Early physics at ALICE

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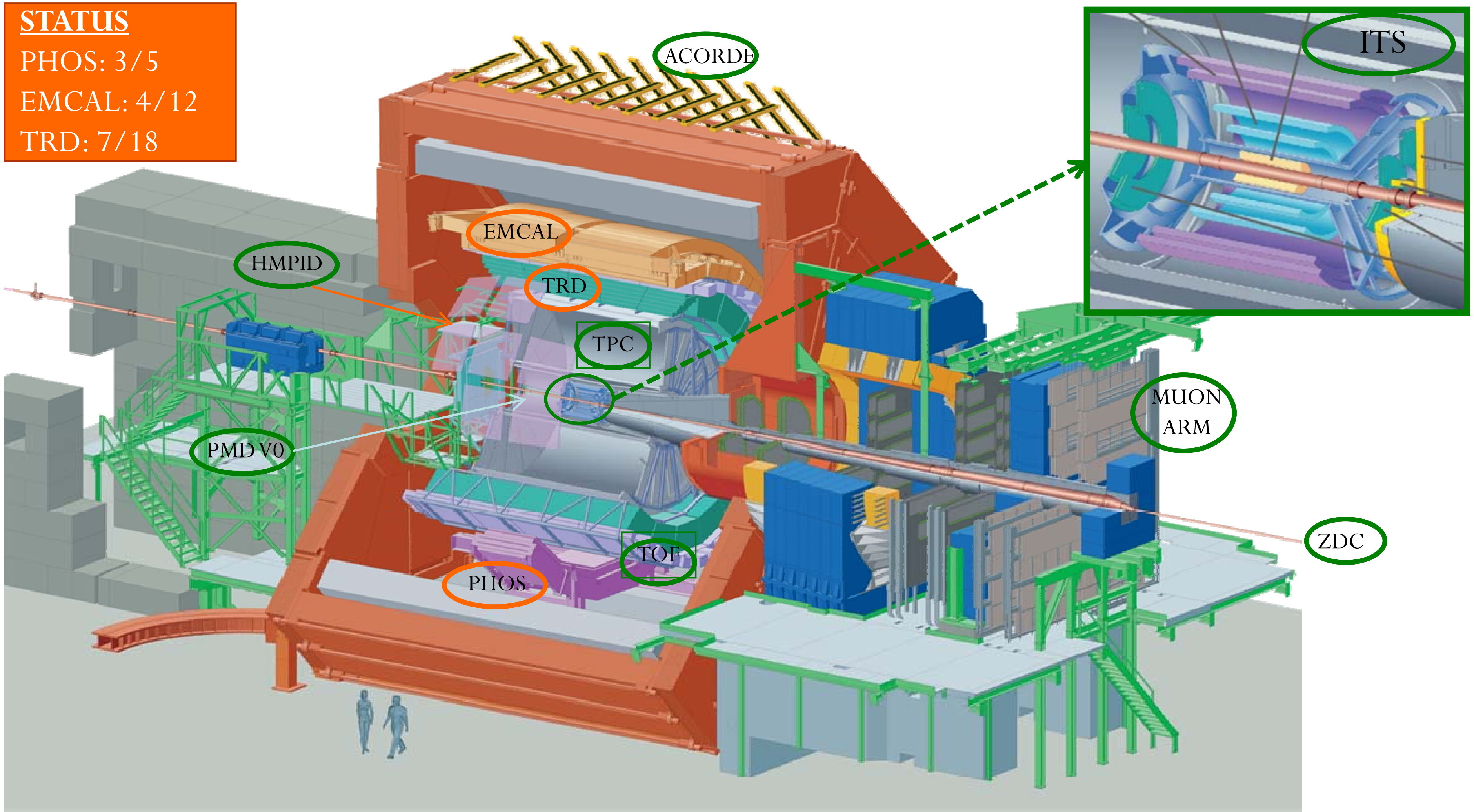
for the ALICE COLLABORATION

XXIV Recontres de Physique de La Vallée d'Aoste, La Thuile, March 2nd 2010

ALICE detector

STATUS
PHOS: 3/5
EMCAL: 4/12
TRD: 7/18



Commissioning phase

First particles from machine
15.6.08

1st Circulating beam
10.9.08

LHC accident
19.9.08

First collisions
23.11.09

2008

1	2	3	4	5	6	7	8	9	10	11	12

2009

1	2	3	4	5	6	7	8	9	10	11	12

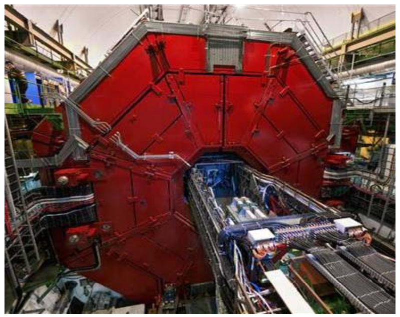
Installation

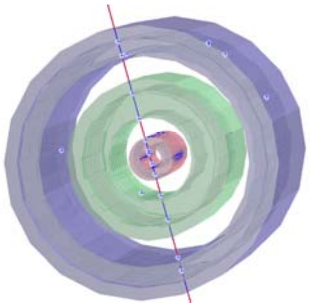
Cosmic Run:
- 24/7 DAQ
- Detector calibration and alignment

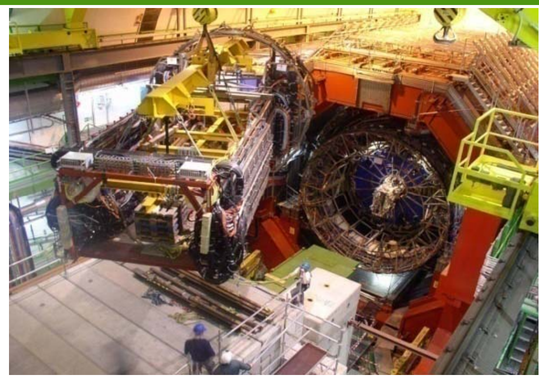
Installation:
- Miniframe refurbishing
- PMD, EMCAL and TRD installation

Cosmic Run:
- 24/7 DAQ
- Detector calibration and alignment

p-p





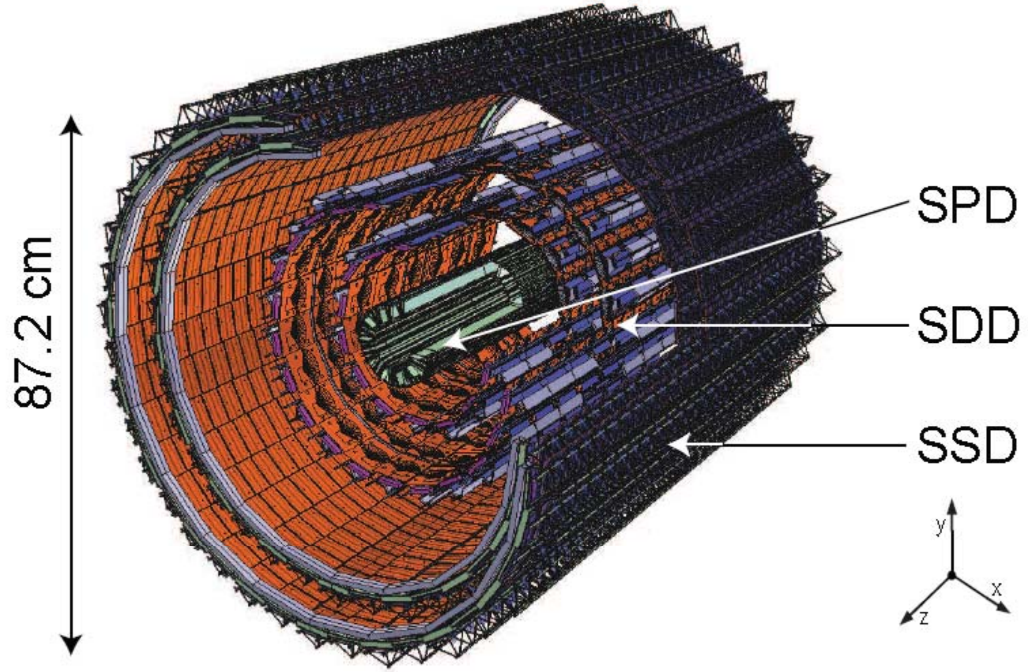


Detector calibration and alignment

ITS, TPC

Inner Tracking System (ITS)

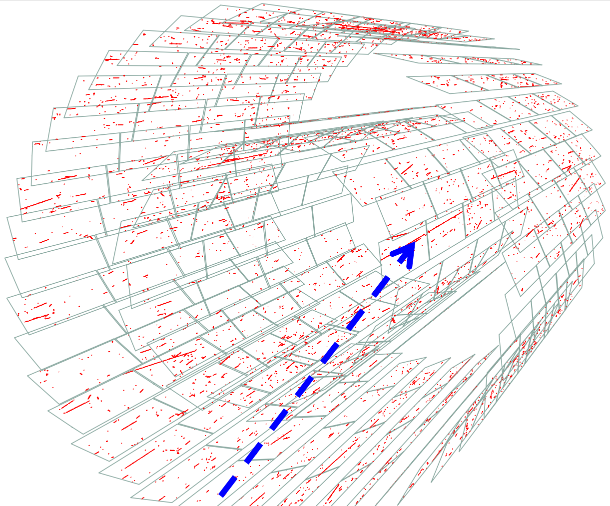
- Six layers of silicon detectors
  - ⇨ Coverage: $|\eta|<0.9$
- Three technologies
  - ⇨ Pixels (SPD)
  - ⇨ Drift (SDD)
  - ⇨ Double-sided Strips (SSD)
- Design goals
  - ⇨ Optimal resolution for primary vertex and track impact parameter
    - ✓ ***Minimize distance of innermost layer from beam axis ($\langle r \rangle \approx 3.9$ cm) and material budget***
  - ⇨ Maximum occupancy (central PbPb) < few %
  - ⇨ 2D devices in all the layers
  - ⇨ dE/dx information in the 4 outermost layers for particle ID in $1/\beta^2$ region



Layer	Det. Type	Radius (cm)	Length (cm)	Resolution (μm)	
				$r\phi$	Z
1	SPD	3.9	28.2	12	100
2	SPD	7.6	28.2	12	100
3	SDD	15.0	44.4	35	25
4	SDD	23.9	59.4	35	25
5	SSD	38.0	86.2	20	830
6	SSD	43.0	97.8	20	830

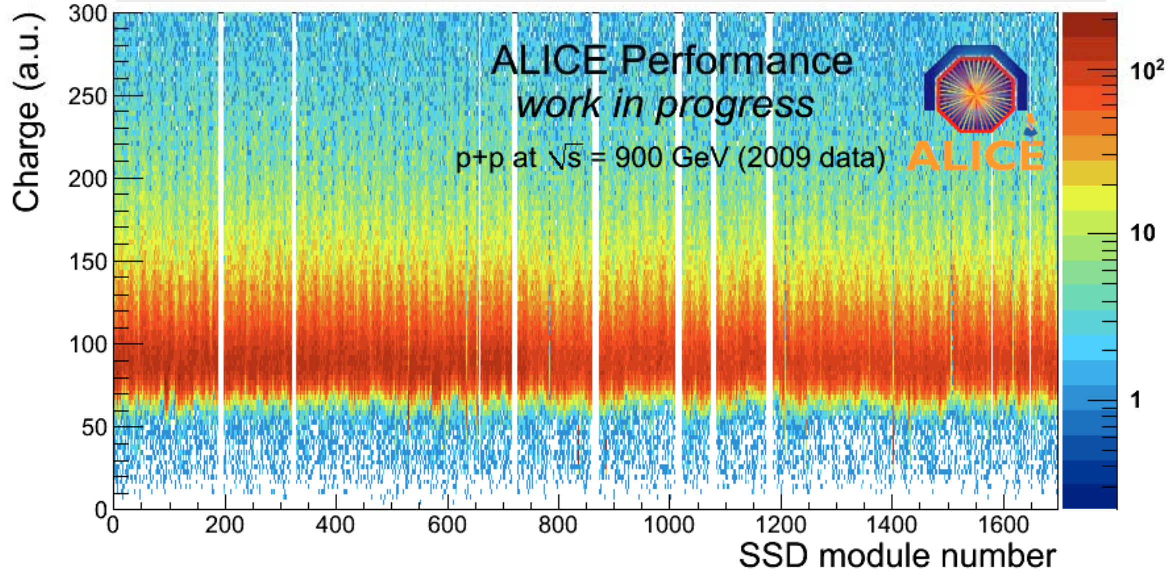
ITS operation and calibration

June 15, 2008
SPD sees the first "signs of life" of the LHC



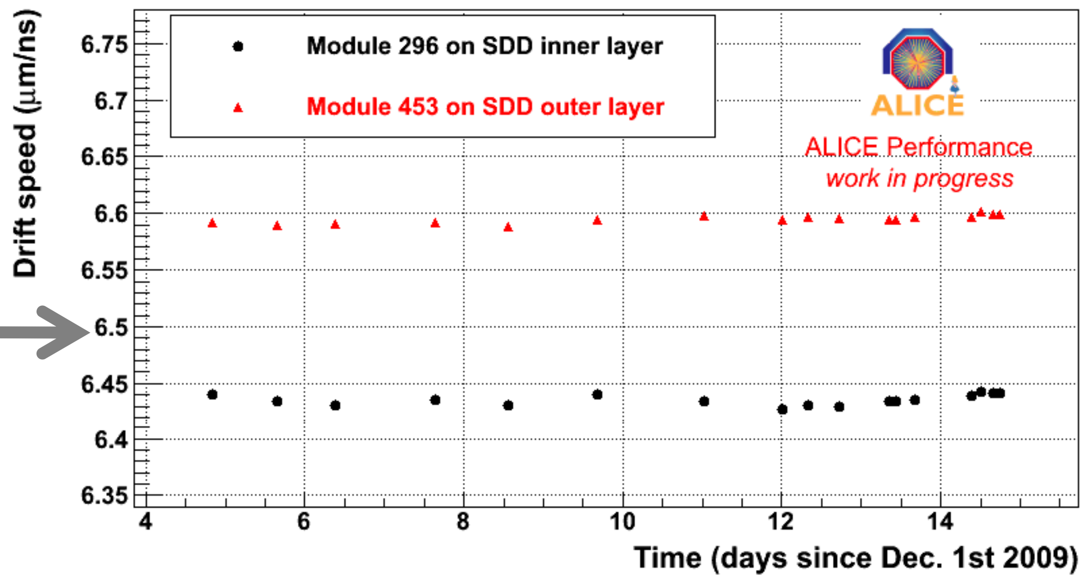
Longitudinal tracks along one half-stave (~14 cm)

