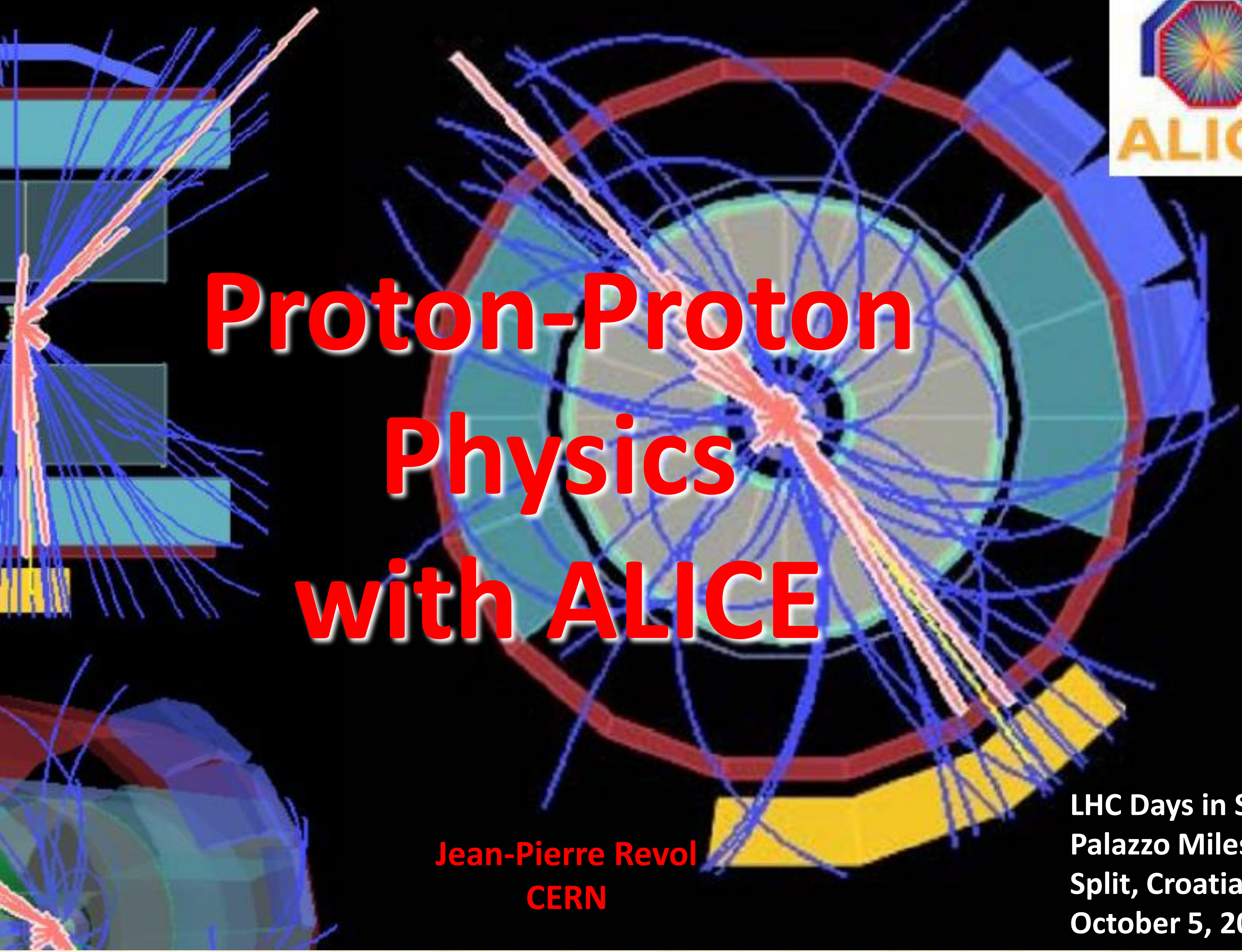
Proton-Proton Physics with ALICE



Jean-Pierre Revol
CERN

LHC Days in Split
Palazzo Milesi
Split, Croatia
October 5, 2010

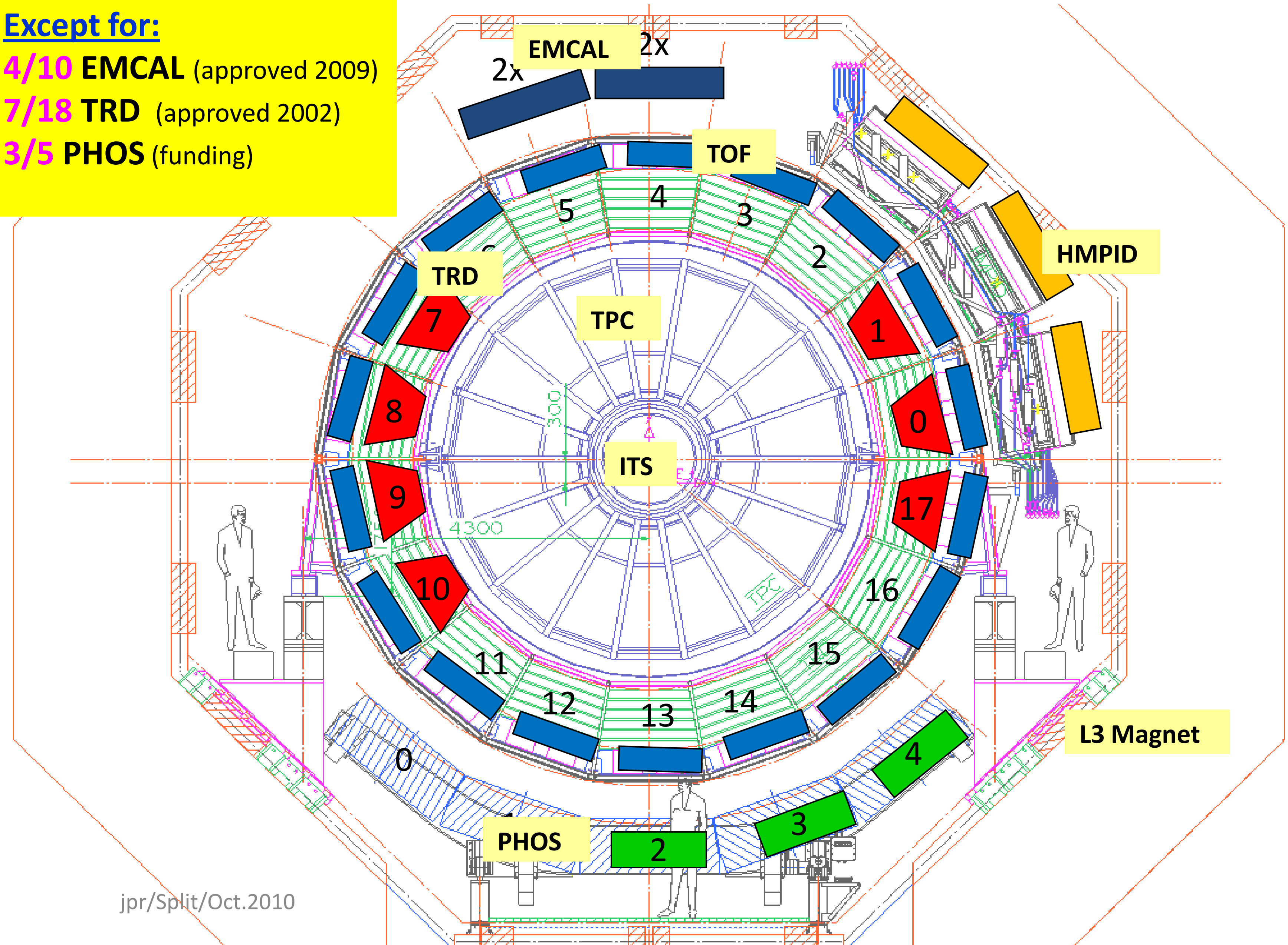
ALICE detector complete

Except for:

4/10 EMCAL (approved 2009)

7/18 TRD (approved 2002)

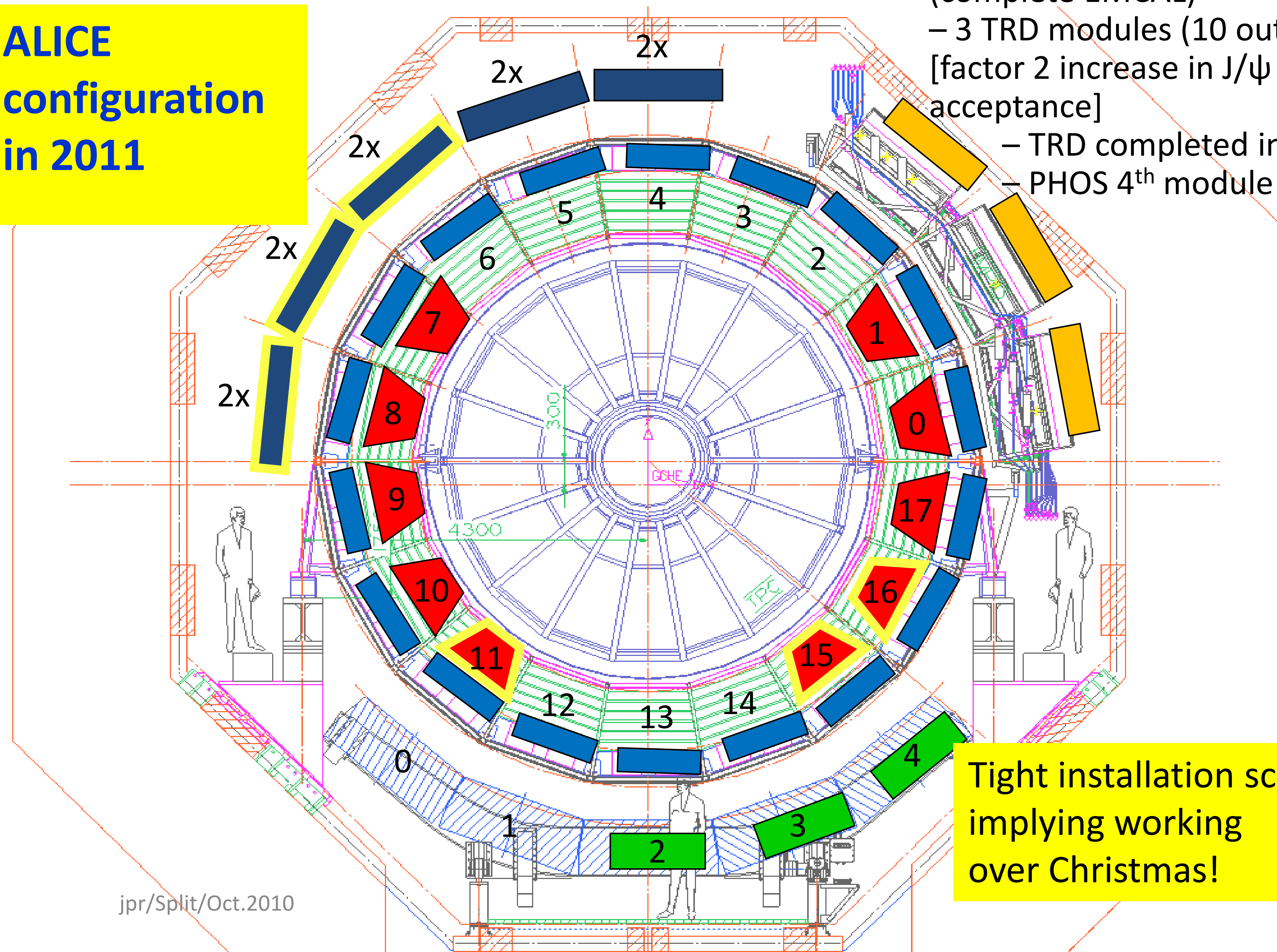
3/5 PHOS (funding)



ALICE configuration in 2011

Installation next Dec. 7-Feb 4 break

- 6 EMCAL supermodules (complete EMCAL)
- 3 TRD modules (10 out of 18) [factor 2 increase in J/ψ trigger acceptance]
  - TRD completed in 2012
  - PHOS 4th module in 2012



Tight installation schedule implying working over Christmas!

ALICE' goals for 2010

μ = interactions/bunch crossing

- **Well within reach!**

Energy	Conditions	Triggers	Status
	$\mu \approx 0.05$	Minimum Bias: 10^9	760 M (11 nb^{-1})
7 TeV pp	$\mu \approx 0.05$	High Multiplicity: $5x10^7$	18.5 M (36 nb^{-1})*
	$L \approx 6x10^{30}\ cm^{-2}s^{-1}$	Muon pairs: 100k-200k J/ψ 1000 ϒ	55 M (55 nb^{-1})**
		(1 to 3 pb^{-1}) (~1 week requested)	
	$\mu \approx 0.05$	EmCal (commissioning)	
2.76 TeV pp	$\mu \approx 0.05$	Minimum Bias: 50 M (1 day)	≥ HI-2010 or 2011
2.76 TeV PbPb	$L \approx 10^{25}\ cm^{-2}s^{-1}$	**Minimum Bias$^{\$}$: fewx$10^7$**	

$$R_{AA}(p_T) = \frac{\left(\frac{dN}{dp_T}\right)_{AA}}{N_{coll}\left(\frac{dN}{dp_T}\right)_{pp}}$$

* Overall goal at least a factor 10 over MB pp (150 nb^{-1})

**Overall goal a few tens of thousand ϒ

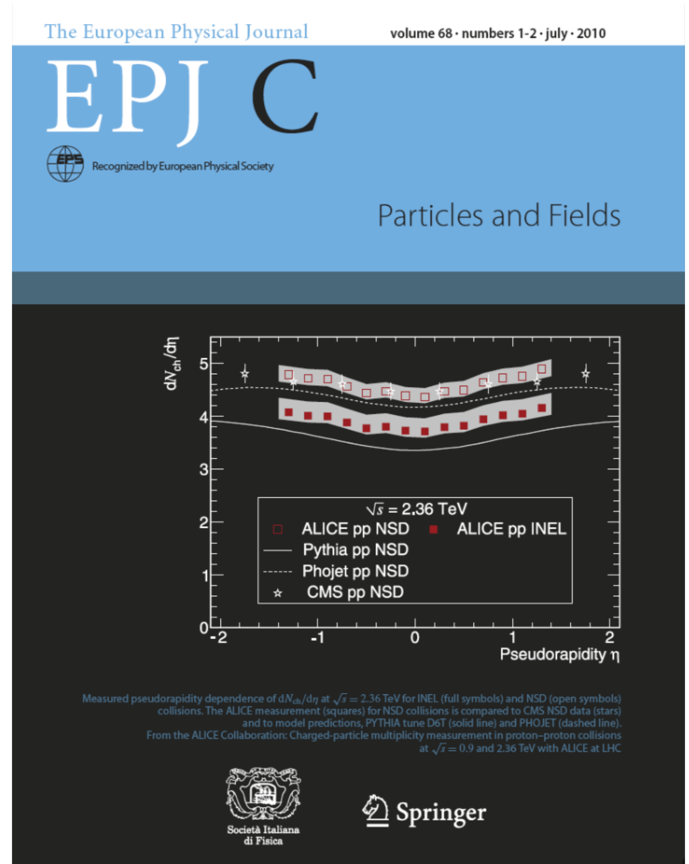
$^{\$} \approx$ 50Hz and 10^6s

First Physics Results

- **ALICE running well; a wealth of physics results already published, mostly on large cross-section phenomena!**
- **ALICE published results (6 publications):**
  - **Multiplicity density and distributions of charged particles**
    - 900 GeV: EPJC: Vol. 65 (2010) 111
    - 900 GeV, 2.36 TeV: EPJC: Vol. 68 (2010) 89
    - 7 TeV: EPJC: Vol. 68 (2010) 345
  - $\bar{p}/p$ 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
- **Many more in preparation (7 TeV)**

First data, first surprise?

