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On behalf of the ALICE Collaboration

EPS-HEP 2013

Stockholm, 18-24 July 2013

CHARGED PARTICLE MULTIPLICITY AND PSEUDORAPIDITY DENSITY IN pp COLLISIONS WITH ALICE AT THE LHC

Analysis carried out within the Minimum Bias and Underlying Event LHC Working Group

INEL>0 class - Definition

- INEL>0 class of events used…
  - Selecting the events with at least one charged particle in $|\eta| < 0.8$ and $p_T > p_{T,\,cut}$
- …where the charged multiplicity distribution from primary particles (excluding weak decays from strange particles) is determined by the number of charged primary particles in the same η and p_T range
  - Tracks in $|\eta| < 0.8$ and $p_T > p_{T,\,cut}$
- Same analysis carried out by ATLAS and CMS
- $p_{T,\,cut}$ set at 0.5, 1. GeV, for the results in common among the experiments
- In addition, $p_{T,cut}$ at 0.15 GeV considered, as this is ALICE intrinsic $p_{T,cutoff}$
- From this selection, $dN_{ch}/d\eta$ and multiplicity distributions were obtained

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Details on the ALICE detector in the backup

Multiplicity Analysis – Response Matrix

- Unfolding technique used (see [EPJ C68 (2010) 89]) to determine the true multiplicity starting from the measured one (χ^2 minimization with regularization)
  - To take into account detector resolution effects
  - Response Matrix (R) represents the probability that a collision with true multiplicity "t" is measured as an event with multiplicity "m"

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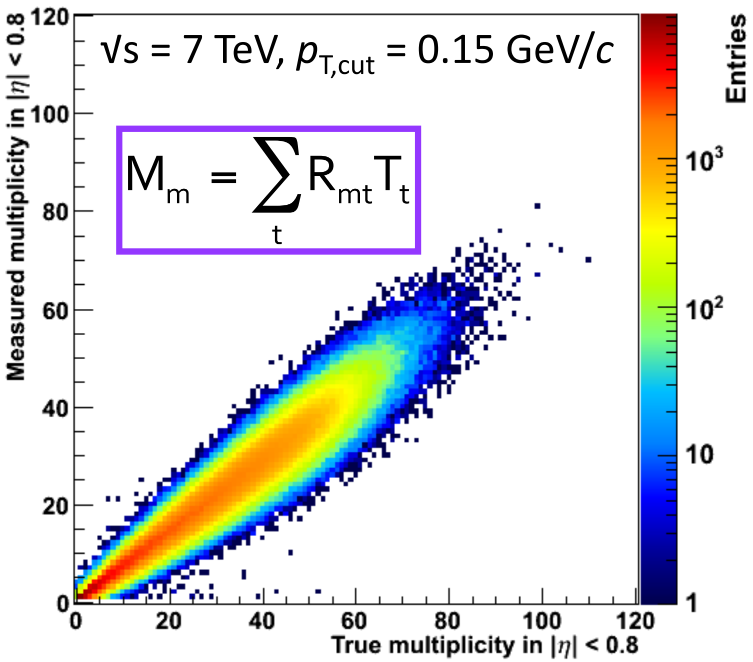


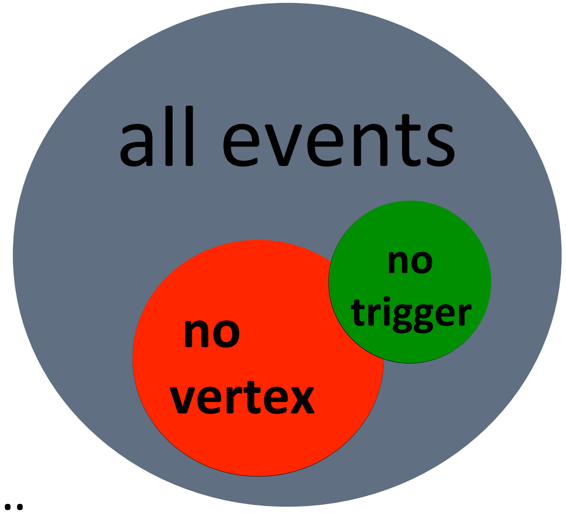
- In order to reduce the effects of low statistics, and to extend the response matrix to higher multiplicity, a parameterization of the response matrix was obtained and used at higher multiplicities
- Event selection efficiency taken into account in unfolded (true) multiplicity

$dN_{ch}/d\eta$ Analysis – Corrections

- Following the same method used for the previous ALICE $dN_{ch}/d\eta$ measurements
- Basically: $\frac{dN_{ch}}{d\eta} = \frac{\text{Tracks}}{\text{Events}}$
  to which the following corrections have to be applied:
  1. Track-to-particle correction
     - Track level
  2. Vertex reconstruction correction
     - Track and event level
  3. Event selection (or Trigger bias) correction
     - Track and event level

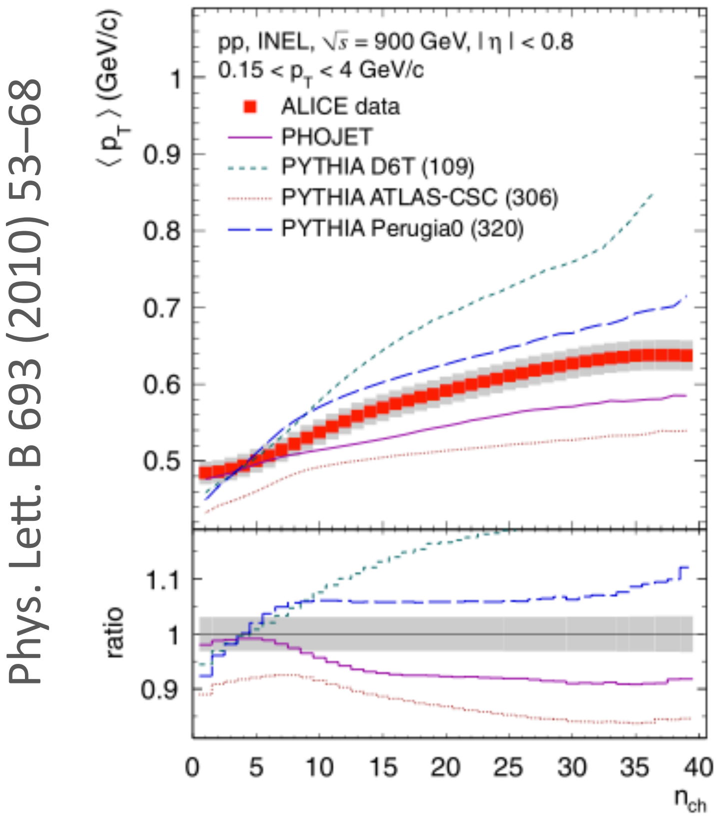
  to take into account detector effects, resolution, decays, event selection efficiency…
- The difference in strangeness content between data and Monte Carlo was taken into account in the correction procedure (as for the Multiplicity analysis)

J.F. Grosse-Oetringhaus, Rencontres de Moriond, 14. – 19. March 2010



Systematics: <p_T> vs Multiplicity

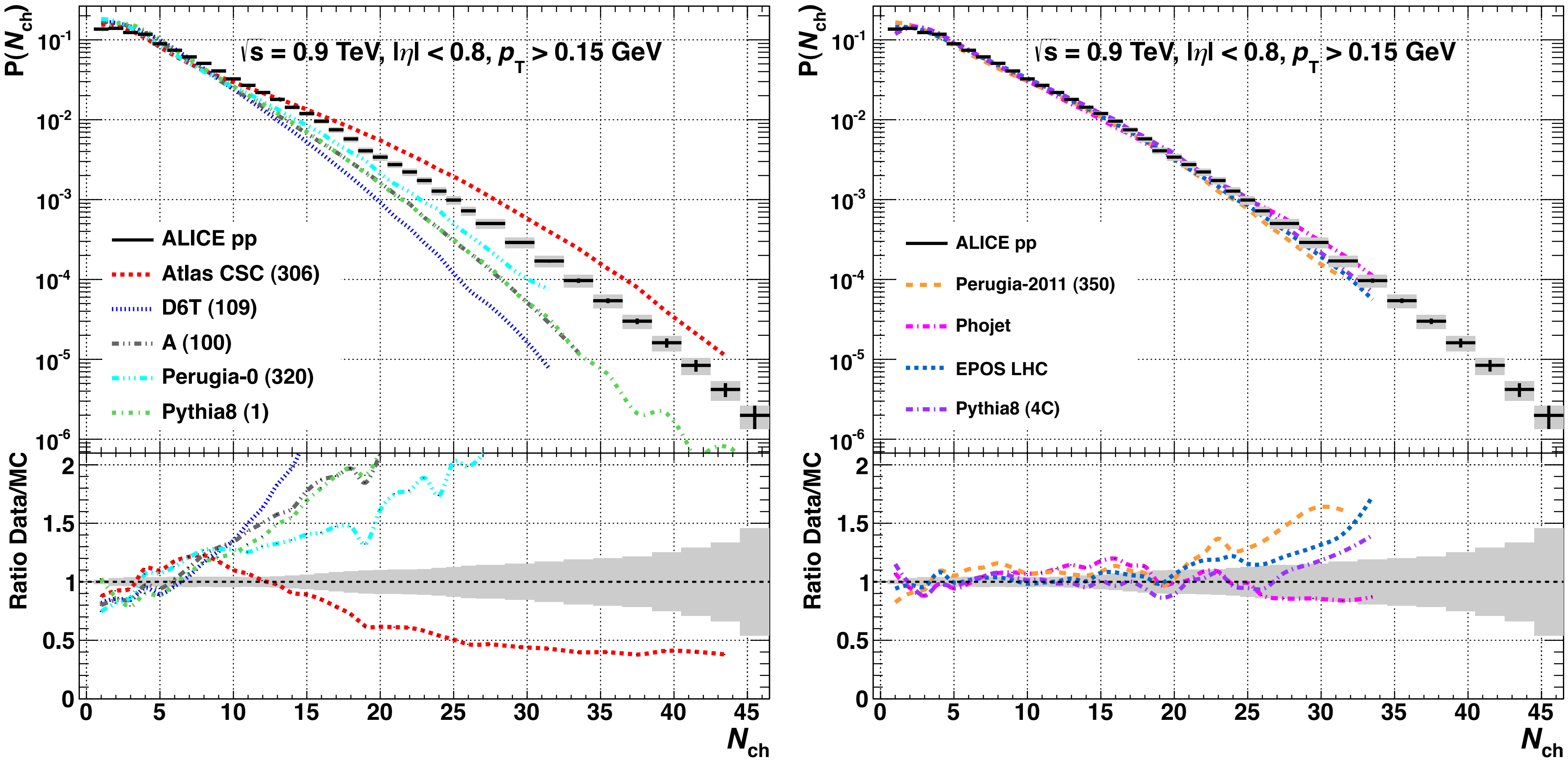
- Many systematic uncertainty sources studied (see backup)
- In particular:
  - Monte Carlo description of <p_T> vs Multiplicity not fully satisfactory



- Important for Multiplicity distribution analysis where correlation between <p_T> and multiplicity plays a fundamental role
- Verified at Monte Carlo level
  - Negligible at 900 GeV, important at 7 TeV, especially in the lowest $p_{T,cut}$, in the high multiplicity region
- Taken into account at 7 TeV unfolding data with two different Monte Carlo (ATLAS-CSC, Perugia-0) and adding an extra systematic uncertainty (up to 10%, 5%, 10% at high multiplicity for $p_{T,cut}$ = 0.15, 0.5, 1.0 GeV/c)

