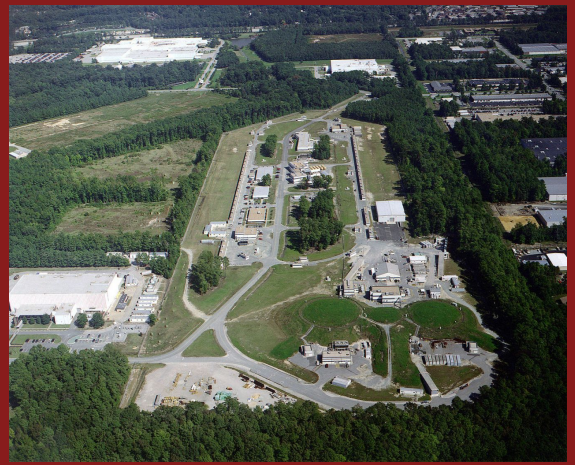
Hyperon Production in MOLLER

Andrew Hurley





University of Massachusetts Amherst

MOLLER Jefferson Lab

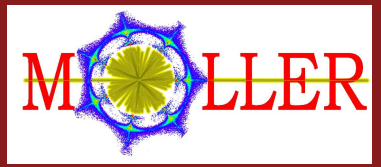
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Overview

- Motivation and physics background
- Y-pion acceptances
- Using CLAS data to build the model.
- Simulation Estimates

Jefferson Lab

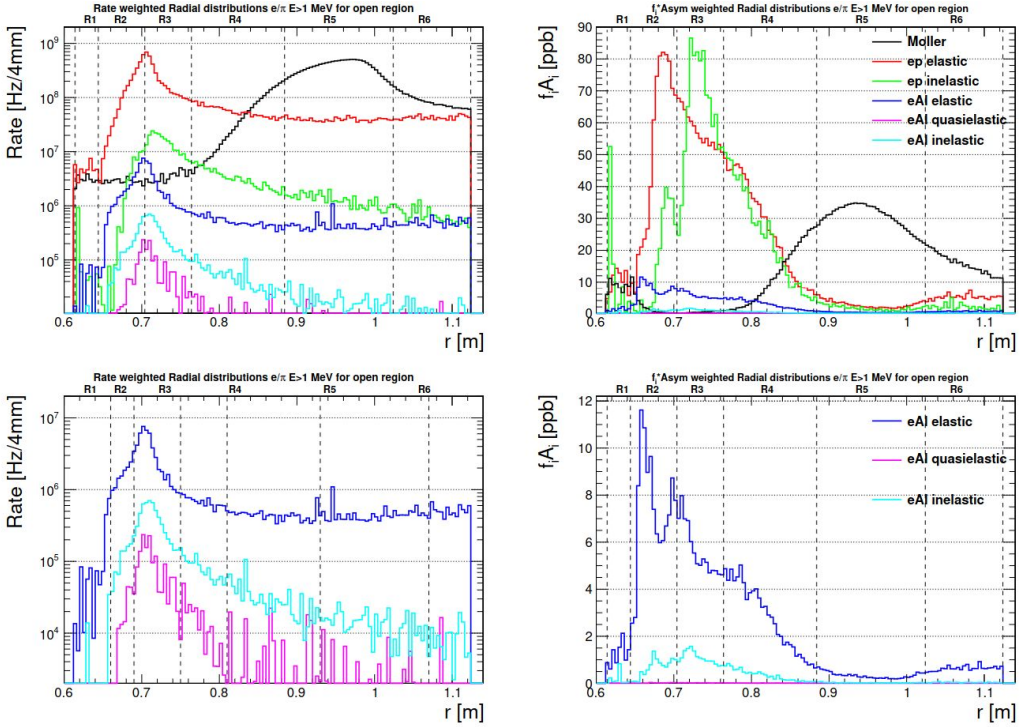
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MOLLER Corrections and Systematics

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Error Source	Fractional Error (%)	
	Run 1	Ultimate
Statistical	**11.4**	**2.1**
Absolute Norm. of the Kinematic Factor	3	0.5
Beam (second moment)	2	0.4
Beam polarization	1	0.4
$e + p(+\gamma) \rightarrow e + X(+\gamma)$	2	0.4
Beam (position, angle, energy)	2	0.4
Beam (intensity)	1	0.3
$e + p(+\gamma) \rightarrow e + p(+\gamma)$	0.6	0.3
$\gamma^{(*)} + p \rightarrow (\pi, \mu, K) + X$	1.5	0.3
$e + Al(+\gamma) \rightarrow e + Al(+\gamma)$	0.3	0.15
Transverse polarization	2	0.2
Neutral background (soft photons, neutrons)	0.5	0.1
Linearity	0.1	0.1
Total systematic	**5.5**	**1.1**

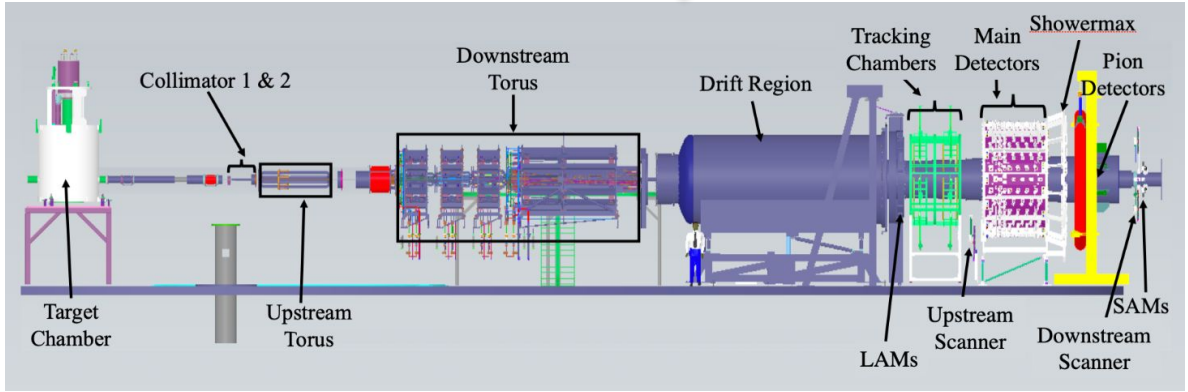


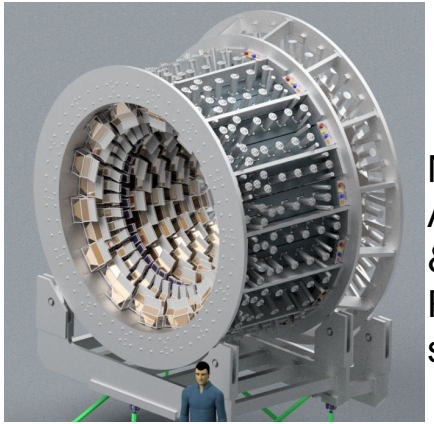
- ep studies shown here do not include asymmetries from weakly decaying hyperons.
- While the rate of pions from hyperons is relatively small, the measured asymmetry may be large

