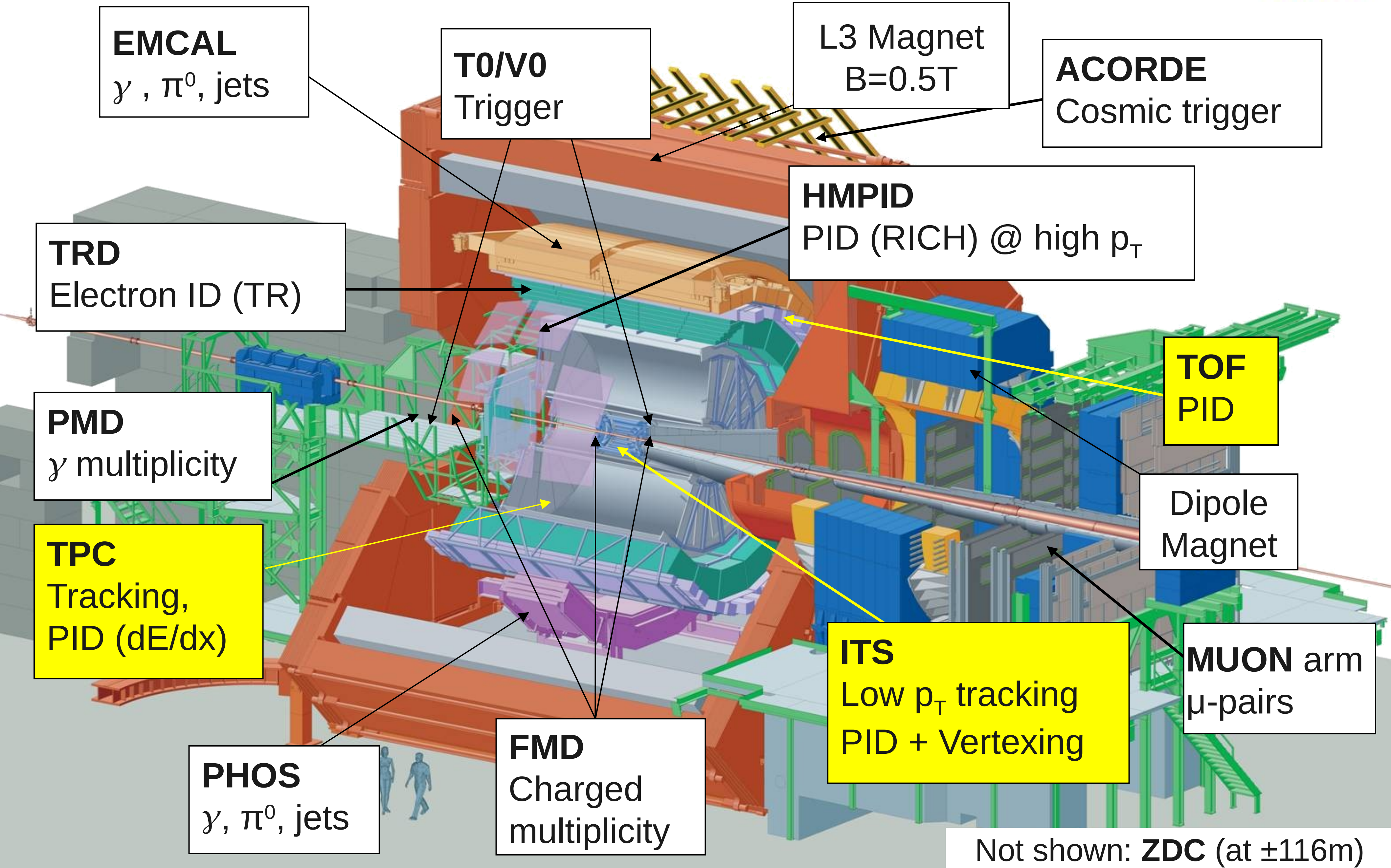
Minimum-Bias Measurements with ALICE

Eva Sicking for the ALICE Collaboration
MPI@LHC Workshop
Glasgow, Scotland, 2010-11-29

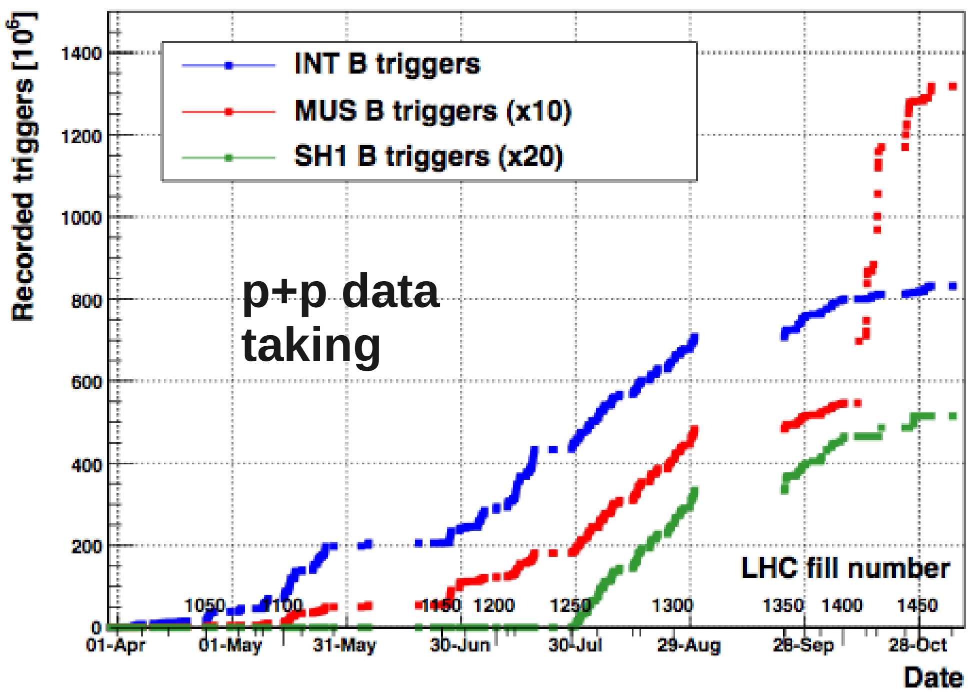
A Large Ion Collider Experiment

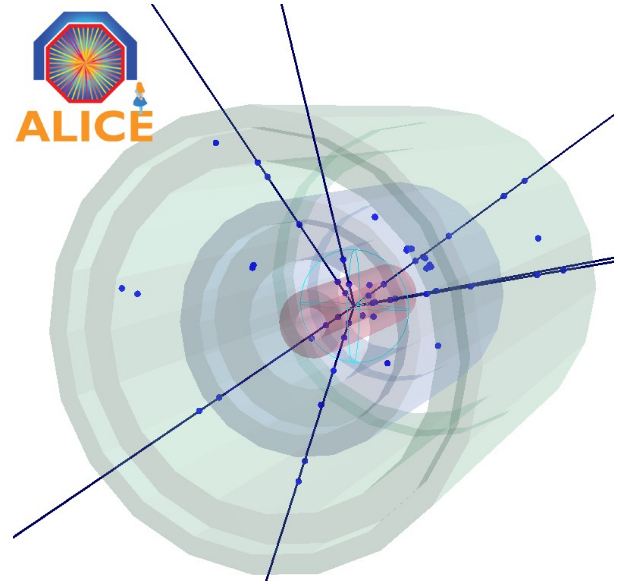
- ALICE is especially designed for heavy-ion collisions
- ALICE studies also p+p
  - Several signals in heavy ion collisions are measured relative to p+p
  - ALICE also has a rich p+p program!
- ALICE special features for p+p minimum bias physics
  - Low momentum sensitivity
    - low material budget and low magnetic field
  - Primary vertex resolution of 100μm in p+p and 10μm in Pb+Pb
  - Excellent Particle Identification (PID) capability
- ALICE can give important input to p+p studies
  - Rare signals need good description of soft underlying event
  - Tuning of MC generators in low-p_T region
  - Study of high-multiplicity collisions

A Large Ion Collider Experiment



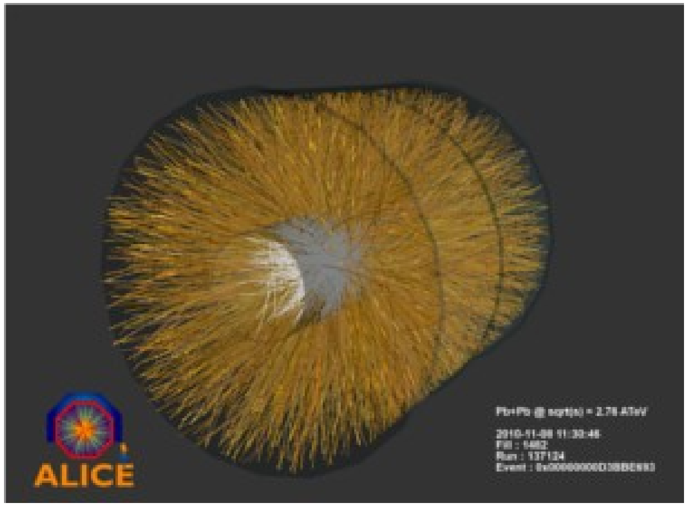
Data Taking Summary





First p+p collision at ALICE, $\sqrt{s}$=900GeV, 2009-11-23

- p+p
  - > 800M min bias triggers
  - > 100M single muon triggers
  - > 25M high multiplicity triggers
- Pb+Pb
  - > 12 M min bias triggers



One of the first Pb+Pb collisions at ALICE, $\sqrt{s_{NN}}$=2.76TeV 2010-11-08

Physics Results, Publications

p+p

- Pseudorapidity density & multiplicity
  - $\sqrt{s}$=900 GeV: **EJC: Vol. 65 (2010) 111**
  - $\sqrt{s}$=900 GeV, 2.36 TeV: **EPJC: Vol. 68 (2010) 89**
  - $\sqrt{s}$=7 TeV: **EPJC: Vol. 68 (2010) 345**
- pbar/p ratio ($\sqrt{s}$=900 GeV & 7 TeV) **PRL: Vol. 105 (2010) 072002**
- Momentum distributions (900 GeV) **PL B: Vol. 693 (2010) 53**
- Bose-Einstein correlations (900 GeV) **PRD: Vol. 82 (2010) 052001**
- Identified Particle spectra (0.9, 7TeV) will be published soon
- Strangeness (900GeV) will be published soon

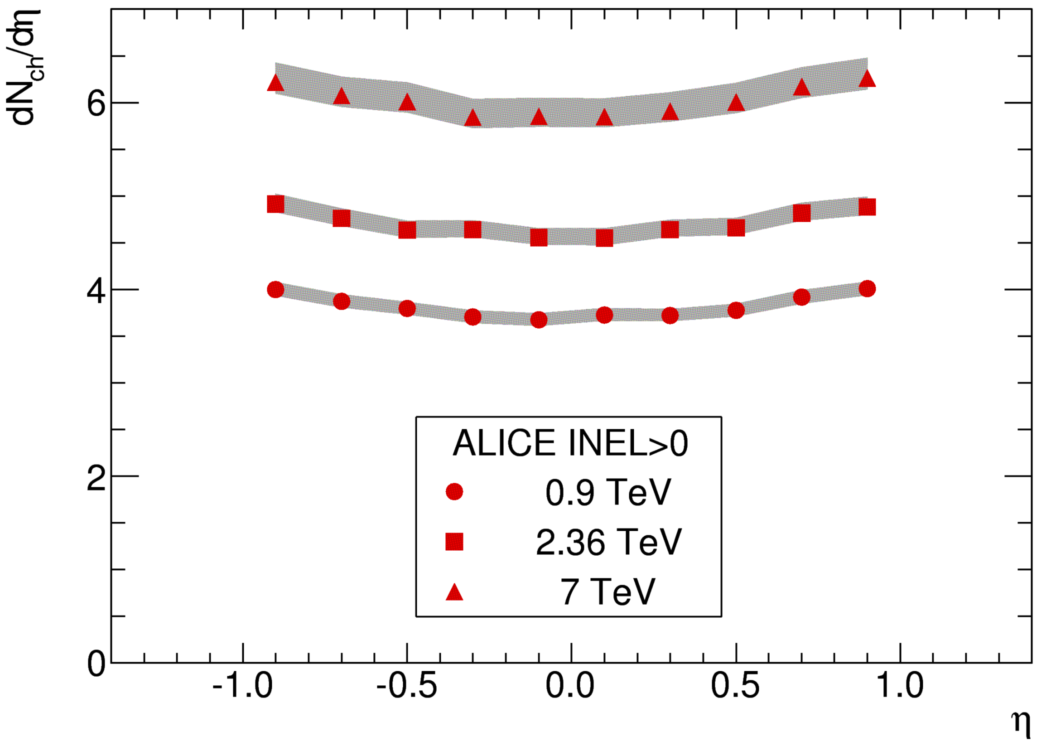
Pb+Pb

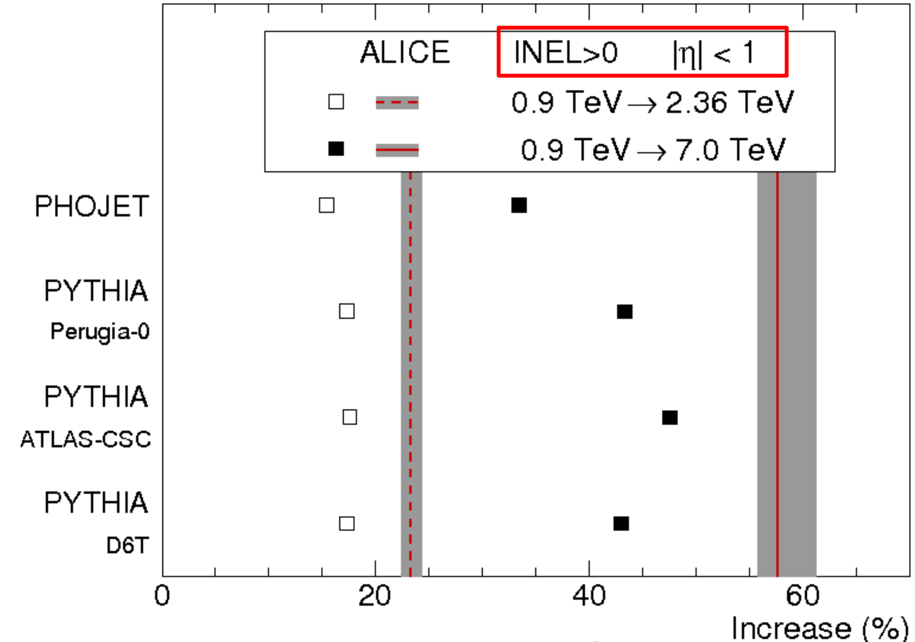
- Multiplicity ($\sqrt{s_{NN}}$=2.76TeV) **arXiv:1011.3916**
- Elliptic flow ($\sqrt{s_{NN}}$=2.76TeV) **arXiv:1011.3914**

And many more in preparation....

