Jefferson Lab
Thomas Jefferson National Accelerator Facility

Super Bigbite experiments

Bogdan Wojtsekhowski, Jefferson Lab

Composite structure of the nucleon

O.Stern,1937

The magnetic moment of the proton was measured by the method of the magnetic deflection of molecular beams employing H_2 and HD. The result is $\mu P=2.46\mu_0 \pm 3$ *percent.*

PHYSICAL REVIEW VOLUME 72, NUMBER 12 DECEMBER 15, 1947

On the Interaction Between Neutrons and Electrons*

E. Fermi and L. Marshall
Argonne National Laboratory and Institute for Nuclear Studies, University of Chicago, Chicago, Illinois

(Received September 2, 1947)

The possible existence of a potential interaction between neutron and electron has been investigated by examining the asymmetry of thermal neutron scattering from xenon. It has been found that the scattering in the center-of-gravity system shows exceedingly little asymmetry. By assuming an interaction of a range equal to the classical electron radius, the depth of the potential well has been found to be 300±5000 ev. This result is compared with estimates based on the mesotron theory according to which the depth should be 12000 ev. It is concluded that the interaction is not larger than that expected from the mesotron theory; that, however, no definite contradiction of the mesotron theory can be drawn at present, partly because of the possibility that the experimental error may have been underestimated, and partly because of the indefiniteness of the theories which makes the theoretical estimate uncertain.

INTRODUCTION

THE purpose of this paper is to investigate an interaction between neutrons and electrons due to the possible existence of a short range potential between the two particles. If such a short range force should exist, one would expect some evidence of it in the scattering of neutrons by atoms. The scattering of neutrons by an atom is mostly due to an interaction of the of nuclear forces. According to these theories, proton and neutron are basically two states of the same particle, the nucleon. A neutron can transform into a proton according to the reaction:

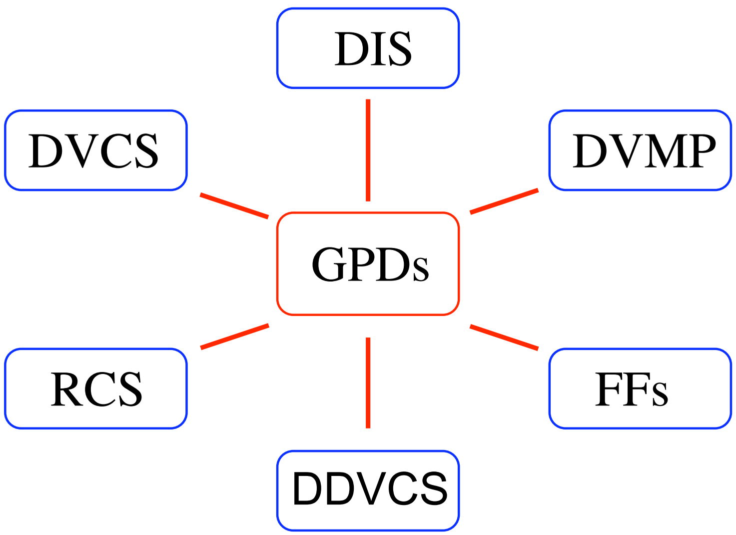
$$N=P+\bar{\mu}. \qquad (1)$$

(N=neutron, P=proton, $\bar{\mu}$=negative mesotron)

Actually, a neutron will spend a fraction of its time as neutron proper (left-hand side of Eq. (1))

E.Fermi,1947

The nucleon structure in terms of GPDs



Reduction formulas at $\xi = t = 0$
for DIS and $\xi = 0$ for FFs

$$H^q(x, \xi = 0, t = 0) = q(x)$$

$$\tilde{H}^q(x, \xi = 0, t = 0) = \Delta q(x)$$

$$\int_{-1}^{+1} dx\, H^q(x, 0, Q^2) = F_1^q(Q^2)$$

$$\int_{-1}^{+1} dx\, E^q(x, 0, Q^2) = F_2^q(Q^2)$$

Experimental Program

- SBS Nucleon FF program will provide precision results up to:

  G^p_E @ 12 GeV^2

  G^n_E @ 10 GeV^2

  G^n_M @ 13.5 GeV^2

Experimental Program

- SBS Nucleon FF program will provide precision results up to:

  G^p_E @ 12 GeV^2

  G^n_E @ 10 GeV^2 75% done

  G^n_M @ 13.5 GeV^2 done

done | in the provisional schedule

- Other items include: nTPE; Pion ALL/KLL; GEn-RP;

approved | new ideas

move to Hall C => SIDIS; TDIS; DVCS; g2p; pDVCS; …

Experimental Program

- SBS Nucleon FF program will provide precision results up to:

  G^p_E @ 12 GeV^2

  ✓ G^n_E @ 10 GeV^2 (g1/g2 as a byproduct)

  ✓ G^n_M @ 13.5 GeV^2

  ✓ | in the provisional schedule

- Other items include: nTPE; Pion ALL/KLL; GEn-RP;

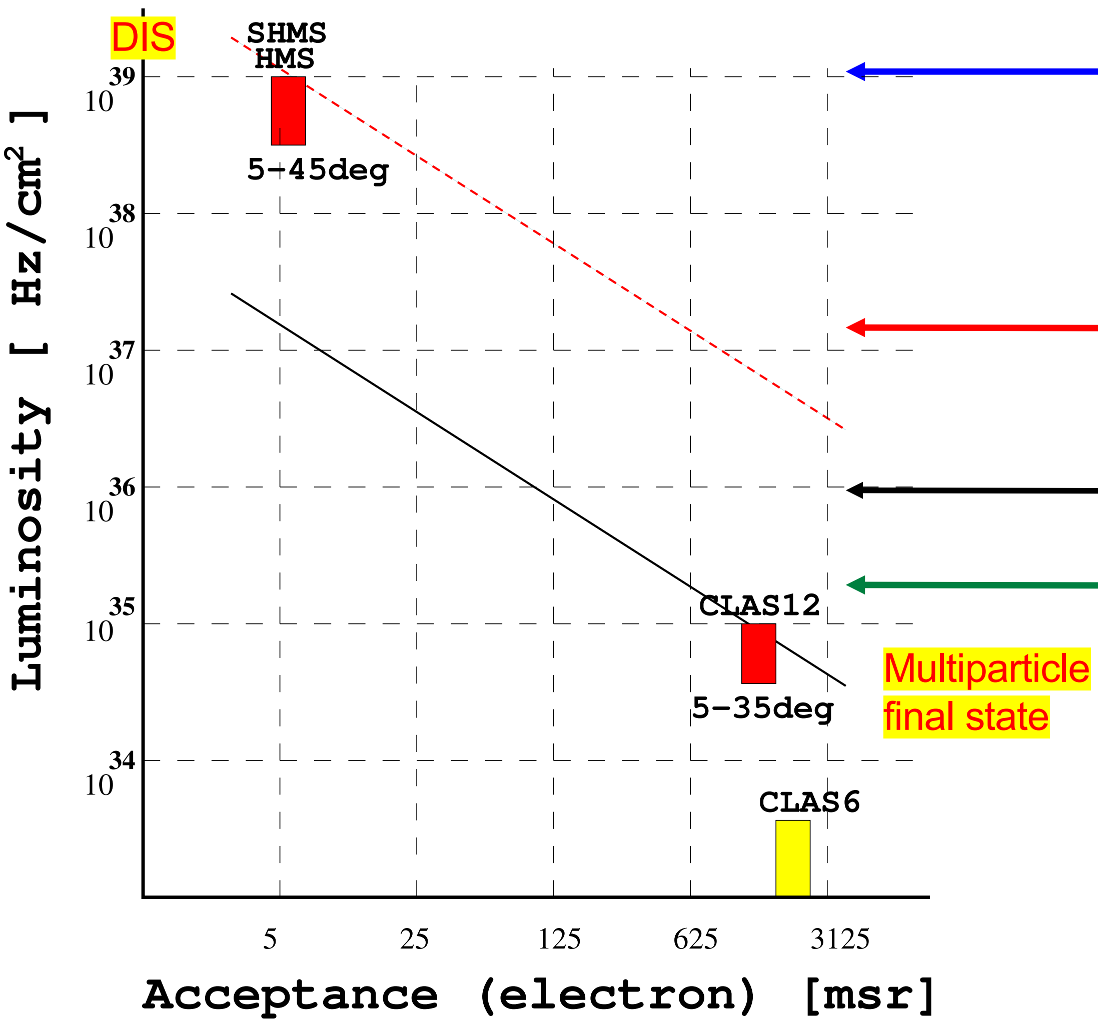
  approved | new ideas with large Ω

  move to Hall C => SIDIS; TDIS; DVCS; SANE; polDVCS; …

  approved | new ideas

  reuse of the detectors: WACS, polWACS, TCS, sFF

JLab detector landscape



A range of 10^5 in luminosity.

