The E158 and MOLLER Experiments

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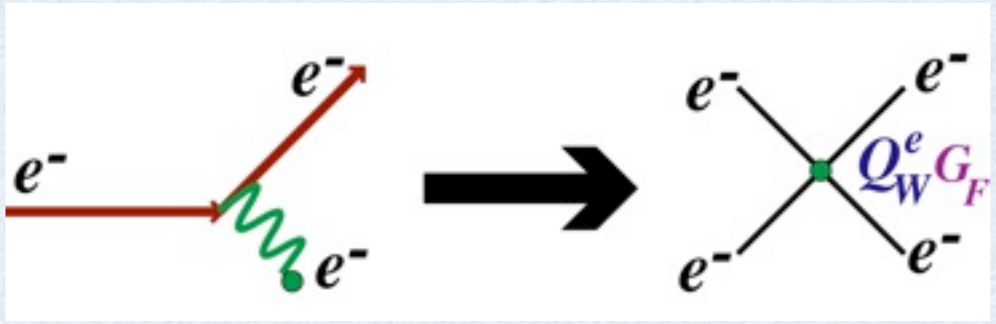
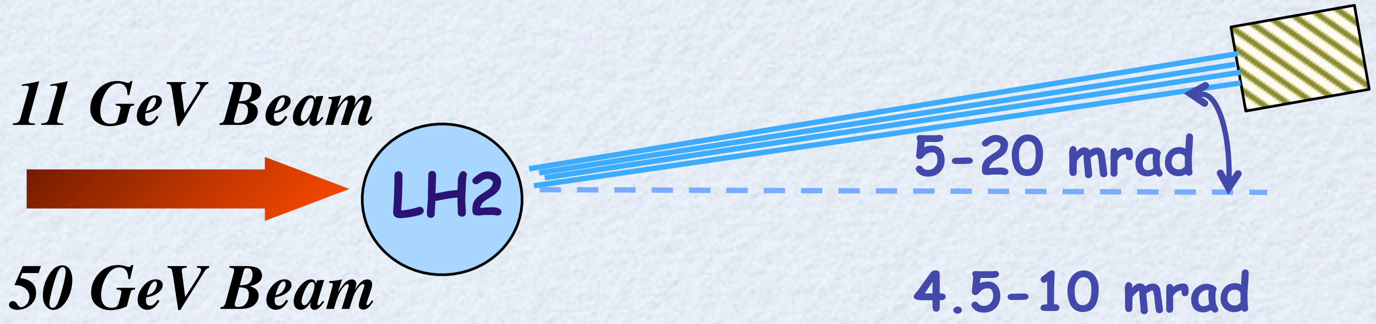
University of Massachusetts, Amherst

Gamma-Z Workshop, JLab, December 16-17, 2013

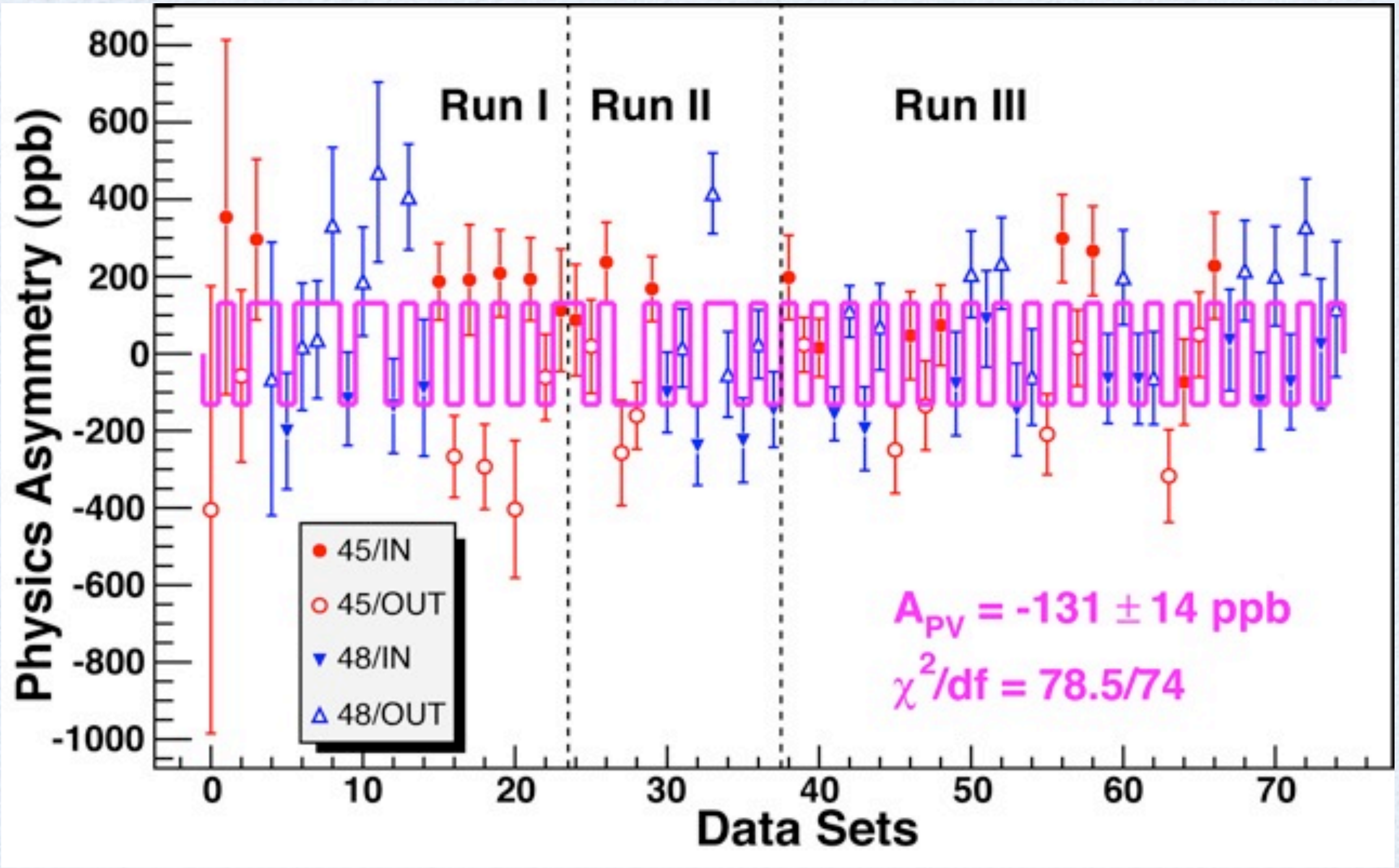
Outline





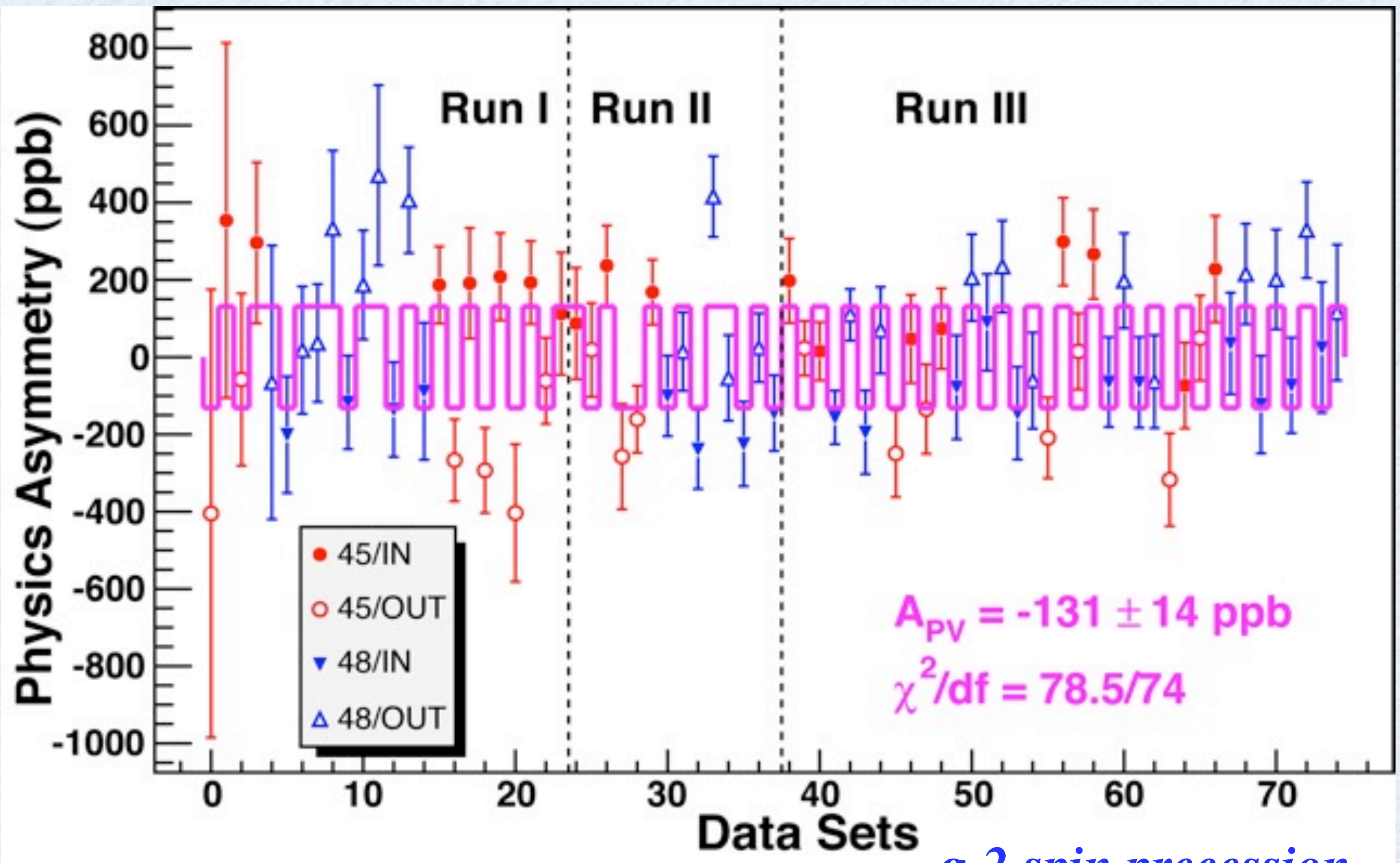
- **Review of SLAC E158**
  - ***extraction of result including radiative corrections***
  - ***inelastic e-p scattering data***
- **MOLLER at JLab**
  - ***theoretical issues***
    - Standard Model prediction with full detector effects
    - two-loop uncertainties
  - ***kinematics of e-p inelastic A_{PV} measurements***

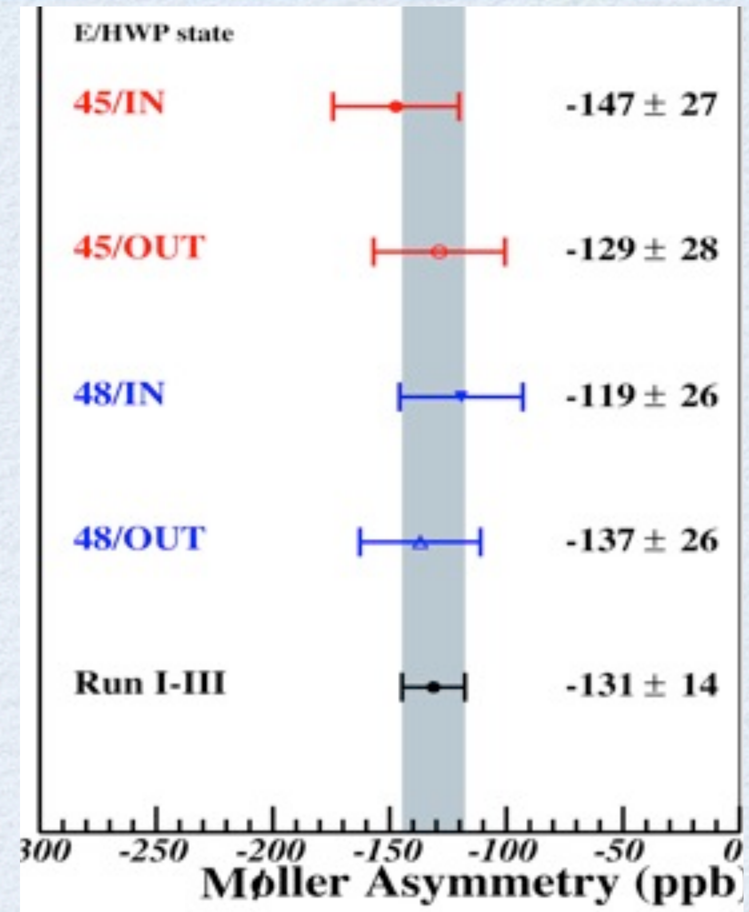
SLAC E158 Result 2002-3

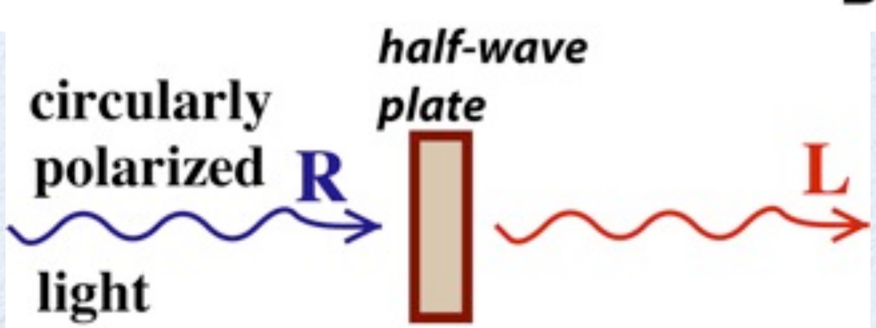


SLAC E158 Result

2002-3



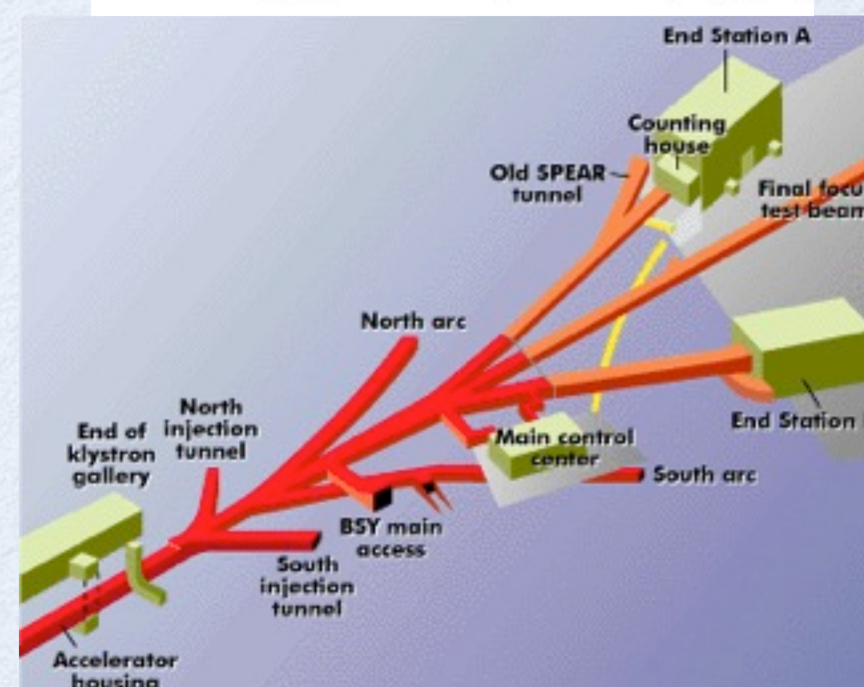




g-2 spin precession

45 GeV: 14.0 revs

48 GeV: 14.5 revs



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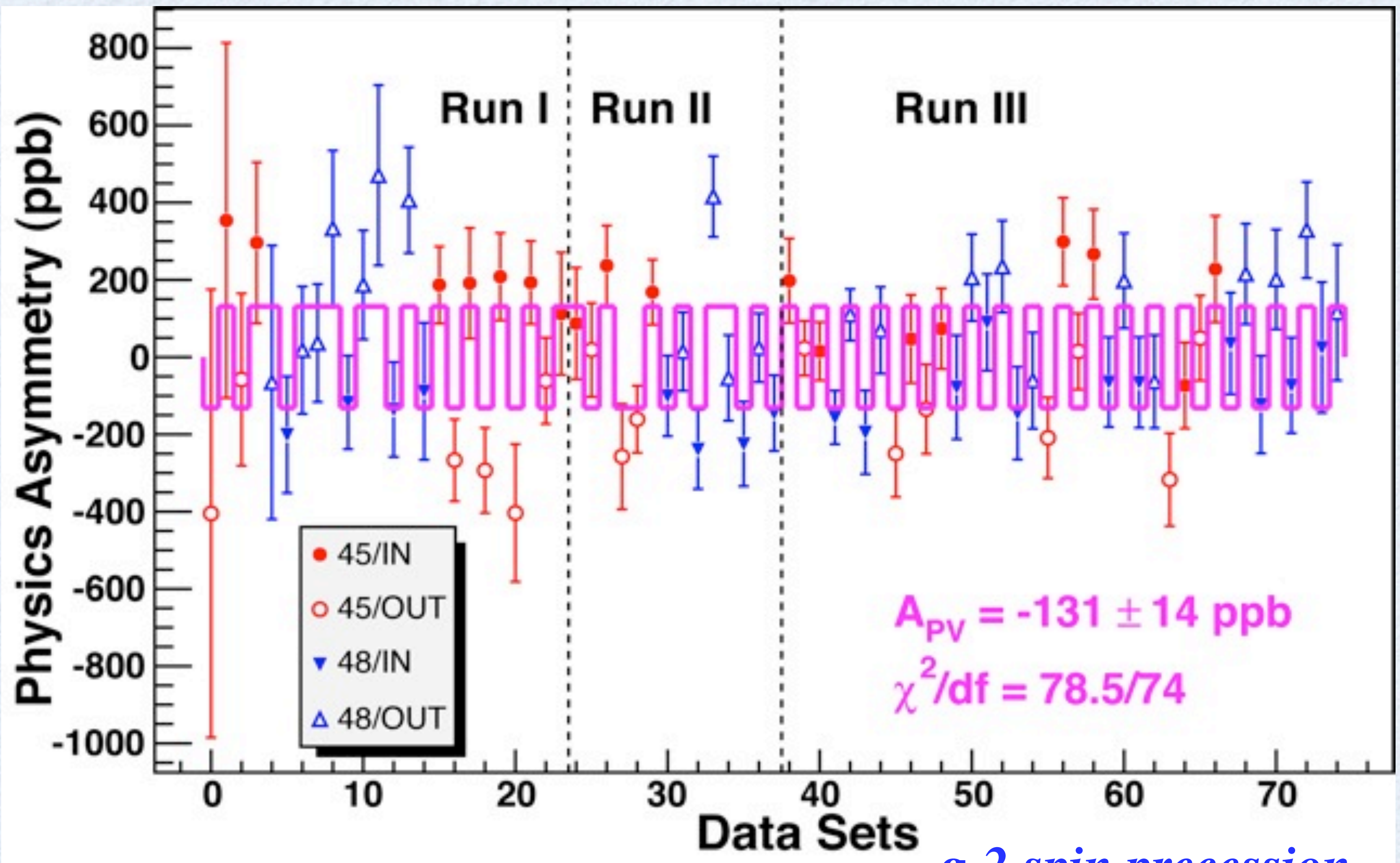