Multiplicity distributions – MC Comparison – I

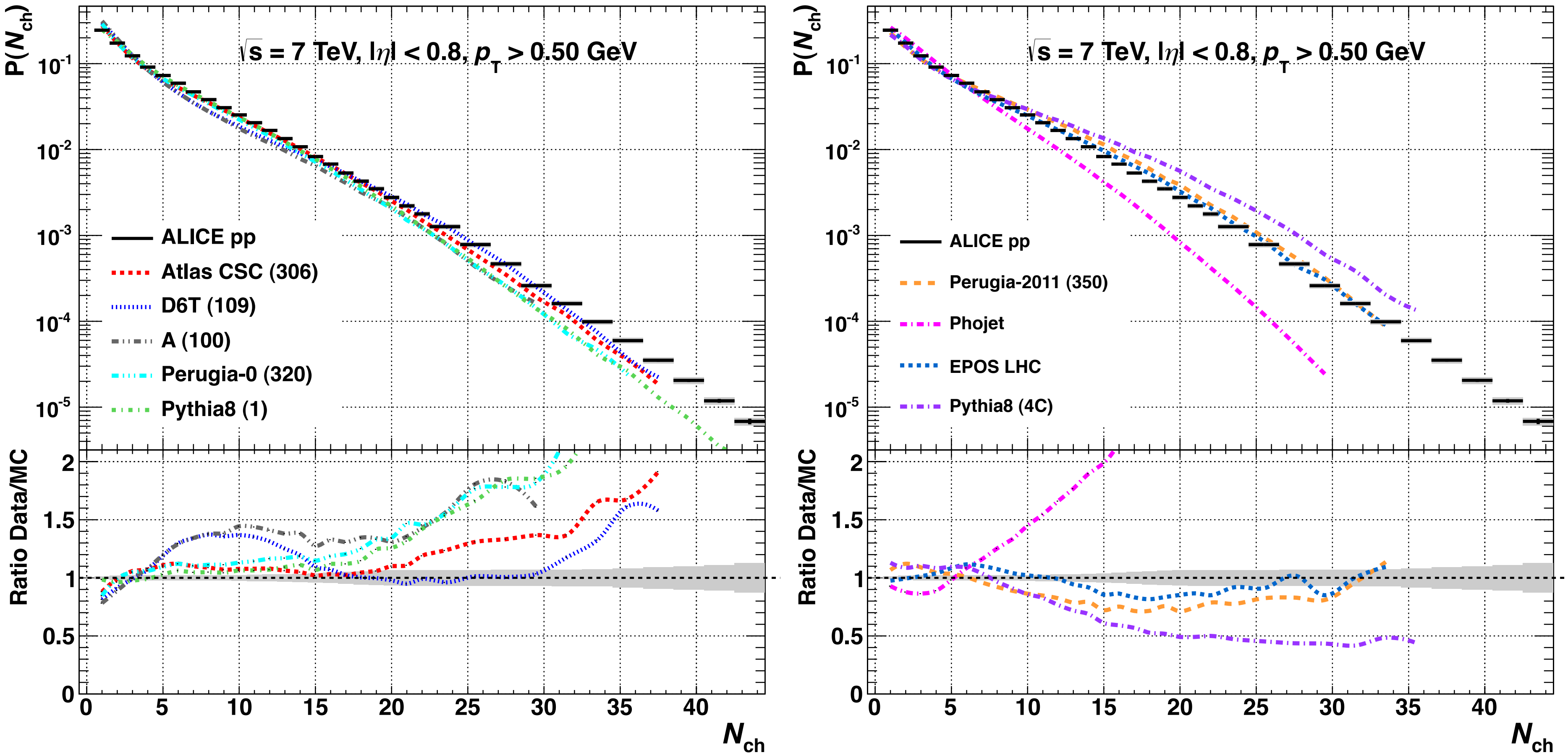
√s = 0.9 TeV, $p_{T,cut}$ = 0.15 GeV/c



- Best Monte Carlo Description by Phojet
- EPOS, Pythia8 (4c) and Perugia-2011 deviate by 50% at high multiplicity
- EPOS is the best at very low multiplicity

Multiplicity distributions – MC Comparison – II

$\sqrt{s}$ = 7 TeV, $p_{T,cut}$ = 0.5 GeV/c



- Best Monte Carlo Description by EPOS
- Perugia-2011 within 20%
- ATLAS-CSC within 30% up to multiplicity 30

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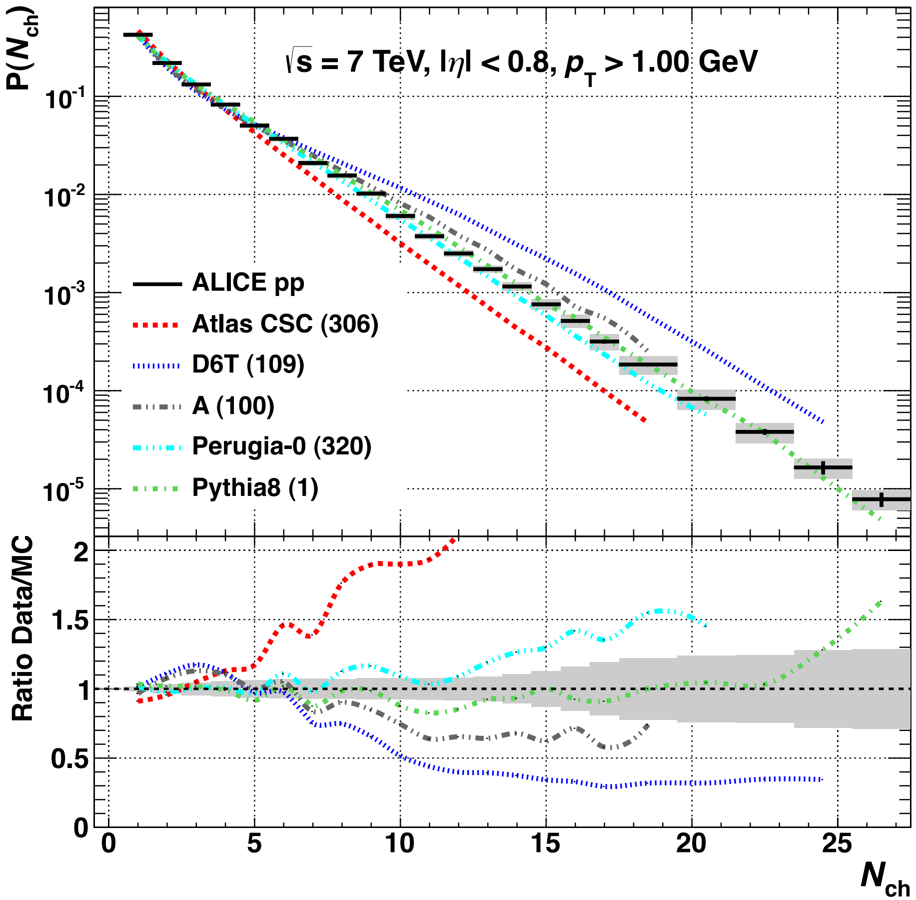
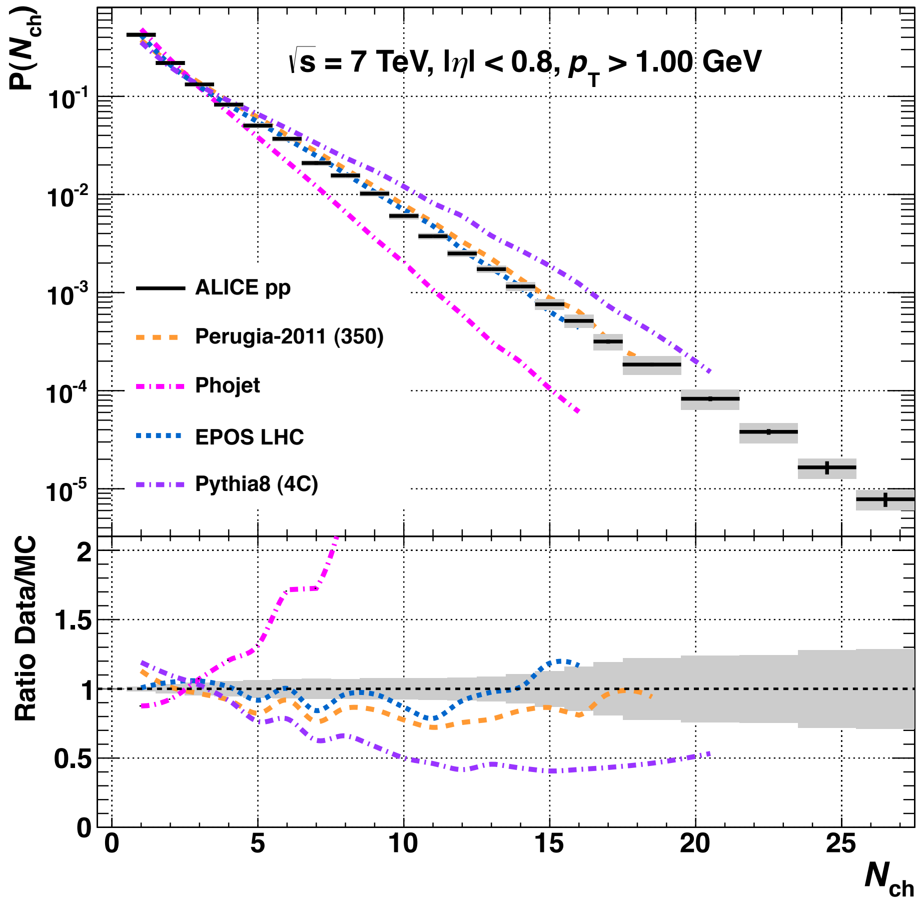
Multiplicity distributions – MC Comparison – III

√s = 7 TeV, $p_{T,cut}$ = 1.0 GeV/c





- Best Monte Carlo Description by Pythia8 (1), EPOS
- Perugia-2011 within 30%, but deviates by 10% at low multiplicity

