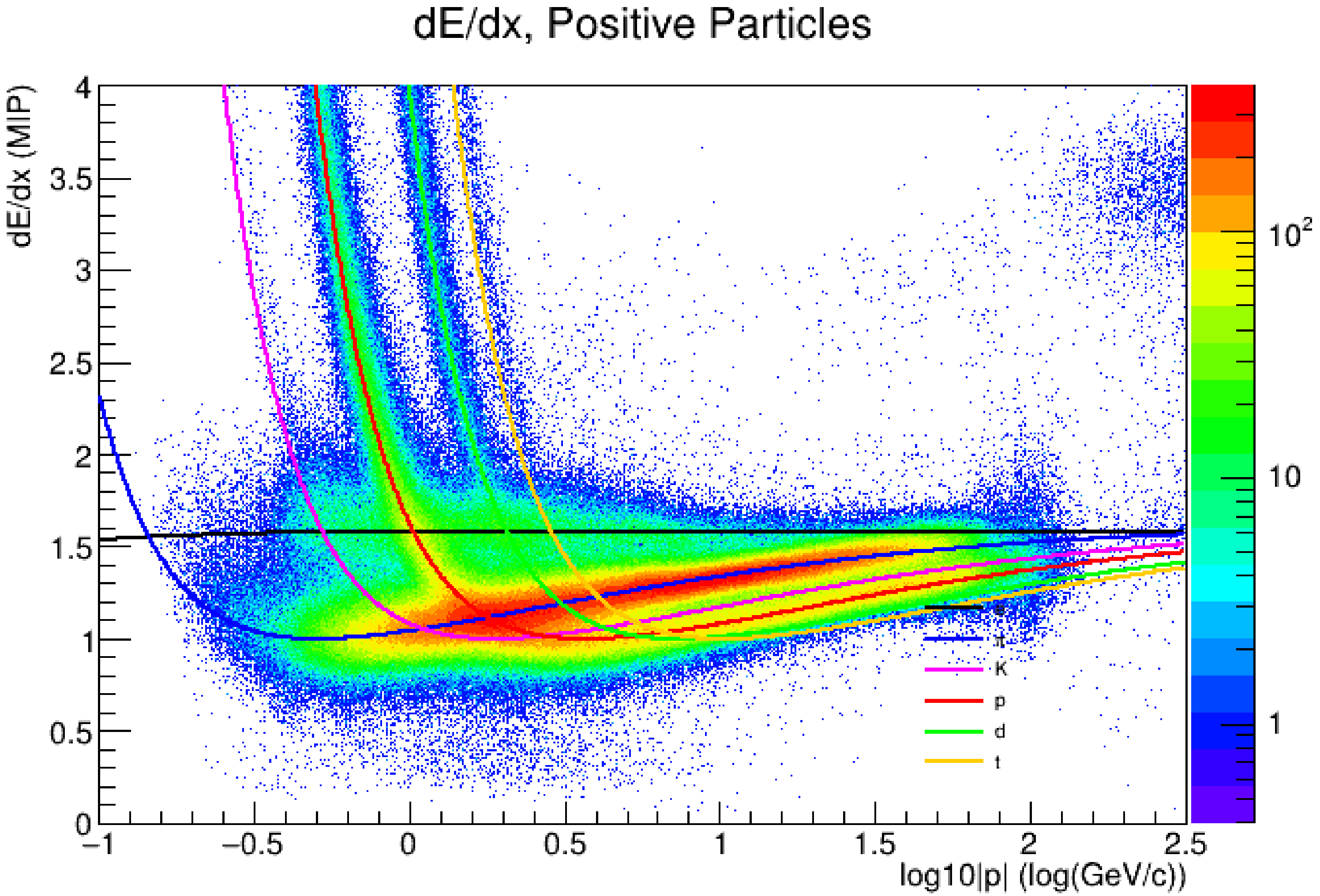
The SHINE-Native dE/dx Calibration Chain

10/5/20

SHINE Autumn School

Brant Rumberger



Overview

- dE/dx Calibration Basics
- Kr^{83} Calibration Software
- dE/dx Calibration Software
  - Time Dependence
  - Y-Dependence
  - Sector Constants
  - Chip Gain
- Performance Evaluation
- Future Plans

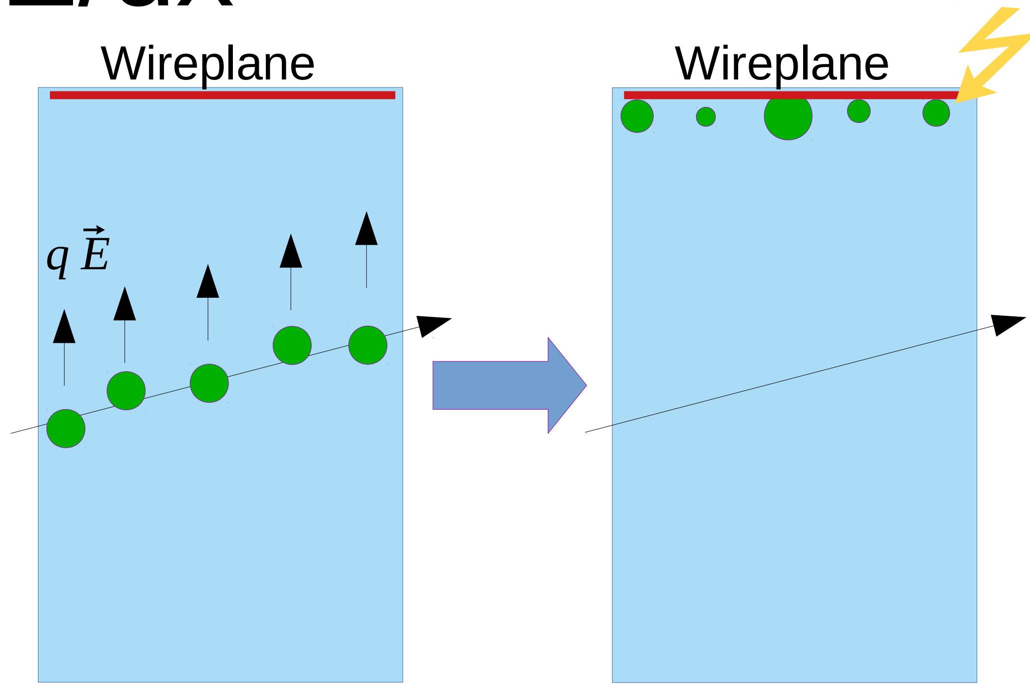
dE/dx Calibration Basics

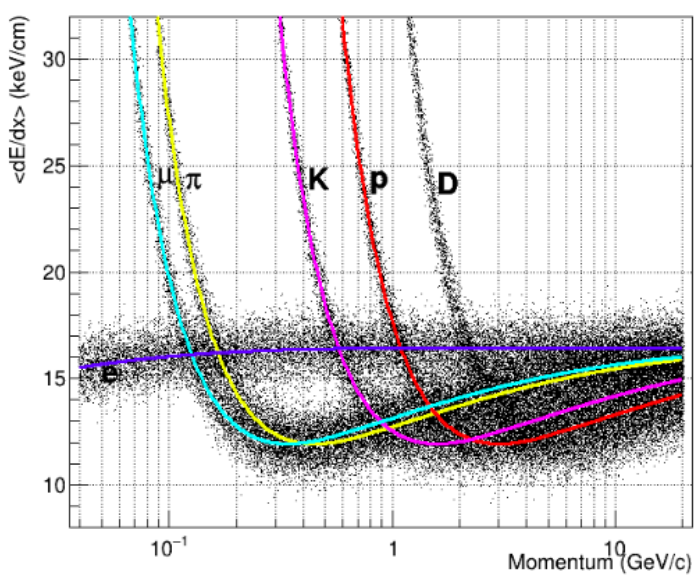
Particle Identification via dE/dx

- TPC provides track **position** and **ionization** measurements
  - Position used for tracking
  - Ionization used for dE/dx estimate
- Particles deposit energy along trajectory according to Bethe-Bloch formula:

$$\frac{dE}{dx} \propto \frac{Z^2}{\beta^2} \ln\left(a\beta^2\gamma^2\right)$$

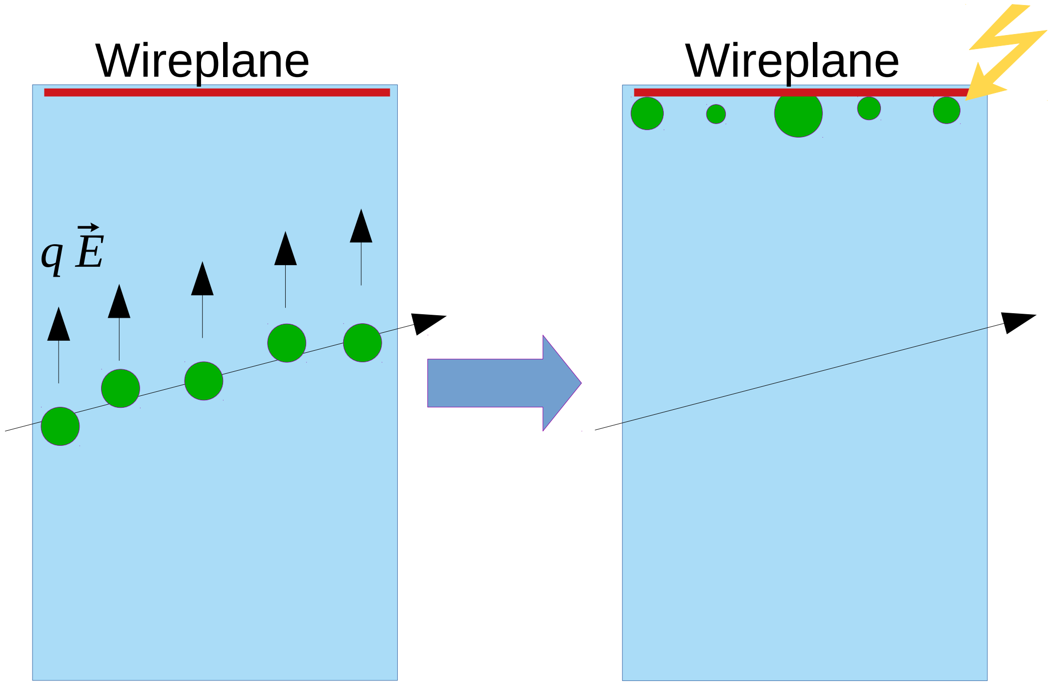
- Dependence on velocity *β* allows **separation of particle species** by mass

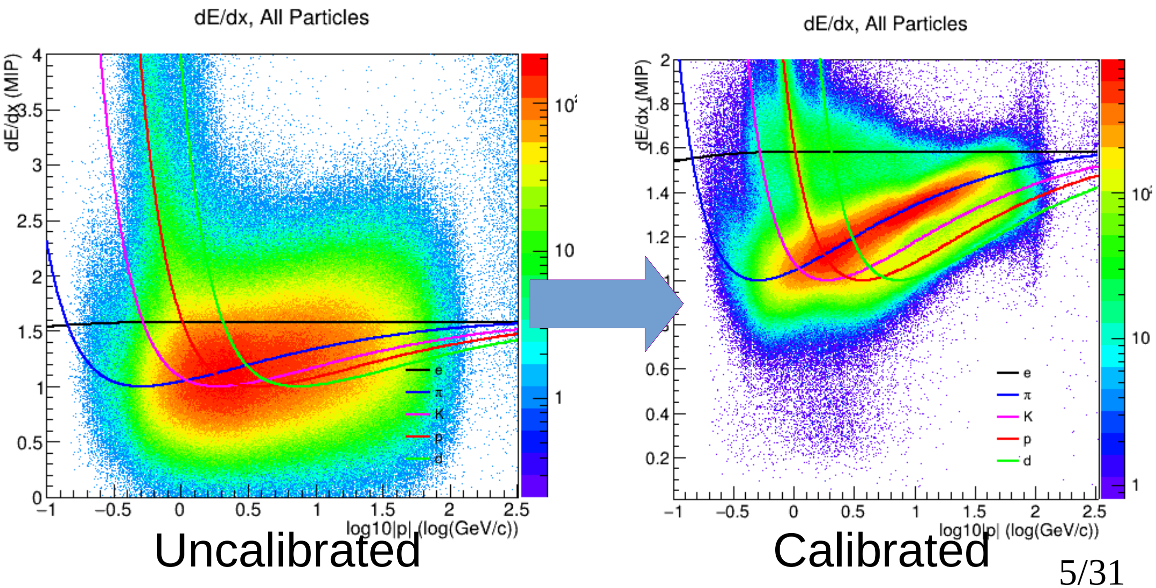




dE/dx Calibration

- Track ionization collected at TPC wireplanes
- Ideally, reconstructed TPC cluster charges represent initial track ionization
- Many effects contribute to distortion of collected charge
  - FEC Electronics Threshold
  - Time variation of gain
  - Electron attachment during drift
  - Atmospheric pressure variation
- dE/dx calibration steps aim to **correct for charge distortion** in order to better estimate PID

