2019 ECal Gain Calibration, hps-mc, & preselection LDA

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Agenda

1. Ecal calibration for 2019 run
2. Setup of whole hps-mc pipeline (generation to recon) on AlmaLinux
3. Some preliminary preselection analysis results

Agenda

1. **Ecal calibration for 2019 run**
2. Setup of whole hps-mc pipeline (generation to recon) on AlmaLinux
3. Preliminary preselection LDA results

Why revisit ECal calibration?

- To see if there is room for improvement
- No detailed documentation of the calibration process

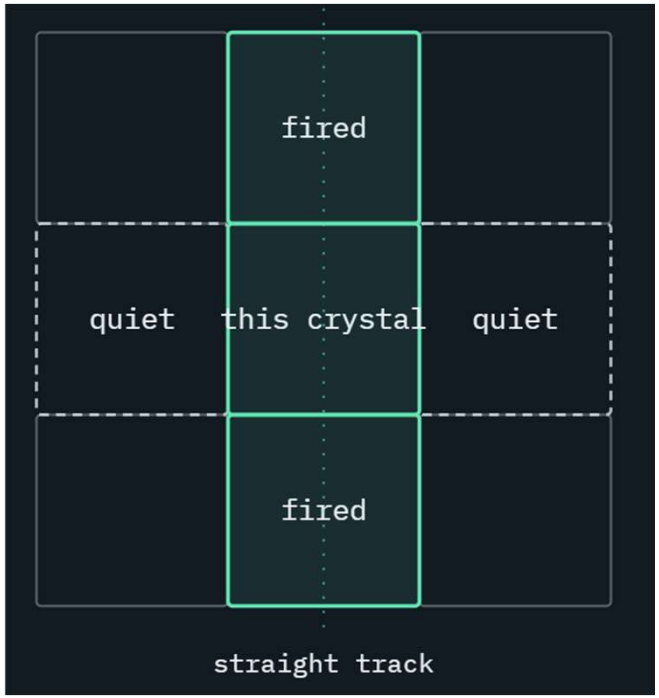
Overall procedure

- Start with cosmic calibration to obtain the **baseline gains**
- Construct **cluster energy distribution** for each seed crystal using FEE clusters
- For each crystal, determine the FEE peak position by **fitting the energy spectrum**
- Repeat the **same procedure for MC**, to determine the FEE peak position
- Compute the **correction factor Peak $_{MC}$/Peak $_{data}$** for each crystal and correct the gains
- **Iterate** until the ratio is close to 1 for all crystal

Cosmic calibration

Cosmic calibration

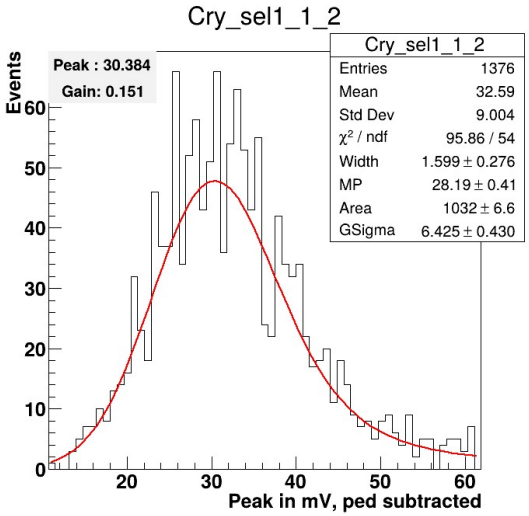
- Runs: `9041, 9044, 9046, 9048, 9064, 9108, 9109, 9175, 9179, 10745, 10748, 10749, 10750`
- Build a pedestal-subtracted, integrated signal from ADC samples for each crystal and fill that crystal's histogram only if
  - `Vertical neighbors fire`
  - `Horizonal neighbors stay quiet`
- Fit each crystal's spectrum with Landau-Gaussian function to find the peak position

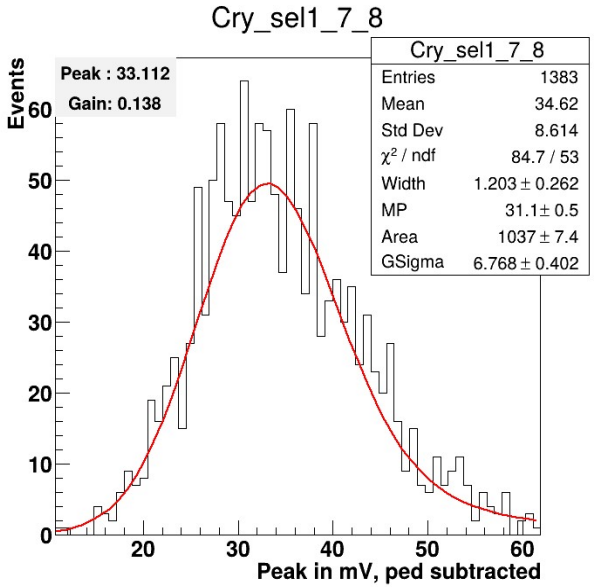


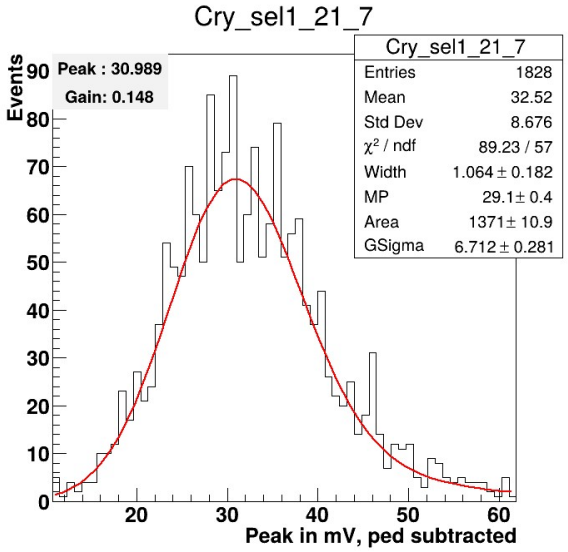
Cosmic calibration

For each crystal:

$$\text{Gain} = \frac{18.3\ \text{MeV}}{\text{Peak}} \times \text{ADC2V} \quad \left[\frac{\text{MeV}}{\text{ADC}}\right], \text{ where ADC2V} = 0.25\ \frac{\text{mV}}{\text{ADC}}$$







FEE corrections

MC and data used

- MC:
  - `hpsForwardFullEnergyElectrons_*_QGSP_BERT_HPS-PhysicsRun2019-v1-4pt5_recon.slcio`
    (nowhere to be found on JLab)

- Data:

  2019 FEE skimmed runs (10022 to 10740)

  JLab location: `/mss/hallb/hps/physrun2019/production/evio-skims/fee`

Run periods and gain drift

- ECal temperature was not stable across the full 2019 run & chiller problems caused the FEE peak in the same crystal to be different across different runs.
- Calibrating the whole run range as one block would smear together different detector responses. So, the runs were split into 6 temperature-stable windows, calibrated independently of each other.
- A linear drift in the FEE peak position was noticed as function of run number in the longer period 6. For the rest of the periods, this effect wasn't noticeable because of shorter length.

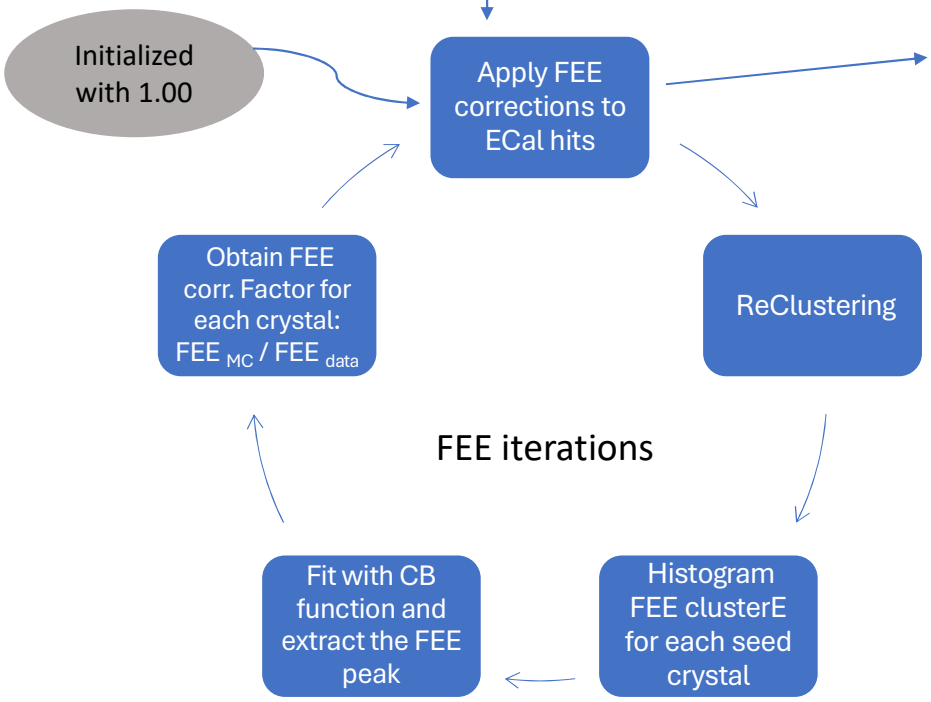
Table 1: 2019 FEE calibration run periods

Period	Run range used	# runs	Runs excluded
1	10030–10064	10	10022, 10028
2	10065–10069	4	10070
3	10072–10084	8	10071, 10085
4	10087–10093	5	–
5	10101–10115	6	–
6 (Golden)	10116–10740	221	–

FEE corrections

`Reconstruct raw data with the baseline gains`

`Correct gain drift (run dependence in period 6)`



$$\text{Final Gains} = \text{cosmics} \times \text{FEE corrections from final iteration}$$

FEE Selection:

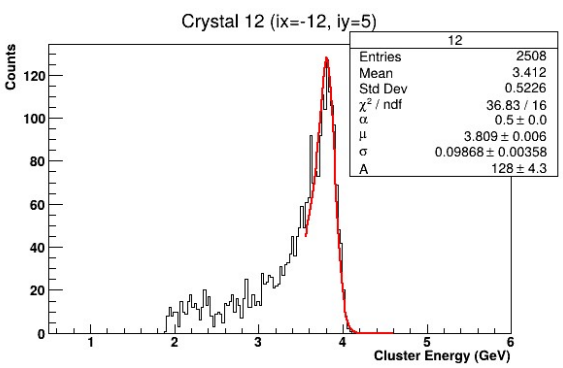
- Only uses the ecal information. No tracking info is used
- The cuts used to get the FEE histograms per crystals (*hps-java*):

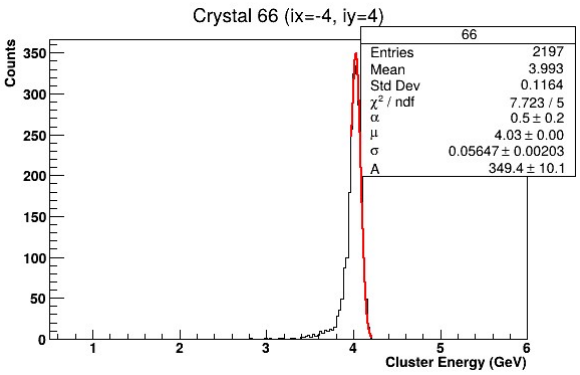
  `clusterE > 2.0 GeV && seedE/clusterE > 0.6`
- Post-fit cuts to discard bad fits (*HPS-CODE*):

