Early p-p physics at ALICE

E. Scomparin (INFN Torino)
for the ALICE Collaboration

- Introduction
- The ALICE experiment
- Results from the 2010 run
  - Soft physics
  - (Selected) hard physics
- Perspectives and conclusions

Ghiacciaio del Rutor, April 2010

Les Rencontres de Physique de la Vallee d' Aoste
La Thuile, February 27 - March 5, 2011

Introduction

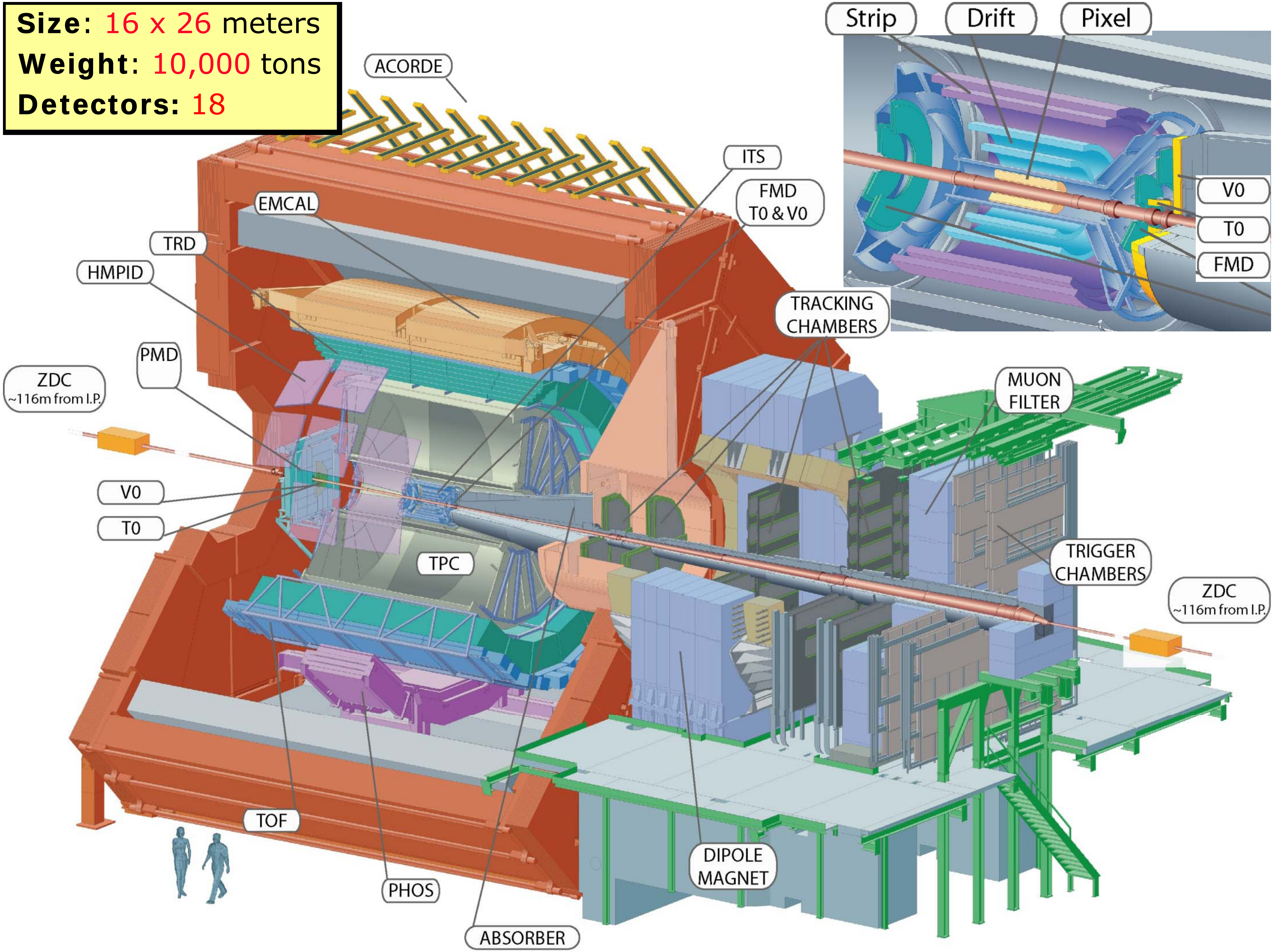
- ALICE (A Large Heavy-Ion Collision Experiment): the dedicated heavy-ion experiment at the LHC

- Main focus on Pb-Pb collisions → QGP studies at the nominal (forthcoming) LHC luminosity, 5×10^{26} cm^{-2}s^{-1}

- p-p collisions are a crucial aspect of the physics program
  - Reference for heavy-ion collision studies
  - Genuine p-p physics
  - Maximum luminosity limited to a few 10^{30} cm^{-2}s^{-1} due to pile-up in slower detectors
  - Faster detectors (e.g. muon spectrometer) may stand a higher luminosity

Running conditions appropriate for soft physics, but also heavy flavor physics can be addressed

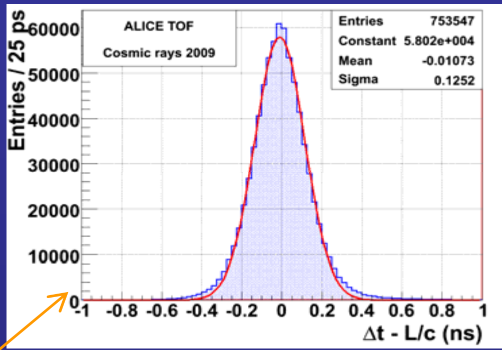
Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18

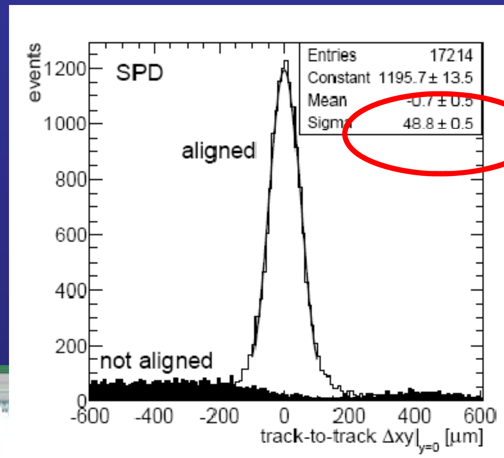


ALICE: the recent history

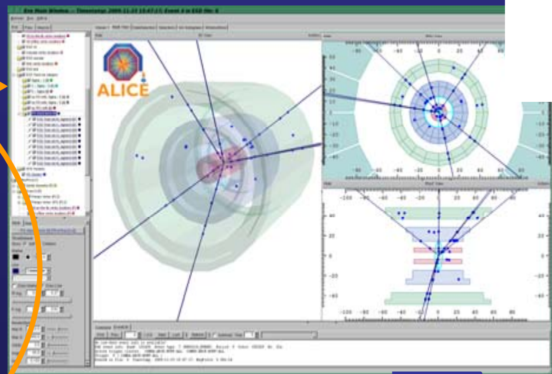
Detector installation until **July 2009**:

Cosmic runs (calibration, alignment) from **August** to mid **November 2009.**
Example: ITS pixel alignment, TOF resolution





23/11/09 **First LHC pp coll. at 900 GeV … and first LHC paper**



14/12/09 **pp coll. at 2.36 TeV**

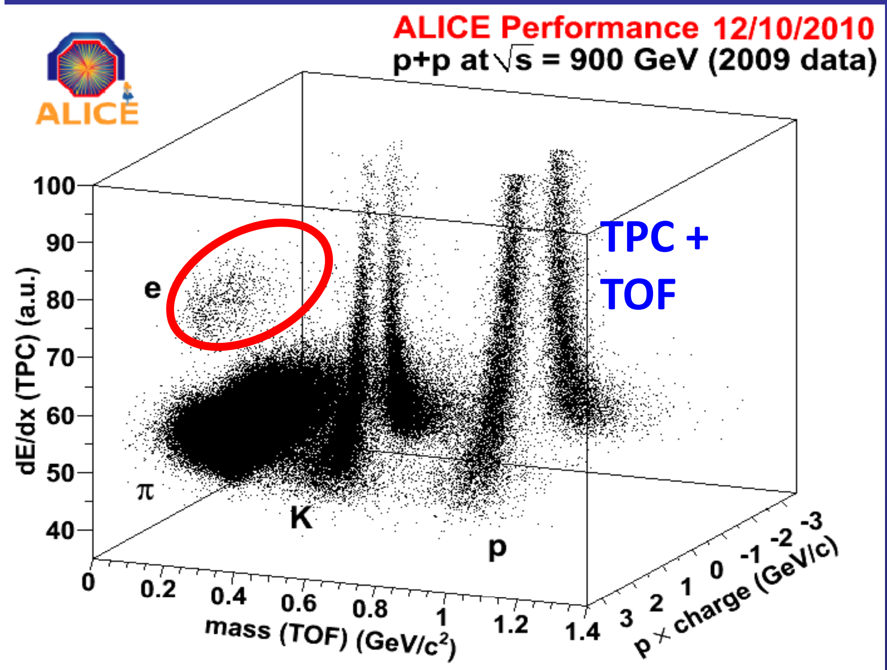
March 2010 **pp coll. at 7 TeV**

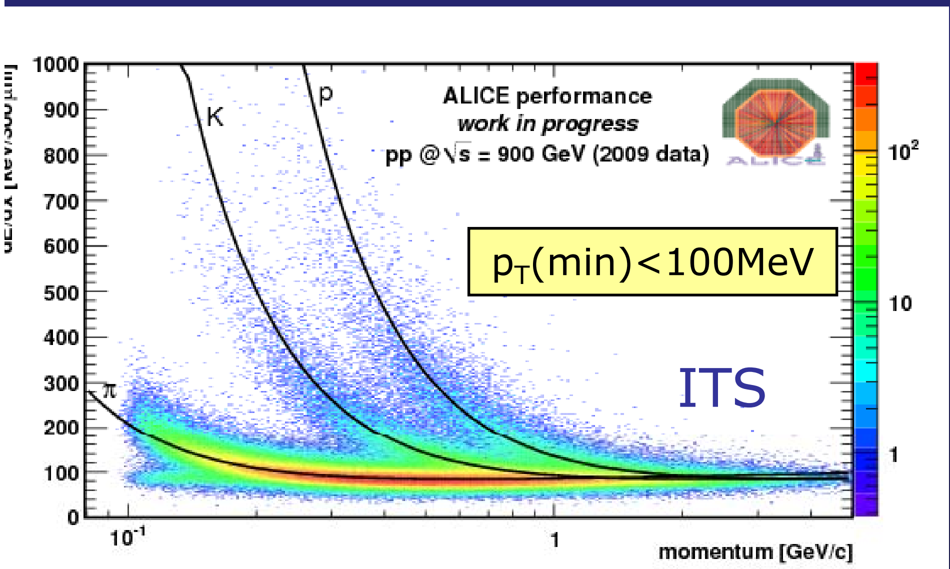
Talk mainly focussed on these results!

