Far-Backward Pair Spectrometer

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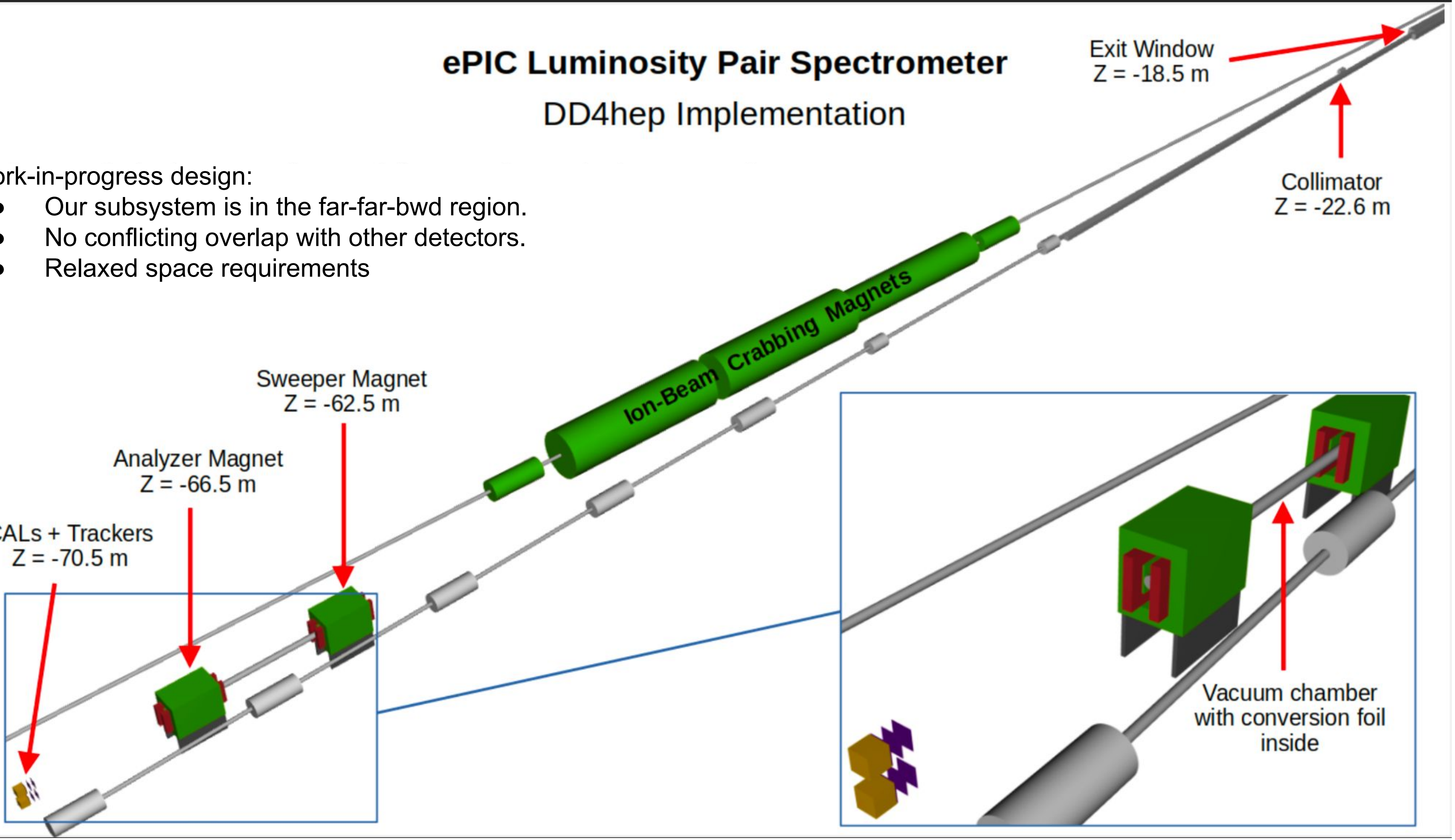
TIC meeting August 21st 2023

