ALICE Alignment, Tracking and Physics Performance results

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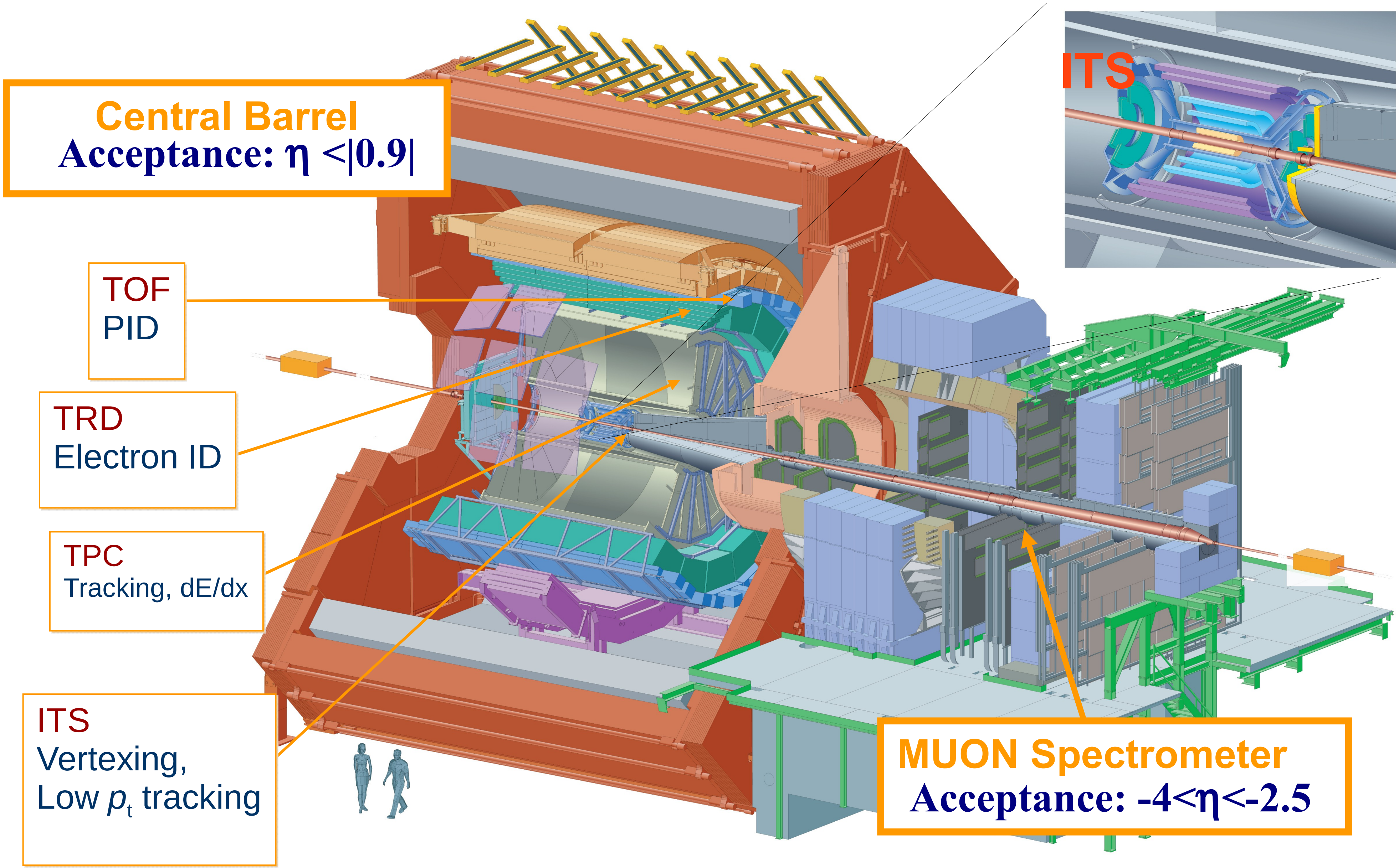
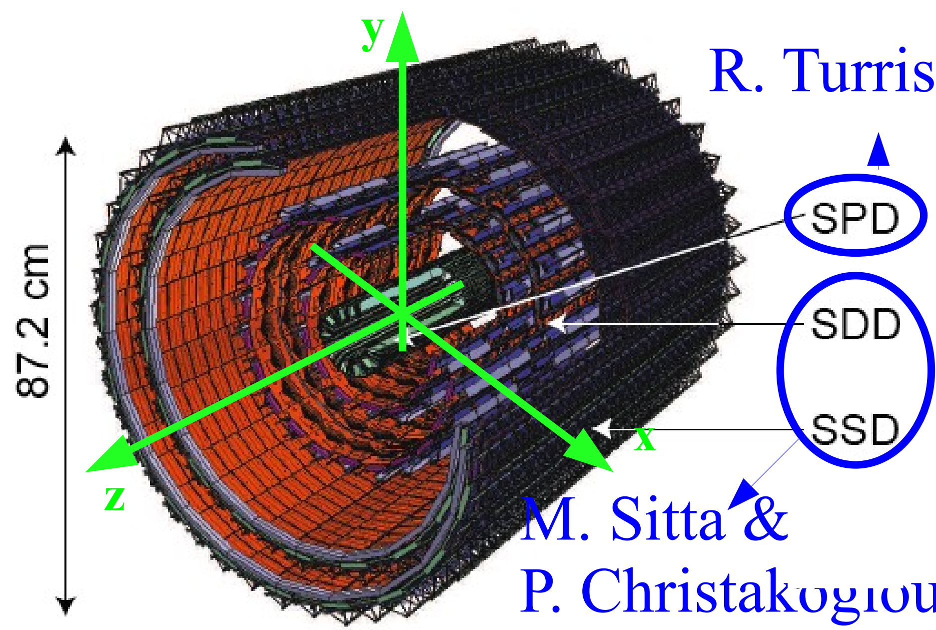
for the ALICE Collaboration

The ALICE detector



ITS: a silicon detector for a high multiplicity environment

Heavy-ion collisions: up to 2000 ÷ 6000 particles per unity of pseudo-rapidity



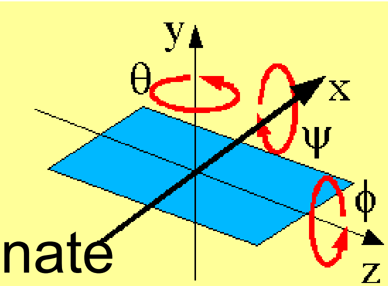
- High granularity
  - Inner SPD: ~30 particles/cm^2 (max occupancy ~1%)
- Low material budget (~7.66% X_0)
- High spatial resolution

<u>ITS tasks</u>:

- Precise tracking
- Primary & secondary vertices
- PID at low p_t via dE/dx

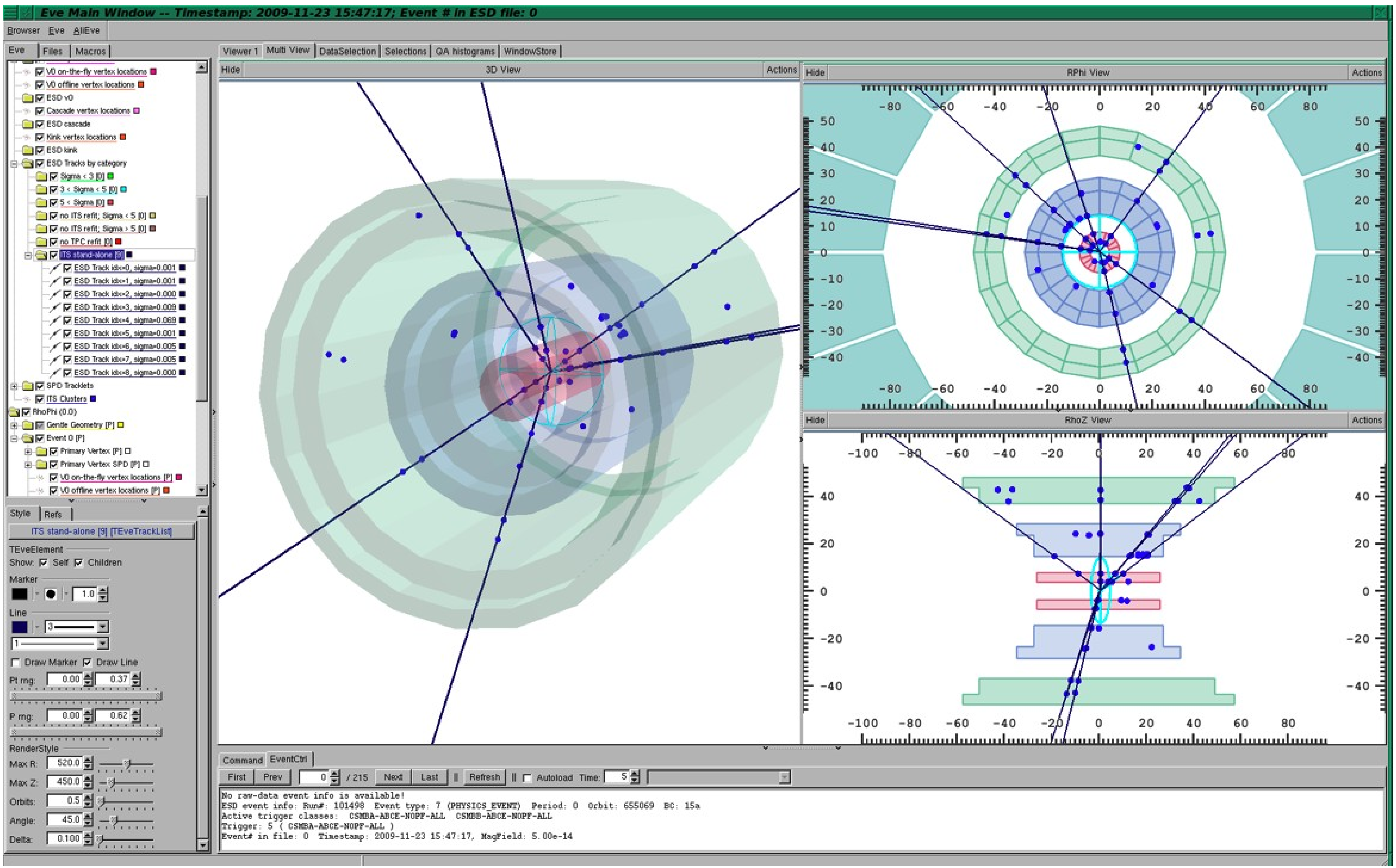
Detector Coordinates:

local x ~ rφ coordinate

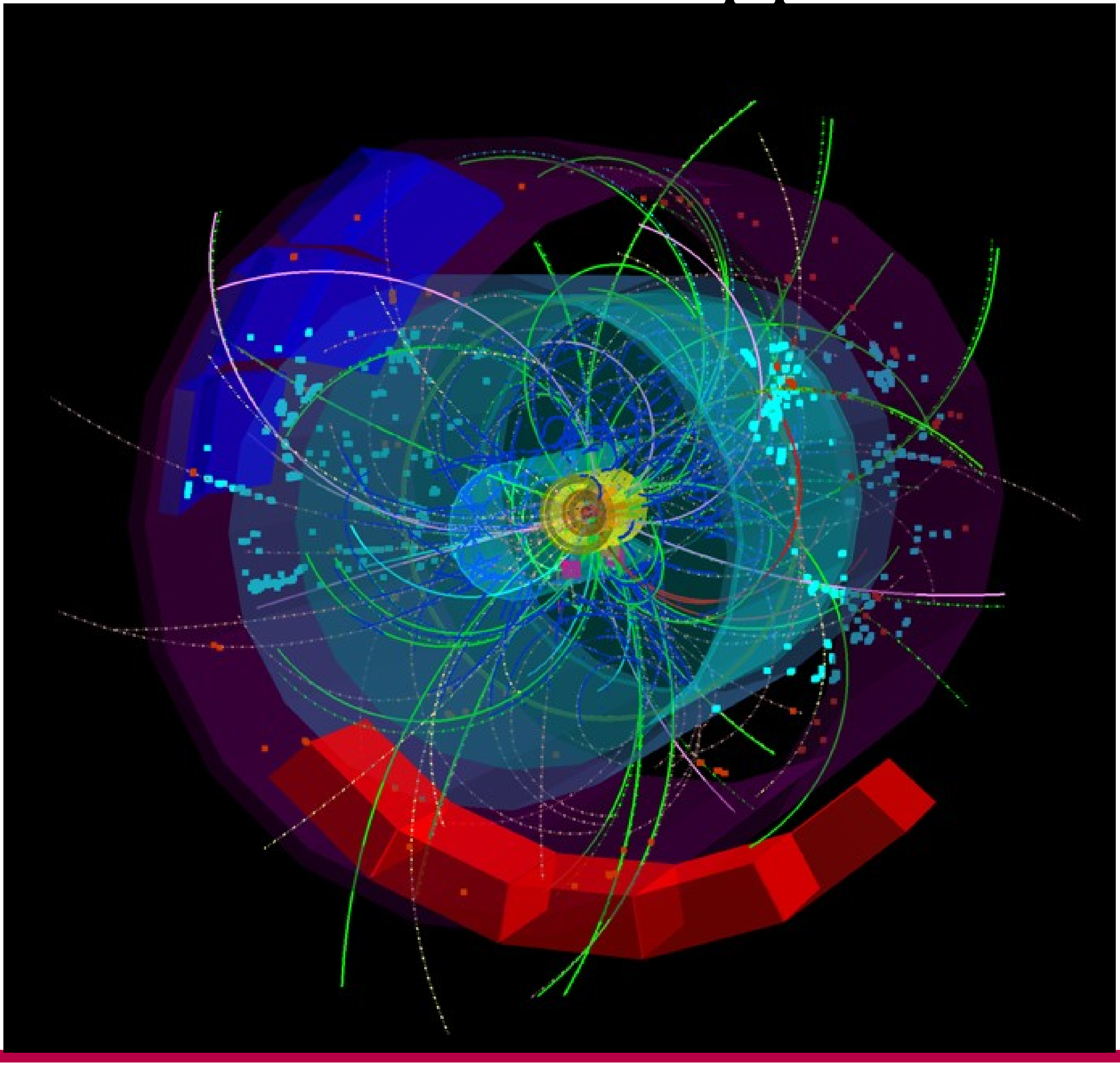


	Detector resolution (μm)		Radius (cm)	
	loc X	Z	inner	outer
SPD	12	100	3.9	7.6
SDD	35	25	15	23.9
SSD	20	830	38	43

First pp event on 23rd November 2009



31st March 2010: pp at 7 TeV



Layout

Part 1: ITS spatial precision for track & vertices reconstruction

- Alignment
- Tracking
- Primary vertex reconstruction

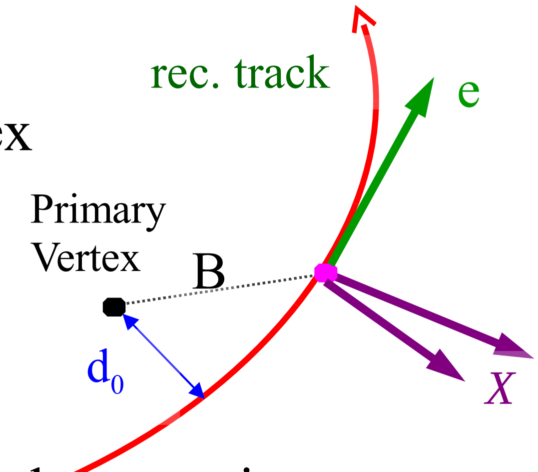
Part 2: PID

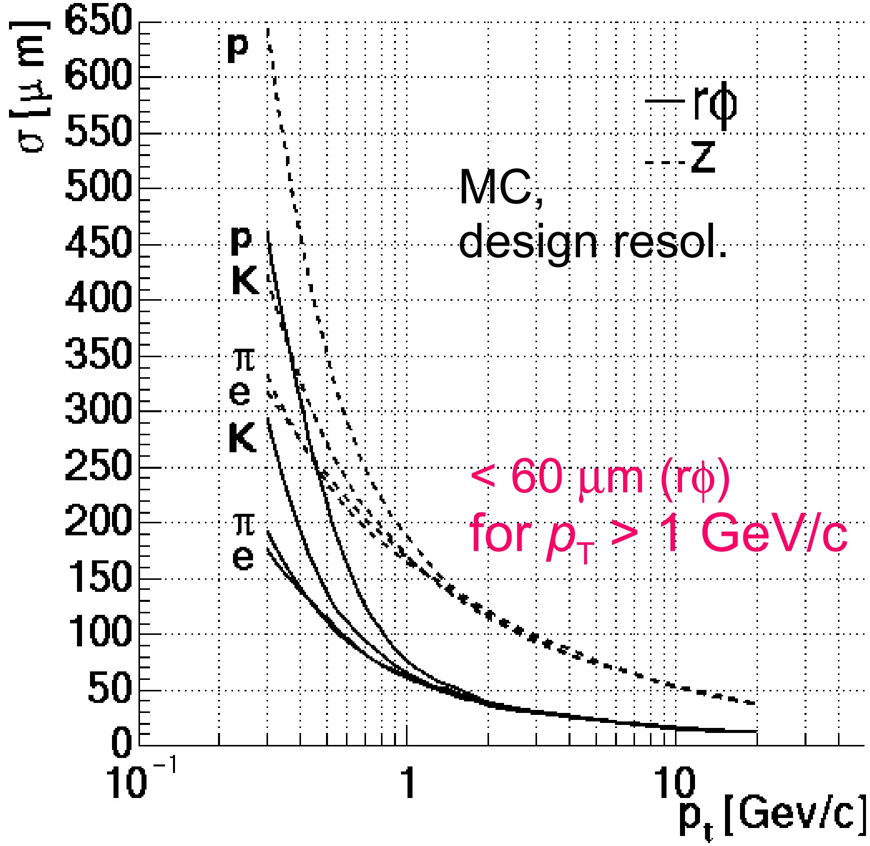
Part 3: Physics performance

Focus on results from pp data

Part1: Finding the impact parameter resolution on data

Reference variable to look for secondary tracks from strange, charm and beauty decay vertices displaced from primary vertex





- p_t dependence: multiple scattering
  - → material budget
- Detector resolution:
  - Intrinsic plus alignment contribution
- Primary vertex reconstruction