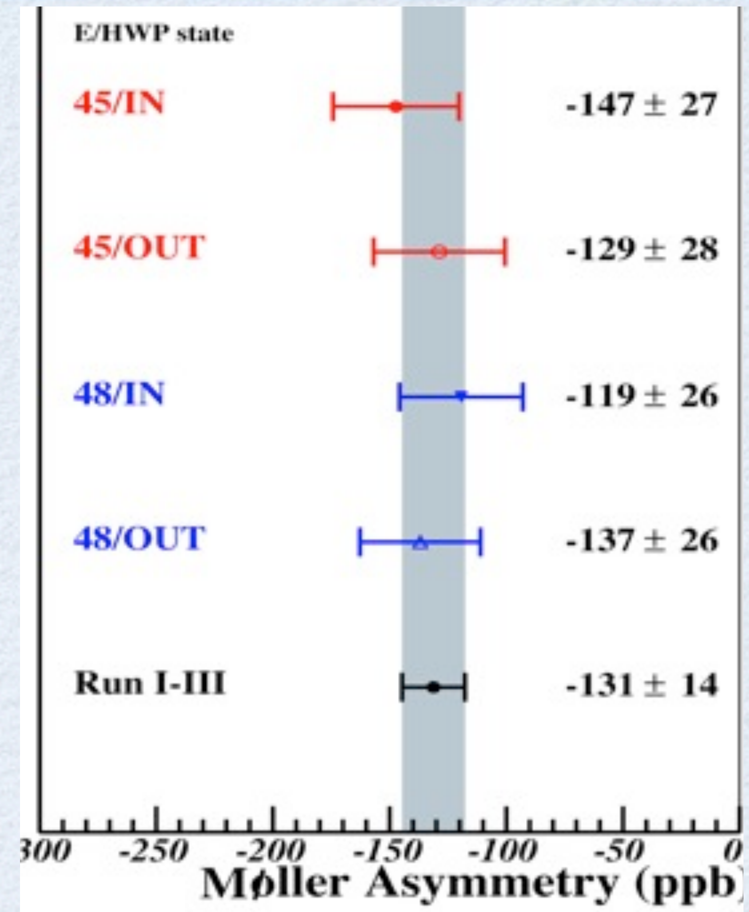

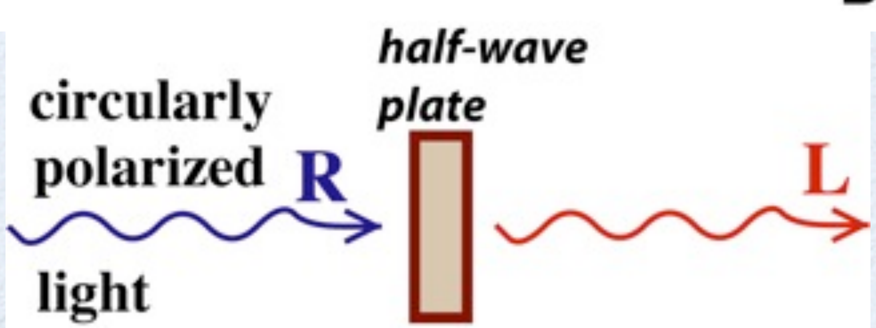

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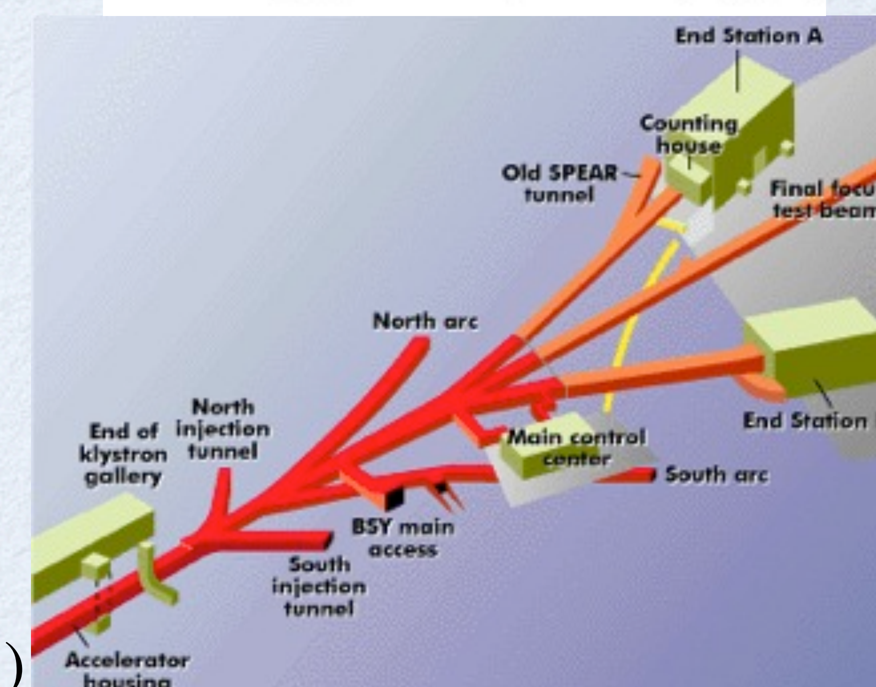
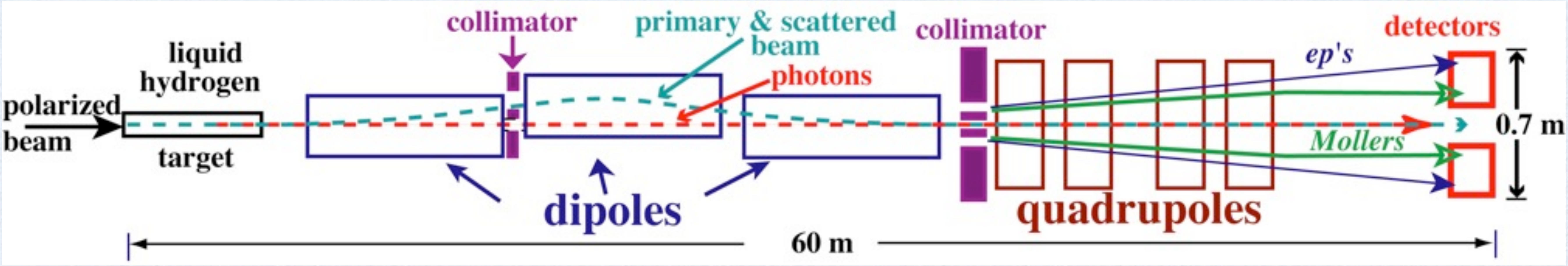


$$A_{PV} = (-131 \pm 14 \pm 10) \times 10^{-9}$$

Phys. Rev. Lett. **95** 081601 (2005)

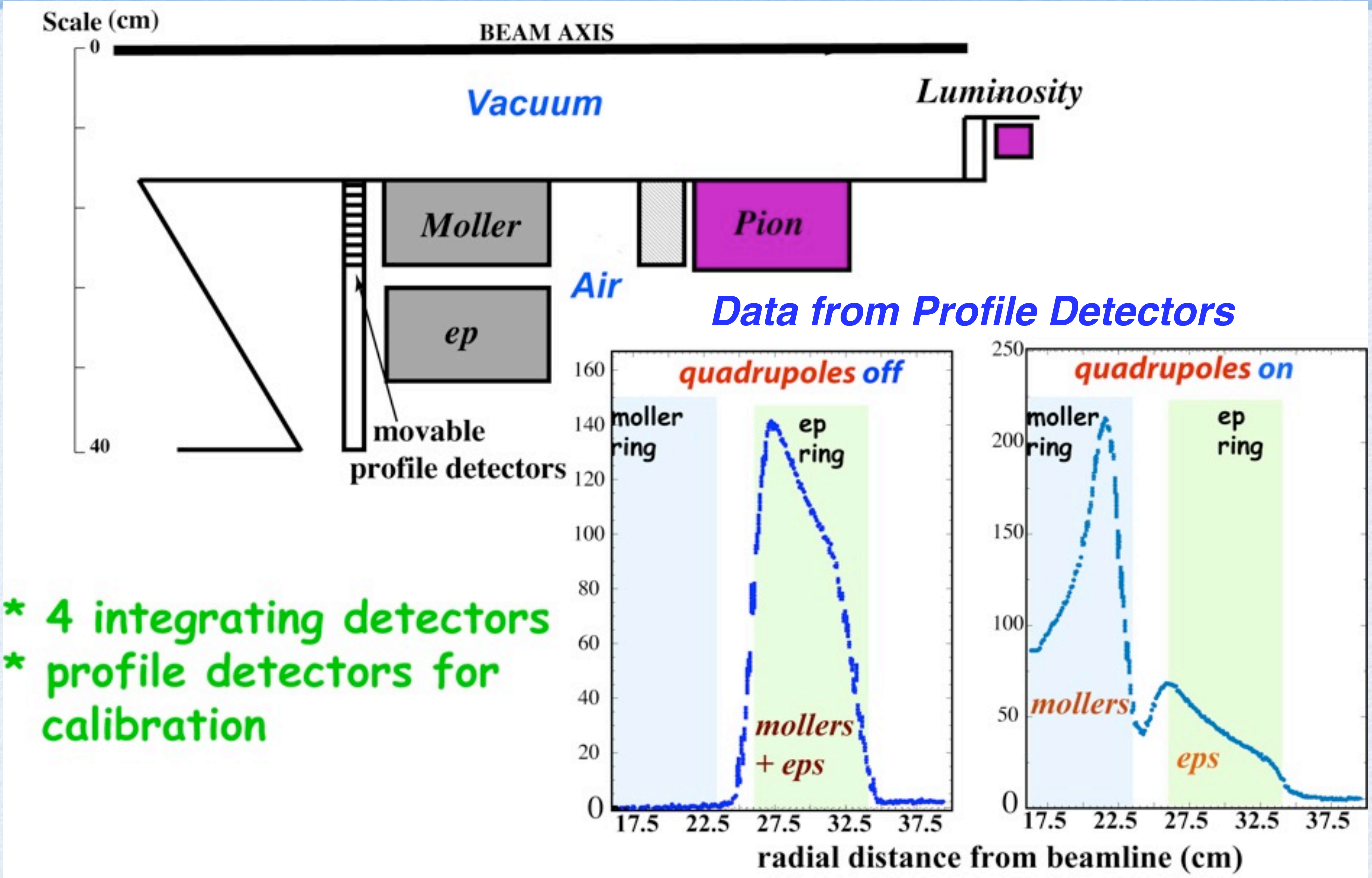
SLAC E158 Layout

~ 11 ppb raw statistical error at highest E_{beam}, ~ 0.4% error on weak mixing angle



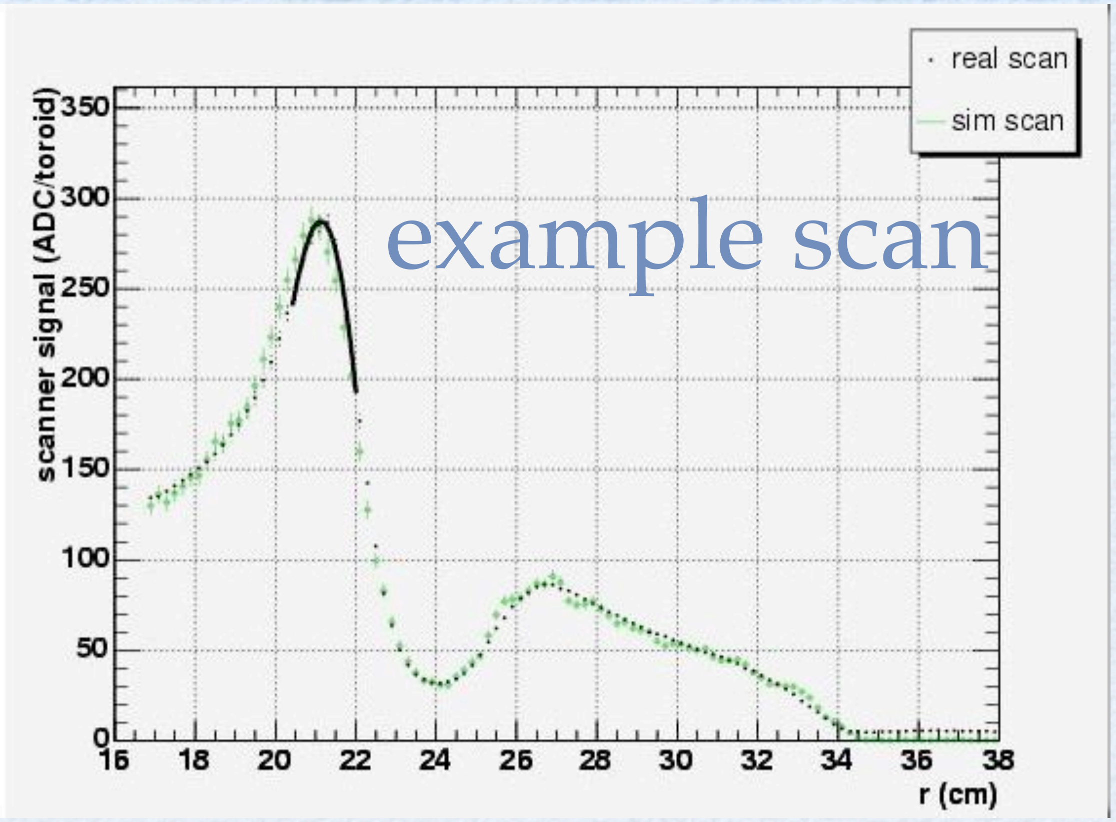
- **4 quadrupoles**
  - focus Mollers and separate from ep's
  - full range of the azimuth
- **3 dipole chicane**
  - entire beam bent and then rebent
  - shields detector rings from target line of sight
  - natural 10 GeV momentum cutoff
- **Precision collimation**
  - Tungsten edges
  - movable "pin-hole" calibration collimators

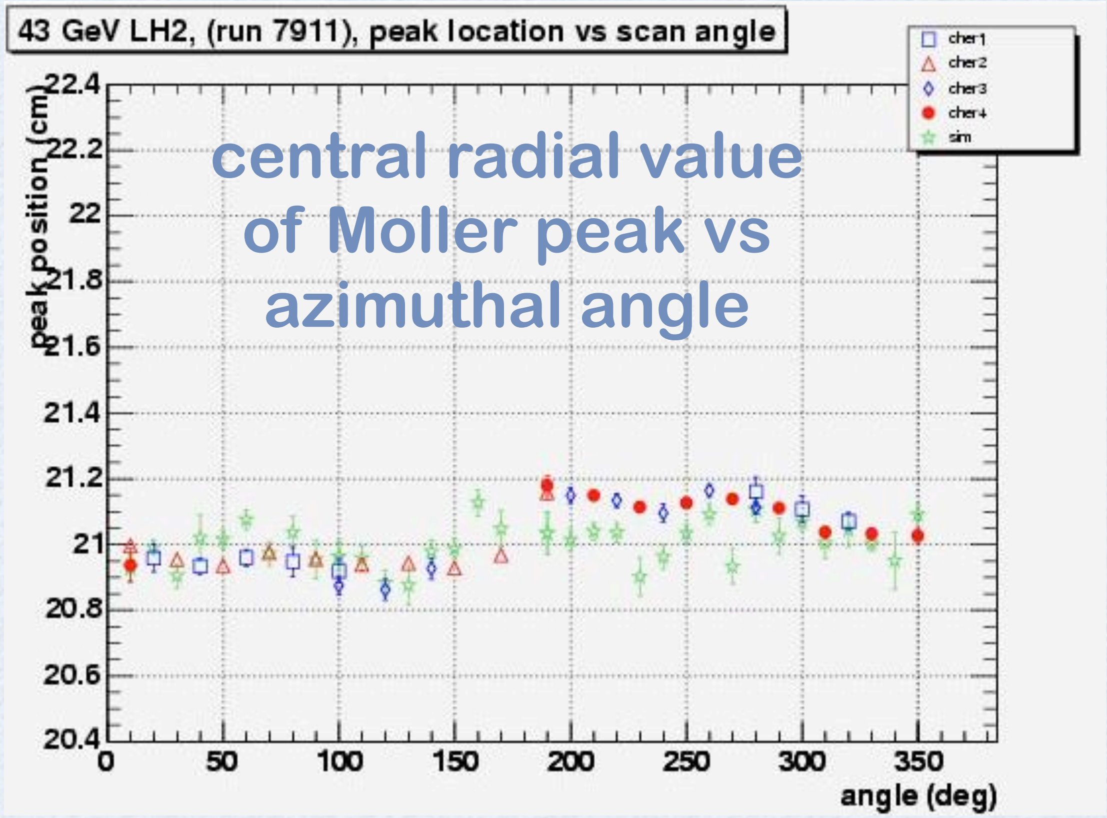
E158: Detector Concept



* 4 integrating detectors
* profile detectors for calibration

E158: Apparatus Acceptance





- **Detailed calibration scans of radial distributions**
  - ***Monte Carlo with full detector geometry and QED radiative corrections***
  - ***Adjust collimators, spectrometer optics and physics to reproduce data***
- **Three physics processes**
  - ***Møller and elastic e-p scattering from first principles***
  - ***inelastic e-p scattering using SLAC code that incorporates world data***

$$A_{\text{phys}} = \frac{1}{P_b \epsilon} \frac{A_{\text{raw}} - \Sigma f_i A_i}{1 - \Sigma f_i}$$

Extraction of Result

E158 procedure: documented in Zykunov et al, arXiv:hep-ph/0507287

$$A_{\rm phys} = \mathcal{A}^0(Q^2,y)\rho(Q^2)(1+\delta A(Q^2,y))(1-4\sin^2\theta_W(Q^2)+\Delta(Q^2))$$

$$\sin^2\theta_W(Q^2) = \kappa(Q^2)_{\overline{MS}}\sin^2\theta(m_Z^2)_{\overline{MS}}$$

δA contained QED corrections including hard bremßtrahlung and γγ and IR divergent pieces of the ϒZ boxes that factorize, and depend on the details of the experimental configuration and acceptance cutoffs

$\Delta(Q^2)$ contains heavy boson boxes as well as leading logarithmic contribution to the ϒZ box

$\kappa(Q^2)$ contains vacuum polarization and heavy boson vertex corrections

$$\delta A(Q^2,y) = 0.006 \pm 0.005$$

$$\Delta(Q^2) = -0.0007 \pm 0.0009$$

size of corrections small due to accidental cancellations

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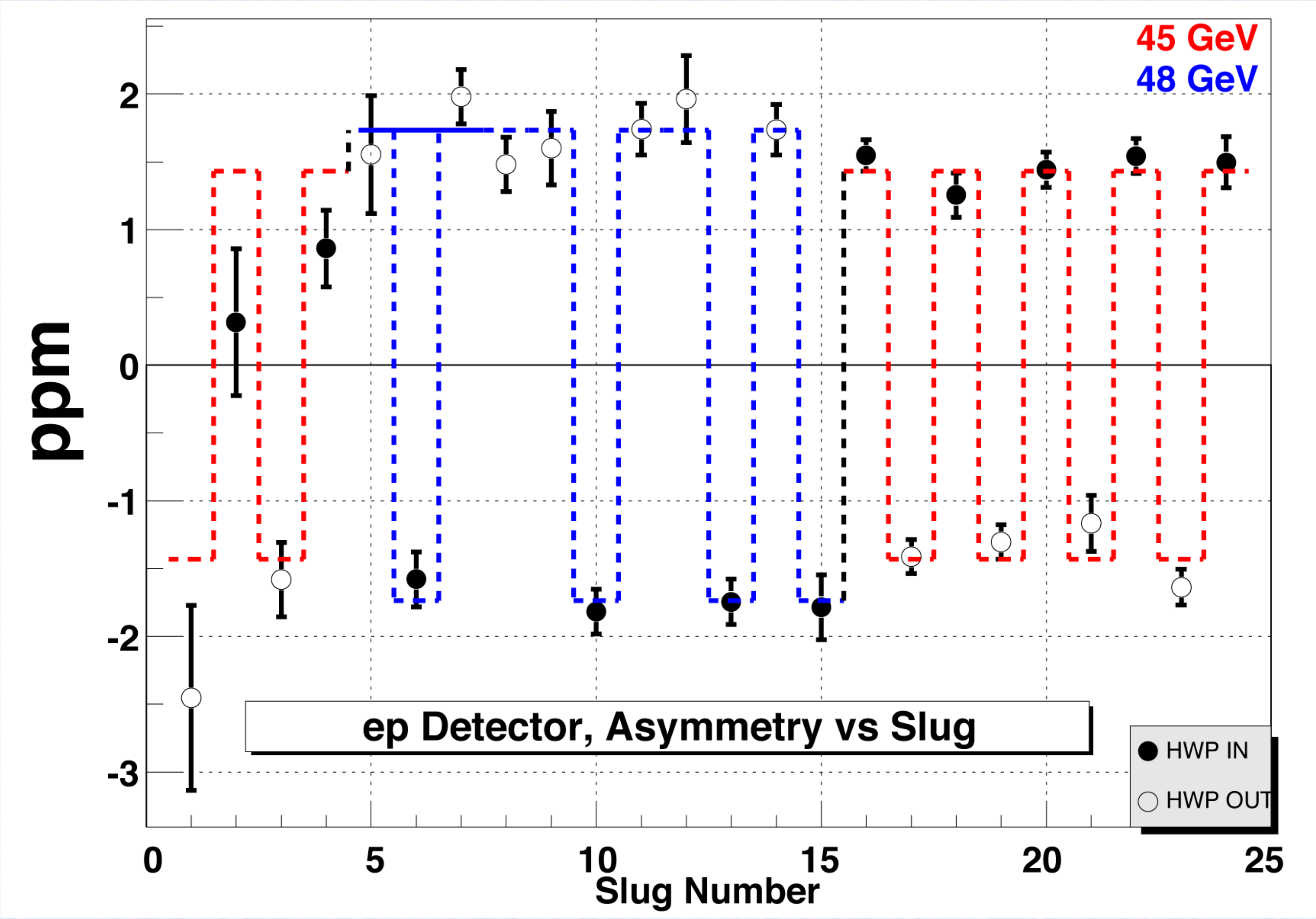
- **Issues for JLab MOLLER**
  - ***Expect a 3-4% correction for 11 GeV***
  - ***Robust prediction for Q^p_W for 11 GeV (done? We assumed 4% error)***
  - ***full two-loop calculation with careful scrutiny for double-counting***
  - ***error on $\Delta(Q^2)$ must be reduced by a factor of 4 to 5 (related to 2-loop)***
  - ***need to develop collaboration between experimentalists and theorists***
  - ***more scrutiny of error going from $\kappa(0) \rightarrow \kappa(Q^2)$***

E158 ep Detector Data

$A_{PV}(ee)$ = -152 ppb for E158-specific kinematics (average 45 & 48 GeV)

A_{PV}(e-p elastic) ~ 500 ppb (at forward angle: $-1 \times 10^{-5} \times Q^2$)



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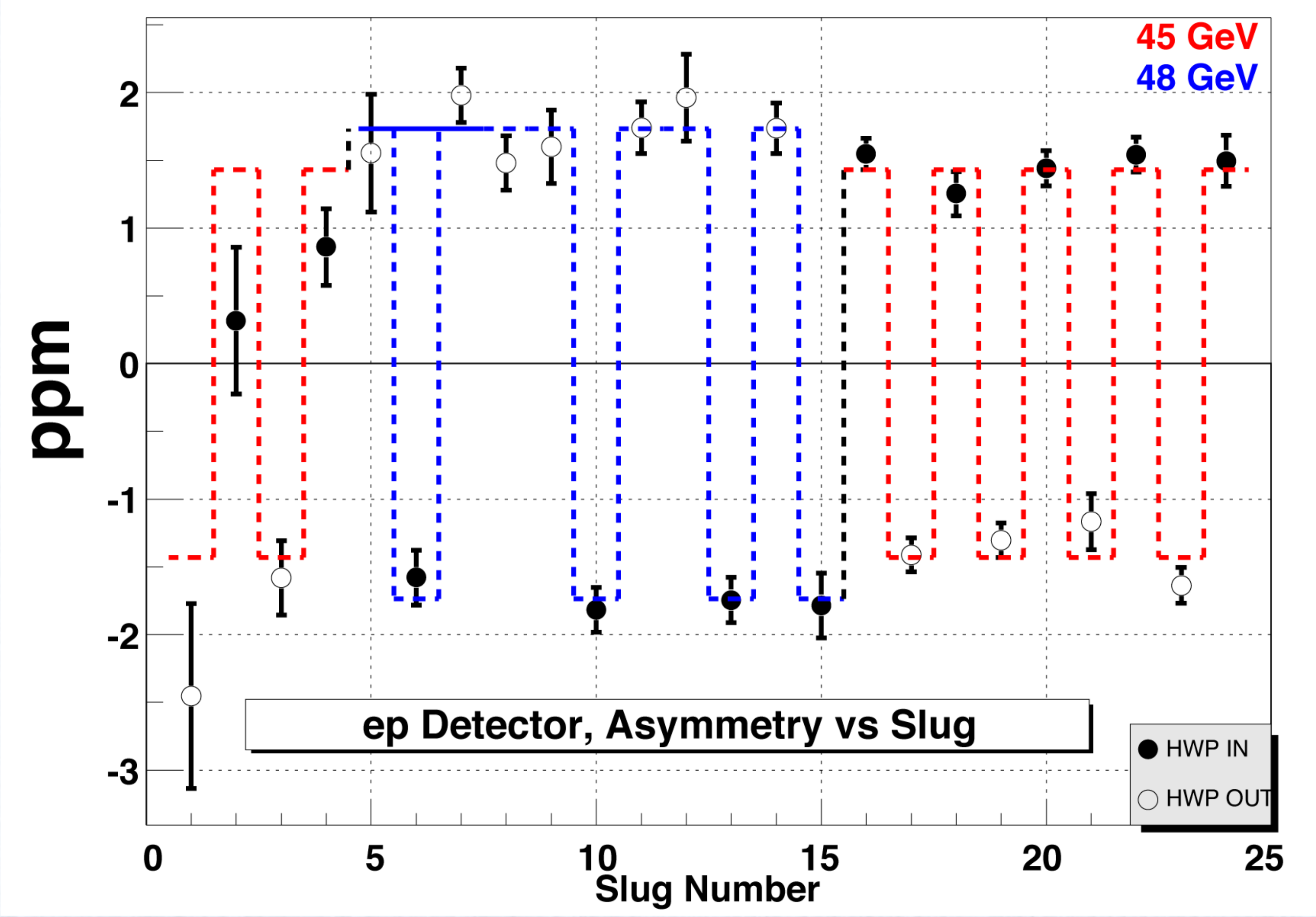

