E158 Review

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ElectroWeak Workshop

December 12, 2006

E158 Collaboration

- UC Berkeley
- Caltech
- Jefferson Lab
- Princeton
- Saclay
- SLAC
- Smith College
- Syracuse
- UMass
- Virginia

7 Ph.D. Students
60 physicists

E158 Chronology

Sep 97: EPAC approval
Mar 98: First Laboratory Review
1999: Design and Beam tests
2000: Funding and construction
2001: Engineering run
2002-2003: Physics Runs I, II & III
2004: Publication of Run I result
2005: Final Publication

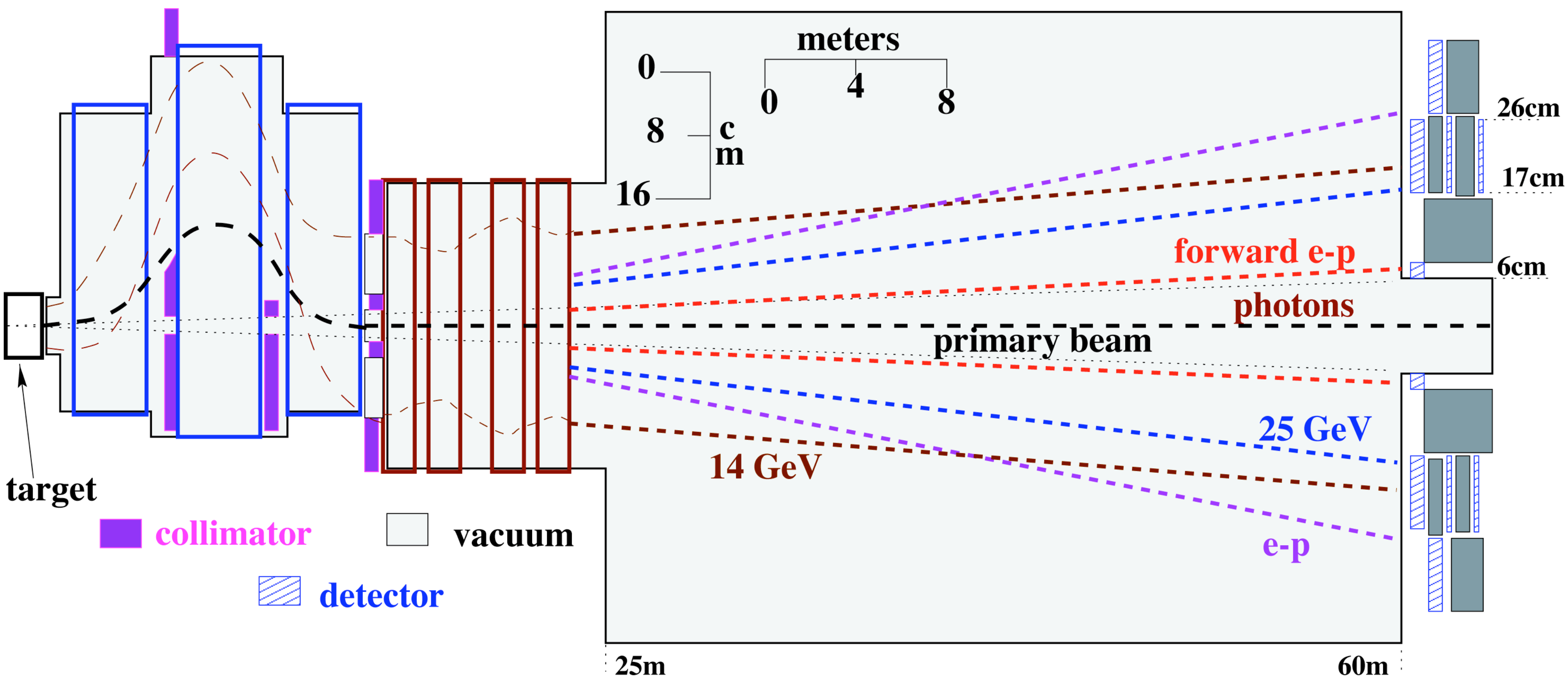
Outline

- Description of the Apparatus
- Backgrounds
- Results
- Advice

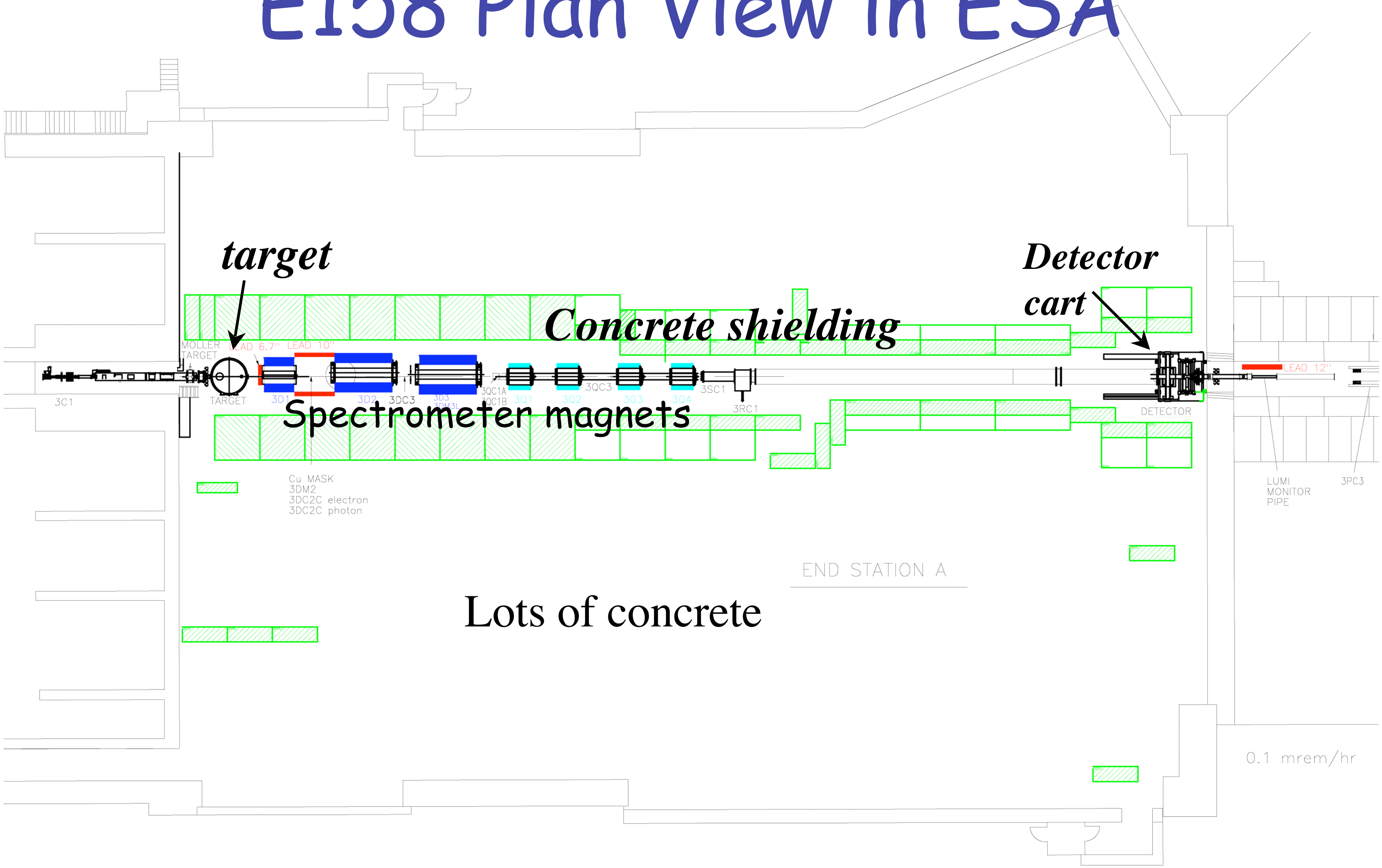
The E158 Apparatus

- *Target is an 18% radiator*
- *Moller ring is 20 cm from the beam*

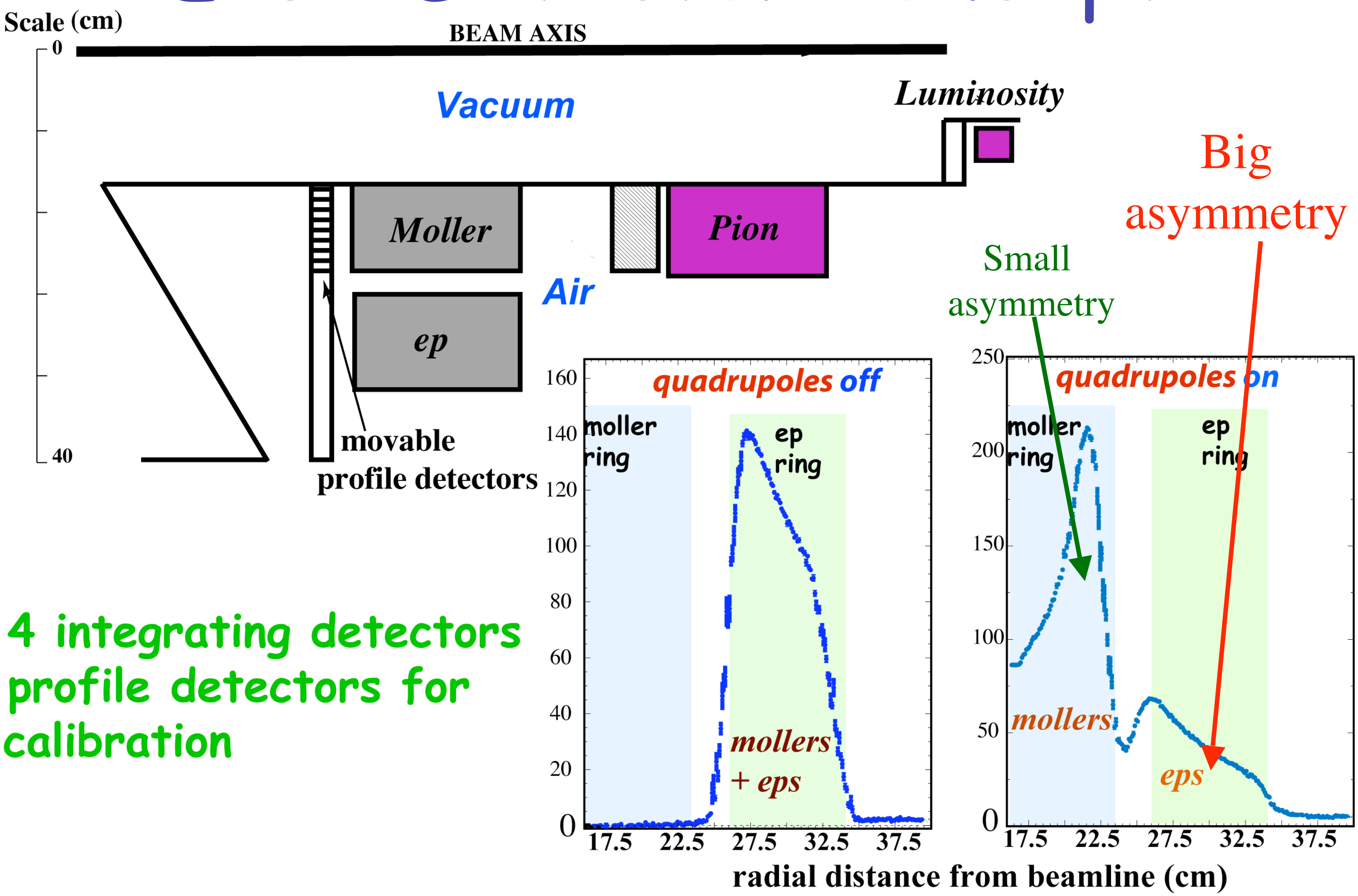
Line-of-sight shielding requires a "dogleg" or "chicane"



