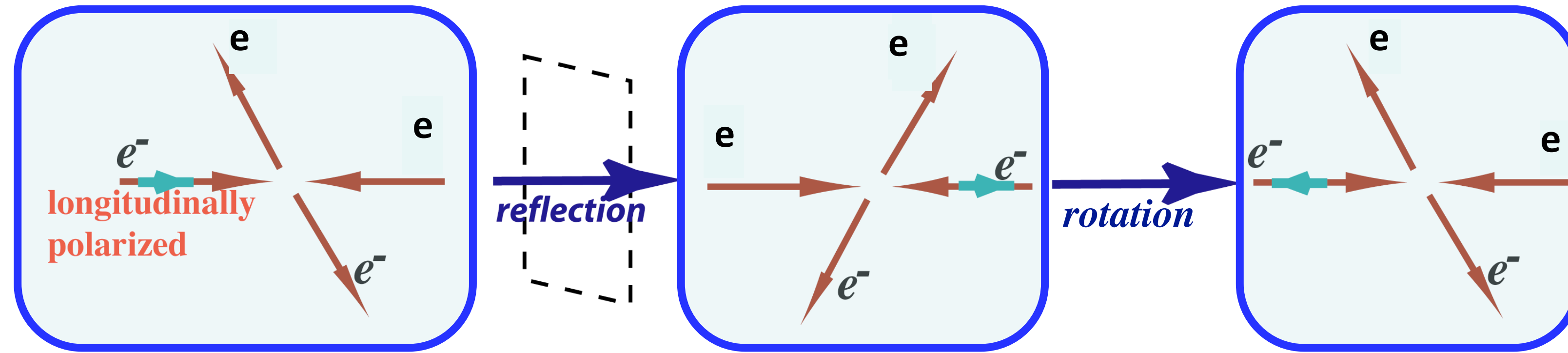# MOLLER Experimental Apparatus Overview

Kent Paschke

Electron Scattering and Parity-Violation

- Incident beam is longitudinally polarized
- Change sign of longitudinal polarization
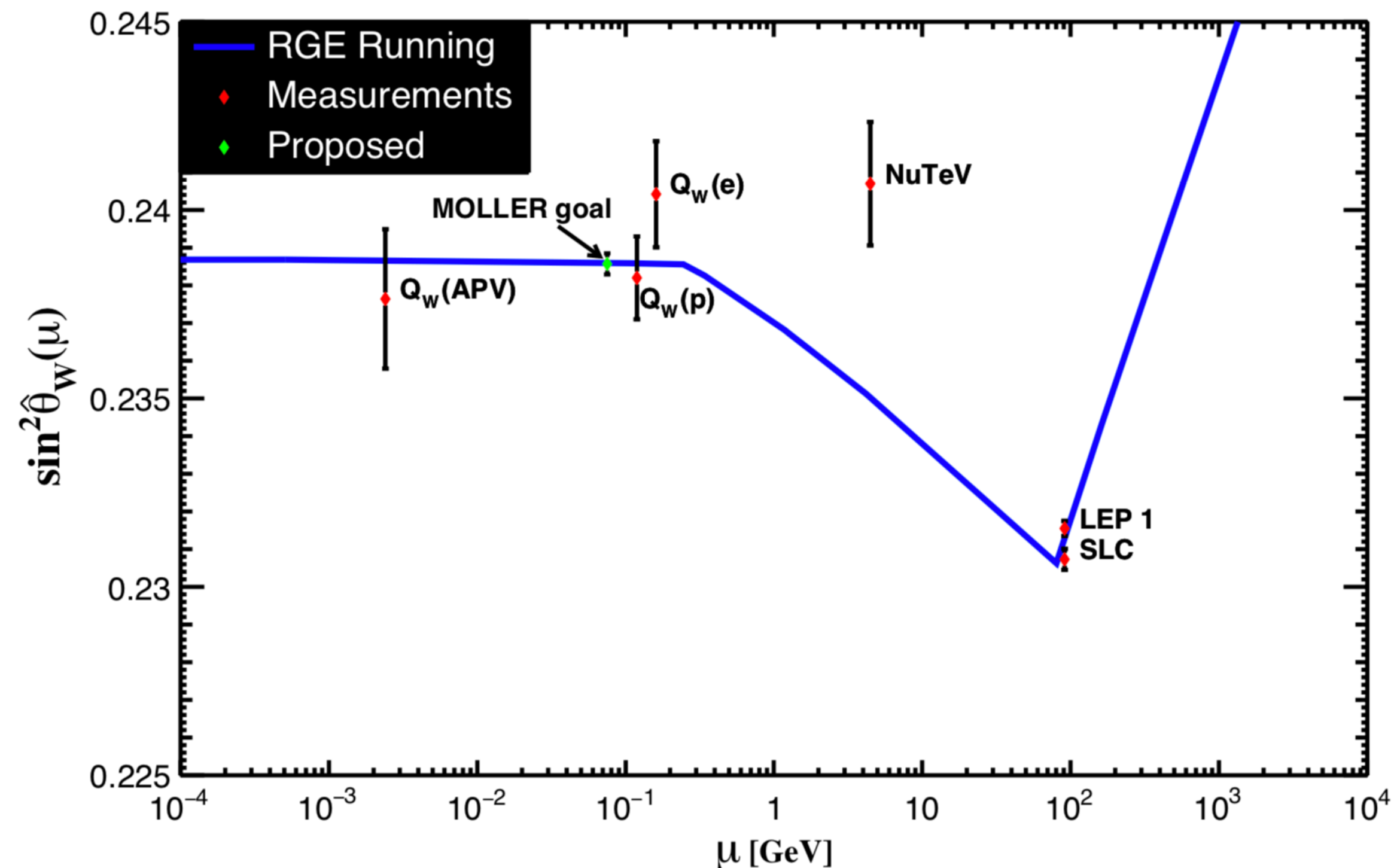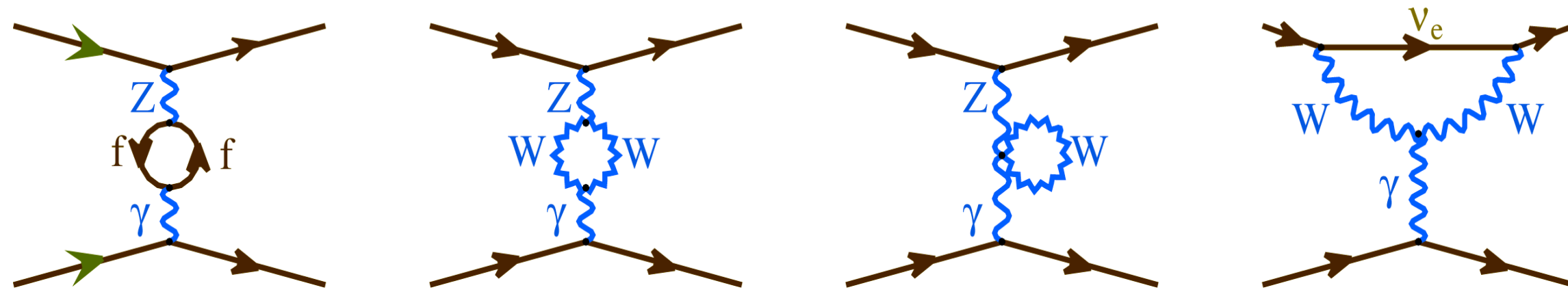- Measure fractional rate difference

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \quad \propto \frac{|\mathcal{M}_Z|}{|\mathcal{M}_\gamma|}$$

Measuring ee elastic (Møller) scattering

$$A_{PV} \propto Q_W^e = 1 - 4\sin^2\theta_W$$

The Weak Mixing Angle

Renormalization scheme defines $\sin^2\theta_W$ at the Z-pole.

γ-Z mixing and other diagrams are absorbed into the coupling constant

At the Z-pole - measuring properties of the SM Z^0 boson

Off the Z-pole, low-energy measurements are sensitive to (new) parity-violating interactions

$\delta(\sin^2\theta_W) = \pm 0.00024 \text{ (stat.)} \pm 0.00013 \text{ (syst.)} \Longrightarrow \sim 0.1\%$

Matches best collider (Z-pole) measurement!

MOLLER

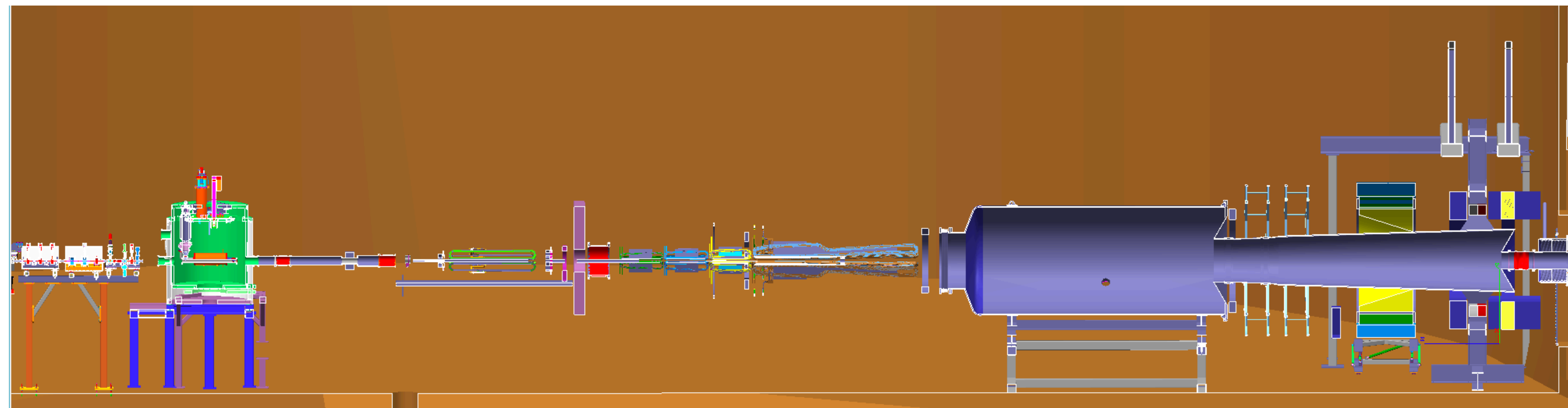parity-violation in e^-e^- elastic scattering

$A_{PV} = 35.6\ ppb$

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

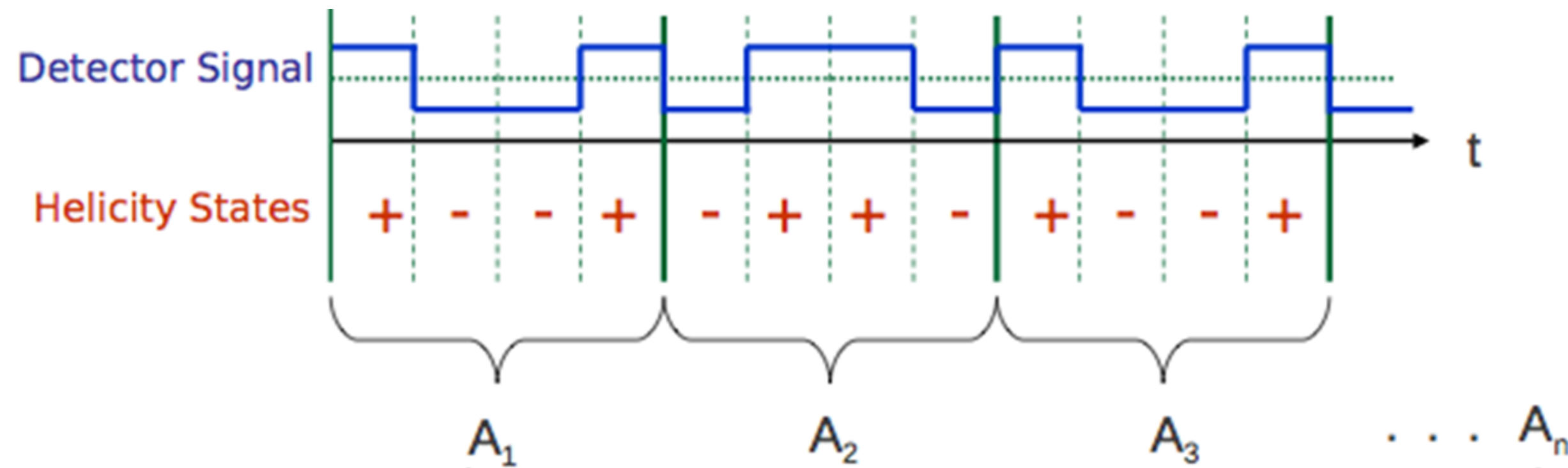$\delta(Q^e_W) = \pm\ 2.1\ \%\ (stat) \pm 1.0\ \%\ (syst)$

signal rate: 135 GHz

run time: 8200 hours

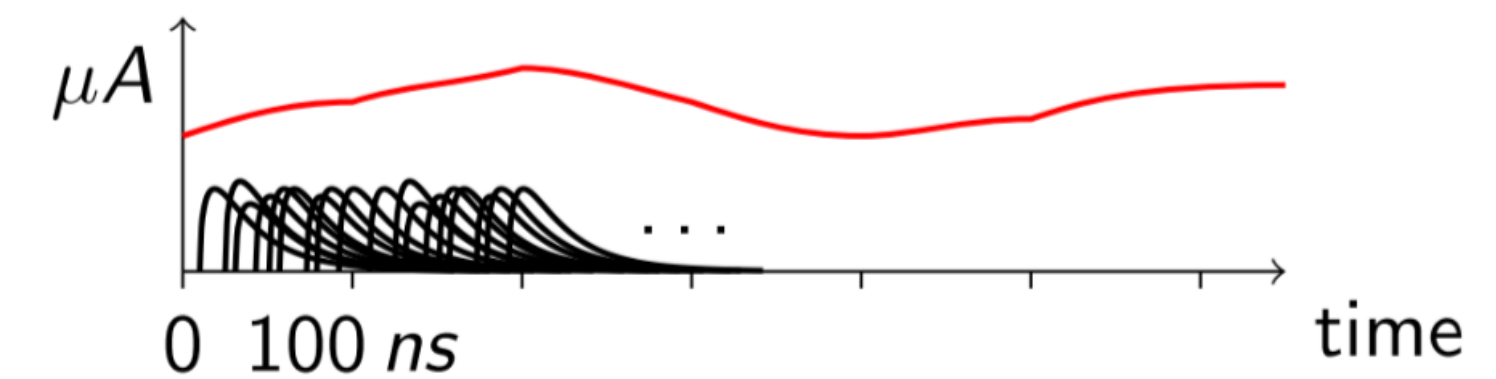~3×10^{18} electrons detected

Measuring this small asymmetry
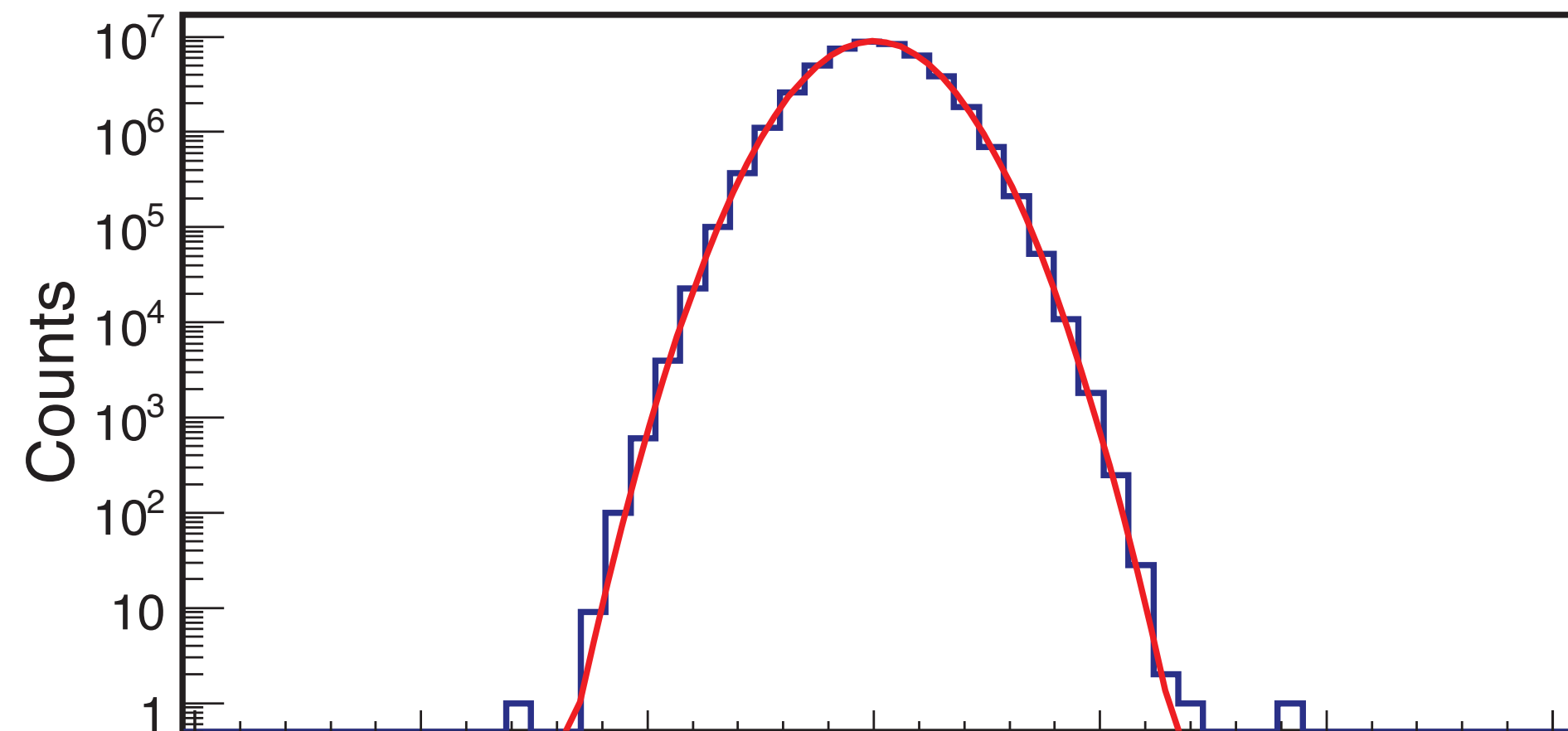
Rapid (2kHz) helicity reversals

