Large Acceptance Proton Form Factor Ratio Measurements up to 14.5 GeV^2 using Recoil Polarization Method

Update on E12-07-109

E.Cisbani, M.Jones, N.Liyanage,
L.Pentchev, A.Puckett, B.Wojtsekhowski

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

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Electron-nucleon elastic scattering

Nucleon current, one-photon approximation, $\alpha_{em} = 1/137$,

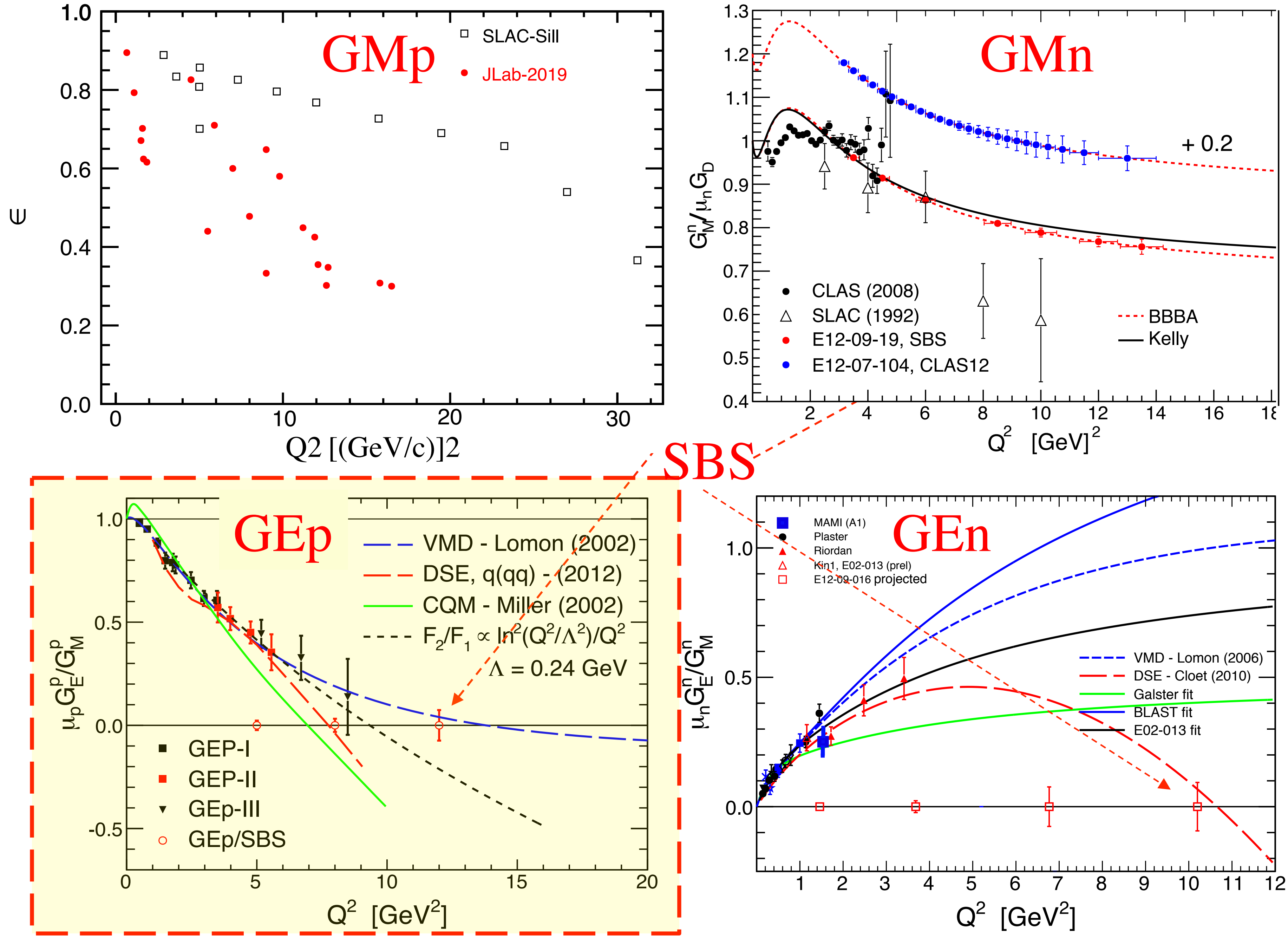
$$\mathcal{J}^{\mu}_{hadron} = ie\bar{N}(p_f)\left[\gamma^{\nu}F_1(Q^2) + \frac{i\sigma^{\mu\nu}q_{\nu}}{2M}F_2(Q^2)\right]N(p_i)$$

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

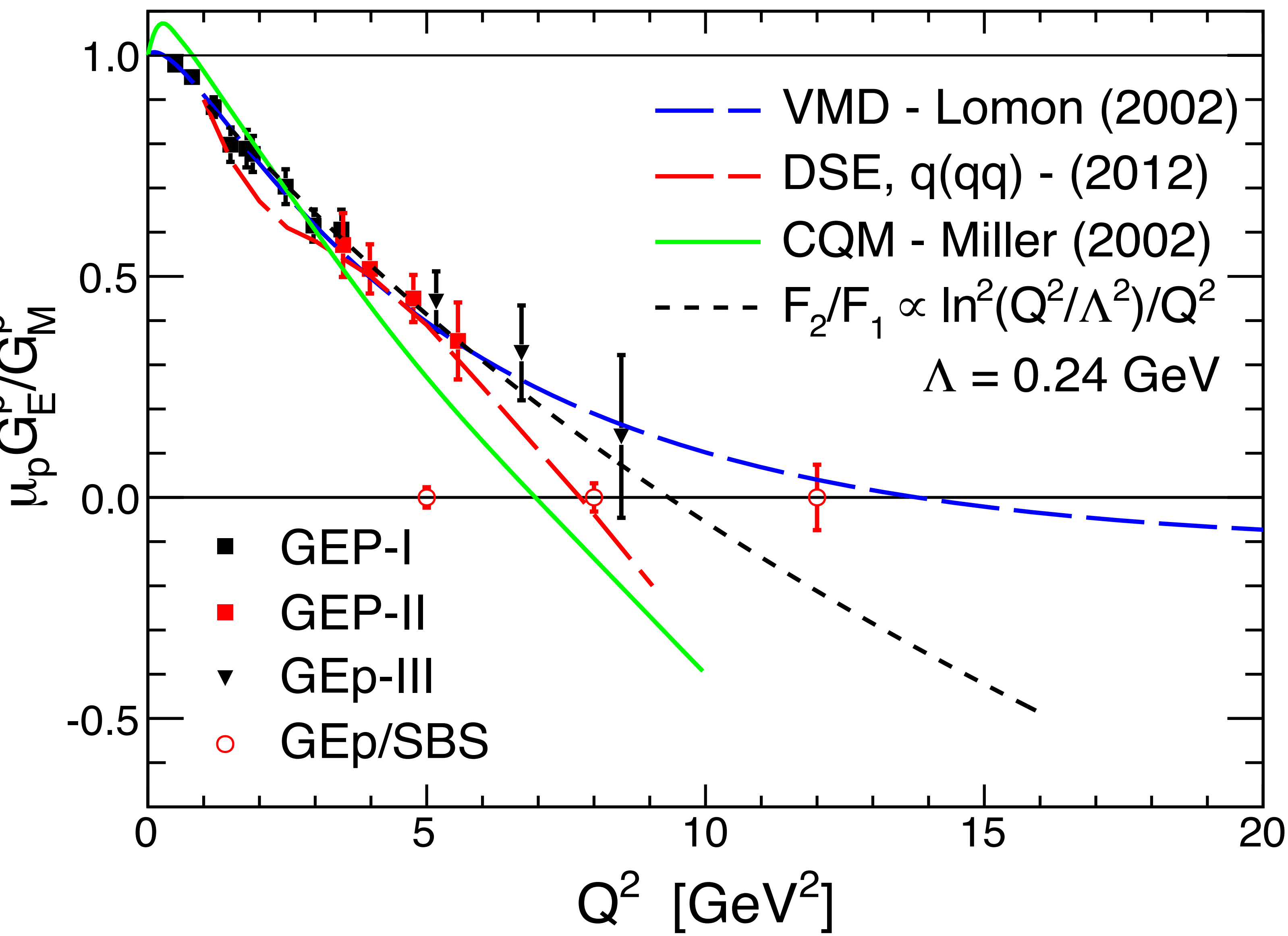
$$\frac{d\sigma}{d\Omega}(E,\theta) = \sigma_M[\frac{G_E^2+\tau G_M^2}{1+\tau}+2\tau G_M^2\tan^2(\frac{\theta}{2})]$$