ePIC Luminosity Pair Spectrometer

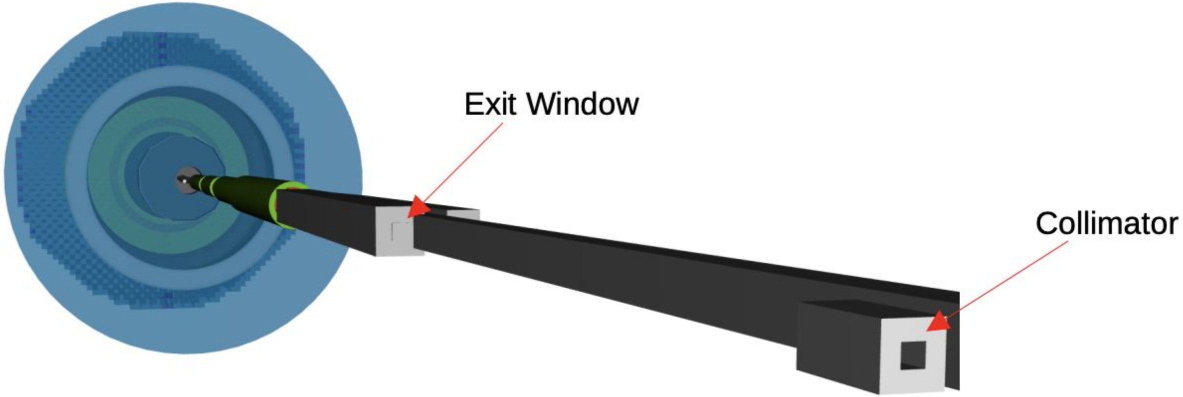
DD4hep Implementation

Work-in-progress design:

- Our subsystem is in the far-far-bwd region.
- No conflicting overlap with other detectors.
- Relaxed space requirements



Design Considerations – **Exit Window and Collimator**



Exit Window (Z = -18.5 m)

- It should have a simple geometry: constant effective thickness vs X and Y.
- Thickness and chemical composition (a% Al + b% Si + …)
  needs to be precisely known before installation!
- Conversion rate in exit window can also be determined in special low-lumi runs by turning off the sweeper magnet

Collimator (shortly after the exit window)

- Just a block of steel to shield our downstream detectors from unnecessary radiation damage.
- It defines the outer limits of our acceptance (aperture size).
- Should have an opening half-width of $5 * \Delta\theta_{max} * Z = 5 * 211e\text{-}6\ \text{rad} * 22.6\ \text{m} = 2.4\ \text{cm}$

Design Considerations – **Dipole Magnets**

Sweeper & Analyzer Dipole Magnets Requirements

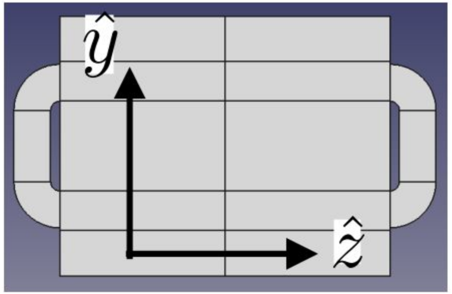
- Large $\int B_x * dz$ ~ 1 Tm to keep our system compact
- 15 cm bore diameter: 5*σ unobstructed photon acceptance
- Fringe fields at electron beam pipe < 10 Gauss

New magnets are to be built.
Magnet designer Peng Xu (BNL) has designed and simulated the magnets for us.
Field maps have been provided and will soon be put in DD4hep

