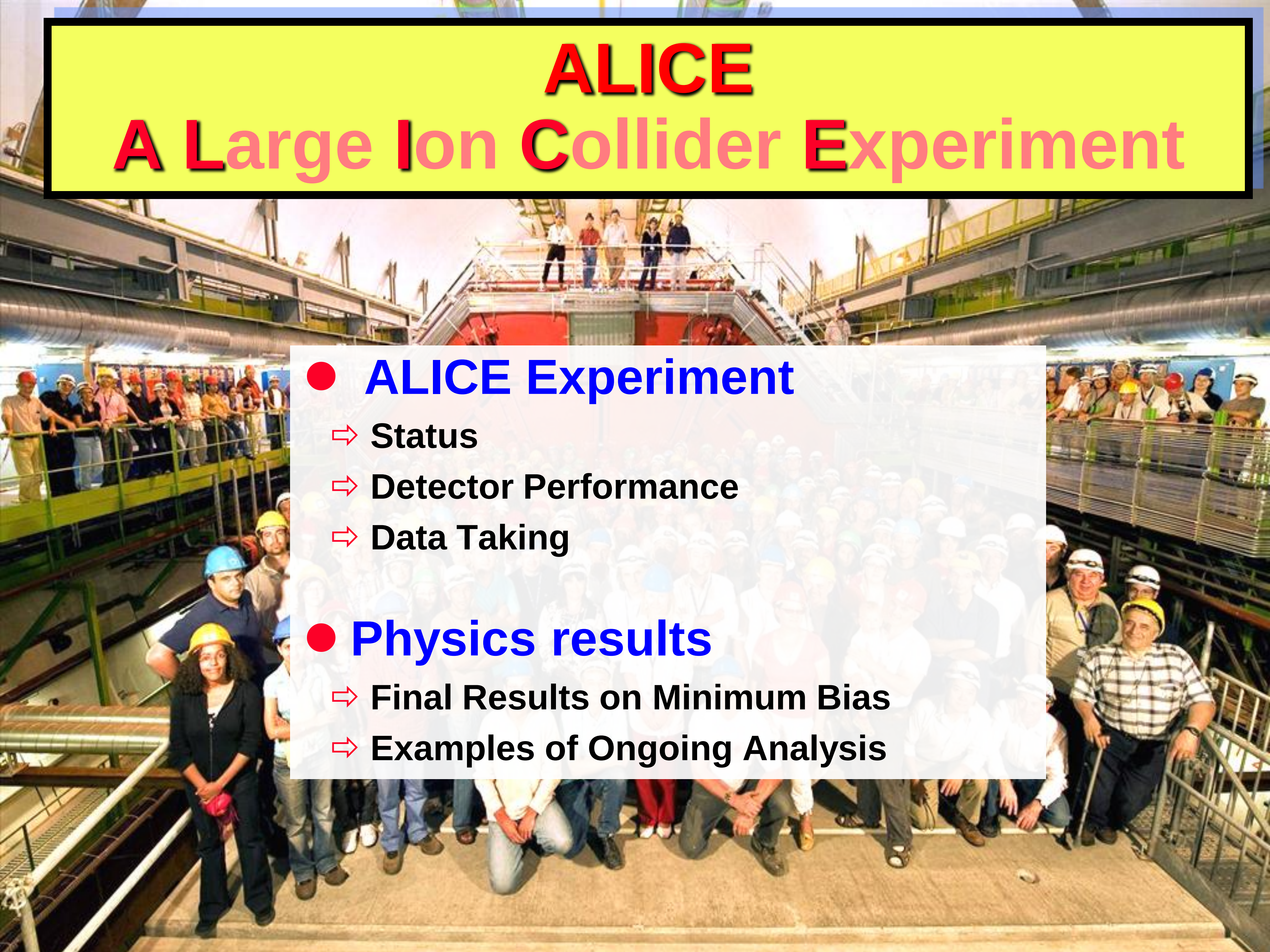
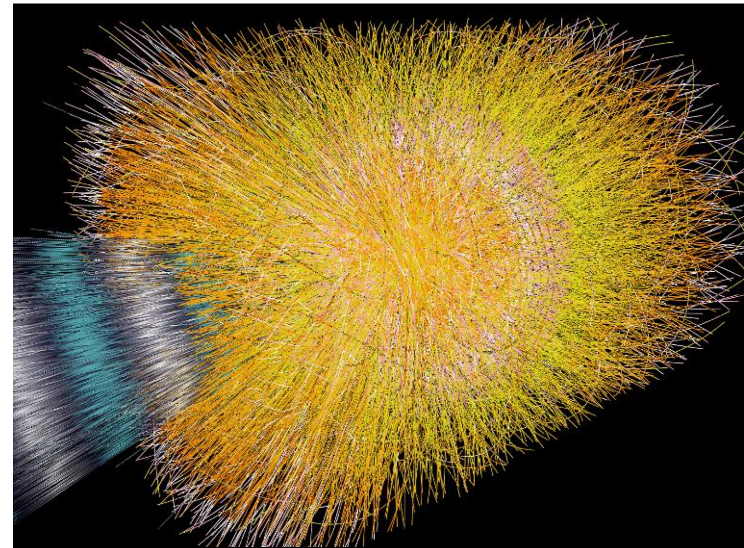
ALICE
A Large Ion Collider Experiment



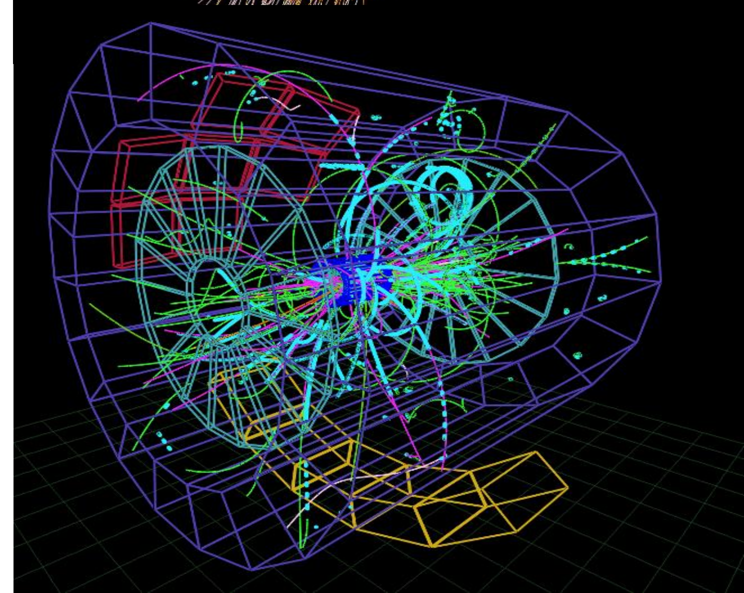
- **ALICE Experiment**
  - ⇨ Status
  - ⇨ Detector Performance
  - ⇨ Data Taking
- **Physics results**
  - ⇨ Final Results on Minimum Bias
  - ⇨ Examples of Ongoing Analysis

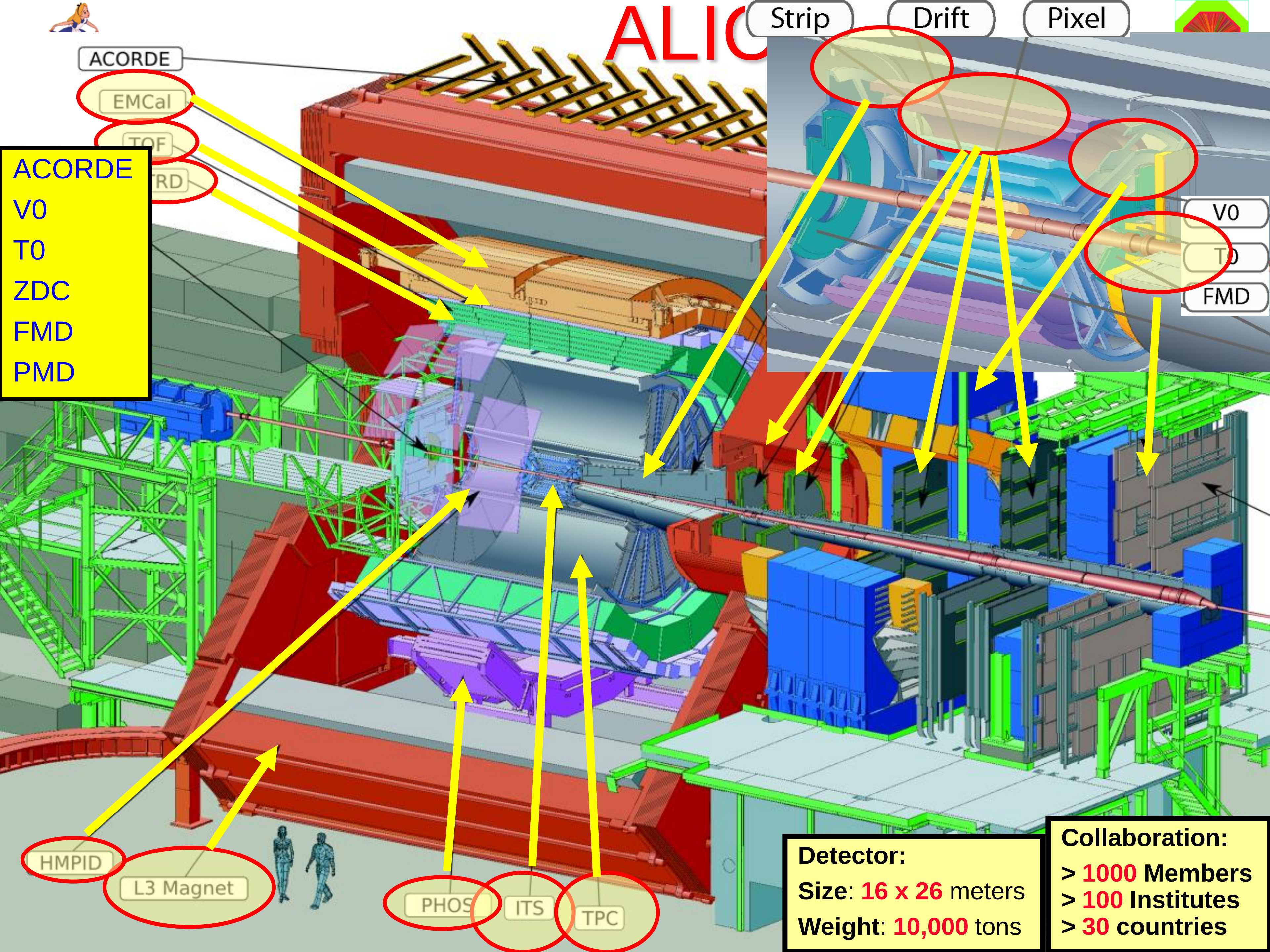
ALICE experiment

- Dedicated heavy ion experiment at LHC:
  - ⇨ study 'state of matter' at high temperature & energy density: '**The QGP**'
    - ✪ 'Standard Model': QCD@finite temperature
  - ⇨ LHC: **30 x energy** of RHIC
    - ✪ expect very different type of 'QGP' (T, τ, V, ..)
    - ✪ 'hard signals' to probe QGP (jets, Y, heavy Q)
    - ✪ first Pb-Pb collisions Nov. 2010



- Physics with pp
  - ⇨ collect 'comparison data' for heavy ion program
    - ✪ many signals measured 'relative' to pp
    - ✪ requires ~ 10^9 MinBias events
  - ⇨ comprehensive study of MB@LHC
    - ✪ tuning of Monte Carlo (background to BSM)
  - ⇨ soft & semi-hard QCD
    - ✪ very complementary to other LHC expts
    - ✪ address specific issues of QCD




ALIC
Strip
Drift
Pixel
ACORDE
EMCal
TOF
TRD
ACORDE
V0
T0
ZDC
FMD
PMD
V0
T0
FMD
HMPID
L3 Magnet
PHOS
ITS
TPC
Detector:
Size: 16 x 26 meters
Weight: 10,000 tons
Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

Detector Status

Complete since 2008:

ITS, TPC, TOF, HMPID, FMD, T0, V0, ZDC, Muon arm, Acorde PMD , DAQ

Partial installation:

4/10 EMCAL* (approved 2009)

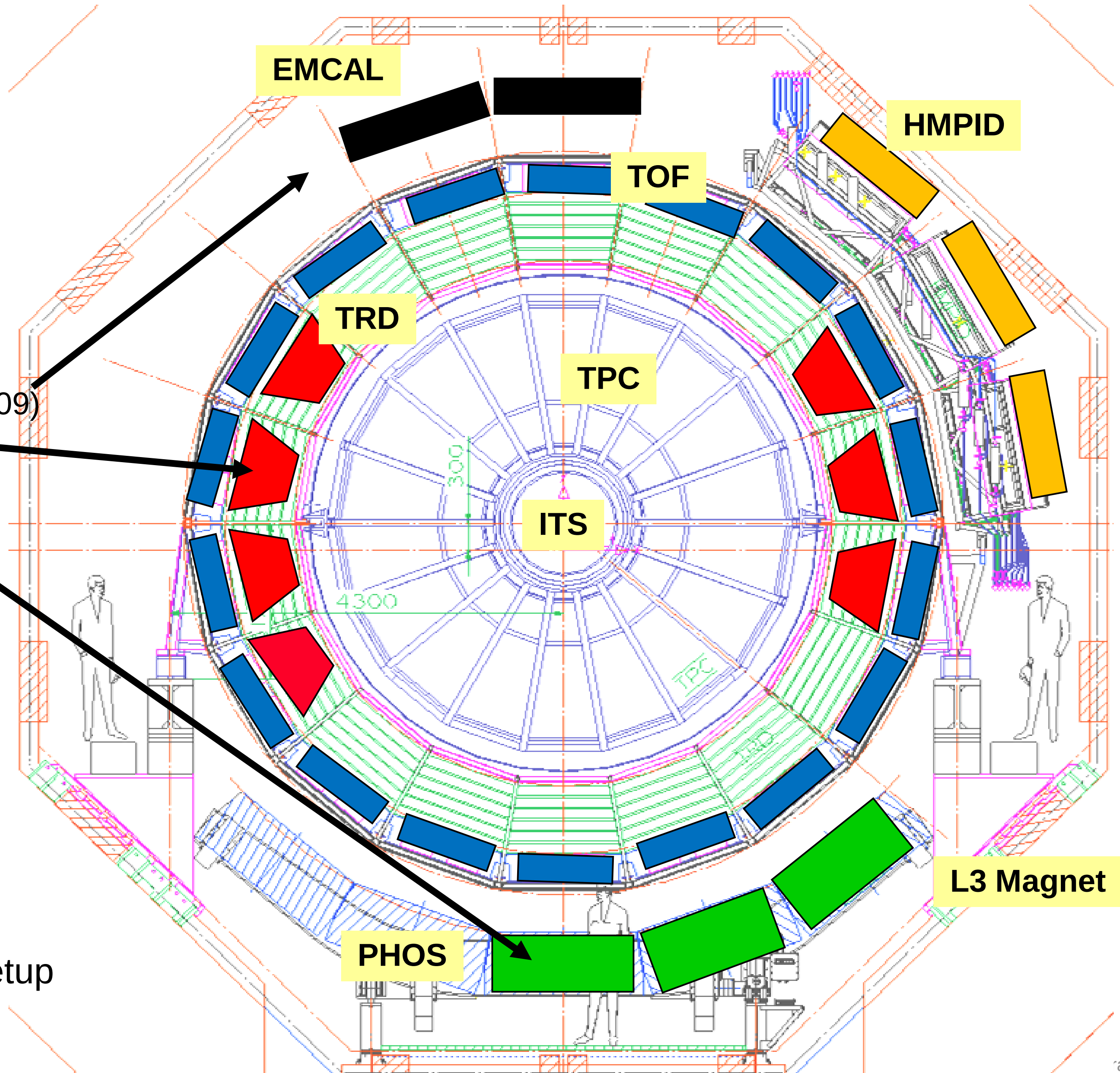
7/18 TRD* (approved 2002)

3/5 PHOS (funding)

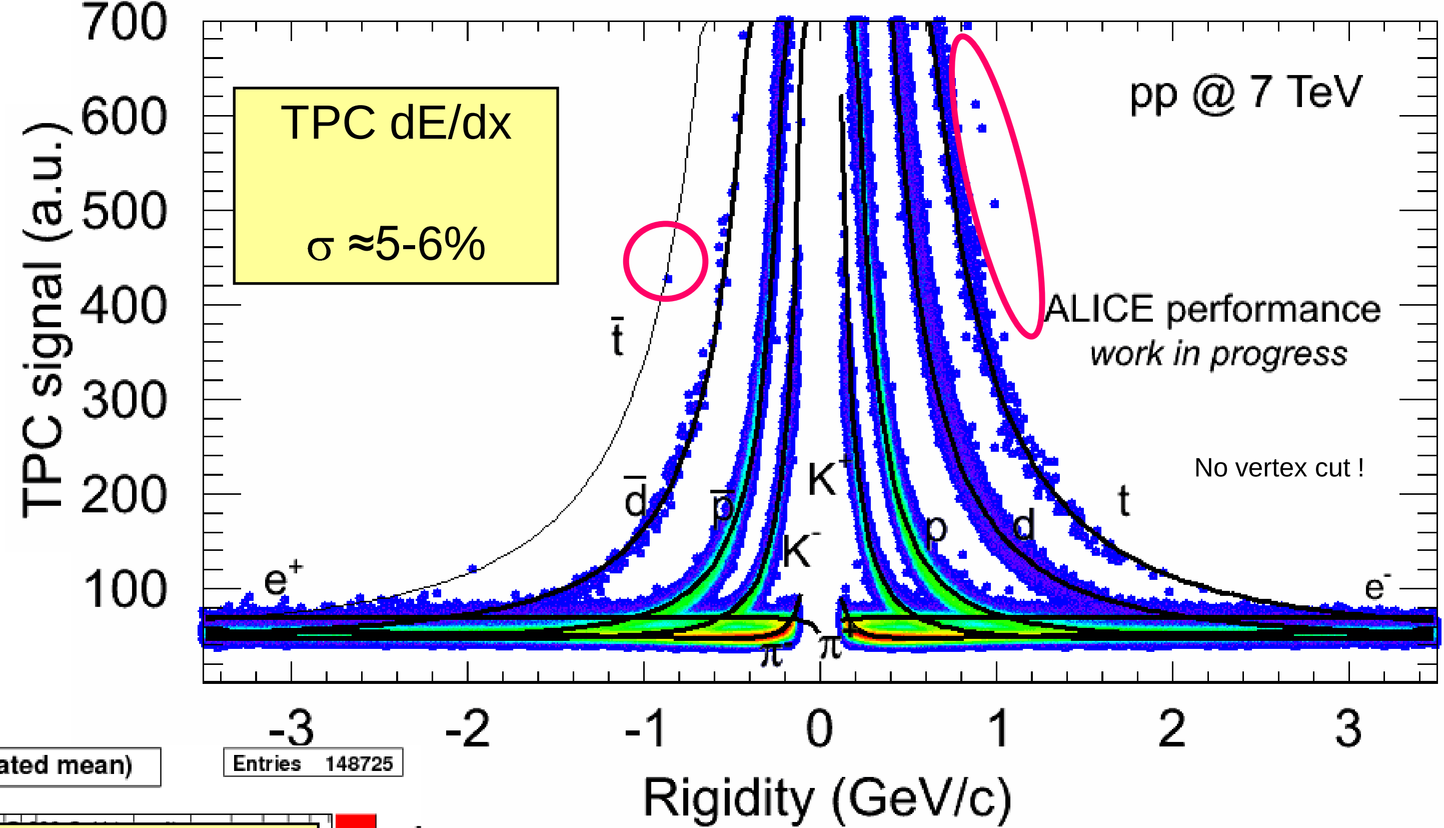
~ **60% HLT** **(High Level Trigger)**

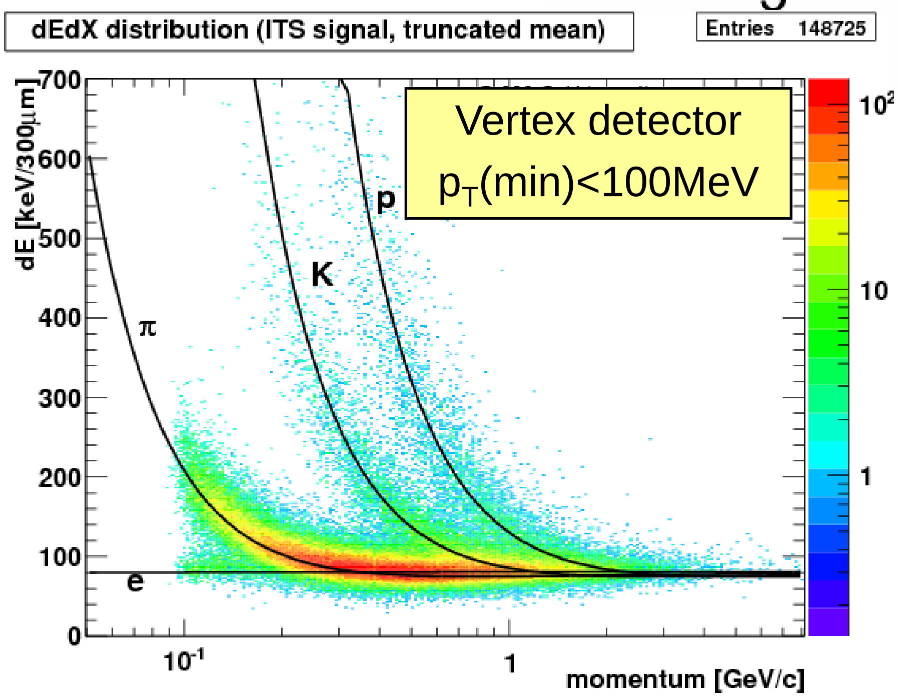
Short Status:
All systems fully operational

