Electron ID and Holistic Reconstruction: Workfest Summary

Shujie Li, Tyler Kutz, Dmitry Kalinkin, Daniel Brandenburg, Derek Anderson

ePIC Collaboration Meeting

07.27.2024

Introduction | workfest scope

Holistic Reco

- Identify what we need for *holistic* reconstruction
- Composed of:
  - > Overview session summarizing where reconstruction currently is
  - > Open discussion session to discuss where and how to get to holistic reconstruction
- Will also help identify development priorities for remainder of 2024 and into 2025

+

Electron ID

- Catalyze work on next-steps for the electron-finder
- Small working session for focused discussion and co-working

+

PID Software

- Report software status
- Talk on PID experience and analysis at BELLE-II

Workfest Agenda [~30 participants!]

1) **[8 – 9:45 am] Morning 1:**
   Intro and Context
   - Flash updates from different *categories* of reconstruction
   - Frames forward-focused open discussion
2) **[9:45 – 10 am] Coffee break**
3) **[10 am – noon] Morning 2:**
   Open Discussion
   - What do we need for truly *holistic* recnonstruction
   - What are the steps to get there?
4) **[noon – 1 pm] Lunch**
5) **[1 – 1:30 pm] Afternoon 1:**
   The BELLE-II PID Experience
6) **[1:30 – 2 pm] Afternoon 2:**
   Overflow Discussion
   - Accommodate discussion from morning or BELLE-II
7) **[2 – 3 pm] Afternoon 2:**
   Electron-Finder Working Session I
   - Focused work session on the electron-finder
8) **[3 – 3:15 pm] Coffee Break**
9) **[3:15 – 4:15 pm] Afternoon 3:**
   Electron-Finder Working Session II
10) **[4:15 – 4:30 pm] Afternoon 4:**
    Closeout discussion

Introduction | some context

- S&C focus during 1st half of 2024 on priorities for (pre-) TDR identified at January CM
  - ⇒ See earlier S&C report on Saturday [8:30 am] for more details
- Workfest part of ongoing discussion for identifying priorities for remainder of year and beyond
  - Previous discussions:
    - 07.09.2024 reco meeting
    - 07.17.2024 S&C meeting
- **Focus for workfest discussion:** what do we need for truly *holistic* reconstruction?
  - ⇒ **Holistic:** something synthesizing information from multiple, distinct sources

Identified priority tasks in 2023

- Primary vertexing
- Electron finder
- Low-Q2 tagger
- Particle flow

All either implemented or in progress

Identified reconstruction priorities from CERN Workshop 2024

- Modularity of algorithms
- Use holistic information from various detector components in algorithms
  - Integration of FF/FB systems
- Web-based event display

Holistic Reconstruction | holistic reconstruction?

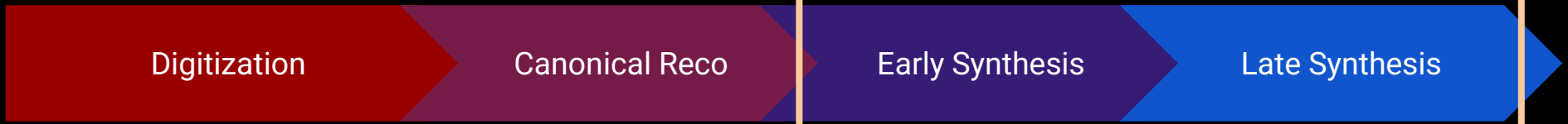
Example algorithms:
- Timeframe unfolder
- Unfolded event assessor
- Digitization

Example algorithms:
- Tracking reco.
- Calorimeter reco.
- PID reco.
- FF/FB reco.

Example algorithms:
- Vertexing (primary and secondary)
- Electron identification
- Early stages of particle flow

Example algorithms:
- DIS electron selector
- Kinematic calculation
- Jet reconstruction
- Final stages of particle flow

Holistic Reconstruction | holistic reconstruction!