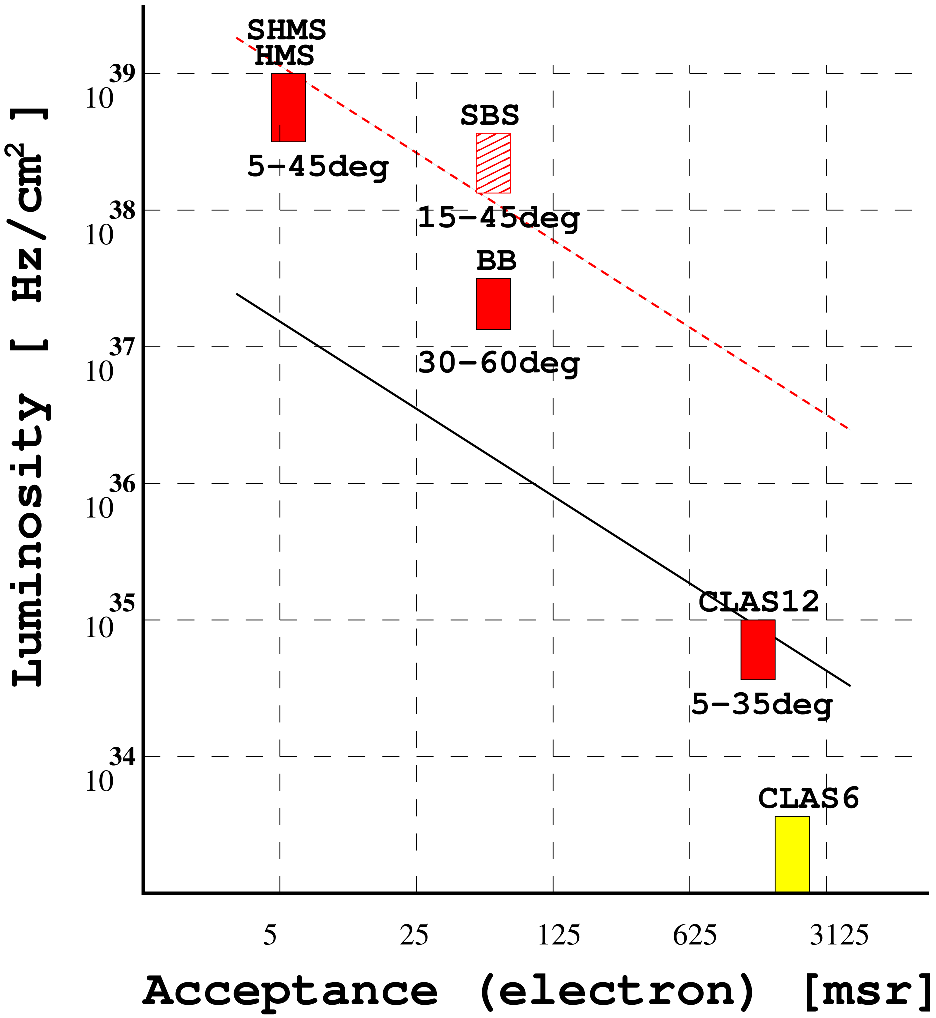
The LH_2 target can be used up to $L \sim 10^{39}$

The polarized ^3He at $L \sim 10^{37}$

Sullivan - tagging on soft proton

The polarized NH_3 at $L \sim 10^{35}$

JLab detector landscape



A range of 10^4 in luminosity.

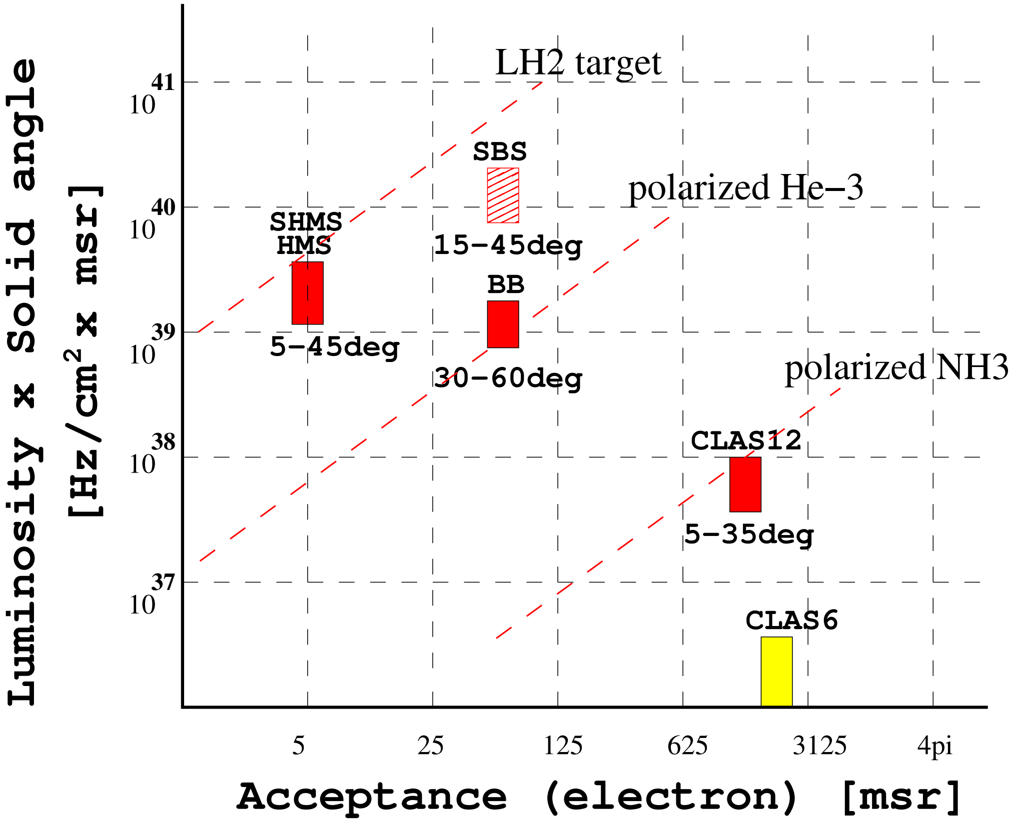
A big range in solid angle:
from 5 msr (SHMS)
to about 1000 msr (CLAS12).
==========================

The SBS is in the middle:
for solid angle (up to 70 msr)
and high luminosity capability.

In several A-rated experiments SBS was found to be the best match to the physics.

GEM allows a spectrometer with open geometry (-> large acceptance) at high L.

JLab detector landscape



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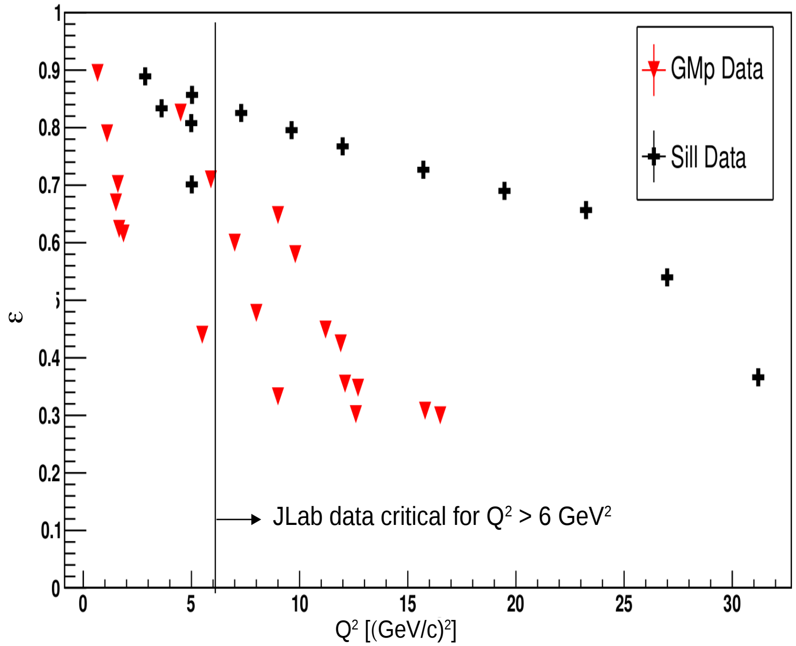
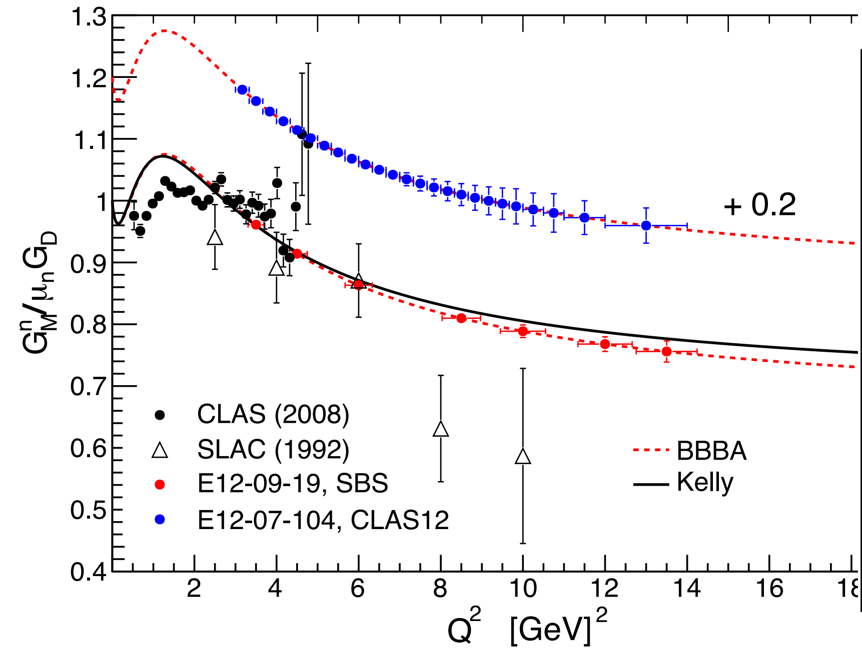
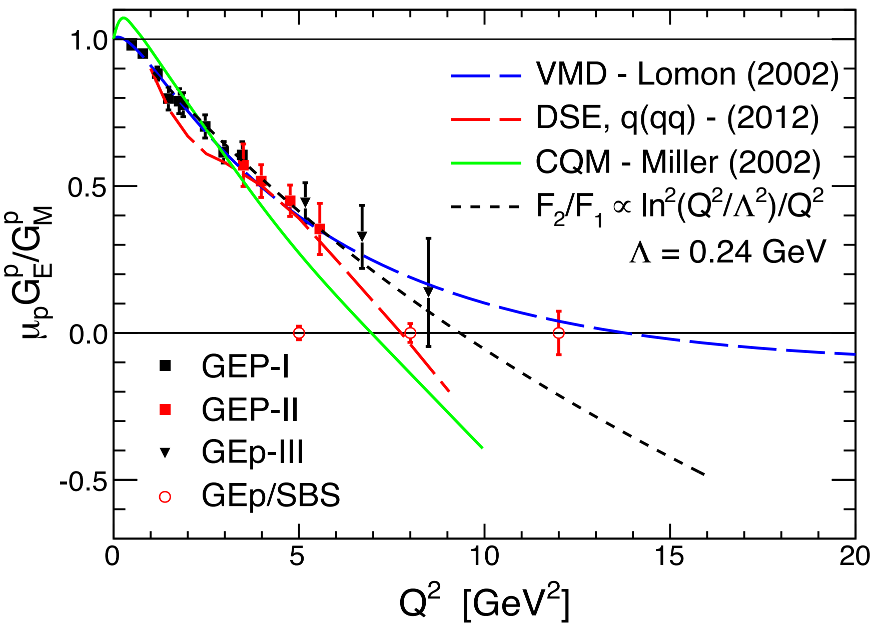
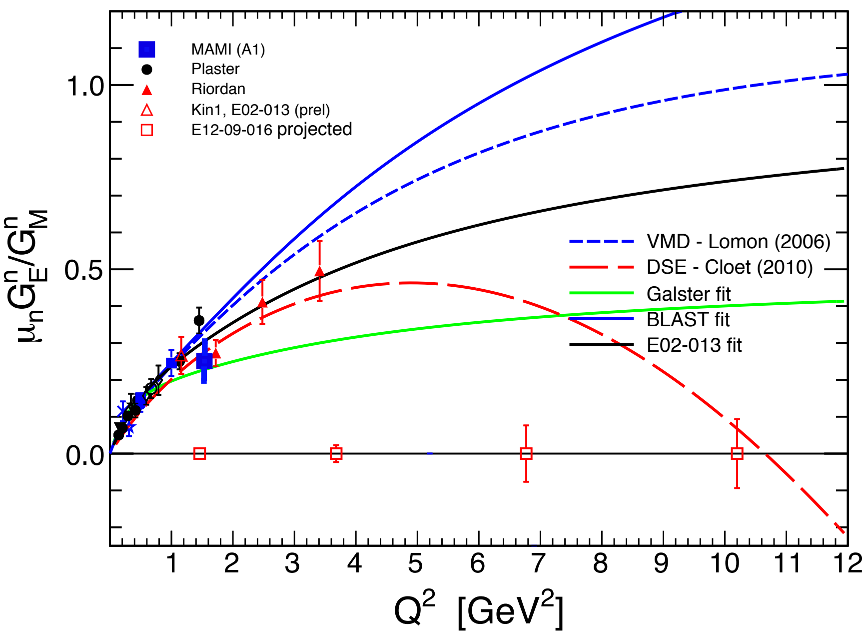
The nucleon FFs

