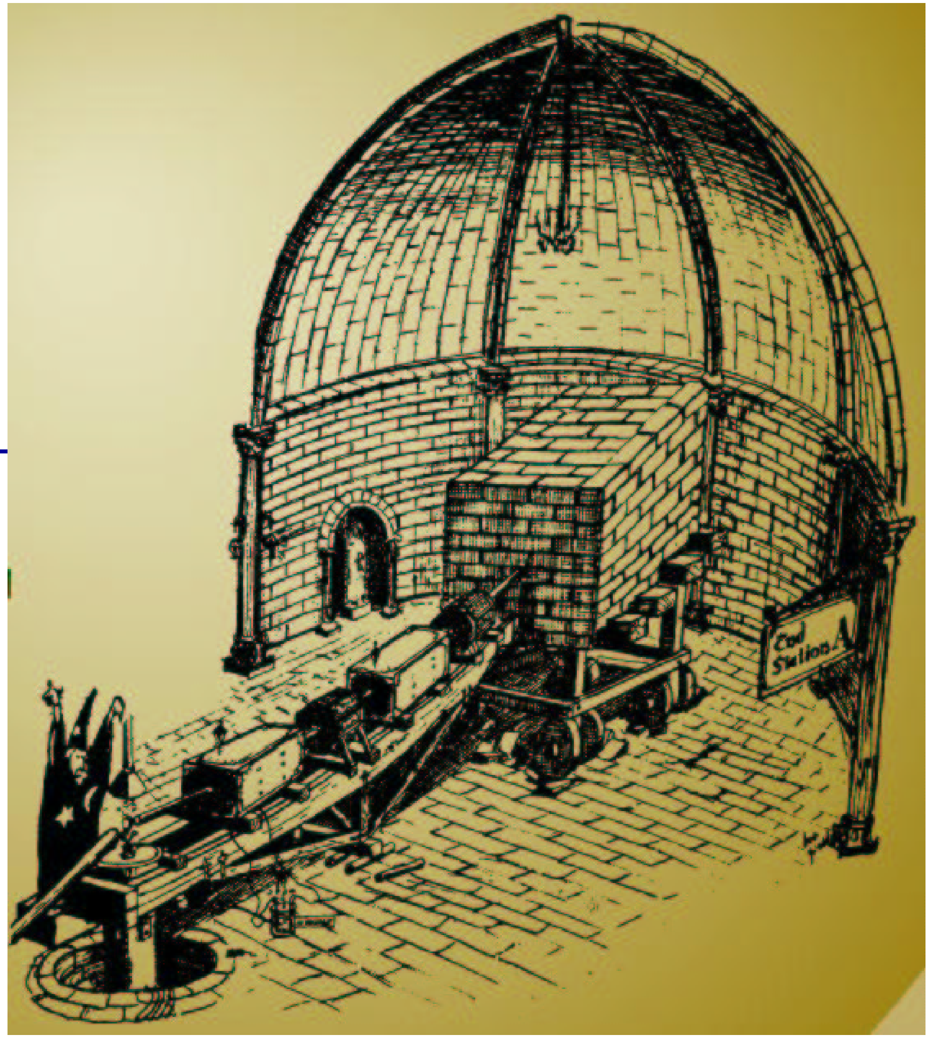
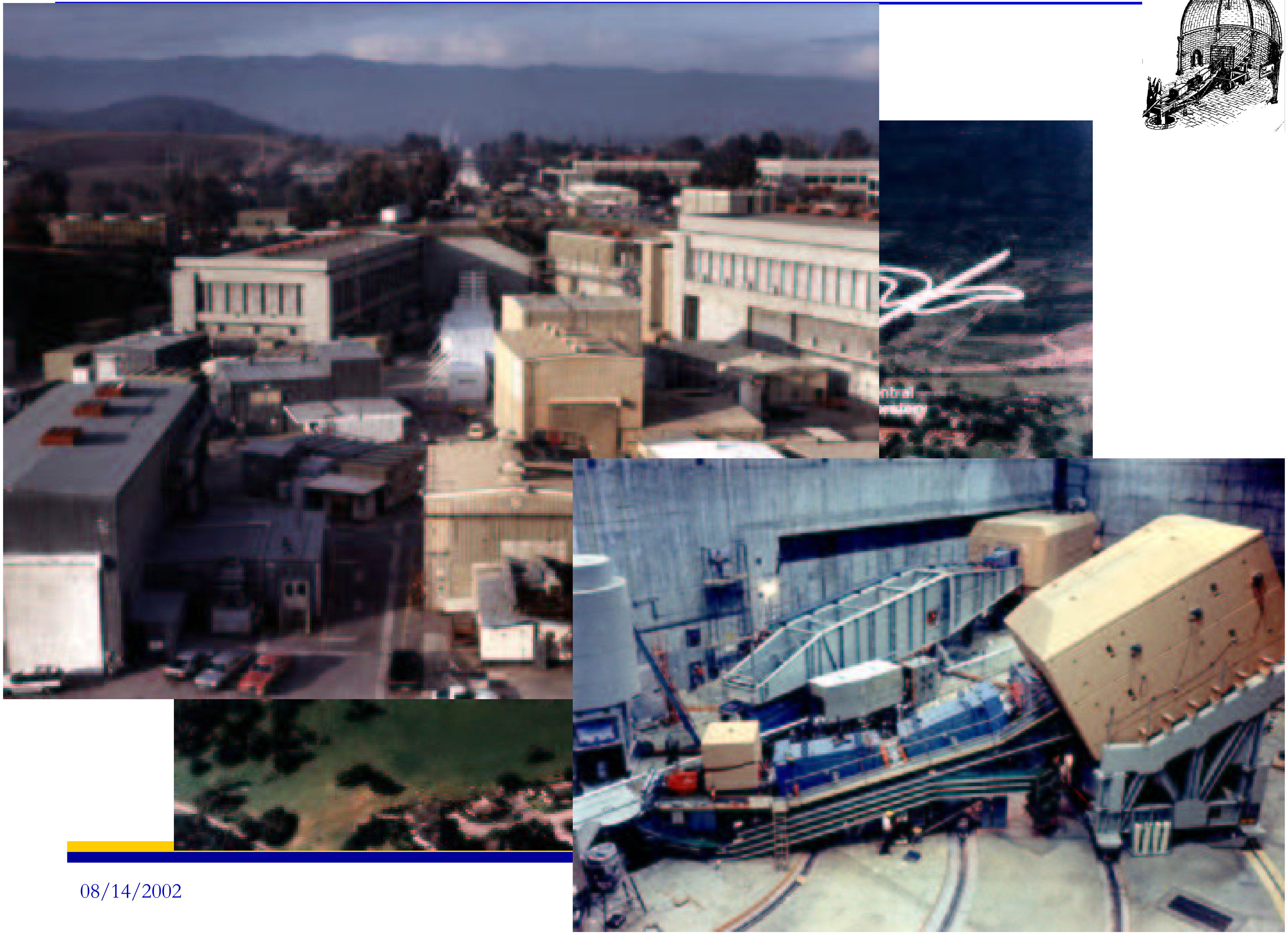
Parity Violation in Møller Scattering

First Results from E158



Yury Kolomensky
UC Berkeley
SLAC Summer Institute
August 14, 2002



Fixed Target Program @ End Station A

☞ Complementary to collider program, building on unique strengths of SLAC

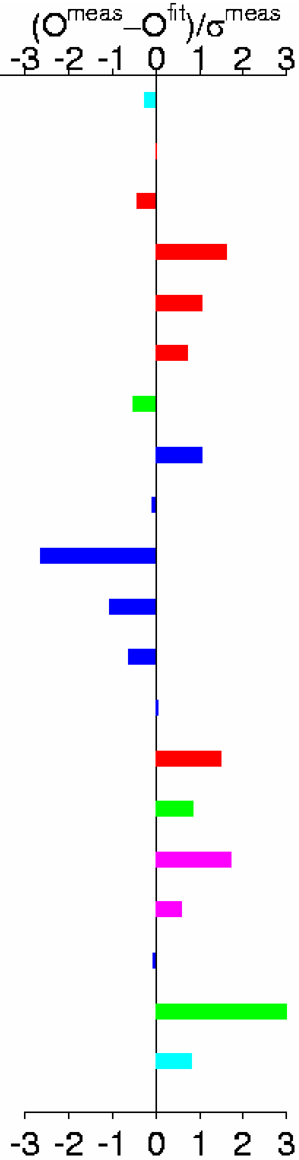
- ❑ Precision spin physics a focus

- 1992-1997: Measurements of spin structure functions
  - ❑ Highly successful program, new window into the nucleon structure and QCD dynamics
- 1997-2003: Measurement of $\sin^2\theta_W$ in Møller scattering
  - ❑ Precision Electroweak measurements
- Beyond 2003: Physics with real photons
  - ❑ Nucleon structure, back to mysteries of QCD

Precision Electroweak Measurements

(LEP Electroweak Working Group)

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.27
m_Z [GeV]	91.1875 ± 0.0021	.01
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.05
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.70
$A_l(P_\tau)$	0.1465 ± 0.0033	-.53
R_b	0.21646 ± 0.00065	1.06
R_c	0.1719 ± 0.0031	-.11
$A^{0,b}_{fb}$	0.0994 ± 0.0017	-2.64
$A^{0,c}_{fb}$	0.0707 ± 0.0034	-1.05
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.50
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
m_W [GeV]	80.451 ± 0.033	1.73
Γ_W [GeV]	2.134 ± 0.069	.59
m_t [GeV]	174.3 ± 5.1	-.08
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	3.00
$Q_W(Cs)$	-72.39 ± 0.59	.84

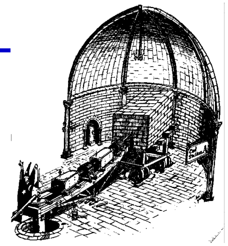


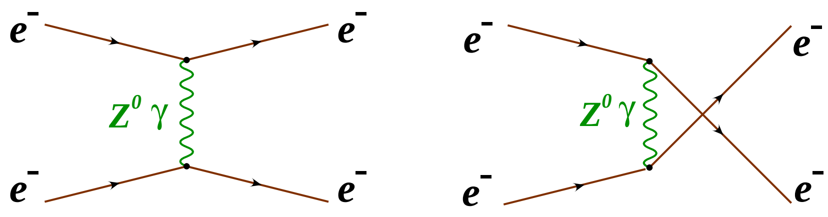
$$\chi^2/dof = 30.4/15$$

Probability ~ 1.5%

Few smoking guns, no definitive clue for New Physics yet

Parity Violation in Møller Scattering



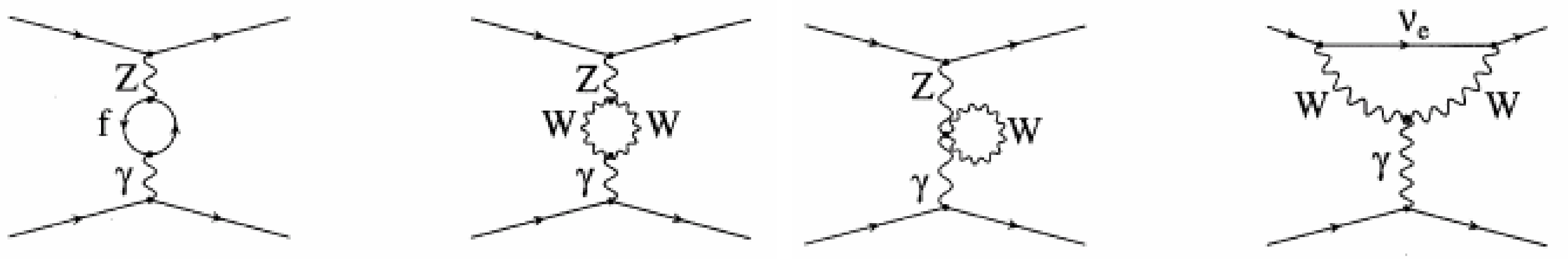


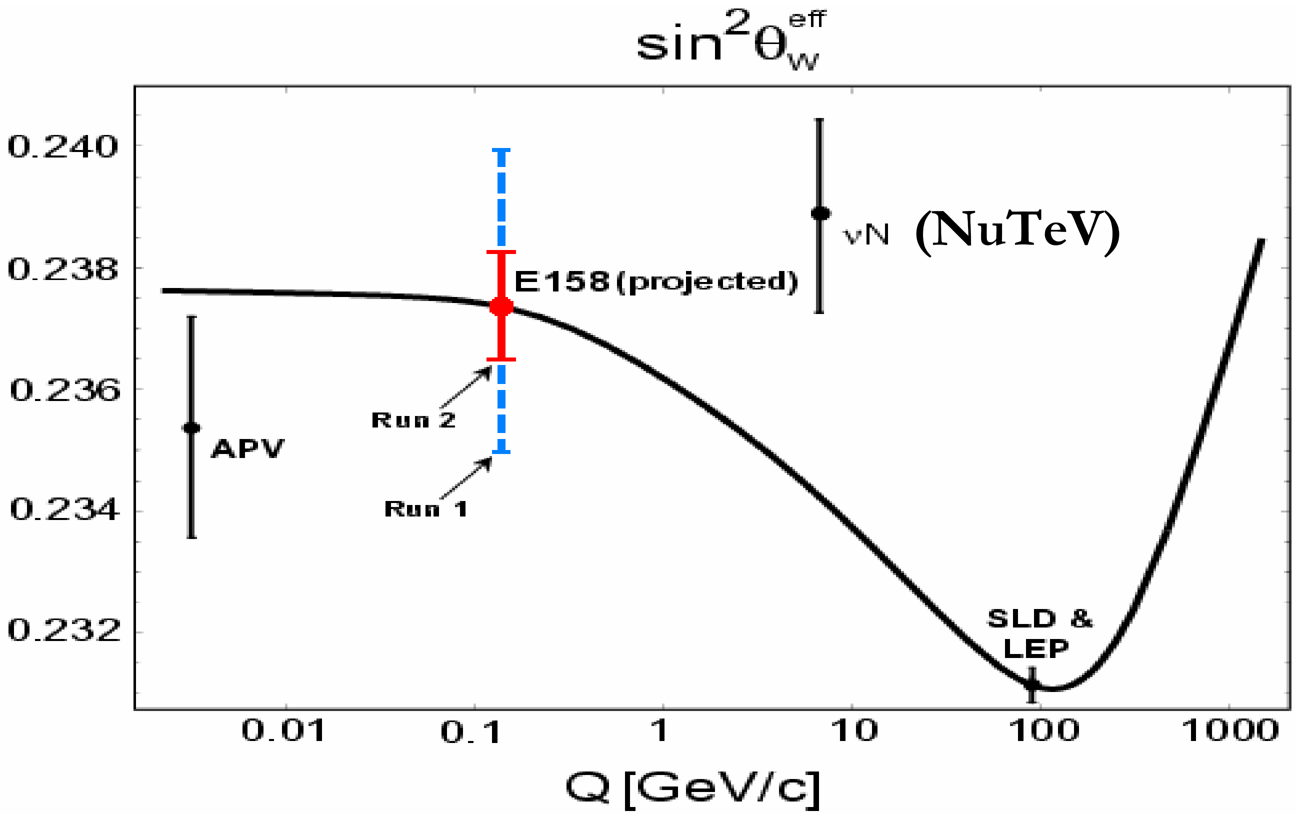
- Scatter polarized 50 GeV electrons off *unpolarized* atomic electrons
- Measure $A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L}$
- Small tree-level asymmetry

