ALICE tracking system

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Fifth International Workshop for Future Challenges in Tracking and Trigger Concepts

Outline

- ALICE experiment
- Offline reconstruction strategy in Run 1
- Run 1 reprocessing and preparation for Run 2
- Summary

Detector description

The ALICE experiment

Dedicated heavy-ion experiment at LHC

- Study of the behavior of strongly interacting matter under extreme conditions of high energy density and temperature

Proton-proton collision program

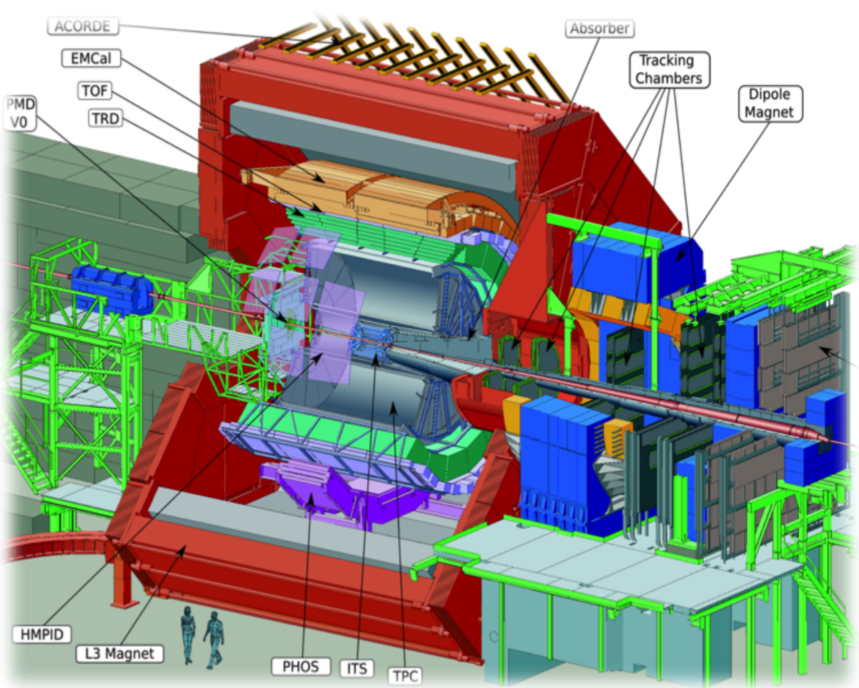
- Reference data for heavy-ion program
- Genuine physics (momentum cut-off < 100 MeV/c, excellent PID, efficient minimum bias trigger)

Barrel Tracking requirements

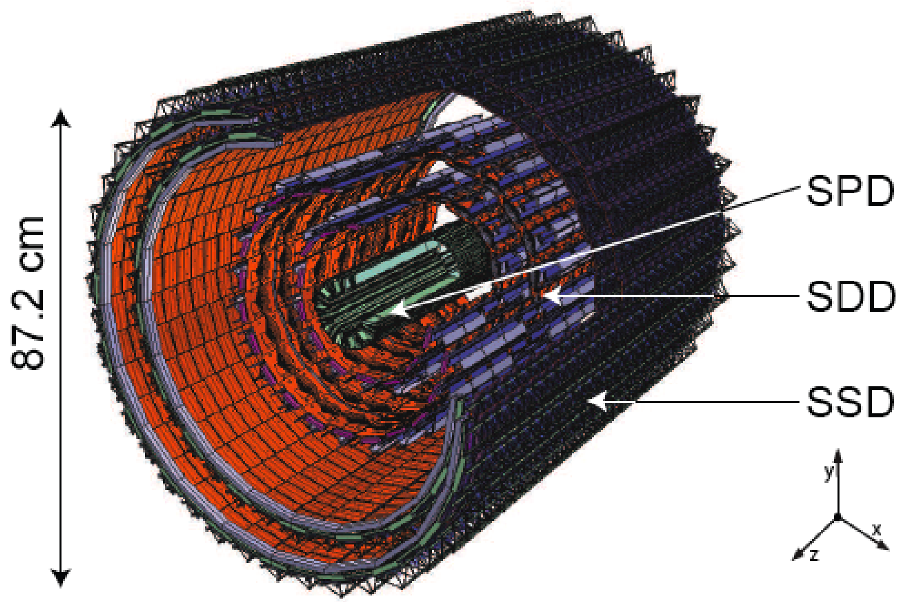
- Pseudorapidity coverage **$|\eta| < 0.9$**
- Robust tracking for heavy ion environment
- Mainly 3D hits and up to 159 (TPC)+ 6 (ITS) points along the tracks
- Wide transverse momentum range (100 MeV/c – 100 GeV/c)
- Low material budget (13% X_0 for ITS+TPC)
- Large lever arm to guarantee good momentum resolution at high p_t

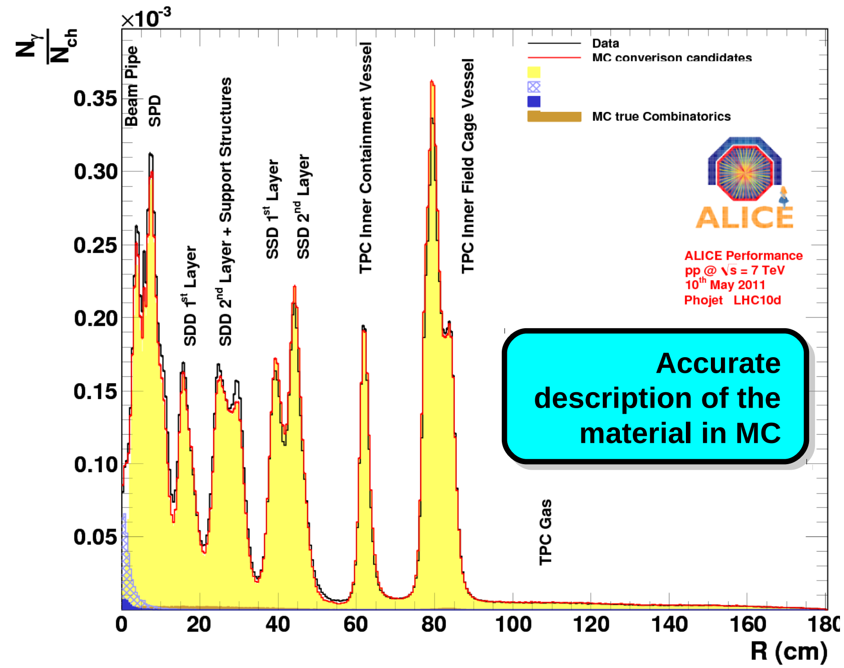
PID over a wide momentum range

- Combined PID based on several techniques: dE/dx, TOF, transition and Cherenkov radiation



Inner Tracking System (ITS)





