An Ultra-precise Measurement of the Weak Mixing Angle with a 11 GeV Electron Beam at Jefferson Laboratory

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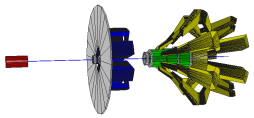


An Ultra-precise Measurement of the Weak Mixing Angle with a 11 GeV Electron Beam at Jefferson Laboratory

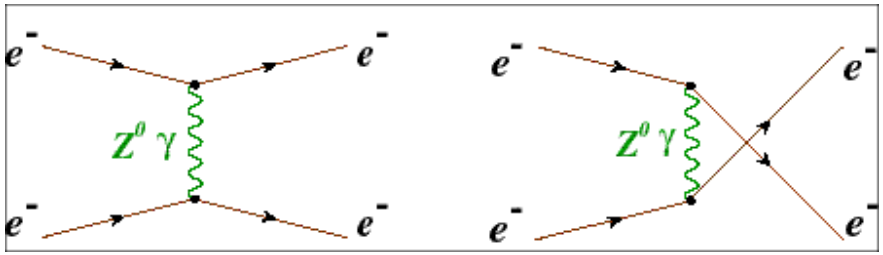
Outline

- Intro: (fully approved at PAC34)
  - Moller Scattering, A_{PV} Measurement
  - Proposed Measurement Details
  - Goals and Motivation
- Experimental Setup/Design
  - Details: Beam, Target, Spectrometer
  - Simulation Studies
  - New Challenges
- Timeline and Status

MOLLER Collaboration

- MOLLER – Measurement of Lepton-Lepton Electroweak Reaction
- $\sim$100 authors from 30 institutions, with veterans from all the JLab parity violating experiments

Moller Scattering, A_{PV} Measurement



- Purely leptonic reaction provides clean probe of weak neutral current interactions via parity violating electroweak interference

$$A_{PV} = m_e E_{lab} \frac{G_F}{\sqrt{2}\pi\alpha} \frac{4\sin^2\theta}{(3+\cos^2\theta)^2} Q_W^e, \quad (1)$$

$$Q_W^e \equiv 4 \cdot g_V^e \cdot g_A^e = (1 - 4\sin^2\theta_W) \quad (2)$$

- e^-_{beam}: 11GeV, 85μA, 85% polarization

  $\rightarrow \langle Q^2 \rangle = 0.0056$ (GeV/c)^2, $\langle A_{PV} \rangle = 35.6$ppb

- For 38 week run: $\delta(A_{PV}) = 0.74$ppb, $\delta(Q_W^e) = \pm 2.1(\text{stat}) \pm 1.0(\text{syst})$:

  $\rightarrow \delta(\theta_W) = \pm 0.00026(\text{stat}) \pm 0.00012(\text{syst}) \sim 0.1\%$ precision!

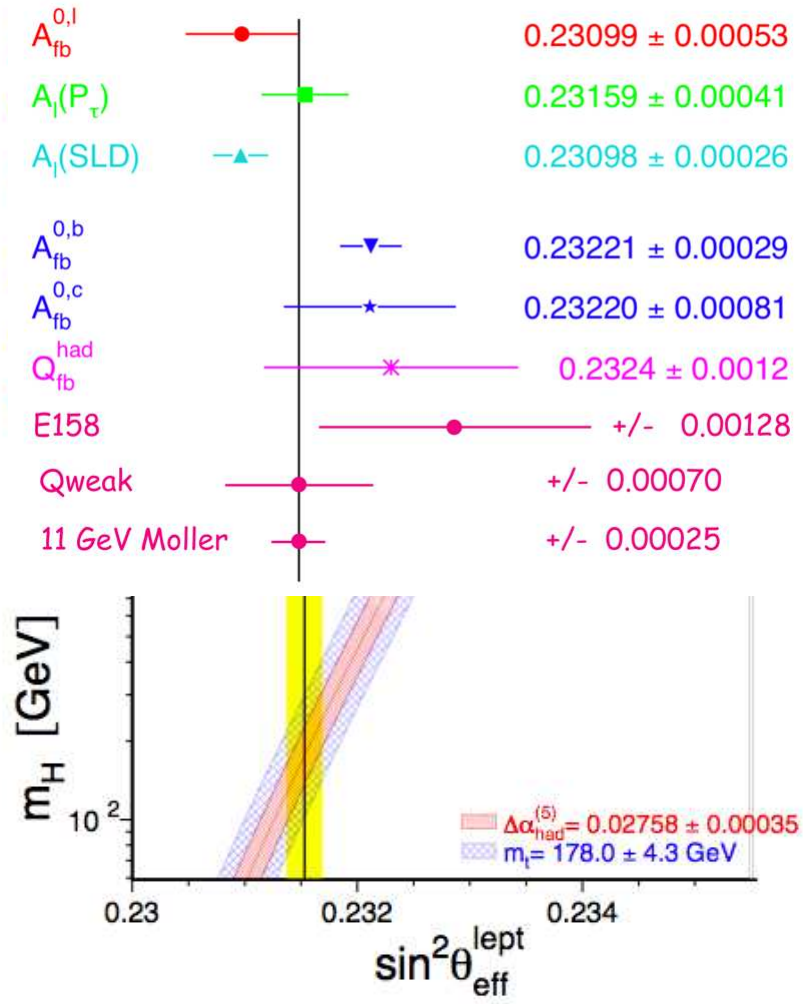
Physics Motivation: $\sin^2\theta_W$, the Higgs Mass, and Beyond the Standard Model

- World data avg: $\sin^2\theta_W = 0.23122(17)$
  $\Rightarrow m_H = 89^{+38}_{-28}$ GeV
  (favors SUSY, rules out Technicolor)
- Avg dominated by two measurements separated by 3σ:

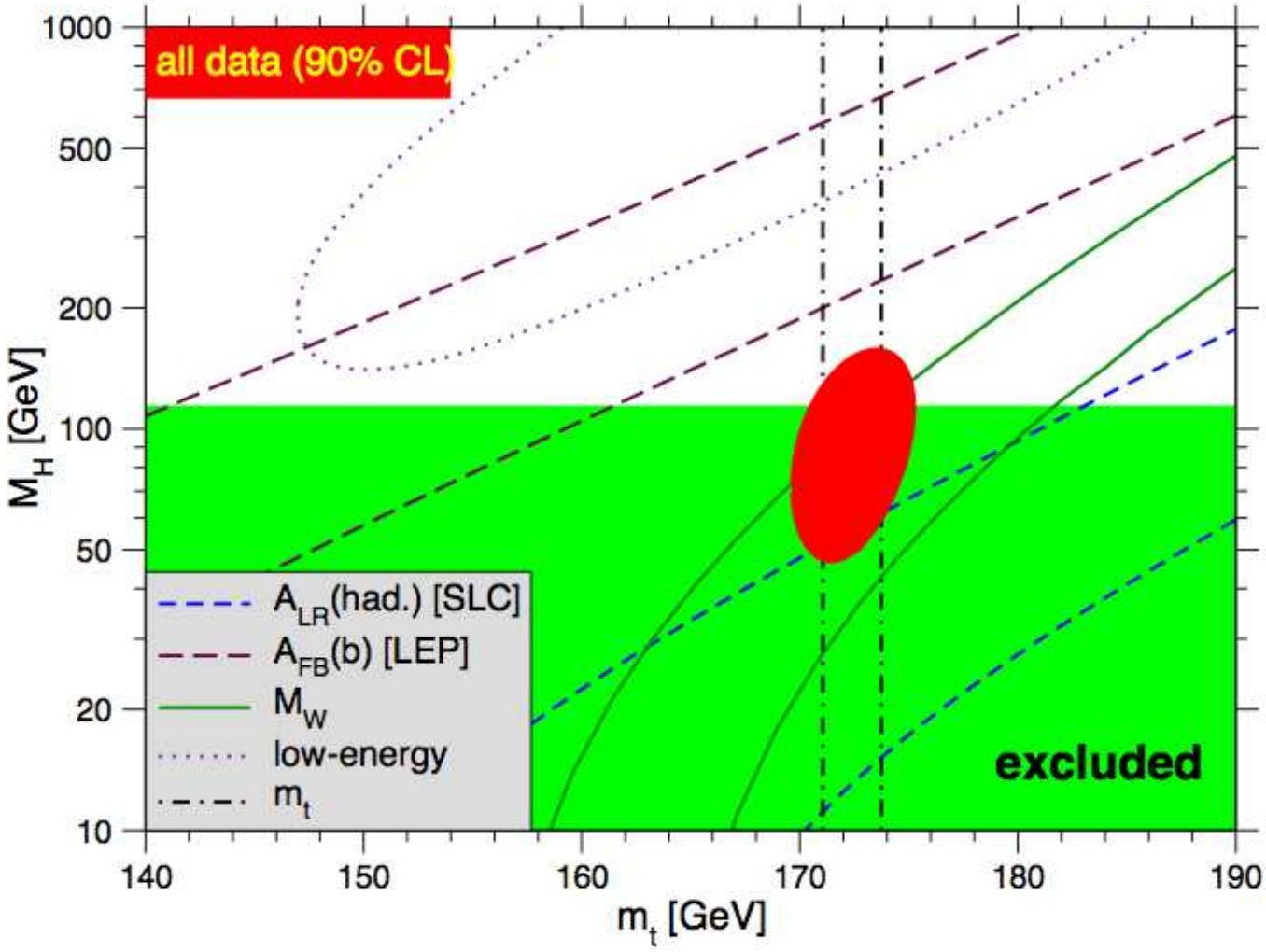
$\rightarrow A_l(SLD)$: 0.2310(3), $\Rightarrow m_H = 35^{+26}_{-17}$ GeV
rules out SM!

$\rightarrow A_{fb}^{0,1}$: 0.2322(3), $\Rightarrow m_H = 480^{+350}_{-230}$ GeV
rules out SUSY, favors Technicolor

- Proposed measurement precise enough to effect the central value of $\sin^2\theta_W$ and its implications for m_H

