FF/FB Cross-Cutting Report

Alex Jentsch (BNL)

For the ePIC FF/FB Cross-Cutting WG

ePIC Collaboration Meeting
July 29th, 2023
Warsaw, Poland

BROOKHAVEN NATIONAL LABORATORY

Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

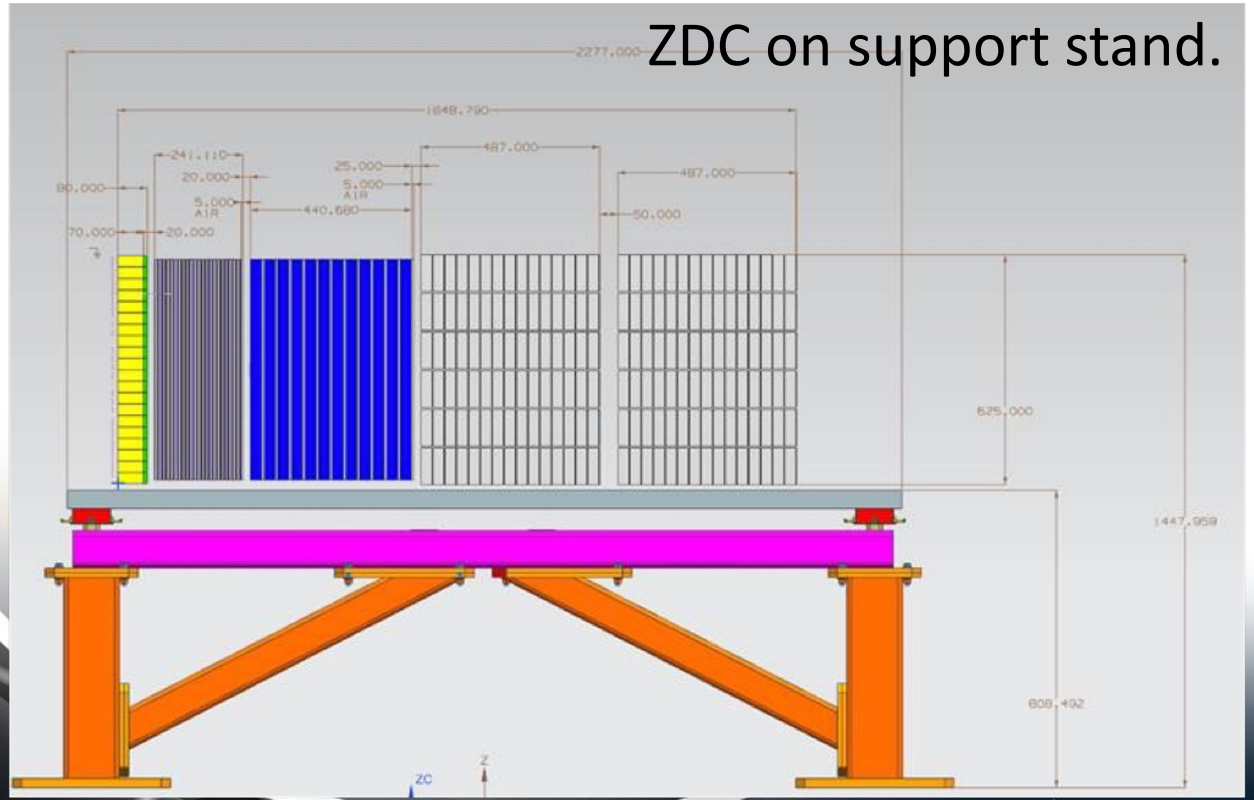
Overview & main issues (non-exhaustive)

- Subsystems have already been (or will be after me) discussed at this meeting.
- What are some issues left on the table?
  - Major integration issues.
  - Reconstruction.
  - Technology choices.
  - Simulation problems (e.g. slow simulations, or non-sensical simulations).

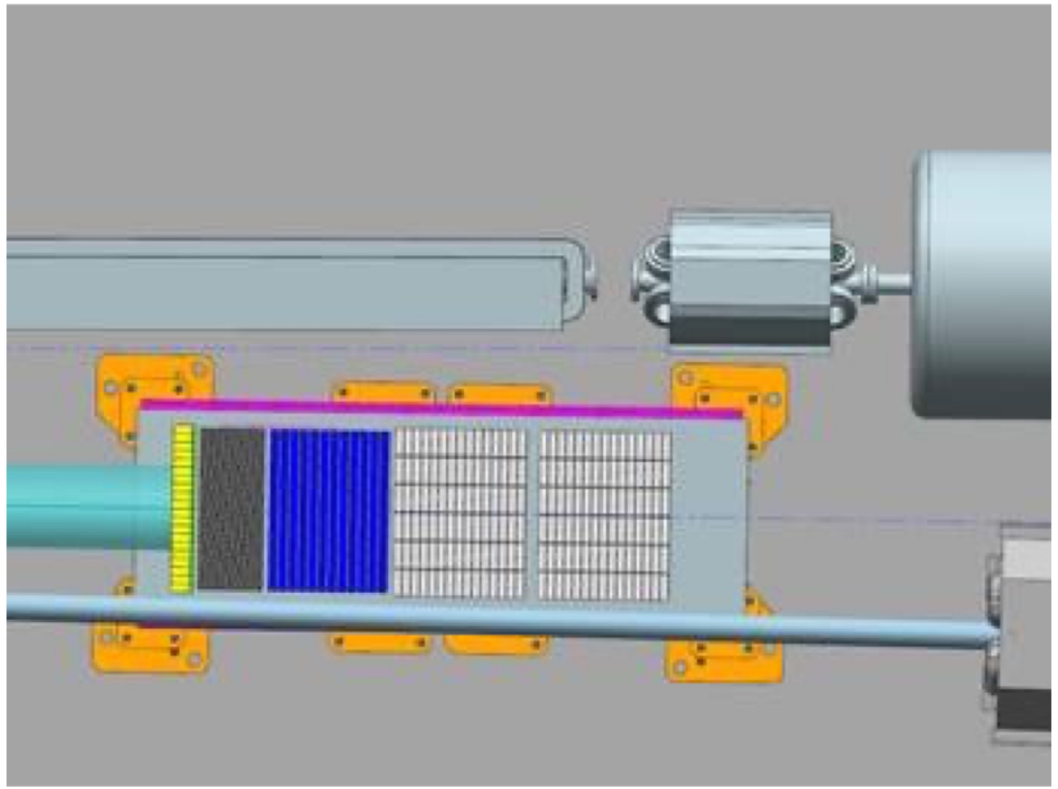
Preliminary design review is slated for roughly Dec. 2023/Jan. 2024 timeline → Much needs to be done before we get to that point!

