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, $\alpha_{em} = 1/137$,

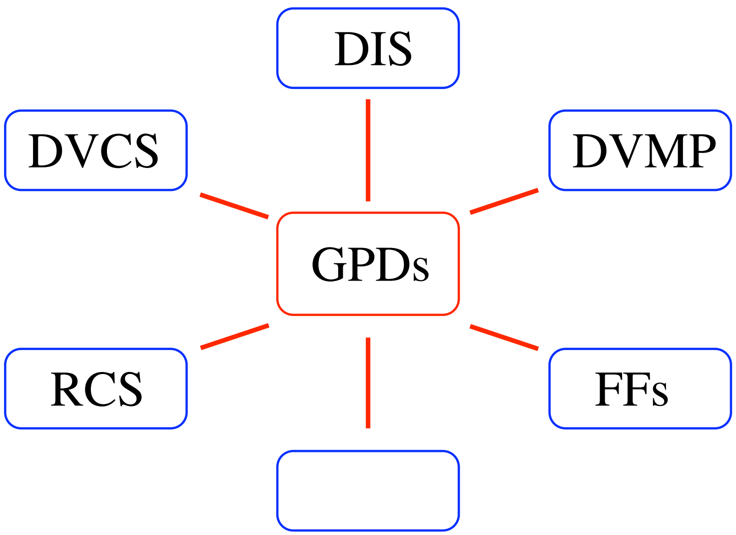
$$\mathcal{J}^{\mu}_{hadron} = ie\bar{N}(p_f)\,[\gamma^{\nu} F_1(Q^2) + \frac{i\sigma^{\mu\nu} q_{\nu}}{2M} F_2(Q^2)]\,N(p_i)$$

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

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

Scientific case

The nucleon structure in terms of GPDs



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

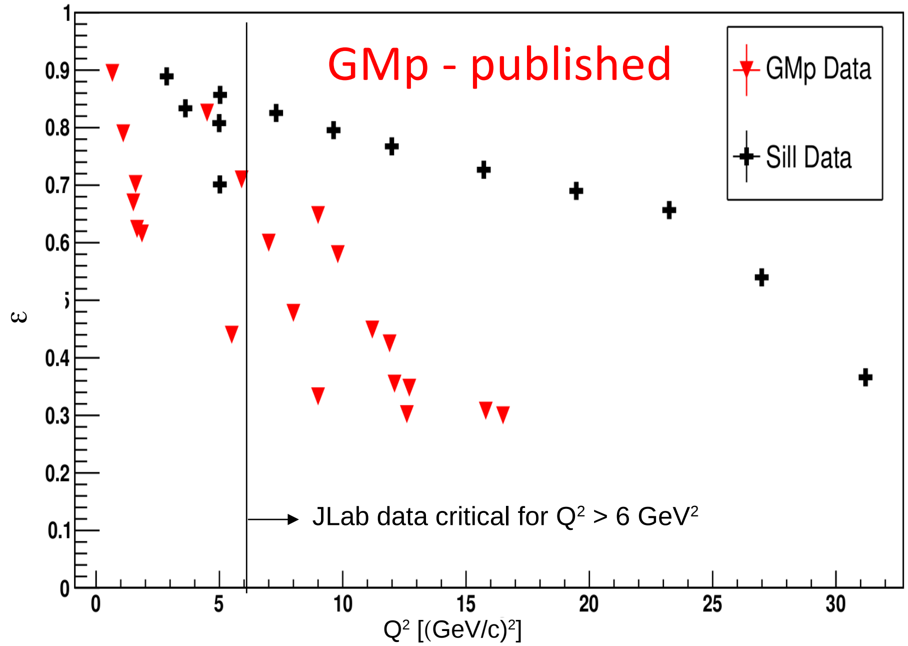
$$H^q(x, \xi = 0, t = 0) = q(x)$$

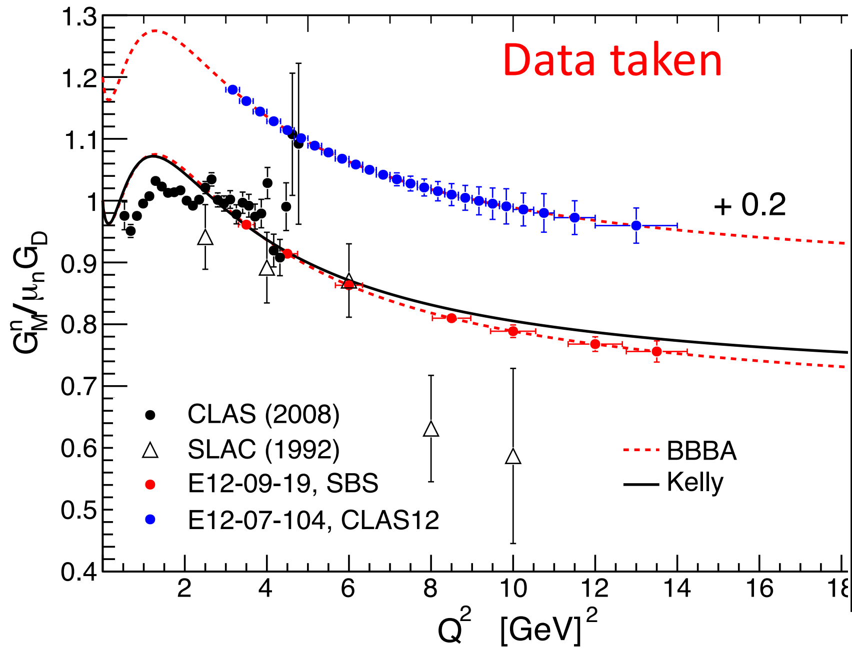
$$\tilde{H}^q(x, \xi = 0, t = 0) = \Delta q(x)$$

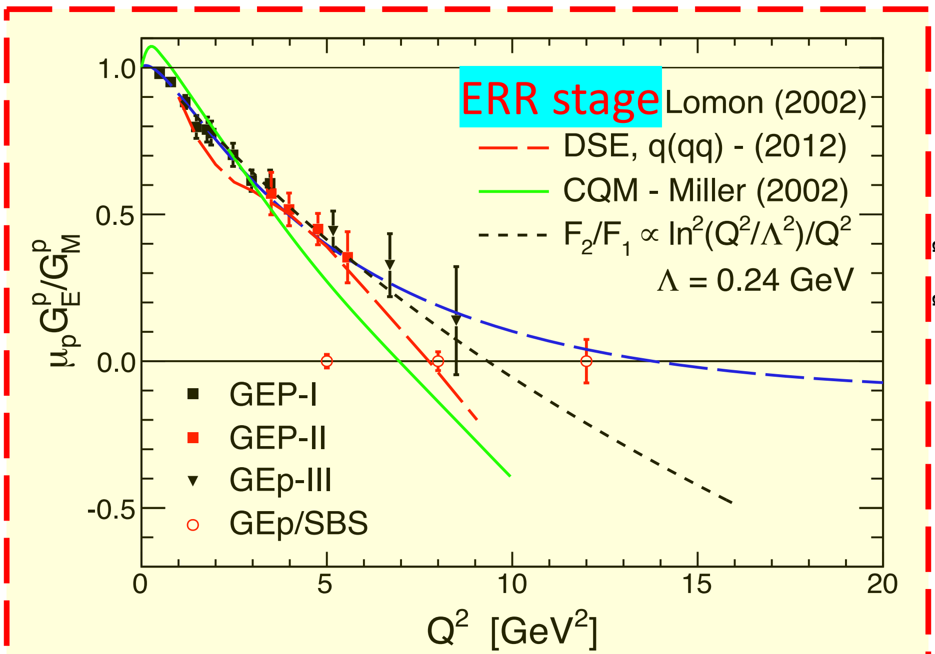
$$\int_{-1}^{+1} dx\, H^q(x, 0, Q^2) = F_1^q(Q^2)$$

