Deconvolution for MOLLER

Ciprian Gal

with a lot of analysis support from Zuhal Demiroglu

and long discussions with Kent Paschke and Krishna Kumar



Goals

- MOLLER

$$A_{PV} = mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{4\sin^2\theta}{(3+\cos^2\theta)^2}Q_W^e$$

$$A_{PV} = 35.60 \pm 0.73\text{ppb}$$

$$\delta(Q_W^e) = 2.1(\text{stat}) \pm 1.0(\text{syst})\%$$

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**

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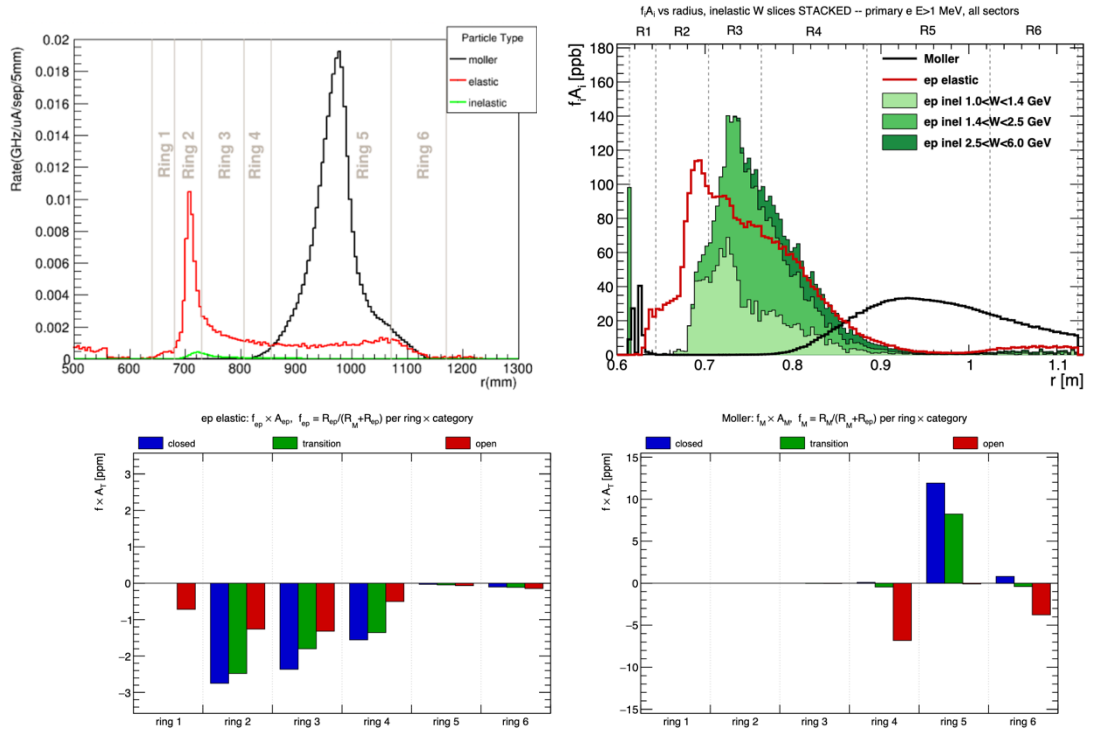
- This talk → Convince you that the extraction is possible

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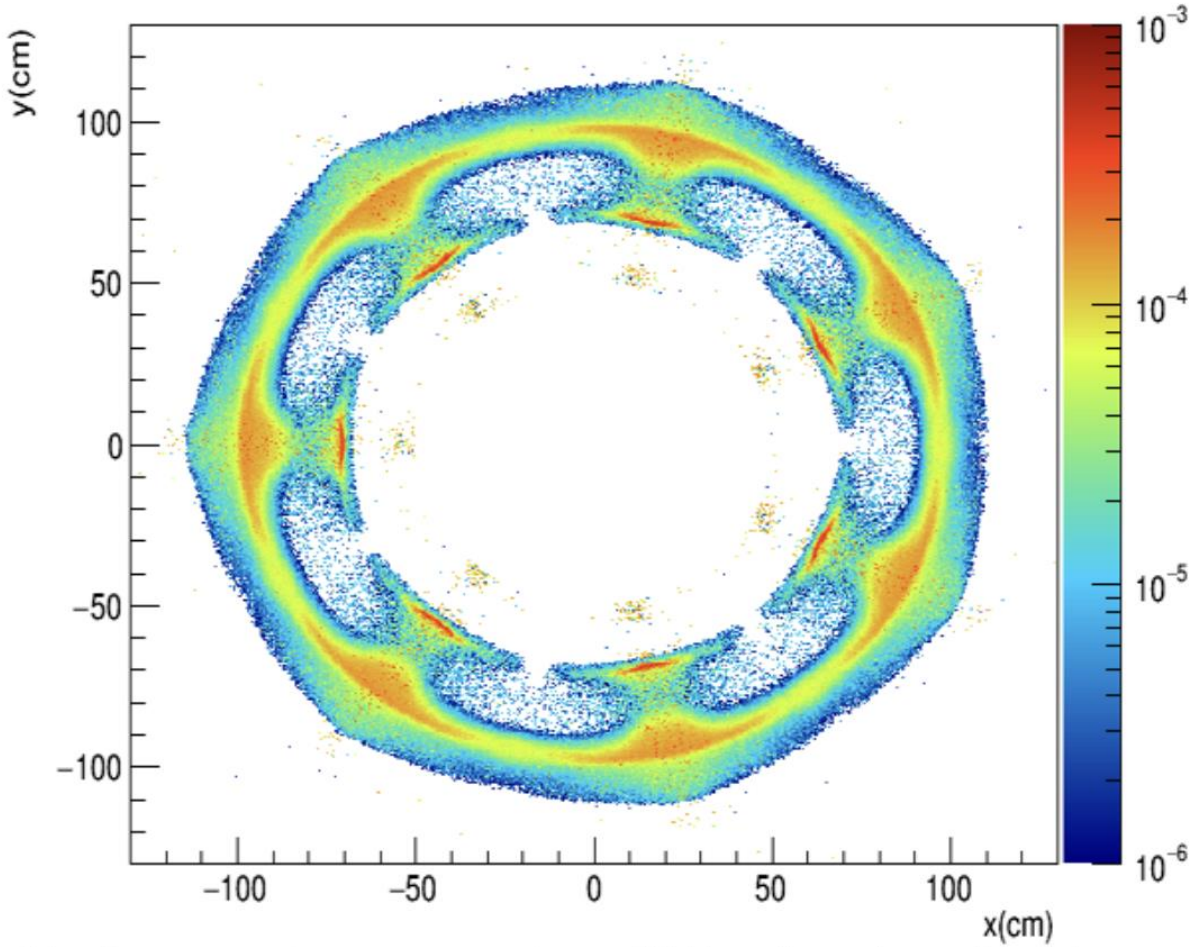
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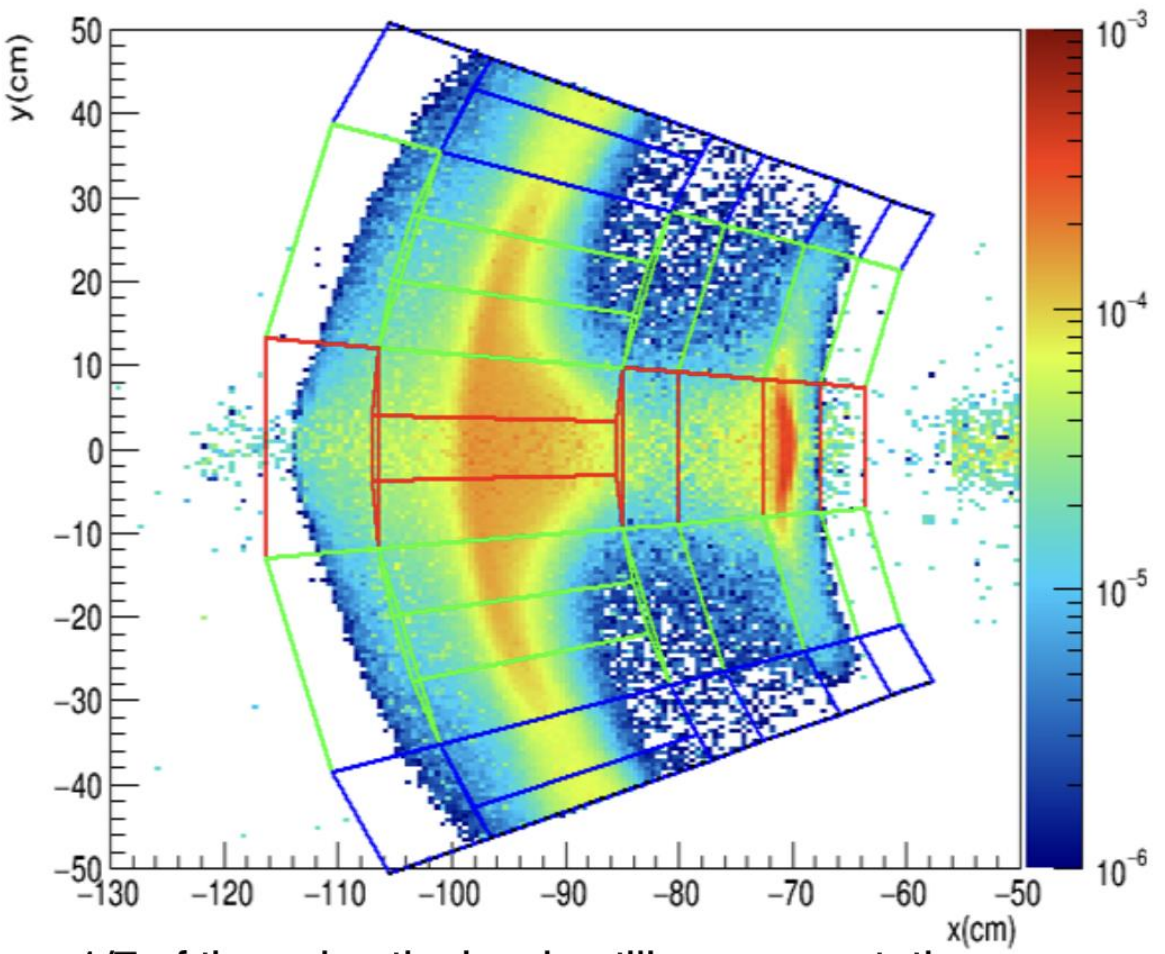
- This talk → Convince you that the extraction is possible

- Discussion → Get feedback (especially on the inelastic backgrounds)

Rates



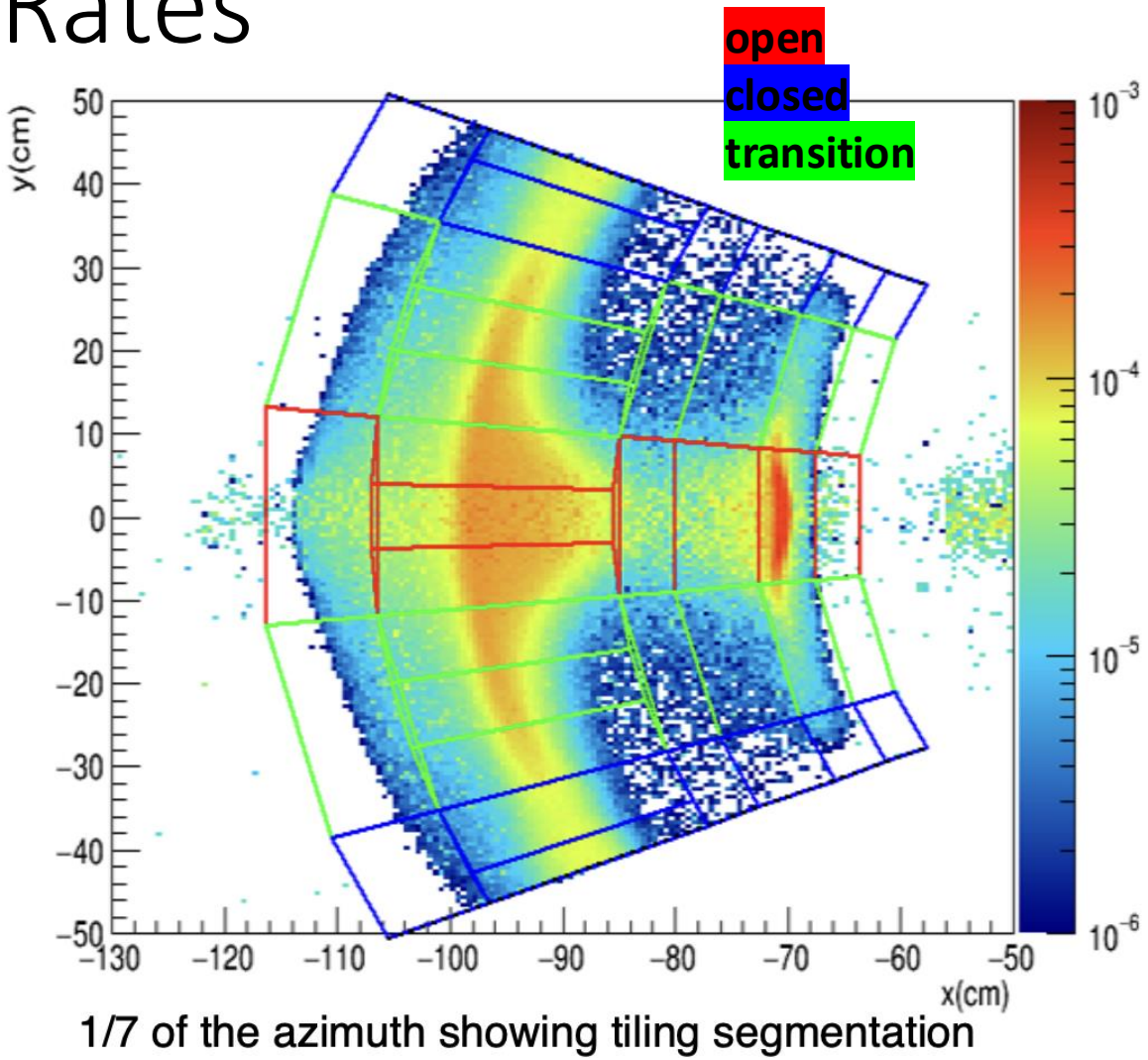
Heat map on transverse plane 26.5 m from target center



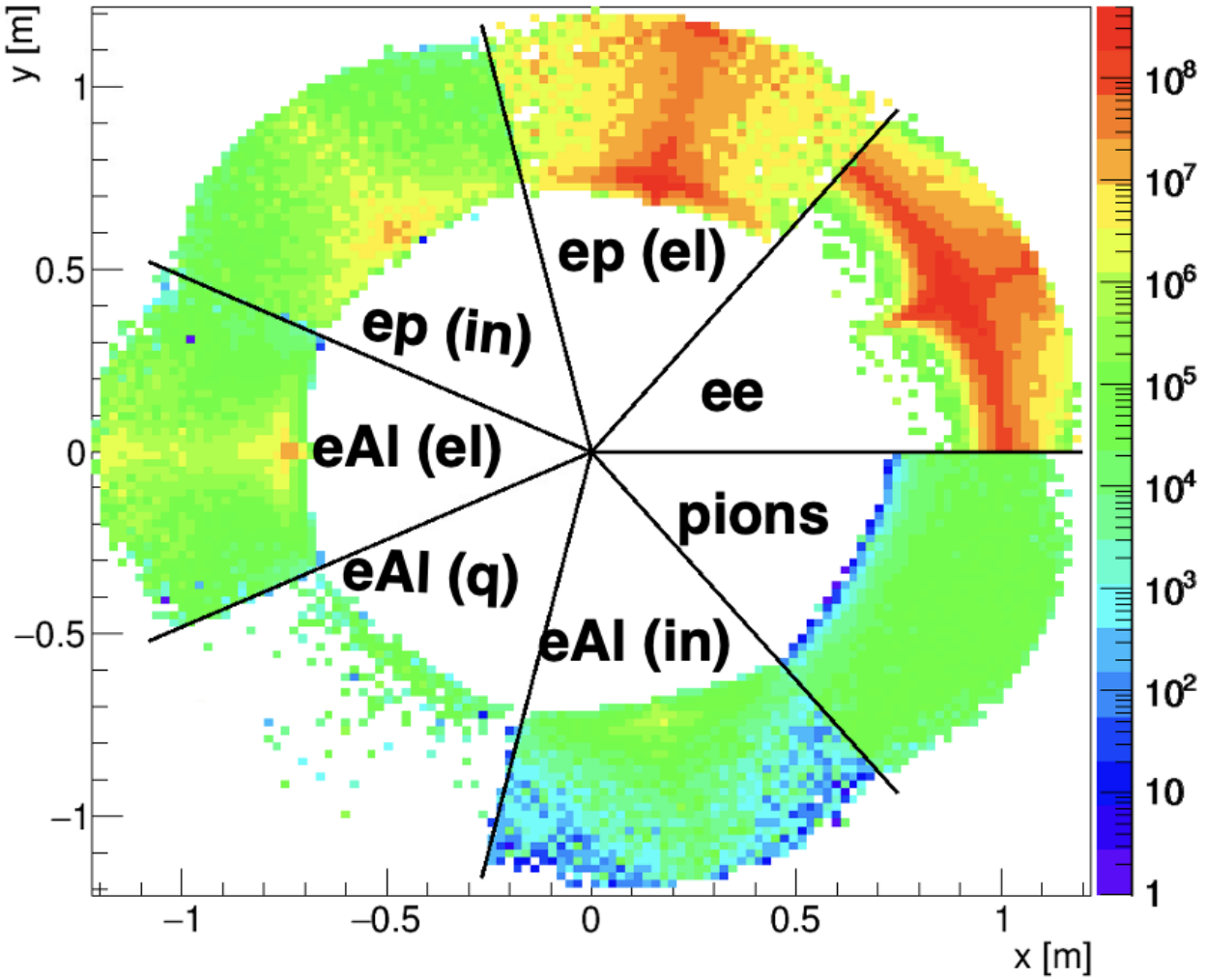
1/7 of the azimuth showing tiling segmentation

