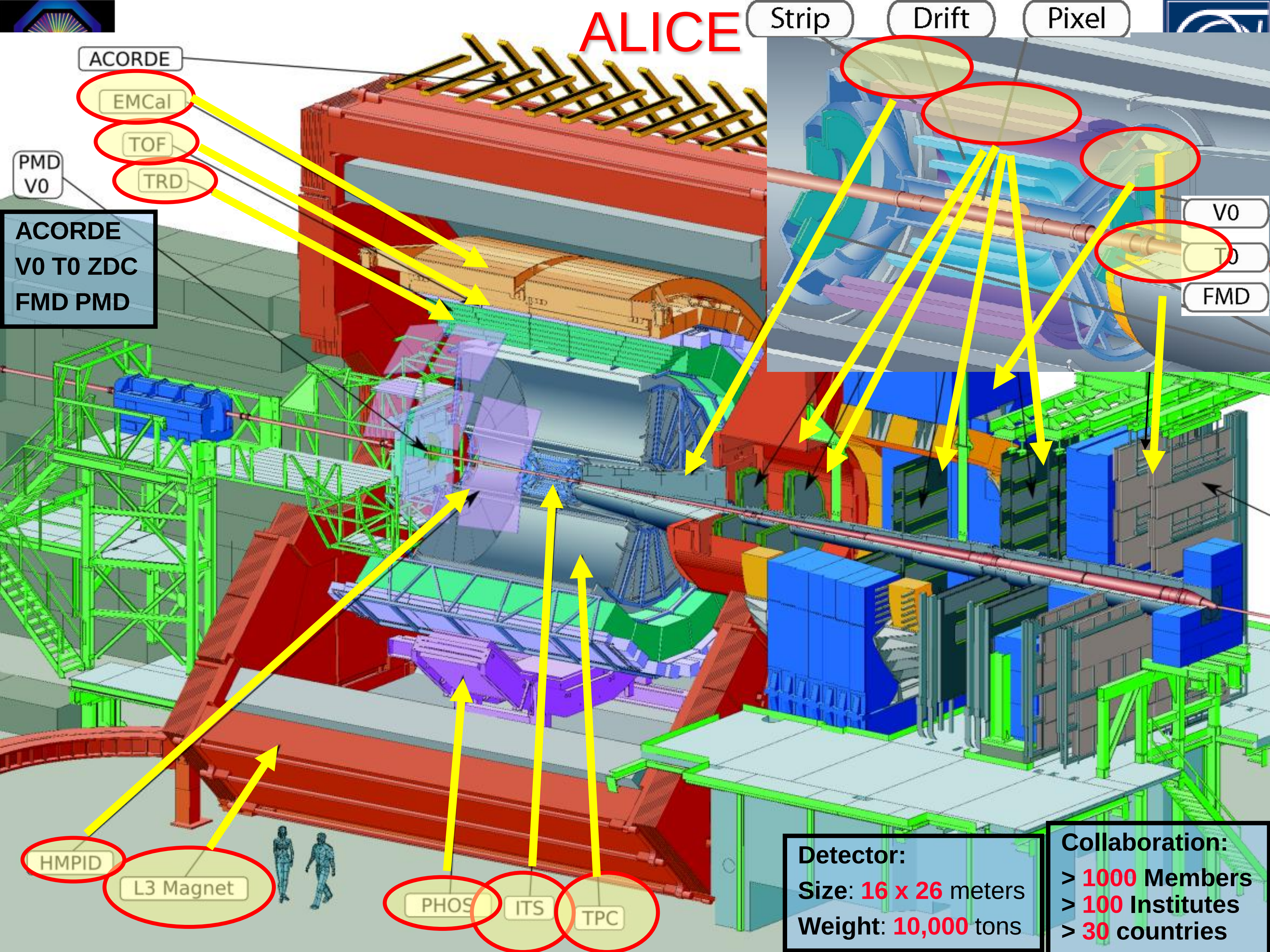
ALICE – results
and
heavy-ion overview

for the ALICE collaboration

Karel Šafařík, CERN

- Detector status and data taking
- Results on pp collisions
- Ongoing analyses
- Preparation for heavy-ion running

ALICE



ACORDE
V0 T0 ZDC
FMD PMD

Detector:
Size: 16 x 26 meters
Weight: 10,000 tons

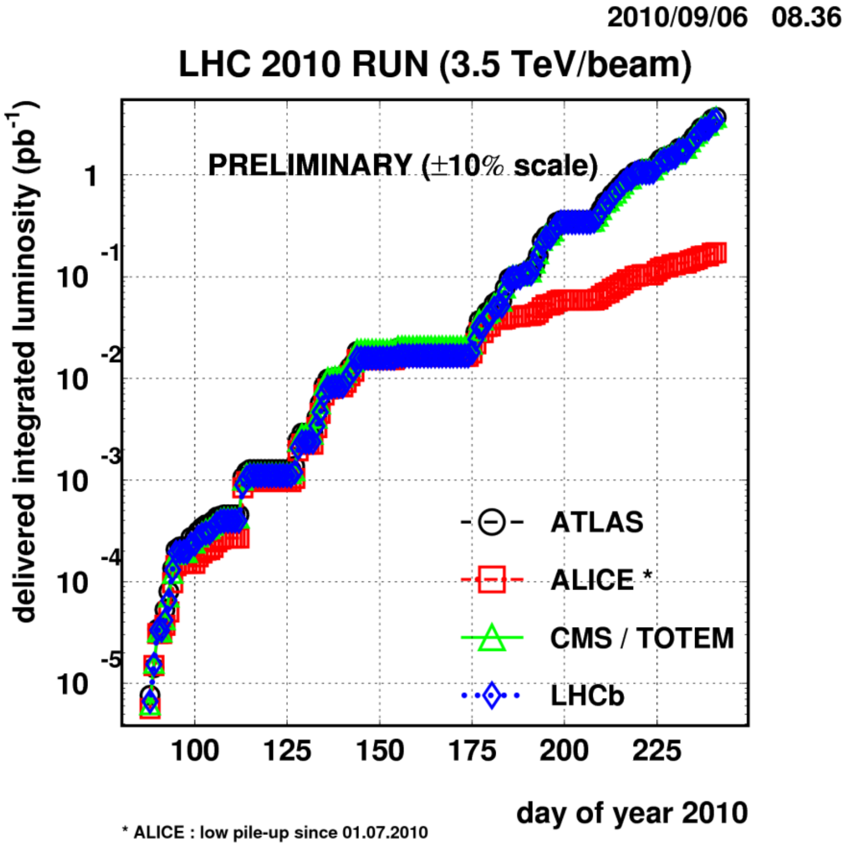
Collaboration:
- **> 1000 Members**
- **> 100 Institutes**
- **> 30 countries**

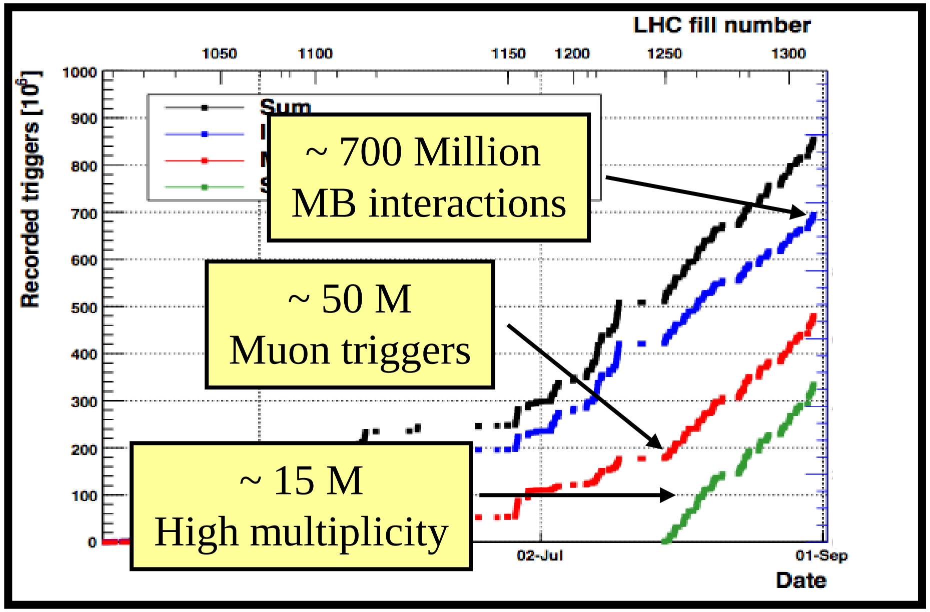
Data taking with pp collisions

Reduced luminosity since 01/07

⇨ **displaced beams (3.8σ)**

➔ **μ < 0.05 (low pileup)**

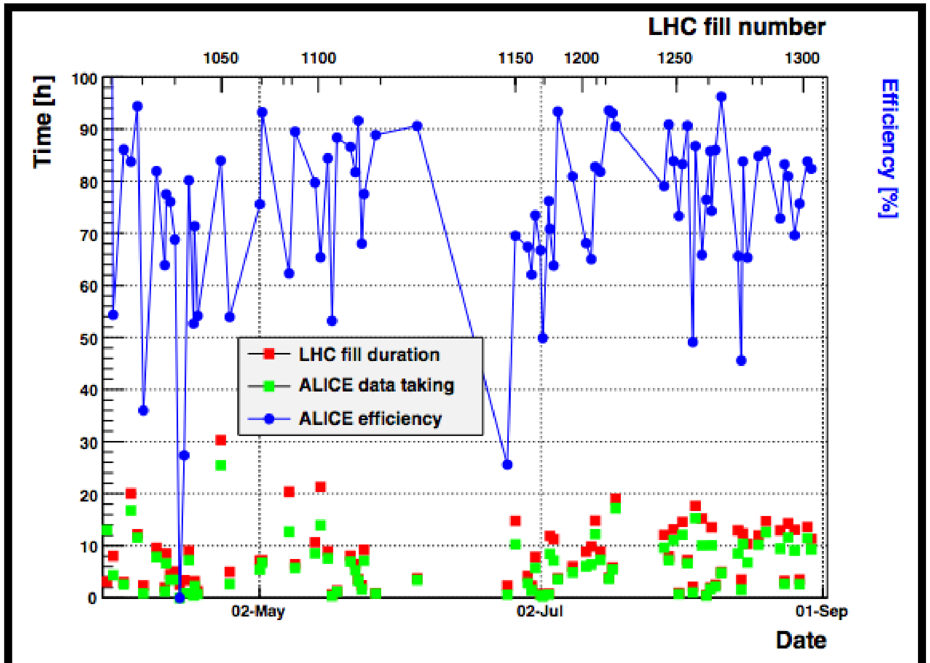




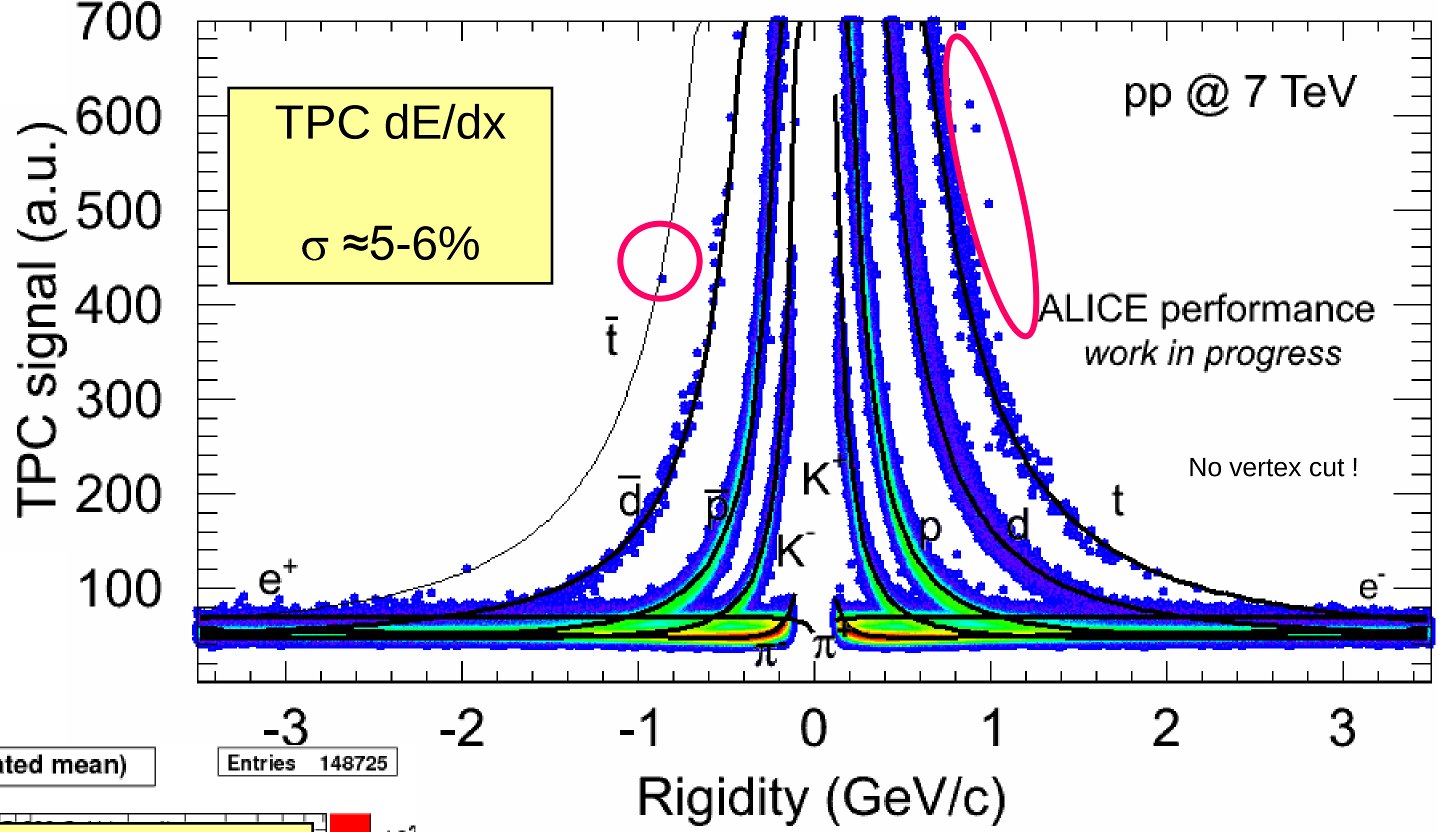
~ 700 Million MB interactions

~ 50 M Muon triggers

~ 15 M High multiplicity



PID detectors

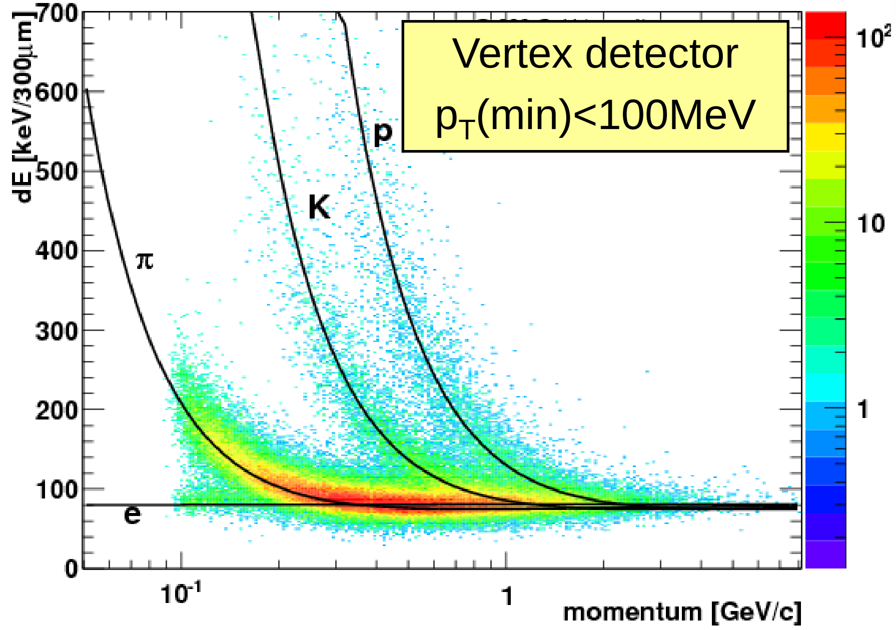


TPC dE/dx

σ ≈5-6%

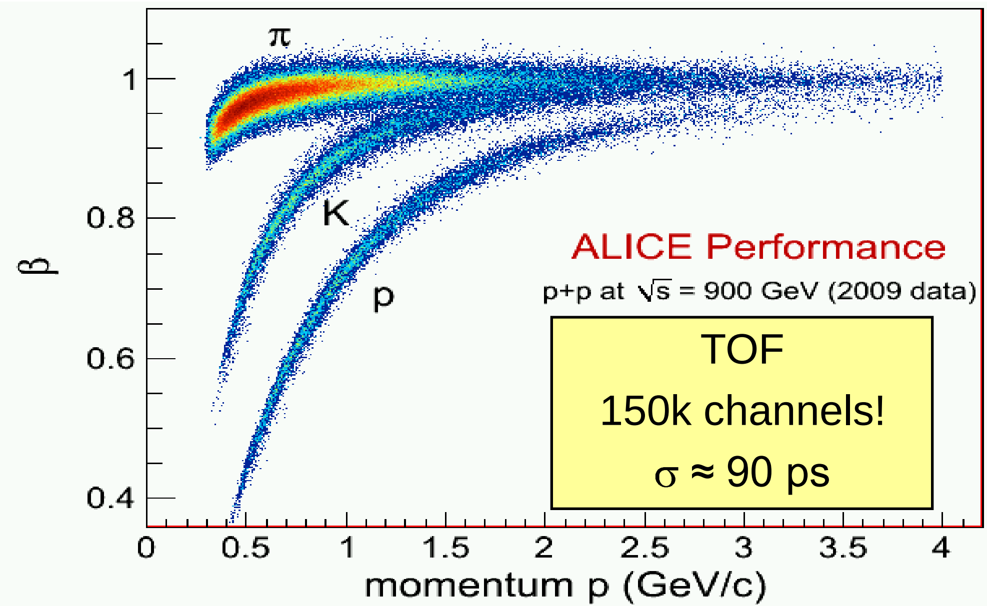
dEdX distribution (ITS signal, truncated mean)

Entries 148725



Vertex detector

p_T(min)<100MeV



TOF

150k channels!

σ ≈ 90 ps

Physics results with pp

Physics with pp

- **collect ‘comparison data’ for heavy-ion program**
  - **many signals measured ‘relative’ to pp**
  - **requires ~ 10^9 minimum-bias events**

- **comprehensive study of MB@LHC**
  - **tuning of Monte Carlo**

● Final Results

⇨ **N_{ch} multiplicity & distributions**

✪ 900 GeV:	EPJC: Vol. 65 (2010) 111
✪ 900 GeV, 2.36 TeV:	EPJC: Vol. 68 (2010) 89
✪ 7 TeV:	EPJC: Vol. 68 (2010) 345
⇨ **pbar/p ratio (900 GeV & 7 TeV)**	**PRL: Vol. 105 (2010) 072002**
⇨ **momentum distributions(900 GeV)**	**PL B: Vol. 693 (2010) 53**
⇨ **Bose-Einstein correlations (900 GeV)**	**PRD: Vol. 82 (2010) 052001**

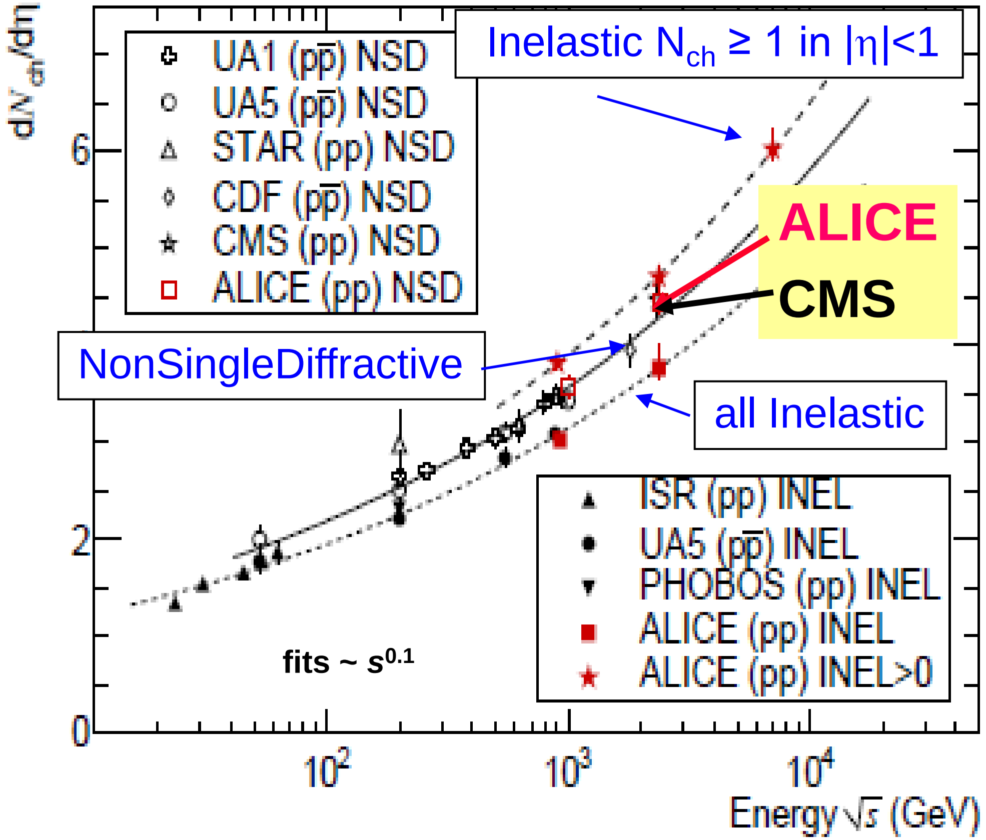
Physics results with pp

- Prepared for submission
  - ⇨ Identified particles (π,K,p)
  - ⇨ Strangeness (K^0,Λ,Ξ,Ω,ϕ)

- Ongoing analyses
  - ⇨ for 7 TeV pp multiplicity, spectra, HBT, identified particles, strangeness
    - ✪ high multiplicity
  - ⇨ π^0 and η transverse momentum spectra
  - ⇨ Heavy flavour: charm (D^0,D^+, D*), c,b –> μ, e^-
  - ⇨ J/ψ –> $\mu\mu$, e^+e^-
  - ⇨ pQCD: Event topology, 2-particle correlations, jet fragmentation, …