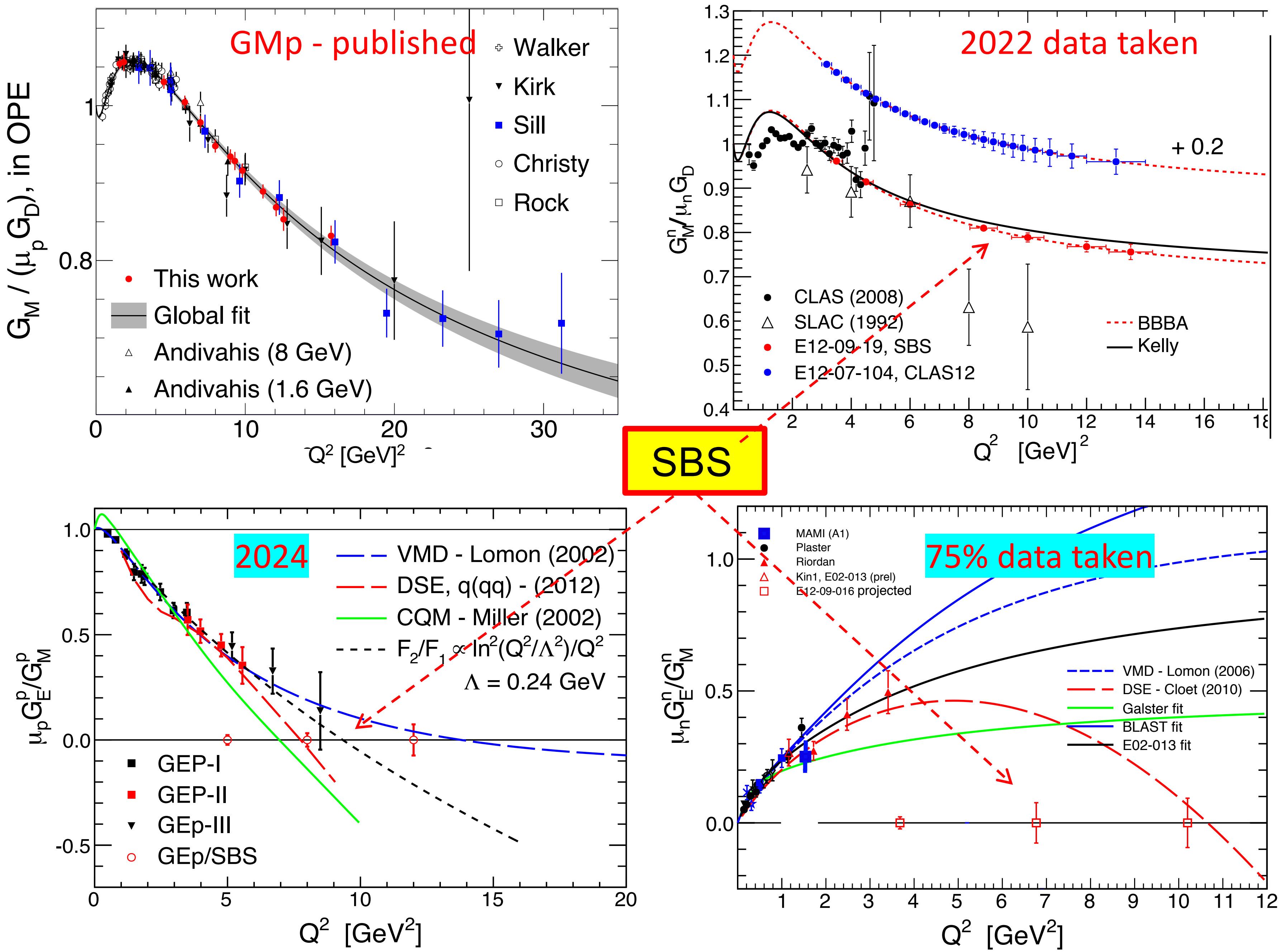




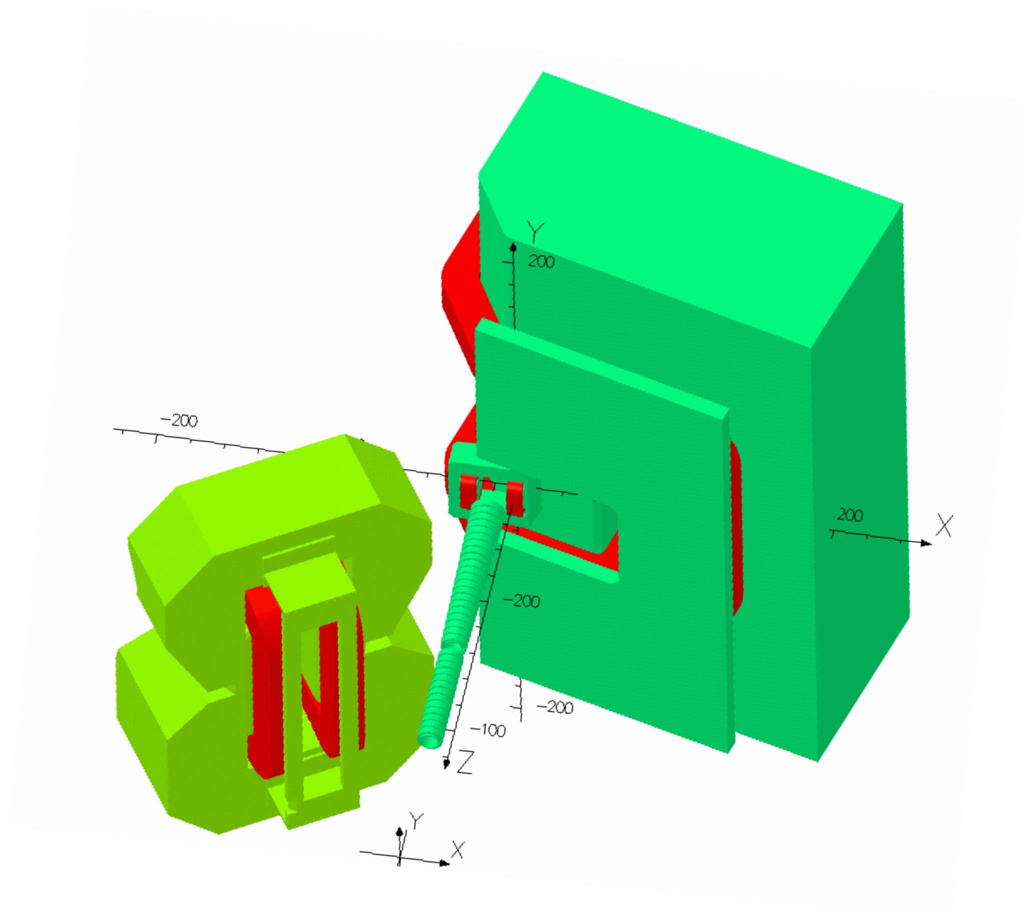




The nucleon FFs



Two-arm setup



$\sigma_p/p = 0.08 + 0.004 \times p[\mathrm{GeV}]$

$\sigma_\theta = 1 - 2$ mrad

$\Omega = 70 - 90$ msr, for $\theta \geq 30^\circ$

$\sigma_p/p = 0.0029 + 0.0003 \times p[\mathrm{GeV}]$

$\sigma_\theta = 0.14 + 1.3/p[\mathrm{GeV}]$, mrad

$\Omega = 72$ msr, for $\theta \geq 15^\circ$

$\Omega = 30$ msr, for $\theta = 7.5^\circ$

One- and Two-Arm experiments (O&TA)

Many productive experiments in the field belong to
the category One- and Two-Arm:
Among them are DIS, SIDIS, FFs (GEP), WACS, DVCS, ...