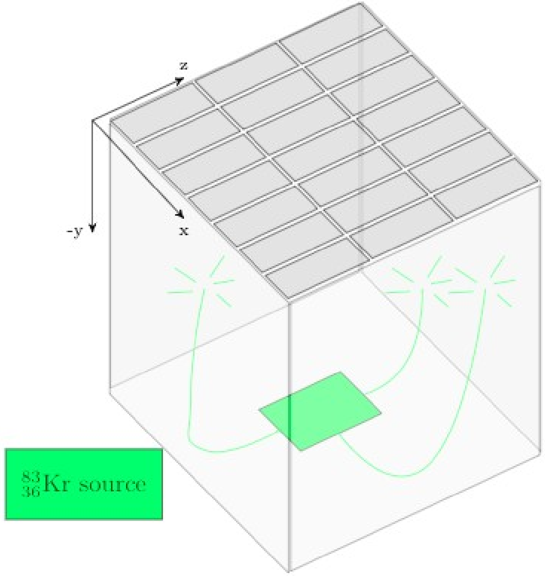




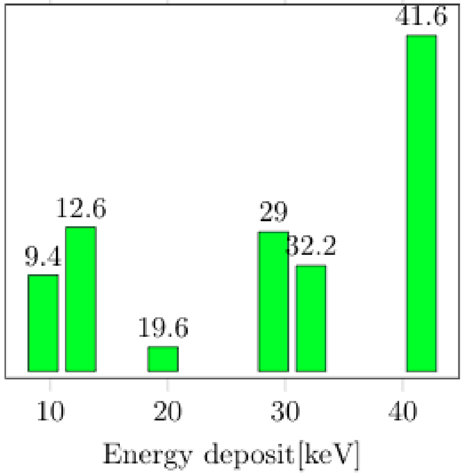
Pre-Calibration: Kr^{83} Correction

TPC Gain Calibration Using Kr^{83}

- Large (up to 80%) variation in TPC electronics channel gains
  - Pad-wire capacitive coupling varies
  - Preamp response can be quite different
- Can calibrate pad-by-pad gains if we have a physical reference
- Introduce Kr^{83} to chamber gas and collect decays
- Reconstruct decay spectrum & use characteristics to determine gain



Expected Energy Peaks

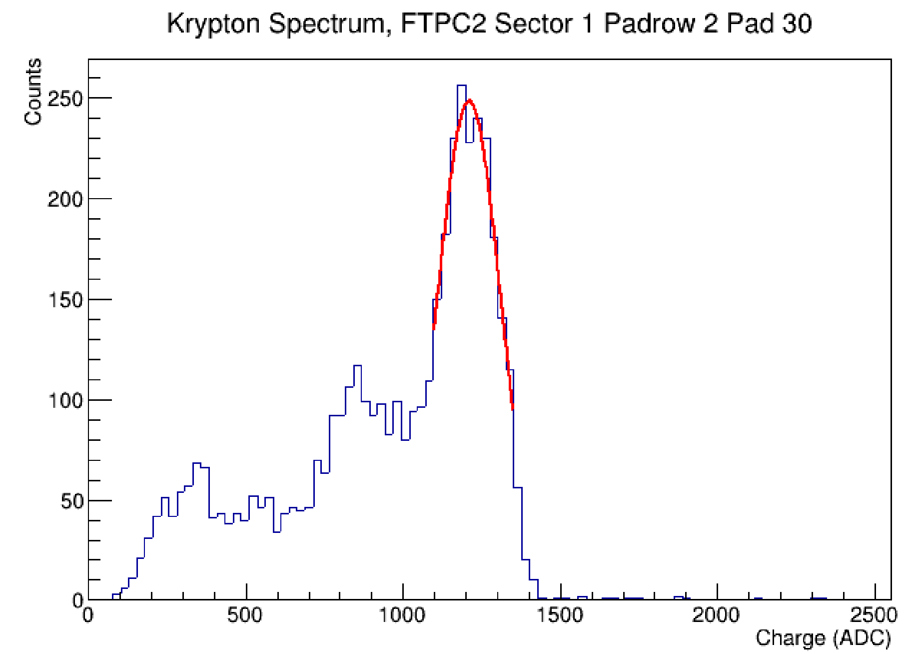


Ref. Michal Naskret

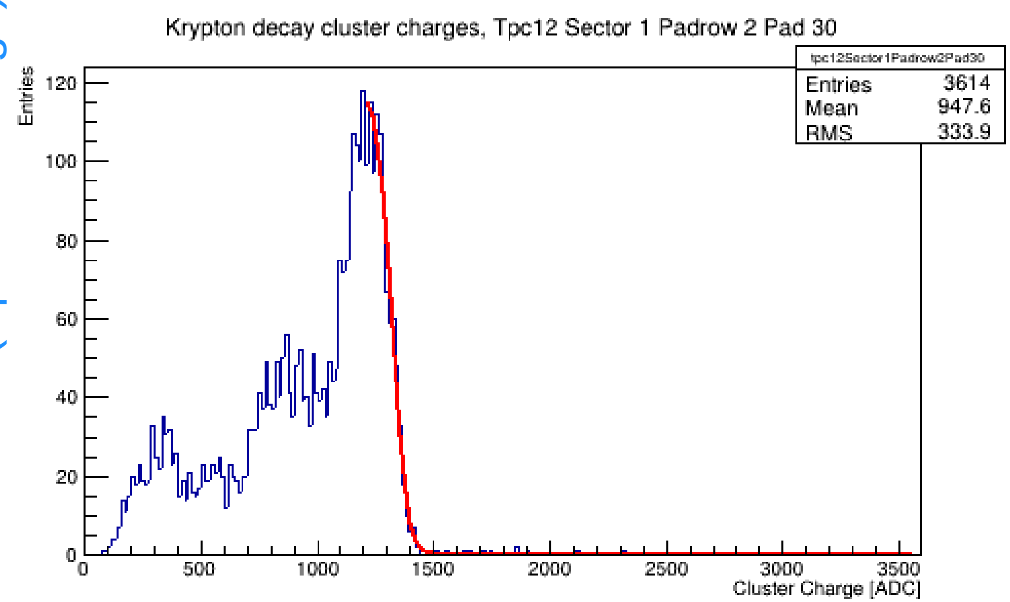
Individual Channels: Spectrum fits

- Software handles difficult-to-calibrate channels due to:
  - Poor statistics
  - Poor spectrum shape
- Spectrum upper edge detection method used
  - Other methods such as peak detection can be unreliable in above scenarios

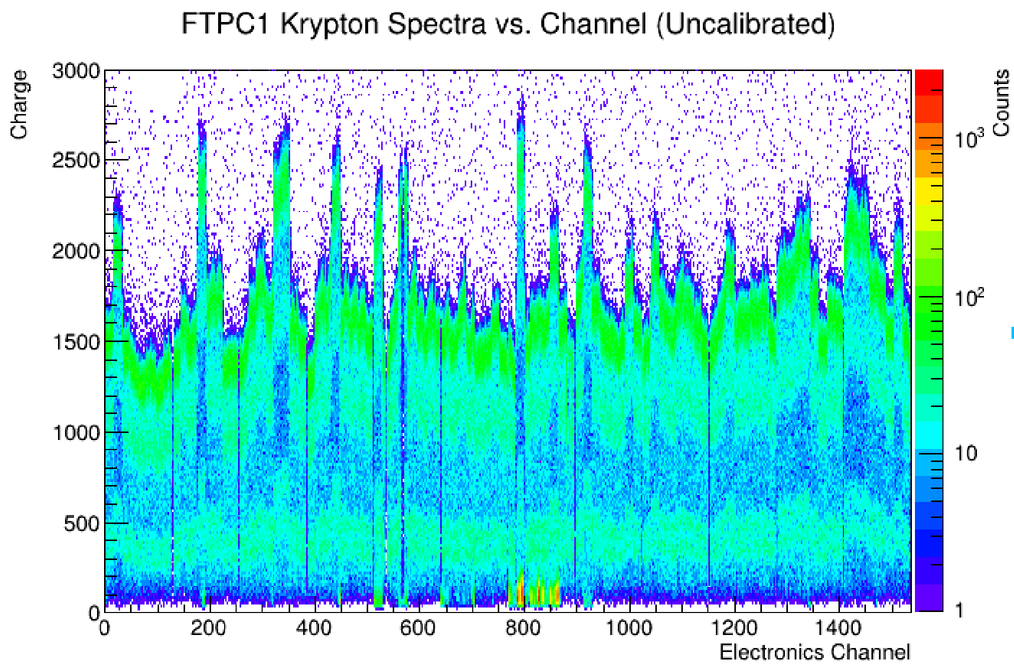
Gaussian Fit (Main Peak)

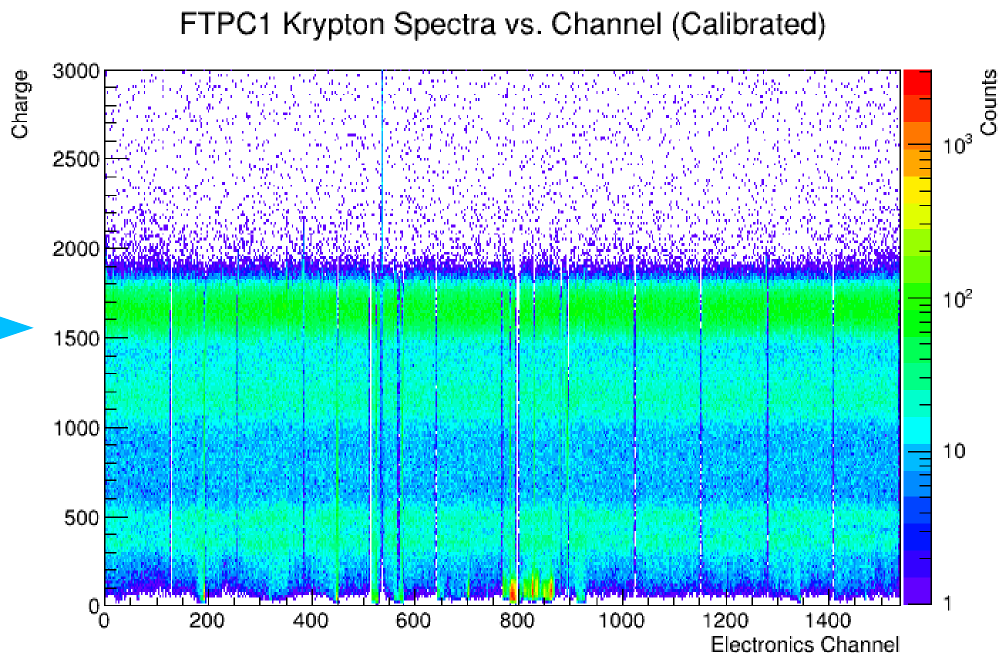


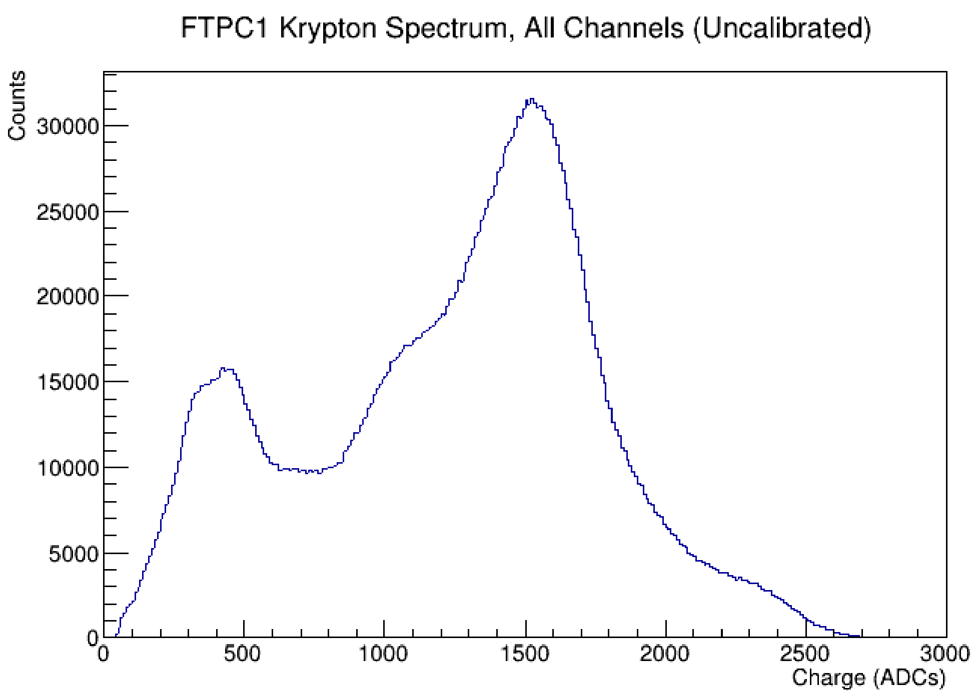
Turn-Off Fit (Spectrum Edge)

