Soft QCD Results from ALICE

QCD @ LHC 2011
St. Andrews, Scotland, 22nd-26th August 2011

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Why pp Physics with ALICE?

- Provide data to constrain and tune Monte Carlo generators and other phenomenological models

- Search for possible signals of a quark-gluon plasma formation in high-multiplicity pp collisions

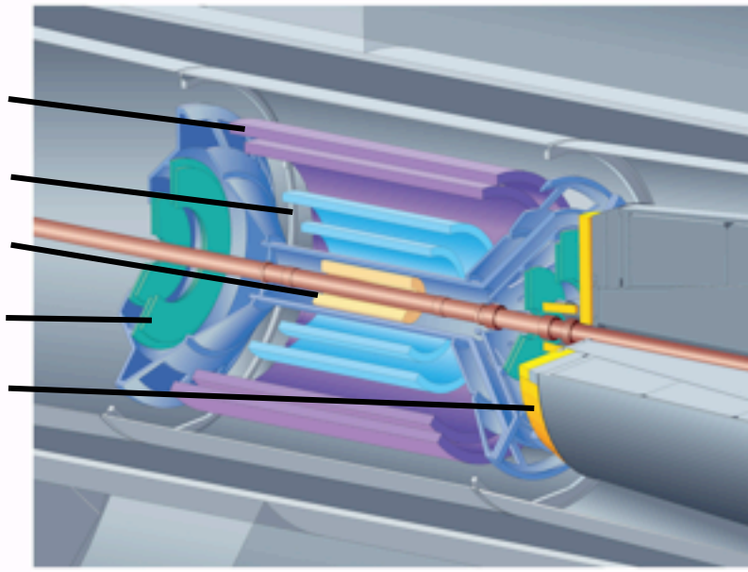
- Provide baseline measurements for the interpretation of A+A data

Related ALICE talks:
K. Safarik, ALICE data for model tuning, QCD@LHC 2010
L. Ramello, Soft QCD results from Alice Experiment, PLHC 2011

ALICE

i.e., at least one charged particle within 8 units of η

pp min. bias trigger: V0-A | SPD | V0-C



EMCAL

HMPID

ZDC

PMD

TPC

V0 and T0 (A side)

ITS

dipole magnet

TRD

TOF

PHOS

ZDC

muon tracking (2.5 < η < 4)

L3 magnet

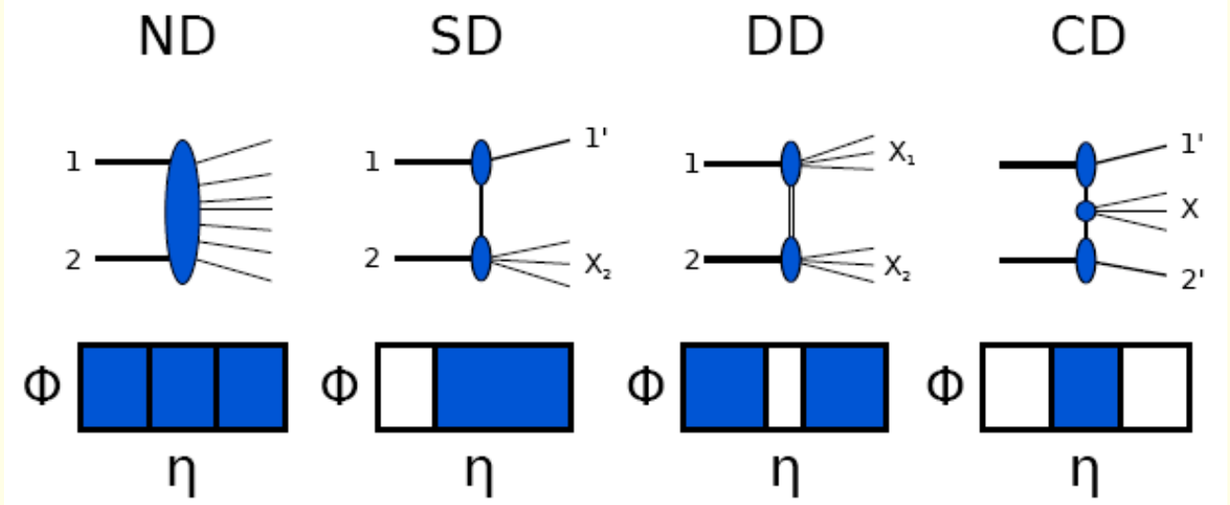
ALICE: Excellent Momentum Reconstruction and Particle ID Capabilities at Low p_T

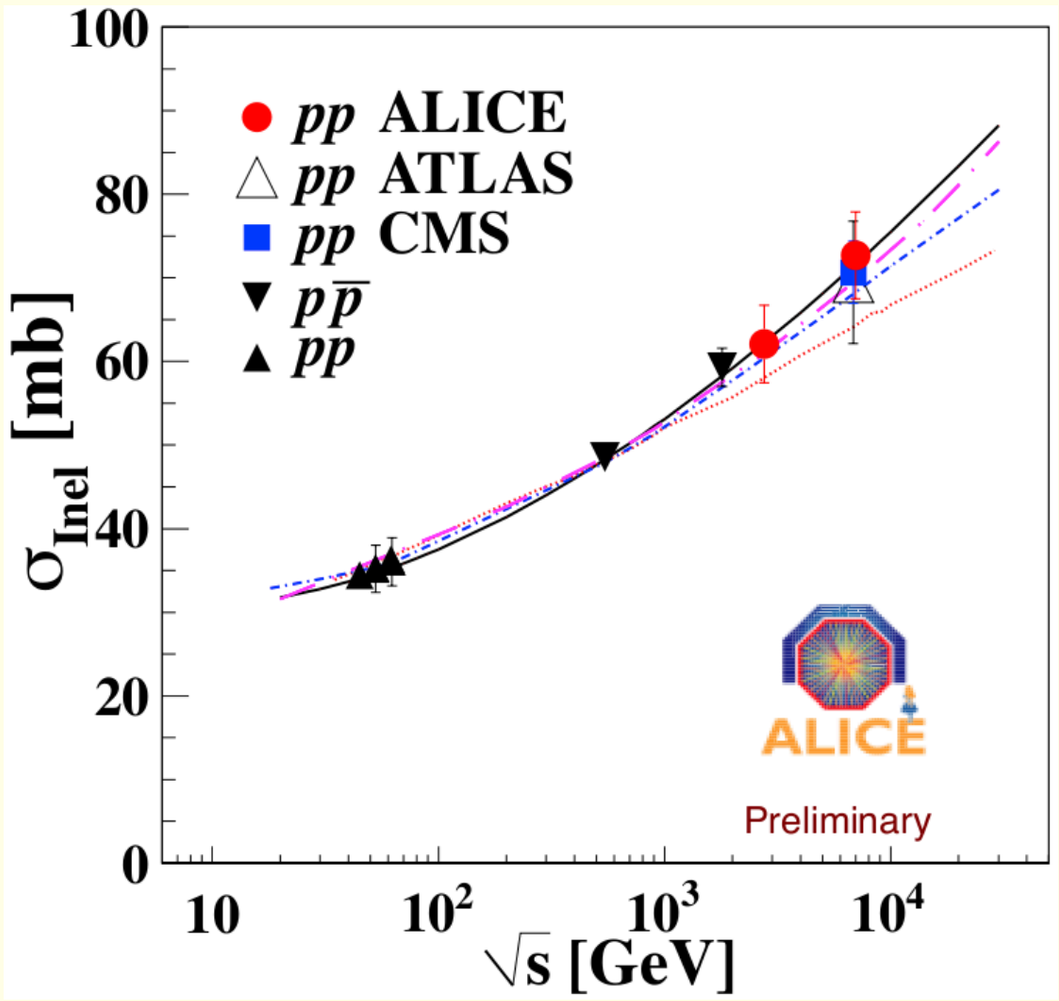
- ALICE designed for Heavy-Ion collisions
- Robust tracking over larger p_T range (~0.1 GeV < p_T < 100 GeV)
  - many space points per track
  - low material budget (~ 11.4% X_0 for R < 2.5 m and |η| < 0.9)
  - moderate magnetic field (0.5 T)
- Excellent vertexing (6 layers of Si) for charm & beauty
- PID over large p_T range
  - 'Stable' hadrons (π, K, p): 100 MeV < p < (few 10 GeV):
    dE/dx in silicon (ITS) and gas (TPC) + time-of-flight (TOF) + Cherenkov (RICH)
  - Decay topologies: Kinks (K^+, K^-) [e.g., K →μ+ν] and
    invariant mass analysis of decay products (K_S^0, Λ, ϕ, D, ...):
    Secondary vertex reconstruction
  - Leptons (e, μ), photons, η, π^0:
    Electrons TRD: p > 1 GeV, muons: p > 5 GeV, π^0 in PHOS/EMCal and via conversions

Cross Sections

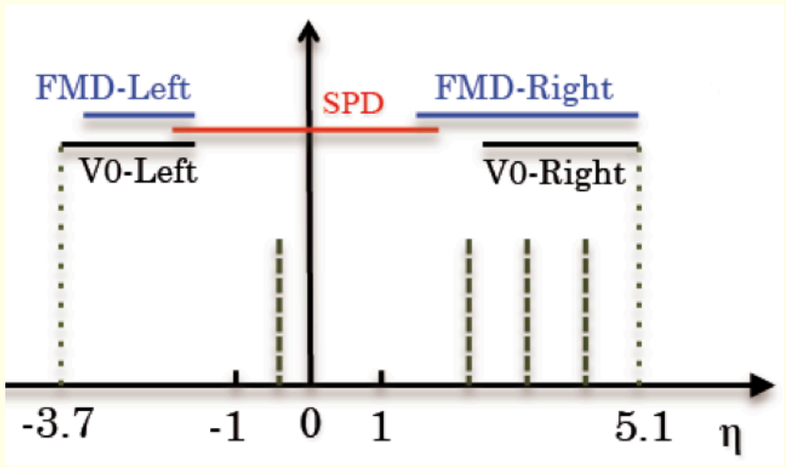
Cross Sections for Inelastic p+p Collisions, and Single-Diffractive and Double-Diffractive Dissociation

$$\sigma_{inel} = \sigma_{ND} + \sigma_{SD} + \sigma_{DD} + \sigma_{CD}$$





- σ_{inel} from van der Meer scans
- SD trigger condition: e.g., no particle with $\eta < -1$
- DD trigger condition: all events with gap $\Delta\eta > 3$

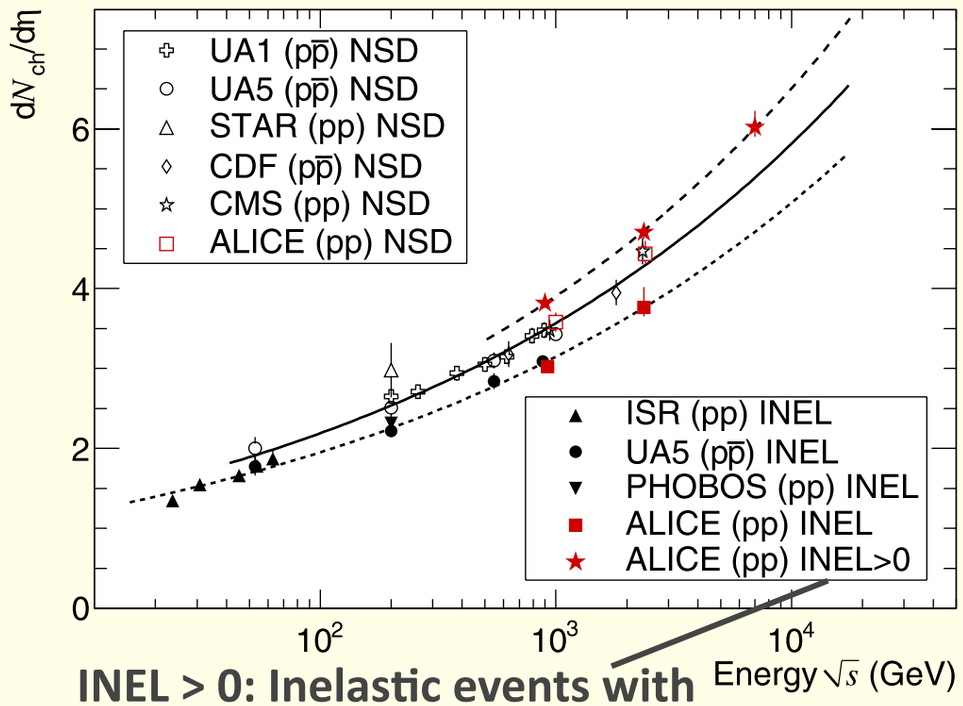


√s (TeV)	σ_{inel} (mb)	$\sigma_{SD}/\sigma_{inel}$	$\sigma_{DD(\Delta\eta > 3)}/\sigma_{inel}$
0.9	no v. d. Meer scan	0.202 ± 0.034	0.113 ± 0.029
2.76	62.1 ± 1.6 ± 4.3	0.187 ± 0.054	0.125 ± 0.052
7	72.7 ± 1.1 ± 5.1	0.201 ± 0.039	0.122 ± 0.036

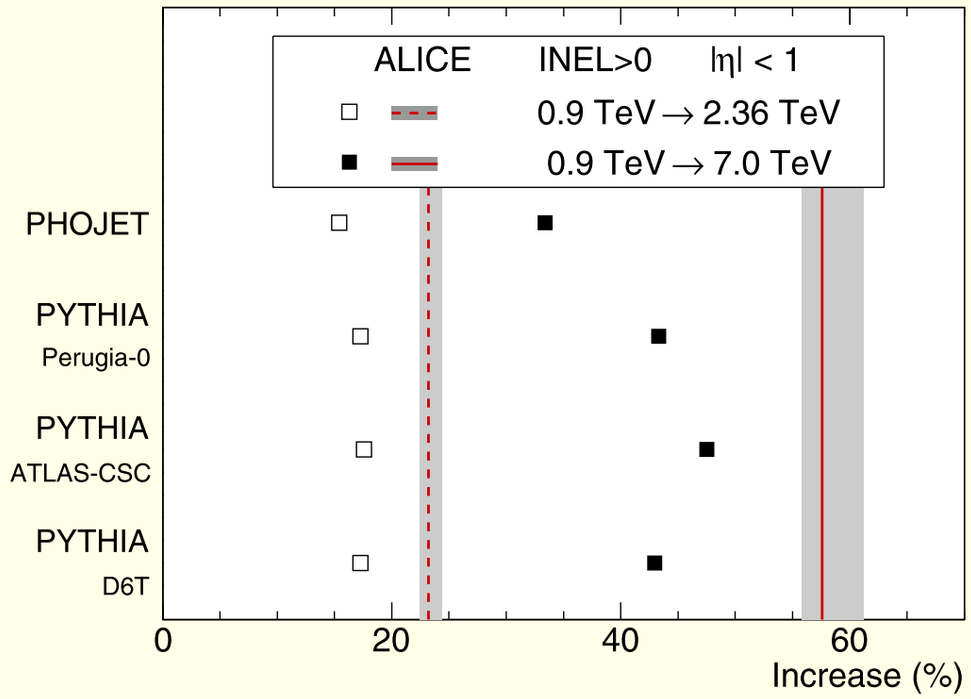
More details: K. Oyama, QM 2011, M. Poghosyan, QM2011

