G-2 experiment

A proposal to measure the muon anomalous magnetic moment to 0.14 ppm precision

Experiment at Fermilab

Built on the foundation of E821, with important new strength added

The New (G - 2) Experiment:

A Proposal to Measure the Muon Anomalous Magnetic Moment to ± 0.14 ppm Precision

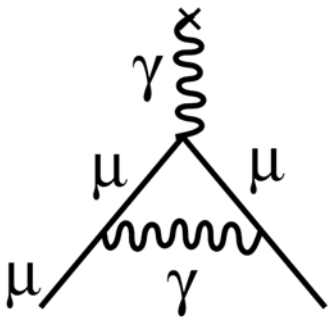
New (*G*-2) Collaboration:

R.M. Carey, K.R. Lynch, J.P. Miller, B.L. Roberts, W.M. Morse, Y.K. Semertzidis, V.P. Druzhinin, B.I. Khazin, I.A. Koop, I. Logashenko, S.I. Redin, Y.M. Shatunov, Y. Orlov, R.M. Talman, B. Casey, J. Johnstone, D. Harding, A. Klebaner, A. Leveling, J-F. Ostiguy, N. Mokhov, D. Neuffer, M. Popovic, S. Strigonov, M. Syphers, G. Velev, S. Werkema, F. Happacher, G. Venanzoni, P. Debevec, M. Grosse-Perdekamp, D.W. Hertzog, P. Kammel, C. Polly, K.L. Giovanetti, K. Jungmann, C.J.G. Onderwater, N. Saito, C. Crawford, R. Fatemi, T.P. Gorringe, W. Korsch, B. Plaster, V. Tishchenko, D. Kawall, T. Chupp, C. Ankenbrandt, M.A Cummings, R.P. Johnson, C. Yoshikawa, Andre de Gouvea, T. Itahashi, Y. Kuno, **G.D. Alkhazov, V.L. Golovtsov, P.V. Neustroev, L.N. Uvarov, A.A. Vasilyev, A.A. Vorobyov, M.B. Zhalov**,
F. Gray, D. Stockinger, S. Baeler, M. Bychkov, E. Frlez, and D. Pocanic

$$\vec{\mu}_\mu = g_\mu \left(\frac{q}{2m} \right) \vec{S}$$

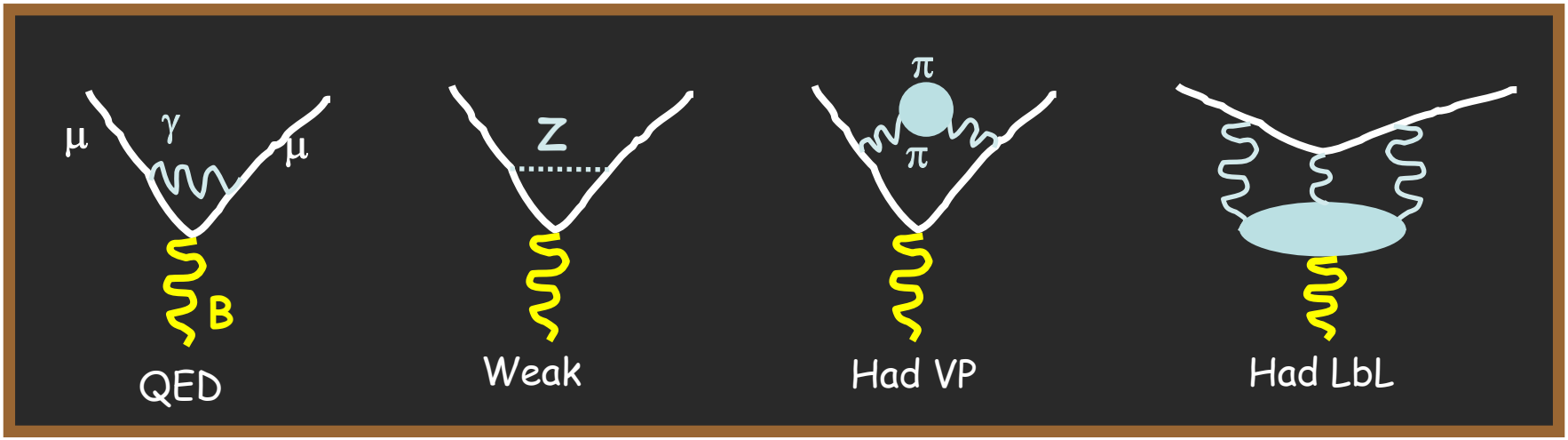
$$a_\mu = \frac{1}{2}(g_\mu - 2)$$

Дирак : для S=1/2 g_μ = 2



LO QCD (Schwinger): $a_\mu = (\alpha/2\pi) = 0.00116\cdots$

$a_\mu = (g - 2)/2$ is non-zero because of virtual loops, which can be calculated very precisely



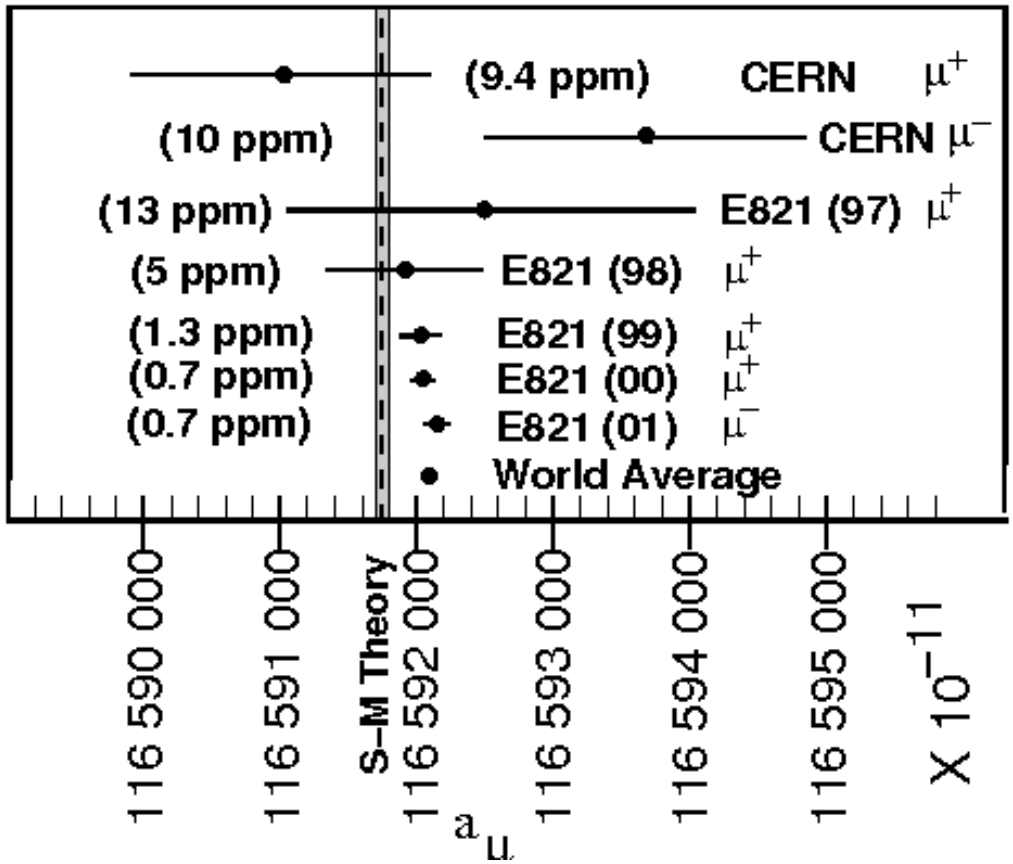
Known well **Theoretical work ongoing**

Contribution	Result ($\times 10^{-11}$) units
QED (leptons)	$116\,584\,718.09 \pm 0.14 \pm 0.04_{\alpha}$
HVP(lo)	$6\,908 \pm 39_{\rm exp} \pm 19_{\rm rad} \pm 7_{\rm pQCD}$
HVP(ho)	$-97.9 \pm 0.9_{\rm exp} \pm 0.3_{\rm rad}$
HLxL	105 ± 26
EW	$152 \pm 2 \pm 1$
Total SM	$116\,591\,785 \pm 51$

$\delta a_\mu = 51 \times 10^{-11}$

Experiment

A consistent set of measurements with a steady improvement in precision.



