

# Analysis coordination - summary

*D. Brown (LBL) and B. Echenard (Caltech)*

*June 2025*

## Analysis is globally in good shape!

### Core group model has been quite successful

- Significant progress in calibration, tools, and computing infrastructure
- All groups have reached their “cruising speeds”, many activities are ballistic
- Shift our focus on integrating the different pieces into a full Pass-1 system

### Analysis work is progressing

- Current efforts covering  $\mu^- \rightarrow e^-$  conversion,  $\mu^- \rightarrow e^+$  conversion, DIO analysis,...
- A limited number of analysis groups have been formed so far, tweak the model to increase the level of interaction with the collaboration

### Review meeting structure

- Reshuffle core group meetings to consolidate discussions in a single morning instead of two
- Increase analysis group reports during Thursday bi-weekly meetings

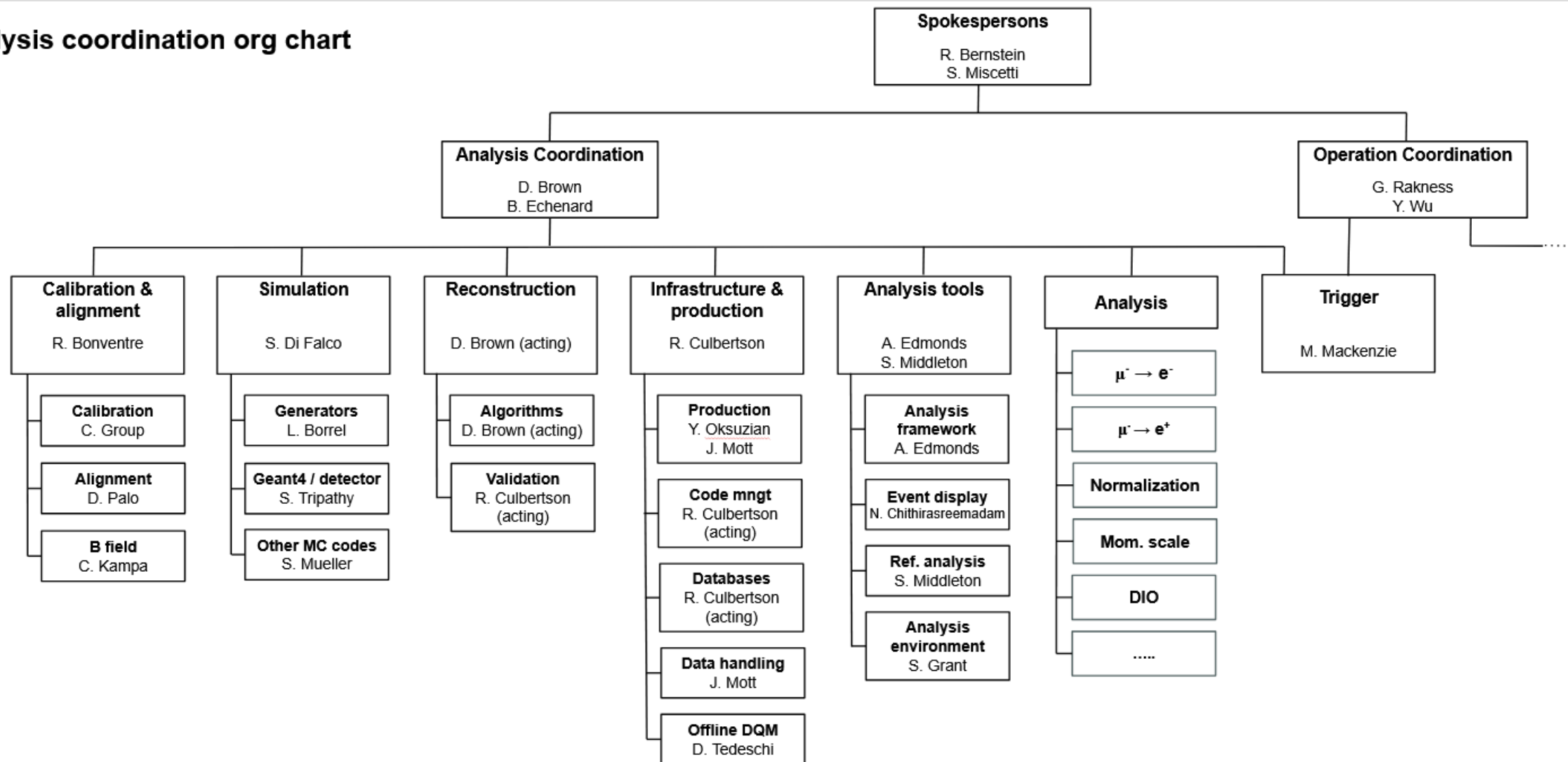
## Two sessions devoted to integration into Pass 1 system and analysis work

Start	Title	Author(s)
07:30	Introduction	<a href="#">Dave Brown</a> <a href="#">Bertrand Echenard</a>
07:40	Calorimeter plans for Pass 1	<a href="#">Simona Giovannella</a> <a href="#">Luca Morescalchi</a>
07:55	STM plans for Pass 1	<a href="#">Andy Edmonds</a>
08:10	<a href="#">CRV Pass1 Status</a>	<a href="#">Ralf Ehrlich</a>
08:25	Tracker needs for Pass 1	<a href="#">Ed Callaghan</a> <a href="#">Vincent Fischer</a>
08:40	Infrastructure for Pass 1	<a href="#">Ray Culbertson</a>
09:00	Calibration for Pass 1	<a href="#">Richie Bonventre</a>
09:20	Simulations for KPP and Run1	<a href="#">Yuri Oksuzian</a>

Start	Title	Author(s)
10:15	Stopping target instrumentation	<a href="#">Tausif Hossain</a>
10:35	Update on mu- ->e- analysis	<a href="#">Susan Dittmer</a>
10:55	Progress on mu- -> e+ analysis	<a href="#">Matthew Stortini</a>
11:15	Analysis Framework in Julia for Bayesian Uncertainty Quantification	<a href="#">Vivek Singh</a>
11:35	<a href="#">Mock Data (MDS) for Physics Analysis</a>	<a href="#">Sophie Middleton</a>
11:55	Meeting structure	<a href="#">Dave Brown</a> <a href="#">Bertrand Echenard</a>

# Analysis coordination organization

Analysis coordination org chart



There are still (great) opportunities in reconstruction and infrastructure for junior people – contact us if interested

This current core group meeting schedule is rather time consuming. Now that the core group are well established and functioning efficiently, it is time to revisit this structure and try to reduce the meeting load

## **New proposal for AnCo meetings (A/B week schedule)**

- One core group meeting per week (Tuesday **or** Wednesday, was Tuesday **and** Wednesday)
- Keep Analysis meeting every other Thursday

## **Core group meeting:**

- Consolidate all core group discussion into a single day
- Each core group presents every-other week
- Agenda posted by Monday

## **Analysis meeting**

- A limited number of analysis groups have been formed so far and meetings are mostly private
- Request analysis group to present progress more frequently during Thursday meeting to get feedback from the collaboration

**Will conduct a poll to decide if we keep Tuesday or Wednesday**

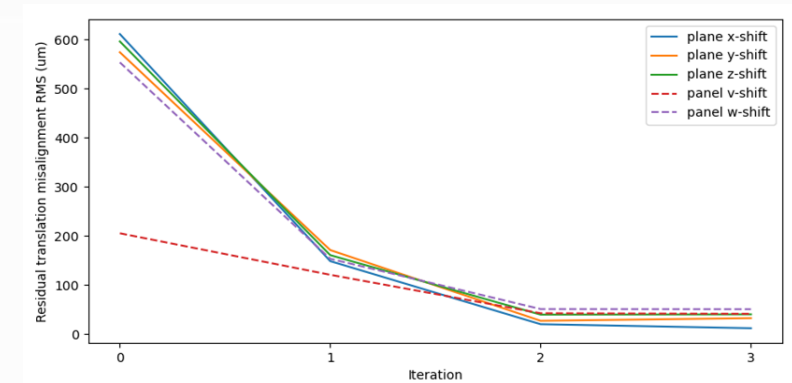
# Core groups

*Recent progress*

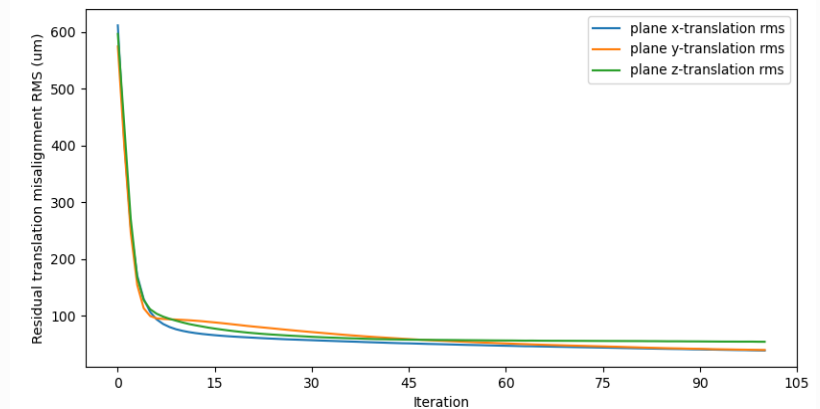
## Alignment, metrology, and magnetic field