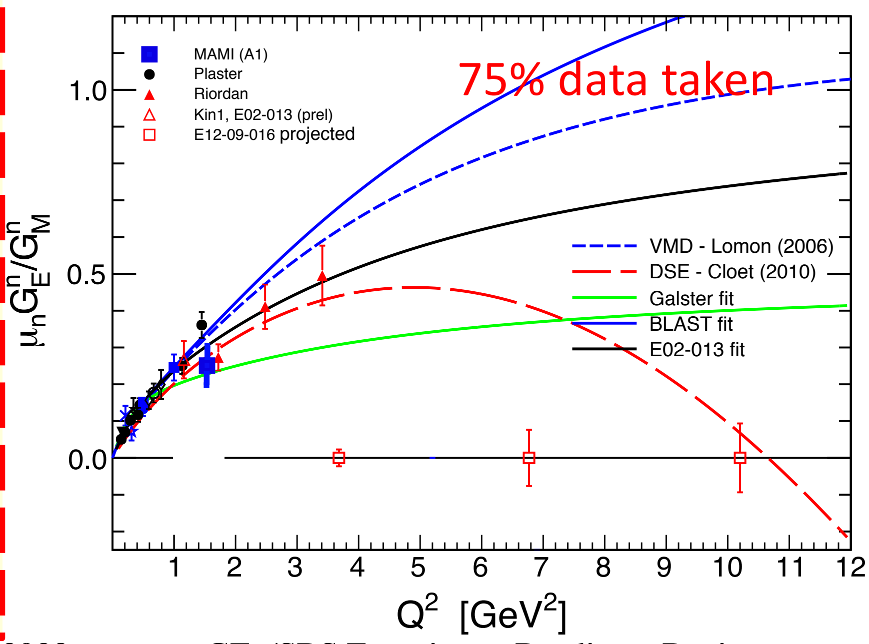
$$\int_{-1}^{+1} dx\, E^q(x, 0, Q^2) = F_2^q(Q^2)$$