Scientific case

The nucleon electromagnetic form factors



The proton GEp form factor



Challenges in this experiment

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

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

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

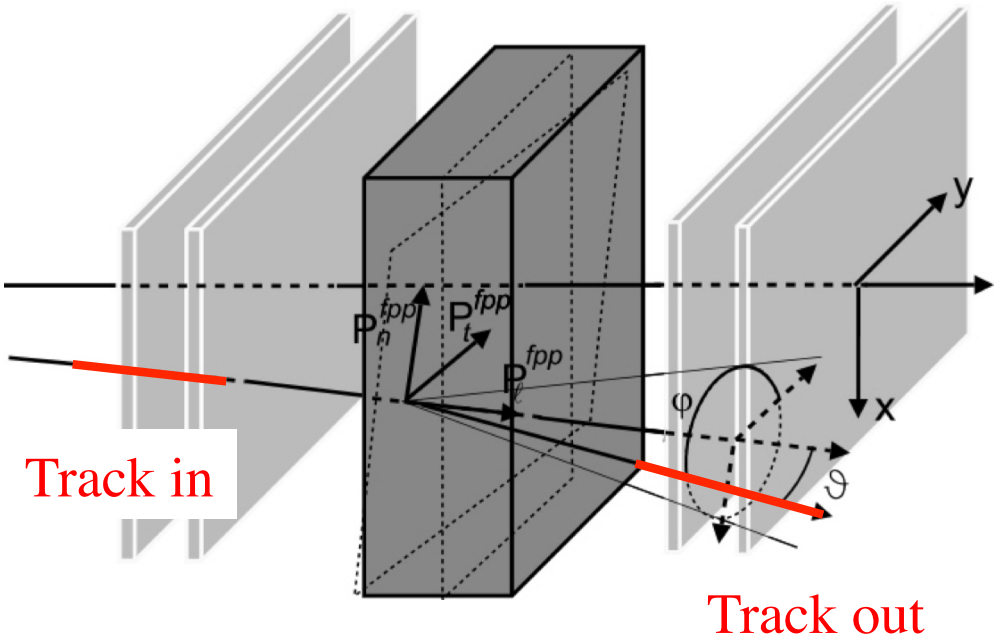
$$\propto E^2/Q^{16}$$

Need large statistics, max luminosity and solid angle

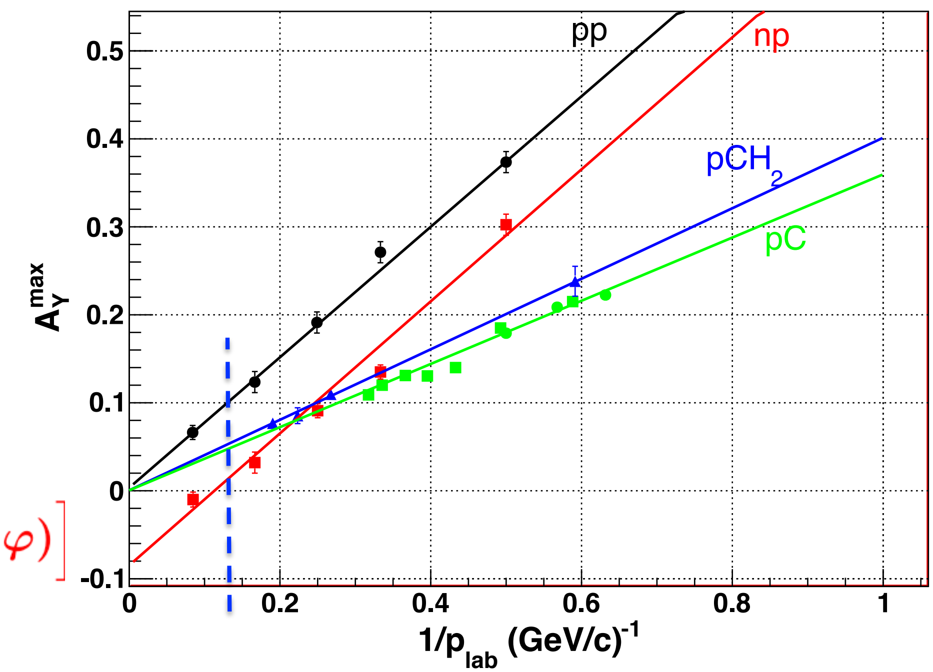
Max luminosity -> large background
Large solid angle -> small bend -> huge background

A solution is a modern tracking detector based on Gas Electron Multiplier (Fabio Sauli, 1997)

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

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

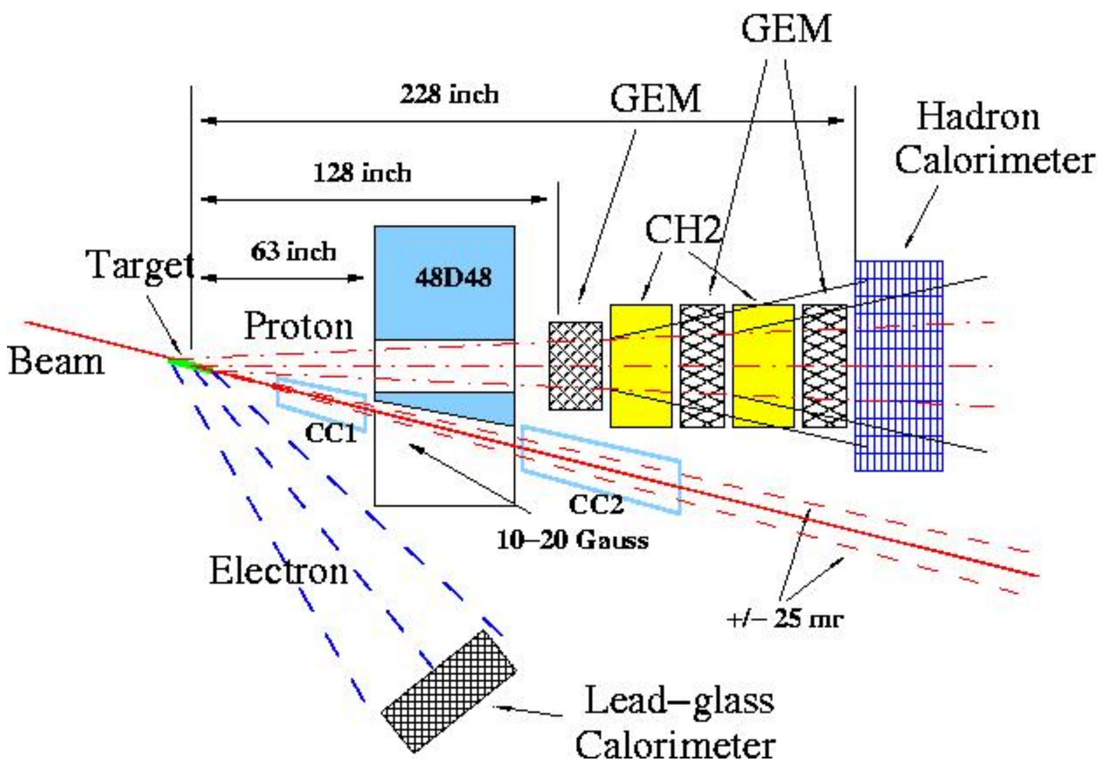
p will be ~ 7 GeV/c

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

fringe field correction

Experiment: Layout and Parameters

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



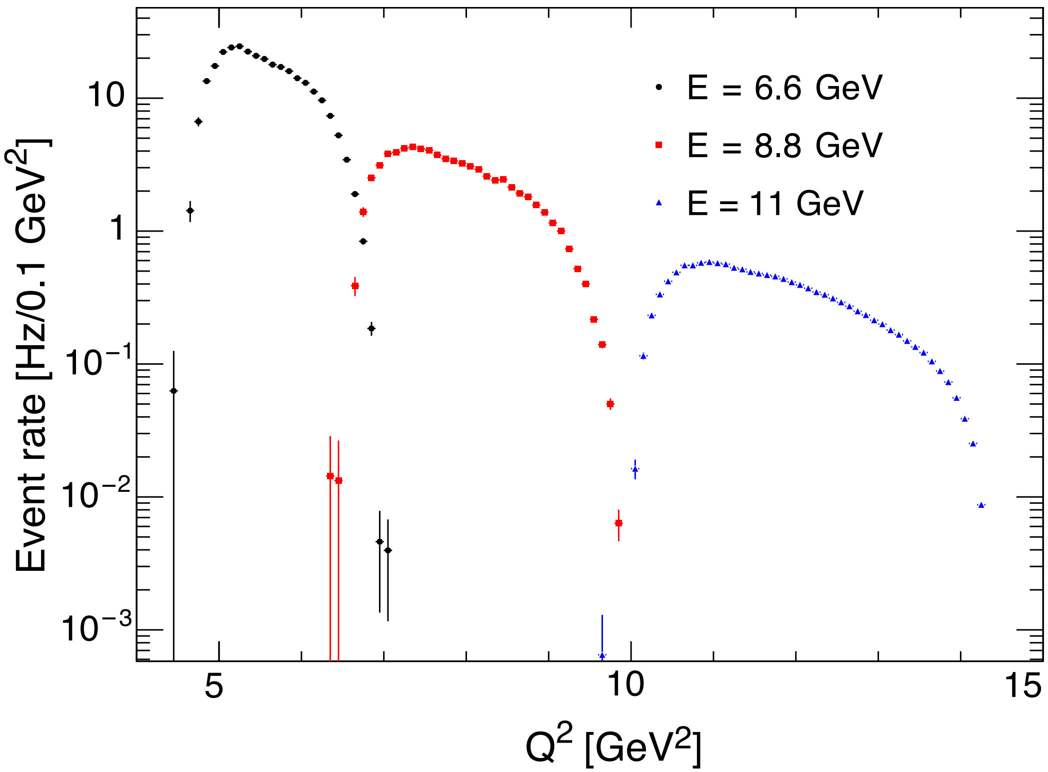
Beam: 75 μA, 85% polarization
Target: 30 cm liquid H_2
Electron arm at 29^o, covers Q^2 range from 12.5 to 16 GeV^2
Proton arm at angle 17^o,
Ω = 35 msr ,
Spin precession angle is ~ 90^o
(it is optimum)

