Physics with ALICE

P.Hristov

Primorsko'10

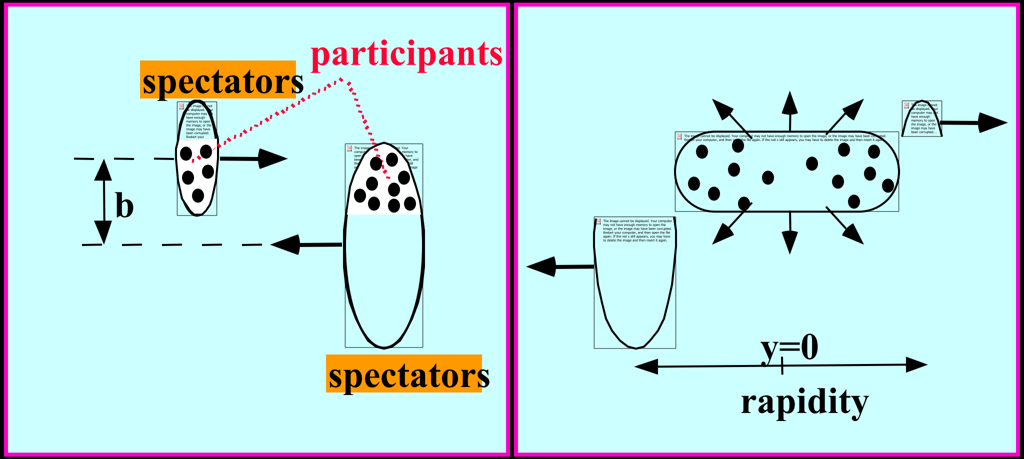
These slides are taken from the following sources:

Lectures of Tapan Nayak, Goa, 09/08
Lectures of Federico Antinori, Padova, 06/09
Presentation of U.Wiedemans, QM'09
Lectures of Y.Foka, Creta'10
Presentation of J.Schukraft, PLHC'10
Presentation of A.Dainese, PLHC'10
Presentation of A.Maire, PLHC'10

INTRODUCTION

Collision centrality

- How far do the centers of the two colliding nuclei pass one another?

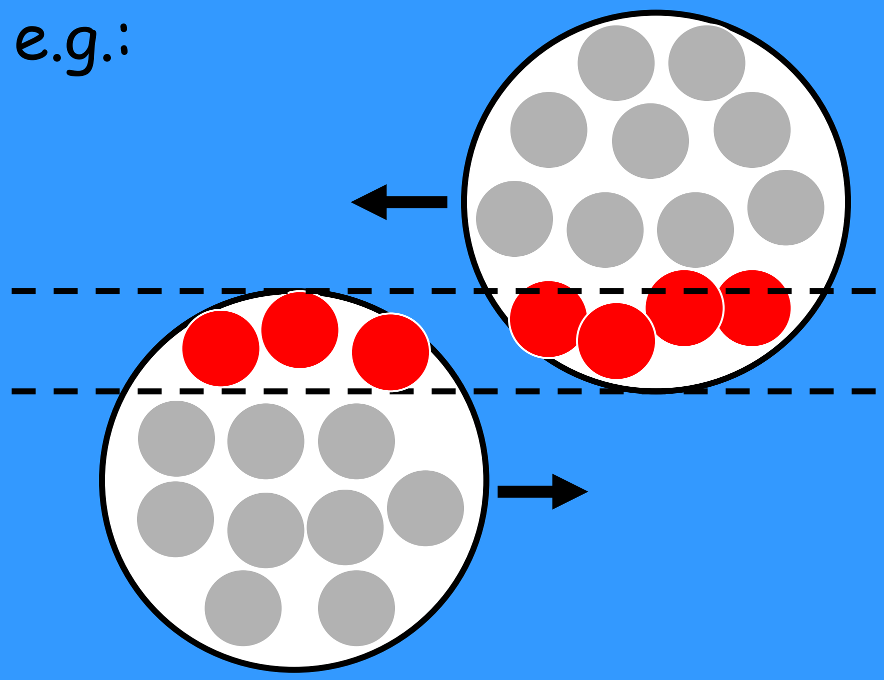


- Usually expressed in terms of:
  - *b* (impact parameter)
  - number of participants $N_{part}(b)$
    - [sometimes one speaks of "number of wounded nucleons": $N_W(b)$]
  - cross section $\sigma(b)$

- Experimentally, the centrality is evaluated by measuring one or more of these variables:
  - N_{ch}: number of charged particles produced in a given rapidity interval (near mid-rapidity)
    - increases (~ linearly) with N_{part}
  - E_T: transverse energy = $\Sigma E_i \sin \theta_i$
    - increases (~ linearly) with N_{part}
  - E_{ZDC}: energy collected in a "zero degree" calorimeter
    - increases (~ linearly) with $N_{spectators}$

Participants Scaling vs Binary Scaling

e.g.:



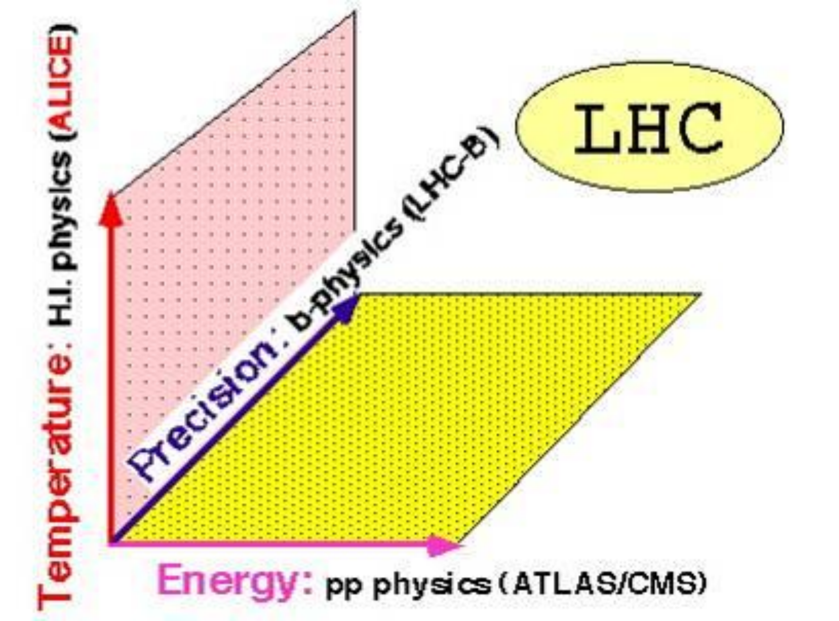
N_{part} (or N_{wound}) = 7 "participants"
N_{bin} (or N_{coll}) = 12 "binary collisions"

- "Soft", large cross-section processes expected to scale like N_{part}
- "Hard", low cross-section processes expected to scale like N_{bin}

Physics at the LHC

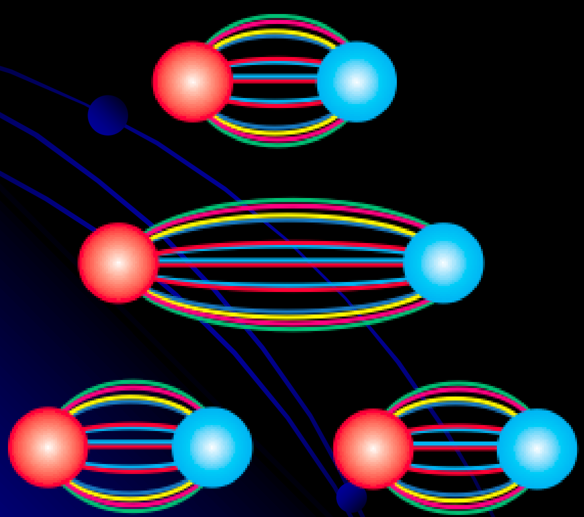
- **Common Questions** Different experiments are optimised in different ways to address common physics questions
  - generation of mass
    - elementary particles => Higgs => Atlas/CMS
    - composite particles => QGP => Alice
  - broken symmetries
    - SuperSymmetry: matter <=> forces => Atlas/CMS
    - ChiralSymmetry: matter <=> QCD vacuum => Alice
    - CP Symmetry: matter <=> antimatter => LHCb

- **Different Approaches**
  - 'Concentrated Energy': Atlas/CMS
    => new high mass particles
  - 'Distributed Energy' : ALICE
    => heat and melt matter
  - 'Borrowed Energy': LHCb
    => indirect effects of virtual high mass particles

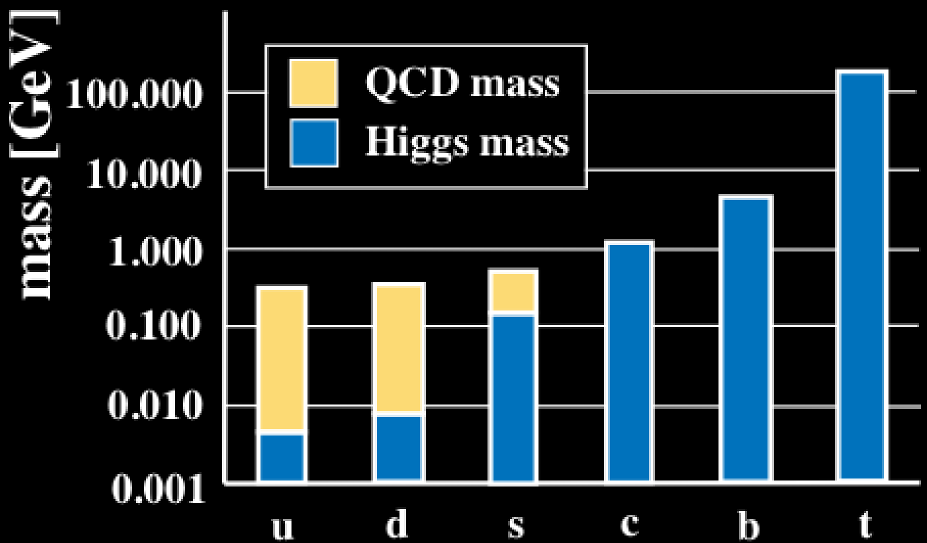


The macroscopic quantities of the QGP will give us better understanding of the underlying microscopic theory (QCD) in the non-perturbative regime