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

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



Inelastic $N_{ch} \geq 1$ in $|\eta|<1$

ALICE

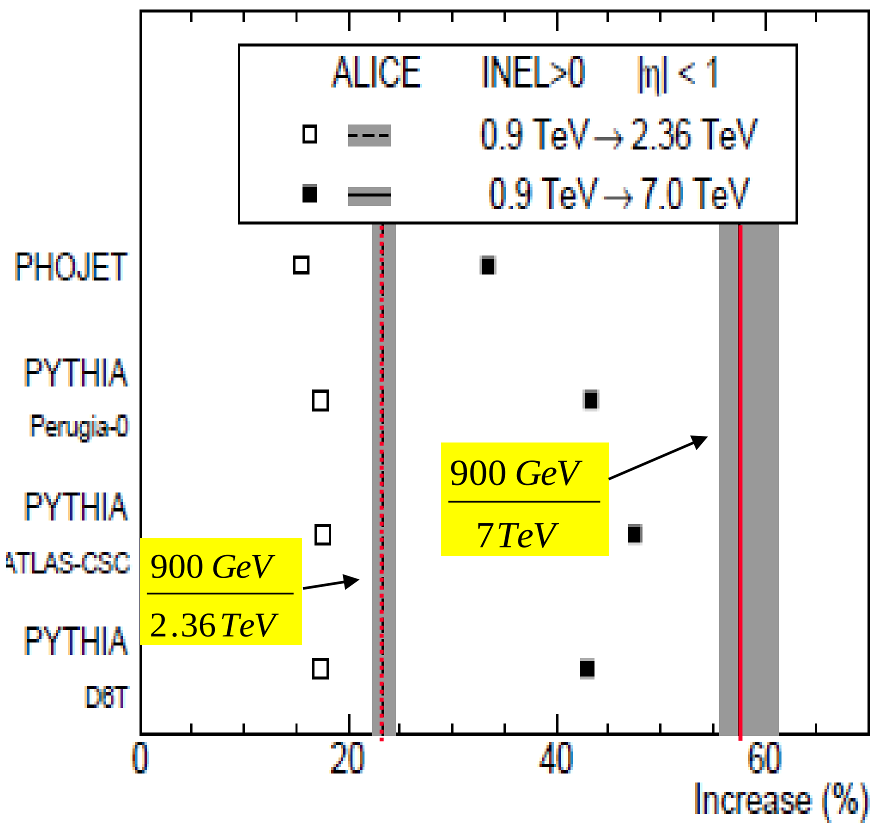
CMS

NonSingleDiffractive

all Inelastic

fits ~ $s^{0.1}$

Relative increase in $dN_{ch}/d\eta$



$\frac{900\ GeV}{7\ TeV}$

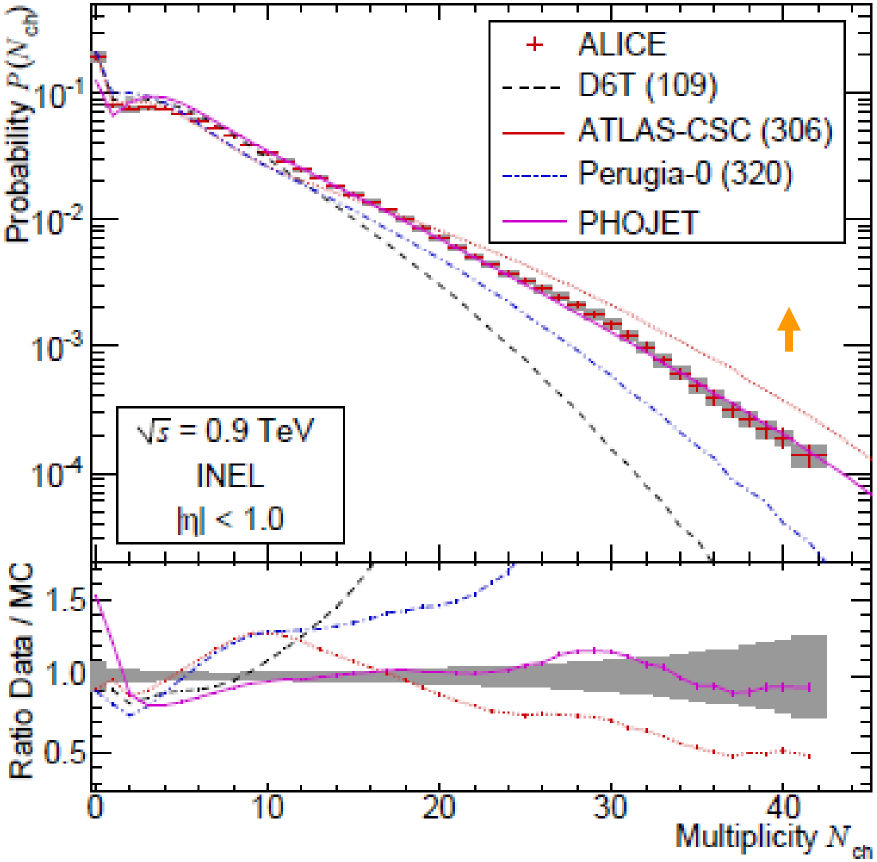
$\frac{900\ GeV}{2.36\ TeV}$

Results:

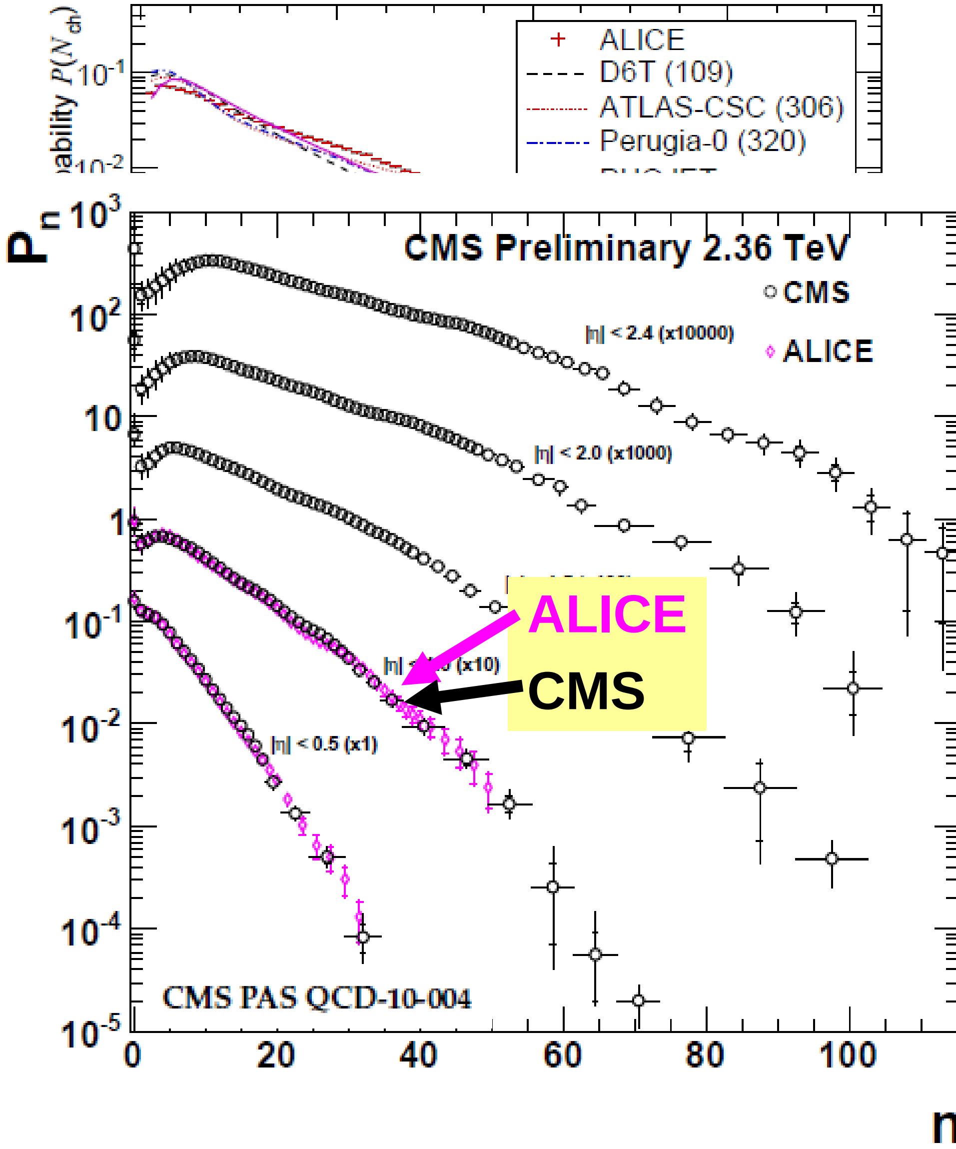
- $dN_{ch}/d\eta$ well described by power law $(\sqrt{s})^{0.2}$
- increase with energy significantly stronger in data than MC’s
- Alice & CMS agree to within 1 σ (< 3%)

Multiplicity distribution

Multiplicity distribution 900 GeV



Multiplicity distribution 7 TeV

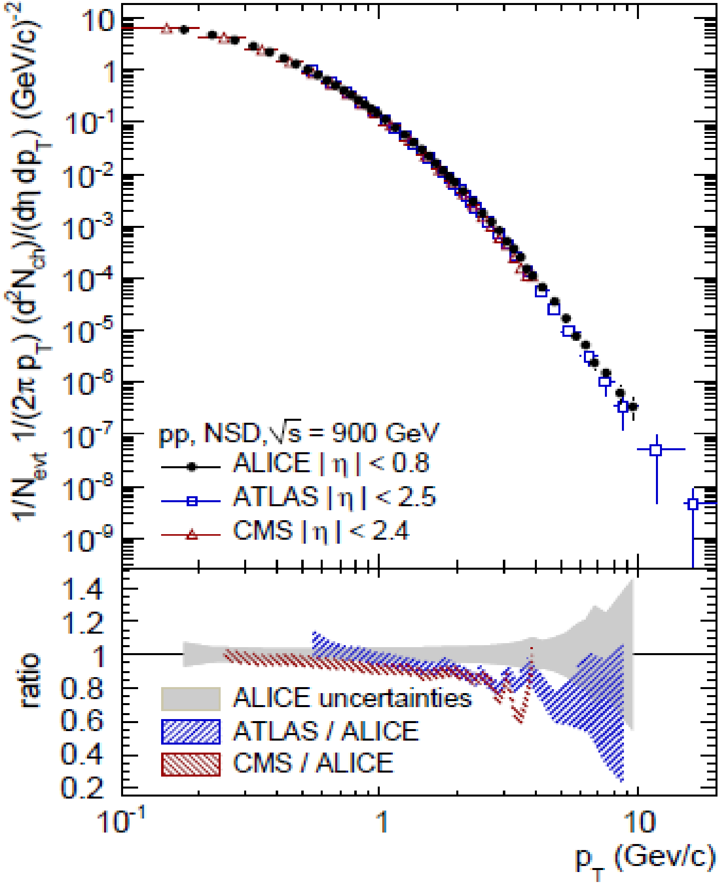


Results:

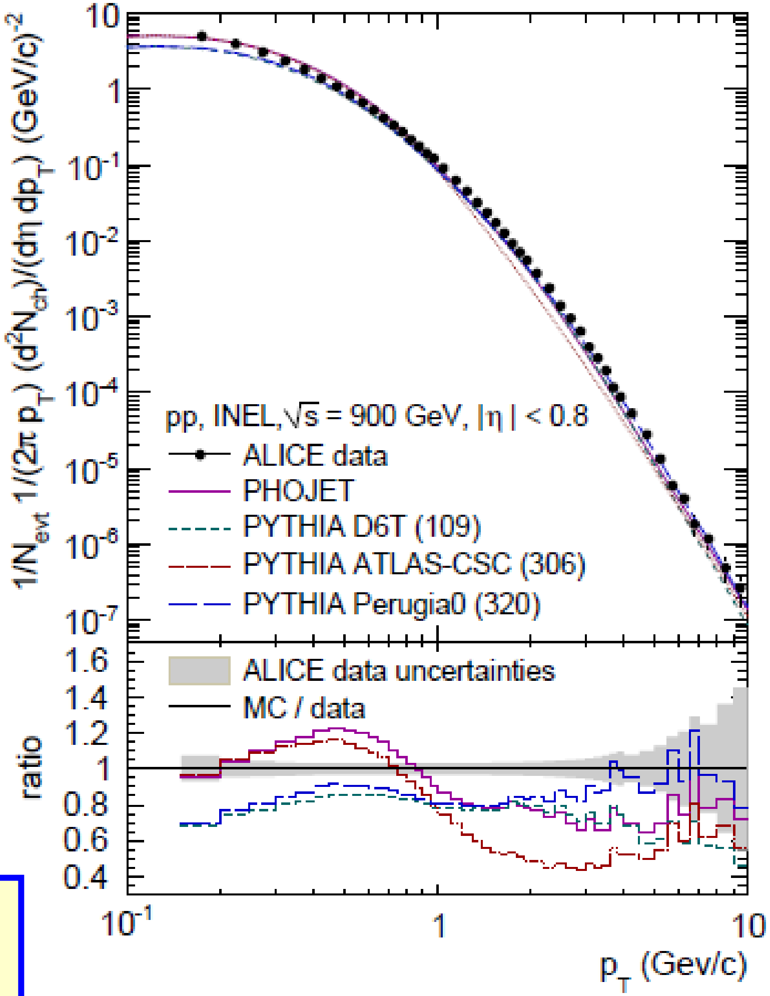
- most of the ‘stronger increase’ is in the tail of N_{ch}
- ALICE & CMS still agree perfectly !

Momentum distribution 900 GeV

p_T distribution



Comparison to MC’s

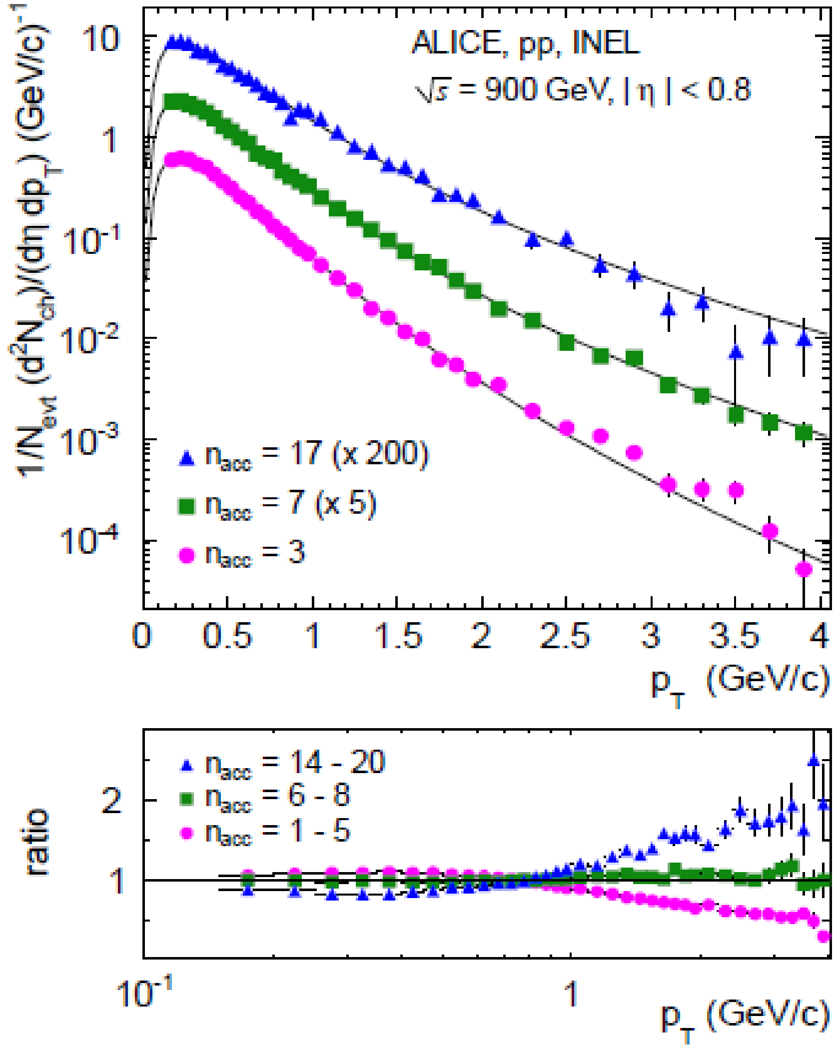


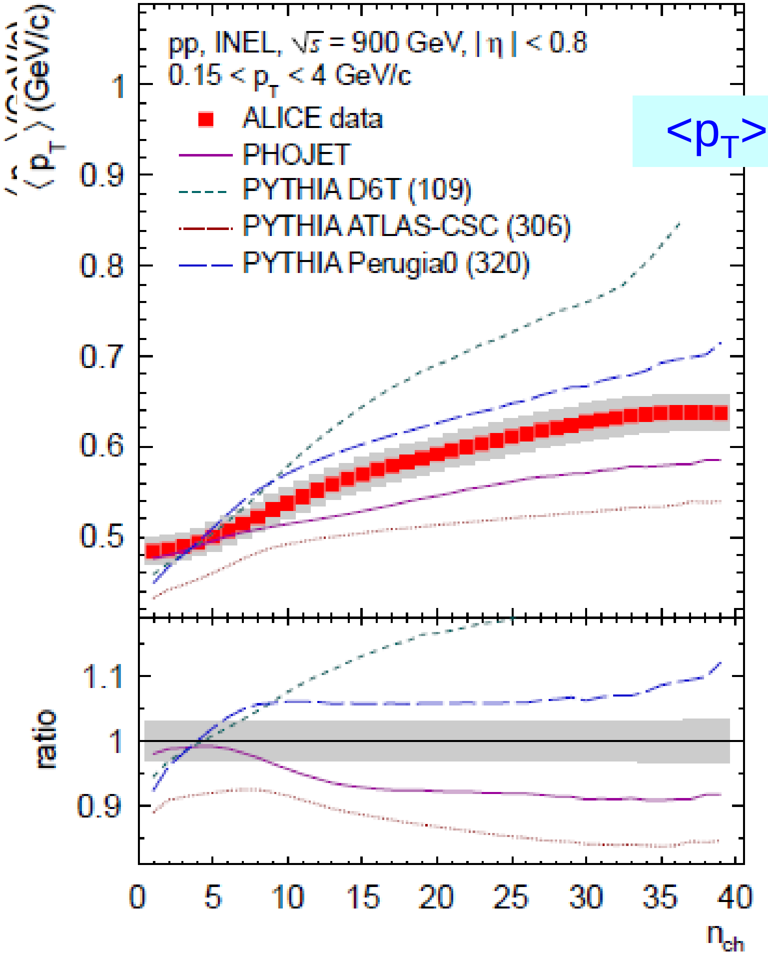
Results:

- Finally some (slight) difference !
- Spectrum seems to get harder towards midrapidity
- MC’s have hard time to describe the full spectrum

$<p_T>$ versus multiplicity

p_T for different multiplicities





$<p_T>$ vs N_{ch}

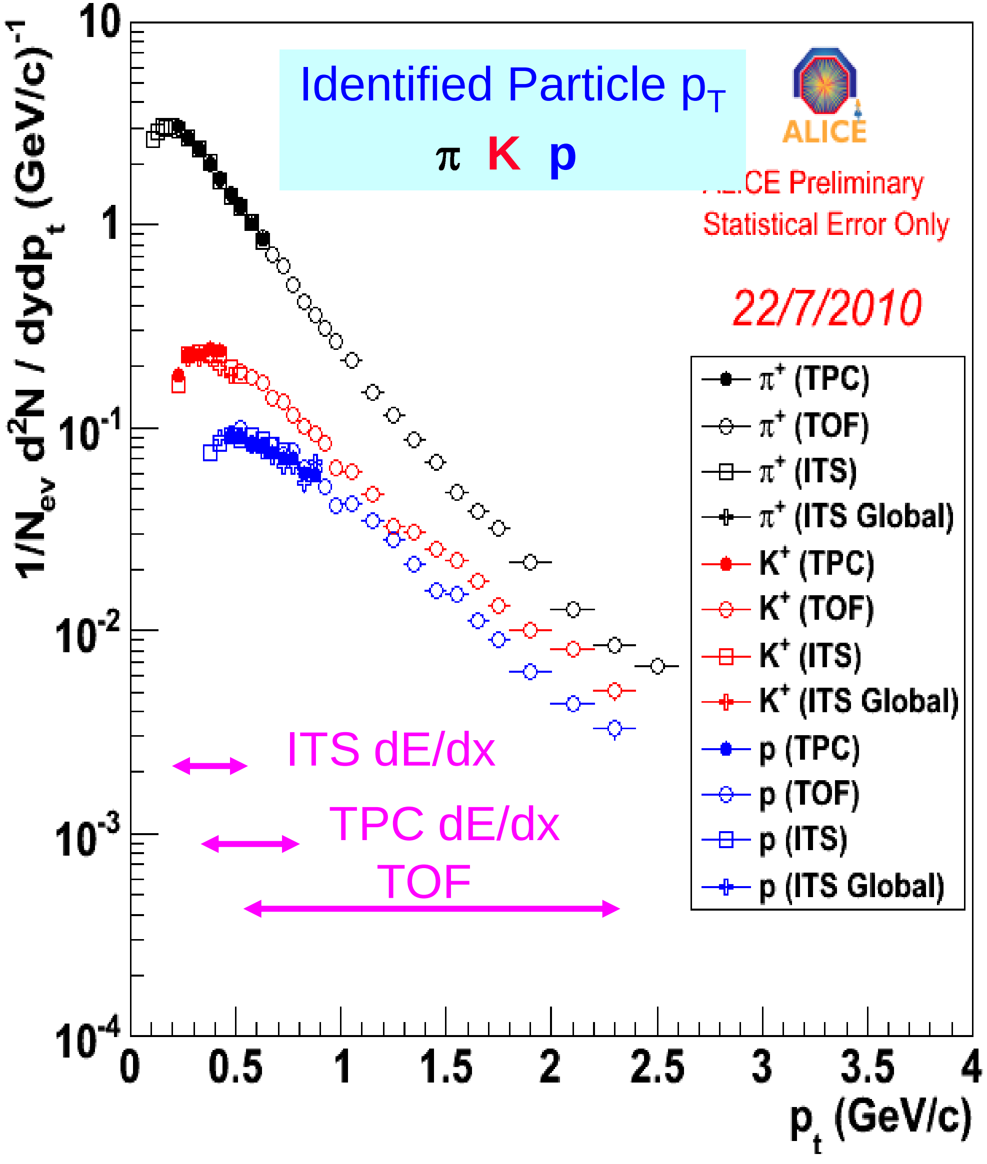
Results:

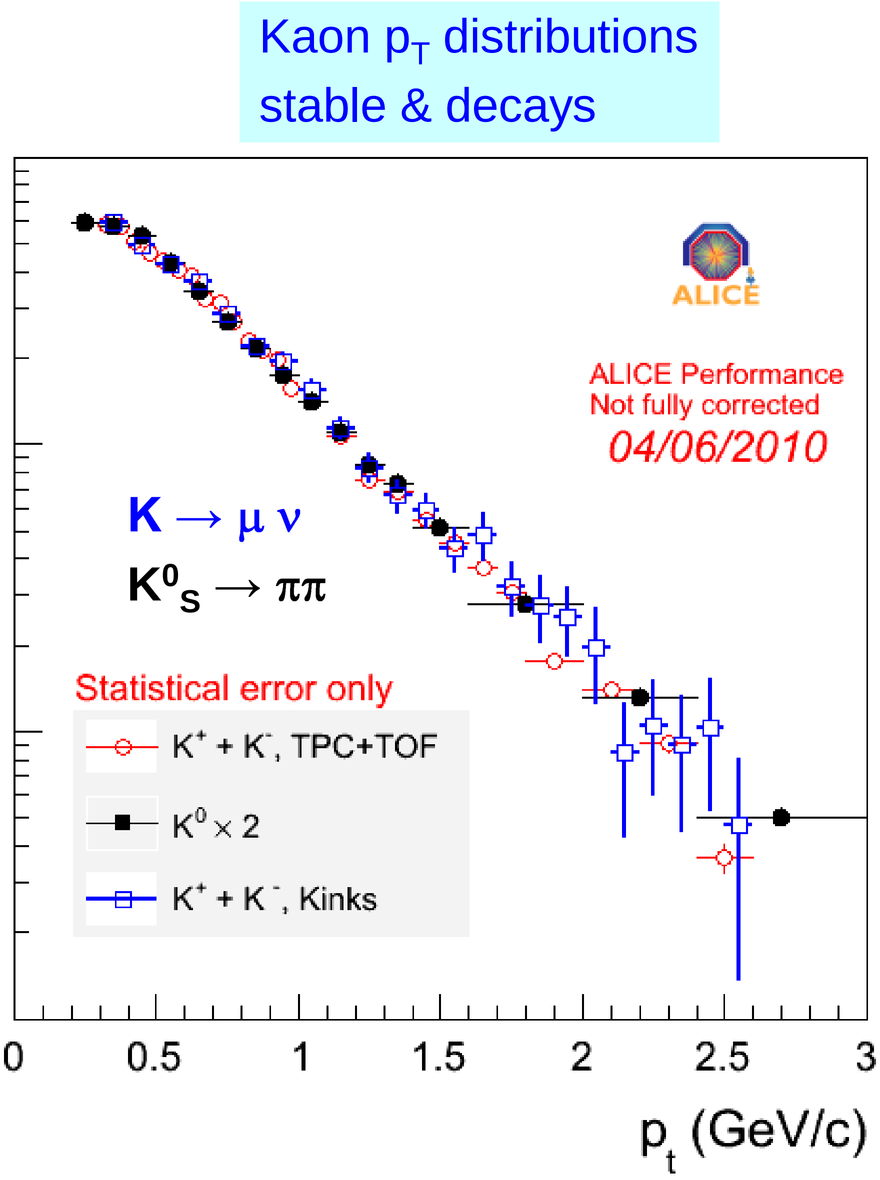
- Change concentrated at pt > 1 GeV (pQCD)