SSD: module-by-module charge distribution



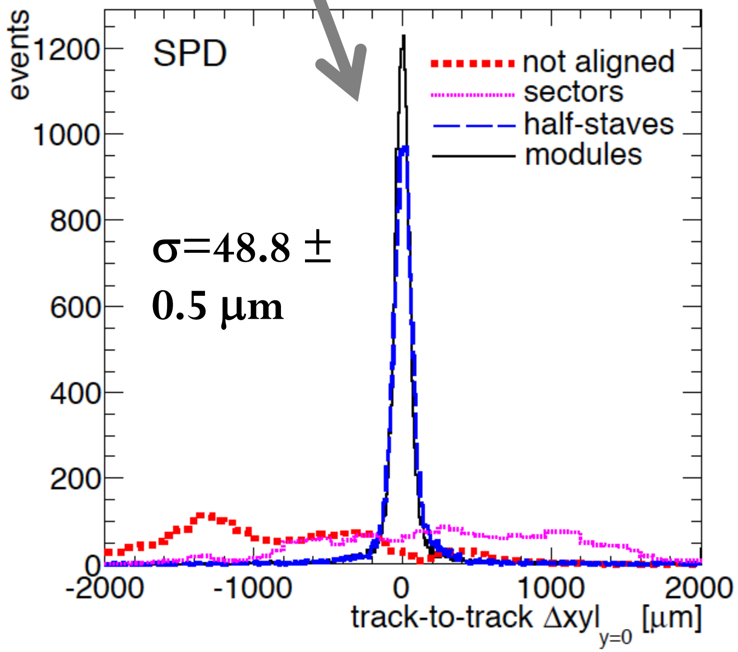
SDD: drift speed vs. time during p-p run in Dec. 2009

→ drift speed stability better than 0.15% for most SDD modules

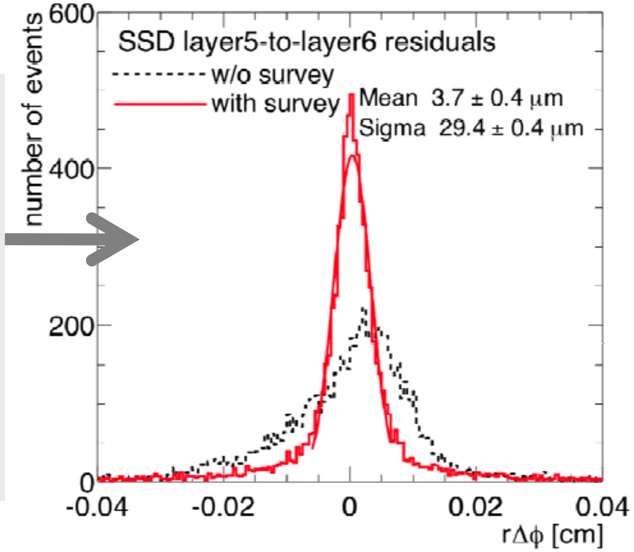


ITS internal alignment

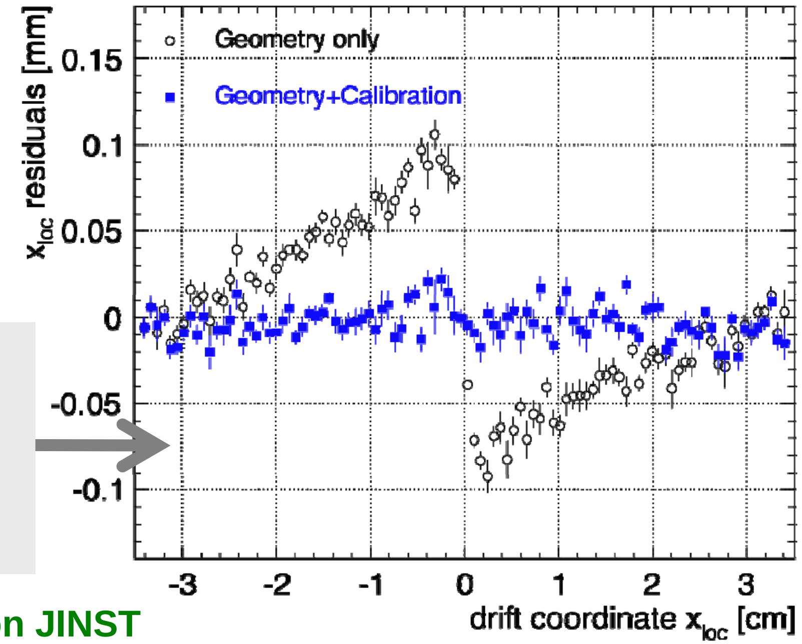
SPD:
•Cosmic tracks splitted in 2 half-tracks
•Track-to-track distance



SSD:
- Good alignment from survey
- Cosmic tracks used to align SSD barrel w.r.t. SPD



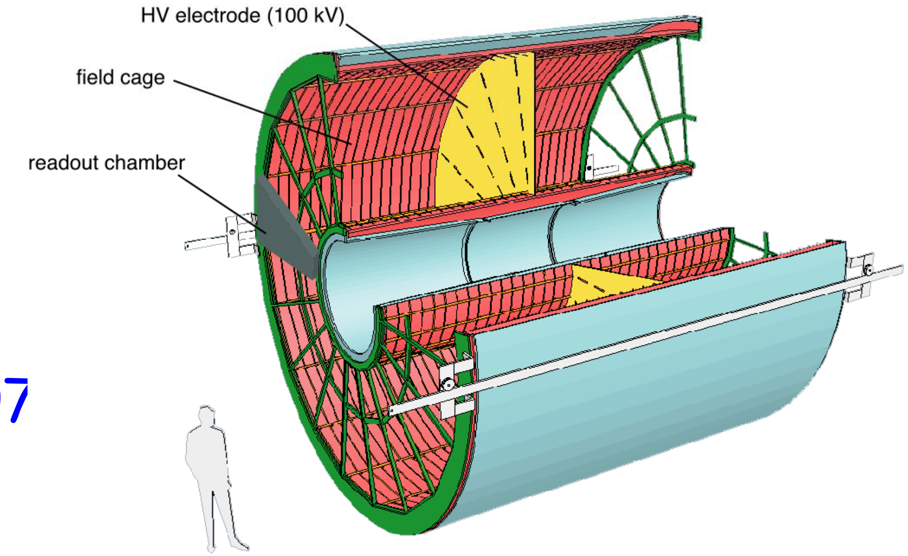
SDD:
•Residuals along drift coordinate
•Alignment + Calibration of Time Zero and Drift speed in Millepede



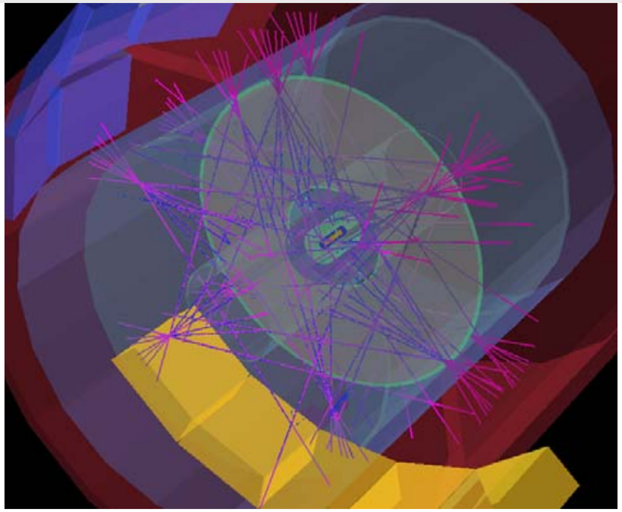
ALICE Collaboration arXiv:1001.0502 to appear on JINST

Time Projection Chamber (TPC)

- Characteristics:
  - ⇨ 85 m^3 - $NeC_2O_2N_2$ gas mixture
  - ⇨ 557,568 readout channels
  - ⇨ Maximum drift time = 92 μs
  - ⇨ Many (>90) 3D points (+dE/dx) per track
- Installation in ALICE since 2007
- Running continuously from May to October 2008 and since August 2009
- Calibration:
  - ⇨ >750 million events (cosmics, krypton, and laser) recorded, with and without B
  - ⇨ First round of calibrations (dE/dx, momentum, alignment, gain) completed before p-p collisions



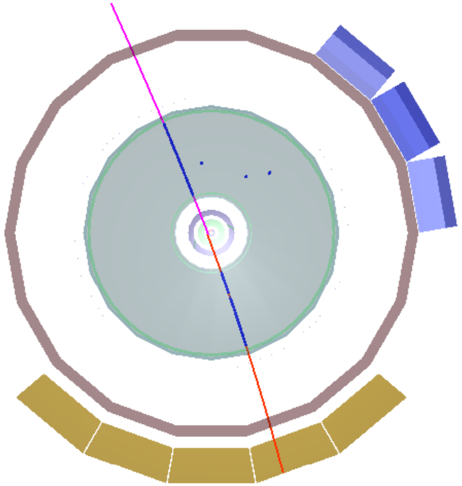
Laser event

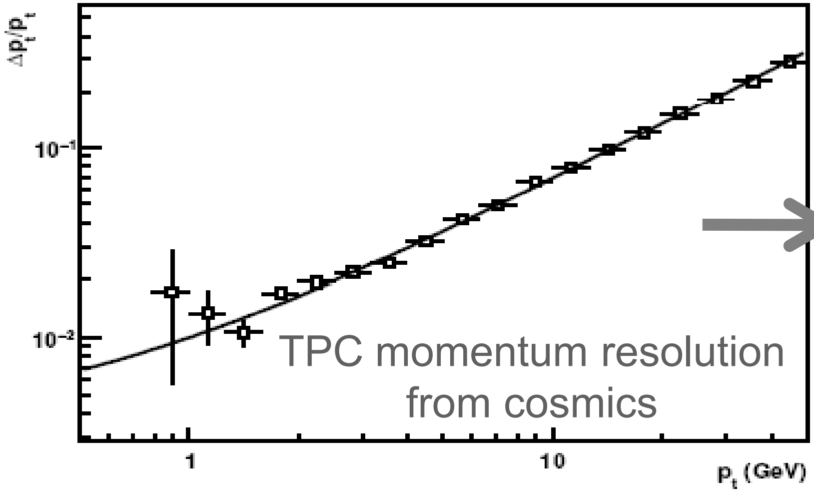


📖 J. Alme et al., TPC collab., arXiv:1001.1950

TPC calibration

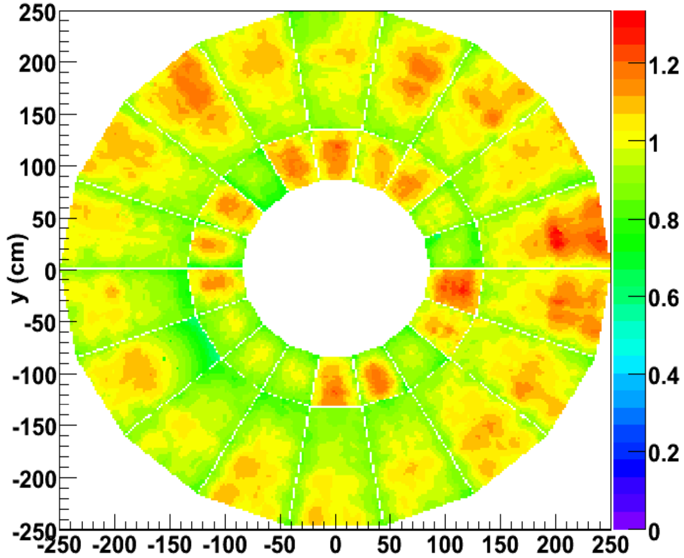
p_T resolution from cosmics: match track segments of upper and lower half



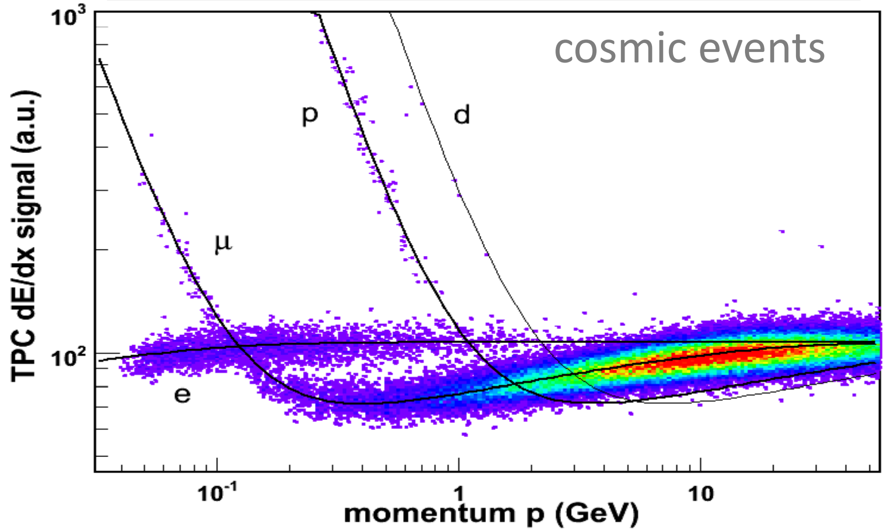


Preliminary p_T resolution:
- ≈ 7% at 10 GeV/c
- → design value (5% at 10 GeV/c)

