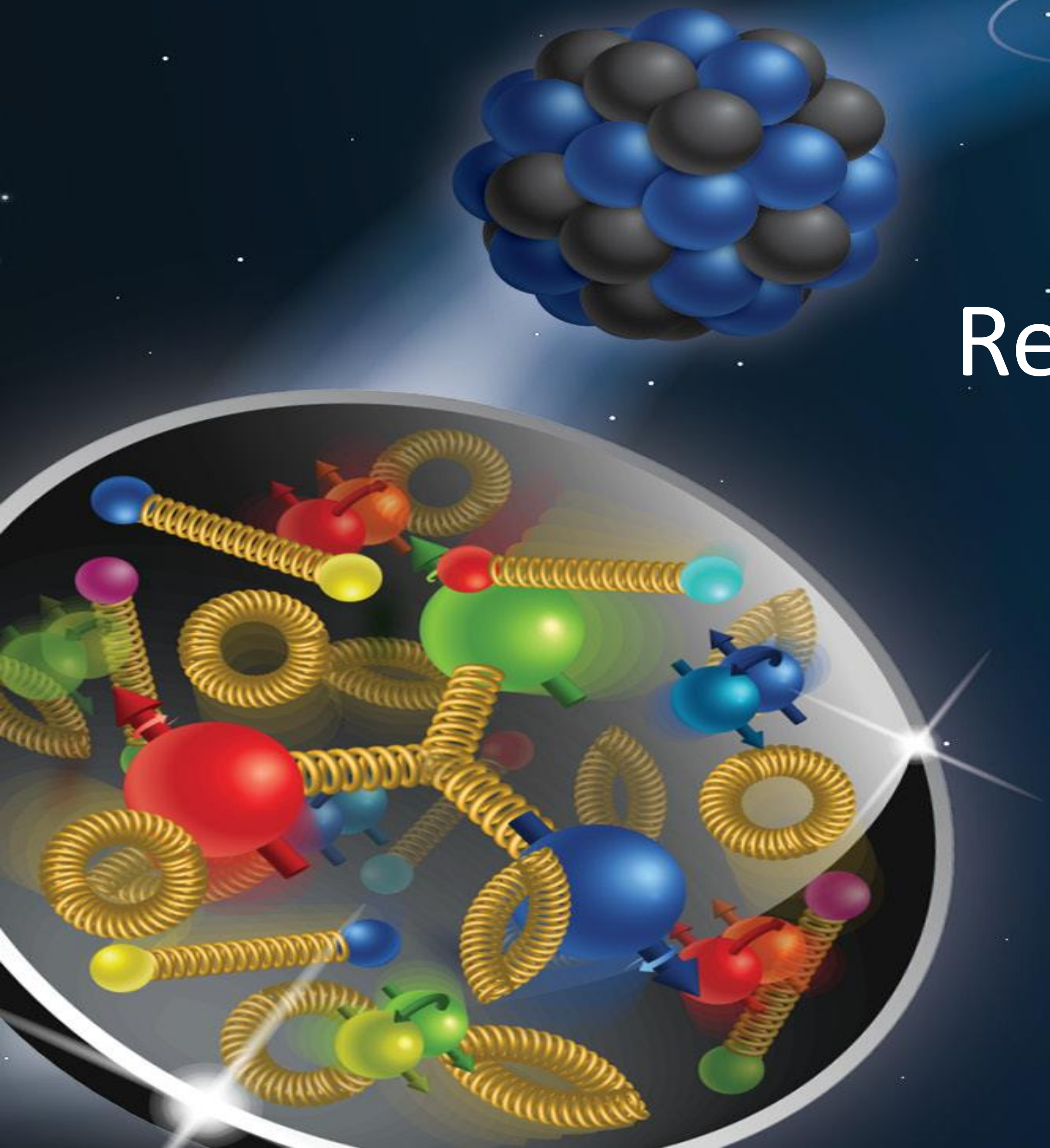
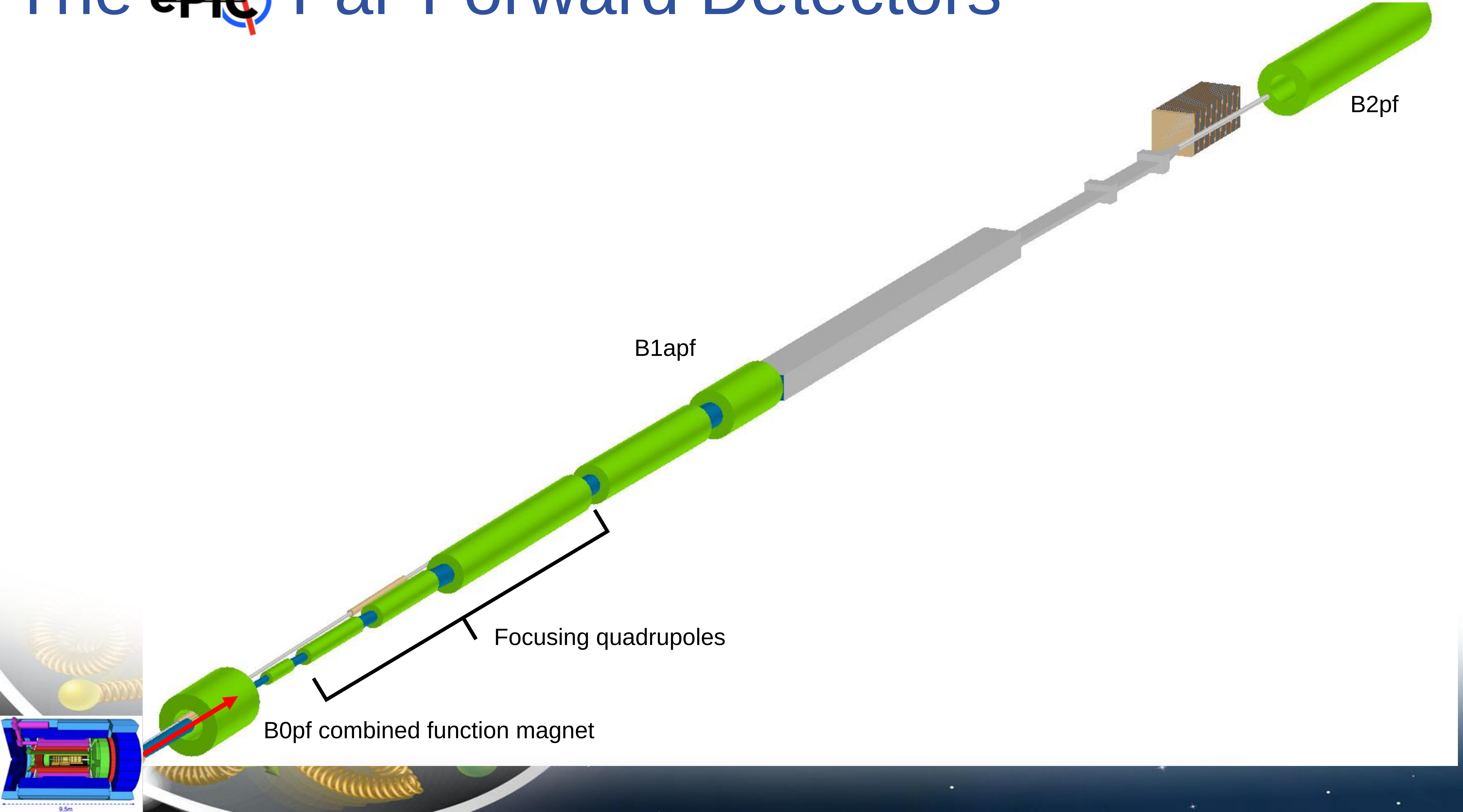


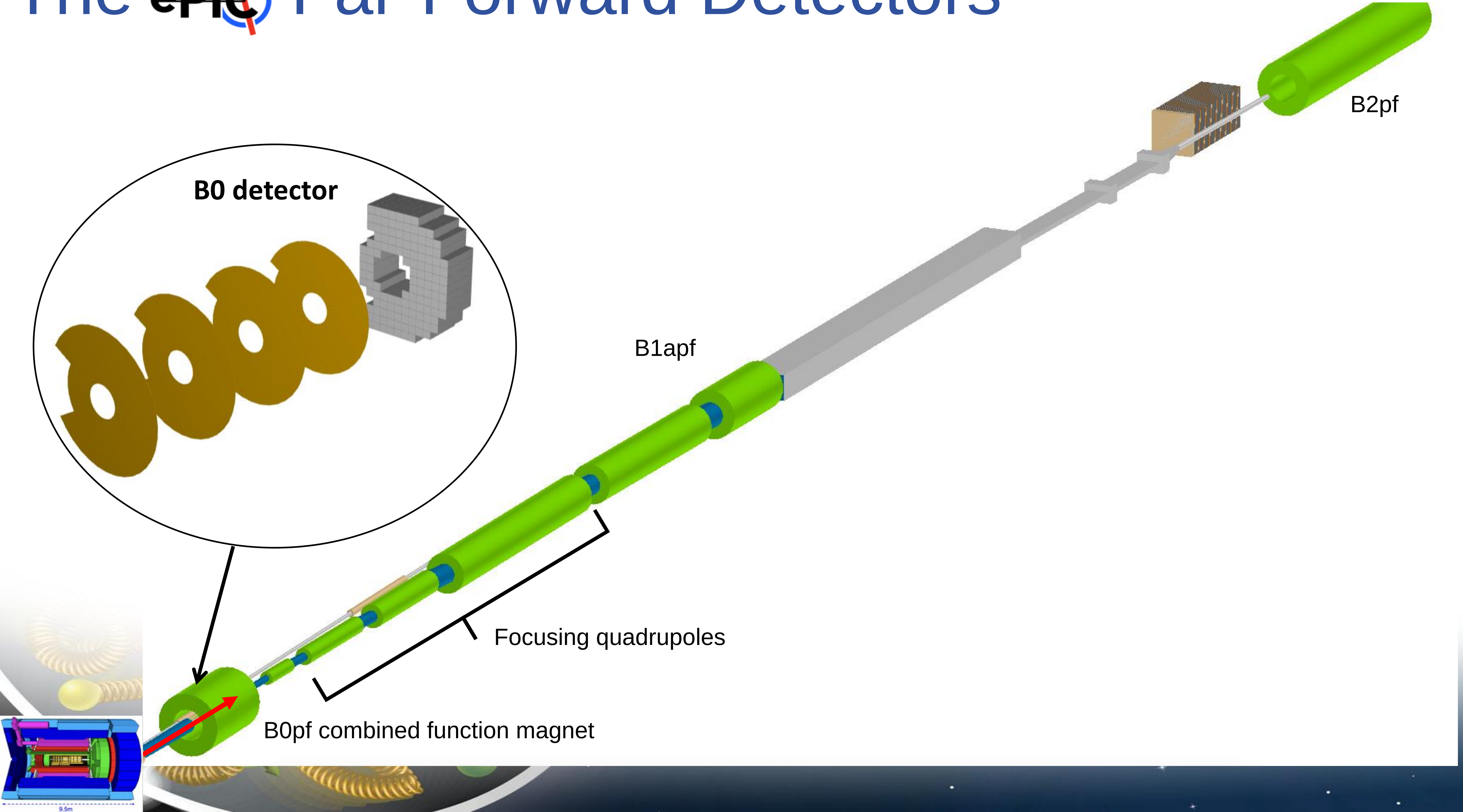
Reconstruction Workflow for FF Detectors

