Minimum bias data and the Underlying event at the LHC - ALICE's current perspective

Helen Caines - Yale University - for the ALICE Collaboration

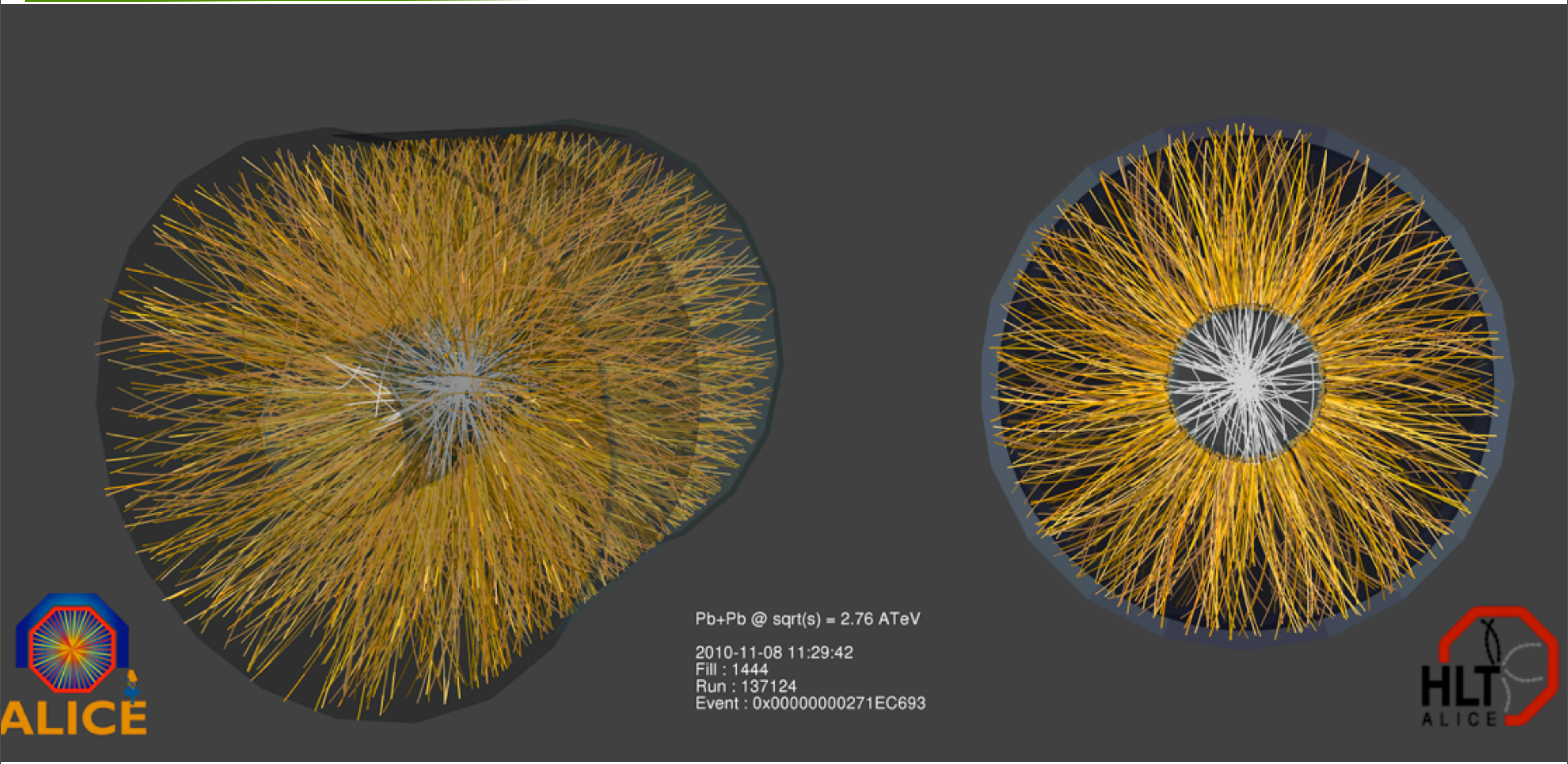
Outline
- ALICE
- Triggering
- Multiplicity
- PID spectra
- Event shapes
- Jet and Underlying event

Standard Model Benchmarks at the Tevatron and the LHC
Fermilab, Chicago
Nov 19-20 2010

LUX ET VERITAS

ALICE

PbPb running has begun!

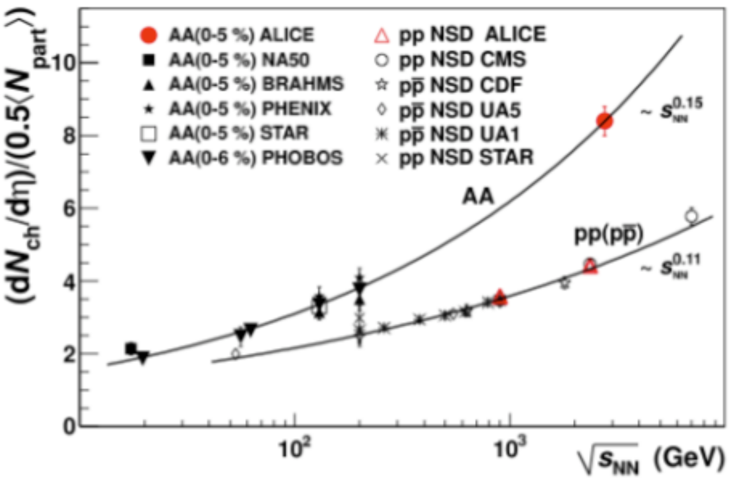


Setup started Nov 4th
First collisions Nov 7
Stable beams Nov 8 - luminosity increased by >factor 100 since then

Highest energy man-made collisions ever! - Total energy 287 TeV/beam

First PbPb results already submitted

$dN_{ch}/d\eta$ = 1584±4(stat)±76 (sys) central PbPb at 2.76 TeV

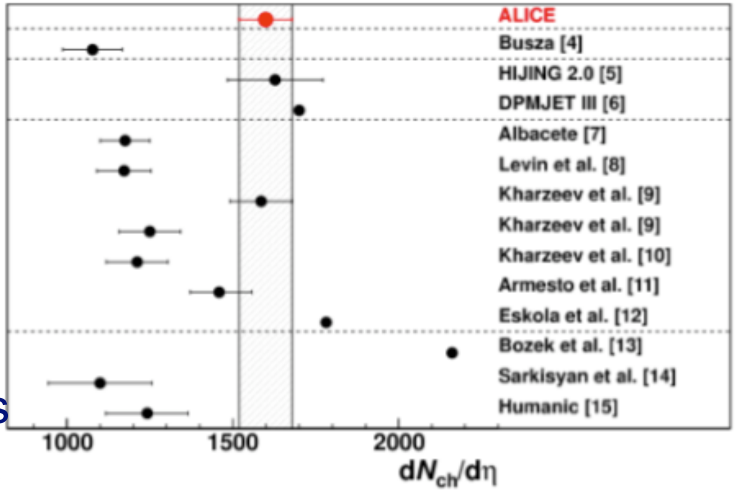


1.9x 2.76TeV pp

2.2x 00 GeV AuAu

AA increase
> pp increase

pQCD-inspired MCs consistent with data



arXiv:1011.3916, arXiv:1011:3914

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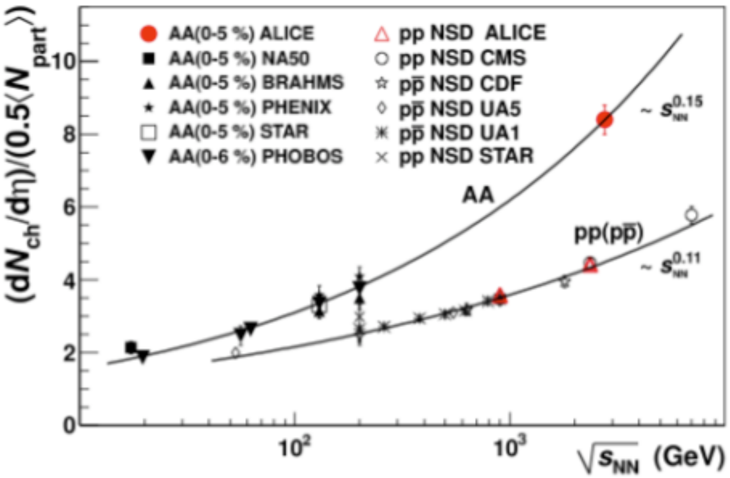

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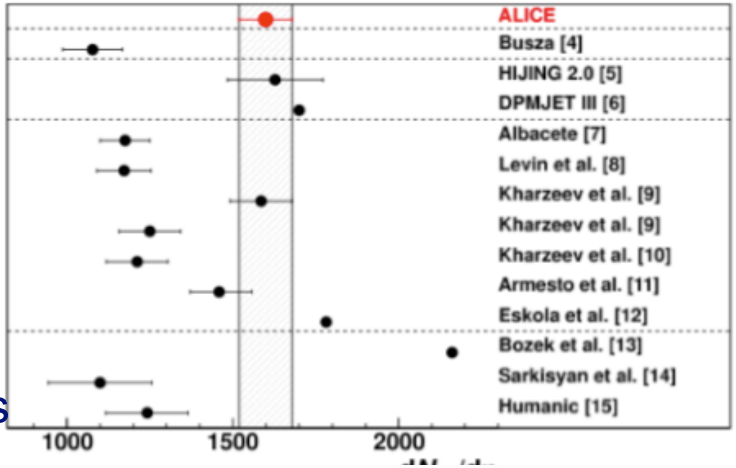
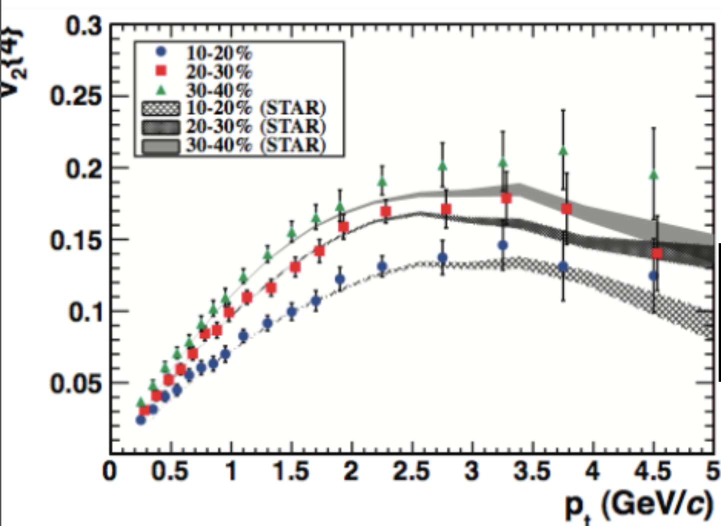
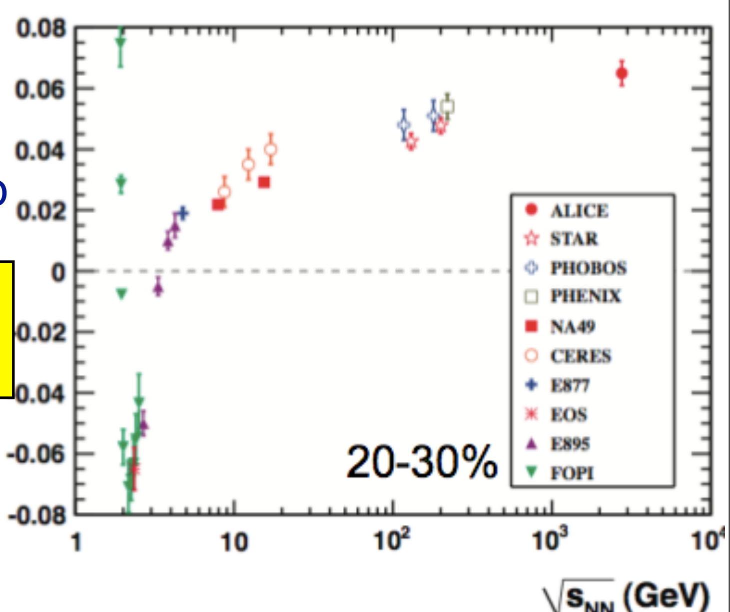




20-30% central PbPb

v_2 (p_T int.)LHC ~1.3x (p_T int.)RHIC

Predicted by hydro with viscosity



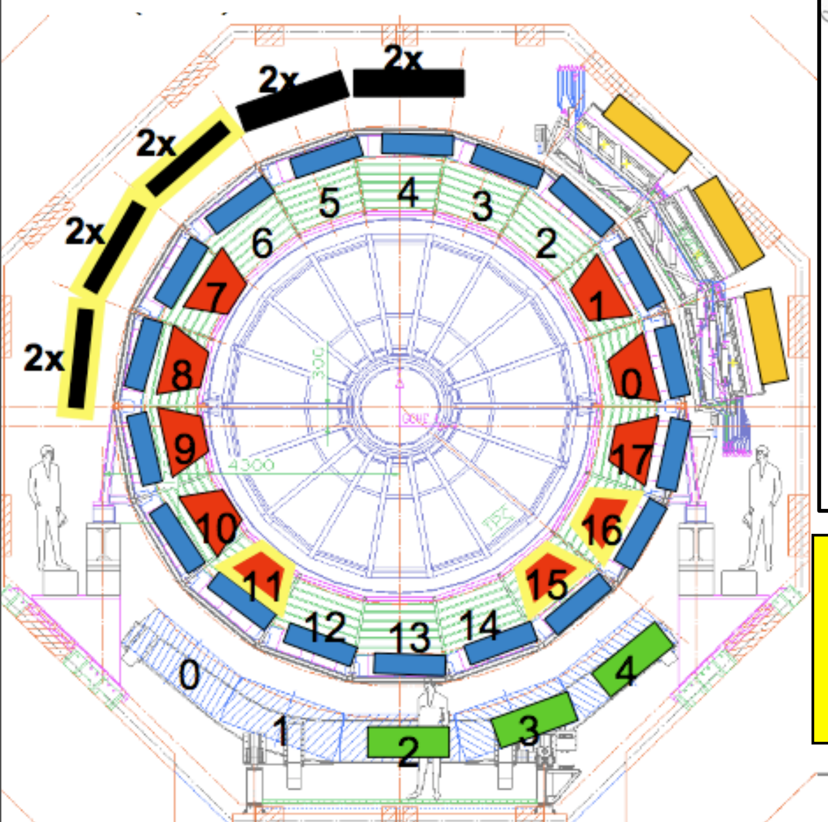
$v_2(p_T)$LHC ~ $v_2(p_T)$RHIC
predicted by hydro

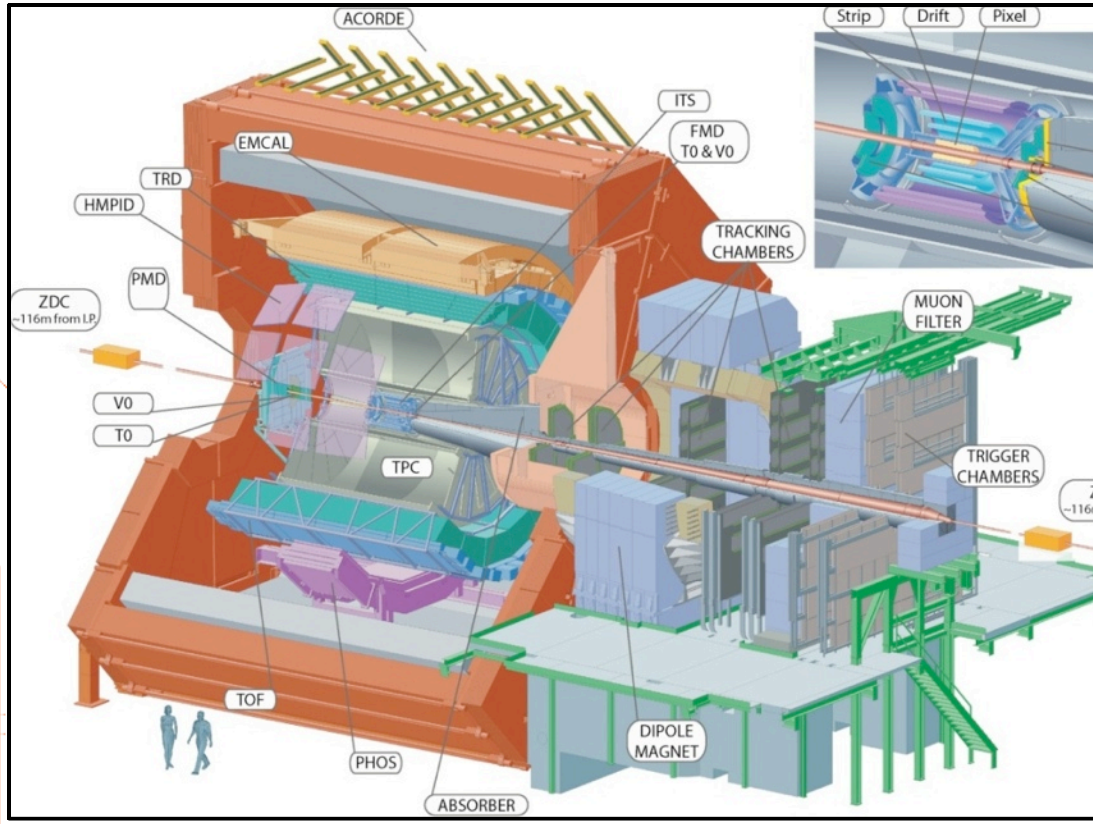
arXiv:1011.3916, arXiv:1011:3914

ALICE - configuration for 2009/10-11

- ITS, TPC, TOF, HMPID, FMD, V0, T0, ZDC, Muon Arm, Acorde, PMD, DAQ (100%)
- TRD* (7/18) (10/18 Dec)
- EMCAL* (4/10) (10/10 Jan)
- PHOS (3/5)
- HLT (~60%)

* upgrade to the original setup





ALICE is fully operational

Detector:

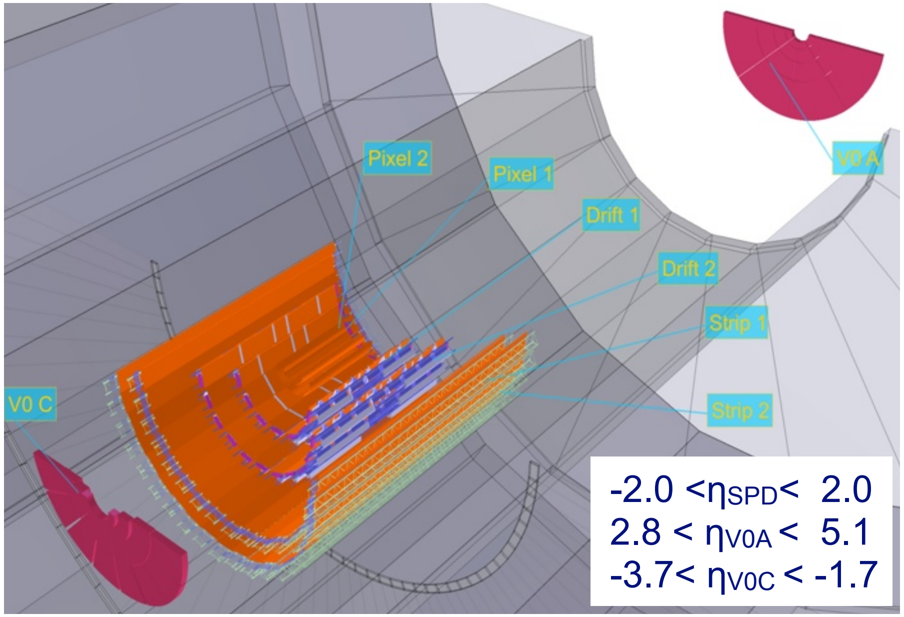
Size: **16 x 26** meters

Weight: **10,000** tons

Collaboration:

> 1000 Members
> 100 Institutes
> 30 Countries

Triggering and data samples



- "Minimum bias" trigger: coincidence with beam pickup counters (BPTX) + at least one charged particle in 8 units of η (All ALICE read out)
  - SPD or V0A or V0C
  - 95% $\sigma_{inelastic}$
- Also a high multiplicity trigger and a muon trigger

Dec 2009:

0.9 TeV ~ 0.3 M min bias

2.3 TeV ~ few 100k min bias

(no stable beams multiplicity measurements only)

