TPC calibration plans

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sPHENIX workfest, BNL, 13 Jan 2020

Summary of relevant calibrations

- Drift velocity
- Gain and dE/dx
- Calibration using external detectors
  - ExB correction
  - Alignment
- Overall detector alignment
- Space-charge (→ see Ernsts presentation)

Drift velocity

Available methods

- Temperature and pressure scaling
- Laser system (anchor)
- Track matching across central electrode
- Reconstructed vertex position from A and C-Side
- Track matching between ITS and TPC
- **Space-point distortion calibration (interpolation method) in voxels**

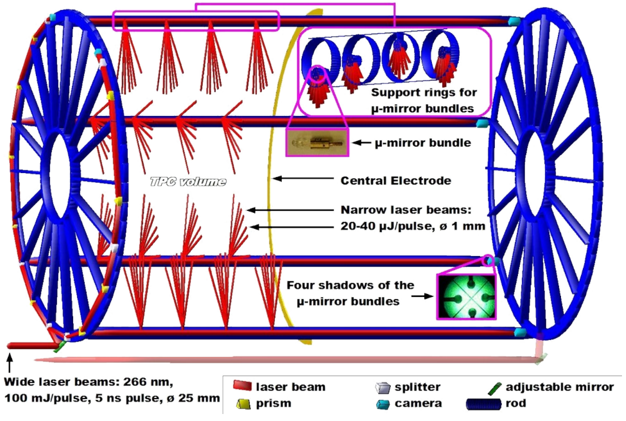
$$\frac{\Delta v_d}{v_{d0}} = k_t(t) + k_{P/T}\frac{\Delta(P/T)}{(P/T)_0}$$

$k_t(t) = k_c(t) + x_G * k_{dx} + y_G * k_{dy}$

kx, ky = f(dT, dP)

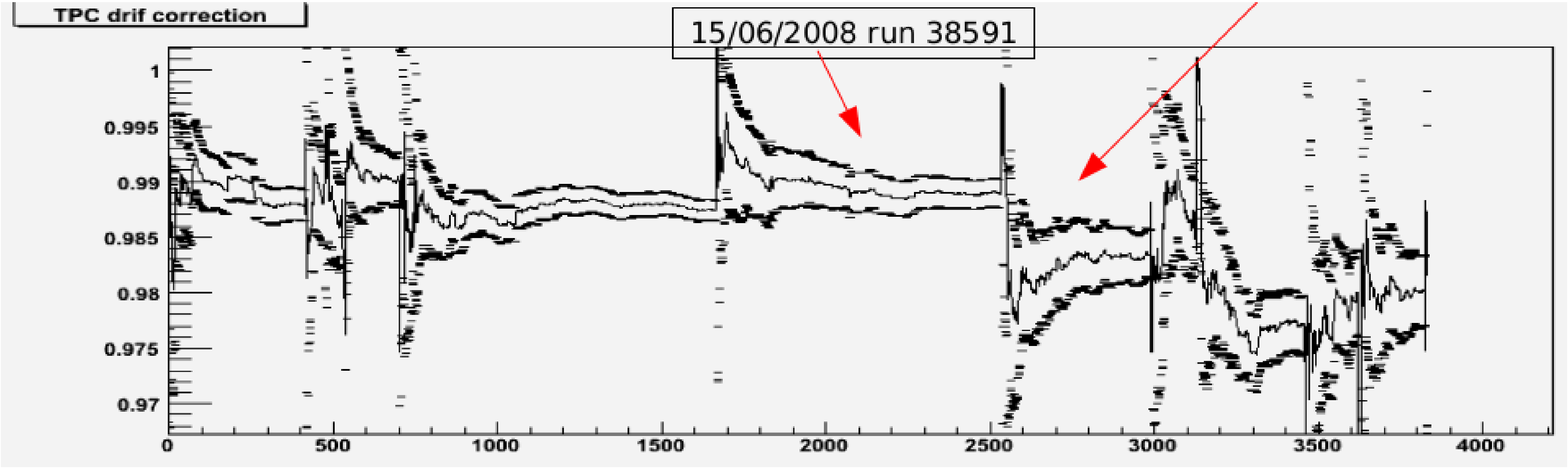
Available methods – Laser system

- Laser fired every 30min – 1h
  (to maximize life time)
- Follow signal from central electrode (CE)
  - Simple to identify due to number of fired digits in few time bins
  - Also used for fast online feedback and monitoring
  - Main method for initial estimate
  - Requires trigger offset for absolute calibration, fine for relative calibration
- Reconstructed laser tracks
  - Mirror positions known
  - Can be used for precise estimates
  - However, signals often weak, not always aligned well
    → not many tracks reconstructable



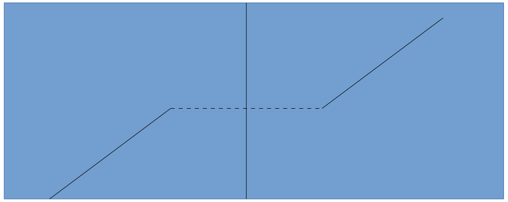
Available methods – Track matching to ITS

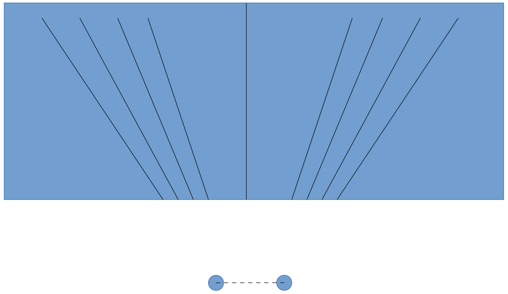
- Kalman filter with drift velocity as parameter
- Was the main method for drift velocity estimate



Available methods – Track matching across CE

- Use time offset of tracks crossing the CE
- Time offset between reconstructed vertex A-, C-Side
- Method not used in present processing



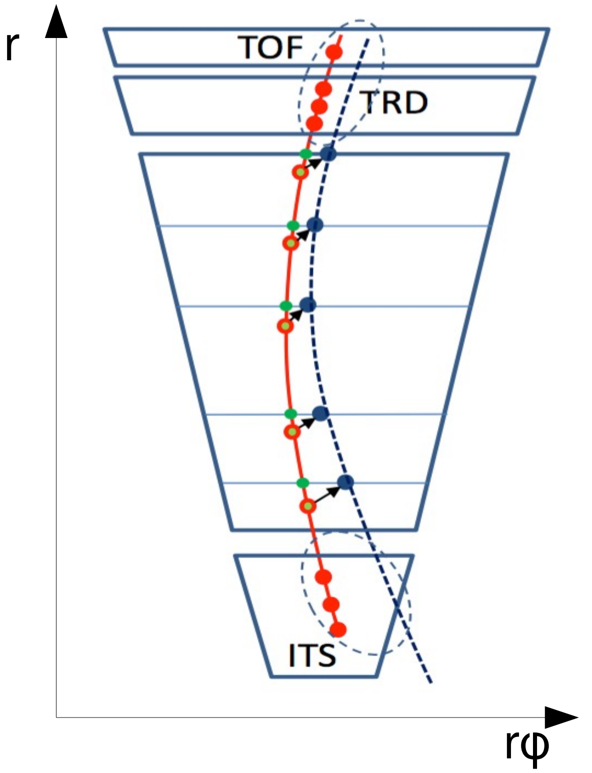


Final estimate

- All methods used in parallel weighting their contribution by
  - The distance to the latest measurements point (e.g. laser available only every 30min-1h)
  - A generic weighting by importance (e.g. 64 for [ITS] matching, 1 for CE measurement)

Calibration using external detectors

- Includes several calibration components
  - Alignment
  - T0
  - Drift velocity
  - ExB (originally based on laser measurements)
  - Distortions
- Disentangle static part by running with low IR
  - Dedicated reference run
  - Might require higher granularity
- Can be obtained with high time granularity
- Extracted distortion maps



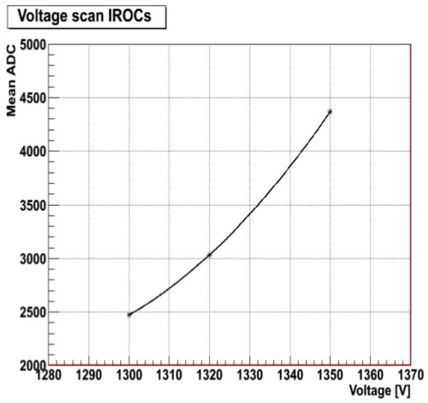
Gain calibration

List of gain calibrations

- ^{83}Kr calibration
  - Chamber-wise gain equalisation
  - Pad-wise gain calibration
- Correction using T, P and HV
- Average gain correction over time
- Average pad-region calibration

^{83}Kr calibration

- Extract gain curve per read-out chamber (ROC)
- Determine voltage for (average) gain equalization over ROCs
- Extract spectrum on pad-level for gain equalization
- For final map
  - need to take into account outlier pads
  - Special treatment of ROC edge (clusters not fully reconstructable)
  - Simple scaling of per-pad gain for varying conditions (HV, gain)



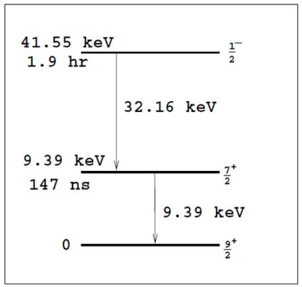
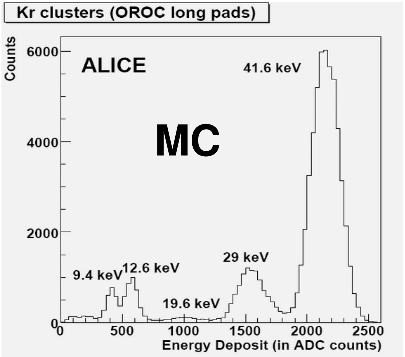
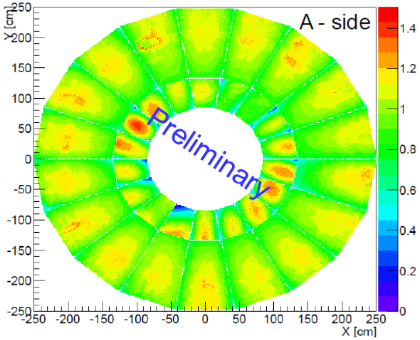
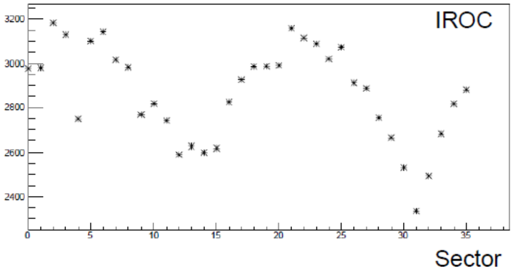


Figure 36: Diagram of deexcitation of the $^{83}_{36}$Kr isotope.