Alex Jentsch (BNL)
July 25th, 2024

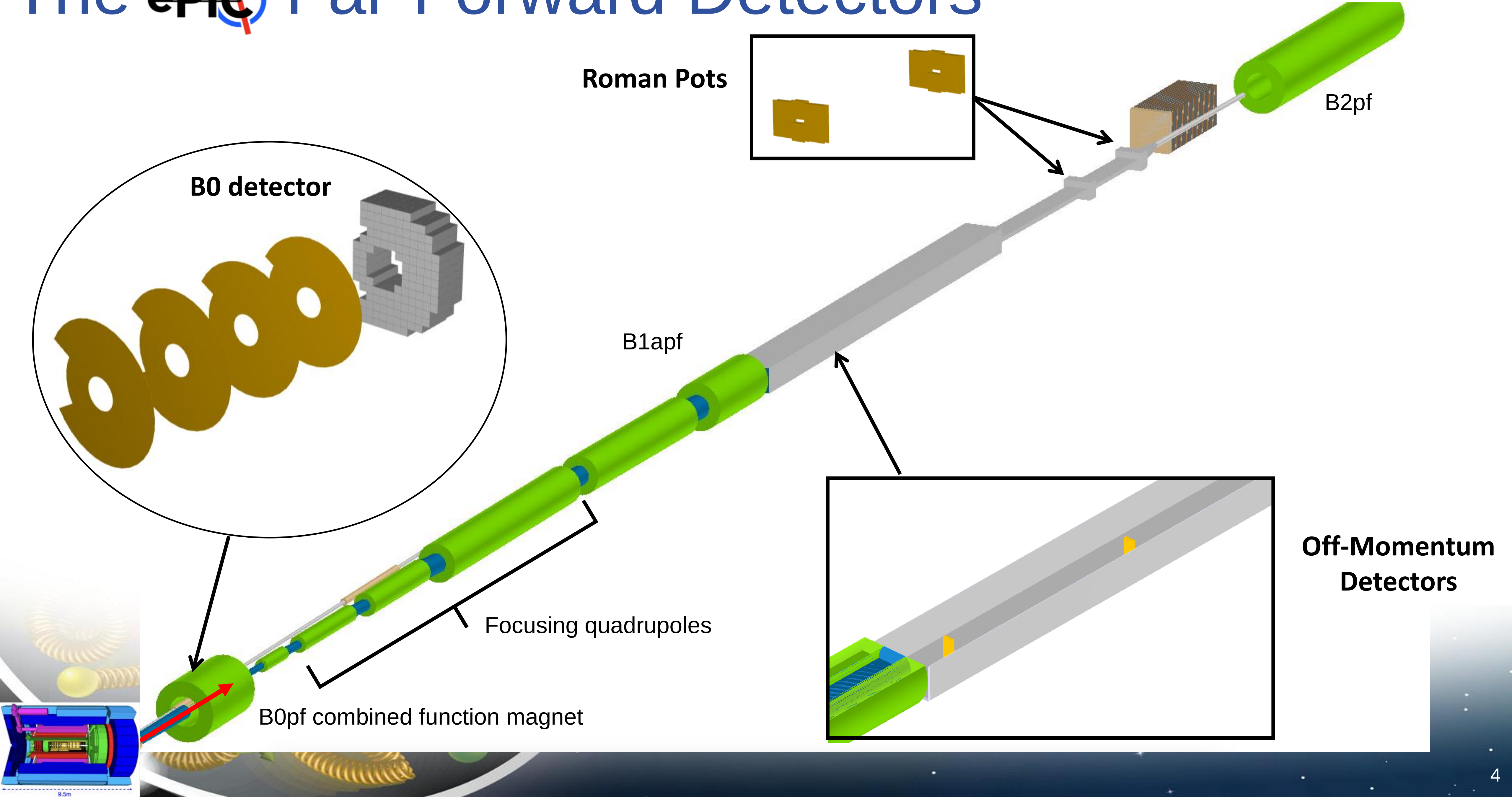
The ePIC Far-Forward Detectors



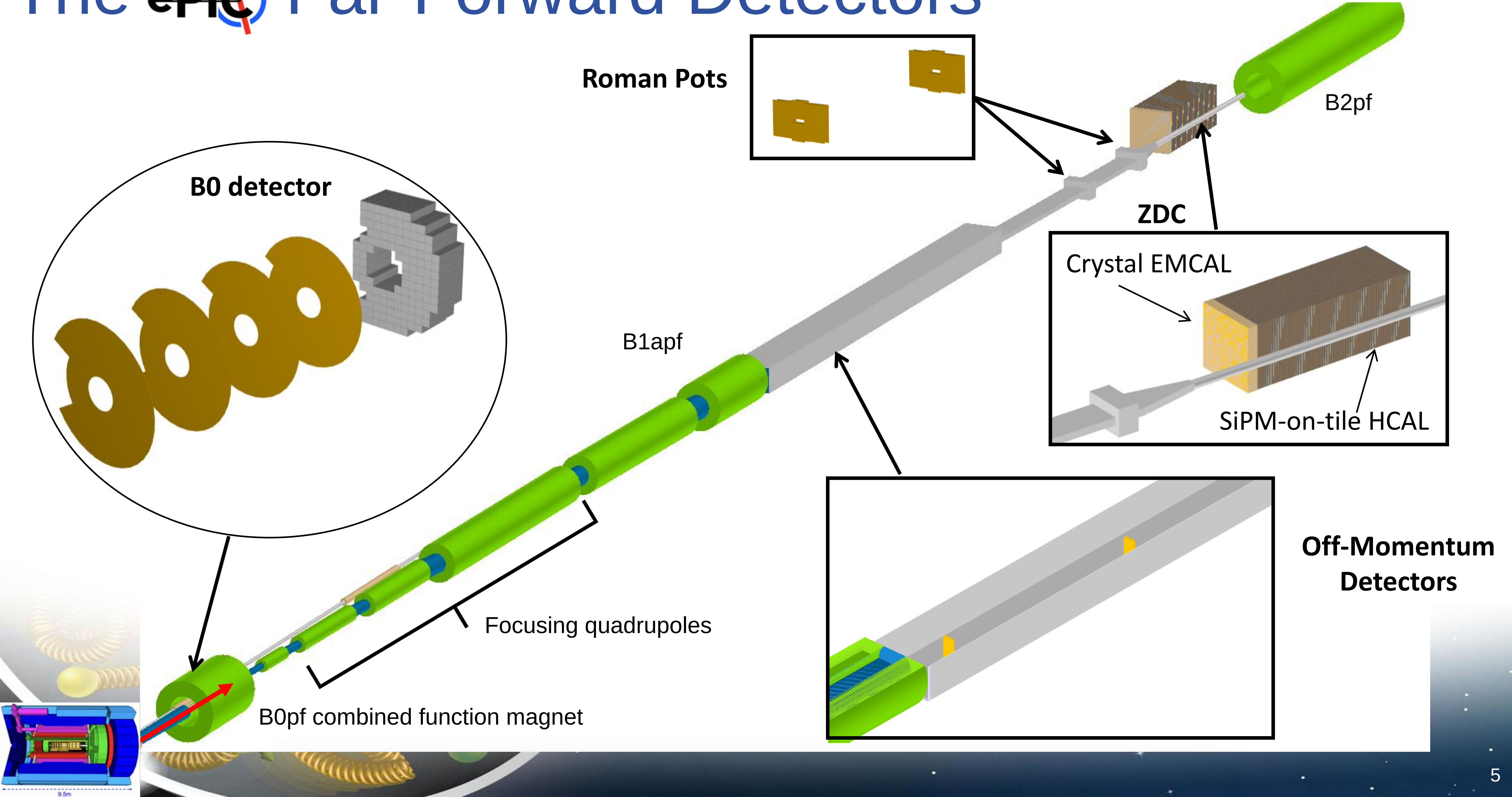
The ePIC Far-Forward Detectors



The ePIC Far-Forward Detectors

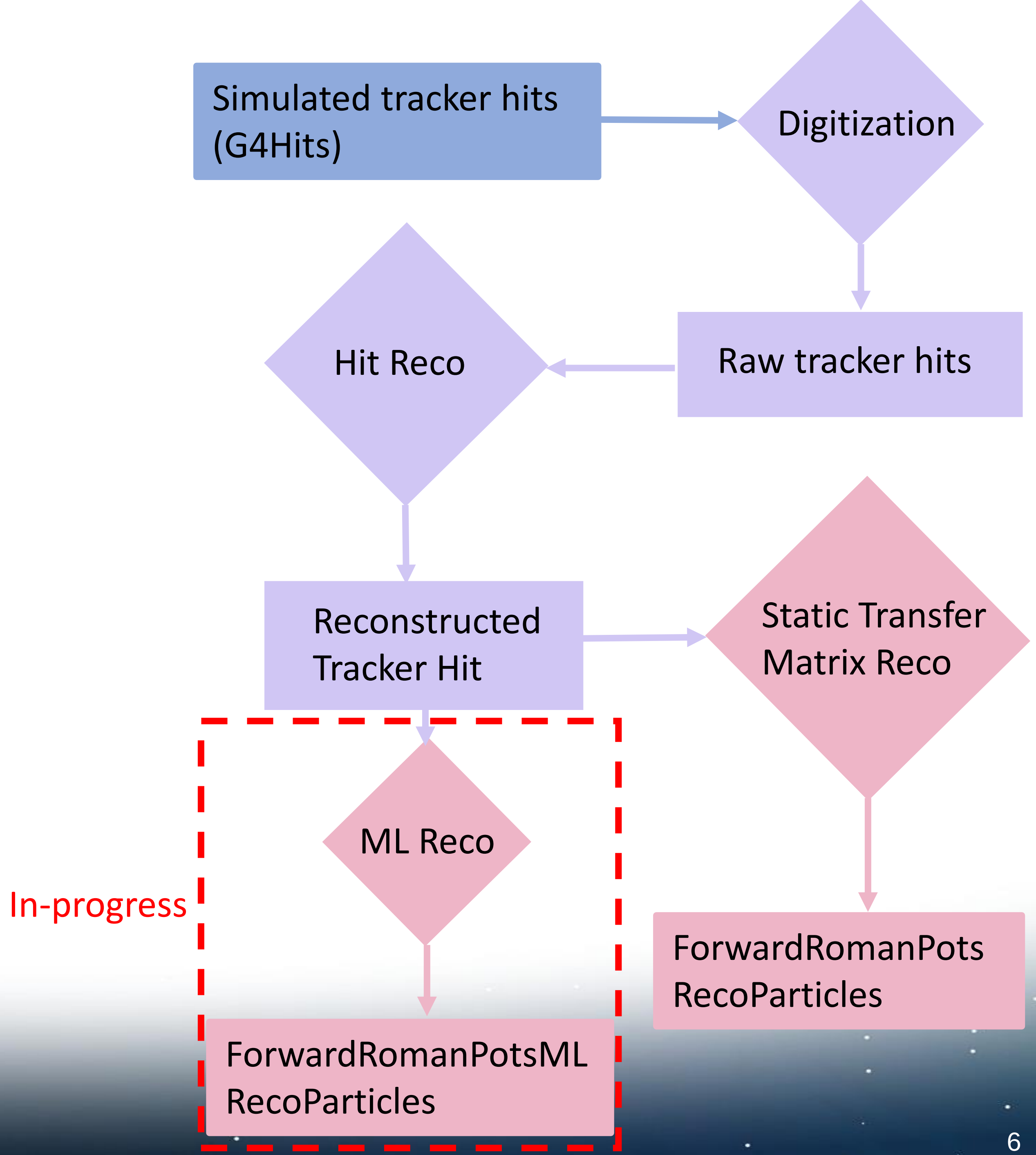


The ePIC Far-Forward Detectors



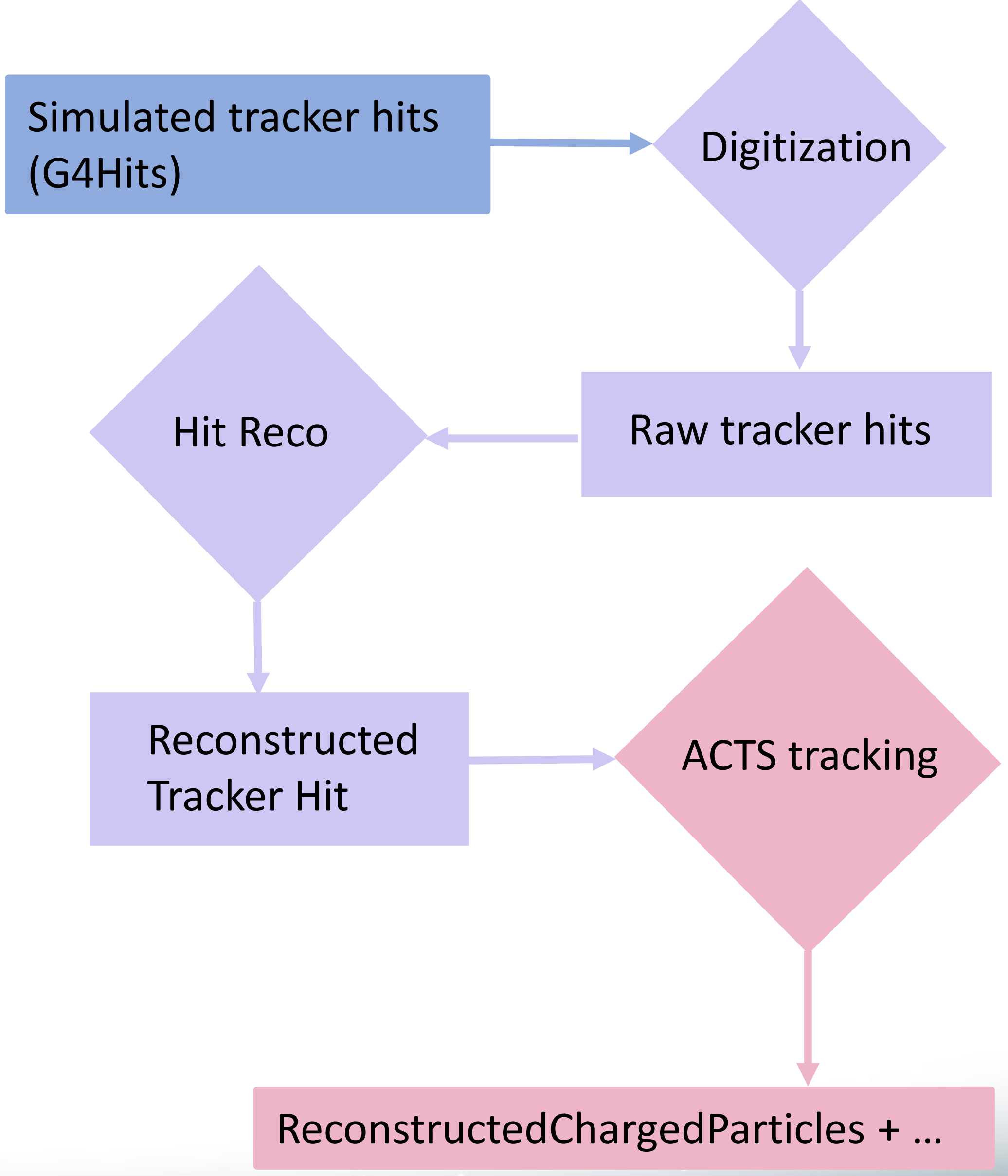
Roman Pots/OMD

- **<u>Overall Status</u>**
  - Full reco with static transfer matrix exists and works. (**<u>note:</u>** special cases need to be considered, e.g. light nuclei).
  - ML algorithm exists, integration with EICrecon in-progress.
- **<u>Workflow</u>**
  - Input(s): ForwardRomanPotsRecoHits
  - Output(s): ForwardRomanPotsRecoParticles
    - (similar for Off-Momentum Detectors)
- **<u>Near-Term goals</u>**
  - Get ML algorithm fully-integrated.