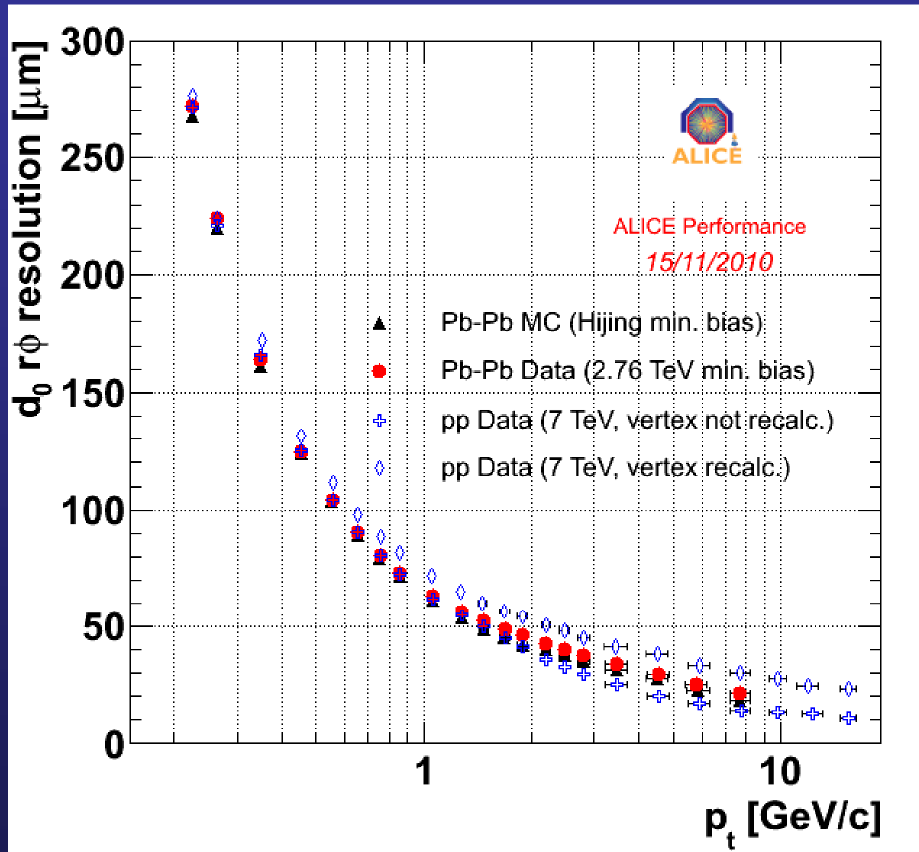
Nov. 2010 **Pb-Pb coll. at 2.76 ATeV**

See talk by A. Dainese later today

PID, vertexing

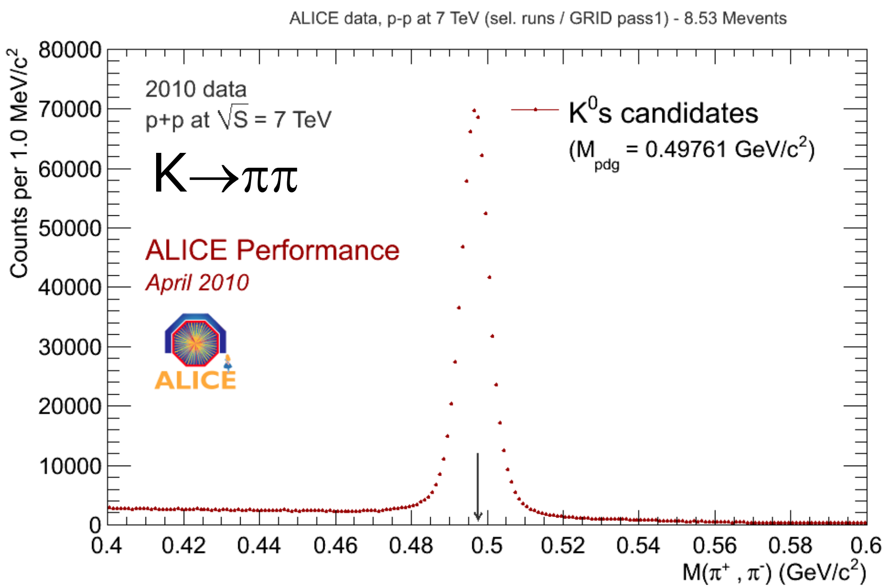


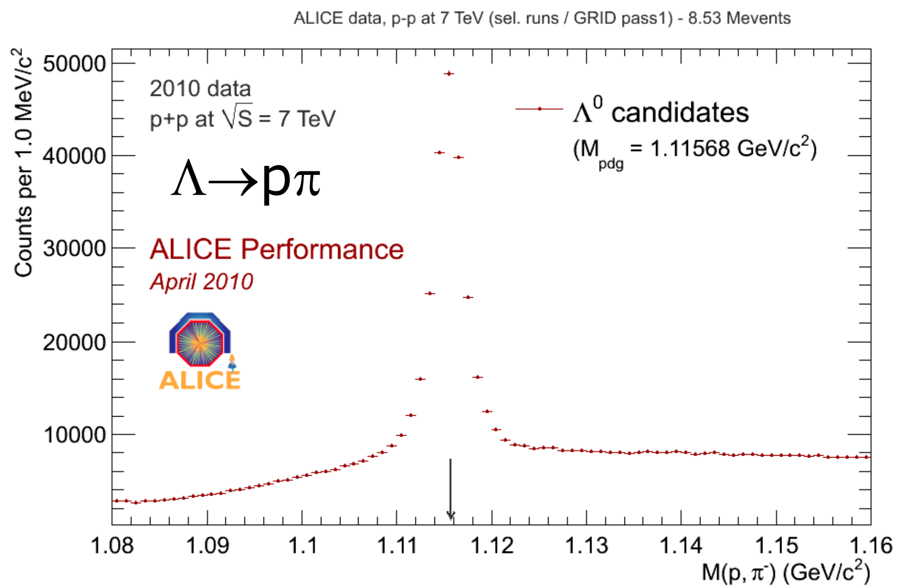


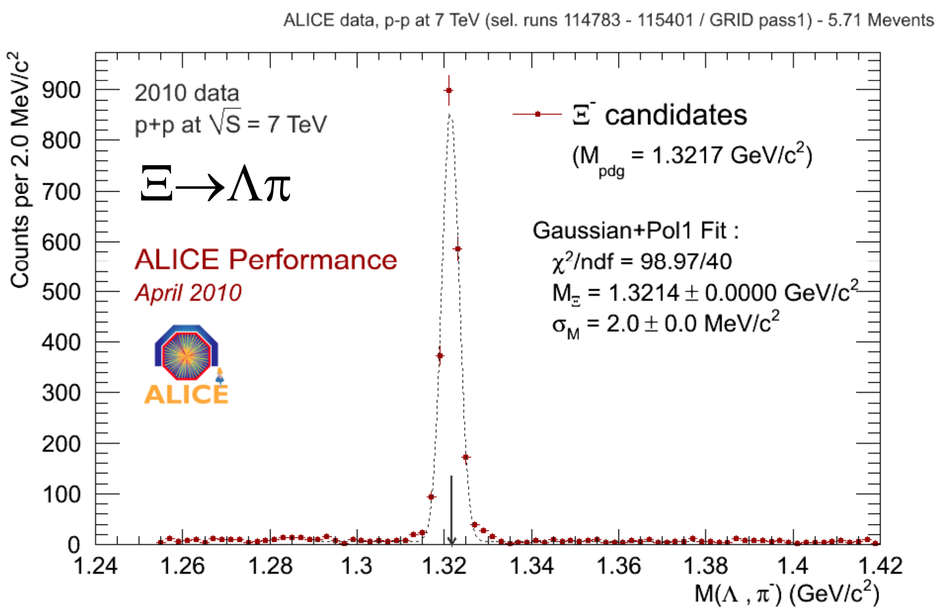


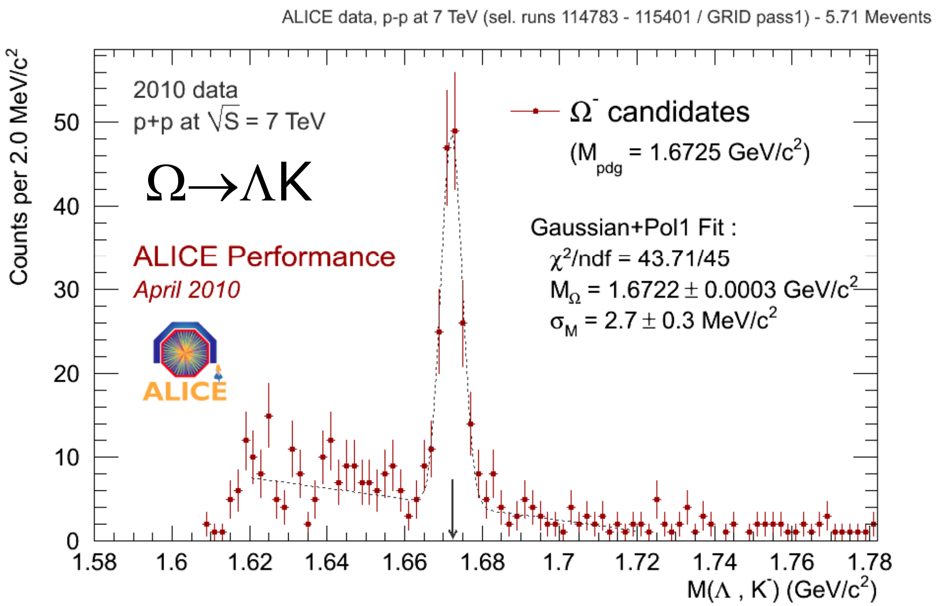
- Resolution better than 75 μm above 1 GeV/c, and very close to target performance
- Essentially the same in PbPb and pp

Strange particle signals

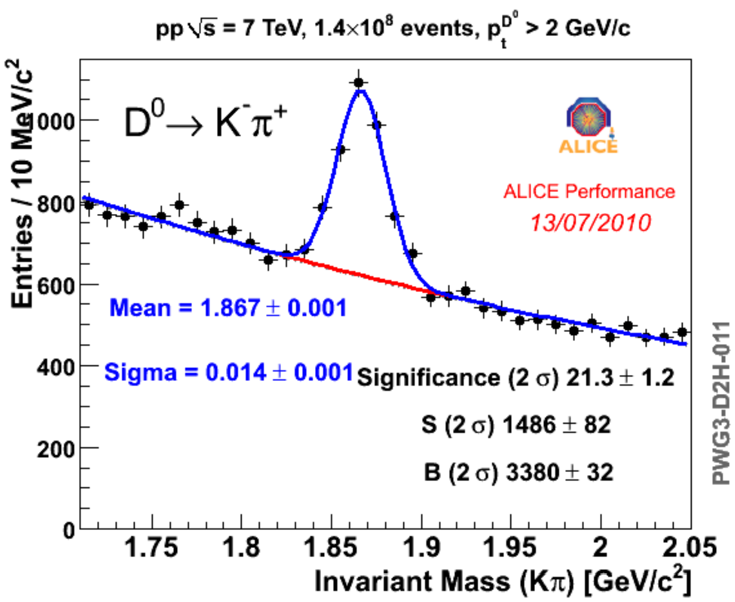


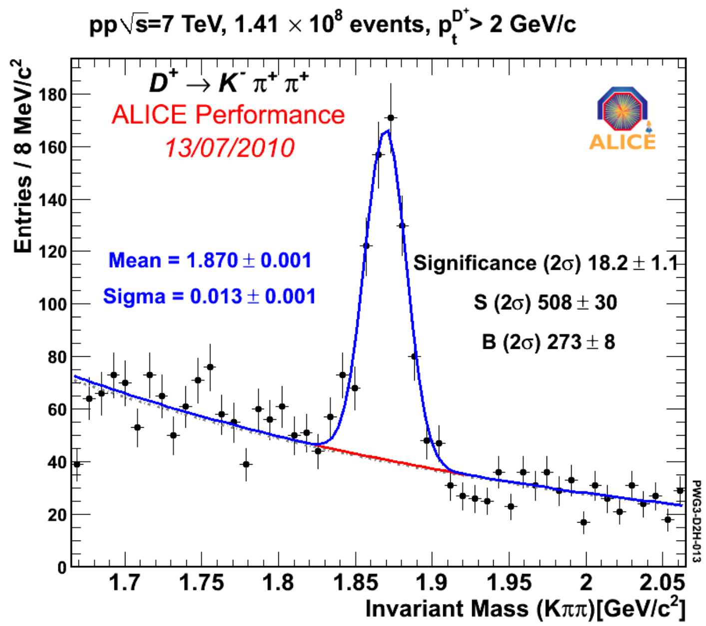


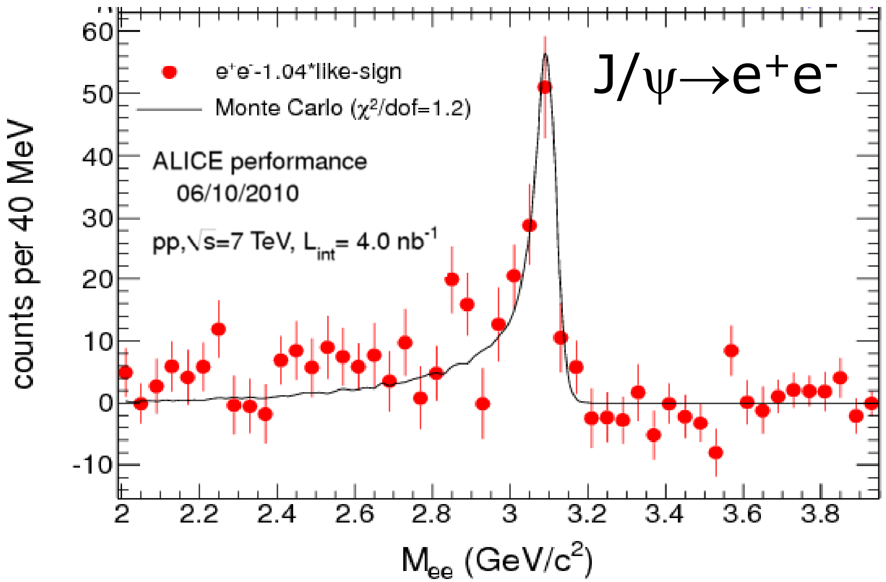


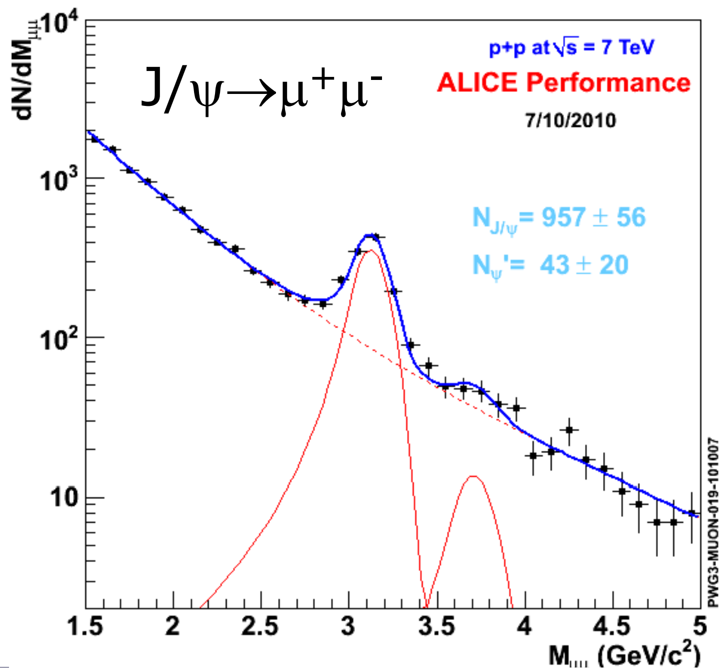


Open charm and charmonium signals





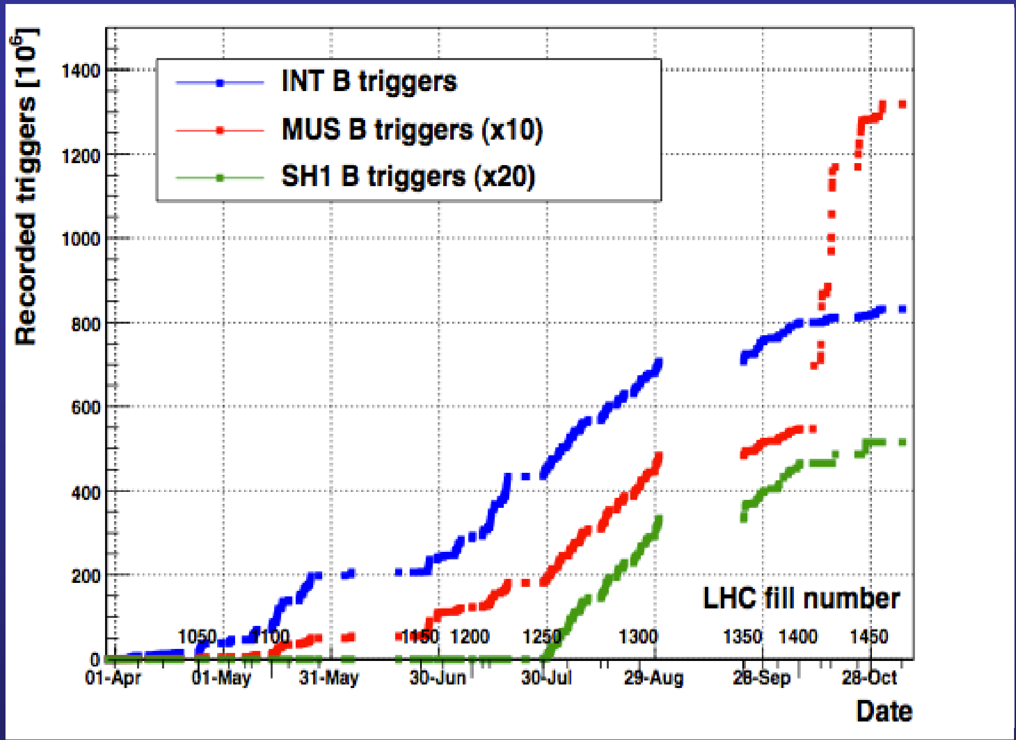




ALICE pp physics approach

- Heavy-ion comparison data
  - → e.g. yields and spectra in Pb-Pb vs "scaled pp"
- Minimum bias events at LHC energies
  - → Compare to lower energies
  - → Tune Monte Carlos for SM background
- Soft & semi-hard QCD
  - → Complementary to other LHC experiments
  - → Address issues of QCD
- Very high multiplicity pp events
  - → $dN_{ch}/d\eta$ comparable to RHIC Cu-Cu data → QGP?

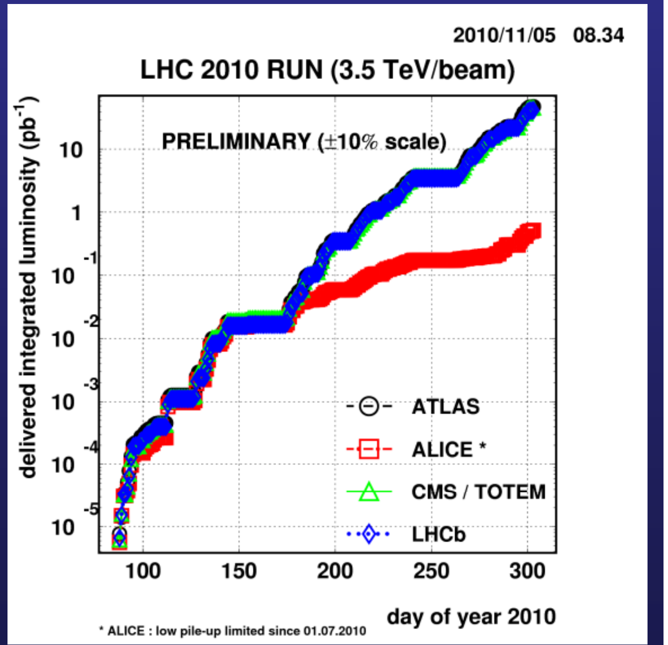
ALICE pp data sample



>100M muon triggers (MUS) (to get >2×10^4 J/ψ)

>800M MB triggers (INT)

>25M high-multiplicity triggers (SH1)



Interaction trigger reading all detectors:

SPD (min bias) or V0-A or V0-C

at least one charged particle in 8 η-units

Single-muon trigger reading MUON, SPD, V0, FMD, ZDC :

single muon, low-p_T threshold, in the muon arm in coincidence with interaction trigger

High Multiplicity trigger

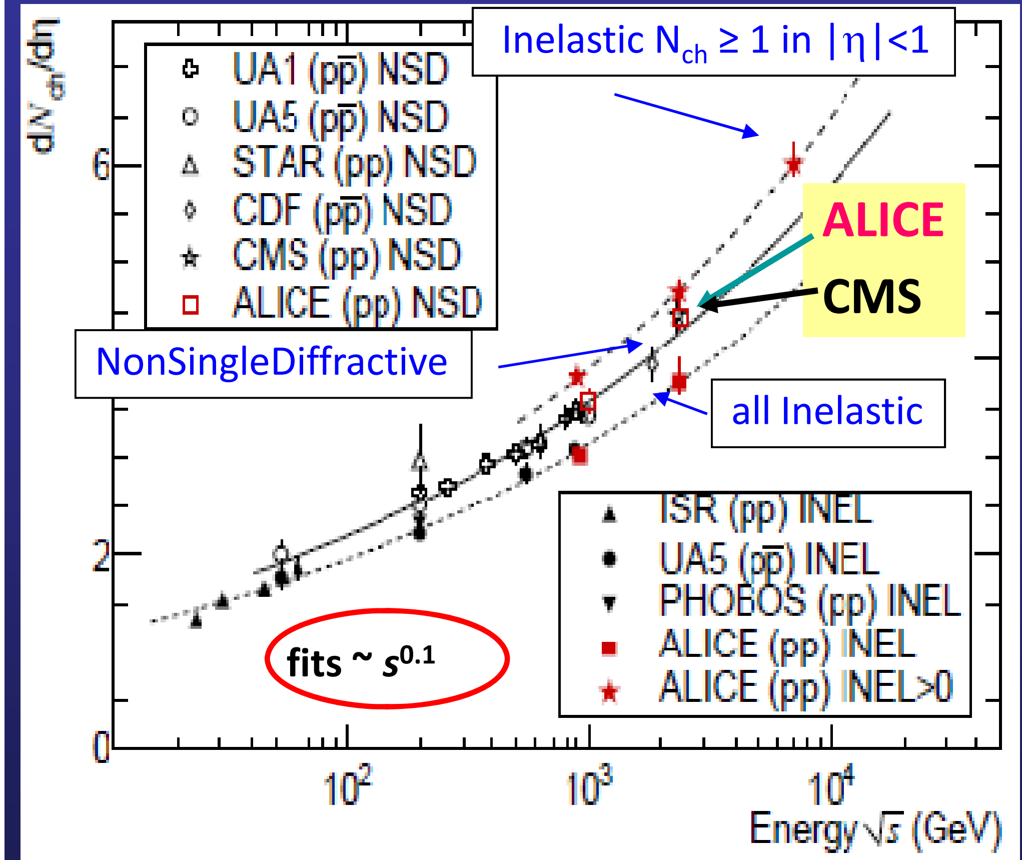
ALICE pp physics results summary

- Global Event Properties
  - N_{ch}, multiplicities & distributions
    - 0.9 TeV: EPJC 65 (2010) 111
    - 0.9 /2.36 TeV: EPJC 68 (2010) 89
    - 7 TeV: EPJC: Vol. 68 (2010) 345
  - pbar/p ratio (0.9 & 7 TeV) PRL 105 (2010) 072002
  - Momentum distributions (0.9 TeV) PLB 693 (2010) 53
- QCD issues
  - Bose-Einstein (HBT) correlations (0.9 TeV) PRD 82 (2010) 052001
- Strangeness
  - K^0_s, ϕ, Λ, Λ, $\Xi^-+\Xi^+$ (0.9 TeV) arXiv:1012.3257 (accepted by EPJC)