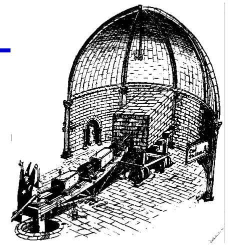
$$A_{PV} = mE \frac{G_F}{\sqrt{2\pi\alpha}} \frac{16 \sin^2 \Theta}{(3 + \cos^2 \Theta)^2} \left(\frac{1}{4} - \sin^2 \theta_W \right)$$

- At tree level, $A_{PV} \approx 320 \cdot 10^{-9}$
- Raw asymmetry about 140 ppb
  - Goal is to measure it with precision of 8%
  - Most precise to date measurement of $\sin^2\theta_W$ at low Q^2 with $\sigma(\sin^2\theta_W)=0.0008$

Radiative Corrections: Running of $\sin^2\theta_W$





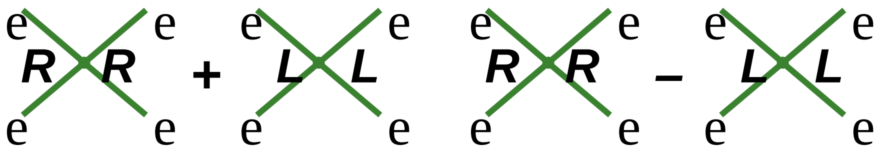


E158: Physics Impact

- Establish running of $\sin\theta_W$ to 8σ level
- Sensitivity to new physics: compositeness up to 14 TeV, Z' (GUTs, extra dimensions) to ~1TeV
  - Complementary to collider limits, different couplings

LEPII **E158**

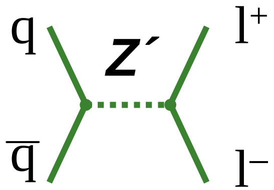
Compositeness

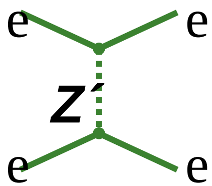


Λ~15 TeV

FNAL

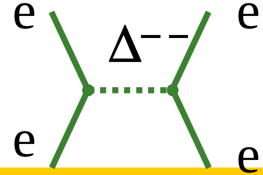
Neutral currents (GUTs, extra dims)





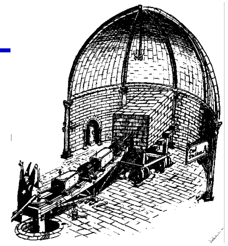
$\mathbf{M_{Z'}}$~1 TeV

Scalar interactions (LFV)



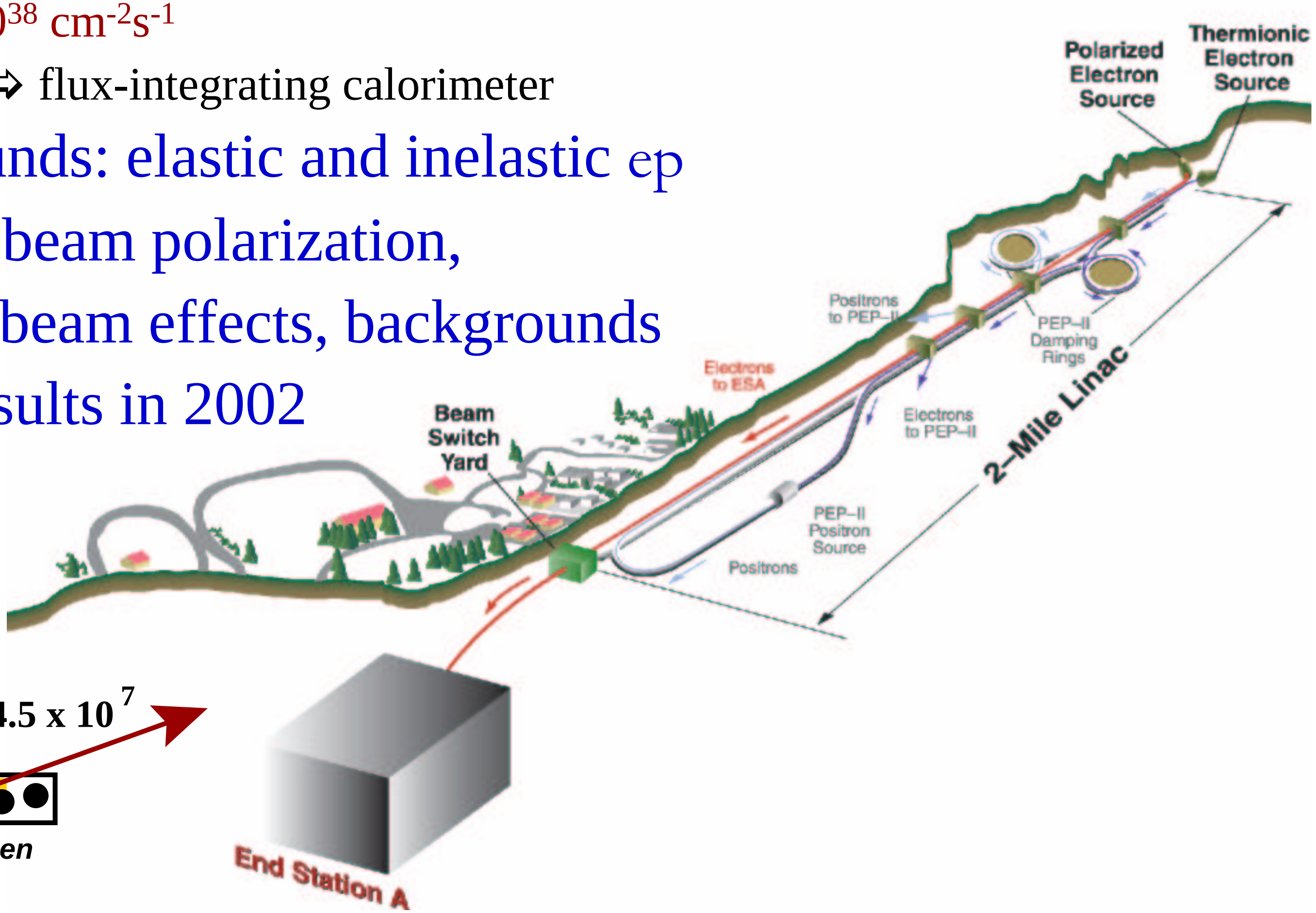
$$\frac{g^2}{2M_\Delta^2} < 0.01 G_F$$

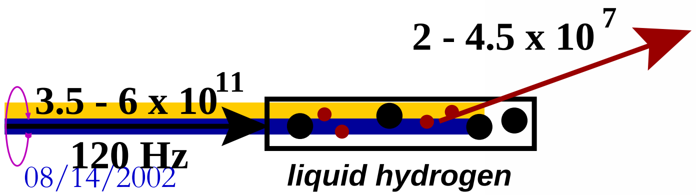
Experimental Technique



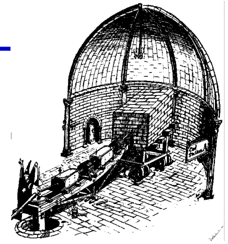
- Scattering of polarized electrons off atomic electrons
  - High cross section (14 μBarn)
  - High intensity electron beam, ~80% polarization
  - 1.5m LH2 target
    - ☞ Luminosity $4*10^{38}$ $cm^{-2}s^{-1}$
  - High counting rates ⇨ flux-integrating calorimeter
- Principal backgrounds: elastic and inelastic ep
- Main systematics: beam polarization, helicity-correlated beam effects, backgrounds

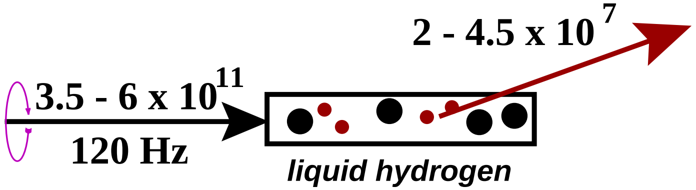
➔ Expect physics results in 2002





Parity-Violating Asymmetry





Measure pulse-pair asymmetry:

$$A_{exp} = \frac{N_R - N_L}{N_R + N_L}$$

Correct for difference in R/L beam properties:

$$A_{raw} = A_{exp} - \sum \alpha_i \Delta x_i$$

← charge, position, angle, energy R-L differences

coefficients determined experimentally

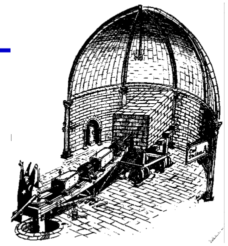
Physics asymmetry:

$$A_{PV} = \frac{1}{P_b} \frac{A_{raw} - f_{bkg} A_{bkg}}{1 - f_{bkg}}$$

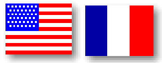
← backgrounds

beam polarization

E158 Collaboration



Institutions



Caltech	Syracuse
Princeton	Jefferson Lab
SLAC	UC Berkeley
Saclay	UMass Amherst
Smith College	U. of Virginia

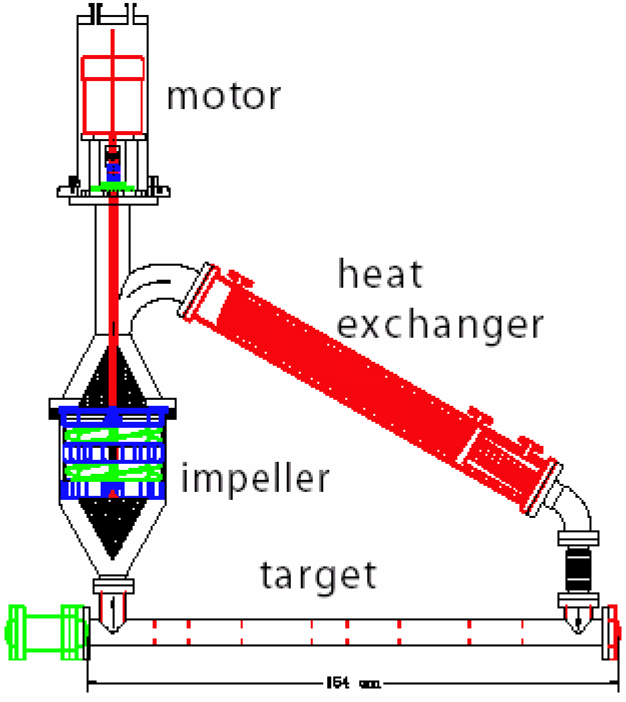
65 physicists

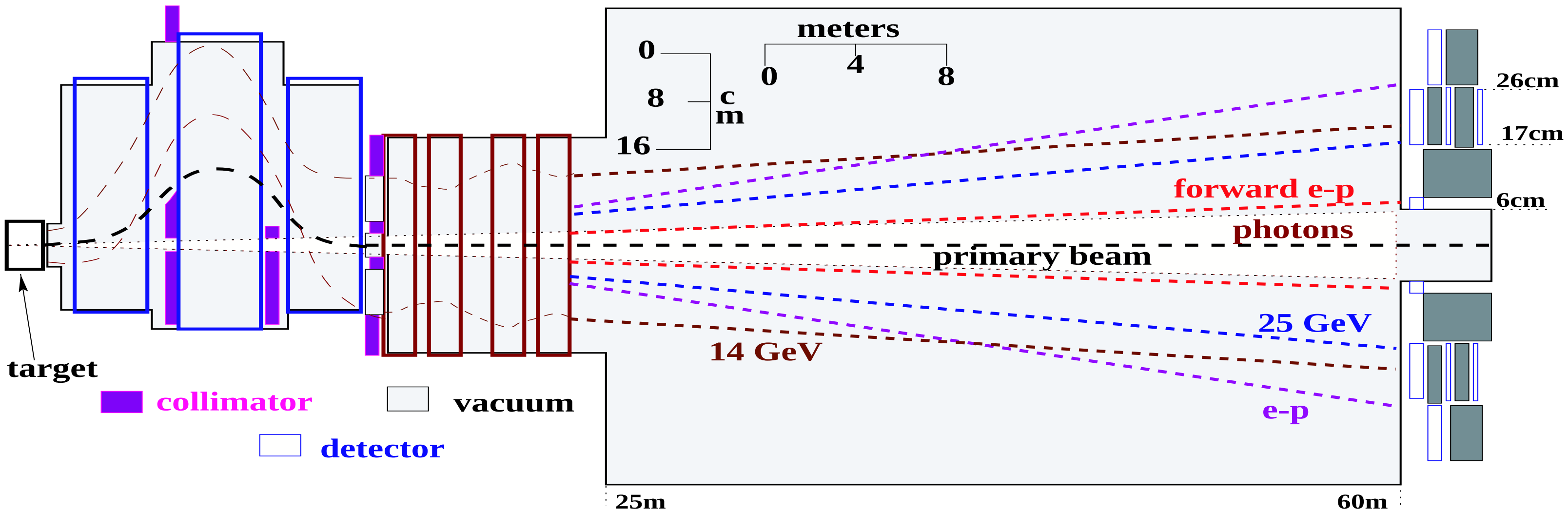
5 grad students

Sept 1997:	PAC approval
1998:	Polarized Beam Instrumentation R&D
1999:	Spectrometer and Detector Design
2000:	Construction Funds and Test Beams
2001:	Commissioning Run
2002:	Physics Run I

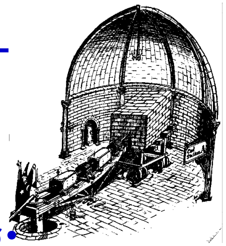
Key Ingredients

- High beam polarization and current
- Largest LH2 target in the world
- Spectrometer optimized for Møller kinematics
- Stringent control of helicity-dependent systematics