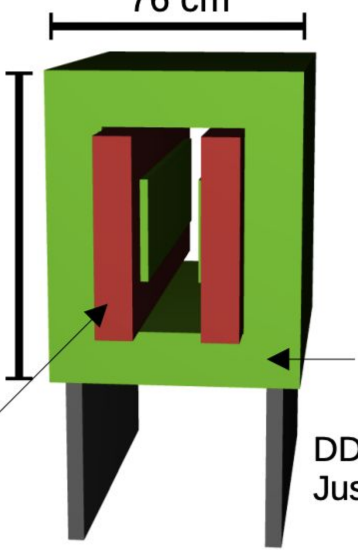
Design properties:

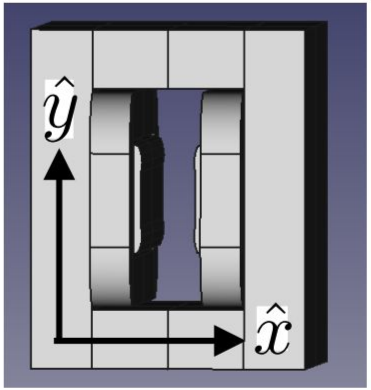
- 1.2 m long with field reaching about 0.8 T
- 15 cm bore diameter
- Fringe field at electron beam pipe < 4 Gauss.
- 6 metric tons each, excluding leg supports.
- Pre-covid cost: ~$3 per kg of soft iron, including machining.
  > $20k per magnet.

Peng's CAD model



DD4hep model

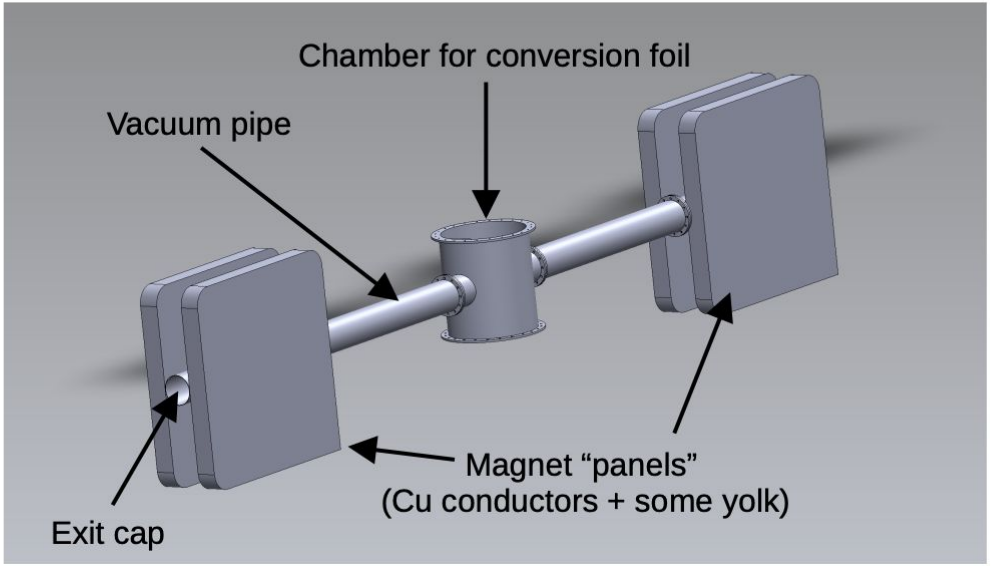




DD4hep model by
Justin Chan (UH)

Design Considerations – **Vacuum Chamber**

Igor Korover (MIT & Tel Aviv University)



July 11th 2023 PS meeting

Vacuum chamber (-67 m < Z < -62 m)

- Allows us to precisely control the Bx*dz for the conversion electrons. Conversions in air in magnet smear the Bx*dz.
  → Easier to get a well defined electron acceptance.
- Foil inside allows us to precisely control the rate of conversions by varying its thickness
  → Avoids pileup.

