Large Acceptance Proton Form Factor Ratio Measurement up to 12 GeV^2 using Recoil Polarization Method

B.Wojtsekhowski for the SBS collaboration

Large Acceptance Proton Form Factor Ratio Measurement at 13 and 15 GeV^2 using Recoil Polarization Method

Experiment E12-07-109

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Electron-nucleon elastic scattering

Nucleon current, one-photon approximation, α_{em} = 1/137,

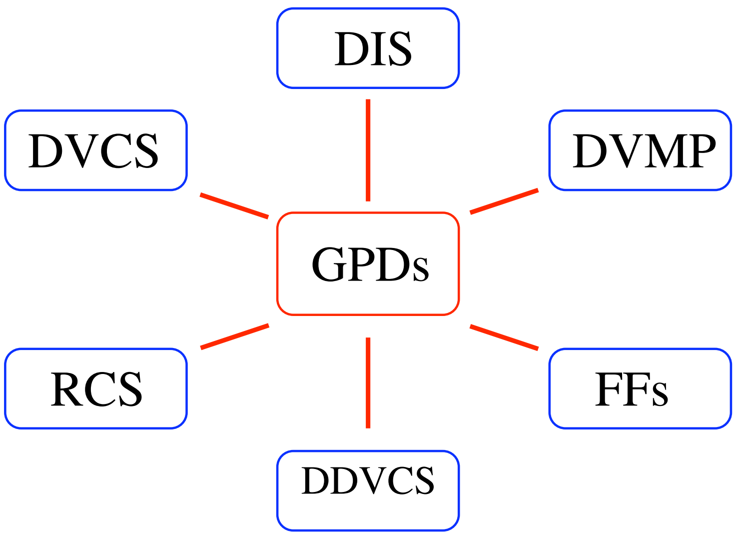
$$\mathcal{J}^{\mu}_{hadron} = ie\bar{N}(p_f)\,[\gamma^{\nu} F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_{\nu}}{2\,M} F_2(Q^2)]N(p_i)$$

$$\frac{d\sigma}{d\Omega}(E,\theta) = \frac{\alpha^2 E' \cos^2(\frac{\theta}{2})}{4E^3 \sin^4(\frac{\theta}{2})}[(F_1^2 + \kappa^2\tau F_2^2) + 2\tau(F_1 + \kappa F_2)^2 \tan^2(\frac{\theta}{2})]$$

$$\frac{d\sigma}{d\Omega}(E,\theta) = \sigma_M[\frac{G_E^2 + \tau G_M^2}{1+\tau} + 2\tau G_M^2 \tan^2(\frac{\theta}{2})]$$

Scientific case

The nucleon structure in terms of GPDs



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

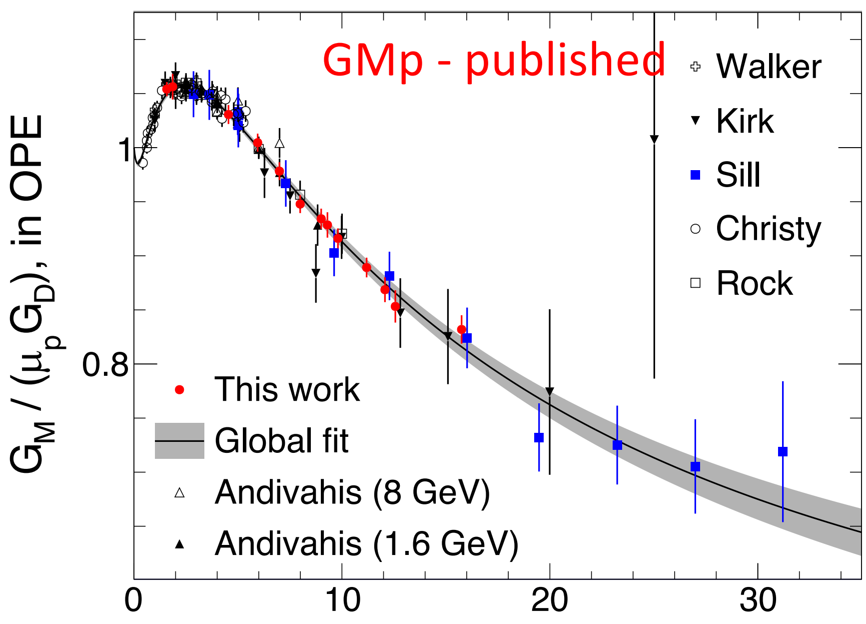
$$H^q(x, \xi = 0, t = 0) = q(x)$$

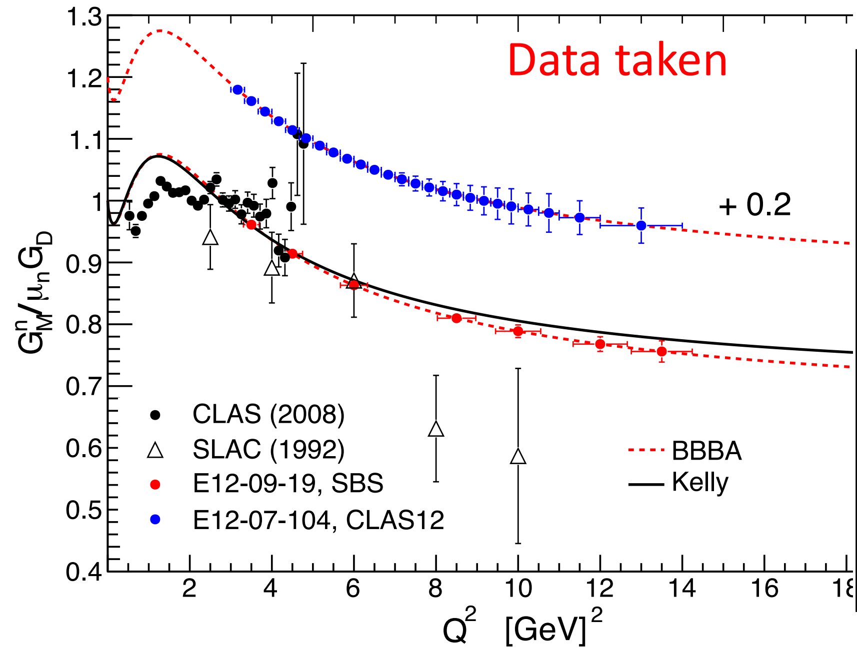
$$\tilde{H}^q(x, \xi = 0, t = 0) = \Delta q(x)$$