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MOLLER Experiment Overview

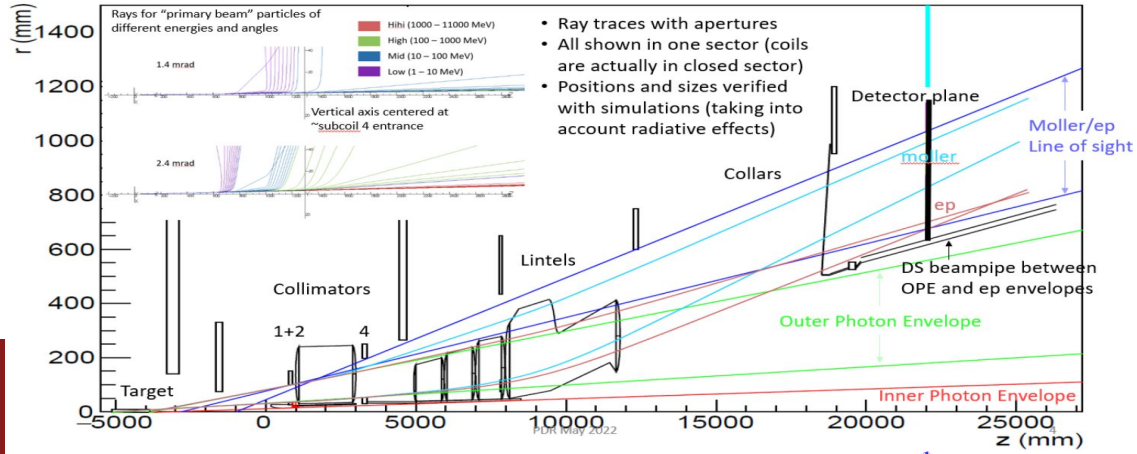
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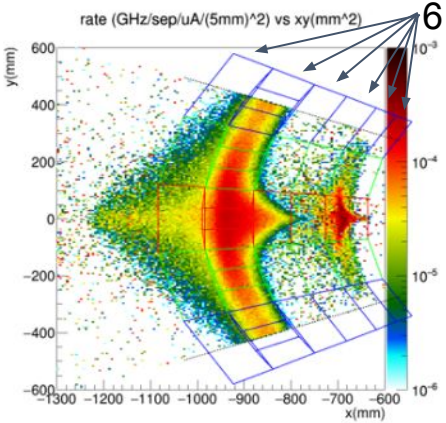




Main Detector:
Azimuthal
&
Radial
segmentation

6 radial rings



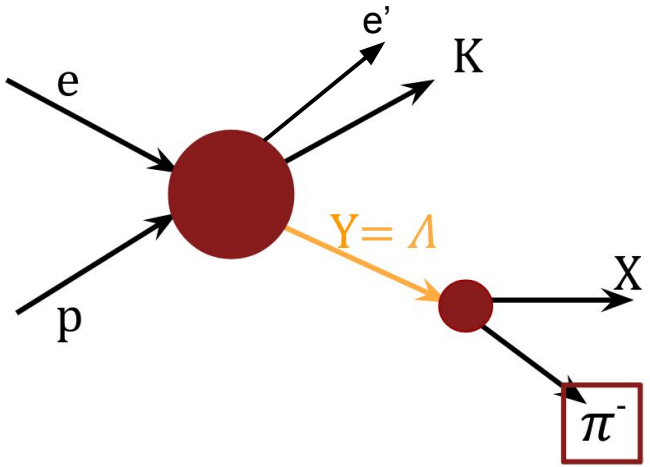


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Hyperon Backgrounds

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- Hyperons produced in ep → e' K Y
  - Y are baryons with s ≠ 0
  - Of interest are $Y = \Lambda, \Sigma^0$
- Hyperon Production has a beam-spin asymmetry
  - Not sensitive to this
- Polarized hyperons have a decay asymmetry
  - Degree of hyperon polarization depends on beam spin
  - We are sensitive to this!
    - Potentially large analysing power
- Ultimate questions are: What is the size of the background asymmetry caused by hyperons decaying to pions in MOLLER, and how do we correct for it.



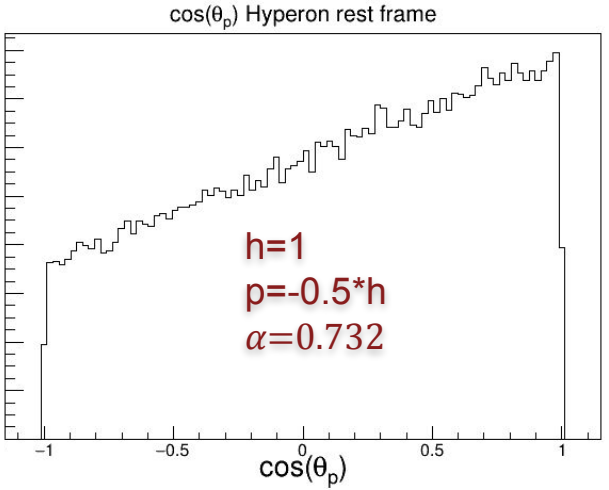
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Polarized Hyperon Decays

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For Λ decays:

- **$O(10^{-10})$s lifetime**
  - ➢ **Displaced vertex**
- **$\Lambda \rightarrow p\pi^-$ ~64%**
- **$P = P^0 \pm hP'$**
- $dN/d\cos\theta_p = N_0(1-\alpha P \cos\theta_p)$
- $\alpha = 0.732$ (from PDG)



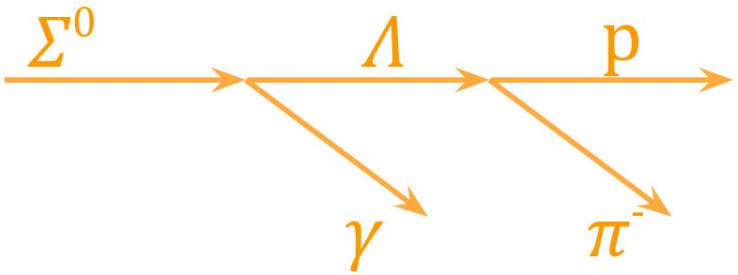
For Σ decays:

Used spin averaged:

$P_\Lambda = -1/3 P_\Sigma$

More General form to be used:

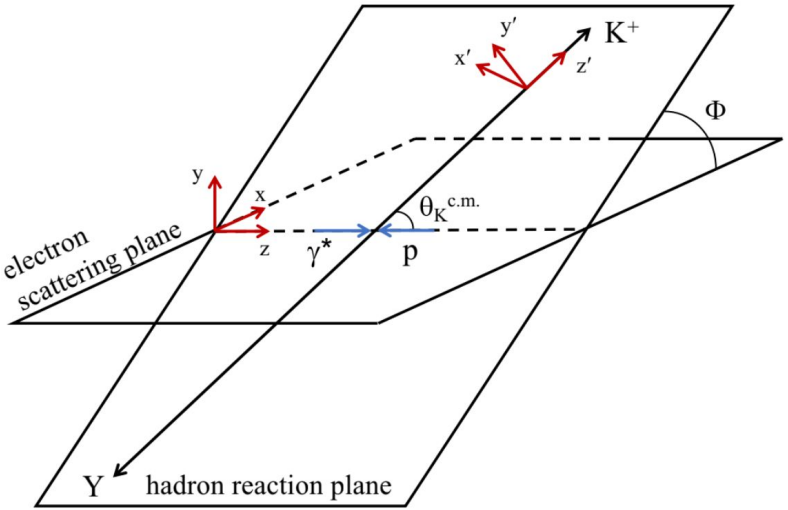
$$P_\Lambda = -P_\Sigma \cos\theta^{\Lambda}_{\Sigma HF}.$$



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Hyperon Electroproduction

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Differential Cross Section:

$$\frac{d^4\sigma_v}{dQ^2 dW d\Omega_K} = \Gamma_v \frac{d^2\sigma_v}{d\Omega_K}$$

$$\Gamma_v = \frac{\alpha}{4\pi}\frac{W}{M_p^2 E^2}\frac{W^2 - M_p^2}{Q^2}\frac{1}{1-\epsilon}$$

$$\epsilon = (1 + 2(E\text{-}E')\tan^2(\theta_e/2)/Q^2)^{-1}$$

$$\frac{d^2\sigma_v}{d\Omega_K} = \sigma_T + \epsilon\sigma_L + \epsilon\sigma_{TT}\cos(2\phi_K) + \sqrt{2\epsilon(\epsilon+1)}\sigma_{LT}\cos(\phi_K) + h\sqrt{2\epsilon(1-\epsilon)}\sigma_{LT'}\sin(\phi_K)$$

Kinematic variables:

θ_K , ϕ_K CoM kaon scattering angles

θ_p , ϕ_p Y-rest frame proton decay angles

$Q^2 = -(q_\mu)^2 = 4EE'\sin^2(\Theta^e/2)$ $(M_e \sim 0)$

$W^2 = s = (q_\mu + p_\mu)^2 = (K_\mu + Y_\mu)^2 = M_p^2 - Q^2 + 2M_p(E\text{-}E')$

Y Rest Frame Polarized Decay:

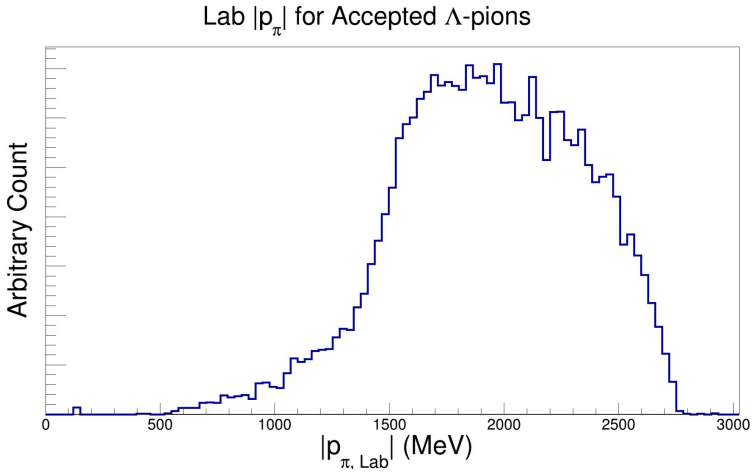
$$\frac{dN}{d\cos\theta_p} = N_0(1 - \alpha P \cos\theta_p)$$

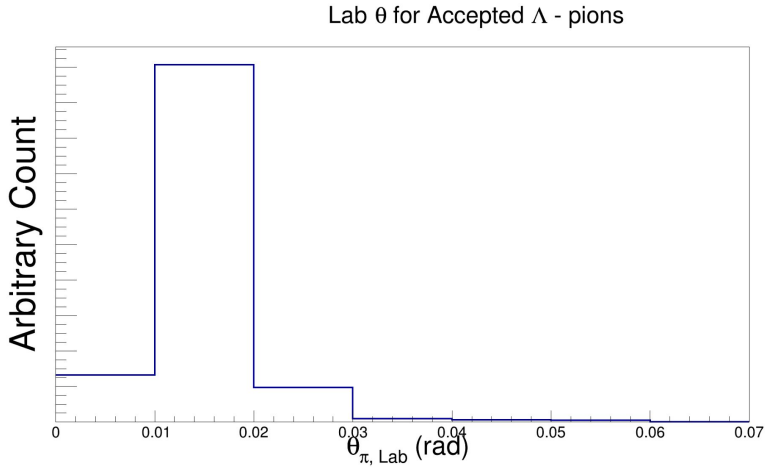
P = P^0 ± *h*P'

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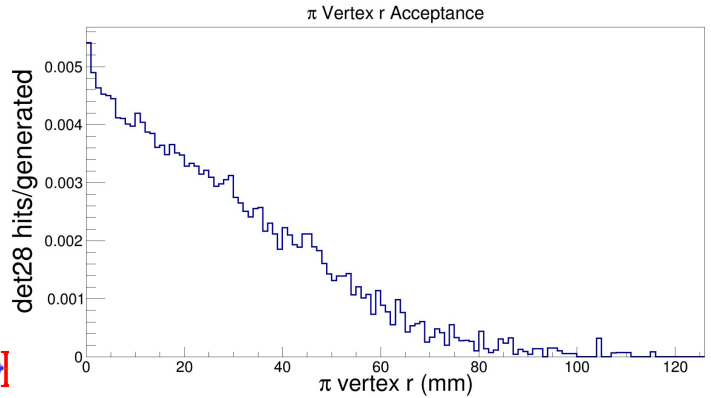
Kinematic coverage: π acceptance

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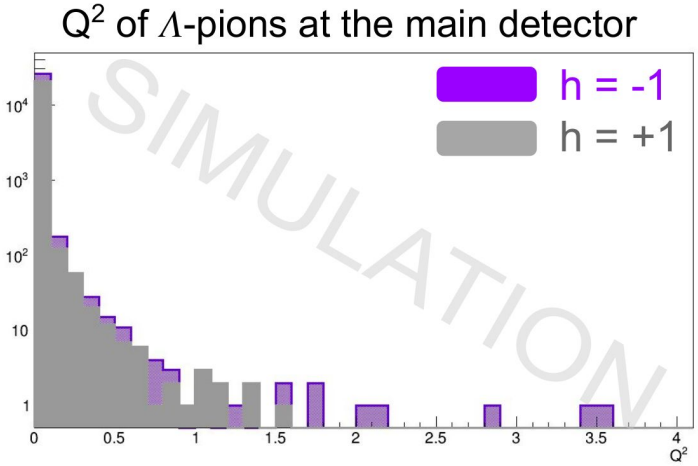