E158 Plan View in ESA



E158 Detector Concept



* 4 integrating detectors

* profile detectors for calibration

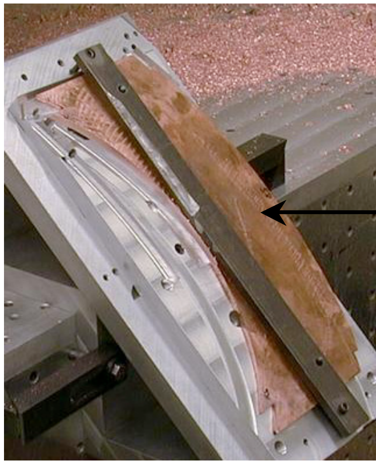
Detector Requirements

- Sharp edges (A^{PV} varies rapidly with R.)
- Small cross-talk
- <30% resolution (including tails)
- Sensitive only to high E electrons
- Rad hard
- Response ~ Energy

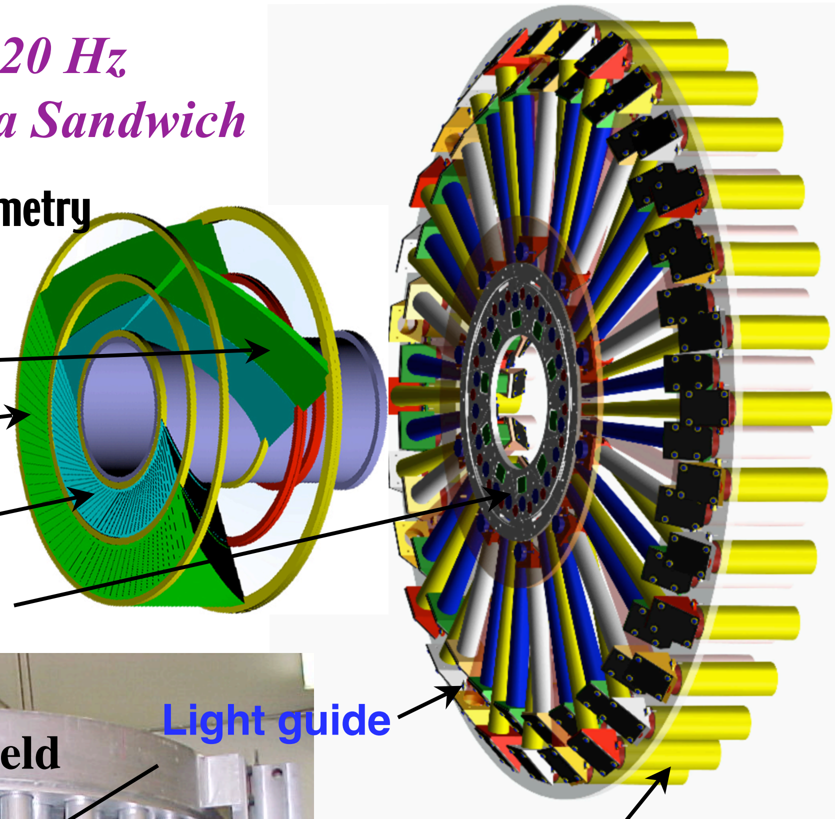
Intelligent compromises must be made

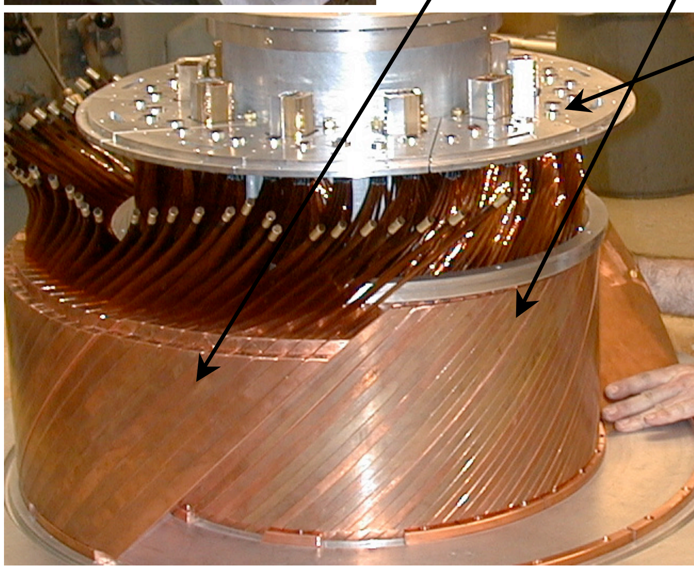
E158 Integrating Calorimeter

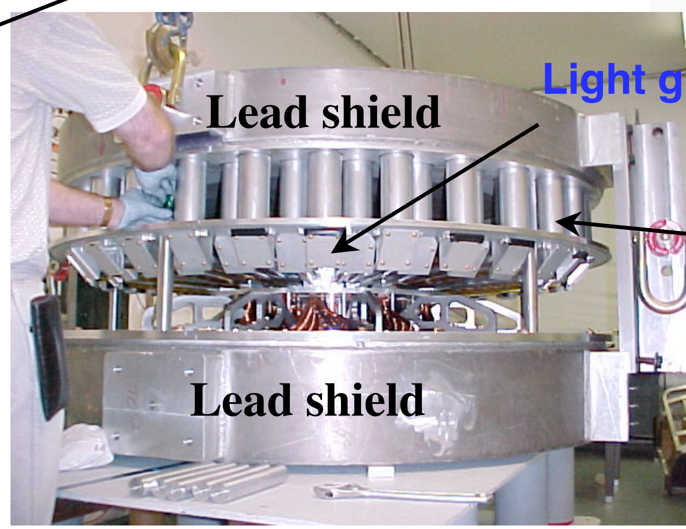
- *20 million 17 GeV electrons per pulse at 120 Hz*
- *100 MRad radiation dose: Cu/Fused Silica Sandwich*



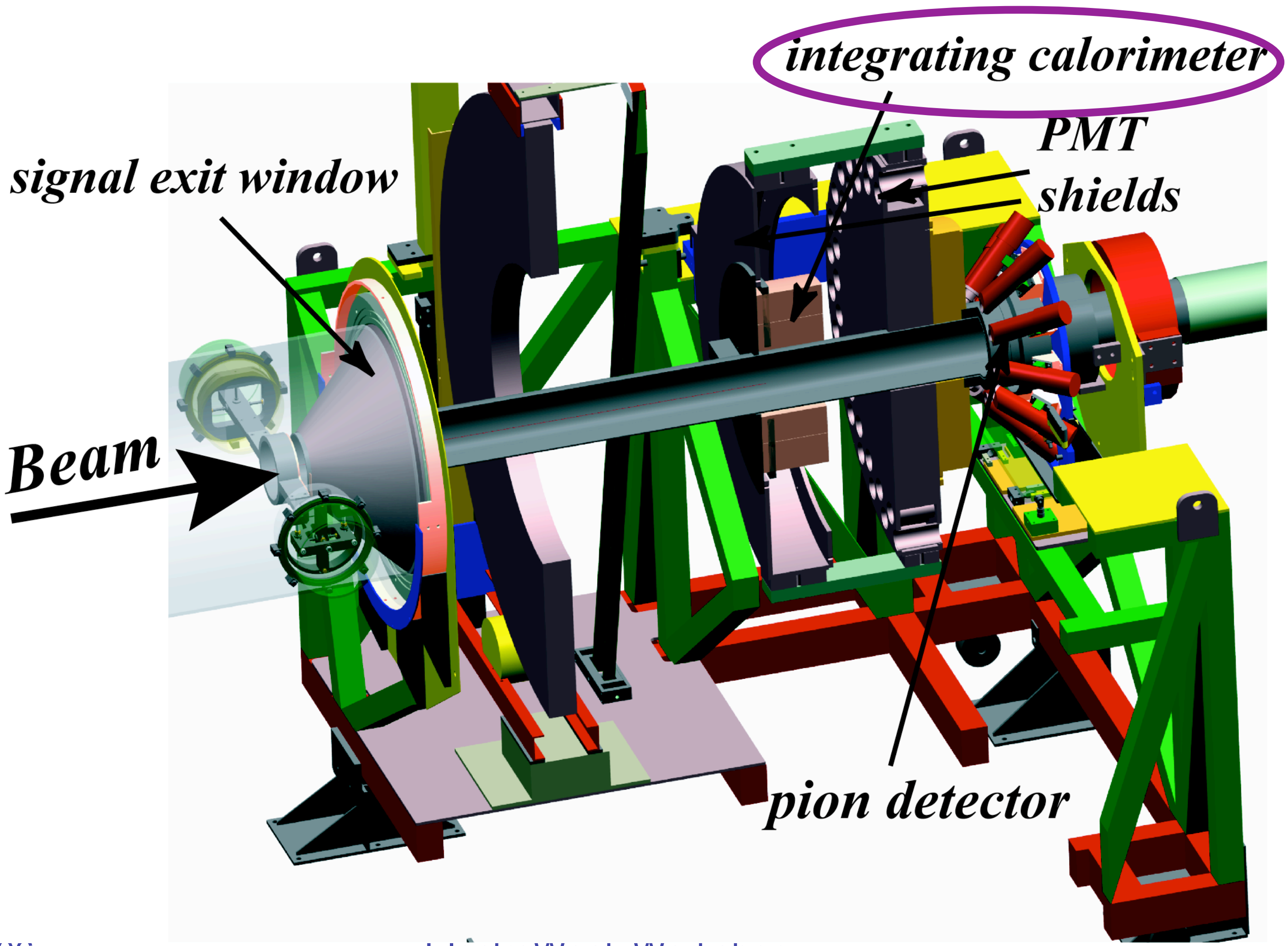
–State of the art in ultra-high flux calorimetry
–Challenging cylindrical geometry