- The rate distributions already show why MOLLER is possible

Rates

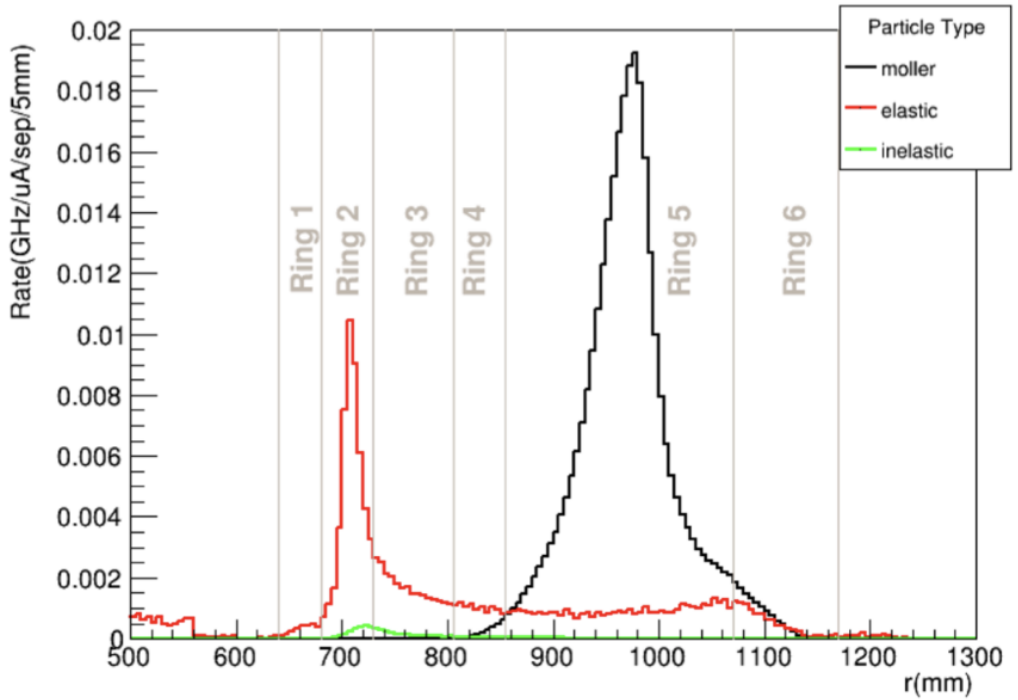


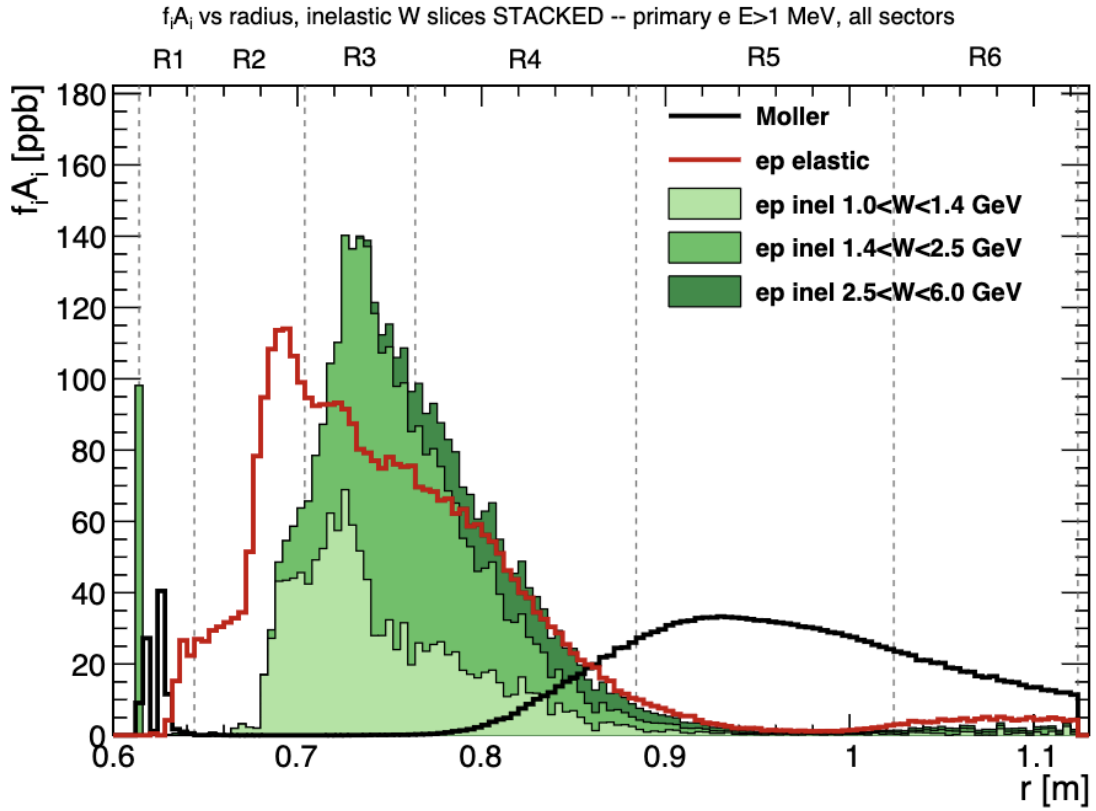
1/7 of the azimuth showing tiling segmentation



- The topological difference between the different processes gives us constraining power

Asymmetries

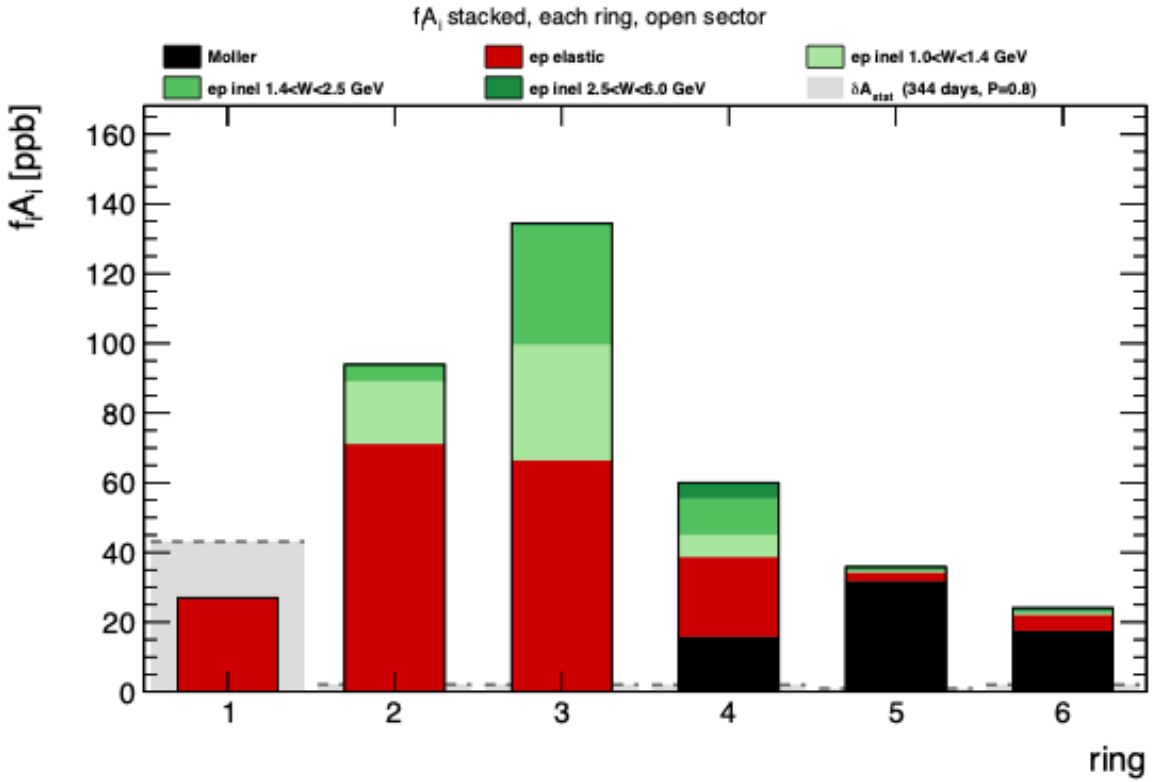




- The spectrometer does a great job separating the ep-elastic from the Moller events
- While the ep-inelastic is small in rate the large associated asymmetries make it very important in the extraction

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = mE \frac{G_F}{\sqrt{2}\pi\alpha} \frac{4\sin^2\Theta}{(3+\cos^2\Theta)^2} Q_W^e$$

Measured asymmetries

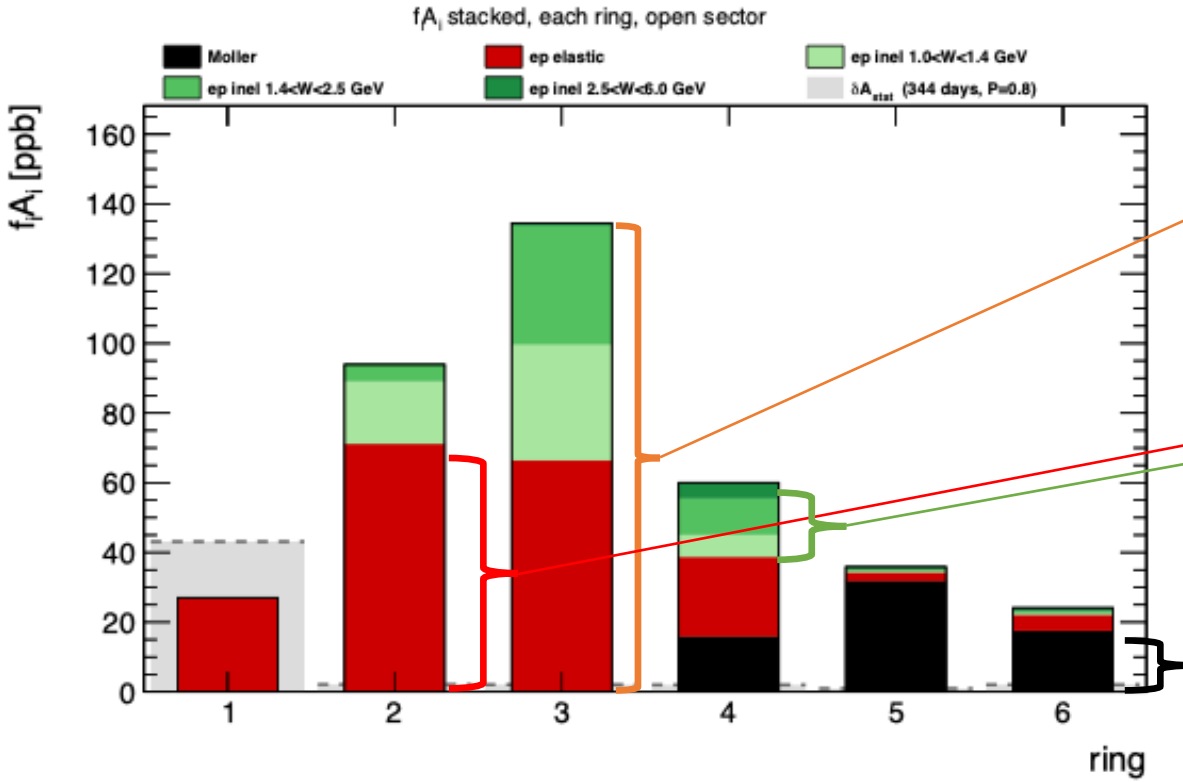


$$A^{\text{meas}} = \underbrace{f_{\text{Møller}} A_{\text{Møller}}}_{\text{signal}} + \underbrace{f_{ep} A_{ep} + f_{\text{inel}} A_{\text{inel}} + f_{\text{Al}} A_{\text{Al}} + f_{\pi} A_{\pi}}_{\text{backgrounds}}$$

$$f_k = \frac{R_k}{R_{\text{tot}}}$$

- The quartz tiles will measure a convoluted asymmetry for all the electrons that make it through the experiment

Measured asymmetries



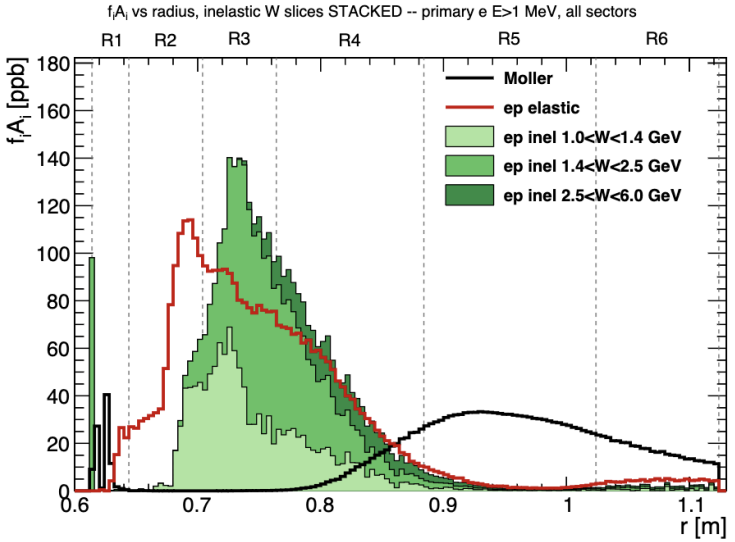
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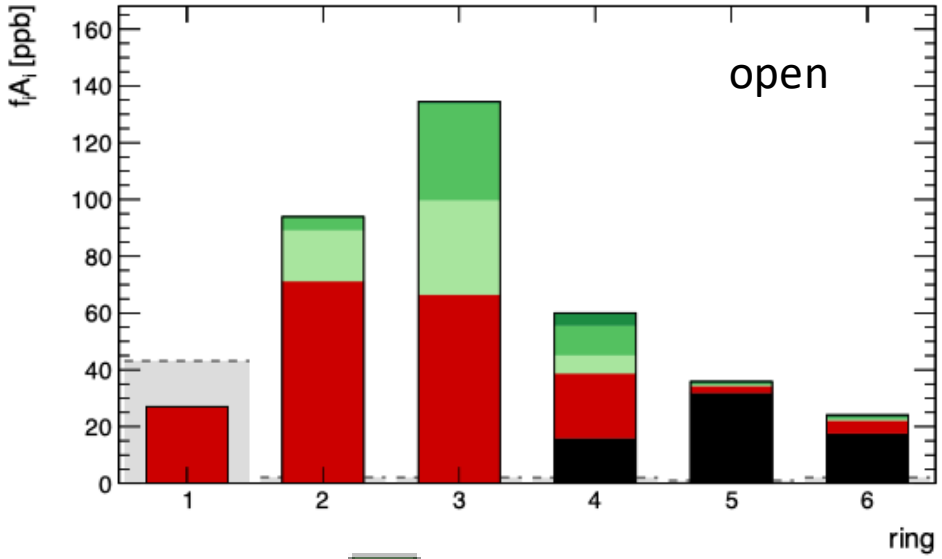
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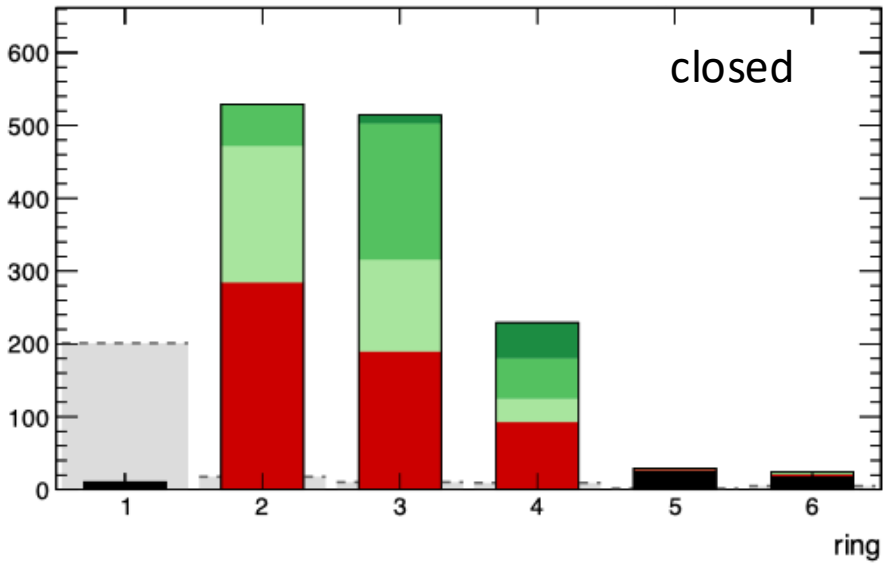
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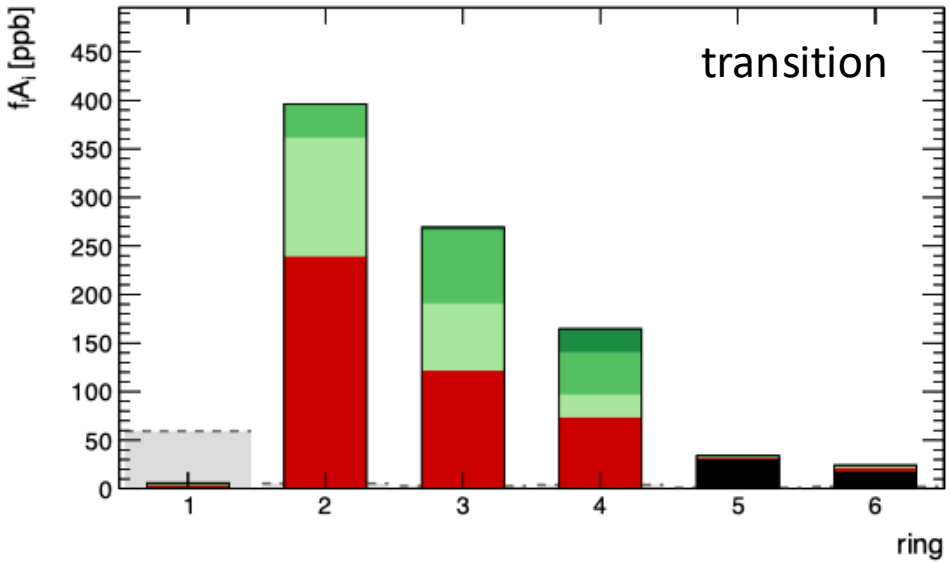
- Part of the challenge is that the large asymmetries in the ep-elastic and ep-inelastic events
- Crucially the ratios between the sectors are different
  - with ring 5 having between 4 to 7 times more signal than background (for the asymmetries)