Pseudorapidity Density $dN_{ch}/d\eta$

EPJC: Vol. 68 (2010) 345





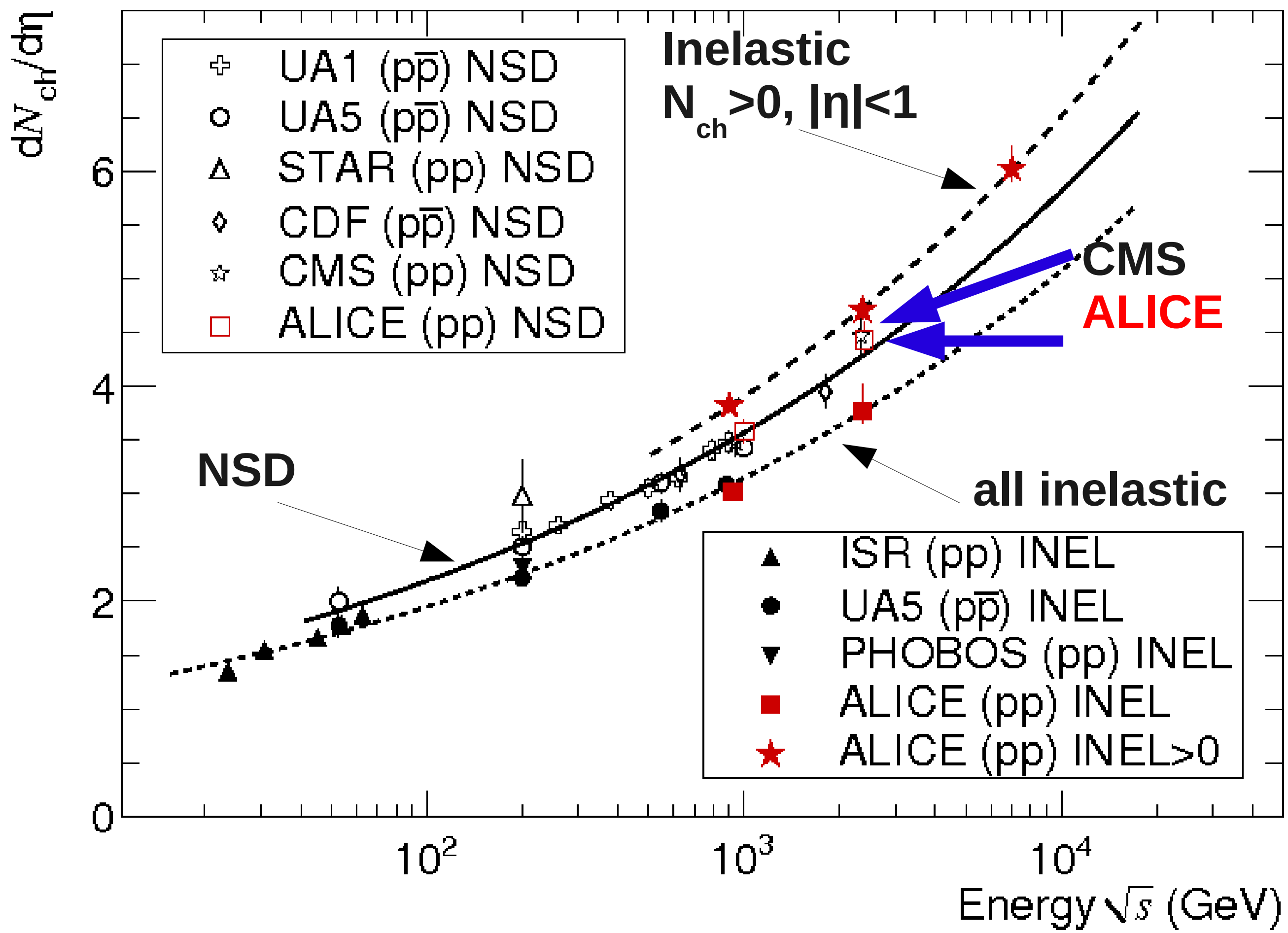
- Relative increase of integrated dN/dη in |η|<1
- Increase in data stronger than predicted by Monte Carlos
- Pythia better than PHOJET

- Pseudorapidity density was measured at ALICE at three different collision energies
- Compare measured dN/dη distributions with predictions of MC generators

√s	ALICE(%)	MCs(%)
0.9 → 2.36TeV:	$23.3 \pm 0.4^{+1.1}_{-0.7}$	15.4-17.6
0.9 → 7TeV:	$57.6 \pm 0.4^{+3.6}_{-1.8}$	33.4-47.6

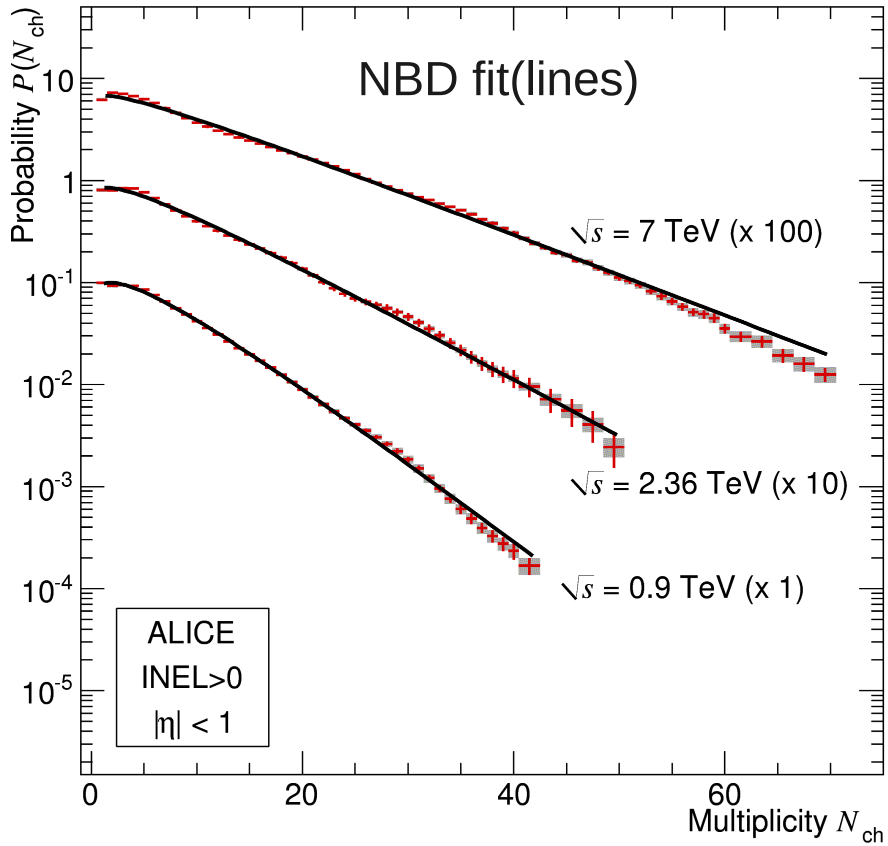
$dN_{ch}/d\eta$ Versus $\sqrt{s}$

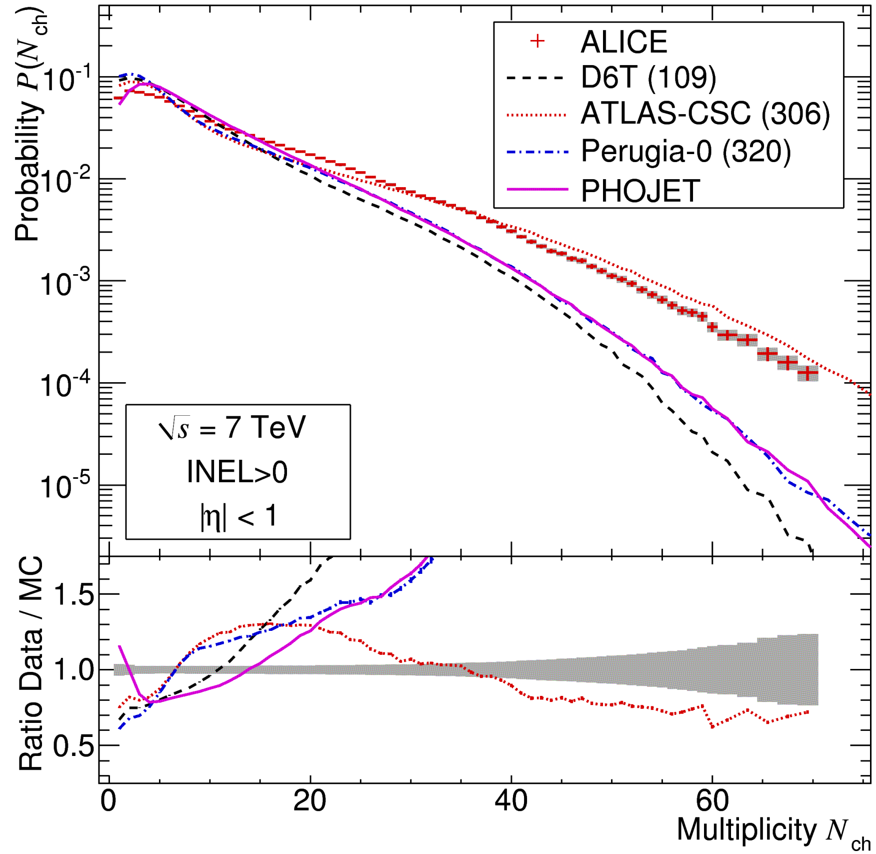
EPJC: Vol. 68 (2010) 345



- $dN_{ch}/d\eta$ increase with $\sqrt{s}$
- Increase well described by a power law $(\sqrt{s})^{0.2}$
- Good agreement between ALICE and CMS results (difference <3%)

Charged Multiplicity

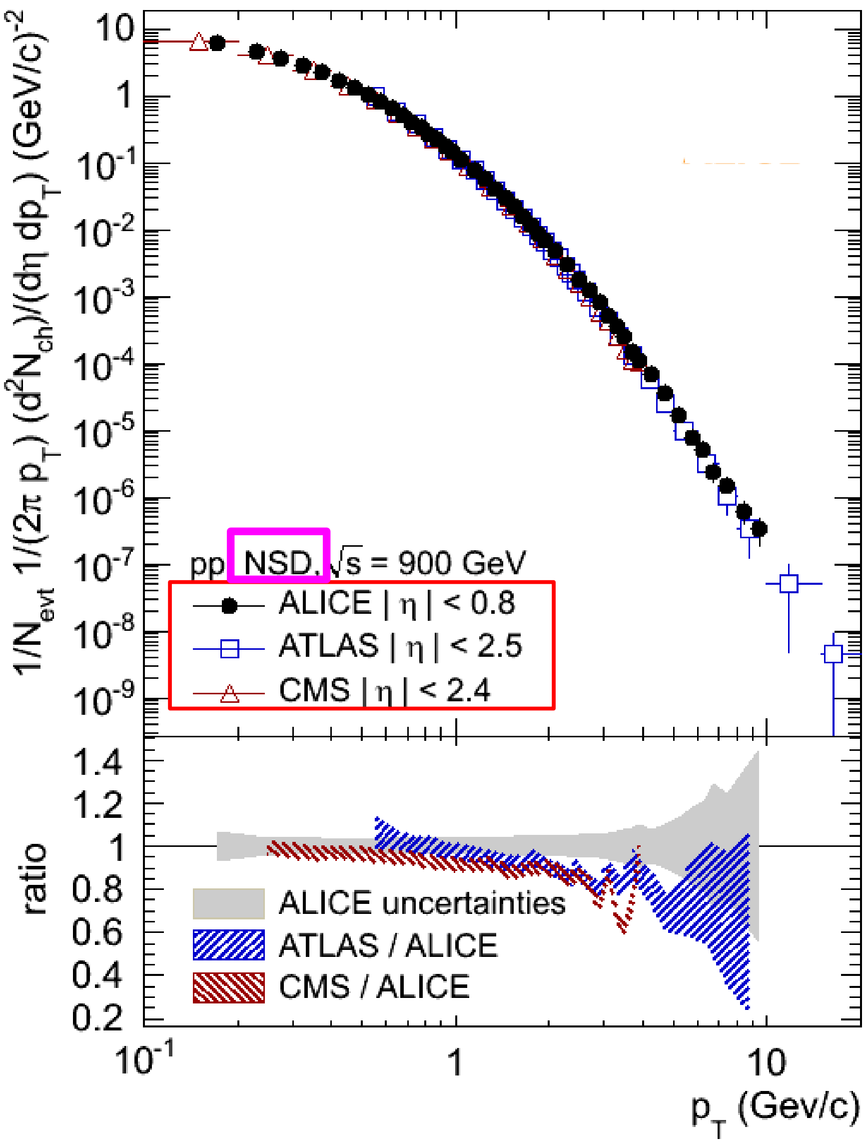




- Measurement of charged multiplicity at 0.9, 2.36 and 7 TeV
  - Negative binomial distribution describes shape of distributions fairly well
- Event generators do not reproduce shape and tail of multiplicity distribution
  - Pythia tune ATLAS-CSC is close to data only at high multiplicities