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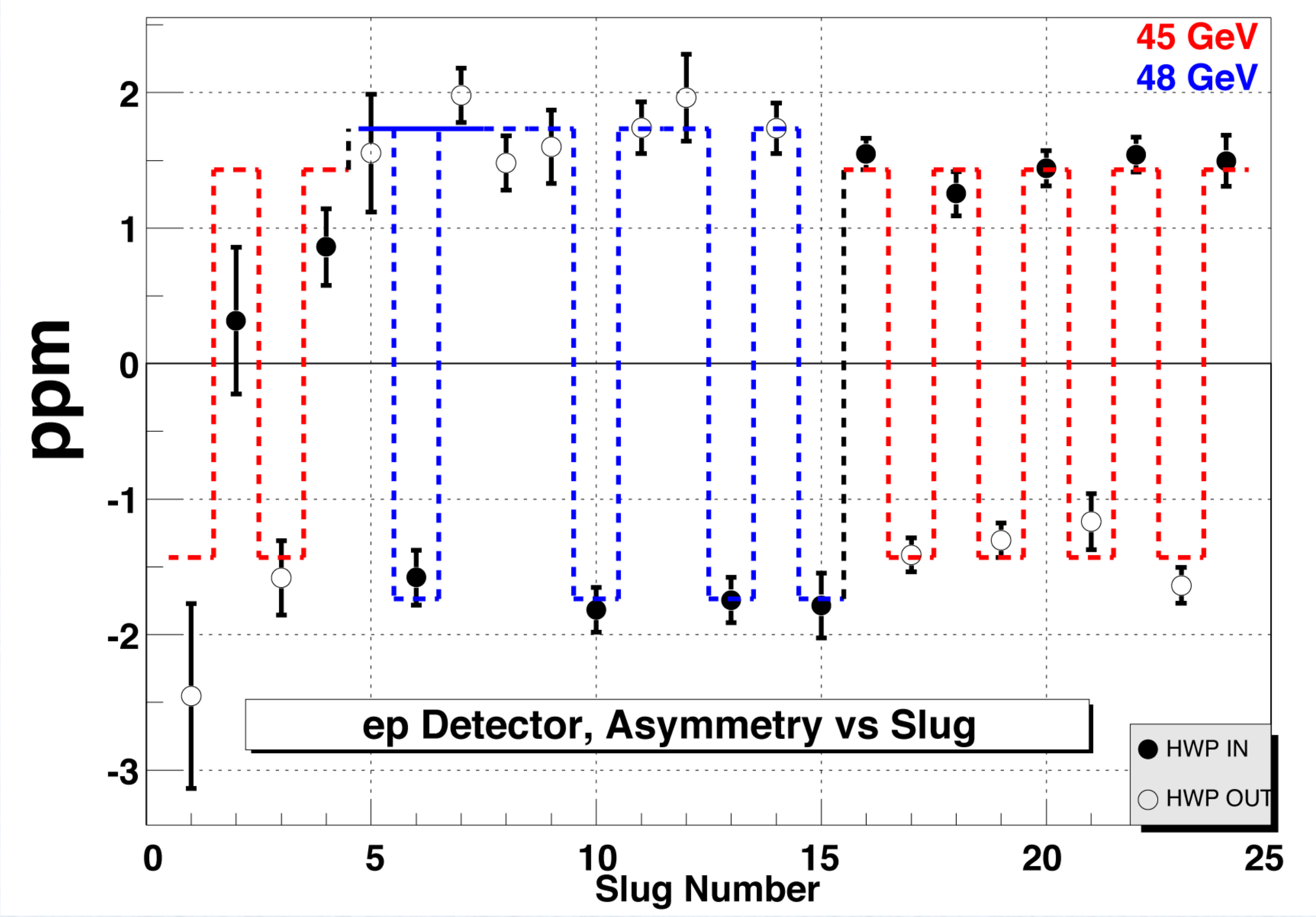

30 % strength in e-p detector from inelastic scattering

Data consistent with:
A_{PV}(inelastic) = $-8 \times 10^{-5} \times Q^2$

elastic ep $Q^2 = 0.05\ \mathrm{GeV}^2$
inelastic ep $Q^2 = 0.07\ \mathrm{GeV}^2$

A_{PV} inelastic ~ 5 ppm

W range: Delta to 8 GeV

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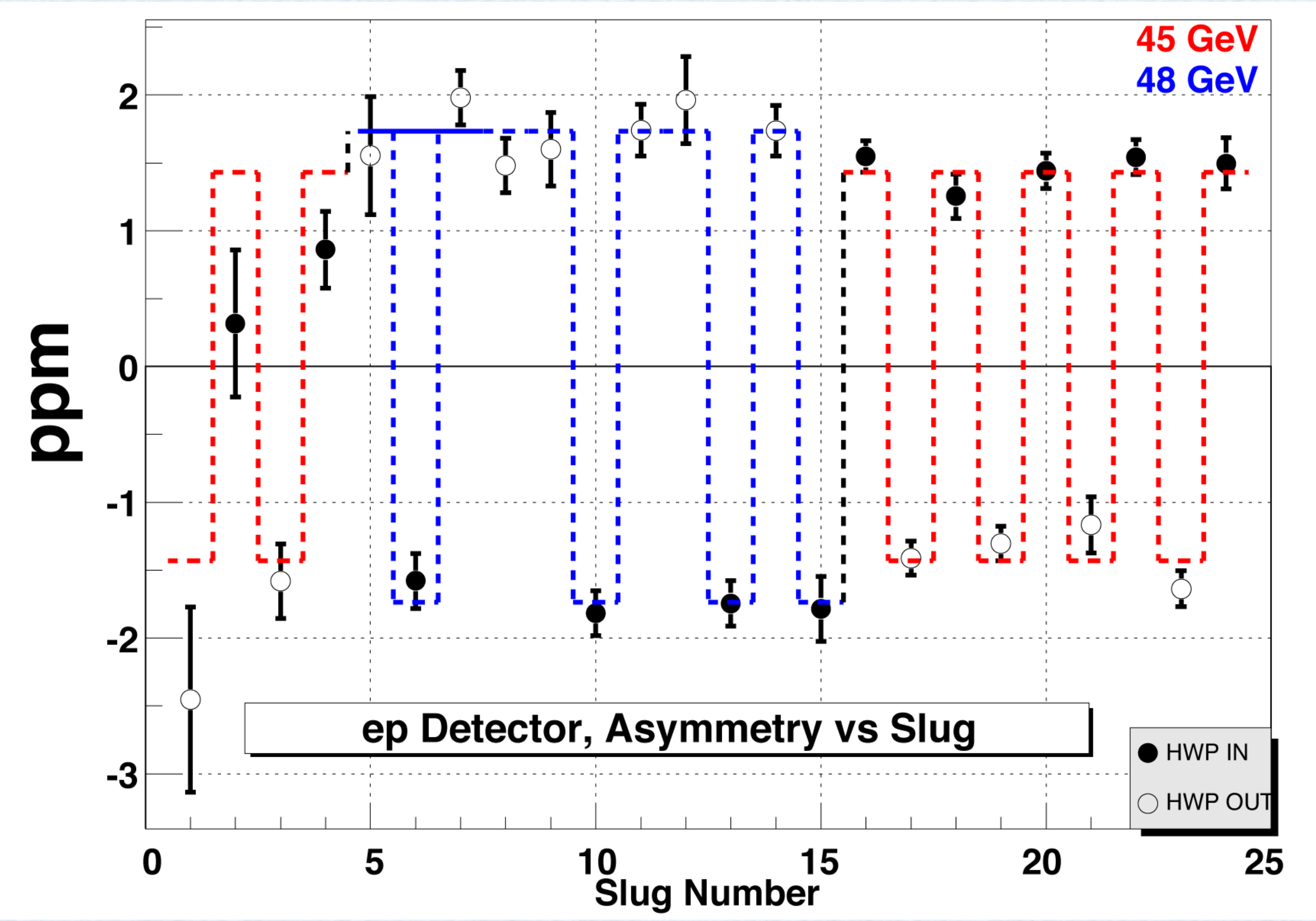

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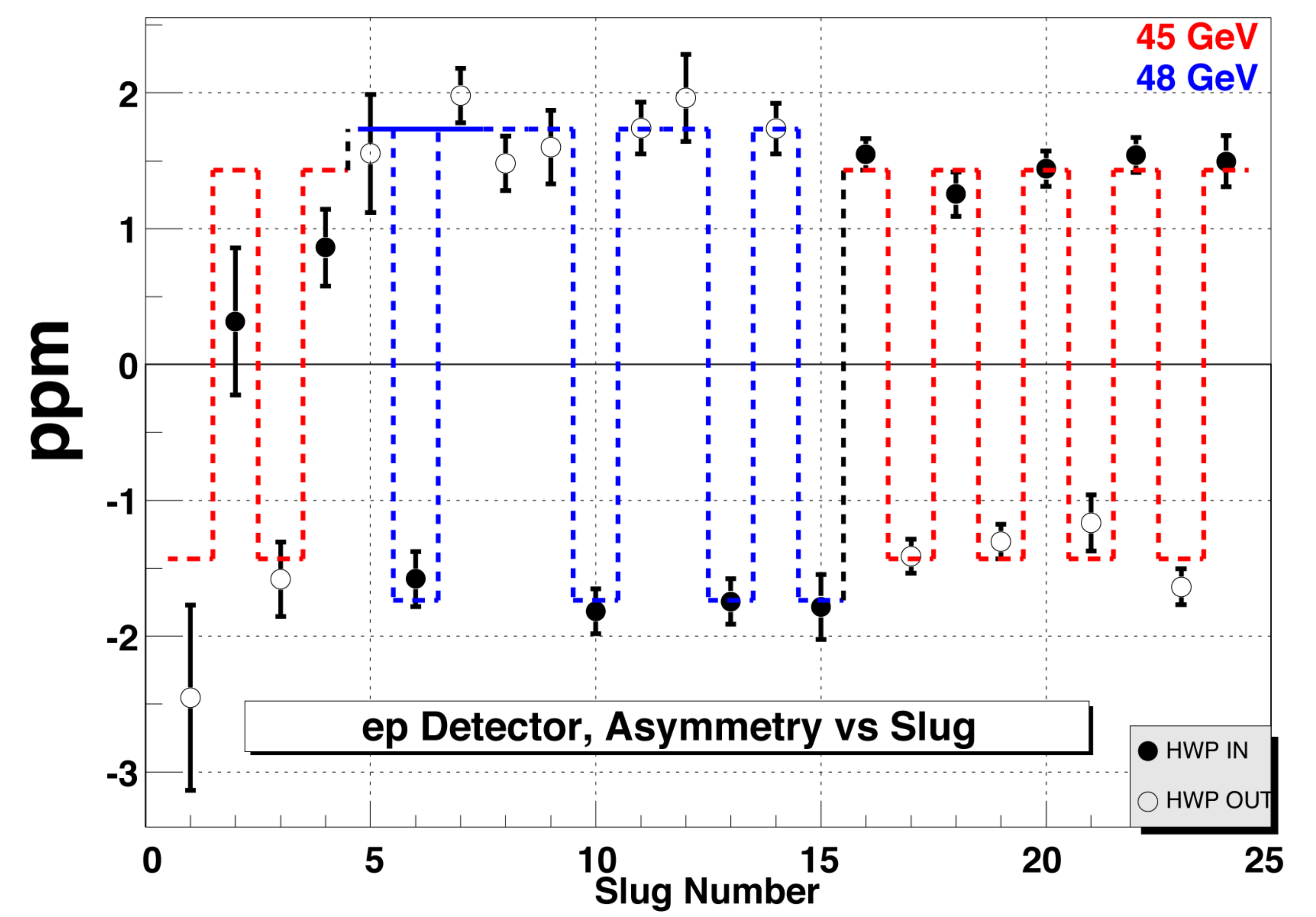

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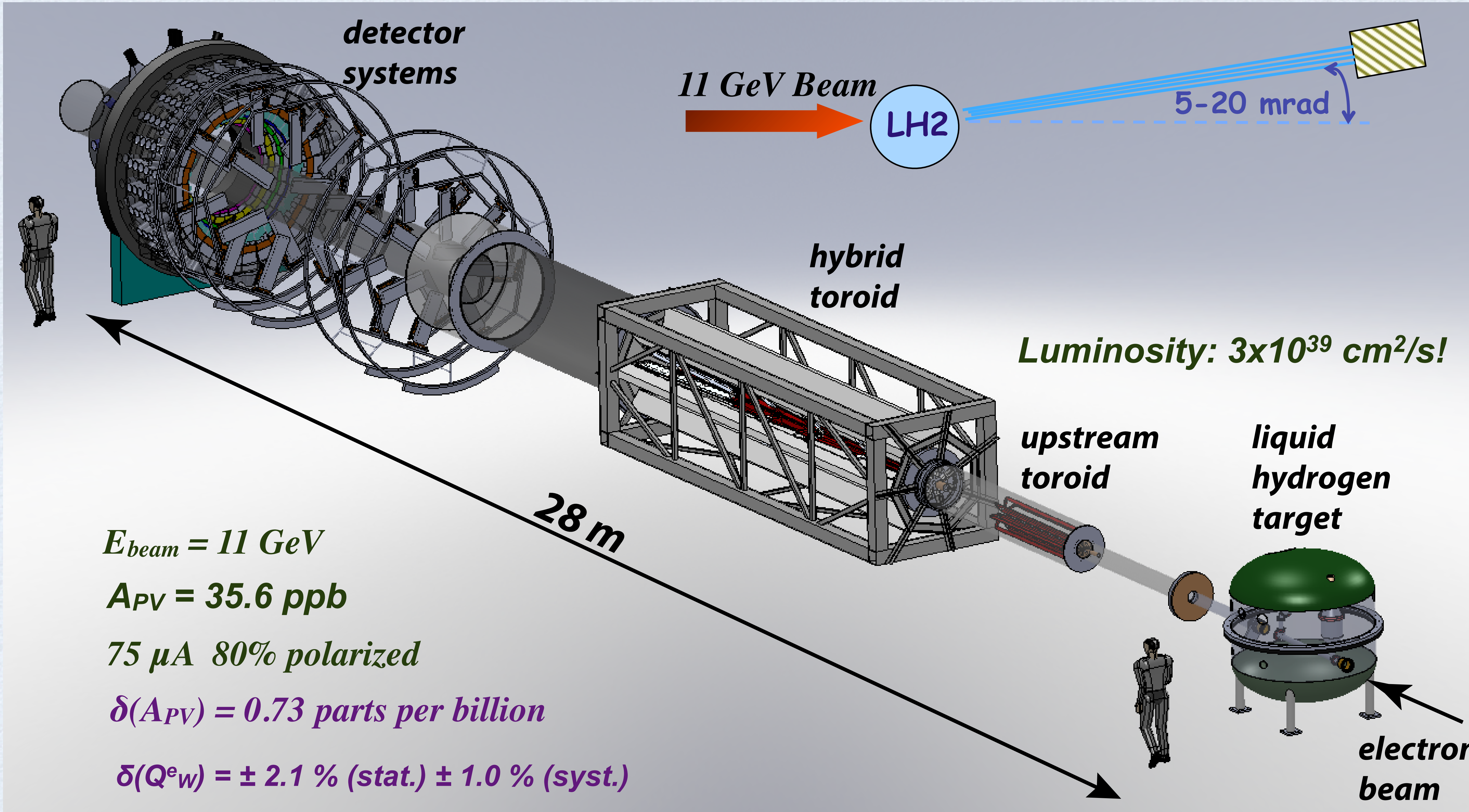
For JLab MOLLER, prediction is -4% +/- 0.4%:
want to achieve 10% correction error