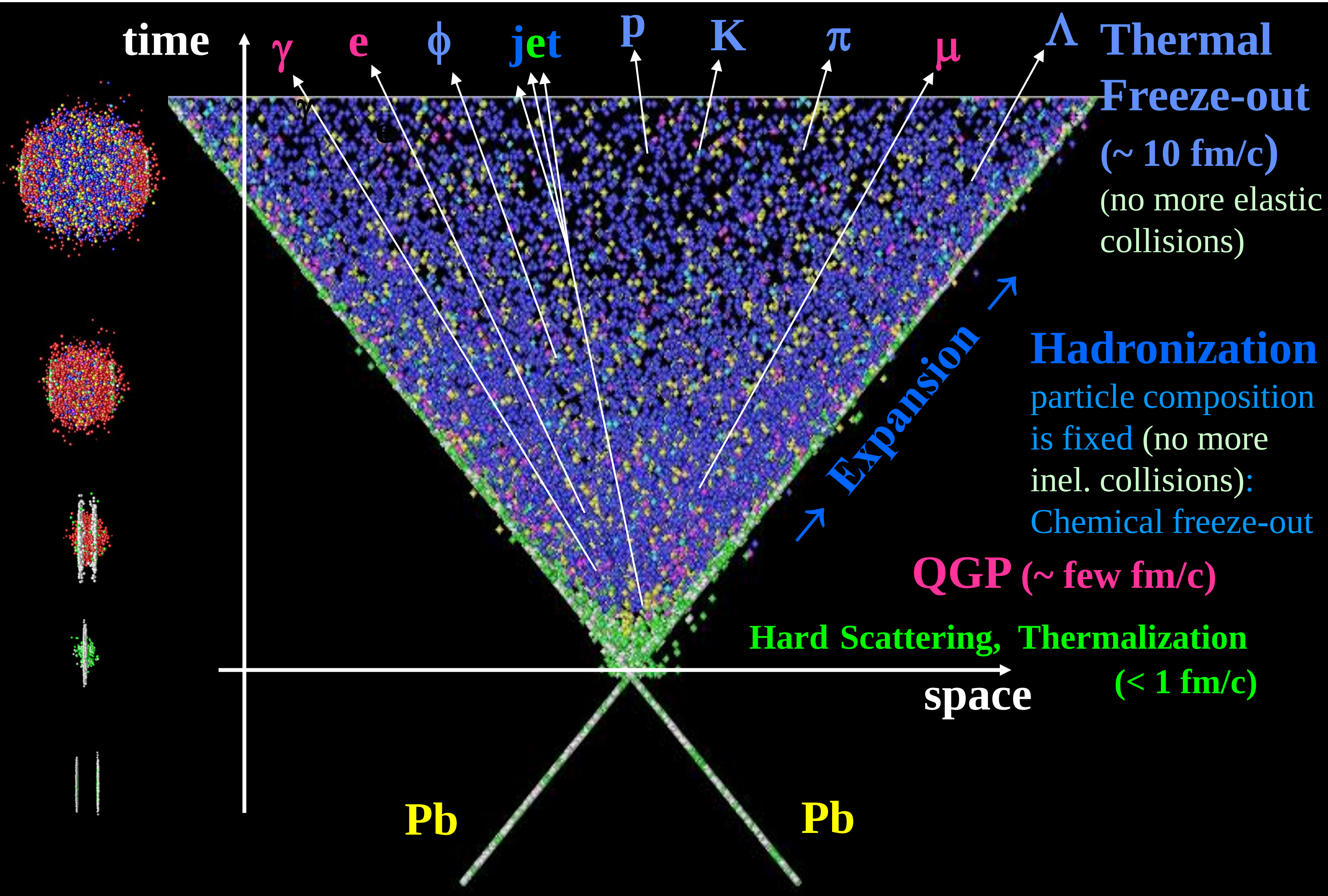
mechanism of confinement



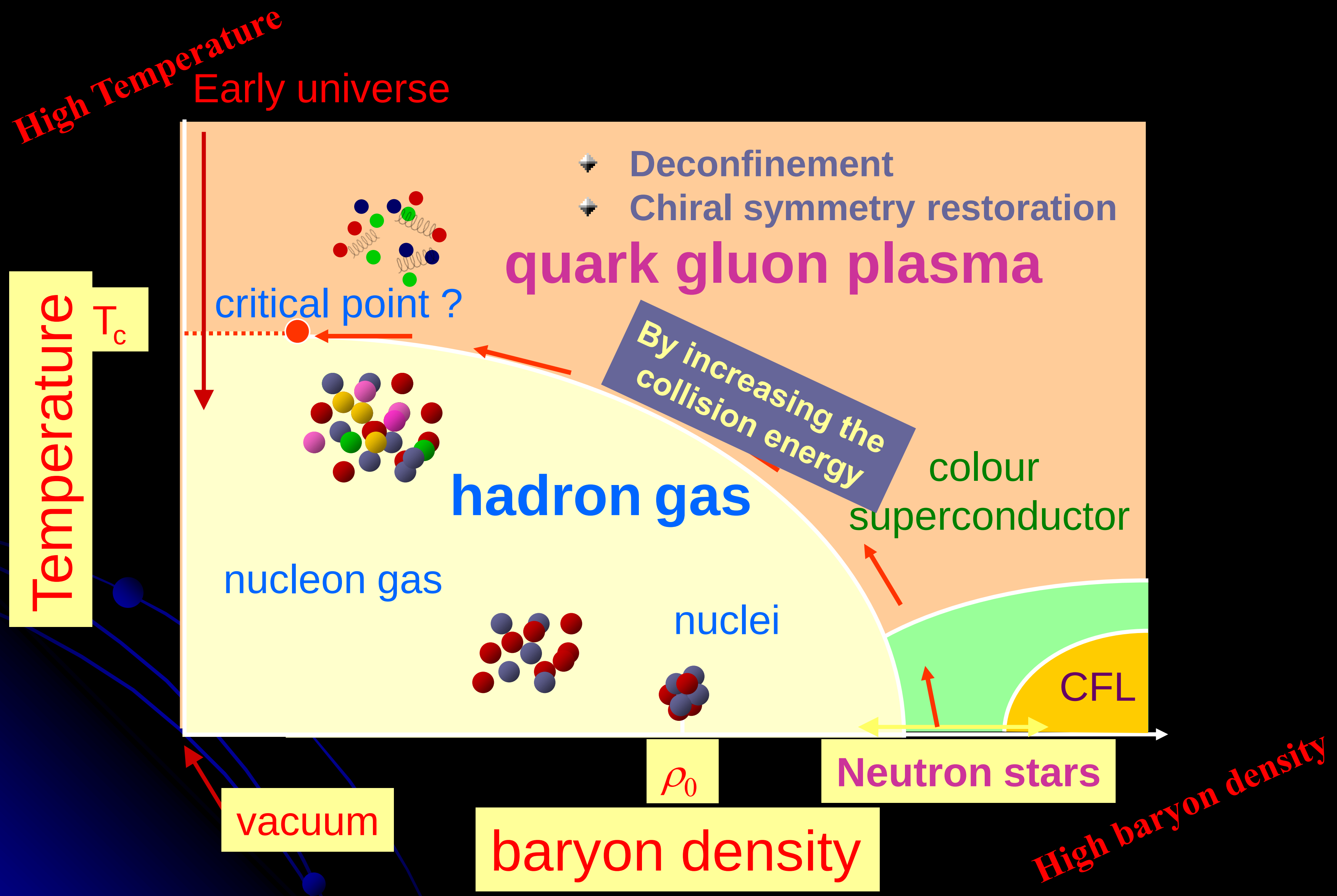
mass generation in the strong interaction



Space-time Evolution of the Collisions

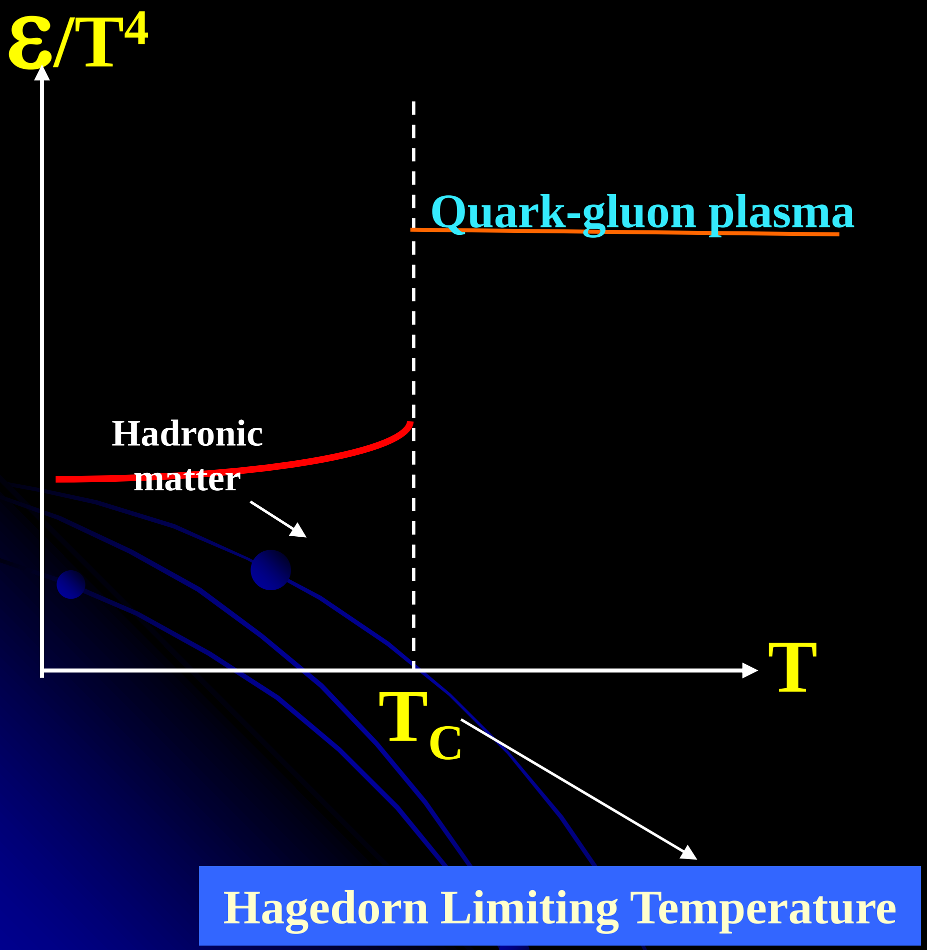


The QCD Phase diagram



Why do we expect in a phase transition from hadronic phase to quark-gluon plasma?

ε is energy density and T is temperature.



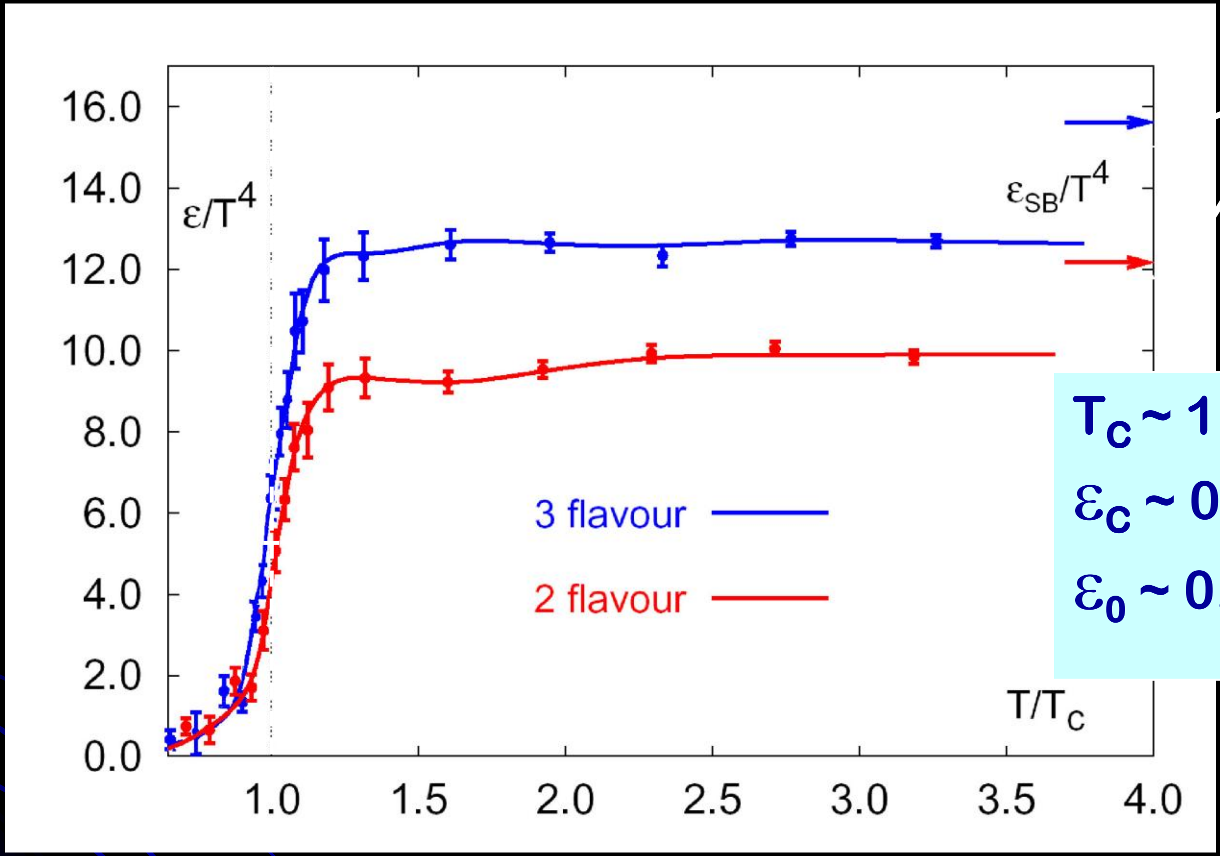
Hagedorn limiting temperature (QM '84 proceedings): when in hadronic matter most energies are used to form pion bubbles. The boilng temp is of the order of pion mass.

Asymptotic freedom: q-q interactions become weaker as the inter-quark distance becomes shorter. The system behaves like free quarks and gluons. Therefore Stephan-Boltzmann law holds and there is no limiting temperature.

Thus we expect a phase transition at $T \sim T_C$.

QCD Equation of State (EoS) from Lattice

Energy Density/ (Temperature)^4



T/Tc

Stephan Boltzman limits for a free Quark Gluon gas

$T_c \sim 170 \pm 15$ MeV

$\varepsilon_c \sim 0.7\text{-}1.2$ GeV/fm^3

$\varepsilon_0 \sim 0.16$ GeV/fm^3

F. Karsch, Prog. Theor. Phys. Suppl. 153, 106 (2004)

Recent Lattice results seem to give a value of T_c to be 190 MeV

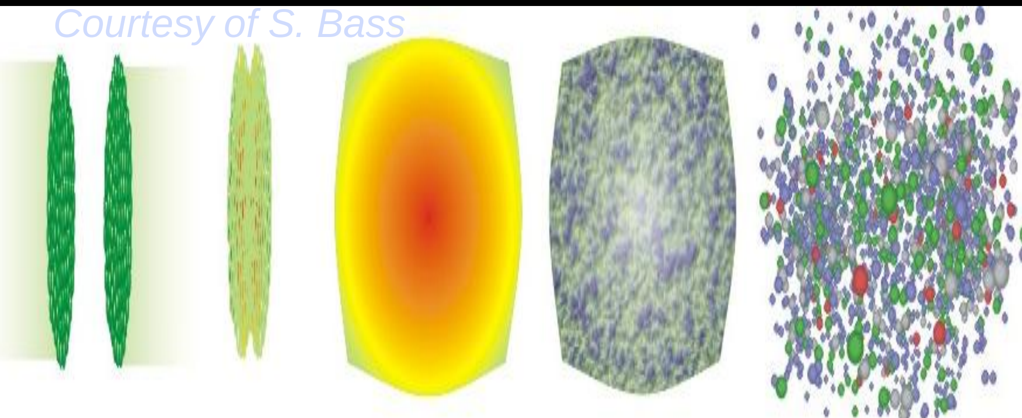
What do we measure?