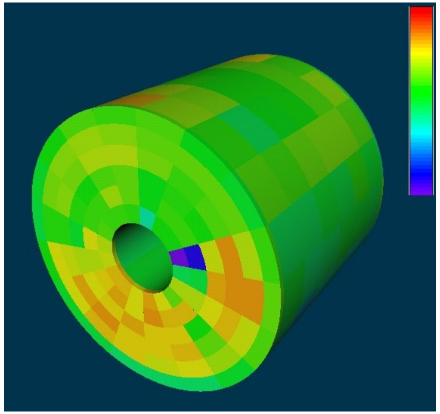


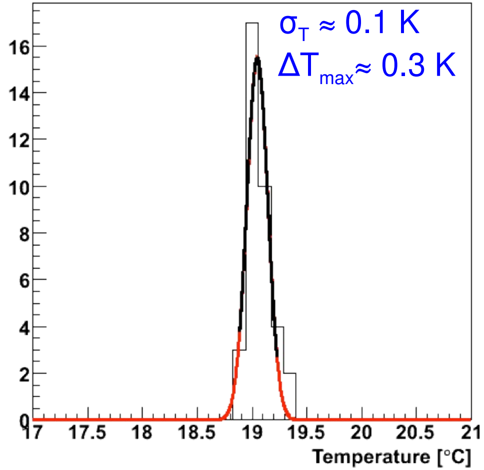




Correction using T, P and HV

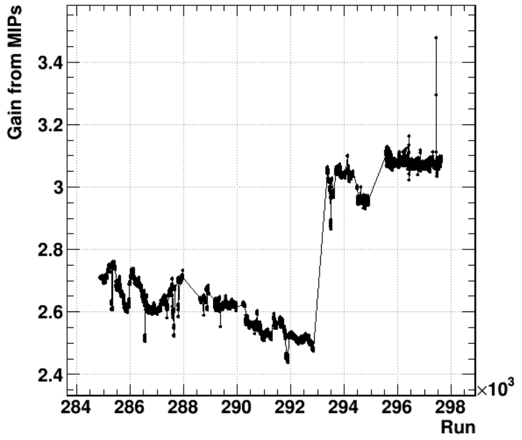
- Temperature measured inside the TPC using 2x18 sensors close to the end plate
  - System precision is ~100mK
  - Possible to measure temperature gradient
  - Number of sensors will be reduced to 2x4 after the upgrade
- Pressure measured centrally in the experimental cavern
- HV curve of every sector known from ^{83}Kr
- HV available from slow control system

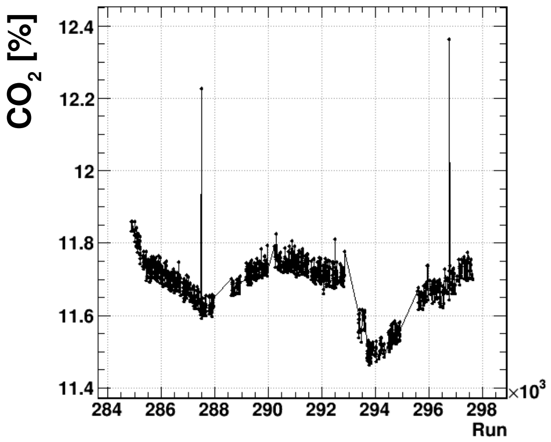




Average gain correction over time

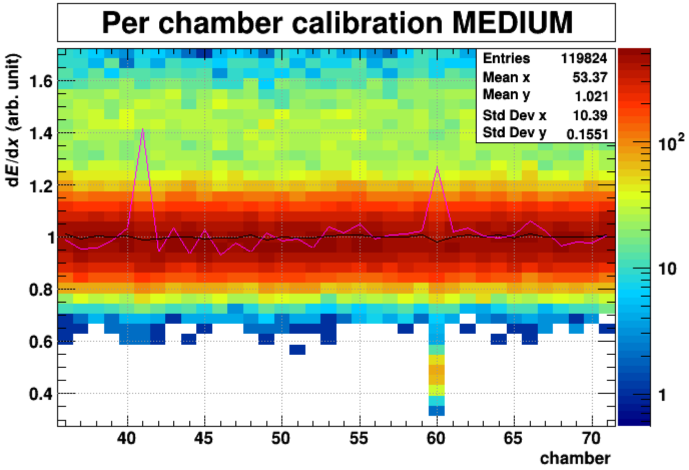
- MIP position monitored over time
- Residual variations mainly due to changes in the gas composition
  - Gas composition monitored using a gas-chromatograph (GC)
  - Correction not implemented
    → gain using tracks more stable
  - Gas composition from GC used in MC
    → correct radiation length of gas
  - Also used for cross-check in QA

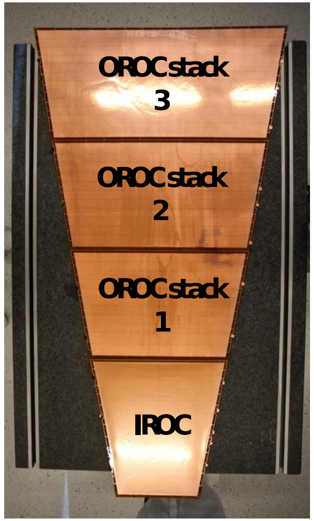




Pad-region calibration

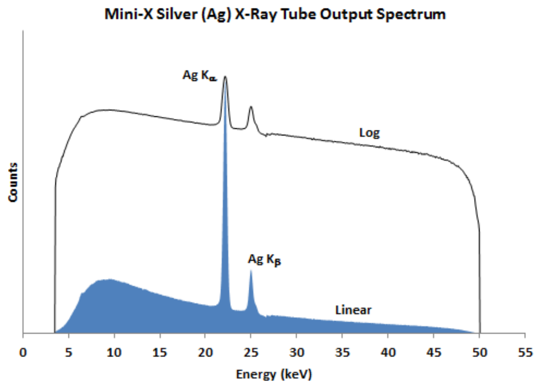
- For each run the average gain variation for each individual pad region is monitored
- IROC, OROC medium and long size pads
- For Run3 OROC is separated into 3 regions





Considerations and plans for run3 I

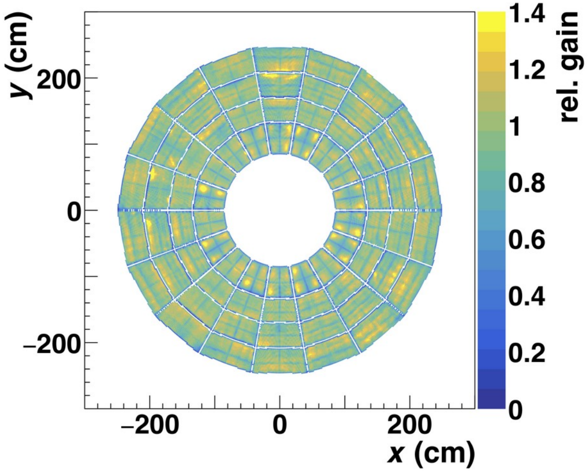
- Pad-wise calibration
  - Investigate if X-ray guns can be used for calibration purposes (e.g. Kα and Kβ Ag lines)
    - No creation and transport of ^{83}Kr source
    - Always available / much more flexible

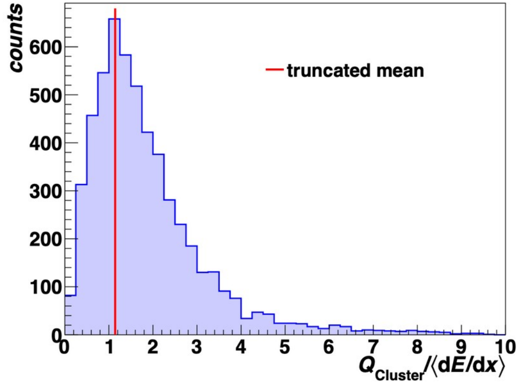


From Amptek Mini-X 2

Considerations and plans for run3 II

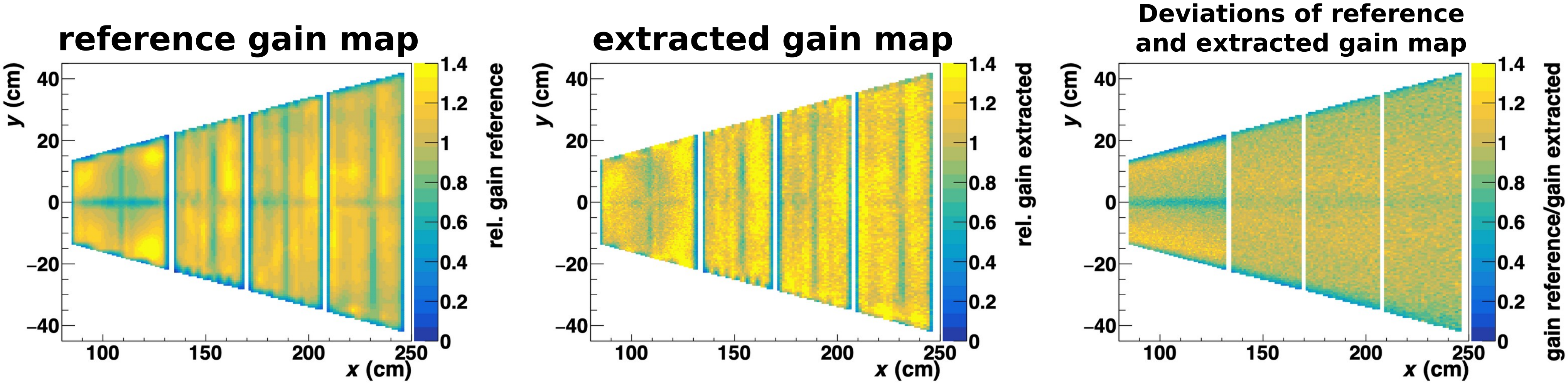
- Pad-wise calibration
  - For monitoring purposes we investigate to follow pad-gain variations using the self-calibrated probe $Q_{cluster}$ / <dE/dx>
    - High statistics in short time intervals → monitor changes over time
    - Always available during data taking
  - Tested with simulated data using a reference gain map





Considerations and plans for run3 II

- High p_T tracks have lower dE/dx in regions of low gain structures
  - resulting gain map is biased
  - deviations to reference gain map at edges and in the center of a sector
- Use only as residual calibration on top of Krypton



Considerations and plans for run3 III

- Gain variations over time
  - Update interval on 1s-1min level (was 15min in run2)
  - Be prepared for short-term fluctuations
  - Measure for each GEM stack individually?
- Distortions change dE/dx by changing dx
  → Needs to be taken into account in the calculation