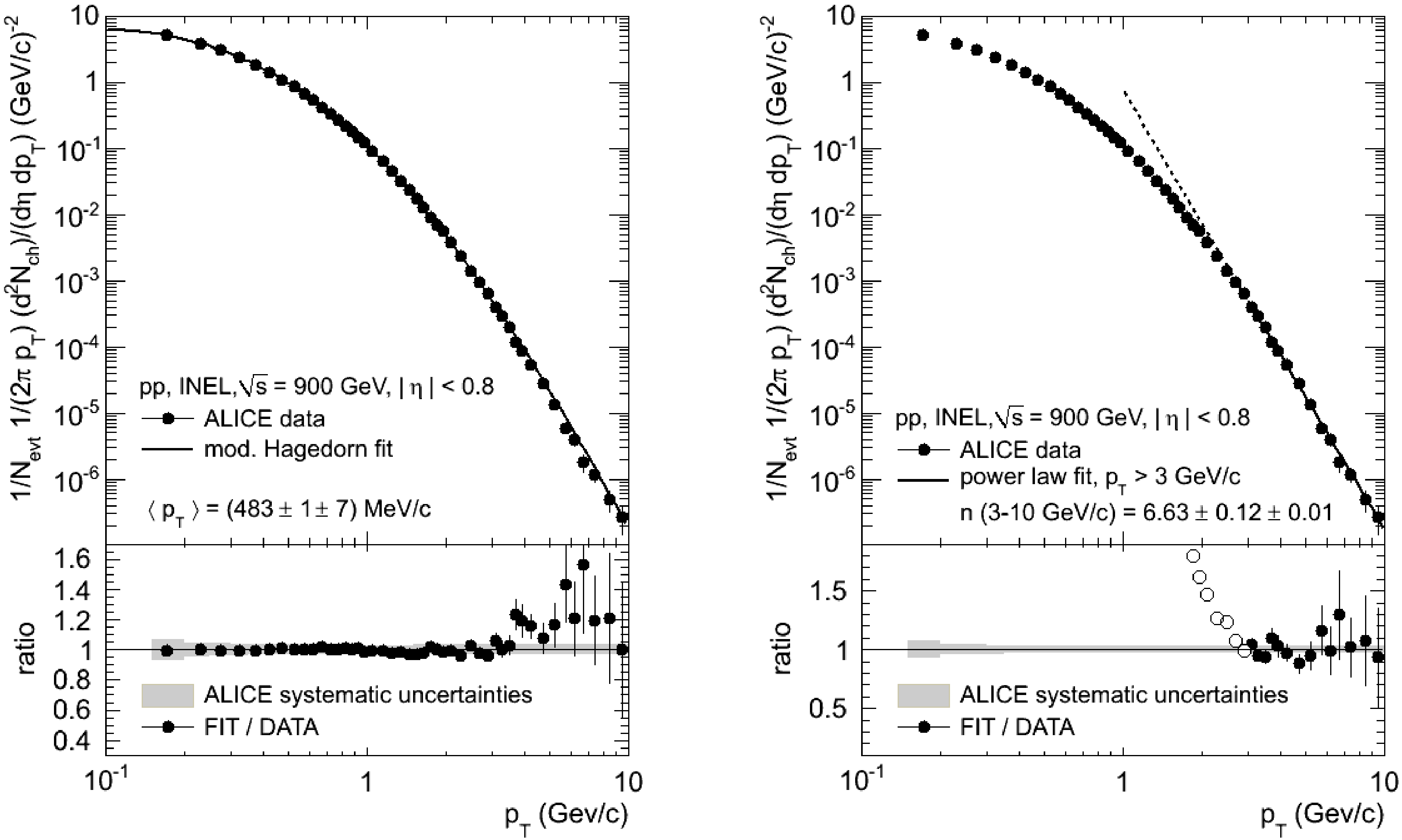
Transverse Momentum Distribution

PL B: Vol. 693 (2010) 53



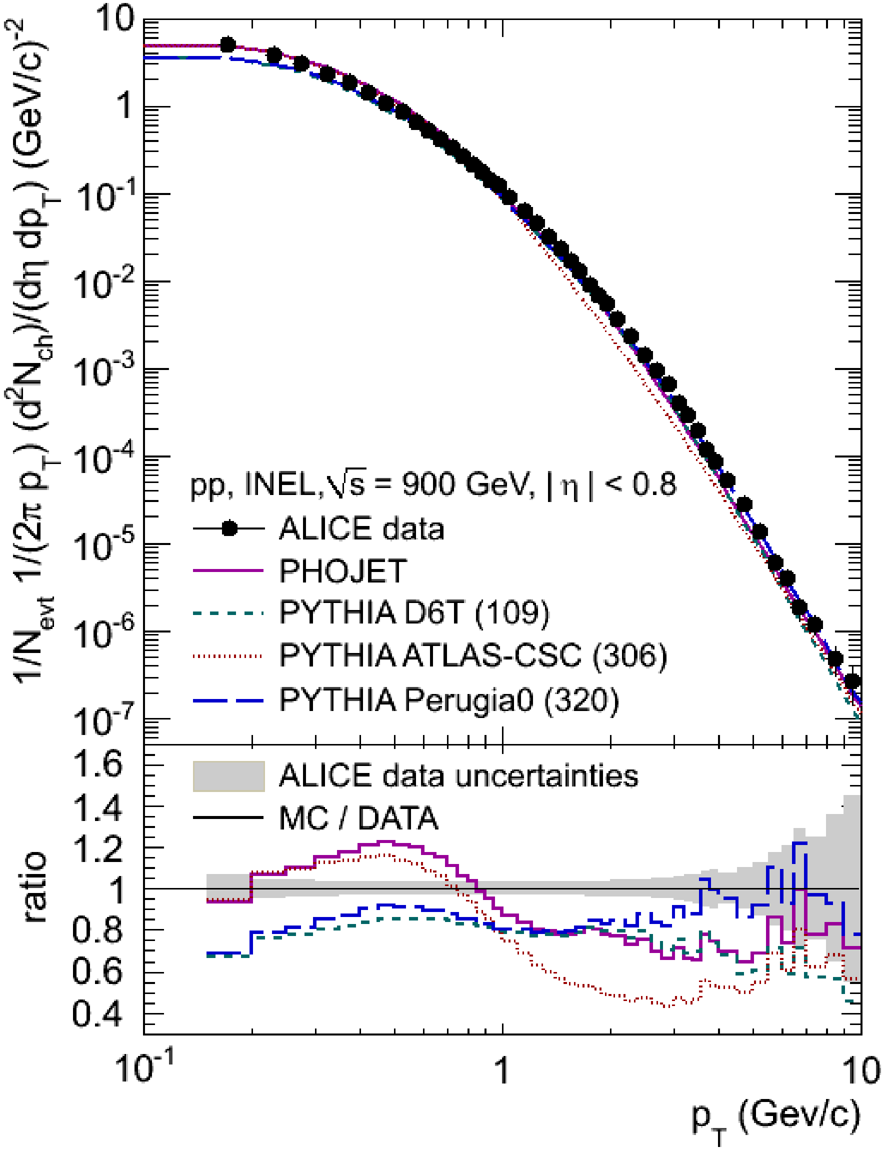
- non-single-diffractive (NSD) events
- p_T spectrum from 0.15 to 10 GeV/c at $\sqrt{s}$=900 GeV
- Comparison to ALICE's dN_{ch}/dp_T to CMS and ATLAS results
  - Different η acceptance at ALICE, ATLAS, and CMS
  - Spectrum seems to be harder at mid-rapidity region

Transverse Momentum Distribution



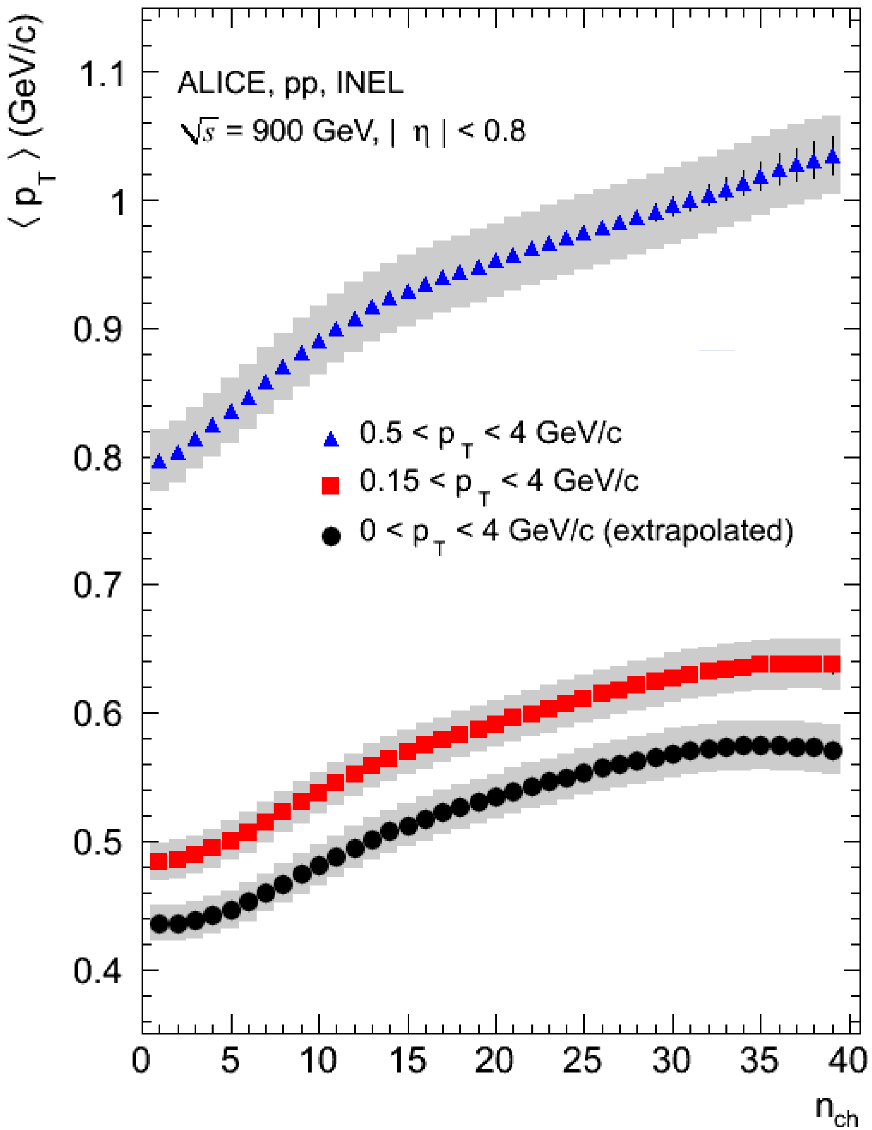
- Modified Hagedorn function describes full range of spectrum
- Starting from 3 GeV/c, the power law fit gives a good description