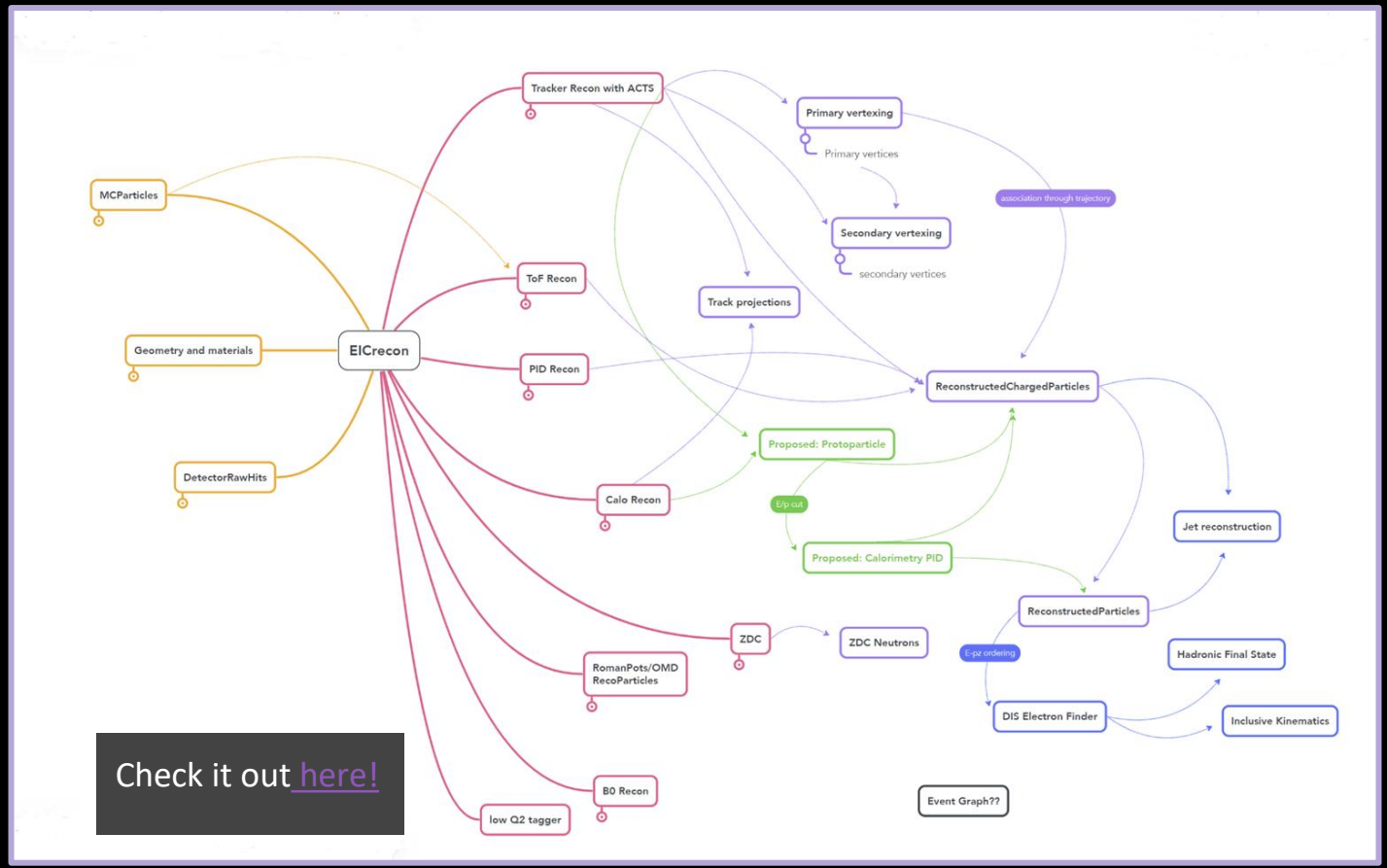
Example algorithms:
- Timeframe unfolder
- Unfolded event assessor
- Digitization

Example algorithms:
- Tracking reco.
- Calorimeter reco.
- PID reco.
- FF/FB reco.