Integration Issues

- ZDC sits outside of the beampipe - main integration issue is keeping it clear of magnet cryostats, crab cavity on electron side, and hadron beam pipe.



ZDC on support stand.



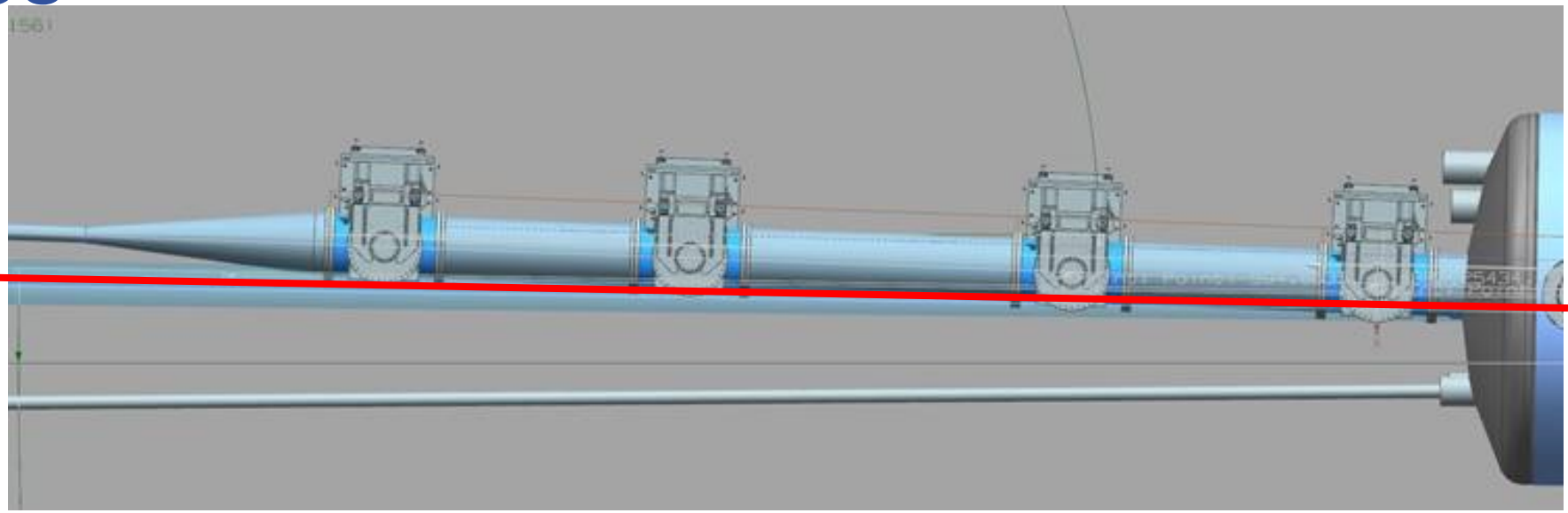
- Potential interference with hadron beamline → needs some follow-up with hadron beamline experts.
  - Need 2-3cm clearance between ZDC components and beam pipe, but this needs follow-up.

Integration Issues

- Neutral particle cone faces two issues:
  - Exit from beampipe at very shallow angle (~ 22mrad) → effective material length O(10cm) for 2mm thick beam pipe wall!