Transverse Momentum Distribution



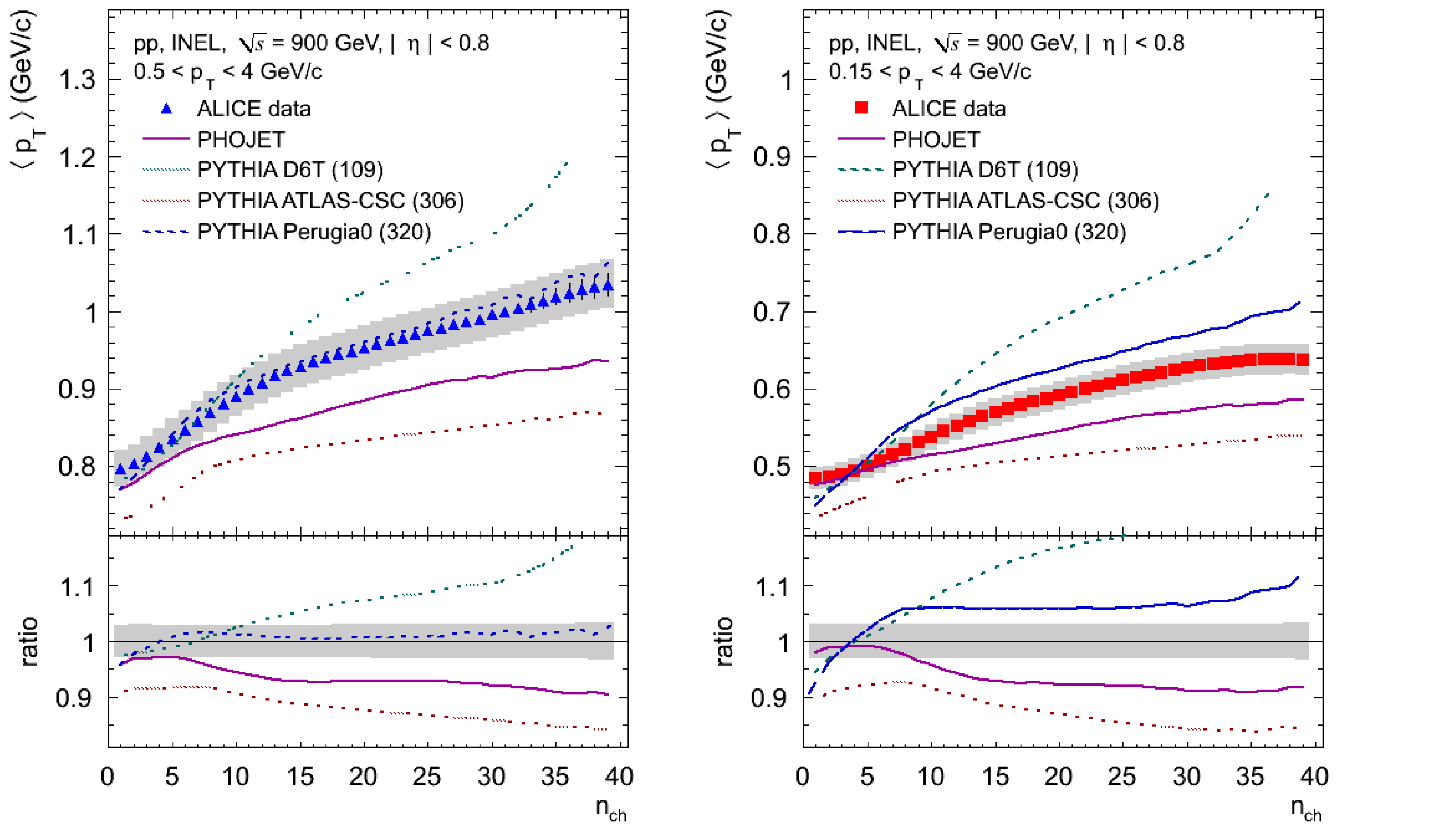
- Pythia Perugia-0 and D6T describe shape of momentum distribution well, but yield is lower than data
- Results of Pythia tune ATLAS-CSC and Phojet differ from data
  - ATLAS-CSC tune described multiplicity distribution better than the other tunes

Average Transverse Momentum



- $<p_T>$ versus charged multiplicity with $p_{T,Min}$ cut of 0.15 and 0.5 GeV/c
- Also extrapolation to 0 GeV/c
- Check for MCs
  - Need to reproduce both, multiplicity distribution and p_T distribution

Average Transverse Momentum

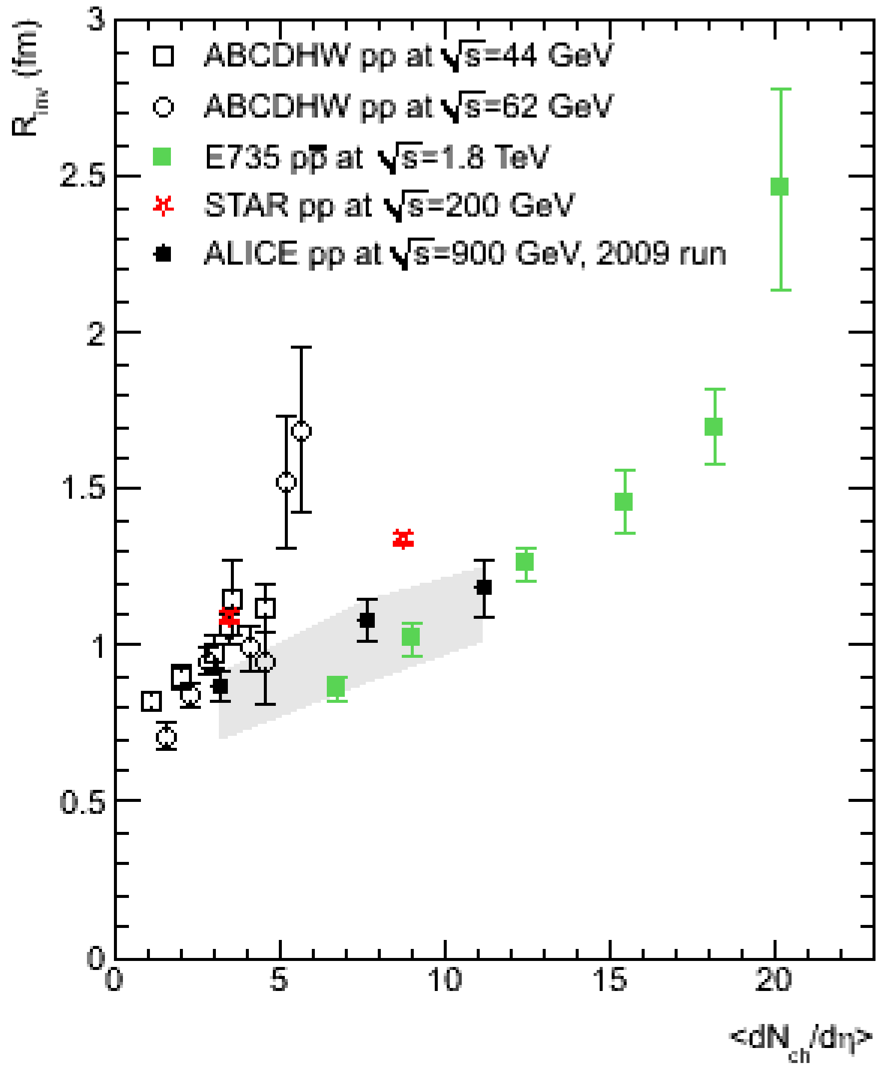


- Pythia Perugia-0 works well for data starting at 0.5 GeV/c
- Distribution including softer particles down to 0.15 GeV/c is not reproduced
  - Soft particles production important to measure
  - Strong point of ALICE

Two-Pion Bose-Einstein Correlations

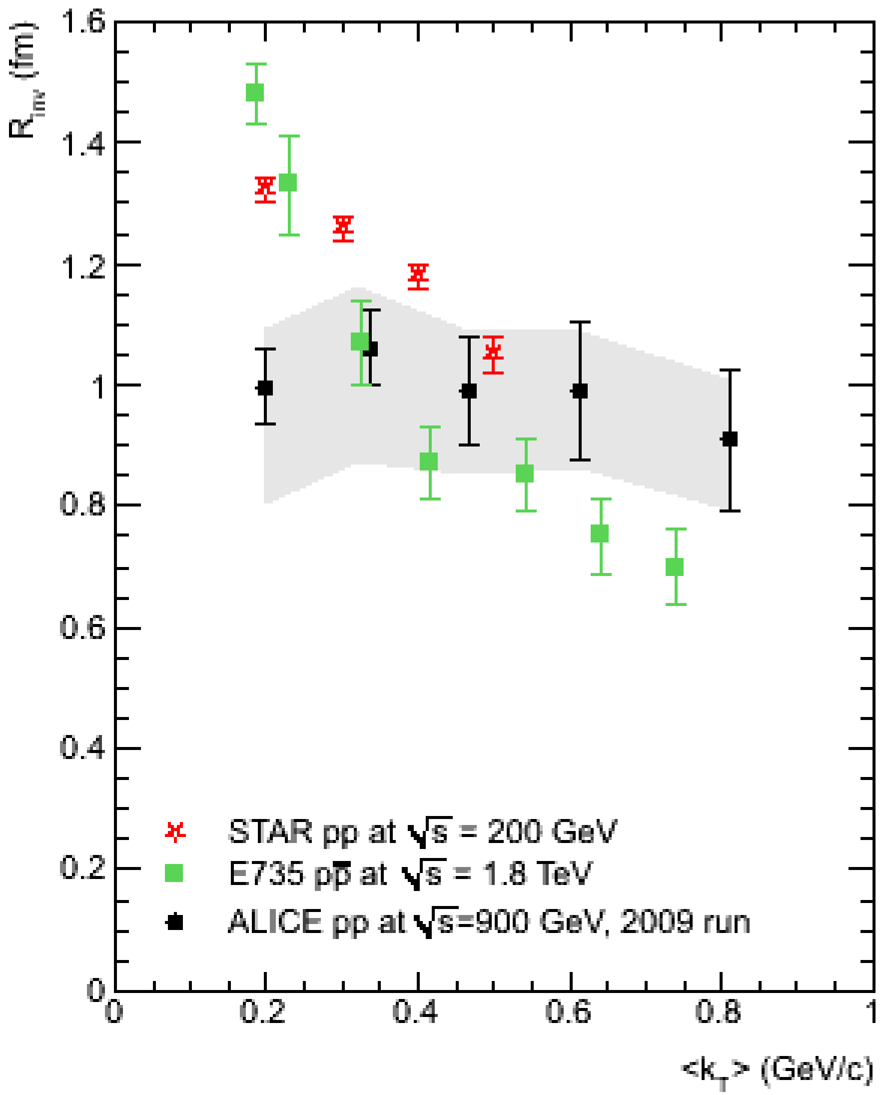
- Bose-Einstein enhancement of identical-pion pairs at low momentum differences $\mathbf{q}=\mathbf{p}_1-\mathbf{p}_2$
  - Asses the spatial scale of the emitting source
  - As function of
    - multiplicity and
    - pair transverse momentum $k_T=|\mathbf{p}_{T1}+\mathbf{p}_{T2}|/2$
- Measure space-time evolution of dense matter systems in heavy-ion collisions
- Increase of one-dimensional HBT radius R_{inv} as function of charged multiplicity at mid-rapidity

PRD: Vol. 82 (2010) 052001



Shaded bands represent the systematic errors related to the baseline shape assumption and the fit range

$<k_T>$ Dependence of R_{inv}



- One-dimensional HBT radius R_{inv} does not change with average pair transverse momentum k_T
- Radii measured at STAR and E735 are inconsistent with results
- Measurement sensitive to choice of baseline (see backup)
- Phojet simulations are used to determine baseline of the correlation

Shaded bands represent the systematic errors related to the baseline shape assumption and the fit range

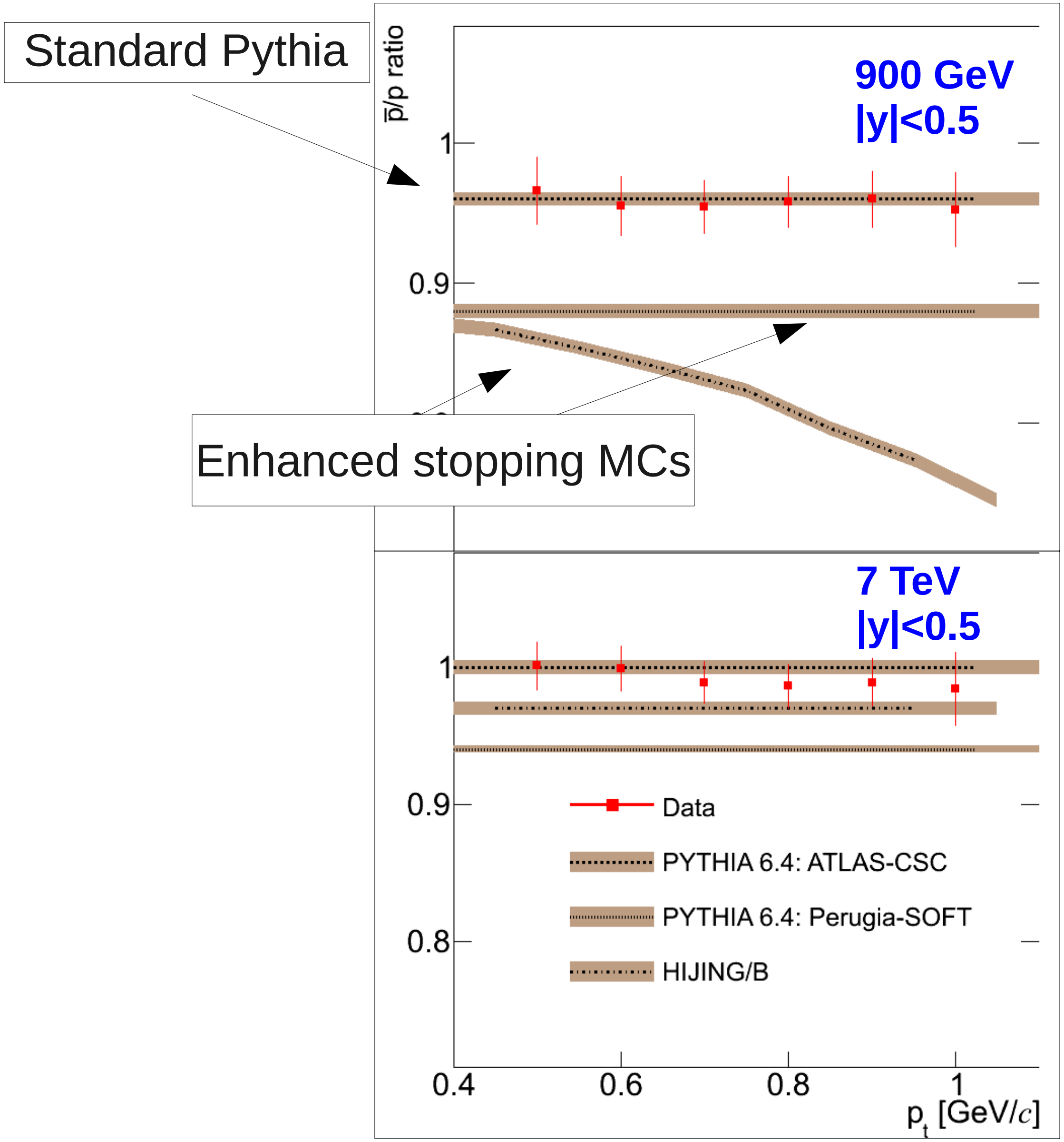
Pair transverse momentum:
$k_T = |\mathbf{p}_{T1} + \mathbf{p}_{T2}|/2$