  (surprisingly little change below)

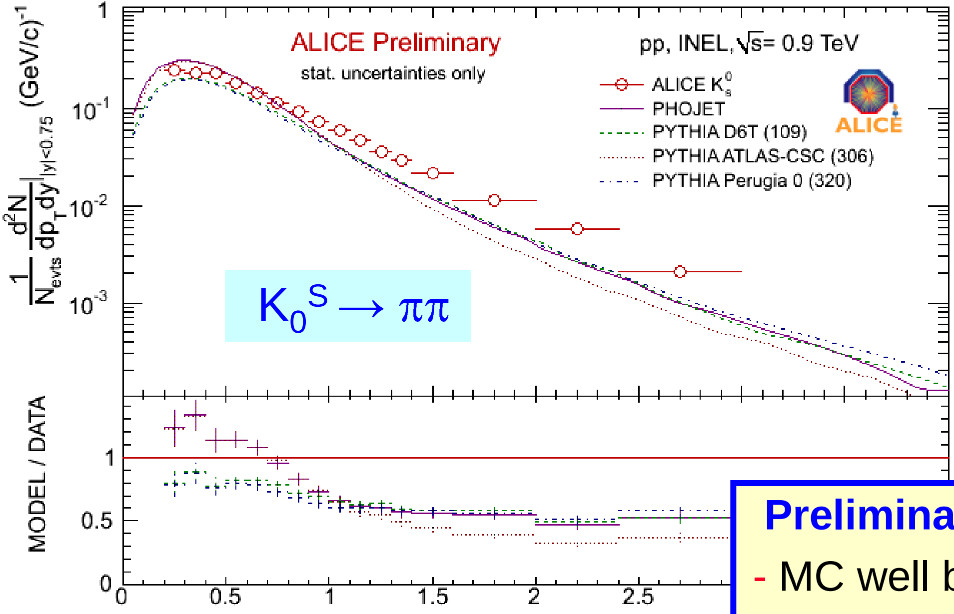
- MC's have hard time…

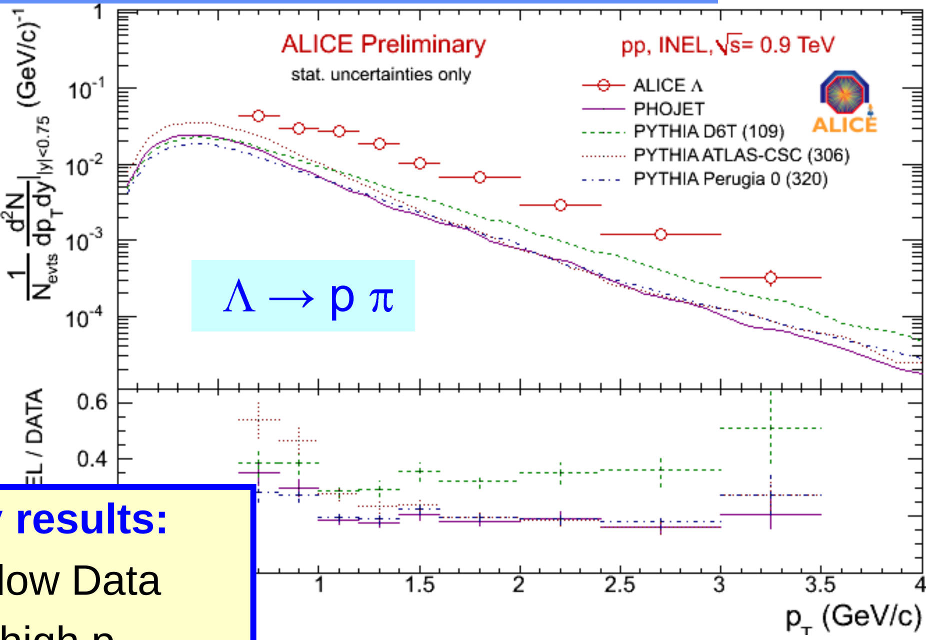
Identified particles





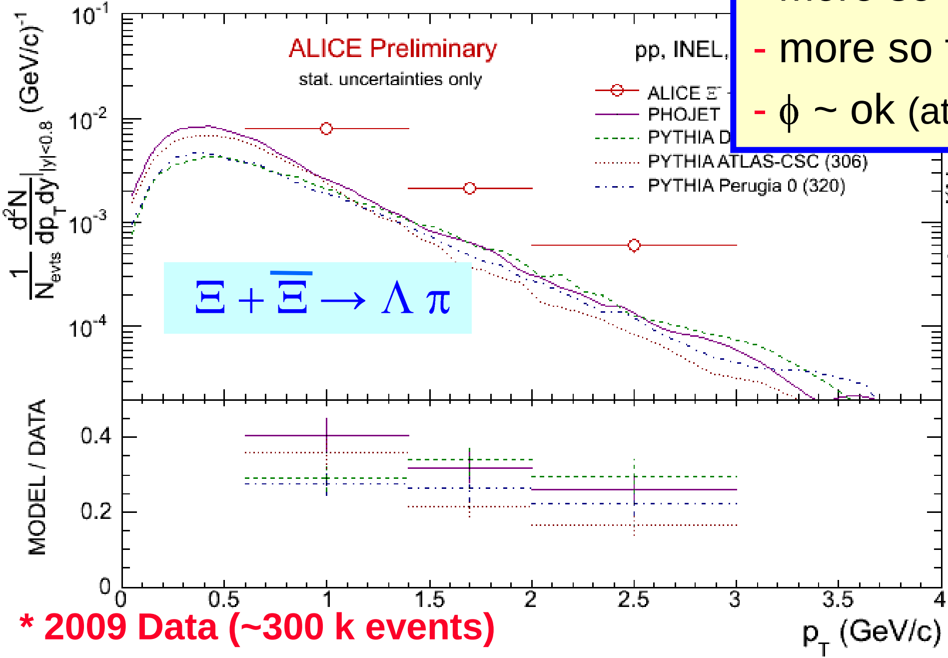
Decays: K_0^S, Λ, Ξ, ϕ at 900 GeV *

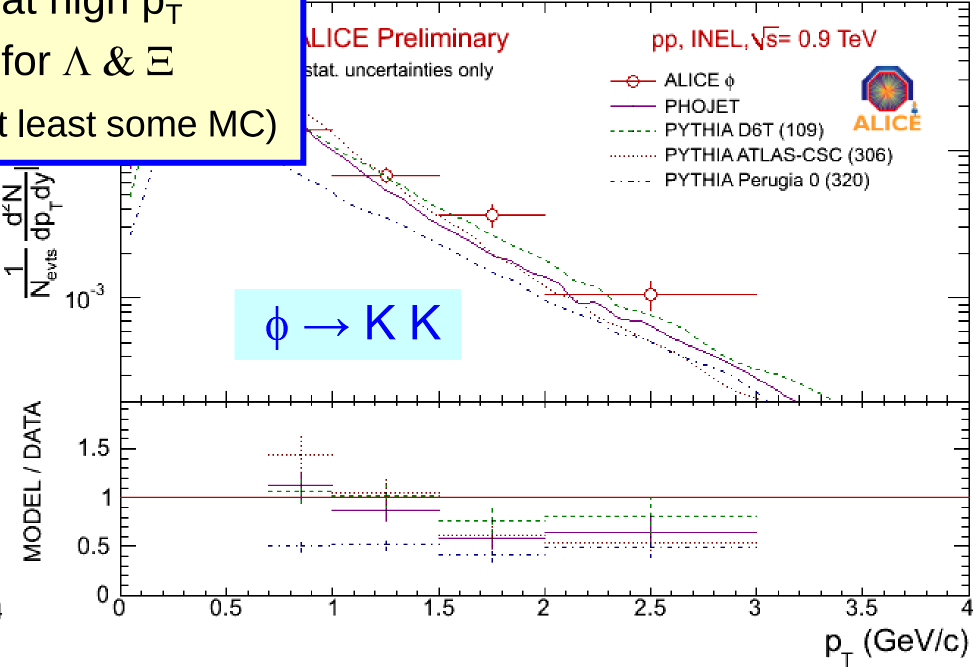




Preliminary results:

- MC well below Data
- more so at high p_T
- more so for Λ & Ξ
- ϕ ~ ok (at least some MC)

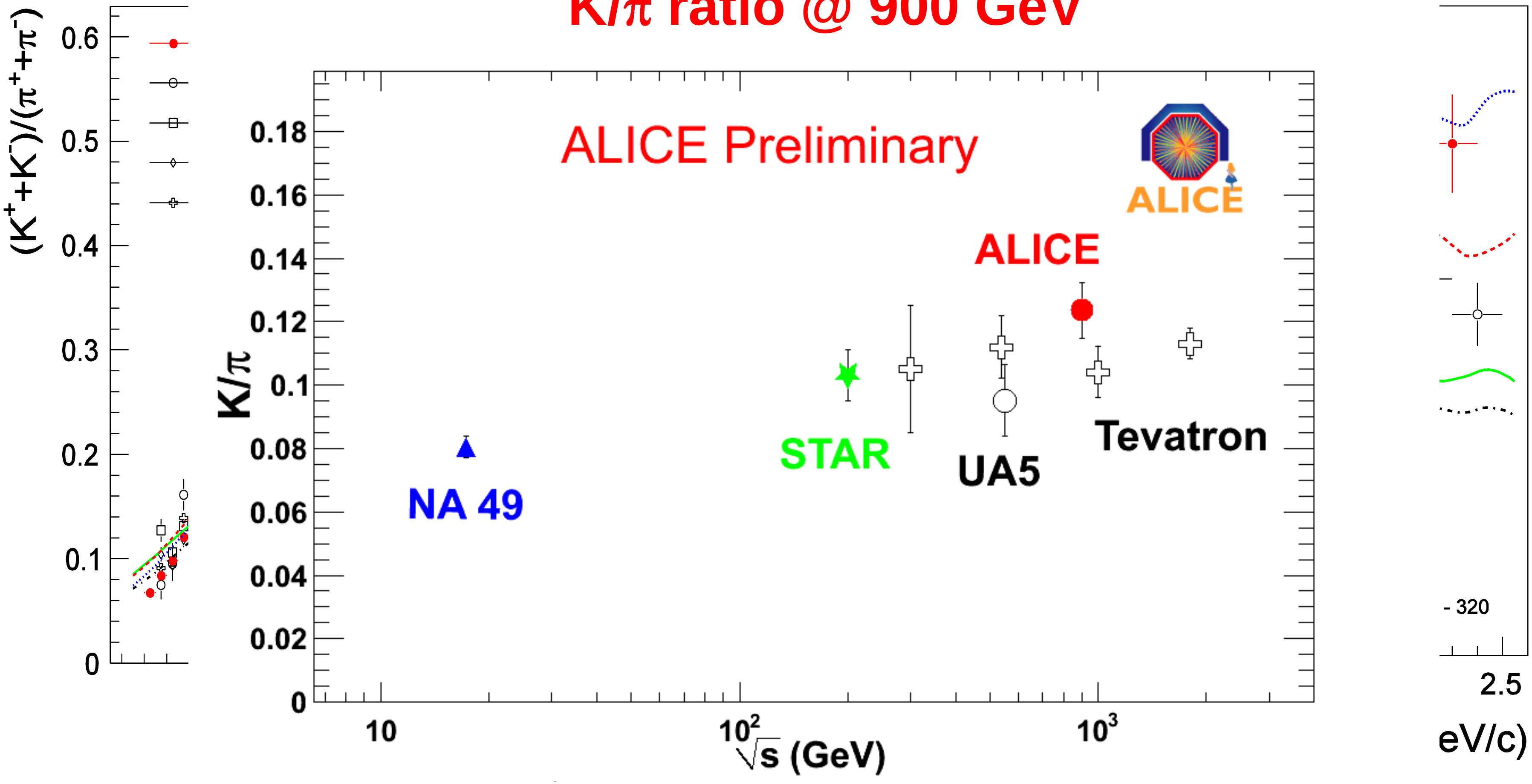




* 2009 Data (~300 k events)

Ratios as a function of p_t

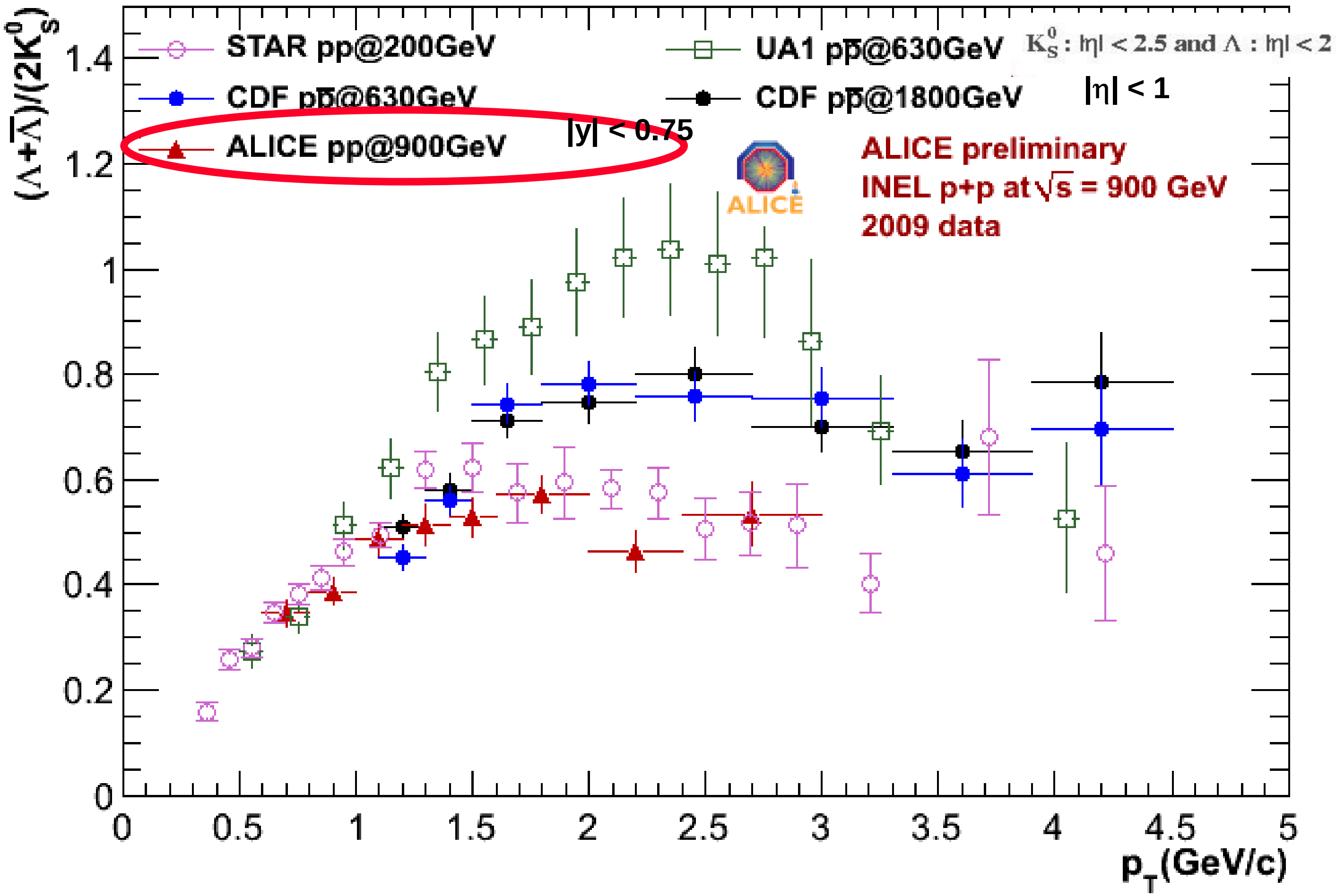
K/π ratio @ 900 GeV



Not a very good agreement with event generators

K/π practically independent on √s

Λ/K_0^S ratio @ 900 GeV

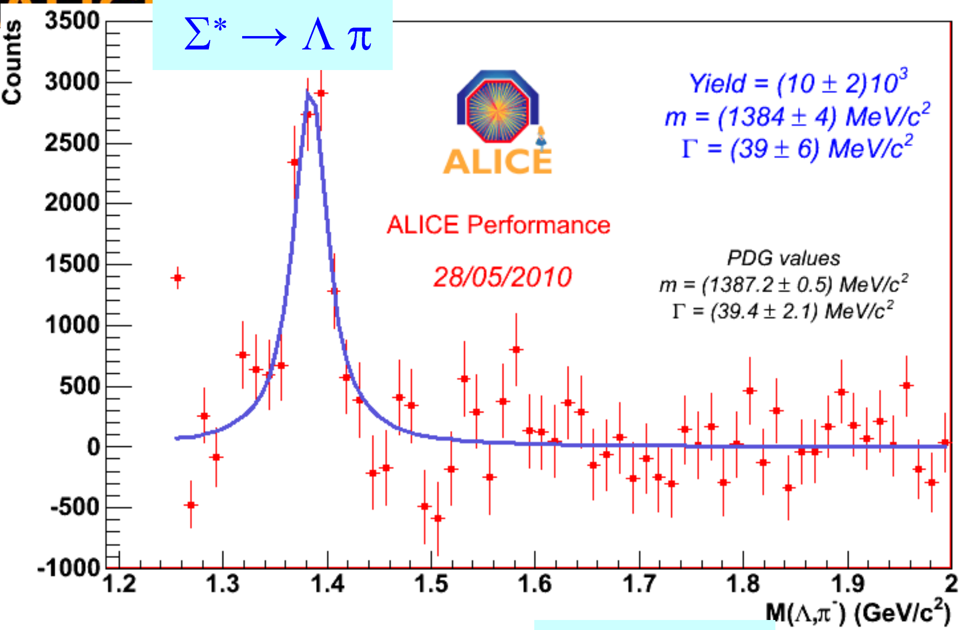


- very good agreement between STAR (200 GeV) and ALICE (900 GeV)
- very different from CDF (630/1800) and UA1 (630) for p_T > 1.5 GeV
- UA1(630) and CDF(630) don't agree either …

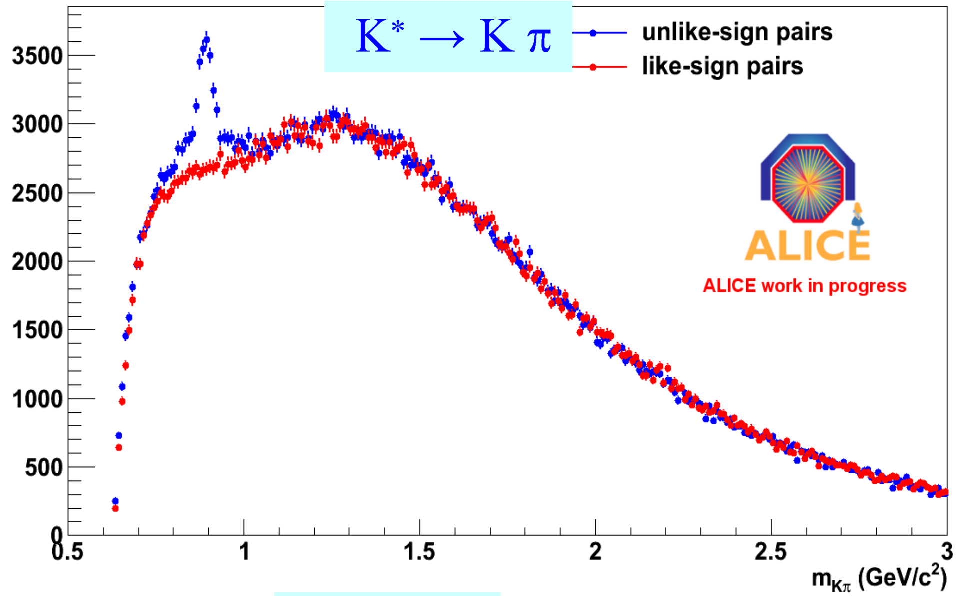
to be further investigated (different triggers, acceptance, feed-down correction ?)

