Status of π^0 calibration

(review of results from last year)

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NPS Collaboration Meeting

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Method of π^0 calibration

- *"A bootstrap method for gain calibration and resolution determination of a lead-glass calorimeter"* *(Nuclear Instruments and Methods in Physics Research A 566 (2006) 366–374)*

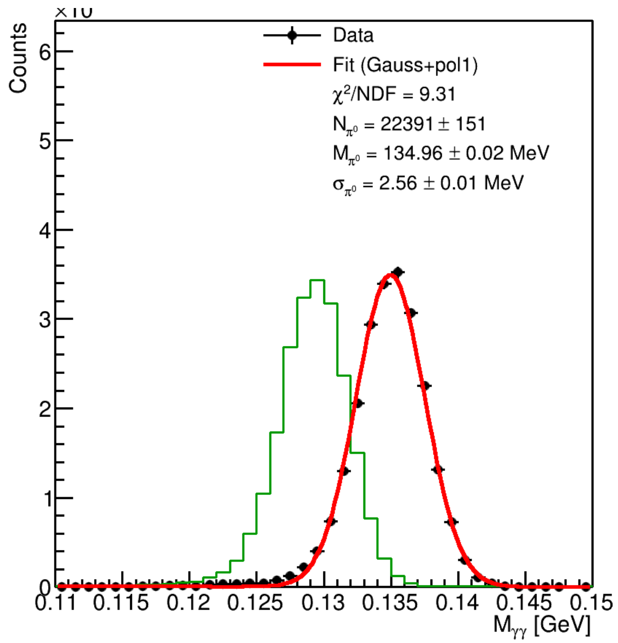
- Optimize the width of π^0 invariant mass peak while constrain the peak position simultaneously using:

$$F = \sum_{i=1}^{N_{events}} (m_i^2 - m_0^2)^2 + 2\lambda \sum_{i=1}^{N_{events}} (m_i^2 - m_0^2)$$

resolution term to optimize

constraint $\langle m_i^2 \rangle = m_0^2$

$m_0 = M_\pi = 0.1349766$ GeV
m_i: reconstructed $M_{\gamma\gamma}$
λ: Lagrange multiplier

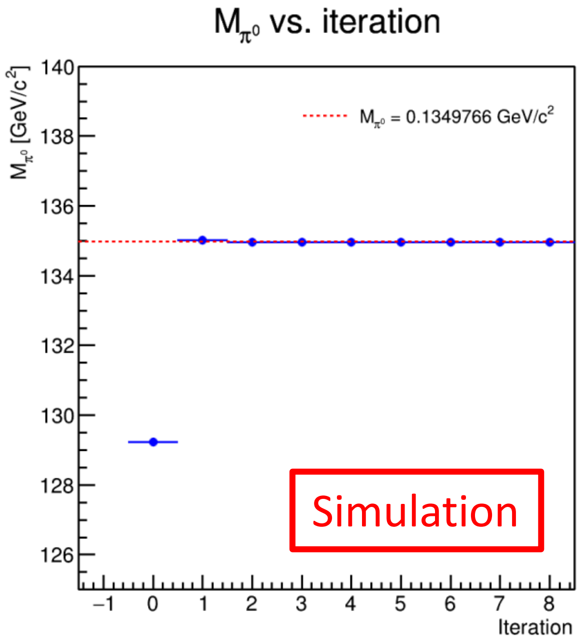


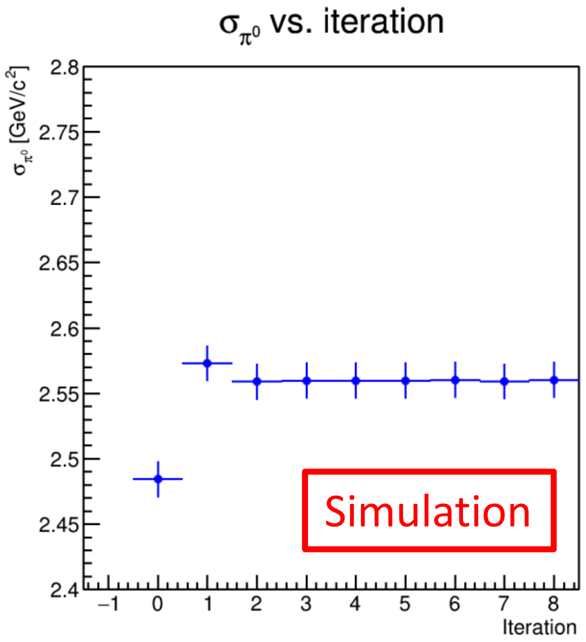
- Let $E'_k = (1 + \varepsilon_k)\, E_k$ be the calibrated deposited energy in block k, the calibration is done by minimizing F respect to correction factor ε_k

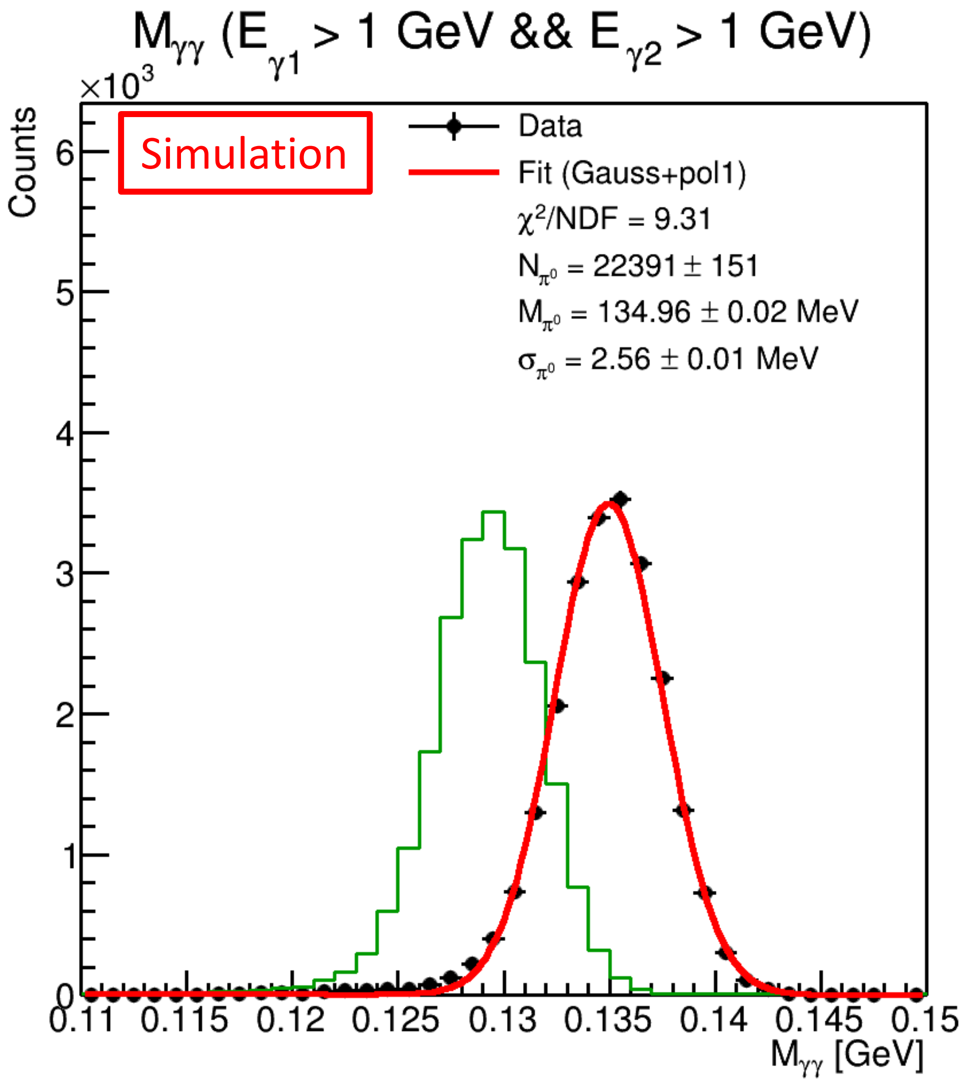
- Iterations are required till the mean and width of π^0 are converged ($\varepsilon_k \to 0$)