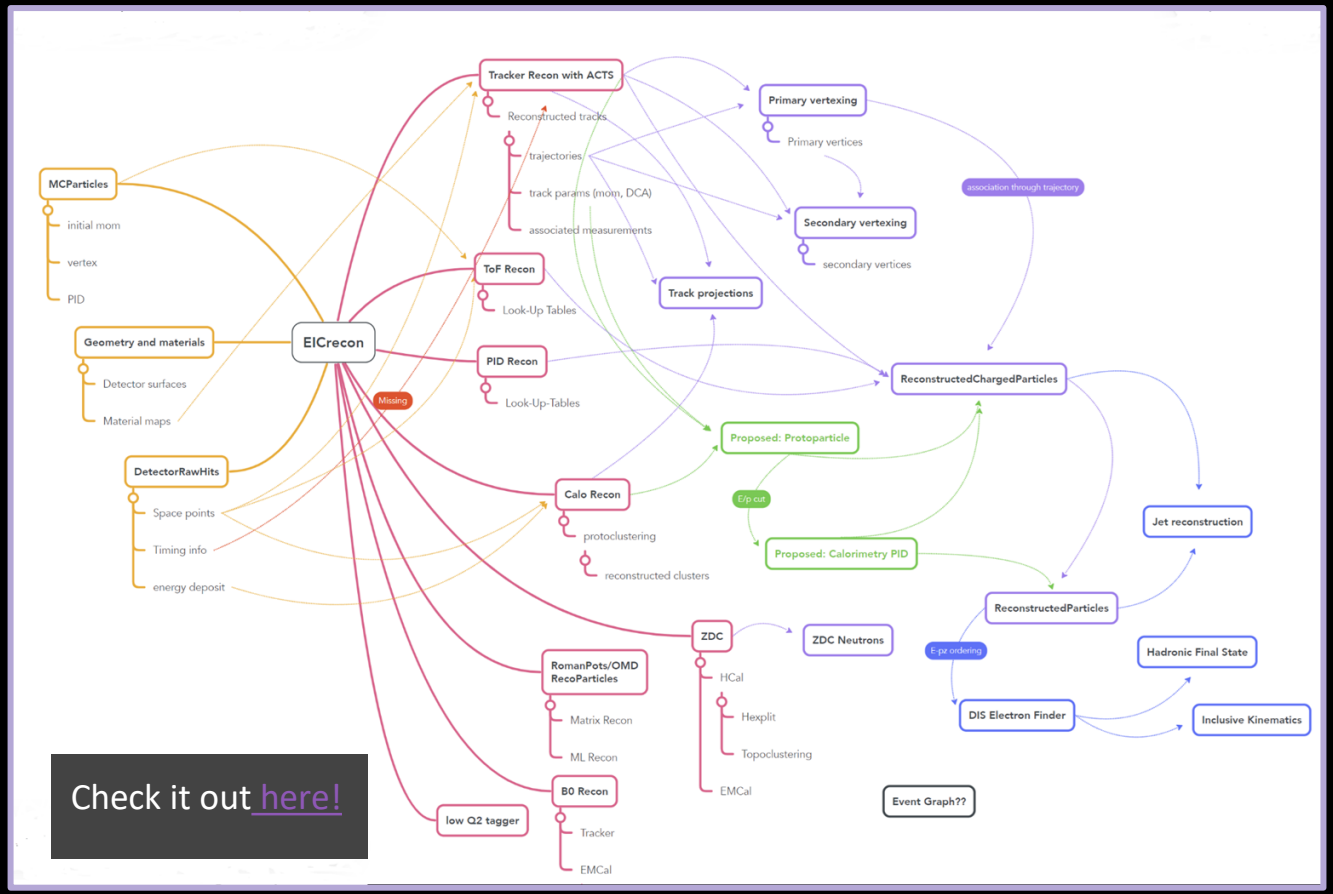
Example algorithms:
- Vertexing (primary and secondary)
- Electron identification
- Early stages of particle flow

Example algorithms:
- DIS electron selector
- Kinematic calculation
- Jet reconstruction
- Final stages of particle flow

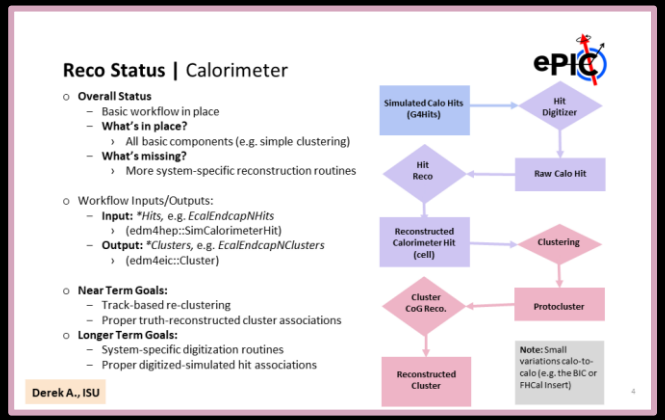
Holistic Reconstruction | mapping out EICrecon