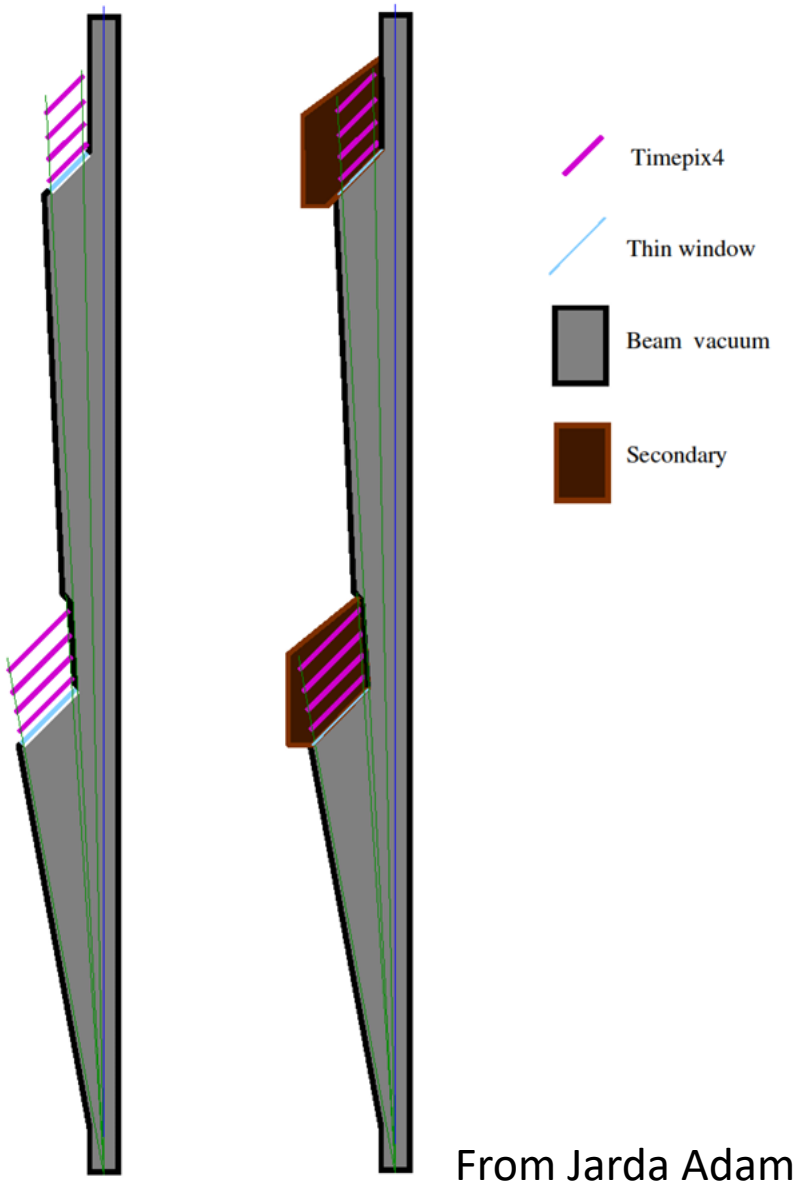
Integration Issues

0 degrees



- Neutral particle cone faces two issues:
  - Exit from beampipe at very shallow angle (~ 22mrad) → effective material length O(10cm) for 2mm thick beam pipe wall!
  - With inclusion of OMD/RP support - interference of zero angle neutrals with flanges/support components!
- **This needs some major optimization (underway).**
  - **The present beampipe design was done by Alex Jentsch as a placeholder back in 2021 - we are in need of an engineer to advance the design and aid in optimization (project is aware – in progress).**

Integration Issues

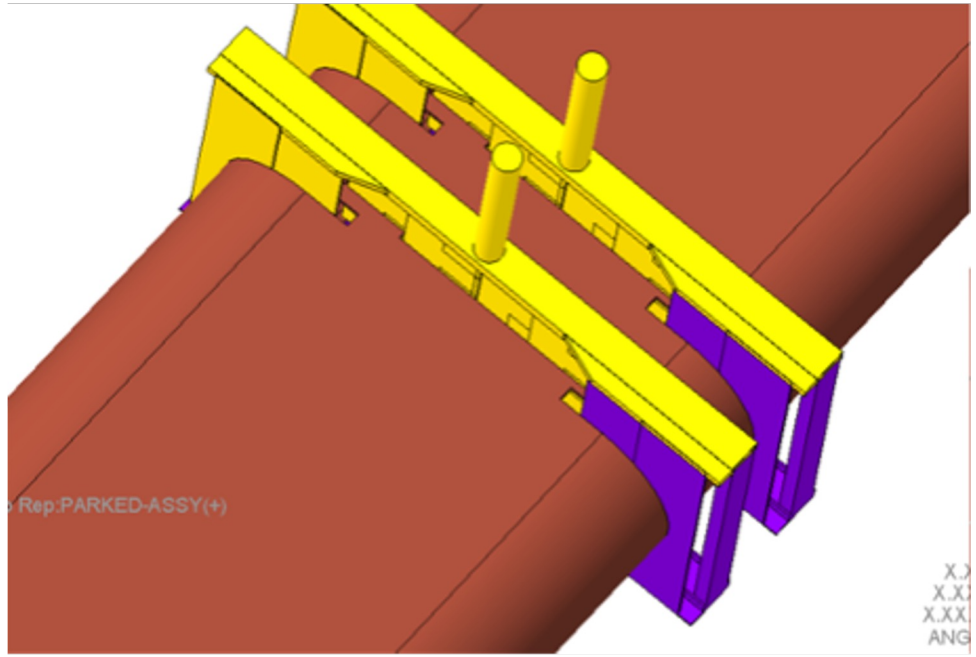


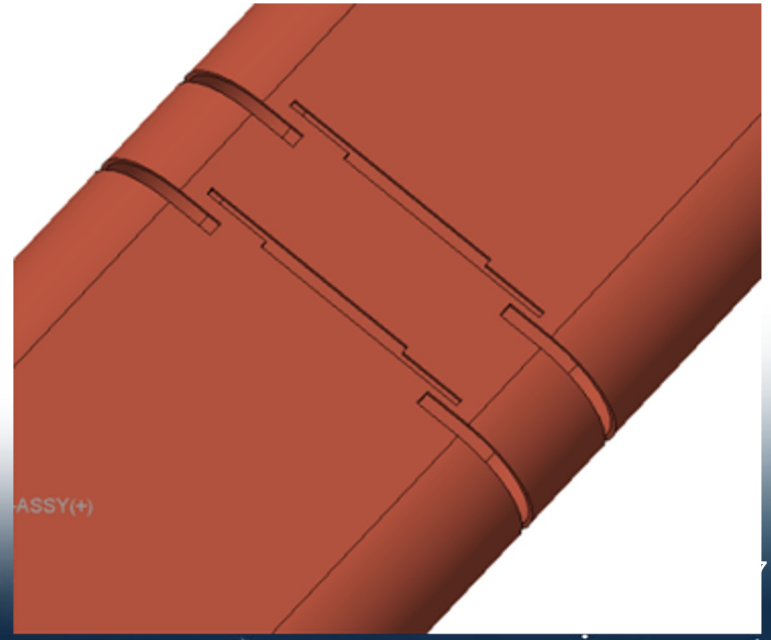
From Jarda Adam

- Need to decide on interface for low-Q2 tagger system.
- Balance between detector operation and impedance impact to the machine (similar issue with Roman pots).