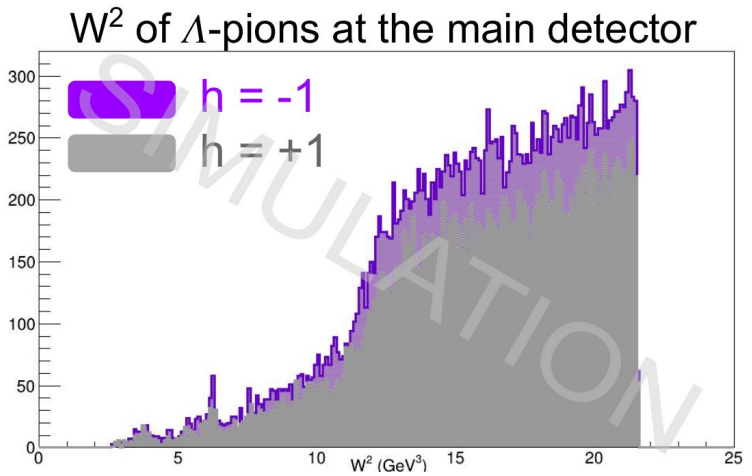
- MOLLER is sensitive to pions coming from Λ, Σ decays with $|p| \sim 2$ GeV in a narrow θ_{Lab}
- Acceptance falls with displaced vertex increase



Kinematic coverage: Q^2 and W^2

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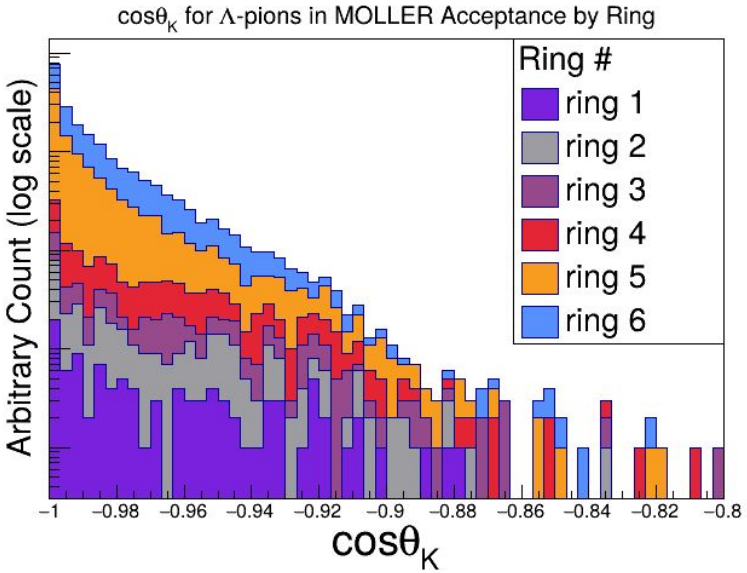


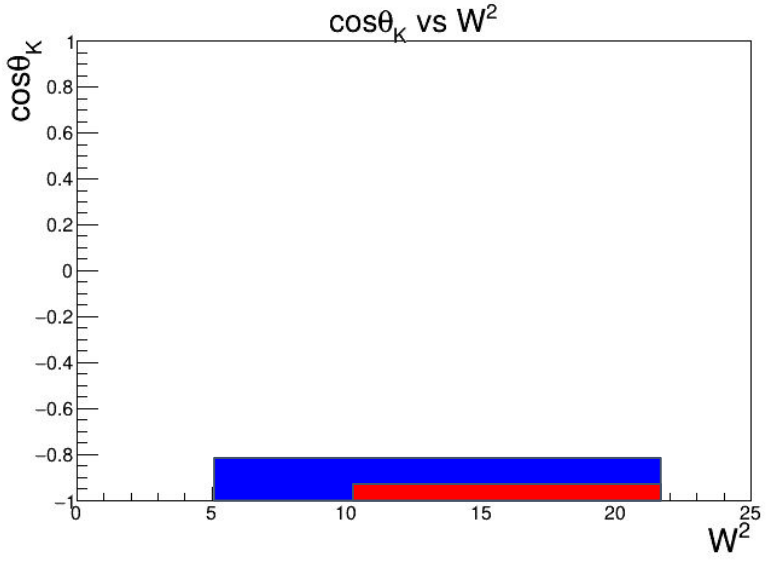
- Acceptance of Λ-pions in MOLLER is largely low Q^2 and high W^2

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Kinematic coverage in $\cos\theta_K$

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- In order for the pion to have enough momentum in the Lab frame to reach the main MOLLER detector, the kaon must go far backward in the CM frame

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Data based Model Overview

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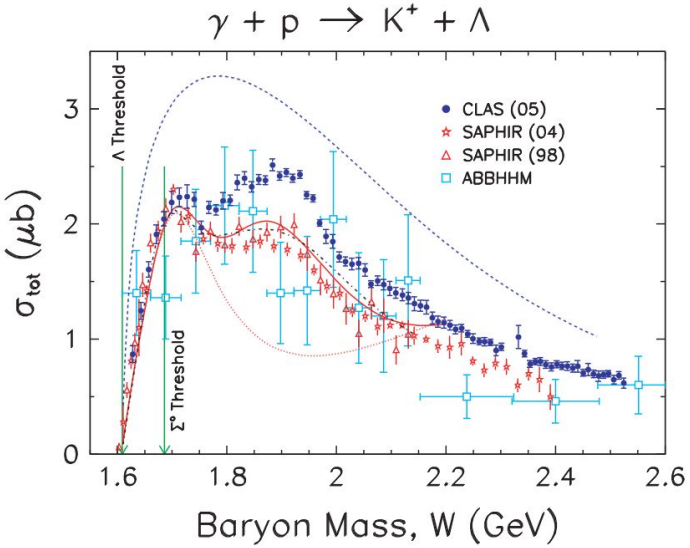
- Model currently uses CLAS and CLAS12 inputs
  - Due to the low Q^2 acceptance, CLAS photoproduction data is used as the main input
  - CLAS12 separated structure function results used to validate non-sensitivty to production asymmetry and extrapolate to $Q^2 > 0$ events
  - CLAS12 results on the transferred polarization used as a guide for choosing polarization values

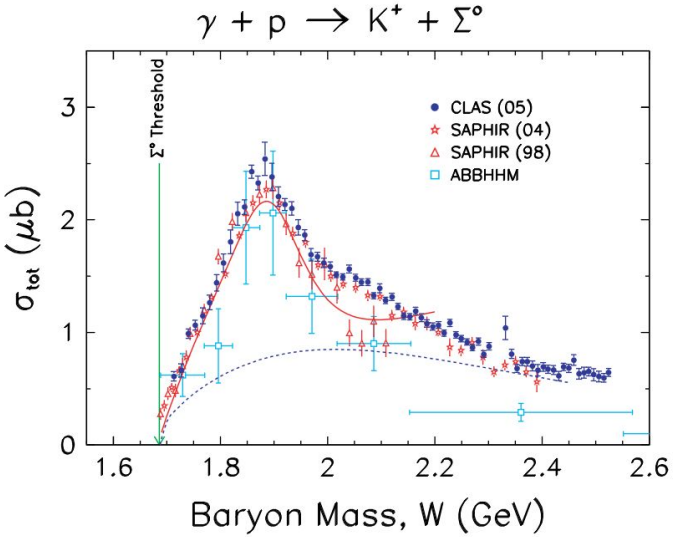
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Model input: CLAS photoproduction

