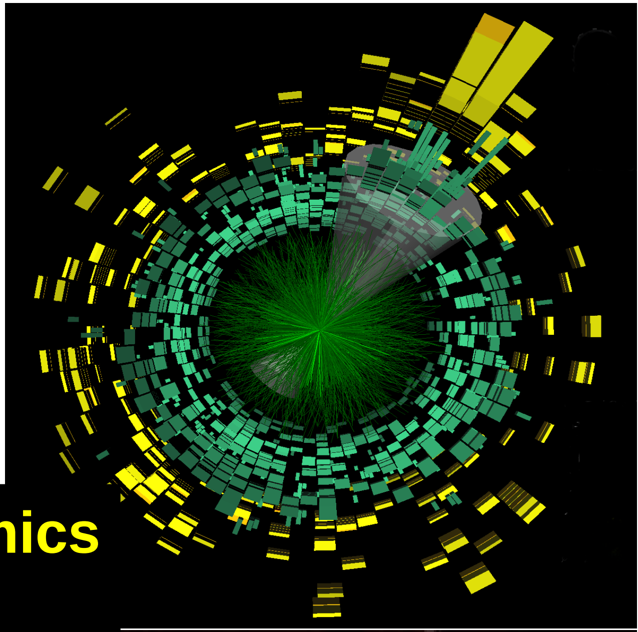
First Run-2 results from ALICE

Alberica Toia
Goethe University Frankfurt & GSI
on behalf of the ALICE Collaboration



XLV International Symposium on Multiparticle Dynamics
Wildbad Kreuth, 4-9 Oct 2015

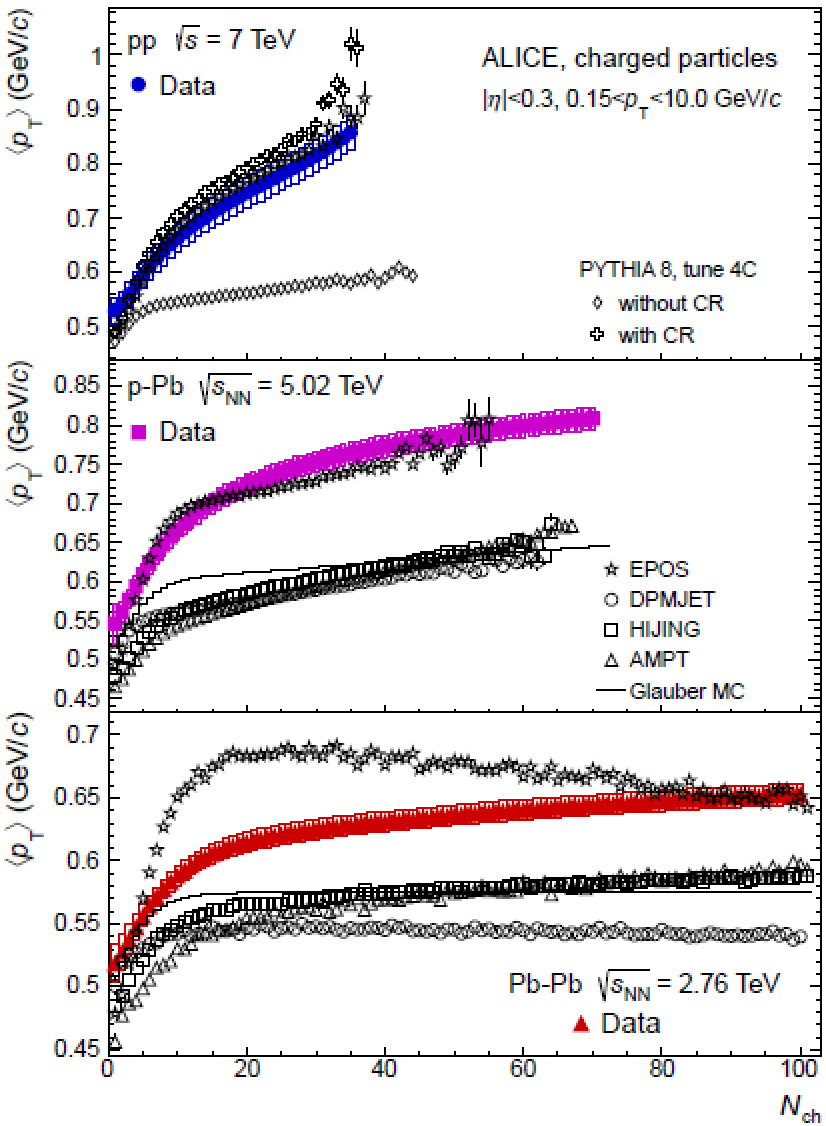
Outline

- Introduction and Motivation
  - pseudorapidity (η) and transverse-momentum (p_T) distributions of primary charged particles: the interplay between hard and soft physics
- ALICE in Run 2
  - Upgrades and Performances
- The measurements
  - Event selection and data analysis
  - Systematic Uncertainties
  - Results

Introduction & Motivation

- 2015: after 2-years shut-down LHC restart at a new higher energy 13 TeV
  - Optimize the delivery of particle collisions for physics research → speed the route to potential new physics
  - New frontiers in physics → study the evolution of the basic event properties MINIMUM BIAS MEASURMENTS
- The inclusive production of charged particles in high-energy proton-proton collisions is a key observable to characterize the global properties of the collision.
- Particle production at LHC energies originates from the interplay of perturbative (hard) and non-perturbative (soft) QCD processes. Soft-scattering processes and parton hadronisation dominate the bulk of particle production at low transverse momenta and can only be modeled phenomenologically.
- These measurements provide constraints to phenomenological models as implemented in pQCD inspired generators such as PYTHIA.
- Data in pp collisions are reference for the study of nuclear effects in nucleus-nucleus and proton-nucleus collisions.

Mean p_T



ALICE Coll. PLB 727 (2013) 371

pp: high-mult through multiple parton interactions BUT incoherent production → same $<p_T>$

→ Color reconnection: strings from independent parton interactions do not independently produce hadrons, but fuse before hadronization

→ fewer, but more energetic hadrons

Sign of collectivity?

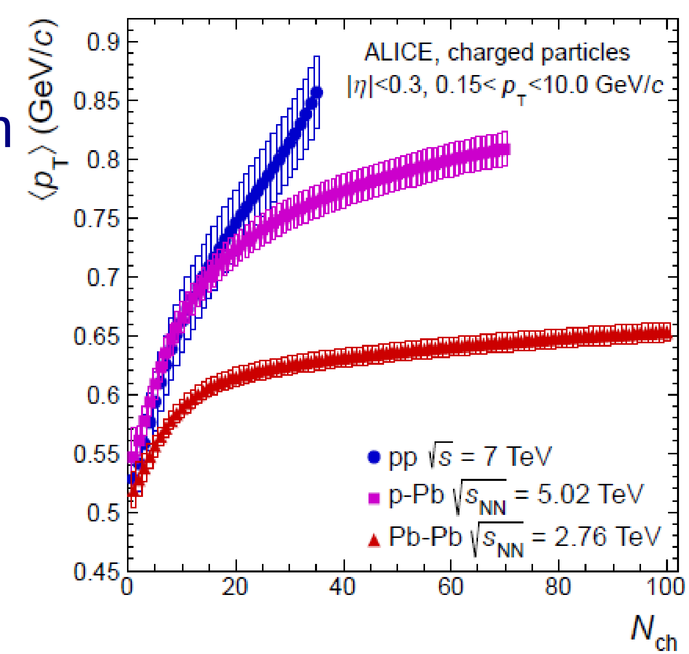
p-Pb: features of both pp and PbPb

less saturation than in PbPb → higher $<p_T>$

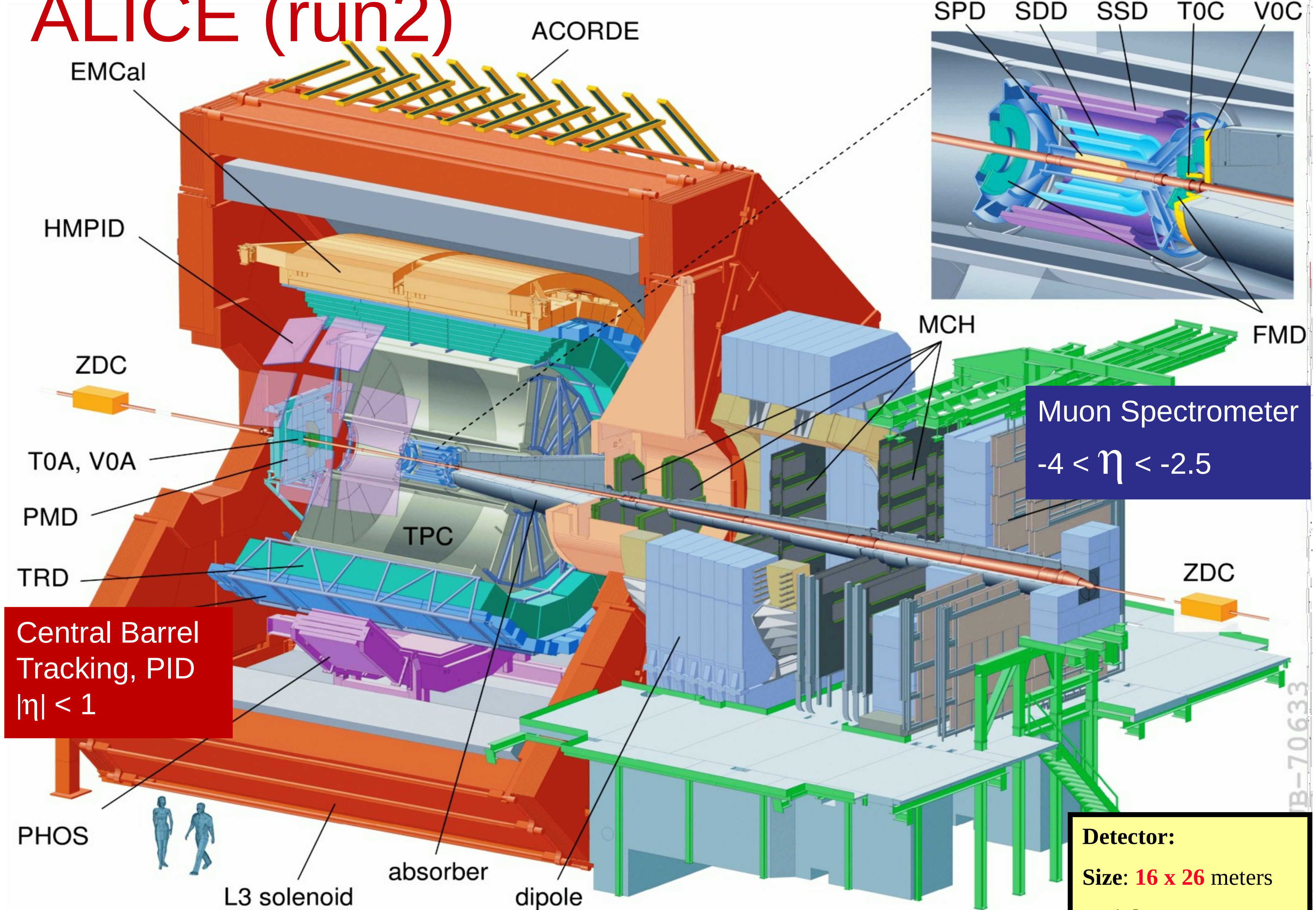
Sign of collectivity?