Where we are and where we are going

Present Status:

Experimental uncertainty = 63 x 10^{-11} (0.54 ppm)

0.46 ppm statistical (limit was counts) 0.28 ppm systematic

Theory uncertainty = 51 x 10^{-11} (0.44 ppm)

Leads to Δa_μ(Expt – Thy) = 295 ± 81 x 10^{-11} 3.6 σ

Expected situation after experiment:

Experimental uncertainty: 63 → 16 x 10^{-11}

0.1 ppm statistical → 21x the E821 events

0.1 ppm systematic overall

Theory uncertainty: 51 → 30 x 10^{-11}

Future: Δa_μ(Expt – Thy) = xx ± 34 x 10^{-11}

(If xx remains 295, the deviation from zero would be close to 9σ)

Precise knowledge of a_μ will aid in discrimination between a wide variety of standard model extensions

- **UED models (1D) typically predict "tiny" effects**
  - **Incompatible with a Δa_μ of ~ 300 x 10^{-11}**
- **SUSY models – there are many – predict a_μ contributions of about the observed magnitude for Δa**
- **The "Uninvented" – perhaps most importantly, sets a stringent experimental constraint for any new models**

Muon g-2 is a powerful discriminator

no matter where the final value lands

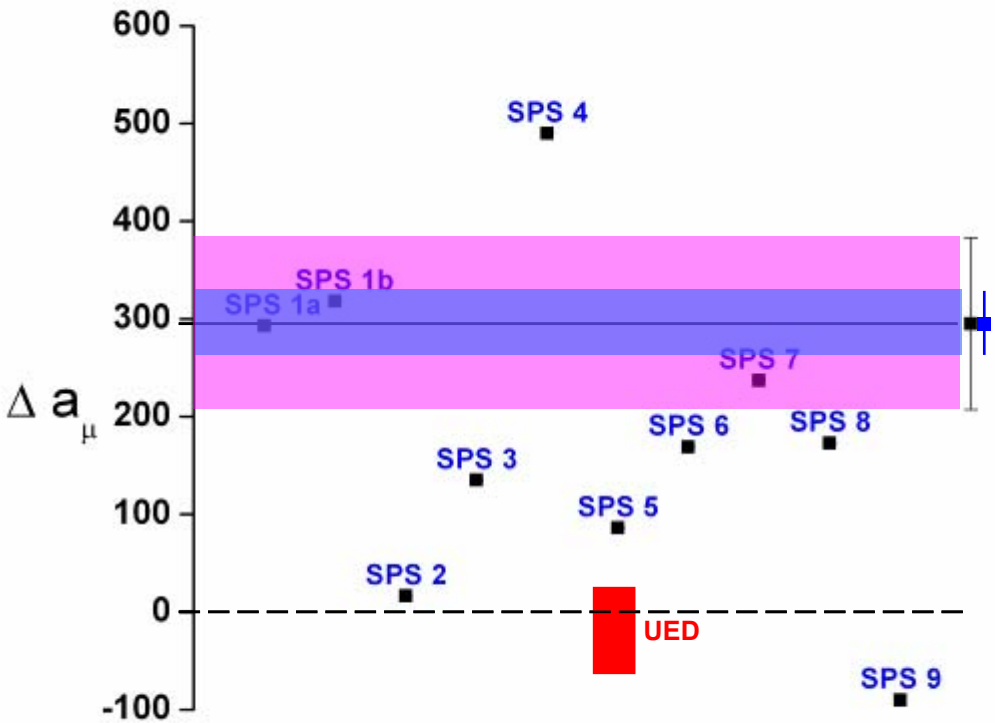


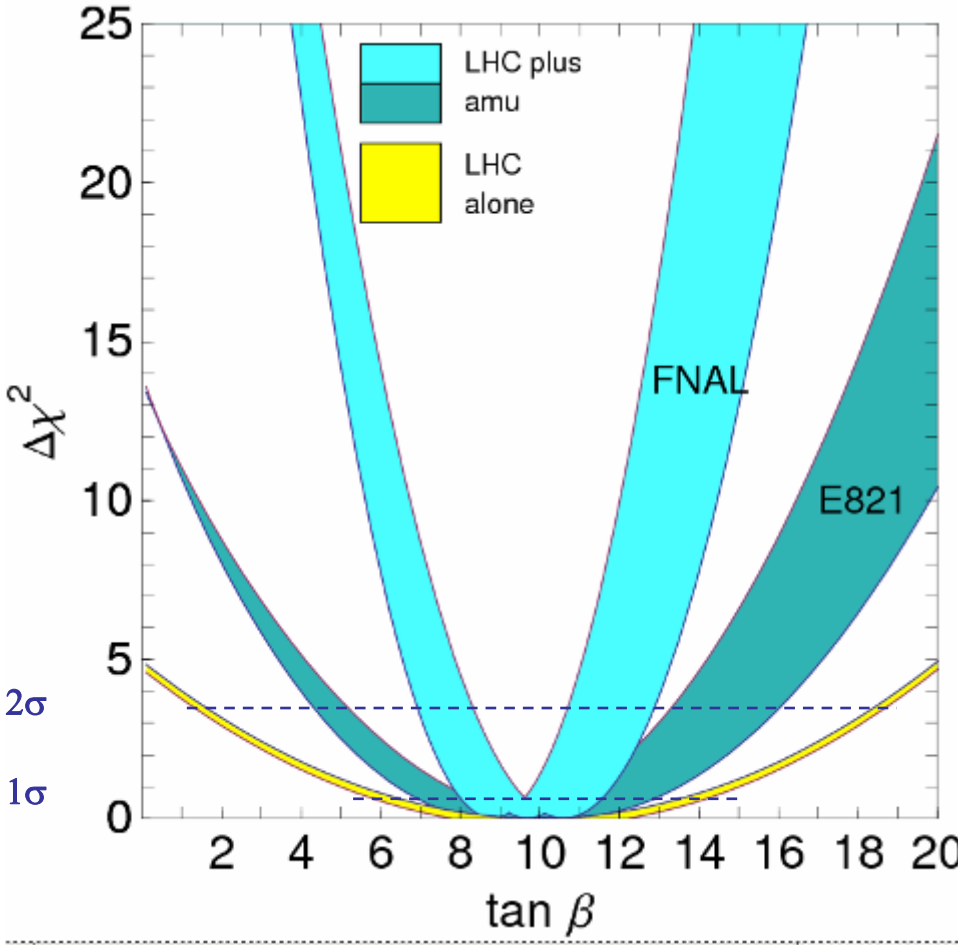
Illustration of "resolving power" among SUSY models

