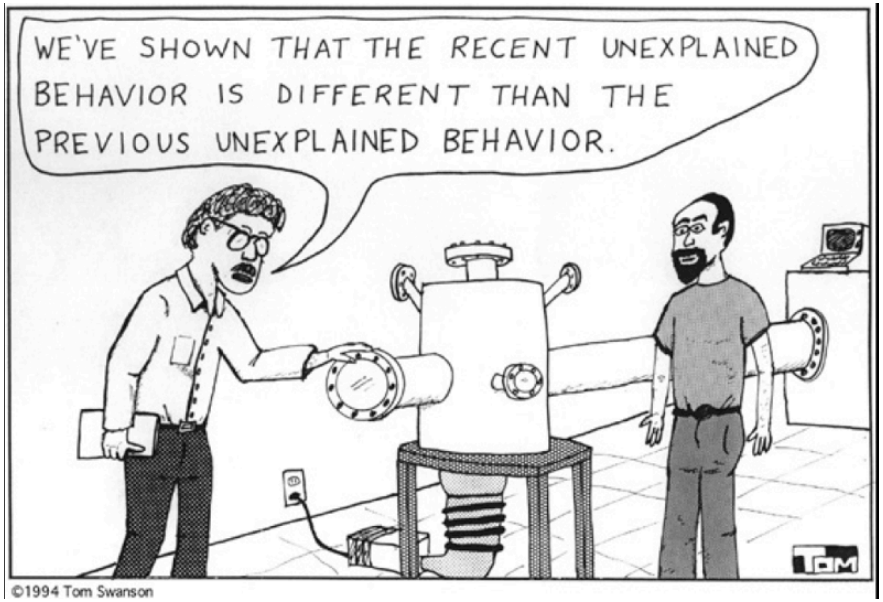
First Pb+Pb results from ALICE

Helen Caines - Yale University - on behalf of the ALICE Collaboration

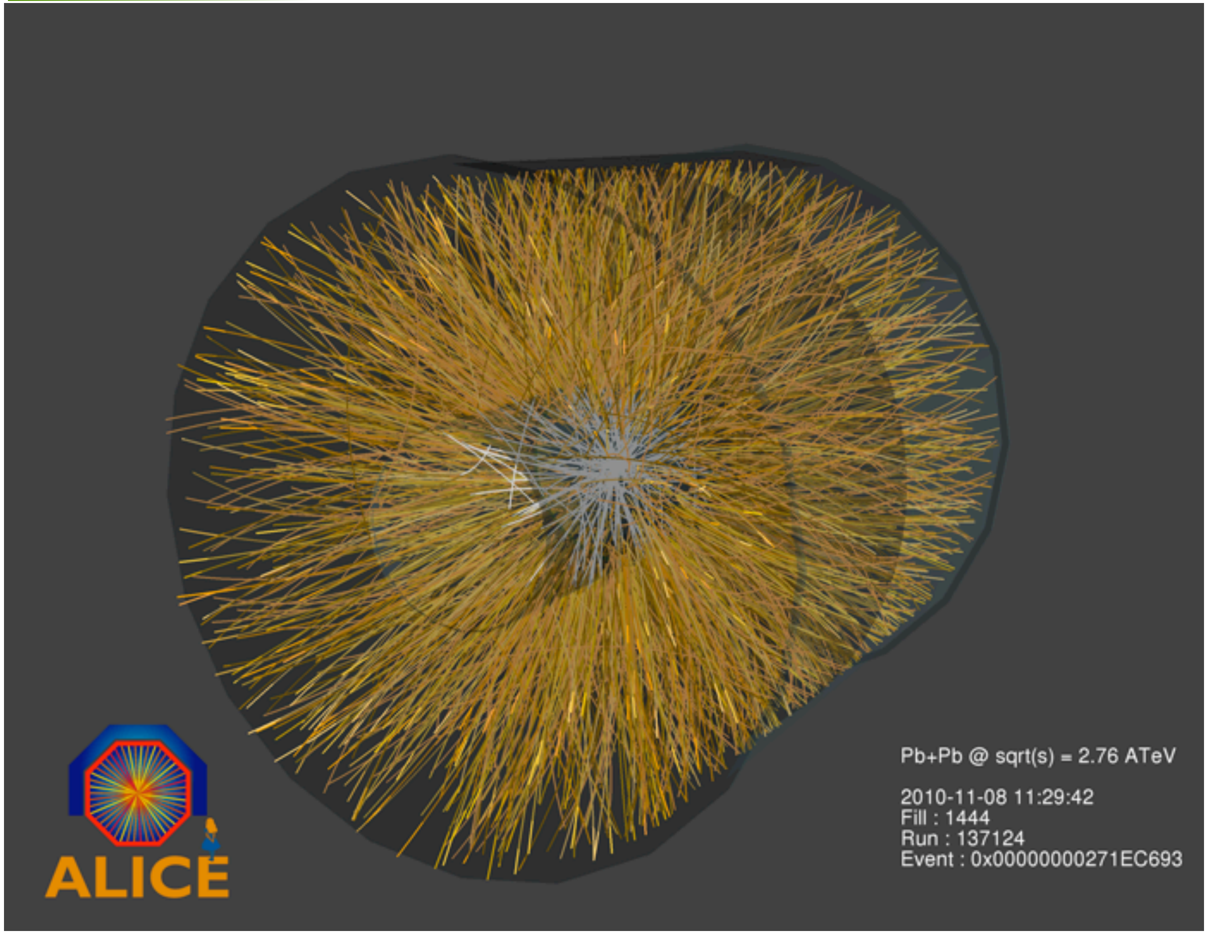


Focus on Heavy-Ion results

Energy density
Size and lifetime
Flow
Jet quenching
Heavy flavor
Extreme events

DIS - Newport News, VA
April 11-15 2011

Highest energy man-made collisions ever!



Setup started Nov 4
First collisions Nov 7
Stable beams Nov 8

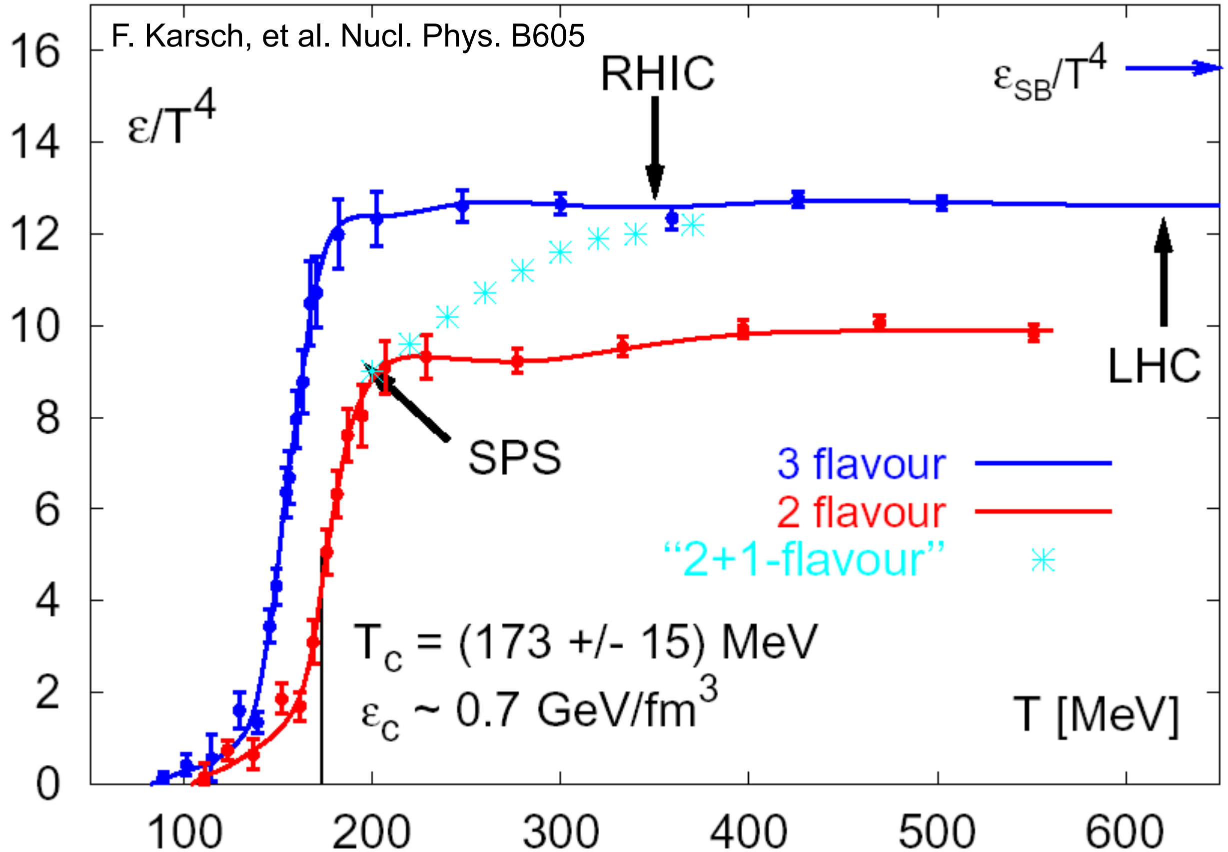
>8μb^{-1} in 4 weeks
$\mathscr{L}_{PbPb} > 2x10^{25}$
(~1/20 $\mathscr{L}_{maxPbPb}$)

Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV
Total energy
287 TeV/beam

p-p $\sqrt{s}$=0.9 TeV ~8x10^{6} MB (+ ~3x10^{5} MB 2009)
$\sqrt{s}$=2.36 TeV ~4x10^{4} MB
$\sqrt{s}$=7.0 TeV ~8x10^{8} MB, (~1x10^{8} muon, ~2x10^{7} high N_{ch}) Increasing daily
$\sqrt{s}$=2.76 TeV ~7x10^{7} MB, (~9x10^{6} muon, ~1x10^{6} high tower (18 nb^{-1} MB))

Expectations based on RHIC results

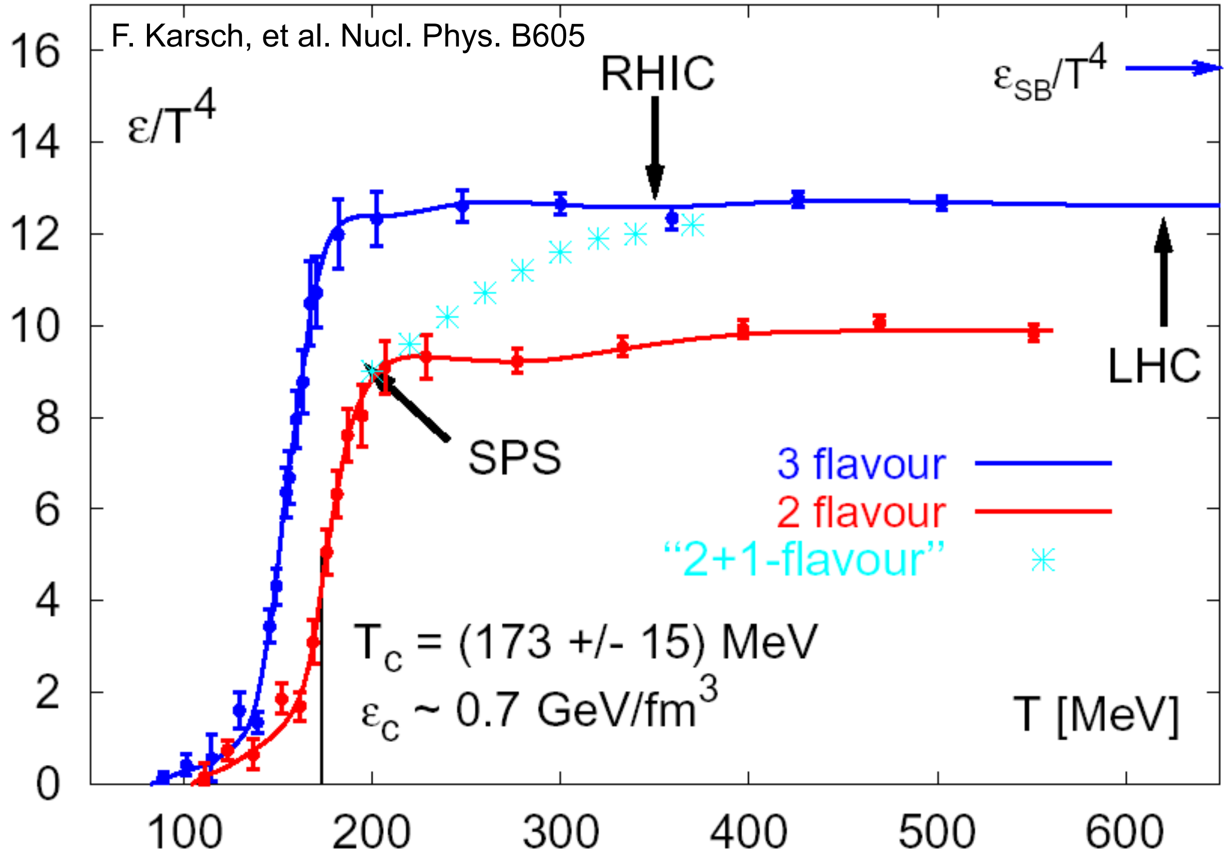
LHC plasma hotter, denser, longer lived



Open questions:

Expectations based on RHIC results

LHC plasma hotter, denser, longer lived



Open questions: same sQGP?

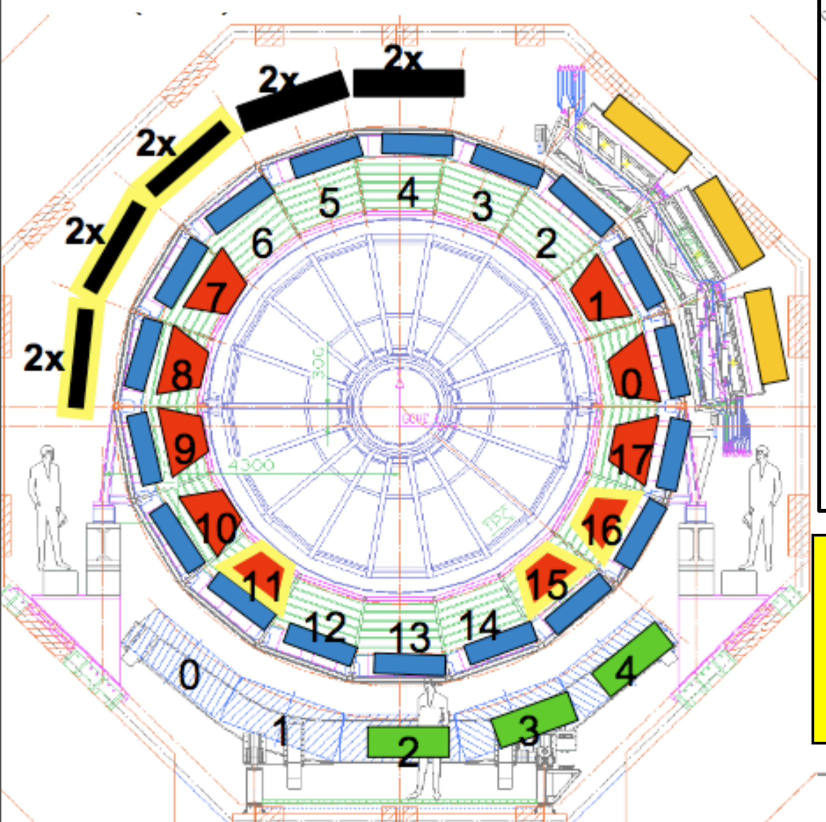
different evolution?

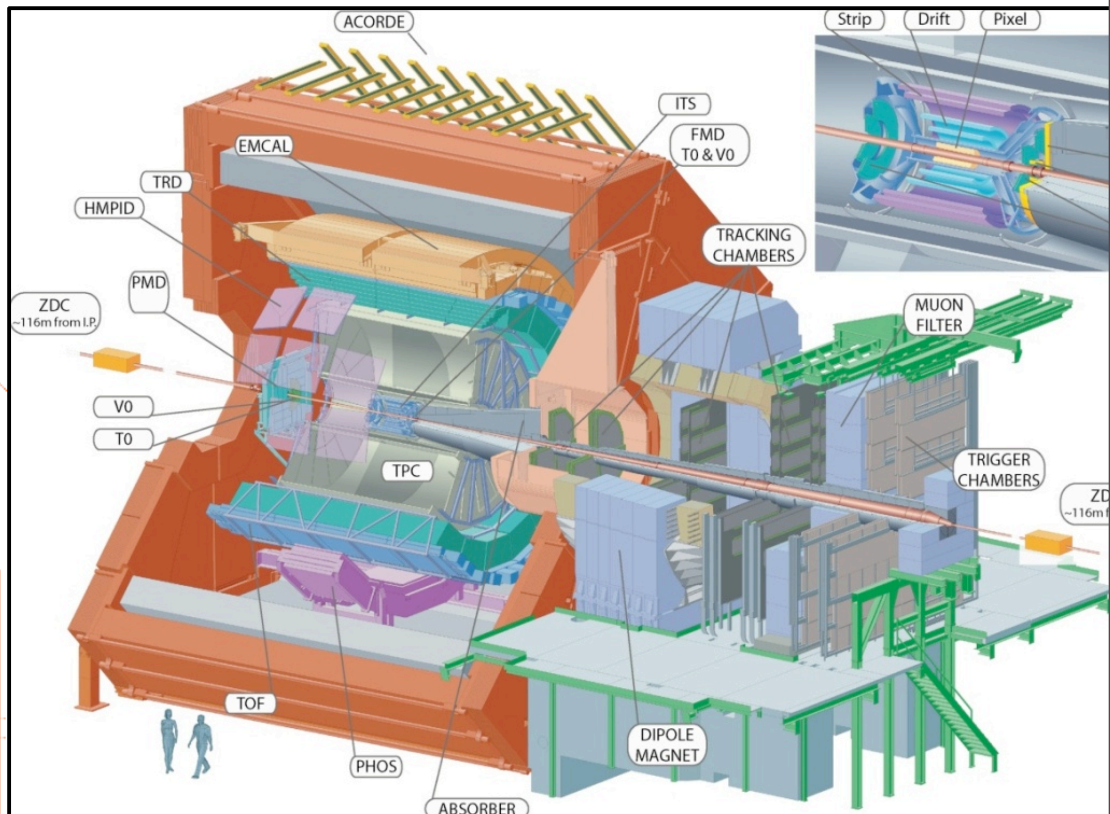
how do heavy quarks interact with the medium?

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 but in (partially) for 1st physics





ALICE is fully operational

Detector:

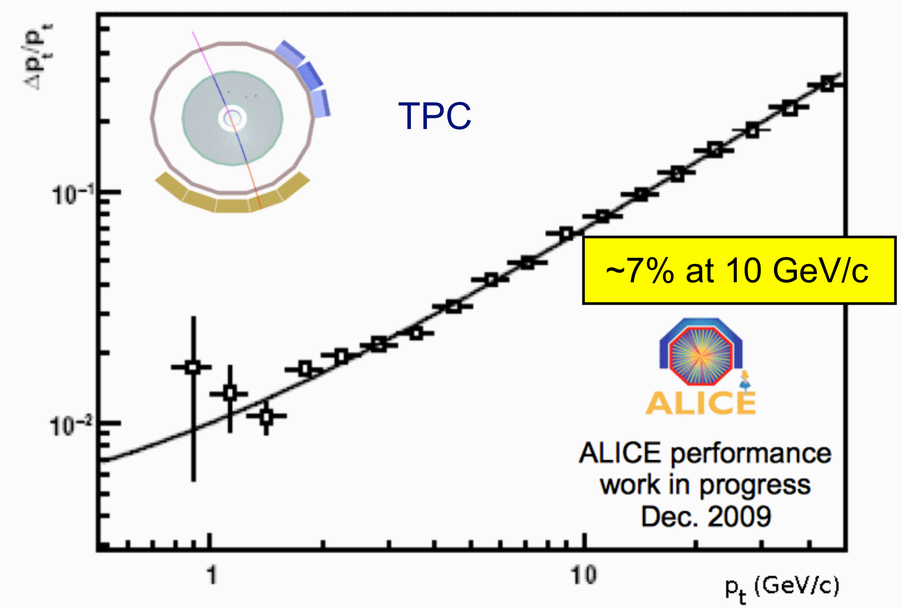
Size: **16 x 26** meters

Weight: **10,000** tons

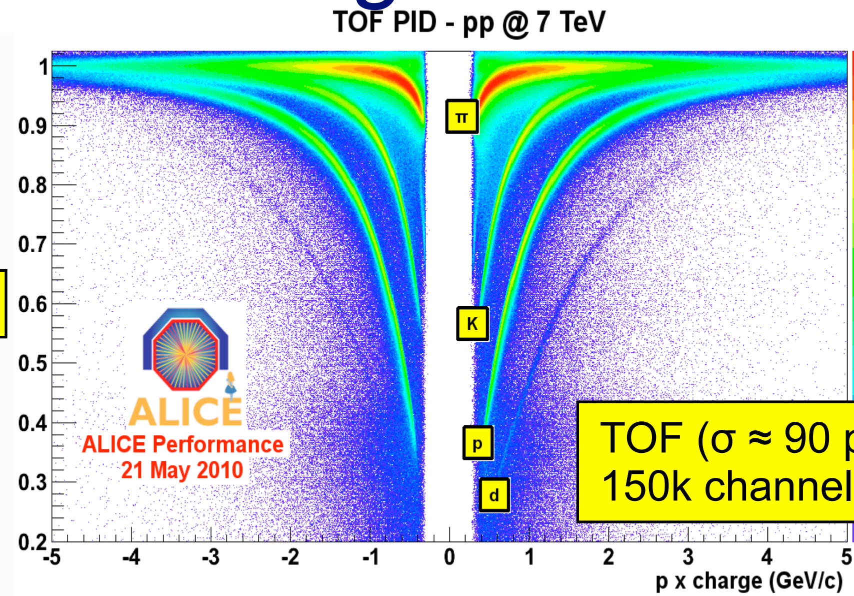
Collaboration:

> 1000 Members
> 100 Institutes
> 30 Countries

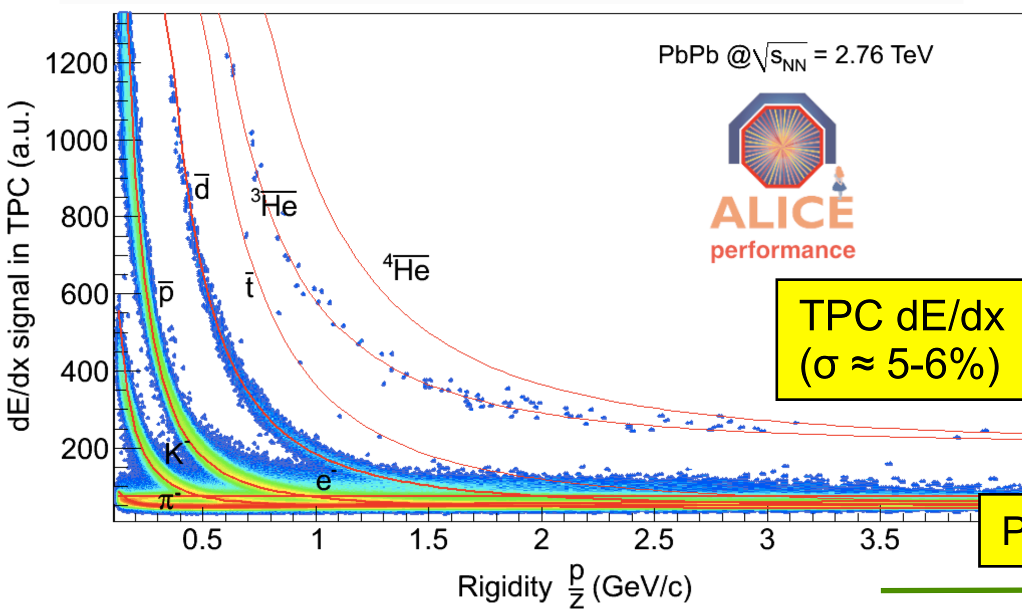
Detector performance: tracking and PID



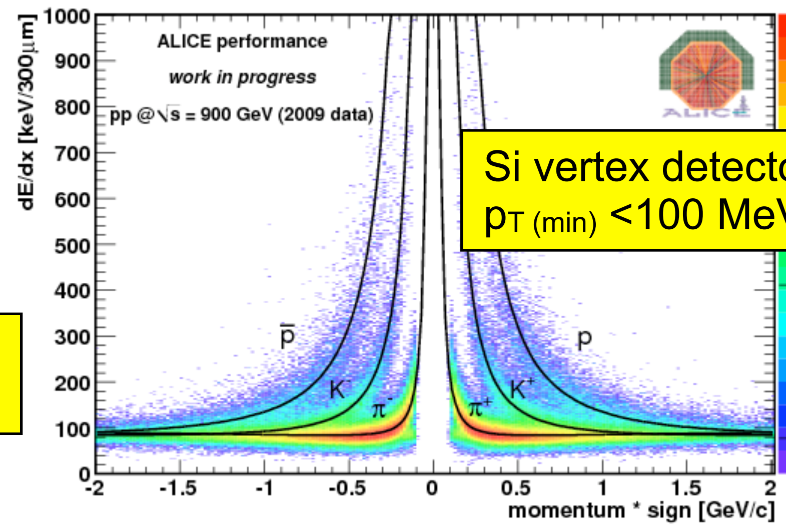
~7% at 10 GeV/c



TOF (σ ≈ 90 ps)
150k channels!