  - Fix a few dangling issues for nuclei, and sorting of hits.
- **<u>Long-Term Goals</u>**
  - Replace static matrix code with dynamic (polynomial) matrix code.



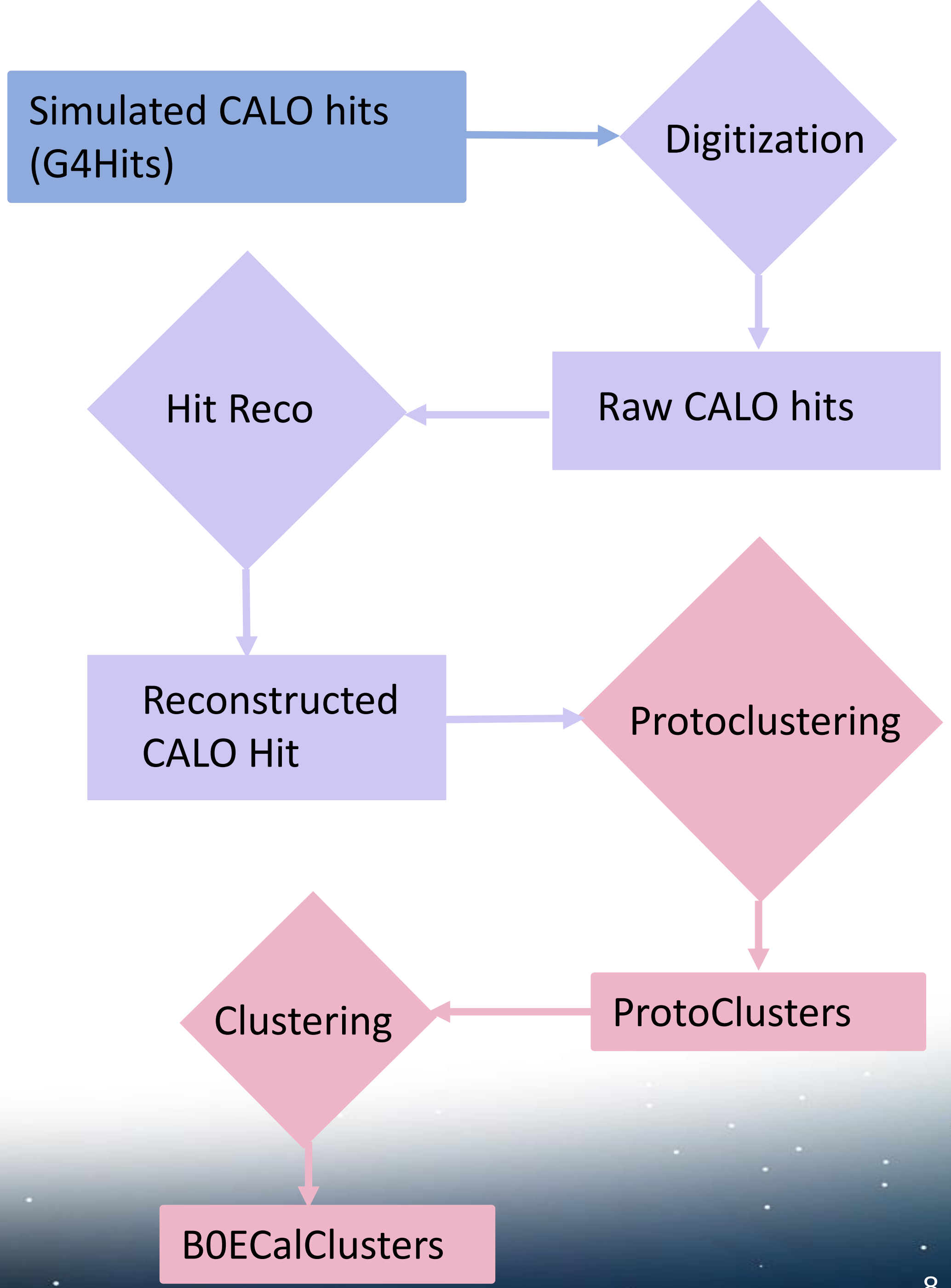
B0 Tracker

- **Overall Status**
  - Full reco has been tested, but with recent changes, correct output for ACTS tracking a bit unclear.
  - B0 field map needs to be put into a PR and merged (see below).
- **Workflow**
  - Input(s): B0TrackerRecoHits
  - Output(s): ReconstructedChargedParticles***
- **Near-Term goals**
  - Make PR for the B0 field map (on a private branch), and get it merged.
- **Long-Term Goals**
  - Include charge sharing digitization and change segmentation to correct value (currently set to a value to provide expected resolutions).