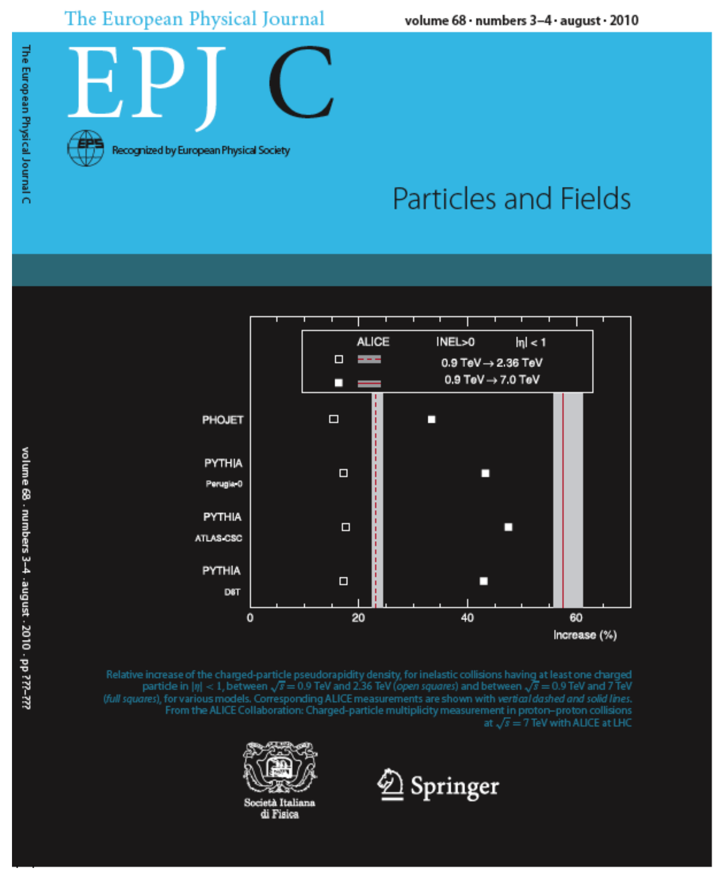
- *Charged-particle multiplicity measurement in proton-proton collisions at √s = 0.9 and 2.36 TeV (above Tevatron) with ALICE at LHC*
  - Measurement at 0.9 TeV consistent with UA5data
  - Average multiplicities at the new energy not described by models
  - Relative multiplicity increase between 0.9 TeV & 7 TeV also not described by models **Not a surprise after all!**



First data at 7 TeV

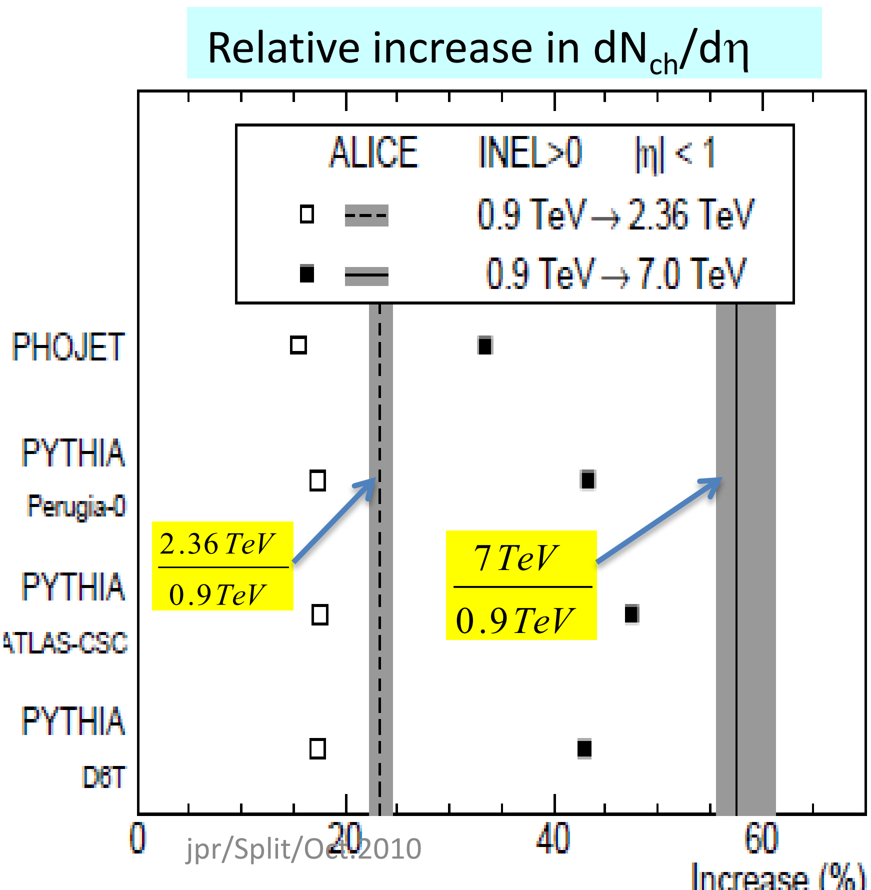
March 30th, First collisions at 7 TeV!

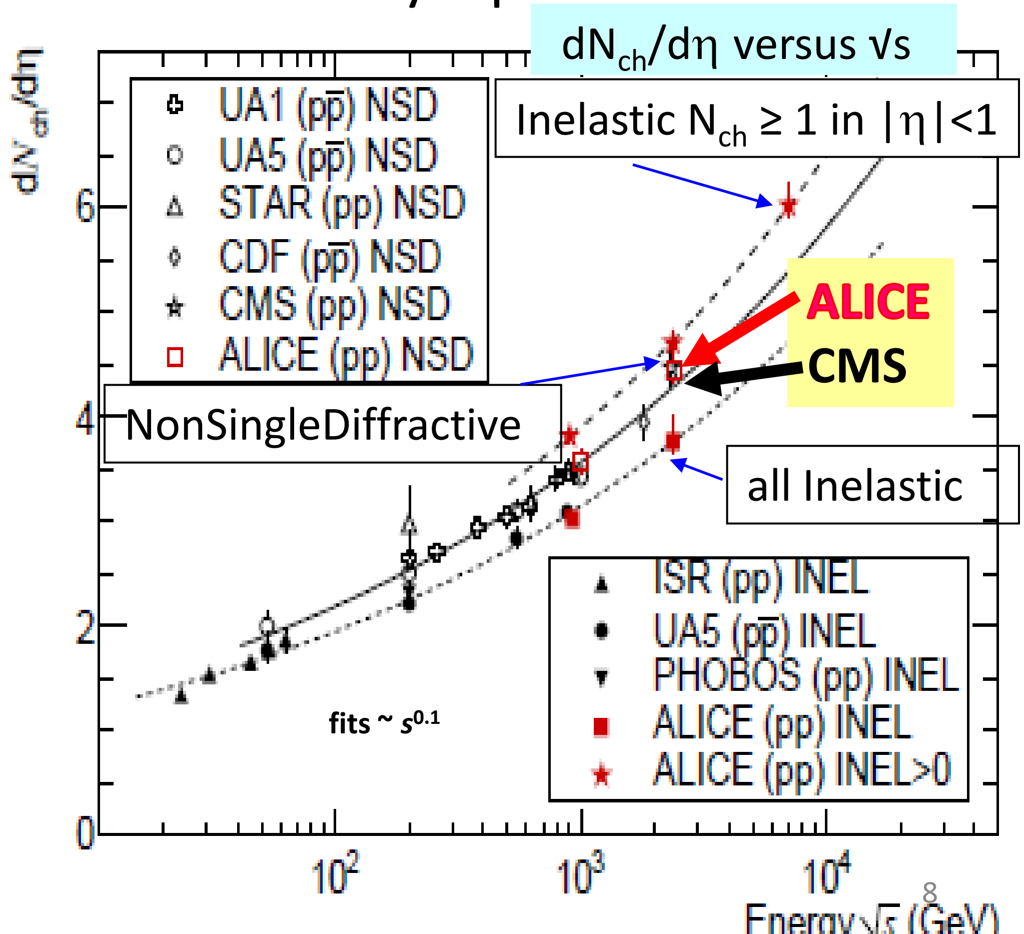
- *Charged-particle multiplicity measurement in proton-proton collisions at √s = 7 TeV with ALICE at LHC*
  - Trend seen between 0.9 TeV and 2.36 TeV for NSD and INEL confirmed by data at √s = 7 TeV;
    However, measurement for event class $INEL_{N>0}$ only, as diffractive processes not yet known at 7 TeV (see later)



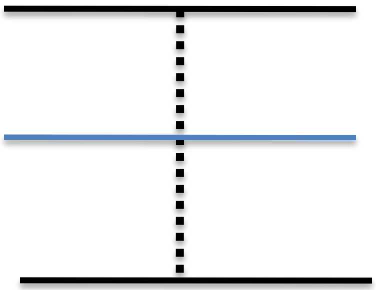
Particle production vs √s

- Increase with energy significantly stronger in data than in MC's
- ALICE & CMS agree to within 1 σ (< 3%) [NSD at 2.36 TeV]
- $dN_{ch}/d\eta$ increase with √s well described by a power law

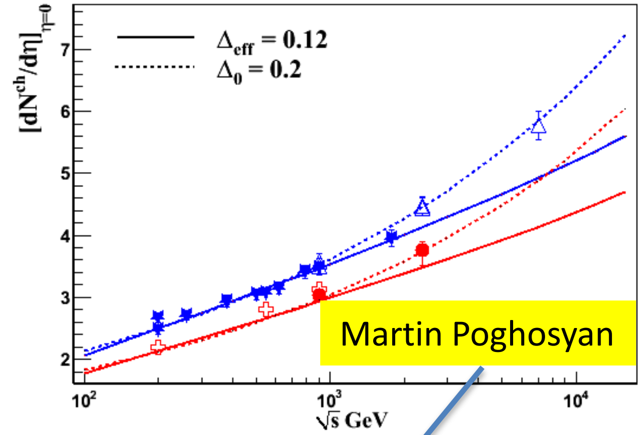




Particle production vs √s



$$\left(\frac{dN}{d\eta}\right)_{\eta=0} \sim s^{0.1}$$



Martin Poghosyan

- At high energy, Mueller-Kancheli graph:

$$\left(\frac{d\sigma^{incl.}}{dy}\right)_{y=0} \sim s^{\Delta} \Rightarrow \left(\frac{dN}{d\eta}\right)_{\eta=0} \sim \frac{1}{\sigma_{inel.}} \frac{p_T}{m_T} s^{\Delta}$$

Predicted correctly the CMS point at 7 TeV

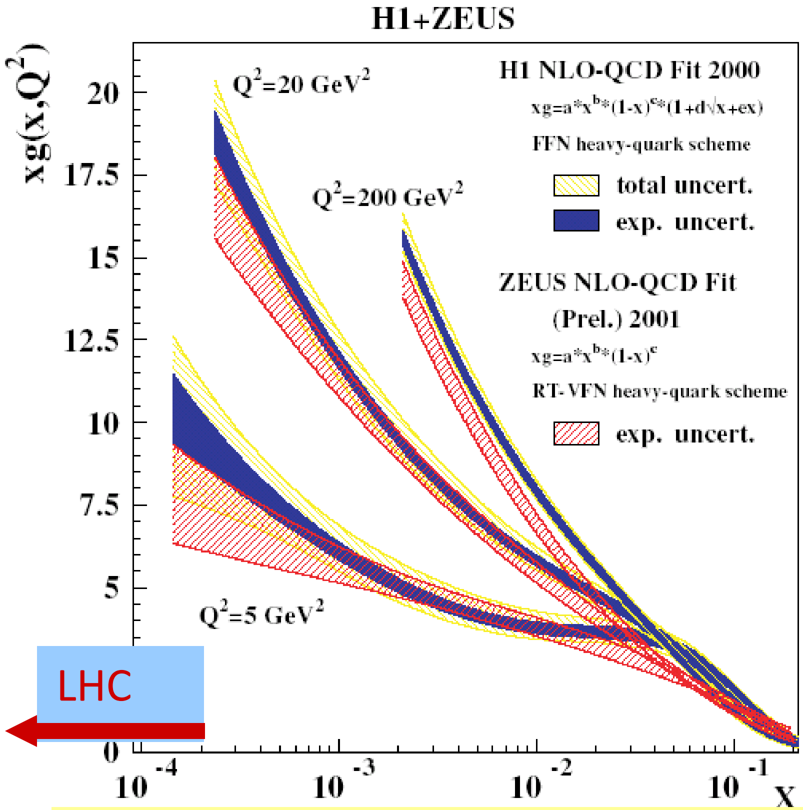
From which we obtain $\Delta \equiv (\alpha_P - 1) = 0.2$ (was 0.12 before).

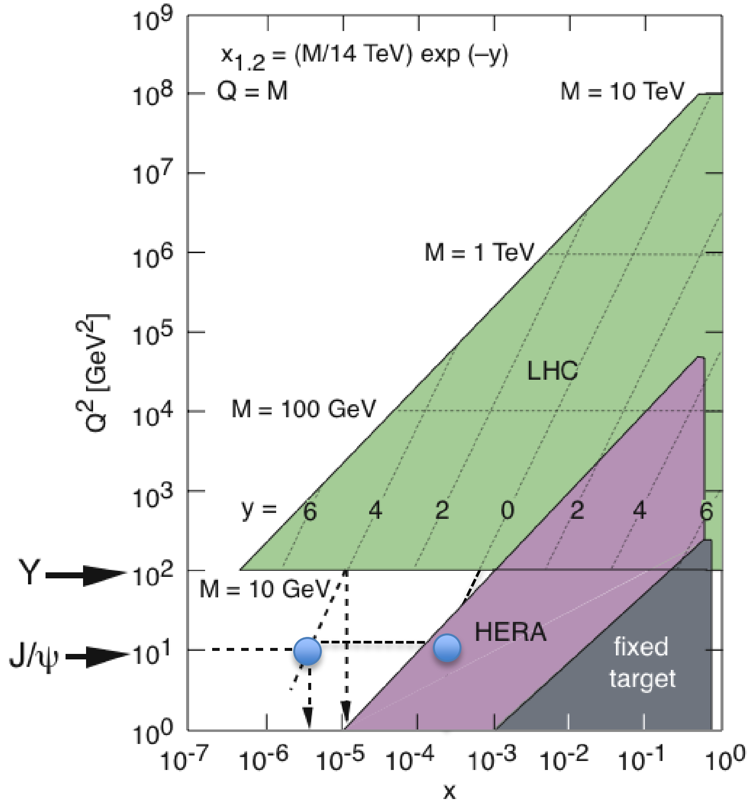
- We have entered the realm of **non-perturbative QCD** and of **Pomerons**, etc., important at LHC:
  - Particle production is dominated by soft mechanisms;
  - Global properties need proper account of non-perturbative processes (Diffractive processes, etc) (in many cases, main source of systematic uncertainties).

Parton overlap

- As low x (~Q^2/s) values are reached, **both the parton density and the parton transverse sizes increase**, there must be a scale ($q^2 < Q_s^2$) where partons overlap. When this happens, the increase in the number partons would become limited by gluon fusion ($gg \rightarrow g$)

Partons are prisoners of the proton whose transverse size only increases as lns





What is new at LHC is that this overlap could occur for relatively high p_T partons (Kharzeev Q_s^2 ~ 0.7 GeV^2)

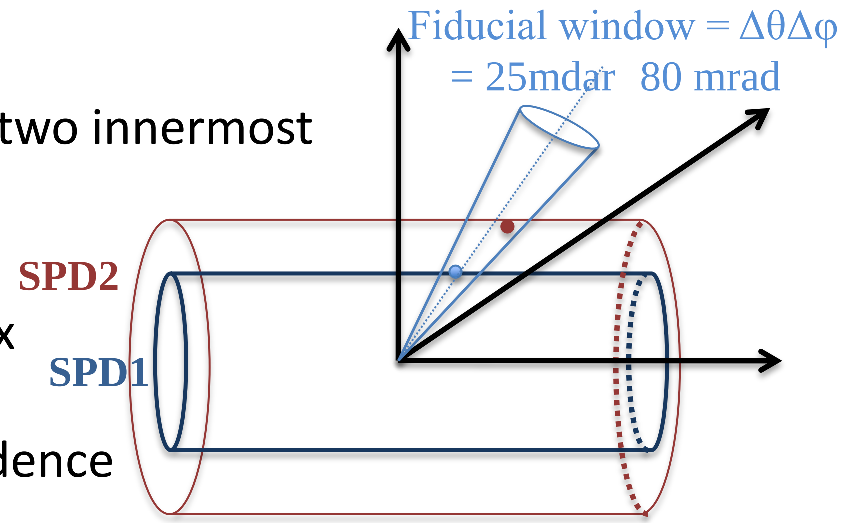
Proton Proton strategy for ALICE

- What we do not know precisely is how parton overlap will manifest itself in pp collisions
  ➔ **study ALL aspects of pp collisions in a systematic way, especially extreme properties**

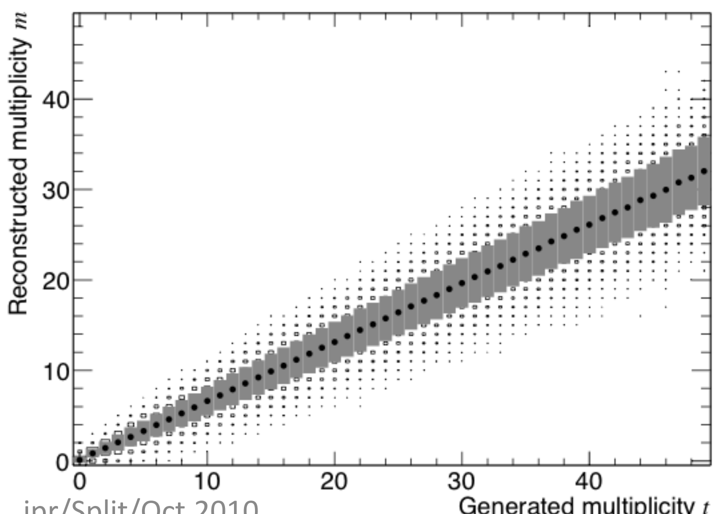
Many reasons for ALICE to take pp collisions very seriously

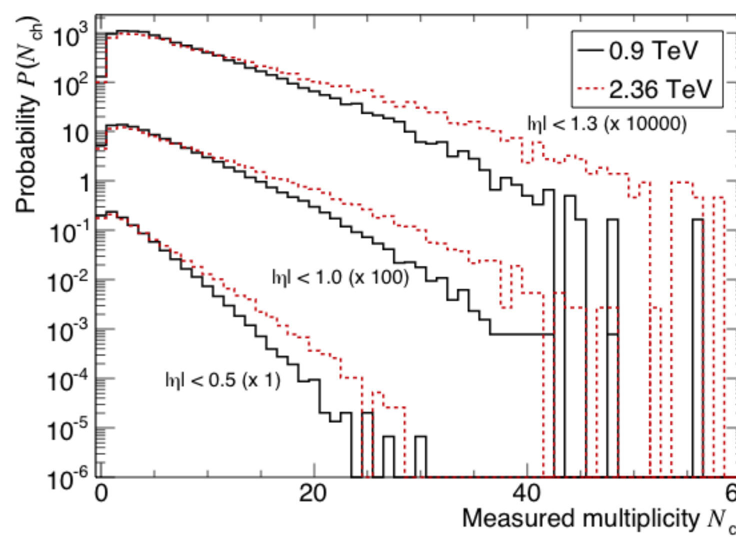
- pp collisions always part of ALICE's programme as they are needed to provide a comparison with future HI collisions
- Comparison goes also the other way (from pp to HI): *"is QGP produced in pp collisions?"*
- Unique features of ALICE (Low p_T and Particle ID capability) can provide unique information