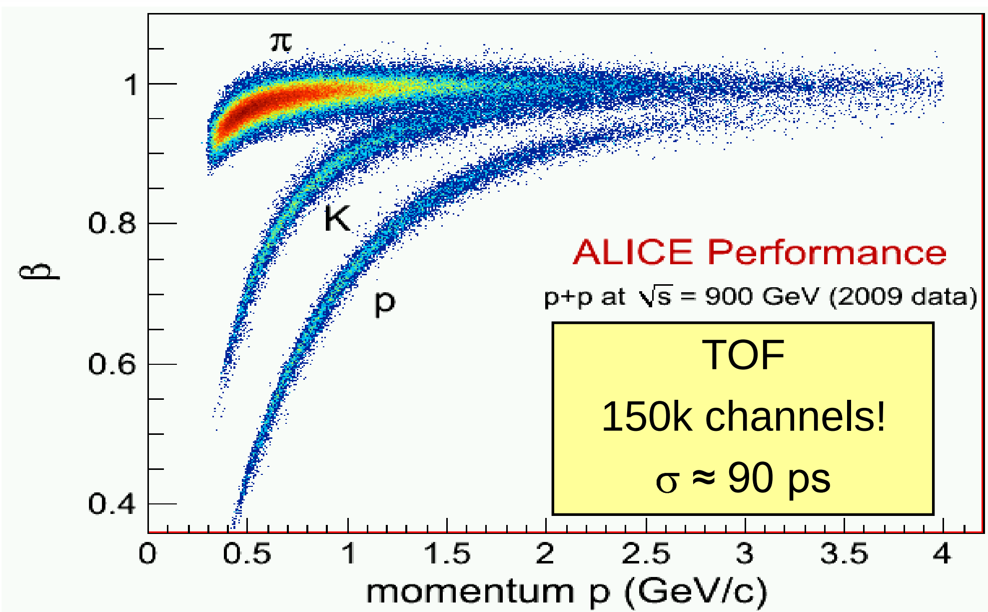
*upgrade to the original setup



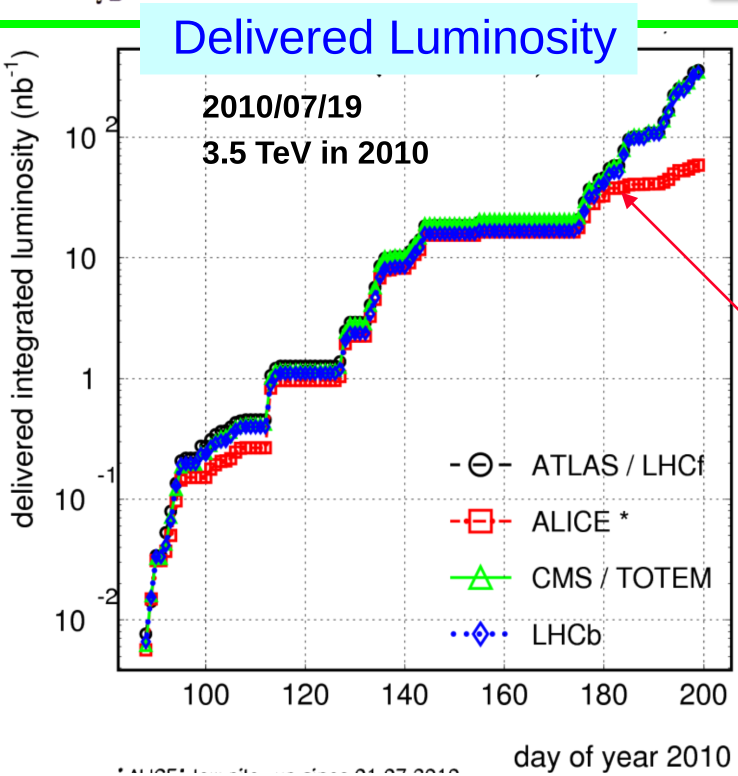
PID detectors

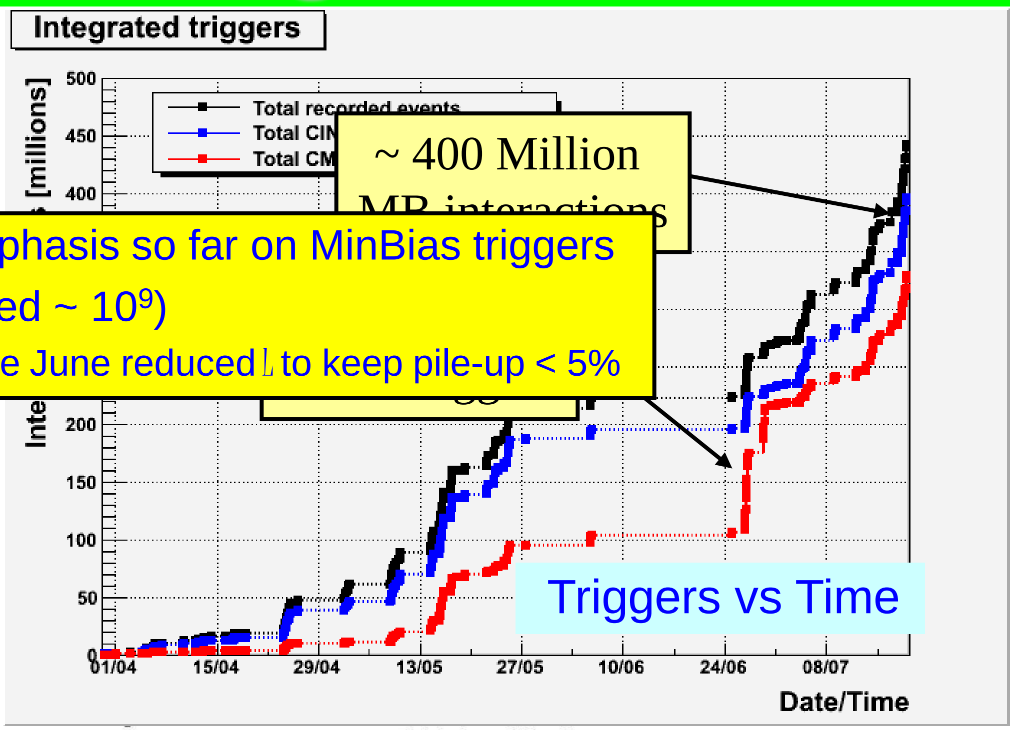


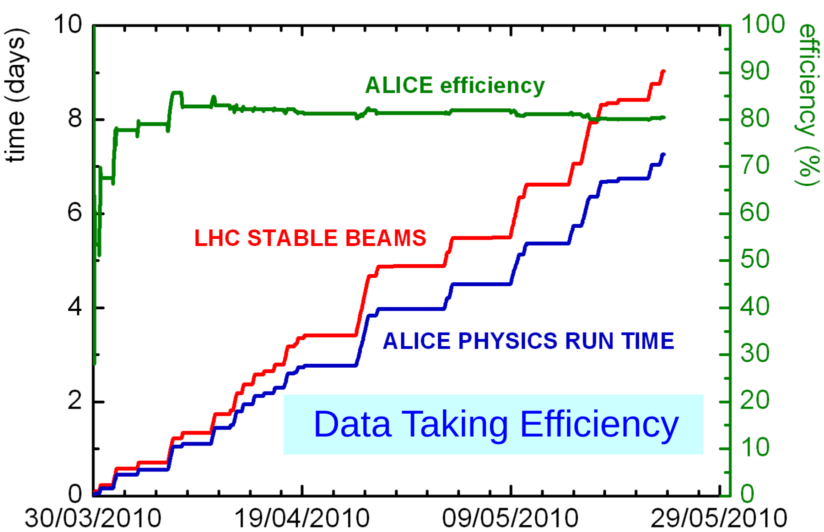


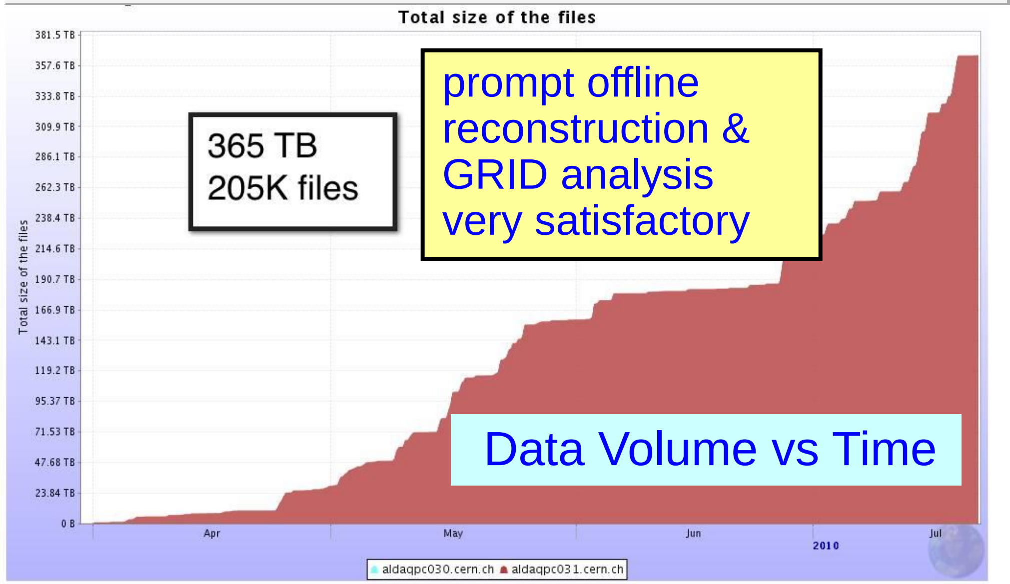


Data Taking


Delivered Luminosity
2010/07/19
3.5 TeV in 2010
delivered integrated luminosity (nb^{-1})
10^2
10
1
10^{-1}
10^{-2}
100
120
140
160
180
200
day of year 2010
ATLAS / LHCf
ALICE *
CMS / TOTEM
LHCb


Integrated triggers
Total recorded events
Total CIN
Total CM
~ 400 Million MB interactions
Emphasis so far on MinBias triggers (need ~ 10^9)
since June reduced L to keep pile-up < 5%
500
450
400
200
150
100
50
0
01/04
15/04
29/04
13/05
27/05
10/06
24/06
08/07
Date/Time
Triggers vs Time


time (days)
efficiency (%)
ALICE efficiency
LHC STABLE BEAMS
ALICE PHYSICS RUN TIME
Data Taking Efficiency
30/03/2010
19/04/2010
09/05/2010
29/05/2010

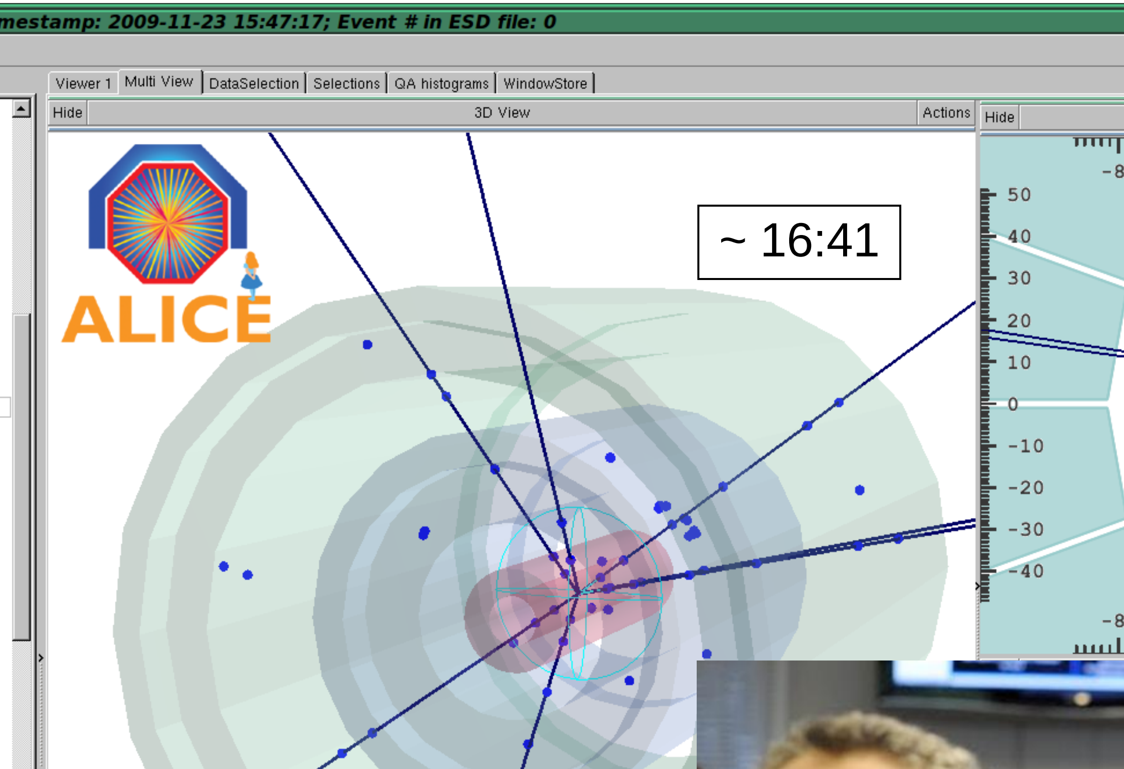

Total size of the files
365 TB
205K files
prompt offline reconstruction & GRID analysis very satisfactory
Data Volume vs Time
Apr
May
Jun
Jul
2010
aldaqpc030.cern.ch
aldaqpc031.cern.ch

Physics results

- **Final Results** → I. Belikov
  - ⇨ N_{ch} multiplicity & distributions
    - 900 GeV: **EPJC**: Vol. **65** (2010) 111
    - **900** GeV, **2.36** TeV: **EPJC**: Vol. **68** (2011) 89
    - **7** TeV: **arXiv:**1004.3514, accepted by EPJC
  - ⇨ Momentum distributions(**900** GeV) **arXiv:**1007.0719
  - ⇨ Bose Einstein correlations (**900** GeV) **arXiv**:1007.0516
  - ⇨ pbar/p ratio (**900** GeV & **7** TeV) **arXiv**:1006.5432, accepted by PRL

- **Ongoing analysis**
  - ⇨ Identified particles (π,K,p,K^0,Λ,Ξ,Ω,ϕ) → M. Lopez Noriega
  - ⇨ Heavy Flavor: charm (D^0,D^+, D*), c,b –> μ, e^- → A. Grelli, R. Bailhache
  - ⇨ J/Ψ –> $\mu\mu$, e^+e^- → J. Castillo, G. Bruno
  - ⇨ pQCD: Event topology, 2-particle correlations, jet fragmentation, … → J. Rak

Very first collisions: 23 Nov. 2009



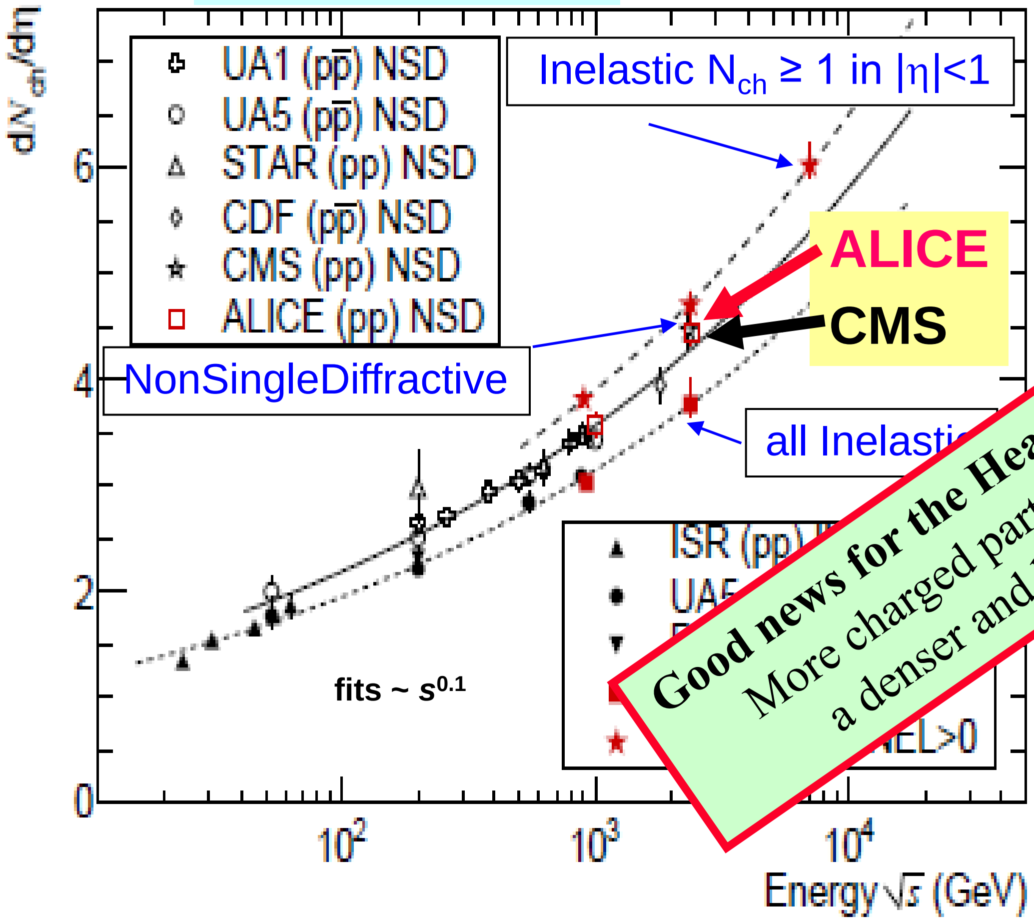
days after submitting our first paper (28 Nov, 2009; ~3 authors/event !)

National Geographic News (4 Dec.)

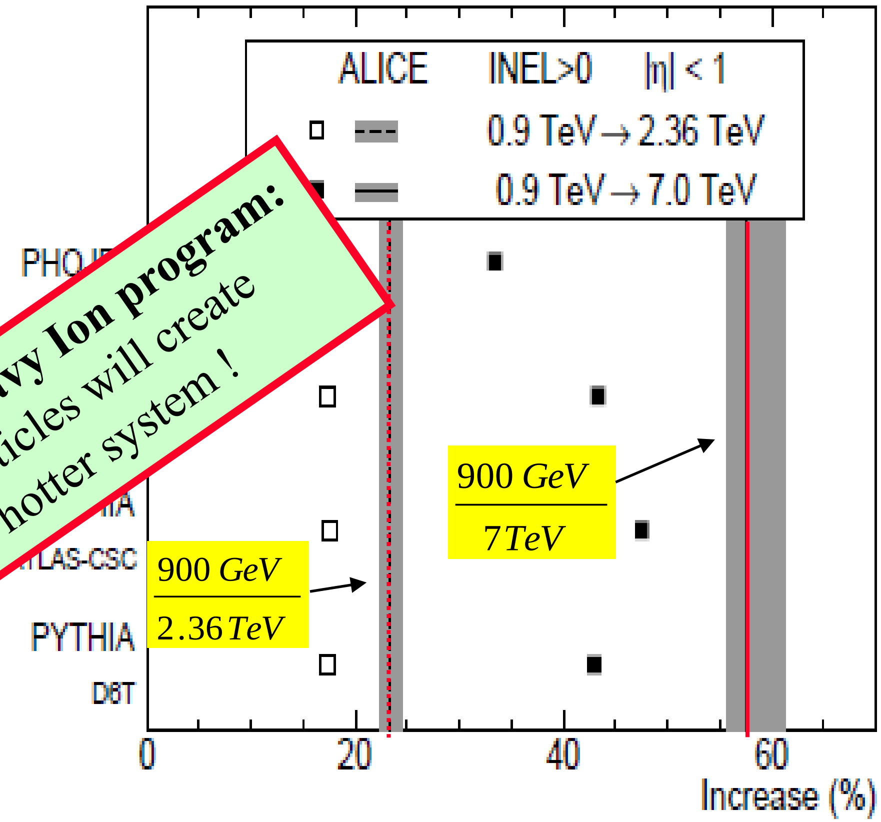
'….a machine called ALICE…. found that **a** (!) proton-proton collision recorded on November 23

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

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



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



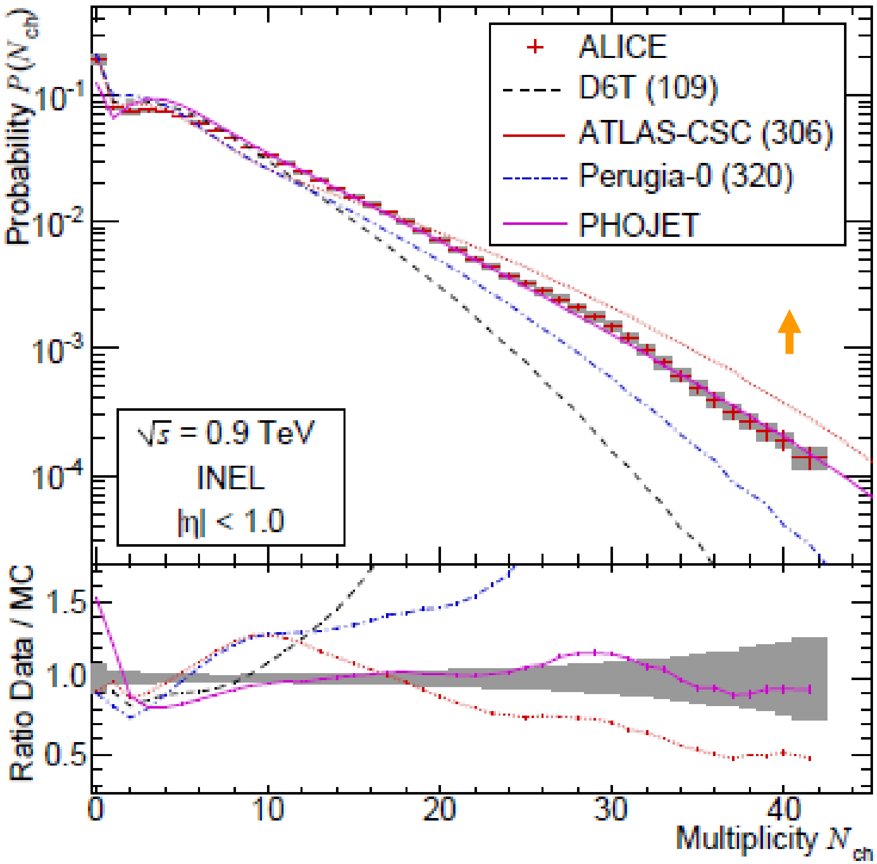
Good news for the Heavy Ion program:
More charged particles will create a denser and hotter system !