The main advantage of these "simple" (e,e') and (e,e'h/g) is
the simplicity of such processes for physics interpretation

The productivity of an experiment or Figure-of-Merit:

$$FOM = \mathcal{L} \times \Omega_1 (\times \Omega_2)$$

One- and Two-Arm experiments (O&TA)

$$FOM = \mathcal{L} \times \Omega_{electron} = 10^{38} \cdot 0.07 = 7 \times 10^{36}$$

$$electron/s \times nucleon/cm^2 \times sr$$

Now we can formulate detector configuration
for productive one- and two-arm experiments

- Magnetic analysis with "vertical bend"
- Moderate solid angle
- Independent arms
- Small angle capability
- Space for segmented PID, polarimeter

One- and Two-Arm experiments (O&TA)

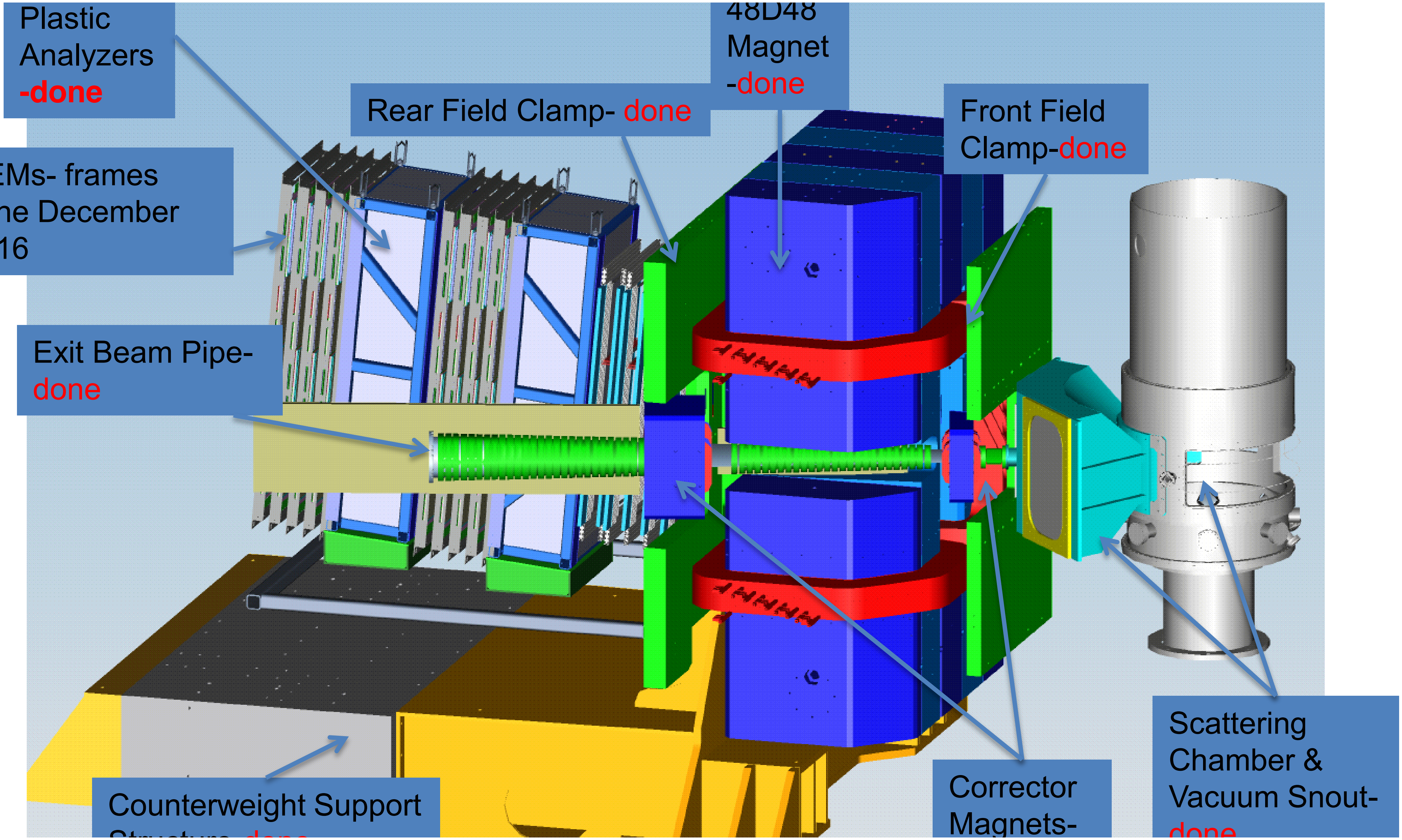
$$FOM = \mathcal{L} \times \Omega_{electron} = 10^{38} \cdot 0.07 = 7 \times 10^{36}$$

$$electron/s \times nucleon/cm^2 \times sr$$

Now we can formulate detector configuration
for productive one- and two-arm experiments

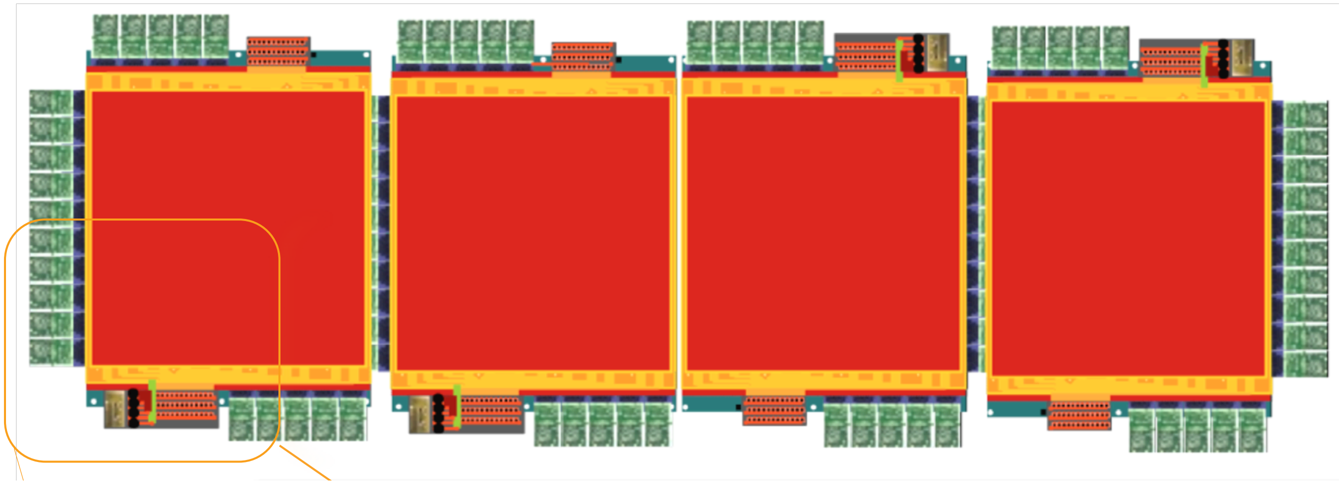
- Magnetic analysis with “vertical bend” => protected detector
- Moderate solid angle => high luminosity
- Independent arms => full range of angles
- Small angle capability => high x, t, low x
- Space for segmented PID, polarimeter => RICH counter, HCAL

Super Bigbite Spectrometer



Solid angle 70 msr for the central angle > 15°

SBS tracking detectors



INFN development of the GEM and the modern readout
UVa development of the world largest GEM chambers
and construction of two multilayer trackers (BB and SBS).

Polarized He-3 target performance

BW, High-t reactions (2002)

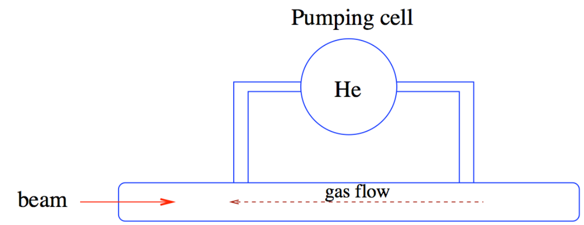
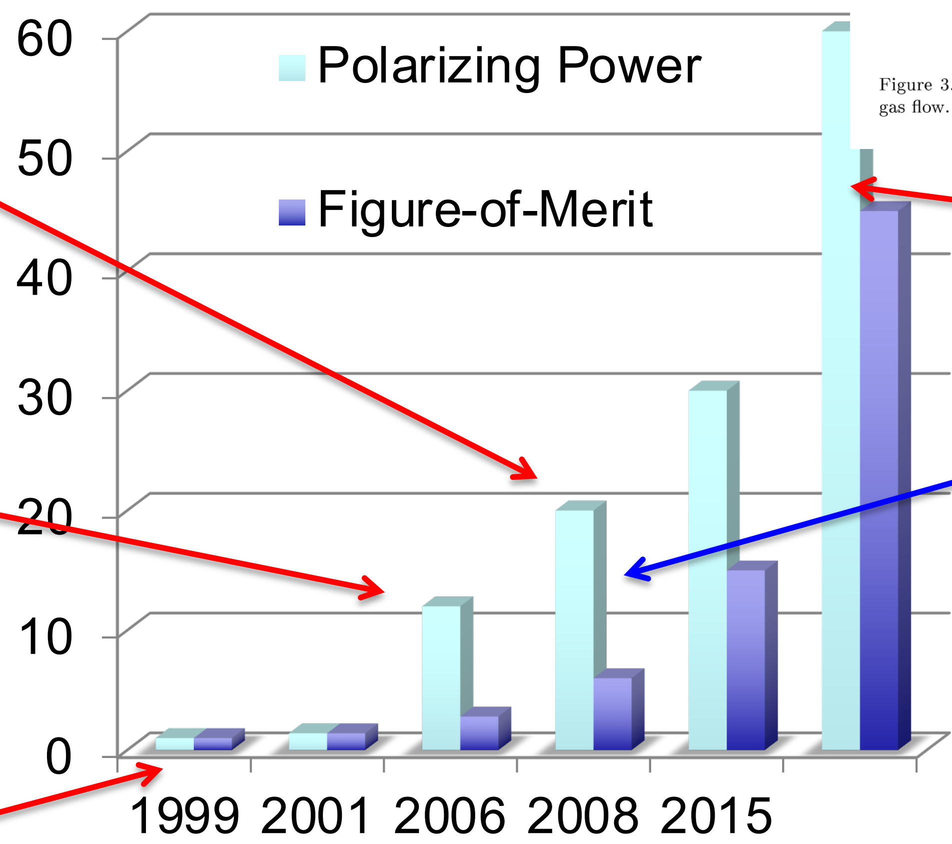


Figure 3. The target cell with two attachments to the pumping cell which allow the gas flow.