Pb-Pb: high-mult from superposition of parton interactions, collective flow

→ moderate increase of $<p_T>$



ALICE (run2)



Central Barrel
Tracking, PID
$|\eta| < 1$

Muon Spectrometer
$-4 < \eta < -2.5$

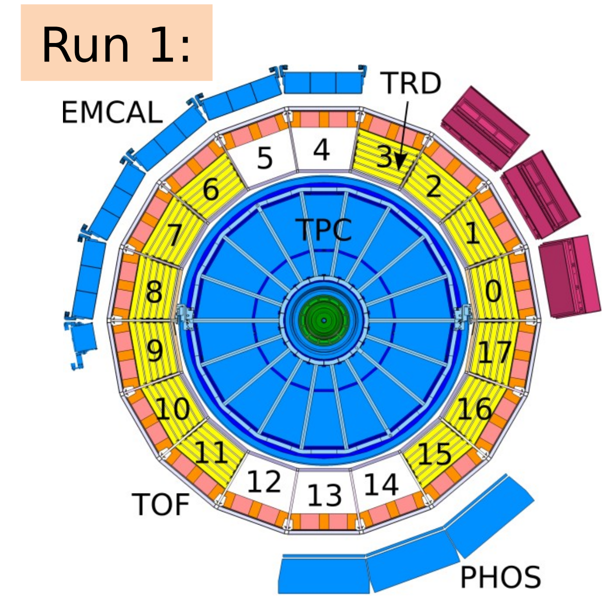
Detector:

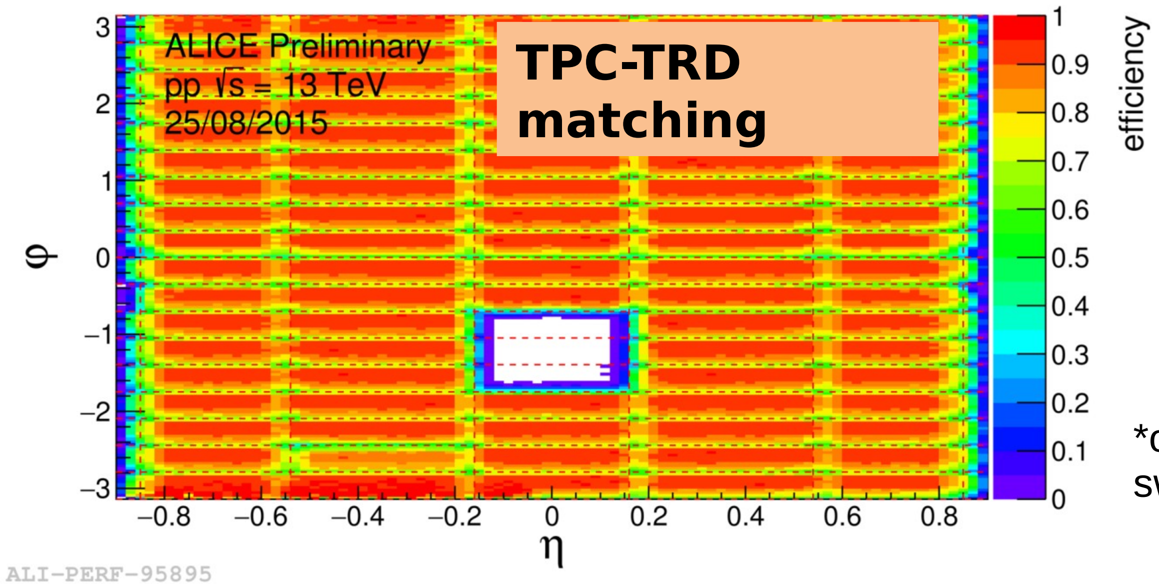
Size: 16 x 26 meters

Weight: 10,000 tons

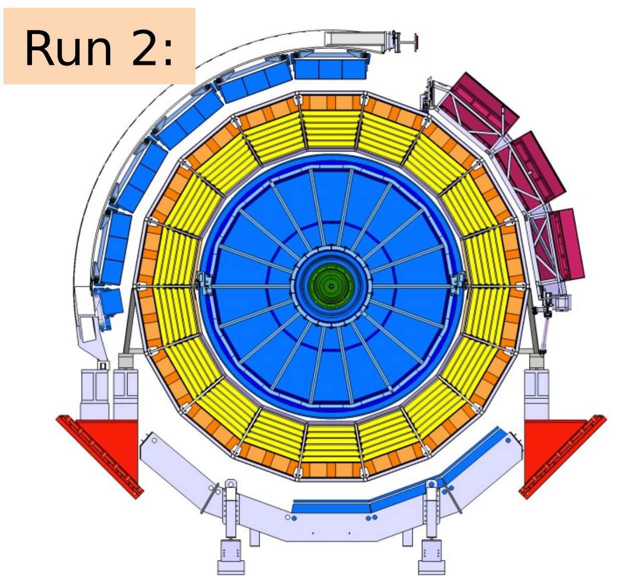
TRD installation & upgrade

- Construction and installation of full TRD completed
- Full central barrel acceptance
  - Improved p_T resolution for global tracks ($4 \rightarrow 2\%$ at 50 GeV/c)
  - Uniform electron and hadron identification
- Read-out upgrade (2.125 Gbit/s → 4 Gbit/s)
- Trigger upgrade





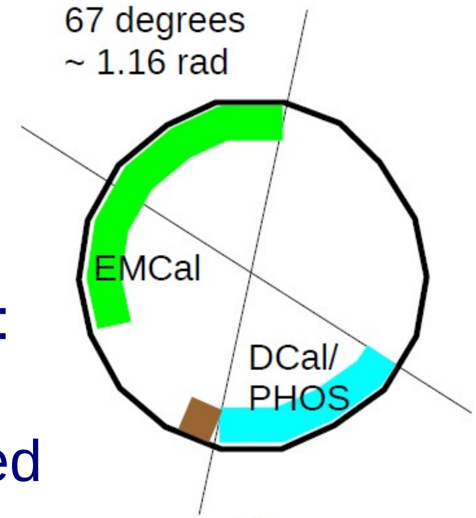
*one TPC sector switched-off



Electromagnetic Calorimeters

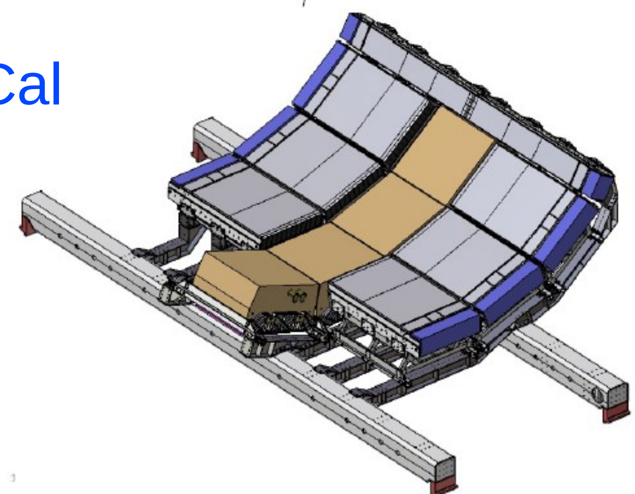
Run1:

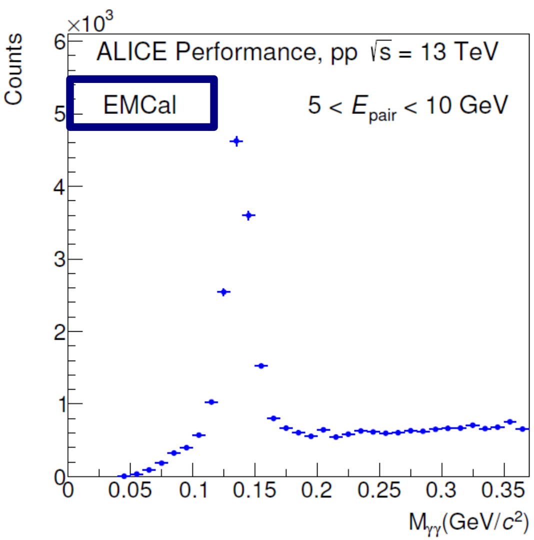
- PHOS: lead-tungstate, $|\eta| < 0.13$, $260 < \phi < 320$
- EMCal: lead-scintillator, $|\eta| < 0.7$, $80 < \phi < 187$

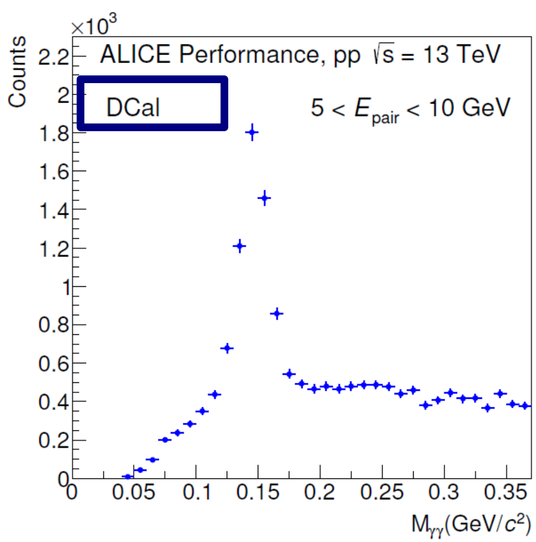


Run2:

- **DCal** calorimeter installed back-to-back to existing EMCal: $0.22 < |\eta| < 0.7$, $260 < \phi < 320$ & $|\eta| < 0.7$, $320 < \phi < 327$
- 4th PHOS module + charged particle veto detector installed
- Readout upgrade (100kHz readout foreseen in run3)
  - New trigger system allowing EMCAL, PHOS and DCal act as a single trigger detector