Performance of π^0 calibration with simulation

- MC data reconstructed using Geant4
  - ~300k events of $\pi^0 \longrightarrow \gamma\gamma$ were generated
  - HMS momentum = -6.667 GeV/c, angle = 12.493 degree
  - SHMS angle = 36.88 degree, NPS angle = 20.58 degree
  - NPS at 3 meter (the first kinematic we took)
- Very good performance of the calibration scripts



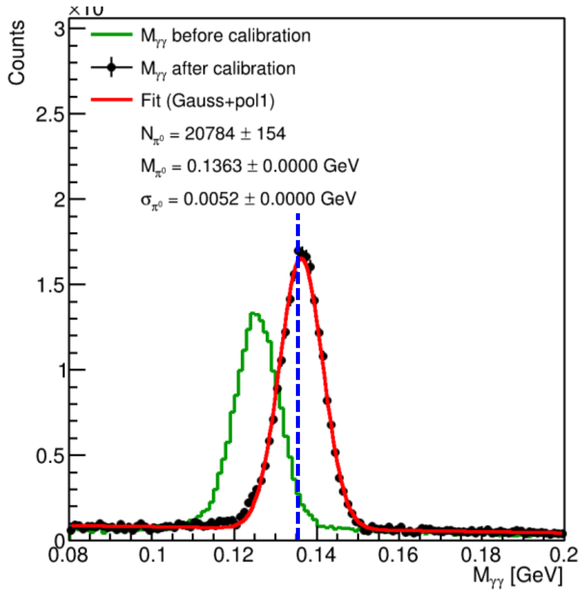




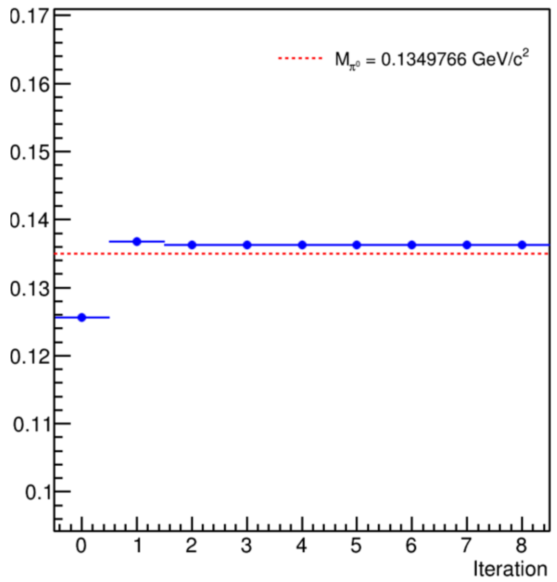
Results of π^0 calibration with real data

- Mean value of π^0 mass is stable after 3 iterations
- At least 5 iterations are required to make its width stable
- Both mean and width are improved after calibration