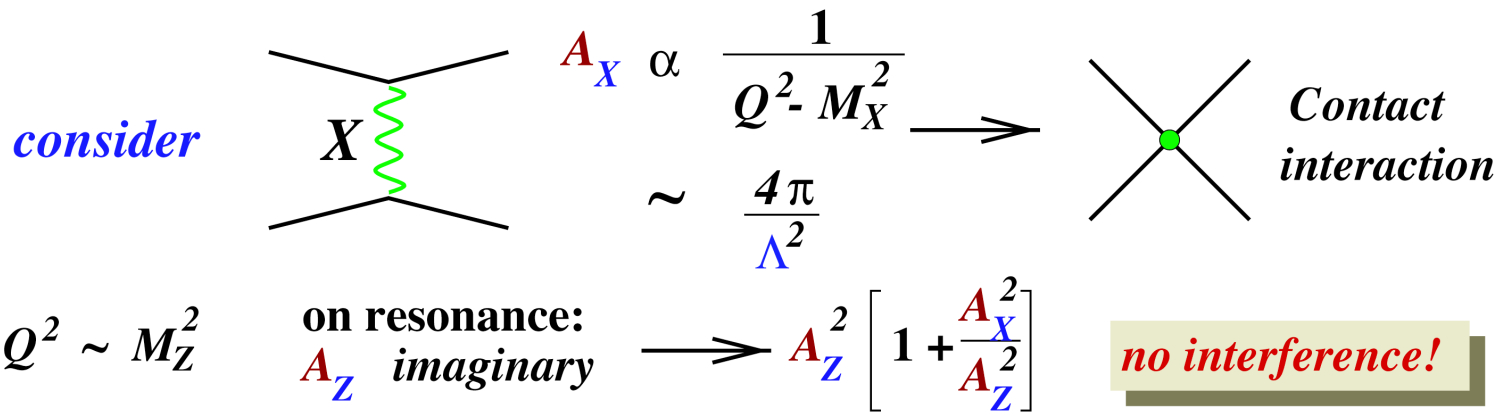


The Search for the Higgs



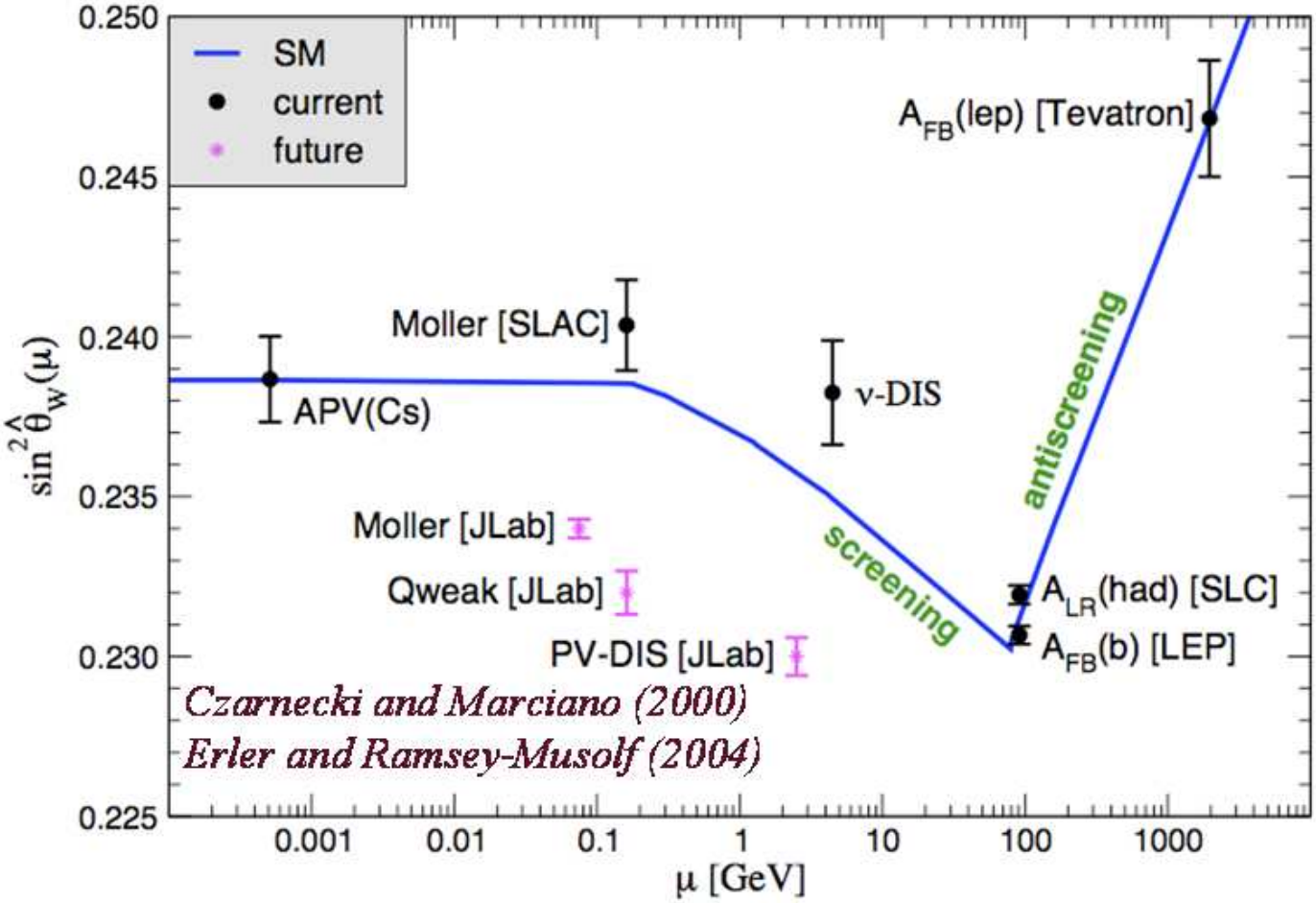
Establishing Limits for New Contact Interactions (Off the Z Resonance)

Important component of indirect signatures for"new physics"

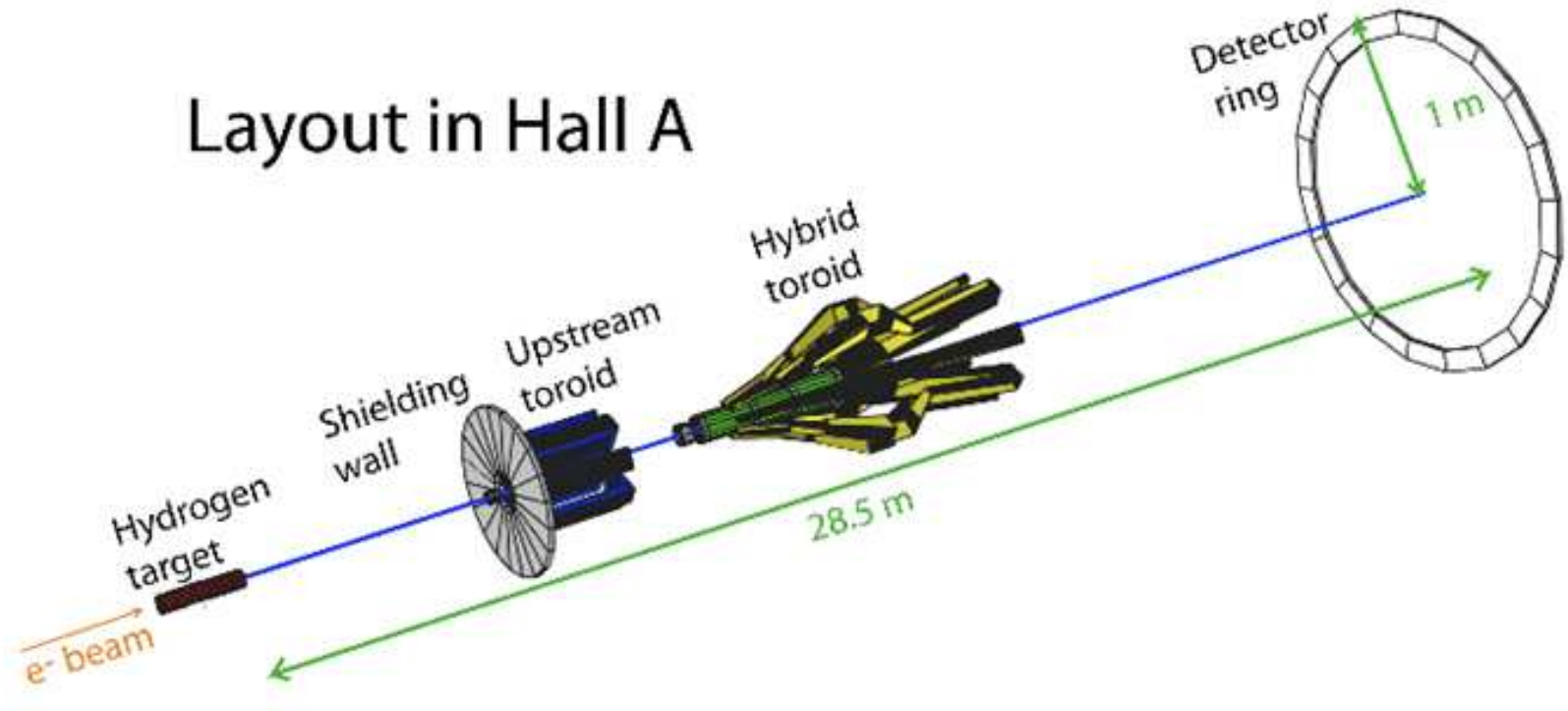


- Proposed Measurement will reach $\sim$ 7.5TeV interaction scale
- Best current limits on $4e^-$ contact interac. come from LEP, LEPII: $\Lambda/g \sim 5$ TeV, but insensitive to $|g_{RR}^2 - g_{LL}^2|$
- Near the Z resonance, new physics interactions (e.g. Z'_X exchange) don't visibly mix with standard model A_Z (Collider Experiments)
- This underscores importance of low energy measurements of Q_W^e: E158, Qweak, PVDIS, and 12GeV Moller