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DOI: https://doi.org/10.1103/PhysRevC.73.035202





- Allows for a good description of the low W dependance
- Extrapolation to high W necessary for MOLLER done using an exponential fit to the W > 2 GeV region
  - BIG ROOM FOR IMPROVEMENT

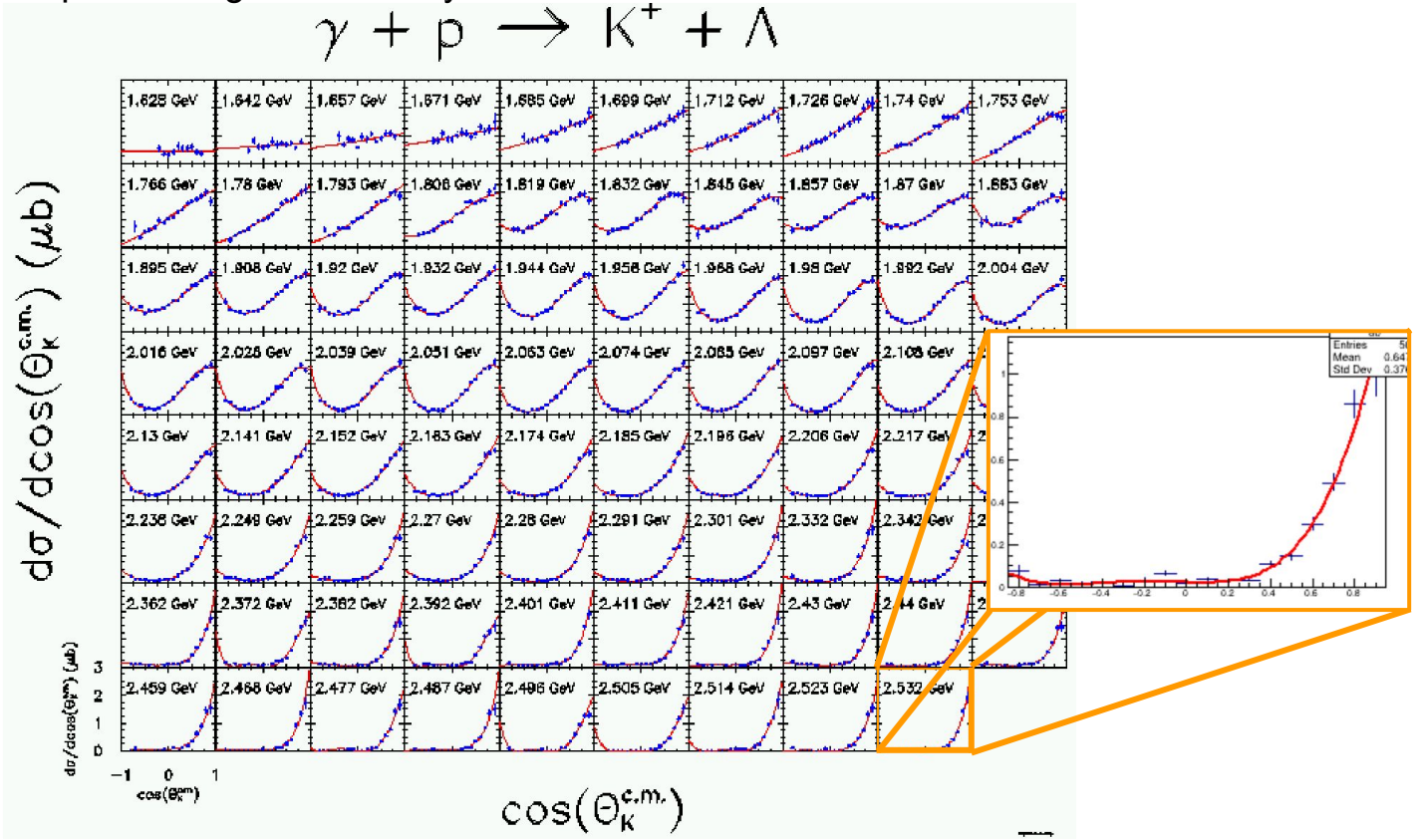
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Model input: CLAS Photoproduction

DOI: https://doi.org/10.1103/PhysRevC.73.035202

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- As W increases, forward cosθ_K dominates. Model assumes this trend holds up to the MOLLER W acceptance



Model input: CLAS12 ep Structure Functions

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https://doi.org/10.48550/arXiv.1212.1336

- Covers $Q^2 = 1.8\ \mathrm{GeV}^2$ and $1.63 < W < 2.575\ \mathrm{GeV}$
- The separated structure functions were used to confirm we are not sensitive to the production asymmetry and used as an extrapolation point for $Q^2 > 0$ behavior

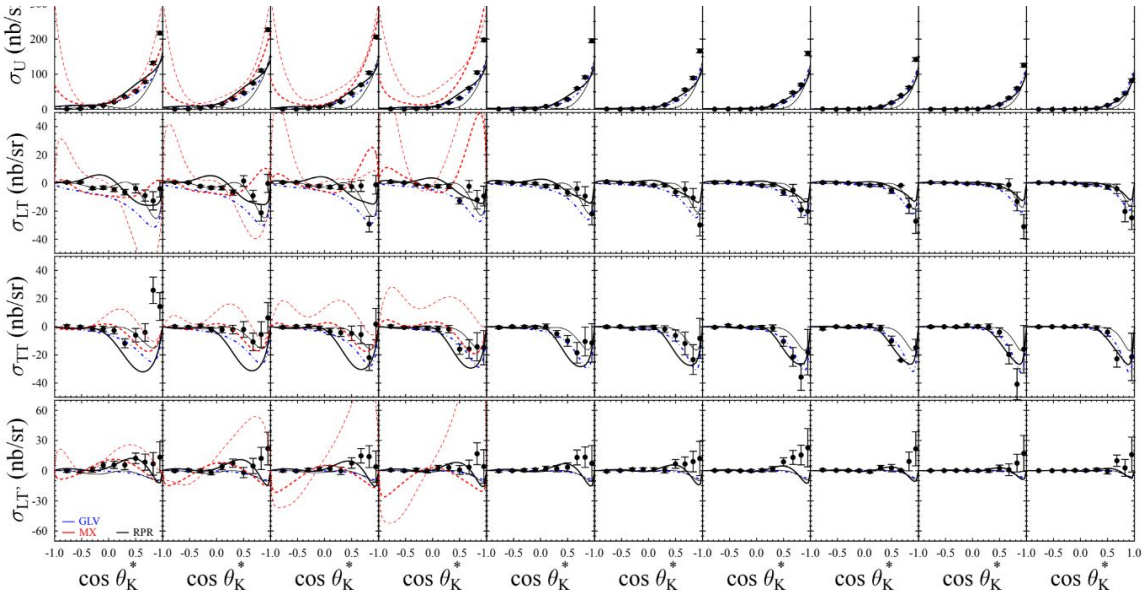


FIG. 13: (Color online) Structure functions σ_U, σ_{LT}, σ_{TT}, and $\sigma_{LT'}$ (in nb/sr) for $K^+\Lambda$ production vs. $\cos\theta^*_K$ at 5.499 GeV for Q^2=1.80 GeV^2 and W from 2.125 to 2.575 GeV. The error bars represent the statistical uncertainties only. The curves are defined in the caption of Fig. 12.