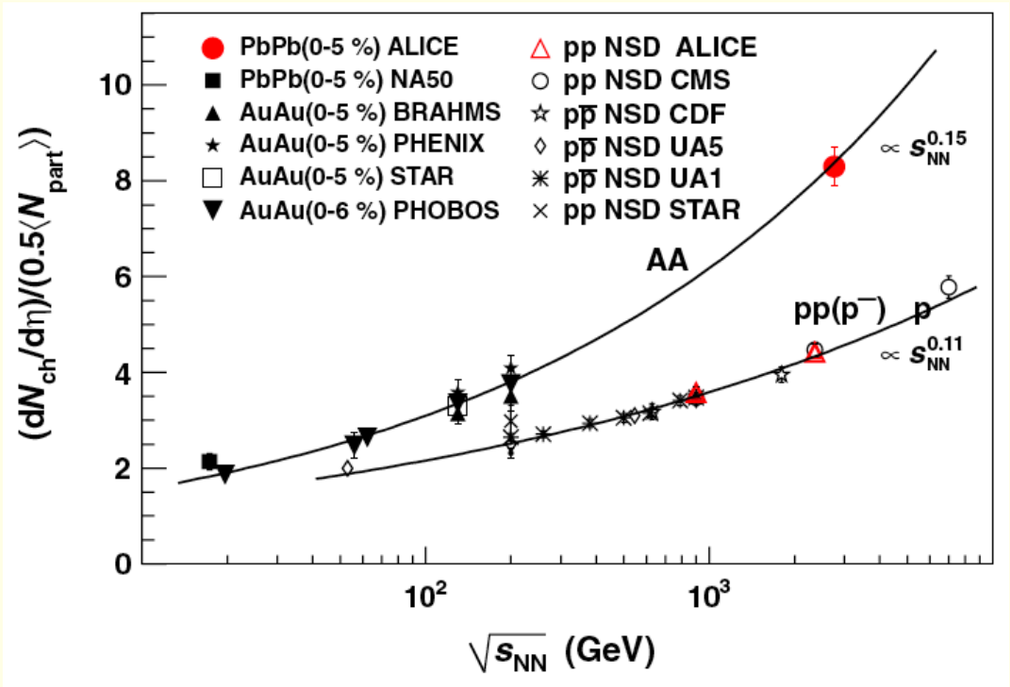
Charged Particles

$dN_{ch}/d\eta$



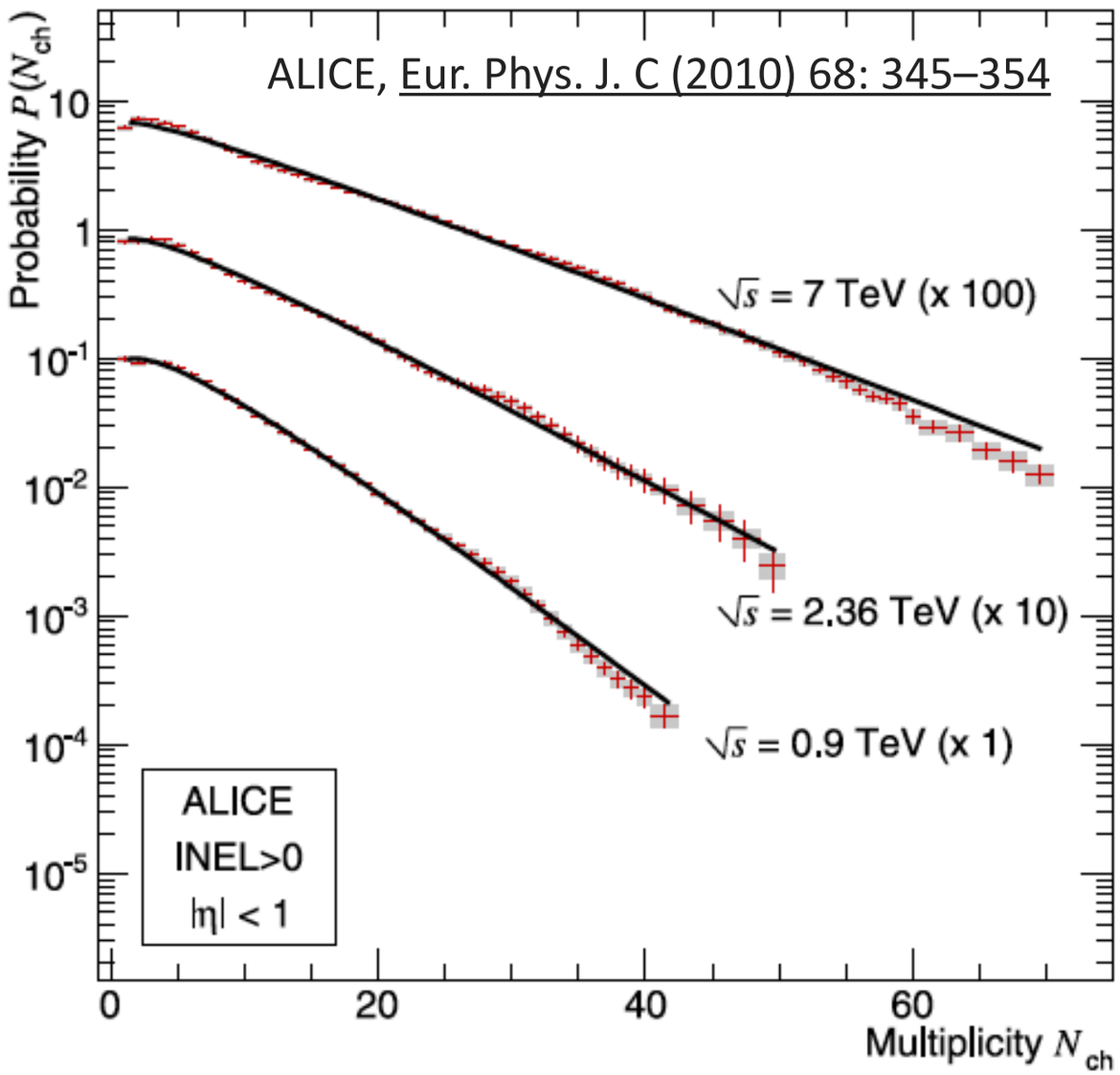
INEL > 0: Inelastic events with at least one charged particle in $|\eta| < 1$

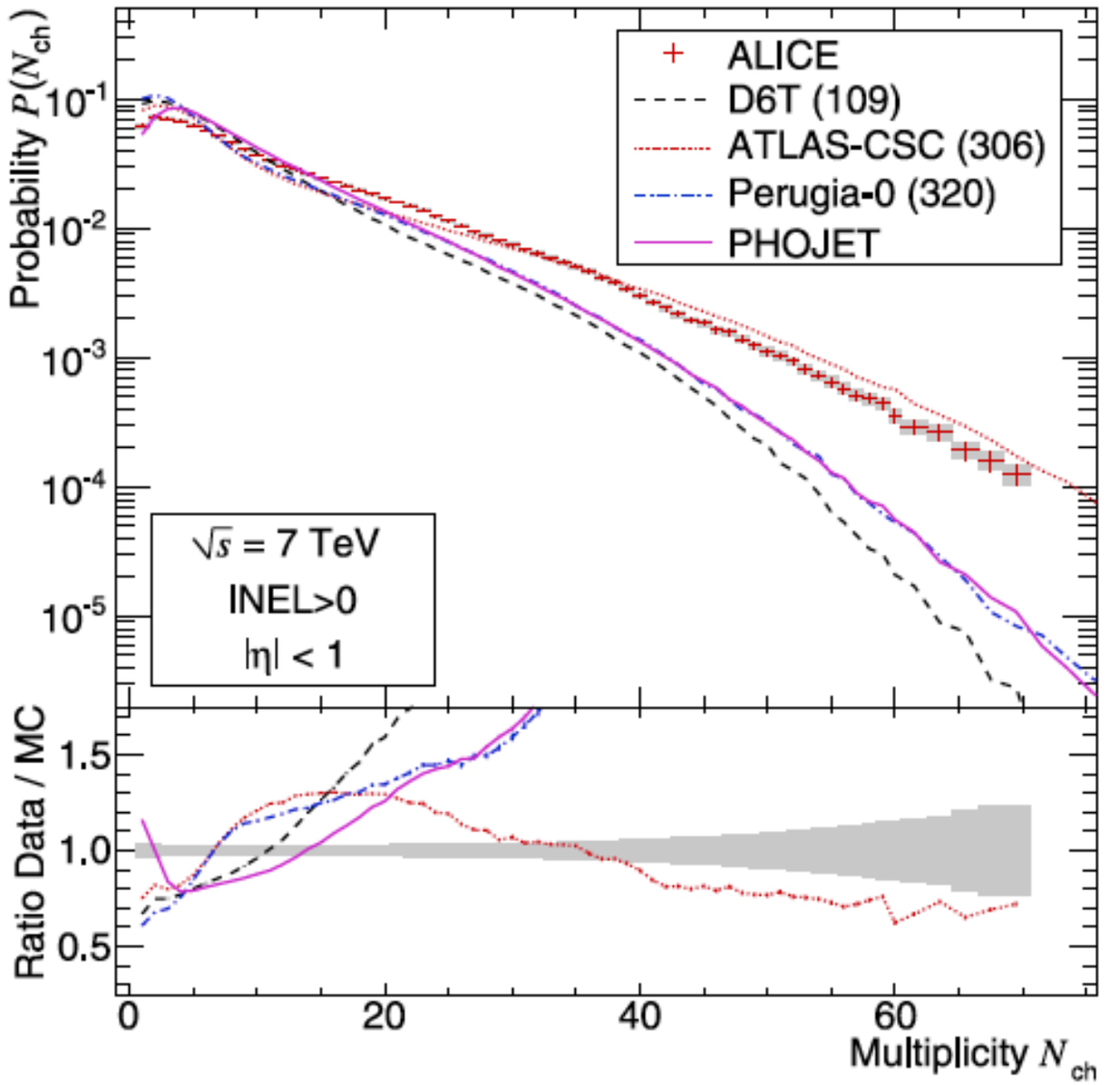




- Increase in $dN_{ch}/d\eta$ from 0.9 TeV to 7 TeV: 60%
- Larger than predicted by Phojet and most Pythia tunes
- √s dependence of charged multiplicity per participating nucleon stronger in A+A than in p+p

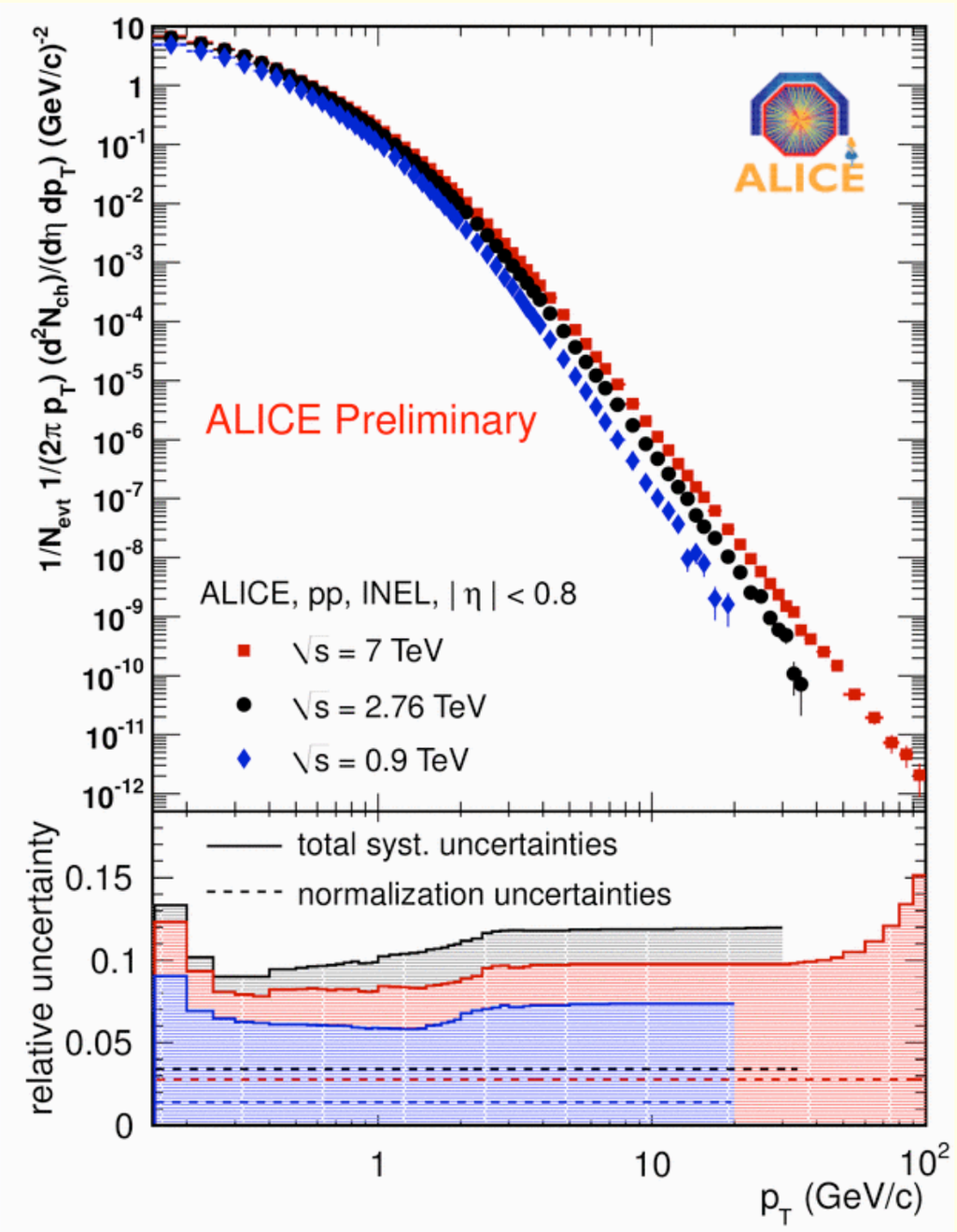
Multiplicity Distributions

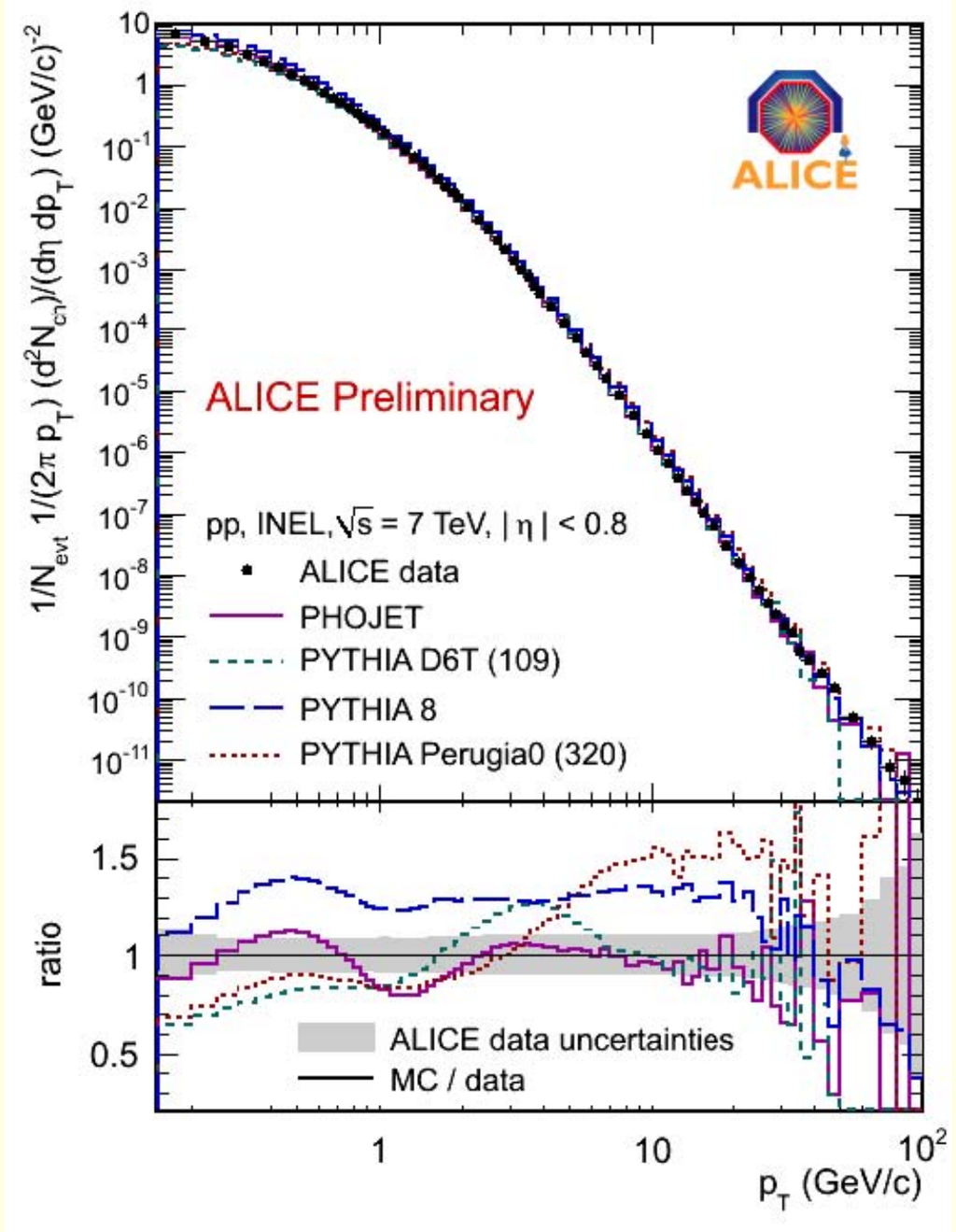




- Single negative binomial distribution provides a decent fit, but fails to describe the large multiplicity tail at 7 TeV
- Most pre-LHC tunes fail to describe multiplicity distributions