Event rate is 10 times higher than with standard spectrometer

From ~~58~~ 45 days of production time resulting accuracy is

$$\Delta(\mu_p G_E^p / G_M^p) < 0.10$$

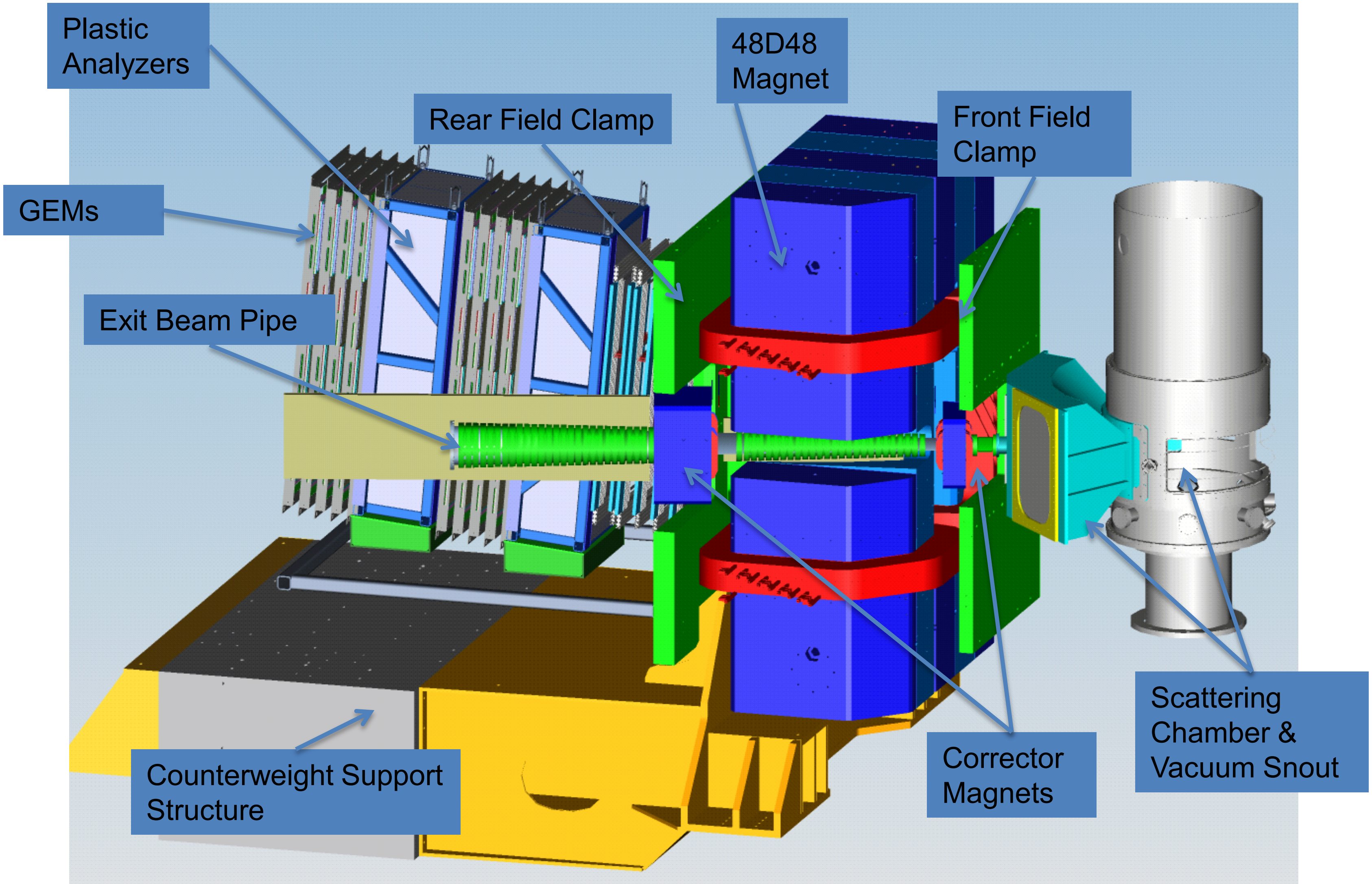
GEp/SBS Q^2 acceptance, projected accuracy, and beam time request



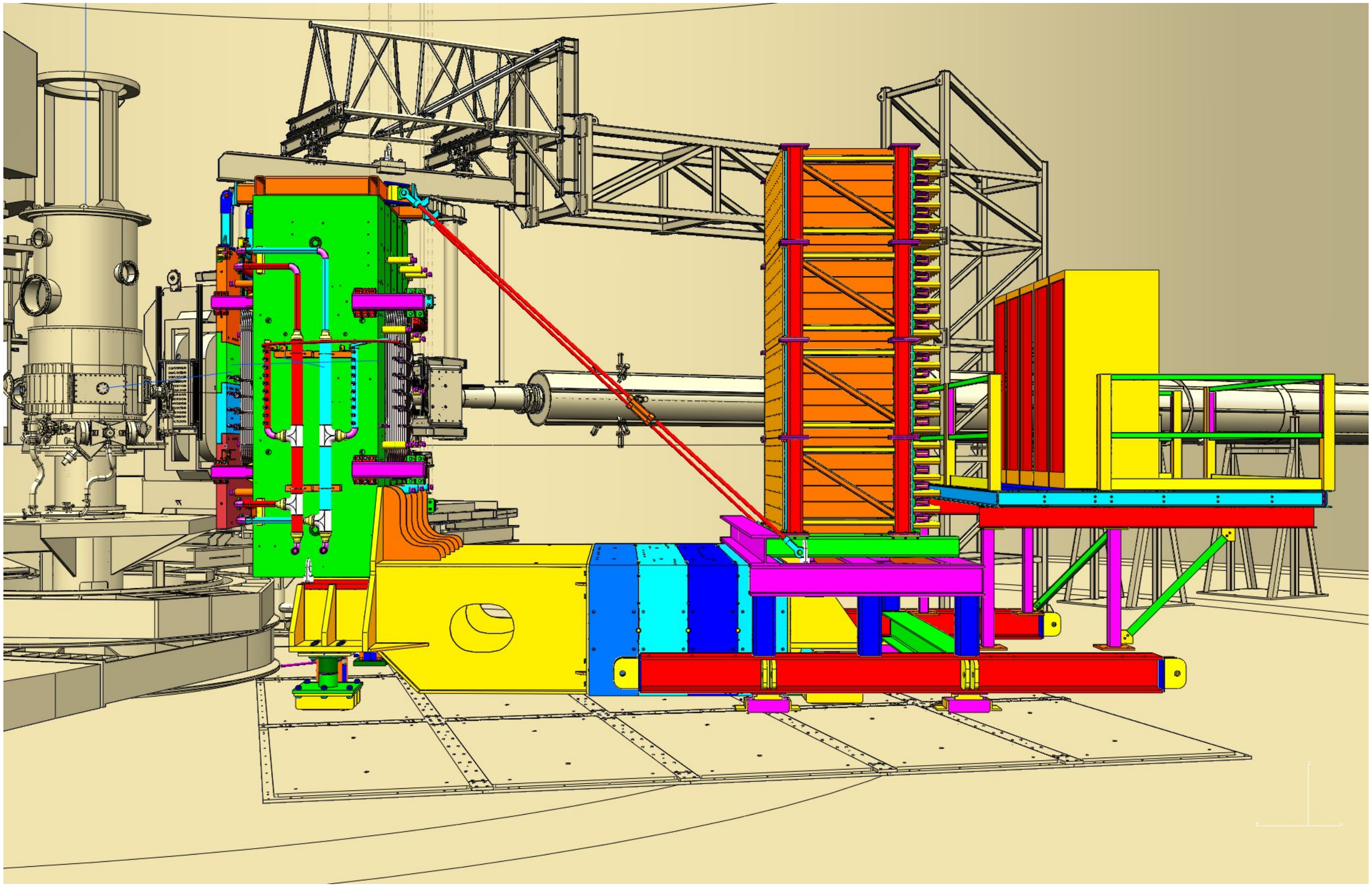
E_{beam}, GeV	Q^2 range, GeV^2	$\langle Q^2 \rangle$ GeV^2	θ_{ECAL} degrees	$\langle E'_e \rangle$, GeV	θ_{SBS} degrees	$\langle P_p \rangle$ GeV	$\langle \sin\chi \rangle$ degrees	Event rate Hz	Days	$\Delta\,(\mu G_E/G_M)$
6.6	4.5-7.0	5.5	29.0	3.66	25.7	3.77	0.72	291	2	0.029
8.8	6.5-10.0	7.8	26.7	4.64	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