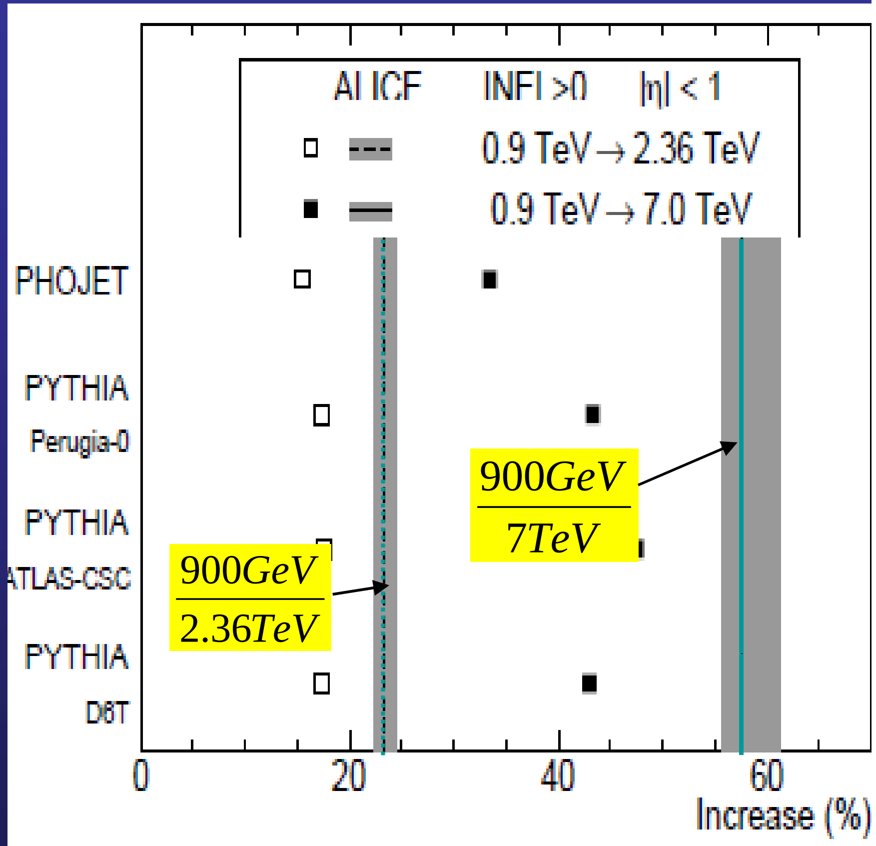
- In progress (several preliminary results available)
  - Identified particles (π,K,p) (0.9, 7 TeV) (arXiv:1101.4110)
  - HBT (7 TeV) (arXiv:1101.3665)
  - 900 GeV/7 TeV 2-particle correlations
  - Strangeness (7 TeV)
  - Heavy flavors
    - charm (D^0,D^+,D^*)
    - heavy quarks (c,b) → μ, e
    - J/ψ → μ+μ-, e+e-
  - pQCD: Event topology, underlying event, jet fragmentation

Charged multiplicity vs √s

$dN_{ch}/d\eta$ vs √s

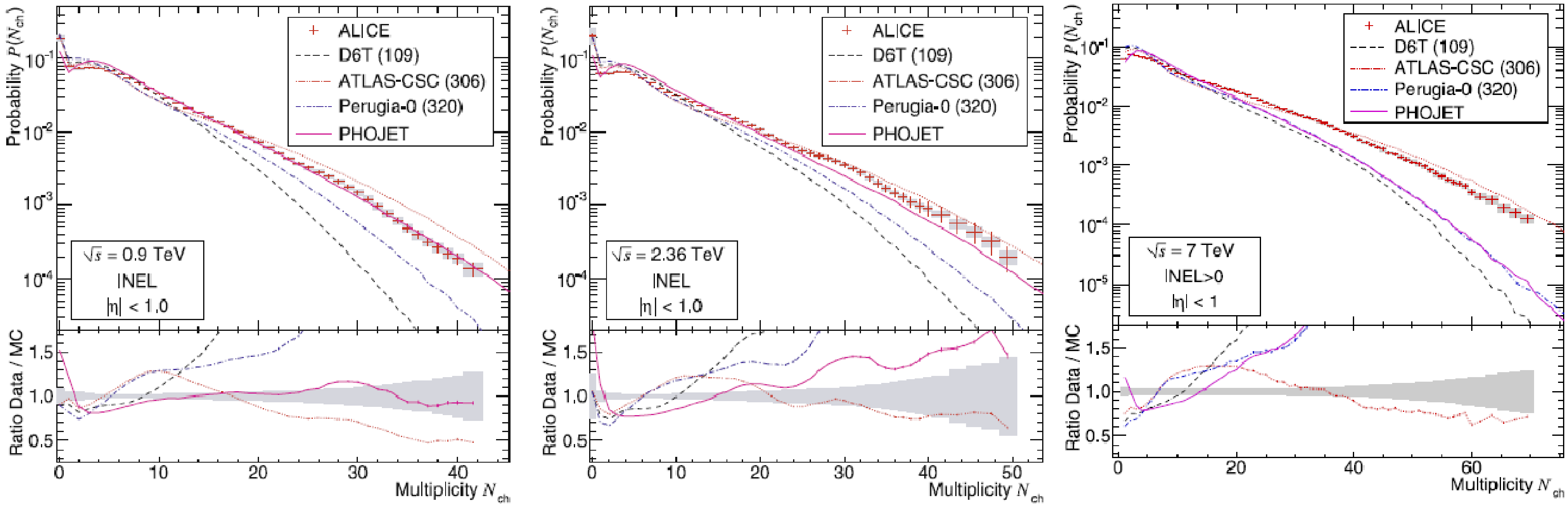


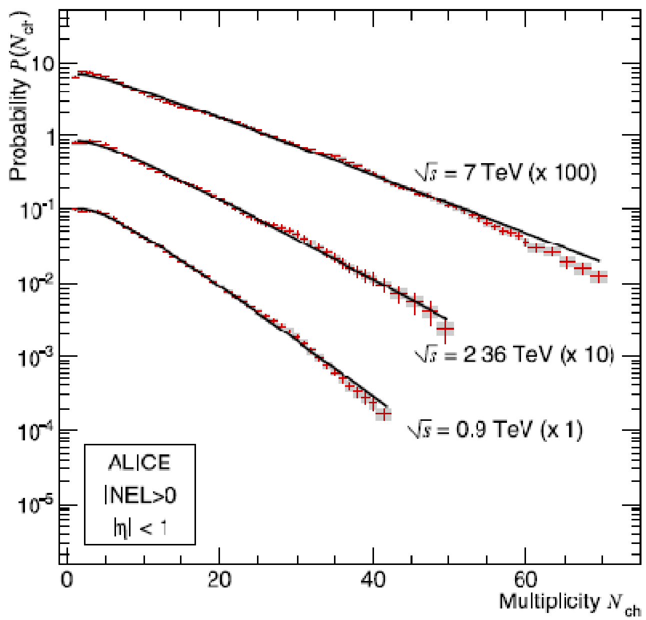
Relative increase in $dN_{ch}/d\eta$



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

Multiplicity distributions



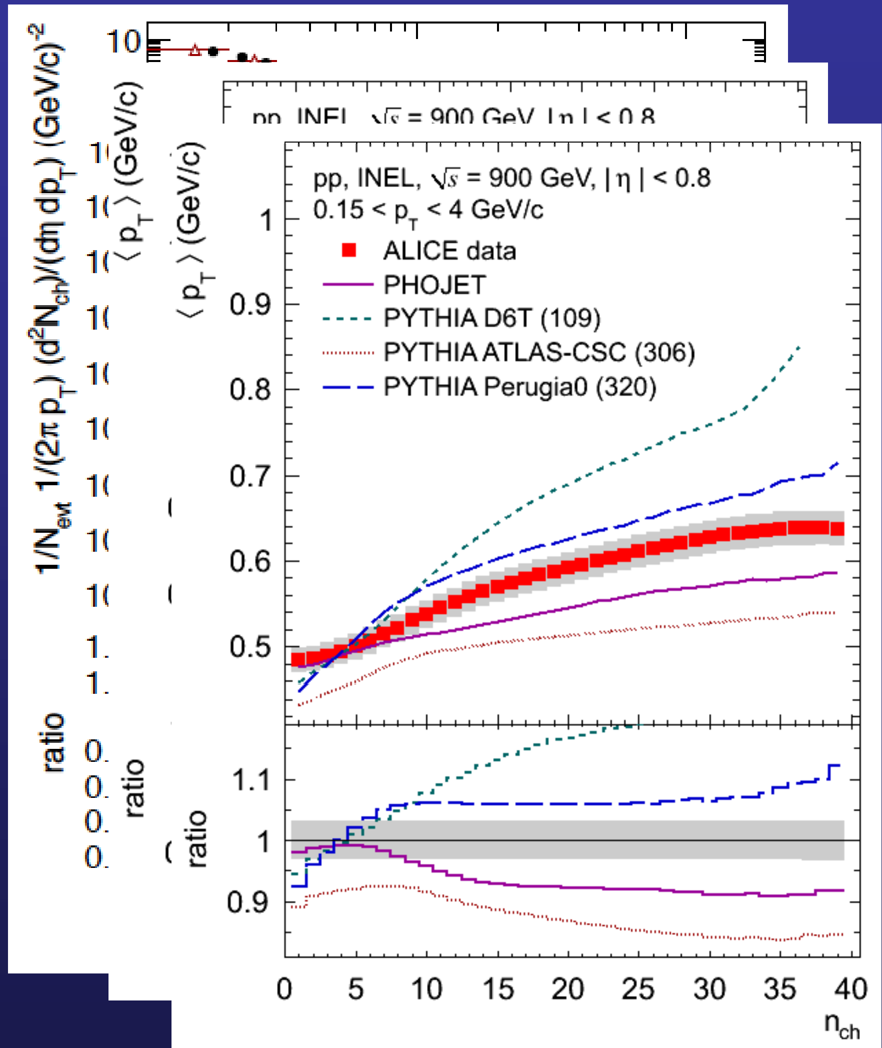


- Measured with the two inner layers of the ITS (Si pixel)
- Multiplicity distributions well described by NBD
- At 7 TeV, only the PYTHIA tune ATLAS-CSC is close to the data (at least at high multiplicity)

Transverse momentum distributions

- dN_{ch}/dp_T
  - harder towards midrapidity
  - Modified Hagedorn function fits full range
  - Exponential fits above 3 GeV/c
- $<p_T>$ vs. N_{ch}
  - Perugia-0 reproduces distribution for p_T > 0.5 GeV/c
  - But not for p_T > 0.15 GeV/c

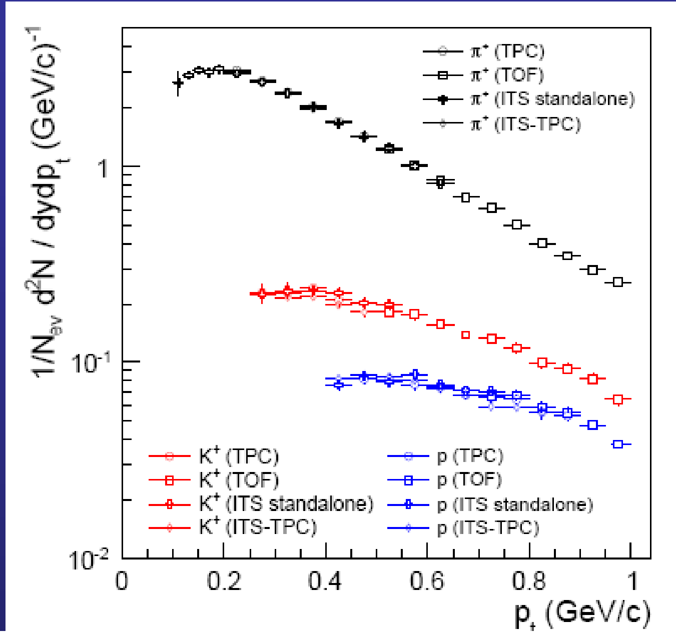
→Important to measure soft particle production (strong point of ALICE)



PLB 693(2010) 53

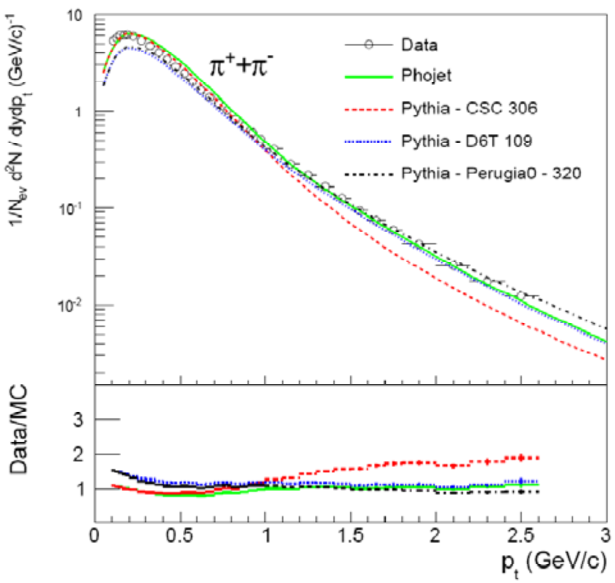
Spectra of identified particles (0.9 TeV)

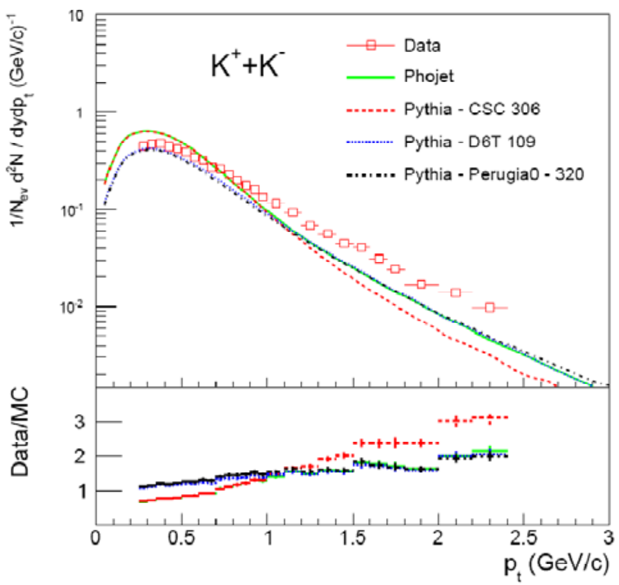
- Extract spectra from p_T = 100 MeV/c to 2.5 GeV/c

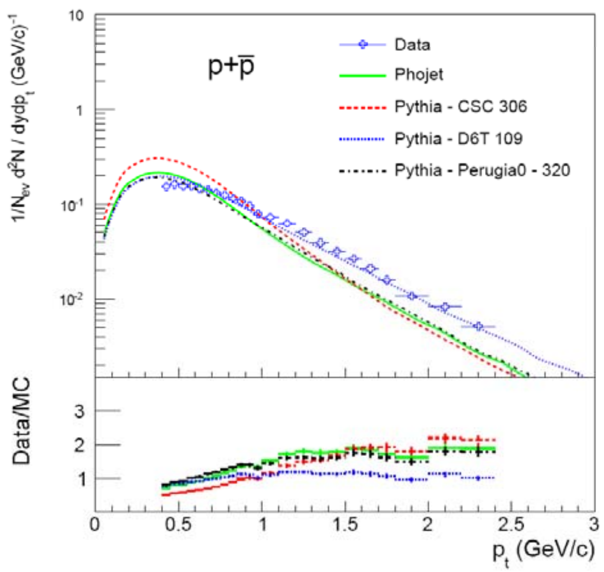


- Excellent agreement between the various PID techniques!
- Agreement in K/π with Tevatron/SppS
- Reasonable description of π spectra by PYTHIA/PHOJET, problems with K and p (except PYTHIA D6T for p)