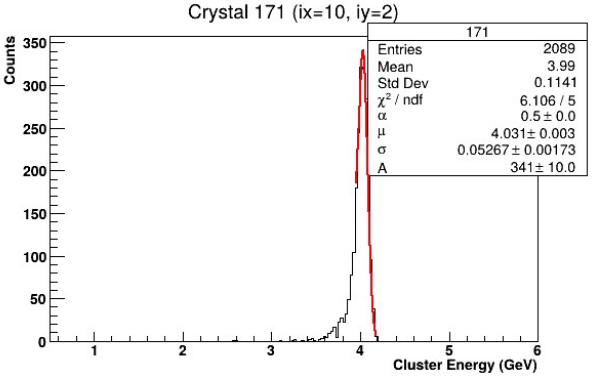
  `Min. entries > 1000 && sigma < 0.24`

Example fits

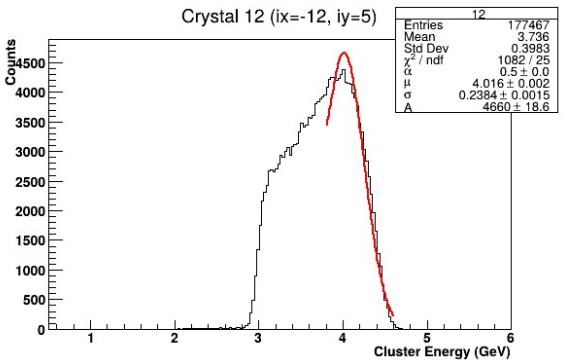
MC

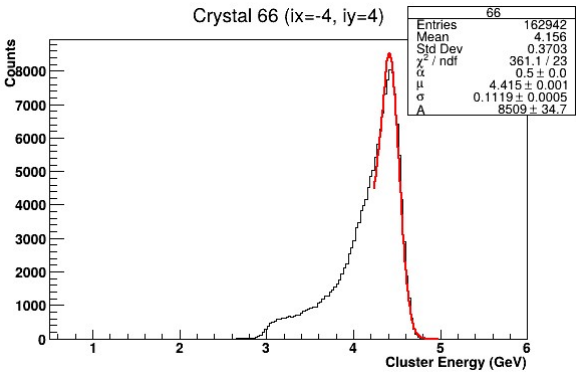


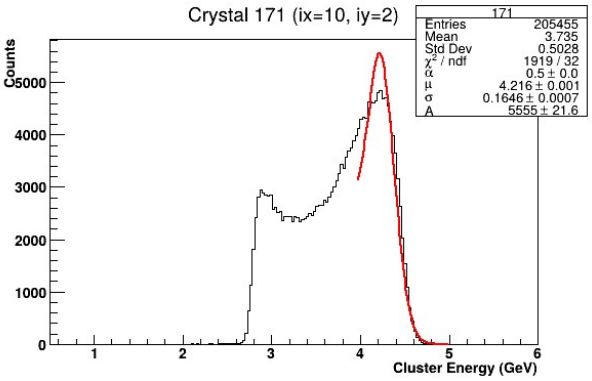




Period 6 data with no corrections



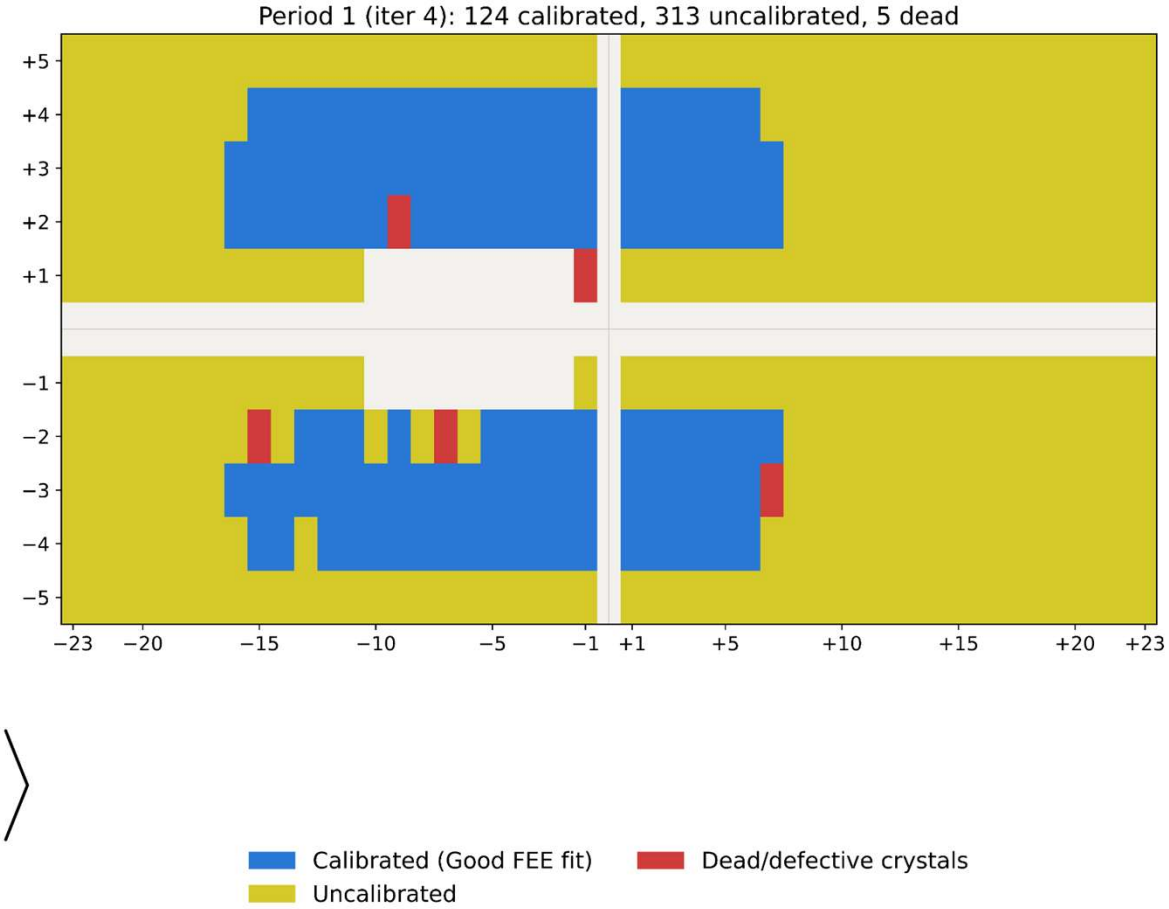




Uncorrected crystals?

- Roughly ~30% crystals are calibrated this way on average across all 6 periods
- Uncorrected and corrected crystals are at two different scales
- Correction factor for the uncorrected crystal is given as:

$$\text{correction factor} = \left\langle \frac{\text{corrected gains}}{\text{baseline gains}} \right\rangle$$



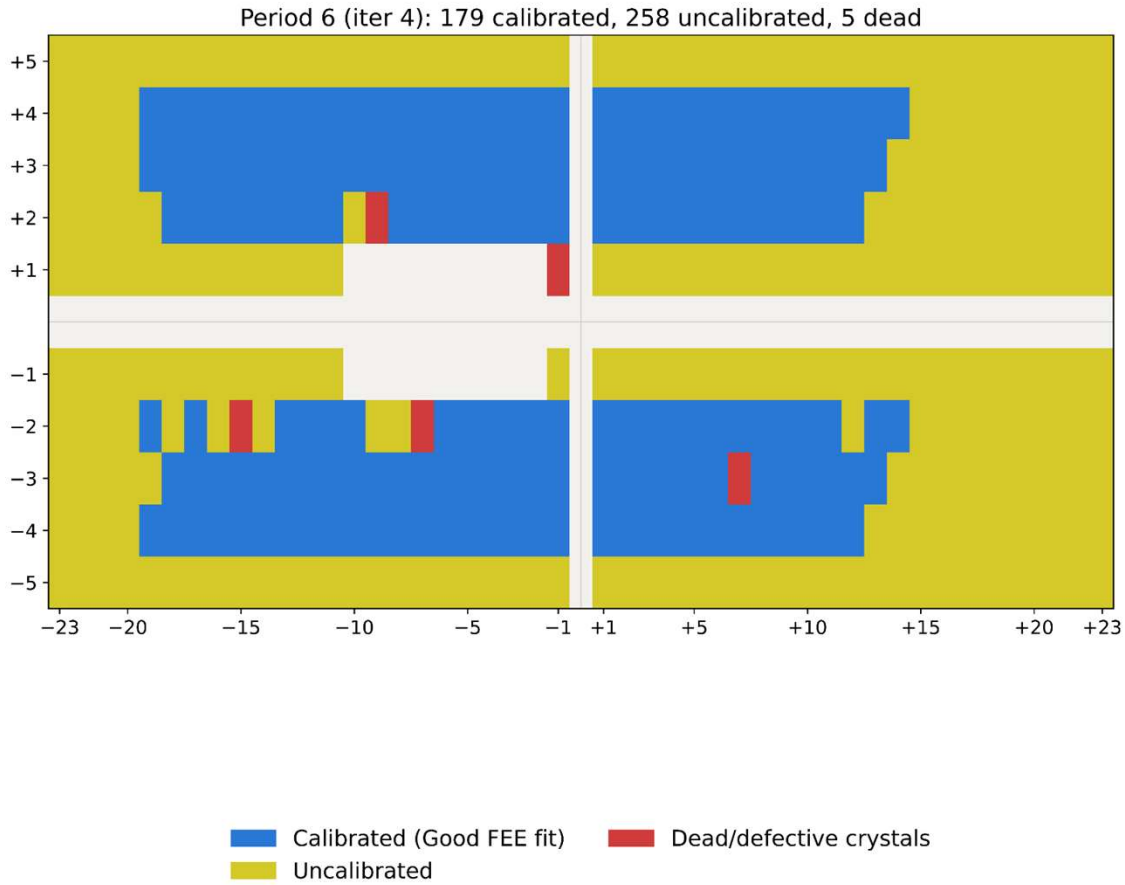
Uncorrected crystals?

- Roughly ~30% crystals are corrected this way on average across all 6 periods

- Uncorrected and corrected crystals would be at different scales if we leave them at baseline cosmics.

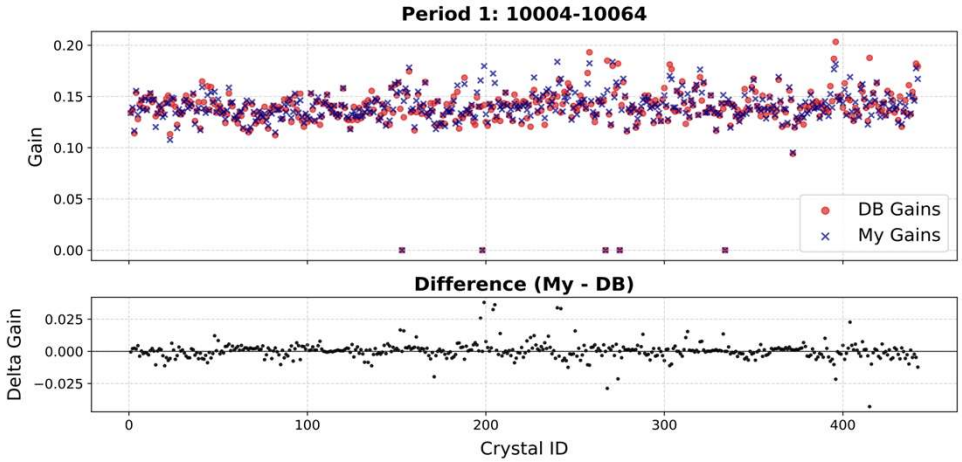
- Correction factor for the uncorrected crystal is given as:

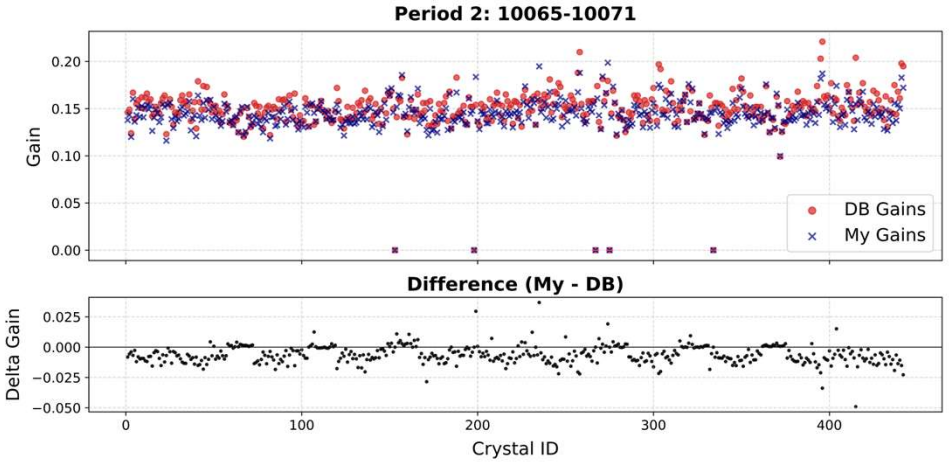
$$\text{correction factor} = \left\langle \frac{\text{corrected gains}}{\text{baseline gains}} \right\rangle$$

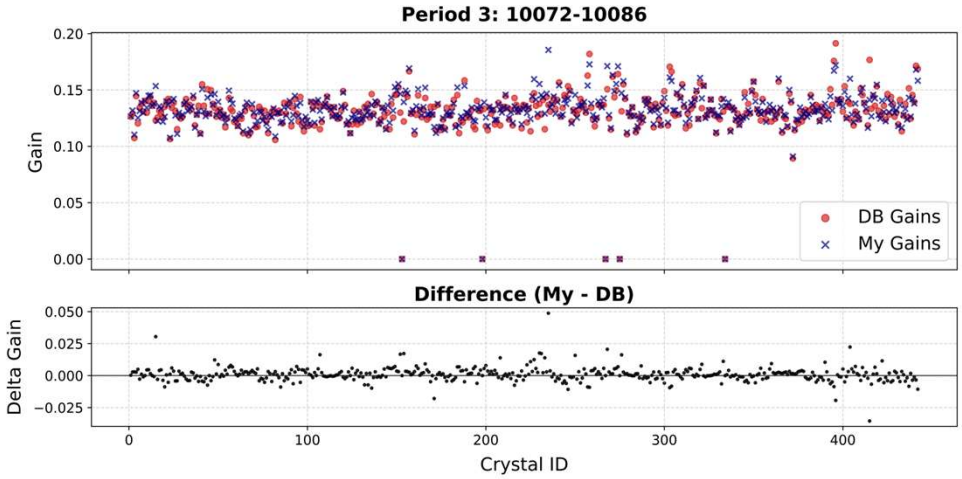


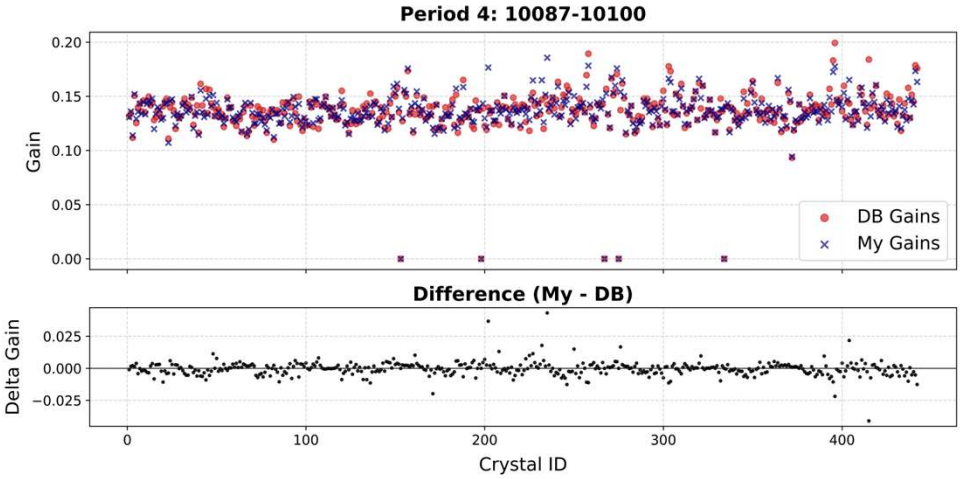
Results

New gains vs hps-db gains (MeV/ADC)