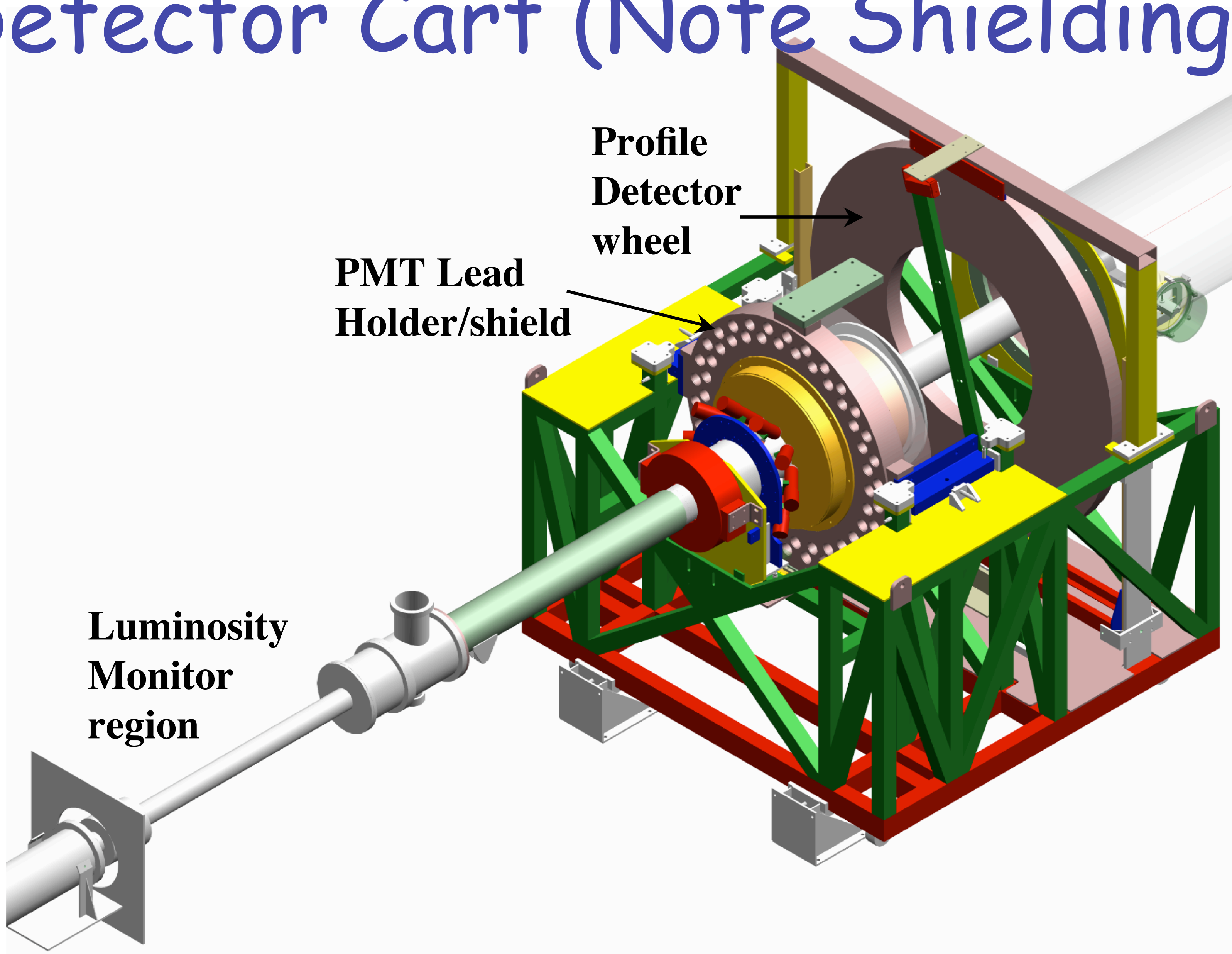




Detector Cart (Cutaway)



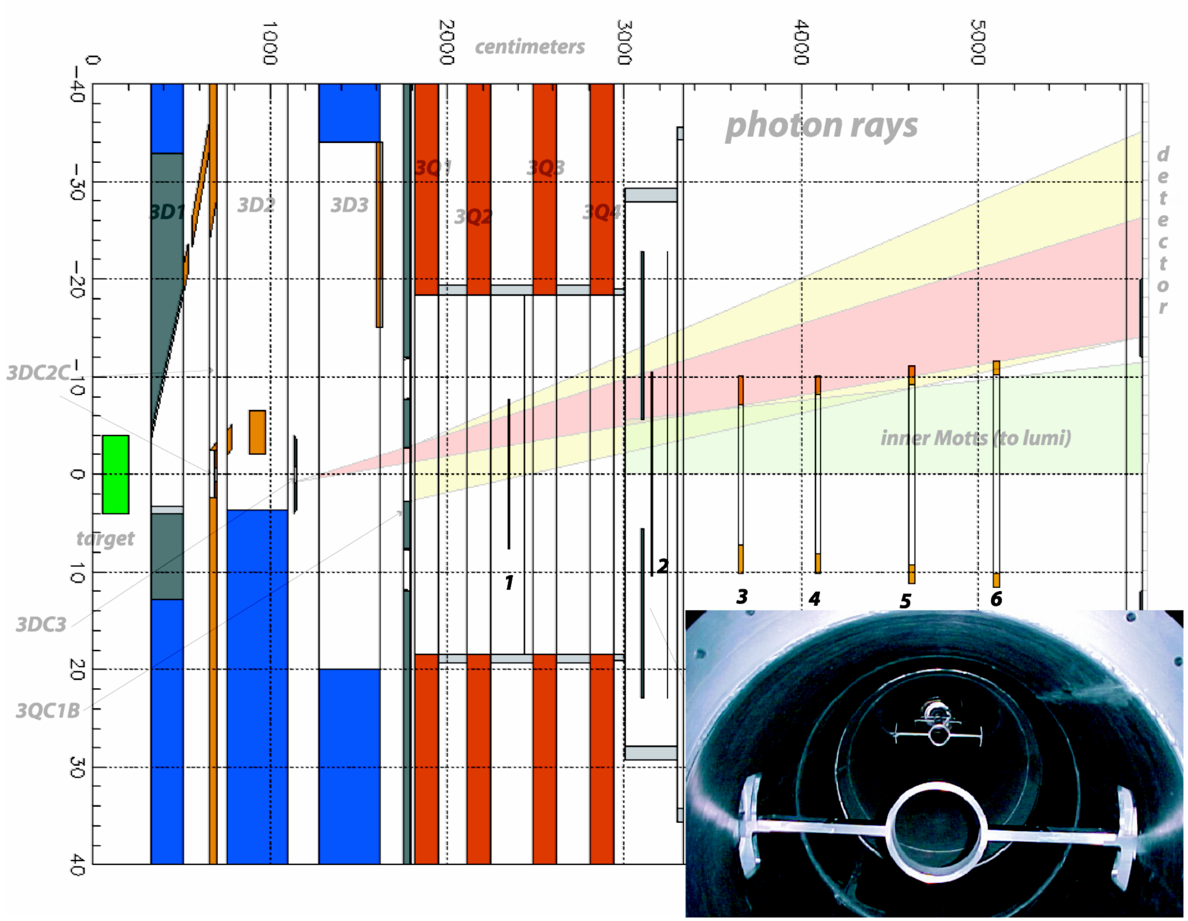
Detector Cart (Note Shielding)



De

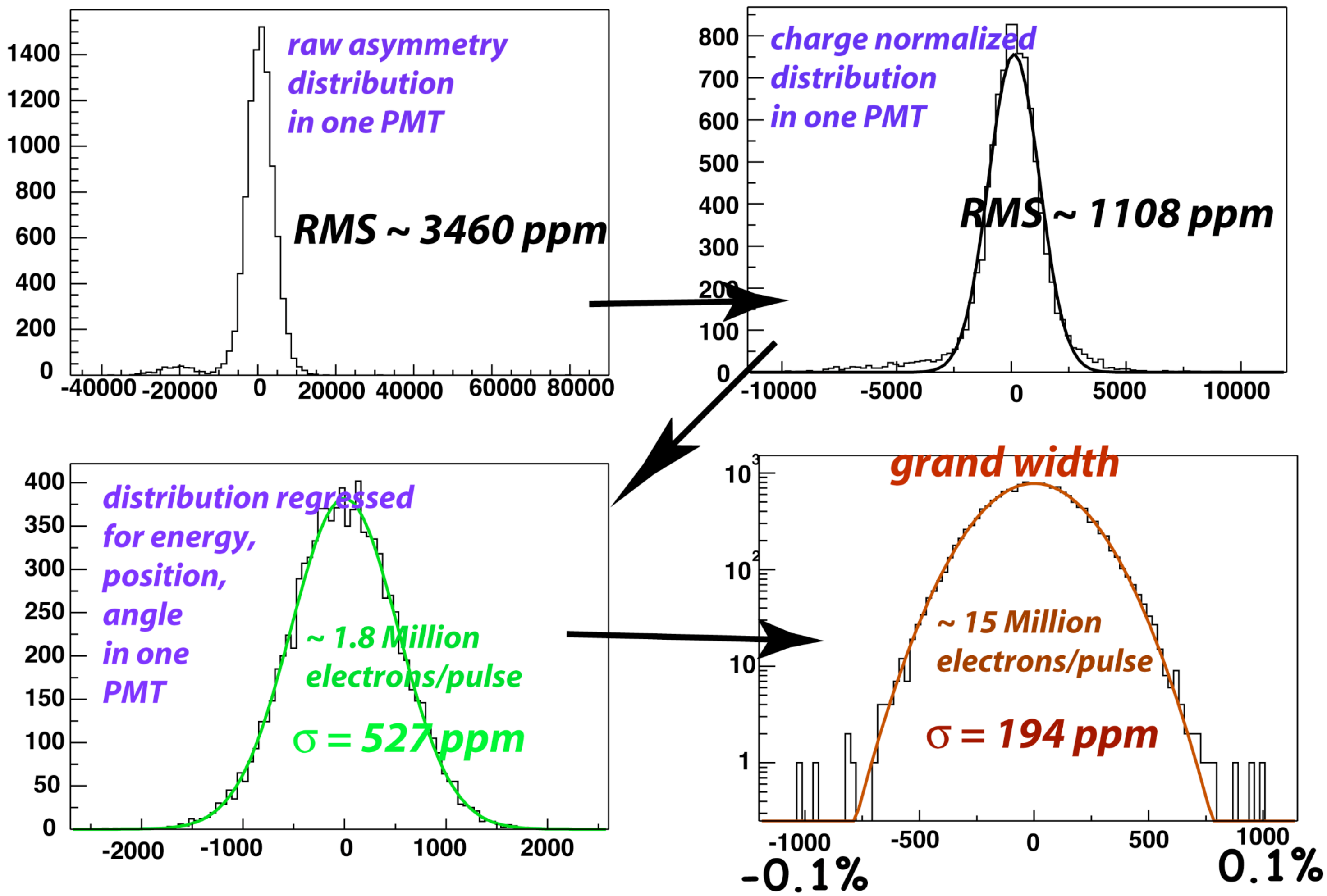
Photon Shielding (retrofit)