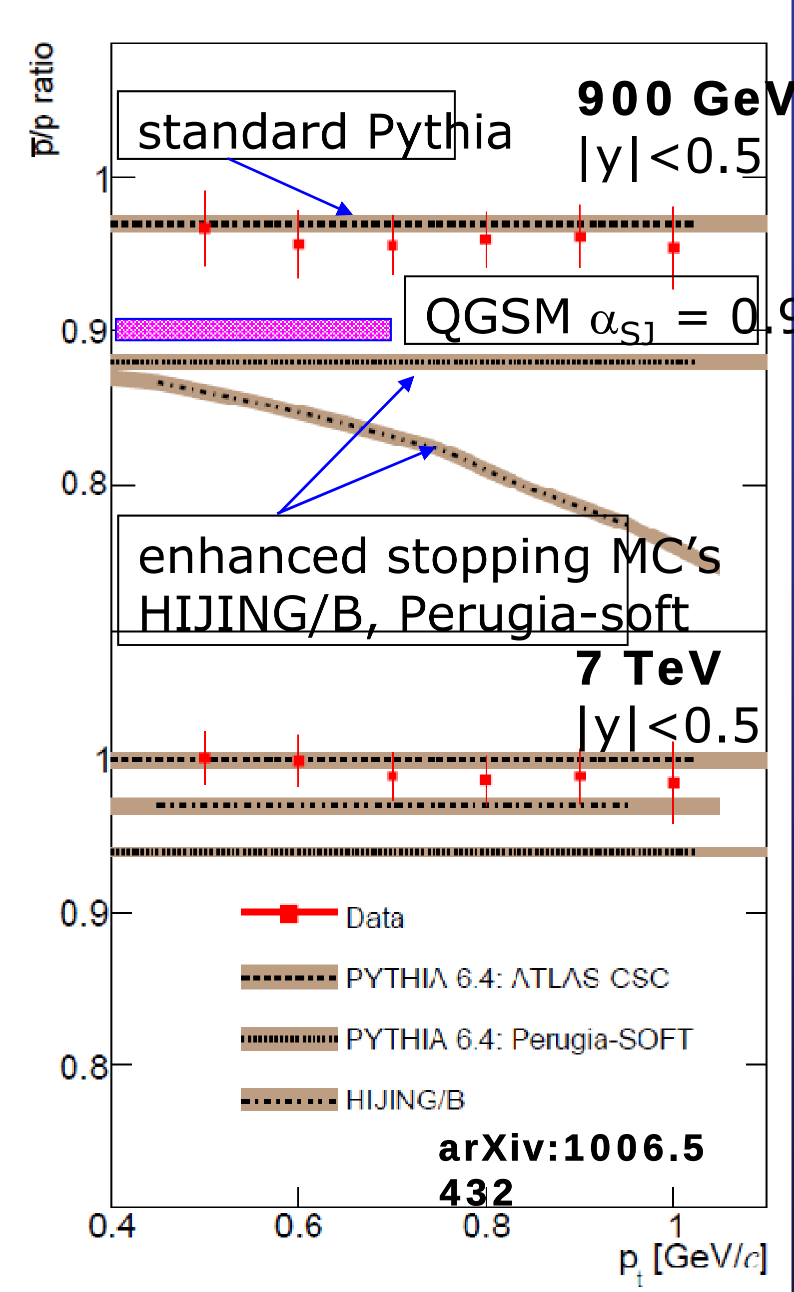
arXiv:1101.4110

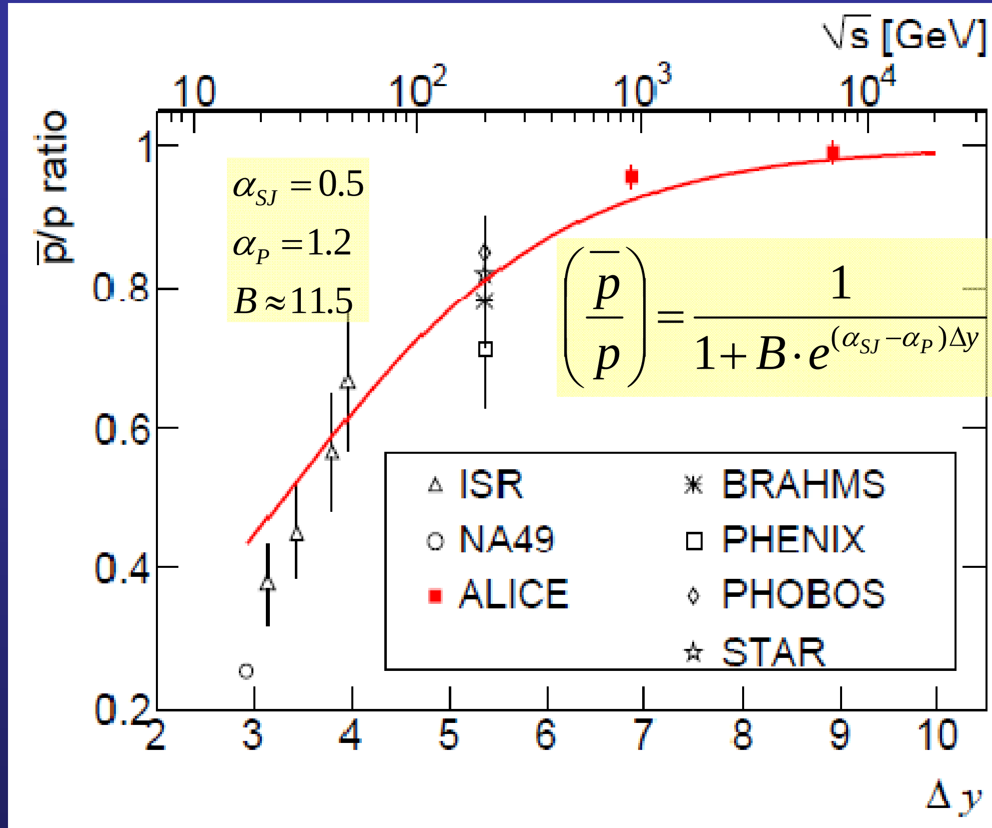






$\bar{p}$/p ratio

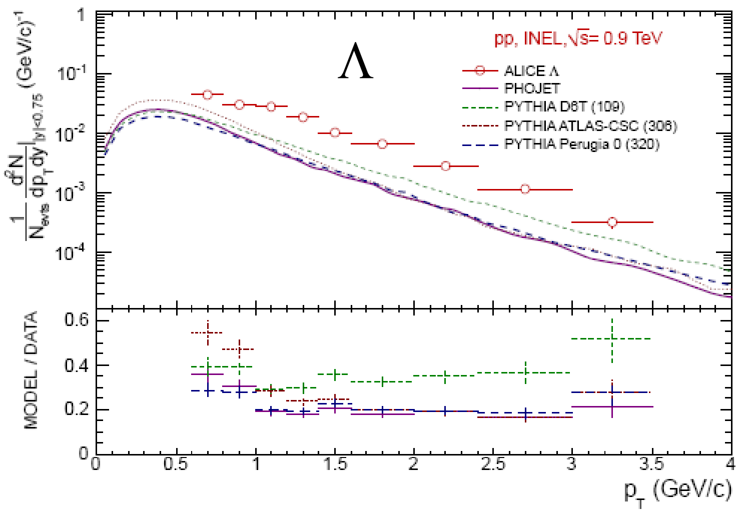


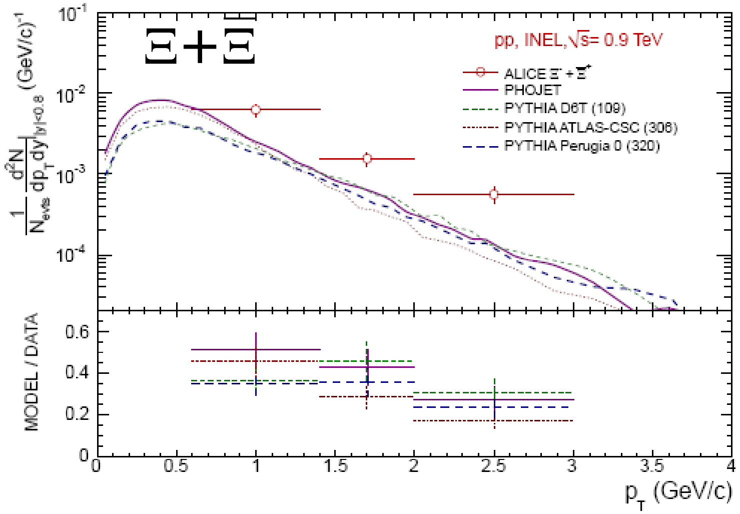


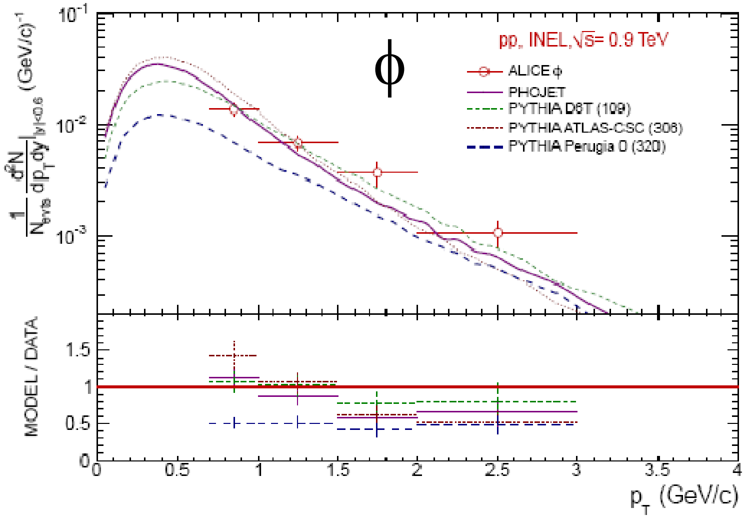
- Data well described by PYTHIA tunes
- Little room for any additional diagrams transporting baryon number over large rapidity gaps

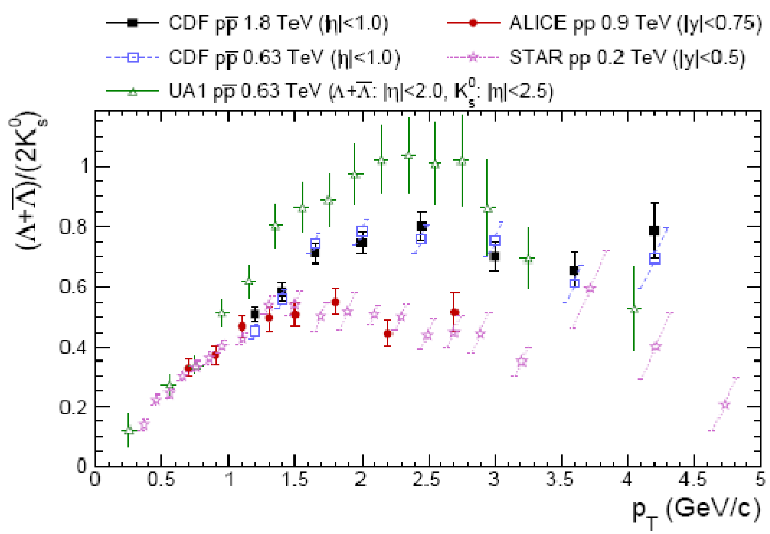
0.9 TeV: $\bar{p}$/p = 0.957±0.006(stat) ±0.014(syst)
7 TeV: $\bar{p}$/p = 0.990±0.006(stat) ±0.014(syst)

Strangeness production at 0.9 TeV







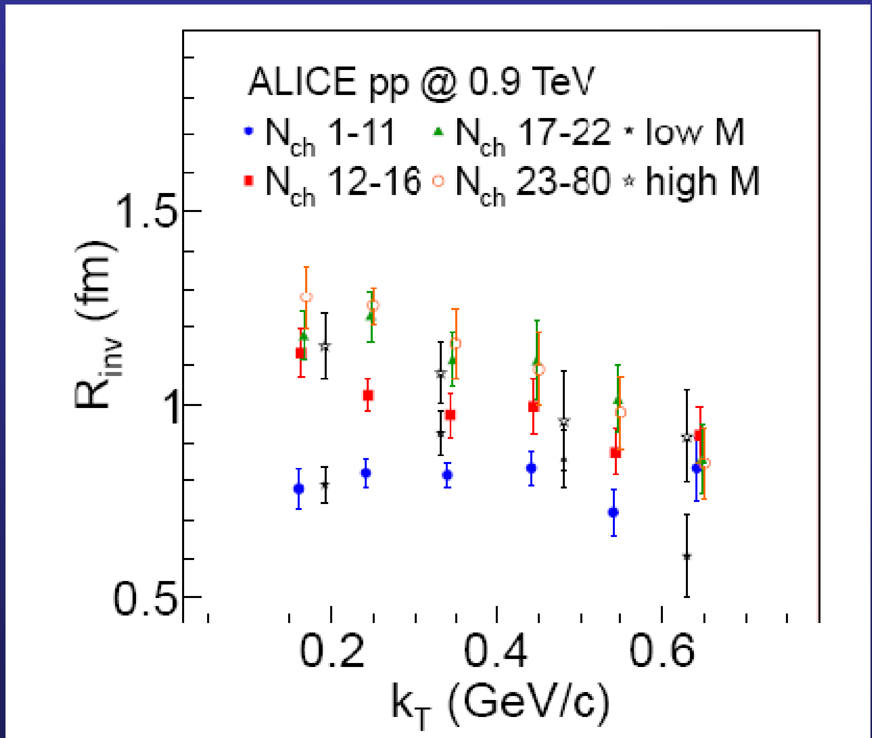


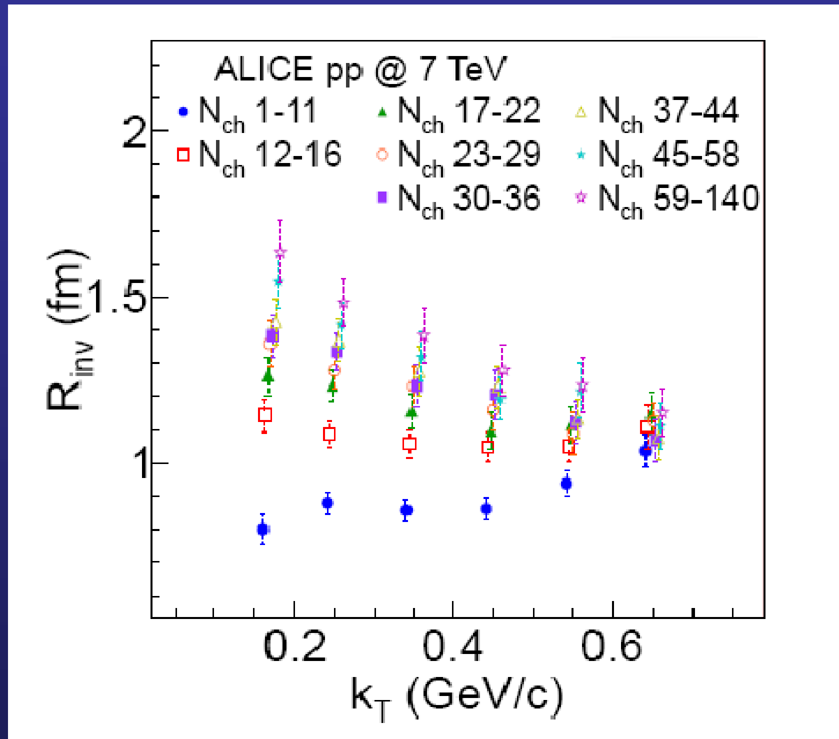
arXiv:1012.3257 (acc. by EPJC)

- Strange baryons significantly underestimated by PYTHIA/PHOJET
- Better agreement with ϕ (PYTHIA D6T, in particular)
- Baryon/meson ratio in agreement with lower energy (STAR), but lower than UA1/CDF (feed-down corrections ?)