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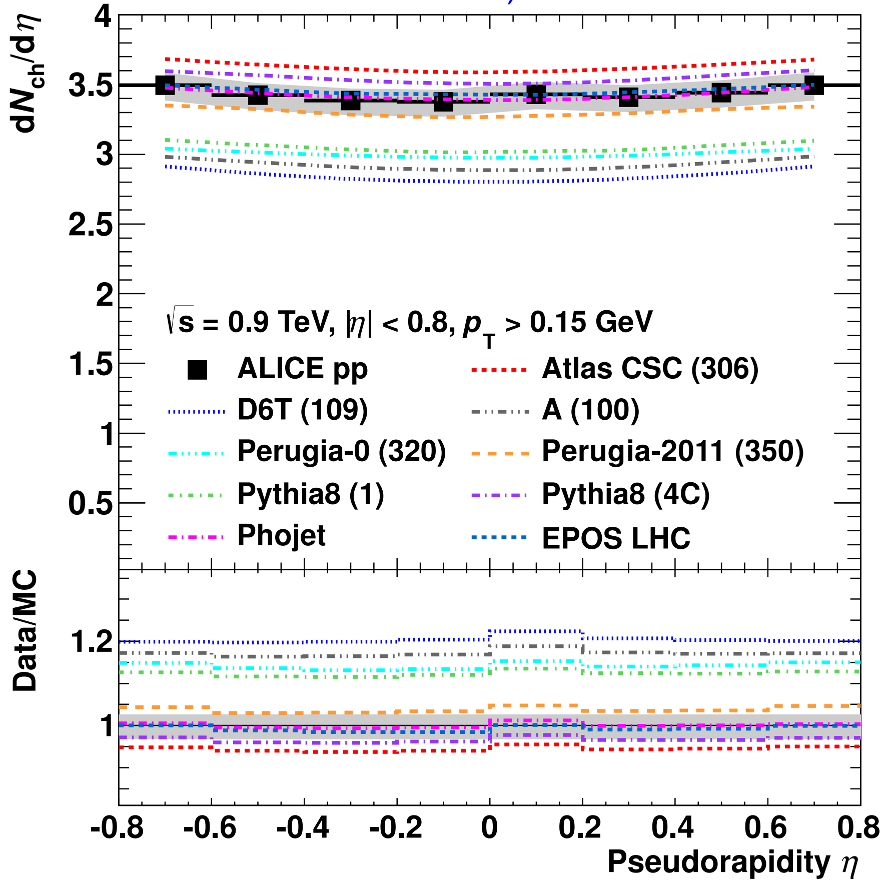
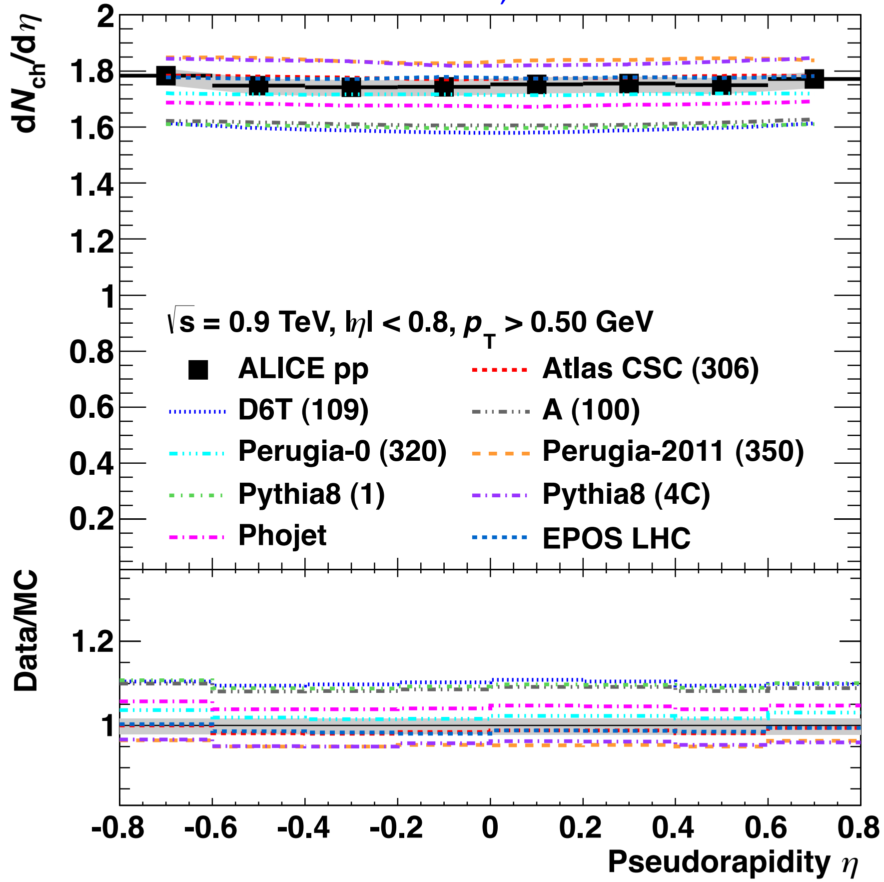
$dN_{ch}/d\eta$ – 0.9 TeV





Best Monte Carlo description:

- $p_{T,cut}$ = 0.15 GeV: EPOS and PHOJET
- $p_{T,cut}$ = 1.0 GeV: (backup): Perugia-0, A100, Pythia8 (4c), Perugia-2011
- $p_{T,cut}$ = 0.5 GeV: EPOS, ATLAS-CSC, Perugia-0

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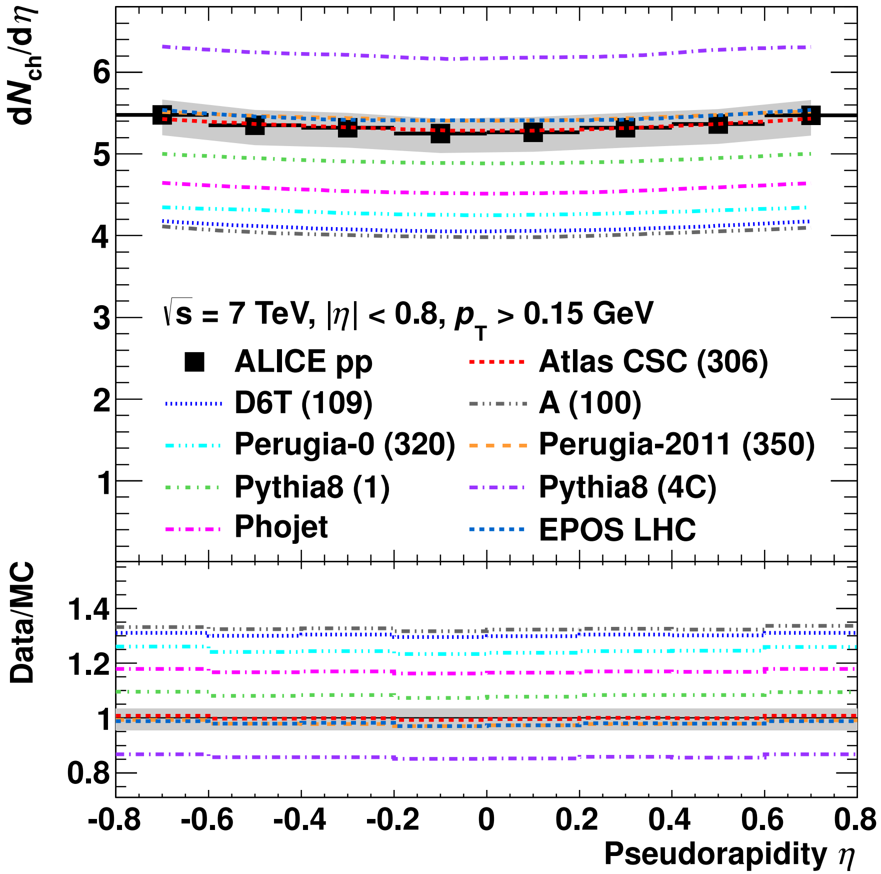
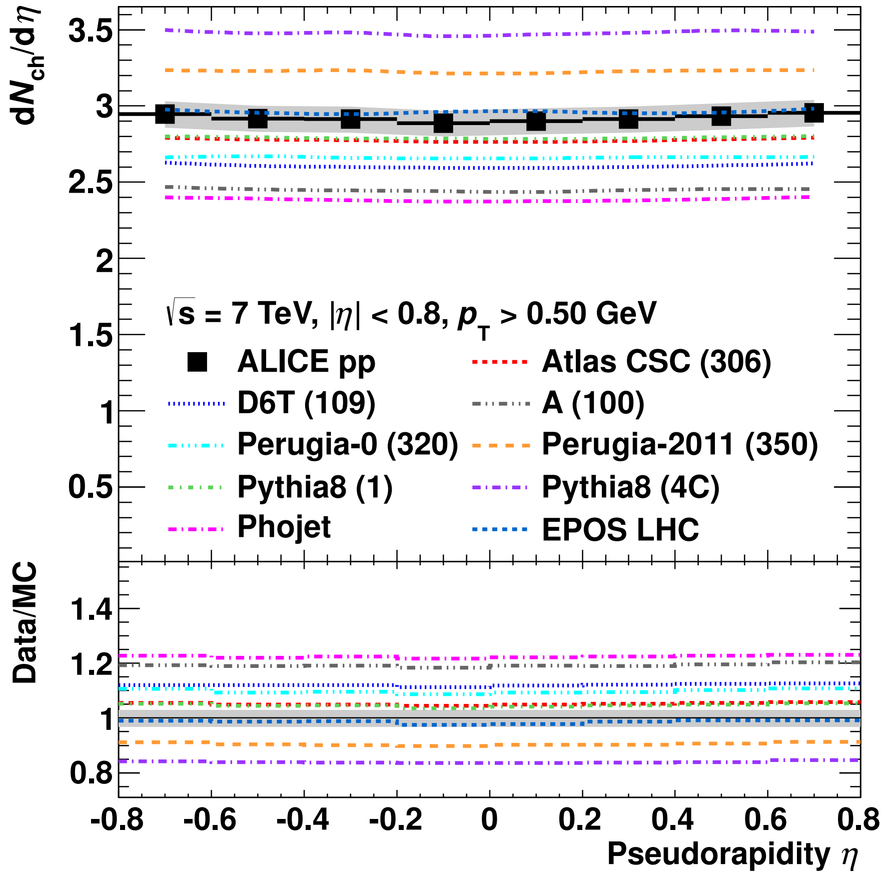
dN_{ch}/dη – 7 TeV

√s = 7 TeV, $p_{T,cut}$ = 0.15 GeV/c



√s = 7 TeV, $p_{T,cut}$ = 0.5 GeV/c



Best Monte Carlo description:

- $p_{T,cut}$ = 0.15 GeV: EPOS, ATLAS-CSC, Perugia-2011
- $p_{T,cut}$ = 1.0 GeV: (backup): EPOS, Perugia-0, A100, Pythia8 (1),
- $p_{T,cut}$ = 0.5 GeV: EPOS

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Monte Carlo Comparison – Summary

ALICE

Qualitative summary

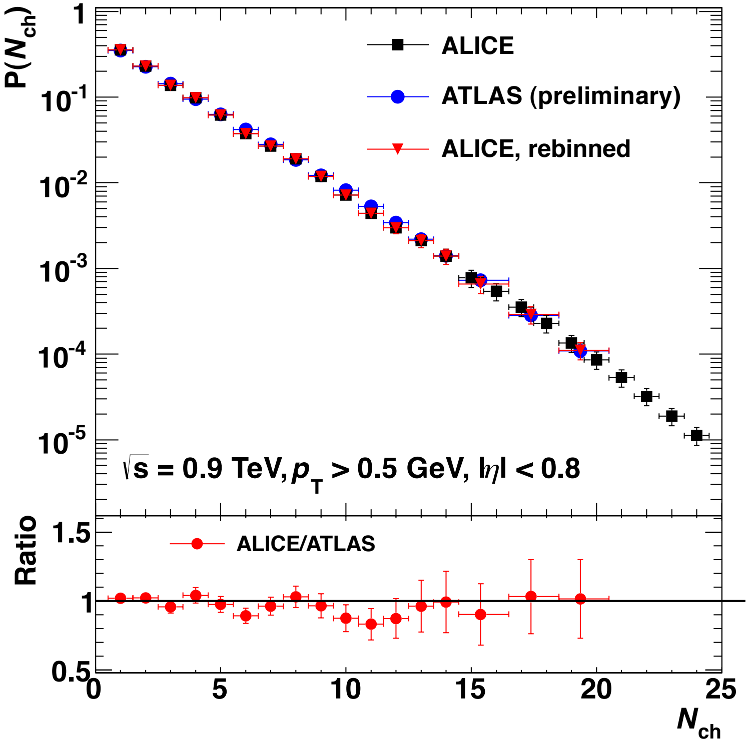
√s (TeV)	$p_{T,\,cut}$ (GeV/c)	Multiplicity	$dN_{ch}/d\eta$
0.9	0.15	Phojet	EPOS Phojet
	0.5	EPOS Perugia-0	EPOS ATLAS-CSC Perugia-0
	1.0	A100 D6T Perugia-2011 Pythia8 (1) Pythia8 (4c)	A100 Perugia-0 Perugia-2011 Pythia8 (4c)
7	0.15	EPOS Perugia-2011	EPOS ATLAS-CSC Perugia-2011
	0.5	EPOS Perugia-2011	EPOS
	1.0	EPOS Perugia-2011 Pythia8 (1)	EPOS A100 Perugia-0 Pythia8 (1)

