Soft QCD / Minimum Bias / Diffraction

Results from ALICE

P. Antonioli (INFN/Bologna)
on behalf of the ALICE Collaboration

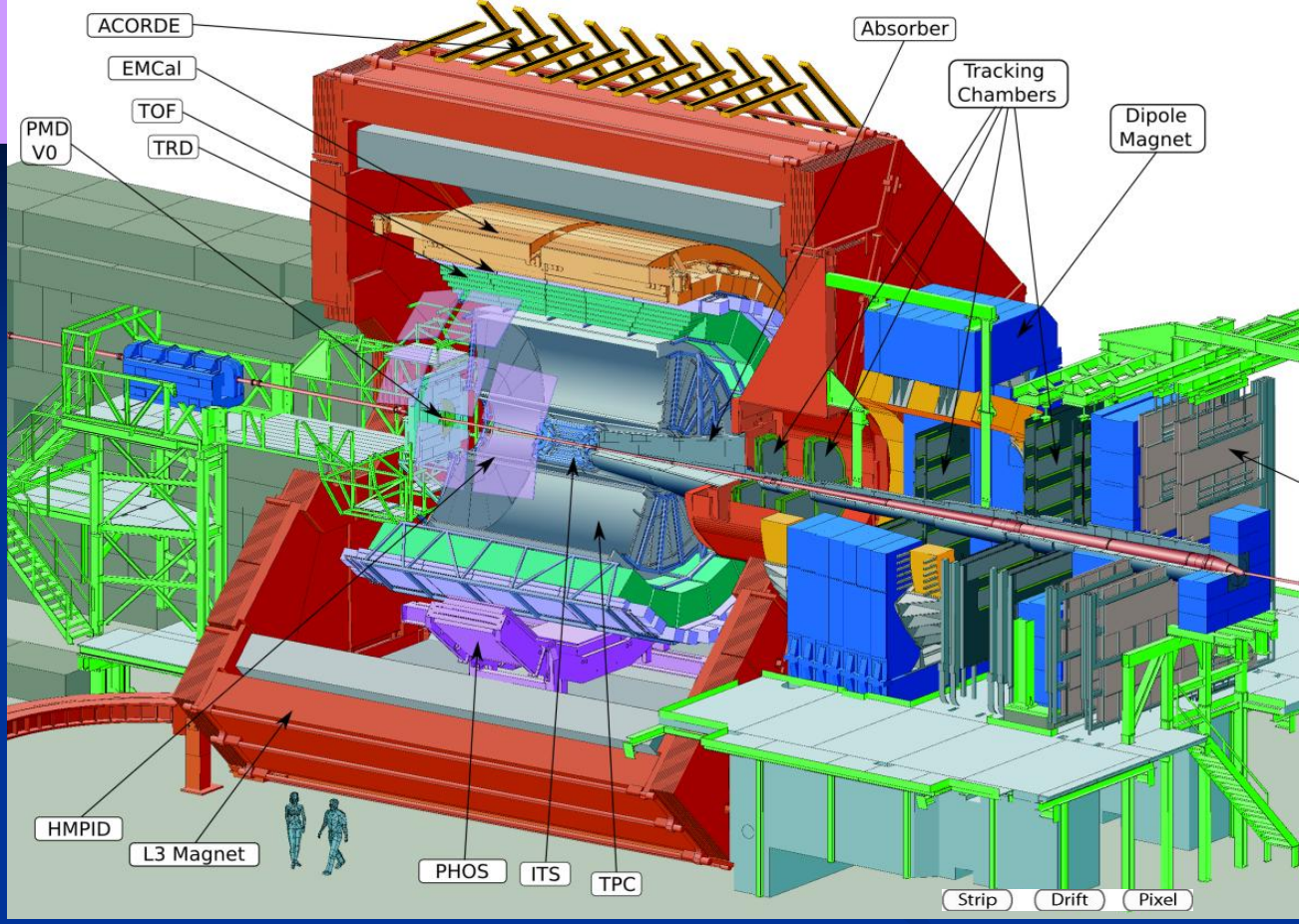
Outline

- ALICE interest in & capabilities for pp physics
- Diffraction and total cross section
- Inclusive production & identified particle production
  - Charged particle multiplicity, $dN_{ch}/d\eta$, dN_{ch}/dp_T
  - Yields and p_T spectra: π/K/p, hyperons
- Correlations and fluctuations
  - HBT correlations, mean p_T fluctuations

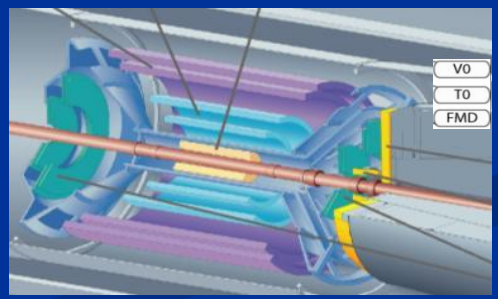
ALICE presentations: Heavy Ion (I) - high p_T @ ALICE: M. van Leeuwen Nov 14
Heavy Quark Production @ ALICE: C. Suire Nov 17
Heavy Ion (II) - soft p_T: ALICE/ATLAS/CMS P. Kujier Nov 18

ALICE detector

Alice numbers:
1300 members
116 institutes
33 countries



Highligths for this talk:



• moderate B (0.5 T), thin material (7% X_0 at perpendicular incidence in ITS)

→ low p_T reach (< 100 MeV/c)

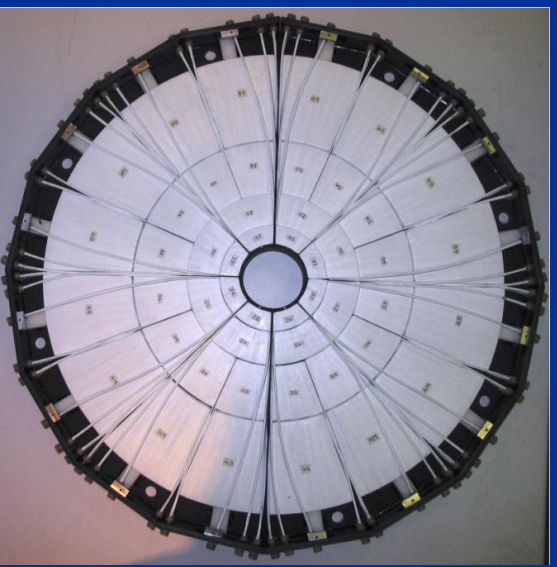
• extended PID capabilities in central barrel: π, K, p and electron identification

Data samples and triggers

System	Energy (TeV)	Trigger	Analyzed events	∫Ldt
pp	7	MB MUON	300M 130M	5 nb-1 16 nb-1
pp	2.76	MB MUON	65M ≈ 9M	1.1 nb-1 20 nb-1

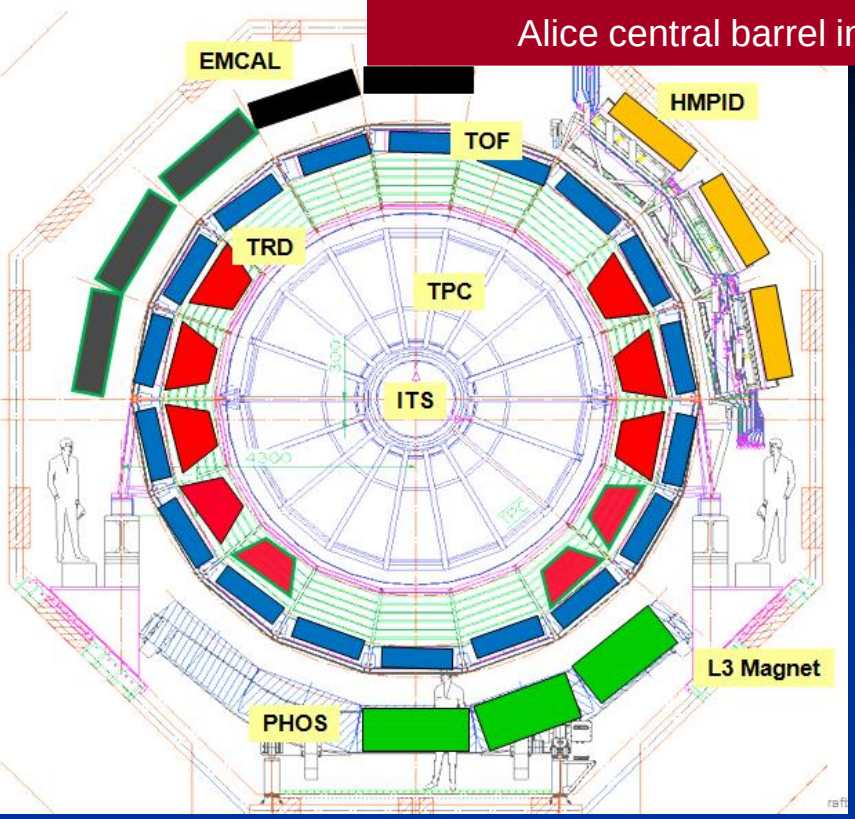
Triggers:
MB: based on VZERO (A and C) and SPD
SINGLE MUON: forward muon in coincidence with MB

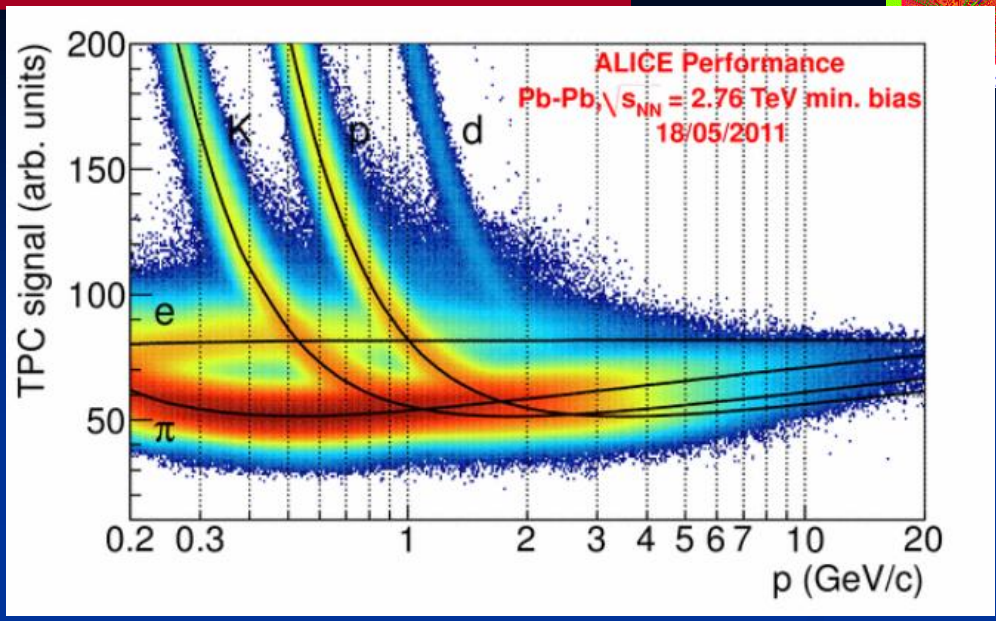
Centrality selection for PbPb:
Based on amplitude on V0

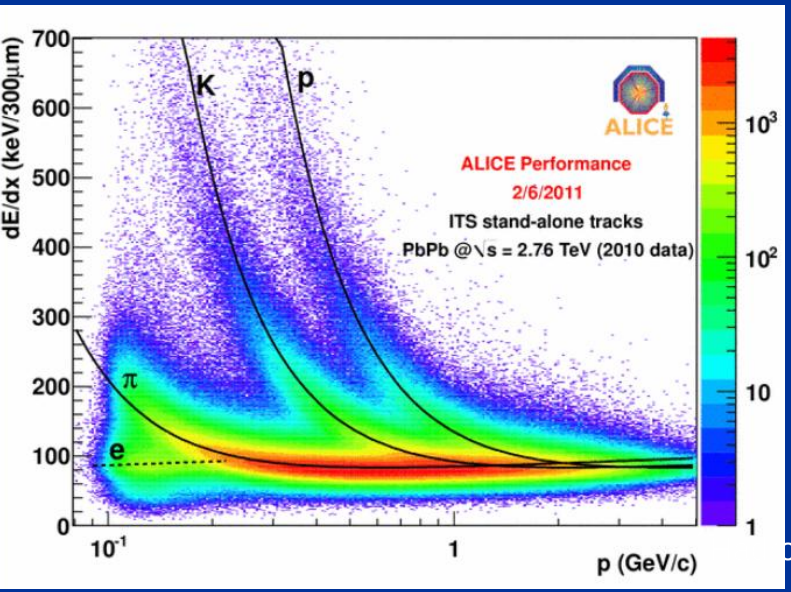


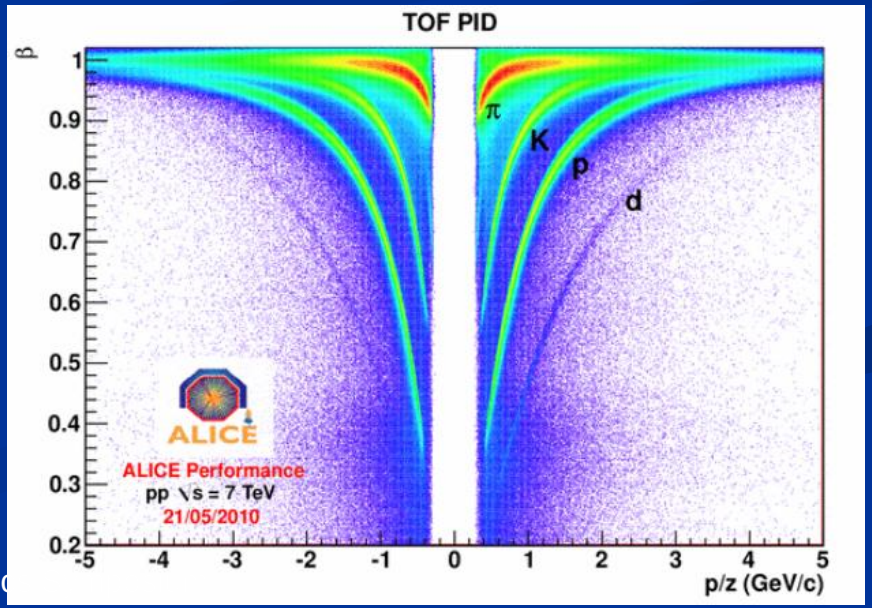
V0 detector (at z=3.3 m (V0A) and -0.9 m (V0C) from I.P.)
Two arrays of 32 scintillator counters
Used for reference cross-section (VdM scans) and diffraction studies