The nucleon FFs

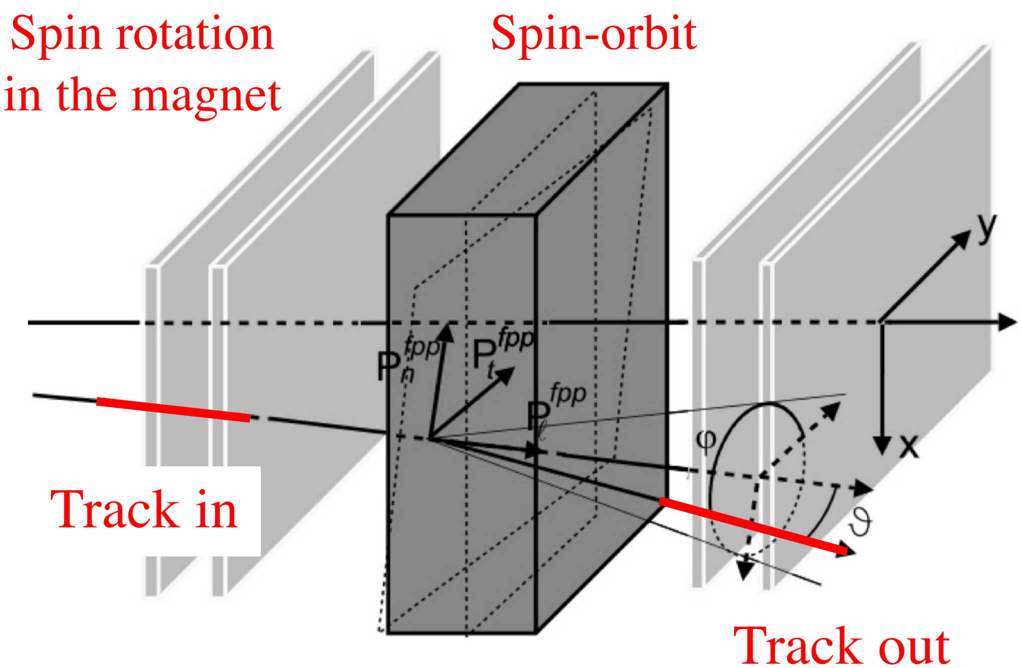


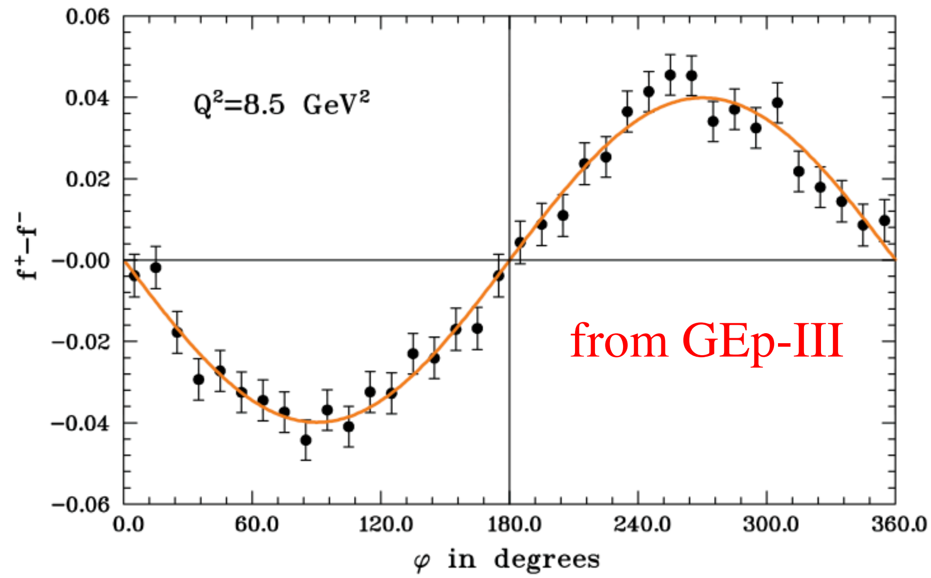






Method: Focal Plane Polarimeter





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

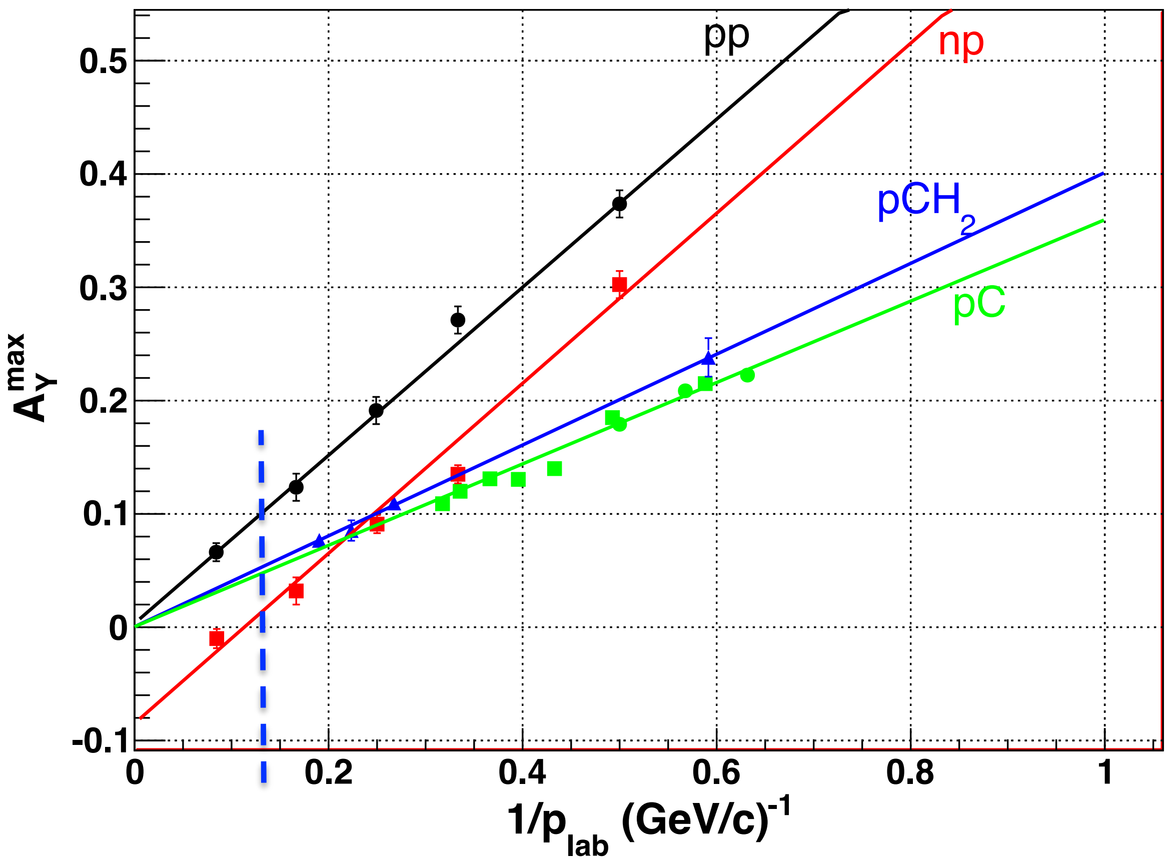
where $\pm$ refers to electron beam helicity

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

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

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

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

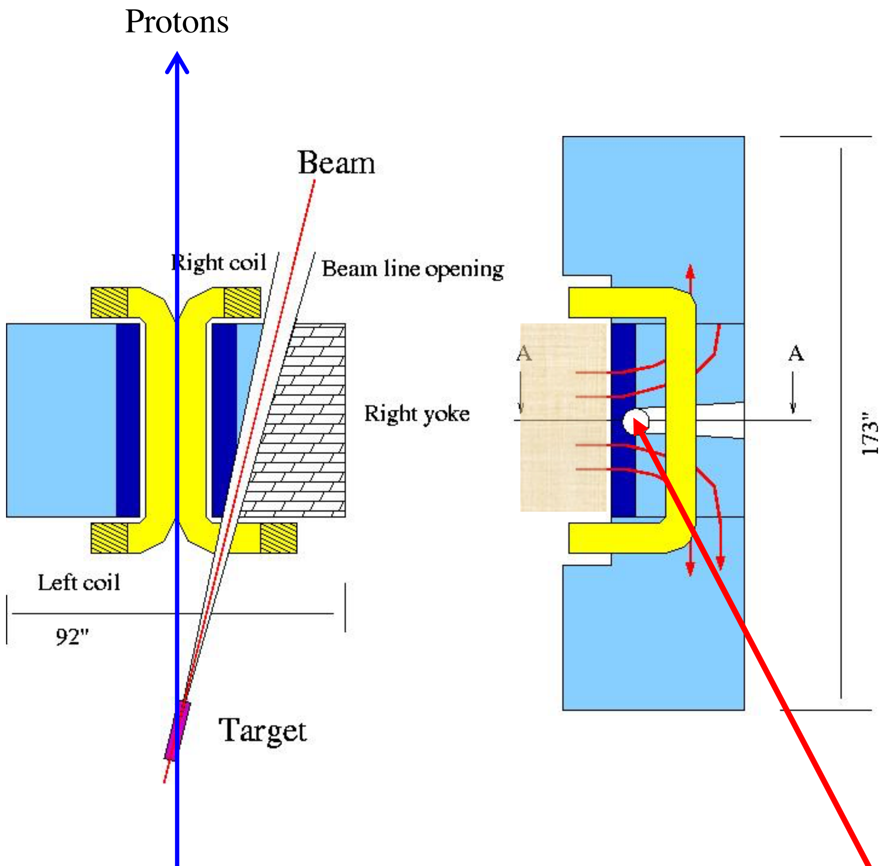
$$\propto E^2/Q^{16}$$

Need large statistics => luminosity and solid angle

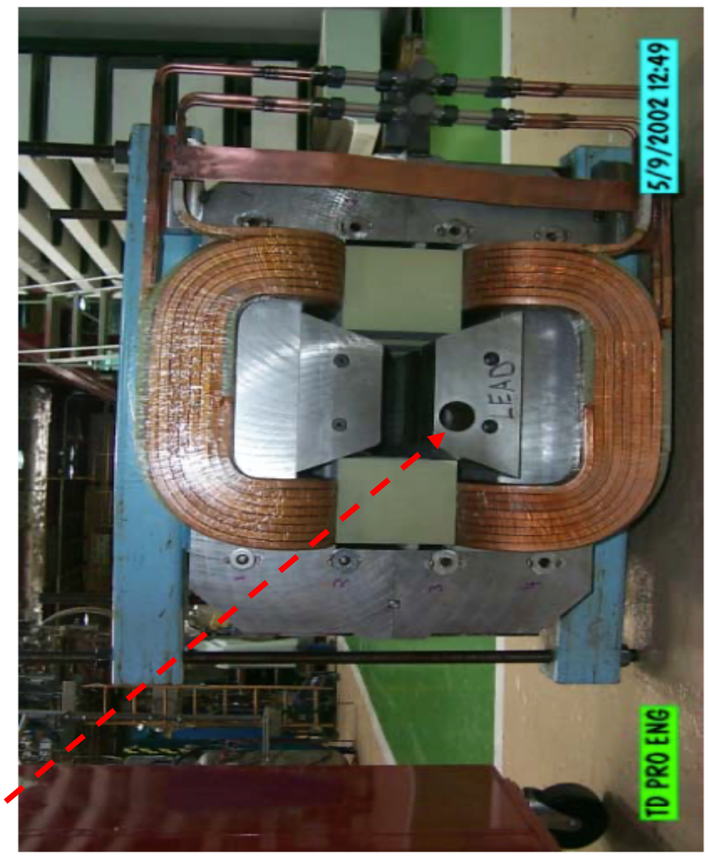
Max luminosity -> large background, radiation damage
Large solid angle -> small bend -> huge background