Antiproton-to-Proton Ratio

- Initial state of p+p collision has baryon number of 2
- Study of redistribution of baryon number in final state allows to investigate baryon number transfer
  - How far towards mid-rapidity can the baryon number be transferred?
  - Model of transfer mechanism
    - Breaking of several strings between valence quarks and so-called string junctions
    - Rapidity loss $\Delta y = y_{beam} - y_{baryon}$
    - Process with large Δy can be described by Regge trajectories
- ALICE has measured $\bar{p}/p$ ratio at mid-rapidity at $\sqrt{s}$ = 0.9 & 7 TeV
  - Challenging measurement: Need to know material budget, cross sections
  - Measurement as function of transverse momentum and collision energy

$\frac{\bar{p}}{p}$ ratio versus Transverse Momentum

- Results of both energies show no dependence on transverse momentum
- Experimental points are compared with different model predictions
  - Models with enhanced stopping do not reproduce the data

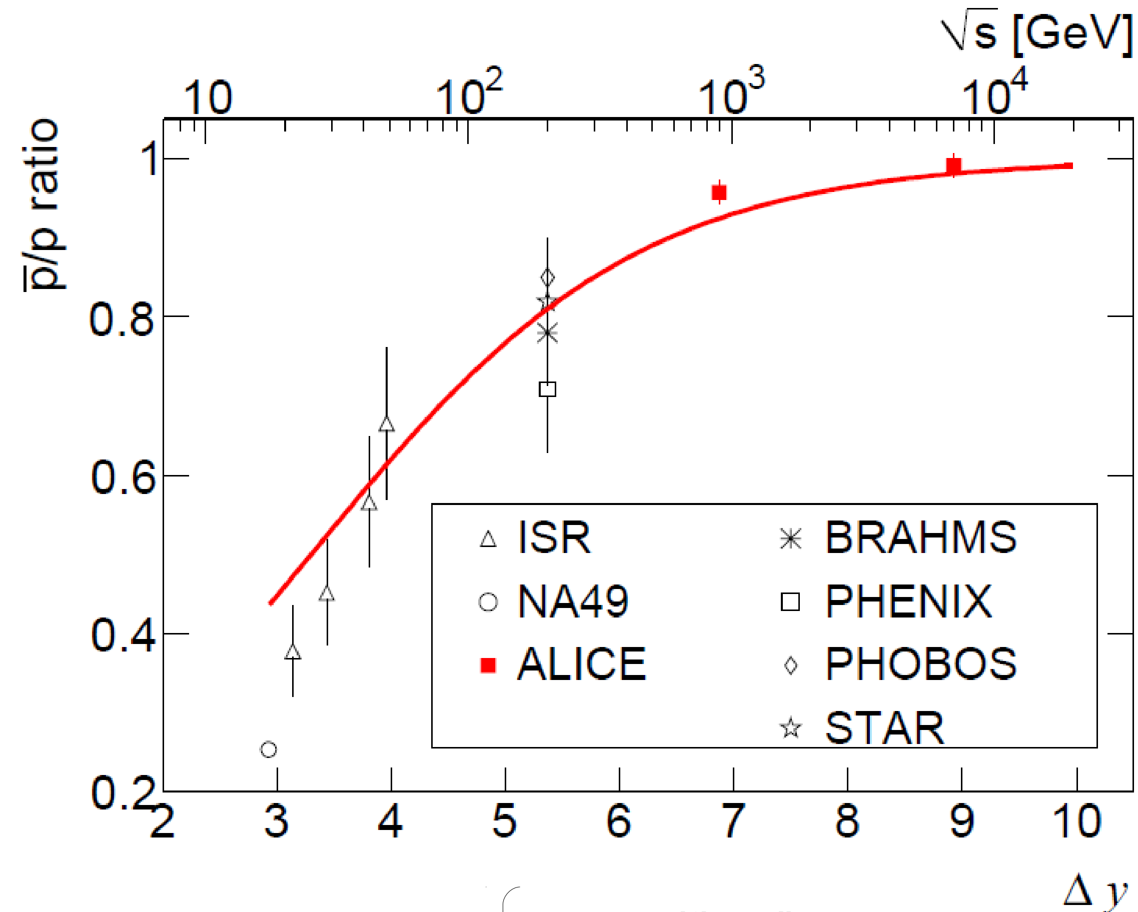


PRL: Vol. 105 (2010) 072002

$\frac{\bar{p}}{p}$ Ratio Versus Collision Energy

- Energy dependence of the ratio can be parameterized based on the contribution of different diagrams
  - Baryon pair production at mid-rapidity and baryon number transfer
  - Junction intercept set to 0.5
  - Result sets tight limits on any additional contributions to baryon number transfer over large rapidity gaps

0.9 TeV: pbar/p = **0.957** ± 0.006(stat) ± 0.014(syst)
7.0 TeV: pbar/p = **0.990** ± 0.006(stat) ± 0.014(syst)



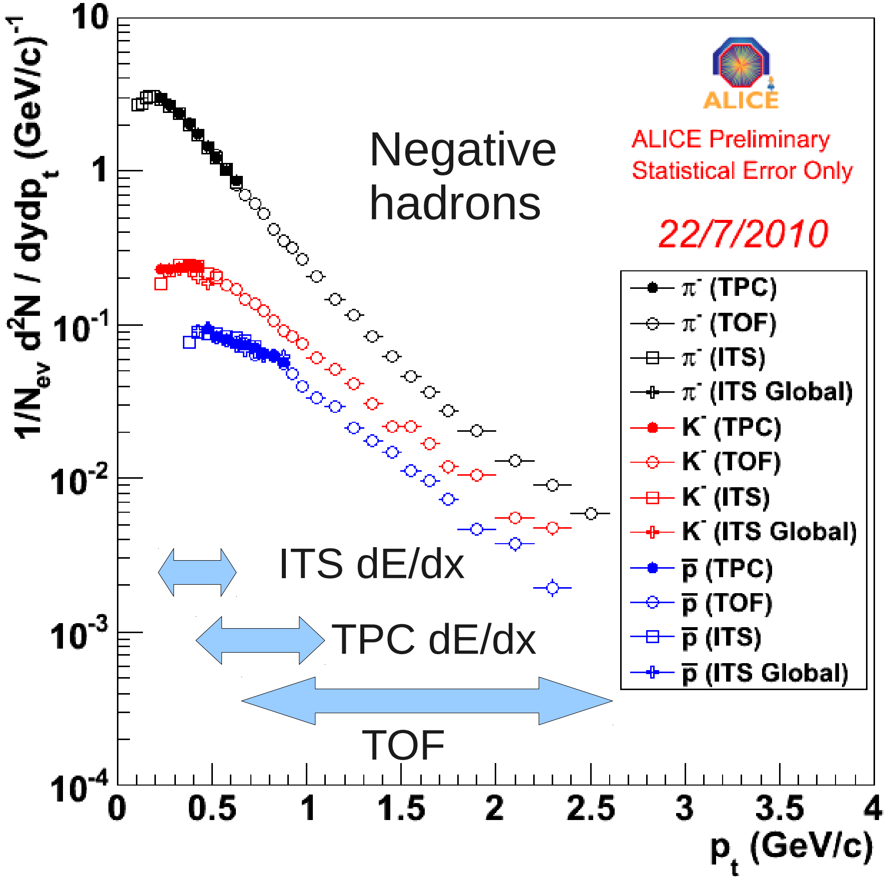
Fit function:

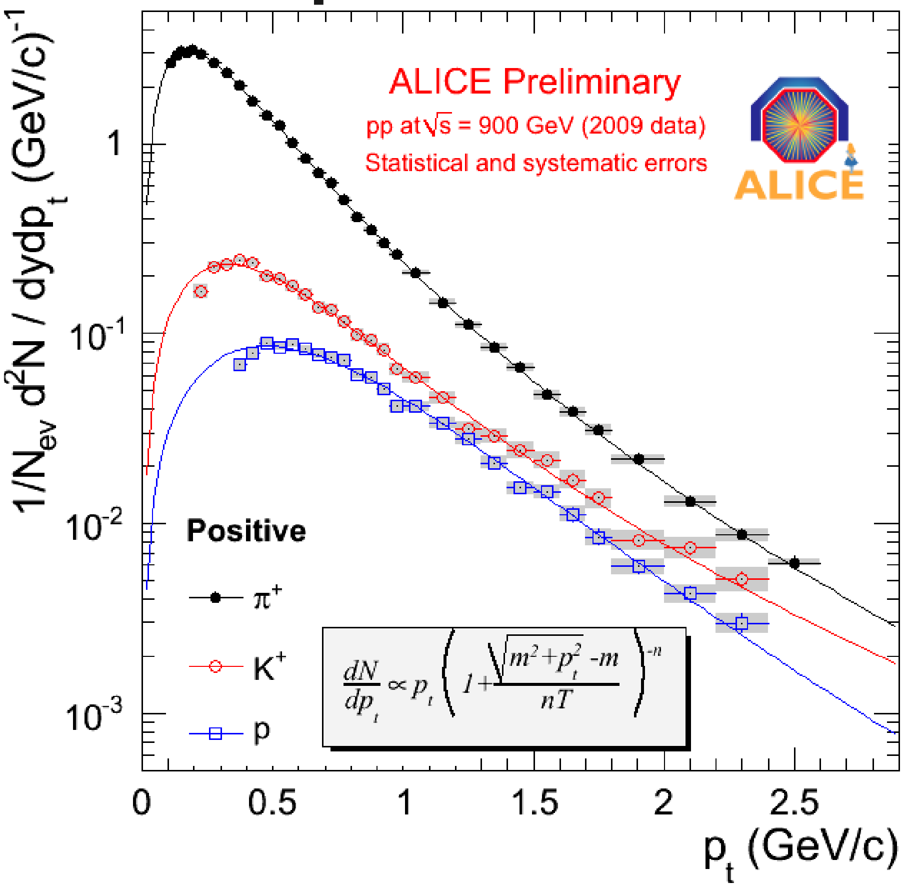
$$\frac{\bar{p}}{p} = \frac{1}{1 + C \cdot e^{(\alpha_J - \alpha_P)\Delta y}}$$

α_J=0.5 (fixed)
α_P=1.2 (fixed)
C=10.0±1.0

PRL: Vol. 105 (2010) 072002

Identified Particle Spectra

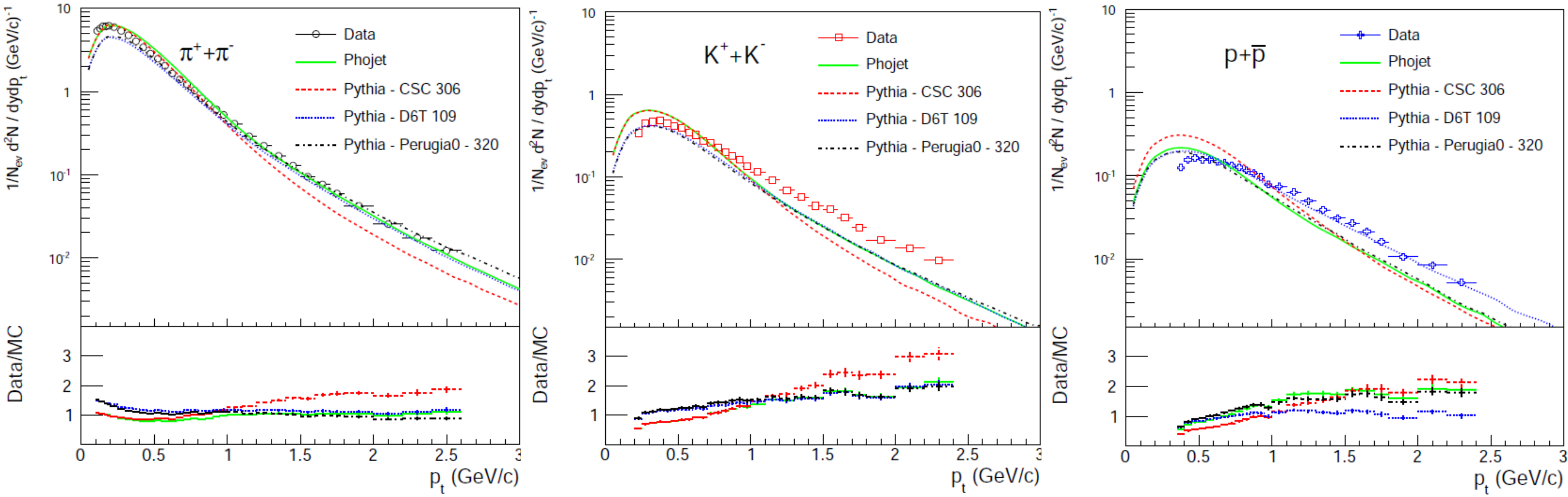




- Identified particle spectra measured with different detectors show good agreement in overlapping areas
  - Details: see backup slides
- All relevant efficiencies are under control