Total 45 days

Proton arm in the model

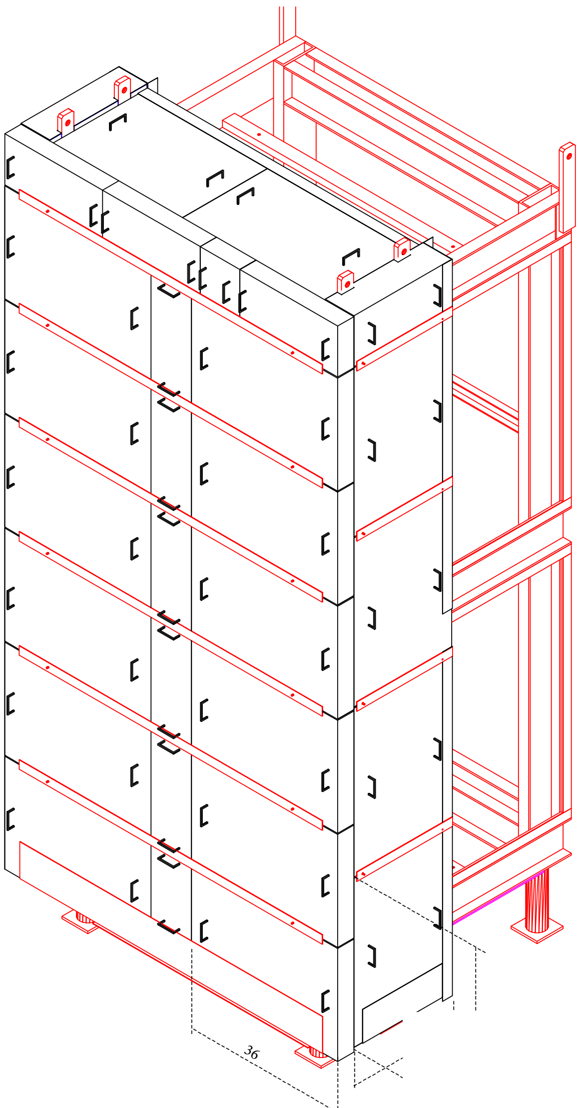


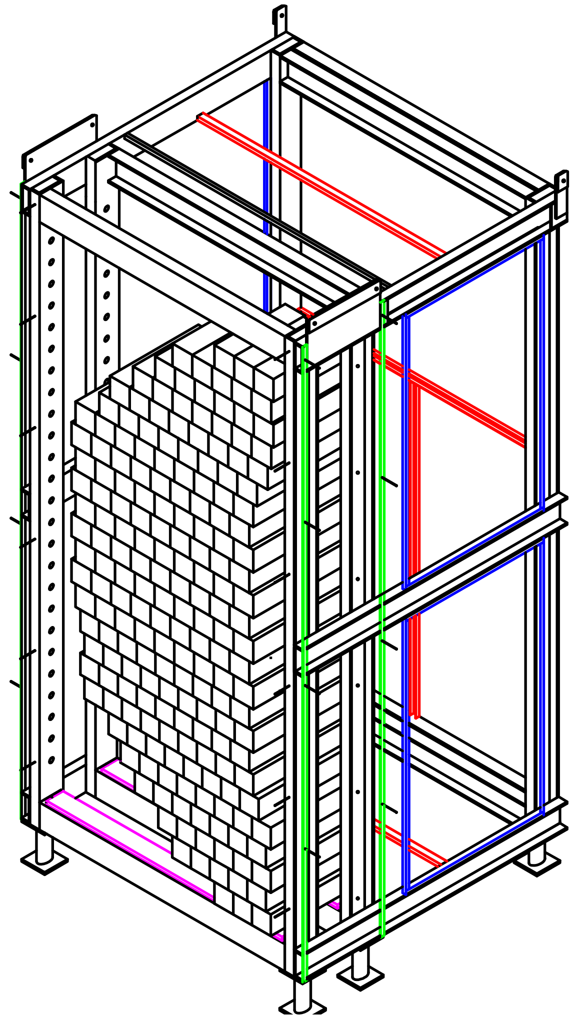
Proton arm calorimeter in the model

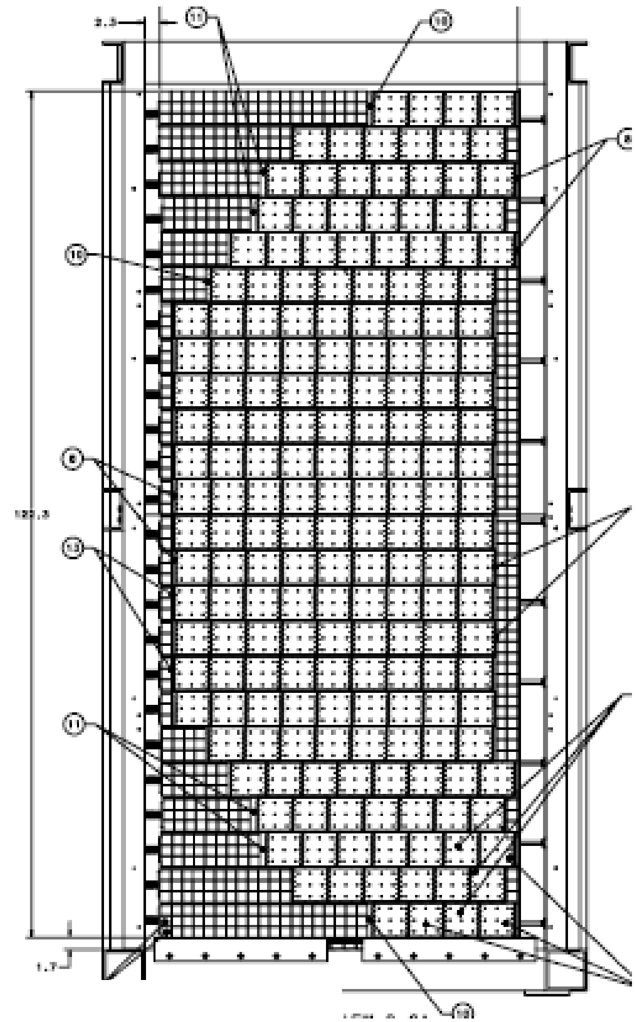


energy resolution $60\%/\sqrt{E[GeV]}$
time resolution ~ 0.5 ns

Electron arm calorimeter in the model





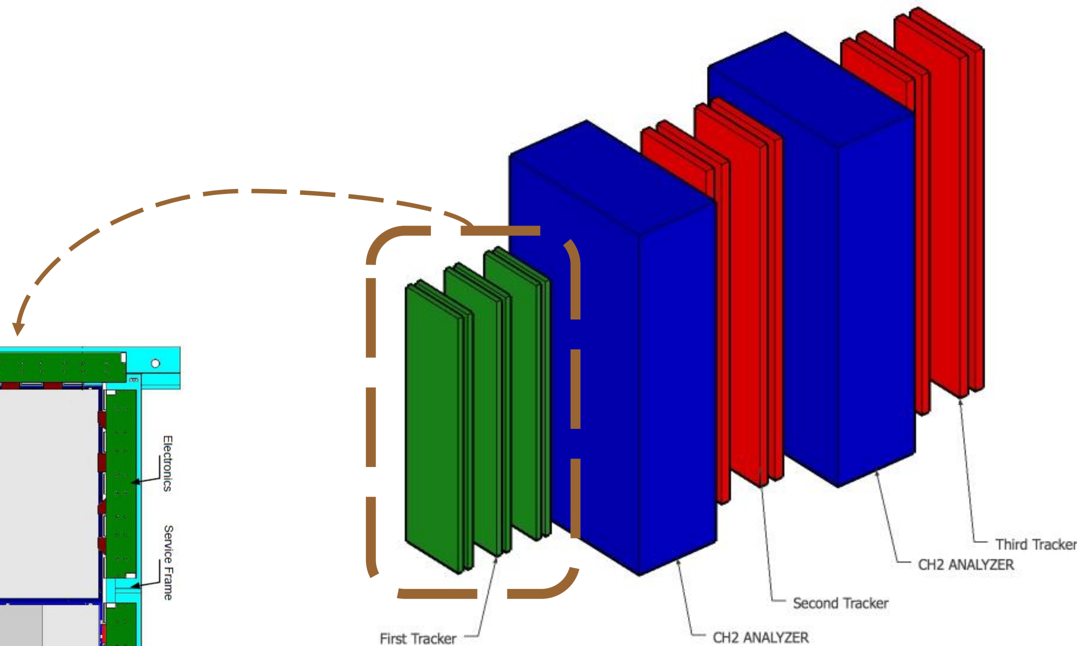


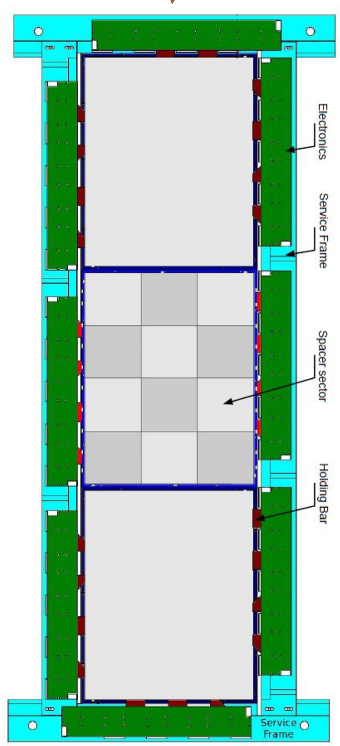
1737 lead-glass modules

Elevated temperature of the glass (225-185 C)