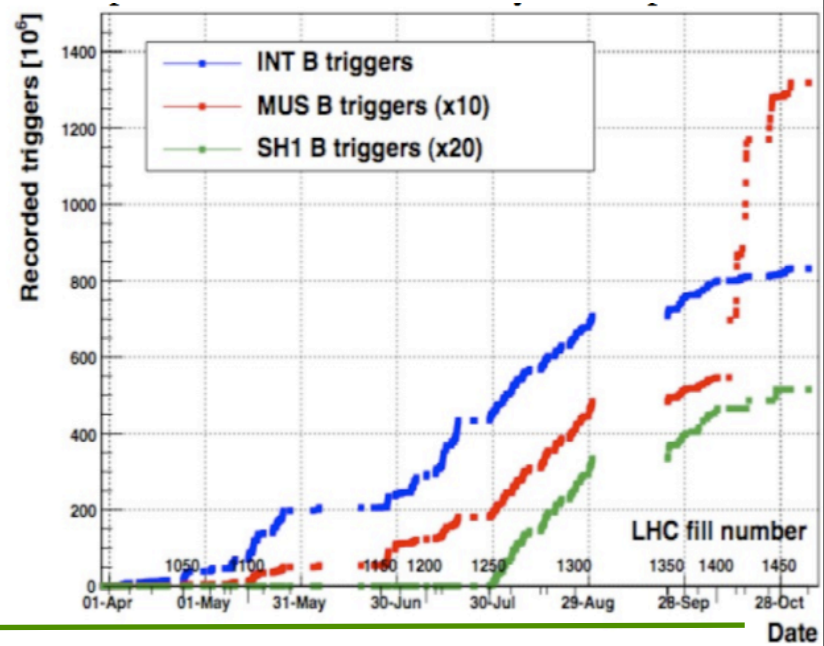
April - Oct 2010:

0.9 TeV ~ 3 M min bias

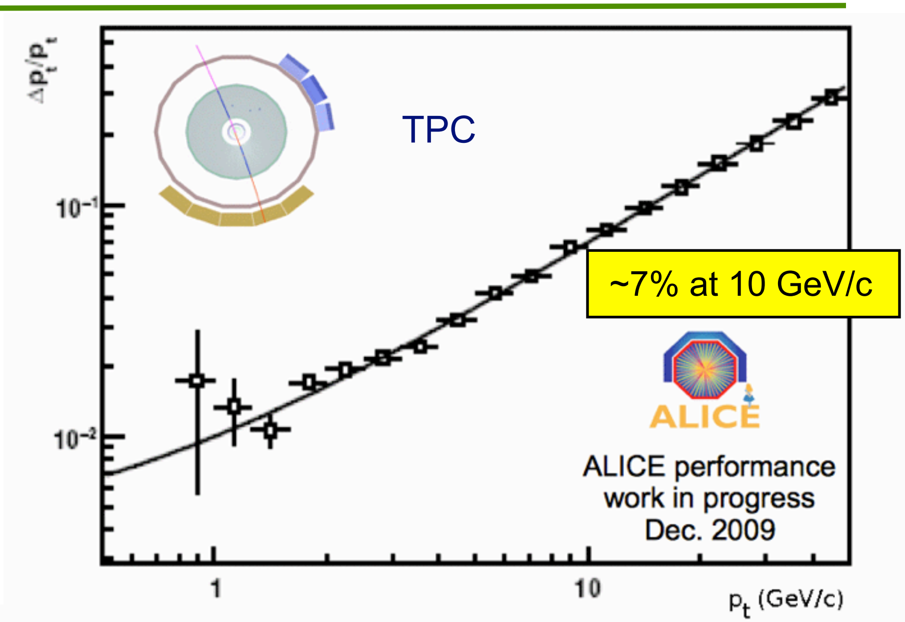
7.0 TeV ~ 800 M min bias

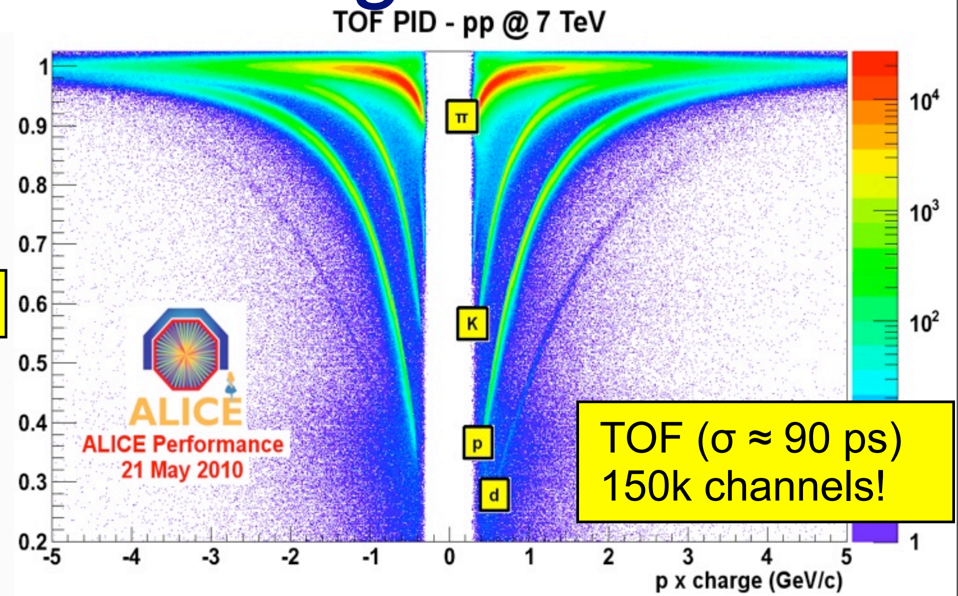
~ 250 k high mult.

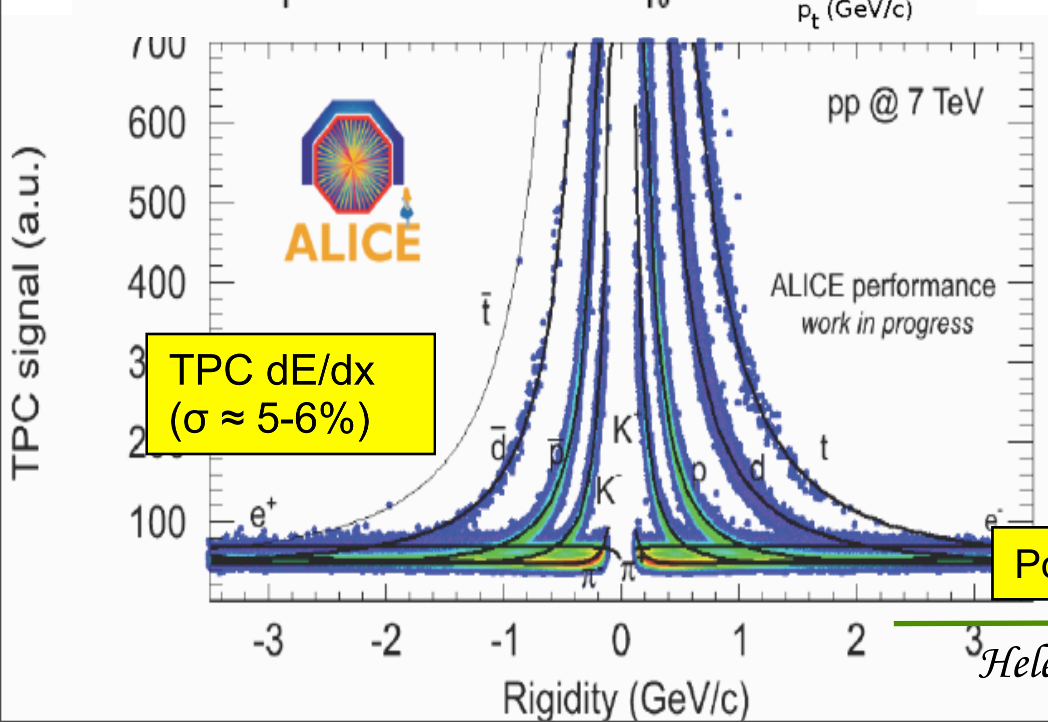
Ran with reduced luminosity after July

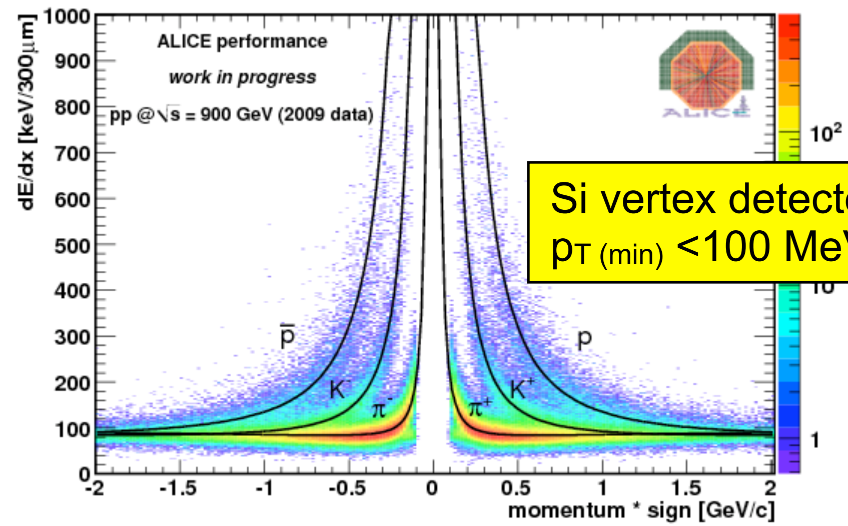


Detector performance: tracking and PID



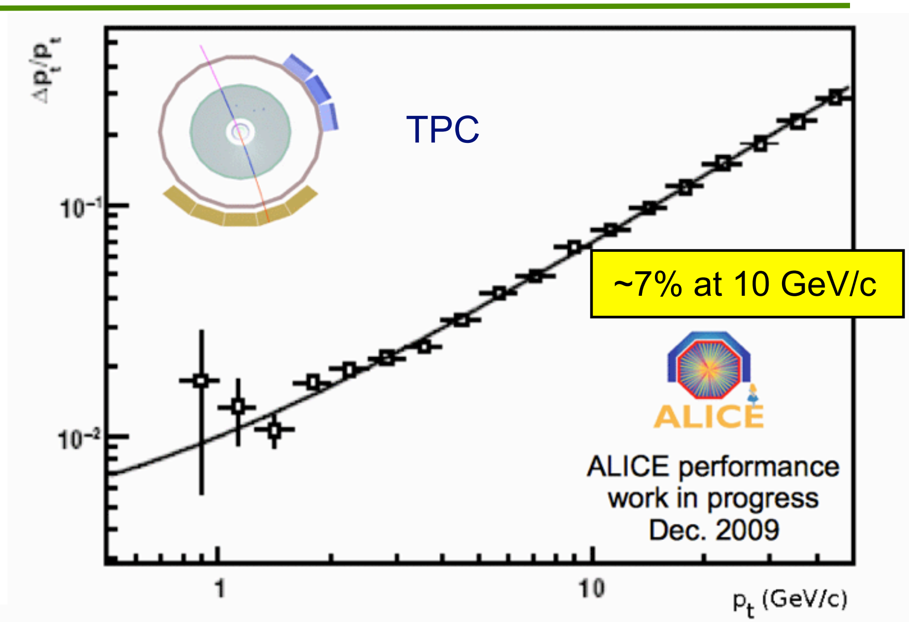




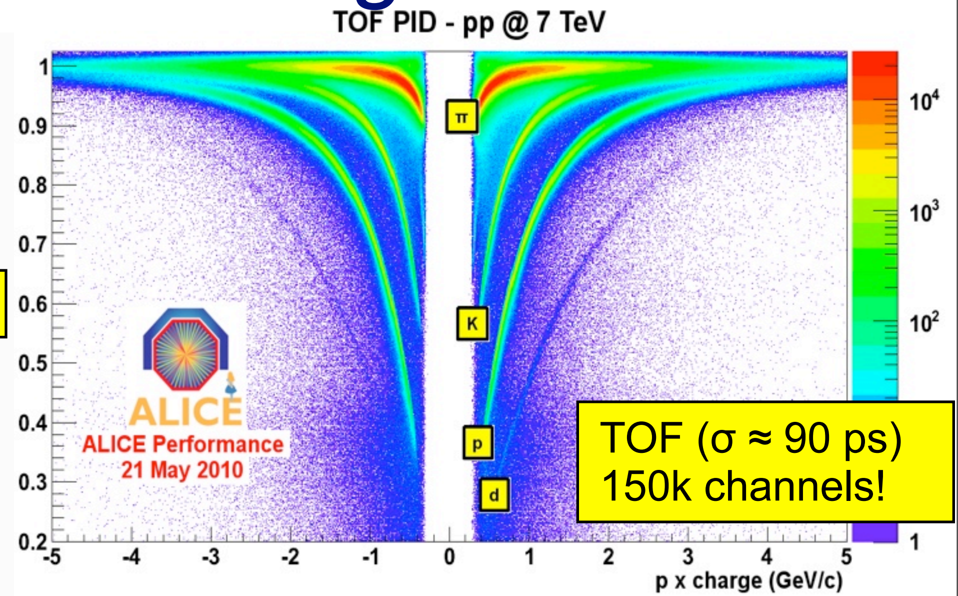


Pointing and vertex resolution also close to design

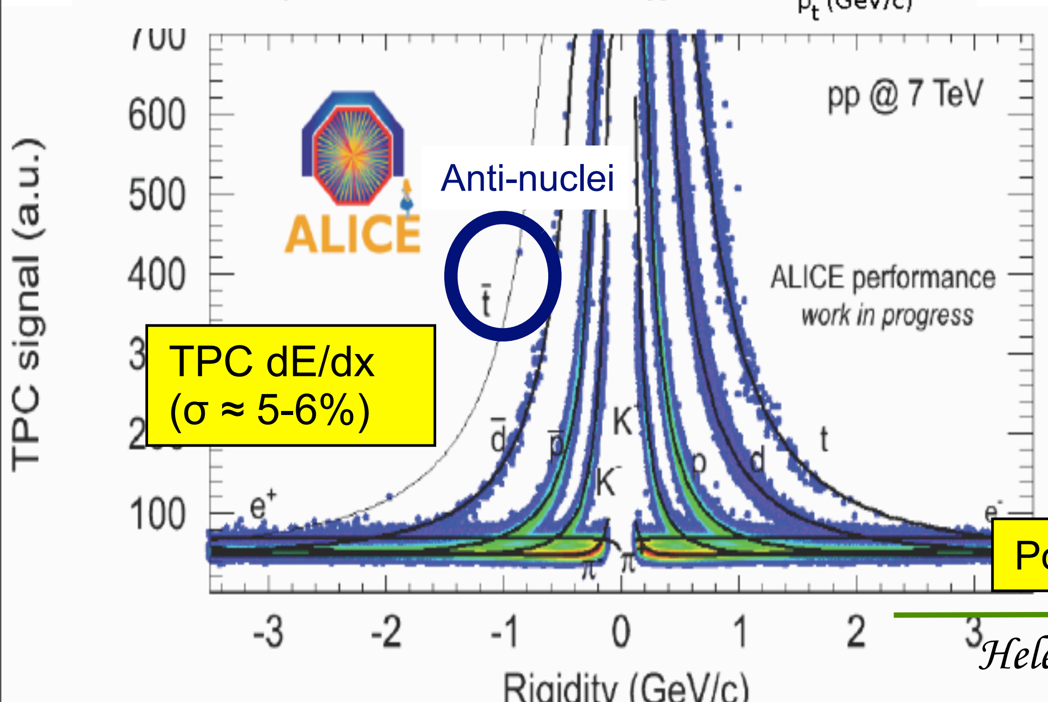
Detector performance: tracking and PID



~7% at 10 GeV/c

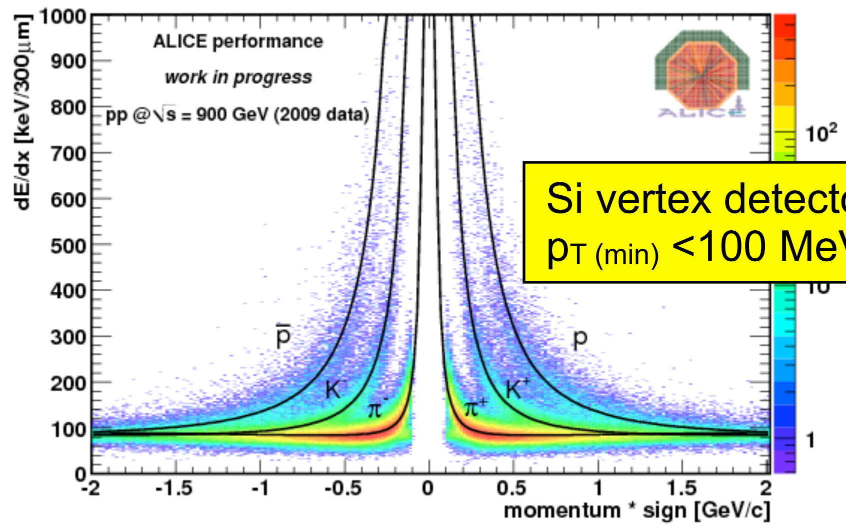


TOF (σ ≈ 90 ps)
150k channels!



Anti-nuclei

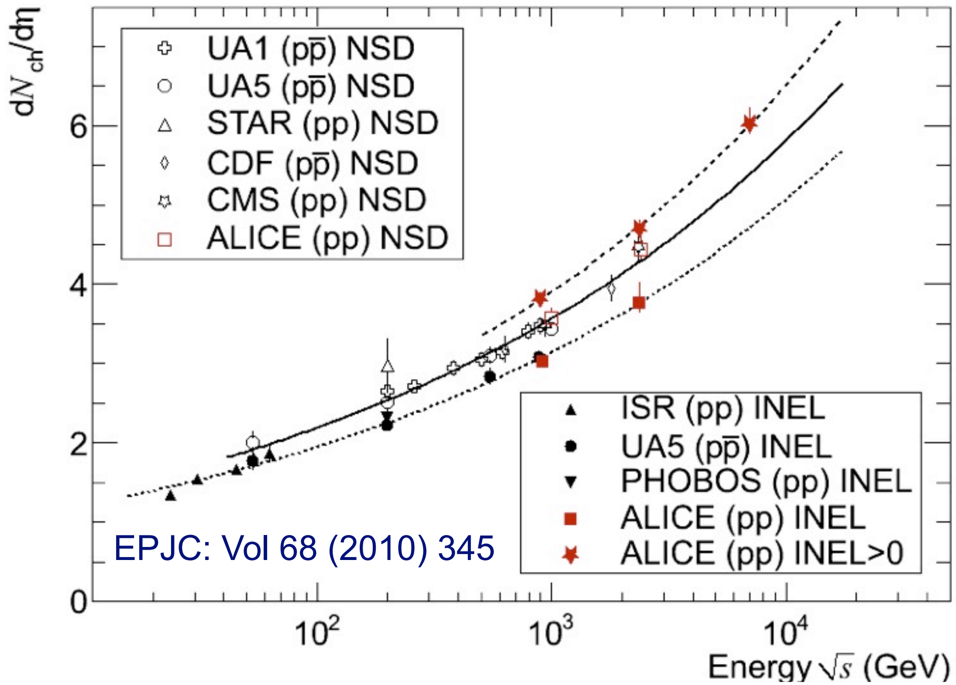
TPC dE/dx
(σ ≈ 5-6%)