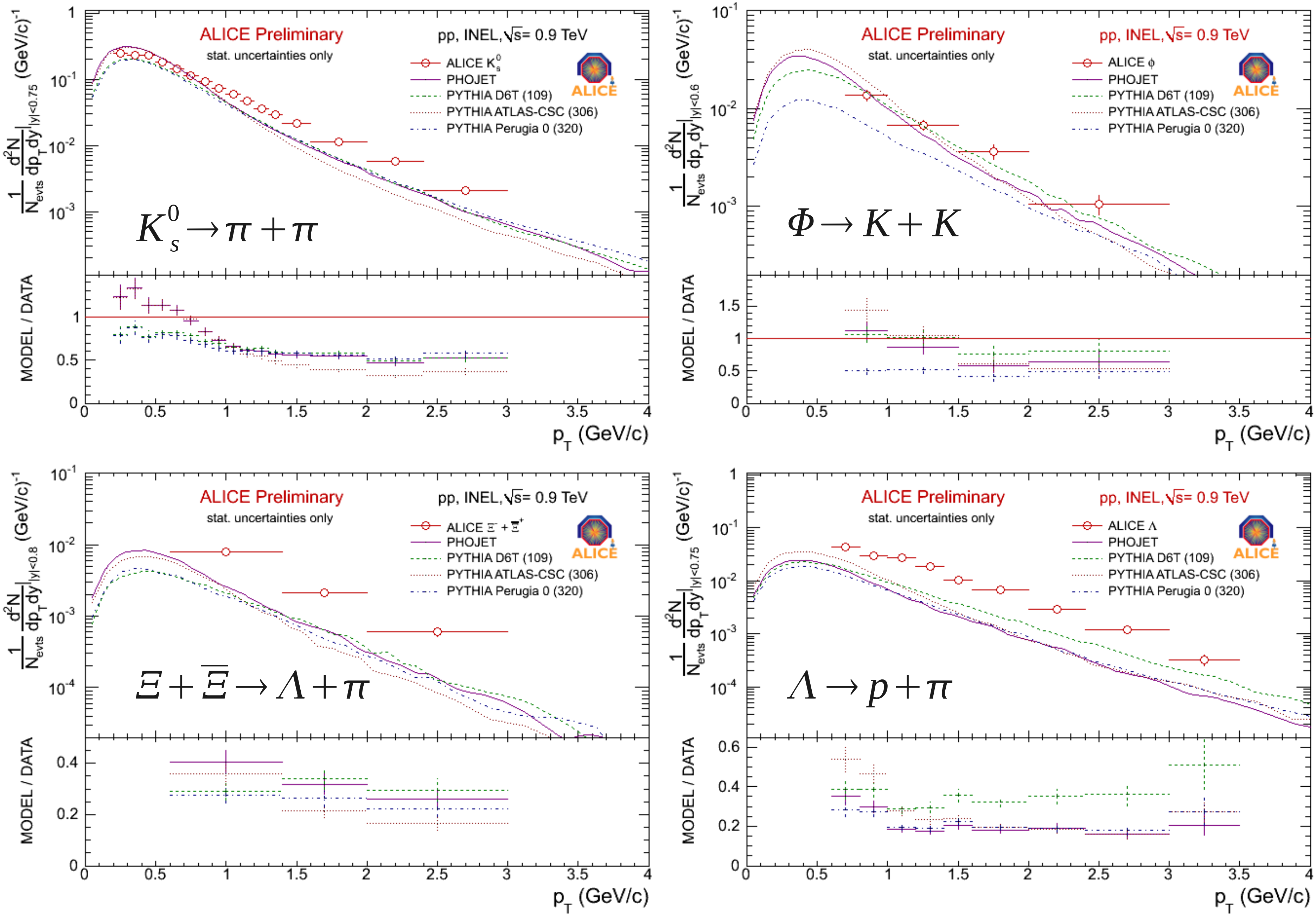
- Combining results of detectors by averaging results using systematic errors as weight
- Lévy (Tsallis) function fits resulting spectra

MC Comparison Hadron Yields

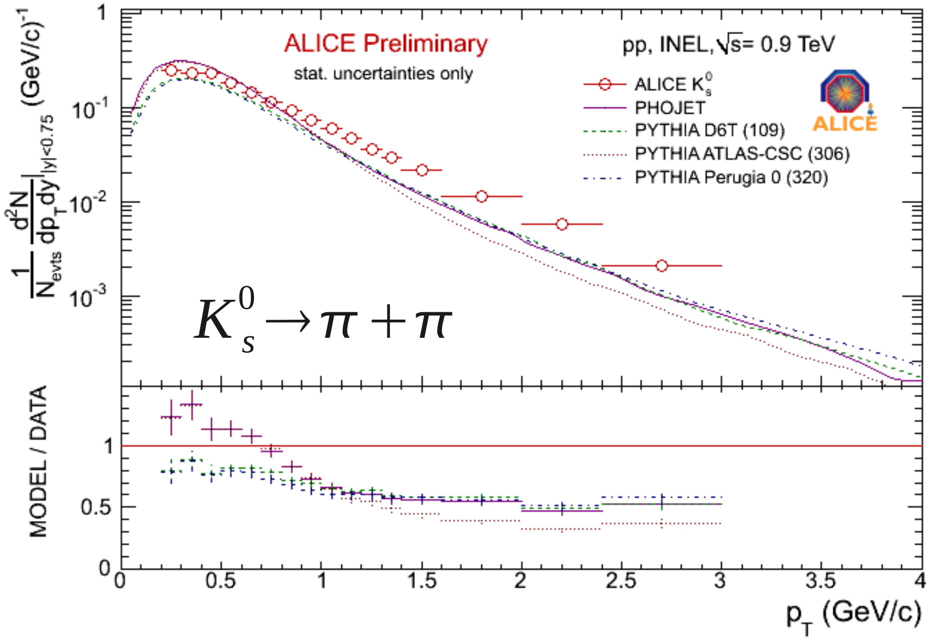


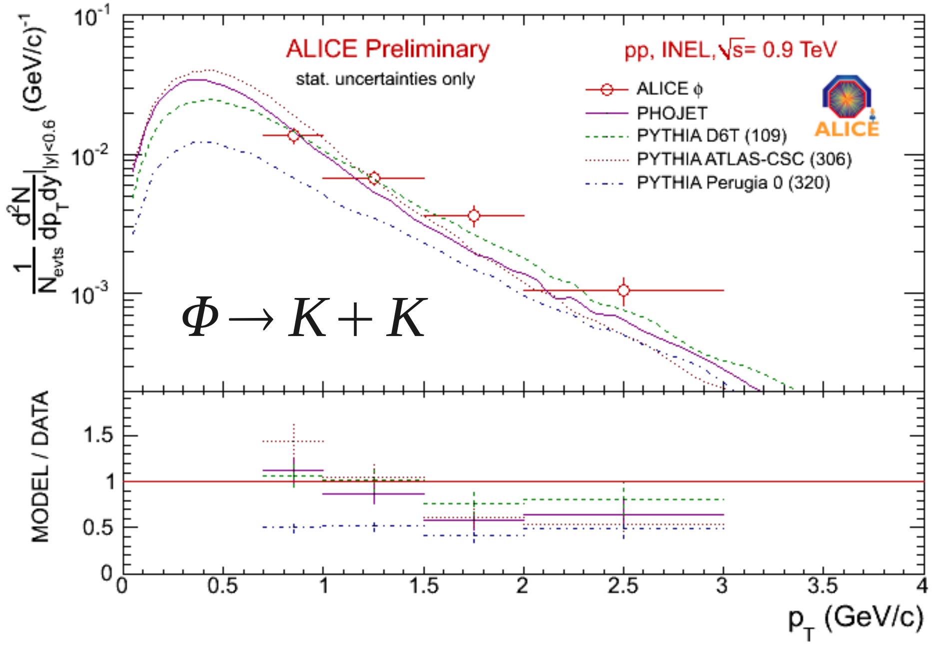
- PYTHIA tunes Perugia0 and D6T gave a reasonable description of the unidentified charged hadron spectra (slide 11)
- Especially kaon and proton spectra show large deviations
  - Kaon yield underestimated at high p_T by all event generators
  - Proton yield underestimated except by Pythia D6T