Layer	Det.	Radius (cm)	Length (cm)	Surface (m2)	Chan.	Spatial precision (mm)		Cell (µm2)	Max occupancy central PbPb (%)	Material Budget (% X/X_0)	Power dissipation (W)	
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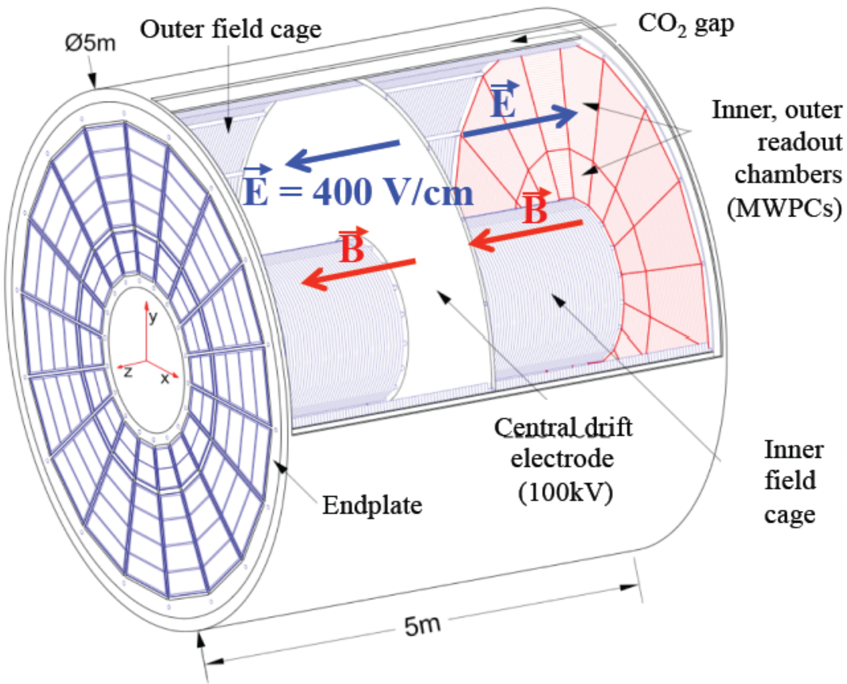
TPC: main tracking device in ALICE



Largest TPC:

- Length 5 m
- Diameter 5 m
- Volume 88 m^3
- Detector area 32 m^2
- Channels ~570 000
- 72 Readout Chambers (32 inner - IROC, 32 outer - OROC)
- Gas Ne/CO_2 90/10%
- Field 400 V/cm
- B-field: 0.5 T
- Gas gain ~ 10^4
- Track position resolution σ= 0.15 mm
- Diffusion: σ_t= 2.50 mm/√m

Pad readout geometry optimization:

- Occupancy
- Space point resolution
- dEdx resolution

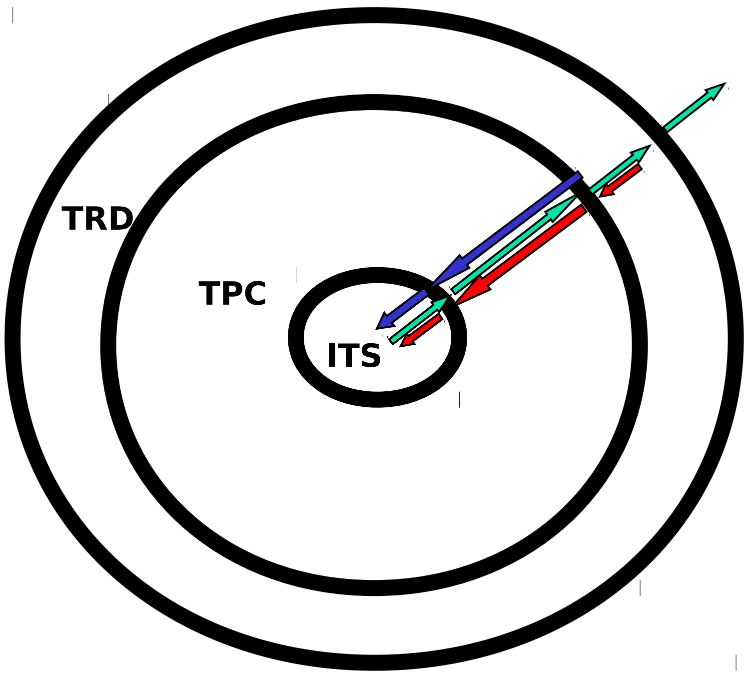
Constraints:

- Signal over noise
- Number of channels

159 measurements along trajectory *

- IROC: 4x7.5 mm (63 rows)
- OROC: 6x10 mm (64 rows) and 6x15 mm (32 rows)

Offline reconstruction algorithm



Kalman Filter tracking approach chosen:

- Space points - clusters reconstructed before tracking
- Simultaneous track recognition and reconstruction
- Natural way to take into account multiple scattering, magnetic field inhomogeneity
- Possibility to take into account mean energy losses
- Efficient way to match tracks between several detectors

Kalman tracking in 3 iteration:

- **Inward tracking** – TPC-ITS
- **Back propagation** –ITS-TPC-TRD-PID detectors
- **Refit** tracks towards the vertex (TRD-TPC-ITS)

***Algorithm optimized for reconstruction of primary tracks. For decay topologies extended versions of algorithm used.**

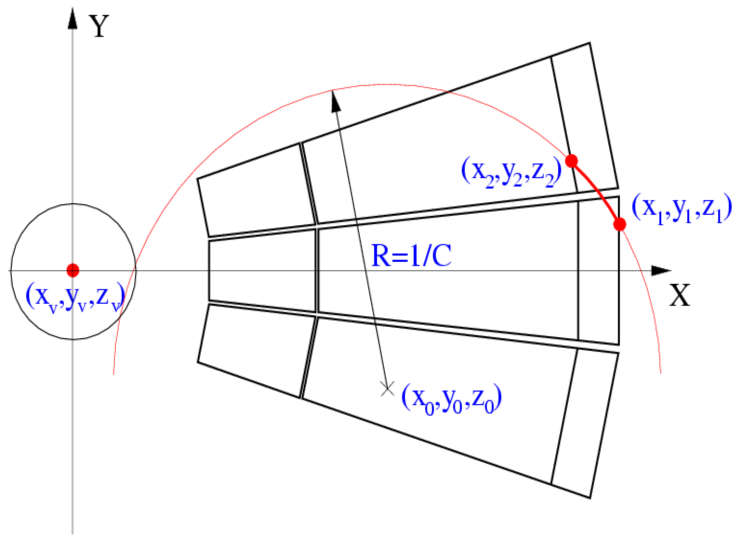
Main assumptions - Space points used for Kalman filtering:

- Gaussian errors with known sigma
- Errors between layers are not correlated

Generate a track seed starting from the 2 (+primary vertex) or 3 (secondary tracks seeding) space points

Iterate the following sequence:

- Kalman extrapolate and look for compatible measurements.
- If there is none, go on.
- If there is one, take the most compatible one and make an Kalman update.
- If no compatible measurements can be found in several active layers, stop the track candidate.



The occupancy in the track prolongation space significantly smaller than in digit space:

- In case good initial track hypothesis seed provided, the probability of fake space point association is small.

The TPC gas gain is time dependent:

- The probability to produce a cluster at given layer (pad-row) is time and dEdx dependent and vary in the range from 70-100 % →
- Seeding procedure repeated several times (parameter of the reconstruction ~10) in different TPC regions to obtain close to 100 % efficiency

Cluster finder efficiency ~ 70-100 % (gain/time dependent). One layer seeding efficiency ~ 50-100 %

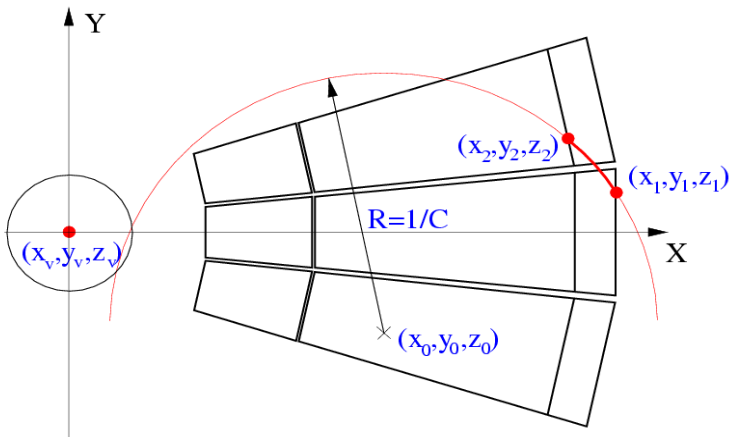
- $p_{1seed} = p_{cl}^3 \rightarrow$
- ~50 % seeding efficiency for 80% cluster efficiency
- $p_{Nseed} = 1-(1-p_{cl}^3)^N \rightarrow$
- 97% for 5 seedings, 99,9% for 10 seeding region
- Seeding procedure repeated several times (>10) in different TPC regions to obtain close to 100 % efficiency.