Alice central barrel in 2011 and some PID highlights

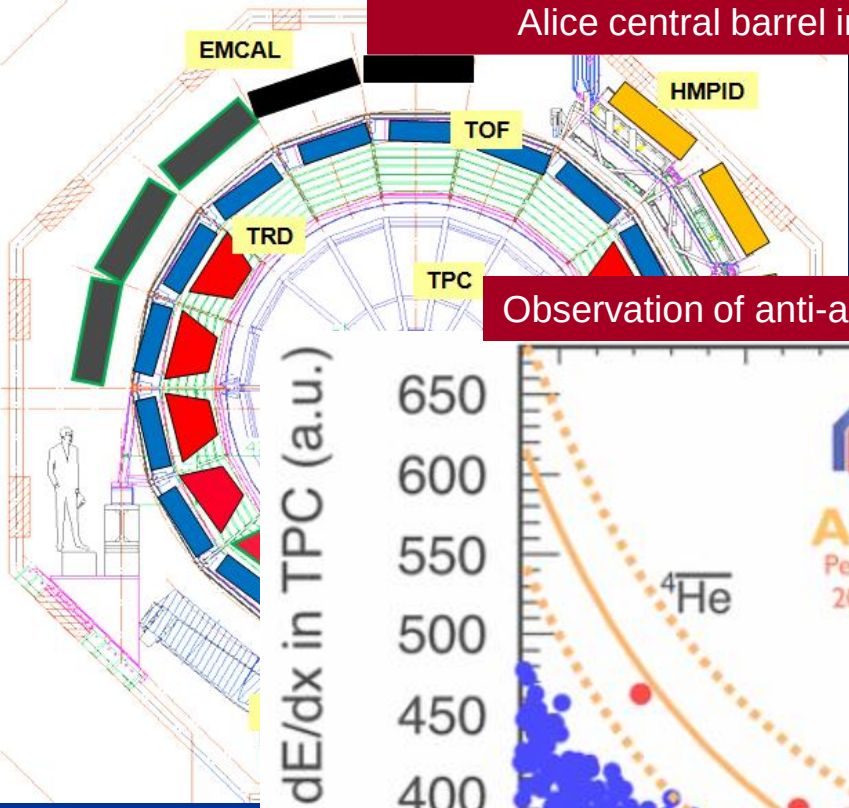


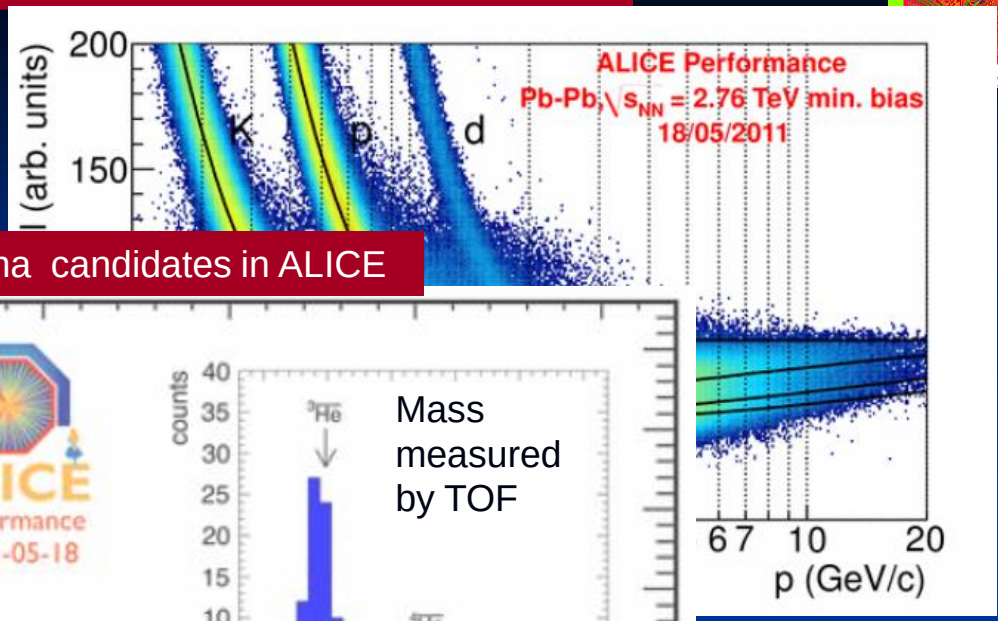




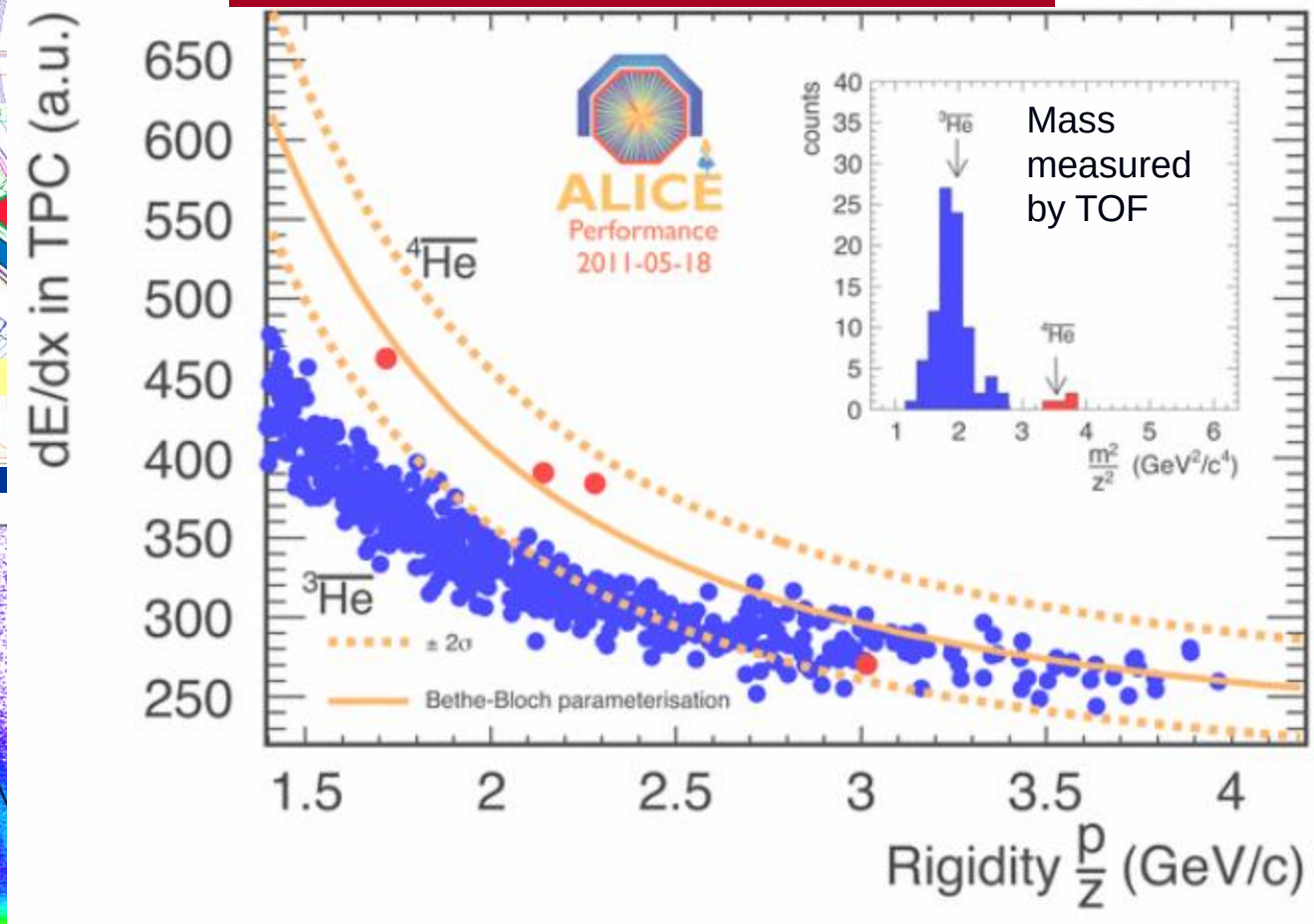


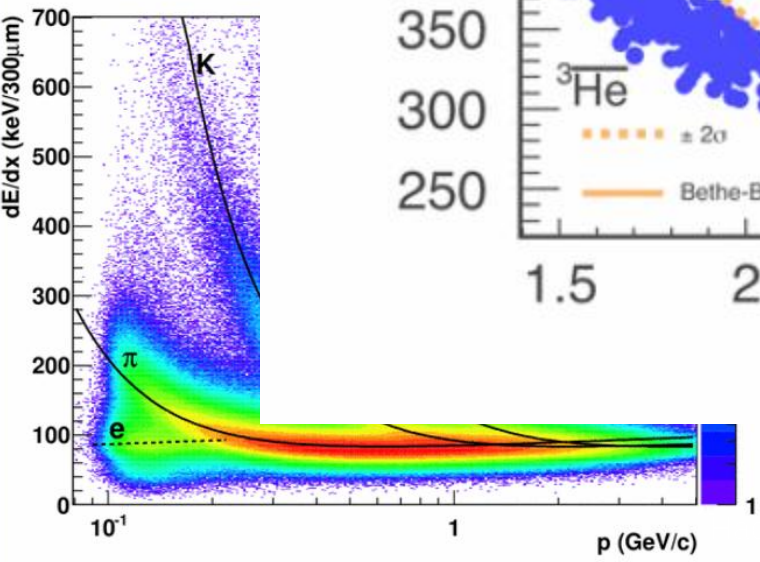
Alice central barrel in 2011 and some PID highlights

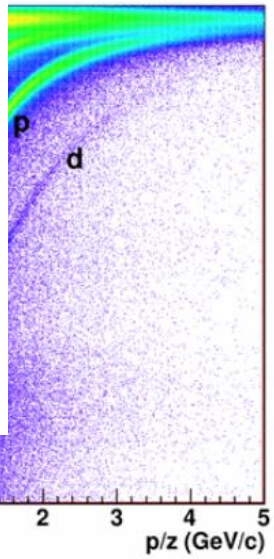


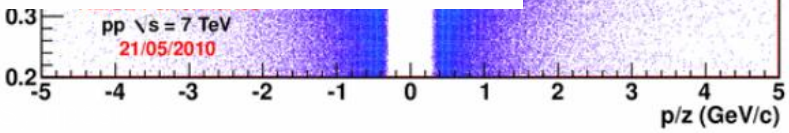


Observation of anti-alpha candidates in ALICE









pp physics in ALICE

Total cross section and diffraction

In this talk

Production mechanism

- inclusive production
- identified particle spectra
- multistrange hadrons

- vector mesons (π^0/η → gluon fragm. function)
- proton/anti-proton ratio (baryon transport mech.)

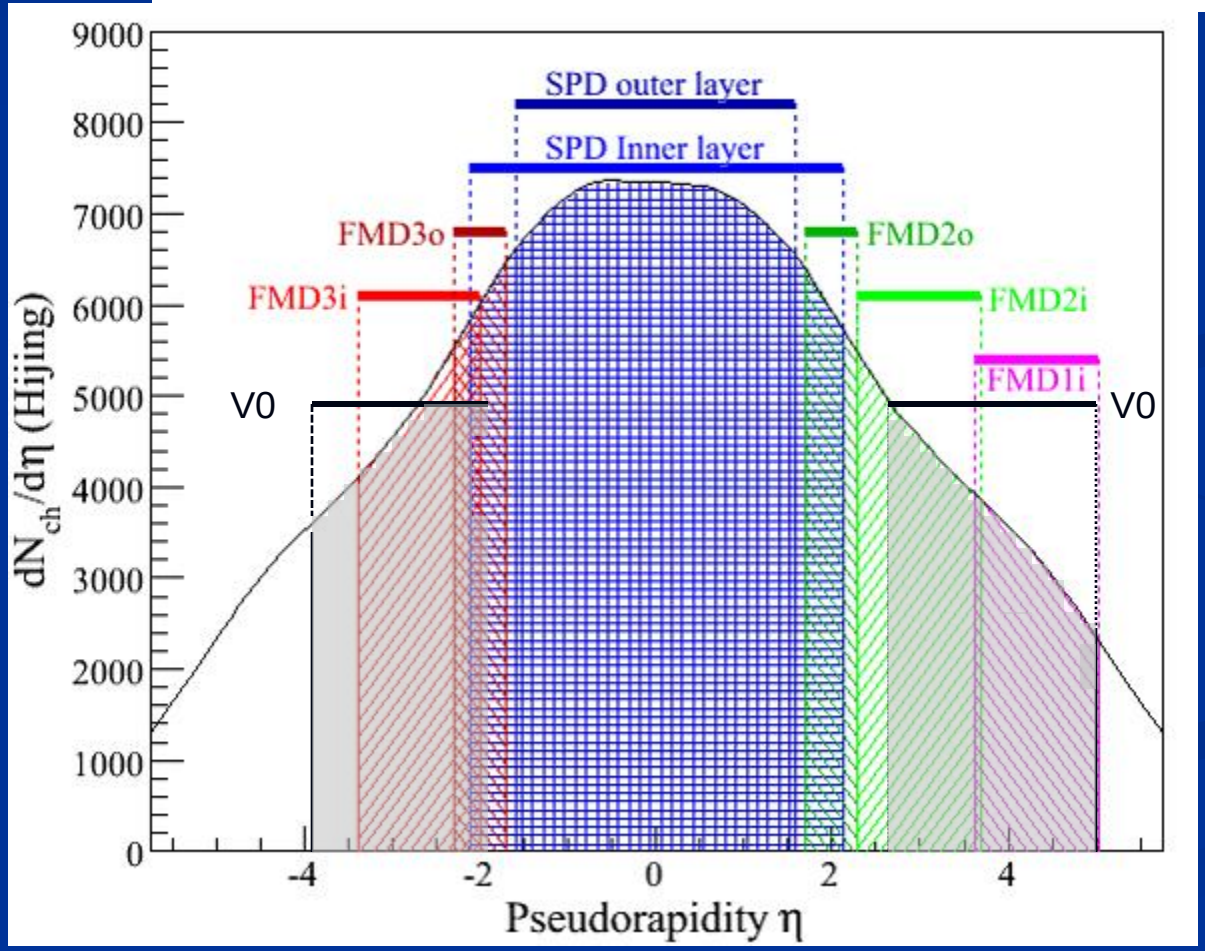
Bose-Einstein correlations and fluctuations

- Heavy Flavour production → see C. Suire talk
- (pp as baseline for HI physics → see M. van Leeuwen/P. Kujier talks)

Total cross section and diffraction

- ✓ measurement of the inelastic p-p cross-section
- ✓ extraction of Single and Double Diffraction cross-sections

Note: ALICE has 1-arm and 2-arm triggers allowing to extract SD and DD cross-sections



Alice detectors used:

- SPD
- V0
- FMD (silicon sensors at large rapidity)

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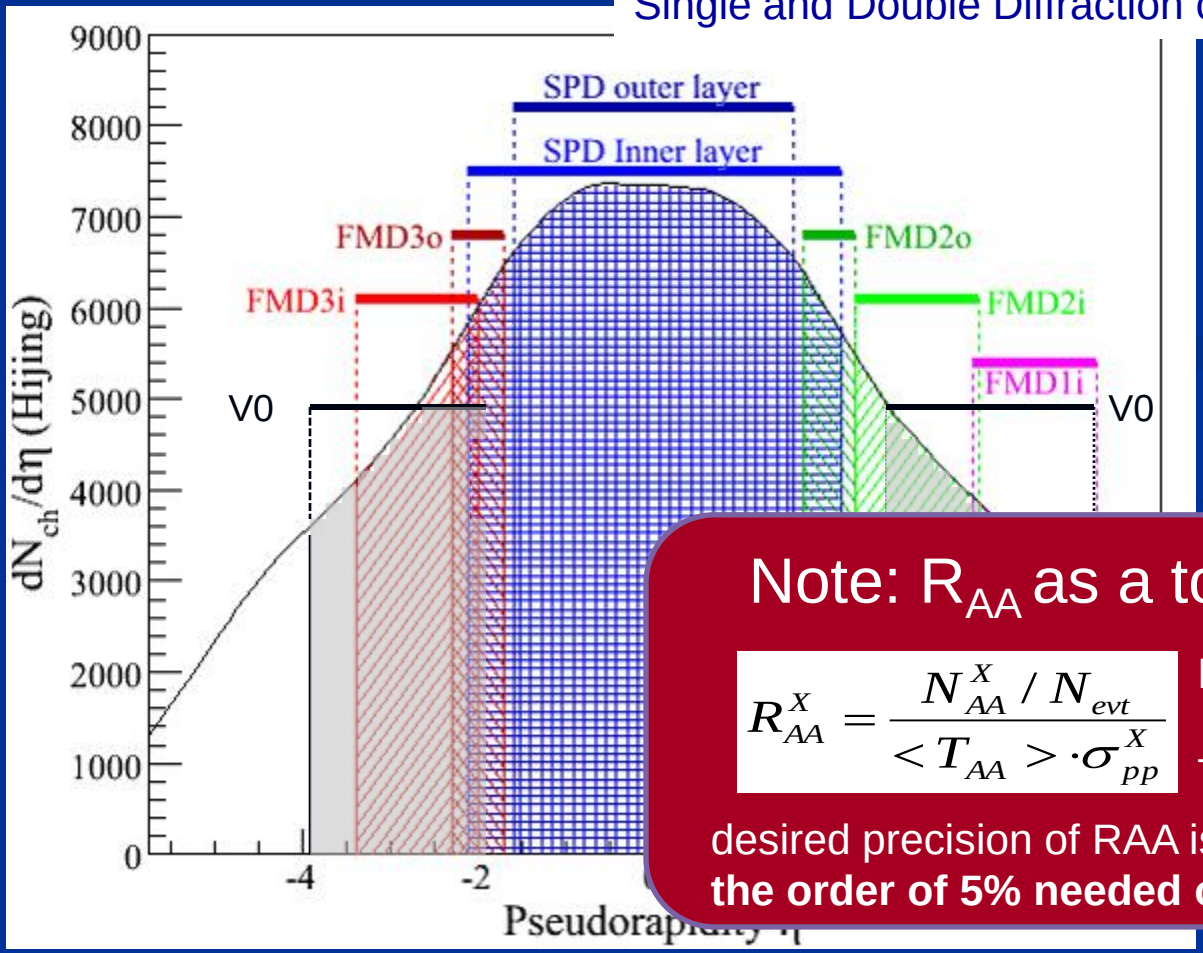