→ Tracking must account for all contributions

→ MC must reproduce various pieces

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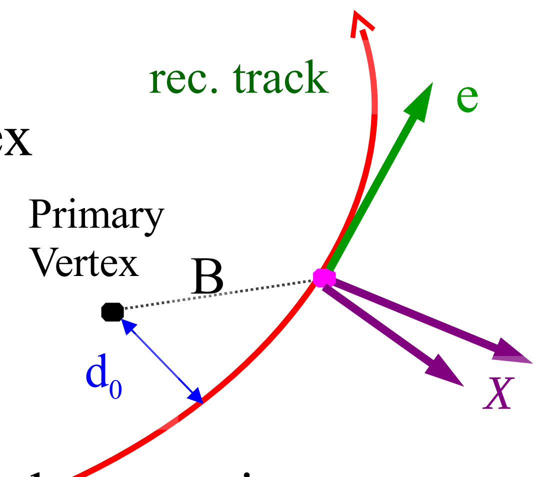
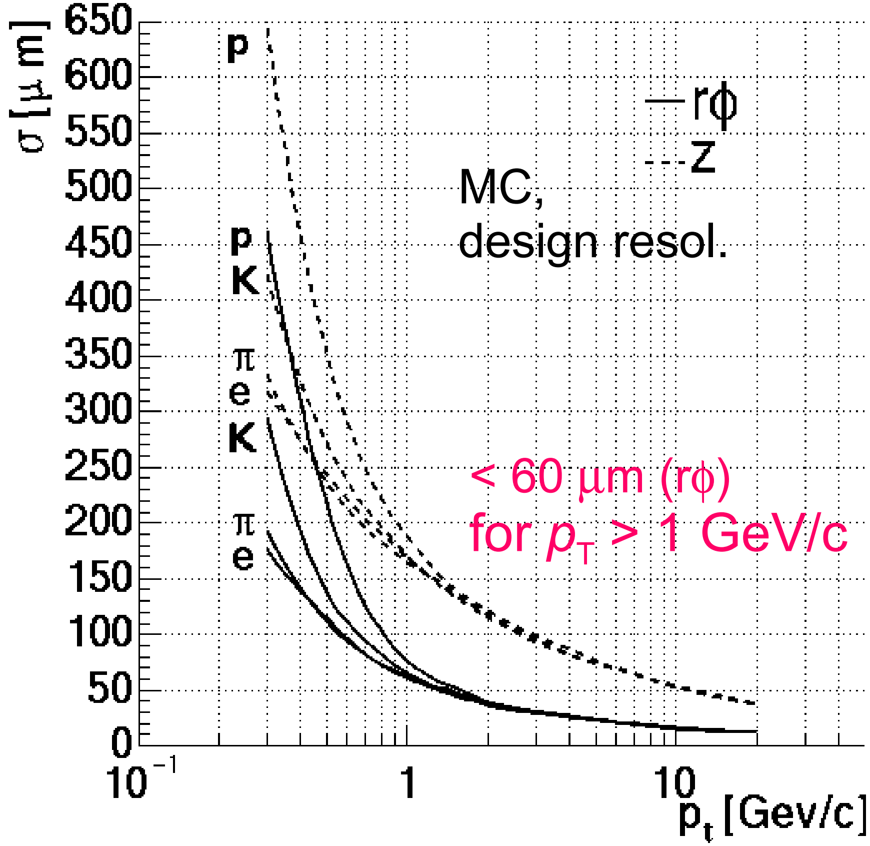
Reference variable to look for secondary tracks from strange, charm and beauty decay vertices displaced from primary vertex





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ITS Alignment

~2200 modules: more than 13000 parameters to be determined

Source of alignment Information:

- Survey measurements during assembly of SSD and SDD
- Track-to-point residuals (cosmic-rays, pp collisions)

ALICE strategy for ITS alignment

- Internal alignment
  1. SSD alignment with survey. Validation of survey measurement with cosmic-rays and tracks from pp collisions
  2. SPD alignment with cosmic-rays and tracks from pp collisions
  3. SPD modules and SSD ladders (if needed) alignment with pp collisions
  4. SDD alignment with cosmic and pp tracks after or in the meanwhile of calibration
- Relative ITS-TPC alignment

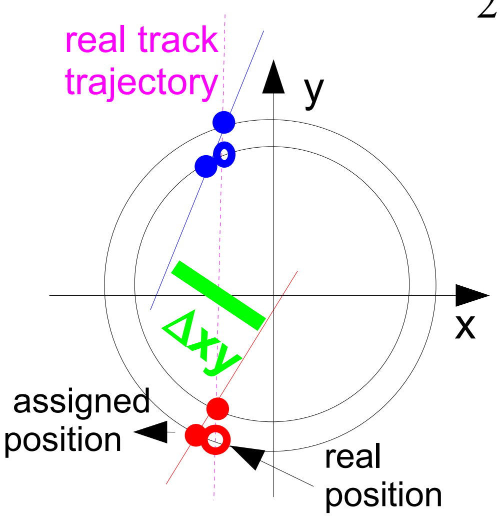
ITS alignment with cosmic data: SPD

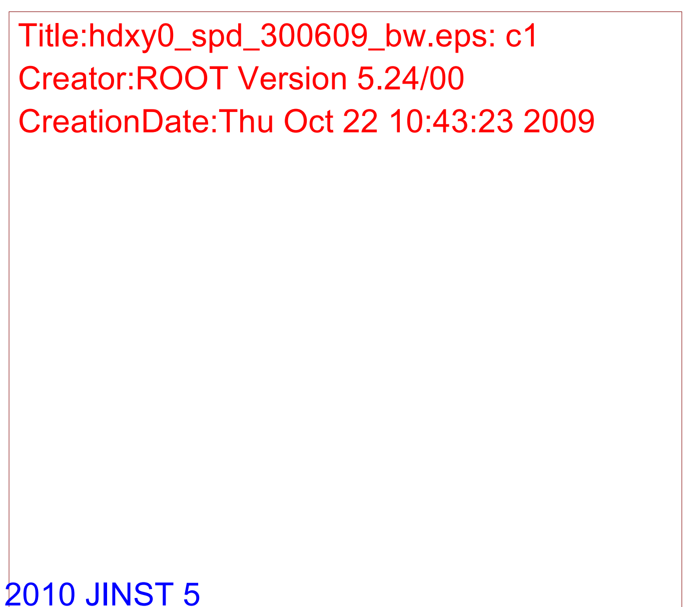
- Two alignment algorithms minimizing track-to-point residuals
  - Iterative module-by-module approach
  - Millepede (by V. Blobel, *http://www.desy.de/~blobel/wwwmille*): global minimization of both tracks and all alignment parameters in the same time
- First alignment in 2008: ~10^5 tracks from cosmic-rays, with B=0

(ALICE coll. 2010 JINST 5 P03003)

- Alignment quality check with $\boldsymbol{\Delta xy|_{y=0}}$

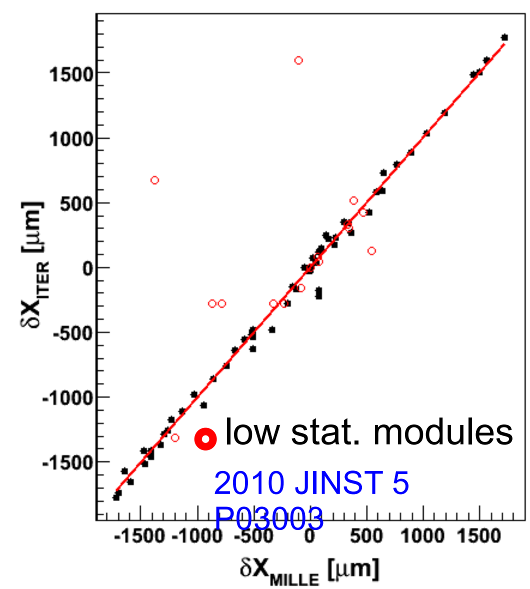
$$\sigma^2(x_{loc}) \approx \sigma^2(\Delta XY_{y=0}) \cdot \frac{1}{2} \frac{(r_2 - r_1)^2}{r_1^2 + r_2^2}$$





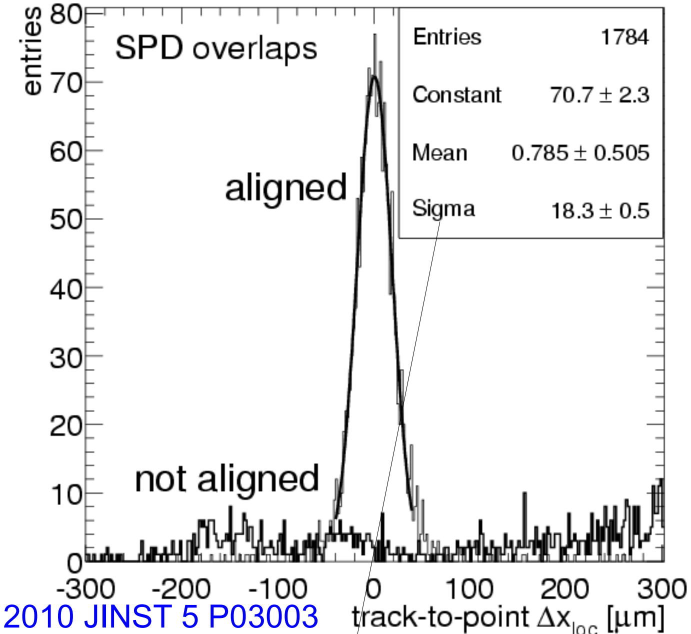
2010 JINST 5 P03003

Iterative-Millepede comparison



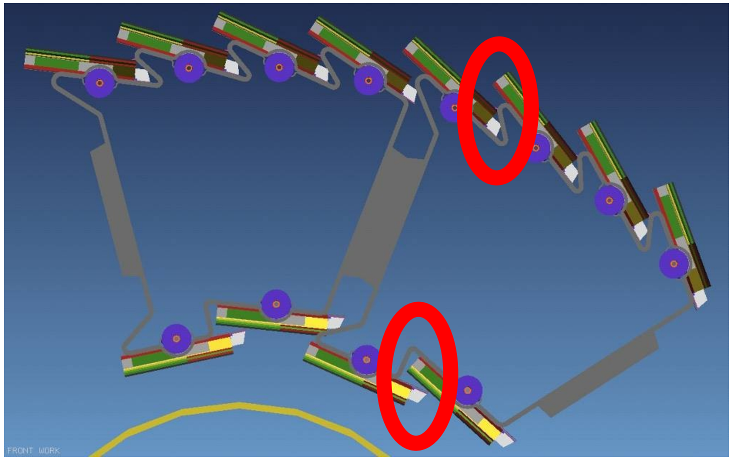
ITS alignment with cosmic data: SPD

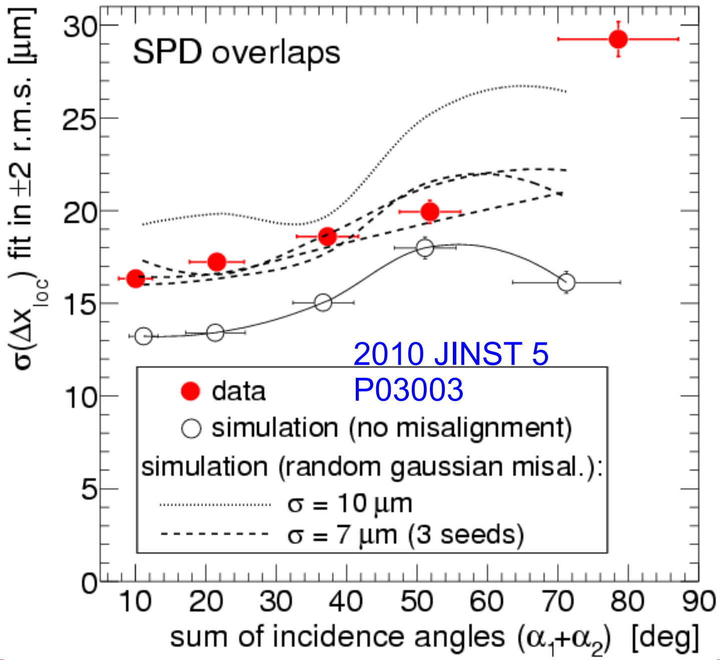
Alignment quality check with **points in overlapping regions**



2010 JINST 5 P03003

$$\sigma^2(\Delta x) \approx 2 \cdot \sigma^2(x_{\mathrm{loc}})$$





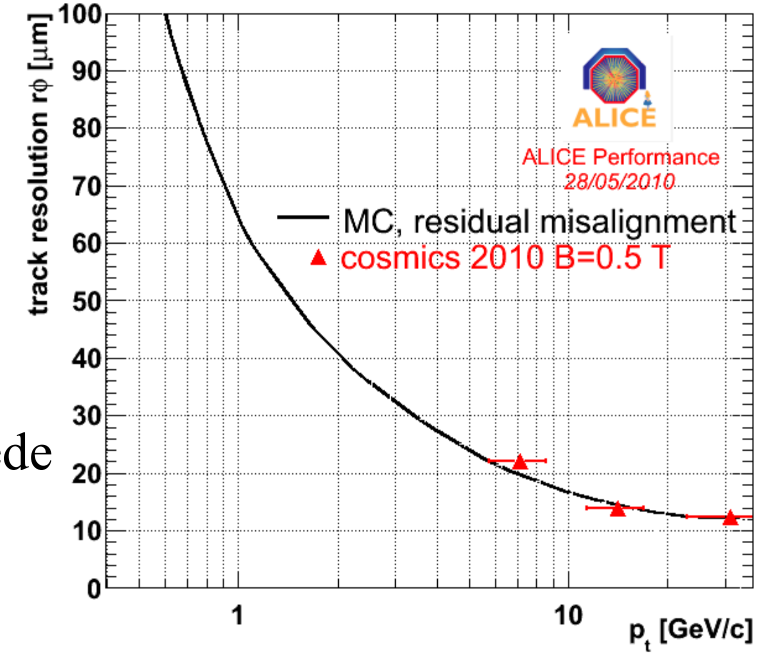
2008 cosmic data: 80% of SPD modules aligned within 7 μm

ITS alignment with pp collisions: SPD

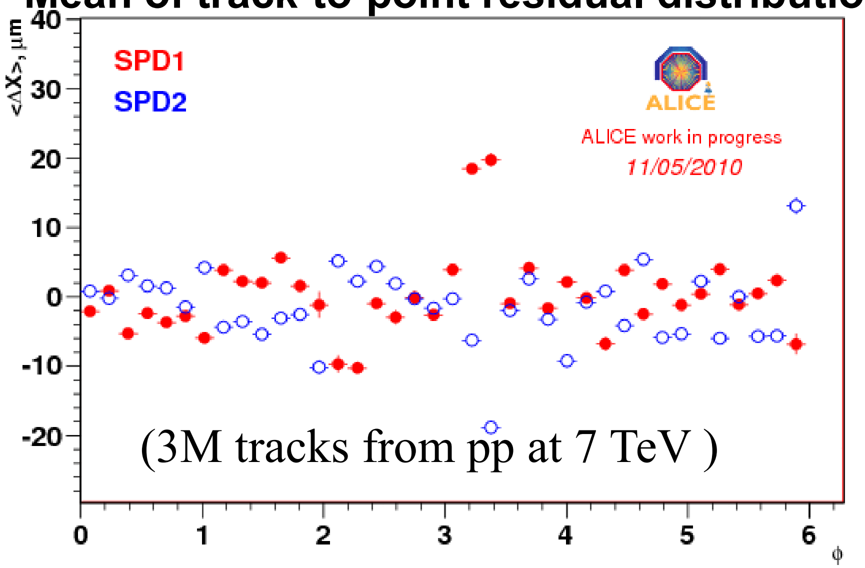
Main differences wrt cosmic:

- tracks with 6 points in the ITS
- B=0.5 T (track p_t fixed from TPC)
- different correlations between modules
  - ✔ all modules illuminated
  - ✗ almost radial tracks

➔ use residuals from cosmic (~30k) and pp data tracks (~20M) together (with different weights) in the Millepede



Mean of track-to-point residual distribution



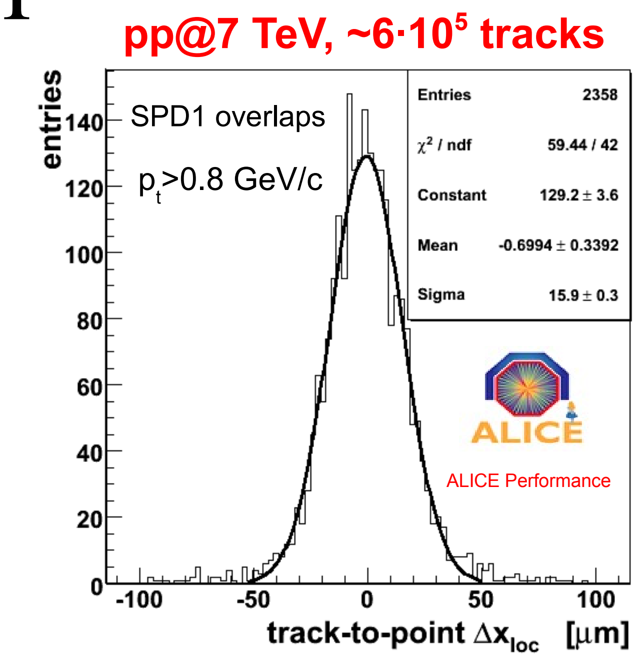
(3M tracks from pp at 7 TeV)

Alignment quality check with **track-to point residuals**

$\Delta xy|_{y=0}$ (with cosmic only)

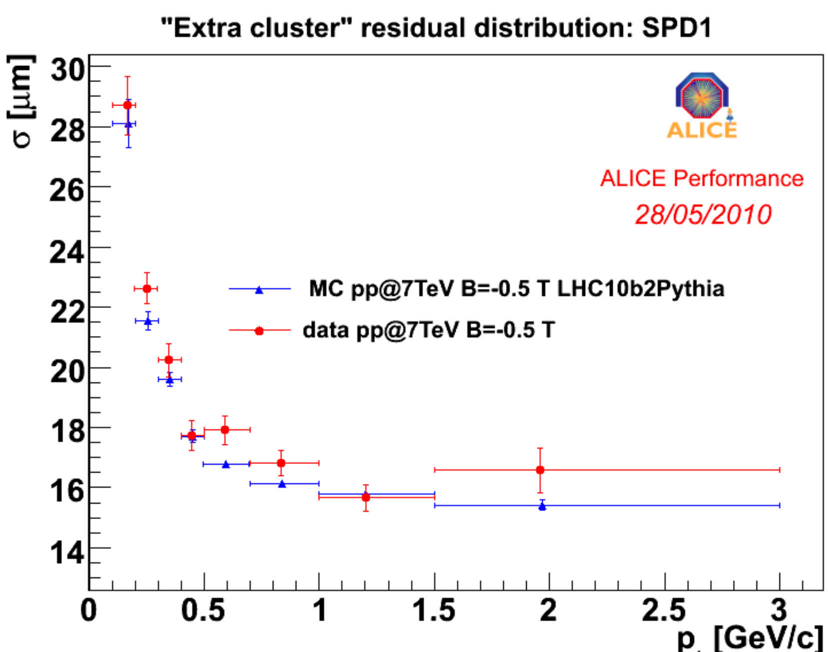
expected same trend as impact parameter with “perfect” primary vtx reconstruction