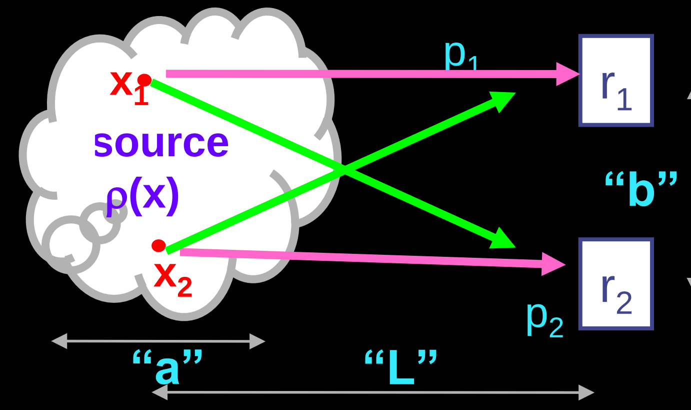
There are no golden observables **Use all the experimental tools!!!**

Glossary

- We all have in common basic nuclear properties
  - *A, Z ...*
- But some are specific to heavy ion physics
  - $v_{1,2}$ "directed/elliptic flow" $\frac{dN}{p_T dp_T dy d\varphi} = \frac{1}{2\pi}\frac{dN}{p_T dp_T dy}\left(1 + 2v_1 \cos(\varphi) + 2v_2 \cos(2\varphi) + \ldots\right)$
  - R_{AA} 1 if yield = perturbative value from initial parton-parton flux
  - T Temperature, "m_T slope" (MeV) $\frac{1}{m_T}\frac{dN}{dm_T} \propto \exp(-\frac{m_T}{T})$
  - μ_B Baryon chemical potential (MeV) ~ *net* baryon density
  - η Viscosity (MeV^3) *indirectly inferred from R_{AA} and v_2*
  - s Entropy density ~ "particle" density
  - ε Energy density (Bjorken 1983): $\varepsilon(\tau) = \frac{dE_T}{dV(\tau)} = \frac{1}{\pi R^2 \tau}\frac{dE_T}{dy}$

Probing source geometry through interferometry





The correlation function is defined as the ratio of the probability for the coincidence of p_1 and p_2 relative to the probability of observing p_1 and p_2 separately :

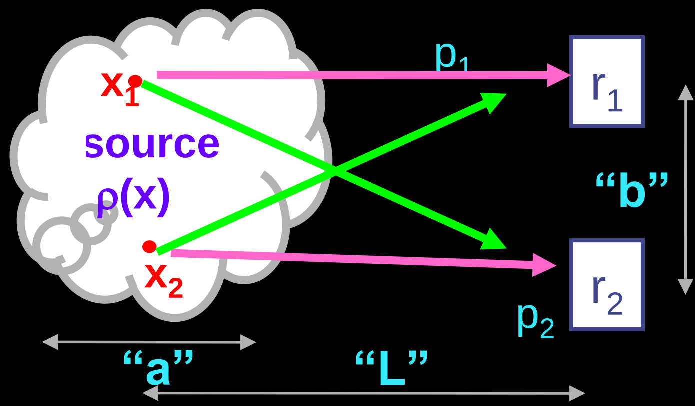
$$C(p_1,p_2) = \frac{P(p_1,p_2)}{P(p_1)P(p_2)} = 1 + |\tilde{\rho}(q)|^2$$

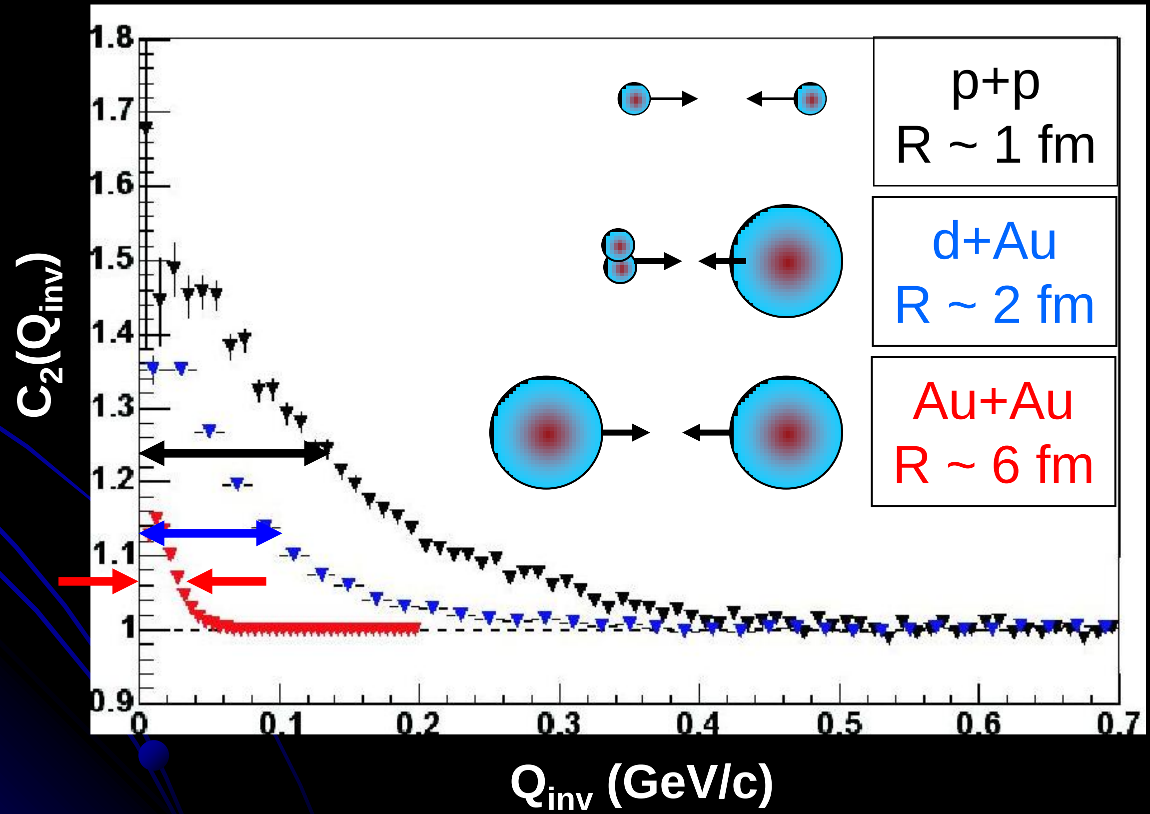
Measurable!

F.T. of pion source

Correlation function constructed experimentally, $C_2(q) = A(q) / B(q)$ (normalized to unity at large q),
A (q) → is the pair distribution in momentum difference $q = p_2 - p_1$ for pairs of particles from the same event. B (q) → is the corresponding distribution for pairs of particles from different events.

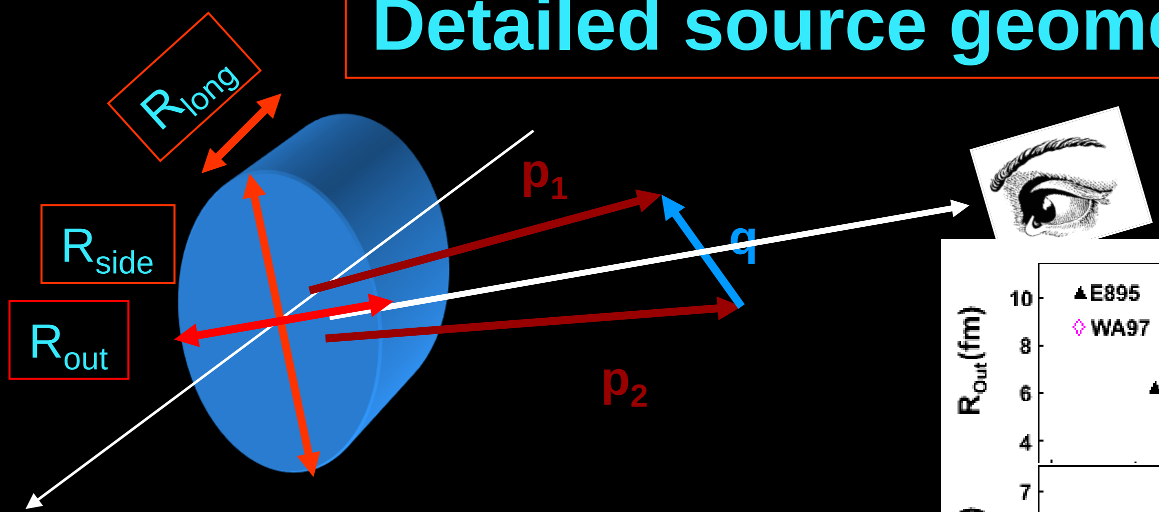
Source geometry

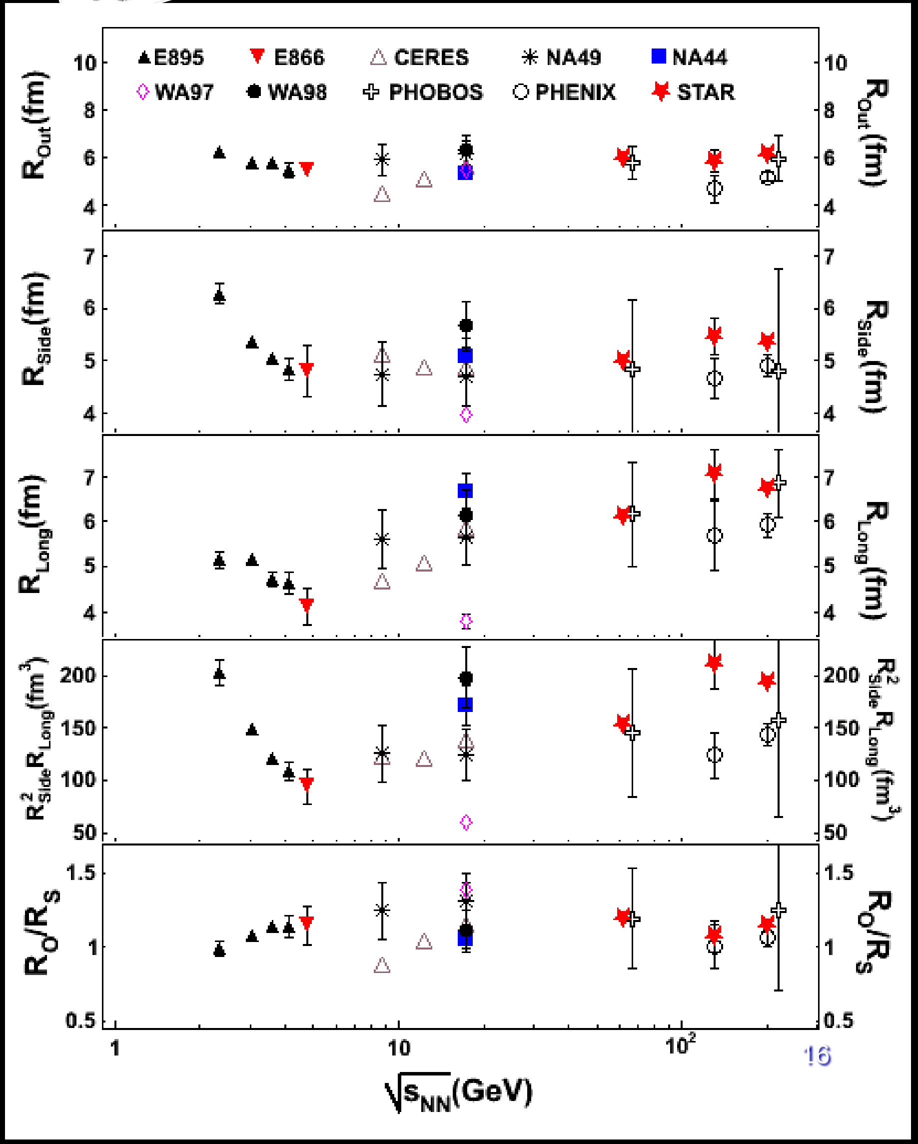




Detailed source geometry

Debasish Das Ph.D. thesis

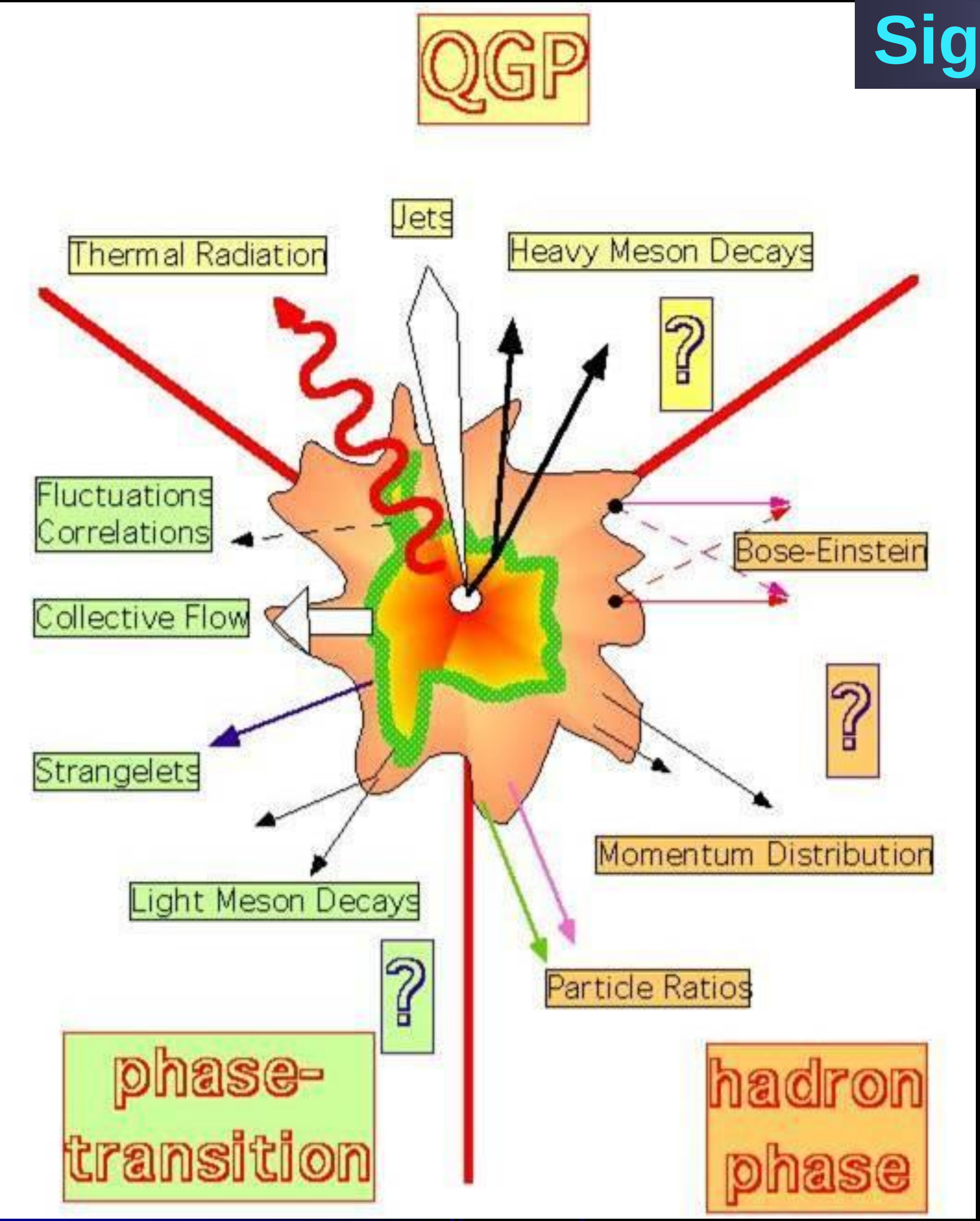




R_{long} – along beam direction

R_{out} – along "line of sight"