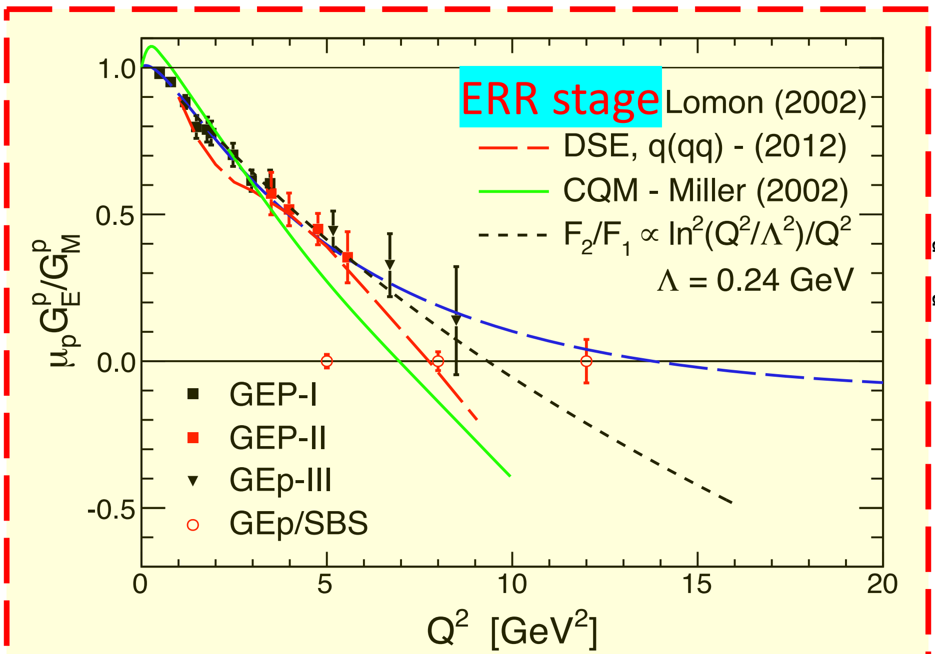
$$\int_{-1}^{+1} dx\, H^q(x, 0, Q^2) = F_1^q(Q^2)$$

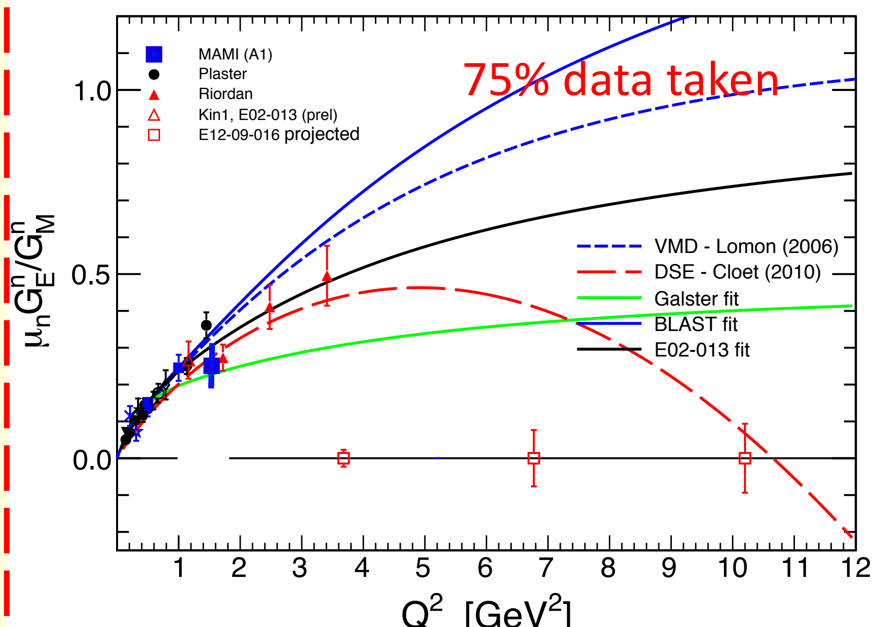
$$\int_{-1}^{+1} dx\, E^q(x, 0, Q^2) = F_2^q(Q^2)$$