MOLLER @ JLab

An ultra-precise measurement of the weak mixing angle using Møller scattering



E_{beam} = 11 GeV

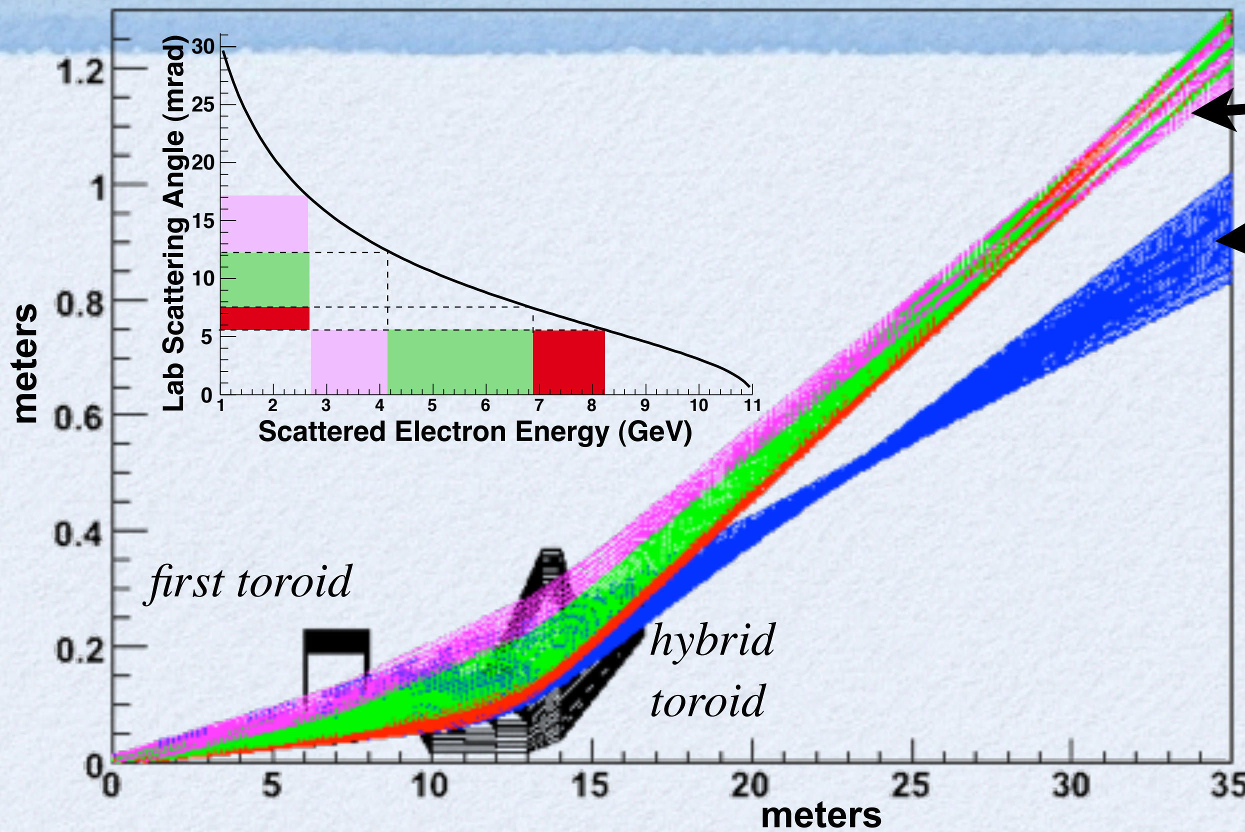
A_{PV} = 35.6 ppb

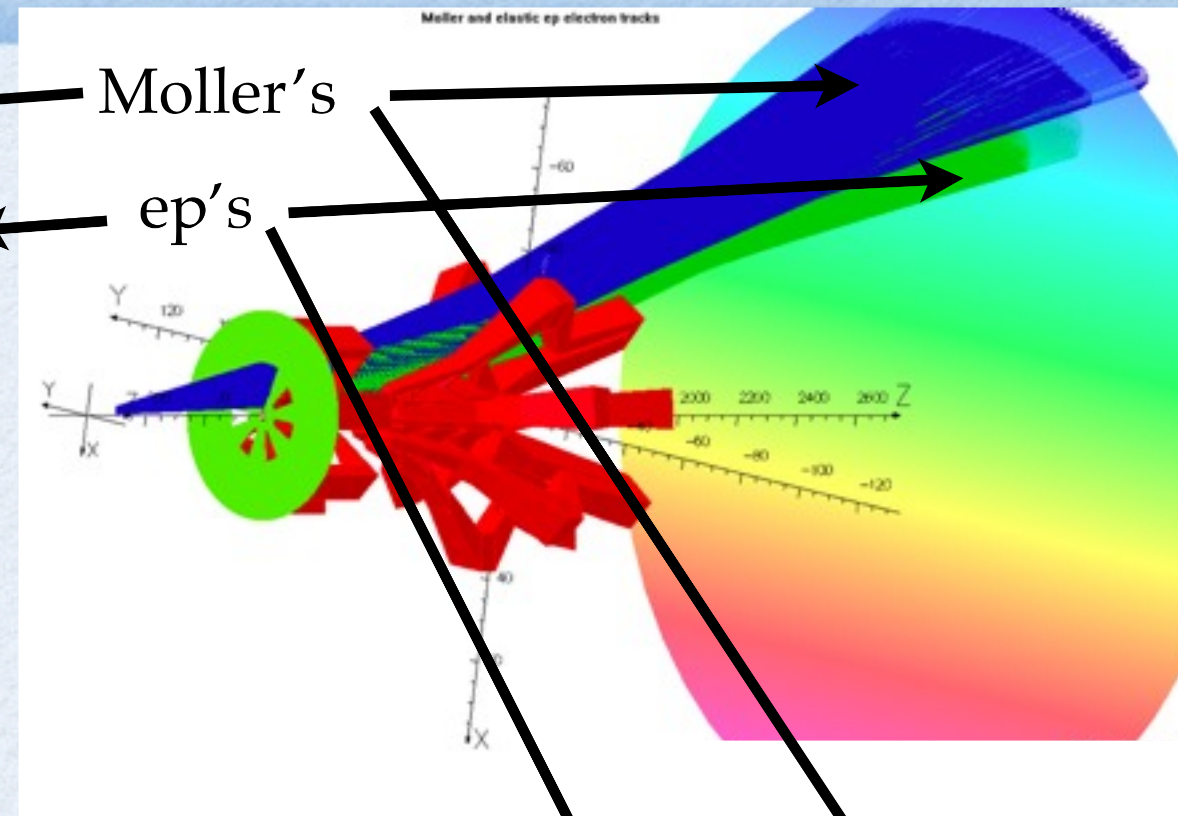
75 μA 80% polarized

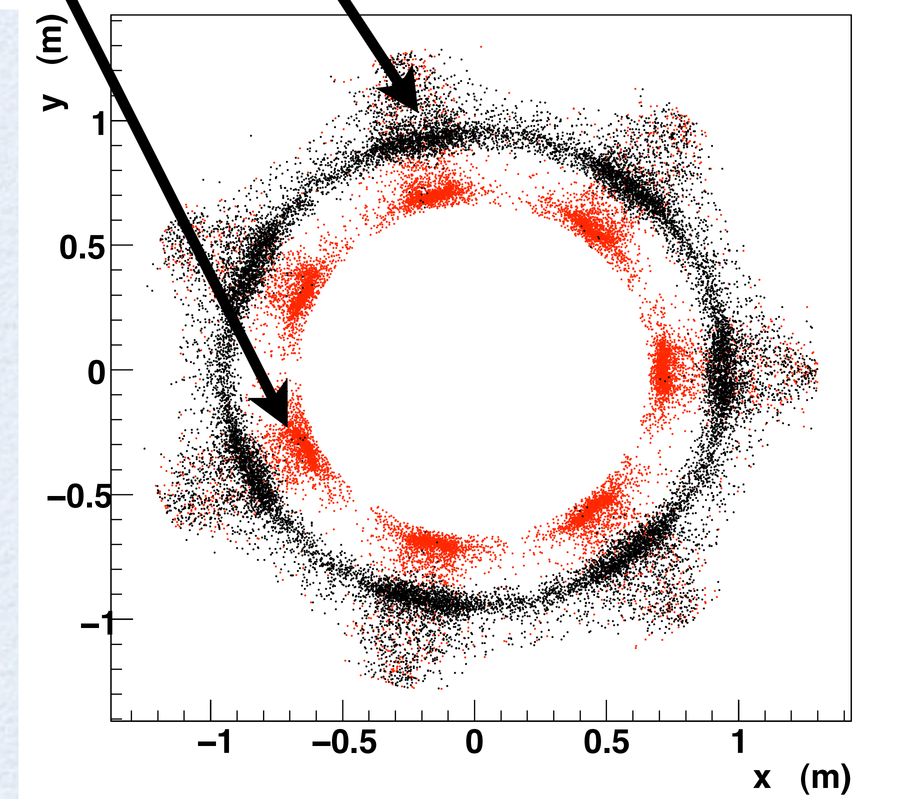
$\delta(A_{PV})$ = 0.73 parts per billion

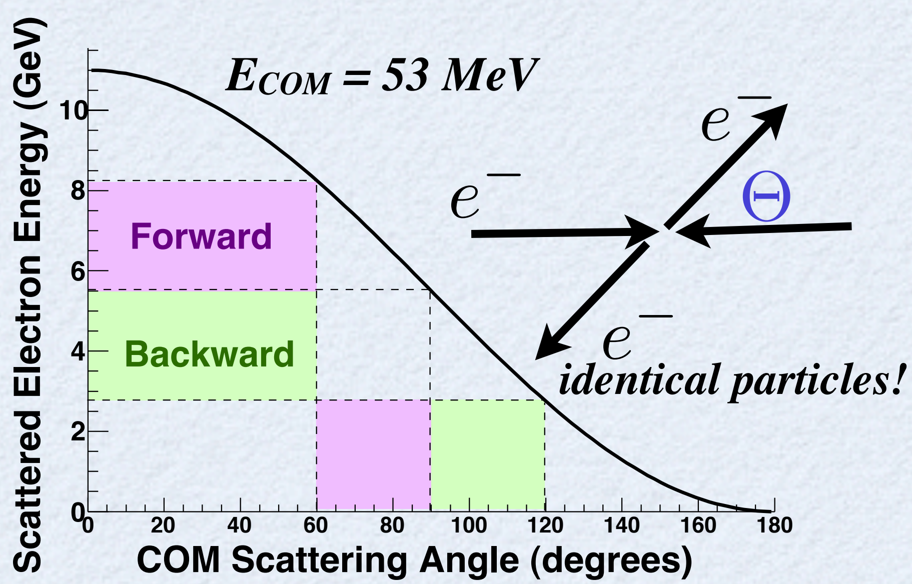
$\delta(Q^e_W) = \pm 2.1\,\%$ (stat.) $\pm 1.0\,\%$ (syst.)

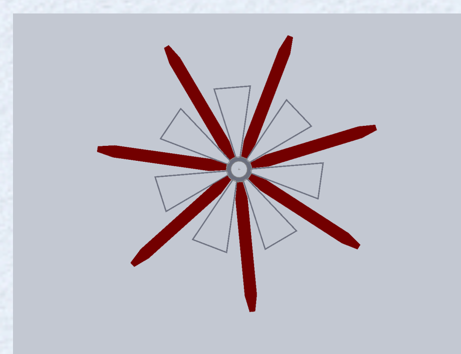
Spectrometer Concept











odd number of coils:
100% azimuthal acceptance

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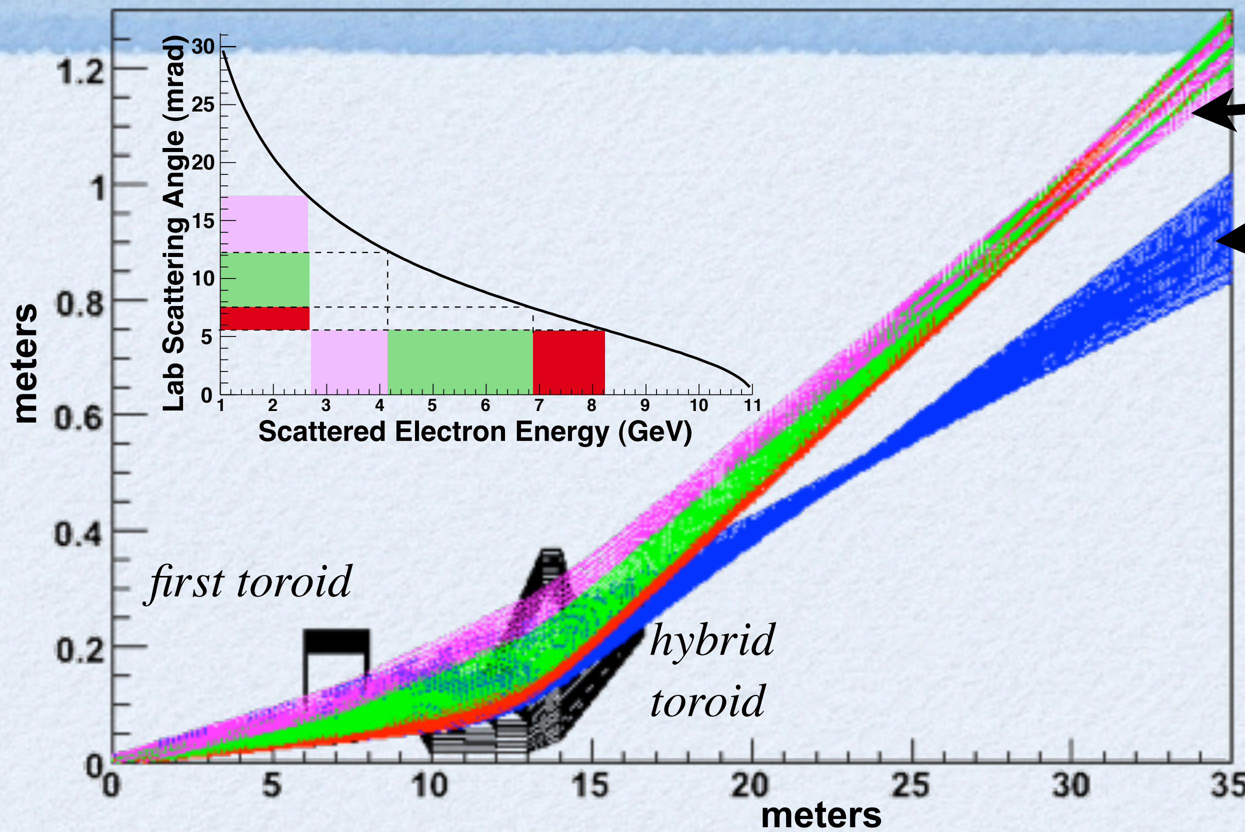