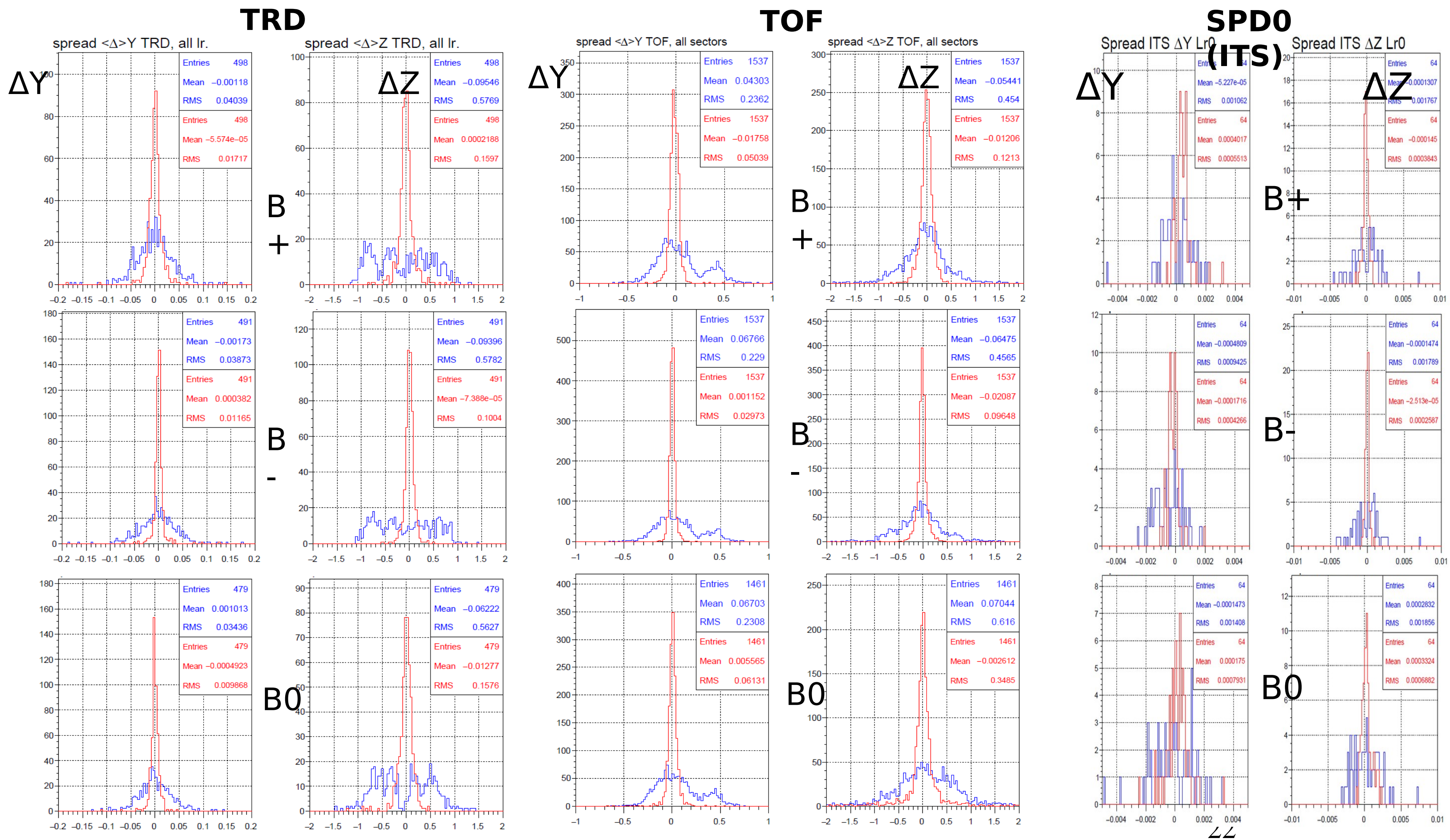
Plans for run3 alignment

→ **Thanks to Ruben!**

Overall detector alignment

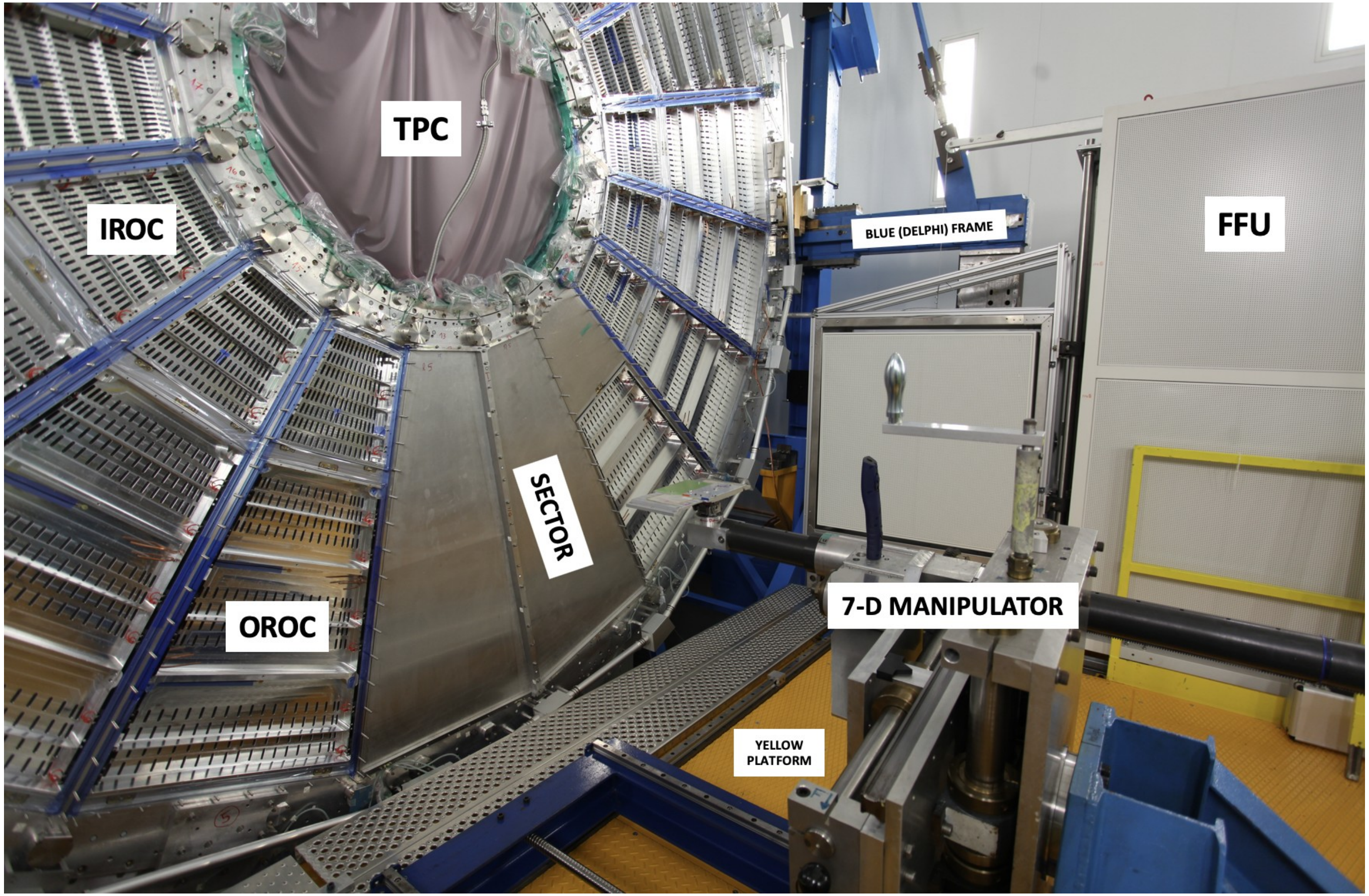
- Use Millepede to align all ~150k DOFs (large number due to new ITS)
- TPC only used as bridge between ITS and outer detectors
  - Will be aligned using the SCD calibration methode
- Initial alignment using cosmics + pp (B+, B-, B0)
- Plans for continuous monitoring with decreased DOF (rest fixed) using tracks / clusters from online reconstruction