The nucleon FFs

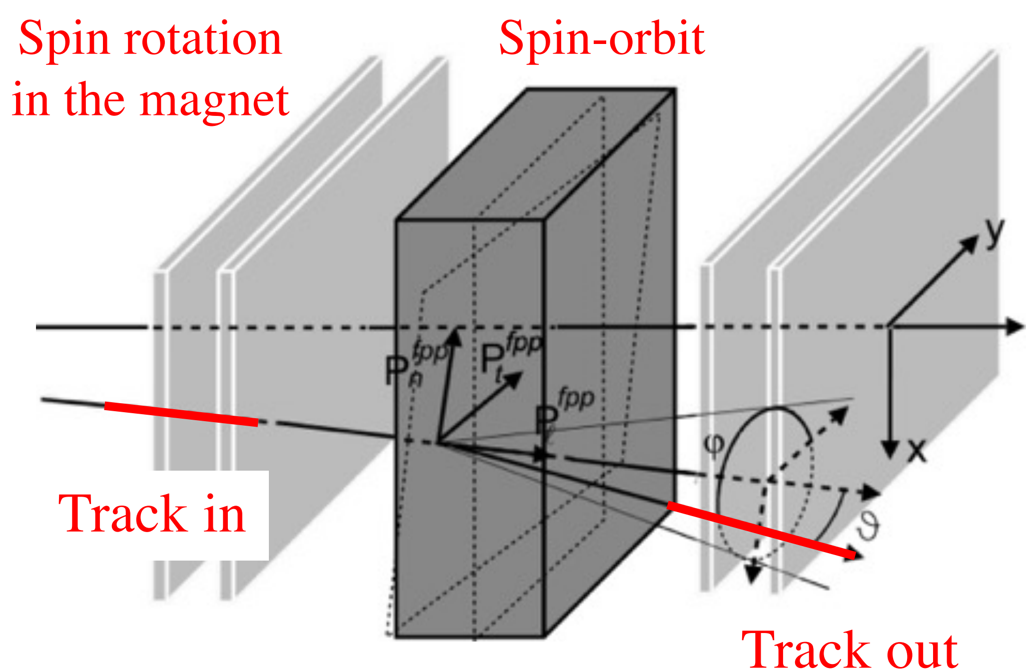


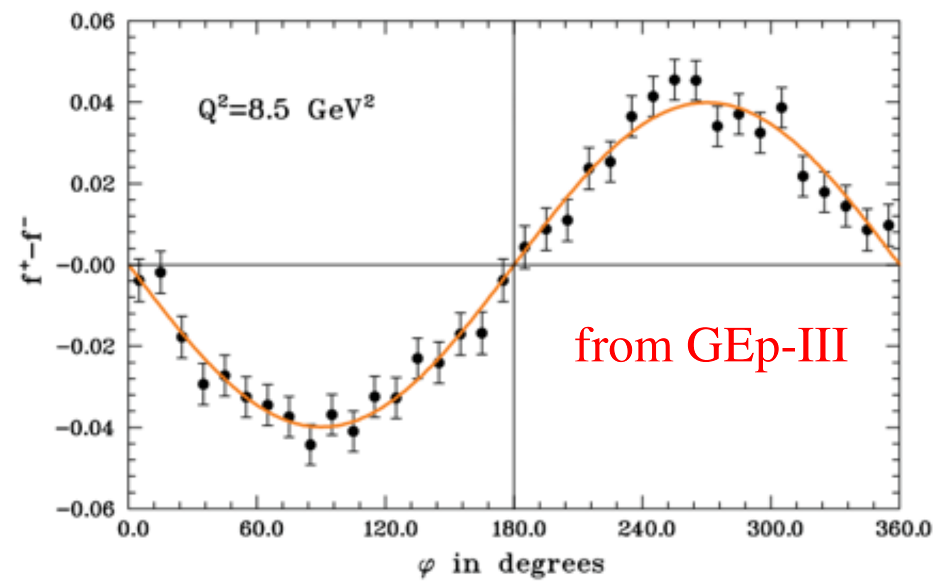






Method: Focal Plane Polarimeter





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

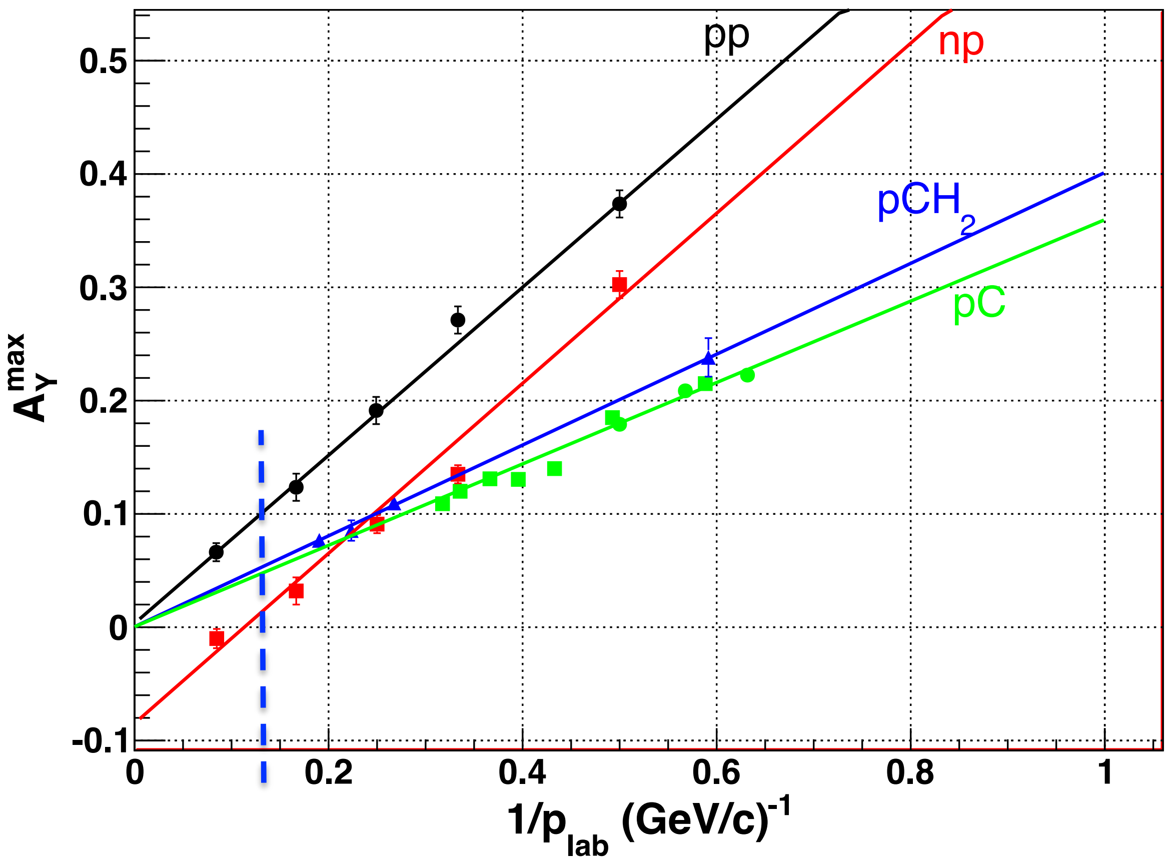
where $\pm$ refers to electron beam helicity

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

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

Method: Focal Plane Polarimeter

A_Y analyzing power vs. inverse proton momentum



proton momentum will be ~ 7.3 GeV/c

$$\mu_p \frac{G_E^p}{G_M^p} = -\mu_p \frac{E_e + E'_e}{2M_p} \tan\frac{\theta_e}{2} \left(\frac{P_x^{fpp}}{P_y^{fpp}} \sin\chi_\theta + \gamma_p(\mu_p - 1)\Delta\phi \right)$$

Challenges in this experiment

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

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

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

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

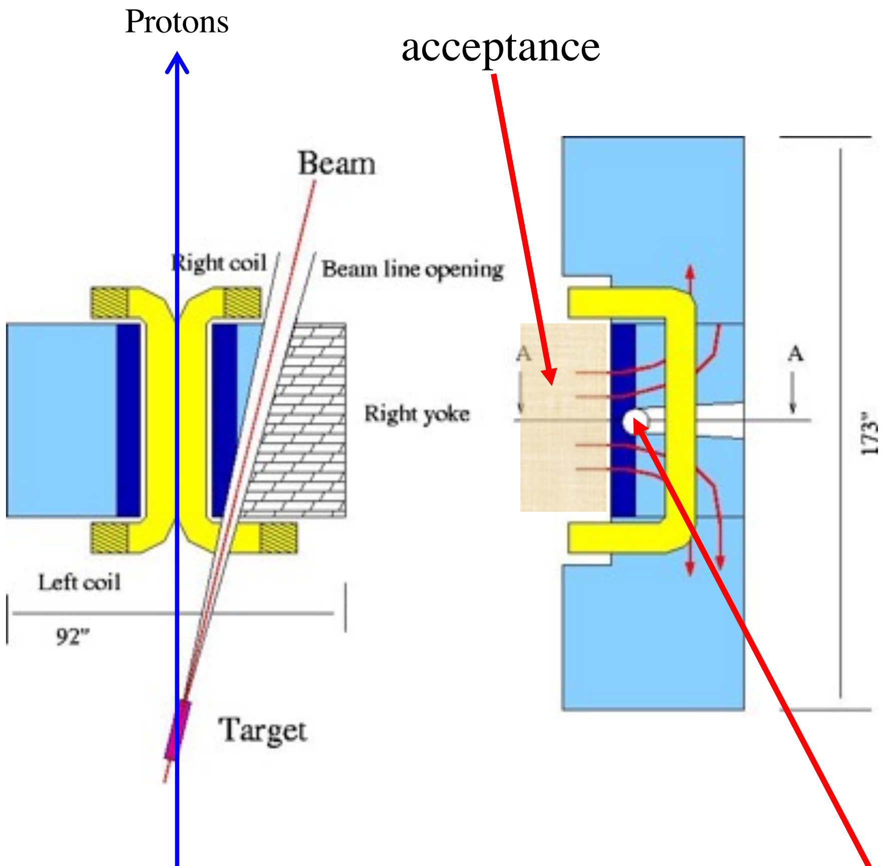
Need large statistics => luminosity and solid angle

Max luminosity -> large background, radiation damage
Large solid angle -> small bend -> huge background