provides continuous annealing of radiation damage

SBS trackers/polarimeters:
Front tracker: INFN/UVa





Hit spatial resolution ~ 70 μm

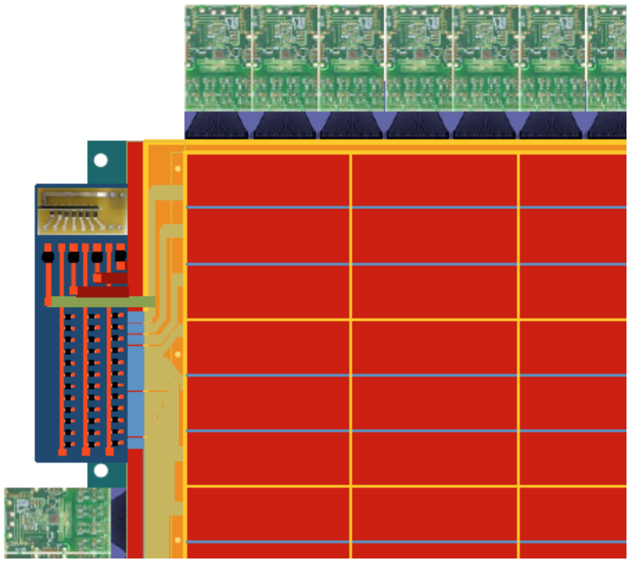
Stand large background $(\gamma \sim 250MHz/cm^2,\ e + \pi \sim 160kHz/cm^2)$

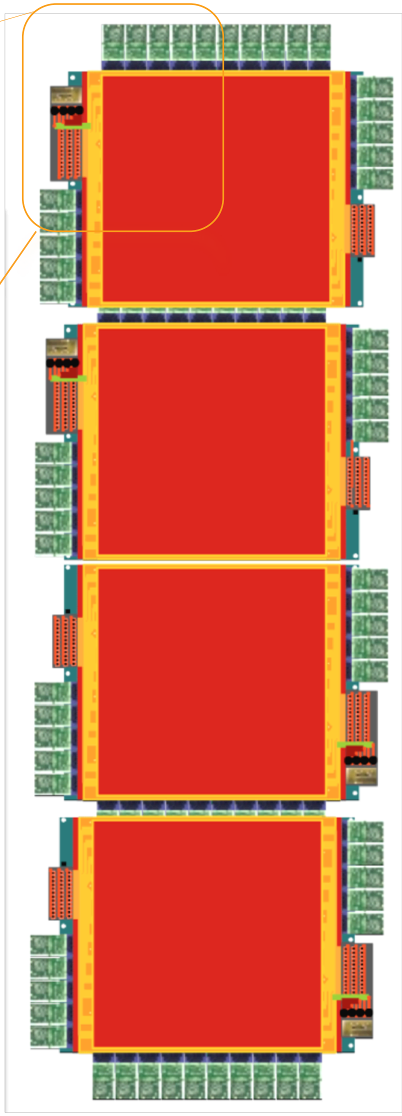
Transverse area at least 40x120 cm^2

Event rate at the level of 20 kevents/s

Reuse in different configurations (SBS/GEp, BigBite/GEn …)

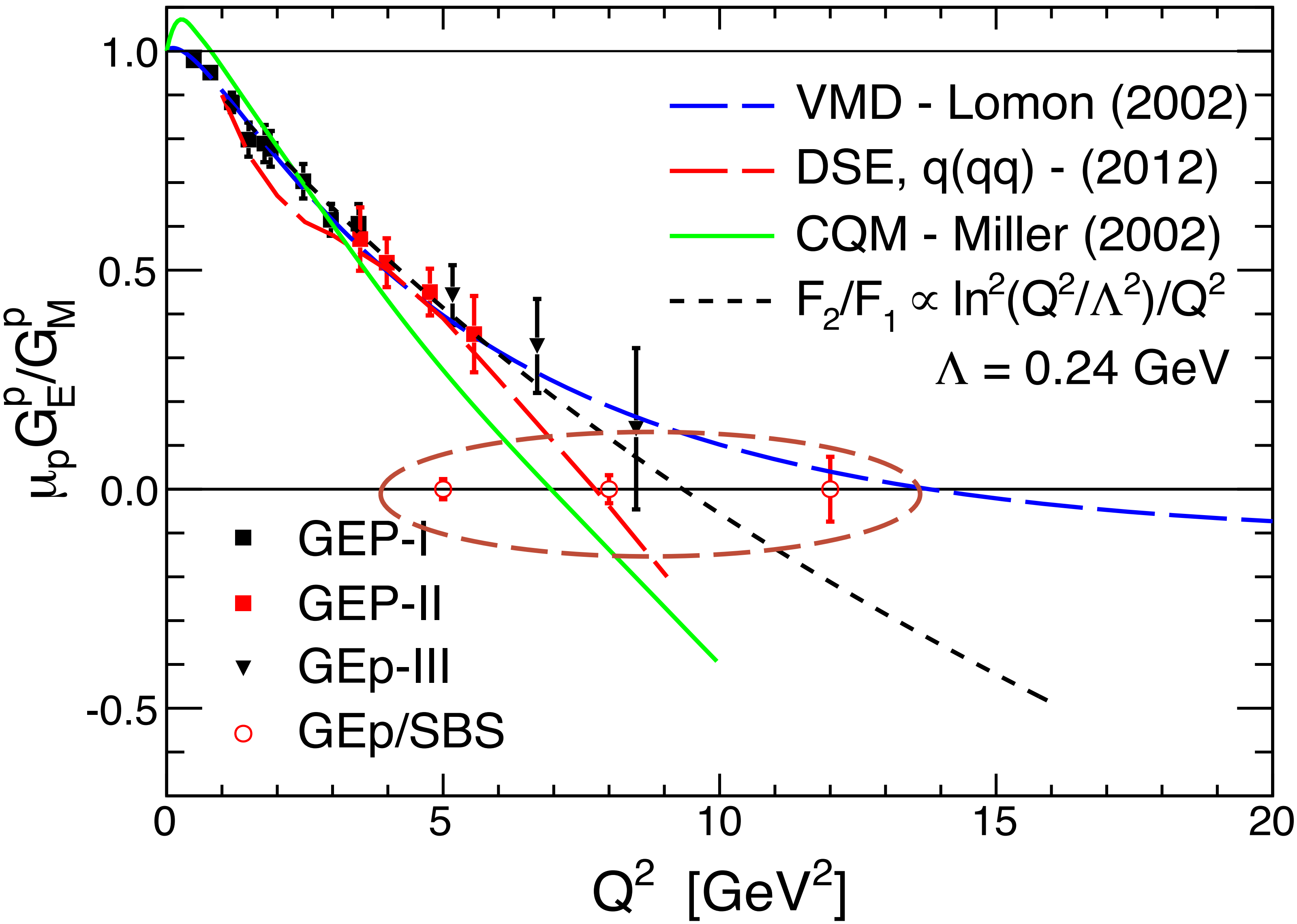
SBS trackers/polarimeters:
Rear tracker: UVa/INFN





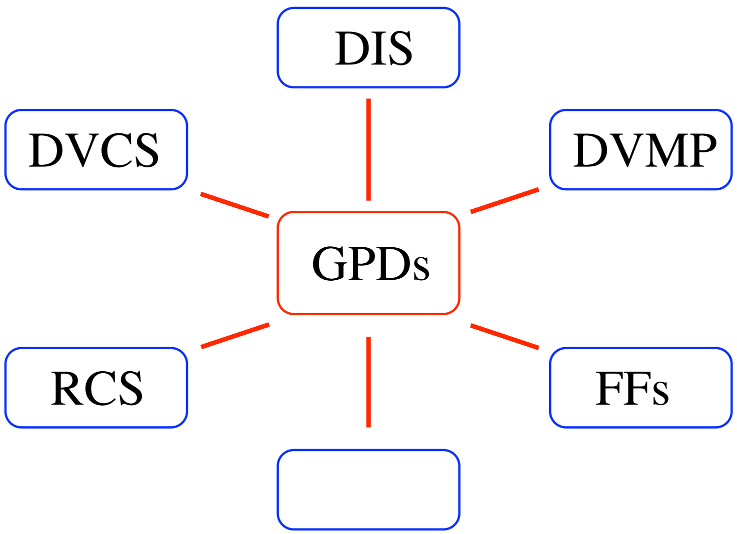
- Protection resistors are outside the chamber: reliable, easy access.
- Large alignment pins, away from the active area
- Wide frames on the two sides not in active area: better mechanical rigidity and more room for gas inlets, HV traces etc.
- Electronics arranged to minimize the material within active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