Studies underway by Igor:

- Exit cap optimization (thickness and material)
  → minimize $e^+ e^-$ multiple scattering.
- Conversion foil thickness and cooling method. Must withstand synchrotron rad heating.
- Vacuum pressure:
  - First, compare conversion rates:
    1 mm Al conversion foil: $P_{conv} = 0.9\%$.
    5 m of STP air (10^3 mbar) inside $P_{conv} = 1.3\%$
  - To reduce conversions in air to well below 1% that of foil, we need a **vacuum with < 1 mbar**. Note that vacuum near the IP = 10^{-9} mbar

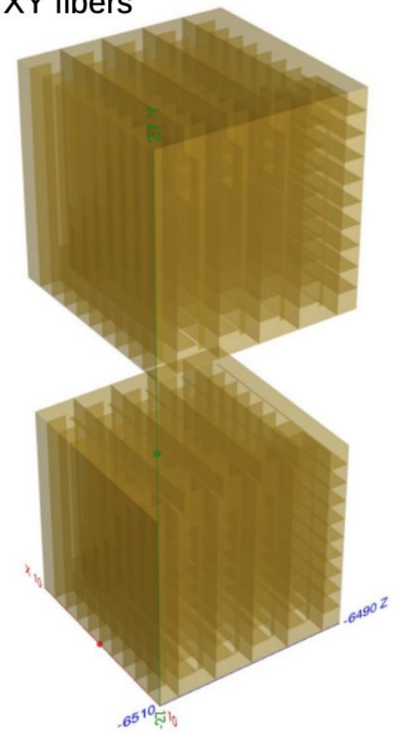
Design Considerations - **CALs**

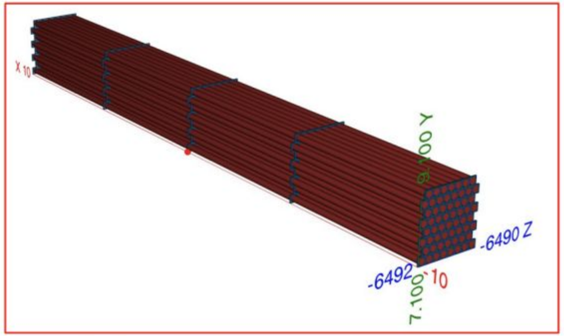
Construction of each module can follow the method of Oleg Tsai,
W-powder + epoxy infused into a bundle of scintillating fibers (like fECAL).

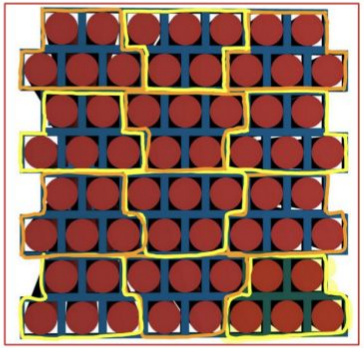
We are exploring a 2D XY fiber design: more detailed shower profiling.