Experimental Challenges



Electron Beam:

i) high intensity: 500 kWatt beam power
ii) stable: <1% intensity jitter, <10% spotsize jitter,
<10% position jitter

iii) small left-right asymmetries:

$$A_I = \frac{\langle I \rangle_R - \langle I \rangle_L}{\langle I \rangle_R + \langle I \rangle_L} < 2 \cdot 10^{-7}$$

$$A_x = \langle x \rangle_R - \langle x \rangle_L < 10 nm$$

$$A_E = \frac{\langle E \rangle_R - \langle E \rangle_L}{\langle E \rangle_R + \langle E \rangle_L} < 2 \cdot 10^{-8}$$

iv) compatibility with PEPII operation

Electron Beam monitoring:

i) toroid resolution: $<3 \cdot 10^{-5}$ per pulse
ii) BPM resolution: <1 μm per pulse
iii) energy resolution: $<5 \cdot 10^{-5}$ per pulse

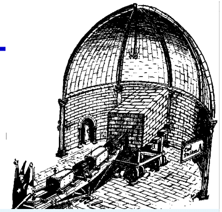
Detectors:

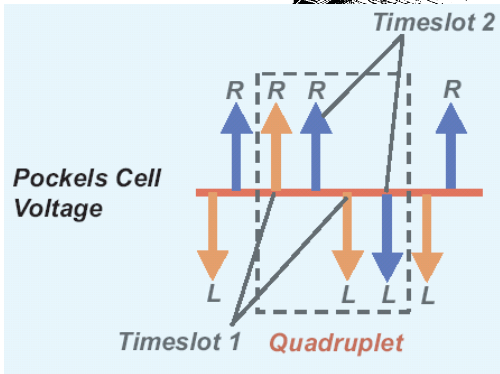
i) detector resolution: $<10^{-4}$ per pulse
ii) backgrounds (thick target; synch radiation)
iii) radiation damage
iv) linearity < 1%

Liquid Hydrogen Target:

i) target density fluctuations: $<10^{-4}$ per pulse
ii) 18% radiation length; absorbs 500W beam power
iii) safety

Control of Beam Systematics





✓ **Beam helicity is chosen pseudo-randomly at 120 Hz**
- use electro-optical Pockels cell in Polarized Light Source
- sequence of pulse quadruplets

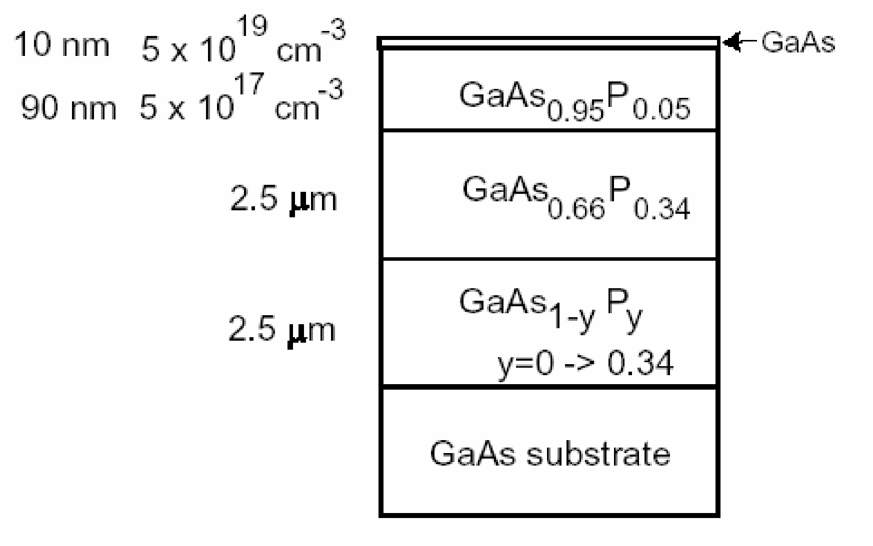
✓ **Reduce beam asymmetries by feedback at the Source**
- Control charge asymmetry and position asymmetry

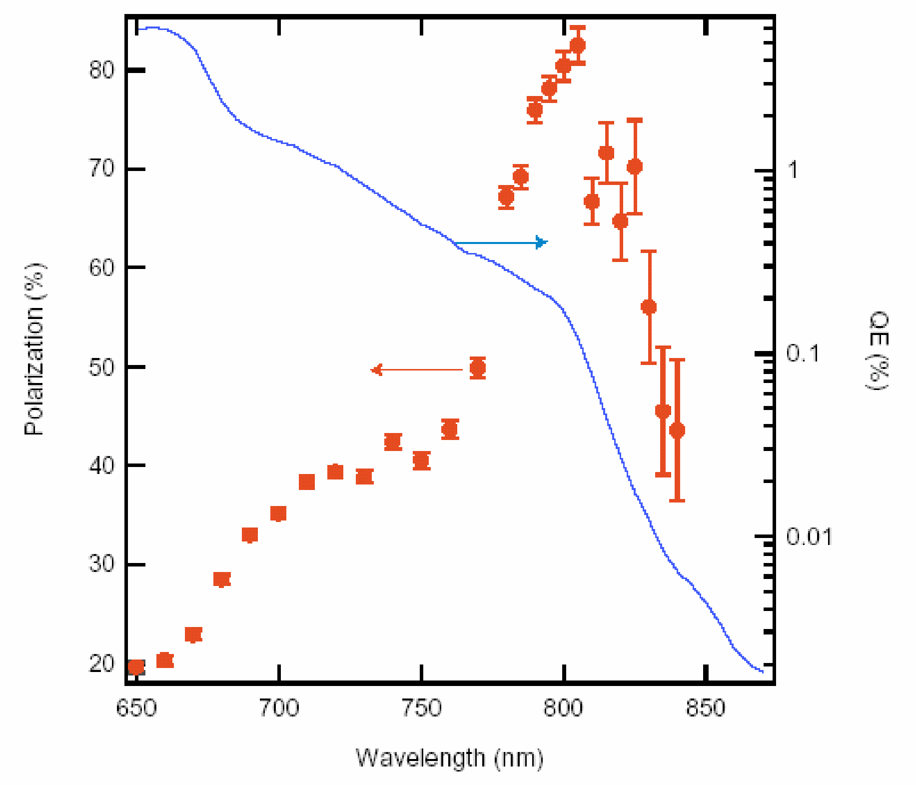
✓ **Physics Asymmetry Reversals:**
- Insertable Half-Wave Plate in Polarized Light Source
- (g-2) spin precession in A-line (45 GeV and 48 GeV data)

✓ **"Null Asymmetry" Cross-check is provided by a Luminosity Monitor**
- measure very forward angle e-p (Mott) and Møller scattering

✓ **Also, False Asymmetry Reversals: (reverse false beam position and angle asymmetries; physics asymmetry unchanged)**
- Insertable "-I/+I" Inverter in Polarized Light Source

Polarized Source Photocathode



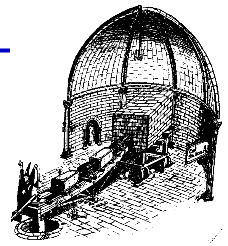


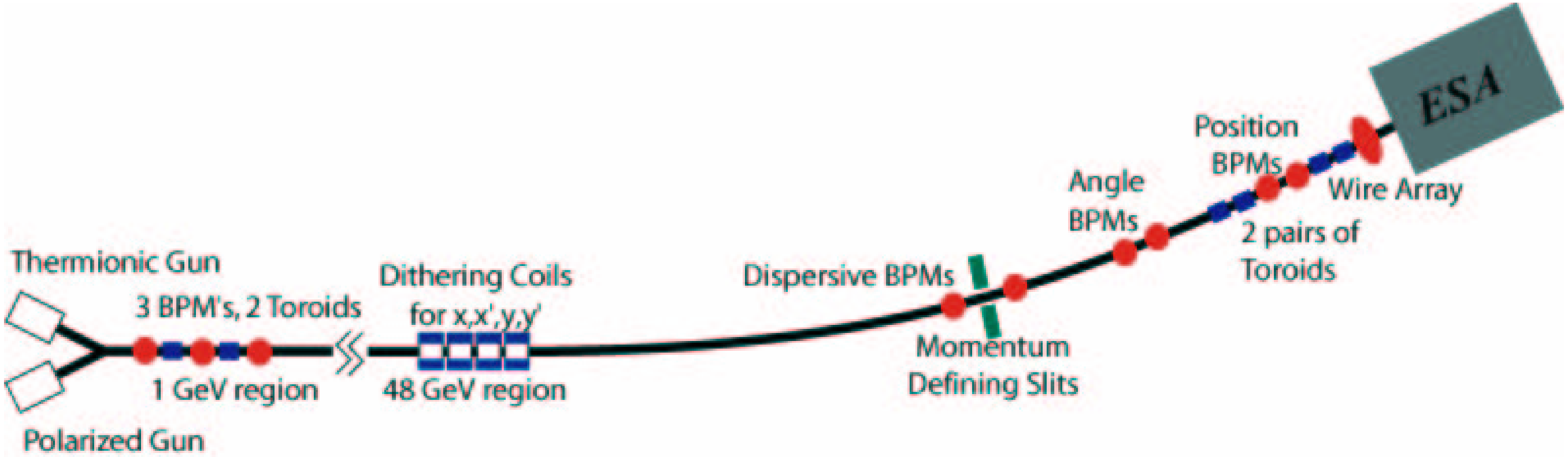
Reference: T. Maruyama et al., SLAC-PUB-9133, March 2002; (submitted to Nucl. Inst. Meth. A).

NOTES:

1. Gradient-doped cathode structure
   - high doping for surface 10nm overcomes charge limit
   - low doping for most of the active layer gives high polarization
2. Previous "standard" cathode was active layer of 100nm GaAs w/ $5\cdot10^{18}$ cm^{-3} doping
3. Small anisotropy in strain: ~3% analyzing power for residual linear polarization

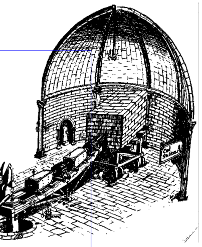
Beam Diagnostics





Also,
- Møller Polarimeter in ESA
- Synchrotron Light Monitor before momentum slits
- Energy dither using Sub-booster phases for Sectors 27, 28

BPM and Toroid Resolutions

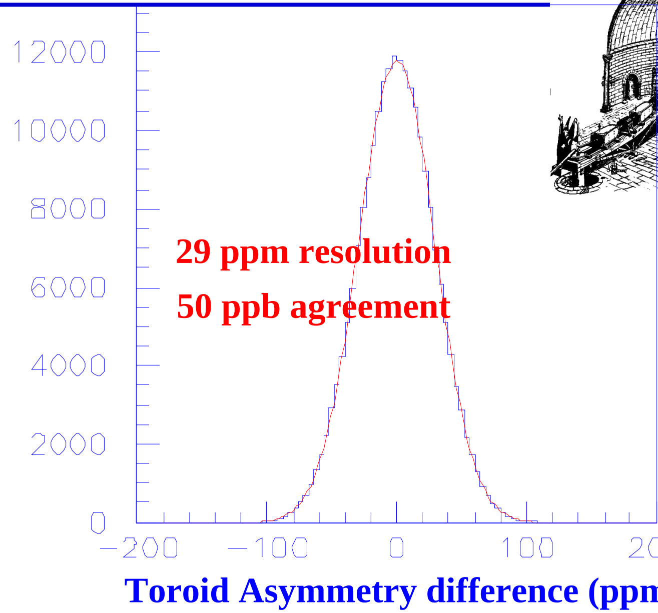


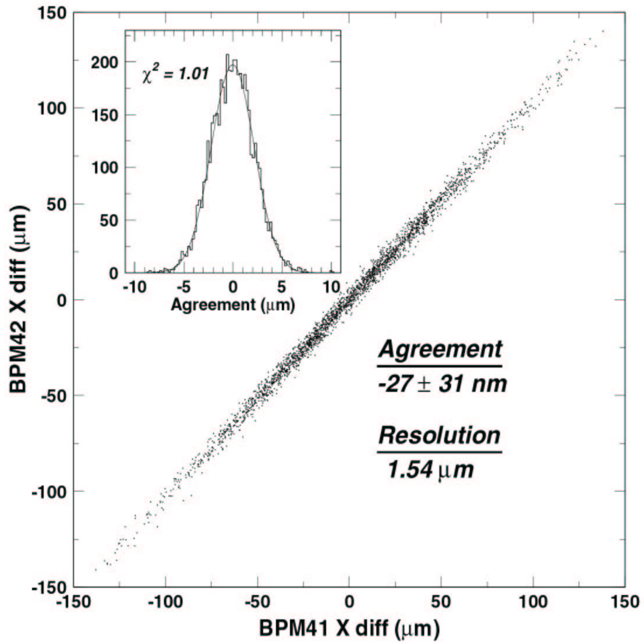
Device	Goal[a]	Tests	Run I[b]
Target x,y	4 µm	0.5 µm	2 µm
Target x',y'	0.4 µrad	0.03 µrad	0.1 µrad
Energy[c]	30 ppm		40ppm
Target Toroid	30 ppm	30 ppm	60 ppm

[a]Resolution goals are to achieve 1ppb error after 600M pulses for each of x, x', y, y', E, I

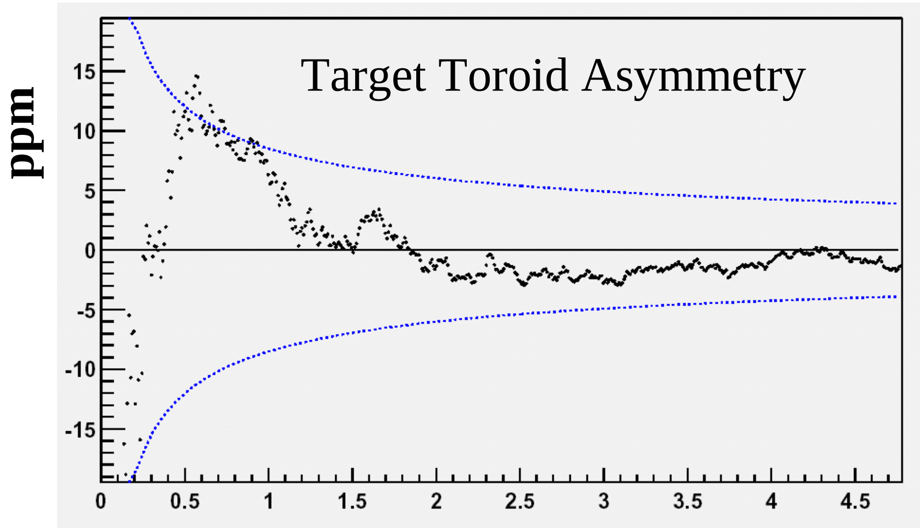
[b]Relaxed goals

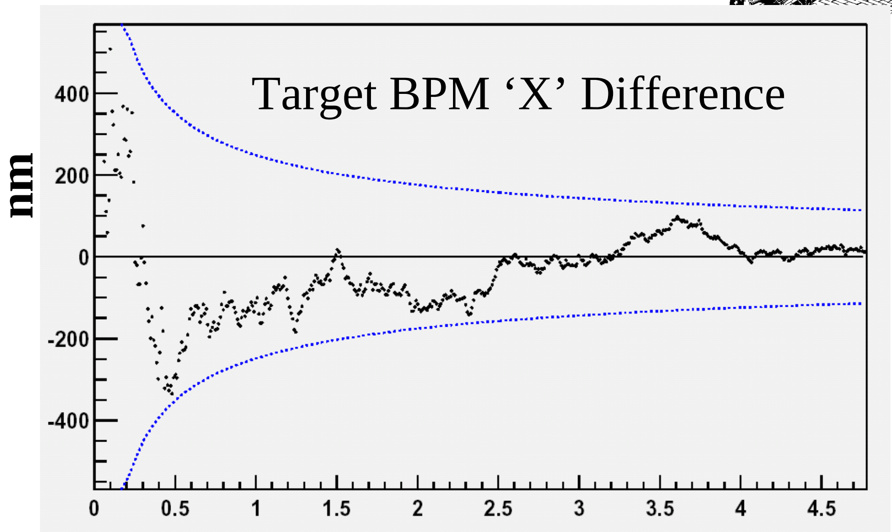
[c]Energy goal ignores detector calorimetric compensation for 1/E – dependence of Møller cross section