…and much more to come…

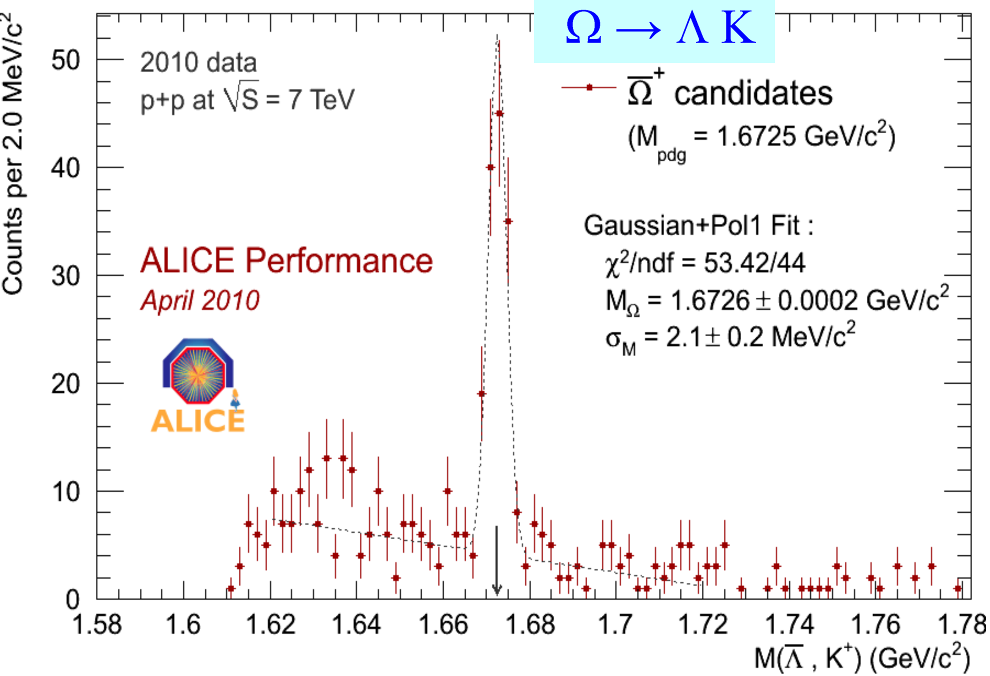
$\Sigma^* \rightarrow \Lambda\,\pi$



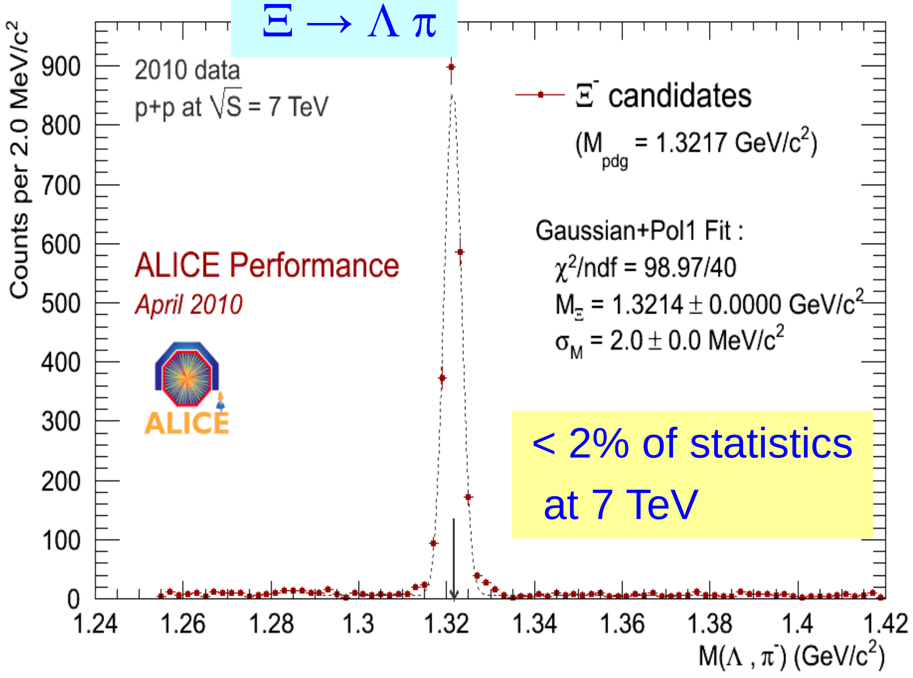
$K^* \rightarrow K\,\pi$



$\Omega \rightarrow \Lambda\,K$



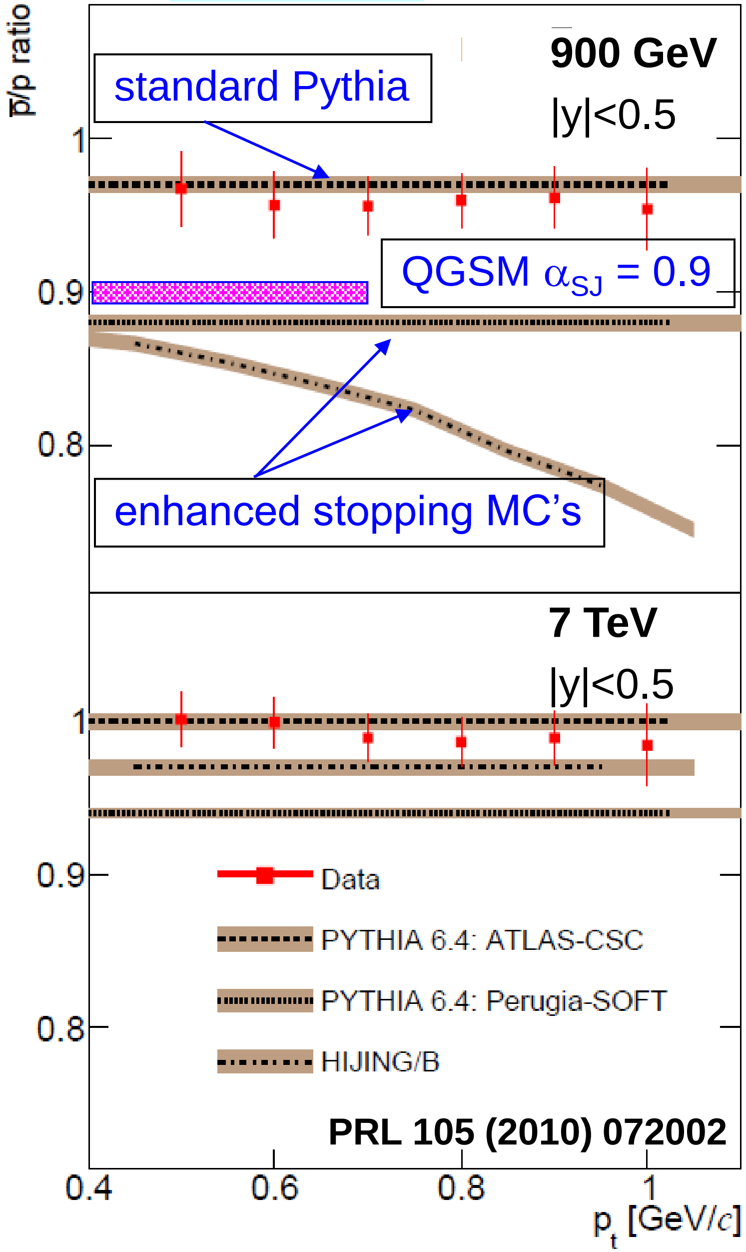
$\Xi \rightarrow \Lambda\,\pi$



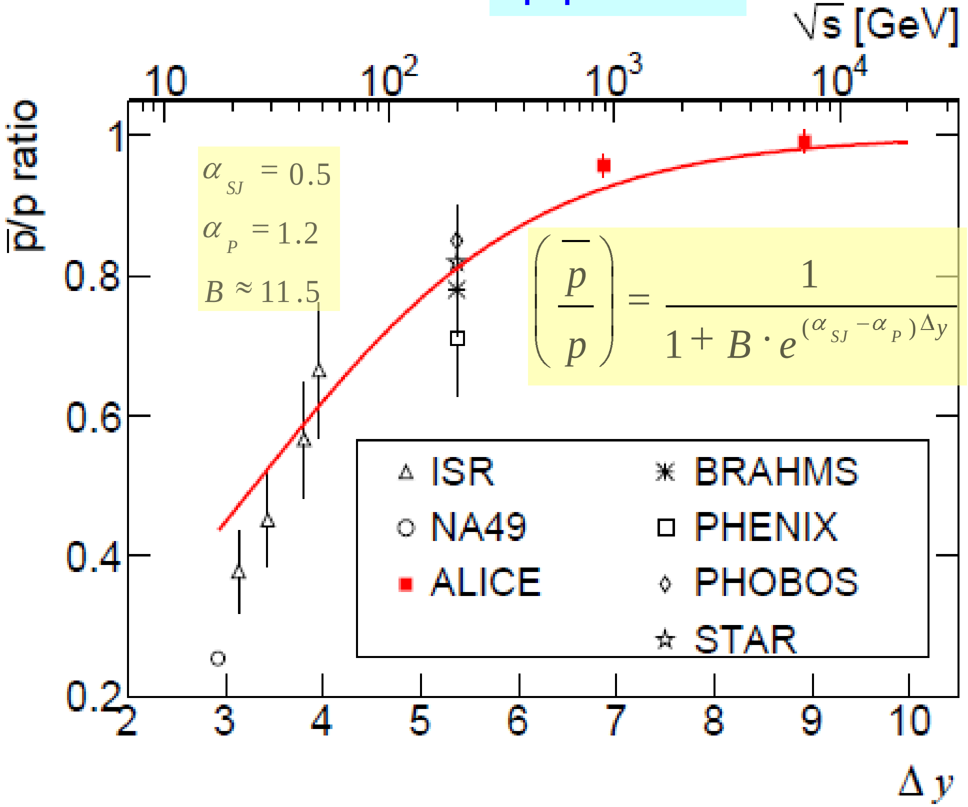
< 2% of statistics
at 7 TeV

$\bar{p}$/p ratio @ LHC

$\bar{p}$/p vs p_T



$\bar{p}$/p vs $\sqrt{s}$



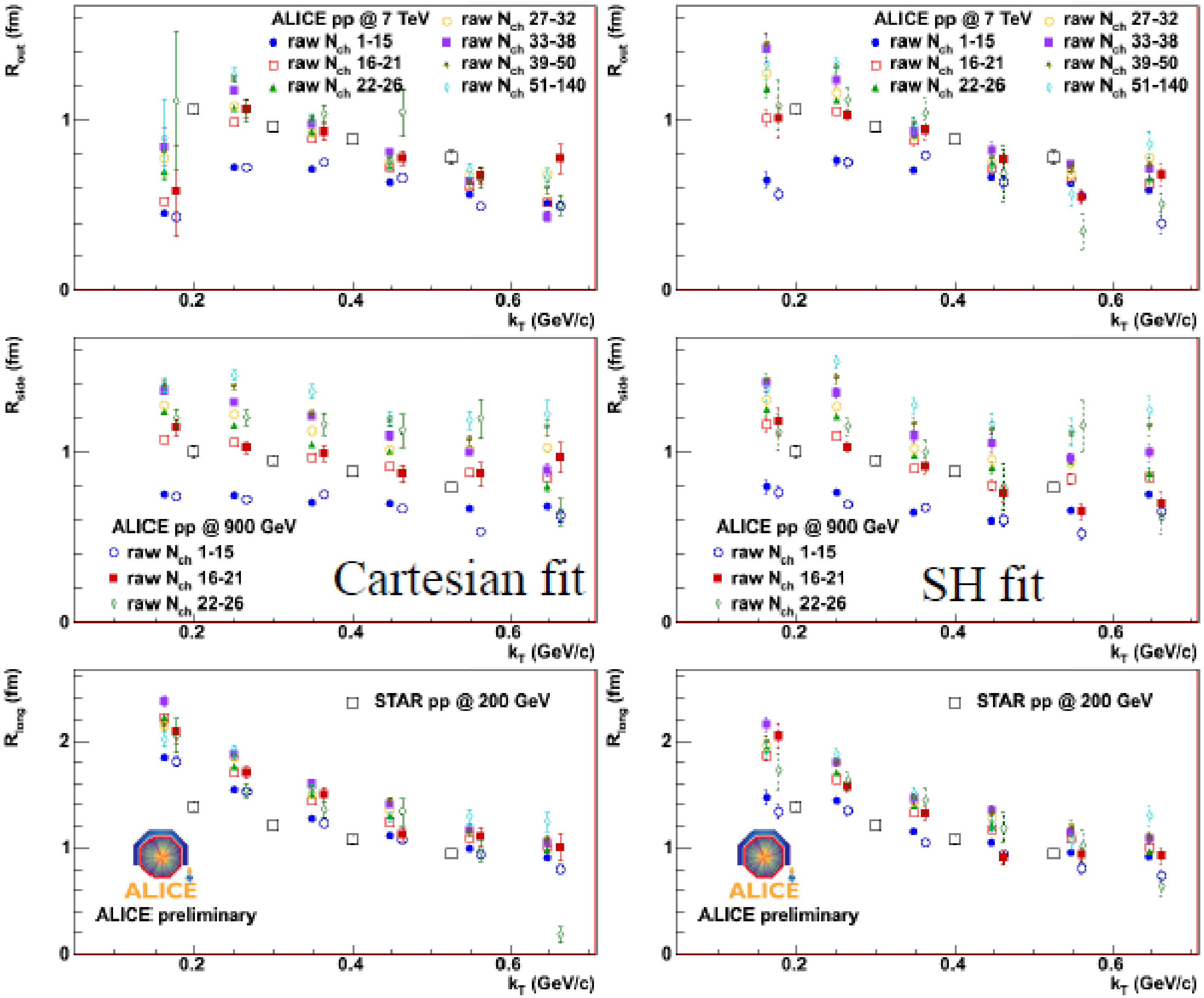
Results:

- you can't stop a proton on its track (at least not at LHC)
- 'string junction' picture: α_{SJ} **≈ 0.5** (G.V. was right !)
- little room for **any** additional diagrams which transport baryon number over large rapidity gaps

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

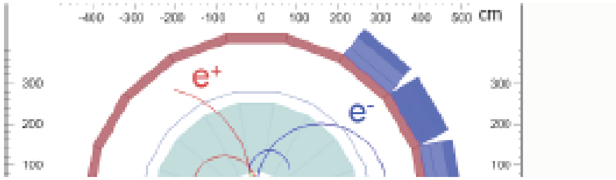
7 TeV: $\bar{p}$/p = **0.990**±0.006(stat) ±0.014(syst)

HBT 3D radii vs. kt



- Gaussian radii in LCMS grow with multiplicity, fall with k_T
- Fall with k_T very prominent for R_{long} , develops with multiplicity for R_{out} , less pronounced for R_{side}
- Radii comparable to STAR (EMCICs fit)

π^0 and η from γ conversion

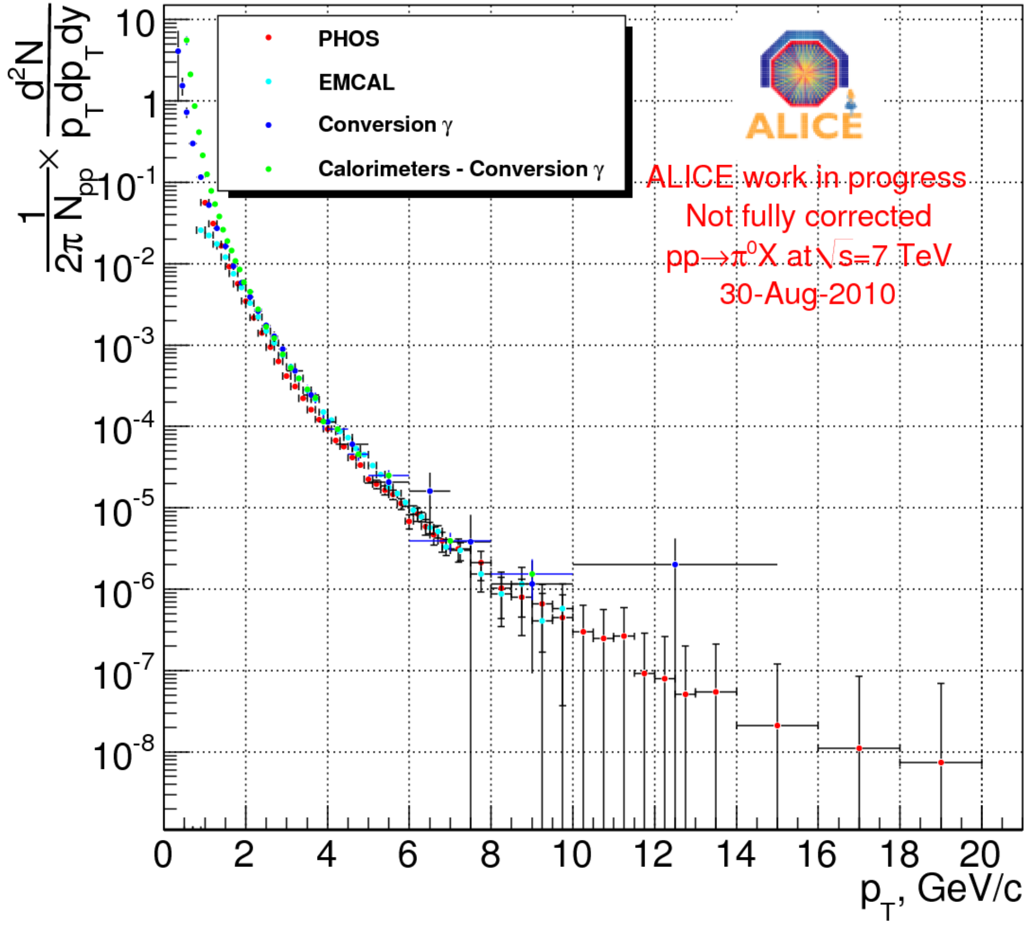


- e identification in TPC (TRD soon)
- study of γ conversion points/material budget

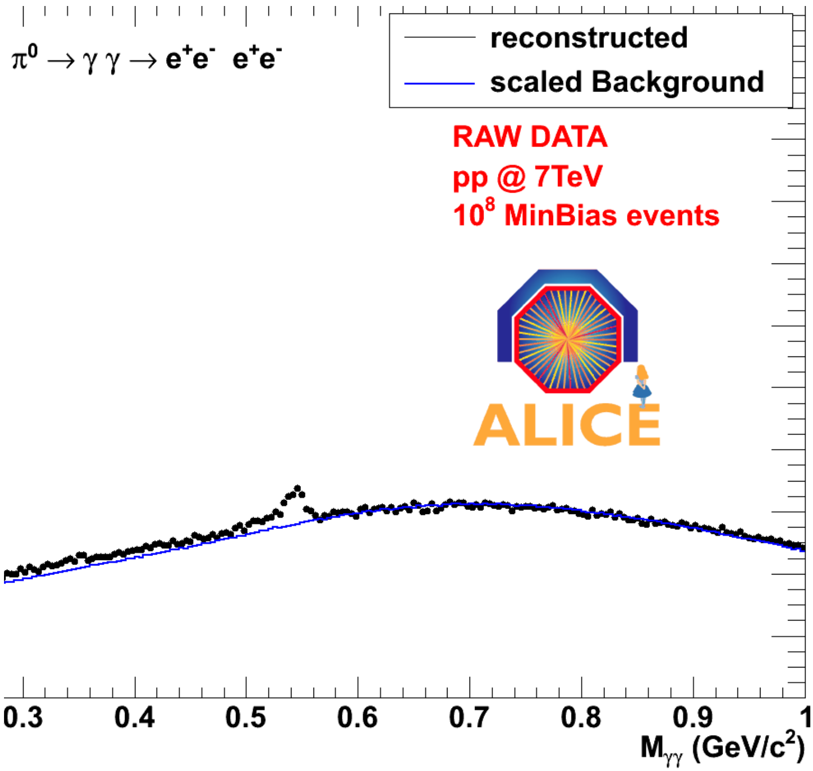
and PHOS, calibration in

ss

π^0 production spectrum

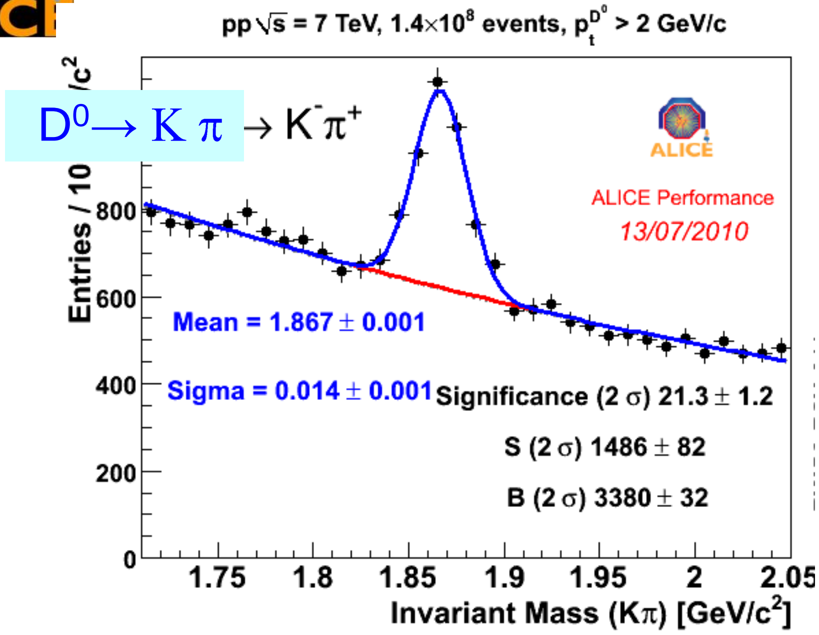


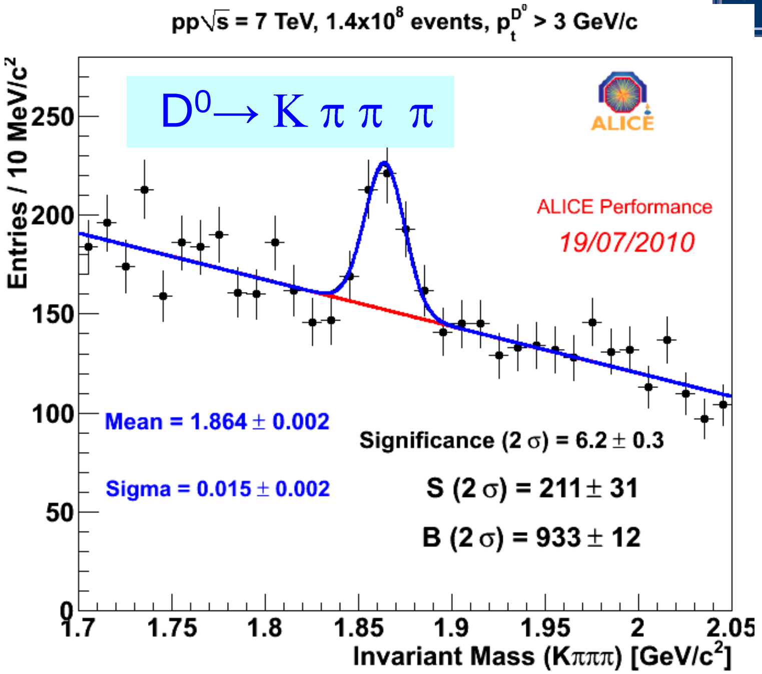
ALICE work in progress
Not fully corrected
$pp \rightarrow \pi^0 X$ at $\sqrt{s}$=7 TeV
30-Aug-2010