Multiplicity – Comparison with ATLAS – 0.9 TeV

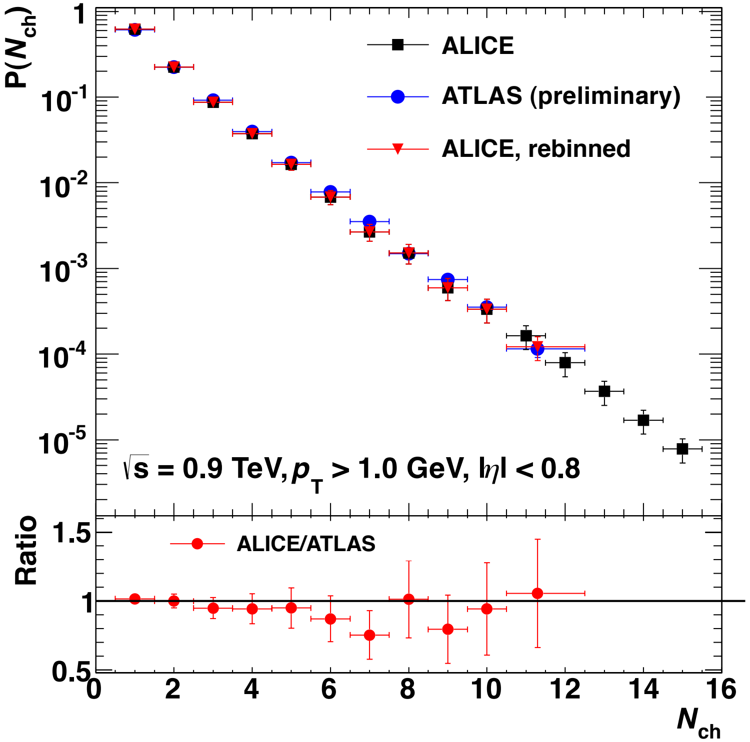
- Comparison with ATLAS in the case of $p_{T,cut}$ = 0.5 and 1.0 GeV/c

ALICE: ALICE-PUBLIC-2013-001
ATLAS: ATLAS-CONF-2010-101

√s = 0.9 TeV, $p_{T,cut}$ = 0.5 GeV/c



√s = 0.9 TeV, $p_{T,cut}$ = 1.0 GeV/c



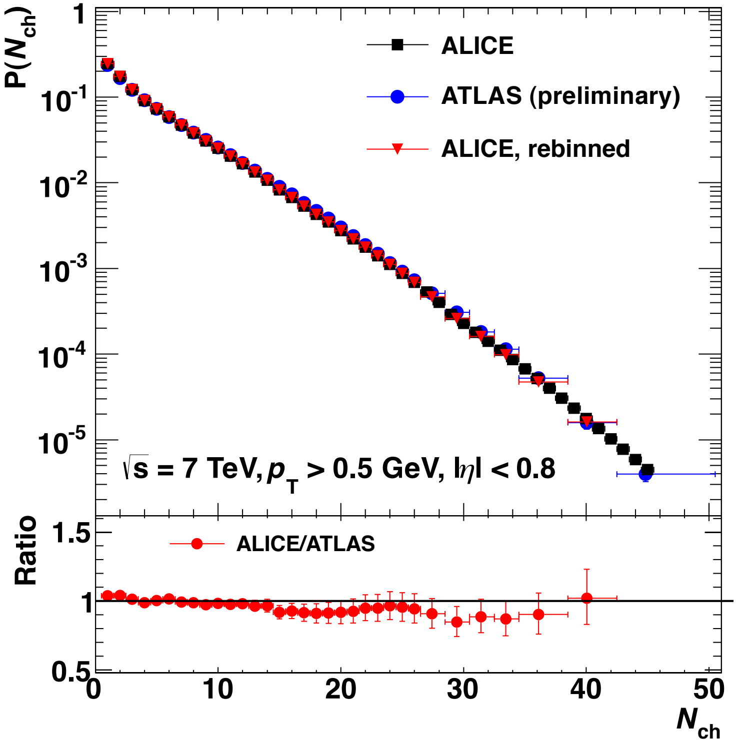
- ALICE and ATLAS in agreement within 10% up to intermediate multiplicity; 20% at high multiplicity
- ALICE measures up to higher multiplicities than ATLAS

Multiplicity – Comparison with ATLAS – 7 TeV

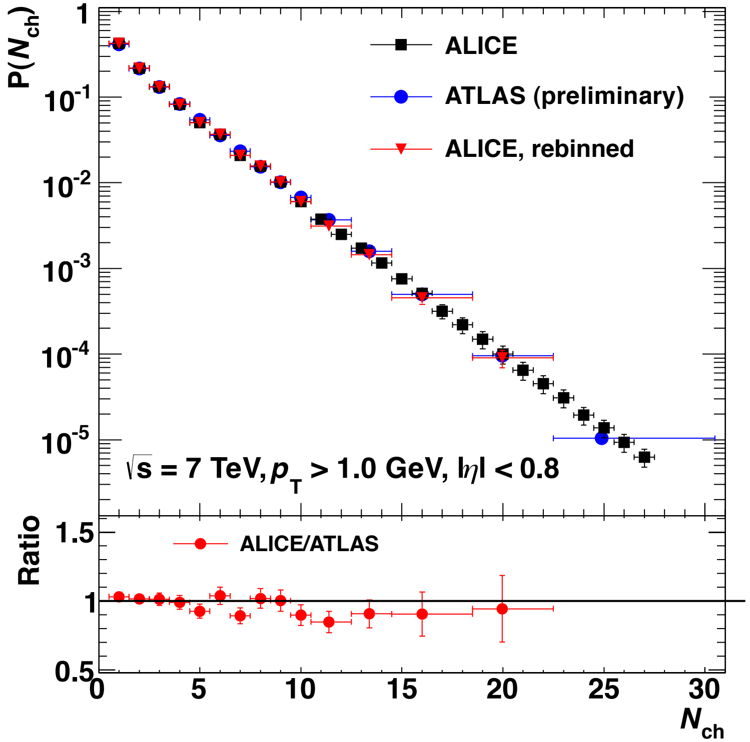
- Comparison with ATLAS in the case of $p_{T,cut}$ = 0.5 and 1.0 GeV/c

ALICE: ALICE-PUBLIC-2013-001
ATLAS: ATLAS-CONF-2010-101

$\sqrt{s}$ = 7 TeV, $p_{T,cut}$ = 0.5 GeV/c



$\sqrt{s}$ = 7 TeV, $p_{T,cut}$ = 1.0 GeV/c



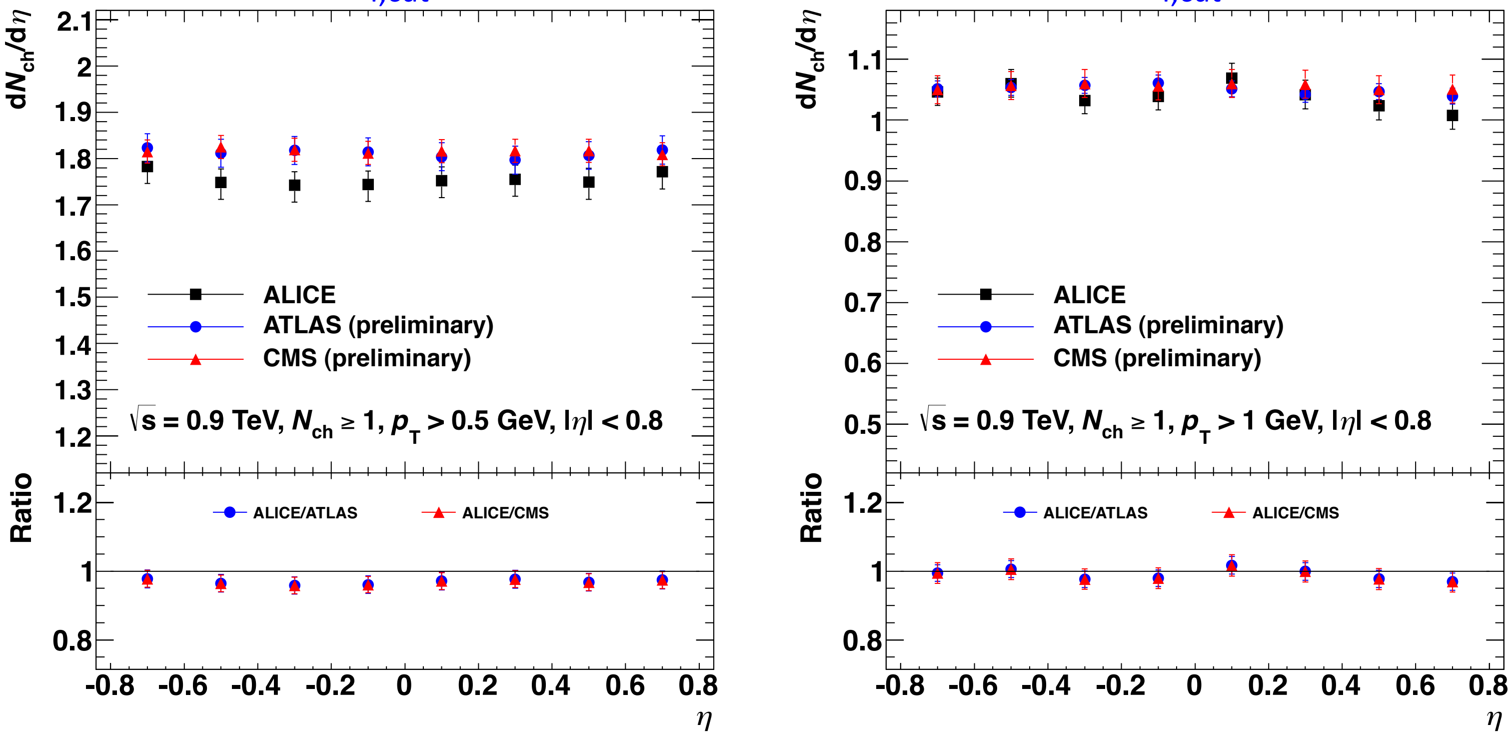
- ALICE and ATLAS in agreement within 10% almost over the whole spectrum
- ATLAS goes to higher multiplicities than ALICE

$dN_{ch}/d\eta$ – Comparison to ATLAS and CMS – 0.9 TeV

- Comparison with ATLAS in the case of $p_{T,cut}$ = 0.5 and 1.0 GeV/c

ALICE: ALICE-PUBLIC-2013-001
ATLAS: ATLAS-CONF-2010-101
CMS: CMS-PAS-QCD-10-024

√s = 0.9 TeV, $p_{T,cut}$ = 0.5 GeV/c √s = 0.9 TeV, $p_{T,cut}$ = 1.0 GeV/c



- Plots already presented within the MB&UE LHC Working Group
- ALICE lower by ~2% wrt ATLAS and CMS for the lowest $p_{T,cut}$
- Very good agreement for $p_{T,cut}$ = 1.0 GeV

$dN_{ch}/d\eta$ – Comparison to ATLAS and CMS – 7 TeV

- Comparison with ATLAS in the case of $p_{T,cut}$ = 0.5 and 1.0 GeV/c

ALICE: ALICE-PUBLIC-2013-001
ATLAS: ATLAS-CONF-2010-101
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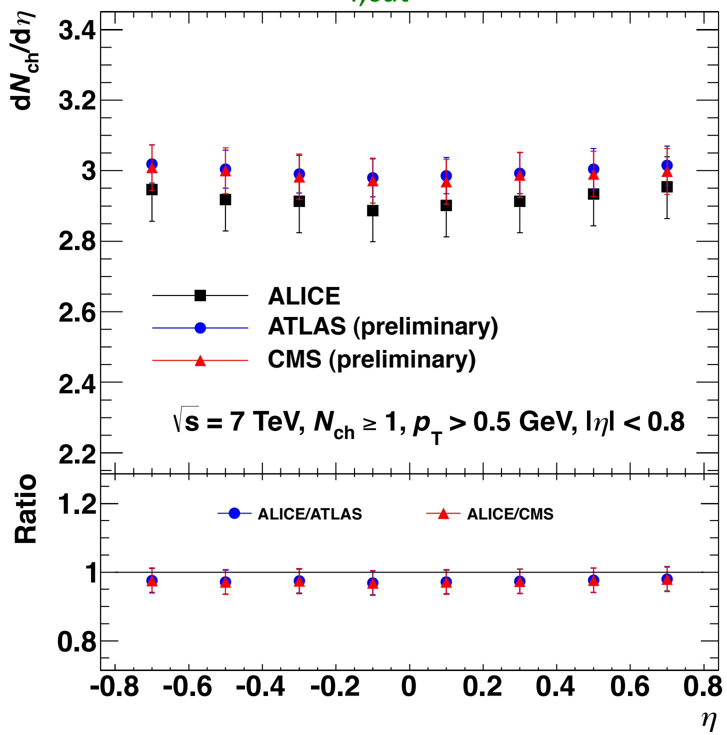
√s = 7 TeV, $p_{T,cut}$ = 0.5 GeV/c