R_{side} – ⊥ "line of sight"



Signals and observables

Soft Physics

- Global observables: T, v_2
- Energy density
- Freeze-out conditions: particle yields
- Strangeness
- Fluctuation measures

Heavy quarks & Quarkonia

- J/Ψ, ® suppression
- Open charm/beauty

Hard Probes

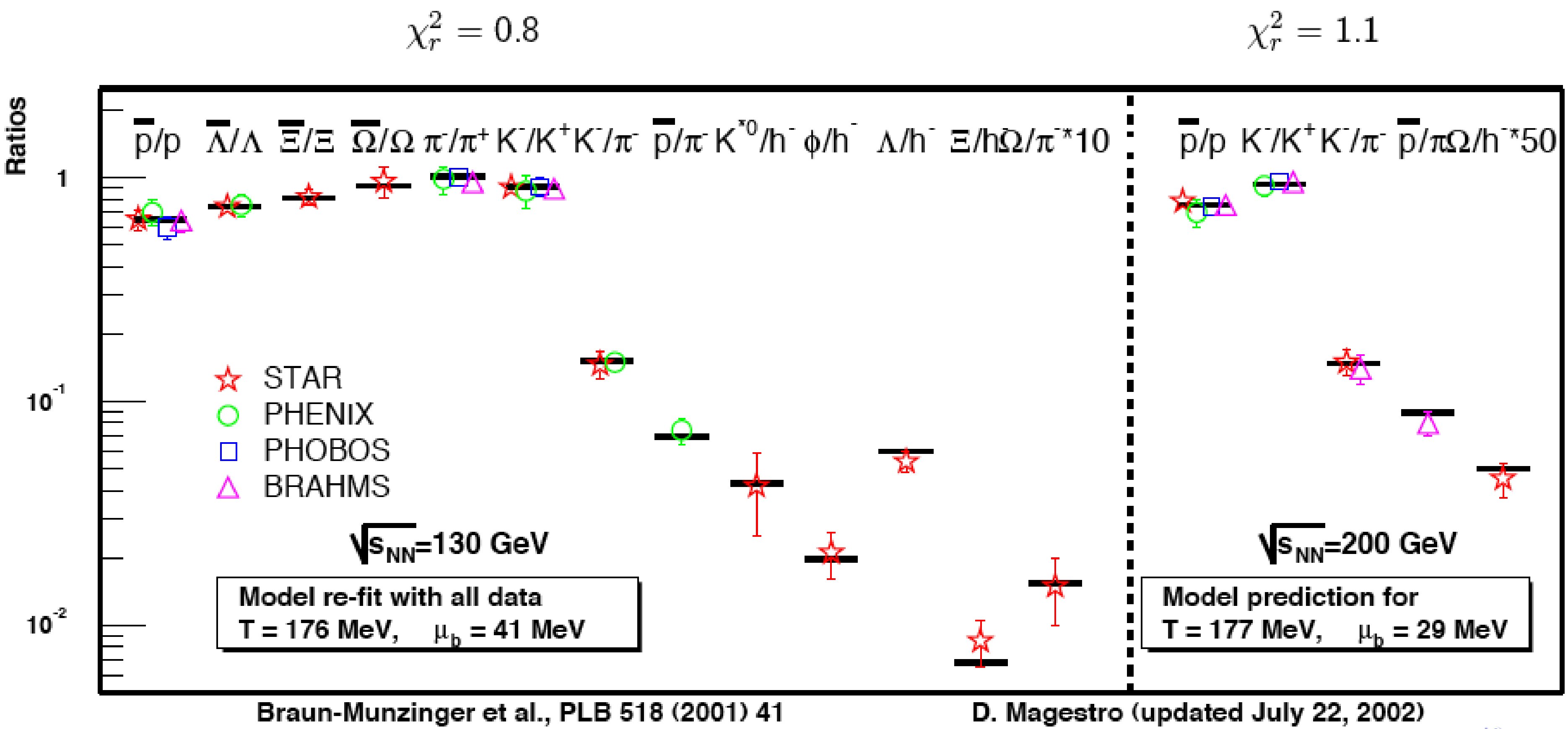
- Jet quenching
- Jet tomography
- Energy loss
- Direct γ/lepton pairs

Example of "hadron" analysis

Particle composition can be described in terms of a statistical model (grand canonical ensemble) with 2 free parameters (thermalization temperature and bariochemical potential).
Consistent with a thermalization of the system with T ~ 170 MeV , μ_B ~ 30 MeV

Limiting temperature reached for large sqrt(s).

First data at LHC will check if the hypothesis survives at *20 the RHIC cm energy



Braun-Munzinger et al., PLB 518 (2001) 41

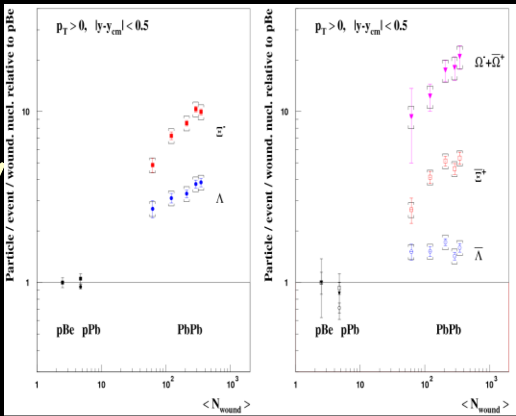
D. Magestro (updated July 22, 2002)

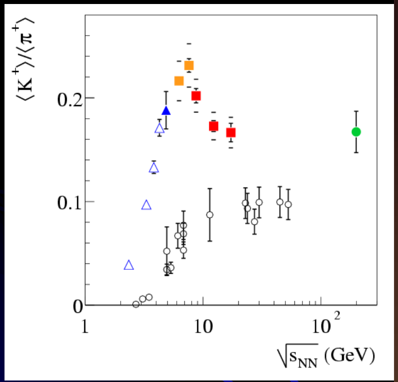
QGP signatures (?)

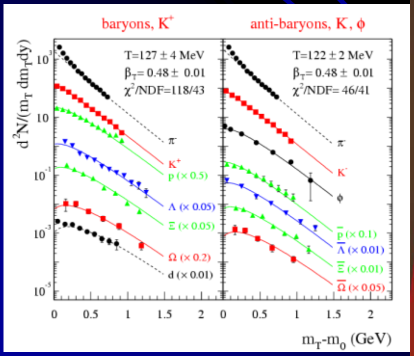
- There are **no golden observables** proving the existence of the QGP… the word "signature" is even no longer used
- We had few predictions at the start of the HI experimental programme: Essentially
  - quarkonium suppression Matsui, Satz (1986)
  - strangeness enhancement Rafelski, Müller (1982)

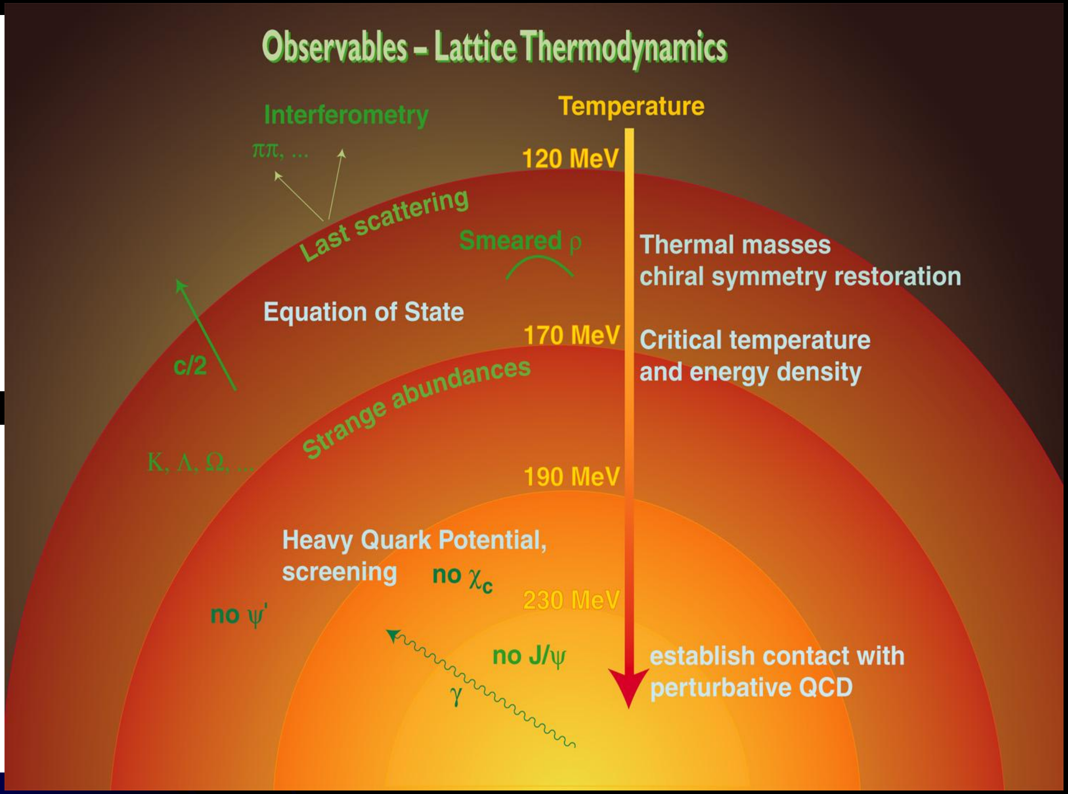
- Use all the experimental tools to probe the evolution of the collision (formation time, thermalization time, collective effects, hard probes,…)

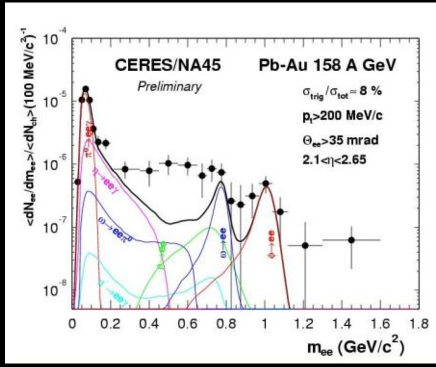
In 2000: Based on the results of different fixed target experiments at the SPS accelerator of CERN we saw evidence of a
deconfined state of matter.
Each one of the experiments was optimised to study specific observables proposed as QGP signatures.
One has to put all the pieces together to make a statement;
one single observable is not enough by itself