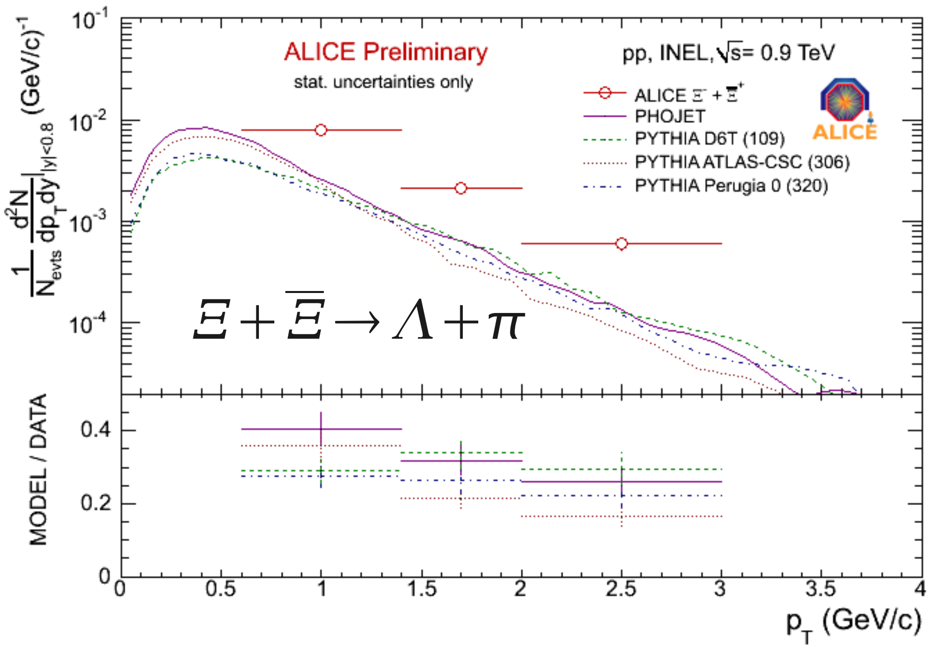
Strange Particle Yields

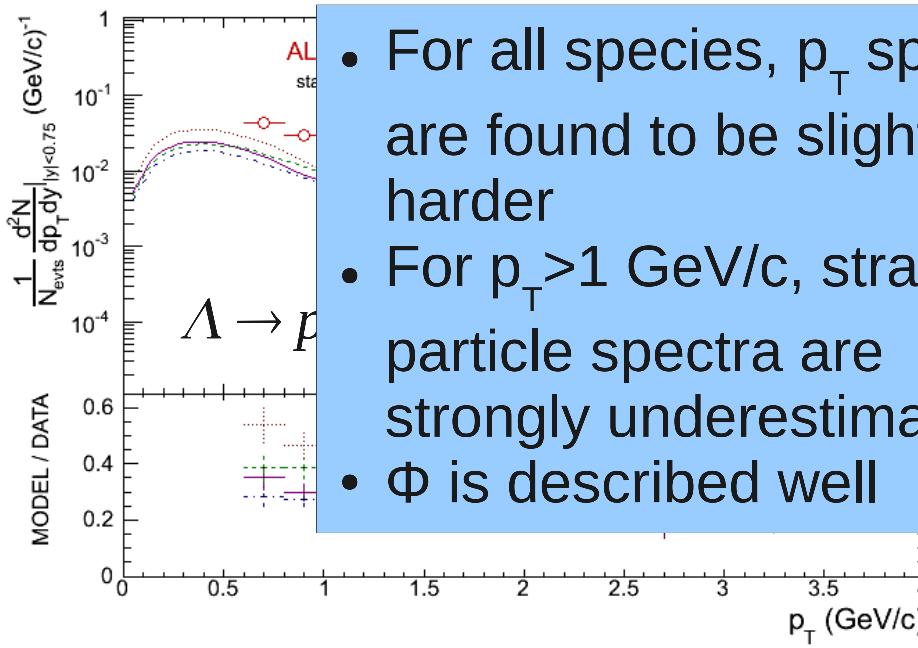


Strange Particle Yields





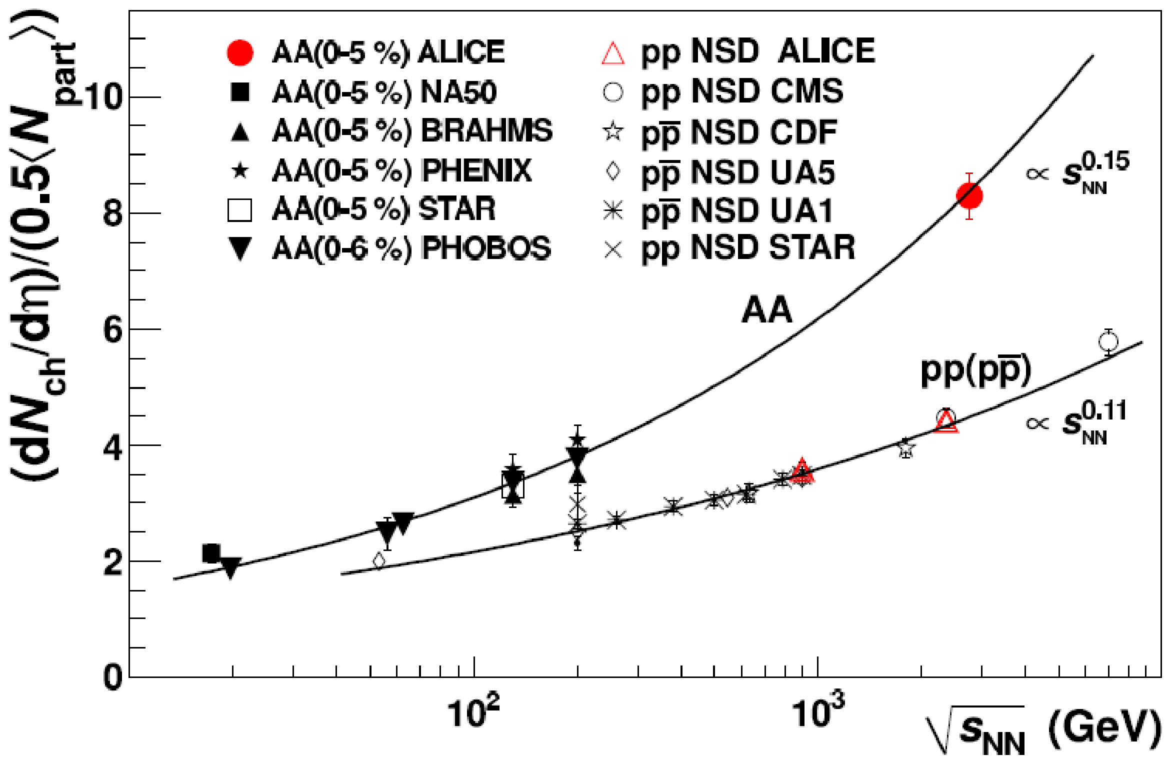




- For all species, p_T spectra are found to be slightly harder
- For p_T>1 GeV/c, strange particle spectra are strongly underestimated
- Φ is described well

$dN_{ch}/d\eta$ in central Pb+Pb at $\sqrt{s_{NN}} = 2.76\,TeV$

arXiv:1011.3916



$dN_{ch}/d\eta = 1584 \pm 4$ (stat.) ± 76 (syst.)

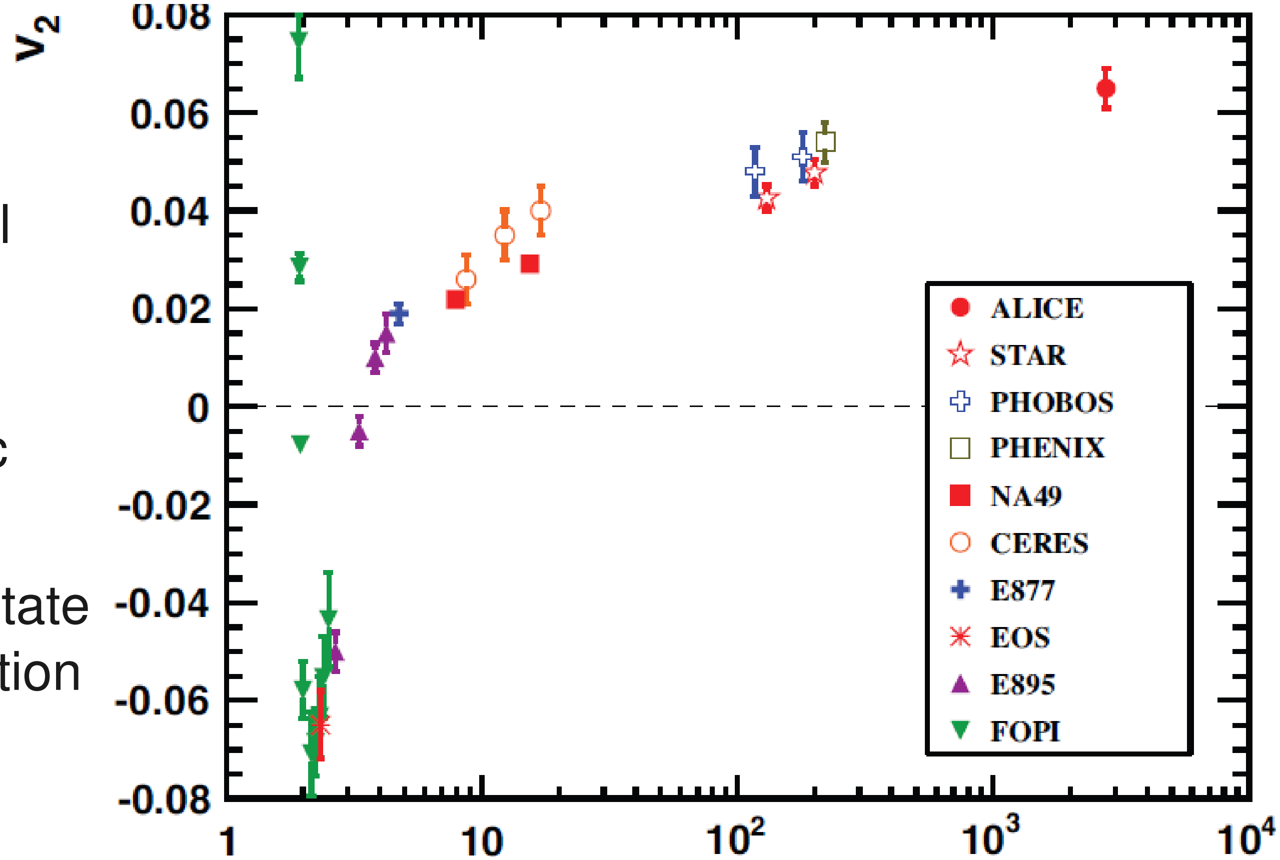
$(dN_{ch}/d\eta)/(0.5\langle N_{part}\rangle) = 8.3 \pm 0.4$ (syst.)
using $\langle N_{part}\rangle = 381 \pm 18$ from Glauber model fit

- Charged-particle pseudo-rapidity density for the most central 5%of hadronic cross section
  - Stronger energy dependence than measured in p+p
  - Values significantly larger than those measured at RHIC
    - Increase by factor 2.2 with respect to RHIC Au-Au 200 GeV
  - Value 1.9 higher as at p+p at same energy

Elliptic flow in Pb+Pb at $\sqrt{s_{NN}} = 2.76\,TeV$

arXiv:1011.3914

- Medium geometry is asymmetric in non-central collision (almond shape)
- Spacial asymmetry is converted into anisotropic momentum distribution
- Second moment of final state hadron azimuthal distribution is call elliptic flow v_2



- Integrated elliptic flow at 20-30% centrality increases about 30% from RHIC to LHC energies
  - Increase is higher than current predictions from ideal hydrodynamic models
  - Hydrodynamical models which incorporate viscous corrections and hybrid models reproduced such an increase

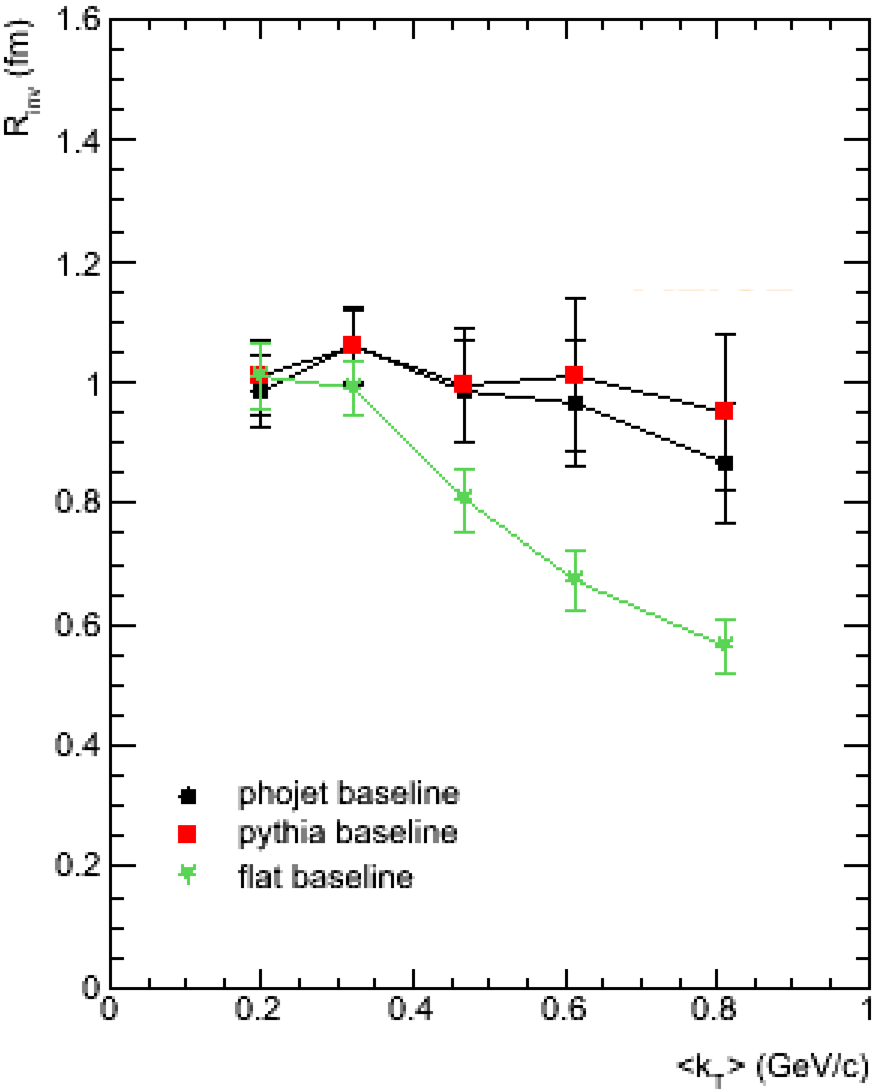
Summary

- Multiplicity
  - Increase with collision energy is significantly larger than expected by MCs
- Transverse Momentum Spectra
  - Correlation of $<p_T>$ and N_{ch} not explained by any MC model, especially at low p_T
- Two-Pion Bose-Einstein Correlations
  - Source size R_{inv} increases with event multiplicity
  - R_{inv} shows no dependence on pair momentum k_T
- Antiproton to Proton Ratio
- Identified particle yields
  - Kaon and proton yields are underestimated by Monte Carlos
- Strangeness
  - Yields of K_S^0, Λ and Ξ are underestimated by MC, whereas Φ is described well
- Heavy Ion collisions
  - Multiplicity
  - Elliptic flow
- Much more to come

Backup

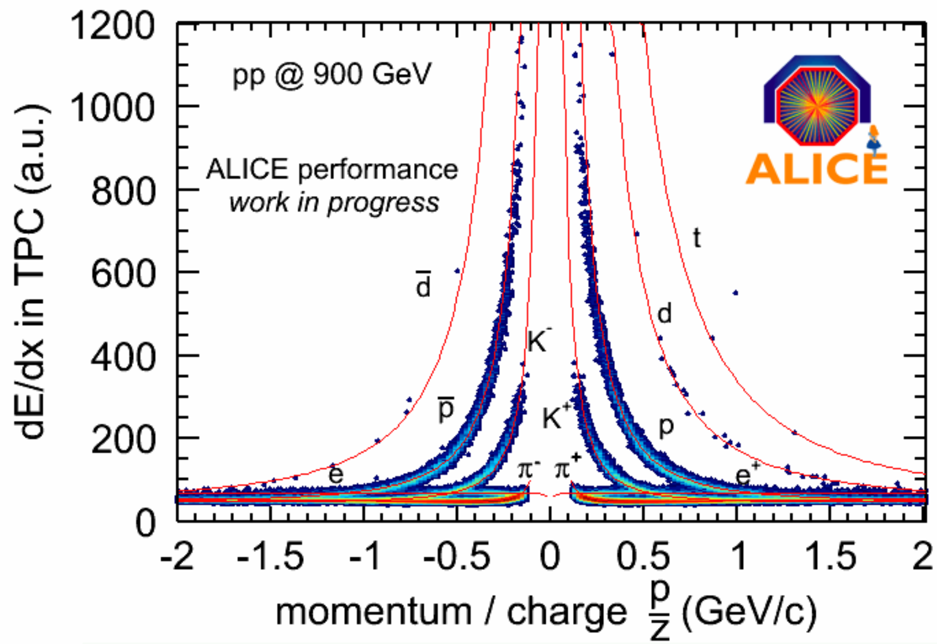
Baseline for k_T Dependence

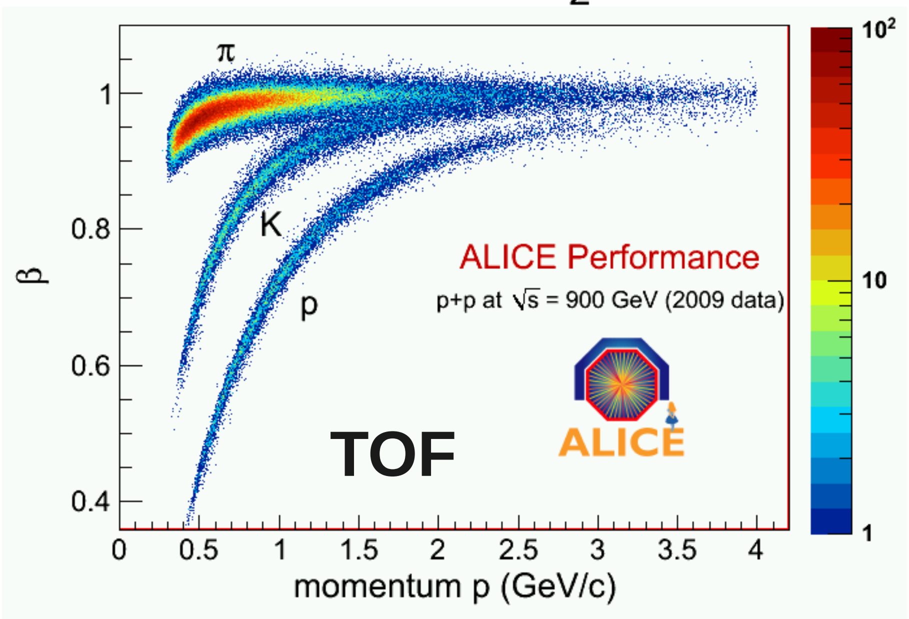
- Measurement sensitive to choice of baseline
- Usage of flat baseline changes k_T dependence
  - R_{inv} is falling with increasing $\langle k_T \rangle$
- STAR and E735 use flat baseline
  - Choice of baseline is again under investigation in STAR