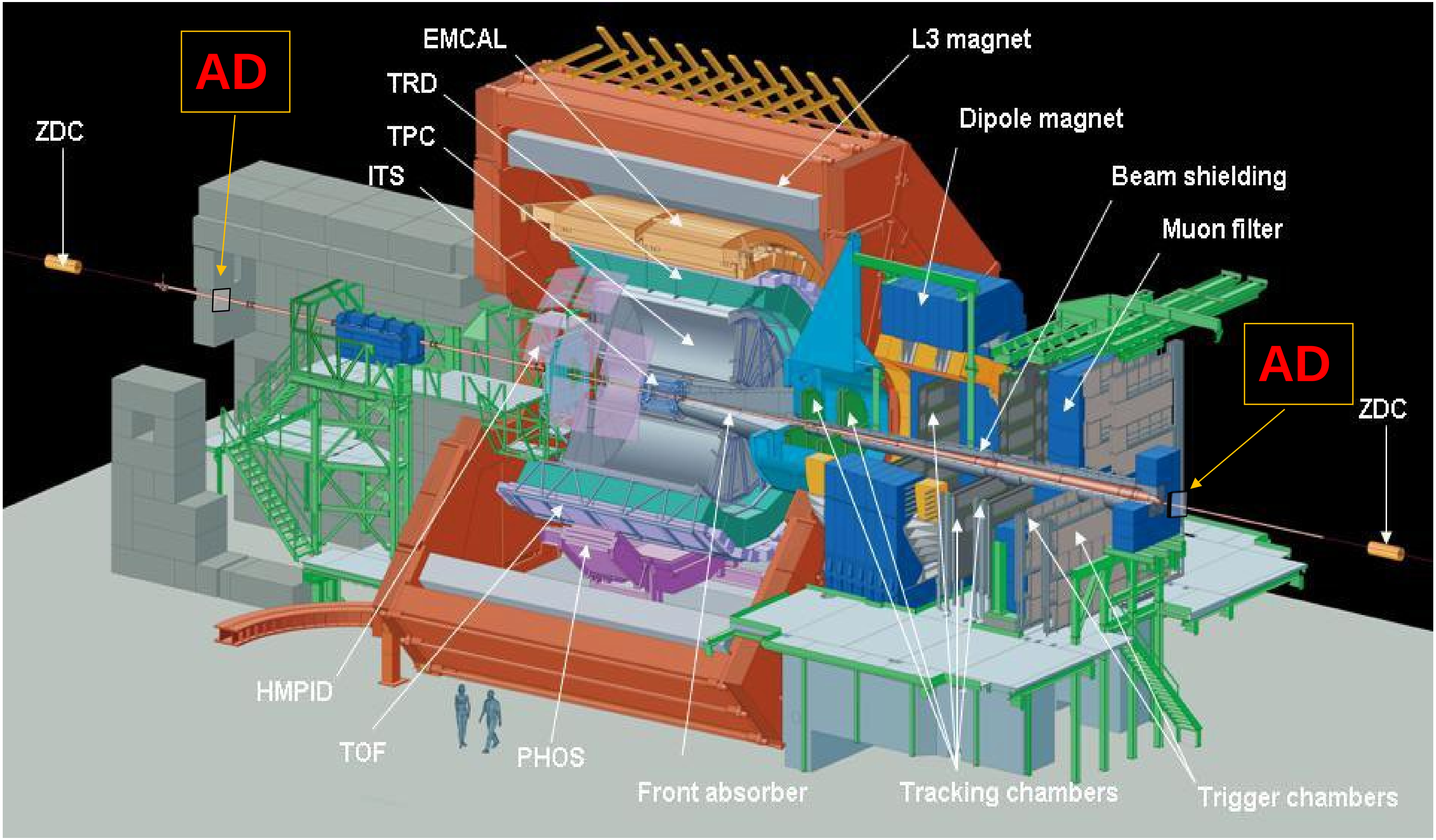






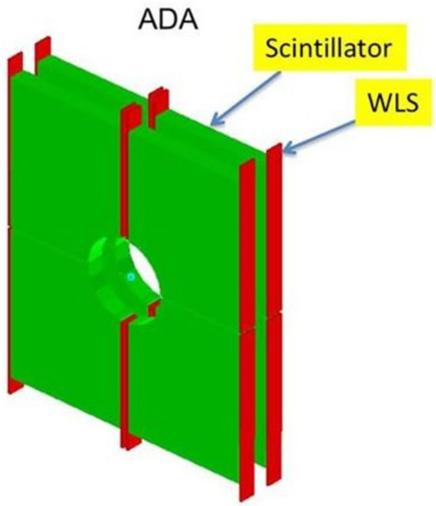
Invariant mass distribution of $\gamma\gamma$ pairs in the range $5 < E_{pair} < 10$ GeV

Alice Diffractive Detectors

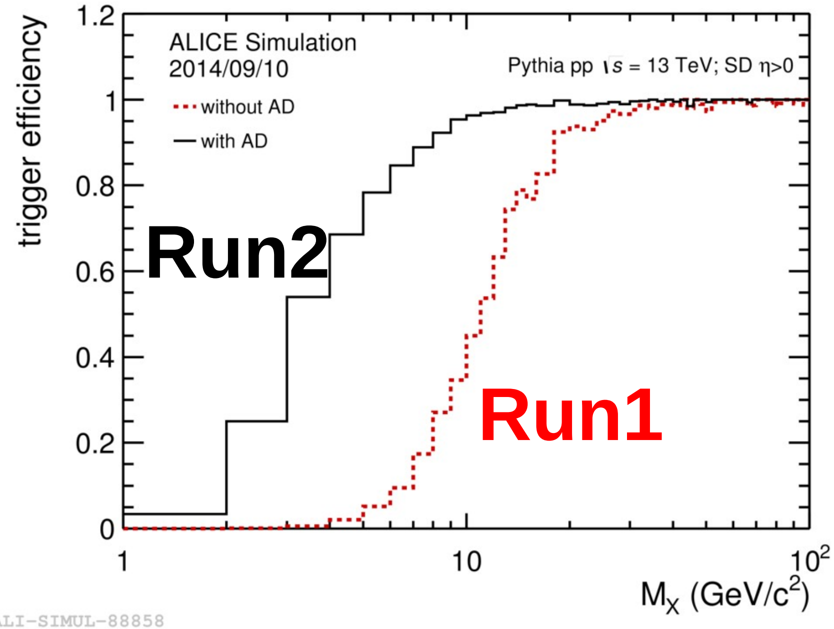


ALICE Diffractive Detectors

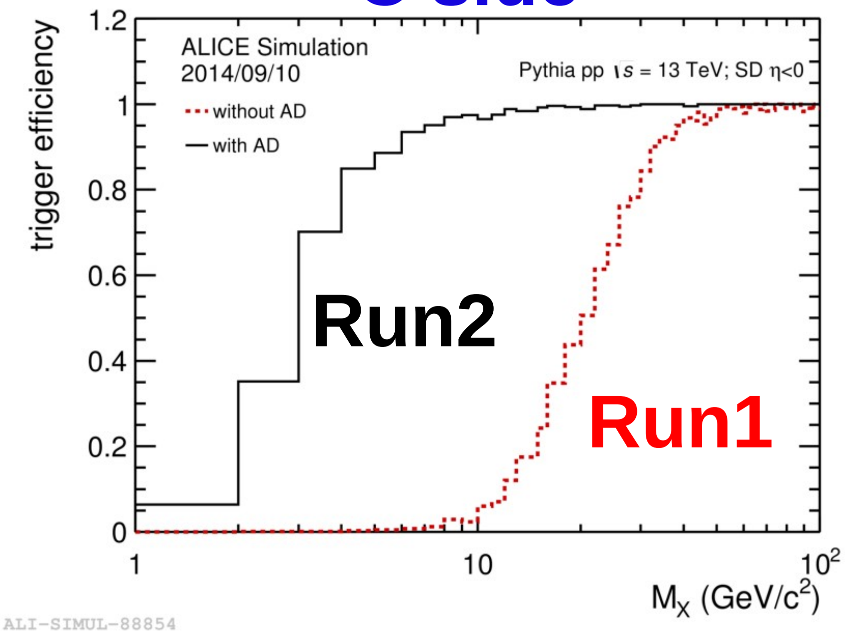
- Double layers of scintillator counters
  - ADA: z = 17.0 m, $4.9 < \eta < 6.3$
  - ADC: z= −19.5 m, $-7.0 < \eta < -4.8$
- Increase pseudorapidity coverage from 8.8 to 13.2 units
- Enhance trigger efficiency at low diffractive masses



A side

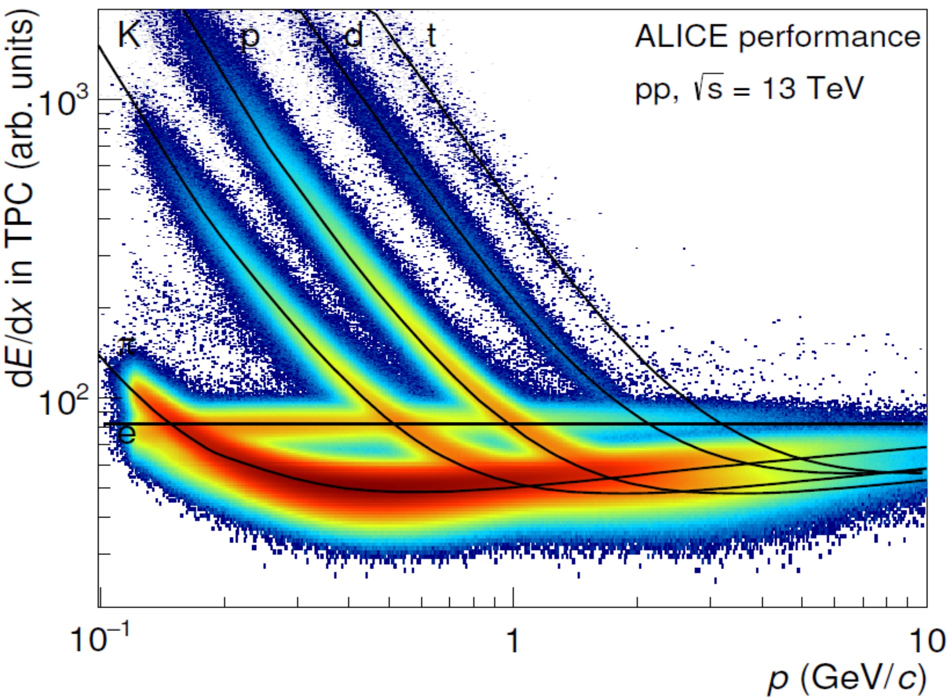


C side



TPC and dE/dx performance

- Gas mixture in TPC
changed from Ne–CO_2 (90:10) to Ar–CO_2 (88:12)
  - ensure a more stable response for the high particle flux generated during p-Pb and Pb-Pb running
  - no degradation of momentum and dE/dx resolution