G. Cates, Optimized lasers width

G. Cates, Hybrid alkali Rb-K

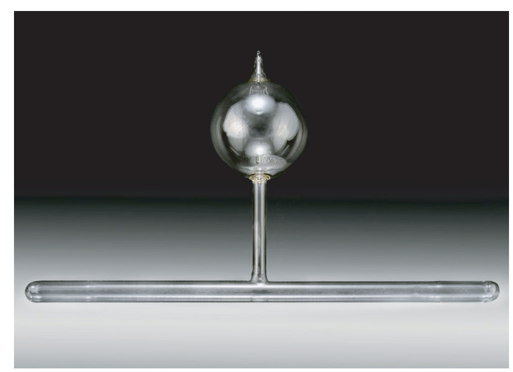
G. Cates, SLAC type



GDH A1n GEn(1) Tranv. A1n GEn-II

Convection gas flow cell

Slow diffusion exchange



SBS physics program

- GMn
- GEn (He-3)
- GEp (p -> p polarimeter)
- GEn-RP (n -> p & n -> n polarimeters)
- SIDIS
- TDIS
- Wide Angle Pion Production $\vec{\gamma}n, \pi^-\vec{p}$ =>KLL
- L/T cross section for neutron - nTPE
- WAPP from polarized He-3: $\vec{\gamma}\vec{n}, \pi^-p$ =>ALL

- Strange FF at 2.5 GeV^2
- J/Psi with proton polarimeter: e+ e- p
- g1, g2 for DIS with 12 GeV and BB/SBS
- DVCS on transversely polarized target and BB/SBS
- ϕ as Deeply Virtual Vector Meson production

GMn group of experiments

- GMn

PI team: J.Annand (emeritus), A.Camsonne, R.Gilman (left), D.Hamilton, B.Quinn, B.Wojtsekhowski*

- GEn-RP

PI team: J.Annand (emeritus), E.Bellini (emeritus), K.Gnanvo (left), D.Hamilton*, M.Kohl*, N.Piskunov (left), B.Sawadsky (left), W.Tireman, B.Wojtsekhowski

- nTPE

PI team: S.Alsalmi, E.Fuchey*, B.Wojtsekhowski

- WAPP

PI team: J.Arrington, A.Puckett*, A.Tadepalli, B.Wojtsekhowski

GEn group of experiments

- GEn

PI team: T.Averett, G.Cates, S.Riordan (left), B.Wojtsekhowski*

- WAPP-ALL

PI team: G.Cates, R.Montgomery, A.Tadepalli, B.Wojtsekhowski*

GEp group of experiments

- WAPP-KLL

PI team: J.Arrington, A.Puckett*, A.Tadepalli, B.Wojtsekhowski

- GEn-RP

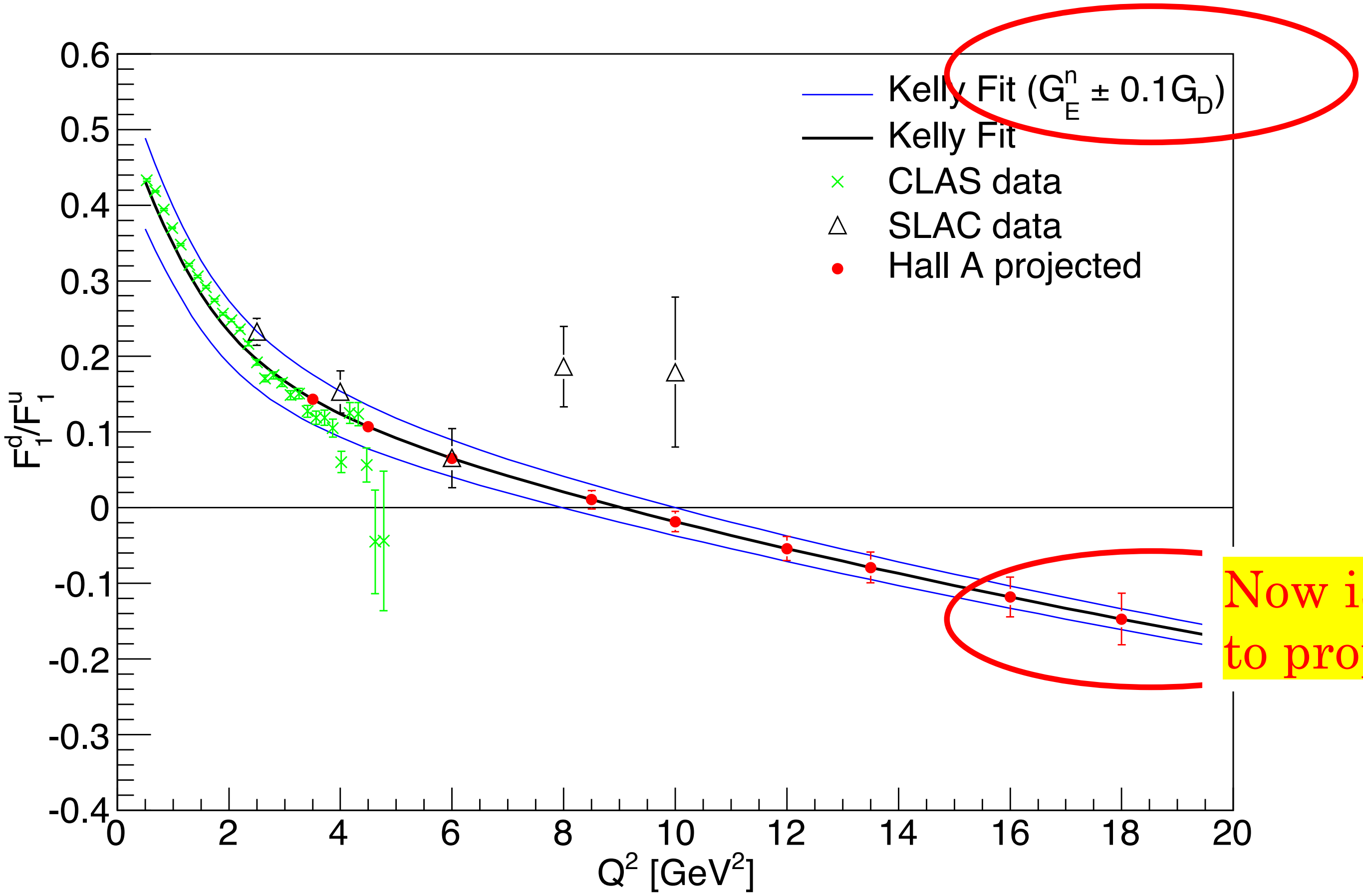
PI team: D.Hamilton*, M.Kohl*, W.Tireman, B.Wojtsekhowski

- GEp

PI team: E.Cisbani, M.Jones, N.Liyanage, L.Pentchev, A.Puckett, B.Wojtsekhowski*

F_1 decomposition at very large Q^2

$$F_1 = \frac{G_E + \tau G_M}{1+\tau} \qquad F_2 = -\frac{G_E - G_M}{1+\tau}$$



Now is right time to propose

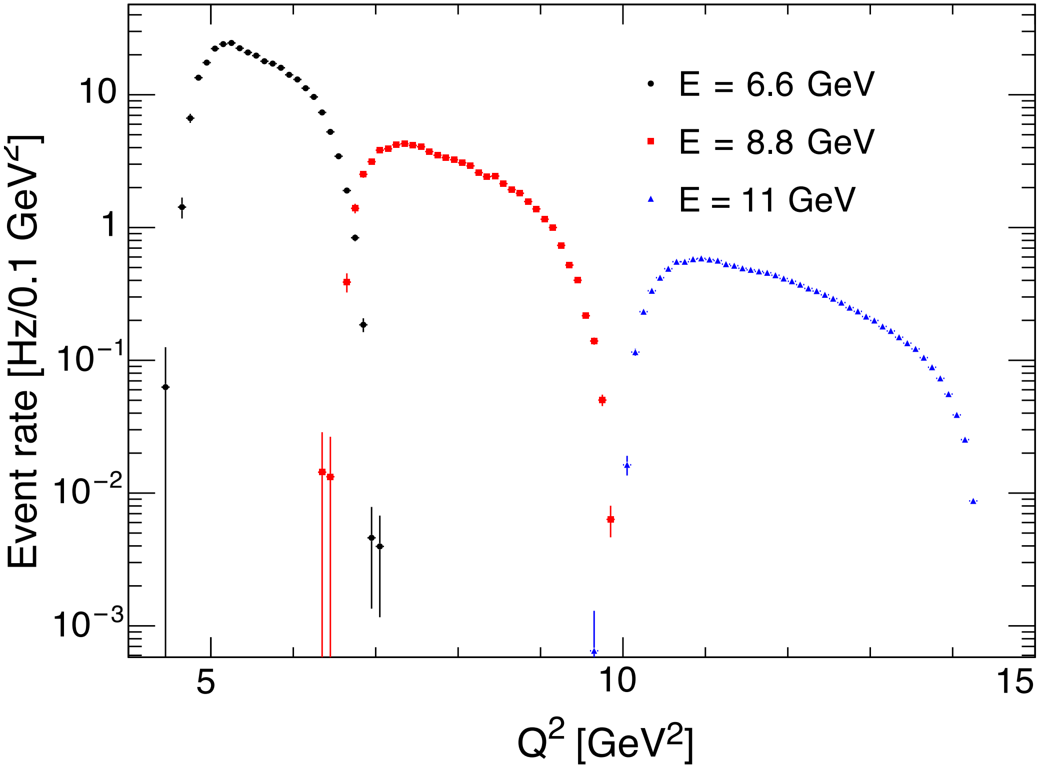
GEp/SBS Q^2 acceptance, projected accuracy