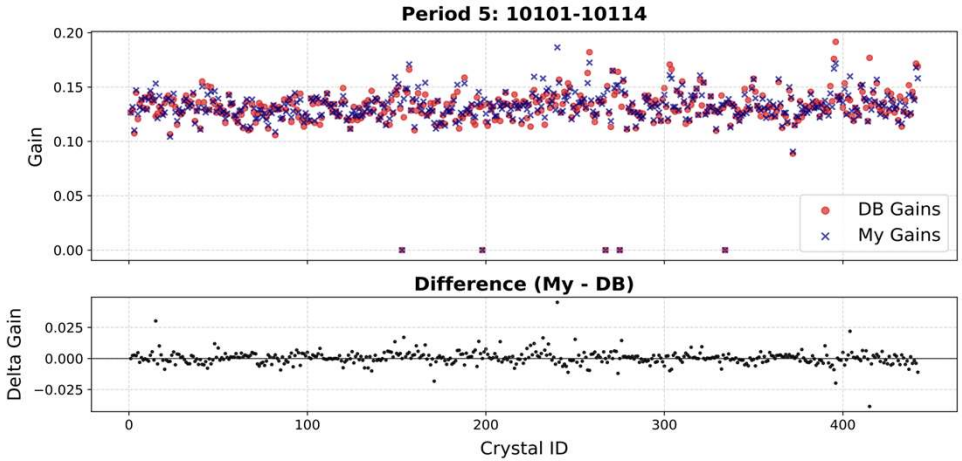


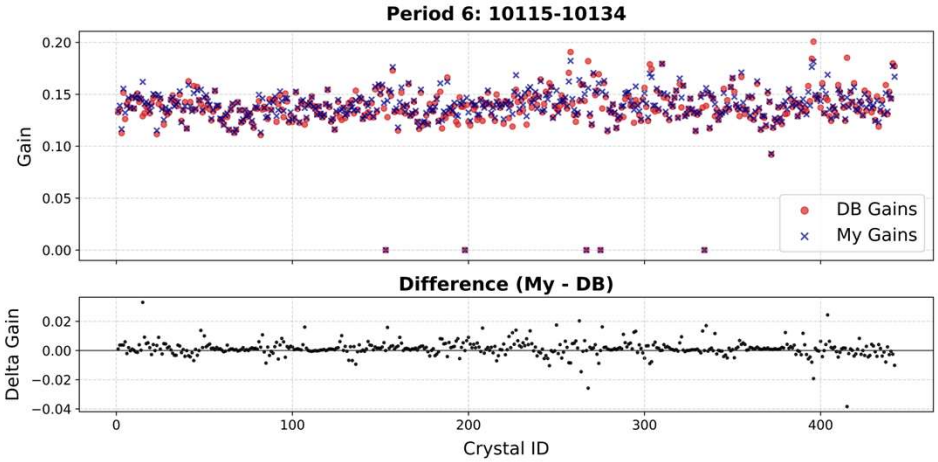


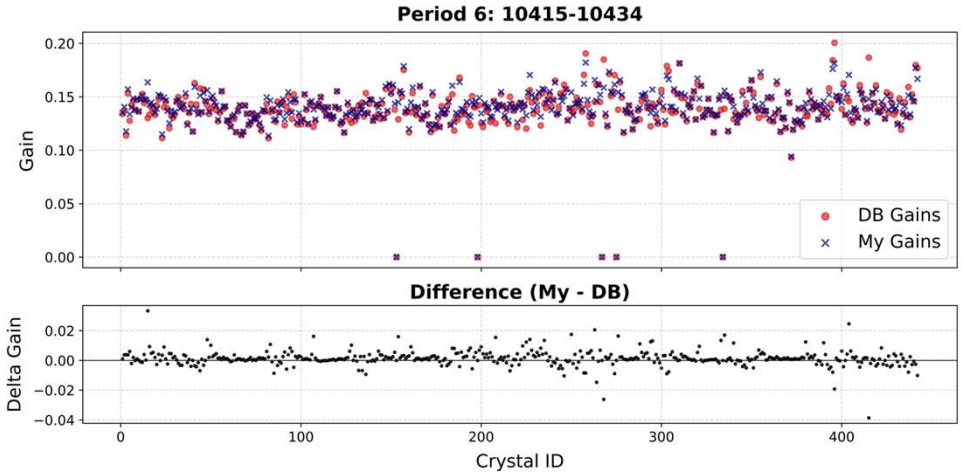


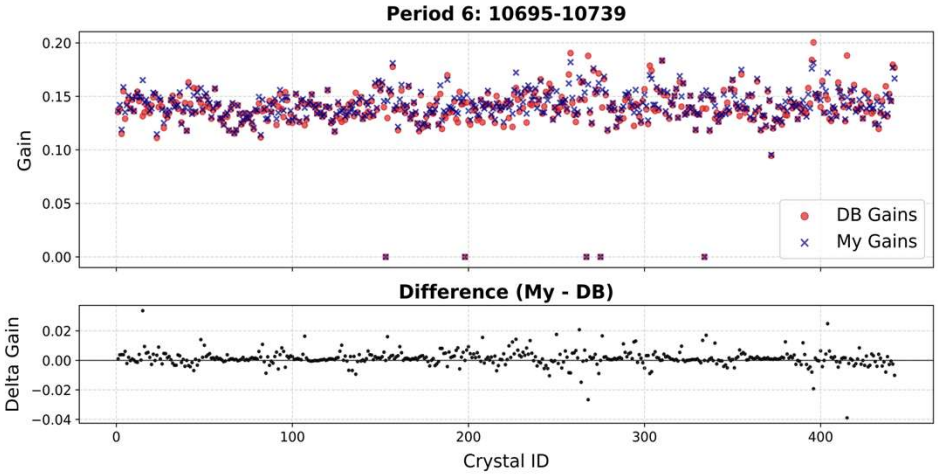


New gains vs hps-db gains









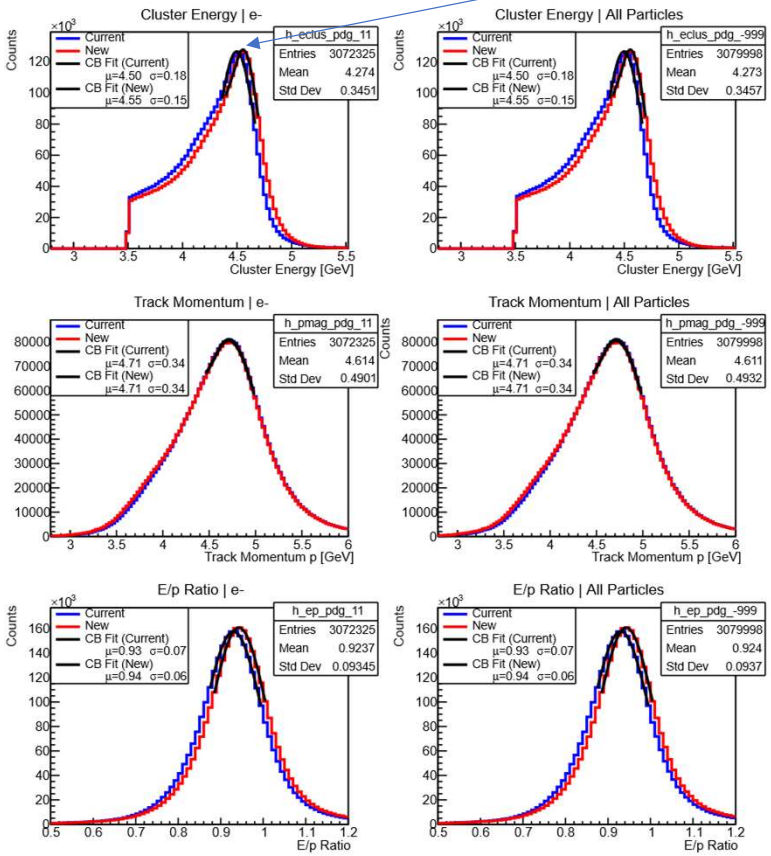
FEE peak test

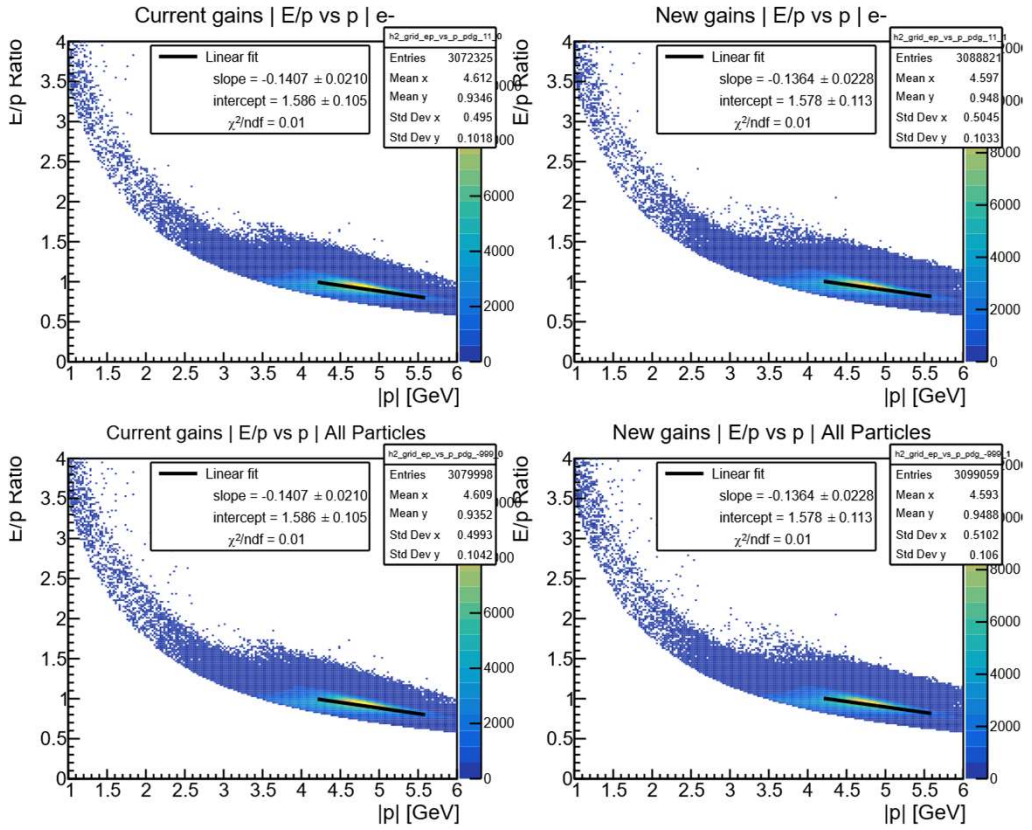
- I reconstructed the same FEE skimmed runs with the new gains and the current DB gain for comparison, to see where the FEE peak and the E/p ratio lands.
- FEEs selection:
  - `Only one cluster with E>3.5 GeV, Eseed/Etot > 60%`
  - `Fiducial region`

FEE peak and E/p

New gains shift the FEE peak 50MeV closer to the beam energy. It's a 1% difference.

E/p has a small slope of ~0.14





Summary

- Reproduced the ecal calibration with 1% difference from the existing one
- FEE peak is closer to the beam energy with the new calibration
- Minimum cluster energy threshold is the reason for this difference
- E/p vs. p is not constant

Resources

- Followed these slides from Andrea from 2019
- hps-ecal-calibration repo contains all the scripts
- Detailed note documenting the whole process

Agenda

1. Ecal calibration for 2019 run
2. **Setup of whole hps-mc pipeline (generation to recon) on AlmaLinux**
3. Preliminary preselection LDA results

Why bother?

- Currently, MC pipeline is split between SLAC and JLab
- Generation is done at SLAC and the rest happens at Jlab
- Setting up the whole pipeline at one place would make it easier to generate MC

Samples produced, and their setup

A′ · MadGraph5 3.3.2	**Tritrig · MadGraph5 2.4.2**	**WAB · MadGraph5 3.3.2**
With pulser: 12 masses, 30–200 MeV Without pulser: 50, 100, 150, 200 MeV	With pulser Without pulser	With pulser

Detector	HPS_Run2021Pass1_v9_14272
Run	14272
Conditions DB	local SQLite: hps_conditions_11102025_moller_5.db
hps-java	5.3.1-SNAPSHOT, commit 4d47d0383 Oct 6 2026 · Matthew Gignac
hps-mc	commit 2c62b2db Oct 1 2026 · Matthew Gignac
SLIC / Geant4	Geant4 10.6.3

```
{
  "run_params": "3pt74",
  "beam_energy": 3740.0,
  "target_x": 0.0,
  "target_y": 0.0,
  "target_z": -1.1,
  "target_thickness": 0.002,
  "num_electrons": 1500,
  "bunches": 10000,
  "beam_sigma_x": 0.055,
  "beam_sigma_y": 0.045,
  "beam_rot_x": 0.0,
  "beam_rot_y": 0.0305,
  "beam_rot_z": 0.0,
  "apmass": <xxx>,
  "ap_decay_dist": "lhe_uniform"
}
```

Job parameters (JSON). apmass and ap_decay_dist: A′ only; the seed is set per job.

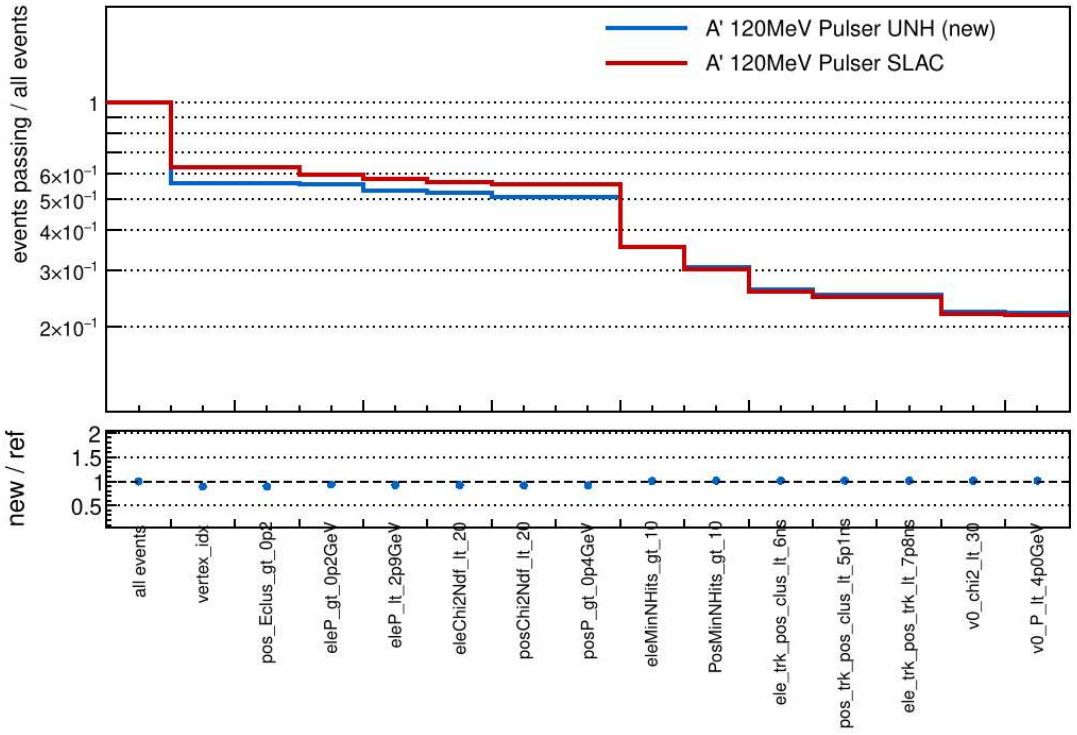
Steering files

Step	Used for	Steering file
Overlay	pulser samples	/org/hps/steering/readout/Overlay.lcsim
Readout	pulser samples	/org/hps/steering/readout/PhysicsRun2021TrigSinglesWithPulserDataMerging.lcsim
Readout	no-pulser samples	/org/hps/steering/readout/PhysicsRun2021TrigMultiSingles.lcsim
Recon	all samples	/org/hps/steering/recon/ PhysicsRun2021MCRecon_KF_WithSpacing_pass5_physics_HitSmear_HitKill_14272.lcsim