Multiplicity measurements



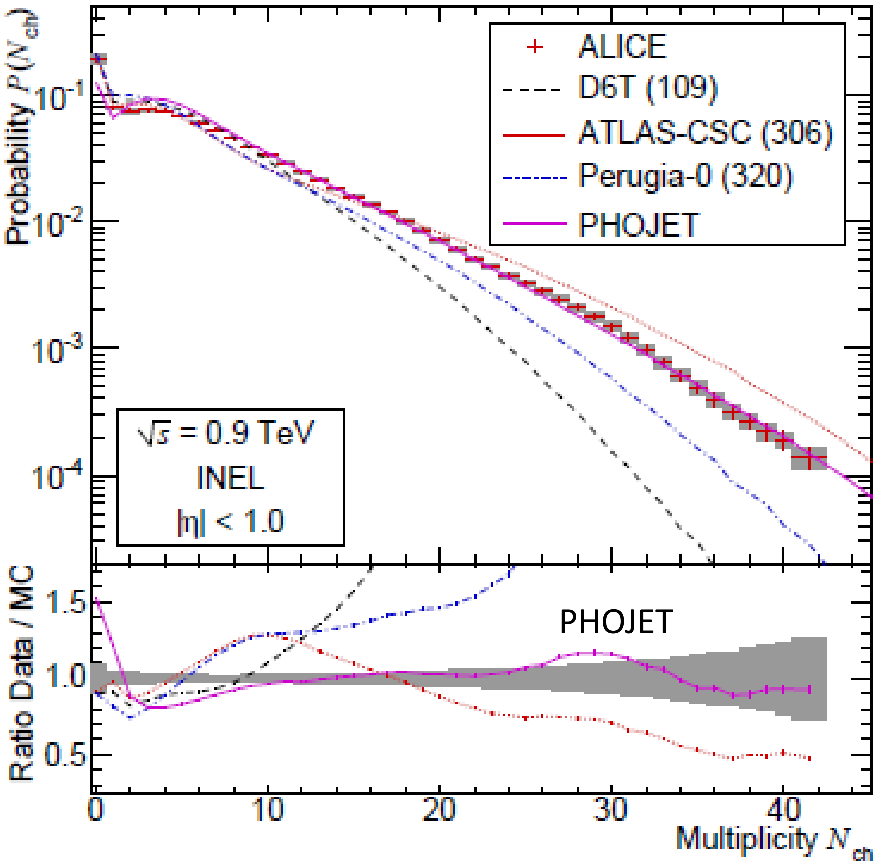
- Count pixel tracklets (vertex + 2 hits) in the two innermost layers of the ITS
- Correct for detector effects (acceptance, efficiency), using a detector response matrix obtained from MC simulations. (deconvolution method to minimize dependence on model)
- Normalize result to specific event class (NSD, INEL or $INEL_{N>0}$)



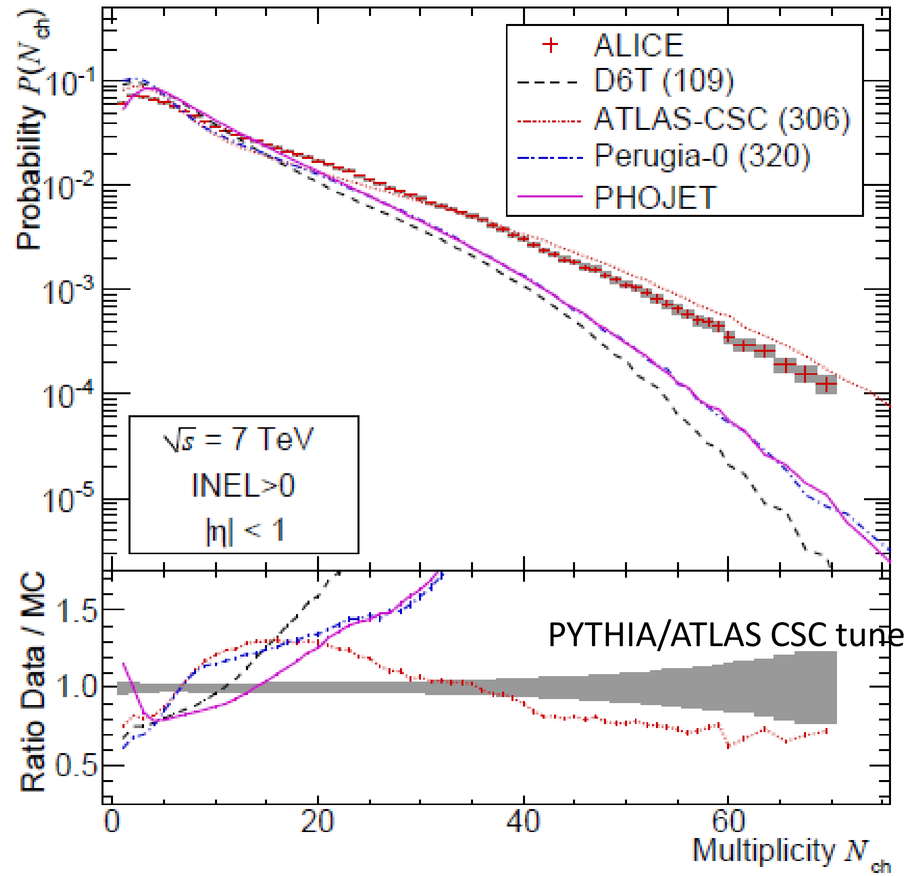


Multiplicity Distributions

Multiplicity Distribution 900 GeV



Multiplicity Distribution 7 TeV

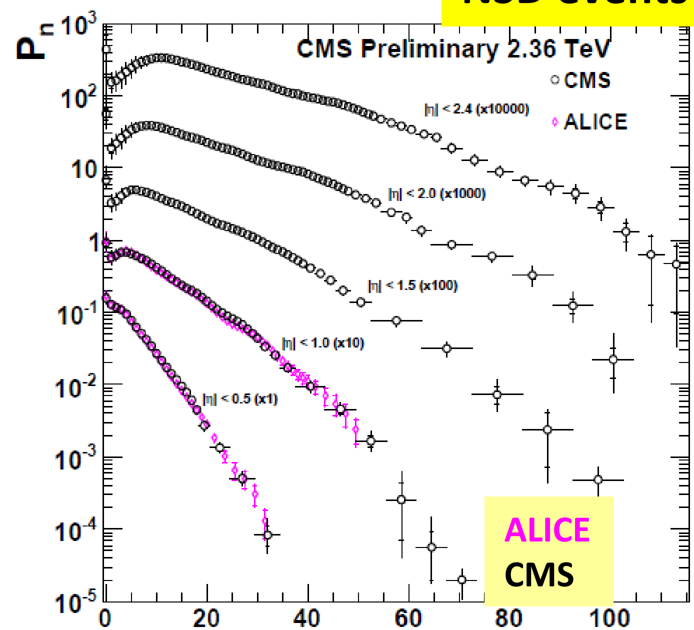


– no model describes correctly the data
– most of the 'stronger increase' is in the tail of N_{ch}

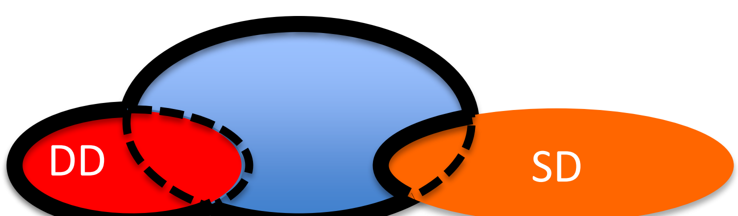
INEL>0 = at least one particle in $|\eta| < 1$)

Comparison with other experiments

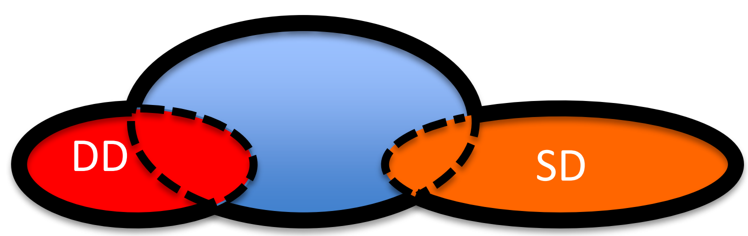
NSD events



- **Comparison with other experiments requires the same event class definition!**
- Excellent agreement with UA5 at 0.9 TeV, with CMS at both 0.9 and 2.36 TeV **for NSD**
- How to go from INEL >0 to INEL, NSD?
  ➔ normalize to an event class used by other experiments, but
  - Model dependent and largest source of systematic uncertainty ➔ must be measured! (cross-section and kinematics)
    - At 0.9 TeV & 1.8 TeV data from UA5 & E710 and CDF (ALICE used measured values)
    - At 7 TeV no data yet! Wait for TOTEM measurement, or measure it ourselves



NSD



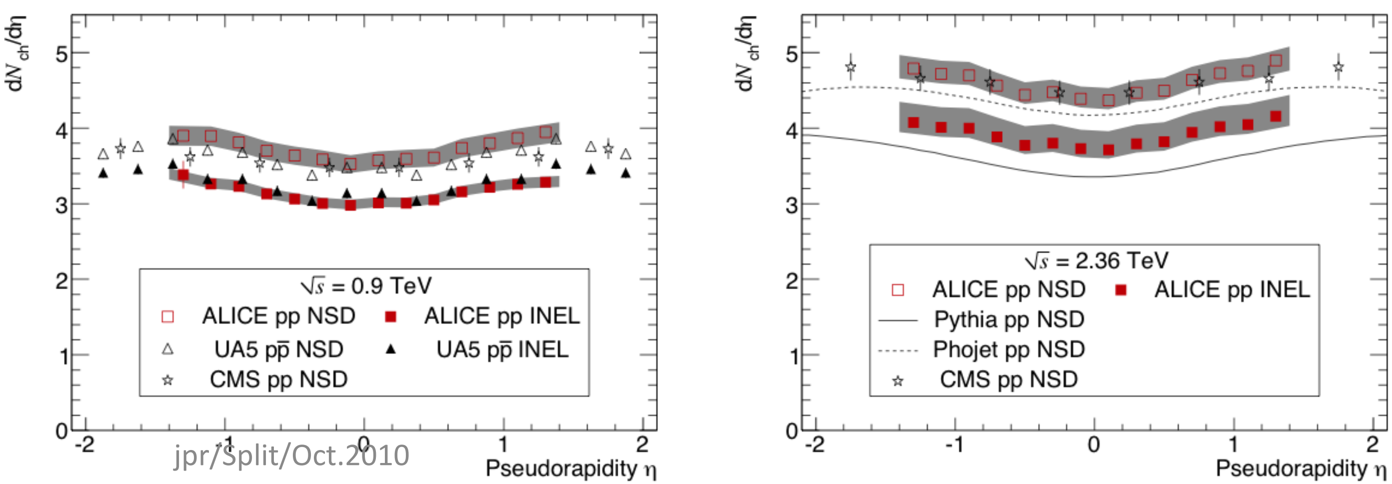
INEL

Systematics and results

Uncertainty	$dN_{ch}/d\eta$ analysis		$P(N_{ch})$ analysis	
	0.9 TeV	2.36 TeV	0.9 TeV	2.36 TeV
Tracklet selection cuts	negl.	negl.	negl.	negl.
Material budget	negl.	negl.	negl.	negl.
Misalignment	negl.	negl.	negl.	negl.
Particle composition	0.5–1.0 %	0.5–1.0 %	included in detector efficiency	
Transverse-momentum spectrum	0.5 %	0.5 %	included in detector efficiency	
Contribution of diffraction (INEL)	0.7 %	2.6 %	3–0 % (0–5)	5–0 % (0–5)
Contribution of diffraction (NSD)	2.8 %	2.1 %	24–0 % (0–10)	12–0 % (0–10)
Event-generator dependence (INEL)	+1.7 %	+5.9 %	8–0 % (0–5)	25–0 % (0–10)
Event-generator dependence (NSD)	−0.5 %	+2.6 %	3–5–1 % (0–10–40)	32–8–2 % (0–10–40)
Detector efficiency	1.5 %	1.5 %	2–4–15 % (0–20–40)	3–0–9 % (0–8–40)
SPD triggering efficiency	negl.	negl.	negl.	negl.
VZERO triggering efficiency (INEL)	negl.	n/a	negl.	n/a
VZERO triggering efficiency (NSD)	0.5 %	n/a	1 %	n/a
Background events	negl.	negl.	negl.	negl.
Total (INEL)	$^{+2.5}_{-1.8}$ %	$^{+6.7}_{-3.1}$ %	9–4–15 % (0–20–40)	25–0–9 % (0–10–40)
Total (NSD)	$^{+3.3}_{-3.3}$ %	$^{+3.7}_{-2.7}$ %	24–5–15 % (0–10–40)	32–8–9 % (0–10–40)

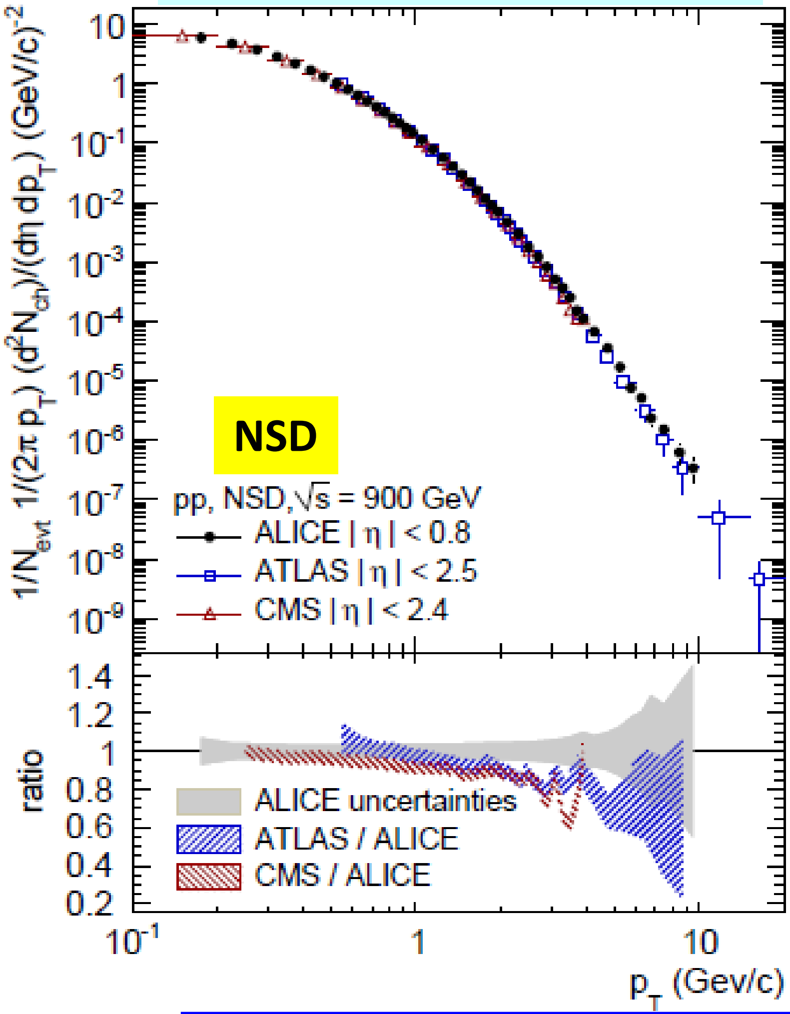
– Diffraction cross-sections somewhat known up to 1.8 TeV; Small extrapolation to 2.36 TeV justified.