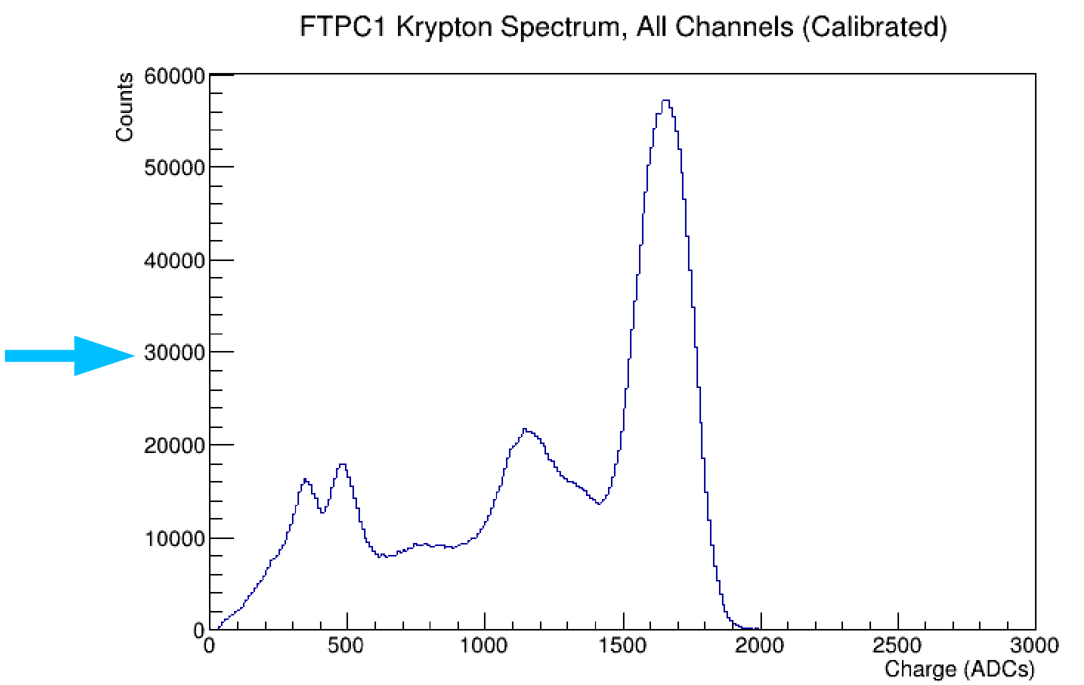


Results: FTPC1

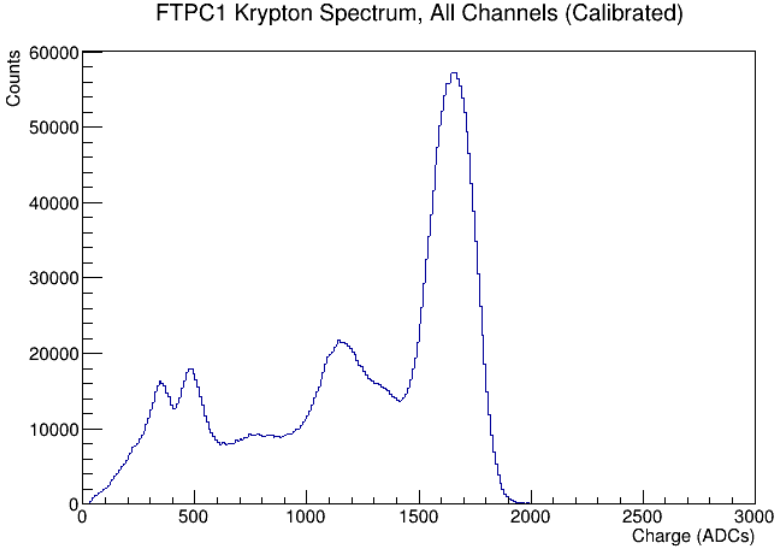




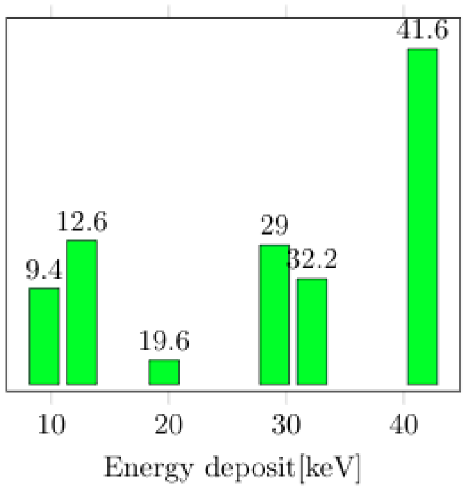




Results



Expected Energy Peaks



ALICE Calibrated Kr83 Spectrum

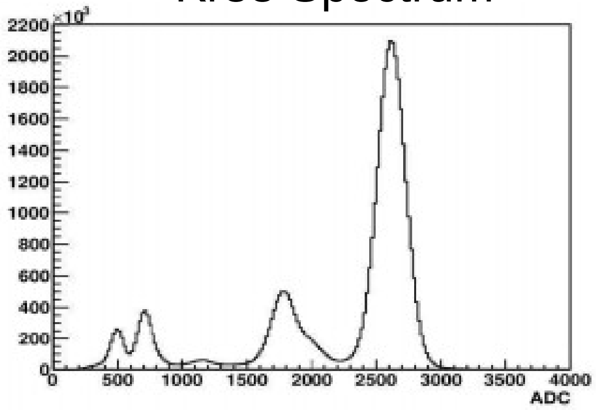
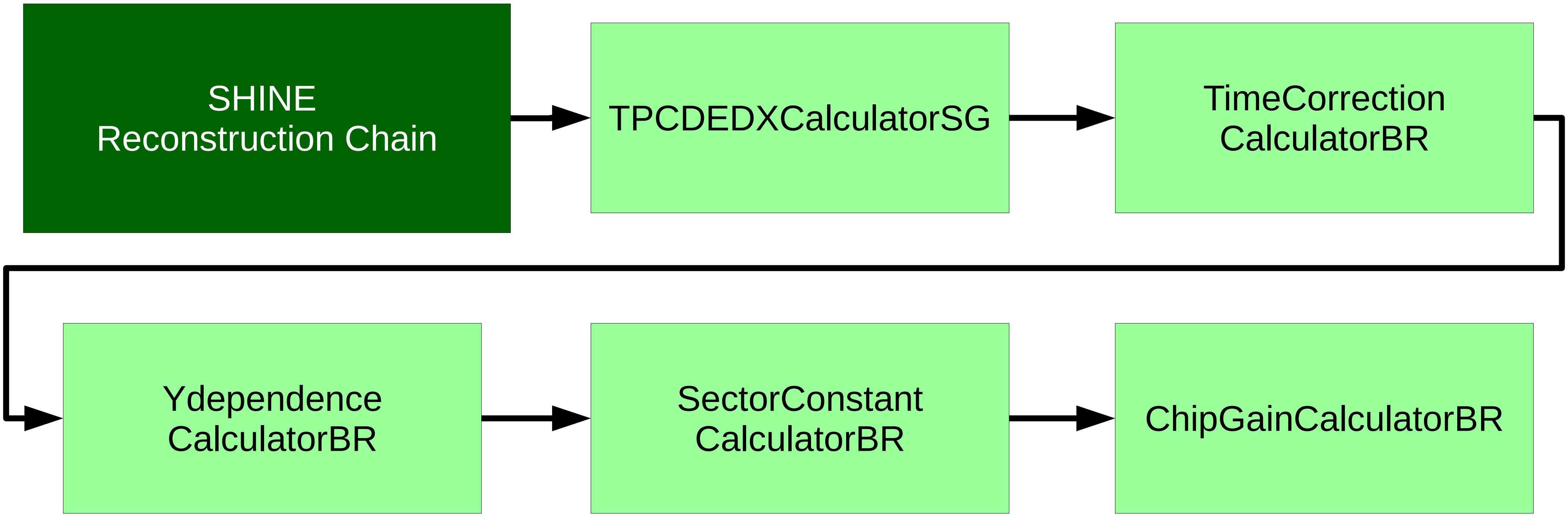


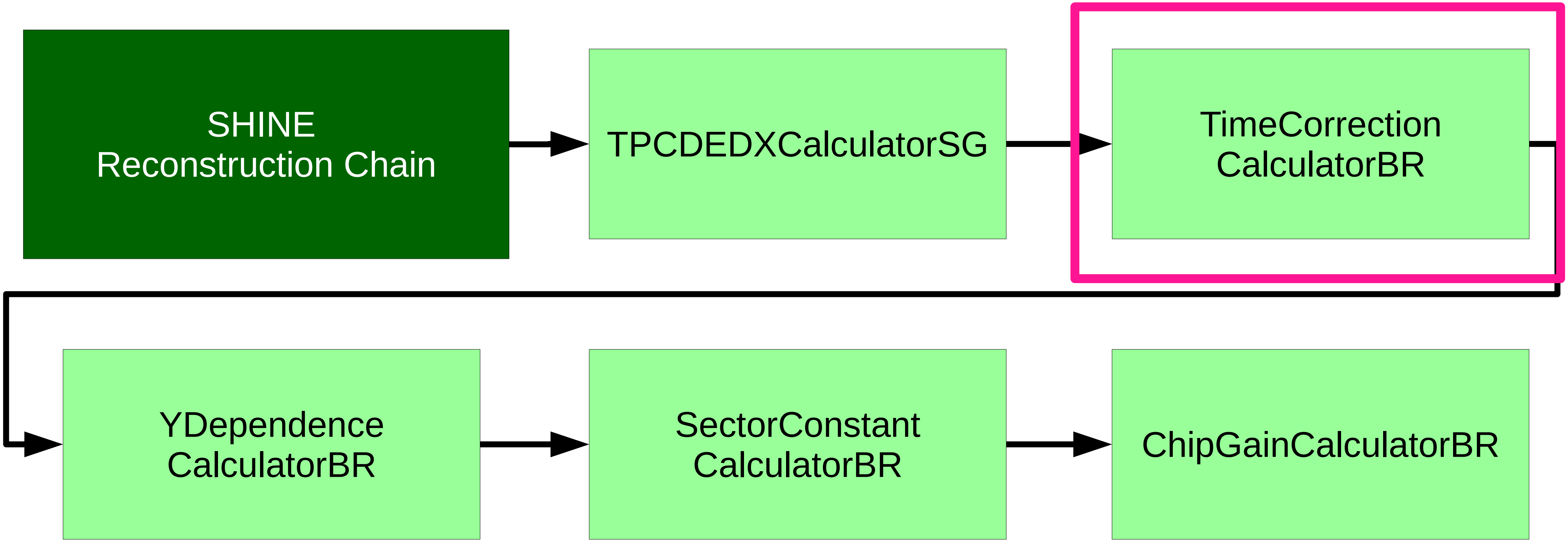
Figure 3: The calibrated Kr spectrum of all OROCs.