- **Alignment algorithm improvements**
  - Improved Millepede plane+panel alignment (R. Bonventre)
  - Local alignment of planes with OffSpill Central Helix (R. Bonventre)
  - Developing track selection criteria (D. Palo)
  
- **Metrology**
  - Production code for x-ray metrology to Offline alignment tables (D. Palo)
  - Panel + plane metrology processing in development
  - Offline vs CAD+metrology corrections for next round of simulations (D. Palo)
  
- **B-Field**
  - Developing new maps including extinction monitor filter magnet (C. Kampa)
  - First calibrated Hall probe (C. Kampa)

Millepede line alignment



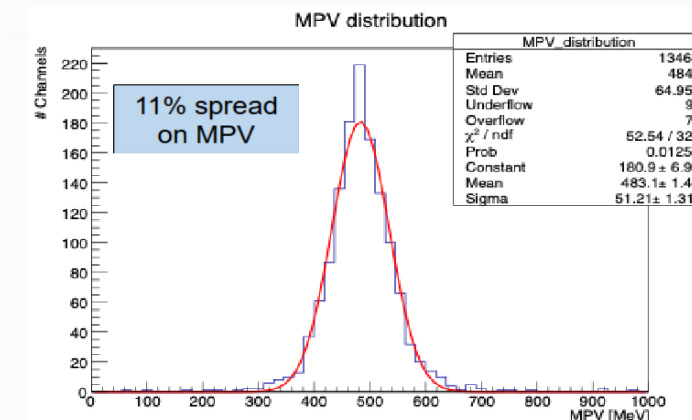
CentralHelix alignment



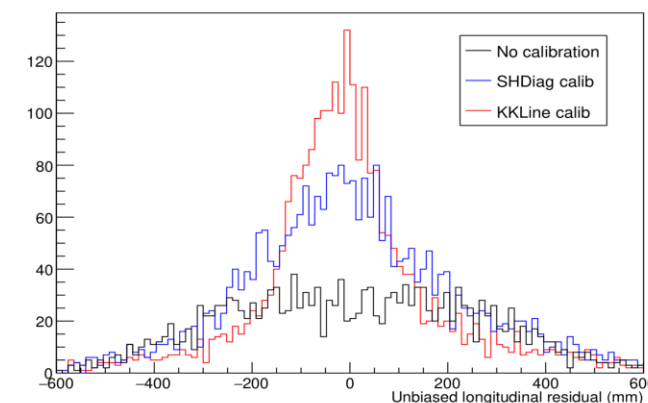
## Calibration

- **CRV and calorimeter calibration algorithms on real data**
- **KinKal improvements (CRV geometry, extrapolation) for inter-detector calibration** (N. Harrison, D. Brown)
- **Tracker algorithm developments**
  - Offline drift T2D improvement and recalibration from MC (G. Diaz)
  - Development of data based calibration algorithm (G. Diaz)
- **Very initial calibrations with real data from tracker station**
  - Track based calibration using KinKal tracks, EventNtuple (R. Bonventre)
  - Beginning charge injection calibration analysis (M. Jangra)
- **Progress towards testing something like calibration pass-1**
  - All detectors now have some DB tables implemented
  - VSTs producing data and calibrations
  - Not yet closing loop of calibrations uploaded to database

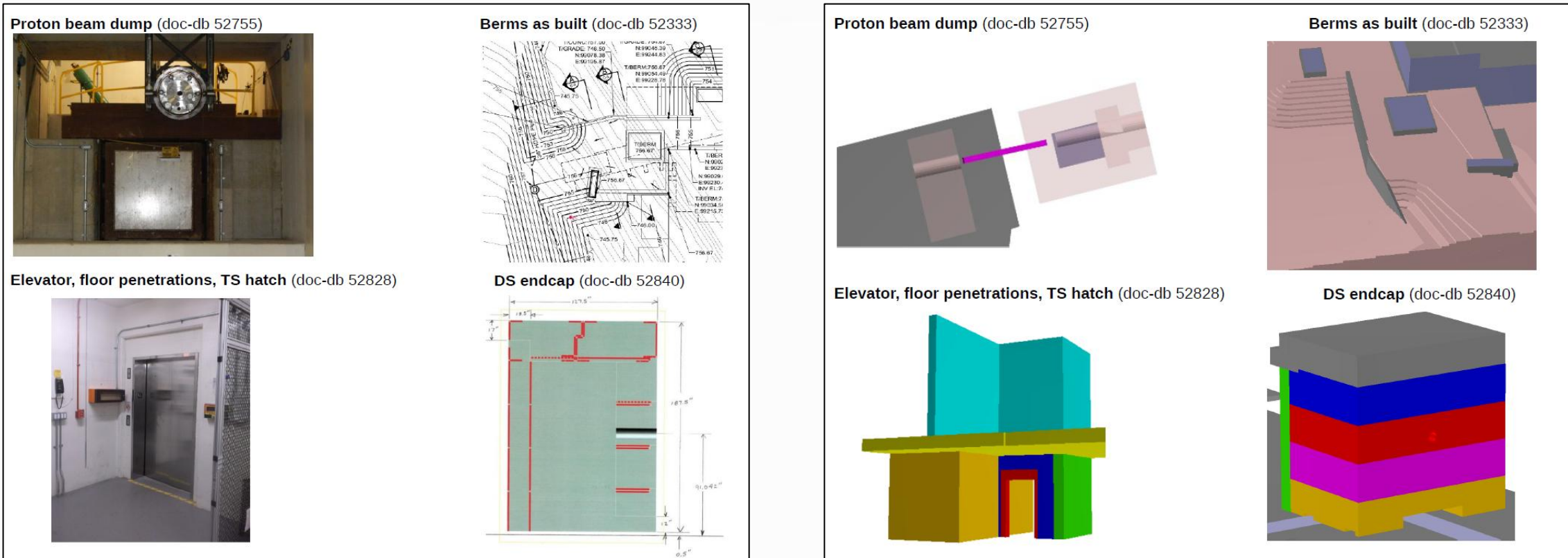
Calorimeter VST energy calibration



Initial tracker VST time-division calibration



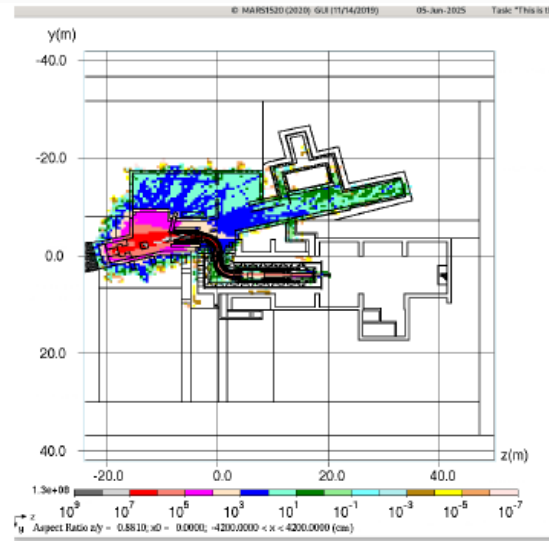
**Geometry update is almost complete – astonishing level of detail (we almost modeled the emergency stop button in the elevator!)**



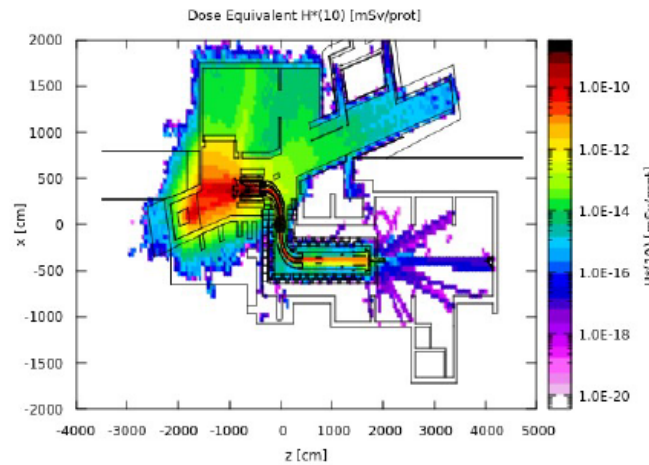
**Heroic effort from Stefano, Sridhar, and Andrei**