Solution is a modern tracking detector - GEM

Concept of a large solid angle proton arm



Lambertson magnet in accelerator

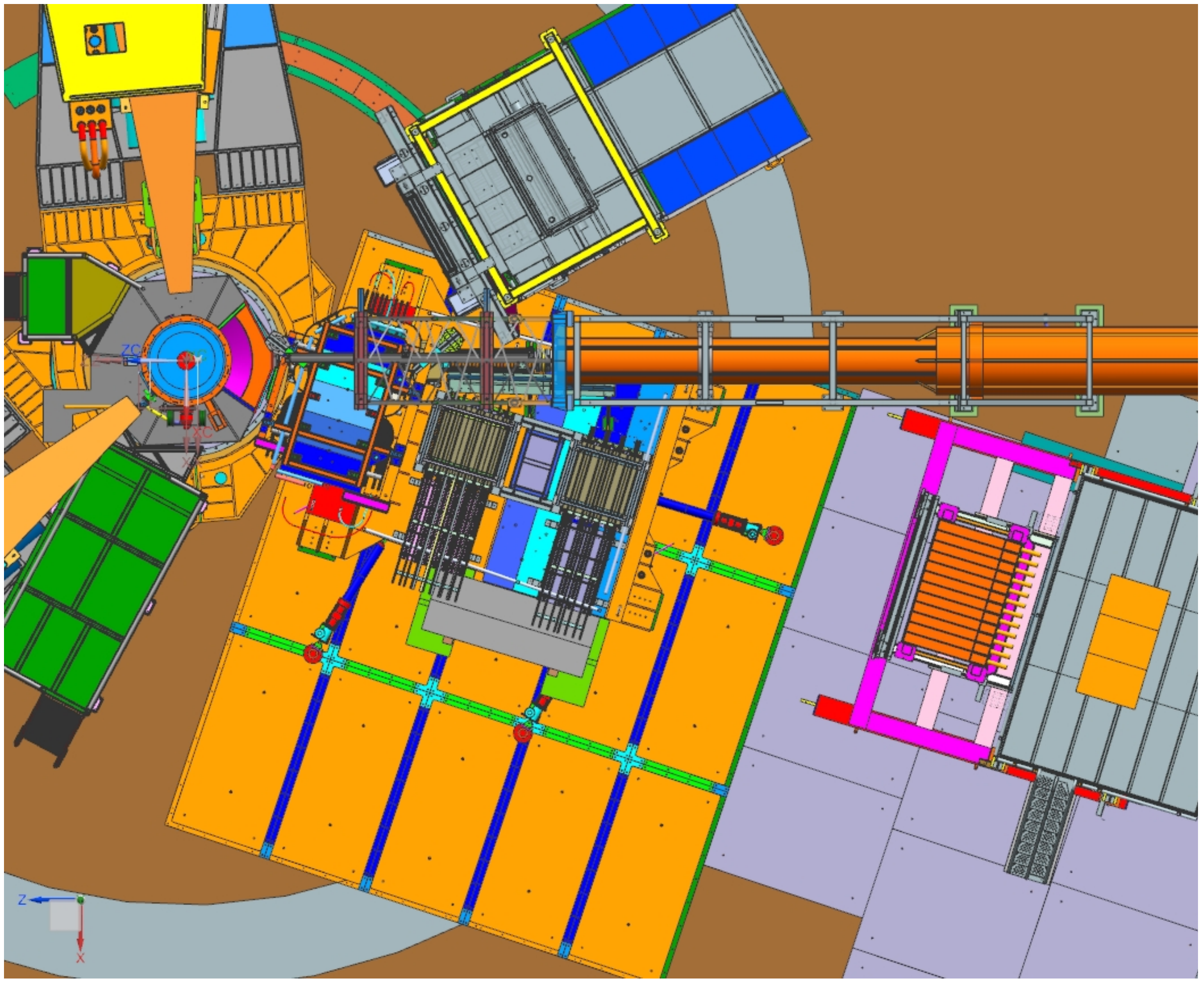


beam

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

Experiment: Layout and Parameters

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

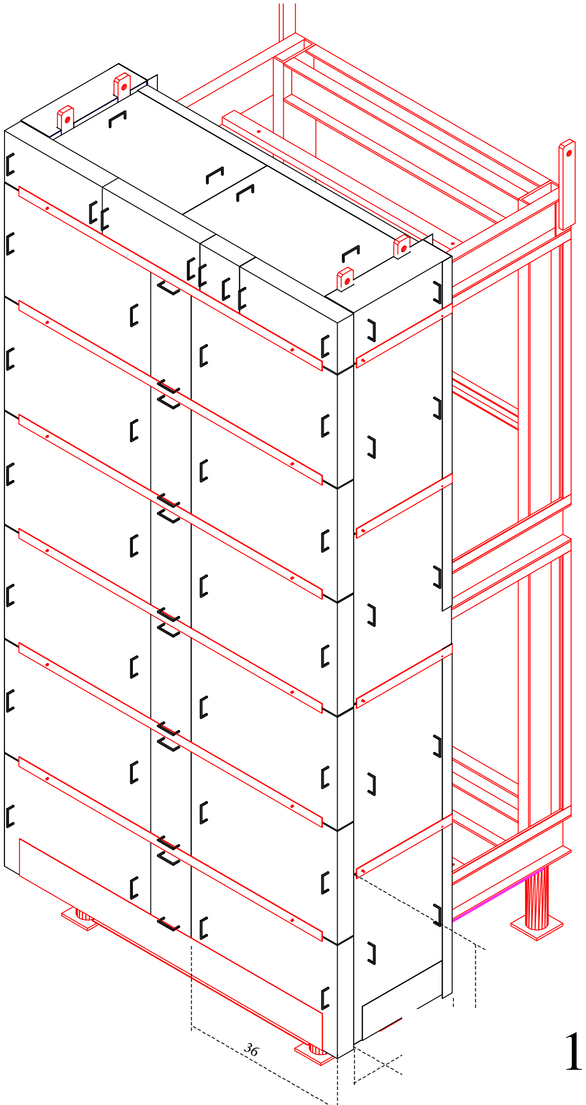


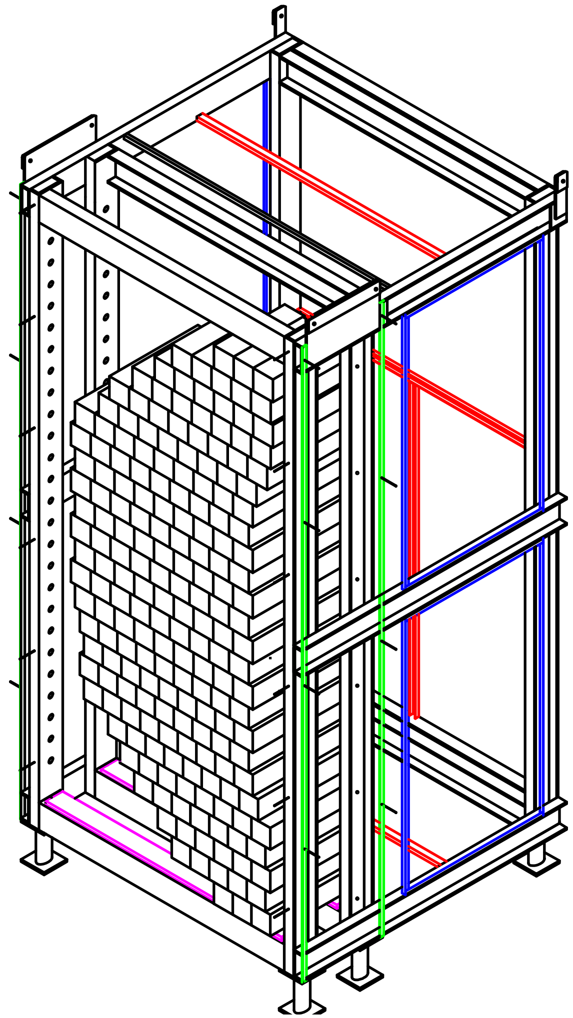
Beam: 75 μA, 85% polarization
Target: 30 cm liquid H_2
Electron arm at 30^o, covers Q^2 range from 11-13 GeV^2
Proton arm at angle 17^o, Ω ~ 0.3 of electron one, => 35 msr,
Spin precession angle is ~ 80^o