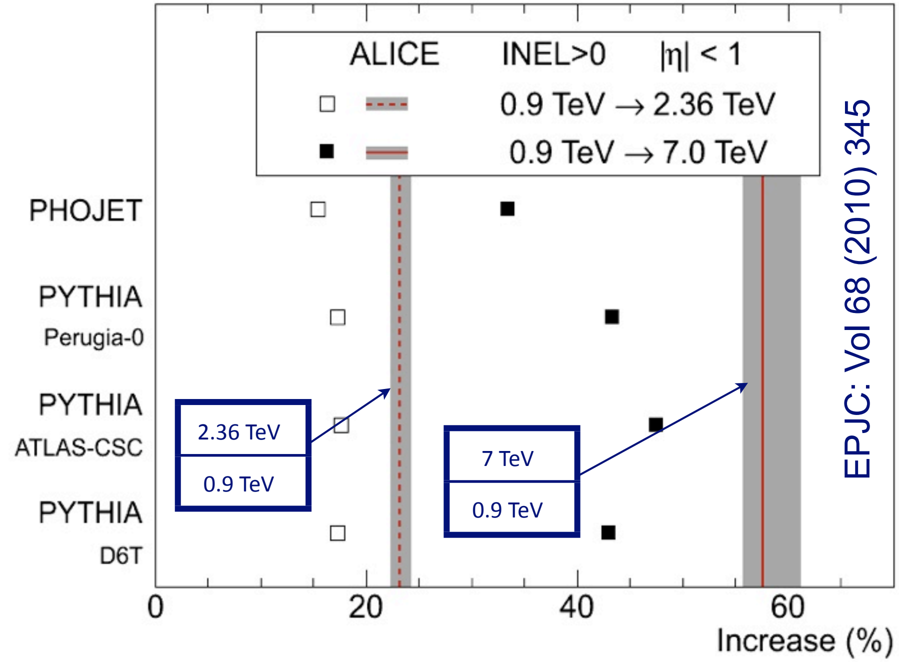


Si vertex detecto
$p_{T\,(min)}$ <100 MeV

Pointing and vertex resolution also close to design

Multiplicity: $dN_{ch}/d\eta$ vs $\sqrt{s}$





Power law dependence fits well ~ $\sqrt{s}^{0.2}$
ALICE and CMS agree to within <3%

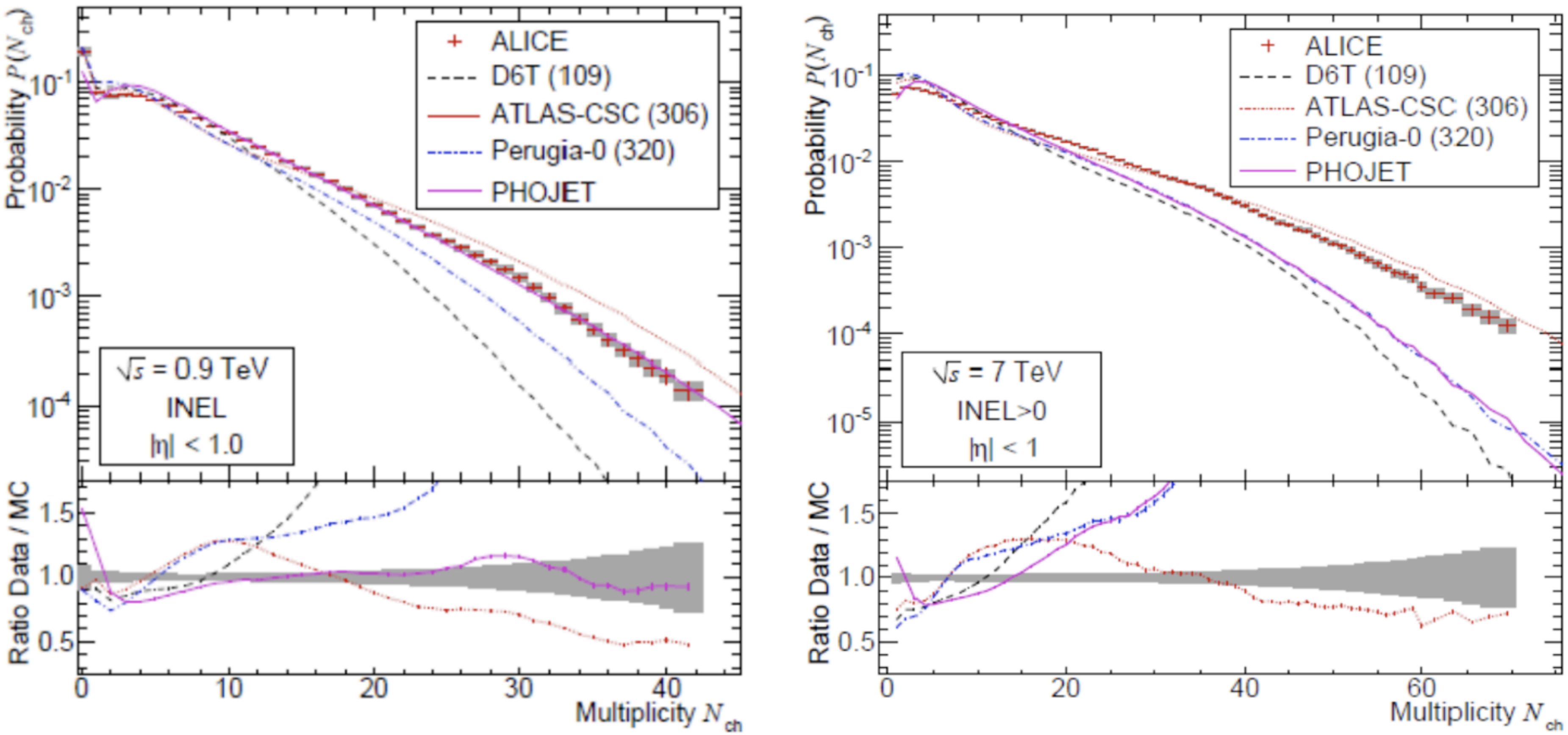
Significantly larger increase with √s than in MC predicts

Increase in $dN_{ch}/d\eta$ in |η| < 1 for INEL > 0 EPJC: Vol 68 (2010) 345	√s	ALICE (%)	MCs (%)
	0.9 → 2.36 TeV	$23.3 \pm 0.4\ _{-0.7}^{+1.1}$	15 – 18
	0.9 → 7 TeV	$57.6 \pm 0.4\ _{-1.8}^{+3.6}$	33 – 48

Multiplicity - probability distributions

References:

0.9 TeV:	EPJC Vol. 65 (2010) 111
0.9 and 2.36 TeV:	EPJC Vol. 68 (2010) 89
7 TeV:	EPJC: Vol 68 (2010) 345



Yield increase is in the tails of the distribution

Multiplicity - probability distributions

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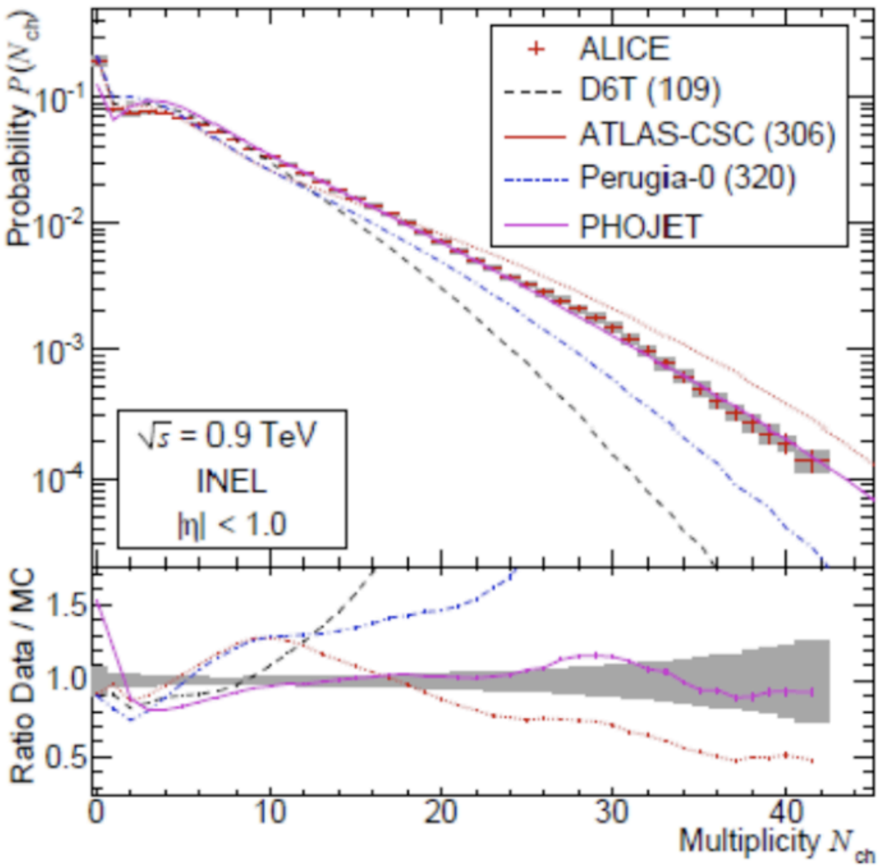
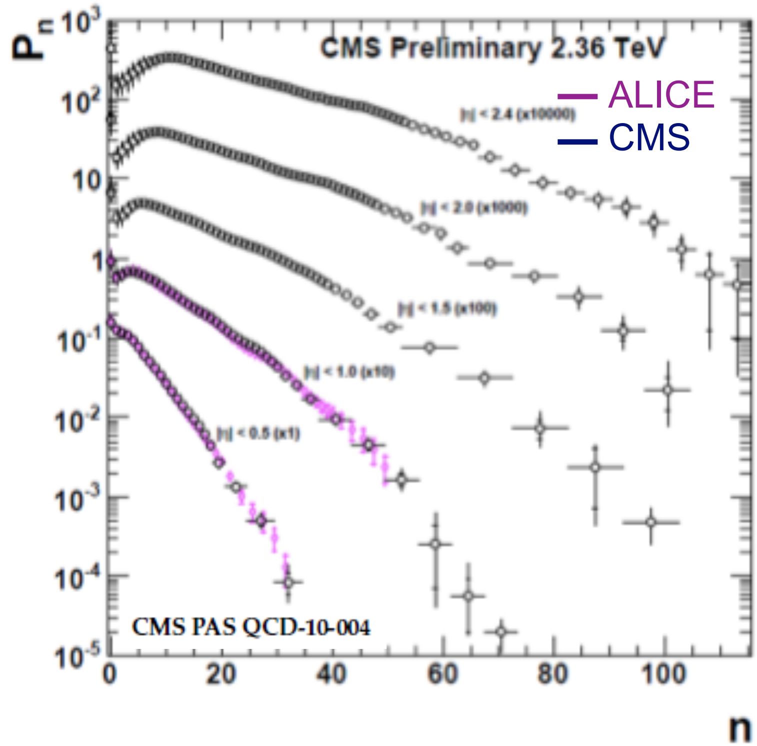
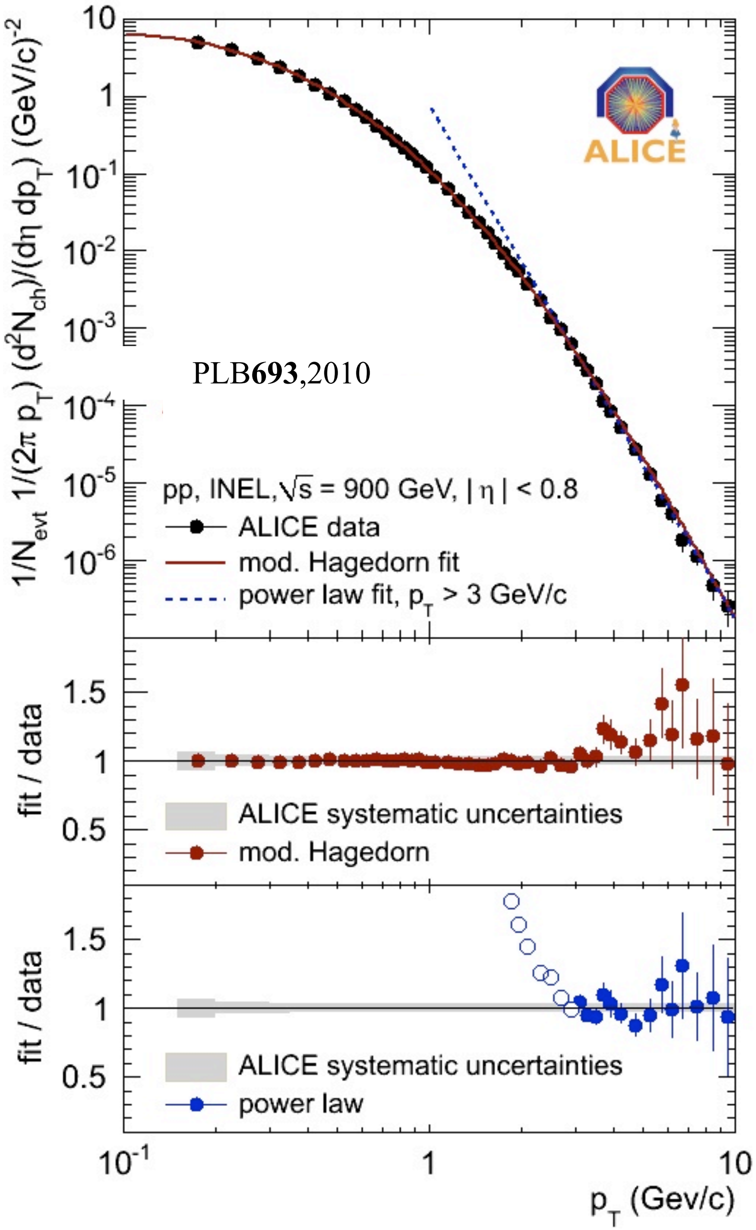
Data consistent with other experiments





Yield increase is in the tails of the distribution

dN_{ch}/dp_T at 0.9 TeV



Invariant cross-section:

Powerlaw fit to flat log-log region (p_T>3 GeV/c)

$n = 6.63 \pm 0.12$ (stat) $\pm$ 0.1 (sys)

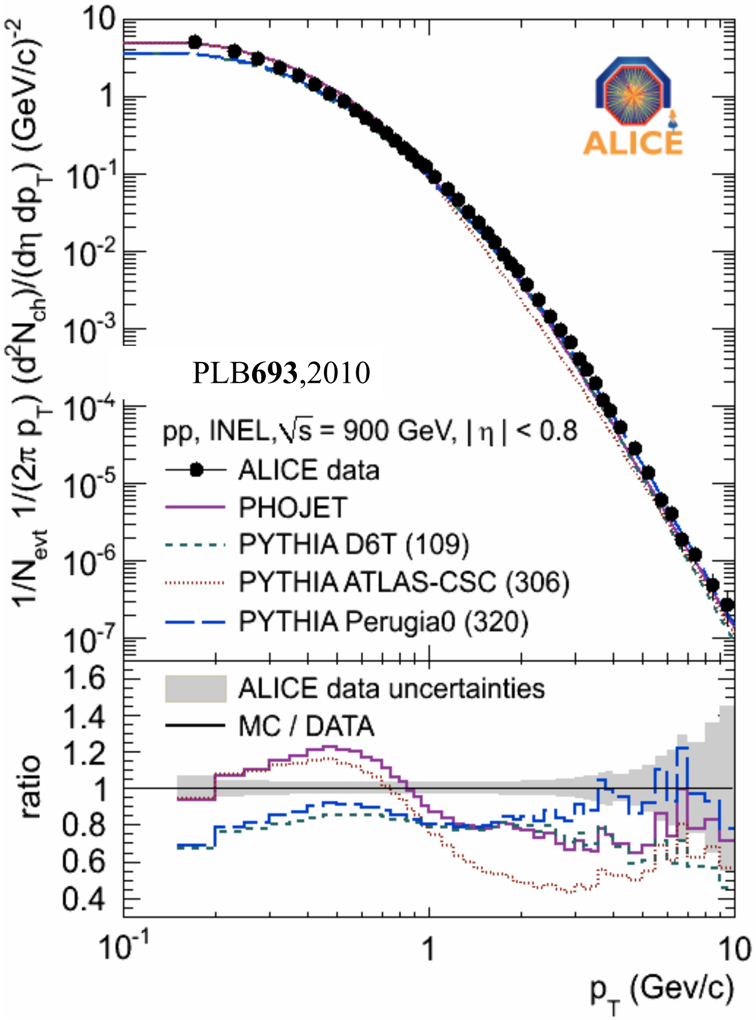
Modified hagedorn distribution gives good description of data over whole p_T range measured

$\langle p_T \rangle_{INEL}$ = 0.483 ± 0.001(stat) ± 0.007(sys) GeV/c

$\langle p_T \rangle_{NSD}$ = 0.489 ± 0.001(stat) ± 0.007(sys) GeV/c

Data not described by MCs

dN_{ch}/dp_T at 0.9 TeV



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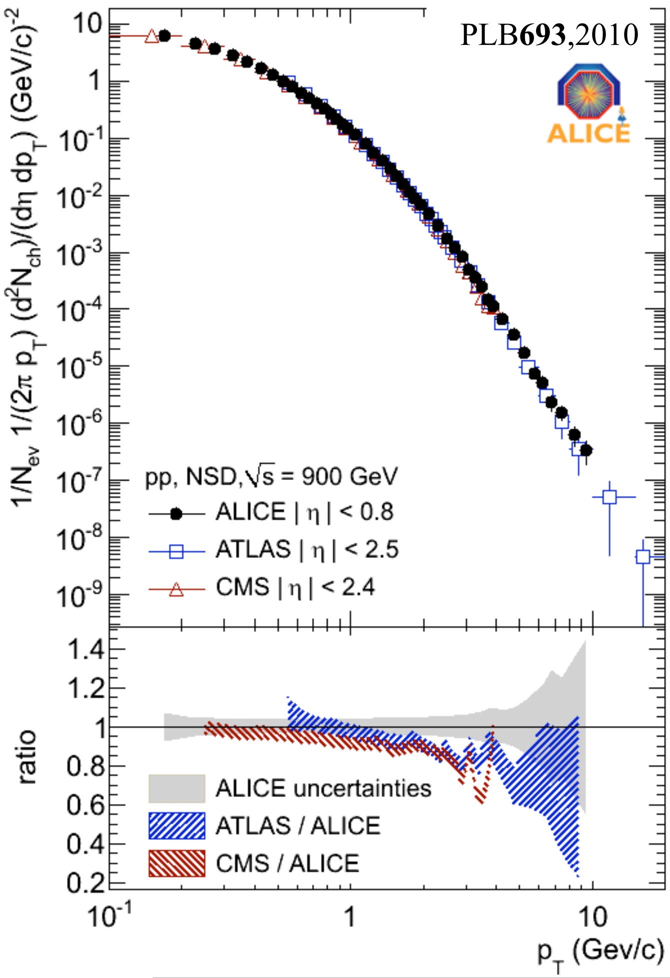
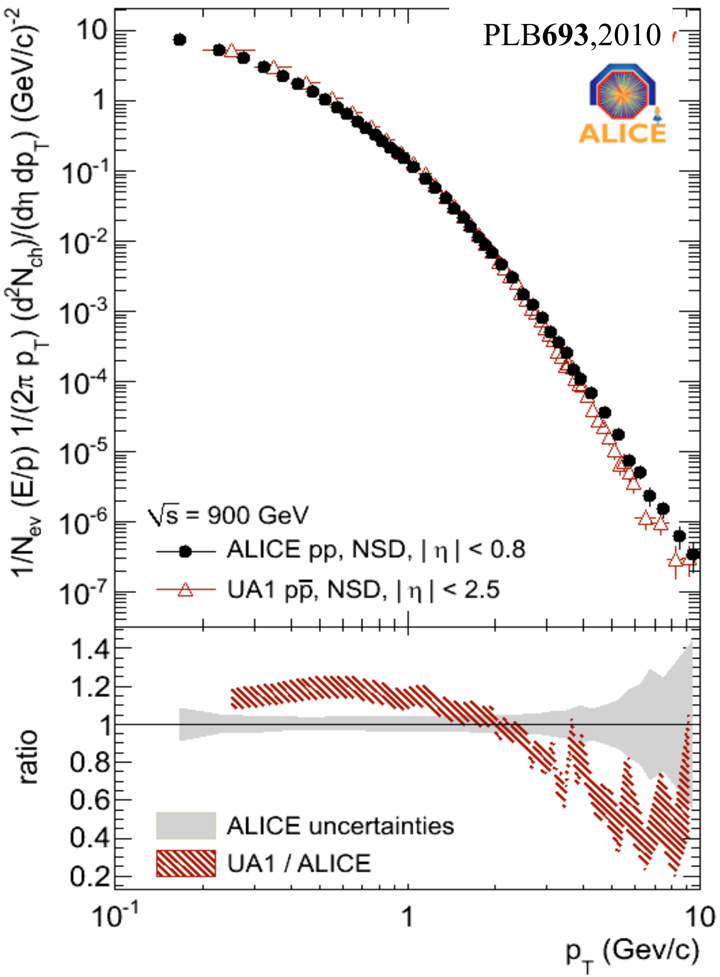
Data not described by MCs

dNch/dpT at 0.9 TeV vs. other experiments

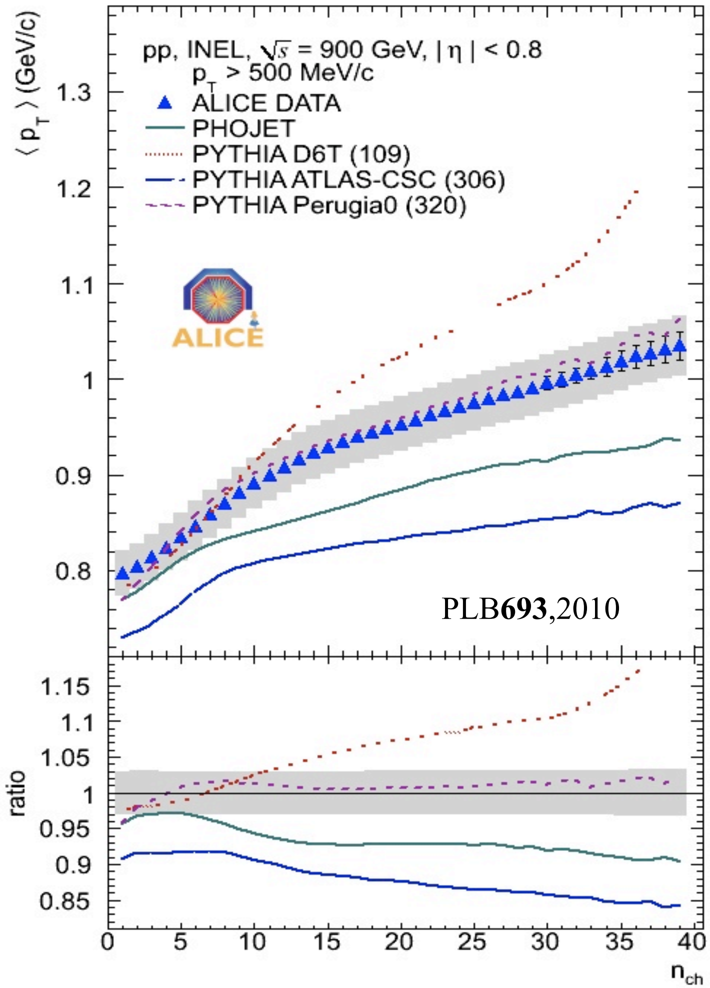




ALICE measures harder spectrum than CMS, ATLAS, UA1
(narrower window at central rapidity ?)