dE/dx Calibration Chain

dE/dx Calibration Chain Overview

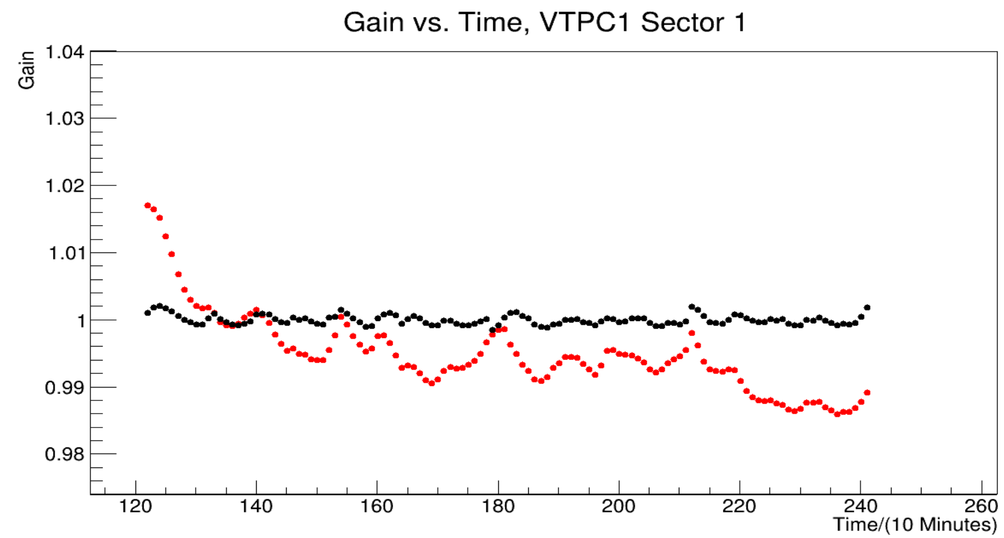


dE/dx Calibration Chain Overview

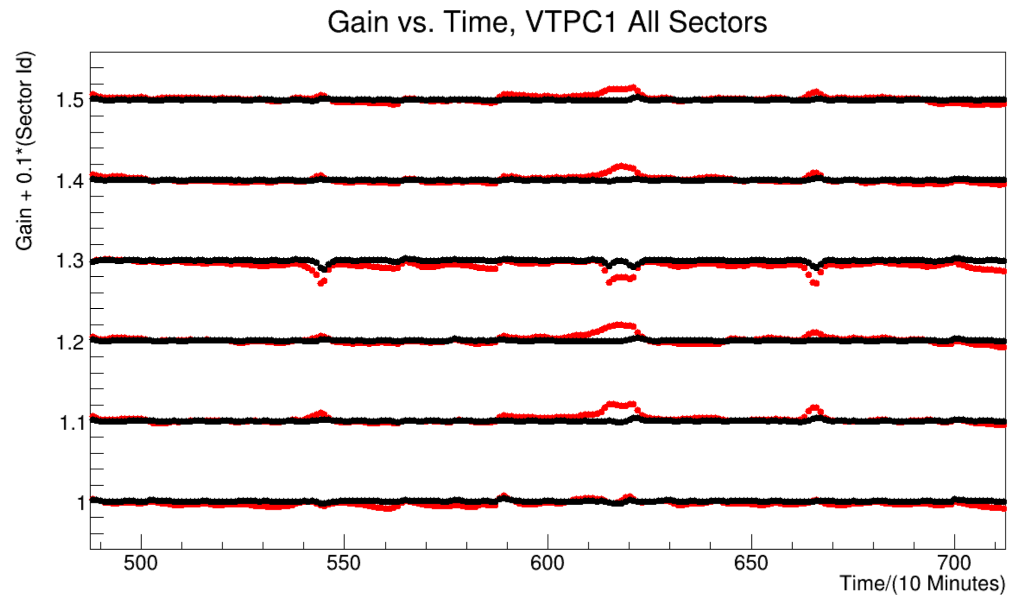


Time Correction

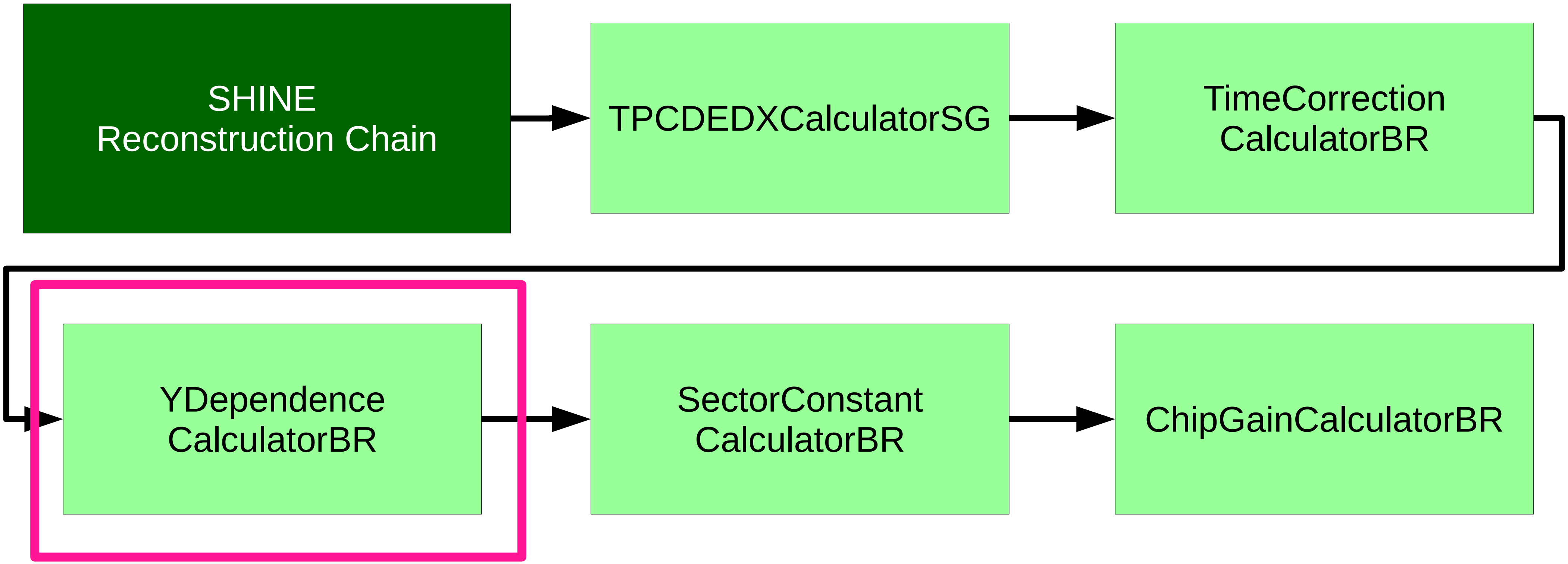
- **Module: TimeCorrectionCalculatorBR**
- Calculates time-dependent gain in each TPC sector
- Variations caused by HV drift, beam intensity fluctuations, inadequate pressure correction, etc
- Output: Sector charge with timestamp (GPS Second)
- Calculator: Smooths calculated gain vs. time & writes timestamped corrections
- Two-step smoothing
  - Low-frequency trends
  - Higher-frequency variations