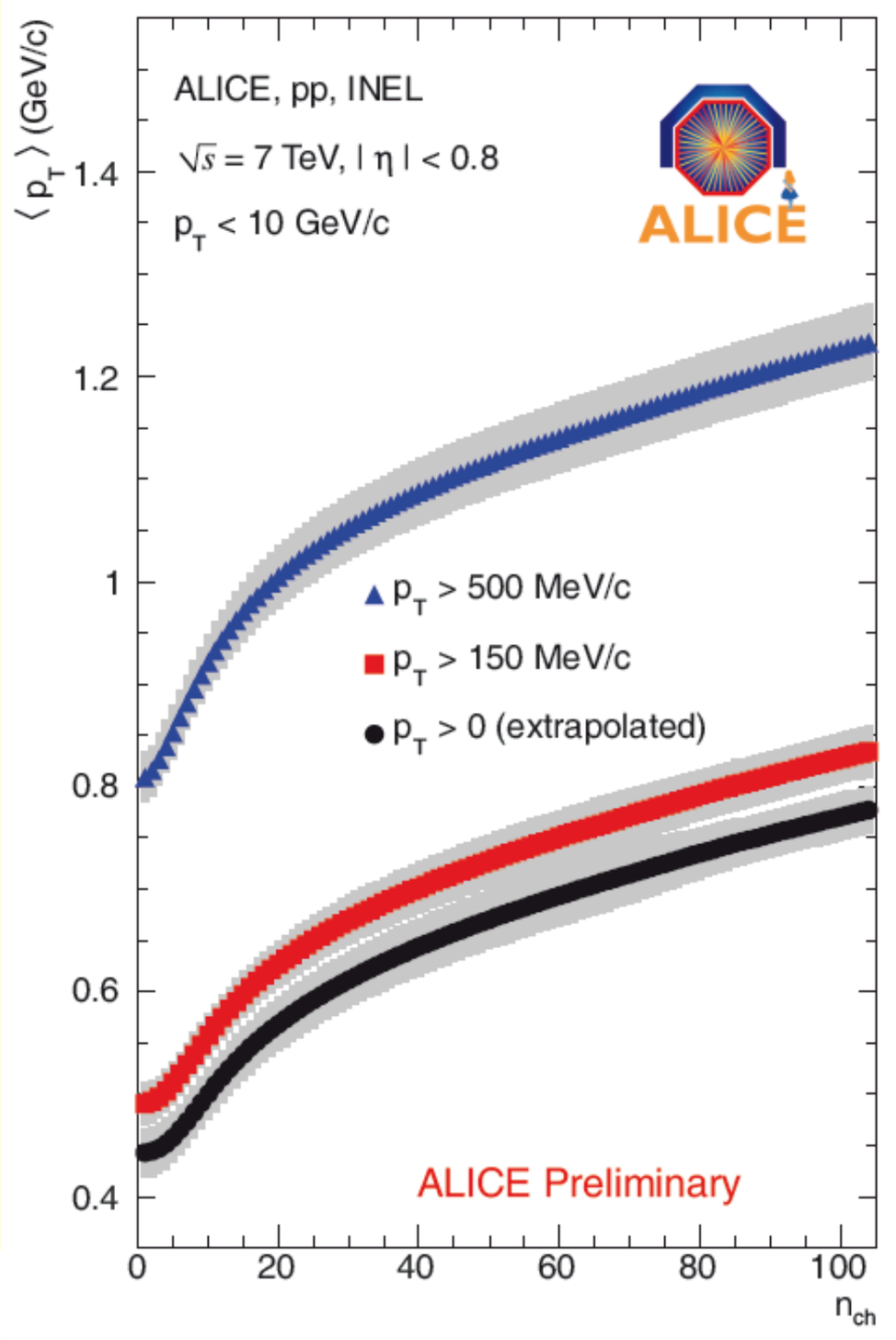
Charged Particles: p_T Spectra

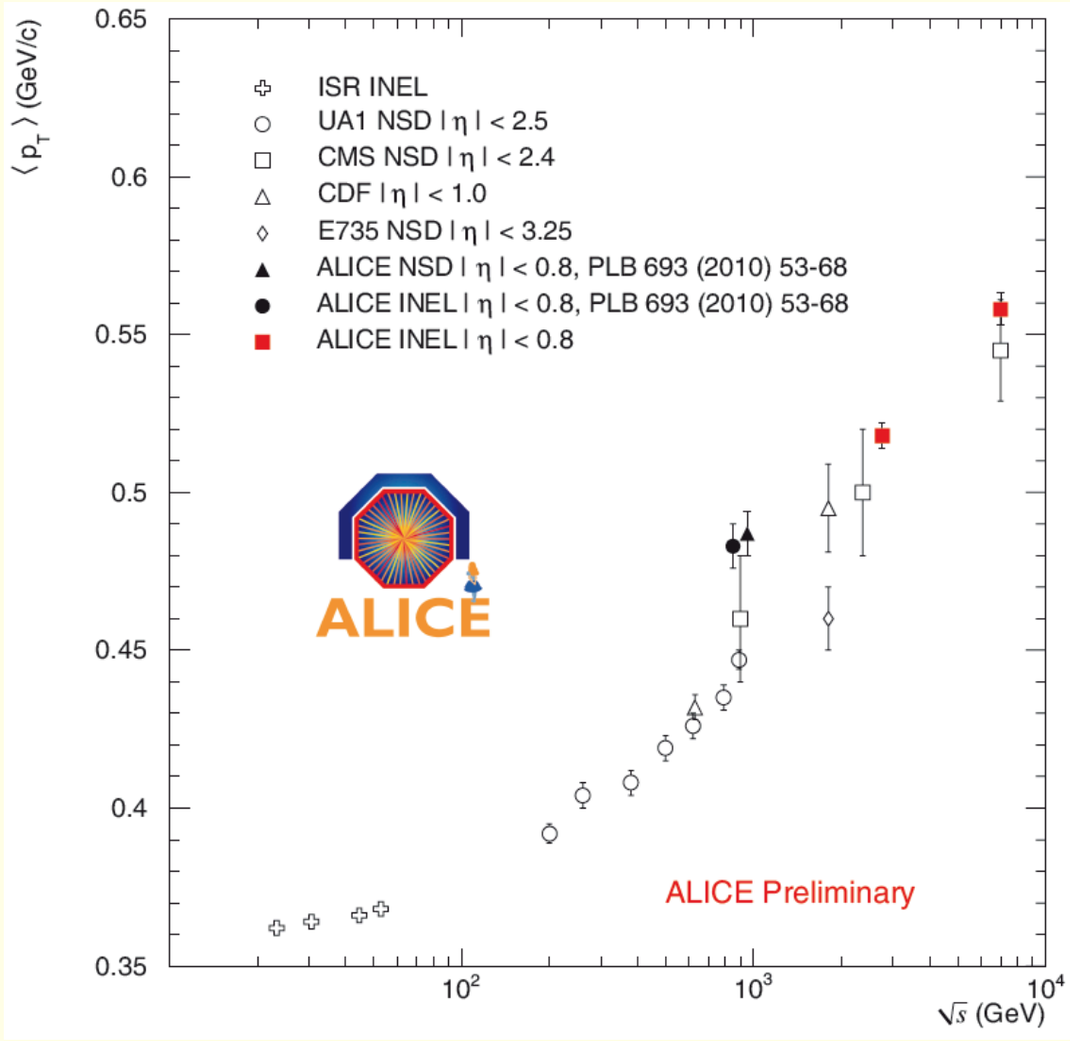




- Invariant yields follow a pure power law p_T^{-n} at high p_T
- No satisfactory description with pre-LHC models

Charged Particles: Mean p_T vs. Charged Multiplicity

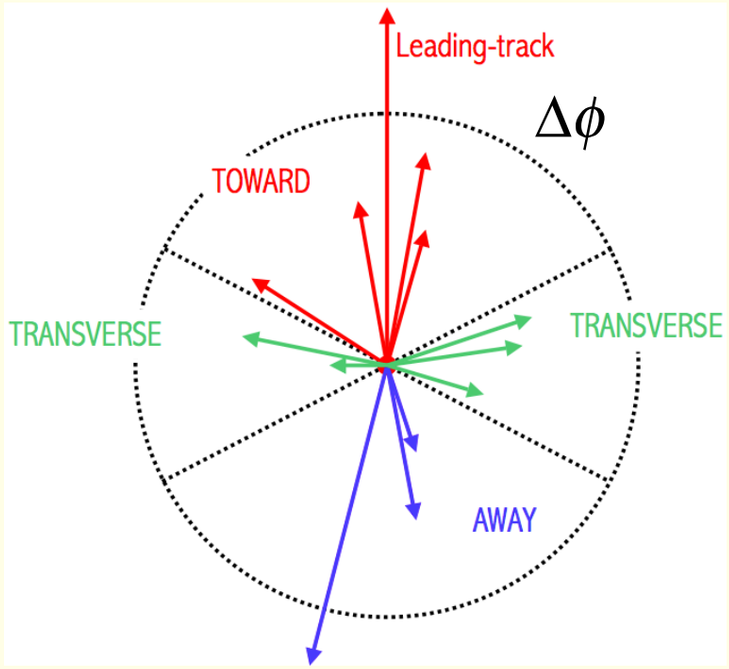




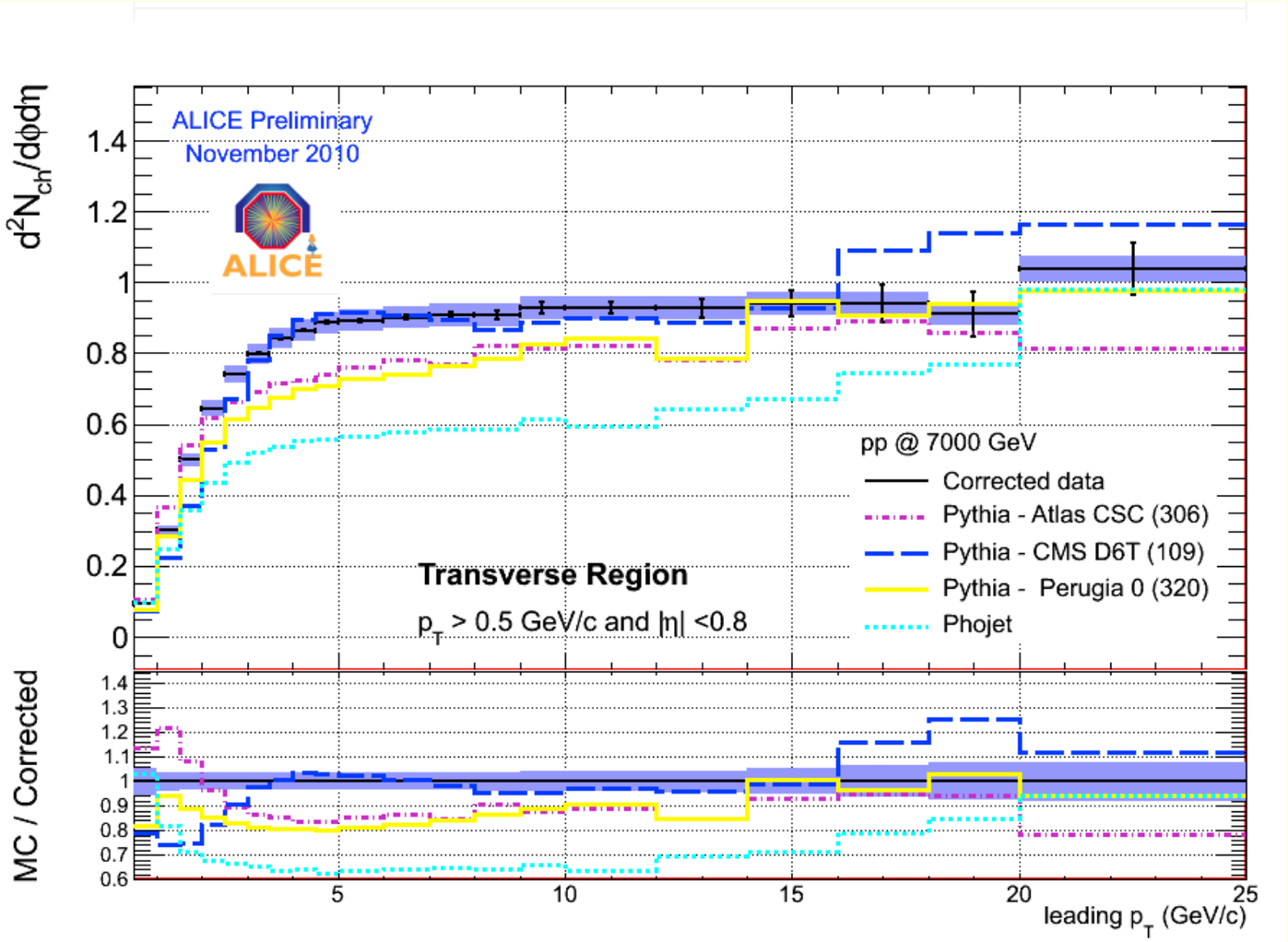
- $\langle p_T \rangle$ vs. n_{ch} important for modeling multiple partonic interactions
- Increase of $\langle p_T \rangle$ with $\sqrt{s}$ in line with data at lower $\sqrt{s}$

Underlying Event

transverse plane:



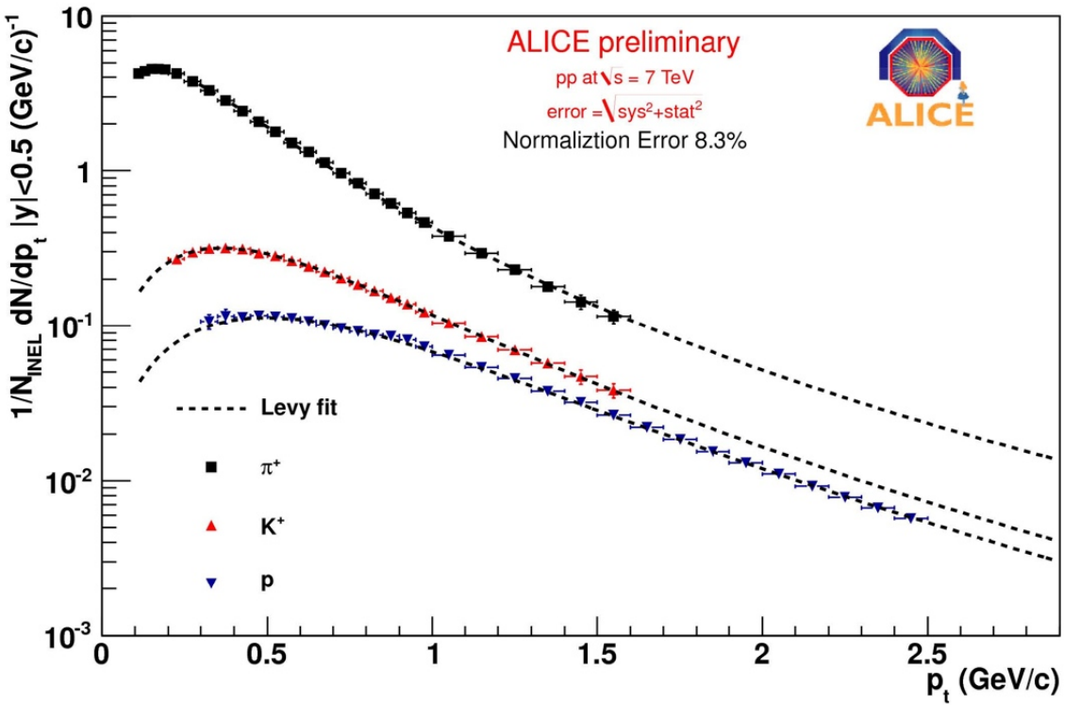
More details: S. Vallero, MPI@LHC2010

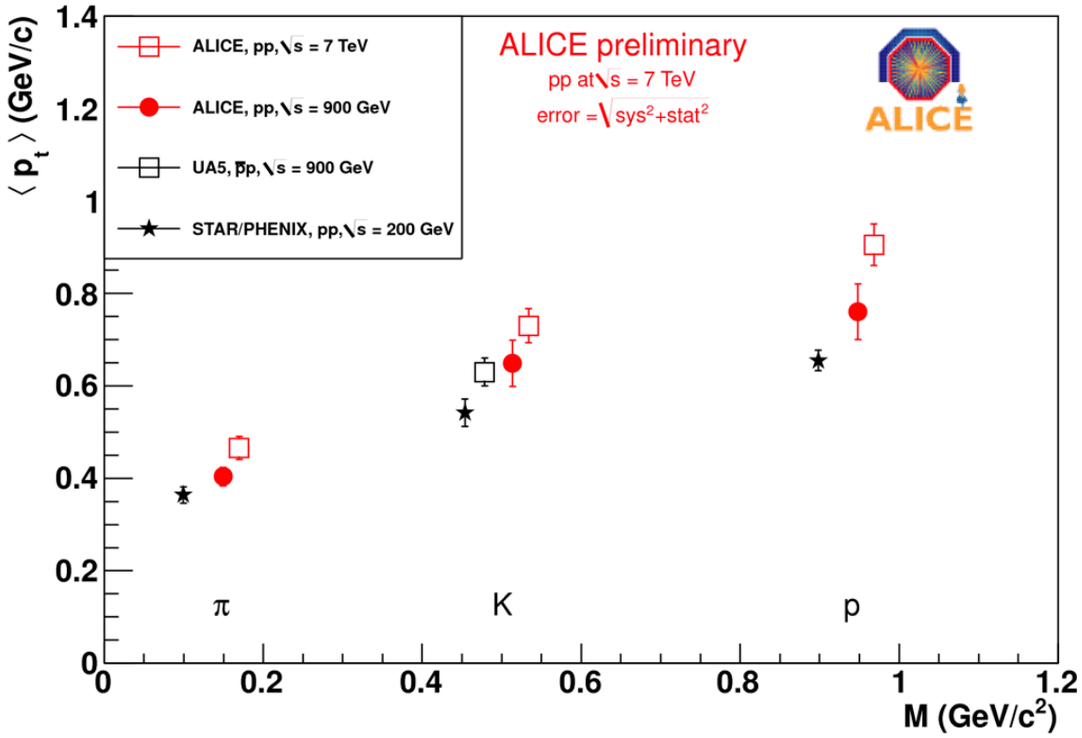


- Study charged particles in different regions with respect to leading track
- Results fully corrected for detector effects
- Pre-LHC models underestimate data by 10-20%
- Factor 2 increase in multiplicity in the transverse region between 0.9 and 7 TeV