Place a detector where it sees the Møller scattered electron

Analog integrate detector current

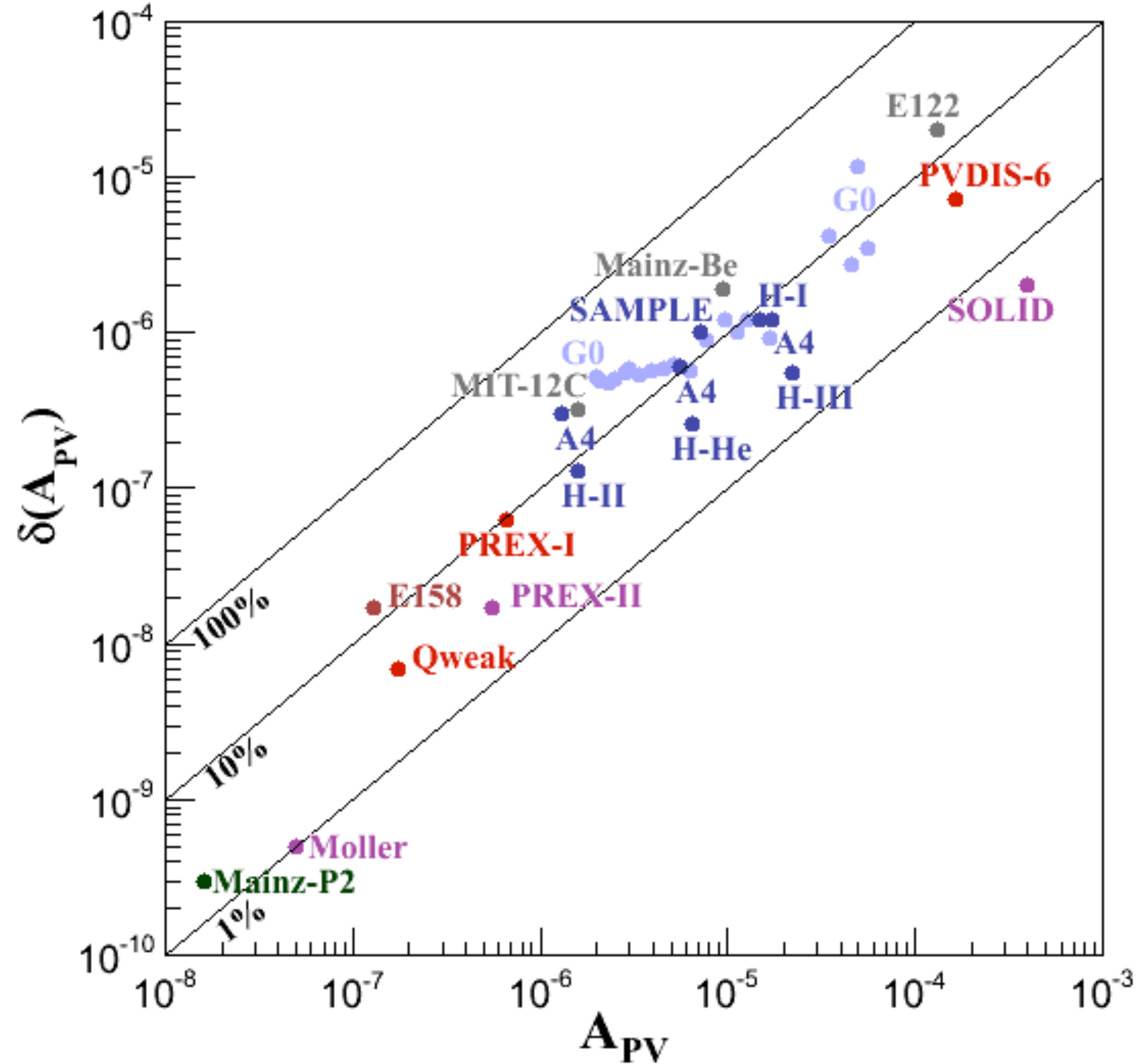Form an asymmetry over the helicity reversal

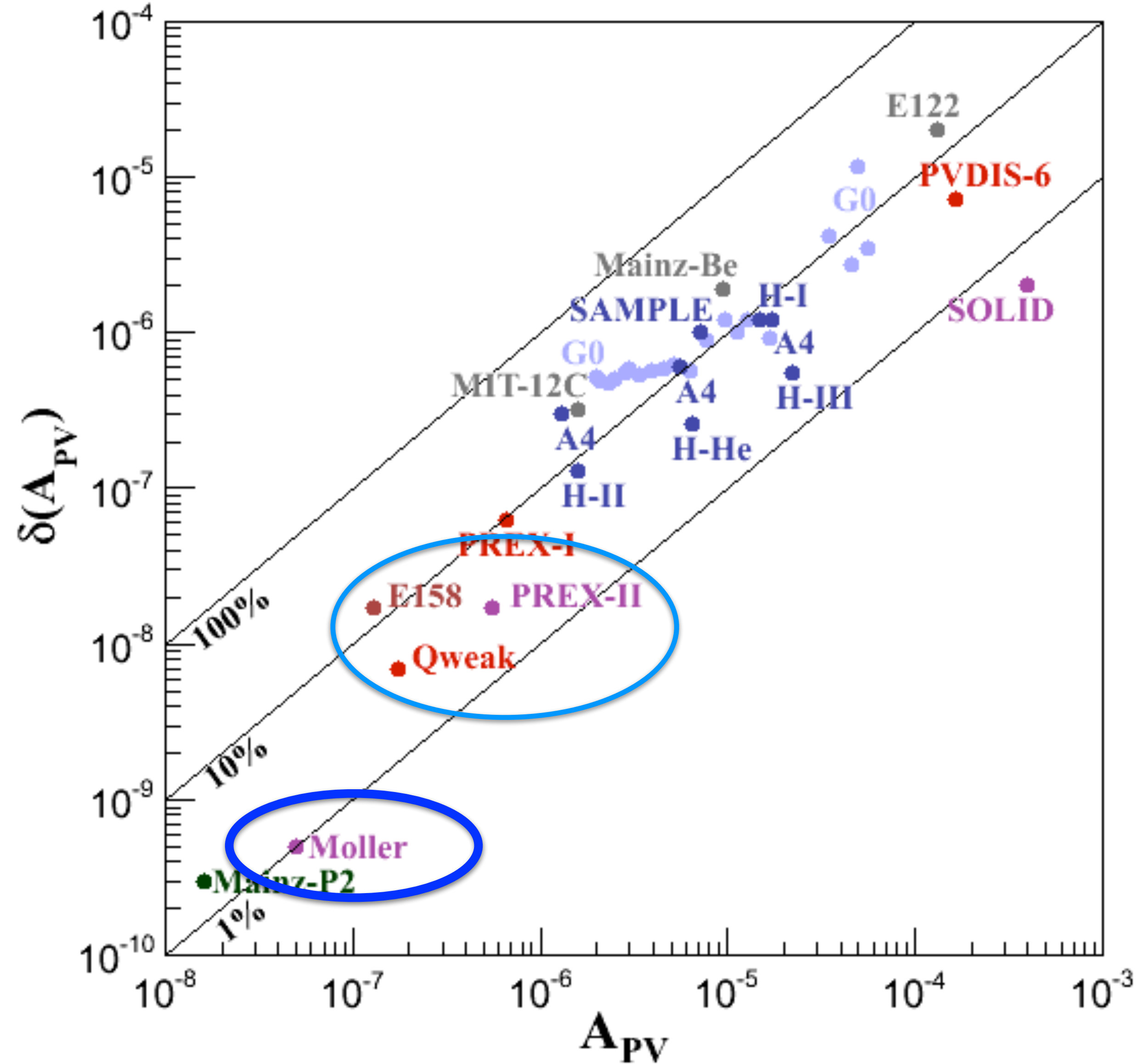Measure to 0.01% at 1 kHz, repeat for a year straight

Specialized experimental techniques
• Precise spectrometer to separate signal
• Low noise electronics
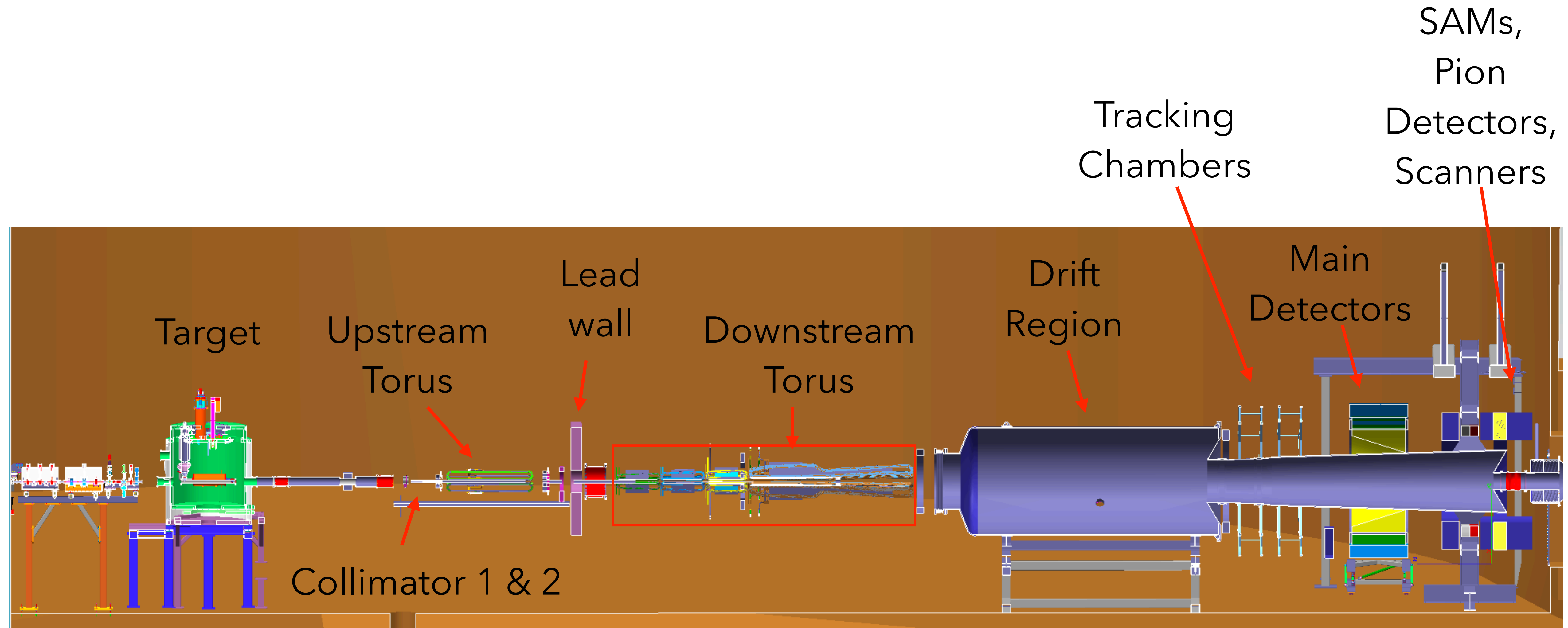• Precise beam control and measurement
• ...

High Precision

High Precision

Experimental Overview

SAMs, Pion Detectors, Scanners

Tracking Chambers

Main Detectors

Drift Region

Lead wall
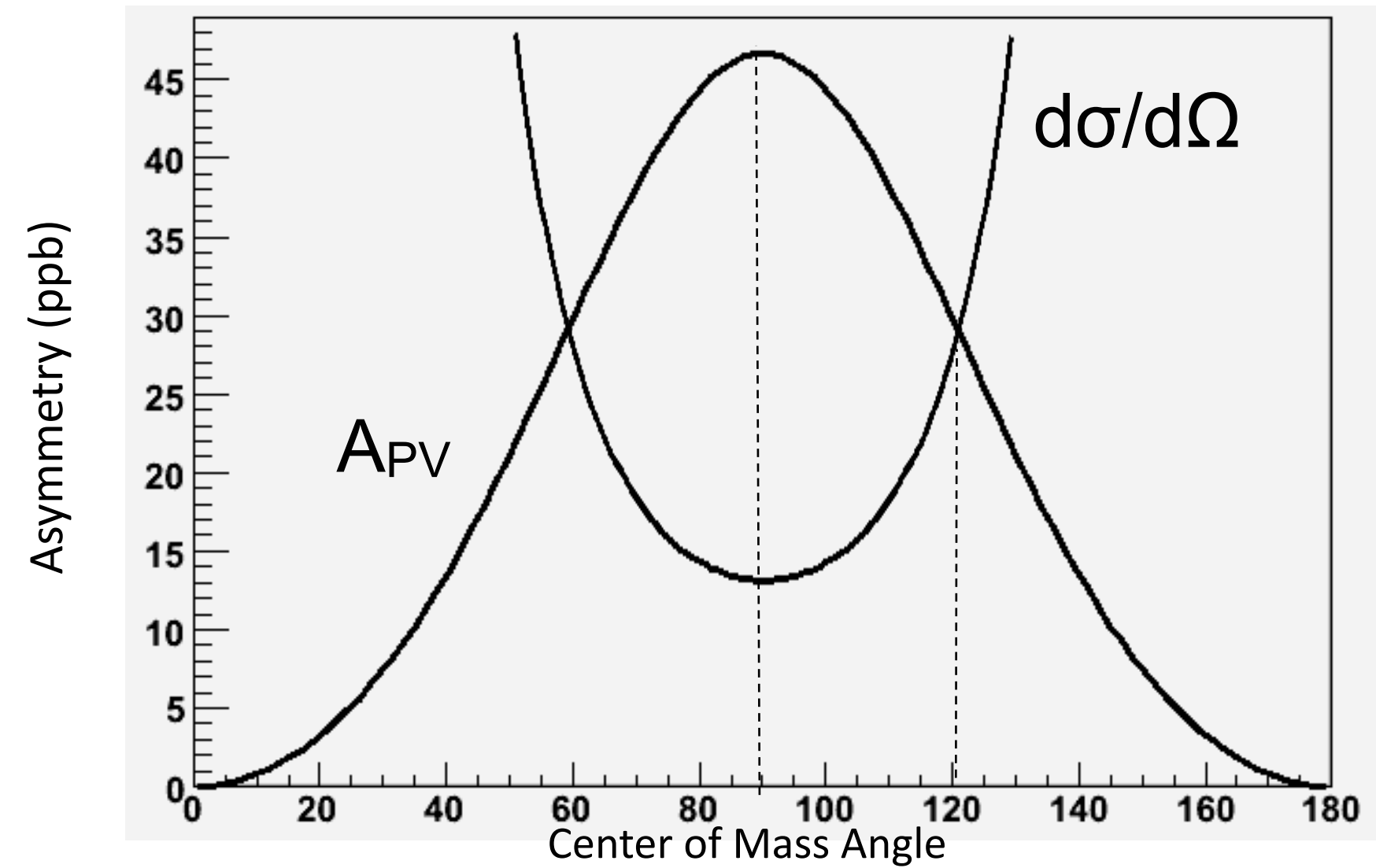
Downstream Torus

Target

Upstream Torus

Collimator 1 & 2

Figure of Merit

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

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

Figure of Merit

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

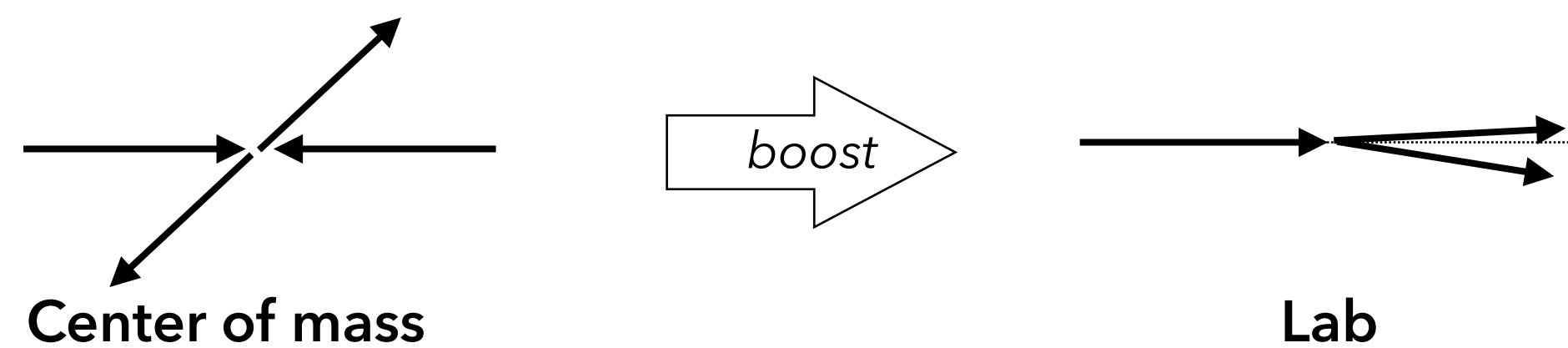**Highest figure of merit at $\theta_{CM} = 90°$**