Results:

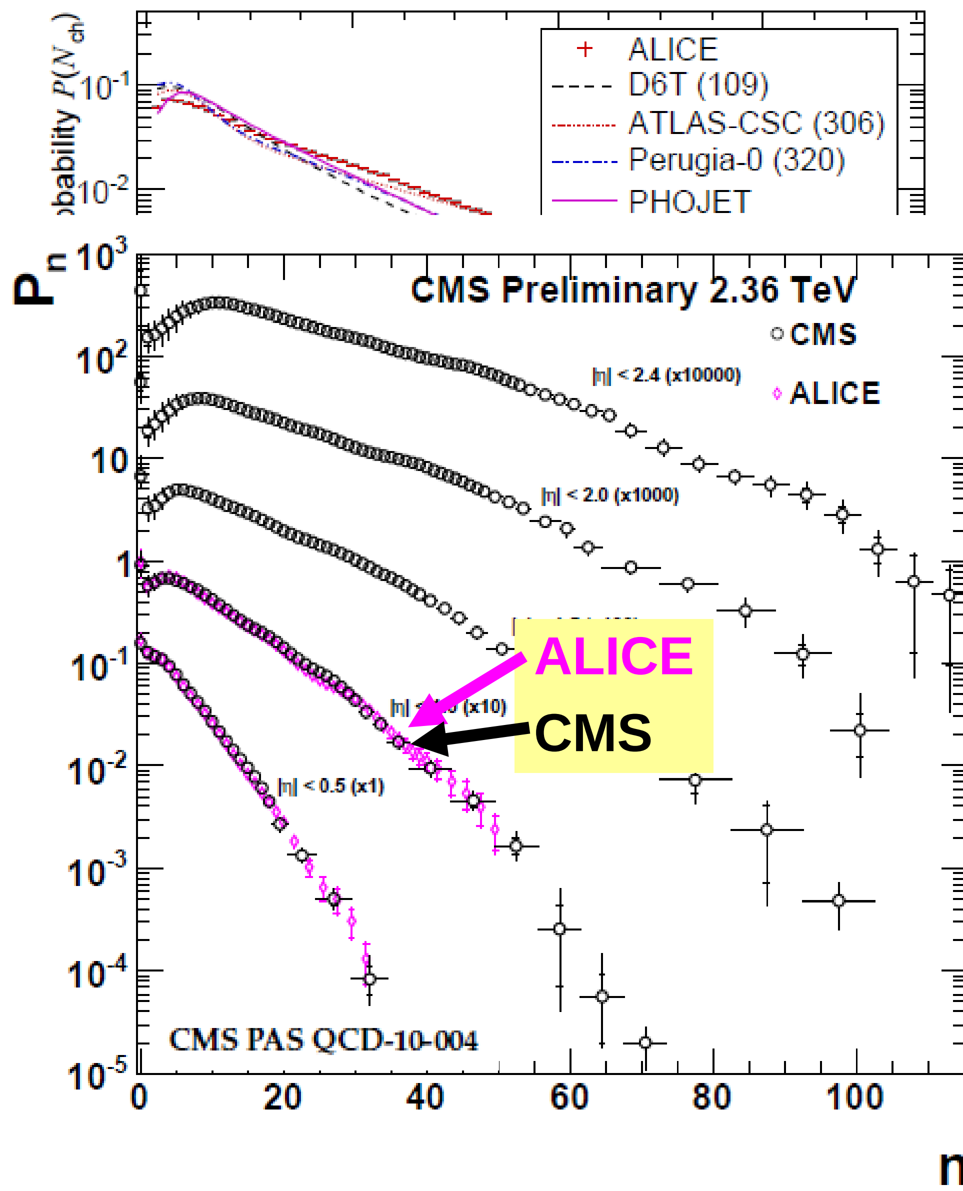
- $dN_{ch}/d\eta$ well described by power law $(\sqrt{s})^{0.2}$
- increase with energy significantly stronger in data than MC's
- Alice & CMS agree to within 1 σ (< 3%)

Multiplicity Distribution

Multiplicity Distribution 900 GeV



Multiplicity Distribution 7 TeV

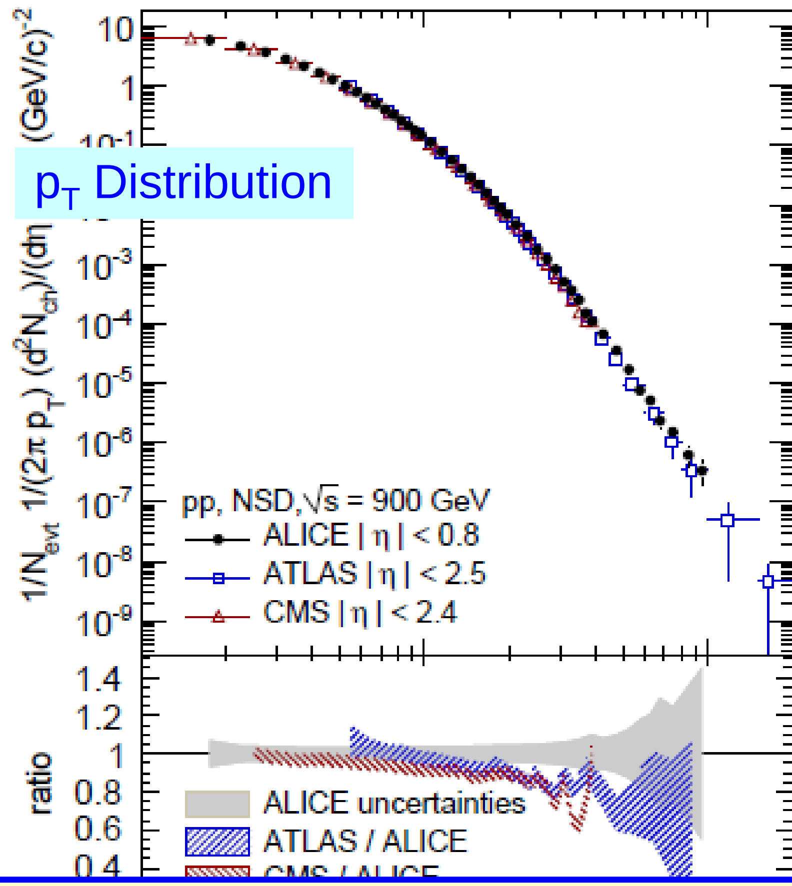


Results:

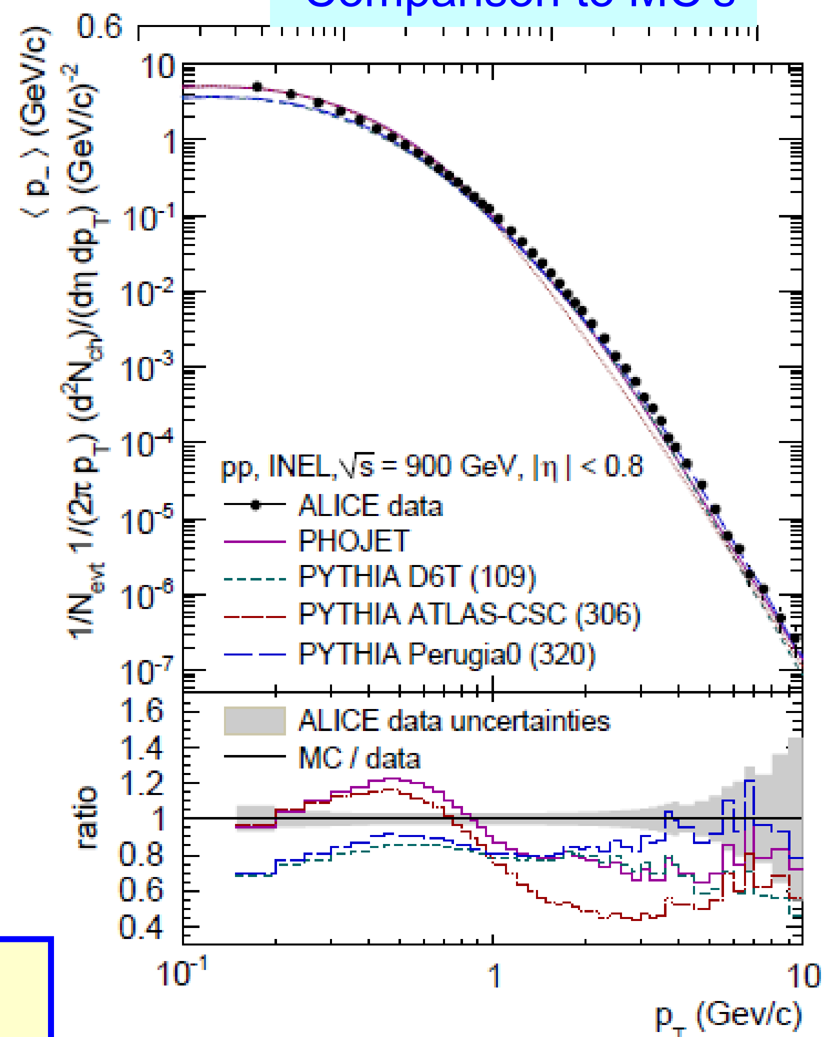
- most of the 'stronger increase' is in the tail of N_{ch}
- ALICE & CMS still agree perfectly !

Momentum Distribution 900 GeV

p_T Distribution



Comparison to MC's

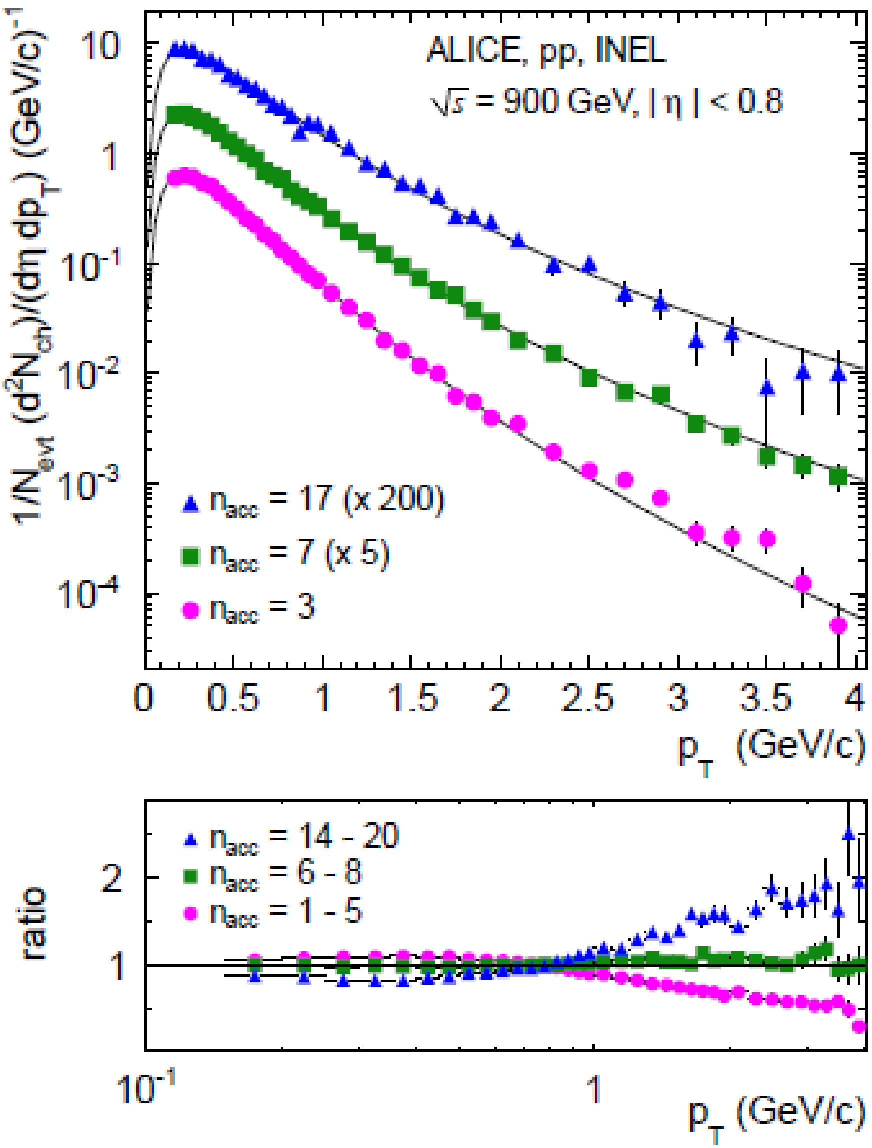


Results:

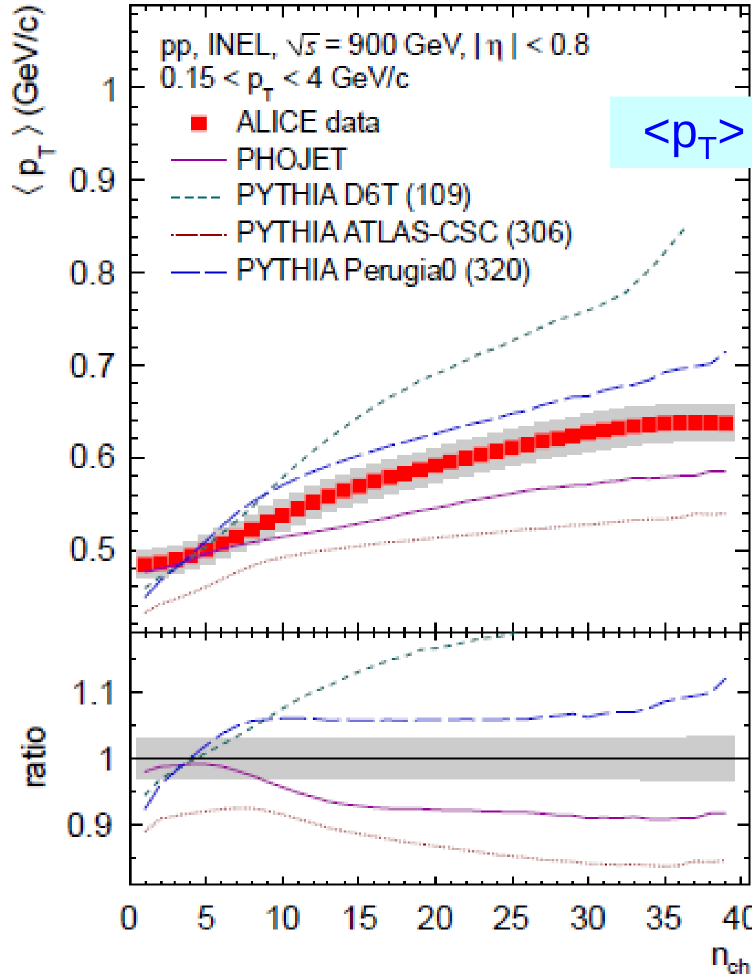
- Finally some (slight) difference !
- Spectrum seems to get harder towards midrapidity
- MC's have hard time to describe the full spectrum

$<p_T>$ 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…

MC Scoreboard

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

Stay tuned !

- MC << data
- MC >> data
- MC ≈ data

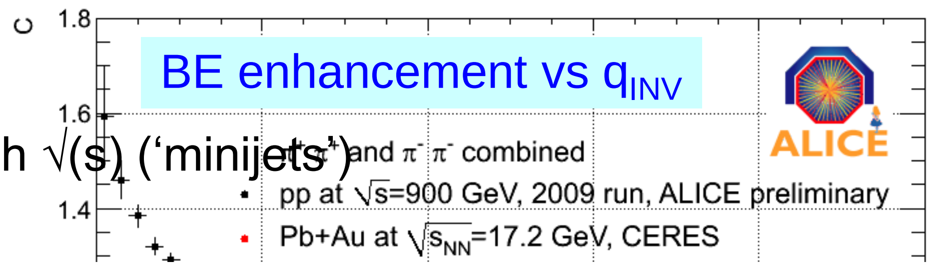
Conclusion:

- none of the tested MC's (adjusted at lower energy) does really well
- tuning one or two results is easy, getting everything right will require more effort

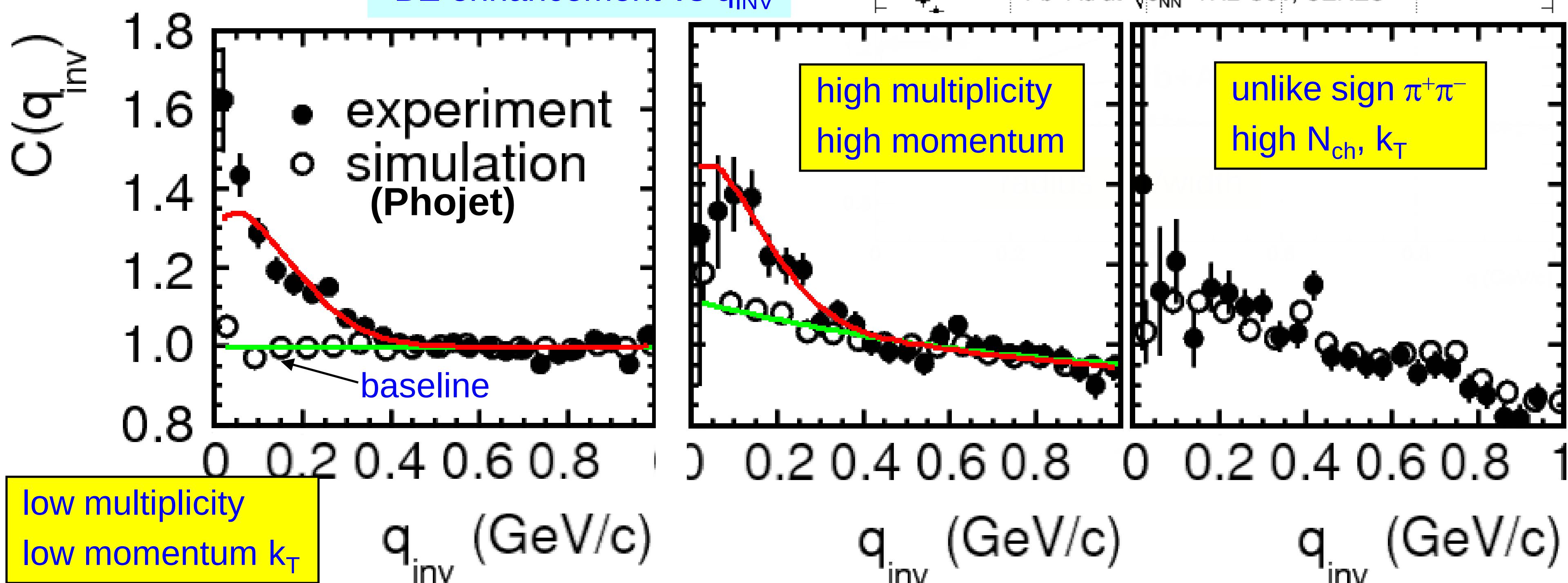
(and may, with some luck, actually teach us something on soft QCD rather than only turning knobs)

Bose Einstein Correlations (HBT)