Yields and run time

Sample	Generated events / job	Recon events / job	Yield (Recon / generated)	Time / job	Total events
A’ + pulser	25k	~890 (30MeV) to ~7960 (150 MeV)	3.6% (30 MeV) to 31.8% (150 MeV)	~70 min	0.5M per mass
A’, no pulser	10k	~1110 (50 MeV) to ~3210 (150 MeV)	11% (50 MeV) to 32% (150 MeV)	~25 min	0.5M per mass
Tritrig + pulser	75k	~1650	2.2%	~60 min	0.99M
Tritrig, no pulser	100k	~2130	2.1%	~68 min	1.01M
WAB + pulser	500k	~280	0.057%	~2.2 h	0.1M

A′ 120 MeV + pulser: UNH (pass5_v9) vs SLAC (pass6_v10)



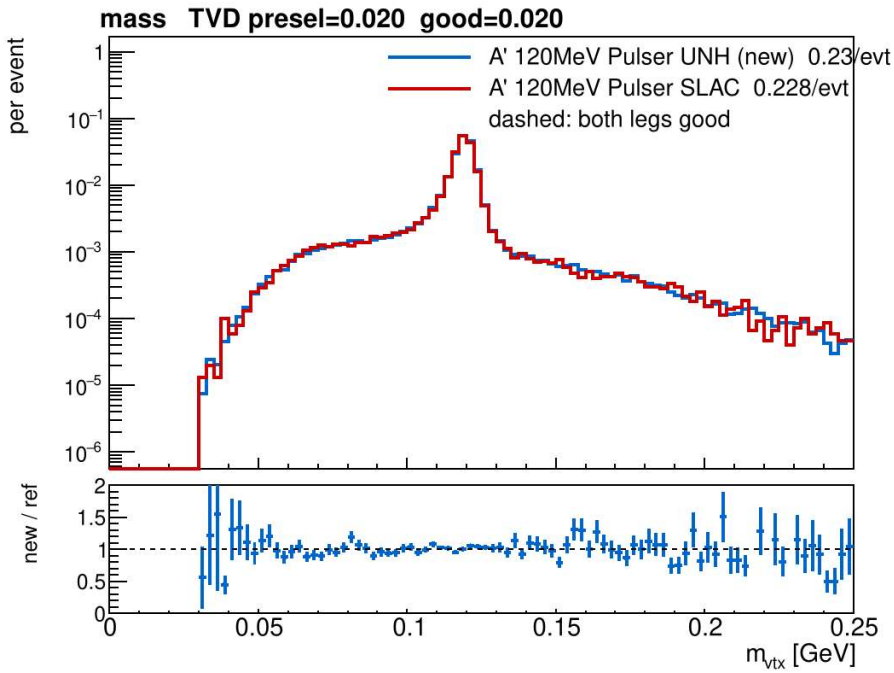
Same vertex preselection on both samples (0.54M vs 0.15M events)

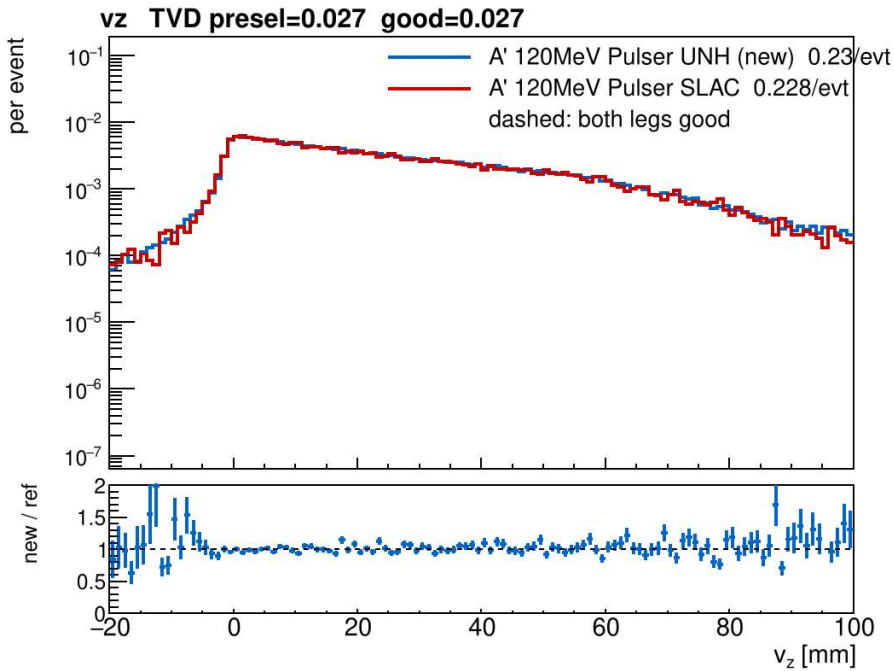
Before the ≥ 10-hit cuts: SLAC sample has more events with a V0 candidate (0.63 vs 0.56)

From the hit cuts on: agree within ~1%

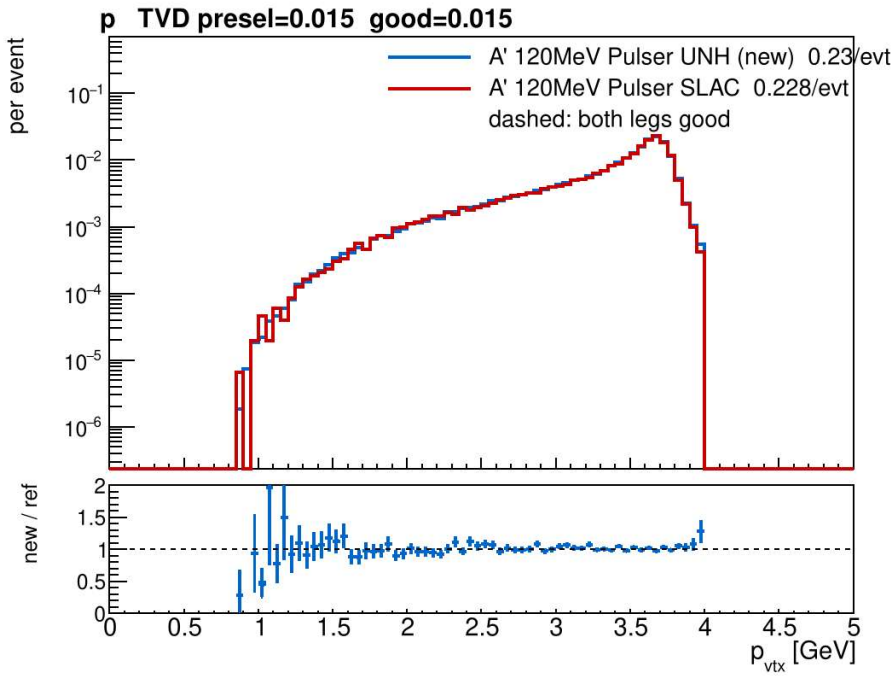
After preselection: 0.230 vs 0.228 vertices per event

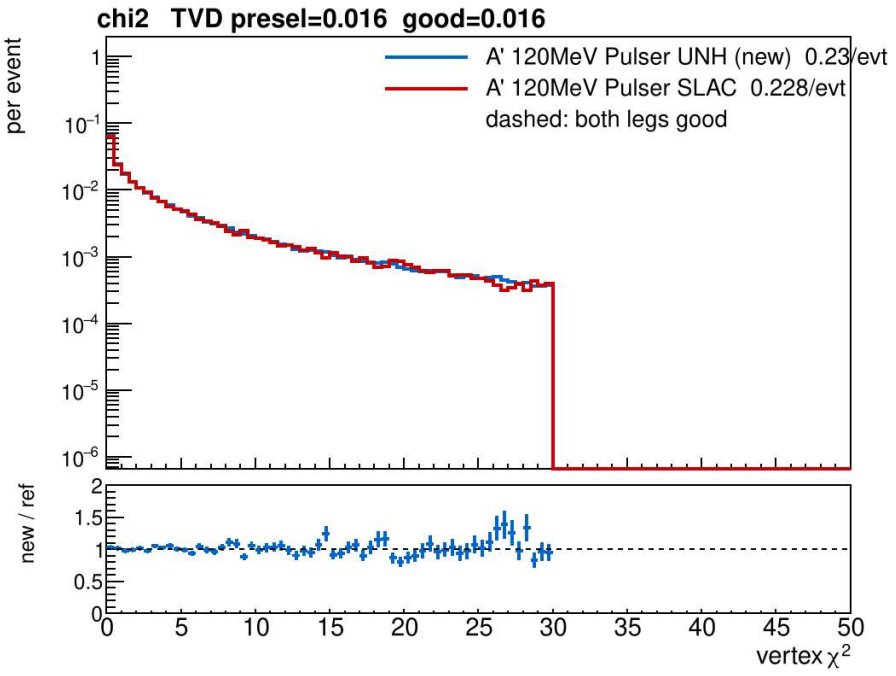
After preselection: vertex mass and z



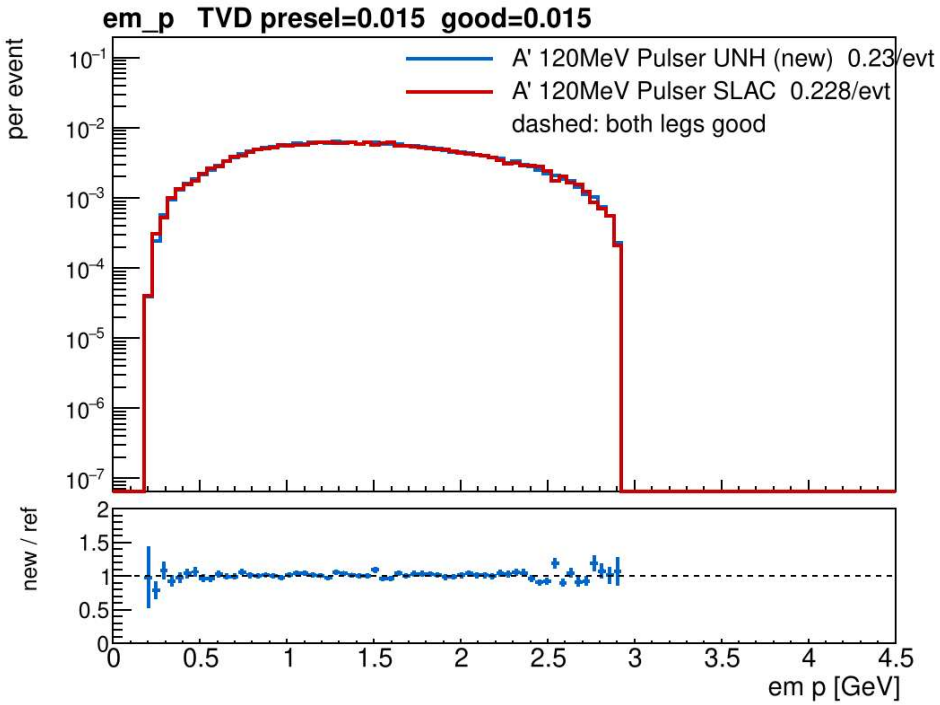


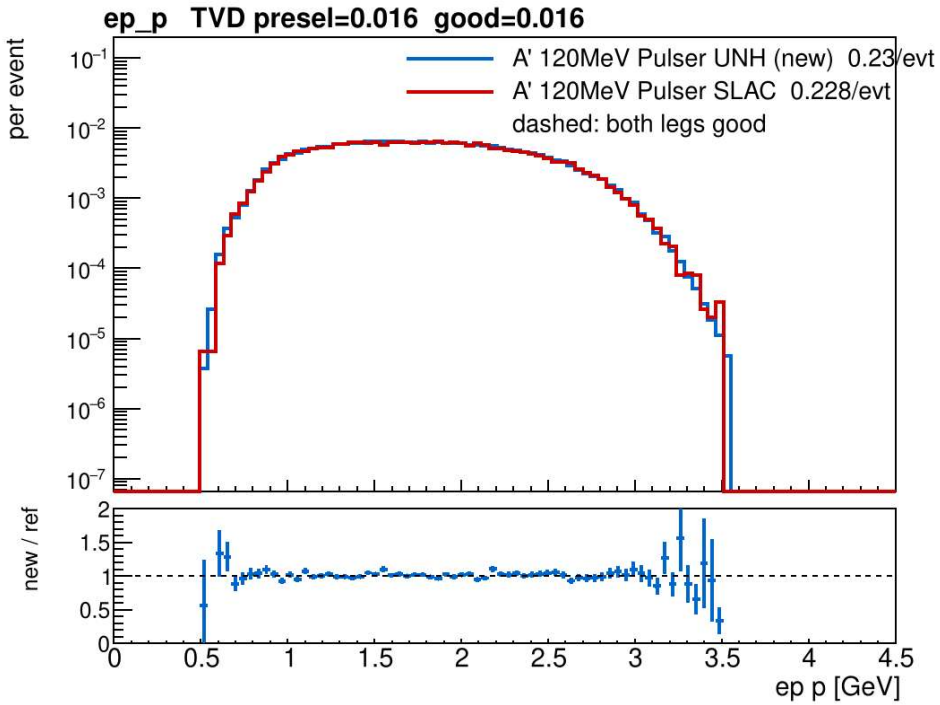
After preselection: vertex momentum and χ^2