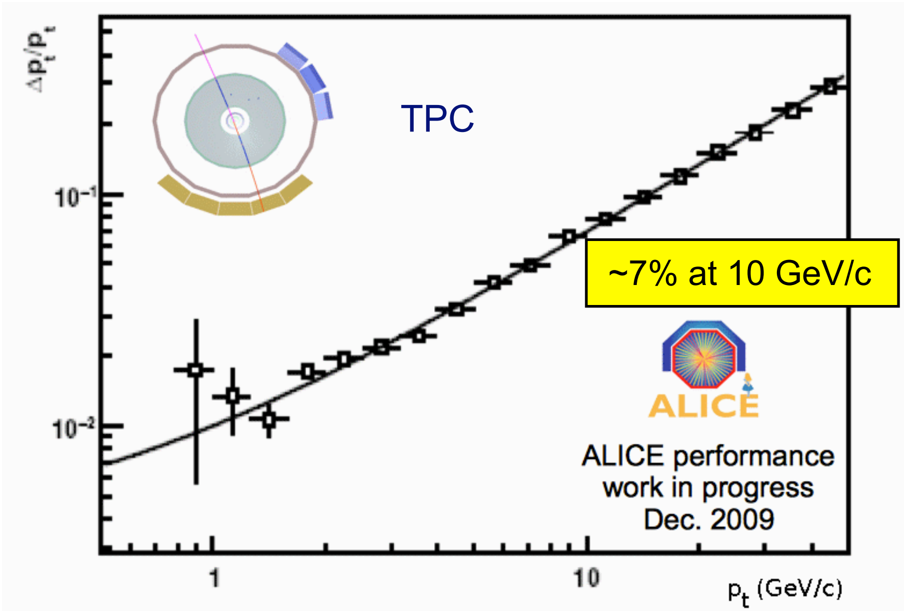
TPC dE/dx
(σ ≈ 5-6%)

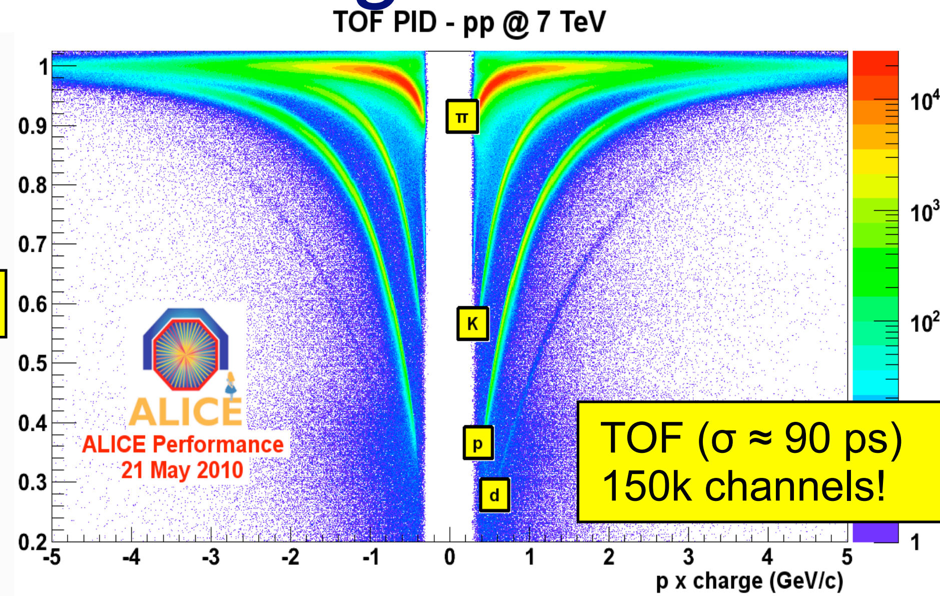


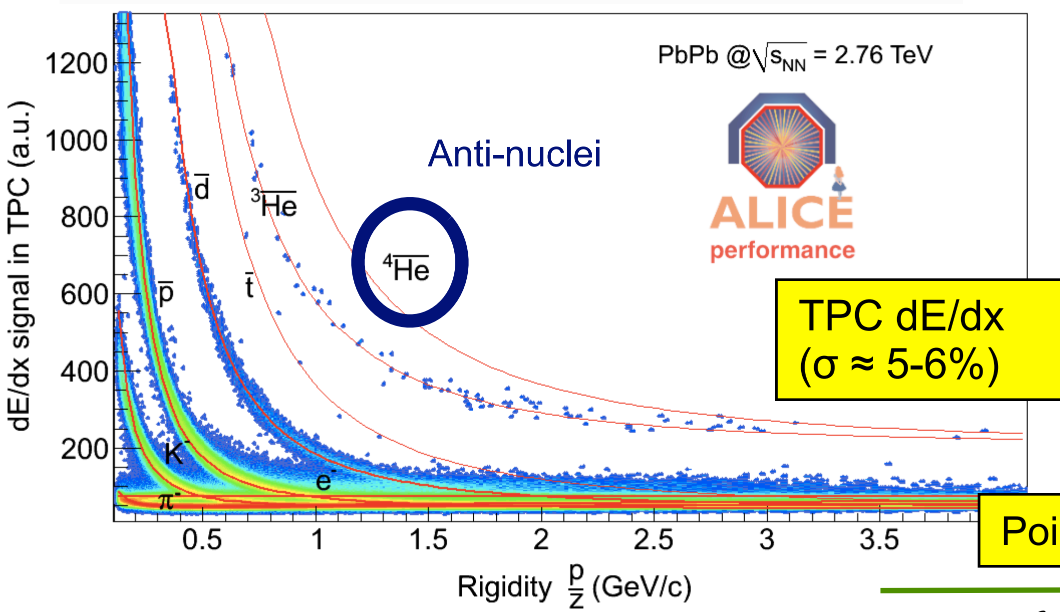
Si vertex detector
$p_{T\,(min)}$ <100 MeV/c

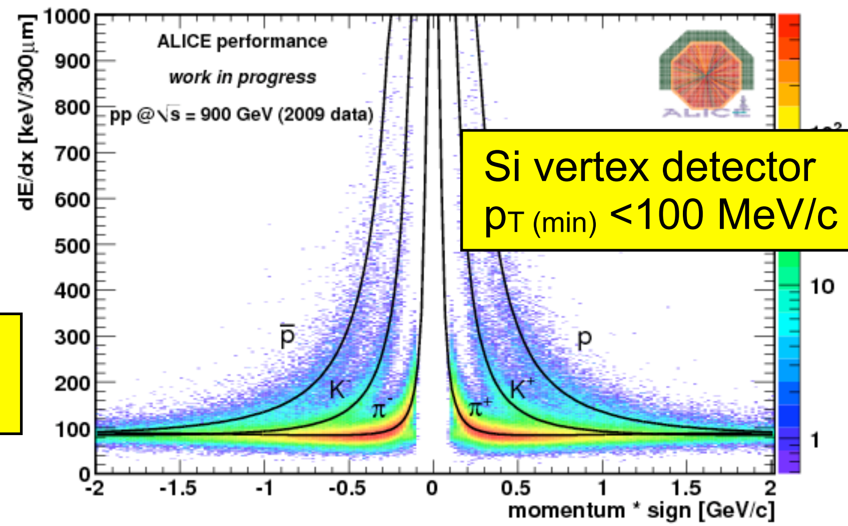
Pointing and vertex resolution also close to design

Detector performance: tracking and PID



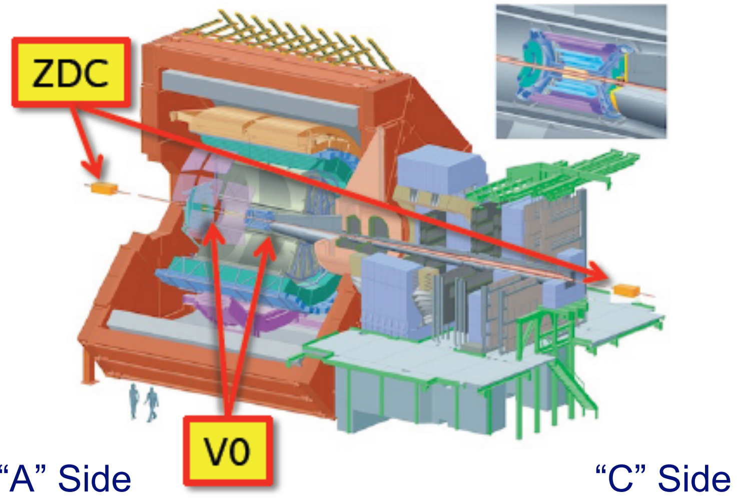






Pointing and vertex resolution also close to design

Centrality and Triggering

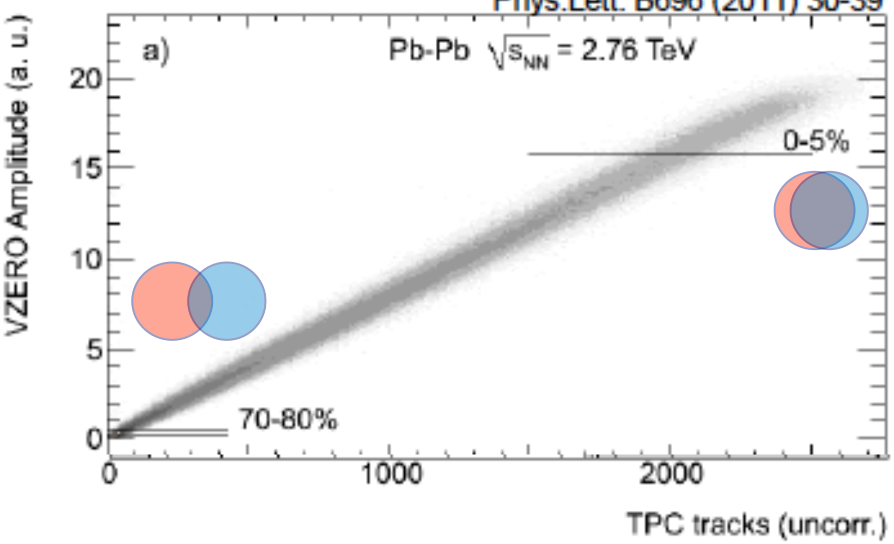


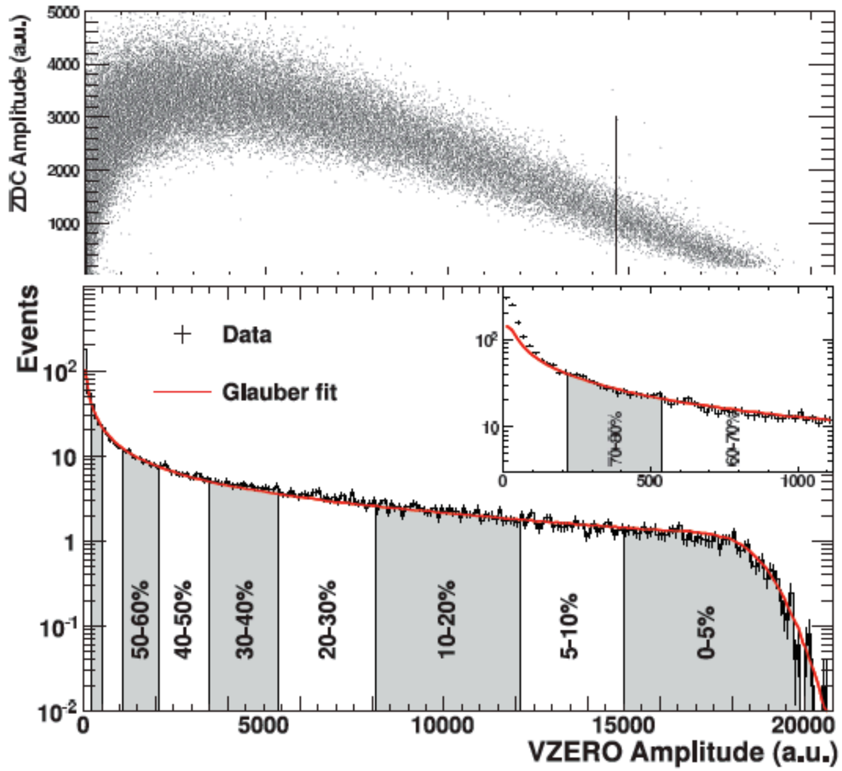
V0A 2.8 < η < 5.1
V0C -3.7< η < -1.7
ZDC |η| < 8.7

Pb-Pb MB Triggers:
2 out of 3 from
- V0A
- V0C
- SPD hits

N_{bin}, N_{part} from Glauber calculations

Phys.Lett. B696 (2011) 30-39

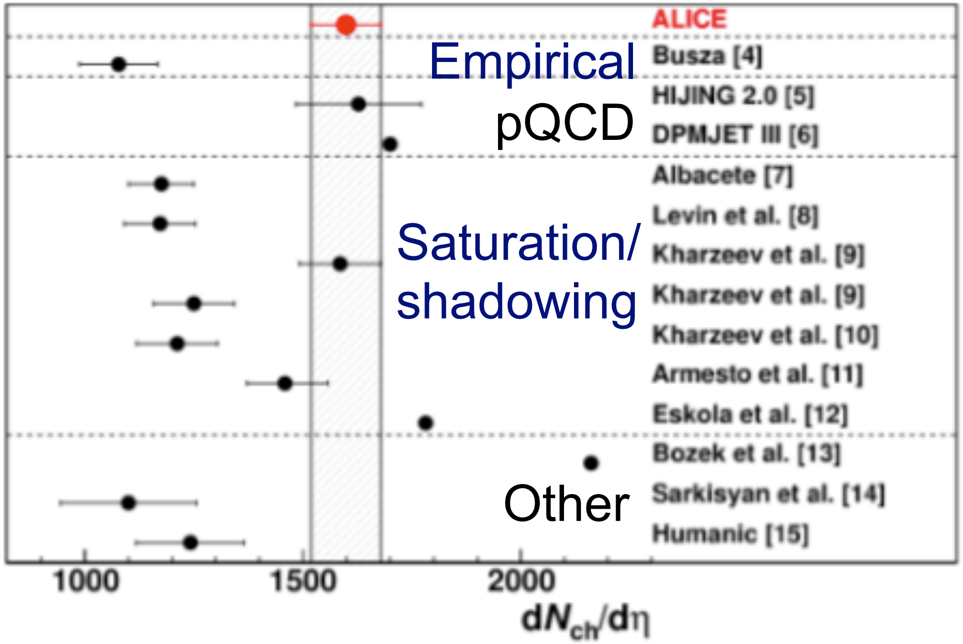




V0 signals and mid-rapidity multiplicity - strong correlation

Charged particle multiplicity

$dN_{ch}/d\eta$ = 1584±4(stat)±76 (sys) 5% most central Pb-Pb at 2.76 TeV



Result on high side of expectations

- opposite to RHIC

PRL 105, 252301 (2010)

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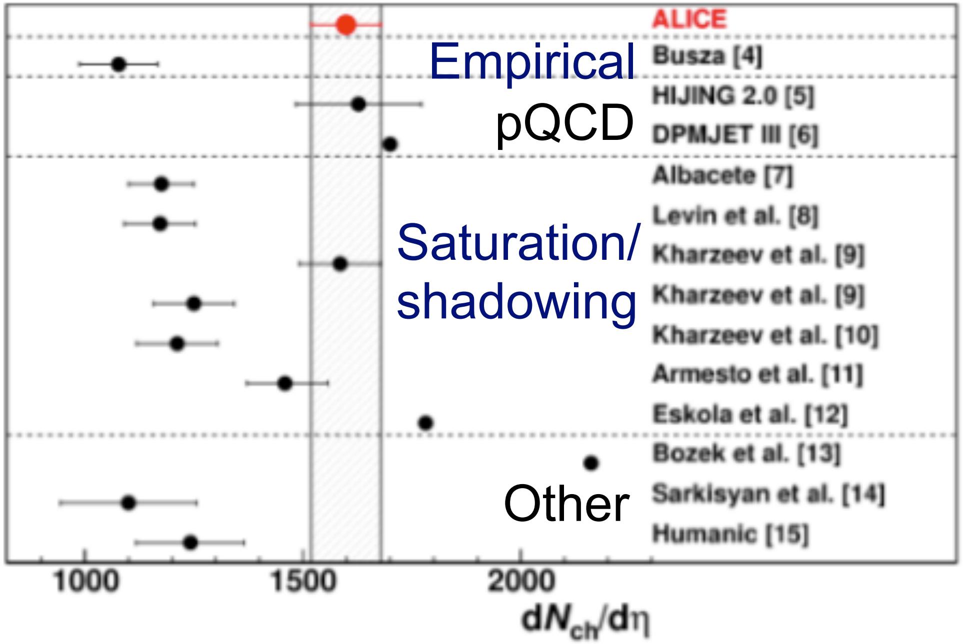

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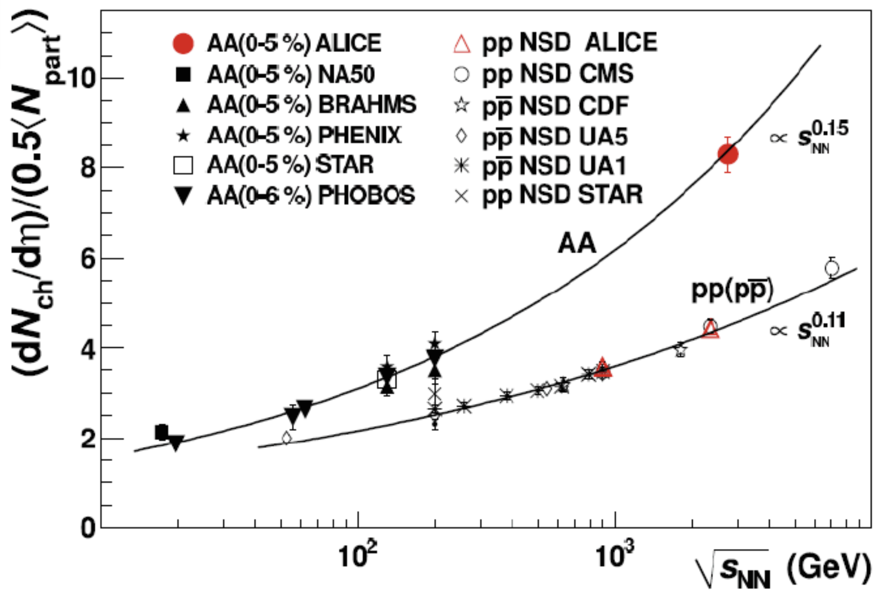


A-A = 1.9x p-p

nuclear amplification!

$$\varepsilon(\tau) = \frac{E}{V} = \frac{1}{A\tau_0}\frac{dN}{d\eta}|_{\eta=0}\langle m_T\rangle$$

$$\varepsilon(\tau)_{LHC} \geq 3 \times \varepsilon(\tau)_{RHIC}$$

Charged particle yields per participant pair

Soft processes:

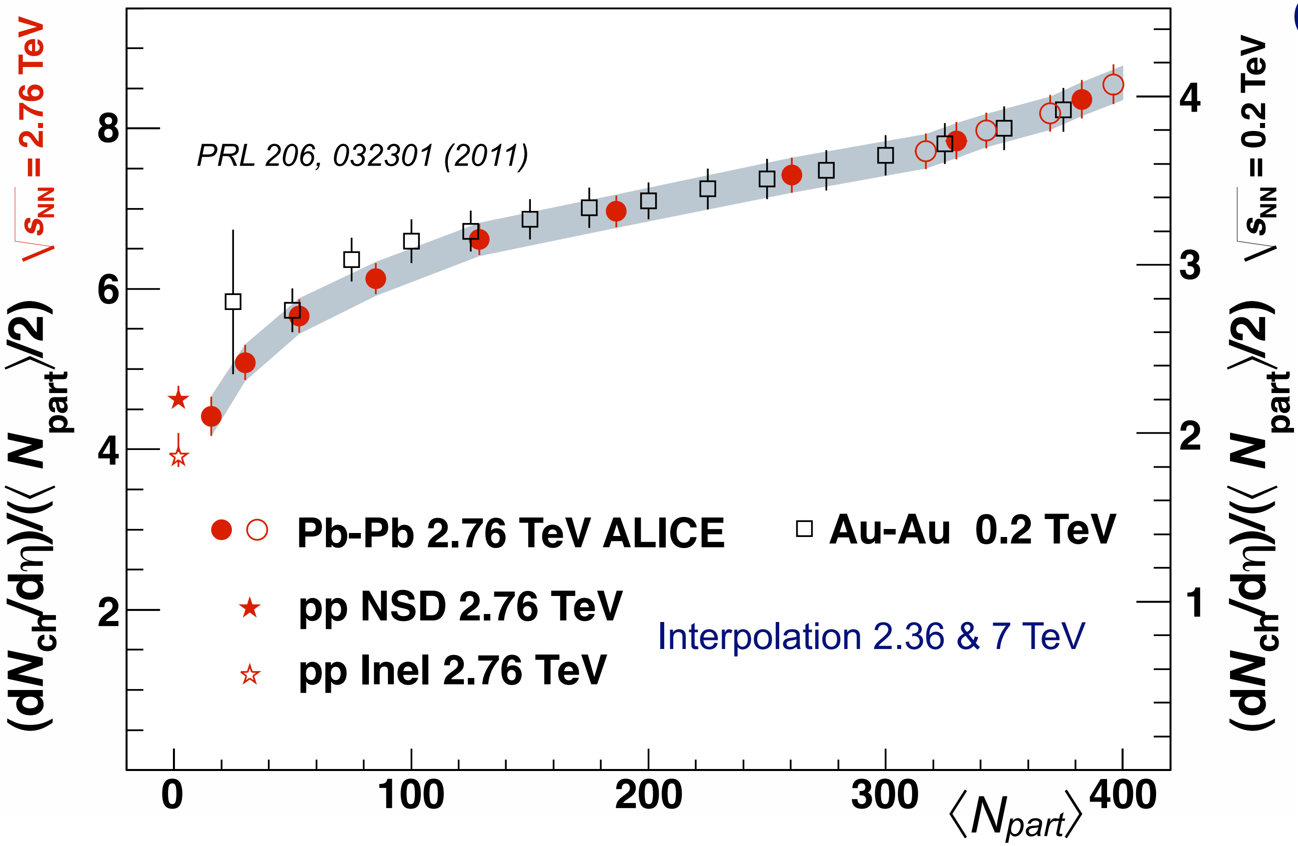
~ N_{part} ~ overlap volume

Independent of √s

Hard processes:

~ N_{bin} ~ N_{part}^n (n=0-1.17)

More important as √s increases



Centrality dependence:

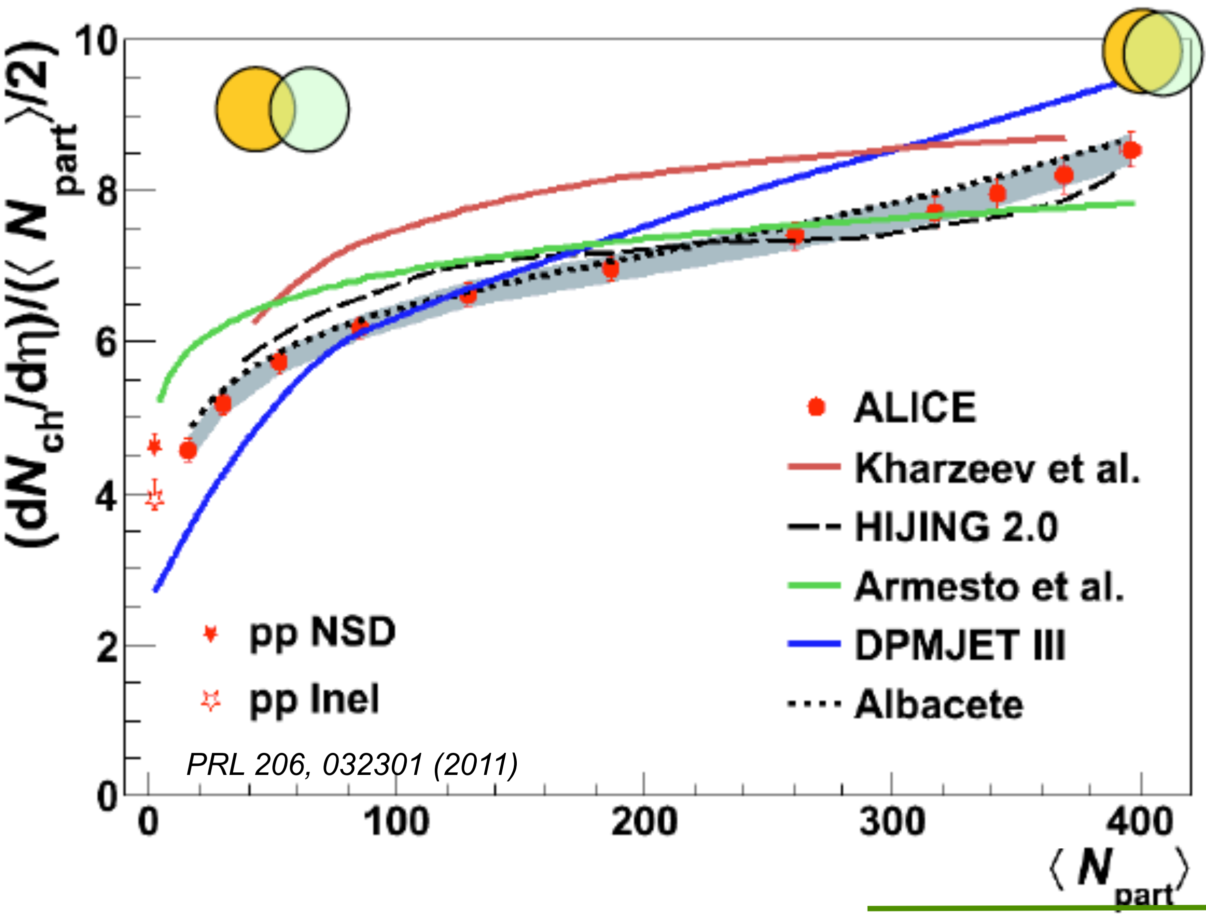
LHC ~ RHIC!

Nuclear amplification independent of √s

Geometry dominates bulk production

Test of shadowing/saturation models

Shadowing/saturation: reduces the number of soft gluons
number hard scattering centers effectively reduced
effect amplified in nuclei
limits rise in multiplicity



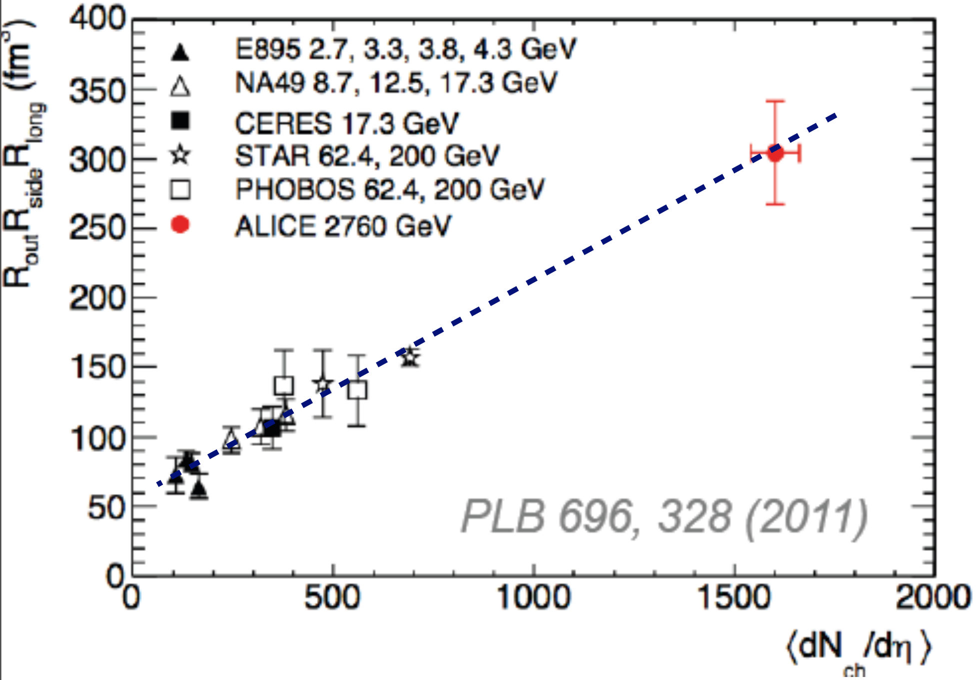
Centrality dependence very sensitive to:

initial conditions
saturation
system evolution

These two "simple" measures place strong constraints on models

Space-time evolution of the system

Two-pion Bose-Einstein correlations - data on source size and lifetime



$R_{out}R_{side}R_{long} = V$

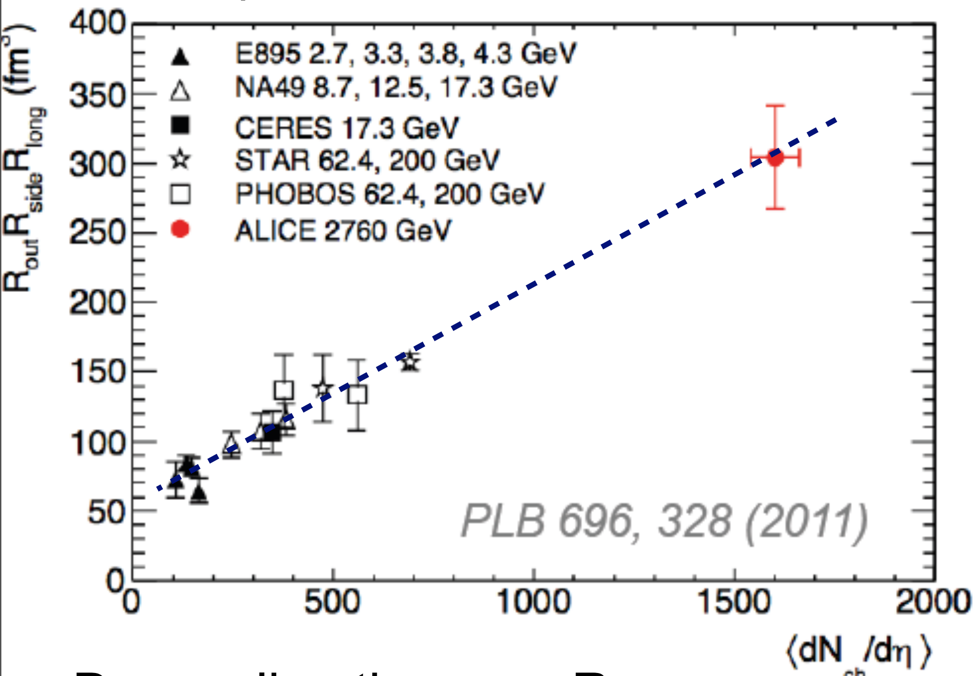
V scales ~ linearly with multiplicity

$V_{LHC}^{central} \sim 2x\ V_{RHIC}^{central}$

$\sim 300\ fm^3$

Space-time evolution of the system

Two-pion Bose-Einstein correlations - data on source size and lifetime



$R_{out}R_{side}R_{long} = V$

V scales ~ linearly with multiplicity

$V^{central}_{LHC} \sim 2x\ V^{central}_{RHIC}$

$\sim 300\ fm^3$

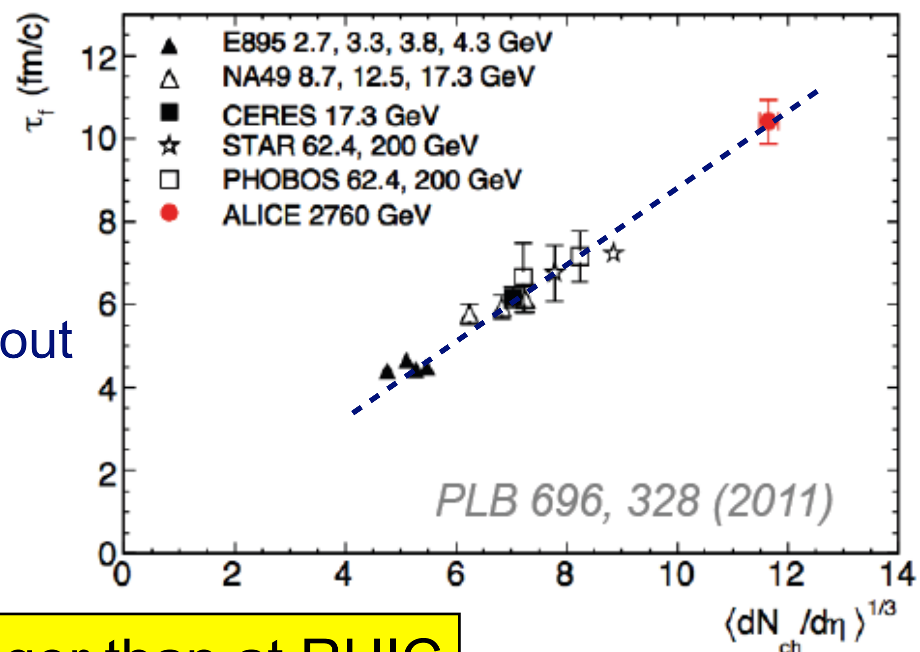
Decoupling time $\tau_f \propto R_{long}$

τ_f from bang to hadronic freeze-out

τ_f scales ~ linearly with multiplicity$^{1/3}$

$\tau^{central}_{fLHC} \sim 1.4x\ \tau^{central}_{fRHIC}$

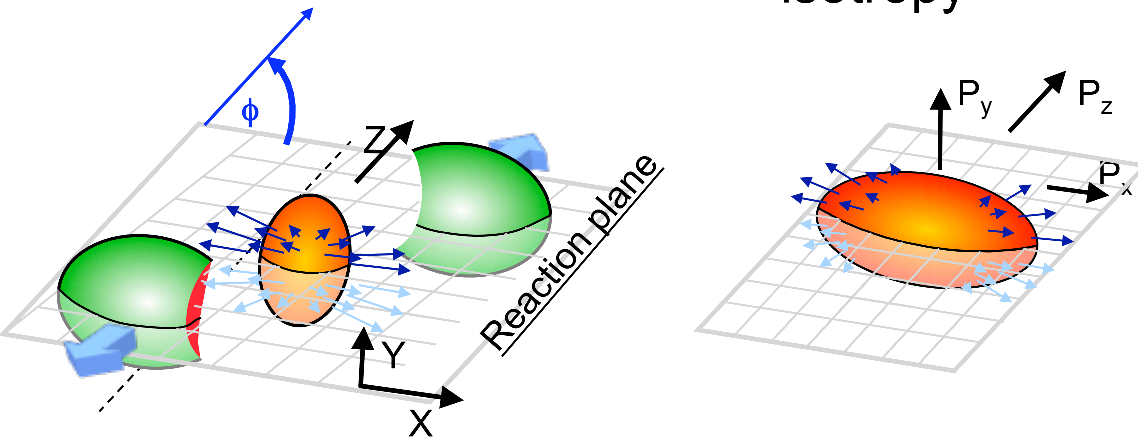
$\sim 10\text{-}11$ fm

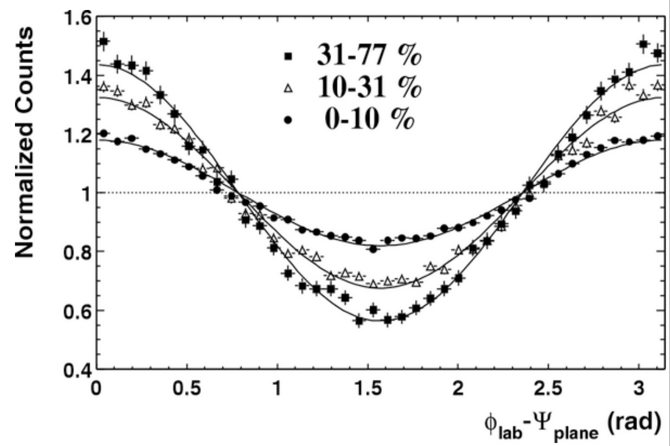


Source at LHC is larger and lives longer than at RHIC

Elliptic flow expectations

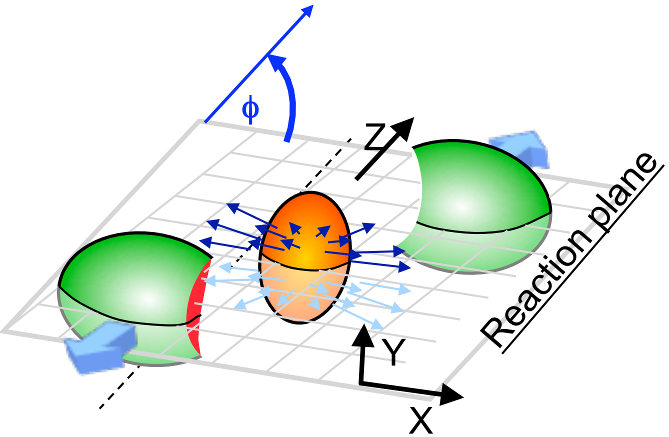
Initial state spatial an isotropy → Final state momentum isotropy → cos(2ΔΦ) modulation in particle distributions

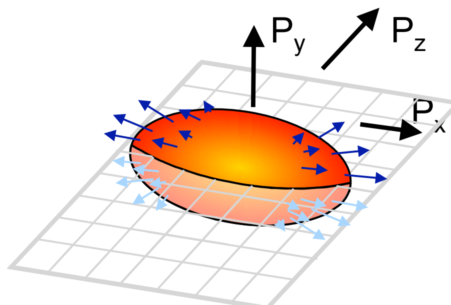


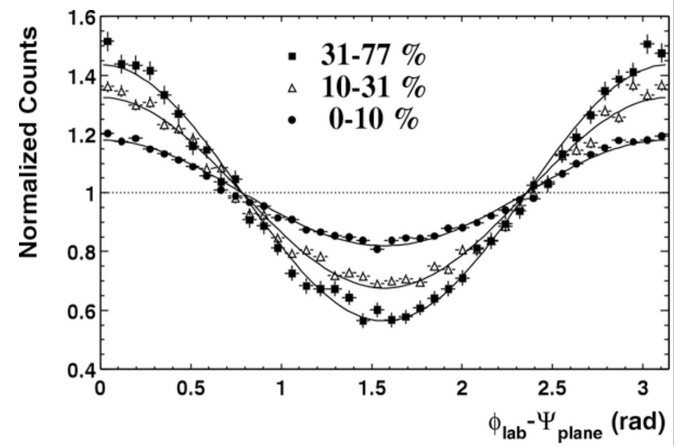


Elliptic flow expectations

Initial state spatial an isotropy → Final state momentum isotropy → $\cos(2\Delta\Phi)$ modulation in particle distributions







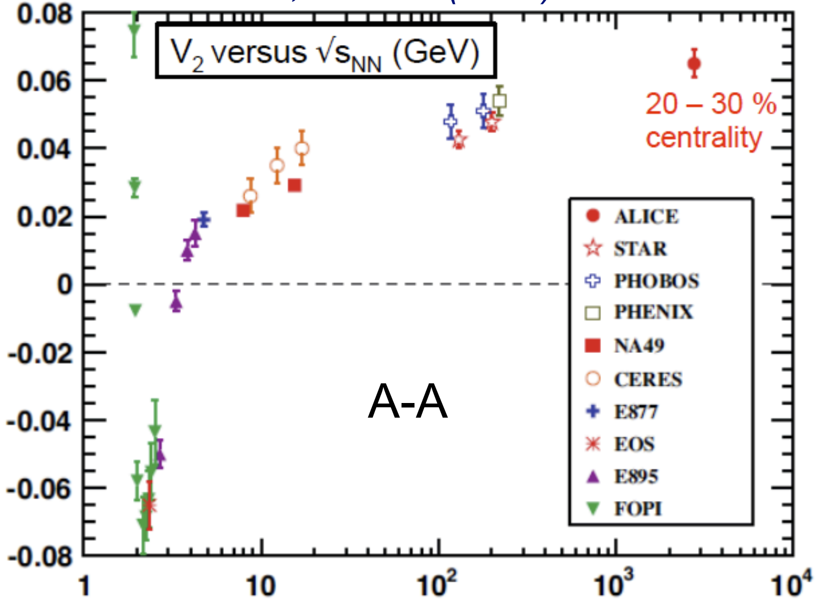
At RHIC: Ideal hydrodynamical models including QGP phase describe elliptic and radial flow

QGP→ perfect fluid

At LHC: Ideal hydrodynamics ~10% increase in elliptic flow consequence of higher $\langle p_T \rangle$

Elliptic flow - unidentified particles

PRL 105, 252301 (2010)



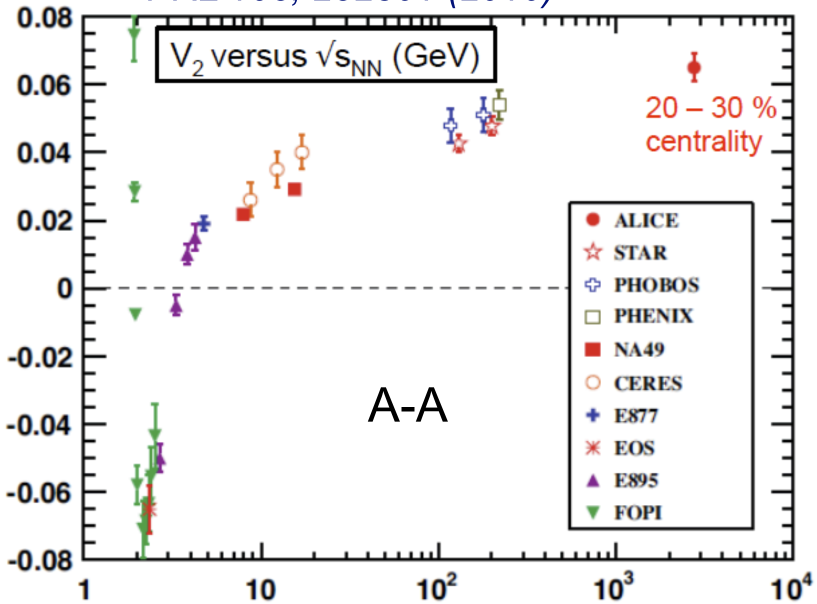
v_2 (p_T int.)LHC ~1.3x (p_T int.)RHIC

Viscous hydro. with smaller corrections at LHC predicts such large increase

G.Kestin & U. Heinz, Eur.Phys. J. C 61, 545 (2009)

Elliptic flow - unidentified particles

PRL 105, 252301 (2010)



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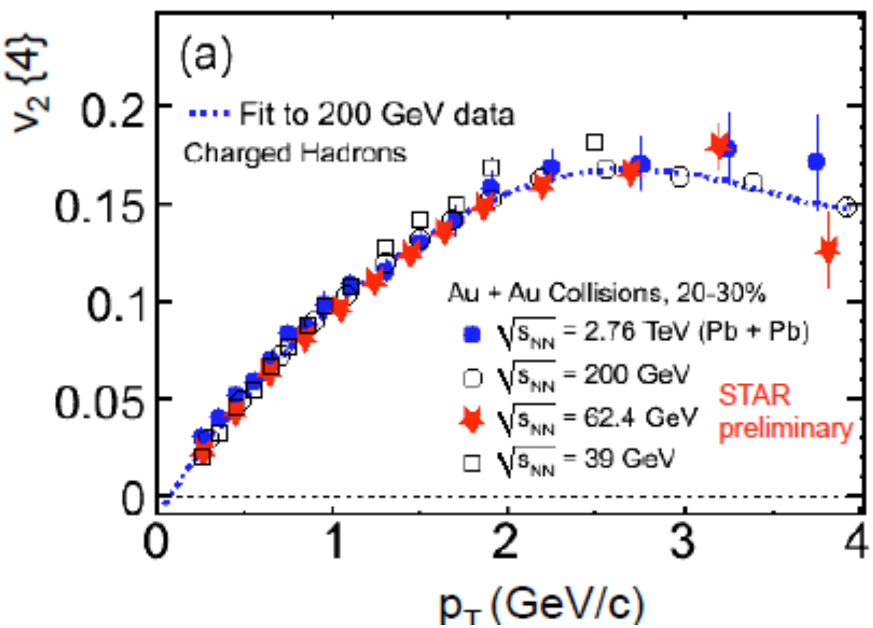
Viscous hydro. with smaller corrections at LHC predicts such large increase

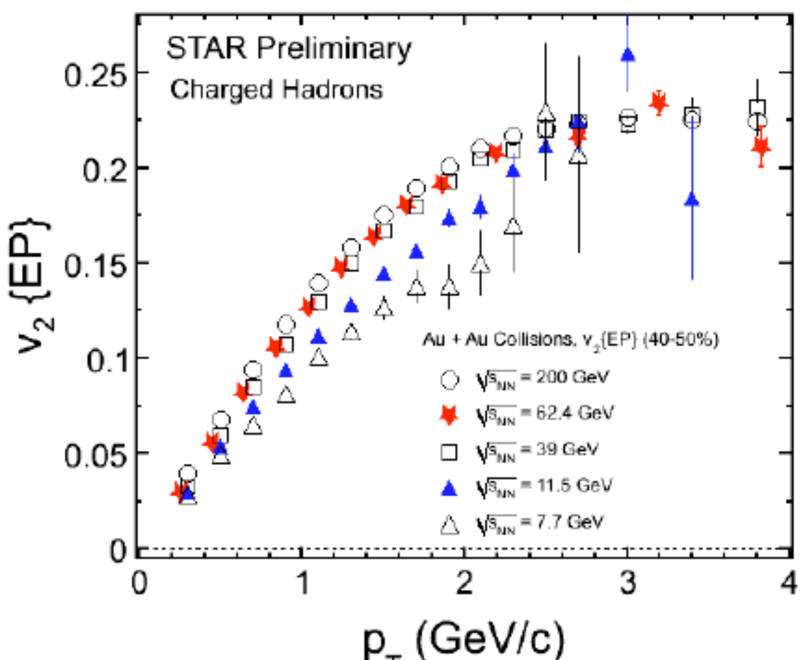
G.Kestin & U. Heinz, Eur.Phys. J. C 61, 545 (2009)