Example of results in Run2 alignment (track cluster residuals): Before / after

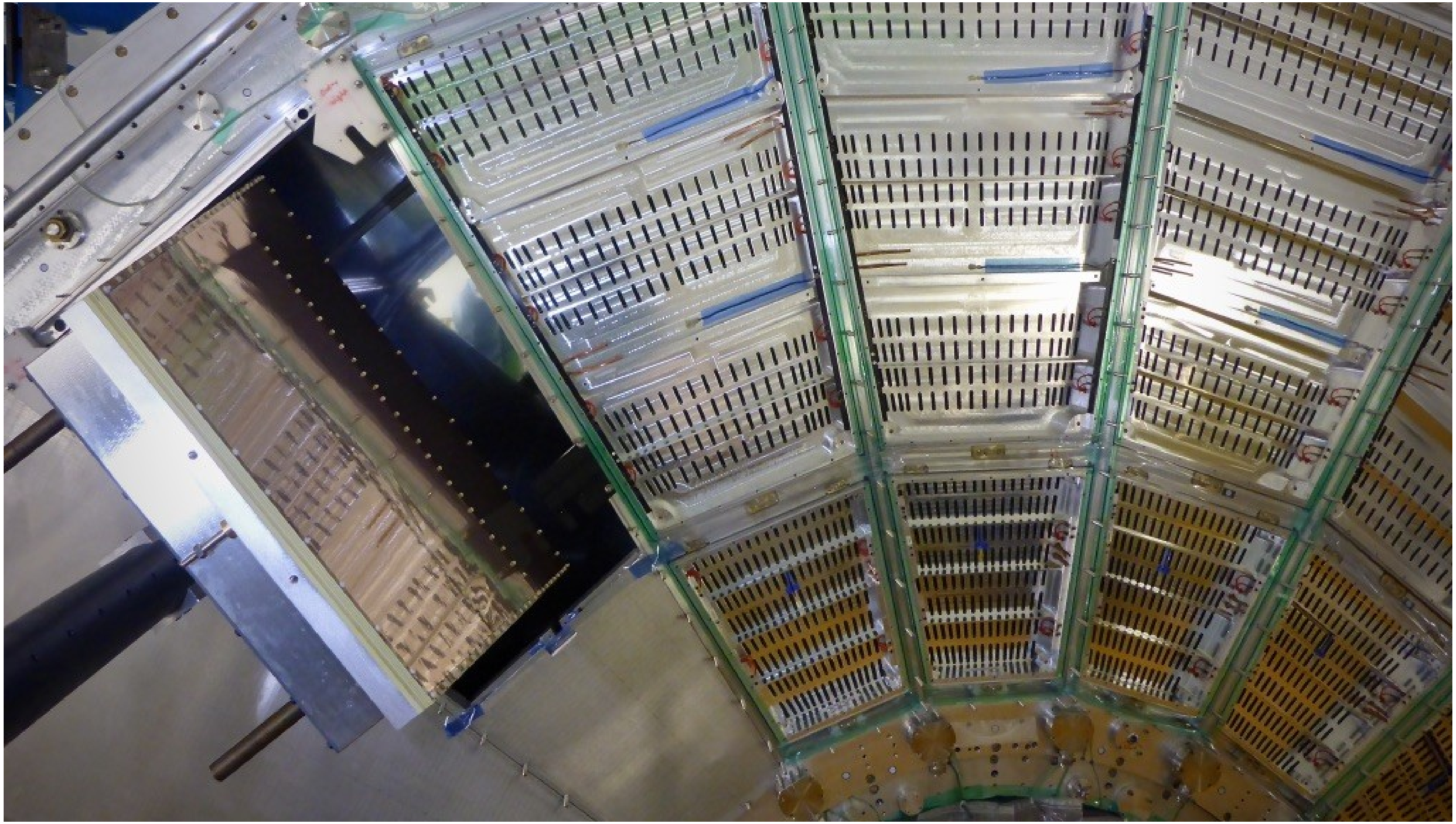


Assembly & Commissioning

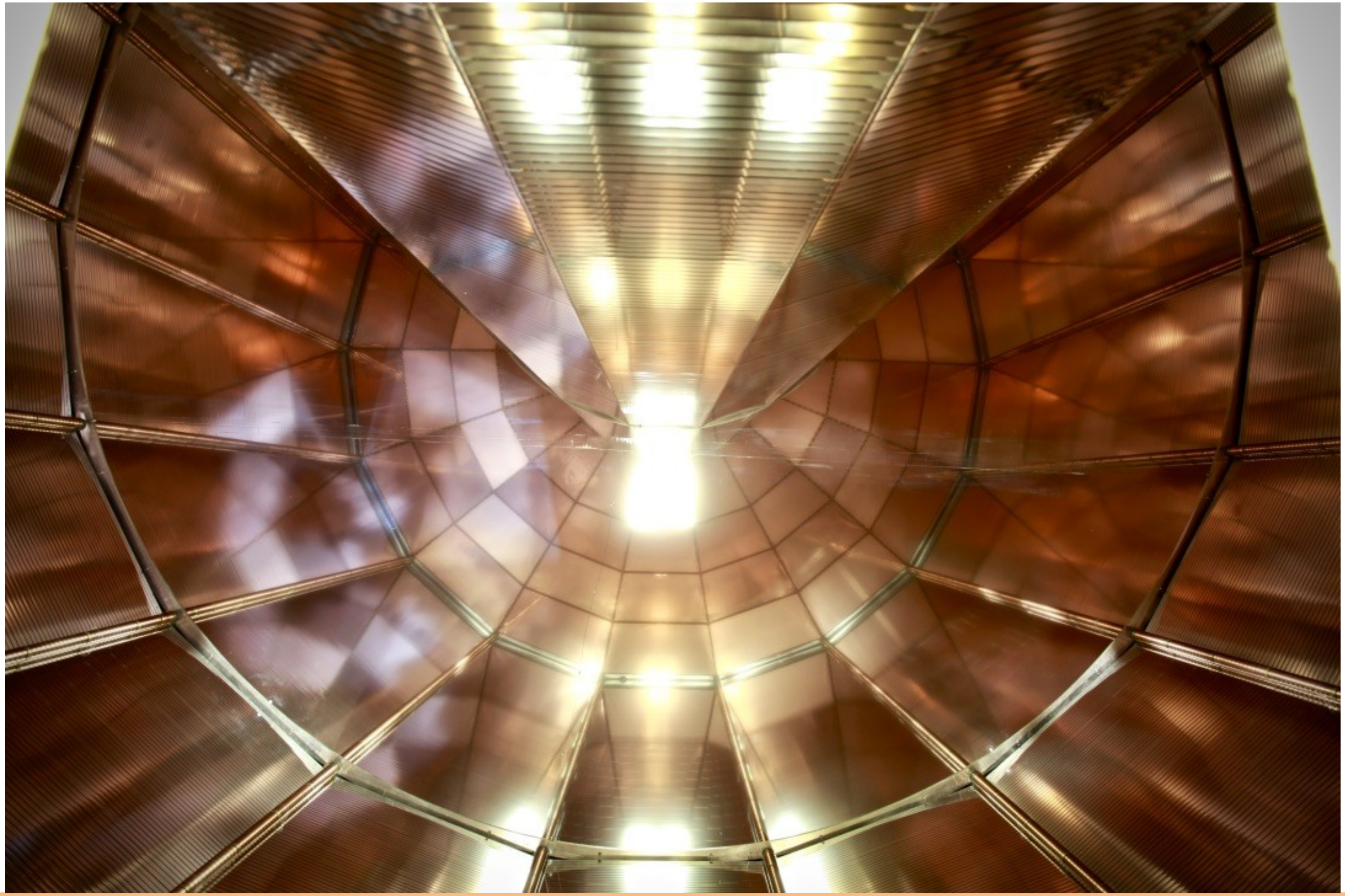
Cleanroom


TPC
IROC
BLUE (DELPHI) FRAME
FFU
SECTOR
OROC
7-D MANIPULATOR
YELLOW
PLATFORM

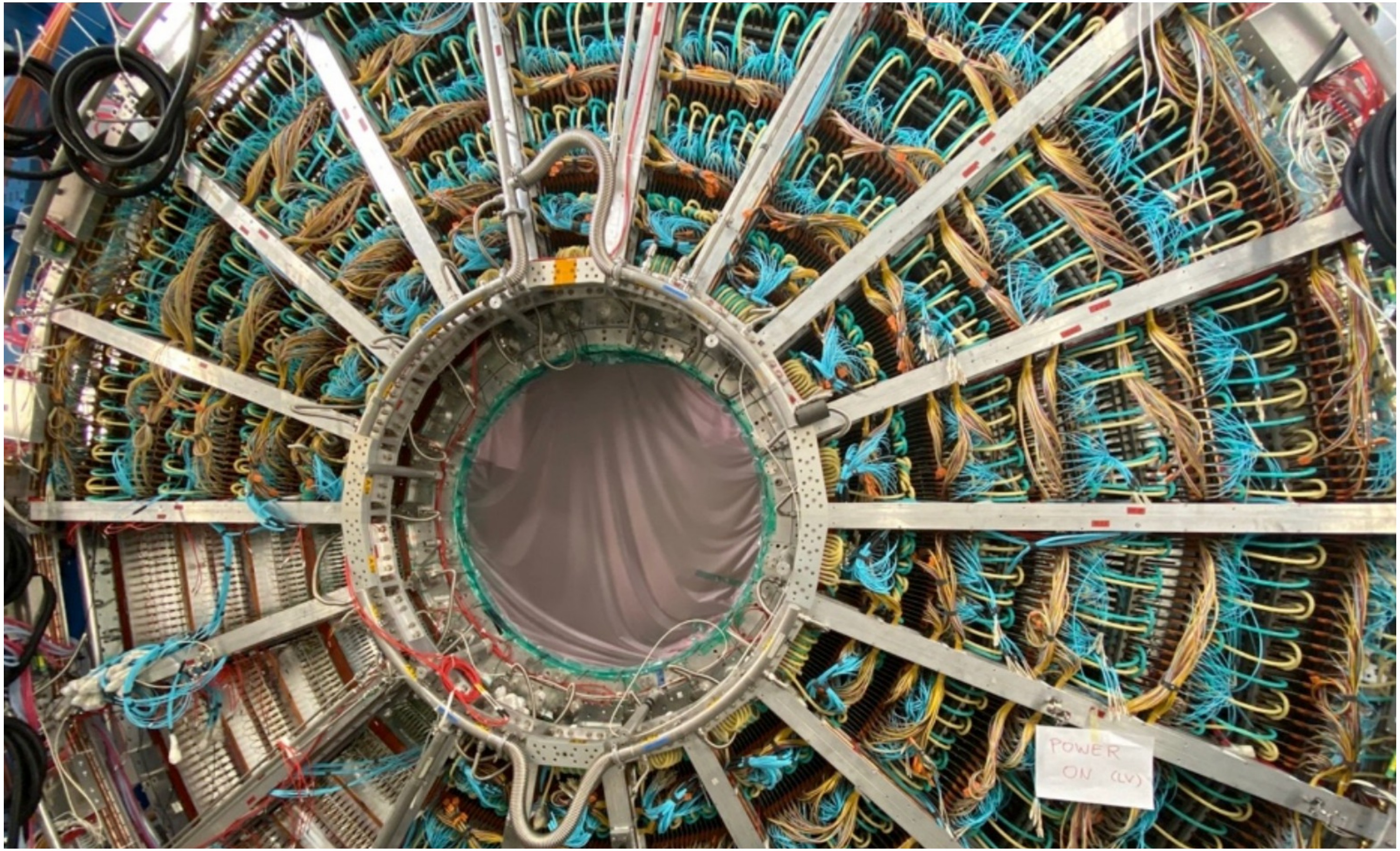
OROC insertion



Inside the TPC

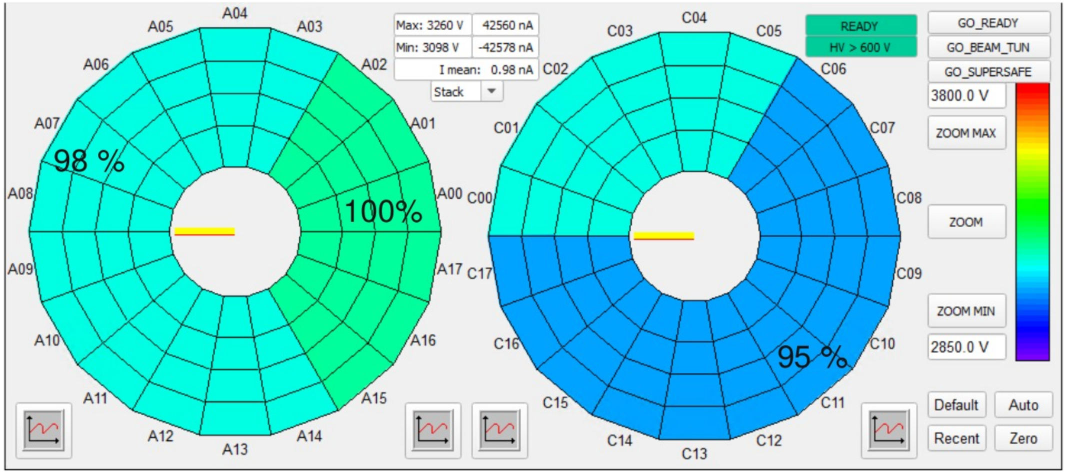


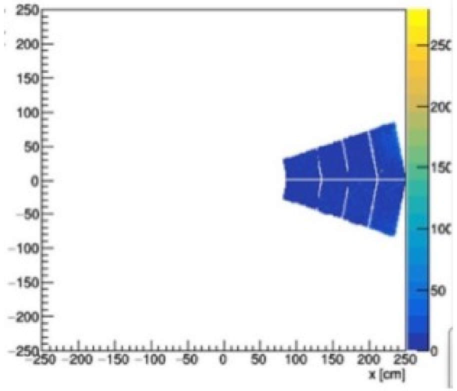
Electronics and services

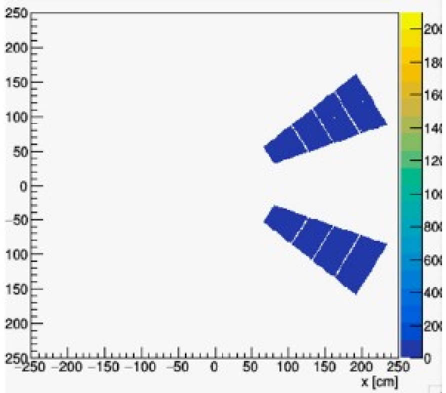


Commissioning procedure

- Apply to HV to all chambers
- Test chambers in pairs
  - Noise measurements
  - Pulse shaping
  - Laser calibration
  - Cosmic muons
  - Load test with X-Rays