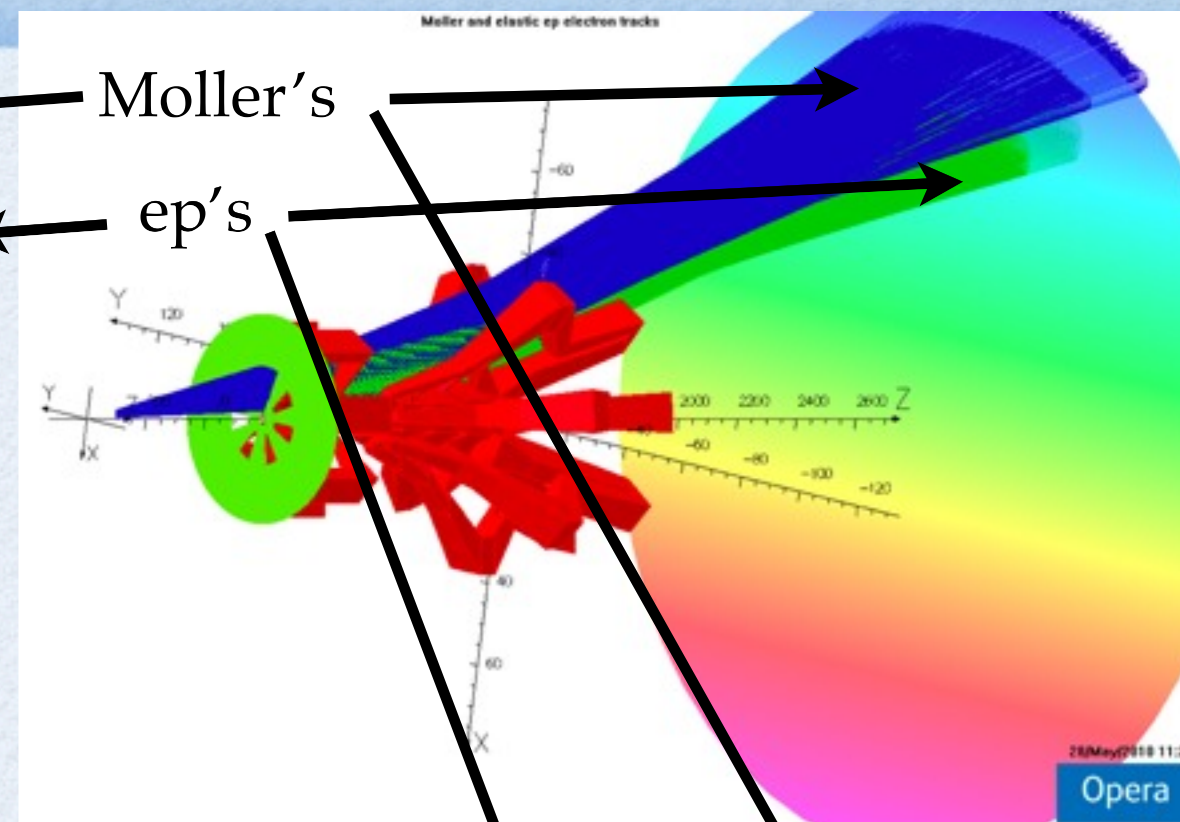

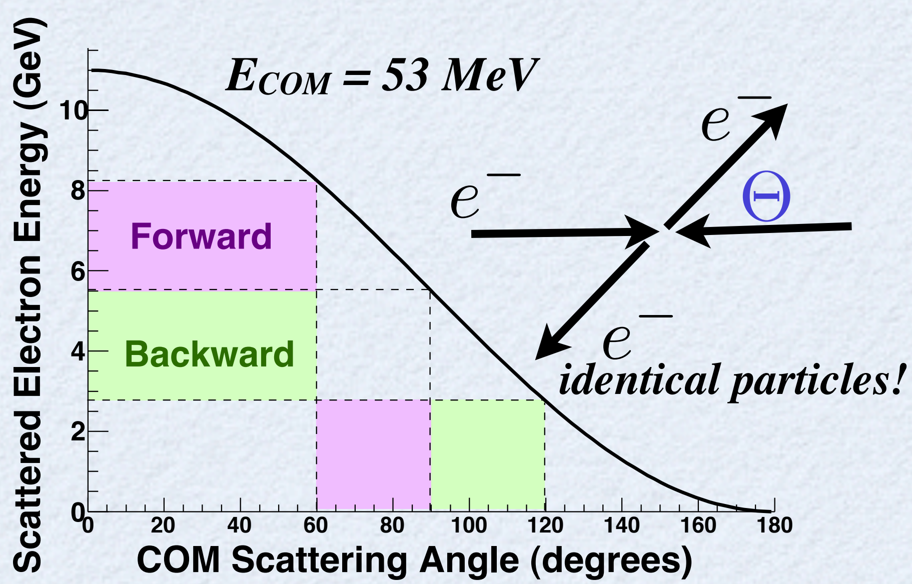

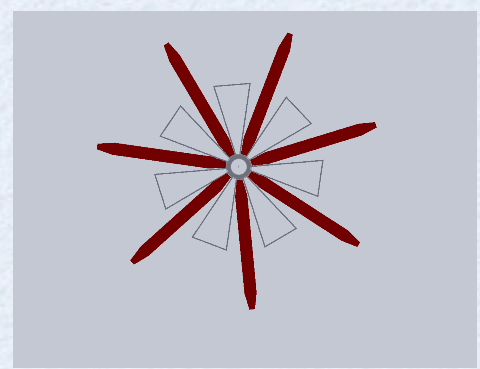

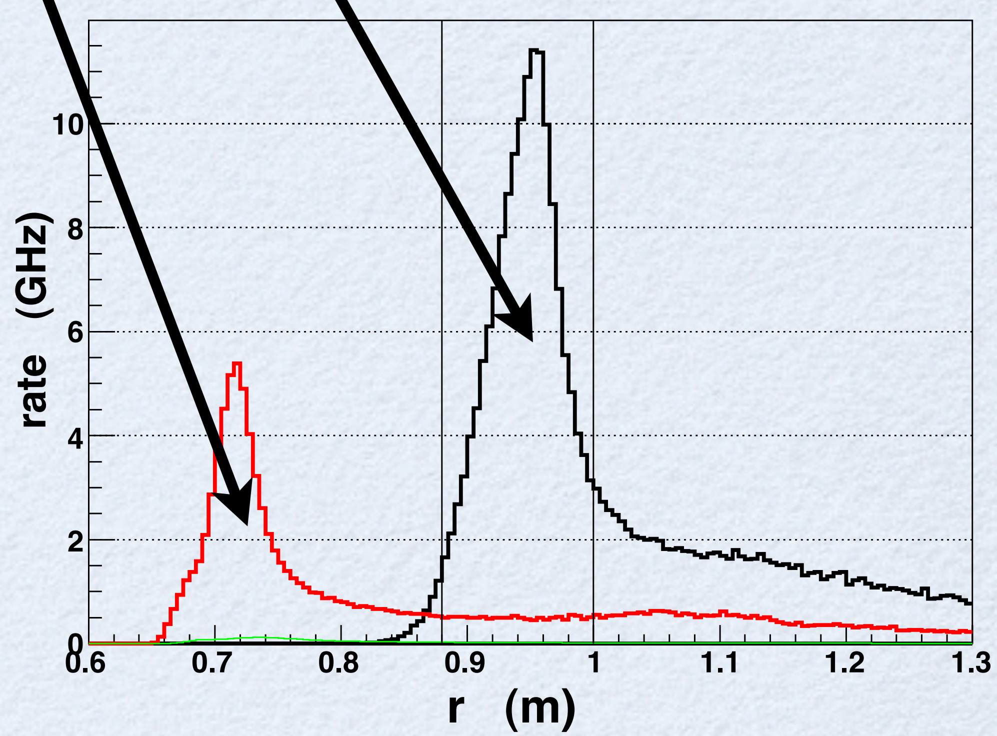

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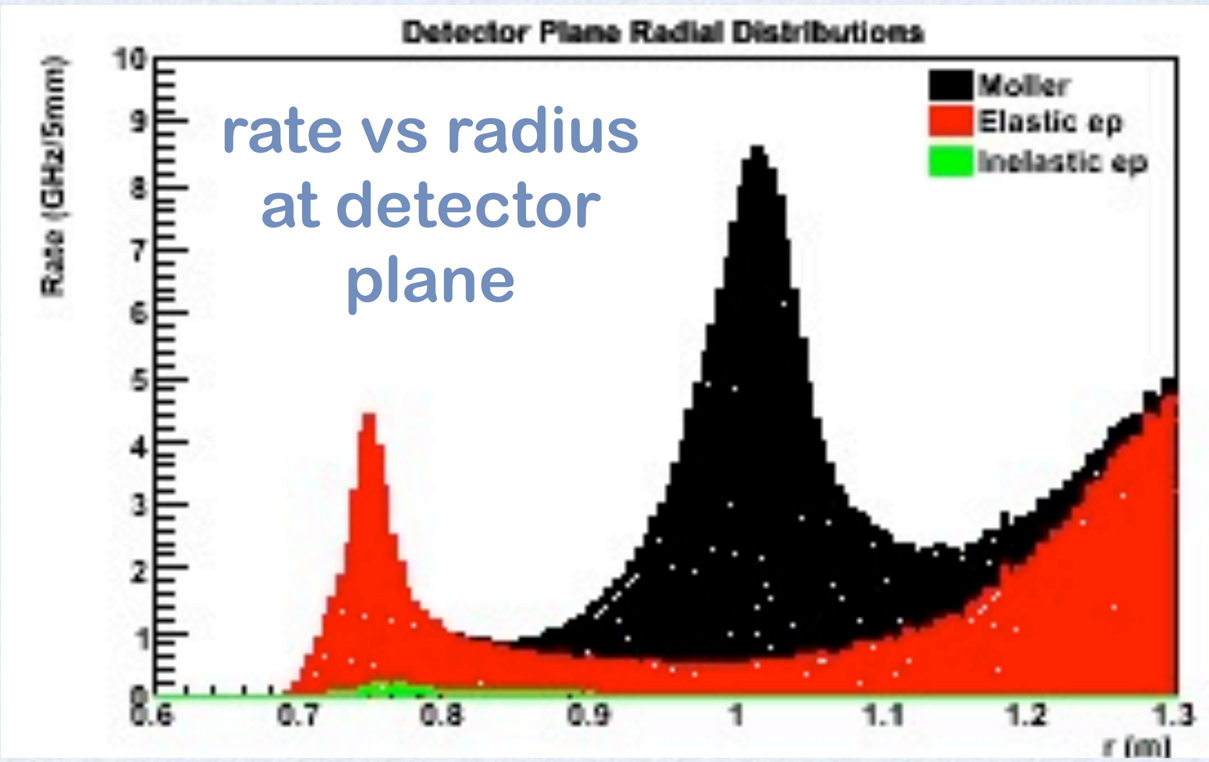
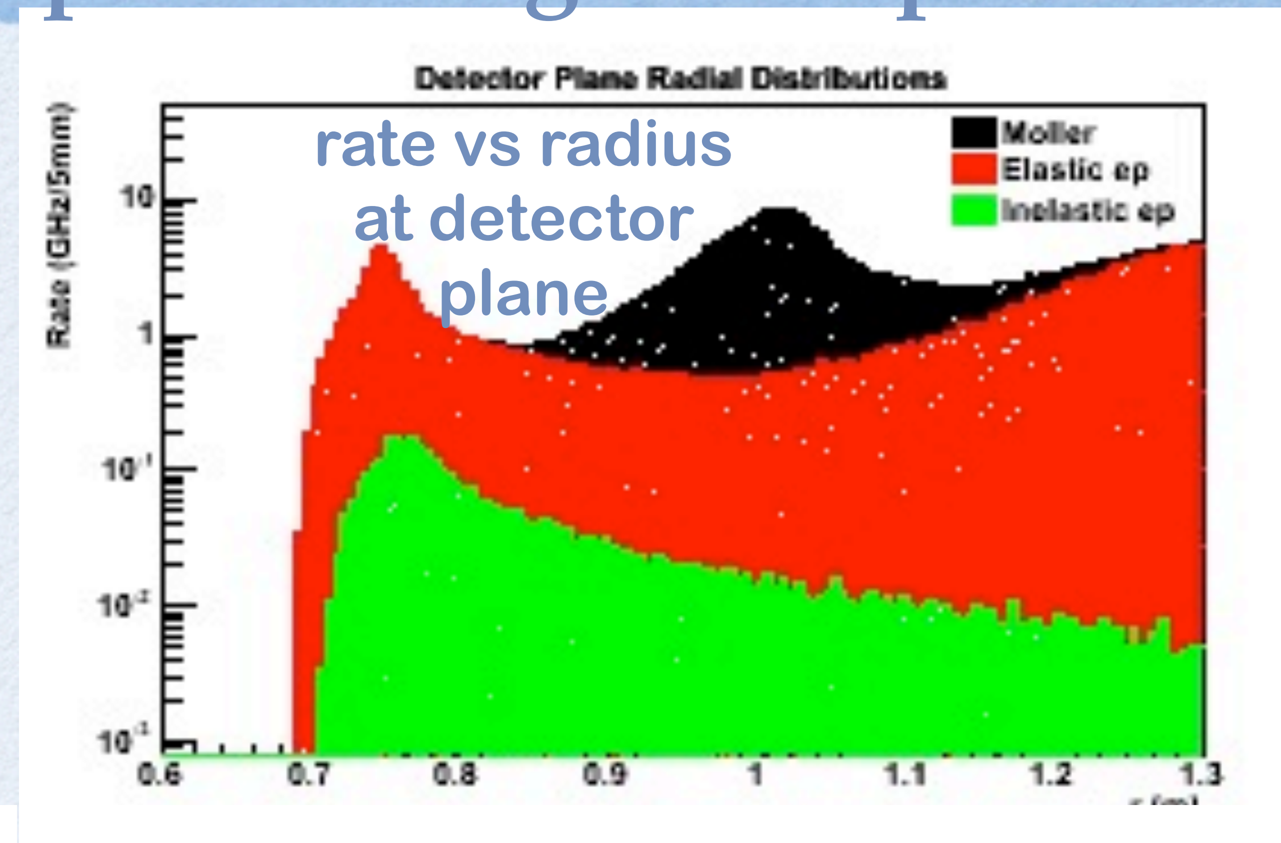
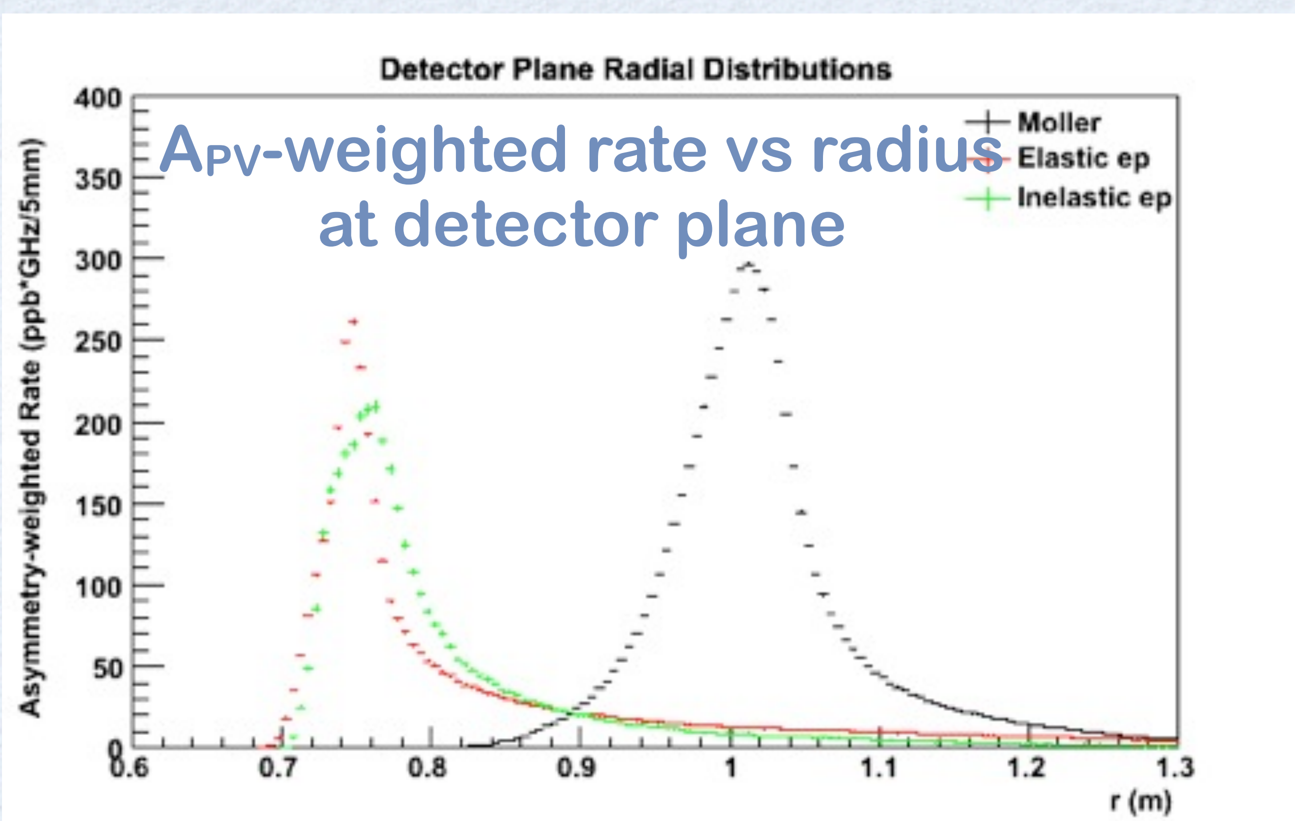
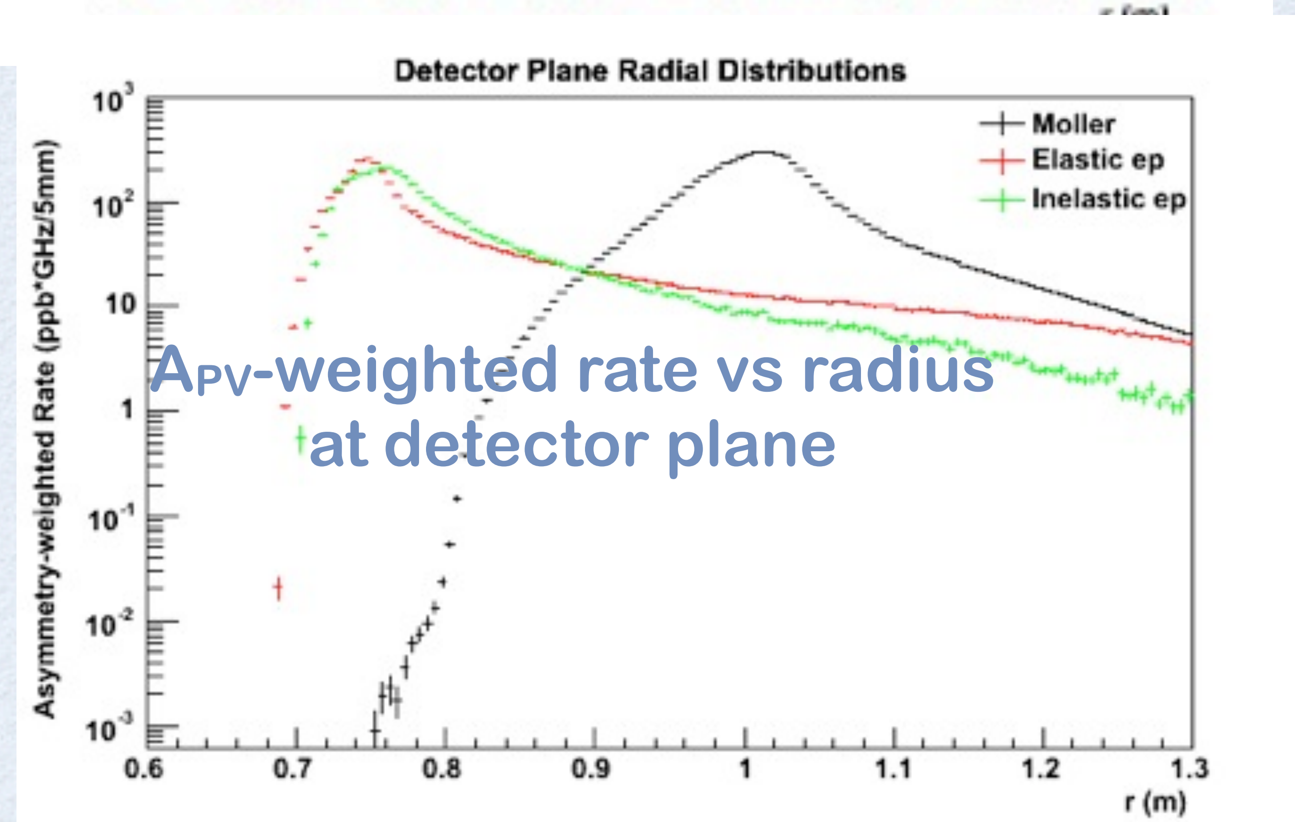
Radial Distributions

both elastic and inelastic ep scattering are important









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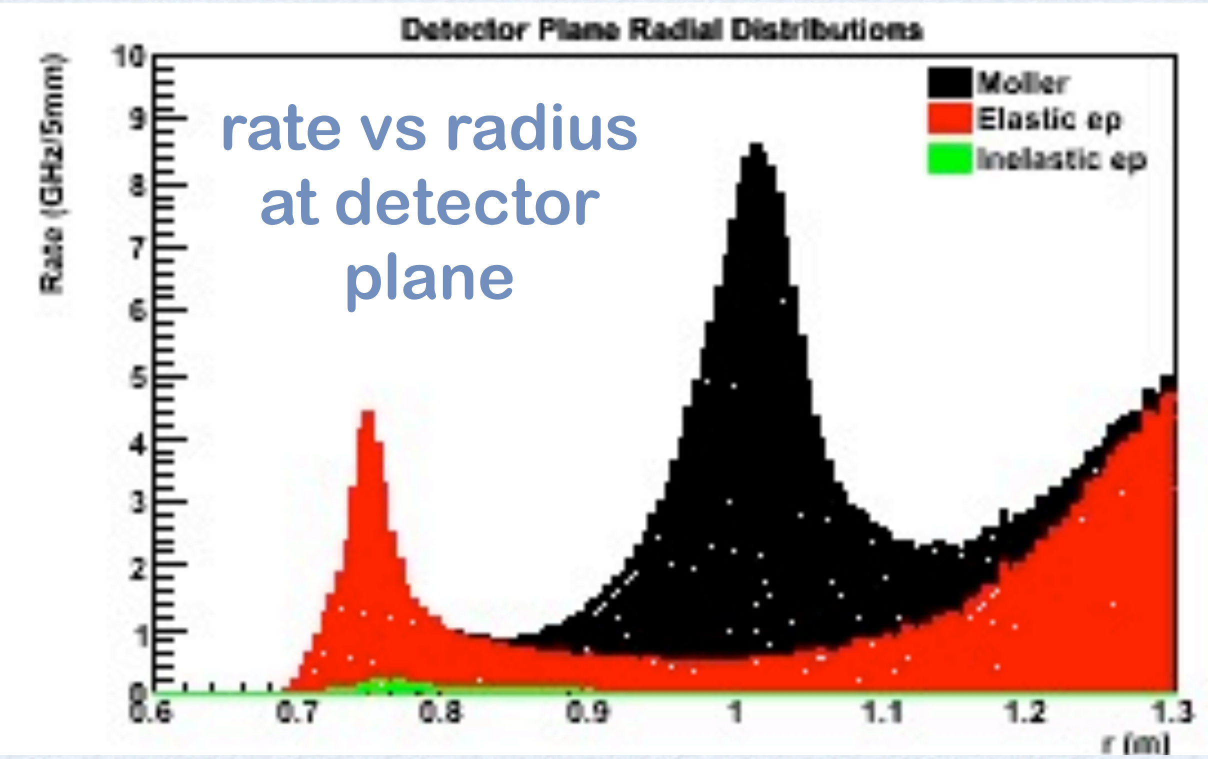
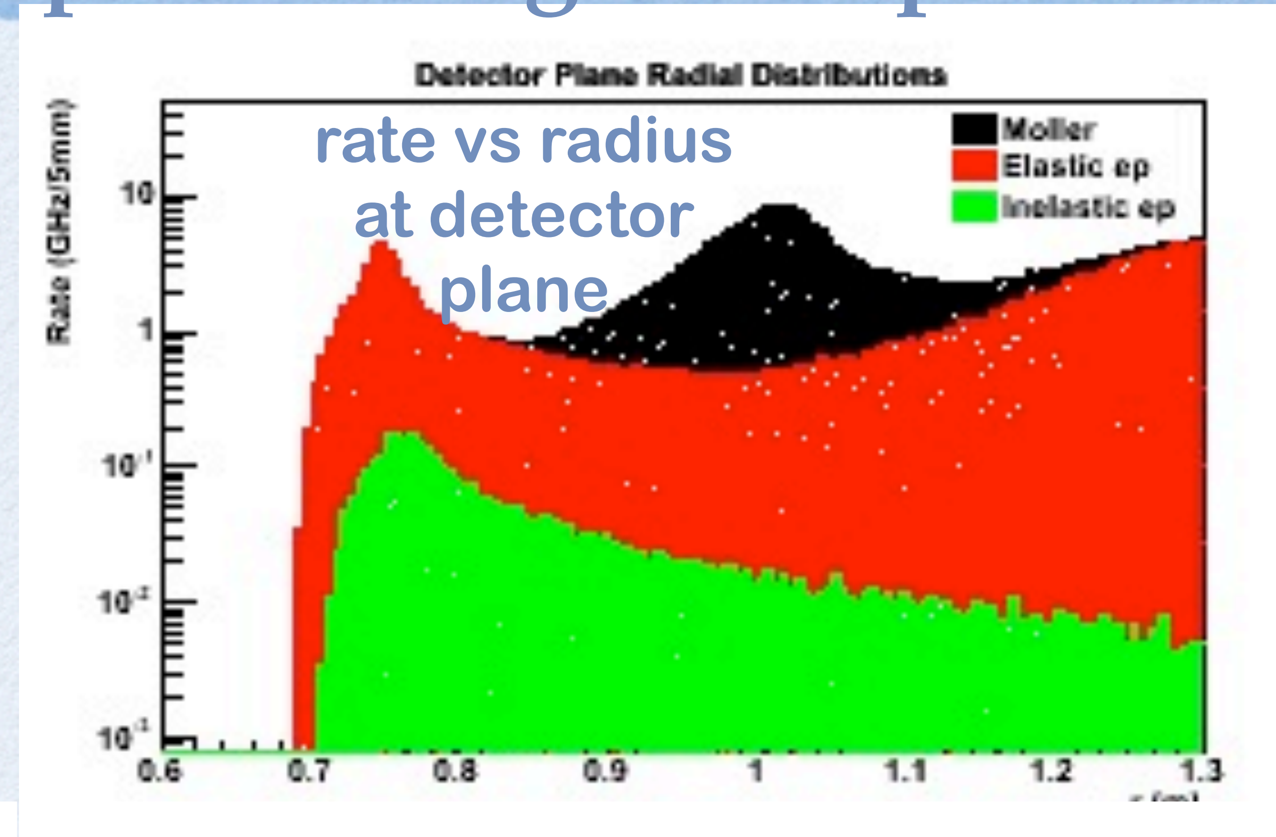
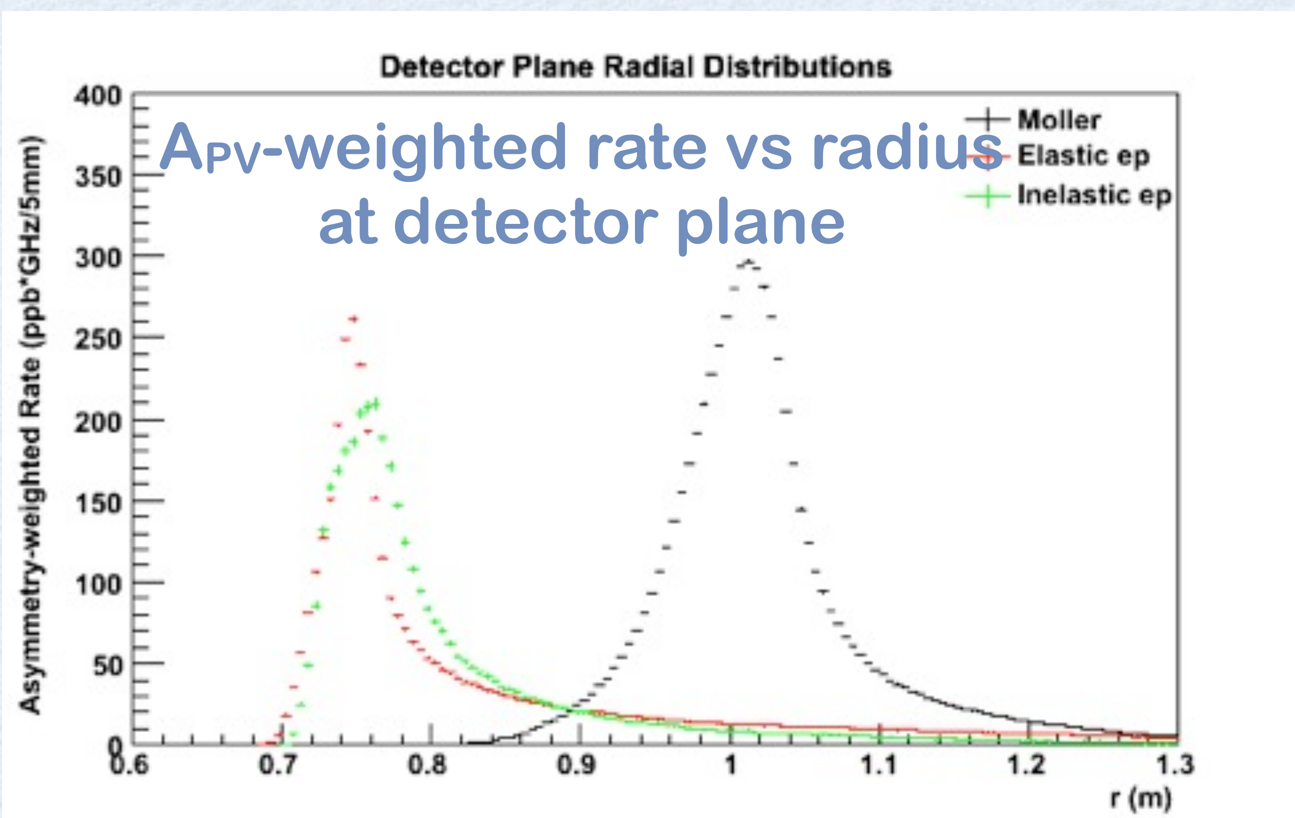
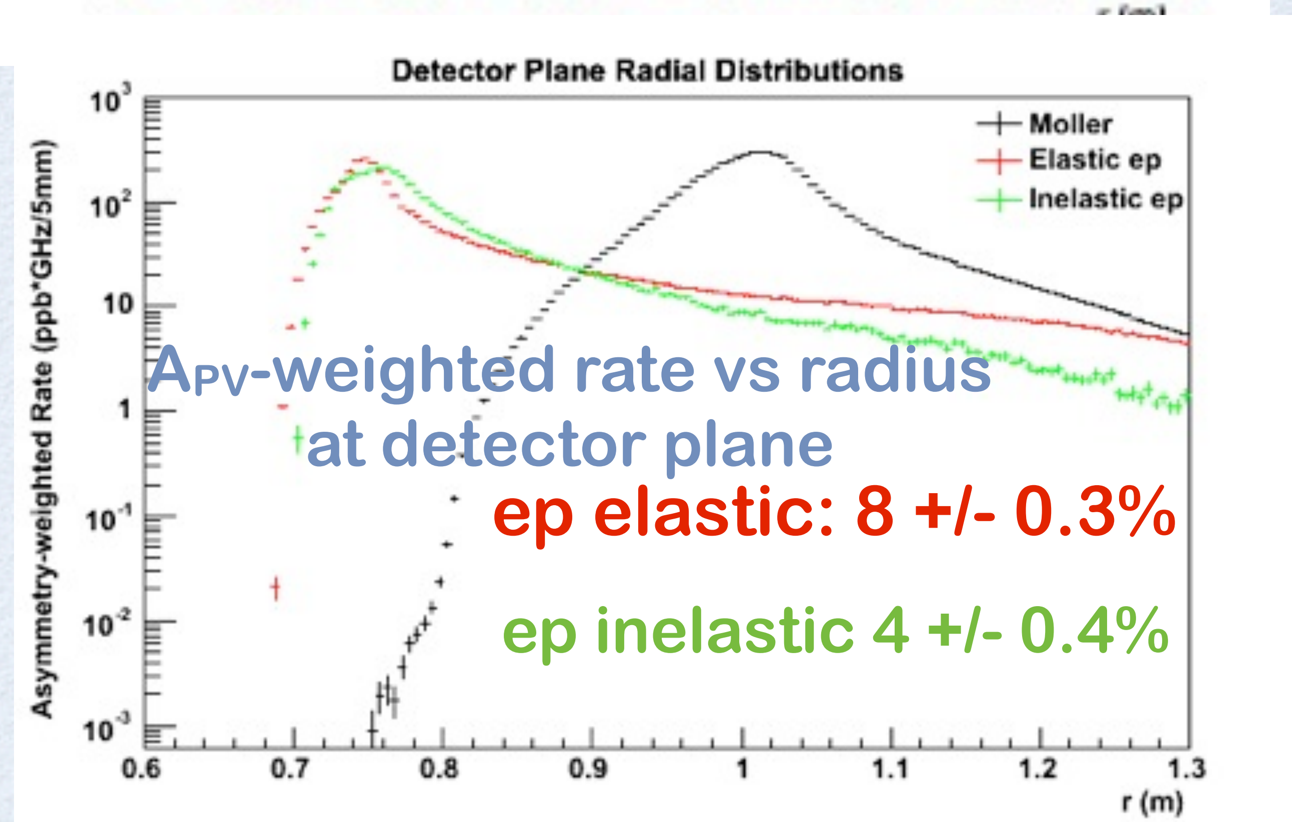
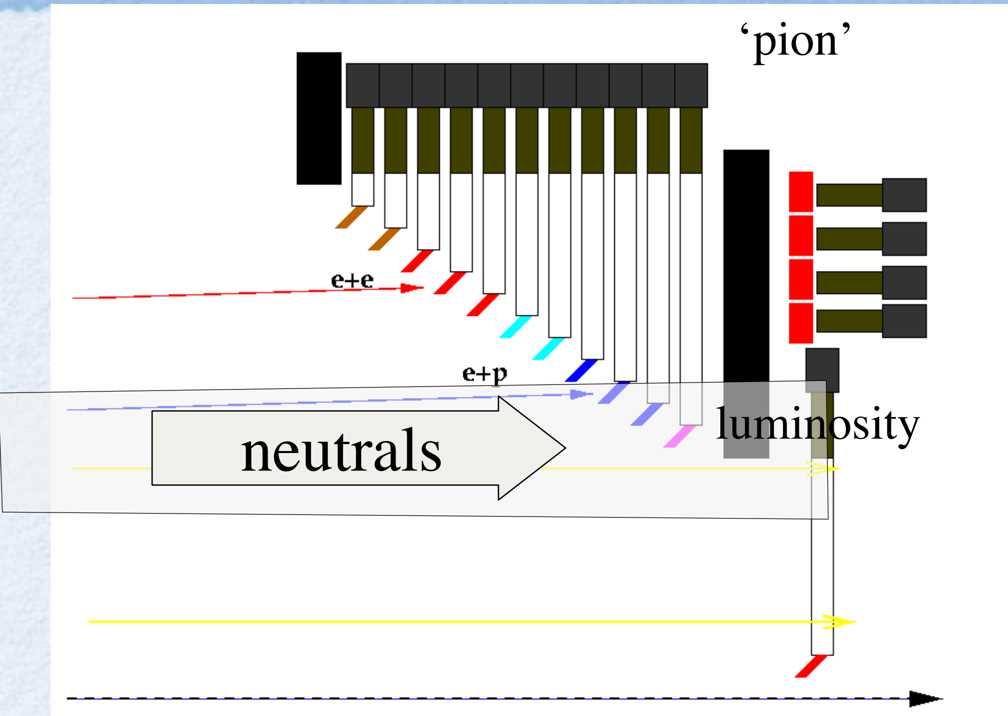