Red: Uncorrected
Black: Corrected

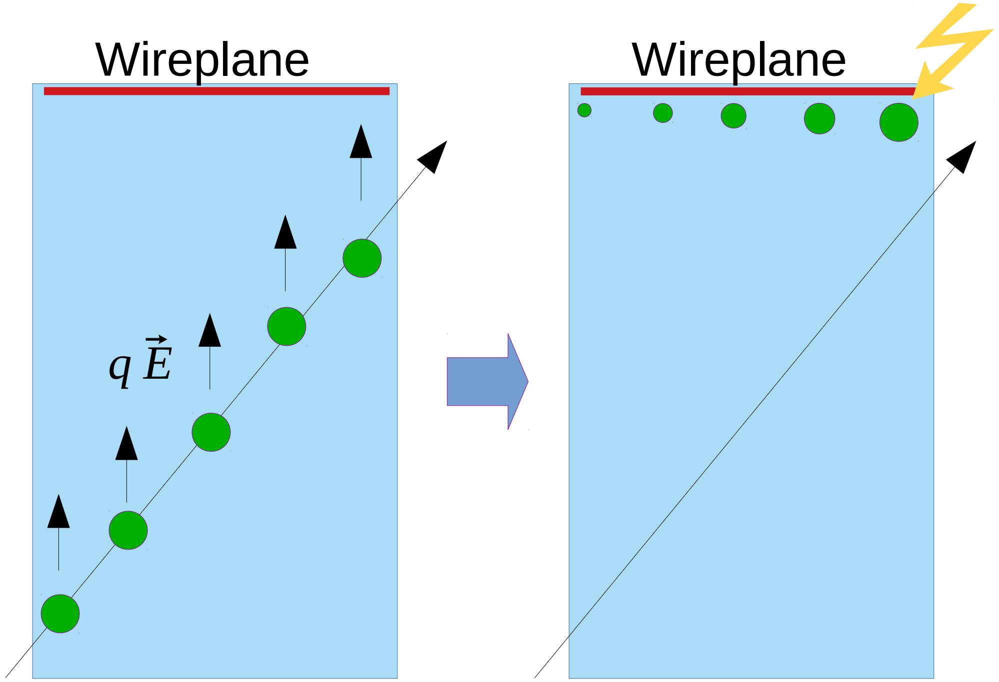


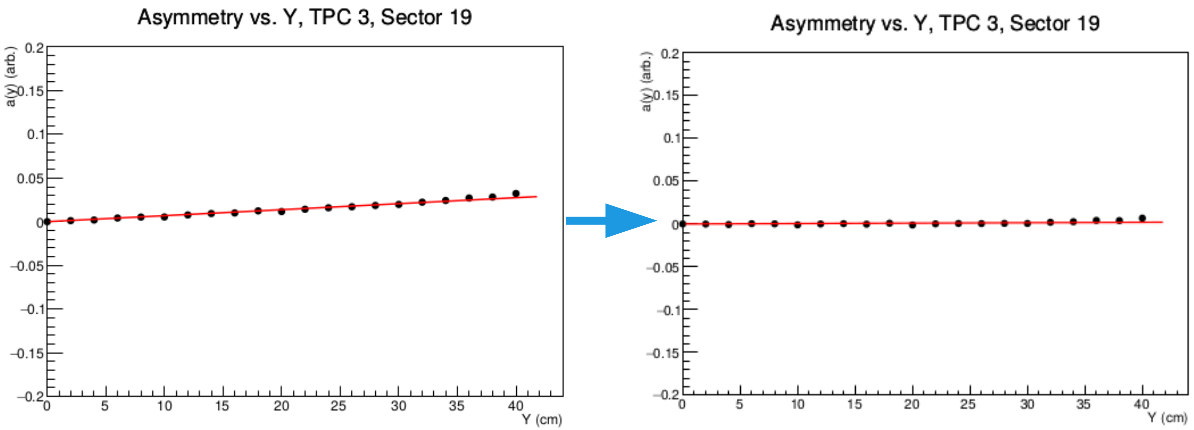
dE/dx Calibration Chain Overview



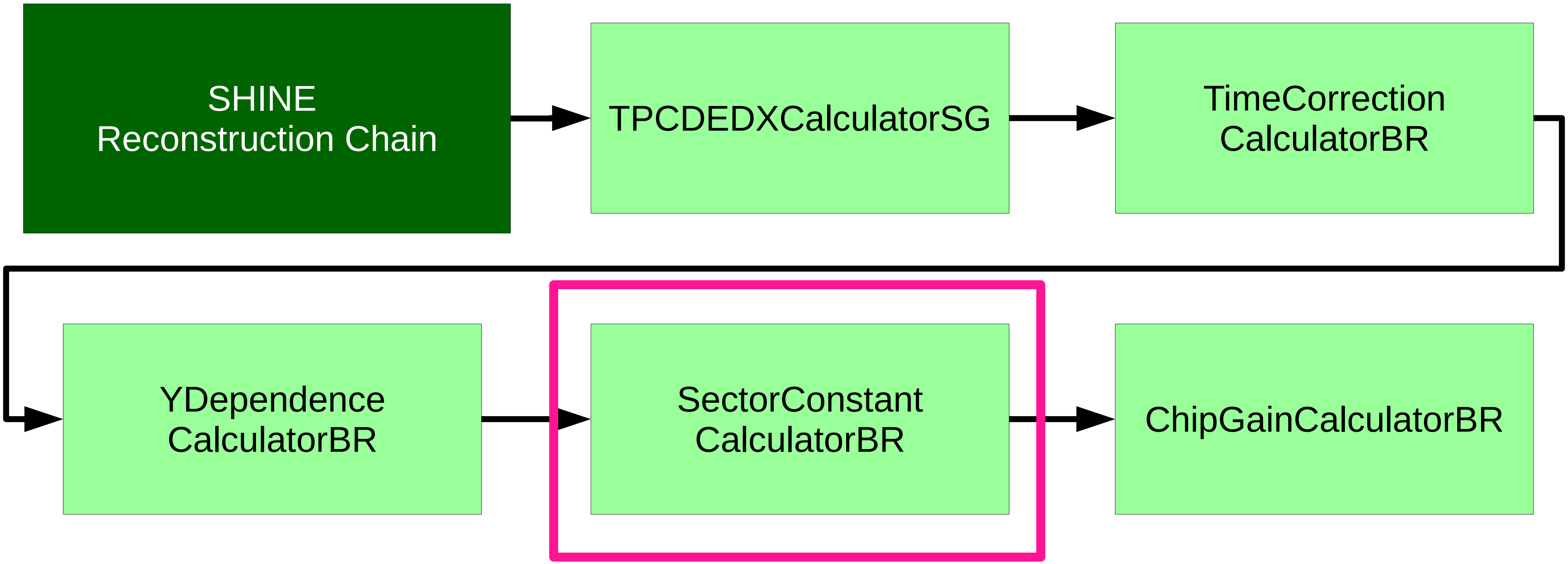
Y-Dependence Correction

- **Module: YdependenceCalculatorBR**
- Calculates charge loss due to drift-dependent effects
- Loss caused by O_2 & H_2O contamination, imperfect threshold correction
- Output: Sector charge binned in Y
- Calculator: outputs “charge asymmetry” & y-dependent correction factor



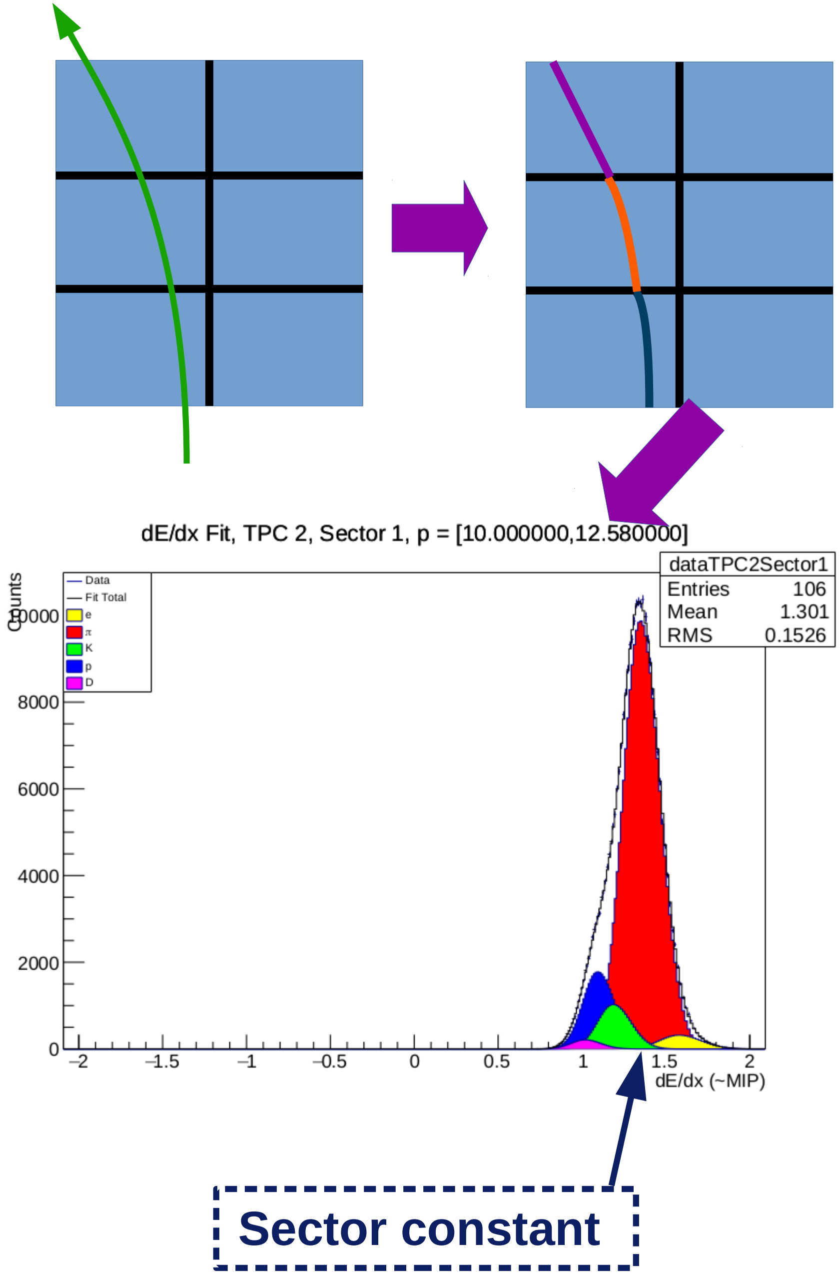


dE/dx Calibration Chain Overview



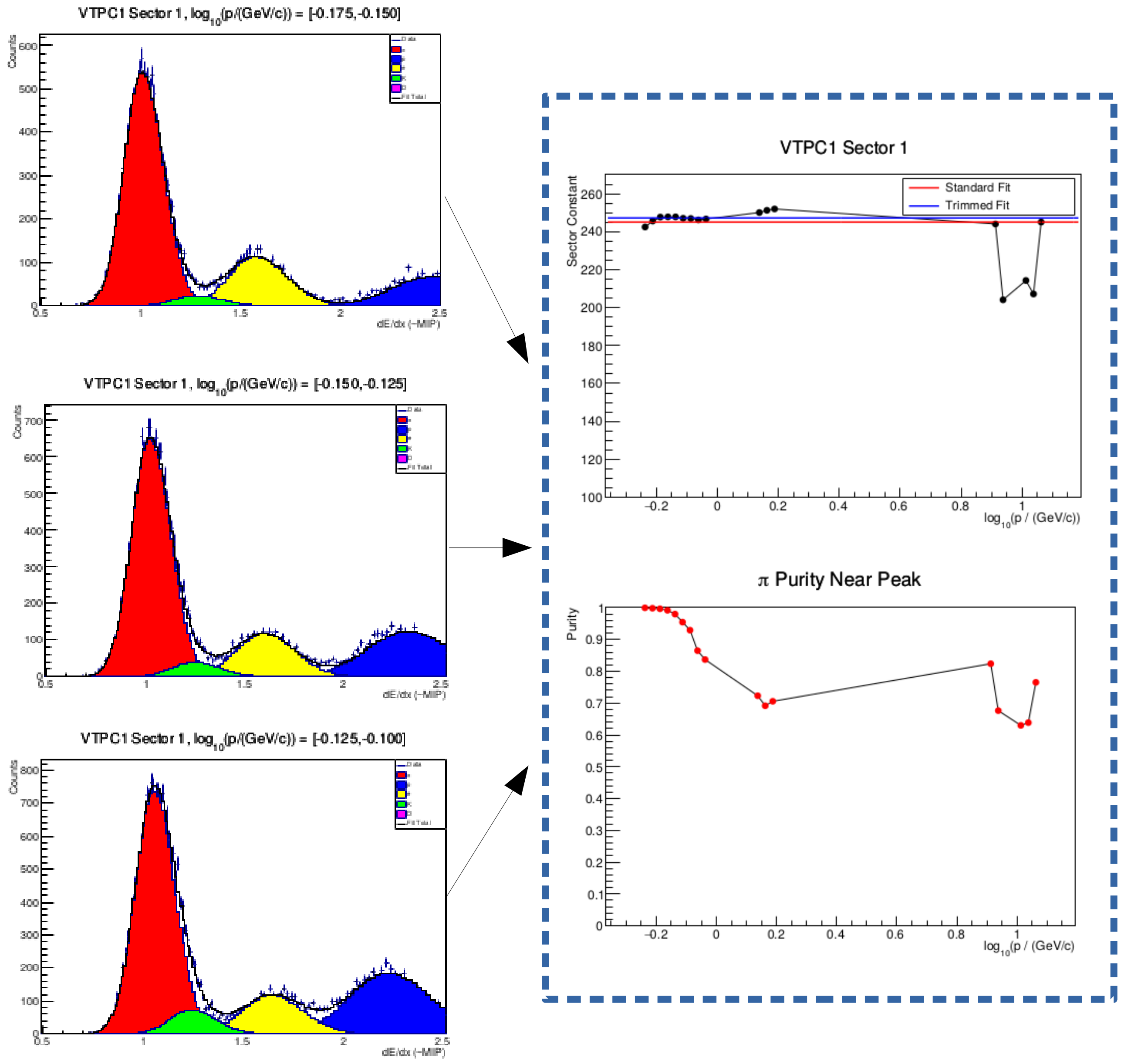
Sector Constants Correction

- **Module:**
  SectorConstantsCalculatorBR
- Procedure:
  - Split tracks by sector ("tracklets")
  - Calculate [0,50]% truncated mean dE/dx
  - Perform fits to tracklet dE/dx distributions
  - Select pion mean dE/dx & use for normalization



Sector Constants Correction: Robust Fits

- Multiple dE/dx spectrum fits performed in fine momentum slices
  - **Gives multiple estimates of sector constant**
  - Poor estimates can be rejected using fit pion purity
  - Good estimates combined into final sector constant
- Acceptance-independent calculation
  - Uniform binning scheme used for all data sets

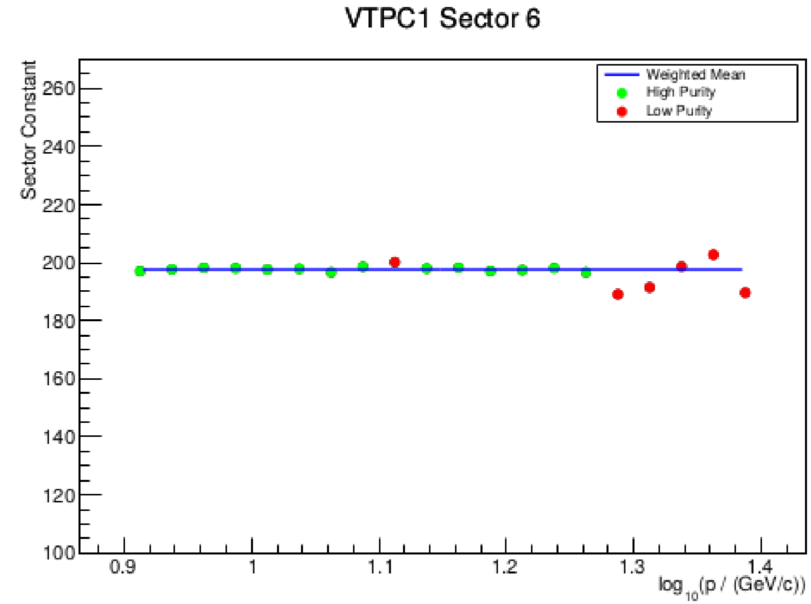


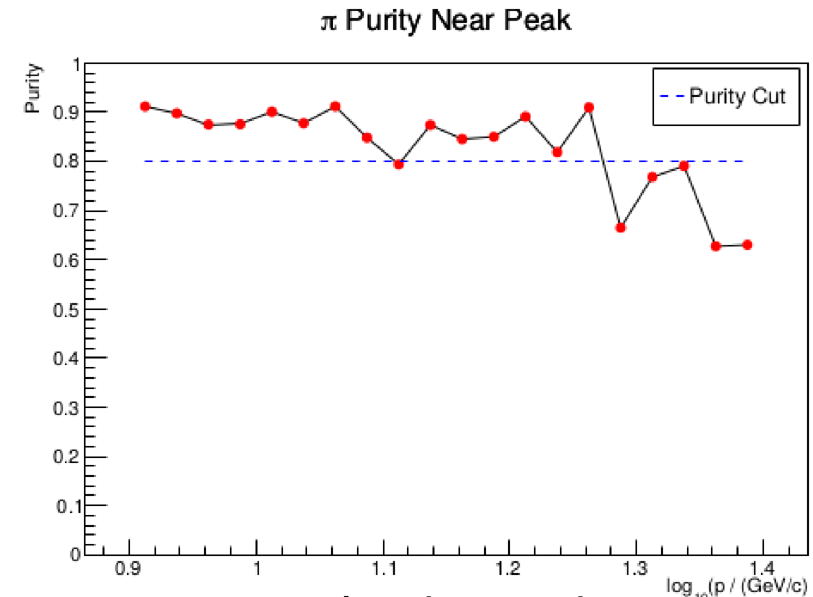
Pion Purity Selection

- Important selection for sector constant estimation
- Lower purity → less-stable pion mean position estimation
  - If particle distributions overlap significantly, pion mean position more difficult to estimate
- Selection: 80% pion purity