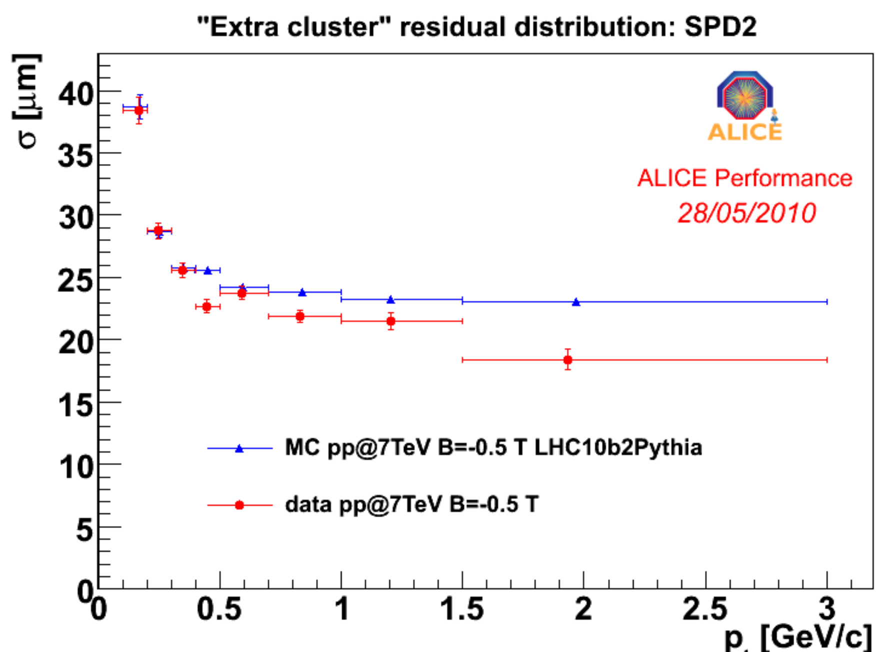
Alignment quality check with points in overlapping regions: SPD



Monitor alignment quality & check agreement MC/data

- σ smaller than with cosmic data alignment only
- σ in the data slightly smaller than in MC for SPD2
  - residual misalignment smaller than MC (to be confirmed, *which is the actual intrinsic resolution?*)





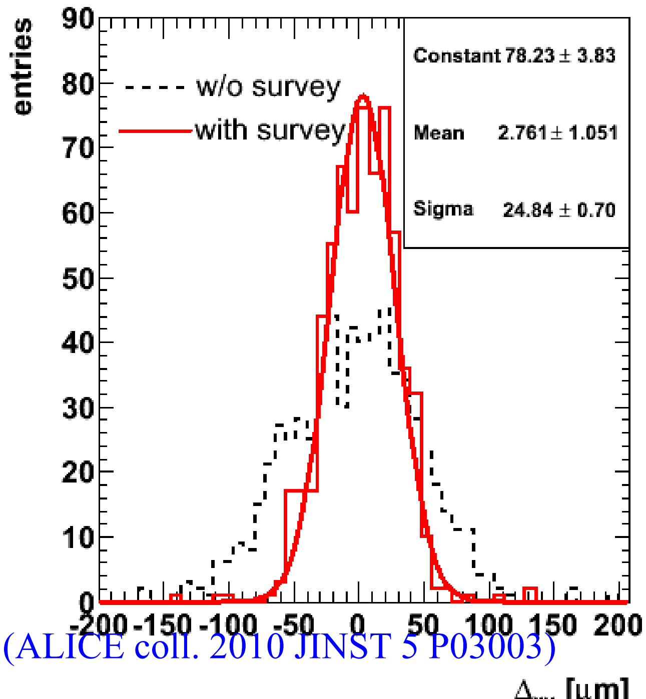
SSD survey validation

Two distinct sets of survey measurements determined SSD initial position:

- module positions on the ladders
- ladder positions with respect to the cone

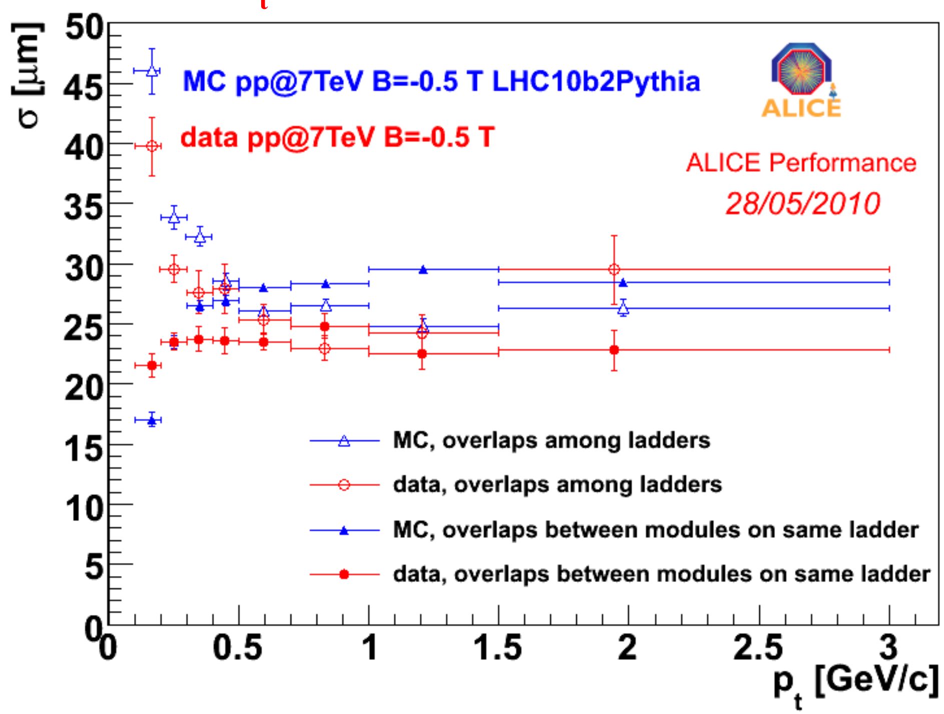
The values found were validated with cosmic tracks first and then with pp data

2009 result with cosmic: SSD1



(ALICE coll. 2010 JINST 5 P03003)

σ (p_t) for pp data at 7 TeV



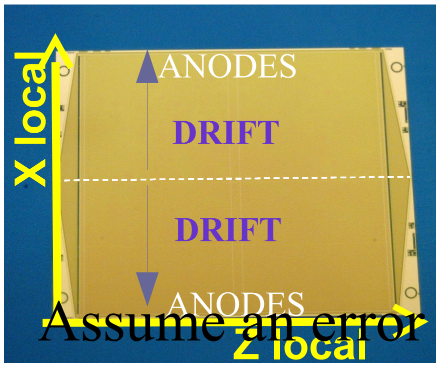
3 kinds of residuals:

- **pair of points in overlapping regions**
- track-to-track
- track-to-point

Residual misalignment ≤ 10 μm, *which is the actual intrinsic resolution?*

SDD alignment with Millepede

see M. Sitta & P. Christakoglou talk



Local x coordinate in the drift direction: $x_l = \pm\left(L - (t - t_0)V_D\right)$

L is the maximum drift length, **t** the measured drift time

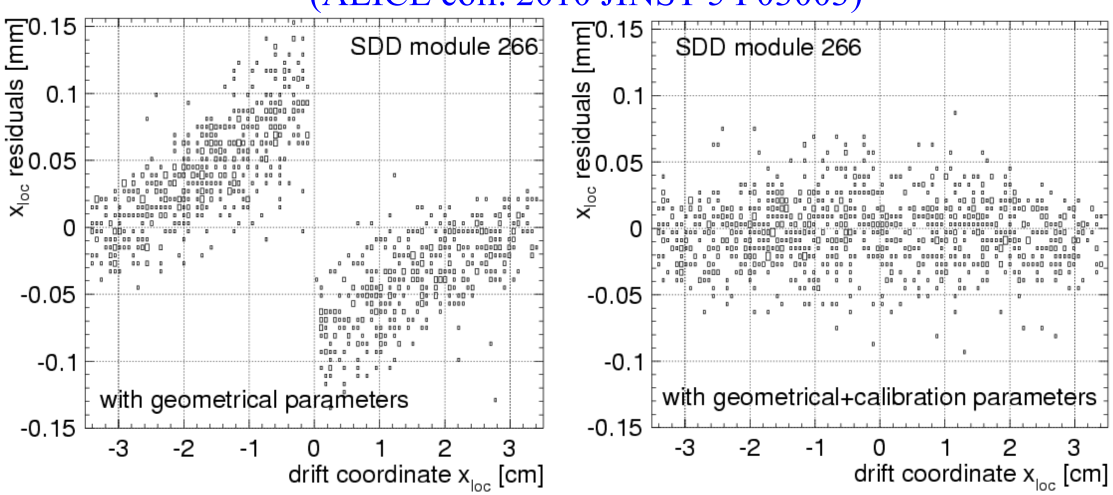
t_0 and V_D are the time offset and drift speed known initially with limited precision.

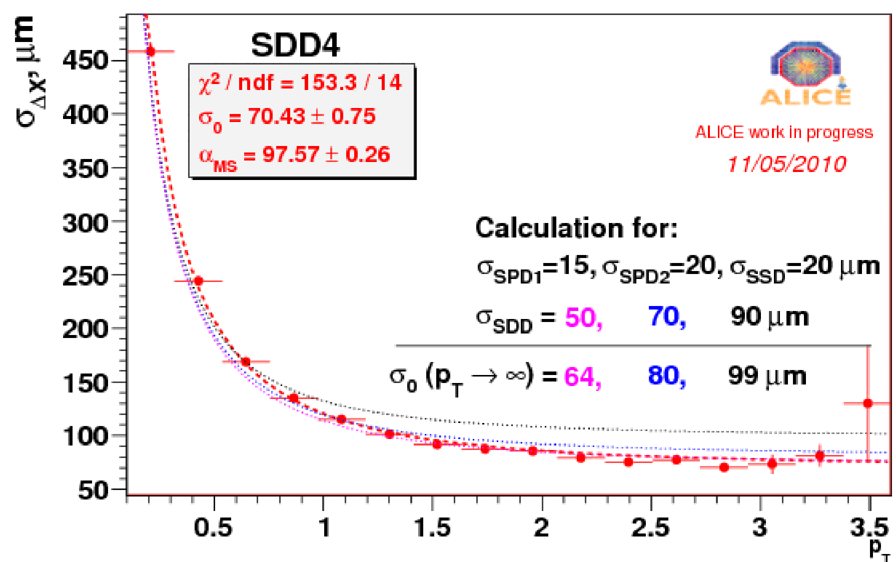
Assume an error for each sensor: a time offset δt_0 and a drift speed δV_D

Local shift in drift direction (linearized):

$$\delta x_l = \pm(\delta t_0 V_D - \delta V_D (t - t_0))$$

(ALICE coll. 2010 JINST 5 P03003)





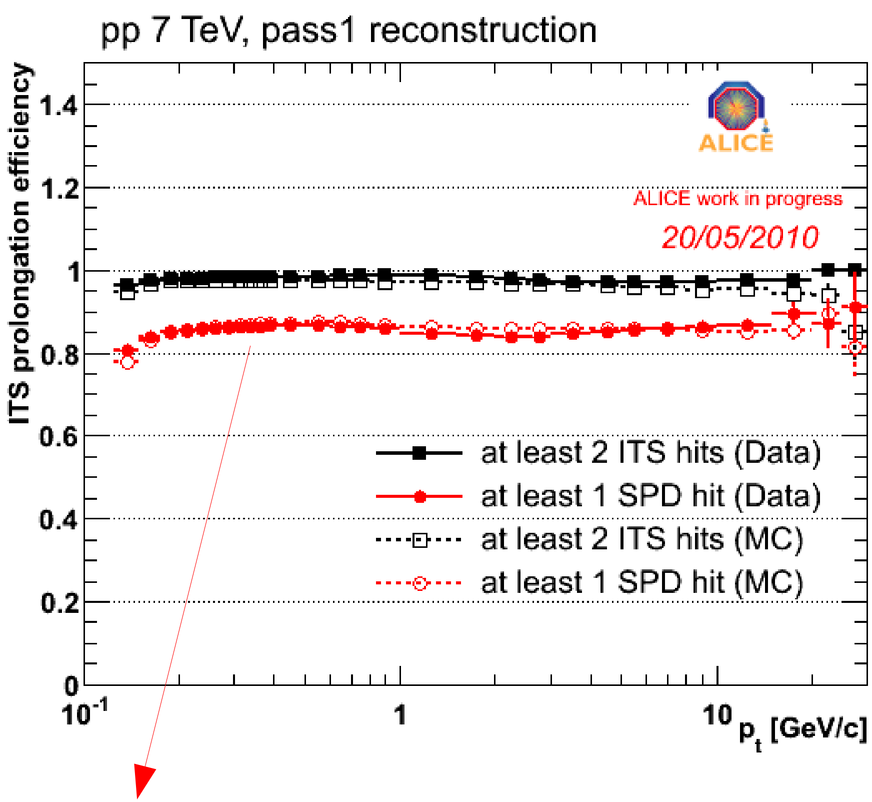
Tracking in the barrel: strategy

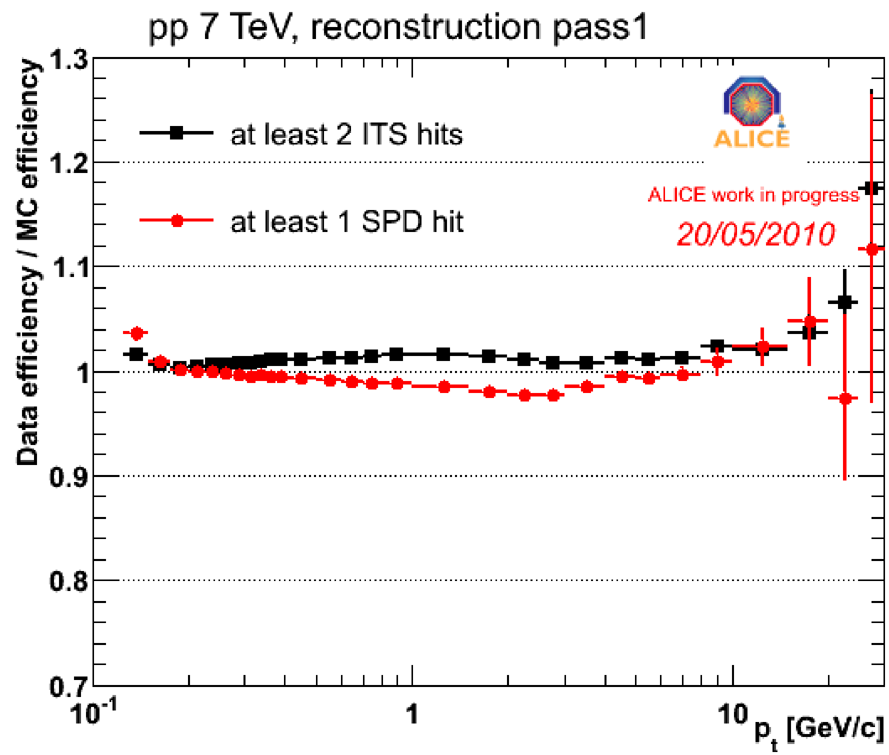
Steps for track reconstruction

- Cluster finder in the detector (centre of gravity)
  - Unfolding of overlapped clusters (optional)
- Primary vertex reconstruction using the SPD
  - used as seed for tracking. Pileup detection at this stage
- "Seeding" in the TPC (with/out the vertex constraint)
  - Later also the seed in the ITS and in the TRD
- Combined tracking with Kalman-filter technique
  - On the fly kink and V0 reconstruction
- Primary vertex using tracks
- Secondary vertices using the tracks (V0s, cascades)