Identified Particles

Identified Particle Spectra: π, K, p



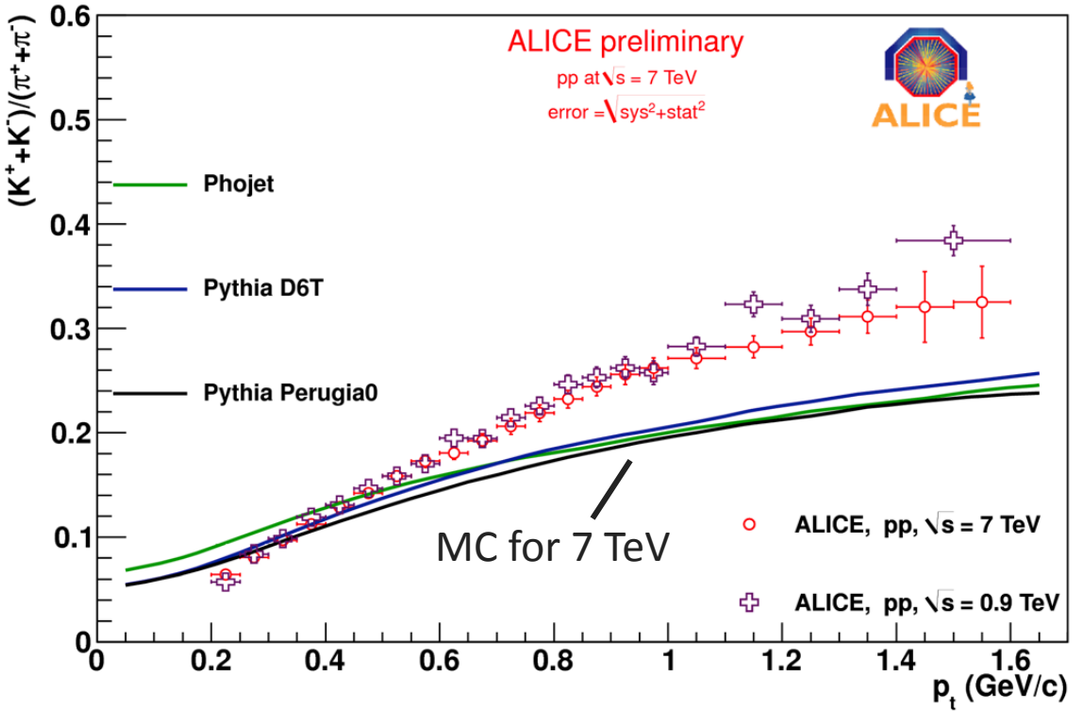


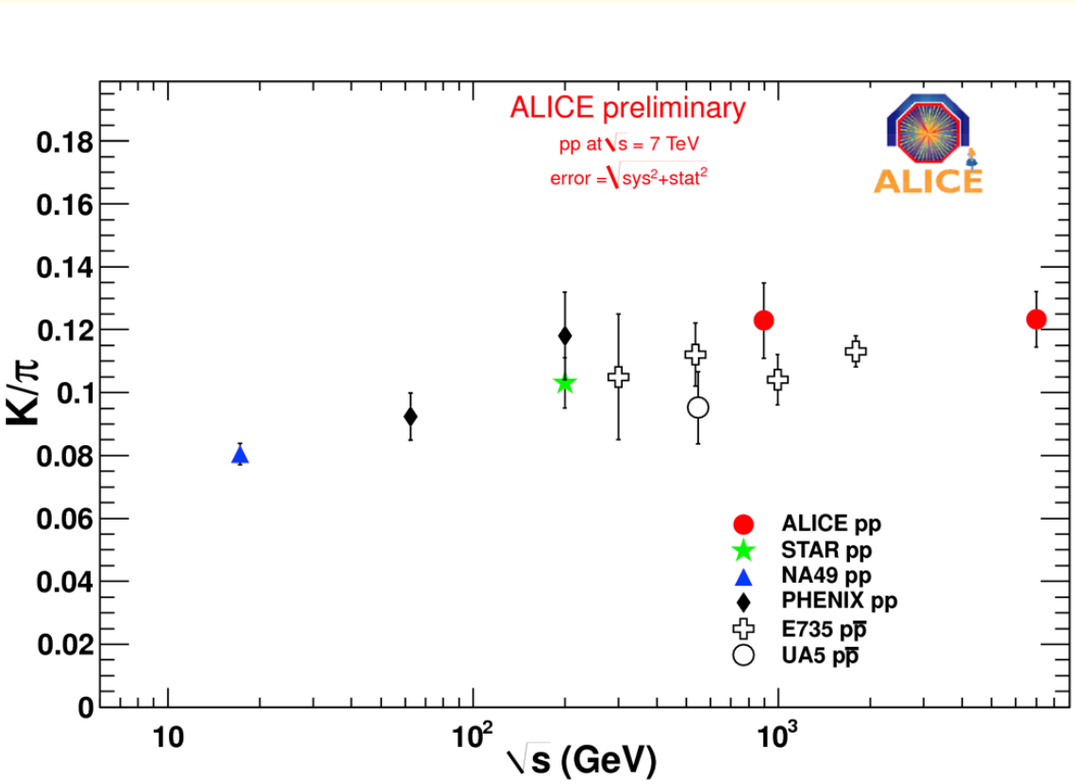
- Proton corrected for feed-down
- Levy/Tsallis function provides a good fit for all particle species

$$\frac{d^2N}{dydp_T} = \frac{(n-1)(n-2)}{nT[nT+m(n-2)]} \times \frac{dN}{dy} \times p_T \times \left(1+\frac{m_T-m}{nT}\right)^{-n}$$

- Linear increase of $\langle p_T \rangle$ with mass (expected in case of m_T scaling)
- π, K, p: increase of $\langle p_T \rangle$ with $\sqrt{s}$

Strangeness Production: K/π Ratio





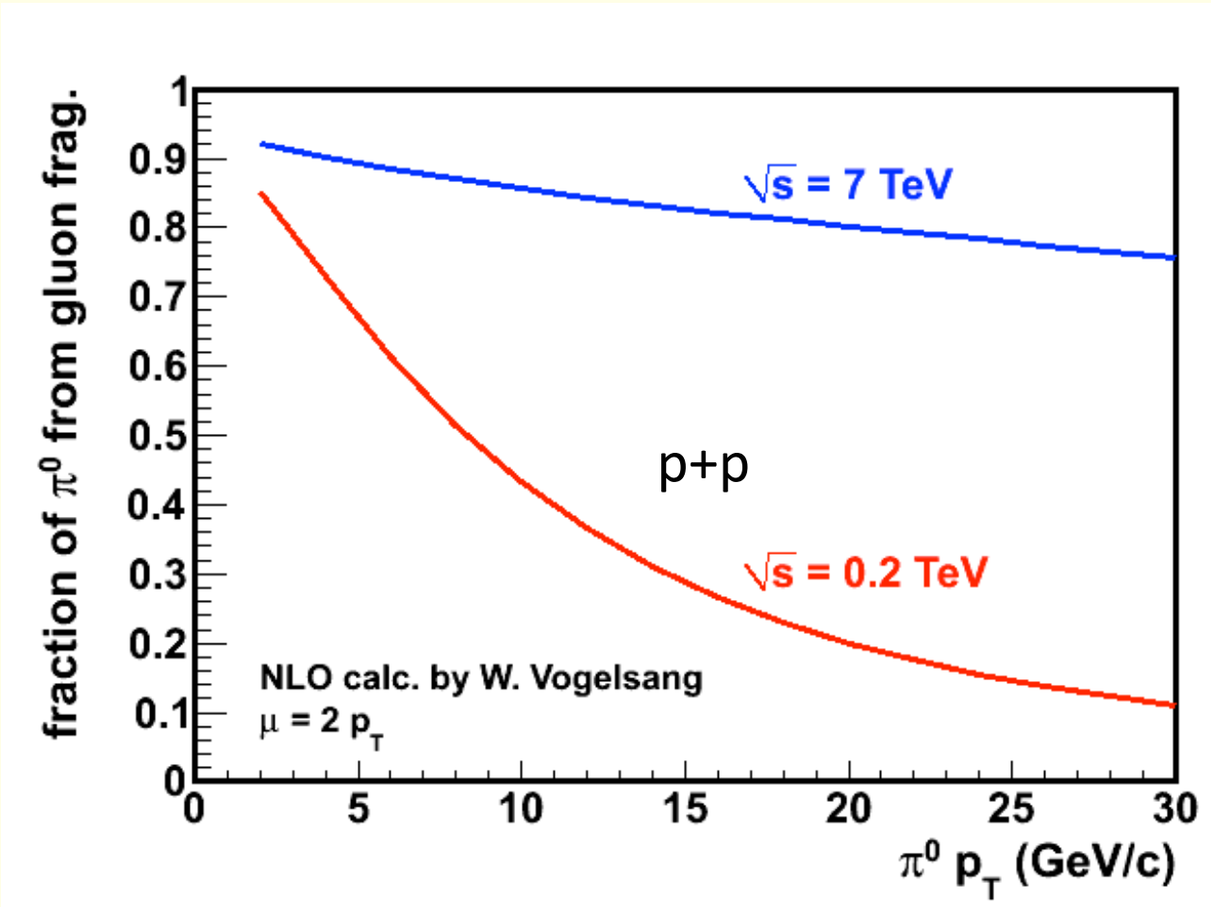
- Significantly larger kaon/pion ratio than predicted by MC models
- Almost identical kaon/pion ratio vs. p_T for 0.9 and 7 TeV
- No discernible energy dependence for K/π ratio for $\sqrt{s} > 0.2$ TeV

More details: M.Chojnacki, QM 2011

π^0 (η) p_T Spectra: Constraining the Gluon Fragmentation Function (I)

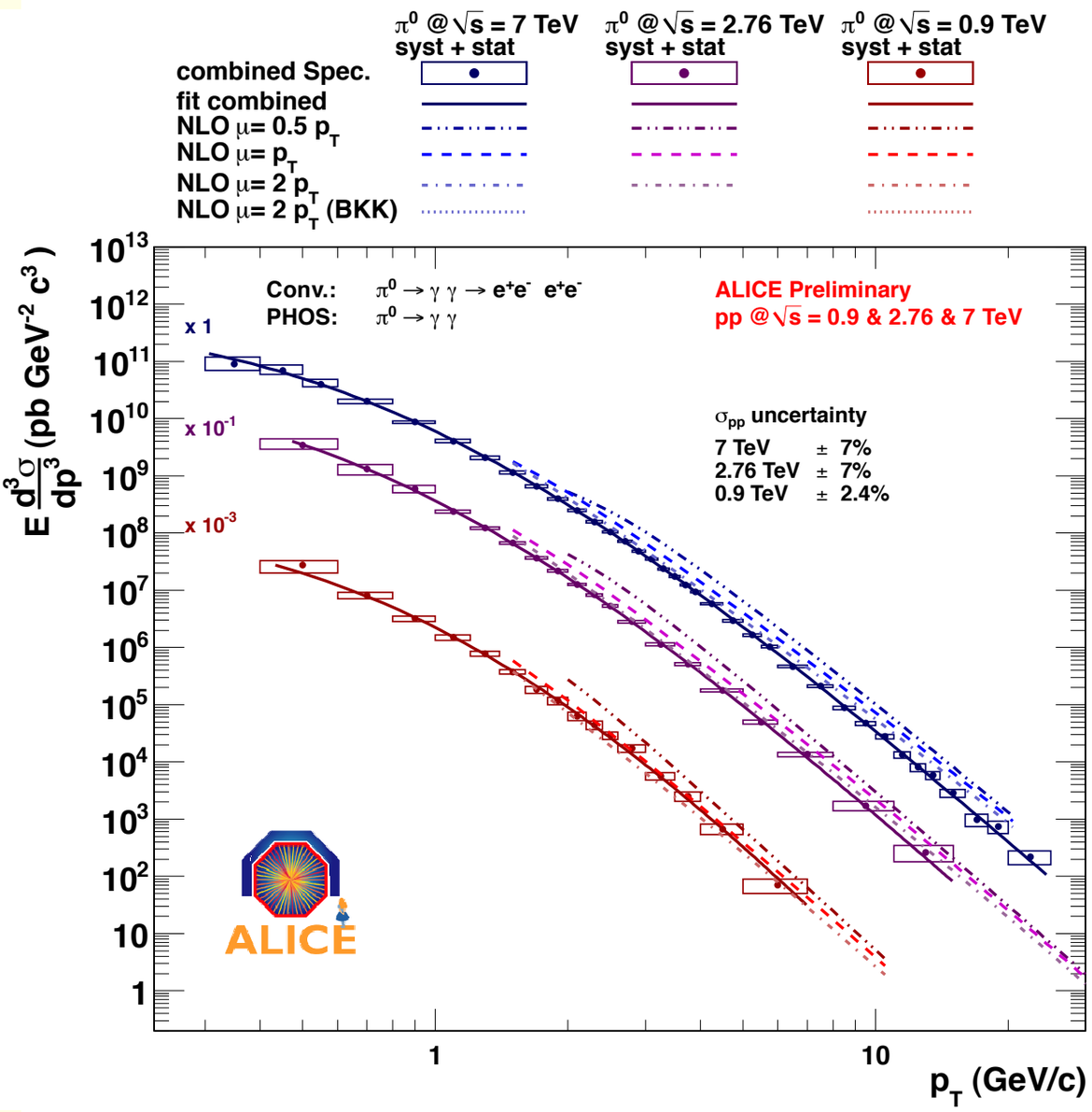
QCD factorization: $$E_h \frac{d^3\sigma}{d^3 p_h} = \sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}^c_{ab} \otimes D^h_c$$

- Gluon fragmentation in e^+e^- not well constrained as gluon jets in e^+e^- are a subleading NLO correction
  $\Rightarrow$ π^0,η spectra in p+p important constraint for gluon FF
- π^0 spectra in pp at RHIC ($\sqrt{s}$ = 0.2 TeV) favor large $g \rightarrow \pi$ FF's
  (e.g., DSS FF's describe the data well)
- Gluon fragmentation at LHC more important than at RHIC