Current and Future $\sin^2\theta_W$ Measurements



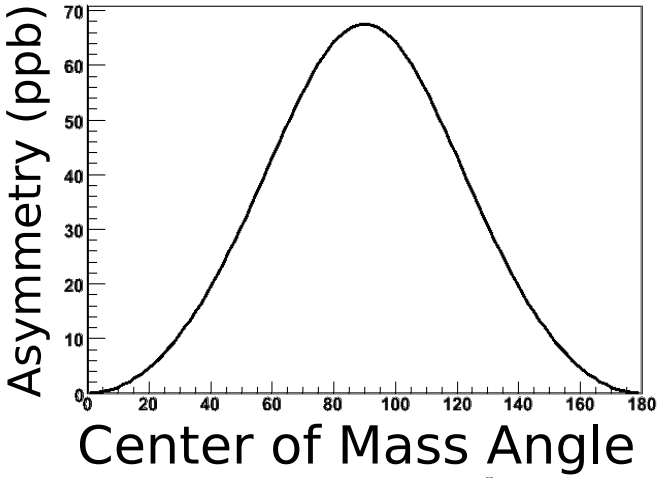
Experimental Setup/Design

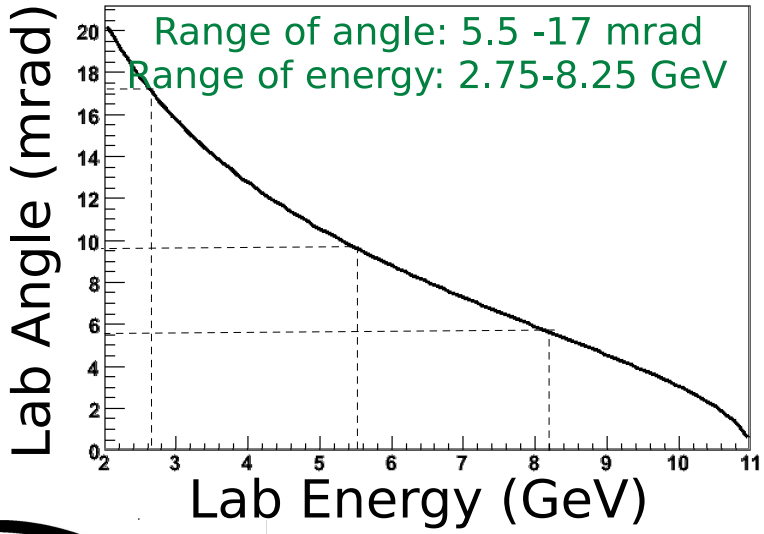


- Long and skinny design (~30m from target to detector)
- 150cm lH_2 target
- Novel two toroid spectrometer design (prebender and hybrid) with full azimuthal acceptance
- Flux integrating detector ring with azimuthal and radial segmentation

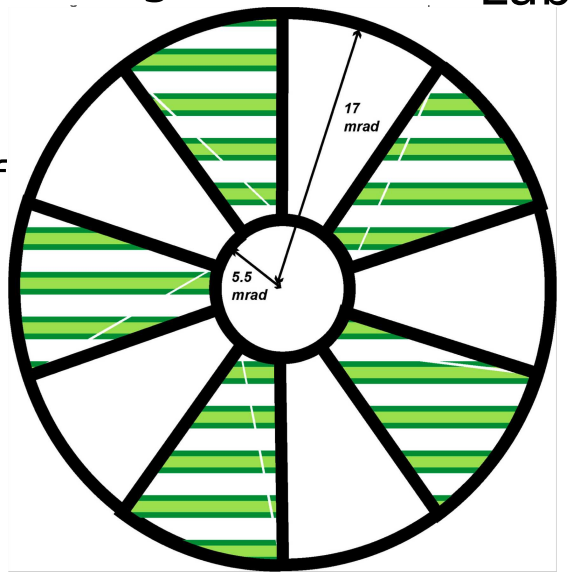
Optimized Spectrometer (~ 100% Acceptance)

Highest figure of merit at $\theta_{CM} = 90^{o}$



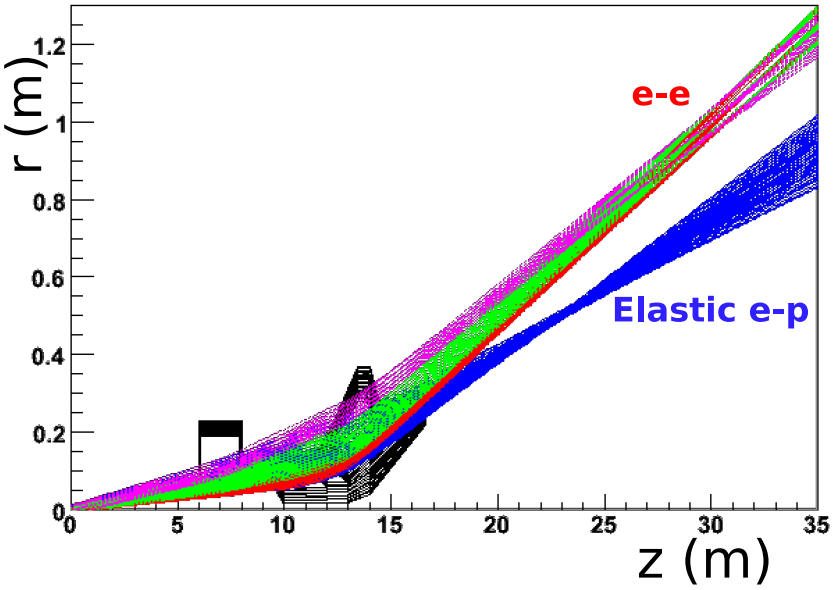


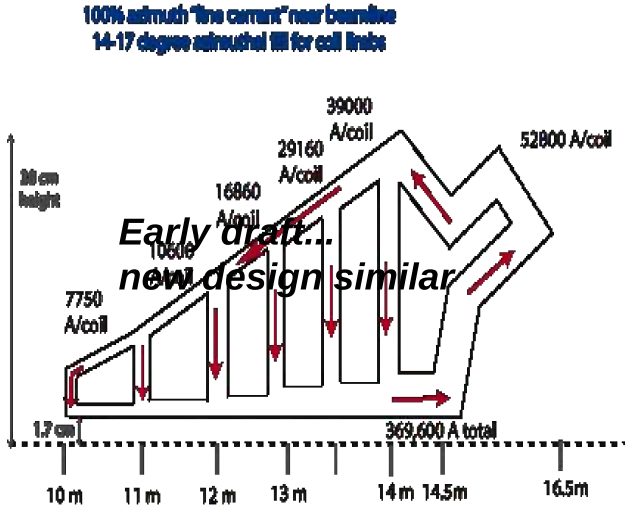
All of those rays of θ_{CM}=[90,120] that you don't get here...