$$p_\pi = n_\pi / \sum_{species} n_i$$

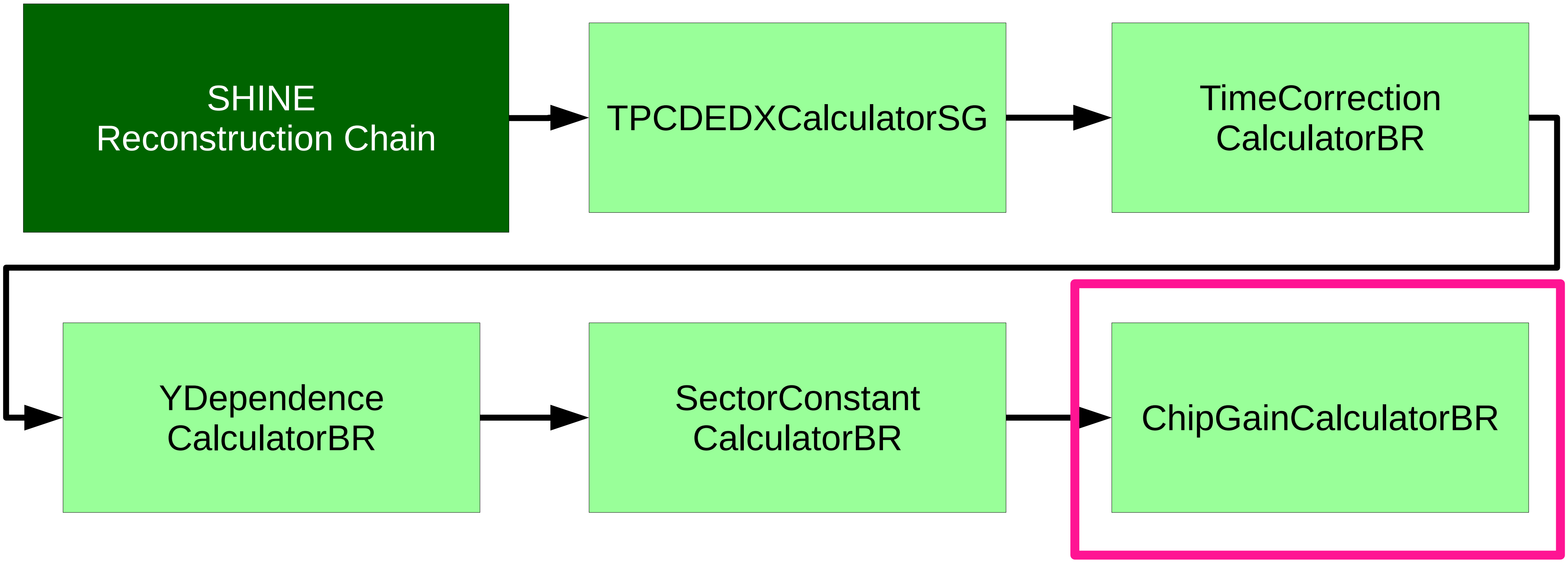
- Results in robust sector constant estimation





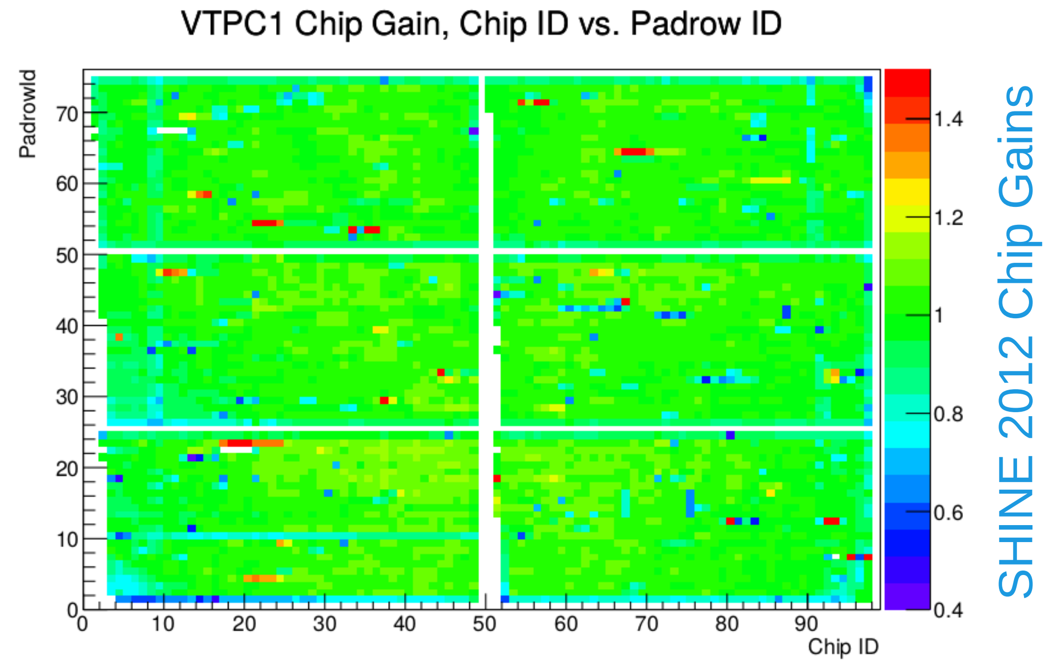
Example Pion Purity & Sector Constant Estimates

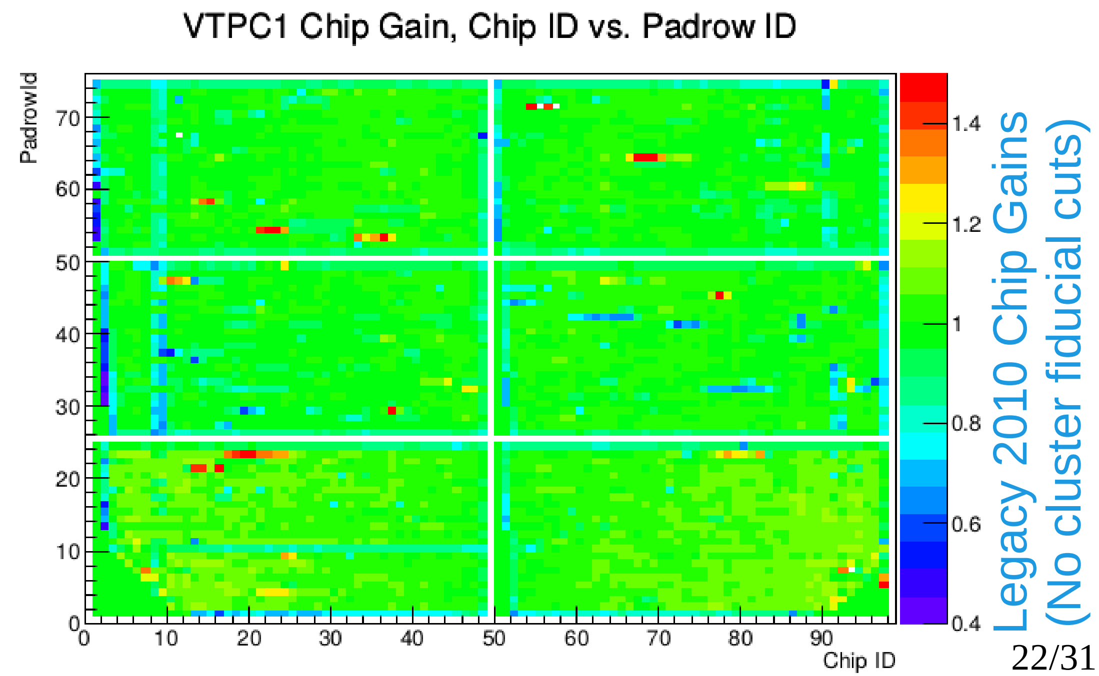
dE/dx Calibration Chain Overview

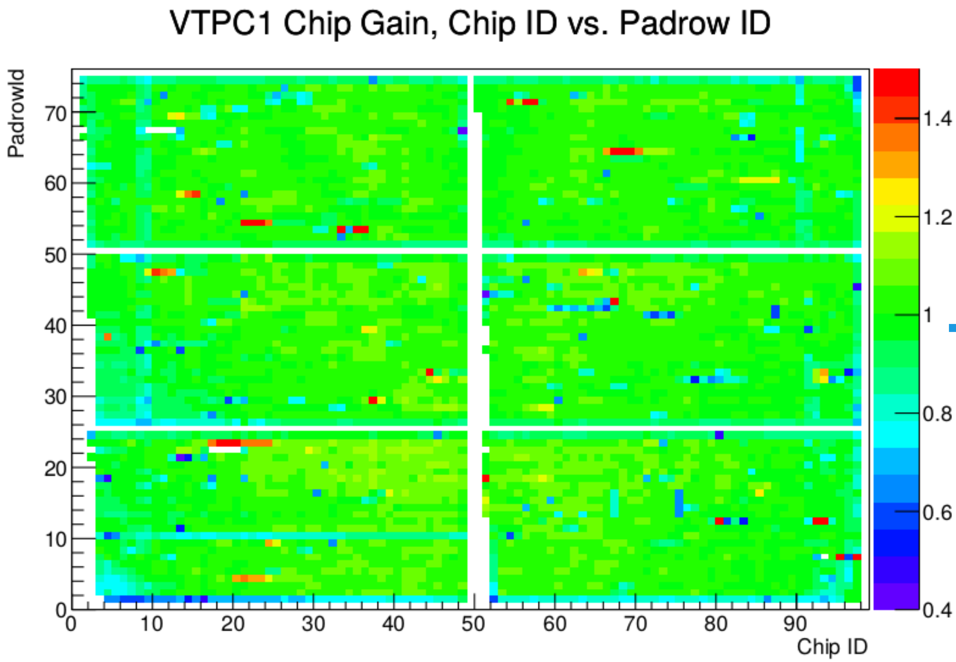


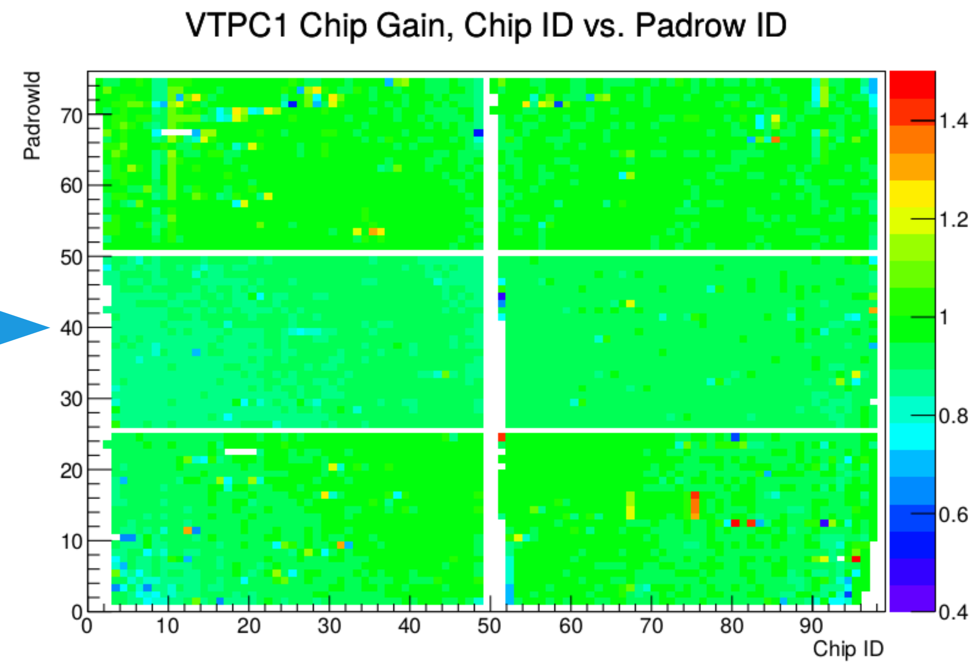
Chip Gain Correction

- **Module: ChipGainCalculatorBR**
- Calculates FEE-dependent gain
- Also calculates XZ-dependent gain (broken wires, fiducial volume effects, etc)
- Chip gain calculation de-coupled from Sector Constant gains
  - Chip gains in each sector normalized by total sector average chip gain
- Chip Gain Calculator gives sector constants for sectors with low statistics(!)