Gain map from ^{83}Kr



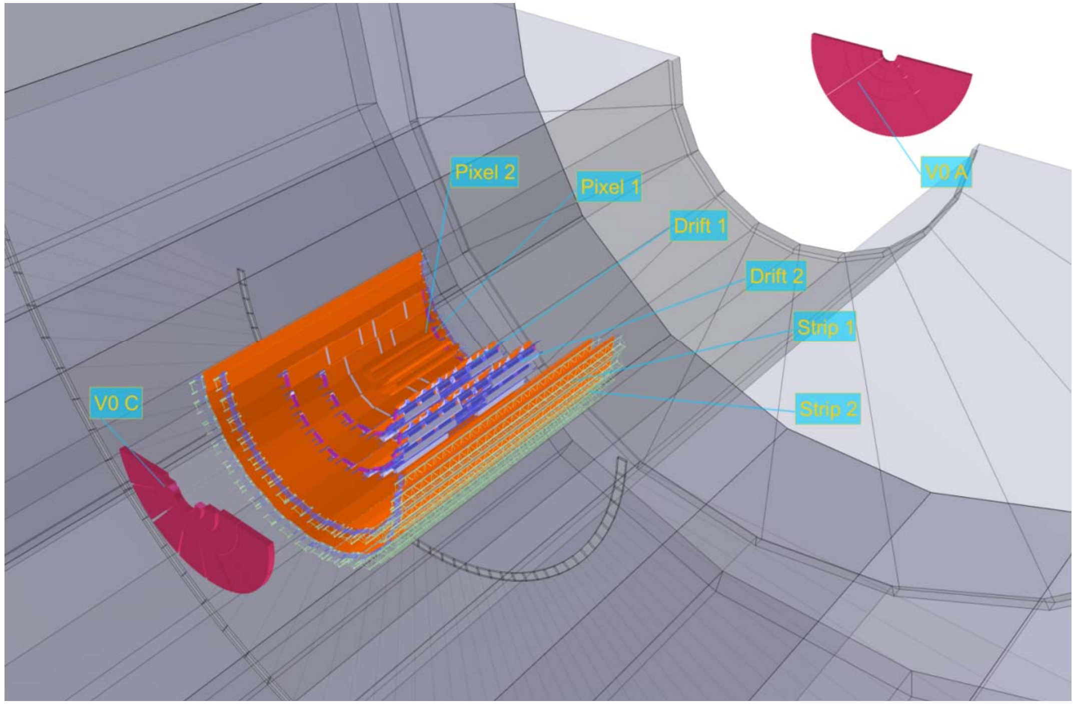
dE/dx calibration from cosmics



p-p data taking in 2009

First collisions: Nov 23, 2009

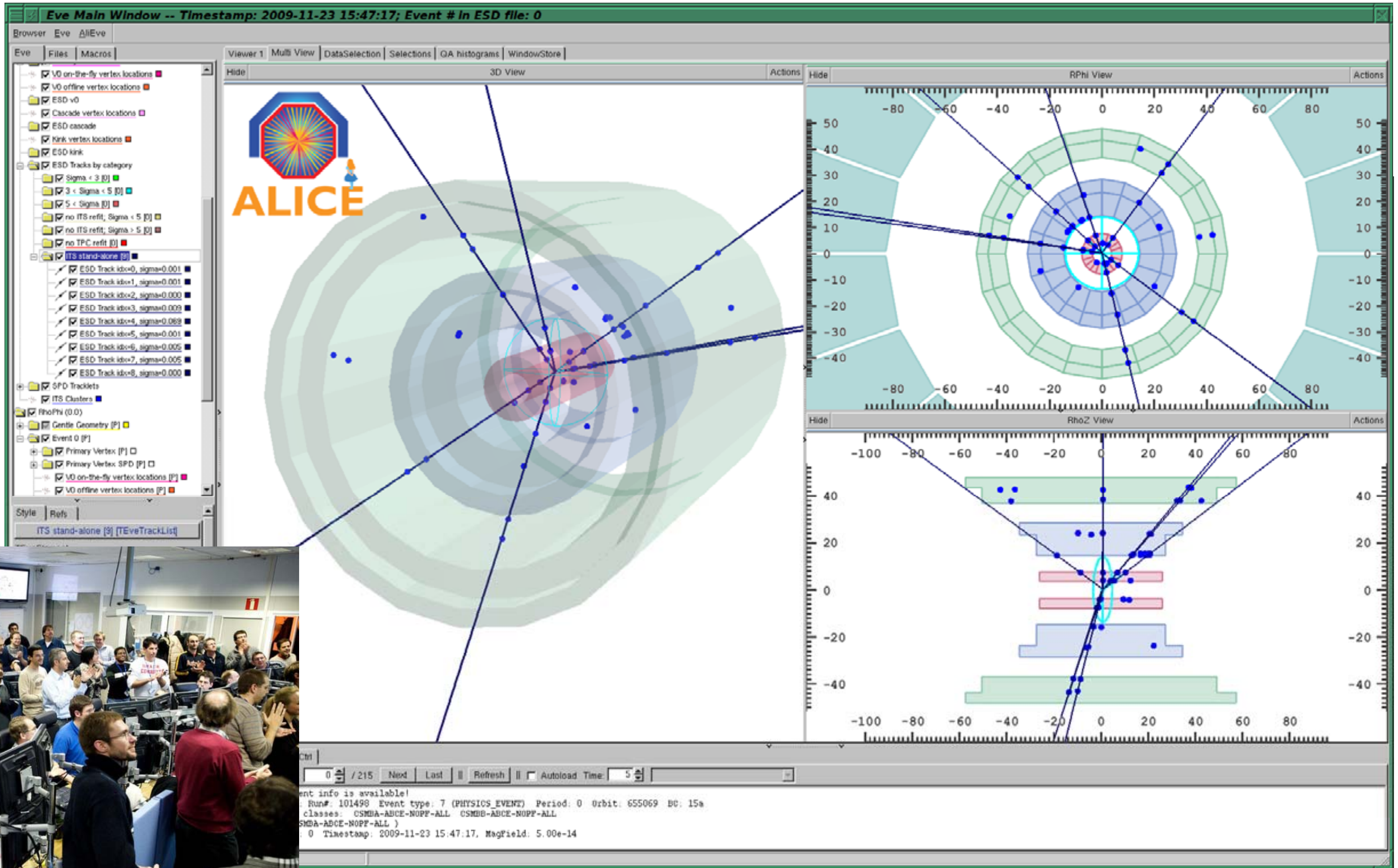
- LHC conditions:
  - ⇨ Two counter-rotating pilot bunches (~10^9 p each) at injection energy ($\sqrt{s}$=900 GeV)



- ALICE conditions:
  - ⇨ No magnetic field
  - ⇨ Active subsystems:
    - ✓ ***ITS***
    - ✓ ***V0***
    - ✓ ***FMD***
    - ✓ ***ZDC***
    - ✓ ***EMCAL***
  - ⇨ Trigger:
    - ✓ ***Coincidence of beam and ≥ 2 firing chips in SPD***
- Interaction rate: ~0.11 Hz
- Data sample collected: 284 events (43 minutes)
  - ⇨ Sufficient to measure $dN_{ch}/d\eta$

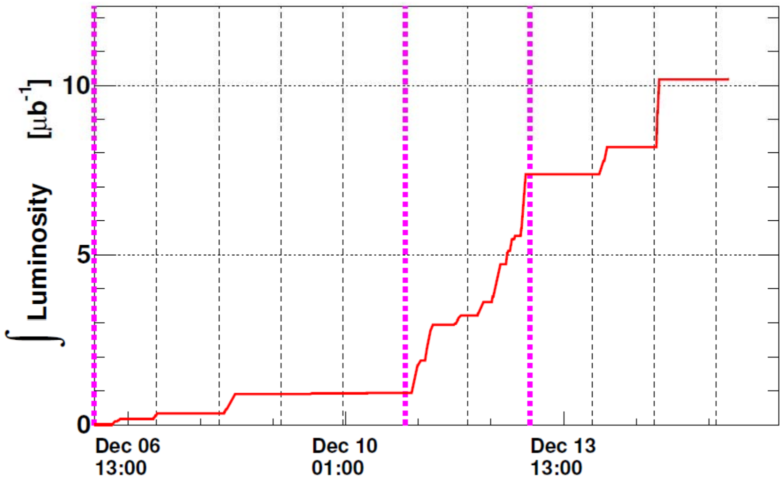
First p-p collision

- First p-p collision in ALICE as seen in the online event display



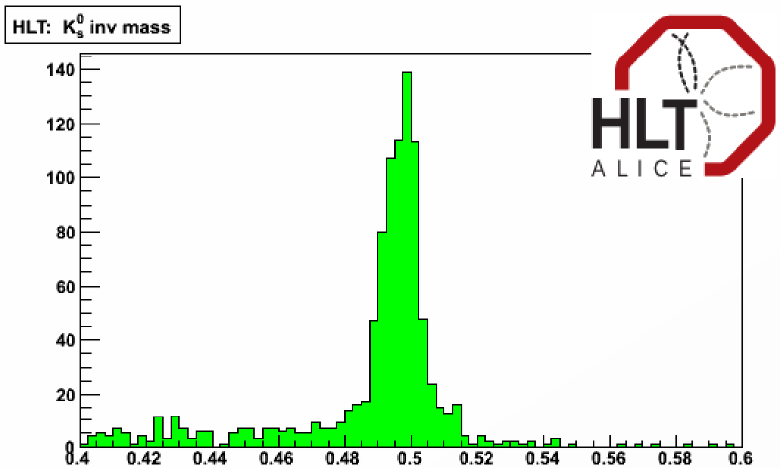
ALICE p-p run in December 2009

- Trigger configuration:
  - Interaction trigger: SPD or V0A or V0C
  - Activated in coincidence with BPTX beam pickups
    - ✓ ***BX with bunches from both sides***
    - ✓ ***control BX with bunch from side A or C only***
    - ✓ ***control BX with no bunches***
  - Single Muon: one muon (any p_T) in muon arm in coincidence with interaction trigger



- Integrated luminosity (stable beams):
  - 0.9 TeV → 470k events → 9.5 μb^{-1}
    - ✓ ***360 k with B on, 100 k with B off, 10 k with B reversed***
  - 2.36 TeV → 30 k events → 0.8 μb^{-1}
  - ~ 10% events w/o TPC