Figure of Merit

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

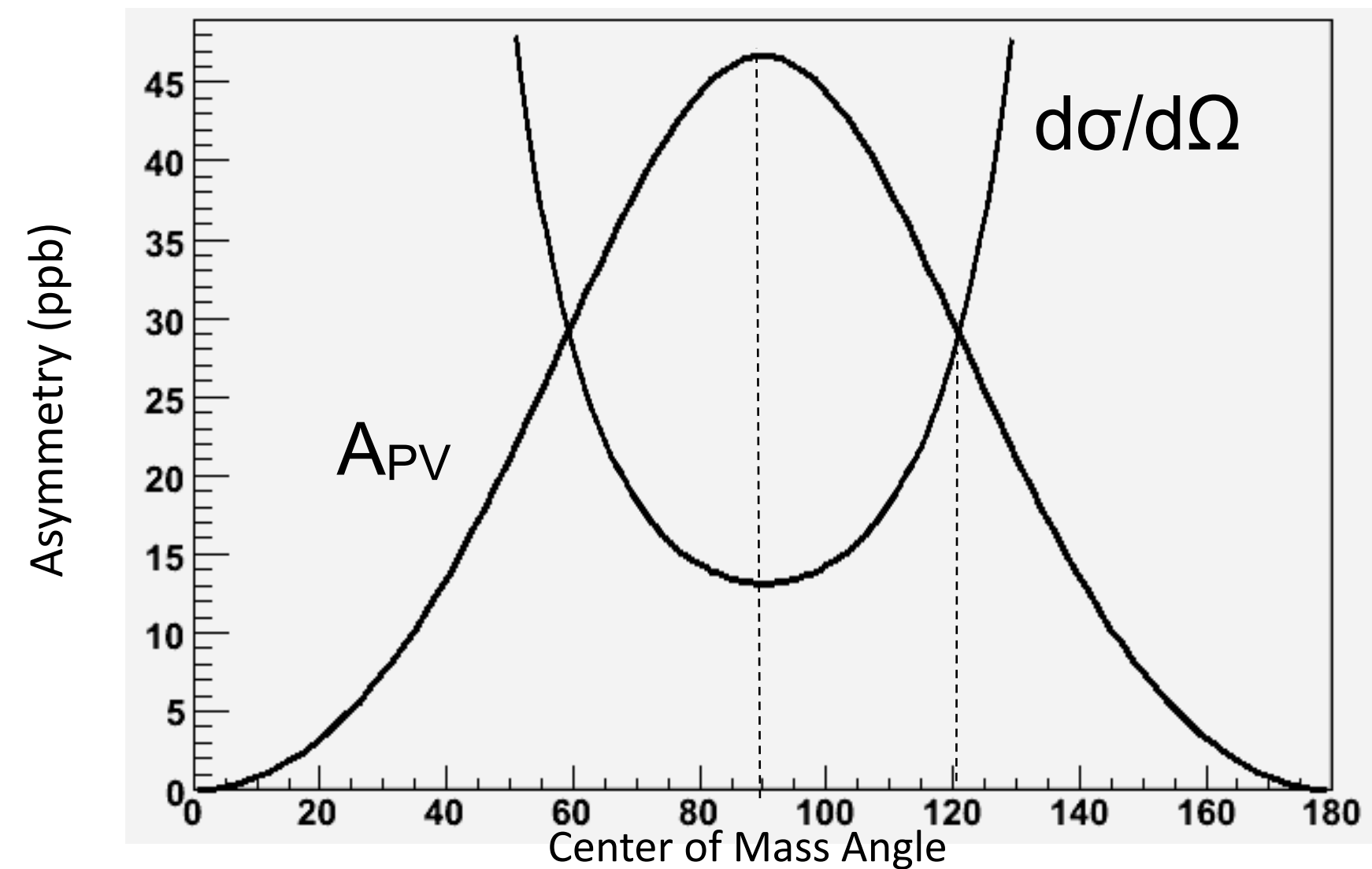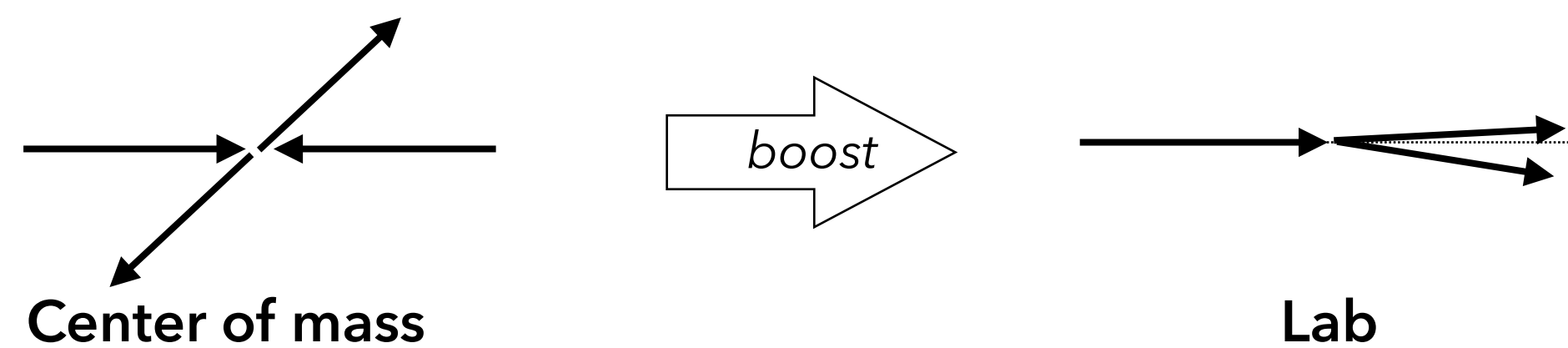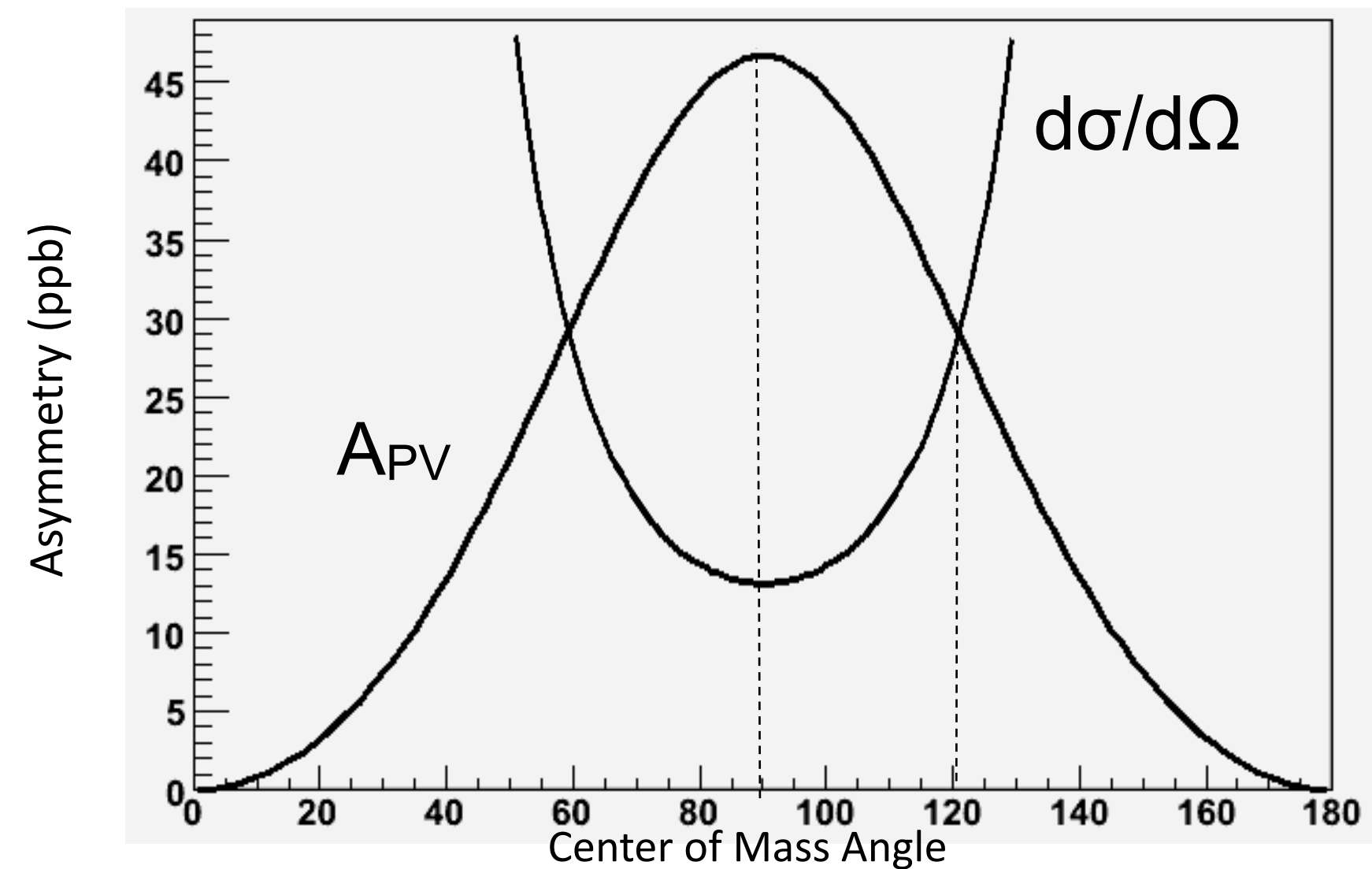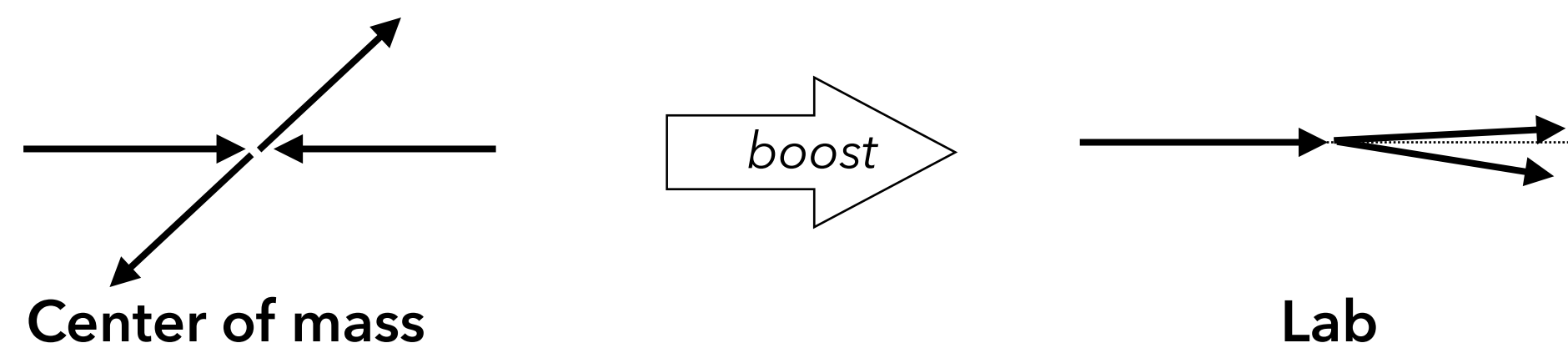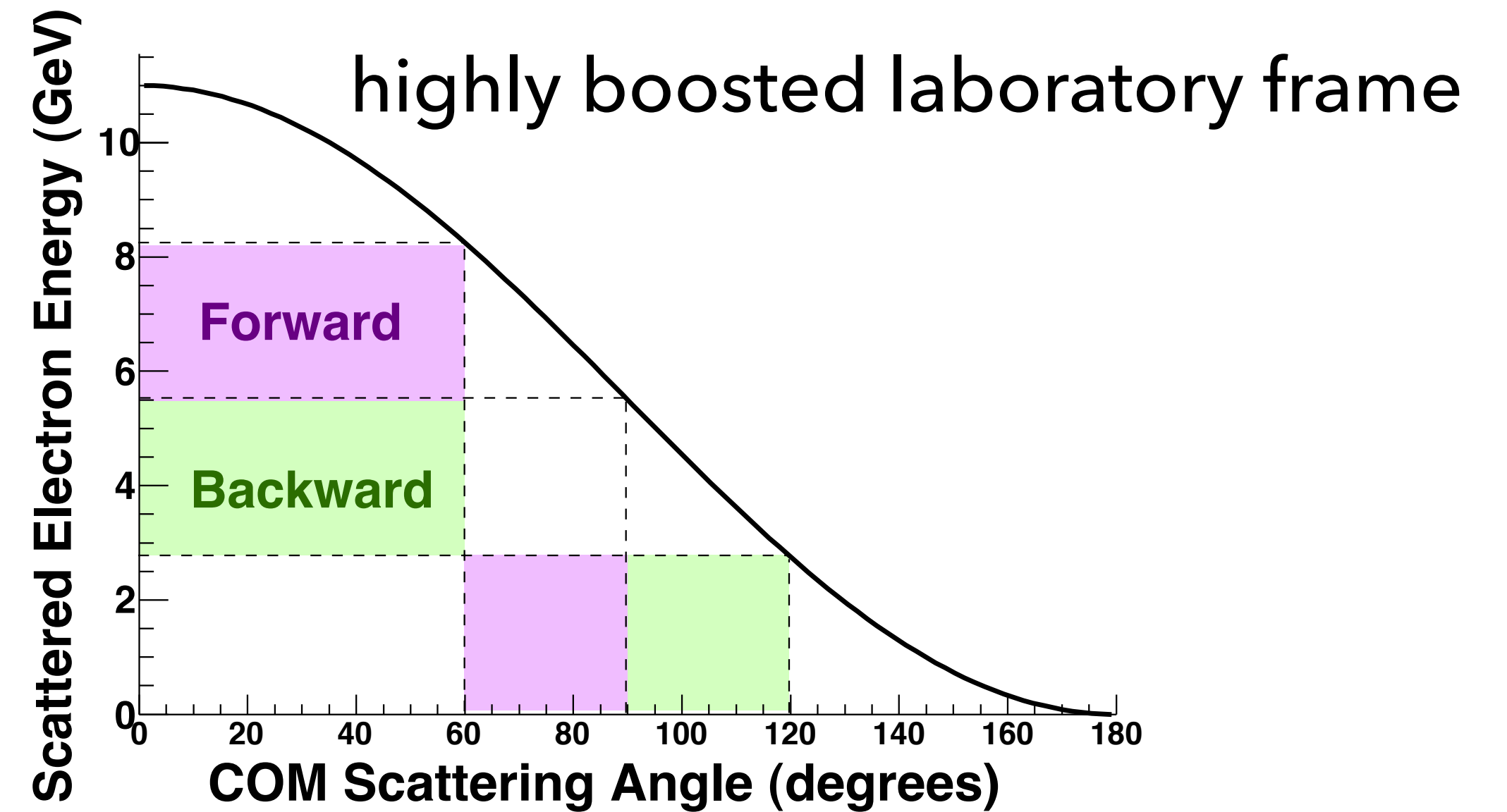**Highest figure of merit at $\theta_{CM} = 90°$**

Identical particles.

Measure either forward or backward scattering.

