km long ring => 10^{14} leads to 30 h life time much longer than beam replacement time (2.4 minutes). With 25 times larger areal density will be 1 hour life time.

The straight section allows
1.5 m long cell



areal density $t \propto L^2/d^3$

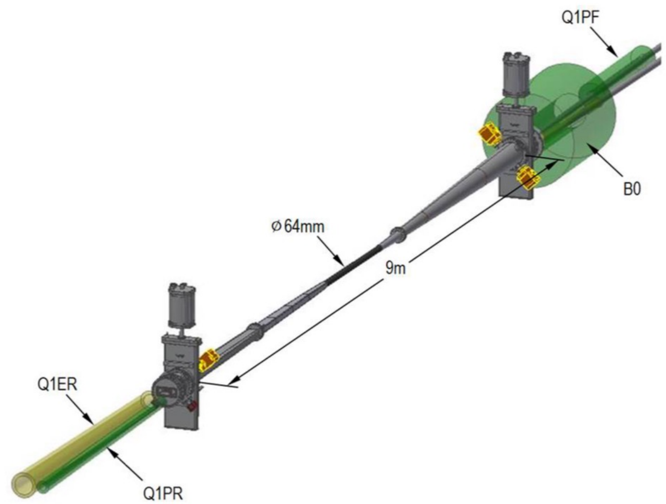


Figure 3.22: Interaction region layout with magnets. The incorporation of gate valves is still under consideration

Heracles parameters vs. other

Internal target will have luminosity $L_{at\ EIC} \sim 3 \times 10^{35}$ e-n/cm^2/s

The experiment FOM gain: ($I_b \times t_t \times P_b{}^2 \times P_t{}^2$): ~ (10-100) x 25 x 4 x 1

A factor of 500+ larger FOM opens a field for many advances in hadron physics

Compare, the polarized NH3 target which is capable to operate at $L \sim 2 \times 10^{35}$ e-nucleon/cm^2/s. However, the dilution factor is of 6, so the FOM (5×10^{33}) is similar to Heracles at 10 GeV.

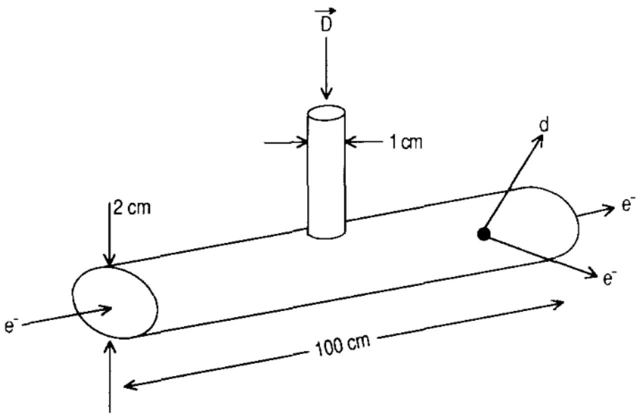
Beam induced target depolarization

Nuclear Instruments and Methods in Physics Research A327 (1993) 277–286
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

A polarized gas internal target using a storage cell in an electron storage ring

R. Gilman [a,1], R.J. Holt [a], E.R. Kinney [a,2], R.S. Kowalczyk [a], J. Napolitano [a,3], A.W. Nikitin [b,4], D.M. Nikolenko [b], S.G. Popov [b], D.H. Potterveld [a], I.A. Rachek [b], D.K. Toporkov [b], E.P. Tsentalovich [b], B.B. Wojtsekhowski [b] and L. Young [a]



Estimate: a 0.6-cm-long EIC beam bunch requires the target holding field of 5 kG

An estimate of the depolarizing transition probability P_t of the passing of a single electron pulse through the target, using perturbation theory, gives (for $|\boldsymbol{B}_0| \gg B_c \approx 117$ G, the critical field of deuterium)

$$P_t \approx \left(\frac{\mu_e B \tau}{\hbar}\right)^2 f(\eta)$$

$$\approx \left(\frac{\mu_e I_{av} T}{\hbar r_{av}}\right)^2 f(\eta).$$

For electron spin-flip transitions

$$f(\eta) = e^{-(E_{if}\tau/\hbar)^2} |\langle f | \hat{\boldsymbol{J}} \cdot \hat{\boldsymbol{B}} | i \rangle|^2,$$

which for deuterium is approximately $\exp(-(2\eta\tau)^2)$.

$$\eta = B_0/B_c$$