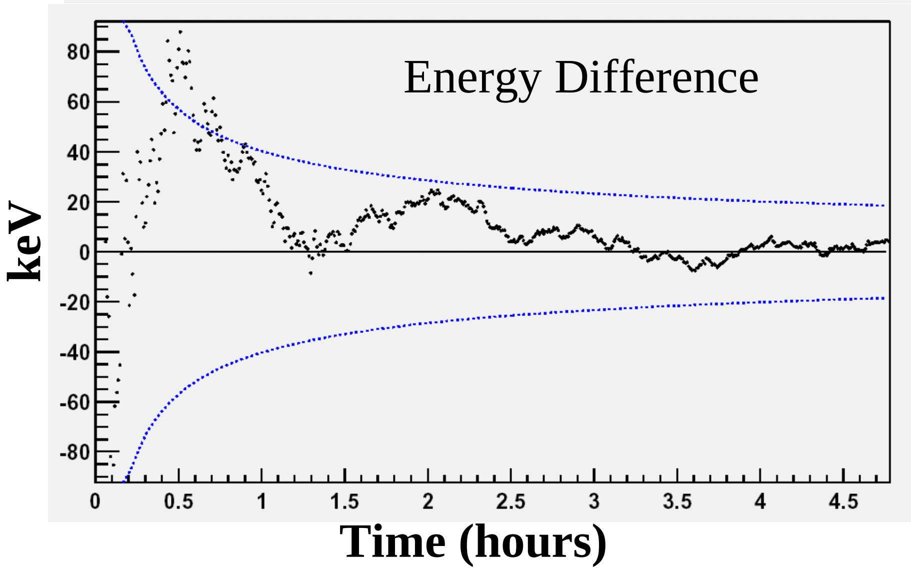


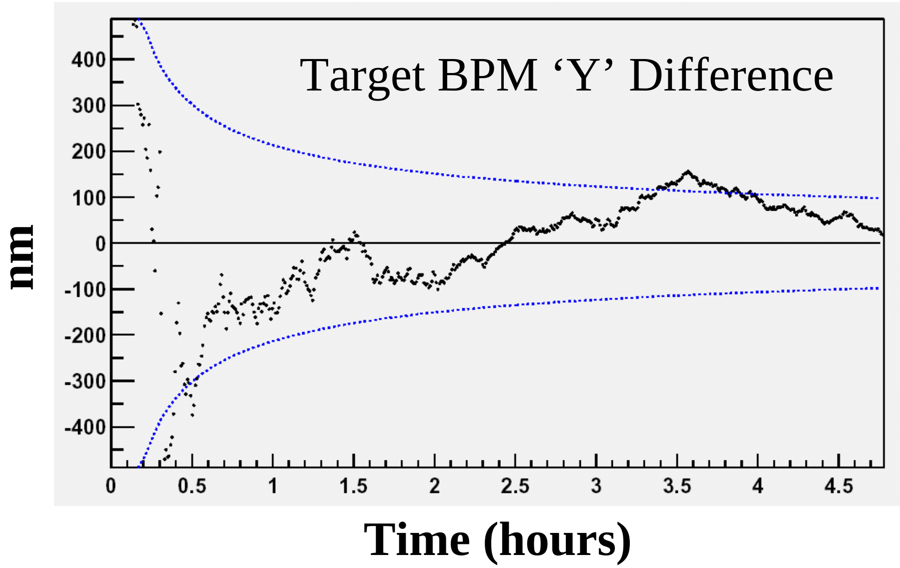


Charge, Energy and Position Asymmetries

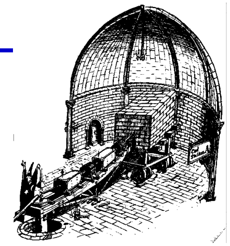


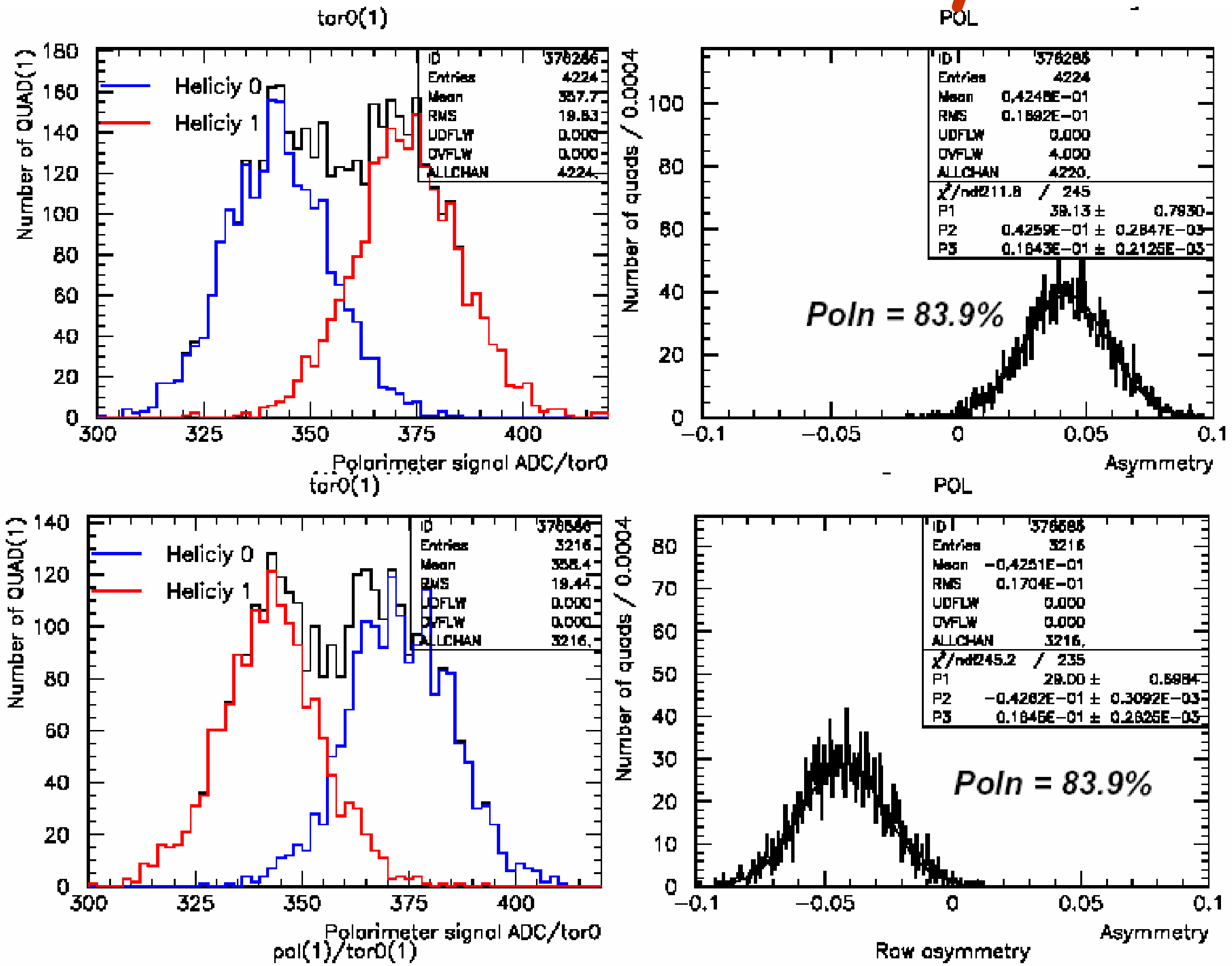






Møller Polarimetry





~ 85 % polarization throughout Run I

Beam Delivery for E158

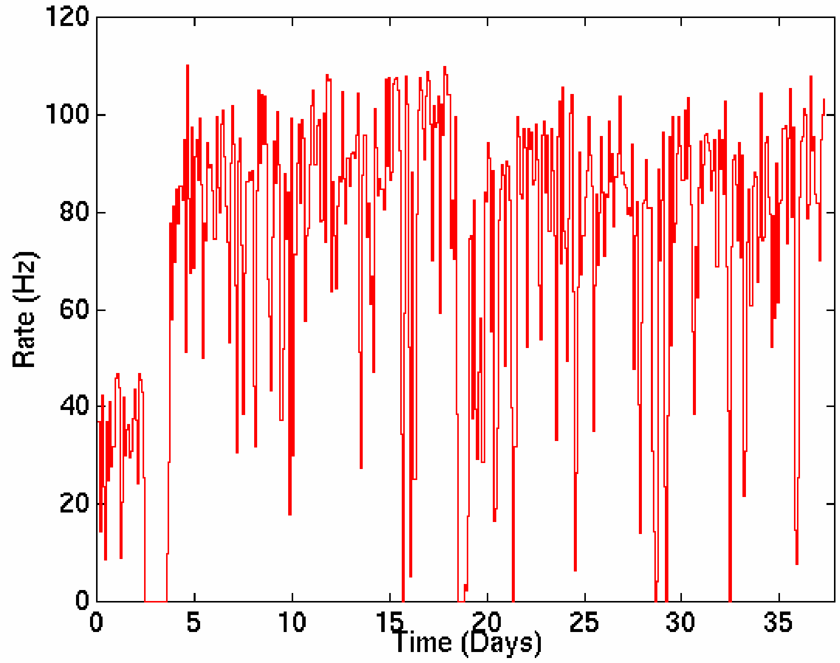
(April 20 - May 27)

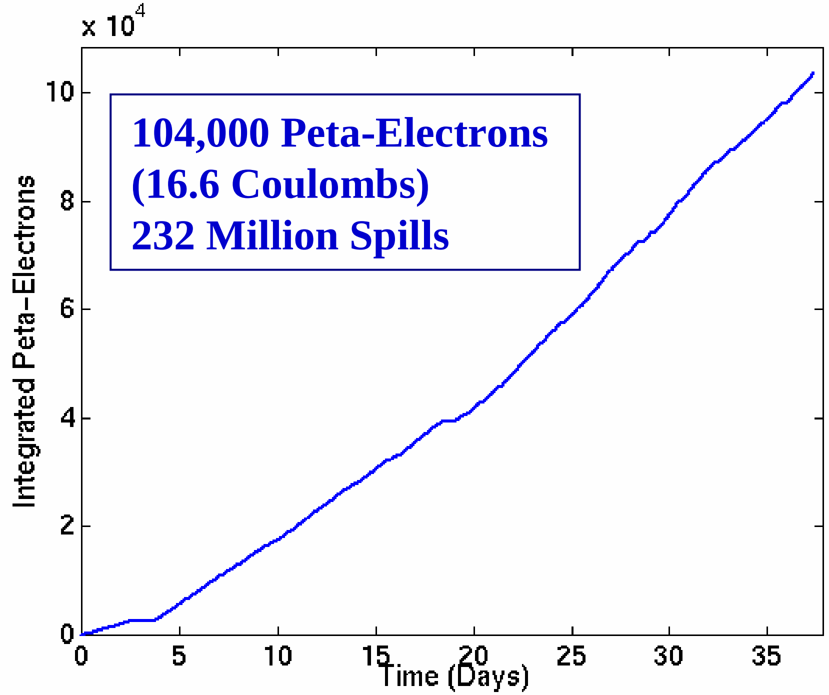
~85% Electron Polarization

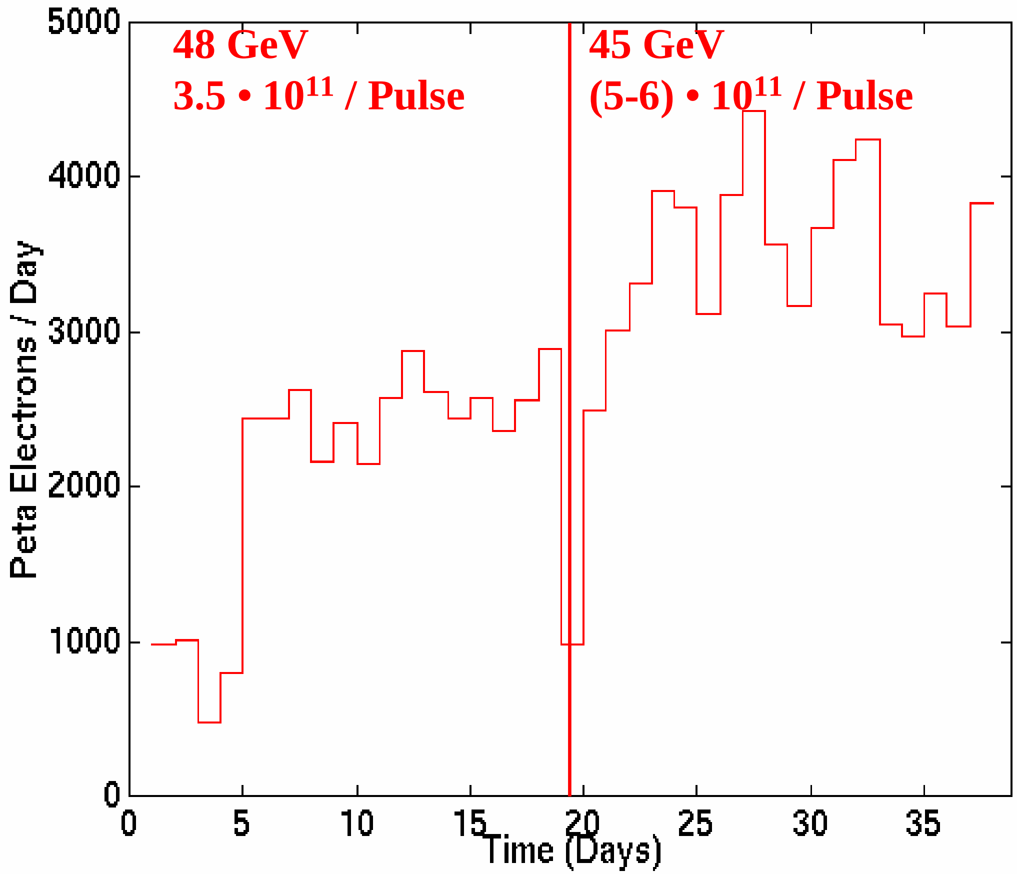
Beam Delivery Efficiency (120Hz running)