Seeding in slice windows:

- Starting from the outermost (159) pad-row
- Last seeding pad-row given by minimal amount of clusters (64) - pt down to 100 MeV (gamma conversion electrons even below)
- Clusters belonging to the golden tracks excluded from following seeding algorithm

CPU consumption minimization:

- Fast primary track seeding with vertex constraint applied first (N^2 problem)
- Secondary seeding without the vertex constrain (N^3 problem) done after TPC cleaning



Track hypotheses clean up done at the end of the TPC tracking at each tracking iteration

Tracks with significant amount of shared space points rejected. Only “best” hypotheses kept

Special treatment of the decay topologies inside of the TPC (decays/Kinks and interaction). Tracks refitted towards to the vertex.

- Identified decay topologies used for the K and π identification

Local occupancy up to 10 % ($dN_{ch}/dy \sim 1600$)

Cluster unfolding necessary

- Performance of the unfolding algorithm limited by the shape fluctuation, and by a-priory unknown shape of clusters
- Correcting for overlapping clusters (OFFLINE clusterer) or splitting clusters (HLT clusterer)

Non Gaussian error of cluster position

- Error estimate strongly dependent on track topology. can not be assigned during the cluster finder. Attribute of the cluster/track pair
- The space point resolution calibrated as a function of the cluster and track topology.
- For clusters, with extended shape in respect to the expected shape for given track topology, cluster position error correspondingly enlarged

Cluster sharing between tracks enabled

- **Non greedy-Algorithm.**
- Tracks competing for clusters.
- Two track fits not independent
- For shared clusters for track overlaps, expected cluster error is increased

Planned Run1 reprocessing modifications

- Unfolding on track/tracklet level to be done, to reduce the fluctuations.
- TPC/ITS standalone tracks recovery
- Usage of the TRD information in refit inward

ITS tracking – Combinatorial Kalman Filter

The ITS "digit" occupancy (1-4 %) smaller than in case of the TPC. Cluster unfolding not the critical issue. But, significant occupancy in the track prolongation roads. Mainly for low momentum tracks (search window ~ 1/p)

Combinatorial Kalman Filter chosen

Use a TPC extrapolated track as a seed.

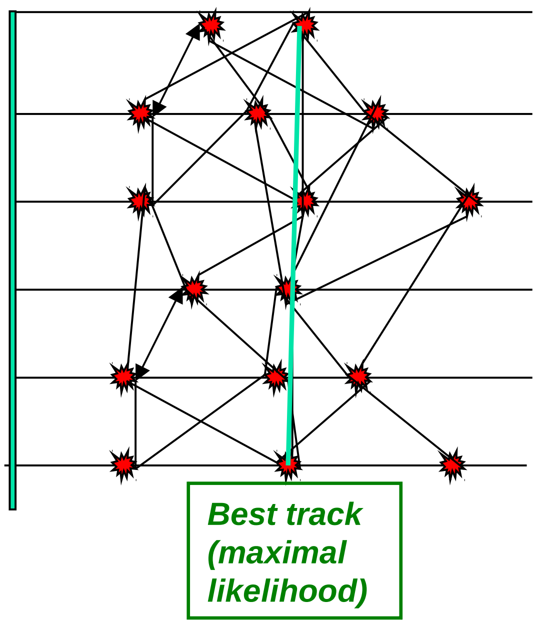
- * The ITS standalone tracking also implemented, but combined tracking more robust - significantly smaller amount of fake tracks

Iterate the following sequence:

- Extrapolate and look for compatible measurements.
- For each compatible measurement, generate a branch and make an update.
  - $N_{branch} \sim (1+k*occu*\chi^2_{cut}/p)^{Nlayers}$
- Generate a branch with no update (**missing space point**)
- If a branch contains no updates for a number of layers,drop the branch.
- Drop the worst branches, and drop branches below some quality limit.
  - The total number of branches limited

Cleanup selecting the "best" branch using global information

- Additional information about the overlap with concurrent TPC tracks used – **conflict resolving algorithm** (maximizing the likelihood of pairs of tracks)
- For V0 topology (K0s, Λ, γ) the position of the decay vertex taken into account.



ITS tracking: special case of primary tracks without conflict with concurrent TPC seeds

HLT- Online TPC reconstruction

The TPC online tracker implementation combines the principle of the cellular automaton and the Kalman filter.

Accelerated by the usage of graphics cards (GPUs).

A pipelined processing allows to perform the tracking on the GPU, the data transfer, and the preprocessing on the CPU in parallel.

A splitting of the tracking in multiple phases searching for short local track segments first improves data locality and makes the algorithm suited to run on a GPU.

Reconstruction optimization.
Preparation for Run2.

Run 2 preparation (0)

Data rate in RUN2 expected to be significantly higher.

- RCU2 format
- Higher efficiency of data taking
- For pp runs pile-up ~ 10-50 events in TPC

Can we speed up the reconstruction by factor (4-10) to adopt for higher data rate in RUN2, using current OFFLINE software?

- Our goal is to speed up the reconstruction part by corresponding factor

Run 2 preparation (1)

Following slides benchmark values for the low intensity (small pile-up) pp runs

- CPU time for pile-up is linearly scaling with the number of events
- Typical pile-up 1 event (in 2010) up to 50 (in 2012,2013)

No evident hot-spots

Reconstruction ~ 20 % of overall ALICE OFFLINE activity

- Material budget queries
- Magnetic field queries
- Track propagation

TPC reconstruction around 30% of overall reconstruction CPU consumption. With non evident hot spots.

- LoadClusters - 11 %
- Cluster2Tracks - 12% (2 times more track hypothesis investigated)
- PropagateBack - 6%
- RefitInward - 6%

Reconstruction process - TPC

Compromise between the CPU consumption and physics performance to be reached.

Partial use of the HLT algorithm (HLT seeds) in OFFLINE reconstruction implemented. Performance under investigation.

- Objective criteria to be defined

Pile-up events rejection (~10-50 events in TPC):

- Pile-up tracks can be rejected using the HLT tracking information
  - Not possible to distinguish pileup tracks from "deep secondaries" (kink decays)
  - Looping tracks can be used for the PID

Reconstruction process - TPC

Track d*E*dx calculation. Correction for missing signal in the clusters ~ 12%

- Cluster by cluster or effective track correction?