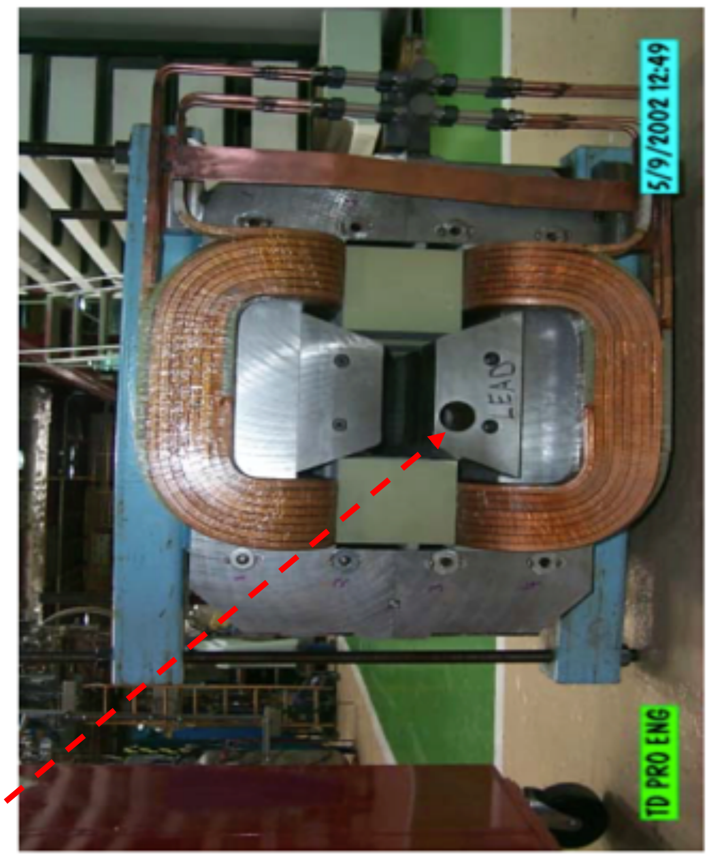
Solution is a modern tracking detector - GEM

Concept of a large solid angle proton arm

acceptance



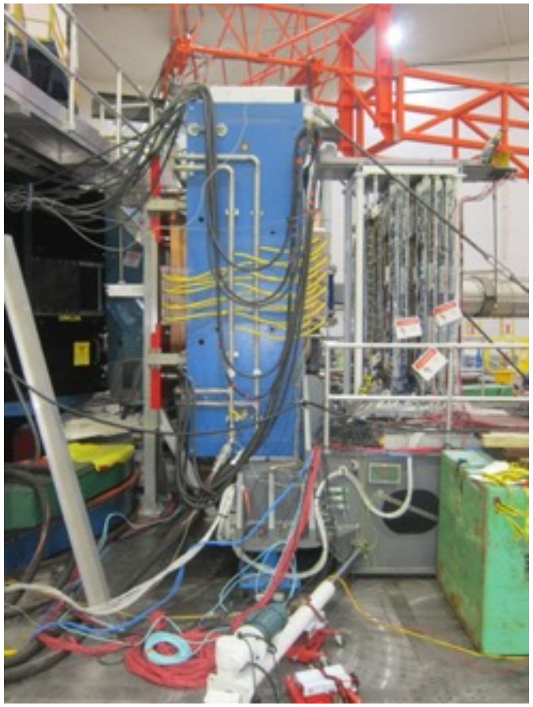
Lambertson magnet in accelerator field



beam

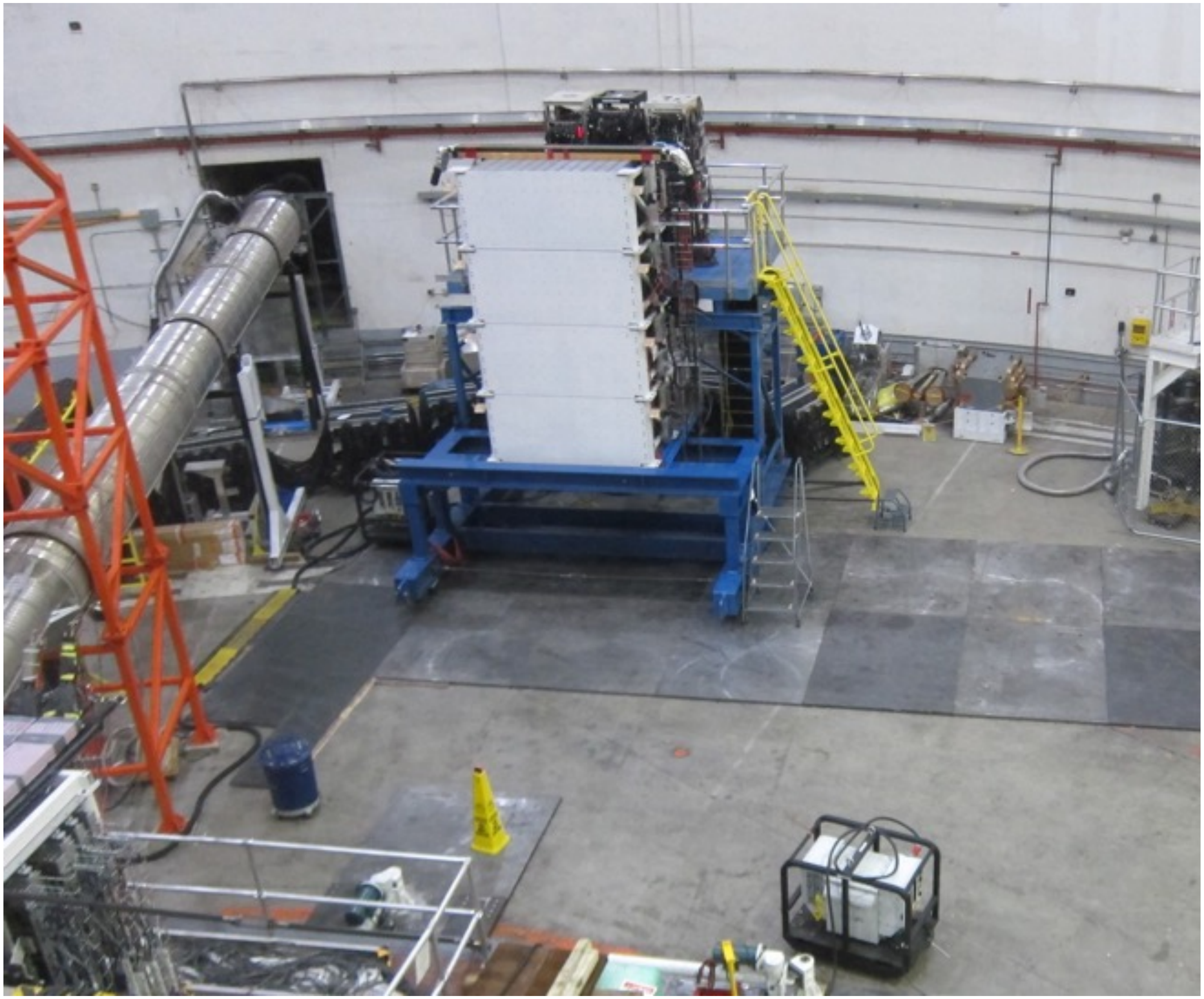
Magnet: 48D48 - 46 cm gap, 2-3 Tesla*m
Solid angle is 70 msr at angle 15 deg.
GEM chambers with 70 μm resolution
momentum resolution is 0.5% for 5 GeV/c
angular resolution is 0.5 mr