Two-pions Bose-Einstein correlations

- Used since many years to assess the spatial scale of the particle emitting source

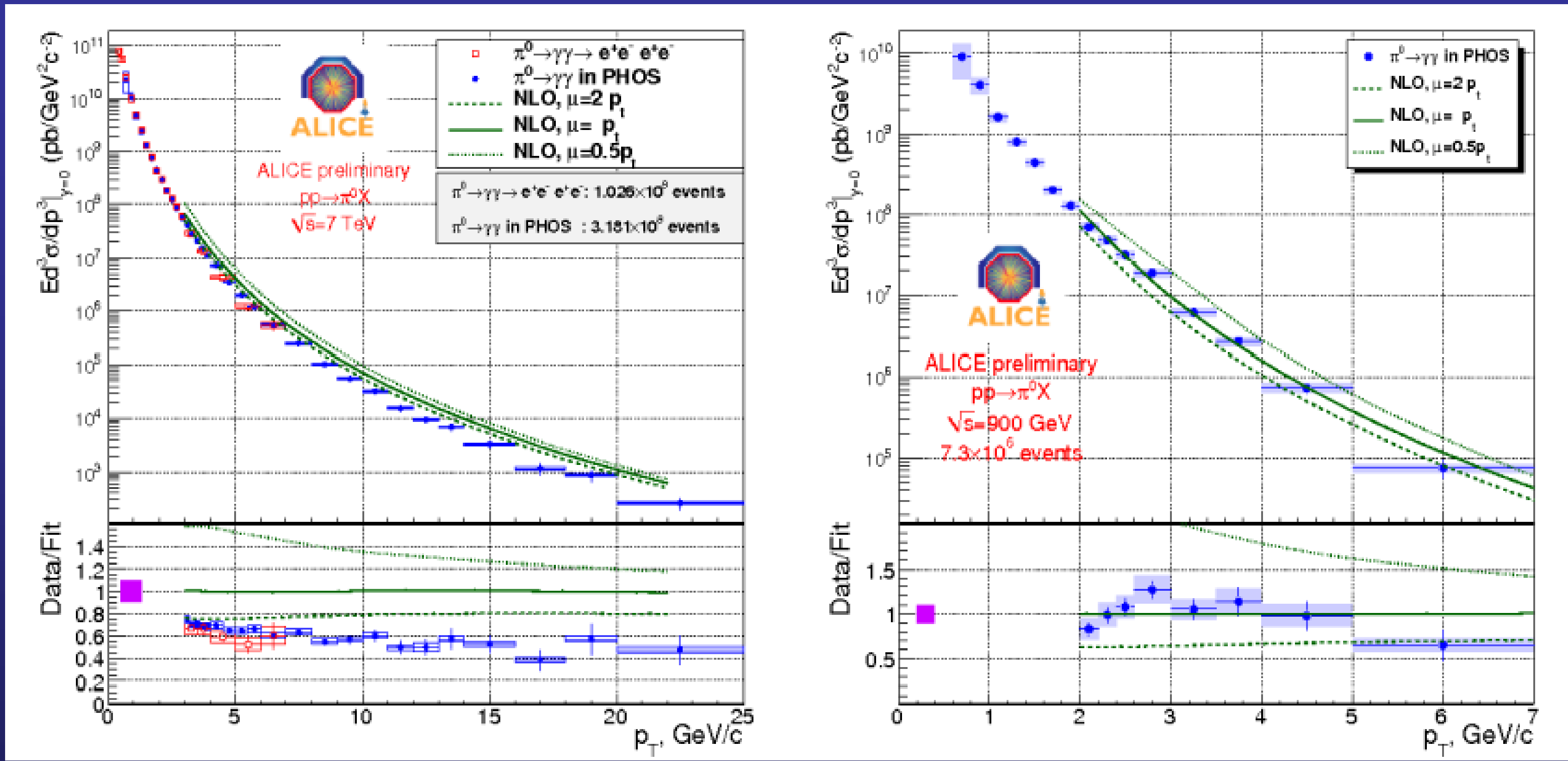




- Radii increase with hadron multiplicity
- k_T dependence develops with multiplicity, suggests a collective behaviour (feature observed in HI collisions)
- 3D analysis results (R_{long}, R_{side}, R_{out}) also available

arXiv:1101.3665

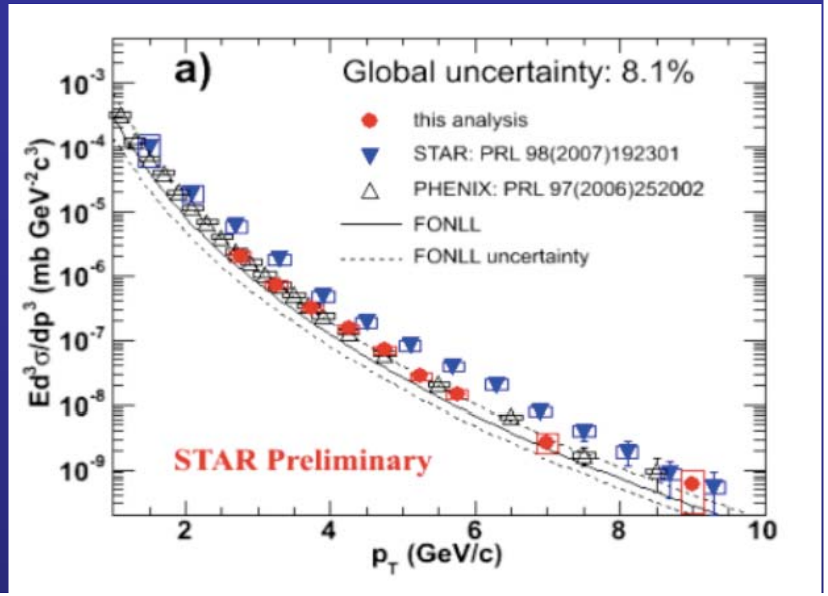
High-p_T π^0 production

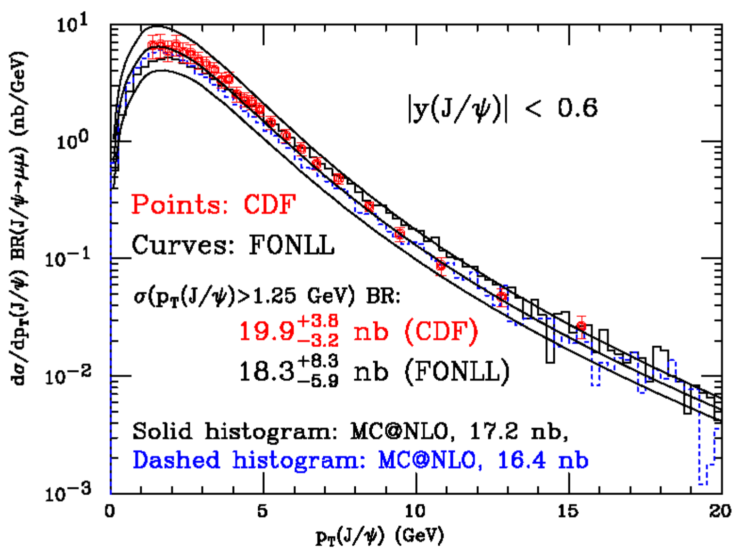


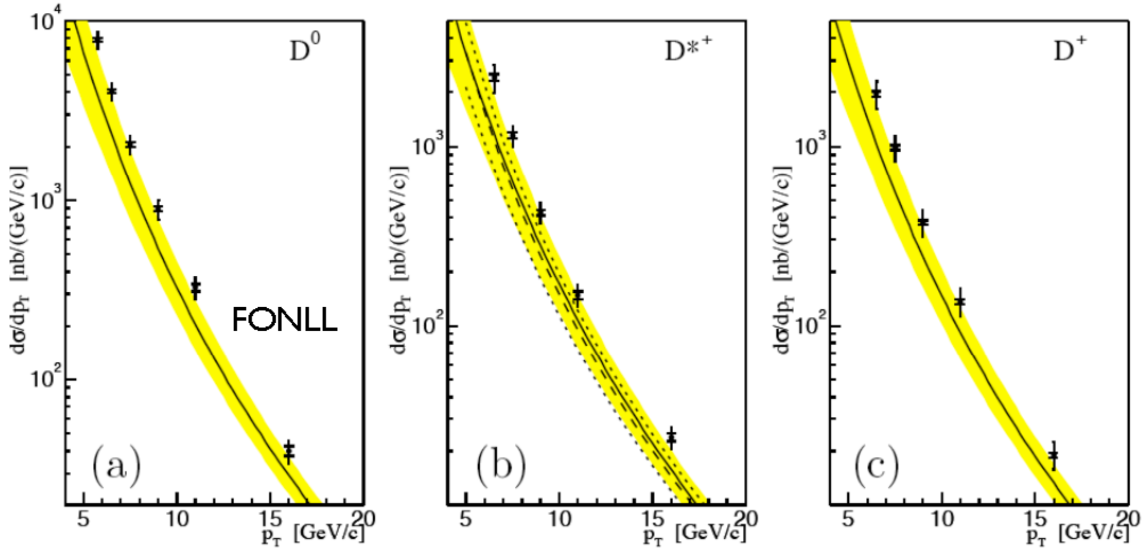
- 3 detection methods
  - in calorimeters: PHOS, EMCal
  - TPC tracking + PID: 4 conversion electrons
- complementary p_T coverage
- very different systematics (acceptance, conversion probability)
- Results in fair agreement with NLO QCD calculations

Heavy quark production

- Charm production on the upper edge of theory predictions at Tevatron and RHIC
- Beauty differential cross section at Tevatron and LHC well reproduced by pQCD calculations (used in our D-meson analysis to remove b-decay contribution)

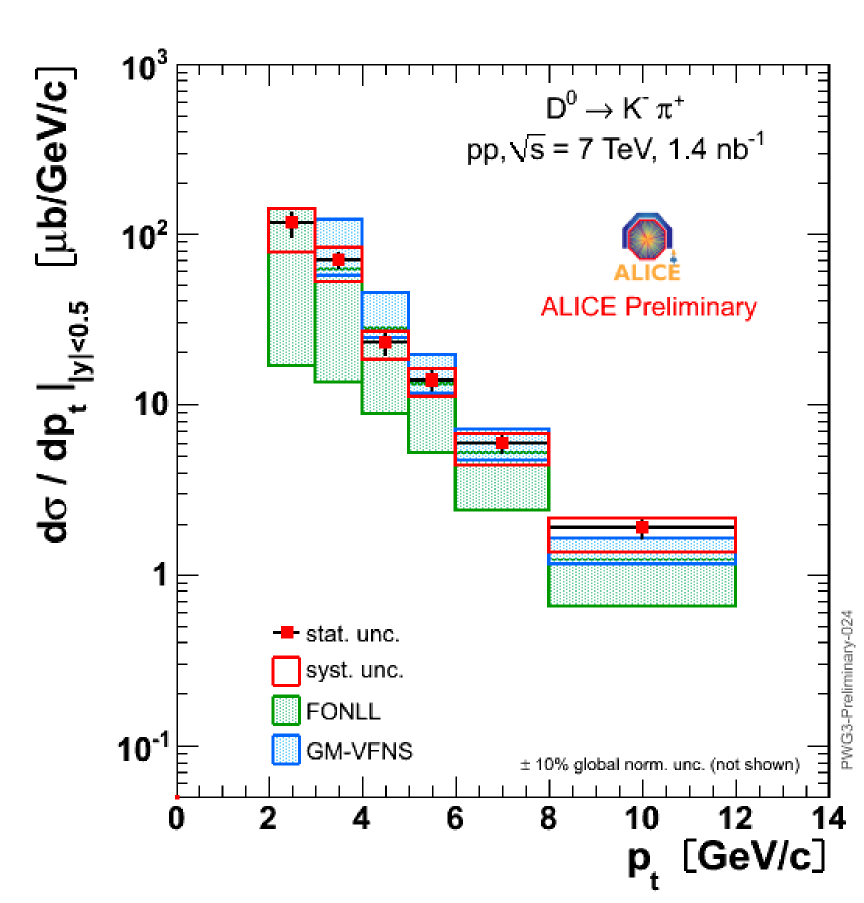


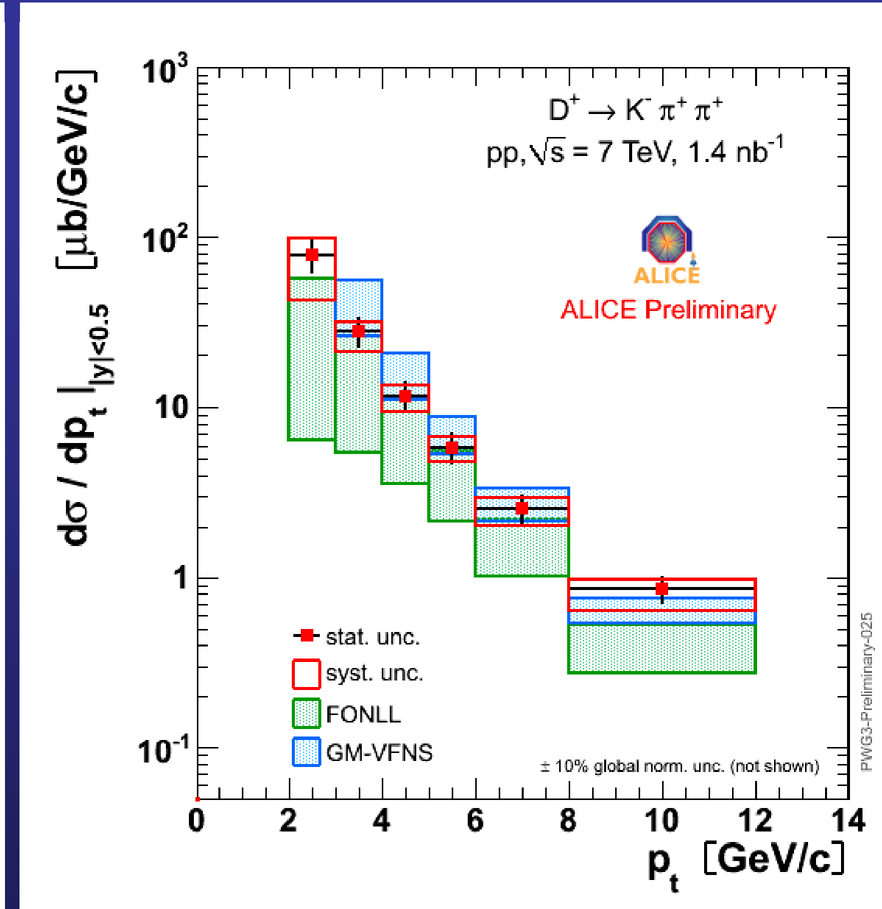




CDF: b->B->J/y **CDF RunII: c->D , PRL 91:241804 (2003)**

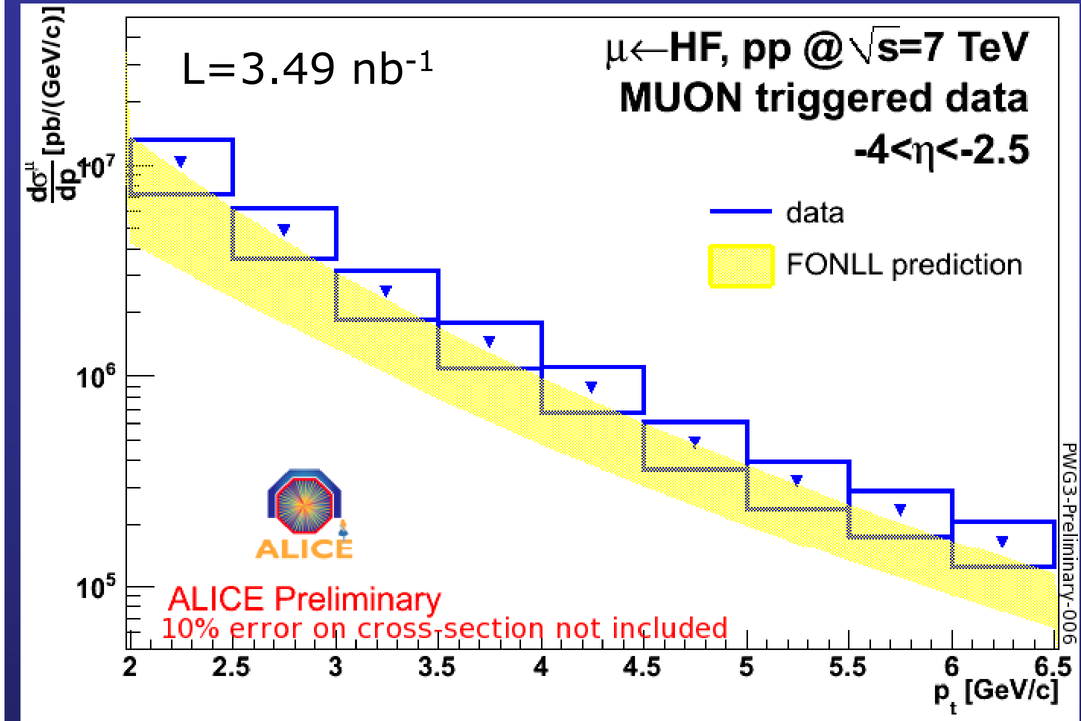
Heavy quark: (hadronic) charm



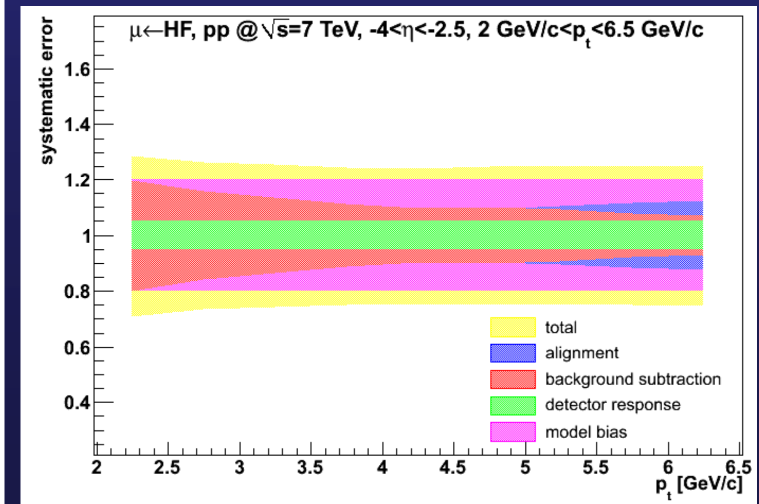


- From an integrated luminosity of 1.4 nb^{-1} (~20% of 2010 statistics)
- Measured p_t differential cross sections described by pQCD predictions (FONLL and GM-VFNS)
- Many other channels (and decay modes) under study!