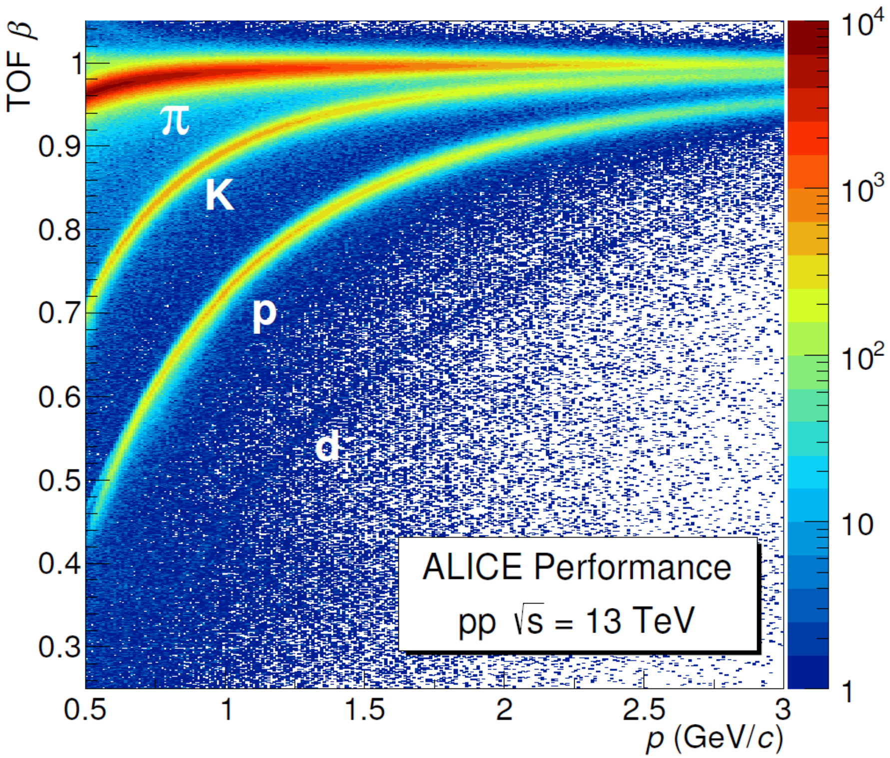


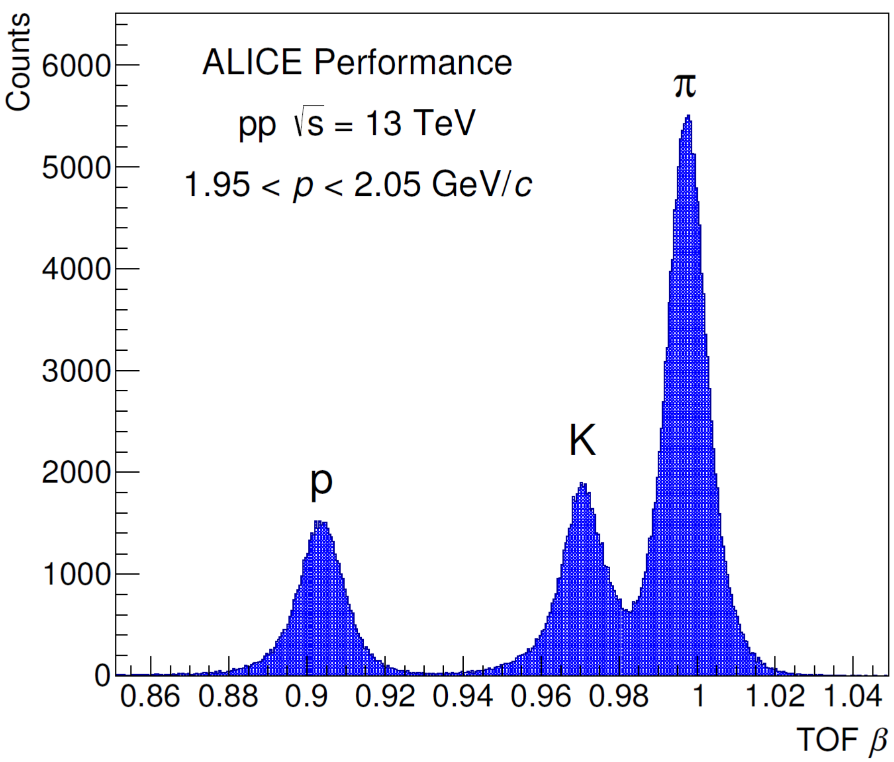
Specific energy loss dE/dx versus particle momentum in the TPC
Lines → parameterization of expected mean energy loss

Clear separation:
Below 1 GeV/c: PID on track-by-track basis
Above 1 GeV/c: statistical PID via multi-Gaussian fits

ALICE-PUBLIC-2015-004

TOF performance



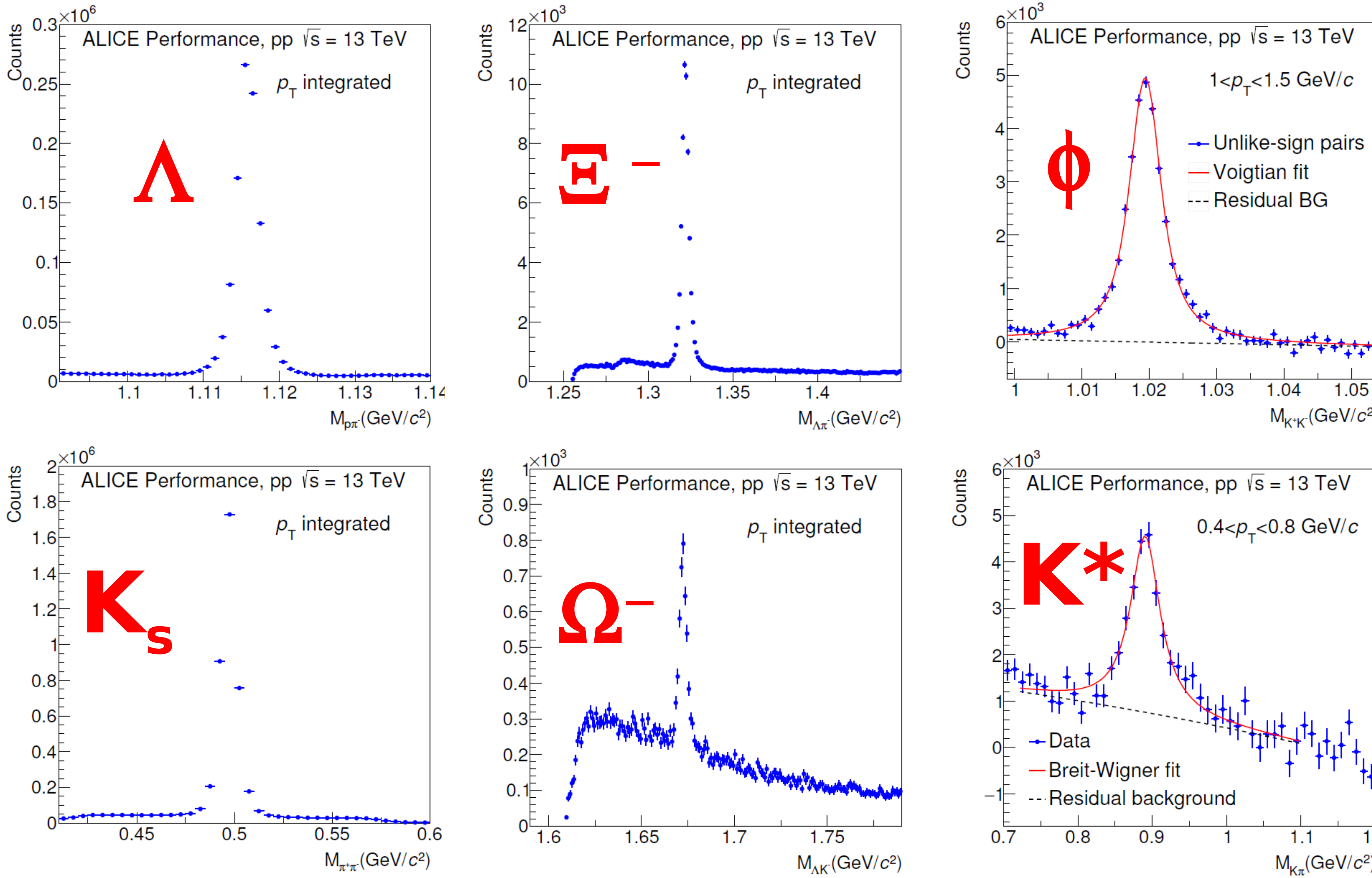


TOF β distribution versus momentum measured by TPC

TOF β distribution for 1.95 < p < 2.05 GeV/c

ALICE-PUBLIC-2015-004

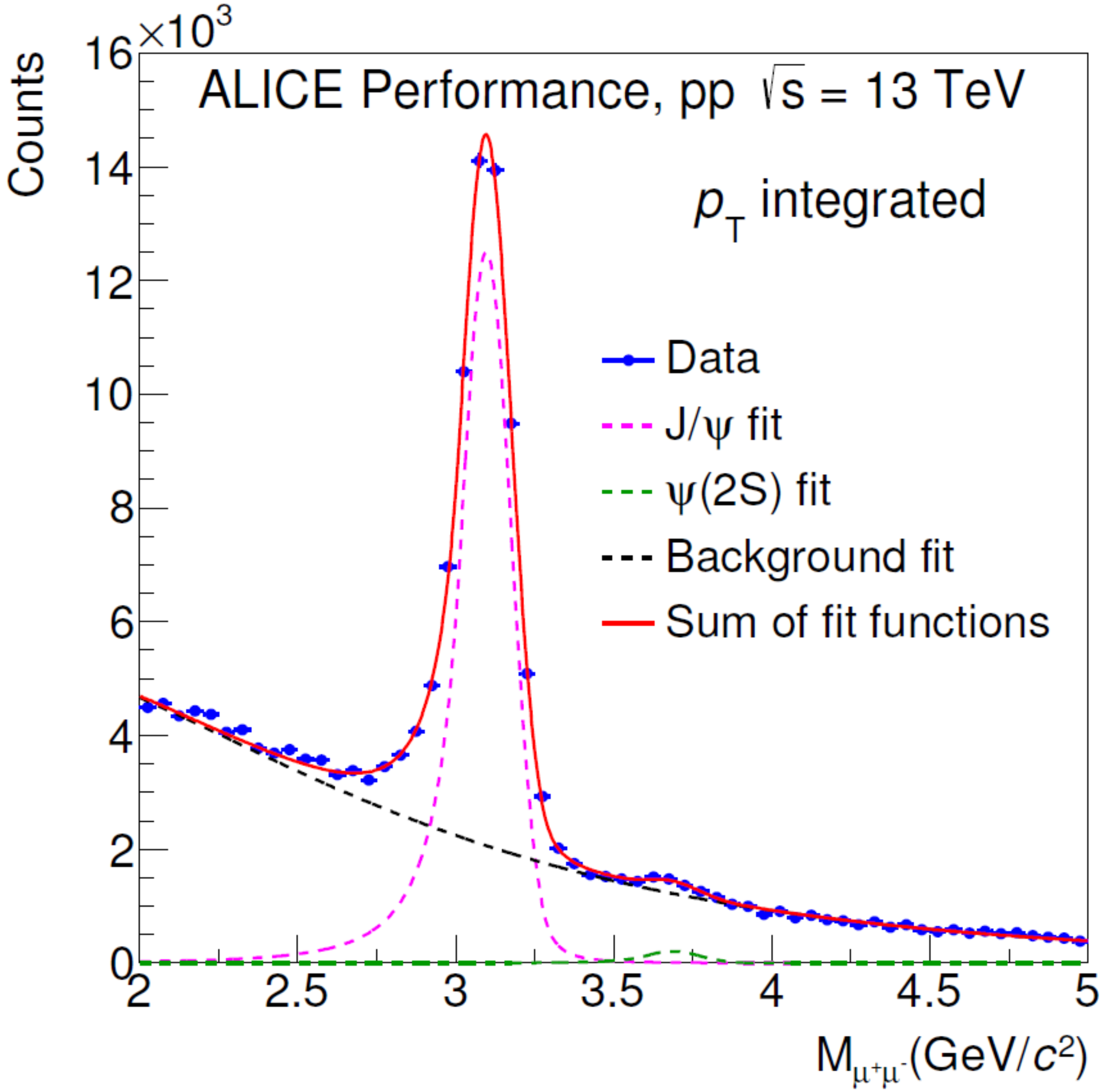
Performance for strangeness



PID + reconstruction of secondary vertices from particle decays

ALICE-PUBLIC-2015-004

...and charm



Dimuon invariant mass distribution reconstructed in the muon spectrometer, p_T-integrated