Universal Extra Dimensions 1D

SPS Definitions

MSSM

– tanβ poorly determined by collider



g-2 is complementary to the LHC

* **SPS1a is a ``Typical '' mSUGRA point with intermediate tanβ = 10**

Another goal of the G-2 experiment is to improve the muon EDM limit by up to a factor of 100 and make a higher-precision test of Lorentz and CPT violation

The measurement principle

$$\vec{\omega}_c = -\frac{q\vec{B}}{m\gamma}$$

$$\vec{\omega}_s = -\frac{gq\vec{B}}{2m} - (1-\gamma)\frac{q\vec{B}}{\gamma m}$$

$$\vec{\omega}_a = \vec{\omega}_s - \vec{\omega}_c = -\left(\frac{g-2}{2}\right)\frac{q\vec{B}}{m} = -a_\mu \frac{q\vec{B}}{m}$$

$\Delta\omega \equiv \omega_a = \omega_s - \omega_c = a_\mu (qB/m)$

$g = 2 \rightarrow a_\mu = 0 \rightarrow \omega_s = \omega_c, \quad \Delta\omega = 0.$

$g \neq 2 \rightarrow \omega_s \neq \omega_c, \quad \Delta\omega/\omega_c = \gamma(\Delta g/g) = \gamma a_\mu$

In our case, $\gamma \approx 30$, $a_\mu \approx 0.001$, $\Delta\omega/\omega_c \approx 0.03$

$\gamma \approx 30$!

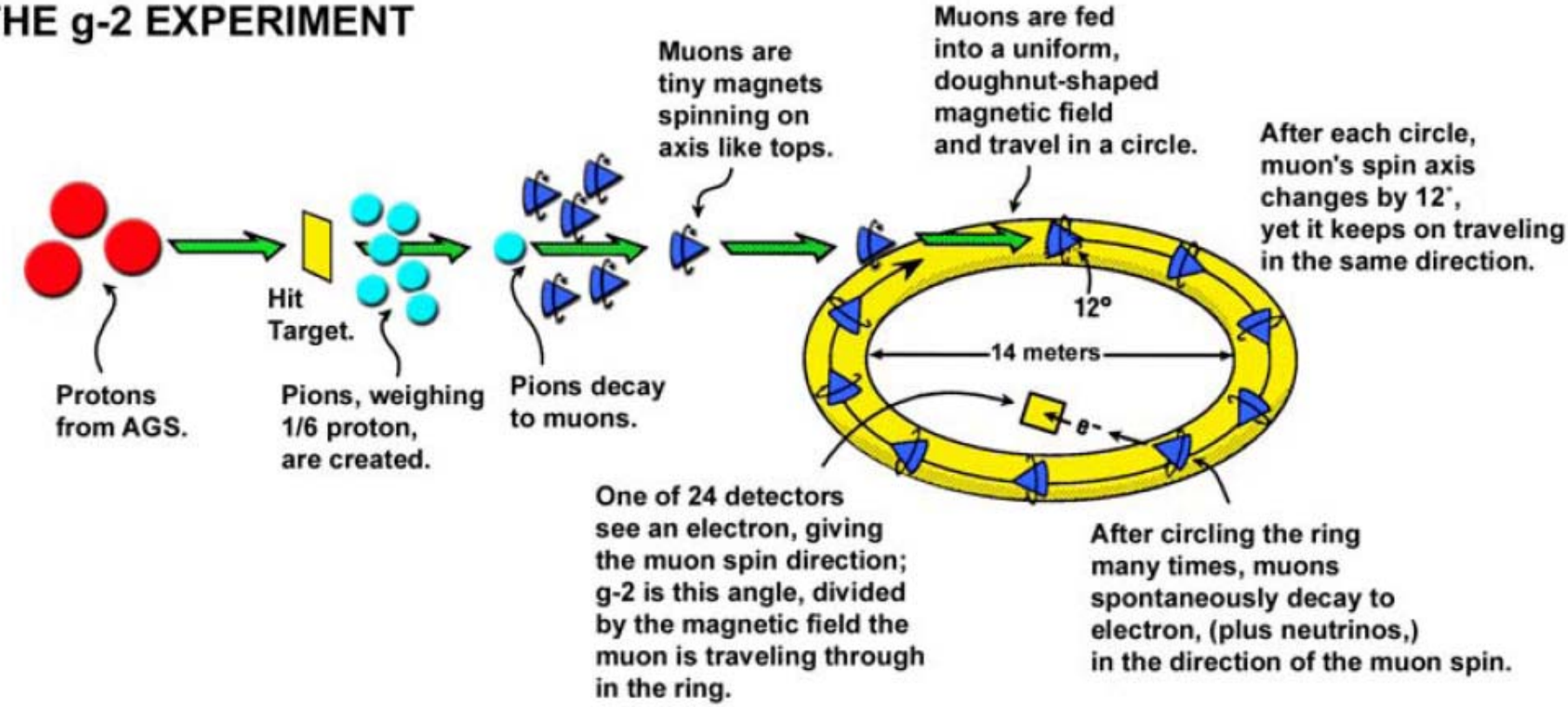
$$\vec{\omega}_a = -\frac{q}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta} \times \vec{E}}{c}\right]$$