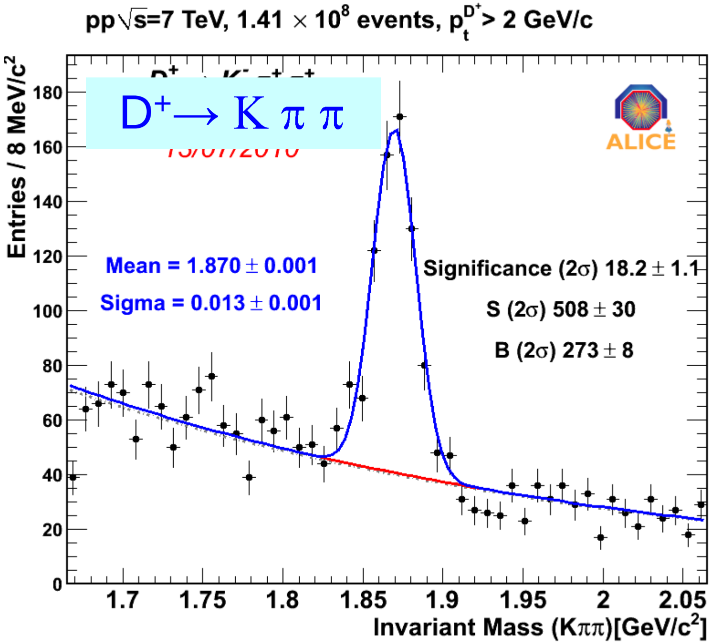


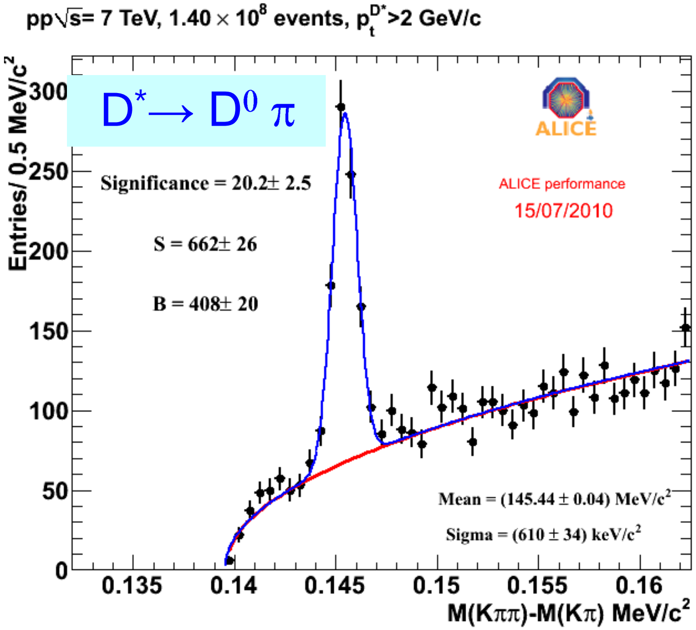
RAW DATA
pp @ 7TeV
10^8 MinBias events

Charm at 7 TeV

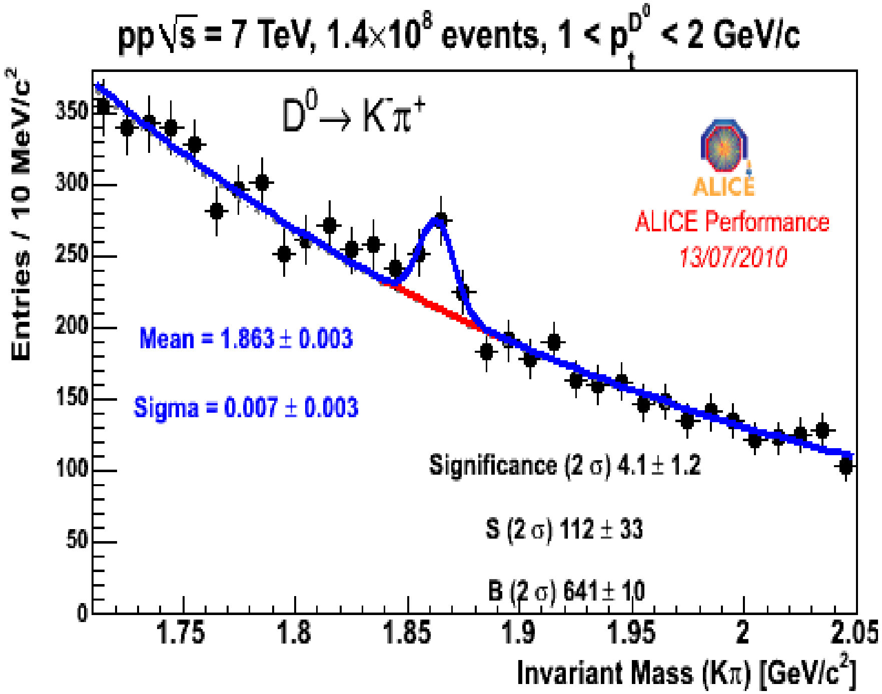

$D^0 \rightarrow K\,\pi$ $\rightarrow K^-\pi^+$

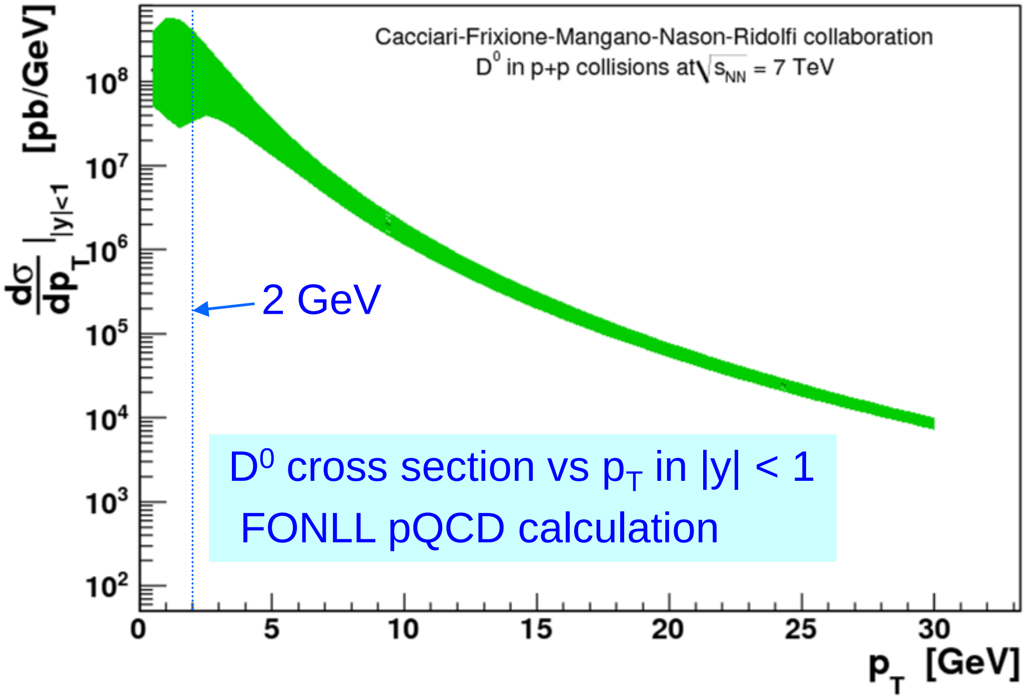

$D^0 \rightarrow K\,\pi\,\pi\;\;\pi$


$D^+ \rightarrow K\,\pi\,\pi$


$D^* \rightarrow D^0\,\pi$

Charm at very low p_T





D^0 cross section vs p_T in $|y| < 1$
FONLL pQCD calculation

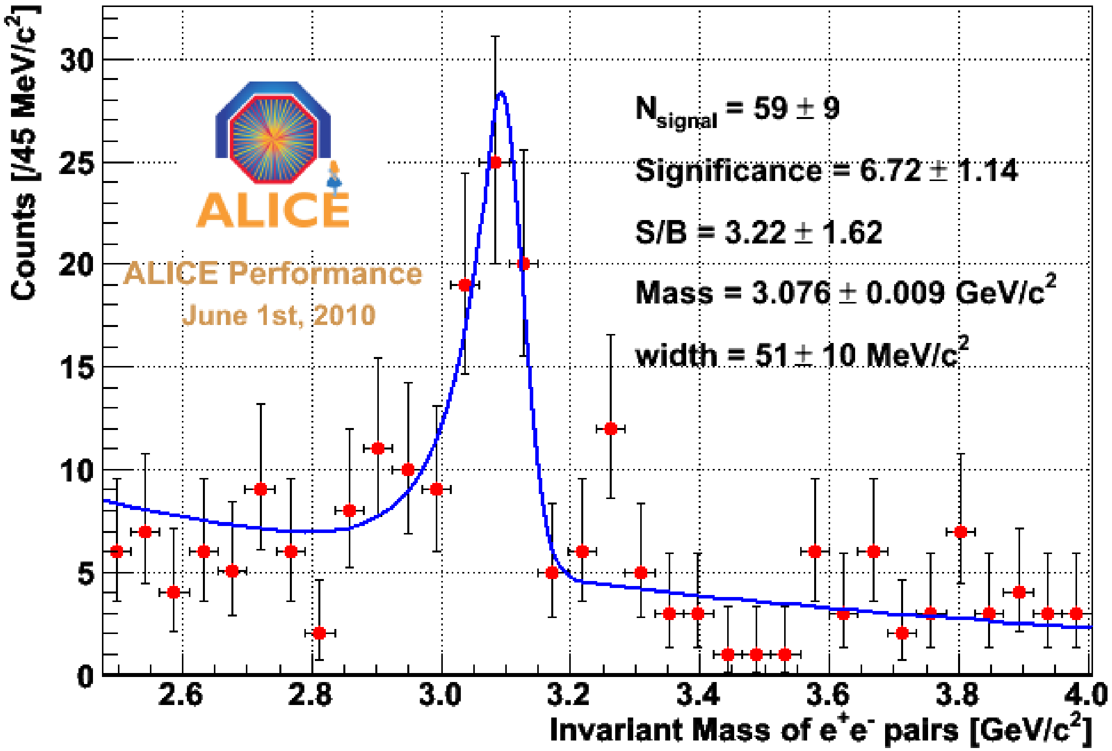
- most of the cross section at low p_T
- shape at low p_T very uncertain
- 10^9 MB events => measure below 1 GeV

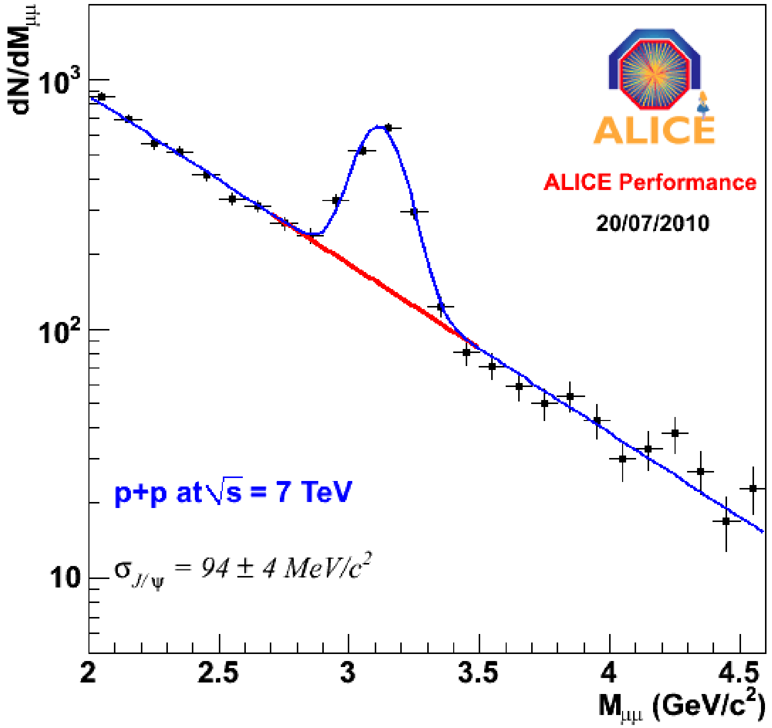
  (PID important at low p_T !)

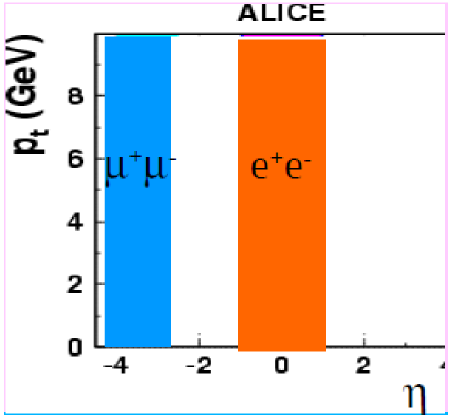
J/ψ @ 7 TeV

J/ψ → e^+e^- |y| < 1

J/ψ → $\mu^+\mu^-$, y = 2.5–4.1



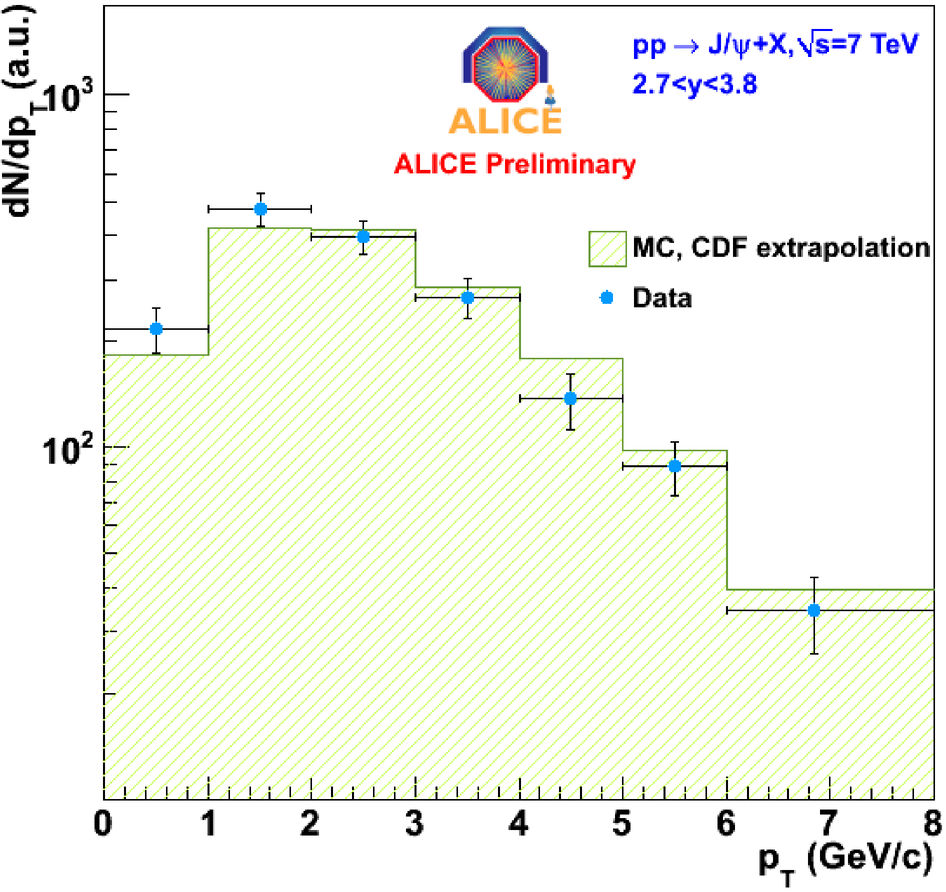


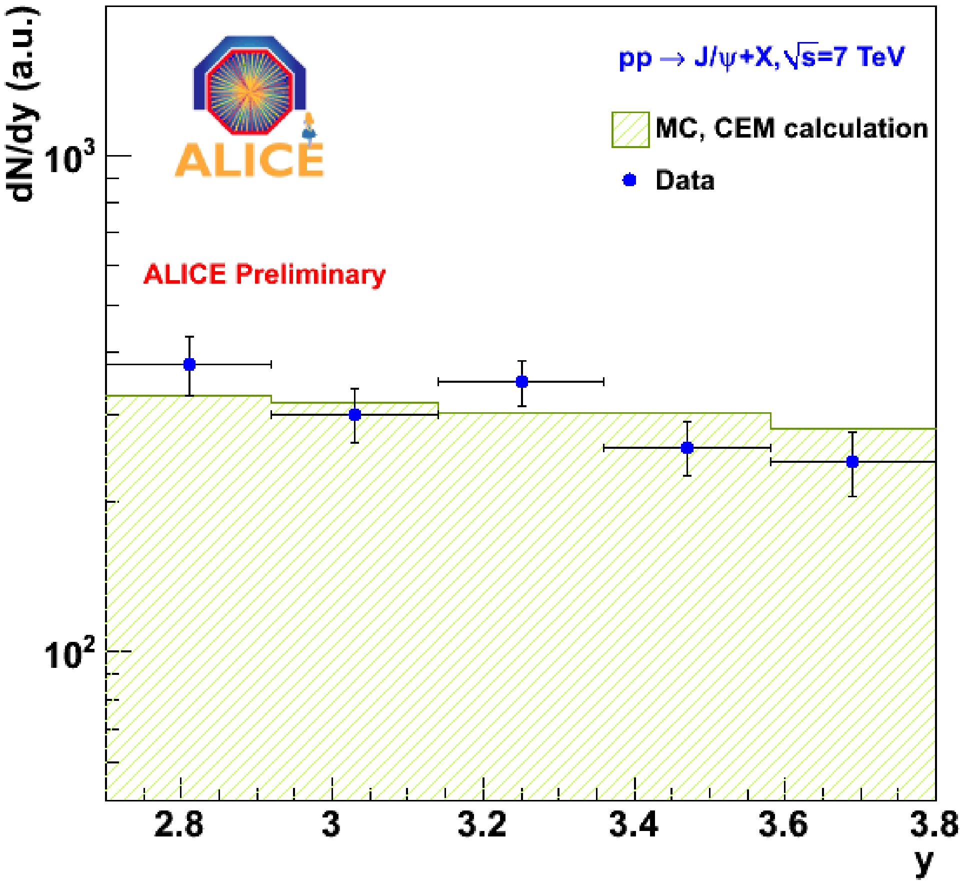


- tough to measure J/ψ with our current low luminosity
  (also 1st year Pb–Pb luminosity will be **very** low -> priority on MB in pp)
- ‘proof of performance’
  higher luminosity later this year and next year

$J/\psi \rightarrow \mu^+\mu^-$

The acceptance and efficiency corrected distributions are compared to generated MC distribution





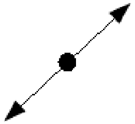
- **“CDF pp 7TeV” parameterization**
  - ⇨ **p_T extrapolated from CDF results**
  - ⇨ **y obtained from CEM calculations**
  - ⇨ **No polarization (λ = 0)**

Event shape analysis

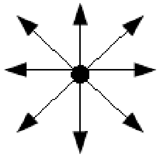
Transverse sphericity $S_\perp$:
eigenvalues of the momentum tensor S_{xy}

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

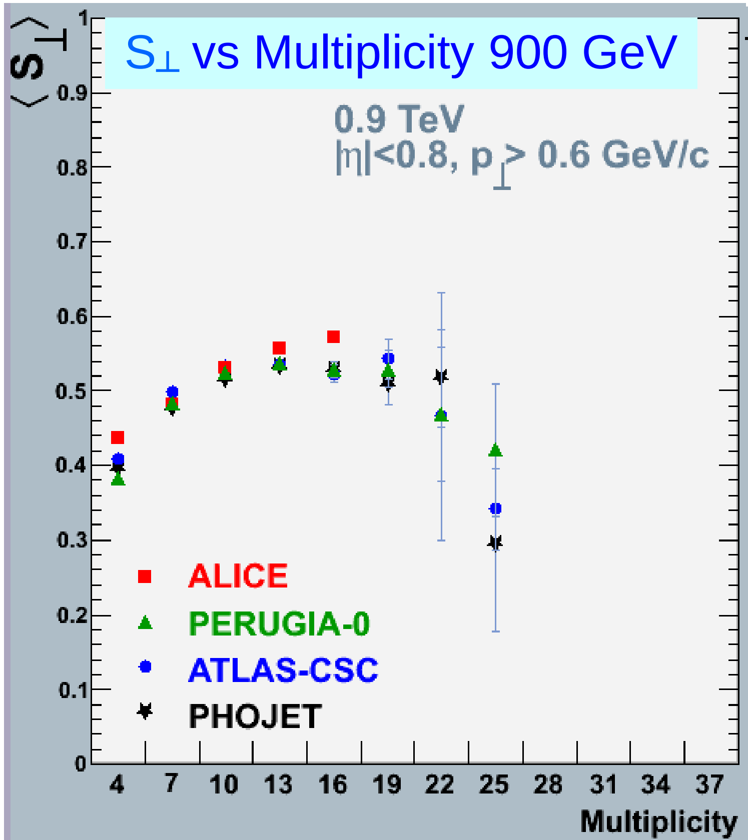
small $S_\perp$:



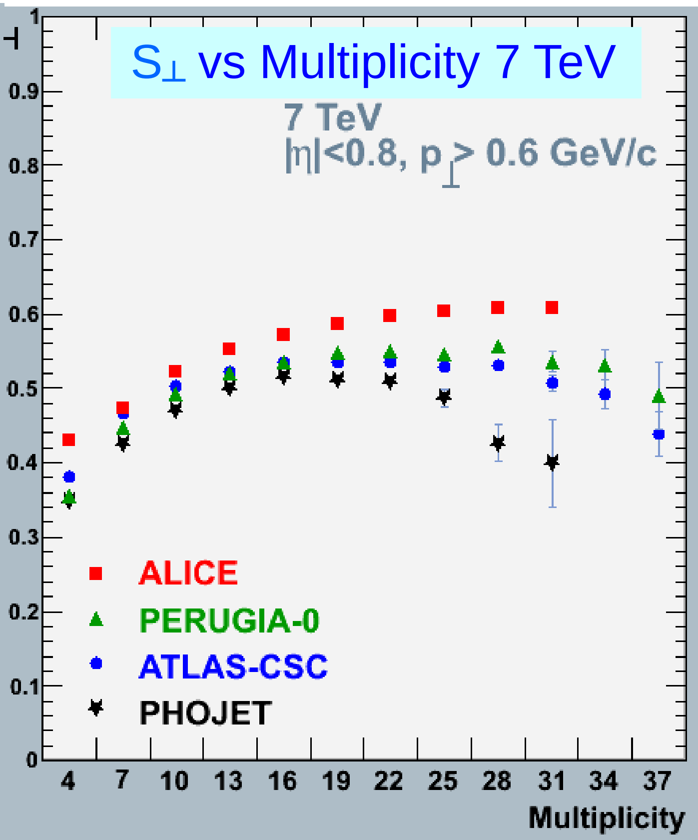
large $S_\perp$:



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



S⊥ vs Multiplicity 900 GeV

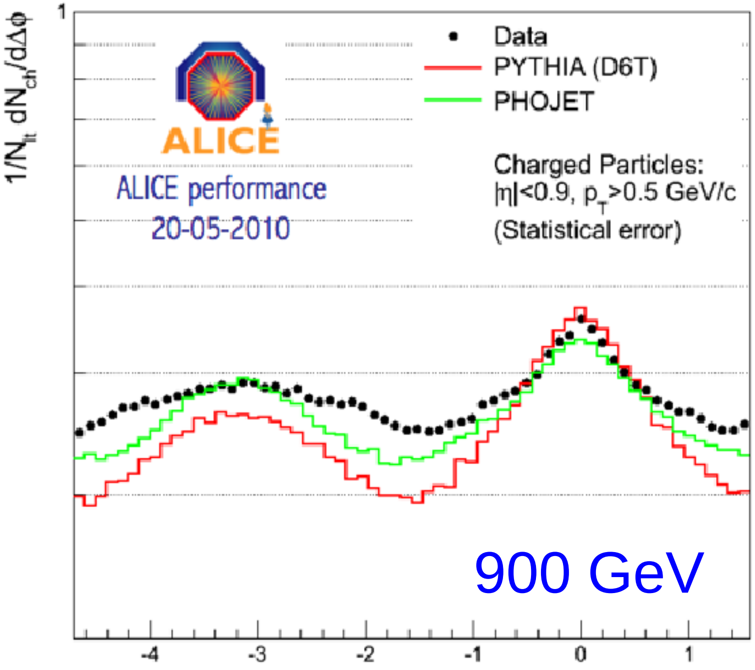


S⊥ vs Multiplicity 7 TeV

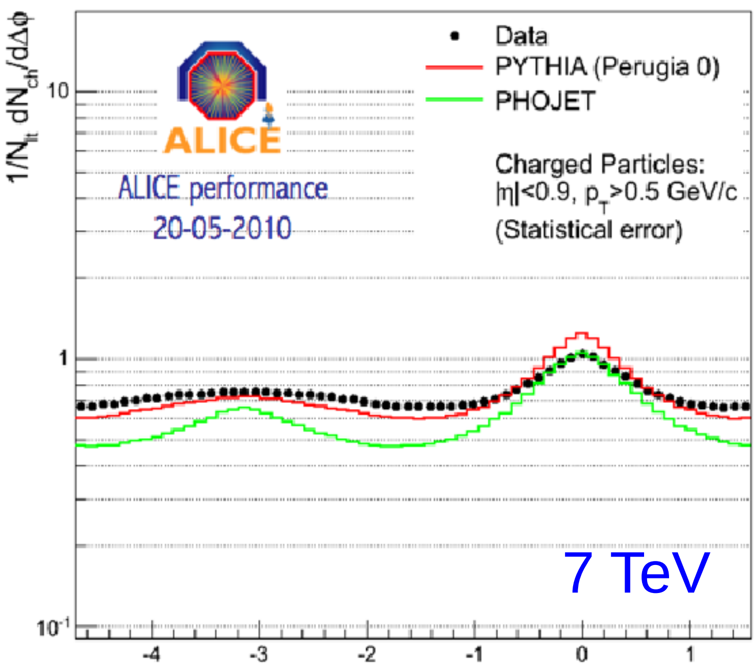
Underlying Event Studies

Uncorrected Data

ALICE Work in Progress



Δϕ (w.r.t. Leading Particle)