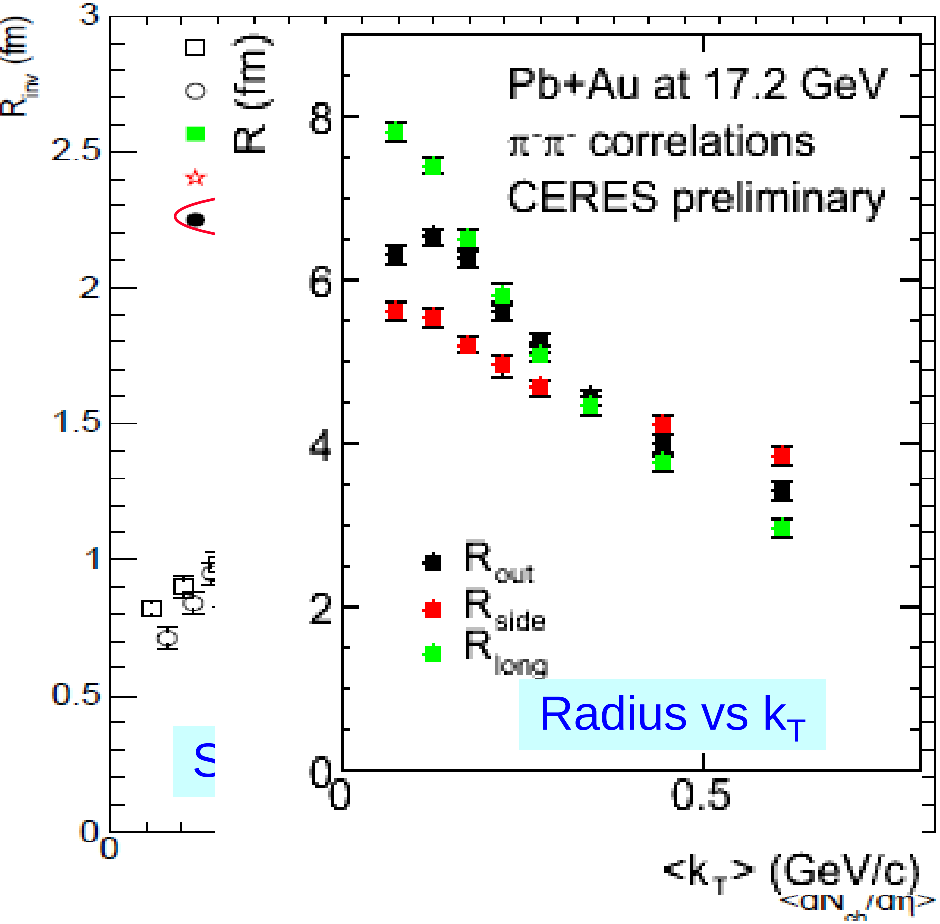
- QM enhancement of identical Bosons at small momentum difference
  - ⇨ enhancement of e.g. like-sign pions at low momentum difference $q_{inv}=|\mathbf{p}_1-\mathbf{p}_2|$, as function of multiplicity and pair momentum $k_T = |\mathbf{p}_{T1}+\mathbf{p}_{T2}|/2$
  - ⇨ measure Space-Time evolution of the 'dense matter' system in heavy ions coll.
    - ✪ interpretation in 'small systems' (pp, e^+e^-) is less obvious..
  - ⇨ 'enhancement' rel. to phase-space **and** any non-BE correlations ('baseline')
    - ✪ non-BE correlations important at high √(s) ('minijets')

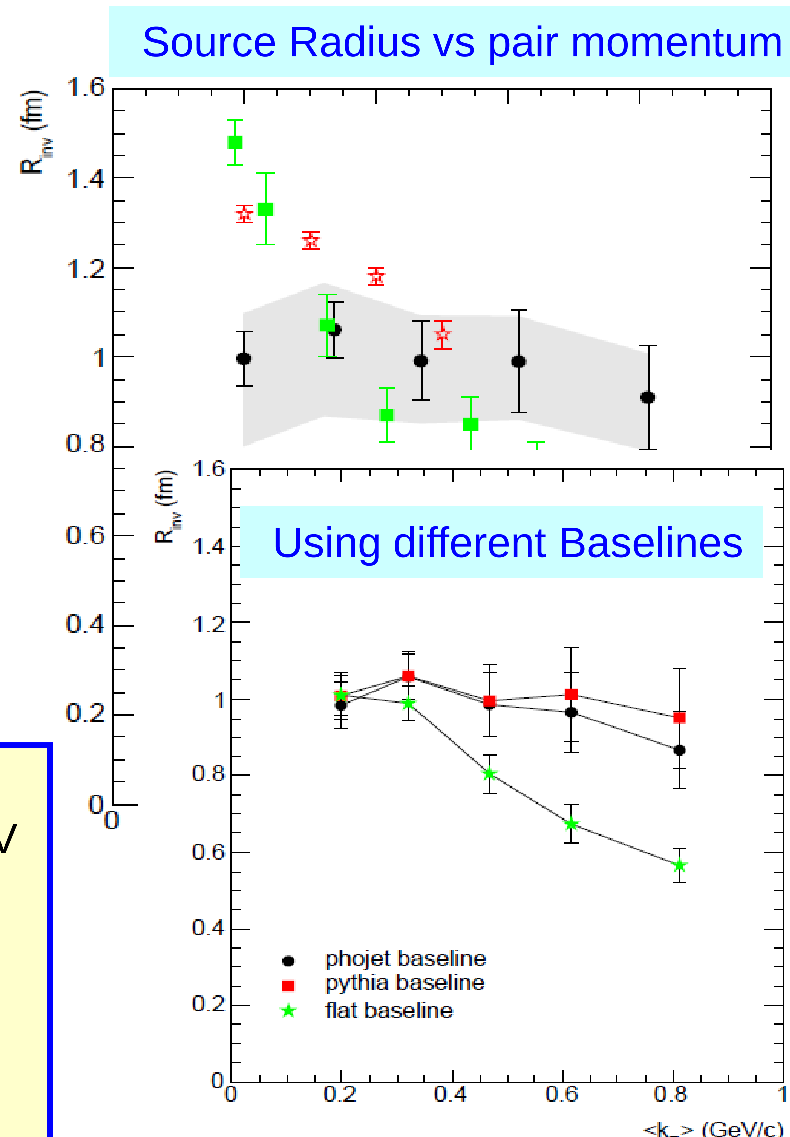


BE enhancement vs q_{INV}



HBT @ 900 GeV





Results:

- Radius increases with N_{ch}, comparable to ISR, RHIC, TeV
- rather constant vs $\langle k_T \rangle$!

  sign. systematic uncertainty from 'baseline' shape

  dependence usually interpreted as sign of 'flow' in heavy ions

- neglecting non-BE correlations ('flat baseline') can cause k_T dependence (at high $\sqrt{s}$)!

$\bar{p}$/p Ratio

- Can one stop a proton 'on its track' at LHC ?
  - ⇨ where does the conserved baryon number reappear after the pp collision ?
  - ⇨ fragmentation function f(z) of baryon number
    - ✪ Di-quark qq: z^2 => α **= -1**, small Δy
    - ✪ single q: $\sqrt{z}$ => α **= 0.5**, medium Δy
    - ✪ no valence q: α **= ??**; large Δy ??

$z^a \sim e^{-a\Delta y} = e^{-(1-\alpha)\Delta y}$ ($\Delta y \gg 1$)

α = intercept of relevant Regge trajectory

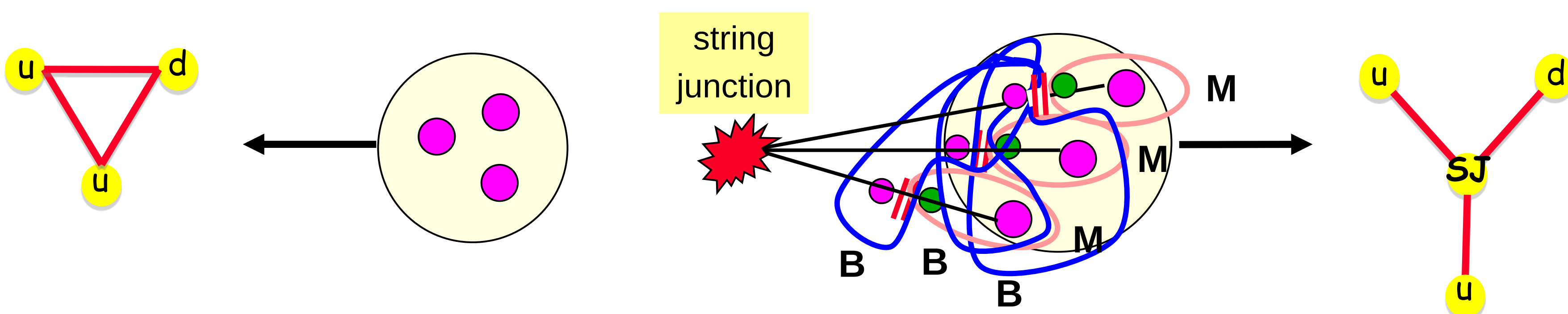
$\Delta y = y_{beam} - y_{baryon}$ = 'rapidity loss'

Veneziano: $\alpha \approx 0.5$ others: $\alpha \approx 1$ (pQCD estimates, σ(p-**pbar** annihilation), 'odderon')

$\alpha \approx 1$ => f(y) = constant, pbar/p < 1 at all energies (< 0.93 at LHC)

G.C. Rossi and G. Veneziano, Nucl. Phys. B123, (1977) 507

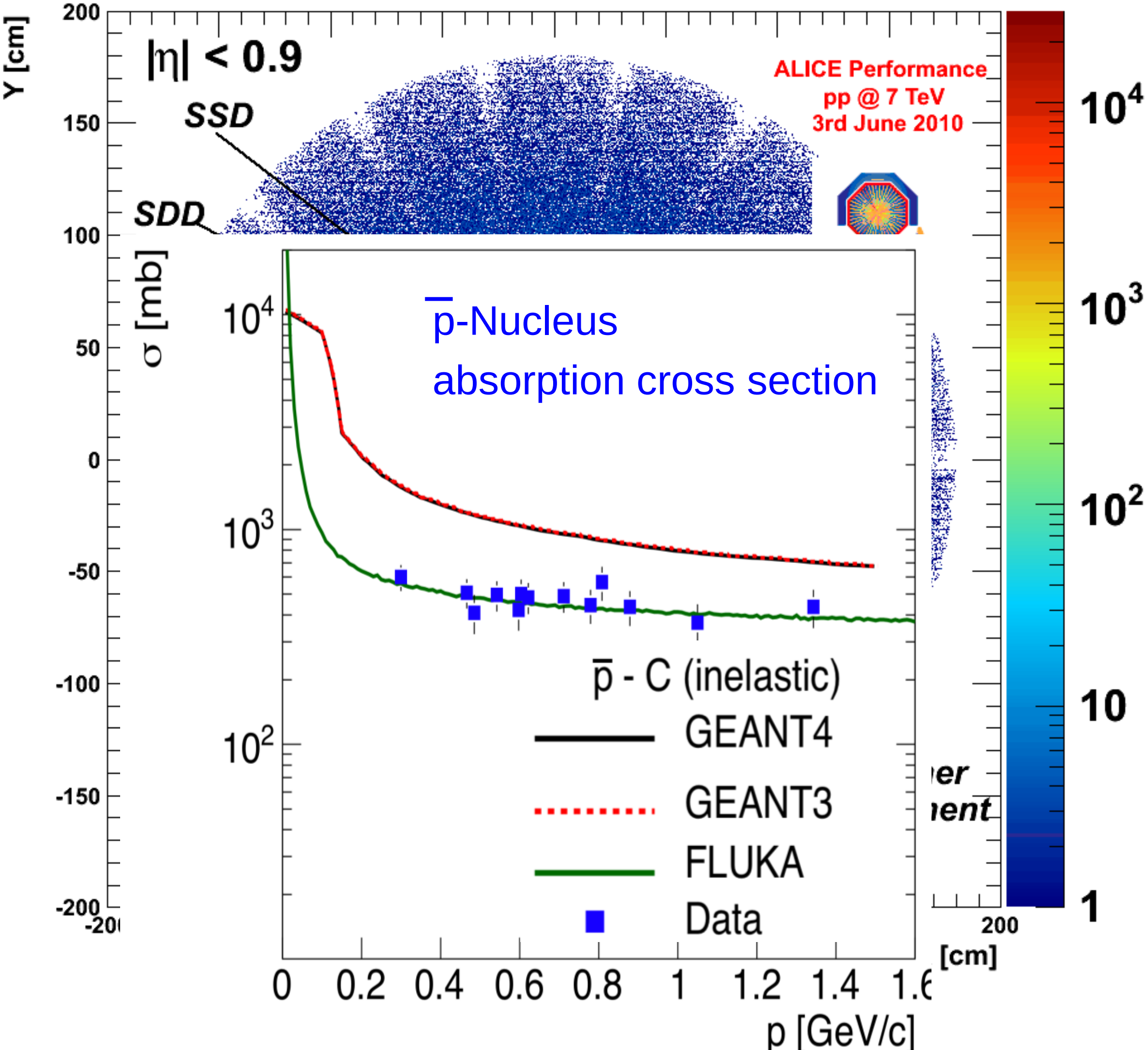
B.Z. Kopeliovich, Sov. J. Nucl. Phys. 45, 1078 (1987);

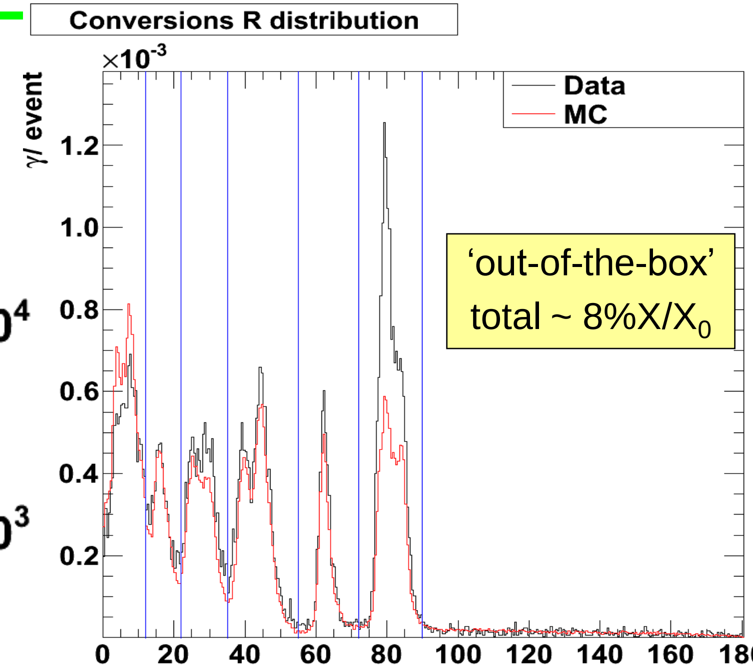


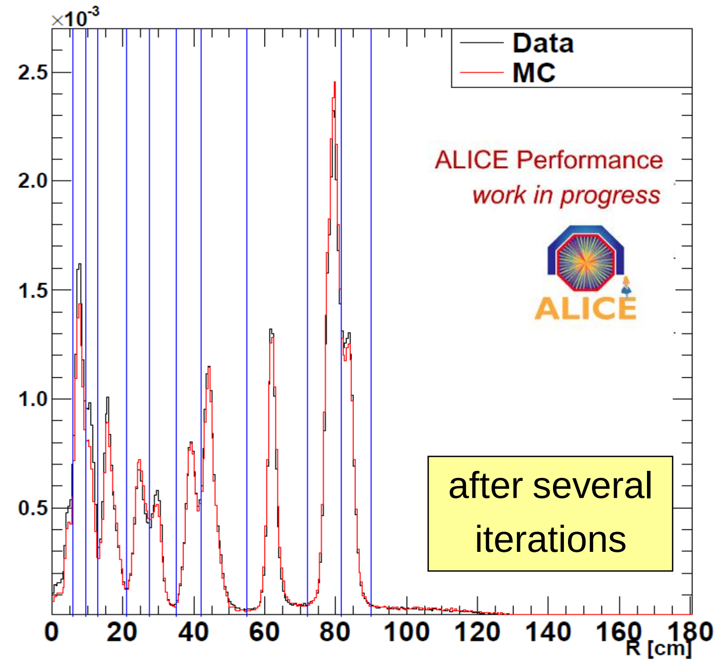
- Intermezzo: How to measure pbar/p to O(1%) ?
  - ⇨ ratio => most instrumental effects cancel
  - ⇨ σ(pbar-Nucleus) » σ(p-Nucleus) => absorption/el. scattering correction of O(10%)

Material Budget (what did we actually built ?)

γ-ray image of ALICE
photon conversion vertices

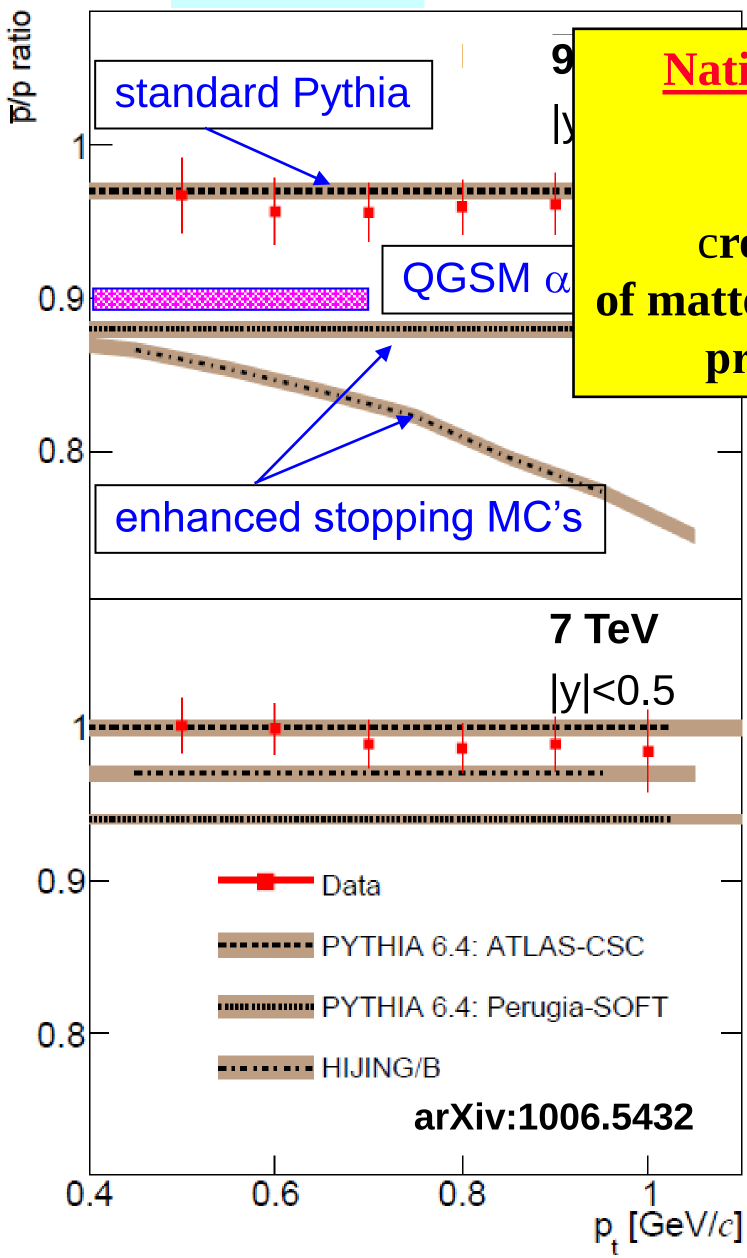




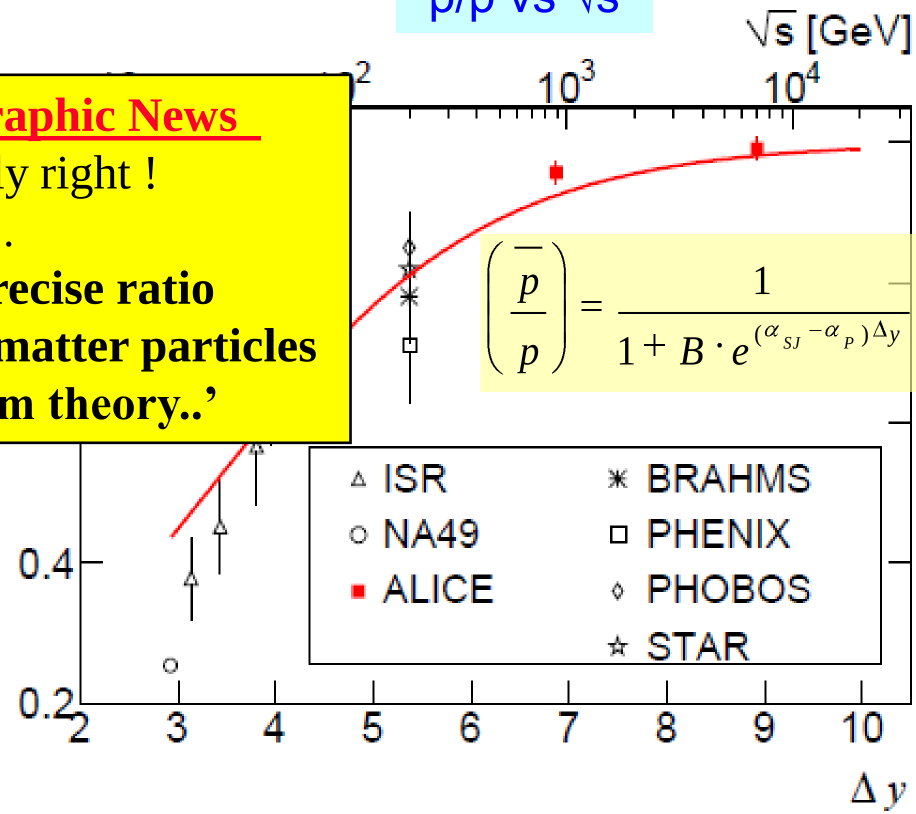


$\bar{p}/p$ Ratio @ LHC

$\bar{p}/p$ vs p_T



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



$$\left(\frac{\bar{p}}{p}\right) = \frac{1}{1 + B \cdot e^{(\alpha_{SJ} - \alpha_P)\Delta y}}$$

<u>National Geographic News</u>

was actually right !