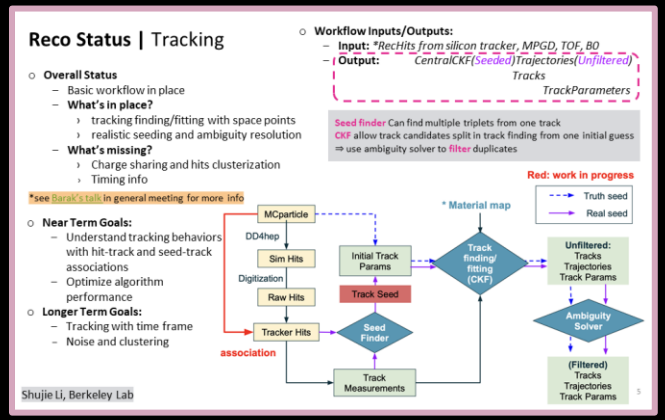


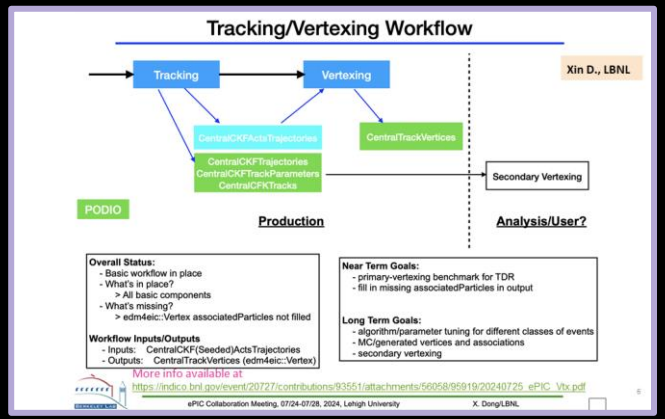
Holistic Reconstruction | mapping out EICrecon

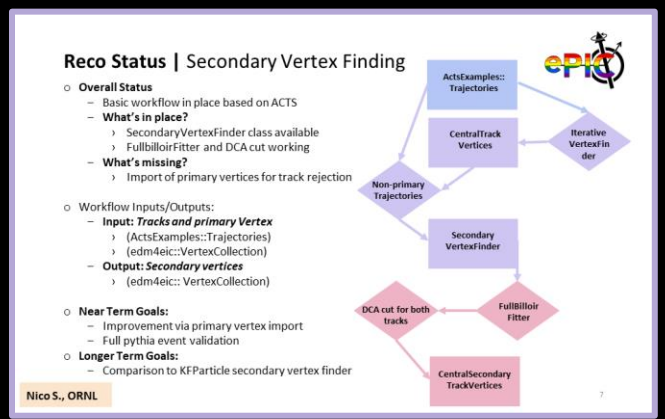


Context Session | snapshots (1/3)





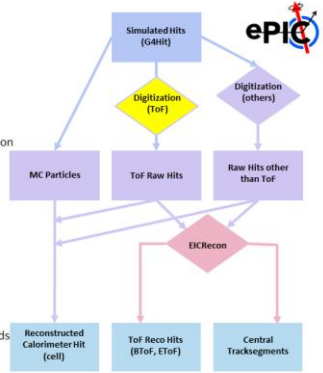




Context Session | snapshots (2/3)

Reco Status | ToF

- **Overall Status**
  - Digitization (Yellow in right chart)
    - in progress
  - **What's in place?**
    - › In progress but EICRecon w/o Digitization looks working
  - **What's missing?**
    - › EICRecon w/ Digitization
- Workflow Inputs/Outputs:
  - **Input: ToF Raw hits + Raw Hits other than ToF**
  - **Output: ToF RecHits**
- **Mid Term Goals (for preTDR):**
  - Complete Digitization
  - Optimize material Budget
  - Performance study under beam backgrounds

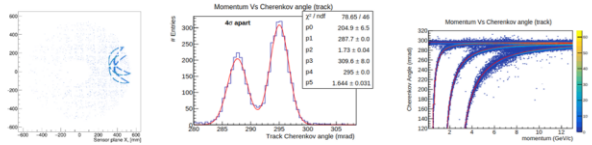


Kentaro K., Shinshu U.

IRTv-2

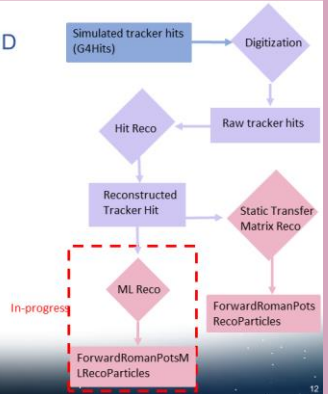
Chandra C., INFN

- A second version of IRT has been developed during backward RICH review.
- A sophisticated chi-square based PID algorithm is used to handle much more complicated event topology.
- Tested thoroughly in a Standalone code.
- Kolja has made an effort to import the stand-alone code to EICRecon. Does not work out-of-the box. Requires, testing and step-by-step debugging.
- Alexander and Chandra plan to work on it. Will be used in both RICHes. Standalone code plots:



Reco Status | Roman pots/OMD

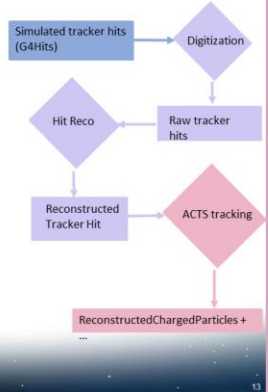
- **Overall Status**
  - Full reco with static transfer matrix exists and works. (**note:** special cases need to be considered, e.g. light nuclei).
  - ML algorithm exists, integration with EICrecon in-progress.
- **Workflow**
  - Input(s): ForwardRomanPotsRecoHits
  - Output(s): ForwardRomanPotsRecoParticles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