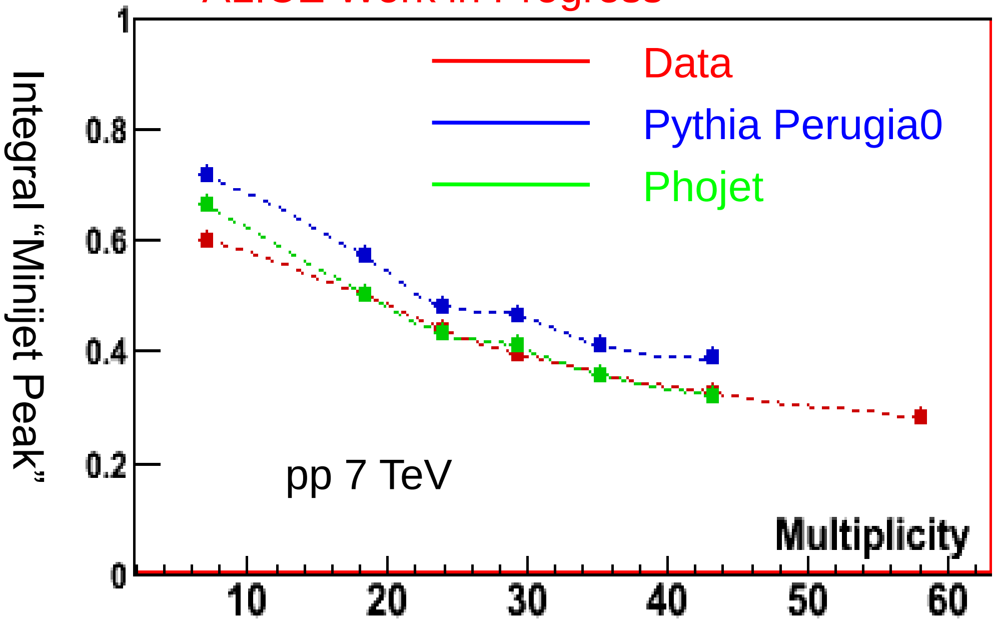


Δϕ (w.r.t. Leading Particle)

→ data more ”spherical“ (less back-to-back-ish) than MCs

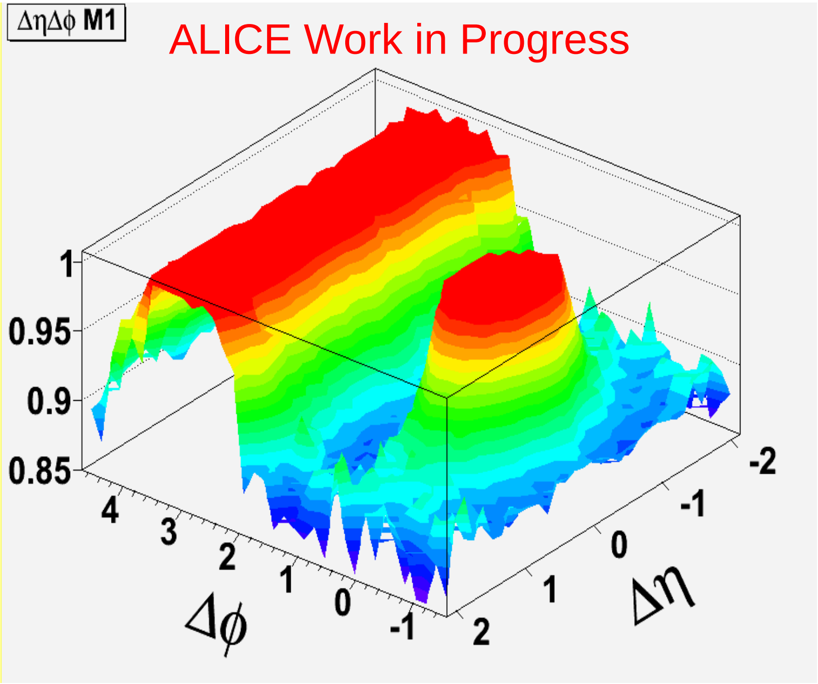
Study of shapes and yields as a function of multiplicity

ALICE Work in Progress



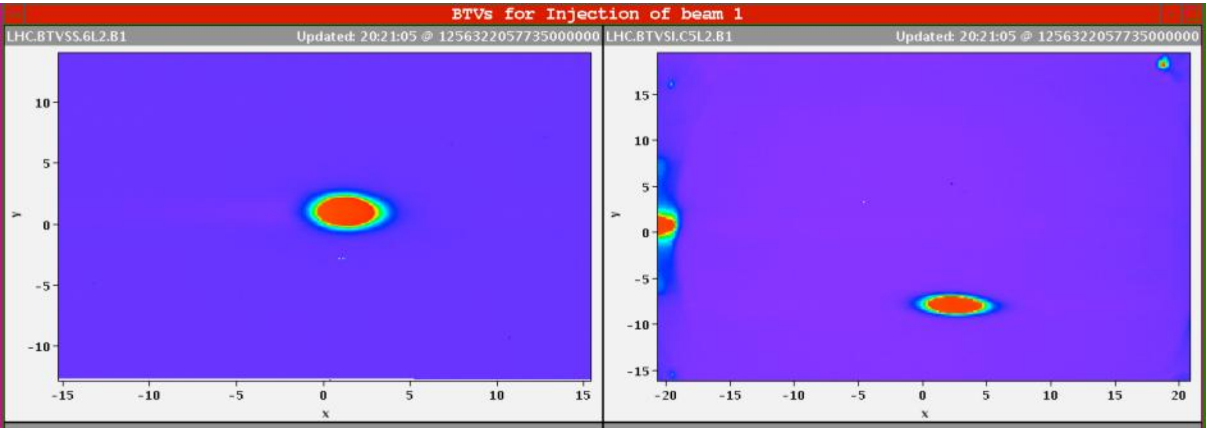
No p_T cut

Nearside Longitudinal Structure ?



5 - 6 x <M> , p_T > 1.5 GeV

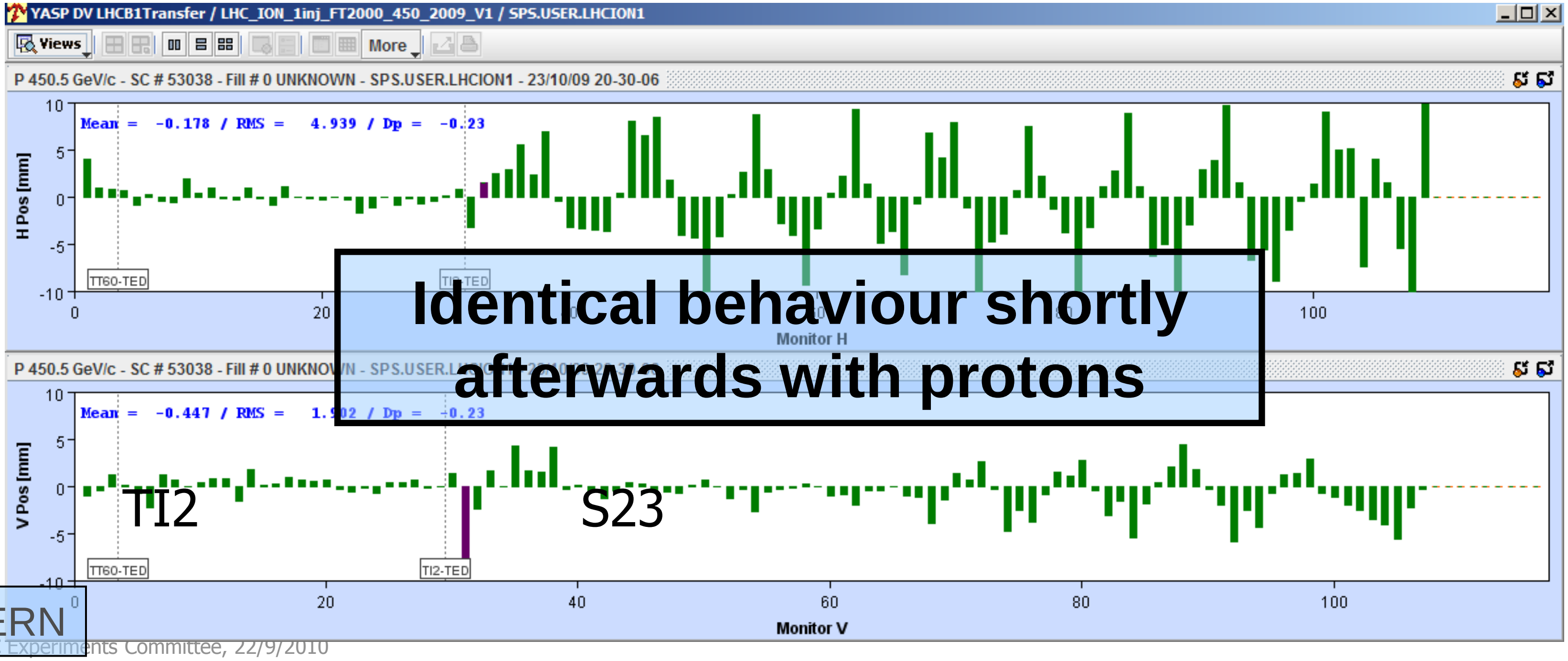
First Pb were in LHC in 2009



First beam to re-awaken LHC after the September 2008 incident

Injection region screens

TI2/Sector 2-3 – first trajectory



Identical behaviour shortly afterwards with protons

Parameters of LHC Pb–Pb

Parameter set established many years ago (2003) before the main performance limitations were understood, but retained as reference

Parameter	Units	Early Beam	Nominal
Energy per nucleon E_b/A	TeV	2.76	2.76
Initial ion-ion Luminosity L_0	$cm^{-2}\ s^{-1}$	$\sim 5\quad 10^{25}$	$1\quad 10^{27}$
No. bunches, k_b		62	592
Bunches per batch from SPS		4,3	52, 48, 32
Minimum bunch spacing	ns	1350	99.8
β^*	m	1.0	0.5 /0.55
Number of Pb ions/bunch		$7\quad 10^7$	$7\quad 10^7$
Transv. norm. RMS emittance	μm	1.5	1.5
Longitudinal emittance	eV s/charge	2.5	2.5
Luminosity half-life (1,2,3 expts.)	h	14, 7.5, 5.5	8, 4.5, 3

At full energy, luminosity lifetime is determined mainly by collisions ("burn-off" from ultra-peripheral electromagnetic interactions)

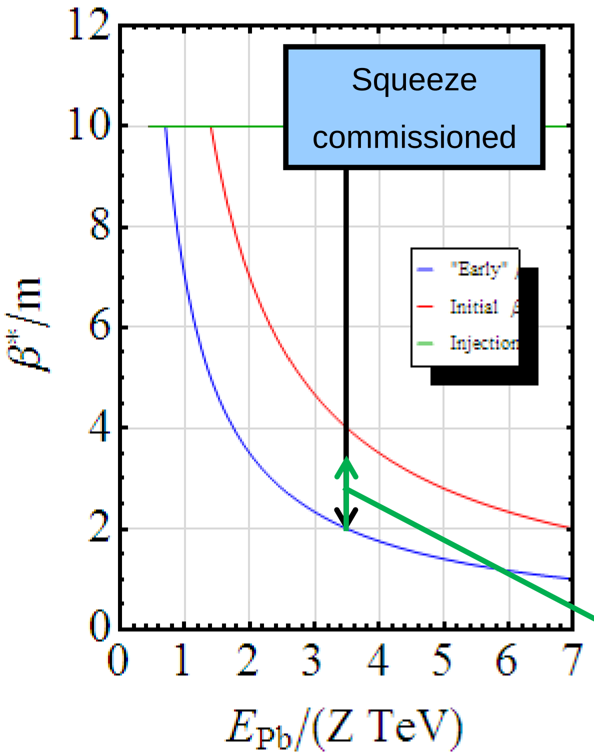
$$\sigma \approx 520 \text{ barn}$$

Do something like this, but at reduced energy, in 2010

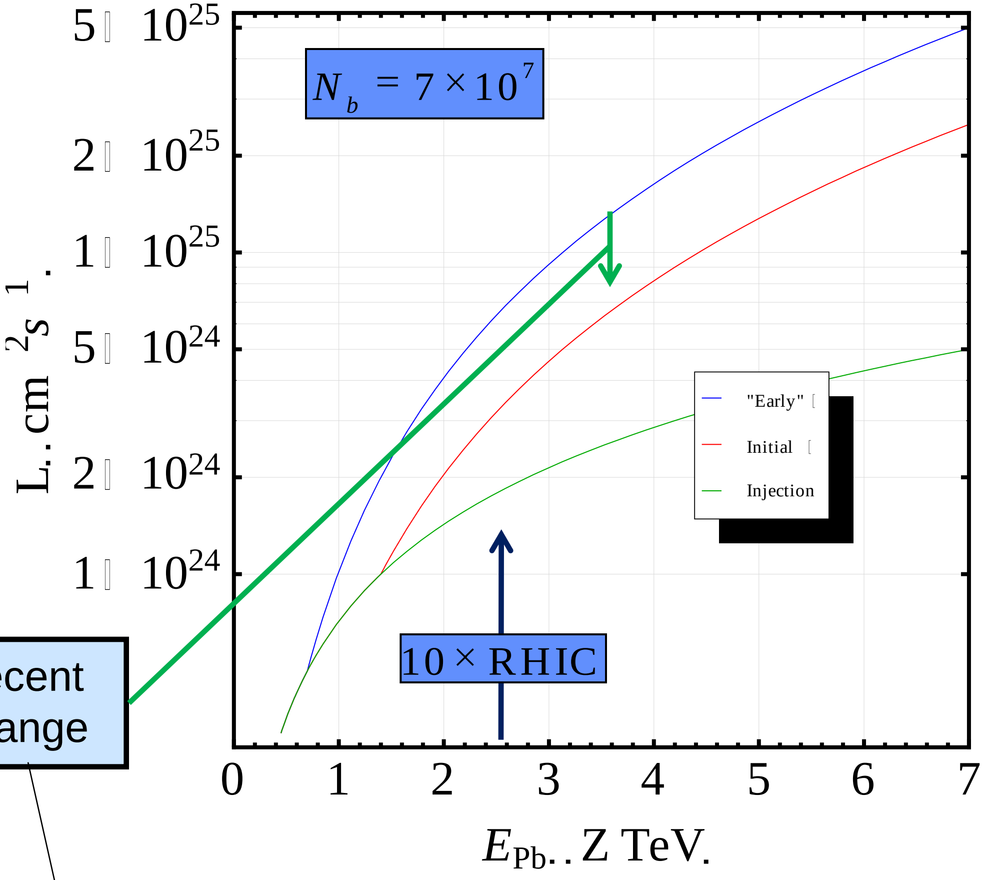
Probably unattainable without new collimators (at least)

Potential peak Pb-Pb luminosity

(62 bunches)



Recent change



Triplet aperture limit scaling: $\beta^* \sim \frac{1}{E_p}$

$$\beta^*(E_p) = \begin{cases} \min(1.7/E_p, 10.)\ \text{m} & \text{"Early"} \\ \min(3.5/E_p, 10.)\ \text{m} & \text{Initial} \\ 10.\ \text{m} & \text{Injection} \end{cases} \Rightarrow L = \frac{k_b N_b^2 f_0}{4\pi\sigma^{*2}} \sim \frac{E_p}{\beta^*}$$

J.Jowett, CERN

$10^{25}\ \text{cm}^{-2}\text{s}^{-1} = 0.864\ \mu\text{b}^{-1}\text{day}^{-1}$

Target luminosity in 2010

		Early (2010/11)	Nominal
$\sqrt{s_{NN}}$ (per colliding nucleon pair)	TeV	2.76	5.5
Number of bunches		62	592
Bunch spacing	ns	1350	99.8
β^*	m	2 → 3.5	0.5
Pb ions/bunch		7×10^7	7×10^7
Transverse norm. emittance	μm	1.5	1.5
Initial Luminosity (L_0)	$cm^{-2}s^{-1}$	(1.25→ 0.7) 10^{25}	10^{27}
Stored energy (W)	MJ	0.2	3.8
Luminosity half life (1,2,3 expts.)	h	τ_{IBS}=7-30	8, 4.5, 3

Caveat: assumes design emittance

Initial interaction rate: 50-100 Hz (5-10 Hz central collisions b = 0–5 fm)

~10^8 interaction/10^6s (~1 month)

In 2010: integrated luminosity 1-3 μb^{-1}

New filling schemes for k_b=124, 140 could allow another factor ~2

Pb–Pb running scenario

- expected luminosity ~ 2 orders of magnitude below nominal
  - ⇨ **10^{27} cm^{-2} s^{-1} → ~ 10^{25} cm^{-2} s^{-1}**
  - ⇨ **factor ~ 10 from number of bunches**
  - ⇨ **factor ~ 10 from increased beam size (lower energy, less focussing)**
  - ⇨ **50 – 100 (– 150) Hz min bias**
    - → **strategy: low bias trigger**
    - → **register all events (minimum bias)**

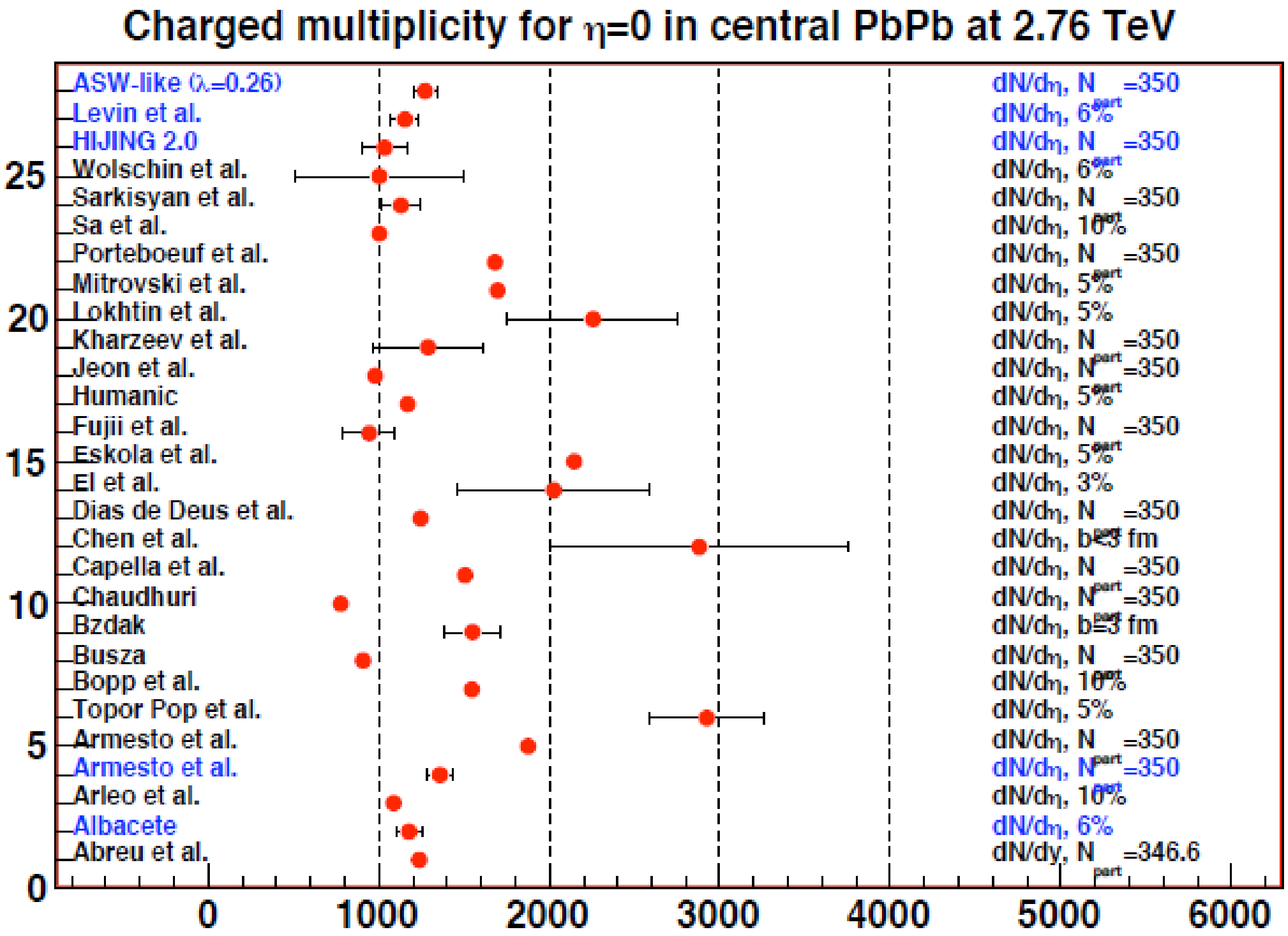
- expected data sample
  - ⇨ **estimate : ~ 1 – 3 µb^{-1} (@ TH workshop, 03/09/2010)**
    - ✪ **e.g.: 2 µb^{-1} = 1.6x10^{7} min bias events**
  - ⇨ **for comparison: ALICE per year (4 weeks run) targets:**
    - ✪ **0.5 nb^{-1} for rare triggers**
    - ✪ **a few 10^{7} central collisions and similar for minimum bias**
- assumption for this year
  - ⇨ **~ 10^{7} minimum-bias events; in that ~ 10^{6} central collisions**

Physics reach…

- global event properties
  - ⇨ multiplicity
  - ⇨ azimuthal asymmetry (v2)
  - ⇨ Bose-Einstein correlations (HBT)
  - ⇨ bulk strangeness
- with a p_T reach dependent on statistics…
  - ⇨ particle correlations
  - ⇨ nuclear modification factors
  - ⇨ strange, identified particle spectra
- a first glimpse of hard probes…
  - ⇨ jets
  - ⇨ J/ψ
  - ⇨ heavy flavour
- surprises? (so far at each new AA energy always there)

Charged particle multiplicity

- connected to temperature, energy density, parton density, …
  - ⇨ day 1 measurement → primary input to models
- considerable spread of predictions…

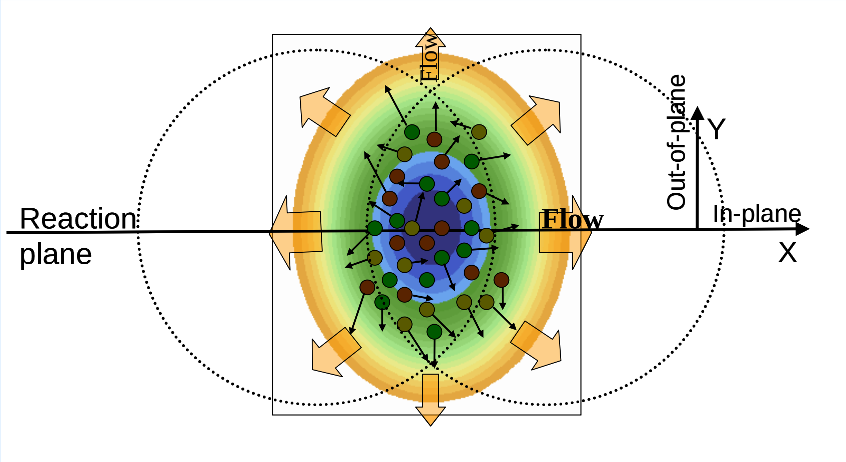


Charged multiplicity for η=0 in central PbPb at 2.76 TeV

from Néstor Armesto
@ CERN TH Institute
3 September 2010

Azimuthal asymmetry (v_2)