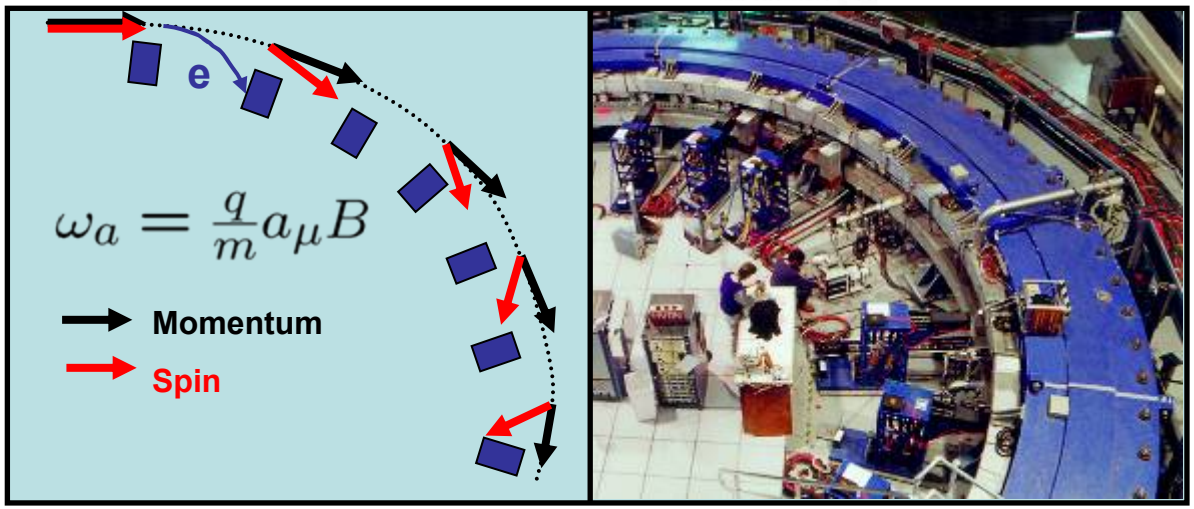
$p_\mu = 3.094$ GeV/c

The existing storage muon ring that will be relocated to FNAL

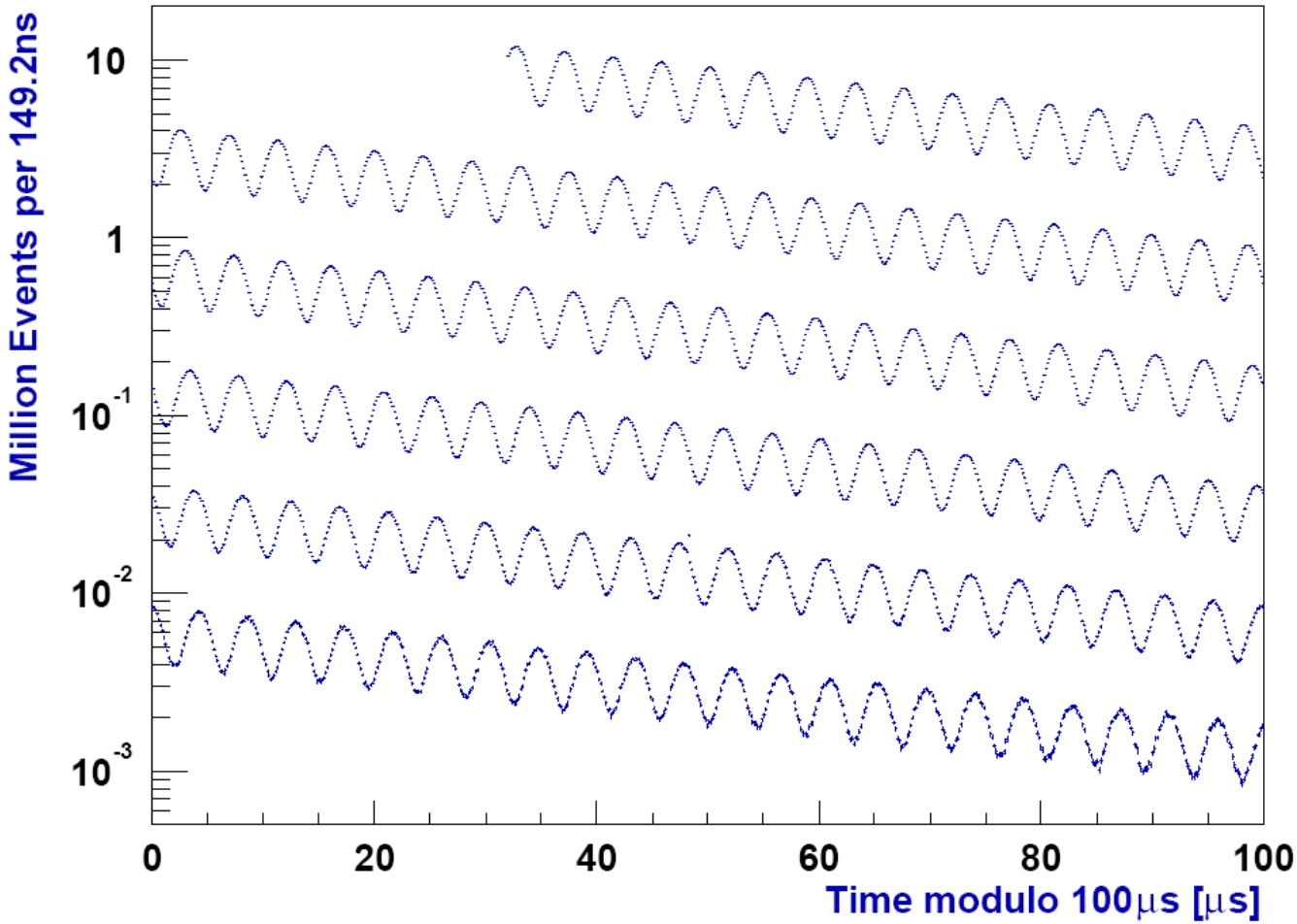
- 8GeV protons from the Booster
- Antiproton target
- 3.1 GeV/c positive pions
- 900 m pion decay line (λ_{decay} = 173 m)
- Polarized muons are injected in the storage ring
- Positrons from the muon decay are registered ($\mu^+ \rightarrow e^+ + \nu_e + \nu_\mu$)
- The frequency of the oscillations in the intensity of the registered positrons is used to determine ω_a

LIFE OF A MUON:
THE g-2 EXPERIMENT





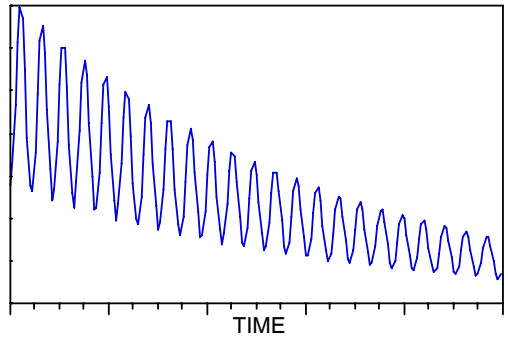
В системе центра масс мюона позитроны с большей энергией испускаются преимущественно в направлении спина.
Т.к. спин прецессирует по отношению к направлению движения мюона, возникают биения интенсивности позитронов, испускаемых вперед.



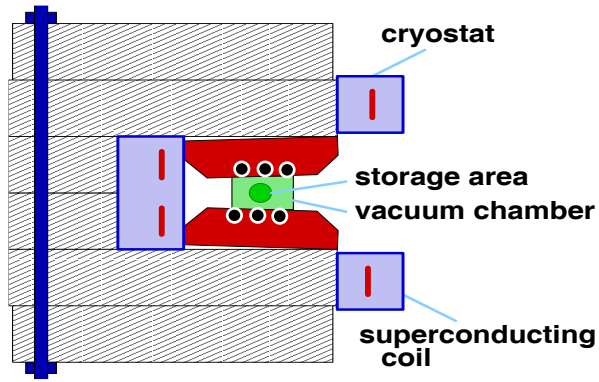
Total number of events in G-2 - ~1.8 x 10^{11} (21 times more than in E821)