The proton GEp/GMp form factor ratio



Scientific case

The nucleon structure in terms of GPDs



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

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

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

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

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

Scientific case

The nucleon structure in terms of GPDs

$$F_1(t) = \sum_q e_q \int dx H_q(x,t)$$

Muller, Ji, Radyushkin

$$q(x,\mathrm{b}) = \int \frac{d^2q}{(2\pi)^2} e^{i\,\mathrm{q}\cdot\mathrm{b}} H_q(x, t=-\mathrm{q}^2)$$

M.Burkardt

P.Kroll: u/d segregation

$$\rho(b) \equiv \sum_q e_q \int dx\; q(x,\mathrm{b}) = \int d^2q F_1(\mathrm{q}^2) e^{i\,\mathrm{q}\cdot\mathrm{b}}$$

$$\rho(b) = \int_0^\infty \frac{Q\cdot dQ}{2\pi} J_0(Qb) \frac{G_E(Q^2)+\tau G_M(Q^2)}{1+\tau}$$

G.Miller

center of momentum $R_\perp = \sum_i x_i \cdot r_{\perp,i}$

b is defined relative to $R_\perp$

Transverse center of the quarks longitudinal momentum fractions

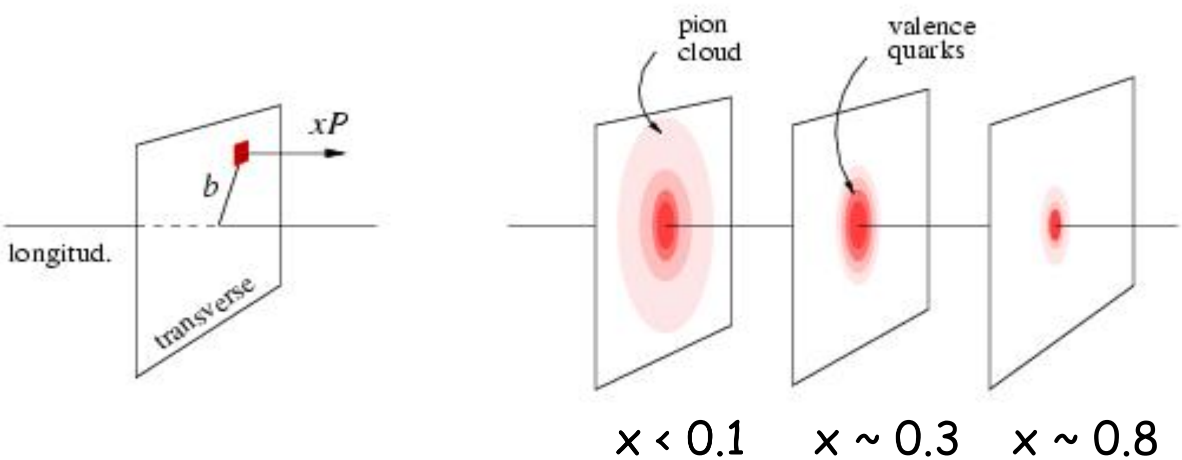
Mapping transverse distribution(s)

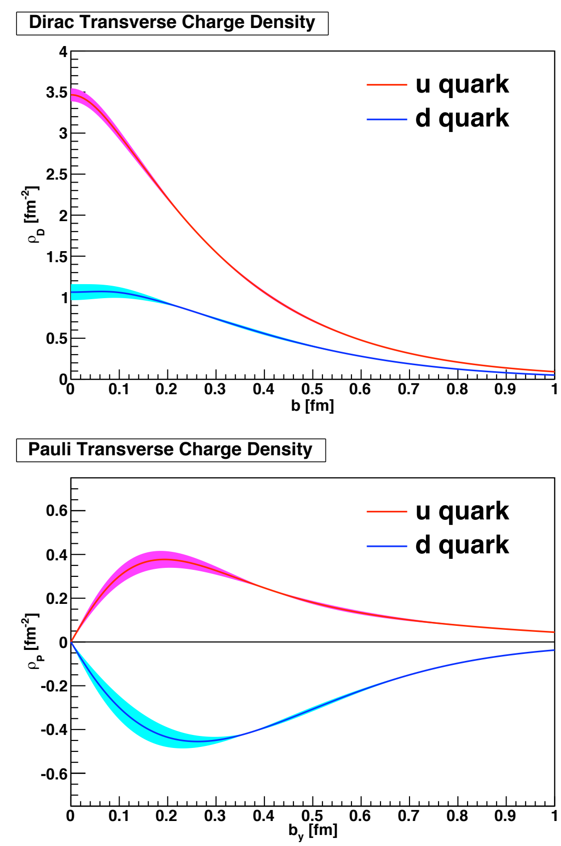
two-photon contributions at high Q^2

$$d\sigma = d\sigma_{NS}\{\epsilon(\tilde{G}_E + \frac{s-u}{4M^2}\tilde{F}_3)^2 + \tau(\tilde{G}_M + \epsilon\frac{s-u}{4M^2}\tilde{F}_3)^2\}$$

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

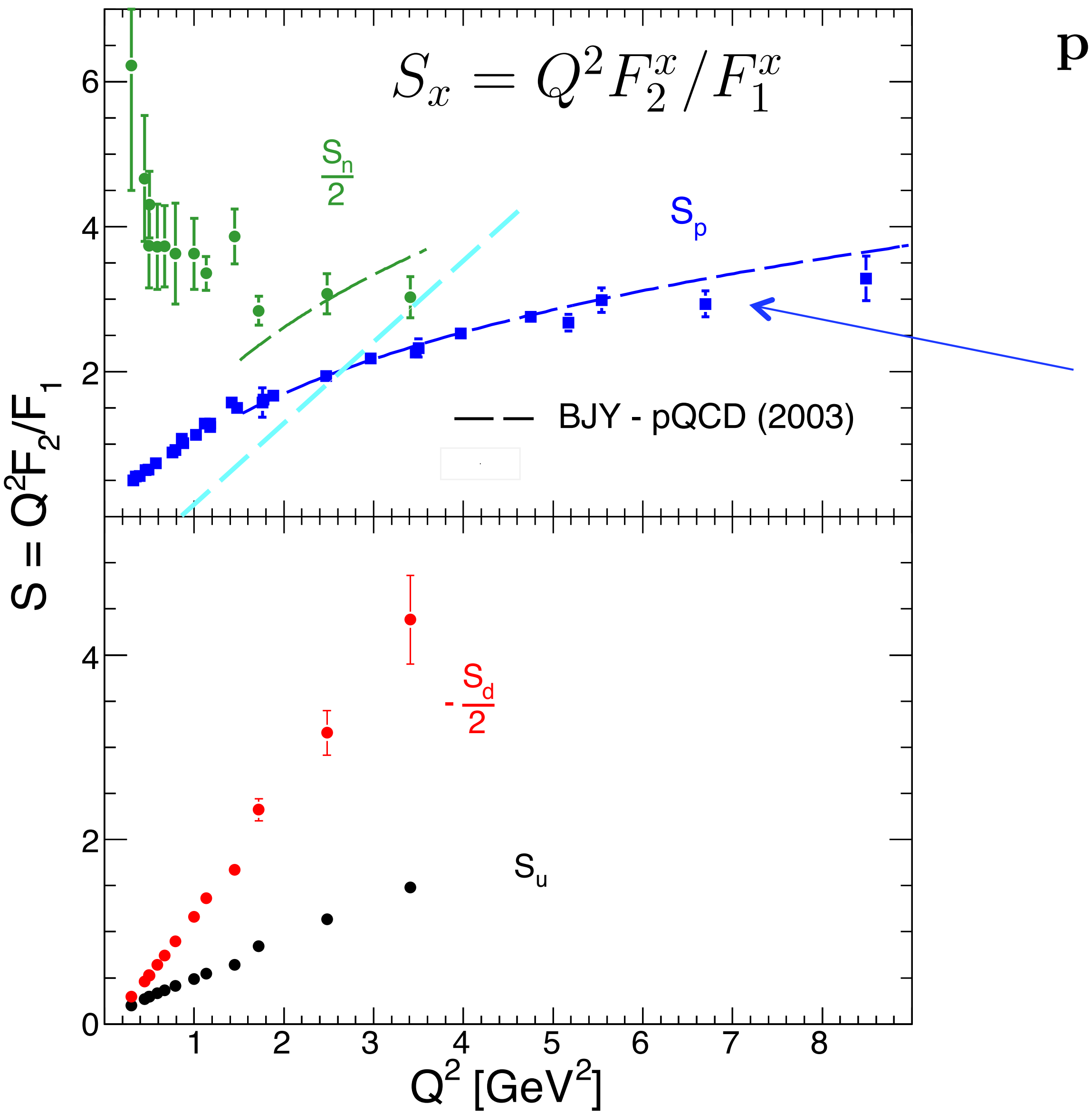
$$\frac{G_E}{G_M}\Big|_{1\gamma} = -\frac{P_x}{P_z}\frac{E_e + E_{e'}}{2M}tan(\theta_e/2)$$





Scientific case

Q^2 dependence of F2/F1



pQCD prediction for large Q^2:

$$S \to Q^2 F_2 / F_1$$

pQCD updated prediction:

$$S \to \left[Q^2 / \ln^2(Q^2/\Lambda^2)\right] F_2 / F_1$$

Flavor separated contributions:
The log scaling for the proton
Form Factor ratio at few GeV^2
is likely "accidental".