**Work is nearly complete, waiting blessing from our Pontifex Maximus (George) to declare victory!**

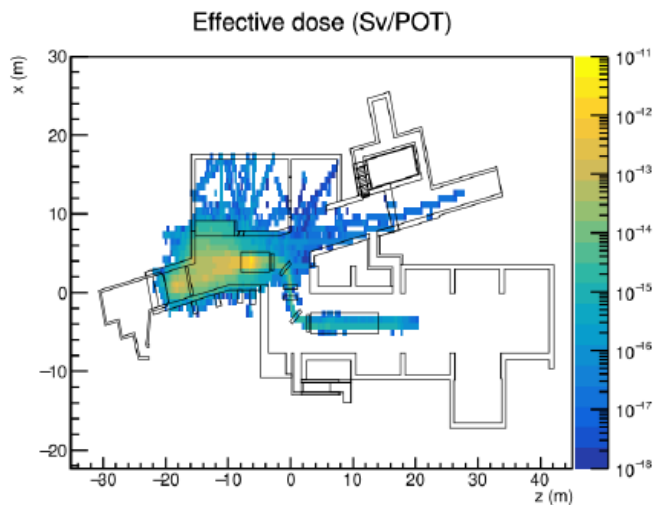
## Preliminary results on dose estimate with MARS, Fluka, and Geant4



**MARS**  
Delayed  
dose after  
90 days  
irradiation



**FLUKA**  
Ambient  
dose  
equivalent  
 $H^*(10)$



**GEANT4**  
Effective  
dose

Geant4 / Fluka are much faster than MARS, but additional work is needed to import geometry in Fluka or calculate delayed dose

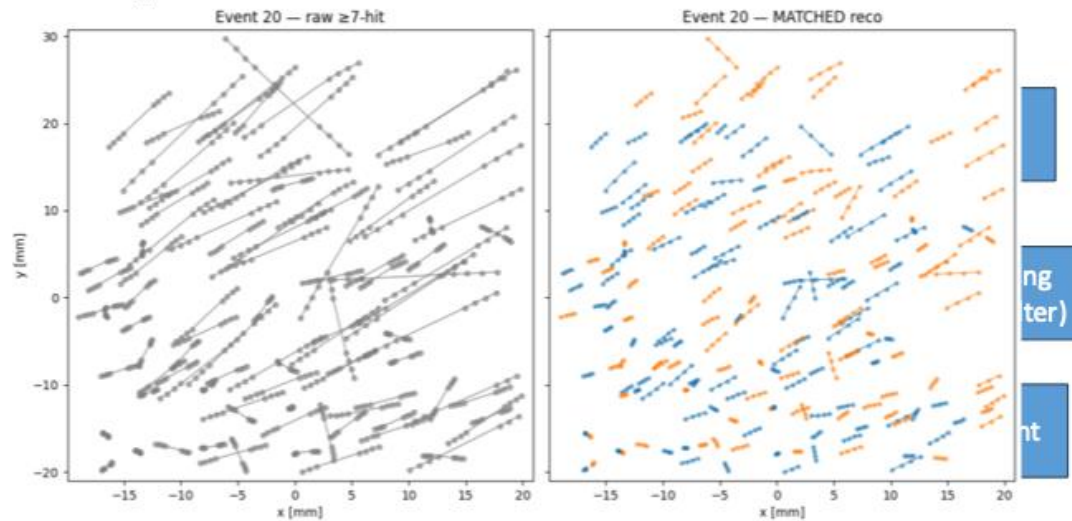
Continue efforts to compare generator predictions and implement delayed dose estimation in Fluka and Geant4

## Overall reconstruction status

- Offline reconstruction is in good shape
  - Reasonable algorithms exist for all our detector, calibration, and physics needs
- Trigger configuration variants satisfy requirements
  - Efforts to optimize the algorithms continue
- Major developments since the last meeting:
  - Central helix ('straight') track fits for OffSpill data
  - Fixes and improvements in KinKal fit extrapolation
- Demonstration of ExtMon reconstruction

## ExtMon reconstruction (M. Jones and J. Lin)

- Two types of reconstruction:



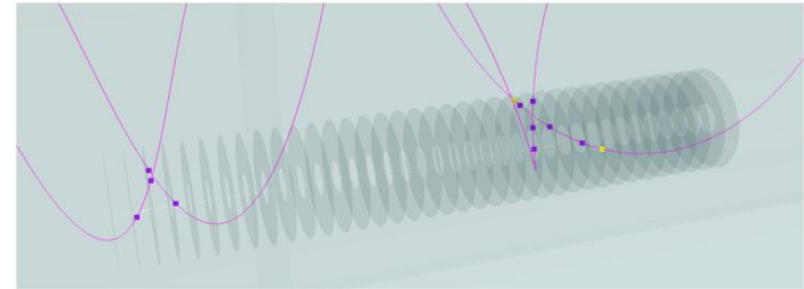
June 10, 2025

Mu2e Collaboration Meeting Extinction Monitor Workshop

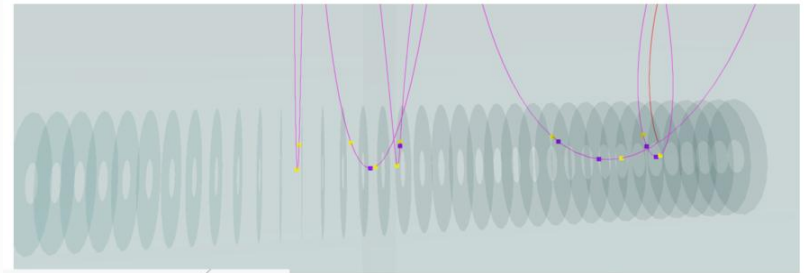
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## Stopping target intersections

MDC2020au



MDC2020aw

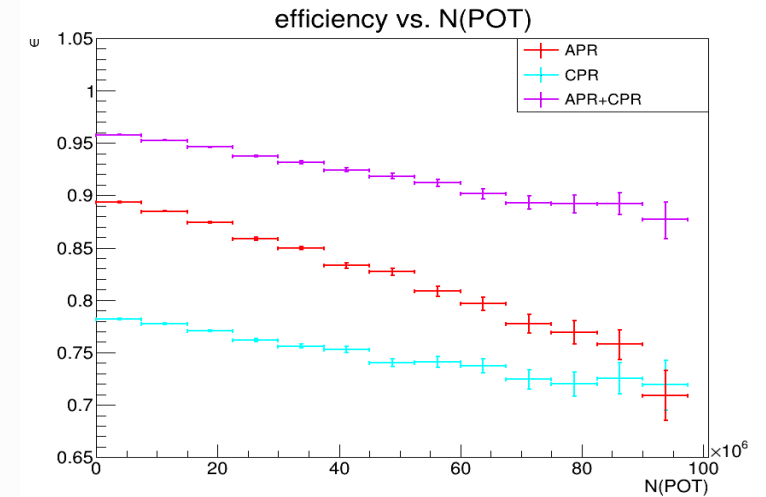
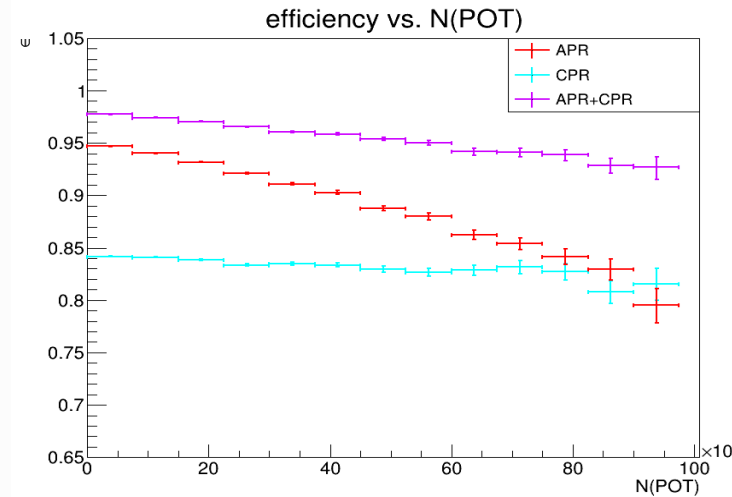
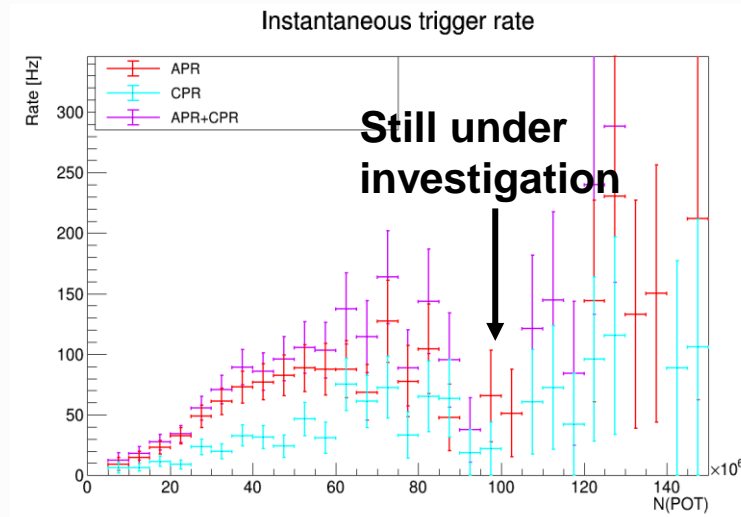