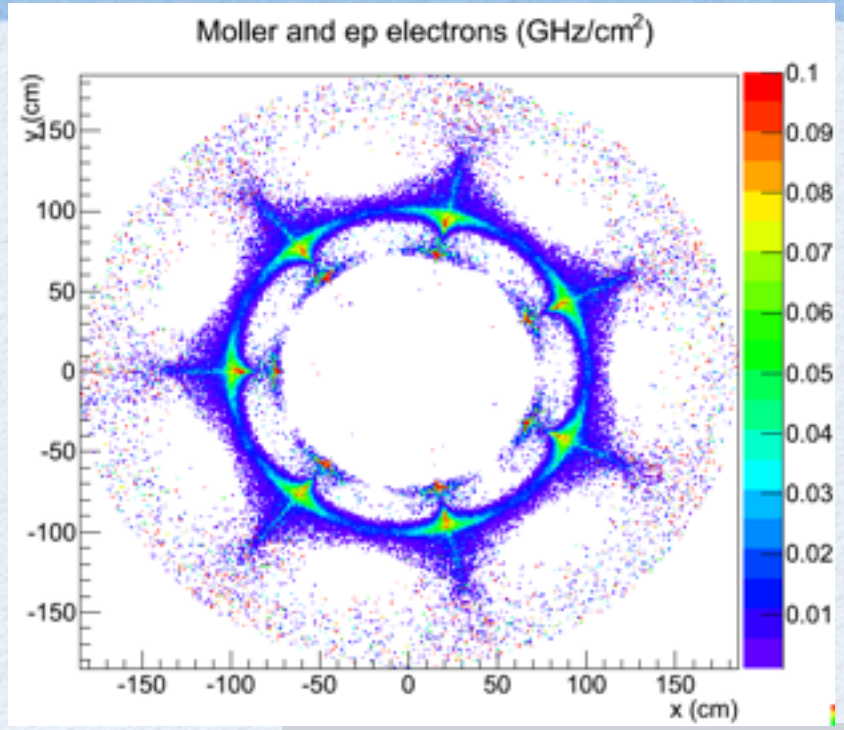


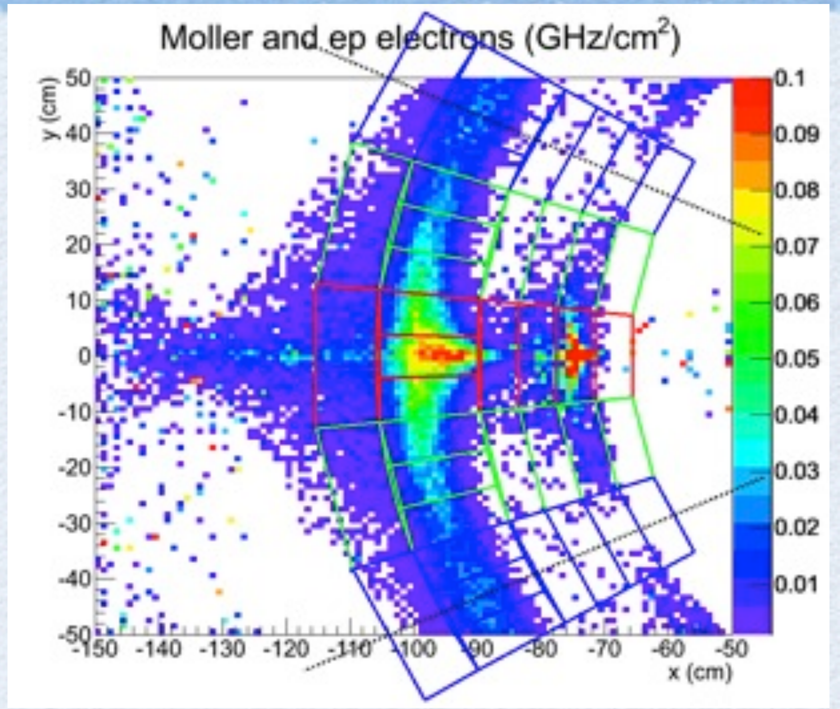




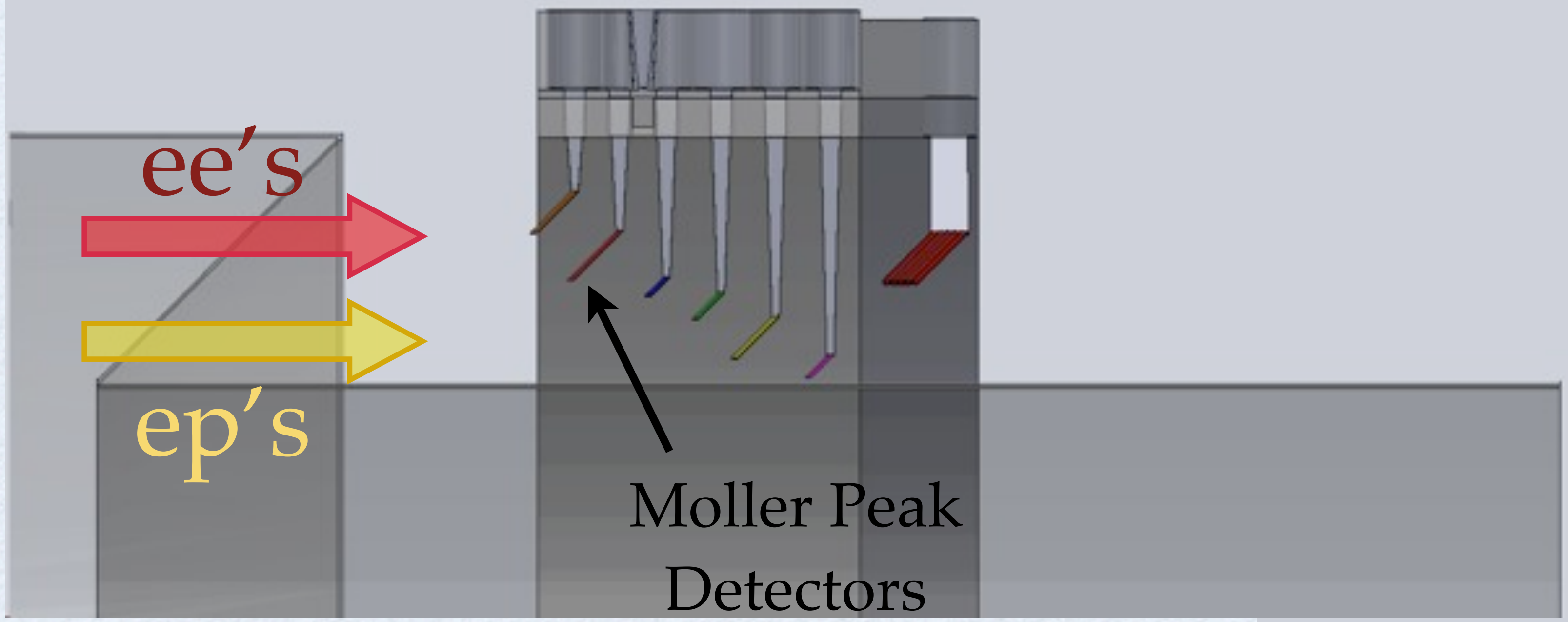
Detector Systems

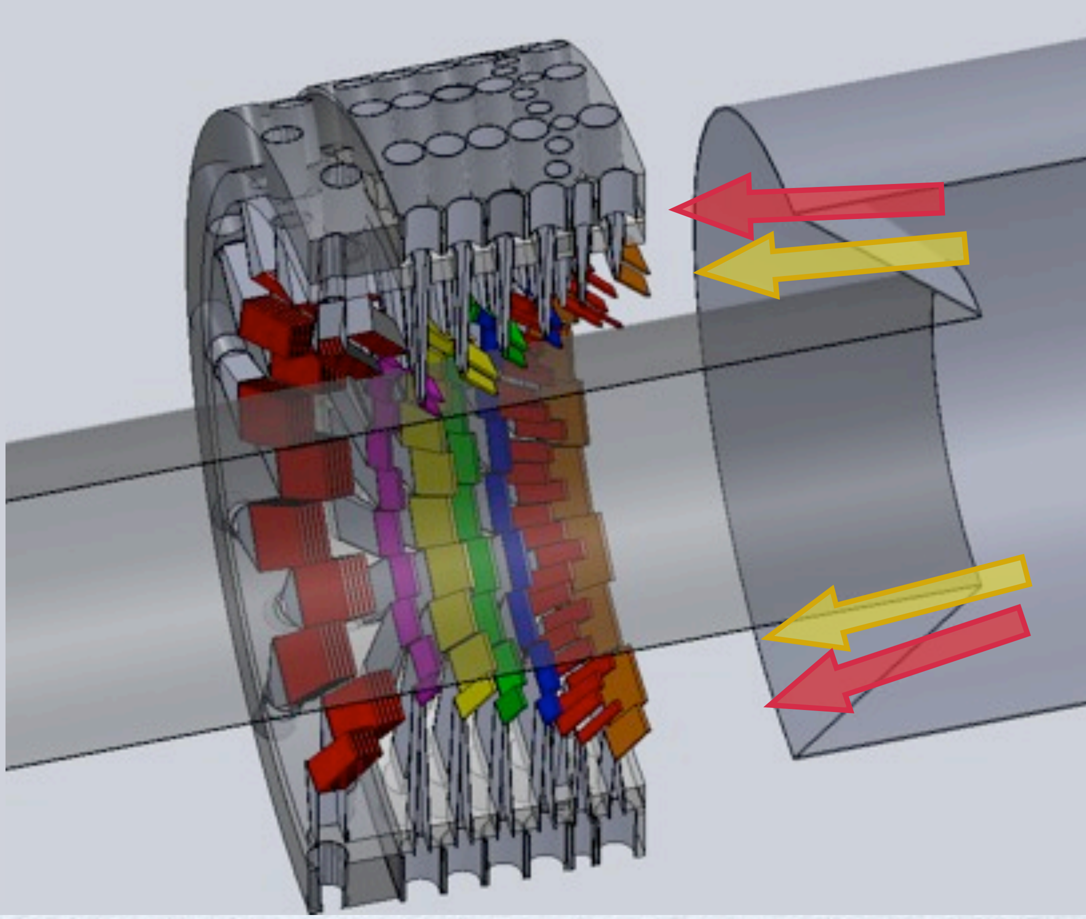






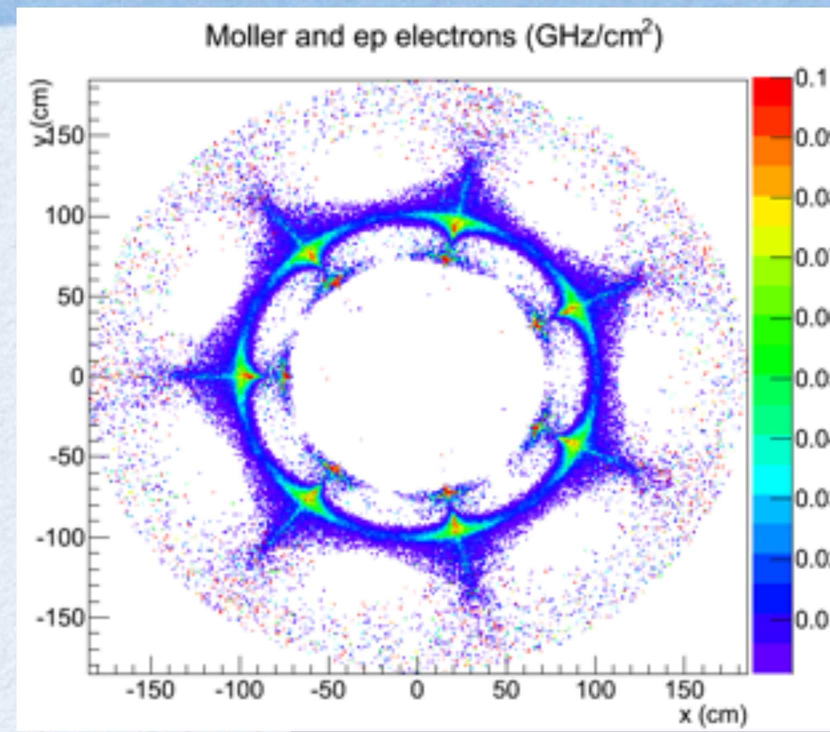
optimized for robust background subtraction

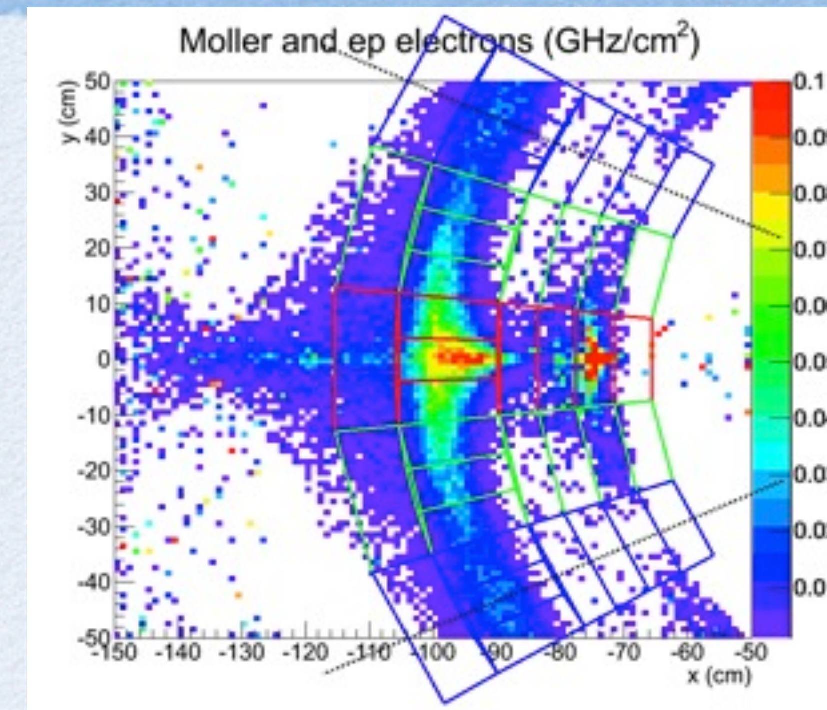




Detector Systems

- **Integrating Detectors:**
  - Moller and e-p Electrons:
    - *radial and azimuthal segmentation*
    - *quartz with air lightguides & PMTs*
  - pions and muons:
    - *quartz sandwich behind shielding*
  - luminosity monitors
    - *beam & target density fluctuations*





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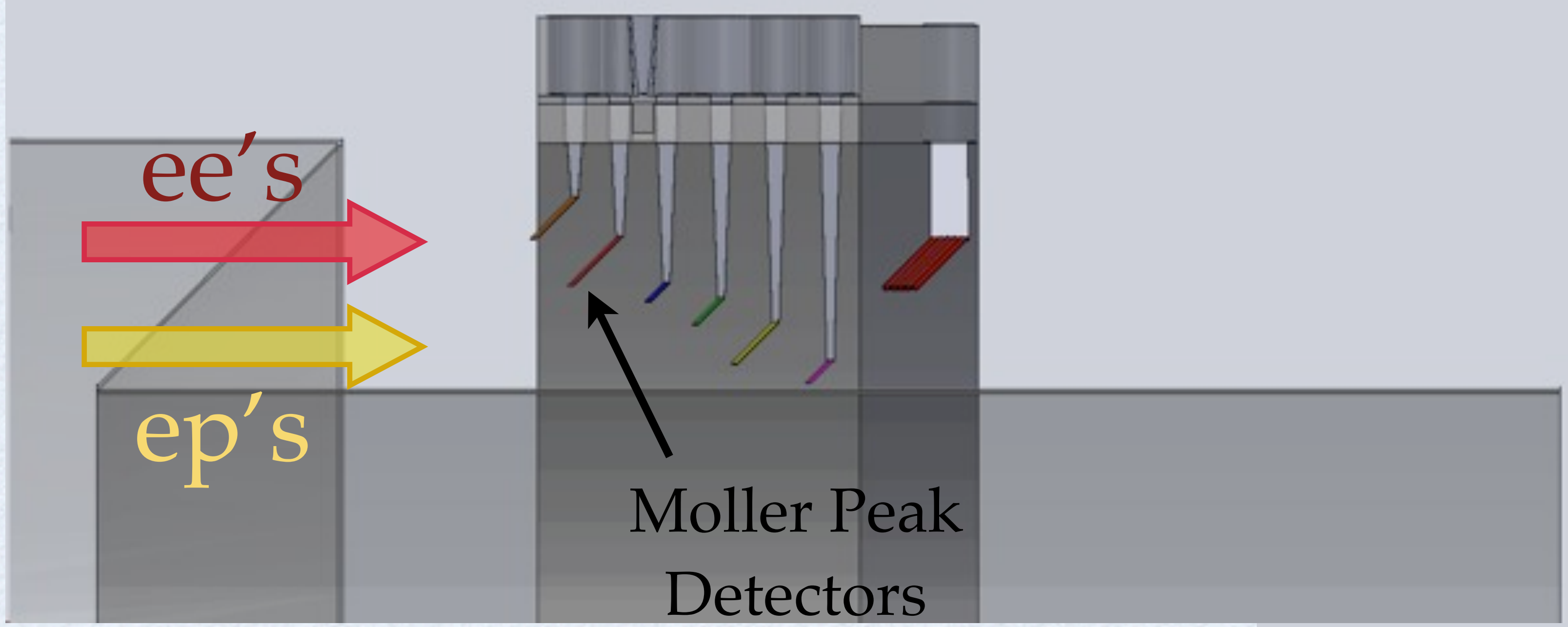

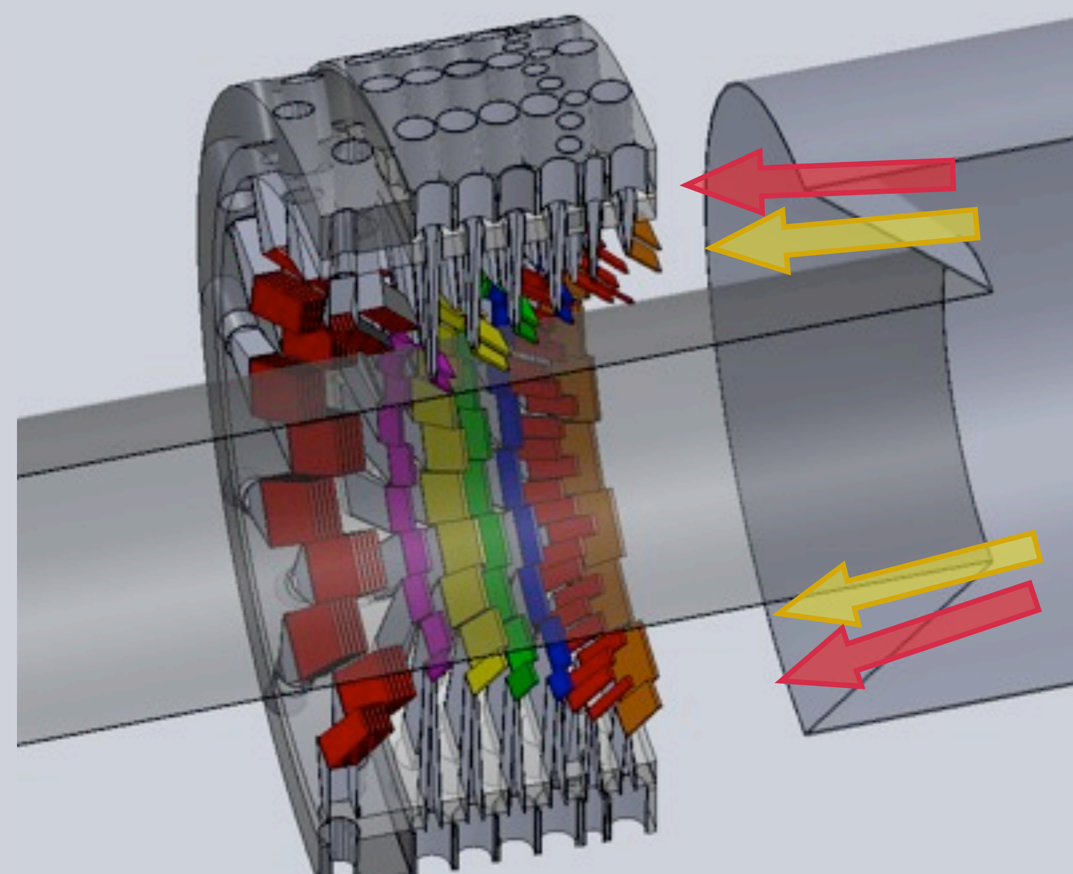

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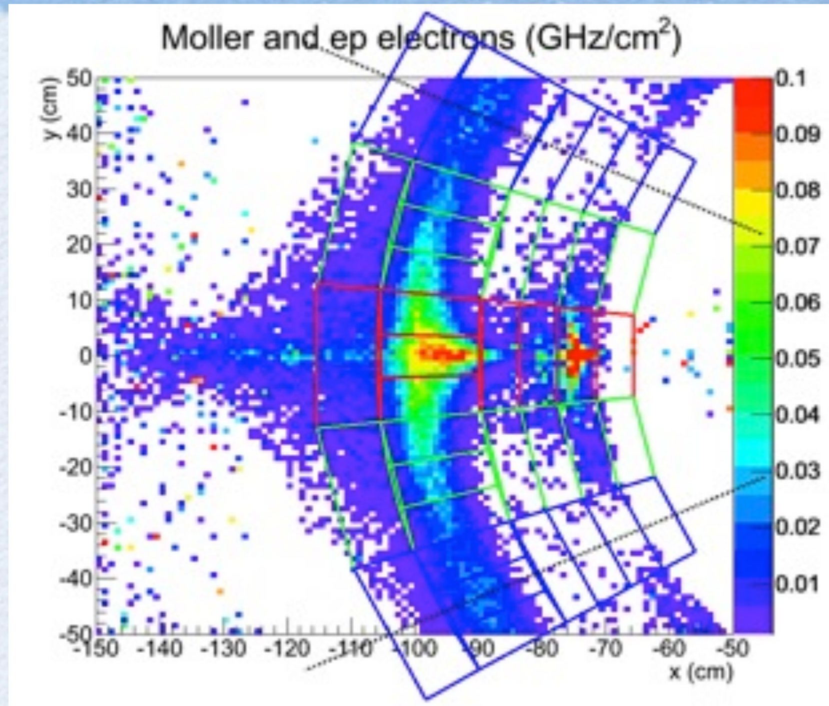
- Auxiliary Detectors
  - **Tracking detectors**
    - *3 planes of GEMs/Straws*
    - *Critical for systematics/ calibration/debugging*
  - **Integrating Scanners**
    - *quick checks on stability*