The lines for individual flavor
are straight!

Scientific case

Summary

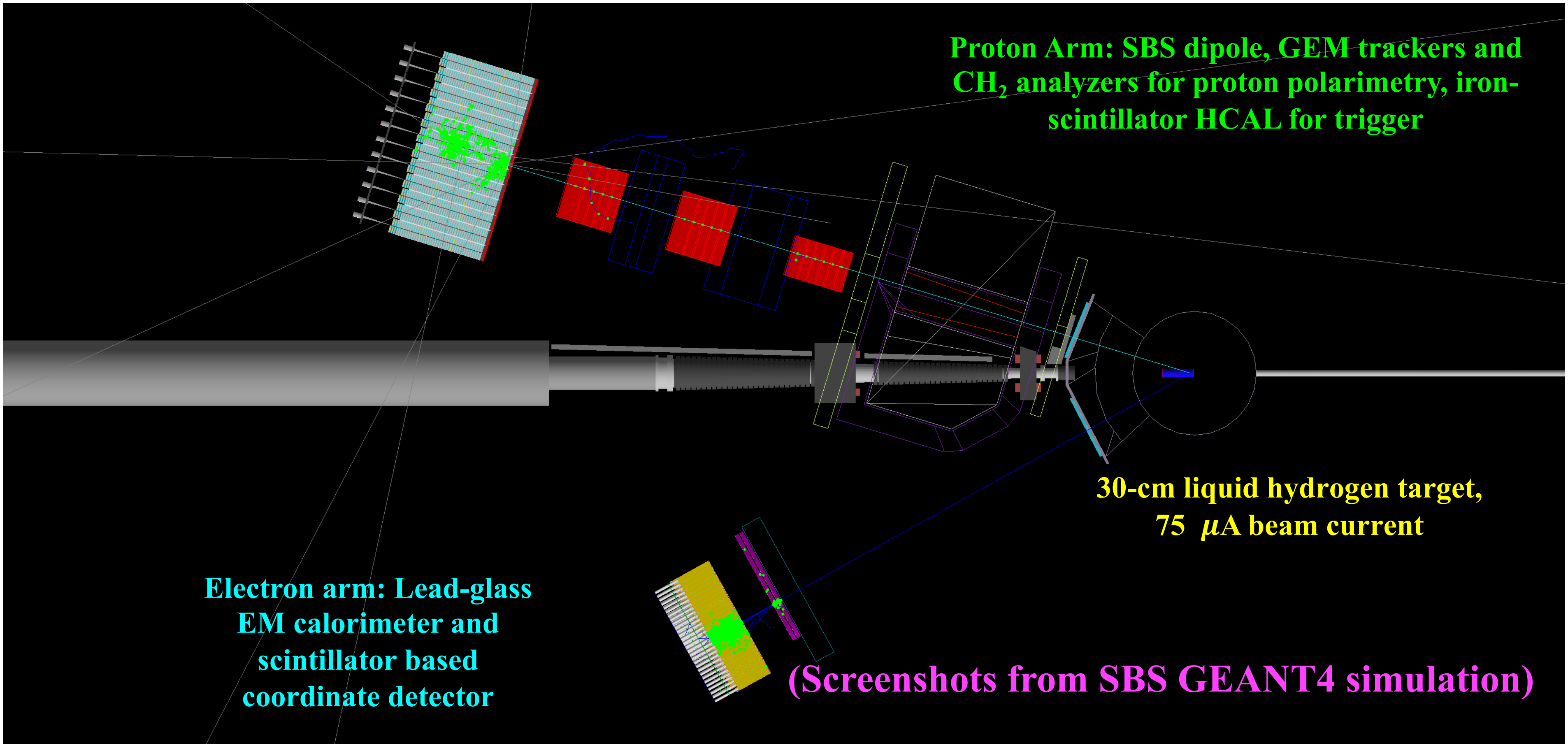
- After 12 years of development the GEp/SBS experiment is on track to be ready for installation in 2022.

- Nucleon elastic form factors are important constraints on QCD-based models in the high-t region.

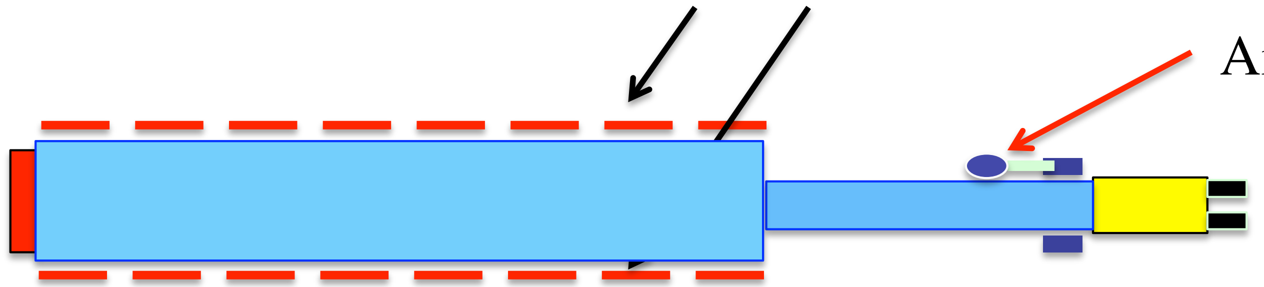
- Flavor composition of the nucleon form factors will be used for testing the DSE and lattice QCD predictions.