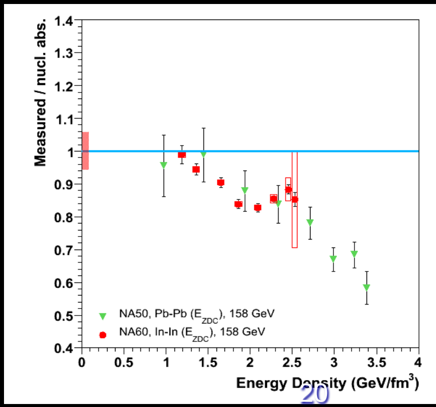




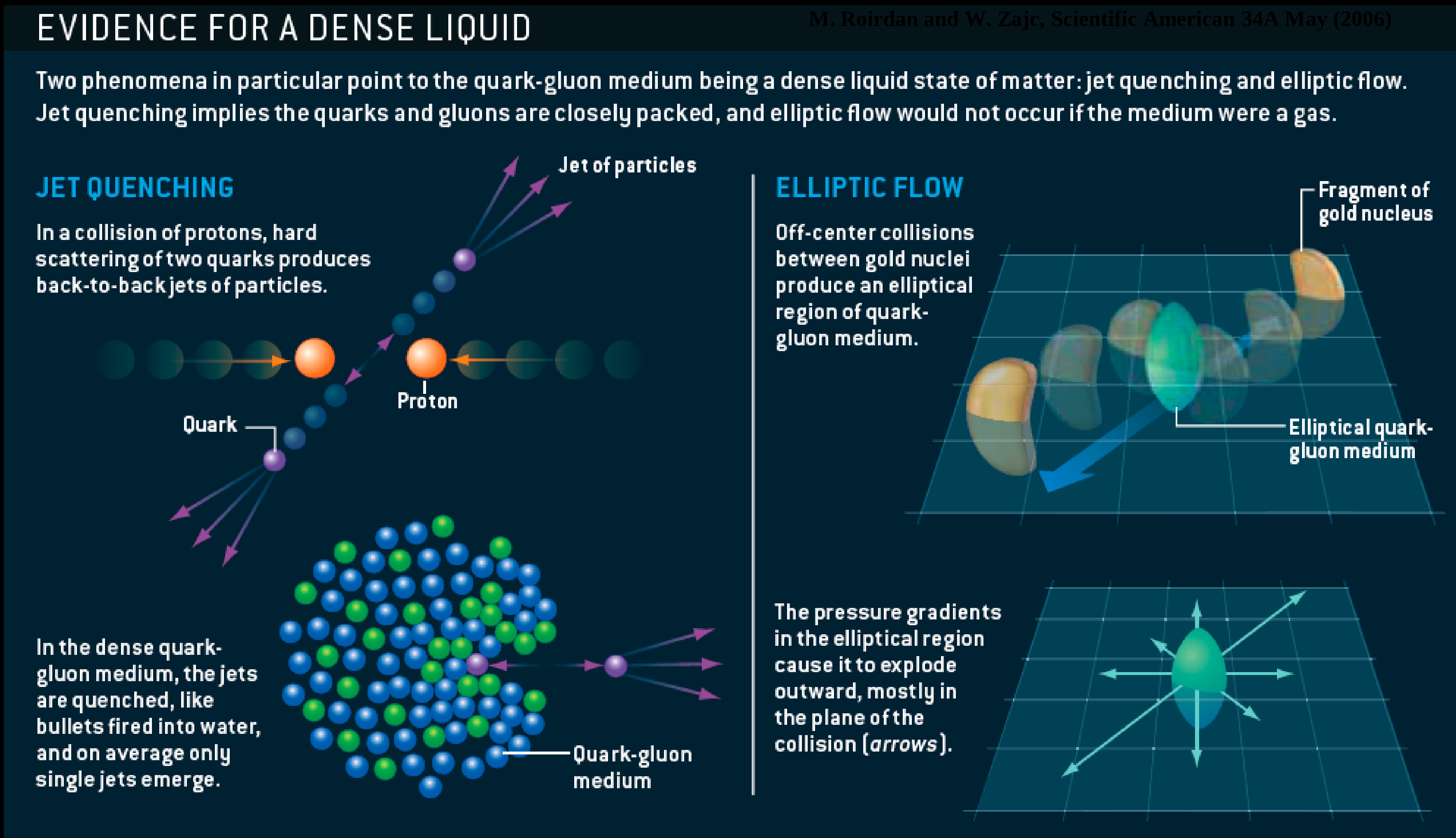








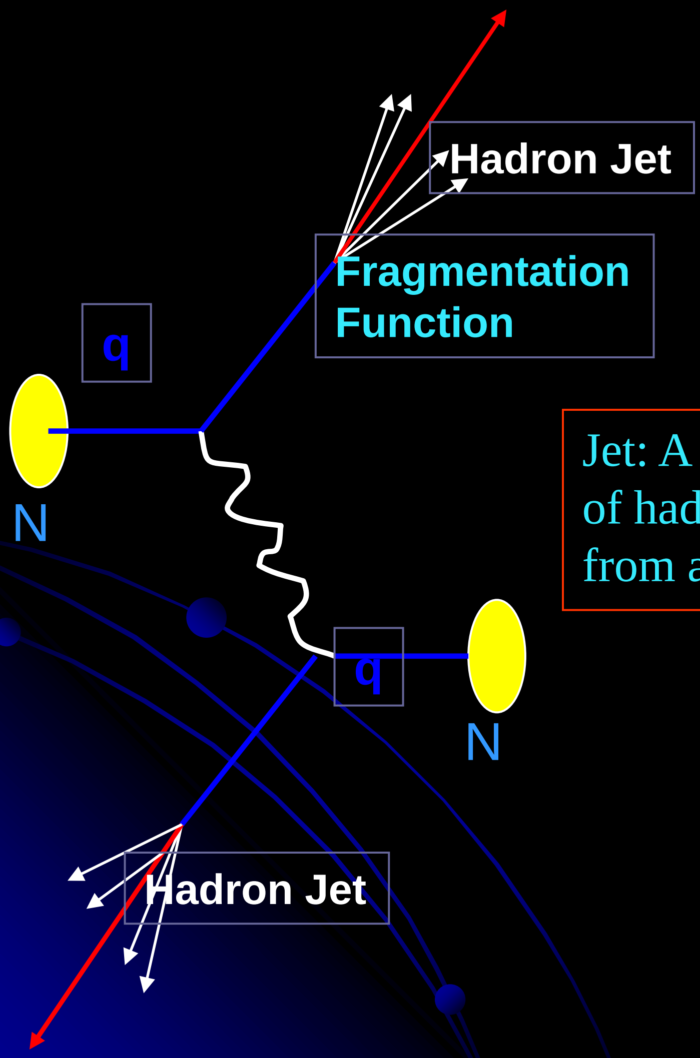
In 2005: Highlights at RHIC



M. Roirdan and W. Zajc, Scientific American 34A May (2006)

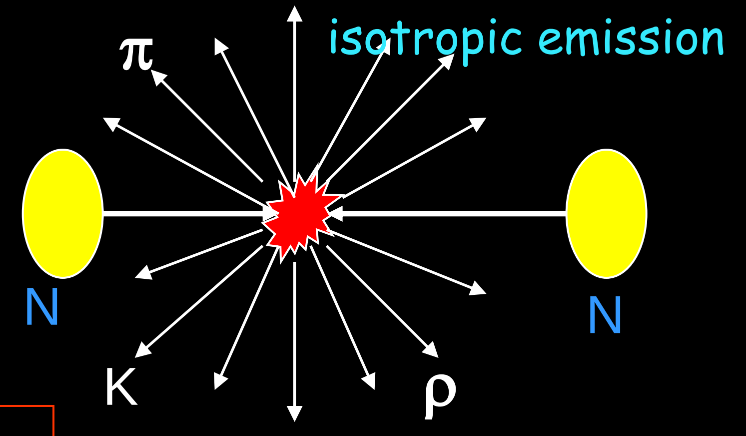
High p_T Probes of the Matter: Jet Study

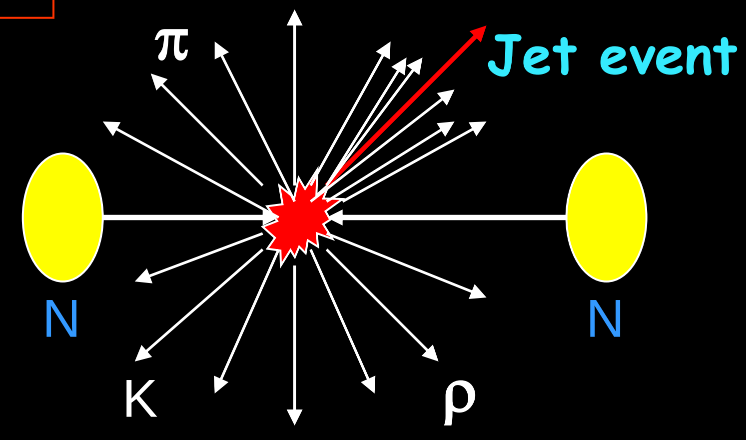
How Jets are produced?



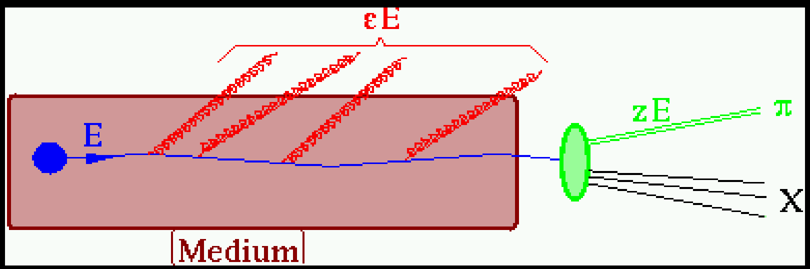
Jet: A localized collection of hadrons which come from a fragmenting parton

Event Topology





Leading hadron suppression



- branching of leading parton based on
  BDMPS-Z-ASW-GLV-WDHG-etc

$$E \gg \omega \gg k_T, q_T^{med} \gg \Lambda_{QCD}$$

- sufficient for leading fragment?

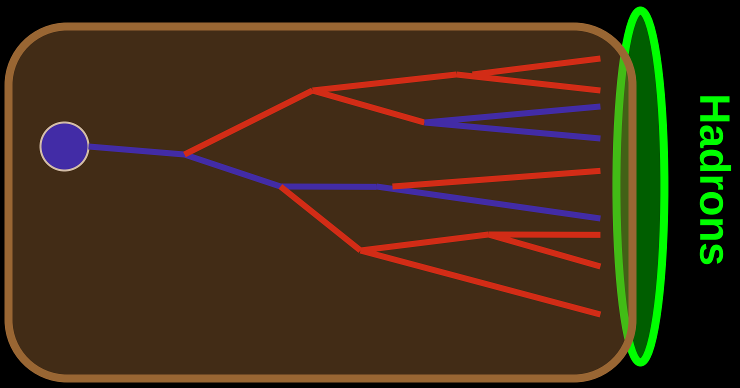
TECHQM – Collaboration
https://wiki.bnl.gov/TECHQM/index.php/Main_Page

- branching of subleading partons not needed

- perturbatrive (vacuum) baseline

analytical calculation or MC

"True" jet quenching



- Exact energy conservation indispensable

$$E \geq \omega \geq k_T, q_T^{med} \geq \Lambda_{QCD}$$

=> **Monte Carlo needed**

- leading and subleading branchings must be treated on equal footing

=> **Monte Carlo**

- perturbatrive (vacuum) baseline

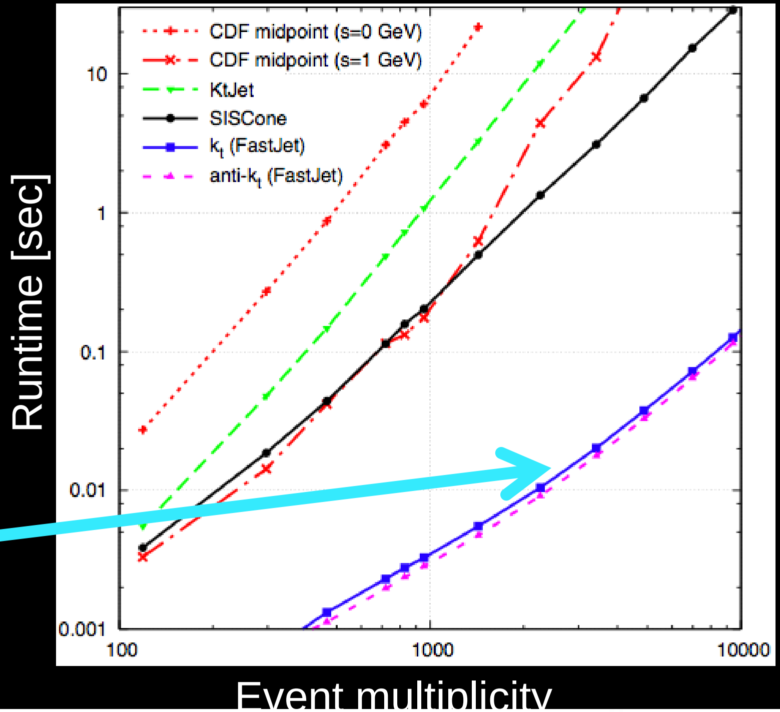
=> **Monte Carlo needed**

Urs Wiedemans, QM'09

Jet Finding Algorithms

- Tremendous recent progress on jet finding algorithms

  - novel class of IR and collinear safe algorithms satisfying SNOWMASS accords
    kt(FastJet)
    anti-kt(FastJet)
    SISCone
  - new standard for p+p@LHC
  - fast algorithms, suitable for heavy ions!

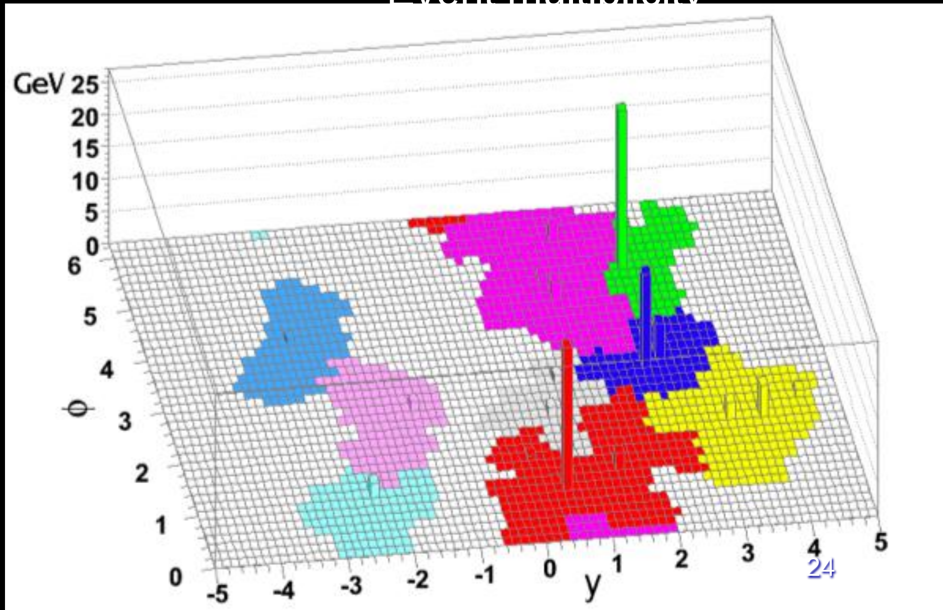


M. Cacciari, G. Salam, G. Soyez, JHEP 0804:005,2008

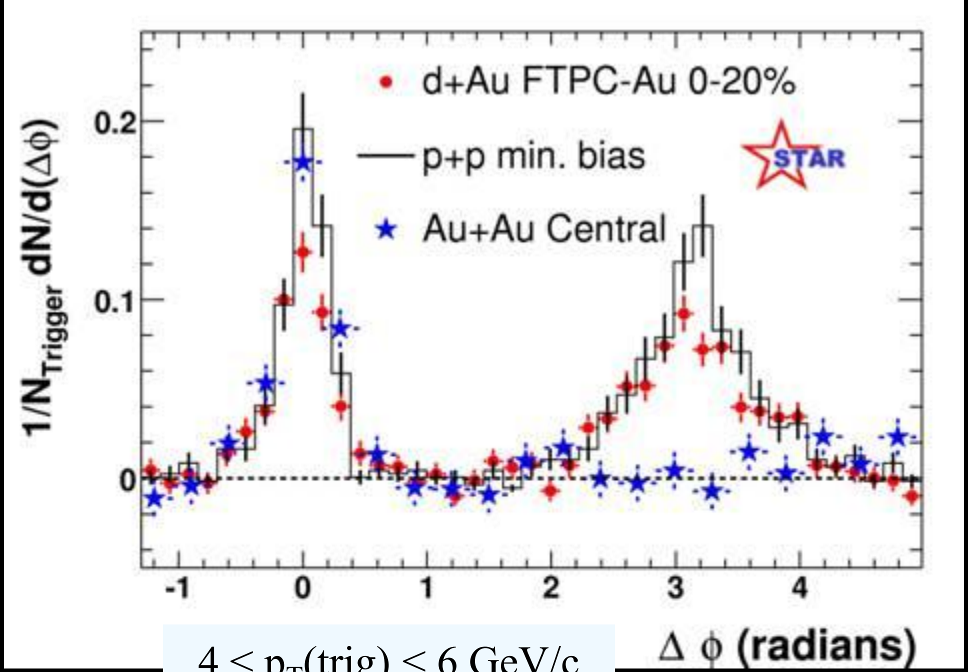
- Catchment area of a jet

  - novel tools for separating soft fluctuations from jet remnants

  - interplay with MCs of jet quenching needed



Jets: Azimuthal Correlation



$4 < p_T(\text{trig}) < 6$ GeV/c
$2 < p_T(\text{assoc.}) < p_T(\text{trig})$

- Identify jets on a *statistical* basis
- Given a trigger particle with $p_T > p_T$ (trigger), associate particles with $p_T > p_T$ (associated)

- ***Away-side correlation suppression in central Au+Au, but not in d+Au.***
- ***d+Au looks like p+p***
- ***Medium density up to 100 times normal nuclear matter !***

For the Energy Scan it will be good to see at what energy the “observed suppression at higher energies disappear.