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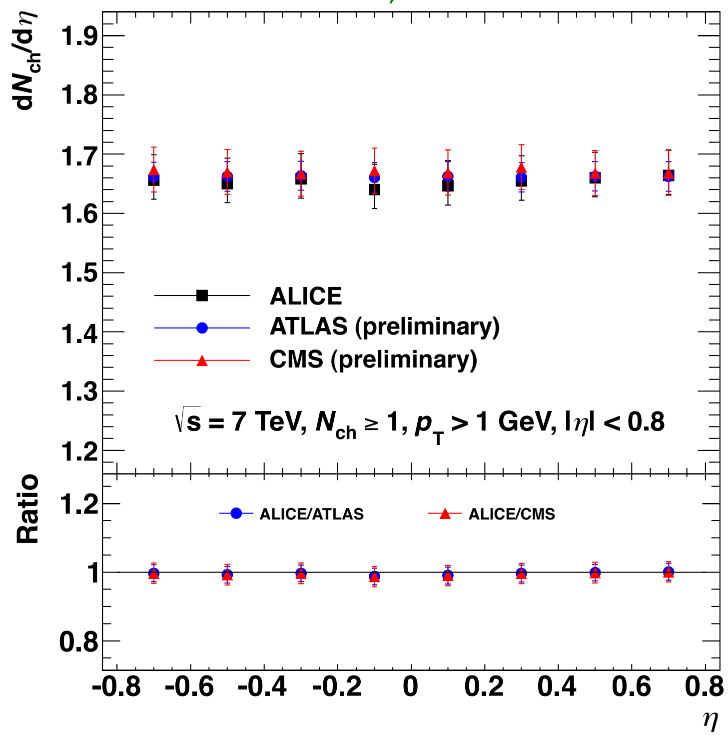

- Plots already presented within the MB&UE LHC Working Group, ALICE points updated
- ALICE lower by ~2% wrt ATLAS and CMS for the lowest $p_{T,cut}$
- Very good agreement for $p_{T,cut}$ = 1.0 GeV

Summary and Conclusions

- INEL>0 class considered for charged particle multiplicity and pseudorapidity density distributions
  - Selecting events with at least 1 charged primary particle in $|\eta| < 0.8$, $p_T > p_{T,cut}$ (0.15, 0.5, 1.0 GeV/c)
  - Counting only the charged primary particles satisfying the same requirement
- Monte Carlo description of the measurements generally not very satisfactory
  - Different behaviour depending on the energy of the system, of the $p_{T,cut}$ and sometimes of the measurement
  - EPOS (LHC) seems to be the Monte Carlo generator that in general best describes the data
    - Consistent treatment of cross-section calculation and particle production including energy conservation
    - Final states of the scattering described as flux tubes, eventually constituting bulk matter which thermalizes and expands collectively (hydrodynamically – statistical decay + flow), or escape and hadronize as jets
    - See Phys.Rev. C74 (2006) 044902, Phys.Rev. C85 (2012) 064907, Phys. Rev. Lett. 109, 102301 (2012), arXiv:1306.0121
- Comparison with ATLAS and CMS (for $dN_{ch}/d\eta$) presented
  - Very good agreement, within systematics

Summary and Conclusions

More Multiplicity measurements by ALICE to come
- **More energies, higher statistics, different multiplicity estimators, more event classes…**

- INEL>0 class considered for charged particle multiplicity and pseudorapidi... y distributions
  - Selecting events with at least 1 charged prim... 1.0 GeV/c)
  - Counting only the charged p... ...urement
- Monte Carlo description of th... ...nerally not very satisfactory
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- Comparison with ATLAS and CMS (for dN_{ch}/dη) presented
  - Very good agreement, within systematics

“so many out-of-the-way things had happened lately, that Alice had begun to think that very few things indeed were really impossible.”
L. Carrol, Alice’s Adventures In Wonderland

ALICE results on the same subject (pp, Pb-Pb, p-Pb):

- *Published:*
  - *Eur. Phys. J. C (2010) 65: 111-125*
  - *Eur. Phys. J. C (2010) 68: 345–354*
  - *Eur. Phys. J. C (2010) 68: 89–108*
  - *Phys. Rev. Lett. 105, 252301 (2010)*
  - *Phys. Rev. Lett. 106, 032301 (2011)*
  - *Phys. Rev. Lett. 110, 032301 (2013)*

- *Submitted:*
  - *arXiv:1304.0347*
  - *arXiv:1307.1094 (pp, Pb-Pb, p-Pb)*
  - *arXiv:1307.1249*

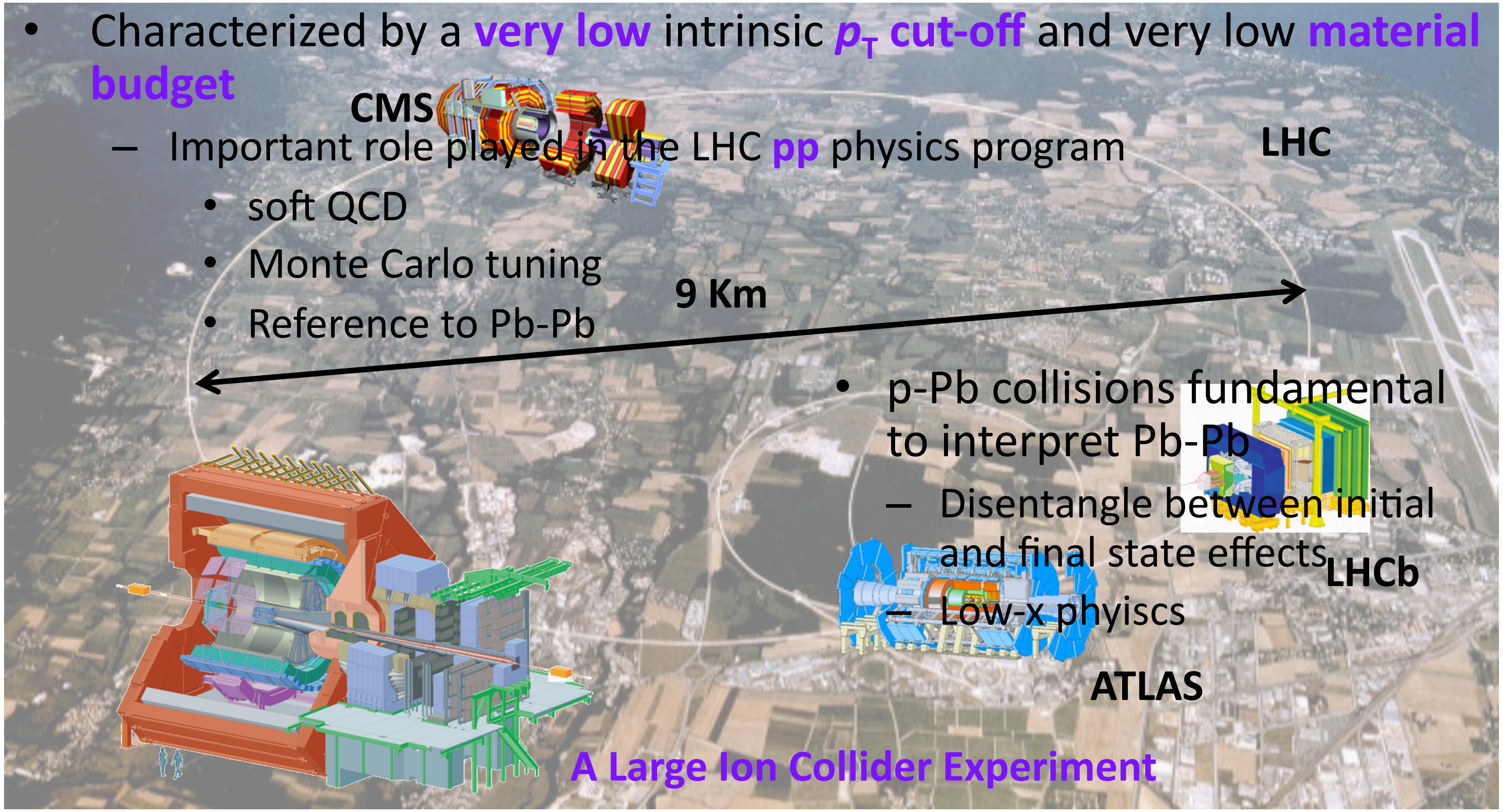
Backup

Outline

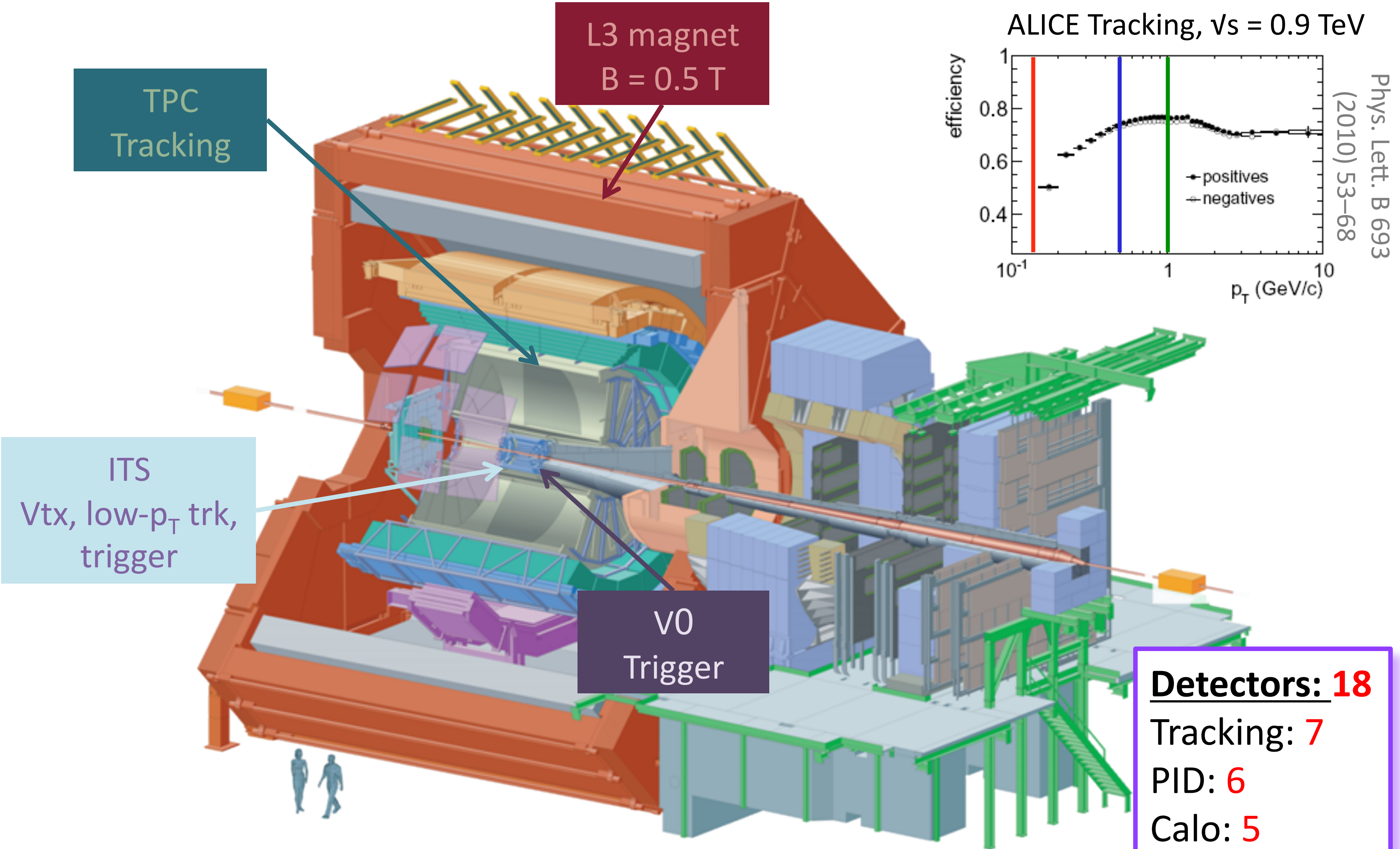
- Definitions
- The ALICE detector
- Analysis strategy
  - Multiplicity distributions
  - Multiplicity densities
- Results
  - Multiplicity distributions
  - Multiplicity densities
- Conclusions