SBS magnet placed near the pivot



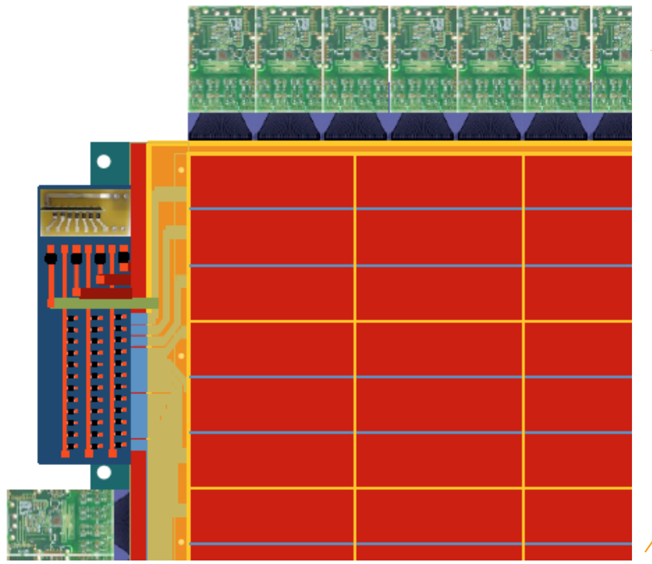
SBS magnet parameters and operation confirmed in GMn and GEn runs