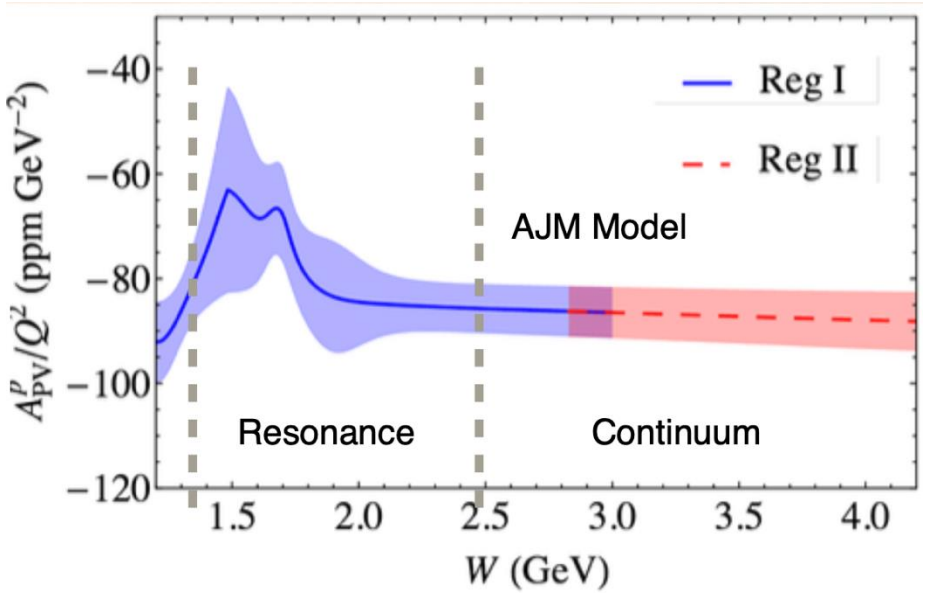
Deconvolution broad strokes

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- Assumes knowledge of the rate and asymmetry dependance on kinematics
- Assumes sufficient knowledge of the rate contributions in each tile from the different processes
  - some of which can be empirically checked through low current tracking runs and comparisons to simulations
- The deconvolution takes all of this combined with the statistical precision of all the tiles to extract a value, quoted for a particular kinematic region (ring 5 open)

Processes	Expected A (ppb)	σ_A (ppb)	$\frac{\sigma_A}{\lvert A \rvert}$ (%)
Moller	-35.20	0.64	1.8
ep-elastic	-19.67	1.82	9.2
ep-inelastic (1)	-439.94	80.6	18.3
ep-inelastic (2)	-433.96	38.3	8.8
ep-inelastic (3)	-384.59	91.5	23.8
eAl-elastic	297.27	83.01	27.9

Deconvolution broad strokes



- Any improvement in our understanding of the ep-inelastic (especially the continuum) would reduce systematics in the extraction

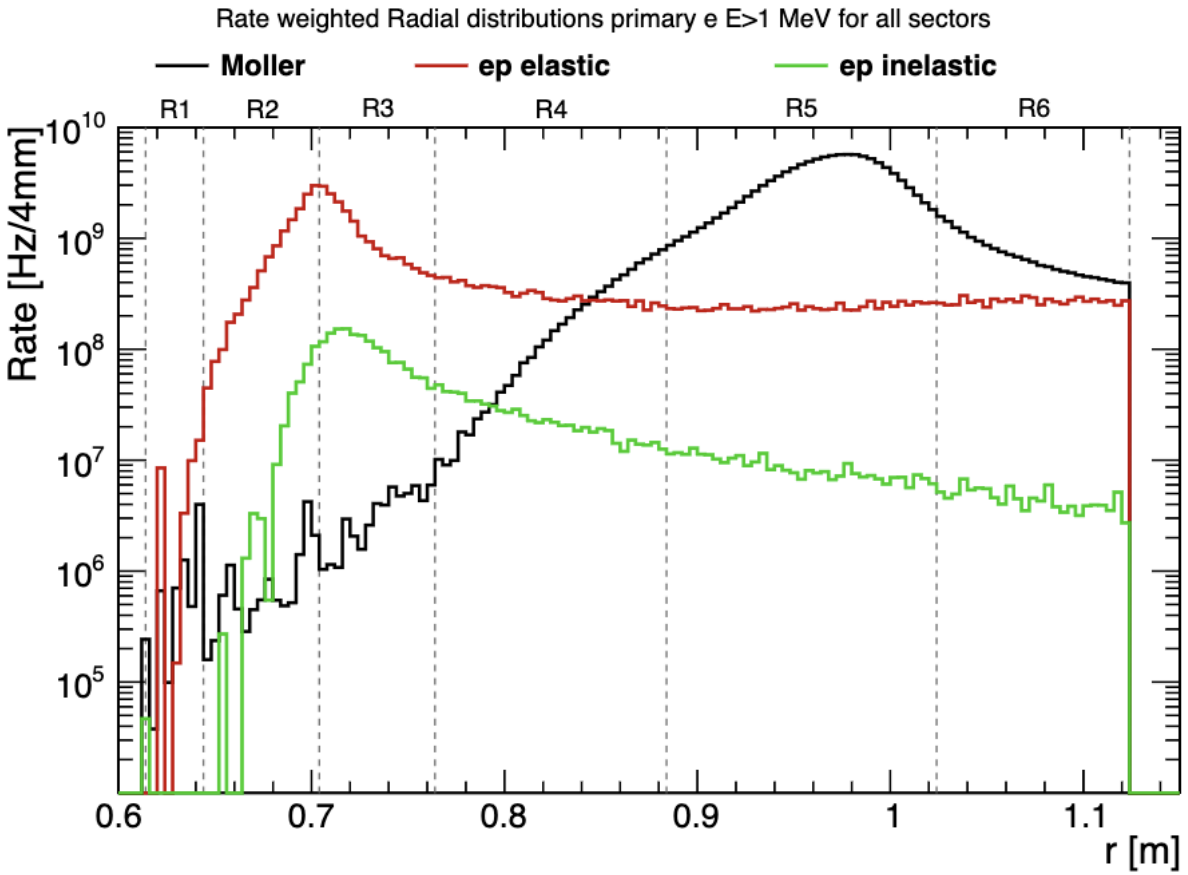
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Process	Correction (%)	Systematic Error (%)
e-p elastic	1.14	0.08
e-p inelastic ($W < 1.4$ GeV)	-1.34	0.22
e-p inelastic ($1.4 < W < 2.5$ GeV)	-1.54	0.11
e-p inelastic ($W > 2.5$ GeV)	-1.66	0.35
e-Al elastic	0.87	0.09
e-Al other	< 0.10	< 0.10

Why will it work!?

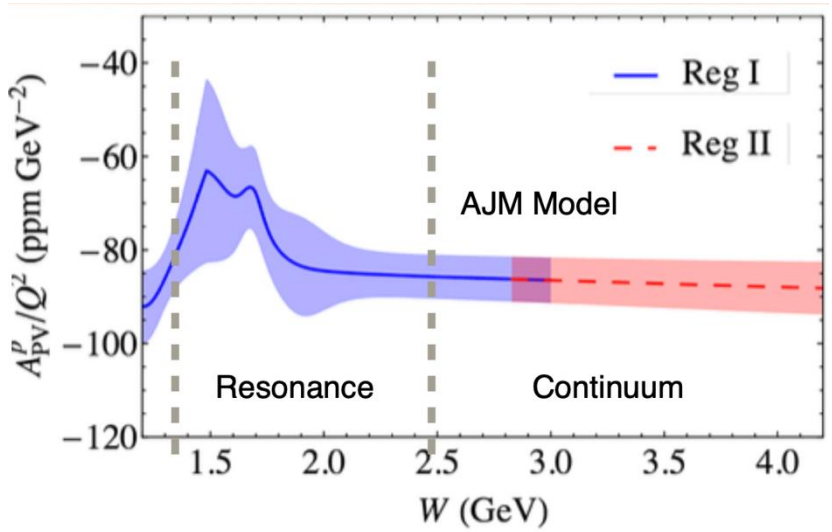
- Because of the significant amount of separation between the difference processes
  - mostly independent measurements (ee, ep-elastic)

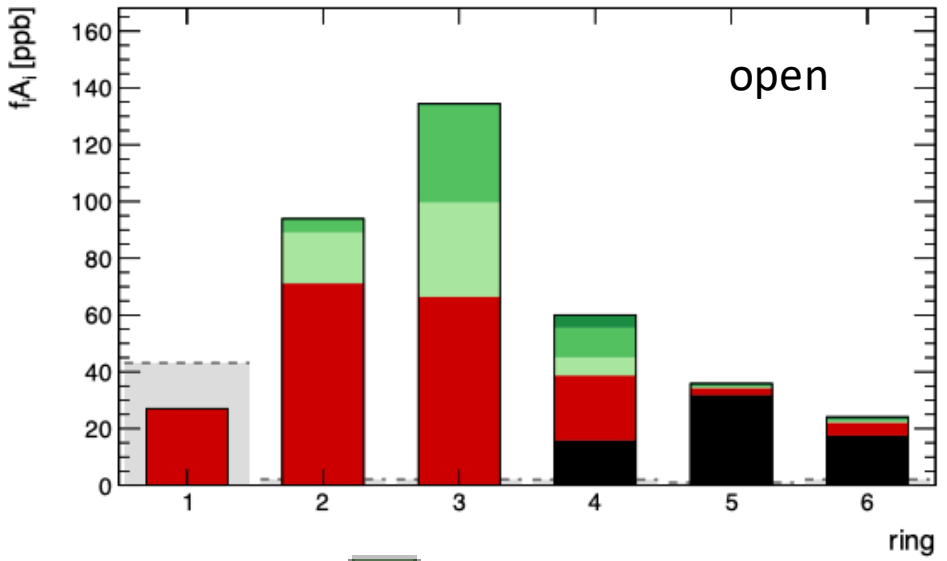
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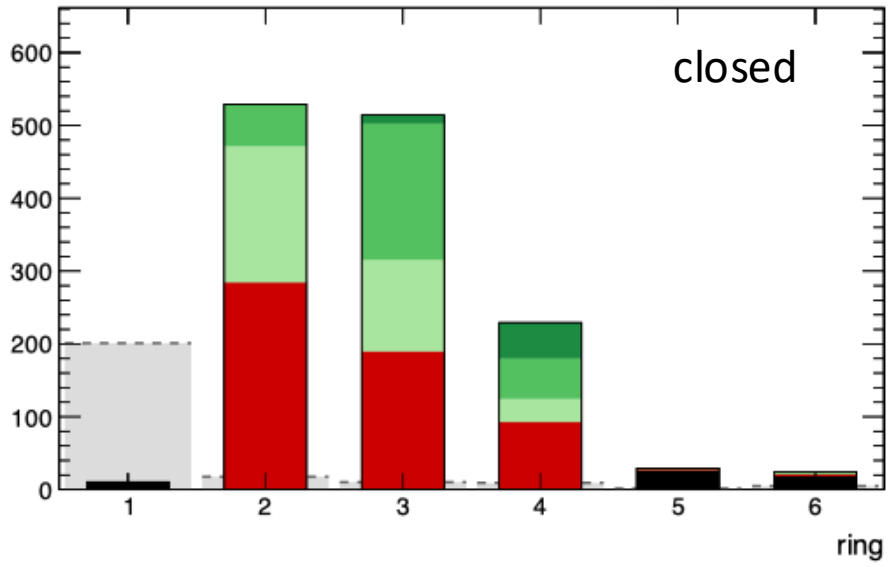


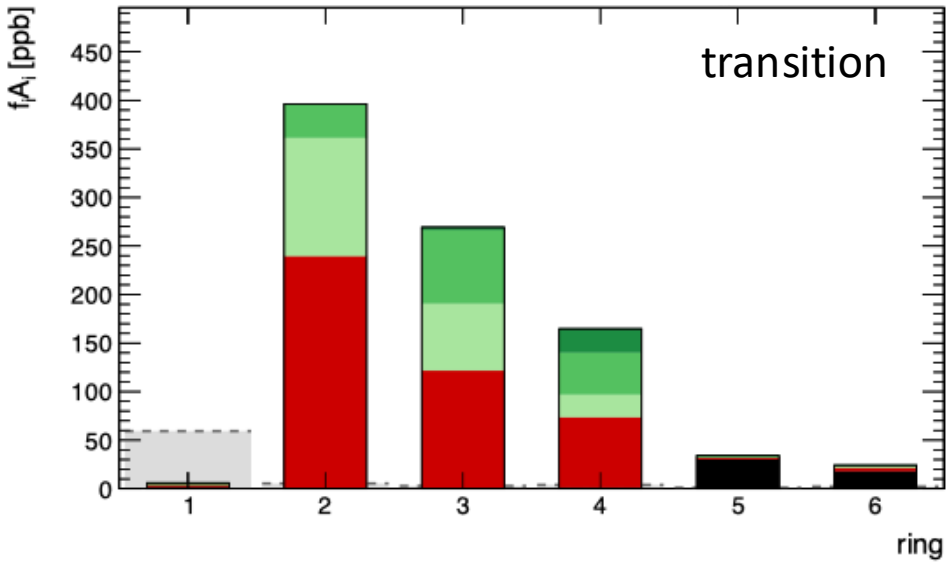
ep-Inelastic

- The ep-inelastic makes potentially significant contributions to both the epE and ee measurements