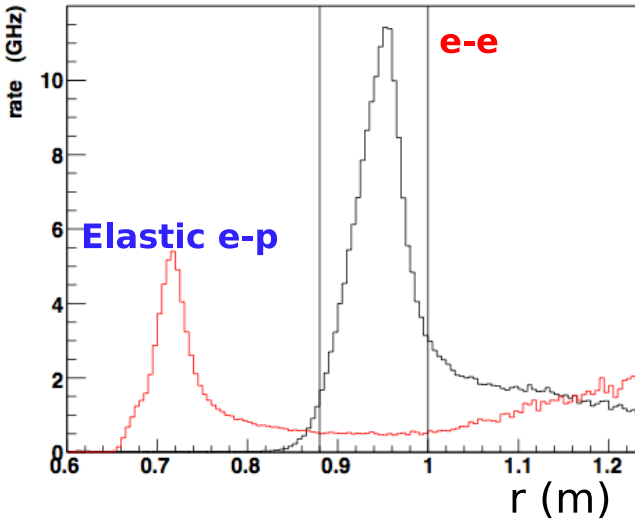
... are collected as θ_{CM}=[60,90] over here!

Toroid Design Concept

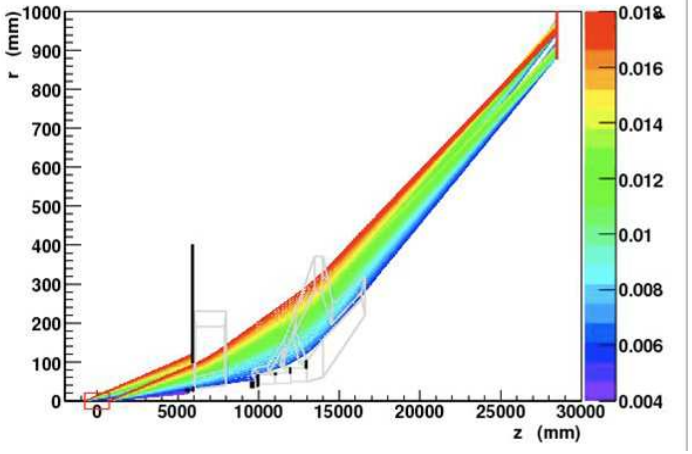




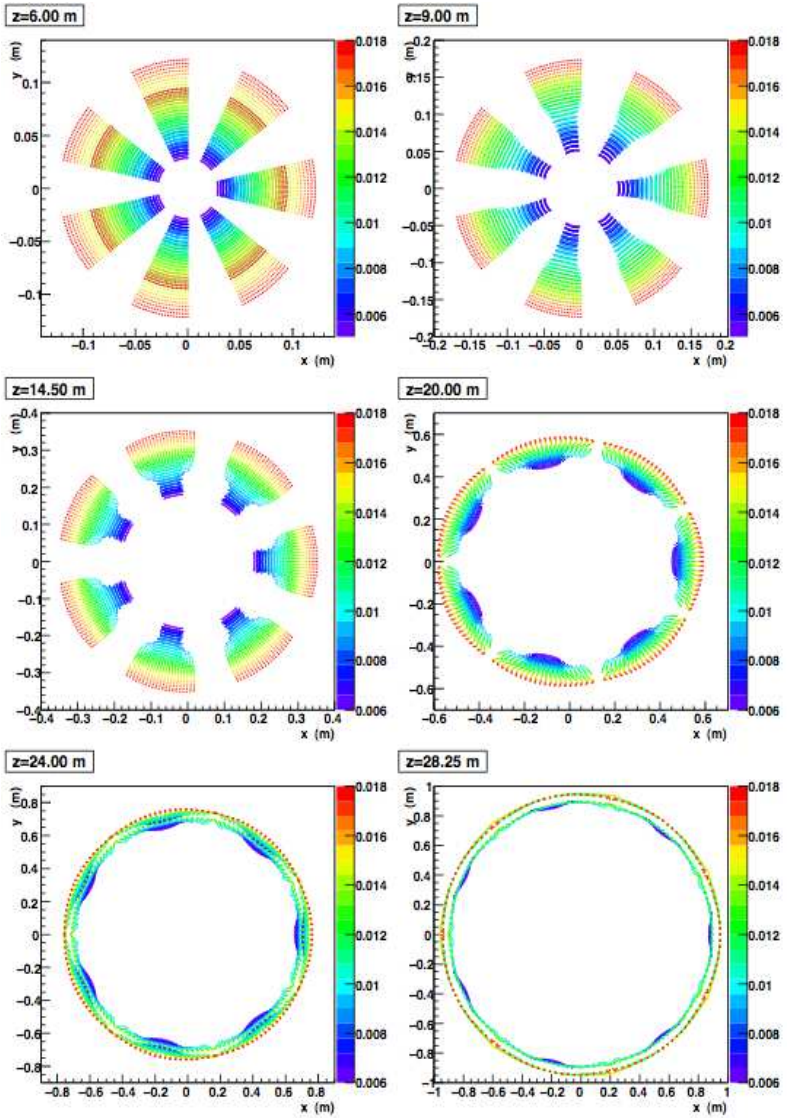
--Two Toroid design facilitates signal and bkgd separation while focusing Moller events onto narrow detector ring