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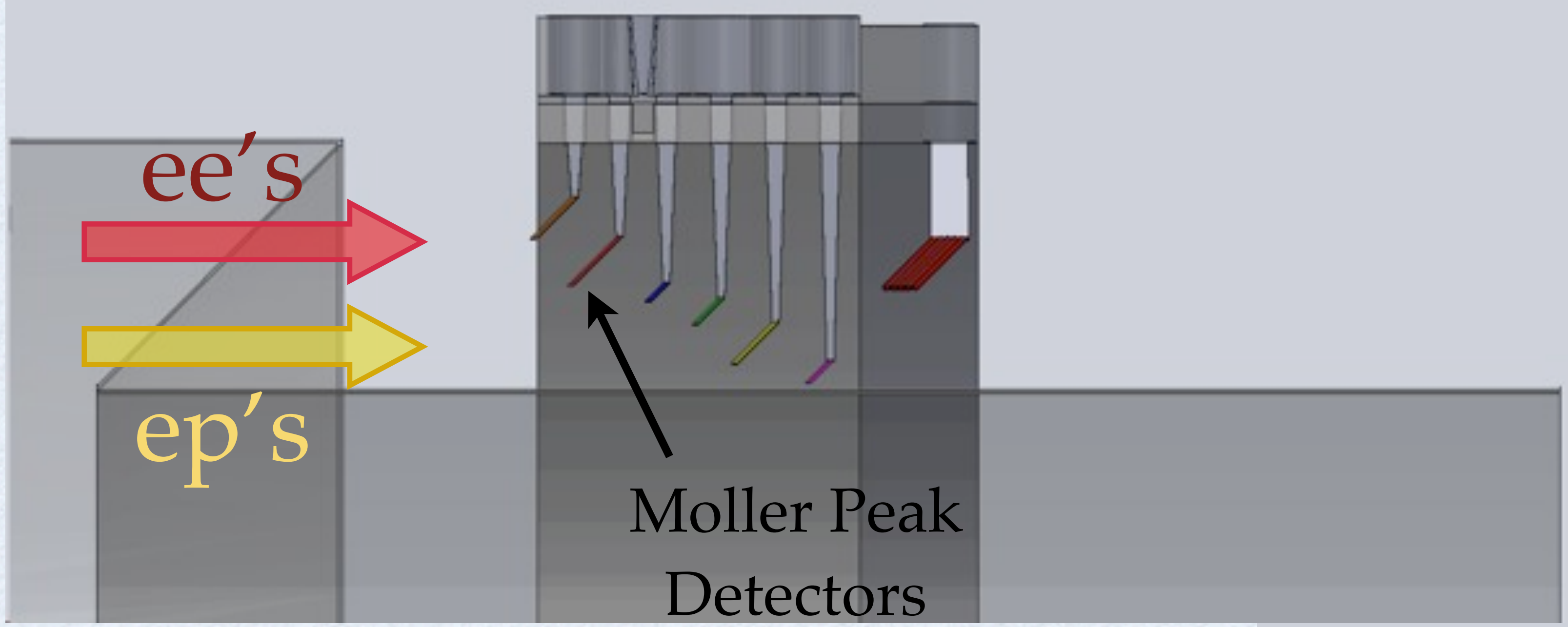
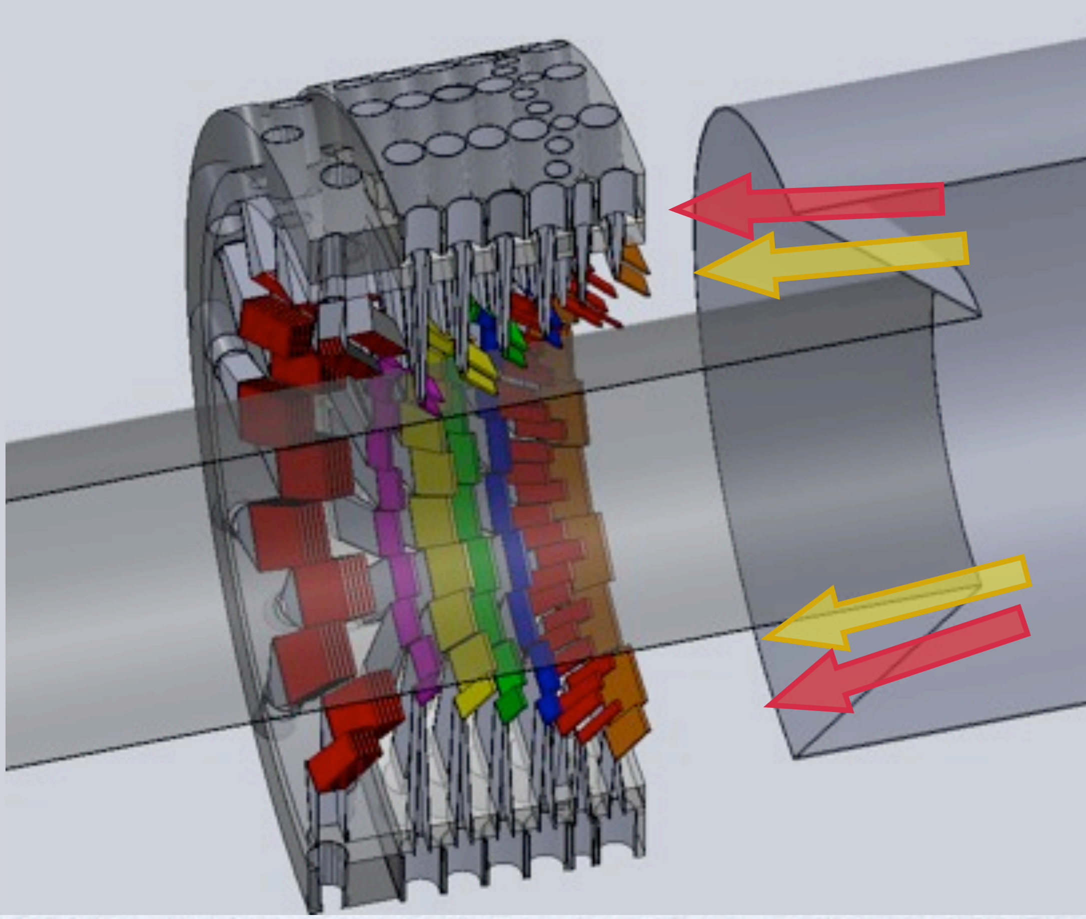
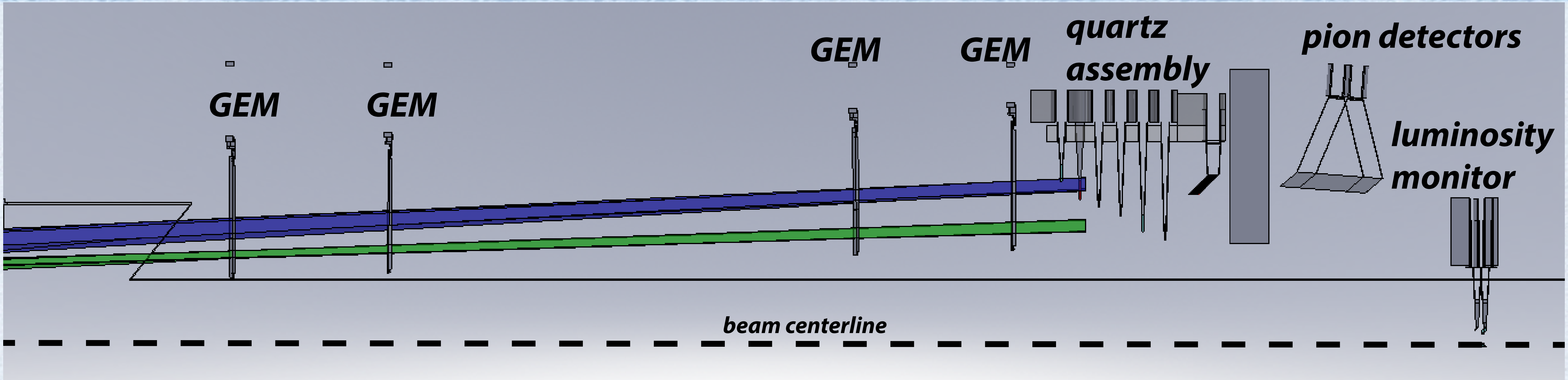
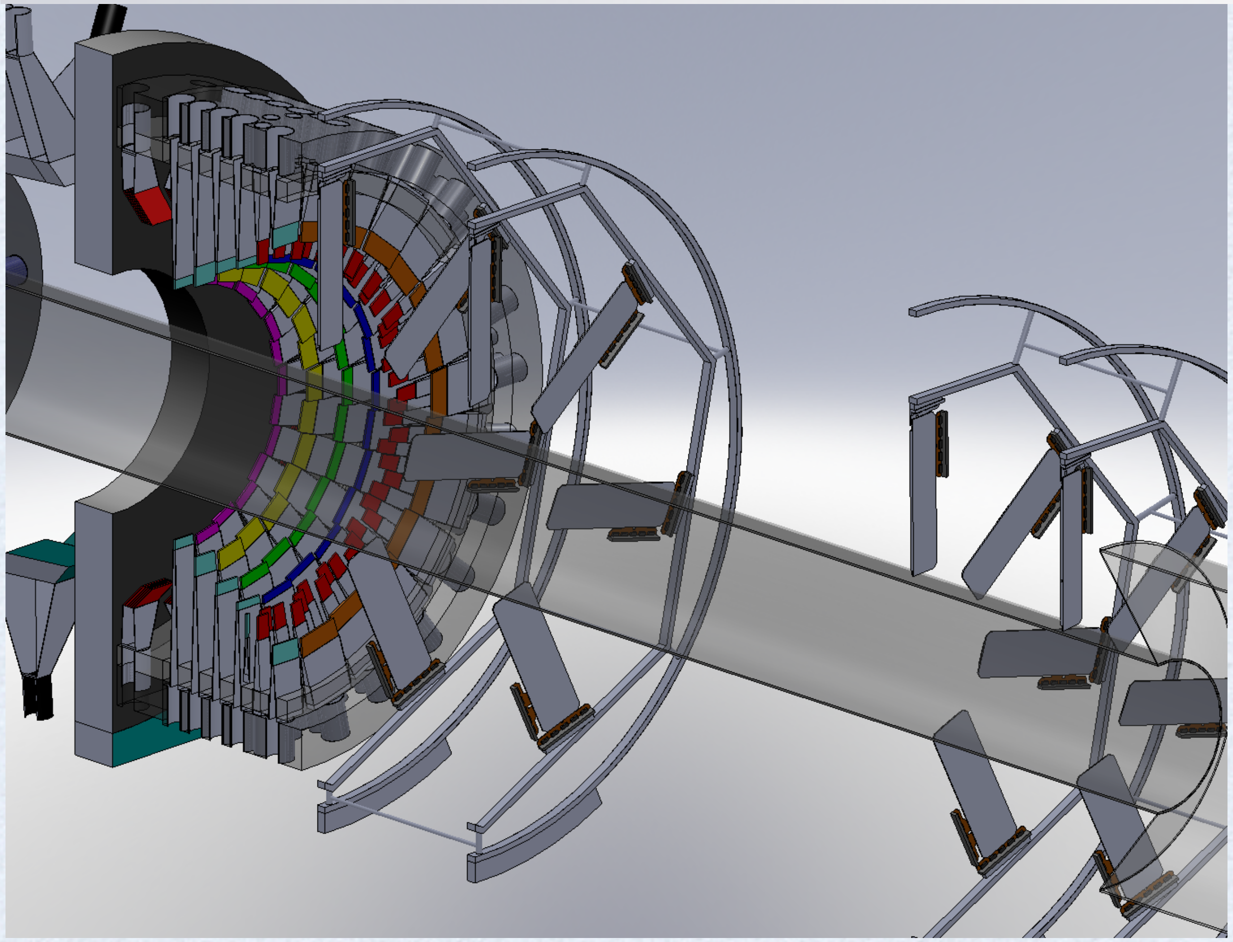
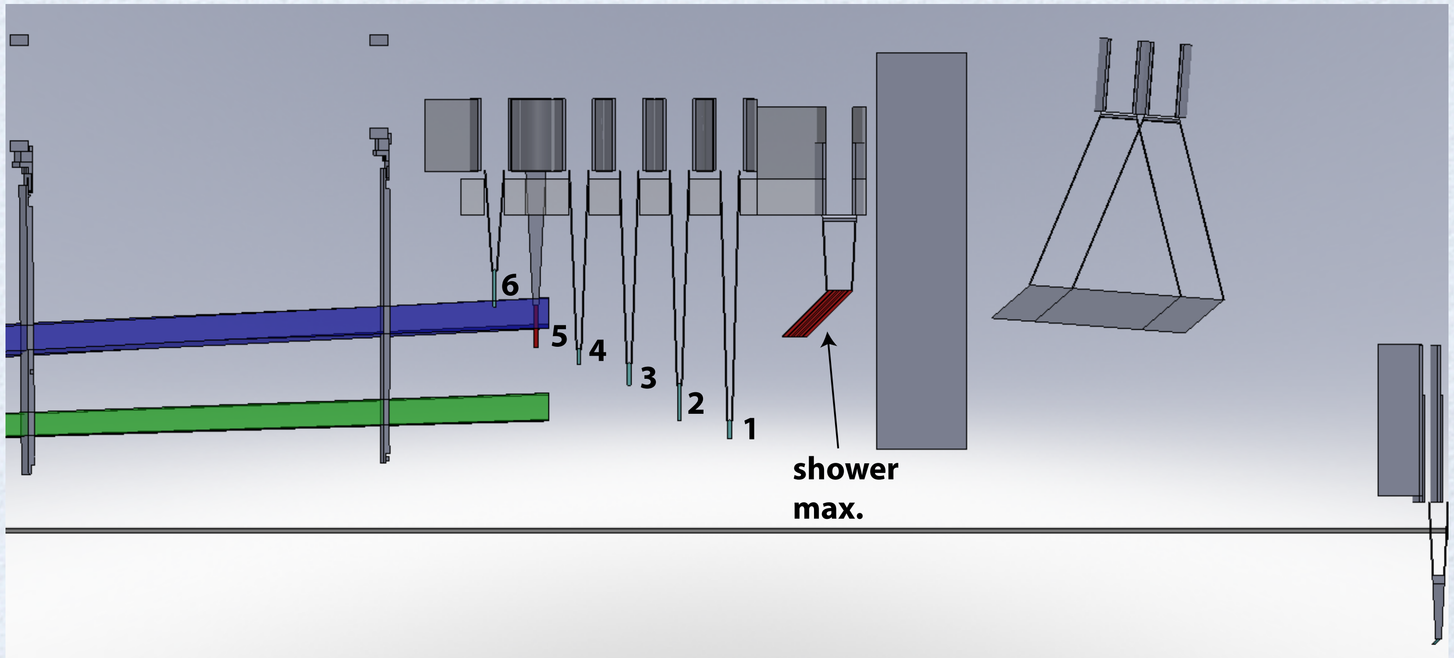