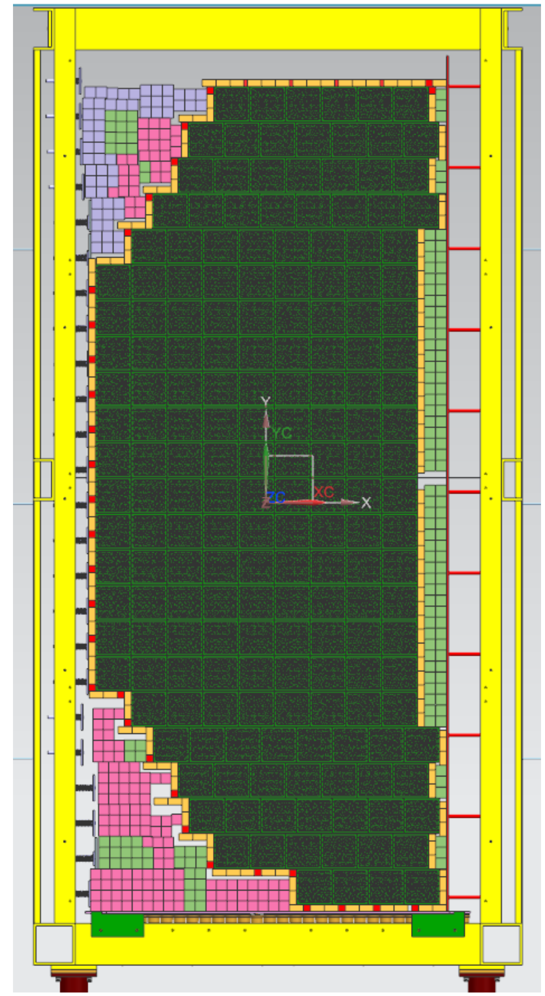
Total 45 PAC days of production time resulting accuracy close to

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

Electron arm calorimeter in the CAD model

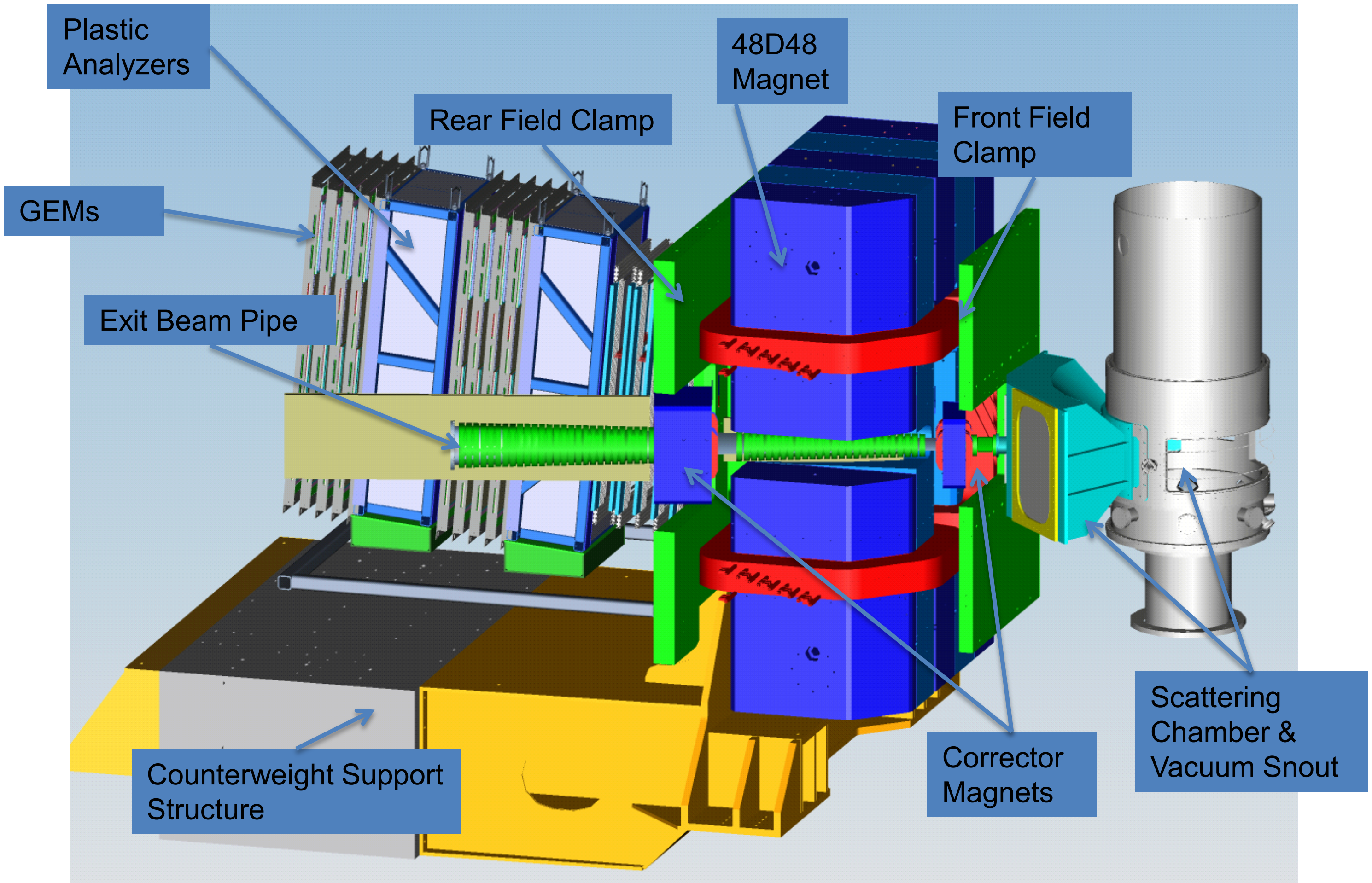






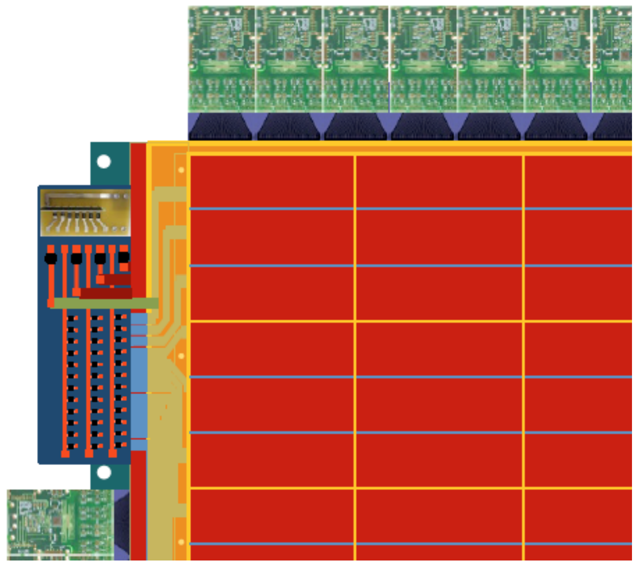
184 SMs (each is a 3x3 group of lead-glass modules),
Elevated temperature of the glass (225-185 C)
provides continuous annealing of radiation damage
(it was confirmed with actual beam test of the 4x4 prototype)