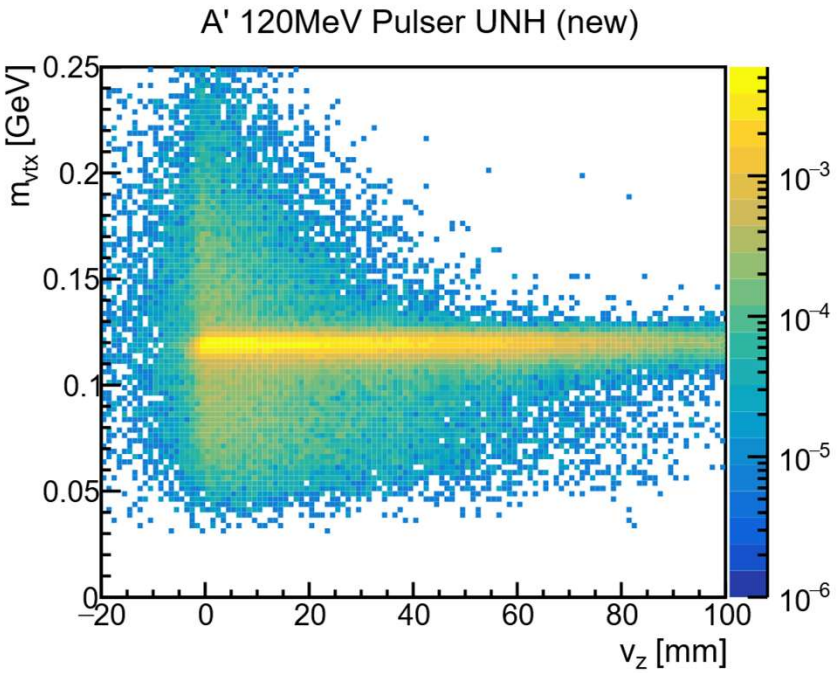


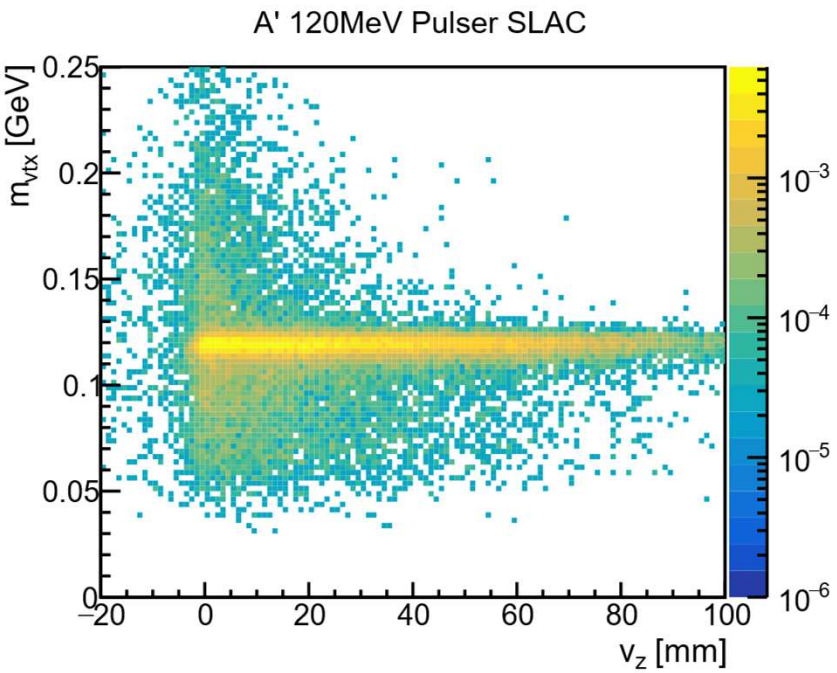
After preselection: electron and positron momenta





After preselection: mass vs. v_z





Problems/solutions

- What job file parameters to use?
- What DB to use?
- What steering files steering files to use (for pulser/pure processes)?
- Software versions?
- How it changes for different run periods?
- **Solution:**
  - Replace the older/incorrect examples in the repo with new/latest ones
  - Add a functionality in hps-mc that would automatically generate a log file in the output directory with all the config, job parameters, sw versions etc.

Agenda

1. Ecal calibration for 2019 run

2. Setup of whole hps-mc pipeline (generation to recon) on AlmaLinux

3. **Preliminary preselection LDA results**

Motivation

- Question: can the current preselection keep more A′ signal for the same background?
- Samples (pulser overlay, run 14272): A′ 30–200 MeV (12 masses), tritrig, WAB
  - Background = tritrig + WAB weighted by their cross-section
- Cross-check: preselection reproduces the 2021 analysis note values (Table 39)

First attempt: PCA

- Principal component analysis (PCA) finds the directions in which the data vary the most
- It is unsupervised: it never sees which vertex is signal and which is background
- Largest variation ≠ best separation
- Vertex momentum alone already does better
- PCA does not give a better selection

Why LDA?

- LDA (Linear Discriminant Analysis) is supervised: it uses the labels
- It asks a different question than PCA:
  - PCA: which direction has the most spread?
  - LDA: which direction pulls signal and background furthest apart?
- Output: one number per vertex (the LDA score), a weighted sum of the input variables
- **Simple, linear, and the weights are readable**

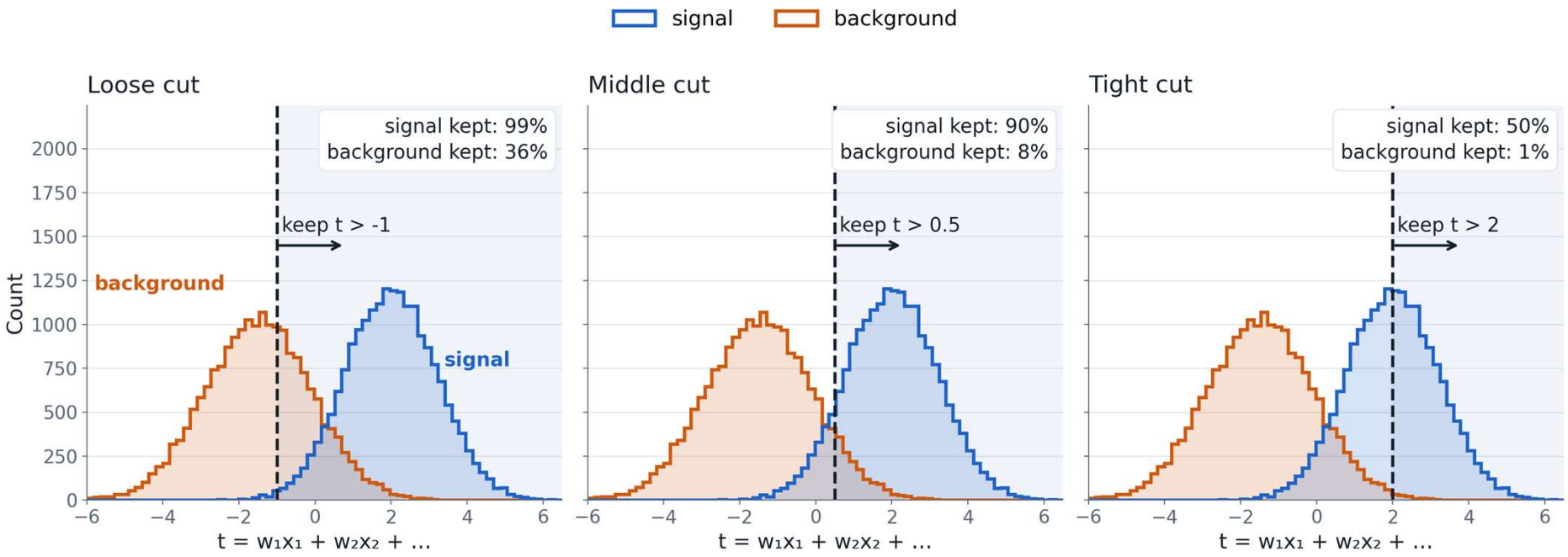
How it works

- Inputs: the variables the preselection already cuts on (momenta, χ^2, hits, track–cluster times, …)
- 1. Compute the means: μ_{sig}, μ_{bkg}
- 2. Compute the spread inside each class (within-class covariance S_W)
- 3. Weight vector $w = S_W^{-1} (\mu_{sig} - \mu_{bkg})$
  - Far-apart means → large weight
  - High spread or correlated variables → down-weighted
- 4. $Score = w \cdot x$ | keep vertices with score above a threshold

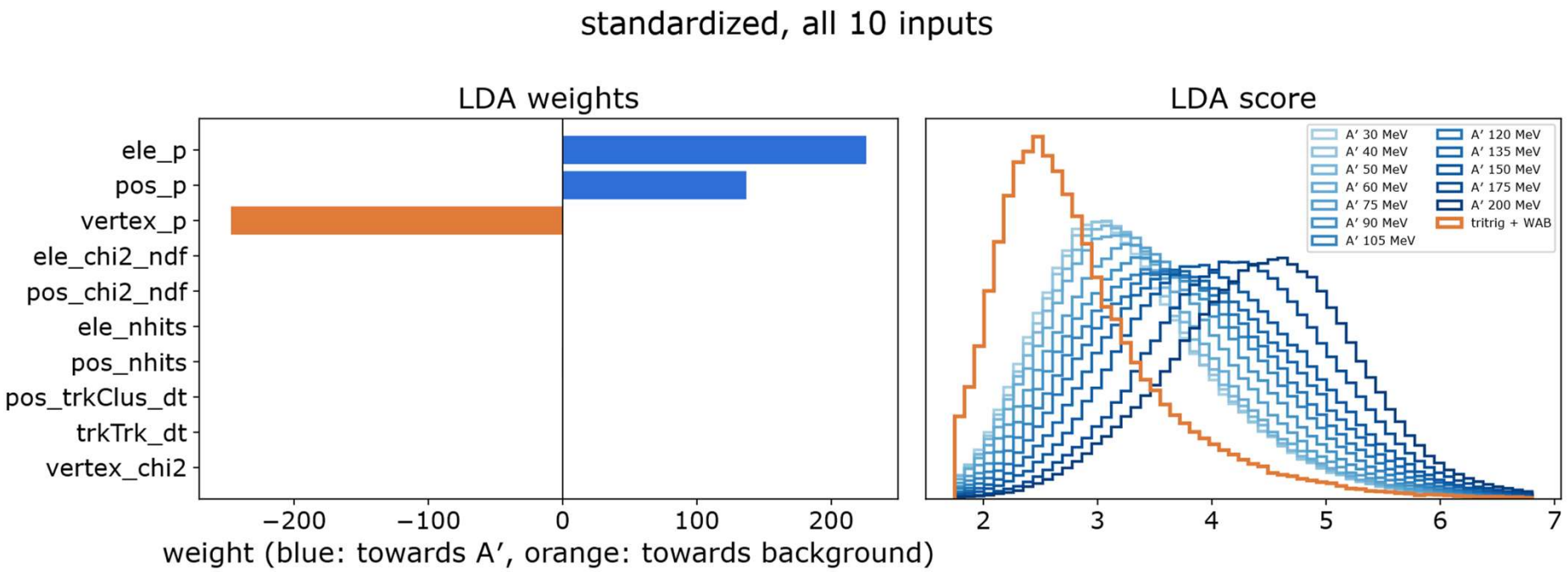
LDA score and cut

We choose where to cut:

$$t = \mathbf{w}.\mathbf{x} = w_1 x_1 + w_2 x_2 + ... w_n x_n$$



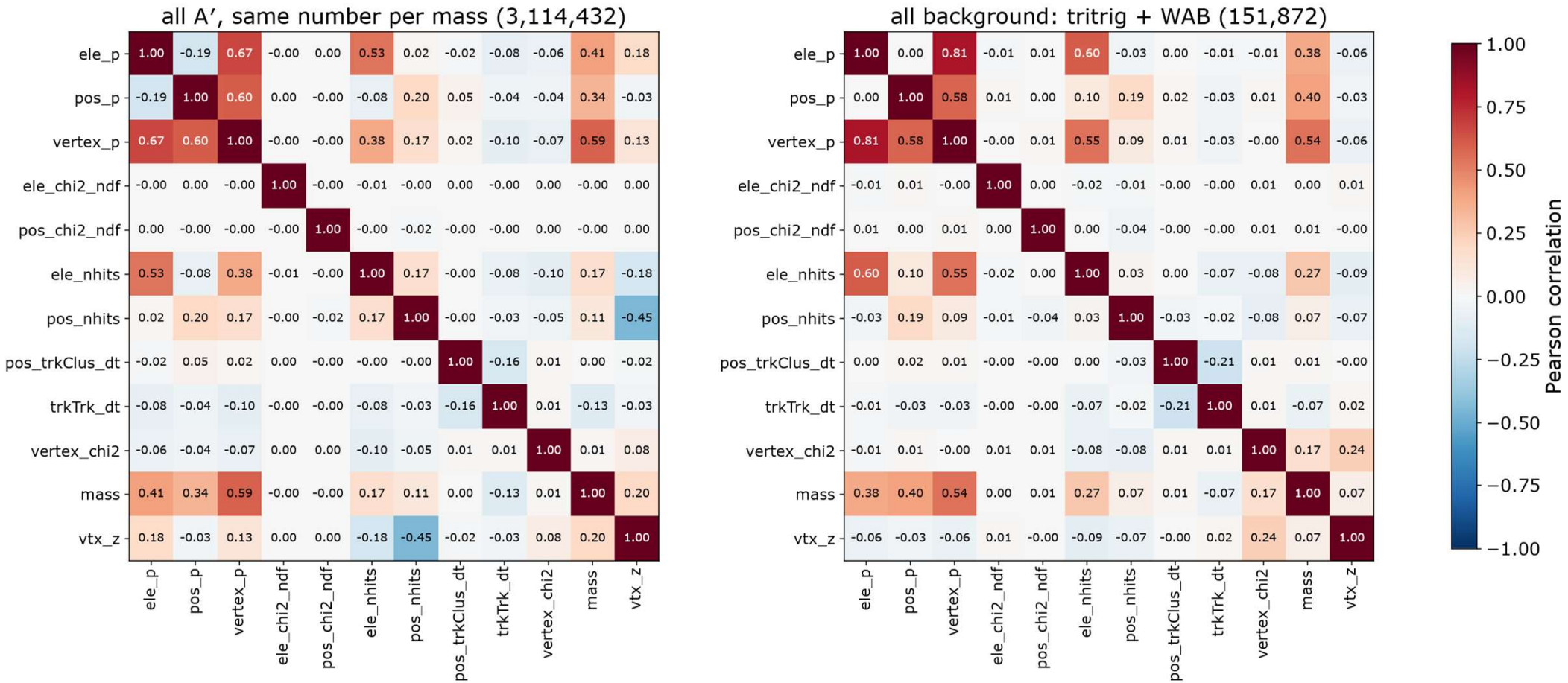
Running naively, it learns the invariant mass



Left: weights (blue → A′, orange → background).