The measurement involves determining 3 quantities to high precision

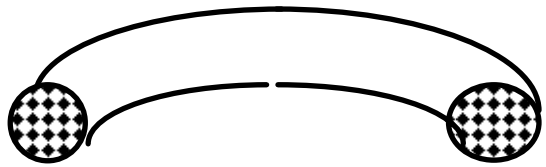
(1) Precession frequency ω_a



(2) Magnetic field map

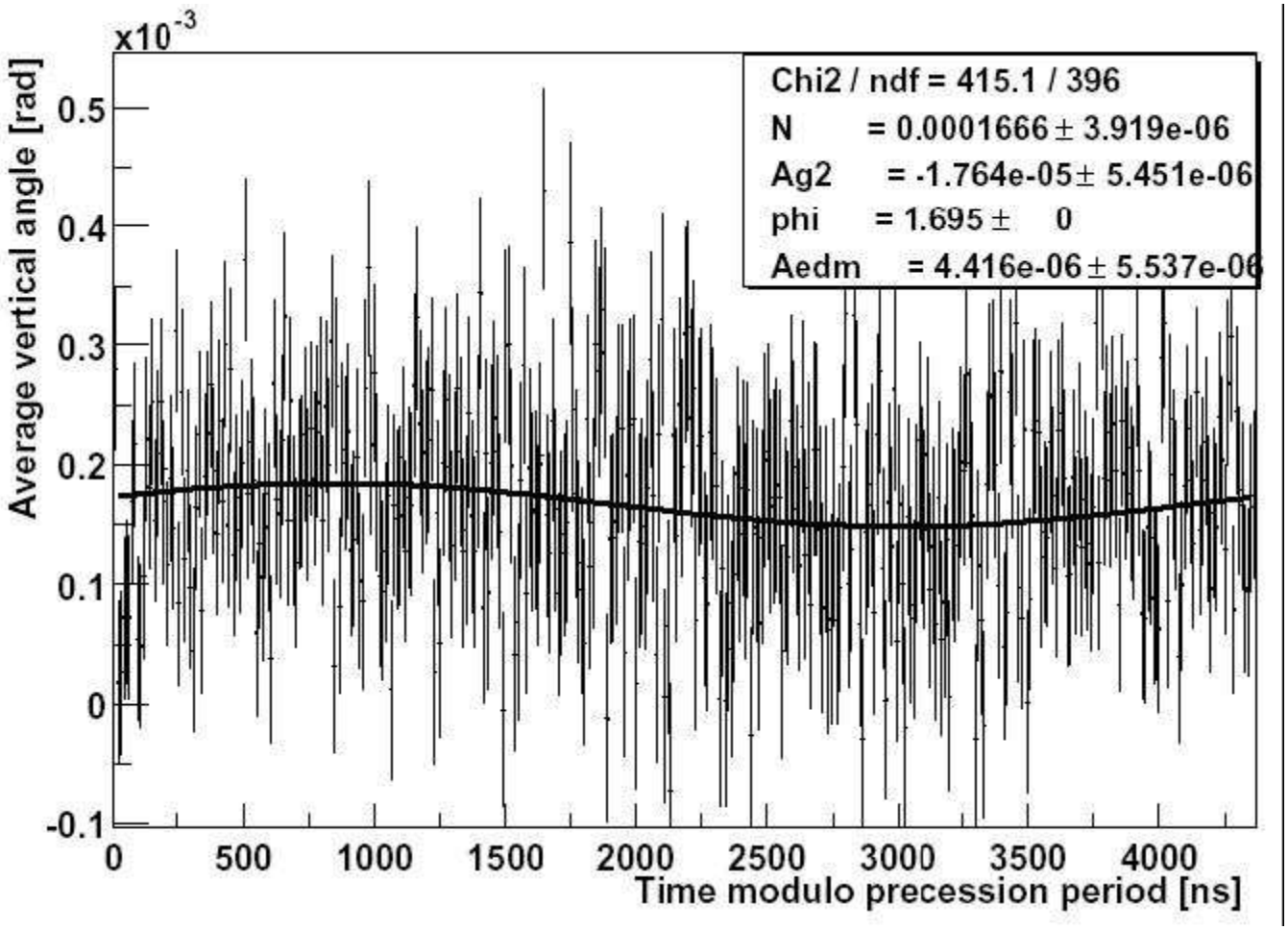


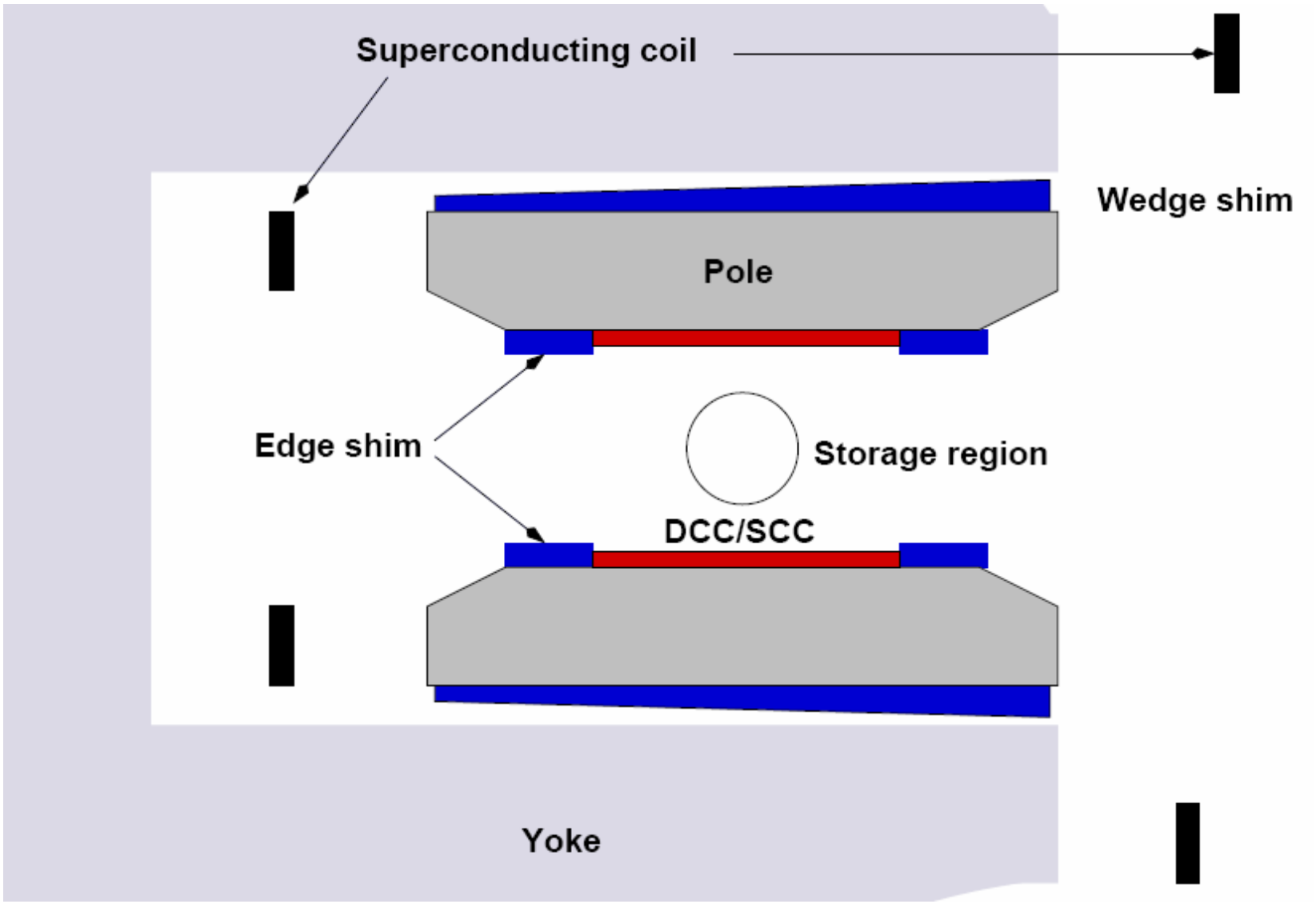