Optics Raytrace

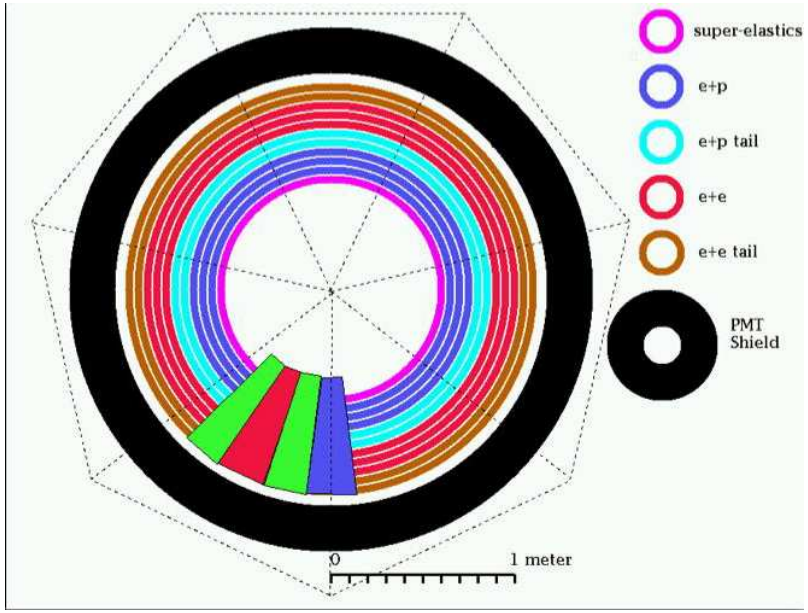


--Defocusing effects results in population of full azimuth



Main Detector Reference Design

Front View

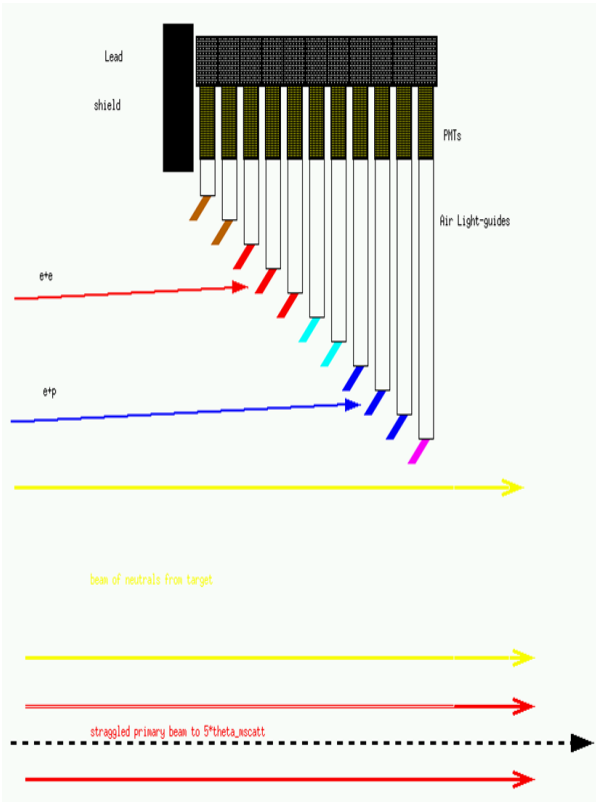


--Rad-hard flux, integrating detectors

--Radial segmentation for systematic checks (backgrounds)

--Azimuthal segmentation for systematic checks (e.g. parity conserving cos(ϕ) asym, azimuthal defocusing, beam sensitivities, backgrounds, etc.)

--Ancillary detectors (not shown): Tracking, pion, and lumi



Side View

New Challenges

- 150GHz total detected Moller event rate
  → Must flip pockels cell at ∼2kHz
  → 80ppm pulse-to-pulse statistical fluctuations
    – Electronic noise and density fluctuations $< 10^{-5}$
    – Pulse-to-pulse beam monitoring res. a few microns at 1kHz
- 0.5nm/0.05nrad control of beam on target
  → Requires improvement on control of pol. src. laser transport
  → Improved methods of "slow helicity reversal" (double wien)
- Target requires ∼5kW of cooling power at 85μA I_{beam}
- Full azimuthal acceptance with θ_{lab} between 5 and 17mrad
  → Aggressive spectrometer design
  → Complex collimation and shielding issues
- Robust and redundant 0.4% beam polarimetry
  → Plan to pursue both Compton and atomic Hydrogen techniques

Timeline and Status

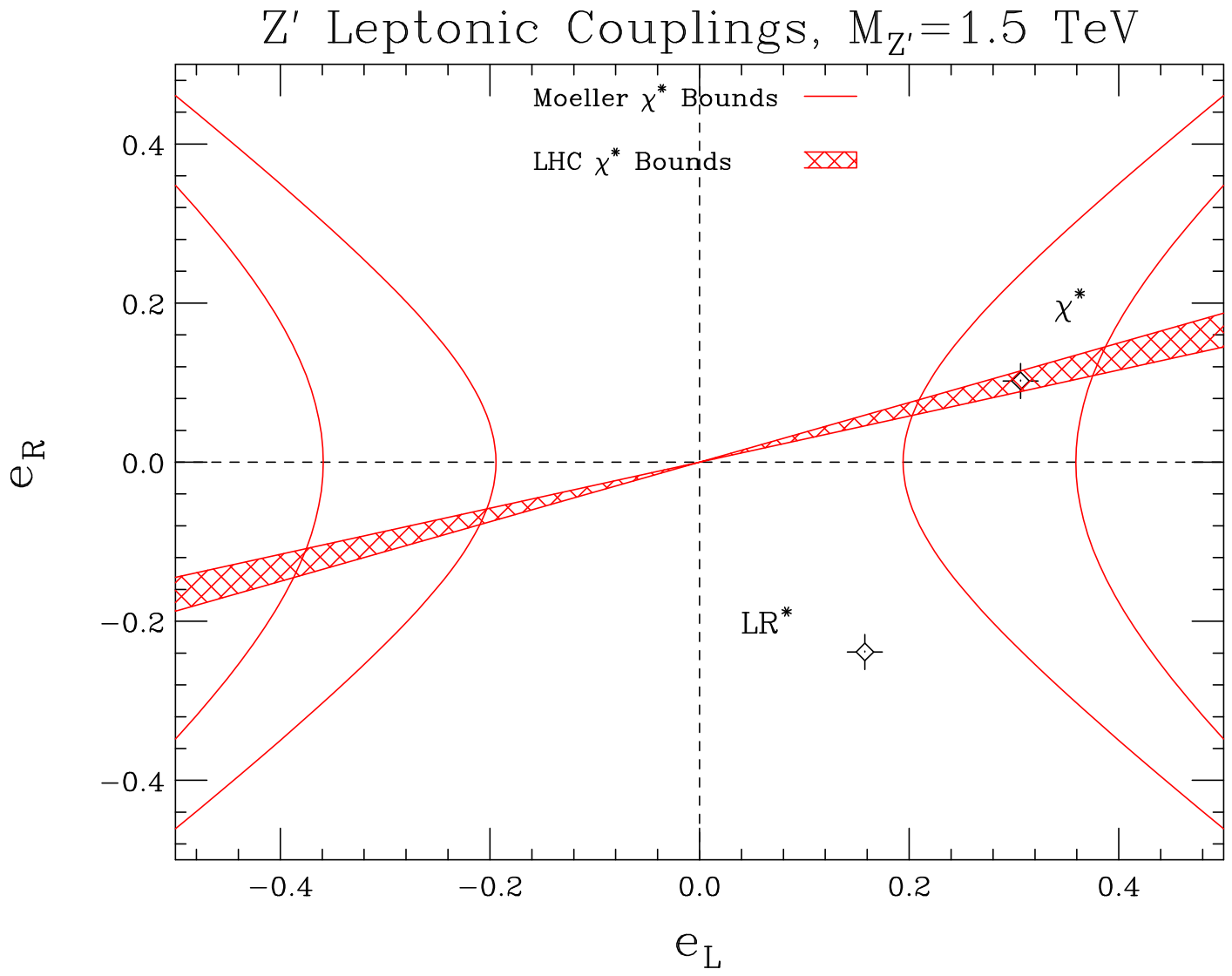
- JLab PAC 34 - full approval - strong endorsement