Heavy quark: single muons

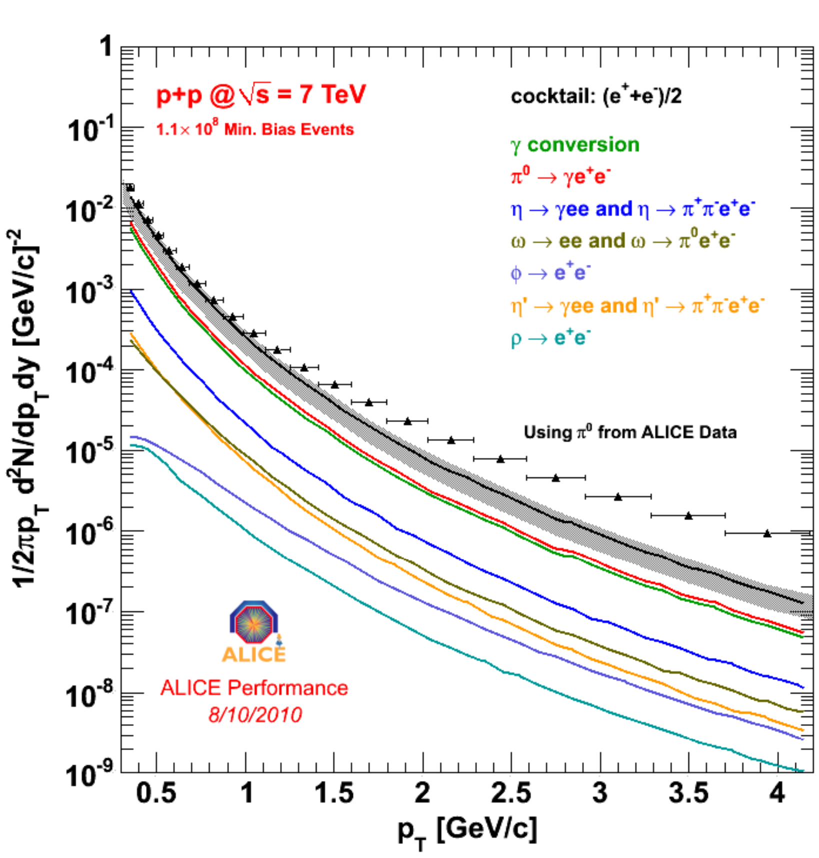


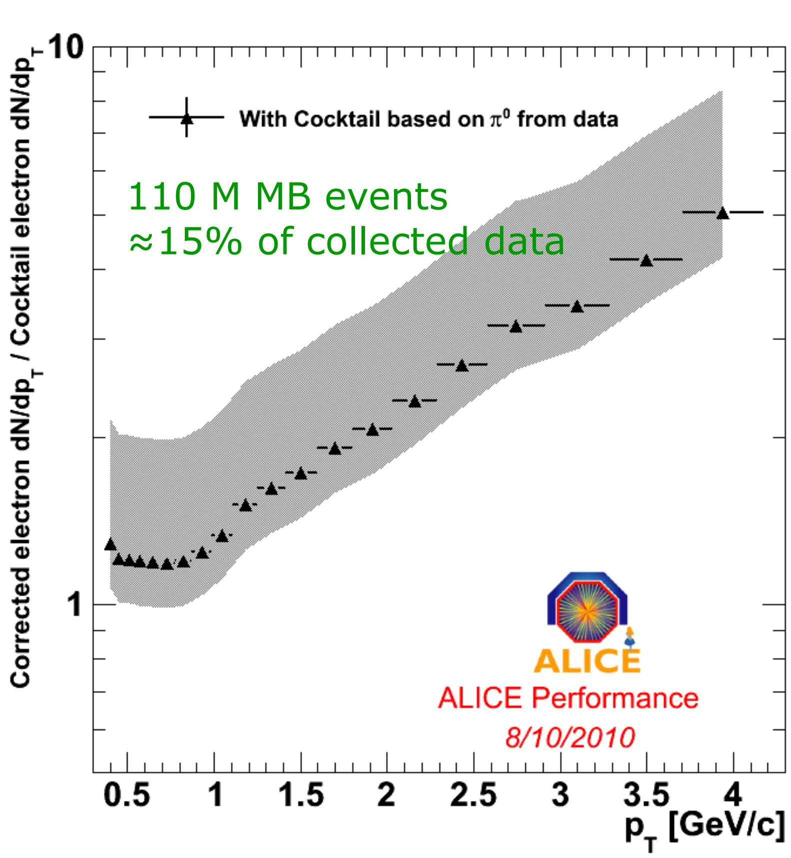
- p_T differential cross section for muons from B and D decays ($2.0<p_T<6.5$ GeV/c)
- Agreement with FONLL within errors
- Coverage can be extended up to 20 GeV/c
  - → Statistics
  - → Alignment



- Systematic errors
- Background from π, K decays ~20% (PYTHIA tunes + uncert. on secondary yield)
- Efficiency correction ~5% (MC detector response and choice of input distributions)

Heavy quark: single electrons

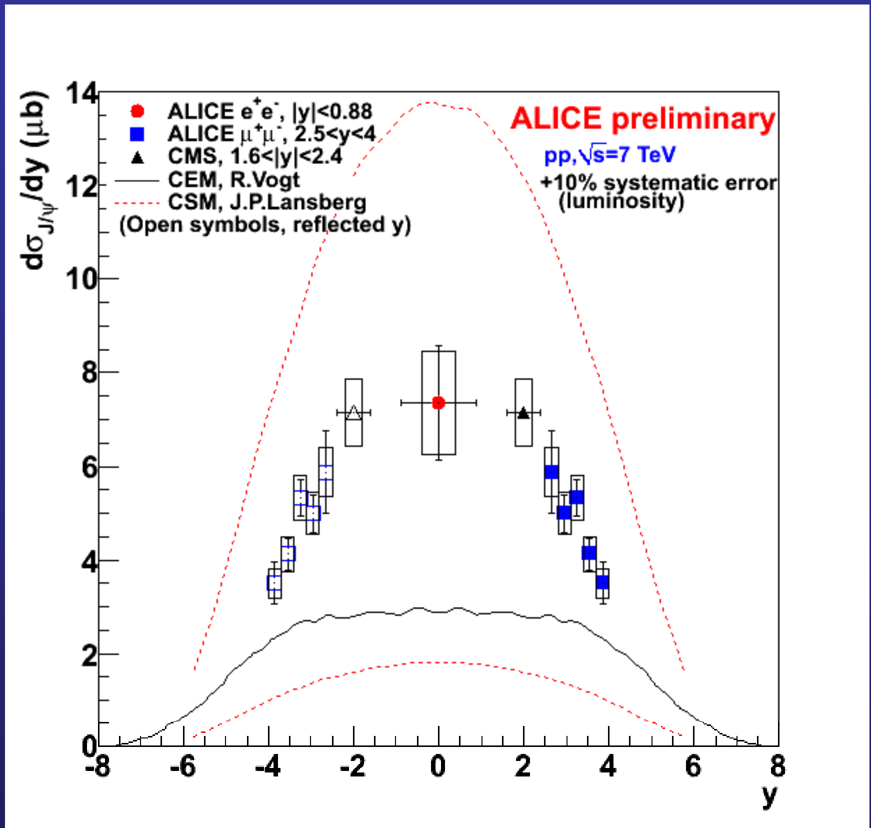


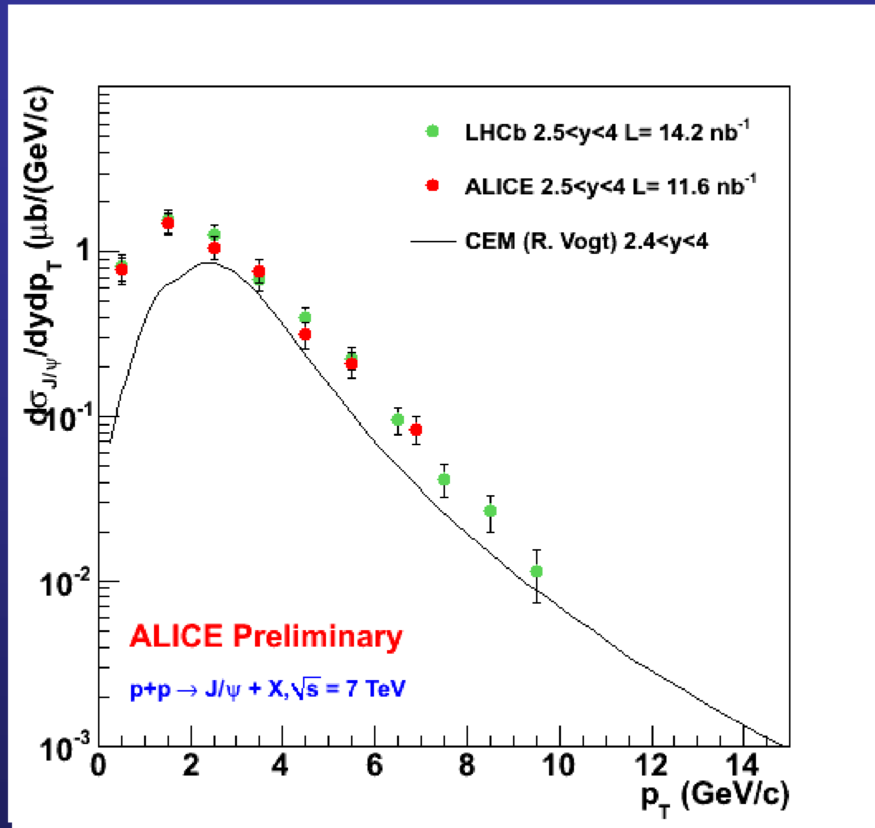


- Cocktail ingredients:
  - Dalitz decay of neutral pions from measured π^0 spectrum
  - Heavier mesons (η, η', ρ, ω, ϕ) implemented via m_T scaling
  - Photon conversion (in beam pipe and innermost ITS layer)
- Excess of electrons wrt the cocktail comes from charm and beauty (+ J/ψ and direct radiation)

J/ψ production

- Heavy quarkonium: still an open field for theory!





- Inclusive J/ψ cross section measured in a broad rapidity range
- Agreement with LHCb on $d\sigma/dp_T$ (2.5<y<4)
- Total syst. error: 18% e^+e^-, 13.5% $\mu^+\mu^-$
- Model calculations
  - CEM prompt J/ψ, R.Vogt (PRC81(2010)044903)
  - CSM LO direct J/ψ, J.P. Lansberg (arXiv:1006.2750)
  - CMS points: integral of $d^2\sigma/dydp_T$ for 1.6<|y|<2.4 (arXiv:1011.4193)

Conclusions and perspectives

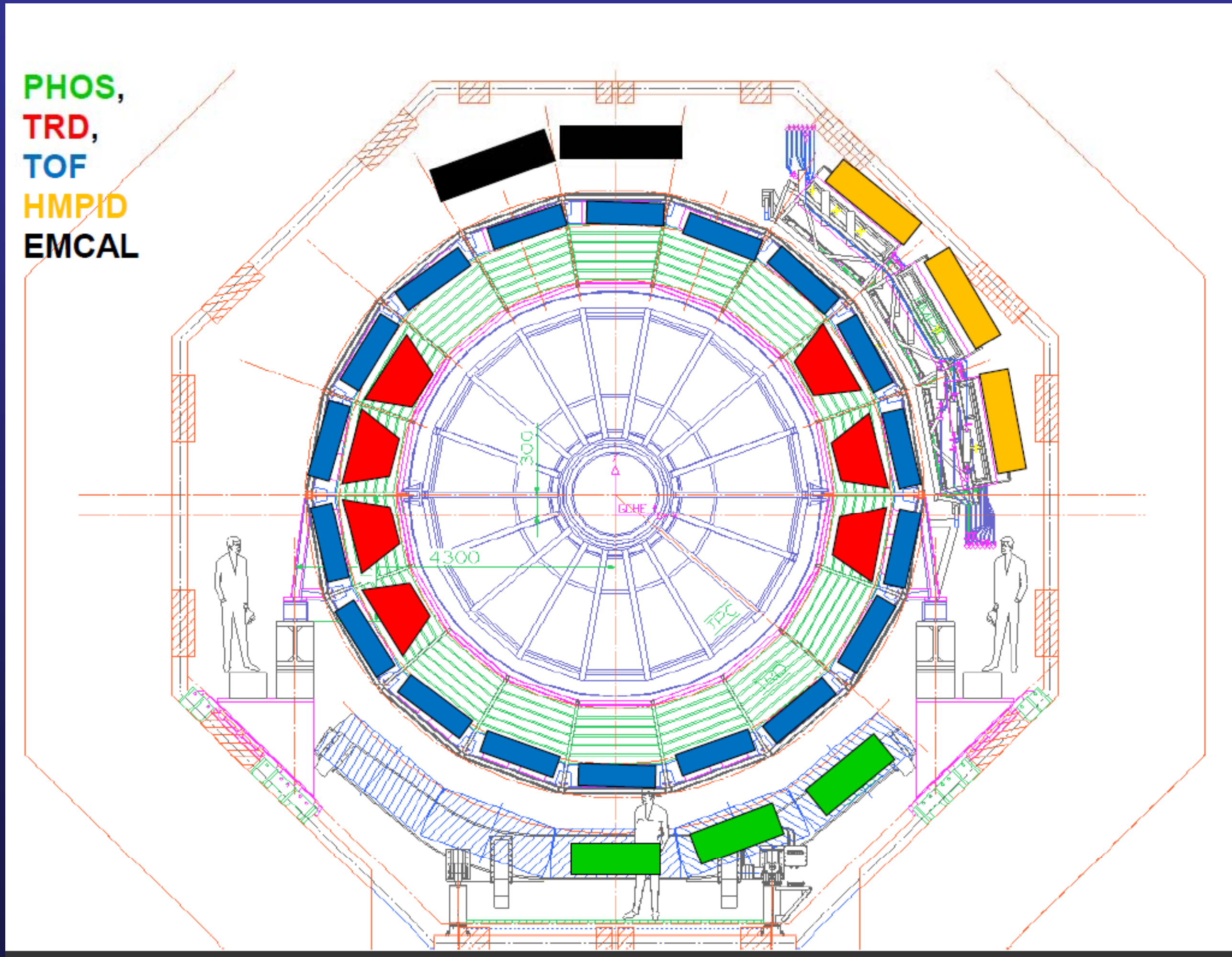
- 2010 has been a memorable year for ALICE !
- Excellent performance of the detector, data analysis has smoothly and quickly delivered the first physics results
- 12 physics papers published so far, many more in the pipeline

- 2011 LHC run about to start
- p-p (short) run at $\sqrt{s}$=2.76 TeV
  → Essential as a reference for heavy-ion results (see Dainese's talk)
- Long run at $\sqrt{s}$ = 7 TeV
  - Mix of low (MB physics) and high (rare triggers) luminosity