J/ψ and ψ(2S) → Crystal Ball functions

Background → variable width gaussian

ALICE-PUBLIC-2015-004

First Results from RUN-2

- **Pseudorapidity and Transverse momentum distributions of primary charged particles**
  → prompt particles produced in the collisions, including all decay products, with the exception of those from weak decays of strange particles.
- **Run Conditions**:
  - One run after the startup in June 2015.
  - Beams of 39 bunches with about 8×10^{9} protons per bunch
  - ALICE interaction region: 15 pairs of bunches
    → luminosity $5 \times 10^{27} cm^{-2} s^{-1}$ (rate ~ 350 Hz for inelastic pp collisions)
  - Pile up probability: 10^{-3} (μ=0.002)
  - Luminous region: RMS 5 cm (z), 85 μm (transverse)
  - Contamination from background events: 10^{-4}
    removed offline with timing cuts on V0 and AD
    estimated with control triggers

Data Analysis & Event Selection

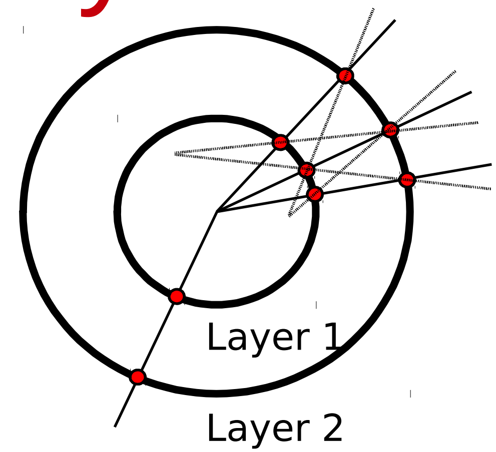
- About 1.5 M events pass the minimum-bias (MB) selection criteria.
- Events must have a valid reconstructed vertex in $|z|< 10$ cm.
- The measurements reported have been obtained for events
  - INEL: all inelastic events
  - INEL>0: having at least one charged particle in $|\eta|<1$
- Minimum bias trigger: V0 or AD
  - V0: $-3.7 < \eta < -1.7$, $2.8 < \eta < 5.1$
  - AD: $-7.0 < \eta < -4.8$, $4.9 < \eta < 6.3$

→ About 96.6% of INEL cross section

Pseudorapidity Density Analysis

- Measure multiplicity of tracklets in SPD:
  - SPD layer 1: R = 3.9 cm,|η| < 2.0
  - SPD layer 2: R = 7.6 cm,|η| < 1.4
  - Reconstructed primary vertex

  → charged particles with p_T > 50 MeV/c (cut-off: particle absorption in material)



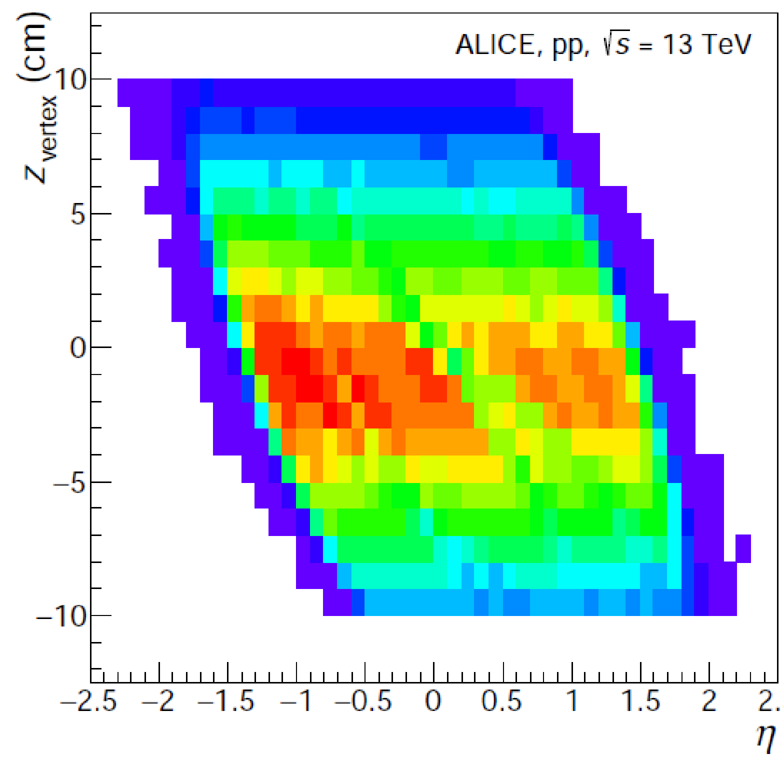
- $dN_{ch}/d\eta = \alpha(1-\beta)dN_{tracklets}/d\eta$

  α → acceptance and efficiency for primary

  β → contamination from combination of hits not from the same primary

- Corrections: from Monte Carlo PYTHIA 6 (Perugia-2011) + GEANT3

Reconstructed tracklets: z(vertex) vs η (tracklet)



Transverse Momentum Analysis

- **Track Selection**
  - Tracks reconstruction: combined info from TPC and ITS
  - Track quality: # of Space-points and Quality of the track fit
  - High-purity selection of primary charged particles is achieved with a p_T-dependent cut on the distance of closest approach in the transverse plane between the track and the primary vertex.

  → **charged particles with $|\eta|<0.8$ and $p_T > 0.15$ GeV/c**

- **Corrections**
  - from Monte Carlo PYTHIA 6 (Perugia-2011) +GEANT3
  - Acceptance x tracking efficiency: 35%-75% (0.15-20 GeV/c): arises from tracks which cross TPC sector boundaries.
  - PID-dependent correction (acceptance x tracking efficiency) factors rescaled using the measured particle fractions
  - Residual contamination from secondary particles determined from Monte Carlo (7 → 1%) subtracted from the spectrum

Systematic Uncertainties

	$dN_{ch}/d\eta$		dN_{ch}/dp_T	
	INEL	INEL>0	0.15	20 GeV/c
Background events and pileup	negligible		negligible	
Normalisation	2.8	2.3	2.3	
Detector acceptance and efficiency	1.5		1.8	5.6
Material budget	0.1		1.5	0.2
Track(let) selection criteria	negligible		1.5	3.0
Particle composition	0.2		0.3	2.4
Weak decays of strange hadrons	0.5		3.4	0.4
Zero-p_T extrapolation	1.0		not applicable	
Total (η, p_T dependent)	1.9		4.4	6.8
Total	3.4	3.0	5.0	7.2

Limited knowledge of cross-section and kinematics of diffractive processes
→ previous experimental data at lower energy and Monte Carlo:

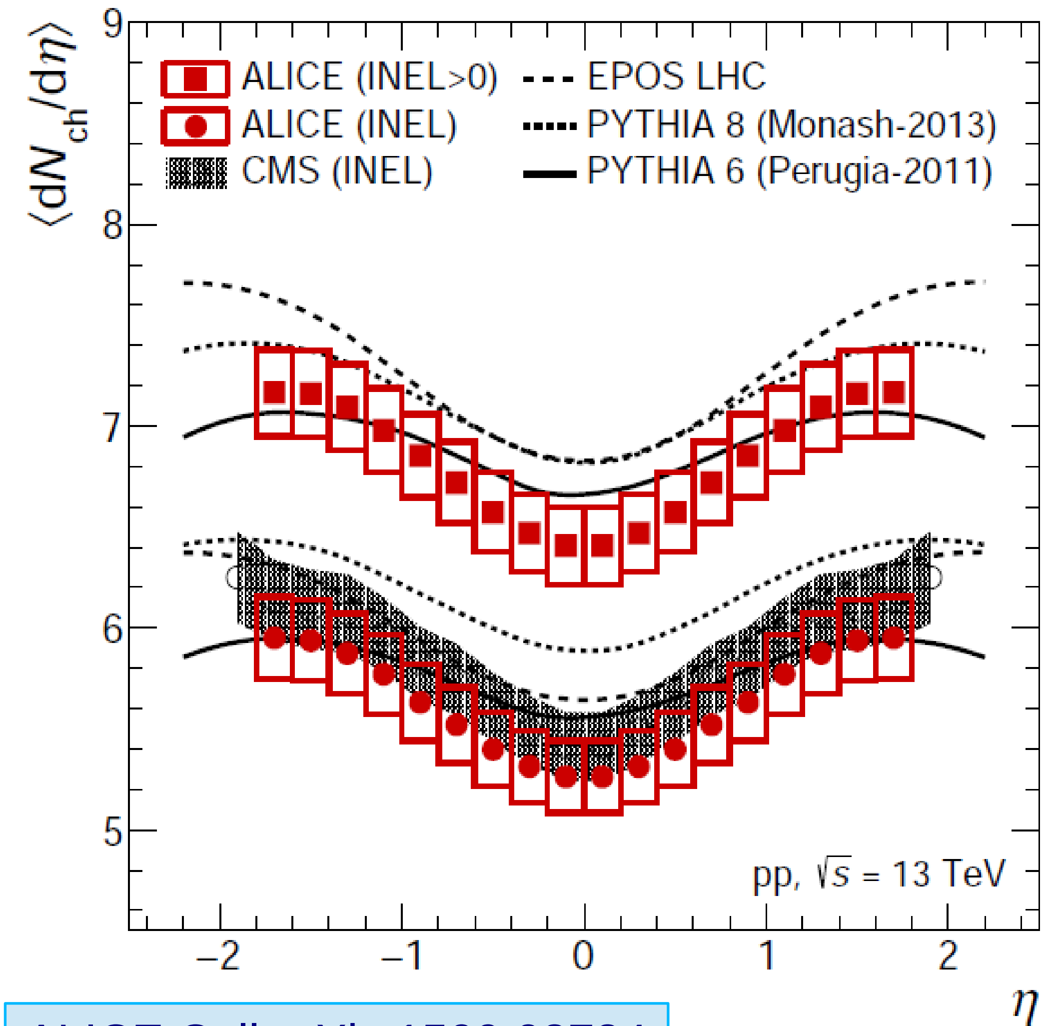
- SD and DD ±50%
- PYTHIA 8 (Monash 2013)
- Vary offline event selection