(3) Muon space distribution



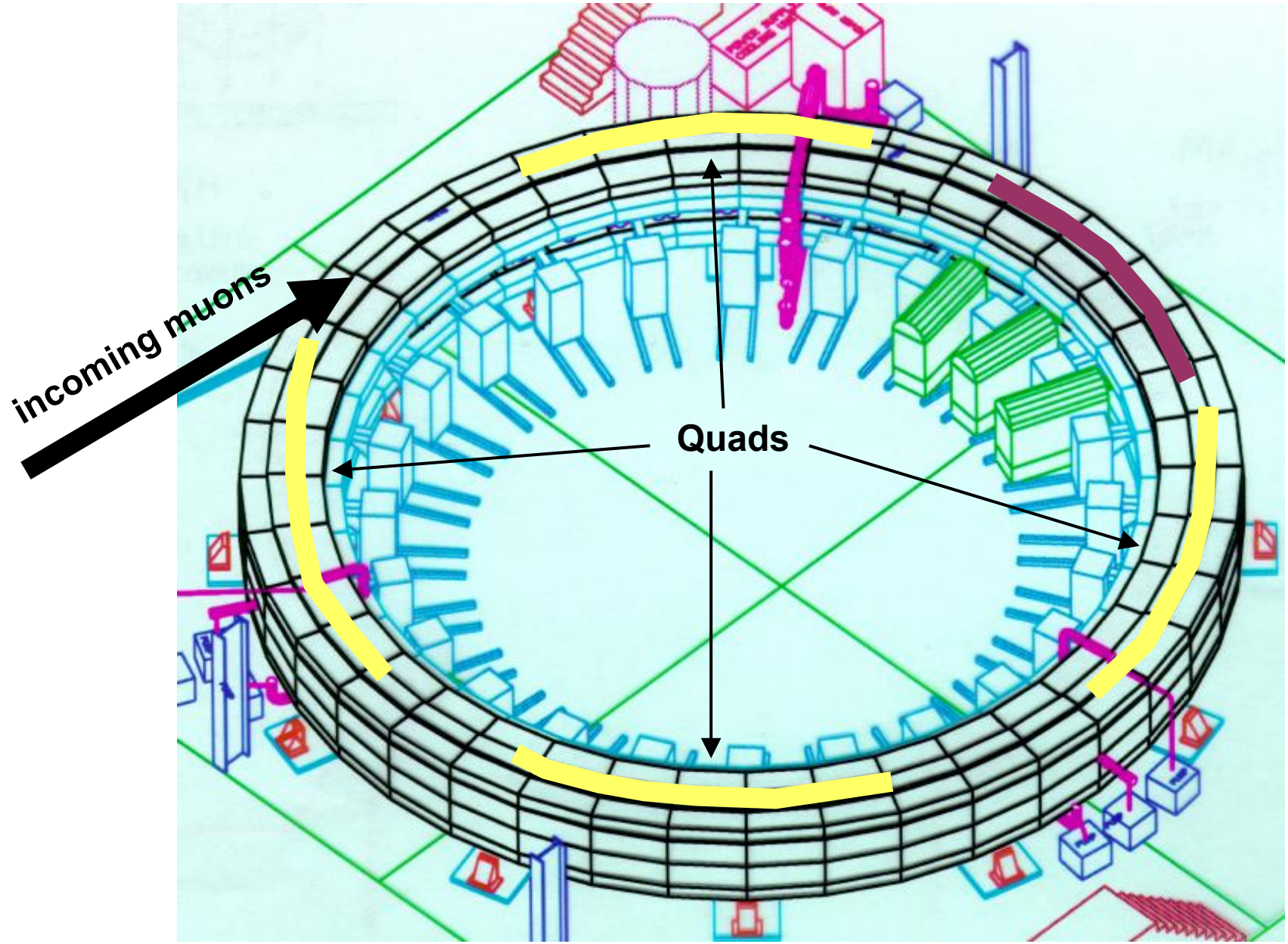
Осцилляции интенсивности испускаемых позитронов в вертикальной плоскости позволяют измерить EDM мюона (дать ограничения на величину EDM)