At a fixed p_T:

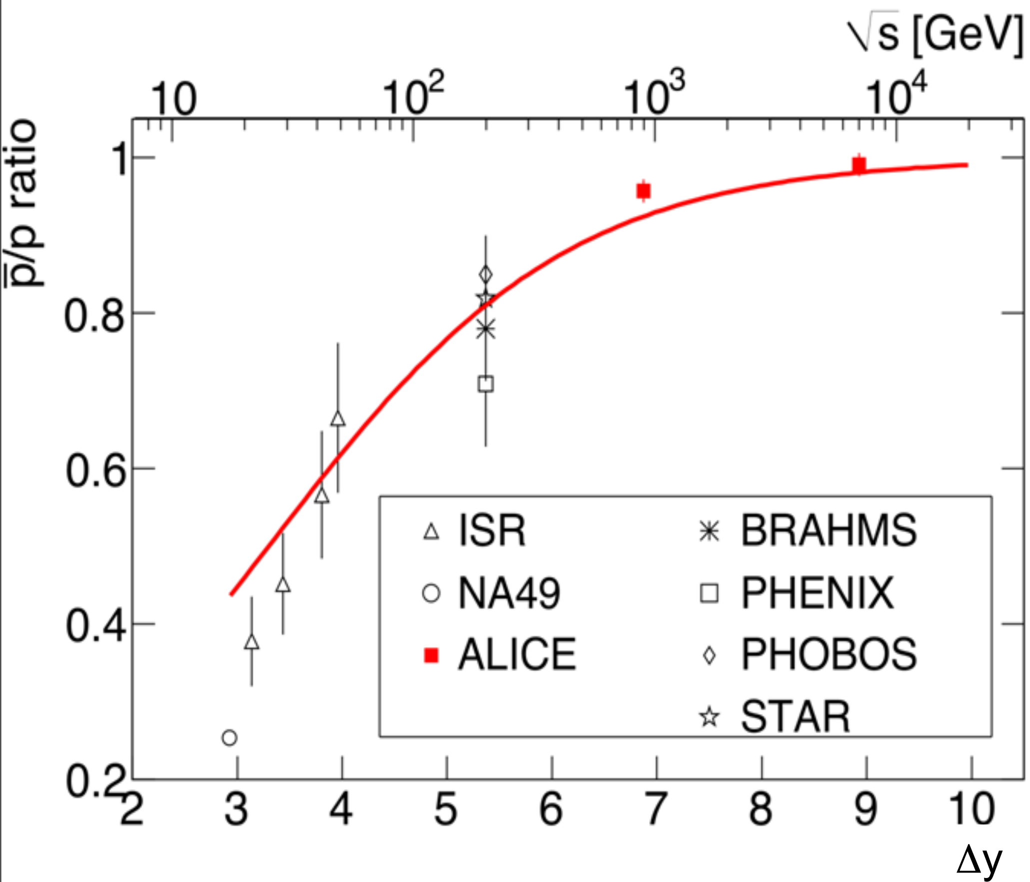
$v_2(2700) \sim v_2(200) \sim v_2(62) \sim v_2(39) > v_2(11) > v_2(7)$

Next step: species/mass dependence





Anti-baryon/baryon ratio at mid-rapidity



PRL 105, 072002 (2010)

ALICE: p-p collisions

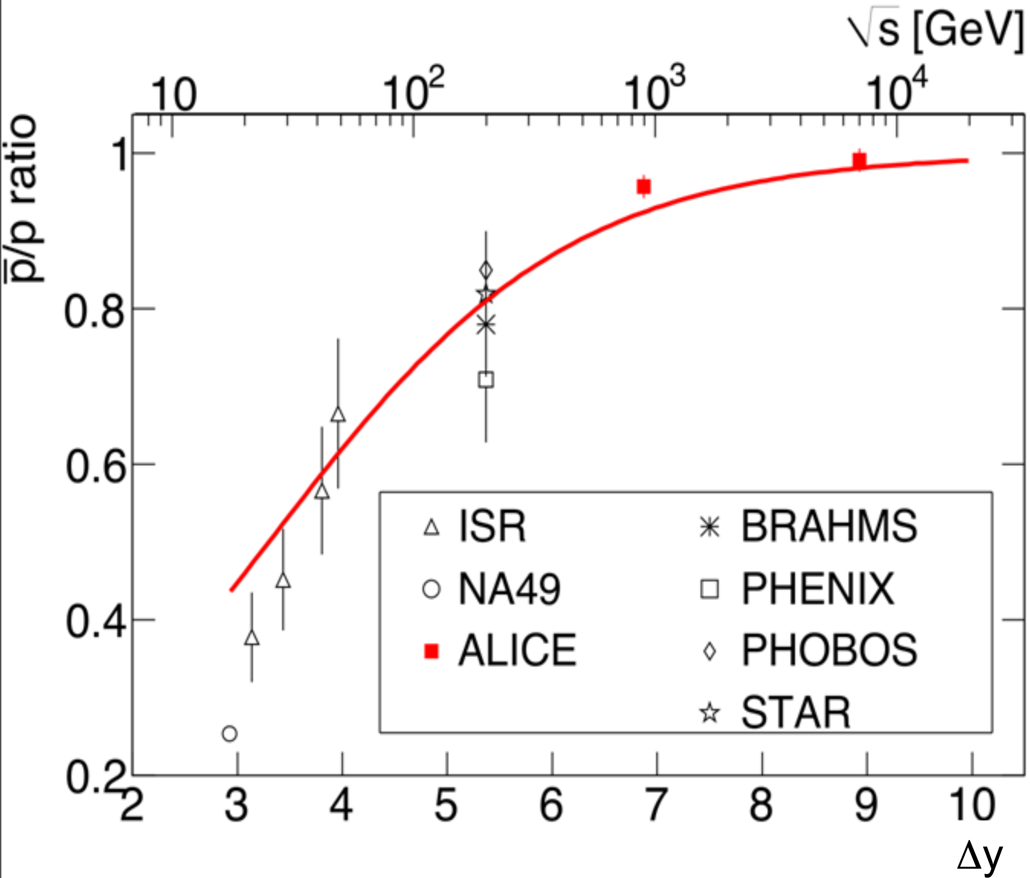
Ratio independent of p_T

√s < 1 TeV:
Ratio < 1 → Finite baryon transfer from beam to mid-rapidity

√s < 7.0 TeV:
Ratio consistent with unity

Results leave little room for any diagrams transporting baryon number to mid-rapidity

Anti-baryon/baryon ratio at mid-rapidity



PRL 105, 072002 (2010)

ALICE: p-p collisions

Ratio independent of p_T

√s < 1 TeV:
Ratio < 1 → Finite baryon transfer from beam to mid-rapidity

√s < 7.0 TeV:
Ratio consistent with unity

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)

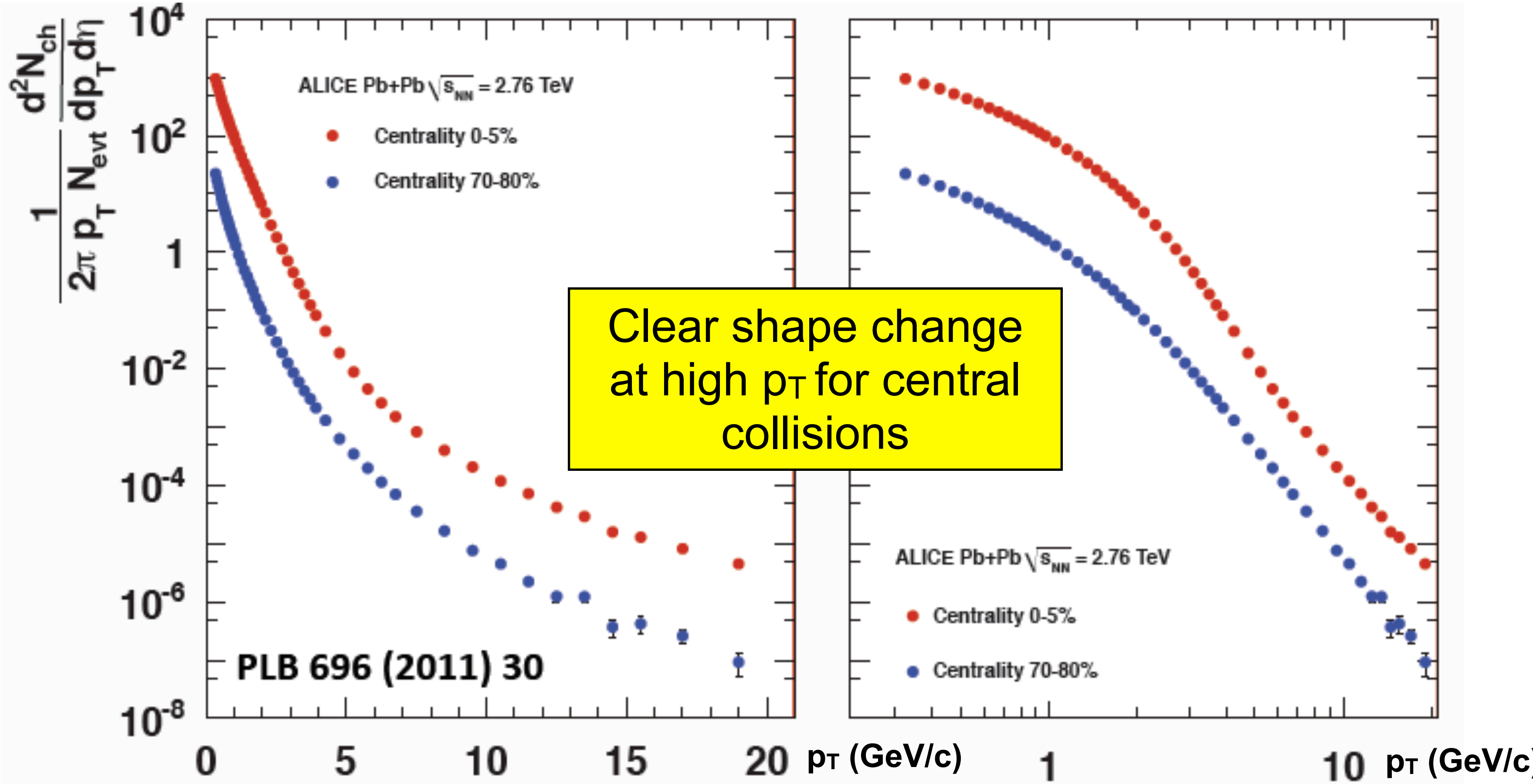
Results leave little room for any diagrams transporting baryon number to mid-rapidity

Global observables summary

Vector mesons, UPC, p+p and low-x physics - Laure Massacrier and Joakim Nystrand

- Energy density > 15 GeV/fm^3 → x3 RHIC
- Freeze-out volume ~300 fm^3 → x2 RHIC
- Time scale until decoupling 10-11 fm/c → x1.3 RHIC
- Essentially no baryon transfer to mid-rapidity at $\sqrt{s}$ =7 TeV
- Elliptic flow as expected from hydro-dynamical calculations → Need $\sqrt{s}$ dependent viscous corrections
- Initial state saturation effects smaller than expected
- PID global/bulk observable studies underway
  - T_{ch}, ,μ_b, T_{fo}, η/s etc etc coming soon

Hard process - high p_T



Clearer picture via
Nuclear Modification Factor:

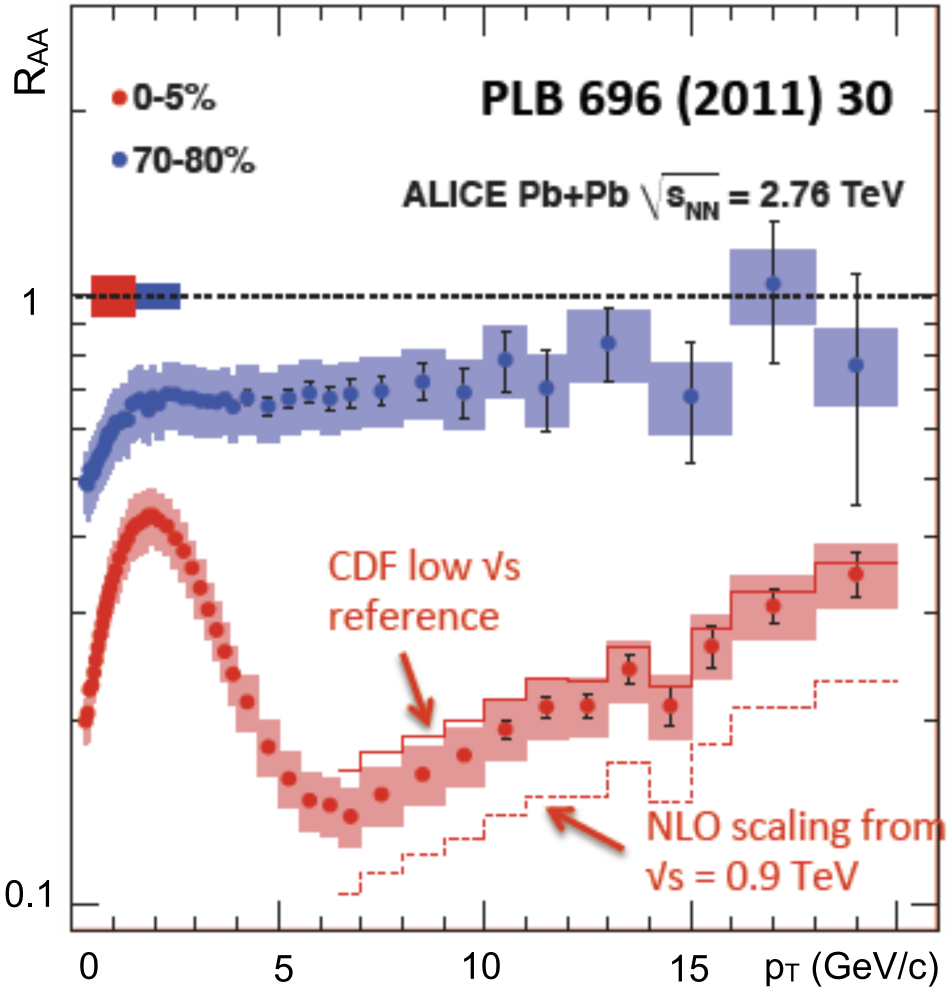
$$R_{AA}(p_T) = \frac{Yield(A-A)(p_T)}{Yield(p-p)(p_T) \times N_{bin}}$$

p-p reference:

Interpolation of 0.9 and 7 TeV data

7 TeV data scaled by NLO QCD calc.

High p_T suppression

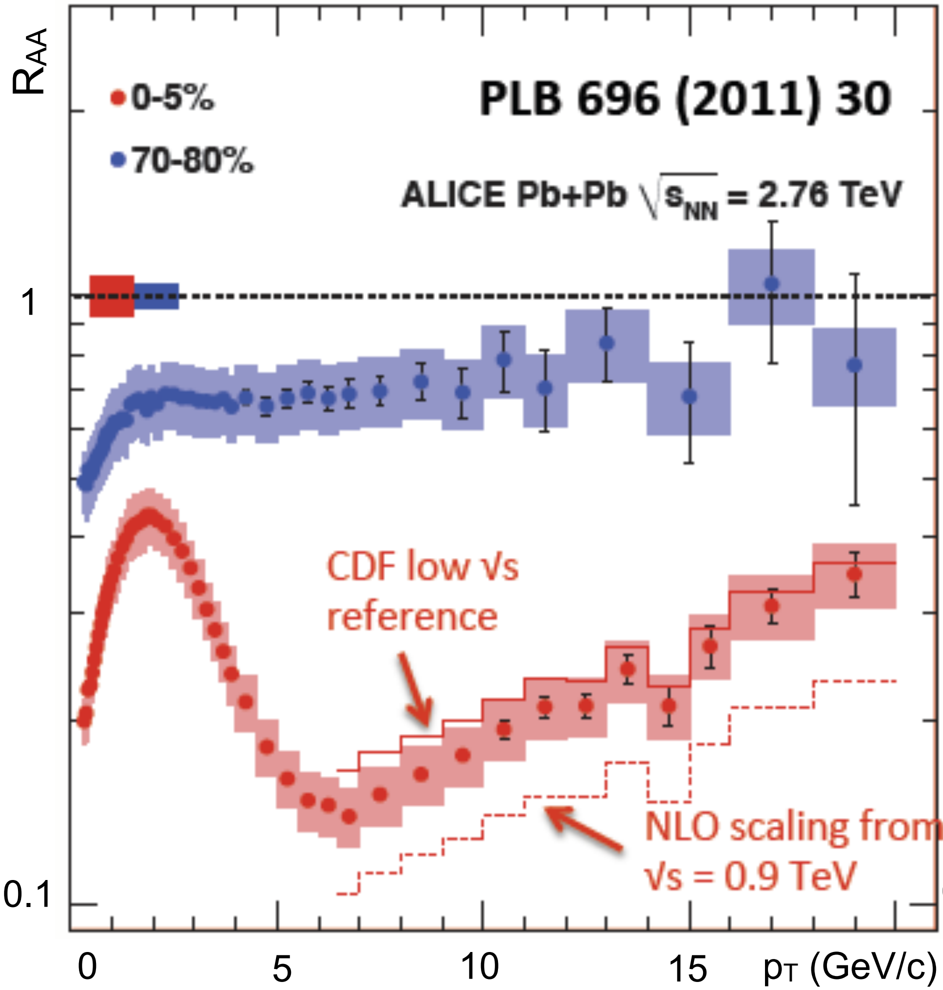


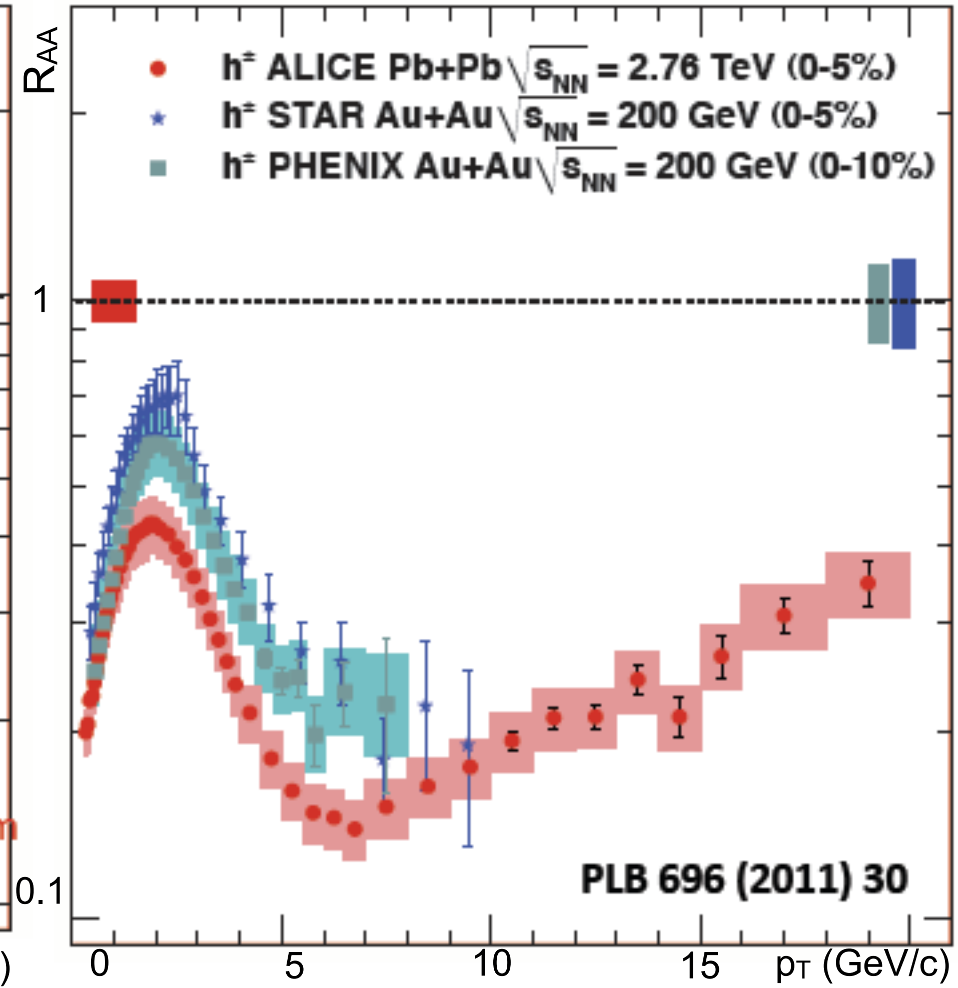
R_{AA}(0-5%) << R_{AA}(70-80%)

For p_T> 7 GeV/c R_{AA} rising

Enough data to reach 50 GeV/c

High p_T suppression





R_{AA}(0-5%) << R_{AA}(70-80%)

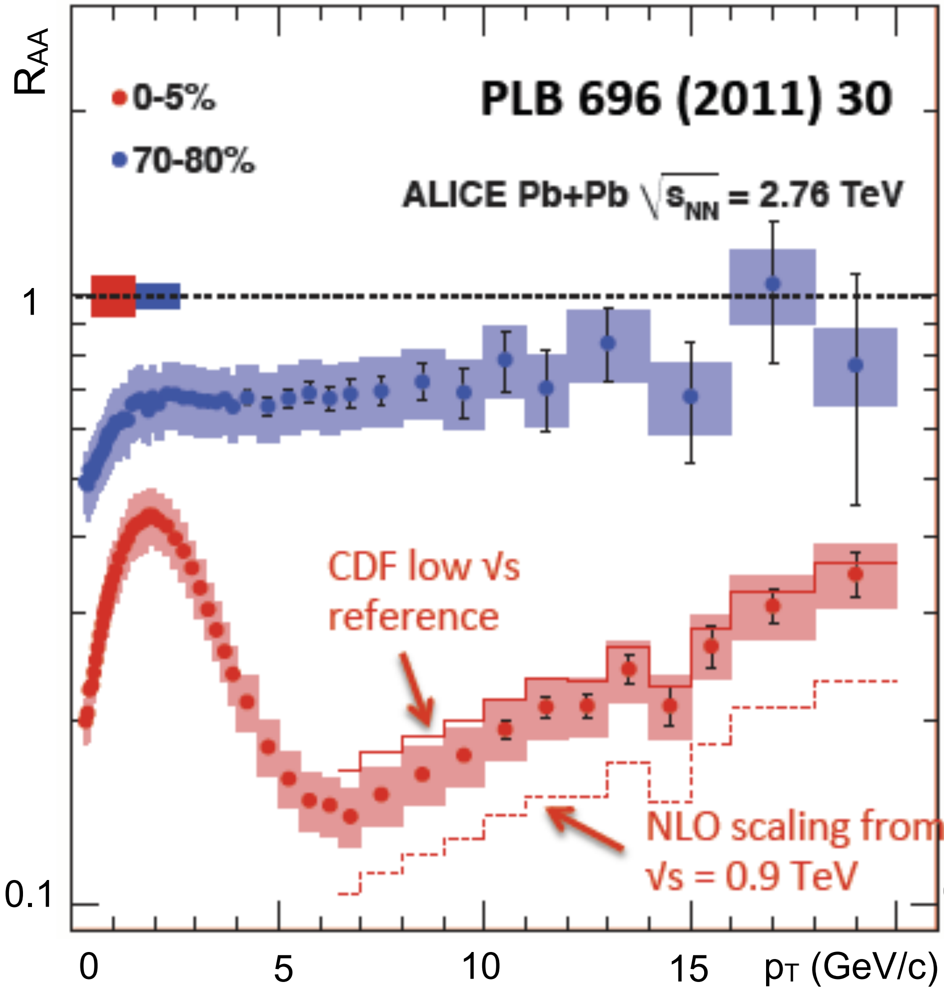
Min.R_{AA}(LHC) = 0.5xMin.R_{AA}(RHIC)