VTPC1 Chip Gain, Chip ID vs. Padrow ID
PadrowId
Chip ID
0
10
20
30
40
50
60
70
80
90
1.4
1.2
1
0.8
0.6
0.4


VTPC1 Chip Gain, Chip ID vs. Padrow ID
PadrowId
Chip ID
0
10
20
30
40
50
60
70
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1.4
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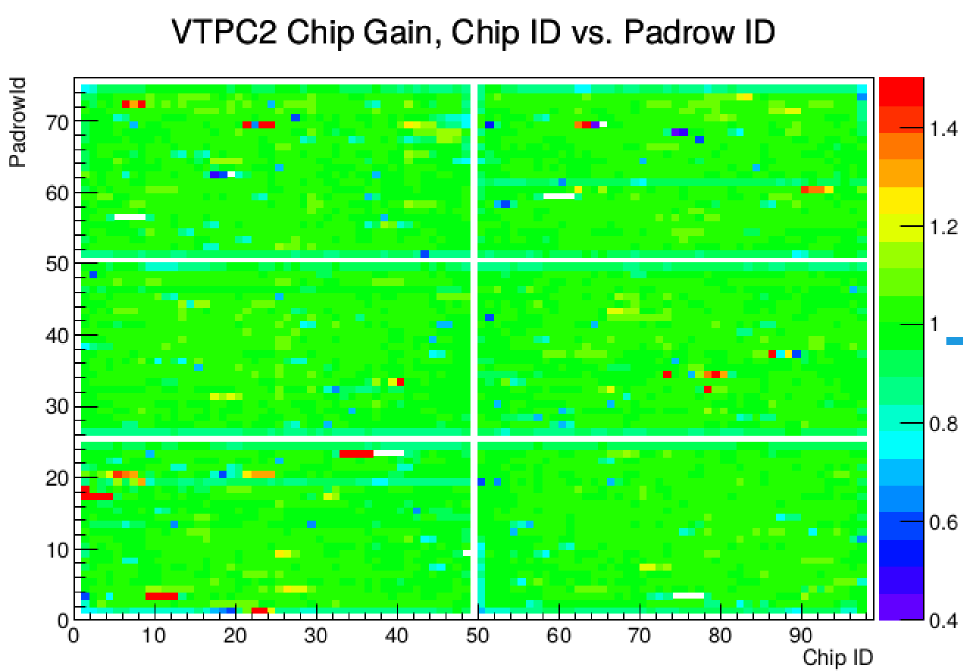
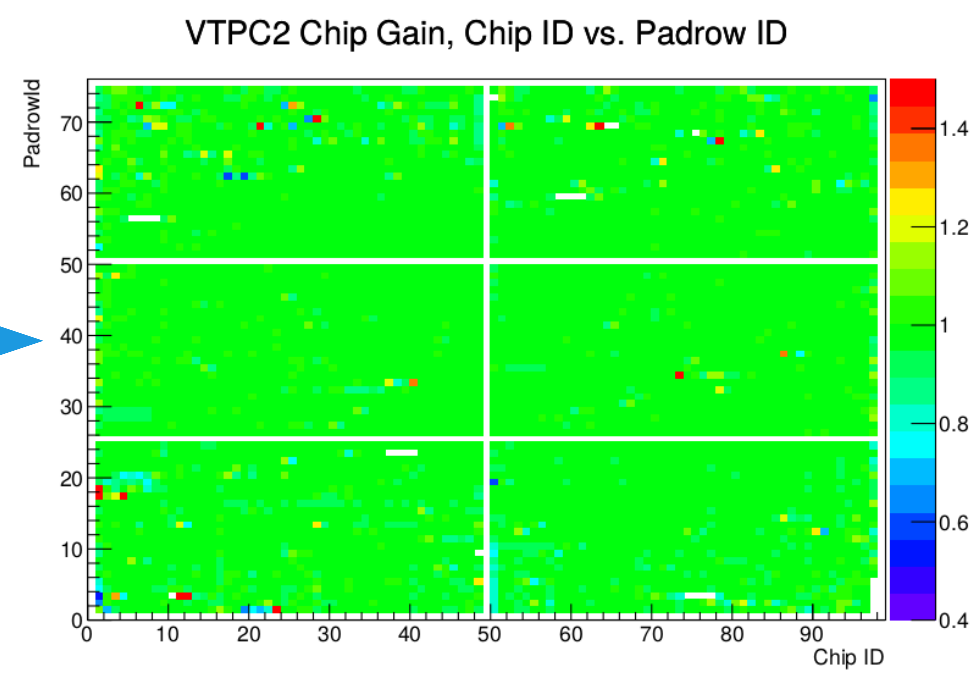
0.6
0.4


VTPC2 Chip Gain, Chip ID vs. Padrow ID
PadrowId
Chip ID
0
10
20
30
40
50
60
70
80
90
1.4
1.2
1
0.8
0.6
0.4


VTPC2 Chip Gain, Chip ID vs. Padrow ID
PadrowId
Chip ID
0
10
20
30
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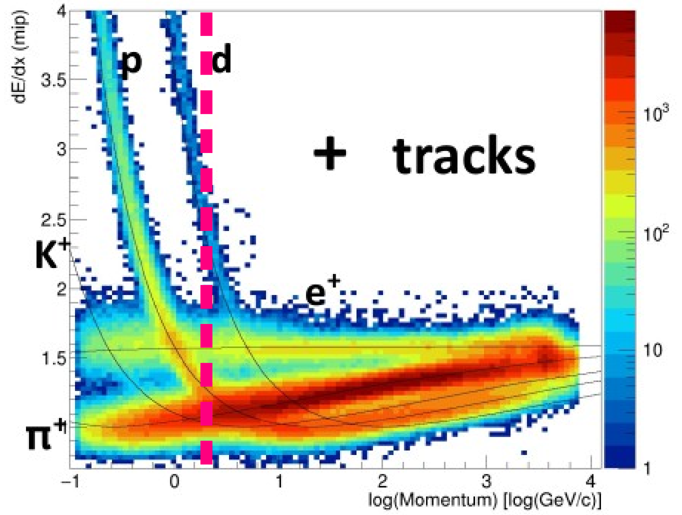
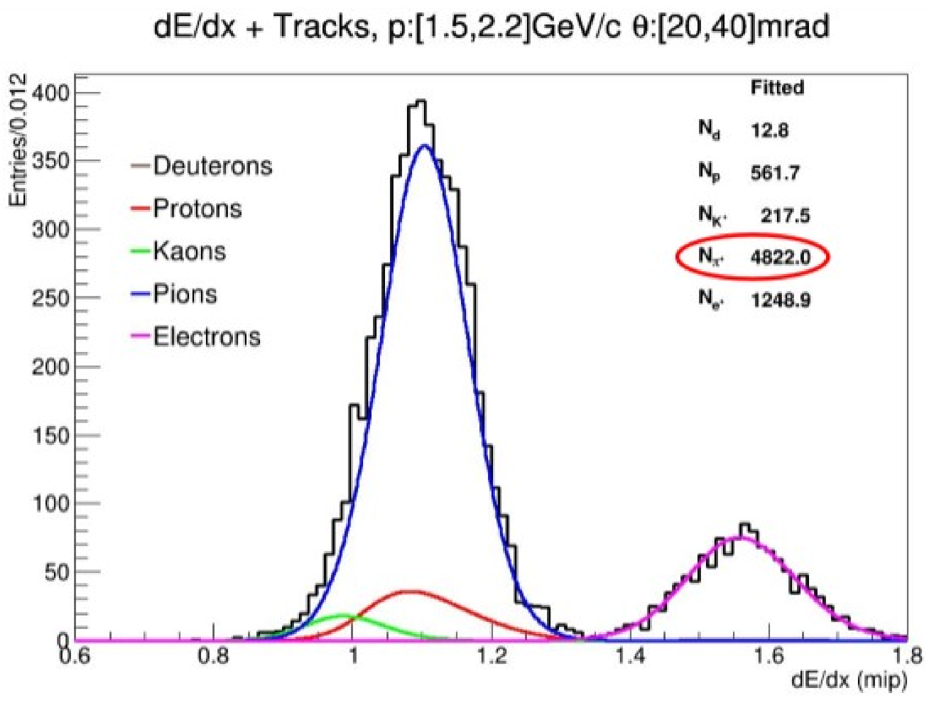
60
70
80
90
1.4
1.2
1
0.8
0.6
0.4

Calibration Chain Performance

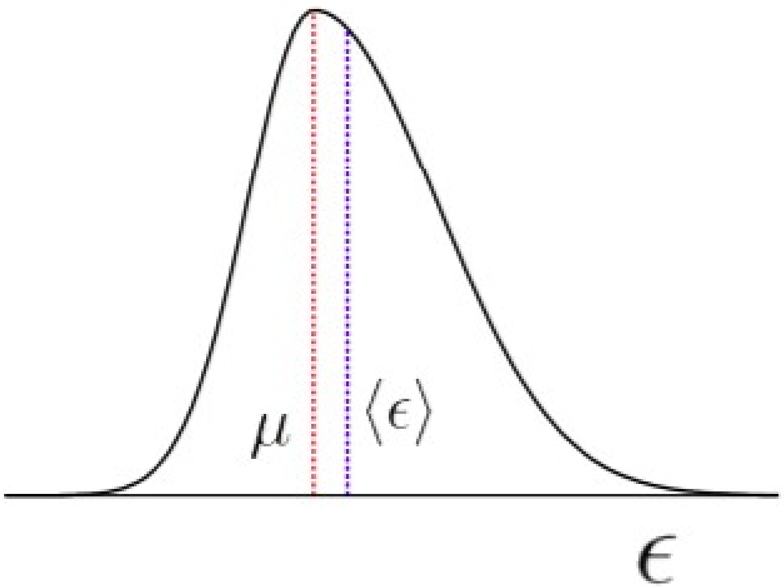
Evaluation: dE/dx Fits

- In order to evaluate performance, we perform dE/dx fits to calibrated data
- Perfectly-calibrated data:
  - Aligns with theoretical Bethe-Bloch across phase space
  - Has smooth variation of fit parameters
- Performance fits tell us how well calibration was performed