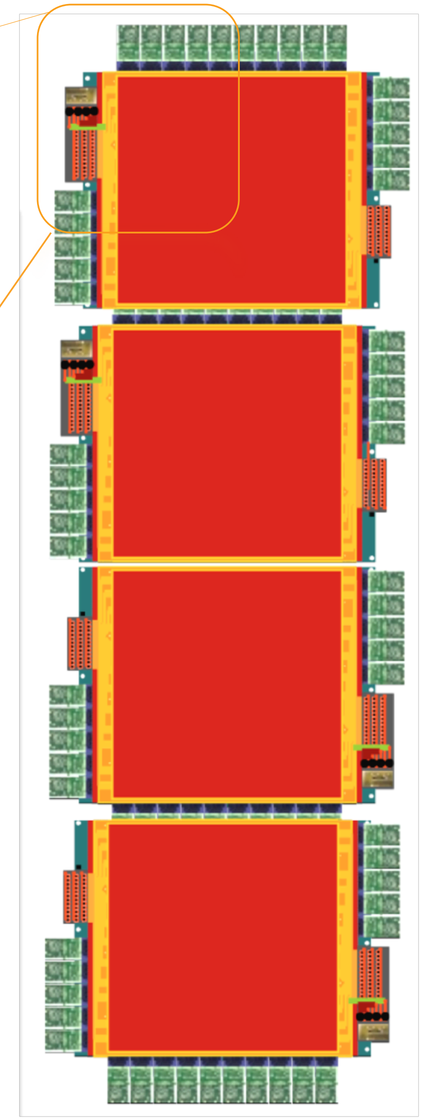
Proton arm: calorimeter



HCAL parameters confirmed in GMn and GEn runs

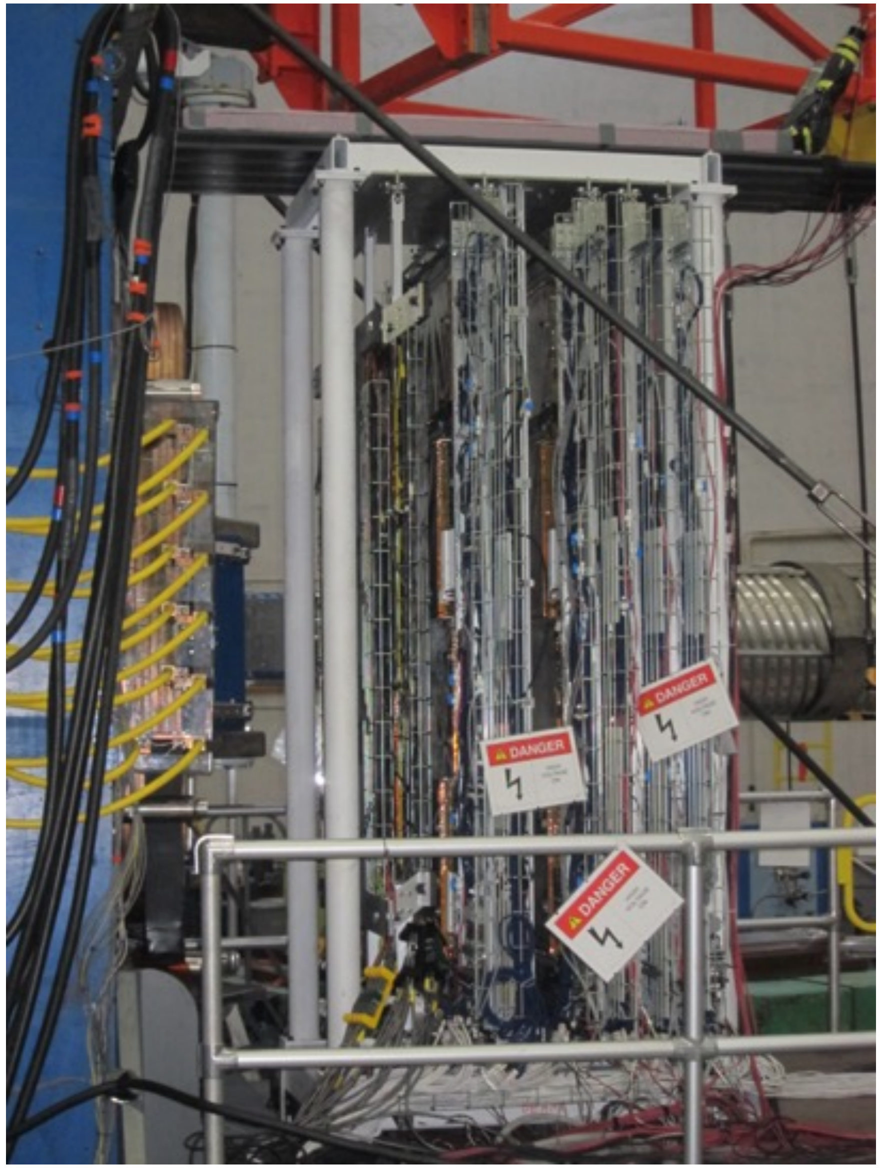
SBS trackers in the polarimeter



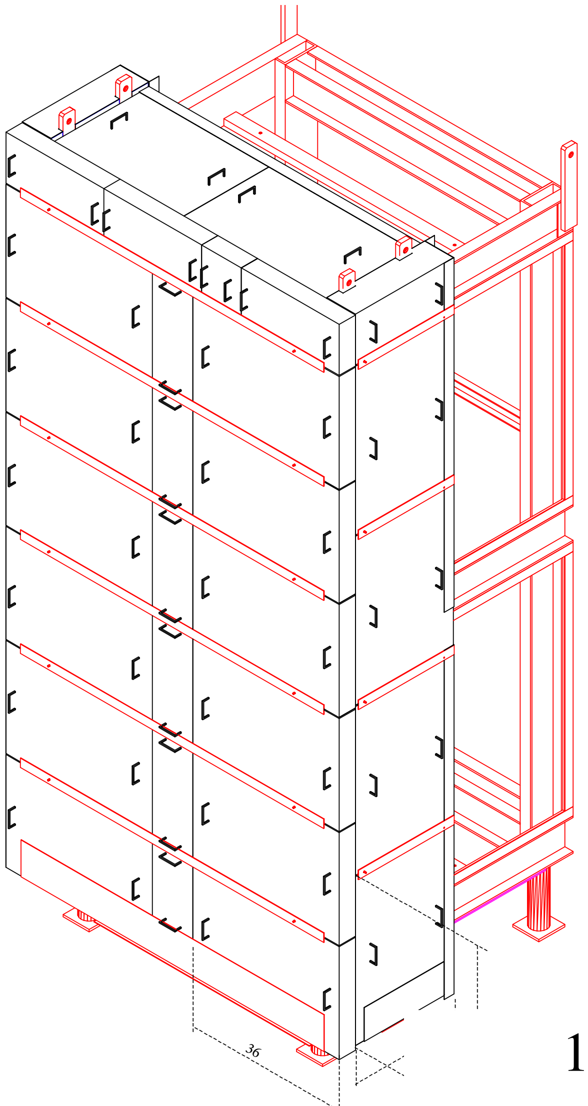


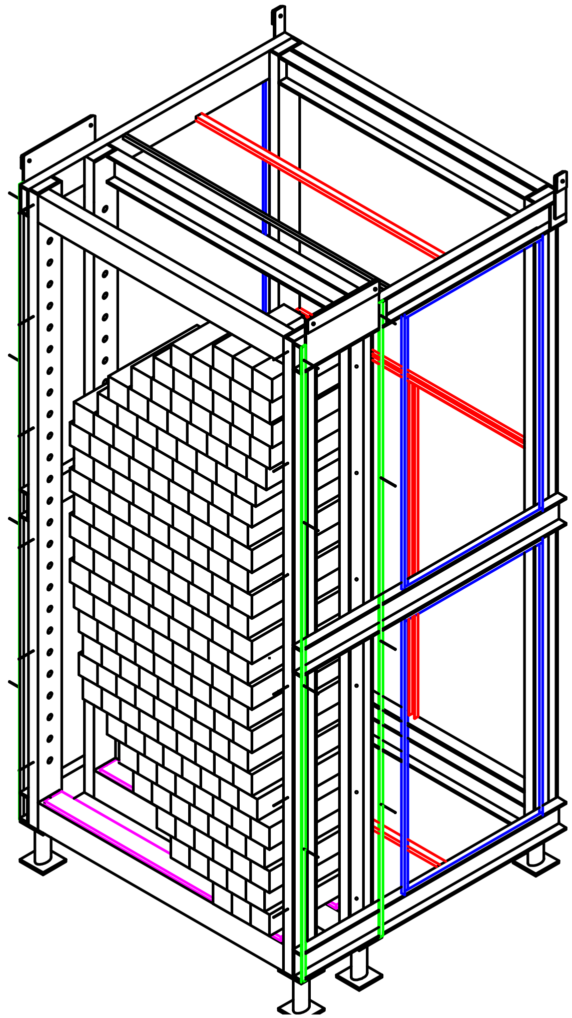
- Protection resistors are outside the chamber: reliable, easy access.
- Large alignment pins, away from the active area
- Wide frames on the two sides not in active area: better mechanical rigidity and more room for gas inlets, HV traces etc.
- Electronics arranged to minimize the material within active area.