Online K0 mass peak from HLT



- General online systems worked to specs
  - + QA from HLT and prompt OFFLINE

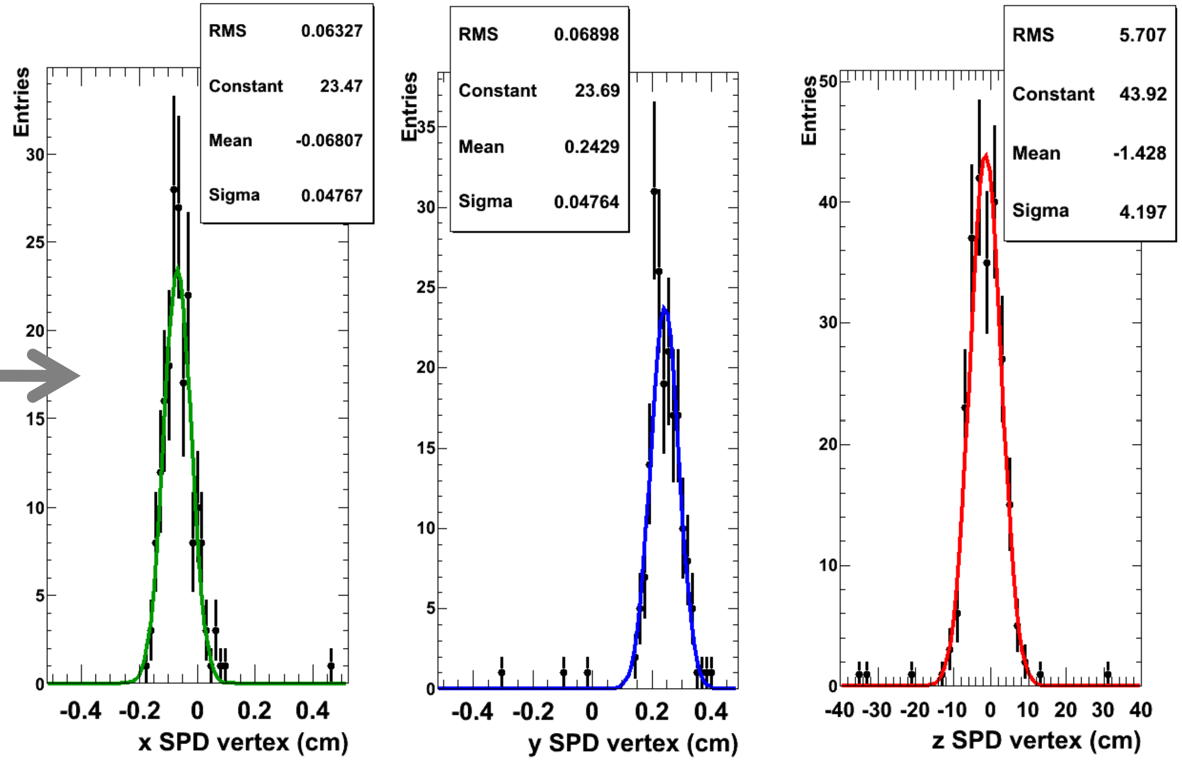
Interaction vertex reconstruction

Primary Vertexing in ALICE

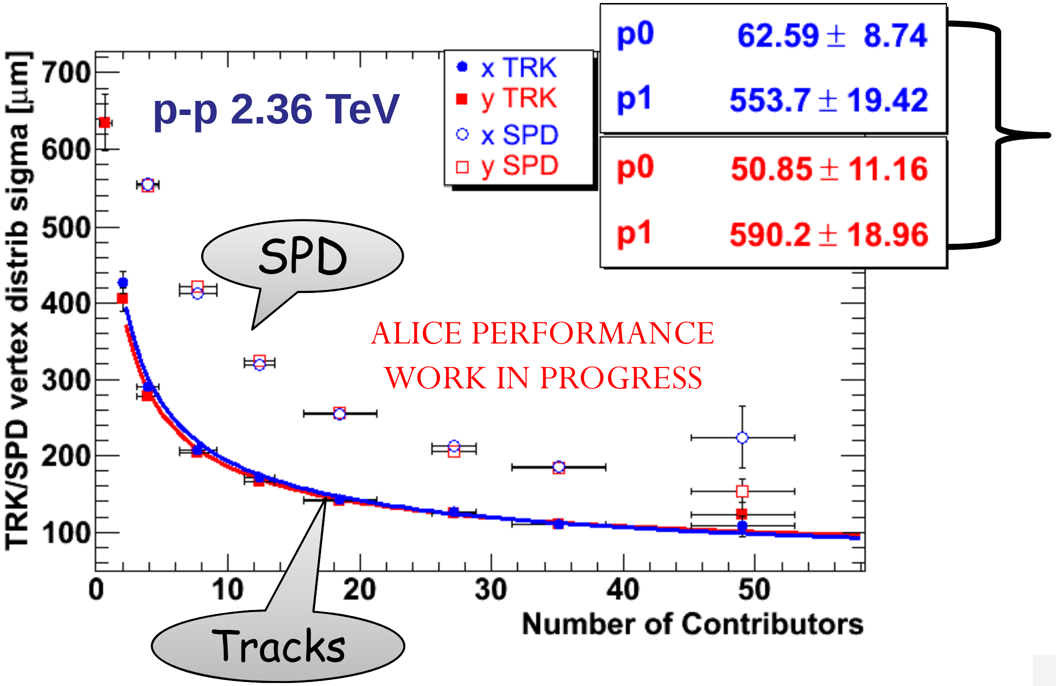
- First reconstruction of interaction vertex from SPD **tracklets** (pairs of points in 2 innermost ITS layers), before tracking
  - ⇨ Initiate barrel tracking + multiple scattering correction in muon arm
  - ⇨ Monitor the interaction diamond position quasi-online
  - ⇨ dN/dη measurement with SPD
- Second reconstruction of interaction vertex from **tracks**
  - ⇨ Accurate determination for physics analysis (e.g. D mesons)

Coordinates of SPD vertices

- From first p-p run (Nov 23,2009)
- Vertex reconstruction efficiency= 94%



Vertexing performance



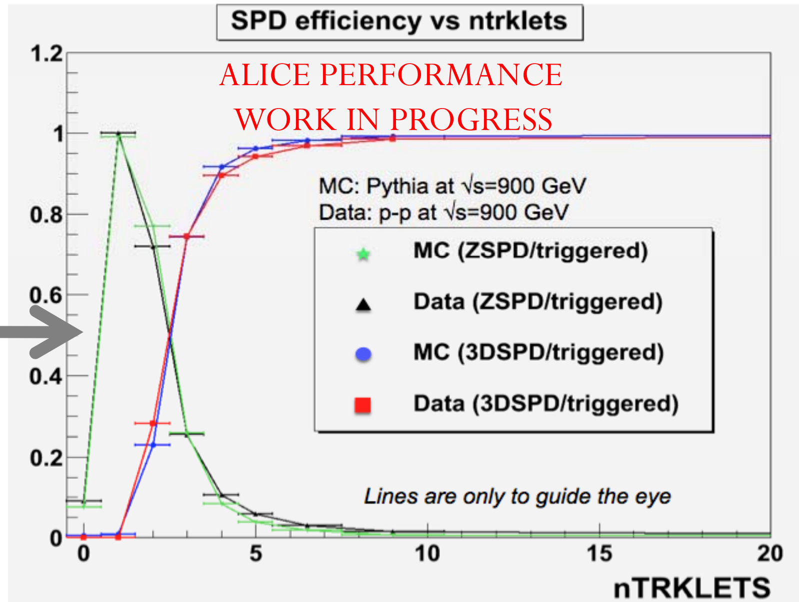
RMS of vertex reconstructed x,y coordinates fitted to:

$$\sigma(N) = \sqrt{p_0^2 + \frac{p_1^2}{N}}$$

- p0 = diamond transverse size
- p1 = vertex resolution
  - ✓Found in agreement with Monte Carlo simulations

SPD vertexing efficiency at 900 GeV:

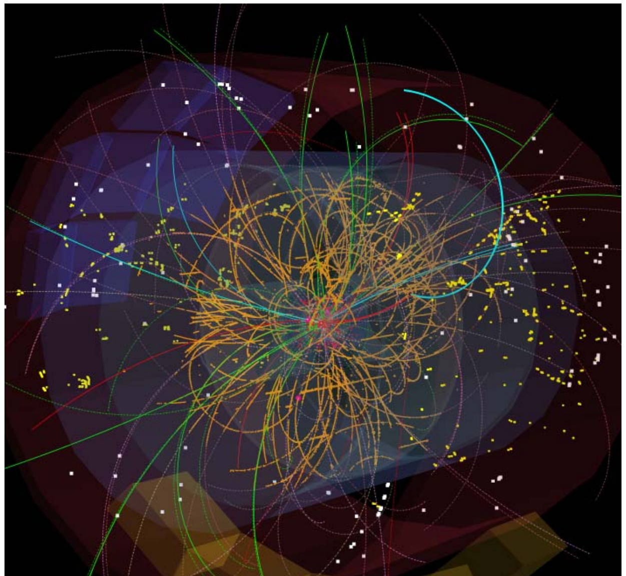
- When a 3D reconstruction fails, an estimate of the sole Z coordinate of the vertex is done
- Combined efficiency close to 100%
- Obtained efficiency in agreement with MC simulations



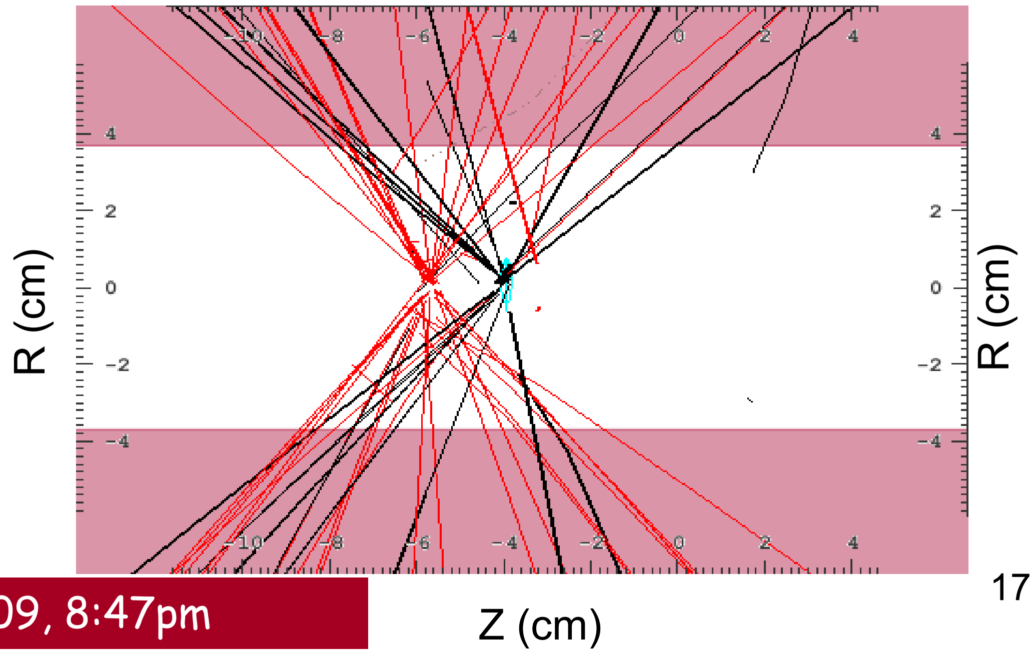
Pileup detection

- Interactions occurring in a time window of 100 ns (4 bunch crossings) pile-up in the SPD
- The SPD vertexer can be used to tag pile-up events
  - ⇨ After finding the first vertex, the tracklets which are not pointing to this ("main") vertex are used to check if there are other vertices originating particles

Event display of a pile-up event at 900 GeV

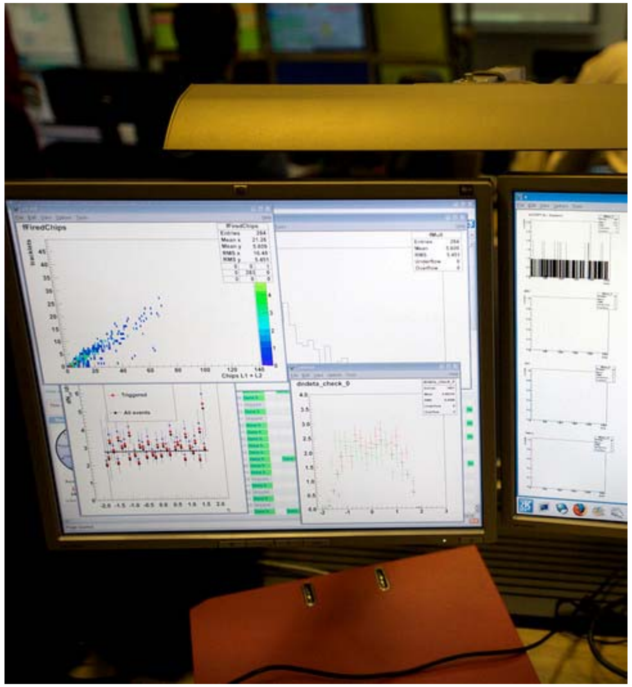


Run 104892, Dec 12th 2009, 8:47pm



Multiplicity analysis

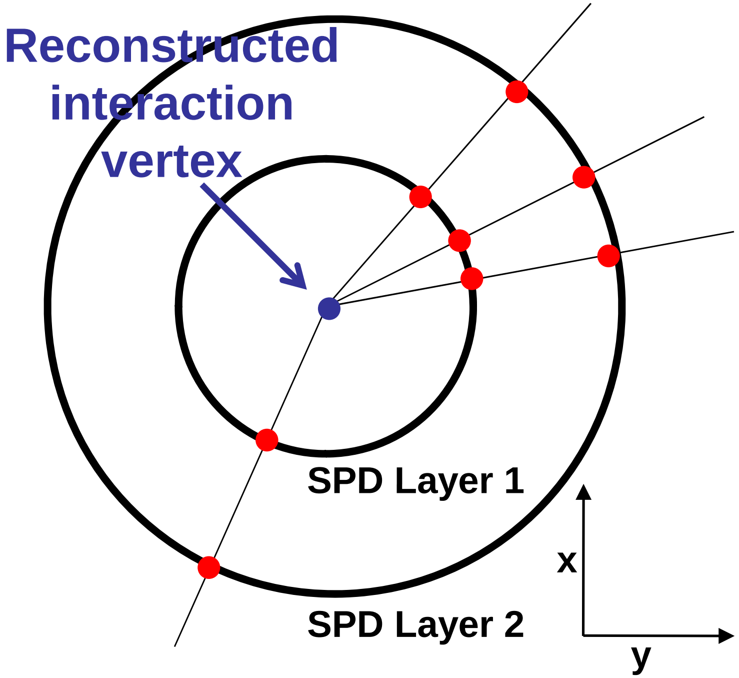
From first analysis in ACR …

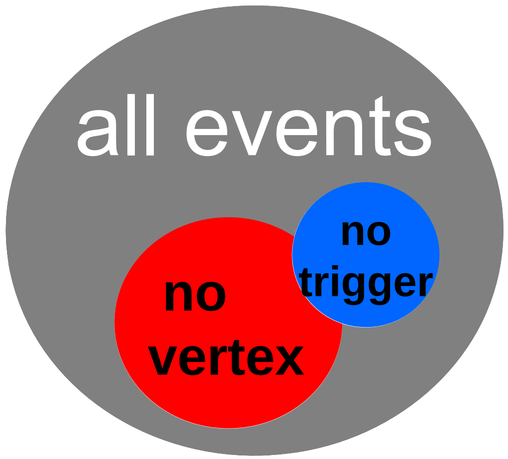


… to the first LHC physics paper

Multiplicity from SPD

- Multiplicity measurement based on the number of tracklets built on:
  - ⇨ Vertex position
  - ⇨ Clusters on the 2 SPD layers are matched with a cut defined on
    - ✓ $\Delta\phi$ *(bending plane)*
    - ✓ $\Delta\theta$ *(polar angle)*
- Three corrections applied
  - ⇨ Track-to-particle correction
    - ✓ *Detector acceptance, trackleting efficiency*
    - ✓ *Particle decays, conversions, secondary interactions*
    - ✓ *Low p_T cut-off*
  - ⇨ Vertex reconstruction correction
  - ⇨ Trigger bias correction