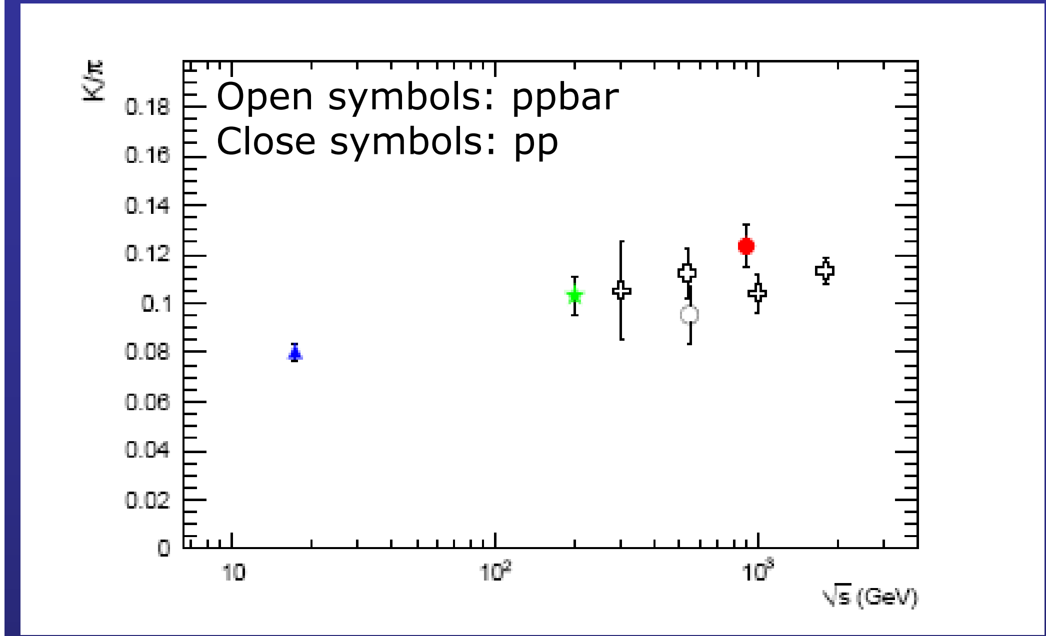
Backup

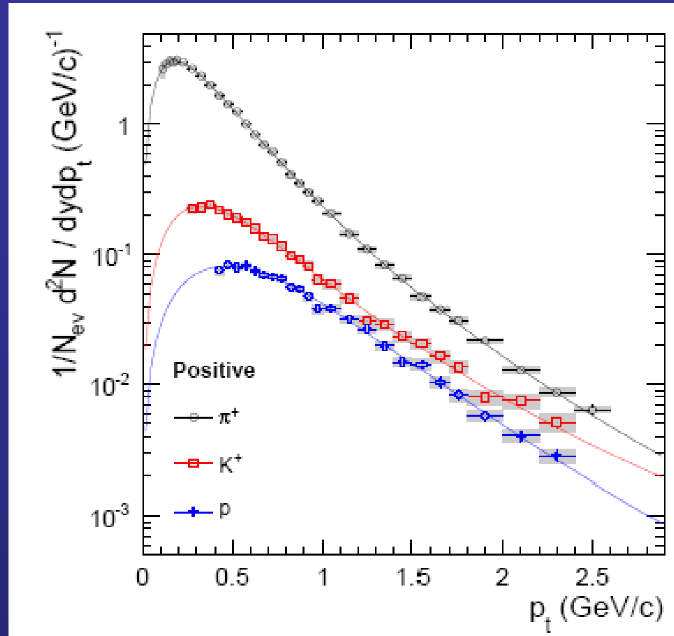
2010 data taking: detector configuration

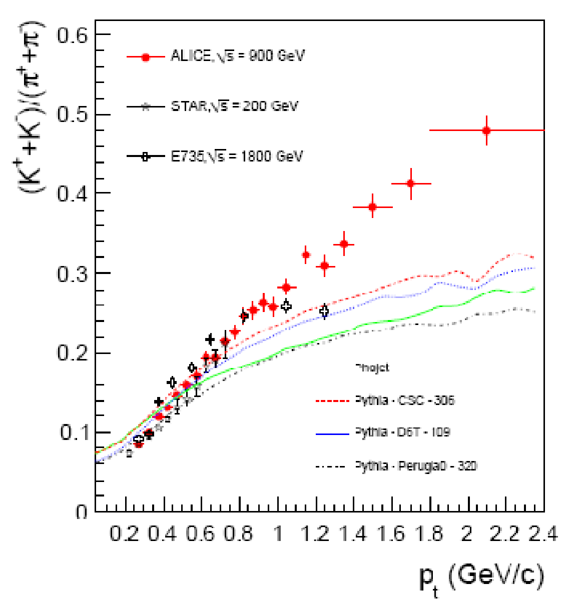
- ITS, TPC, TOF, HMPID, MUON, V0, To, FMD, PMD, ZDC (100%)
- TRD (7/18)
- EMCAL (4/10)
- PHOS (3/5)
- HLT (60%)

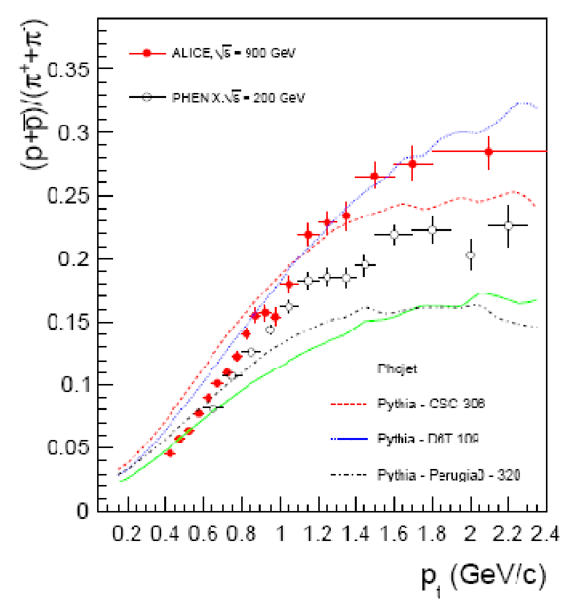


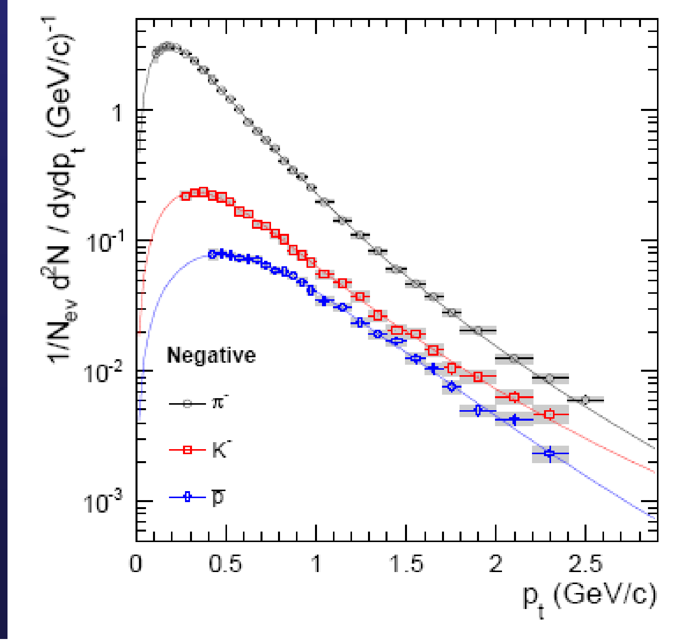
Identified particle spectra



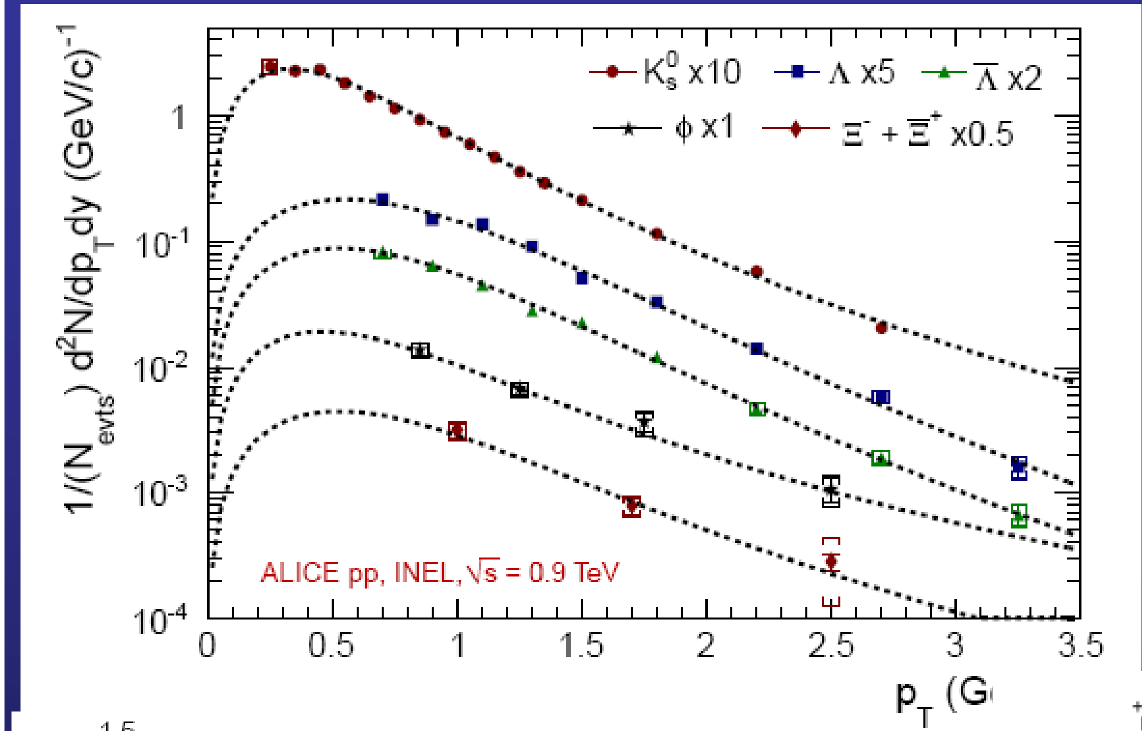








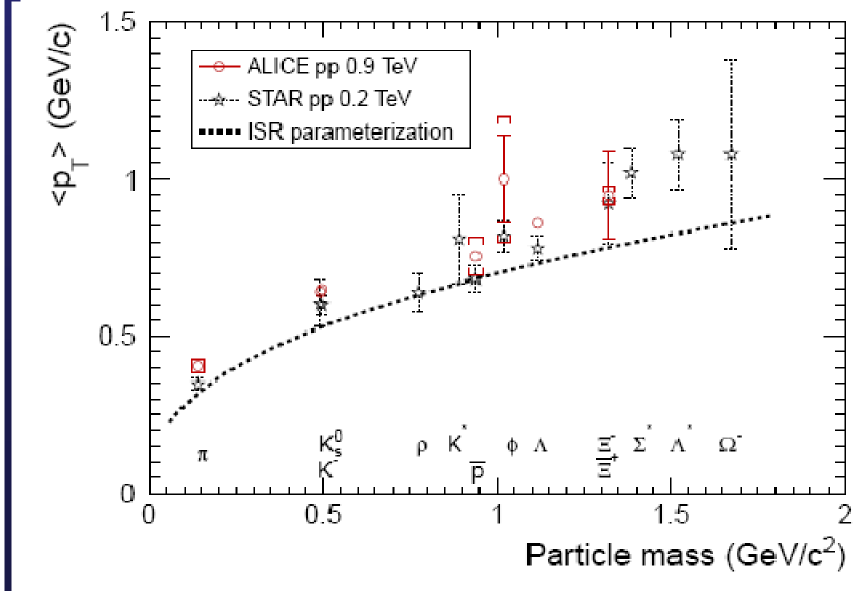
More on strangeness

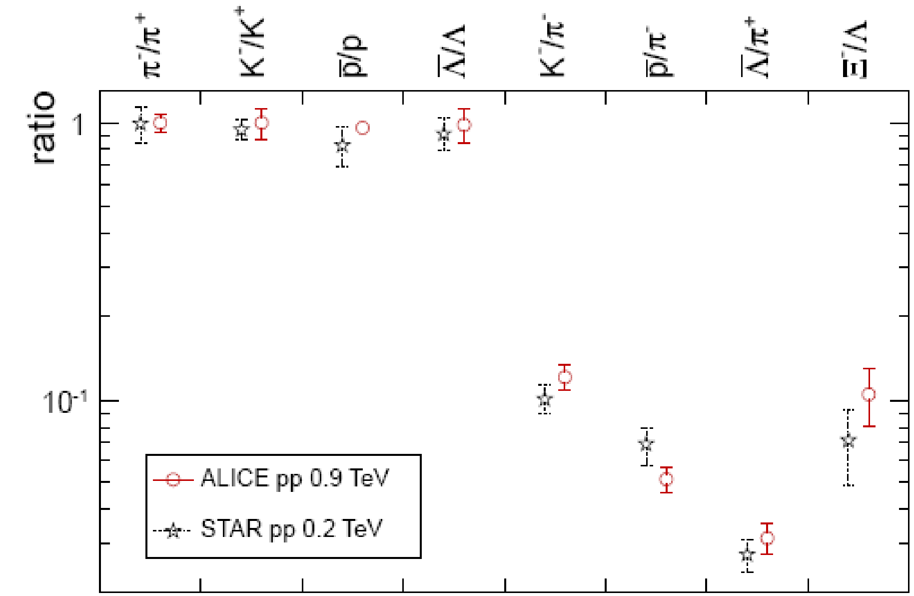


Inverse slope increases with mass

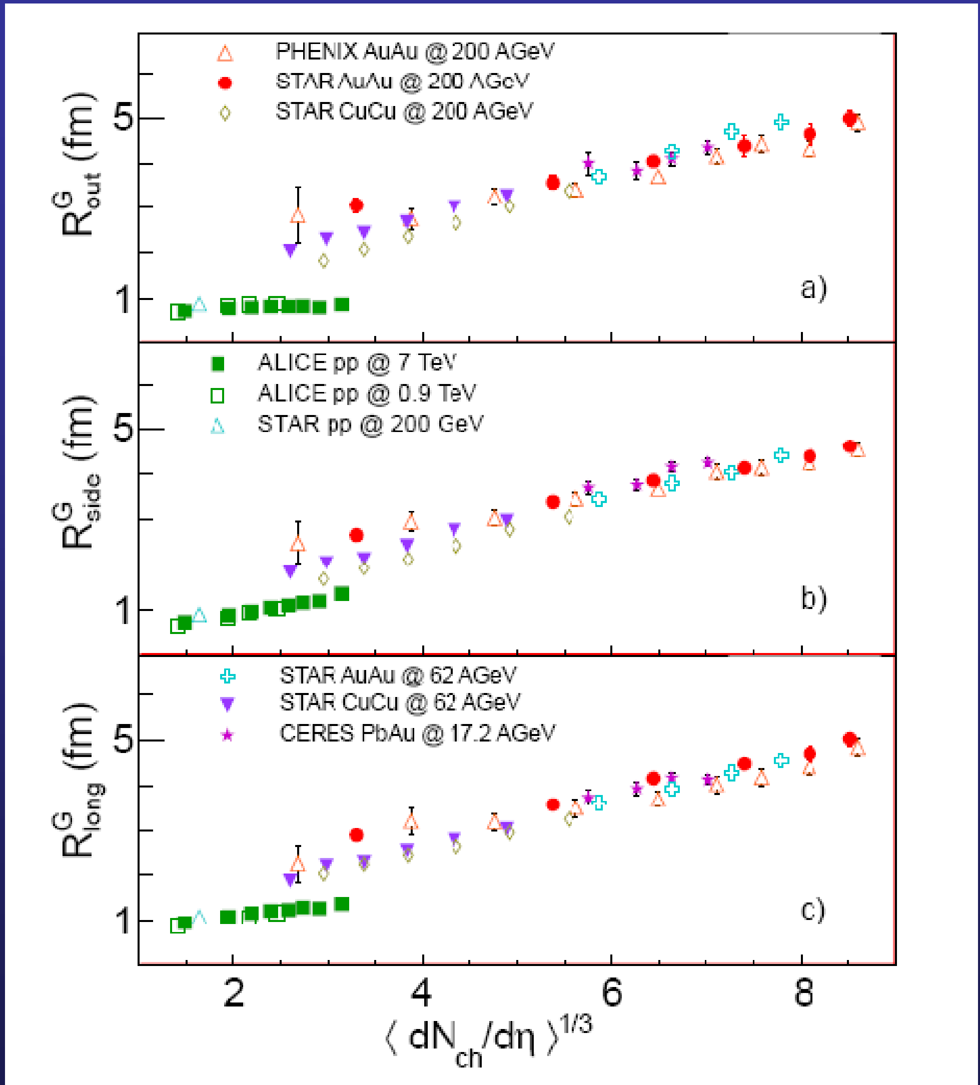
Ξs do not follow this trend (limited statistics?)