OFFLINE Ion tail cancellation ~ 7 %

Cluster space point correction ~ 7 %

- Common HLT/OFFLINE approach for caching

Track seeding ~2%

- CA seeding from HLT to be compared with the OFFLINE seeding
- Usage of the HLT seeds, implemented/tested. Reducing the number of track hypotheses to be investigated.
- Fast helix seeding, instead of the Kalman

Track propagation and update ~2 %

- Speedup <2. Double → Float, enabling vectorization
- Speedup ~ 5-10. Propagate and update per cluster → Propagate and update per tracklet

Cluster navigation

Kink finder combinatorial search

Double track removal and track unfolding

Track loop finder

Track matching recovery

Reconstruction process - Combined tracking

Local Event reconstruction ~ 30 %

Tracking ~ 50 %

Cluster navigation

Track propagation

- Number of steps to be tuned

Energy loss correction

Material budget queries

- Effective/exact material description

B field queries

- Piecewise Chebyschev, vs global 3d polynomial parameterization for Barrel

Conclusion: our experience

Alice OFFLINE tracking for Run1:

- TPC: seeding + Kalman following
- ITS: multi track hypothesis

Possible improvement of algorithm for Run2

- Better treatment of the combined TPC/ITS/TRD information and track based unfolding

Reconstruction processes decomposed, and benchmarked

- Most time spent in accessing information (dEdx correction, space point distortion correction, B-field)
- Actual track fitting insignificant
- Propagate and Update per tracklet to be investigated

CPU usage for Run2:

- Not obvious hotspot, several processes to be optimized
- Compromise with physical program (pile-up track rejection)

Conclusion: possible common tools

B field parametrization, table, queries

- precision/CPU as parameters

Material budget parameterization

- precision/CPU as parameters

Kalman filter

- Internal representation?
- Propagate
- Per point, per tracklet update
- Enabling procedures
  - Parallel hypothesis tracking
  - Cluster/track interaction: Expected cluster error and shape parameterization ?
  - Track/track interaction

Cluster navigation

Multidimensional correction tables

Backup

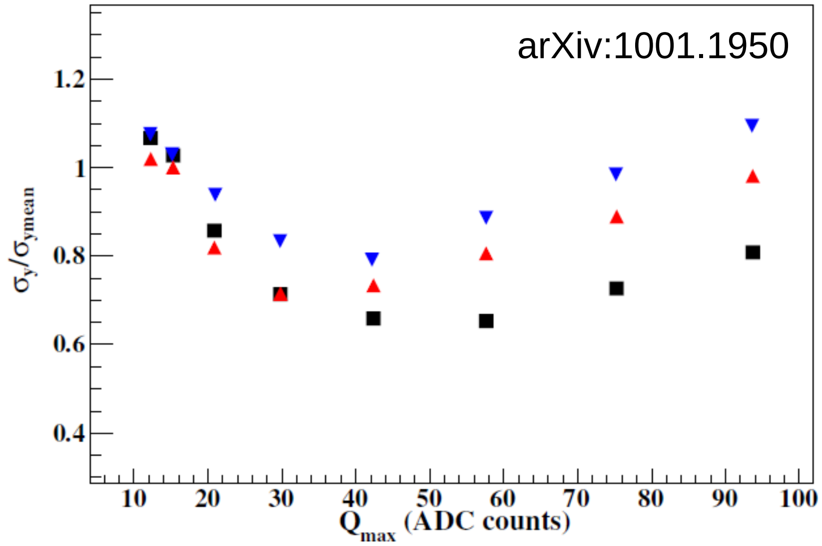
Up to 159 space points measured with the typical position resolution of about σ ~ 0.6 mm (for high momenta tracks small inclination angle)

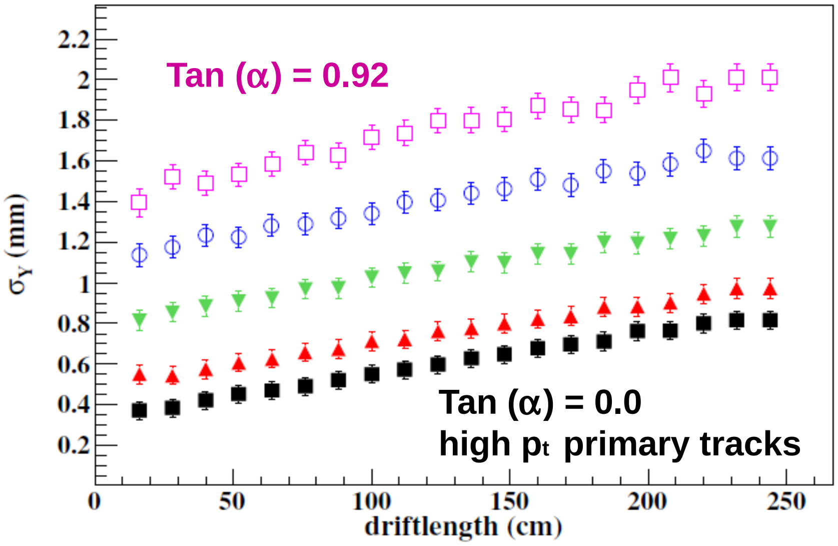
- **Track extrapolation precision** at the entrance of the TPC **of about σ ~ 0.15 mm** in both directions

Space point resolution depends on

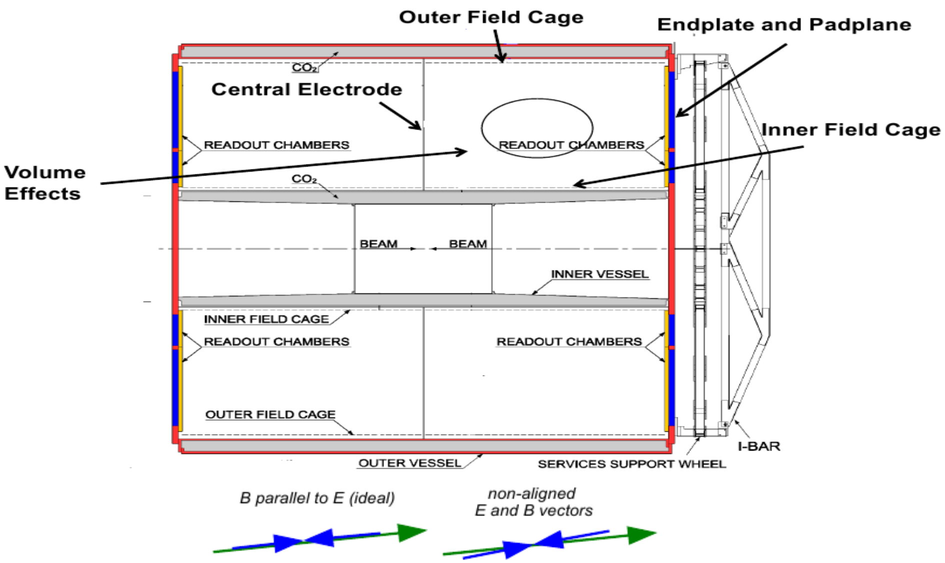
- The drift length
- The track inclination angle α
- The charge deposited Q
- Pad geometry (mainly pad length)

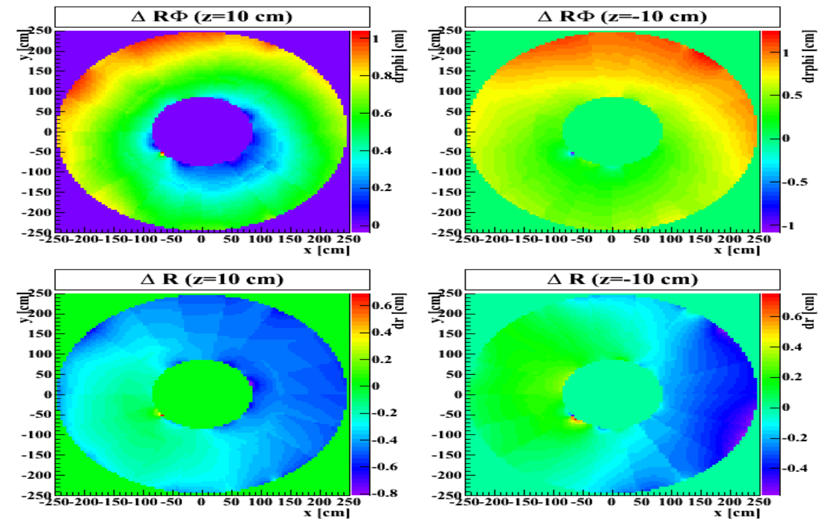
Requirement - the TPC alignment and the space position distortion calibration should be optimally kept below σ ~ 0.15 mm