1. Reduced dilution factor.
2. Reduced helicity correlations



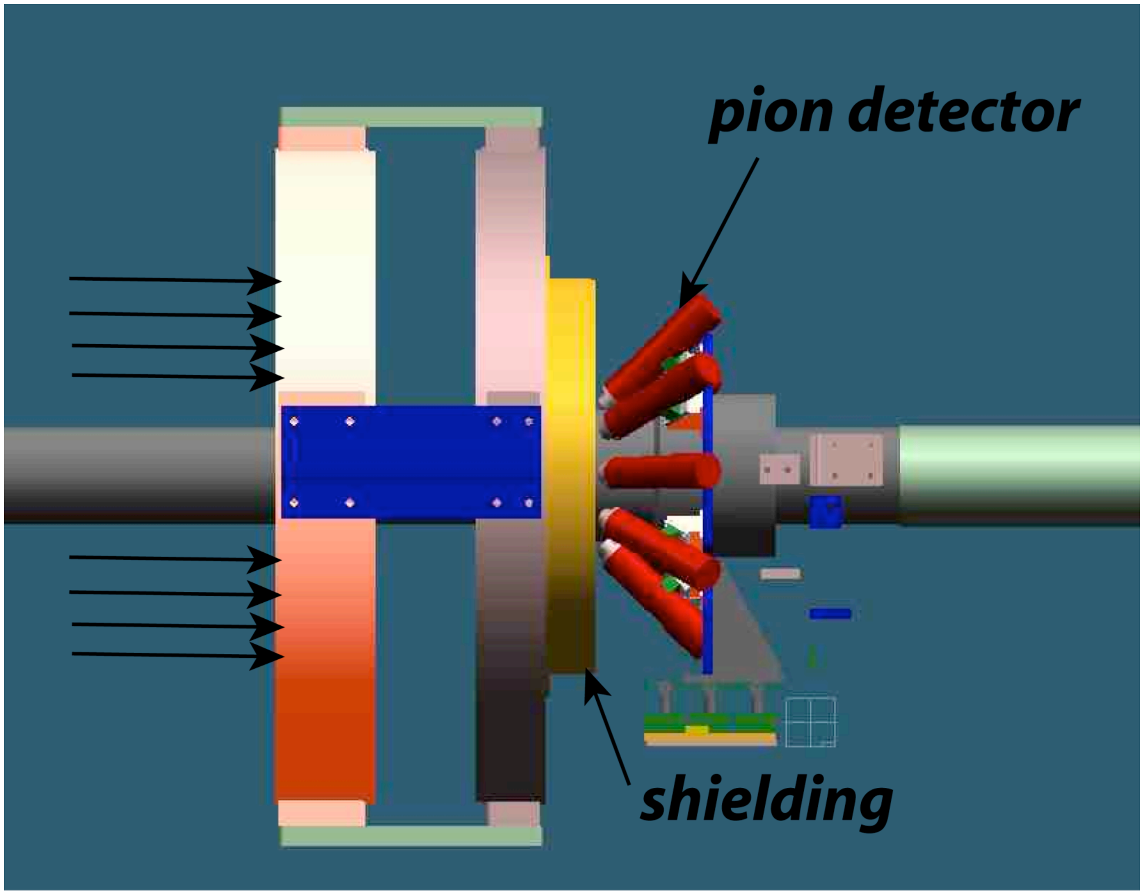
Detector Performance

observed left-right asymmetry distribution



In addition, independent analysis based on beam dithering

Pion Detector



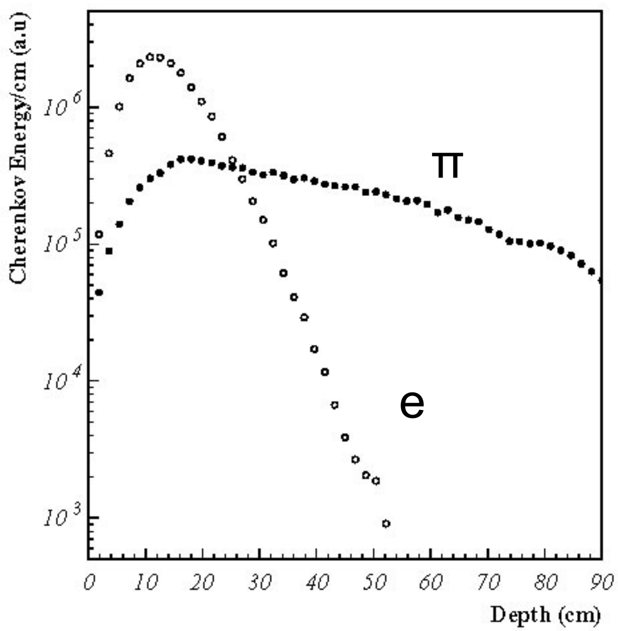
Problem: rare events with a potentially large asymmetry
Probably worse for e2e.

Hard part: identify the rare pions in the large electron flux

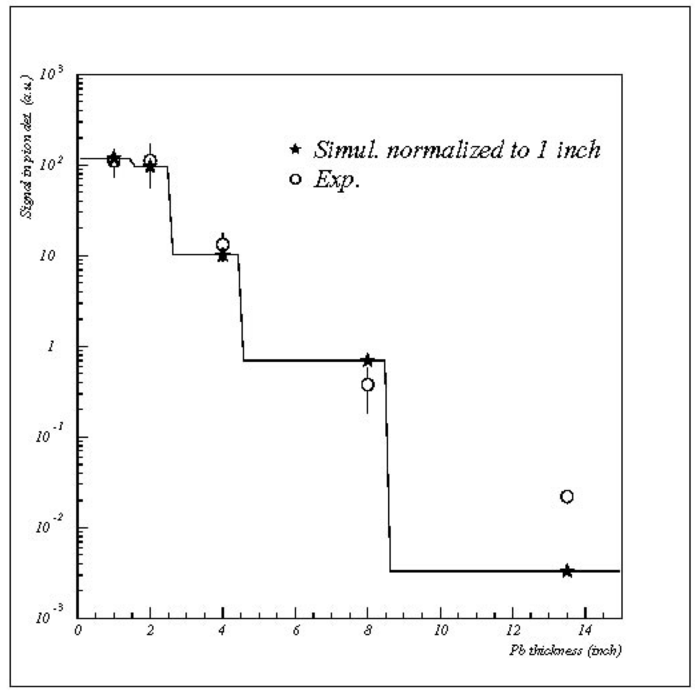
- *~ 0.5 % pion flux*
- *~ 1 ppm asymmetry*
- *~ 1 ppb correction*

π/e Separation

Quite a challenge at low duty factor

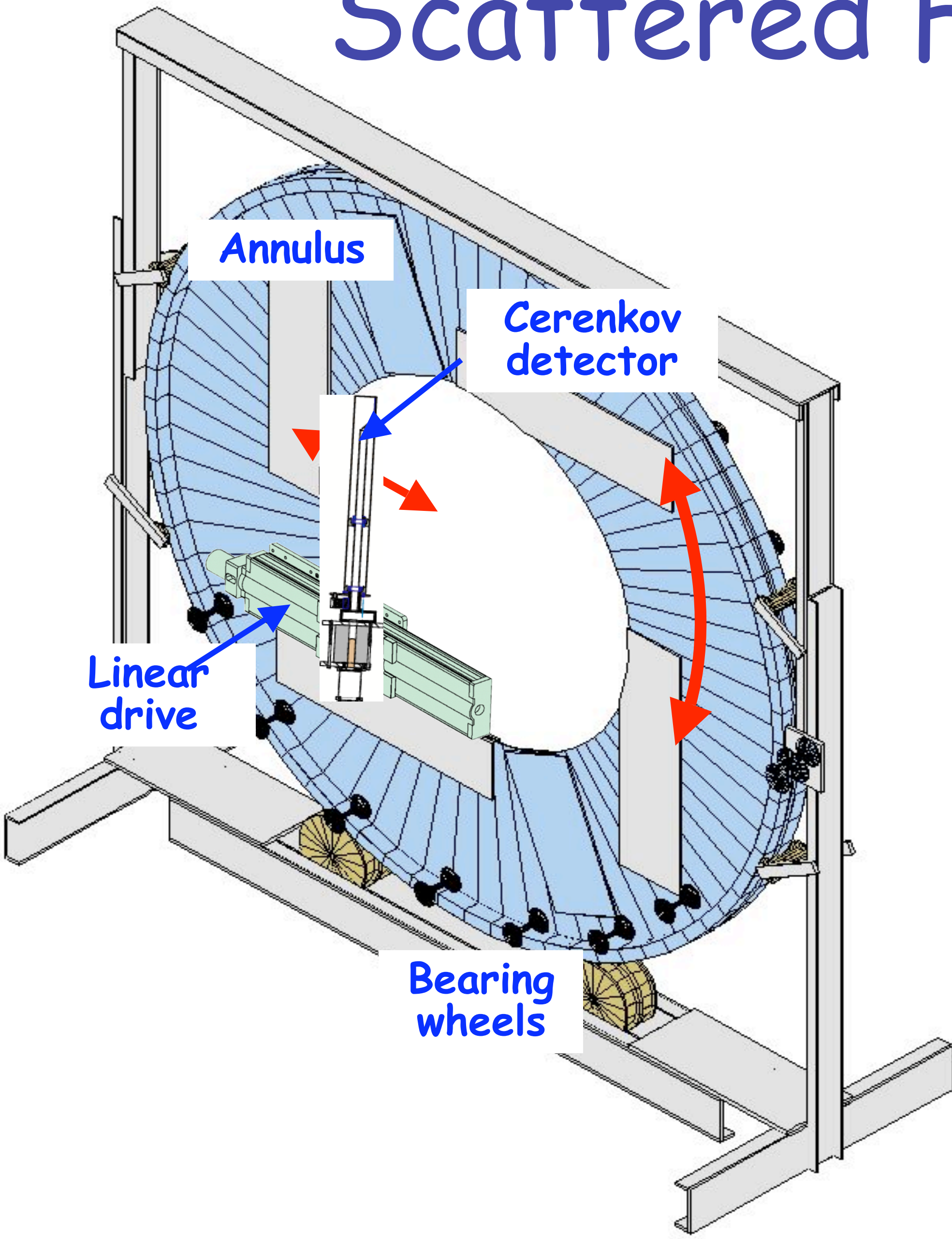


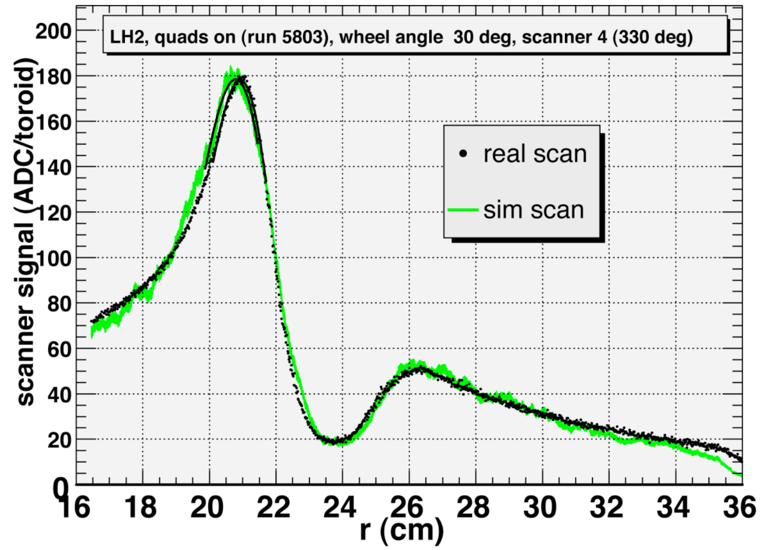
Attenuation of signal vs depth in detector