Roman Pots/Off-Momentum Detectors

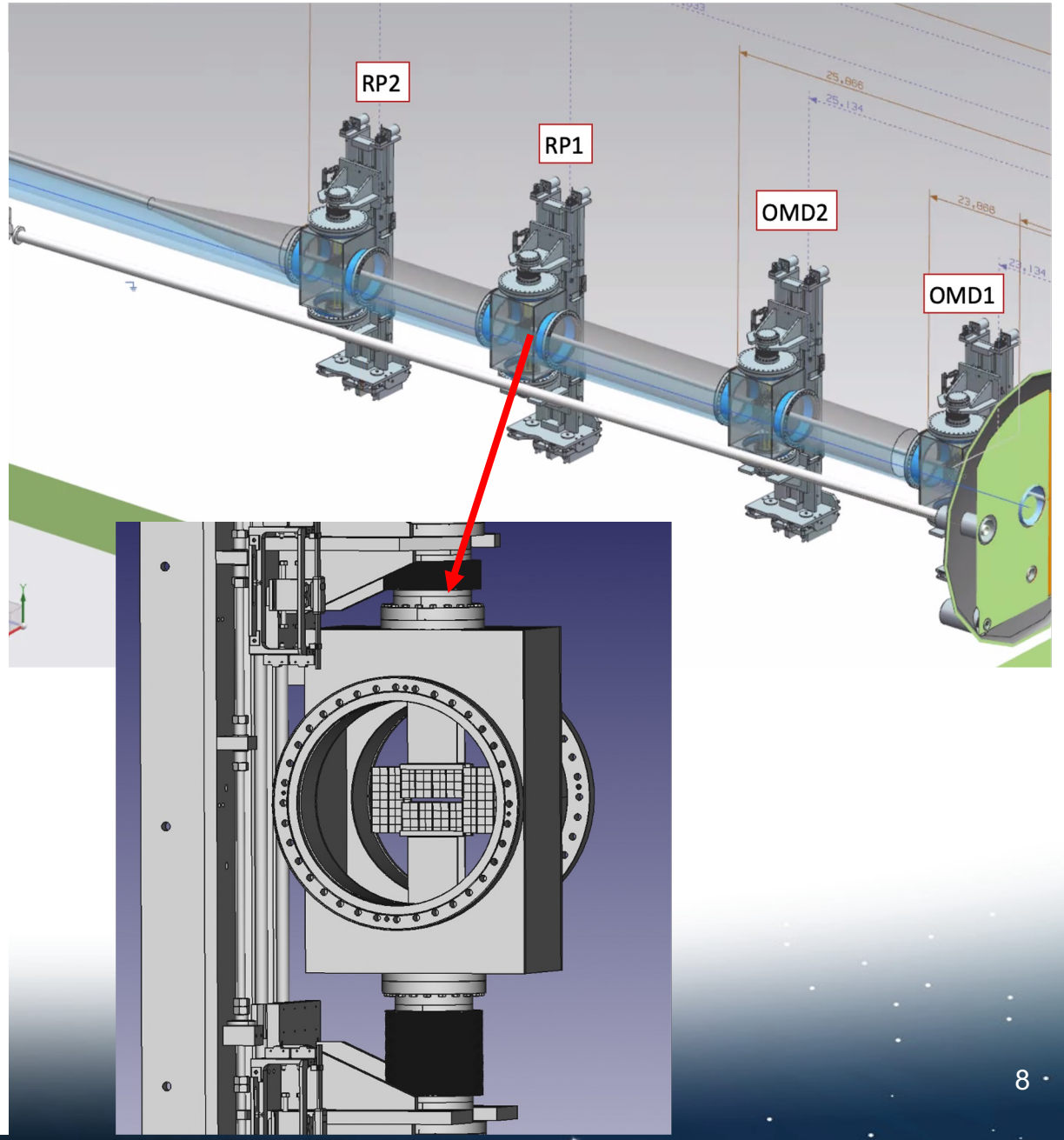
- RP/OMD most-challenging of the FF systems for machine integration.
  - AC-LGAD sensors directly integrated into beamline vacuum → creates issues for detector technology and **beam impedance**.
  - Requires special consideration for **beam pipe design and support system.**





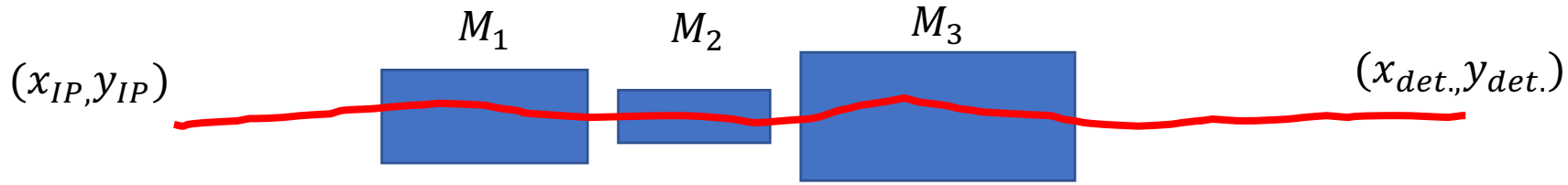
Roman Pots/Off-Momentum Detectors

- RP/OMD most-challenging of the FF systems for machine integration.
  - AC-LGAD sensors directly integrated into beamline vacuum → creates issues for detector technology and **beam impedance.**
  - Requires special consideration for **beam pipe design and support system.**
- **Current design meets physics requirements from YR.**
  - **BUT → major changes/solutions will be needed to address impedance and integration issues, which could impact physics (especially at acceptance edges/gaps).**
  - **Common issue with beampipe design for the ZDC neutral exit.**



Reconstruction

- **Two general issues:**
  - Calorimetry (EMCAL in FB, EMCAL + HCAL in FF)
  - Tracking of particles in drift region after passing through magnets.