3 detectors employed for track reconstruction: TPC, ITS and TRD

TPC-ITS prolongation tracking efficiency





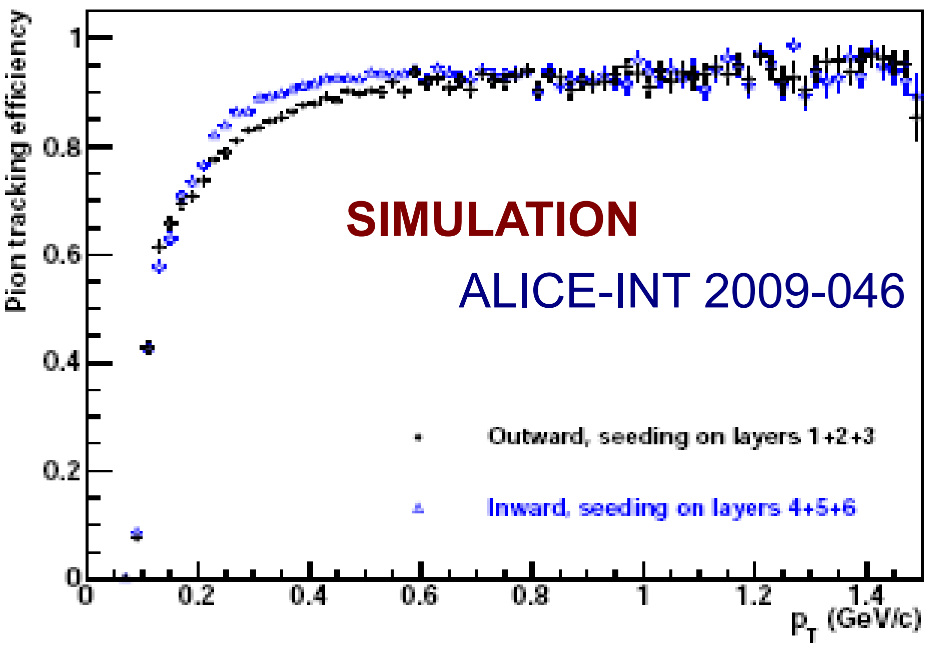
~15% modules missing in the SPD

see R.Turrisi talk

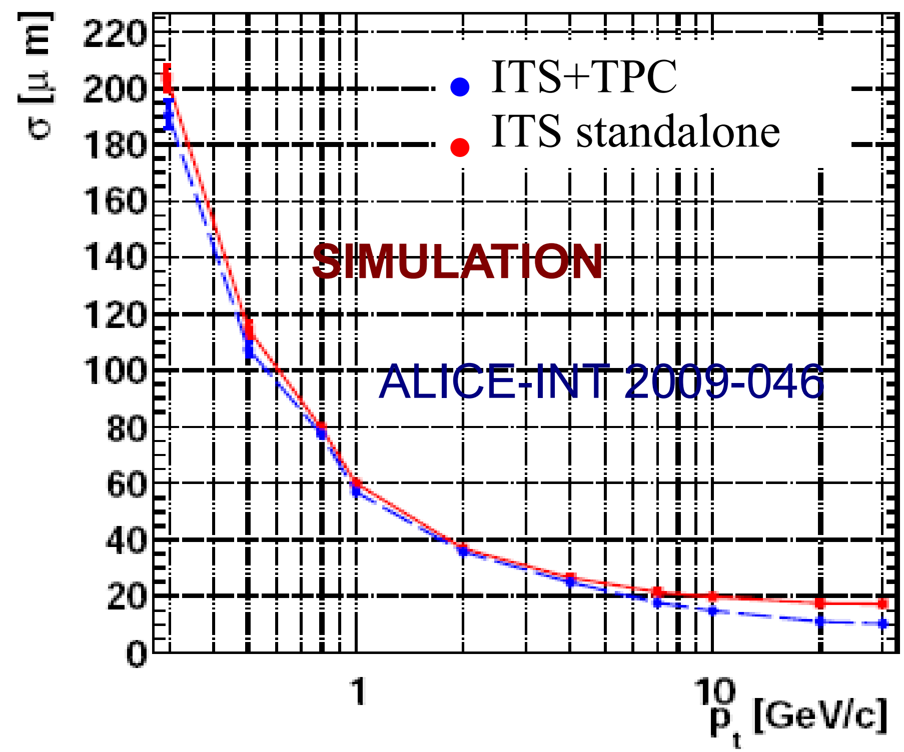
ITS standalone tracking

Aimed at extending p_t acceptance down to 100 MeV/c

Efficiency



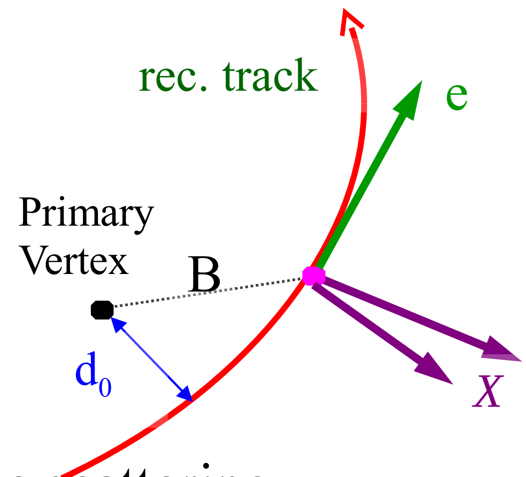
Impact parameter resolution

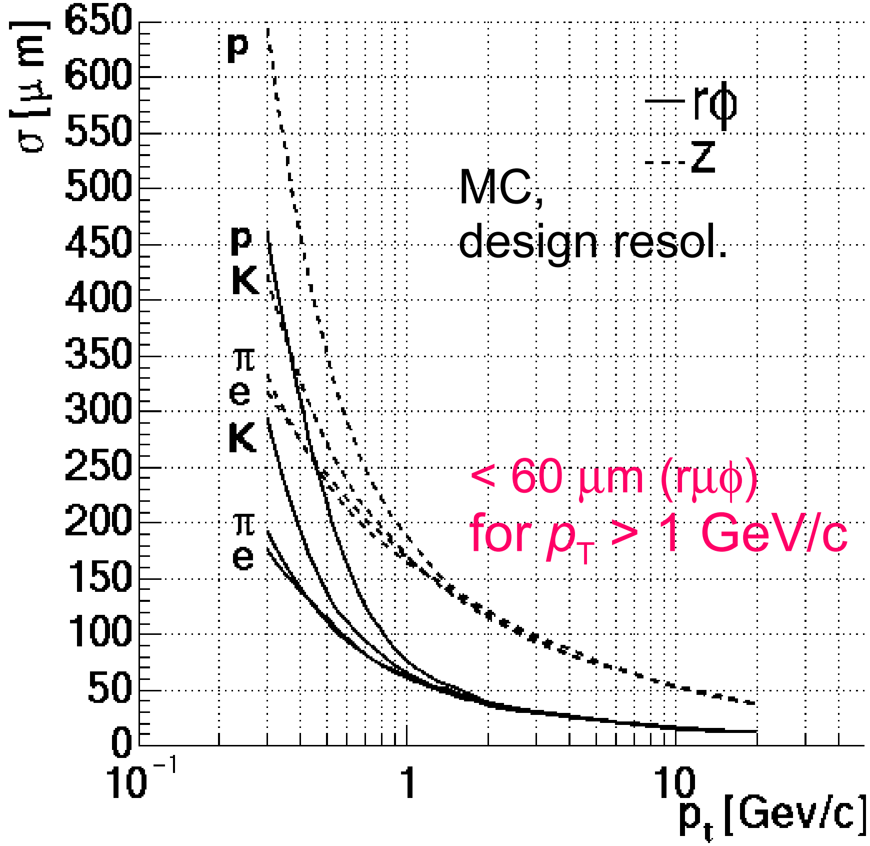


Two possible track finding directions:
- outward
- inward (optimized for low p_t tracks)

Part1: Finding the impact parameter resolution on data

Reference variable to look for <u>secondary tracks</u> from strange, charm and beauty decay vertices displaced from primary vertex





- p_t dependence: multiple scattering
  - → material budget
- Detector resolution:
  - Intrinsic plus alignment contribution
- Primary vertex reconstruction

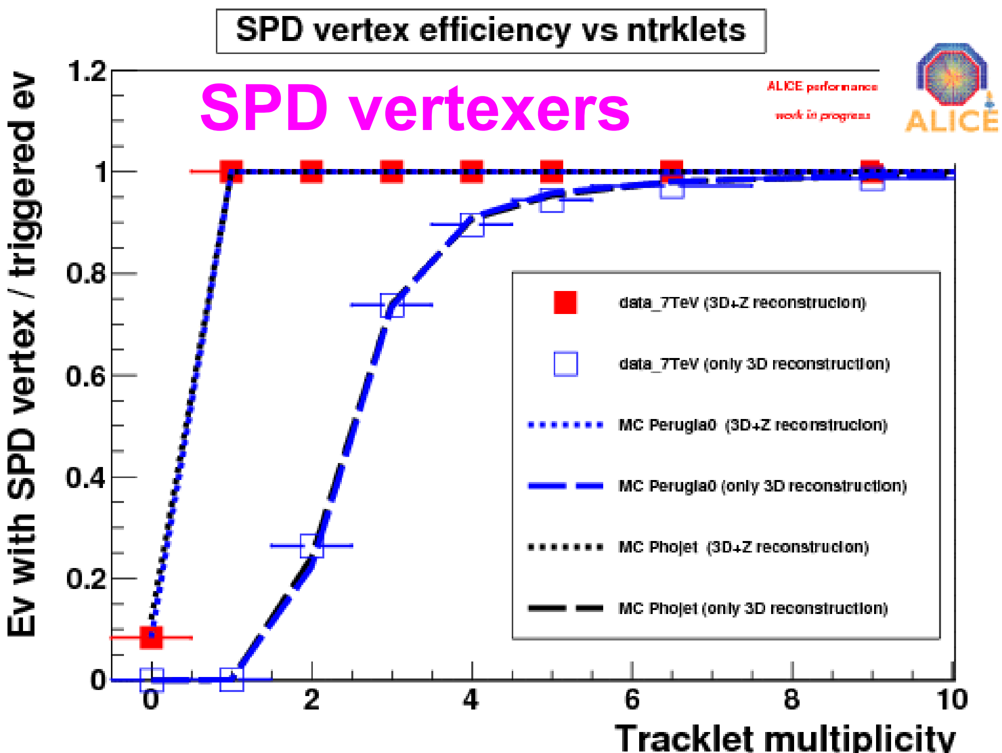
→ Tracking must account for all contributions

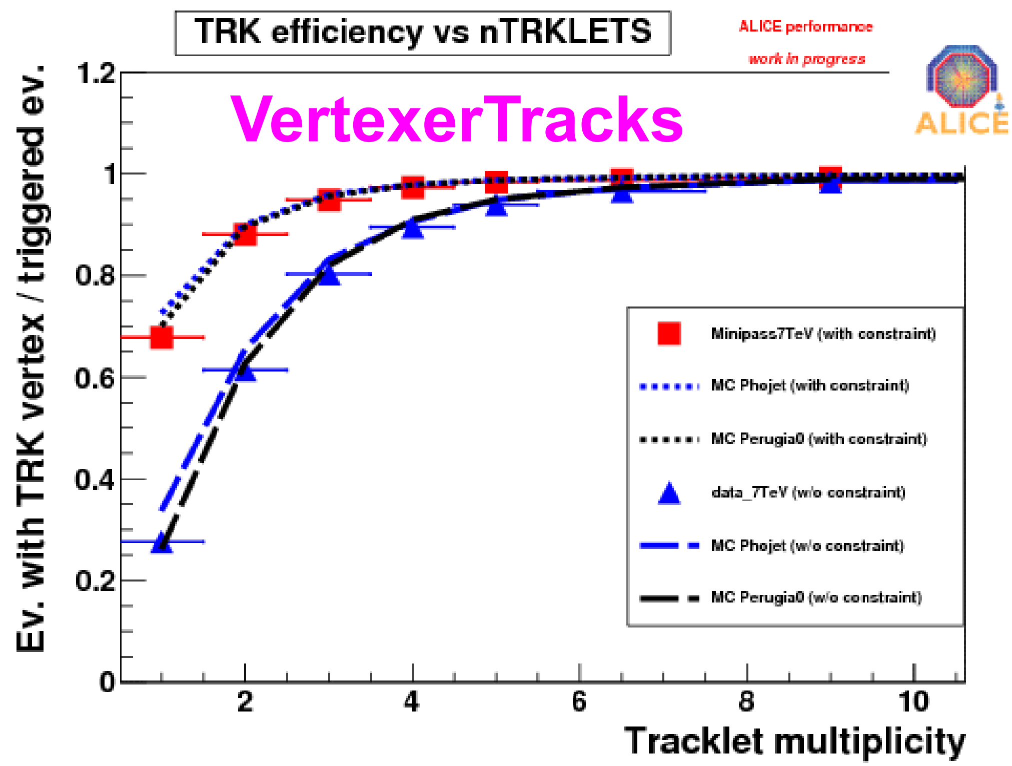
→ MC must reproduce various pieces

Primary Vertex reconstruction

<u>2 vertexing algorithms</u>:

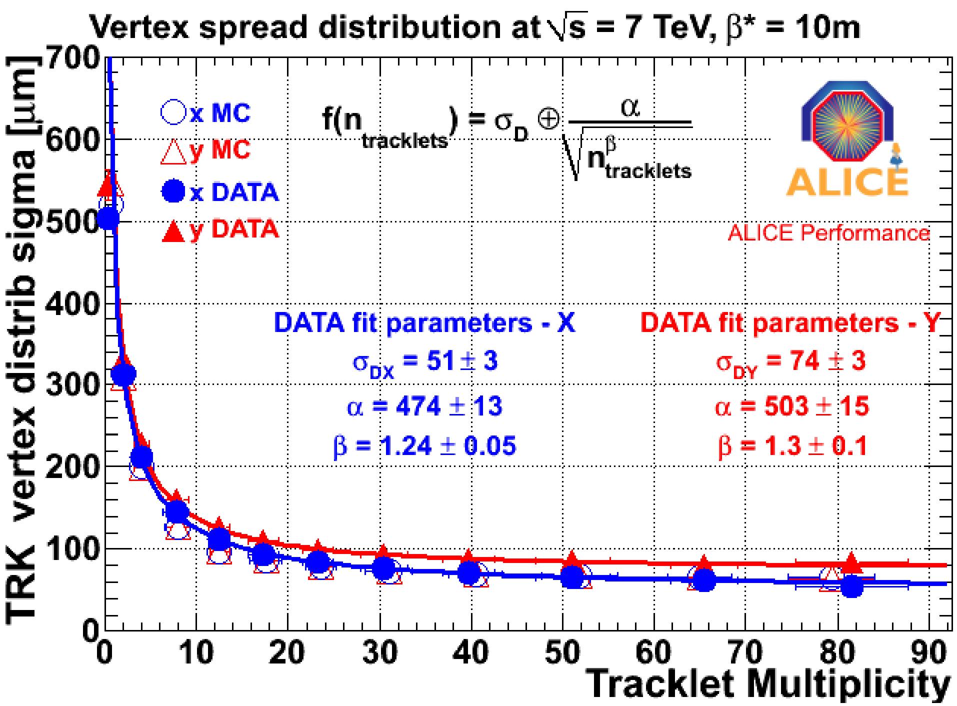
- with SPD tracklets (high efficiency, poorer resolution)
- with reconstructed tracks (poorer efficiency, high resolution)

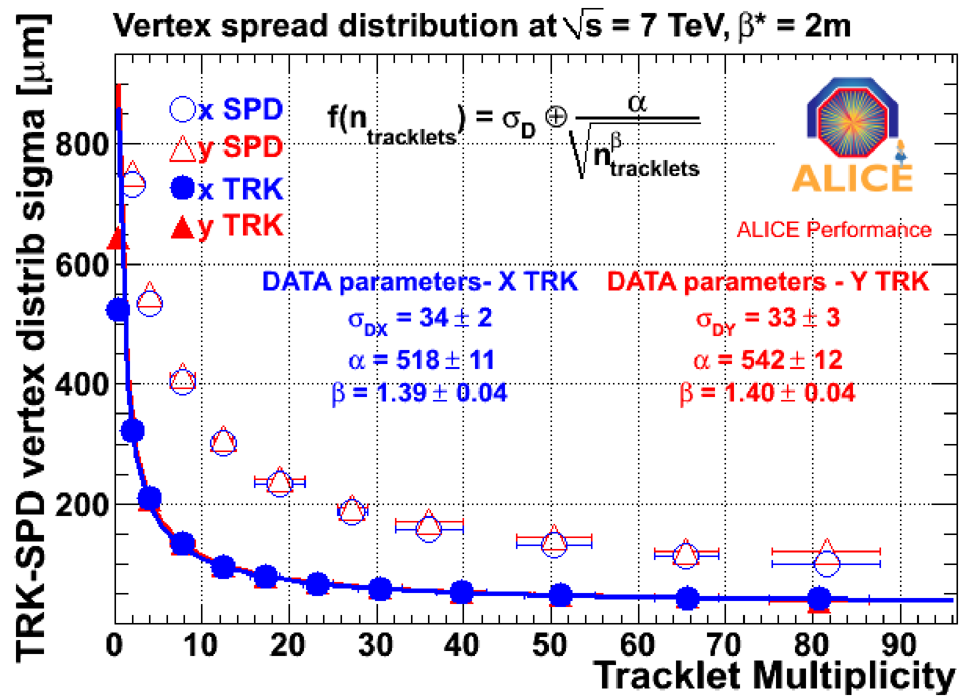




For z coordinate: 100% efficiency with 1 tracklet

Primary Vertex resolution

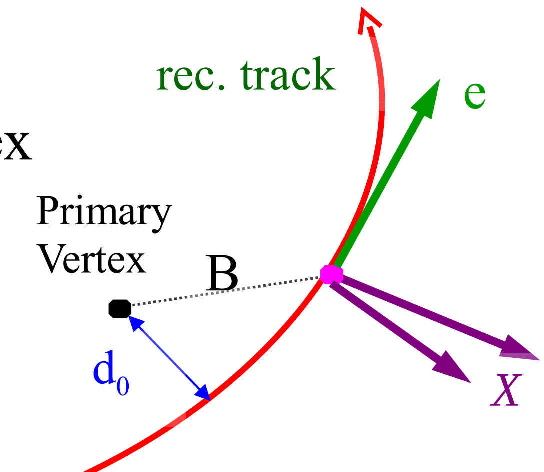


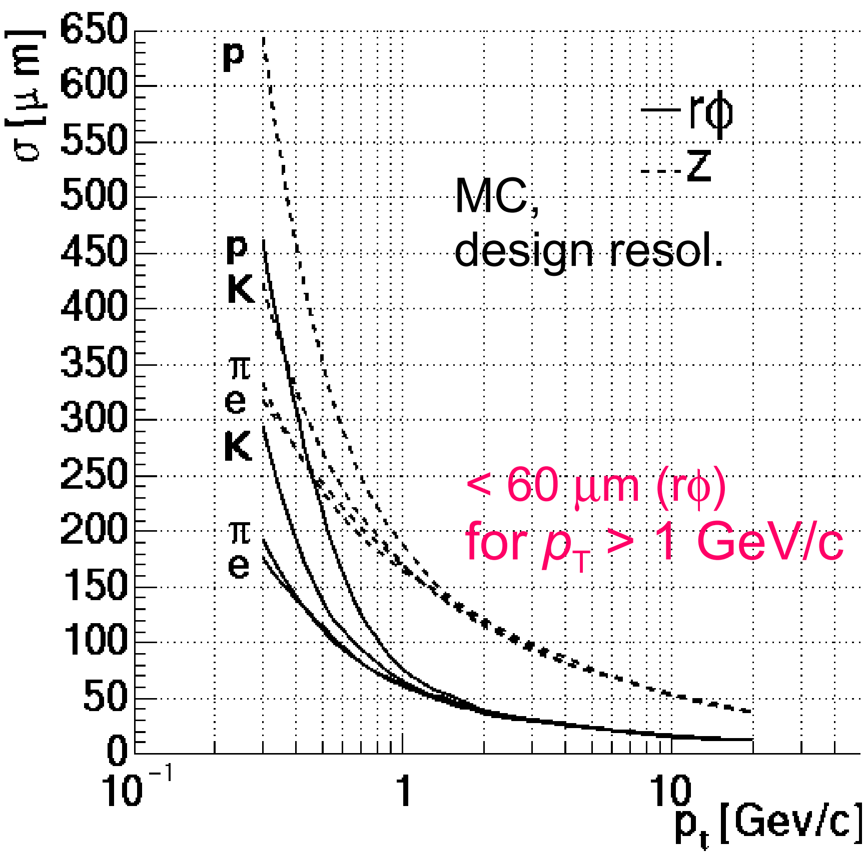


different beam spot size due to different β*

Part1: Finding the impact parameter resolution on data

Reference variable to look for secondary tracks from strange, charm and beauty decay vertices displaced from primary vertex





- p_t dependence: multiple scattering
  - ➔ material budget
- Detector resolution:
  - Intrinsic plus alignment contribution
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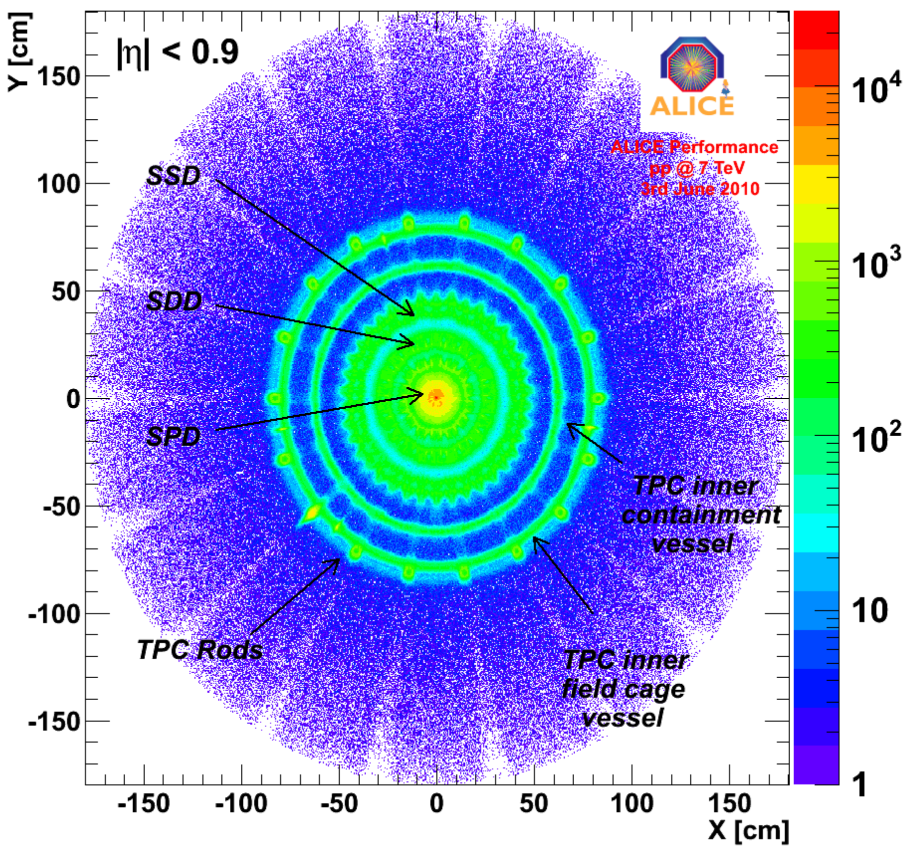
➔ Tracking must account for all contributions