What is left to do at LHC ?

Assumption: '<u>QGP' has been produced at RHIC/SPS prior to LHC</u>

- **Search** for the 'QGP' is essentially over
- **Discovery** of QGP is well under way (with fantastic results & surprises at RHIC)
- **Measuring** QGP parameters in progress

- pre-RHIC tasks: <u>'precision' measurements</u>
  - quantitative and systematic study of this state of matter
    (' LEP after W/Z discovery at SppS')
    - different state (by large factors) in <u>energy density, lifetime, volume</u>
    - new signals ('hard probes') : heavy quark states (b,c), jets

- post – RHIC result tasks: <u>continue discovery !</u>
  - confirm interpretations by testing predictions/extrapolation to LHC
  - transition from strongly coupled QGP -> ideal QGP ?

- surprises may still lie ahead <u>more to search for ?</u>
  - is initial state dominated by yet another new state of matter (dense quantum state) ?
    - **Color Glass Condensate ?** (QCD in classical Field Theory limit)

H.I. Physics@LHC: Caveat

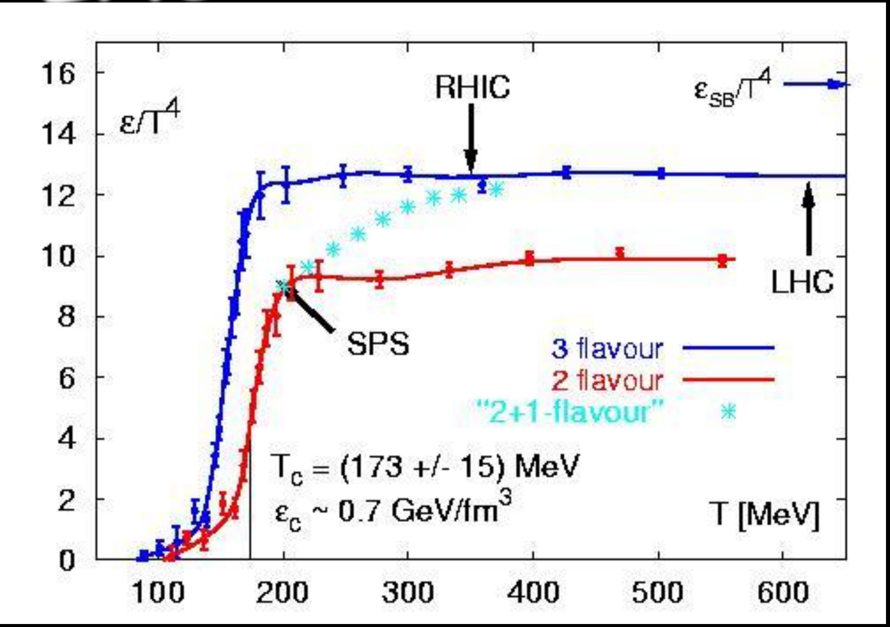
BIG Step ahead: SPS $\xrightarrow{\times 13}$ RHIC $\xrightarrow{\times 28}$ LHC

Predictions are notoriously difficult, in particular if they concern the future..

- long distance QCD is difficult to predict
  - Theory well known, not so its consequences or manifestation
- several surprises (both + and -) at SPS and RHIC
  - RHIC: large elliptic flow, 'baryon anomaly', very large jet-quenching
    - 'QGP' is not a weakly interacting plasma, but behaves like an 'ideal fluid'
  - SPS, RHIC: no strong event-by-event fluctuations (for 1st order phase transition)
- lesson when preparing for LHC
  - guided by theory and expectations, but **stay open minded** !
- 'conventional wisdom'
  - **soft physics**: smooth extrapolation of SPS/RHIC necessary, but boring ???
  - **hard physics**: new domain at LHC

QGP @ LHC

- Vanishing net baryon density, $\mu_B \sim 0$
- Kinematic region at small Feyman x
- High energy density → limit of an ideal gas of QCD quanta
- Fast thermalisation
- Stronger thermal radiation
- Parton saturation
- Hard probes:
  - ✓Heavy flavours
  - ✓Jets and jet quenching



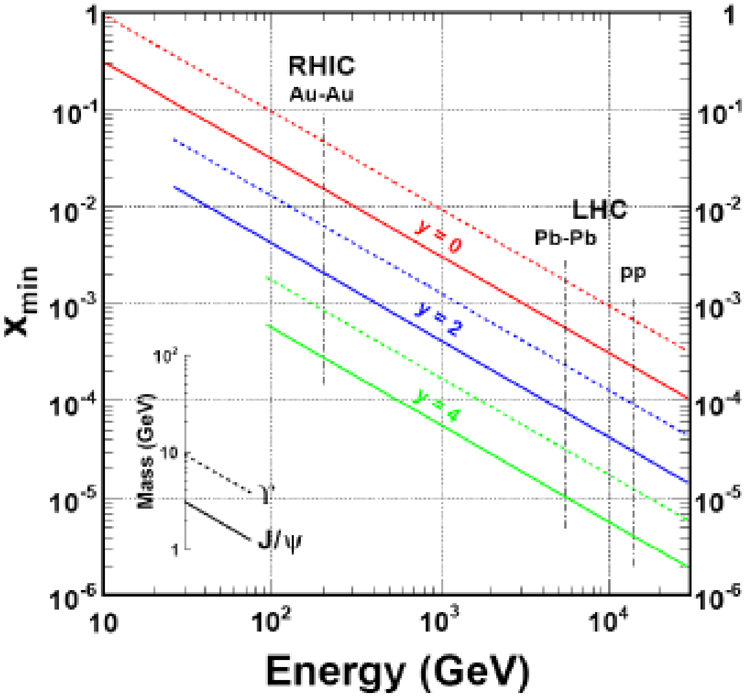
$\varepsilon_{LHC} \geq \varepsilon_{RHIC} \geq \varepsilon_{SPS}$

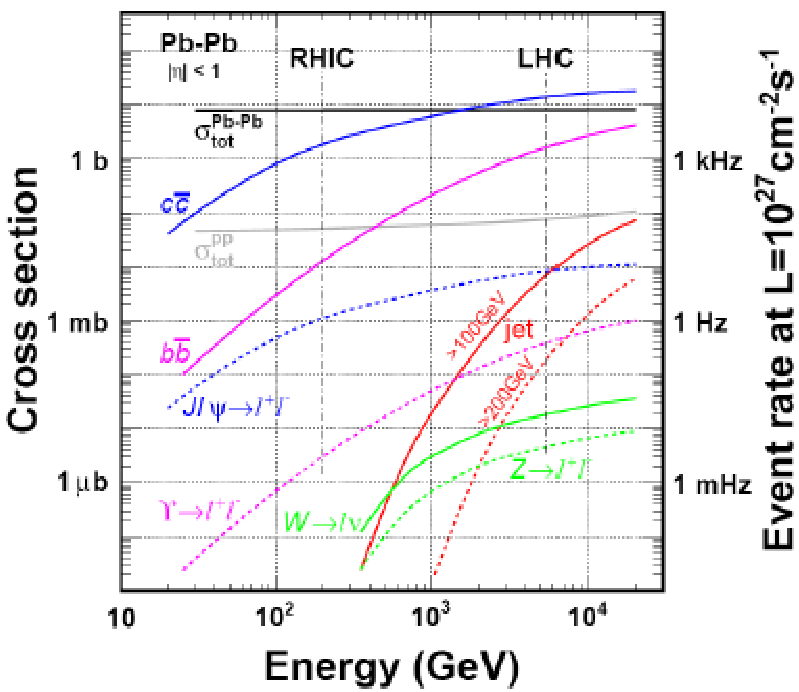
$\varepsilon_{LHC} = 15 - 40\ \mathrm{GeV/fm^3}$

hotter, bigger, longer !!

sqrt(s)	SPS(17)	RHIC(200)	LHC(5500)
ε	1	2	10
V_f	1	7	20
τ_{QGP}/τ_0	1	6	30

New domain at @ LHC





LHC will extend the low x frontier by a factor of ~ 30 to:
(with J/ψ at η ~ 4)

- $x = 3 * 10^{-6}$ in p-p
- $x = 10^{-5}$ in Pb-Pb collisions

Hard and heavy probe yields significantly increase wrt. RHIC by a factor of:

- ~ 10 c-cbar
- ~ 10^2 b-bbar
- ~ 10^6 high p_T jets

ALICE DETECTOR

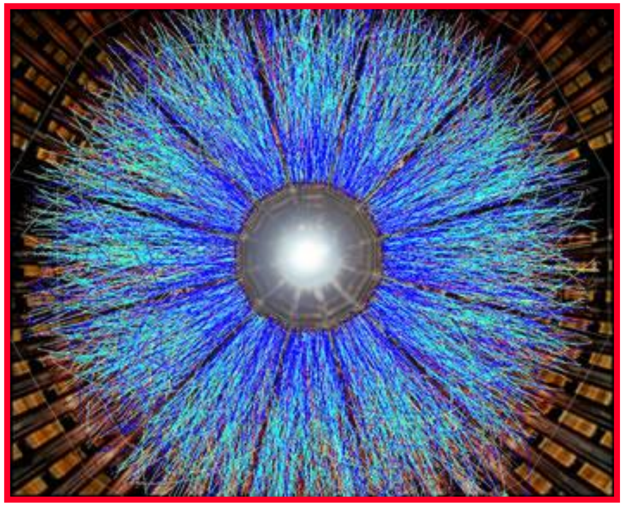
HI @LHC: Constraints and Solutions

- Extreme particle density : $dN_{ch}/d\eta$ ~ 2000 – 8000
  x 500 compared to pp@LHC; **x 30** compared to ^{32}S@SPS

  ⇨ high granularity, 3D detectors
  - ✪ Silicon **pixels** and **drift** detectors, **TPC** with low diffusion gas mixture ($Ne\text{-}CO_2$)

  ⇨ conservative & redundant tracking
  - ✪ up to ~**200 space points** per track

  ⇨ large distance to vertex
  - ✪ e.g. EMCAL at **4.5 m** (typical is 1-2 m !)



- Large dynamic range in p_t:
  from very soft (**0.1 GeV**) to fairly hard (**100 GeV**)

  ⇨ very thin detector, modest field **0.5 T** (low p_t),
  - ✪ ALICE: **~ 10%X_0** in r < 2.5 m (typical is 50-100%X_0)
  - ✪ vertex detector works as 'standalone low p_t spectrometer' (tracking & PID)

  ⇨ large lever arm + good hit resolution (large p_t)
  - ✪ B= **0.5T**, tracking **L ~ 3.5m**, **BL^2** ~ like CMS !

HI @LHC: Constraints and Solutions

- Both partons & hadrons matter:

fragmentation (i.e. hadrons) is part of the signal, not of the problem

⇨ partons (heavy quarks): secondary **vertices**, lepton ID

⇨ hadrons: use of essentially all known **PID** technologies

- dE/dx, Cherenkov & transition rad., TOF, calorimeters, muon filter, topological

- Modest Luminosity and interaction rates; short runs

10 kHZ (Pb-Pb), (< 1/10000 of pp@10^{34}) ~ 1 month/year

⇨ allows slow detectors (TPC, SDD), moderate radiation hardness

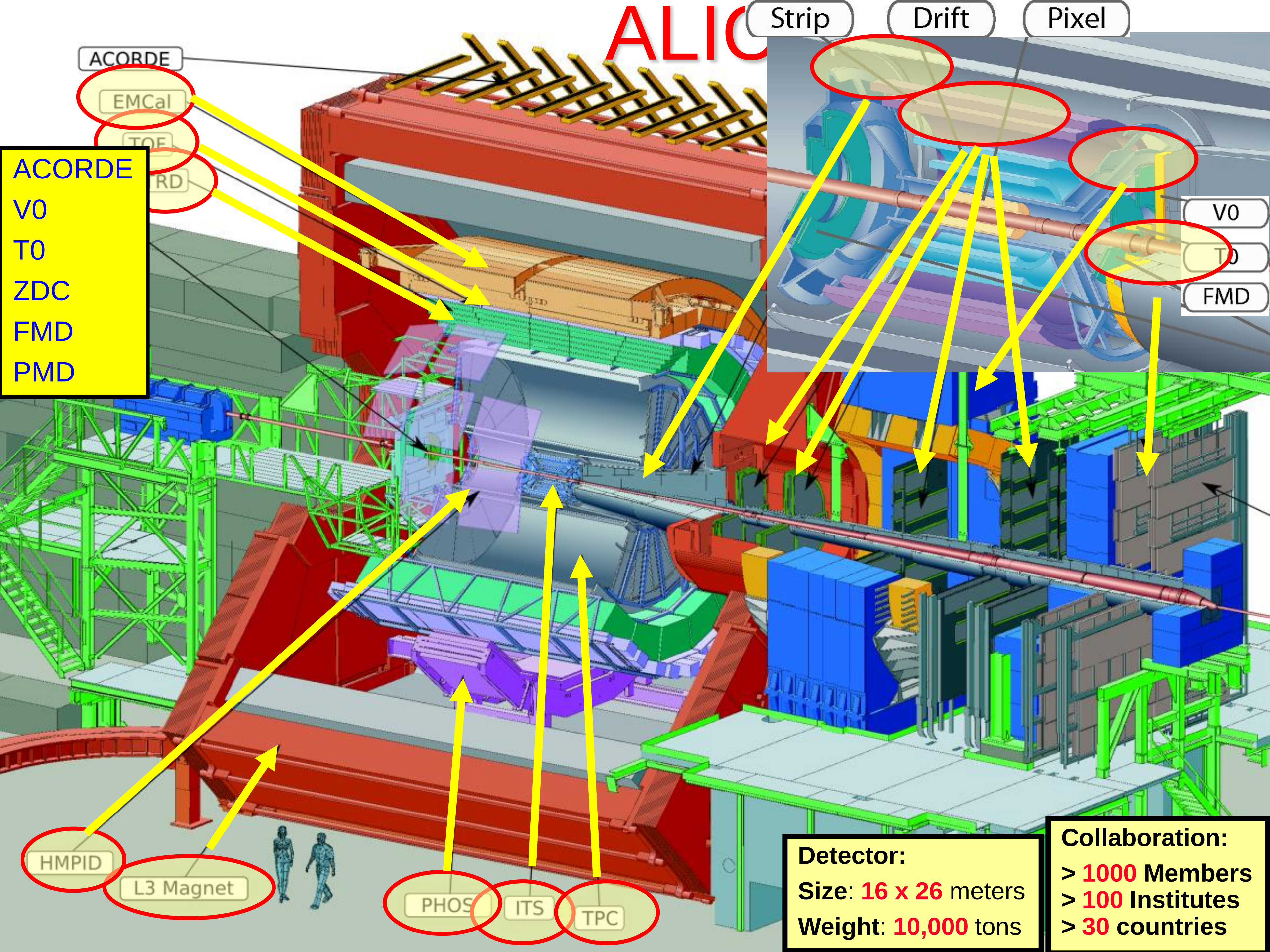
- moderate trigger selectivity, no pipelines (mostly 'track & hold' electronics)