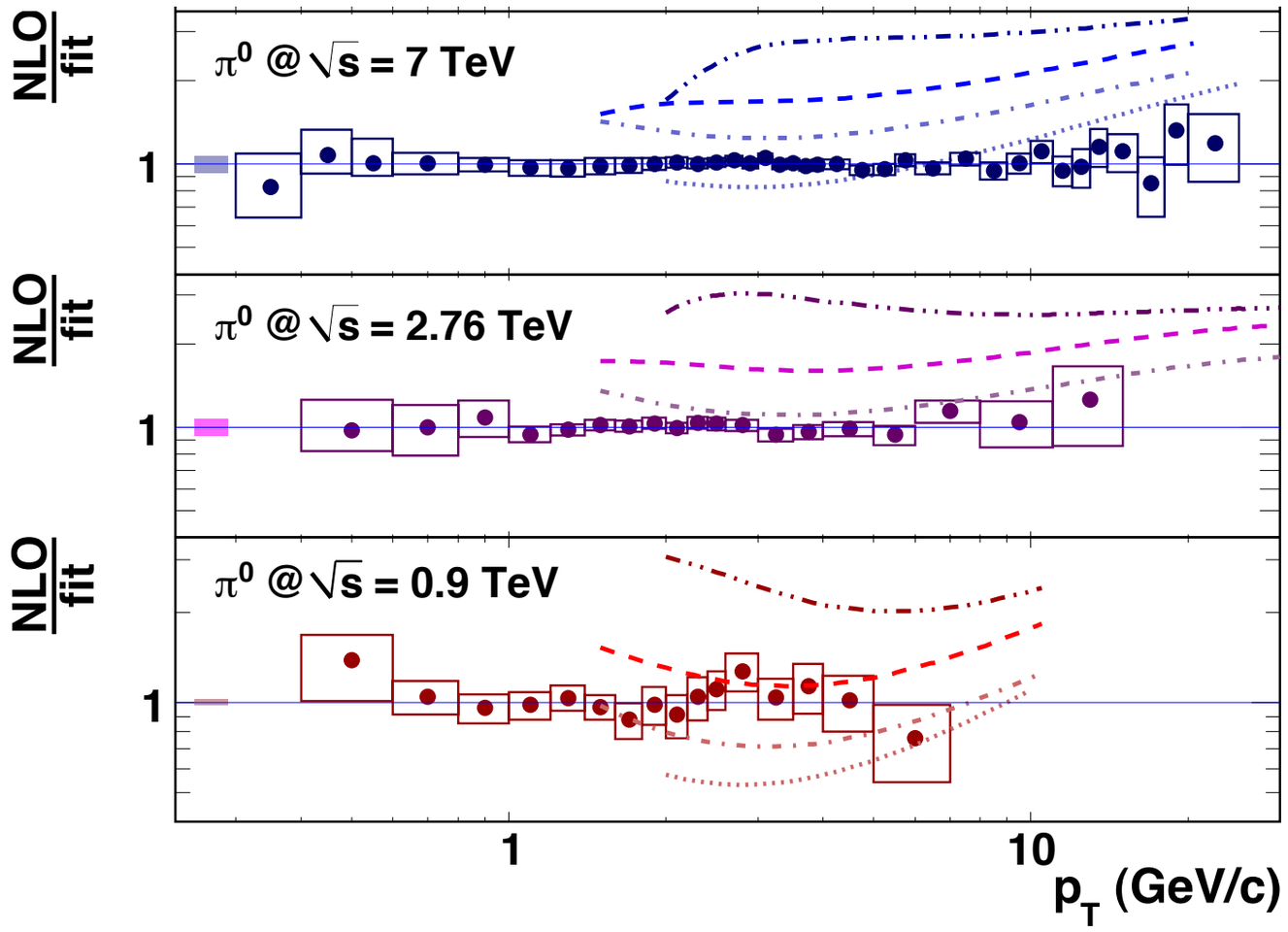


More details: K. Reygers, QM 2011

π^0 (η) p_T Spectra: Constraining the Gluon Fragmentation Function (II)



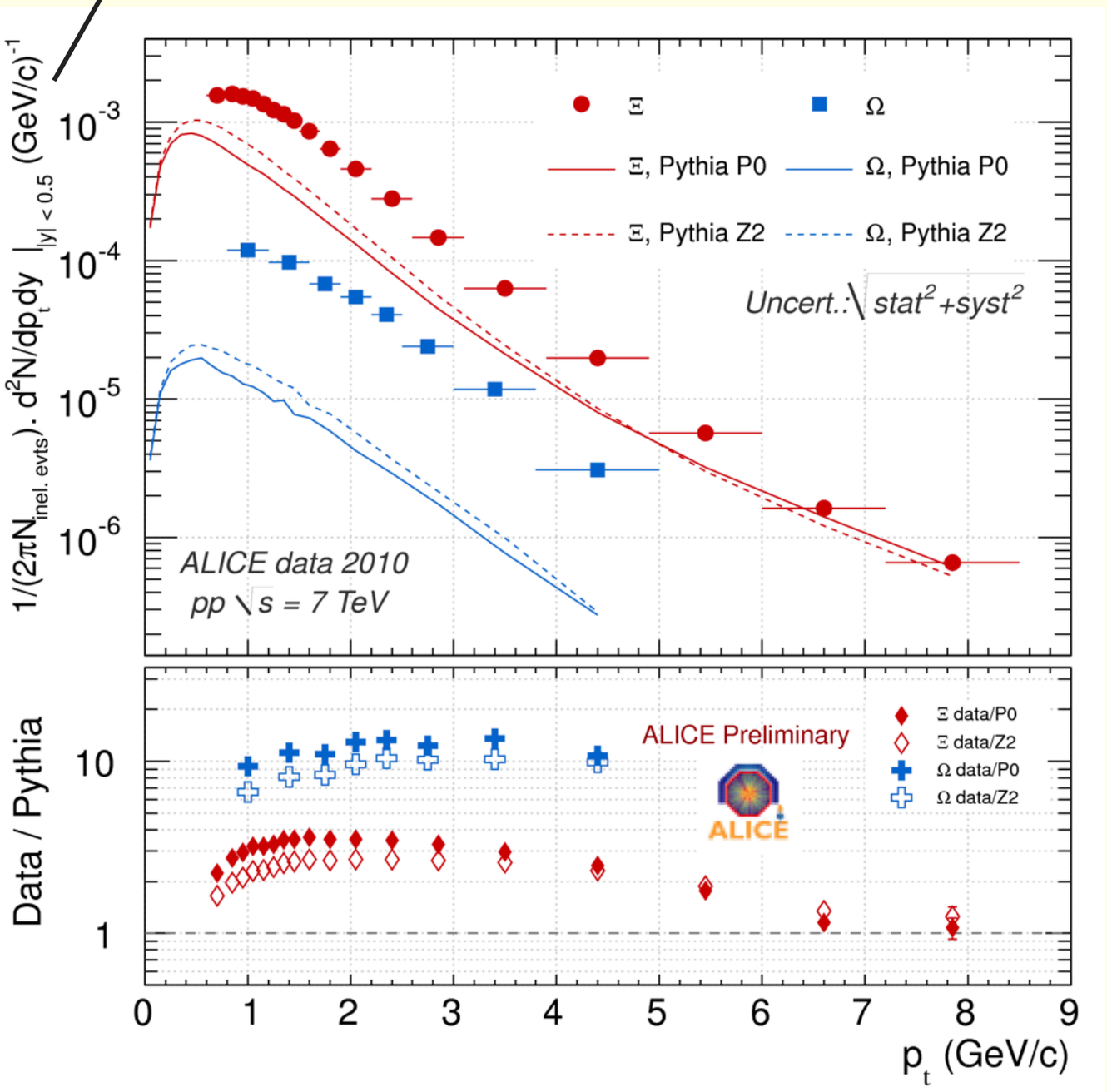
NLO pQCD (W. Vogelsang):
PDF: CTEQ6M5, FF: DSS, scales, $\mu = 0.5\ p_T,\ p_T,\ 2\ p_T$
Also: INCNLO with BKK FF



- NLO pQCD with DSS FF describes 0.9 TeV data, but overestimates cross sections at 2.76 TeV and 7 TeV for all scales (same trend for η, not shown)
- DSS FF, which nicely describes p+p $\rightarrow \pi^0$+X at RHIC, fails at LHC

Multi-strange Hadrons (I): Yields in p+p at 7 TeV

Yields per *inelastic* collision
(standard normalization for yields in ALICE)

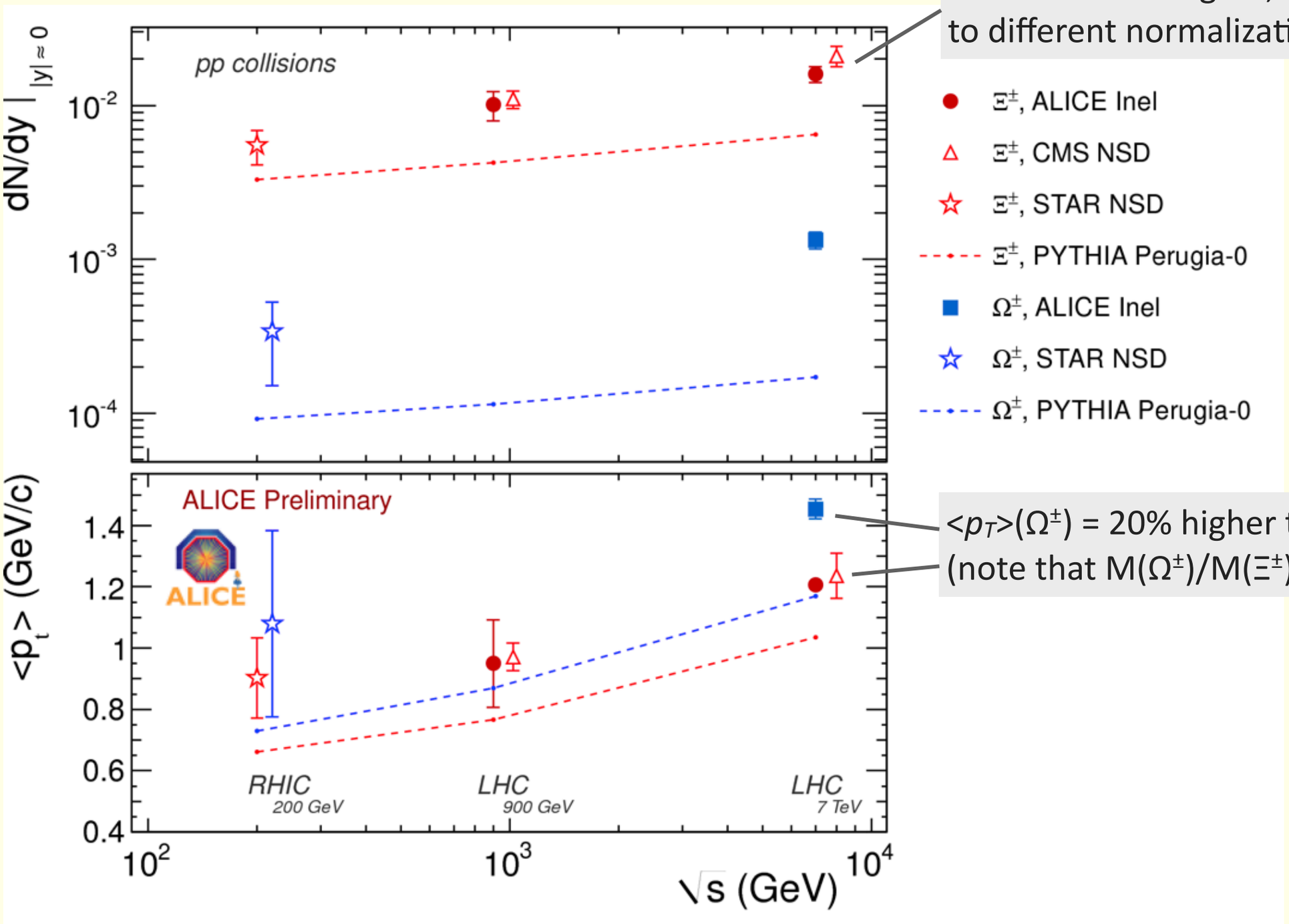


- Pythia tunes Perugia-0 and Z2 significantly underestimate measured $\Xi^- + \Xi^+$ and $\Omega^- + \Omega^+$ yields
- Ξ^+/Ξ^- and Ω^+/Ω^- ratios consistent with unity for all p_T (not shown)

More details: D. D. Chinellato, QM 2011

Multi-strange Hadrons (II): √*s* Dependence of d*N*/dy and $\langle p_T \rangle$

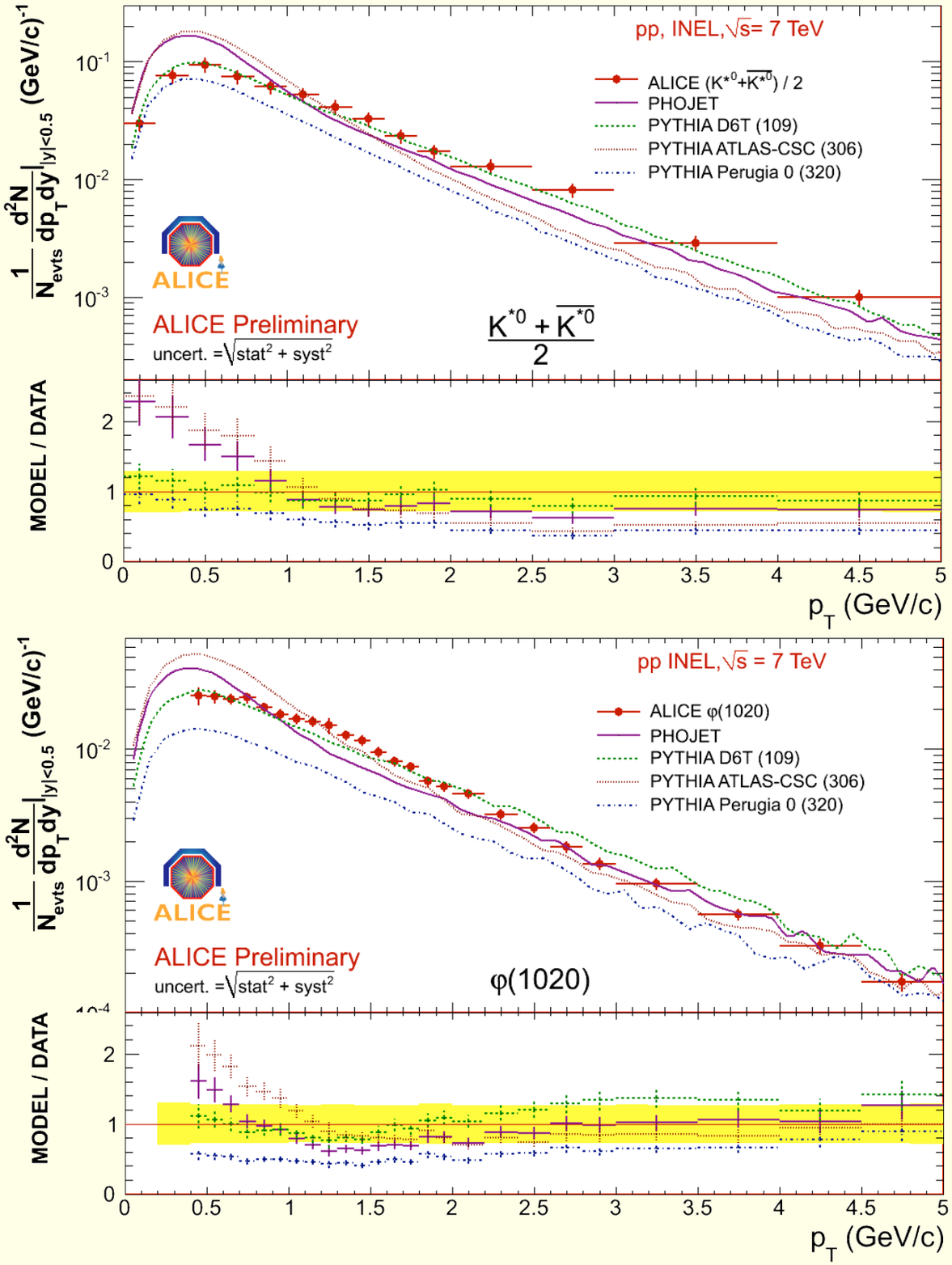
CMS and ALICE agree, difference only due to different normalization (INEL vs. NSD)