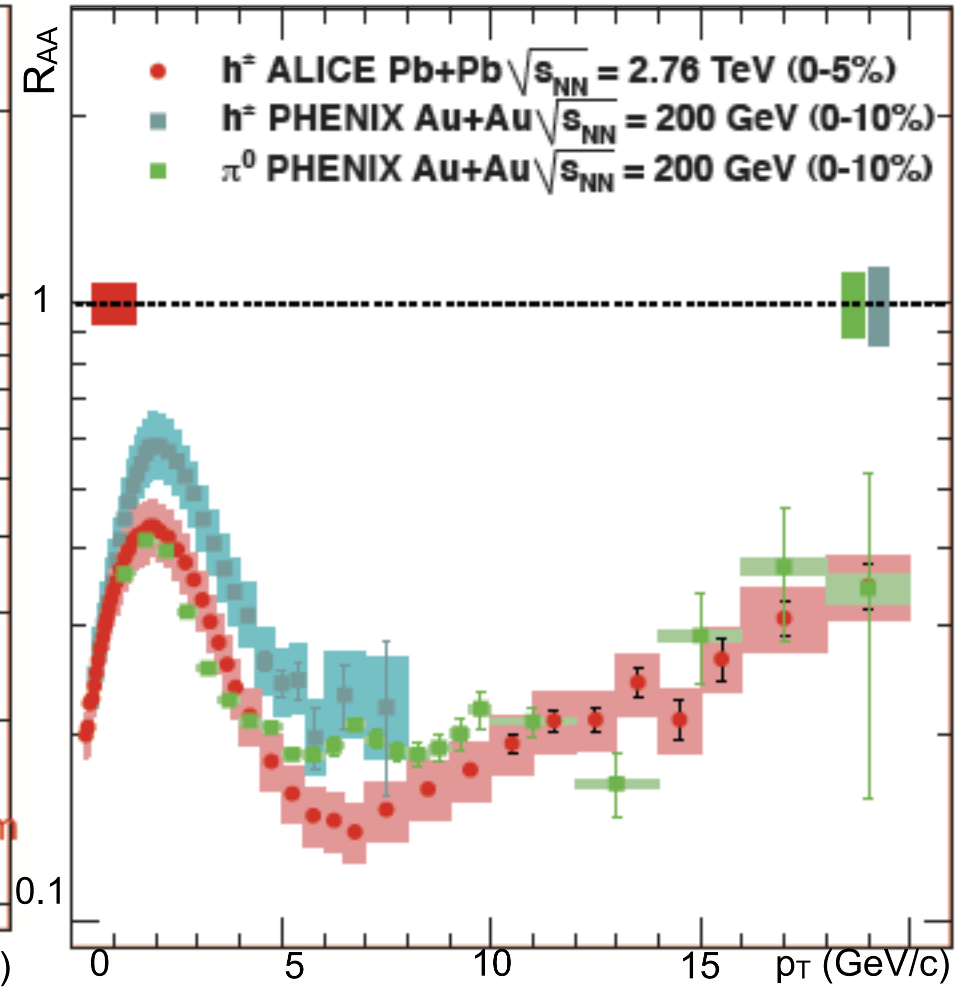
For p_T> 7 GeV/c R_{AA} rising

flatter spectrum → more opaque medium

Enough data to reach 50 GeV/c

High p_T suppression





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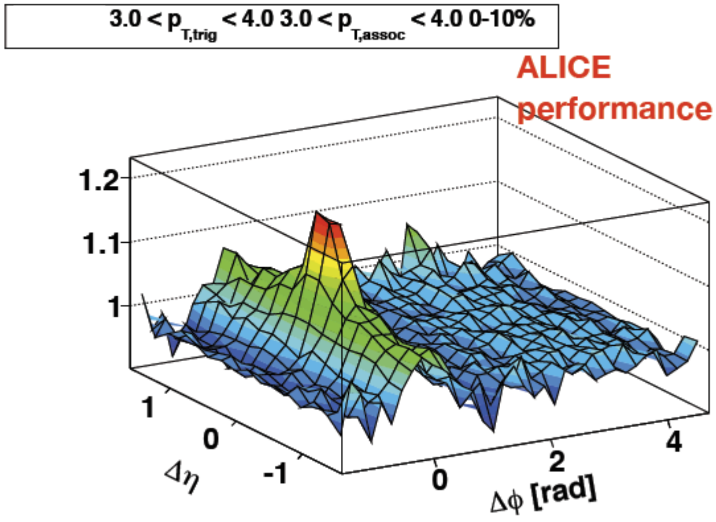
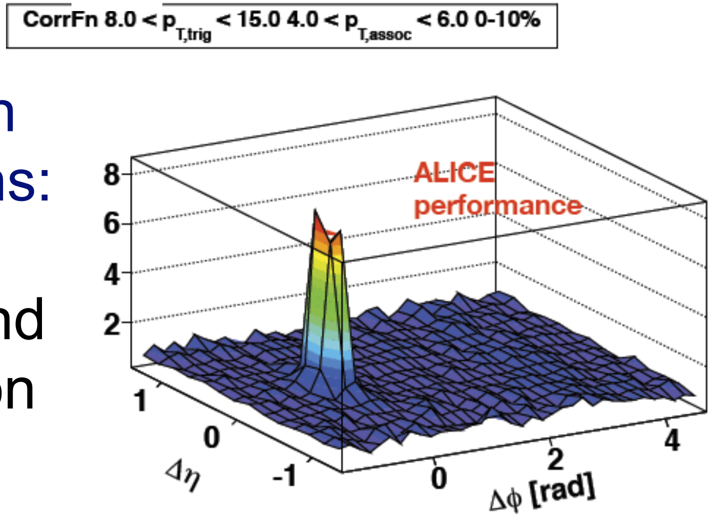
Jet like correlations

Jet reconstruction - Leticia Cunqueiro



di-hadron correlations: No background subtraction



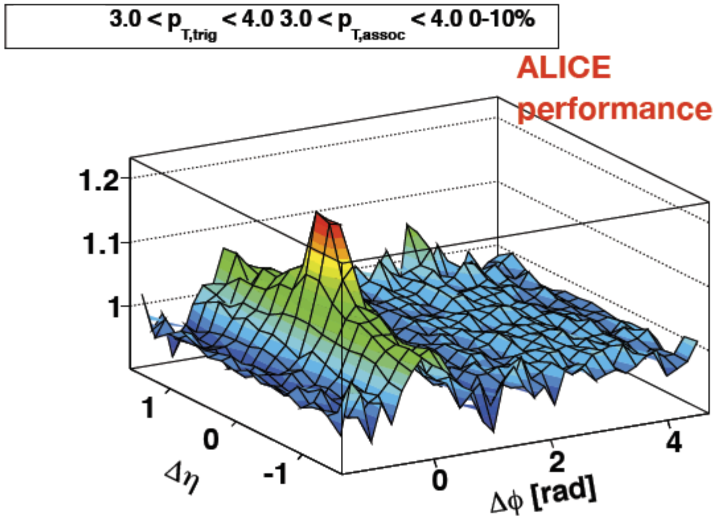
Near-side jet correlation: Evident for all p_T

"ridge" structures: There at low p_T
Not at high p_T

Away side jet correlation: Small even in p-p due to x-swing

Jet like correlations

Jet reconstruction - Leticia Cunqueiro



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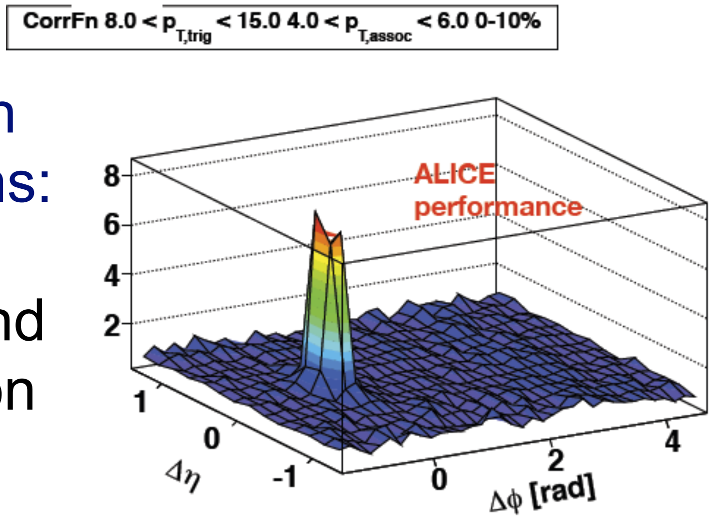
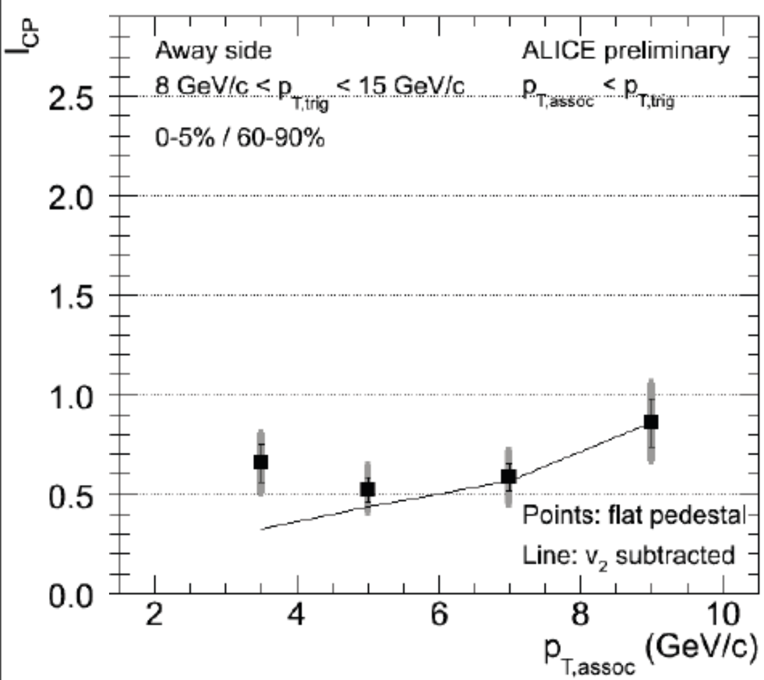




Near-side jet correlation: Evident for all p_T

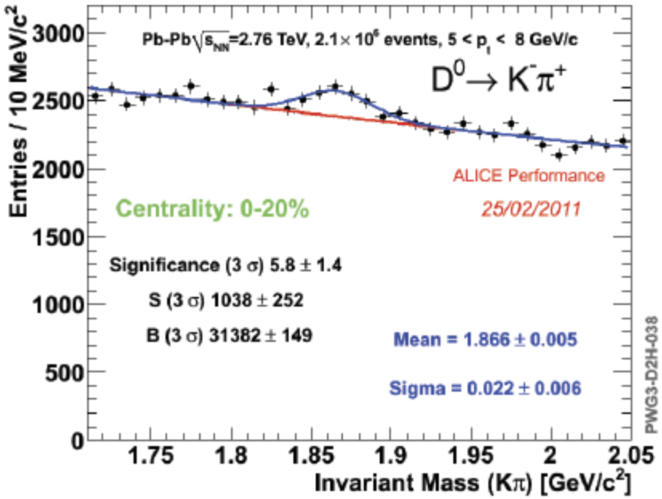
"ridge" structures: There at low p_T
Not at high p_T

Away side jet correlation: Small even in p-p due to x-swing

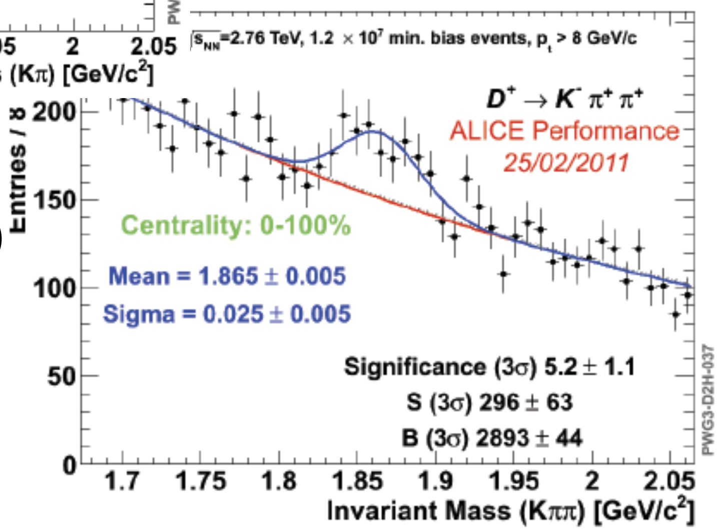
$I_{AA} < 1$ even for high p_{Tassoc}

Heavy flavor

HF in p-p - Chiara Bianchin and Martino Gagliardi



D^0 and D* via secondary vertices



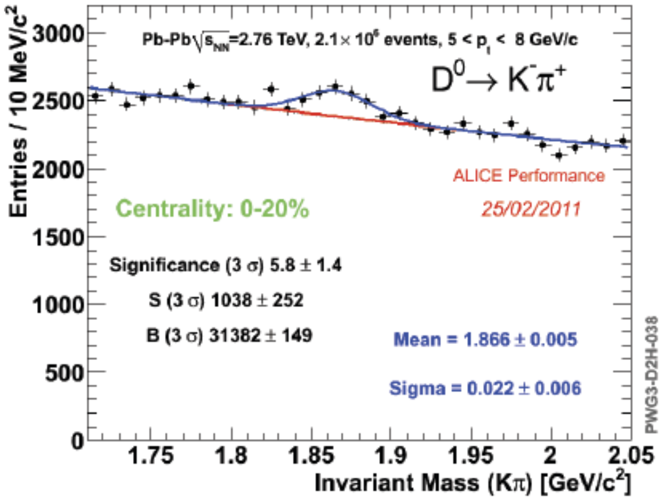
High p_T (5-15 GeV/c) expected from full 2010 Pb-Pb dataset

Bottom deduced from leptonic decays

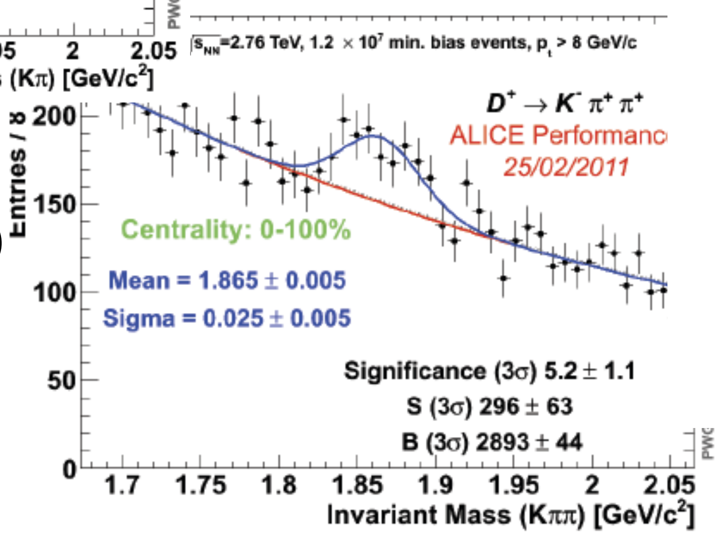
Charm vs bottom high p_T suppression measurements possible

Heavy flavor

HF in p-p - Chiara Bianchin and Martino Gagliardi

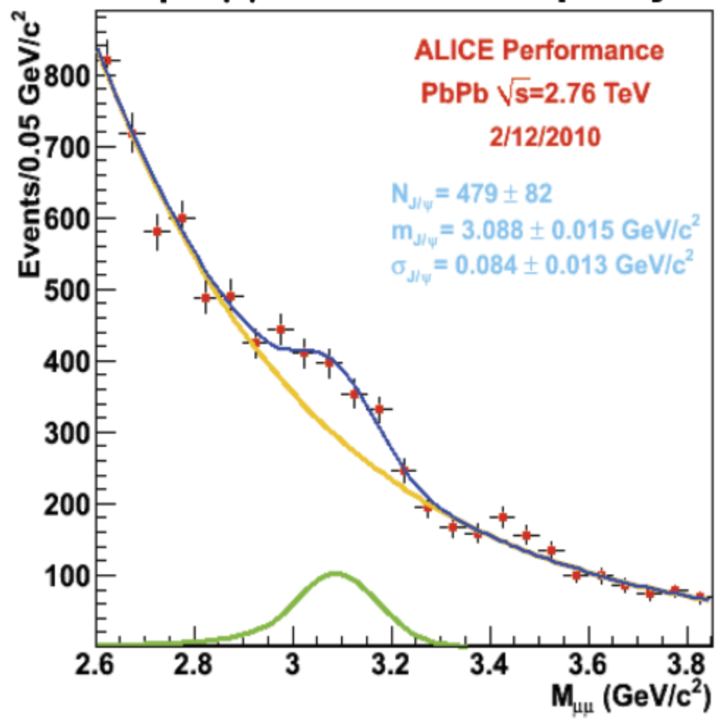


D^0 and D* via secondary vertices



High p_T (5-15 GeV/c) expected from full 2010 Pb-Pb dataset

J/ψ→μμ at forward rapidity



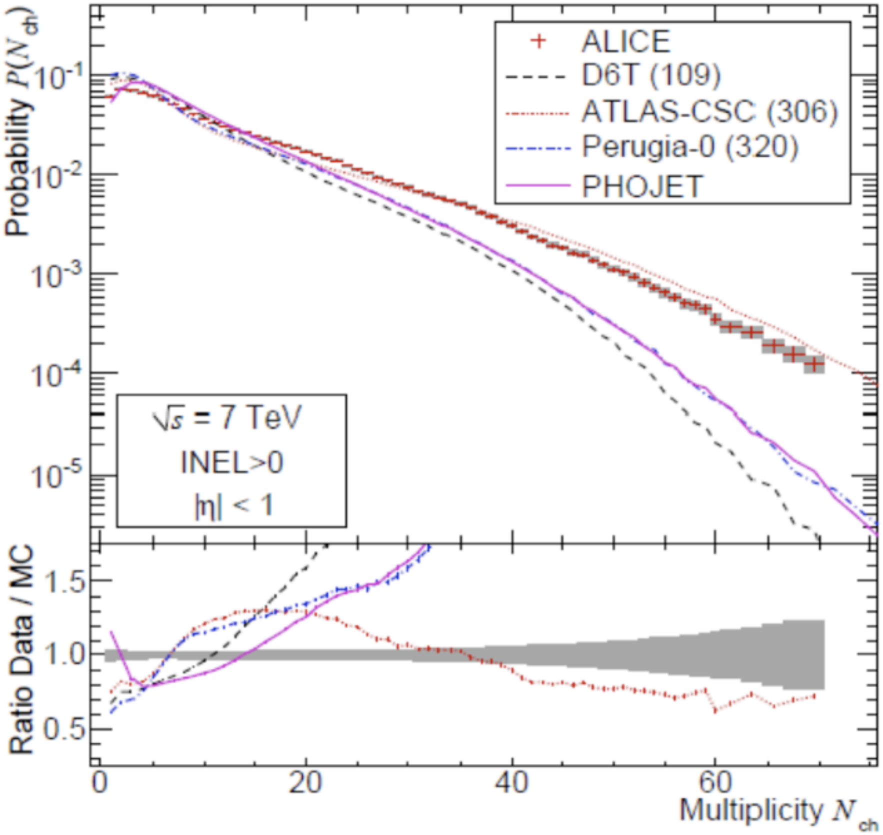
Expect a few 1000 J/Ψ from full 2010 Pb-Pb dataset

Bottom deduced from leptonic decays

Charm vs bottom high p_T suppression measurements possible

Quarkonia suppression/ enhancement results also possible

Extreme p-p events

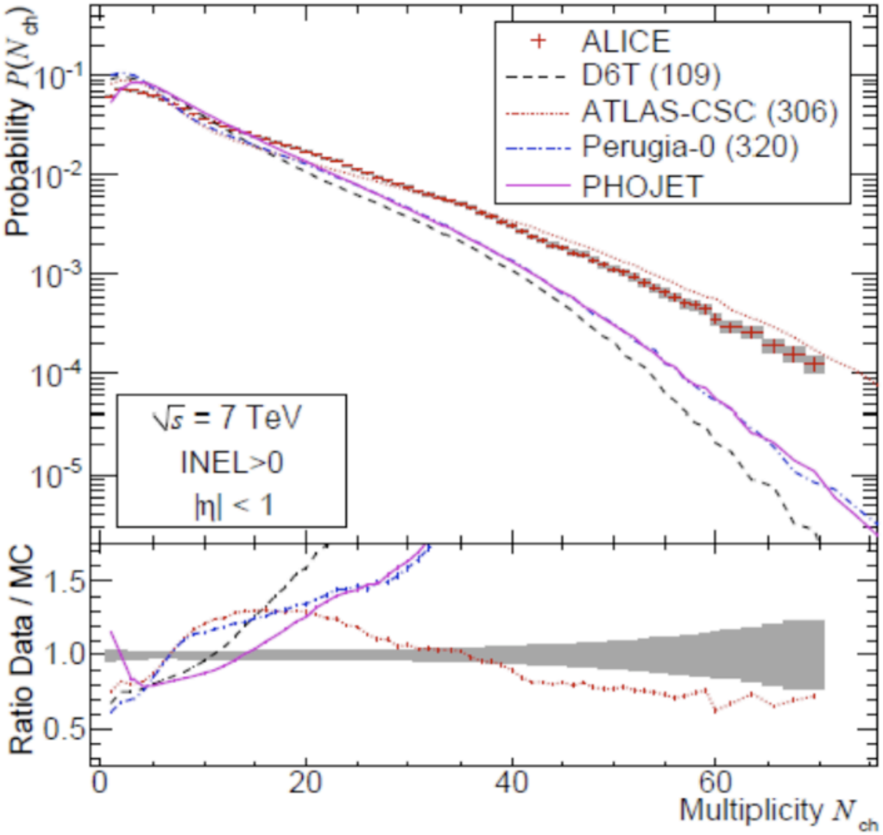


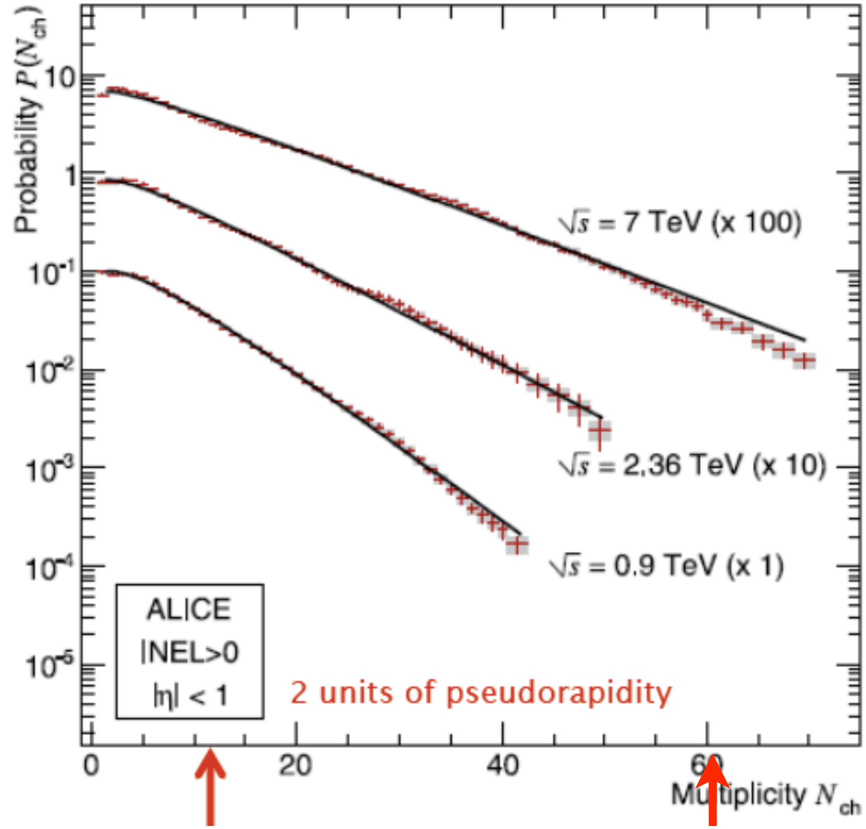
p-p data hard for models to describe

Here ATLAS-CSC OK but fails to describe pT distribution

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*

Extreme p-p events





p-p data hard for models to describe

Here ATLAS-CSC OK but fails to describe pT distribution

$\sqrt{s}$=7 TeV
$\langle dN_{ch}/d\eta \rangle \sim 6$

1:100 events
$dN_{ch}/d\eta \sim 30$

Similar multiplicities to Cu-Cu events collectivity and QGP???