The ALICE Experiment

- **A L**arge **I**on **C**ollider **E**xperiment is the experiment at the CERN Large Hadron Collider (LHC) **dedicated to heavy-ion physics**
  - **The ultimate goal is the study of the Quark Gluon Plasma (QGP)**
- Characterized by a **very low** intrinsic **p_T cut-off** and very low **material budget**
  - Important role played in the LHC **pp** physics program
    - soft QCD
    - Monte Carlo tuning
    - Reference to Pb-Pb
- p-Pb collisions fundamental to interpret Pb-Pb
  - Disentangle between initial and final state effects
  - Low-x phyiscs



The ALICE Detector



Detectors: 18

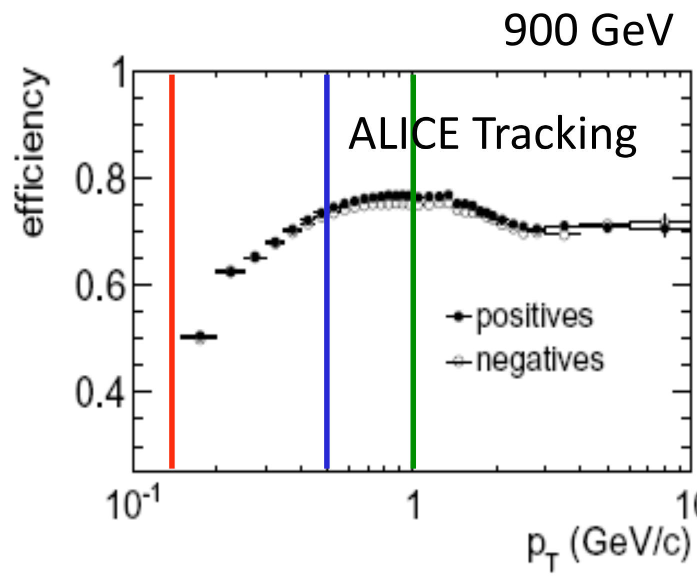
Tracking: 7

PID: 6

Calo: 5

ALICE ITS, TPC, V0

- The Inner Tracking System - ITS ($|\eta| < 0.9$)
  - Six layers, three technologies: SPD, SDD, SSD
  - Primary and secondary vertex reconstruction
  - Tracking + standalone reconstruction
  - PID via dE/dx (SDD+SSD analog read-out)
  - Trigger provided by SPD Fast-OR
    - MB, high multiplicity, topologies



Phys. Lett. B 693 (2010) 53–68

- The Time Projection Chamber – TPC
  - Efficient tracking (~80%) in $|\eta| < 0.8$, $\sigma(p_T)/p_T$ ~ 5% (simulation, current performance within expectations)
  - Momentum resolution (TPC+ITS) $\sigma(p_T)/p_T < 2.5\%$ up to 10 GeV/c
  - Two-track resolution < 10 MeV
  - PID (truncated mean over a max of 159 signals) with $\sigma_{dE/dx}$~5% (isolated tracks, max number of clusters)
  - Space-point resolution 0.8 (1.2) mm in xy (z)

ALICE ITS, TPC, V0

- The Inner Tracking System - ITS ($|\eta| < 0.9$)
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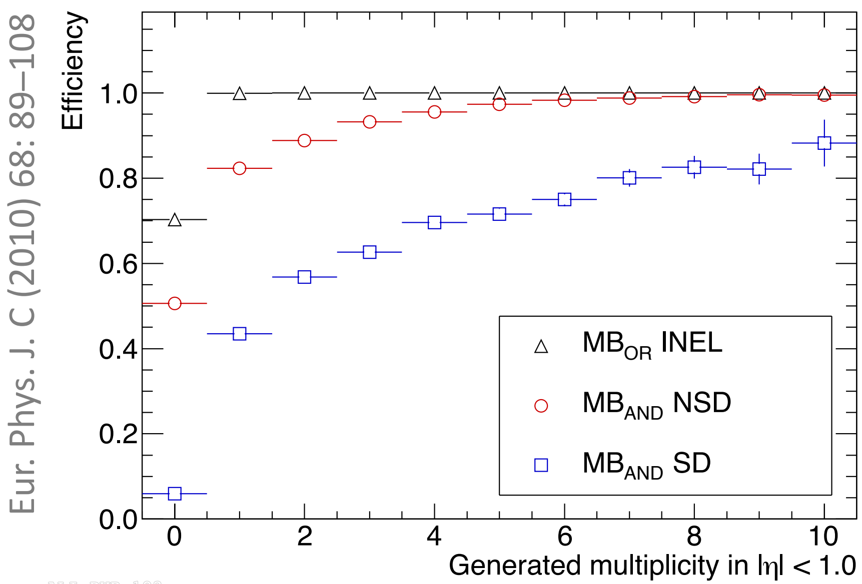

- The VZERO detector
  - Two arrays (VZERO-A, VZERO-C) of 32 scintillators each, at $2.8 < \eta < 5.1$ and $-3.7 < \eta < -1.7$
  - Providing trigger, luminosity and centrality (PbPb, pPb) measurement, event plane, charged-particle multiplicity at forward rapidity

MB_{OR} trigger – used here – defined as a hit in either the SPD or in either VZERO-A or VZERO-C

Multiplicity Analysis – χ^2 Minimization

- χ^2 minimization with regularization

$$\chi^2(U) = \sum_m \left(\frac{M_m - \sum_t R_{mt} U_t}{e_m} \right)^2 + \beta P(U)$$

M_m = Measured multiplicity at m, with error e_m
R_{mt} = Response matrix for measured mult m and true mult t
U_t = Guessed unfolded spectrum for true mult t
P(U) = Regularization function
β = Regularization weight

→ Regularization damped at low multiplicity where data do not follow the constraint

- Two regularizations tried

$$P_1(U) = \sum_t \frac{(U_t')^2}{U_t} = \sum_t \frac{(U_t - U_{t-1})^2}{U_t}$$

– Constant relative "fluctuations"
→ Used mainly for systematic studies

$$P_2(U) = \sum_t \frac{(U_t'')^2}{U_t} = \sum_t \frac{(U_{t-1} - 2U_t + U_{t+1})^2}{U_t}$$

– Minimal relative curvature
→ Preferred and used for the results showed here

Multiplicity Analysis – Event Selection Efficiency

ALICE

- Correction for event selection efficiency applied in unfolded (true) multiplicity variable

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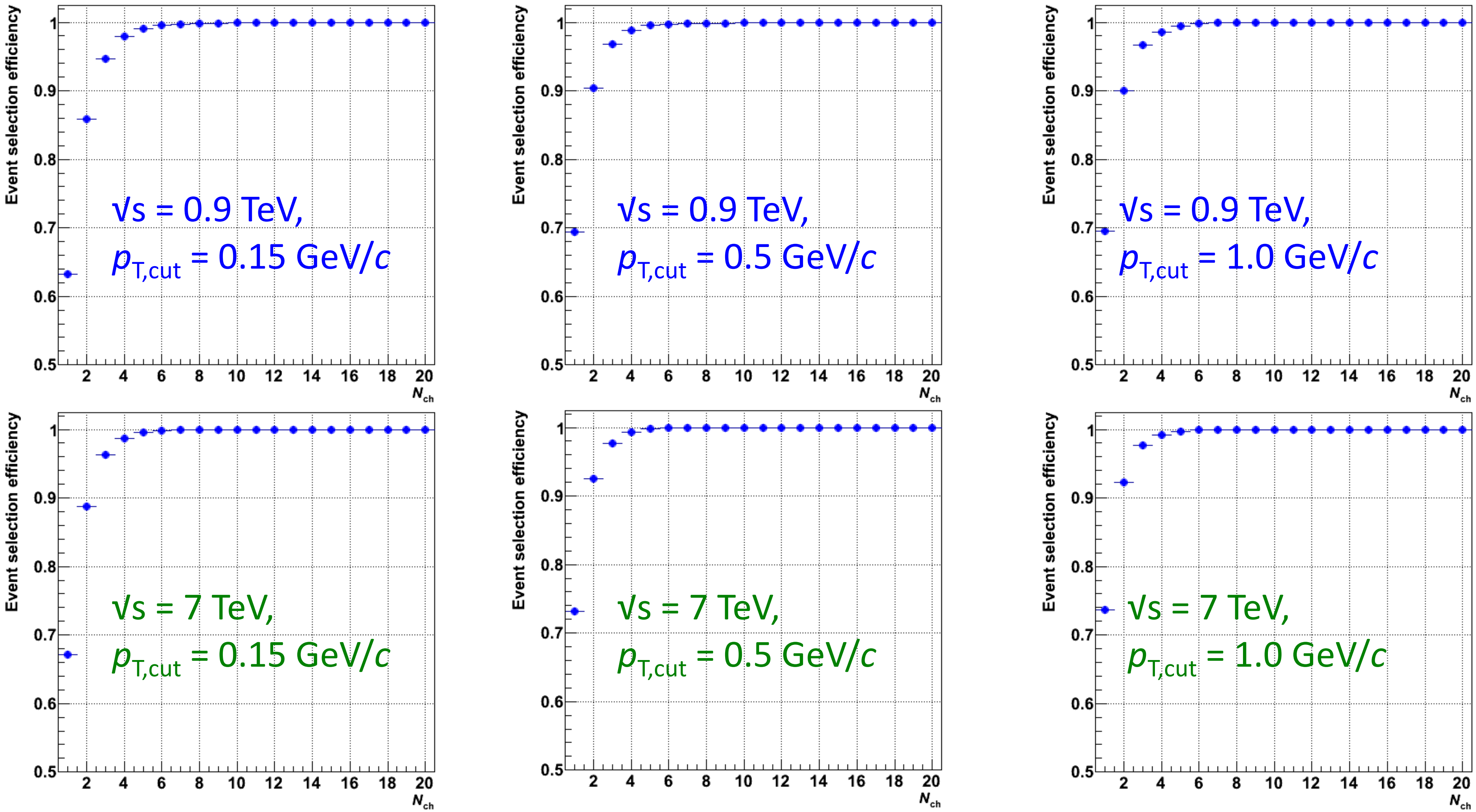
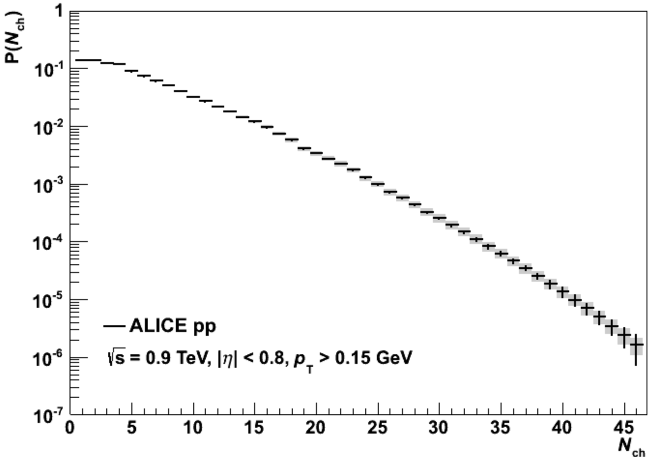