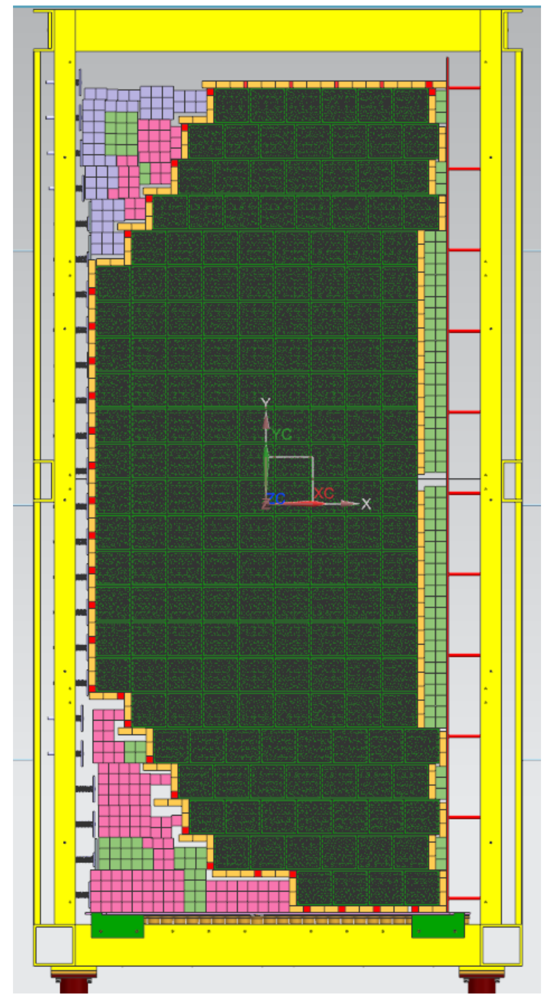
SBS trackers under tests during GEn run



Electron arm: calorimeter CAD model



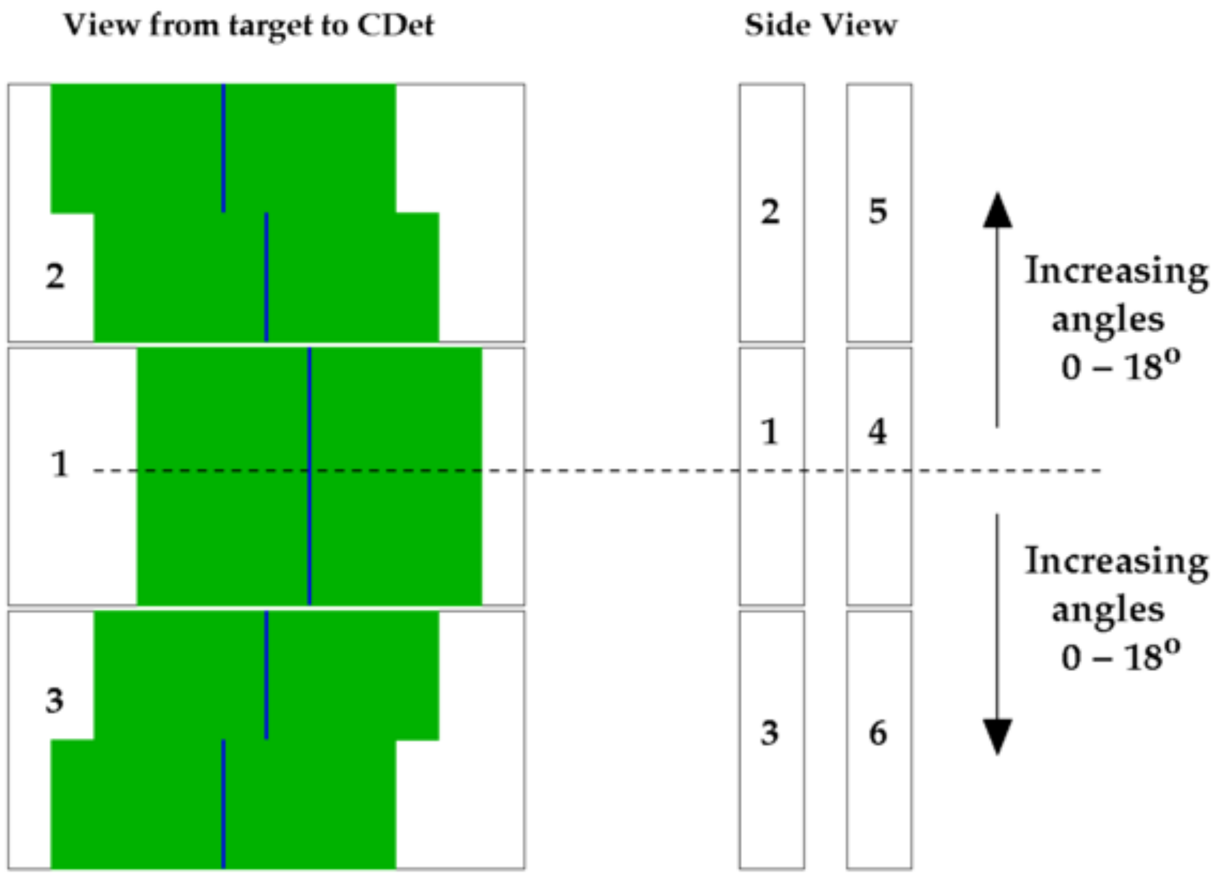




184 SMs (each is a 3x3 group of lead-glass modules),
Elevated temperature of the glass (225-185 C)
provides continuous annealing of radiation damage
(confirmed with actual beam test of the 4x4 prototype)

B. Wojtse

Electron arm: coordinate detector

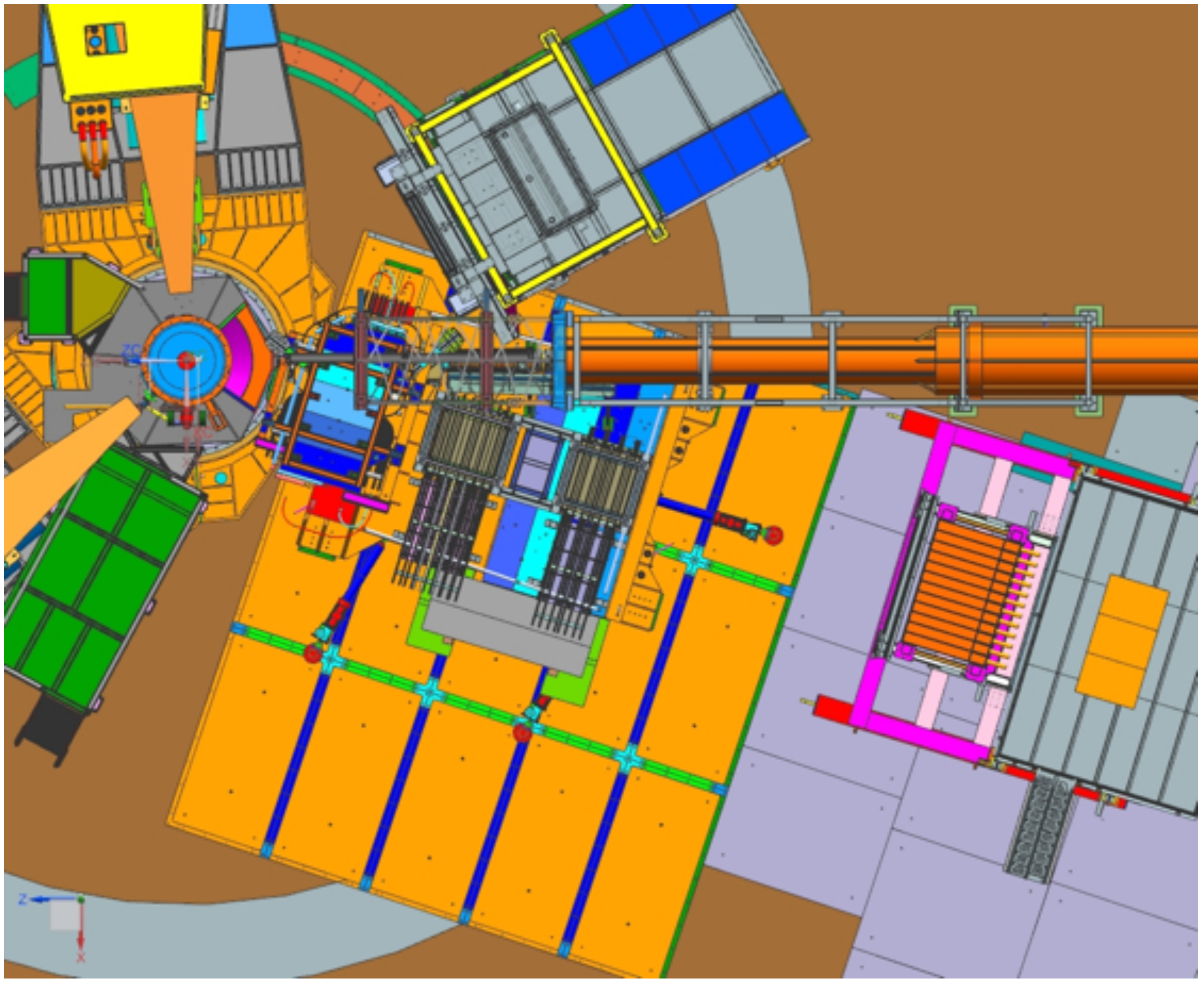


Two layers: 6 modules (each has 16 x 14 x 2 counters)