……

created the precise ratio of matter and antimatter particles predicted from theory..'

Results:

- you can't stop a proton on its track (at least not at LHC)
- 'string junction' picture: $\alpha_{SJ} \approx 0.5$ (G.V. was right !)
- little room for **<u>any</u>** 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)

Physics results

- Final Results
  - ⇨

- Ongoing analysis
  - ⇨ Identified particles (π,K,p,K^0,Λ,Ξ,Ω,ϕ)
  - ⇨ Heavy Flavor: charm (D^0,D^+, D*), c,b –> μ, e^-
  - ⇨ J/Ψ –> $\mu\mu$, e^+e^-
  - ⇨ pQCD: Event topology, 2-particle correlations, jet fragmentation, …

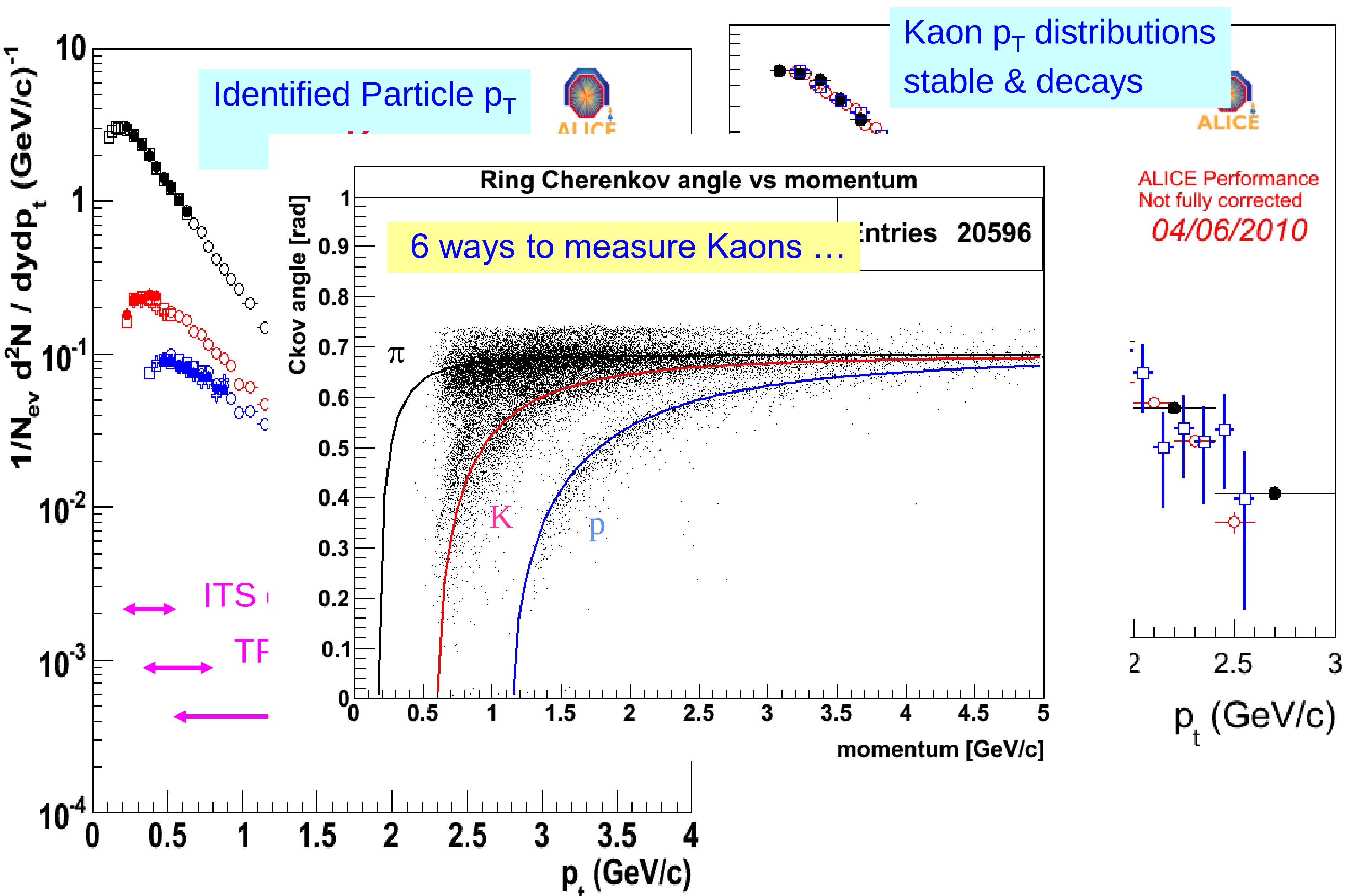
→M. Lopez Noriega

→A. Grelli, R. Bailhache

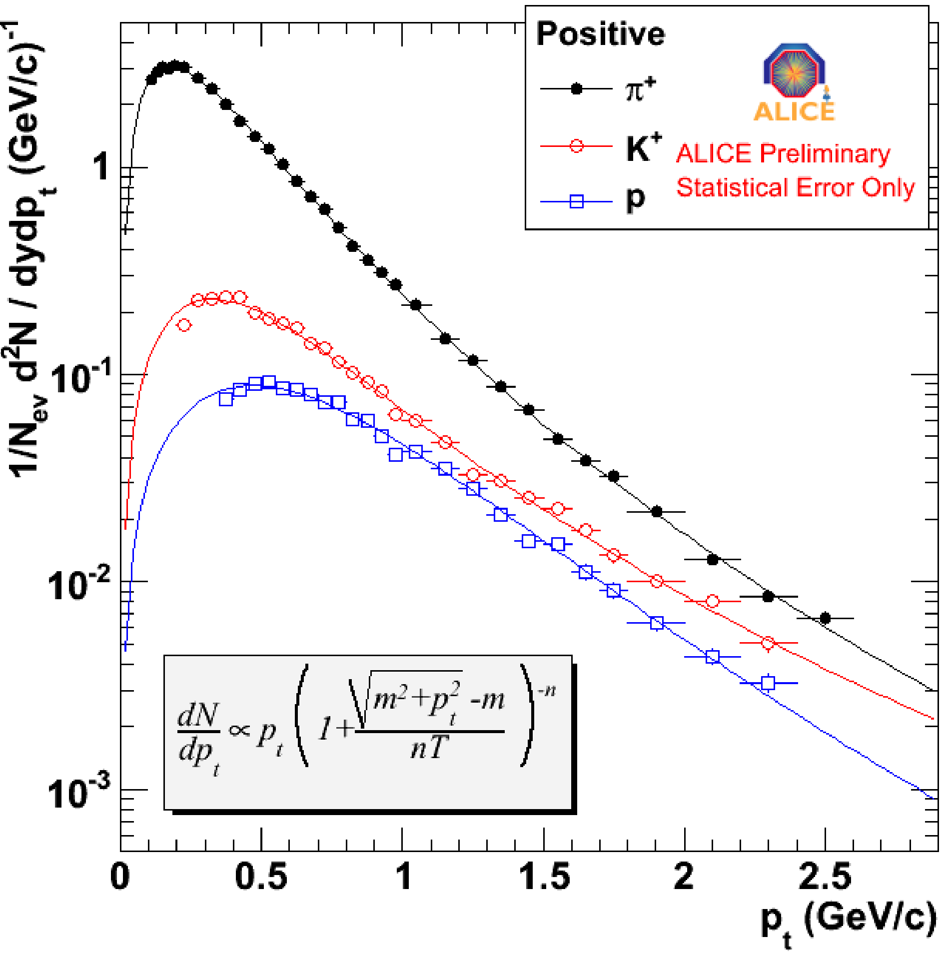
→J. Castillo, G. Bruno

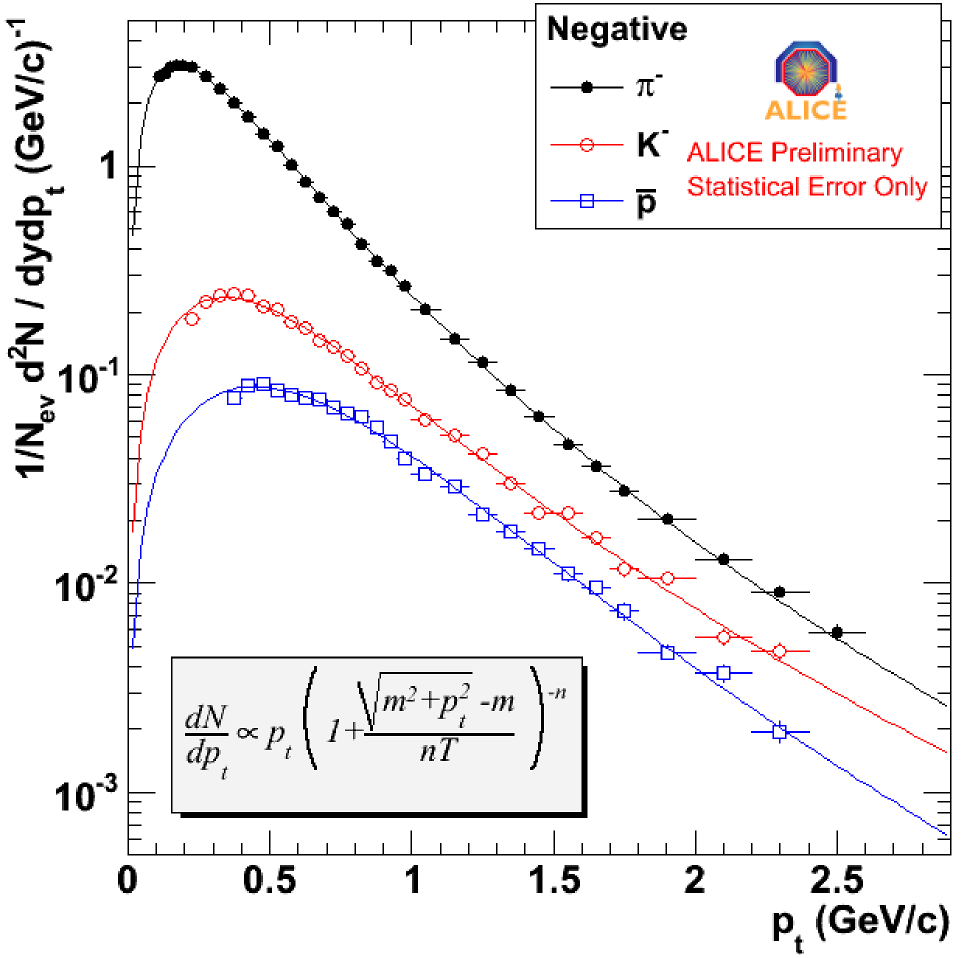
→J. Rak

Identified Particles

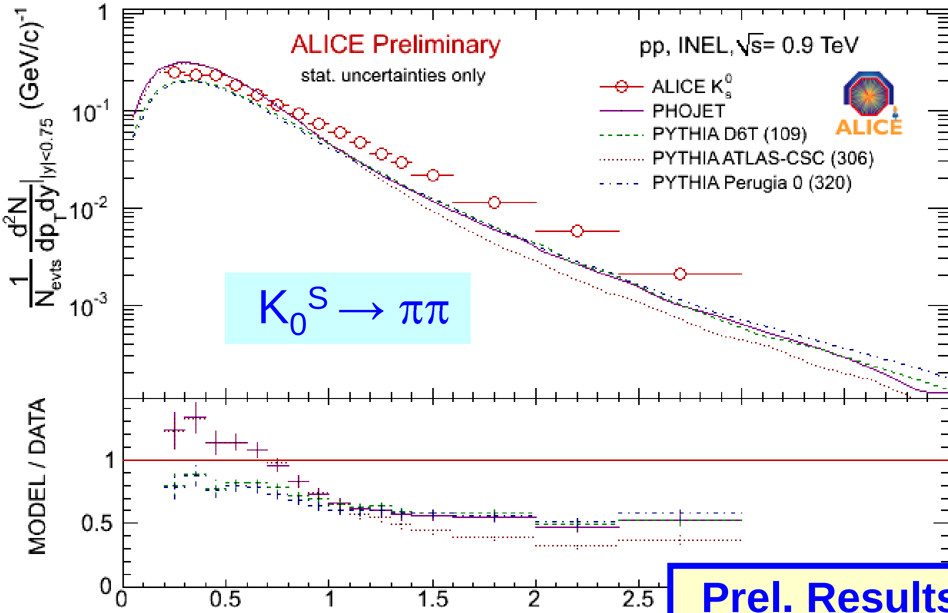


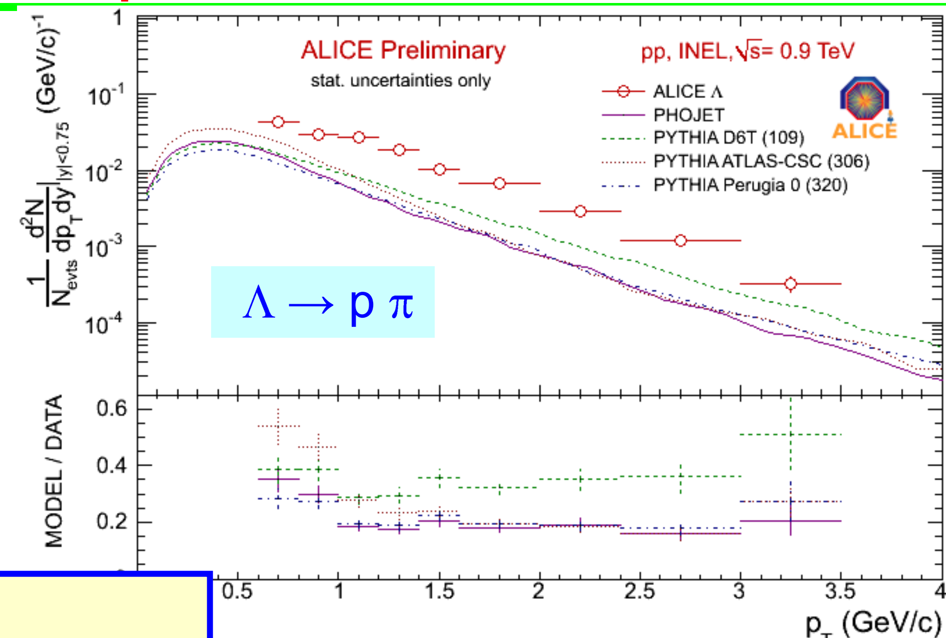
Stable: π, K, p at 900 GeV





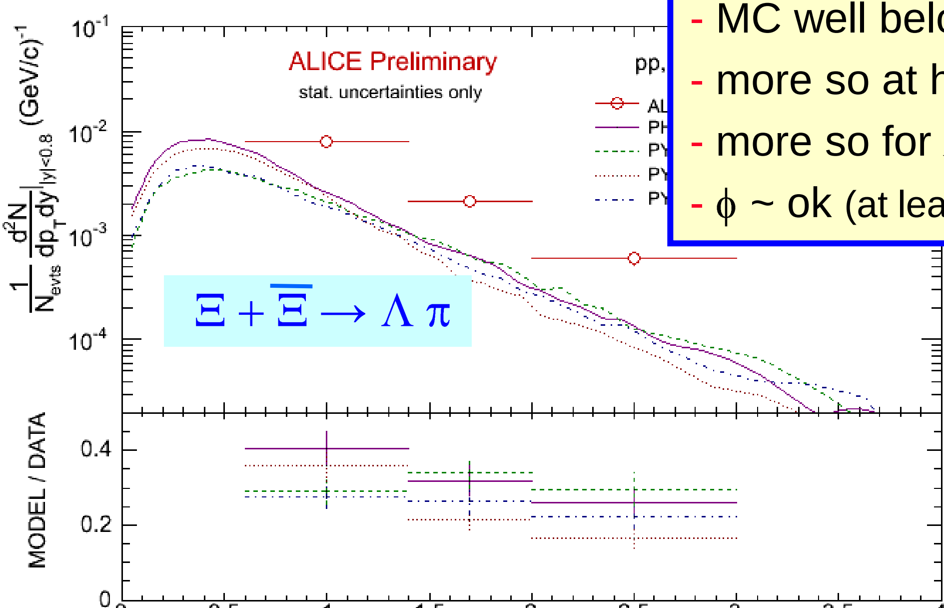
Decays: K_0^S, Λ, Ξ, ϕ at 900 GeV *

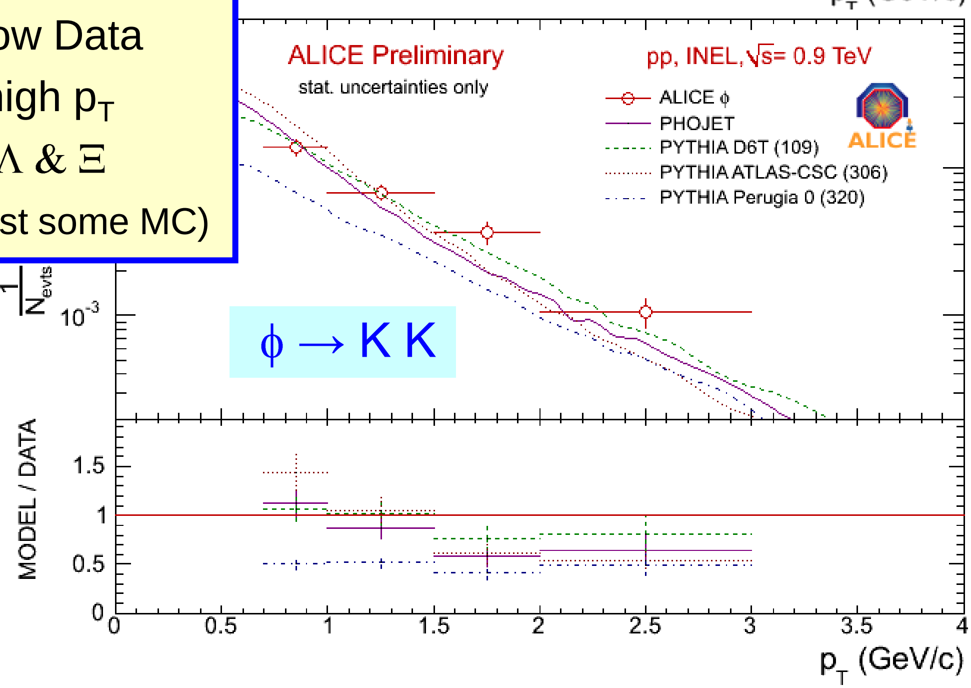




Prel. Results:

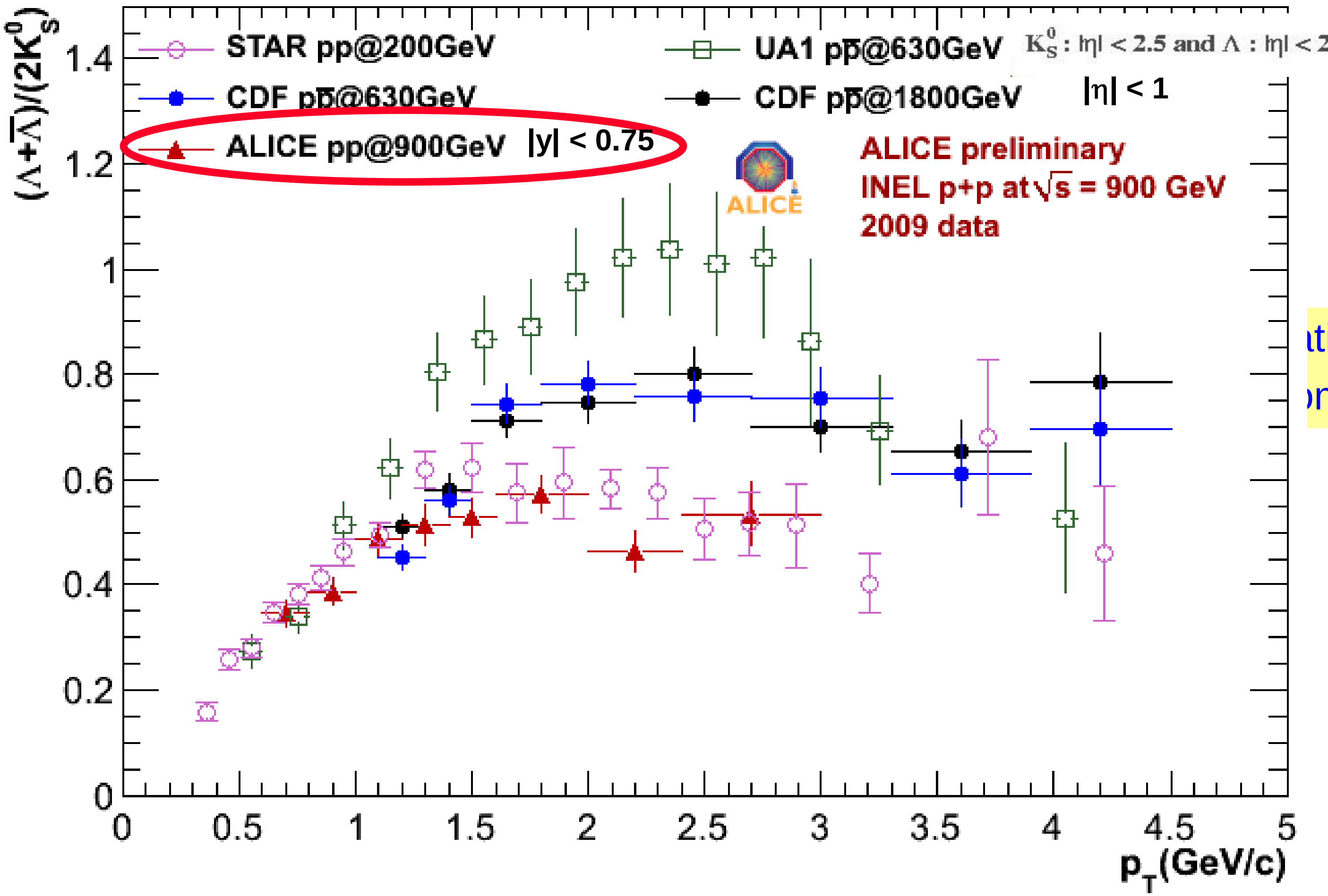
- MC well below Data
- more so at high p_T
- more so for Λ & Ξ
- ϕ ~ ok (at least some MC)