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

Summary and outlook

- Strong high p_T suppression observed → highly opaque medium
- Jet/High p_T and heavy flavor studies just starting
- Investigating extreme p-p events → who knows what they will reveal?

As expected larger, denser, longer lived and more opaque source created at LHC than at RHIC

Outlook

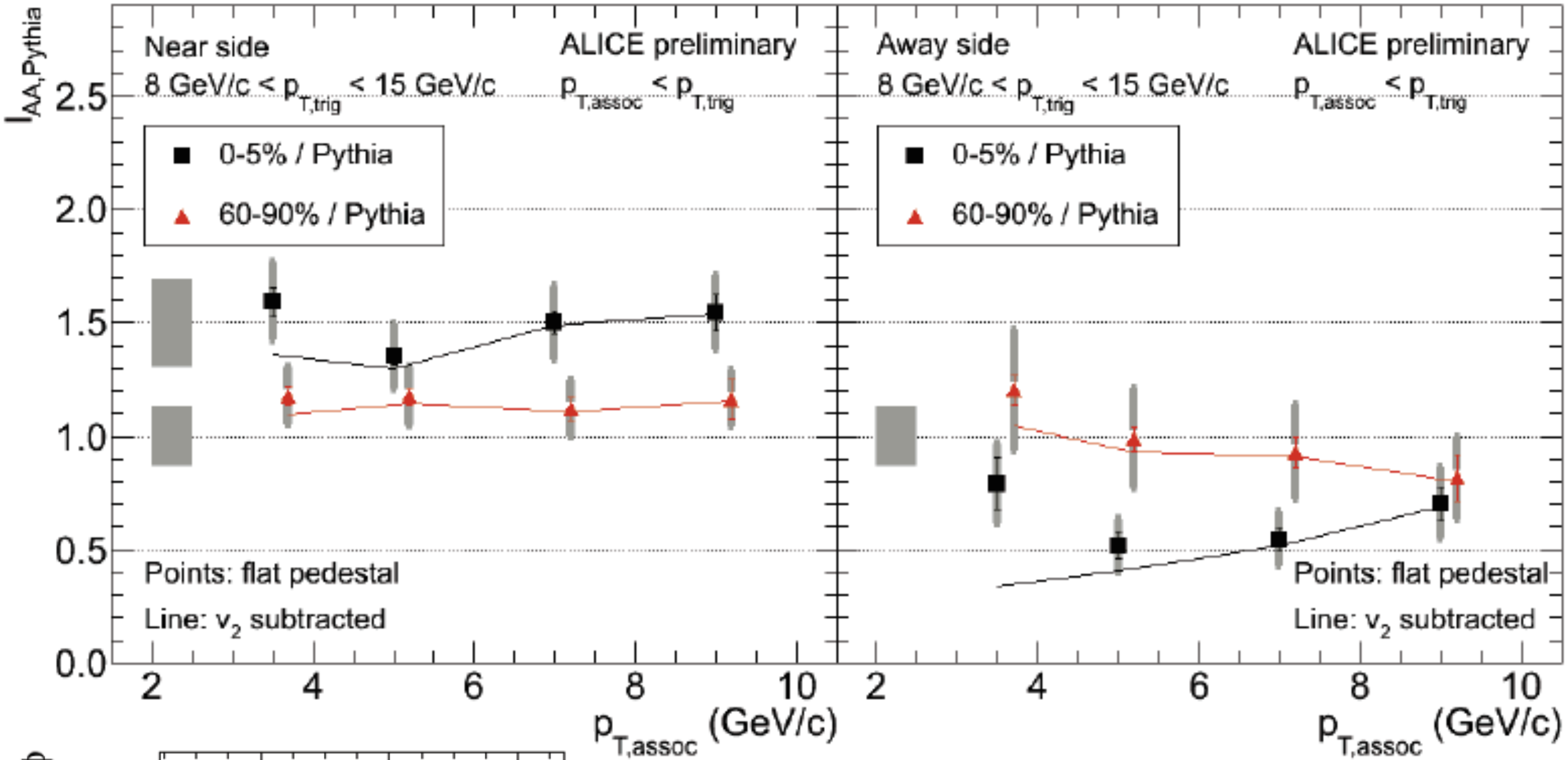
- Long shutdown delayed until 2012
- Pb-Pb running expected in 2011 and 2012

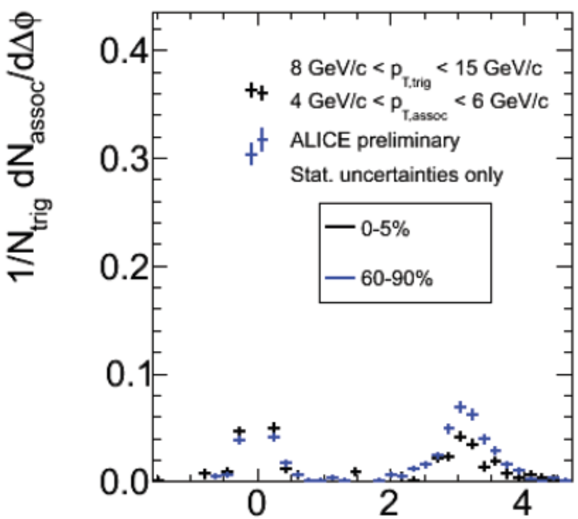
ALICE and the LHC operating wonderfully

Details of the QGP at 2.7 TeV emerging rapidly

Back-up slides

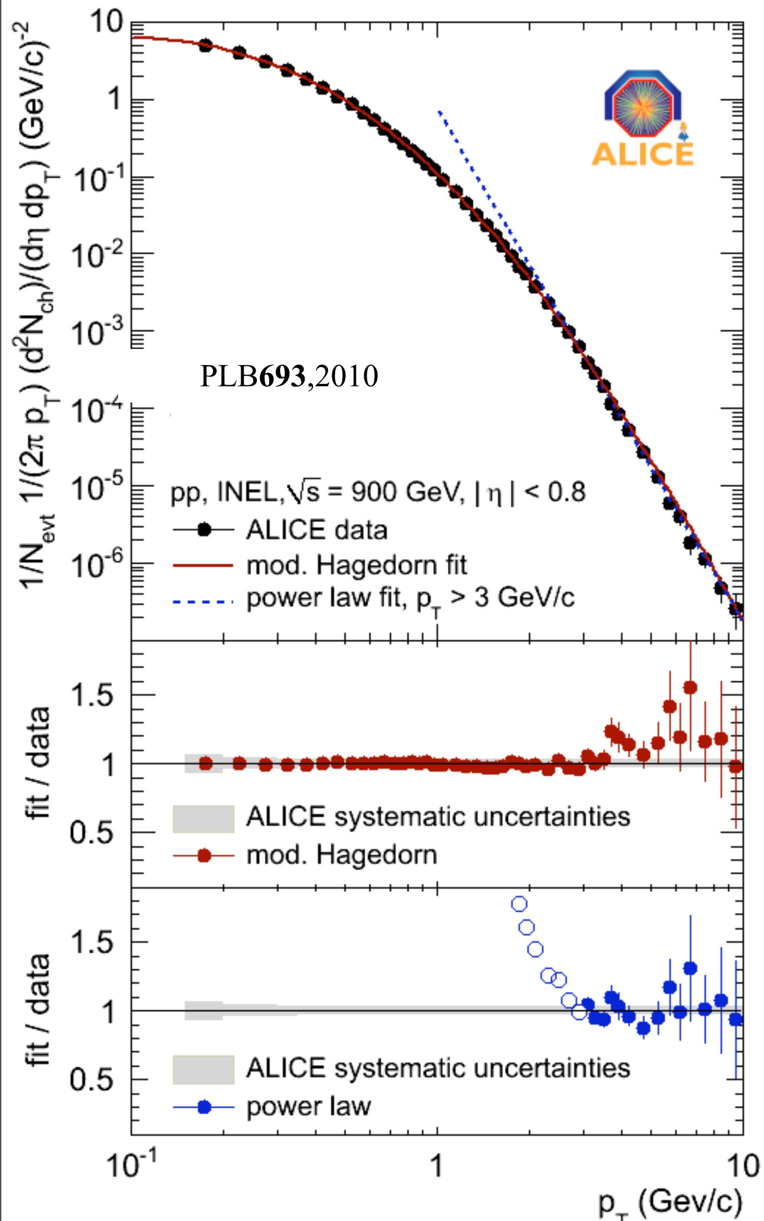
Di-hadron correlations: I_{AA}





Near side: Yield enhanced in central Pb-Pb
Away side: Yield suppressed in central Pb-Pb

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 ± 0.12 (stat) ± 0.1 (sys)

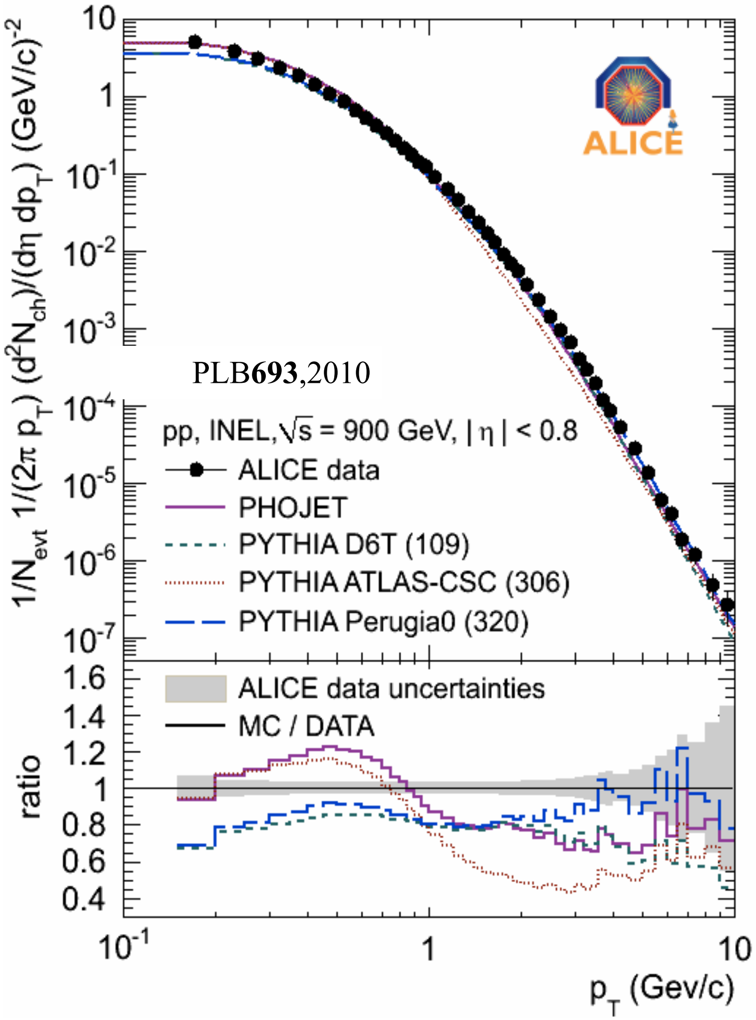
Modified hagedorn distribution gives good description of data over whole p_T range measured

$\langle p_T \rangle_{INEL}$ = 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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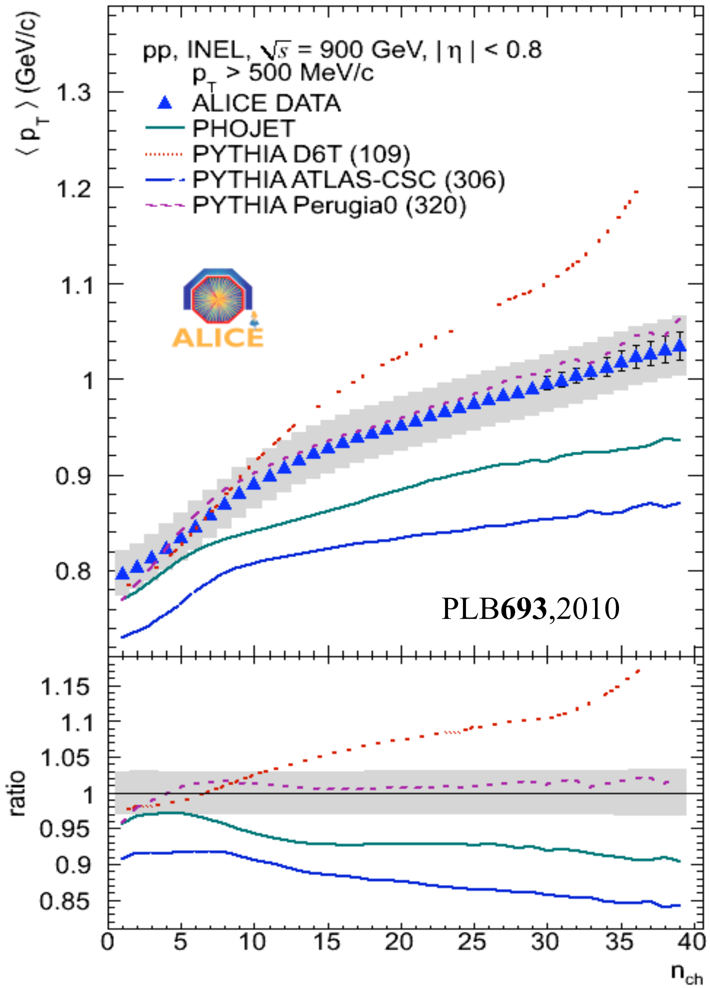
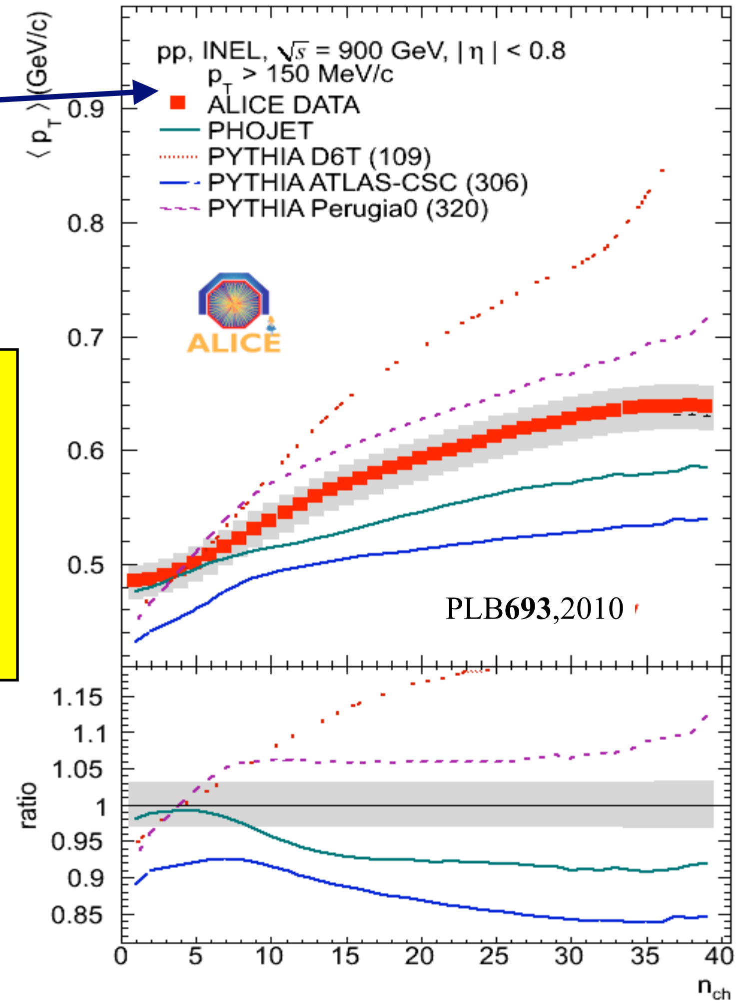
Data not described by MCs

⟨p_T⟩ as function of multiplicity at 0.9 TeV



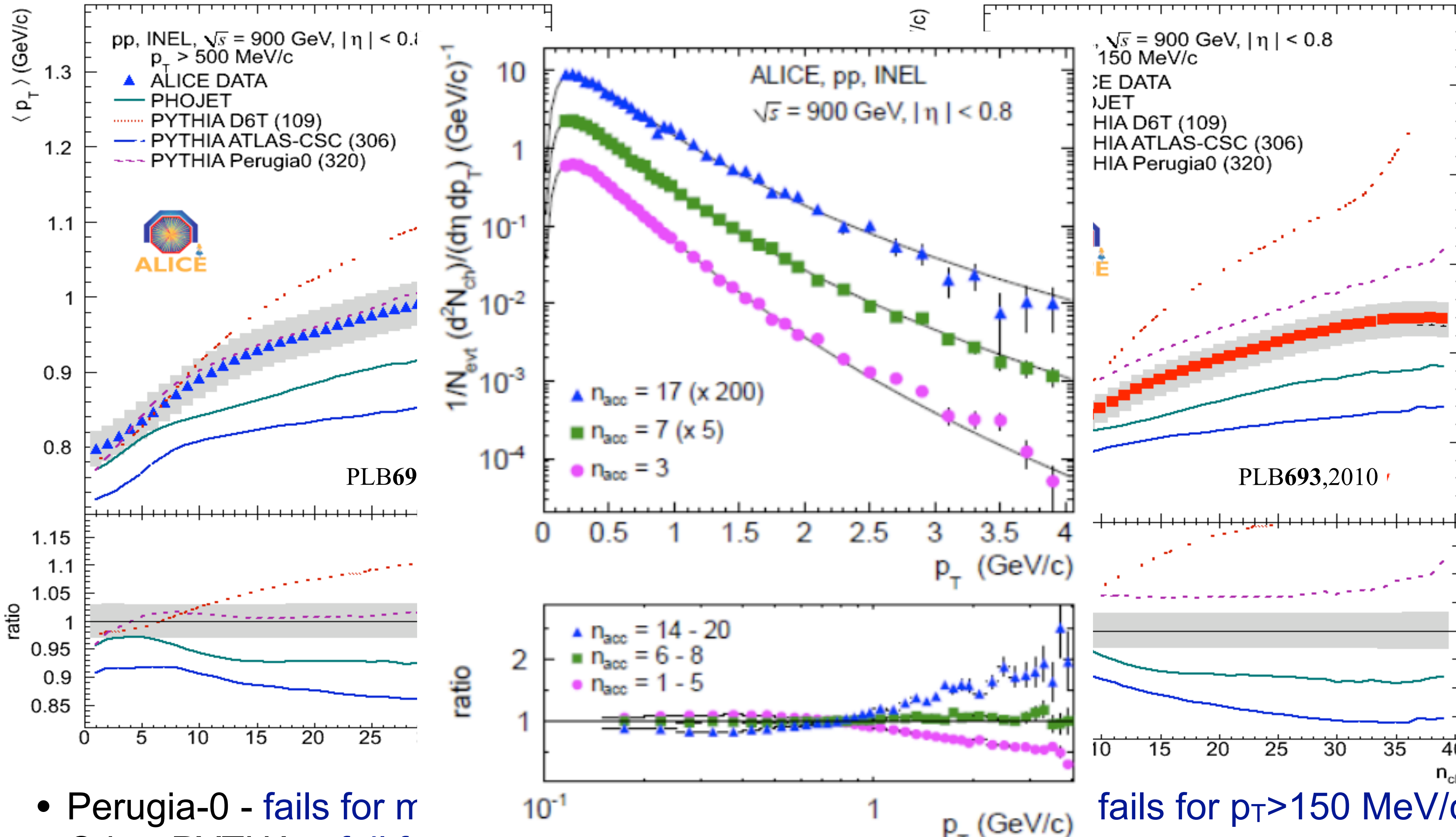
ALICE data goes down to 150 MeV/c

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

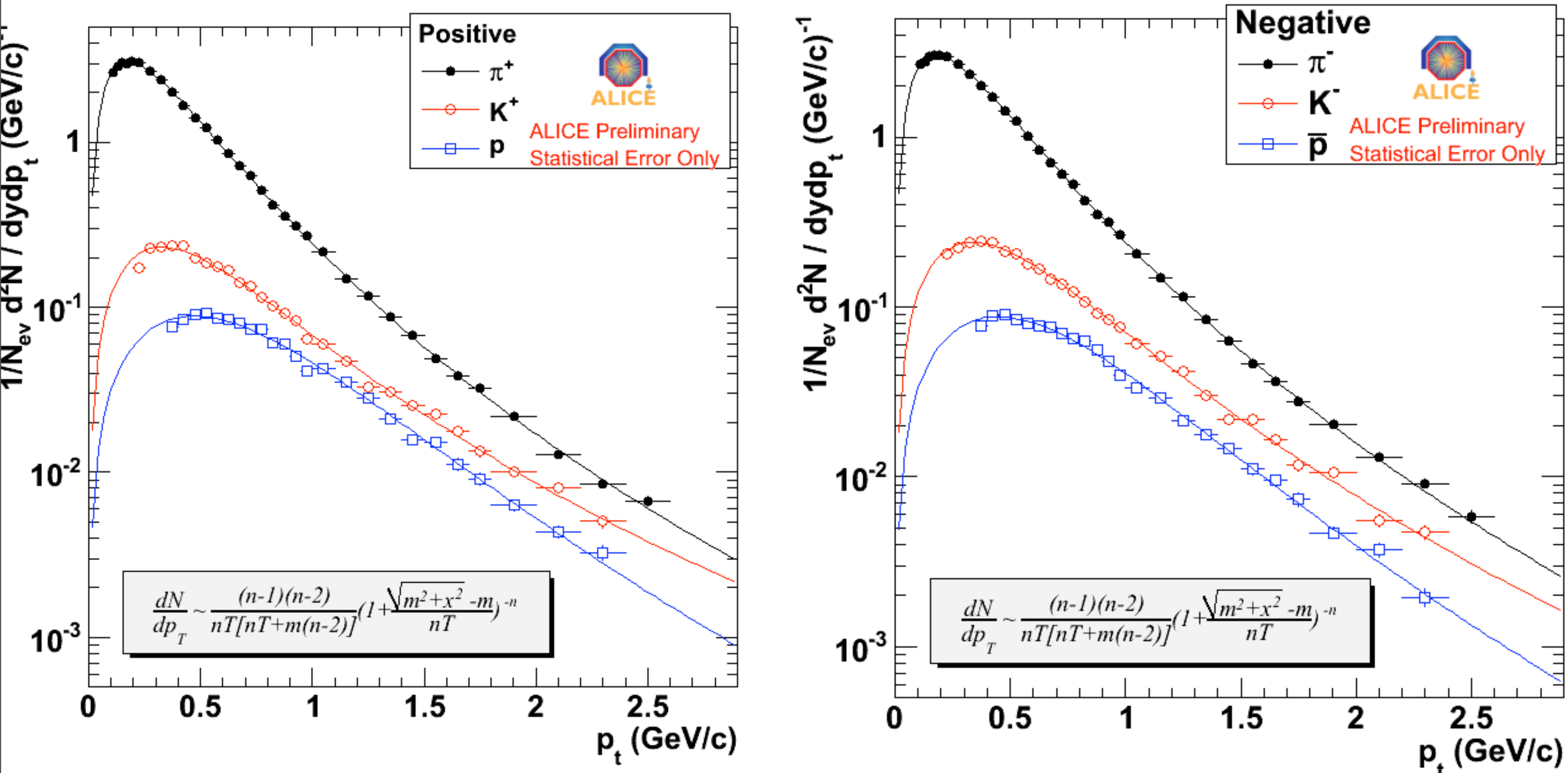


- Perugia-0 - fails for m … fails for p_T>150 MeV/c
- Other PYTHA - fail fo…
- Phojet - describes mult…