Alex J., BNL

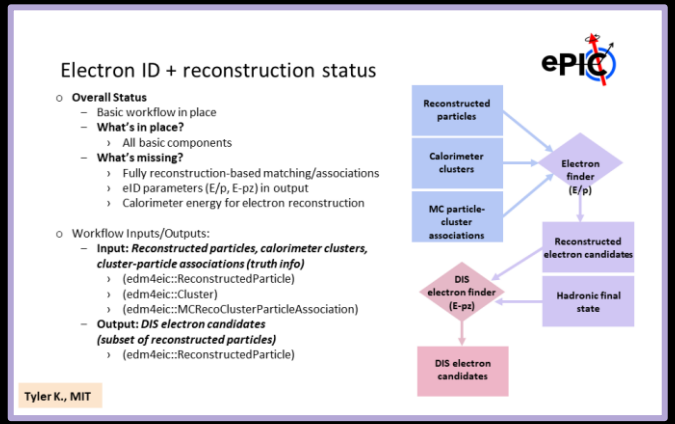
Reco Status | B0 tracker

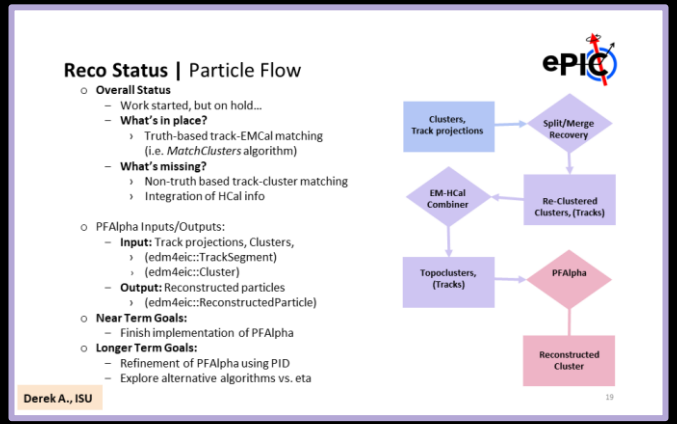
- **Overall Status**
  - Full reco has been tested, but with recent changes, correct output for ACTS tracking a bit unclear.
  - B0 field map needs to be put into a PR and merged (see below).
- **Workflow**
  - Input(s): B0TrackerRecoHits
  - Output(s): ReconstructedChargedParticles***
- **Near-Term 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).



Alex J., BNL

Context Session | snapshots (3/3)