"The proposed physics reach is outstanding and capable of making this effort a flagship experiment at JLab. The PAC believes the mission of this experiment... is so important that the Laboratory should make every effort to support the securing of the resources required"

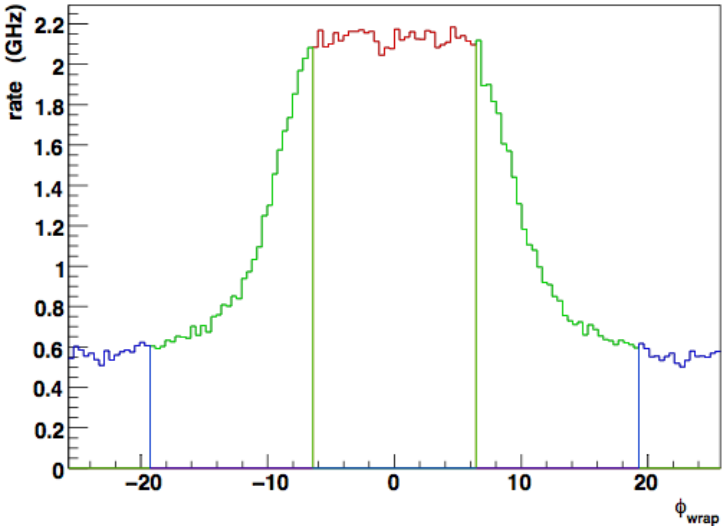
- Detailed cost estimates and R&D plan formulation underway
- Working with lab management to prepare funding request (DOE, NSF, and international funding agencies)
- First review (JLab director's review) took place last January – Addressed charges: Physics case, and experimental approach
- Construction/Installation: 2012 - 2015
- Experiment likely to have two running periods: The first 6 months, and second 2 years