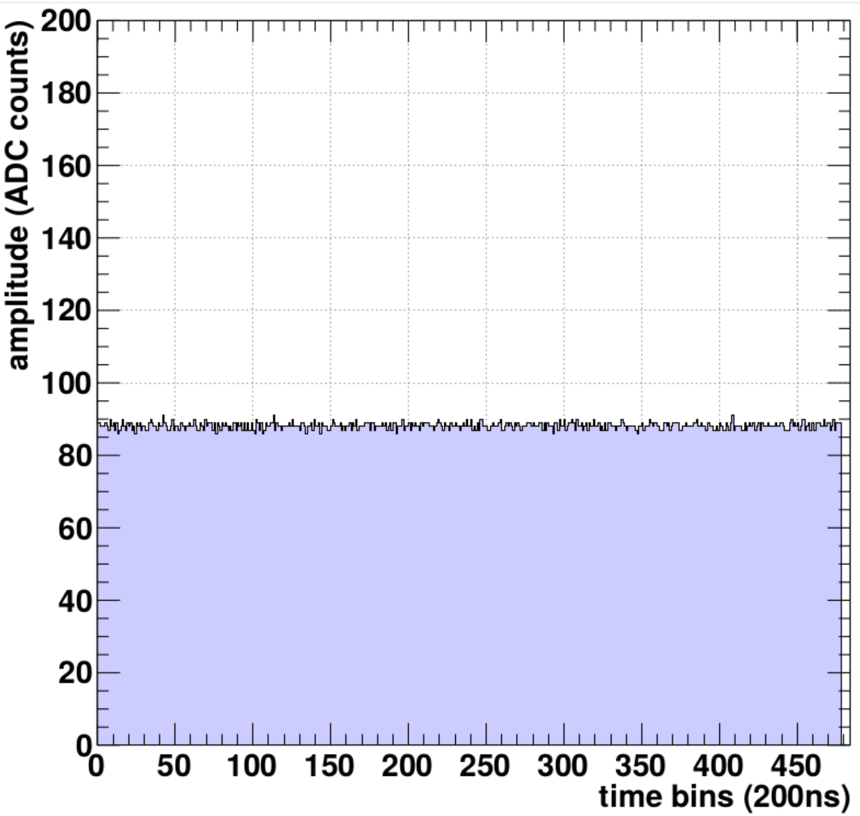






Noise measurements

- Goal: Noise ~1ADC reached
- Good signal to noise at nominal operating conditions
- Requires some optimisation
- Specific pattern



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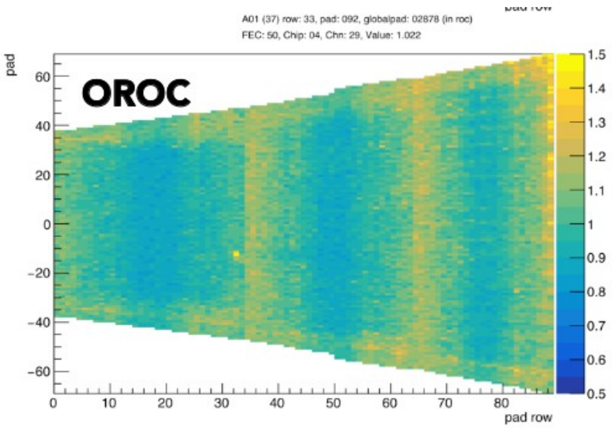
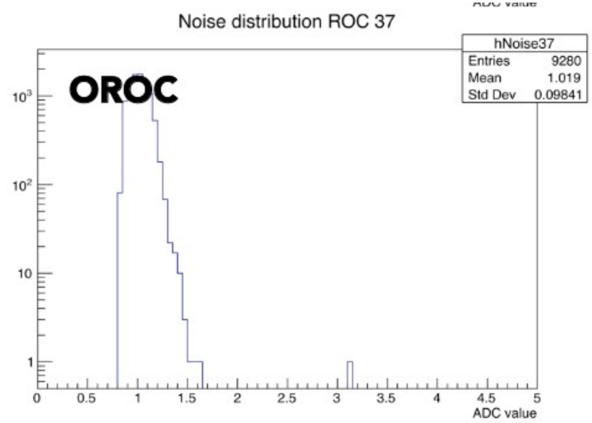
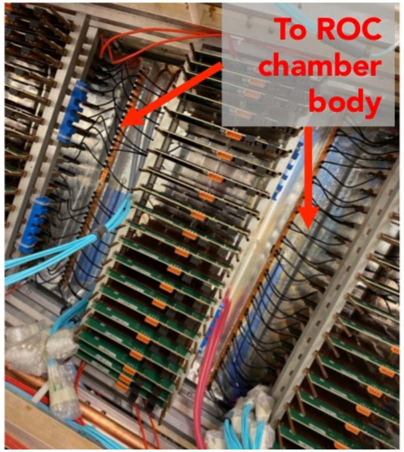
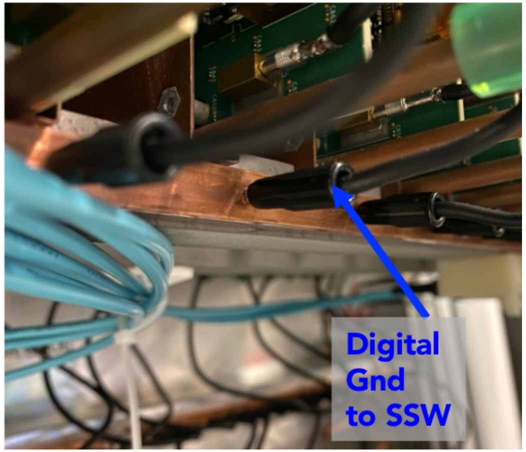
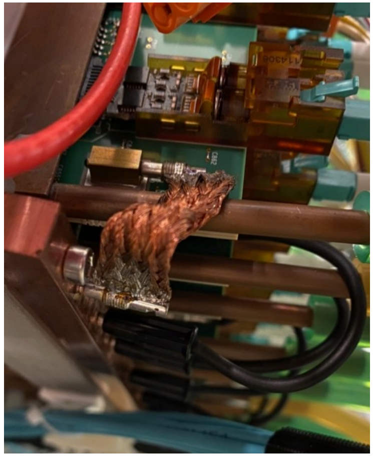