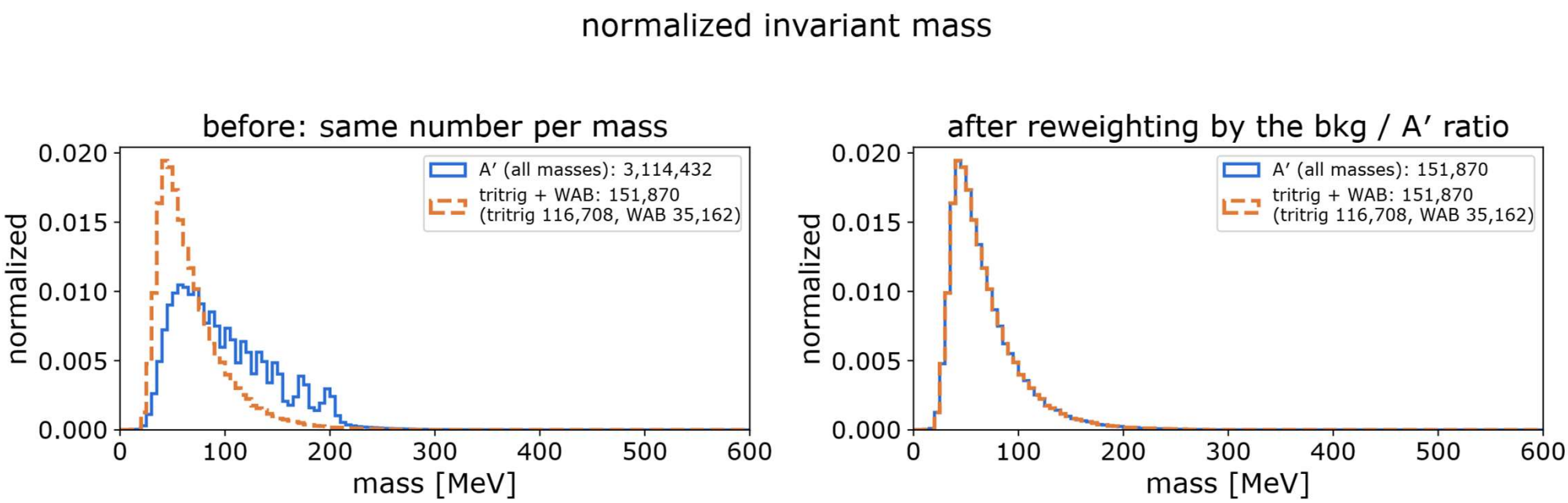
Right: LDA score, A′ masses (blue) vs tritrig + WAB (orange).

Running naively, it learns the invariant mass



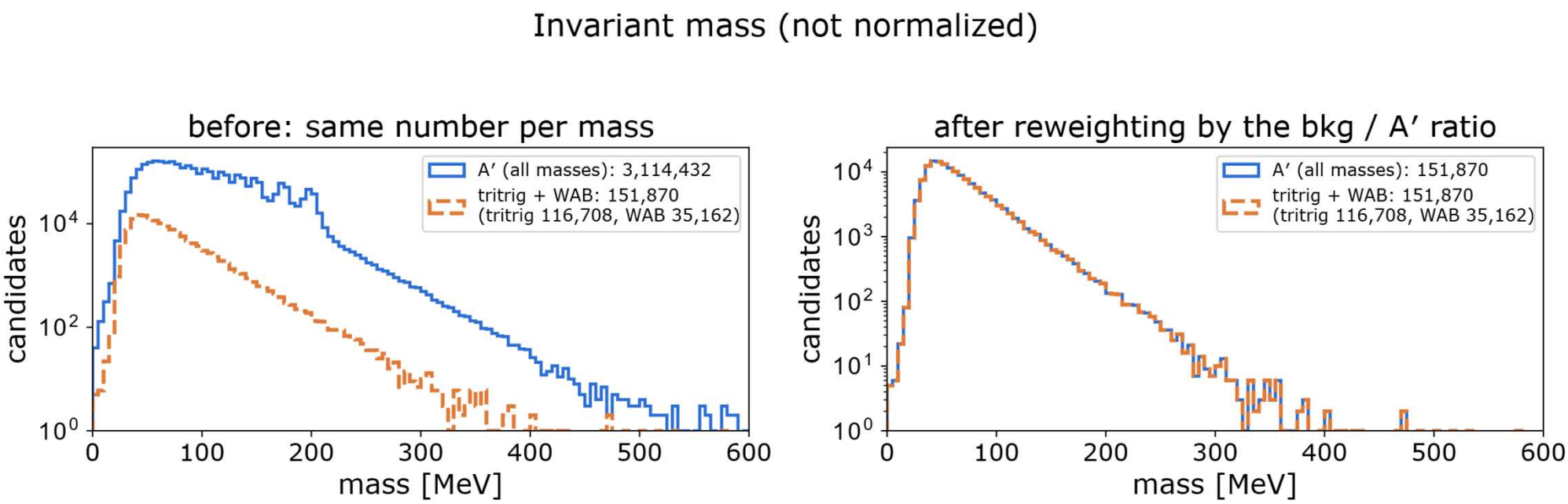
How to be mass agnostic?

- Get rid of vertex_p
- Rescale signal mass distribution to match background mass distribution

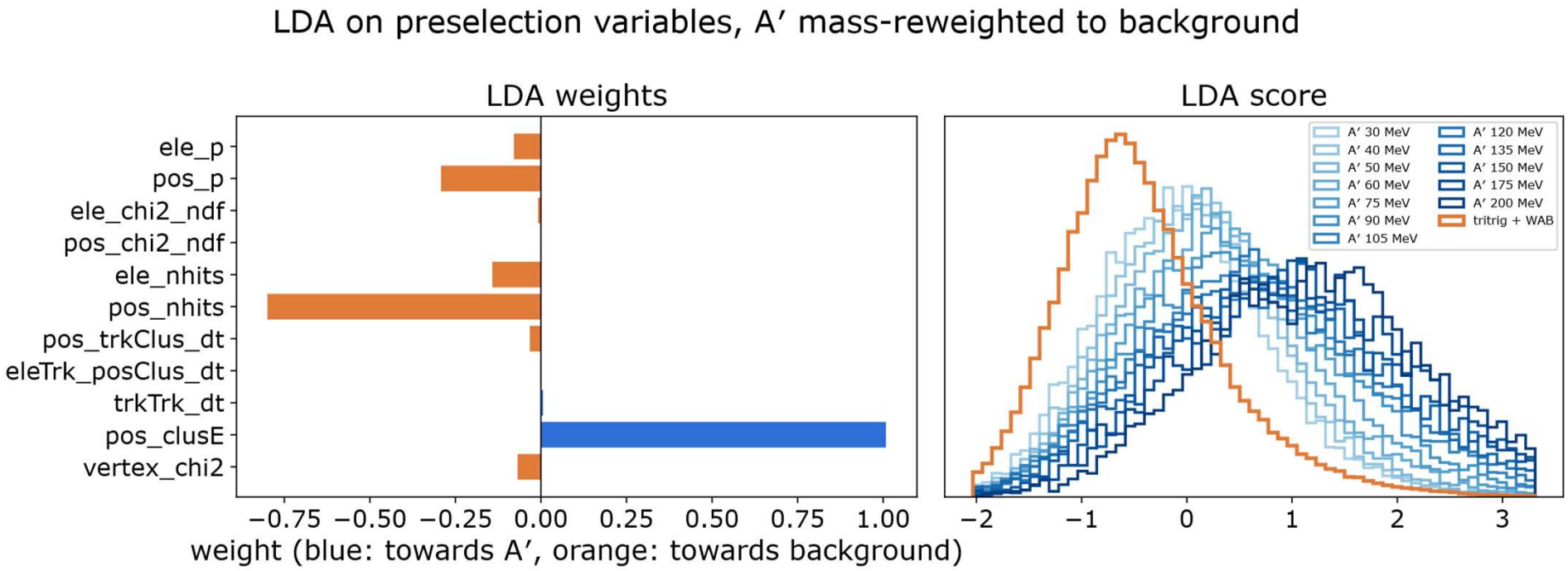


How to be mass agnostic?

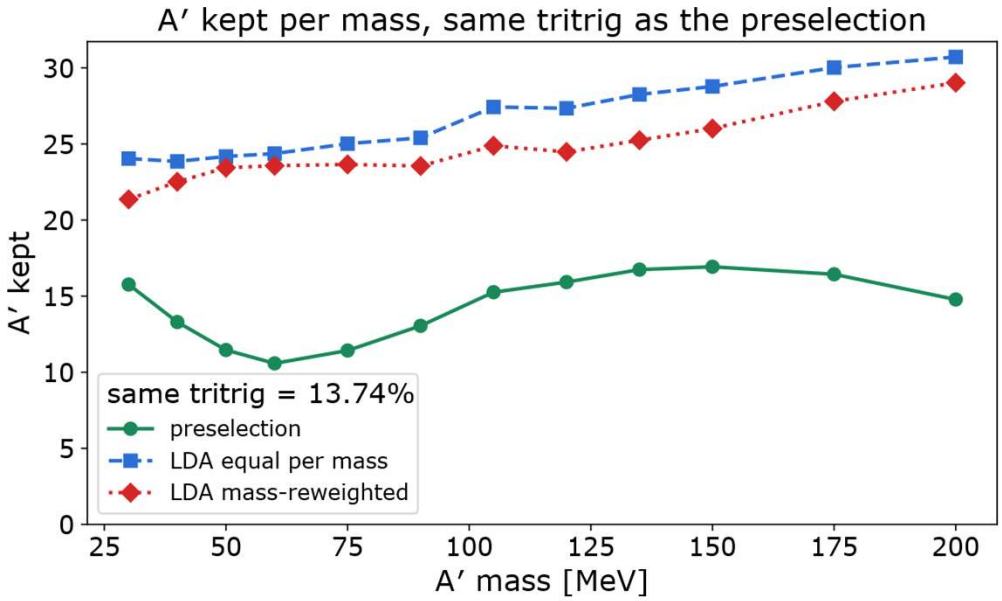
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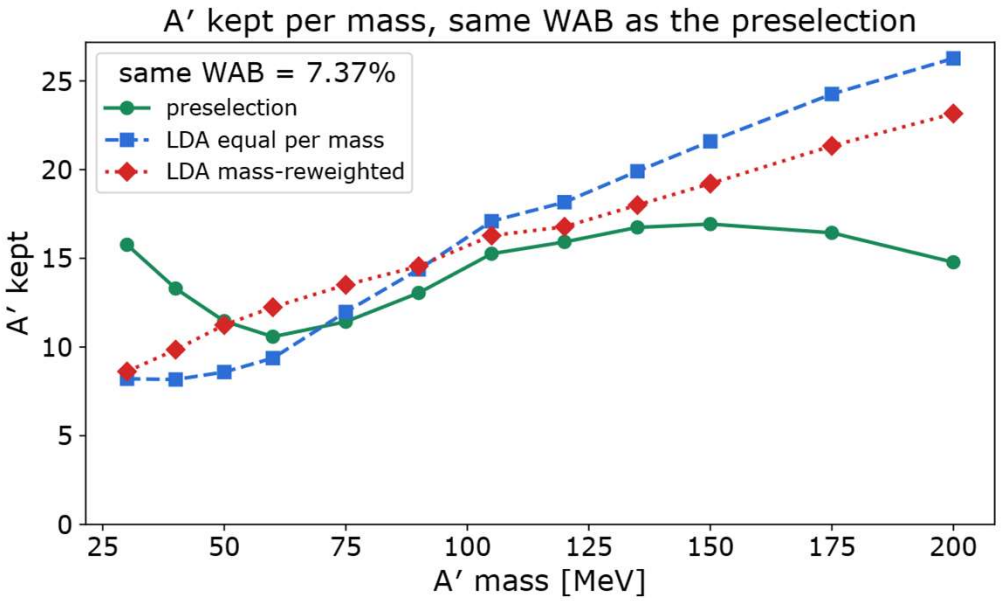


LDA on the preselection variables



Results (preliminary): A′ efficiency vs mass





Summary: matching on tritrig vs matching on WAB in percentage

	preselection	same tritrig, equal per mass	same tritrig, mass-reweighted	same WAB, equal per mass	same WAB, mass-reweighted
A’ 30 MeV	15.76	24.01	21.41	8.22	8.57
A’ 60 MeV	10.58	24.37	23.59	9.43	12.19
A’ 120 MeV	15.92	27.31	24.50	18.17	16.75
A’ 200 MeV	14.78	30.70	29.05	26.26	23.14
tritrig	13.74	**13.74 (matched)**	**13.74 (matched)**	1.81	2.31
WAB	7.37	18.72	16.52	**7.37 (matched)**	**7.37 (matched)**

- LDA cuts: same tritrig −0.65 / −0.40, same WAB +0.70 / +0.54 (equal per mass / mass-reweighted).
- Same tritrig: LDA keeps 1.5–2.3× more A’ at every mass, but WAB more than doubles.
- Same WAB: LDA wins above ~75–90 MeV, loses at low mass; tritrig nearly vanishes.

Next steps

- Do some more tests like mass sculpting
- Quadratic DA and some other classifiers for comparison
- Test on data

Extras

Mass reweighting: numbers before and after

mass [MeV]	A′ before (available)	background	A′ after (picked)	fraction of A′ kept
0–20	1,182	113	113	0.096
20–40	139,763	24,526	24,526	0.175
40–60	569,821	53,832	53,832	0.094
60–80	612,776	33,344	33,344	0.054
80–100	462,556	18,305	18,305	0.04
100–120	390,457	9,937	9,937	0.025
120–140	314,561	5,297	5,297	0.017
140–160	223,414	2,821	2,821	0.013
160–180	176,081	1,622	1,622	0.009
180–200	123,113	887	887	0.007
200–220	67,696	480	480	0.007
220–240	14,194	310	310	0.022
240–400	18,593	382	382	0.021
>400	225	16	14	0.062
total	**3,114,432**	**151,872**	**151,870**	**0.049**