**ExtMon track reconstruction with good efficiency (toy MC data) - track fit unnecessary?**

**Fix to ~1% missing fit extrapolations deployed in MDC2020aw**

## The trigger already satisfies all of the system requirements

- Handle 145 kHz On-Spill + 7.5 kHz Off-Spill (5 ms / event)
  - Main triggers run in 2 ms / event
- Rejection factor for On-Spill data
  - Main triggers on average have a rejection factor of  $\sim 2,000$  ( $< 100$  Hz) with a peak instantaneous rate of  $\sim 200$  Hz
- 90% trigger efficiency for signal tracks reconstructable in Offline
  - The average muon to electron (positron) trigger efficiency is 97% (95%)



Documentation summarizing trigger estimates for primary physics triggers available in docdb-52246

## Code Management

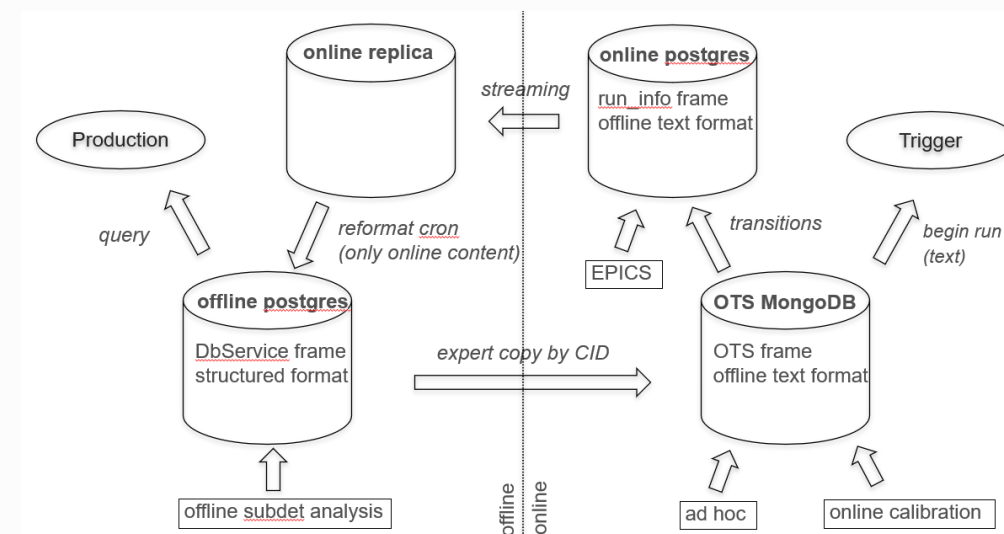
- Spack development continue, gen2 scripts running with new features
- New cmake/spack builds (EventNtuple, EventDisplay, Stntuple, geant4 11.3.2)
- Priorities: new packages (CORSIKA, mu2egrid, mu2efiletools), automatic gdmf for EventDisplay, development builds run on the grid

## Conditions Database

- First real calo table is in operation
- EPICS, run info and good run database tools available
- Online/offline coordination: conceptual design, details and prototypes soon

## Offline DQM

- Basic infrastructure in place
  - Automatic DQM on CRV wideband production
  - Development of limits, alarms, displays,...



## Data processing

- Commissioning POMS with Metacat is the main task
  - CSAID experts engaged, multiple weekly meetings, fixes in
  - regularly running 1000-file test jobs
  - ongoing major effort to move server into production
  - pushing hard on logical/precise monitoring
- **Fixing a last few details before declaring minimal functionality, but committed to moving forward with POMS w/ metacat as our production system**

## Data handling / transfer

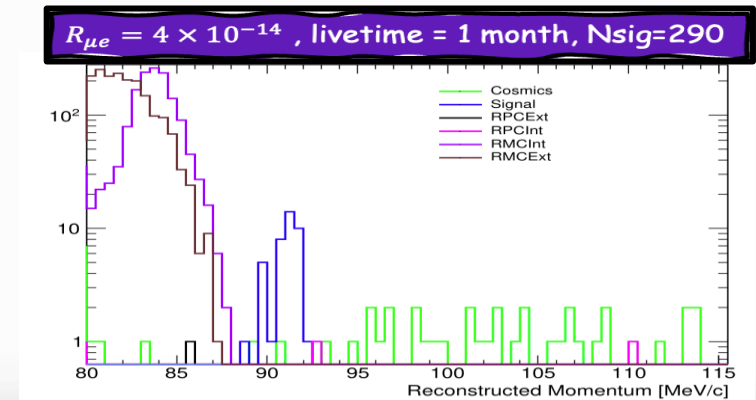
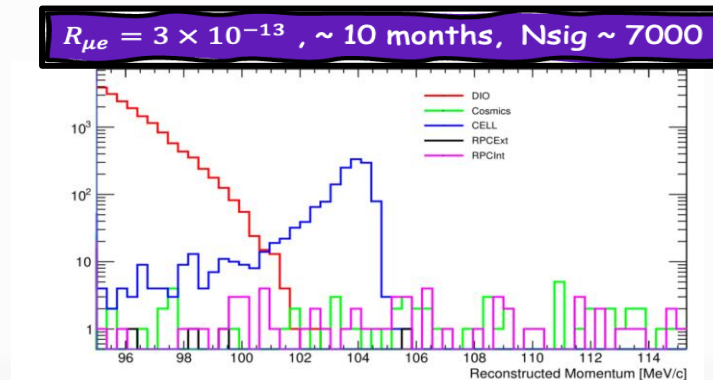
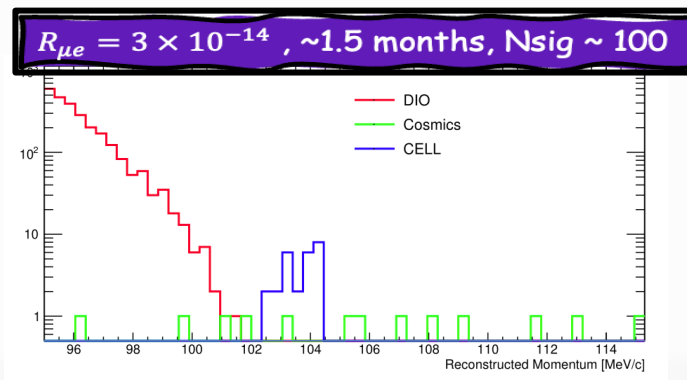
- The lab has transitioned us from Enstore to CTA tape management
  - **we need to avoid sending small files to tape - no longer automatic. Contact Ray if you need advice on how to deal with small files**
  - Simulation workflows need updating
- declad moving raw data to tape
  - Nam Tran regularly load tests - meets requirements
  - convenience uploader available, working on monitoring, control

## EventNtuple and utilities

- Progress towards integration into VST efforts
- On-going large efforts on integrating calorimeter, track PID, trkQual,...
- Python-based framework for EventNtuple analysis has matured significantly, integration with EAF and consolidated with other python tools
- Analysis teams are using these tools already, but more feedback is welcome