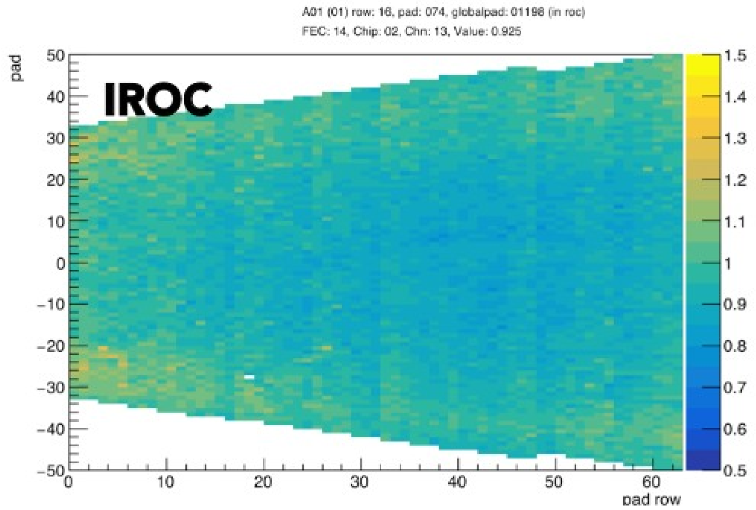


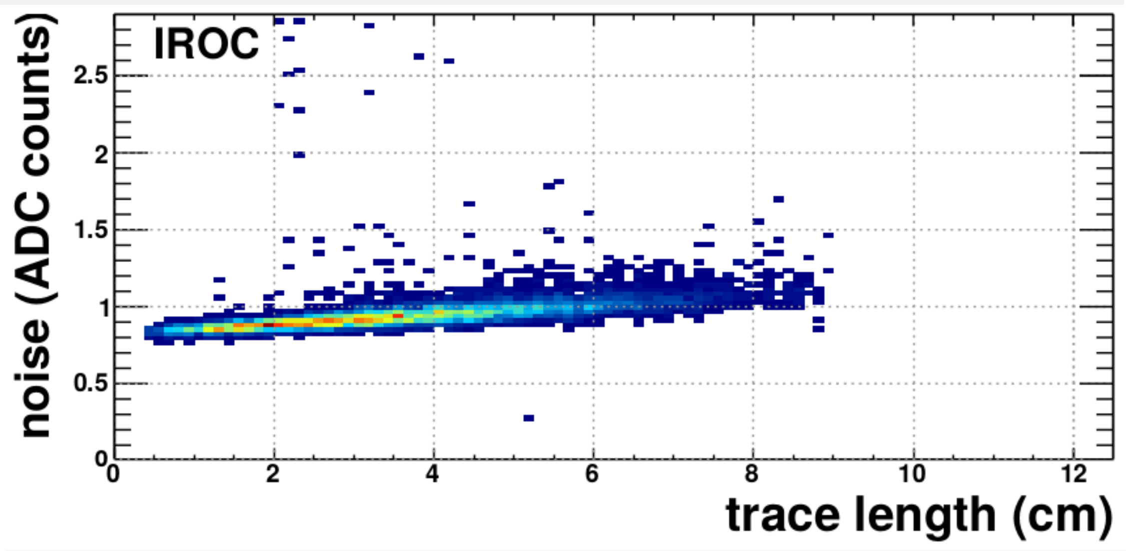






Noise measurements

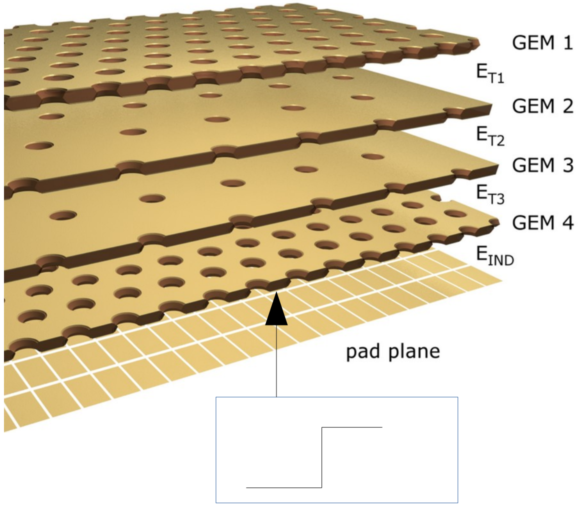


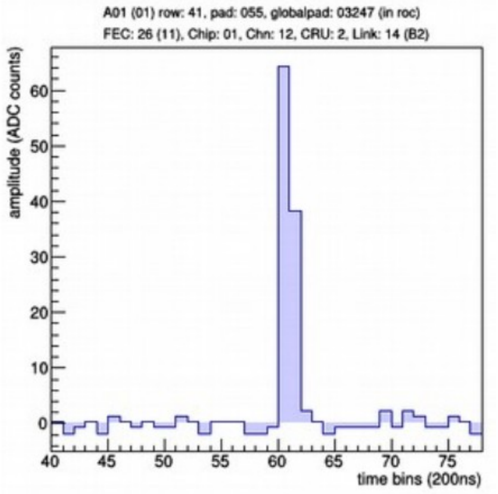


- Charge sensitive amplifiers
- Noise increases with capacity ↔ trace length

Pulse shaping

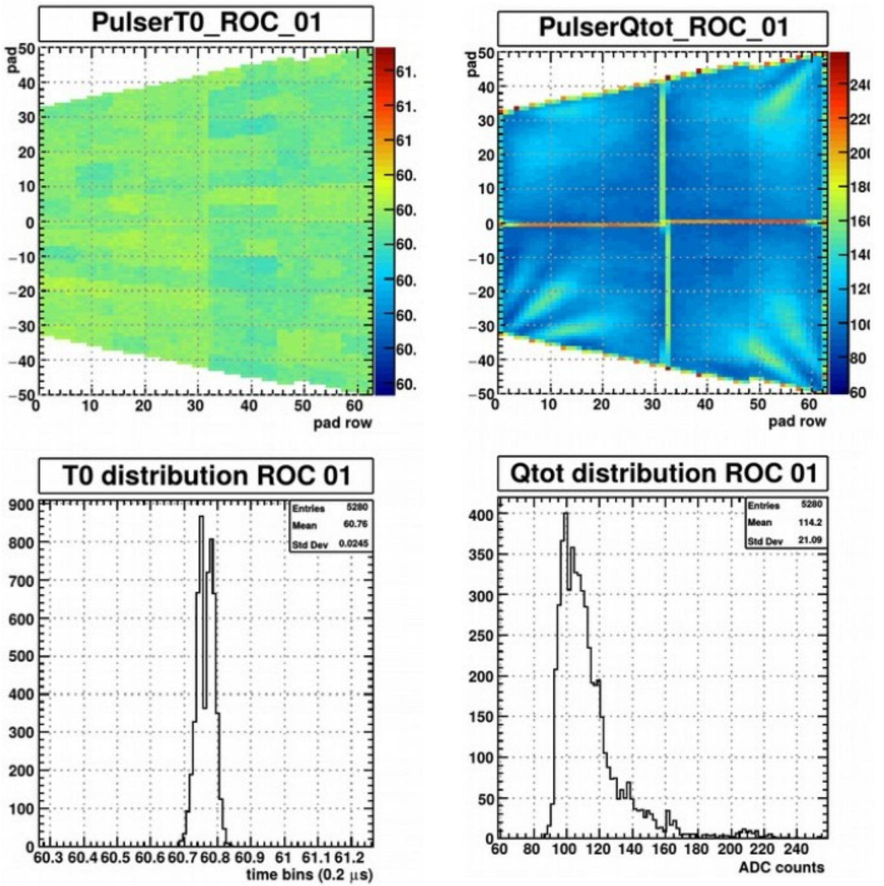
- Induce pulse to lowest GEM electrode
- Functional test of each pad
- Determine shaping behavior
  - Shaping time
  - Shaping width
  - Charge integral





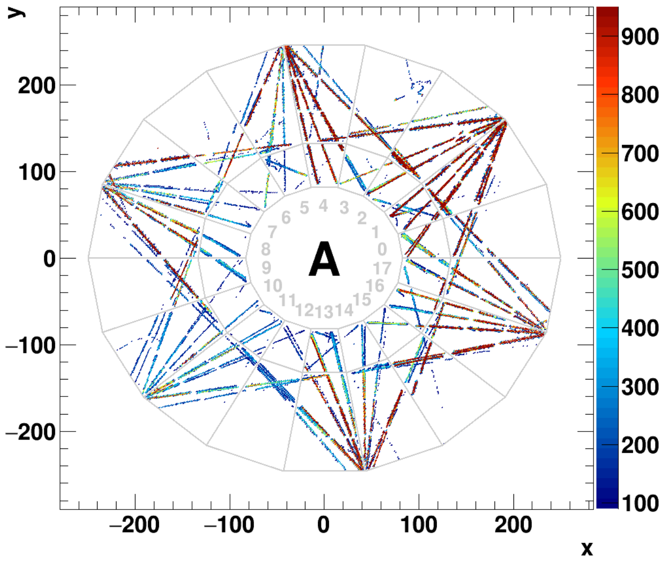
Pulser shaping: results

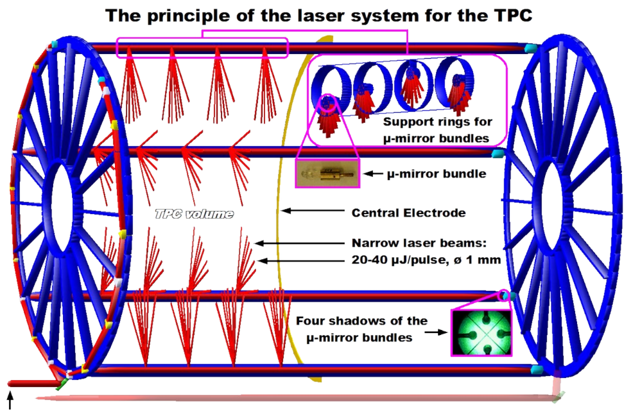
- Pattern in shaping time corresponds to chip pattern
  → Production tolerances
  → Variations ~ 5ns
- Pattern in charge integral due to wrinkels in lowest GEM-foil
  → Variations ~20% ↔ 400µm

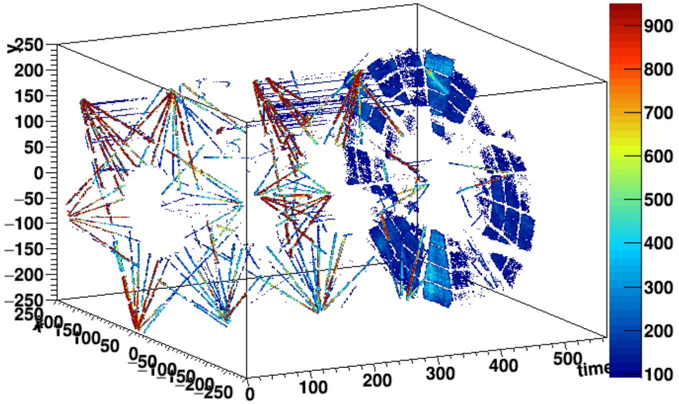


LASER Calibration

- Used for
  - Drift velocity
  - Chamber alignment
  - Static distortion measurements

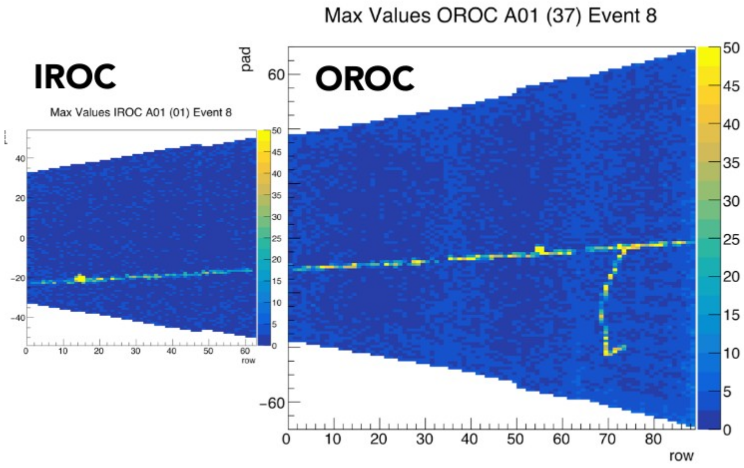


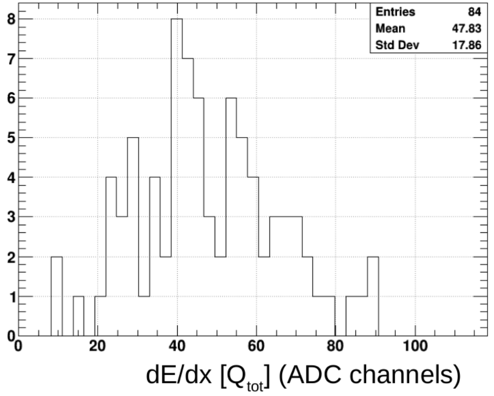




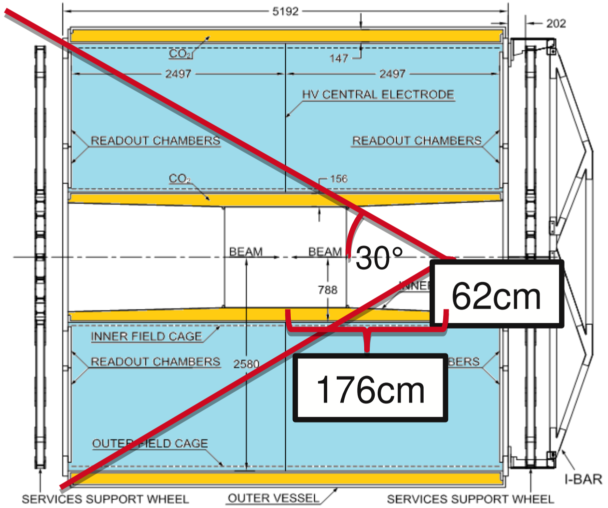
Cosmic Myons

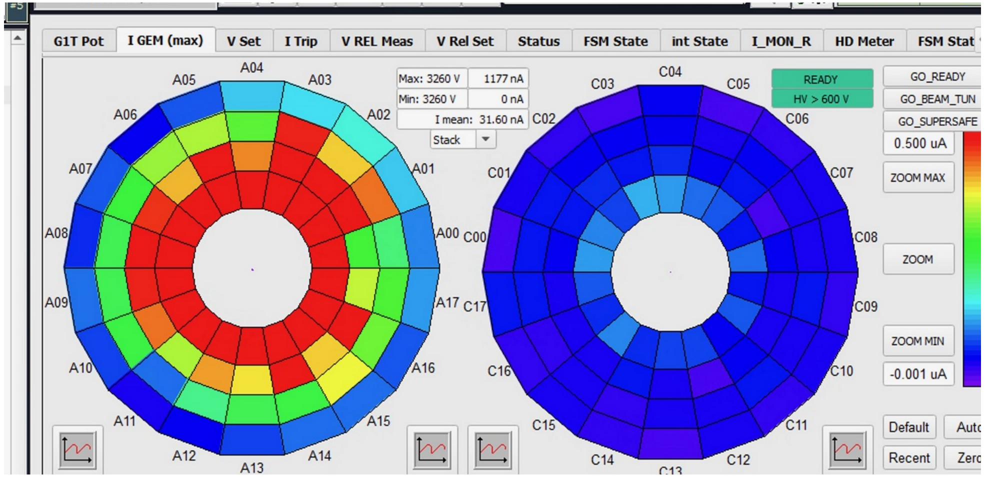
- First charged particle tracks
- Reconstruction working
- First energy-loss spectrum (uncorrected)
- Up to now: random triggers
- Goal: continuous reconstruction
  - Verify concept
  - Identify bottlenecks
  - Learn as much as posible