Background weighted with the cross-section

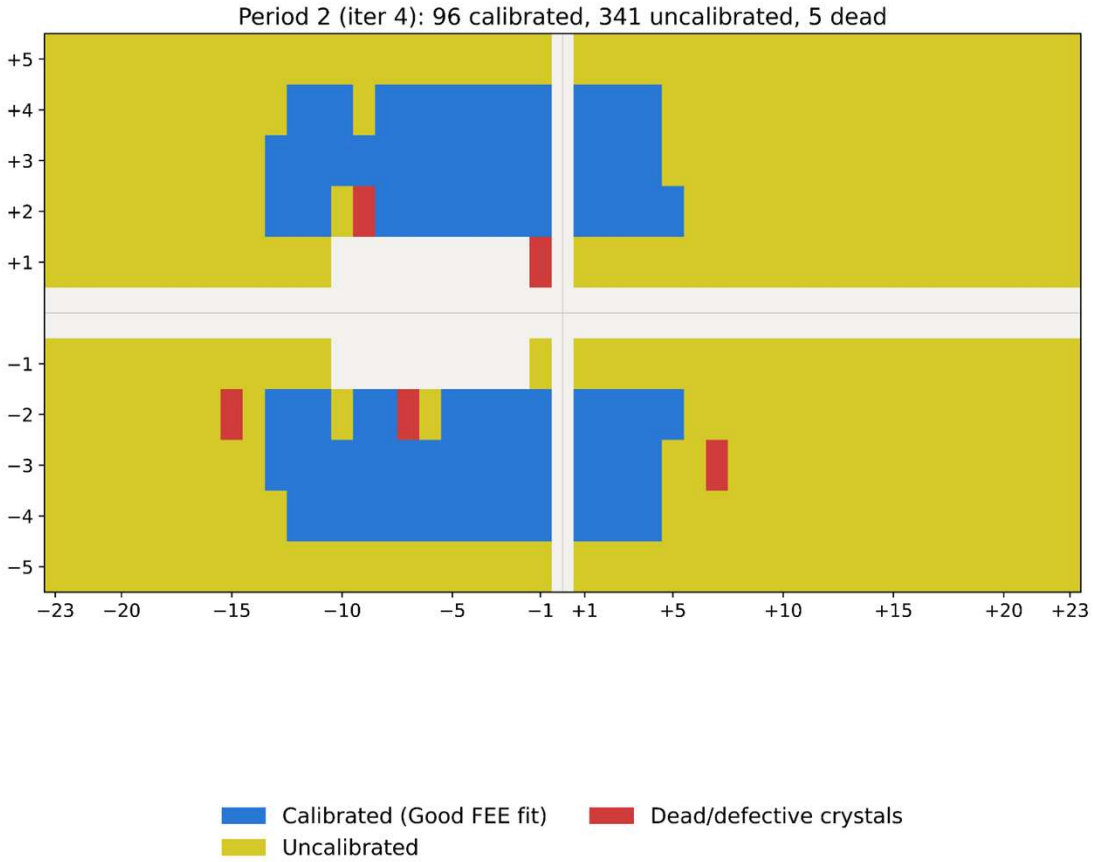
- Each sample is worth a luminosity $L = N_{generated} / \sigma$
- tritrig: 44,827,903 / 4.026×10^9 pb = 0.0111 pb^{-1}
- WAB: 177,747,546 / 8.239×10^{10} pb = 0.00216 pb^{-1}
- σ from MadGraph output
- WAB weight = L_tritrig / L_WAB = 5.16 (tritrig weight = 1)
- WAB ≈ 24% of background vertex candidates after weighting

```
== tritrig_pulser_beamspot_run14272
files 601  plain mean 4.0263e+09 pb  inverse-variance mean 4.0263e+09 +- 1.46e+05 pb
== wab_pulser_run14272
files 360  plain mean 8.2391e+10 pb  inverse-variance mean 8.2386e+10 +- 7.56e+08 pb
```

Uncorrected crystals?

- Only ~30% crystals are corrected this way
- Uncorrected and corrected crystals would be at different scales if we leave them at baseline cosmics.
- Correction factor for the uncorrected crystal is given as:

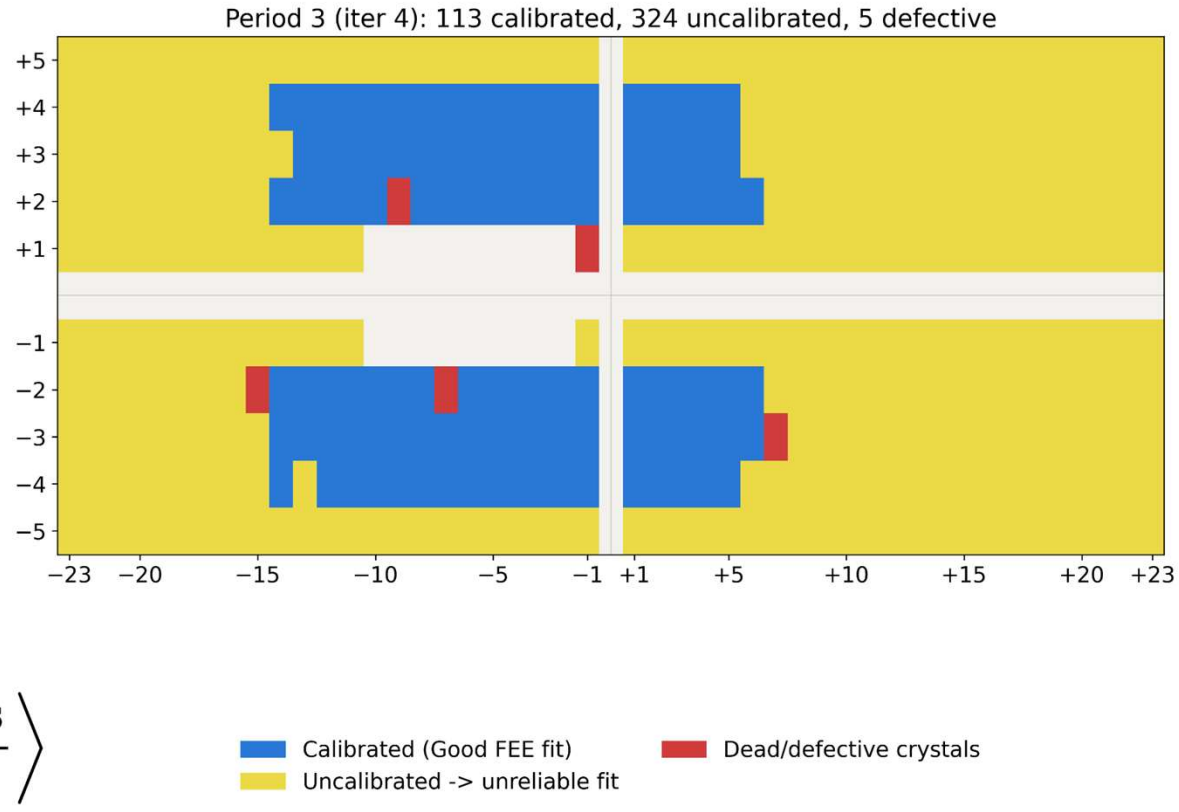
$$\text{correction factor} = \left\langle \frac{\text{corrected gains}}{\text{baseline gains}} \right\rangle$$



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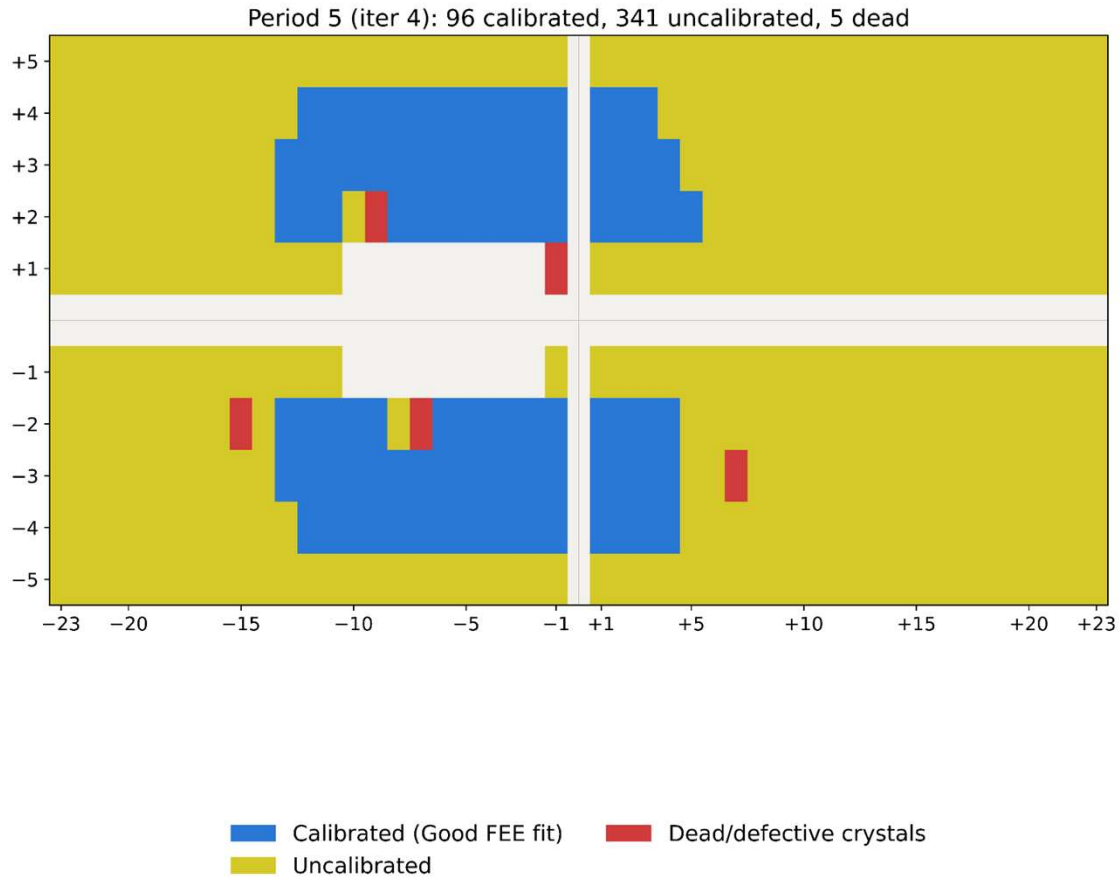
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CosmicCalibration Driver

```
for each event:
  for each crystal (x,y) not in the beam hole:
    pedestal = sum(adc[pedestal window])
    pulse = sum(adc[signal window])
    for each sample in signal window:
        peak = (adc - pedestal/window_width) * ADC2V
        if peak > THR: trigger[x][y] += 1
    signal[x][y] = (pulse - pedestal) * ADC2V

  for each crystal (x,y) not in the beam hole:
    reject if left or right neighbor fired (trigger > 0)
    reject if crystal above/below did NOT fire (trigger == 0)
    reject if the crystal itself did not fire
    otherwise: fill Cry_<selection>_x_y with signal[x][y]
```

The reason for the 50MeV difference

- 2019 slides on ecal calibration indicate the following FEE selection criteria:
  - `Only one cluster with E>2 GeV, Eseed/Etot > 0.6 AND`
  - `Only one cluster with E>0.2 GeV`

- The second cut (i.e. cluster energy threshold) has been changed to `0.4 GeV` in `hps-java`. This is less harsh compared to the previously reported `0.2GeV` cut

- In other words, all events with >1 clusters are accepted if secondary cluster's energy is less than 0.4GeV. This means we get more events with lower FEE energy.

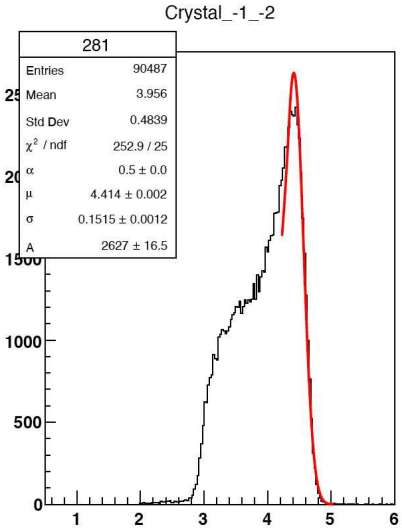
- This pushes the data FEE peak lower making the correction factor ($Peak_{MC}/Peak_{data}$) and global gain higher.

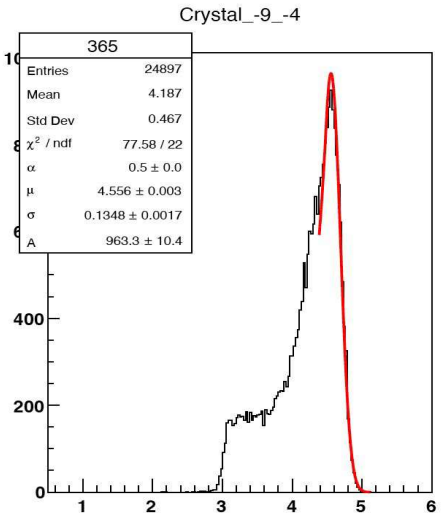
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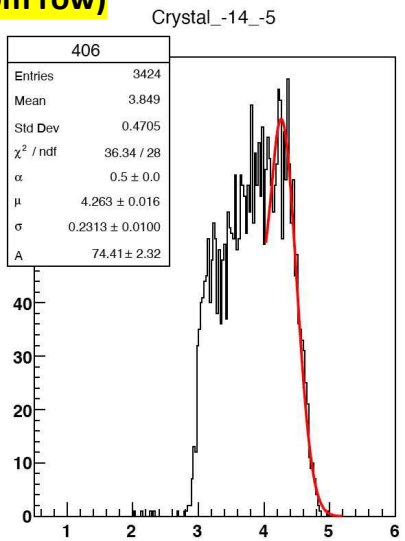
Comparison of a few crystals FEE peaks from 1st iteration of the same run, with different clusterE threshold.