Model



$$\frac{dE}{dX} = \epsilon$$

$$\langle\epsilon\rangle^{ref} \rightarrow energy\ loss\ function$$

Resolution

$$\sigma_i = \sigma_0^{\pm} \frac{(\langle\epsilon\rangle_i)^p}{\sqrt{N_{cl}}}$$

Calibration constants

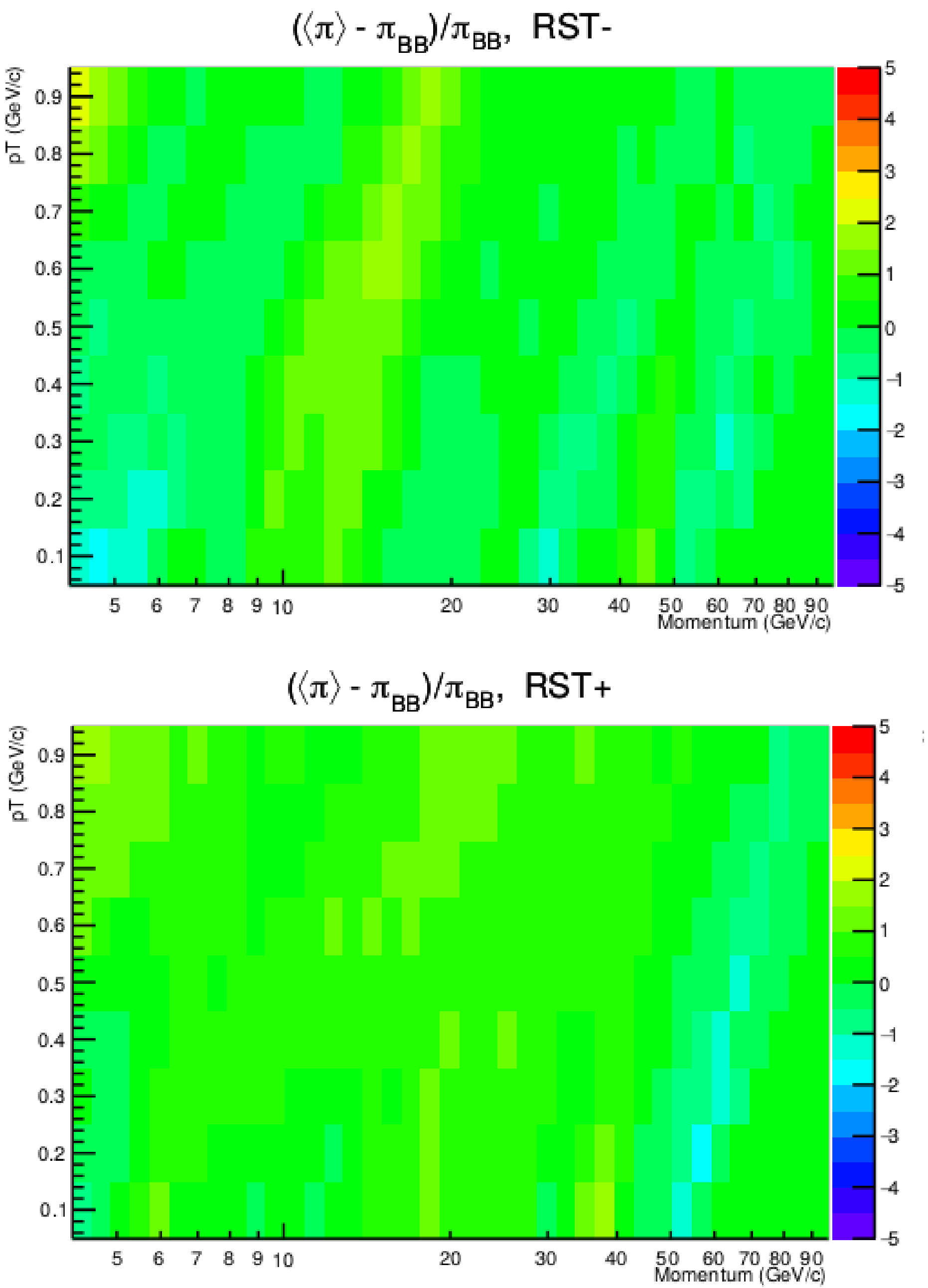
$$\langle\epsilon\rangle_i = \langle\epsilon\rangle_i^{ref} \cdot exp(X_{\pi^\pm}) \cdot exp(X_i)$$

PDF → Asymmetric gaussian

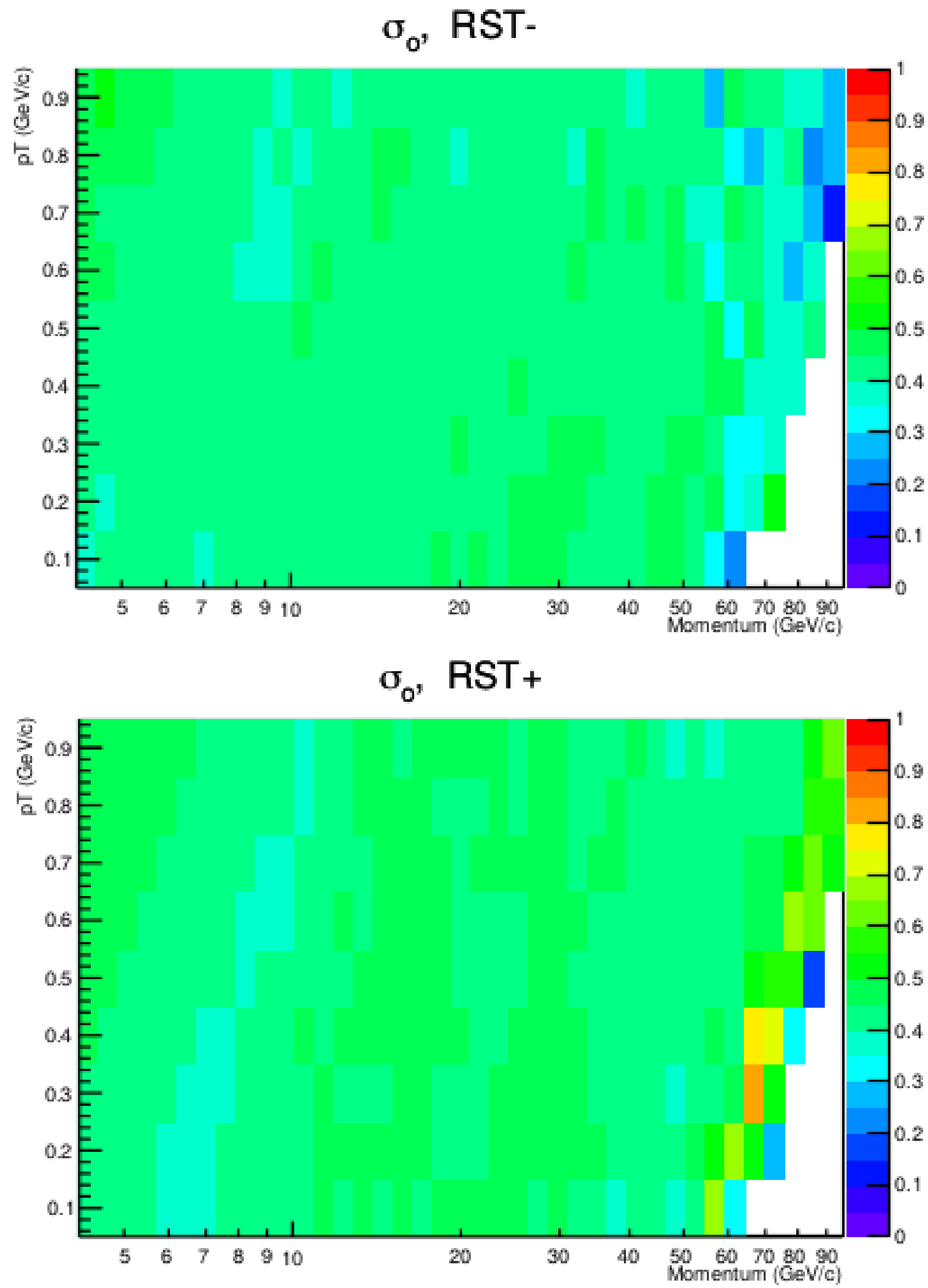
$$f(\epsilon) = \frac{1}{\sqrt{2\pi}\sigma} exp\left[-0.5\left(\frac{\epsilon-\mu}{\delta\sigma}\right)^2\right]$$

$$\delta = \begin{cases} 1-d & \epsilon < \mu \\ 1+d & \epsilon > \mu \end{cases}$$

Calibration Evaluation



Bethe-Bloch Deviation



Resolution Parameter

Automation

dE/dx Calibration Framework

- Calibration procedure is now automated
  - Final tests being performed
  - No direct intervention required by calibrator between steps
  - Package of QA plots produced
- Will allow testing of iterative calibration
  - Running entire chain multiple times may further improve calibration

New Framework: dE/dx Calibration 2020+

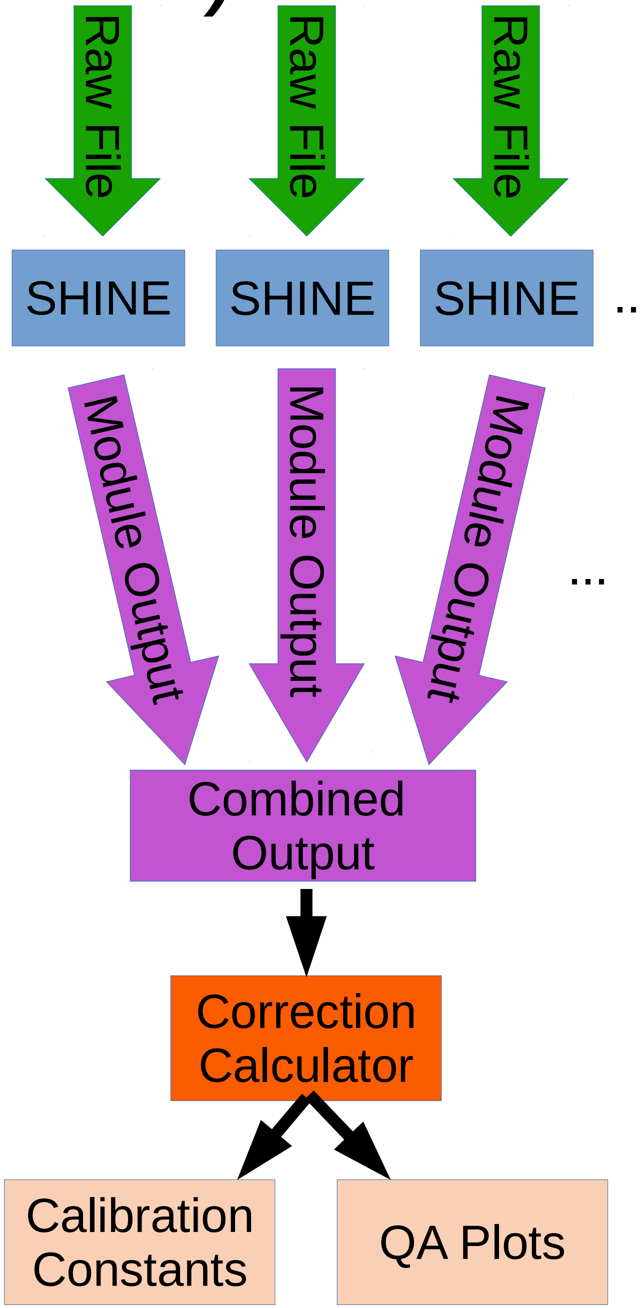
- Significant development required for 2020+ dE/dx calibration
  - New electronics will require update to threshold corrections (Gabor tables)
    - Will probably have other unknown effects
  - Higher beam intensity will likely require new correction on top of current ones
- **Person-power needed here!**

Thanks!

BACKUP

Correction Structure (General SHINE Structure)

- Modules run after reconstruction and TPCDEDXCalculator
- Store TTrees with cluster-specific information in output file
- Correction-specific Calculator runs on combined file
- Calculator produces:
  - QA plots
  - ROOT file with input for QA plots
  - Text file to be moved by user to Database



Performance Evaluation

- To test performance, compare pion peak in calibrated data to pion Bethe-Bloch
- Look for deviations from pion Bethe-Bloch in regions of phase space
- Binning scheme (2D):
  - Track charges & topologies separated
  - Total momentum (39 bins): 4 GeV/c – 96 GeV/c
  - Constant widths in log(p)
  - PT (9 bins): 0.5 – 9.5 GeV/c
  - Constant widths in pT
- Identical binning scheme to Legacy evaluation