Systematic Uncertainties

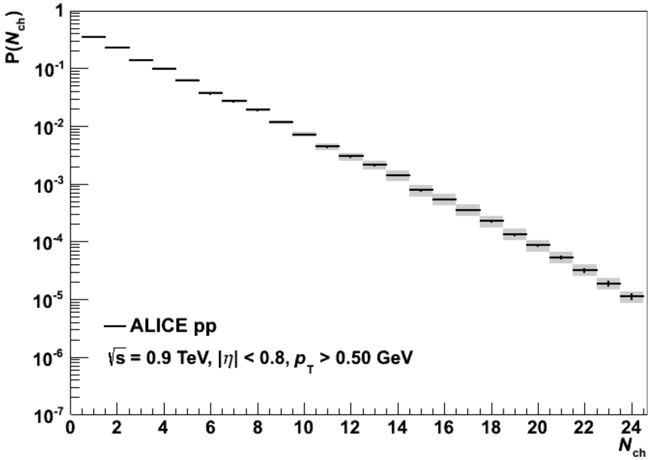
- Both for Multiplicity Distributions and $dN_{ch}/d\eta$
  - Track cuts (including primary selection)
  - Particle composition
  - Diffraction (SD, ND, DD fractions)
  - Material Budget
  - Pile-up
  - Event selection efficiency
  - Tracking (ITS and TPC) efficiency difference between data and MC
  - Strangeness
- For Multiplicity Distributions only
  - Unfolding
    - Bias
      - Derivative used for determining the bias affected by low statistics in the high-multiplicity bins (see G. Cowan, Conf. Proc. C 0203181 (2002) 248)
    - Regularization

Multiplicity

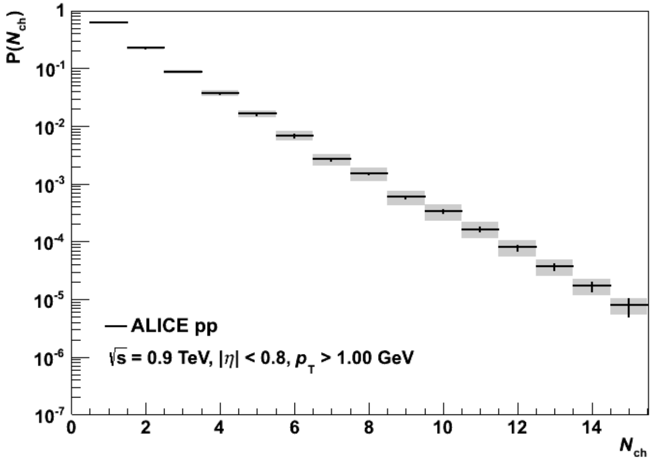
$\sqrt{s}$ = 0.9 TeV, $p_{T,cut}$ = 0.15 GeV/c



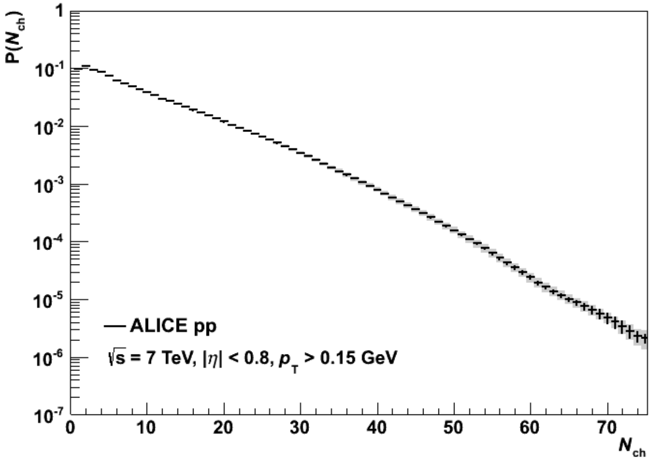
$\sqrt{s}$ = 0.9 TeV, $p_{T,cut}$ = 0.5 GeV/c



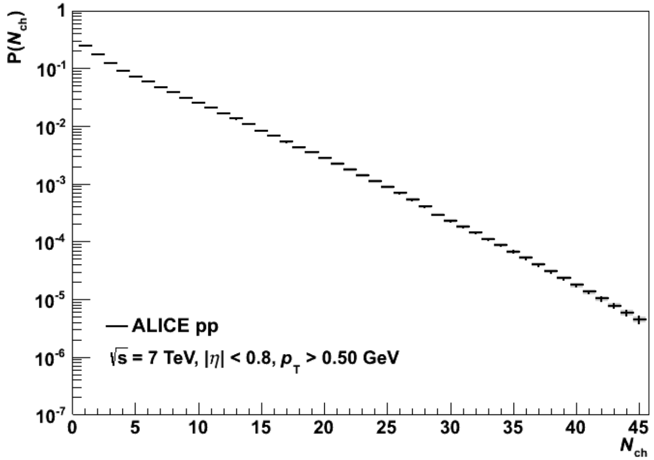
$\sqrt{s}$ = 0.9 TeV, $p_{T,cut}$ = 1.0 GeV/c



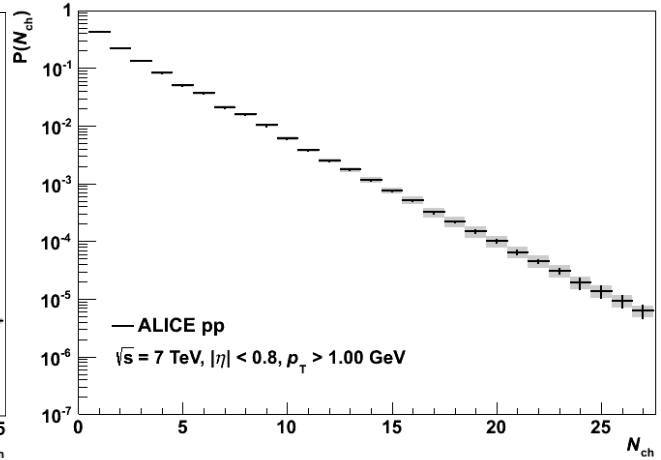
$\sqrt{s}$ = 7 TeV, $p_{T,cut}$ = 0.15 GeV/c



$\sqrt{s}$ = 7 TeV, $p_{T,cut}$ = 0.5 GeV/c



$\sqrt{s}$ = 7 TeV, $p_{T,cut}$ = 1.0 GeV/c

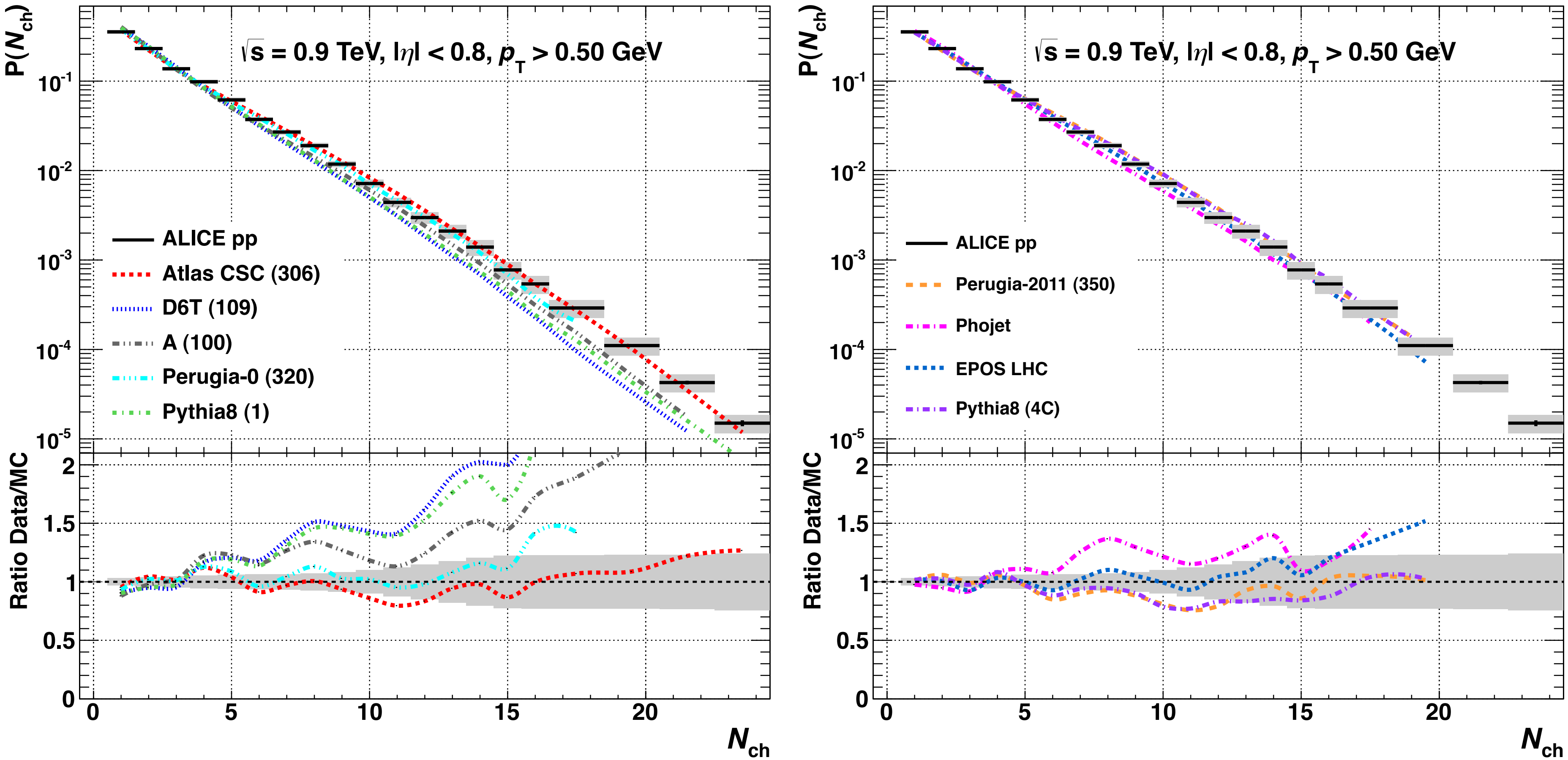


Spectrum limit defined taking into account the measured spectrum and the efficiency from the response matrix