ALICE Coll arXiv:1509.08734

Results

Pseudorapidity density

- Minimum bias trigger: V0 or AD
  → 96.6% of INEL cross section



ALICE Coll arXiv:1509.08734
CMS Coll arXiv:1507.05915

$dN_{ch}/d\eta$ measured for two normalisation classes:
INEL: inelastic events
INEL>0: events having at least one charged particle in |η|<1

	INEL	INEL>0
ALICE	5.31±0.18	6.46±0.19
CMS	5.49±0.17	

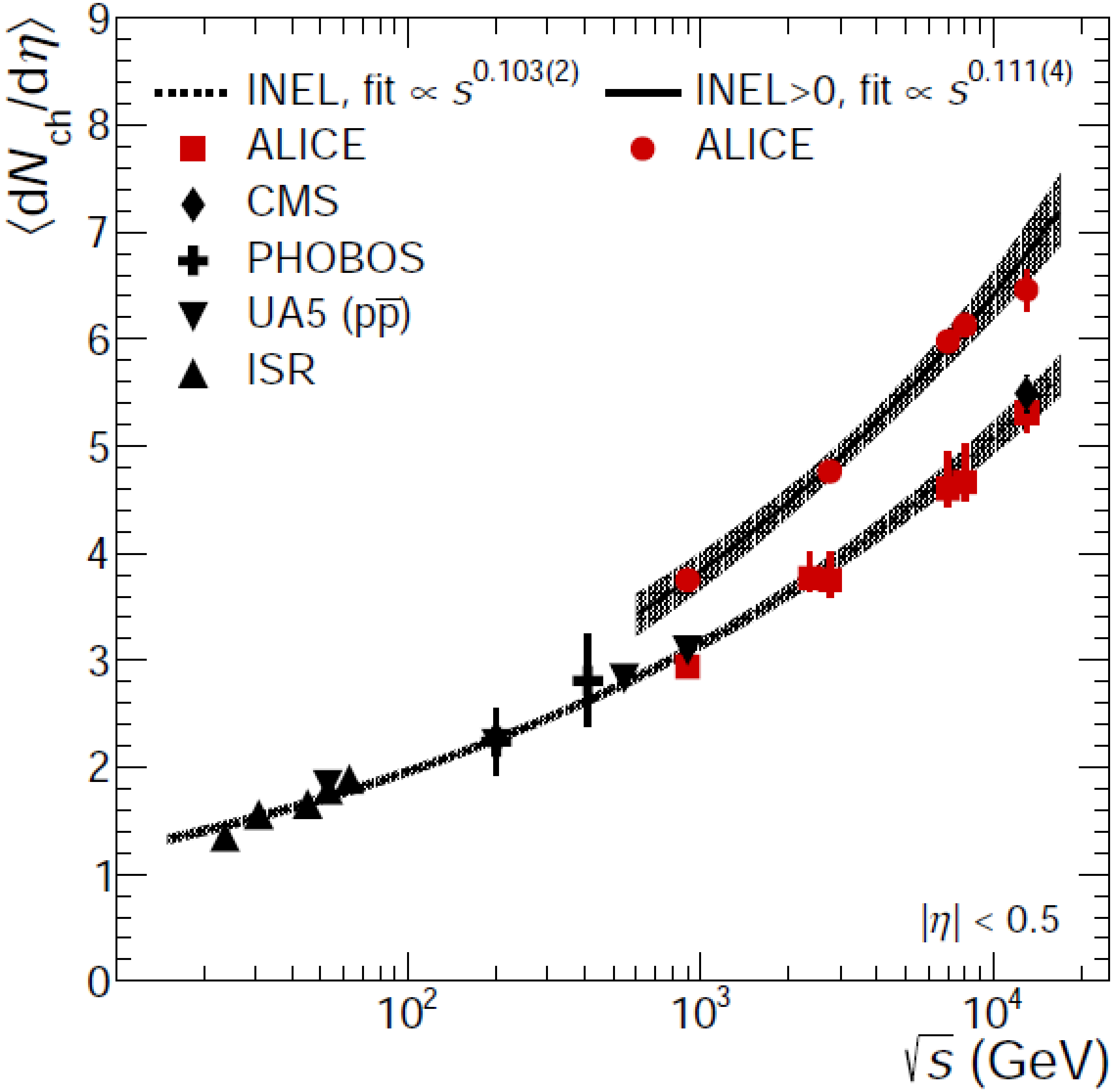
	INEL		INEL>0	
	η~0	η~1.5	η~0	η~1.5
PYTHIA6	+6%	0%	+3%	0%
PYTHIA8	+12%	+7%	+7%	+2%
EPOS-LHC	+7%	+4%	+7%	+5%

Fair agreement with Monte Carlo

Pseudorapidity density vs energy

- INEL: dN/dη in |η|<0.5
- INEL>0: dN/dη in |η|<1.0

- Energy dependence fitted with power-law function as^b:
- INEL: b = 0.103(2)
- INEL>0: b = 0.111(4)



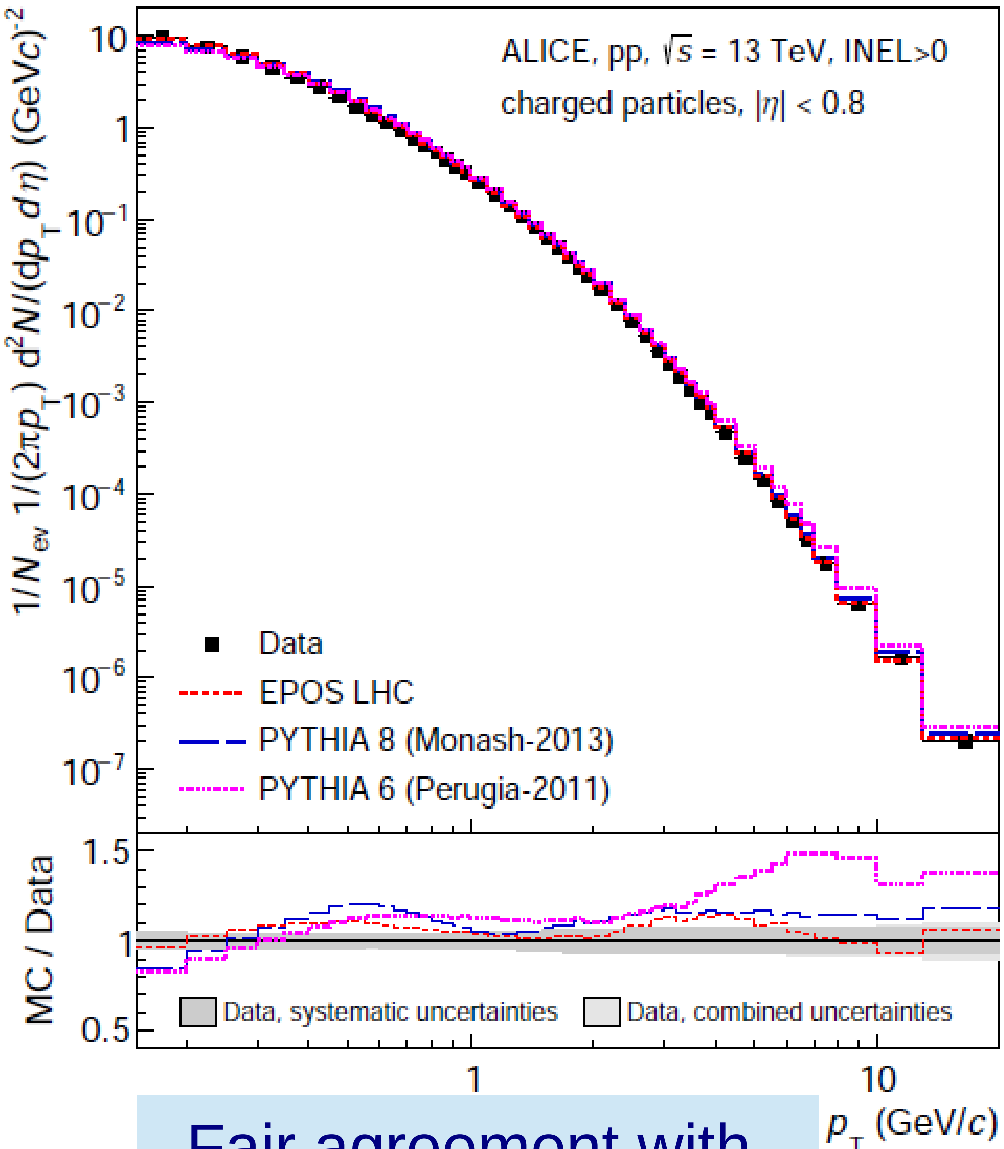
Fair agreement with the expectations from low energy extrapolations

ALICE Coll arXiv:1509.08734
CMS Coll arXiv:1507.05915

Transverse momentum spectra

- p_T distribution measured in $0.15 < p_T < 20$ GeV/c and $|\eta|<0.8$
- Comparison with Monte Carlo
  - EPOS LHC
    → collective (flow-like) effects
  - PYTHIA 8 (Monash-2013)
    PYTHIA 6 (Perugia 2011)
    → color reconnection
- The general features seen in the data are reproduced well by the models.
- Not all details
  - PYTHIA8 and EPOS: discrepancies up to 20%
  - PYTHIA 6 overestimates high p_T yield