Experiment: Layout and Parameters

$H(\vec{e}, e'\vec{p})$

High Q^2 kinematics

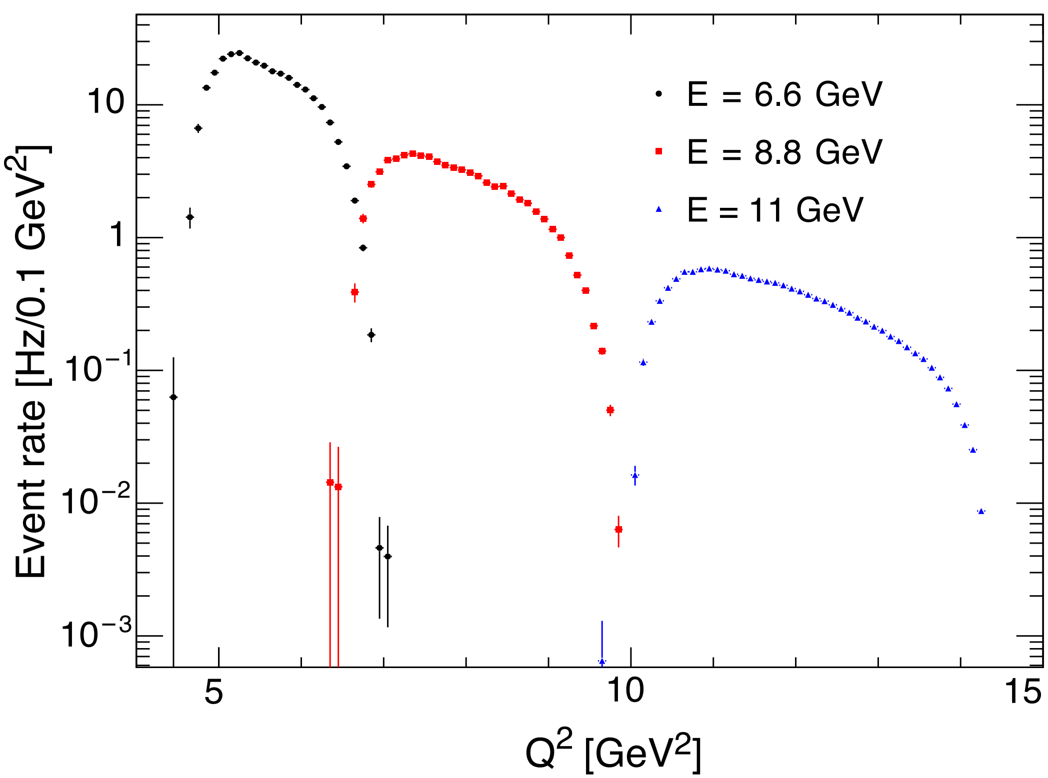


Beam: 75 μA, 85% polarization
Target: 30 cm liquid H_2
Electron arm at 30°, covers Q^2 range from 11-13 GeV^2
Proton arm at angle 17°, $\Omega \sim$ 0.3 of electron one, => 35 msr,
Spin precession angle is ~ 80°

Total 45 PAC days of production time resulting accuracy close to

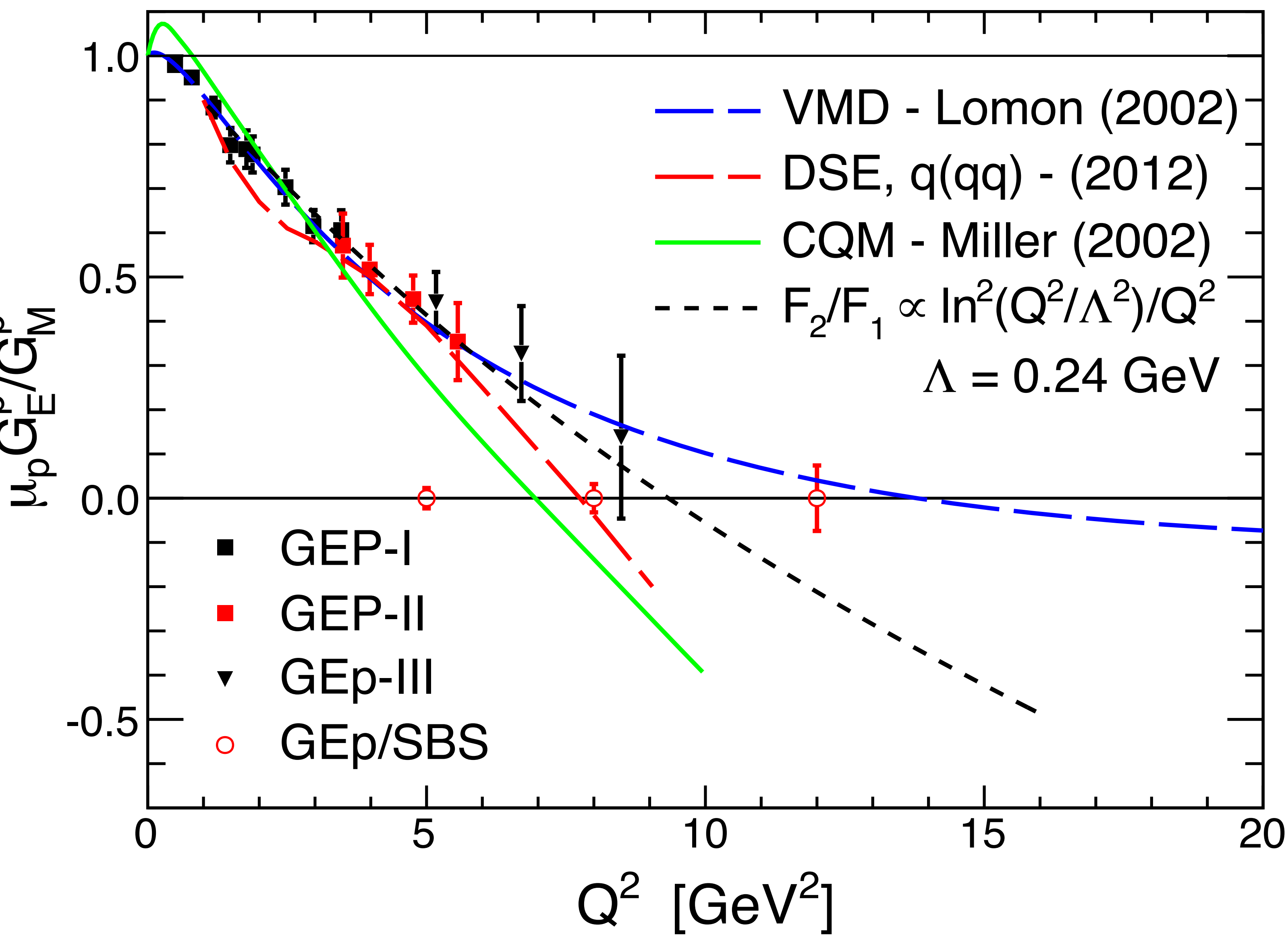
$\Delta(\mu G_E^p / G_M^p) = \pm 0.10$

GEp/SBS Q^2 acceptance and projected accuracy



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

The proton GEp form factor



Summary

After years of development the GEP experiment is on track to be ready for installation in spring 2024