72% for 48 GeV, 3.5 x 10^{11}

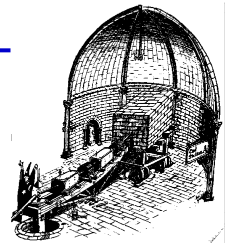
65% for 45 GeV, (5-6) x 10^{11}



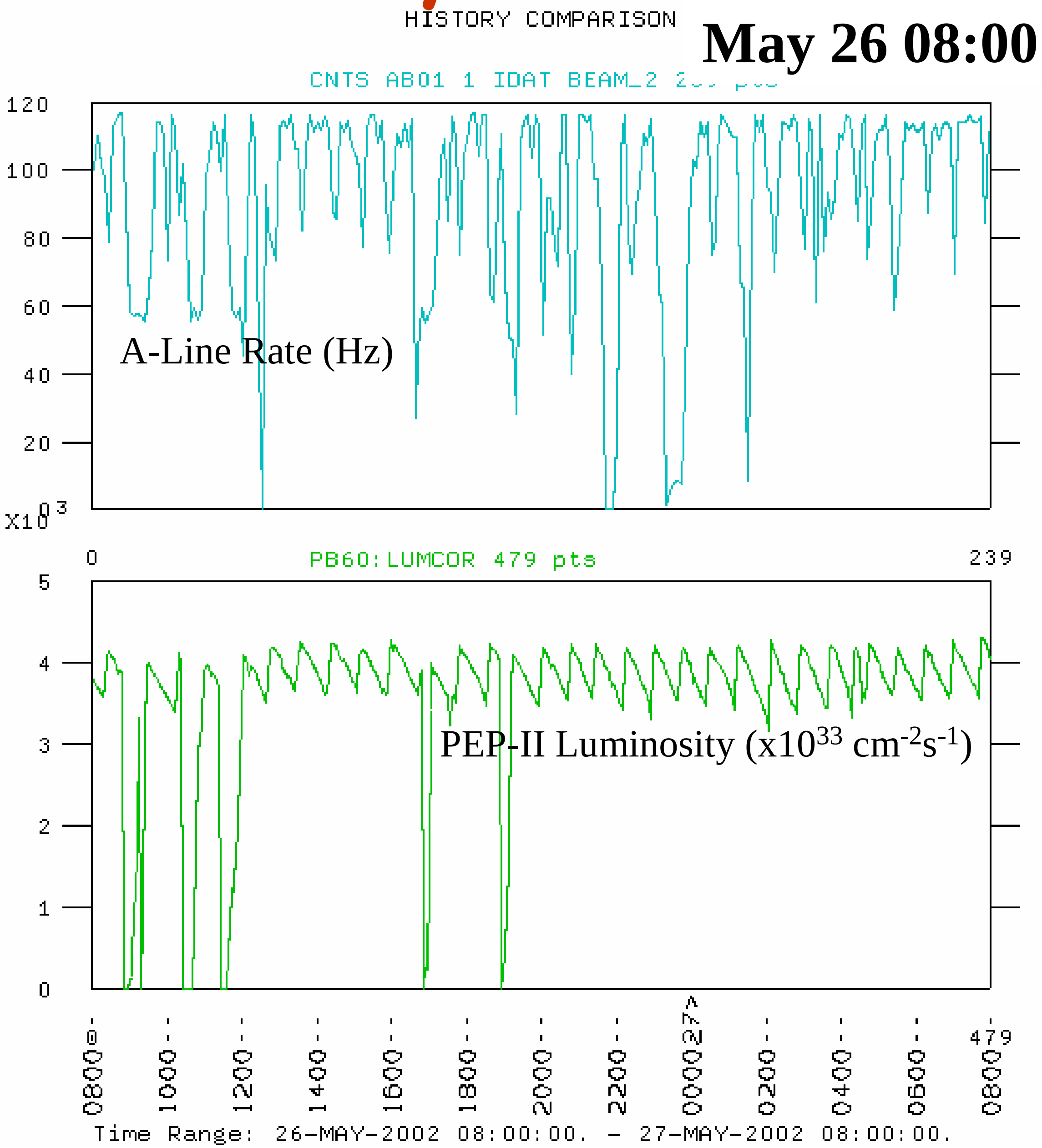




Best Day @ 45 GeV



May 26 08:00 → May 27 08:00



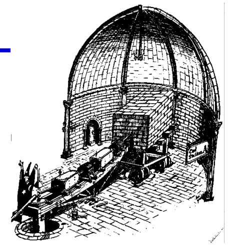
24-hr Totals

E158: 3816 Peta-E

PEP-II: 272 pb^{-1}

Smooth operations concurrent with BaBar

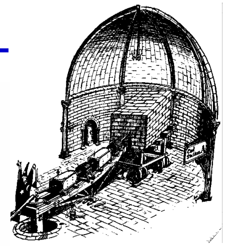
E158 Beam Delivery Summary



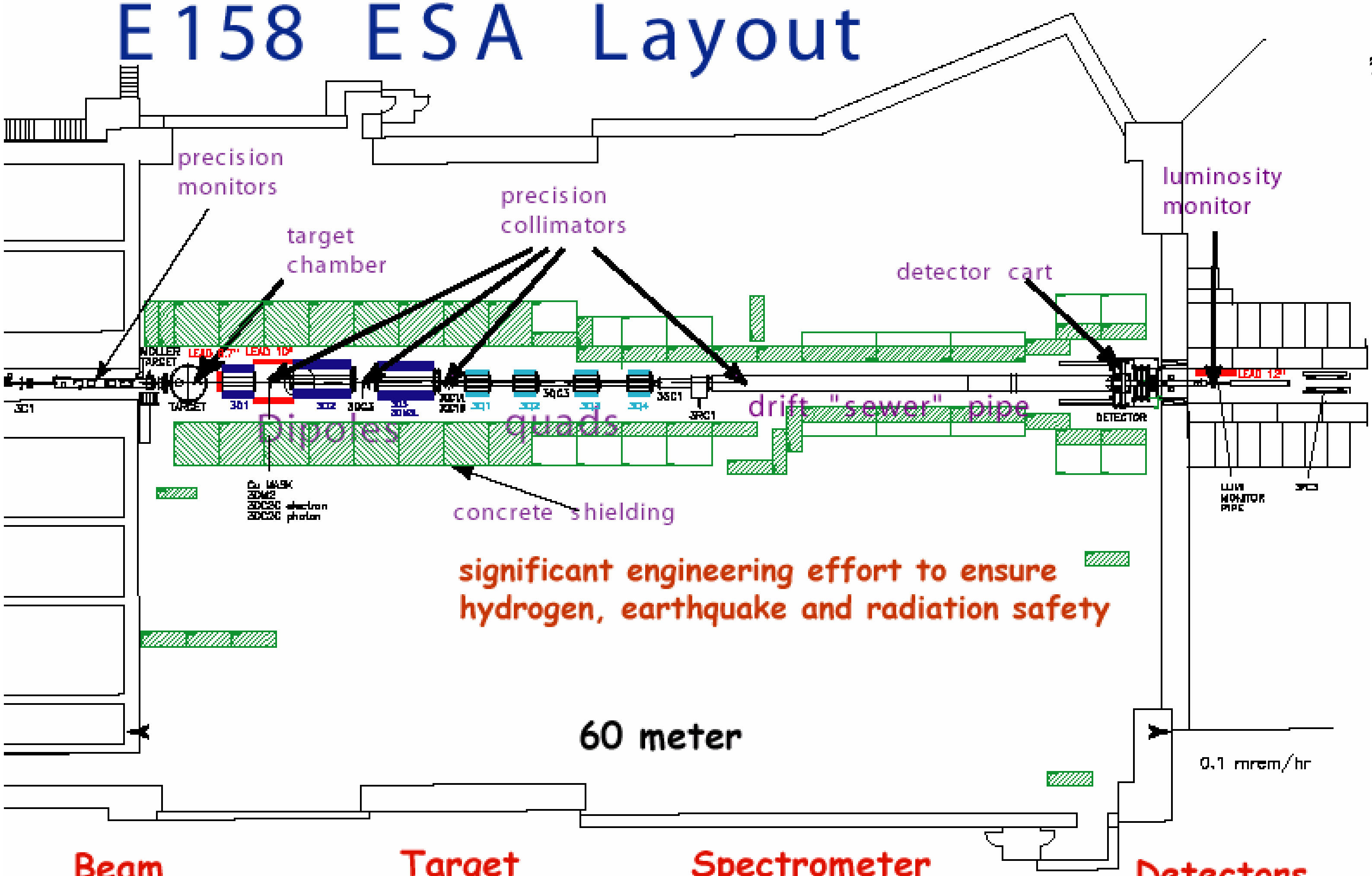
ITEM	Goal	MAY 2001	Run I (2002)
Beam Charge	6×10^{11}	2.4×10^{11}	6×10^{11}
Intensity Jitter	2% rms*	1.5% rms	0.5% rms
Position Jitter	<10% of spotsize	5% of spotsize	5% of spotsize
Spotsize Jitter	<10% of spotsize	10% of spotsize	5% of spotsize
Energy Spread	0.3% rms	0.3% rms	0.1% rms
Energy Jitter	0.2% rms	<0.1% rms	0.03% rms
Polarization	75%	(67 +/- 8)%	~85%

*2% required for physics measurement;
1% required for accelerator operation

Key for successful physics run !



E158 ESA Layout



Beam
High intensity,
precision monitoring

Target
liquid hydrogen,
1.5 m long

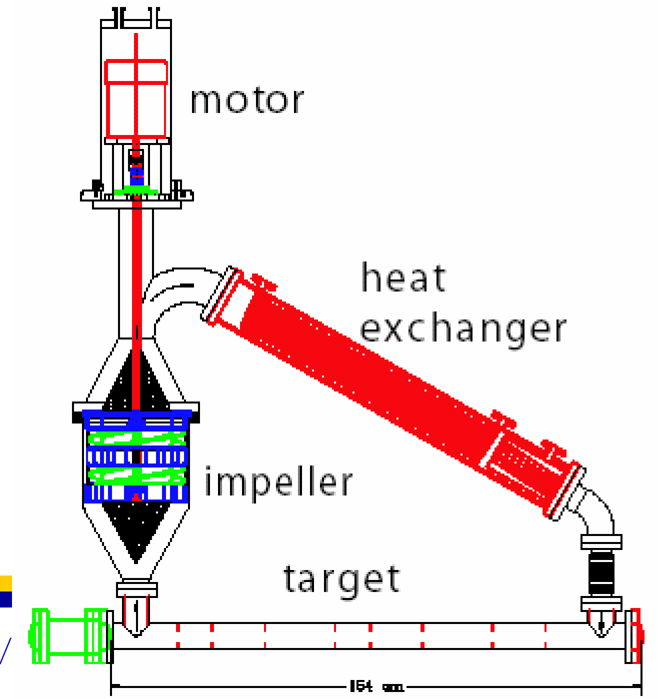
Spectrometer
3 dipoles, 4 quadrupoles,
precision collimators

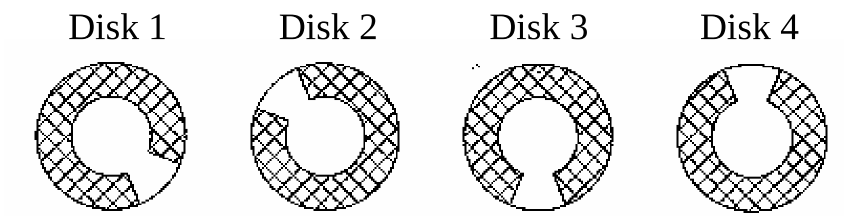
Detectors
measure signal,
background


rf BPM
Scattering Chamber and
Spectrometer Magnets
LH_2
Scattering Chamber
Spectrometer Collimator

Liquid Hydrogen Target

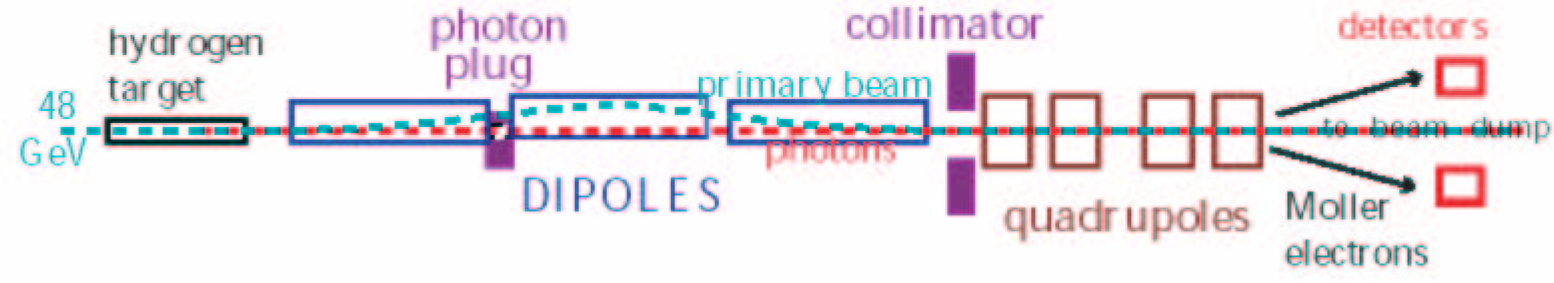
Refrigeration Capacity	1000W
Max. Heat Load:	
- Beam	500W
- Heat Leaks	200W
- Pumping	100W
Length	1.5 m
Radiation Lengths	0.18
Volume	47 liters
Flow Rate	10 m/s
Reynolds number in target cell	10^6