➔ MC must reproduce various pieces

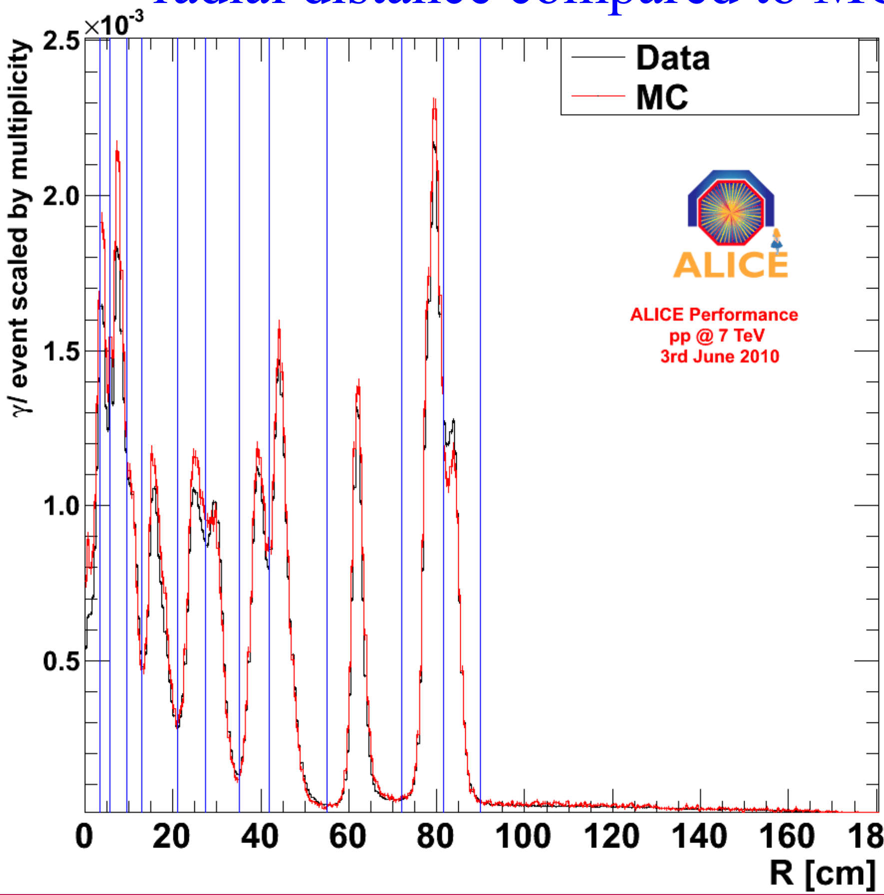
Material budget

Detector radiography exploiting gamma conversion ($\gamma \rightarrow e^+e^-$ in material) reconstruction

e^+e^- reconstructed with V0 topology identification + PID selection (TPC) + inv. mass cut
XY coordinates calculated by imposing the two tracks are parallel at conversion point



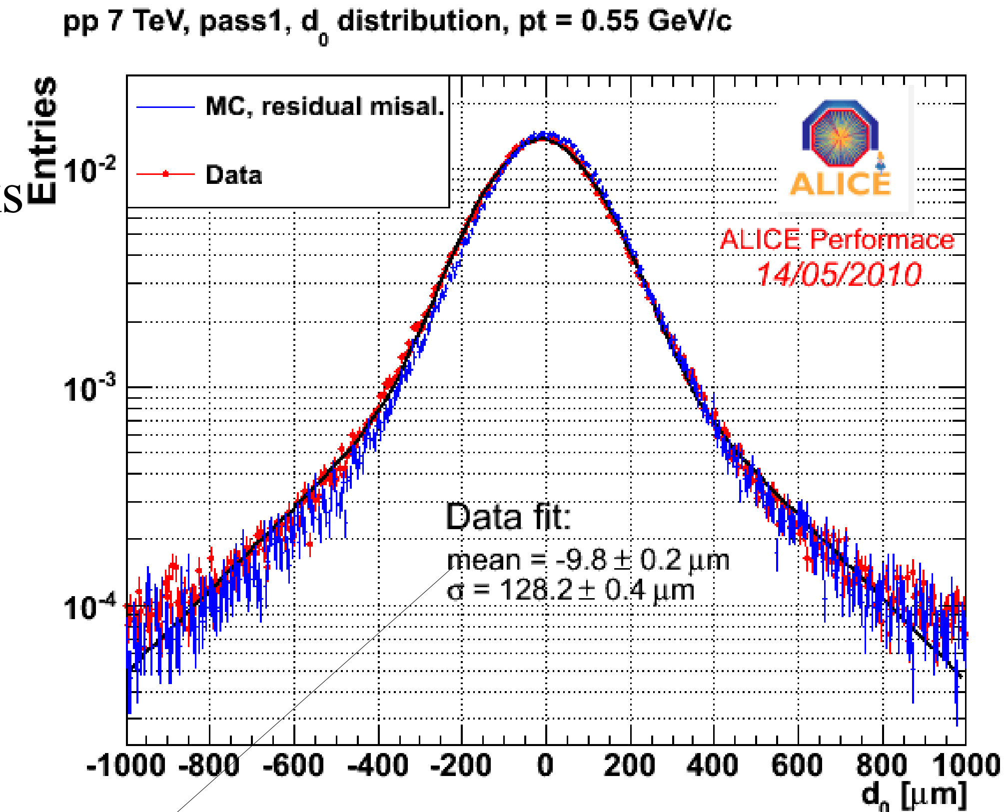
radial distance compared to MC



Impact parameter resolution

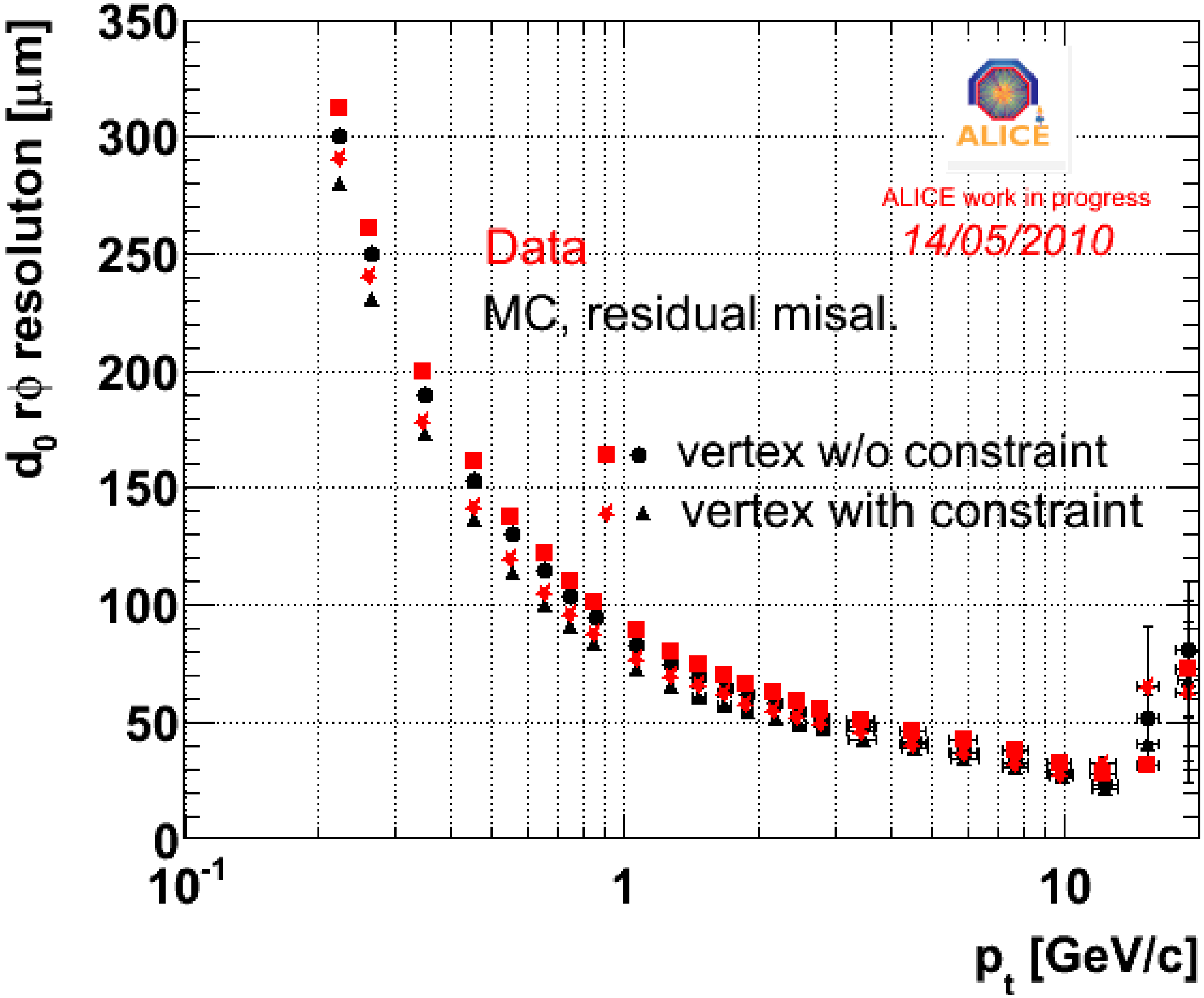
d_0 resolution from data

- Calculate d_0 wrt primary vertex from tracks without the current track
- Gaussian fit to d_0 distribution in ± 2 RMS (negligible contribution of secondaries)
  - Gaussian+Exp-tails fit under study
- Check sigma (estimates track + vertex resolution) and mean

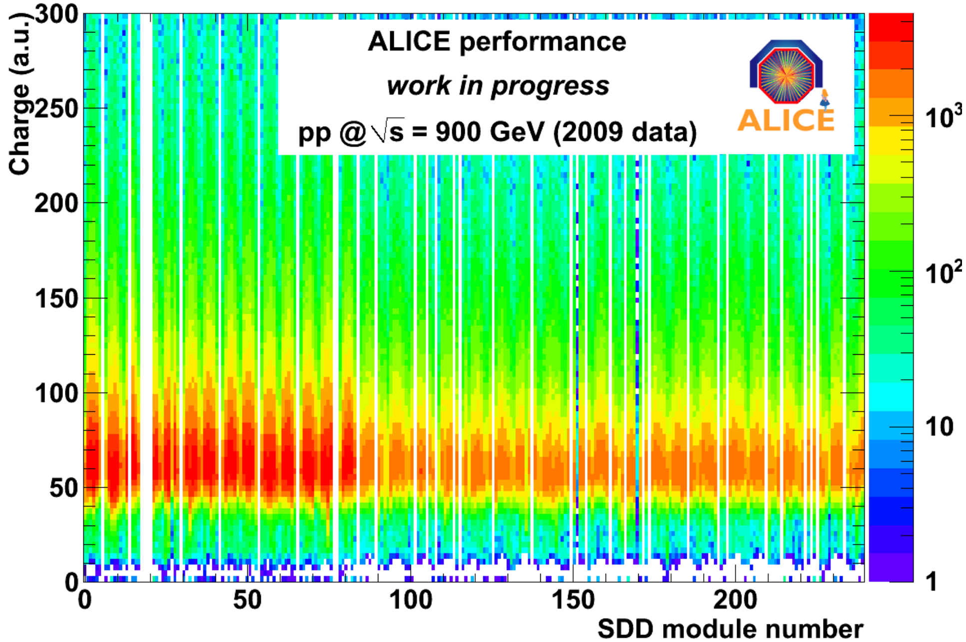


under study: caused by a weak-mode misalignment?

Impact parameter resolution



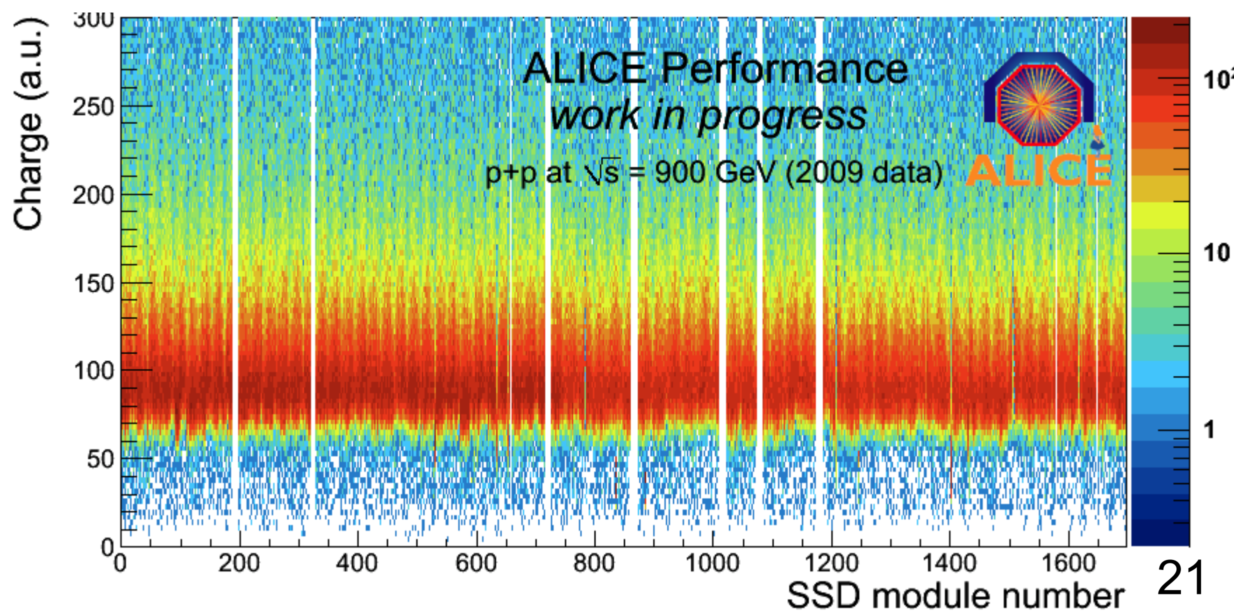
Part 2: PID with ITS



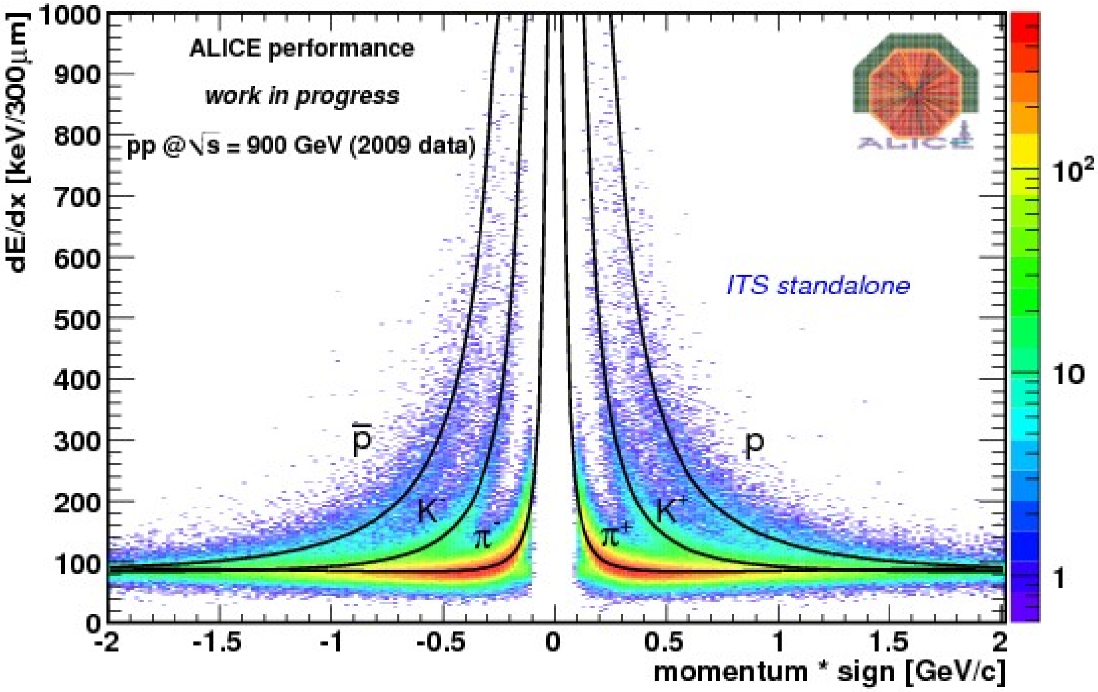
Analyses of charge released in SSD and SDD detectors allow PID via energy loss study (see M. Sitta-P. Christakoglou talk)