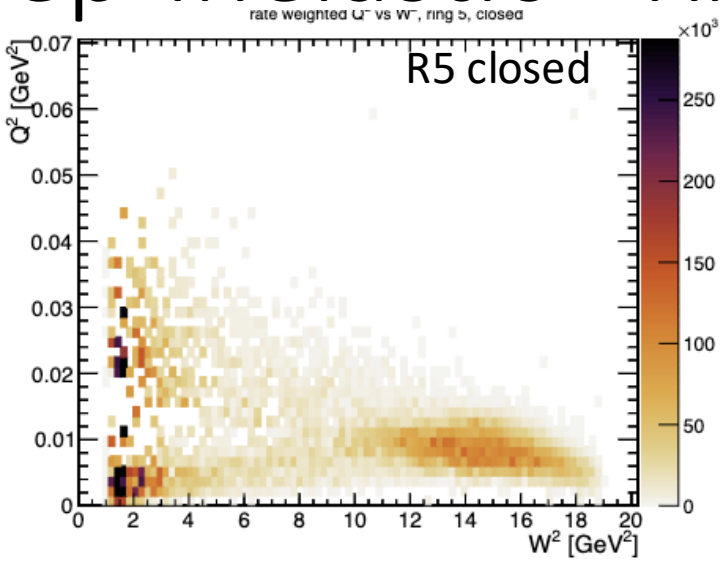


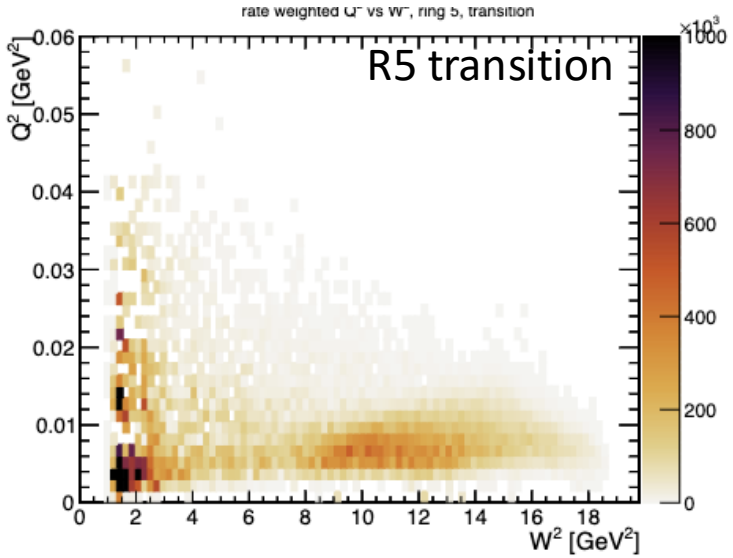


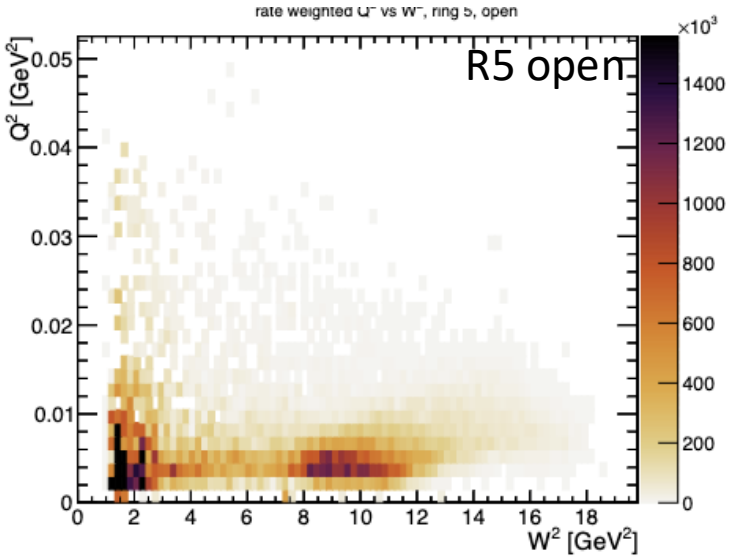




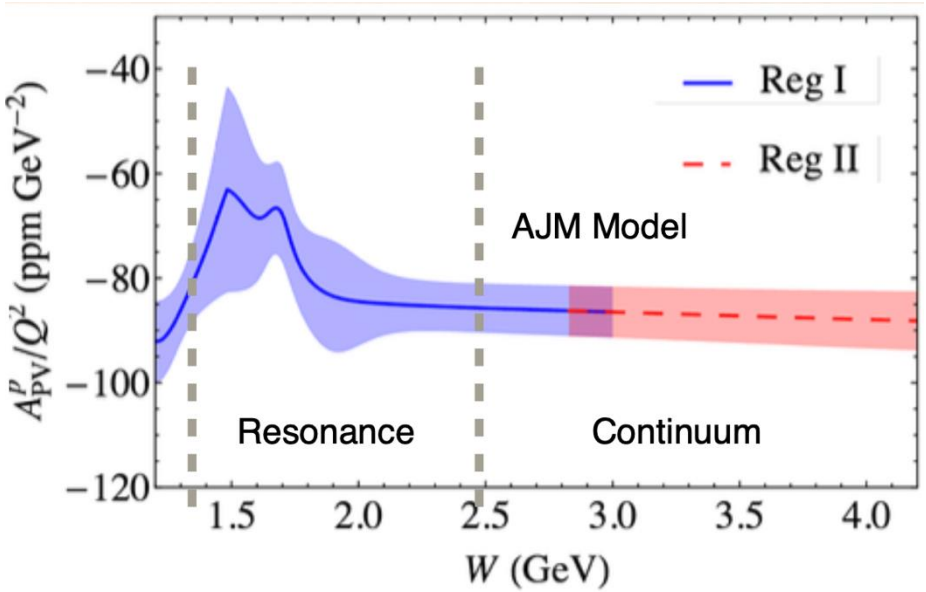
ep-Inelastic - Ring 5

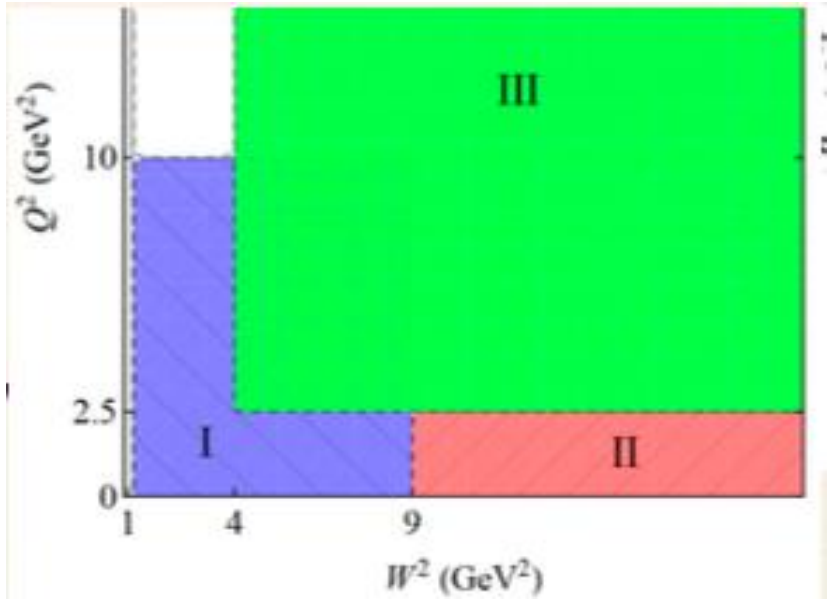




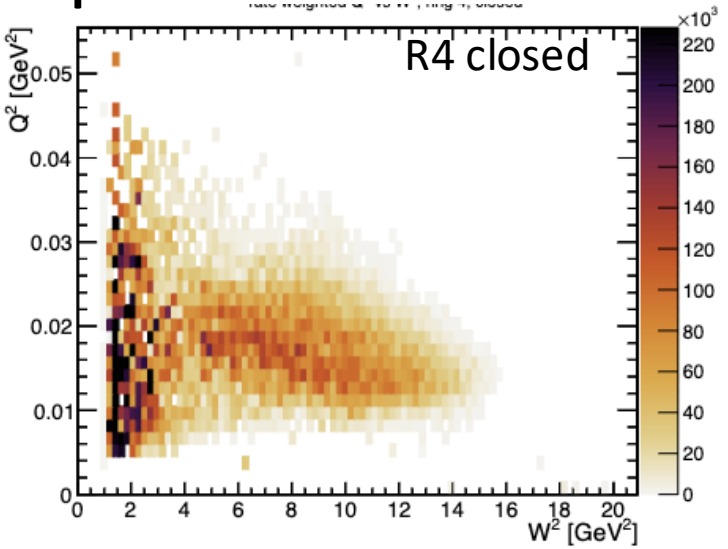


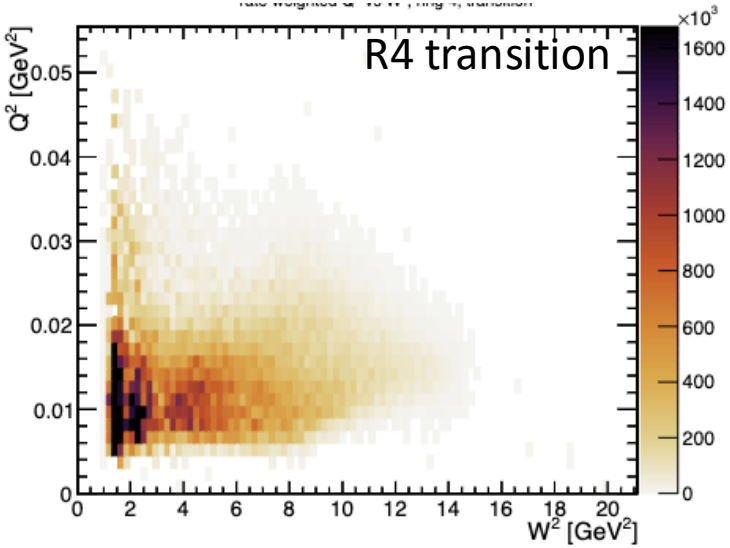
- For very low Q^2 one needs a model as a function of W
  - we assume a constant A_{PV}/Q^2 in the Delta, Resonance, and Continuum regions

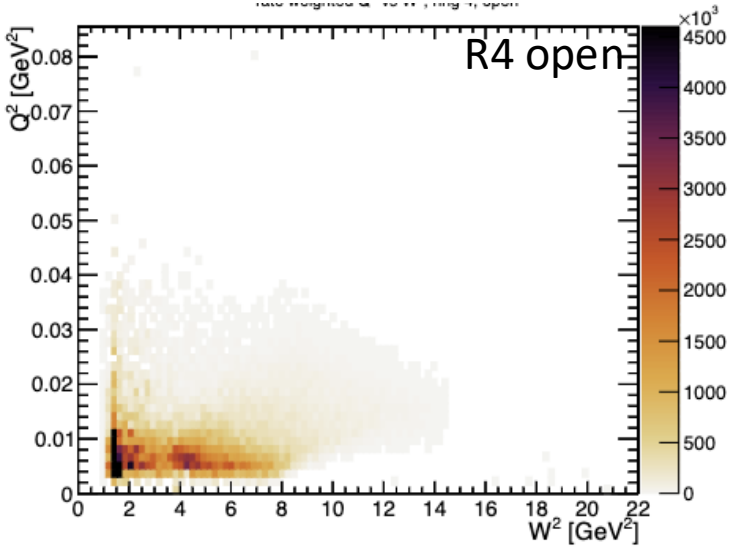




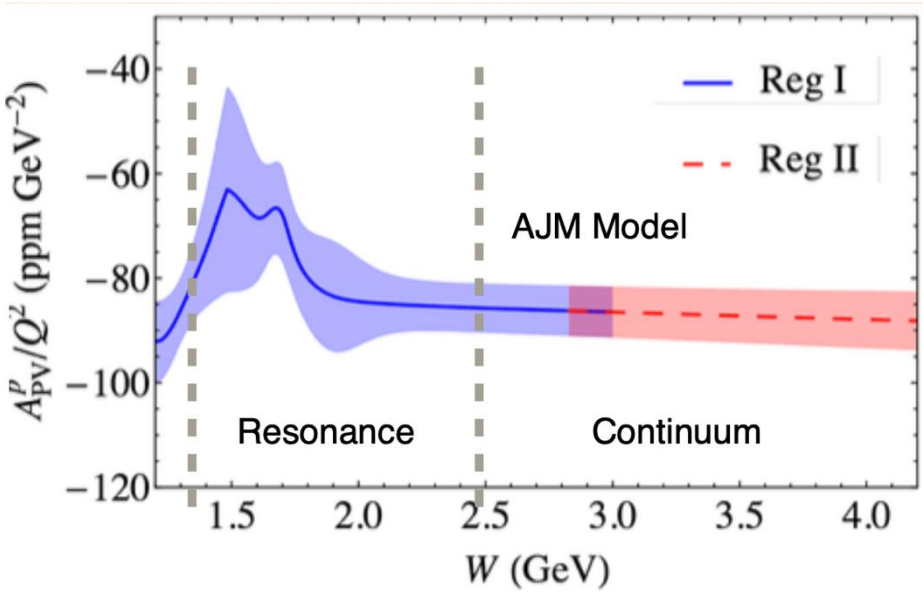
ep-Inelastic - Ring 4

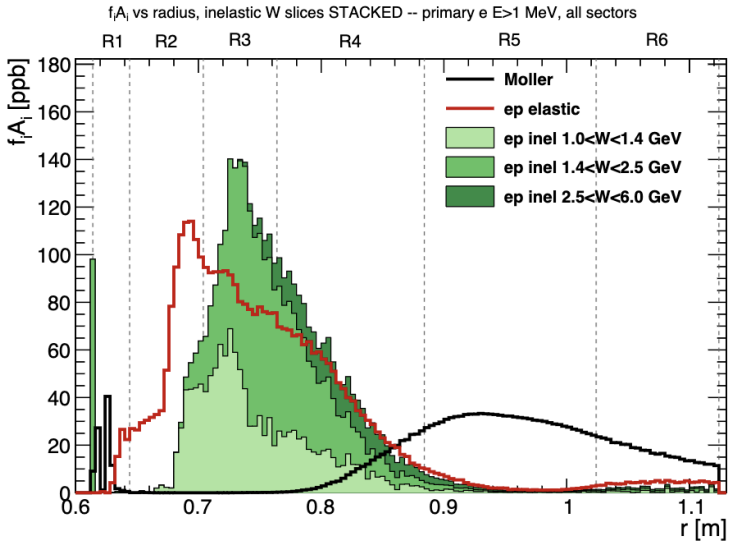




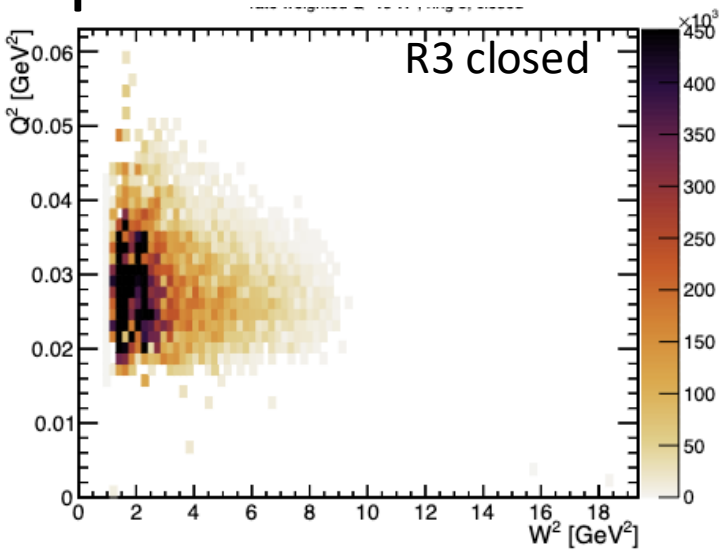


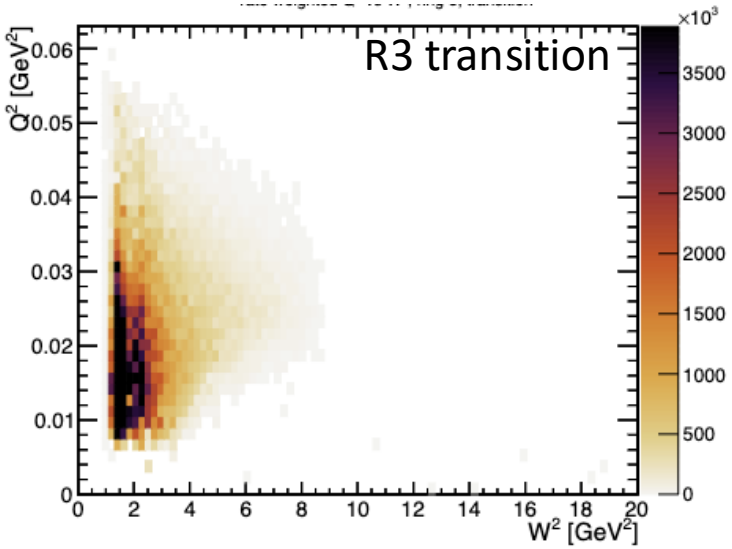
- Ring 4 - closed has the largest fraction of continuum events

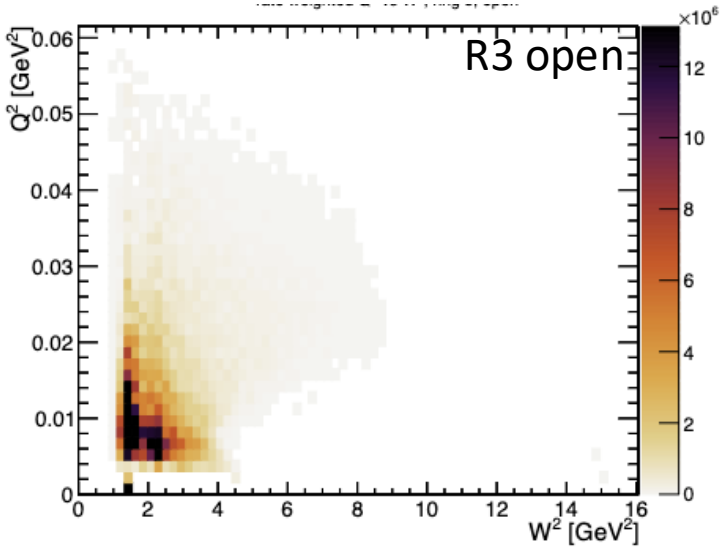




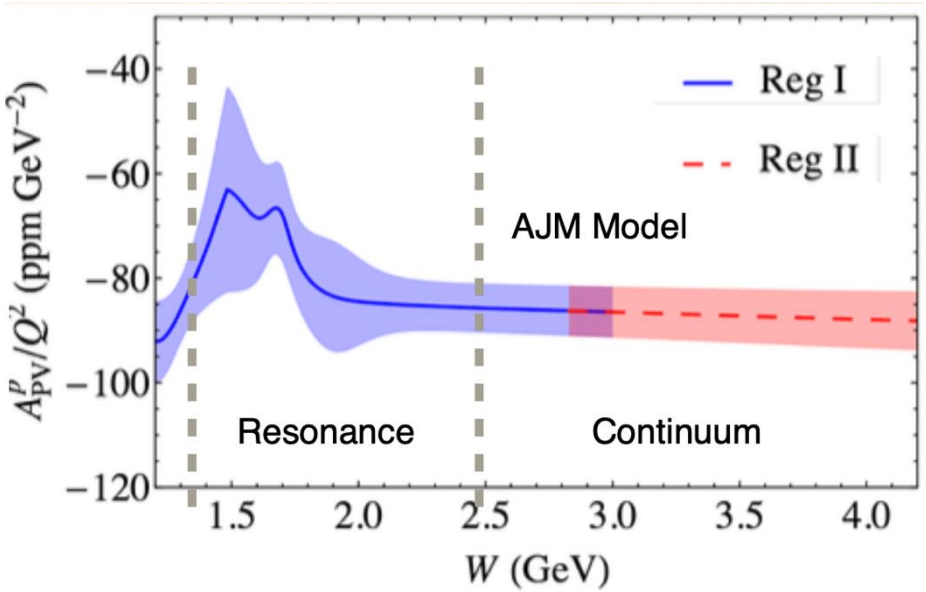
ep-Inelastic - Ring 3

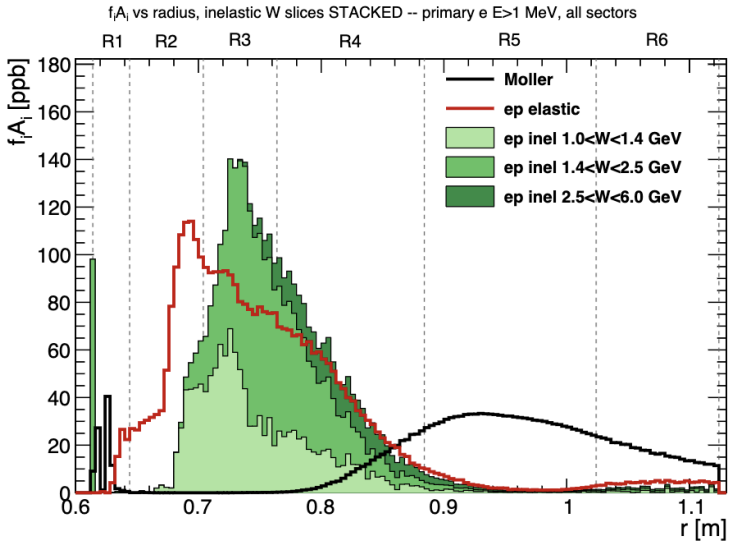




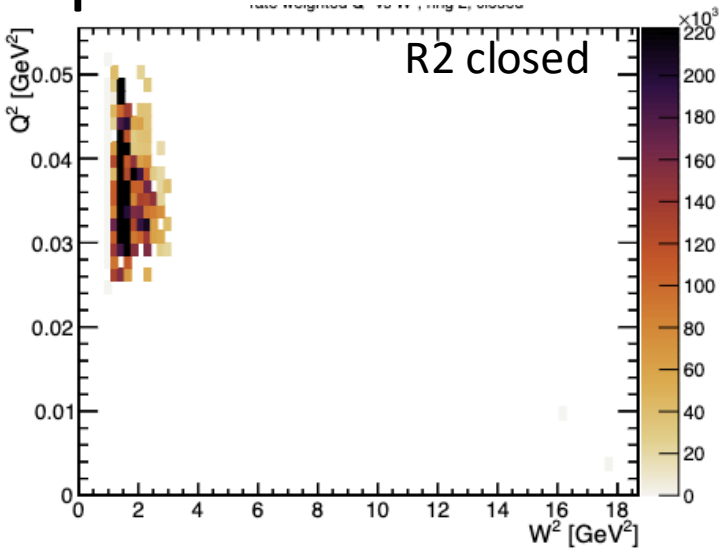


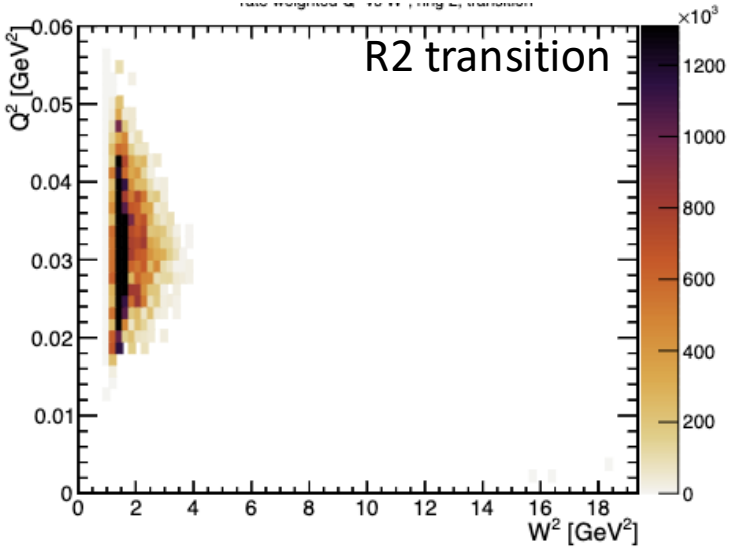
- Ring 3 - transition constrains the resonance region