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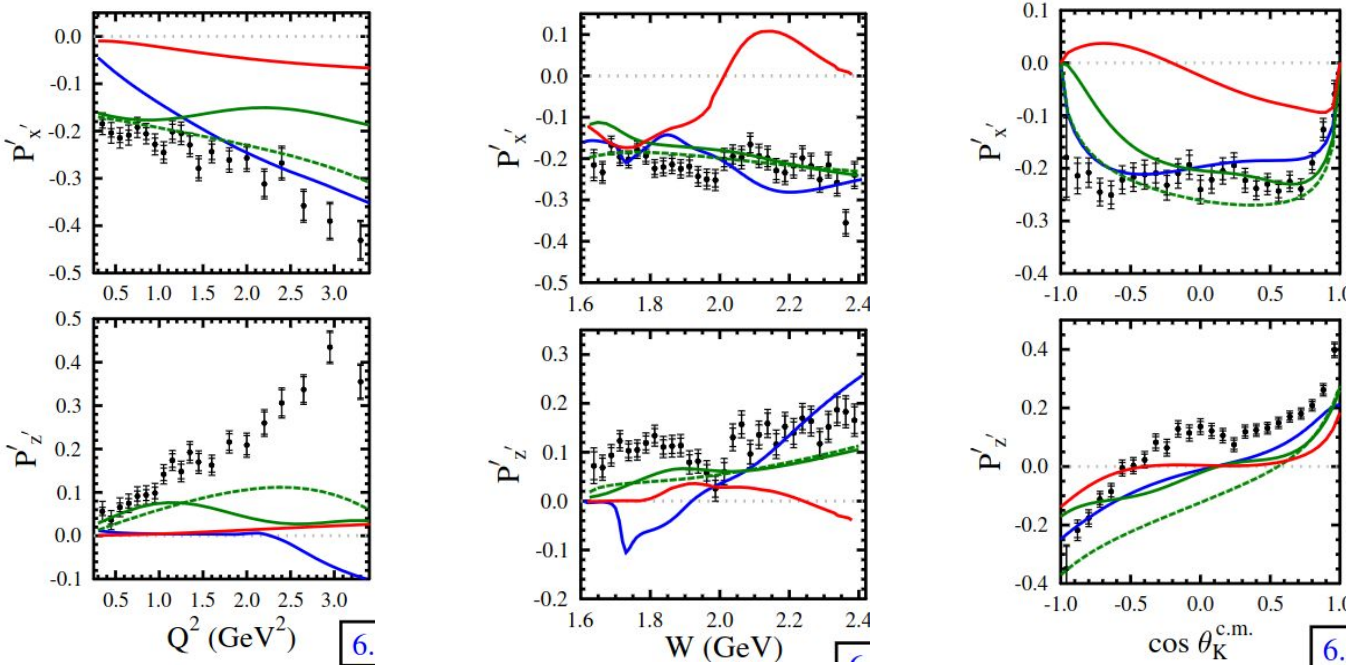
Model input: CLAS12 Transfer Polarization

DOI: https://doi.org/10.1103/PhysRevC.105.065201

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MOLLER

- Covers $Q^2 = 1.8\ \mathrm{GeV}^2$ and $1.63 < W < 2.4\ \mathrm{GeV}$
- Binned in Q^2 or W or $\cos\theta_K$



Model blind spots and extrapolation

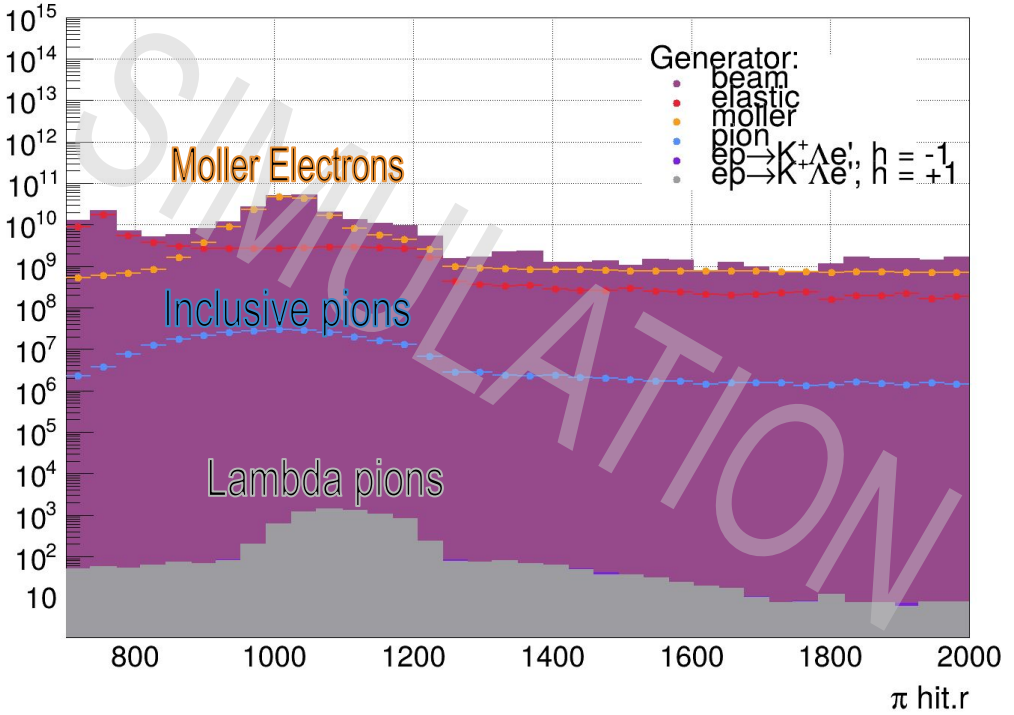
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- Input data from CLAS used in the model is all $W^2 < 7$ GeV^2
  - ➢ MOLLER acceptance largely favors $W^2 > 10$ GeV^2
- Polarization data is not binned in Q^2 and $\cos\theta_K$
  - ➢ It would be useful to have a measurement or theory estimate of P' at low Q^2 and $\cos\theta_K$
- See Justin's following talk for discussion on possible future experimental input