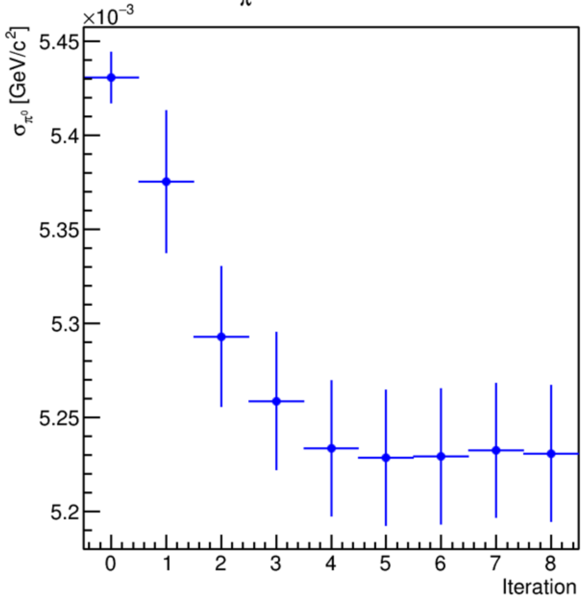
π^0 invariant mass



M_{π^0} vs. iteration



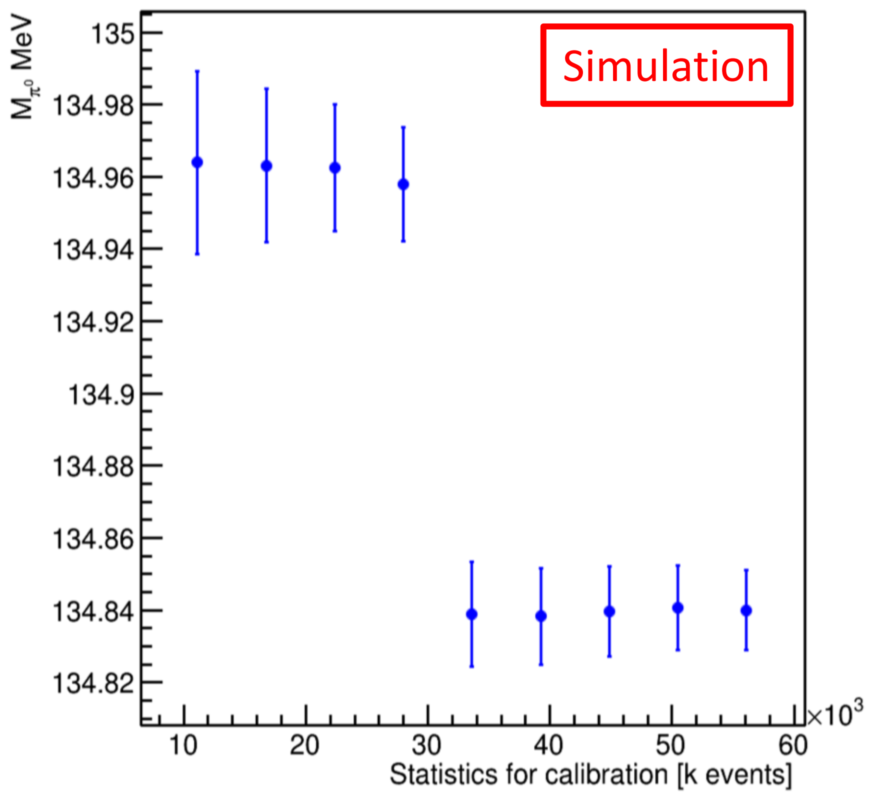
σ_{π^0} vs. iteration



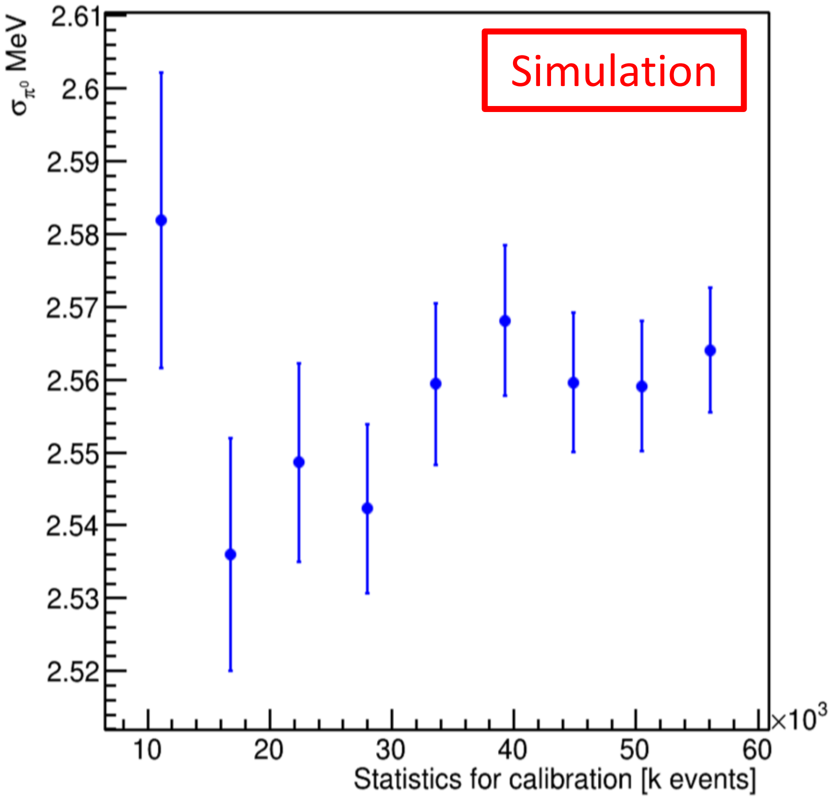
Required statistics for calibration

- 20k of π^0 events seems to be enough for calibration based on the width (0.5 hours of beam time with KinC_x36-5; 2-3 hours with x60-3 and x60-4 on LH2)

M_{π^0} vs. number of π^0 used for calibration



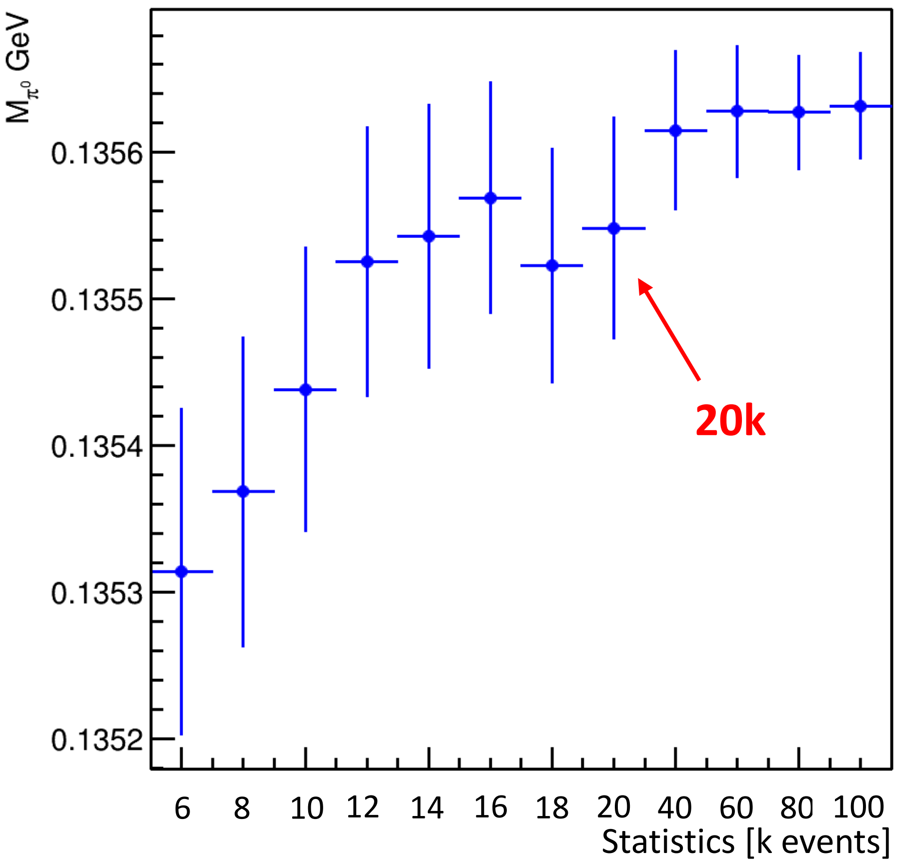
σ_{π^0} vs. number of π^0 used for calibration