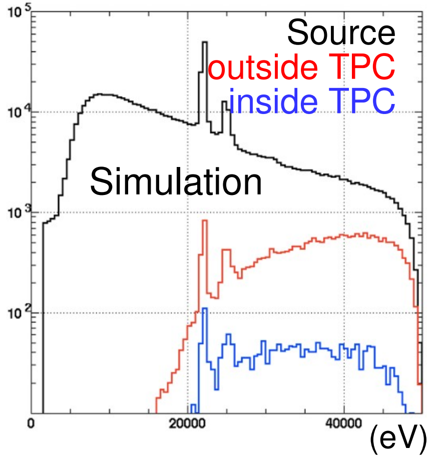
Load tests with X-rays

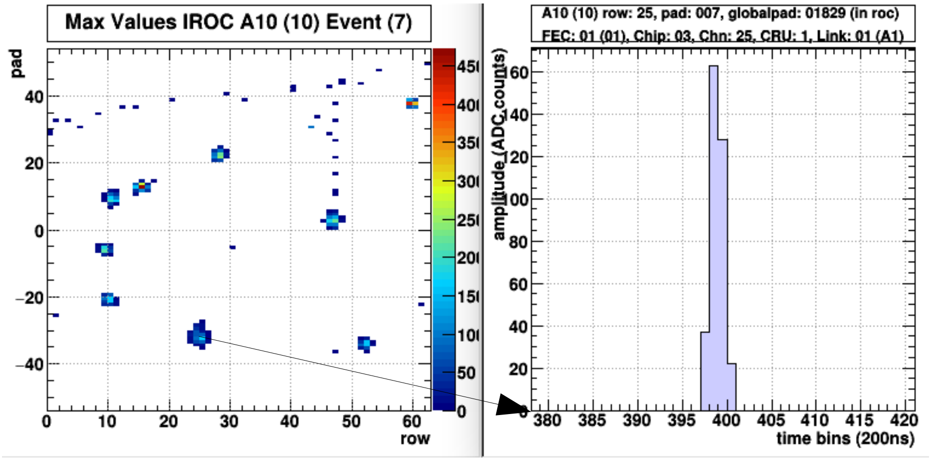


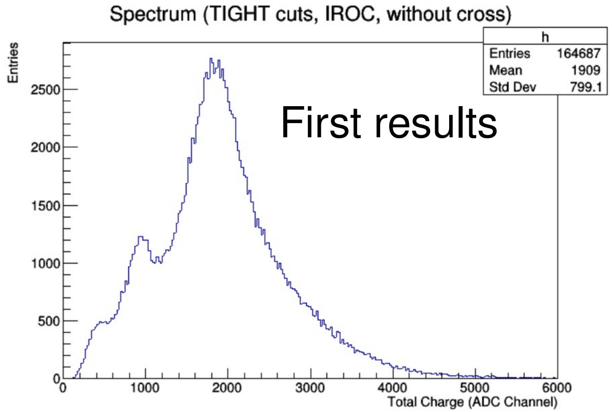


- Higher load than at LHC
- Stable operation of all chambers
- Plan:
  - Run laser tracks together with X-rays to see distortions and try correction procedure

Gain calibartion using X-rays







- Spectrum can be used for calibration → Pad-wise gain calibration
- Requires reconstruktion of decay clusters (3D)
- Second peak at ~ half the X-ray energy → might be fluorescence of Cu
  → Ideal calibartion source: no drift → no diffusion
- First Spectrum → Still much to optimize

Summary

- Main calibrations used for TPC summaries
- Outlook for calibration plans in Run3
- First results from commissioning

Backup

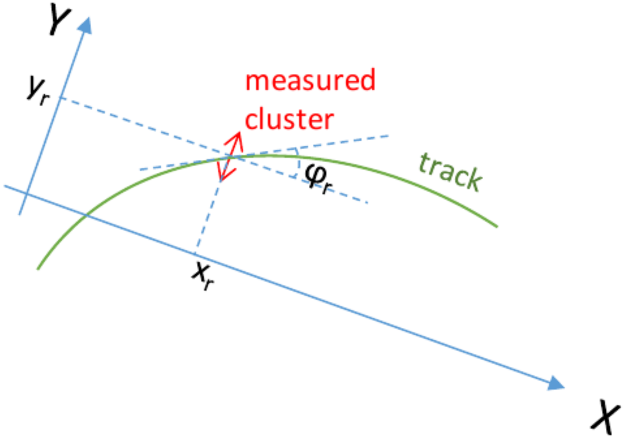
Plans for alignment in Run3

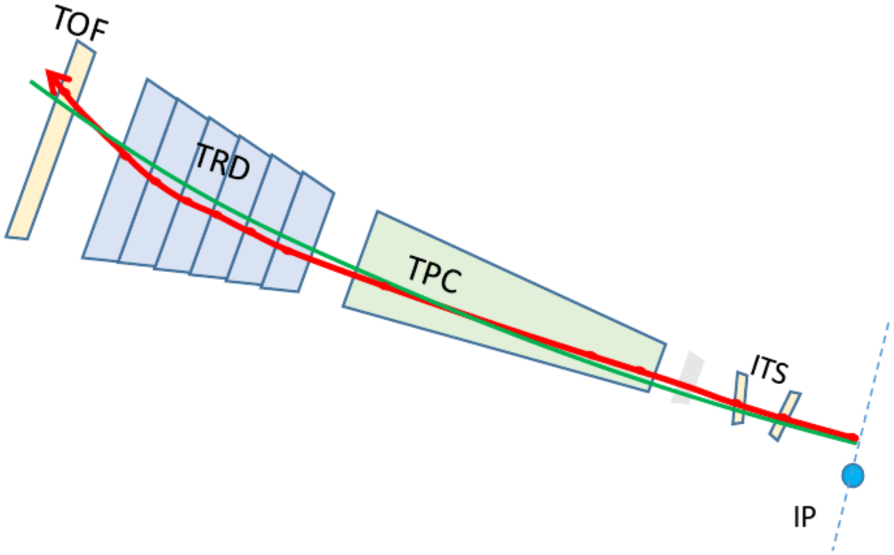
- Global alignment with Millepede package was developed in the beginning of Run2 (see following slides)
  - Allowed to optimize ~27K of alignment DOFs of ALICE barrel (6 DOF per sensitive volume)
  - Calorimeters and HMPID were not involved.
  - TPC was used only as a bridge between ITS and TRD/TOF but did not participate in alignment per se (dominated by drift lines distortions)
- Will be ported to Run3 O2 package with some improvements (1 PhD student + 1 senior part time)
  - In Run3 ALICE barrel will have ~150K DOFs due to the new ITS.
  - better constrains for week modes
  - minimization of manual operations
  - add calorimeters and HMPID)
  - sags in ITS (~200μm) exceed expected assembly precision, introduce sagging parameters as separate DOFs
- Initial alignment to be done in the commissioning p-p run for all DOFs starting with alignment from survey
  - Will require ~20M collisions for B+, B- and B=0 settings each + cosmics, details not planned yet
- Plans for continuous monitoring of alignment (with reduced DOFs, rest kept fixed) using tracks/clusters from the online reconstruction (was not done in Run2)

- Target precision: <2 μm in ITS, <100 μm in TRD and TOF

Alice track model

- Every sensitive volume (TPC sector, ITS sensors etc.) defines its own tracking frame: lab frame rotated around Z (beam) axis to have X axis normal to 2D measurement plane
- Track parameterized as local (accounting for non-uniformity of B-field) in detector tracking fame, with parameters $\boldsymbol{P_o}: \{y_r, z_r, \sin\varphi_r, \tan\lambda, qp_{Tr}^{-1}\}$ at local reference x_r.
- Tracks propagated accounting for mult.scattering and e.loss contribution to covariance matrix and for e.loss correction to p_T.
- Corrected at measured points by Kalman update (only 2D matrix inversion)





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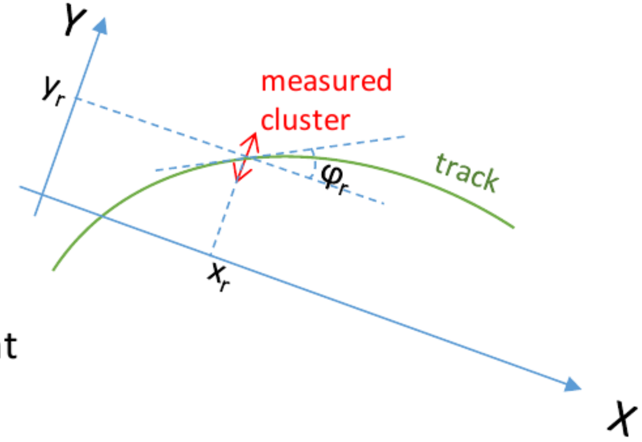
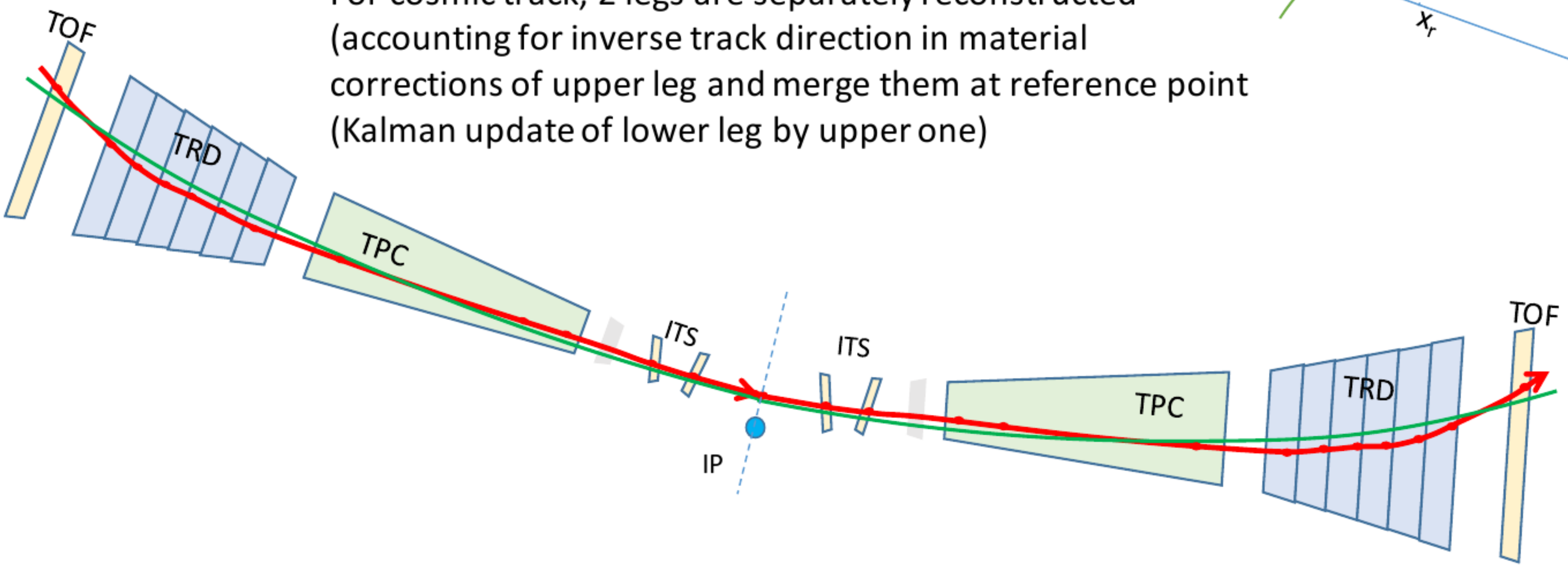
- Tracks propagated accounting for mult.scattering and e.loss contribution to covariance matrix and for e.loss correction to p_T.
- Corrected at measured points by Kalman update (only 2D matrix inversion)