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- V0
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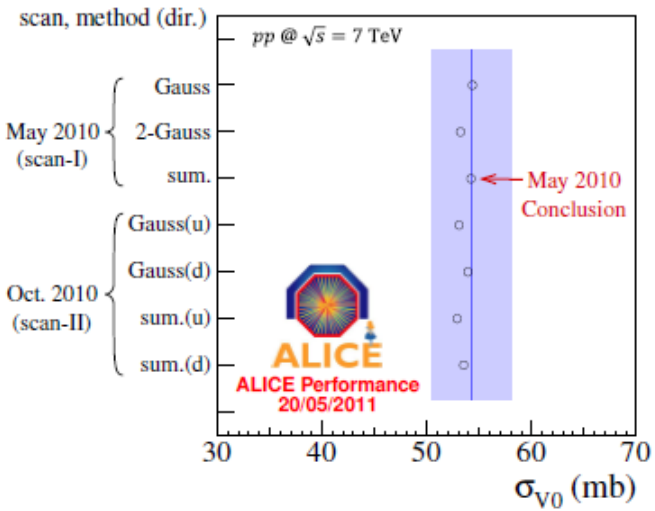
Note: R_{AA} as a tool to investigate QGP

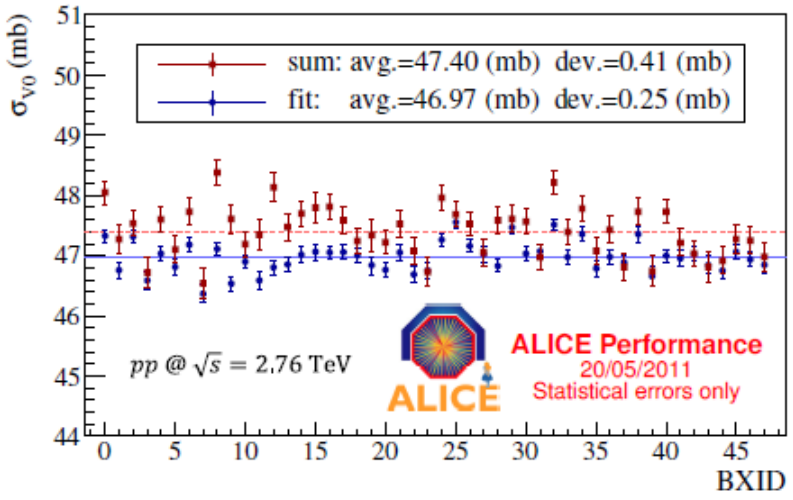
$$R_{AA}^{X} = \frac{N_{AA}^{X} / N_{evt}}{< T_{AA} > \cdot \sigma_{pp}^{X}}$$

Nuclear modification factor

T_{AA}: average nuclear overlap function

desired precision of RAA is typically 10%, **thus precision of the order of 5% needed on σ_{pp}**

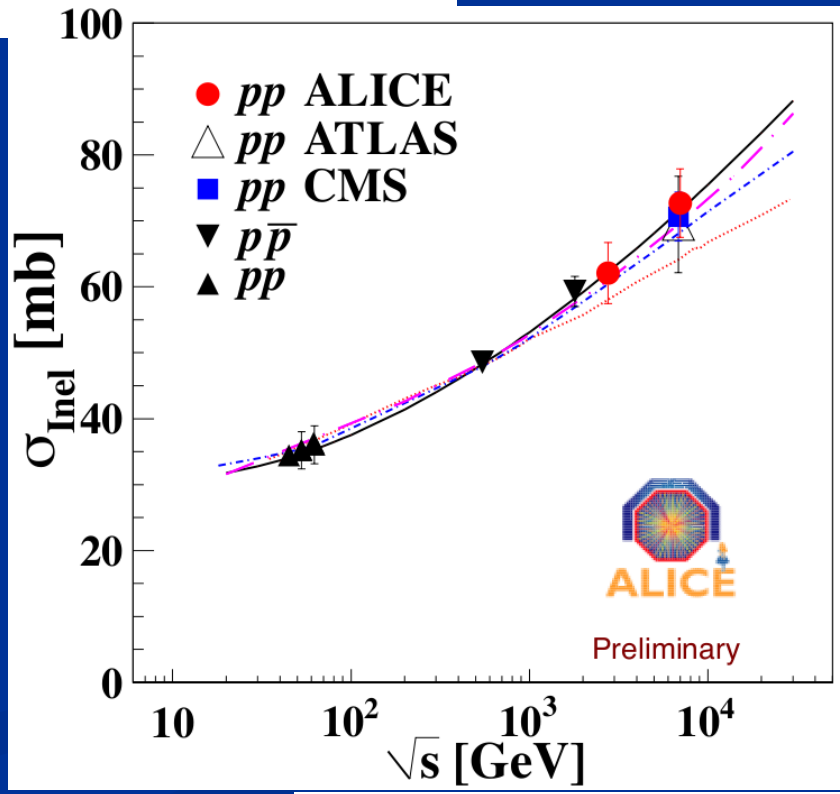




Van der Meer scans @ 2.76 TeV and 7 TeV

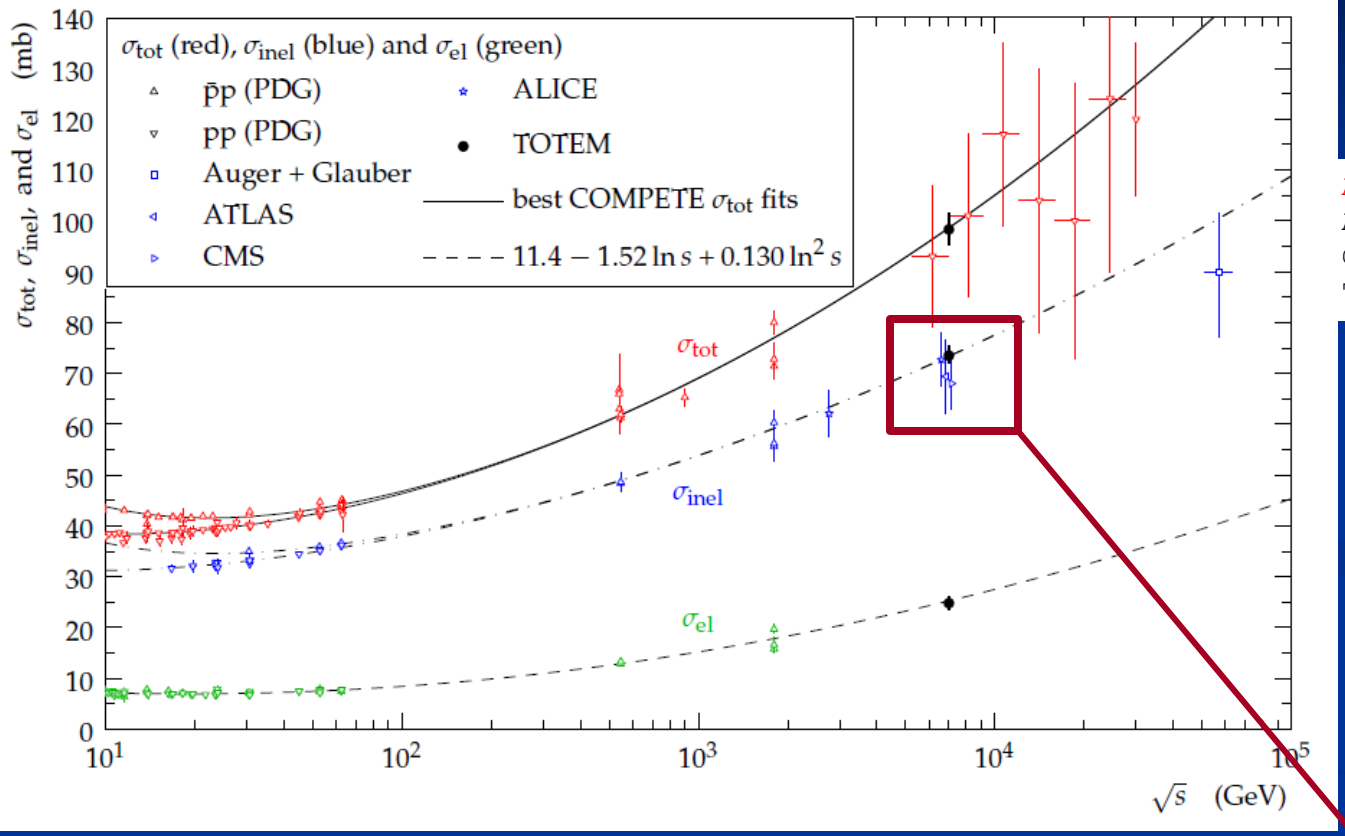
Comparison with other experiments:
$\sigma^{N\geq 1}$ = production of ≥1 charged part.
with $|\eta|<0.8$, $p_T>0.5$ GeV/c
showed agreement between experiments

For details:
K. Oyama, arXiv:1107.6902
M. Pogoshyan, arXiv:1109.4510

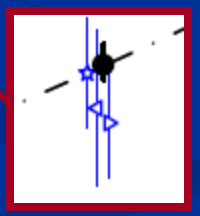


Gotsman et al., arXiv:1010.5323, EPJ. C74, 1553 (2011)
Kaidalov et al., arXiv:0909.5156, EPJ. C67, 397 (2010)
Ostapchenko, arXiv:1010.1869, PR D83 114018 (2011)
Khoze et al., EPJ. C60 249 (2009), C71 1617 (2011)

From TOTEM Coll., CERN-PH-EP-2011-158 (Sep. 2011)



ALICE: arXiv hep-ex/1109.4510
ATLAS: arXiv hep-ex/1104.0326
CMS: CMS-PAS-FWD-11-001
TOTEM: CERN-PH-EP-2011-158

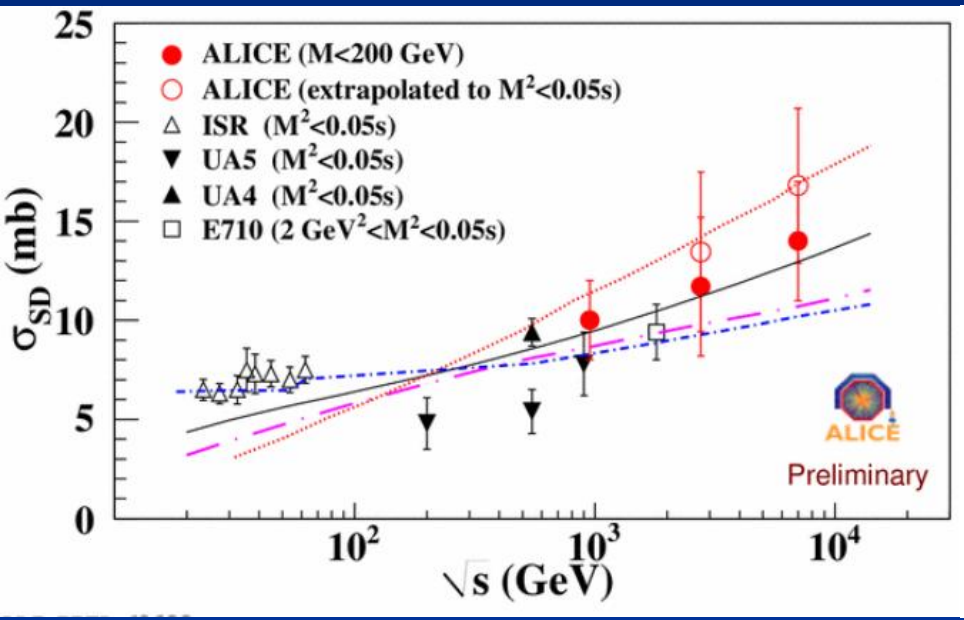


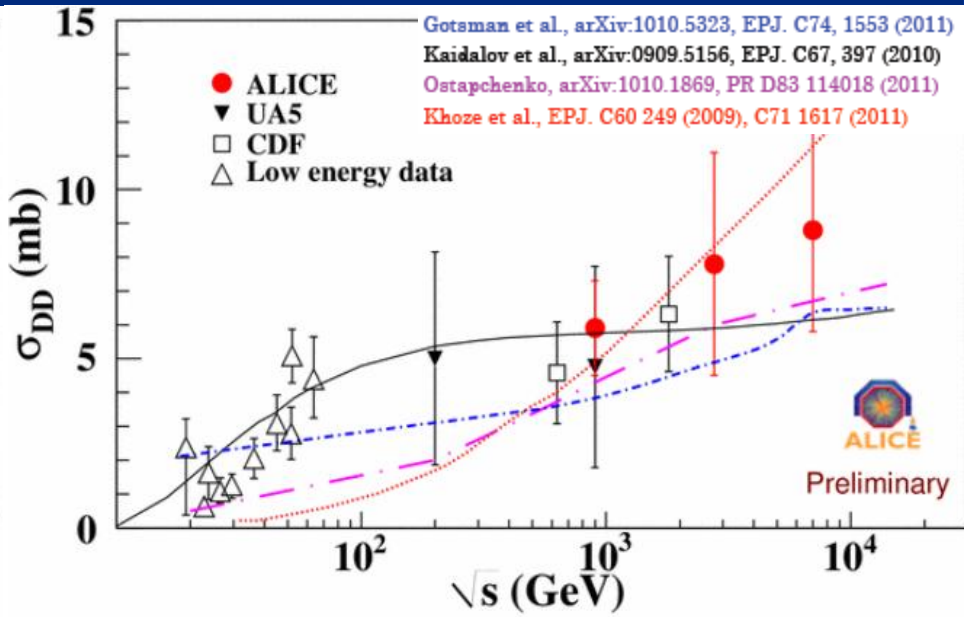
Very good agreement between LHC experiments
ALICE final result is in agreement with our preliminary result at 7 TeV within less than 1% (and reduction of error due to lumi contribution)

σ_{inel} ($\sqrt{s}$=7 TeV) = 73.2 ± 1.1 (model) ± 2.8 (lumi)

Single and double diffractive

Study of pseudo-rapidity distribution of tracks made by event vertex and a hit either in SPD, VZERO or FMD cells



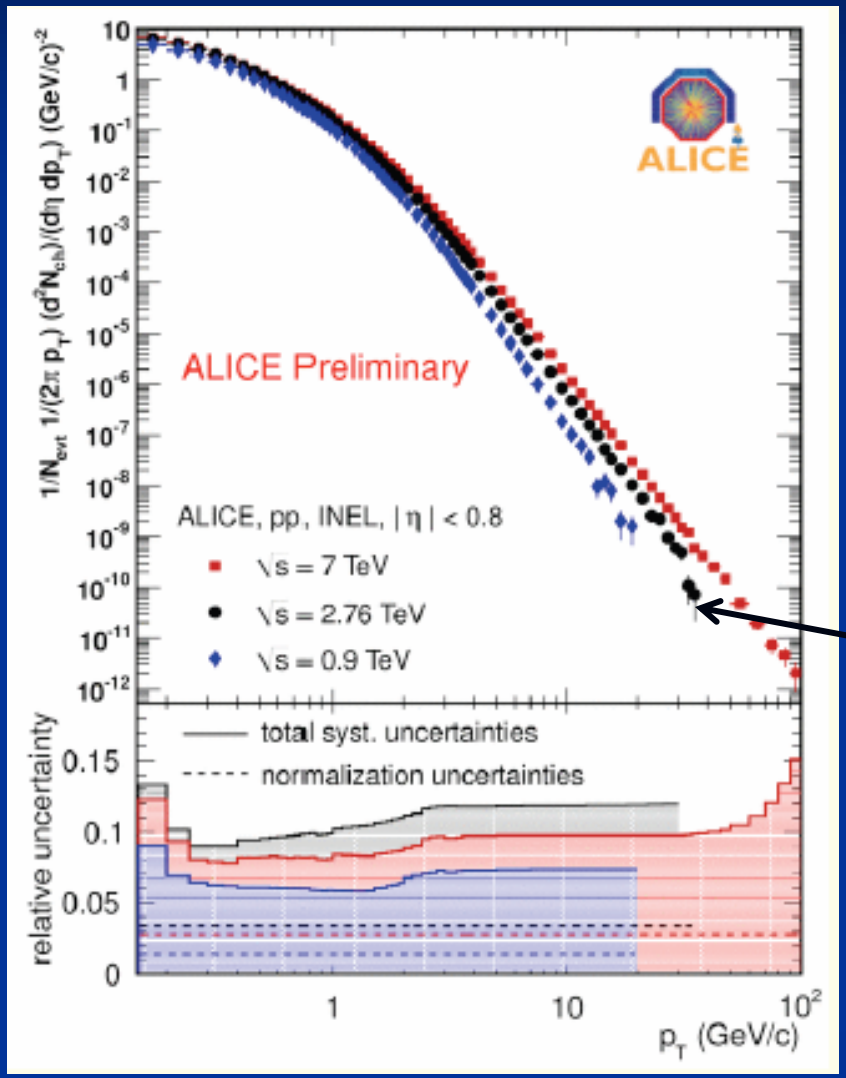


Within accuracy, ratio is constant

$\sqrt{s}$ (TeV)	$\sigma_{SD}/\sigma_{inel}$	$\sigma_{DD}/\sigma_{inel}$
0.9	0.202 ± 0.034	0.113 ± 0.029
2.76	0.187 ± 0.054	0.125 ± 0.052
7	0.201 ± 0.039	0.122 ± 0.036