Figure of Merit

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

Highest figure of merit at θ_CM = 90°
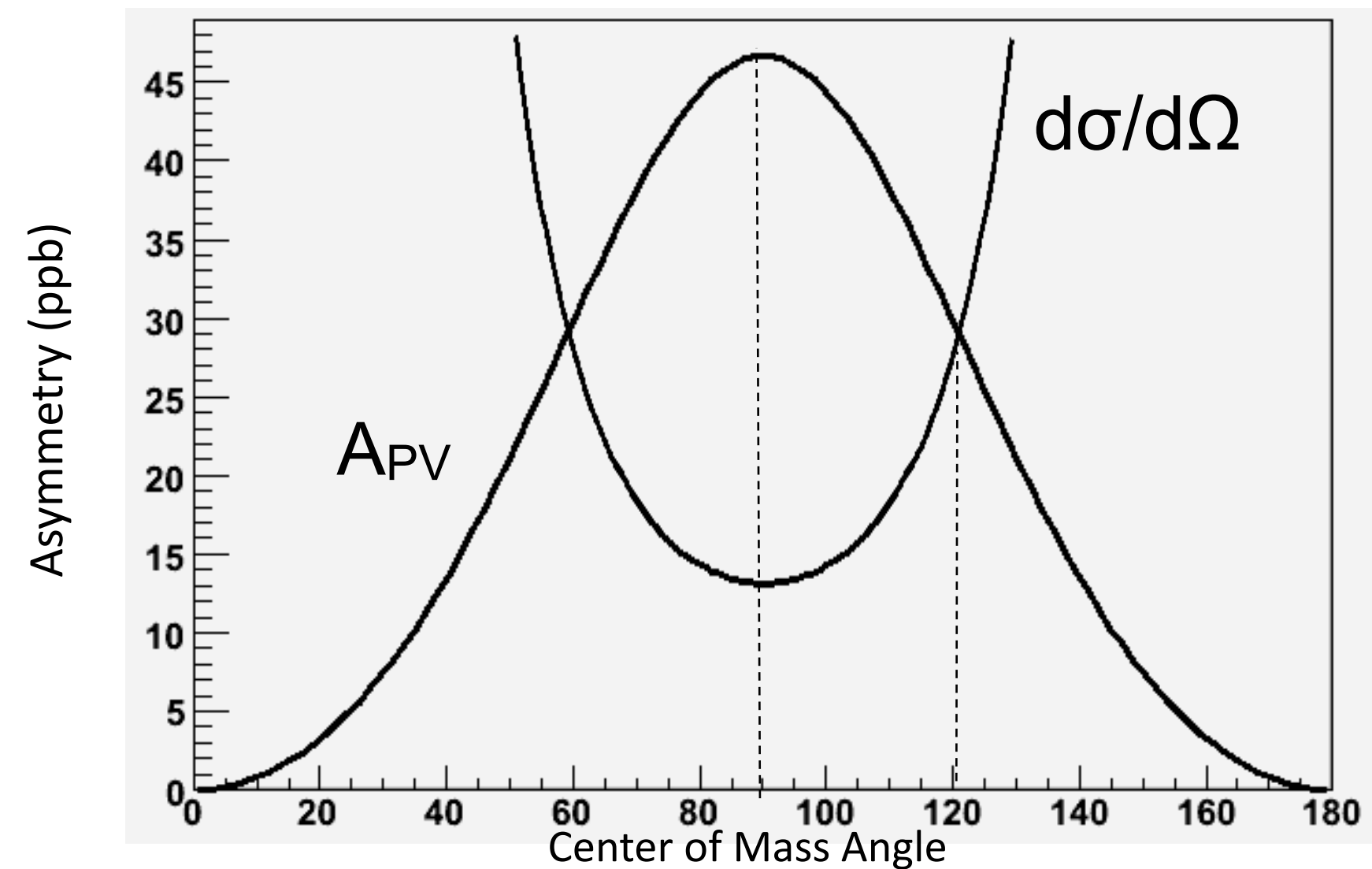

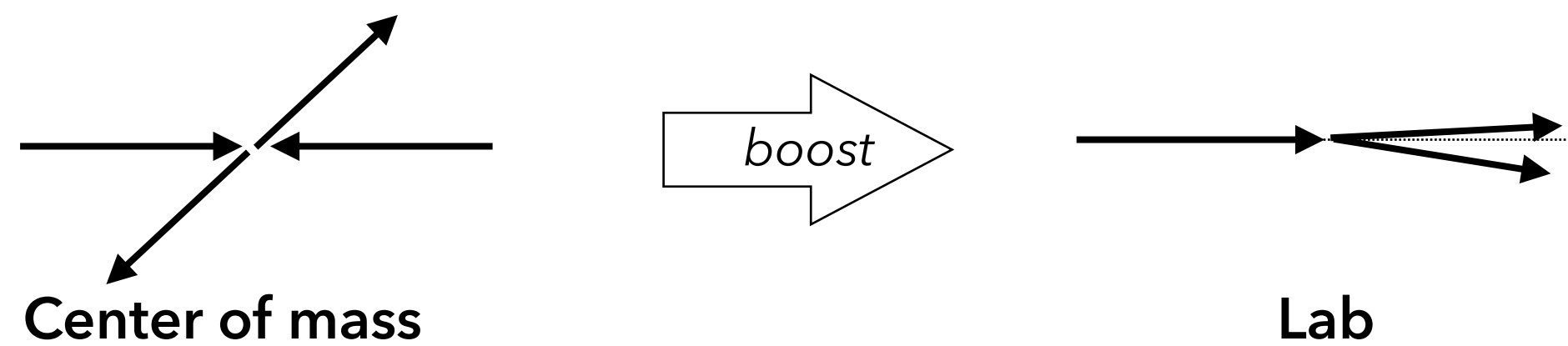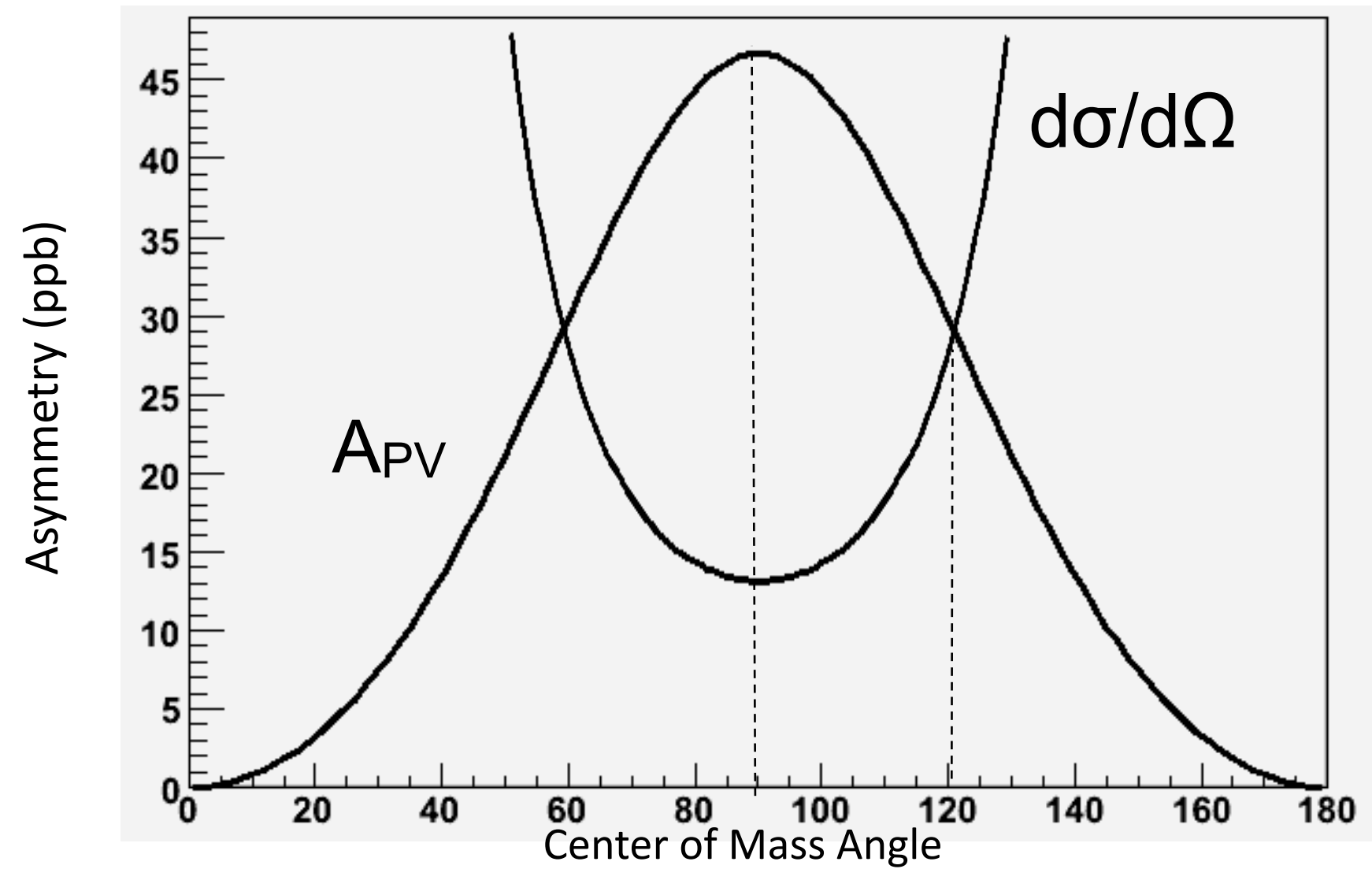highly boosted laboratory frame

Identical particles.

Measure either forward or backward scattering.

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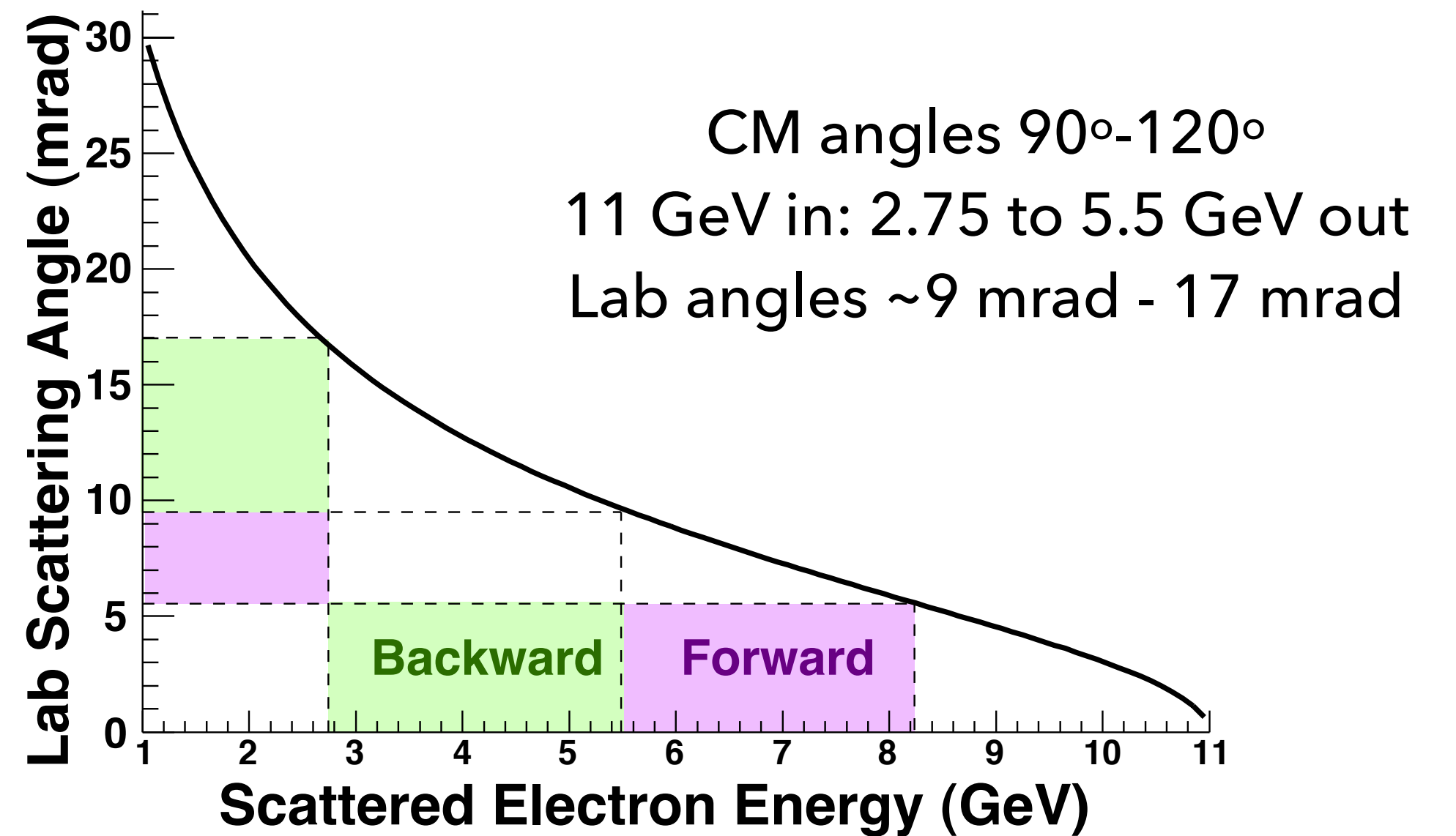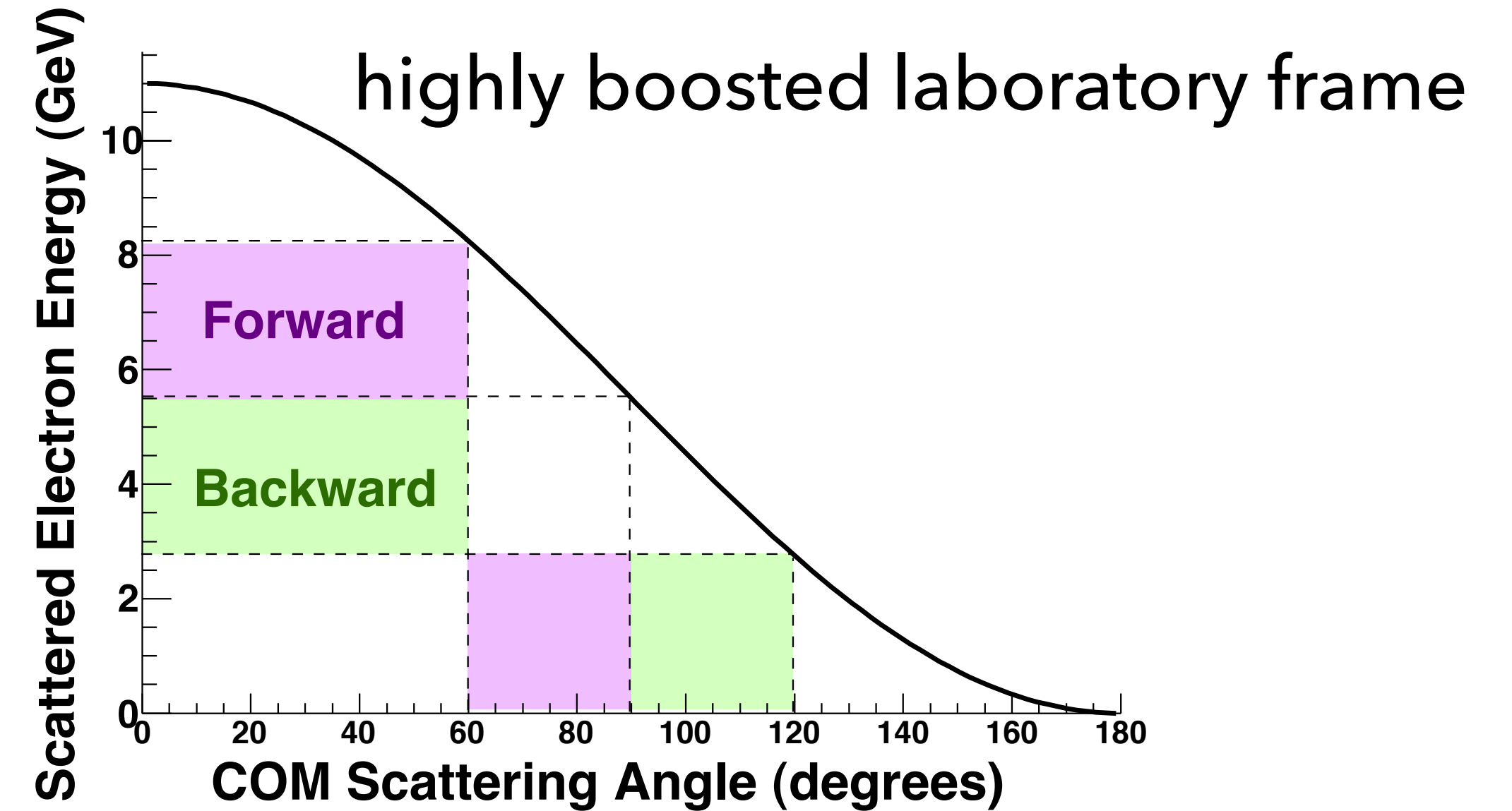
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{4\sin^2\theta}{(3+\cos^2\theta)^2}Q_W^e$$

Highest figure of merit at θ$_{CM}$ = 90º

highly boosted laboratory frame

CM angles 90º-120º
11 GeV in: 2.75 to 5.5 GeV out
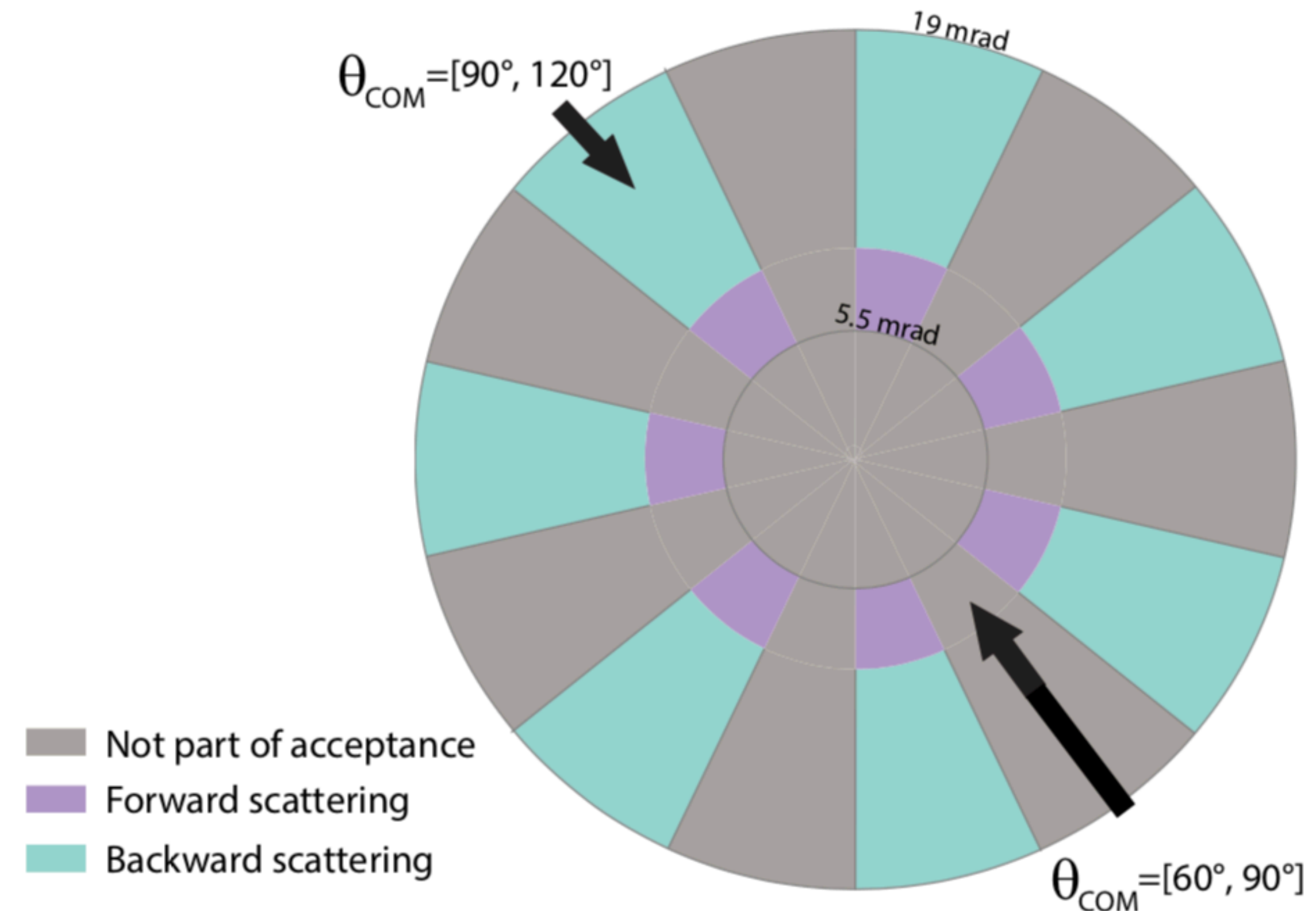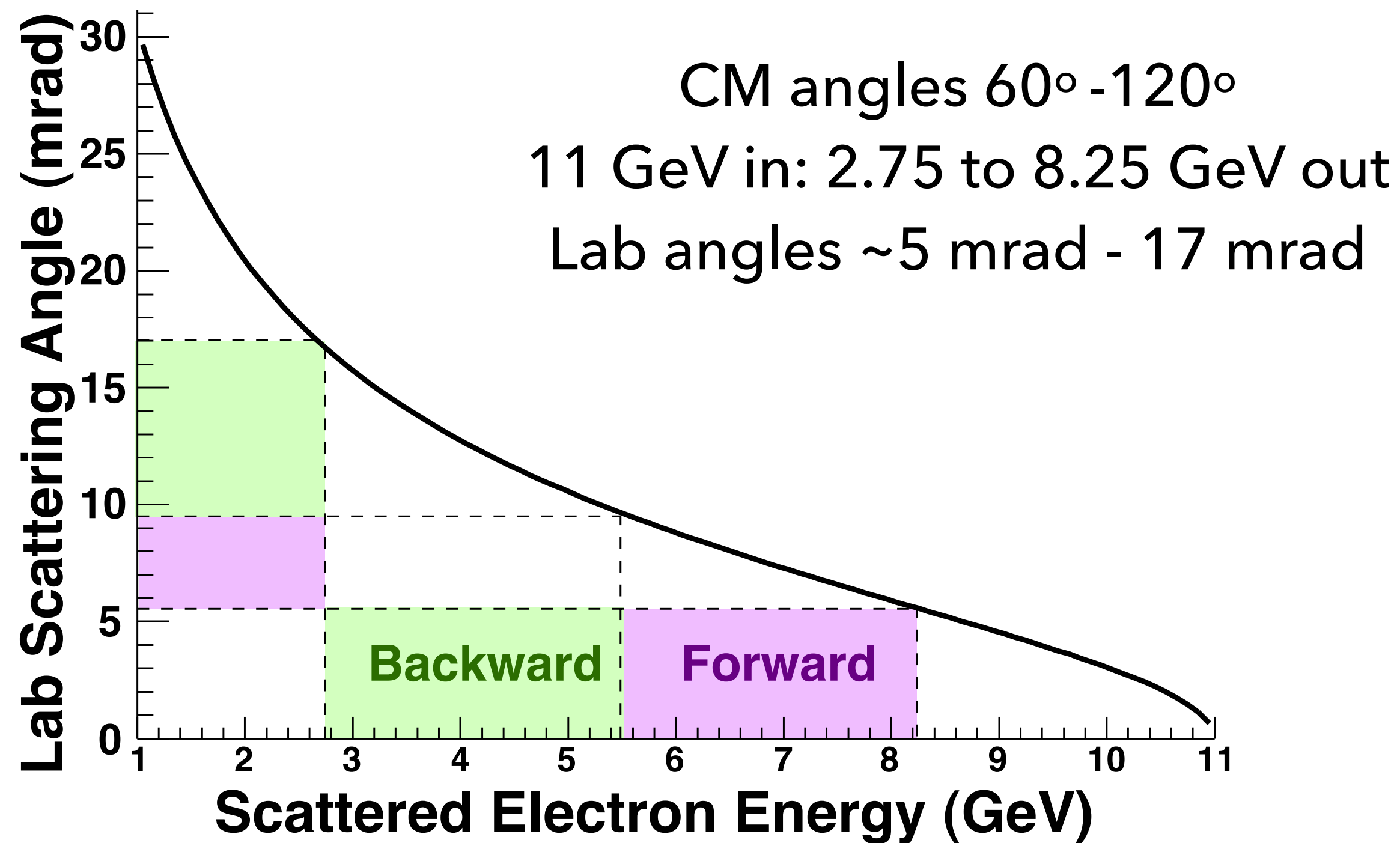Lab angles ~9 mrad - 17 mrad

Identical particles.
Measure either forward or backward scattering.