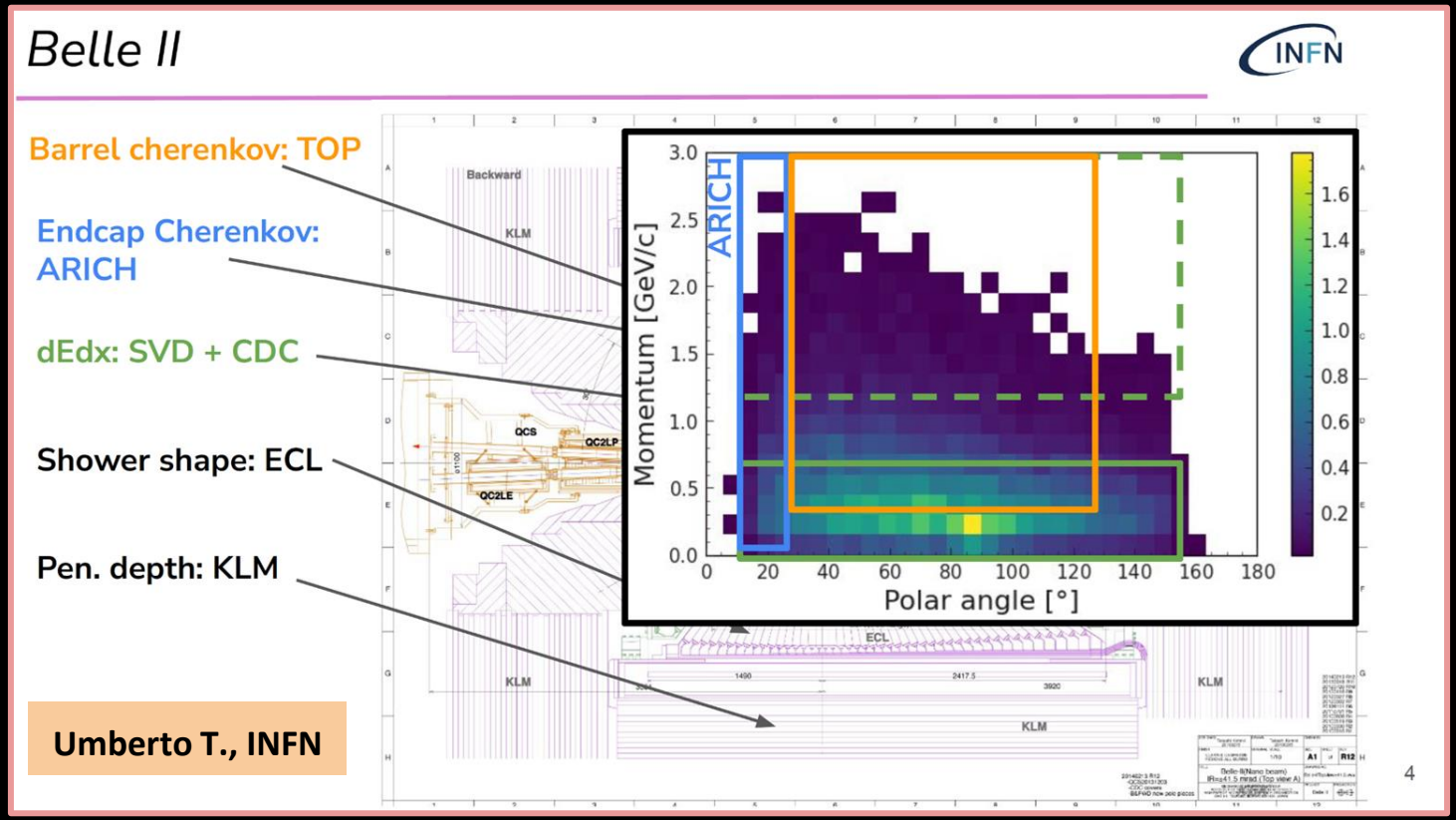


- Strongly recommend checking out both slides and live notes!
  - All are on indico page

- **Summary:** (almost) all of our canonical reconstruction is in place
  - 👉 Reconstruction moving from truth to enhanced realism

- **Example**: Reconstructed Charged Particles
  - Default will use KF seeds by September
    - Now: realistic seeded quantifies flagged by "seeded" in name
  - Now use LUTs instead of truth PID

PID at BELLE-II | PID subsystems



Check out recording and slides here!

PID at BELLE-II | how to combine hypotheses?

Combining information

Each sub-detector provides a likelihood value for 6 possible PID hypotheses:

→ electron, muon, pion, kaon, proton, deuteron

→ The likelihood values are calculated comparing the observed signal with the expectation for each particle hypothesis (based in MC, data template, or analytic models)

→ If particle is out-of-acceptance, LogL = 0 for all hypotheses

$\mathcal{L}_\alpha^d = \mathcal{L}^d(\mathbf{x}|\alpha)$ Likelihood for hypothesis α from detector *d* that observed **x** hits

$$\mathcal{L}(\mathbf{x}|i) = \exp\left(\sum_d^{d\in D} \log\mathcal{L}^d(\mathbf{x}|i)\right)$$ Likelihood for hypothesis α from all detectors

Umberto T., INFN

$$P(A_i|\mathbf{x}) = \frac{P(\mathbf{x}|A_i)\cdot P(A_i)}{\sum_j P(\mathbf{x}|A_j)P(A_j)} \Rightarrow P(i|\mathbf{x}) = \frac{\mathcal{L}_i}{\sum_j \mathcal{L}_j}$$ **PID probability**