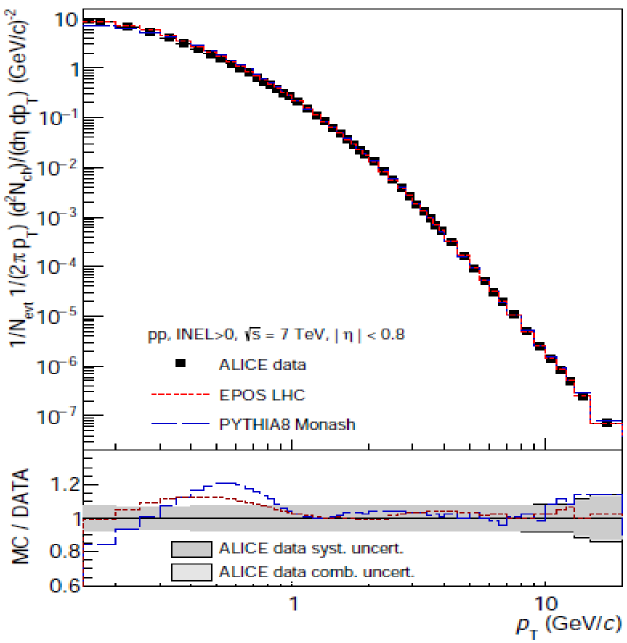
ALICE Coll arXiv:1509.08734



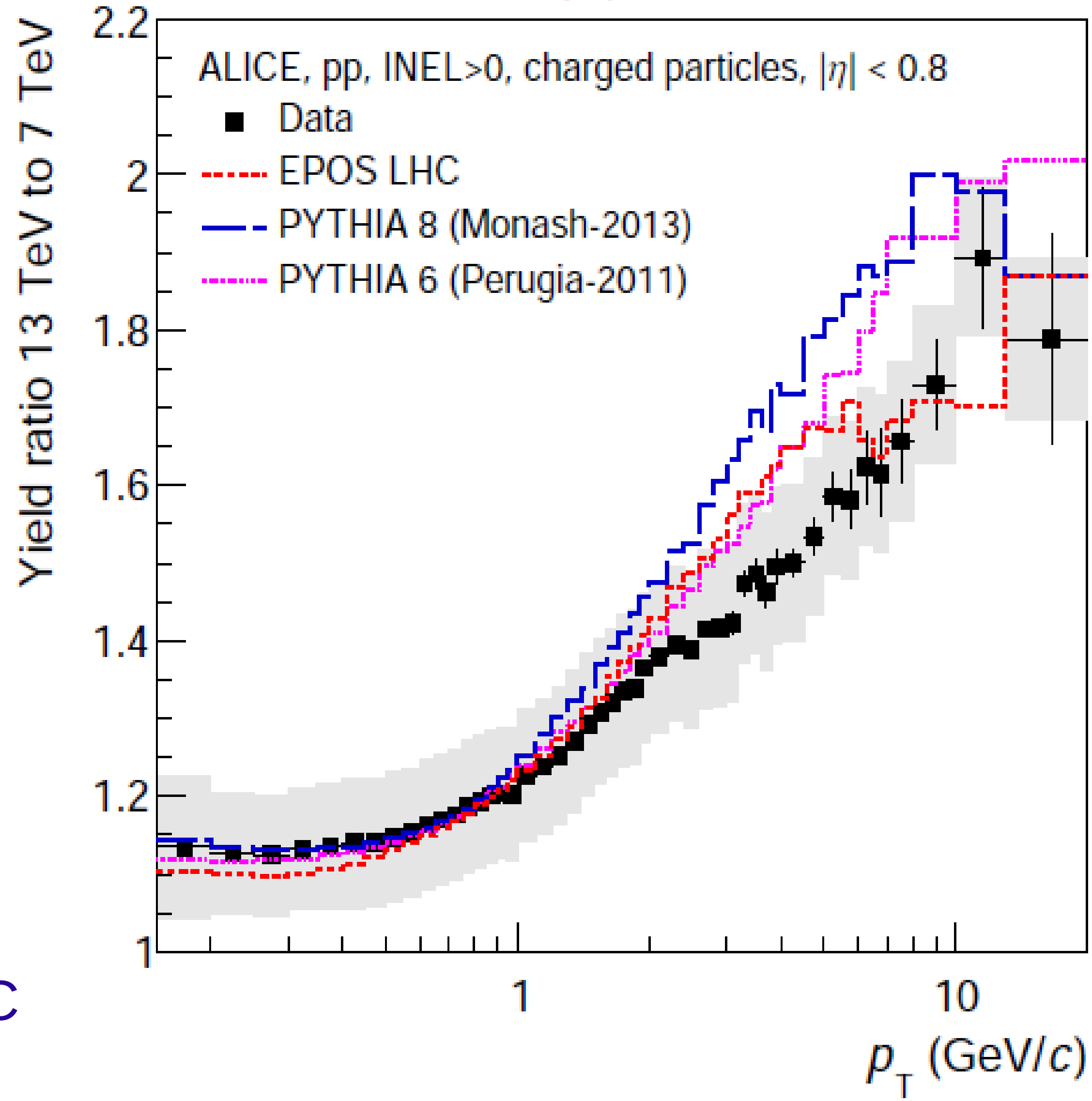
Fair agreement with Monte Carlo

Evolution with energy

- pp @ 7 TeV
  renormalized to INEL>0



- p_T spectrum harder at 13 TeV than at 7 TeV.
- Pythia 6, Pythia8 and EPOS LHC reproduce the trend in the data but exhibit a more pronounced hardening with energy than data in the region of a few GeV/c.



ALICE Coll Eur. Phys. J. C (2013) 73-2662
ALICE Coll arXiv:1509.08734

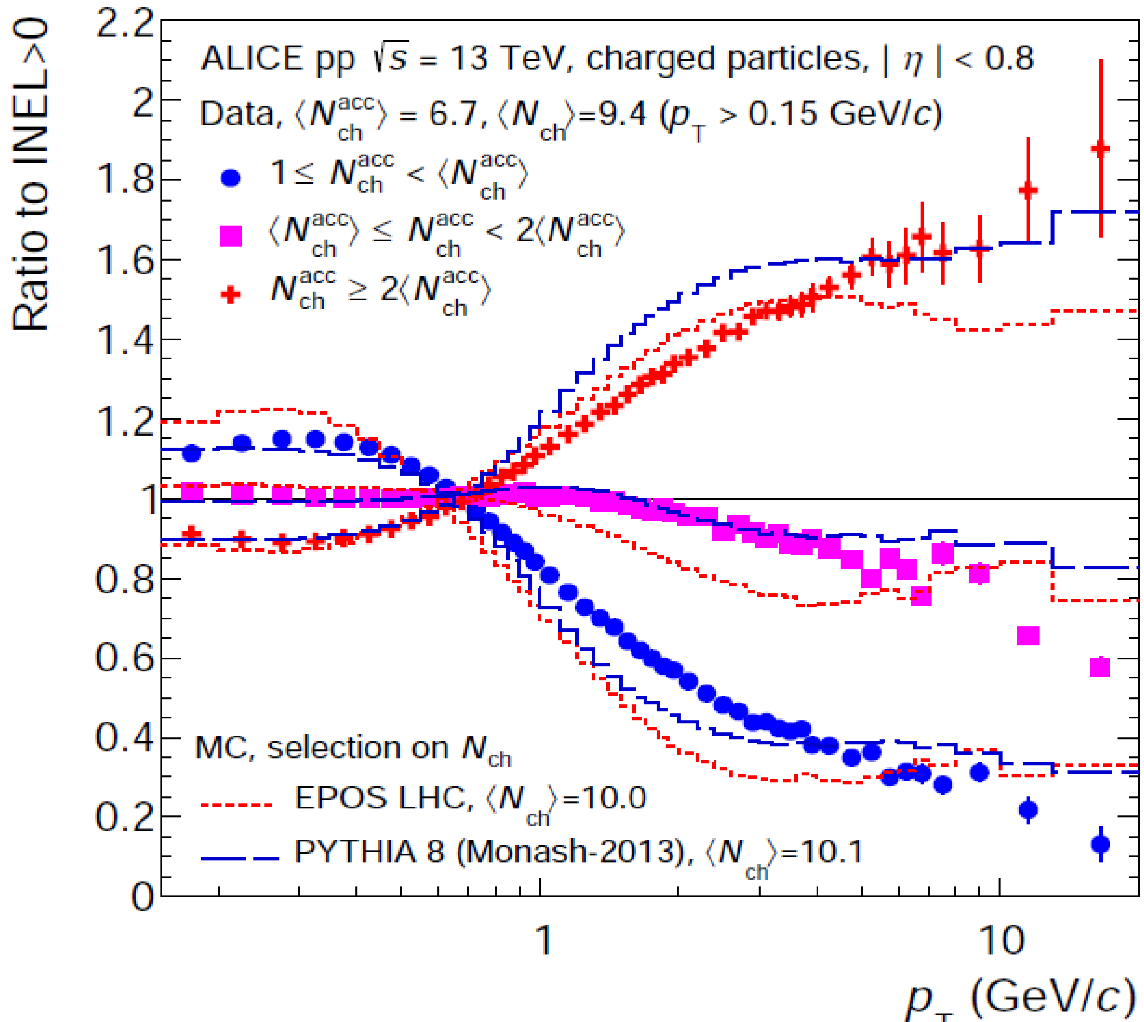
Spectra in multiplicity bins

Bins selected by multiplicity measured in the same kinematic region as the spectrum ($|\eta| < 0.8$, $0.15 < p_T < 20$ GeV/c)