TPC distortions





The TPC was internally mechanically aligned to the 0.1 mm level

Biggest observed distortion in the bending plane due to the ExB effect

- **B field inhomogeneity** – distortions up to **8 mm**
- **E field nonlinearities due misalignments** – distortions up to the **6 mm**
- **E and B field main component misalignment** – distortions up to **2 mm**

Right plot - resulting space point correction map as used currently in the Alice reconstruction

- The ExB effect time dependent (pressure, temperature, gas composition) – parameters updated on the run level

TPC space point correction framework developed - ALICE & STAR collaboration

- Physical (numerical solution of the Poisson equation) and effective distortion models

TPC distortion/alignment fitting

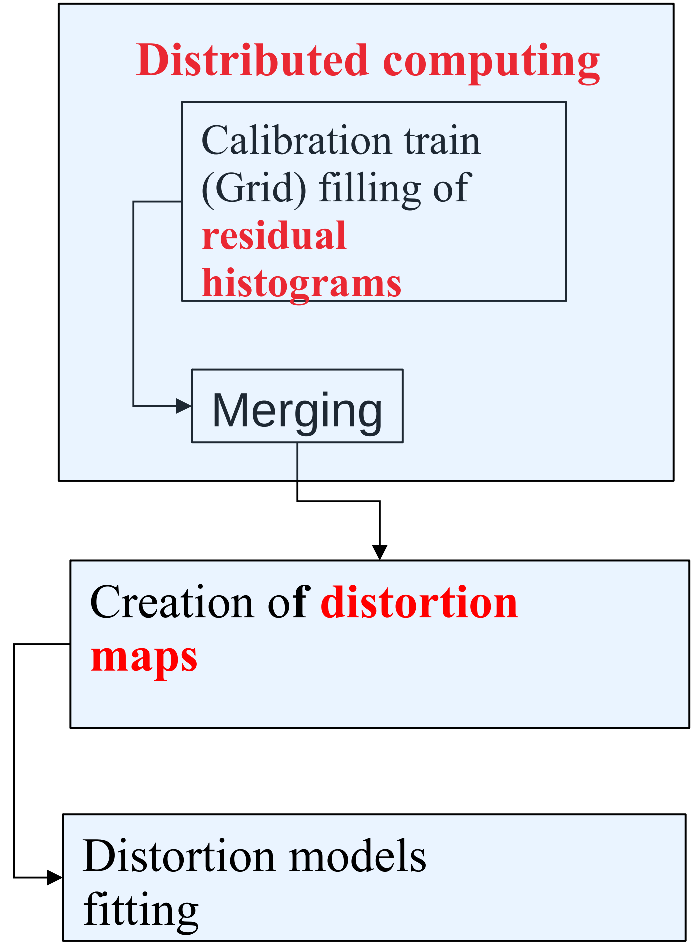
Assumptions:

- Space point distortion transformation commute (the order of applying of corrections is not important)
- Space point distortion can be approximated as a linear combination of the "partial distortion" functions with given parameter:
  - $\Delta = \Sigma\ k_i E_i$
- Space point distortion not directly observed. We define the set of observables O.
  - $\Delta O = \Sigma\ k_i O_{ei}$
- Under given assumption the analytical (non iterative) global minimization of distortion maps can be performed solving the set of linear equations.
- Assumptions were tested for the typical distortion in the TPC, moreover the assumption were tested also for the fitted parameters.

Numerical part based on the linear fitting package implemented in the ROOT

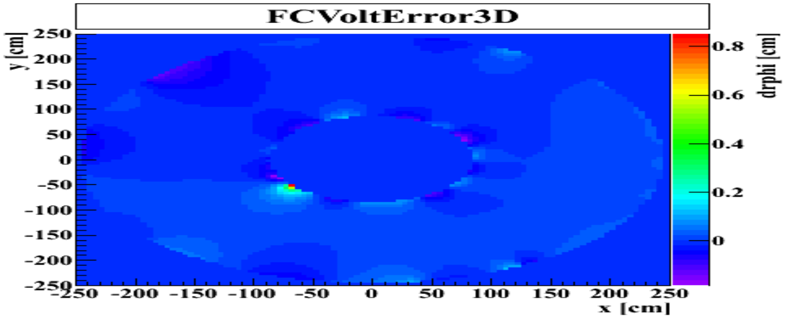
Additional functionality implemented in the AliRoot (Alice framework)

- Input data observables and fit models from the tree
- Possibility to add constrains
- Possibility to check the the fit values (return value of the FitPlaneConstrain can be used as a alias in tree)
- Extraction of the partial fits

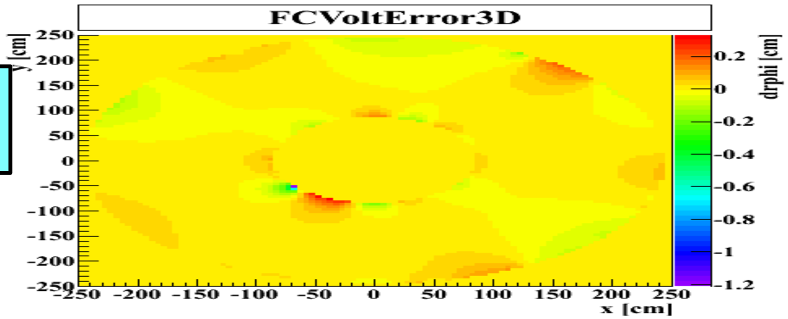


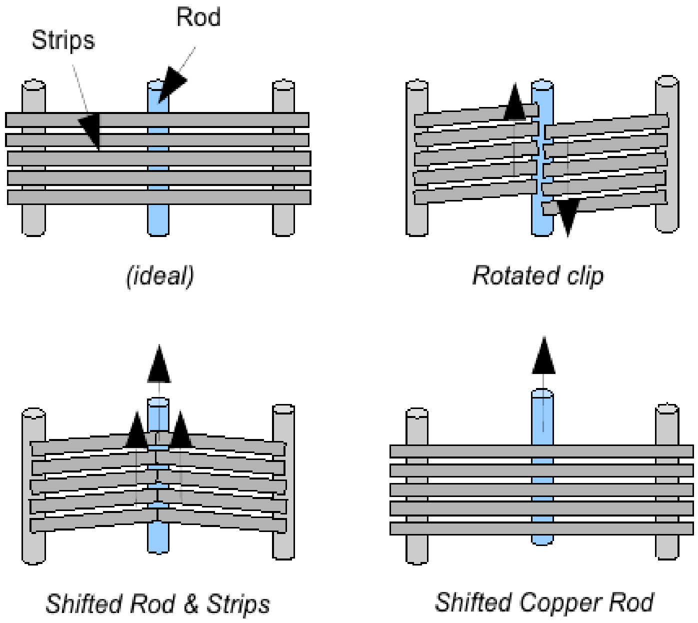
Example distortion fits - Field cage and Rod alignment