Design by Aranya Giri

2D
XY fibers



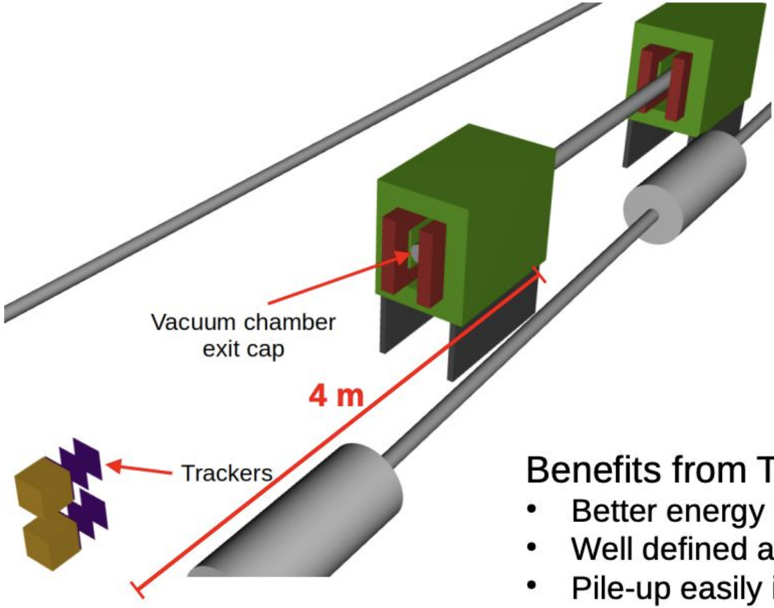




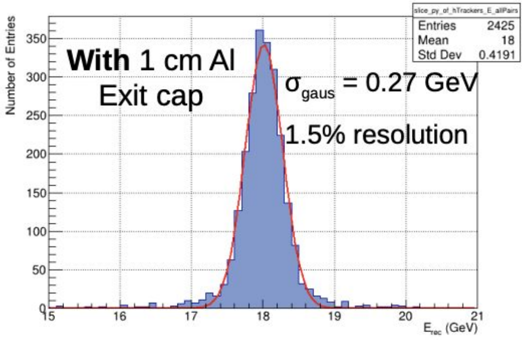
- Calorimeter size - 20 x 20 x 20 cm^3
- Alternating Layer of Y-rot and X-rot module
- Each Layer has 10 modules
- Module size - 2 x 2 x 20 cm^3
- Fiber Size - radius – 0.1 cm , height - 20 cm
- Fiber # in a module - 60
- W-Scifi Ratio - 1 : 1
- Fiber Holder
  - Material - Brass
  - thickness – 0.05 cm
  - 5 x Fiber Holders 5 cm apart
- 5 closest fibers are bundled to make a single readout channel.

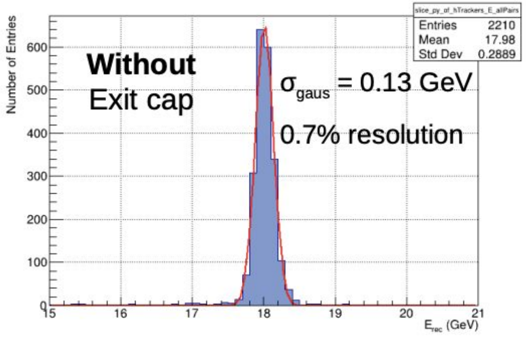
University of York In kind contribution (awaiting decision on proposal)

Design Considerations - **Trackers**



Energy Resolutions
for 18 GeV electrons





Benefits from Tracking Planes in front of CALs:

- Better energy resolutions attainable than from CALs.
- Well defined acceptance, no “fuzzy” edges as with CALs.
- Pile-up easily identified and treated.
- Tracks allow rejection of background particles (beam-gas) and assessments of the electron beam divergence.

3 Timepix4 tracking planes assumed so far, but given the rough $2M price tag, we will explore the performance with 2 or even just 1 plane (acceptance and pile-up treatment only).

In principle, either trackers or CALs alone can do the job, but having both is advantageous

Lessons Learned from ZEUS Lumi Systematics

EIC Yellow Report Requirements:

- ~1% uncertainty for absolute luminosity.
- Less than 10^{-4} for relative lumi.

NIM A 744 (2014) 80-90

Component		Sub-Component systematics
Acceptance	(**1.6%: Total**)	**1.0%:** Aperture and detector alignment
		1.2%: X-position of photon beam
Photon conversion in exit window	(**0.7%: Total**)	0.1%: Thickness
		0.3%: chemical composition
		0.6%: photon conversion cross section
RMS-cut correction	(**0.5%: Total**)	Rejection of proton gas interactions
Total		**1.8%**

Reduction routs for ePIC:

1) 5*σ obstruction-free aperture
2) low-lumi runs with coincidences of low-Q2 tagger and pair spec. **Tagger critical for pair spec calibration/verification**

With a well understood acceptance, 1% absolute lumi precision within reach.