Identical Particles

Since you only need either the forward or the backward scatter,
accept forward+backward for half the azimuth

CM angles 60° -120°
11 GeV in: 2.75 to 8.25 GeV out
Lab angles ~5 mrad - 17 mrad

Unique concept allows for full azimuthal acceptance (effectively)
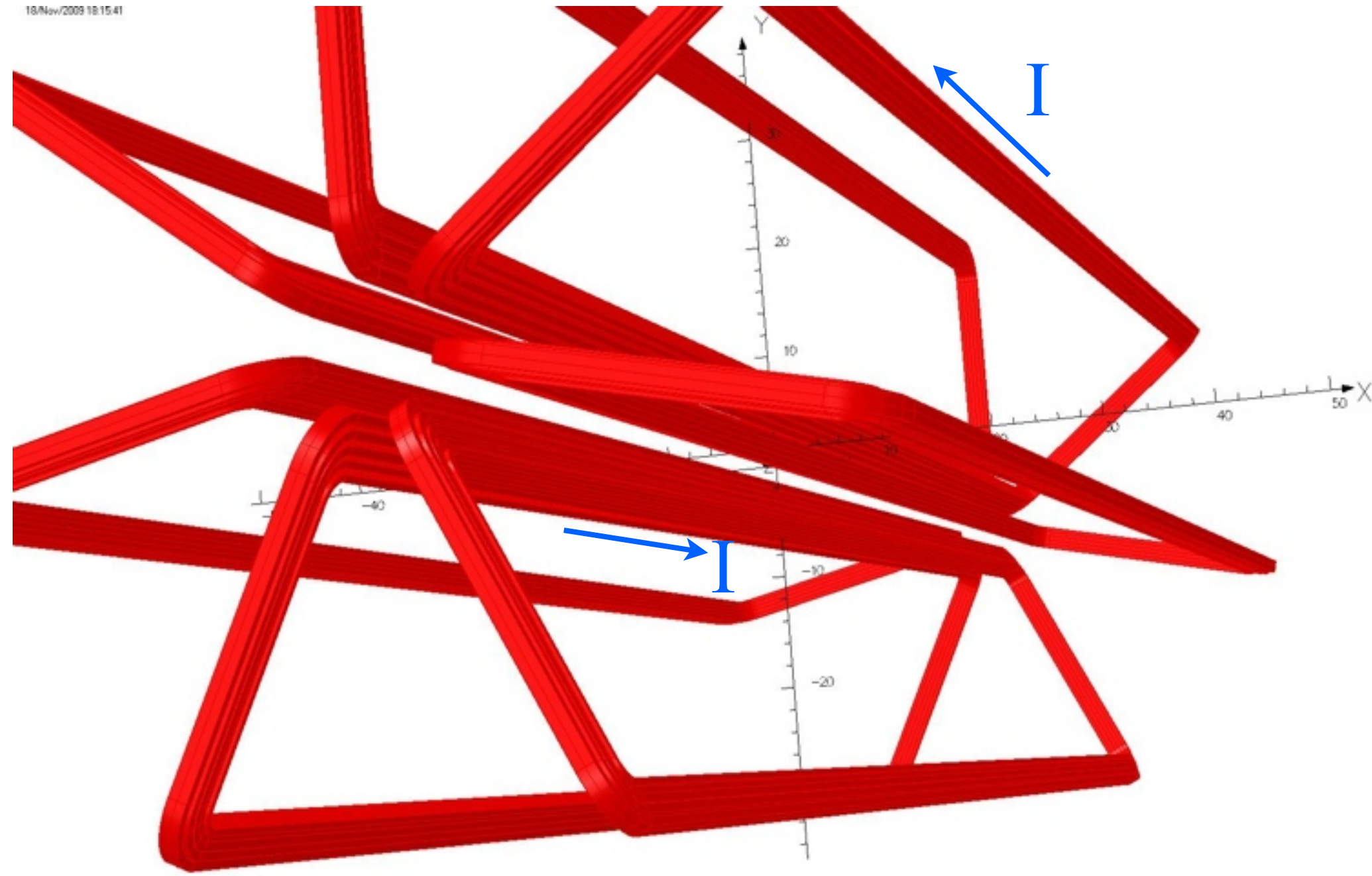even leaving space for coils but makes for a challenging design

Spectrometer Concept

- Bend scattered particles, separate ee from ep and photons
- Small angles and high beam power
- Large energy range (3-8 GeV)
- Long target

26.5 m target to detector
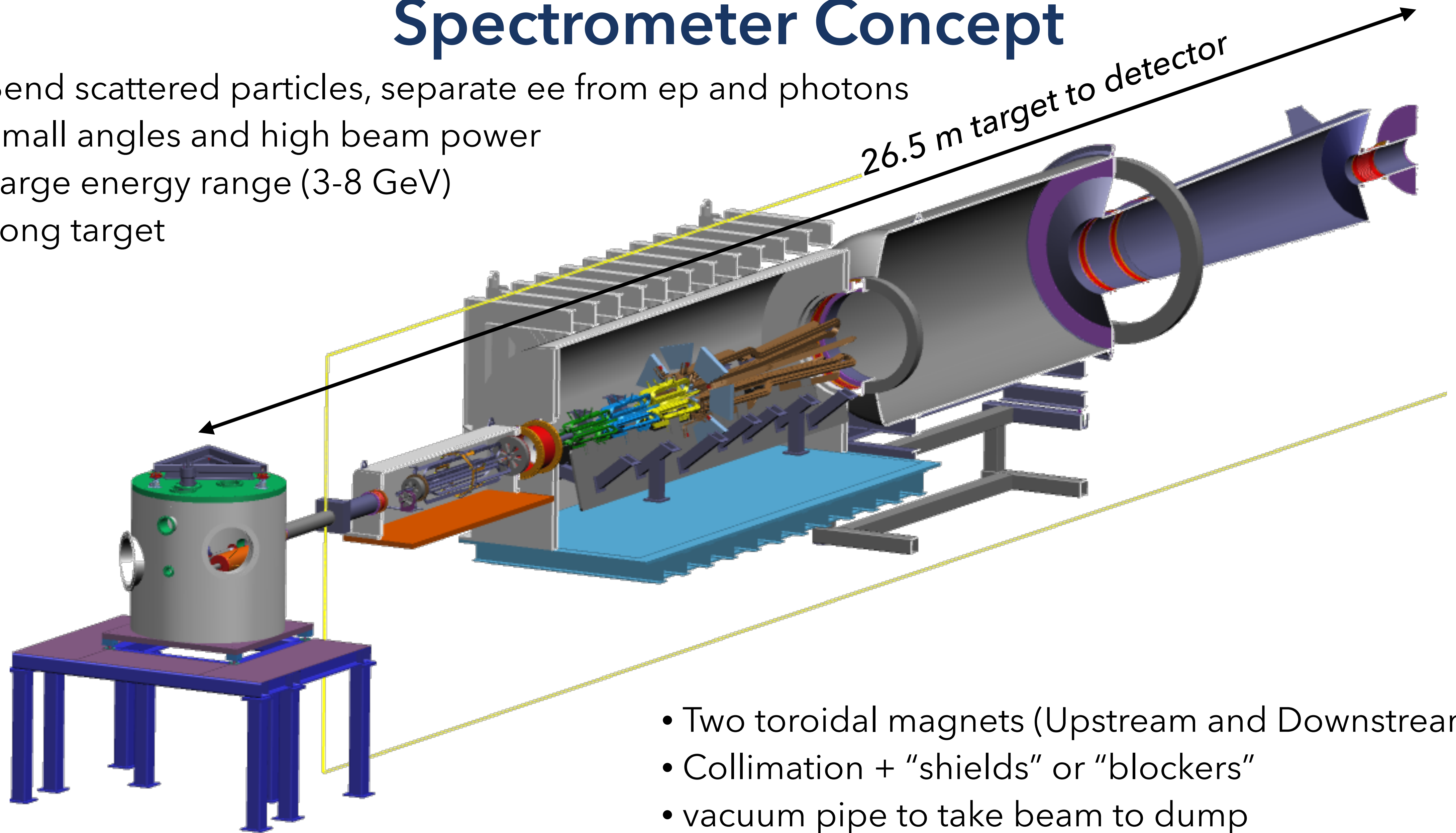
- Two toroidal magnets (Upstream and Downstream)
- Collimation + "shields" or "blockers"
- vacuum pipe to take beam to dump

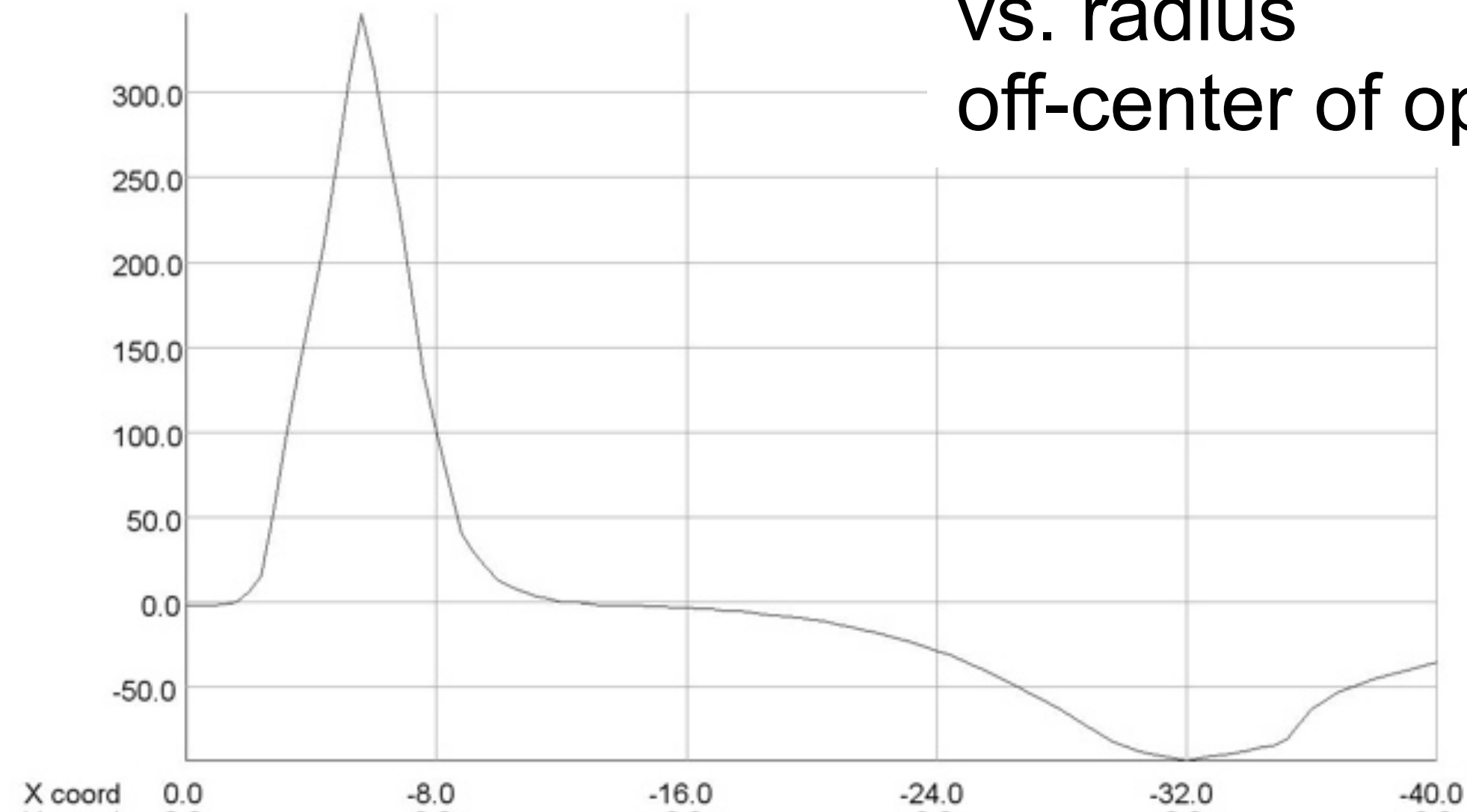# Radial and Azimuthal Fields

I

I

Inner and outer edges of toroids have significant radial field components

Radial field component
vs. radius
off-center of open sector

repels electrons
from coil
"focussing"