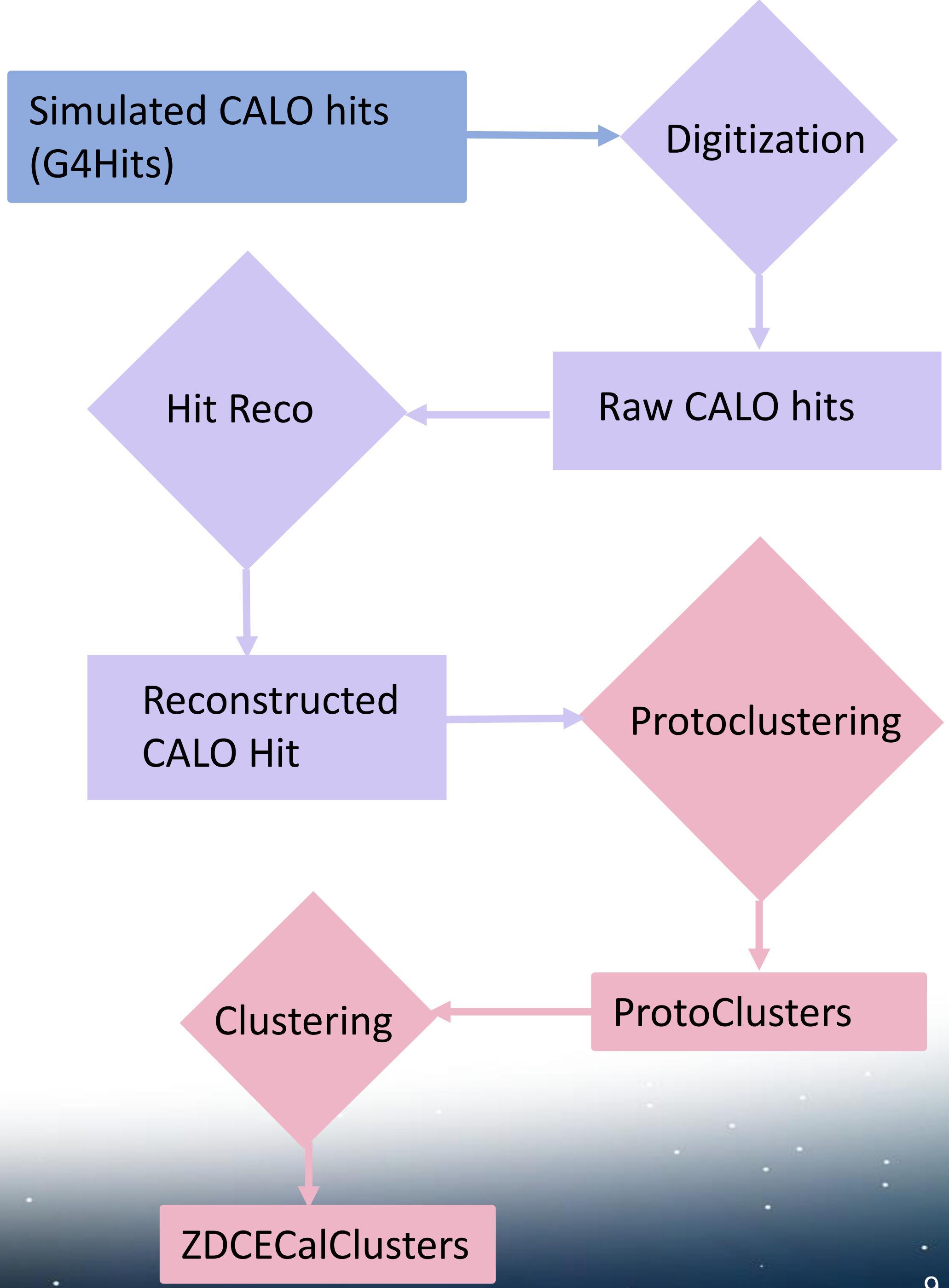
B0 EMCAL

- **Overall Status**
  - B0 EMCAL is a crystal EMCAL – uses components which already exist.
- **Workflow**
  - Input(s): B0ECalRecHits
  - Output(s): B0ECalClusters
- **Near-Term goals**
  - TBD
- **Long-Term Goals**
  - Include any changes to digitization to reflect final choice of electronics (SiPM).



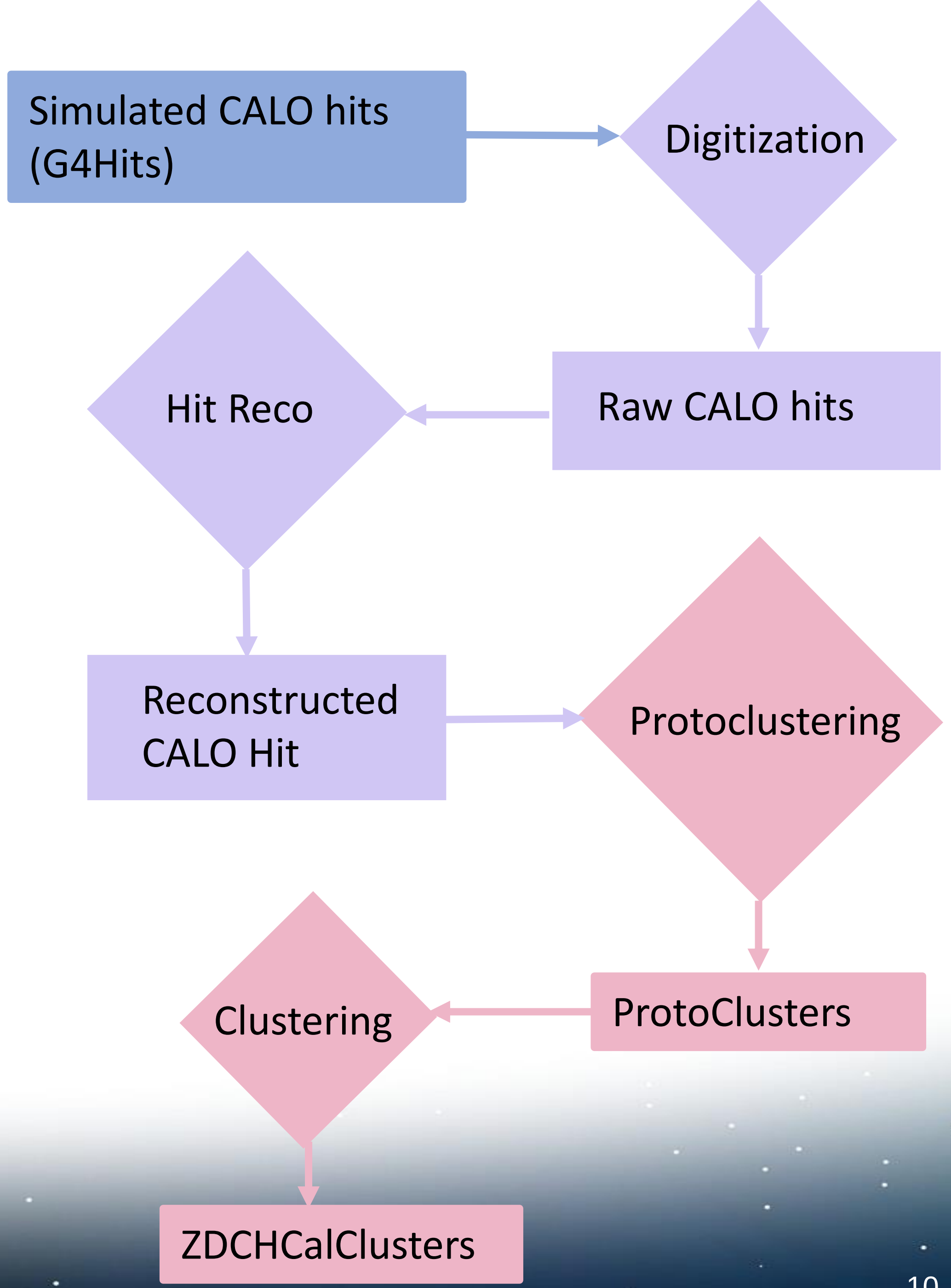
ZDC EMCAL

- **Overall Status**
  - ZDC EMCAL is a crystal EMCAL – uses components which already exist.
- **Workflow**
  - Input(s): EcalFarForwardZDCHits
  - Output(s): EcalFarForwardZDCClusters
- **Near-Term goals**
  - TBD
- **Long-Term Goals**
  - Include any changes to digitization to reflect final choice of electronics (SiPM, APD).
  - Work on integrated reconstruction for full ZDC (HCAL + EMCAL).



ZDC HCAL

- **Overall Status**
  - ZDC HCAL is the same SiPM-on-Tile technology and reco as the HCAL insert
- **Workflow**
  - Input(s): HcalFarForwardZDCHits
  - Output(s): HcalFarForwardZDCClusters
- **Near-Term goals**
  - TBD
- **Long-Term Goals**
  - Work on integrated reconstruction for full ZDC (HCAL + EMCAL).



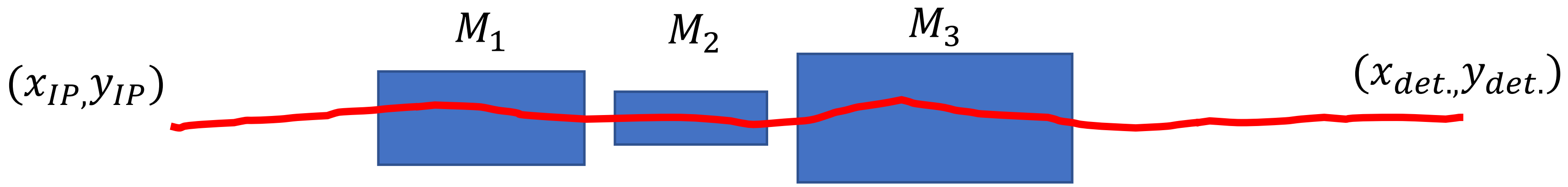
Backup

Preliminaries

- The EIC physics program includes reconstruction of final states with very far-forward protons, from many different possible collision systems.
  - e+p scattering, e+d/e+He3/e+A (proton(s) from nuclear breakup).
  - Produces protons with a broad range in longitudinal momentum, which then traverse the full hadron-going lattice (dipoles and quads).

Preliminaries

- The EIC physics program includes reconstruction of final states with very far-forward protons, from many different possible collision systems.
  - e+p scattering, e+d/e+He3/e+A (proton(s) from nuclear breakup).
  - Produces protons with a broad range in longitudinal momentum, which then traverse the full hadron-going lattice (dipoles and quads).
- Momentum reconstruction requires *transfer matrices* to describe particle motion through the magnets.