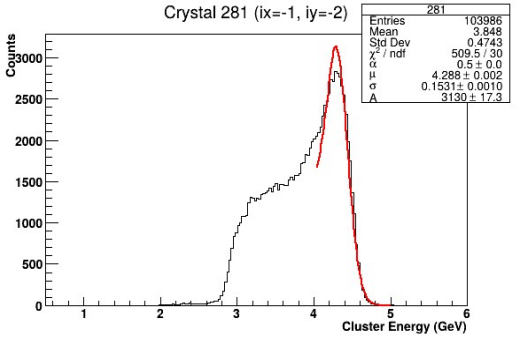
0.2GeV (top row)

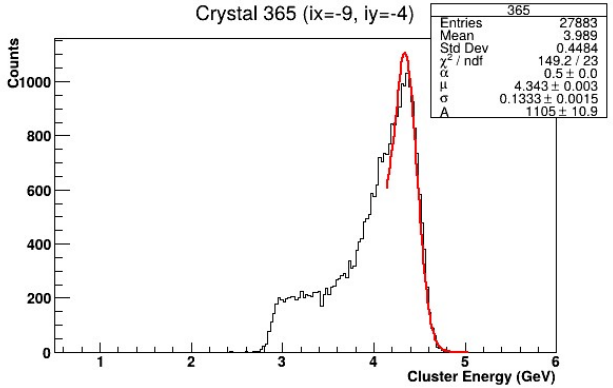
0.4GeV (bottom row)

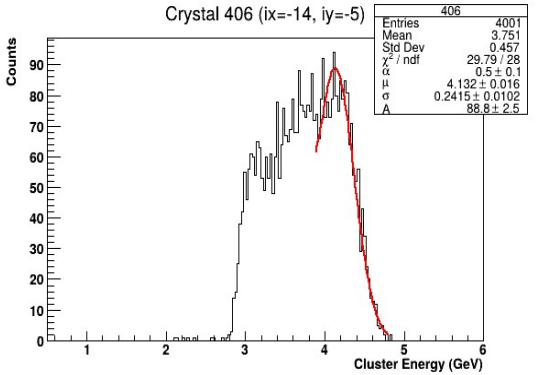








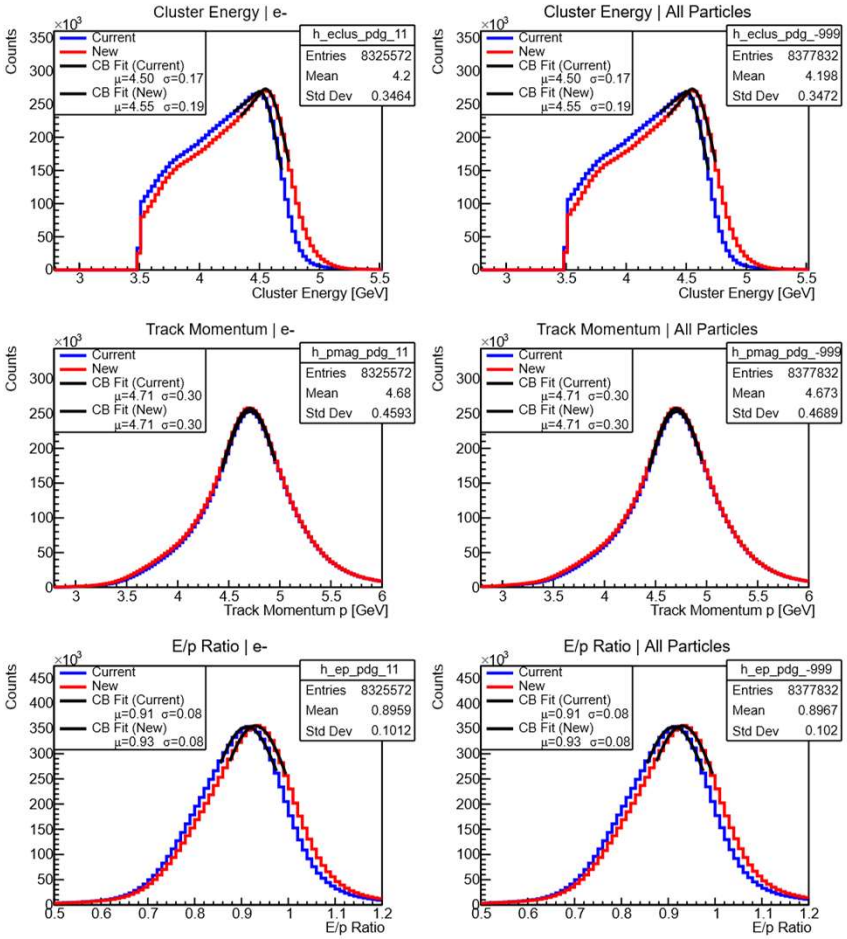


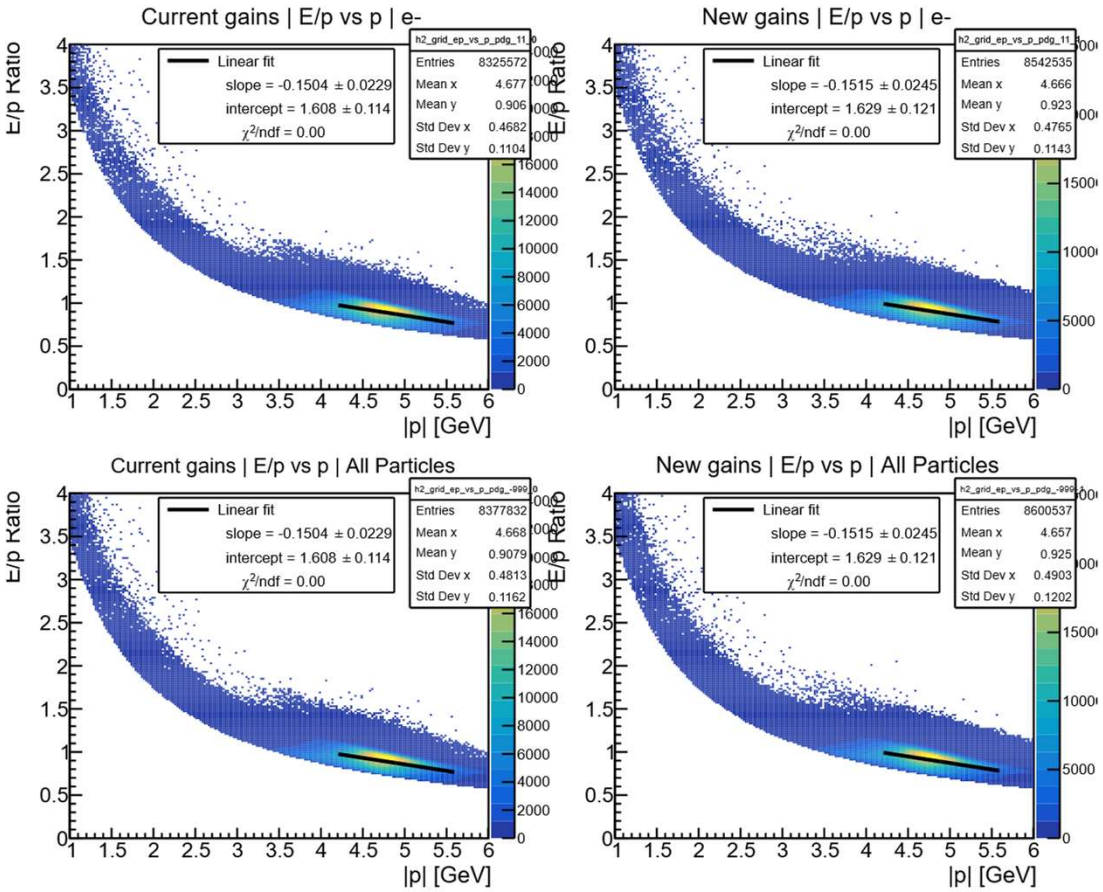


Next steps

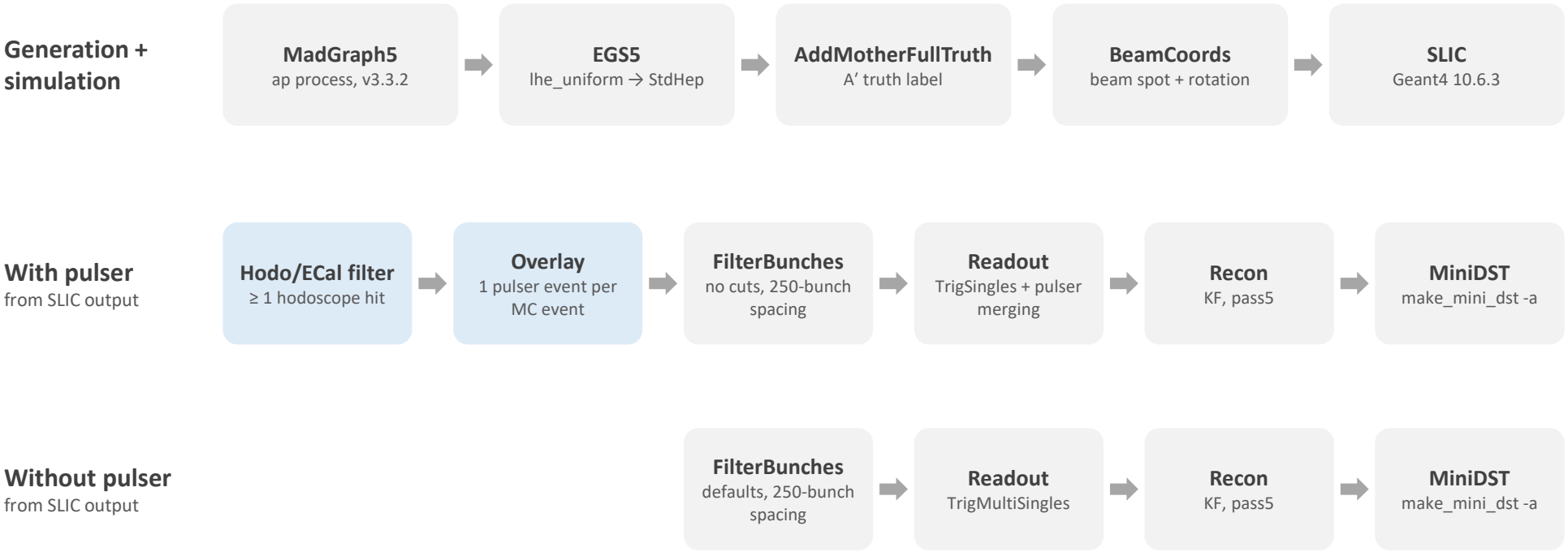
- Check that LDA does not sculpt the mass spectrum
- Try Quadratic DA and other classifiers to compares
- Apply it on data

FEE peak (whole ecal, not just fiducial region)



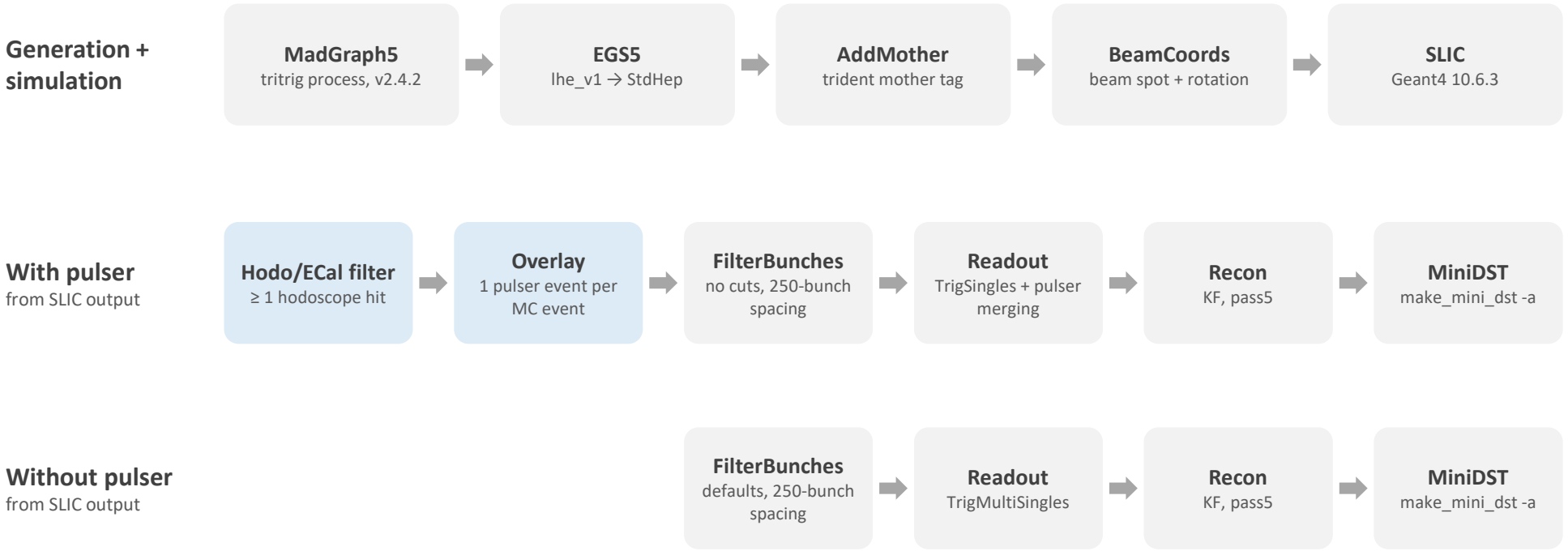


A′ processing chain

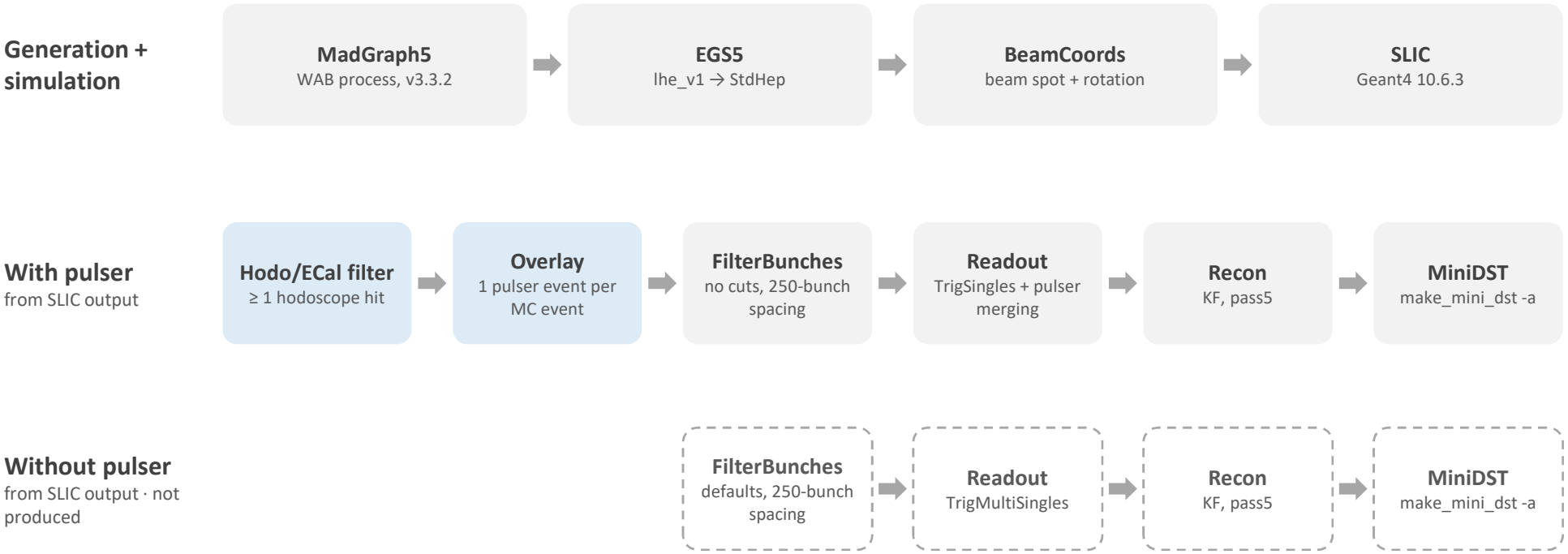


With pulser: 12 masses, 30–200 MeV · without pulser: 50, 100, 150, 200 MeV · blue boxes: pulser-only steps

Tritrig processing chain



WAB processing chain



Without pulser: not produced yet; dashed boxes show the chain it would use · blue boxes: pulser-only steps