– Precision totally dominated by systematic errors

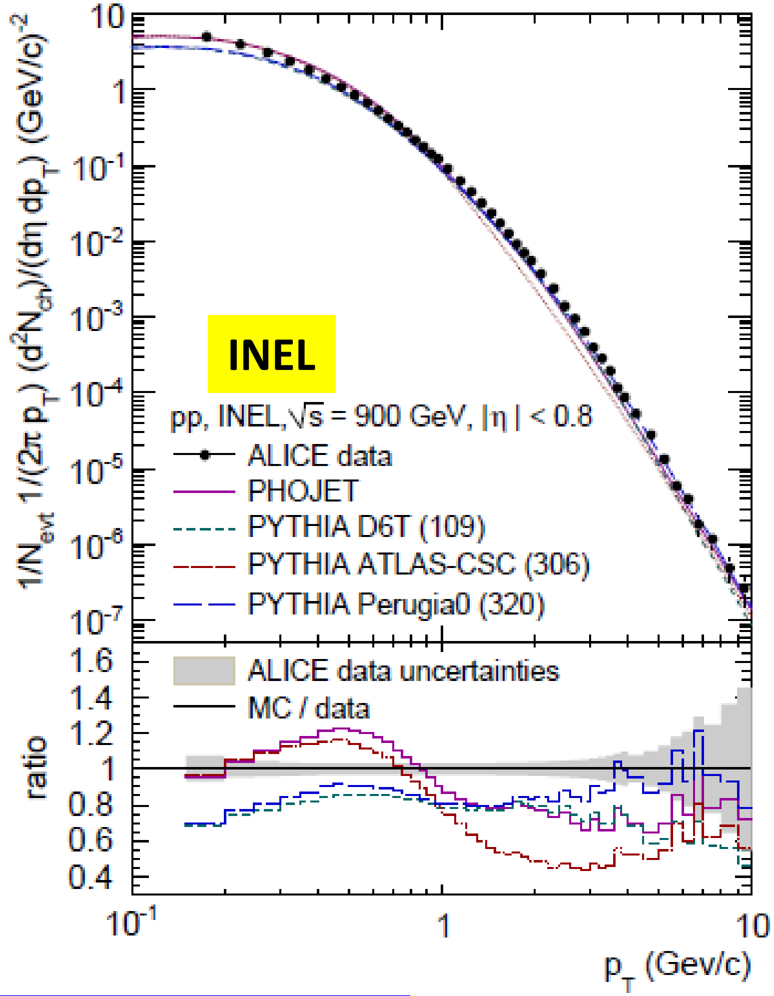


p_T Distributions at 900 GeV

Comparison with other data



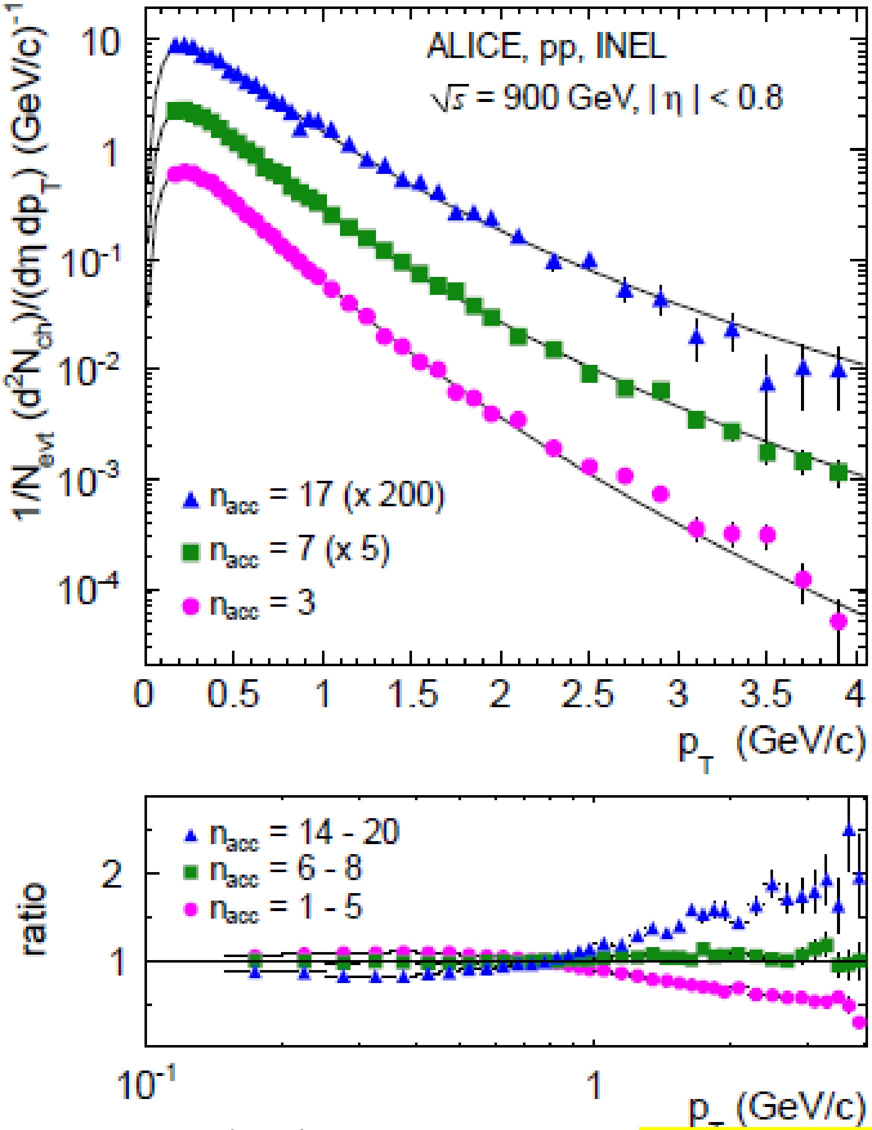
Comparison with MC's



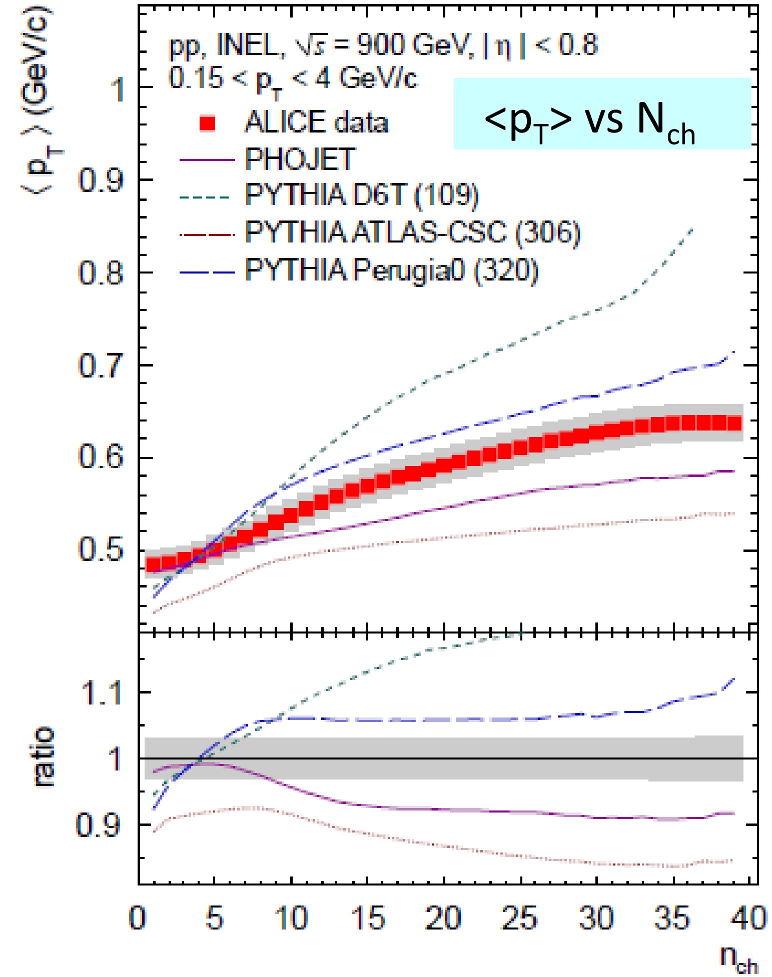
– Spectrum seems to get harder for more central rapidity
– MC's have hard time describing the full p_T spectrum

$<p_T>$ versus Multiplicity

p_T for different Multiplicities



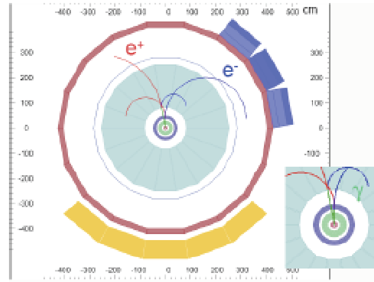
$<p_T>$ vs N_{ch}

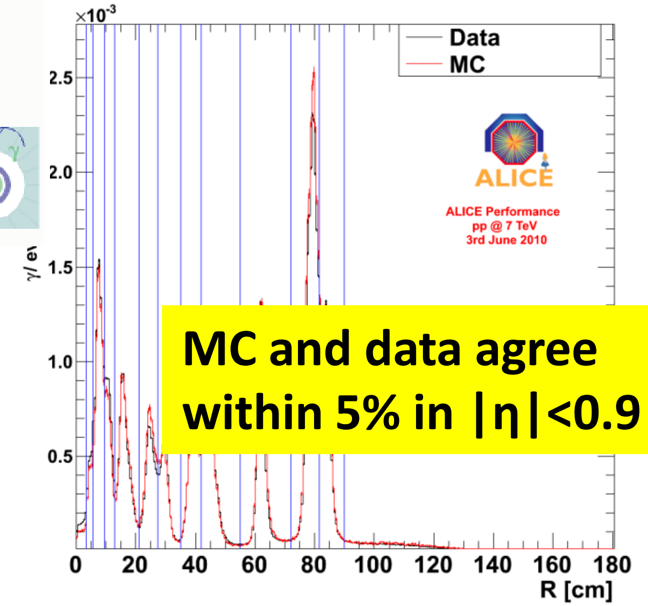


– Change concentrated at p_T > 1 GeV/c (pQCD) (surprisingly little change below 1 GeV/c)
– MC's have hard time… again!

Study pioneered by UA1

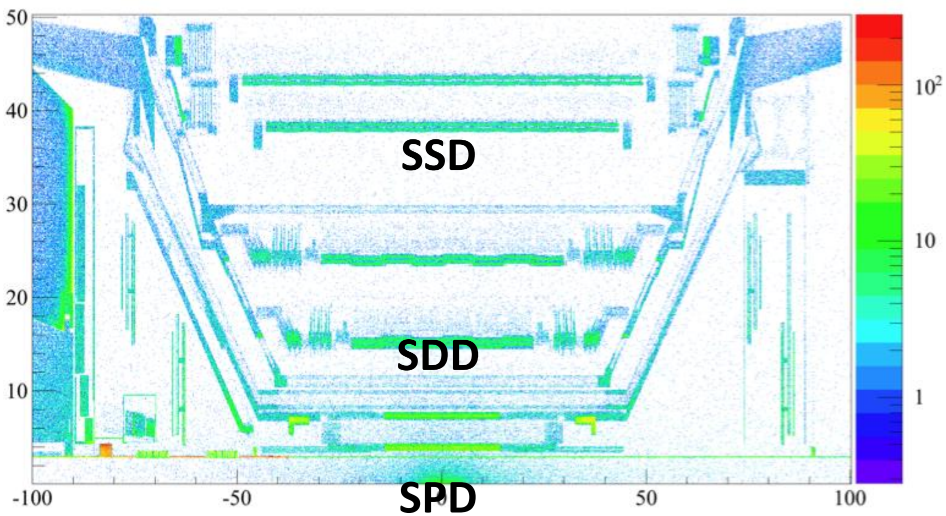
Material budget

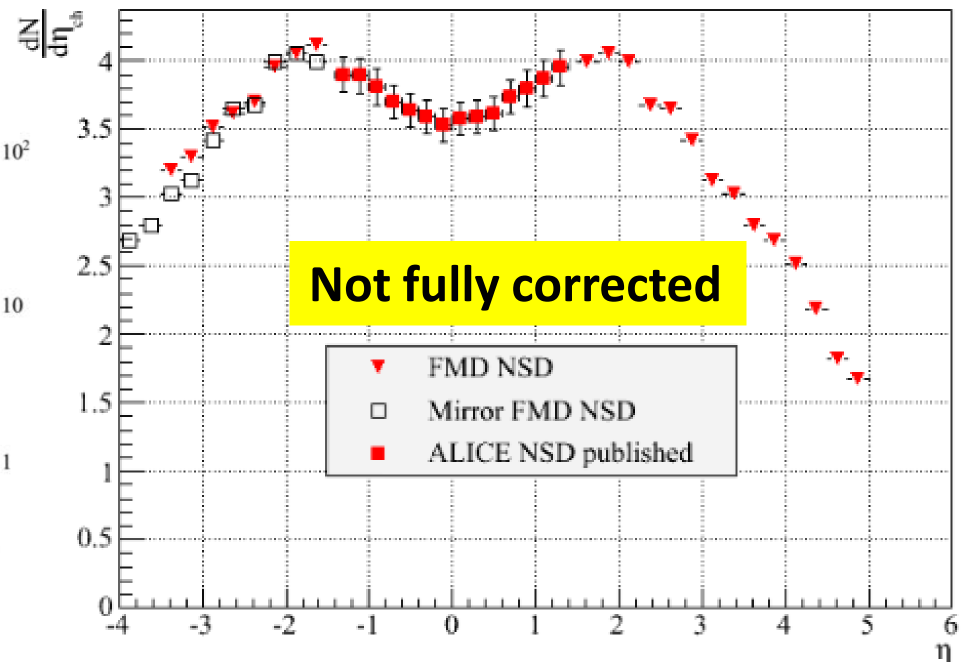




- High precision reached in central region (crucial at low p_T ($\mathbf{p} \;/\; \overline{\mathbf{p}}$, etc.)
- Expanding the charged particle multiplicity measurement to the forward region with the FMD

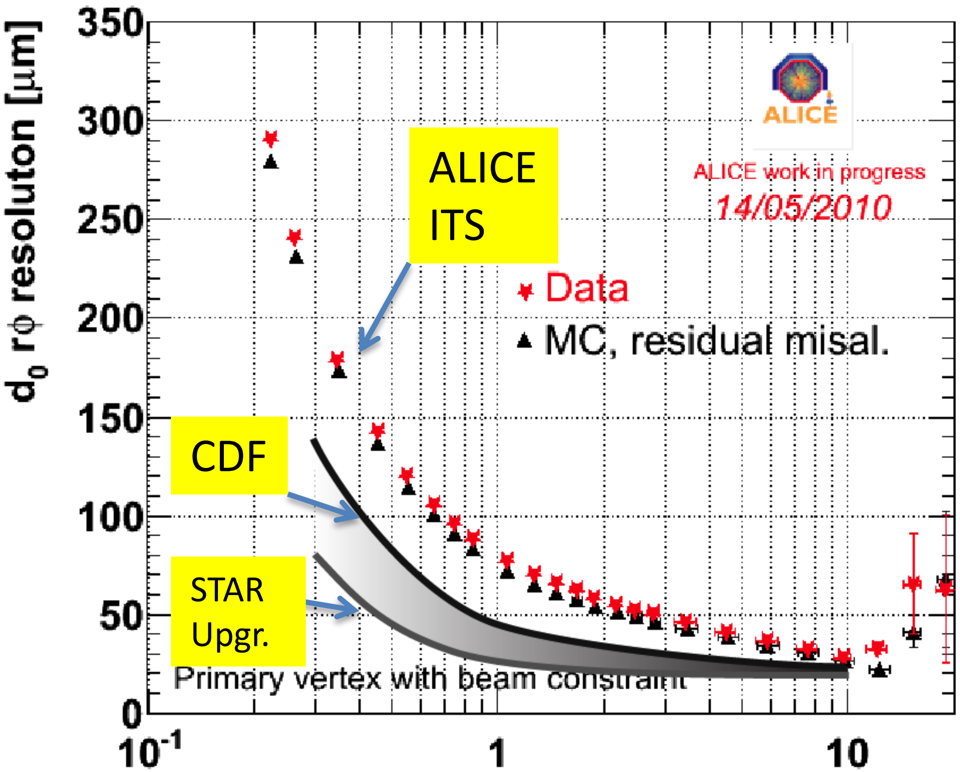
ITS material in simulation

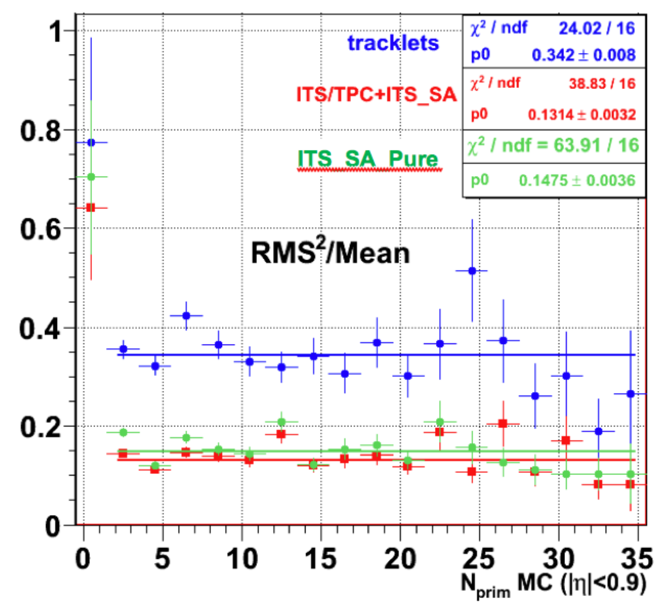




Tracking improvements

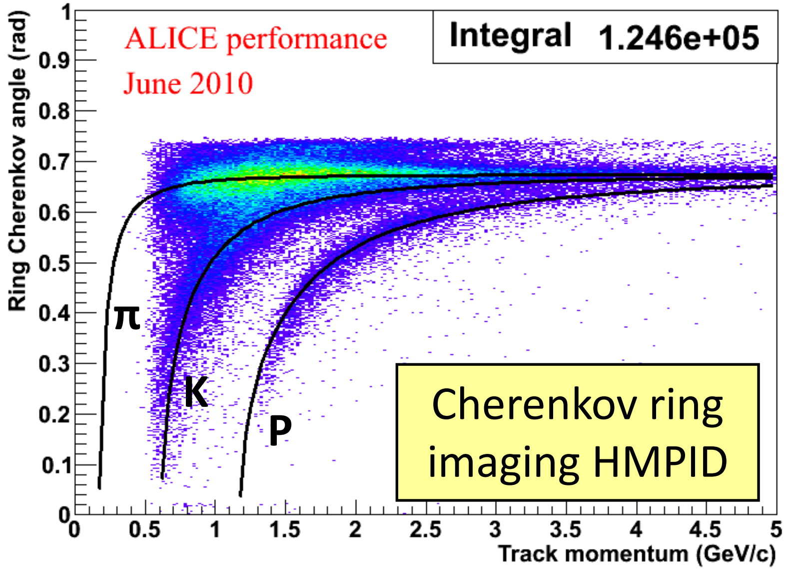
- ITS resolution well comparable to simulation and close to design value (CDF/running and STAR/future upgrade for comparison)
- Improved tracking for multiplicity measurement (40% gain in resolution compared to Pixel tracklets): **Important for best use of high statistics**