ITS very important at low momentum

Tails typical of Landau distribution



PID with ITS: dE/dx determination

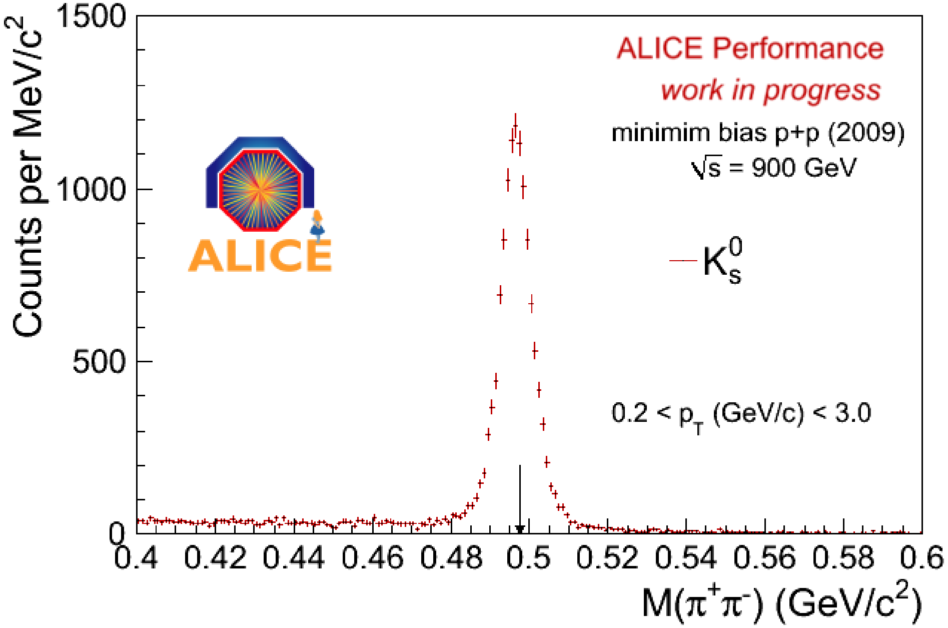


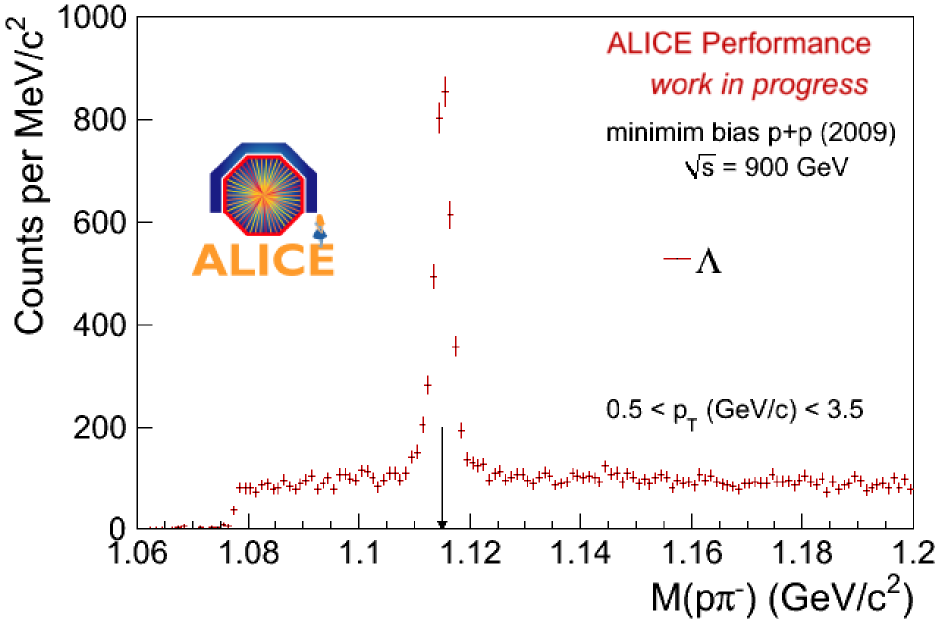
dE/dx given by the truncated mean (← Landau distribution) of the SSD/SDD signals:

- on 4 clusters: cut the 2 highest values
- on 3 clusters: cut the highest value, put a weight of 0.5 to the middle one, 1 to the lowest one

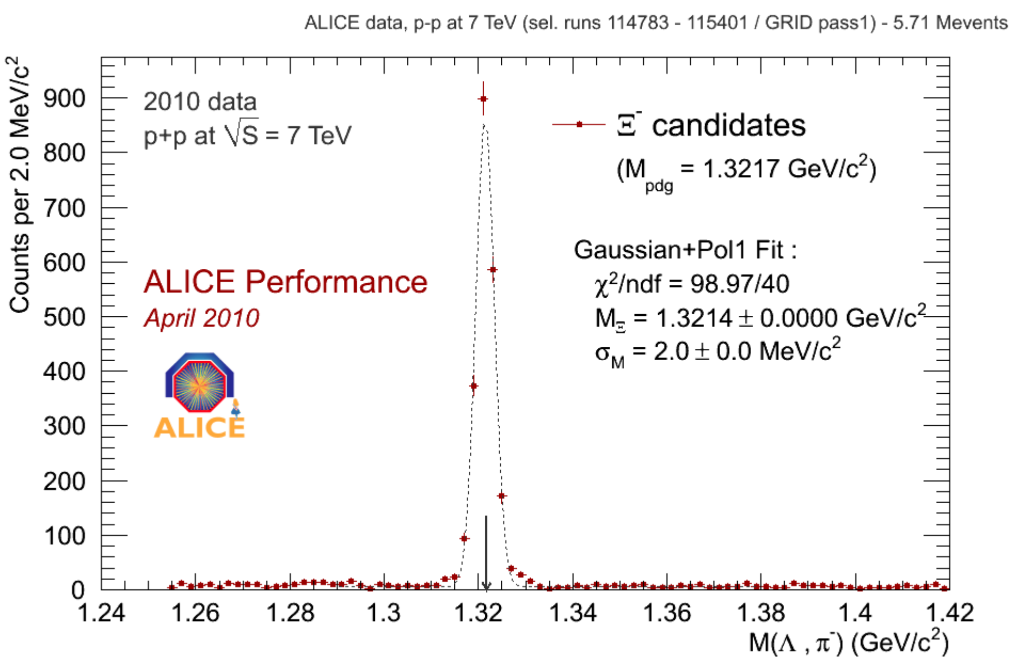
Part 3: Physics performance

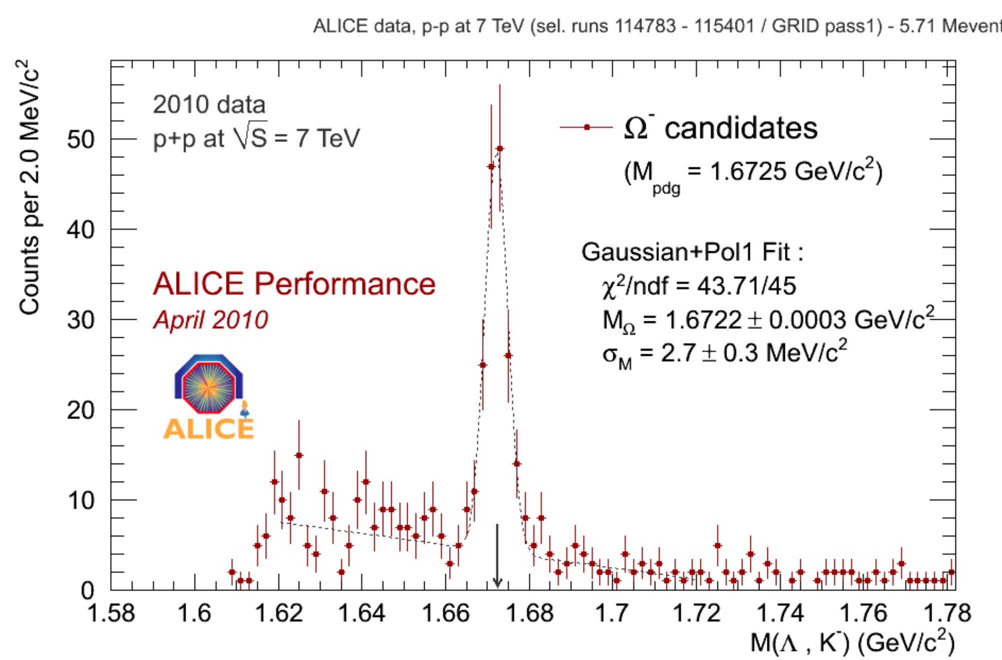
The familiar strange world rediscovery at 900 GeV...



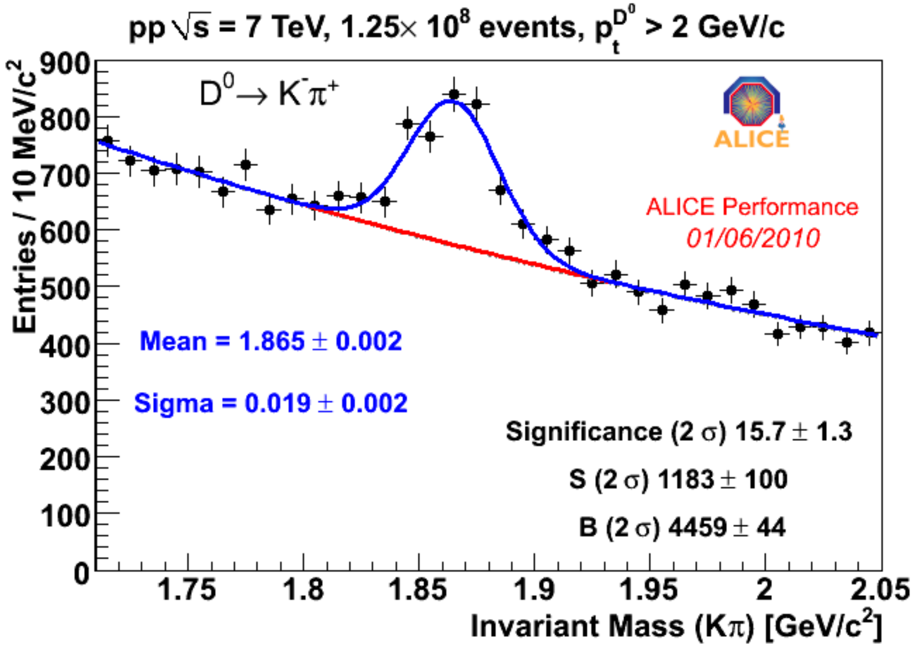


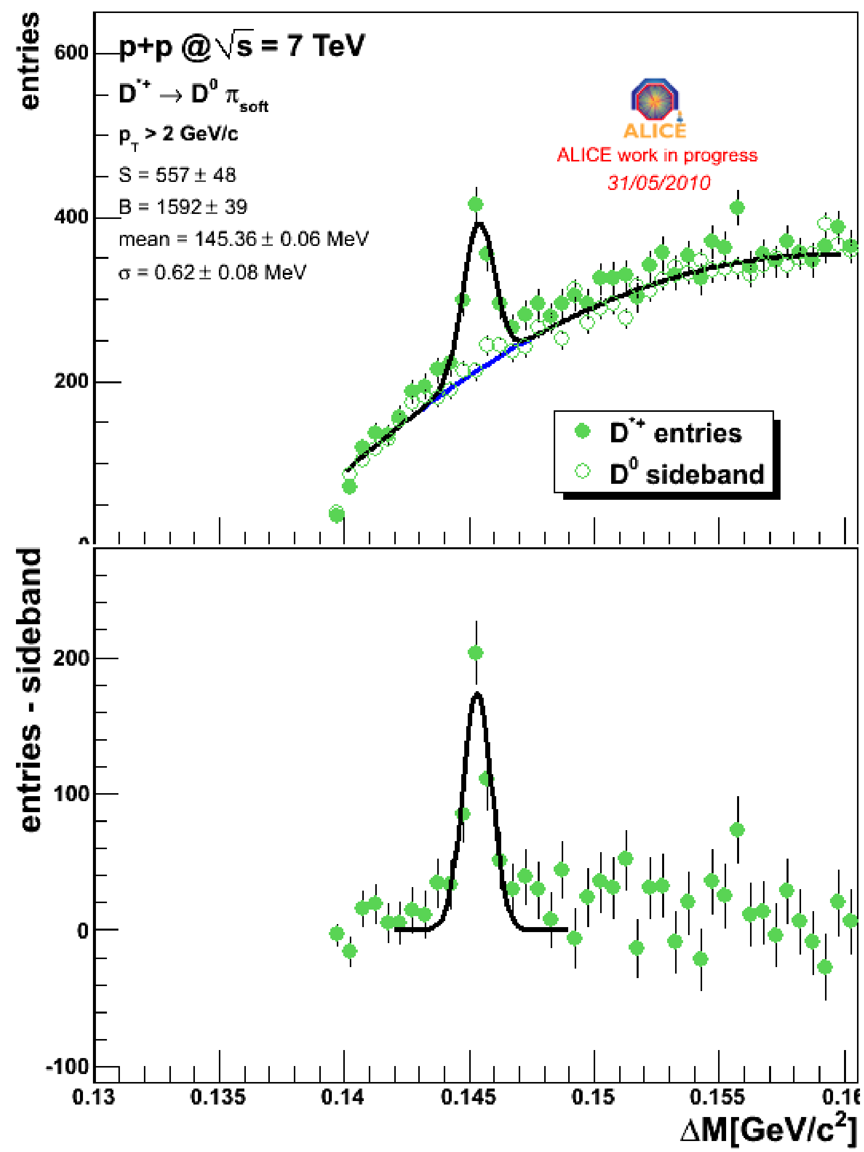
The familiar strange world rediscovery … and at 7 TeV

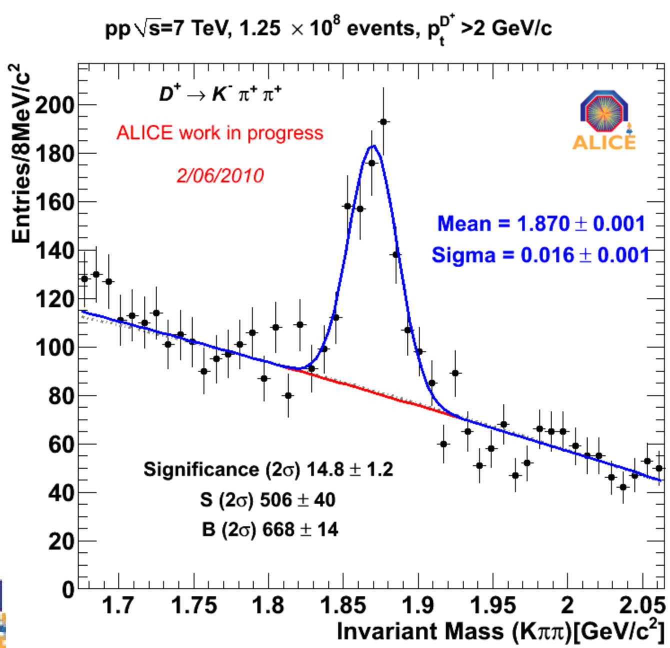




Charm at 7 TeV







Conclusions

- ALICE ITS detector working properly
  - Close-to-nominal resolutions achieved with alignment with cosmic-ray and pp data
  - Fine tuning: need to completely understand detector response and tune the MC to reproduce data distributions
- Track reconstruction & primary vertex reconstruction in good agreement with MC:
  - Efficiency
  - Resolution
- Material budget well described in MC ← γ conversion reconstruction
- PID information with ITS via dE/dx measurement down to 0.1 GeV/c

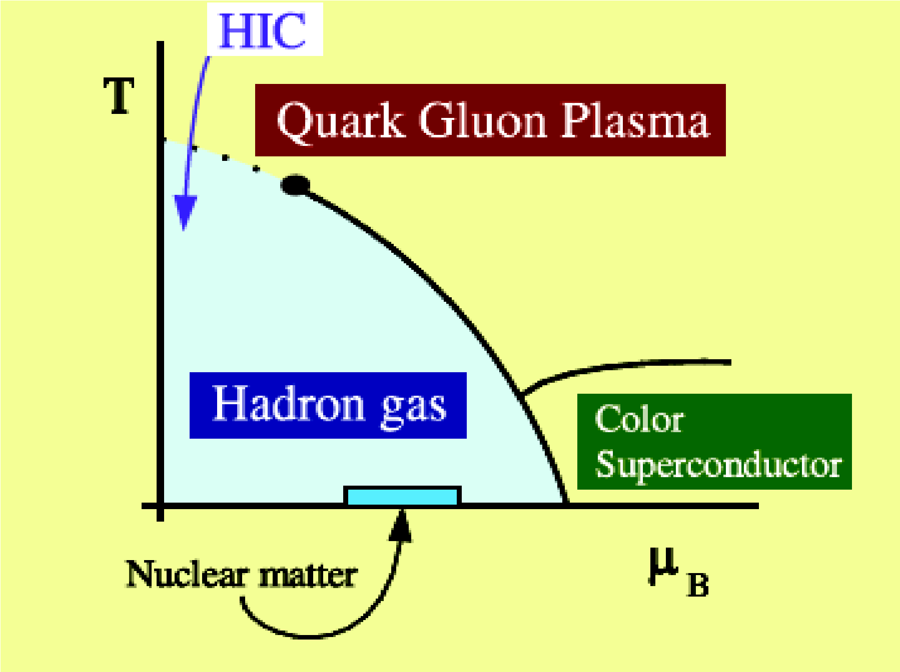
ITS covered a fundamental role for the first 3 ALICE papers on physiscs

Very good perspectives for physics analyses in the next years!

Extra

ALICE: a heavy-ion experiment

- A heavy-Ion experiment at the LhC
- Will study the medium formed in very high energy nucleus nucleus (lead nuclei) collisions and investigate:



- global properties (thermalization, energy density,...)
- possible phase transition to a state (QGP) in which quarks are no longer imprisoned into hadrons (deconfinment)
- test of pQCD and QCD predictions

Multi purposes detector capable to measure global observable (multiplicity, pt-spectra, flow), reconstruct resonances, strange and heavy-flavour hadron decays, jet

Iterative module-by-module alignment

Minimize module by module the χ^2 function

$$\chi^2 = \sum_k (\vec{x}_k^{PCA} - (\delta R \vec{x}_k^{cl} + \delta \vec{t}))^T (C_k^{PCA} + C_k^{cl})^{-1} (\vec{x}_k^{PCA} - (\delta R \vec{x}_k^{cl} + \delta \vec{t})) \, ,$$

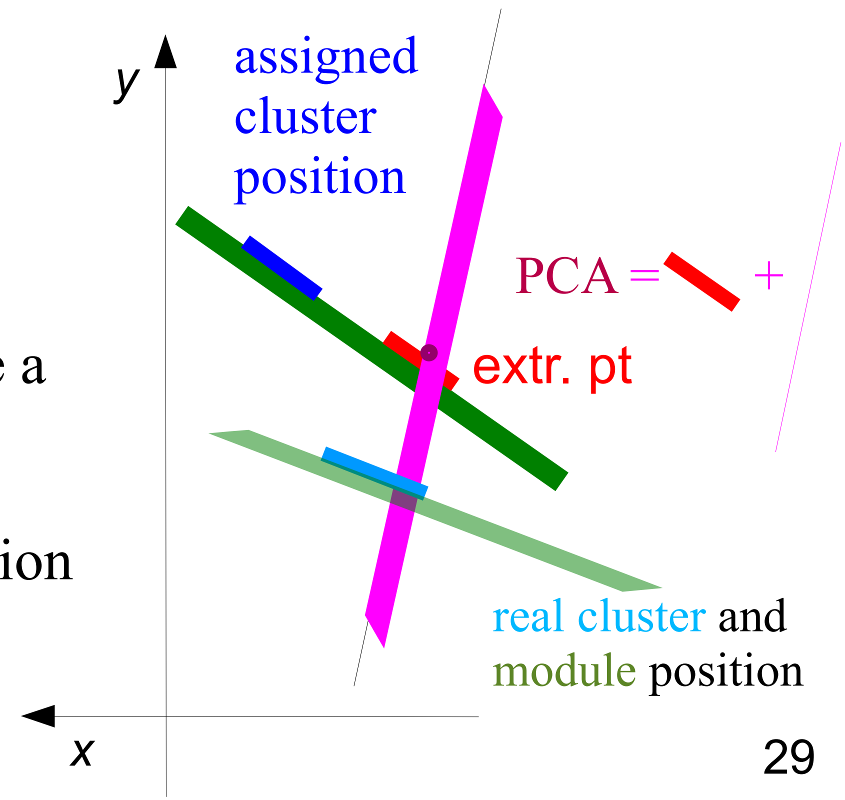
a linear function of the alignment parameters ($\delta \vec{t}$ is the translation vector and δR is the (δ)rotation matrix for small angles)

The sum runs over tracks (PCA -> extrapolated, cl = cluster, *C* are the point cov. matr.)