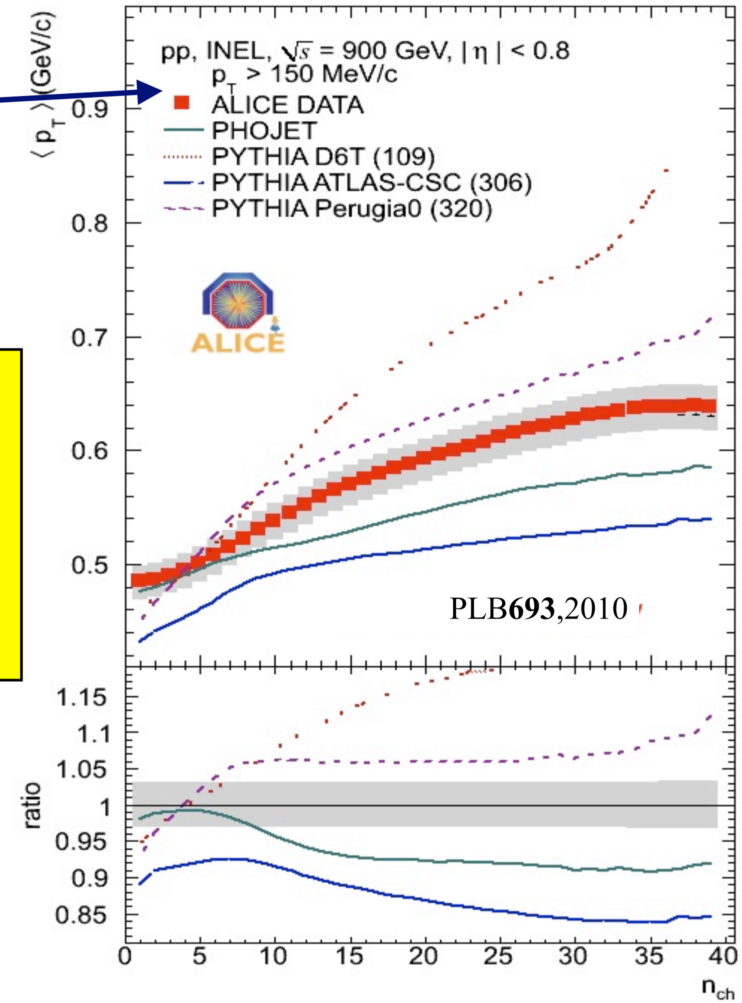
We can't extend our reach would be interesting to squeeze down to our acceptance

$\langle p_T \rangle$ as function of multiplicity at 0.9 TeV



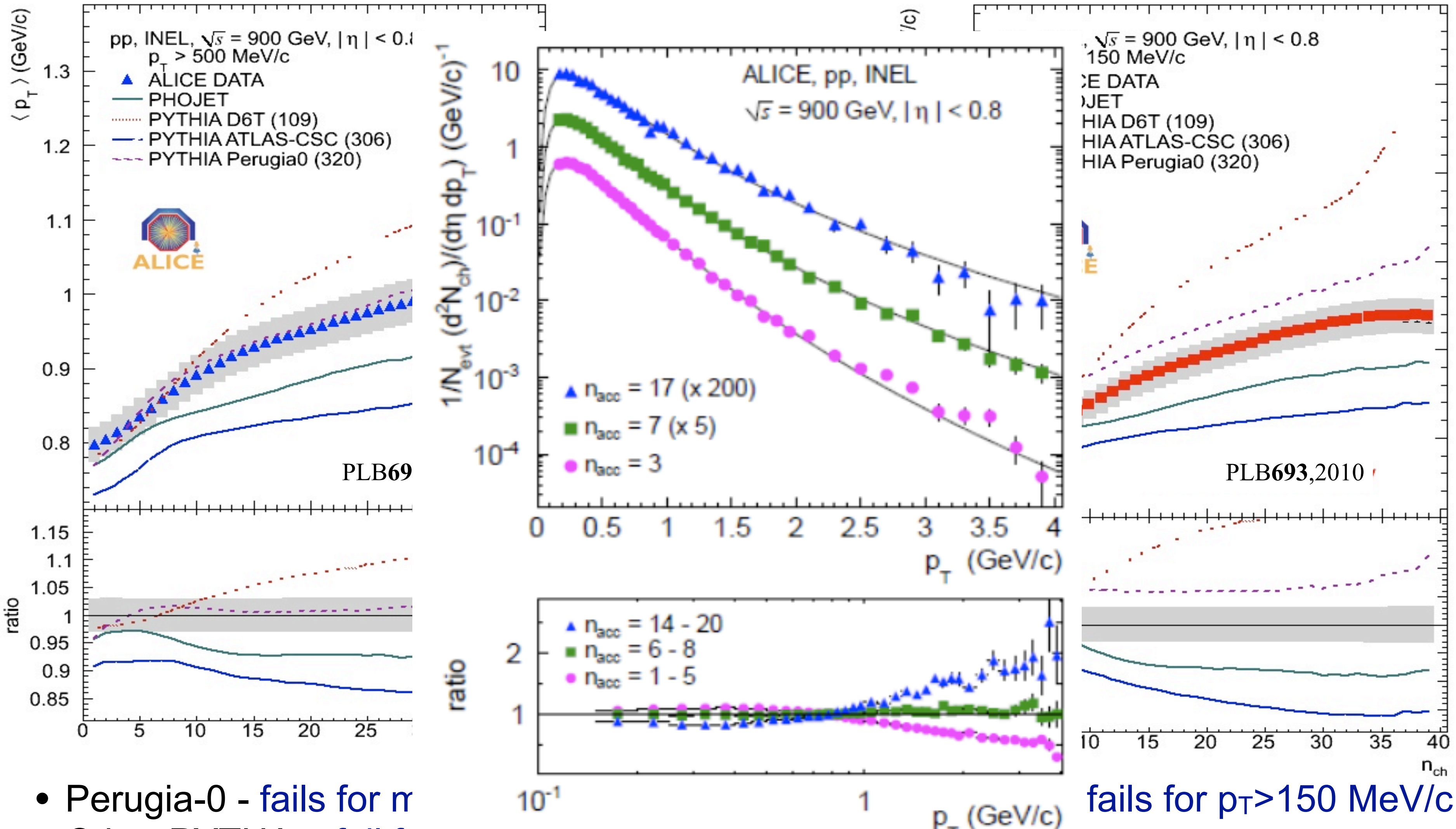
ALICE data goes down to 150 MeV/c

Details of low p_T production important - not well described by any model



- Perugia-0 - fails for mult. - describes $<p_T>$ for p_T>500 MeV/c - fails for p_T>150 MeV/c
- Other PYTHA - fail for $<p_T>$ in both cases
- Phojet - describes mult - fails for $<p_T>$ in both cases

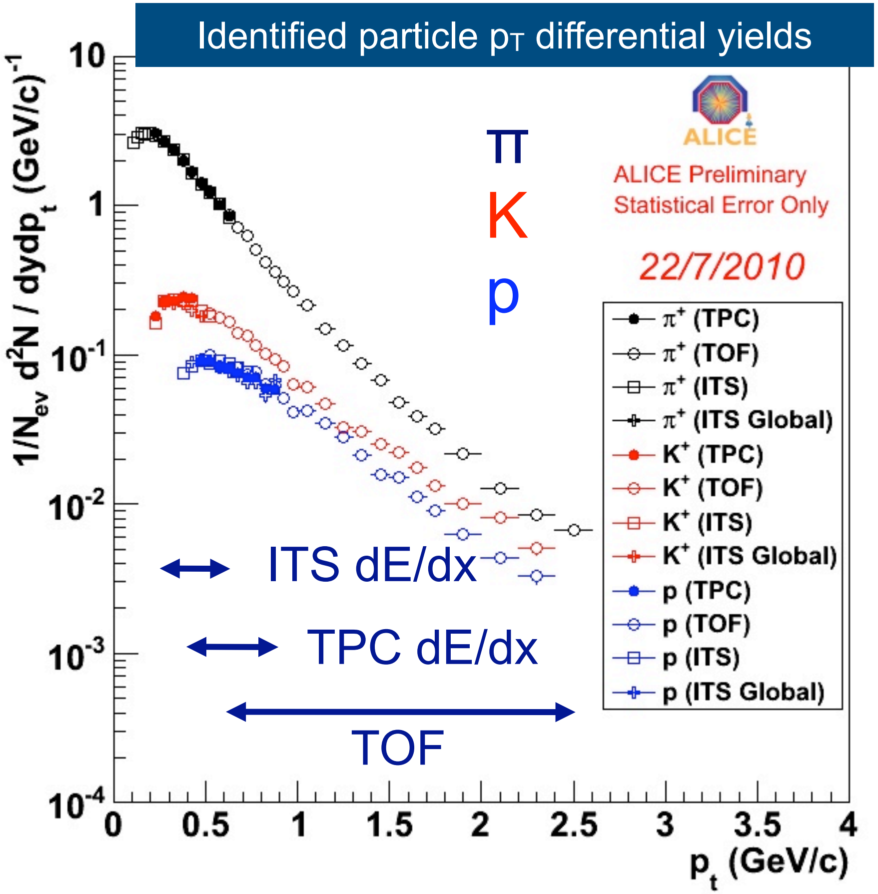
$\langle p_T \rangle$ as function of multiplicity at 0.9 TeV

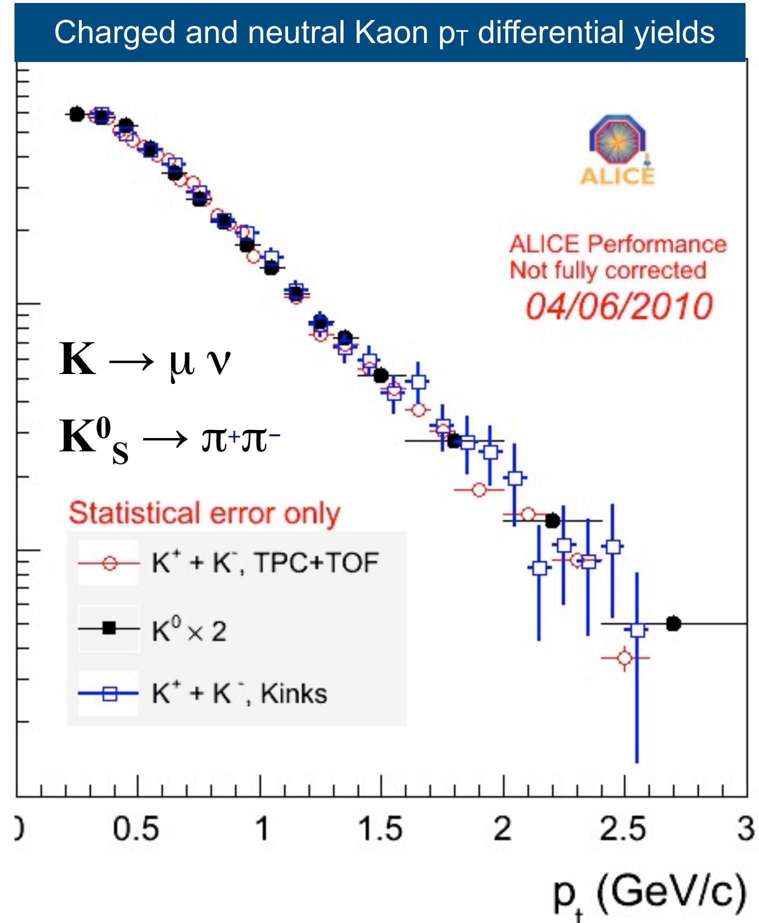


- Perugia-0 - fails for m… fails for p_T>150 MeV/c
- Other PYTHA - fail fo…
- Phojet - describes mult…

Main shape difference at high p_T

Identified particle spectra at 0.9 TeV





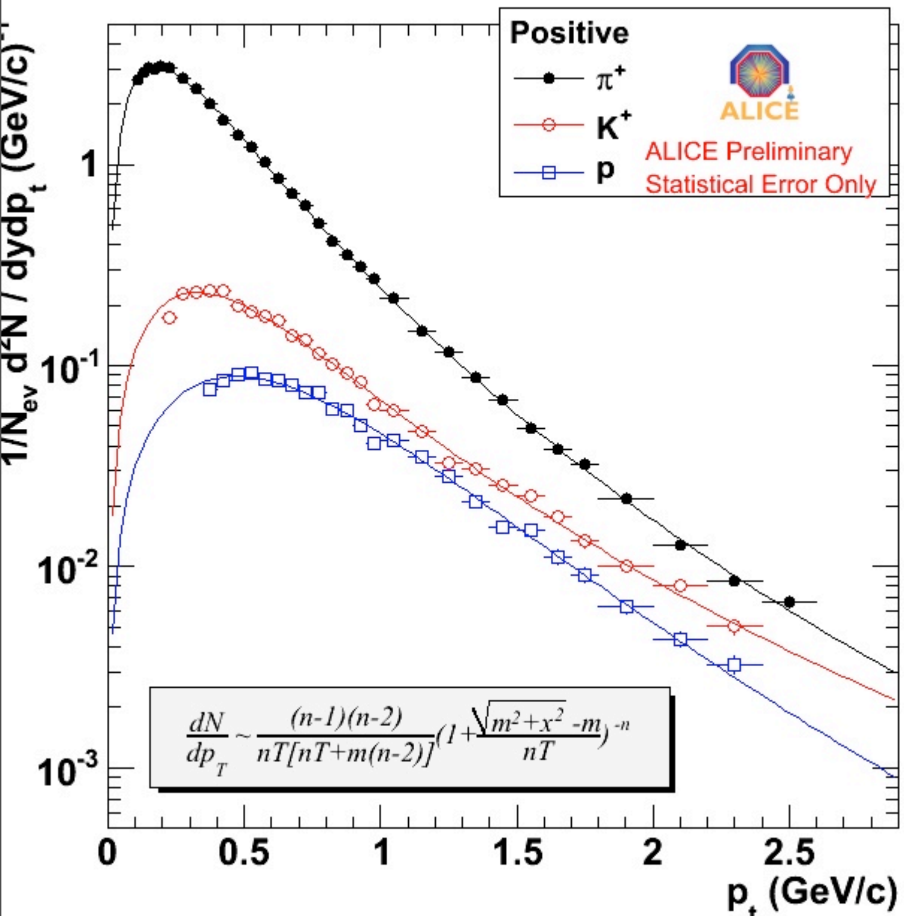
All detectors for obtaining particle p_T spectra in agreement

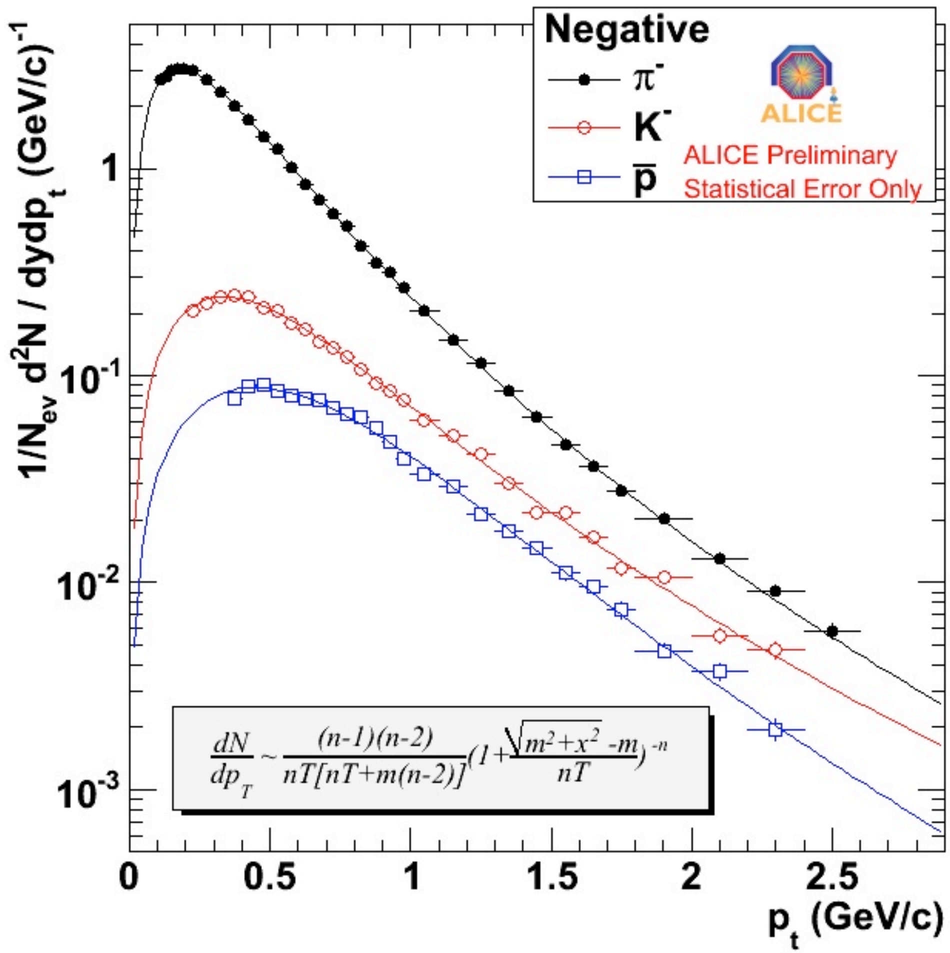
All methods for obtaining kaon p_T spectra in agreement

ALICE designed for good PID - see talk by A. Rossi in Heavy flavor session

Identified particle spectra at 0.9 TeV

TPC, ITS and ToF used to identify particles



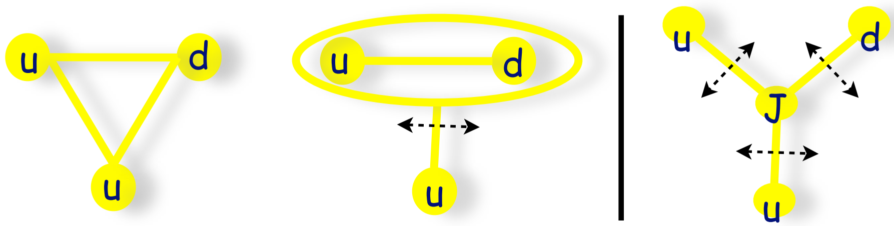


Good description of low p_T data using Lévy (Tsallis) functions

$\overline{p}$/p measurement at mid-rapidity at 0.9 TeV

- Baryon number transport by a di-quark and/or a string junction?