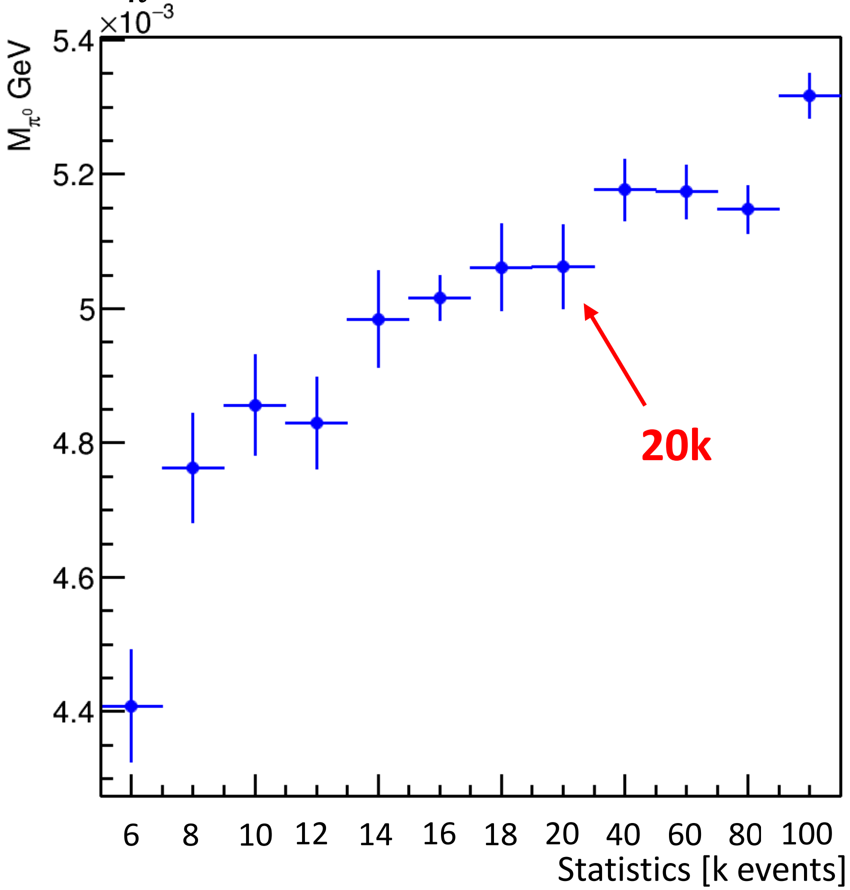
Required statistics for calibration with data

- Kinematics: KinC_x36-5
- Same conclusion as simulation: 20k of π^0 events may be enough

M_{π^0} vs. number of π^0 used for calibration

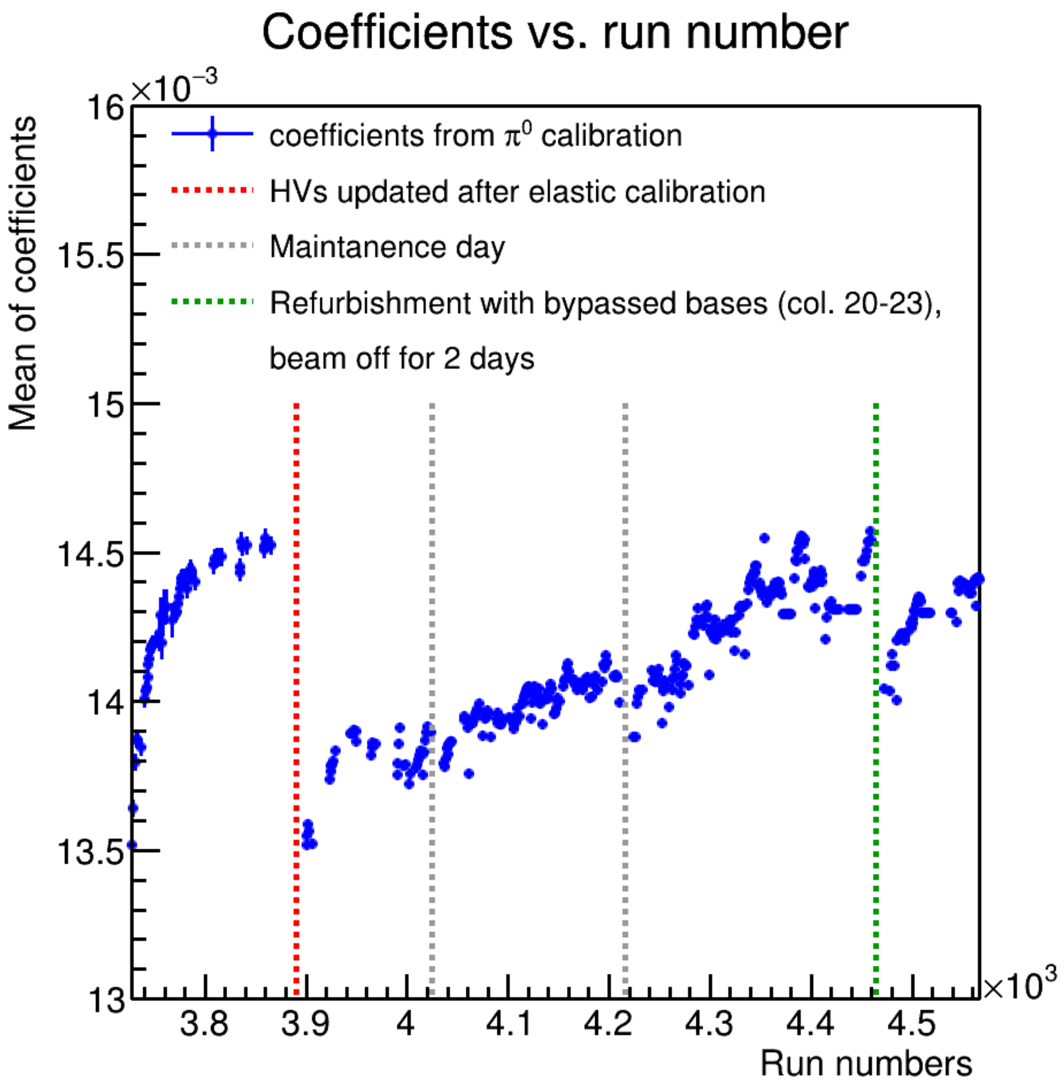


σ_{π^0} vs. number of π^0 used for calibration



Results of calibration as a function of run number

- First month of data in 2024
- 8 kinematics, run 3728-4550
- Calibrated using ~100k π^0 events
- Elastic calibration was done after taking 7 days of production data
- Decrease of coefficients after updating HVs and long time of beam OFF