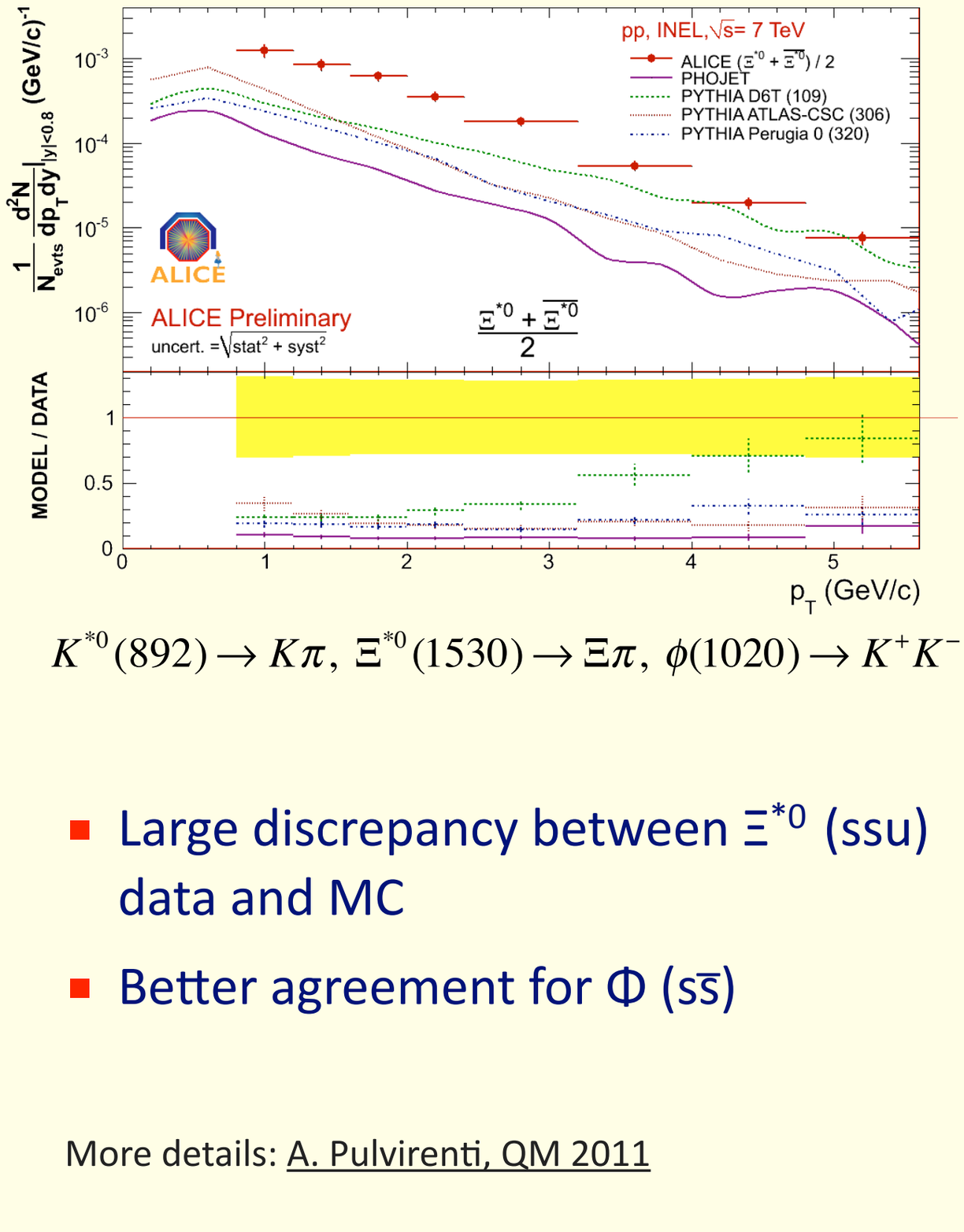


$\langle p_T \rangle(\Omega^{\pm})$ = 20% higher than $\langle p_T \rangle(\Xi^{\pm})$
(note that $M(\Omega^{\pm})/M(\Xi^{\pm})$ = 1.265)

- Also for multi-strange hadrons: increase with of $\langle p_T \rangle$ with √*s* and mass

K^{*0}, Ξ^{*0}, and Φ



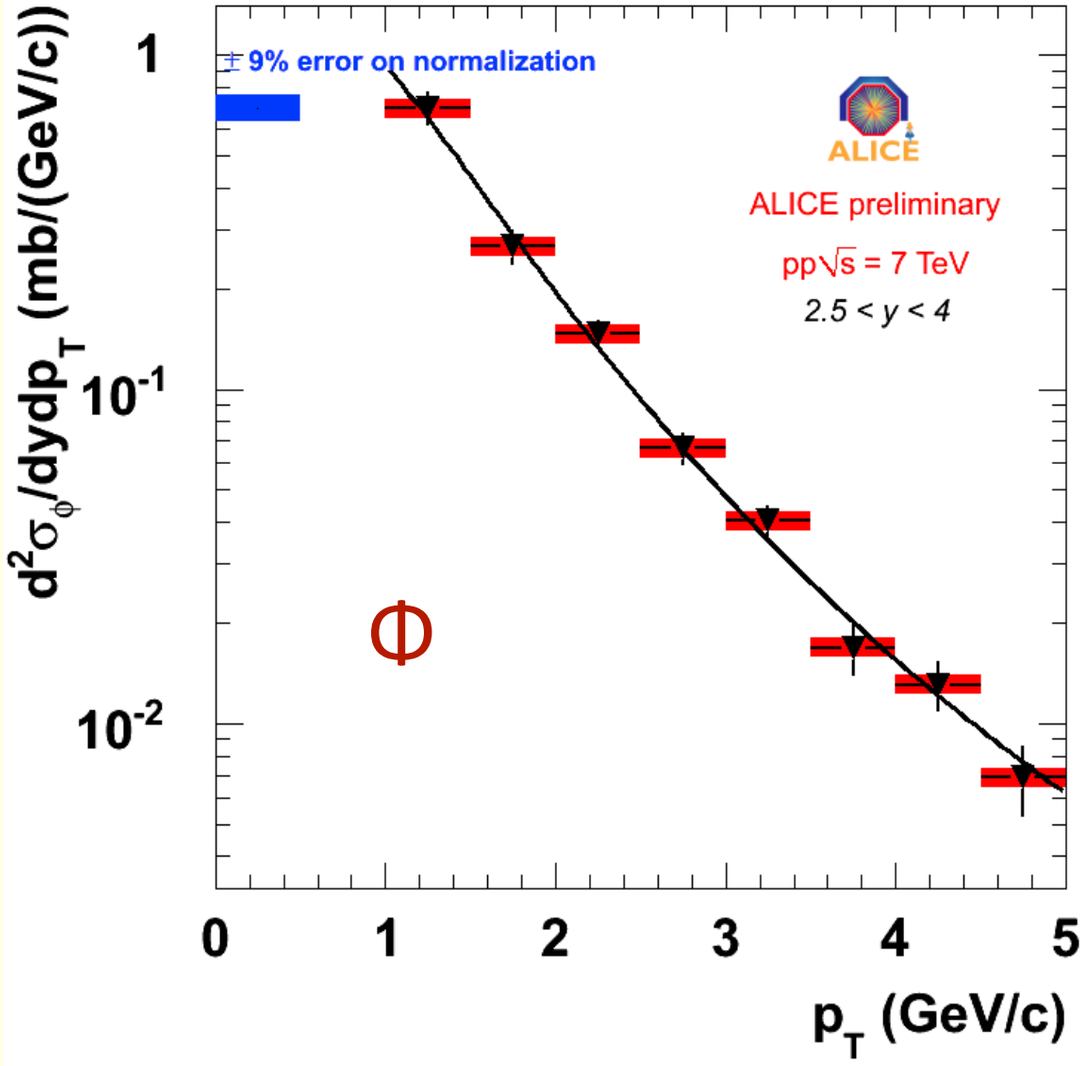


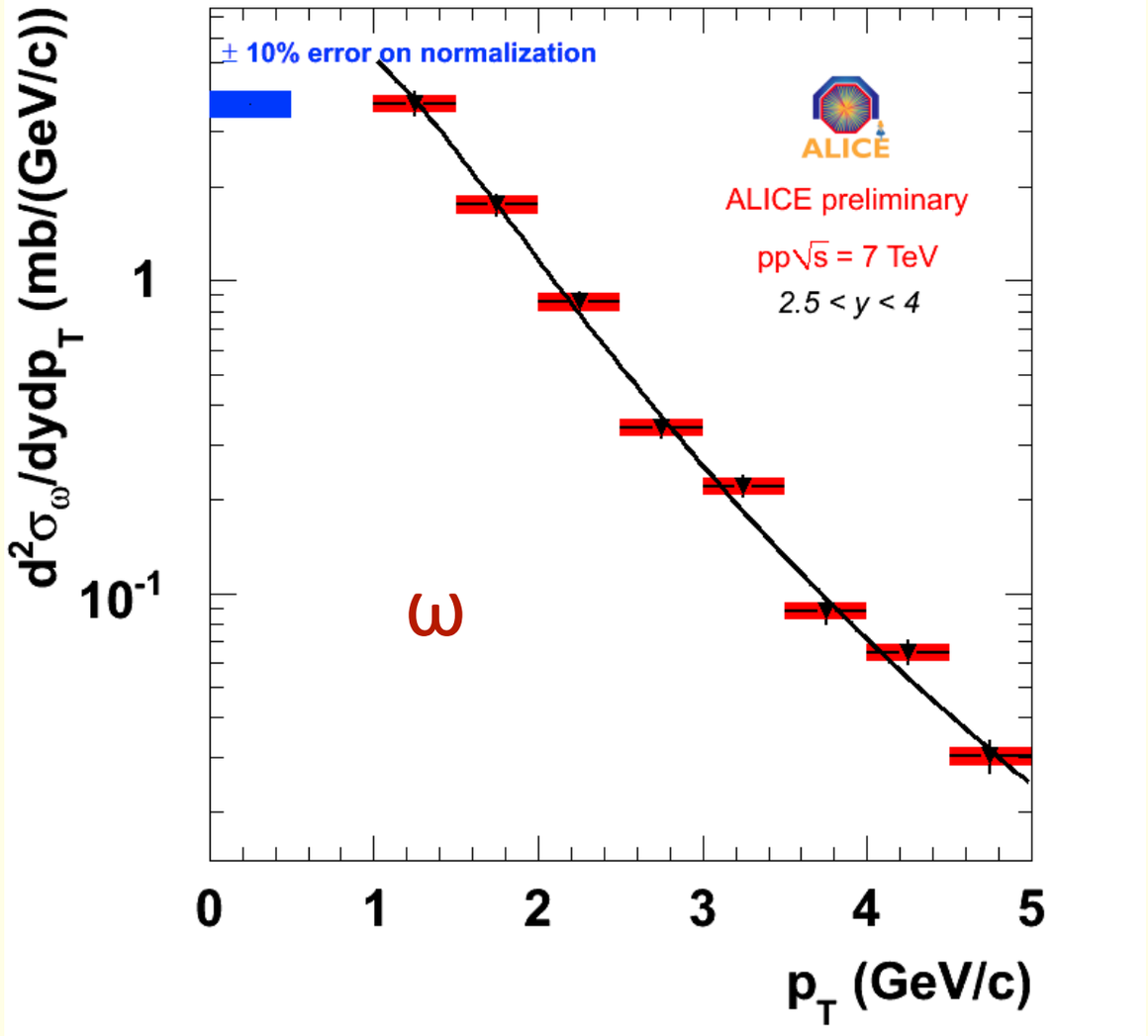
$$K^{*0}(892) \rightarrow K\pi,\ \Xi^{*0}(1530) \rightarrow \Xi\pi,\ \phi(1020) \rightarrow K^+K^-$$

- Large discrepancy between Ξ^{*0} (ssu) data and MC
- Better agreement for Φ ($s\bar{s}$)

More details: A. Pulvirenti, QM 2011

p_T Spectra for Φ and ω Mesons (di-muon channel)

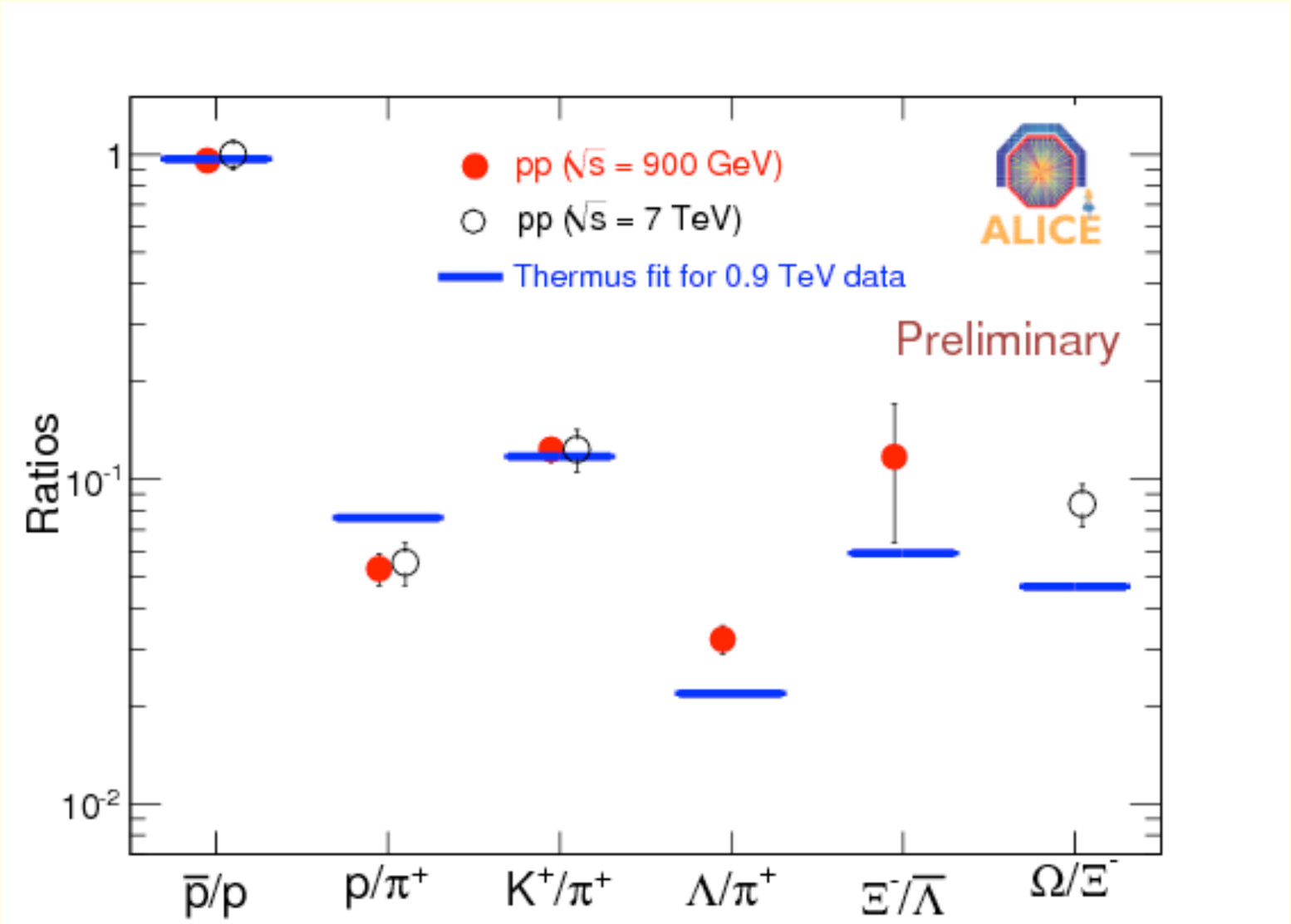




- Φ and ω yields extracted from di-muon mass spectrum
- Cross section for $2.5 < y < 4$, $1 < p_T < 5$ GeV/c:
  $\sigma_\Phi = 0.940 \pm 0.084$ (stat.)± 0.095(syst.) mb, $\sigma_\omega = 5.28 \pm 0.46$ (stat.) ± 0.58 (syst.) mb
- Ratio $\sigma_\Phi/\sigma_\omega$ is constant vs. p_T