➡ Study $\overline{p}$/p Δy asymmetry at LHC energies



- Conventional approach: QGSM

  pbar/p Δy asymmetry ~ 0 at LHC energies

  (di-quark f.f. exponentially suppressed for large Δy)

- Valence quarks: Rossi and Veneziano, NPB123 (1977) 507

  strong suppression with Δy $P(\Delta y) \sim e^{(a_J - 1)\Delta y}$

- Gluonic field: Kopeliovich and Zakharov, ZPC43 (1989) 241

  weak suppression with Δy $P(\Delta y) = const$

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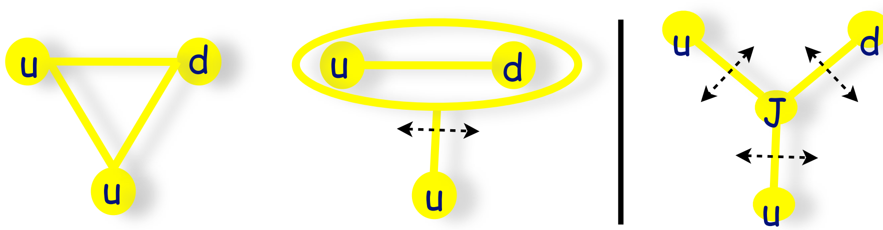

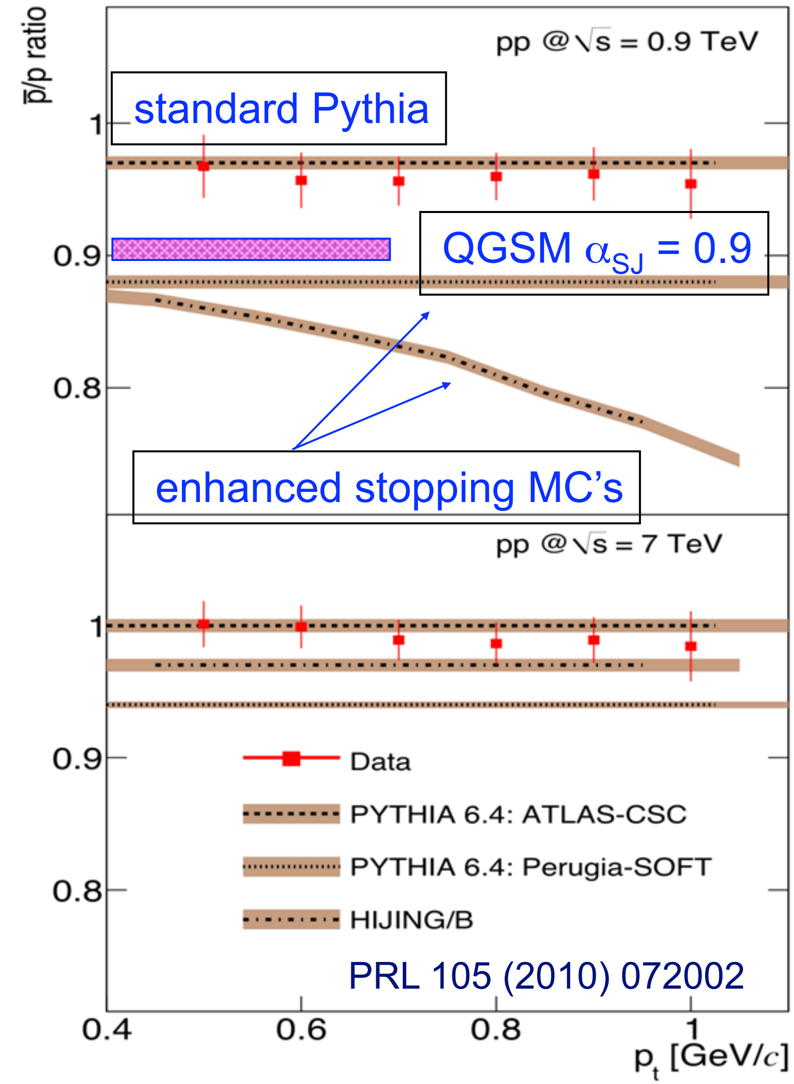

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0.9 TeV: $\bar{p}$/p = **0.957**±0.006(stat) ±0.014(syst)

7 TeV: $\bar{p}$/p = **0.990**±0.006(stat) ±0.014(syst)

Little room for any diagrams transporting baryon number to mid-rapidity

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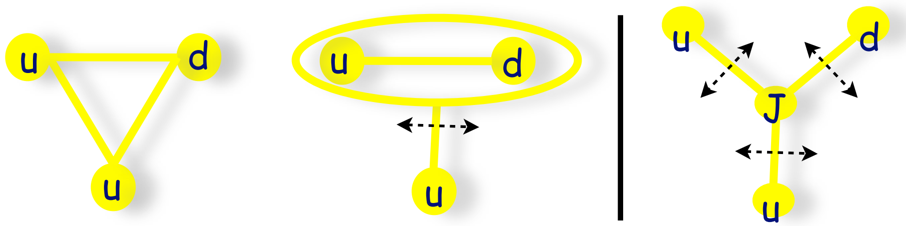

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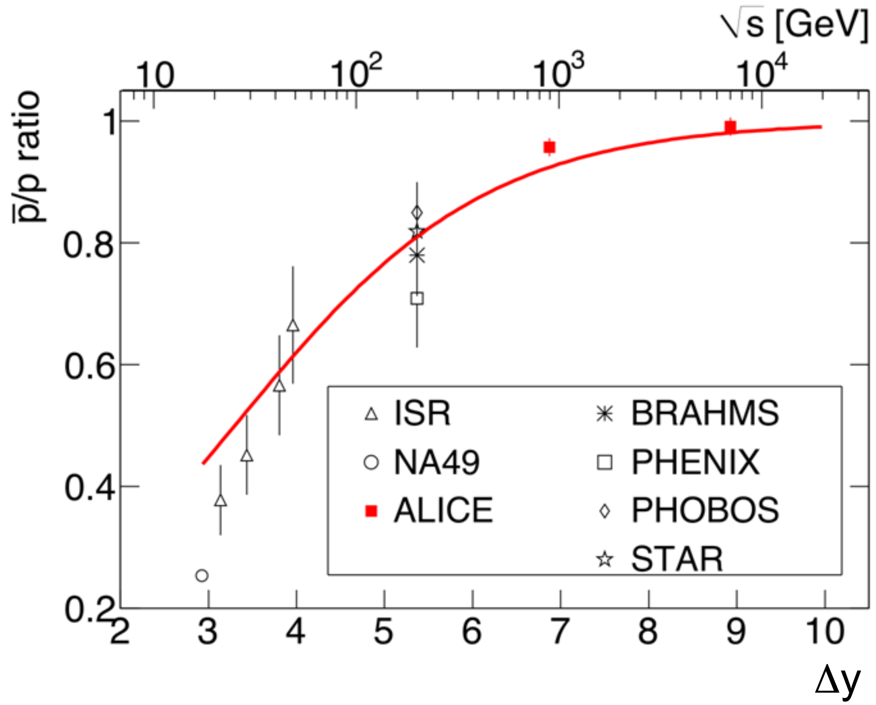

$$\left(\frac{\bar{p}}{p}\right) = \frac{1}{1 + C \cdot e^{(\alpha_J - \alpha_P)\Delta y}} \rightarrow \begin{cases} a_J = 0.5\ (fixed) \\ a_P = 1.2\ (fixed) \\ C = 10.0 \pm 1.0 \end{cases}$$

0.9 TeV: $\bar{p}$/p = **0.957**±0.006(stat) ±0.014(syst)

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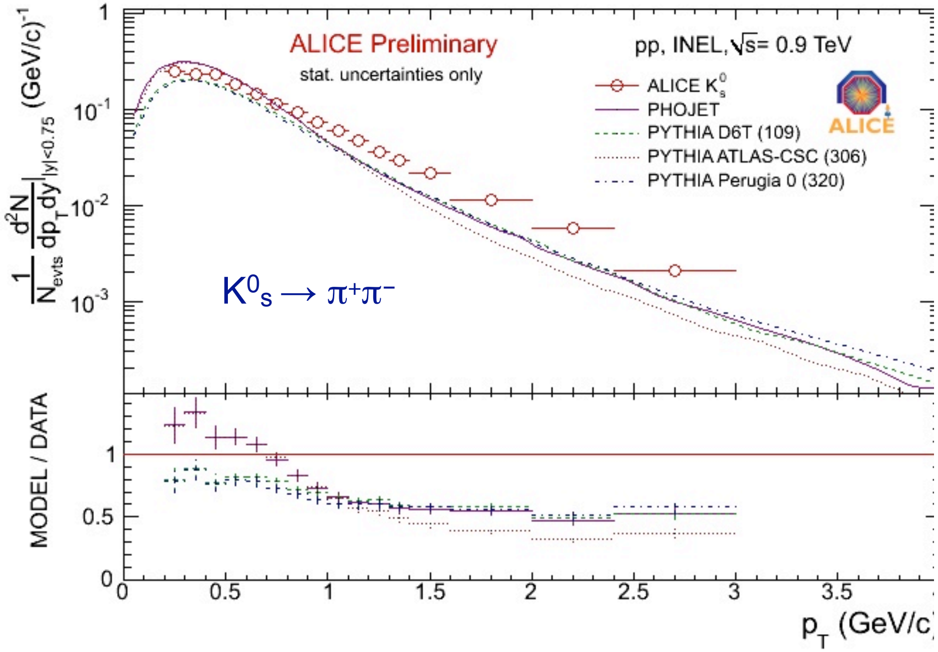
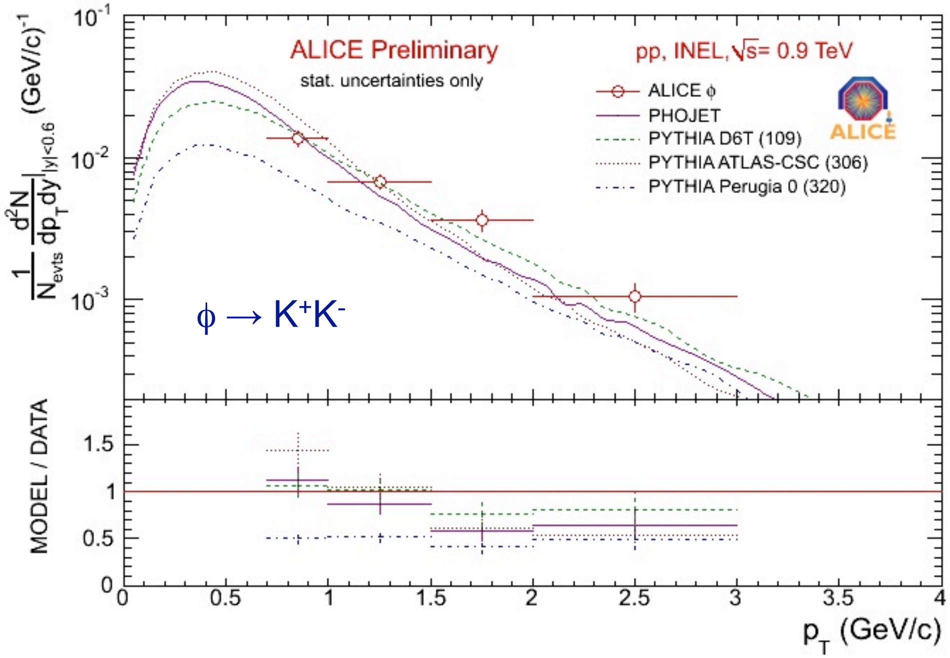
Strange hadron spectra at 0.9 TeV





K^0_s underestimated at high p_T,

Φ OK within uncertainties !

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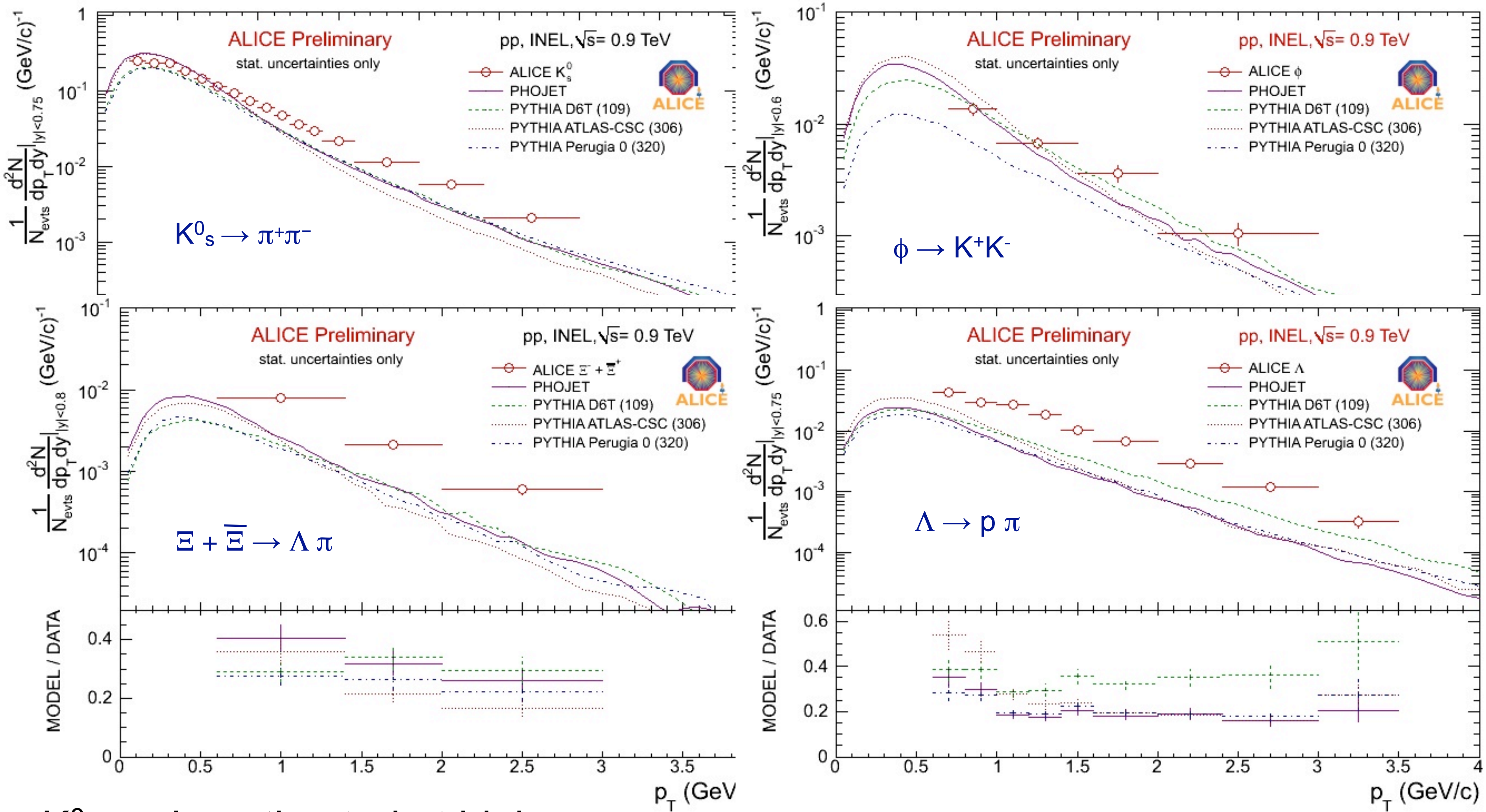

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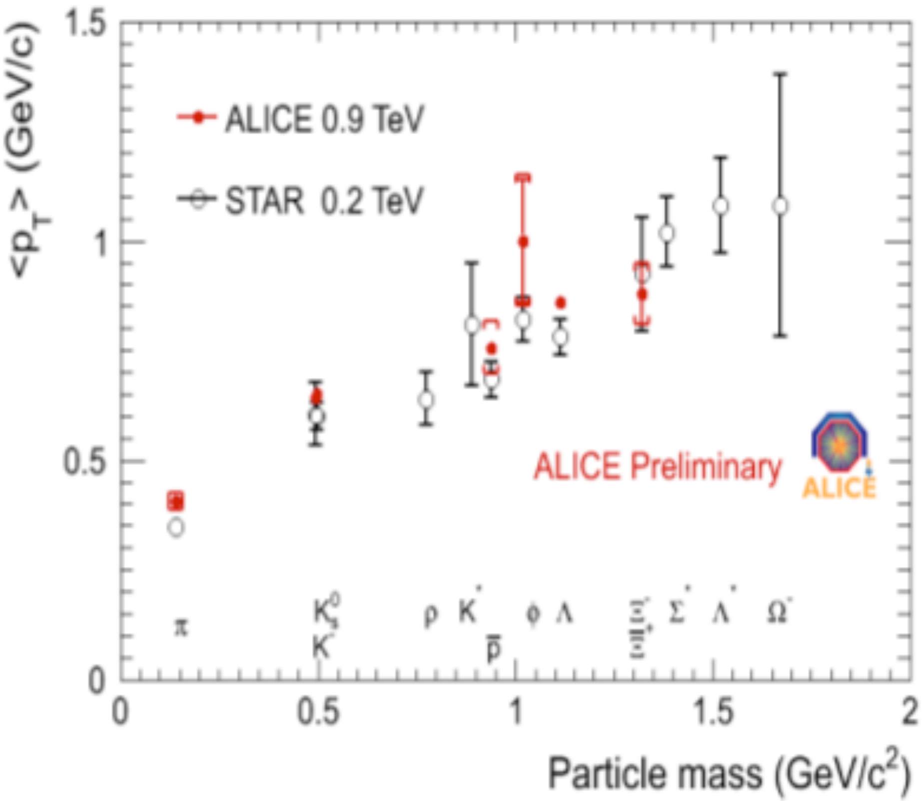
Φ OK within uncertainties !

Strange baryons off by factor 3!