Inclusive production

Charged multiplicity at 7 TeV: Eur. Phys. Journal **C 68** (2010), 345
Charged multiplicity (900 GeV & 2.36 TeV): Eur. Phys. Journal **C 68** (2010), 89



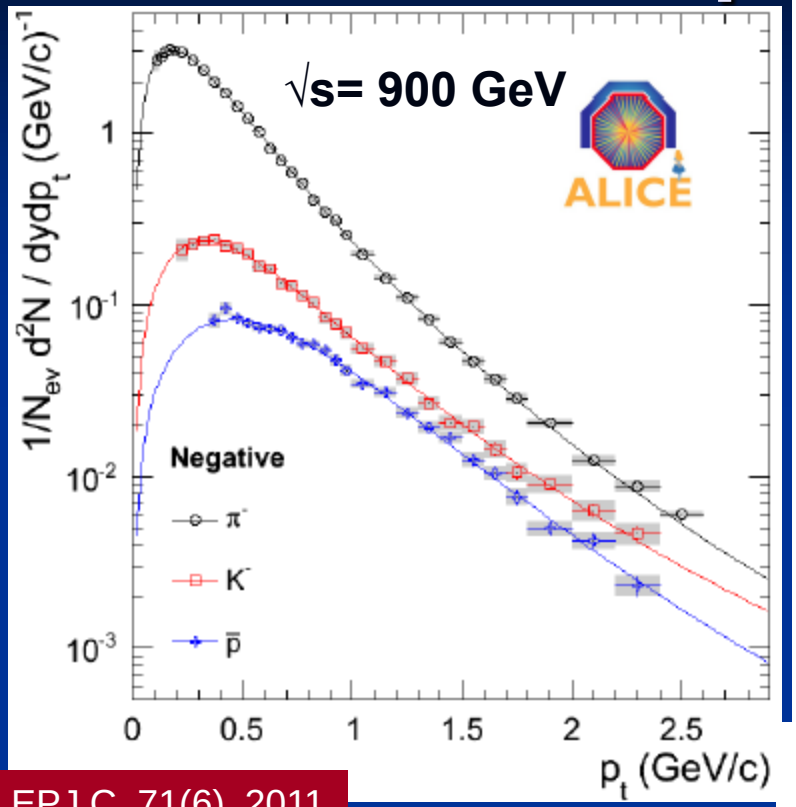
(Already published results summarized in backup slides)

Modified Hagerdon function used for fit
p_T^{-n} power law observed at high p_T (above 3 GeV)

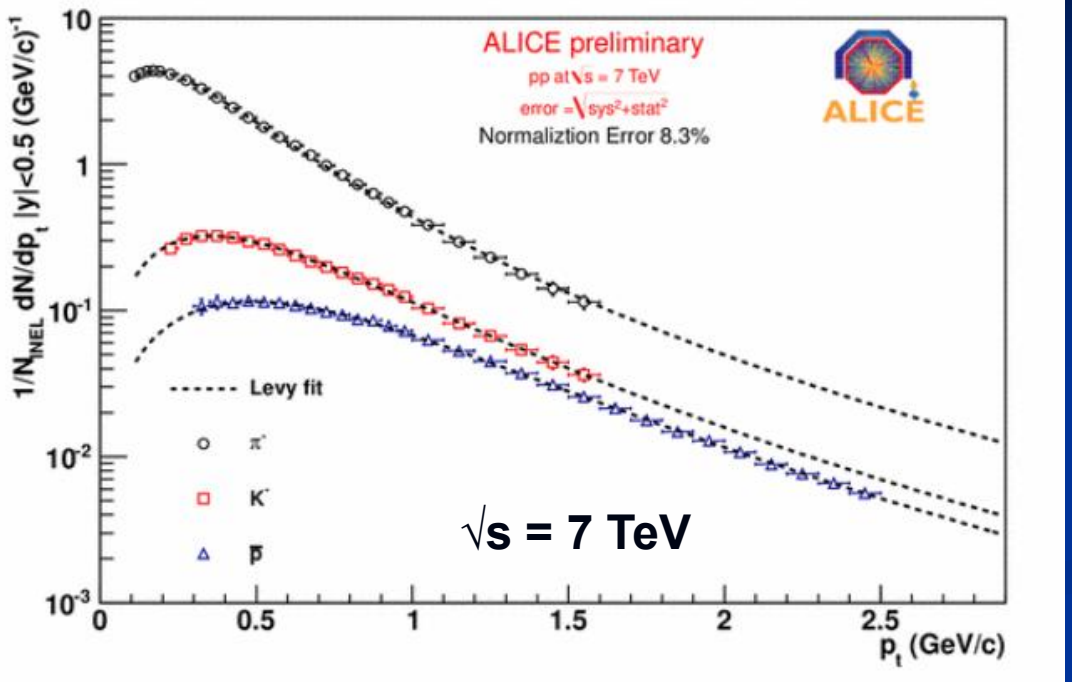
$$\left(1+\frac{p_t}{p_0}\right)^{-n} \longrightarrow \begin{cases} \exp\left(-\frac{n}{p_0}p_t\right) & \text{for } p_t \to 0, \\ \left(\frac{p_0}{p_t}\right)^n & \text{for } p_t \to \infty. \end{cases}$$

added spectra from 'low' energy run in 2011 pp @ √s =2.76 TeV

Identified particle spectra



EPJ C, 71(6), 2011



$$\frac{d^2N}{dp_t dy} = p_t \frac{dN}{dy} \frac{(n-1)(n-2)}{nC(nC + m_0(n-2))} \left(1 + \frac{m_t - m_0}{nC}\right)^{-n}$$

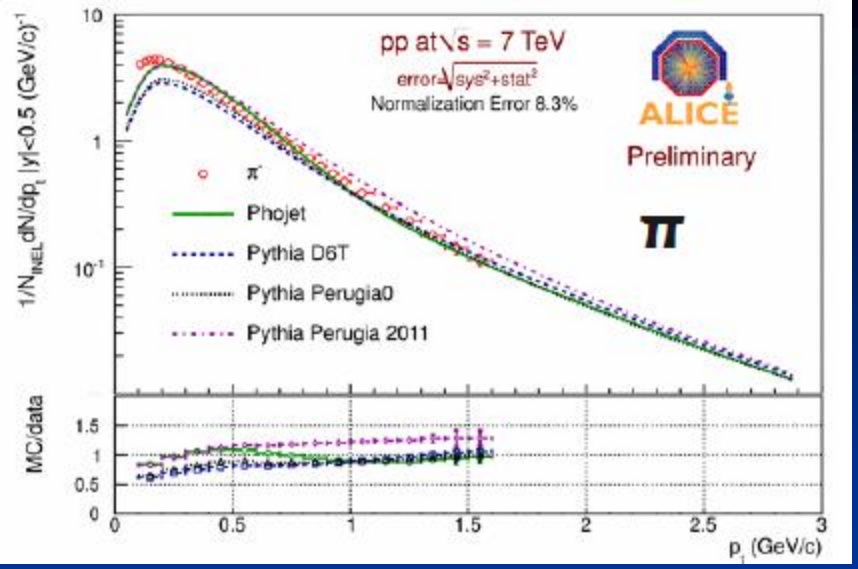
use of ITS-TPC-TOF, individually and in combination in different p_T ranges

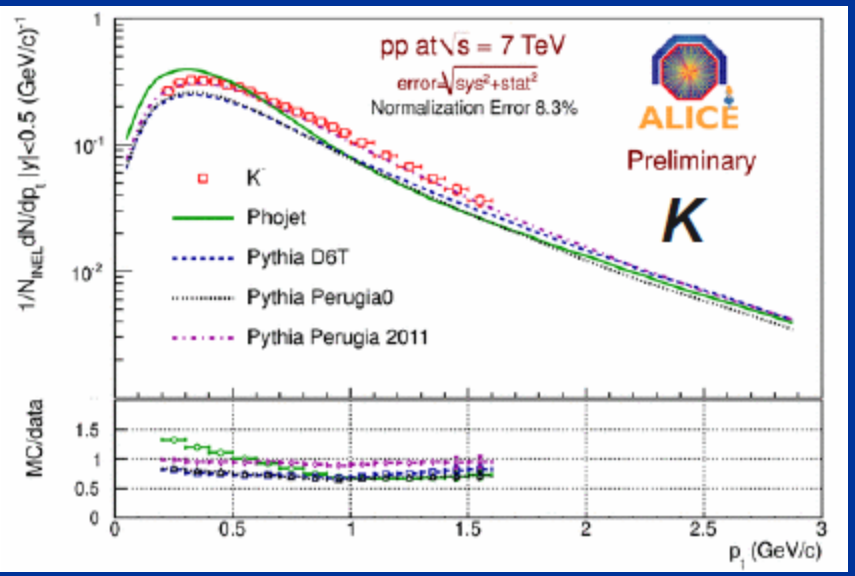
P_t ranges (GeV/c)	ITSsa	ITSTPC	TPCTOF	TOF
π	0.1-0.5	0.2-0.55	0.2-1.4	0.5-1.6
K	0.2-0.5	0.25-0.5	0.25-1.4	0.5-1.6
p	0.3-0.55	0.4-0.85	0.45-1.7	0.9-2.5

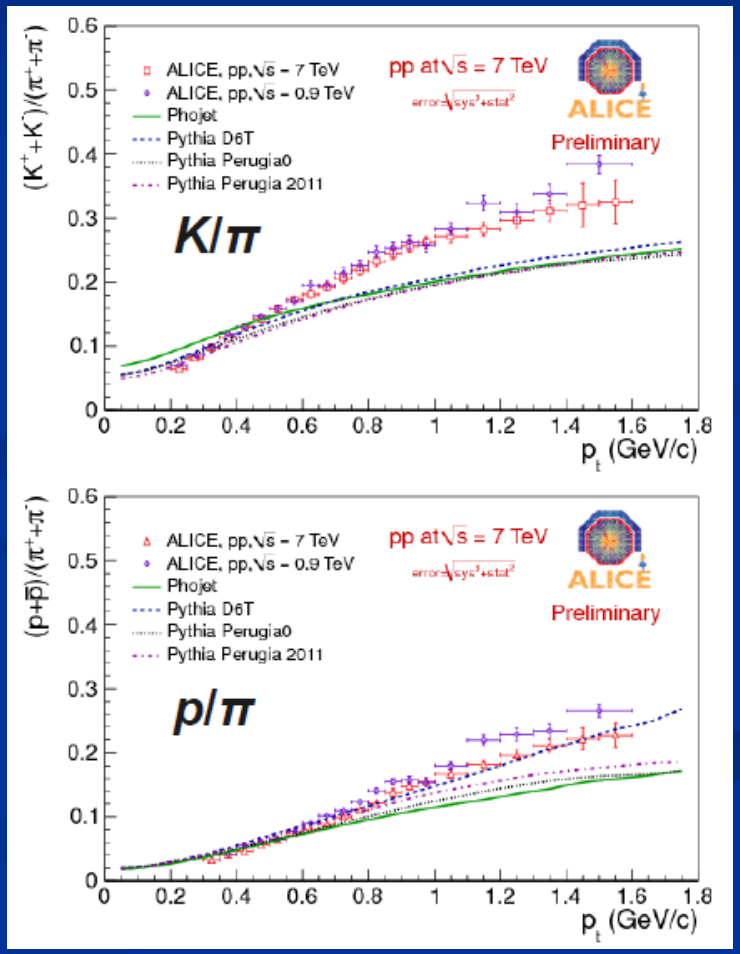
Details: B. Guerzoni at SQM 2011

Spectra / Particle ratios and MC

- comparison with Perugia 2011 shows nice agreement with kaons and overestimation for pions
- particle ratios plots generally challenge MC







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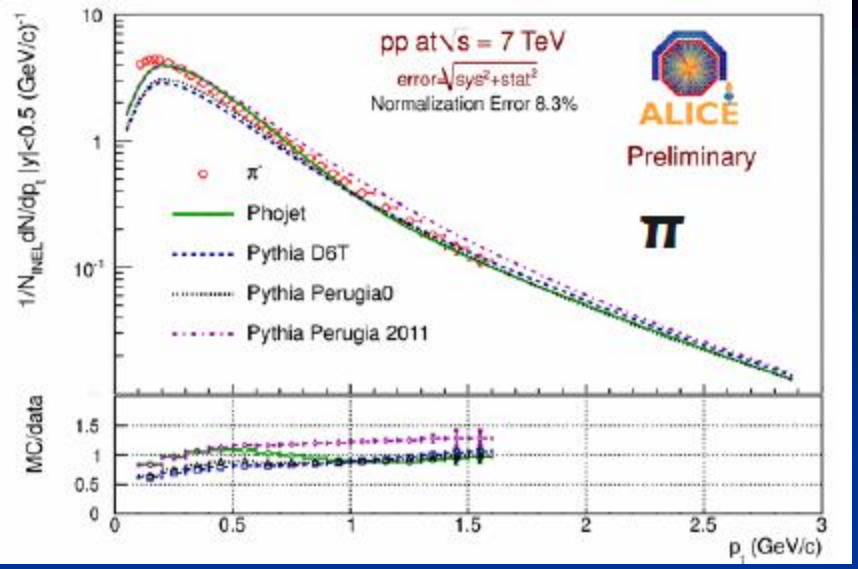
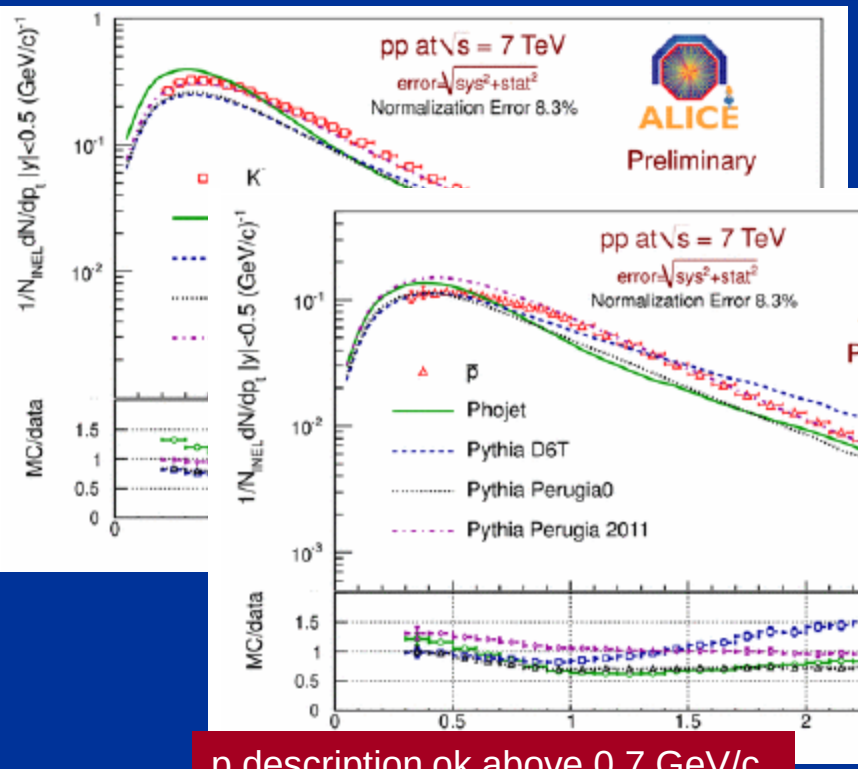
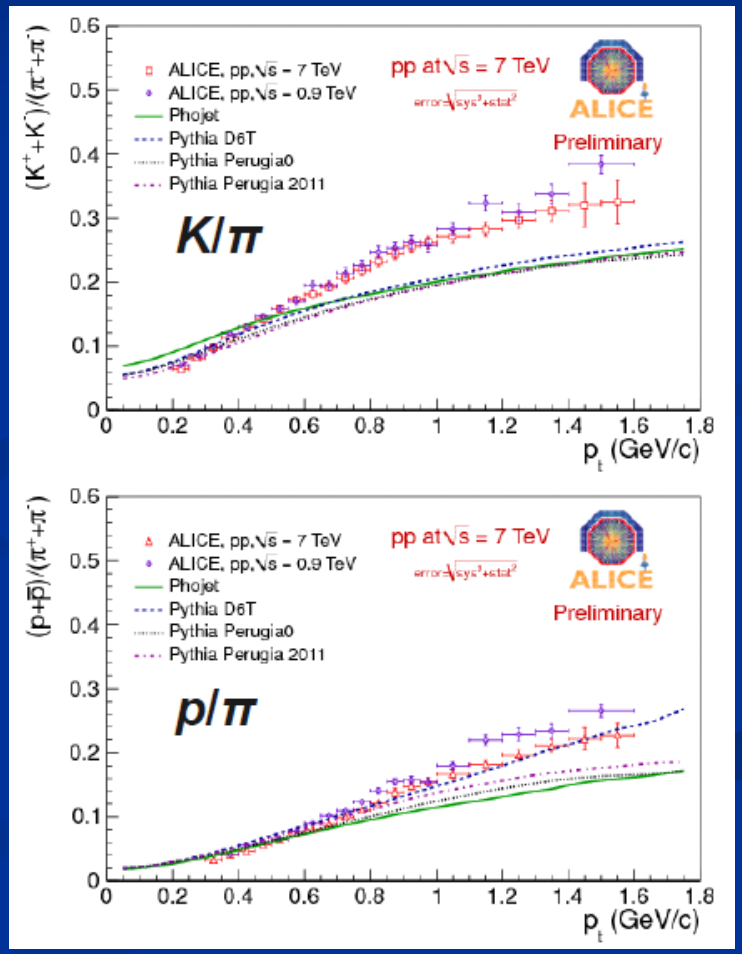
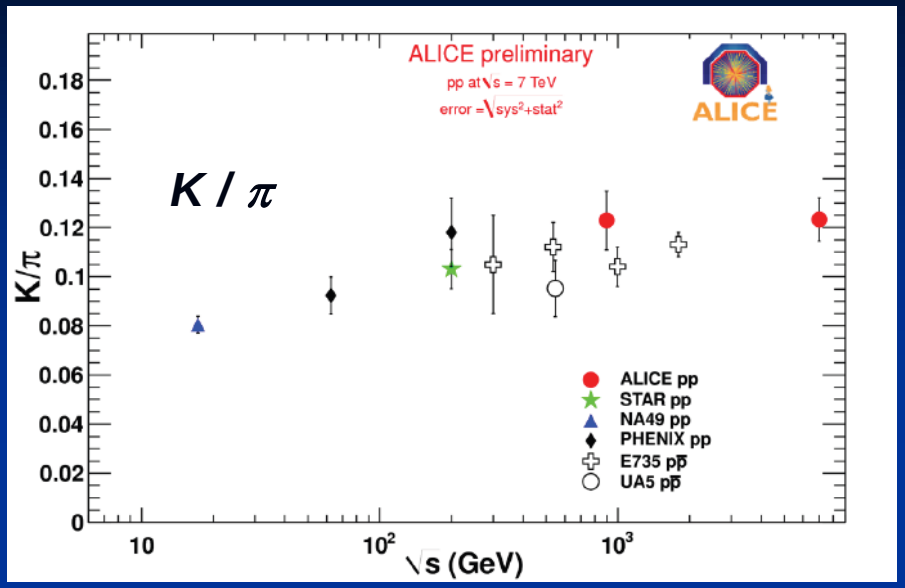