"**Point of Closest Approach**"

To take into account the uncertainty on the module position we construct the PCA:

- propagate the track to the plane of a module where a cluster not used in the fit of the track lies
- take the extrapolation point
- enlarge (> 1 cm) its variance along the track direction



Iterative module-by-module alignment

Assumptions

• The misalignments parameters of the modules are not strongly correlated
• The number of modules crossed by the tracks passing through the module under study must be large (> 80)

→ The influence of the misalignments of the modules on the fits of the tracks is not systematic and statistically sums up to zero

→ To take account of the residual correlations between the results:

- the procedure is **iterated** until convergence is reached
- the modules are realigned according to a sequence based on the number of tracks passing through them

Further improvements from track selection (χ^2 of the fits, rejection of outliers)

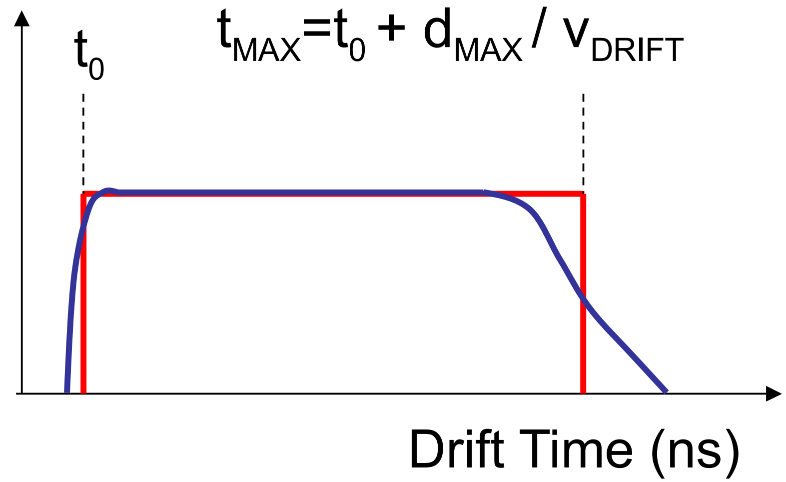
Millepede settings for pp collisions

- p_t selection: all tracks above 1 GeV/c, "p_t" fraction (80% for p_t=0.8, 20%for p_t=0.2) below 1 GeV/c
  - possibility to set weight $w=p_t^n$, n settable
- track curvature (-> p_t) fixed from TPC
  - set to 0 for events with B=0
- ~20M pp tracks, ~30K tracks from cosmic-rays weighted by a factor 5÷10
- "Hierarchical" levels switched on (calculated along with module levels):
  - SPD sectors
  - SPD staves
  - (SSD half-barrels, SSD ladders)
  - possibility to constrain the mean/median for the daughter volumes

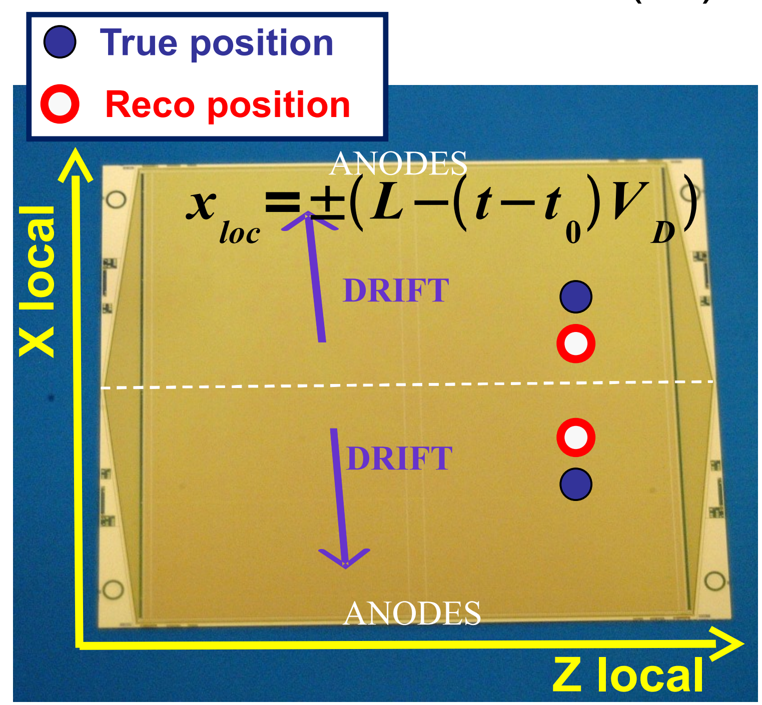
Silicon **Drift** Detector Time Zero calibration

Two strategies developed on simulated data

- Time Zero from minimum drift time
  - Time offset extracted from time distribution of measured clusters
  - Particles crossing the detector on the anodes have drift distance = 0 and should be measured at time = 0.
  - The minimum drift time observed ($t_0 > 0$) is the time zero



- Time Zero from track-to-cluster residuals
  - Time Zero extracted by exploiting the opposite sign of residuals in the two detector sides
  - A bad calibrated time zero leads to overestimate / underestimate the drift path on both drift sides and therefore to residuals XMEAS – XTRUE of opposite sign in the two sides



ITS alignment: summary

Understanding and improvement of the alignment quality requires a micrometric understanding of each detector response:

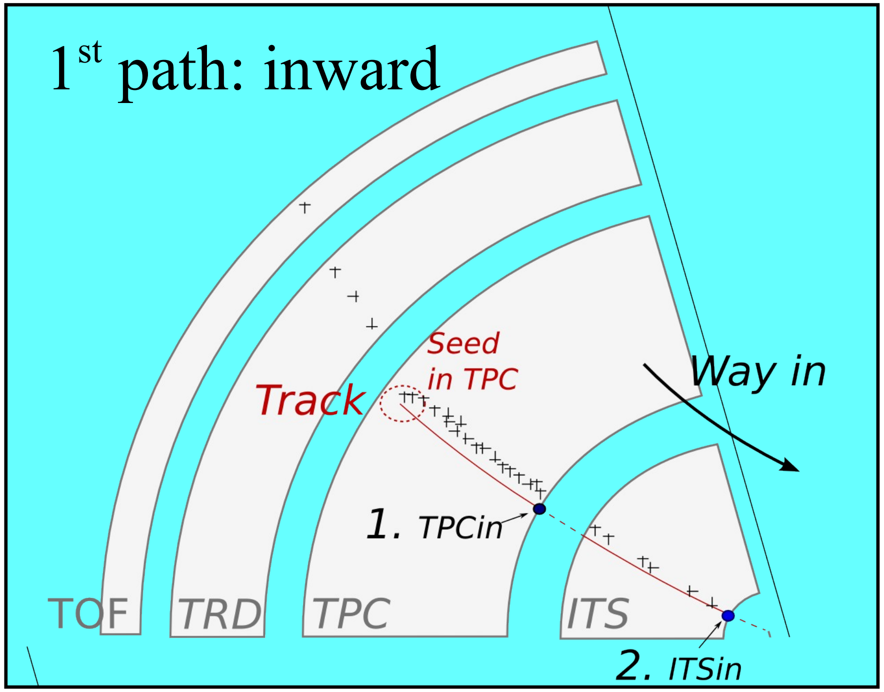
- SPD: cluster type dependence on electronic thresholds and track incidence angle
- SSD: multi-strips clusters, centre of gravity determination, dependence on track incidence angle
- SDD: interplay of alignment and calibration (v_{drift}, t_0)

The combined tracking in three paths

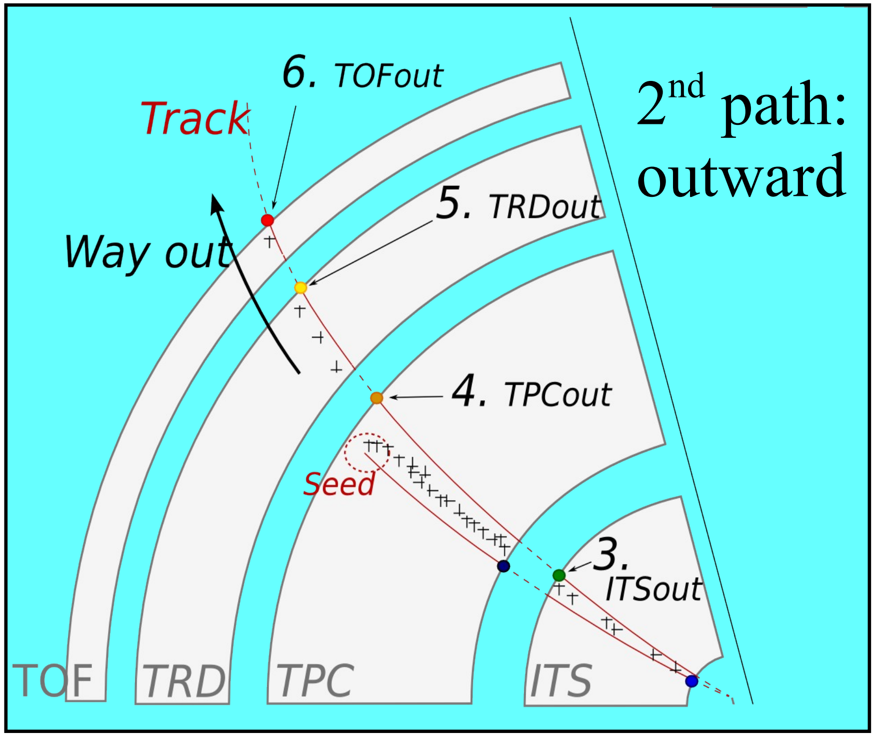
1st path

"Seeds" in outer part of TPC (lowest track density per unit area). Kalman-filter based tracking from the outer to the inner wall of TPC. The same in ITS.

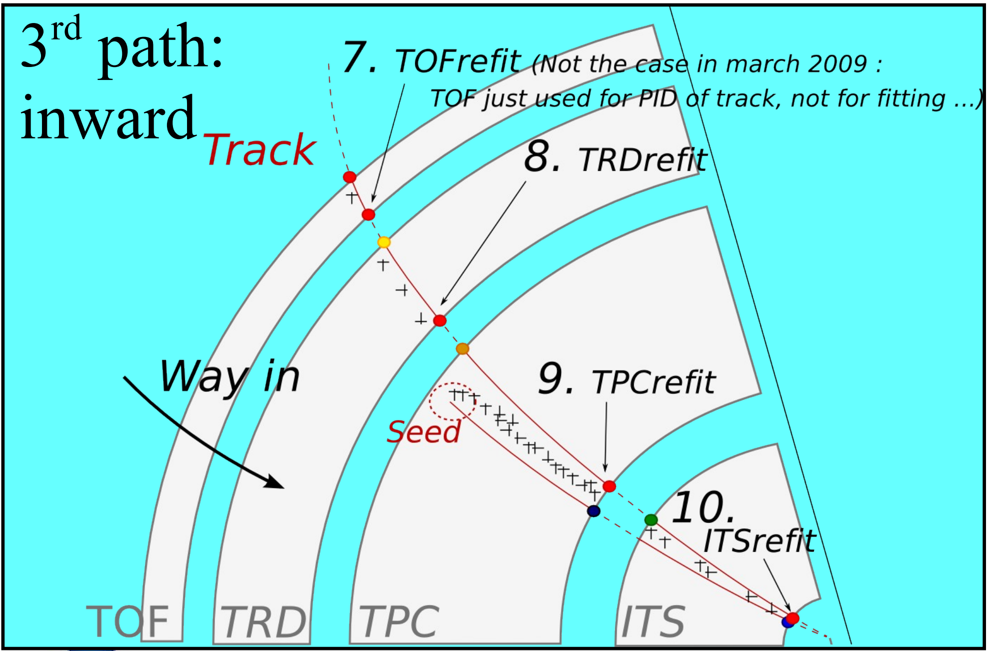
- Track parameters are ok
- PID not ok



The combined tracking in three paths

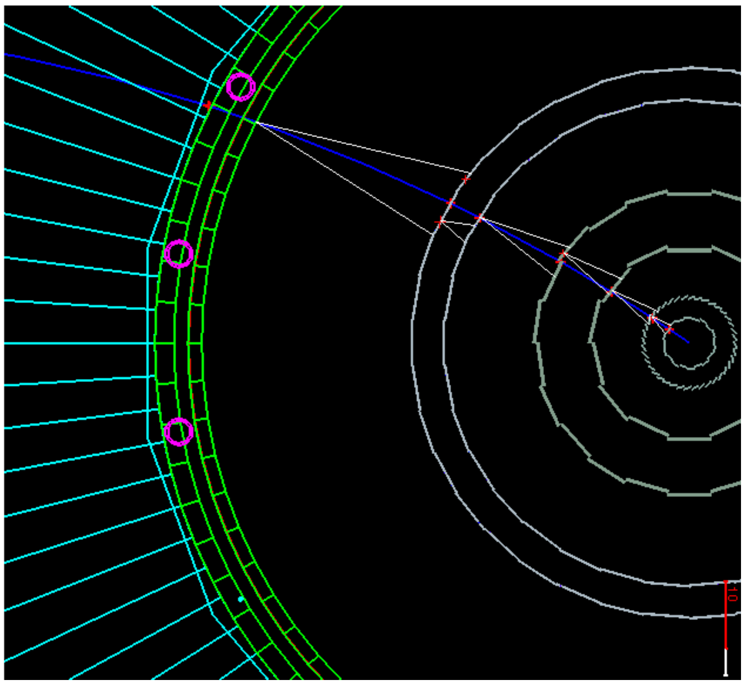


2nd path
Tracking from the inner to outer layer of ITS.
The same in TPC. The same in TRD.
Matching with TOF, HMPID, PHOS/EMCAL
- PID is OK
- Track parameters are not OK



3rd path
Tracking from the outer to inner TRD wall.
The same in TPC. The same in ITS.
- PID is OK
- Track parameters are also OK

Tracking with a Kalman-Filter technique



Kalman filter technique:

0) Starting from a seed
1) Track extrapolation to next layer
2) Track-cluster χ^2 prediction
3) Track parameters and errors update with cluster info

Local model for a track (parameters are always local)

→ account for material effects

Tracking settings to face realistic ITS status

	SPD1	SPD2	SDD1	SDD2	SSD1	SSD2
active [%]	75-80	82-89	91	90	92	89
intrinsic resolution [μm] rϕ z	10 120	10 120	35 25	35 25	20 830	20 830
residual misalignment level* rϕ z	<10 negl	<10 negl	60** 50	60** 50	<15 ~100	<15 ~100
additional error in tracking*** rϕ z	10 100	30 100	500 100	500 100	20 500	20 500

* excluding "weak modes" (global distortions)
** well-behaved modules (calibration, vdrift uniformity)
*** optimized for high-tracking eff. and good track precision

Primary Vertex reconstruction

3 algorithms:

ITSVertexerZ: based on SPD tracklets, only z coordinate

- Vtx z coordinate (z^{trklet} weighted average at beam axis)
- ✓ very efficient

ITSVertexer3D: based on SPD tracklets, xyz coordinates

- curvature not taken into account
- 3D vtx (point of minimum distance among selected tracklets)
- not 100% efficient (at least 2 tracklets)

VertexerTracks: xyz from tracks- only after tracking

- 3D vtx reconstruction, cov. matrix, χ^2

Vertex reconstruction with tracks

VertexerTracks algorithm reconstructs the vtx in 3 iterations

Iteration 0

- Track pre-selection (ITS point ≥ 4, TPC clusters > 50)
- Vertex finder → vertex 0

Iteration 1

- Track selection ($|d_0^{3D}| < 0.5\,\mathrm{cm}$ from vertex 0)
- Vertex finder
- Vertex fitter → vertex 1

Iteration 2

- Track selection ($|d_0^{3D}| < 0.5\,\mathrm{cm}$ from vertex 1)
- Vertex finding
- Vertex fitter → vertex 2, also covariance matrix and χ^2
  - Possibility to use the diamond information to constrain the result

Vertex fitter algorithm & diamond inclusion

Based on fast vertex fitting method V. Karimaki *et al.*, CMS Note 1997/051 (1997)

Minimized the following χ^2 function, in the straight-line track approximation in the vicinity of the vertex position $\vec{r}_v$:

$$\chi^2(\vec{r}_v) = \sum_i (\vec{r}_v - \vec{r}_i)^T V_i^{-1} (\vec{r}_v - \vec{r}_i)$$

$\vec{r}_i$ is the current global position of track *i* and V_i^{-1} its covariance matrix

The vertex and its cov. matrix C_v are calculated as $(W_i \equiv V_i^{-1})$:

$$\vec{r}_v = \left(\sum_i W_i\right)^{-1} \left(\sum_i W_i \vec{r}_i\right); \quad C_v = \left(\sum_i W_i\right)^{-1}$$

The diamond information (position $\vec{r}_d$ and size described by the cov. matrix C_d) can be used to constrain the vertex position as follow:

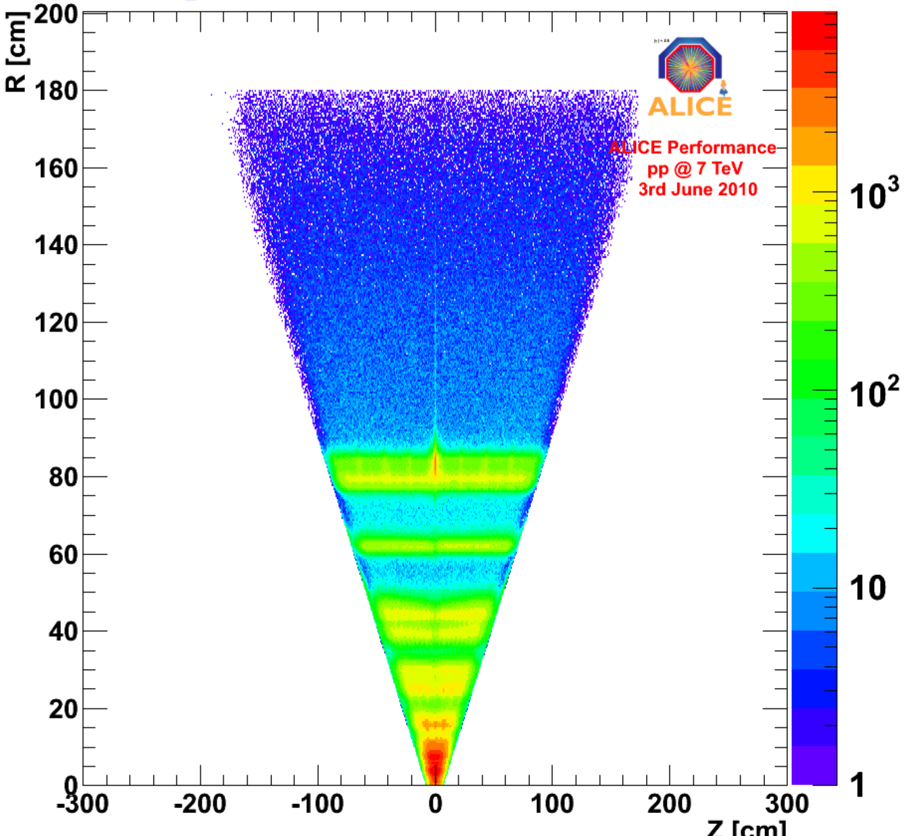
$$\vec{r}_v = \left(W_d + \sum_i W_i\right)^{-1} \left(W_d \vec{r}_d \sum_i W_i \vec{r}_i\right); \quad C_v = \left(W_d + \sum_i W_i\right)^{-1}$$