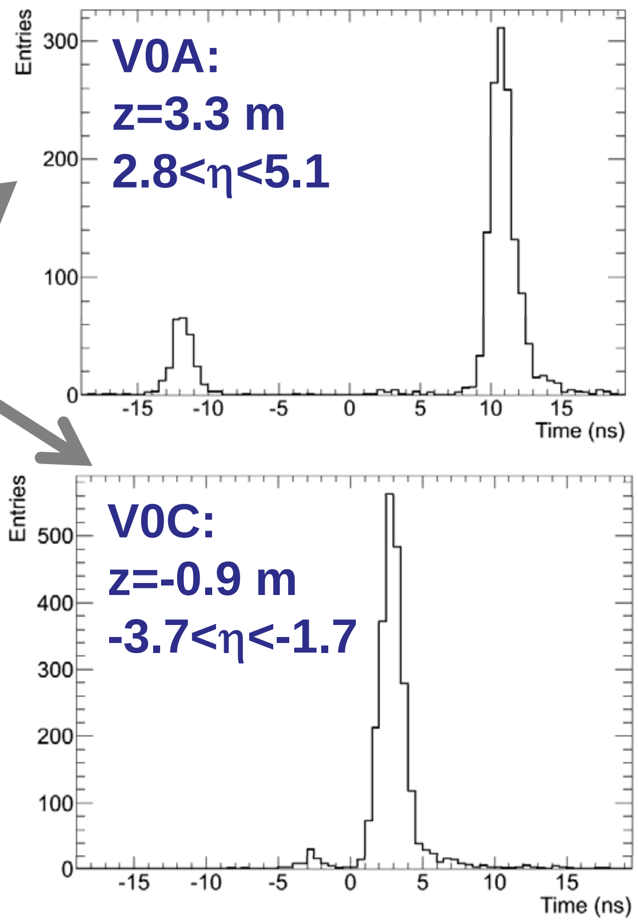




Event selection

- Out of a total of 284 events, 227 events have been used for the analysis
- Event rejection criteria:
  - ➩ Exclude beam-gas, beam-halo
    - ✓ *Timing information from V0 scintilators*
    - ✓ *Ratio between number of tracklets and number of ITS clusters*
  - ➩ Exclude events with $|z_{vert}|$>10 cm
    - ✓ *Select the region where vertexing efficiency is maximal and independent of z_{vert}*
    - ✓ *Allows accurate $dN_{ch}/d\eta$ measurement with SPD in $|\eta|<1.6$*
- Confirmed by visual scan of all events

Arrival time of particles in V0 relative to beam crossing time



Trigger efficiency

- Trigger efficiencies determined from Monte Carlo simulations with detailed detector response:
  - ⇨ PYTHIA 6.4.14 (tune D6T) and PHOJET
  - ⇨ Three process types considered separately
    - ✓ ***Single Diffractive (SD) , Double Diffractive (DD), Non Diffractive (ND)***

Trigger Efficiency	SD	DD	ND
PYTHIA	48%	53%	98%
PHOJET	58%	76%	99%

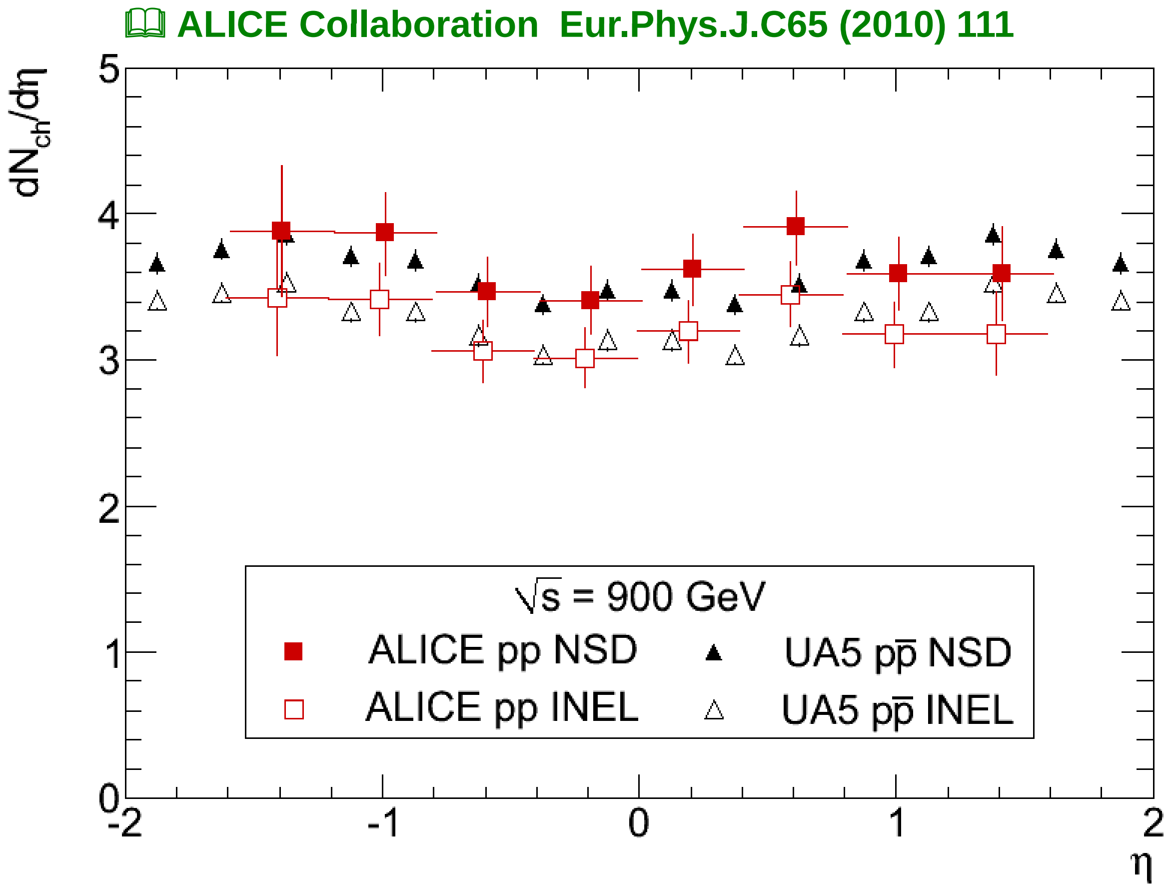
- Weighted with relative process fractions from UA5
  - ⇨ R.E. Ansorge, et al., Z. Phys. C33 (1986) 175.

Relative fractions	SD	DD	ND
UA5	0.153±0.031	0.08±0.05	0.767±0.059

- Total trigger efficiencies for INEL and NSD processes

Trigger Efficiency	INEL	NSD
UA5+PYTHIA	87%	94%
UA5+PHOJET	91%	97%

Pseudorapidity distribution



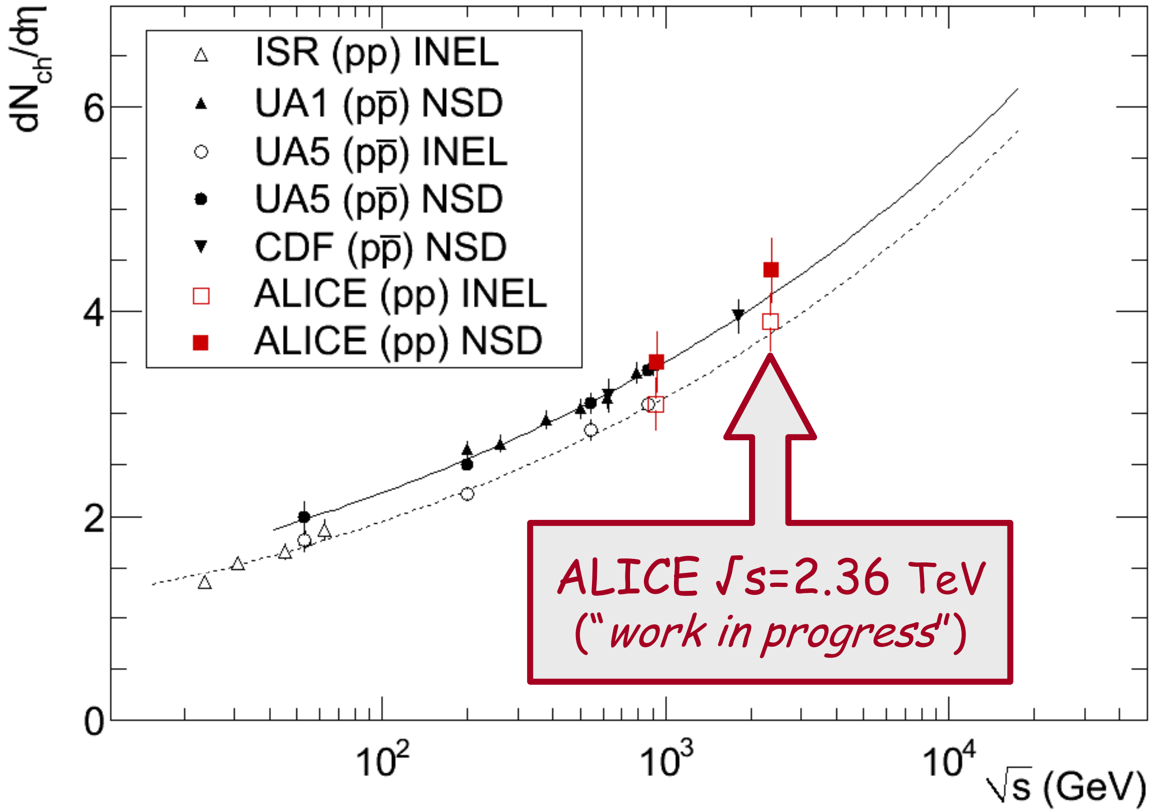
Only statistical errors shown in the plot

- $dN_{ch}/d\eta$ in pp at $\sqrt{s}$=900 GeV consistent with p-$\bar{p}$ from UA5
- Systematic error:
  - 7.1% (NSD)
  - 7.2% (INEL)
  - dominated by fraction and kinematics of diffractive processes

$dN_{ch}/d\eta|_{max}$ vs. $\sqrt{s}$

Experiment / Model	ALICE pp	UA5 $p\bar{p}$ [3]	QGSM [42]	PYTHIA [32, 33] D6T	PYTHIA [32, 33] Atlas CSC	PYTHIA [32, 33] Perugia-0	PHOJET [16]
INEL	$3.10 \pm 0.13 \pm 0.22$	3.09 ± 0.05	2.98	2.33	2.99	2.46	3.14
NSD	$3.51 \pm 0.15 \pm 0.25$	3.43 ± 0.05	3.47	2.83	3.68	3.02	3.61

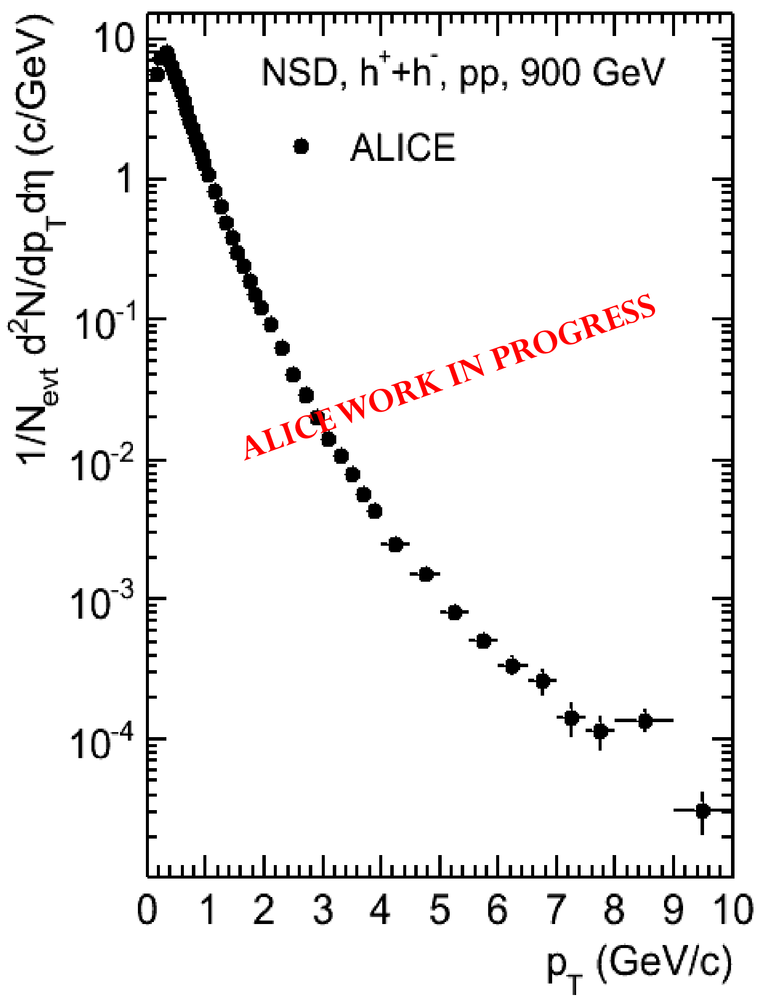
- Result at $\sqrt{s}$=0.9 TeV agrees with UA5 measurement
- Result at $\sqrt{s}$=2.36 TeV
  - Small statistical error, same systematic error (7%) as for first paper
  - Consistent with CMS result
- Work in progress on systematics
  - Aim: 3-4% syst. err.