Λ-pion Main Detector Rates using $P_{\Lambda} = 0.1*h$

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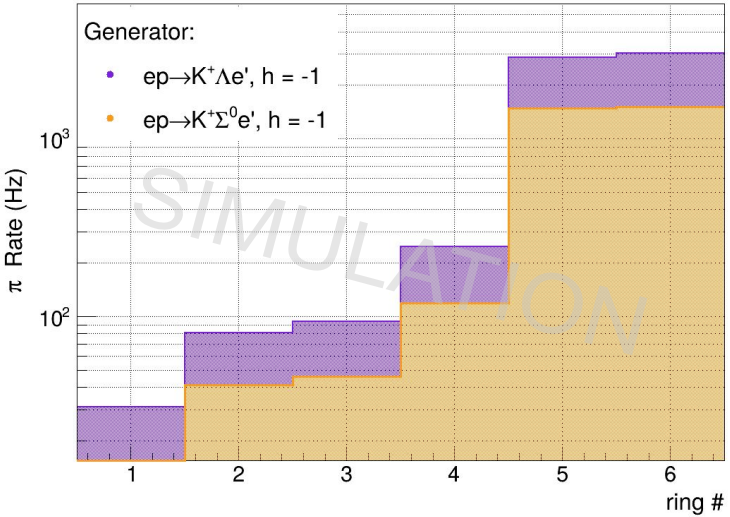
- Pions from hyperons have a rate 10^{-8} of the Møller electron rate in ring 5
- The rate of these pions is much higher in the outer ring (6) and beyond the main detector

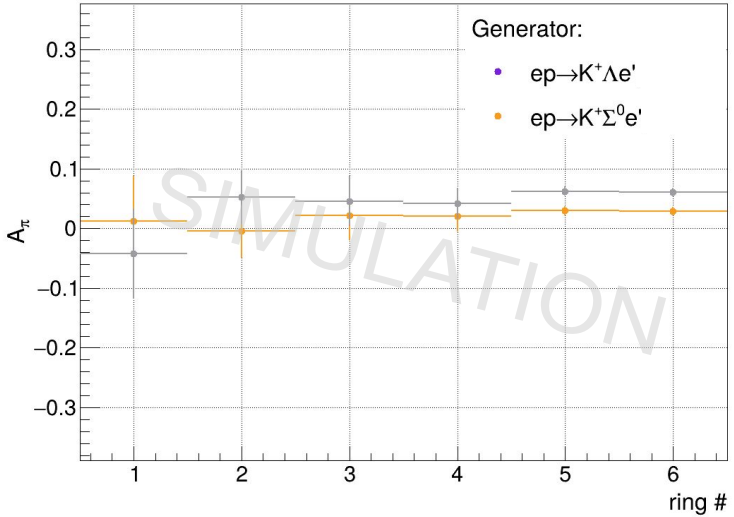


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Comparing Λ and Σ^0 rate and asymmetries

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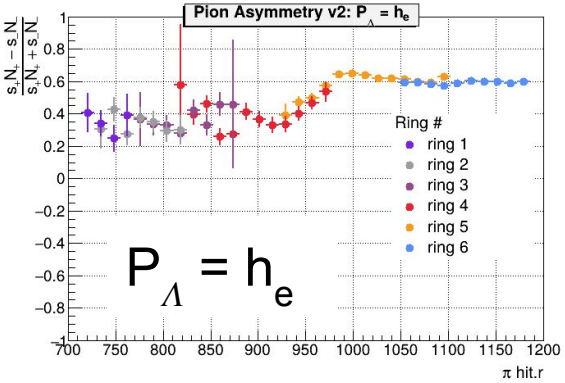


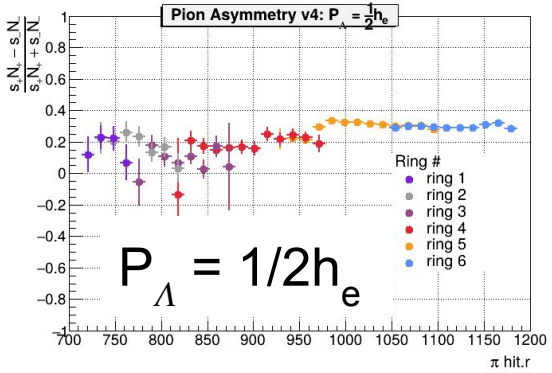
- Compared to the Møller electron hit rate in ring-5 of O(10^{11}) Hz with an asymmetry of ~33ppb, the estimated hyperon-pion rate and asymmetry corresponds to a 1-2% level correction, conservatively.
- MOLLER goal of δA_{PV}~ 0.8ppb, or 2.4%

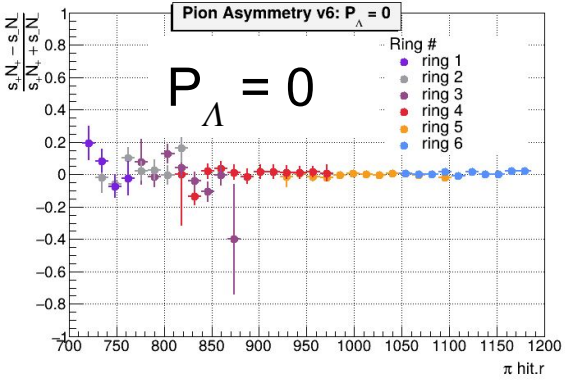
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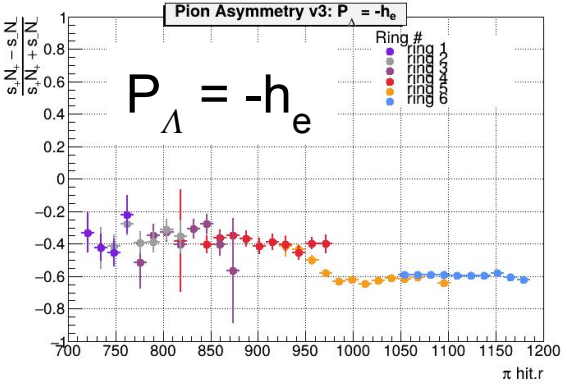
Asymmetry sensitivity to choice of p’