$<p_T>$ has almost no increase over a factor 36 in √s (ISR→LHC)



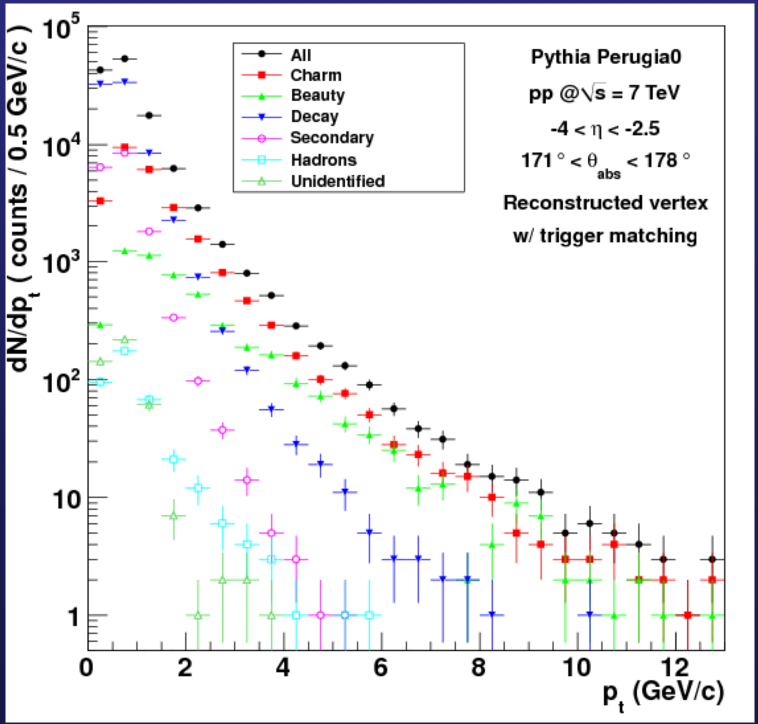


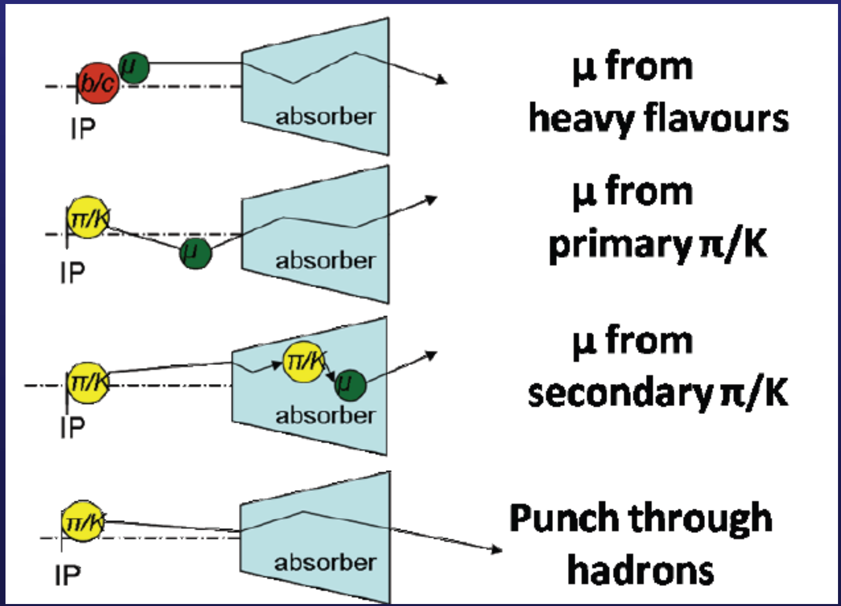
Still on HBT radii



Increase with multiplicity
both in p-p and A-A, but different
features

- Analysis strategy
  - Require muon trigger signal to remove hadrons and low p_t secondary muons
  - Remove residual decay muons by subtracting MC dN/dp_t normalized to data at low p_t
    - Alternative method: use muon distance-of-closest-approach to primary vertex
    - What is left are muons from charm and beauty
  - Apply efficiency corrections





D meson reconstruction

- Analysis strategy: invariant-mass analysis of fully-reconstructed topologies originating from displaced vertices
  - Build pairs/triplets/quadruplets of tracks with correct combination of charge signs and large impact parameters
  - Particle identification from TPC and TOF to reject background (at low pt)
  - Calculate the vertex (DCA point) of the decay tracks
  - Require good pointing of reconstructed D momentum to the primary vertex

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

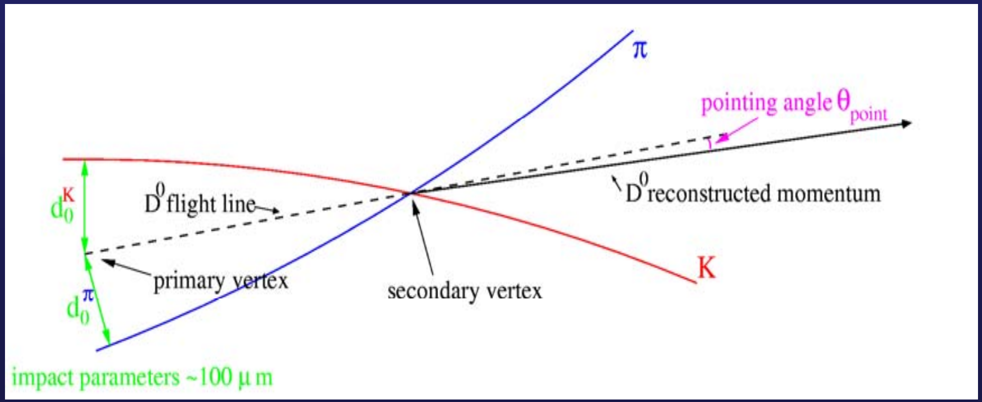
$D^+ \rightarrow K^-\pi^+\pi^+$

$D^{*+} \rightarrow D^0\pi^+$

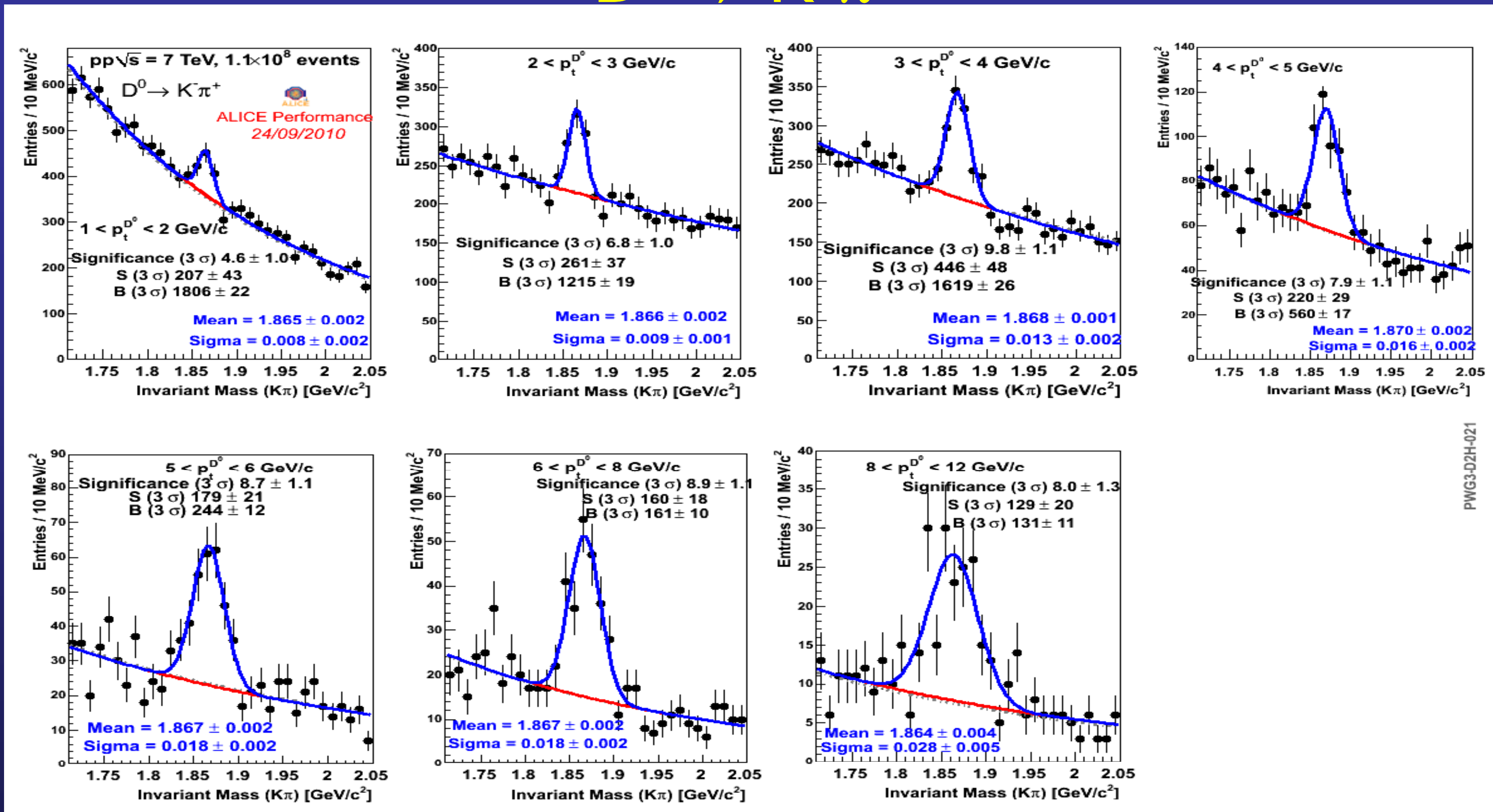
$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$

$D_s \rightarrow K^-K^+\pi^+$

$\Lambda_c^{\ +} \rightarrow pK^-\pi^+$

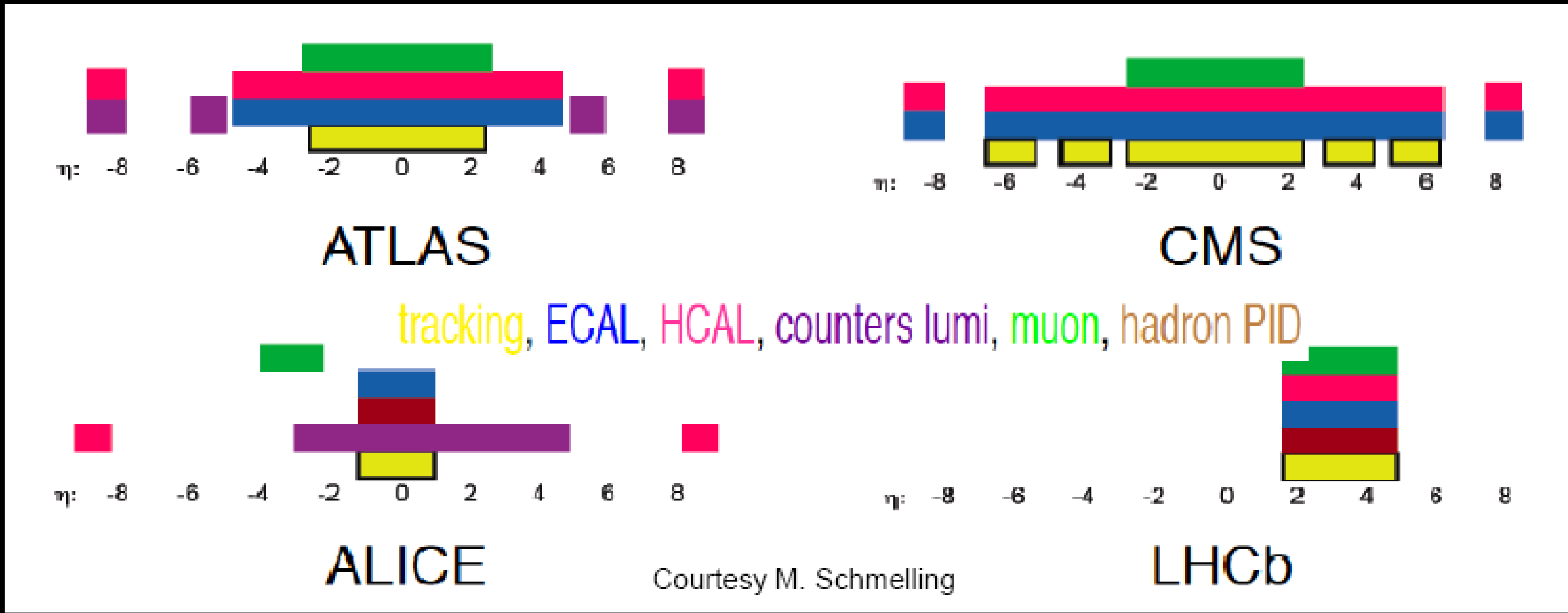


$D^0 \rightarrow K^- \pi^+$



- Signals from 10^8 events
  - 7 p_t bins in the range $1<p_t<12$ GeV/c
- Selection based mainly on cosine of pointing angle and product of track impact parameters ($d_0^K \times d_0^\pi$)

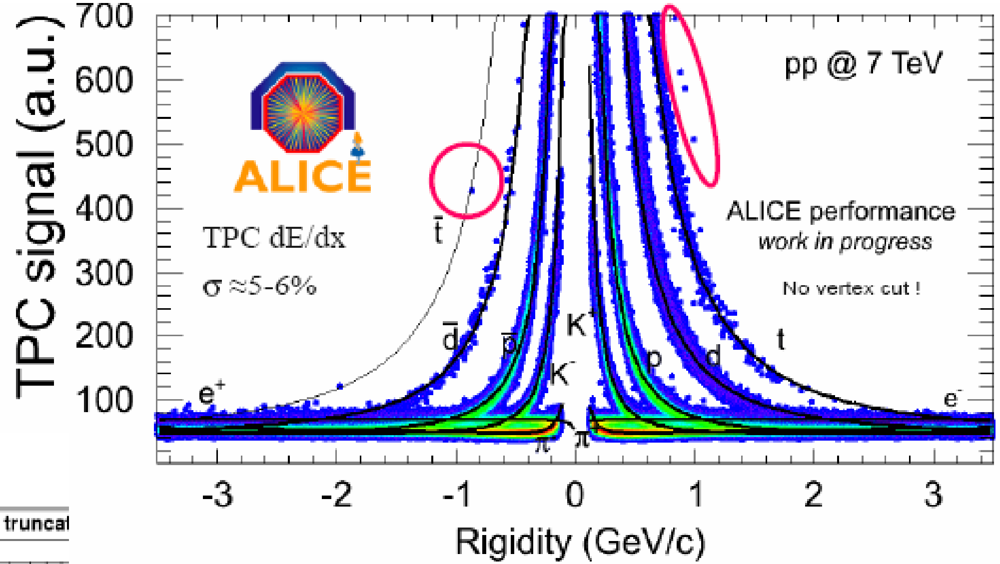
Angular Acceptance of LHC Experiments

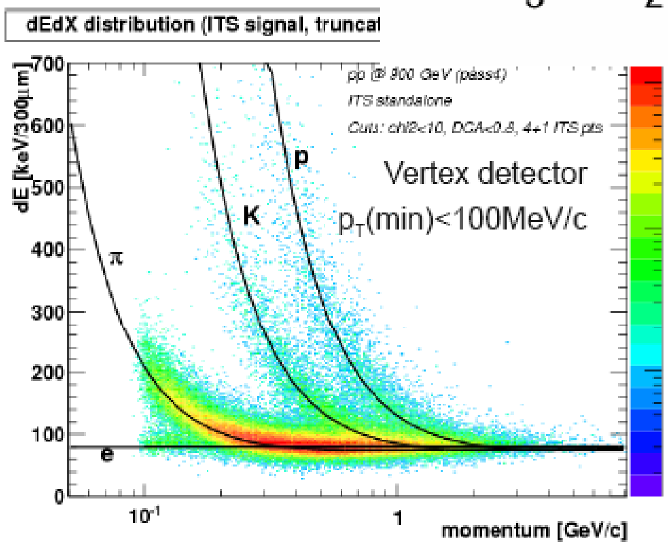


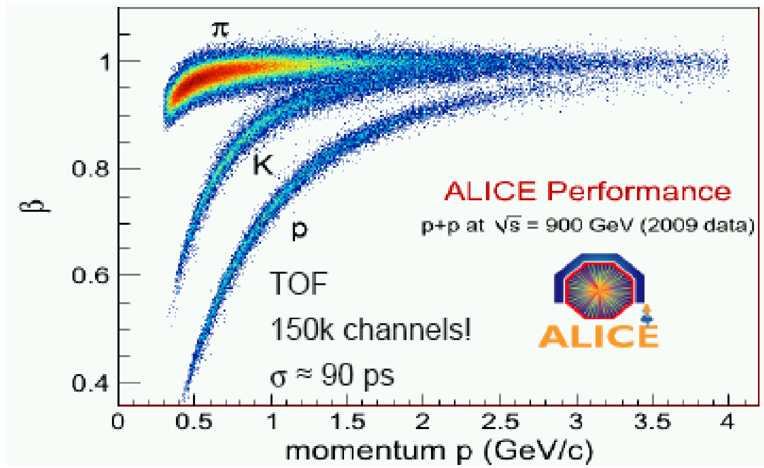
Complementary measurements

- **ATLAS, CMS: Large acceptance for charged hadrons, leptons and neutral energy**
- **Hadron PID ALICE |η| < 1 and LHCb 2 < η < 5**
- **ALICE/LHCb: Full tracking down to very low p_T (100 MeV)**
- **ATLAS, CMS also reach low p_T with vertex detectors**
- **ALICE: FAST-OR Pixel multiplicity trigger**

PID (ITS, TPC, TOF)







MonteCarlo scoreboard

	variable/tune	D6T	Perugia0	CSC	PHOJET
900 GeV	$dN_{ch}/d\eta$	-20%	-17%	+3%	-2%
	N_{ch}	$N_{ch}>10$	$N_{ch}>5$	$N_{ch}>15$	$N_{ch}>10$
	p_T		$p_T > 4$ GeV/c	$p_T > 1$ GeV/c	$p_T > 1$ GeV/c
	$\langle p_T \rangle$				$p_T > 1$ GeV/c
	$K^0_S, \Lambda, \bar{\Lambda}$				
	φ				
2.36 TeV	$dN_{ch}/d\eta$	-24%	-21%	-2%	-8%
	N_{ch}	$N_{ch}>10$	$N_{ch}>5$	$N_{ch}>20$	$N_{ch}>15$
7 TeV	$dN_{ch}/d\eta$	-27%	-24%	-4%	-17%
	N_{ch}			$N_{ch}>30$	

MC <<<< Data | 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 doable, getting everything right will require more effort

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