* 2009 Data (~300 k events)

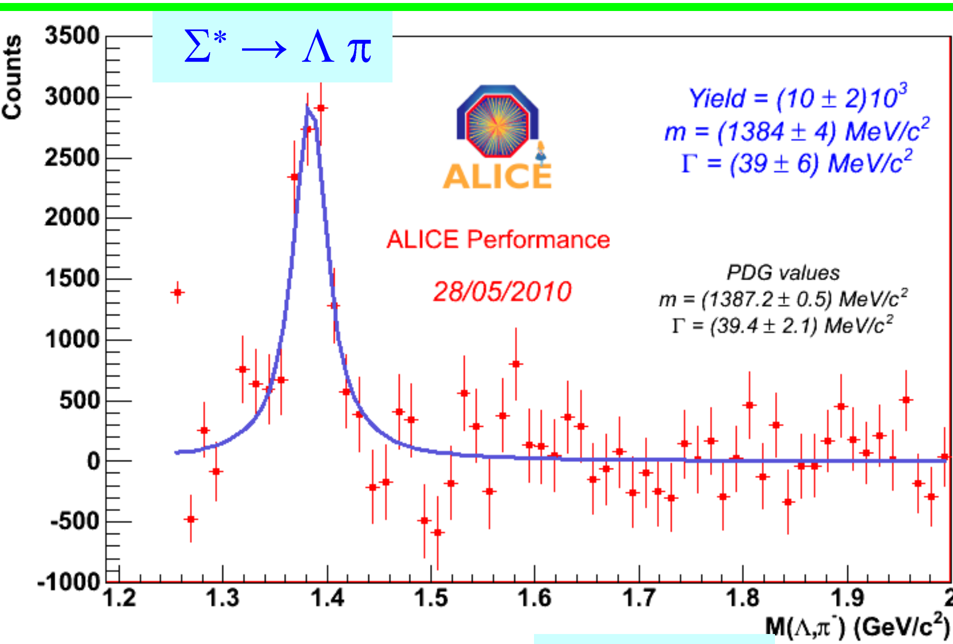
Λ/K_0^S Ratio 900 GeV

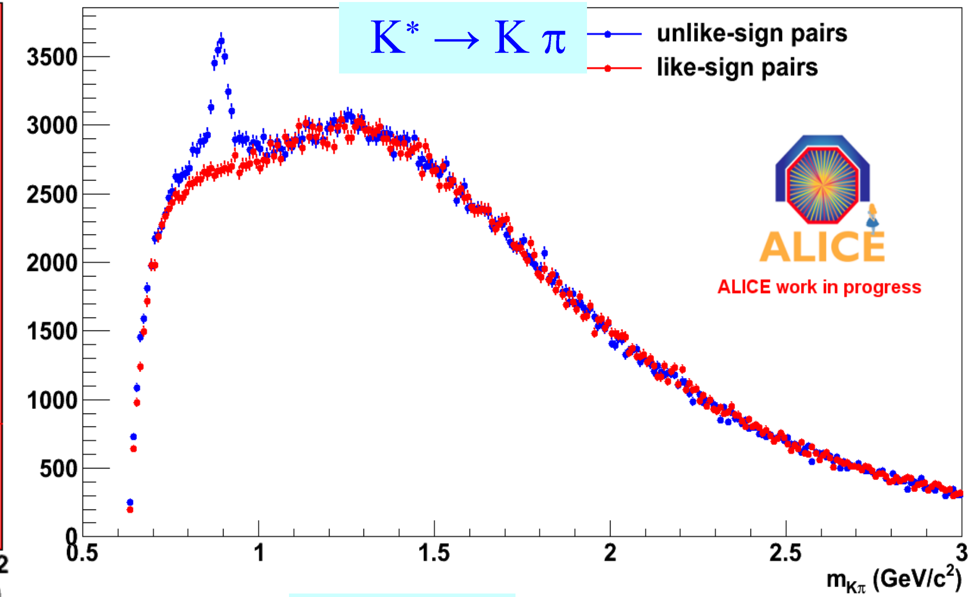


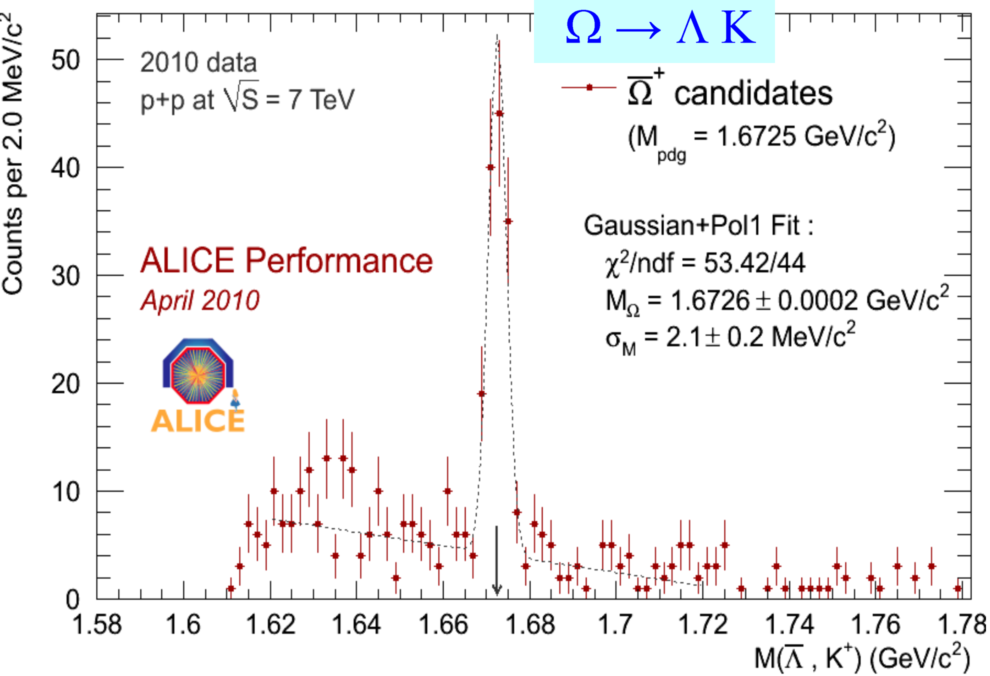
- very good agreement between STAR (200 GeV) and ALICE (900 GeV)
- very different from CDF (630/1800) and UA1 (630) for p_T > 1.5 GeV
- UA1(630) and CDF(630) don't agree either …

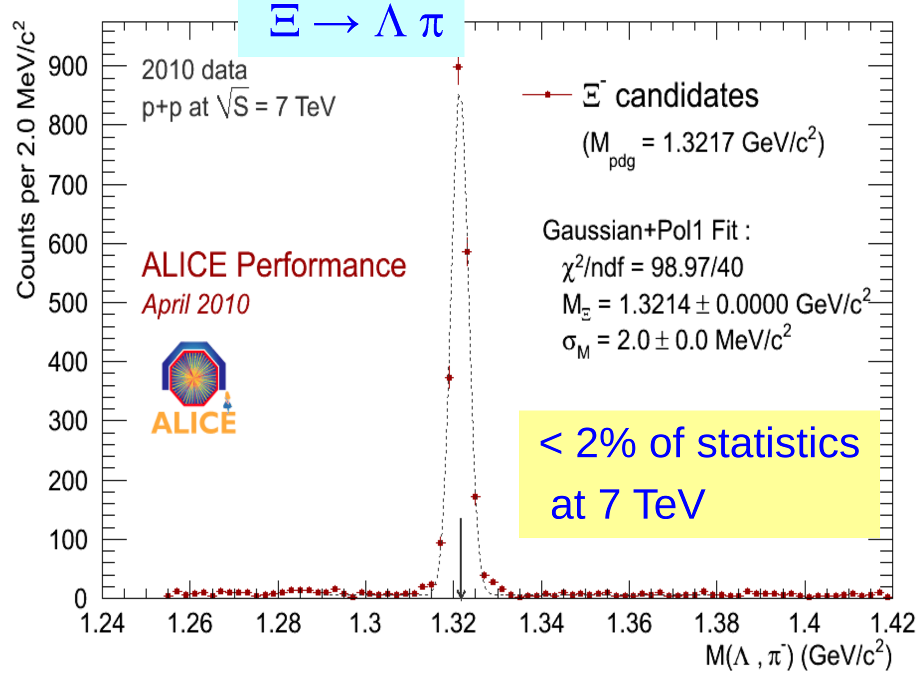
to be further investigated (different triggers, acceptance, feed-down correction ?)

Much more to come..

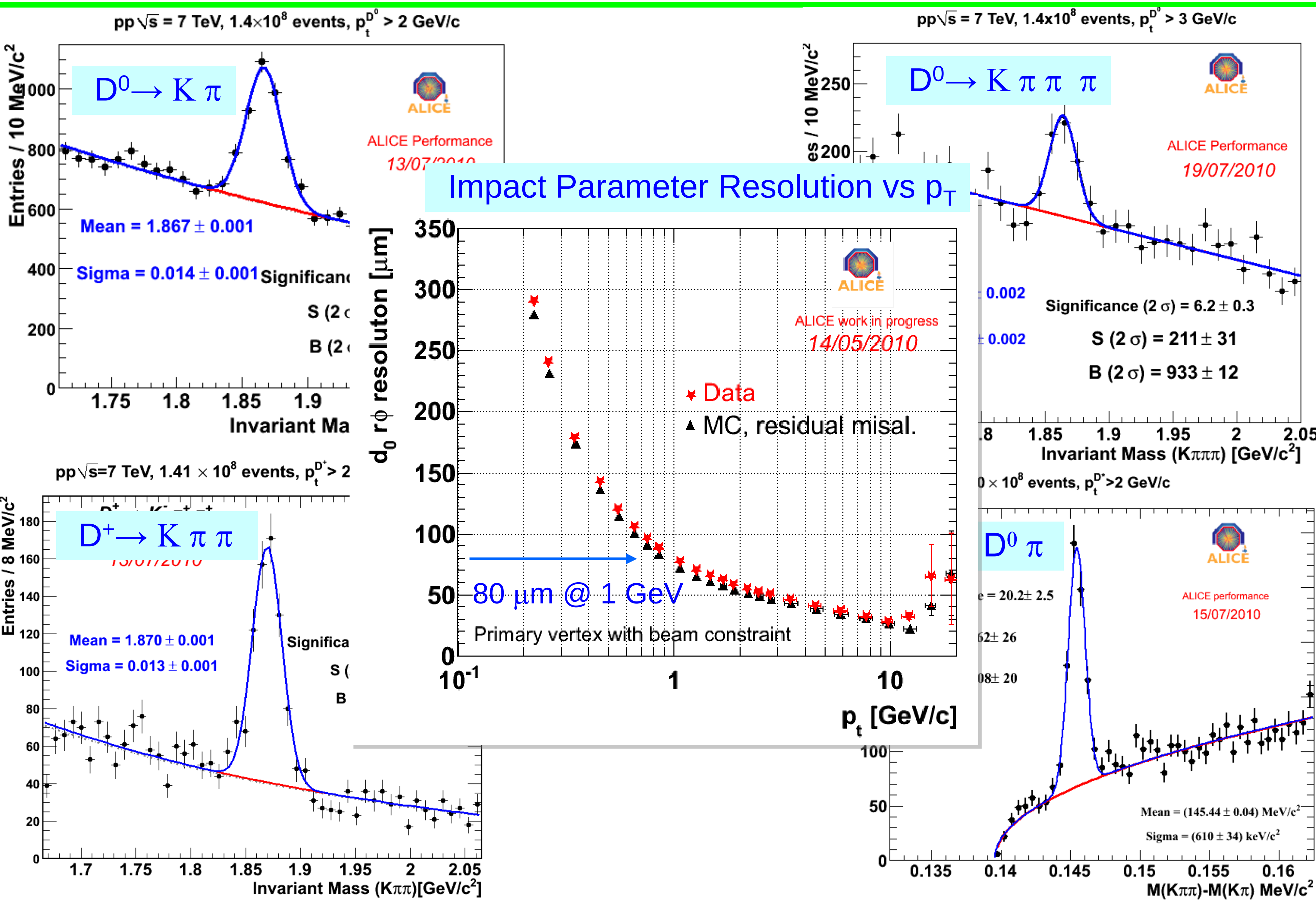




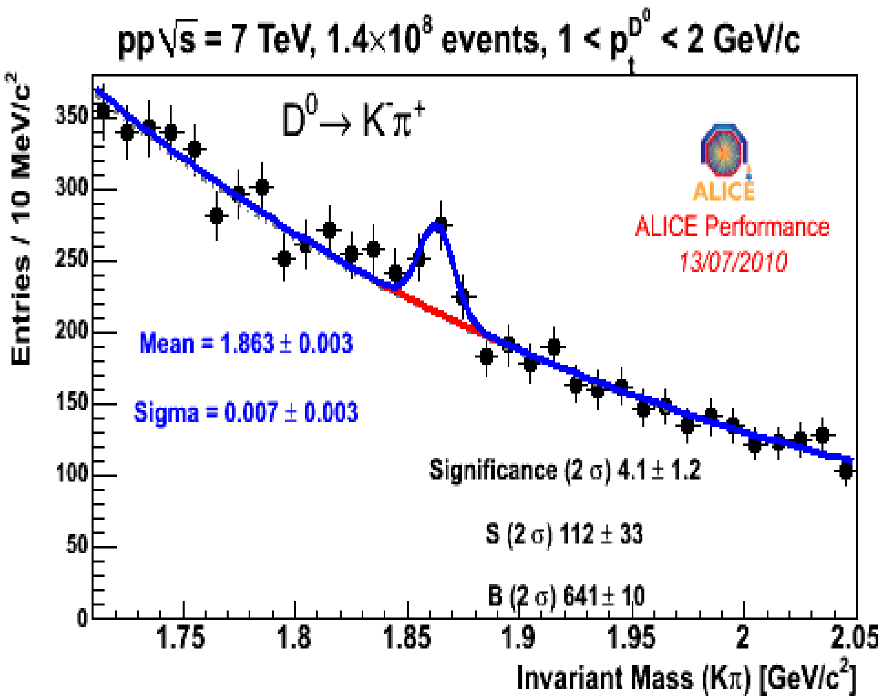


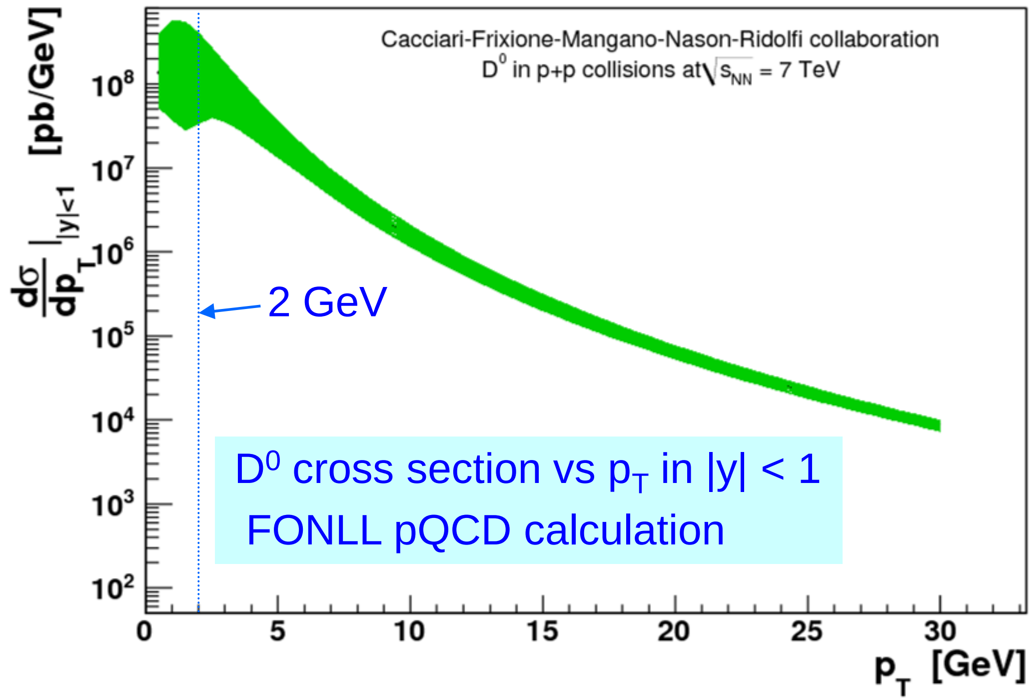


Charm at 7 TeV



Charm at very low p_T



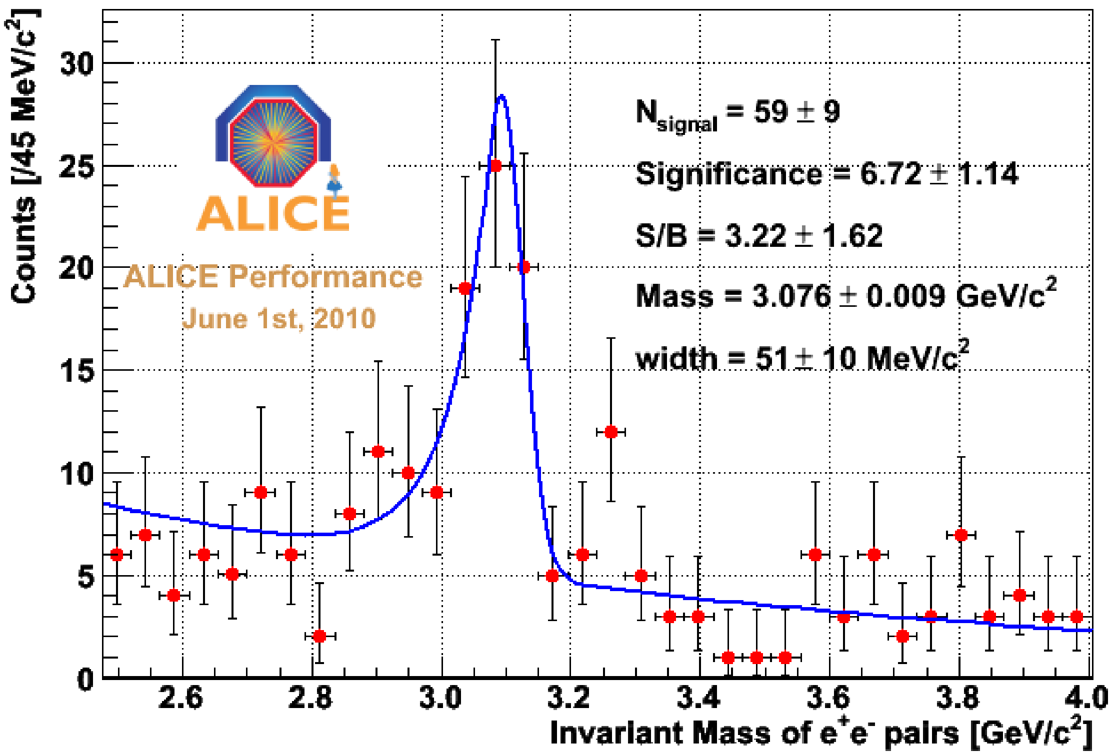


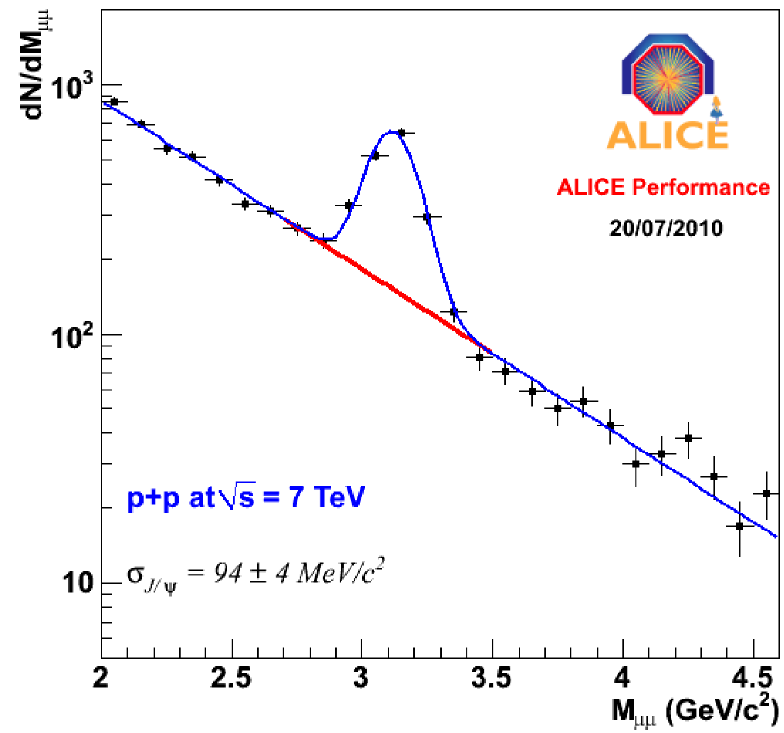
- most of the cross section at low p_T
- shape at low p_T very uncertain
- 10^9 MB events => measure below 1 GeV
  (PID important at low p_T !)