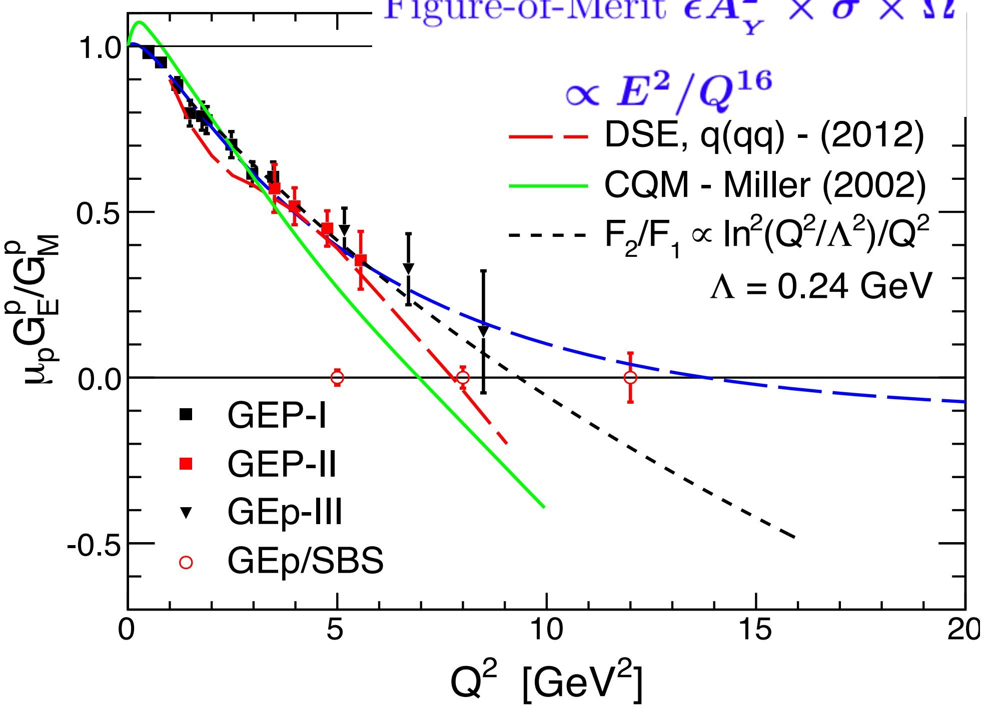
Form factor $\propto Q^{-4}$

Cross section $\propto E^2/Q^4 \times Q^{-8}$

Figure-of-Merit $\epsilon A_Y^2 \times \sigma \times \Omega$

$\propto E^2/Q^{16}$



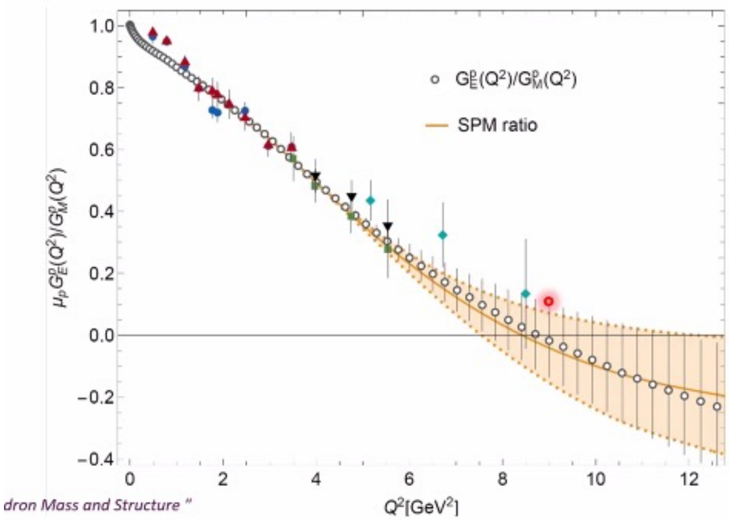


E_{beam}, GeV	Q^2 range, GeV^2	$\langle Q^2 \rangle$ GeV^2	θ_{ECAL} degrees	$\langle E'_e \rangle$, GeV	θ_{SBS} degrees	$\langle P_p \rangle$ GeV	$\langle \sin \chi \rangle$ degrees	Event rate Hz	Days	$\Delta\,(\mu G_E/G_M)$
6.6	4.5-7.0	5.5	29.0	3.66	25.7	3.77	0.72	291	2	0.029
8.8	6.5-10.0	7.8	26.7	4.64	22.1	5.01	0.84	72	11	0.038
11.0	10.0-14.5	11.7	29.0	4.79	16.9	7.08	0.99	13	32	0.081

45 PAC days

GEp/SBS Q^2 acceptance, projected accuracy

C.Roberts' talk 6/29/23

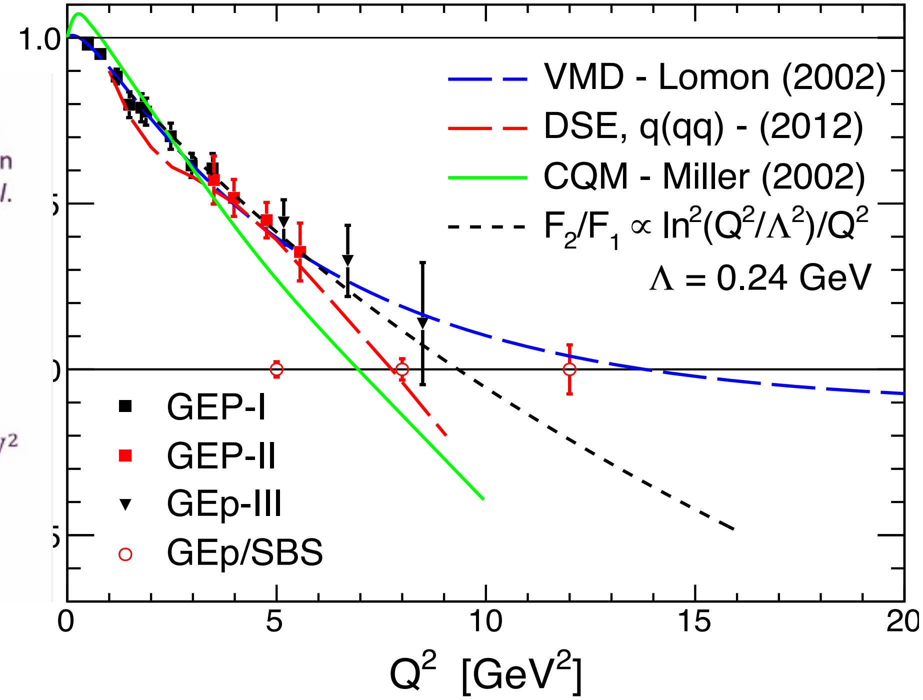


Unification of Weak and EM form factors of octet baryons Zhao-Qian Yao (姚照千), Daniele Binosi, *et al.* – nearing completion

Parameter-free prediction using solutions of 3-body Poincaré-covariant Faddeev equation

$$\frac{\mu_p G_E^p}{G_M^p} = 0 \text{ at } Q^2 = 8.42^{+3.76}_{-0.86}\text{GeV}^2$$

1st study of its kind to deliver prediction for location of zero



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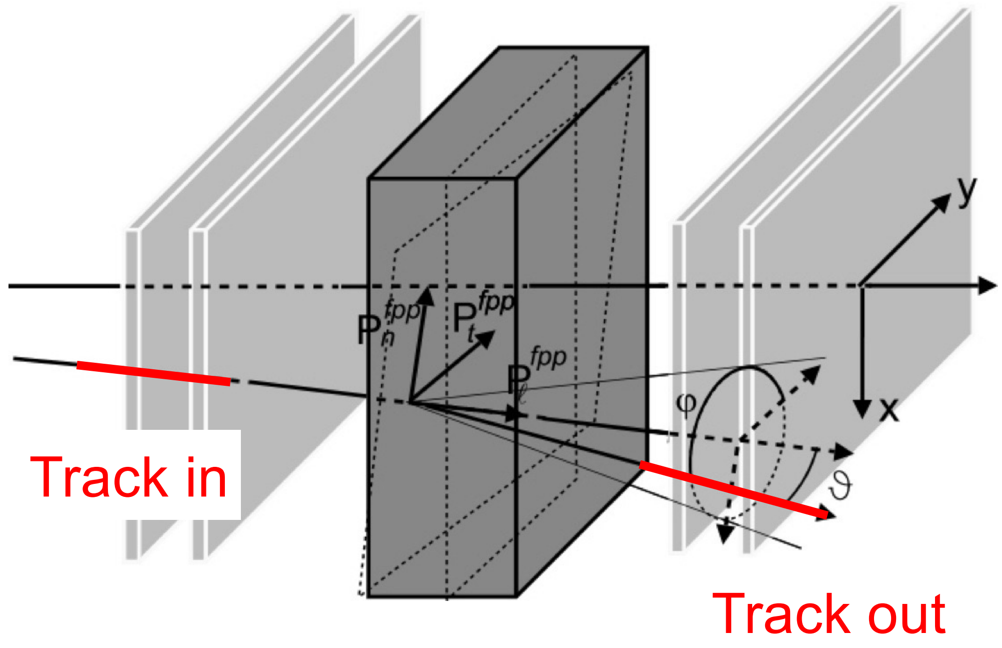
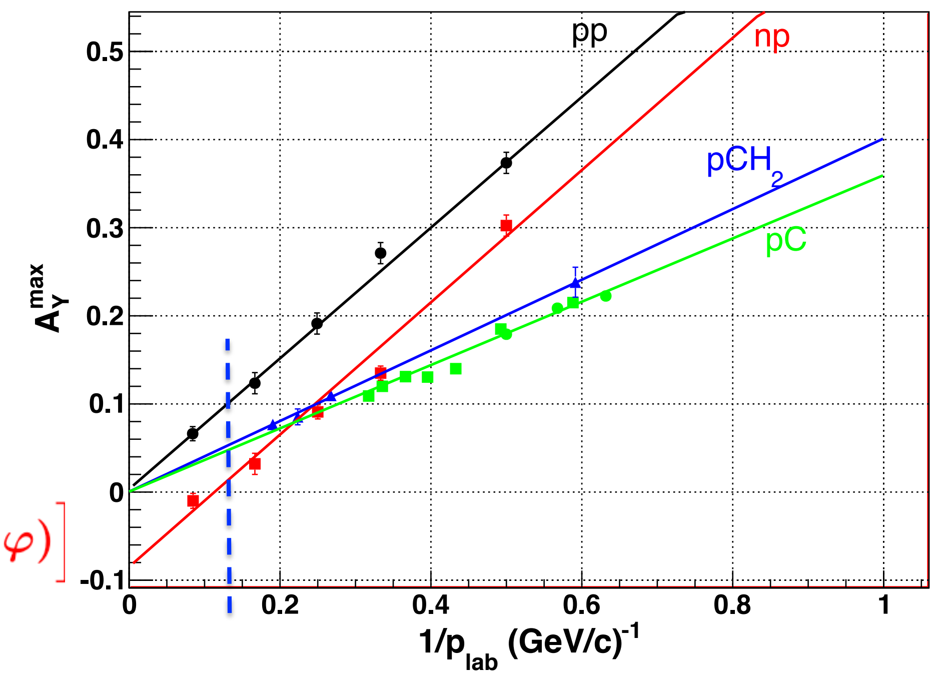
45 PAC days