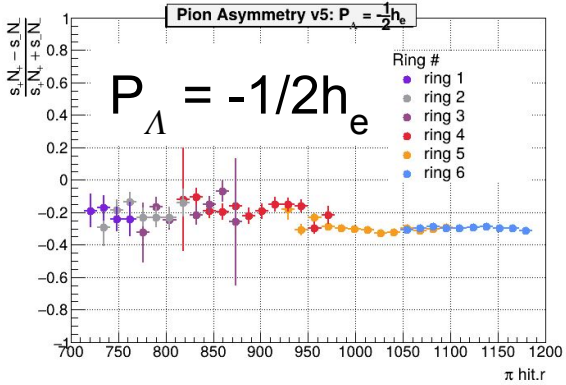
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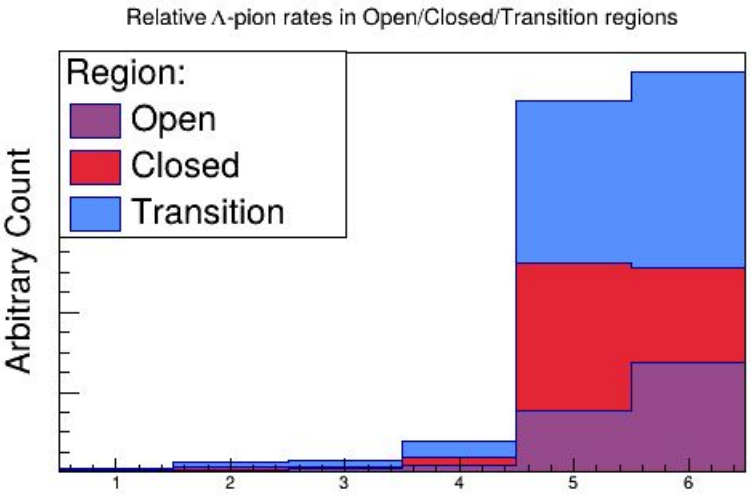


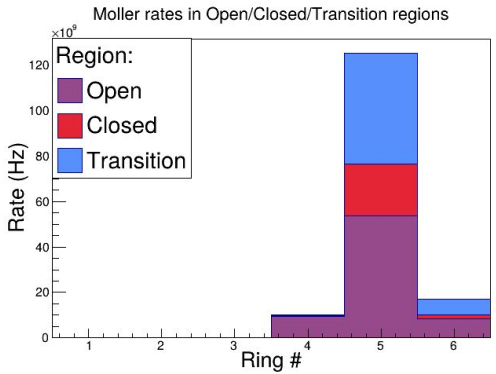


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Relative Λ-pion rates in the open/transition/closed regions

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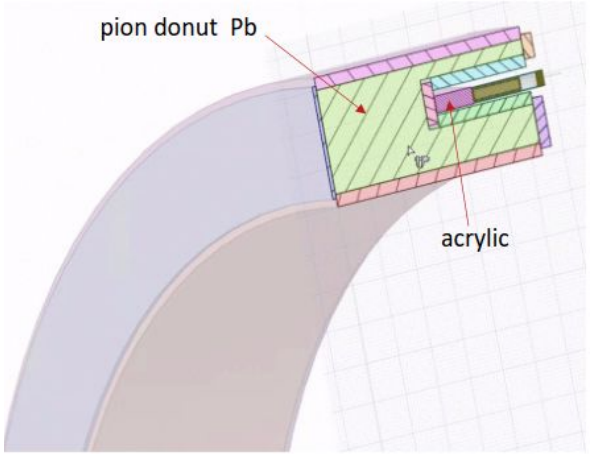


- Azimuthal defocusing means the rates from Λ-pions are higher in the closed sectors than the open sectors in ring 5.
  - Gives us a lever arm for deconvolution (see Ciprian's talk yesterday)

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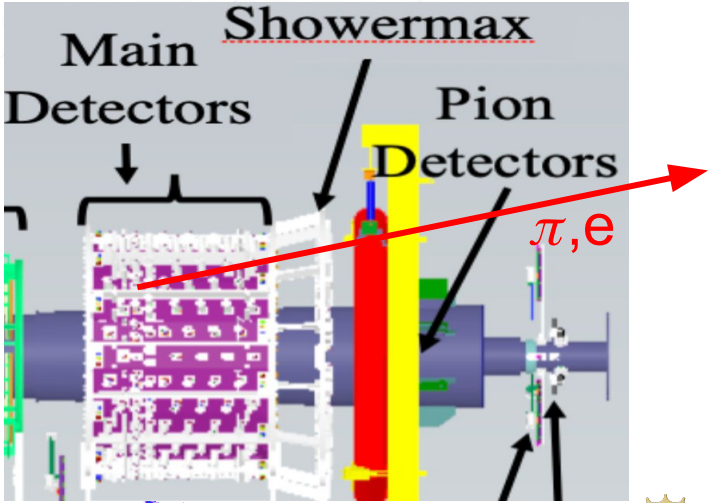
Measuring pion Rates and Asymmetry in MOLLER

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- 45 X_0 in direction of scattered Moller electrons
- π/e ratio of photoelectrons in pion detector = 107%
  (design goal: > 50%)



Slide adapted from David Armstrong of William & Mary

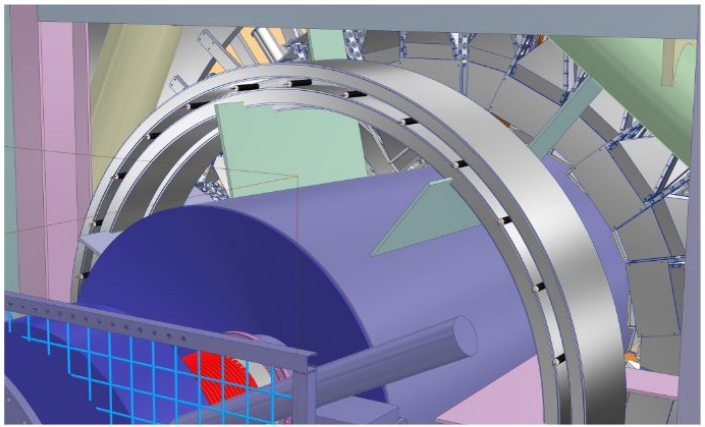
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Measuring pion Rates and Asymmetry in MOLLER

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- Need to determine, for Ring 5,
  - i) asymmetry: A_{PV}^{π}
  - ii) $f^{\pi} = \frac{R^{\pi}}{R^{\pi} + R^{e}}$

- Estimate: f^{π} ~0.13% with A_{PV}^{π} ~500 ppb
  Need to determine $f^{\pi} A_{PV}^{\pi}$ to 20% relative precision



- Range out majority of electrons with Pb absorber (donut)
- A_{PV}^{π} measurement from 20 MHz total pion rate over full azimuth
  - during main asymmetry data-taking
    - moderately radiation-hard integrating detectors
      - ∴ Acrylic Cerenkov detectors

- f^{π} measurement of MIP pion signal during Counting-Mode data-taking
  (supplemented by ShowerMax, Ring 5, GEMs, Trigger Scintillators)

Slide courtesy of David Armstrong of William & Mary

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Summary

- A data based model has been created to simulate the effect of Hyperon pions.
  - The correction due to hyperon-pions to the moller asymmetry is expected to be at the percent level based on this study; <u>This is heavily dependent on Hyperon Polarization input</u>
  - Future improvements can be made with additional data from experiments like GlueX, CLAS12, or Kaon-LT and theory input
- The deconvolution of pion asymmetry will be aided by measurements made by the pion (and other) detectors.

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