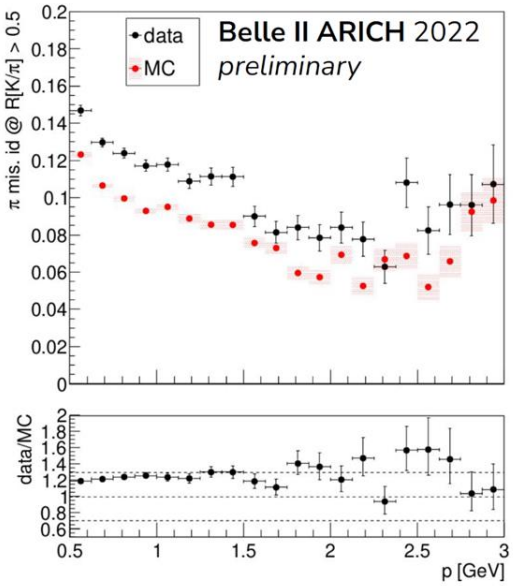
5

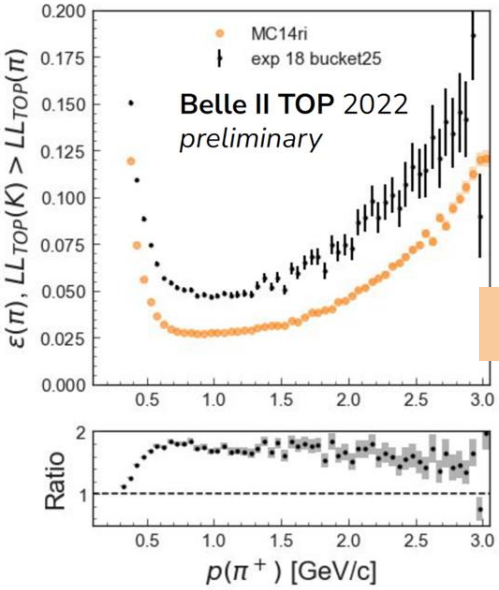
Check out recording and slides here!

PID at BELLE-II | reality check (1/2)

Expectations VS reality

Performance observed in data still don't match with (optimistic) MC
- Many lessons learned so far!





Umberto T., INFN

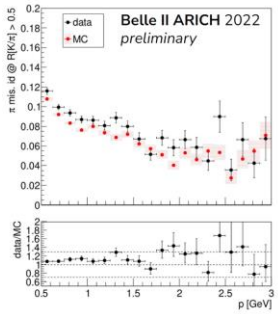
18

Check out recording and slides here!

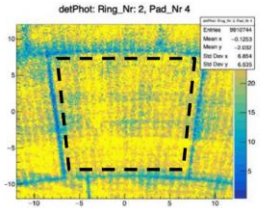
PID at BELLE-II | reality check (2/2)

Lessons learned: ARICH tile alignment

Aerogel tile edges are responsible for most of the disagreement in ARICH



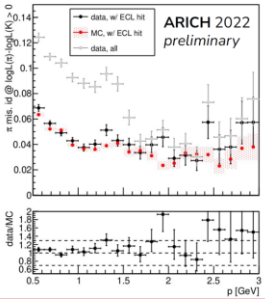
Removing tracks extrapolated in the edges
- Improves PID (expected) reducing acceptance
- Improves data/MC (not expected)
  - Work towards better tile alignment

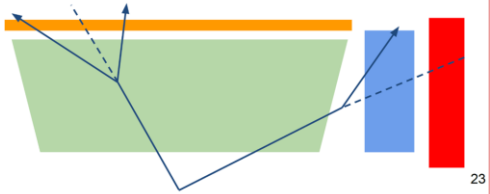


19

Mitigating material scattering

Use the Calorimenter behind ARICH and TOP to remove bad extrapolations
- Require a cluster matched with the track
- Powerful tool, but introduced correlation between subdetectors...



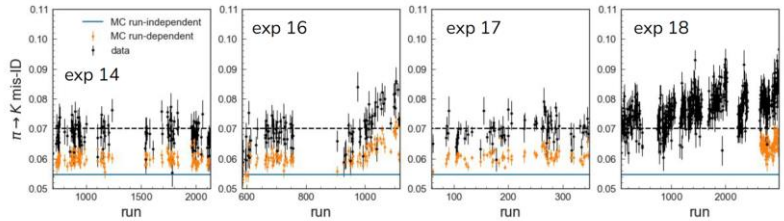


23

Umberto T., INFN

Lessons learned: background effects on TOP

For TOP, half of the data/MC disagreement is recovered with more realistic simulation
→ Actual dead/hot channel maps form data
→ Backgrounds from random triggers instead of simulation



Residual discrepancy is under investigation.

20

PID at BELLE-II | user interface

User's end-point

We save only the LogL values in the mDST

- ~20% of raw data are always available for extra studies

Particle identification probabilities are calculated on-fly by the analysis libraries

- Users can choose which type or probability (global, binary, ternary…)
- Users can choose which detectors are to be used

```
electronID, muonID, pionID, kaonID, protonID, deuteronID

pidPairChargedBDTScore(pdgCodeHyp, pdgCodeTest)
```