MC: true value of $\mathbf{N_{ch}}$

data: measured track multiplicity $\mathbf{N_{ch}^{acc}}$

	N_{ch}^{acc}	N_{ch}
data	6.73	9.41
PYTHIA8	-	10.13
EPOS-LHC	-	9.97



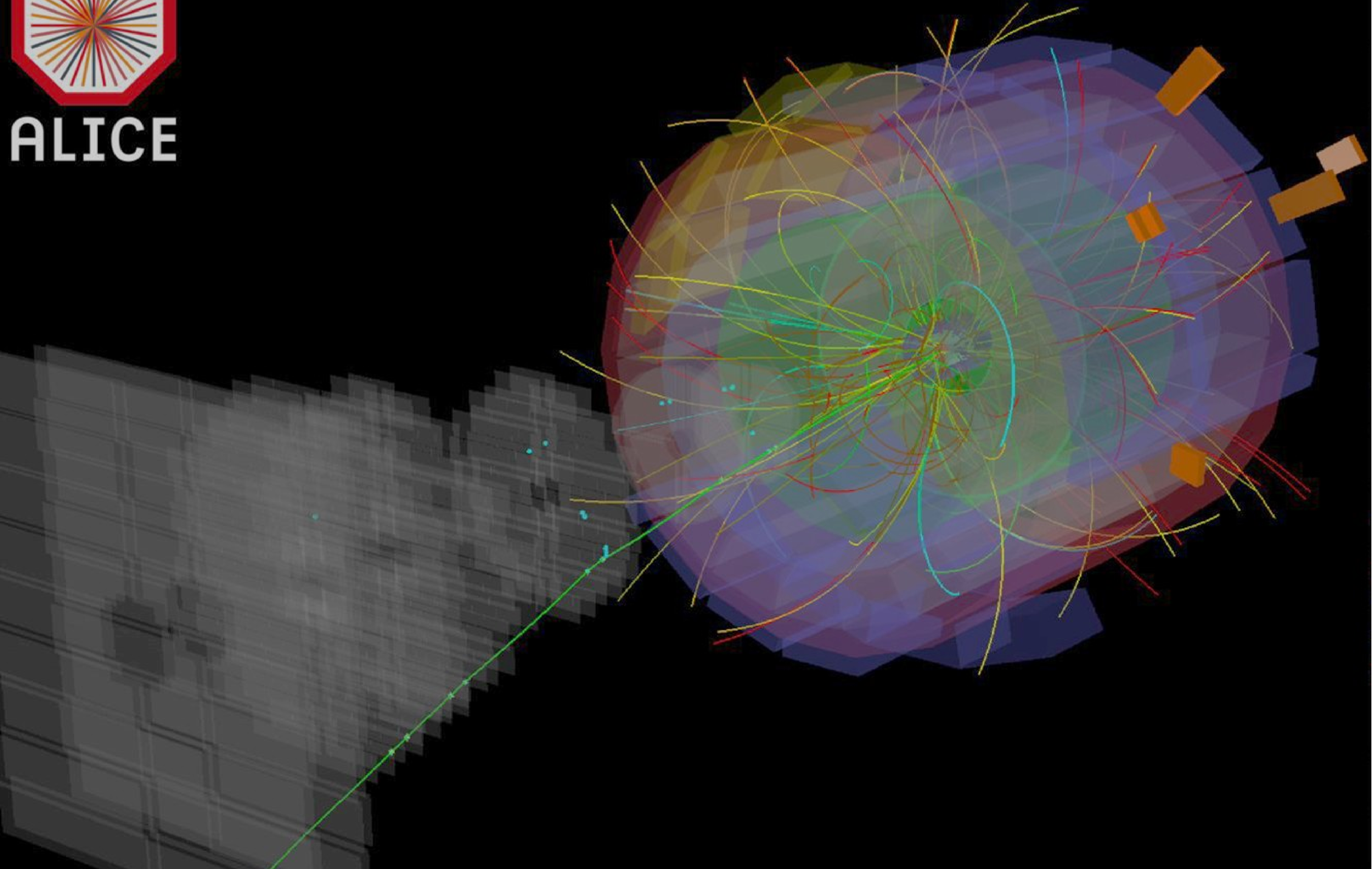
- The correlation of the spectrum with multiplicity is prominent for the whole p_T range and in particular it is stronger at high p_T, then it saturates
- The general features seen in the data are reproduced by the models, but not in all details

ALICE Coll arXiv:1509.08734

Conclusions

- Measurement of the **pseudorapidity** and **tranverse-momentum** distribution of charged particles produced in proton-proton collisions at $\sqrt{s}$ = 13 TeV.
  - N_{ch} in $|\eta| < 0.5$: 5.31 ± 0.16 (INEL) and 6.46 ± 0.18 (INEL>0)
  - p_T measured in $|\eta|<0.8$ and $0.15 < p_T < 20$ GeV/c
- Spectrum significantly harder than at $\sqrt{s}$ = 7 TeV
- Shapes depend strongly on multiplicity (same kinematic region)
  - correlation of the spectrum with multiplicity is prominent for all p_T (stronger at high p_T) influenced by hard parton production, which, through fragmentation (leading to jets), contributes to charged-particle multiplicity and this contribution is increasing with the parton energy.
- **Fair agreement**
  - with expectations from **lower energy extrapolations**
  - with **Monte Carlo**: PYTHIA6, PYTHIA8, EPOS-LHC

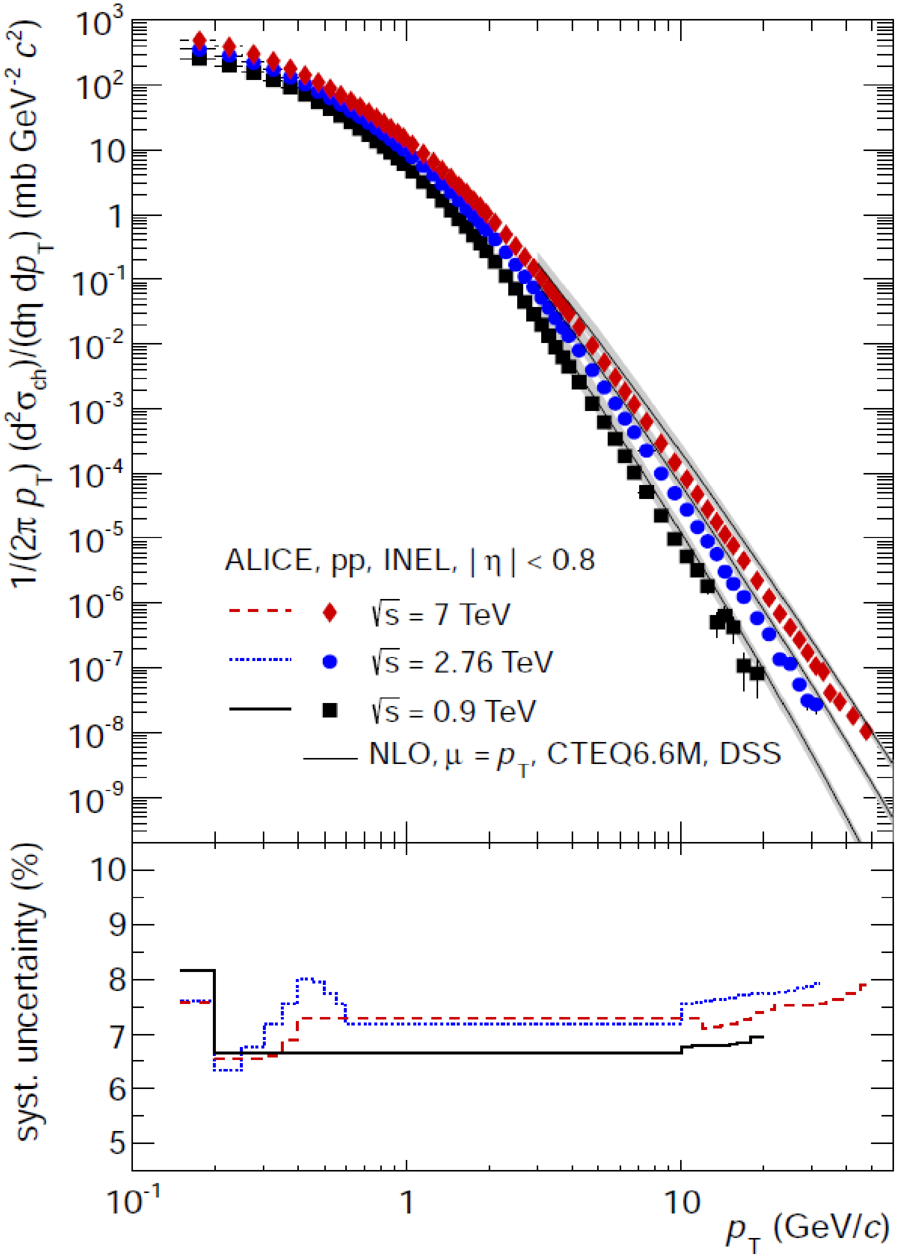
ALICE



Night wraps the sky in tribute from the stars.
(Vladimir Mayakovsky, 1930)

Extra

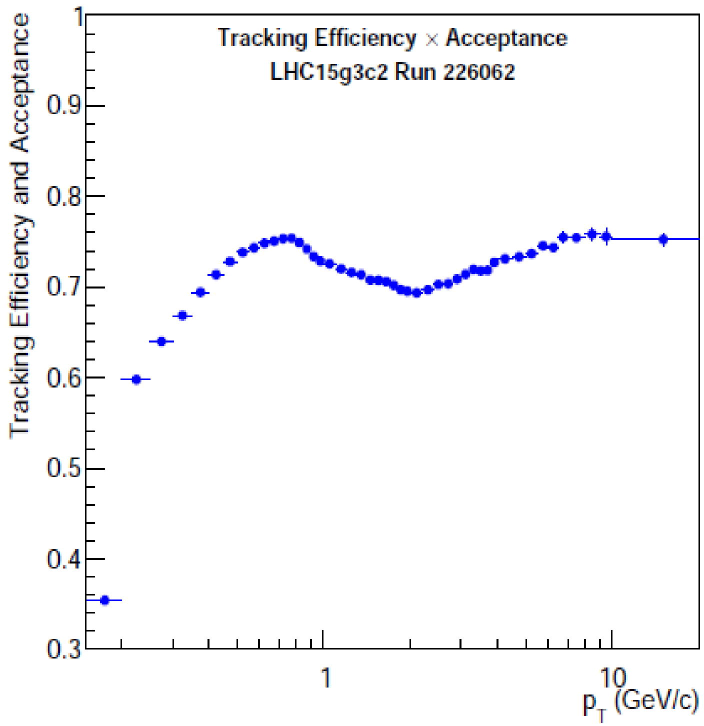
pT-spectrum at lower energy



ALICE Coll Eur. Phys. J. C (2013) 73-2662

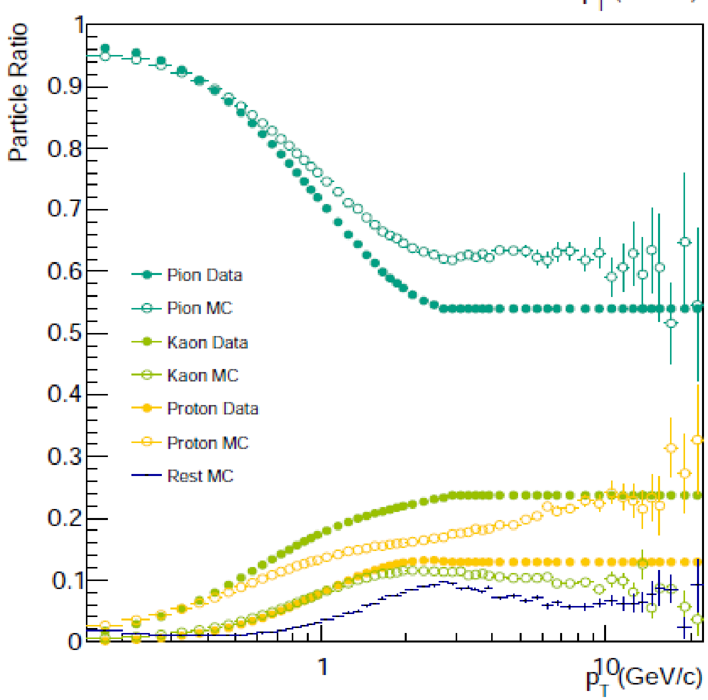
Corrections

Figs?
Performance?



Corrections: from Monte Carlo
PYTHIA 6 (Perugia-2011) +GEANT3
shape with the dip at p_T ~ 2 GeV/c arises
from tracks which cross the TPC sector boundaries.

The correction for reconstruction (in)efficiency is based on MC with correction factors rescaled using the measured particle fractions



Longed-lived strange hadron rejection based on the data driven method (DCArphi fits).
Residual contamination from secondary particles determined from Monte Carlo (7 → 1%)
→ subtracted from the spectrum