- **azimuthal asymmetry in geometry of non-central collisions**



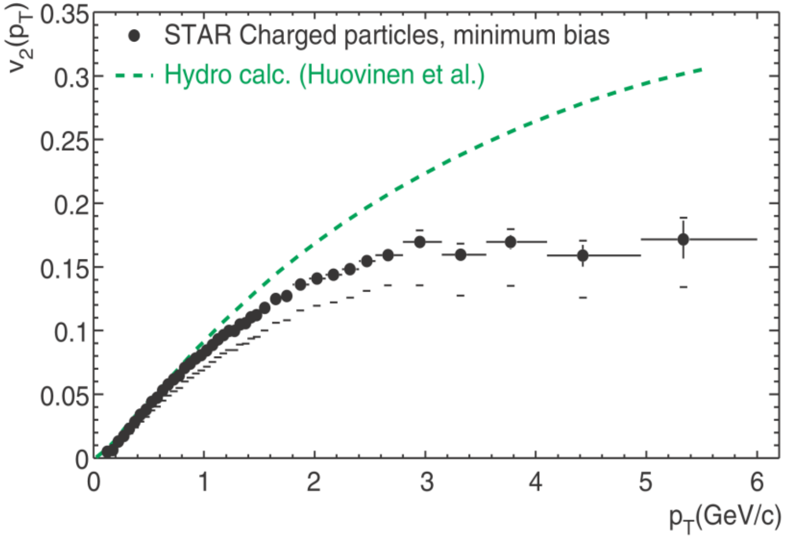
- **transfer of asymmetry to momentum space measures strength of collective phenomena**

- **asymmetry of momentum distribution measured by second coefficient of Fourier expansion (v_2)**

$$\frac{dN}{p_T\,dp_T\,dy\,d\varphi} = \frac{1}{2\pi}\frac{dN}{p_T\,dp_T\,dy}\left(1 + 2\cancel{v_1}\cos(\varphi) + 2\boxed{v_2}\cos(2\varphi) + \dots\right)$$

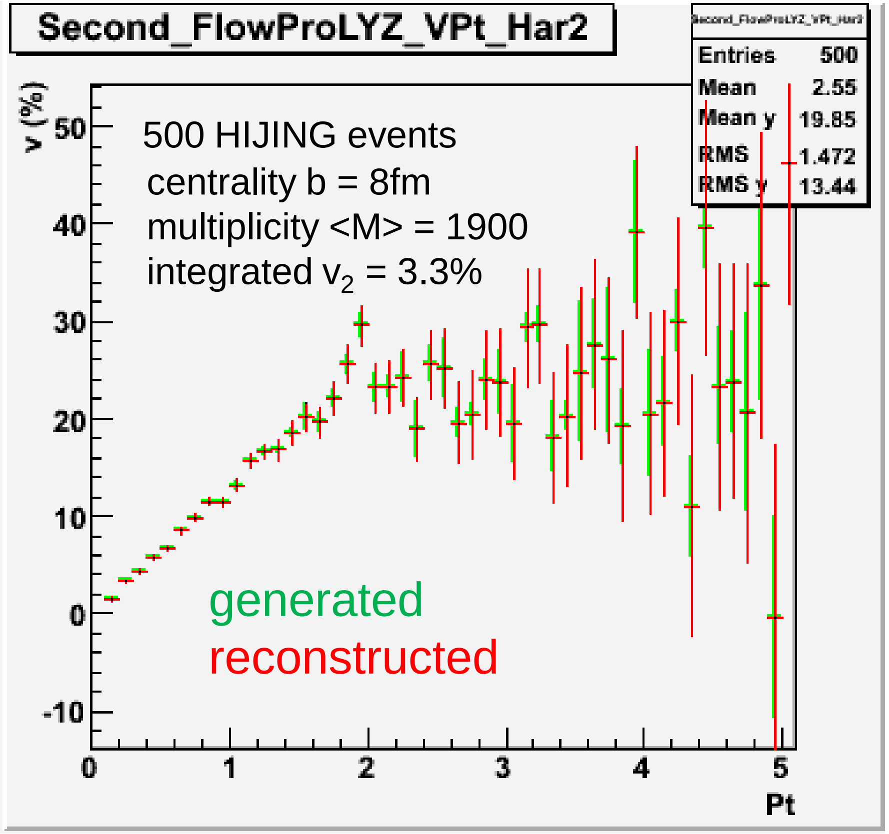
$v_1 = 0$ at central y

- **v_2 close to hydrodynamic limit at low p_T at RHIC**



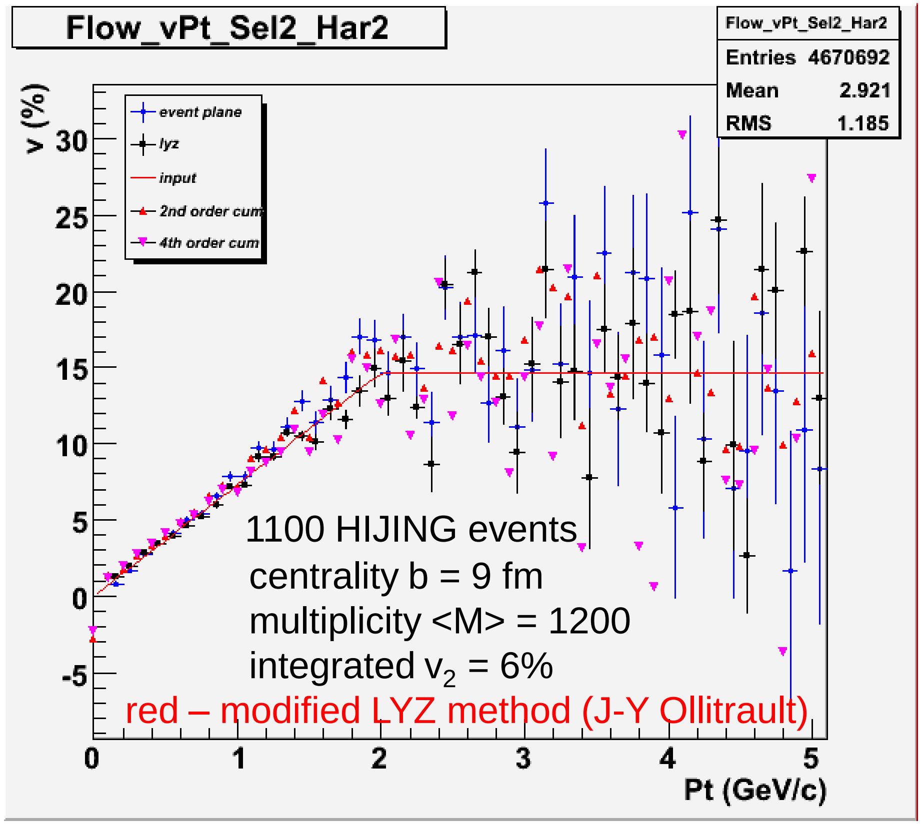
v_2 measurement studies

Standard event-plane method



500 HIJING events
centrality b = 8fm
multiplicity <M> = 1900
integrated v_2 = 3.3%

Lee-Yang Zero method



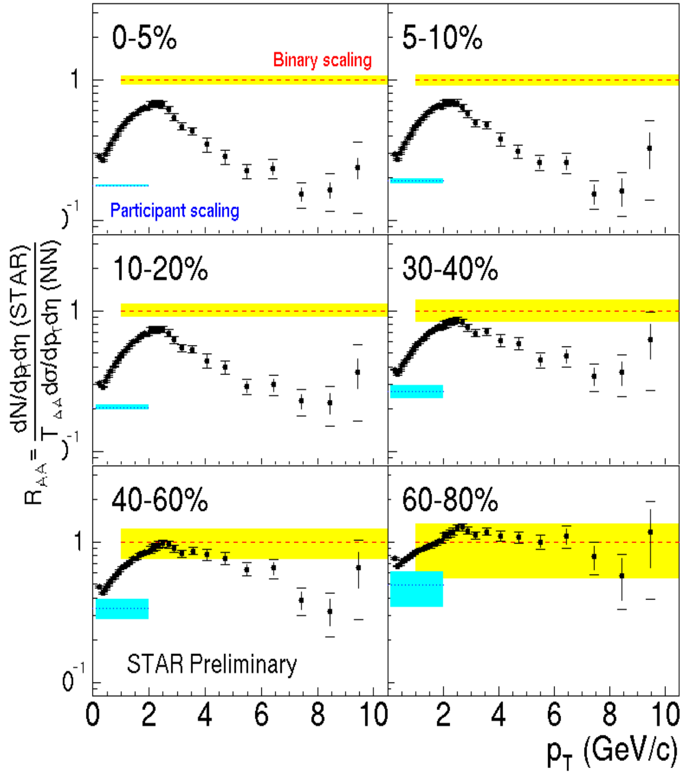
1100 HIJING events
centrality b = 9 fm
multiplicity <M> = 1200
integrated v_2 = 6%
red – modified LYZ method (J-Y Ollitrault)

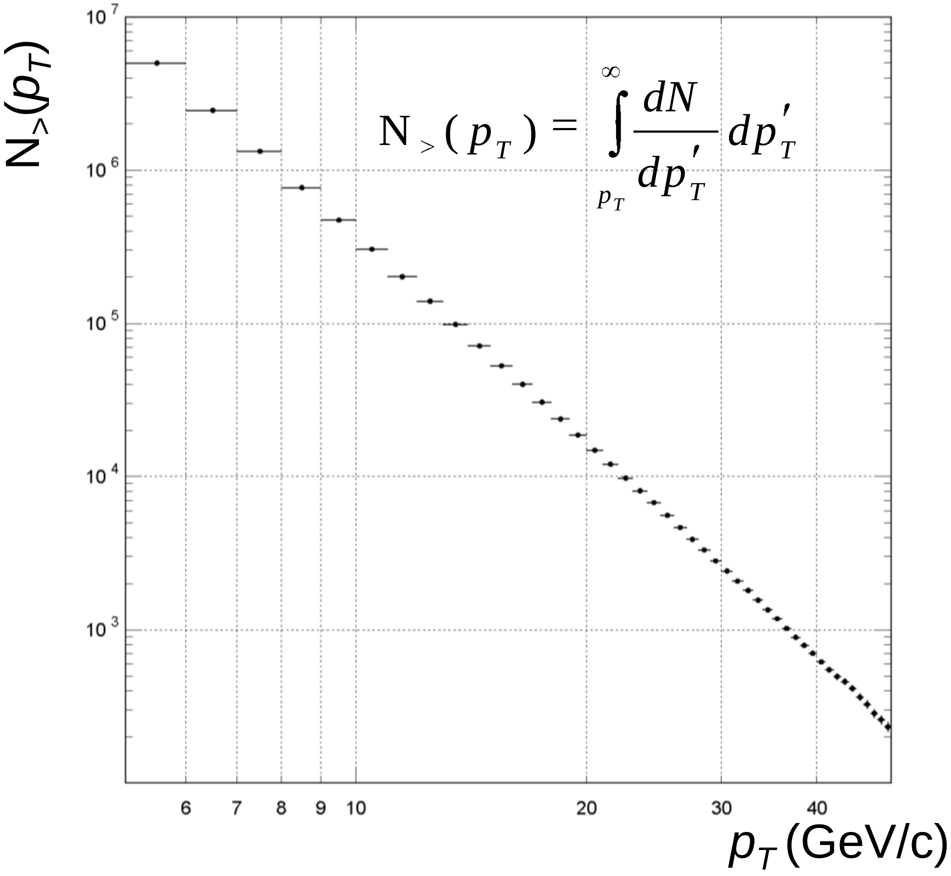
10^7 events → approach 20 GeV (is asymmetry still there?)

Nuclear modification factor

- in Au-Au @ RHIC particle production suppressed by factor ~ 5 at high p_T w.r.t. binary-scaled p-p

- e.g.: expected reach in ALICE for 10^6 central (with no suppression):



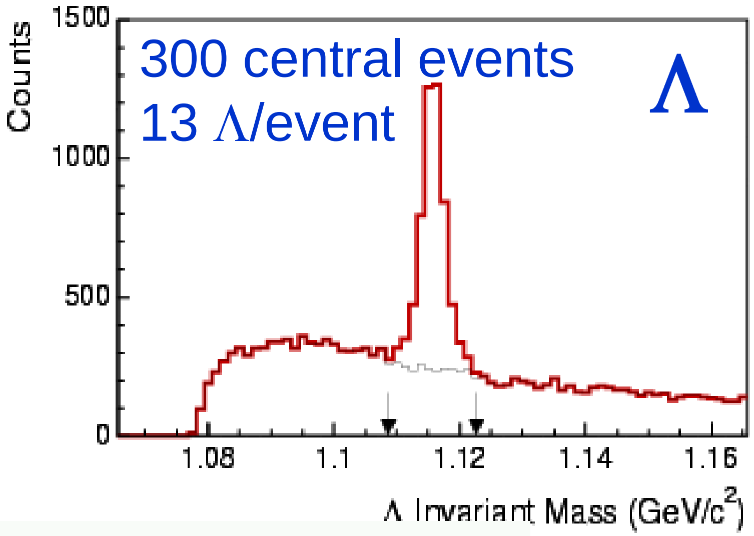


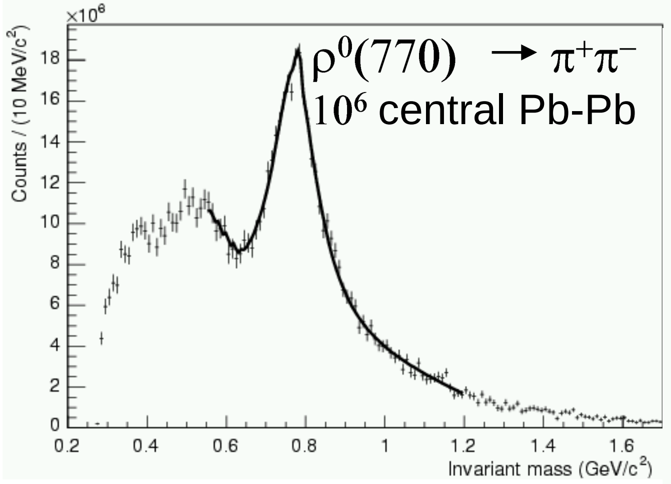
ρ, ϕ,K* ,K^0_s, Λ, Ξ, Ω…

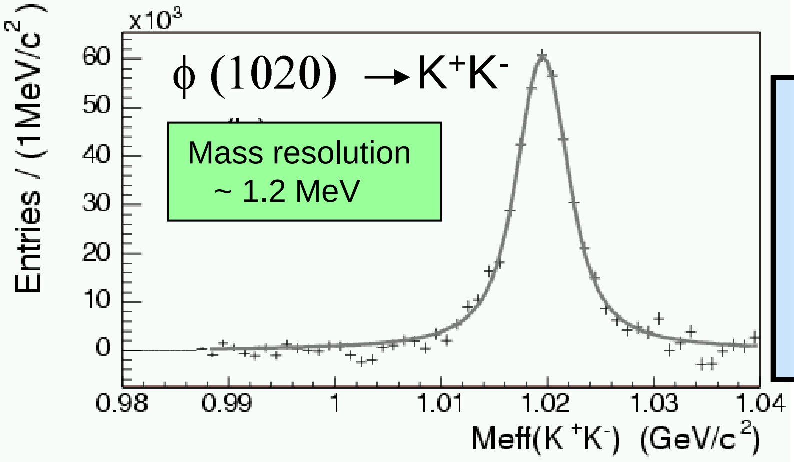
10^7 events:

p_t reach ϕ,K,Λ ~ 13-15 GeV

p_t reach ρ,Ξ,Ω ~ 9-12 GeV





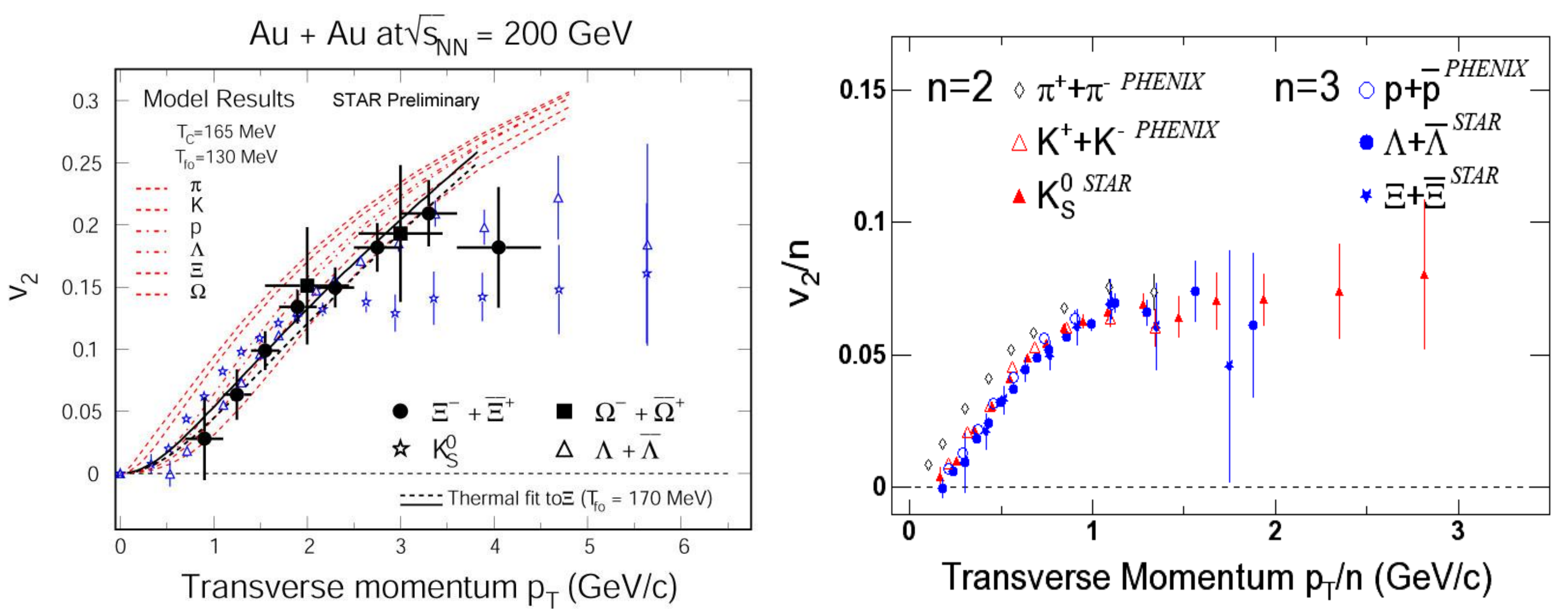


- **hadro-chemical analysis**
- **chemical/kinetic freeze-out**

- **medium modifications of mass, widths (needs hadronic and leptonic channels**

Identified particles v_2

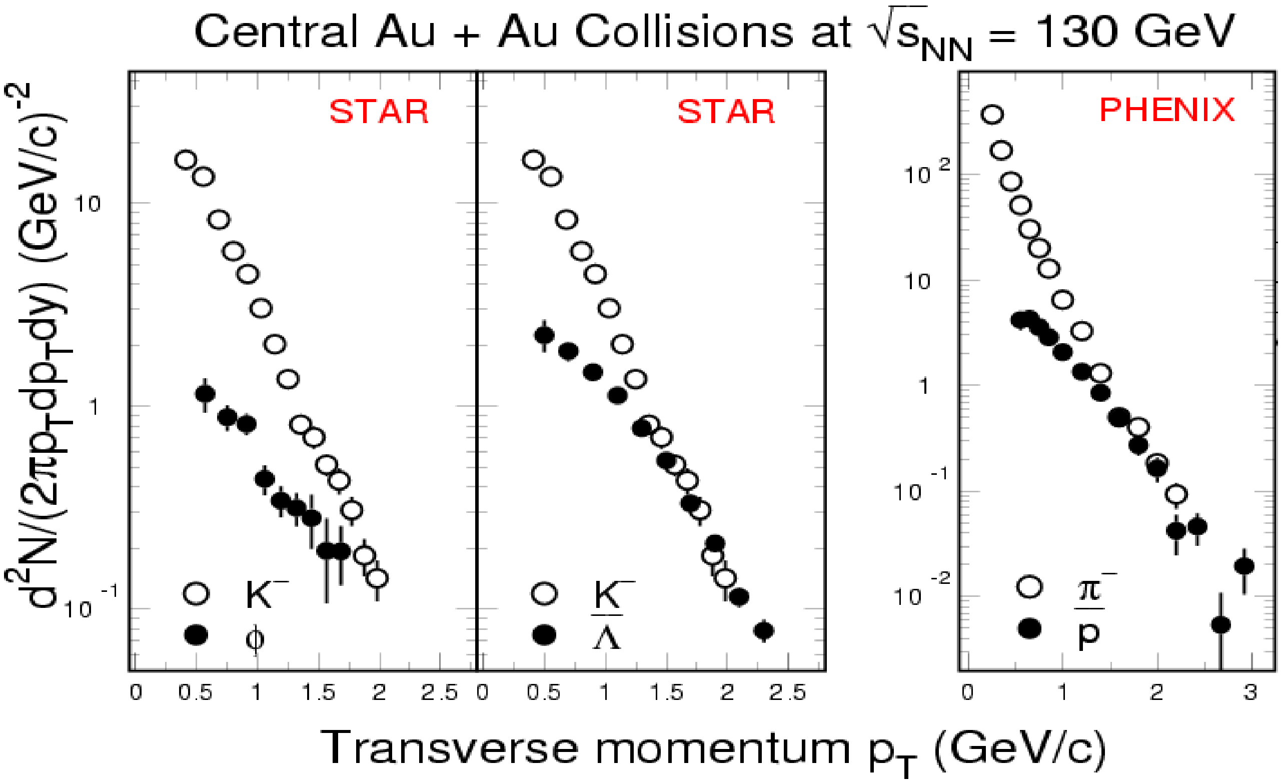
- sensitive to hydrodynamics and recombination effects
  - ⇨ **e.g. @ RHIC: ~ scales with # of valence quarks**



10^7 events → strange particles' v_2 out to ~ 10 GeV/c

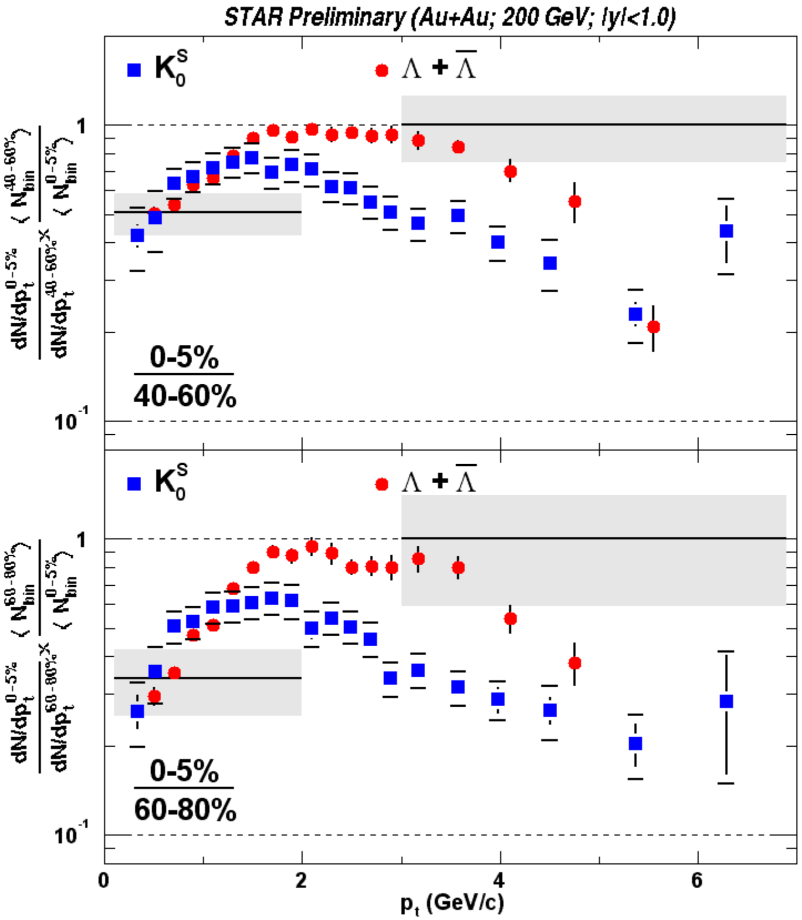
Identified particles p_T

- @ RHIC : as many π^- (K^-) as p (Λ) at p_T ~ 1.5 ÷ 2.5 GeV



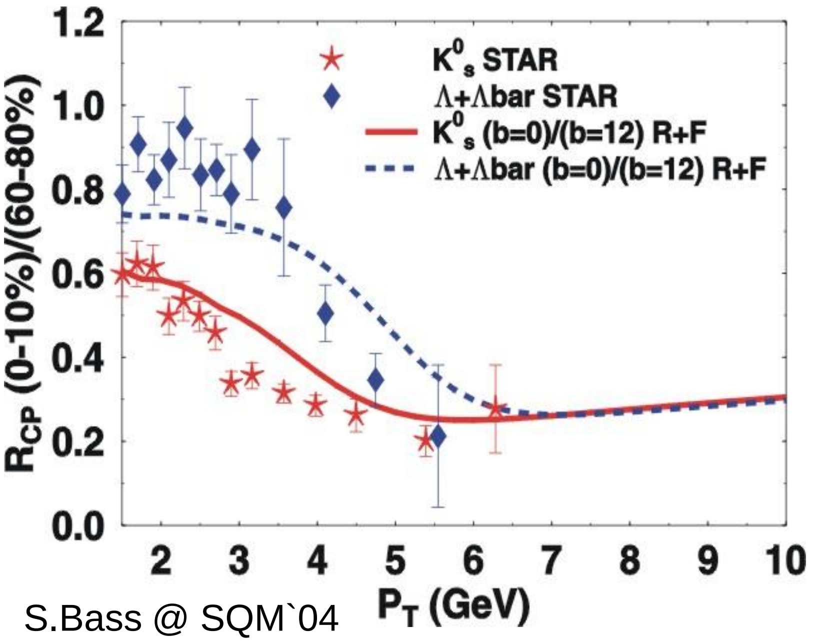
e.g.: identified particles R_{cp}

- @ RHIC: suppression sets on at larger p_T for baryons



$$R_{cp} = \frac{\text{Yield}_{\text{AA, central}}}{\text{Yield}_{\text{AA, periph}}} \cdot \frac{\langle Ncoll \rangle_{\text{AA, periph}}}{\langle Ncoll \rangle_{\text{AA, central}}}$$

- recombination?