"Expert" variables

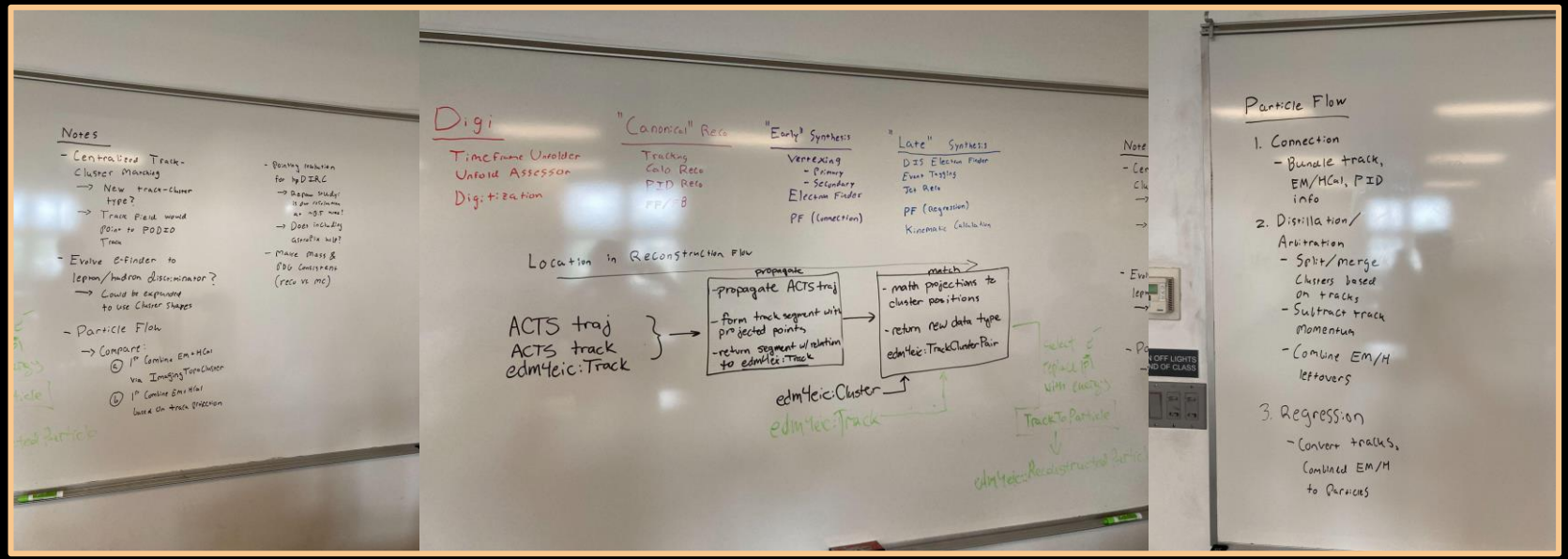
```
pidLogLikelihoodValueExpert(pdgCode, detectorList)

pidDeltaLogLikelihoodValueExpert(pdgCode1, pdgCode2, detectorList)

pidPairProbabilityExpert(pdgCodeHyp, pdgCodeTest, detectorList)

pidProbabilityExpert(pdgCodeHyp, detectorList)
```

Umberto T., INFN

24

Check out recording and slides here!

Discussion, Work Sessions | overview



- Open discussion spilled over into afternoon working session
  - Was extremely productive!
  - **Above:** discussion notes left on the whiteboard
- Bulk of discussion was on interplay of two early/late synthesis algorithms:
  - **Electron-Finder, and**
  - **Particle Flow**

Discussion, Work Sessions | PF and eID synergies

Schematic Outline of PF: refactor current work-in-progress to modularize

1) **Connection**
   - Bundle tracks, clusters, and PID hypotheses into proto-particles
2) **Arbitration**
   - Split/merge clusters based on tracks
   - Subtract track momentum
   - Combine EM/HCal leftovers
3) **Regression**
   - Convert proto-particles into reconstructed ones

Electron-Finder Evolution: excise truth info and refactor for synergy with other projects

1) **Implement track-cluster matching algorithm**
   - Would produce new track-cluster data type
2) **Identify hadrons using track-cluster matches**
   - Start with E/p (can expand later)
3) **Convert identified electrons to reconstructed particles**
   - And pass to DIS electron selector

Discussion, Work Sessions | notes and action items

- **Should centralize track-cluster matching**
  - Need new data type?
    - A *TrackClusterPair* or *ProtoParticle* to bundle matched tracks and clusters
    - Track field would point to PODIO tracks (naturally)
- **Could evolve e-finder to a lepton/hadron discriminator**
  - Also could extend lepton ID to use cluster shapes
- **Compare two approaches to PF:**
  - Combine EMCal and HCal clusters via TopoClustering *before* connection + arbitration
  - Or combine EM/HCal clusters based on track projections
- **Recheck pointing resolution to hpDIRC:**
  - Repeat study to see if recent tracking changes improve resolution
  - Check if including AstroPix helps
- **Bug to fix:** make mass & PDG consistent (i.e. based on LUTs) in Reco. Charged Particles

Join in Reco WG Meetings!

Tuesdays at 3:30 pm EDT!

Thanks!