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

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

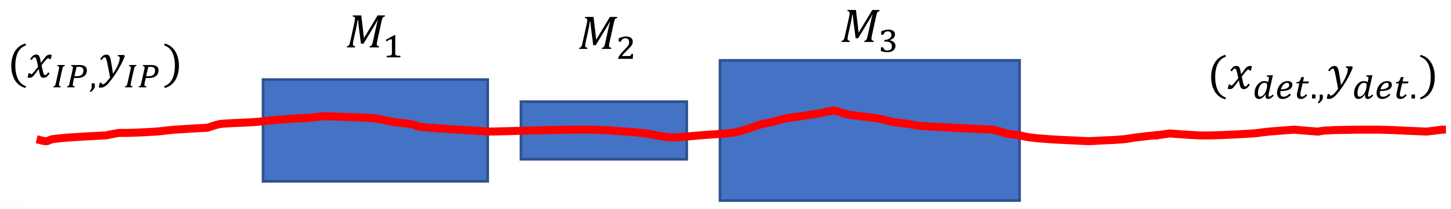
- Transforms coordinates at detectors (position, angle) to original IP coordinates.
- Matrix unique for different positions along the beam-axis!

Preliminaries

$$\begin{pmatrix} 1.88 & 28.97 & 0.0 & 0.0 & 0.0 & 0.25 \\ -0.0211 & 0.21 & 0.0 & 0.0 & 0.0 & -0.034 \\ 0.0 & 0.0 & -2.26 & 3.78 & 0.0 & 0.0 \\ 0.0 & 0.0 & -0.18 & -0.145 & 0.0 & 0.0 \\ 0.057 & 1.014 & 0.0 & 0.0 & 1.0 & 0.026 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{pmatrix} \begin{pmatrix} x_{ip} \\ \theta_{xip} \\ y_{ip} \\ \theta_{yip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} x_{28m} \\ \theta_{x,28m} \\ y_{28m} \\ \theta_{y28m} \\ z_{28m} \\ \Delta p/p \end{pmatrix}$$

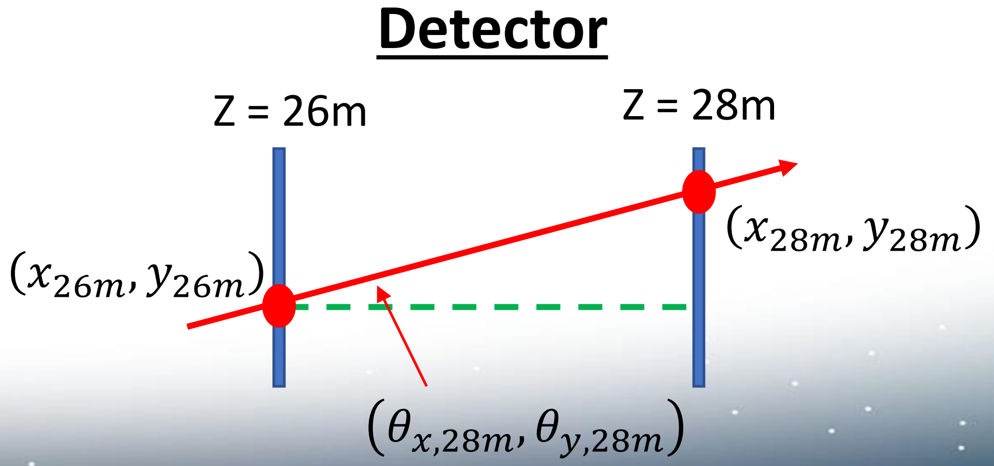
From BMAD – central trajectory 275 GeV proton

- Matrix describes how particles travel through the magnets toward the detector.



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

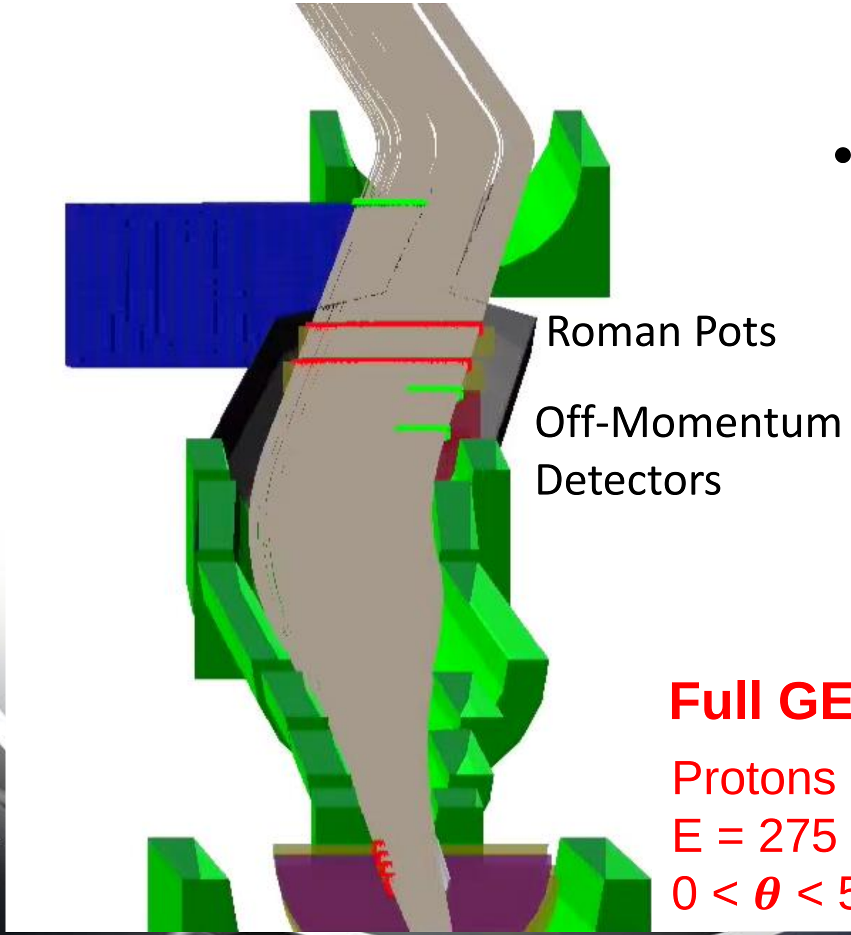
Matrix enables reconstruction of scattering information at the IP using only local hits at the detector.



The Problem

$$\begin{pmatrix} 1.88 & 28.97 & 0.0 & 0.0 & 0.0 & 0.25 \\ -0.0211 & 0.21 & 0.0 & 0.0 & 0.0 & -0.034 \\ 0.0 & 0.0 & -2.26 & 3.78 & 0.0 & 0.0 \\ 0.0 & 0.0 & -0.18 & -0.145 & 0.0 & 0.0 \\ 0.057 & 1.014 & 0.0 & 0.0 & 1.0 & 0.026 \\ 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \end{pmatrix} \begin{pmatrix} x_{ip} \\ \theta_{xip} \\ y_{ip} \\ \theta_{yip} \\ z_{ip} \\ \Delta p/p \end{pmatrix} = \begin{pmatrix} x_{28m} \\ \theta_{x,28m} \\ y_{28m} \\ \theta_{y28m} \\ z_{28m} \\ \Delta p/p \end{pmatrix}$$

From BMAD – central trajectory 275 GeV proton



- Protons from nuclear breakup, or high-Q^2 e+p interactions → protons can have large deviations from central orbit momentum → **require unique matrices!**

longitudinal momentum fraction

$$x_L = \frac{p_{z,proton}}{p_{z,beam}}$$

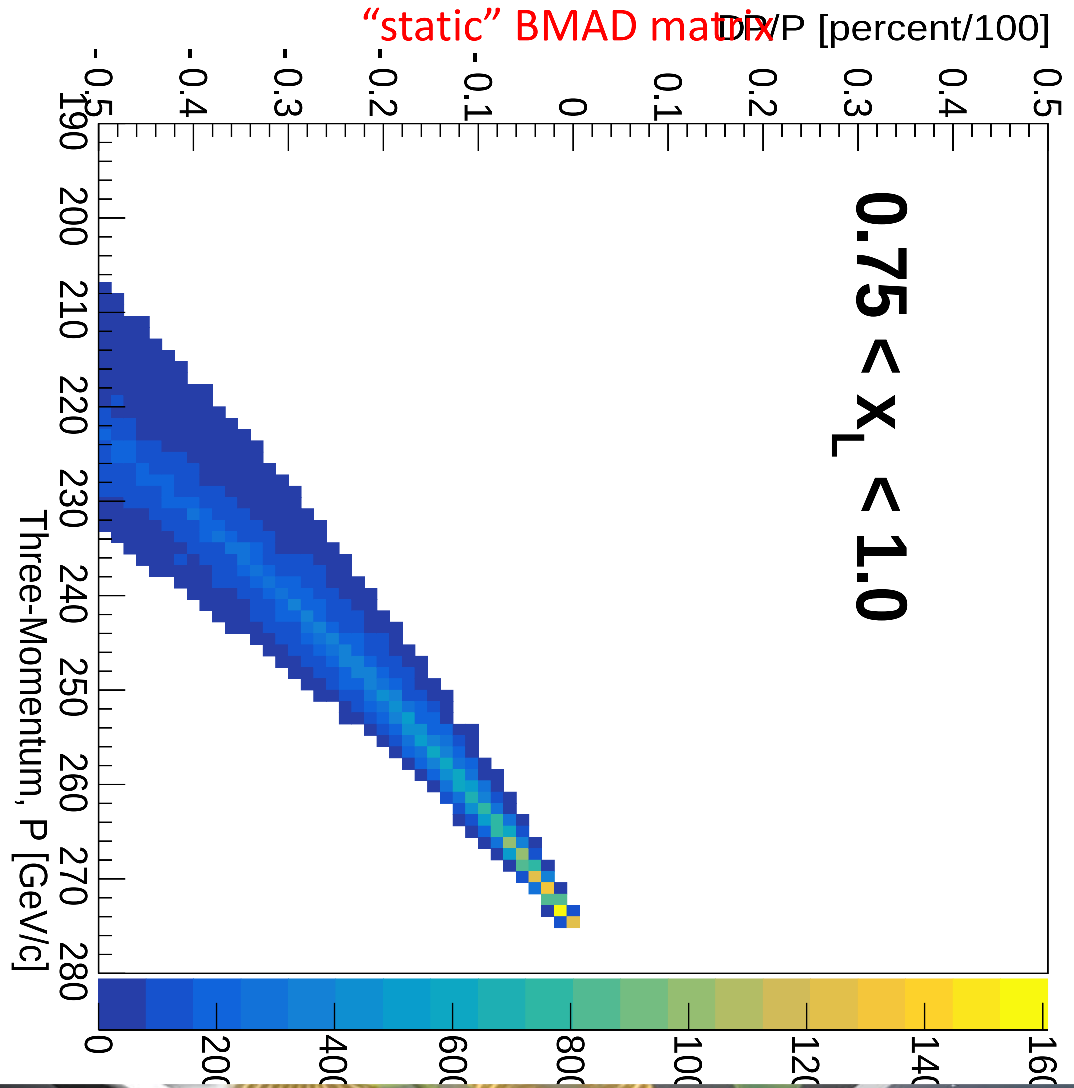
Full GEANT4 simulation.