Transverse momentum spectra

Charged particle p_T spectra

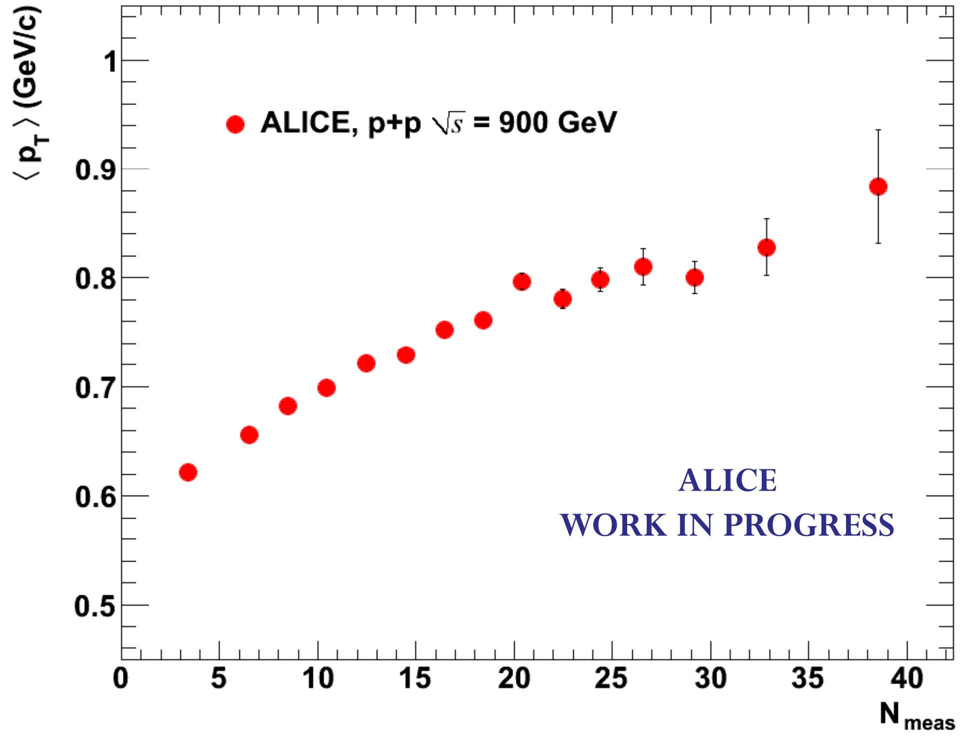
- ALICE ongoing analysis at $\sqrt{s}$=900 GeV
  - ⇨ SPD vertex
  - ⇨ TPC reconstructed tracks
- p_T reach 0.15-10 GeV/c
- Preliminary corrections for
  - ⇨ Efficiency
  - ⇨ Contamination from secondaries
- Work in progress on systematic errors



$<p_T>$ vs. multiplicity

- Increase of $<p_T>$ with mupliticity observed at ISR, Sp$\bar{p}$S and Tevatron
  - ⇨ Observable sensitive to QCD phenomenology

- ALICE ongoing analysis:
  - ⇨ p_T spectra in bins of multiplicity of TPC tracks
  - ⇨ Average p_T in $0.3<p_T<4$ GeV/c and $|\eta|<0.8$
  - ⇨ NOTE: multiplicity scale from number of TPC tracks not yet corrected for efficiency



Instead of summarizing and concluding …

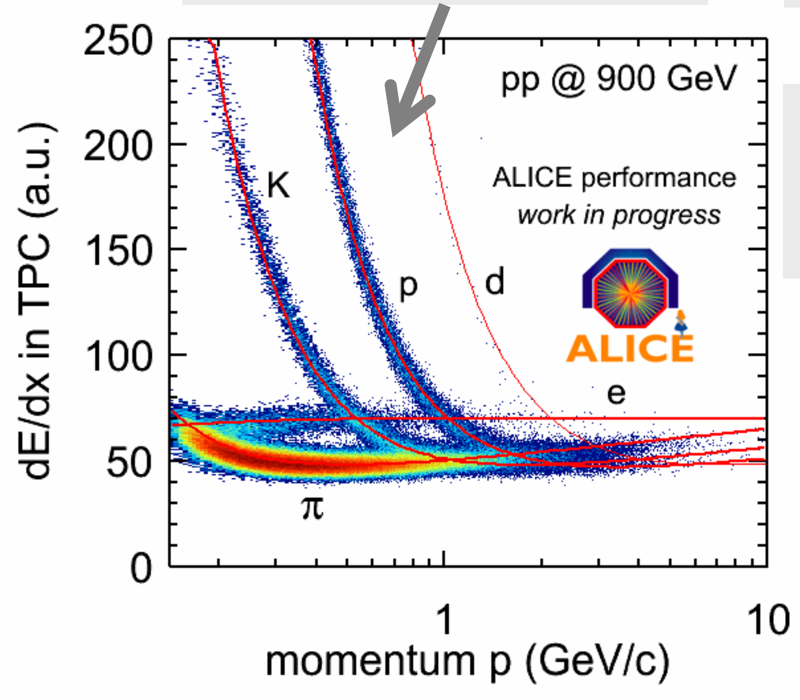
- Non-exhaustive list of other ongoing analyses
  - Multiplicity distributions at 0.9 and 2.36 TeV
  - p_T spectra of identified hadrons (π, K, p)
  - Strangeness production (K^0_s, Λ, Ξ, ϕ)
  - Baryon-antybarion asymmetry
  - Bose-Einstein correlations
  - Azimuthal correlations
  - ...

→ Few "work in progress" plots in the next slides

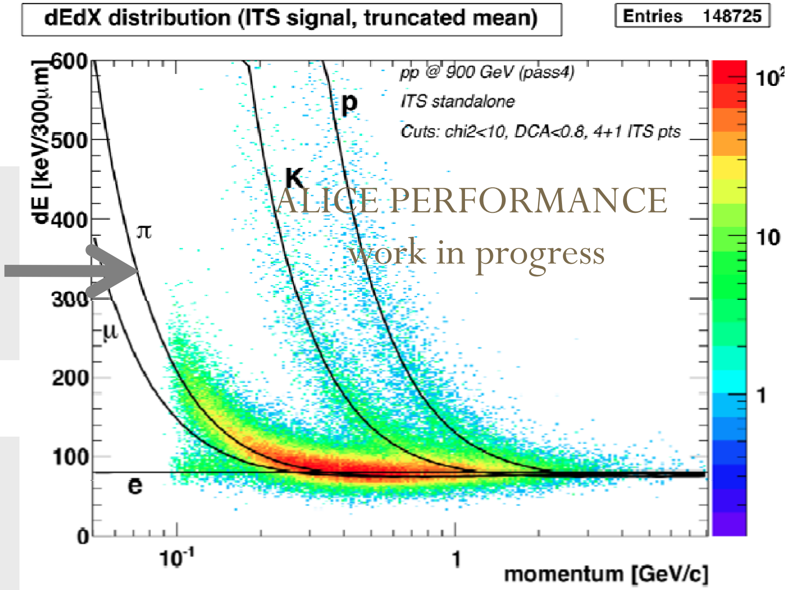
Spectra of identified hadrons

- Exploit PID capabilities of different detectors

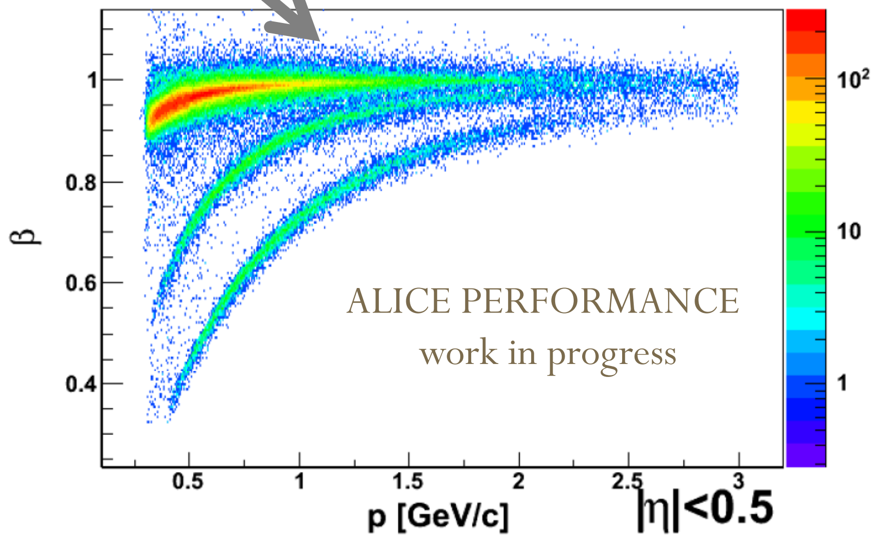
TPC dE/dx



ITS dE/dx
-> down to
100 MeV/c

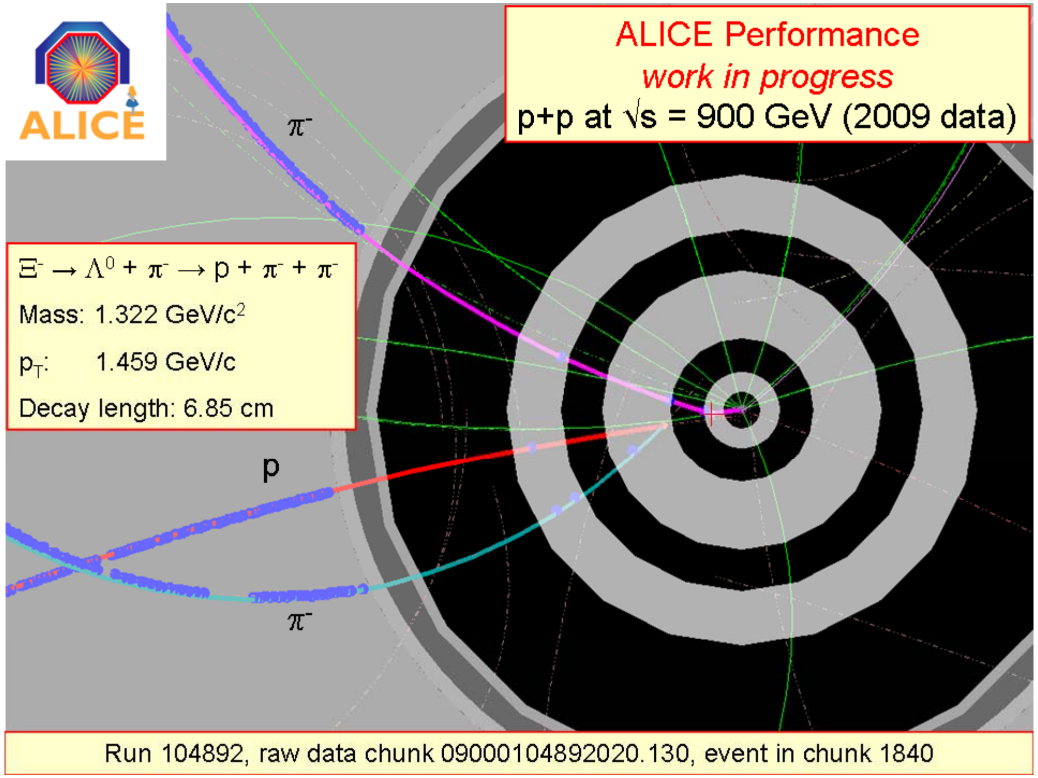


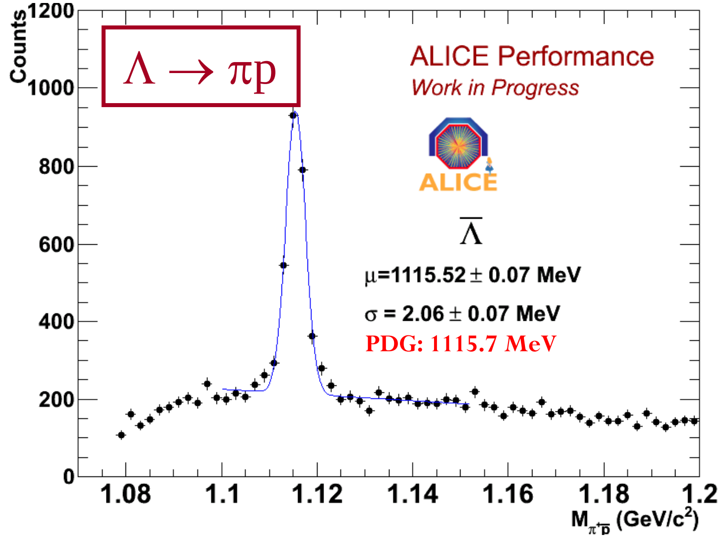
TOF
-> ideal for
high momenta

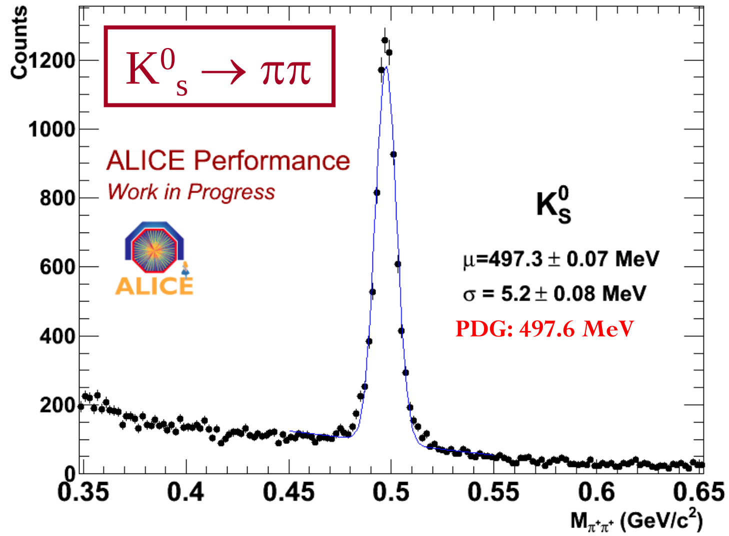


Strangeness

- Various ongoing analysis
  - Exclusive reconstruction of Λ, K^0_s, ϕ, Ξ
  - $K^{\pm}$ from kinks