attracts electrons
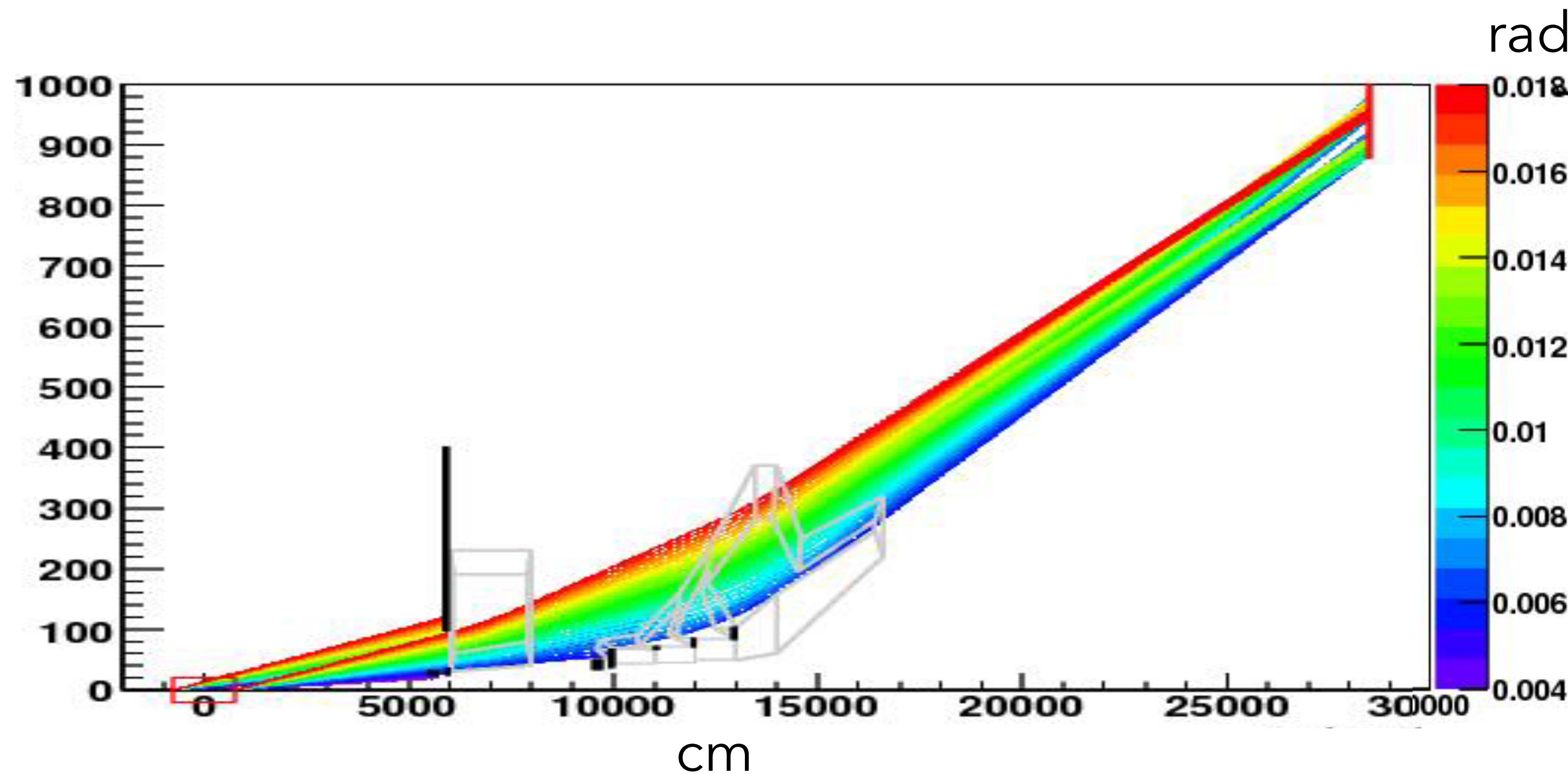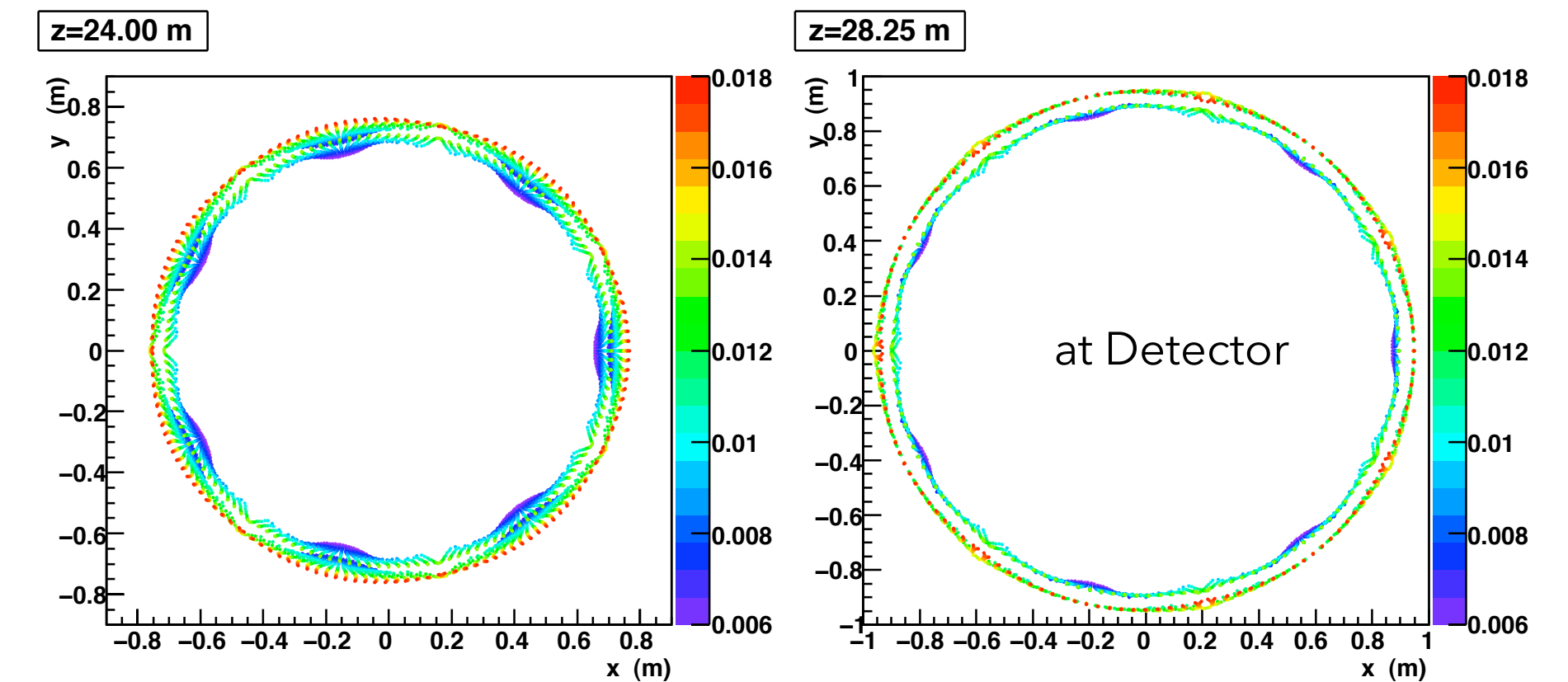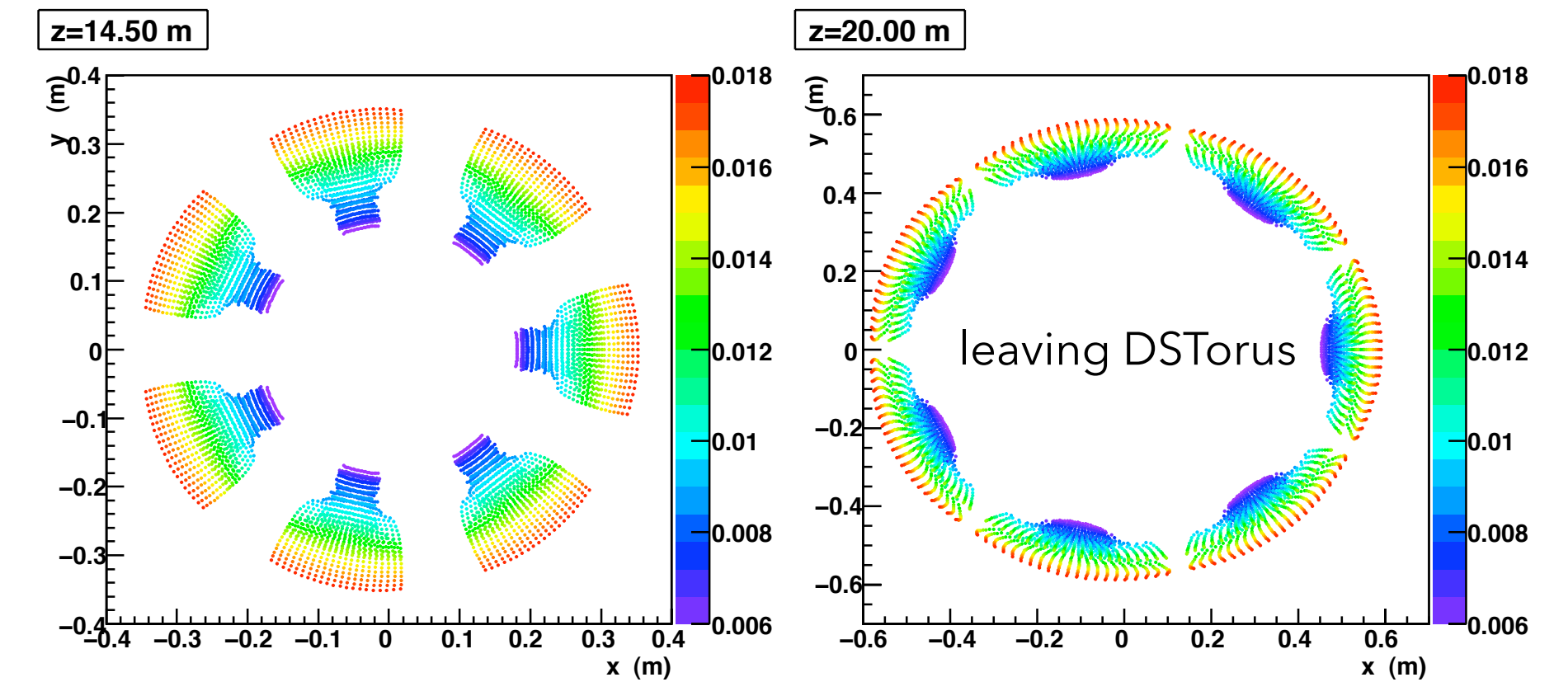toward coils
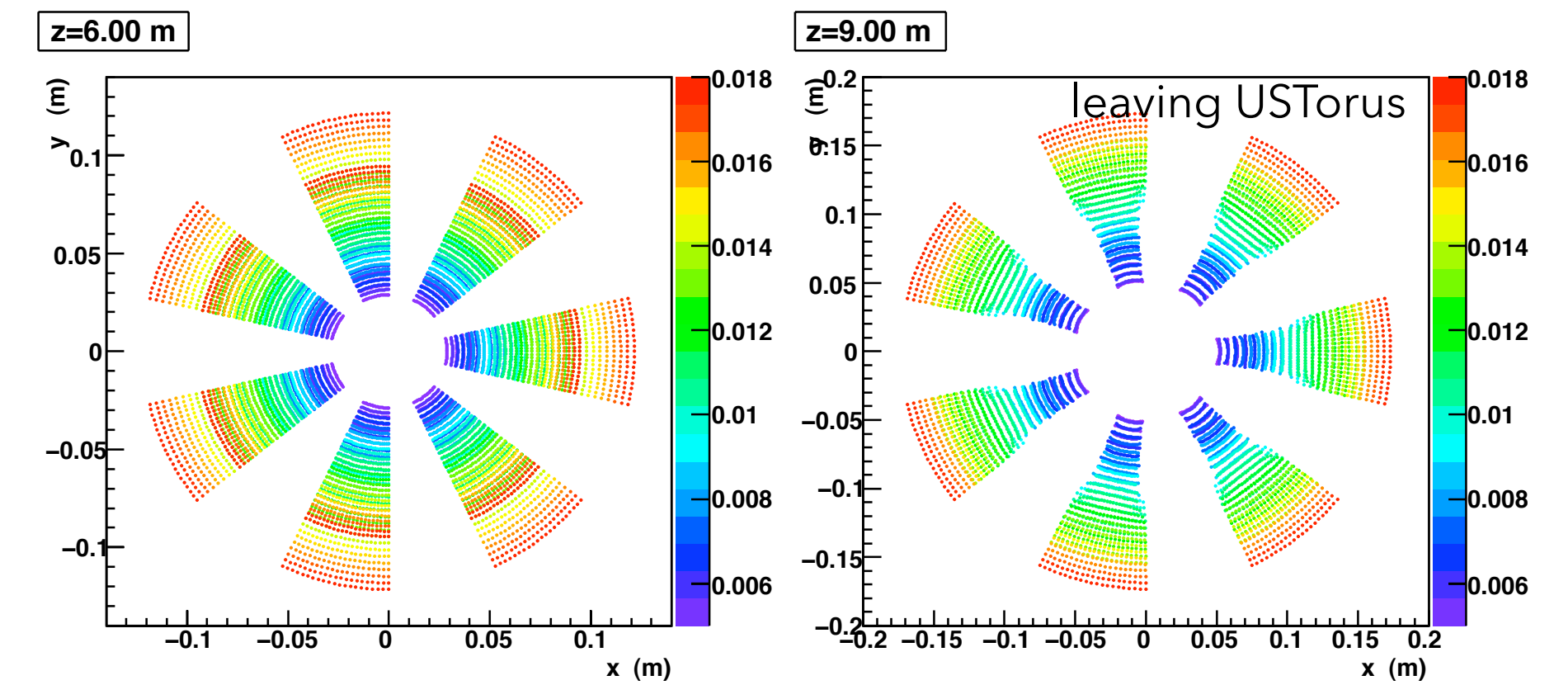"defocussing"

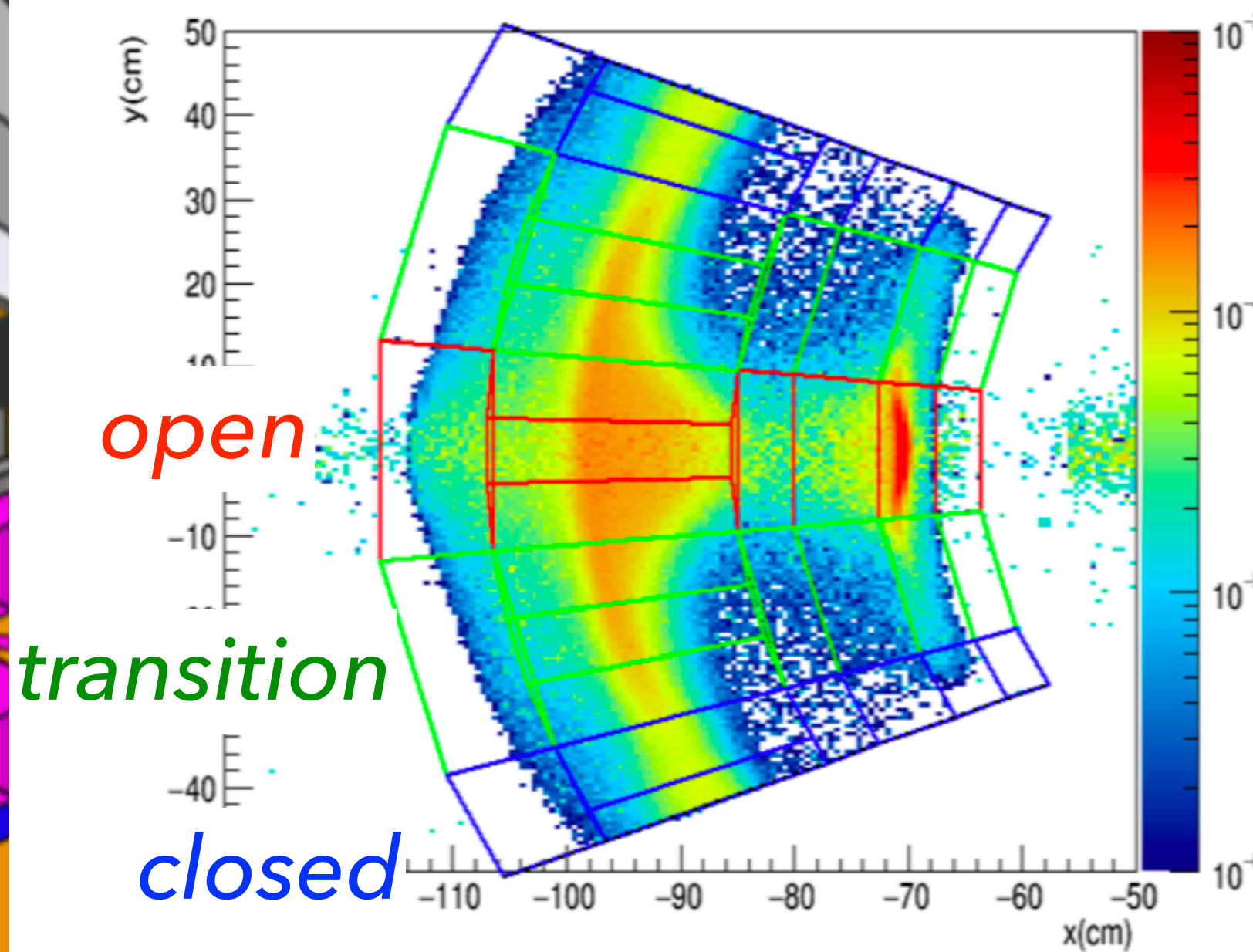**Effectively focuses or defocusses azimuthally!**
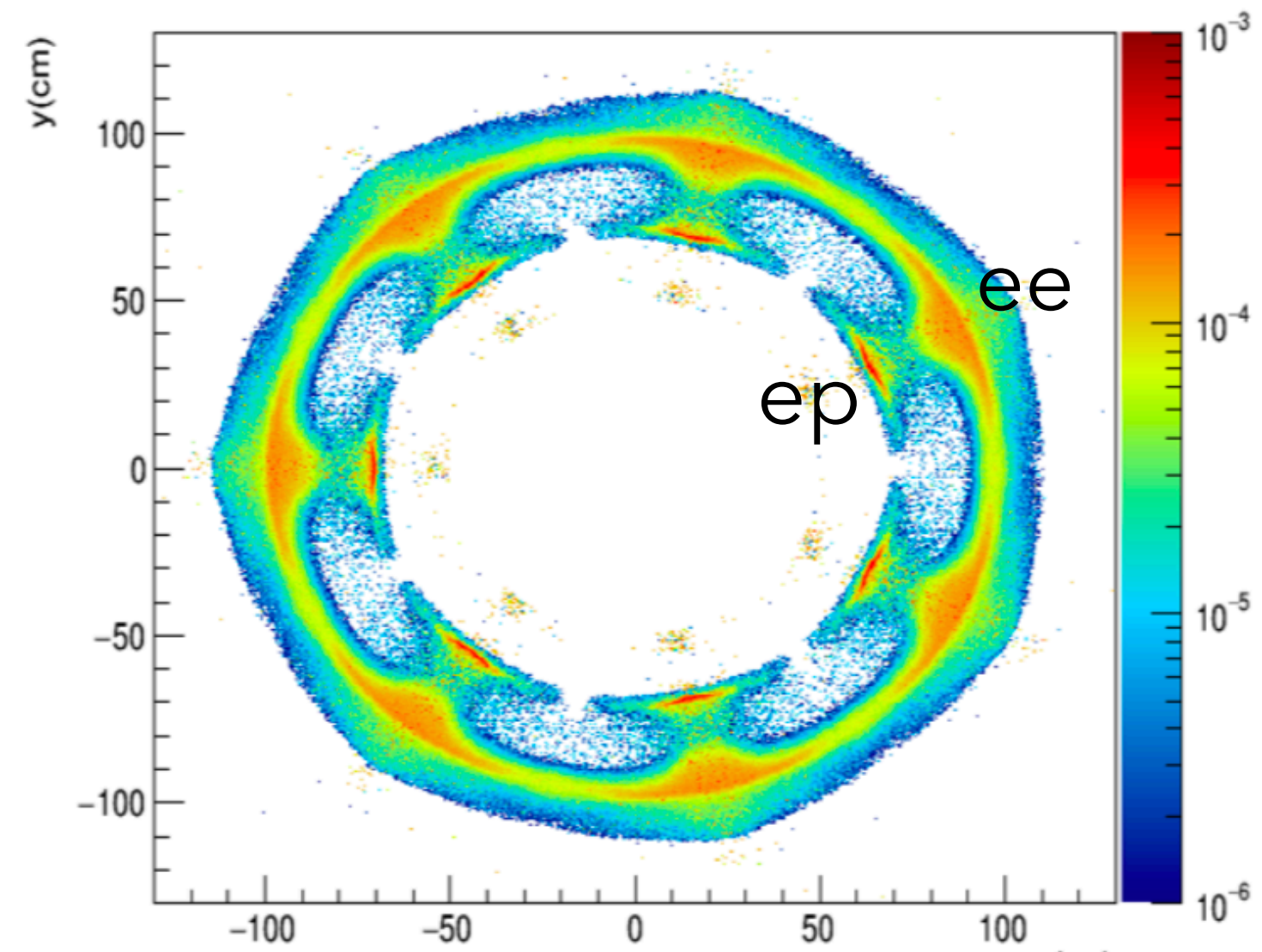
Magnet Concept