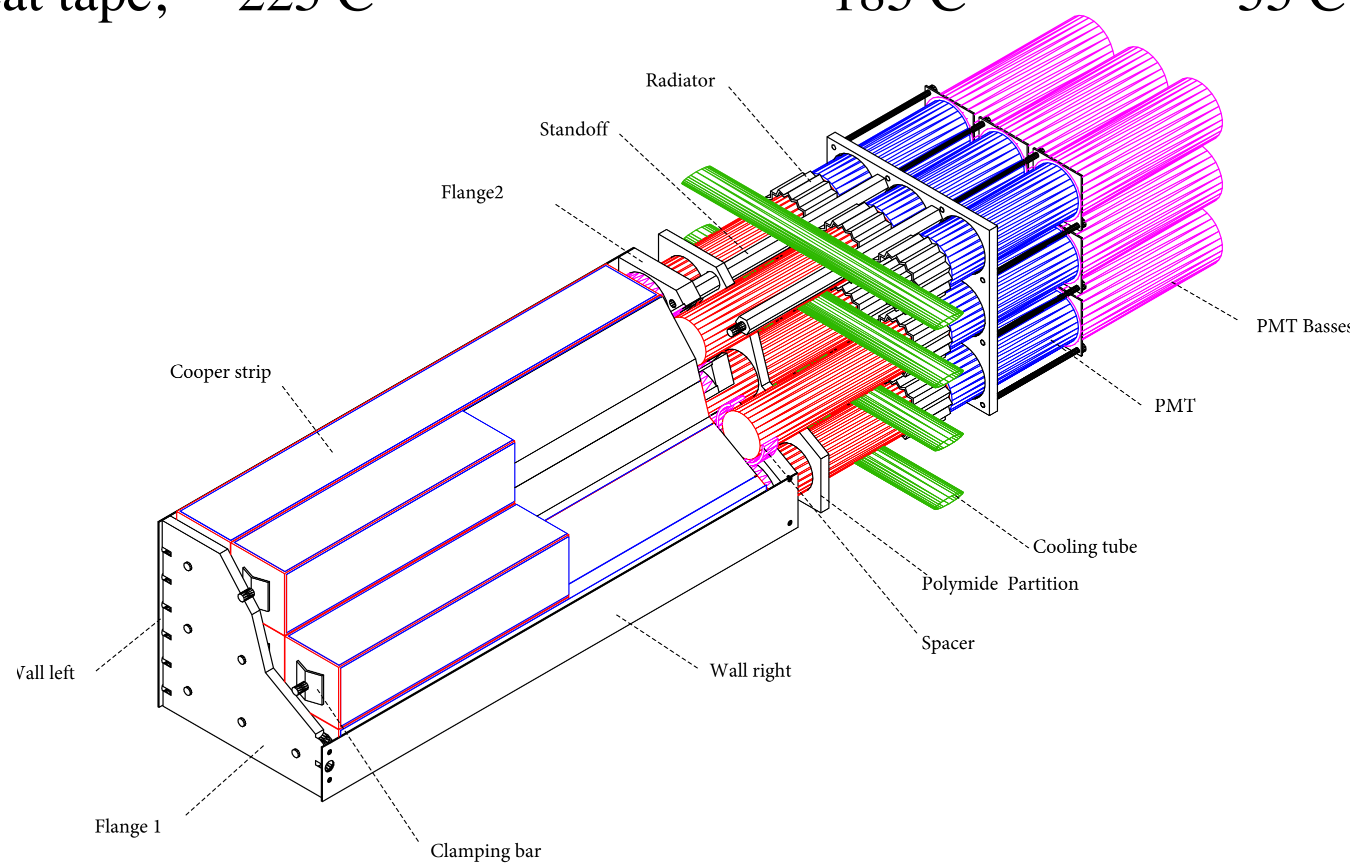
Backup slides

MC simulation



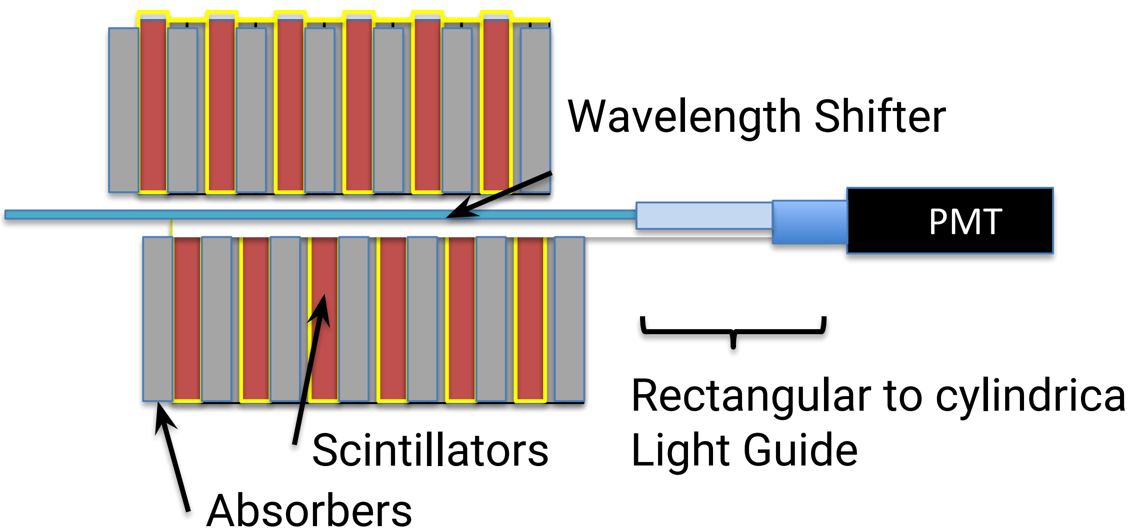
Electron arm: Calorimeter's temperature, 3x3 group

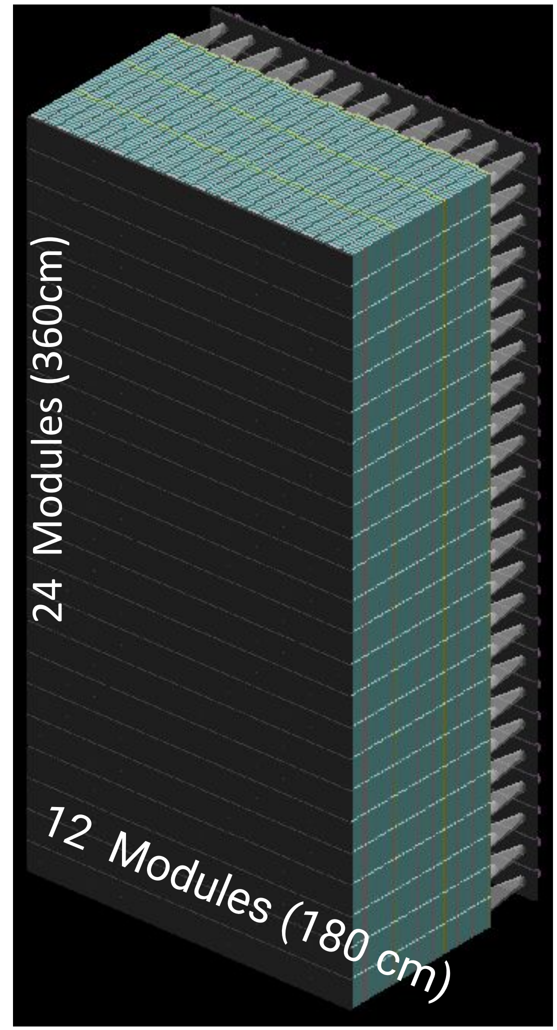




Proton arm: Calorimeter counter structure

- Each module is 15 cm x 15 cm x ~1 m
  - Plus light guide and PMT at end
- 40 layers scintillators + iron per module
  - Staggered to increase light output





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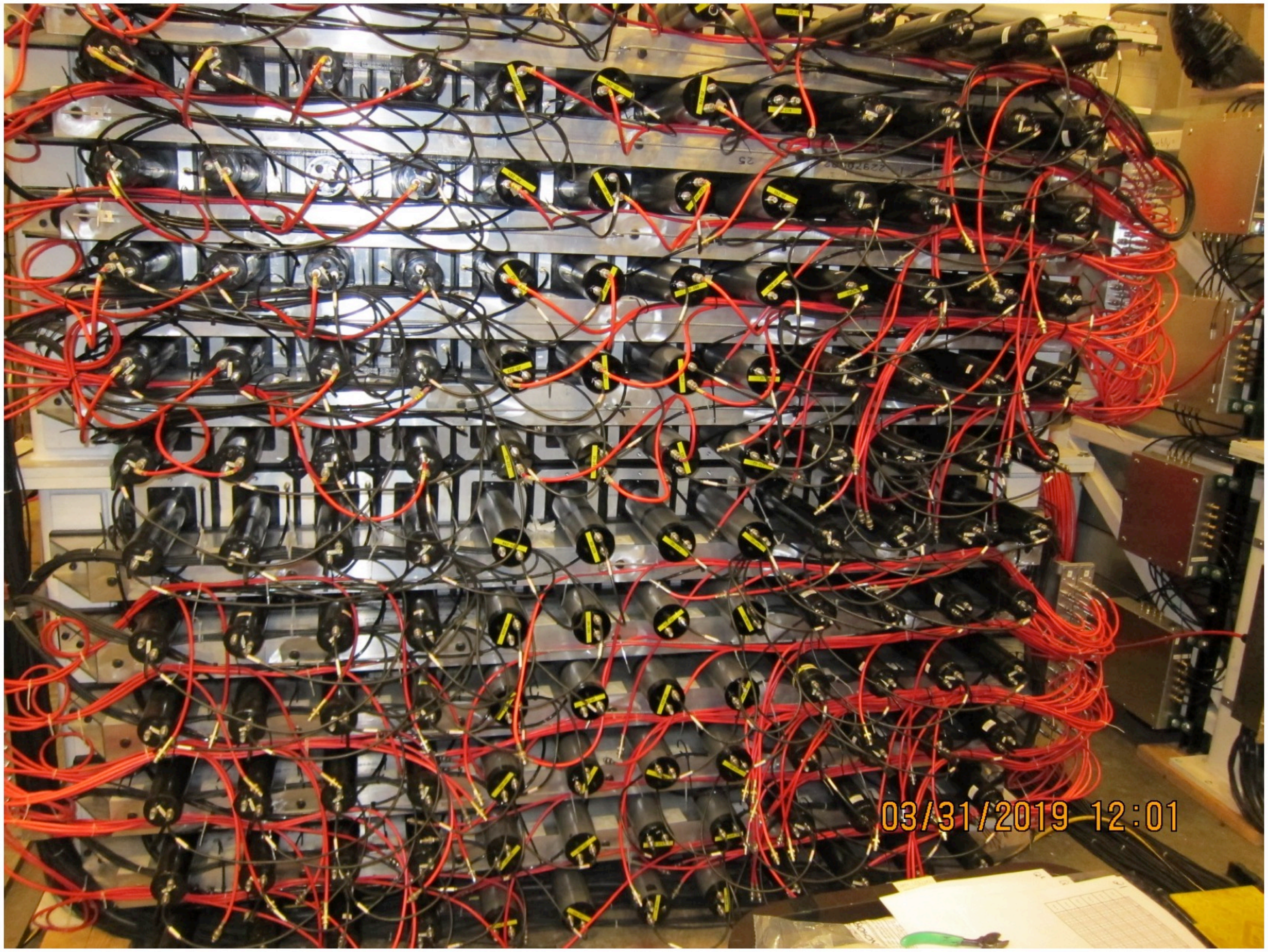
Proton arm: Calorimeter commissioning



HCAL has 288 counters (in 12 x 24 array)

Proton arm: GEM chambers commissioning