⇨ large event size (~ 100 MB) + short runs => high throughput DAQ (> 1GB/s)

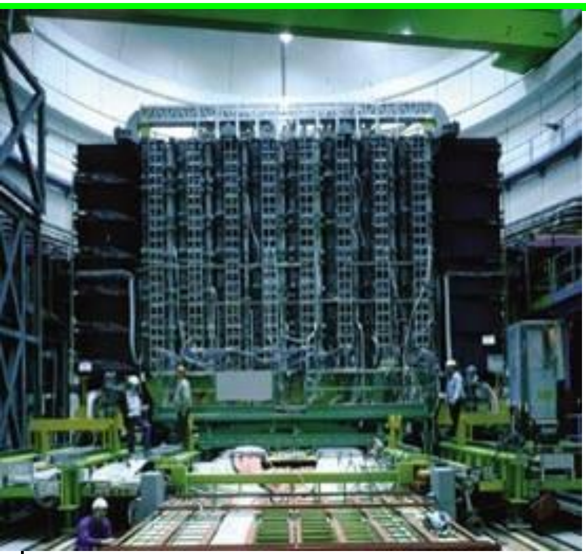
- Single dedicated heavy ion experiment

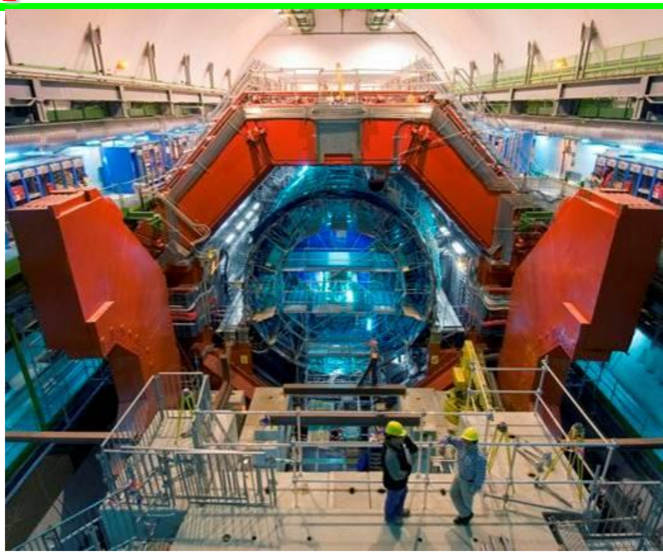
combine capabilities of a handful of more specialized HI expts at AGS/SPS/RHIC

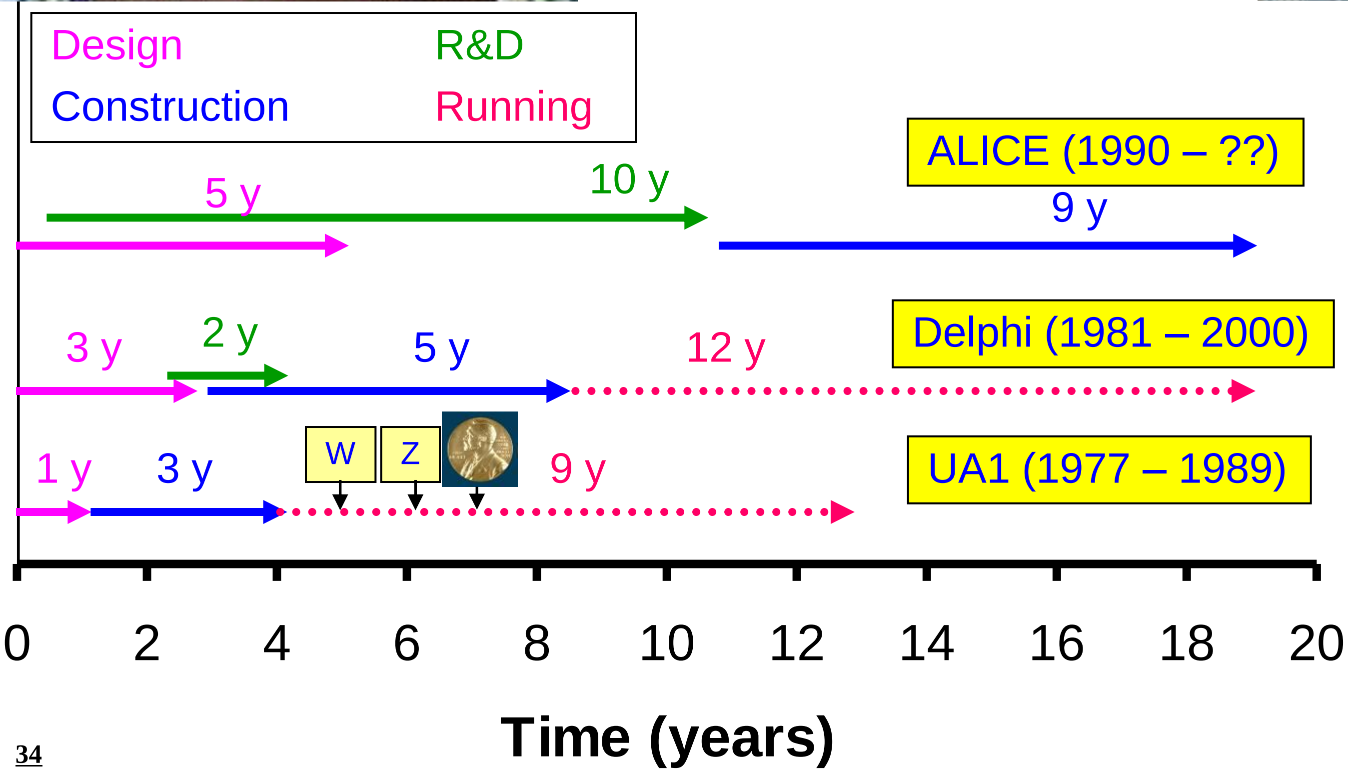
- 18 detector technologies, several smaller 'special purpose' detectors (HMPID, PHOS, PMD, FMD, ZDC..)
- central barrel (~ STAR) + forward muon arm (~PHENIX)


ALIC
Strip
Drift
Pixel
ACORDE
EMCal
TOF
RD
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

The Life of Collider Experiments







ALICE R&D

1990-2002: Strong, well organized, well funded R&D activity

- Inner Tracking System (ITS)
  - ⇨ Silicon Pixels (RD19)
  - ⇨ Silicon Drift (INFN/SDI)
  - ⇨ Silicon Strips (double sided)
  - ⇨ low mass, high density interconnects
  - ⇨ low mass support/cooling

RHIC

RHIC

- PID
  - ⇨ Pestov Spark counters
  - ⇨ Parallel Plate Chambers
  - ⇨ Multigap RPC's (LAA)
  - ⇨ low cost PM's
  - ⇨ CsI RICH (RD26)

RHIC

RHIC

- TPC
  - ⇨ gas mixtures (RD32)
  - ⇨ new r/o plane structures
  - ⇨ advanced digital electronics
  - ⇨ low mass field cage

RHIC

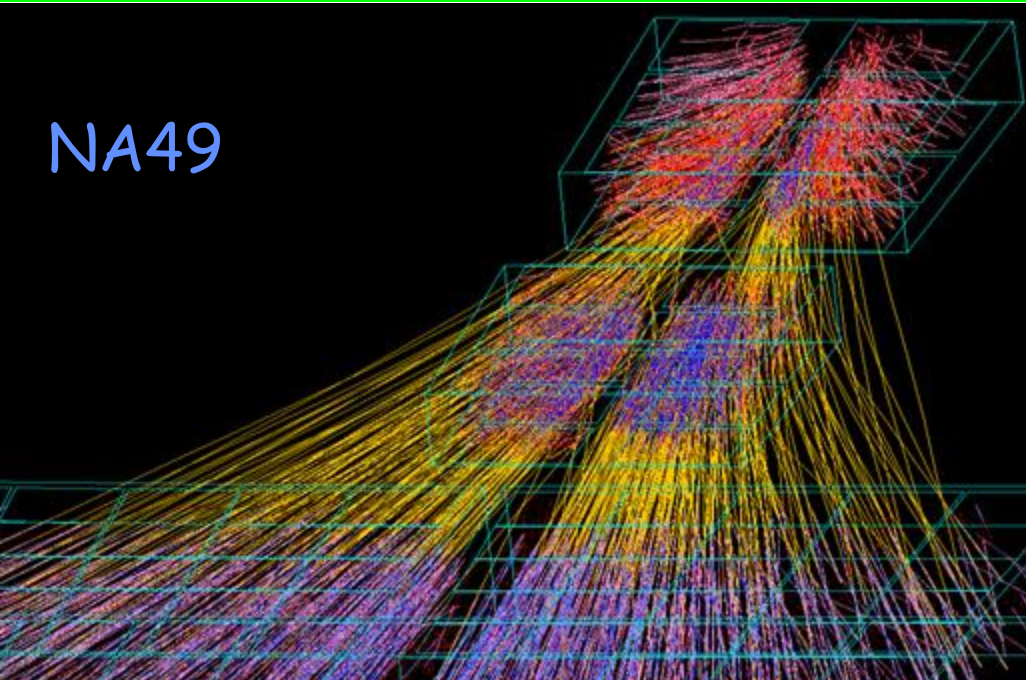
- DAQ & Computing
  - ⇨ scalable architectures with COTS
  - ⇨ high perf. storage media
  - ⇨ GRID computing ?

- em calorimeter
  - ⇨ new scint. crystals (RD18)

- misc
  - ⇨ micro-channel plates
  - ⇨ rad hard quartz fiber calo.
  - ⇨ VLSI electronics

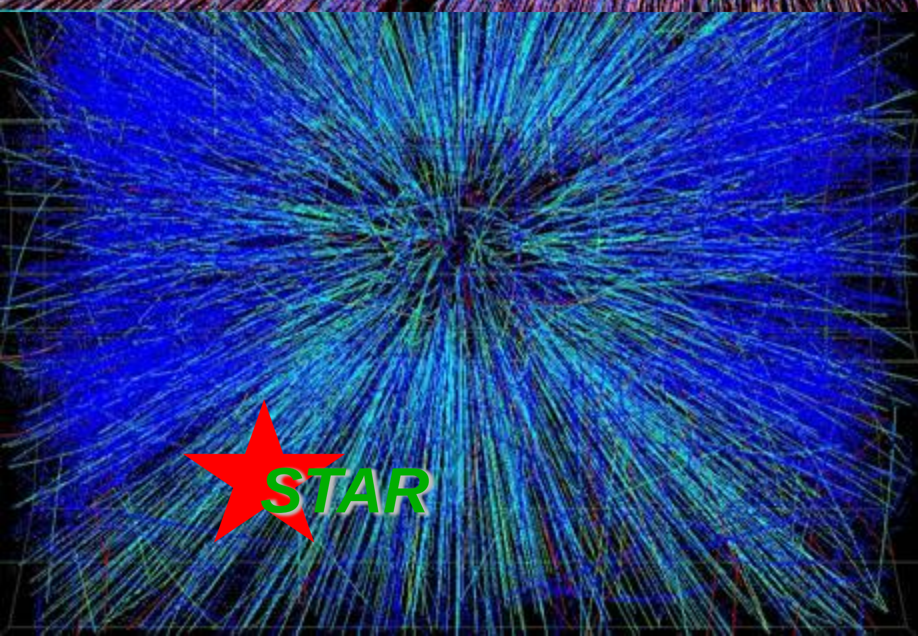
- **R&D made effective use of long (frustrating) wait for LHC**
- **was vital for all experiments to meet LHC challenge !**