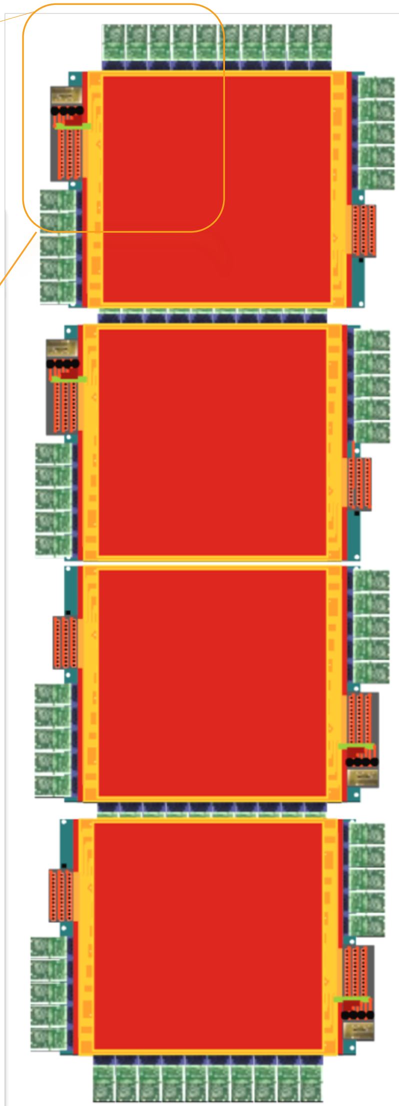
Proton arm in the CAD model



Magnet operation was confirmed in GMn and GEn runs

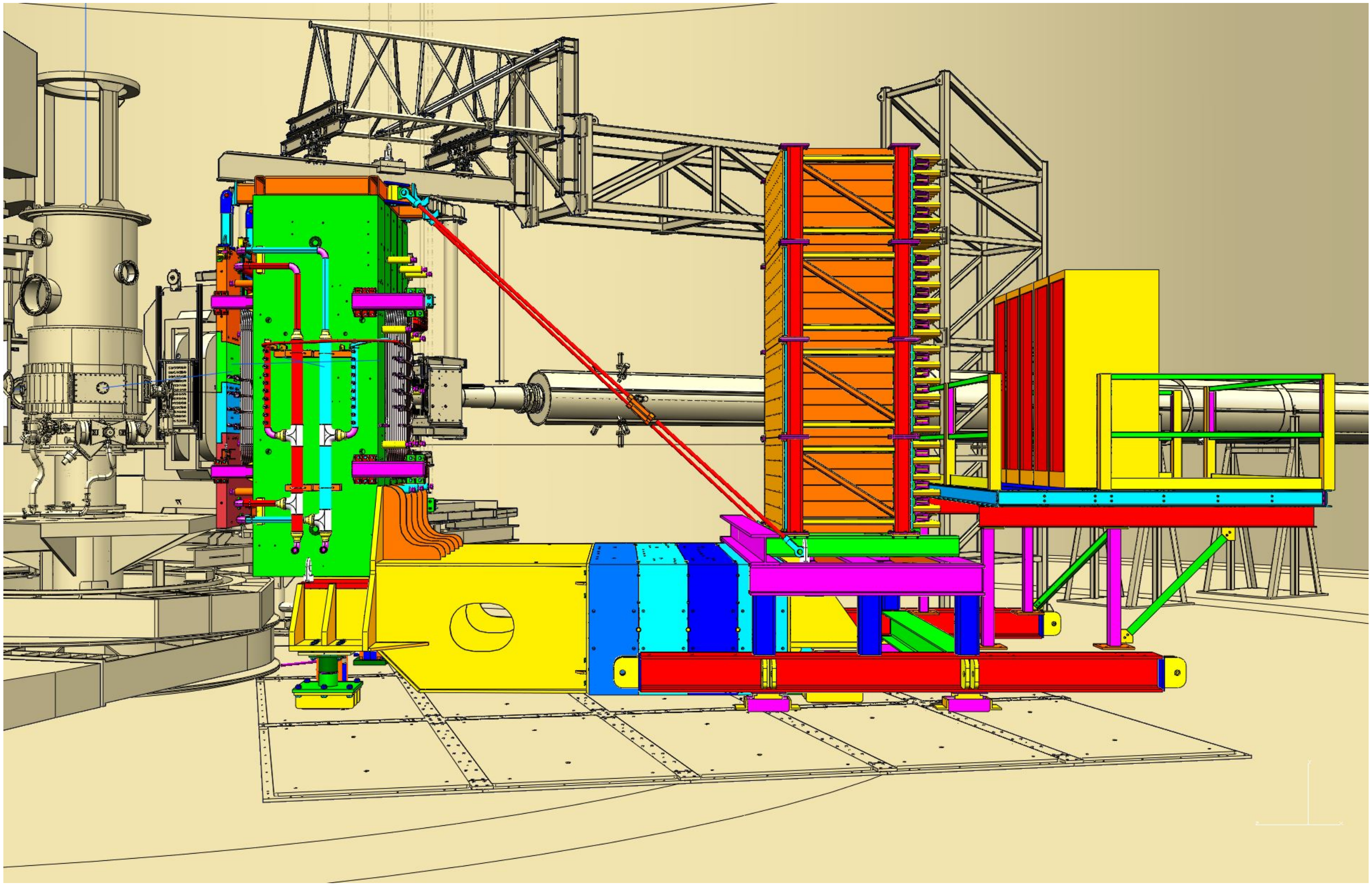
SBS trackers in polarimeter





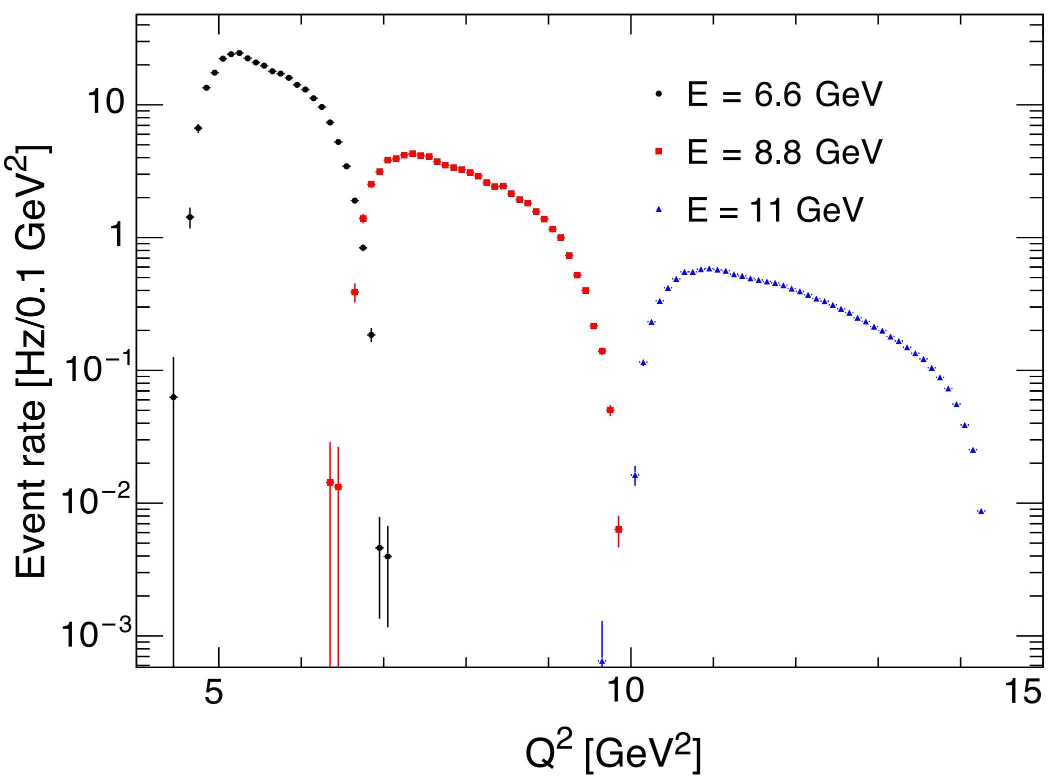
- Protection resistors are outside the chamber: reliable, easy access.
- Large alignment pins, away from the active area