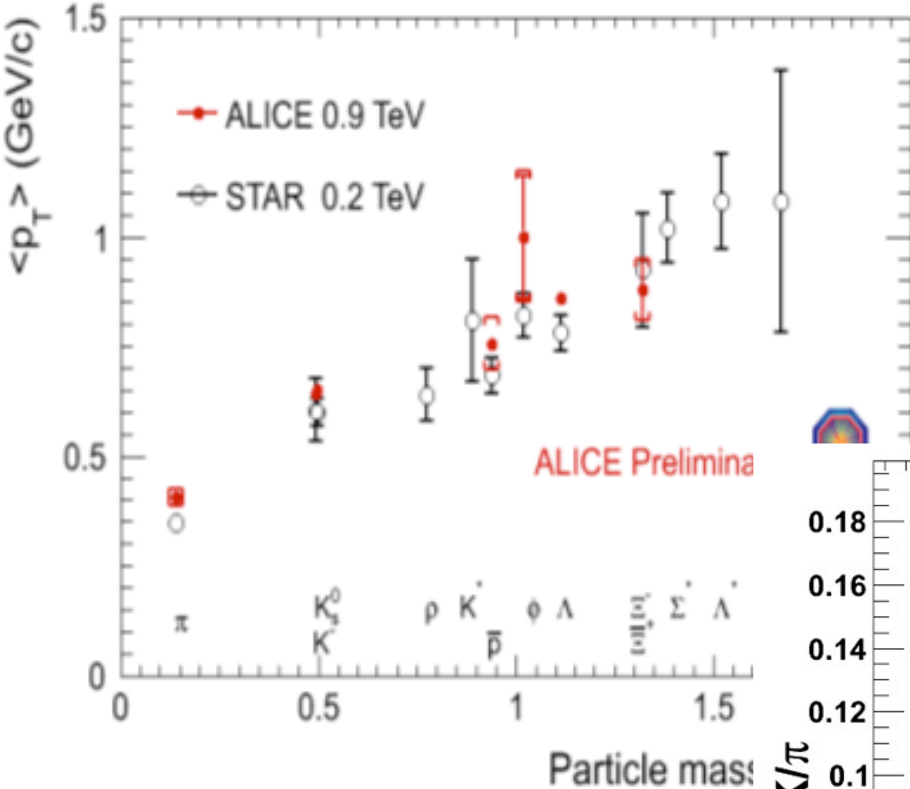
Lots of work to do for strangeness

0.9 TeV compared to other energies



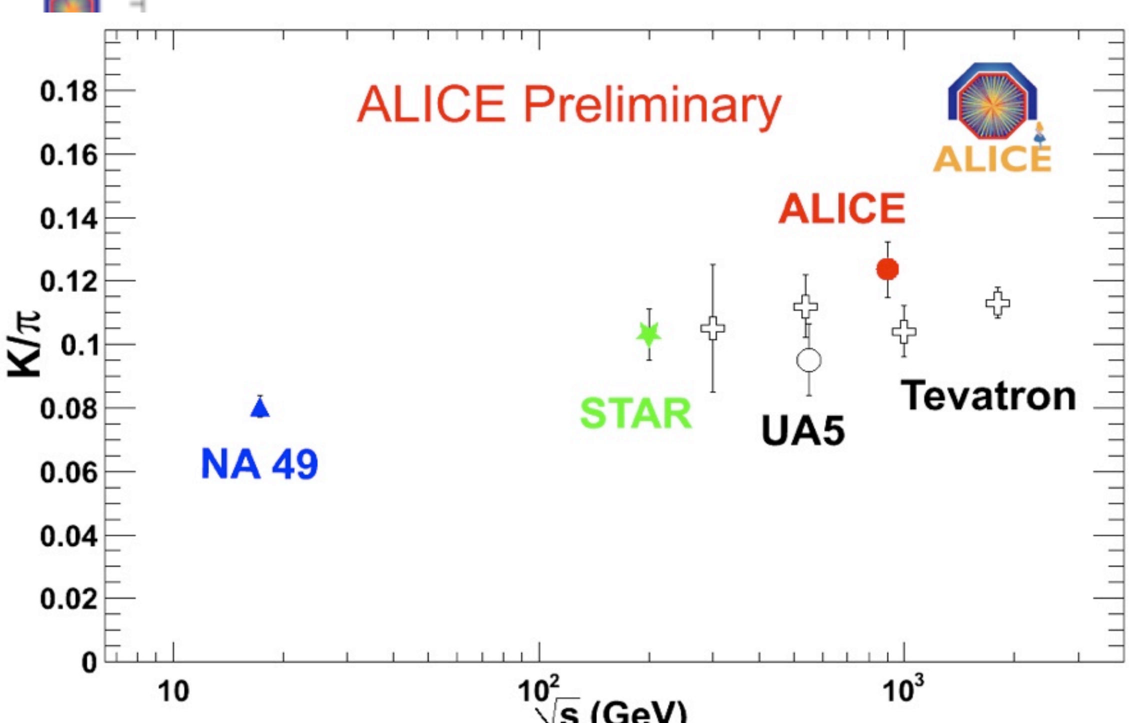
Species dependence of $\langle p_T \rangle$ very similar to RHIC

0.9 TeV compared to other energies



Species dependence of $\langle p_T \rangle$ very similar to RHIC

Integrated K/π has little dependence on √s

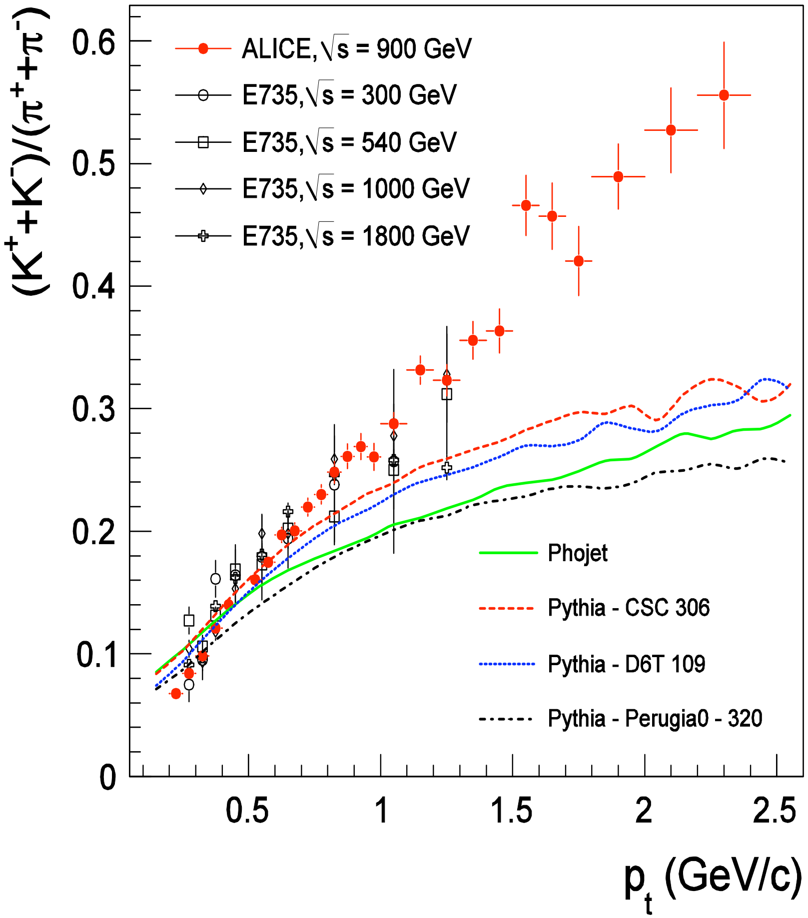


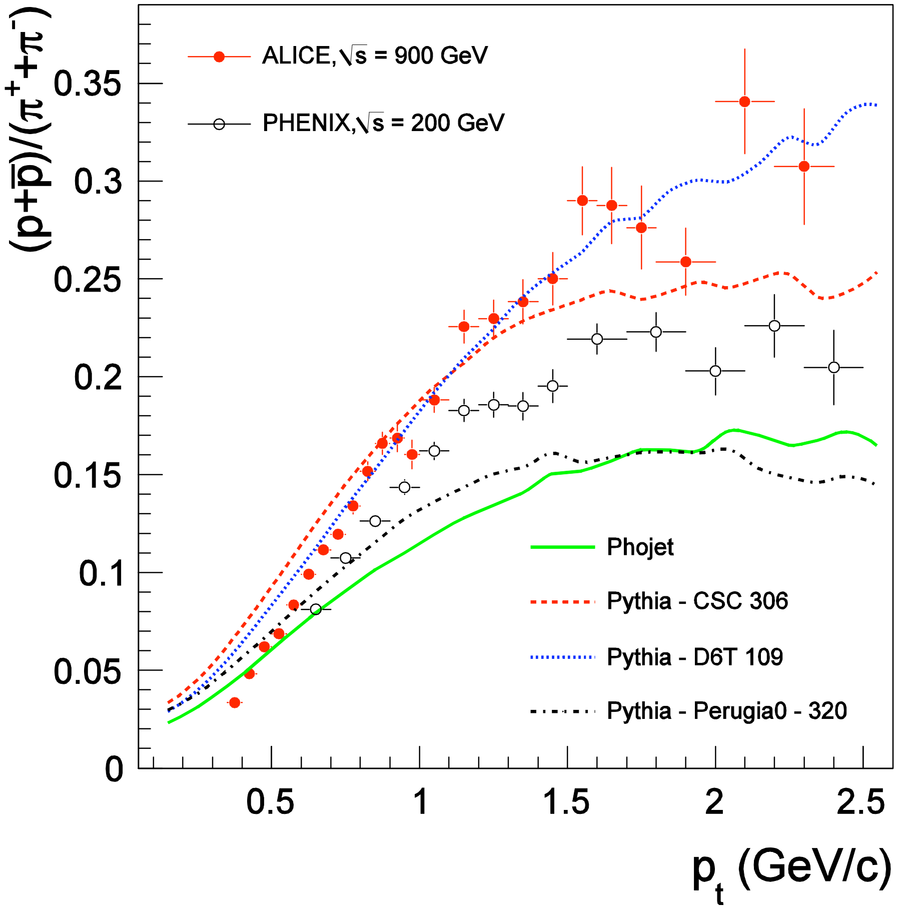
Very interesting to see what happens at 7 TeV (and 14 TeV)

K/π & p/π ratios as function of p_T

Not very good agreement with event generator (not surprising)

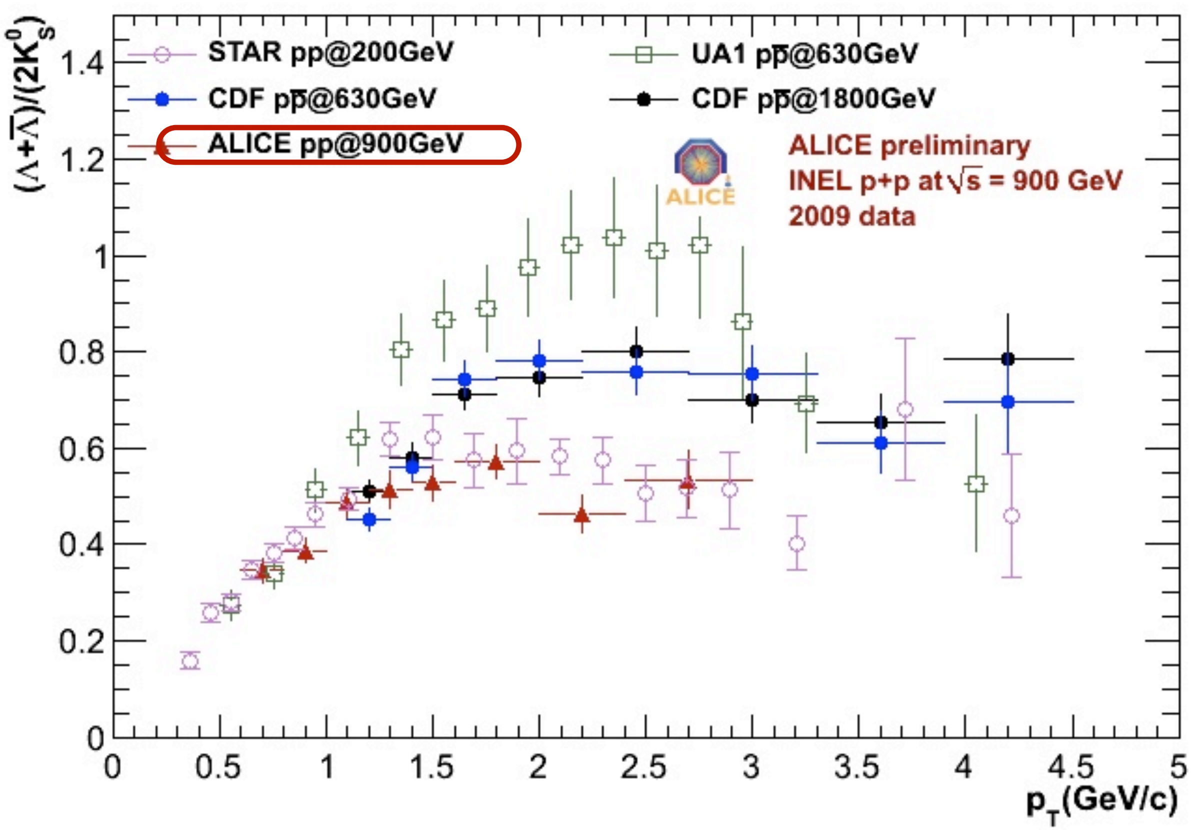
ALICE data for 0.9 TeV





K/π practically independent on √s

Λ/K^0_S ratio at 0.9 TeV



Need further investigation

Is it due to different triggers, acceptances, feed-down corrections.... ?

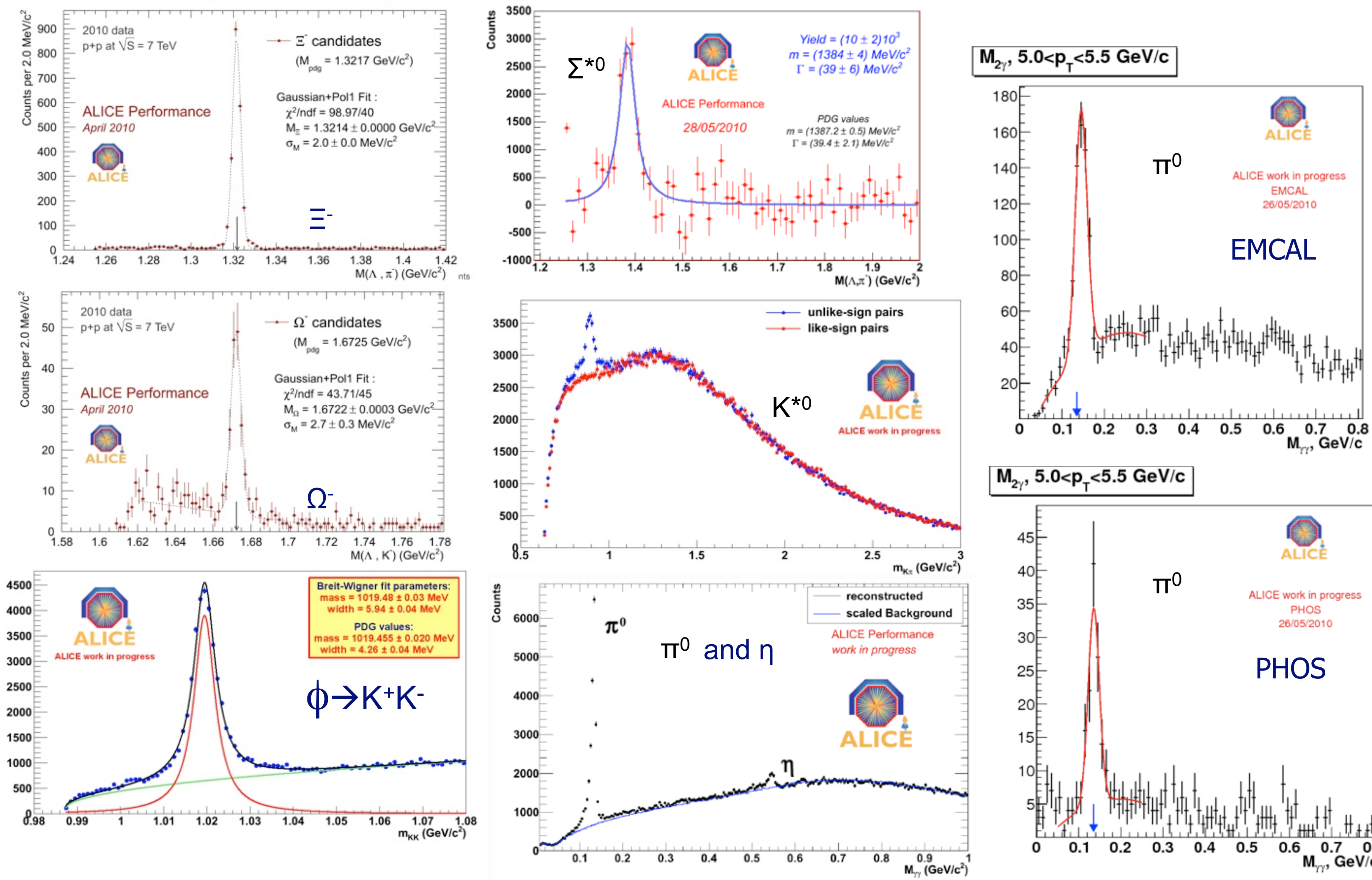
Baryon/Meson ratio for different collision energies

Surprising agreement between RHIC (200) and LHC (900)

Surprising lack of agreement between LHC (900), CDF (630,1800) and UA1 (630)

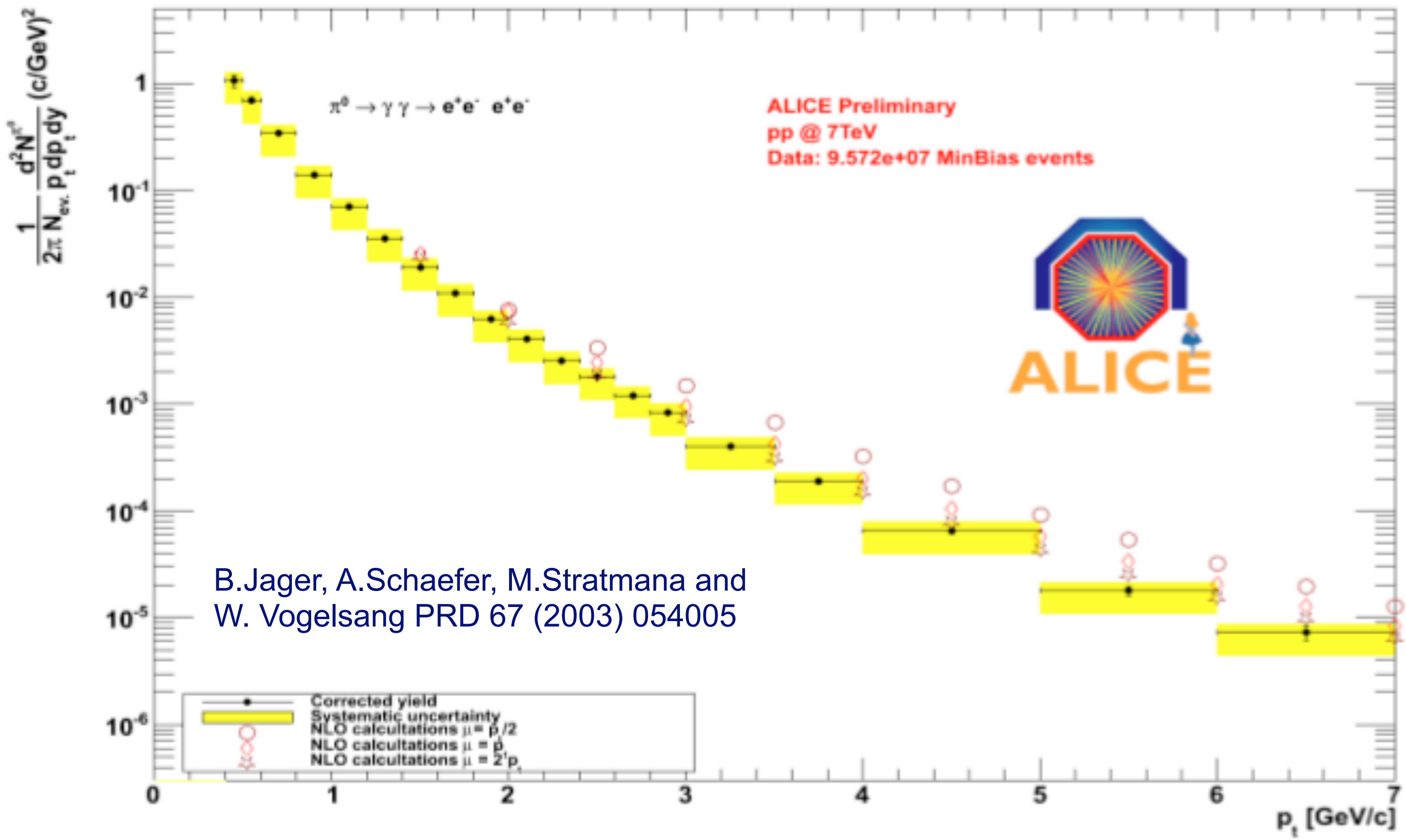
Surprising lack of agreement between CDF (630) and UA1 (630) for p_T > 1.5 GeV/c

More data coming 7 TeV: Ξ,Ω φ, Σ^{*0},K^{*0}, π^0,η



π^0 at 7 TeV

Study $\pi^0 \rightarrow \gamma\gamma$ via conversion into e+e- pairs in the detector material



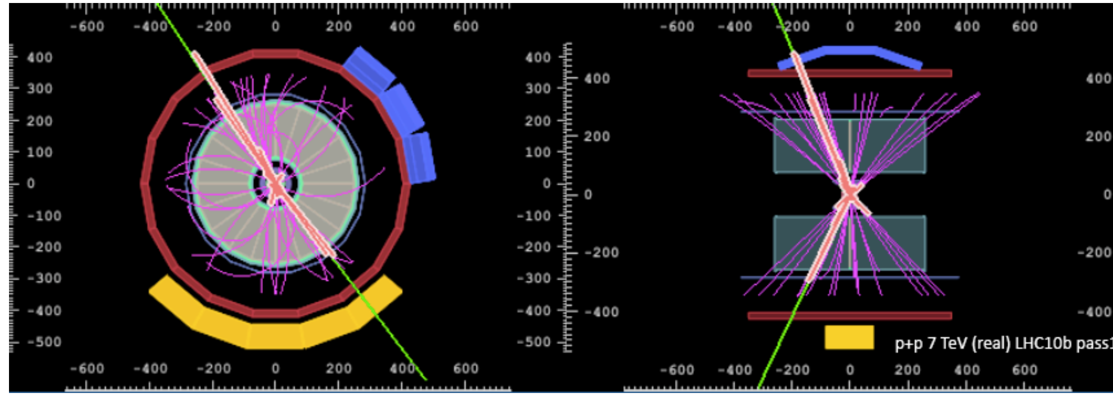
Reasonable agreement with NLO pQCD predictions