Material budget

Detector radiography exploiting gamma conversion ($\gamma \rightarrow e^+e^-$ in material) reconstruction

e^+e^- reconstructed with V0 topology identification + PID selection (TPC) + inv. mass cut
XY coordinates calculated by imposing the two tracks are parallel at conversion point

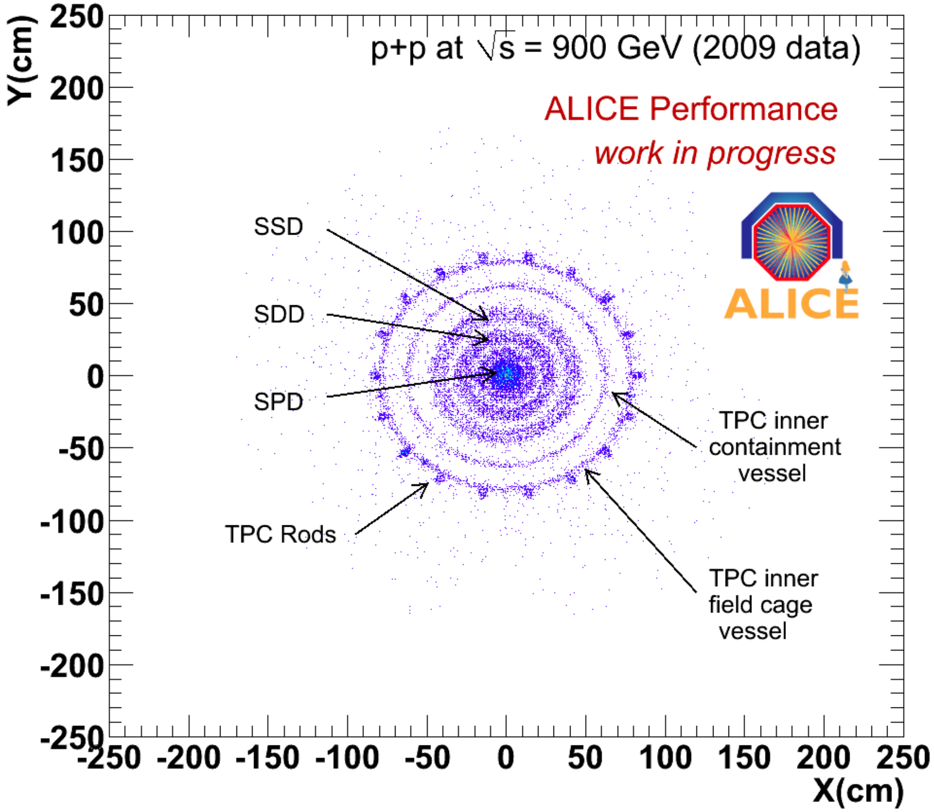
ZR plane



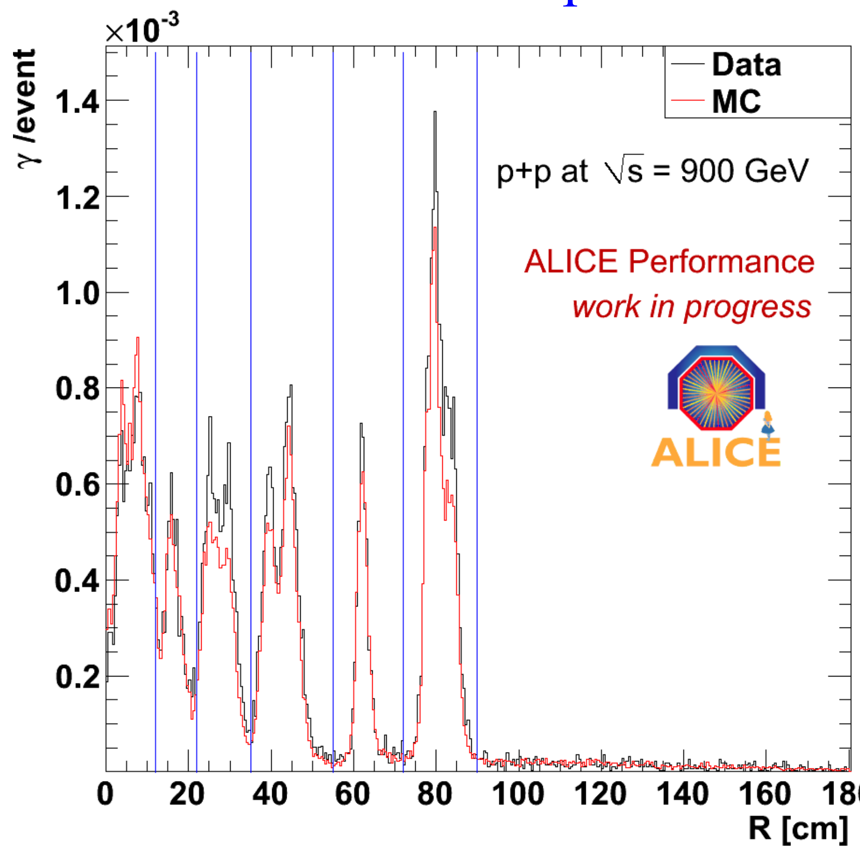
Material budget

Detector radiography exploiting gamma conversion (γ -> e^+e^- in material) reconstruction

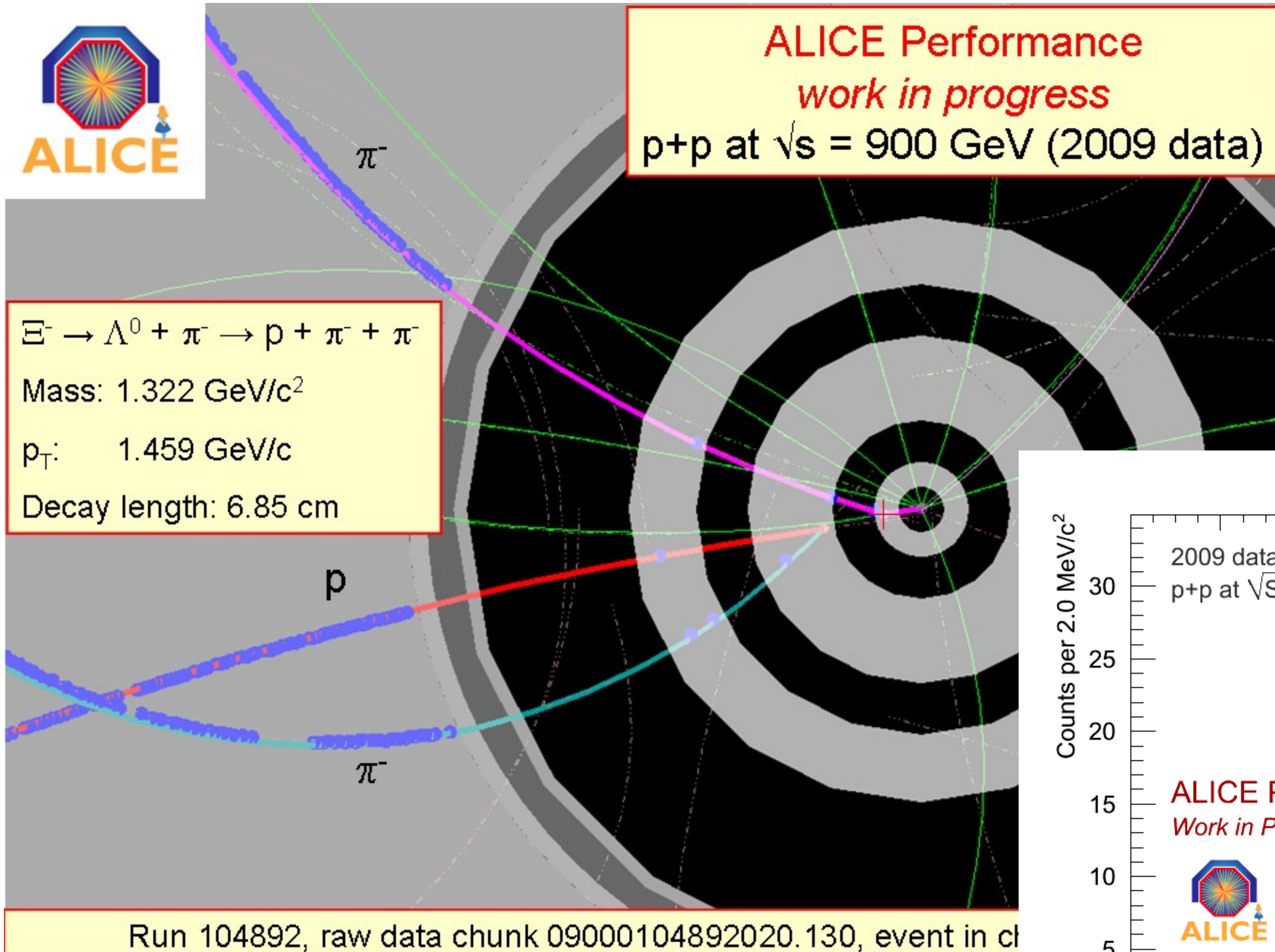
e^+e^- reconstructed with V0 topology identification + PID selection (TPC) + inv. mass cut
XY coordinates calculated by imposing the two tracks are parallel at conversion point

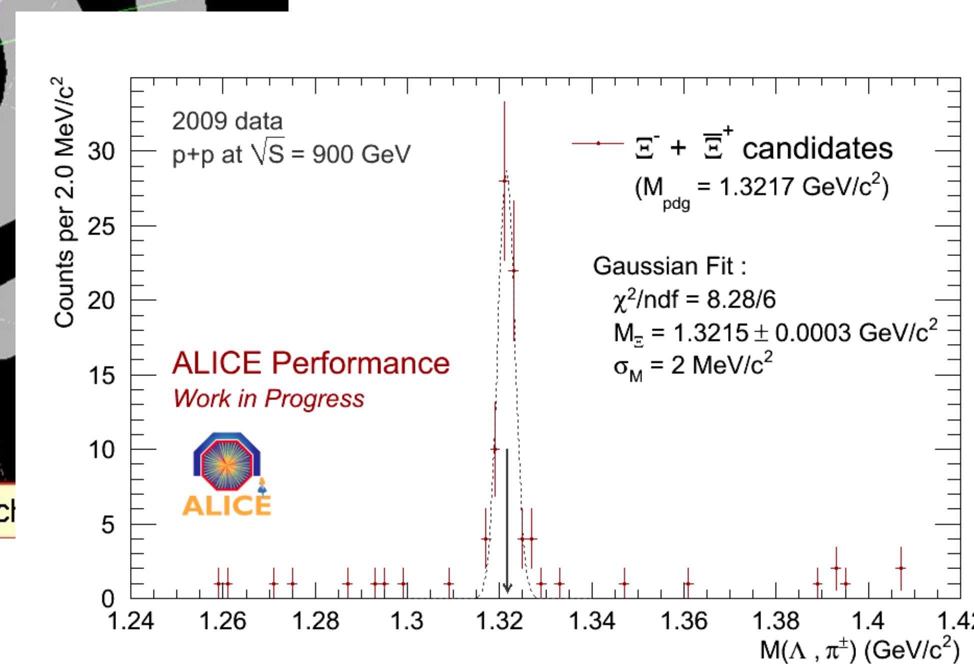


radial distance compared to MC

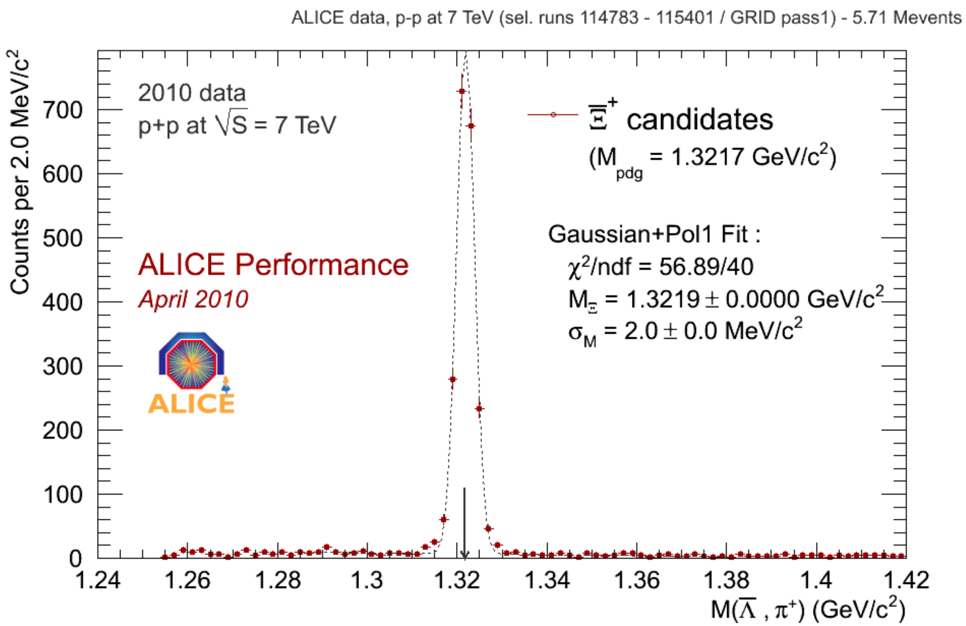


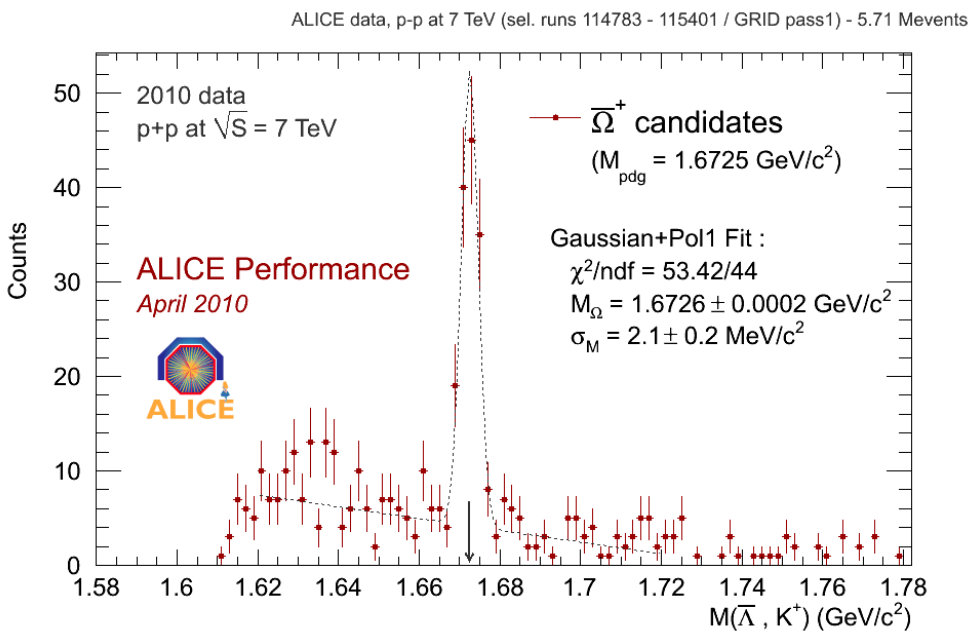
The familiar strange world rediscovery at 900 GeV...





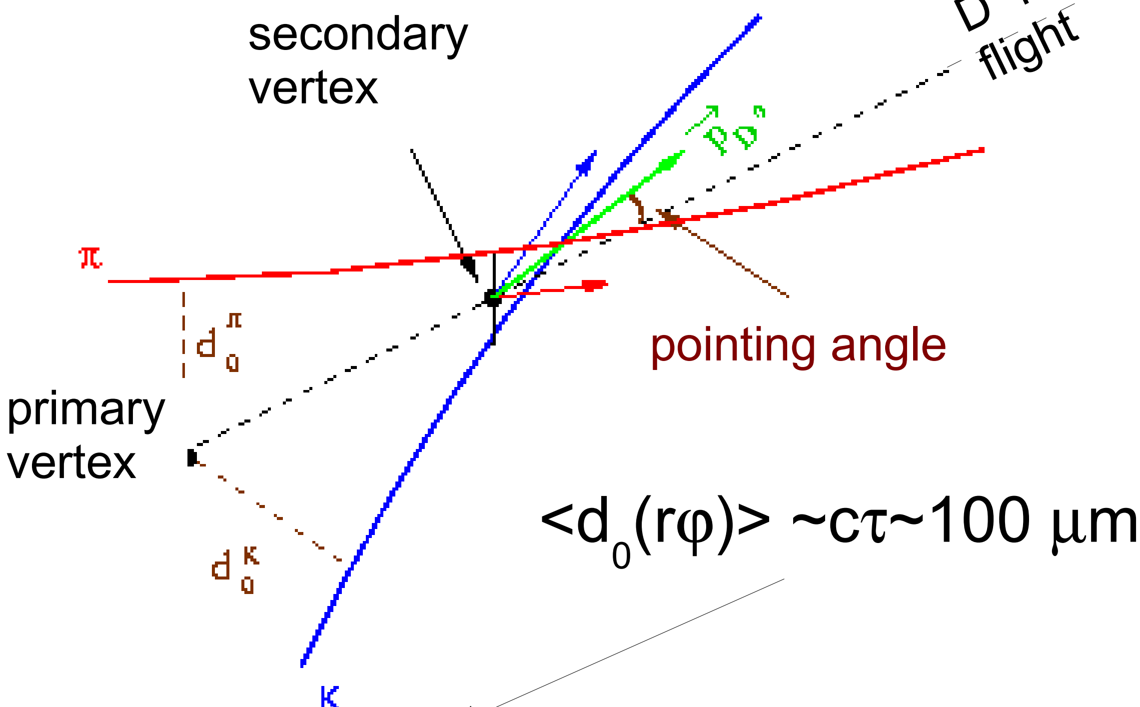
The familiar strange world rediscovery … and at 7 TeV





Charm at 7 TeV

$$D^0 \rightarrow K^- \pi^+$$



$<d_0(r\varphi)> \sim c\tau \sim 100\ \mu m$

Exclusive reconstruction of charmed hadron decays in hadronic channels

Invariant mass analysis of selected pairs/triplets/quadruplets of tracks

Main selection critera:
look for tracks displaced from the primary vertex

decay signature:
two charged tracks displaced from the primary vertex of interaction

Good resolution on impact parameter ITS is crucial for charm analyses