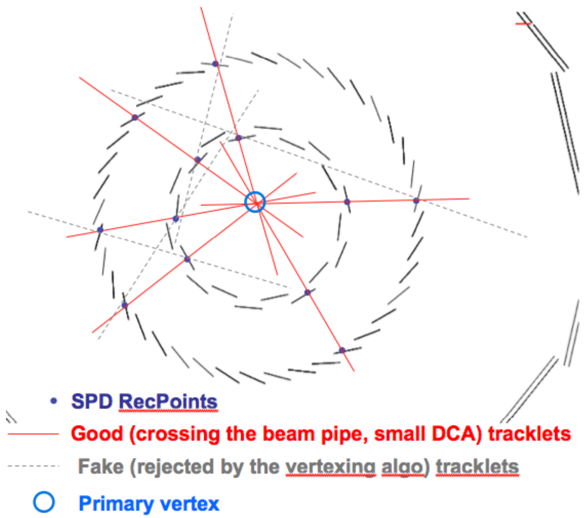
Backup

ITS internal alignment - method

- Two independent track-based alignment methods:
  - ⇨ **Global**: Millepede (default method)
  - ⇨ **Local**: iterative method based on residuals minimization
- Data sets: cosmics + first pp collisions (and beam gas)
  - ⇨ Use cocktail of tracks from cosmics and pp to cover full detector surface and to maximize correlations among volumes
- Start with B off, then switch on B (pp)
  - ⇨ Possibility to select high-momentum (no multiple scattering) tracks for alignment
- General strategy:
  - ⇨ Validation of survey measurements with cosmics
    - ✓ ***Use geometrical survey data as a starting point for track based alignment***
  - ⇨ Start with layers easier to calibrate: SPD and SSD
    - ✓ ***Use a hierarchical approach: start from assemblies of sensitive elements mounted on common mechanical supports and then move to smaller and smaller structures***
  - ⇨ Global ITS alignment relative to TPC (already internally aligned)
  - ⇨ Finally, inclusion of SDD, which need longer calibration (interplay between alignment and calibration)
    - ✓ ***SDD calibration parameters (Time Zero and Drift Speed correction) used as free parameters in the Millepede***

Primary Vertexing in ALICE

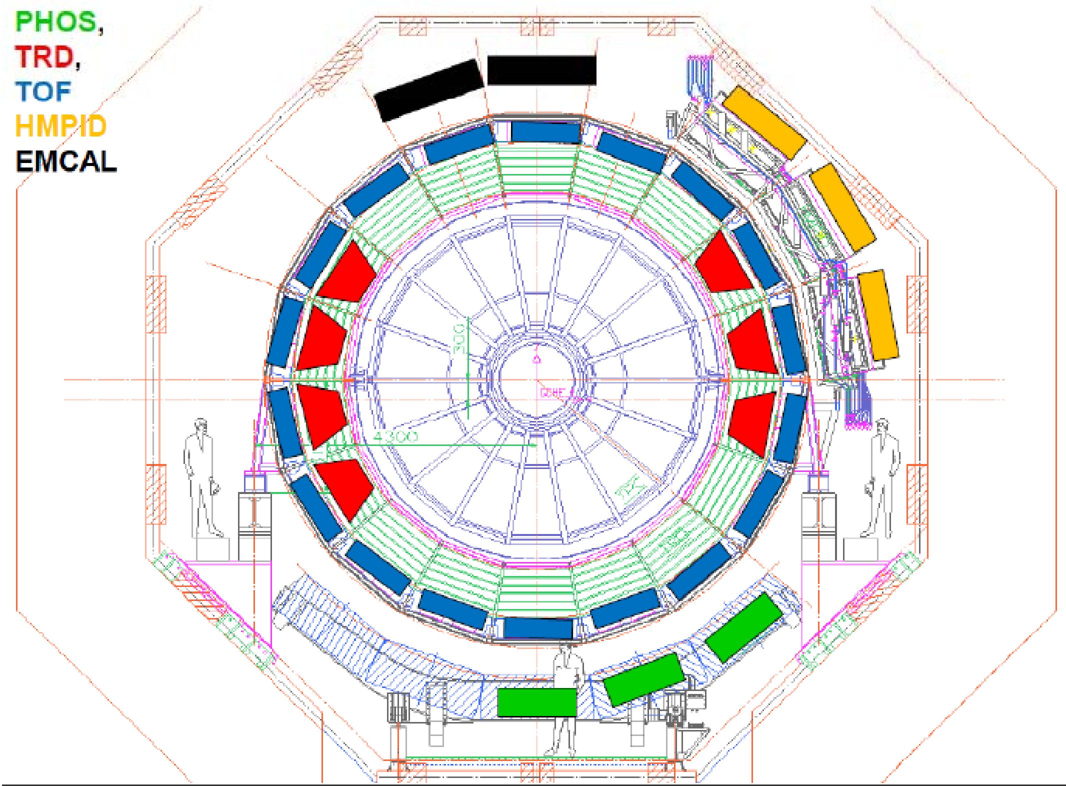
- First reconstruction of interaction vertex from SPD **tracklets** (pairs of points in 2 innermost ITS layers)
  - ⇨ Computed after local reconstruction, before tracking
  - ⇨ Motivation:
    - ✓ ***Initiate trackers (barrel and muon arm)***
    - ✓ ***Monitor the interaction diamond position quasi-online***
    - ✓ ***dN/dη measurement with SPD***
  - ⇨ Method:
    - ✓ ***Tracklet build-up and selection (based on DCA to beam axis)***
    - ✓ ***Vertex = best common origin of selected tracklets***
    - ✓ ***Two iterations with increasing cut selectivity***
      - – Independence of possible beam displacements
  - ⇨ High efficiency: when a 3D reconstruction fails, an estimate of the sole Z coordinate of the vertex can be done with a single tracklet



- Second reconstruction of interaction vertex from **tracks**
  - ⇨ Motivation:
    - ✓ ***Accurate determination for physics analysis (e.g. D mesons)***
  - ⇨ Method:
    - ✓ ***Track selection (quality cuts + track impact parameter selection)***
    - ✓ ***Vertex finding and fitting***
    - ✓ ***Two iterations with increasing cut selectivity → efficient removal of secondaries***

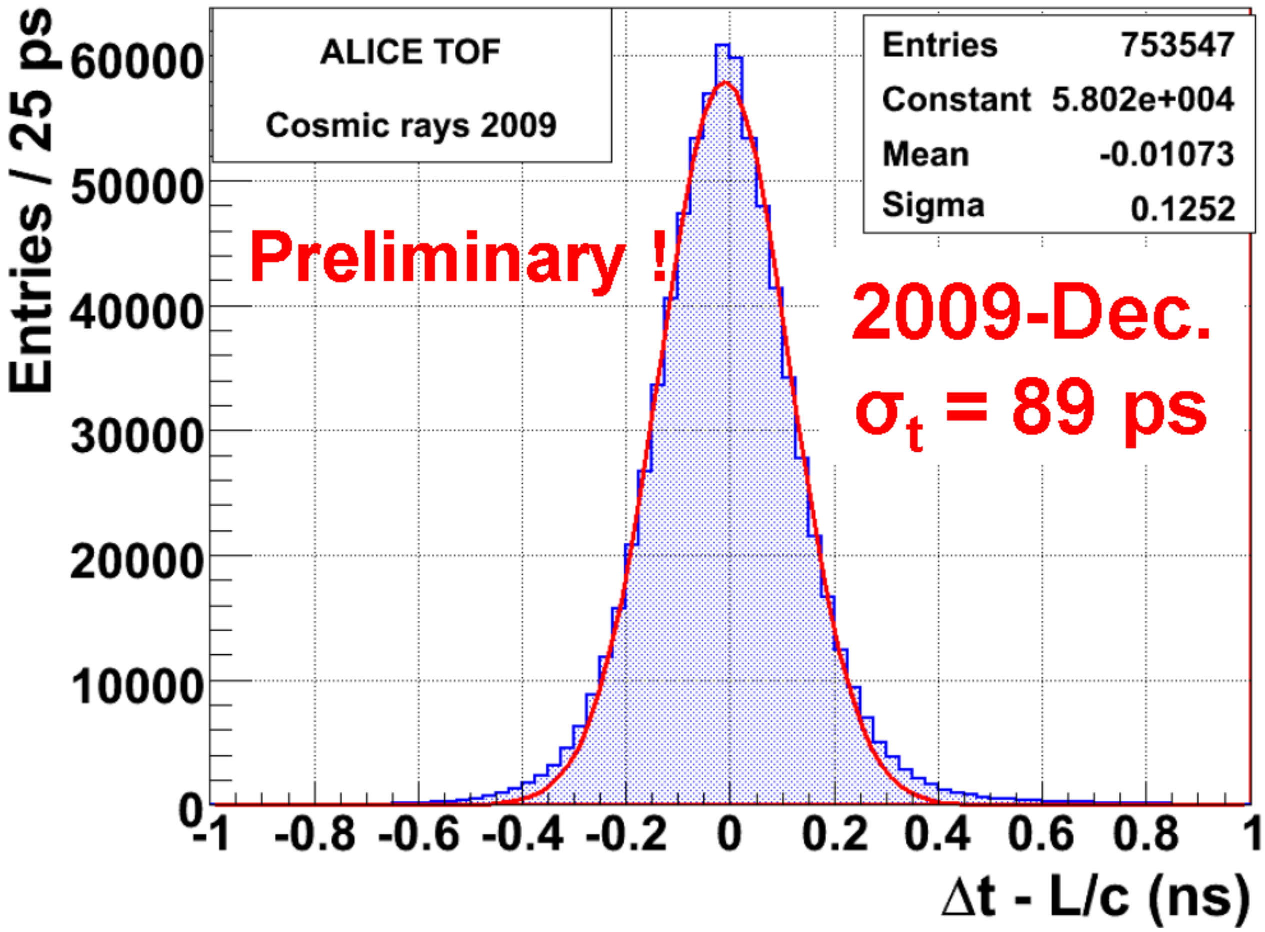
ALICE detector status in 2009

- Central Barrel:
  - ITS, TPC, TOF, HMPID 100%
  - TRD 7/18
  - EMCAL 4/12
  - PHOS 3/5
- Forward detectors:
  - V0, T0, PMD, FMD, ZDC 100%
- Muon arm 100%