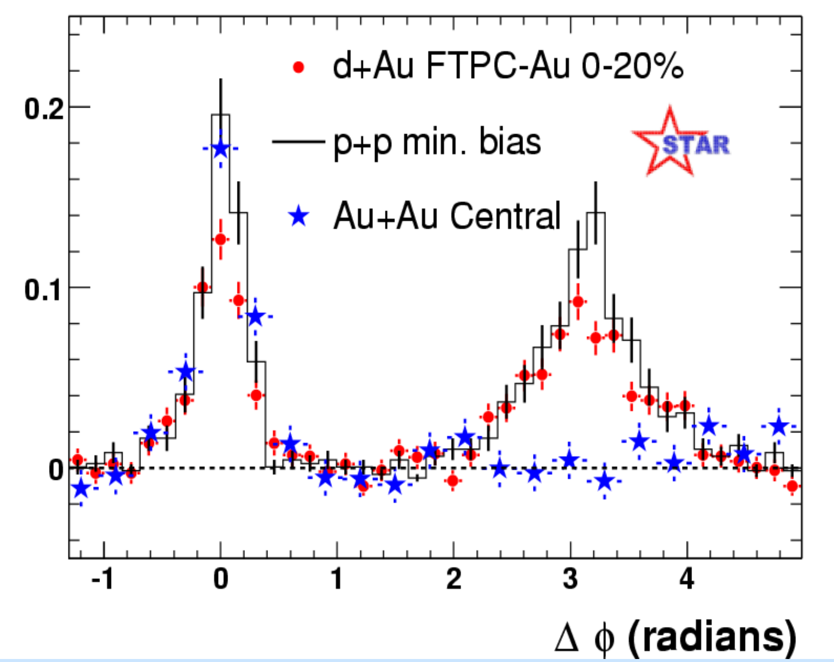
S.Bass @ SQM`04

e.g.: 10^6 central → Λ, K^0_s out to ~ 10 GeV

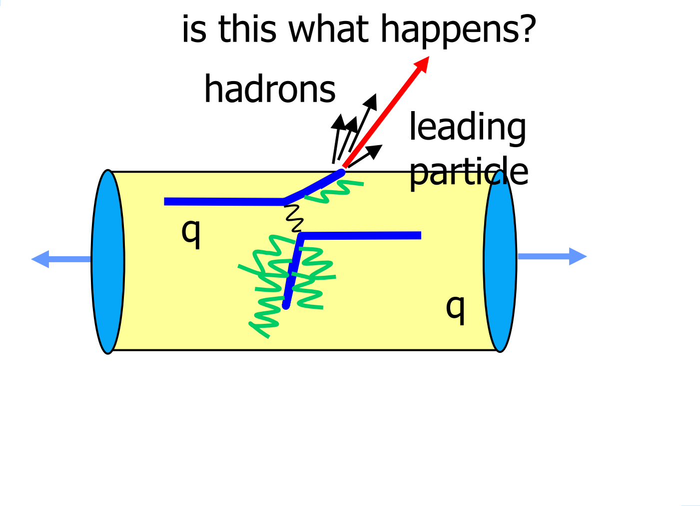
High p_T correlations

- **e.g.: disappearance of away-side peak at RHIC**

Adams *et al*., Phys. Rev. Let. 91 (2003) 072304



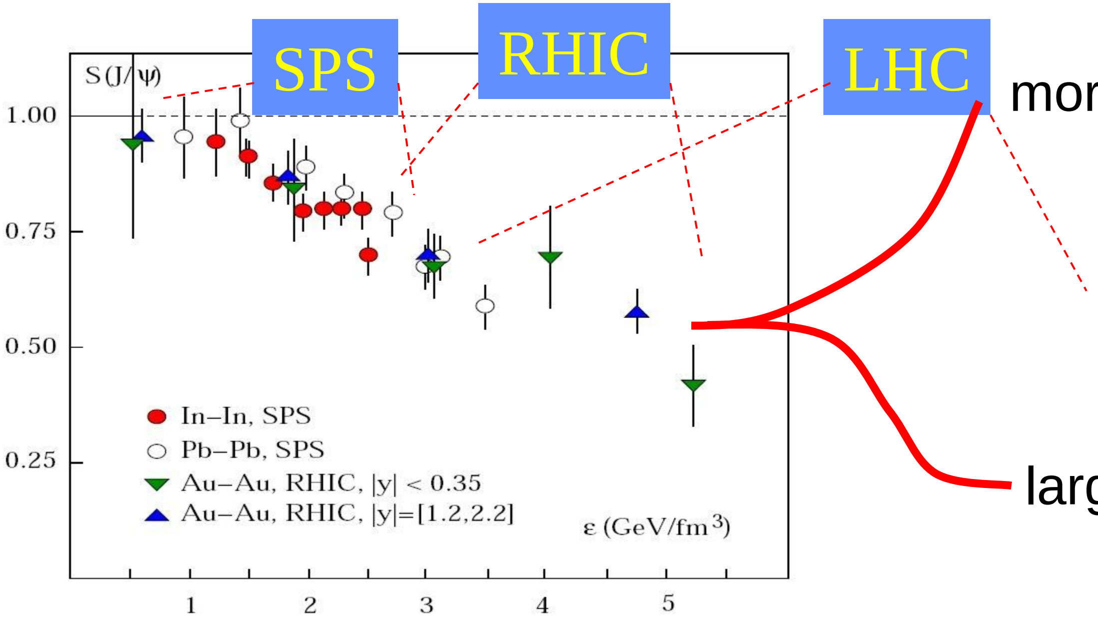
trigger particle: $4 < p_T < 6$ GeV/c
associated particles: $p_T > 2$ GeV/c



- **STAR Au-Au sample ~ $1.5\ 10^6$ central**

Quarkonia

- **present status:**



more $c\bar{c}$ → reco dominates?

larger ε → J/ψ finally melts?

- very similar suppression at RHIC and SPS...
  - only ψ'and χ_c melt?
  - J/ψ melting – compensated by cc recombination?

• performance critically dependent on ∫L

eg: for 2 μb^{-1}, no suppression, no enhancement

→ a few 1000s J/ψ

say 5 centrality bins → significance ~ 15-20

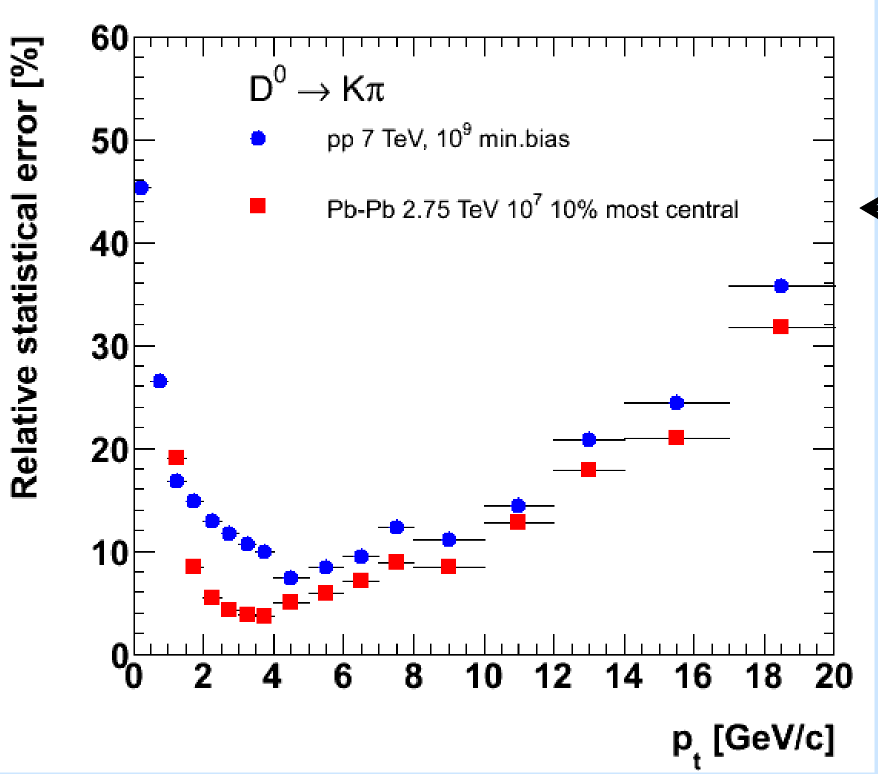
out to 6-7 GeV pT?

→ψ' marginal…

→a few 10s of Y at significance ~ 5?

What about charm?

- **heavy flavour: study colour charge and parton mass dependence of parton energy loss**



- expected performance for 10^7 central Pb-Pb events at 2.75 TeV

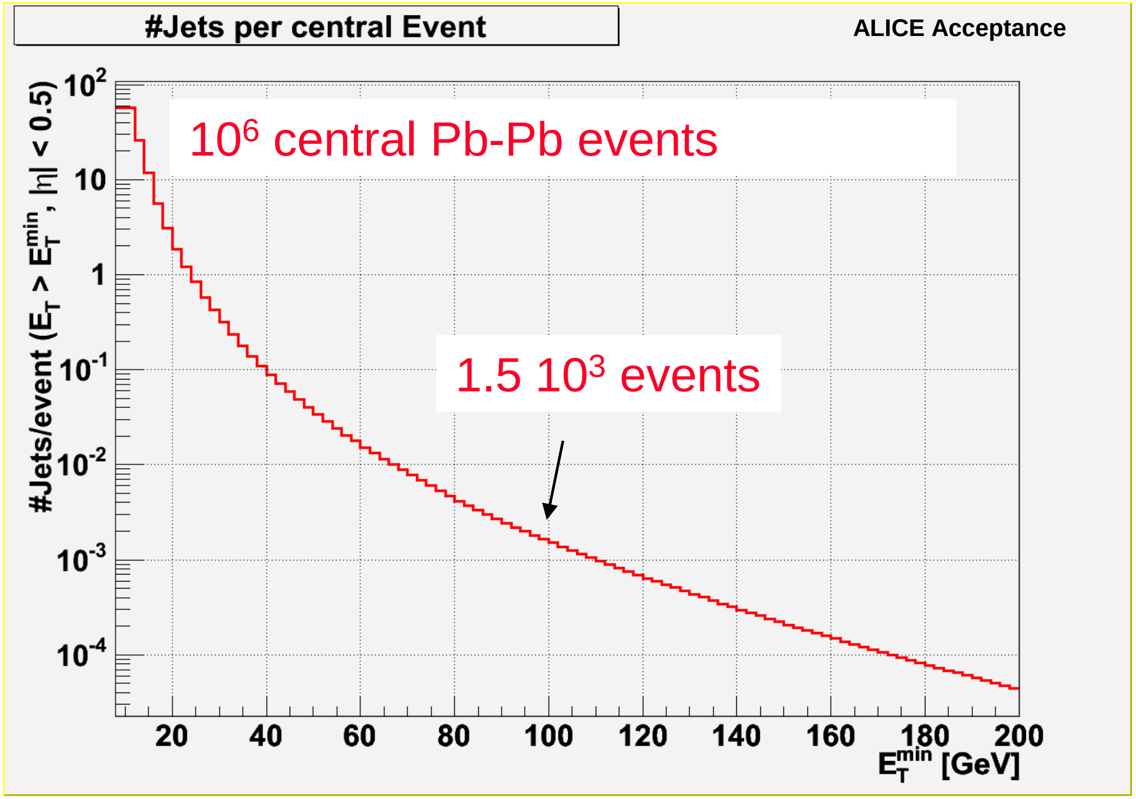
- **for O(10^6) central, ~ multiply errors by 3 → marginal…**

→ **needs as much statistics as possible!**

Jets

Jets are copiously produced…

2	20	100	200	p_t (GeV)
100/event	1/event	10^3 in first 10^6 Pb-Pb events		



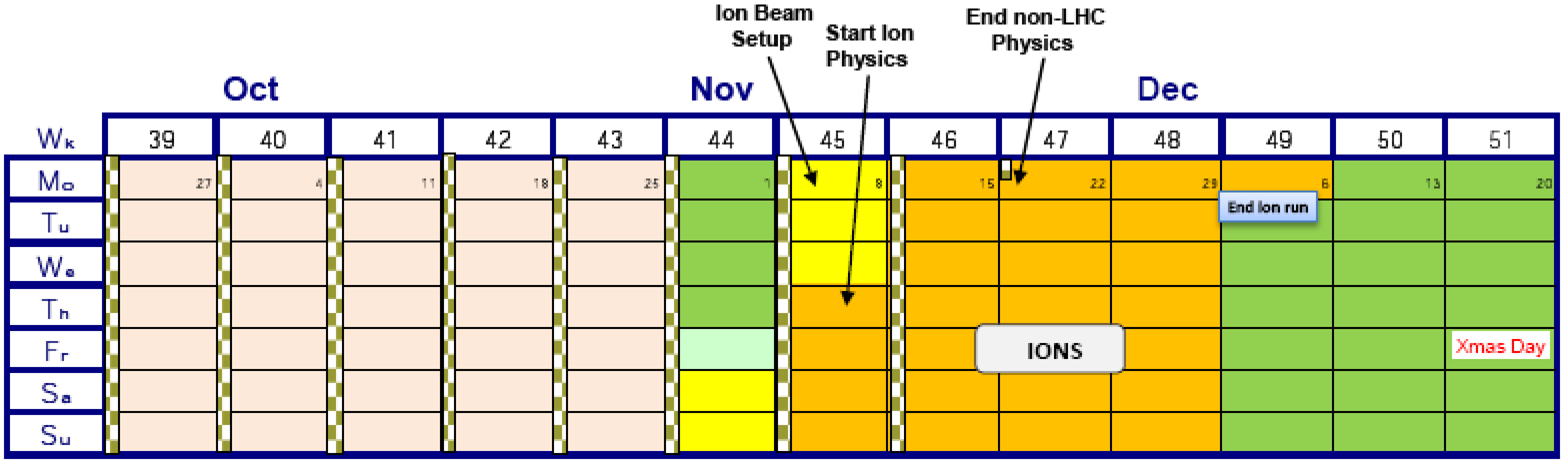
10^6 central Pb-Pb events

1.5 10^3 events

10^6 central Pb–Pb events

E_T threshold	N_{jets}
50 GeV	5×10^4
100 GeV	1.5×10^3
150 GeV	300
200 GeV	50

LHC schedule (as of 15/8/2010)



Wk	39	40	41	42	43	44	45	46	47	48	49	50	51
Mo	27	4	11	18	25	1	8	15	22	29	6	13	20
Tu											End Ion run		
We													
Th													
Fr									IONS				Xmas Day
Sa													
Su													

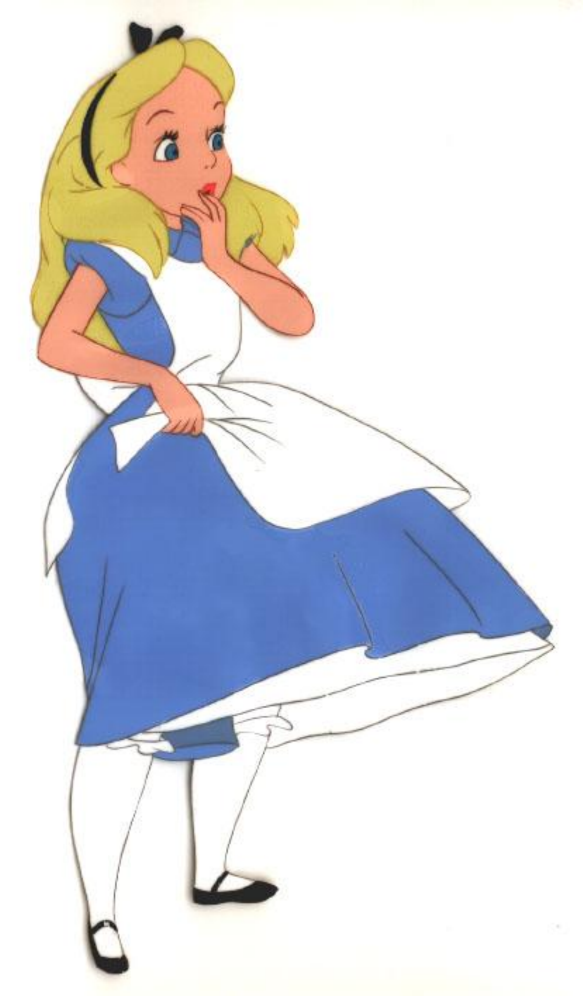
Lead-up to lead in LHC involves a lot of work in the ion injectors

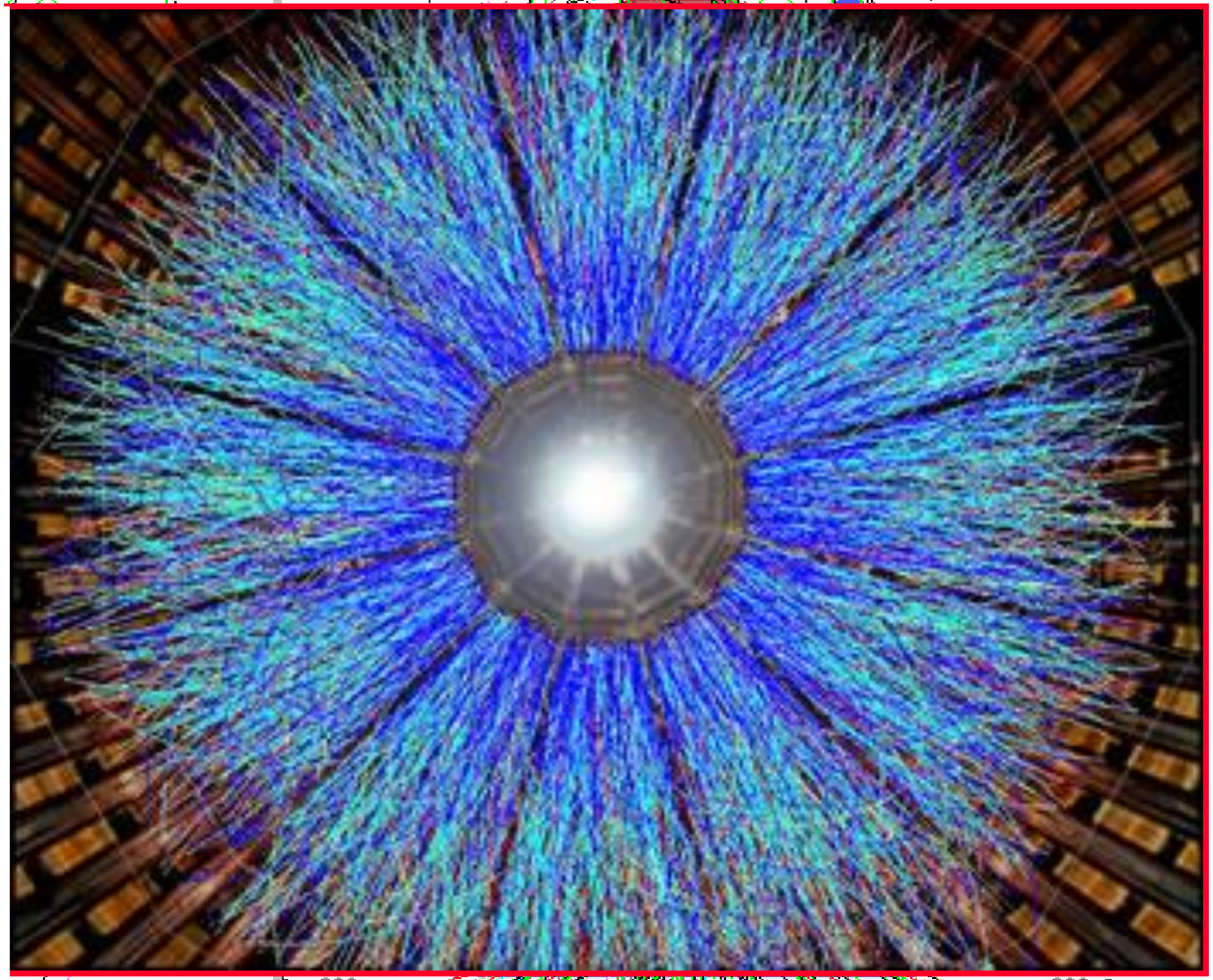
At present, we can only anticipate that the "Early Beam" can be delivered to LHC with the design parameters

🟩 Technical Stop
🟩 Recommisssoning with beam
▨ SPS et al - physics
🟧 Ion run
🟨 Ion setup

J.Jowett, CERN

High-multiplicity event





No match for heavy ions, but not too bad for pp (>120 charged tracks in TPC)

Conclusions

- results with pp collisions
  - ⇨ multiplicity, spectra
  - ⇨ baryon-antibaryon asymmetry
  - ⇨ identified particles
  - ⇨ event characteristics
  - ⇨ open-charm and J/ψ production coming

alyses at 7 TeV and at hig

as events at 7 TeV

osity using rare triggers

y trigger with SPD (low μ ~0.05 – 0.1

trigger) we plan 1-2 weeks “high”

- we are waiting for the first heavy-ion run:
  - → essential information on general features of Pb-Pb events at LHC

    + a glimpse of harder physics