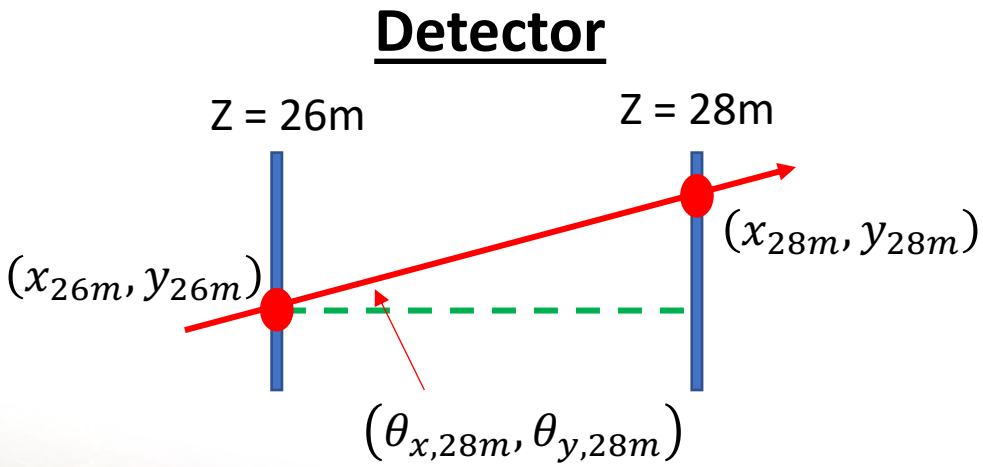


$$M_{transfer} = M_1 M_2 M_3 \ldots$$

- Transforms coordinates at detectors (position, angle) to original IP coordinates.
- Matrix unique for different positions along the beam-axis!
- See slides: https://indico.bnl.gov/event/19978/
- Problem present on both sides of the IR!

Reconstruction

- **General methods for tracking:**
  - **Matrix method (standard)** → should always have access to this to check performance.
  - **Machine learning methods** → more-general for broader set of final-state momenta.



$$\begin{pmatrix} x_{ip} \\ \theta_{x,ip} \\ y_{ip} \\ \theta_{y,ip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} a_0 & a_1 & a_2 & a_3 & a_4 & a_5 \\ b_0 & b_1 & b_2 & b_3 & b_4 & b_5 \\ c_0 & c_1 & c_2 & c_3 & c_4 & c_5 \\ d_0 & d_1 & d_2 & d_3 & d_4 & d_5 \\ e_0 & e_1 & e_2 & e_3 & e_4 & e_5 \\ f_0 & f_1 & f_2 & f_3 & f_4 & f_5 \end{pmatrix} \begin{pmatrix} x_{det.} \\ \theta_{x,det.} \\ y_{det.} \\ \theta_{y,det.} \\ z_{det.} \\ \Delta p/p \end{pmatrix}$$

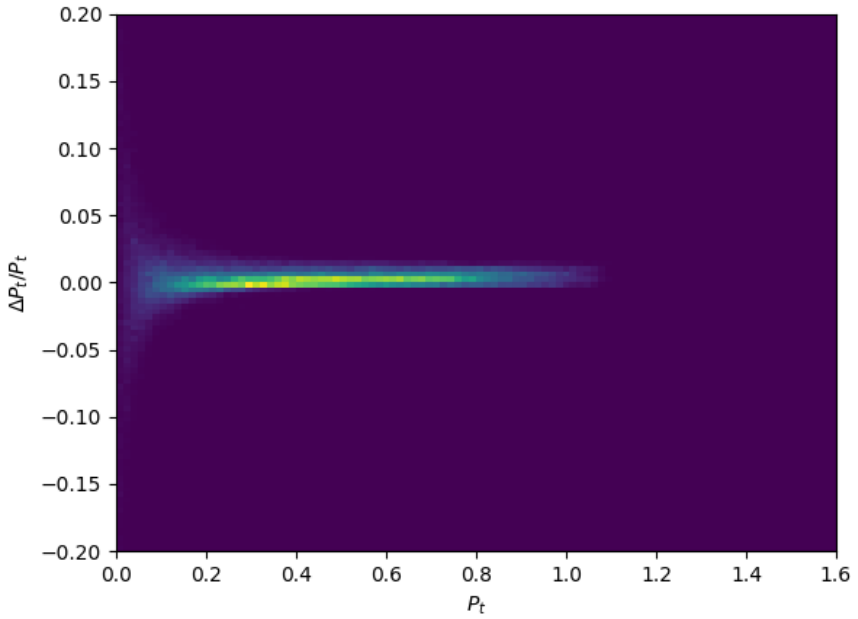
Reconstruction

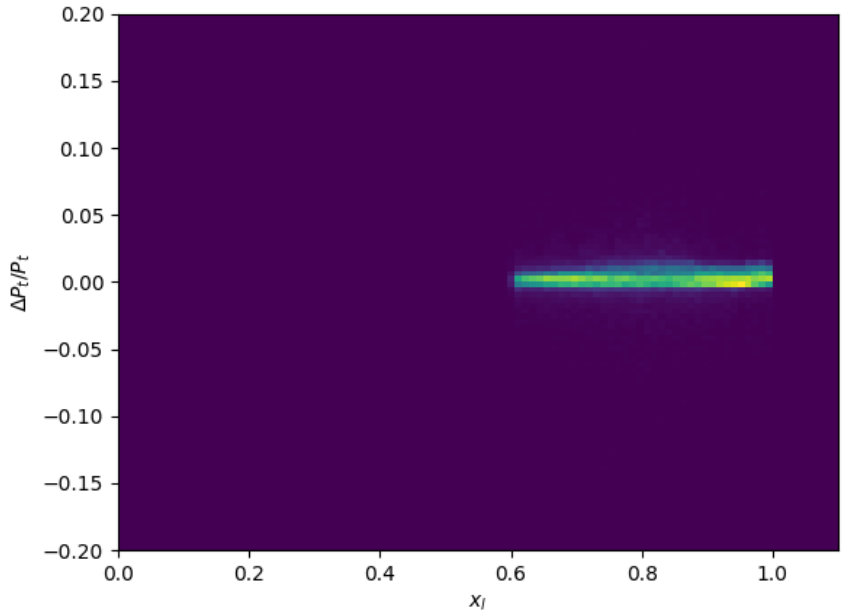
- **General methods for tracking:**
  - **Matrix method (standard)** → should always have access to this to check performance.
  - **Machine learning methods** → more-general for broader set of final-state momenta.

$$\begin{pmatrix} x \\ \theta_x \\ y \\ \theta_y \end{pmatrix} \rightarrow (P_z)$$

$$\begin{pmatrix} x \\ \theta_x \\ P_z \end{pmatrix} \rightarrow (P_x)$$

$$\begin{pmatrix} y \\ \theta_y \\ P_z \end{pmatrix} \rightarrow (P_y)$$





- **Framework:** PyTorch
- **Architecture:** Multi-Layer Perceptron
- **3 Independent Models:**
- **5 Hidden Layers, 128 Neurons**
- **Loss Function:** Huber Loss
- **Optimizer:** Adam
- Performance is excellent for P_z and shows little dependence on x_L
- P_t performance is good, but needs further optimization, and performance suffers at very low P_t

Progress on RP reconstruction.