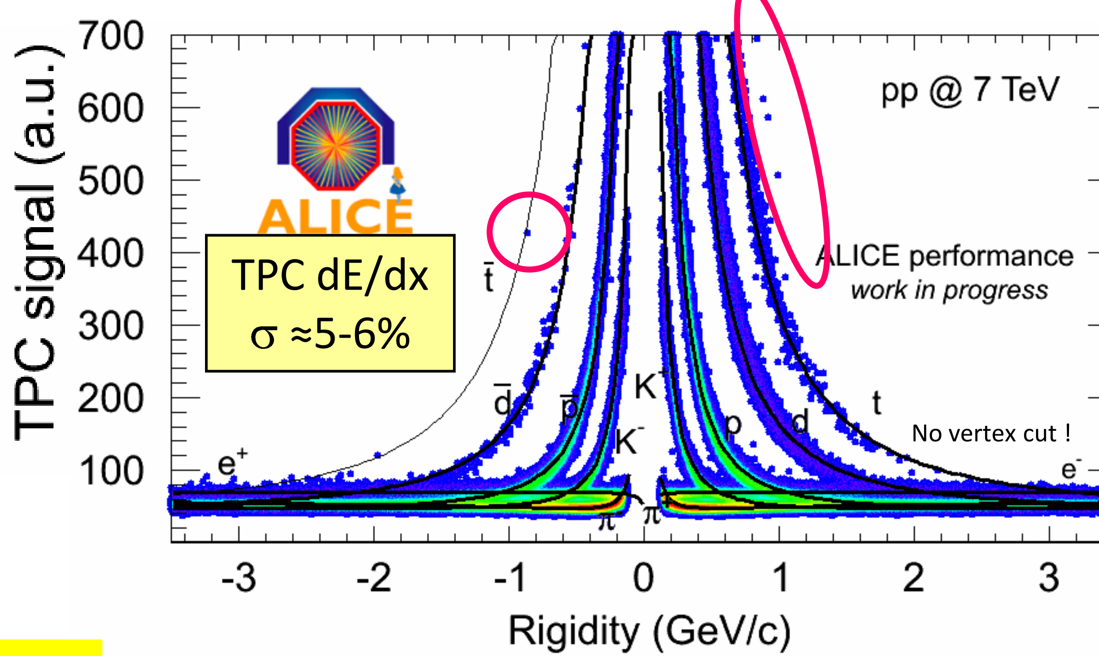


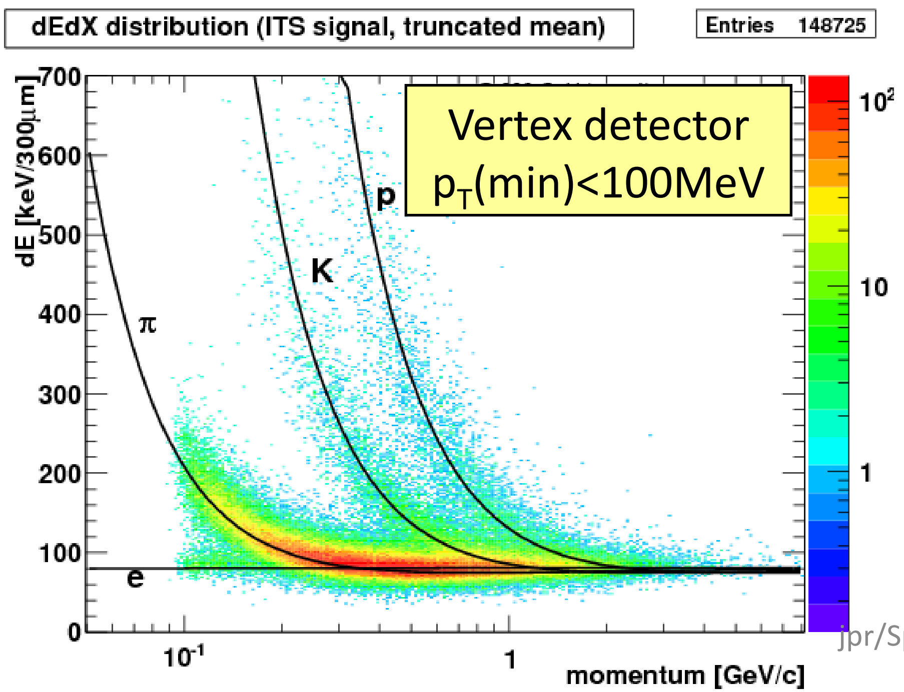


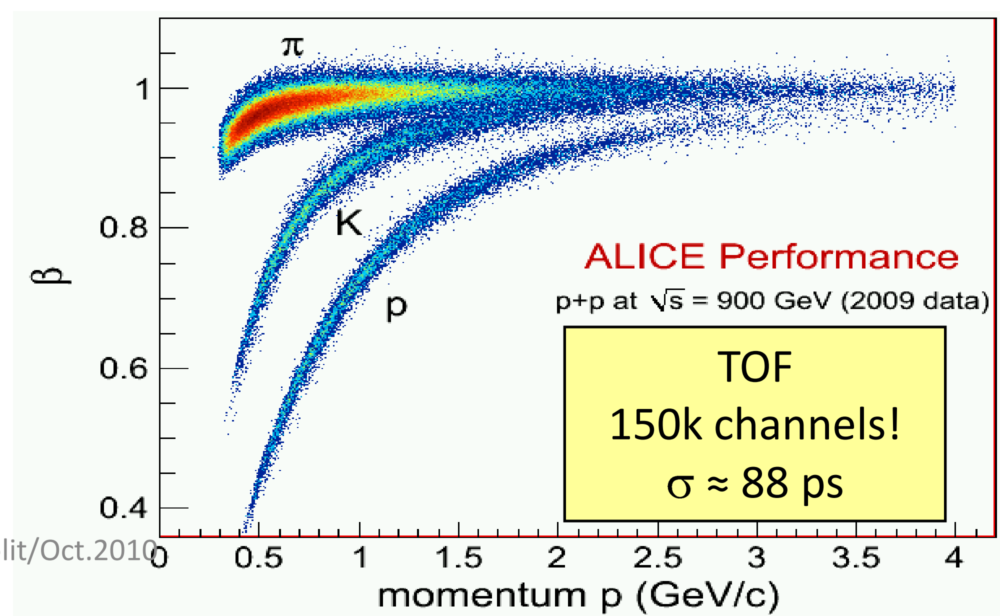
ALICE PID detectors

ALICE has excellent particle identification









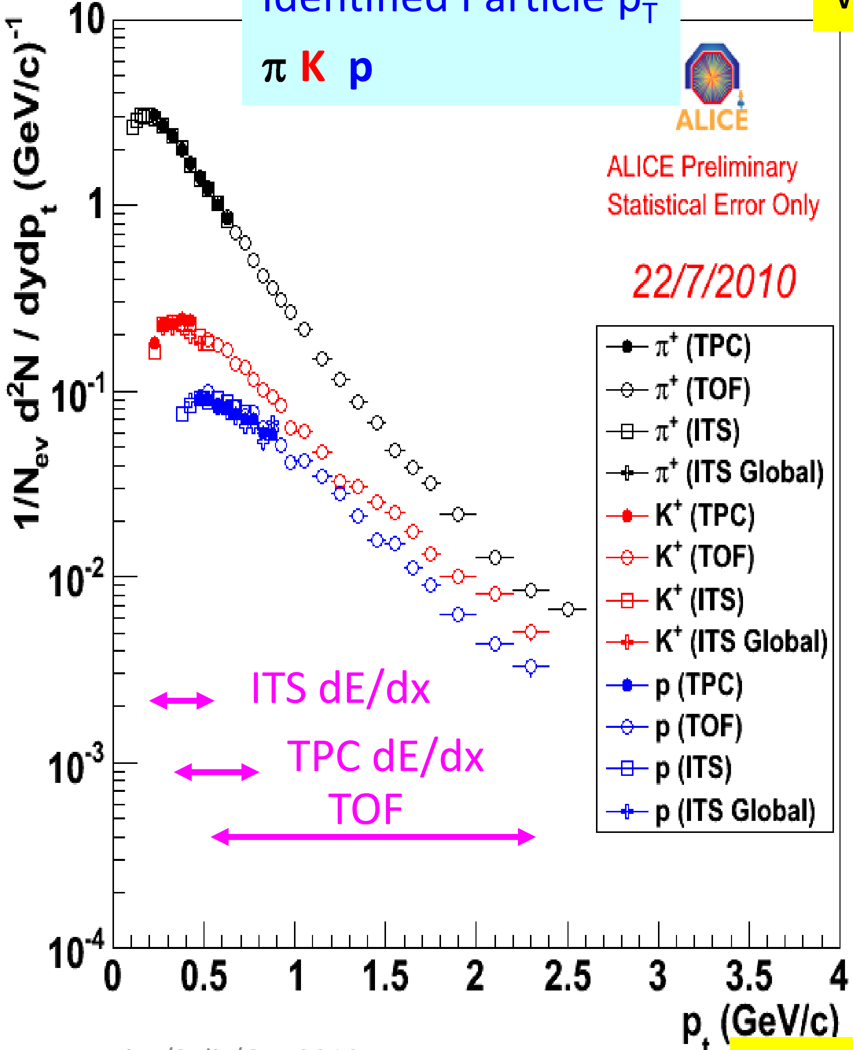
Identified particles

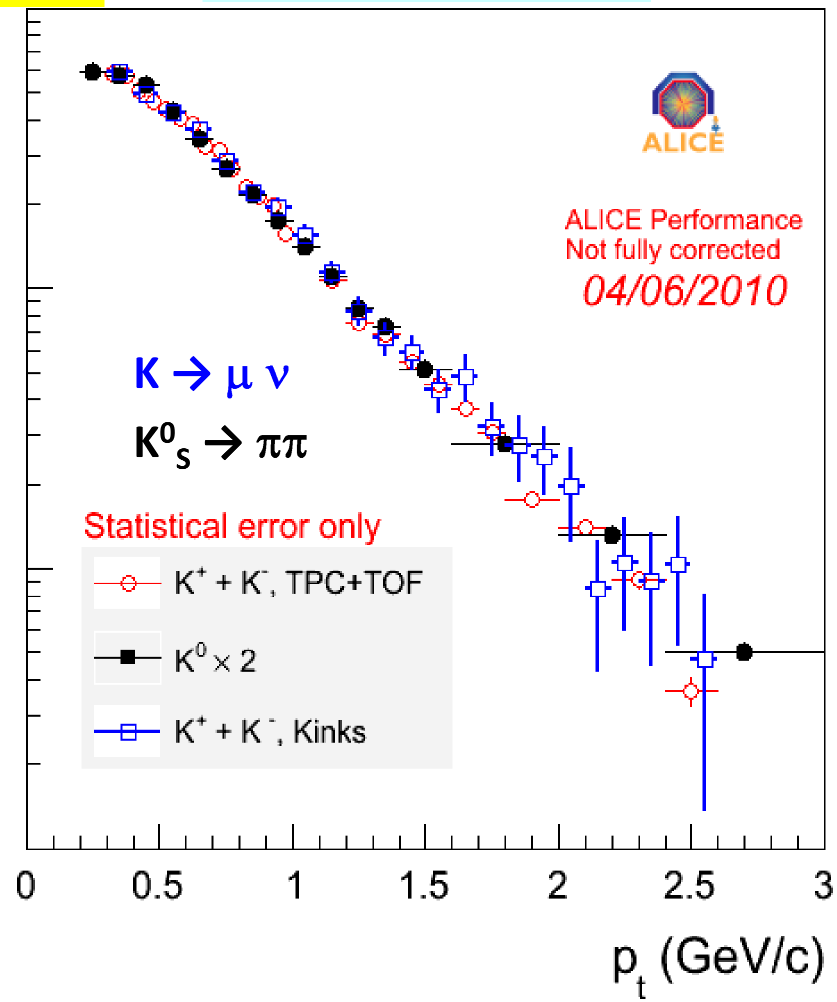
Identified Particle p_T

π K p

$\sqrt{s}$ = 900 GeV

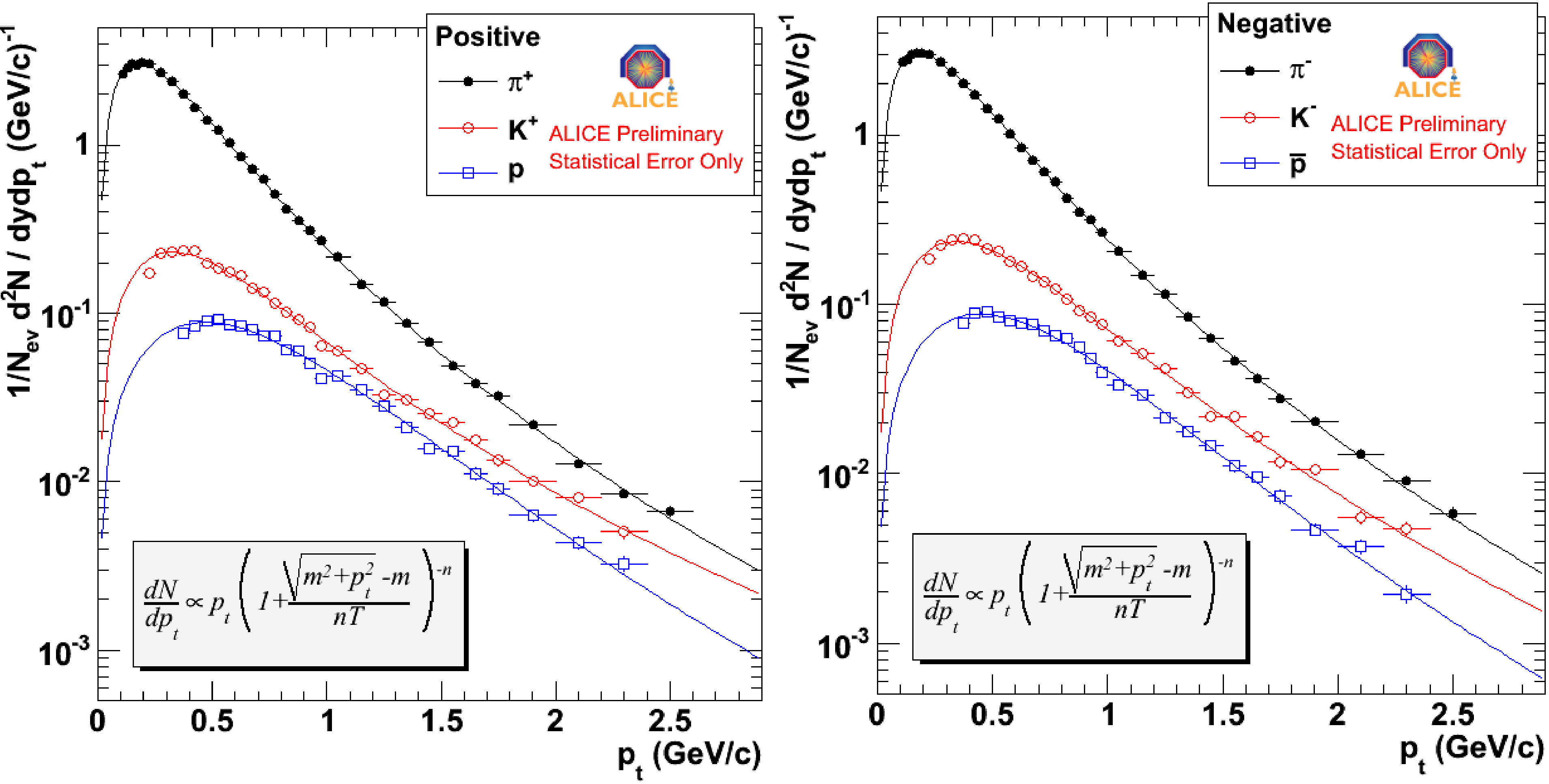
Kaon p_T distributions





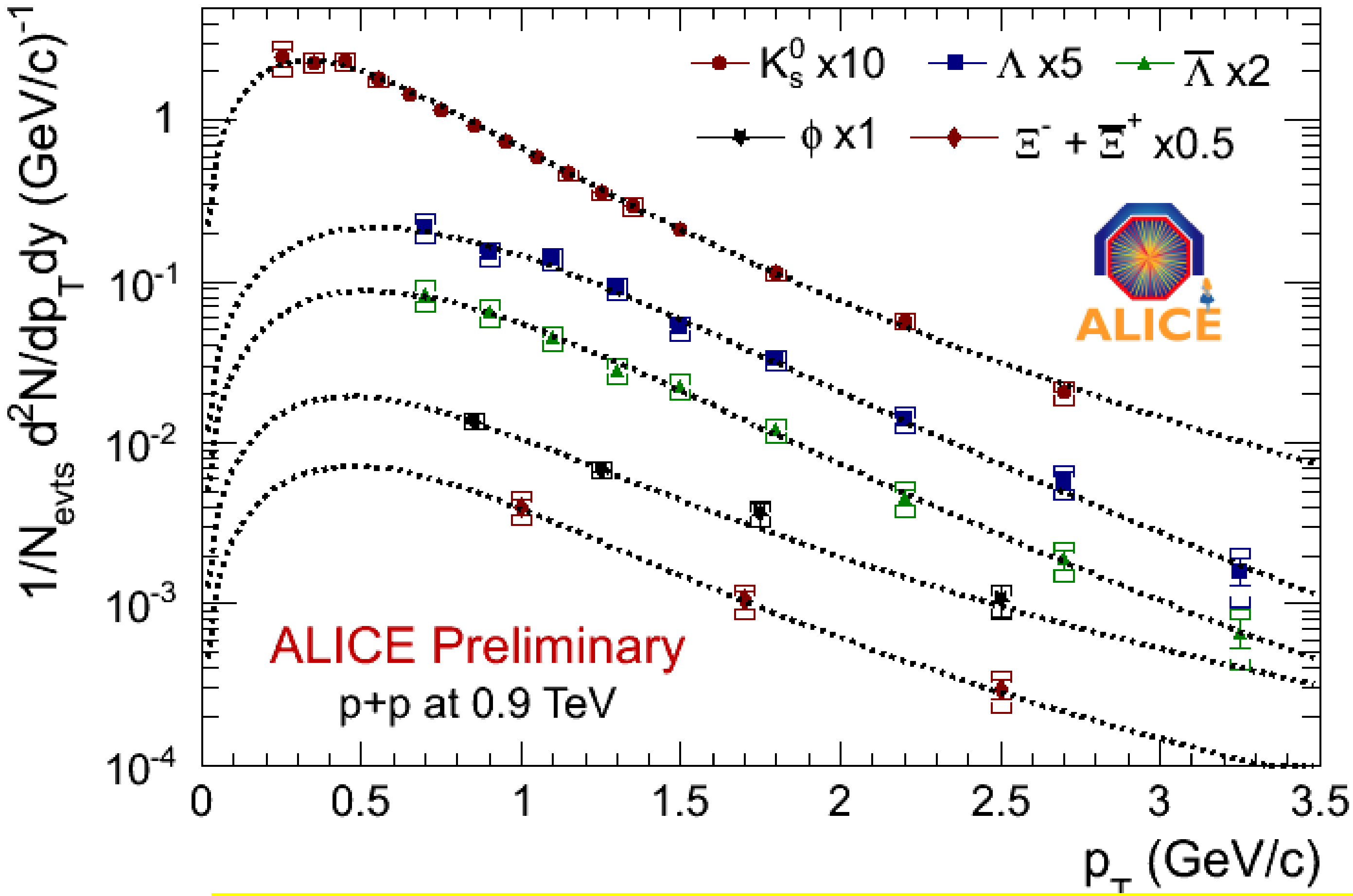
Many cross-checks: for kaons (6 measurements)