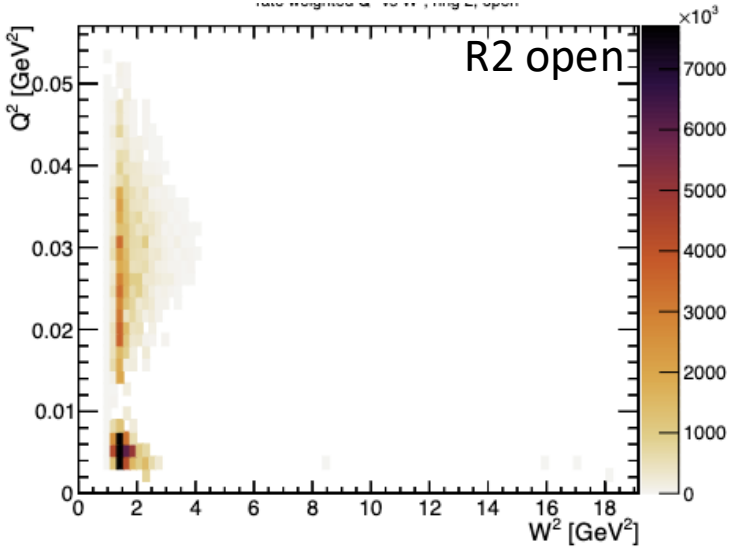




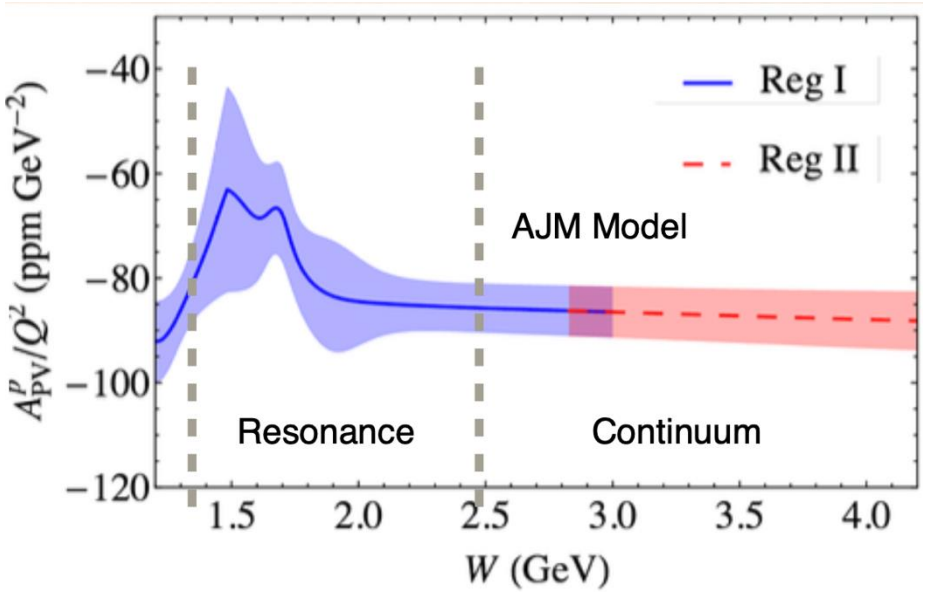
ep-Inelastic - Ring 2

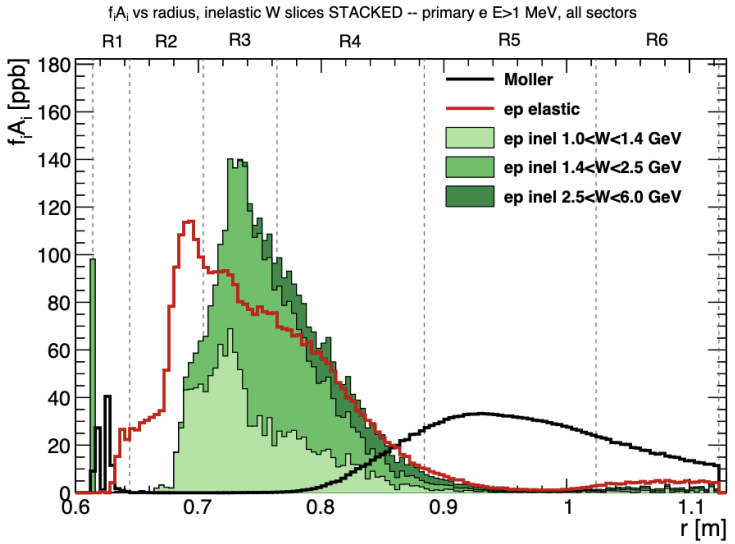




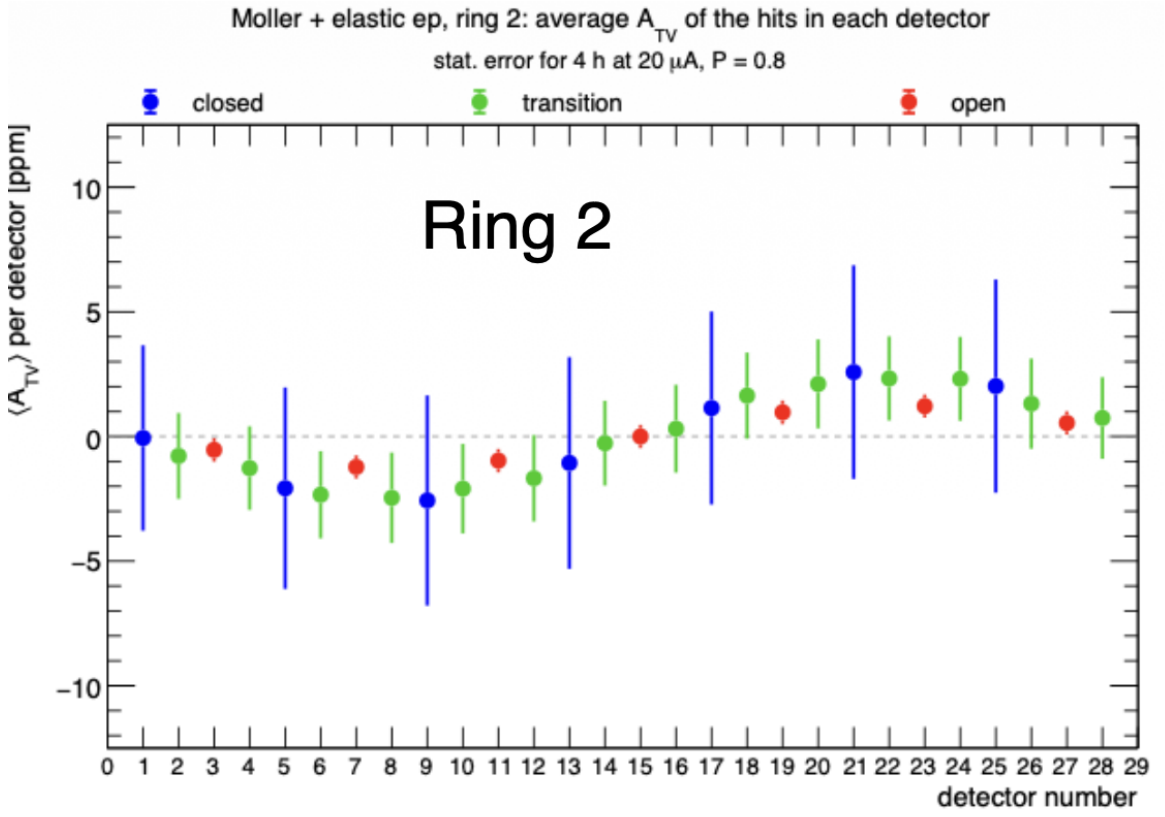


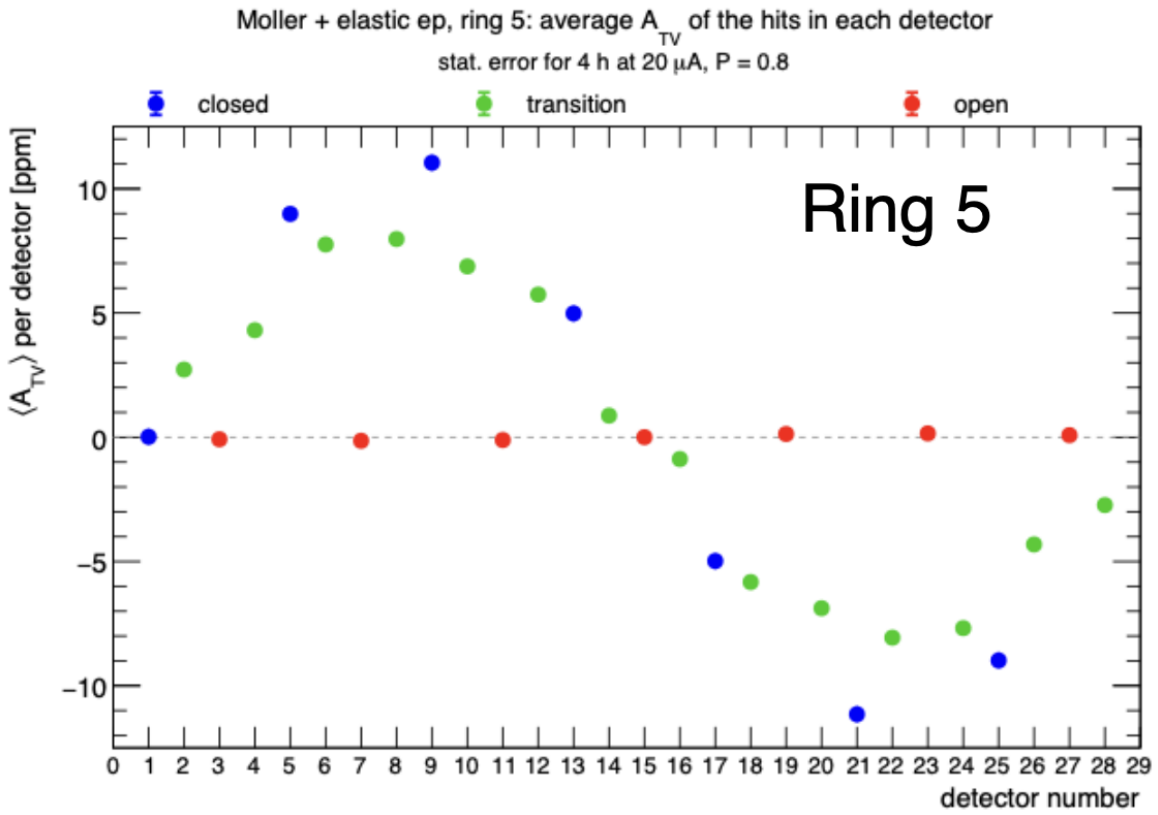
- Ring 2 - closed constrains the Delta region





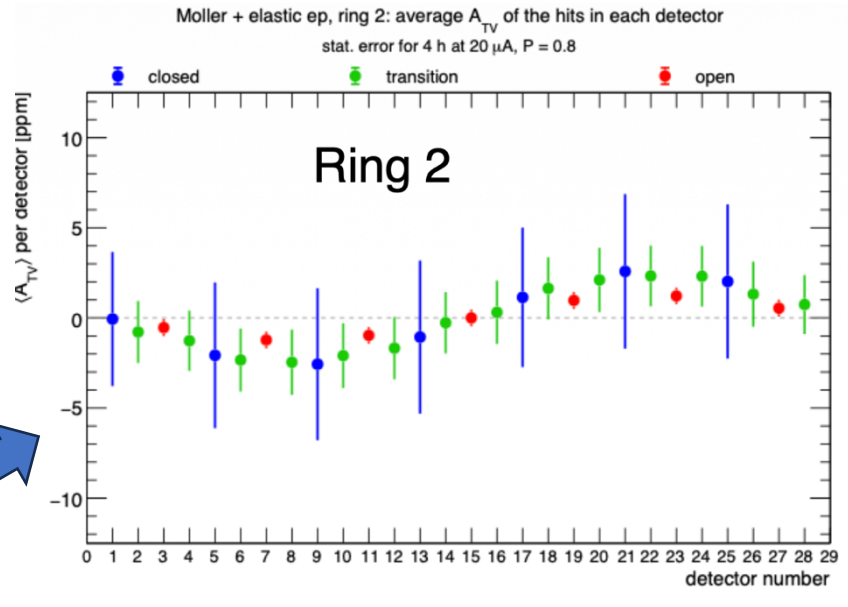
First physics

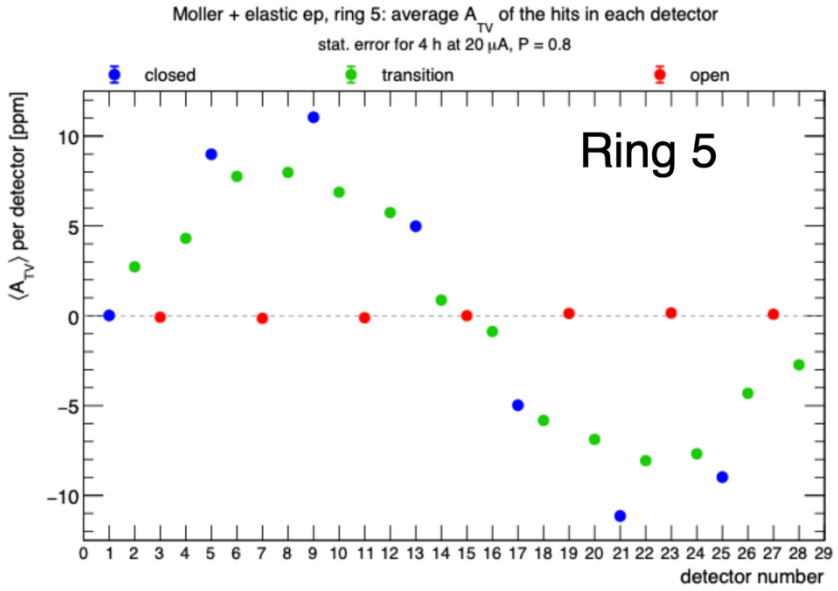




- First physics results next summer will come from the transverse running with the LH2 target

First physics





$$A_n^e = \frac{m_e\sqrt{Q^2}\sigma_{tot}^{\gamma p}}{8\pi^2}\frac{F_1 - \tau F_2}{F_1^2 + \tau F_2^2}\left(-\log\frac{Q^2}{m_e^2} + 2\right). \quad (24)$$

Phys.Lett.B 599 (2004) 48

https://arxiv.org/pdf/hep-ph/0407167

$$A_T(\phi) \equiv \frac{2\pi}{\sigma^{\uparrow} + \sigma^{\downarrow}}\frac{d(\sigma^{\uparrow} - \sigma^{\downarrow})}{d\phi} \equiv \alpha_T \cdot \sin\phi\,,$$

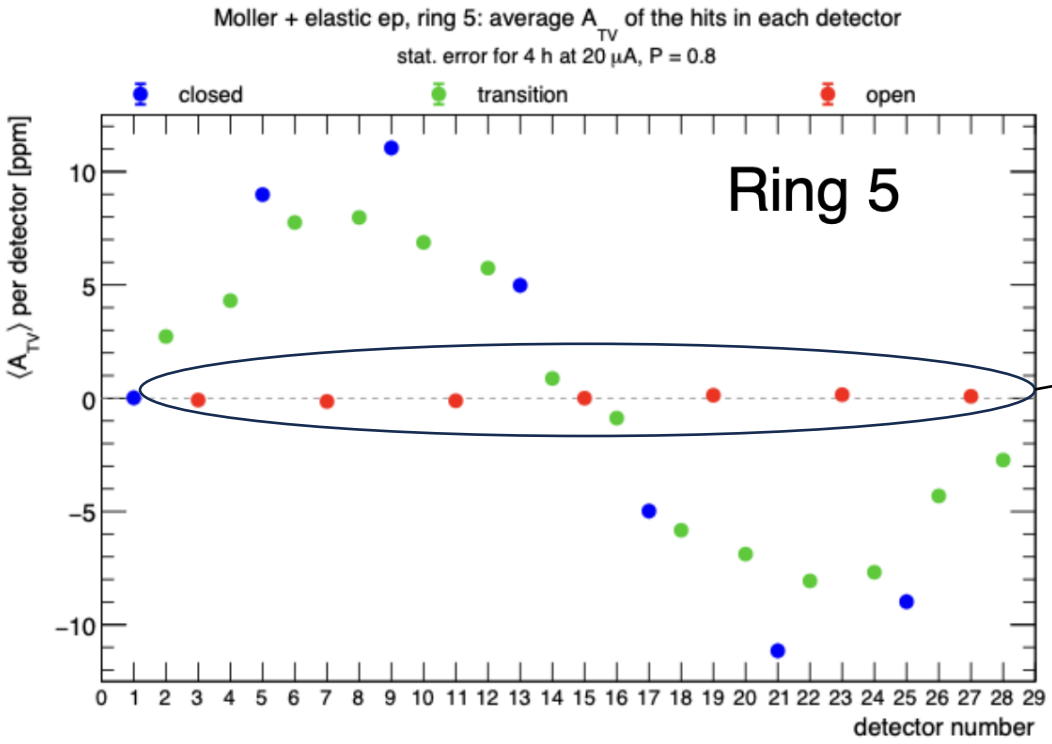
$$\alpha_T^{LO} = \frac{1}{\sin\phi}\frac{d\sigma^{\phi}/d\Omega}{d\sigma^{\mathrm{Born}}/d\Omega}\,.$$

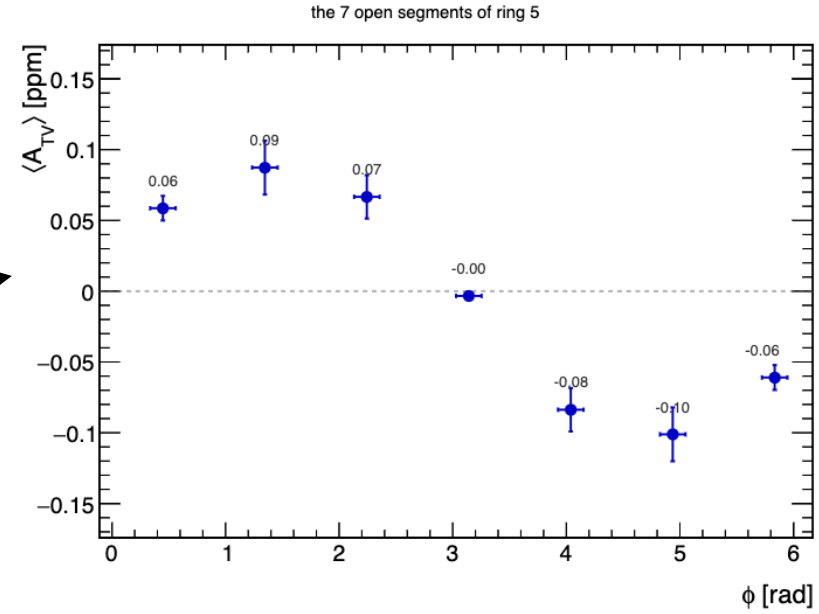
Phys.Rev.D 69 (2004) 113001, *Phys.Rev.D* 71 (2005) 059903 (erratum)