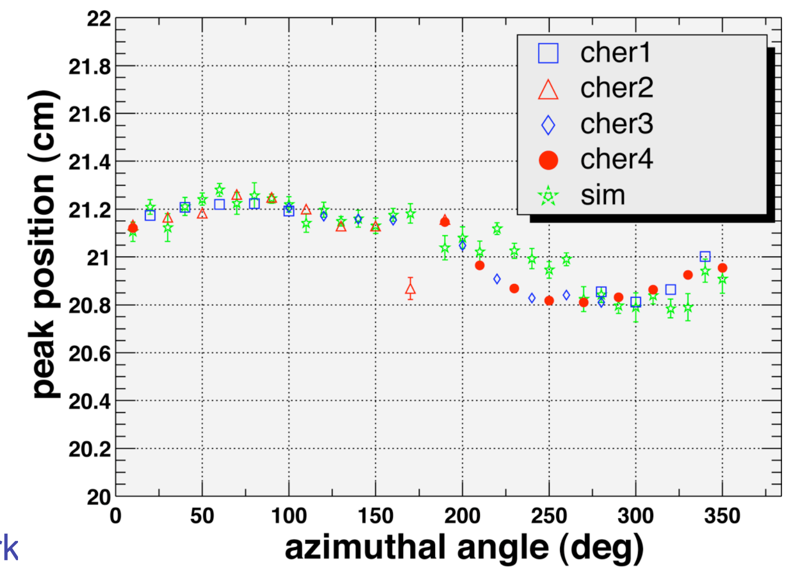


Observed signal vs depth

Scattered Flux Profile





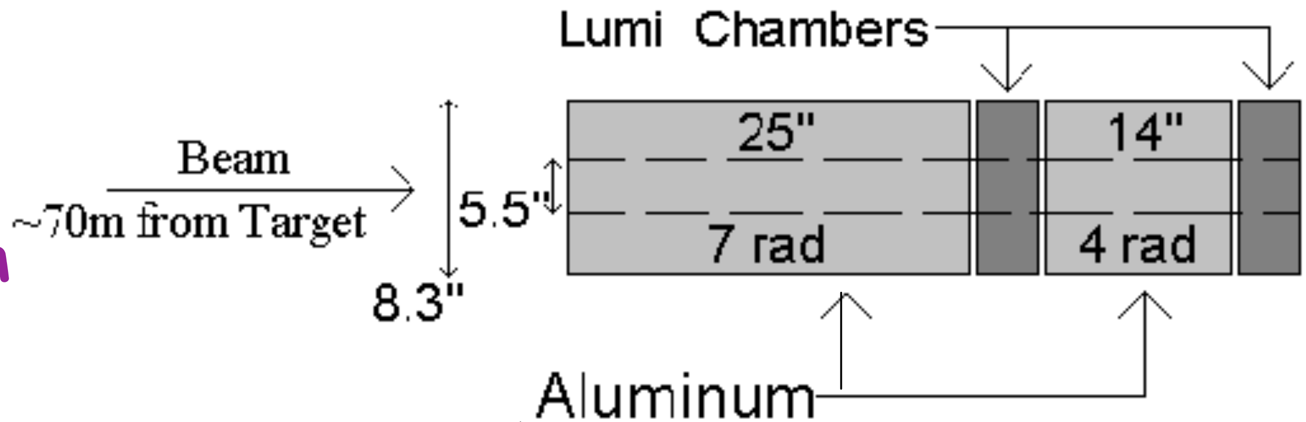


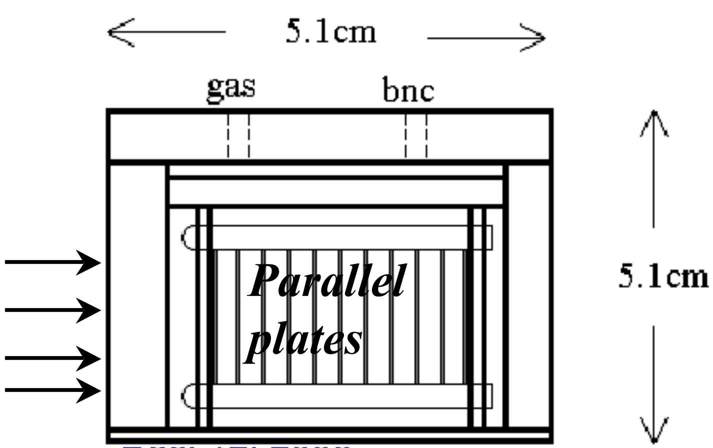
Work

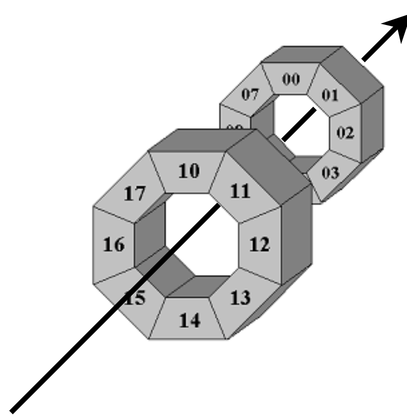
Luminosity Monitor

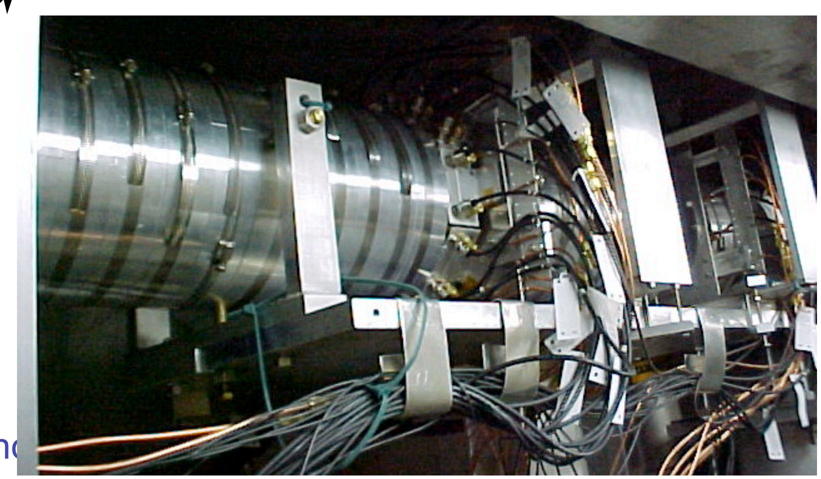
more than 10^8 scattered electrons per spill at $\theta_{lab} \sim 1$ mrad

- Null asymmetry test
- Density fluctuations monitor
- Enhanced sensitivity to beam fluctuations







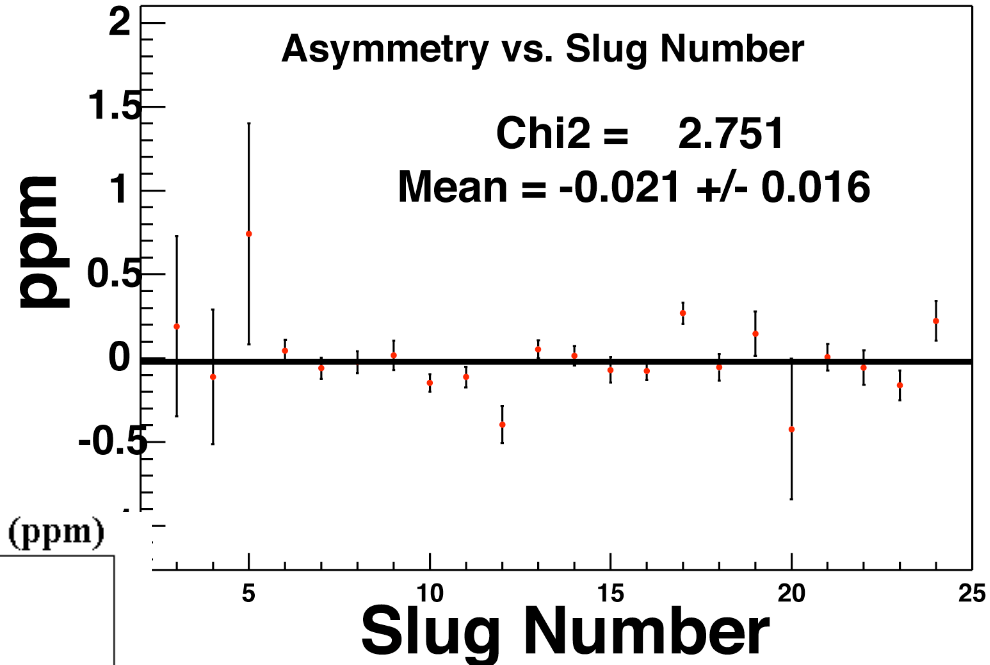


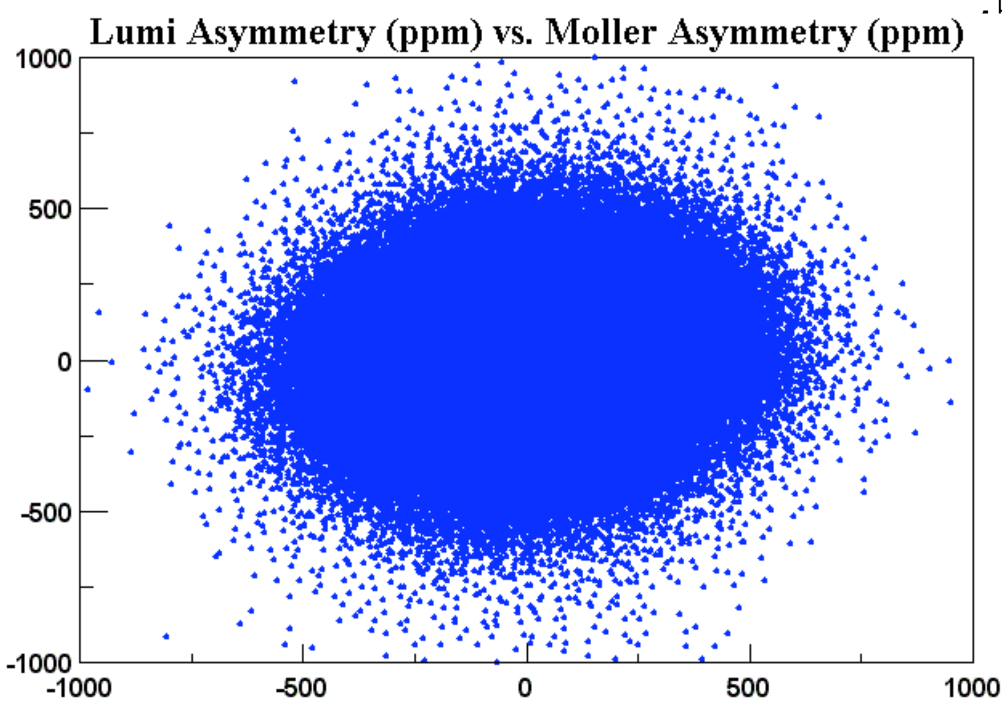
Performance of LUMI

- "Perfect" LUMI
- Resolution probably inadequate for moller
- Background rejection unknown(more sensitive to pions?)