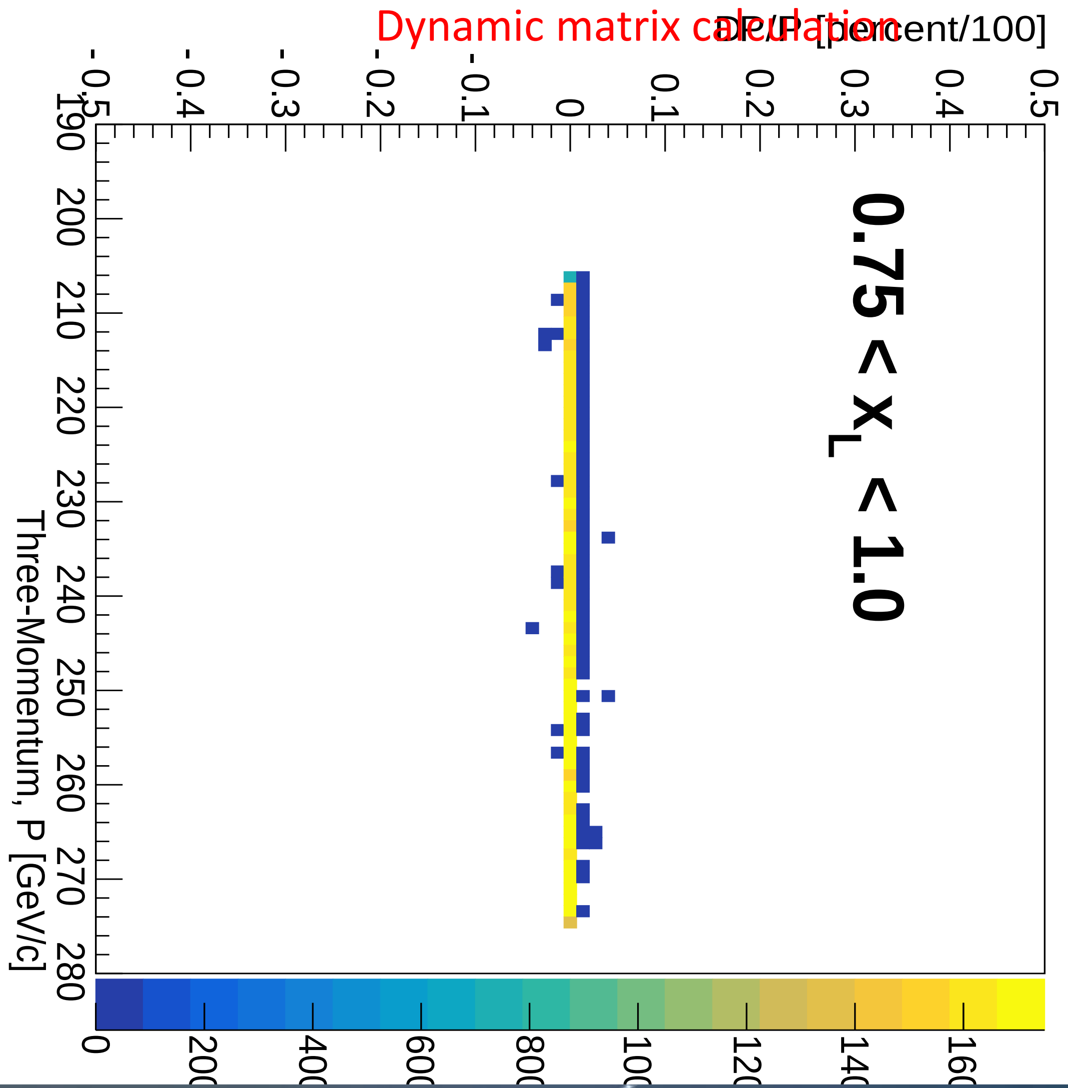
Protons
E = 275 GeV
0 < θ < 5 mrad

For a 275 GeV beam, a 270 GeV proton has an x_L of 0.98.

Results - Momentum

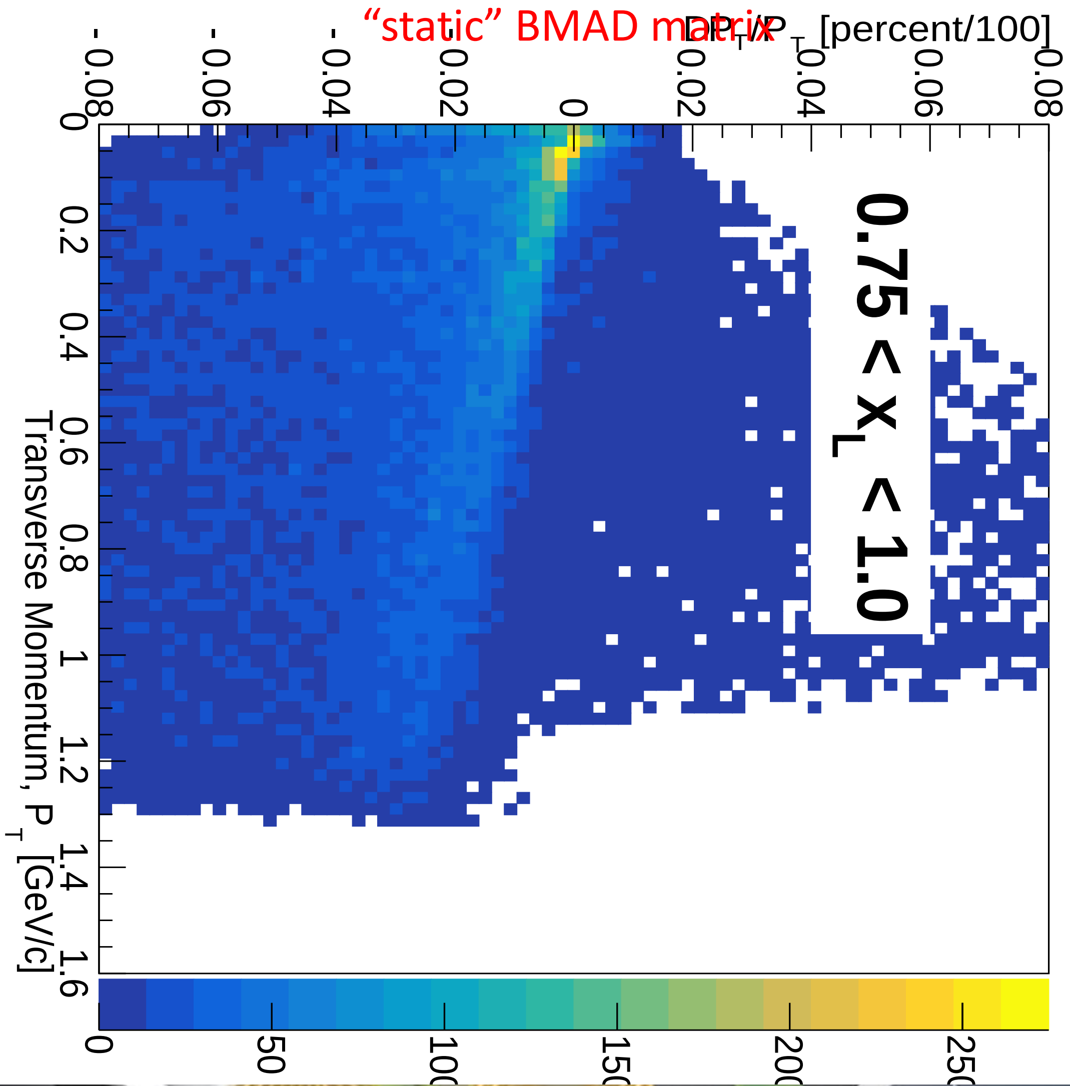
- Comparing “static” BMAD matrix (left) with dynamic matrix calculation (right).

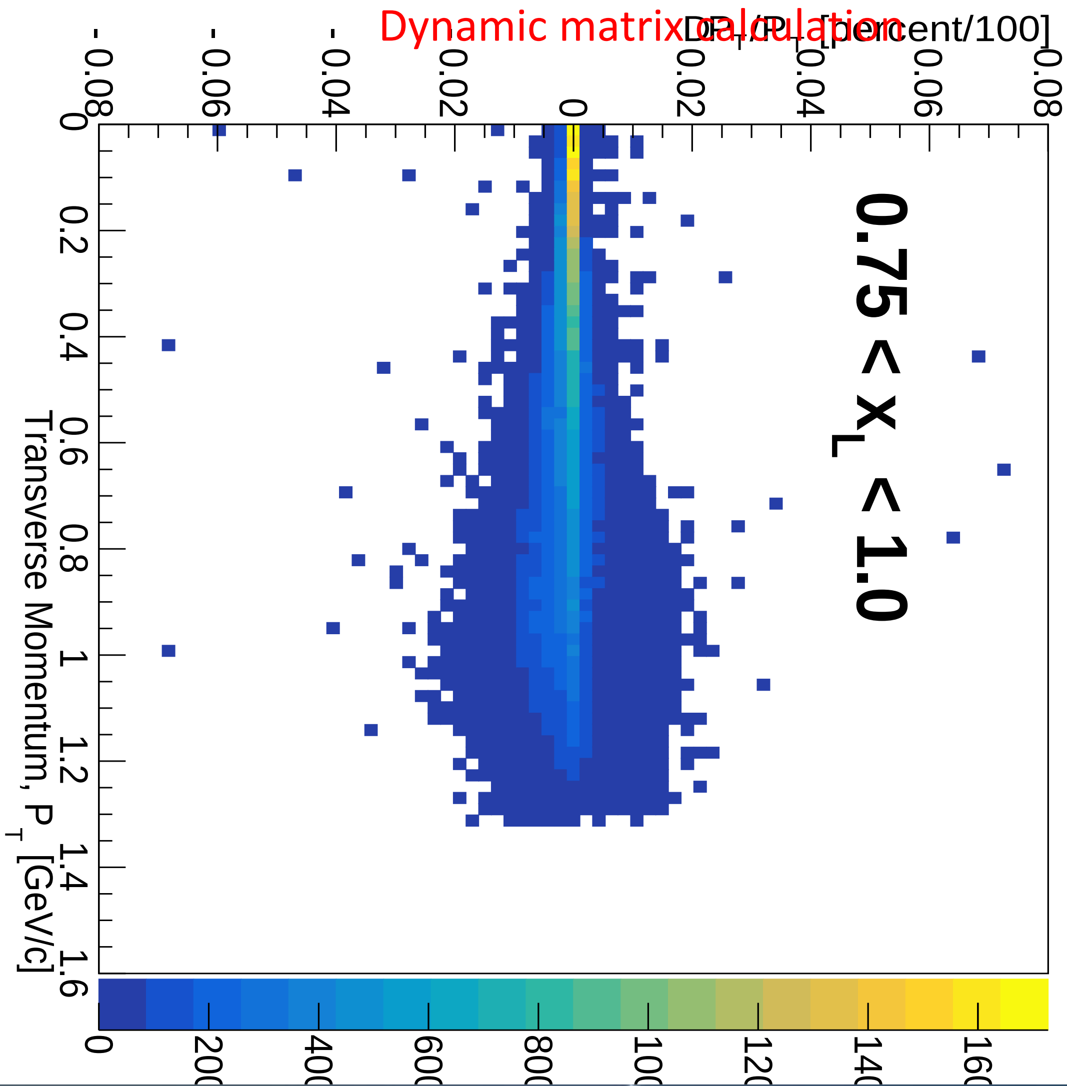




Results - p_T

- Comparing “static” BMAD matrix (left) with dynamic matrix calculation (right).