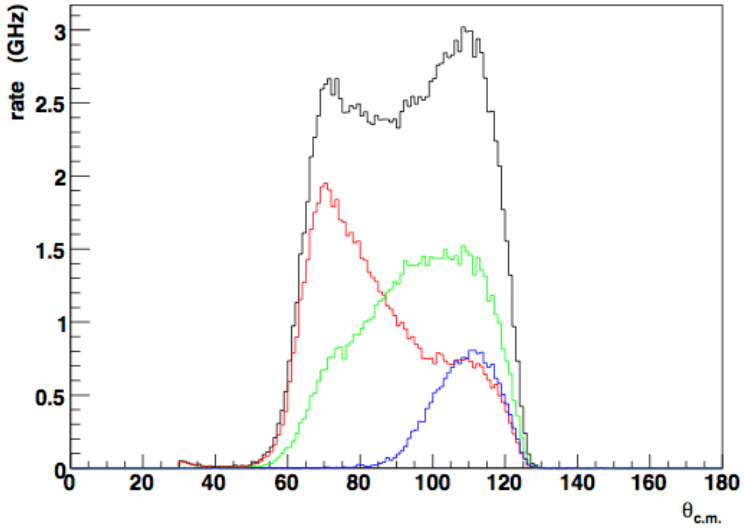
Extra Slides

Complimentary Measurement to LHC



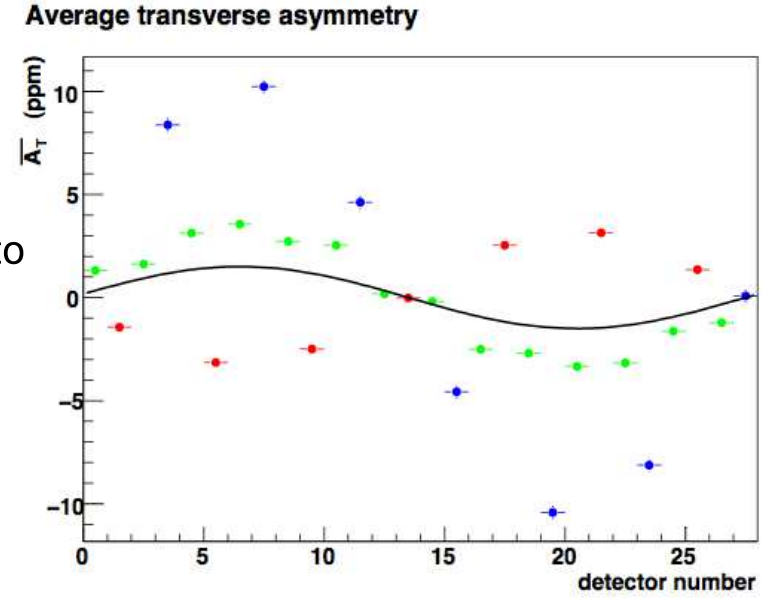
Transverse Asymmetry Measurement



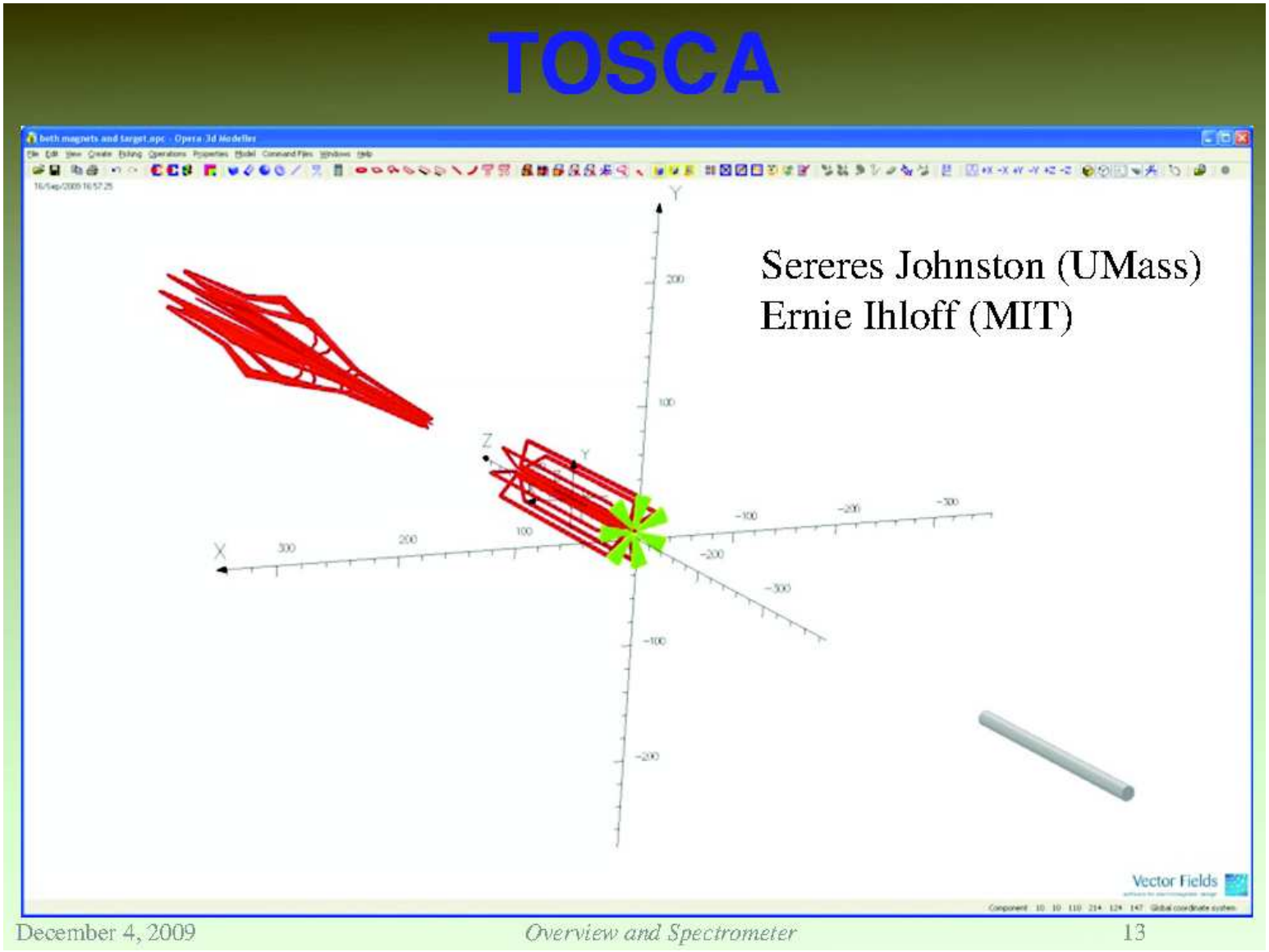


--A_T ~ 12 parts per million ... 3 orders of magnitude bigger than A_{PV}

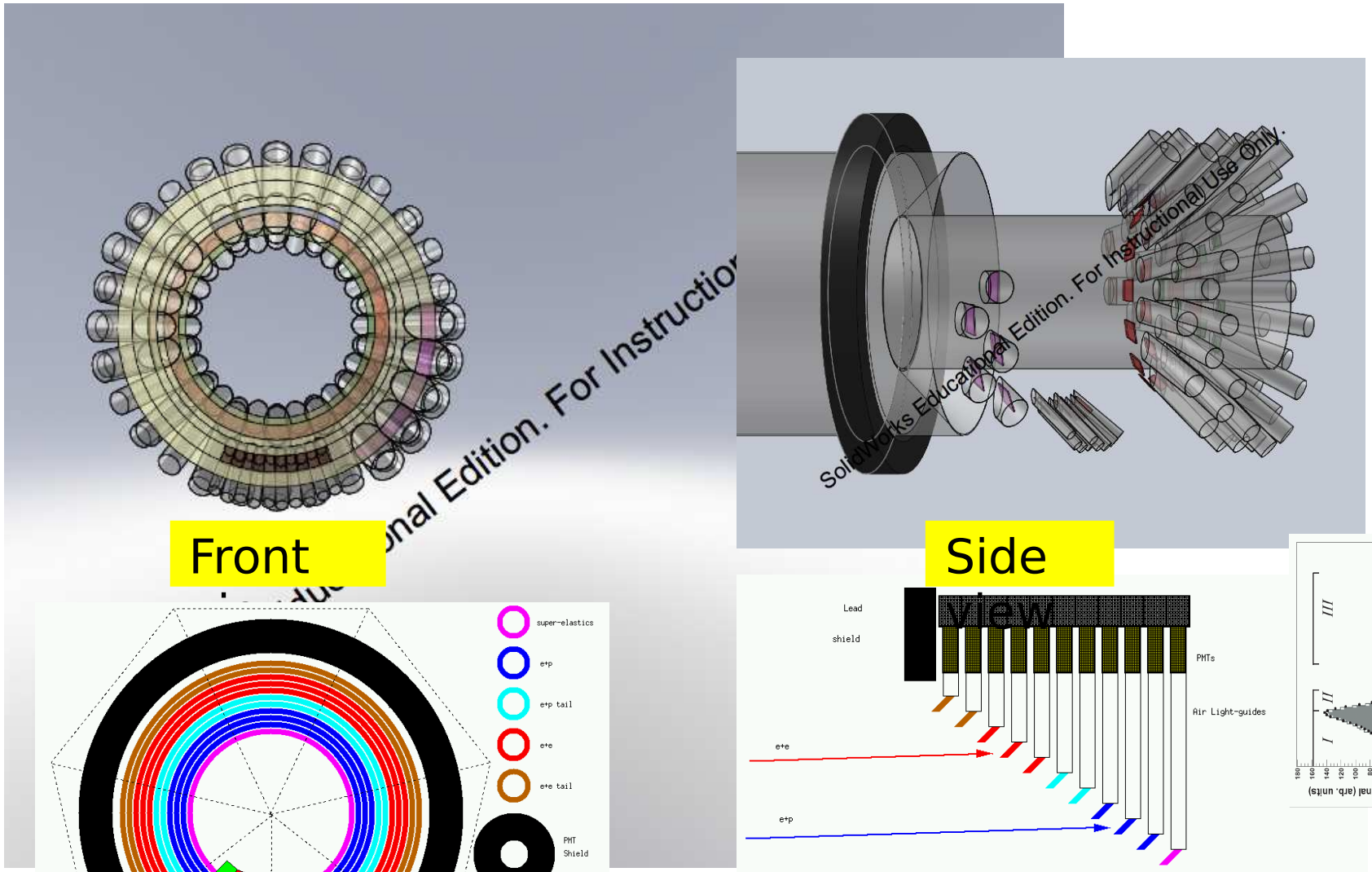
--We must be sure that this averages to a negligible contribution!



Magnet Design



Main Detector Reference Design


Front
Side
super-elastics
e+p
e+p tail
e+e
e+e tail
PMT Shield
Lead shield
PMTs
Air Light-guides
e+e
e+p
beam of neutrals from target
straggled primary beam to 5*theta_mscatt

Spectrometer Beamline Draft