More details: A. De Falco, QM 2011

Particle Ratios vs. Statistical Model Predictions



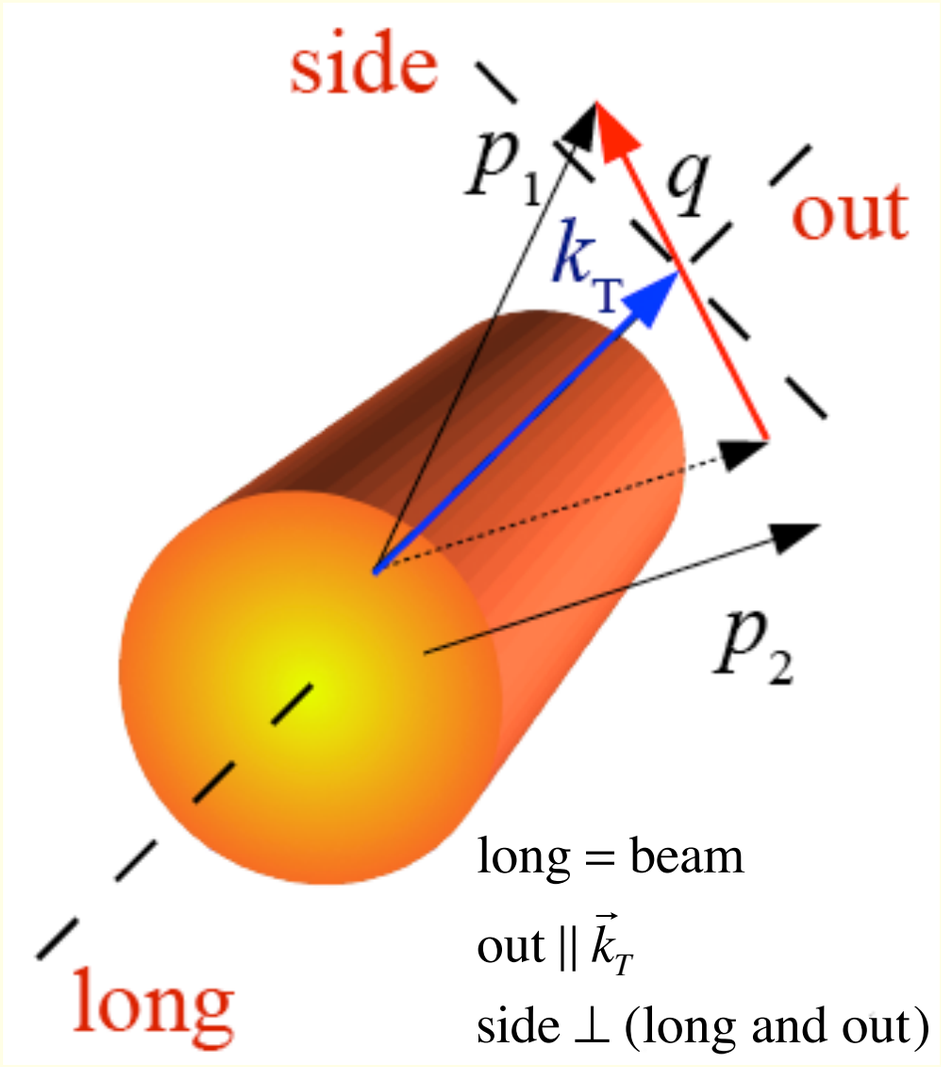
- Particle ratios in general not well described by statistical model fit
- However, statistical model predictions for multi-strange hadron yields better than Pythia predictions

Hanbury Brown / Twiss Correlations (HBT)

Bose-Einstein Correlations of Identical Pions (I)

- Study space-time characteristics of particle emission
- Characterized by HBT radii R_{long}, R_{side}, R_{out} (homogeneity region)
- Large particle multiplicities, comparable to peripheral Pb+Pb data, can now be reached in p+p:
  Compare with A+A and address the question of collectivity in p+p

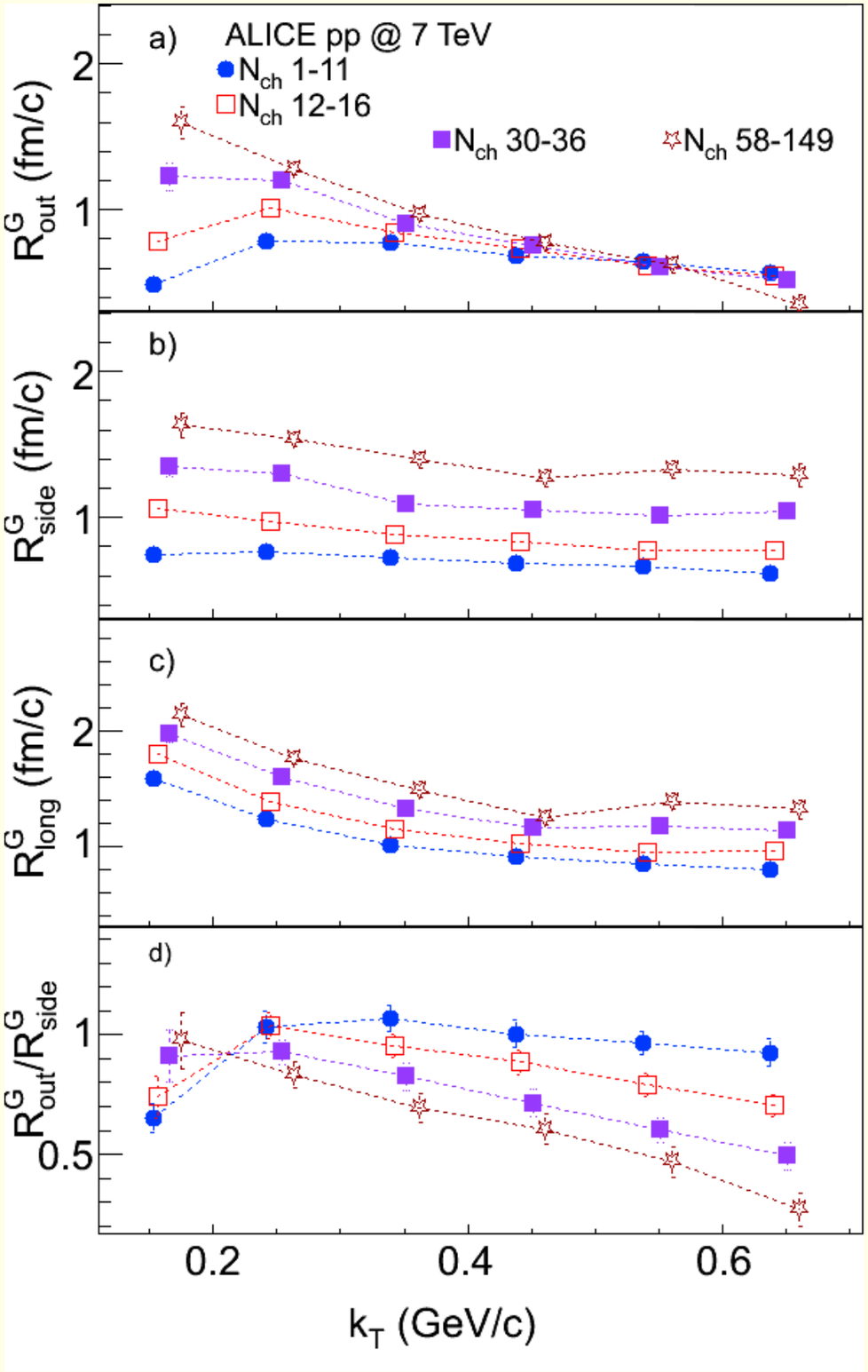
out-side-long ref. frame:



HBT in p+p at 0.9 and 7 TeV with ALICE:
arXiv:1101.3665

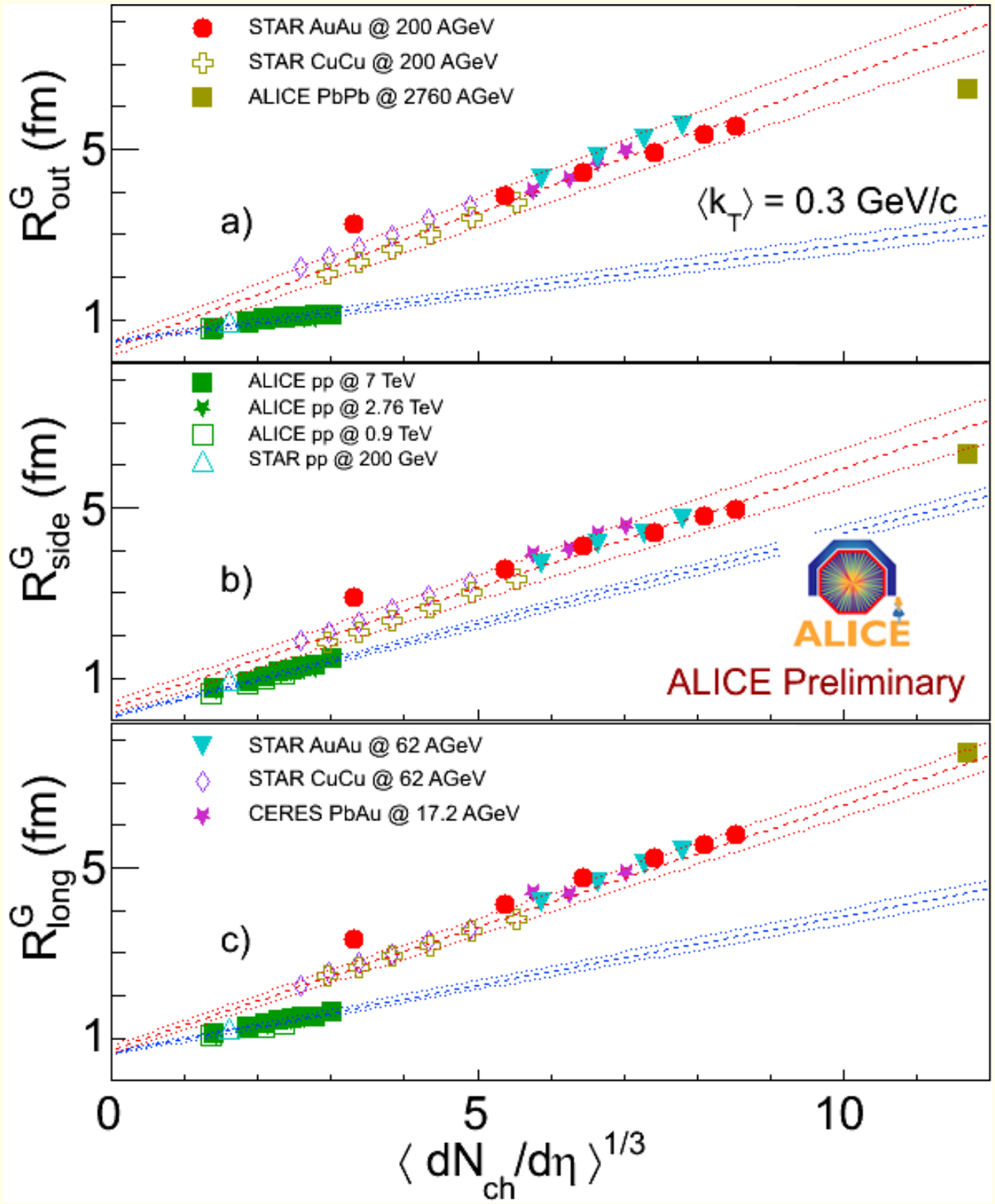
$$\vec{q} = \vec{p}_1 - \vec{p}_2, \quad \vec{k} = \frac{(\vec{p}_1 + \vec{p}_2)}{2}, \quad \vec{k}_T = \frac{(\vec{p}_{T,1} + \vec{p}_{T,2})}{2}$$

Bose-Einstein Correlations of Identical Pions (II): HBT Radii vs. k_T



- Radii falling with k_T a signature of collective medium in heavy-ion collisions
- R_{out} and R_{side} in p+p at 7 TeV decrease with k_T for large multiplicities
- EPOS event generator describes the p+p HBT data under the assumption of a phase with hydrodynamical evolution (arXiv:1104.2405)

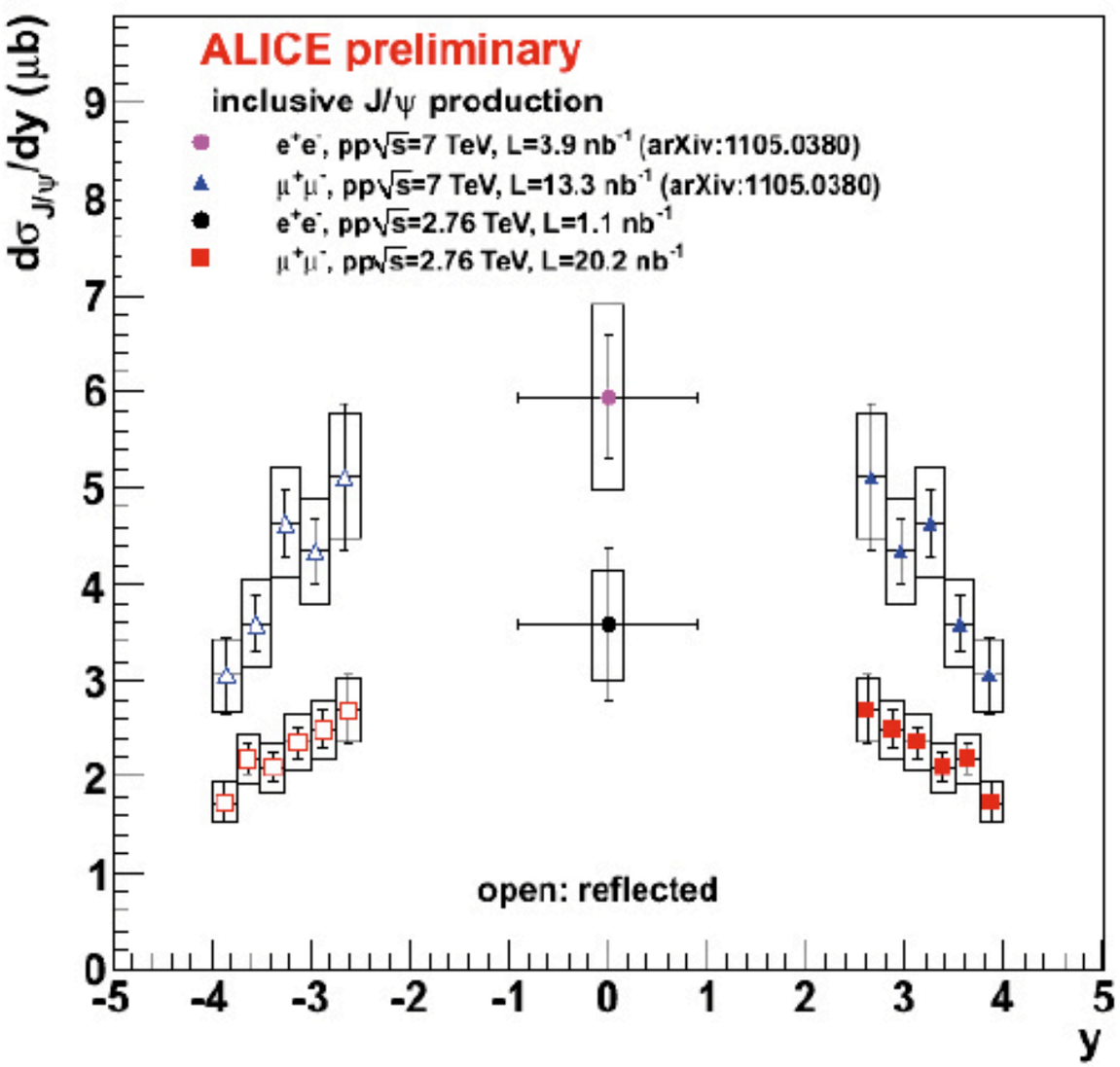
Bose-Einstein Correlations of Identical Pions (III): pp vs. AA

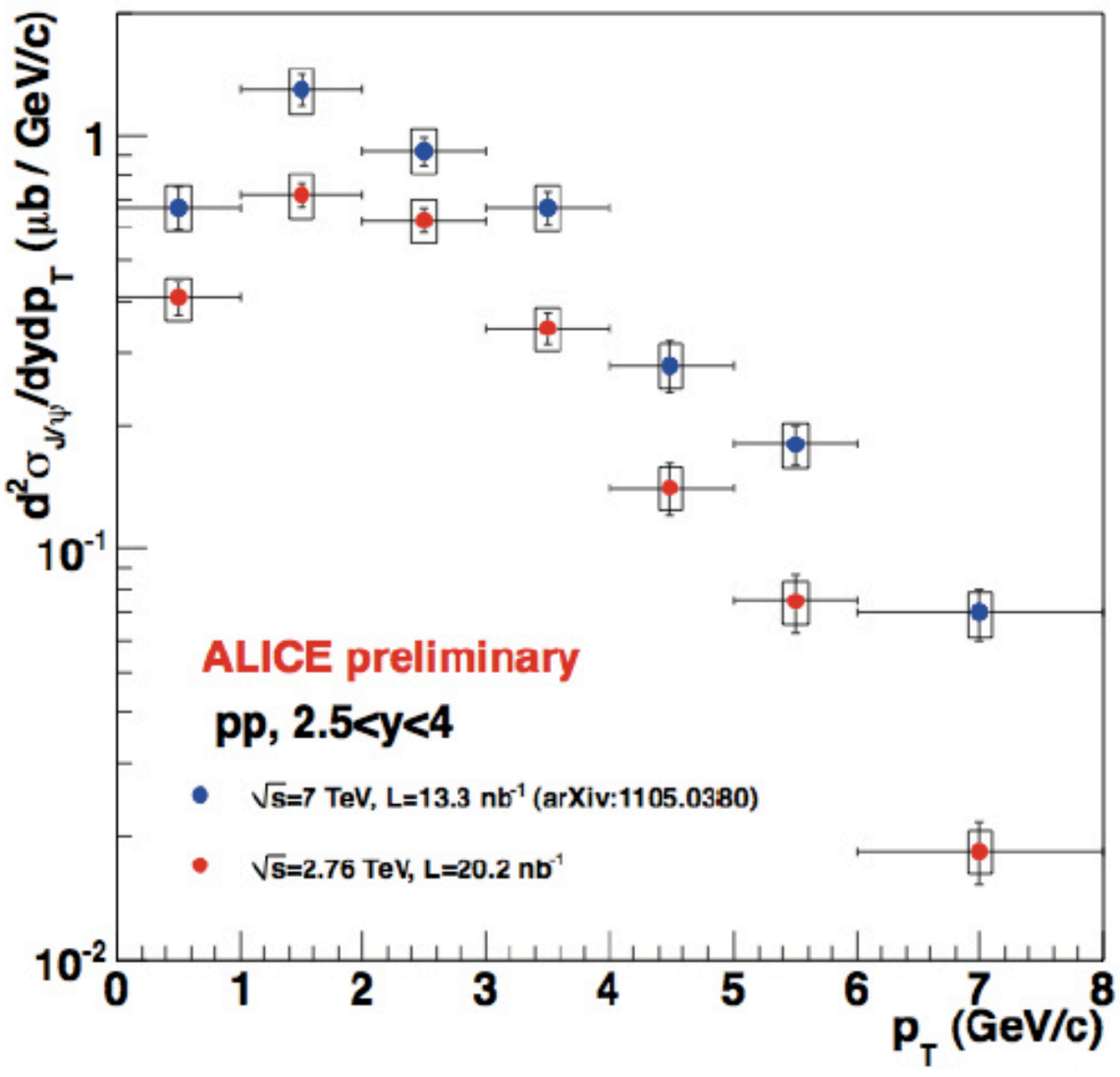


- pp HBT result compared to AA
- Radii scale with $(dN_{ch}/d\eta)^{1/3}$: Indication for a constant freeze-out density
- Freeze-out volume in p+p for same $dN_{ch}/d\eta$ smaller than in A+A: p+p collisions and AA collisions with the same multiplicity are different