David Ruth & Sakib Rahman

Simulation Issues

- Very slow running of incoherent e+Pb events
- Bizarre behavior of coherent e+Pb events (100% vetoing efficiency)
- Improper steering of nuclei in magnets
- Materials/vacuum system

Simulation Issues

- Very slow running of incoherent e+Pb events
  - Issue with stepping in ZDC (also present in EICROOT) – function calls to GEANT stepping come with high computing overhead →is that what is happening?
  - **Solutions:** increase step size, lower maximum number of steps, solve actual problem.
- Bizarre behavior of coherent e+Pb events (100% vetoing efficiency)
  - Main ePIC volume is air – vacuum volume wasn't working.
  - **Solution:** change default world volume to vacuum → problem went away. Vacuum volume to fill FF beampipe almost ready (few days).
- Improper steering of nuclei in magnets
  - Constant B0 magnet causes an issue when scaling fields for ion beams.
  - **Solution (short-term)**: use 18x275 magnets, scale all magnets by equivalent proton beam momentum (based on q/m for nucleus, and gamma factor). Assume variable B0 – BE CAREFUL → B0 tracking will be WRONG.
- Materials/vacuum system
  - As mentioned before, vacuum system design needs work → also important for physics studies: affects acceptance and smearing.

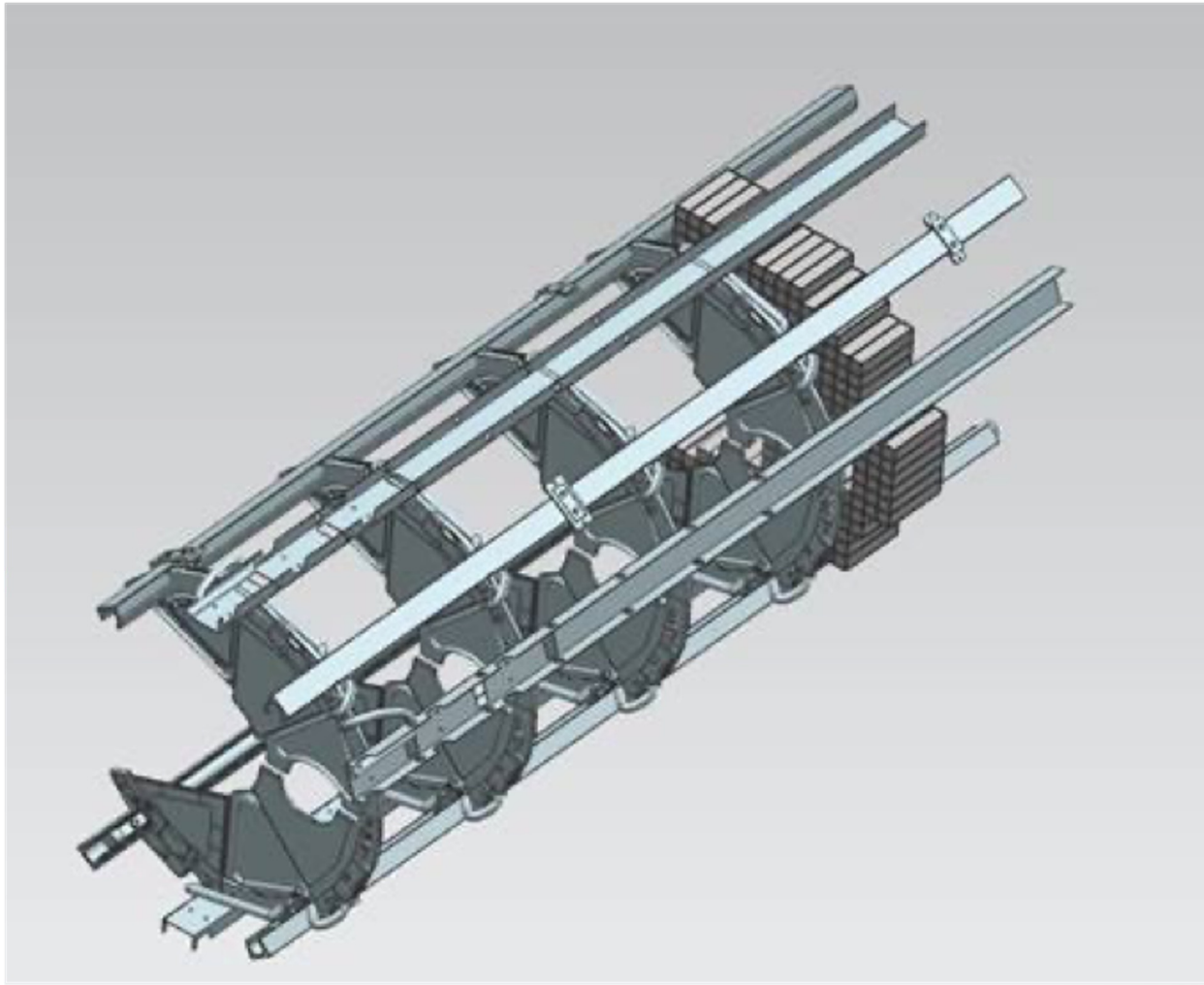
Next steps → What is needed?

- Engineering support to aid in optimization of layout (Fall 2023).
  - Preserving/improving physics performance is the primary goal → Technology choice not the bottleneck!
  - Need vacuum engineer to advance beam pipe design and ensure it can be successfully pumped → New preliminary design in-progress to provide a better starting point.
  - Need expertise on impedance to solve issues with RP/OMD/Low-Q2.
- Design of cooling system(s) for in-vacuum detectors.
  - Preliminary ideas are on the table, but need someone with expertise to advance the conceptual design to something which can be built (need to cool ~100 watts per active plane for AC-LGADs).
- Iteration with accelerator experts as hadron lattice evolves (ongoing).
  - Need lattices for light ions.
- Finalize technology options and alternatives for any remaining subsystems (next 1-2 months, maximum).
  - Some of this depends on final engineering choices.