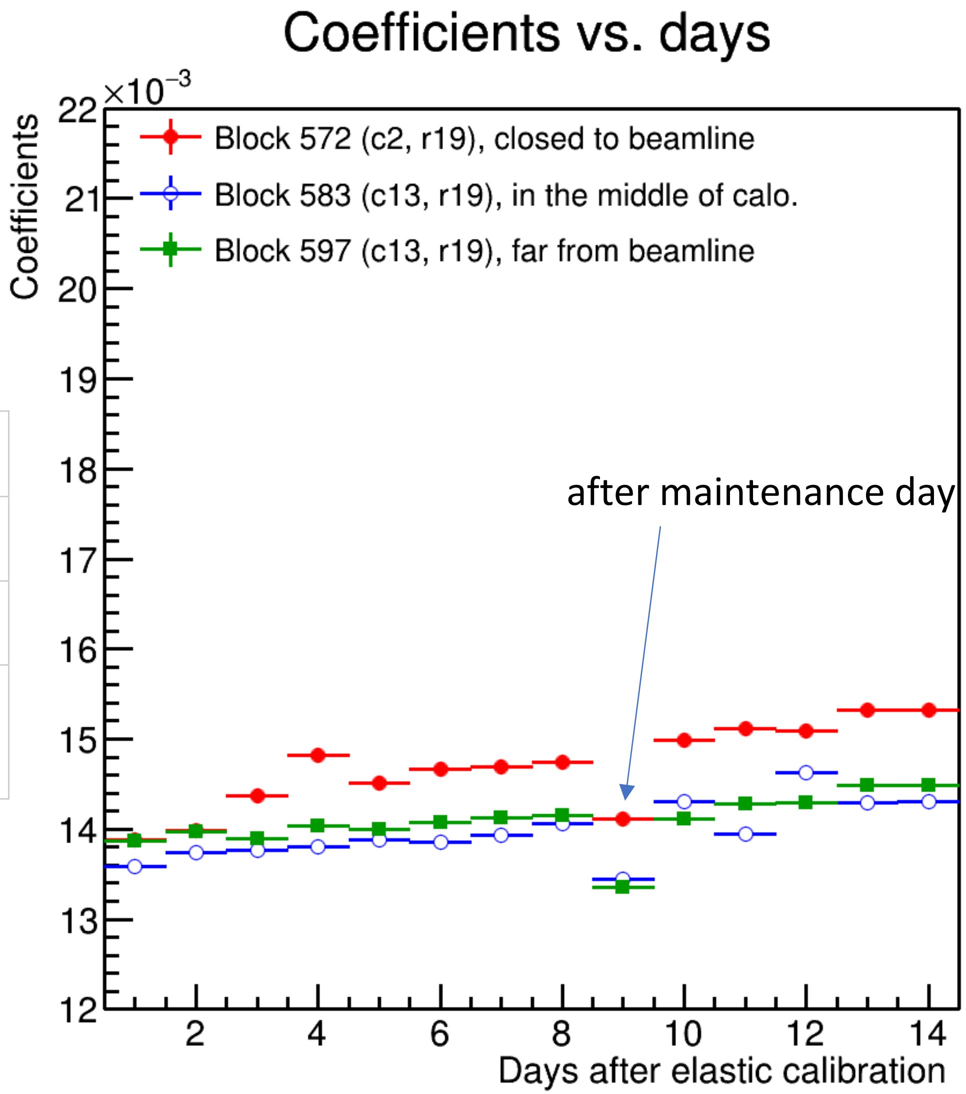


Comparison between different blocks

- Average of coefficients after elastic calibration at the edge and in the middle of calorimeter
- Coefficients of blocks closed to the beamline were increased more than the others as we expected

Block number	572	583	597
Coefficients (right after elastic calibration) [MeV/mV]	13.8860	13.5846	13.8736
Coefficients (two weeks after elastic calibration) [MeV/mV]	15.3157	14.2997	14.4826
Increased coefficients [MeV/mV]	1.4297 (10.3%)	0.7157 (5.27%)	0.6090 (4.39%)