Luminosity Monitor Data

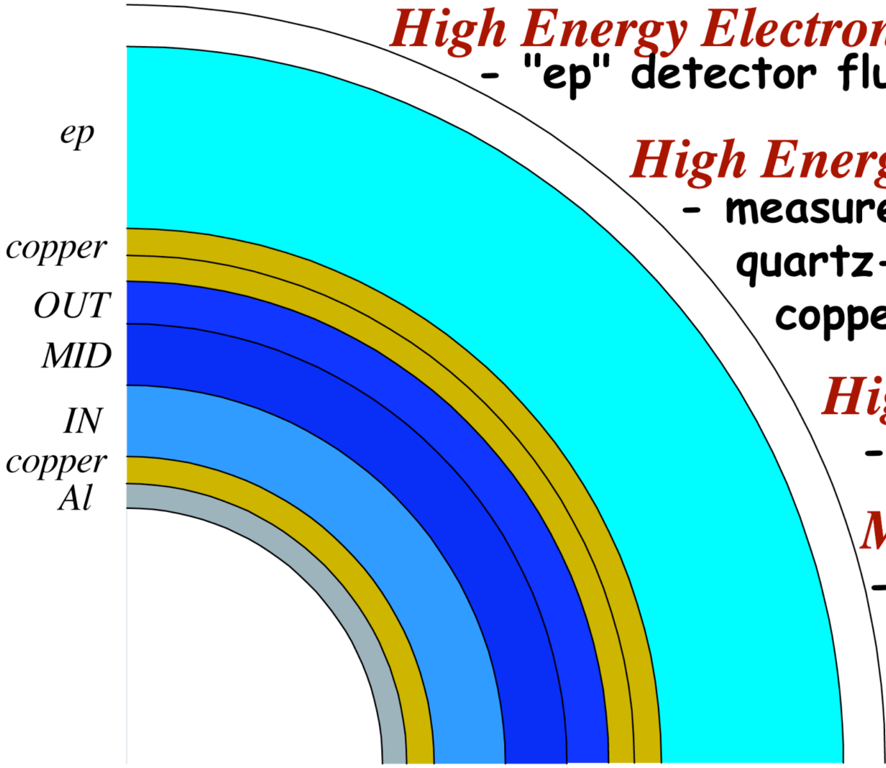
- *Null test at level of 20 ppb*





- *Density fluctuations small*
- *Limits on second order effects*

Backgrounds



High Energy Electrons:
- "ep" detector flux and asymmetry measurements

High Energy Pions:
- measure calibrated response to quartz-bar detectors behind 15 cm of copper + 20 cm of lead

High Energy Photons:
- Negligible due to collimation

Multibounce Photons:
- Quads off/on data with main detector & profile detector

Soft Photons and Neutrons:
- Quads off/on data with "blinded" PMTs

Synchrotron Photons:
- "target out" runs

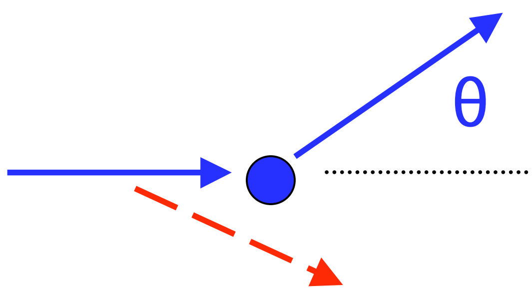
integrating calorimeter:
All dilutions and asymmetries must be measured or bounded

Final state radiation dominates!

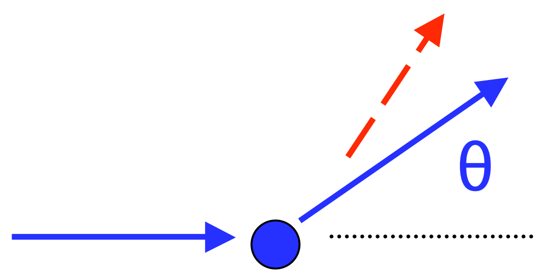
Usually initial state radiation dominates backgrounds because $\sigma \approx 1/Q^n$

For Møller, things are different

1. Relative σ for inelasitics has an extra factor of Q^2
2. $A \approx Q^2$, and Q^2 larger for final state radiation

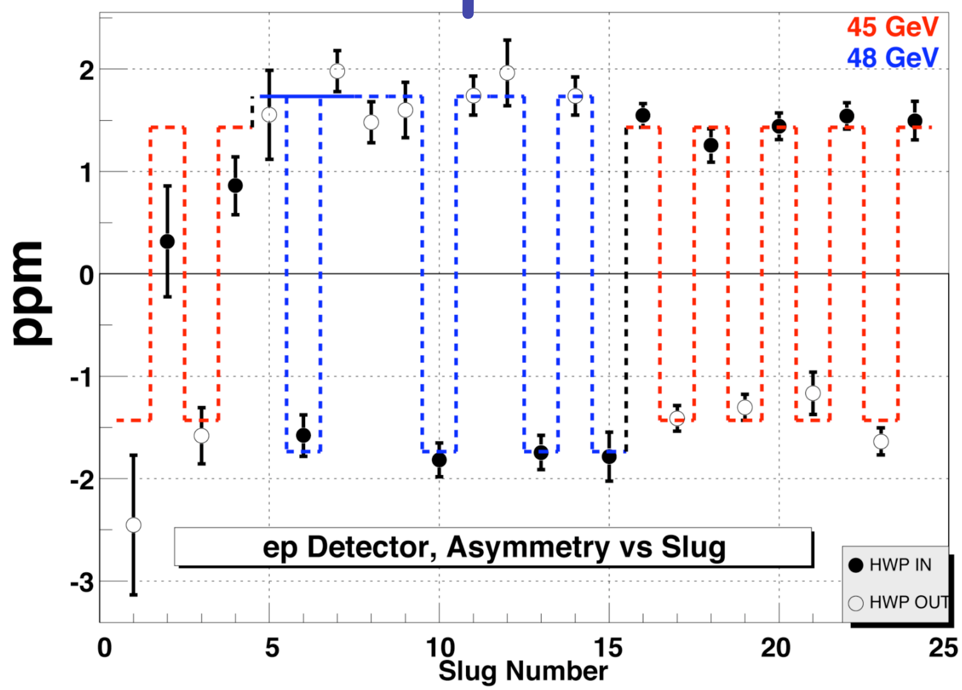


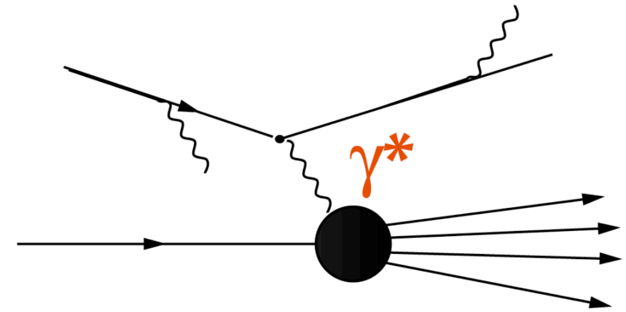
Initial state radiation: low Q^2



Final state radiation: high Q^2

"ep" Detector Data





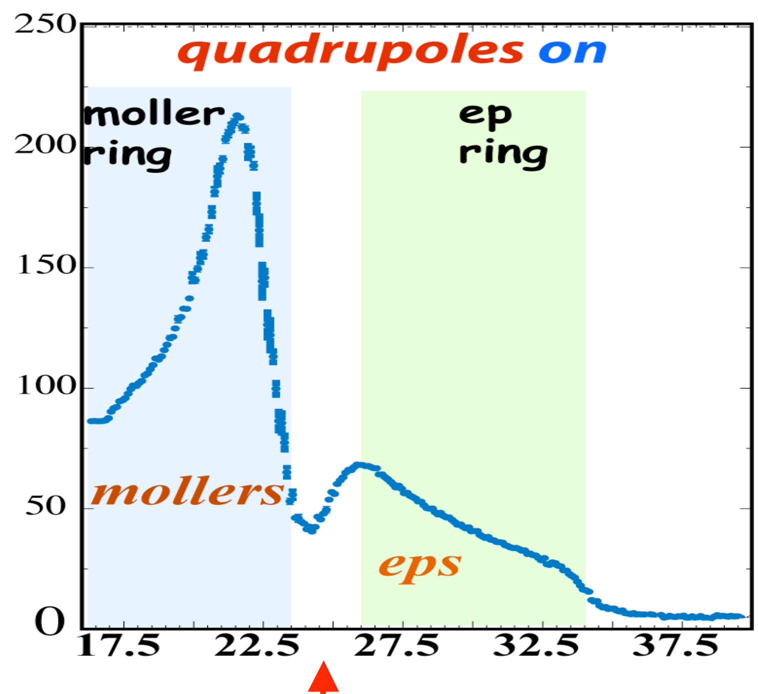
inelastic scattering

At low Q^2 : $A_{LR} \sim 10^{-4} * Q^2$

Improvement: Measure inelastic PV at low Q^2

- *Radiative tail of elastic ep scattering is dominant background*
- *6% under Moller peak*
- *Additional 1% from inelastic e-p scattering*
- *Coupling is large: similar to 3 incoherent quarks: $0.8 \times 10^{-4} \times Q^2$*
- *Background reduced in Run II & III with additional collimation*

Measure background asymmetry

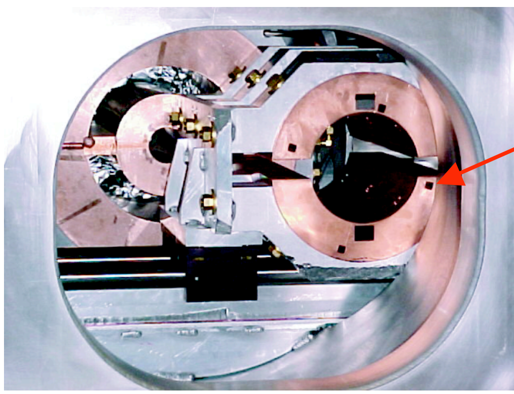


If there is a focus for the Møller events, the background asymmetry can be cleanly measured