long and skinny

0.5 x 2m

0.9 x 6.5m

Main Detector
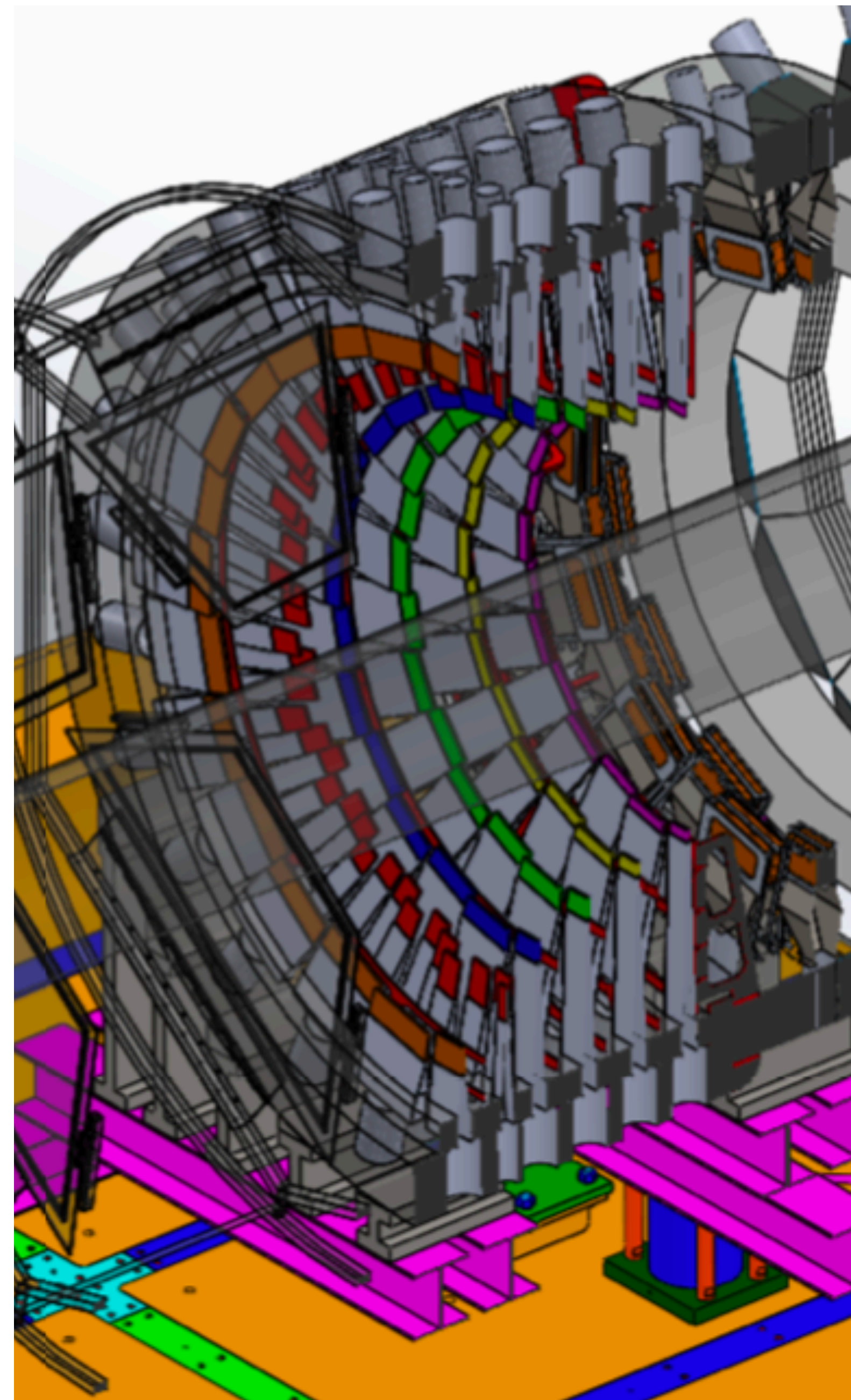
Radial distribution at detector plane 26.5 m from target

open

transition

closed

ee

ep

ep

ee
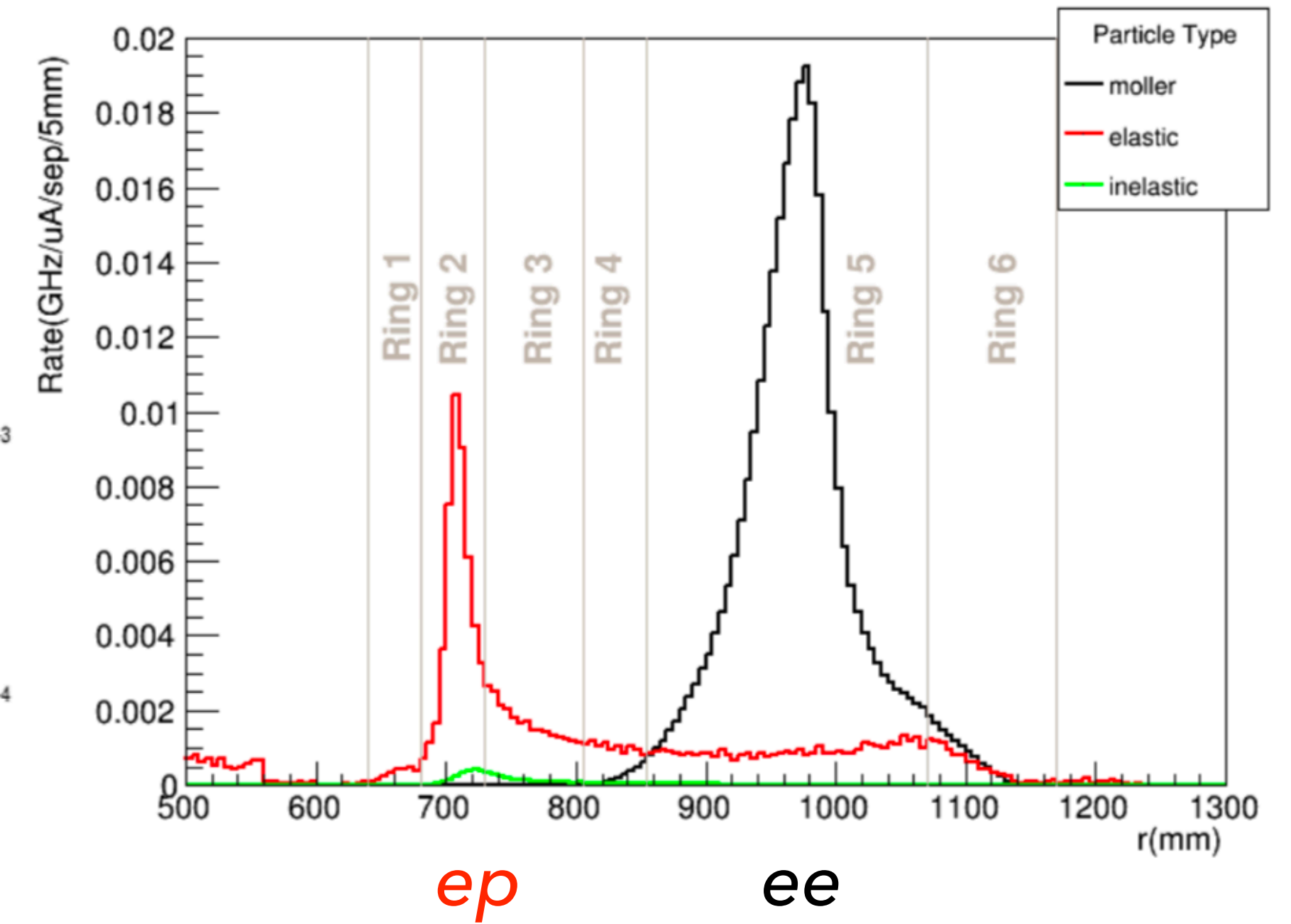
Backgrounds (irreducible)

*Illustration with each septant a different fundamental background*
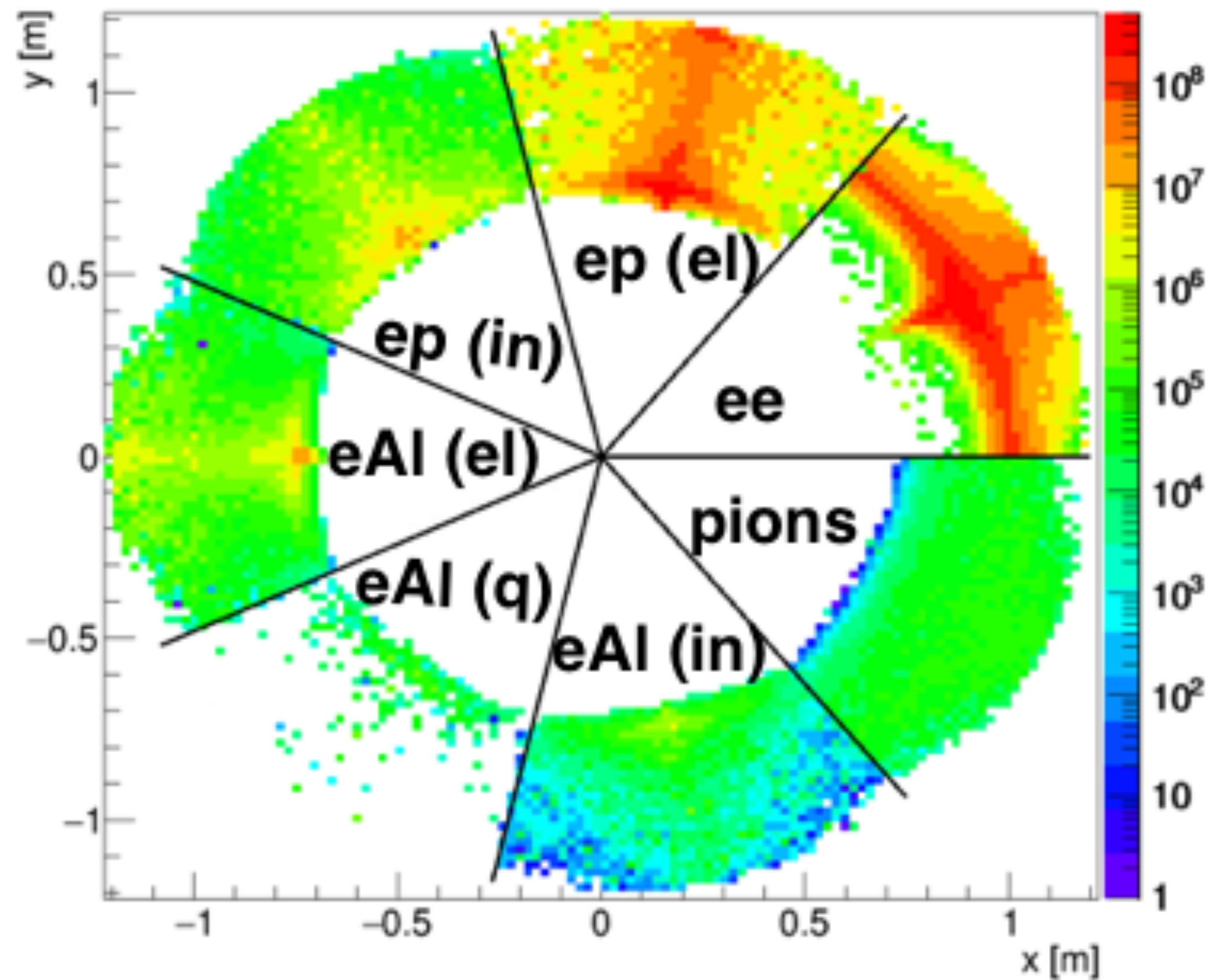
There are various sources of backgrounds arising from scattering in the target that will pass through the spectrometer and arrive at the detector plane.

We must deconvolute the signal from the background using the segmented detector plane

Backgrounds (rescattering)

Other backgrounds aren't directly through the acceptance channel, but are
• from rescattering of the beam as it makes its way through the spectrometer to the dump
• from off-energy particles in the acceptance that rescatter from edges or surfaces, and go
  on to find the detector