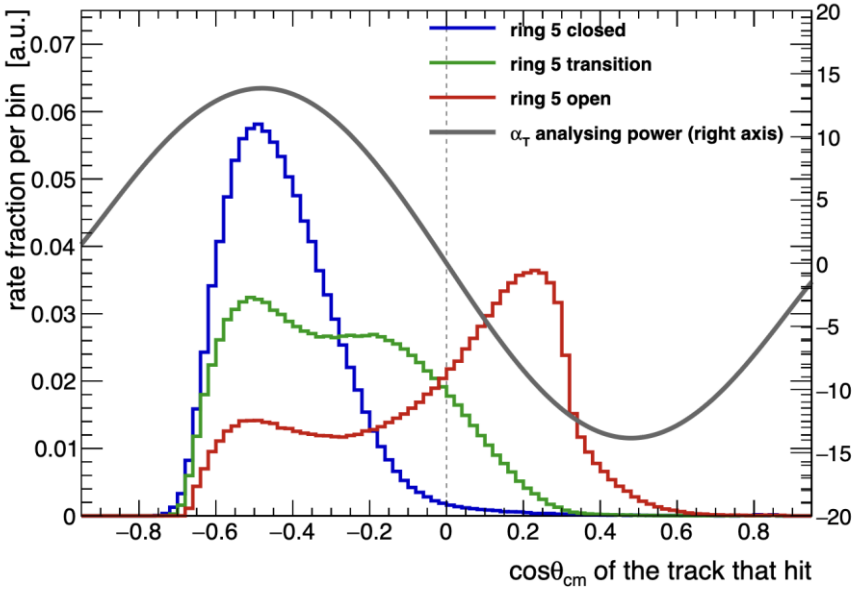
https://arxiv.org/pdf/hep-ph/0402221

- Our simulations results are based on the Afanasev & Merenkov (ep-Elastic) and Dixon & Schreiber (ee)

About zero asymmetry in R5 - open

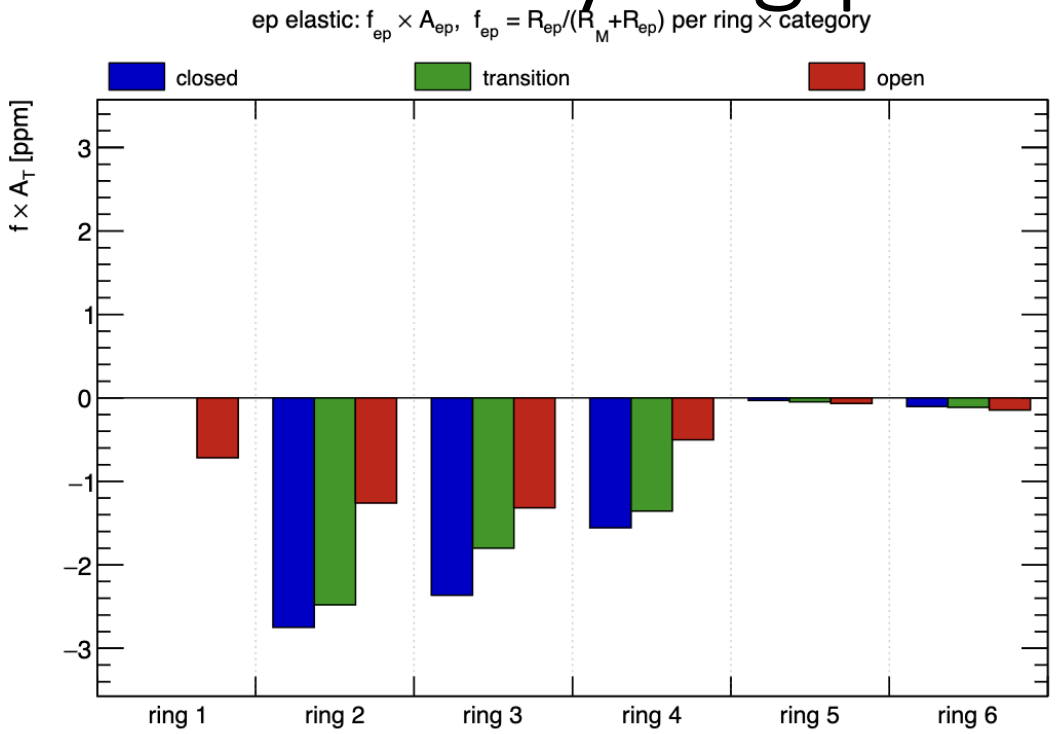


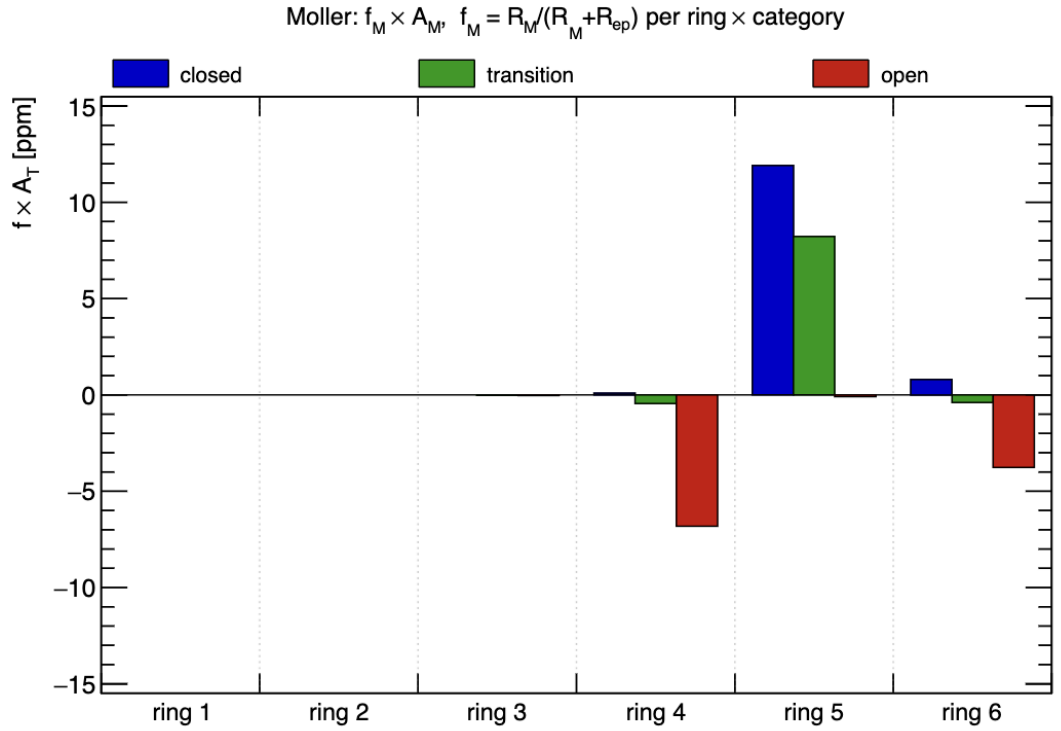




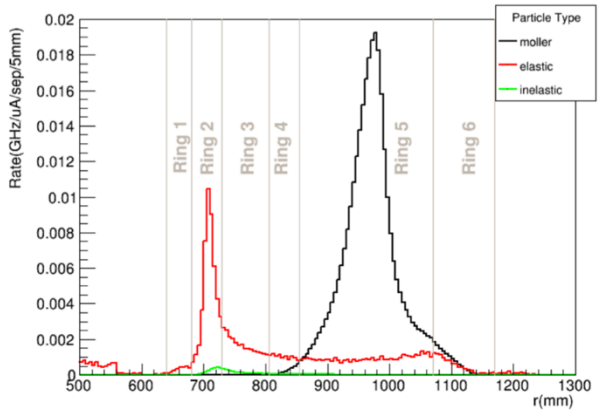
- The closed and transition sectors mostly sample backwards electrons with large positive analyzing powers
- The open sector has approximately equal weights of positive and negative analyzing powers from forward and backward electrons

Measured Analyzing powers

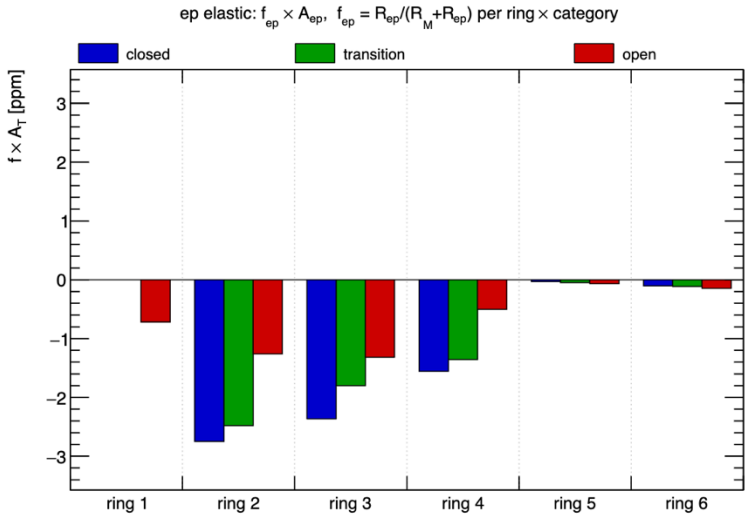


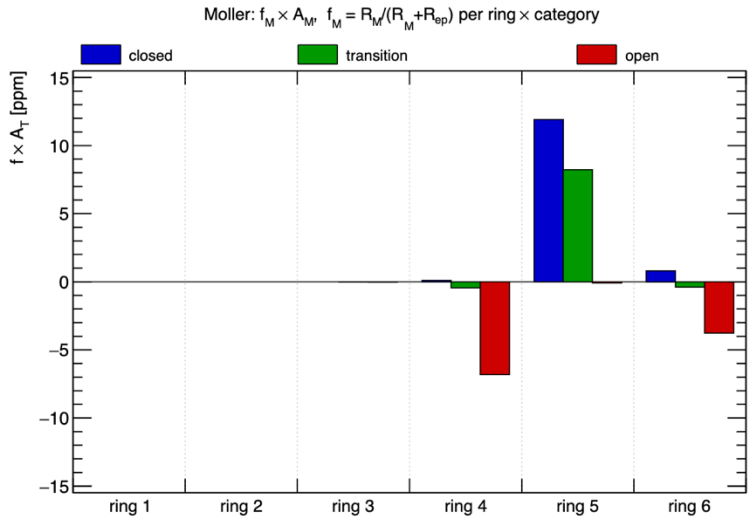


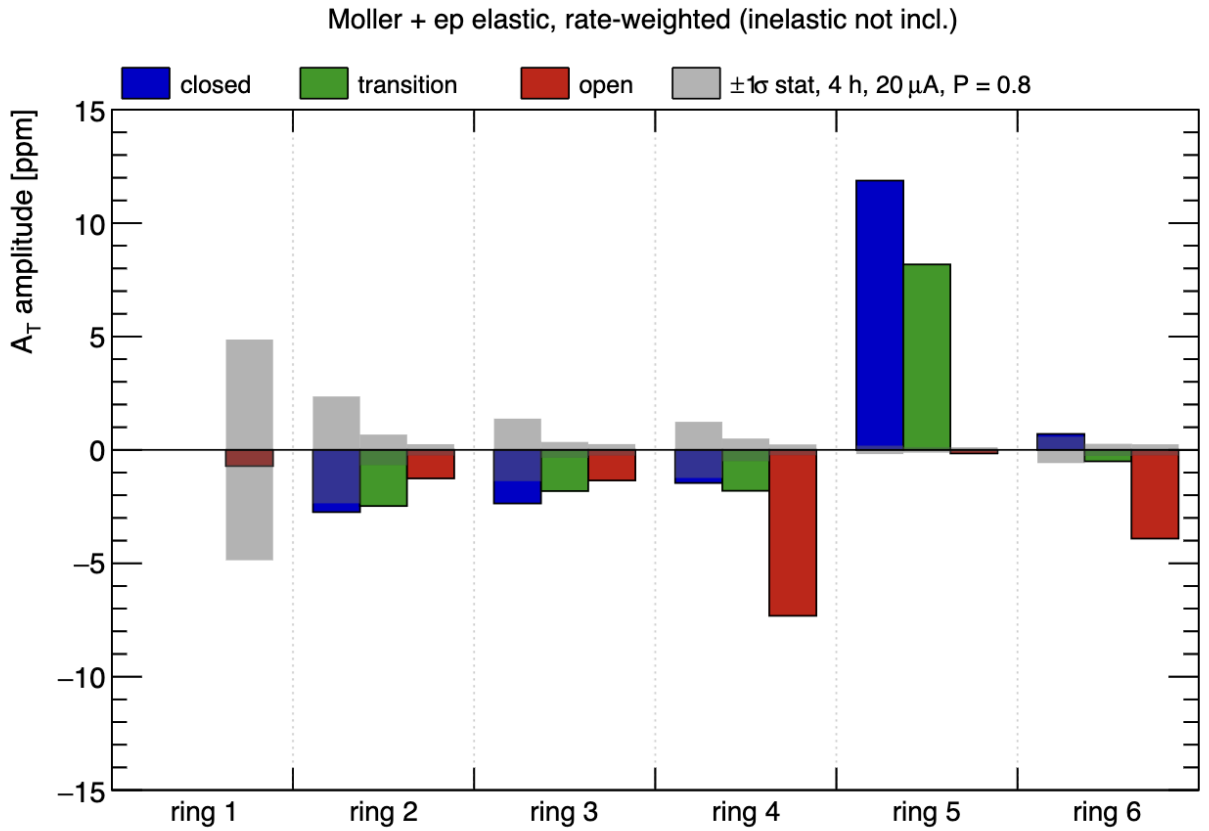
- Ignore the ep-inelastic for transverse results:
  - Rates are small
  - The asymmetry is expected to be small or comparable to the ep-elastic



Measured Analyzing powers



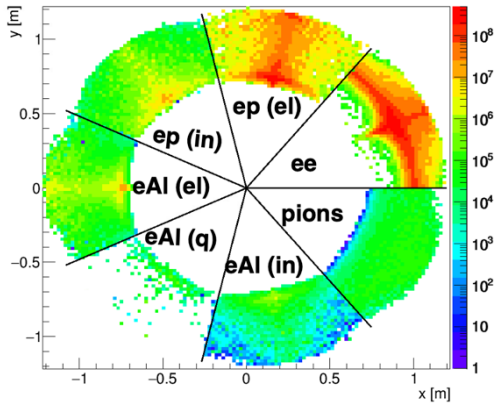




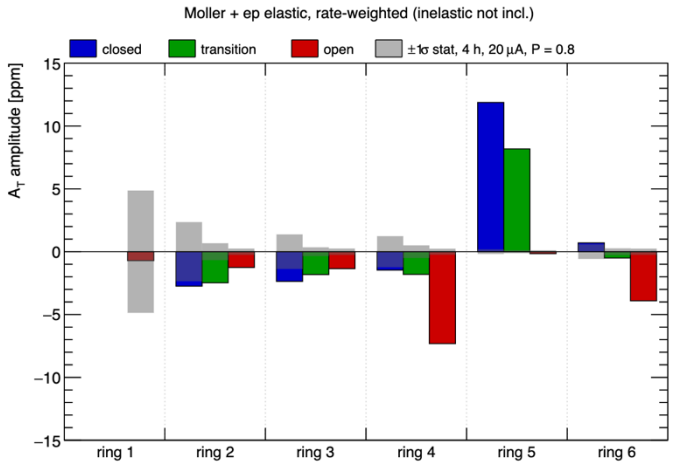
- What we will measure will be compared directly to our simulation
  - testing kinematic behaviour

Summary

- The experimental setup gives allows us to make (largely) independent measurements of both signal and the different backgrounds
- The deconvolution analysis makes use of the known kinematic dependances for rates and asymmetries to extract the highest precision possible for our signal
- The first test for theory will come in the first few hours of MOLLER running



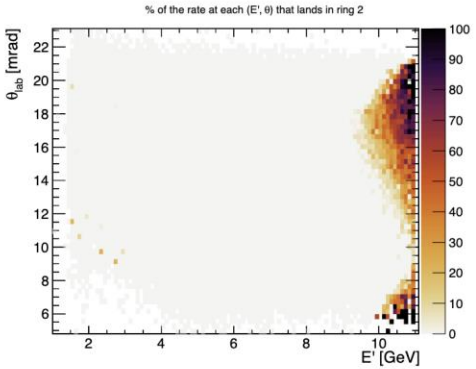
Processes	Expected A (ppb)	σ_A (ppb)	$\frac{\sigma_A}{\lvert A \rvert}$ (%)
Moller	-35.20	0.64	1.8
ep-elastic	-19.67	1.82	9.2
ep-inelastic (1)	-439.94	80.6	18.3
ep-inelastic (2)	-433.96	38.3	8.8
ep-inelastic (3)	-384.59	91.5	23.8
eAl-elastic	297.27	83.01	27.9