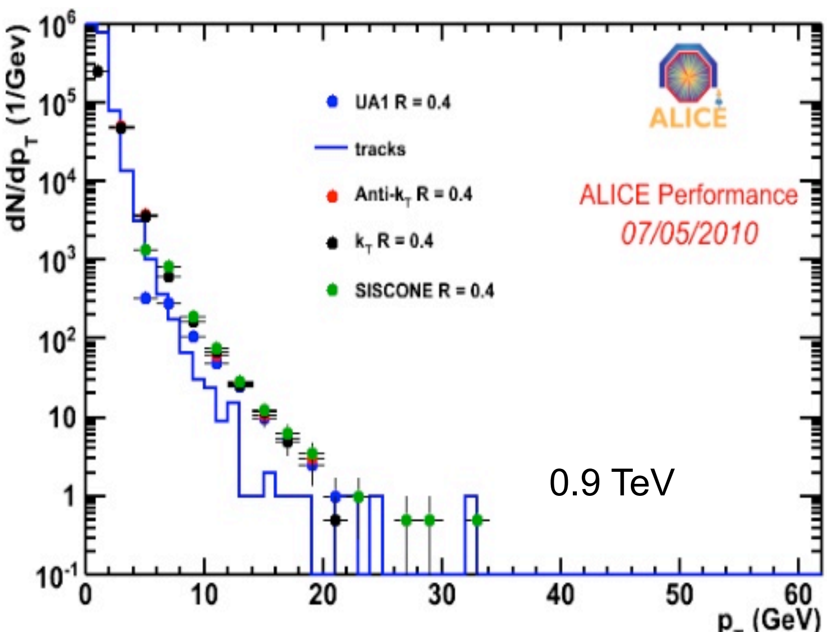
High p_T and Jets: just beginning

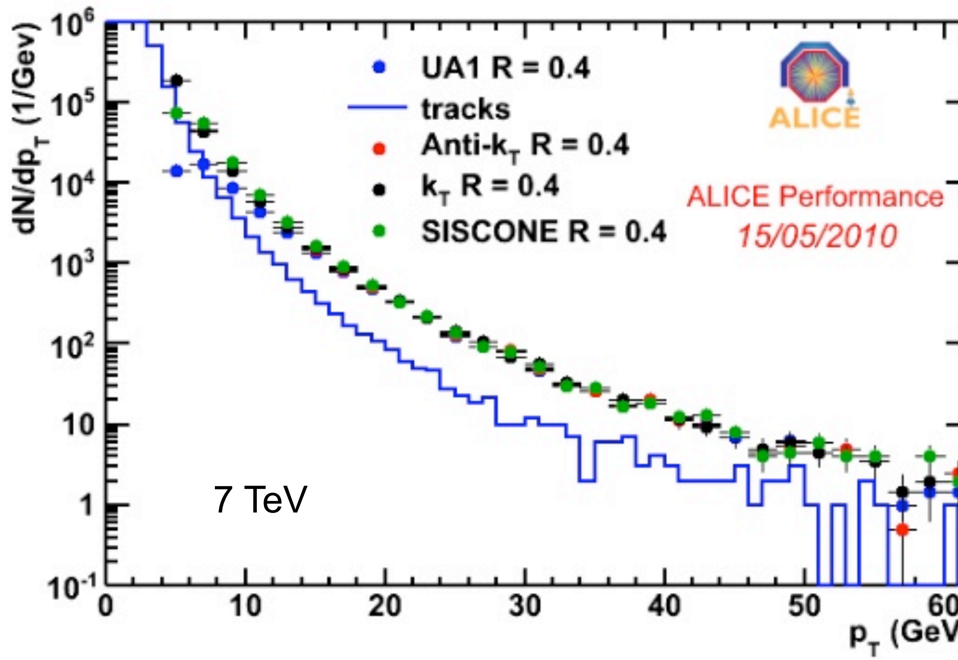
Full EMCal not there yet so missing neutral energy

⇨ Charged-track jets raw spectra at 0.9 and 7 TeV

- |η|<0.5
- 4 jets algorithms compared
- uncorrected spectra







Jets are there!

Start to look at underlying event and event topology

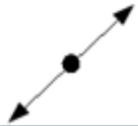
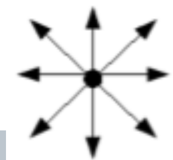
Event shape analysis

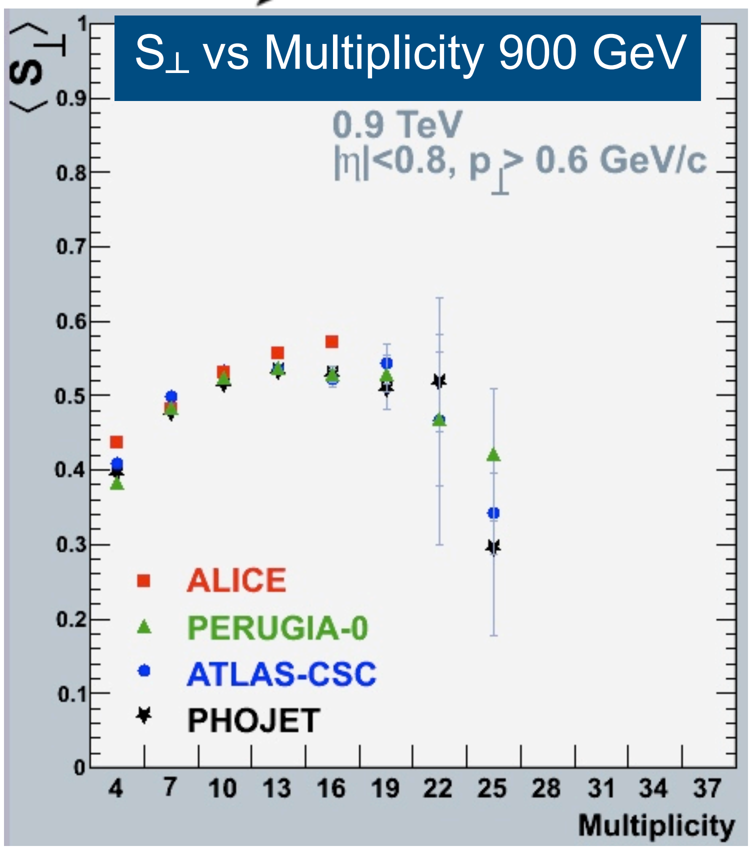
- Transverse Sphericity $S_\perp$:

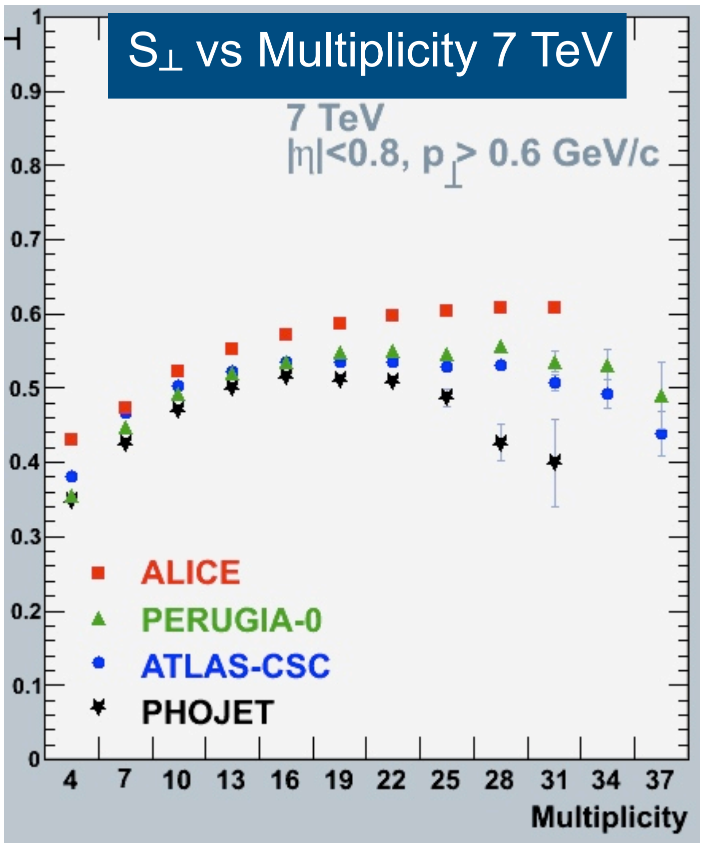
  λ_1 , λ_2: eigenvalues of momentum tensor

$$\mathbf{S_{xy}} = \sum_i \begin{pmatrix} p_x^{(i)\,2} & p_x^{(i)} p_y^{(i)} \\ p_x^{(i)} p_y^{(i)} & p_y^{(i)\,2} \end{pmatrix}$$

$$S_\perp \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$

small $S_\perp$  large $S_\perp$: 

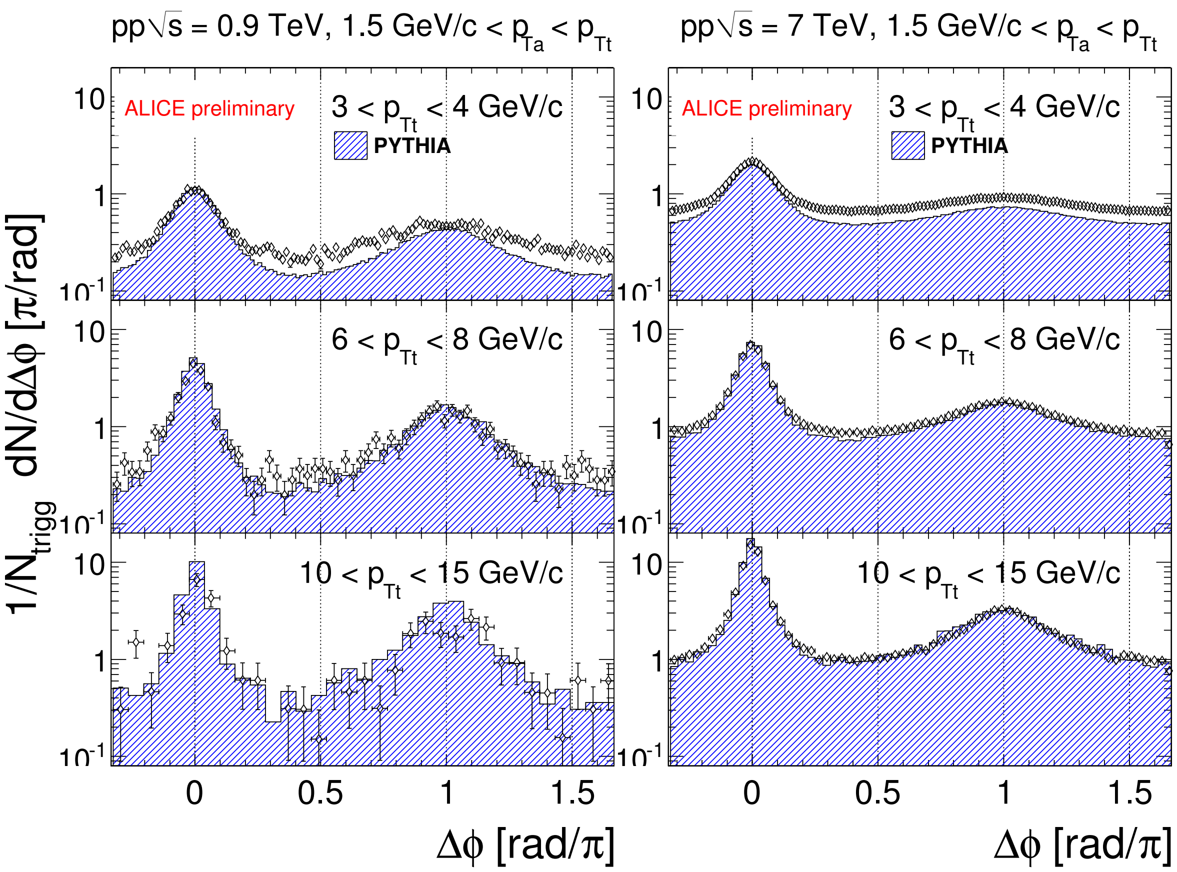




Data "rounder" than simulations

Particle correlations √s=0.9 and 7 TeV

Background not subtracted dΔφ



Uncorrelated background at 7 TeV >> 0.9 TeV

Correlations present down to low p_T

Perugia good at high p_{Tt} but not correct below $p_{Tt} \sim 4$ GeV/c

Particle correlations √s=0.9 and 7 TeV

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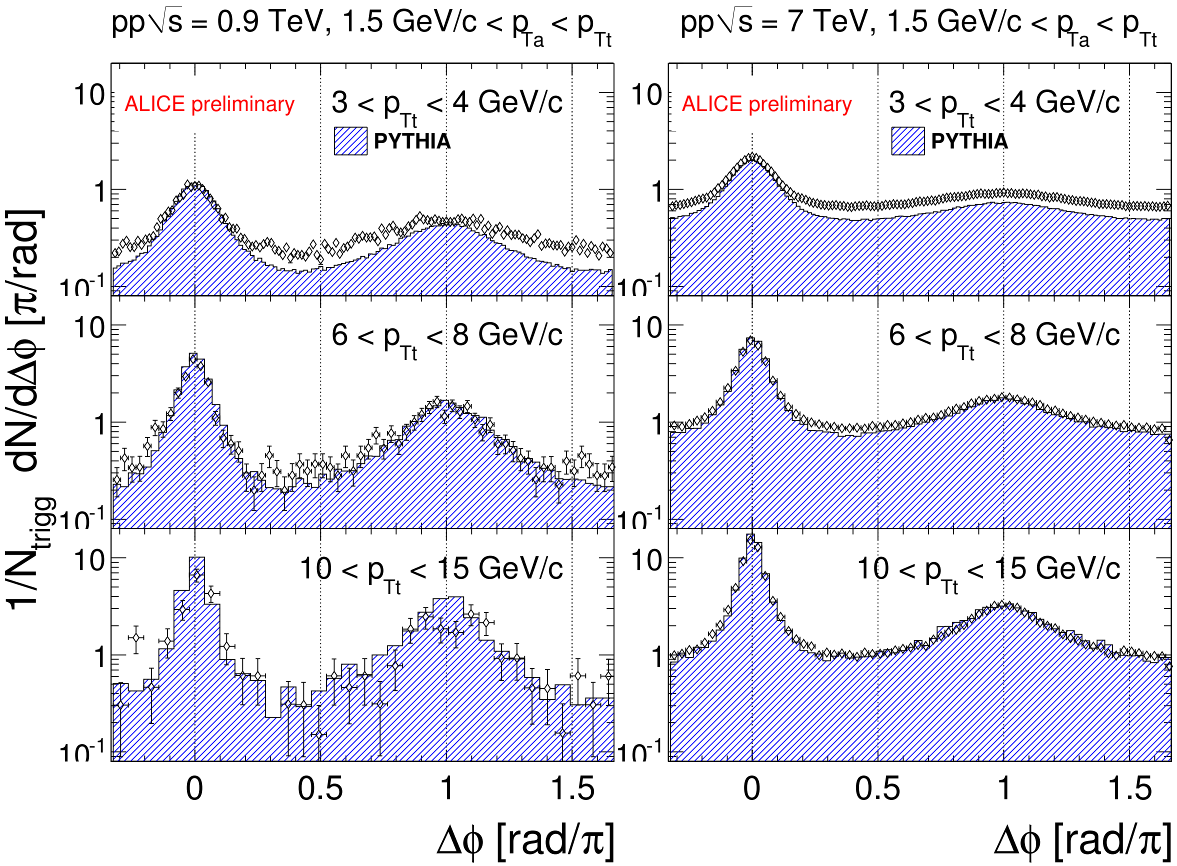
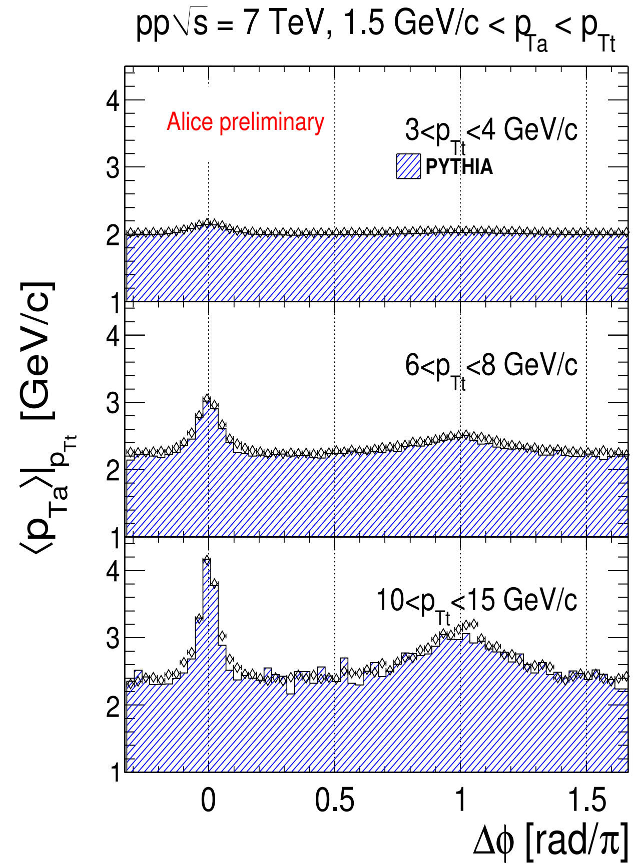


Mean $p_T(\Delta\varphi)$



Uncorrelated background at 7 TeV >> 0.9 TeV

Soft UE multiplicity not correct, $\langle p_T \rangle$ OK

Correlations present down to low p_T

Perugia good at high p_{Tt} but not correct below $p_{Tt} \sim 4$ GeV/c

Summary

ALICE (and all experiments) and the LHC have made a great start

A large amount of data has been collected and analyzed already

No single Monte-Carlo describes all aspects of the data

A lot of results are just around the corner

Much work remains to be done on the data analysis side and with the simulation

6 papers have been published 10 more are in the works

Starting to collect triggered data sets to look at “interesting” regions in more detail

Now taking data with PbPb beams at 2.67 TeV

Back-up slides

Monte Carlo score card so far

	MC/	D6T	Perugia0	CSC	PHOJET
0.9 TeV	$dN_{ch}/d\eta$	-20%	-17%	+3%	-2%
	N_{ch}	$N_{ch}>10$	$N_{ch}>5$	$N_{ch}>15$	$N_{ch}>10$
	p_t		$p_t>4GeV/c$	$p_t>1GeV/c$	$p_t>1GeV/c$
	$<p_t>$				$p_t>1GeV/c$
2.36 TeV	η	-24%	-21%	-2%	-8%
	N_{ch}	$N_{ch}>10$	$N_{ch}>5$	$N_{ch}>20$	$N_{ch}>15$
7 TeV	η	-27%	-24%	-4%	-17%
	N_{ch}			$N_{ch}>30$	

- MC << data
- MC >> data
- MC ≈ data

Conclusion:

no tested MC's (adjusted at lower energy) does really well

tuning 1-2 results is doable, getting everything right will require more effort (hopefully during the exercise we'll learn us something on soft QCD