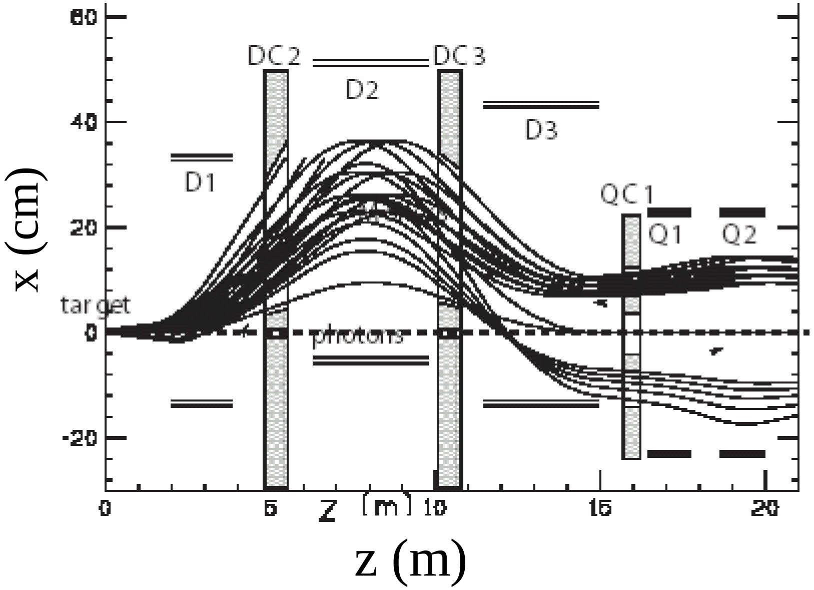


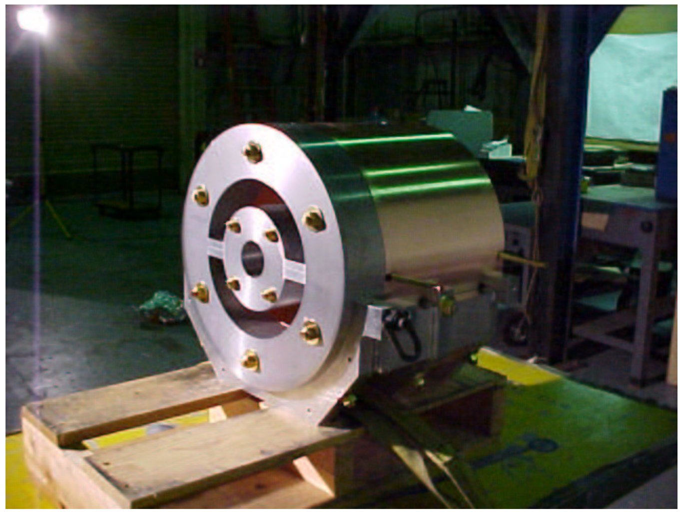


Wire mesh disks in target cell region to introduce turbulence at 2mm scale and a transverse velocity component. Total of 8 disks in target region.

Spectrometer

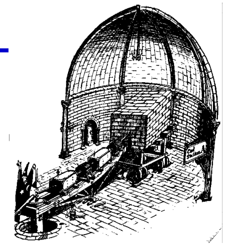


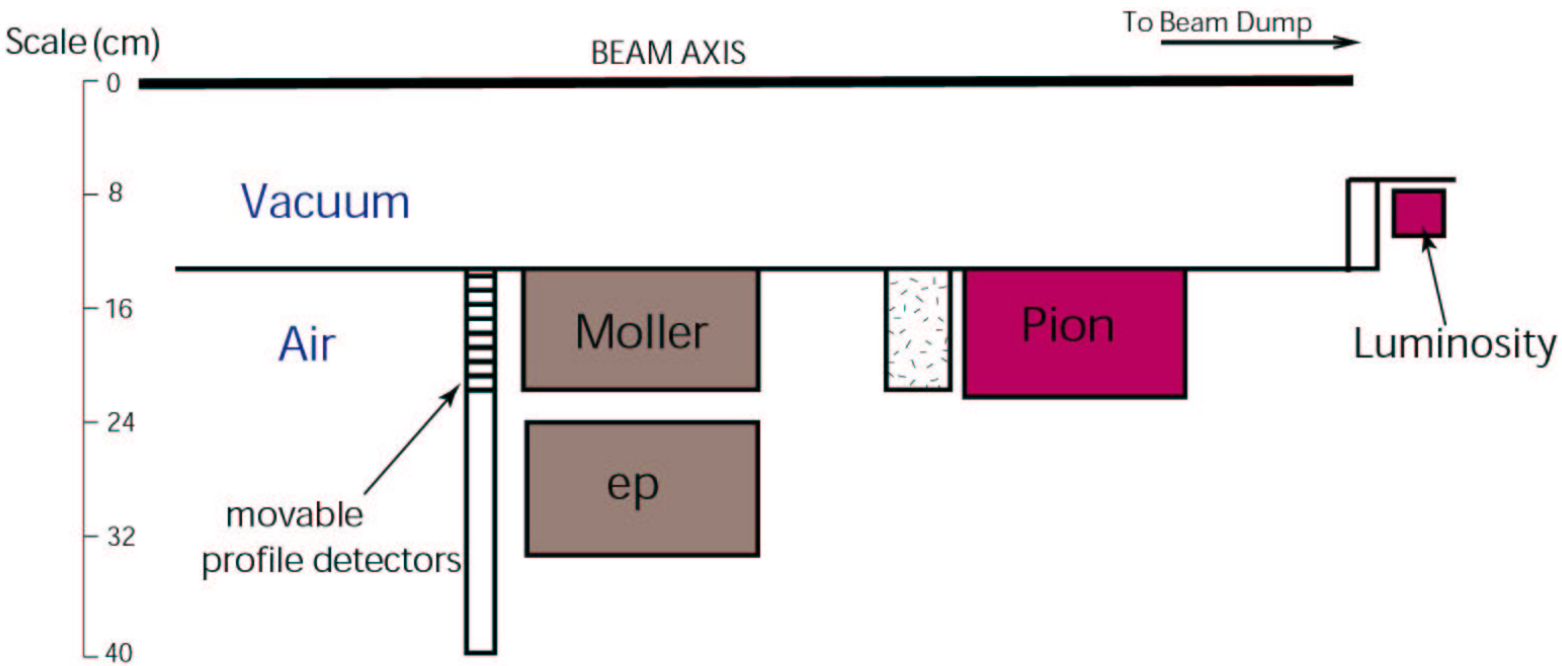




QC1B Acceptance Collimator

Detectors





MOLLER, ep are copper/quartz fiber calorimeters
PION is a quartz bar Cherenkov
LUMI is an ion chamber with Al pre-radiator

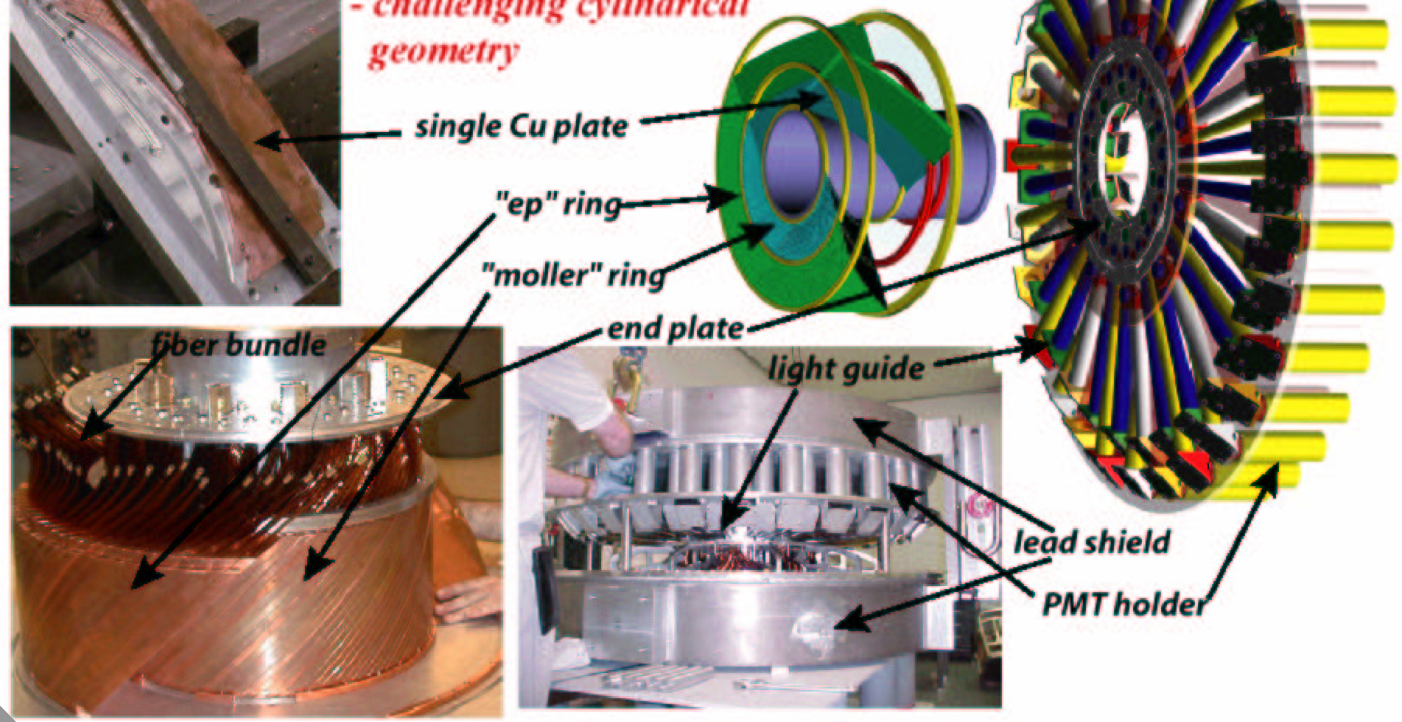
$$\langle \theta_{lab}^{LUMI} \rangle = 1.5mrad$$

$$\langle \theta_{lab}^{MOLLER} \rangle = 6.0mrad$$

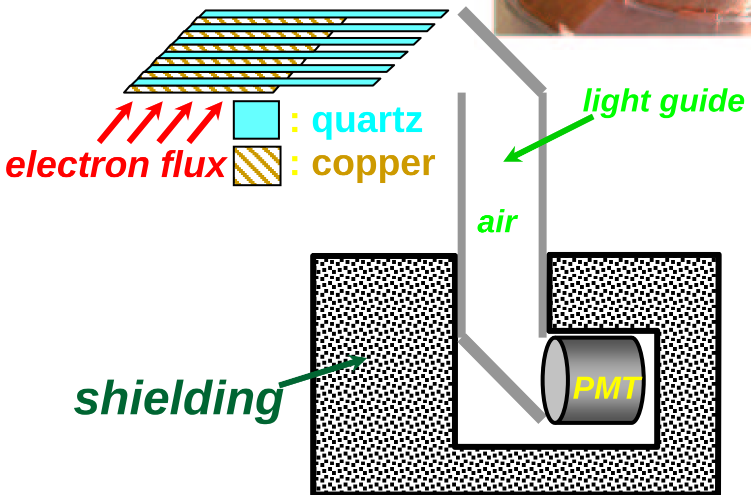
All detectors have azimuthal segmentation,
and have PMT readout to 16-bit ADC

MOLLER Detector

- 20 million electrons/pulse at 120 Hz
- 100 MRad radiation dose
- Copper/fused silica fiber sandwich
  - *- state of the art in calorimetry at ultra-high flux*
  - *- challenging cylindrical geometry*

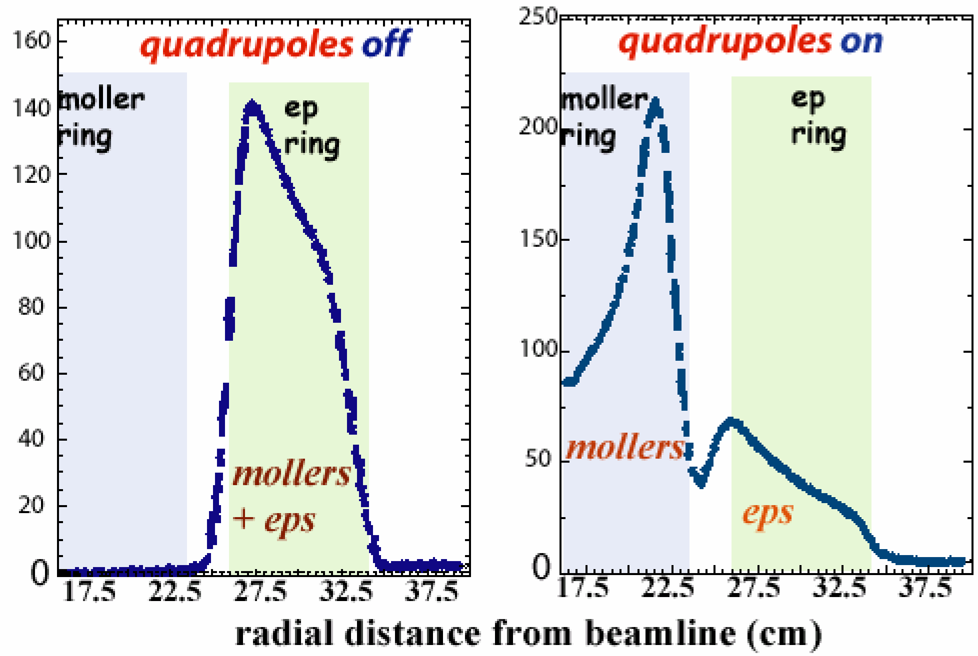


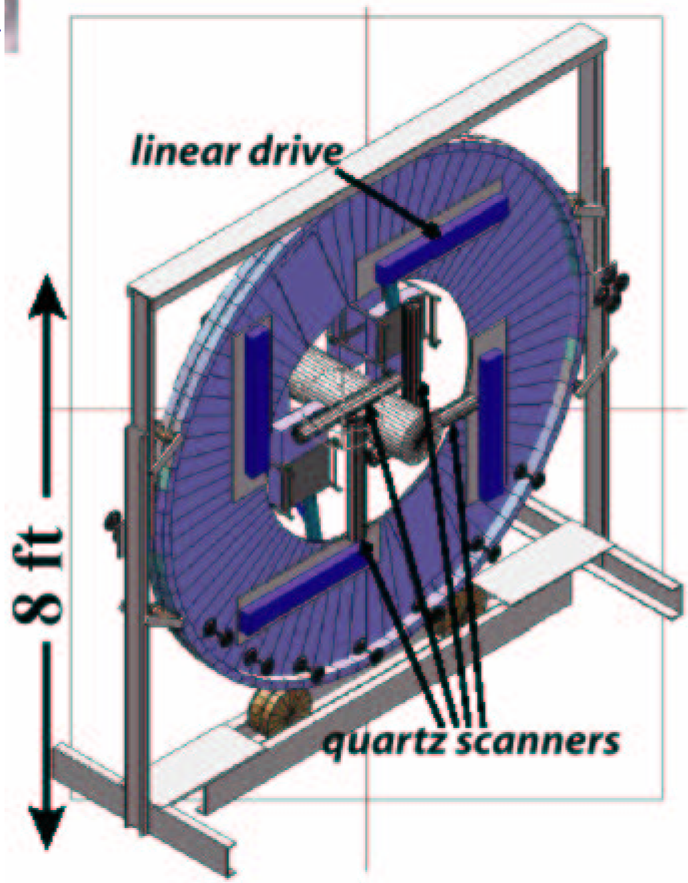
Basic Idea:



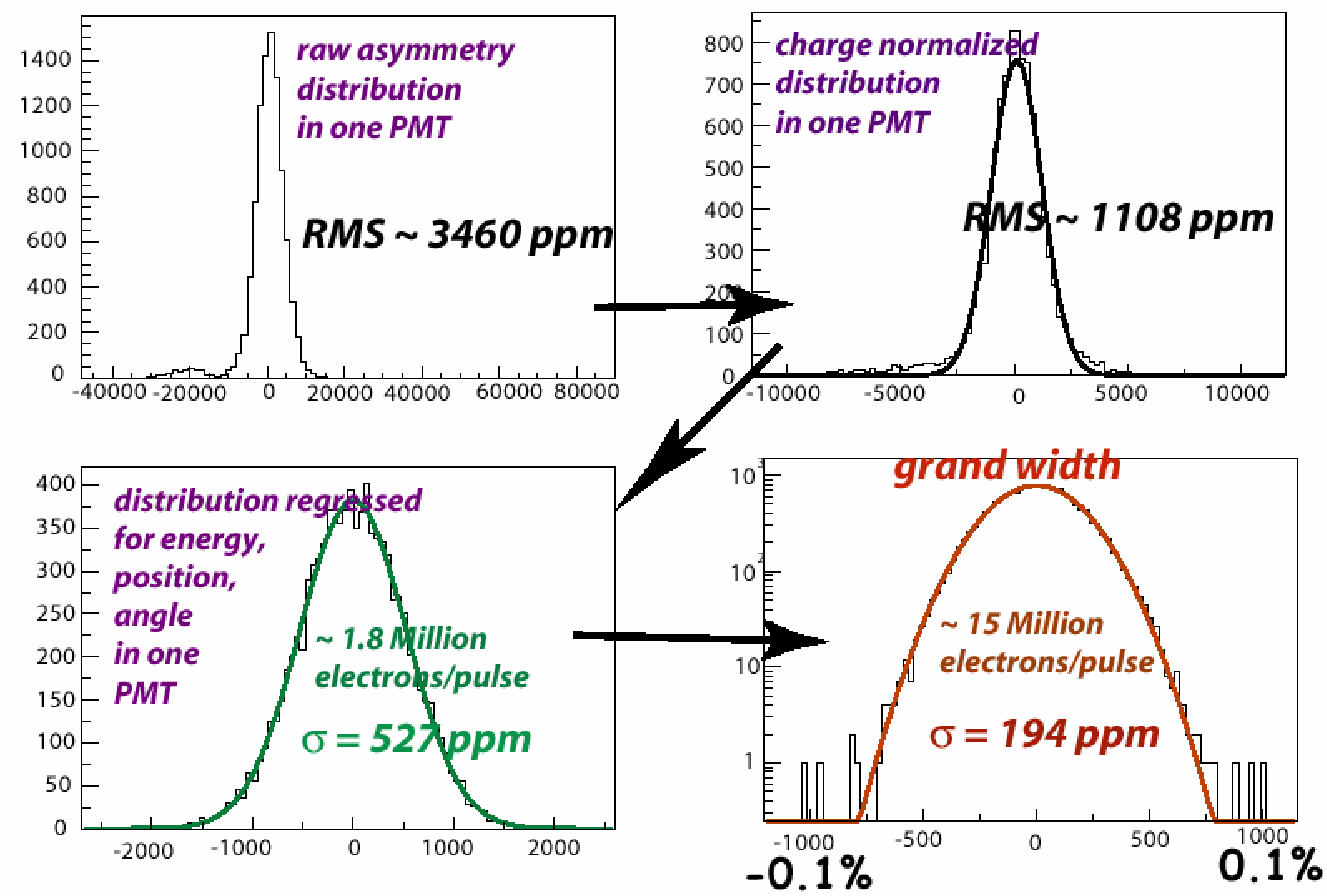
Profile Detector

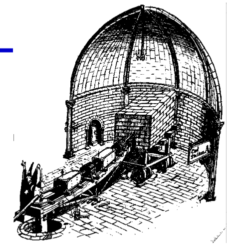
- ✓ 4 Quartz Cherenkov detectors with PMT readout
  - ☞insertable pre-radiators
  - ☞insertable shutter in front of PMTs
- ✓ Radial and azimuthal scans
  - ➢ collimator alignment, spectrometer tuning
  - ➢ background determination
  - ➢ Q^2 measurement





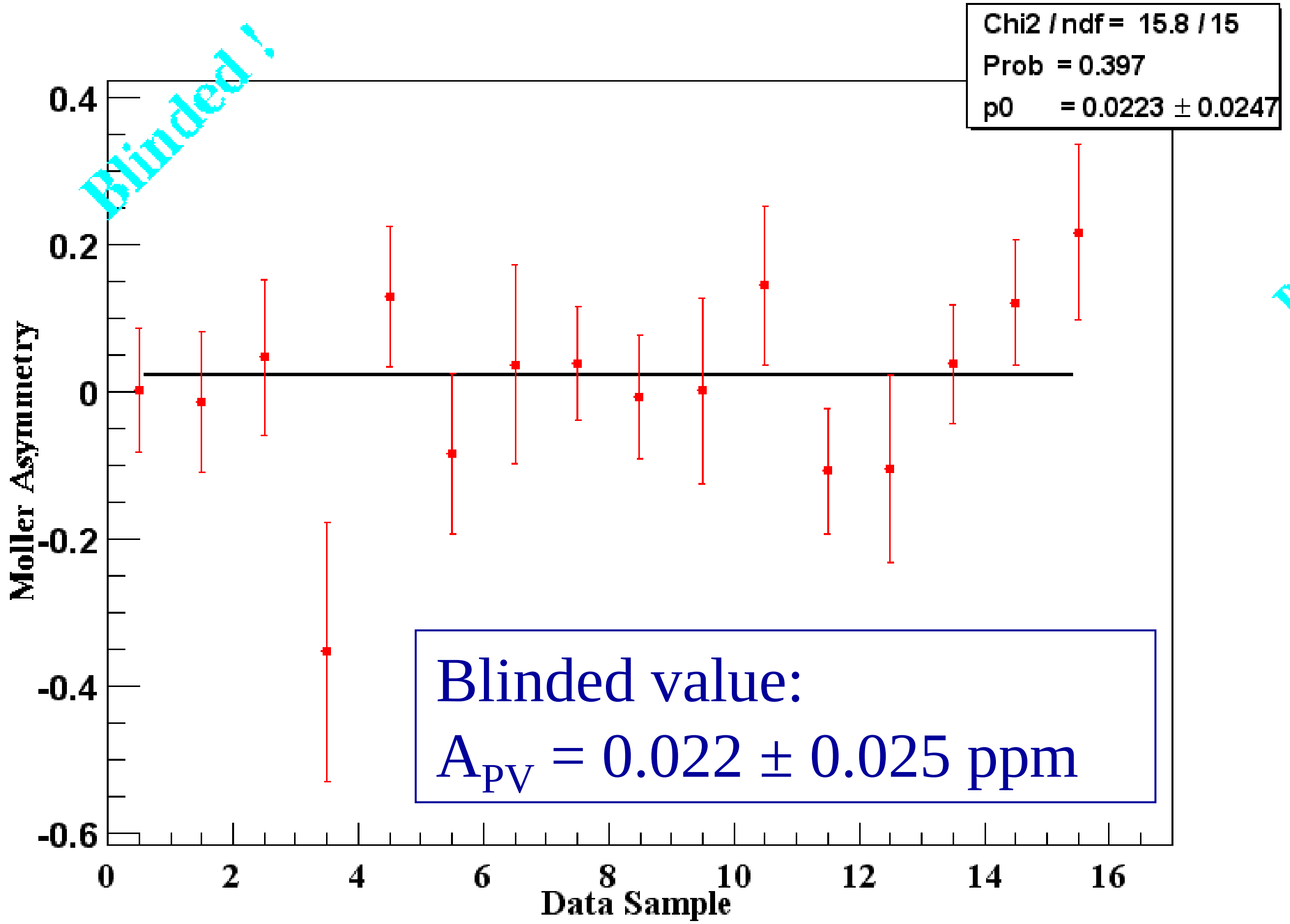
MOLLER Asymmetry Widths



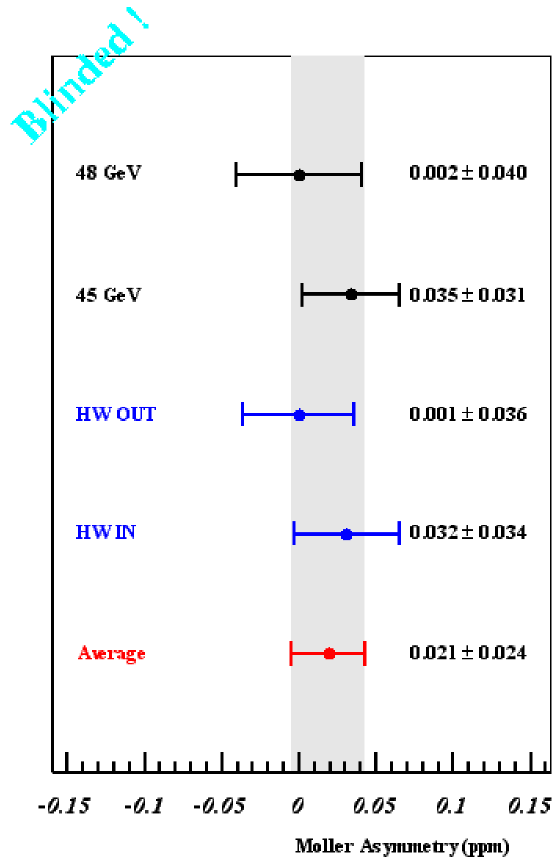


Preliminary Results

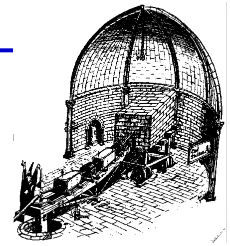
- ✓ Based on analysis of 146M spills collected in April-May 2002
  - ☞ Asymmetry blinded to avoid bias (expect ~ –0.14 ppm)

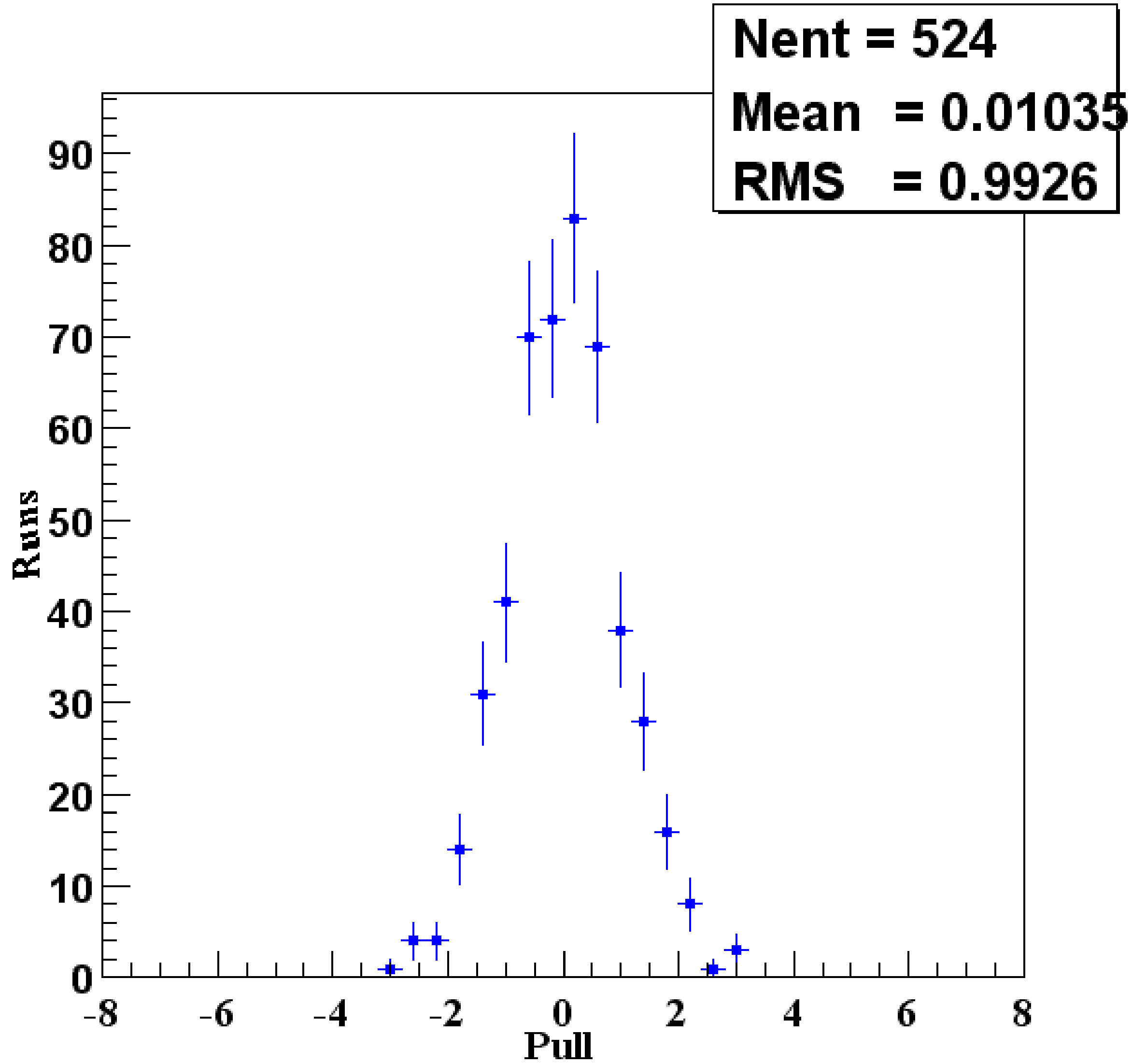


Systematic check:

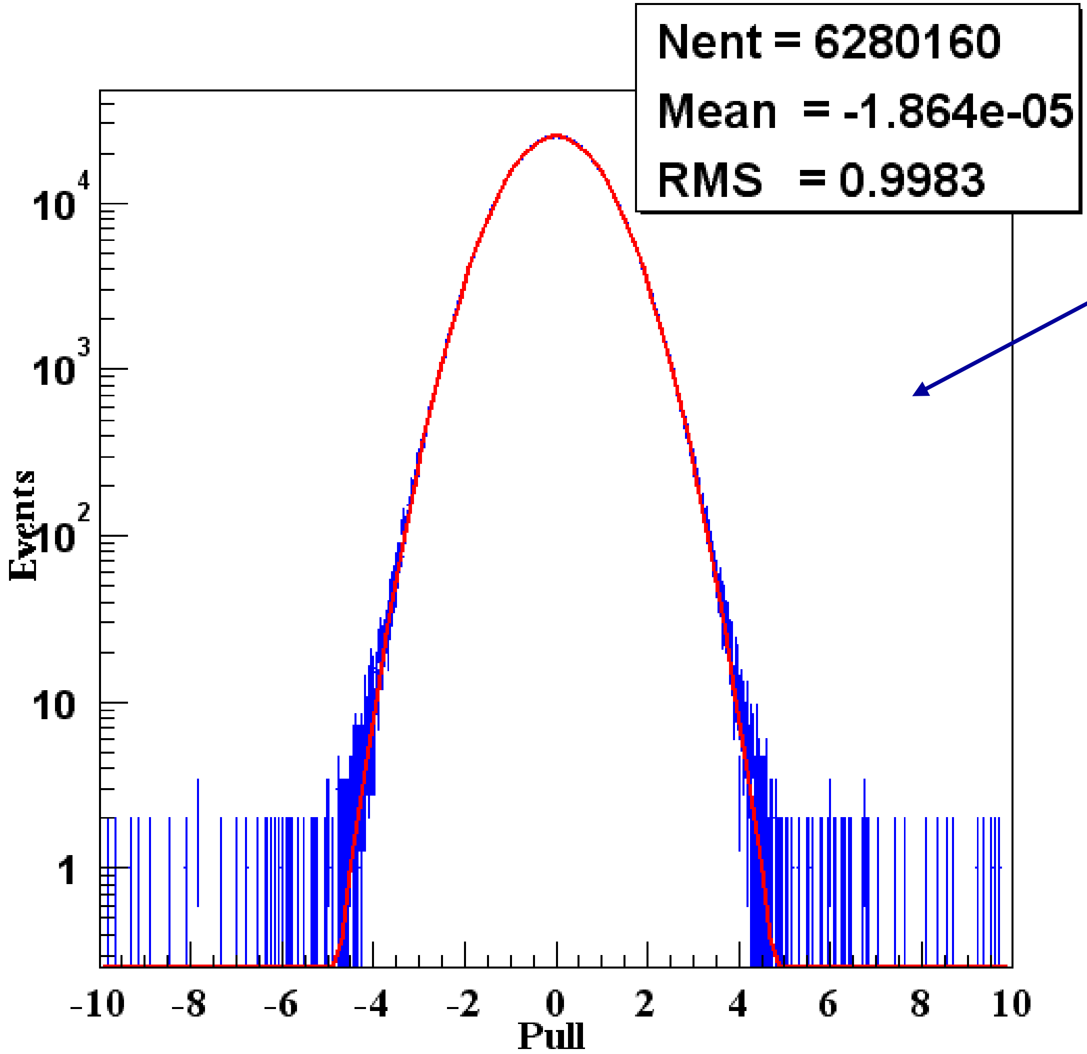


Asymmetry Pulls Per Run





Statistics and Systematics

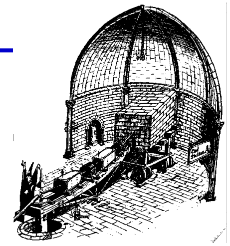


Asymmetry pulls
per event pair: 12M spills
(about 2 days of data)

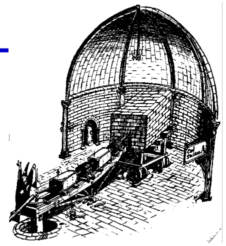
Average asymmetry
width: 195 ppm

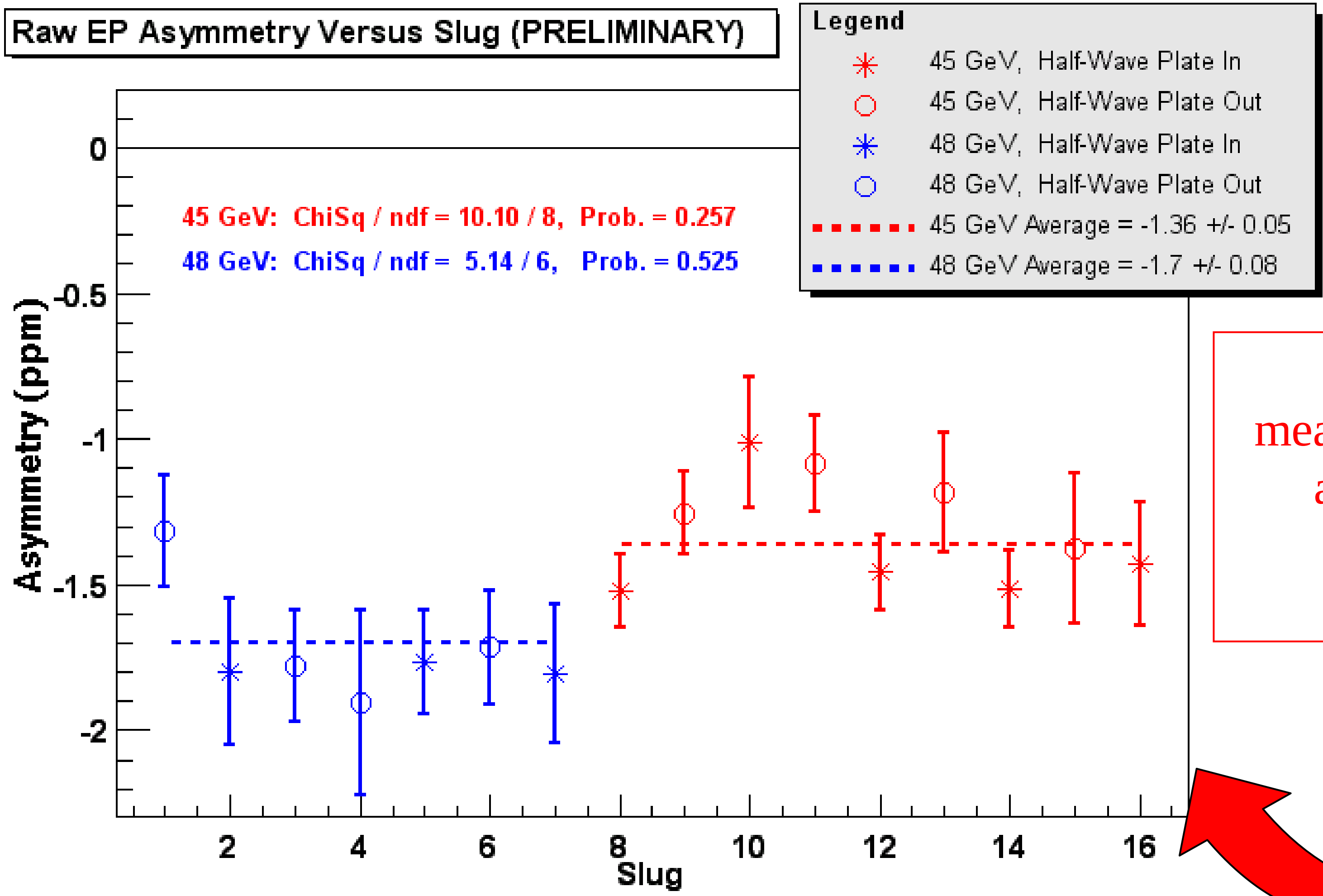
Expected systematic error
in Run I ~ 10-15 ppb

☞ Dominated by background subtraction (inelastic ep) and polarization measurement



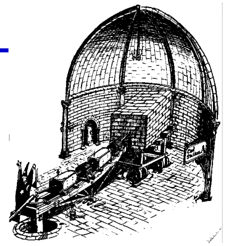
EP Asymmetry Results



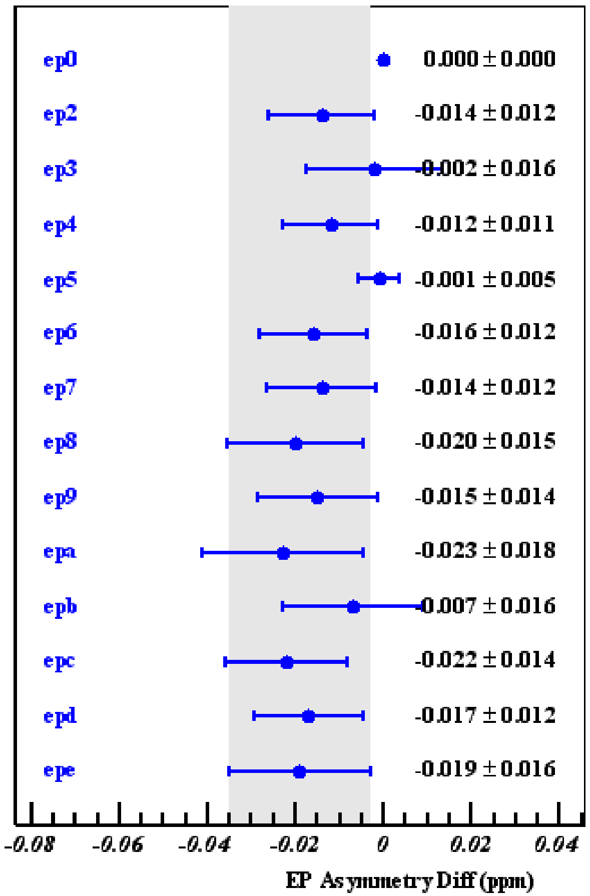


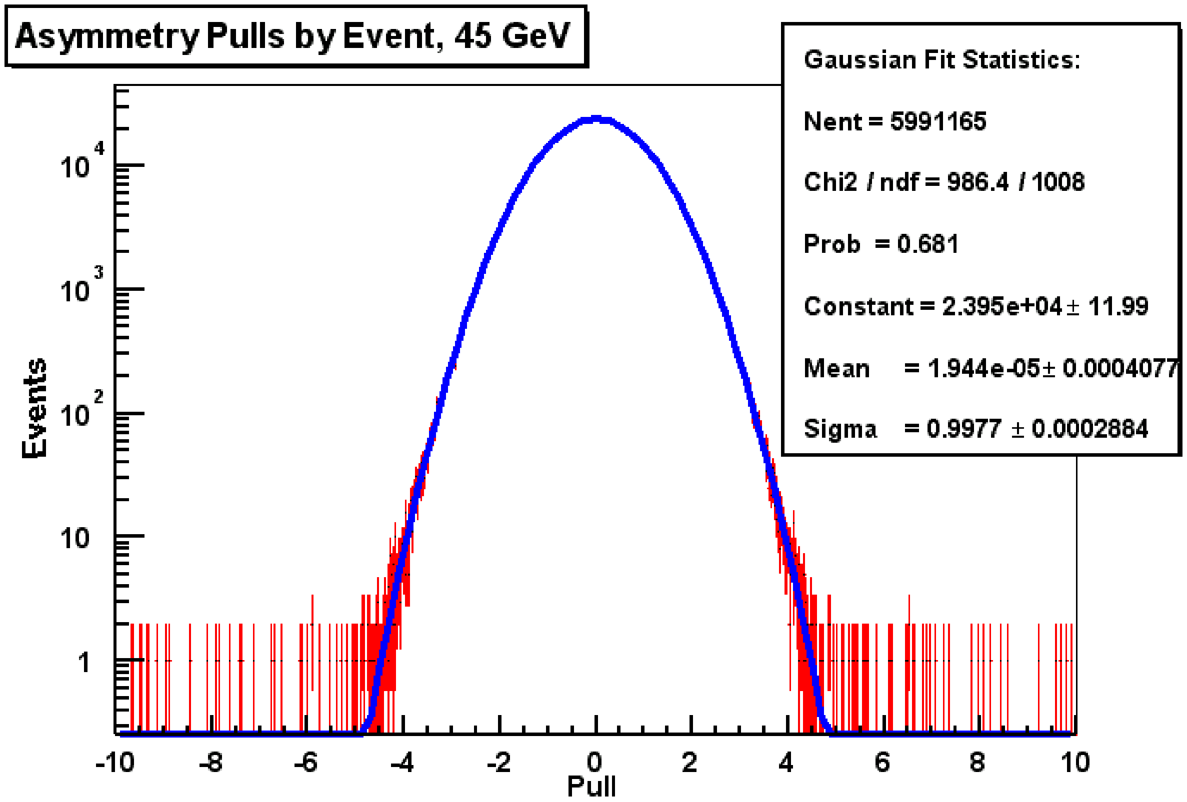
Most precise measurement of PV asymmetry in electron scattering !

EP Sample: Consistency

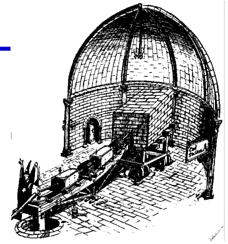


EP Asymmetry Diff vs cut, 45 GeV





EP Sample: Summary



Preliminary (raw asymmetries)

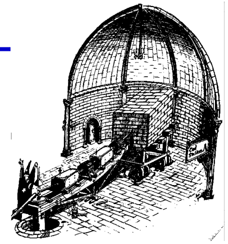
A_{RAW}(45 GeV) = -1.36 ± 0.05 ppm (stat. only)
A_{RAW}(48 GeV) = -1.70 ± 0.08 ppm (stat. only)

Ratio of asymmetries:

A_{PV}(48 GeV) /A_{PV}(45 GeV) = 1.25 ± 0.08 (stat) ± 0.03 (syst)

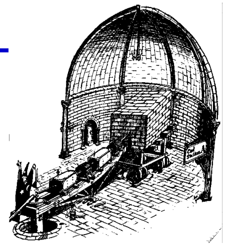
- ☞ Consistent with expectations for inelastic ep asymmetry, but hard to interpret in terms of fundamental parameters
- ☞ 20-30 ppb correction to Møller asymmetry in Run I, below 20 ppb for Run II

E158 Summary



- High quality physics data collected in the 5 week Run I
  - Excellent beam quality: Big Thanks to the SLAC Operations !
    - High intensity (500 kW!), high polarization, low jitter
    - Smooth concurrent running with BaBar with minimal impact on both experiments
  - All experimental systems working reliably
- Expected physics result in 2002
  - Goal: first observation of Parity Violation in Møller scattering $\delta\sin^2\theta_W < 0.003$ (stat and syst)

Future



- ☞ Experiment poised to achieve proposal goals
- Nontrivial constraints on New Physics with $\delta\sin^2\theta_W < 0.001$
  - ☞ Unique window of opportunity, complementary to FNAL Run II
  - ☞ Need 4 months of data taking at 120 Hz
- Current plan at SLAC:
  - ❑ 1.5 months October-November 2002: limited by available budget in FY03
  - ❑ We hope to complete the experiment by the end of calendar 2003