A side Positive



C side Negative





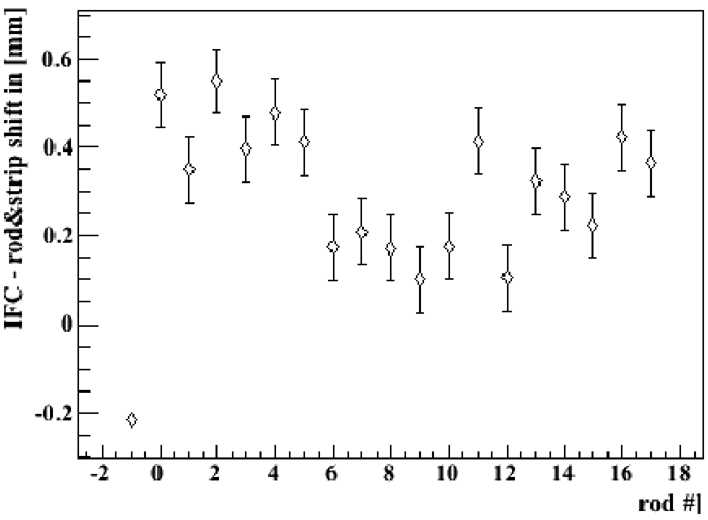
18 (rods) x 2 (IFC,OFC) x 2 (A side, C-side) + 2 rotated clips x 2 (at the resistor rod)

- Small misalignment (**σ ~ 0.1 mm**) leads to a significant non linear distortion up to 6 mm

B field 0 data (4D histograms of residuals between the line and space points) used as a input for the alignment and E field distortion calibration

3D Distortion map obtained from the track residual histograms

- Linear fit with 796 parameters



TPC - drift velocity (v_D) not saturated (Neon based gas, E=400 V/cm)

- v_d changes strongly with p, T and gas composition.
- e.g $\Delta v_d/v_d \sim 1 \times \Delta P/P - 1 \times \Delta T/T$

Spatial resolution requirement below 1 mm

- Temperature uniform within ~ 10^{-4}

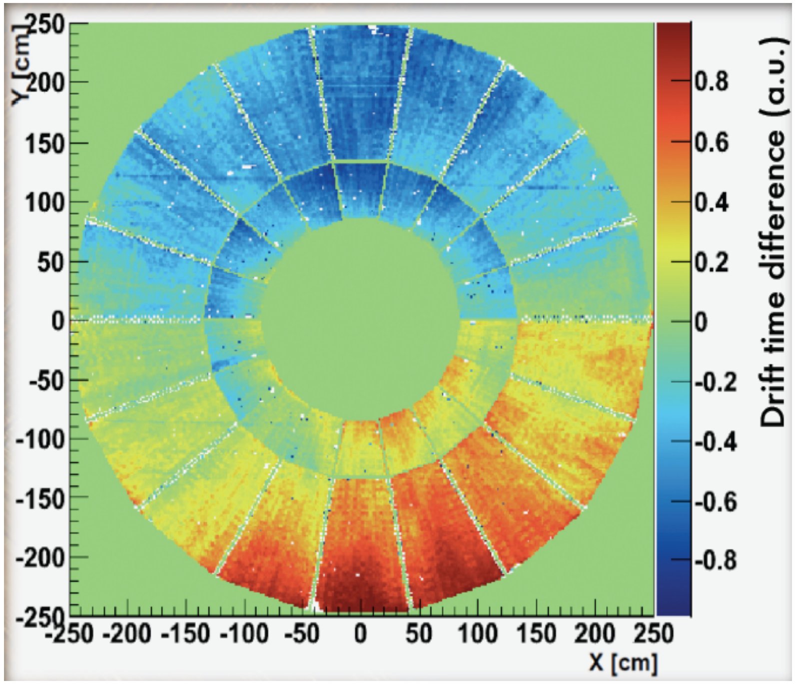
Typical drift variation ~ 5-7 % (10-14 cm)

- Due to the pressure changes – ~ 5 %
- Due to the gas composition changes – ~ 2 %

ONLINE/OFFLINE Calibration:

- Laser data and external v_D monitor (ONLINE)
- Matching of tracks in TPC and ITS(Offline)

P and T measured with seconds granularity, gas composition calibration updated every 15 min



Online calibration example (Laser):

- Photoelectrons knocked out from the central drift electrode by scattered laser light. 1.5 ‰ drift velocity variation observed (due to the vertical temperature and pressure gradient in the gas volume.)
- Linear correction applied later during the reconstruction

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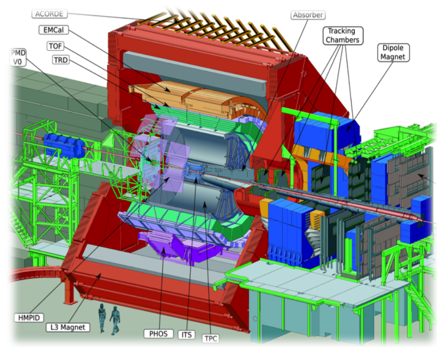

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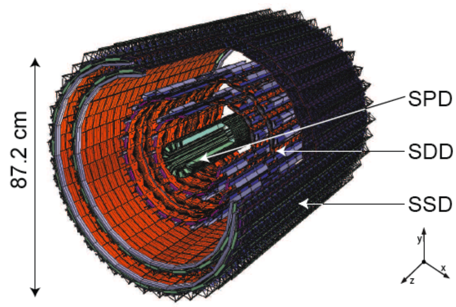

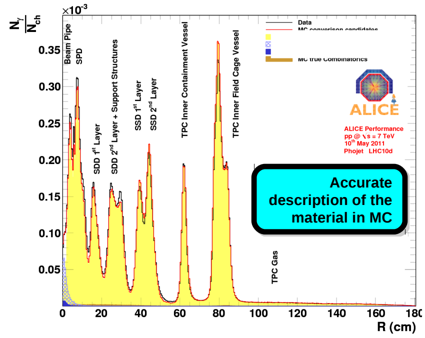

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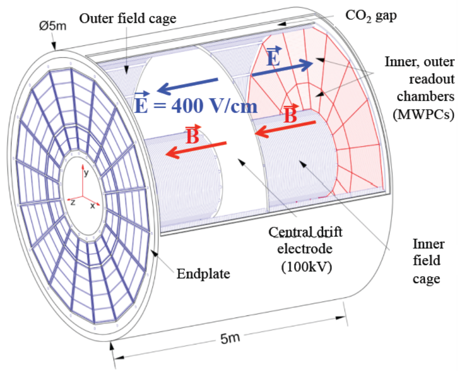

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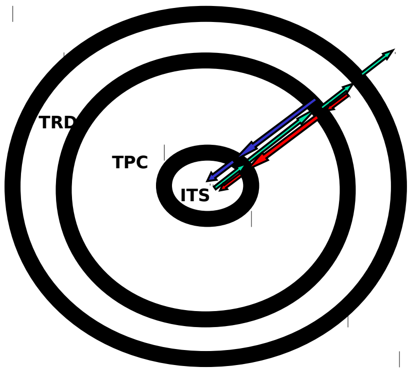

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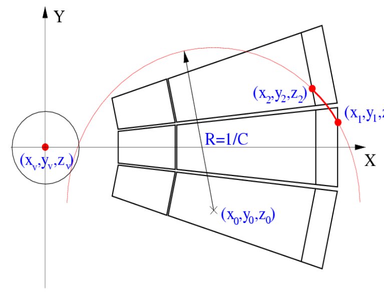

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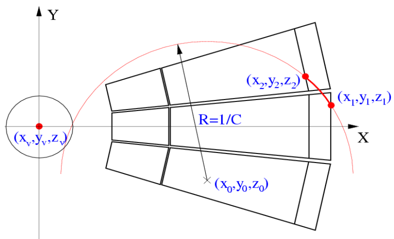
- Fast primary track seeding with vertex constraint applied first (N^2 problem)
- Secondary seeding without the vertex constrain (N^3 problem) done after TPC cleaning



Track hypotheses clean up done at the end of the TPC tracking at each tracking iteration

Tracks with significant amount of shared space points rejected. Only "best" hypotheses kept

Special treatment of the decay topologies inside of the TPC (decays/Kinks and interaction). Tracks refitted towards to the vertex.