Drawbacks of current approach

- Solution dependent on choice of initial “tuning cards” (e.g. test trajectories).
  - Matrix may not capture non-linear effects for large angles/small x_L.
- Current approach will not be able to help with more-complicated interactions (e.g. Sullivan process), where tagged particles may not come from IP.
- The current method needs to be run separately for the Roman Pots and Off-Momentum Detectors.

Dedicated R&D can generalize approach to easily extend x_L range

- The present method works reasonably well, and has the benefit of using calculated matrices following a similar method as BMAD.
- **But:** we care about describing a full range of momenta (present study only went down to x_L of 0.75).
- **A more modern method with ML techniques, integrated with the EPIC simulation framework would enable easy evolution of the reconstruction method as the detector descriptions are updated*.**

*Will also make it easier for more collaborators to get involved, long-term.

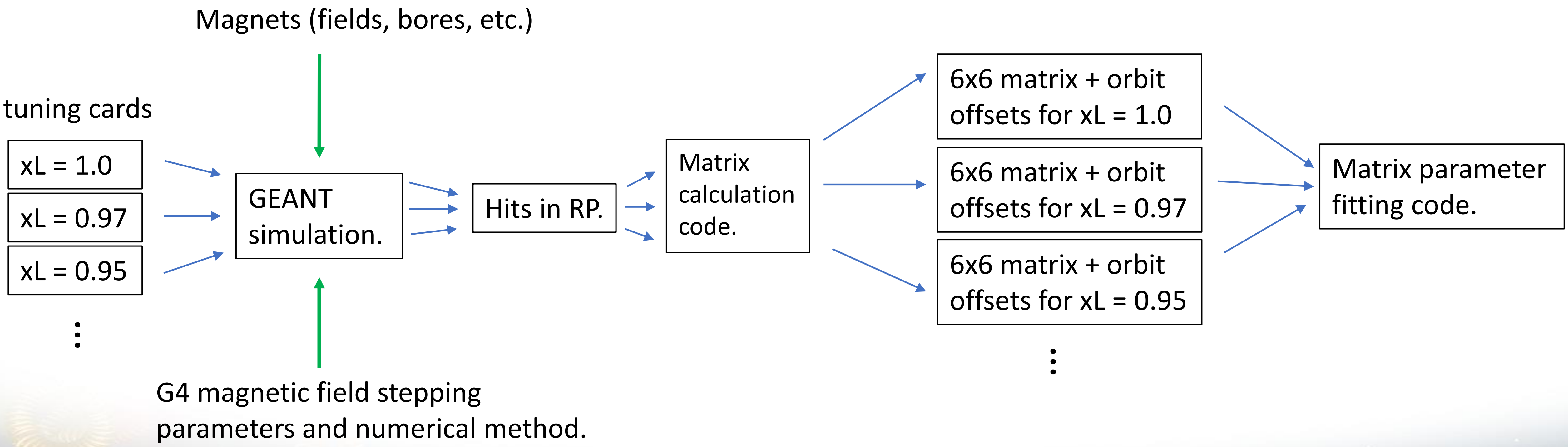
Takeaways and Next Steps

- General approach for accurately reconstructing far-forward particles demonstrated.
  - Would benefit from a more-modern approach using ML techniques to provide easier adaptability as the EIC far-forward design evolves.
  - Need to extend this approach to the off-momentum detectors.
    - More-challenging problem – particles more severely off-momentum (x_L ~ 50%, or less).
- Once a method is put in place, integration with the EPIC detector framework would be required.

Backup

The (current) Basic Solution

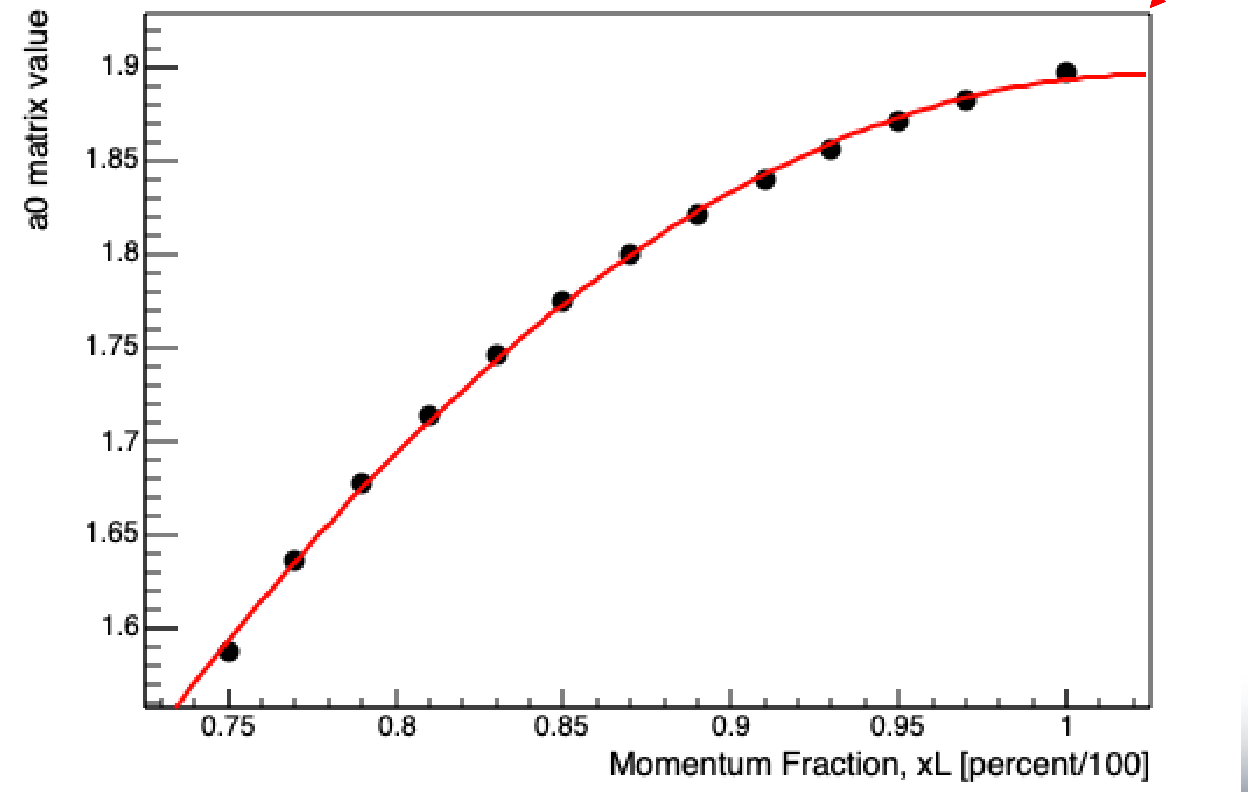
- Begin with a set of “input tuning cards” which contain the trajectories for calculating the matrices.



The (current) Basic Solution

- Plot the 36 matrix values (and 4 offsets) as a function of xL.
- Fit the resulting plots with 2nd-degree polynomials.

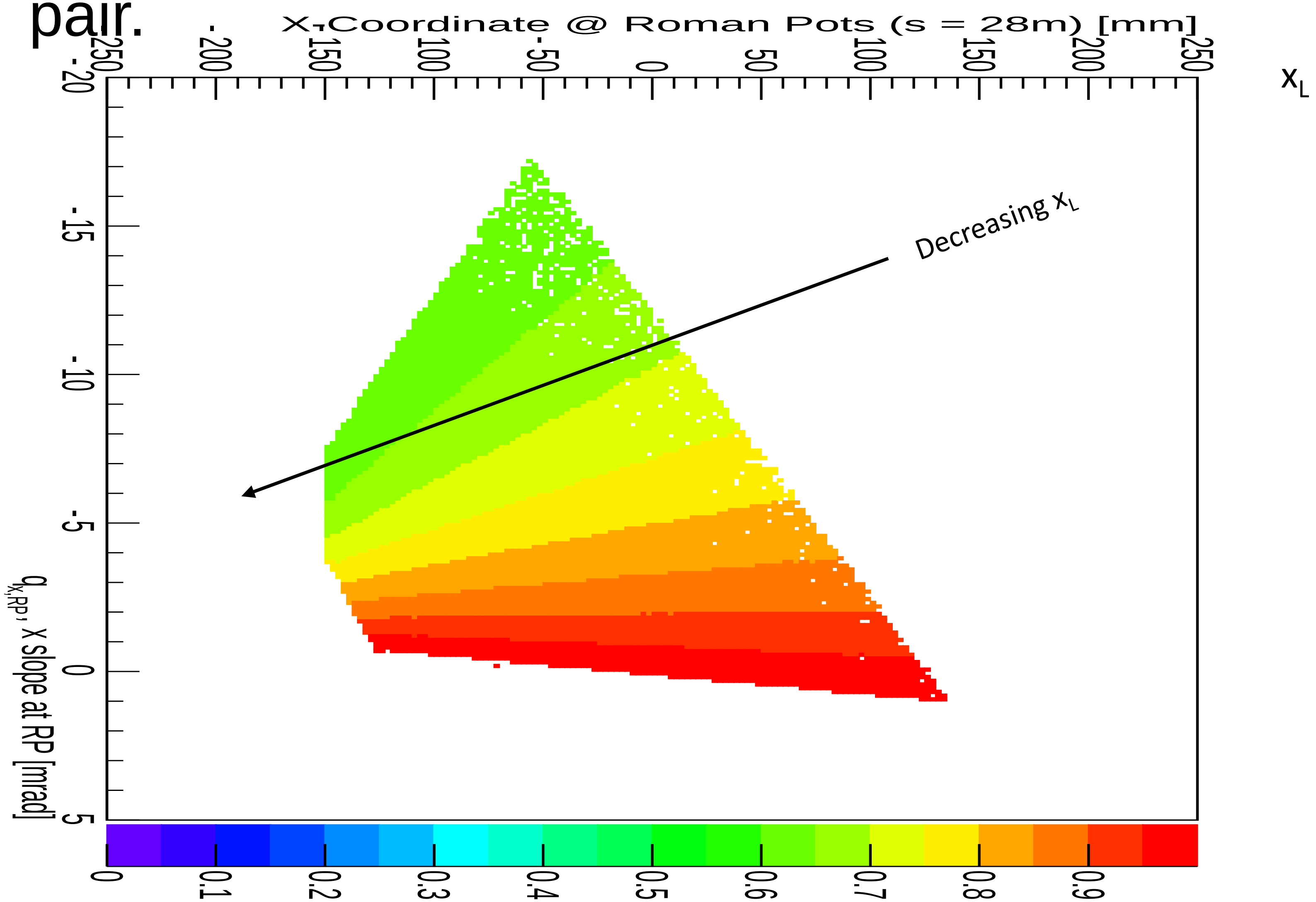
$$\begin{pmatrix} \boxed{1.88481537} & 28.96766544 & 0.0000 & 0.0000 & 0.0000 & 0.24906255 \\ -0.02114673 & 0.20555261 & 0.0000 & 0.0000 & 0.0000 & -0.03322467 \\ 0.0000 & 0.0000 & -2.25541901 & 3.78031509 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & -0.17782524 & -0.14532313 & 0.0000 & 0.0000 \\ 0.05735551 & 1.01363652 & 0.0000 & 0.0000 & 1.0000 & 0.02568709 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{pmatrix}$$