Latest Configuration

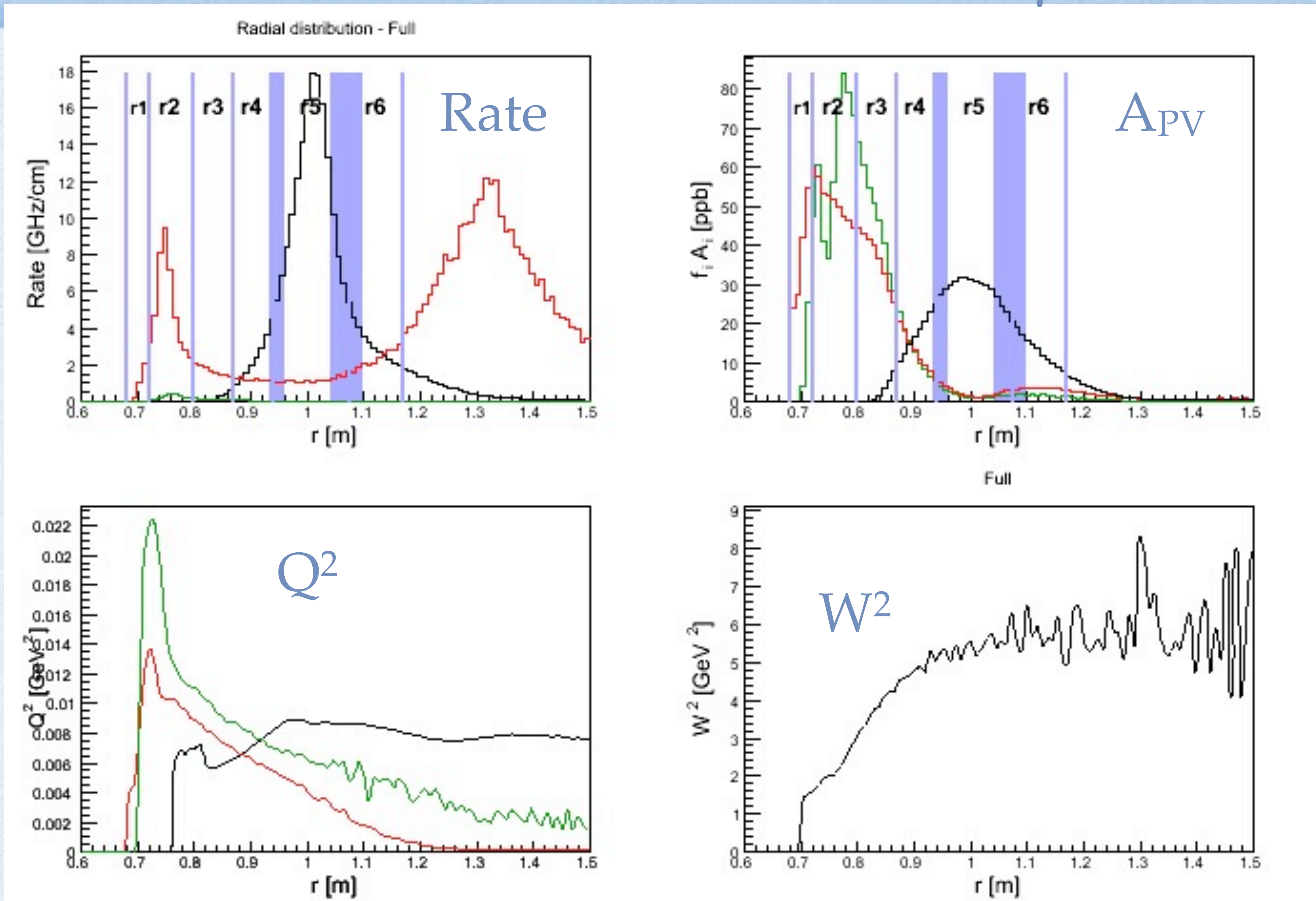






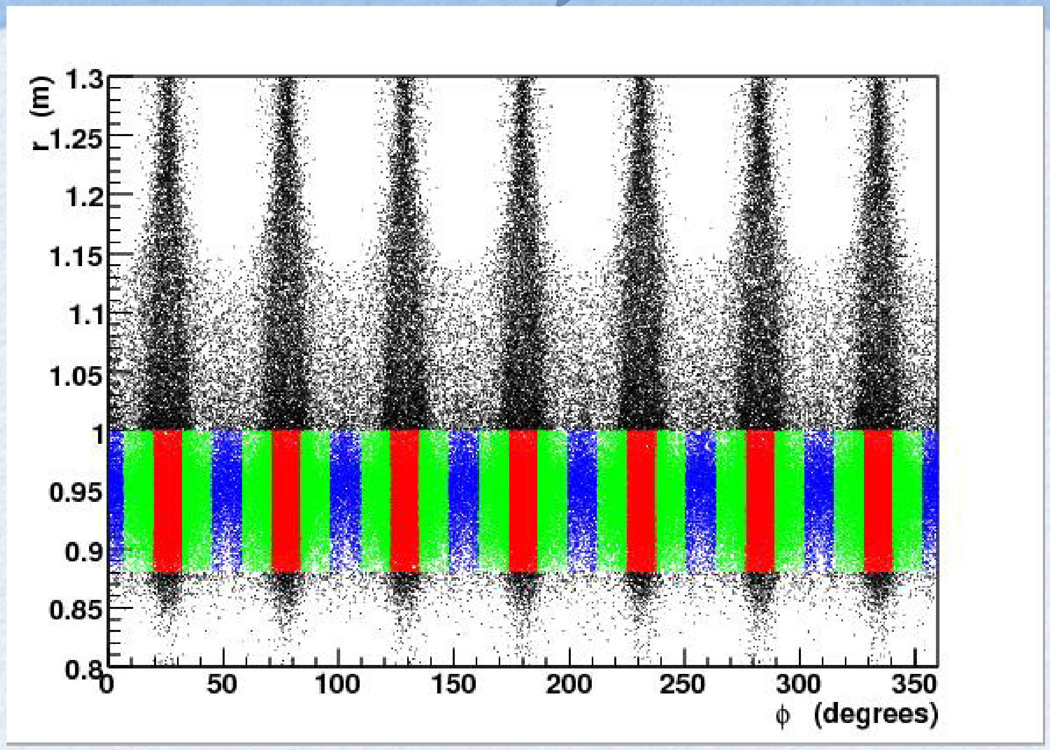
Radial Distributions

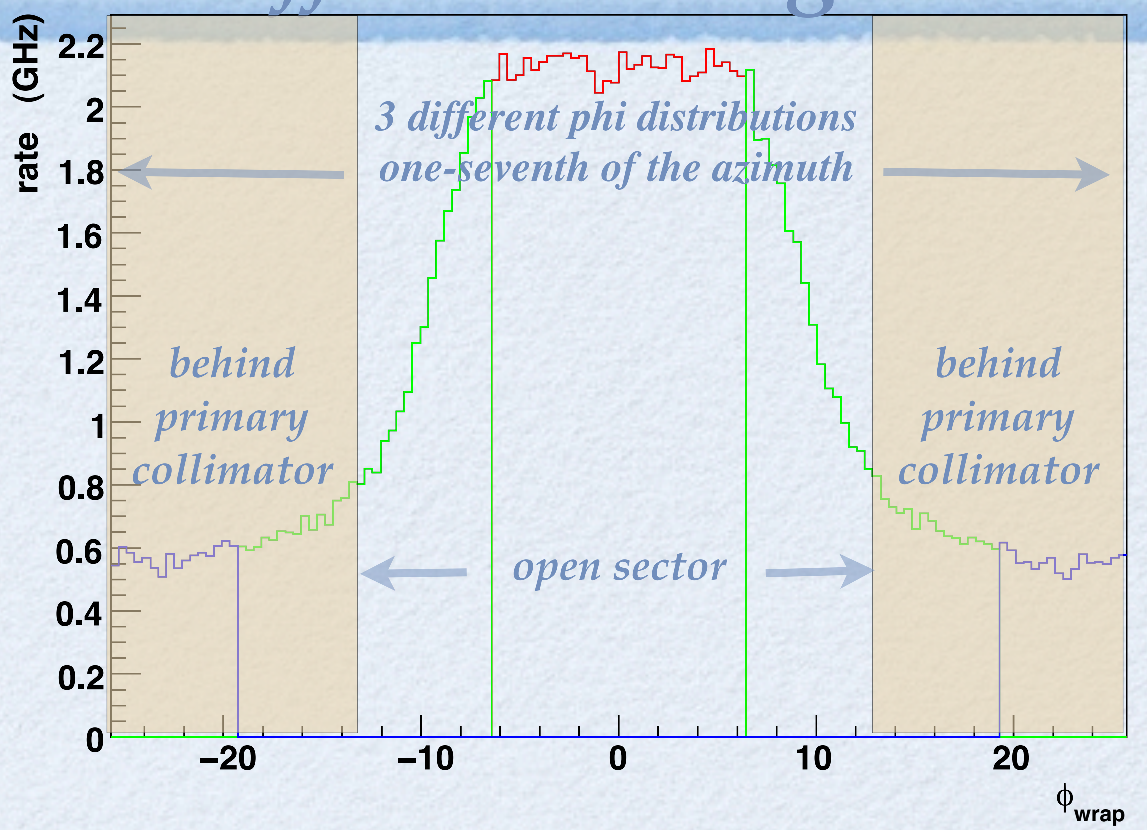
color code same as slide 11 for first 3 plots

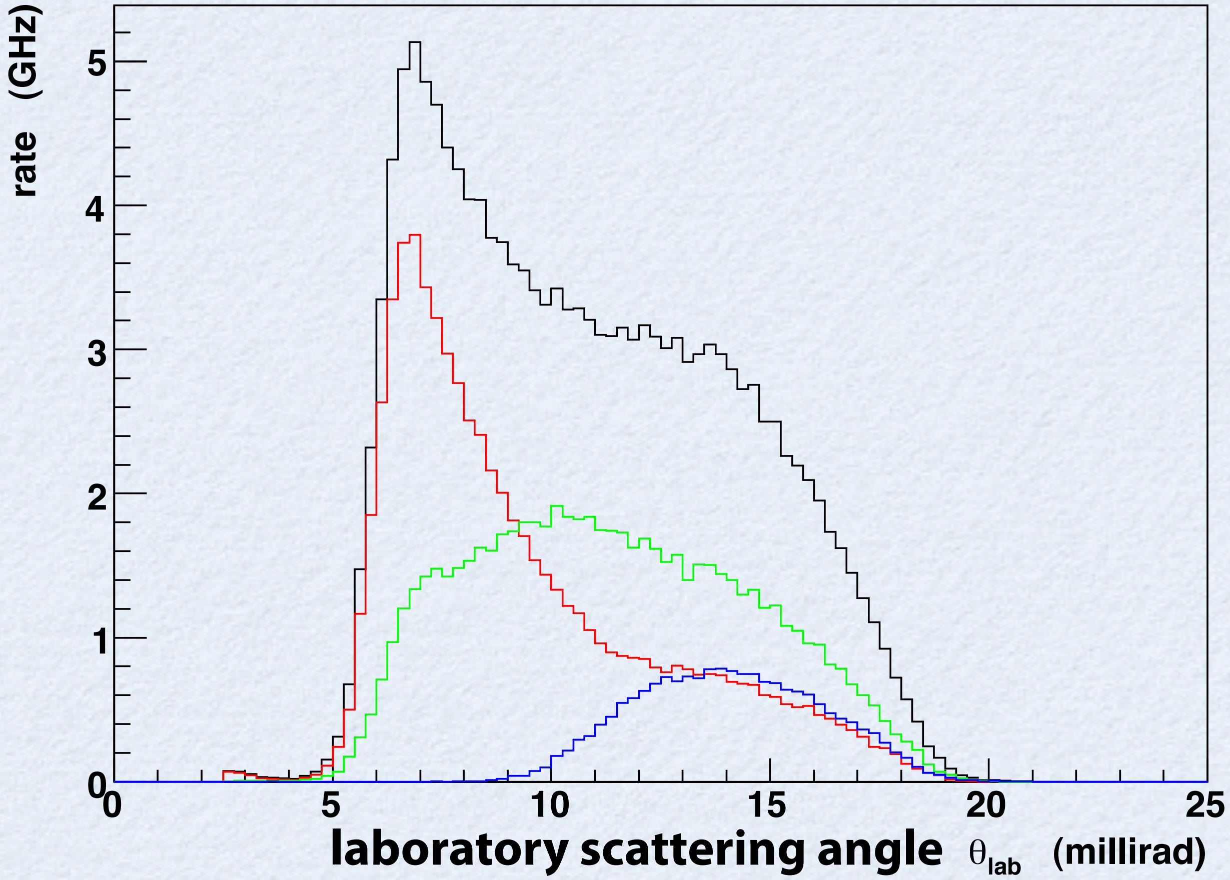


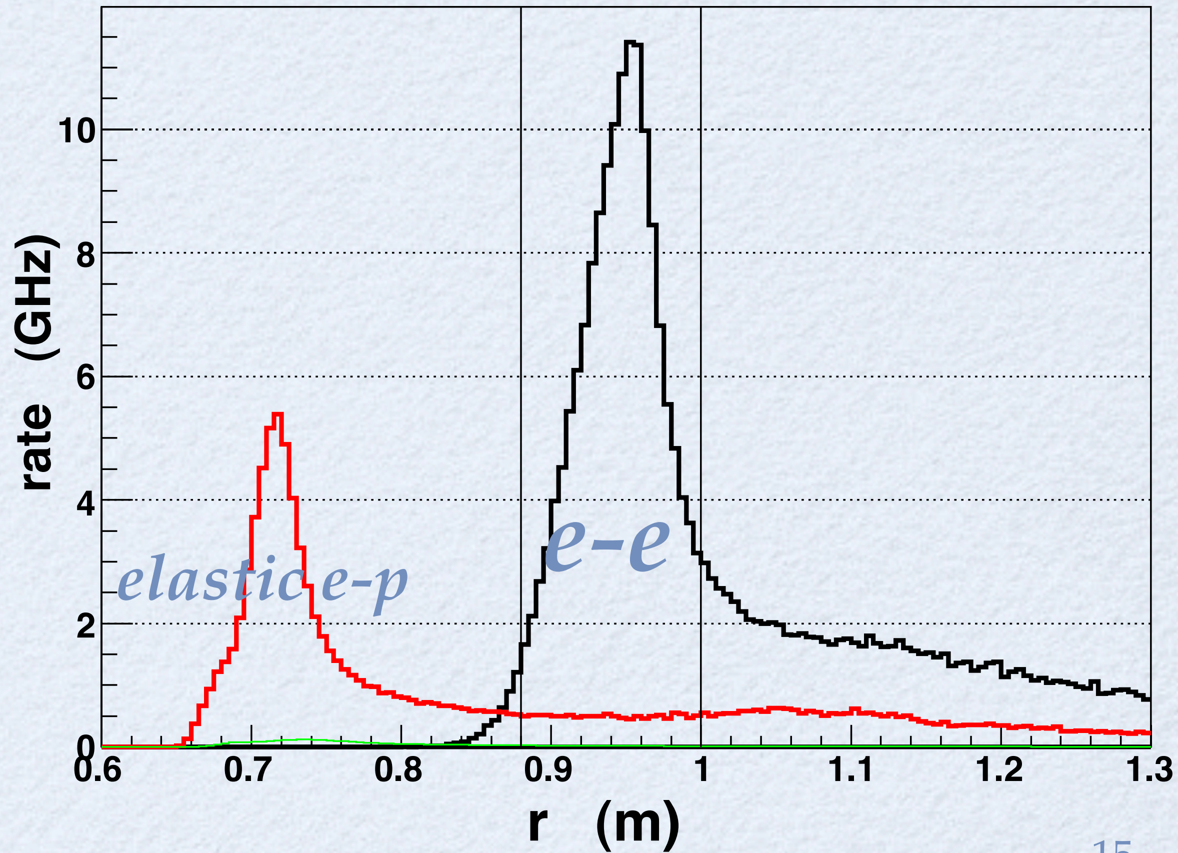
Phi Segmentation

Initial and final state radiation effects in target

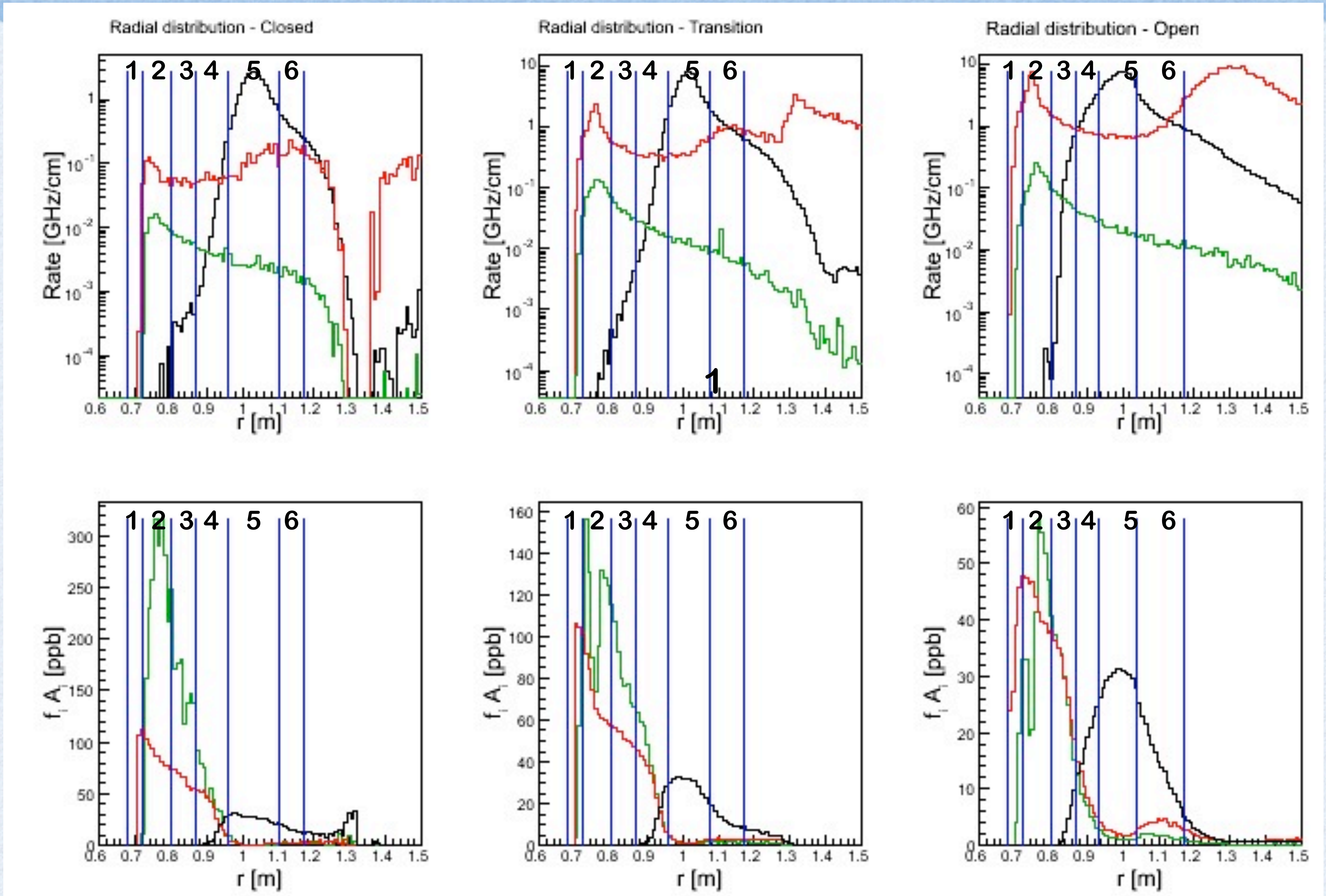








Rate and A_{PV} vs Phi

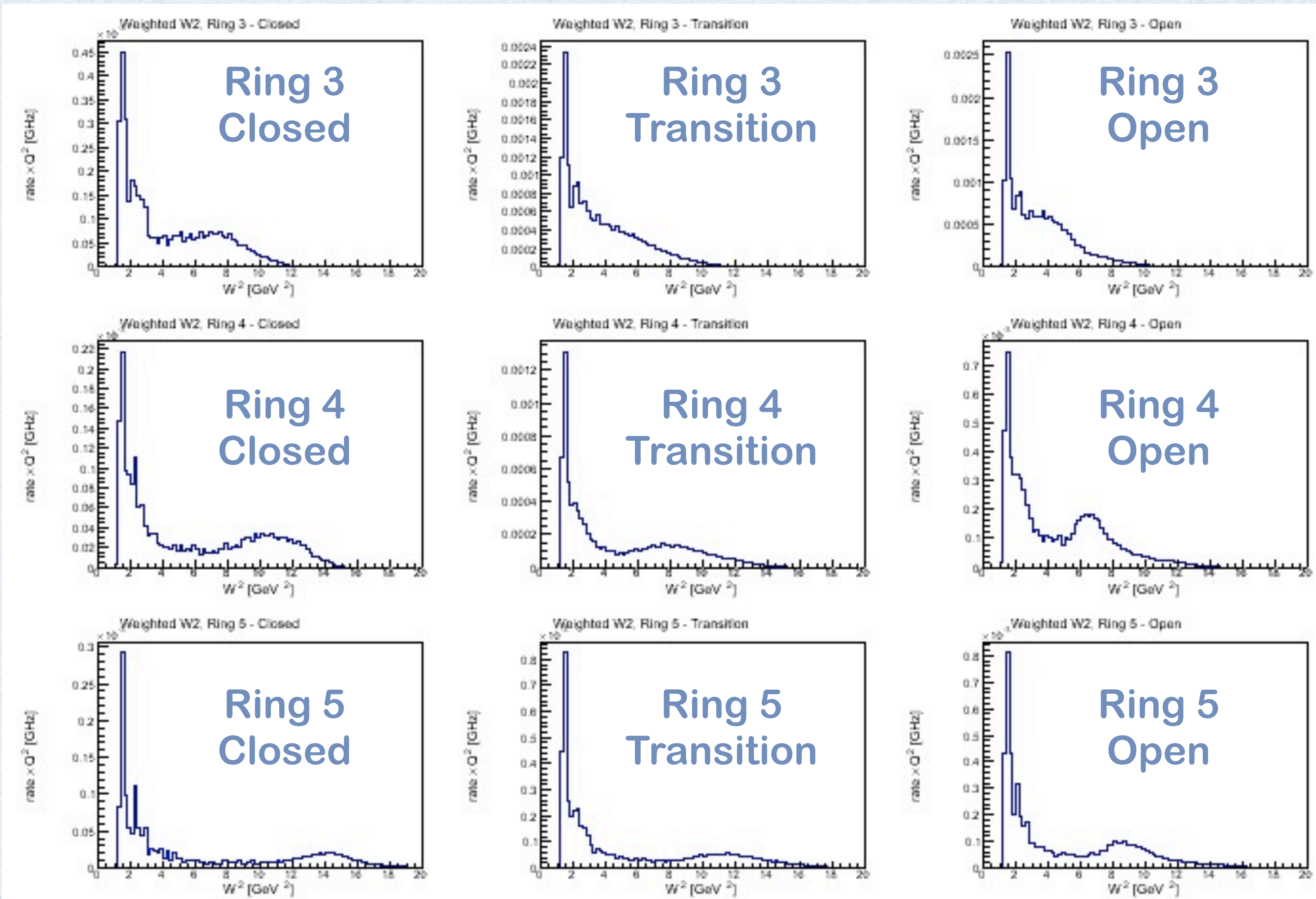


Q^2-weighted W^2 distributions

Ansatz: $A_{PV}(ep \rightarrow eX)/Q^2 = B(W)$

Assume B(W) is constant for M_Δ, M_Δ<W<2, and W > 2

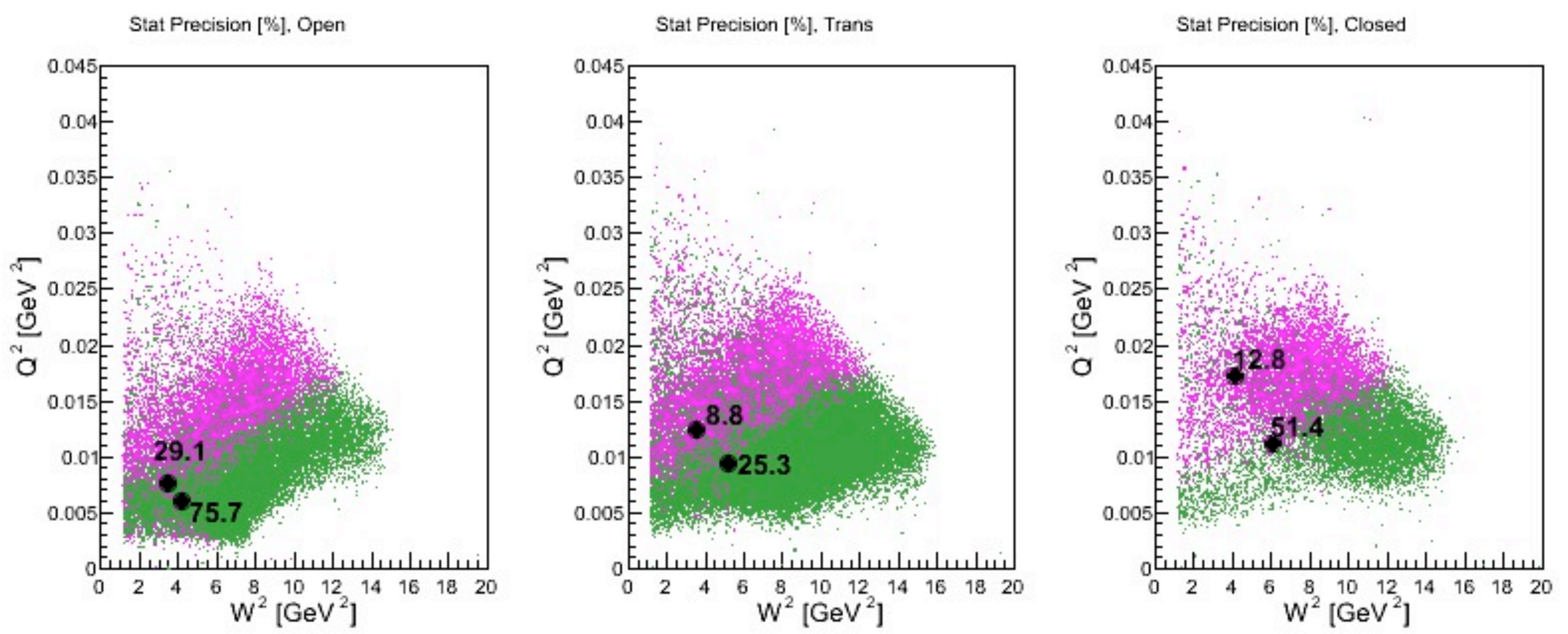
cross-check with measured asymmetries in rings 2, 3 and 4



Projected Precision

Example segmentation

Needs optimization and input from theorists



Summary

- **Unpublished E158 data supports the notion that A_{PV} in inelastic e-p scattering is roughly constant with W^2, and roughly consistent with the QPM prediction**
- **MOLLER needs a dedicated effort of phenomenologists working with experimentalists to set up the framework to extract the weak charge measurement with full treatment of 2-loop effects**
- **MOLLER will make measurements of A_{PV} in inelastic e-p scattering in several interesting regions of (Q^2, W^2) space with significant contribution from the diffractive region**
  - ***useful for reduction of error in*** $\square_{\gamma Z}$ ***prediction?***
- **MOLLER needs theory and phenomenology input to come up with an optimum strategy (combination of parasitic measurements, theory and phenomenology) to constrain the roughly 4% correction from the irreducible background due to inelastic electron-proton scattering to 10% of itself**