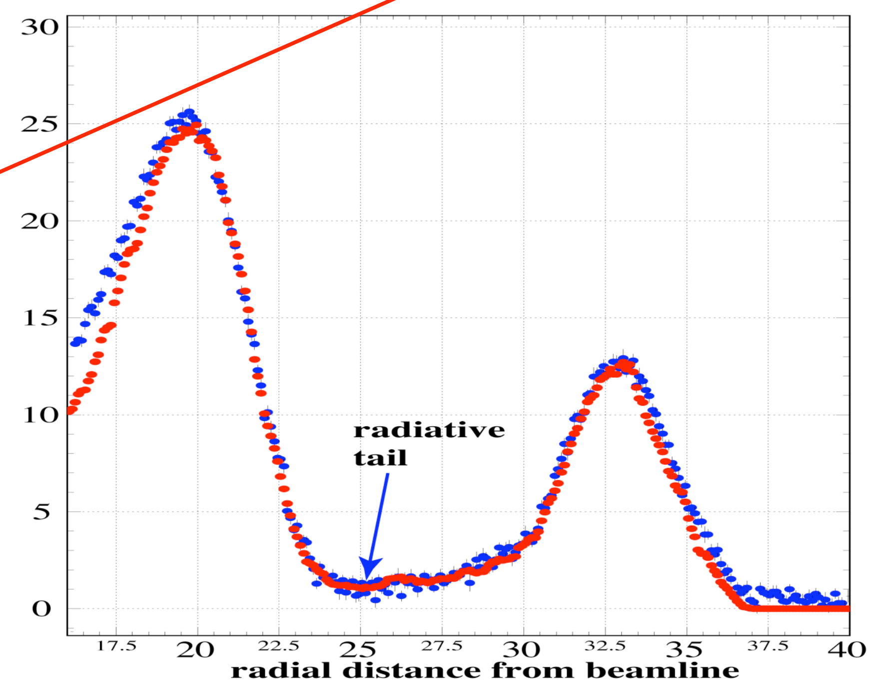
With E158 resolution, there was little room between the Moller and ep peaks for clean background measurements

Monte-Carlo tested with small apertures

Insertable collimator

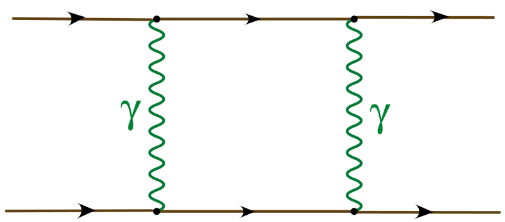


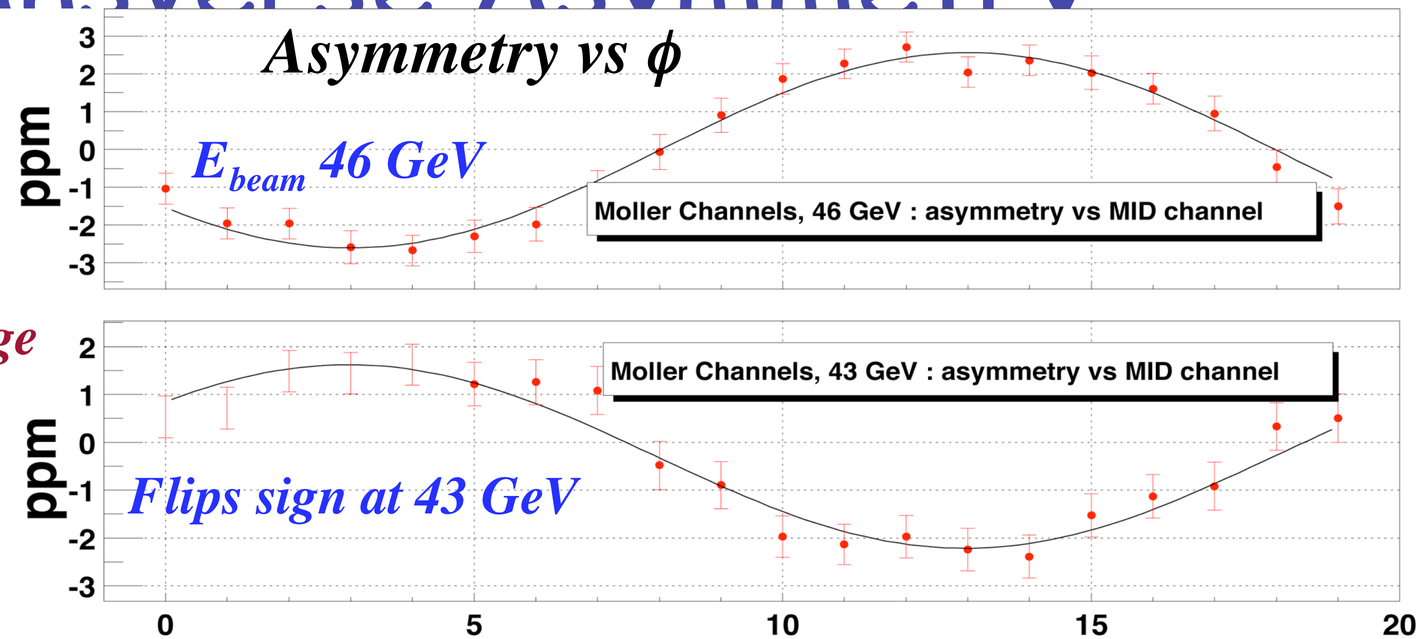
Peak with small aperture



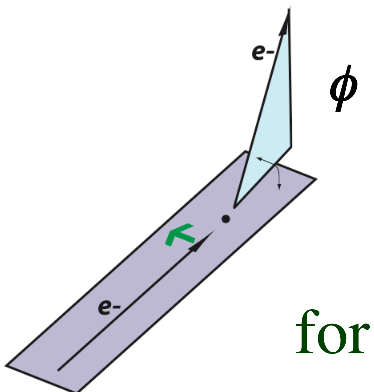
With reduced aperture,
there is plenty of room
to measure background asymmetry

Transverse Asymmetry





Two-photon exchange
QED effect



for Møller scattering
at 46 GeV

$$A_T \propto \frac{\alpha m_e}{\sqrt{s}} = -3.5 \text{ ppm} \bullet \sin\phi$$

Observe ~ 2.5 ppm up-down asymmetry
w/ horizontal polarization
First measurement of single-spin
transverse asymmetry in e-e scattering.

Theory References:

1. **A. O. Barut and C. Fronsdal, (1960)**
2. **L. L. DeRaad, Jr. and Y. J. Ng (1975)**
3. **Lance Dixon and Marc Schreiber (2004)**

Summary of Corrections

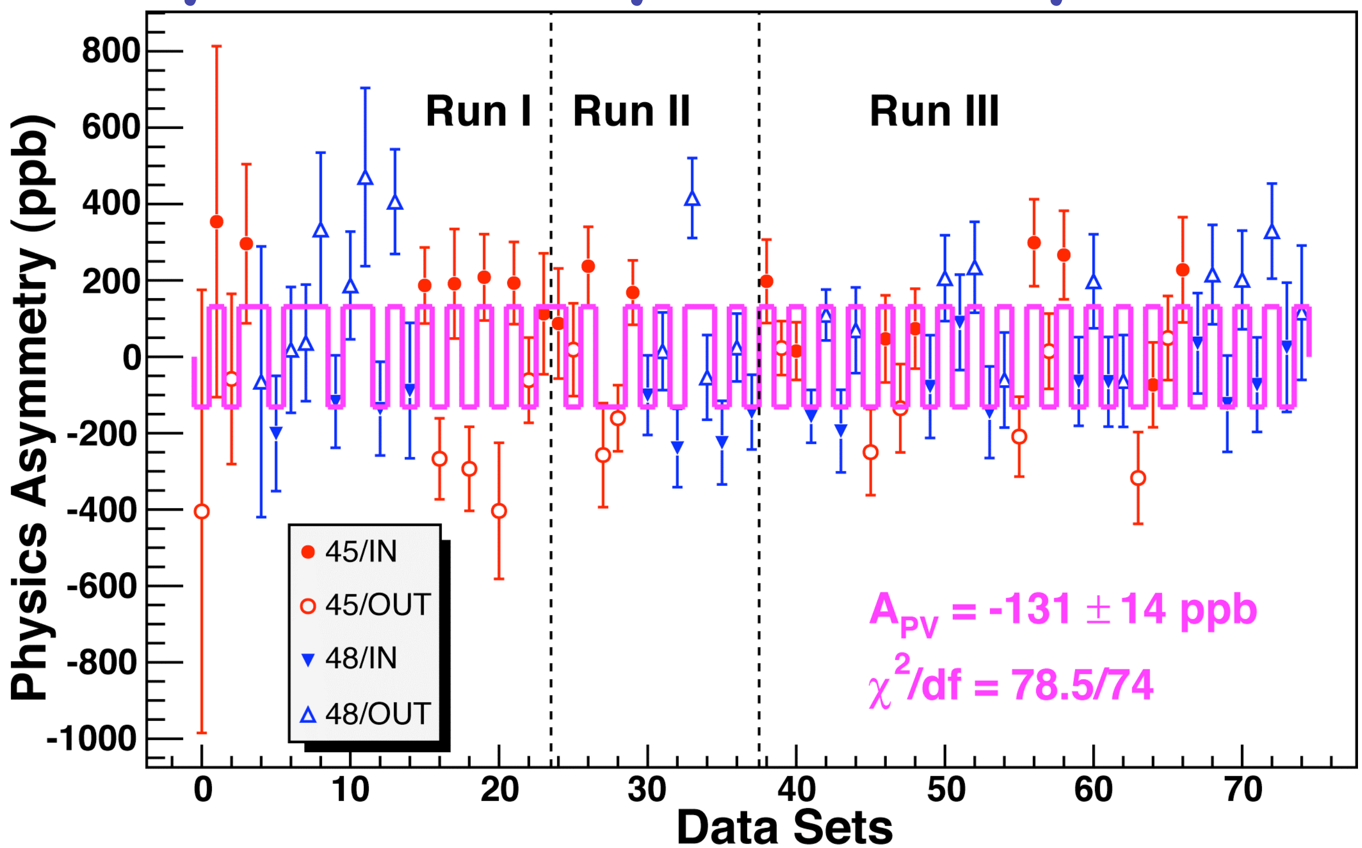
Correction	f_{bkg}	$\sigma(f_{bkg})$	A_{corr} (ppb)	$\sigma(A_{corr})$ (ppb)
Beam first order	-	-	-10	1
Beam higher orders	-	-	0	3
Beam spotsize	-	-	0	1
Transverse asymmetry	-	-	-4	2
High energy photons	0.004	0.002	3	3
Synchrotron photons	0.002	0.001	0	1
Neutrons	0.003	0.001	-1	1
ep elastic ep inelastic	0.056 0.009	0.007 0.001	-7 -22	1 4
Pions	0.001	0.001	1	1
TOTAL	0.075	0.008	-40	6

Normalization

Normalization Factor	f	$\sigma(f)$
Dilutions	**0.92**	**0.01**
Polarization	**0.88**	**0.05**
Analyzing power	**1.01**	**0.02**
Linearity	**0.99**	**0.01**

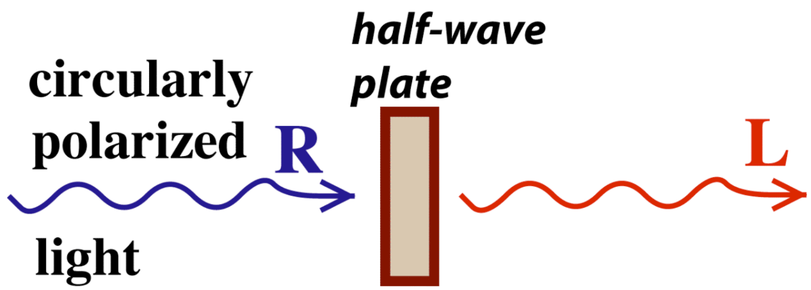
- ***Beam polarization measured using polarized foil target***
- ***Same spectrometer used with dedicated movable detector***