Charged π, K and p at √s = 900 GeV



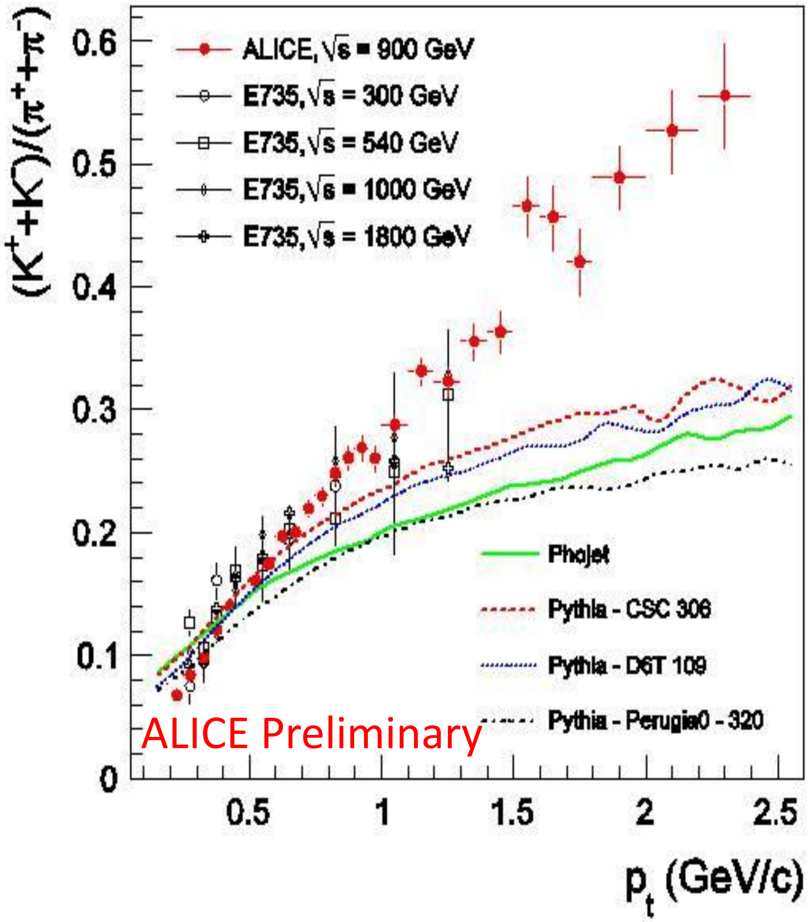
Spectra with statistical and systematic uncertainties
Lévy function fits describe data well

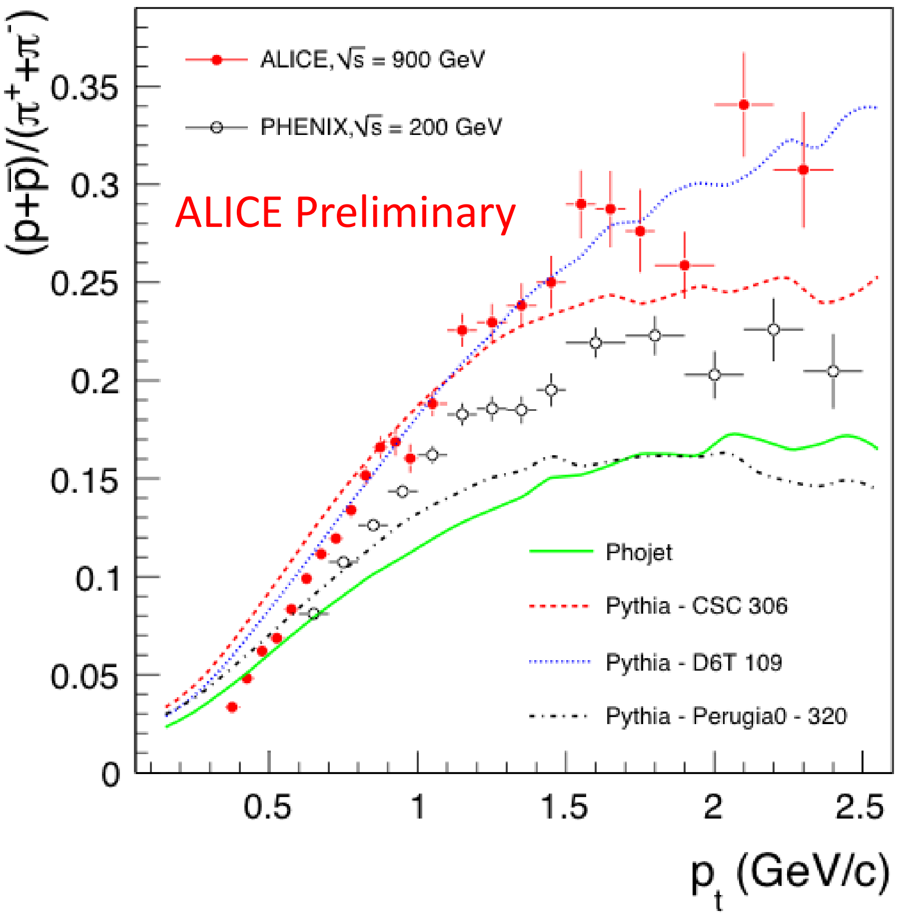
Strange particles at √s = 900 GeV



Very detailed study of identified particle production,
useful for model tuning and for comparison with Heavy Ions

Particle ratios vs p_T

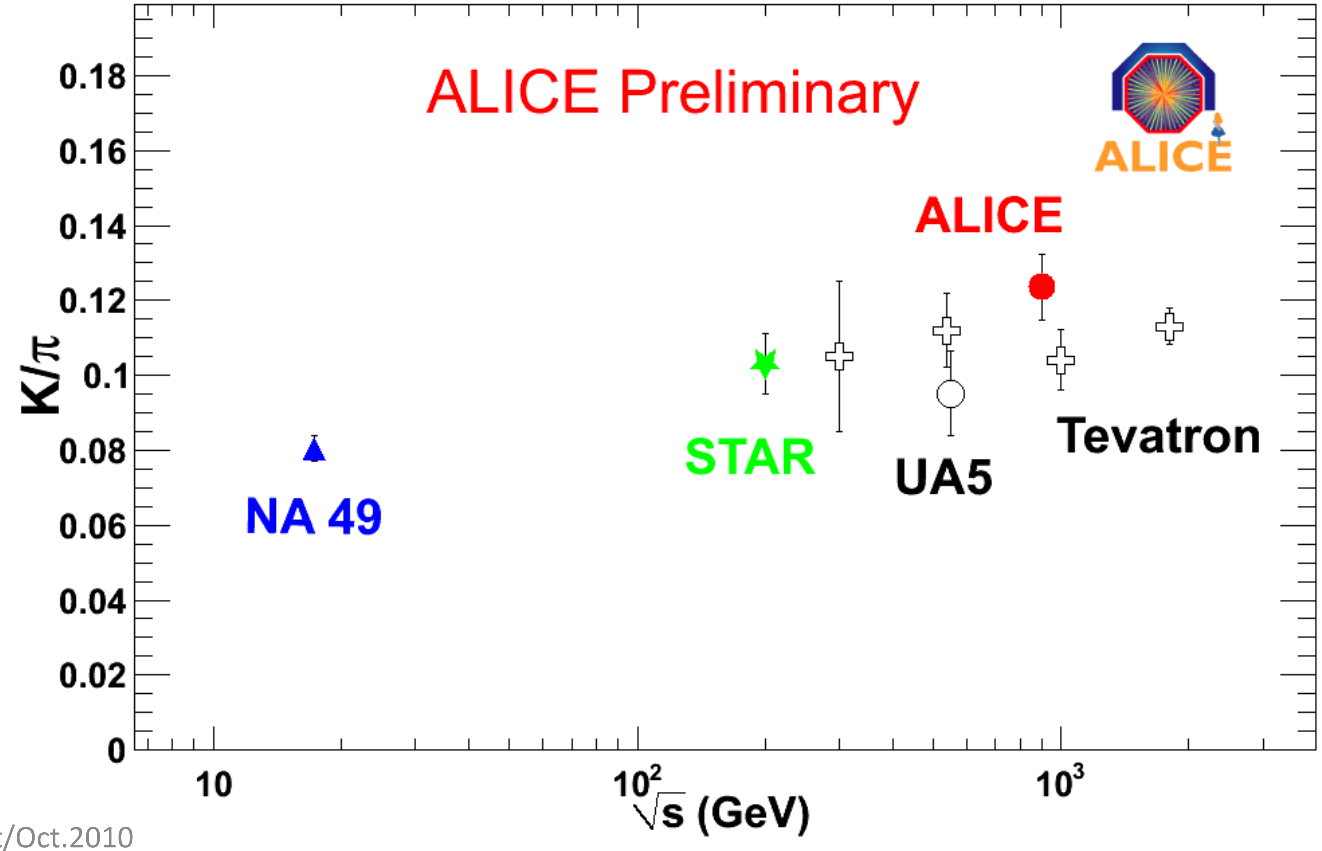




Poor agreement with Monet Carlo,
but good agreement with other experiments …

K/π ratio at √s = 900 GeV

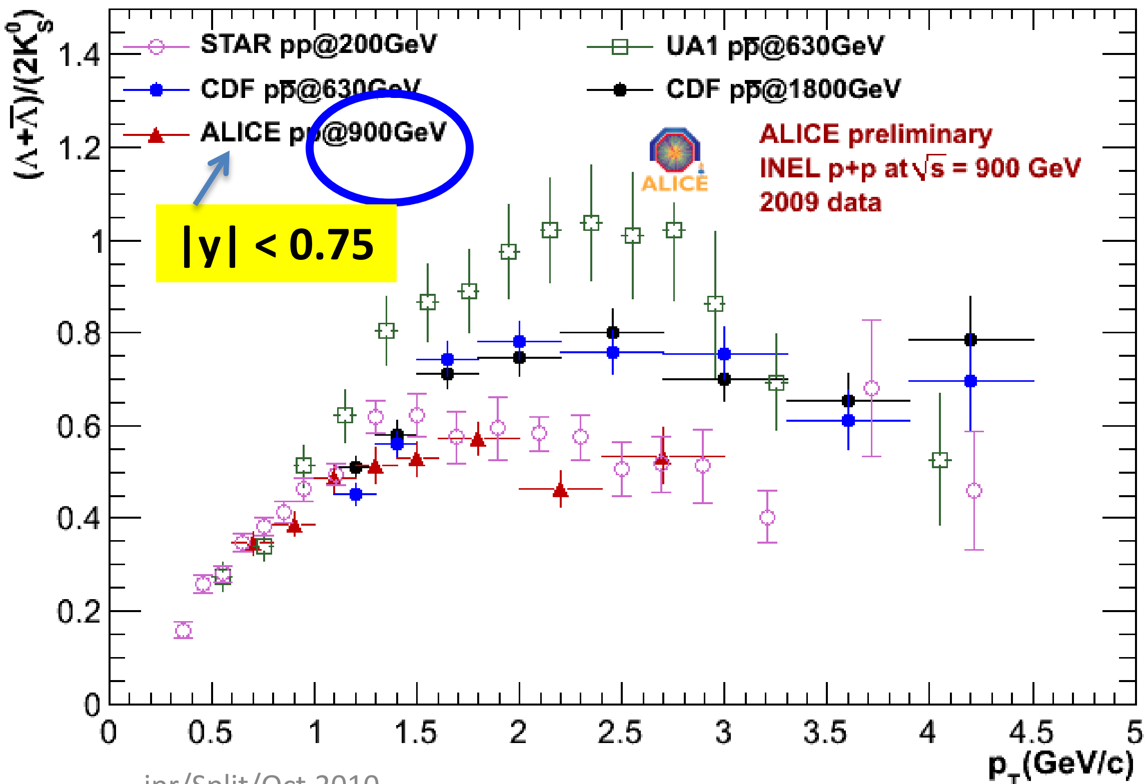
- Confirming slow rise vs √s
  7 TeV data analysis in preparation



$\Lambda/2K_s^0$ ratio at $\sqrt{s}$ = 900 GeV

- ALICE pp at 900 GeV similar to STAR at 200 GeV
- But different from CDF (630GeV/1800GeV) and UA1 (630GeV) proton-antiproton data for $p_T > 1.5$ GeV/c

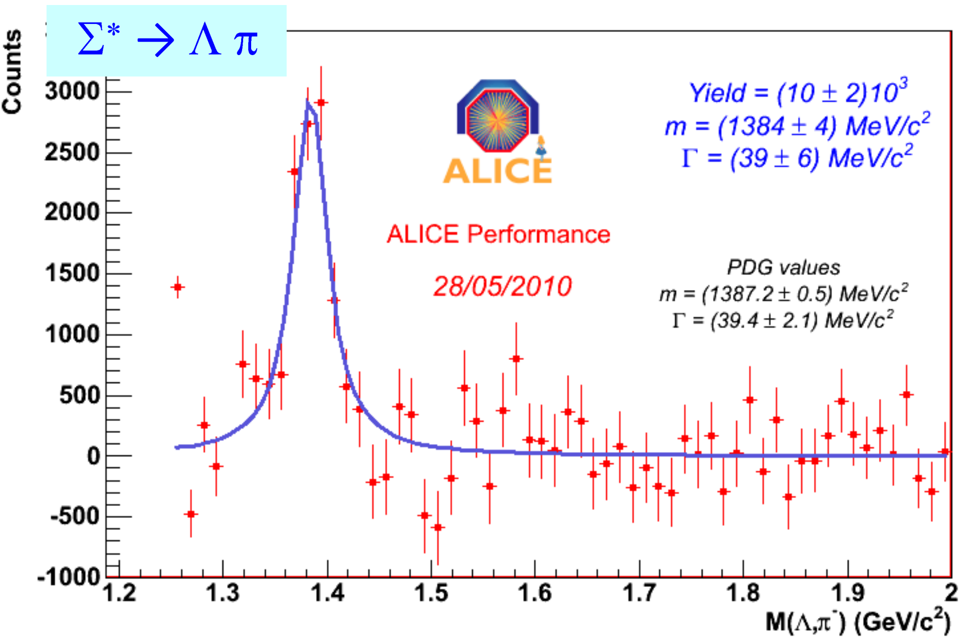
  Comparison under study: trigger, acceptance, feed-down corrections,

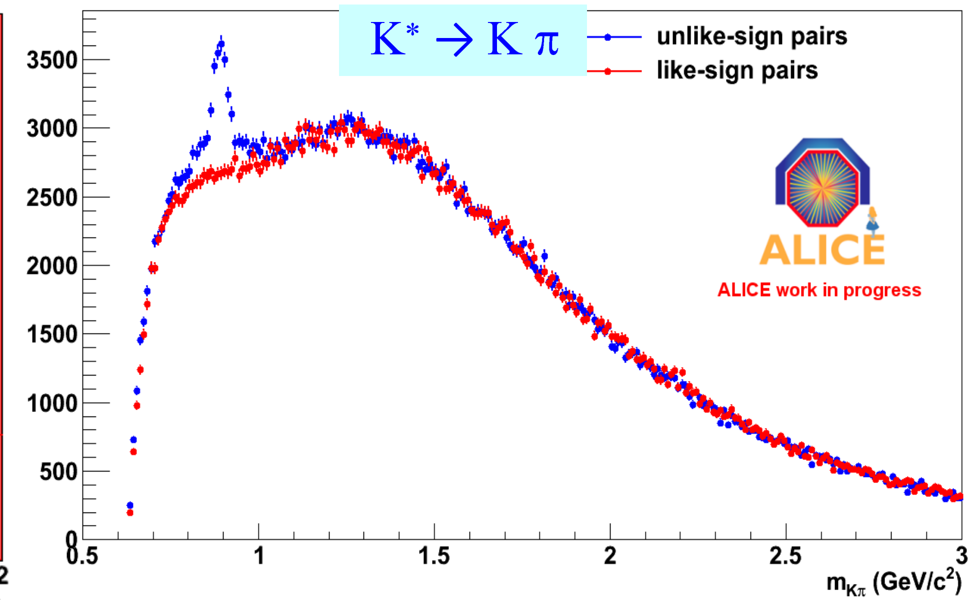


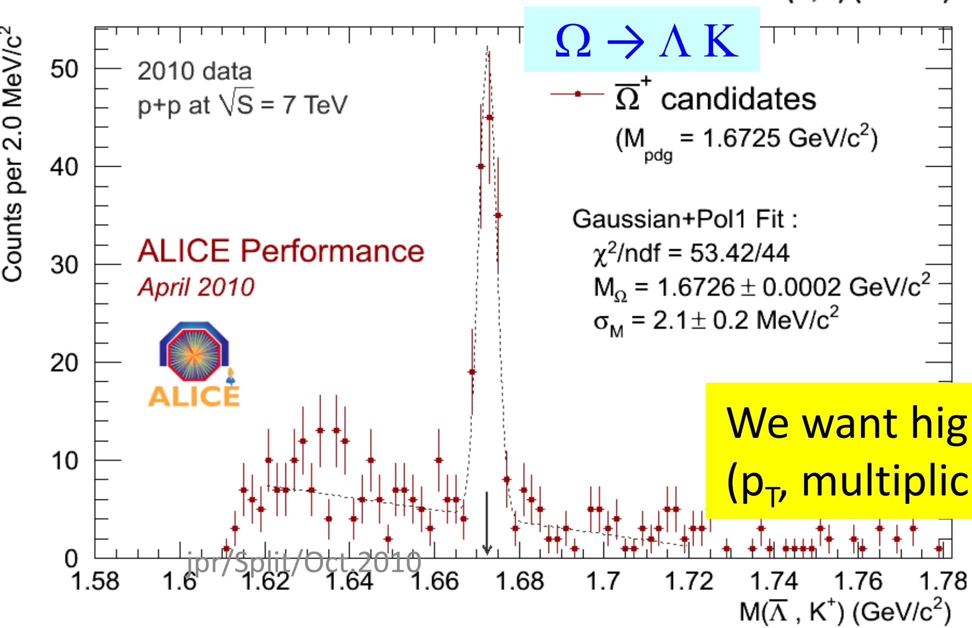
Note: STAR and ALICE data are Feed-down corrected (12-15% correction at ~ 2 GeV/c)