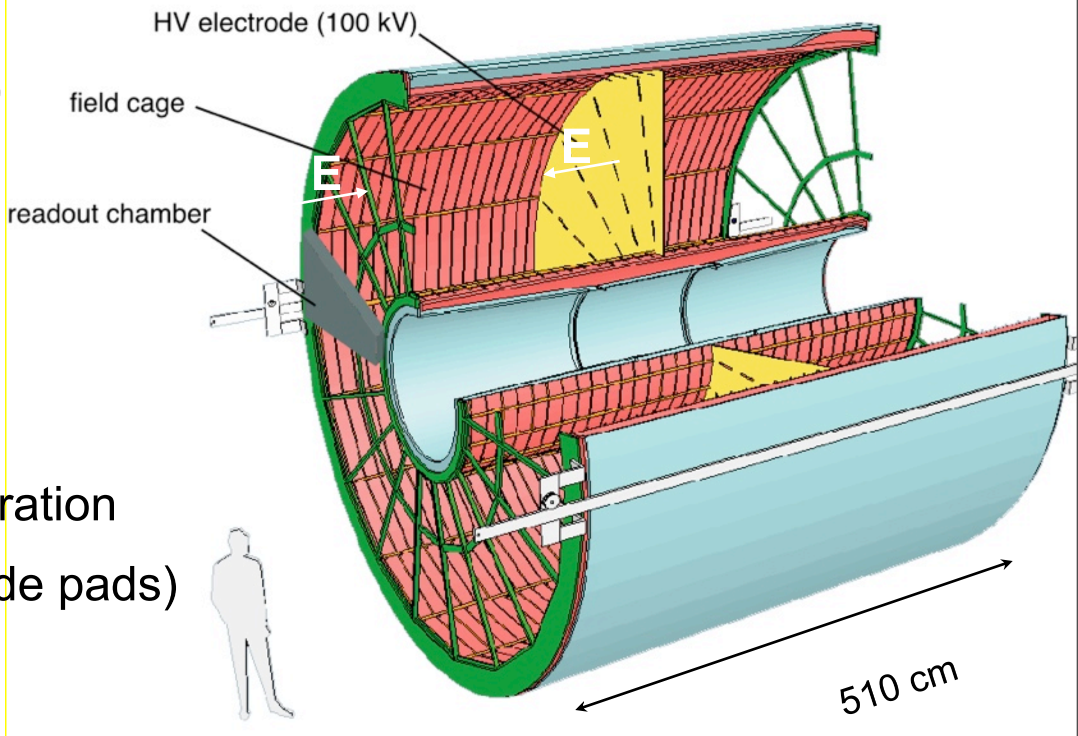
pp Physics Analysis

- 6 papers published – accepted
  - **Charged-particle density in 900 GeV pp collisions**
    - K. Aamodt et al. (ALICE), EPJC: vol 65 (2010) 111
  - **Charged-particle multiplicity in 0.9 and 2.36 pp collisions**
    - arXiv:1004.3034[hep-ph] EPJC: Vol. 68 (2010) 89
  - **Charged-particle multiplicity in 7 TeV pp collision – letter**
    - arXiv:1004.3514[hep-ph] EPJC: Vol. 68 (2010) 345
  - **Measurement of antiproton/proton ratio in pp at 0.9 and 7 TeV**
    - Phys.Rev.Lett Vol 105, 072002 (2010)
  - **Charged-particle transverse momentum spectra at 0.9 TeV**
    - http://arxiv.org/abs/1007.0719, PL B: Vol. 693 (2010) 53
  - **Identical particle correlation in pp at 0.9 TeV**
    - http://arxiv.org/abs/1007.0516, PRD: Vol. 82 (2010) 052001

- 2 papers in draft
  - **Identified charged hadron spectra and yields in pp at 0.9 TeV**
  - **Strange particle production in pp at 0.9 TeV**
- Other analyses well underway
  - High multiplicity pp events, azimuthal correlations, event structure, π^0 and η spectra, charm production,jet fragmentation, UE,...+ 7 TeV and PbPb

ALICE TPC

- minimal material budget
  - ☺ composite materials => 3.5% X0
  - ☹ sensitive to stress and deformations



- high track density
  - ☺ low diffusion & low space charge
    'cool' drift gas ($Ne/CO_2/N_2$)
  - ☹ electric field (400 V/cm), V_{drift} calibration
  - ☺ high granularity (550 k few mm wide pads)
  - ☹ tight tolerances in construction

- advanced readout electronics
  - ☺ digital pulse shaping and 0-supression
  - ☺ > 2 kHz readout of $0.5x10^9$ 10 bit ADC's

Event classes

p+p collisions at 0.9 and 2.36 TeV

- INEL and NSD
- Use measured cross sections for diffractive processes
- Change MC generator fractions (SD/INEL, DD/INEL) so that they match these fractions
- Use Pythia and Phojet to assess effect of different kinematics of diffractive processes

p+p collisions at 7 TeV

- Diffraction is quite unknown
- Hadron-level definition of events (similar to ATLAS: Phys. Lett. B 688 (2010) 21)
- All events that have at least one charged primary particle in $|\eta|<1$ “INEL>0”
- Minimises model dependence

INEL: MB_{OR} (SPD or VZEROA or VZEROC) + offline background suppression
NSD: MB_{AND} (VZEROA and VZEROC) + offline background suppression
INEL>0: INEL and at least one charged primary particle in $|\eta| < 1$

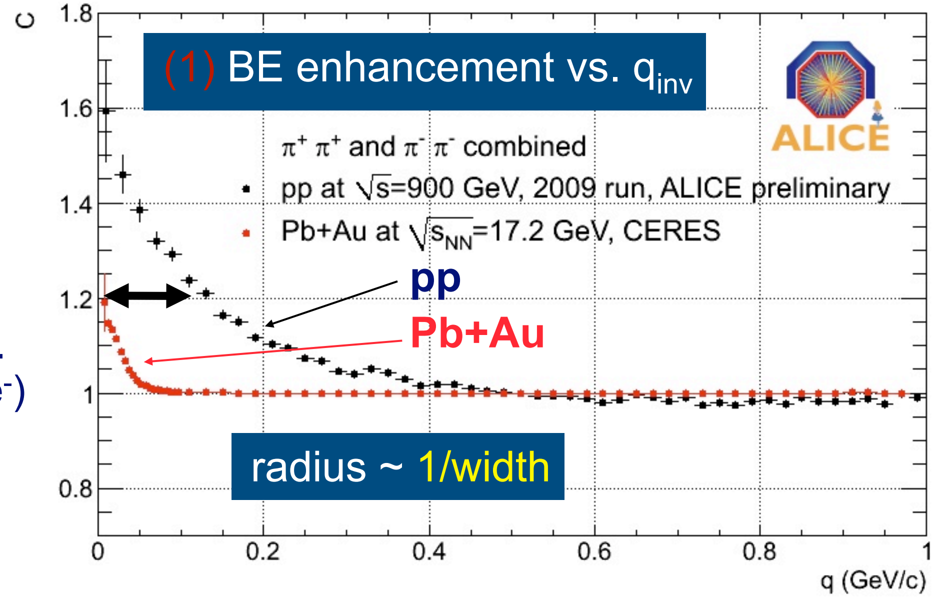
Bose-Einstein Correlations

QM enhancement of identical Bosons at small momentum difference;

- enhancement of e.g. like-sign pions at
  (1) low momentum difference $q_{inv}=|p_1-p_2|$,
  (2) vs. event multiplicity and
  (3) vs. $k_T = |p_{T1}+p_{T2}|/2$

➡ measure the space-time evolution of the dense matter formed in heavy-ion collisions.

➡ interpretation for “small systems” (p+p, e^++e^-) is less obvious...



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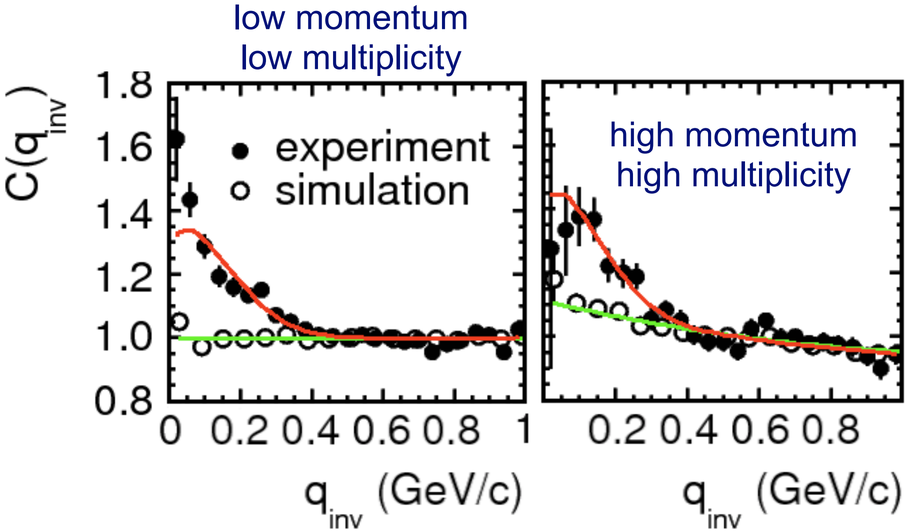
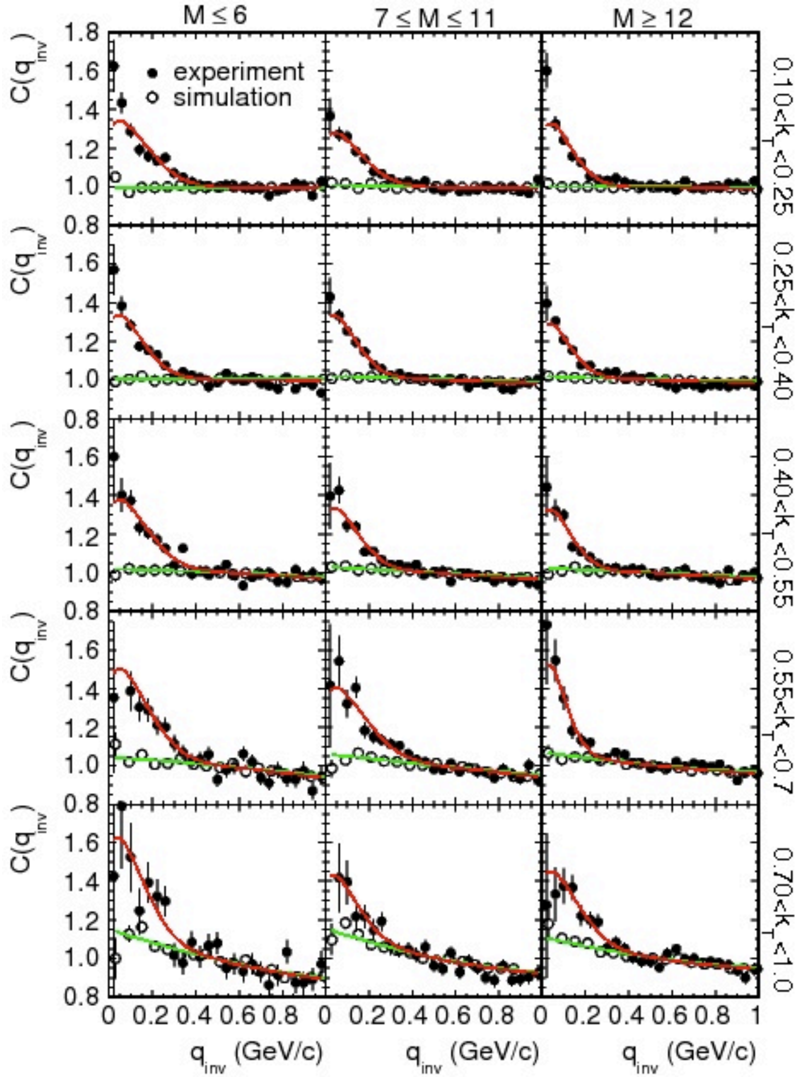
- enhancement rel. to phase-space and any non BE correlation ("baseline"):





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➡ measure the space-time evolution of the dense matter formed in heavy-ion collisions.

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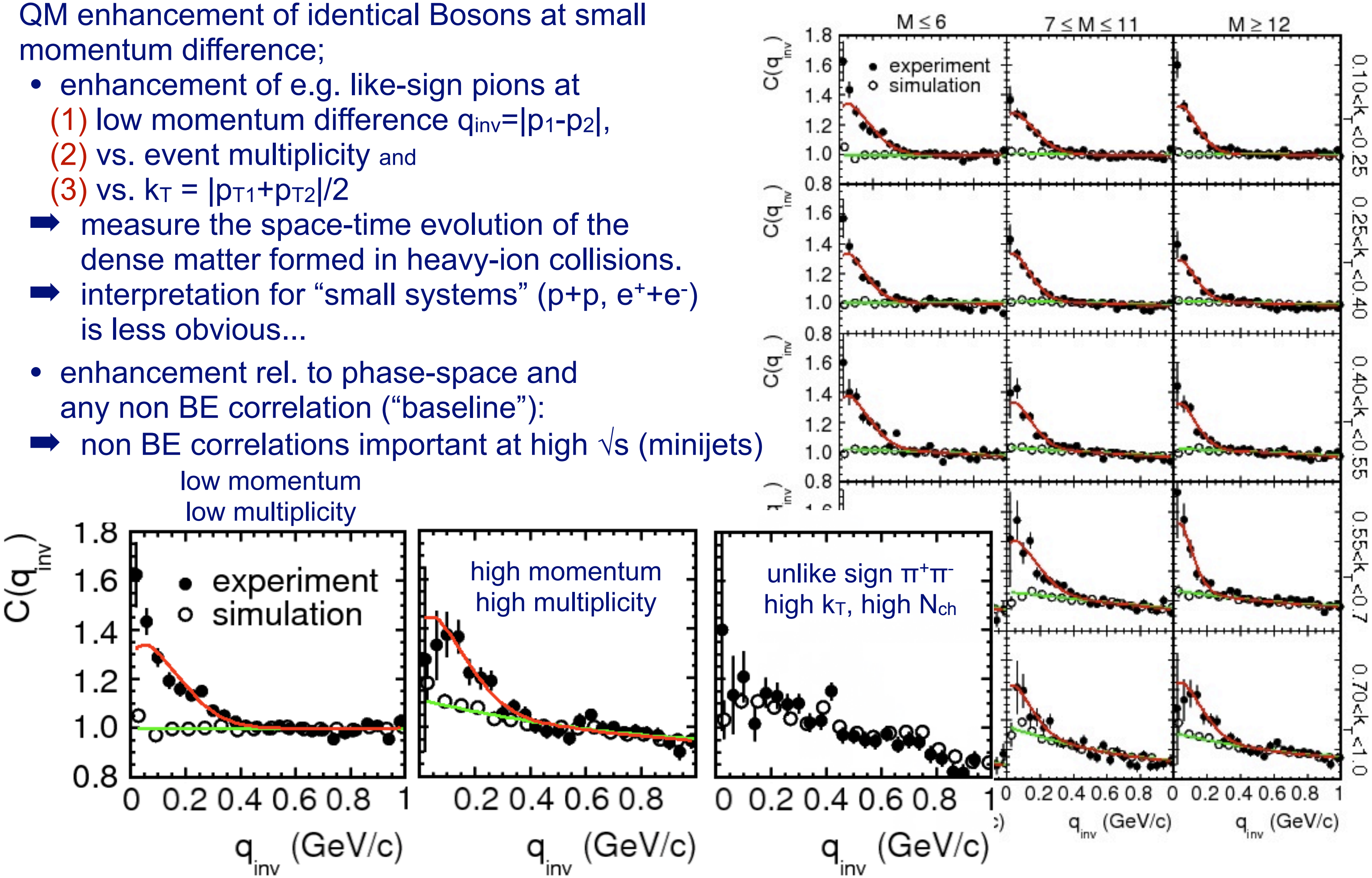
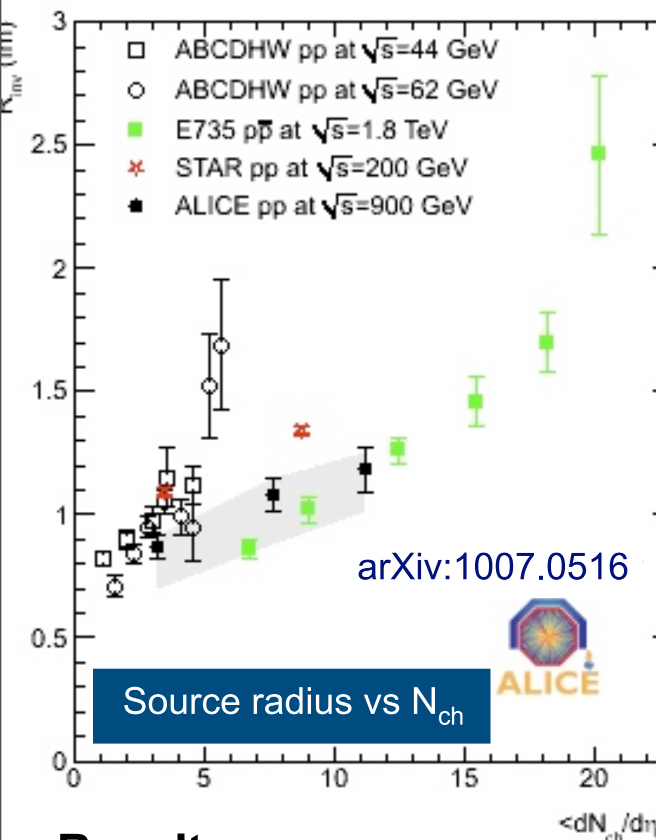
- enhancement rel. to phase-space and any non BE correlation ("baseline"):

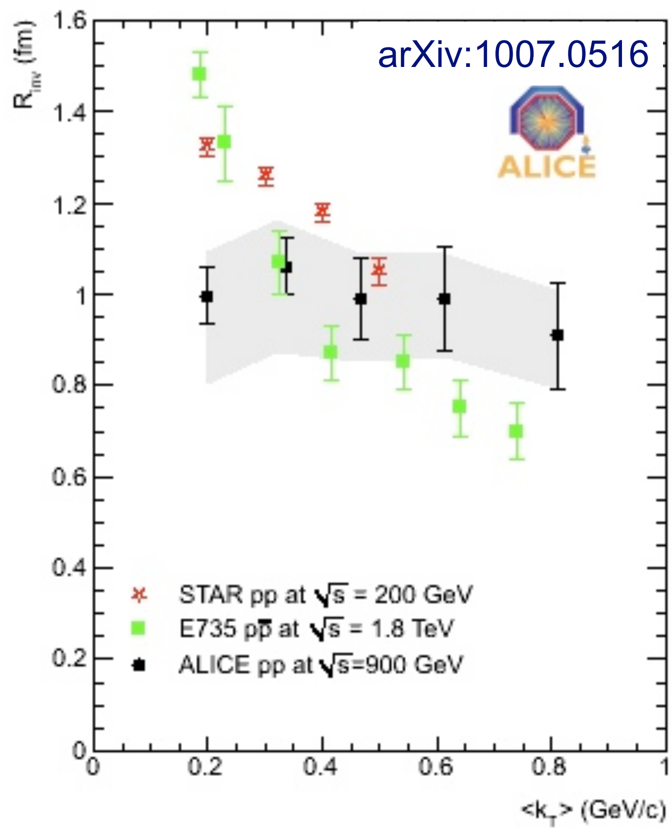
➡ non BE correlations important at high √s (minijets)

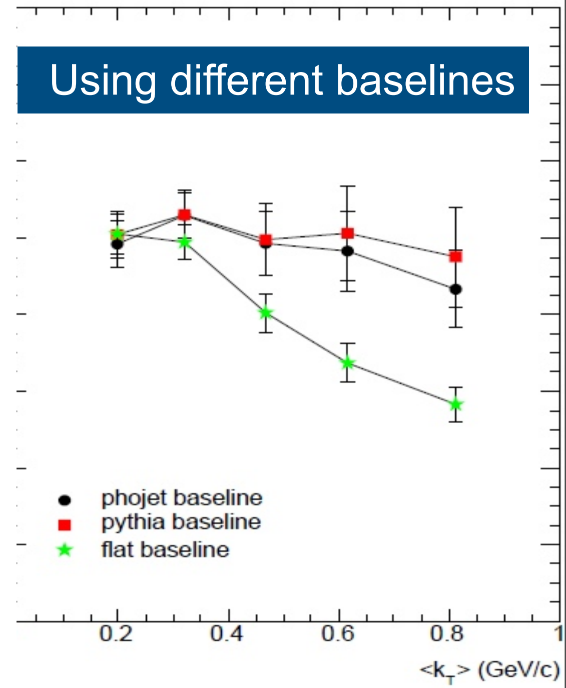


Bose-Einstein Correlations



Source radius vs pair momentum





Results:

- Radius increases with N_{ch}, comparable to ISR, RHIC, TeVatron
- ~ constant vs $<k_T>$! dependence usually interpreted as sign of ‘flow’ in HIC
- neglecting non-BE correlations (‘flat baseline’) can cause $k_T$dependence (at high $\sqrt{s}$) !