- Wide frames on the two sides not in active area: better mechanical rigidity and more room for gas inlets, HV traces etc.
- Electronics arranged to minimize the material within active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

Proton arm calorimeter in the CAD model



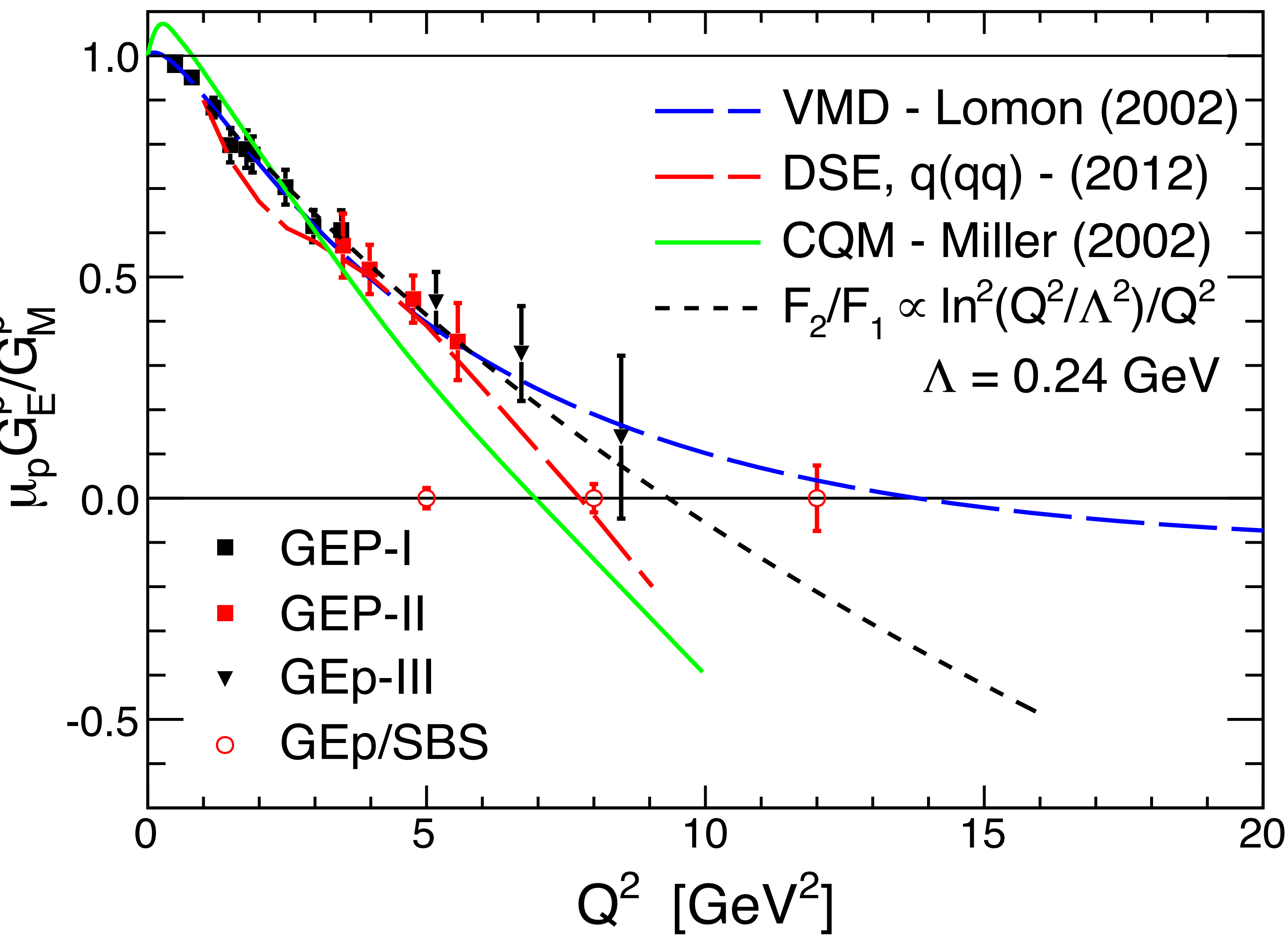
HCAL parameters confirmed in GMn and GEn runs