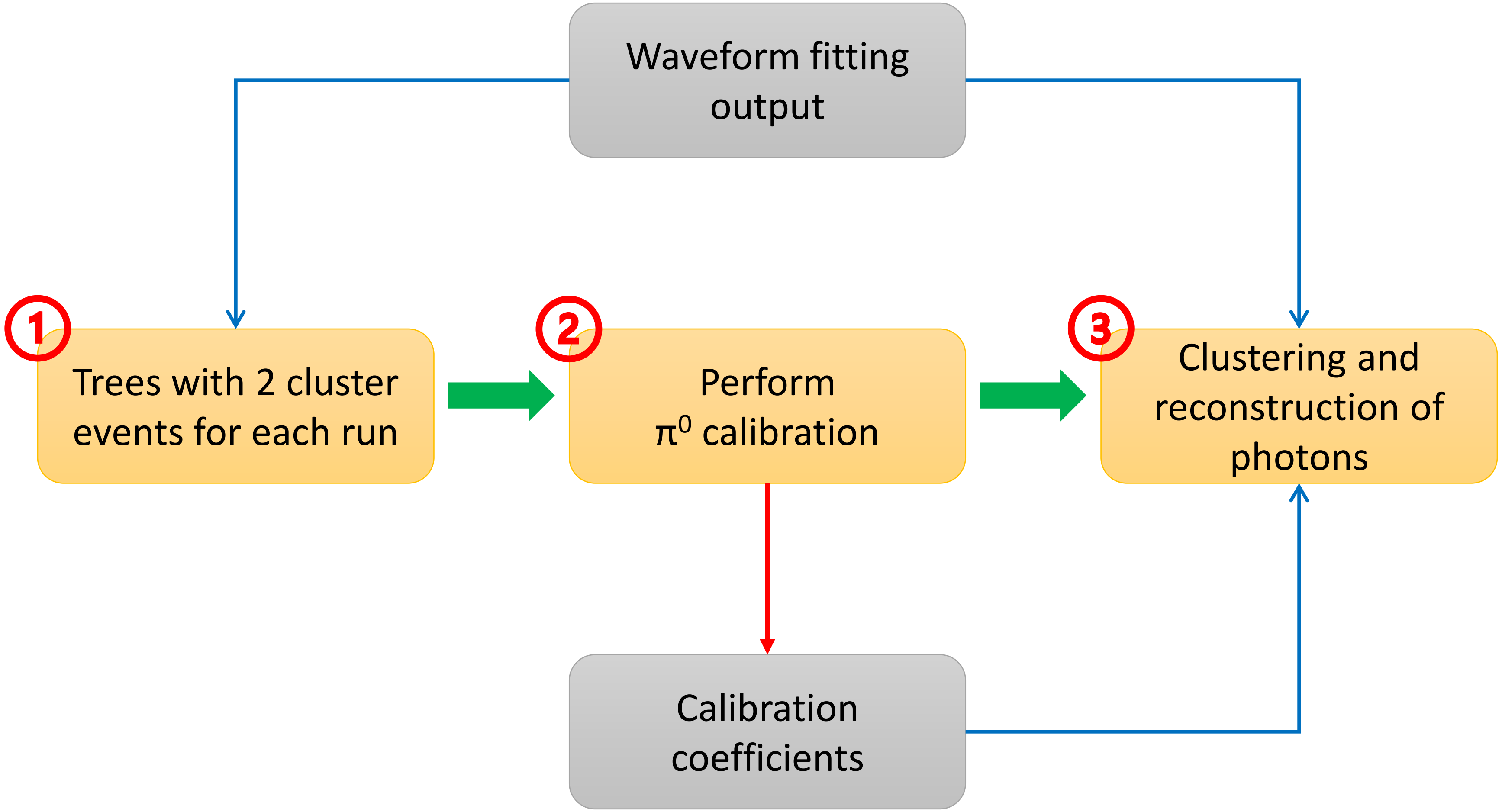
BEAM



Conclusion

- The script for π^0 calibration is ready
- Study of the π^0 calibration performance was done using simulated and real data
- 20k of pure π^0 events seems to be enough for calibration
- The frequency of calibration depends on kinematics and beamtime
- π^0 calibration using the 1st month of pass0 data in 2024 was done
- Calibration coefficients changed when the beam was OFF or elastic calibration was performed
- The new calibration will start once we have the output from waveform analysis