- Identified decay topologies used for the K and π identification

TPC reconstruction (2)

Local occupancy up to 10 % (dN_{ch}/dy ~ 1600)

Cluster unfolding necessary

- Performance of the unfolding algorithm limited by the shape fluctuation, and by a-priory unknown shape of clusters
- Correcting for overlapping clusters (OFFLINE clusterer) or splitting clusters (HLT clusterer)

Non Gaussian error of cluster position

- Error estimate strongly dependent on track topology. can not be assigned during the cluster finder. Attribute of the cluster/track pair
- The space point resolution calibrated as a function of the cluster and track topology.
- For clusters, with extended shape in respect to the expected shape for given track topology, cluster position error correspondingly enlarged

Cluster sharing between tracks enabled

- **Non greedy-Algorithm.**
- Tracks competing for clusters.
- Two track fits not independent
- For shared clusters for track overlaps, expected cluster error is increased

Planned Run1 reprocessing modifications

- Unfolding on track/tracklet level to be done, to reduce the fluctuations.
- TPC/ITS standalone tracks recovery
- Usage of the TRD information in refit inward

ITS tracking – Combinatorial Kalman Filter

The ITS "digit" occupancy (1-4 %) smaller than in case of the TPC. Cluster unfolding not the critical issue. But, significant occupancy in the track prolongation roads. Mainly for low momentum tracks (search window ~ 1/p)

Combinatorial Kalman Filter chosen

Use a TPC extrapolated track as a seed.

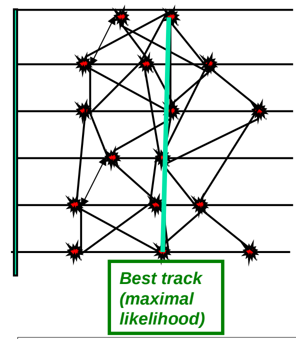
- * The ITS standalone tracking also implemented, but combined tracking more robust - significantly smaller amount of fake tracks

Iterate the following sequence:

- Extrapolate and look for compatible measurements.
- For each compatible measurement, generate a branch and make an update.
  - $\mathbf{N_{branch} \sim (1+k*occu*\chi^2_{cut}/p)^{Nlayers}}$
- Generate a branch with no update (**missing space point**)
- If a branch contains no updates for a number of layers,drop the branch.
- Drop the worst branches, and drop branches below some quality limit.
  - The total number of branches limited

Cleanup selecting the "best" branch using global information

- Additional information about the overlap with concurrent TPC tracks used – **conflict resolving algorithm** (maximizing the likelihood of pairs of tracks)
- For V0 topology (K0s, Λ, γ) the position of the decay vertex taken into account.



ITS tracking: special case of primary tracks without conflict with concurrent TPC seeds

HLT- Online TPC reconstruction

- The TPC online tracker implementation combines the principle of the cellular automaton and the Kalman filter.
- Accelerated by the usage of graphics cards (GPUs).
- A pipelined processing allows to perform the tracking on the GPU, the data transfer, and the preprocessing on the CPU in parallel.
- A splitting of the tracking in multiple phases searching for short local track segments first improves data locality and makes the algorithm suited to run on a GPU.

Reconstruction optimization.
Preparation for Run2.

Run 2 preparation (0)

Data rate in RUN2 expected to be significantly higher.

- RCU2 format
- Higher efficiency of data taking
- For pp runs pile-up ~ 10-50 events in TPC

Can we speed up the reconstruction by factor (4-10) to adopt for higher data rate in RUN2, using current OFFLINE software?

- Our goal is to speed up the reconstruction part by corresponding factor

Run 2 preparation (1)

Following slides benchmark values for the low intensity (small pile-up) pp runs

- CPU time for pile-up is linearly scaling with the number of events
- Typical pile-up 1 event (in 2010) up to 50 (in 2012,2013)

No evident hot-spots

Reconstruction ~ 20 % of overall ALICE OFFLINE activity

- Material budget queries
- Magnetic field queries
- Track propagation

TPC reconstruction around 30% of overall reconstruction CPU consumption. With non evident hot spots.

- LoadClusters - 11 %
- Cluster2Tracks - 12% (2 times more track hypothesis investigated)
- PropagateBack - 6%
- RefitInward - 6%

Reconstruction process - TPC

Compromise between the CPU consumption and physics performance to be reached.

Partial use of the HLT algorithm (HLT seeds) in OFFLINE reconstruction implemented. Performance under investigation.

- Objective criteria to be defined

Pile-up events rejection (~10-50 events in TPC):

- Pile-up tracks can be rejected using the HLT tracking information
  - Not possible to distinguish pileup tracks from “deep secondaries” (kink decays)
  - Looping tracks can be used for the PID

Reconstruction process - TPC

Track d*E*d*x* calculation. Correction for missing signal in the clusters ~ 12%

- Cluster by cluster or effective track correction?

OFFLINE Ion tail cancellation ~ 7 %

Cluster space point correction ~ 7 %

- Common HLT/OFFLINE approach for caching

Track seeding ~2%

- CA seeding from HLT to be compared with the OFFLINE seeding
- Usage of the HLT seeds, implemented/tested. Reducing the number of track hypotheses to be investigated.
- Fast helix seeding, instead of the Kalman

Track propagation and update ~2 %

- Speedup <2. Double → Float, enabling vectorization
- Speedup ~ 5-10. Propagate and update per cluster → Propagate and update per tracklet

Cluster navigation

Kink finder combinatorial search

Double track removal and track unfolding

Track loop finder

Track matching recovery

Reconstruction process - Combined tracking

Local Event reconstruction ~ 30 %
Tracking ~ 50 %

Cluster navigation
Track propagation
- Number of steps to be tuned

Energy loss correction
Material budget queries
- Effective/exact material description

B field queries
- Piecewise Chebyschev, vs global 3d polynomial parameterization for Barrel

Conclusion: our experience

Alice OFFLINE tracking for Run1:

- TPC: seeding + Kalman following
- ITS: multi track hypothesis

Possible improvement of algorithm for Run2

- Better treatment of the combined TPC/ITS/TRD information and track based unfolding

Reconstruction processes decomposed, and benchmarked

- Most time spent in accessing information (dEdx correction, space point distortion correction, B-field)
- Actual track fitting insignificant
- Propagate and Update per tracklet to be investigated

CPU usage for Run2:

- Not obvious hotspot, several processes to be optimized
- Compromise with physical program (pile-up track rejection)

Conclusion: possible common tools

B field parametrization, table, queries

- precision/CPU as parameters

Material budget parameterization

- precision/CPU as parameters

Kalman filter

- Internal representation?
- Propagate
- Per point, per tracklet update
- Enabling procedures
  - Parallel hypothesis tracking
  - Cluster/track interaction: Expected cluster error and shape parameterization ?
  - Track/track interaction

Cluster navigation

Multidimensional correction tables

Backup

TPC performance - space point resolution

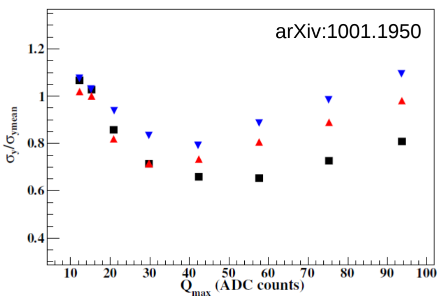
Up to 159 space points measured with the typical position resolution of about σ ~ 0.6 mm (for high momenta tracks small inclination angle)