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

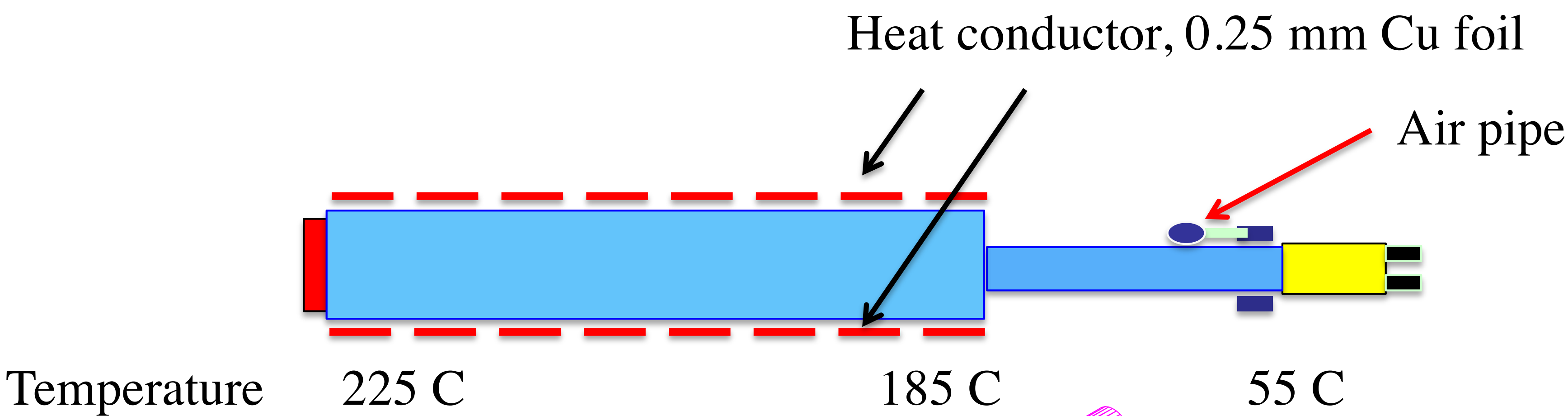
The proton GEp form factor

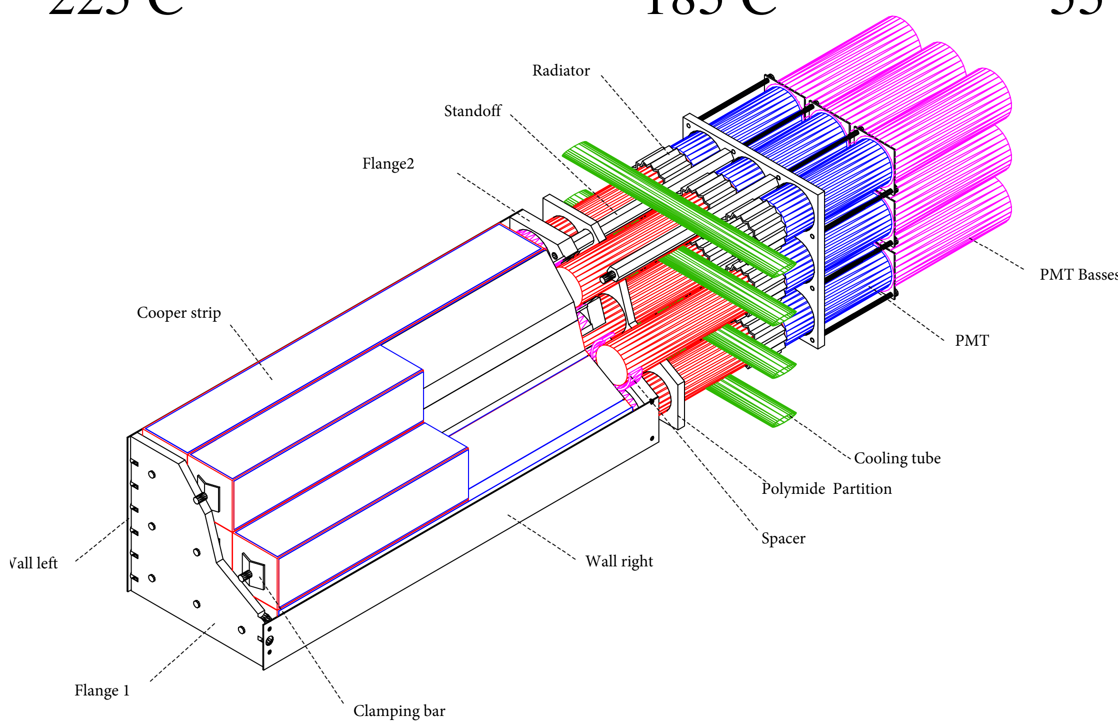


Summary

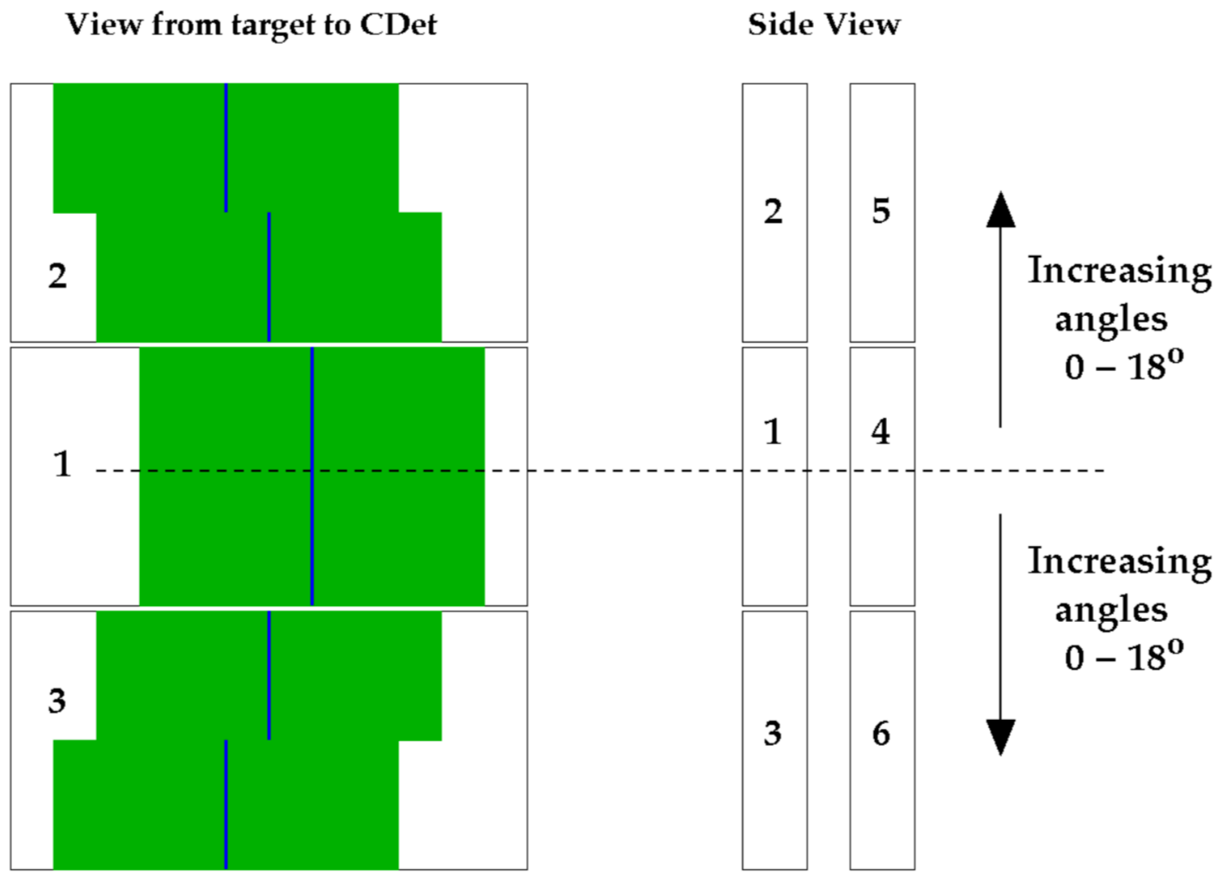
After 16 years of development the GEP experiment is on track to be ready for installation in spring 2024

Electron arm: Calorimeter's temperature, 3x3 group





Electron arm: Coordinate detector



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