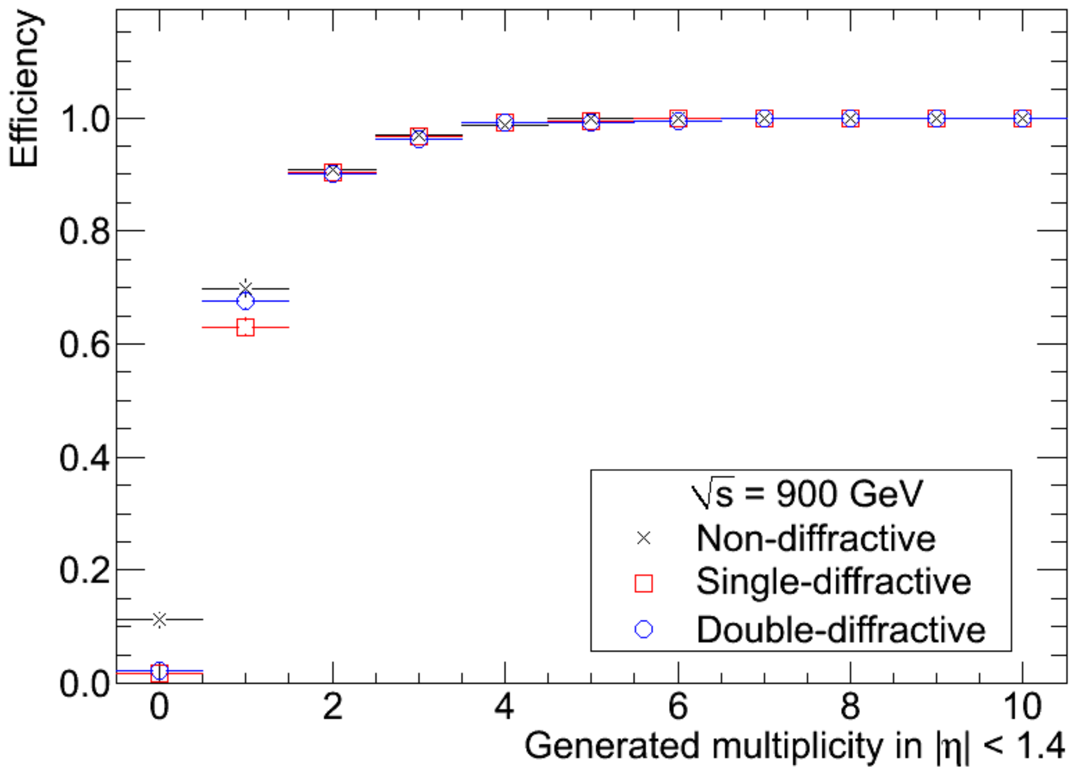
TOF performance

- Time resolution from cosmics

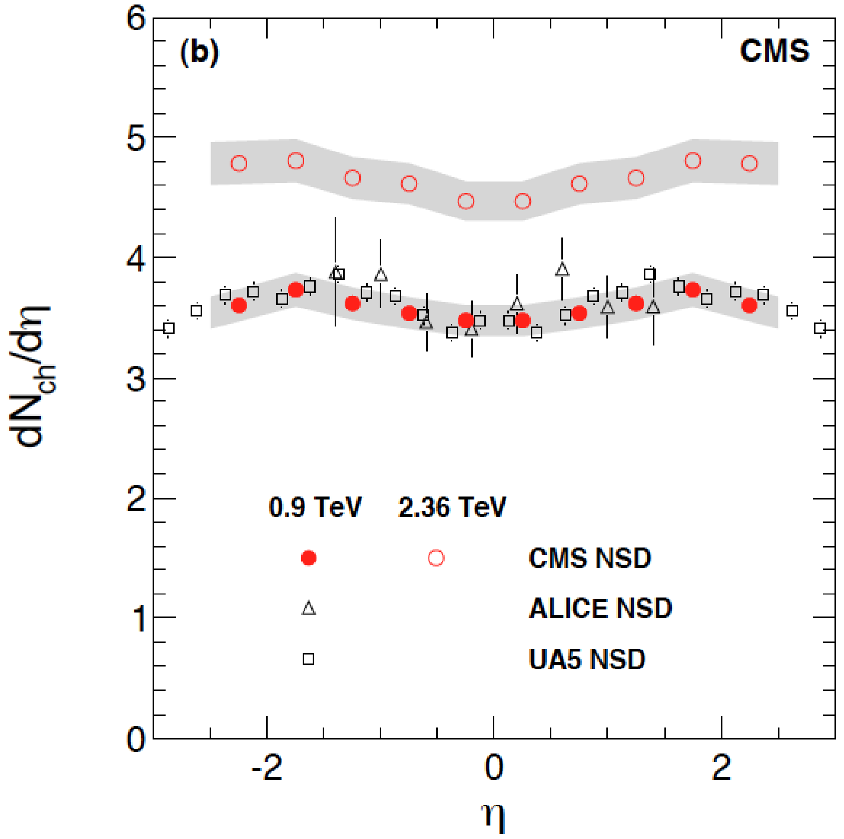


Trigger+Vertex efficiency

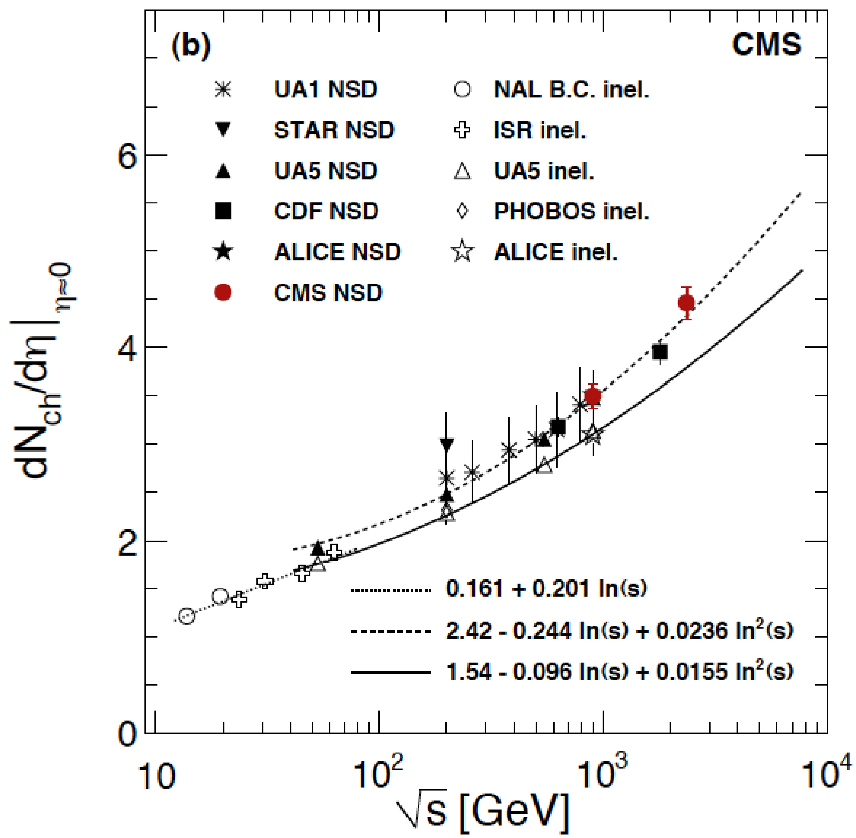
- Multiplicity dependence of the combined efficiency to select an event as minimum bias and to reconstruct its vertex in SPD
  - Separated for non-diffractive, single-diffractive, and double-diffractive events
  - Based on PYTHIA events.



CMS results

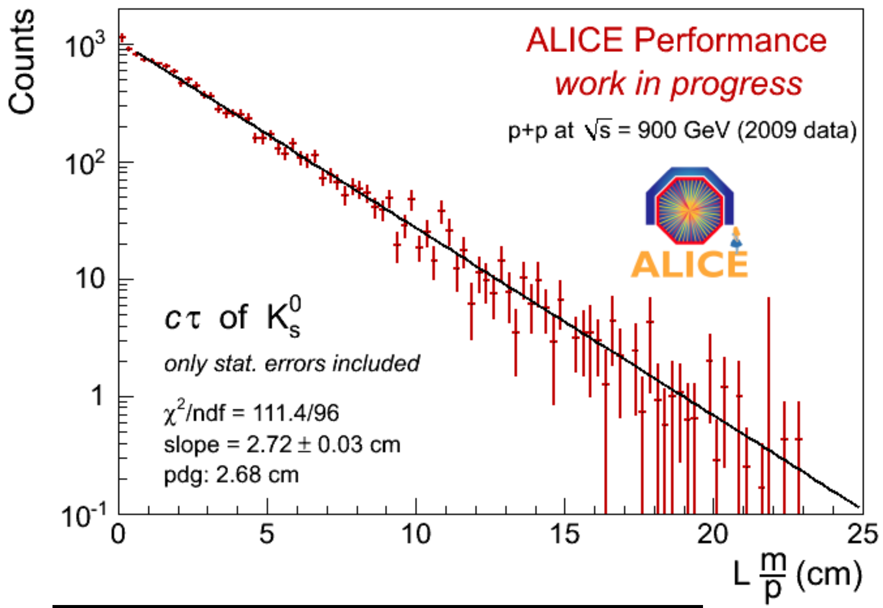


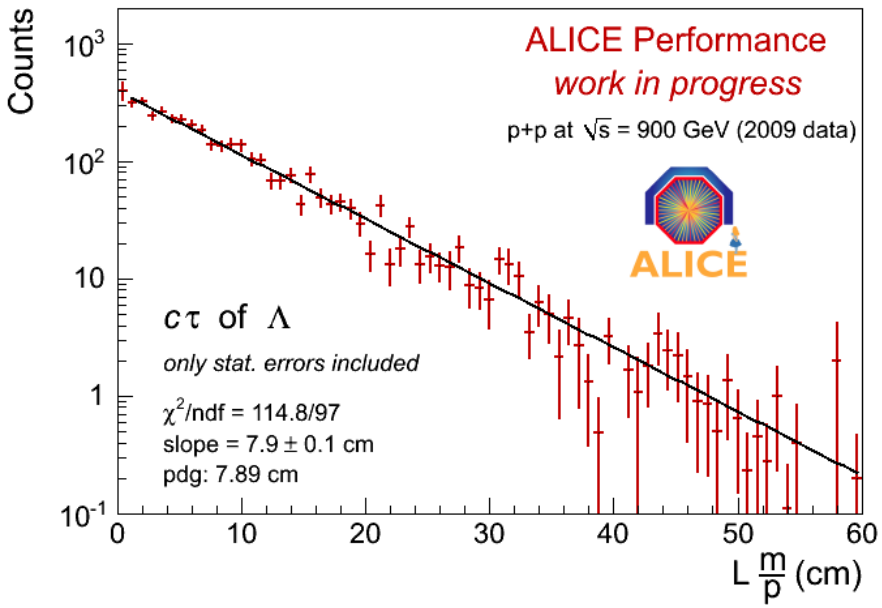
(b)
CMS
0.9 TeV
2.36 TeV
CMS NSD
ALICE NSD
UA5 NSD
$dN_{ch}/d\eta$
η

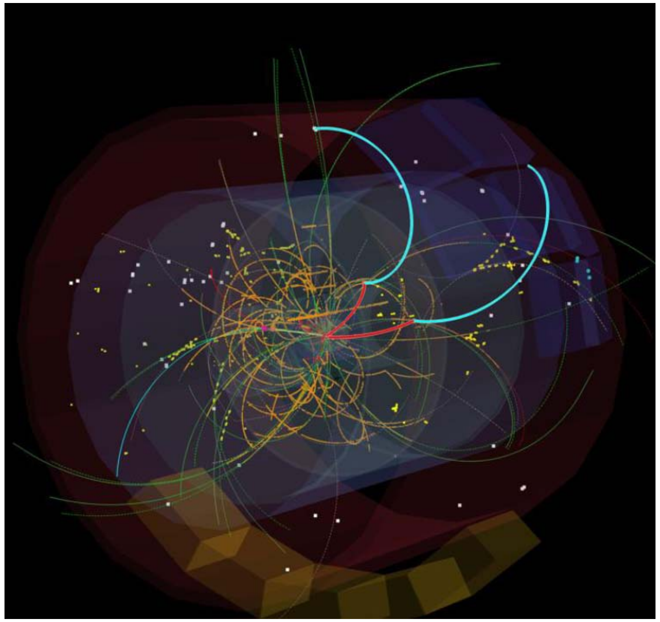


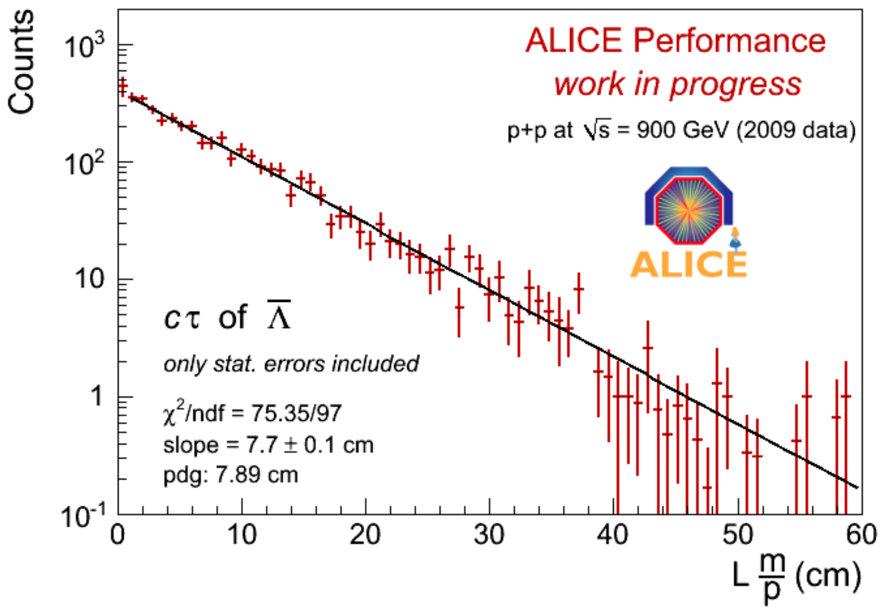
(b)
CMS
UA1 NSD
STAR NSD
UA5 NSD
CDF NSD
ALICE NSD
CMS NSD
NAL B.C. inel.
ISR inel.
UA5 inel.
PHOBOS inel.
ALICE inel.
0.161 + 0.201 ln(s)
2.42 - 0.244 ln(s) + 0.0236 ln^2(s)
1.54 - 0.096 ln(s) + 0.0155 ln^2(s)
$dN_{ch}/d\eta|_{\eta\approx 0}$
$\sqrt{s}$ [GeV]

Strangeness (II)



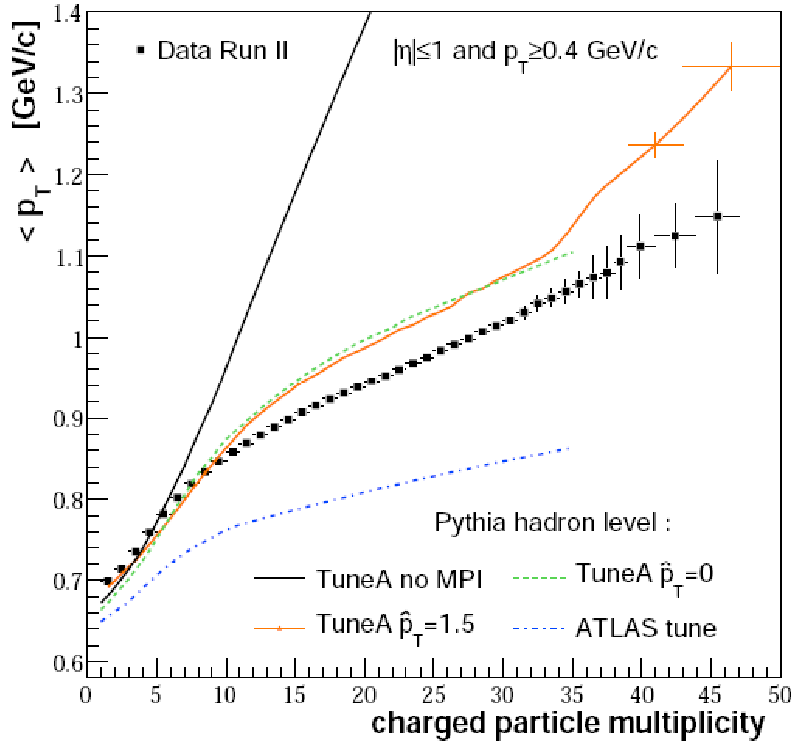






$\langle p_T \rangle$ vs. N_{ch} from CDF

- Transverse momentum spectra for multiplicity classes and as a function of energy are crucial tests of soft QCD understanding



CDF: Phys. Rev. D 79/2009, 112005