## Mock Data Challenge

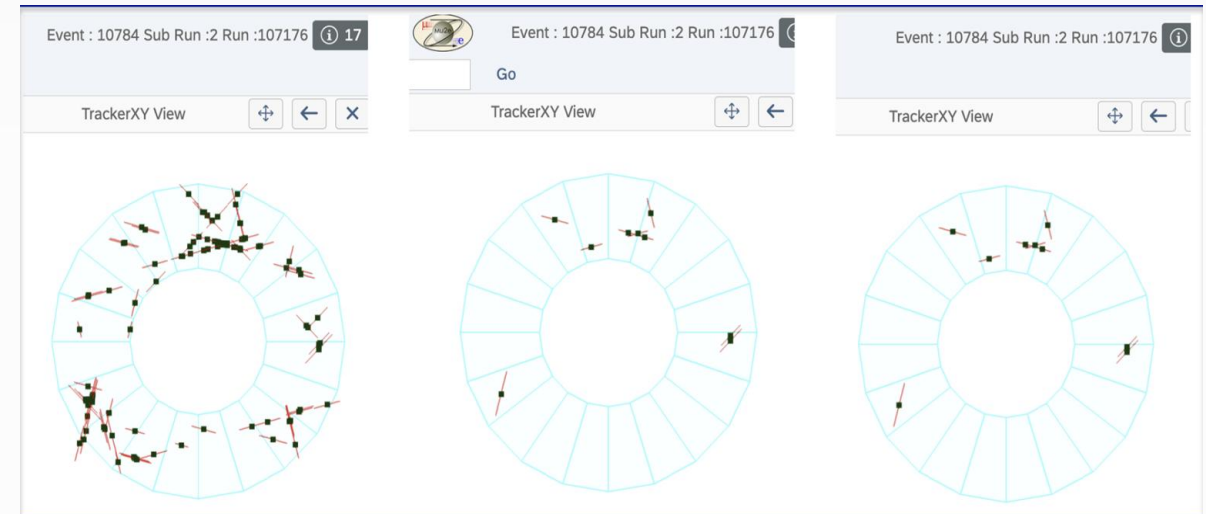
- New samples looking like real data!
- MDS2 is complete, many new background components added
- Very flexible, any livetime and signal can be added by user
- See Sophie's talk during Analysis session



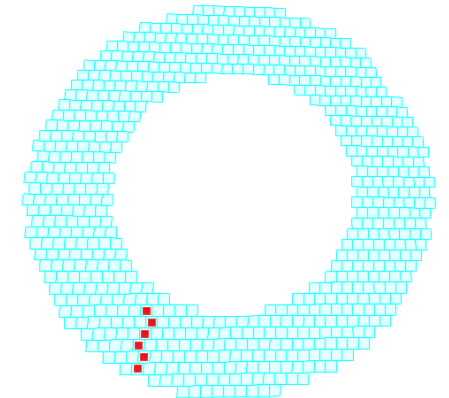
## EventDisplay

- Several bugs fixed, and new features added.
- Name changed to unify with other products.
- Namitha Chithirasreemadam (L4 Display) has begun work with visualizing VST data.
- Integration into online workflow continues.

**New Analysis musing combining  
EventNTuple(+utils), EventDisplay  
and Tutorial is now available**



**Namitha  
Chithirasreemadam  
Top: Tracker VST  
Bottom: Calo VST**



**Do not forget the “office ½ hour” for analysts to drop by and give us their feedback or ask for help**

# Pass 1 readiness

*Summary needs*

Pass 1 is the prompt Offline processing of data arriving from the DAQ

We organized a session to examine our readiness for running pass 1

We asked each subsystem to answer the following for their system:

- What volumes of data do you expect during VST and KPP operations?
- What kind of automated data processing is needed for your data?
- What is the status of the art modules and scripts (fcl files) you need for Pass1?
- What are the types and volumes of data you expect pass1 to produce?
- What kinds of automated Offline data monitoring is needed?
- What calibrations are produced and uploaded from your Pass 1?

We also asked the relevant core groups to summarize the status of Pass1 support

- Calibration, Infrastructure, and simulations

## **Every system has solid preliminary ideas of what they need for pass 1**

- Currently being exercised in various VSTs
- Use a mix of official Offline and private codes
- Mostly being processed by hand (except CRV)

## **The proposed Pass 1 needs are reasonable**

- Data payloads are reasonable
- Initial running will require additional payloads
- NZS data prescale values need to be studied/finalized

## **System hardware / firmware are still evolving**

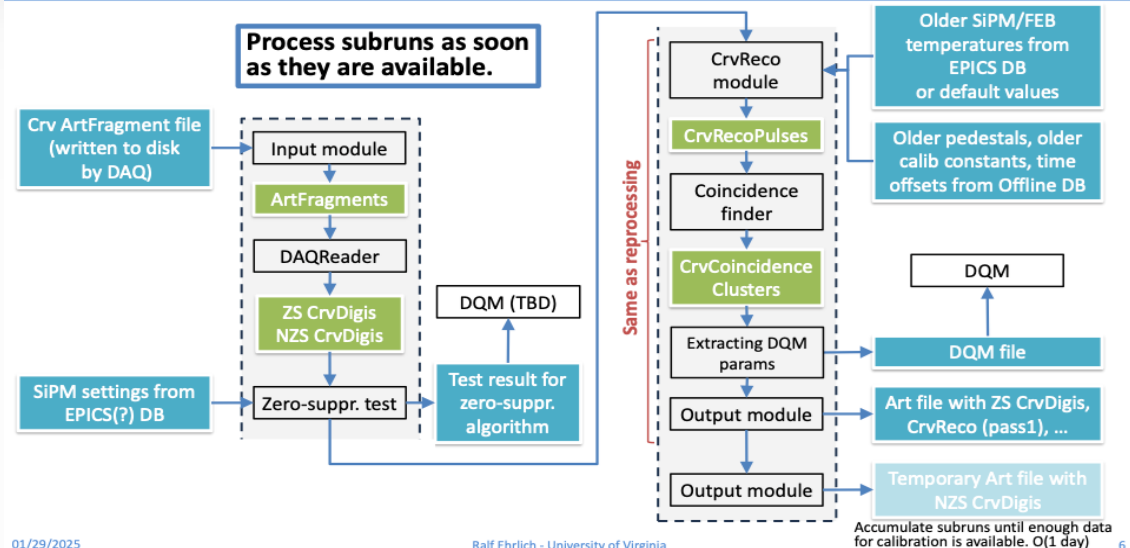
- Inputs and environment are not final  $\Rightarrow$  data processing will need to evolve too

## **Processing infrastructure and simulations are (nearly) ready**

## **Calibration and Monitoring are functional but need further development**

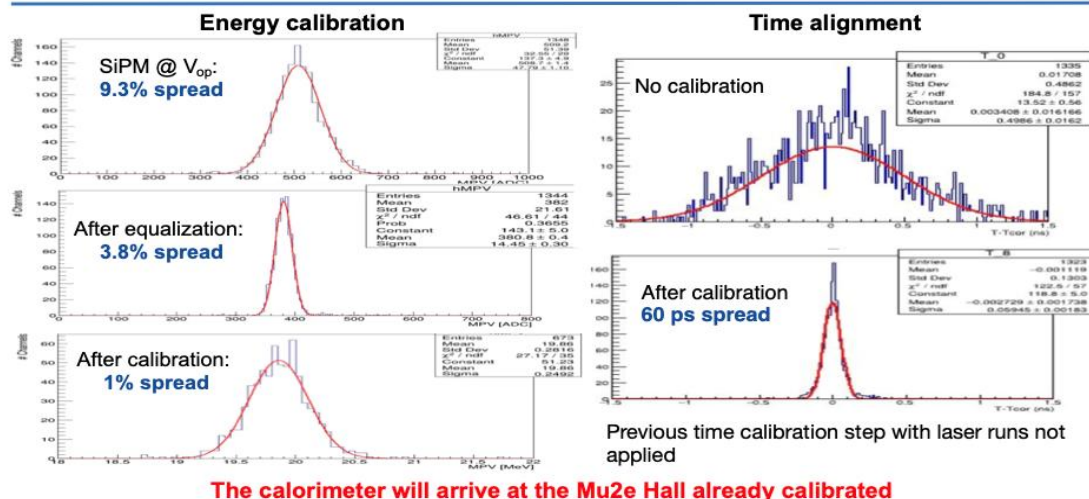
- Some fully-worked examples for all systems
- Logistics for multi-run accumulation, Offline  $\Leftrightarrow$  Online interaction needs work
- Cross-calibration is missing

## CRV Pass1



## Calo calibration in SiDet

S. Salamino, this CM calo workshop

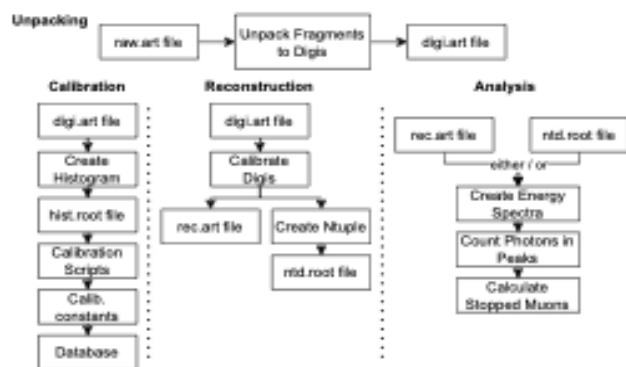


S. Giovannella – Calorimeter plans for Pass 1 – 11 June 2025

## Offline Tasks for STM

STM DAQ will have calibration constants to keep waveforms around peaks of interest