E821

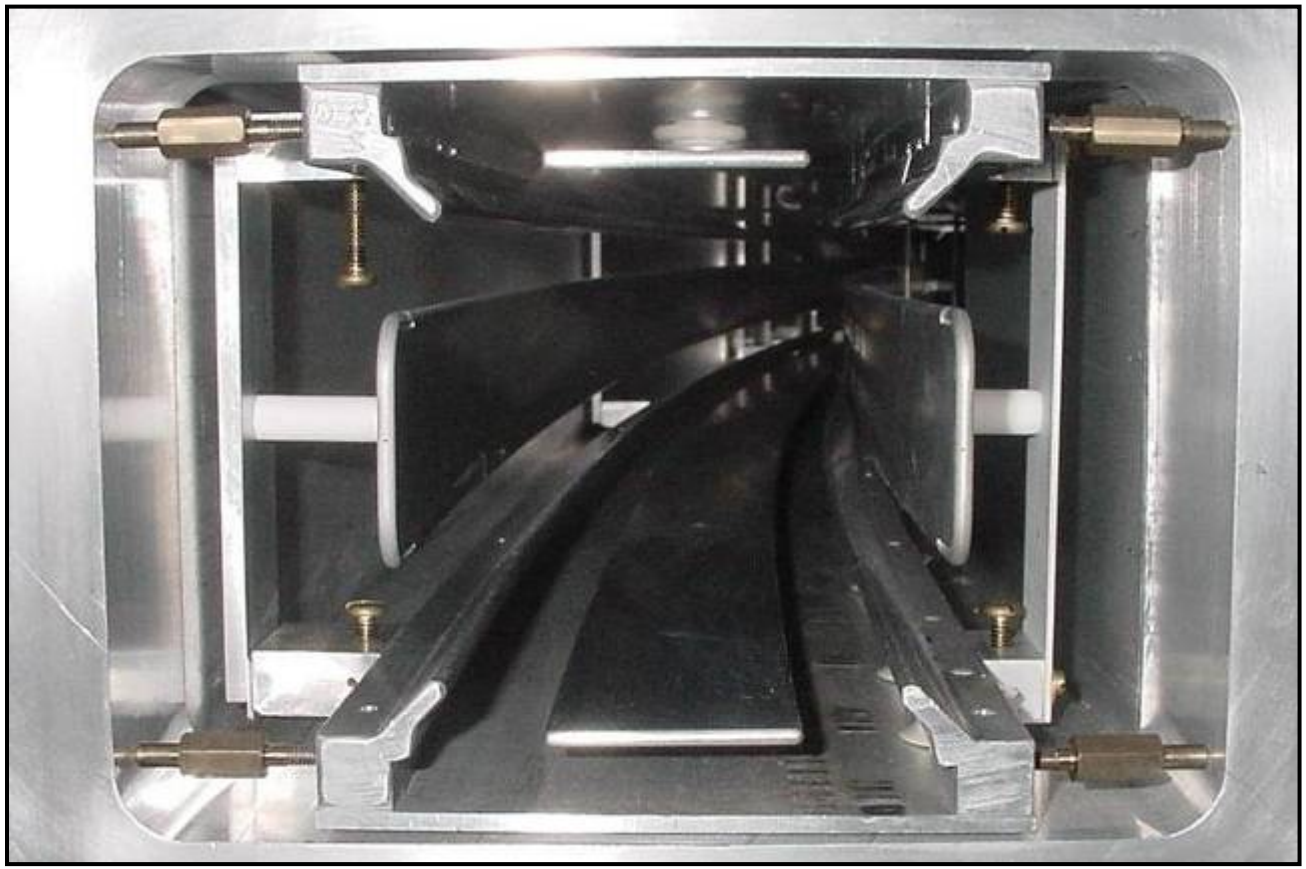



Superconducting coil
Wedge shim
Pole
Edge shim
Storage region
DCC/SCC
Yoke

The Storage Ring exists and will be moved to FNAL

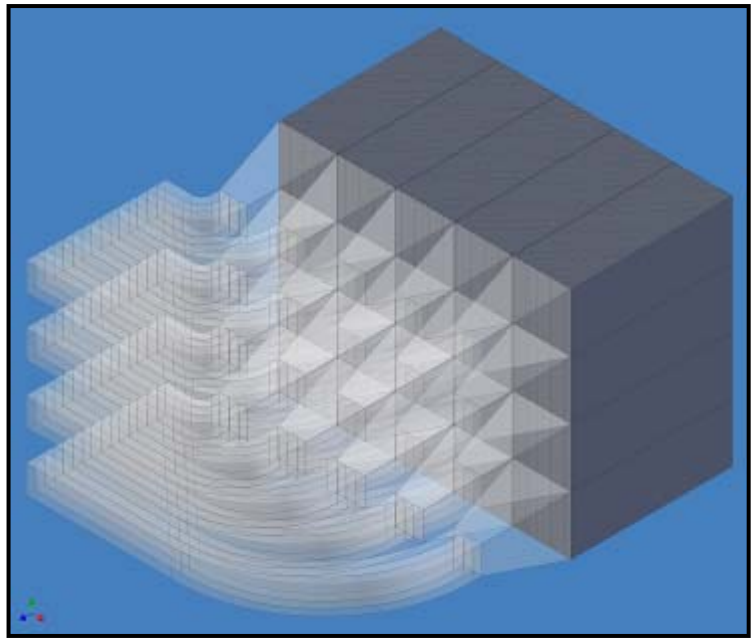


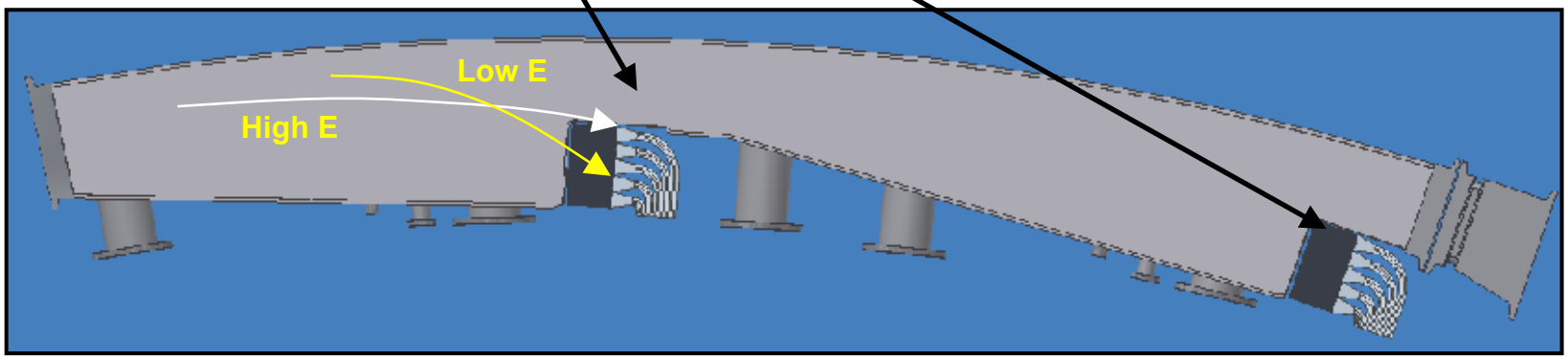
Electrostatic quadrupoles



Segmenting detectors will reduce pileup. New W-SciFi calorimeter

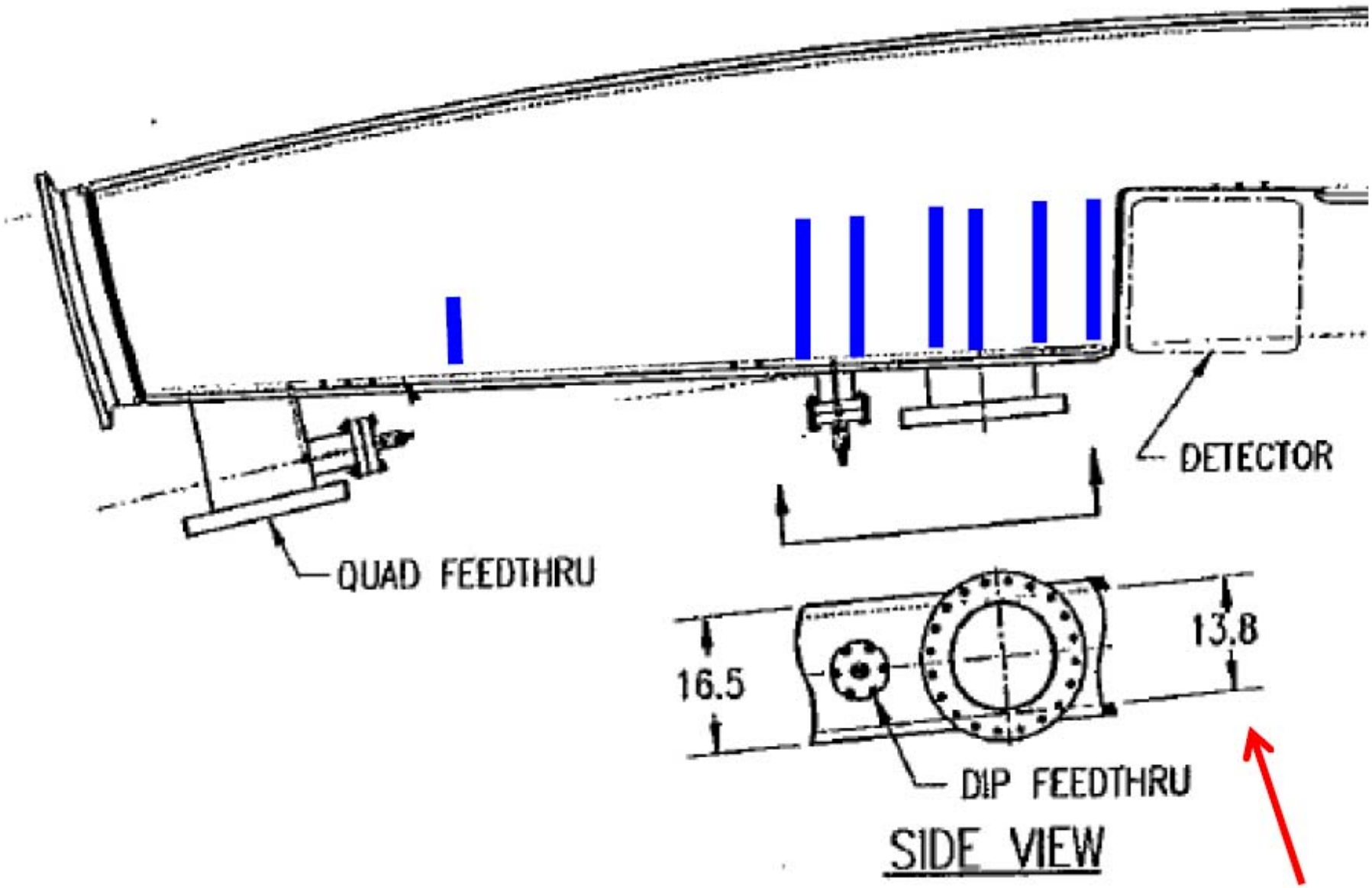
- 20-fold segmentation for PMTs
- 0.7 cm X_0
- 10% resolution at 2 GeV
- R&D option, 35-fold segmentation using onboard SiPM