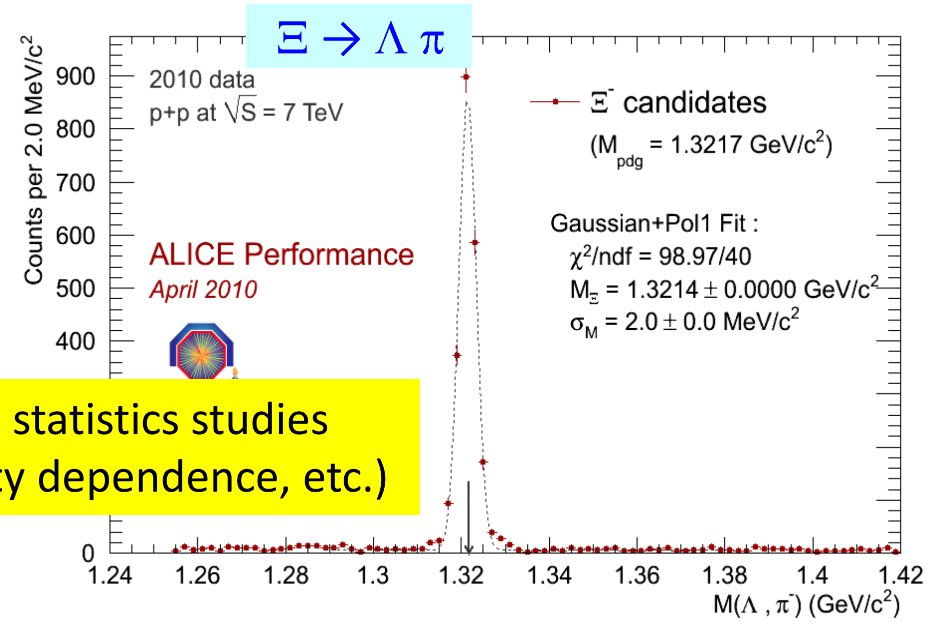
7 TeV data analysis (huge statistics) will tell us more

Much more to come: strange particles



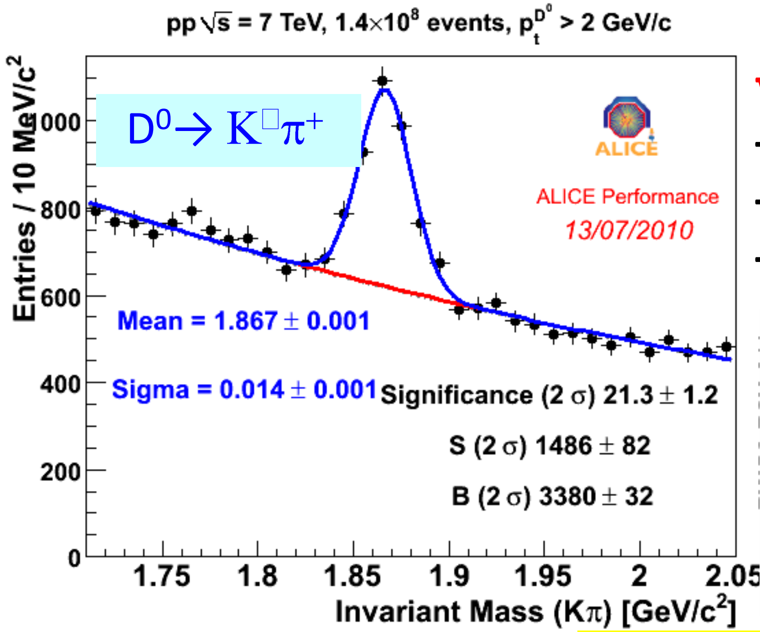






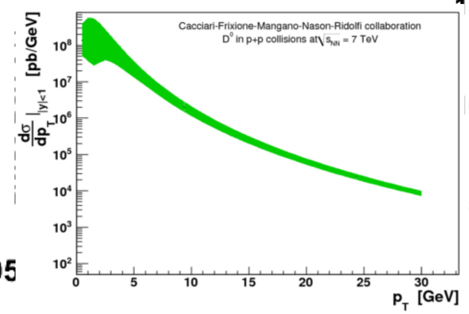
We want high statistics studies (p_T, multiplicity dependence, etc.)

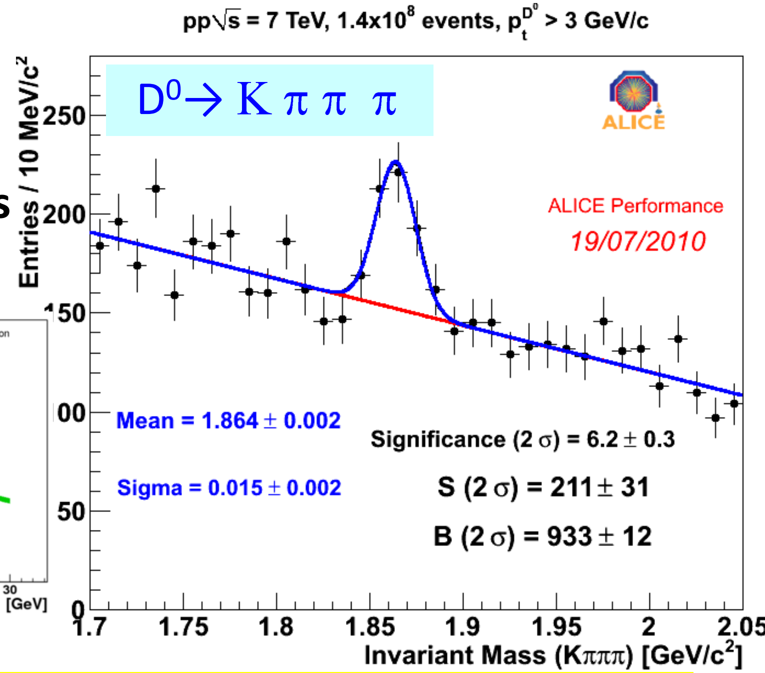
Charmed particles



√s = 7 TeV:

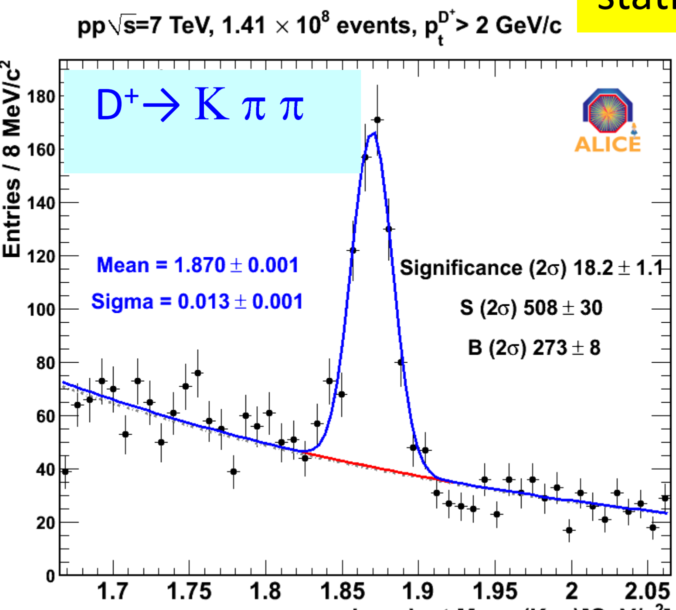
- new signals
- more decay modes
- p_T distributions

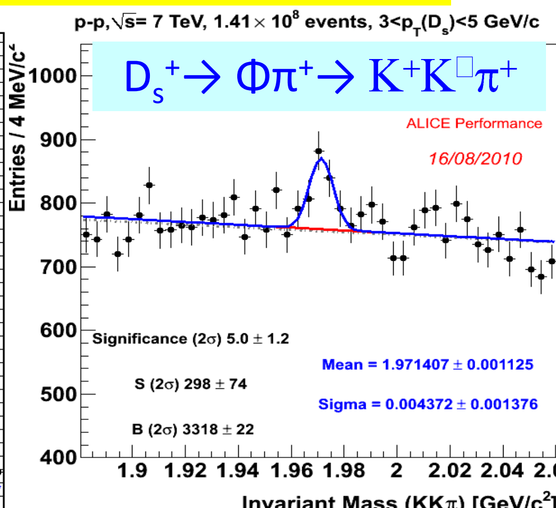


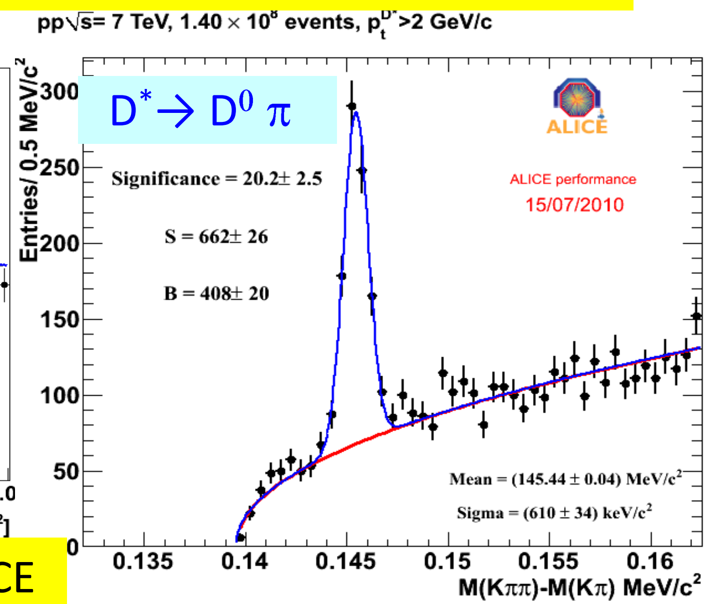


Goal: total cross section statistics limited at low p_T

10^9 evts to measure below 1 GeV/c



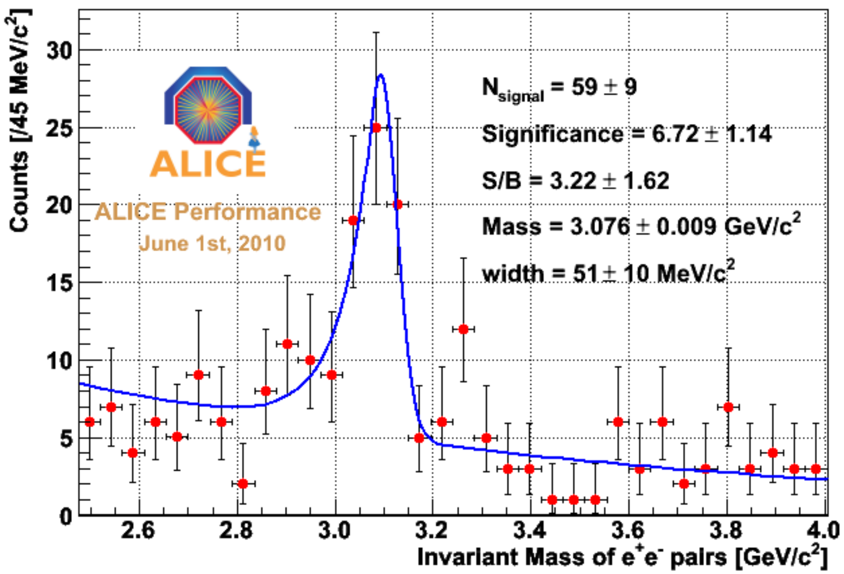




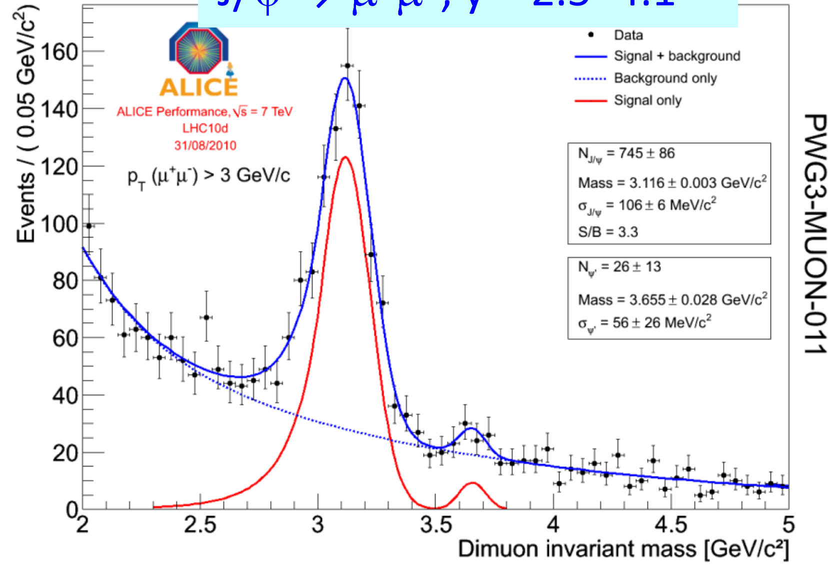
Lowest p_T reach for ALICE

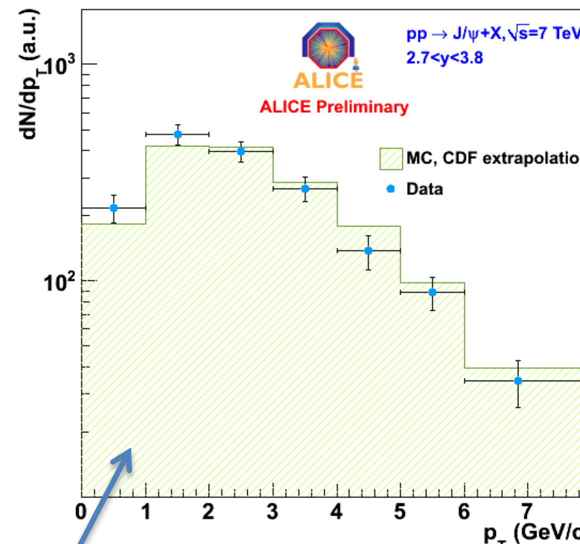
J/ψ at √s = 7 TeV

J/ψ → e^+e^- |y| < 1



J/ψ → $\mu^+\mu^-$, y = 2.5–4.1

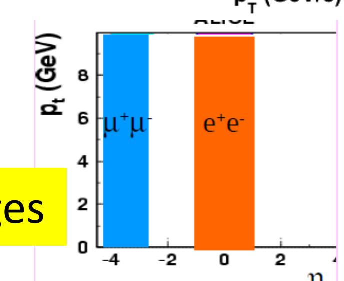




- Hard to measure J/ψ with our current low luminosity (also 1st year Pb–Pb luminosity will be **very** low ➔ priority to MB in pp)
- ‘proof of performance’ higher luminosity later this year (μμ) and next year

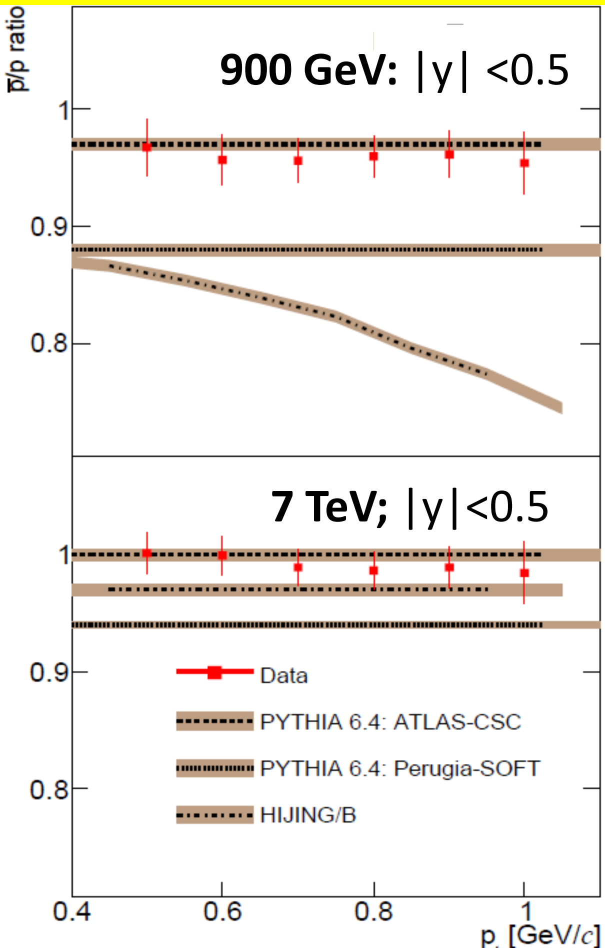
Acceptance and efficiency corrected distributions
Compared to MC generator (CDF parameterization)