- Pass 1 can copy these for Reconstruction
- Calibration does not need to run in Pass 1



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## Raw data payloads

In these slides, all hit-rates are summed over detector

Stable cosmics: Average  $\sim 20$  hits @  $\sim 300$  Hz w/ full detector

- ▶ 20 GB / day of fragments
- ▶ + factor of 2 (very generous) for in-window noise
- ▶ Generally  $\lesssim 10$  GB / day for single-station running

Pulser data: benchmark at  $10^4$  pulses per hour  $\approx 50$  kHz average

- ▶ Specialized run type
- ▶ Additional  $\sim 140$  GB / day
- ▶ Only really relevant after achieving stable running

Ed Callaghan

Near-term tracker needs for pass-1

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## NEXT STEPS

- pass-1 sequences including calibration output in Production fcl
- Demonstrate full loop with VST
  - pass-1 conditions in database, extend for new runs
  - trigger?
  - run pass-1 sequence from database, produce ntuples
  - run calibration
  - insert results into pass-2 purpose, update for next pass-1 runs
- Need a working example of Offline / Online flow
- Need a working example of EPICS to conditions
- Determine how to do bookkeeping for accumulated calibration inputs
- Remaining fcl conditions moved to DB

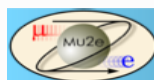
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## Production Pass1 - status

- POMS/metacat is still anticipated ready for cosmic run
- Computing experts are engaged
  - regular meetings and many requests, conversations
- Completed many 0.1k, 1k and 10k file tests
  - running every day or two
- Many problems uncovered and fixes implemented
- Currently no blockers on minimal functionality
  - Test algorithm not operating as expected
- Next big problem - merge code into POMS production
- Making progress on monitoring and displays
- Expecting a fully-instrumented test, from DAQ to tape, based on a sim cosmic dataset, within a few weeks

11 CM/Analysis

6/11/2025



## KPP simulated datasets



- KPP configuration has been [simulated](#), digitized and reco'd

Stage	S1	Size [T]	Event count	Livetime [s] per file	nFiles	Live-time [sec]
S+	dts.mu2e.CosmicCRYExtractedCat.MDC2020y.art	0.5	234E+6	7.8	9641	75102
S1	dts.mu2e.CosmicCRYExtracted.MDC2020av.art	3.5	497E+6	7.8	19996	155000
dig	dig.mu2e.CosmicCRYExtractedTriggered.MDC2020aw.art	0.6	59E+6	39	4000	155000
mcs	mcs.mu2e.CosmicCRYExtractedTriggered.MDC2020aw.art	0.4	59E+6	390	400	155000

**Calorimeter will be the first system for ‘completing the loop’**

**Sims for tools and algo development are in good shape, new production with “final” detector to follow**

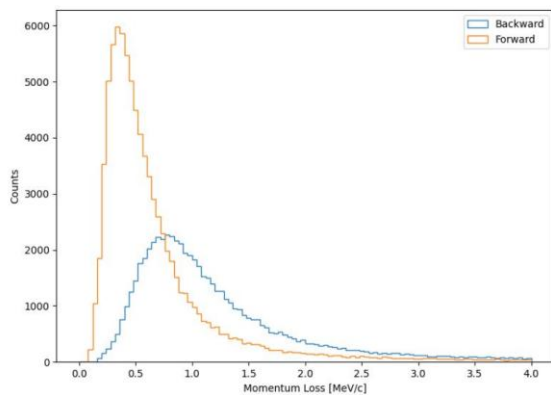
# Physics analysis

*Recent efforts*

## Proposal for instrumenting the stopping target – still at conceptual phase

### Momentum Loss Comparison (Forward vs. Backward)

- Momentum Loss = MC Momentum at Creation - MC Momentum at Tracker Entrance



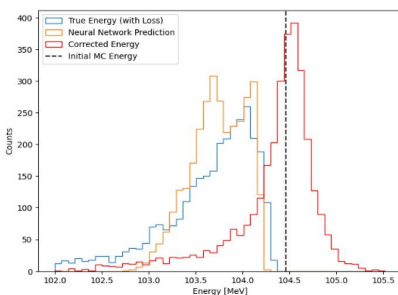
Current optimized momentum window is:  
 $103.60 < p < 104.90 \text{ MeV}/c$

Higher Resolution for Forward

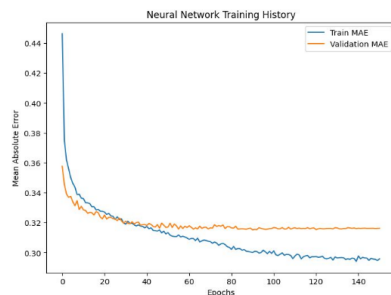
Low Resolution for Backward (~42.7% of Tracks)

### Machine Learning to Predict Energy Loss (Known Origin)

Features = Helix Fit Params + New Detector Hits+ Track Type + Origin

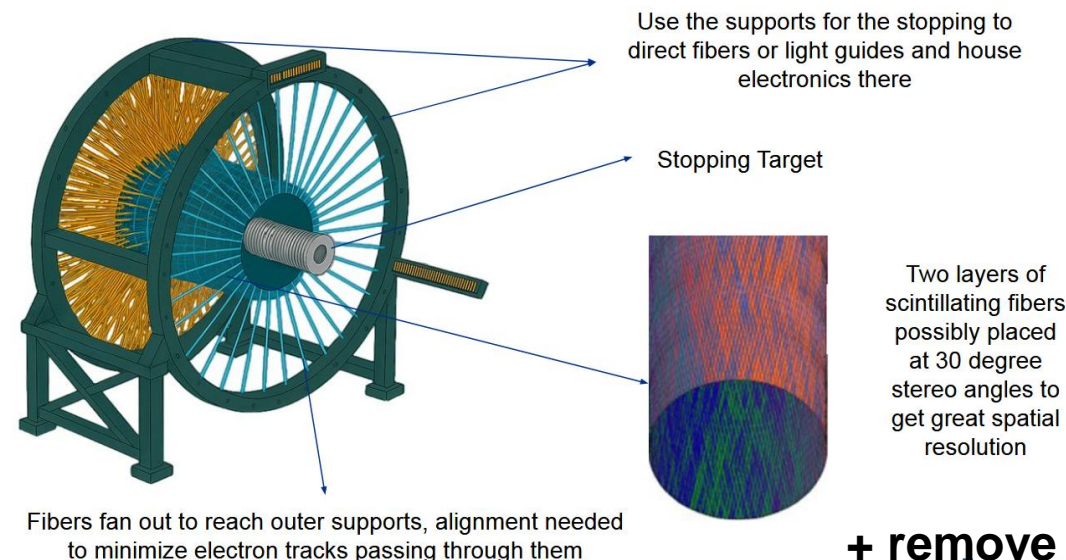


E true Peak: 104.048, FWHM: 0.783  
 E<sub>corrected</sub> Peak: 104.551, FWHM: 0.384



Performance Comparison:  
 Neural Network MAE: 0.3154229553723244,  
 Linear Regression MAE: 0.3605964082072967  
 Percentage Difference = 12.527427286242787%

### Rudimentary Detector Concept: Scintillating Fibers



**+ remove IPA**

**Multidimensional optimization problem (energy loss, proton absorption, resolution gain,...), need dedicated studies to optimize detector concept and assess effect on experimental sensitivity**