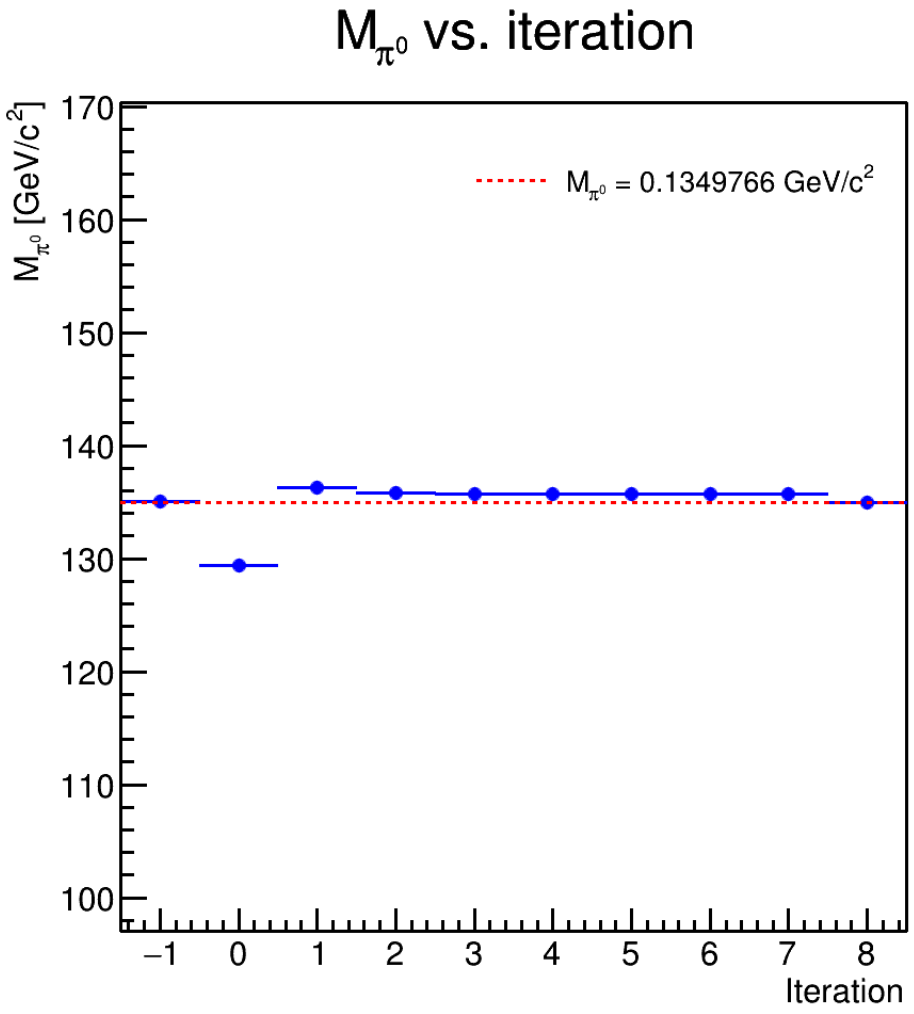
Calibration workflow



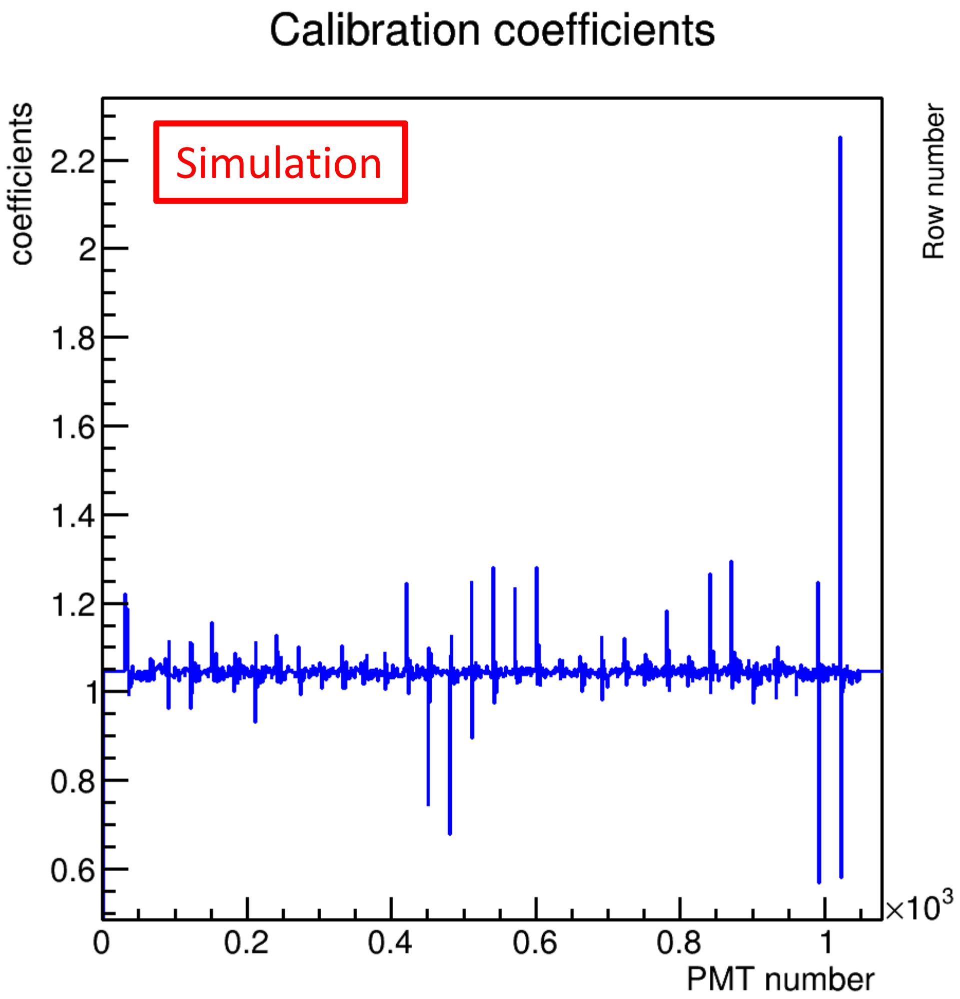
Backups

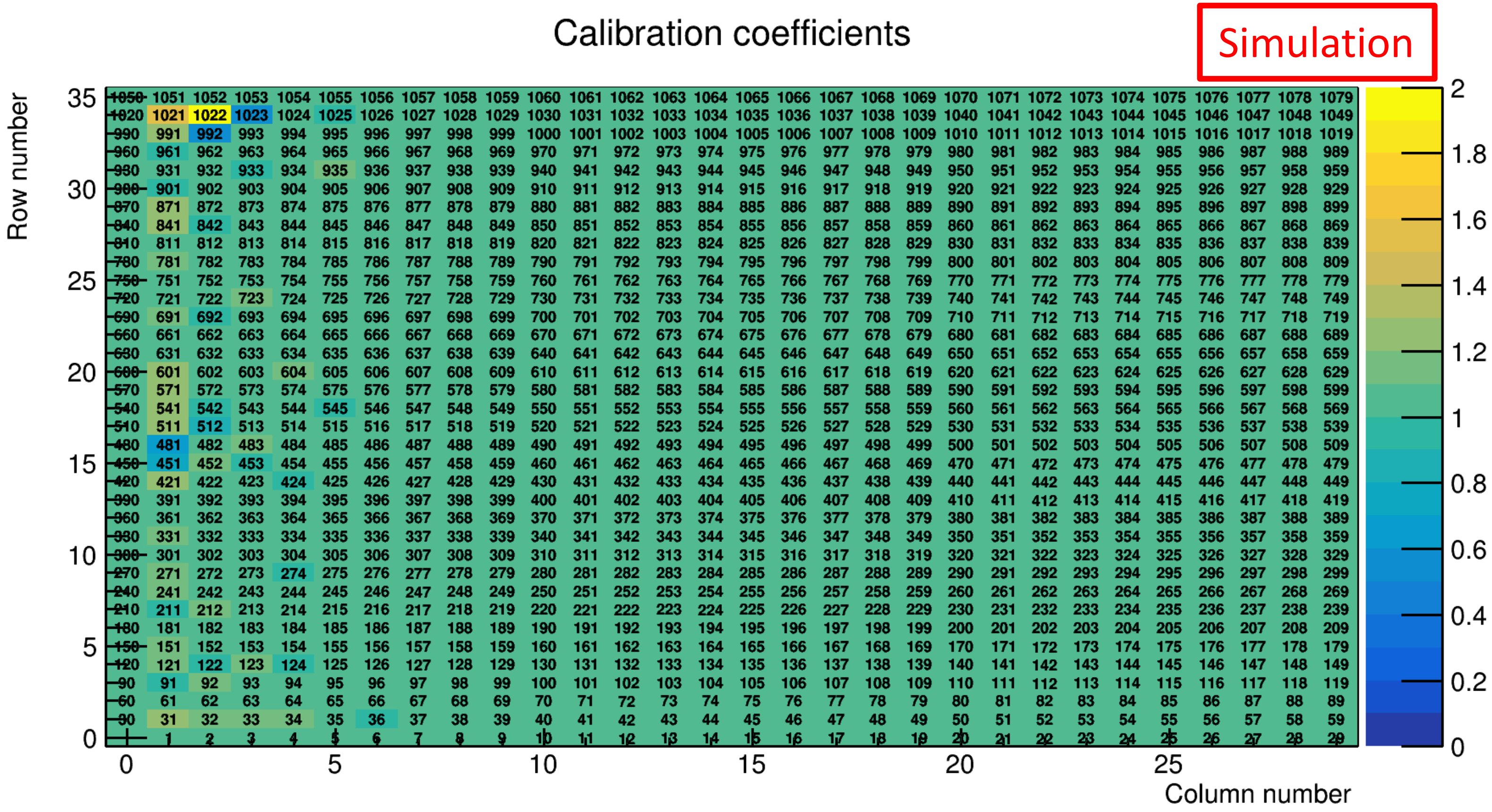
Additional correction for π^0 calibration

- Used in previous DVCS experiment in Hall A for the fast darkening of crystals
- $C'_k = C_k \times \frac{m_\pi = 0.1349\ GeV}{< m_\pi^{reconstruct} >}$ for each block k