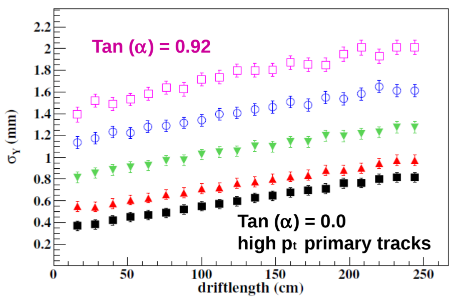
- **Track extrapolation precision** at the entrance of the TPC **of about σ ~ 0.15 mm** in both directions

Space point resolution depends on

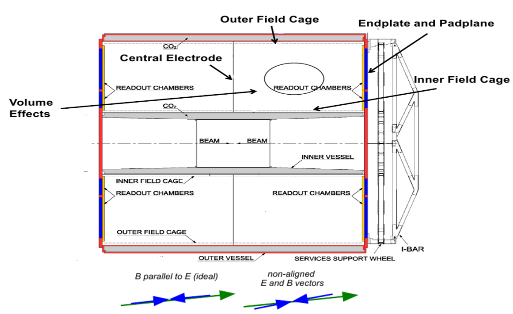
- The drift length
- The track inclination angle α
- The charge deposited Q
- Pad geometry (mainly pad length)

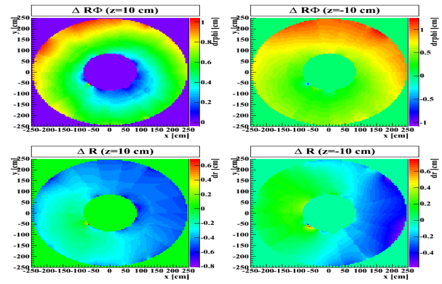
Requirement - the TPC alignment and the space position distortion calibration should be optimally kept below σ ~ 0.15 mm





TPC distortions





The TPC was internally mechanically aligned to the 0.1 mm level

Biggest observed distortion in the bending plane due to the ExB effect

- **B field inhomogeneity** – distortions up to **8 mm**
- **E field nonlinearities due misalignments** – distortions up to the **6 mm**
- **E and B field main component misalignment** – distortions up to **2 mm**

Right plot - resulting space point correction map as used currently in the Alice reconstruction

- The ExB effect time dependent (pressure, temperature, gas composition) – parameters updated on the run level

TPC space point correction framework developed - ALICE & STAR collaboration

- Physical (numerical solution of the Poisson equation) and effective distortion models

TPC distortion/alignment fitting

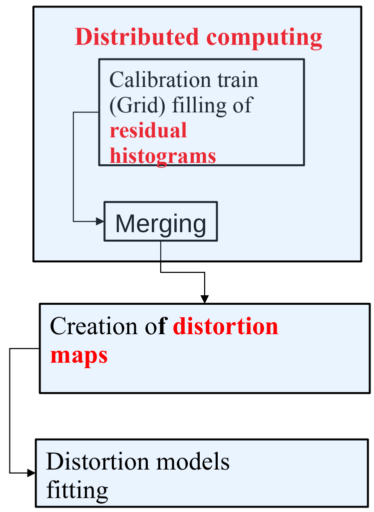
Assumptions:

- Space point distortion transformation commute (the order of applying of corrections is not important)
- Space point distortion can be approximated as a linear combination of the "partial distortion" functions with given parameter:
  - $\Delta = \Sigma$ ki Ei
- Space point distortion not directly observed. We define the set of observables O.
  - $\Delta O = \Sigma$ ki Oei
- Under given assumption the analytical (non iterative) global minimization of distortion maps can be performed solving the set of linear equations.
- Assumptions were tested for the typical distortion in the TPC, moreover the assumption were tested also for the fitted parameters.

Numerical part based on the linear fitting package implemented in the ROOT

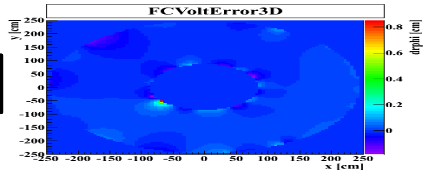
Additional functionality implemented in the AliRoot (Alice framework)

- Input data observables and fit models from the tree
- Possibility to add constrains
- Possibility to check the the fit values (return value of the FitPlaneConstrain can be used as a alias in tree)
- Extraction of the partial fits

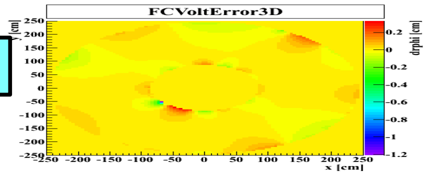


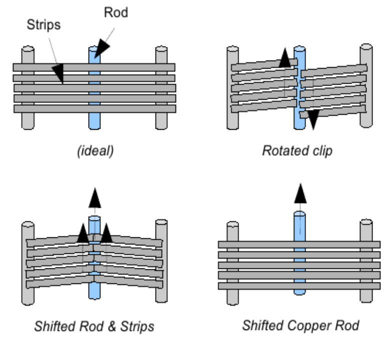
Example distortion fits - Field cage and Rod alignment

A side
Positive



C side
Negative





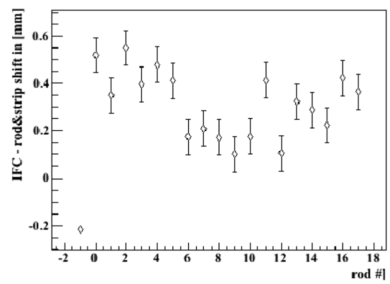
18 (rods) x 2 (IFC,OFC) x 2 (A side, C-side) + 2 rotated clips x 2 (at the resistor rod)

- Small misalignment (**σ ~ 0.1 mm**) leads to a significant non linear distortion up to 6 mm

B field 0 data (4D histograms of residuals between the line and space points) used as a input for the alignment and E field distortion calibration

3D Distortion map obtained from the track residual histograms

- Linear fit with 796 parameters



TPC z coordinate - Drift Velocity Calibration

TPC - drift velocity (v_D) not saturated (Neon based gas, E=400 V/cm)

- **v_d** changes strongly with p, T and gas composition.
- e.g **$\Delta v_d/v_d \sim 1 \times \Delta P/P - 1 \times \Delta T/T$**

Spatial resolution requirement below 1 mm

- Temperature uniform within ~ 10^{-4}

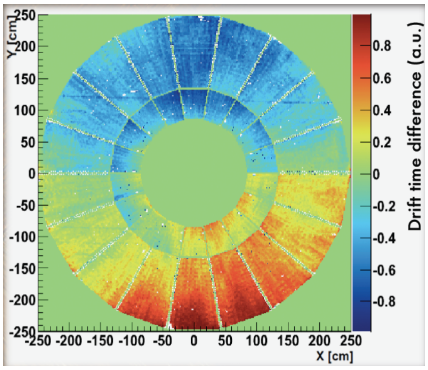
Typical drift variation ~ 5-7 % (10-14 cm)

- Due to the pressure changes – ~ 5 %
- Due to the gas composition changes – ~ 2 %

ONLINE/OFFLINE Calibration:

- Laser data and external v_D monitor (ONLINE)
- Matching of tracks in TPC and ITS(Offline)

P and T measured with seconds granularity, gas composition calibration updated every 15 min



Online calibration example (Laser):

- Photoelectrons knocked out from the central drift electrode by scattered laser light. 1.5 ‰ drift velocity variation observed (due to the vertical temperature and pressure gradient in the gas volume.)
- Linear correction applied later during the reconstruction