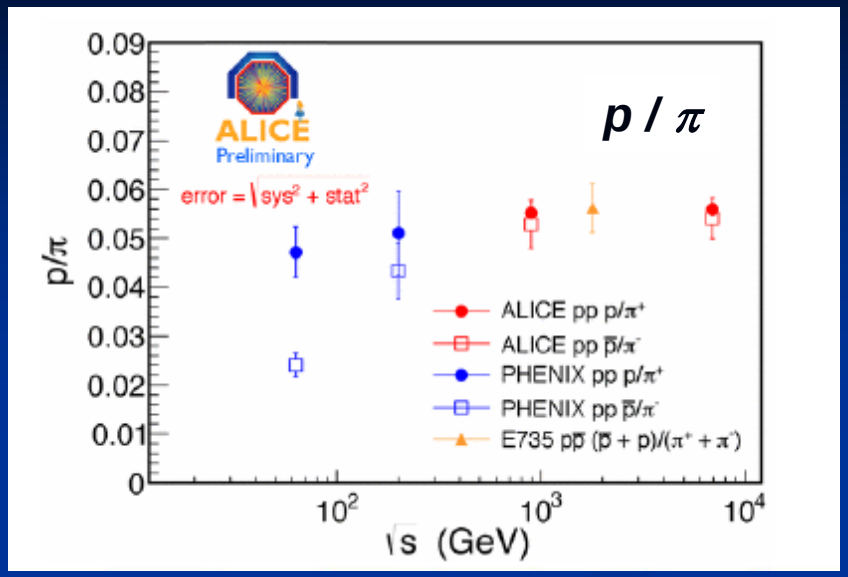




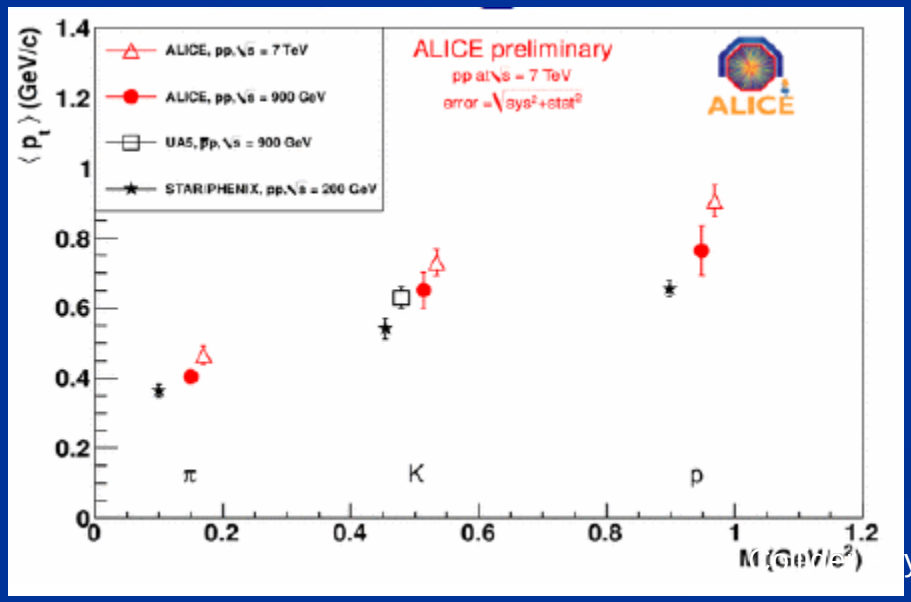
p description ok above 0.7 GeV/c

Particle ratios (2) and <p_T>





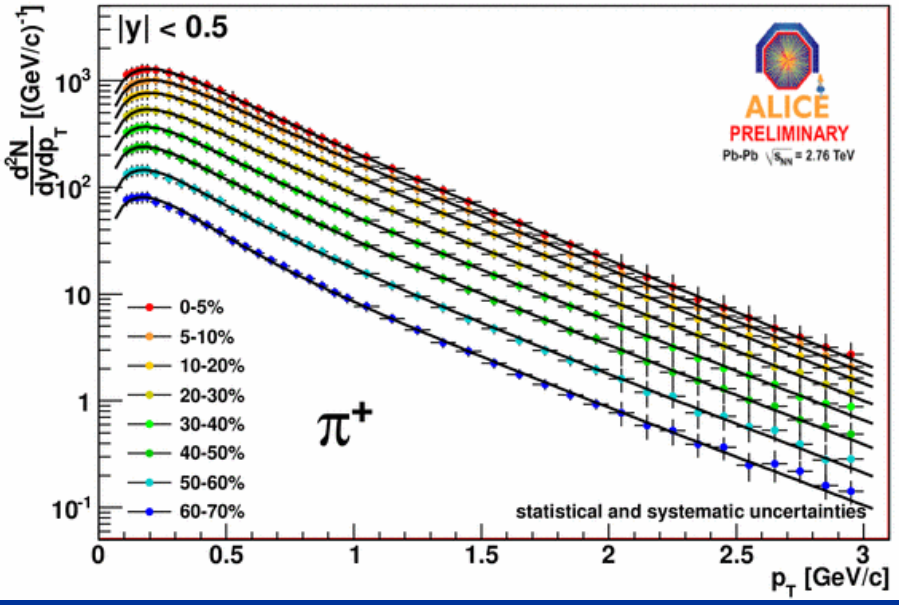
No energy dependence on K/π and p/π ratios

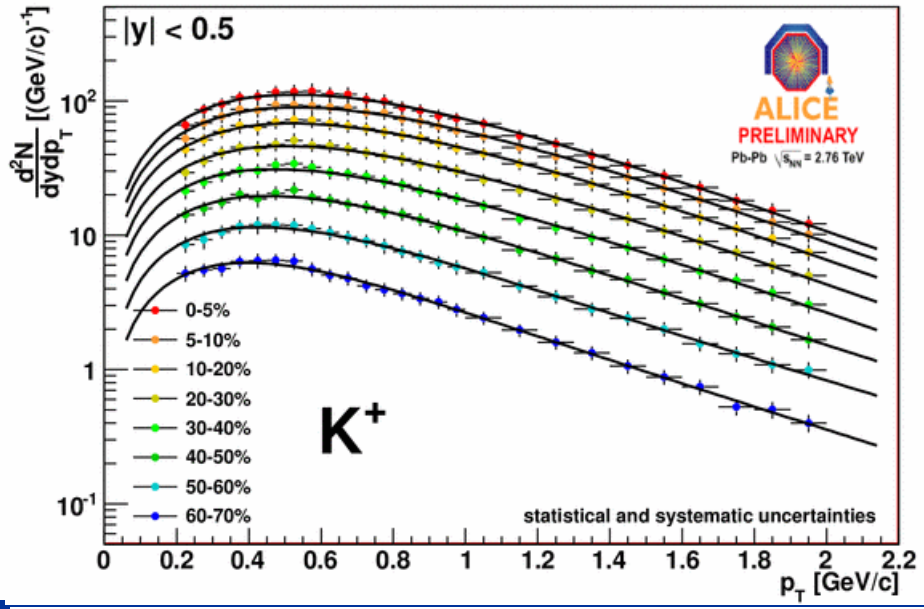


modest increase of <p_T> (consistent with linear expectation from m_T scaling)

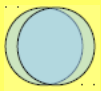
$$E\frac{d\sigma}{dp_T} = A\frac{e^{-m_T/T}}{m_T^{\lambda}}$$

Identified Spectra in heavy ions collisions

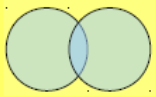




Again measurement with ITS-TPC-TOF
Blast wave fits to extract yields and $\langle p_T \rangle$

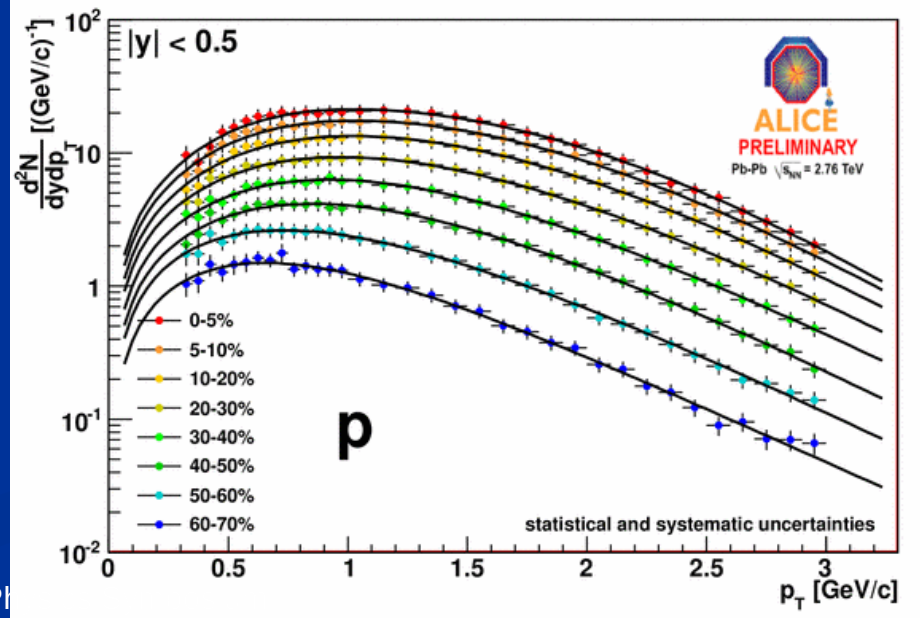


0-5% central



80-90% peripheral

→ P. Kujier talk next Friday in heavy ion – soft session



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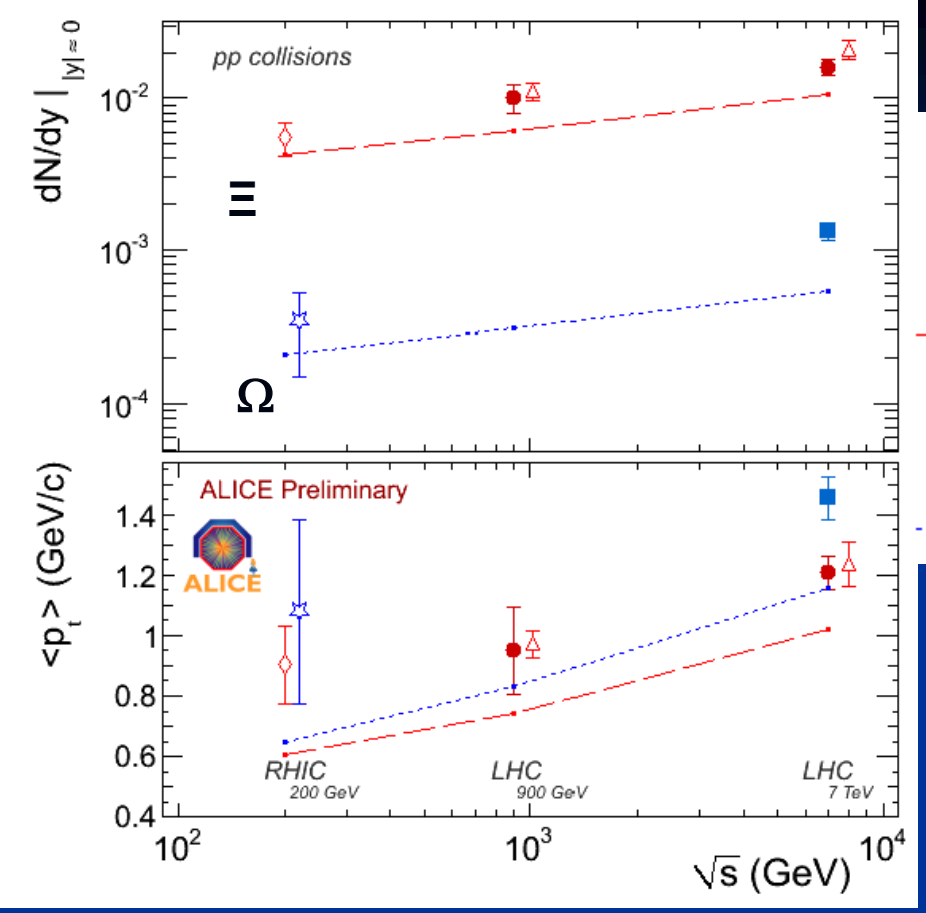
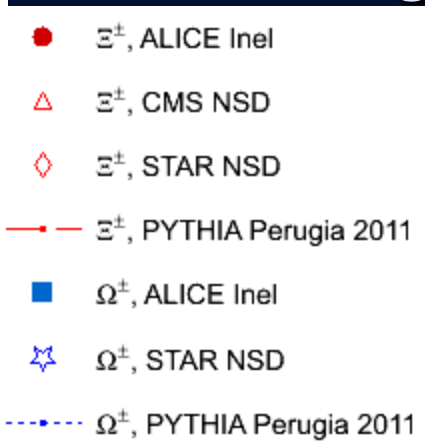
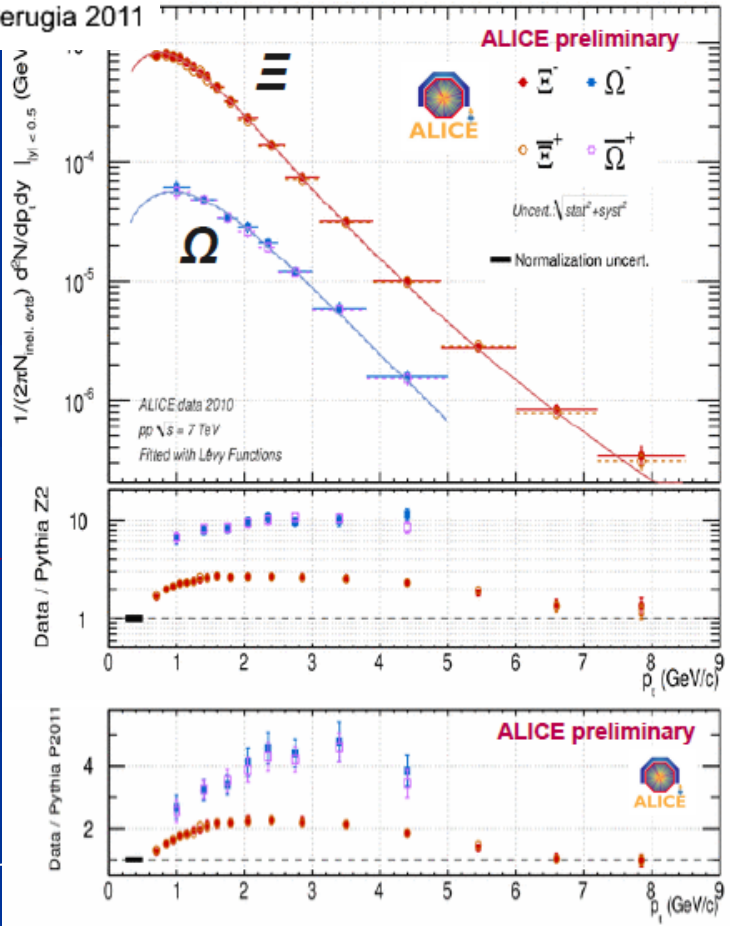
Multi strange hadrons