Backup

B0 Integration

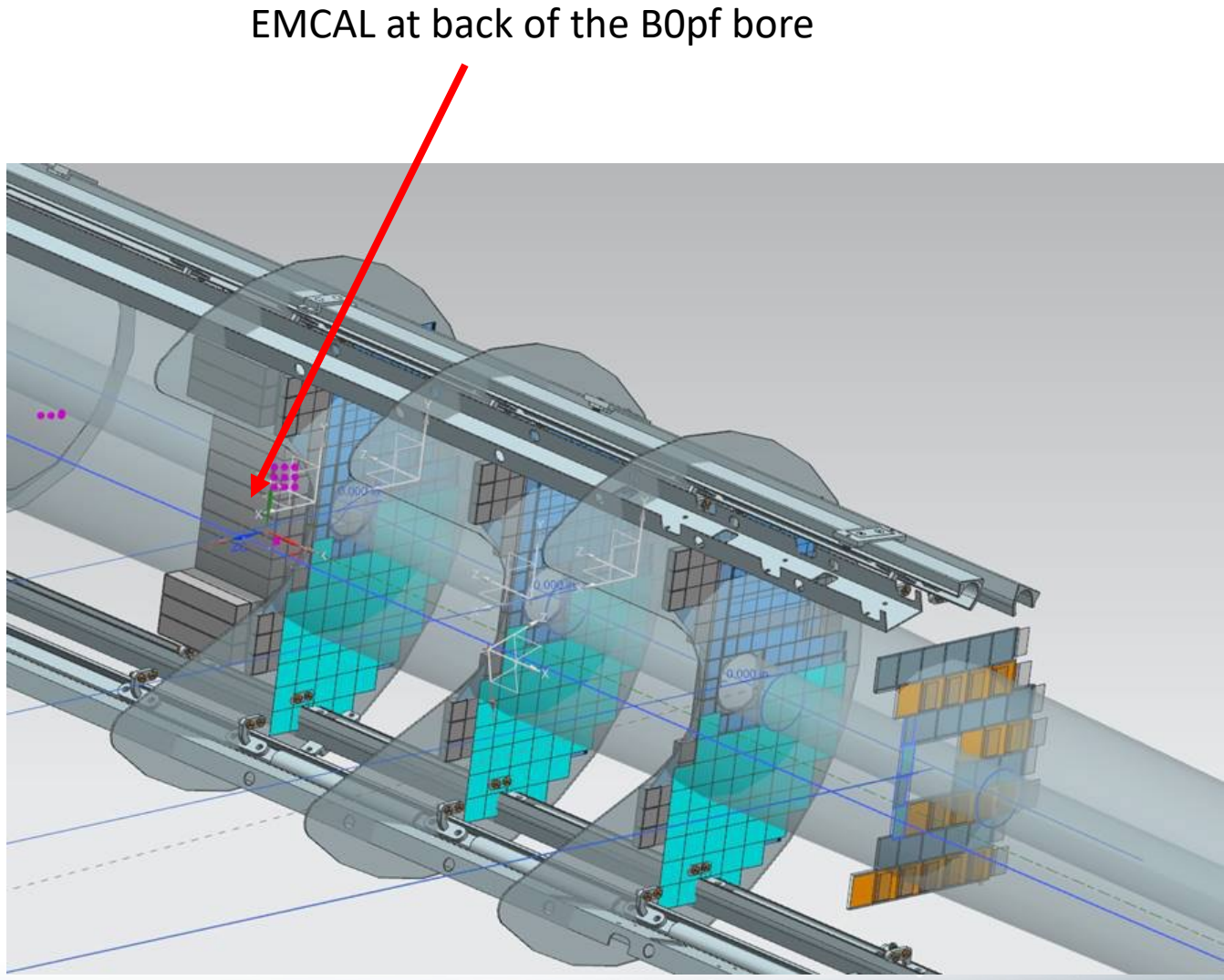
- Silicon tracking detectors + crystal EMCAL installed into combined function B0pf magnet.
  - Contains both hadron beam and electron beam + quadrupole and shielding.
- Integration includes support structure + installation rails, readout and power cabling.
- Main problems are longitudinal space, transverse acceptance, and radiation loads in the B0 (rather high compared to most of ePIC).
- Preliminary solutions in place, but much remains to be designed.