Method: Focal Plane Polarimeter



A_Y analyzing power vs. inverse proton momentum



$$f^{\pm}(\vartheta,\varphi) = \frac{\epsilon(\vartheta,\varphi)}{2\pi}\left[1 \pm A_y(P_x^{fpp}\sin\varphi - P_y^{fpp}\cos\varphi)\right]$$

where ± refers to electron beam helicity

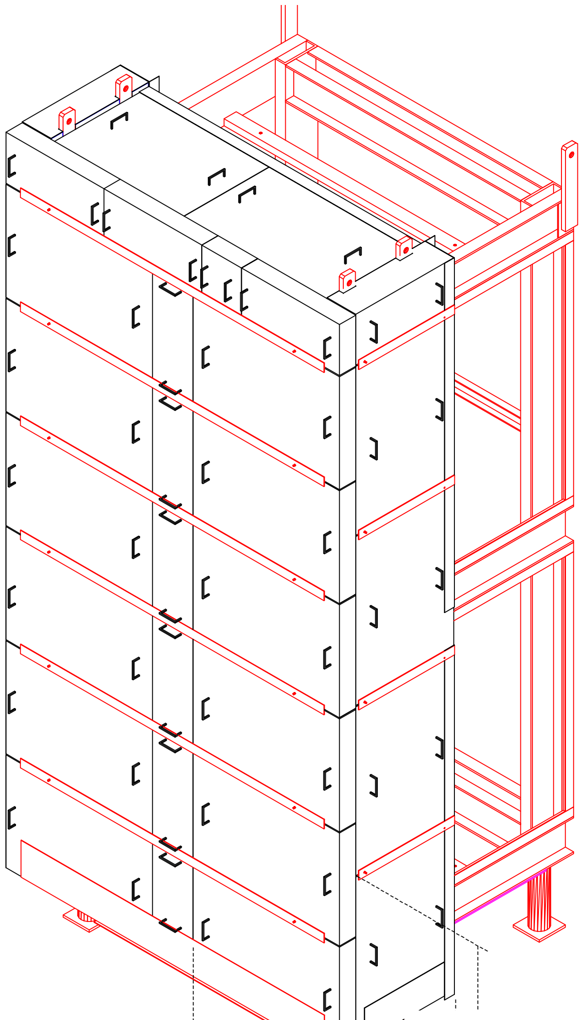
$$A = \frac{f^+ - f^-}{f^+ + f^-} = A_y\left(P_x^{fpp}\sin\varphi - P_y^{fpp}\cos\varphi\right)$$

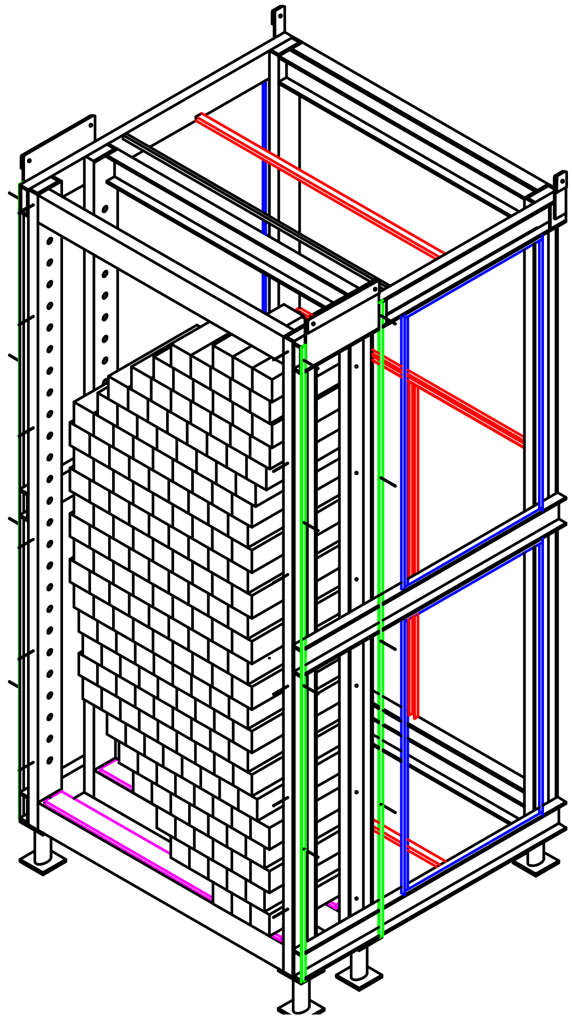
p will be ~ 7 GeV/c

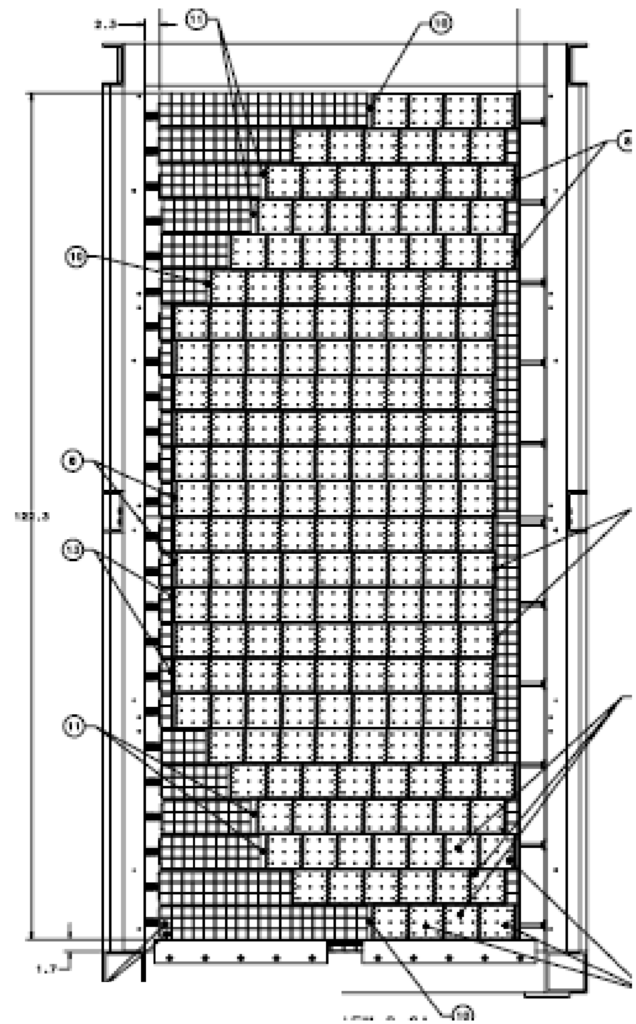
$$\frac{G_E^p}{G_M^p} = -\frac{E_e + E_{e'}}{2M} tan(\frac{\theta_e}{2})\left(\frac{P_y^{fpp}}{P_x^{fpp}}\sin\chi_e + \gamma_p(\mu_p - 1)\Delta\phi\right)$$

fringe field correction

Electron arm calorimeter CAD model







1737 lead-glass modules
Elevated temperature of the glass (225-185 C)
provides continuous annealing of radiation damage

Twist-3 contributions to wide-angle photoproduction of pion

P. Kroll

Fac *rmany*

Theoreti *ᵉb, Croatia*

We investigate to twist-3 accuracy. In contrast to earli butions are taken into account. It is show variance and crossing properties. The nu With it fair agreement with the recent C ly comment also on wide-angle photo

DOI: 10.1103/PhysI

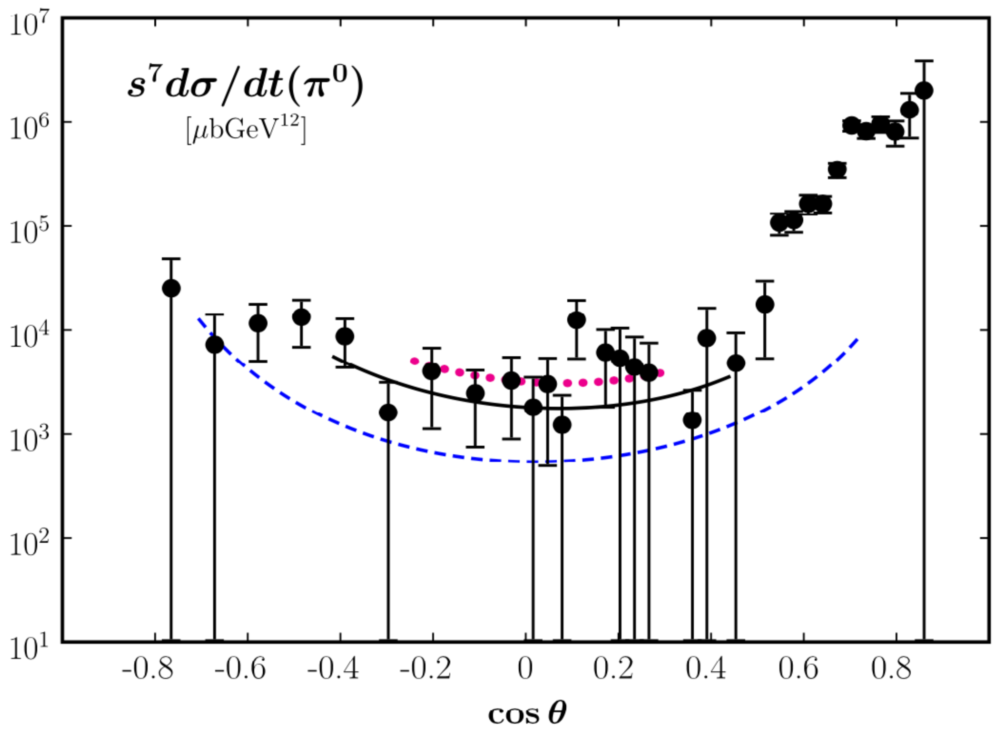


FIG. 3. Results for the cross section of π^0 photoproduction versus the cosine of the c.m.s. scattering angle, θ. The solid (dashed, dotted) curves represent our results at $s = 11.06(20, 9)$ GeV^2. The data at $s = 11.06$ GeV^2 are taken from CLAS [34]. The cross sections are multiplied by s^7, and the theoretical results are only shown for $-t$ and $-u$ larger than 2.5 GeV^2.