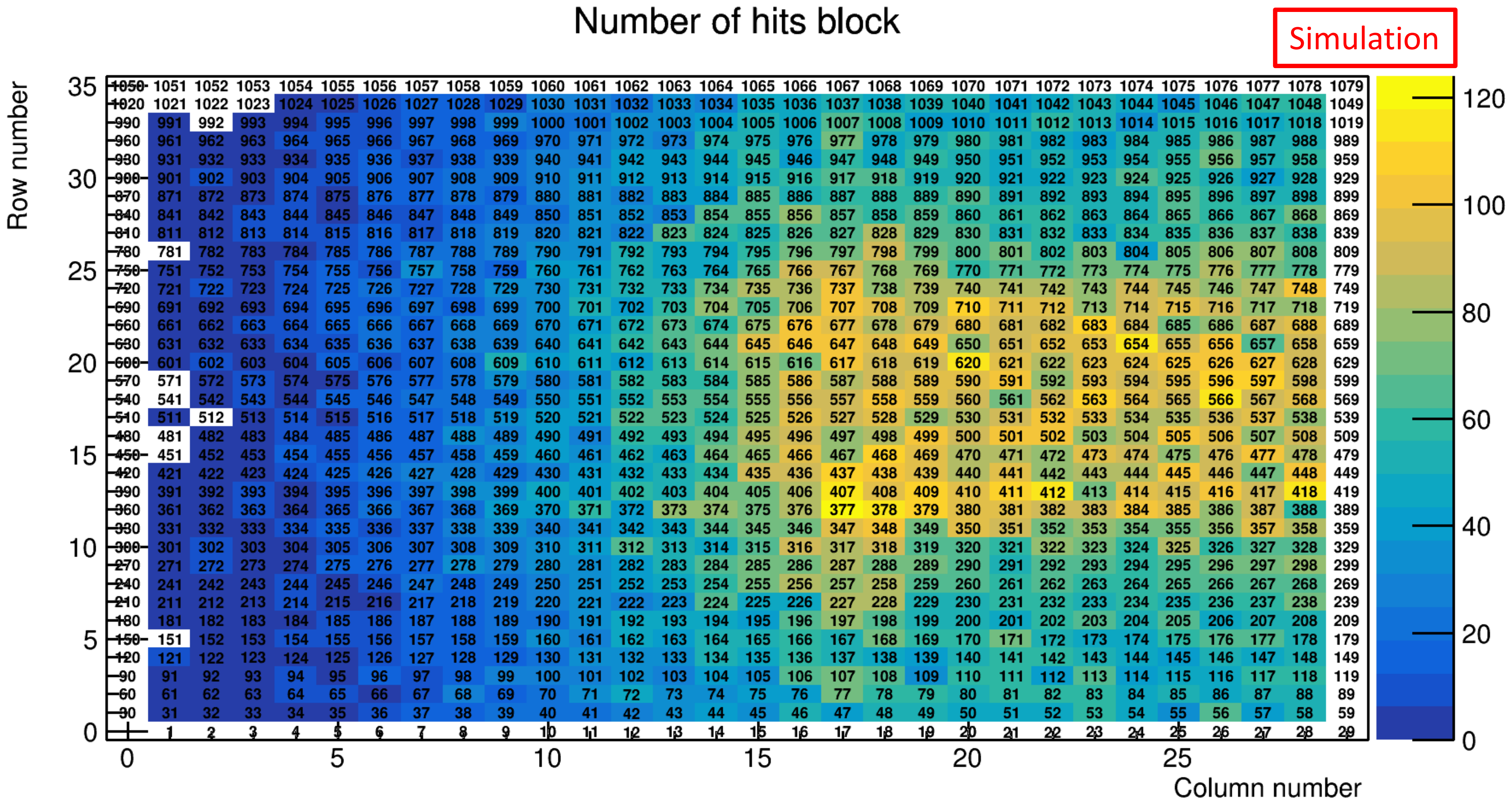
Calibration performance with 20k π^0 events





Number of photons per block with 20k π^0 events

Simulation

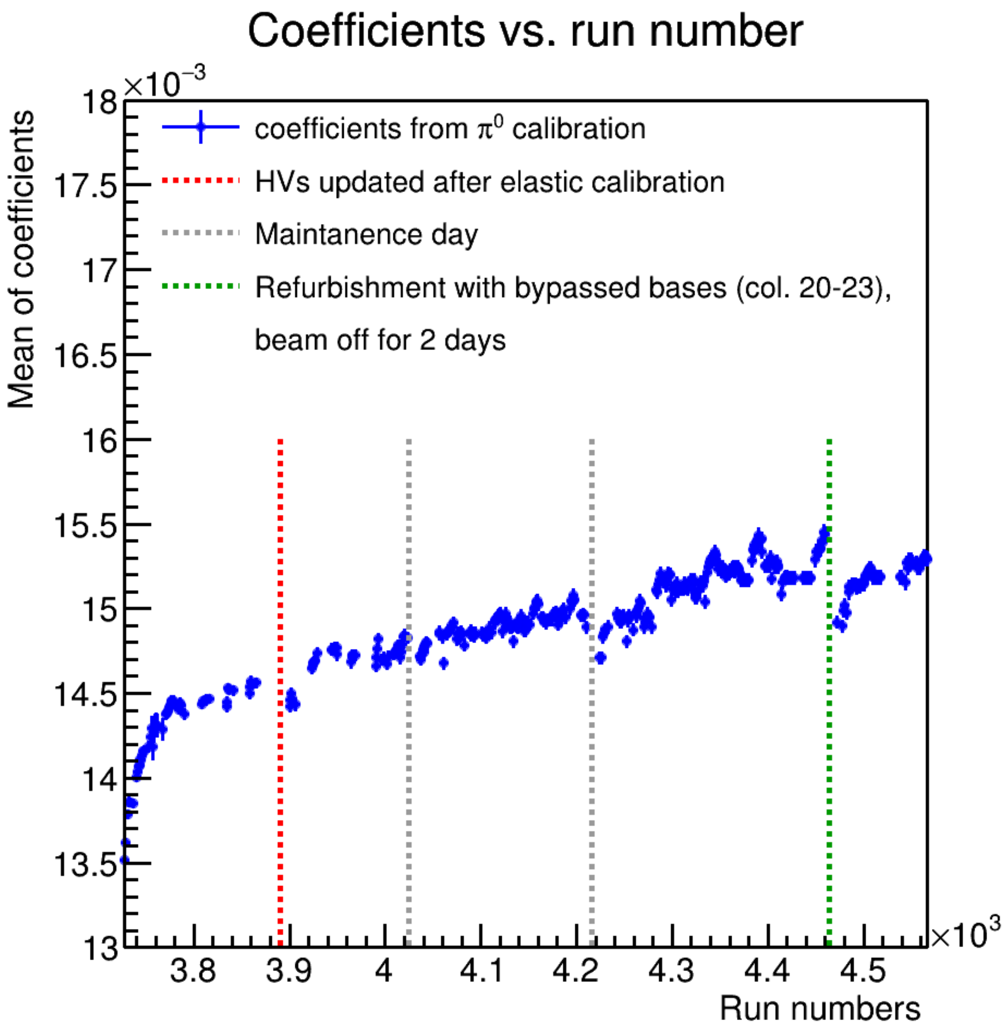


If we didn’t update HVs

- Restore to the old coefficients with

$$C^k_{old} = C^k_{new} \times \left(\frac{\mathrm{HV}_{new}}{\mathrm{HV}_{\mathrm{old}}}\right)^b,\ b = 5.9$$

- Radiation damages of the crystal were saturated and increased steady after some point
- Cure of the crystals might be meaningless if the damages come back too fast



π^0 mass position vs. run number (pass1)

- Stable around ~130 MeV
- 130 MeV rather than 135 MeV may be due to a slightly wrong distance of NPS during previous calibration