Karim Hamdi and Ron Lassiter

B0 Integration

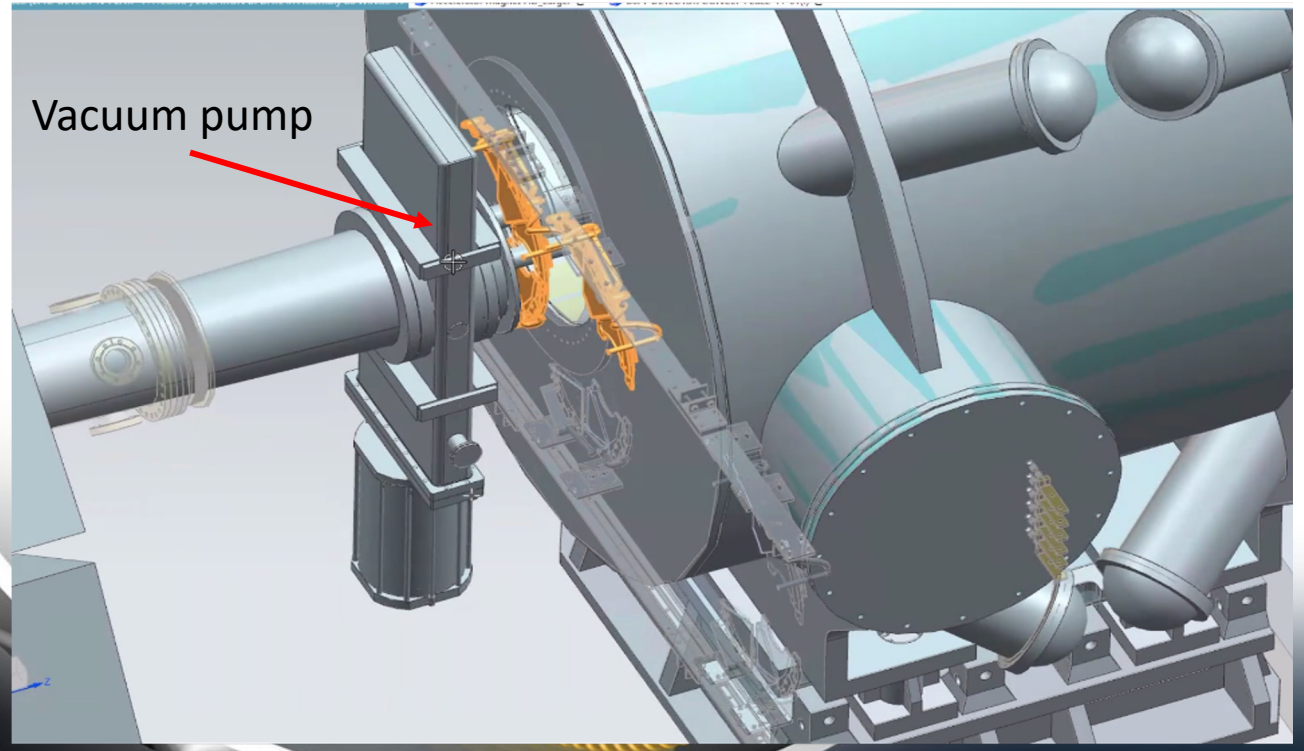
- Crystal EMCAL weight is ~50kg (for PbWO4) → **support system and installation procedure for the blocks needs to be designed.**
  - Readout? → SiPMs optimal for size, but radiation loads in B0 substantial.
  - Access to B0 system requires removal of pump in front of magnet (see next slide) → not easy to simply reach in and replace PMTs.

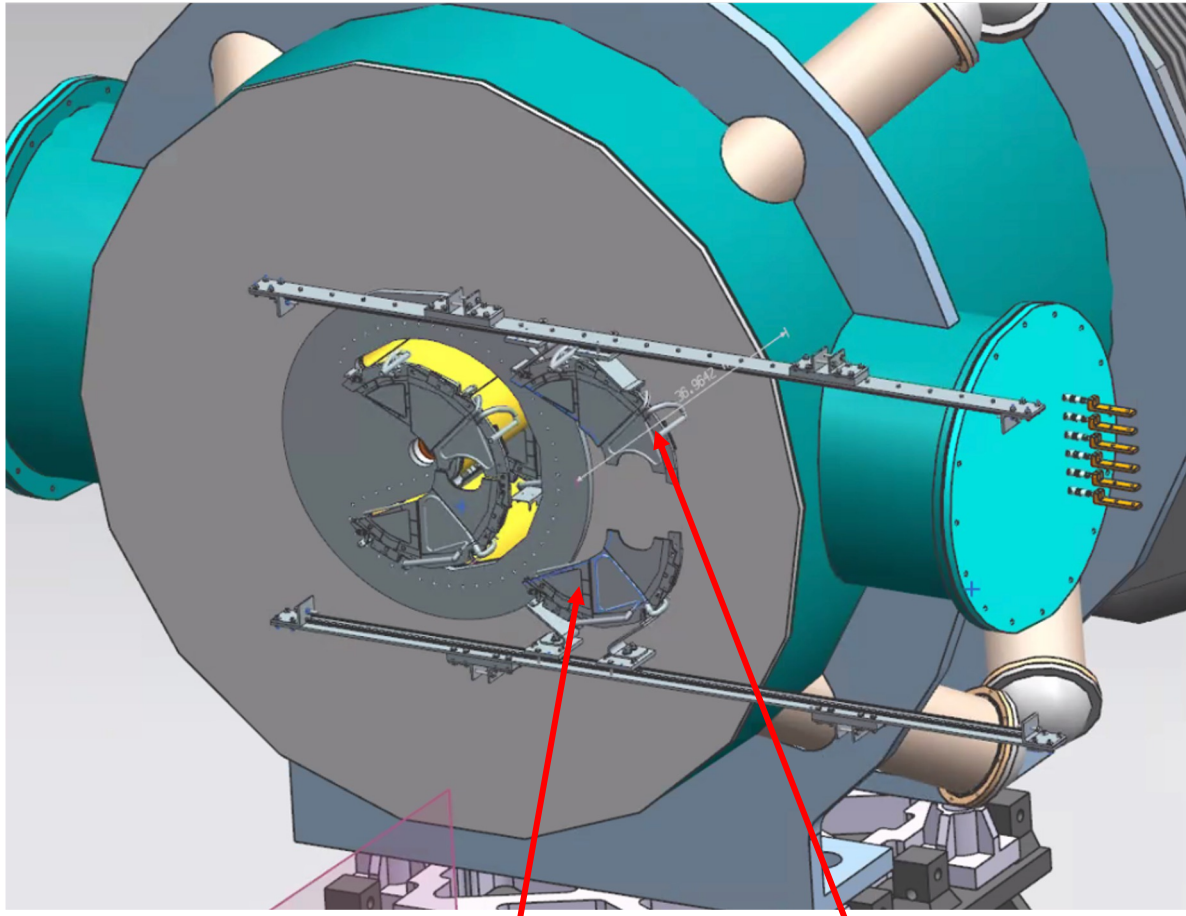


B0 Integration

Ron Lassiter

- Pump in front of detector package - only 13cm of space between pump and detector.
- Not currently in DD4HEP geometry - another source of secondaries (impact to be evaluated).





- Tracking planes separate into two pieces - top and bottom - for insertion into bore.
- Need concept for EMCAL.