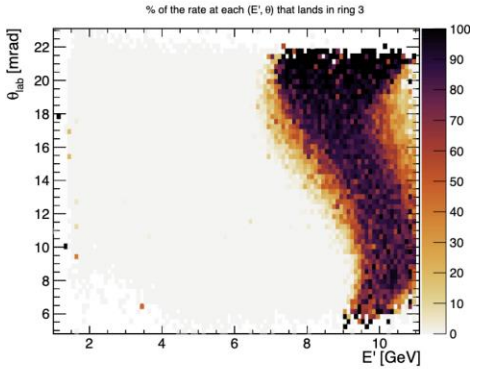


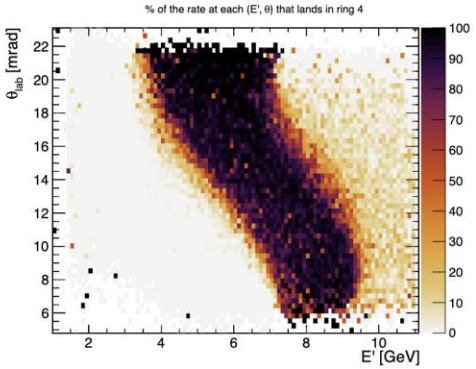
Backups

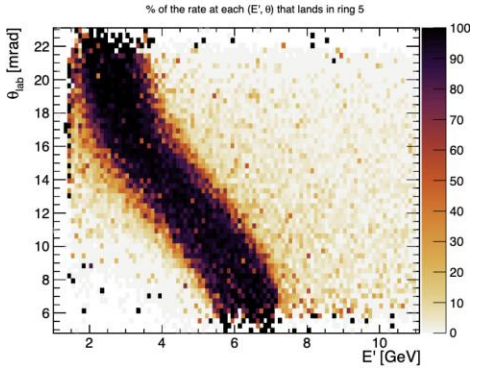
ep-inelastic

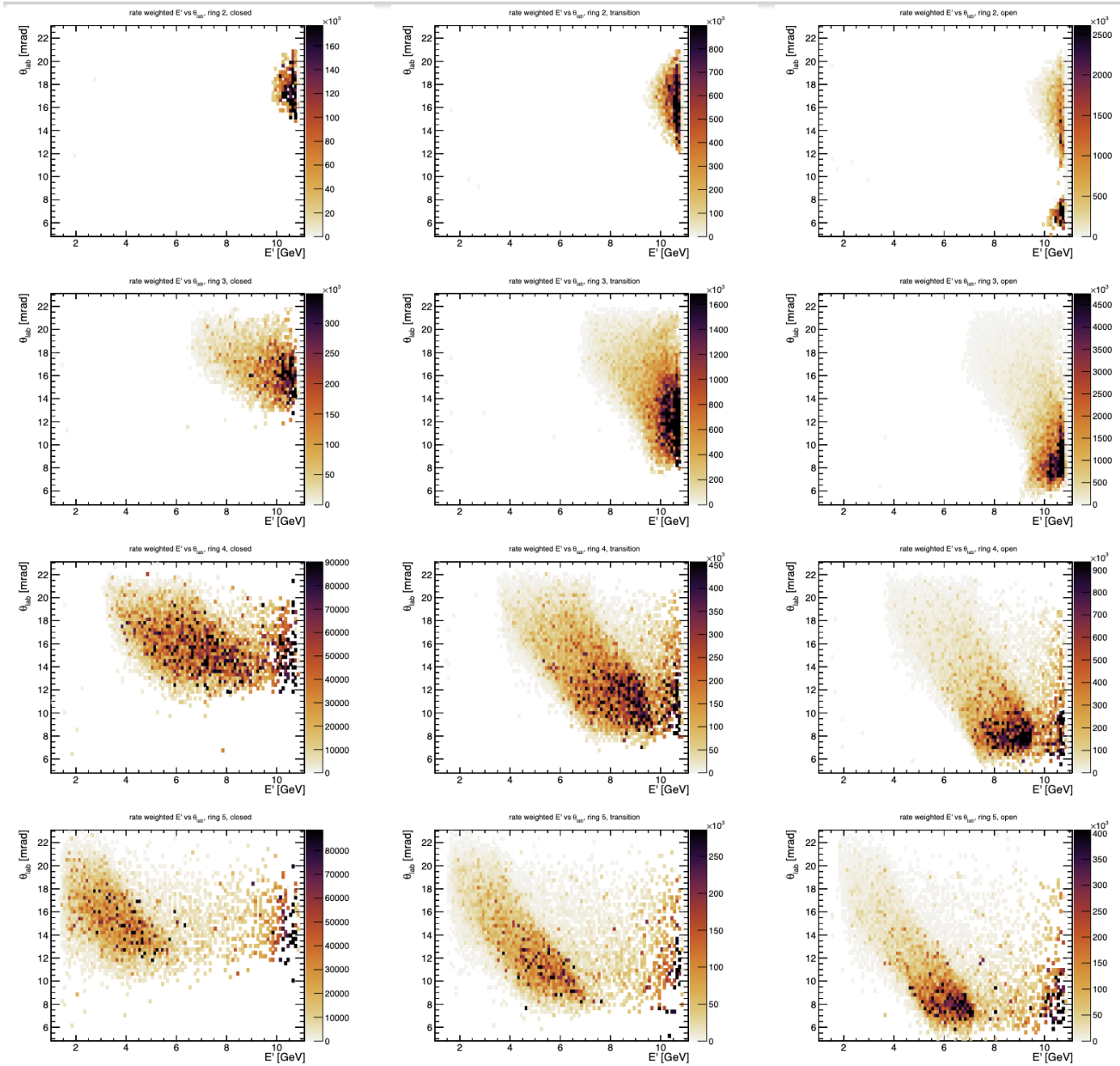
- E’ vs theta_CM





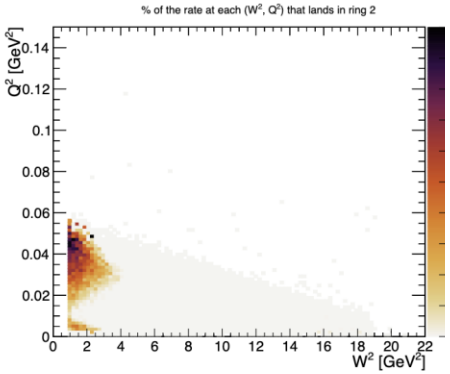


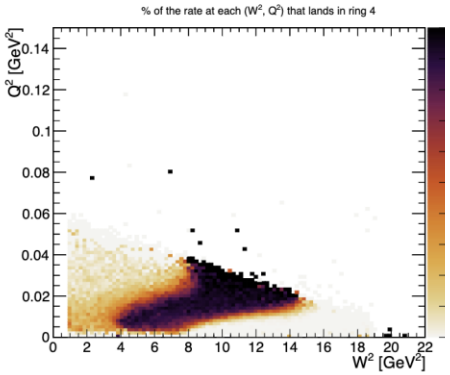


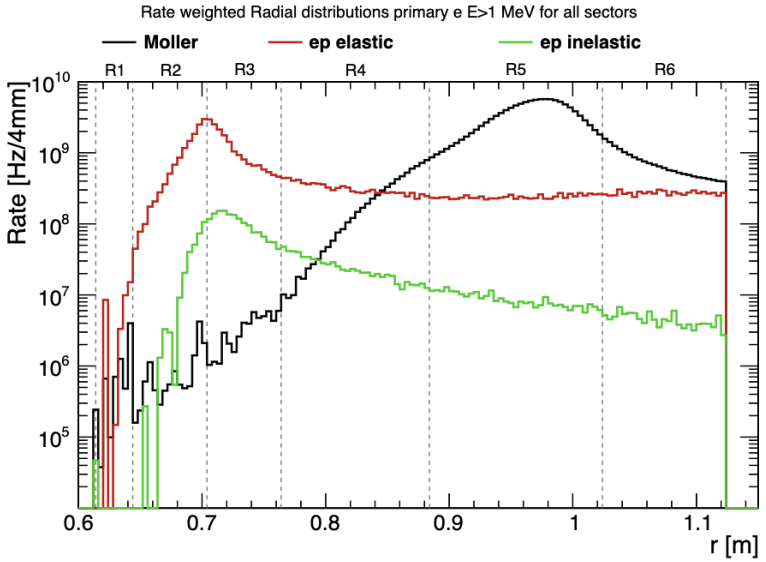


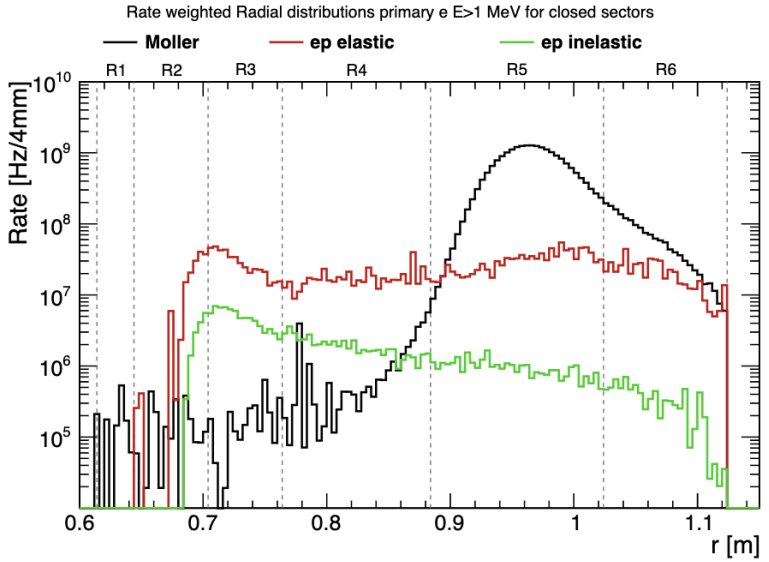
ep-inelastic

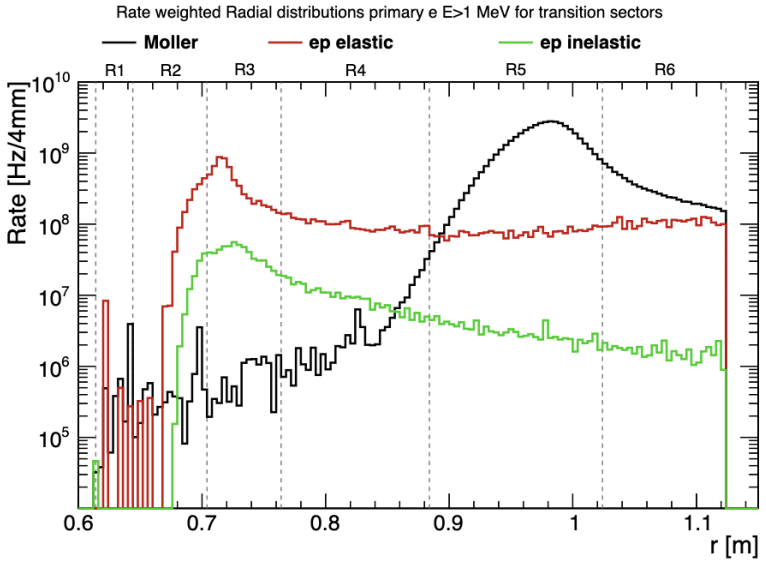
- W2 vs Q2

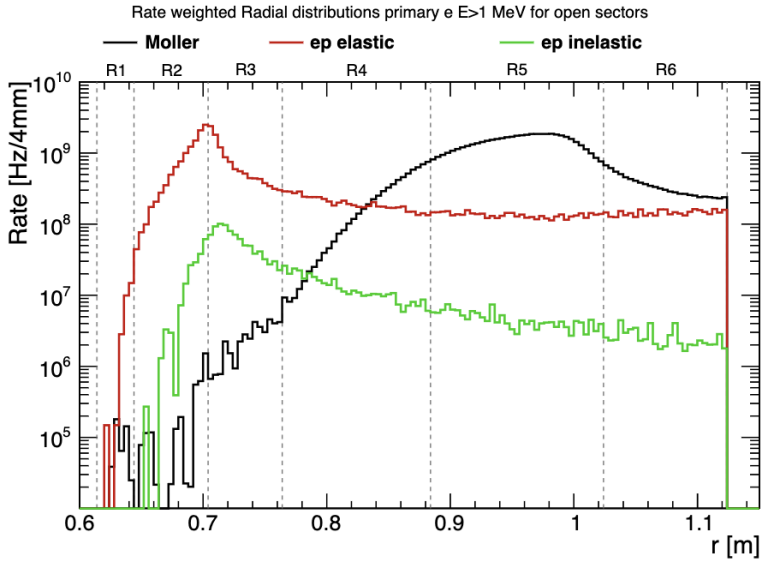


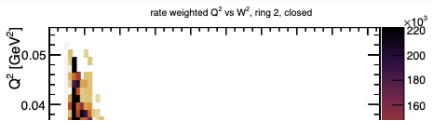


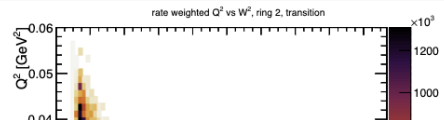


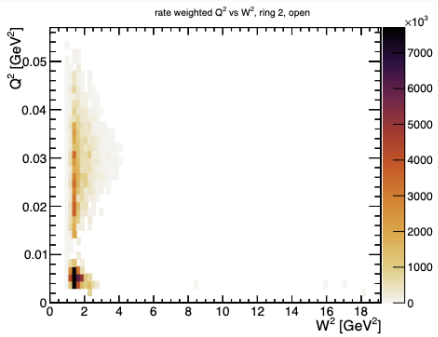


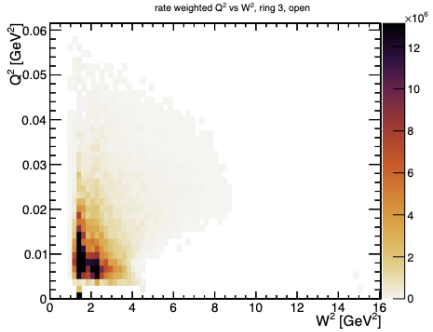


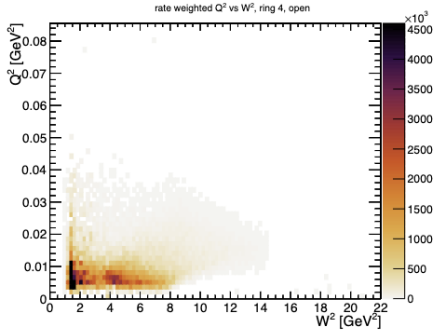


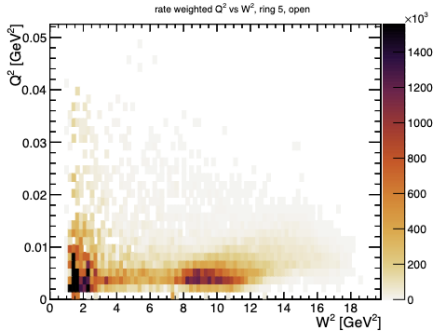


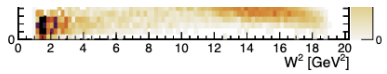


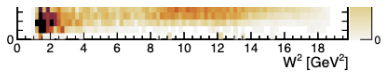




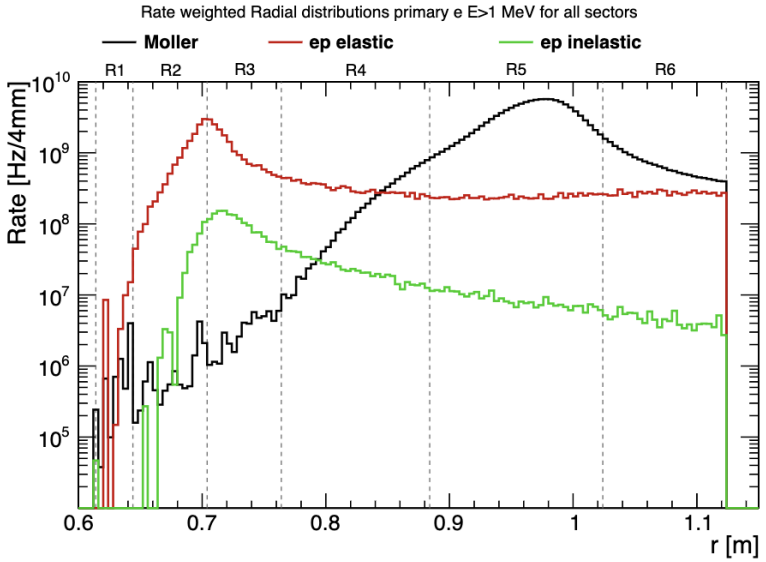


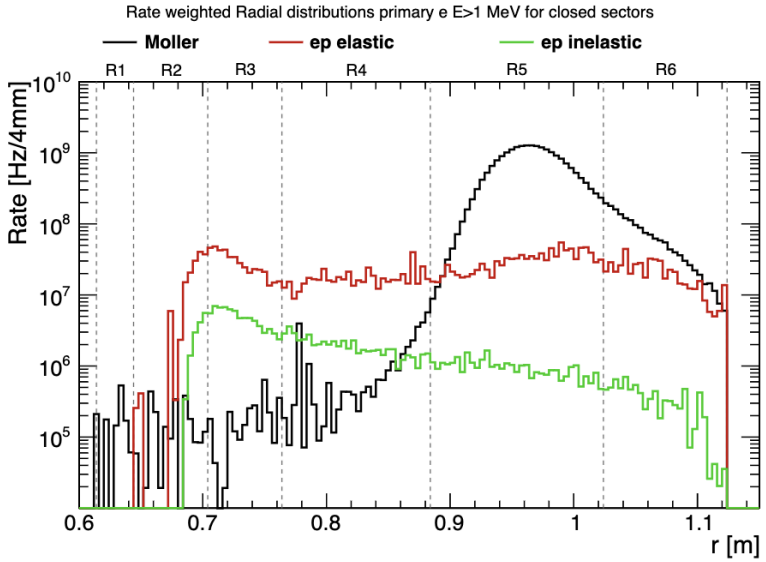


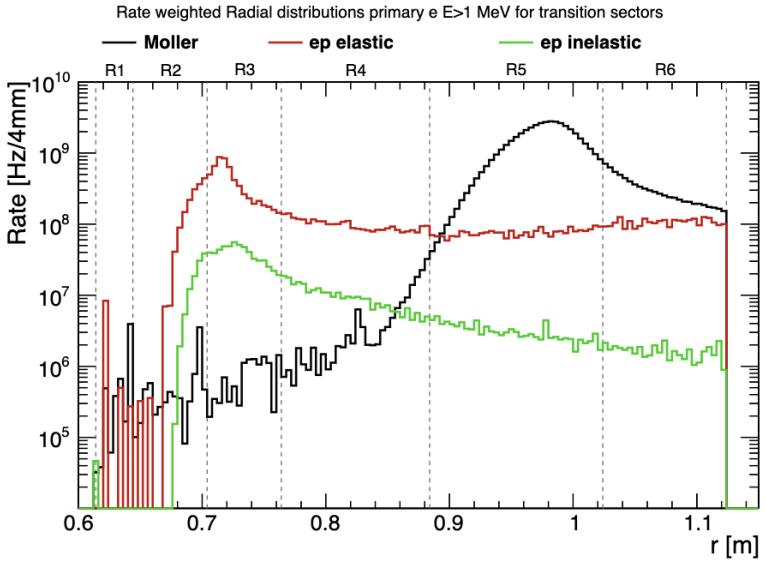


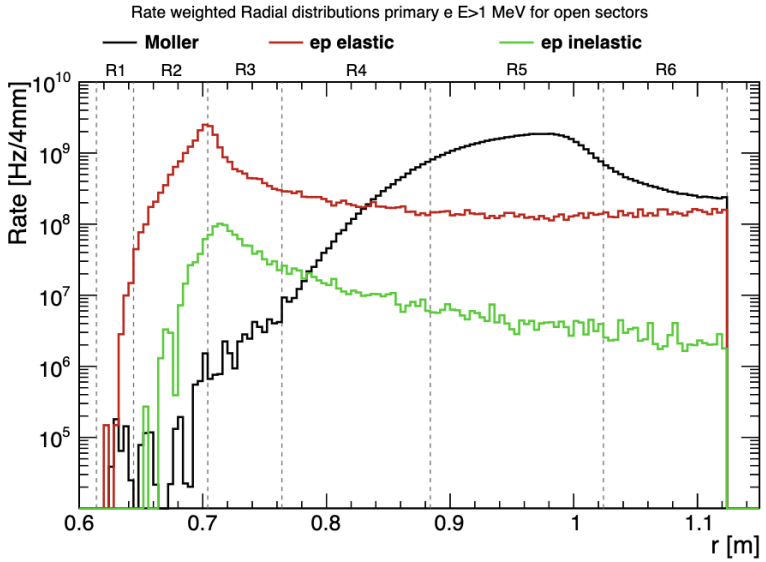