Heavy Quarks

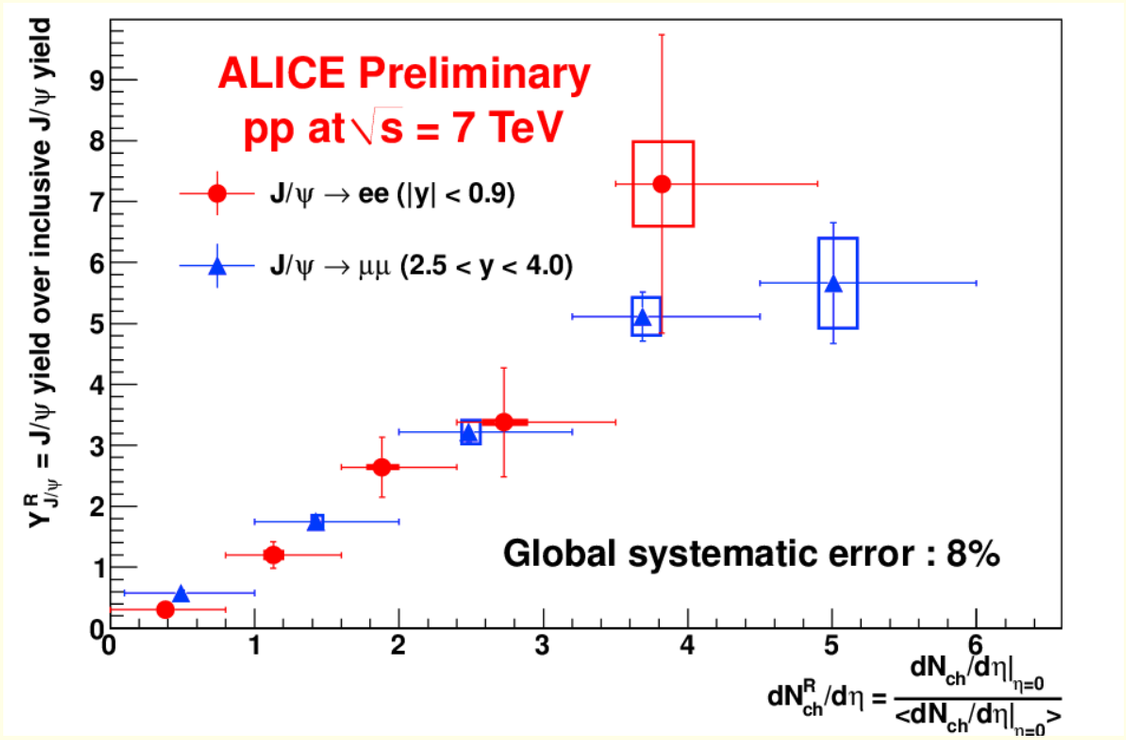
J/Ψ: Rapidity Distr. and p_T Spectrum in p+p at 2.76 and 7 TeV

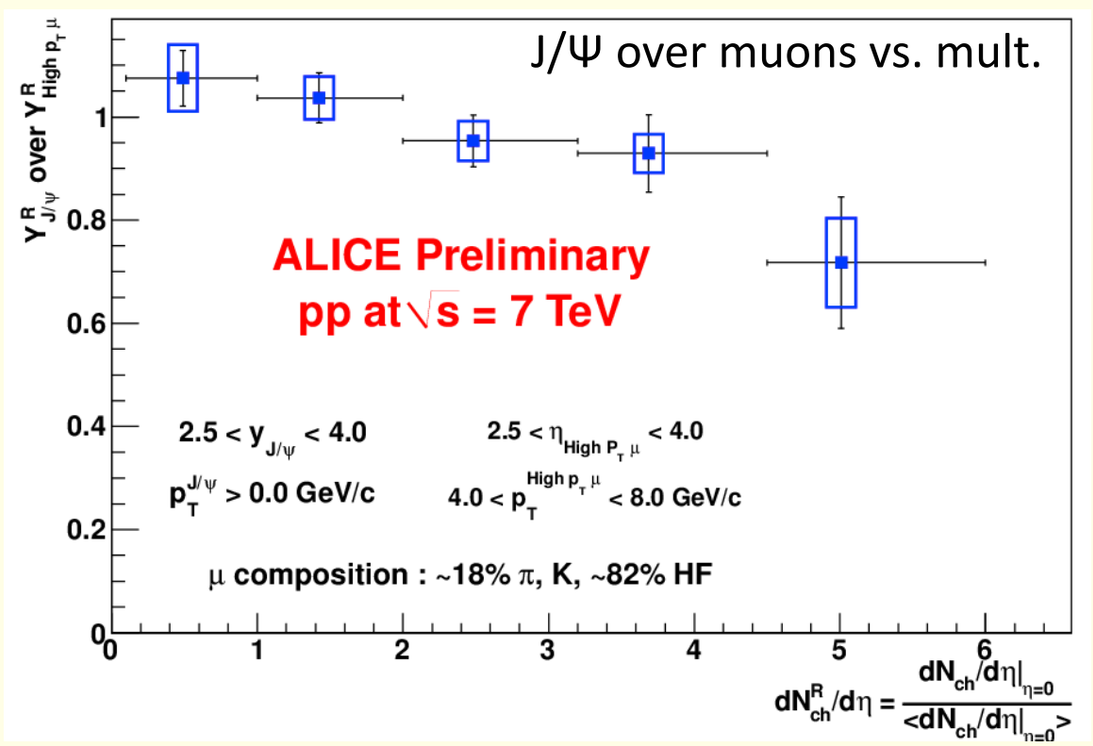




- Unique feature of Alice: broad *y* coverage down to $p_T \approx 0$

J/Ψ Yield as a Function of Charged-Particle Multiplicity



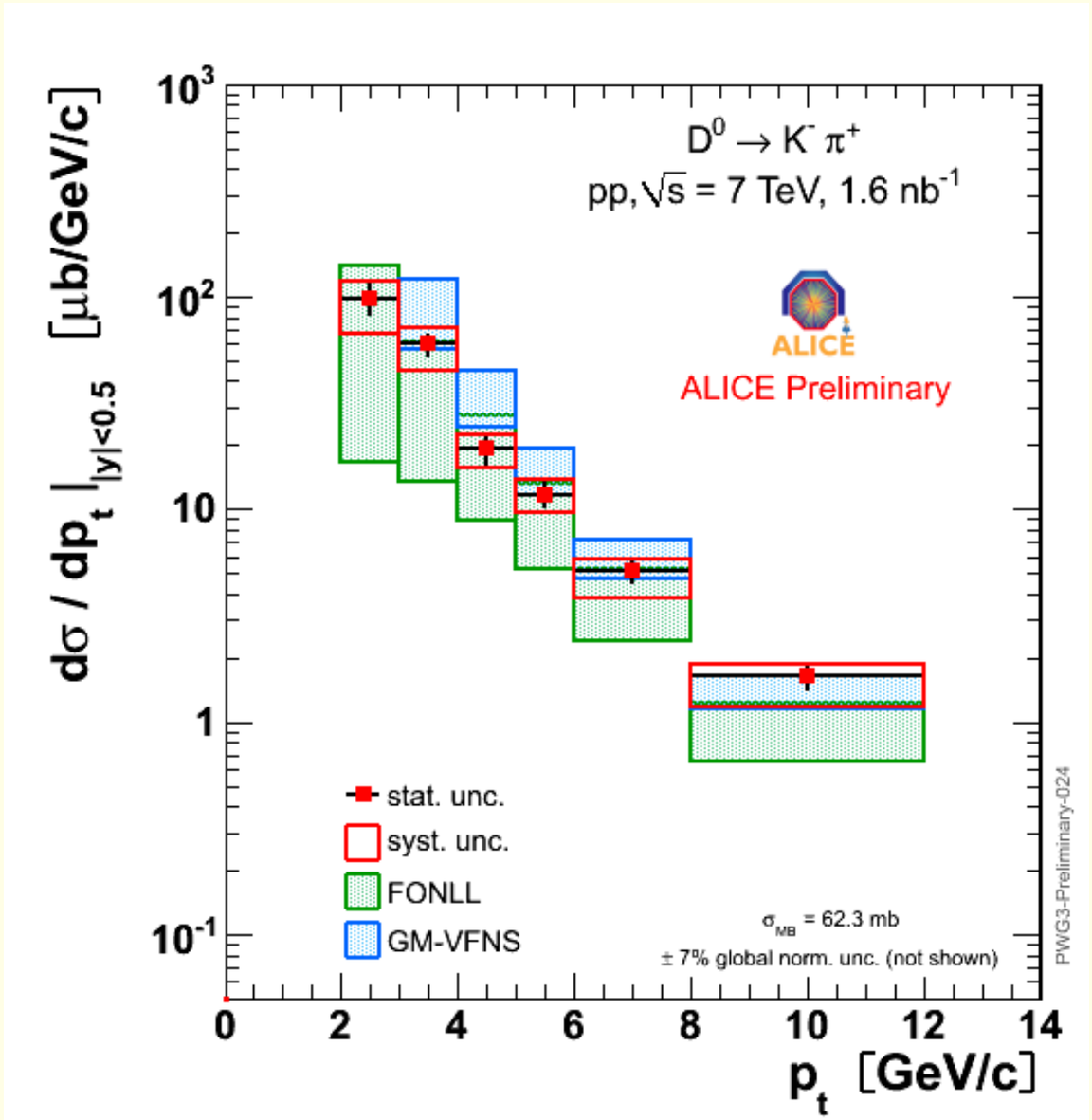


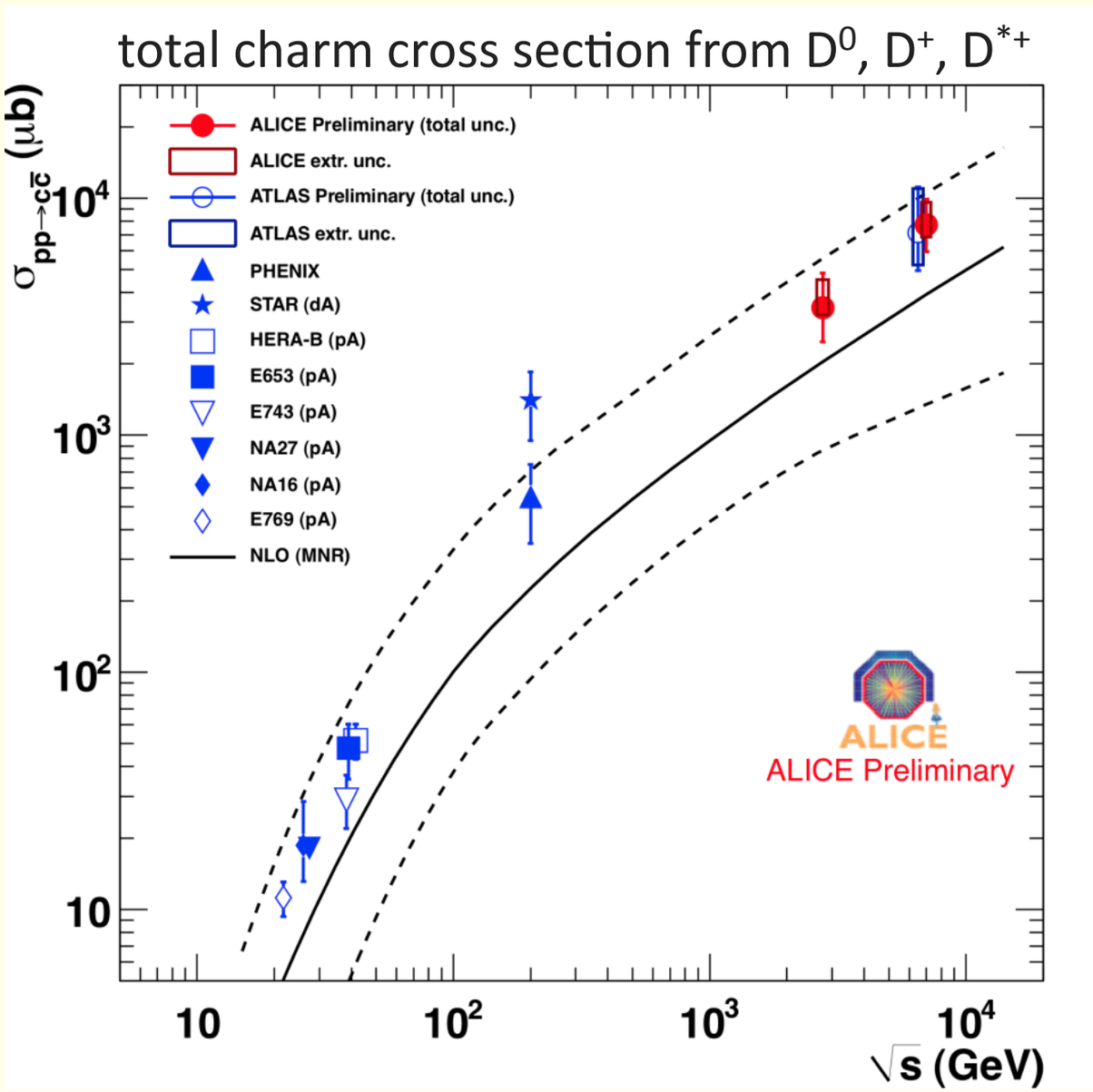
- In heavy-ion collisions J/Ψ is an important probe of the quark-gluon plasma
- J/Ψ potentially also a probe of medium effects in high-multiplicity p+p events at the LHC

- J/Ψ yields scales linearly with charged-particle multiplicity
- Interesting:
  Normalized to muons (mostly from heavy flavor decays), the J/Ψ yield shows a slight suppression in high multiplicity events

More details: R. Arnaldi, QM 2011

D Meson and Total Charm Cross Section





- D^0, D^+, D^{*+} cross sections in agreement with pQCD (FONLL, GM-VFNS)
- Total $c\bar{c}$ cross section: extrapolation from p_T = 2 GeV/c to p_T = 0 with FONNL

More details: D. Caffarri, PLHC2011

Conclusions

- dN_{ch}/dη, Multiplicity distributions, Charged Particle p_T Spectra, Underlying Event
  - In general not well described by pre-LHC Pythia tunes and Phojet
- Identified Particles
  - π, K, p, π^0, η, hyperons, ω, Φ, and other resonances measured
  - Hyperons: Large discrepancy between data and Pythia
  - π^0 : Gluon FF's that work at RHIC fail to describe data in p+p at 7 TeV
- HBT
  - Indications for collective (hydro-like) behavior in large-multiplicity p+p collisions
  - However, p+p and A+A collisions with same multiplicity have a different HBT volume
- Heavy Quarks
  - D mesons and total $c\bar{c}$ cross section described by pQCD
- ALICE has taken a first look into heavy-ion-like effects in high-multiplicity p+p collisions (HBT, J/Φ).
  - Results are encouraging enough to further pursue this