Physics Asymmetry vs Time



$$A_{PV} = (-131 \pm 14 \pm 10) \times 10^{-9}$$

Systematic Checks

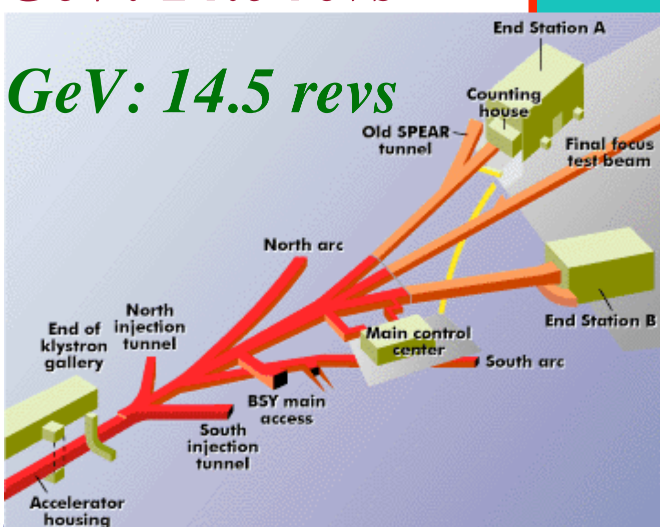


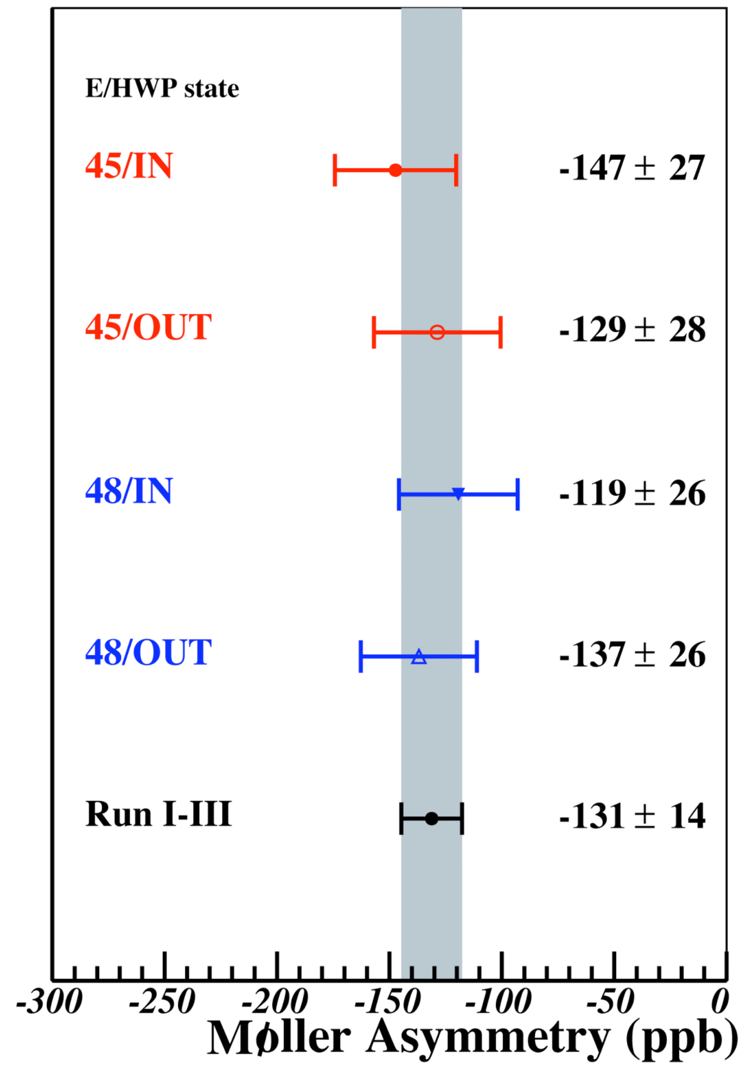
g-2 spin precession

45 GeV: 14.0 revs

48 GeV: 14.5 revs

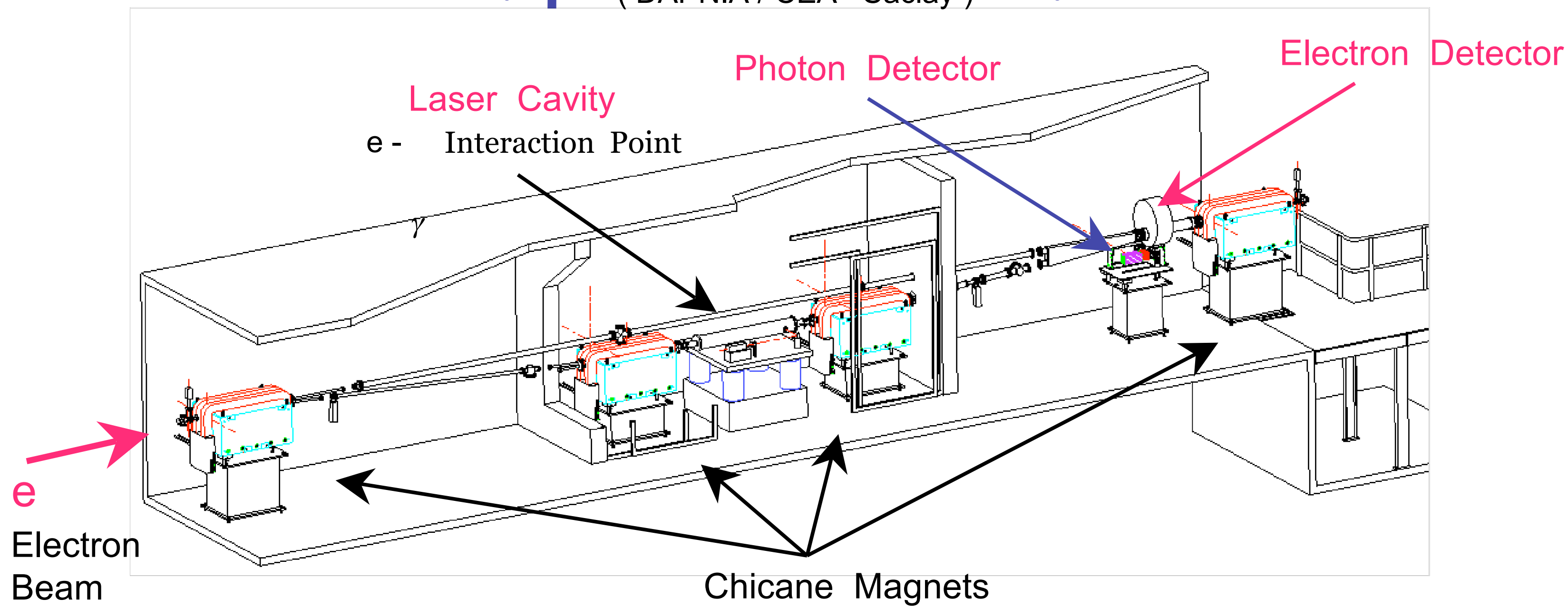
g-2 flip is essential!





Compton Polarimeter

(DAPNIA / CEA Saclay)



Upgrades to achieve dP/P ~1.5 % for E > 0.85 GeV

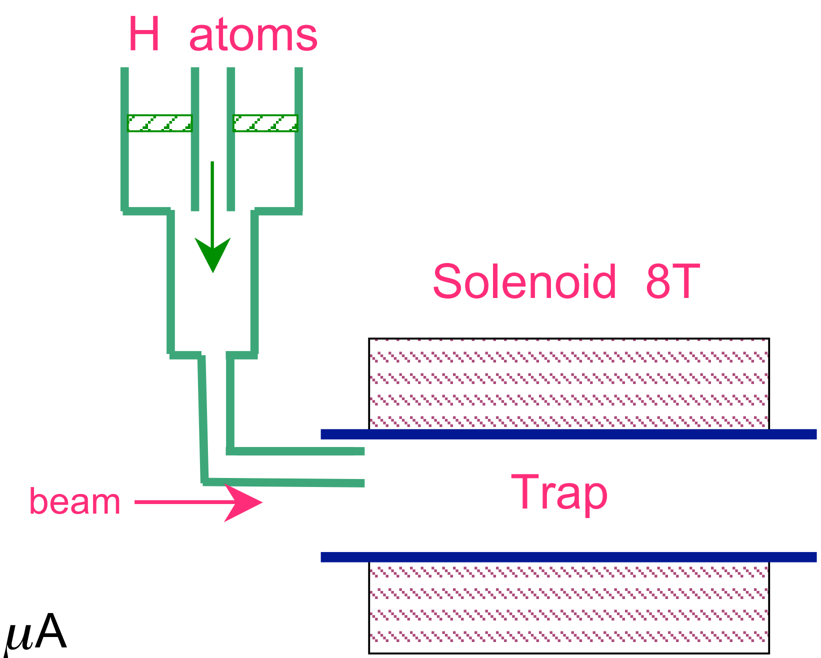
- Green Laser
- New integrating photon detector
- Finer (50 m) μstrip e^- detector, closer (4.5 mm) to beam.

Mołler Polarimetry with Atomic Hydrogen Target

(E. Chudakov, V. Luppov)

Ultra Cold Traps

- Polarization ~ 100%
- Density
- Lifetime > 10 min



Polarimetry

- 1% stat. err. in 30 min at 30 μA
- Low background
- High beam currents allowed (100 μA)
- Goal: ~ 0.5 % systematic error

Making a Convincing Measurement

- Verify asymmetry with g-2 flips.
- Understand backgrounds so that conservative errors are negligible.
- Redundant polarimetry.

SLAC VS JLab

	SLAC	JLab
E	48	11
E’	24	5.5
θ	5	10
L_{Hall}	60 m	30 m

Perfect Scaling?

Choice of detector

- Quartz fiber total absorption
- Quartz bar
- Ion chamber

In E158, we used all three

Backgrounds & Normalization

Integrating calorimeter:

background dilutions and asymmetries must be separately measured or bounded.

- *Elastic and inelastic e-p scattering and radiative tail*
- *High energy pions*
- *High and low energy photons*
- *Neutrons*
- *Synchrotron radiation*

Total dilution: 9.3% in Run I, 7.6% in Run II & III

- *Beam polarization measured using polarized foil target*
  - *Same spectrometer used with dedicated movable detector*
- *Energy scale and spectrometer alignment to determine <Q^2>*
- *Linearity of PMTs*

Largest systematic errors:

- ***Inelastic ep: -24 ± 6 ppb (Run I), -20 ± 5 ppb (Run II, III)***
- ***Beam polarization: 0.85 ± 0.05 in Run I, 0.90 ± 0.05 (Run II, III)***

At JLab, the problem is 5x bigger

1. PREX has a similar but slightly smaller problem.
2. Symmetric 2ø acceptance helps
3. Need small feedback system on beam spin direction to null ø dependence
4. Apparatus must have good symmetry