Main shape difference at high p_T

Identified particle spectra at 0.9 TeV

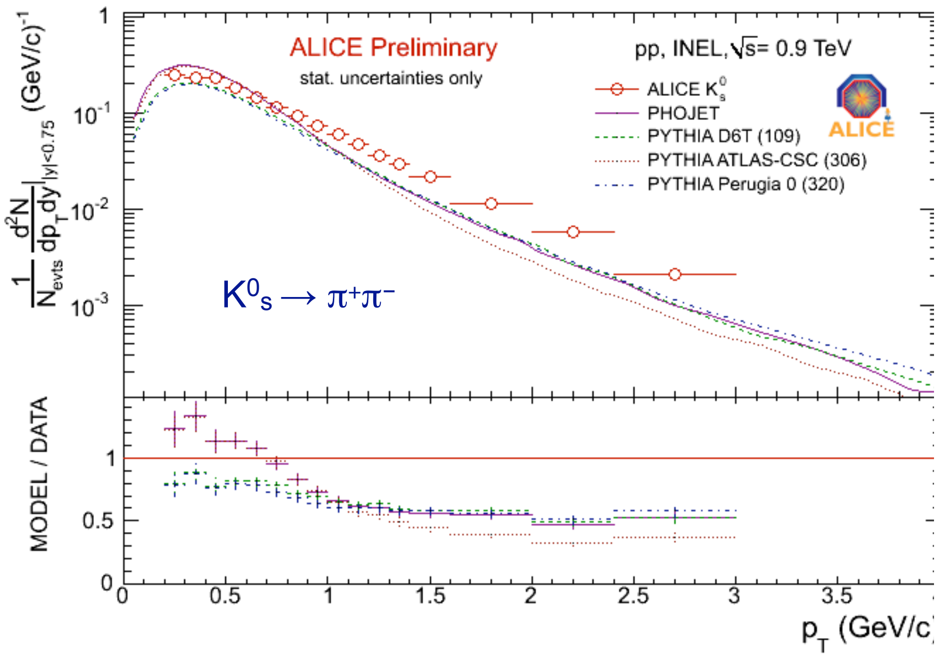
TPC, ITS and ToF used to identify particles

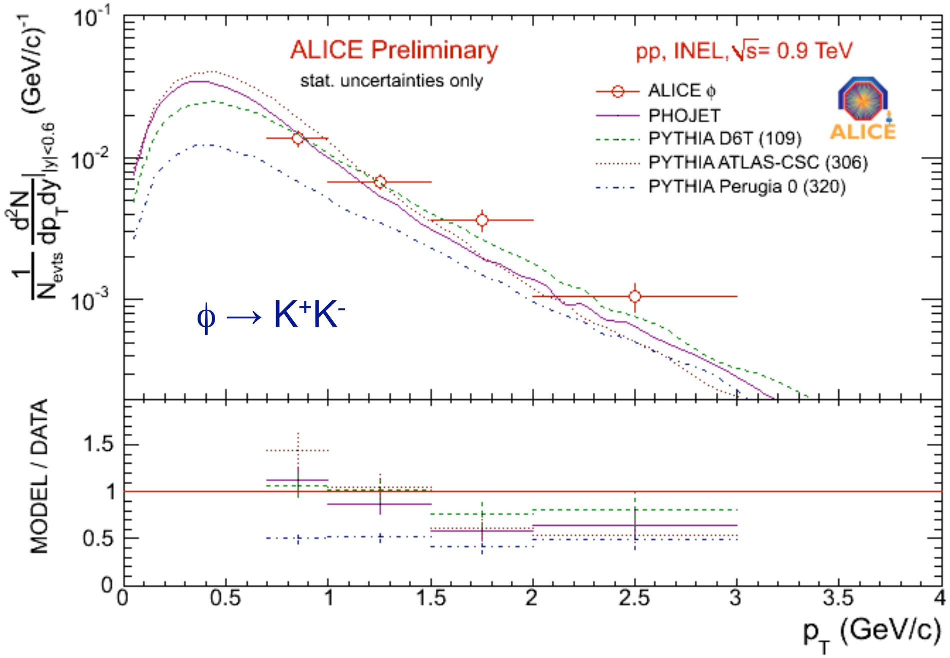


$$\frac{dN}{dp_T} \sim \frac{(n-1)(n-2)}{nT[nT+m(n-2)]}\left(1+\frac{\sqrt{m^2+x^2}-m}{nT}\right)^{-n}$$

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

Strange hadron spectra at 0.9 TeV

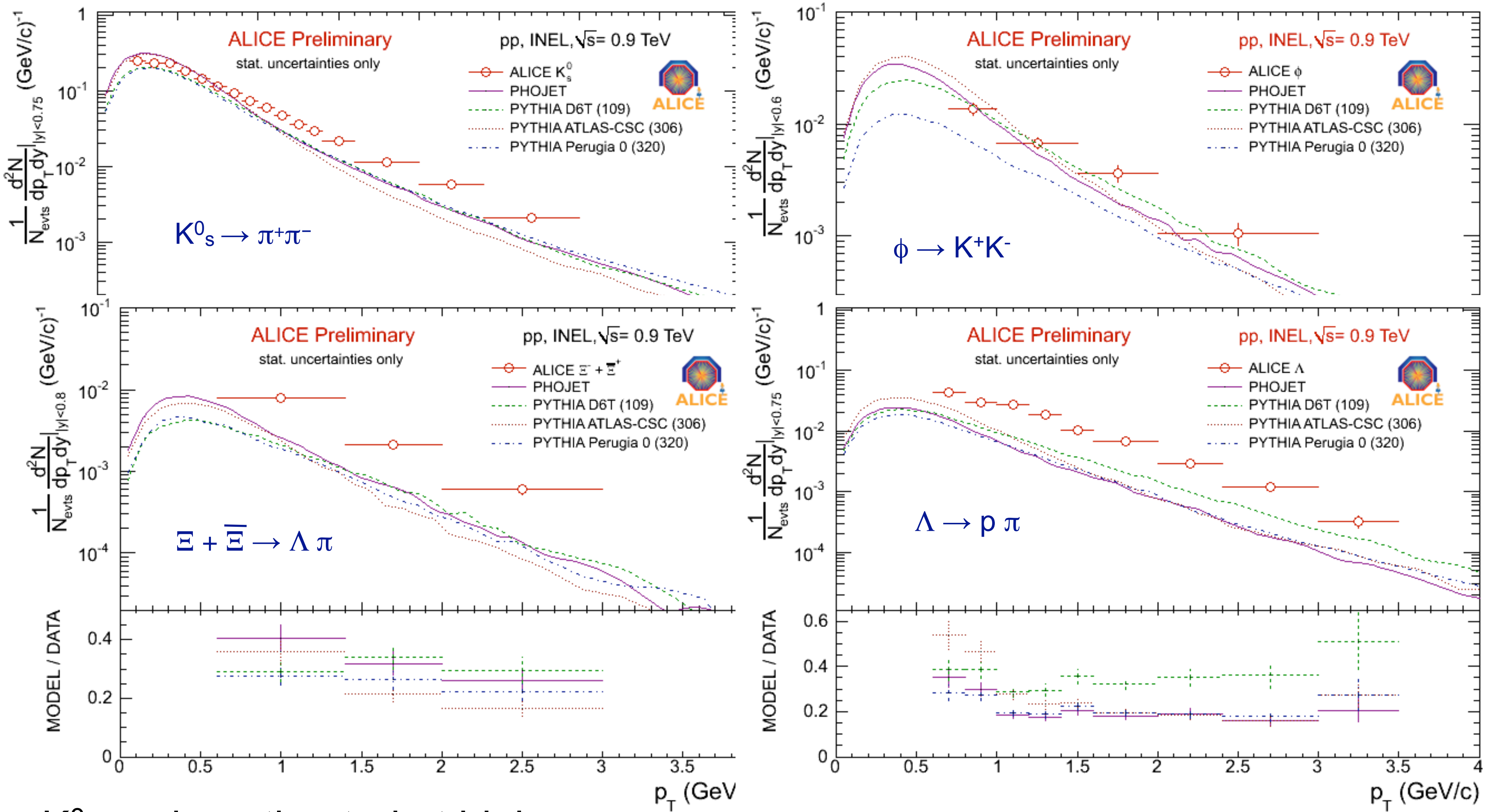




K^0_s underestimated at high p_T,

Φ OK within uncertainties !

Strange hadron spectra at 0.9 TeV



K^0_s underestimated at high p_T,

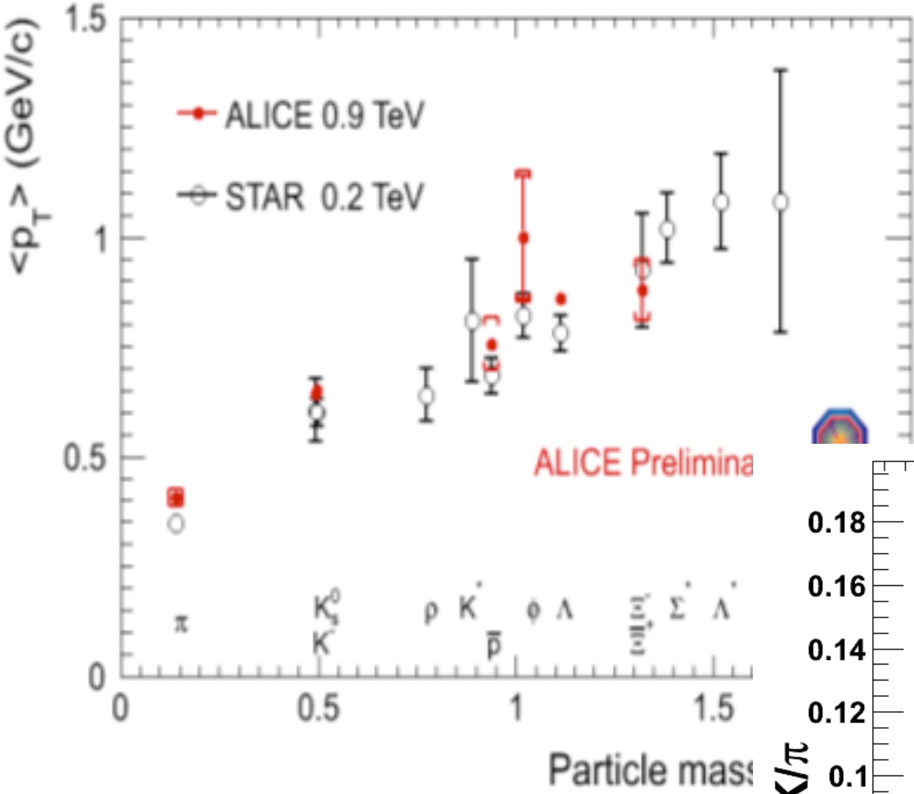
Φ OK within uncertainties !

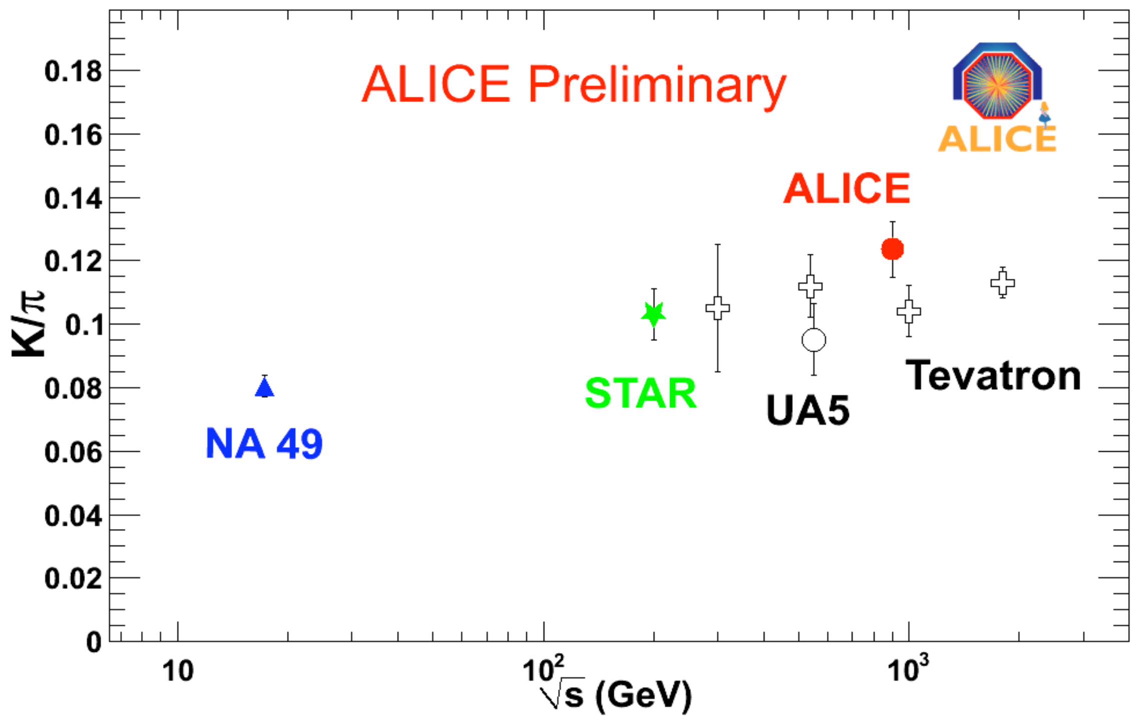
Strange baryons off by factor 3!

Lots of work to do for strangeness

0.9 TeV compared to other energies

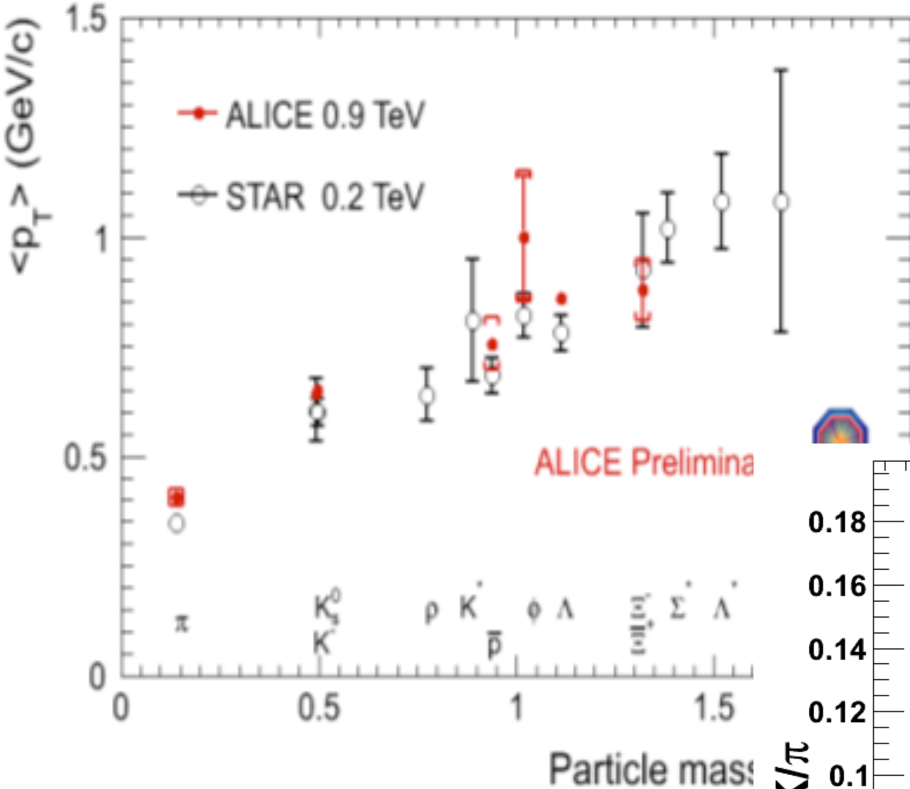
Species dependence of ⟨p_T⟩ very similar to RHIC





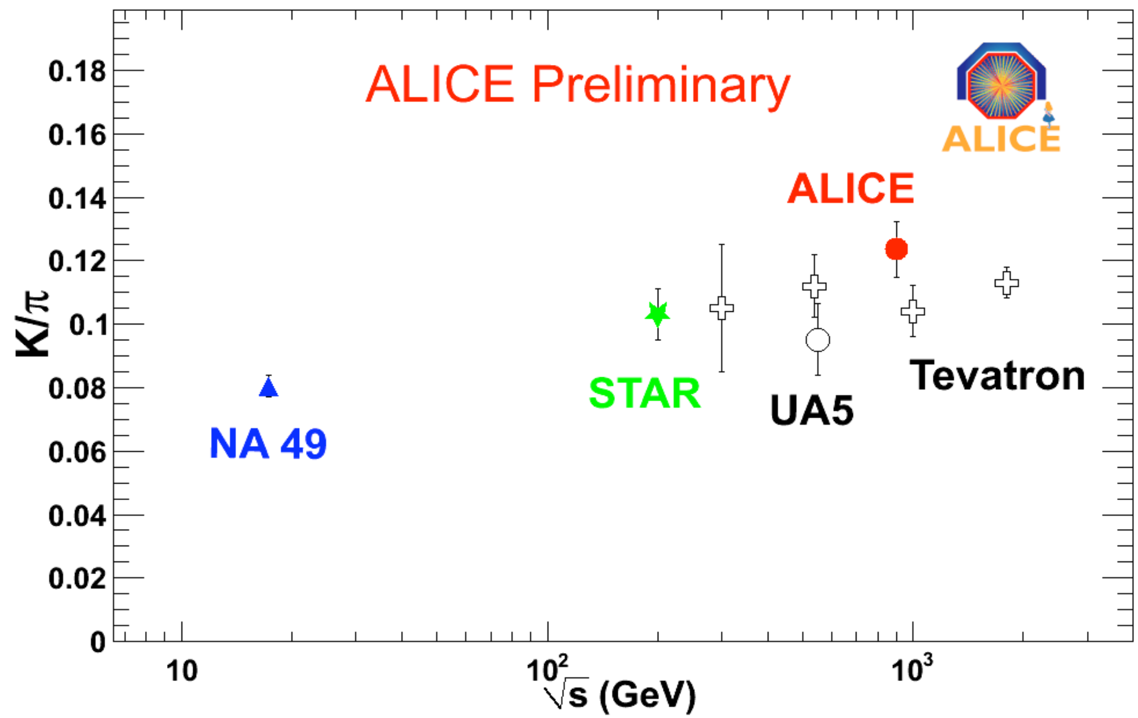
Very interesting to see what happens at 7 TeV (and 14 TeV)

0.9 TeV compared to other energies



Species dependence of ⟨p_T⟩ very similar to RHIC

Integrated K/π has little dependence on √s

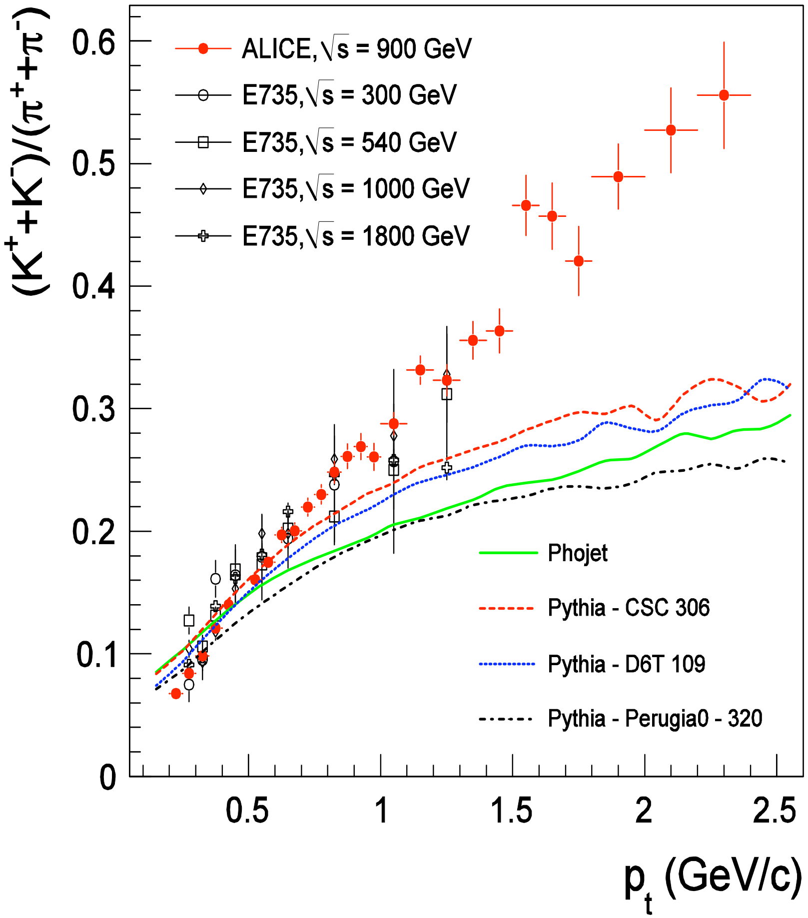


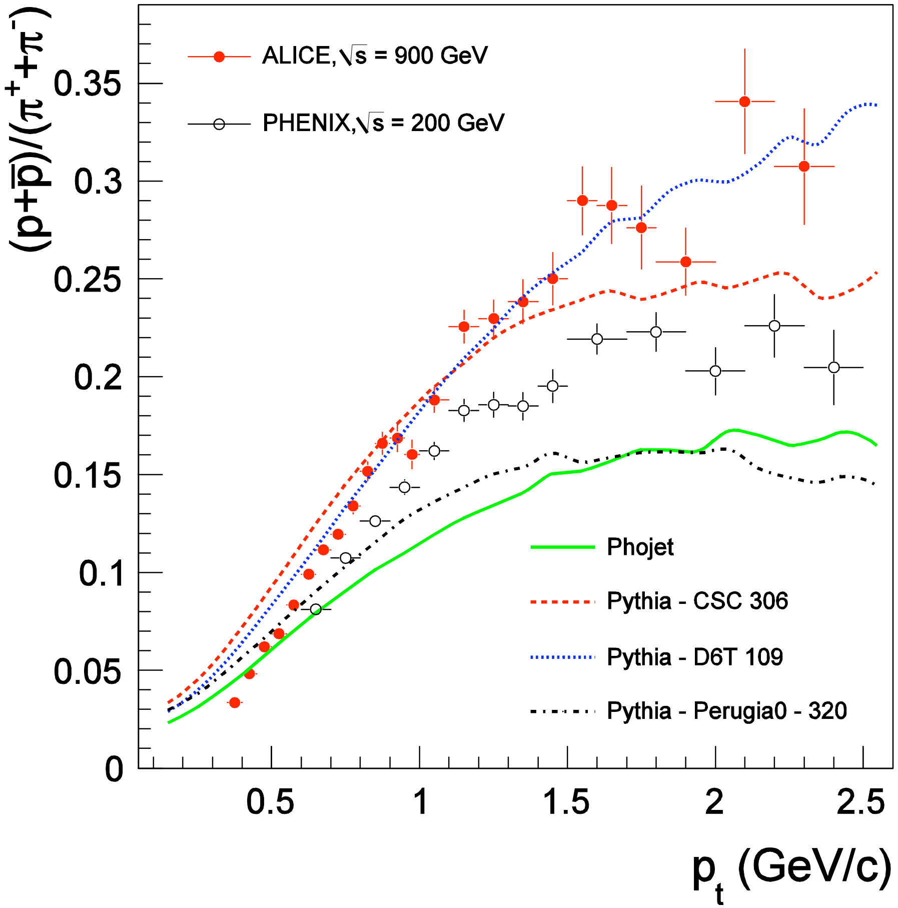
Very interesting to see what happens at 7 TeV (and 14 TeV)