- For cosmic track, 2 legs are separately reconstructed (accounting for inverse track direction in material corrections of upper leg and merge them at reference point (Kalman update of lower leg by upper one)

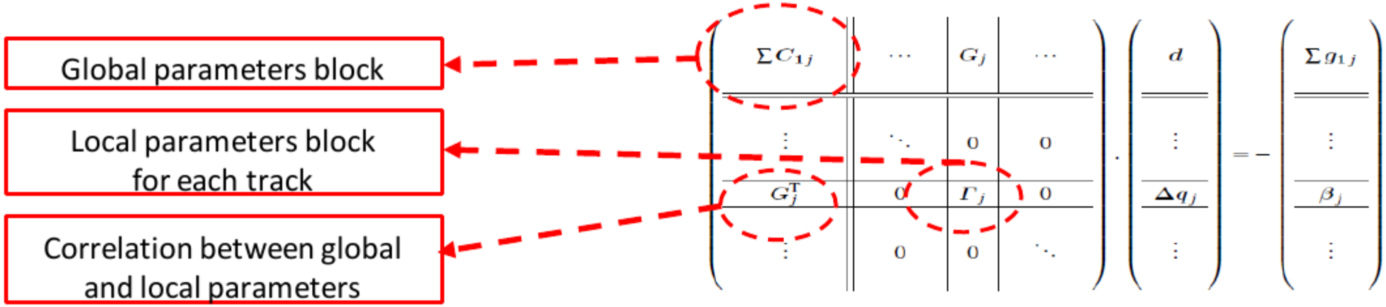


Millepede II (MP)

https://www.wiki.terascale.de/index.php/Millepede_II

- Alice global alignment is done using Millepede package
- Assumes that for every track the residuals z_i wrt every measurement y_i with error σ_i at point x_i can be represented in linearized form as : $$z_i = y_i - f(x_i, \boldsymbol{q}, \boldsymbol{p}) = \sum_{j=1}^{\nu} \left(\frac{\partial f}{\partial q_j}\right) \Delta q_j + \sum_{\ell \in \Omega} \left(\frac{\partial f}{\partial p_\ell}\right) \Delta p_\ell \,.$$

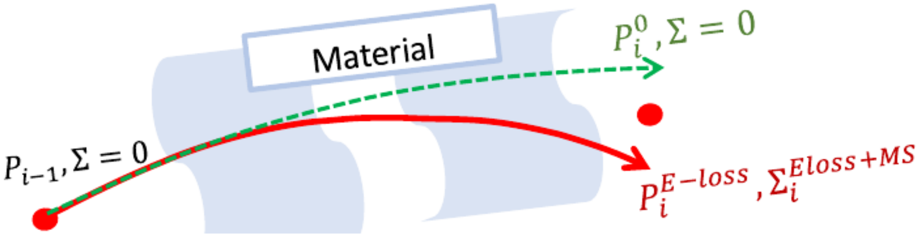
  where $f(x_i, q, p)$ is track model depending on set of **local parameters** q (unique for each track) and set of **global parameters** p (describing detector's DOFs both for calibration and alignment)
- Idea of Millepede is to minimize residuals not only wrt global parameters (alignment+calibration) but also wrt parameters of each track (reconstructed with misaligned setup)
- Building huge sparse matrix equation and solves by partitioning, first iteratively solving local (track) submatrices blocks then remaining global parameters matrix block



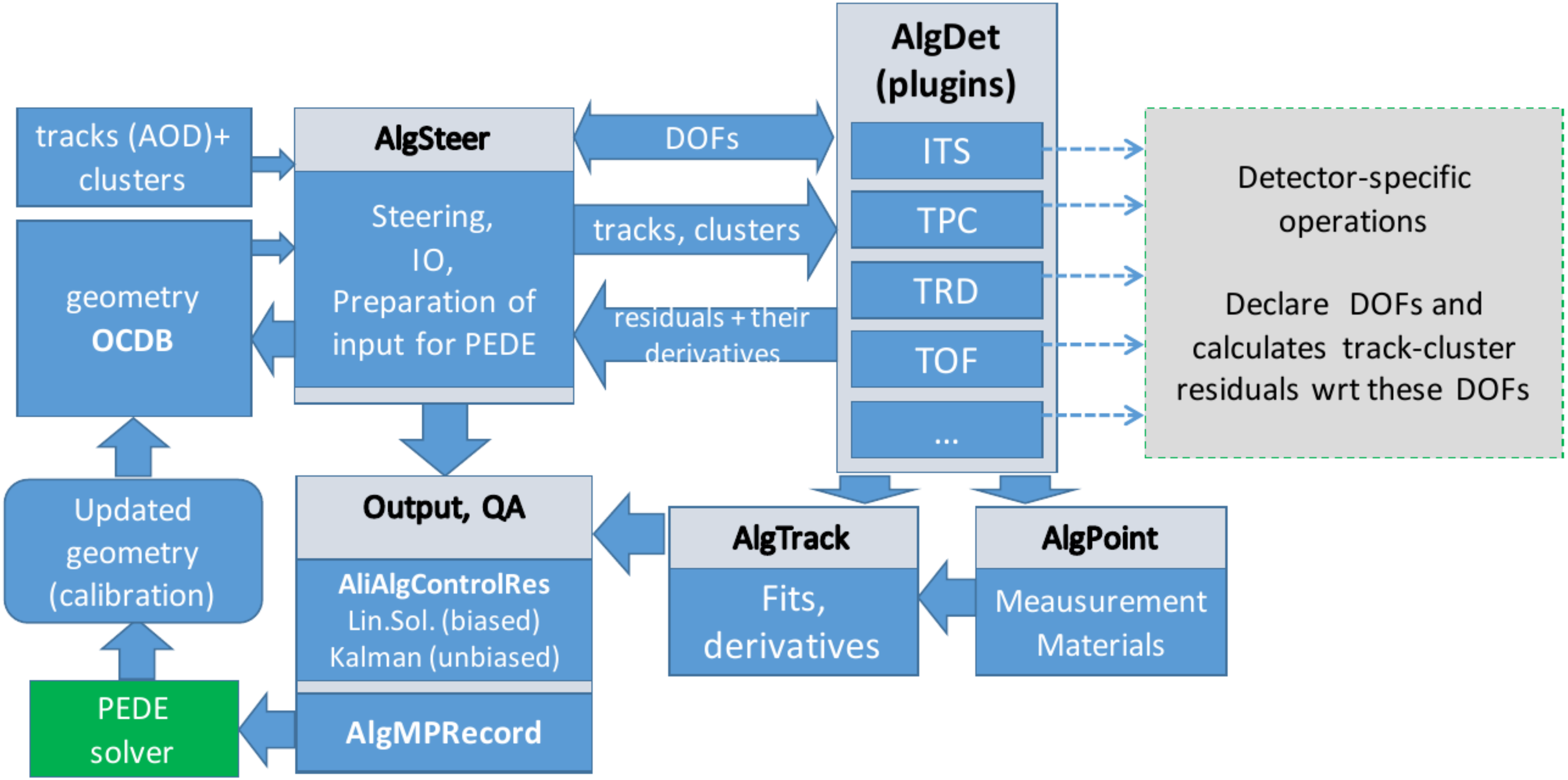
- → **Need global track model (orthogonal to idea of Kalman filter) to calculate at different points track position and its derivatives wrt single track parameters to be fitted by Millepede**

Alice track model adapted for alignment with Millepede

- → Use global synthetic track model consisting of usual $\boldsymbol{P_o}$: $\{y_r, z_r, \sin\varphi_r, \tan\lambda, qp_{Tr}^{-1}\}$ parameters defined in the single reference point (e.g. closest to IP) + corrections (parameterized in a same way by $\boldsymbol{P_k}$) for kinks due to the mult.scattering between measurements separated by material.
- Kinks in material layers are considered as measurements with errors (0 mean for Mult.Scattering, average e.loss) constrained by our knowledge of material budget.
- Track seed is built by usual Kalman fit, propagated to reference point (PCA to vertex) to define reference $\boldsymbol{P_o}$, then full alignment track is built defined as:
  - reference kinematic parameter (5 independent variables) $\boldsymbol{P_o}$
  - reference parameters propagated to each point of interest i (where derivatives are needed), corrected for deterministic e-loss $\boldsymbol{\Delta P_l}$ and corrected by random 4-parameter kink ΔP_i^{MS}, constrained by its cov. matrix $\boldsymbol{\Delta\Sigma_i}$
- "Measured" covariance matrix for kink parameters obtained by propagating track parameterization + its covariance matrix through the material layer two times: with and without material corrections then taking difference $\Delta\Sigma_i = \Sigma_i^{MS} - \Sigma_i^0$ (error of effective kink ΔP_i^{MS})
- Derivatives are calculated by numerical differentiation



Alice Millepede global alignment framework



Blue: preparation of input data for PEDE II, processing of its output, various utilities for OCDB manipulation

Green: external PEDE II solver (Fortran 90 + OpenMP) supported by DESY