J/Ψ at 7 TeV

$J/\Psi \rightarrow e^+e^-$ $|y| < 1$

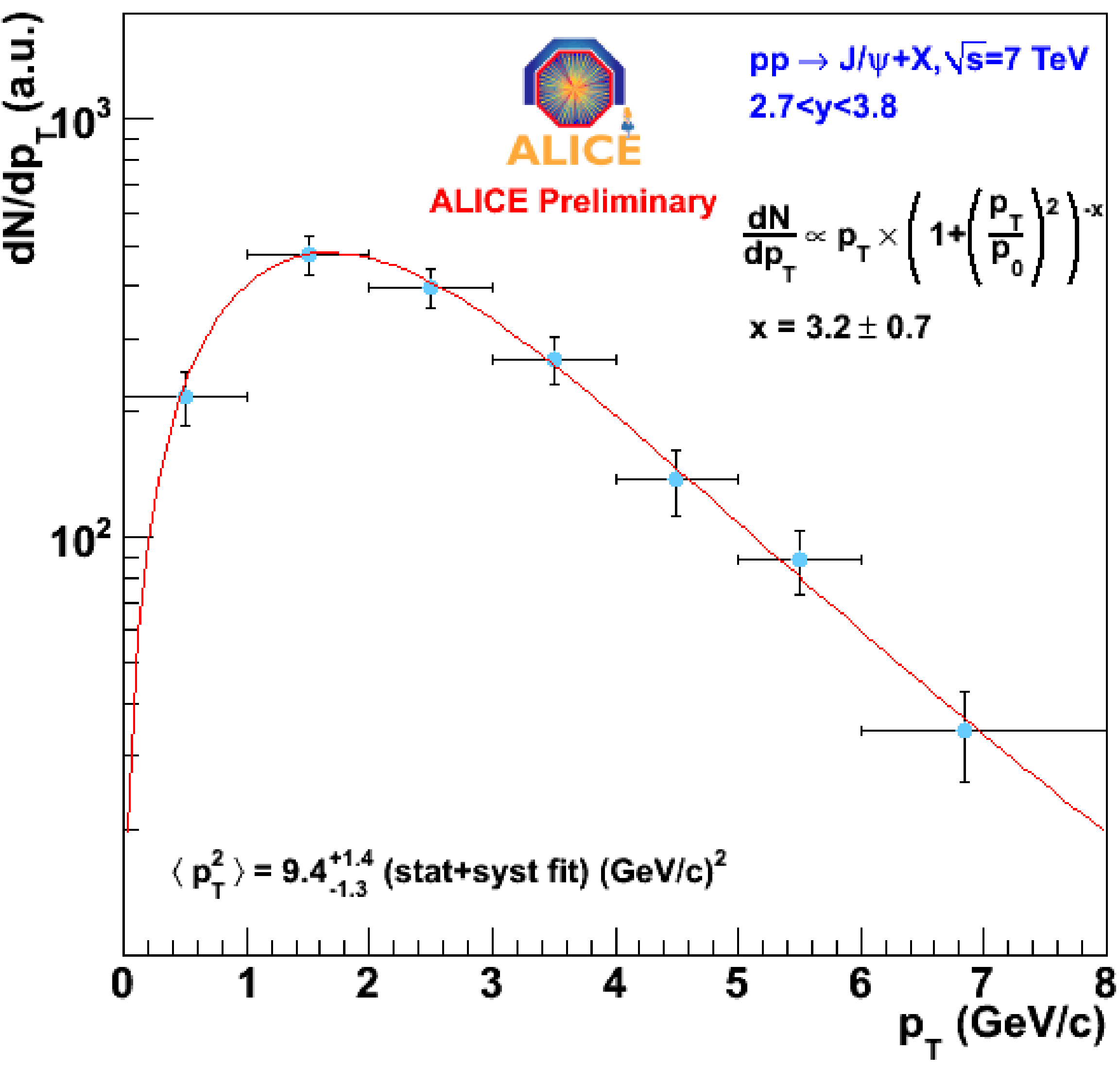
$J/\Psi \rightarrow \mu^+\mu^-$, $y = 2.5 - 4$ 1

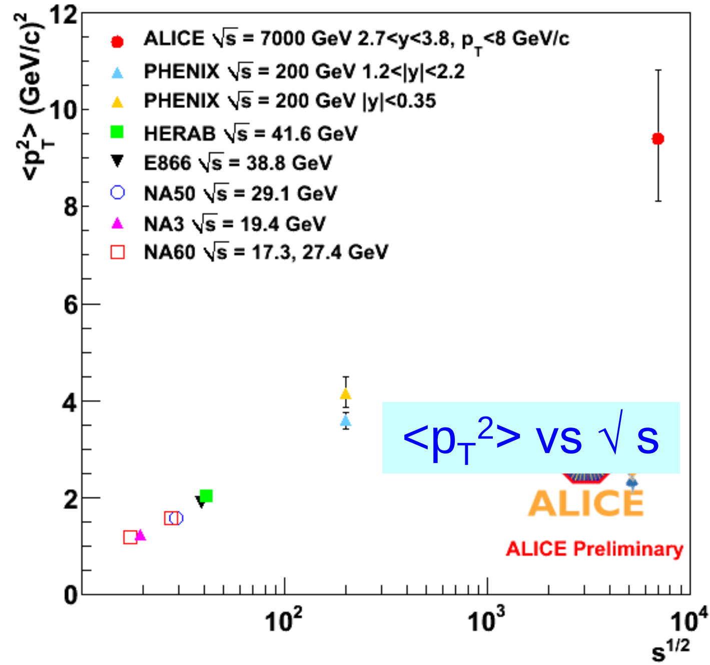


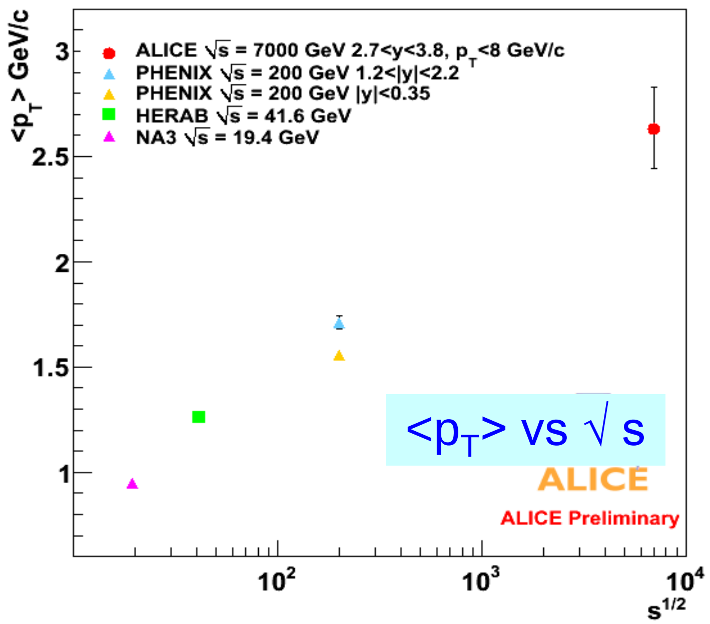


- tough to measure J/Ψ with our current low $\mathcal{L}$
  (also 1st year Pb Lumi will be **very** low -> priority on MB in pp)
- 'proof of performance'
  higher $\mathcal{L}$ later this year and next

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



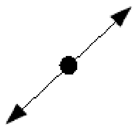
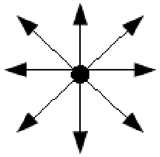




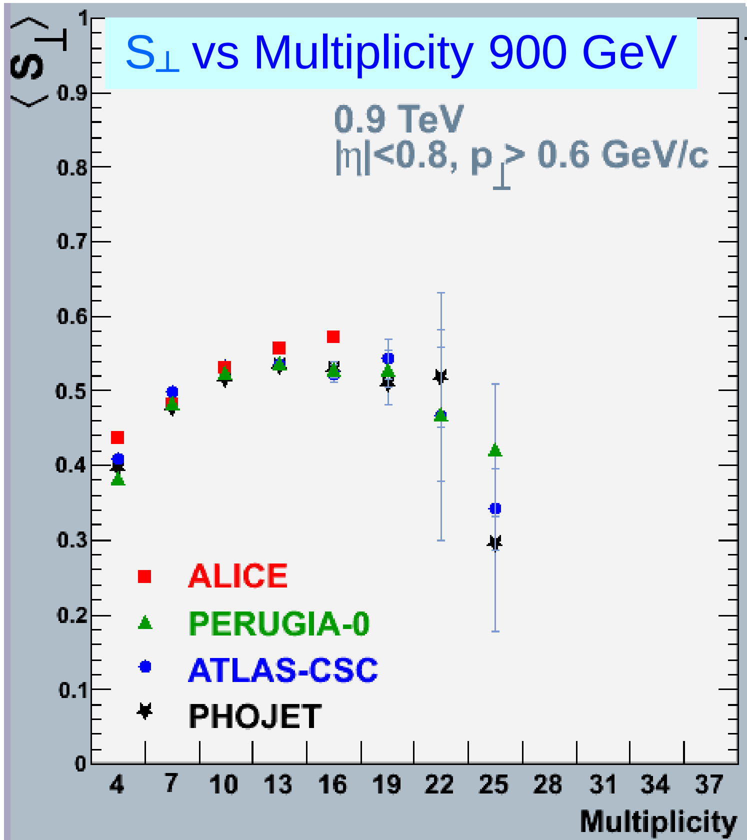
Event Shape Analysis

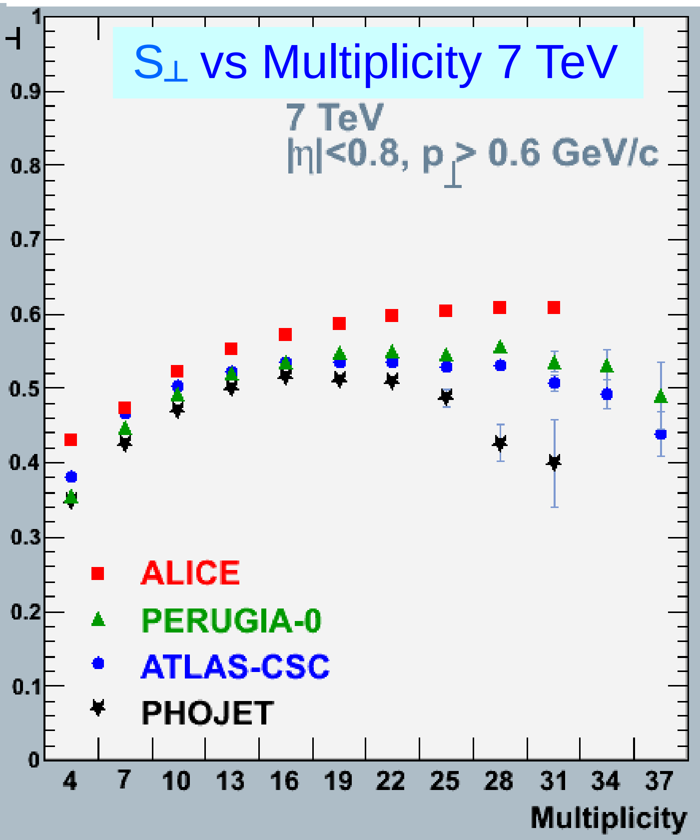
Transverse Sphericity $S_\perp$:
eigenvalues of the momentum tensor S_{xy}

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

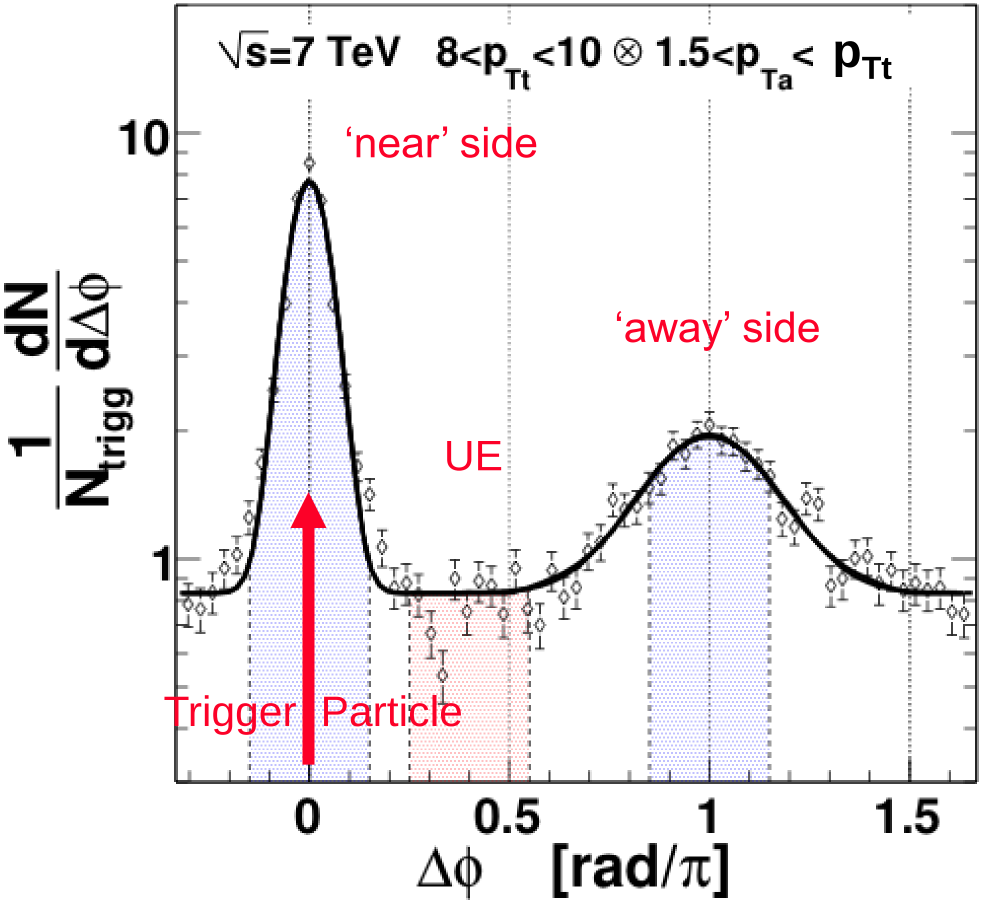
small $S_\perp$:  large $S_\perp$: 

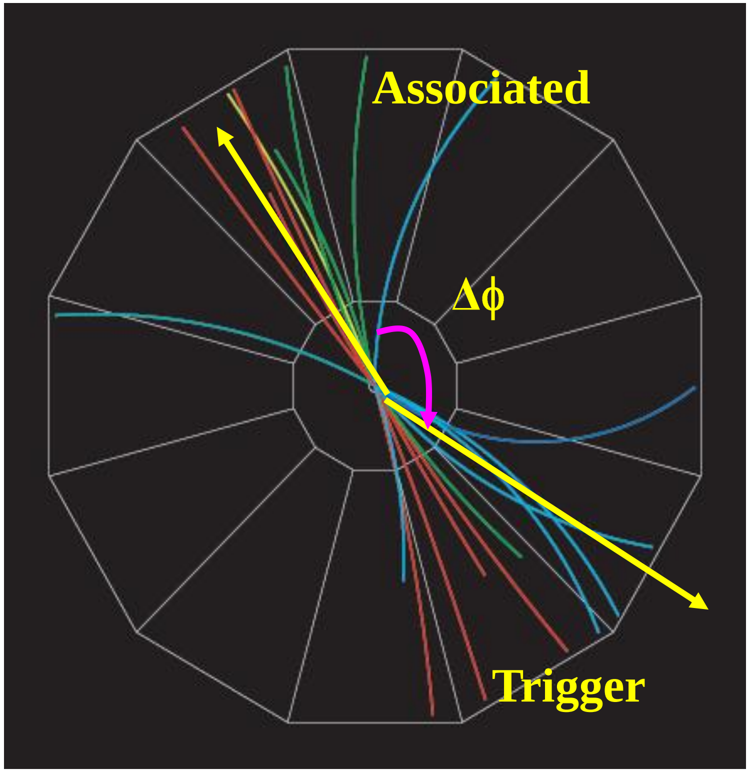
$$S_\perp \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$