- The only needed additional component is a way to get x_L from the local detector hits, which is used to evaluate the matrix elements.

The (current) Basic Solution

- Extract x_L value from lookup table for the $(\theta_{x,rp}, x_{rp})$ @ z = 28m ordered pair.

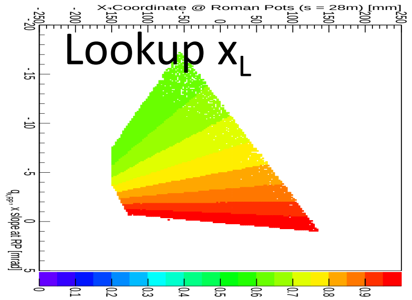


- "Chromaticity plot" serves as a lookup table.
- xL is used to evaluate the correct matrix entries.

The (current) Basic Solution

- Now we can "build" the correct matrix with the correct offset values for a given trajectory and perform our kinematic reconstruction.

Detector "hit" coordinates →



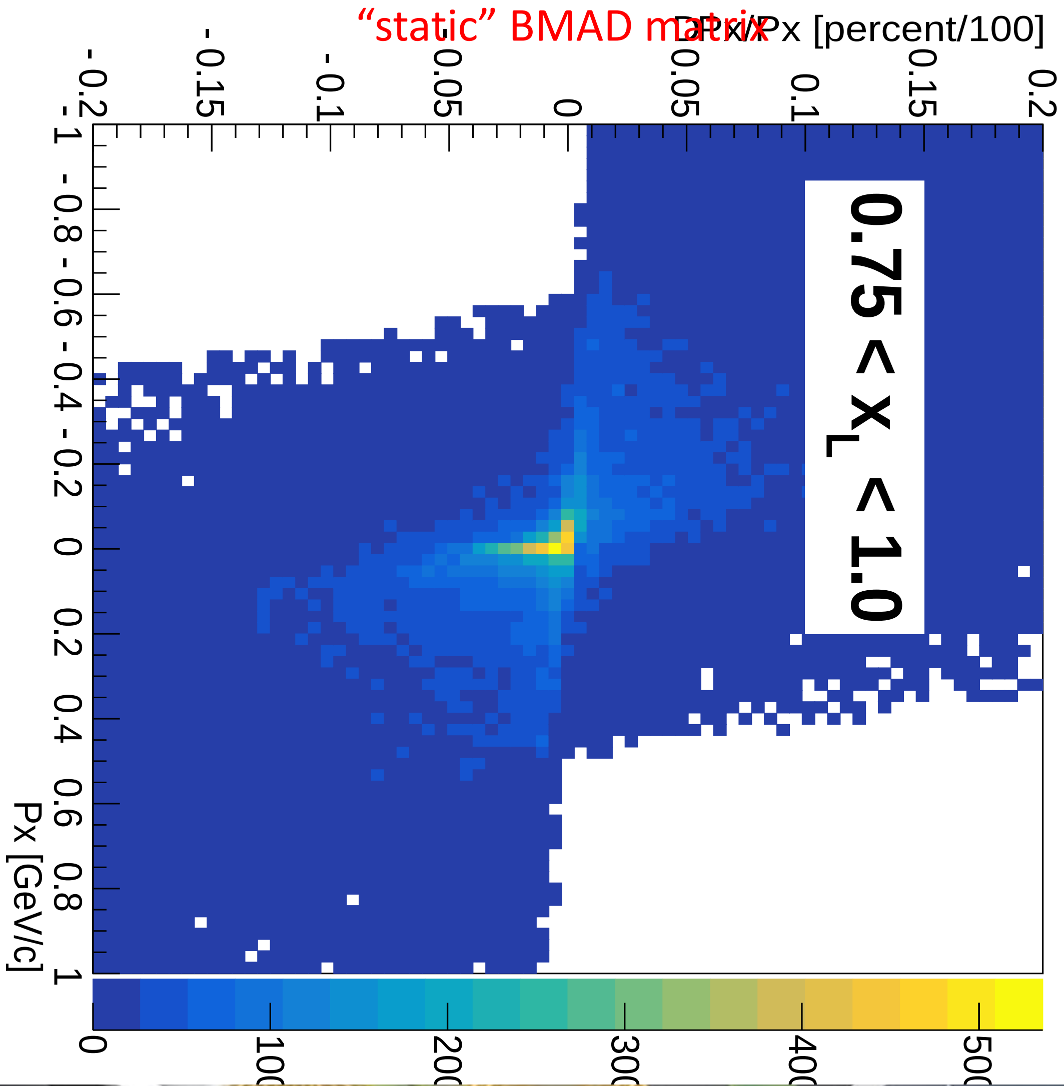
→ Calculate matrix parameters and offsets from fit equations.

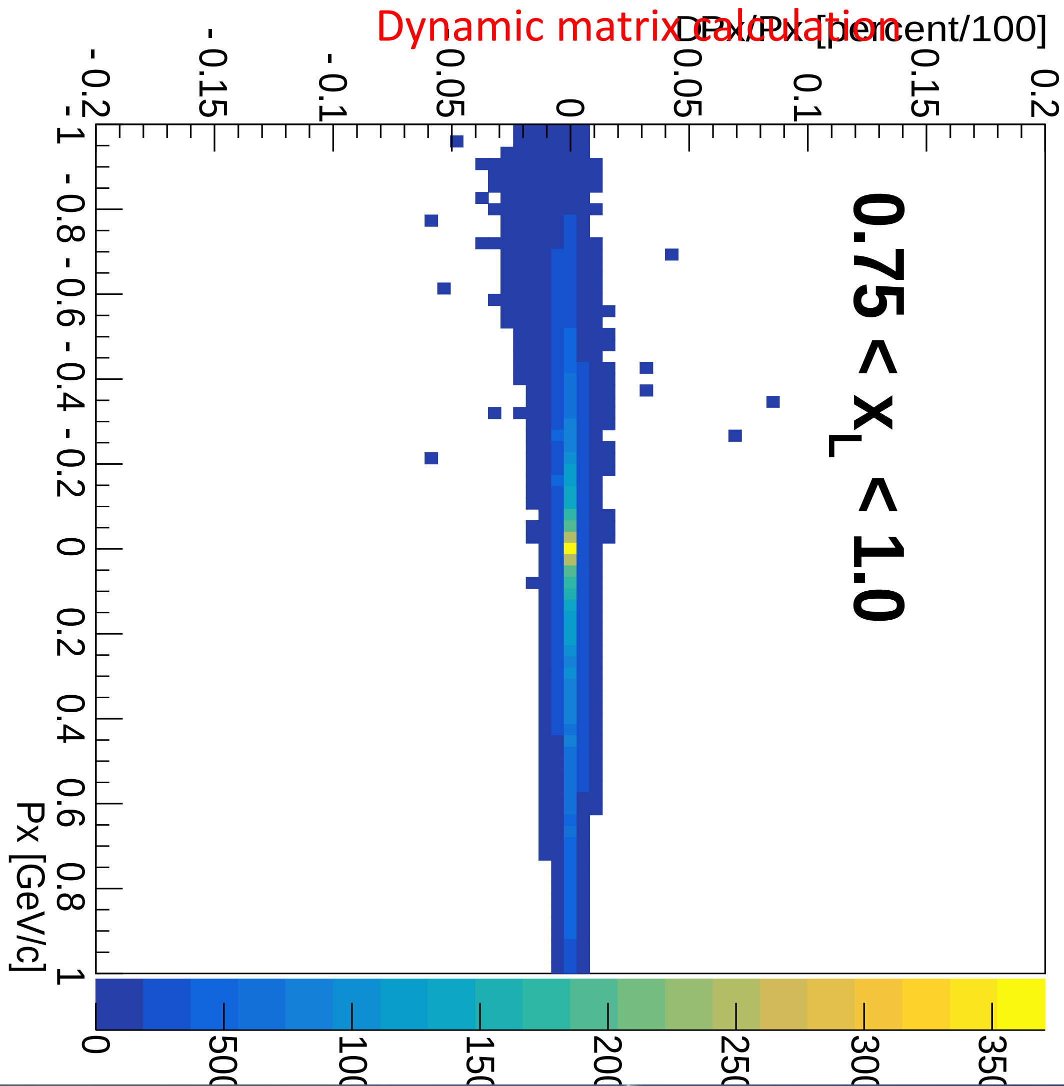
$$\begin{pmatrix} 1.88481537 & 28.96766544 & 0.0000 & 0.0000 & 0.0000 & 0.24906255 \\ -0.02114673 & 0.20555261 & 0.0000 & 0.0000 & 0.0000 & -0.03322467 \\ 0.0000 & 0.0000 & -2.25541901 & 3.78031509 & 0.0000 & 0.0000 \\ 0.0000 & 0.0000 & -0.17782524 & -0.14532313 & 0.0000 & 0.0000 \\ 0.05735551 & 1.01363652 & 0.0000 & 0.0000 & 1.0000 & 0.02568709 \\ 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000 \end{pmatrix}$$

→ Reconstructed momentum vector.

Results - Px

- Comparing “static” BMAD matrix (left) with dynamic matrix calculation (right).





Results - Py

- Comparing “static” BMAD matrix (left) with dynamic matrix calculation (right).