For relative lumi, all systematics should cancel, and required statistical precision reached in less than 1 hour.

ePIC luminosity Pair Spectrometer

The ePIC design goes beyond the ZEUS one in 3 noteworthy ways:

- Broad and well-defined photon acceptance.
- Controlled low conversion rate with sweeper magnet + vacuum chamber +conversion foil.
- Tracking planes in front of CALs

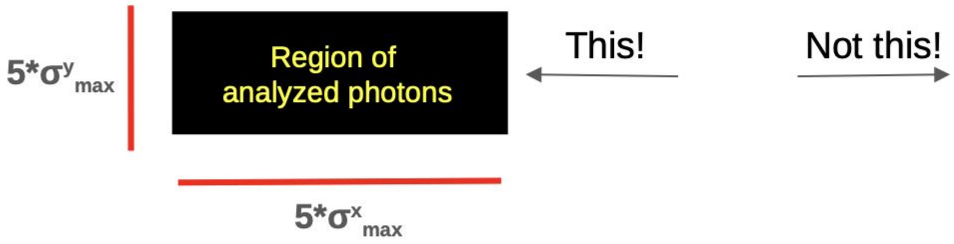
Photon Acceptance

Need to provide an unobstructed path for Bremsstrahlung photons to propagate from the IP to the lumi exit window, and then from the exit window to the Pair Spectrometer.

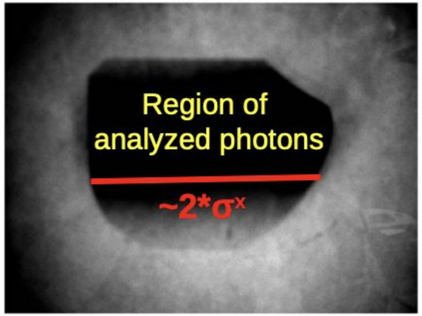
Photon beam width $\sigma(Z) = \Delta\theta$ (electron beam divergence) * Z.

$3*\sigma_{Gaus}$ covers 99.7% of population, but beam may not be Gaussian and it's preferable not to extrapolate.

$5*\sigma_{max}(Z)$ conical region should provide adequate acceptance.



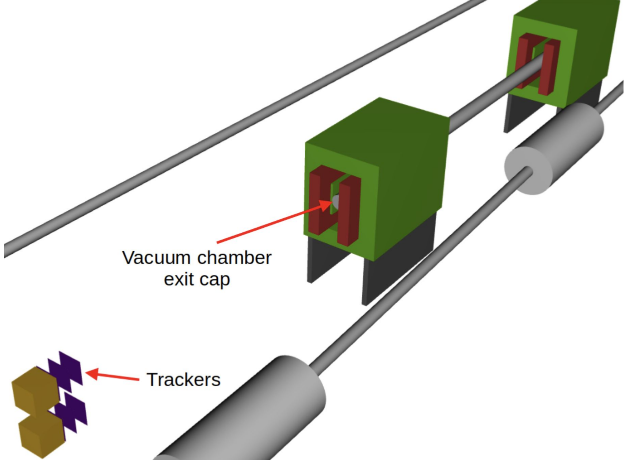
ZEUS photon aperture



This was the dominant source of uncertainties for the HERA luminosity

We need a simple and broad acceptance!

Pair Spectrometer Tracking planes



Tracking planes allow us to:

- Better define calorimeter fiducial area
- Reconstruct photon position with higher precision
- Calibrate calorimeter energy
- Technologies considered: Timepix, AC-LGAD, microstrip sensors, …

Current efforts are underway to establish the impact of a design with no trackers

- Current Cal design with segmentations in x/y/z allows hit position determination (studies underway to establish resolution)

In Zeus:

- Calorimeter acceptance reduced to exclude for edge hits
- detector hit positions determined using weighted energy depositions
- calibration done using special runs with narrow horizontal collimator.

Pair Spectrometer concluding remarks

- No outstanding integration issues:
  - Detail integration plans still need to be performed for vacuum pipe, movable table for PS converter, magnet installation.
- Technical issues to be addressed:
  - Quantify the need for trackers and the impact they will have
  - Eliminate the need of dedicated calibration runs as system can be self calibrated.