ALICE-PUBLIC-2013-001

Multiplicity distributions – MC Comparison – IV

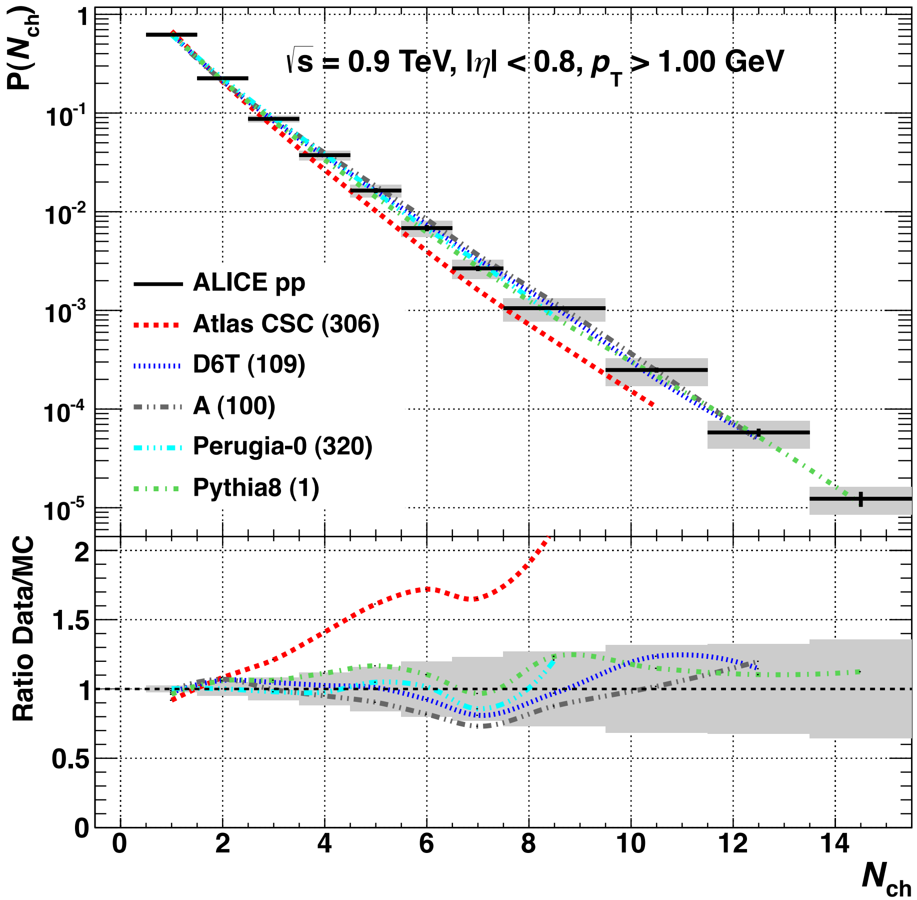
√s = 0.9 TeV, $p_{T,cut}$ = 0.5 GeV/c

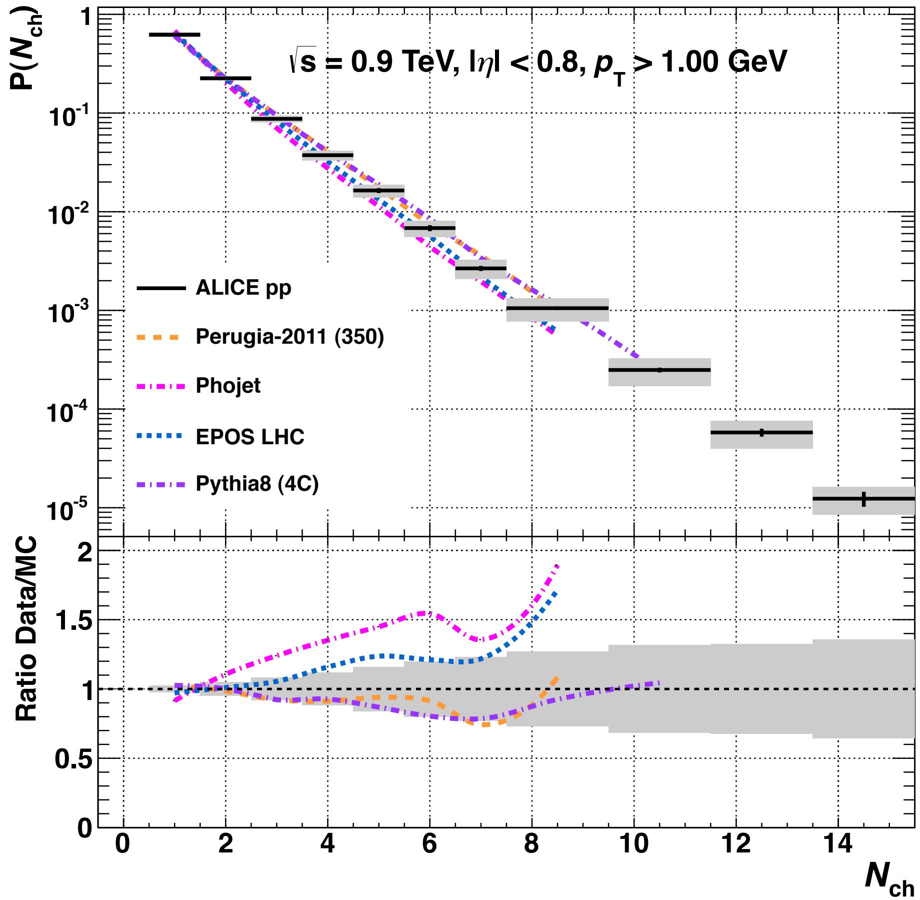


- Best Monte Carlo Description by EPOS, Perugia-0 up to multiplicity = 15
- ATLAS-CSC, Perugia-2011, Pythia8 (4c) within 20%, better than EPOS and Perugia-0 for multiplicity in [15, 20]

Multiplicity distributions – MC Comparison – V

$\sqrt{s}$ = 0.9 TeV, $p_{T,cut}$ = 1.0 GeV/c





- Best Monte Carlo Description by D6T, A100, Perugia-2011, Pythia8 (4c), Pythia8 (1)
- Perugia-0 pretty good but seems to underestimate at high multiplicities
- Phojet, EPOS pretty far especially at high multiplicities

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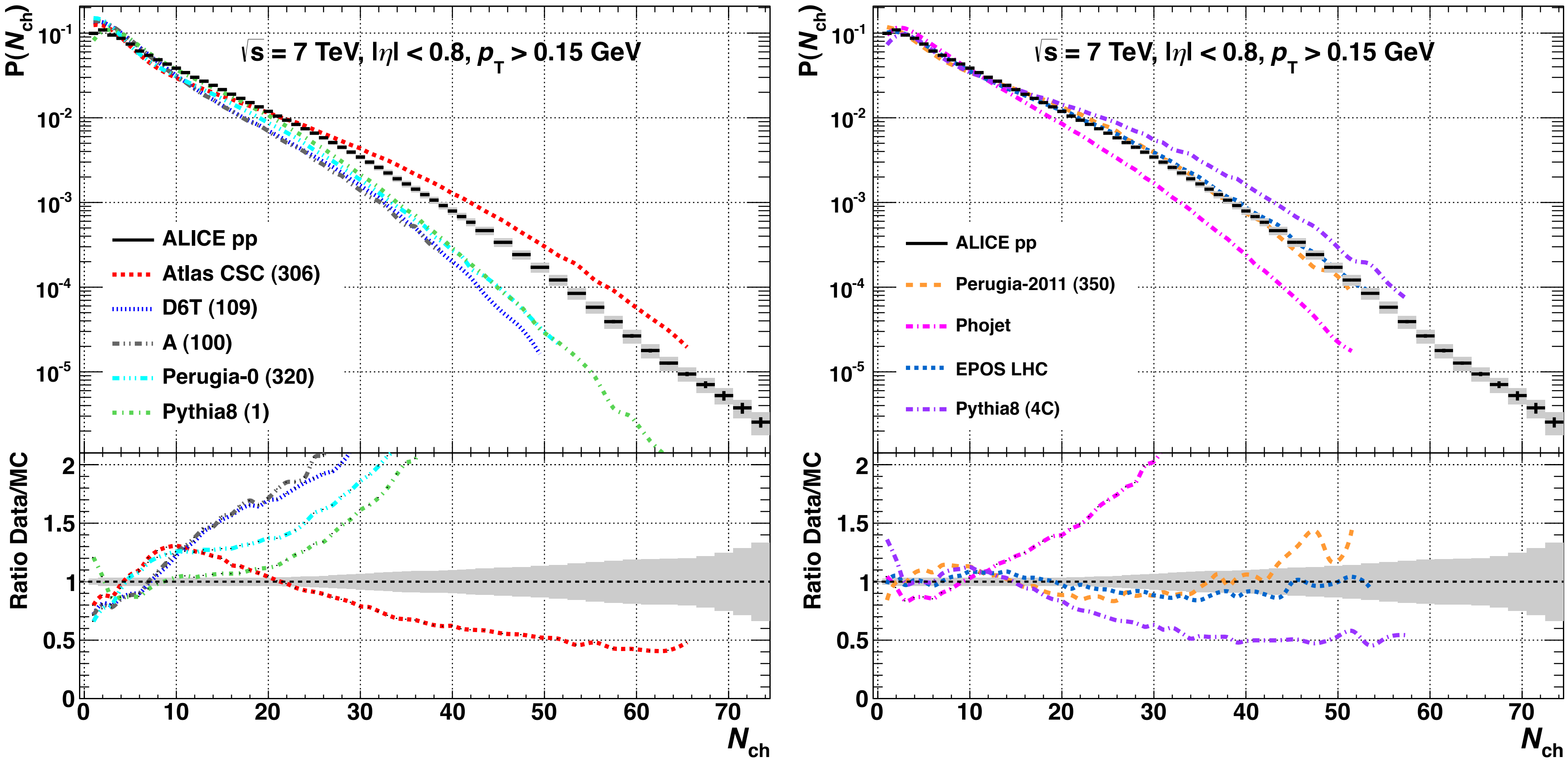
Multiplicity distributions – MC Comparison – VI

$\sqrt{s}$ = 7 TeV, $p_{T,cut}$ = 0.15 GeV/c



- Best Monte Carlo Description by EPOS and Perugia-2011
- EPOS good along the whole spectrum
- All the others pretty far

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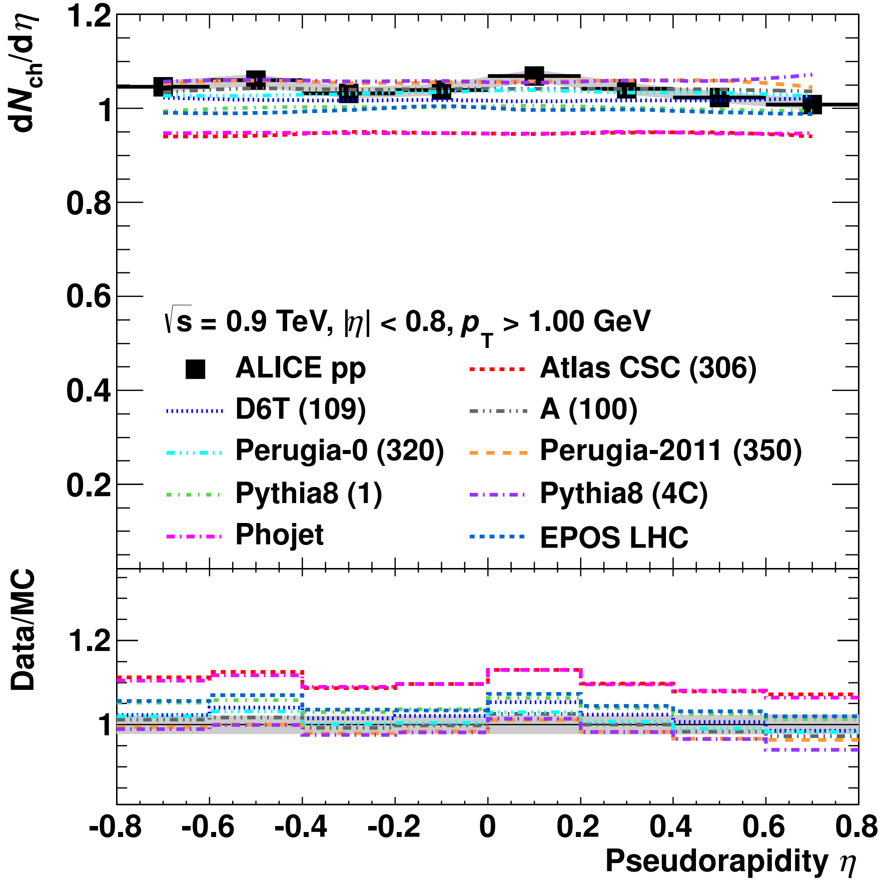
$dN_{ch}/d\eta$ – $p_{T,cut}$ = 1 GeV/c

√s = 0.9 TeV, $p_{T,cut}$ = 1.0 GeV/c



√s = 7 TeV, $p_{T,cut}$ = 1.0 GeV/c