Particle Identification

- Identification of charged hadrons (π, K, p) using ITS, TPC, TOF
  - Specific energy loss dE/dx in ITS and TPC
  - Time of flight (TOF) information for particle
- Identification on a track-by-track basis where bands are clearly separated
- Identification on statistical basis in overlapping regions
- Complementary measurement of kaons via identification of weak decay kink topology in TPC

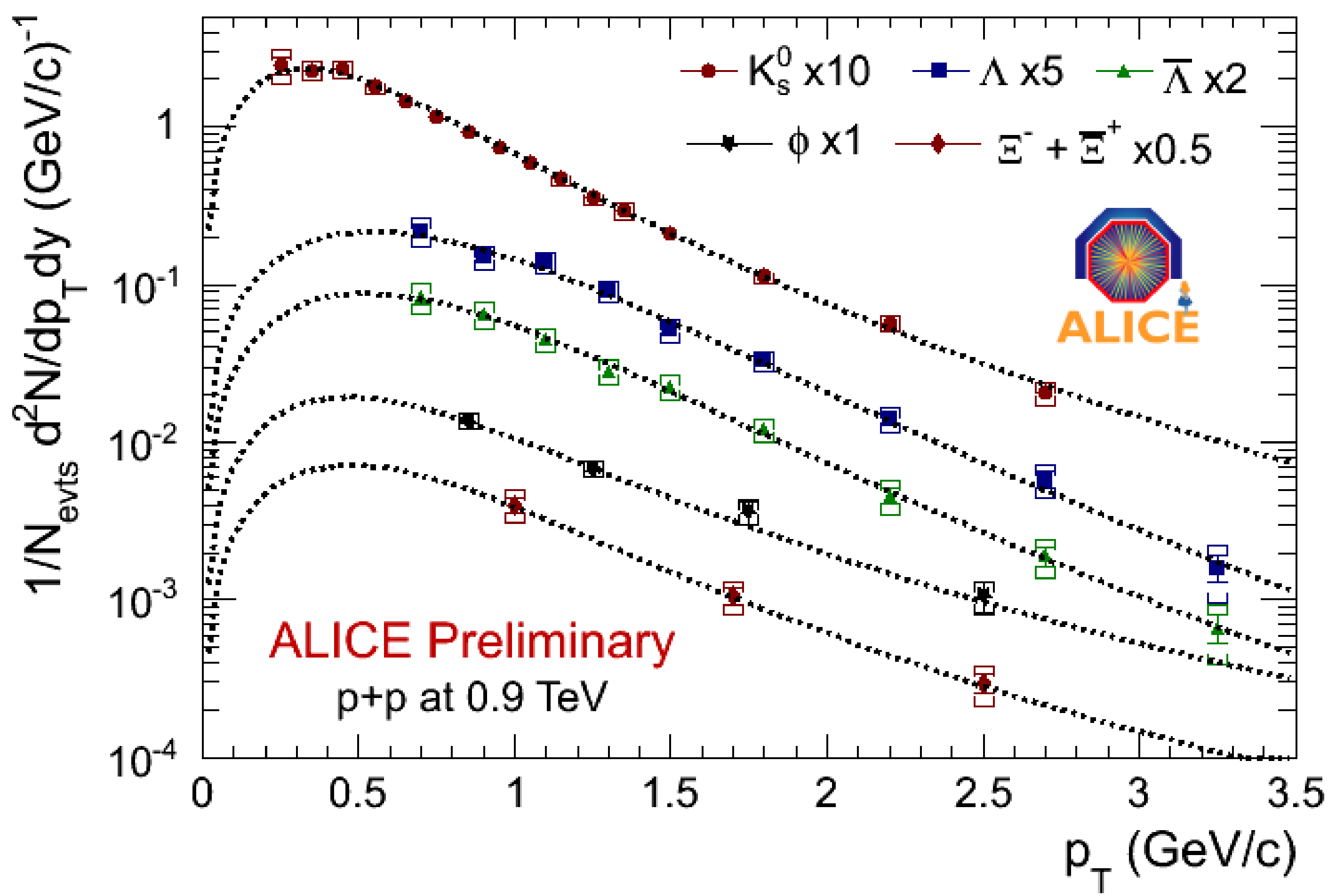




Strange Particle Yields

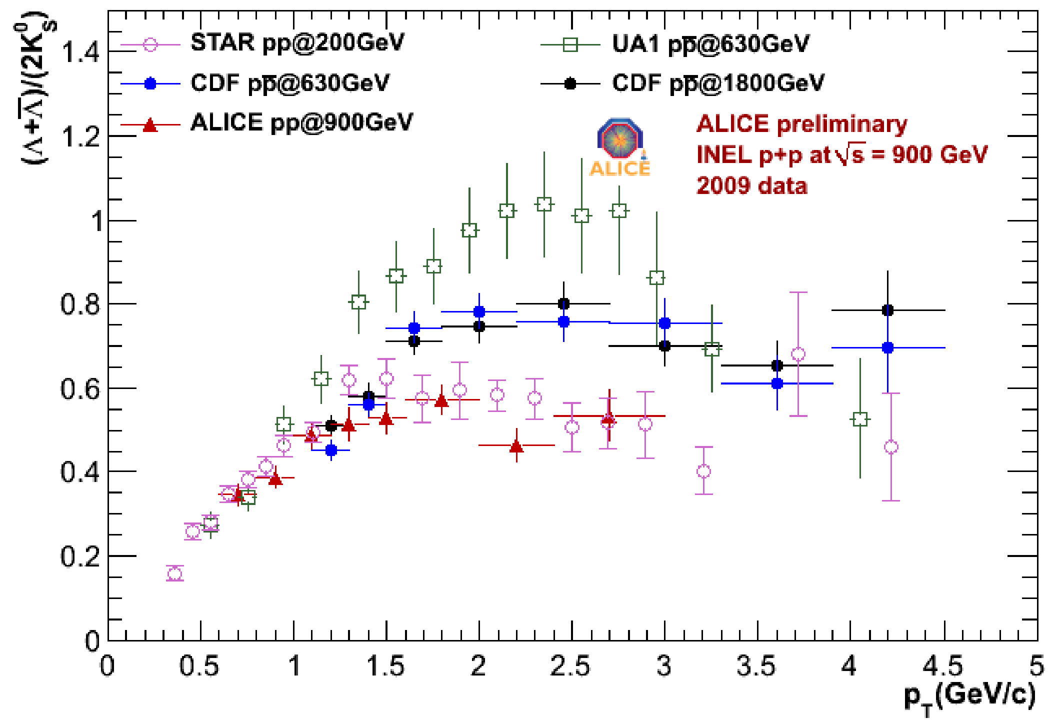
- Measurement of strange mesons and single and double strange baryons at central rapidity and √s=900GeV
  - K_S^0, Φ and Λ, Ξ

- Scaled for visibility
- Fit with Levy function
- Fit values are used in combination with measured range to estimate the the integrated yields



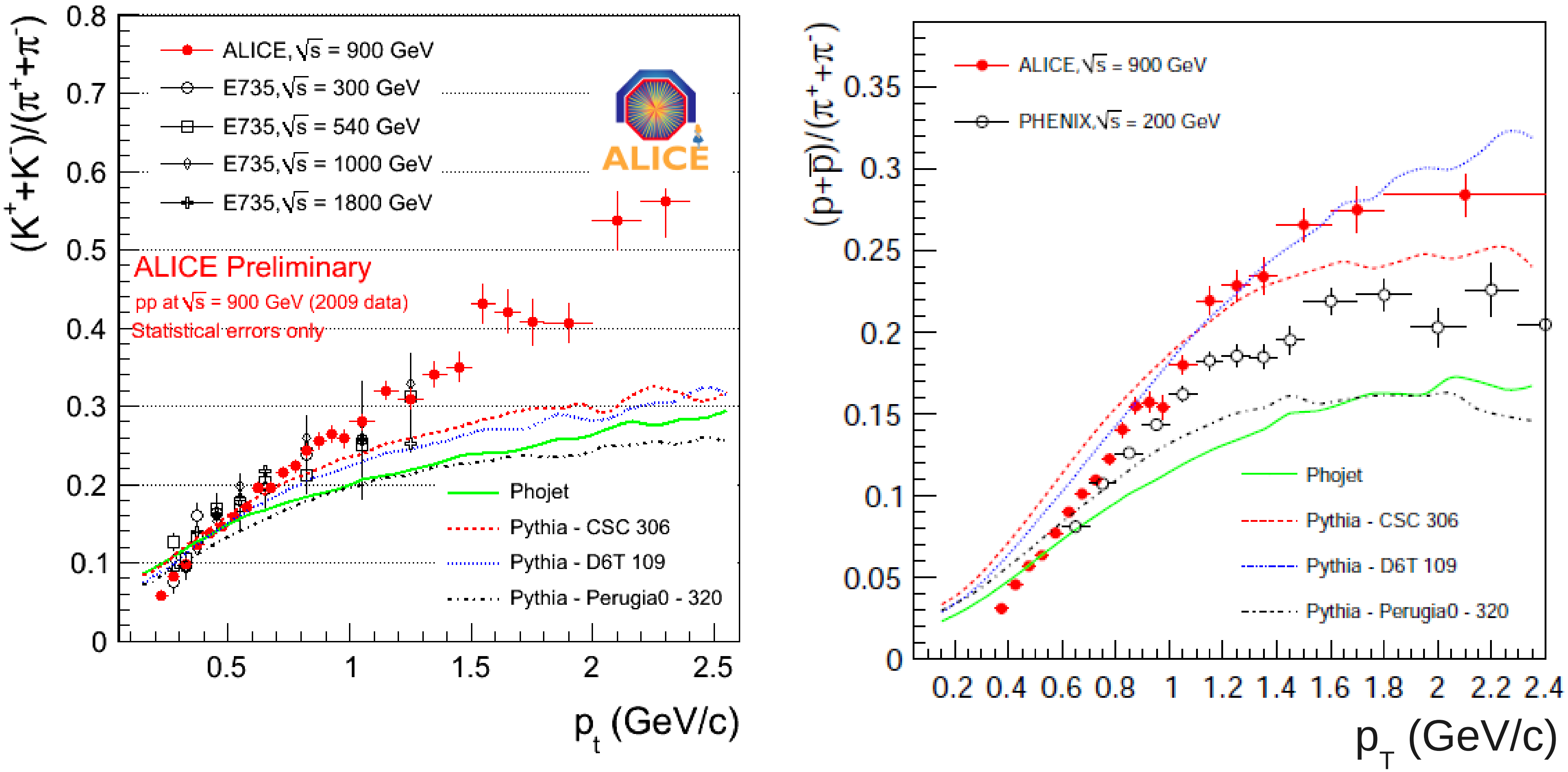
Baryon to Meson (Λ-K_S^0) Ratio

- Acceptance windows of experiments differ significantly
- Good agreement between STAR (200 GeV) and ALICE (900 GeV)
- Results of CDF at two energies are close
  - Both results would suggest no energy dependence
- ALICE results are different from CDF and UA1 results for p_T>1.5
- Results at same energy of 630 GeV from CDF and UA1 do not agree with each other
  - Not feed down corrected
- To be further investigated



ALICE:	0.9 TeV,	|y|<0.75
STAR:	0.2 TeV,	|y|<0.5
CDF:	0.63 TeV,	|η|<1.0
CDF:	1.8 TeV,	|η|<1.0
UA1:	0.63 TeV	Λ: |η|<2.0,K:|η|<2.5

Hadron Yield Ratios



- K/π ratio almost independent of √s
- both ratios (kaons/pions and protons/pions) obtained from real data are not completely described by any model prediction