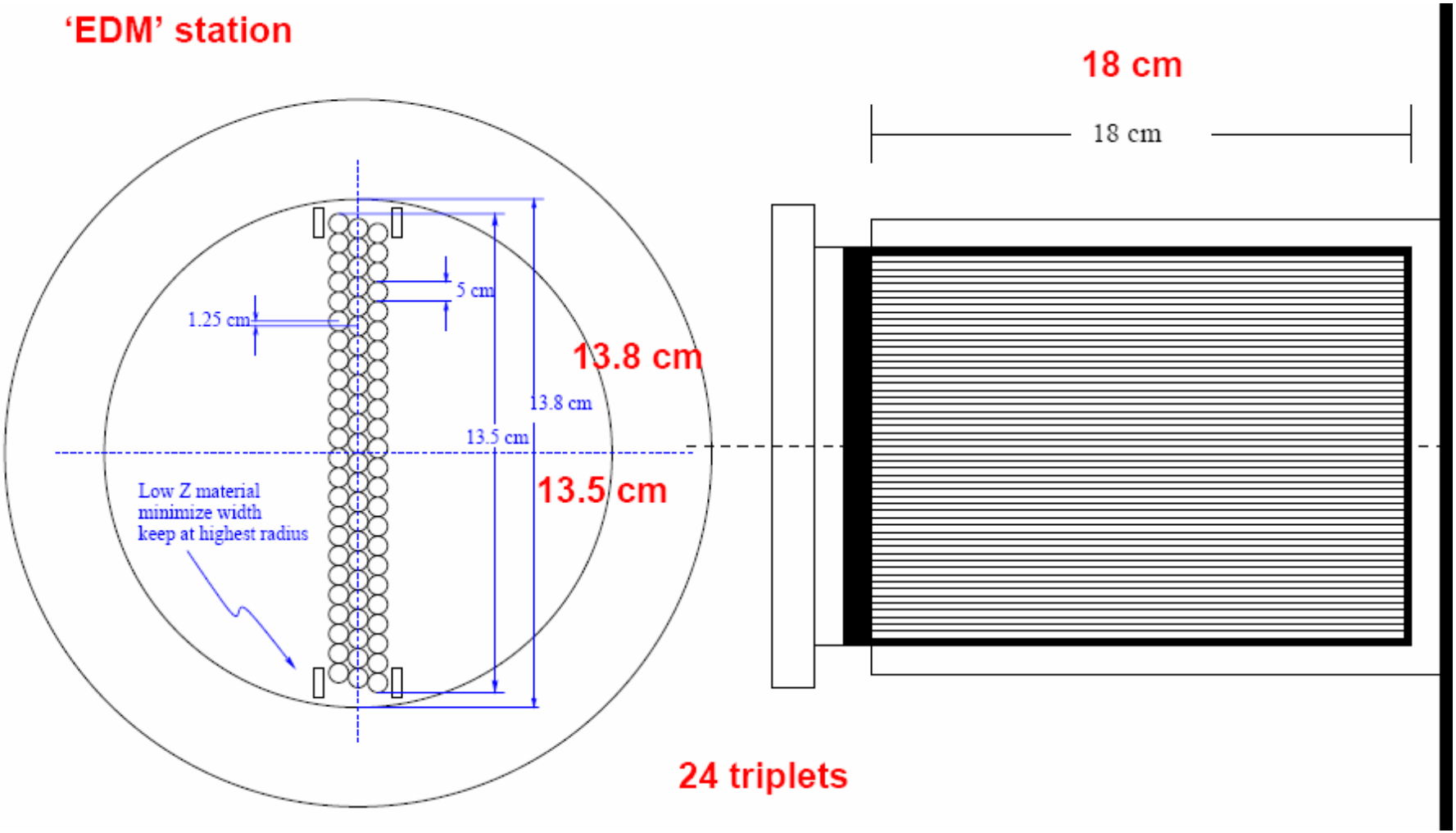


24 calorimeter stations

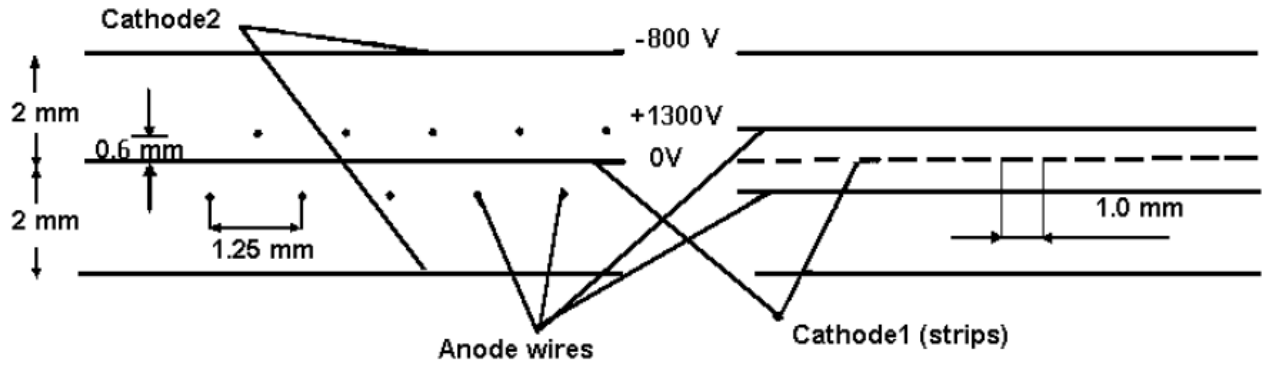
Straw tube detectors ?

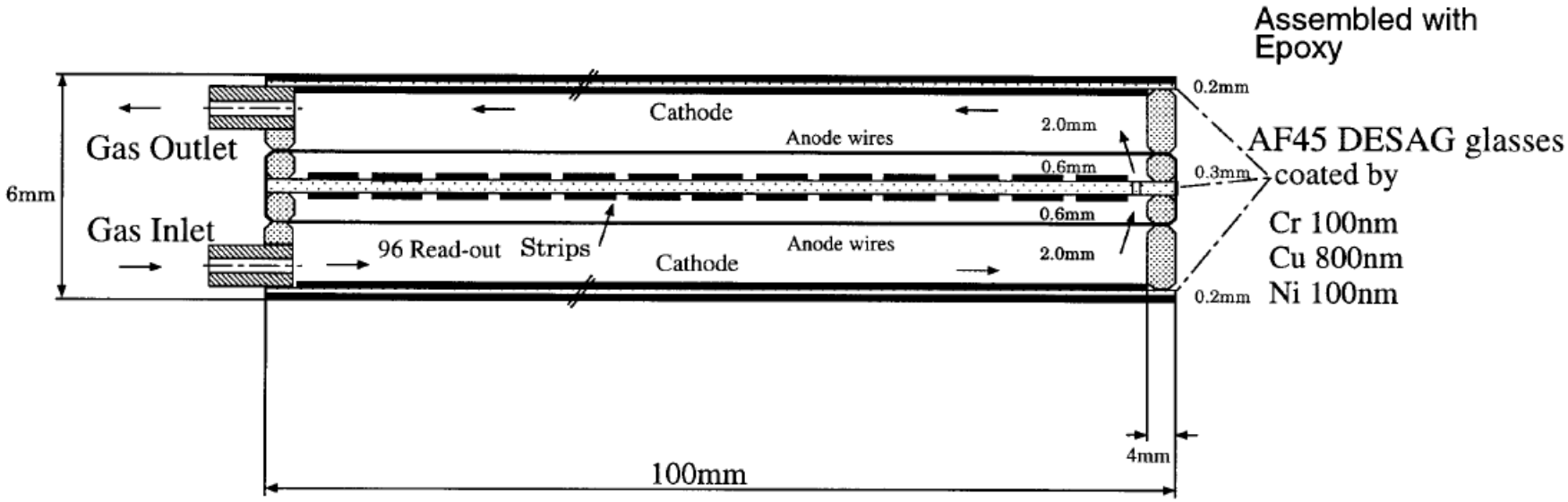


‘EDM’ station


18 cm
18 cm
5 cm
1.25 cm
13.8 cm
13.8 cm
13.5 cm
13.5 cm
Low Z material
minimize width
keep at highest radius
24 triplets

Micro-cathode strip chambers





Technically driven schedule