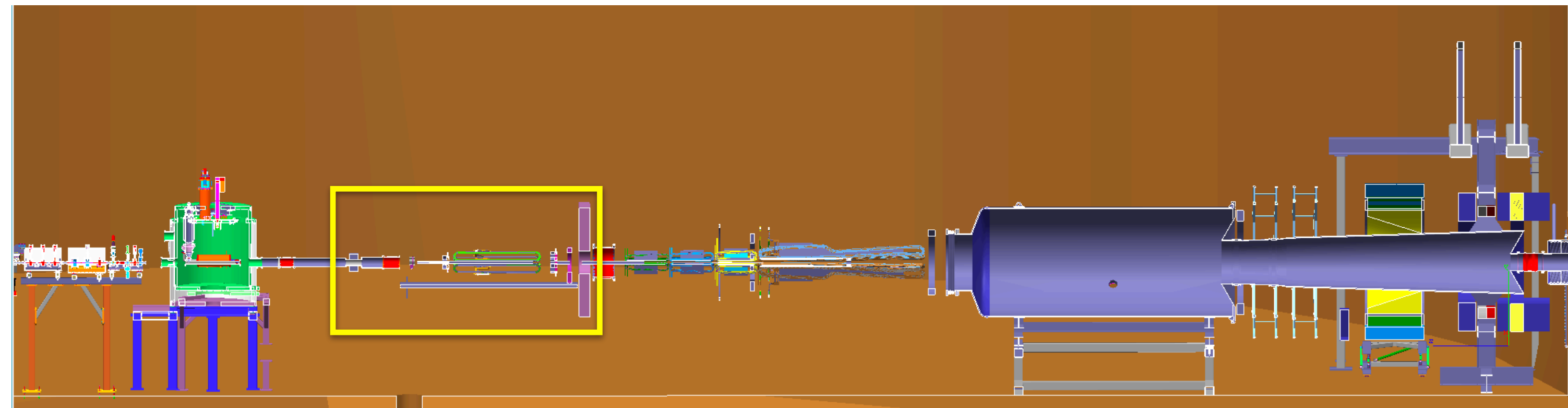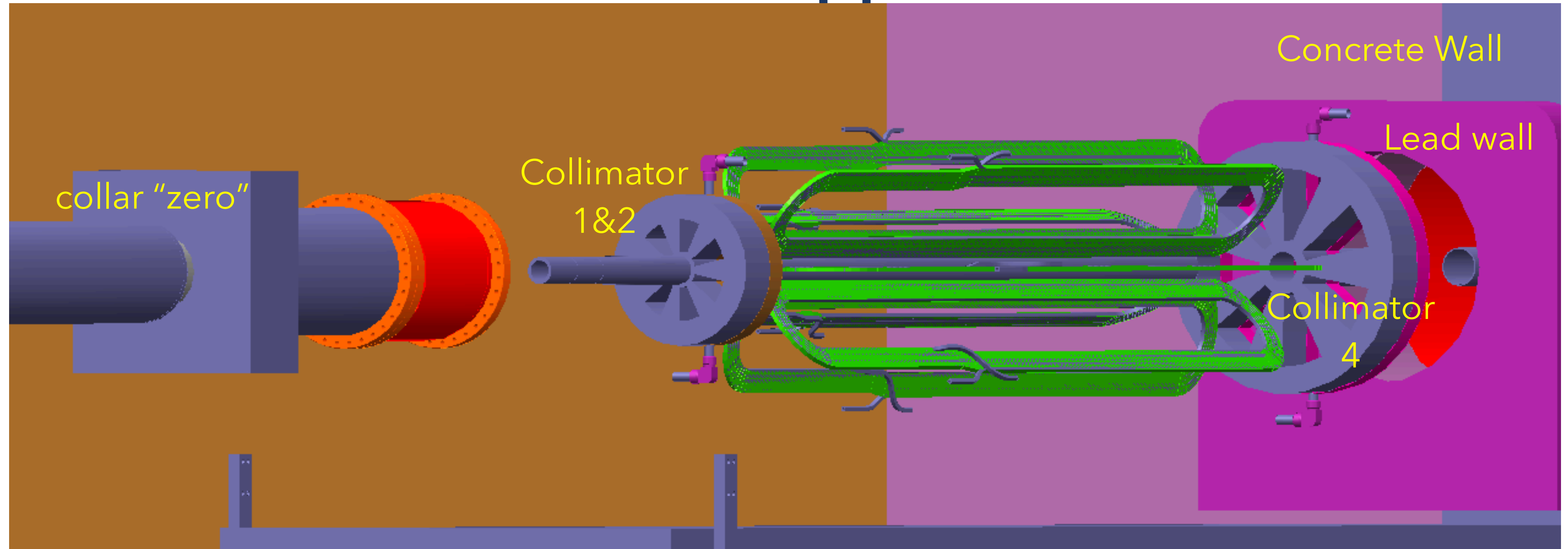*where stuff that hit the detector came from…*
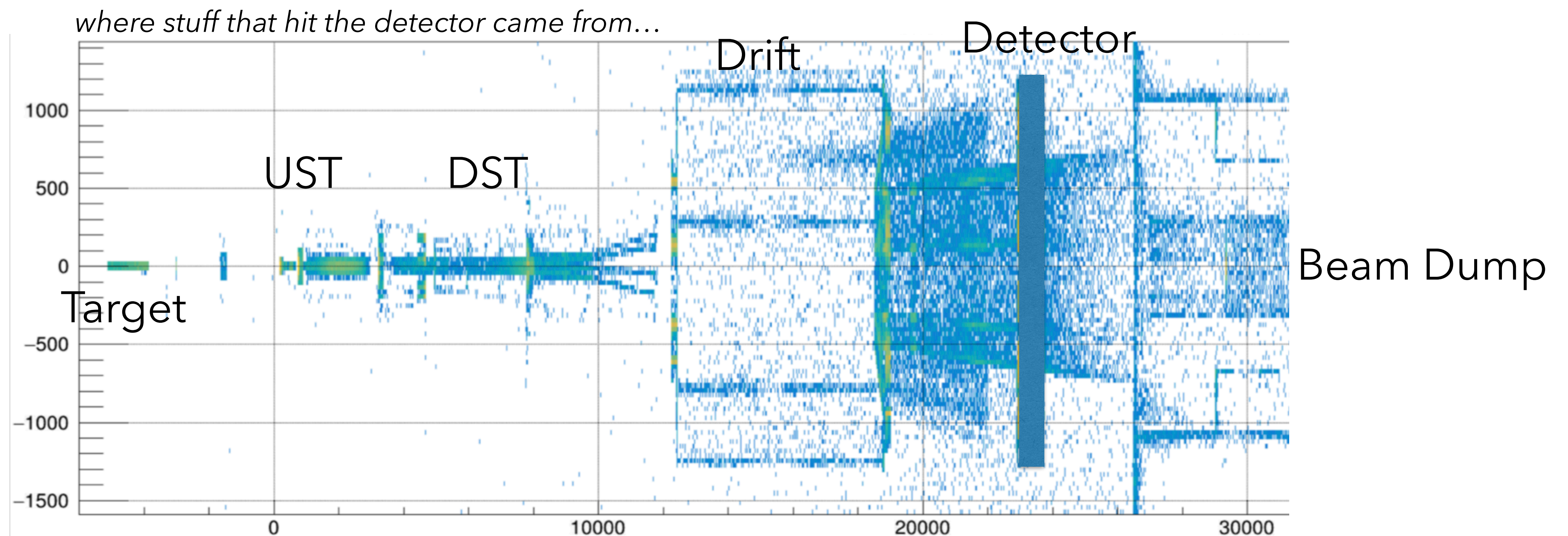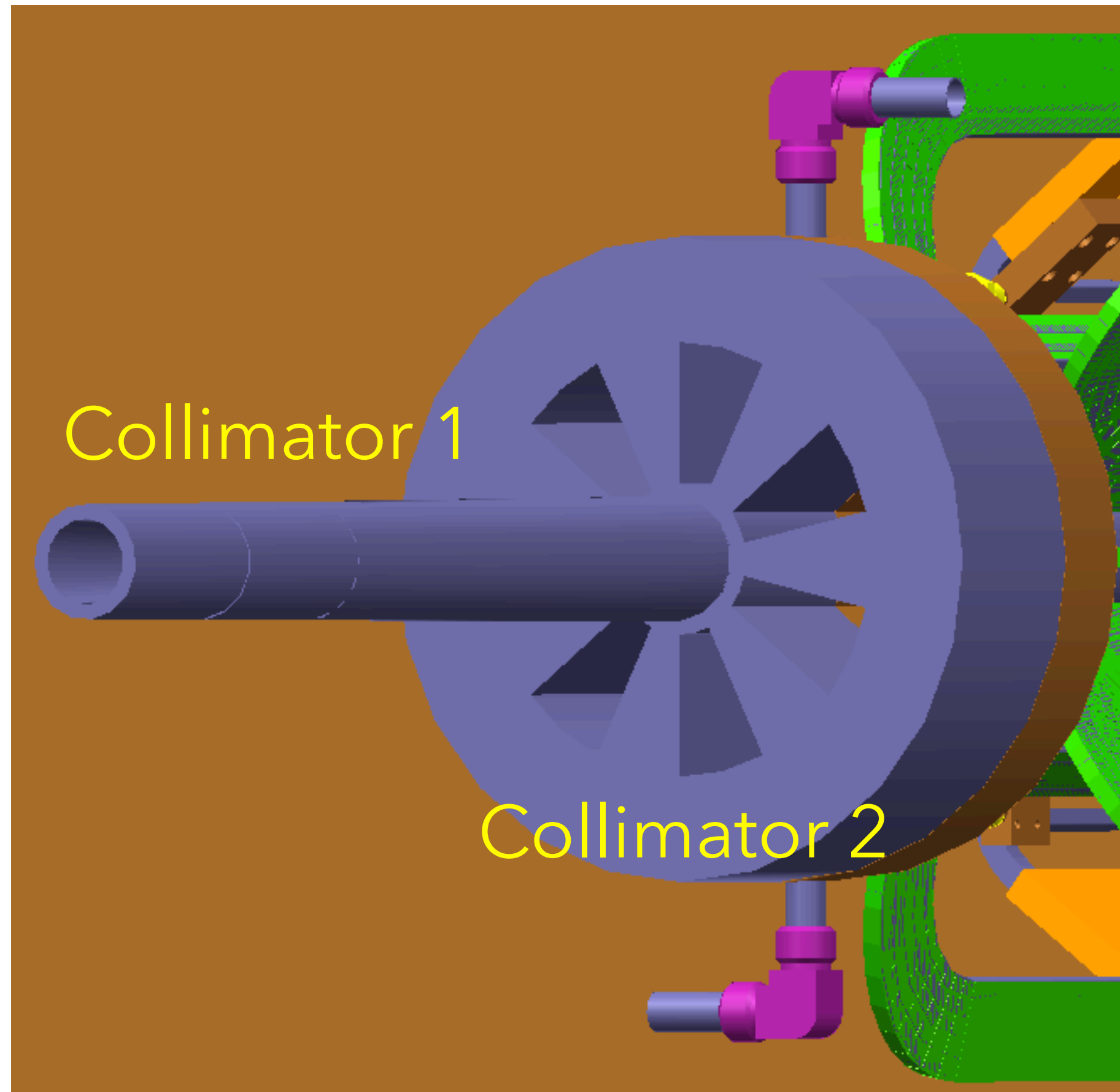
Beam Collimation
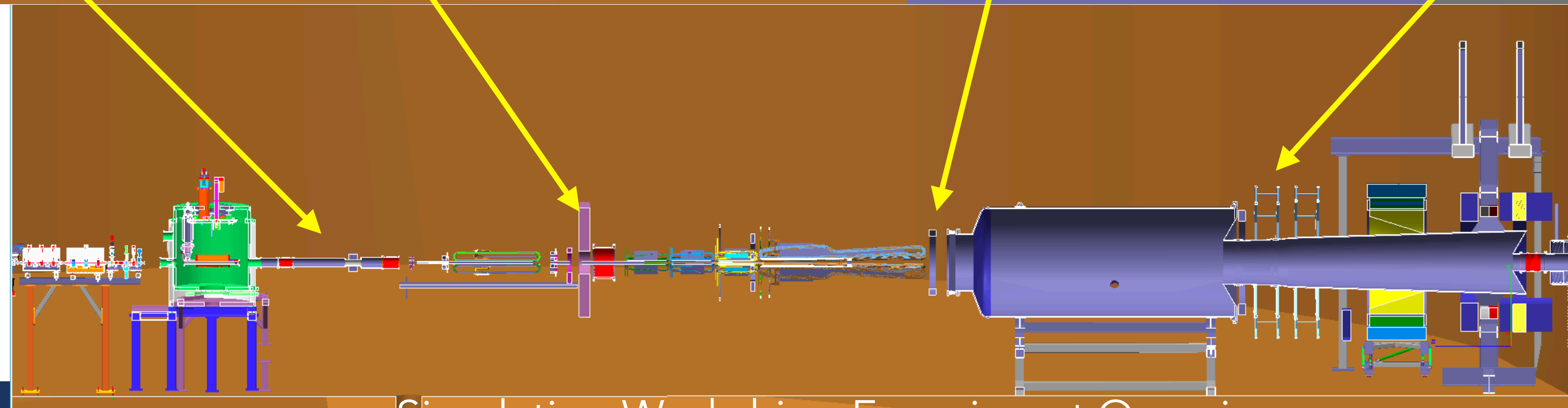

Collimator 1: long snout, collimates primary beam so what remains can go to the dump. ~3200 W
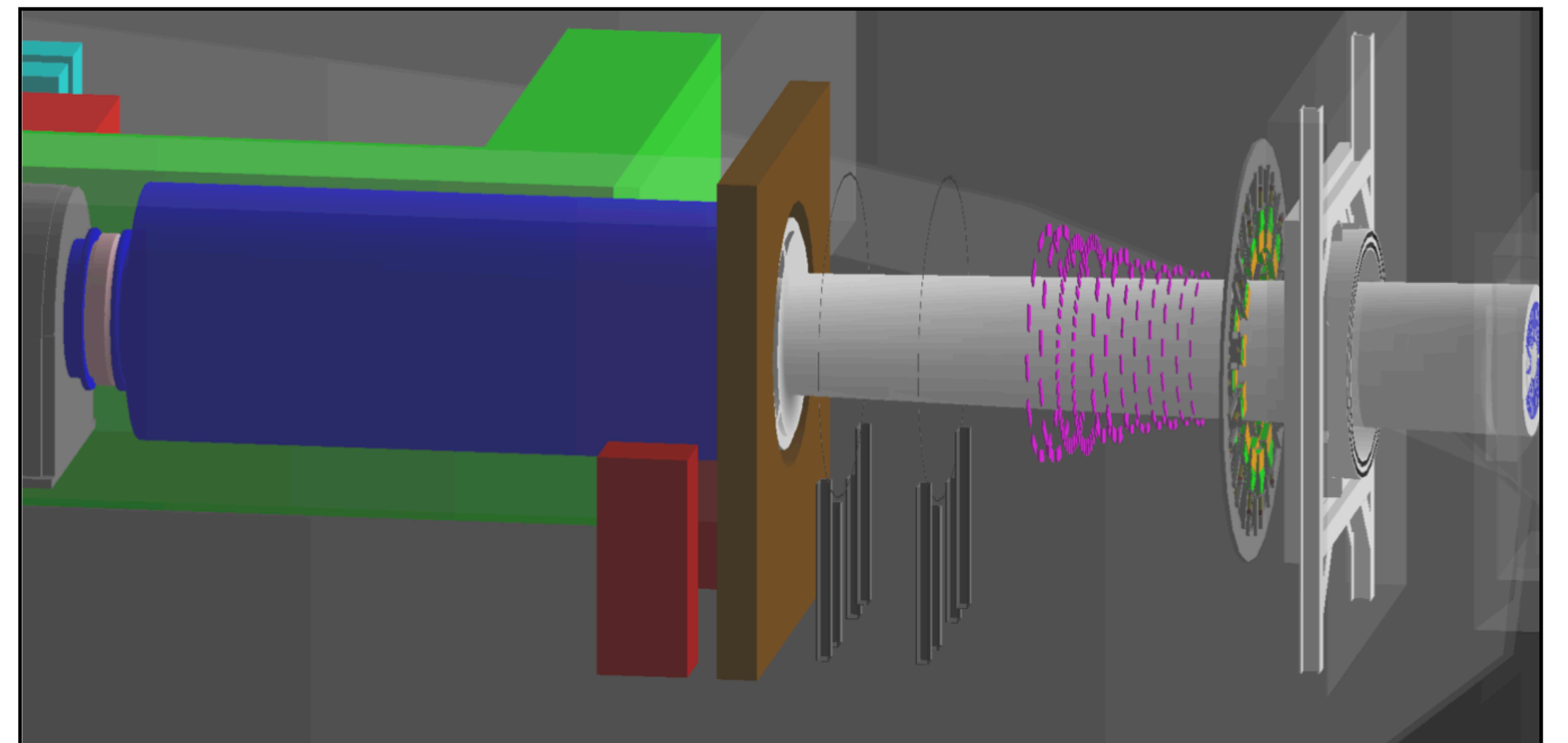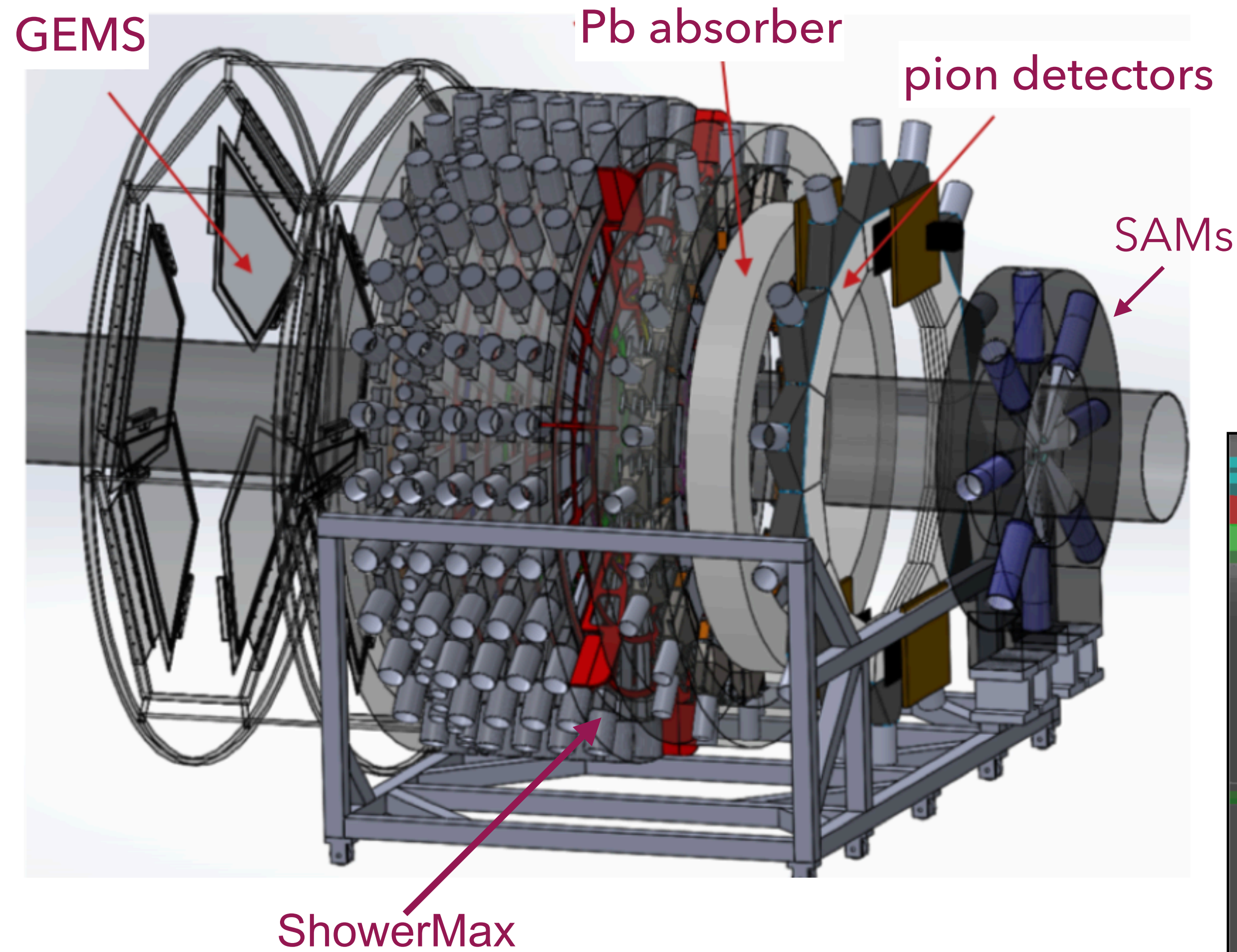
Collimator 2: wedges define the acceptance of the 7 septants

Walls, collars, and lintels supplement the collimation

Walls, collars, and lintels supplement the collimation

collar "zero"

Collimator 1&2

Concrete wall

Lead wall

Collimator 4

Collimator 5 and lintels

Collar 1

GEM trackers

More Detectors

GEMS

Pb absorber

pion detectors

SAMs

ShowerMax
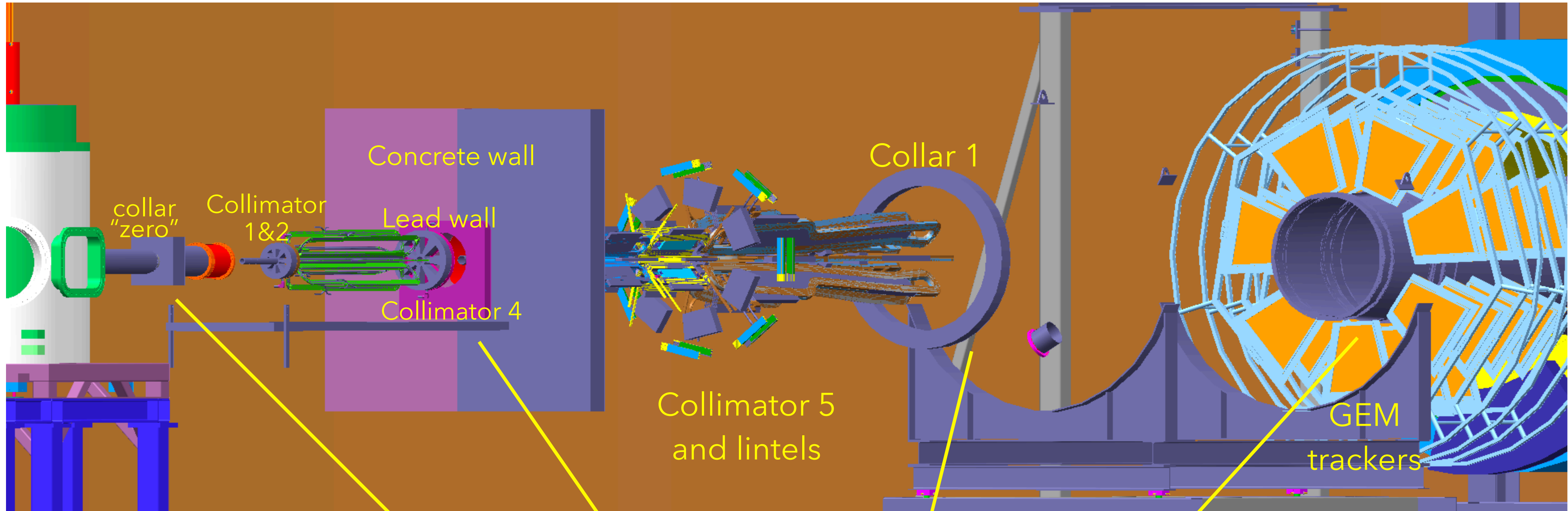
Simulation Topics

Most everything we do falls in to one of these categories

- Radiation control for equipment (hall electronics) and personnel protection (boundary)
- Radiation estimates for radiation damage in apparatus (coils, o-rings)
- Rescattering for control of measurement in main detector (or other detectors)
  - Edges, field imperfections…
  - rare events (e.g. ferromagnetic materials)
- Maintain Spectrometer and Detector optimization through final engineering
- Physics extraction

This ~50M$ project is taking off, and responding to engineering/design topics must remain our top priority

But we are also pivoting to figuring out the details of using this apparatus to measure A_{PV}, developing run and calibration plans, and writing analysis software

We're looking forward to having your help with this work!