pQCD: High p_T Particle Correlations

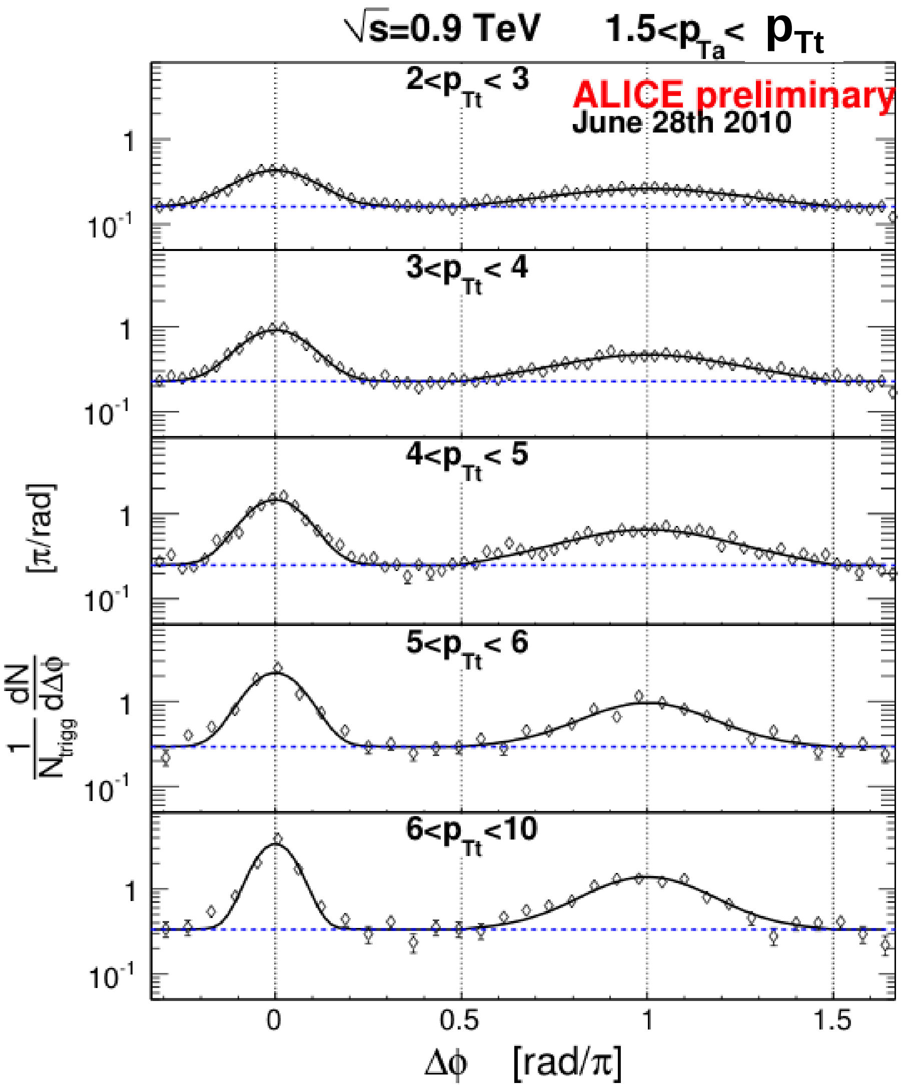


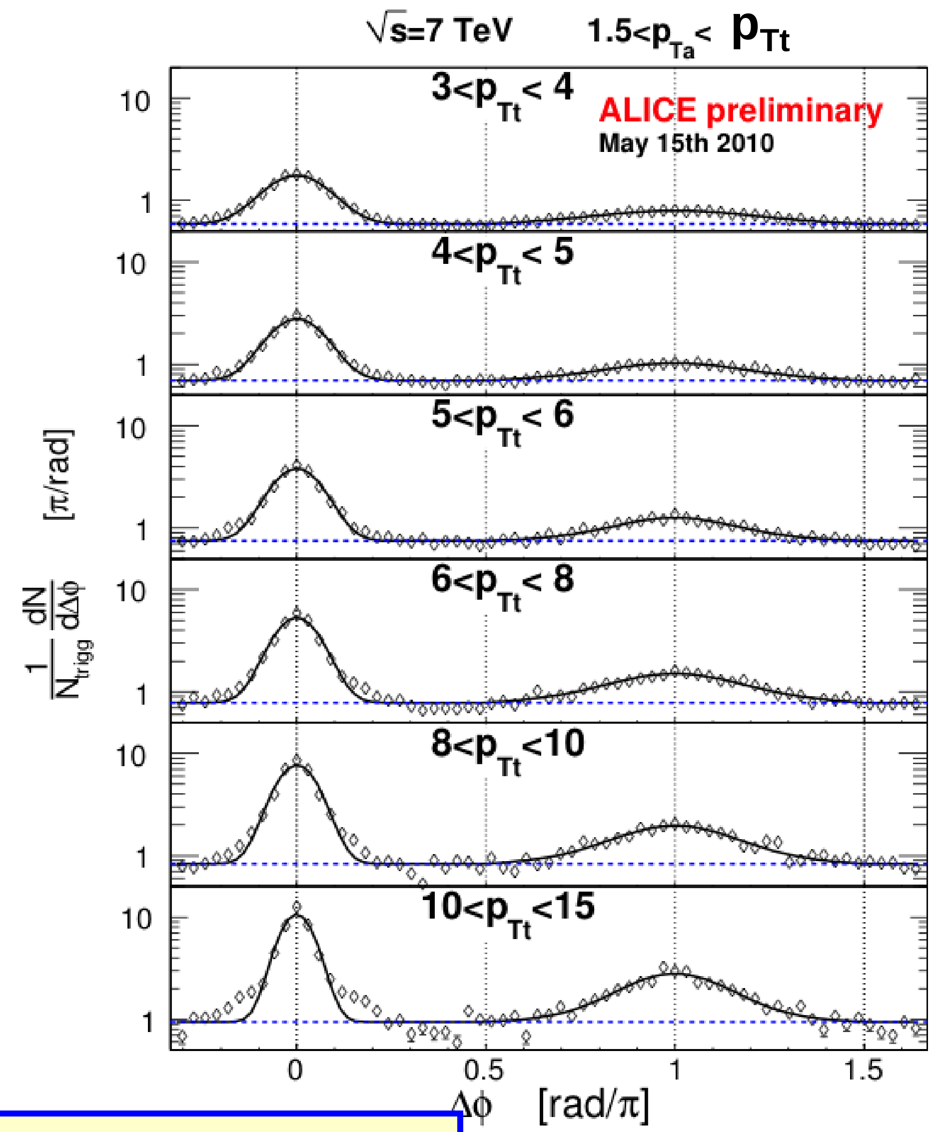


Trigger Particle: highest p_T particle in event (p_{Tt})

Associate Particle: all the others (p_{Ta})

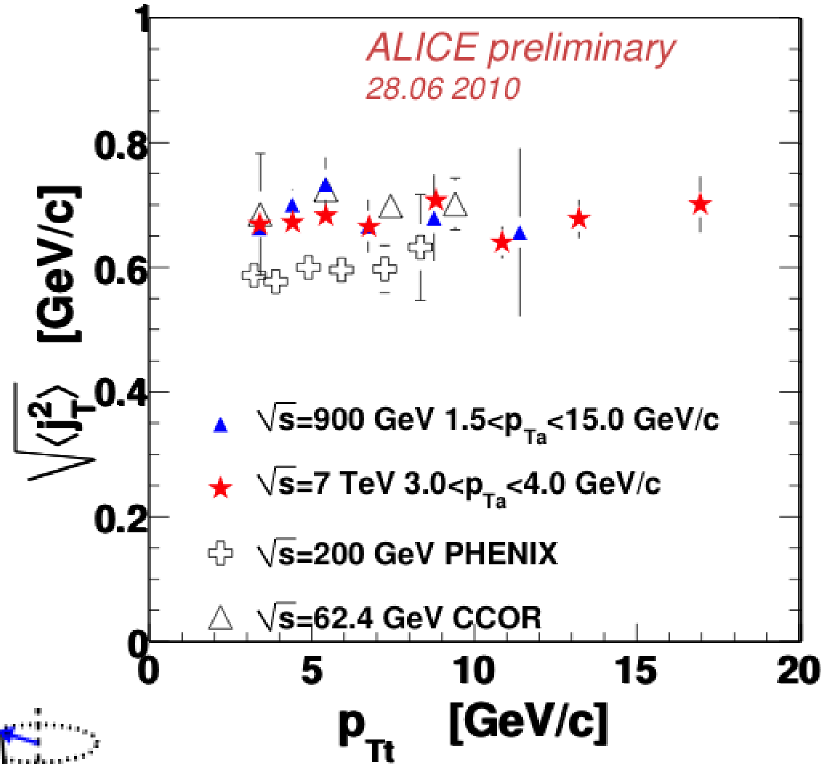
‘High’ p_T Particle Correlations

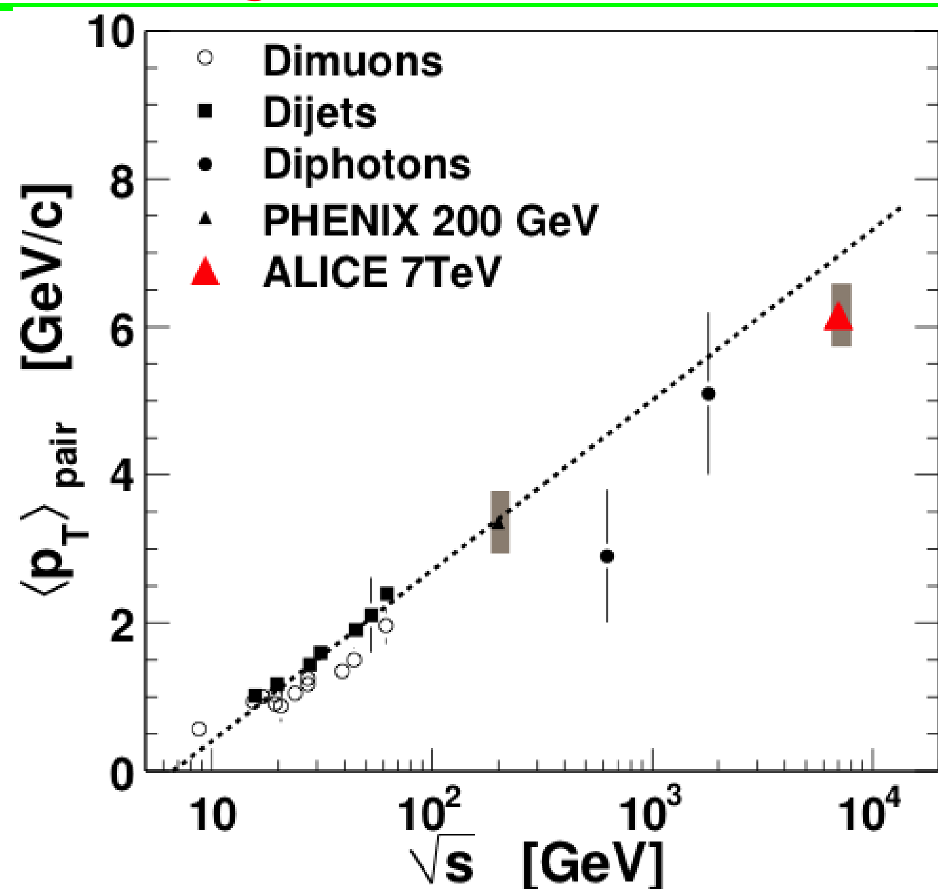


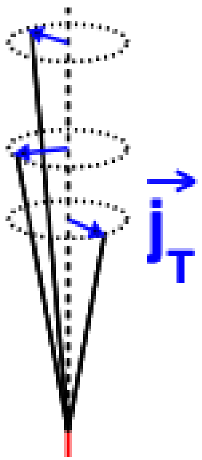


- correlations present down to very low p_T
- study ‘mini-jet region (difficult with fully reconstructed jet ?)

Charged 'mini-jets'







Width of 'near' side correlation => j_T

average transverse momentum
of fragments relative to jet axis

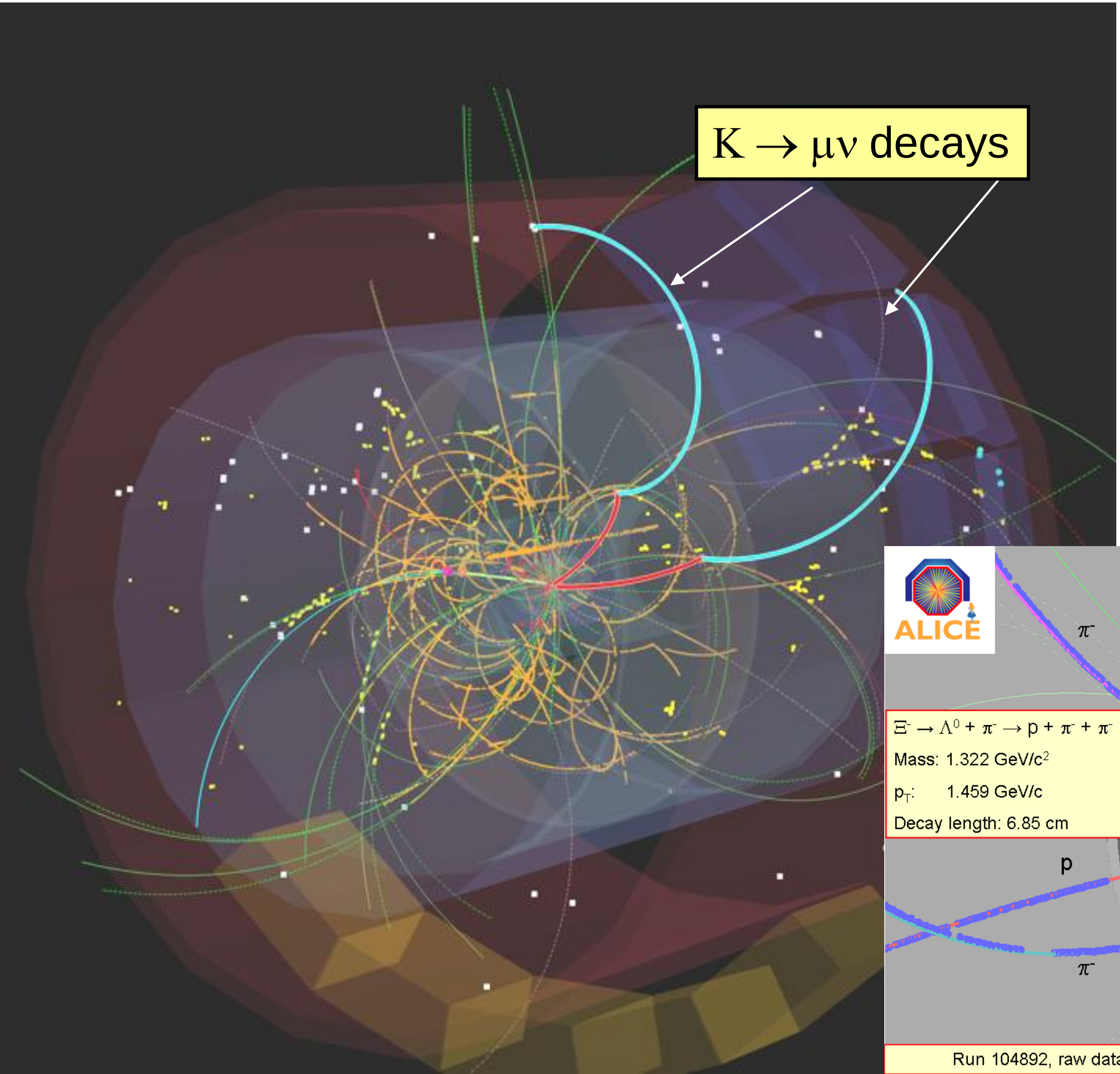
independent of √ s (well known)

Width of 'away' side => $\langle p_T \rangle_{pair}$

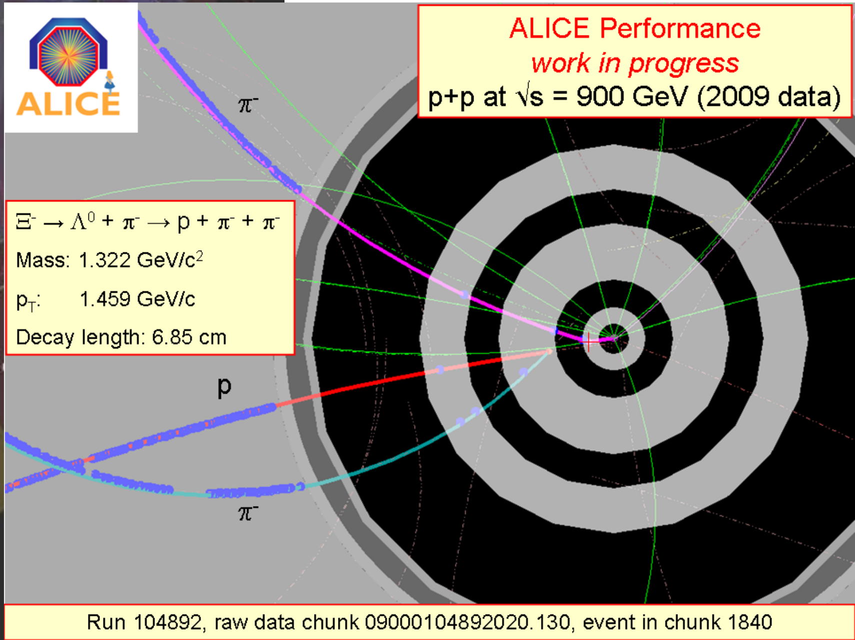
~ mean jet acoplanarity (~ k_T)

increases with √ s

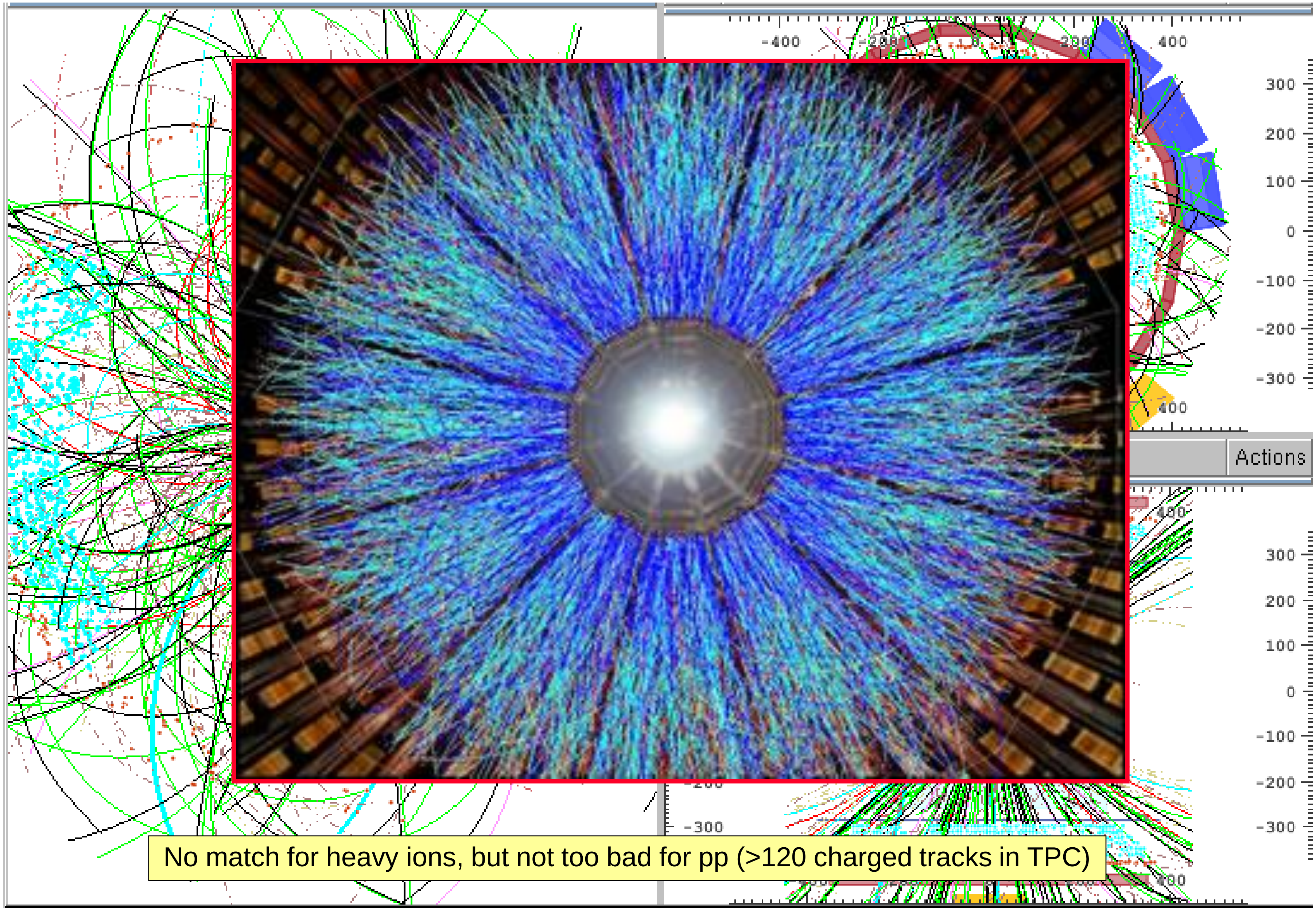
Event Displays



$\Xi \rightarrow \Lambda\pi \rightarrow \pi p\ \pi$



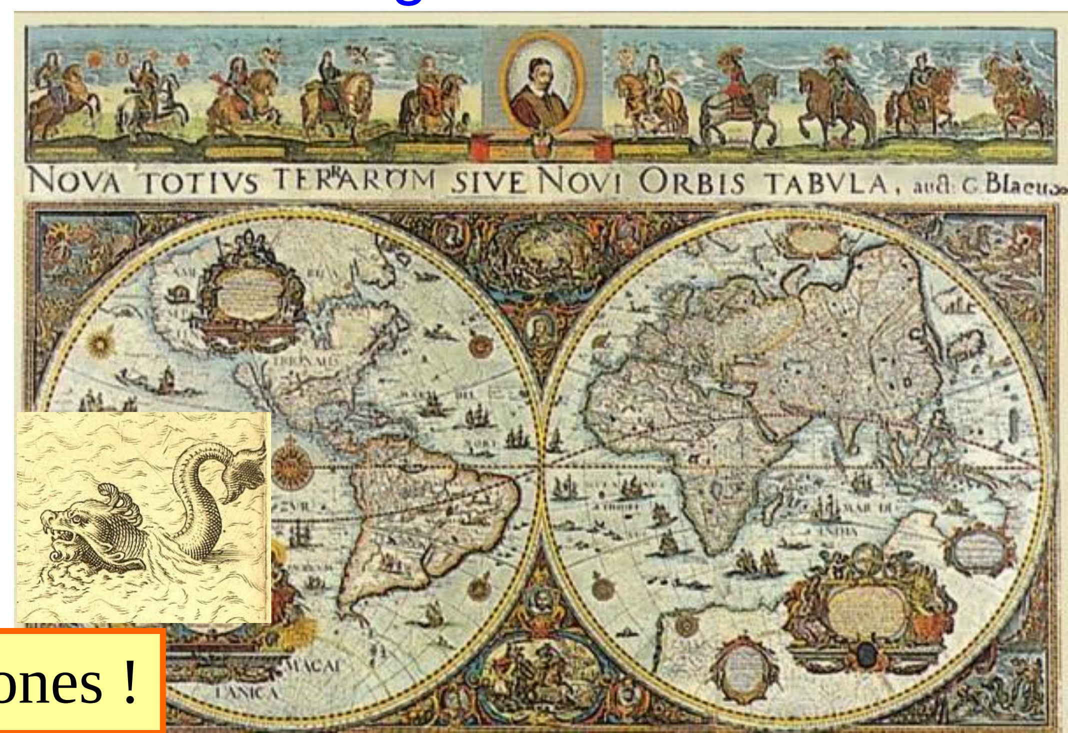
High Multiplicity Event



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

Summary

- ALICE is in good shape
  - ⇨ most **detectors** perform already at or **close to specifications**
  - ⇨ **physics is in full production**
    - heavy ions are our ‘core business’, starting in November this year
    - meanwhile study QCD with pp collisions
    - while ‘rediscovering’ the SM, we can clean up some bits here and there… ($\bar{p}$/p, HBT R vs $<k_T>$, Λ /K^0, …)
- Looking forward to explore the ‘terra incognita’ at LHC



Hic sunt Leones !