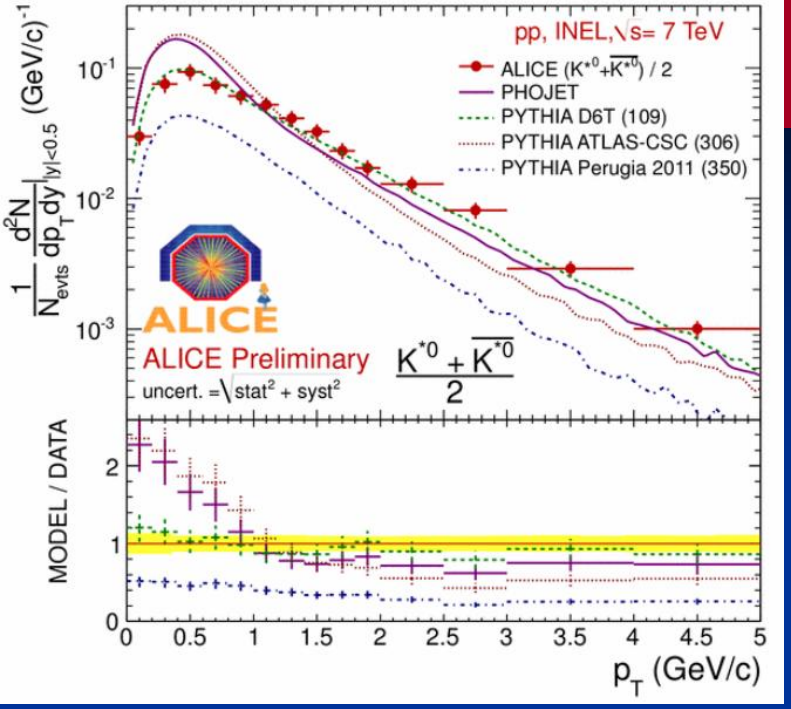


agreement between ALICE and CMS, difference (20%) arising from different normalisation (INEL/NSD)



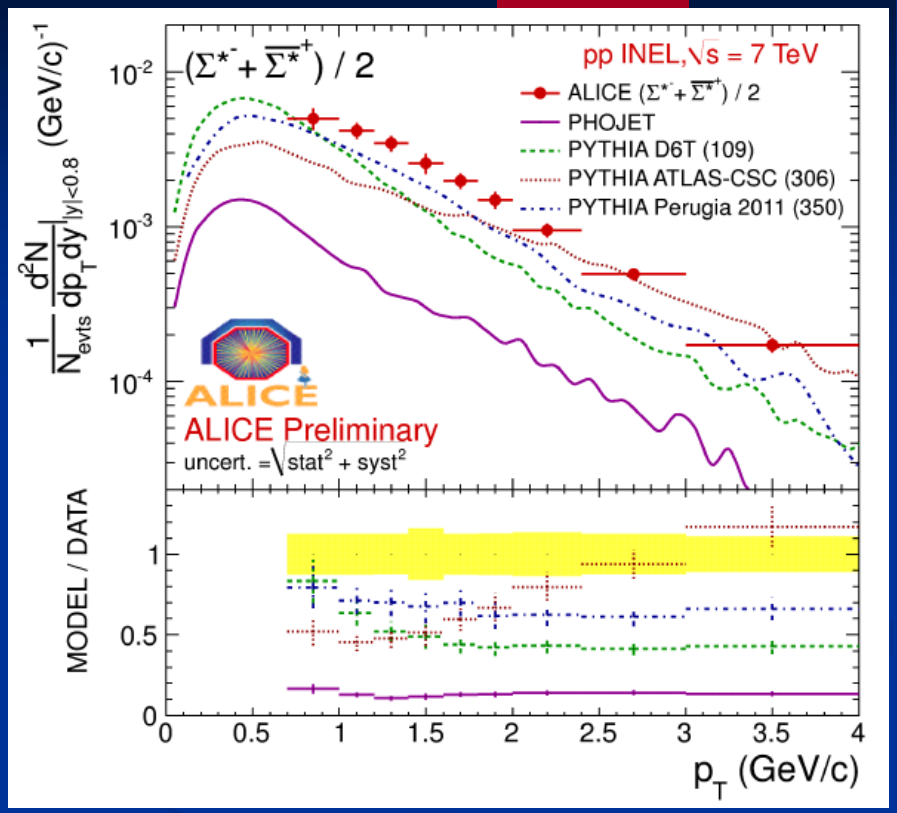
- yields and $\langle p_T \rangle$ increases with energy also for multistrange hadrons
- not discussed here, but note multi-strange hadrons production enhancement in PbPb reported by ALICE at SQM 2011

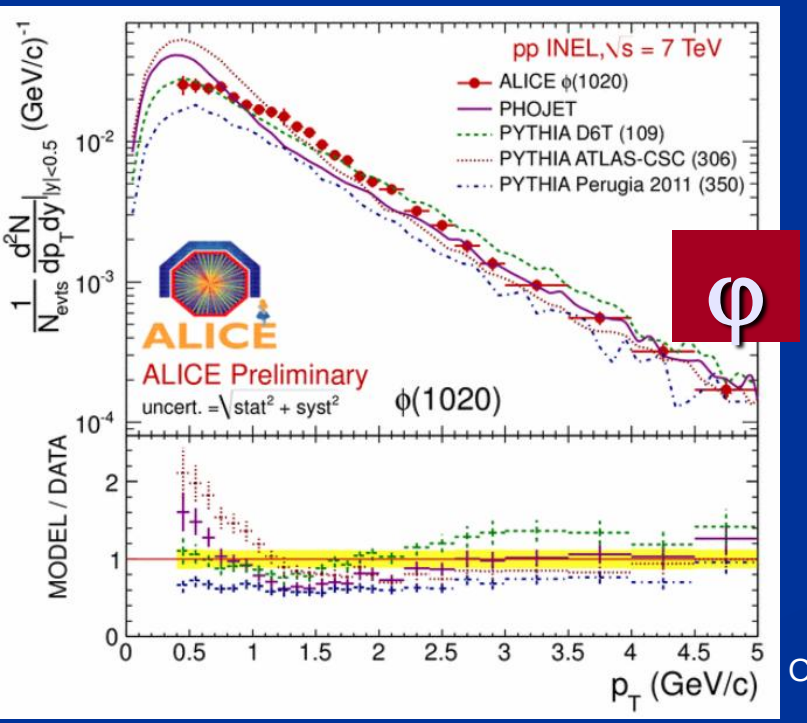
Updated MC-tune works better, still underestimation of multistrange production at intermediate p_T



K*0

Σ*





φ

Generally better agreement with φ, Perugia 2011 tends to underestimates yields in these channels

K^{*0} (892) → Kp

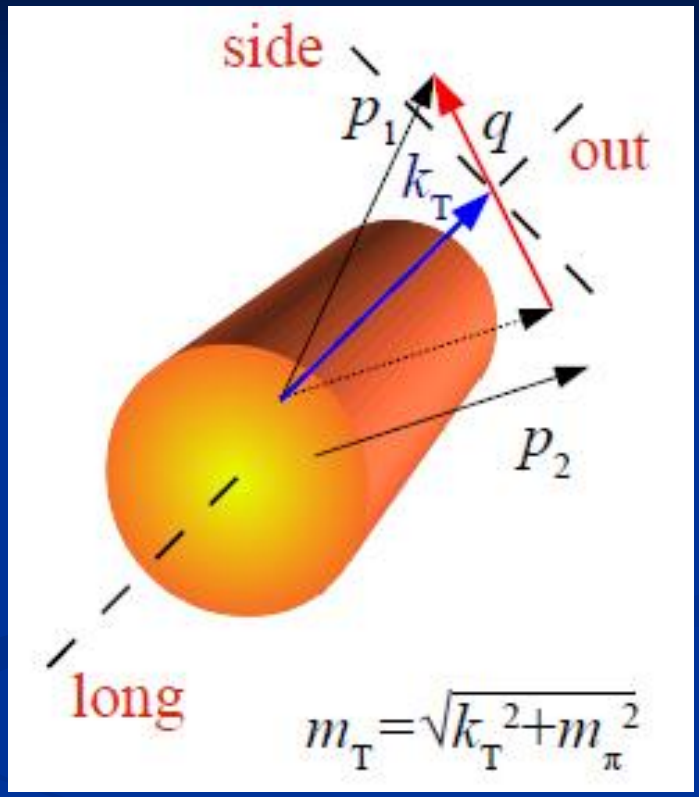
φ (1020) → K^+K^-

Σ^{*-} (1385)→ $\Lambda^0\pi^-$ → $p\pi^-$

Correlations

Two particles (identical pion pairs) to study Bose-Einstein correlations

Hanbury-Brown (*) and Twiss radii extracted to study spatial scale of the emitting source (“femtoscopy”)



Femtoscopy in pp

- precise data of ‘elementary’ systems
- now comparable multiplicities in pp and PbPb → direct comparison
- study of the emitting source size in pp

Two-pion Bose-Einstein correlations in pp collisions at $\sqrt{s}$=900 GeV Phys. Rev. D82 (2010) 052001

Femtoscopy in PbPb

-allow to study spatial distribution of decouping hadrons

-track collective motion of matter from radius dependence on p_T

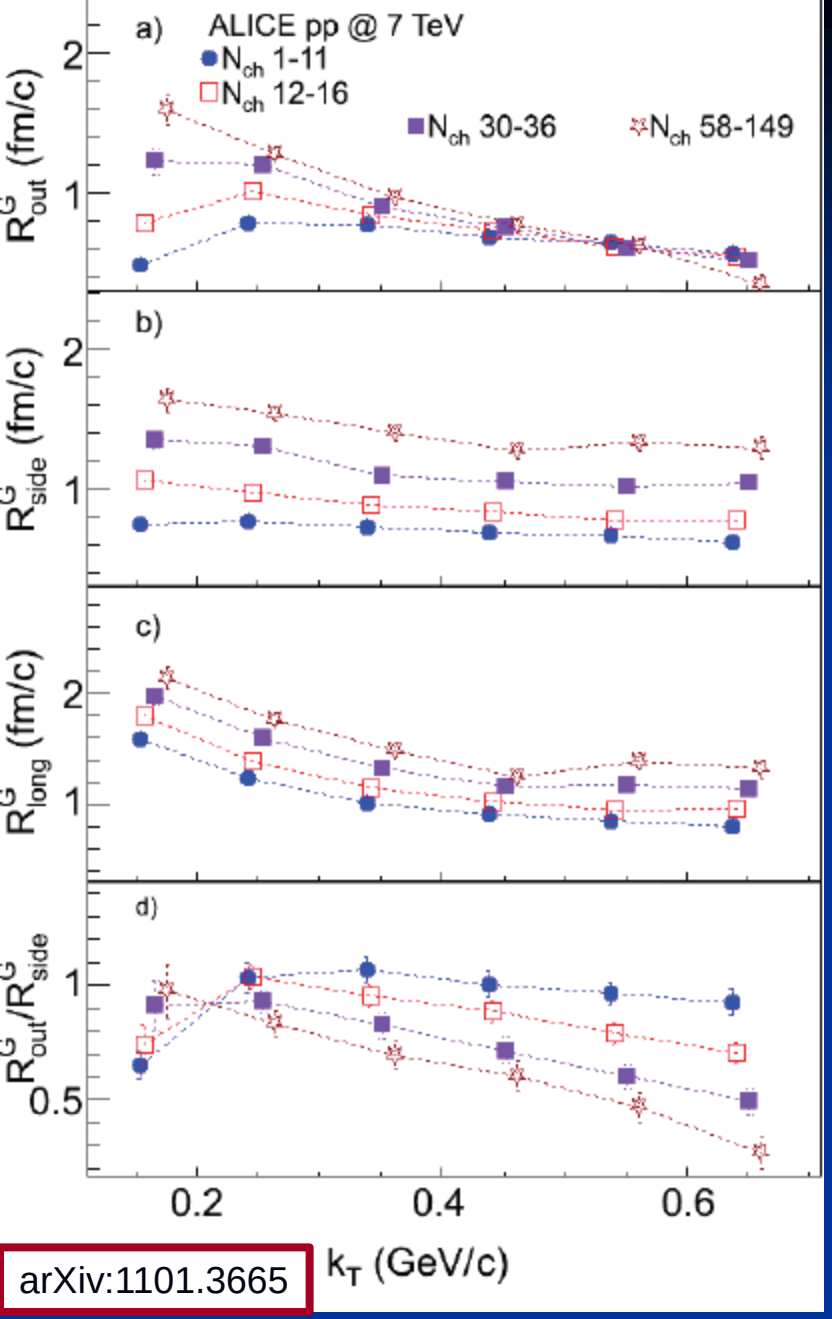
Two-pion Bose-Einstein correlations in central PbPb collisions at $\sqrt{s_{NN}}$=2.76 TeV Phys. Lett. B, 704 (2011) 442

(*) interferometry tecnique first time used in 1956 by Hanbury-Brown in Australia to measure stars radius

radii vs k_T

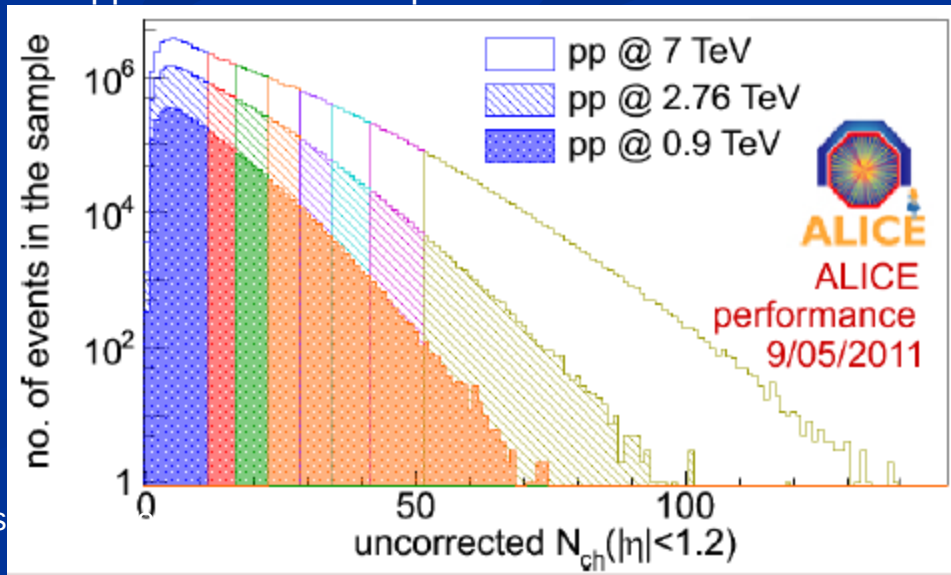
- R_{out} and R_{side} decrease with k_T at large multiplicities
- R_{long} falls with k_T at all multiplicities

in pp we observe dependence on k_T (in heavy ions collisions radii decrease with k_T is a signature of collective motion)