## Exploit signal and background kinematics to refine analysis over cut-and-cut analysis

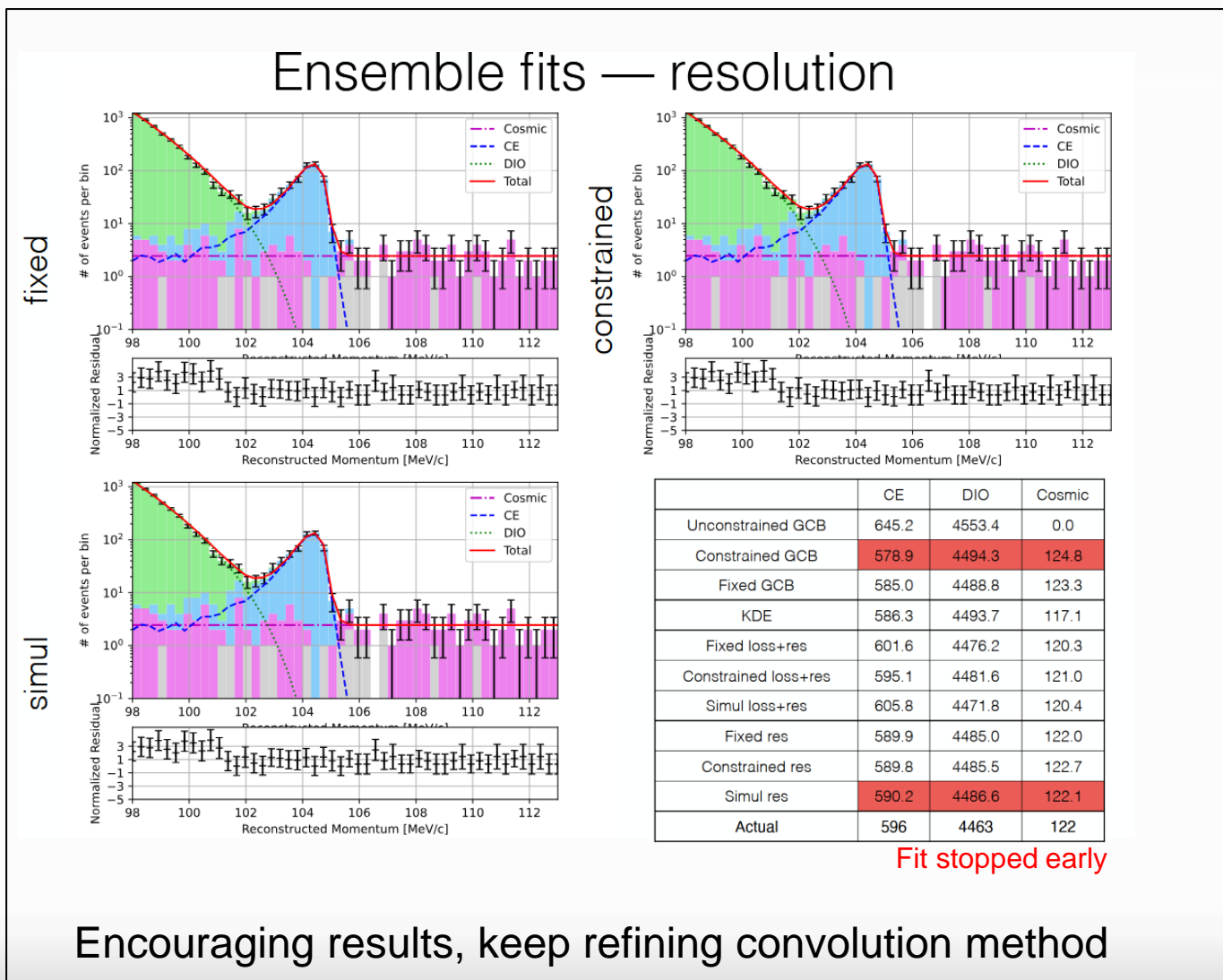
### Many options to explore

#### Shape options

- Analytic (directly model rec. momentum)
  - Simple parametric (double-sided crystal ball or generalized crystal ball)
  - Histogram-like (kernel density estimator)
- Resolution  $\otimes$  'true' momentum
  - Resolution  $\otimes$  particle momentum at surface
  - Loss+resolution  $\otimes$  particle momentum at production

#### Parameter treatment options

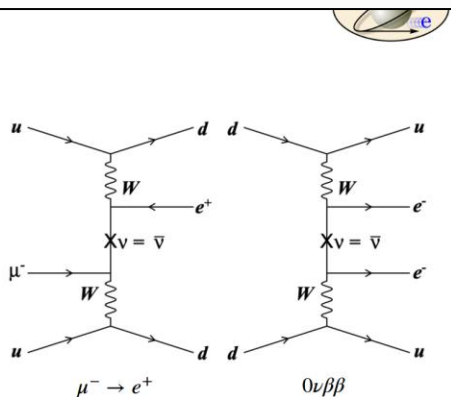
- Float freely
- Fix or constrain within uncertainties from fit to independent sample
- Simultaneous fit to independent sample



## Recent progress on $\mu^- \rightarrow e^+$ analysis

### Motivation cont.

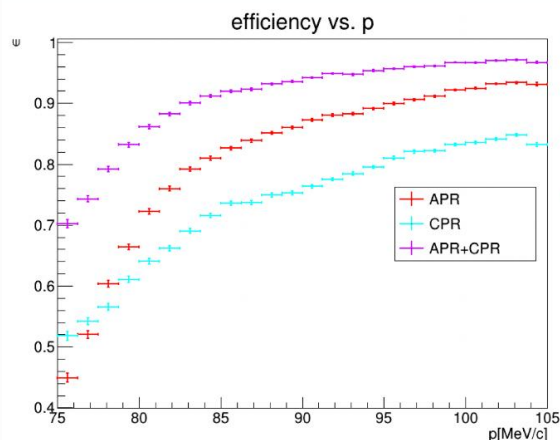
- Because  $0\nu\beta\beta$  involves flavor diagonal terms, and neutrinoless  $\mu^- \rightarrow e^+$  involves flavor off-diagonal terms, it is unlikely for both rates to vanish if LNV is allowed and dominated by neutrino exchange ... thus the search for neutrinoless  $\mu^- \rightarrow e^+$  conversion compliments searches for  $0\nu\beta\beta$
- Searching for neutrinoless  $\mu^- \rightarrow e^+$  conversion allows Mu2e to go beyond being a single search experiment, increasing its scientific impact and potential to probe new physics beyond the Standard Model



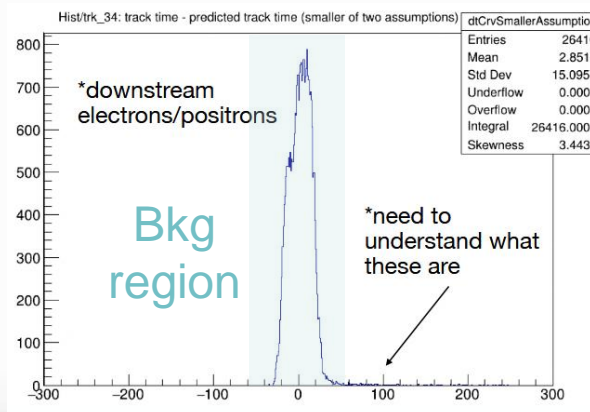
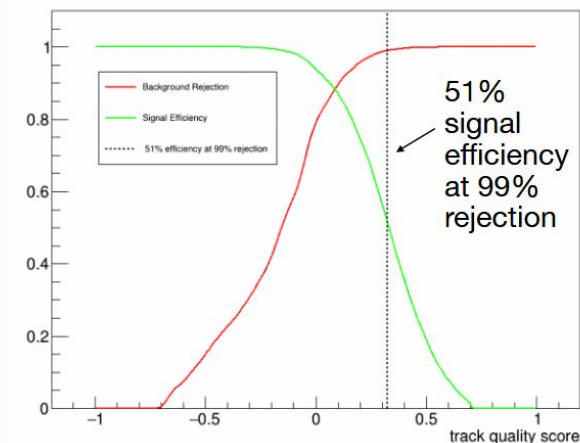
### Analysis update

- Cut and count search with FC
- Assess trigger / track reco efficiency and potential improvement
- Track quality selection (prel. BDT)
- Cosmic background rejection
- RMC is still the big question...