K/π & p/π ratios as function of p_T

Not very good agreement with event generator (not surprising)

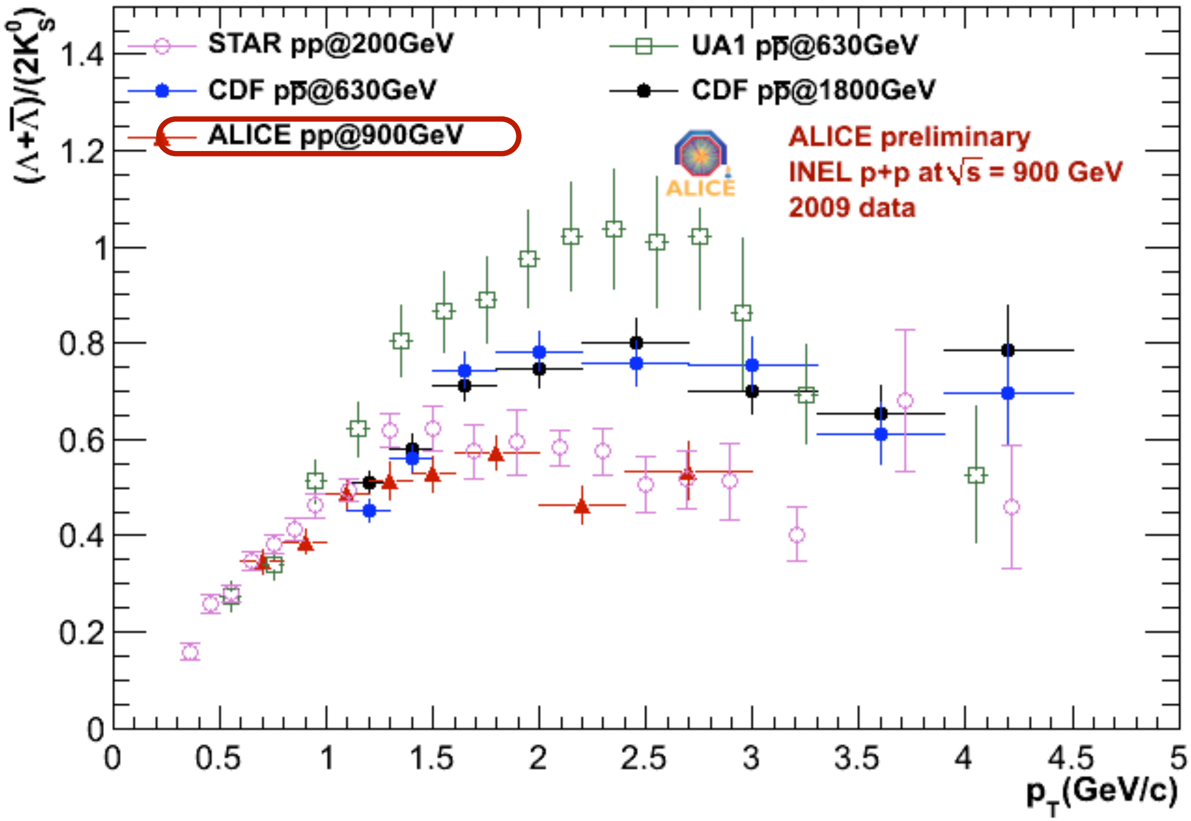
ALICE data for 0.9 TeV





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)

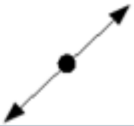
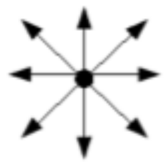
Surprising lack of agreement between CDF (630) and UA1 (630) for p_T > 1.5 GeV/c

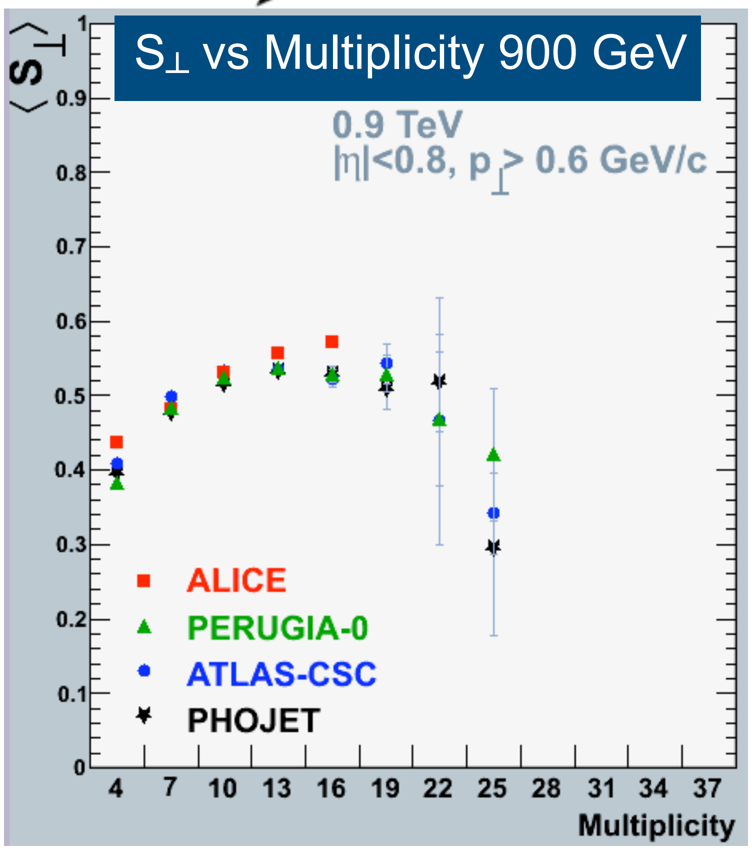
Event shape analysis

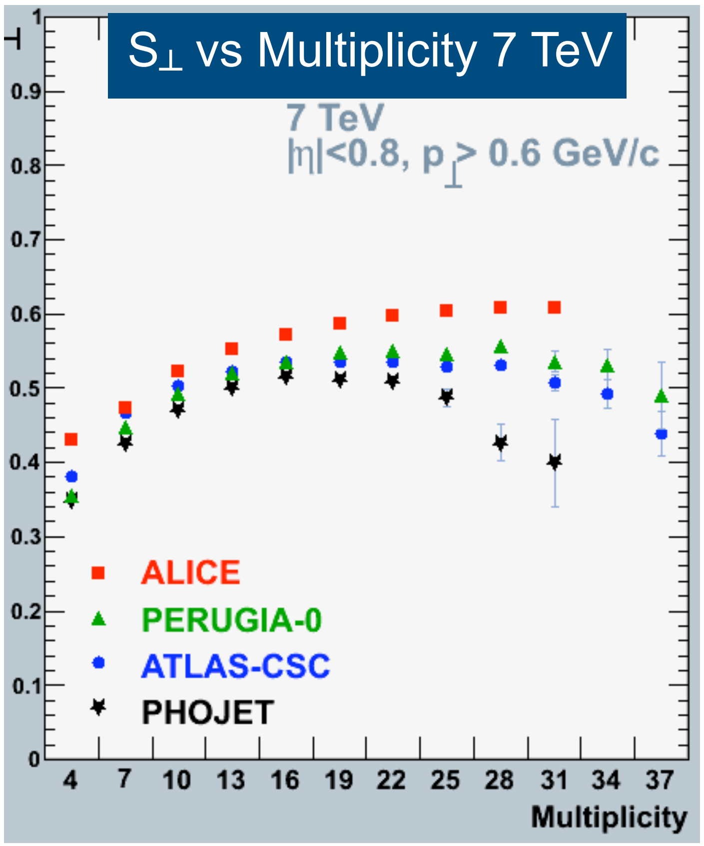
- Transverse Sphericity $S_\perp$:
  λ_1, λ_2: eigenvalues of momentum tensor

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

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

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

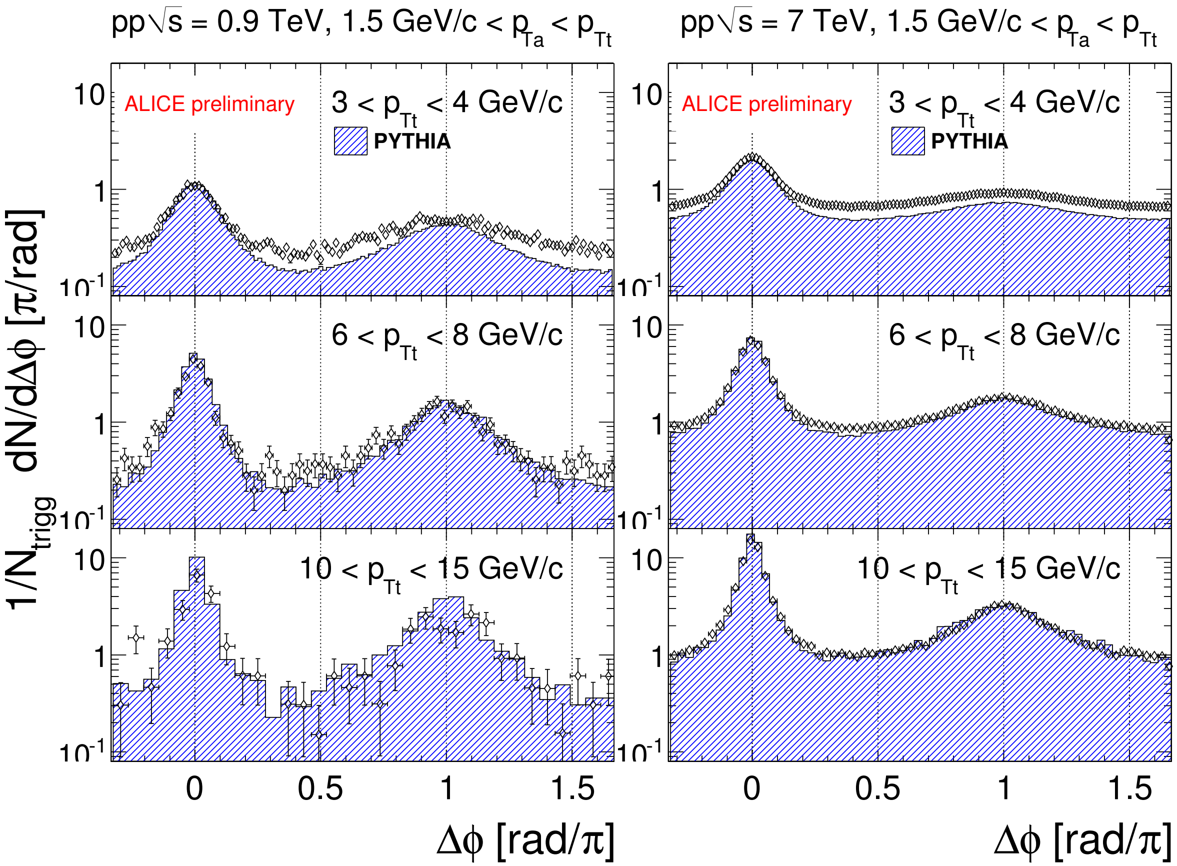




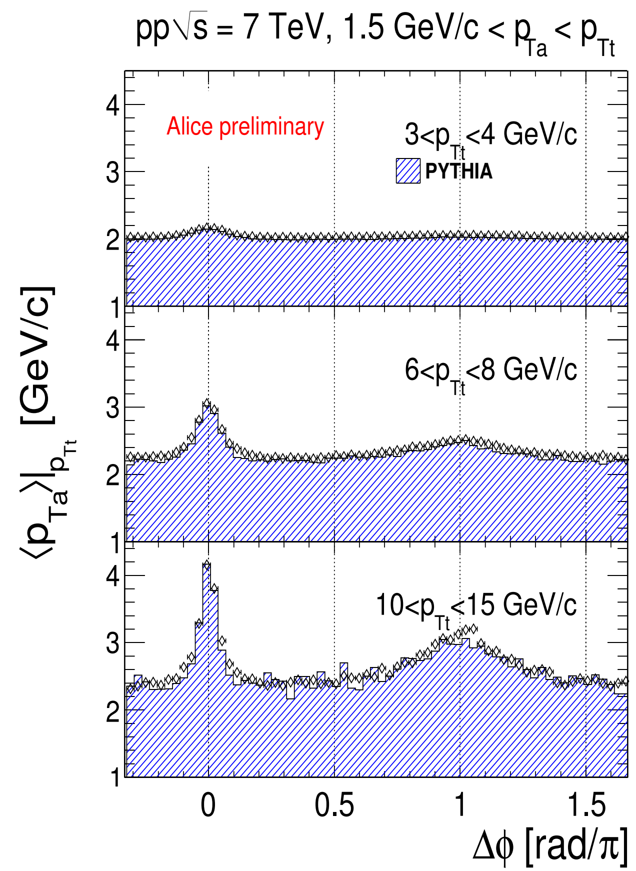
Data “rounder” than simulations

Particle correlations √s=0.9 and 7 TeV

Background not subtracted dΔφ



Mean $p_T(\Delta\varphi)$



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

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

Monte Carlo score card so far

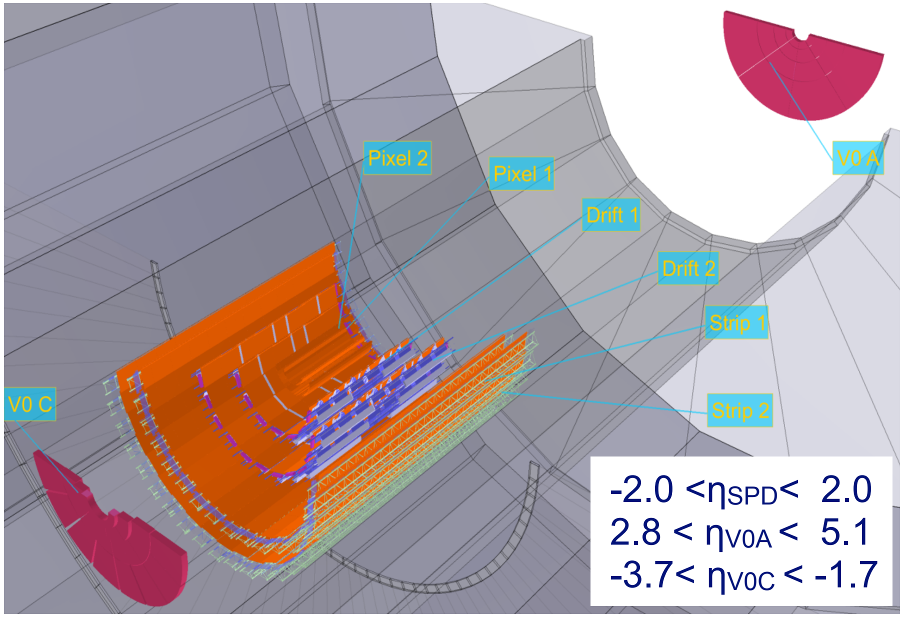
	MC/	D6T	Perugia0	CSC	PHOJET
0.9 TeV	$dN_{ch}/d\eta$	-20%	-17%	+3%	-2%
	N_{ch}	$N_{ch}>10$	$N_{ch}>5$	$N_{ch}>15$	$N_{ch}>10$
	p_t		$p_t>4GeV/c$	$p_t>1GeV/c$	$p_t>1GeV/c$
	$\langle p_t \rangle$				$p_t>1GeV/c$
2.36 TeV	η	-24%	-21%	-2%	-8%
	N_{ch}	$N_{ch}>10$	$N_{ch}>5$	$N_{ch}>20$	$N_{ch}>15$
7 TeV	η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

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)

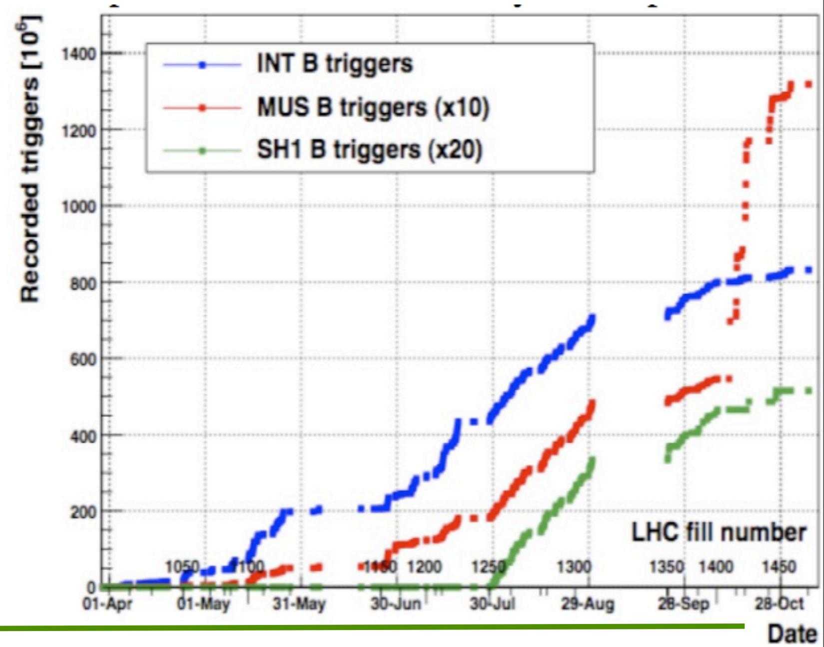
April - Oct 2010:

0.9 TeV ~ 3 M min bias

7.0 TeV ~ 800 M min bias

~ 250 k high mult.

Ran with reduced luminosity after July



Event classes

p-p collisions at 0.9 and 2.36 TeV

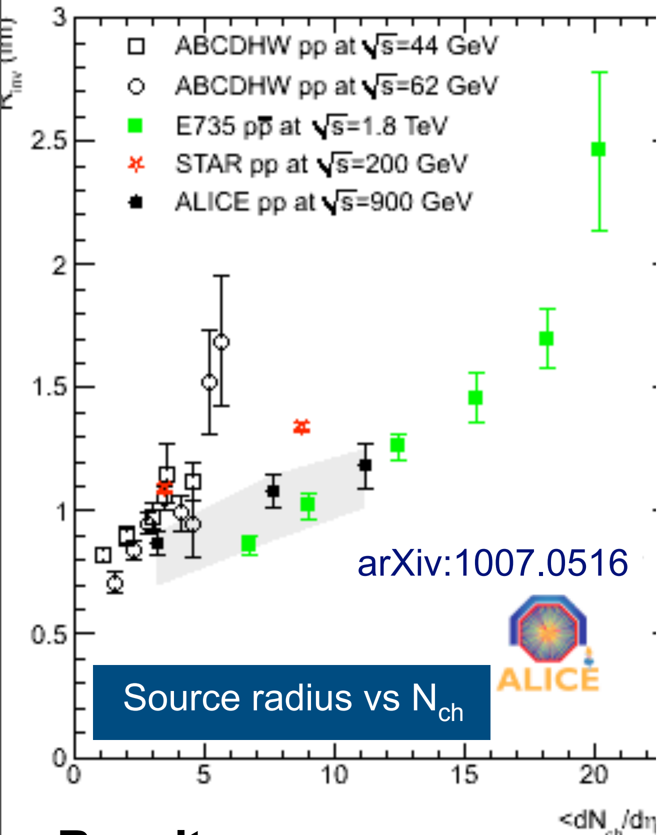
- INEL and NSD
- Use measured cross sections for diffractive processes
- Change MC generator fractions (SD/INEL, DD/INEL) so that they match these fractions
- Use Pythia and Phojet to assess effect of different kinematics of diffractive processes

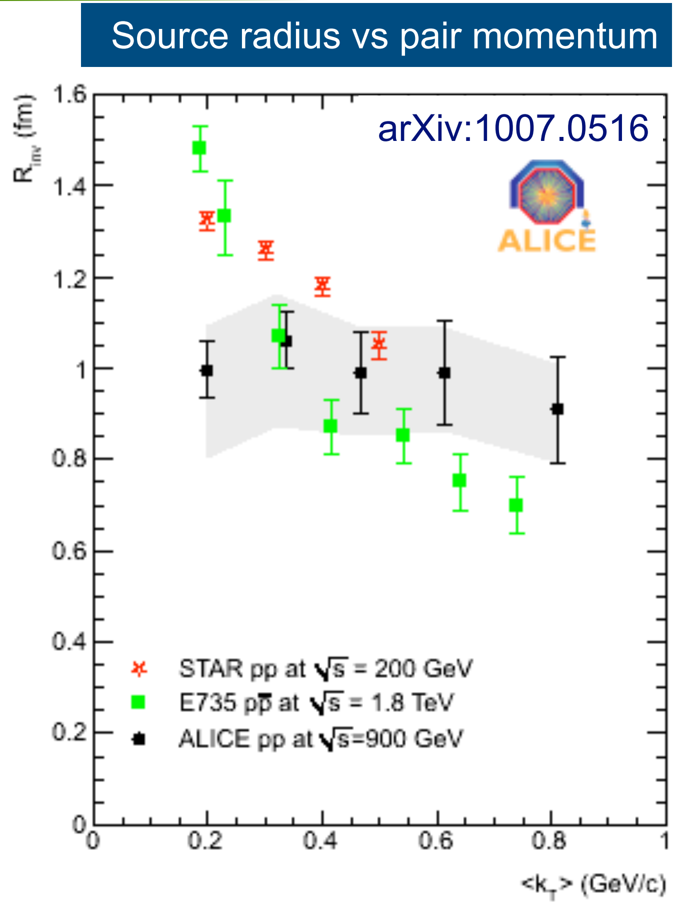
p-p collisions at 7 TeV

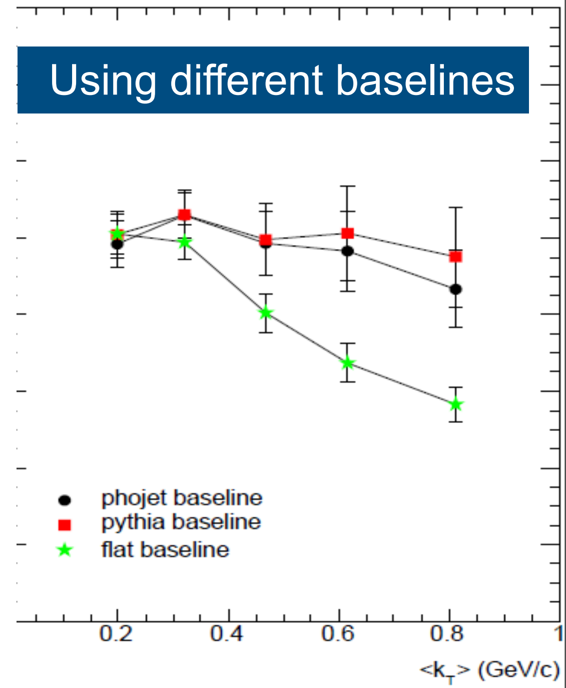
- Diffraction is essentially unknown
- Hadron-level definition of events (similar to ATLAS: Phys. Lett. B 688 (2010) 21)
- All events that have at least one charged primary particle in $|\eta|<1$ "INEL>0"
- Minimizes model dependence

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







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 √s) !