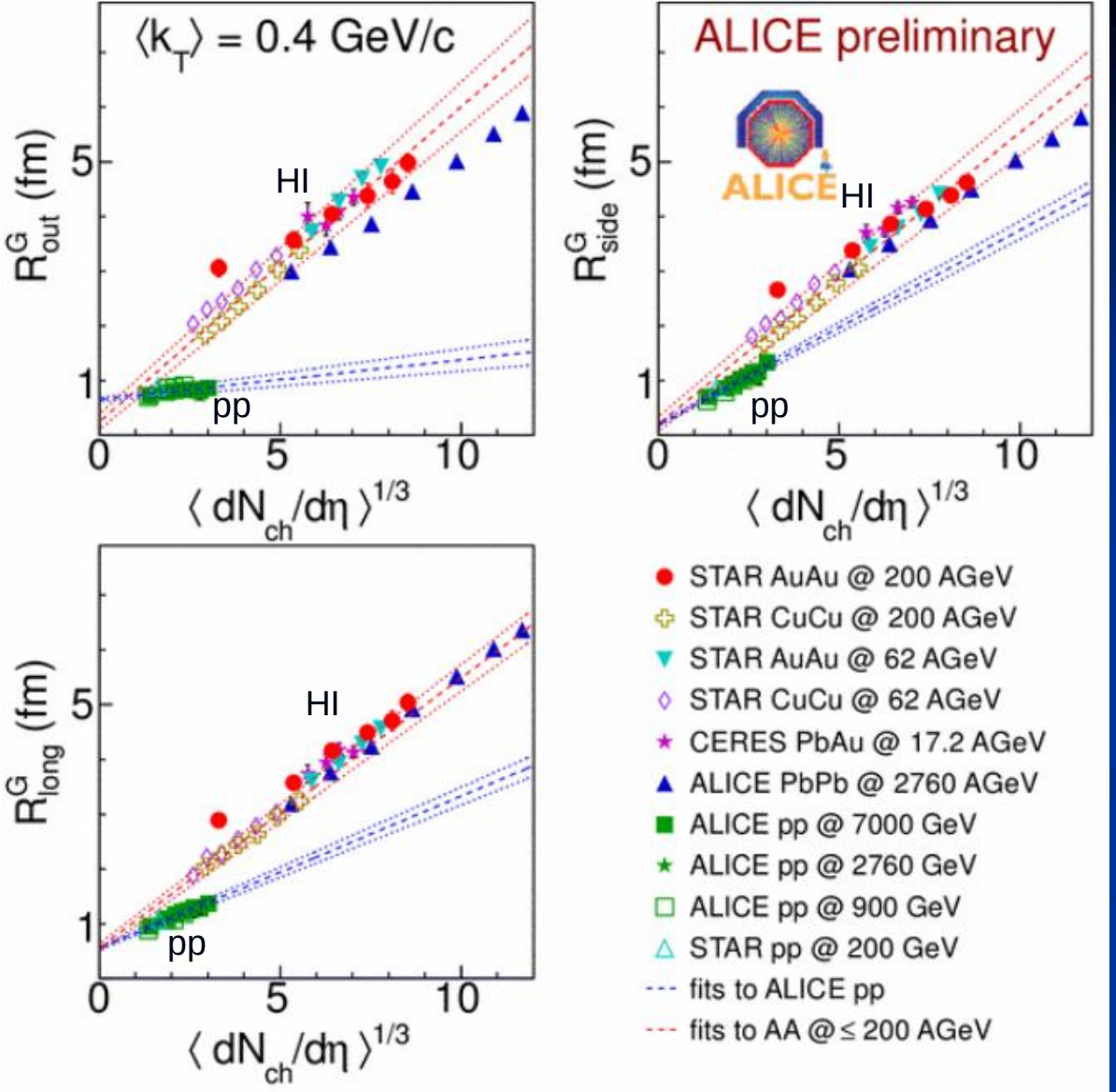


arXiv:1101.3665

pp data-set for comparison with PbPb



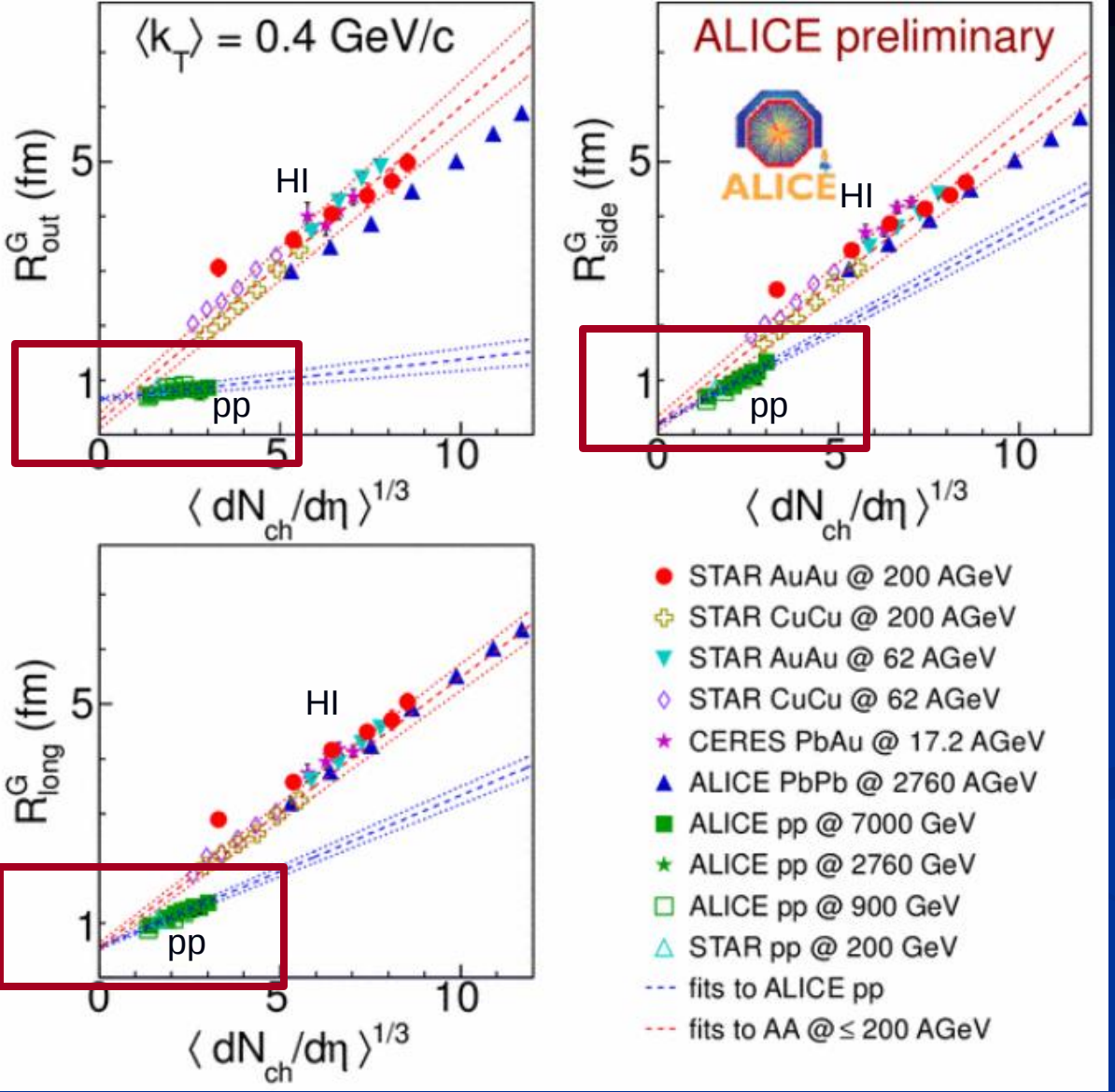
radii vs $dN_{ch}/d\eta$



- linear scale expected with mult$^{1/3}$, but different slopes and offset for pp and AA
- possible direct comparison between elementary and 'compound' system
- in pp size of emitting source ≈ 1 fm
- comparison with trend inferred by other (lower energies) HI data ok for R_{long} not for R_{out}
- qualitative agreement with hydro models

Note: correlations with kaons (not shown) limited to 1D radii but help to extend k_T range (up to 1.8 GeV/c)
Details: A. Kiesel at QM2011

radii vs $dN_{ch}/d\eta$



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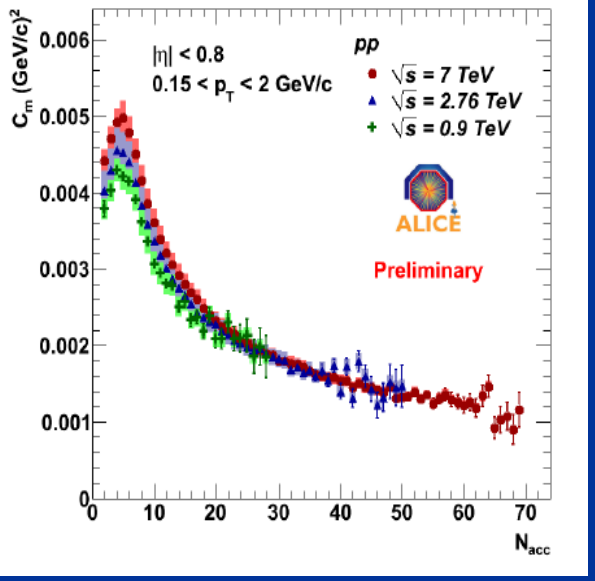
Fluctuations: $\langle p_T \rangle$

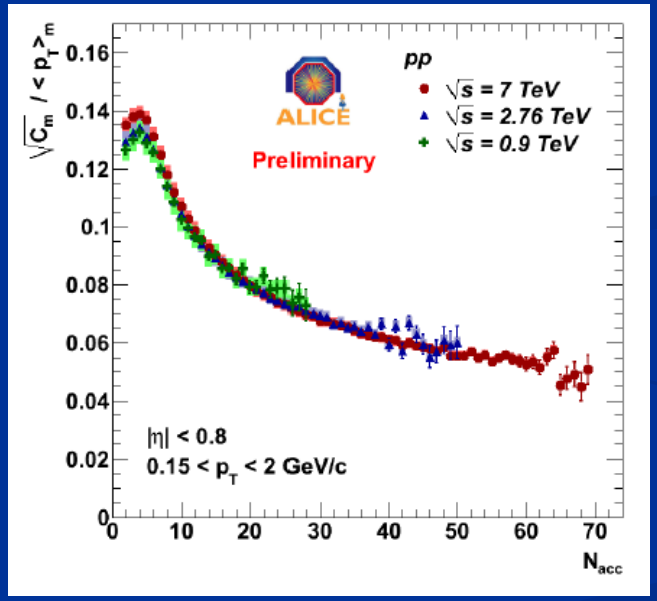
- fluctuations in pp are expected to be dominated by known physics as resonance decays, HBT and mini-jets
- we study fluctuations on $\langle p_T \rangle$ event-by-event over all tracks pairs via particle correlator C_m

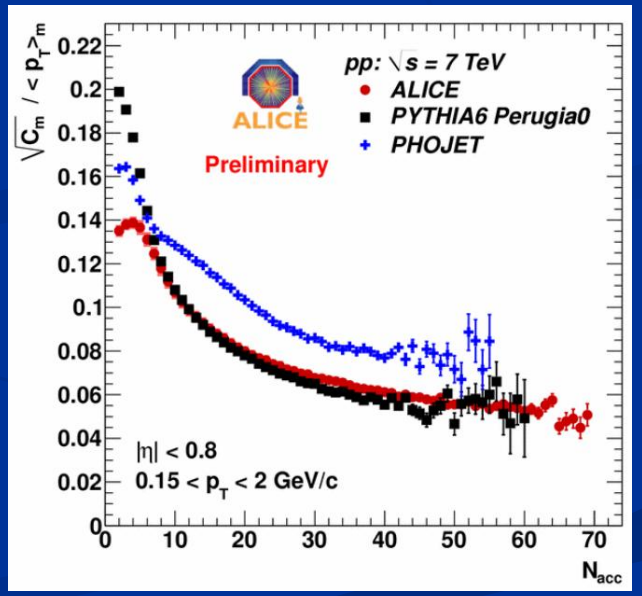
$$\sigma^2_{dyn} = C_m = \left\langle \Delta p_{T,i}, \Delta p_{T,j} \right\rangle = \frac{1}{\sum_{k=1}^{n_{ev}} N_k^{pairs}} \cdot \sum_{k=1}^{n_{ev}} \sum_{i=1}^{N_k} \sum_{j=i+1}^{N_k} \left(p_{T,i} - \langle p_T \rangle_m\right) \cdot \left(p_{T,j} - \langle p_T \rangle_m\right)$$

C_m expected ≡ 0 for statistical fluctuations only

N_{acc} = # of accepted tracks







Relative fluctuations seem universal at LHC (except at small multiplicity).
Perugia-0 reproduces well data but not at small multiplicity.

Conclusions

Cross sections: σ_{INEL}, σ_{SD} and σ_{DD} measured

Very good agreement with other LHC experiments

Particle production: charged particles up to 100 GeV/c; π, K, p, π^0, η, hyperons, ω, φ, resonances up to 5-10 GeV/c

*Extensive **comparison with pQCD** and MC models, discrepancy with MC data for hyperons at intermediate p_T*

Correlations and fluctuations studies:

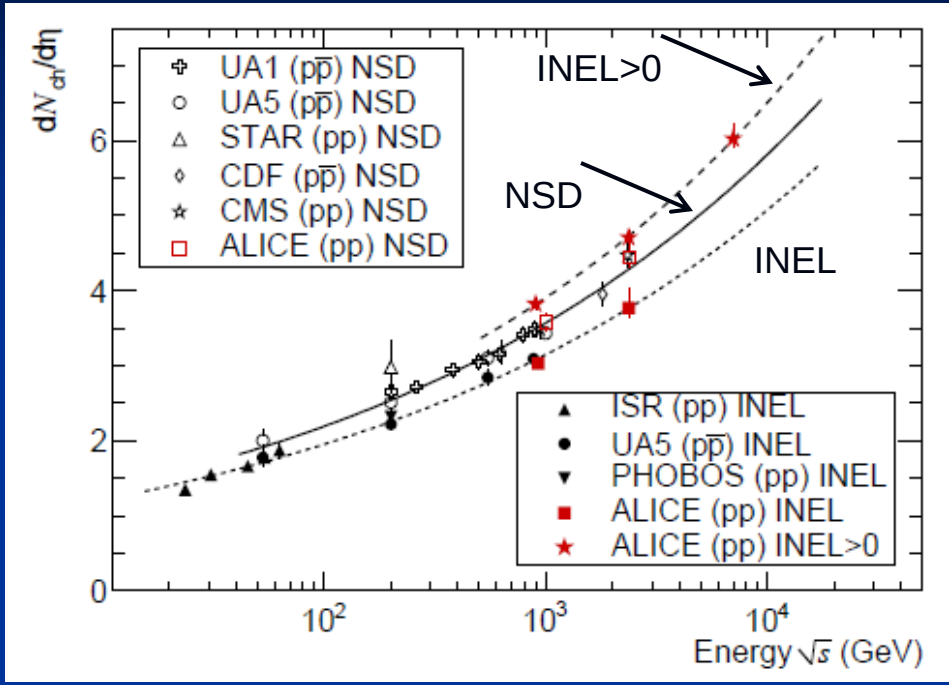
Studied behavior of pp events via femtoscopy

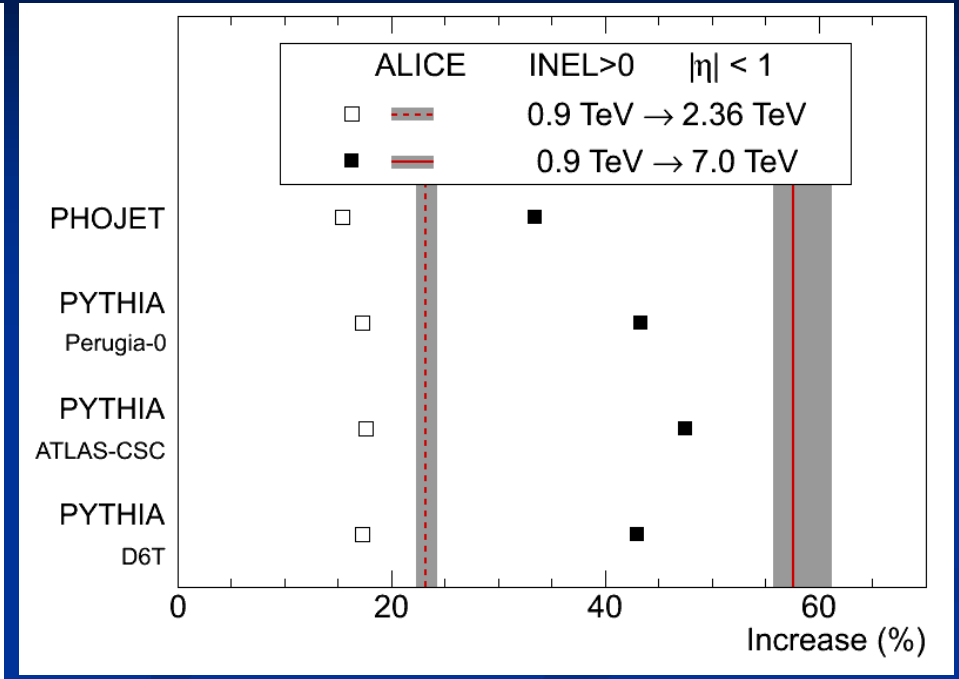
pp baseline for Pb-Pb studies ($\sqrt{s_{NN}}$=2.76 TeV) successfully established, here discussed application for HBT and identified spectra analysis

Rich **proton-proton physics programme** developed by ALICE (measurements shown at 0.9, 2.36, 2.76 and 7 TeV c.m. energies) exploiting its detector capabilities, particularly relevant for soft QCD studies.