### Trigger efficiency

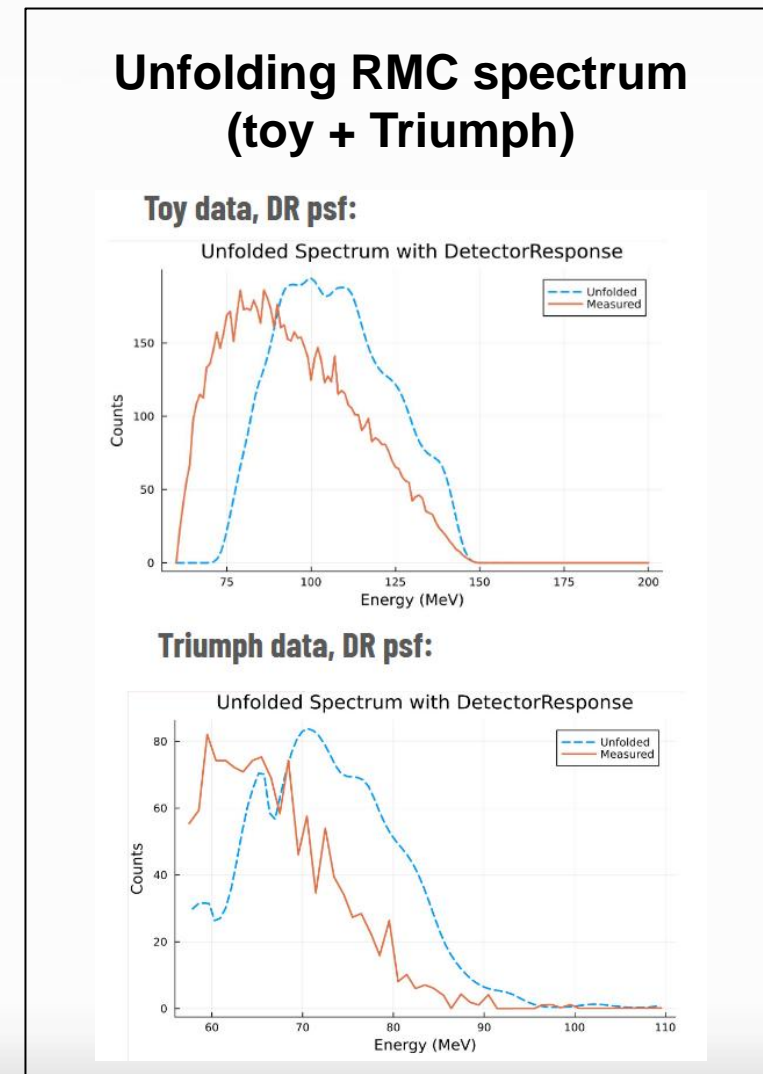
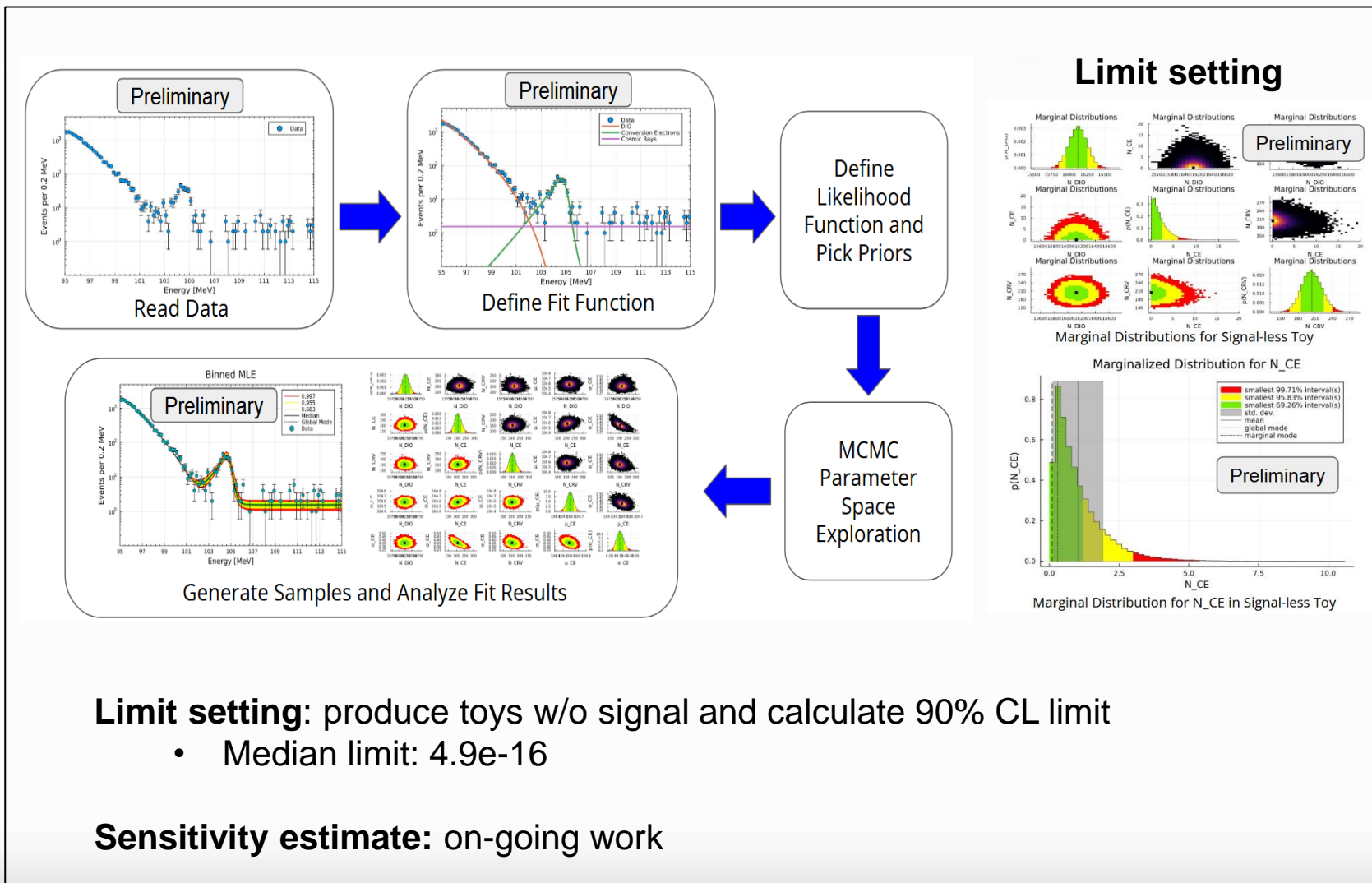


### BDT Track Qual



**One interesting idea:**  
Running at 90% B-field would significantly improve  $\mu^- \rightarrow e^+$  reach w/o impacting  $\mu^- \rightarrow e^-$   
Need to study this further!

## Develop a Bayesian framework in Julia for conversion and RMC analysis



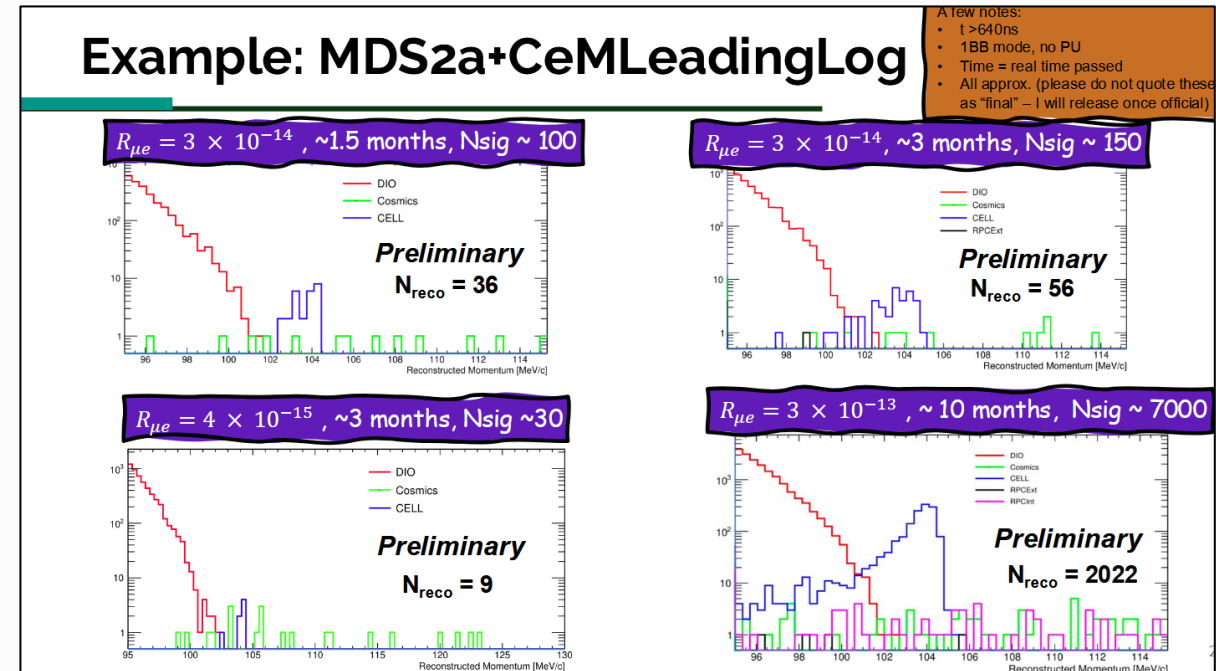
## New Mock data sets – all you ever wanted to analyze your data

New sample with comprehensive set of backgrounds

- Cosmics: used as the standard, cosmic livetime
- RPC: introduce energy cut (already cut on time) to speed things up;
- IPA Michel electron: added as primary (Ed) and removed duplicates from PU stream;
- DIO tail: remove duplicated from PU stream
- RMC: We now have an MDC2020 compatible RMC campaign
- Signals/New physics: new mechanism allows more possible signals to be added and possibility to test blinding

Simplified scripts to generate any livetime and Rmue combo

- Work for all signal scenarios



Last few fixes needed before rolling this out for production and data analysis

**Concluding words**

**Analysis is globally in good shape**

**Focus on setting up Pass 1 infrastructure with minimal functionalities in the near future and keep improving capabilities as more sub-systems get online**

**Increase public discussion of analysis activities**