Twist-3 contributions to wide-angle photoproduction of pion

Fa … nany

Theore … Croatia

We investigat… twist-3 accuracy.
In contrast to ear… tions are taken into
account. It is sho… riance and crossing
properties. The n… th it fair agreement
with the recent … comment also on
wide-angle photo…

DOI: 10.1103/Phys…

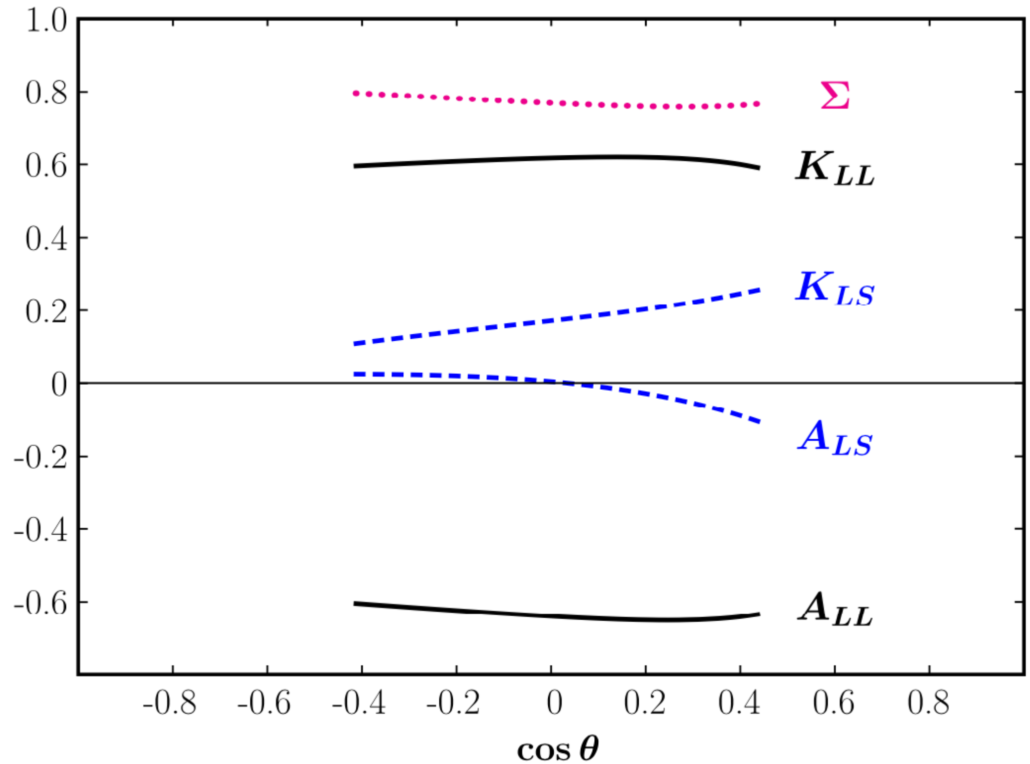


FIG. 4. Predictions for spin observables of π^0 photoproduction at $s = 11.06$ GeV^2. The parametric uncertainty is $\simeq$15% near 90 deg.

In Fig. 4 we show predictions on the spin-dependent observables for π^0 photoproduction. One sees that A_{LL} and K_{LL} are large in absolute value and almost mirror symmetrical. The observables A_{LS} and K_{LS} are small in

How to do experimental study?

The case for π^- from a neutron (see also talk in SBS-2019)

ALL from $^3\vec{H}e(\vec{e}, \pi^- \, p)epp$

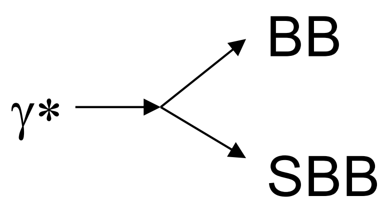
KLL from $D(\vec{e}, \pi^- \vec{p})ep$

SBS and BB are as in the GEn-II experiment
(thanks to the two-arm detector system)

ALL experiment challenges and solutions

- The goal is to measure ALL asymmetry, so the target polarization should be oriented along the beam direction.
  However, the design of the mirror mounts does not allow it.
- The natural way to study photo-production requires a radiator
  However, the radiator was not designed and which holded ERR

- Solution is to measure ALL and ALS with two symmetrical arms.
  Design group confirmed space availability of such geometry.



Call event L
if Pion in BB
Proton in SBS

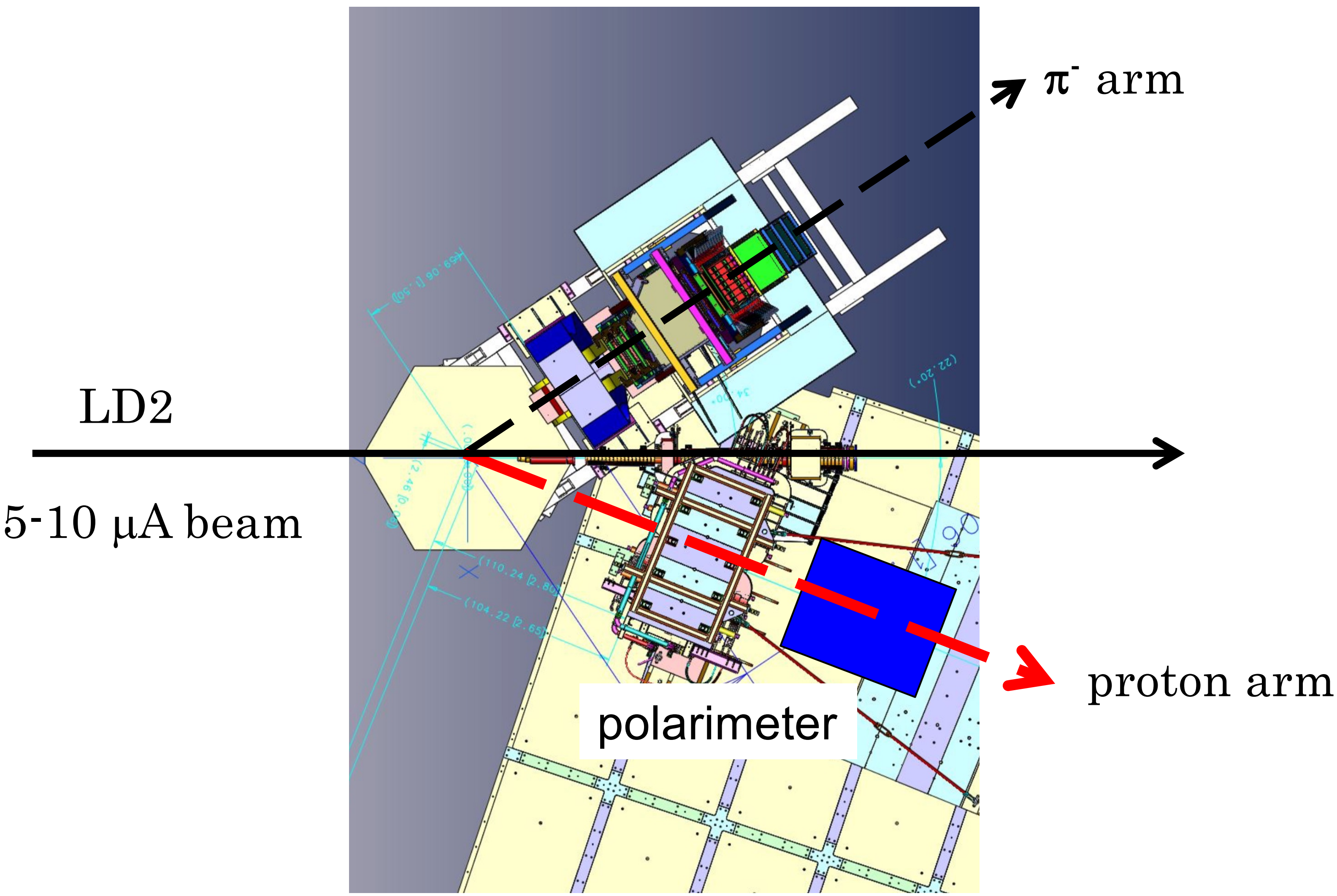
Call event R
if Pion in SBS
Proton in BB

$$A_L = ALL^*P_n \cos\theta + ALS^*P_n \sin\theta$$

$$A_R = ALL^*P_n \cos\theta - ALS^*P_n \sin\theta$$

- The high performance polarized target allows us to use intensive electron beam, so quasi real photons will be used.

Layout for the KLL experiment



Summary

- SBS + BB provide a flexible instrument which is the best choice for many high-z high-Q^2 exclusive reactions.

- Approved experimental program is large and additional important physics proposals could be developed.