Backup / published results

Inclusive production (1): dN/dη



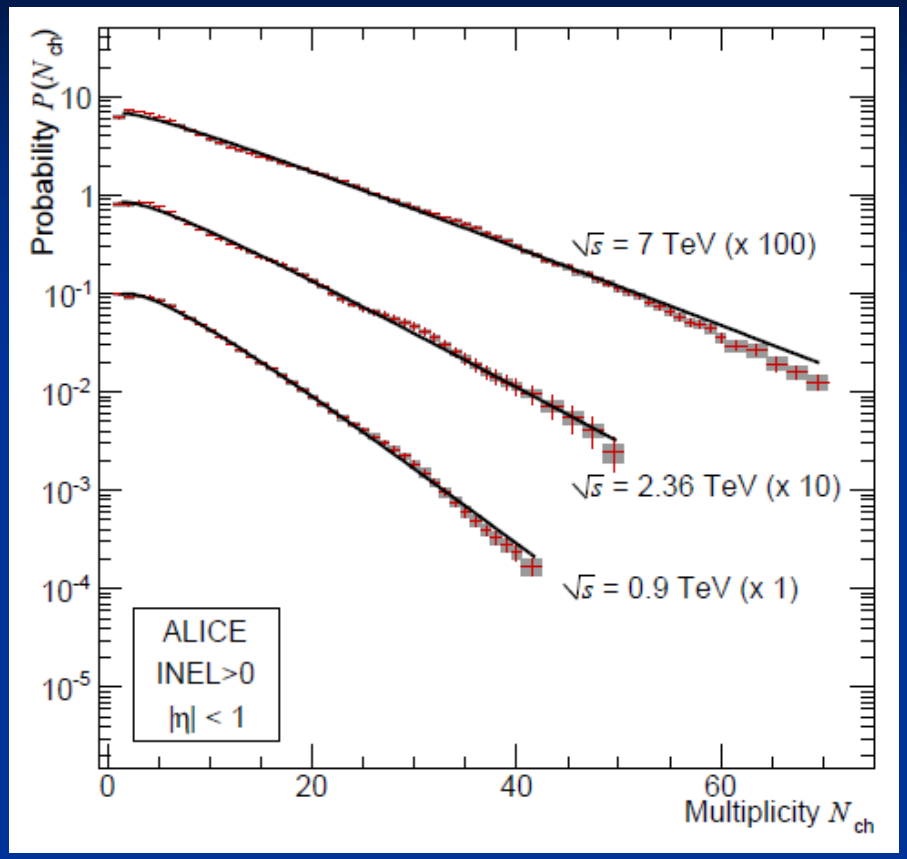


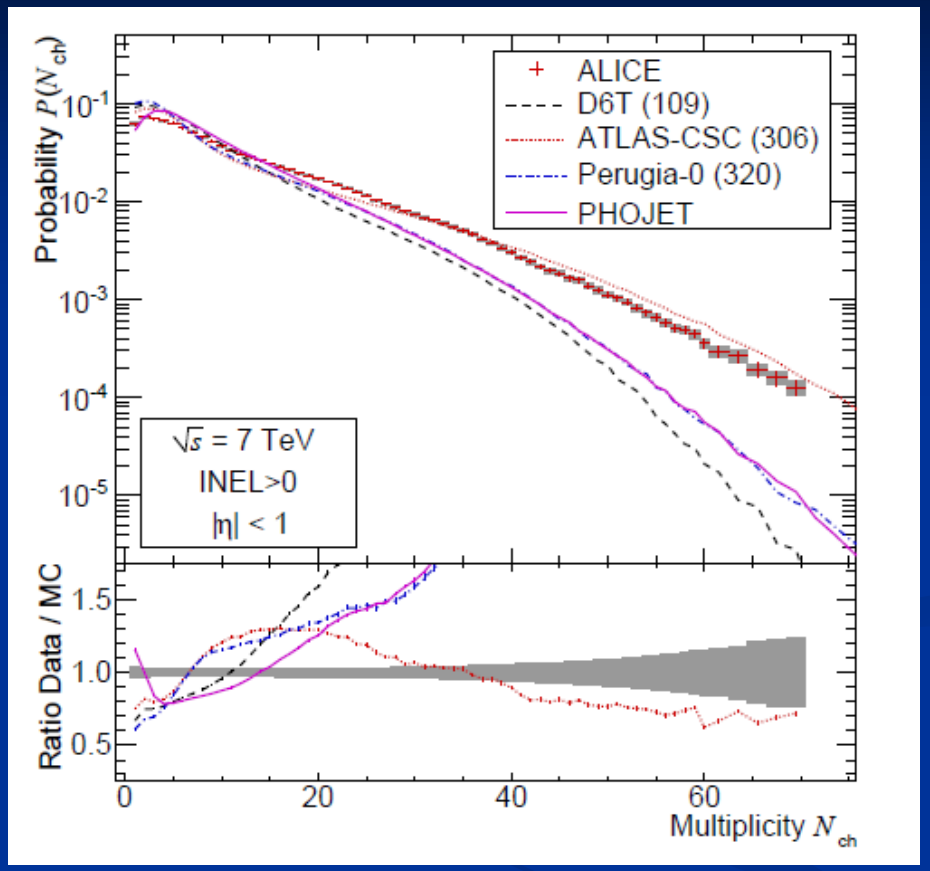
Relative increase of the pseudorapidity charge density

power law dependence fits well, but large discrepancy with MC, increasing with energy

Charged multiplicity at 7 TeV: Eur. Phys. Journal **C 68** (2010), 345
Charged multiplicity (900 GeV & 2.36 TeV): Eur. Phys. Journal **C 68** (2010), 89

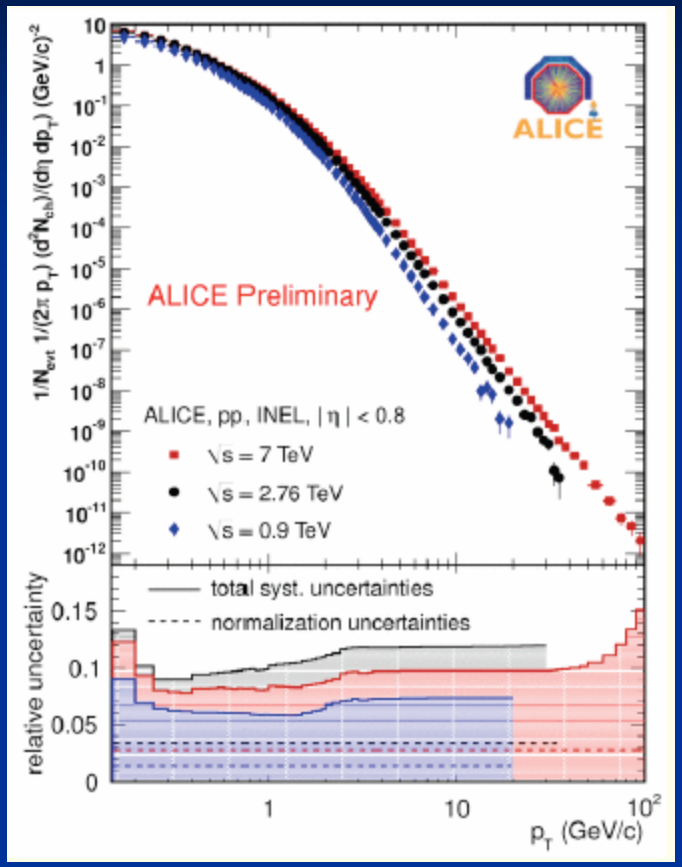
Inclusive production (2): multiplicity

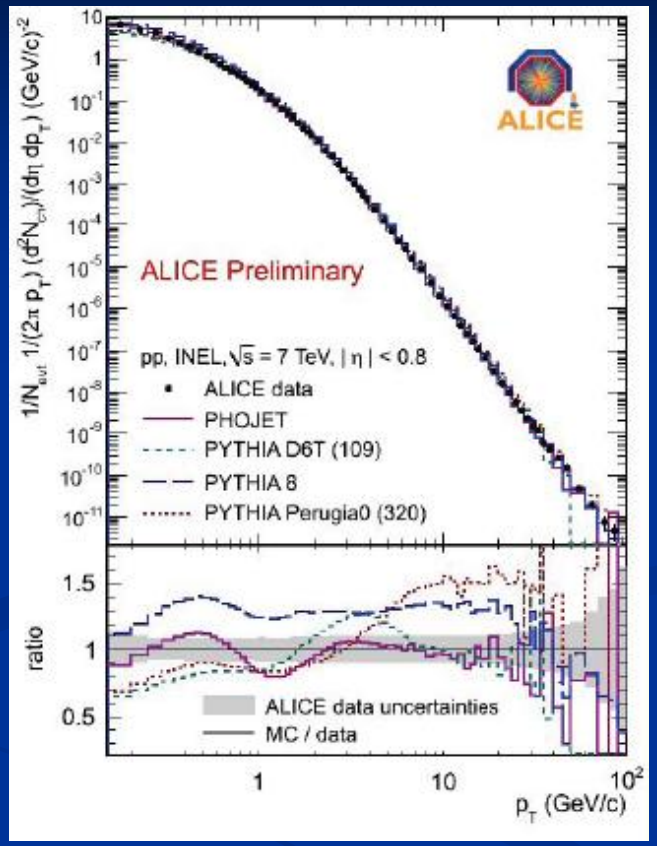




- Multiplicity predictions from MC pre-LHC lower than measured, with ATLAS-CSC exception
- Negative Binomial fit provides good descrtipion but not for large tail (especially for 7 TeV data)
- Very good agreement with CMS (not shown)

Inclusive production (3): p_T spectra

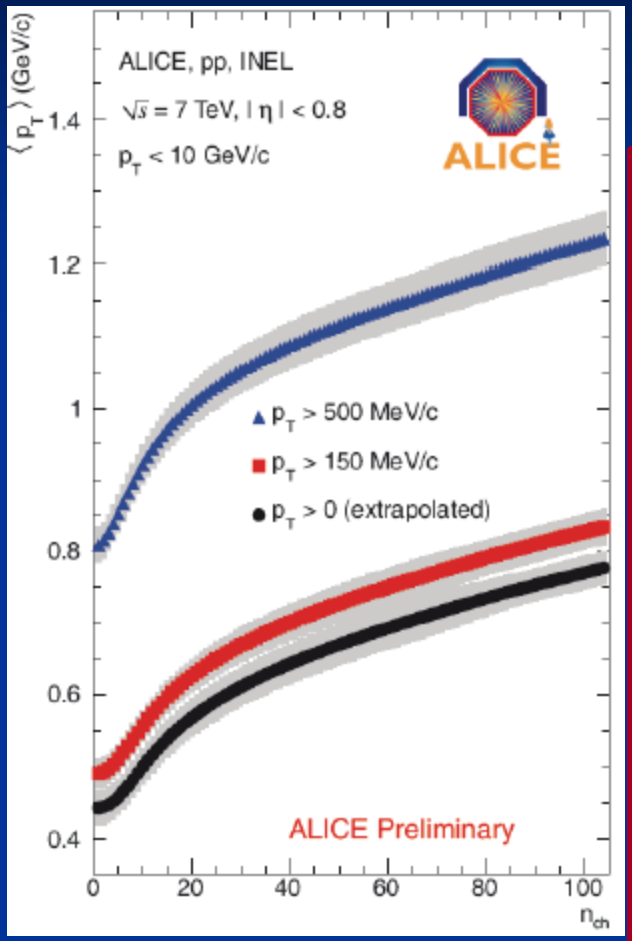




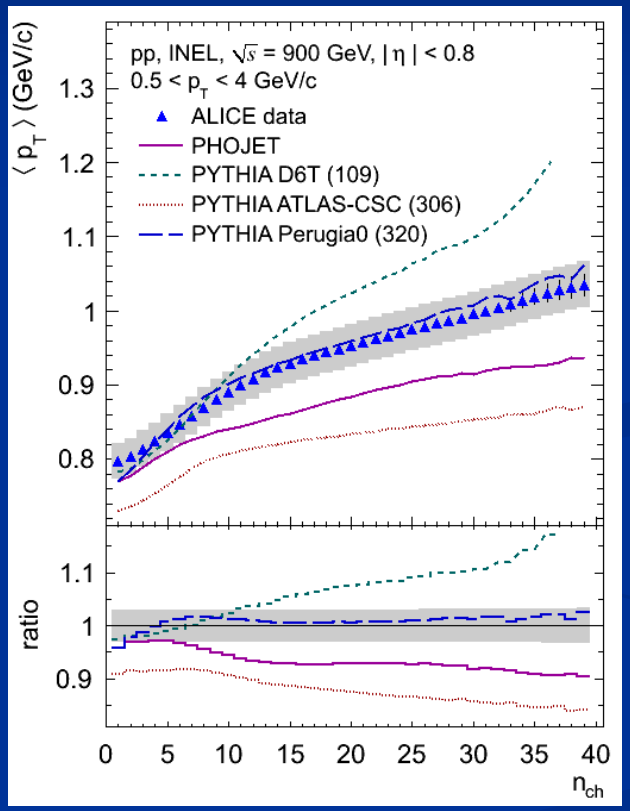
Again not satisfactory agreement with pre-LHC MC tunes
Modified Hagerdon function used for fit
p_T^{-n} power law observed at high p_T (above 3 GeV)

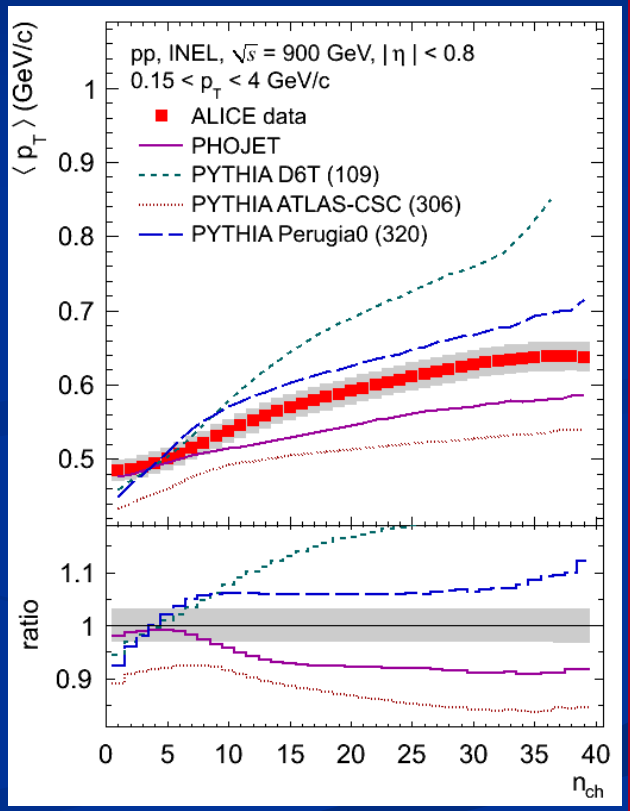
$$\left(1+\frac{p_t}{p_0}\right)^{-n} \longrightarrow \begin{cases} \exp\left(-\frac{n}{p_0}p_t\right) & \text{for } p_t \to 0, \\ \left(\frac{p_0}{p_t}\right)^n & \text{for } p_t \to \infty. \end{cases}$$

Inclusive production (4): $\langle p_T \rangle$ vs n_{ch}



- $\langle p_T \rangle$ as a function of charged multiplicity is observable relevant to model multiple interactions
- note **ALICE low p_T reach**





Perugia-0 agrees above 0.5 GeV but not above 0.15 GeV

SD/DD analysis: 1-arm and 2-arm triggers

Pseudorapidity distribution of "tracks" (SPD/FMD/V0) event by event:

✓identify pseudorapidity gap with the widest width

✓compute pseudorapidity distances (d_1 and d_2)of each edge of the measured η distribution from the corresponding nearest edge of the acceptance.

Classification of events

✓ if maximum gap width is greater than both d_1 and d_2 → 2-arm trigger event.

✓ if the edge is at η<1 or η>-1 and d_1 or d_2 > gap → 1-arm trigger event.