Two η ranges



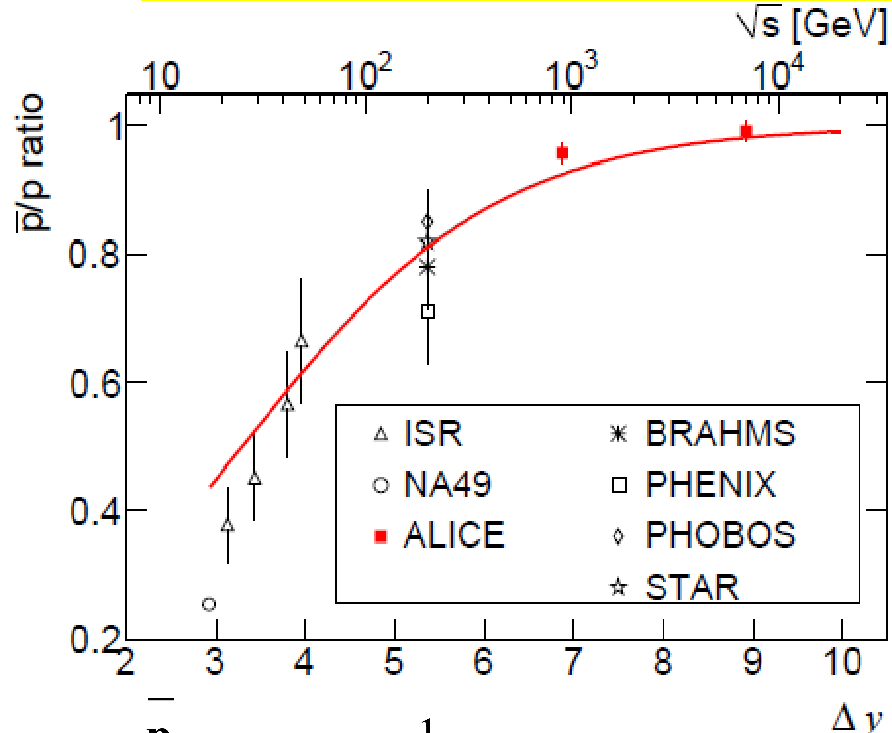
Proton-antiproton ratio

Related to probability to transport baryon number from η= 8.9 to 0



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)

Measurement suggested by B. Kopeliovich



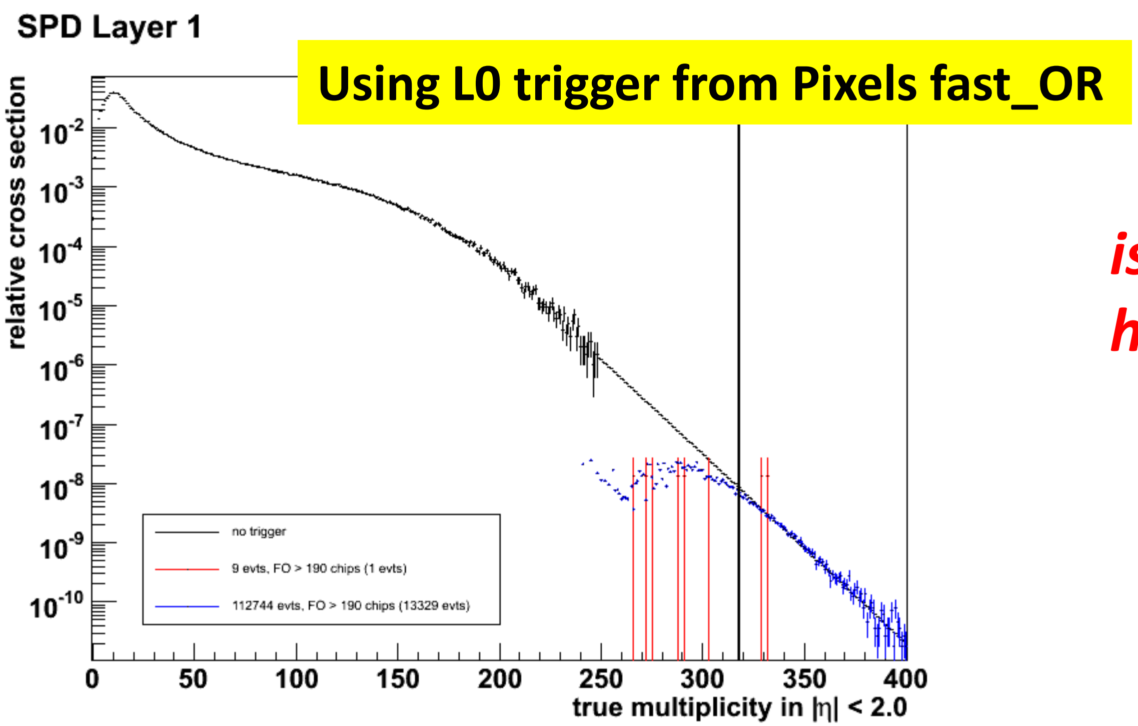
$$\frac{\bar{p}}{p} = \frac{1}{1 + C \times e^{(\alpha_{SJ} - \alpha_{P})\Delta y}}$$

α_{SJ} = 0.5, and α_P = 1.2, C ~ 9 (Red curve)

– Most precise ratio measurements so far
– For the first time, compatible with no asymmetry, in central region

Multiplicity dependence of pp properties

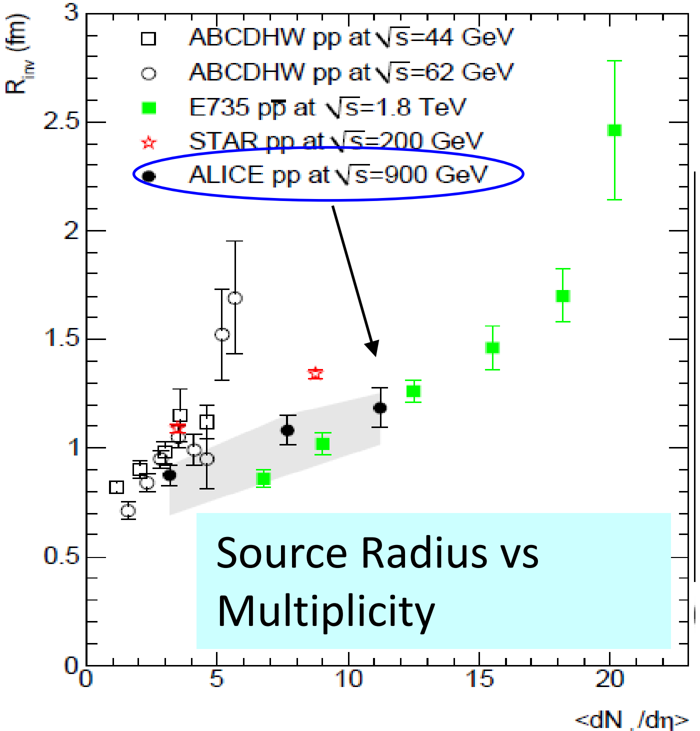
- Dependence of <p_T>, size of interaction region, topology, strangeness and charm contents, correlations, $\mathbf{p}/\bar{\mathbf{p}}$, etc. being studied. To be extended using high multiplicity triggers.

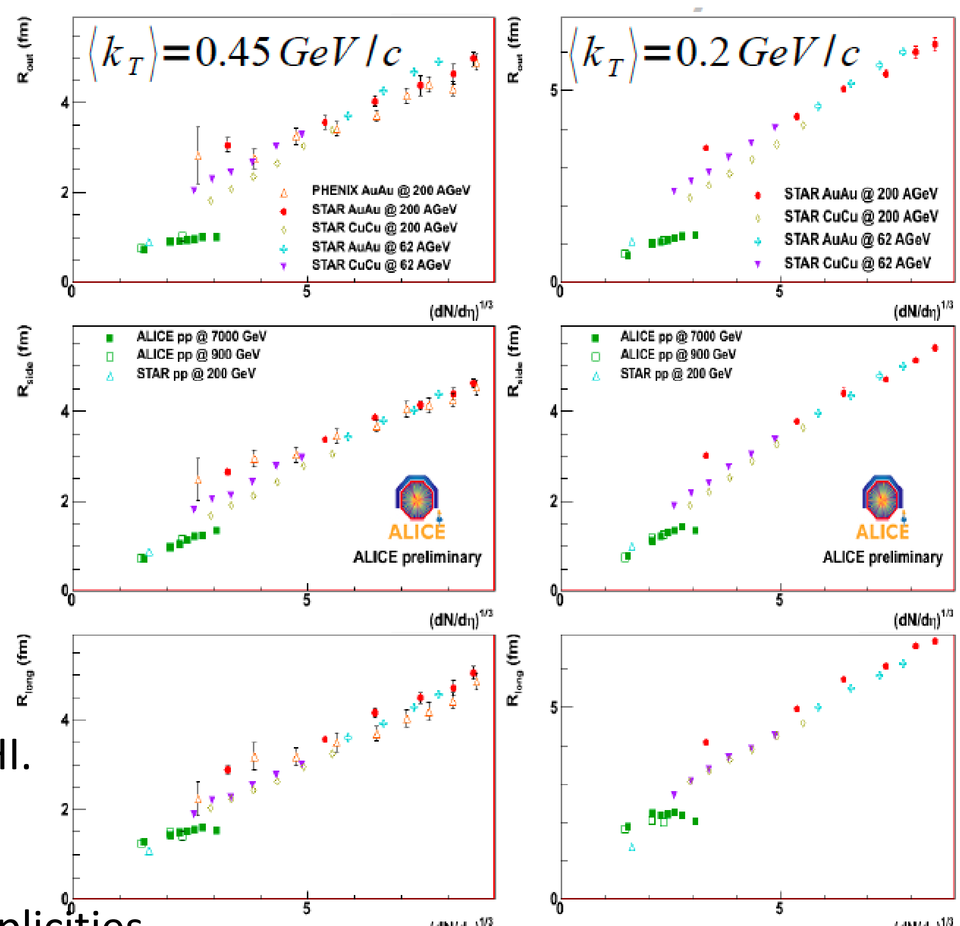


is QCD describing all high multiplicity events?

Bose Einstein Correlations

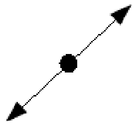
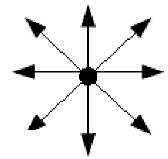
- Quantum Mechanical enhancement of identical Bosons at small momentum difference
  - enhancement of like-sign pions at low momentum difference $q_{inv}=|\mathbf{p}_1-\mathbf{p}_2|$, as function of multiplicity and pair momentum $k_T = |\mathbf{p}_{T1}+\mathbf{p}_{T2}|/2$





Multiplicity overlap between pp and HI.
Scaling with M similar to STAR
but different from HI
pp sizes smaller than HI at same multiplicities

Event shape analysis

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

Transverse sphericity $S_\perp$, defined as a function of eigenvalues of the momentum tensor S_{xy}

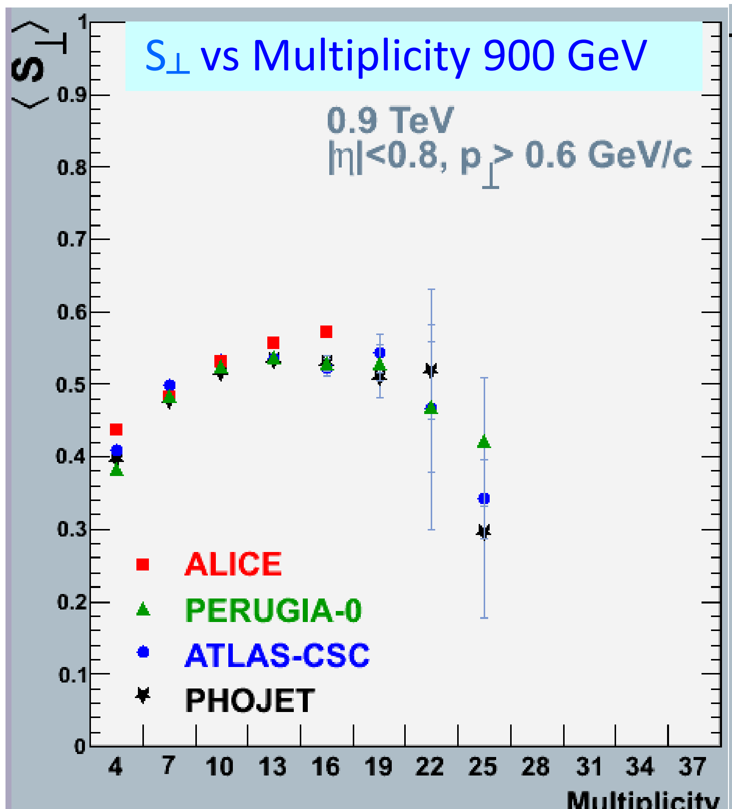
$$\mathbf{S_{xy}} = \sum_i \begin{pmatrix} {p_x^{(i)}}^2 & p_x^{(i)} p_y^{(i)} \\ p_x^{(i)} p_y^{(i)} & {p_y^{(i)}}^2 \end{pmatrix}$$

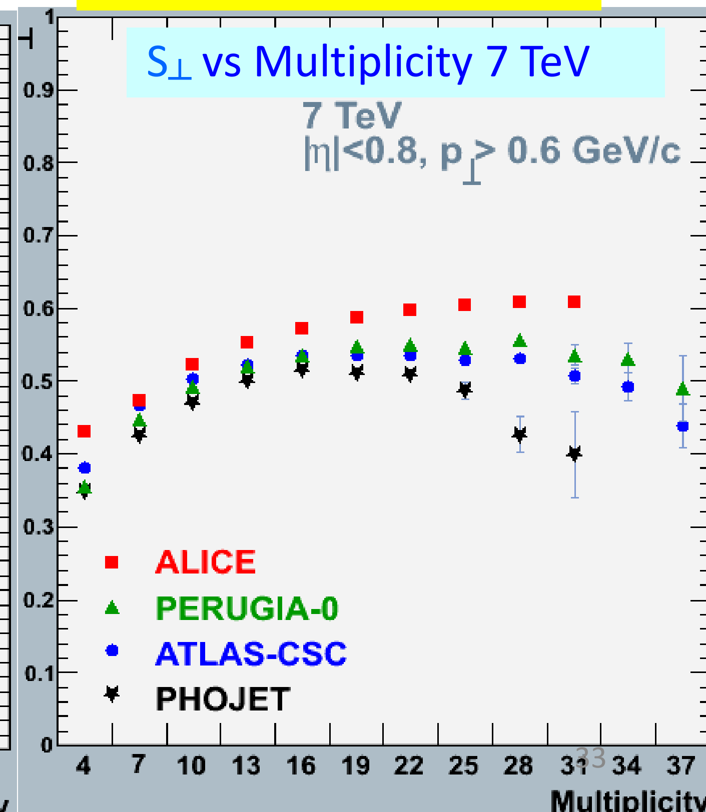
$$S_\perp \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$

HM events more spherical than models

ALICE performance

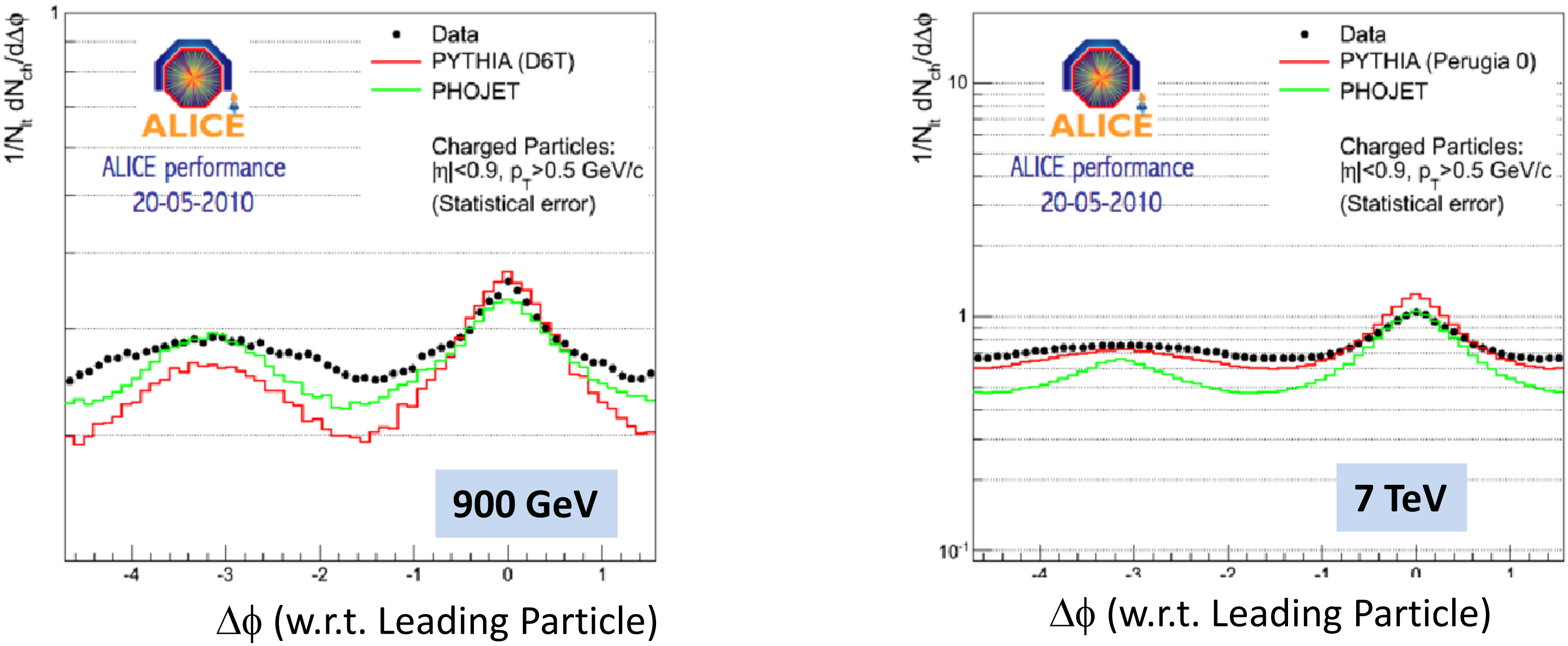
Guy Paic & Antonio Ortiz





Underlying Event Studies

Uncorrected Data



→Less back-to-back-ish than MC
→Is it related to the effect seen in shape analysis

Conclusion

- Many signs that pp collisions are not yet well understood:
  - Global event properties (Multiplicity, p_T spectra, etc.)
  - Identified particle production
  - $\sqrt{s}$ dependence of multiplicity
  - Particle correlations, etc.
- All current MC generators need tuning
- We have already learned a lot with our first ~ 10 nb^{-1}
- ALICE is now concentrating its effort on the preparation for first Heavy Ion collisions (on November 11?)