Radial distributions

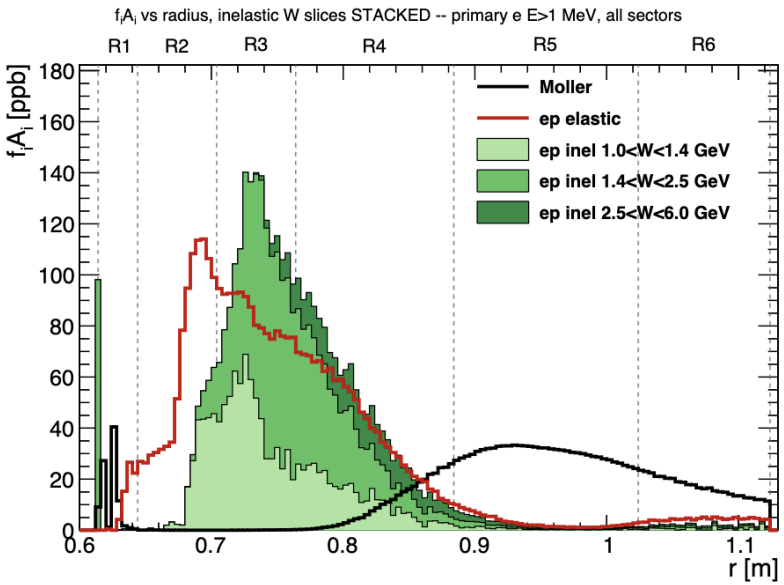


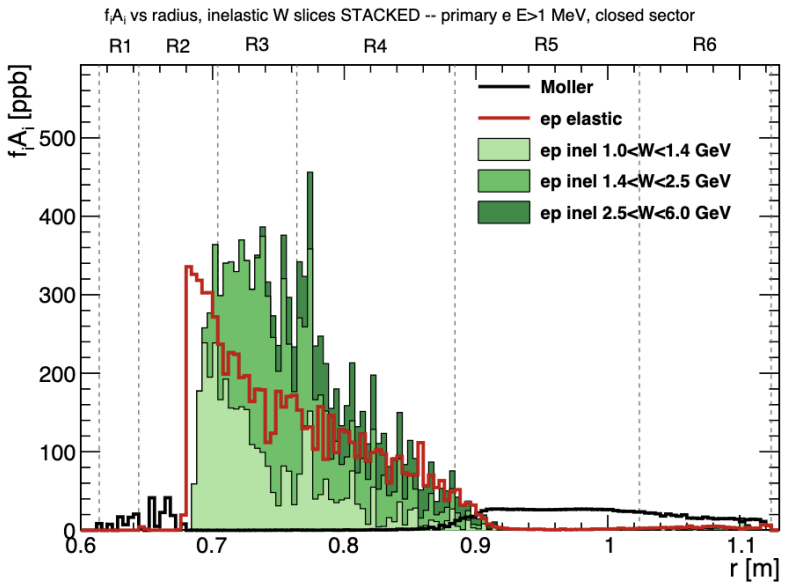


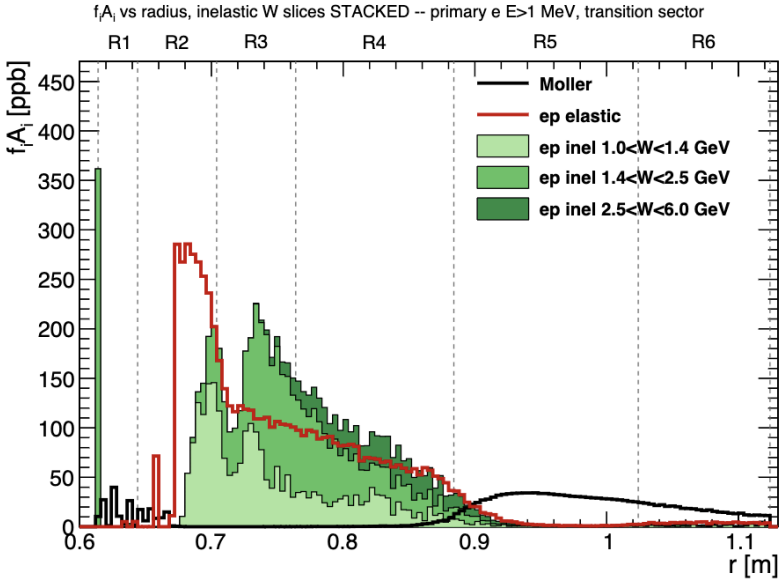


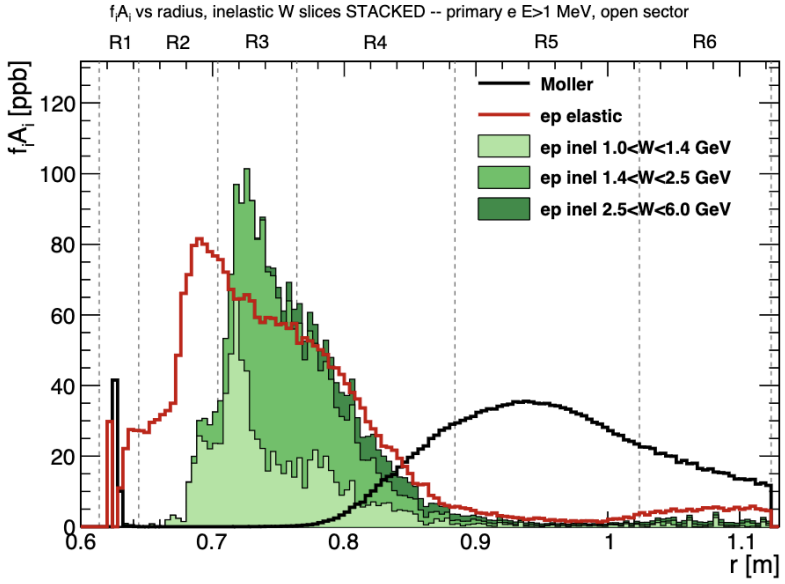


Radial distributions

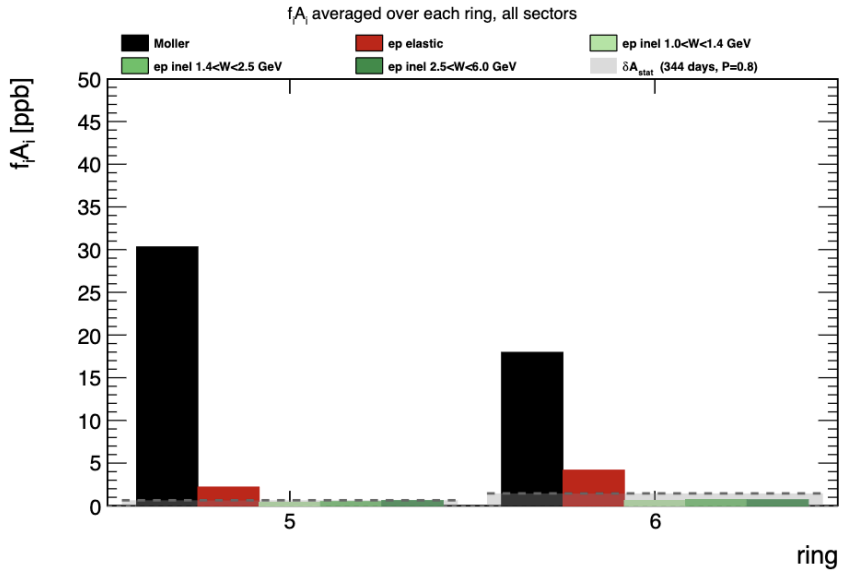


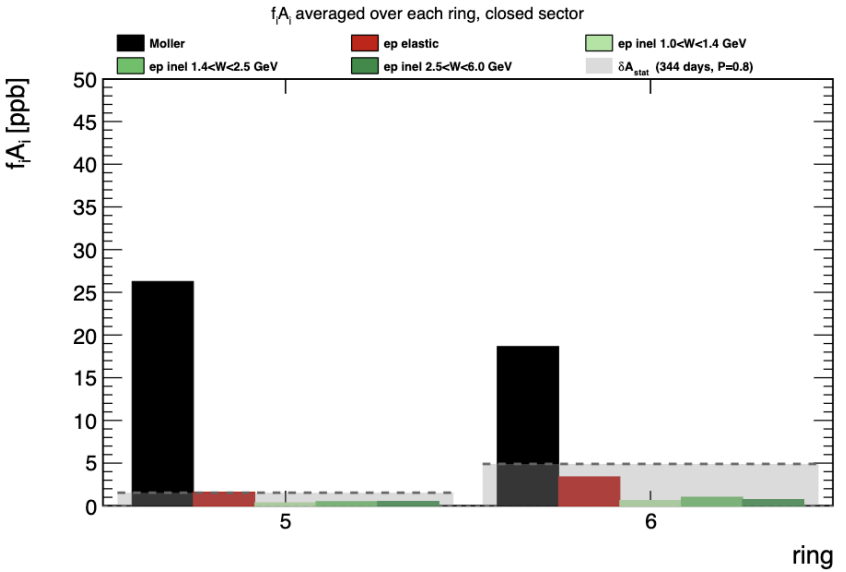


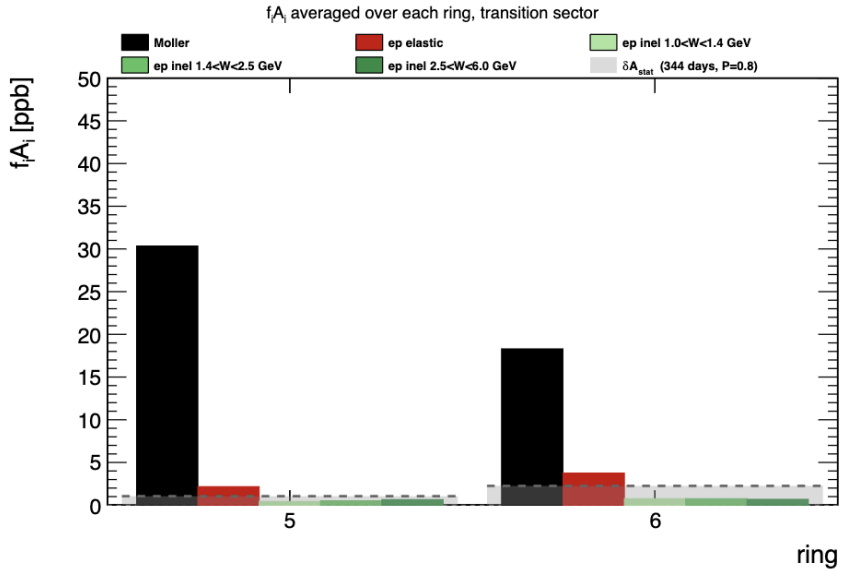


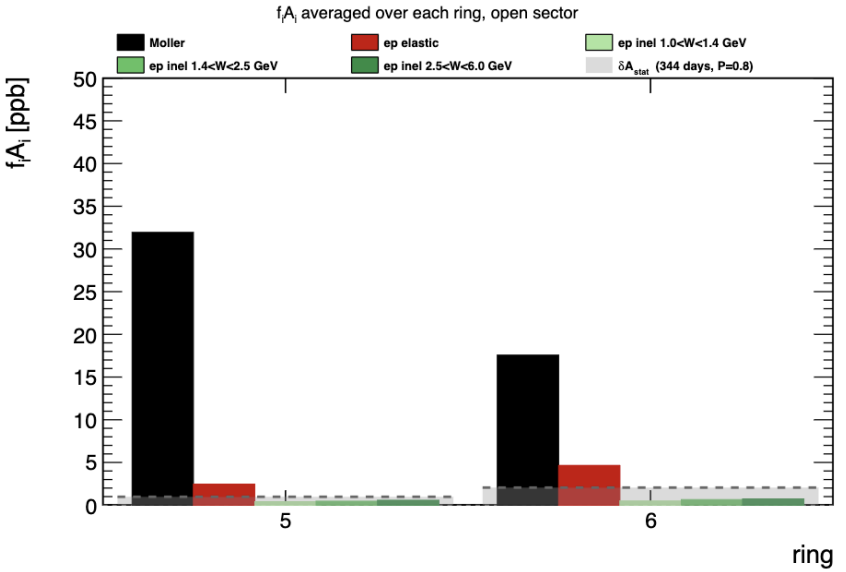


Ring 5 and 6 asymmetries

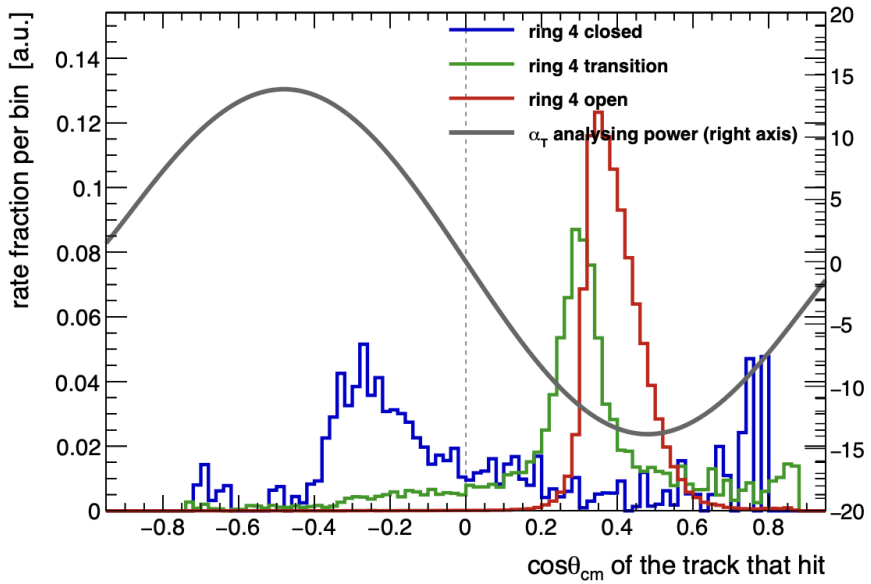


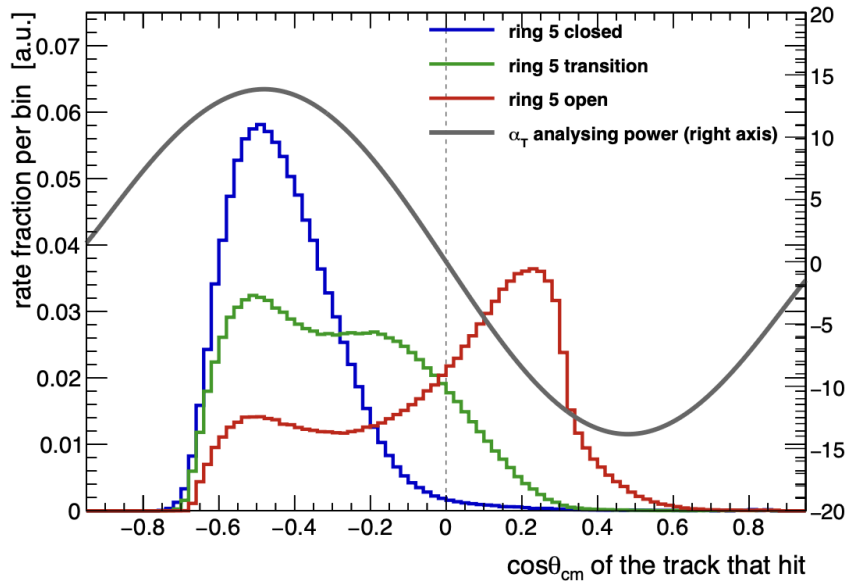


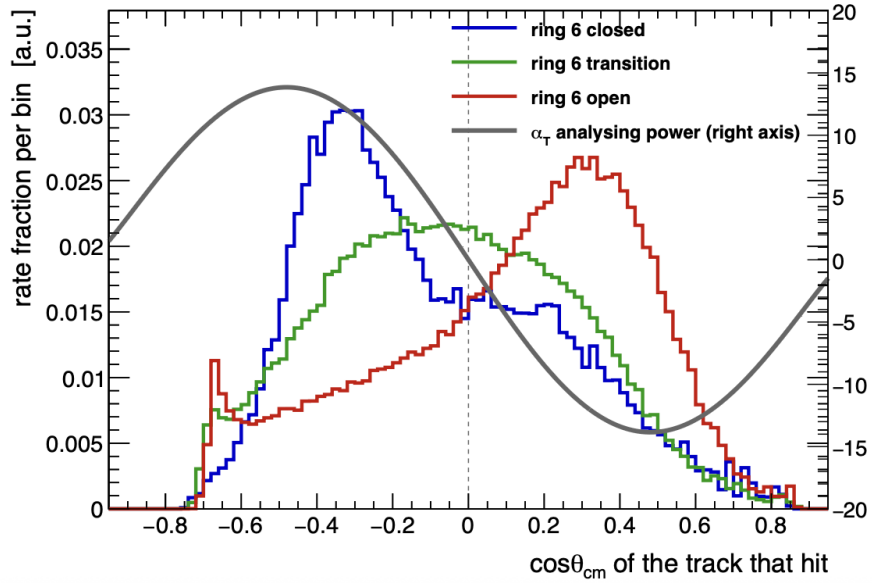




alpha_t


ring 4 closed
ring 4 transition
ring 4 open
α_T analysing power (right axis)
rate fraction per bin [a.u.]
$\cos\theta_{cm}$ of the track that hit


ring 5 closed
ring 5 transition
ring 5 open
α_T analysing power (right axis)
rate fraction per bin [a.u.]
$\cos\theta_{cm}$ of the track that hit


ring 6 closed
ring 6 transition
ring 6 open
α_T analysing power (right axis)
rate fraction per bin [a.u.]
$\cos\theta_{cm}$ of the track that hit