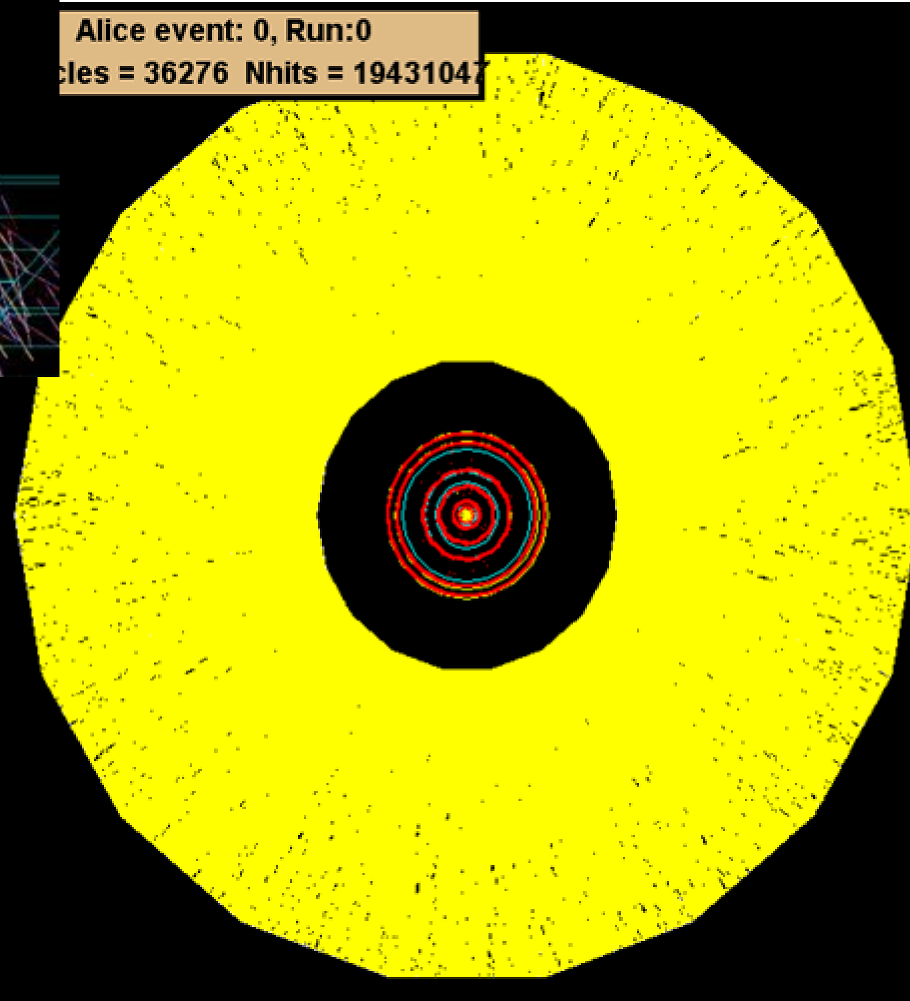
TPC: meeting the Tracking Challenge



ALICE 'worst case' scenario:

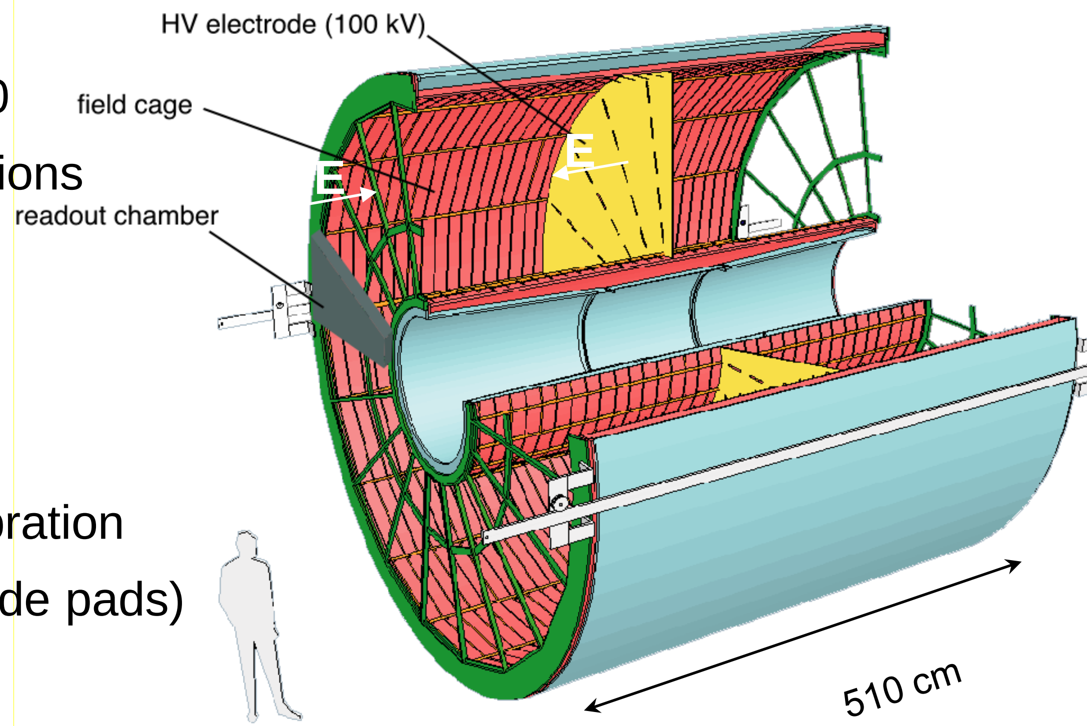
dN/dy_{ch} = 8000





ALICE TPC

- minimal material budget
  - ☺ composite materials => 3.5% X0
  - ☹ sensitive to stress and deformations

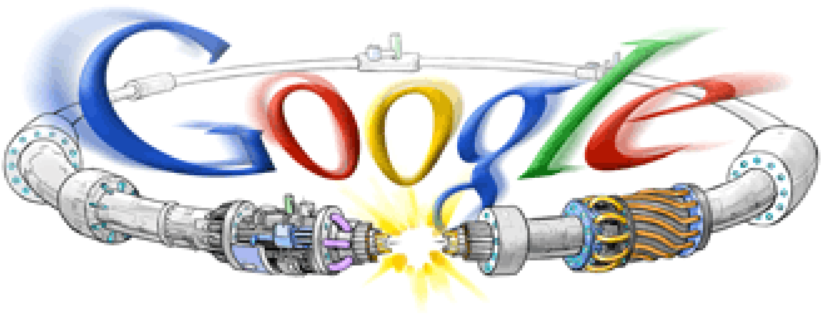


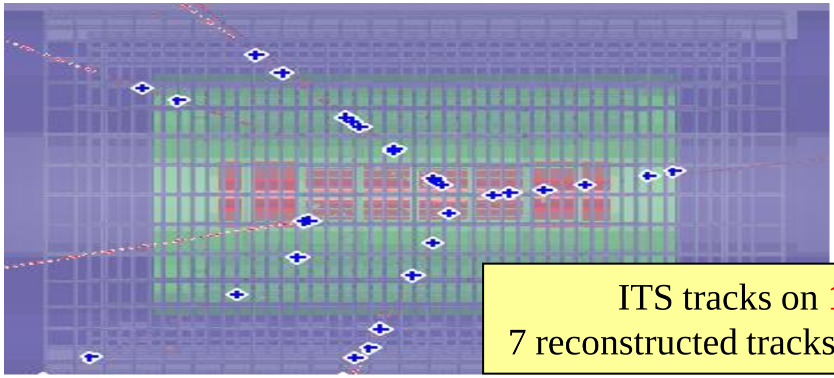
- high track density
  - ☺ low diffusion & low space charge
    'cool' drift gas (Ne/C0$_2$/N$_2$)
  - ☹ electric field (400 V/cm), V_{drift} calibration
  - ☺ high granularity (550 k few mm wide pads)
  - ☹ tight tolerances in construction

- advanced readout electronics
  - ☺ digital pulse shaping and 0-supression
  - ☺ > 2 kHz readout of 0.5x10^9 10 bit ADC's

Fast Forward to

- September 2008:
  - ⇨ LHC starts with a ‘Big Bang’





ITS tracks on **12.9.2008**
7 reconstructed tracks, common vertex

- November 2009:
  - ⇨ Start of Physics @ LHC

The LHC (and everything else) accelerates ..

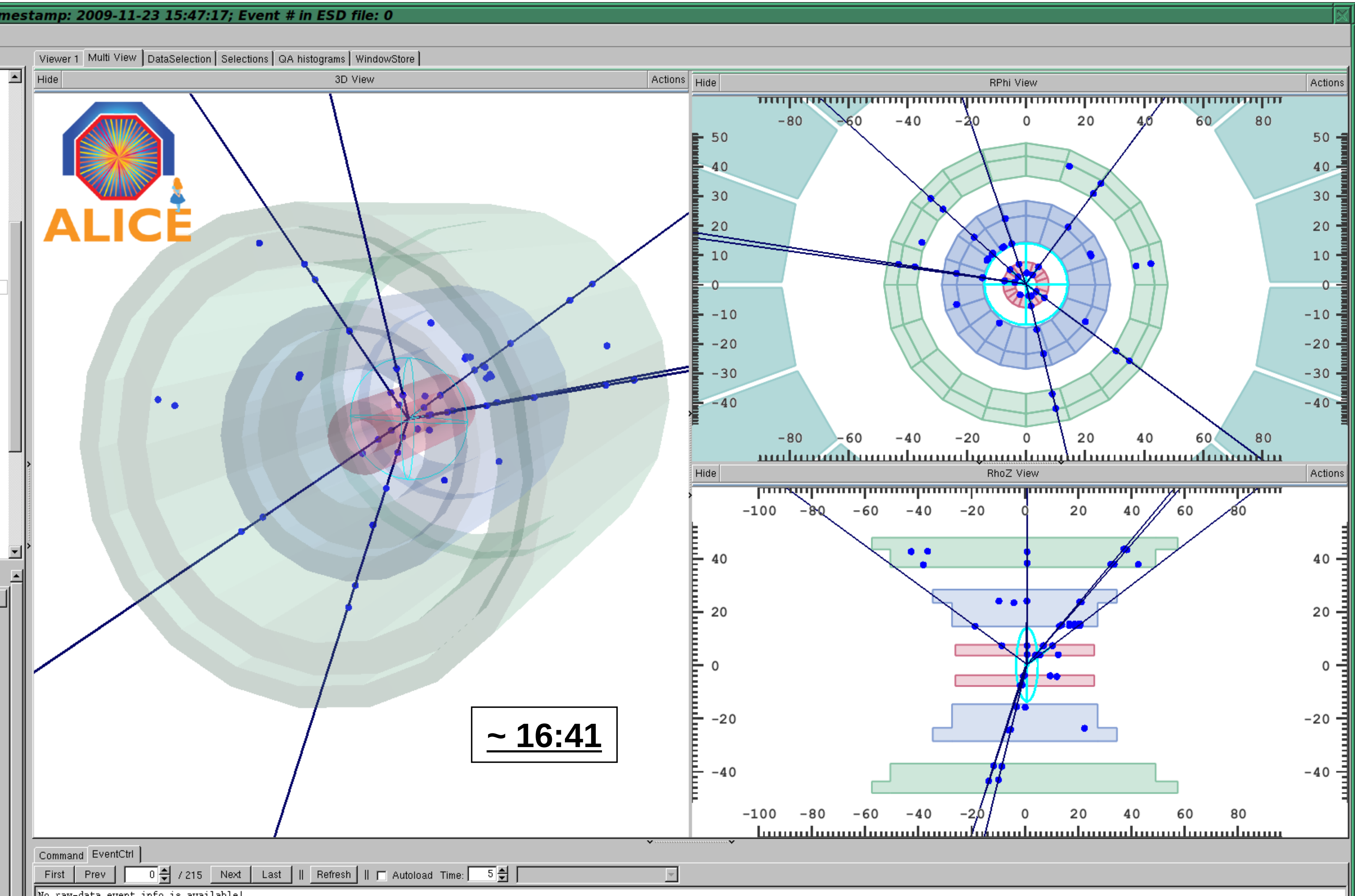
..after concentrated preparations..

.. and tense anticipation..

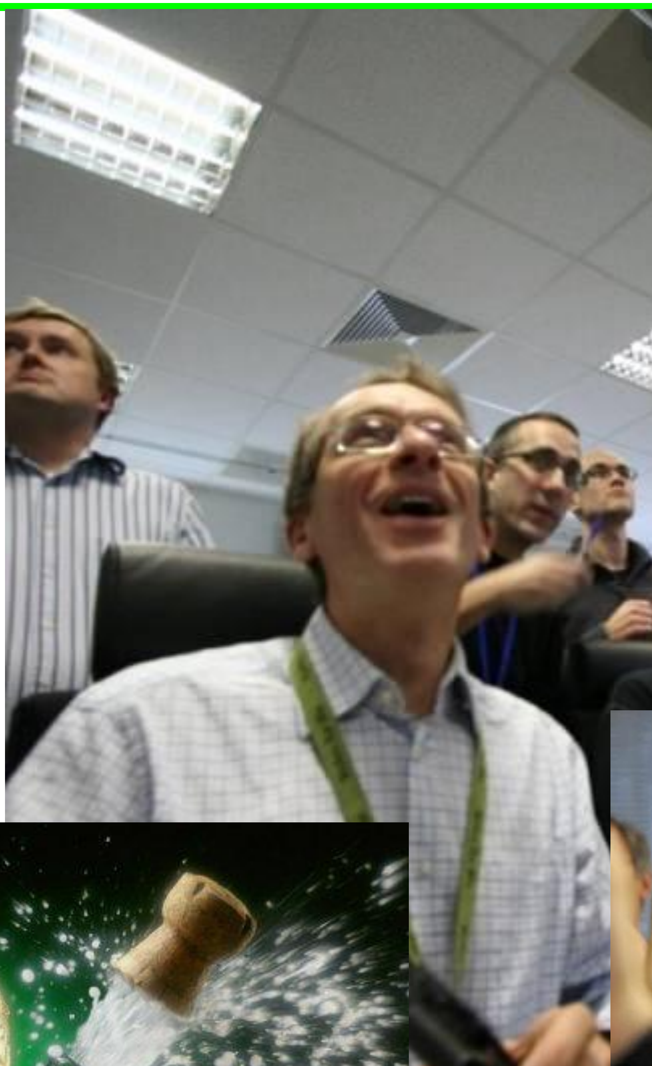
Monday, 23rd November, ~15:30
in the ALICE Control Room

some anxious minutes waiting for collisions..

The first ‘event’ pops up in the ACR



Relief and jubilation..



Collisions in ALICE !!

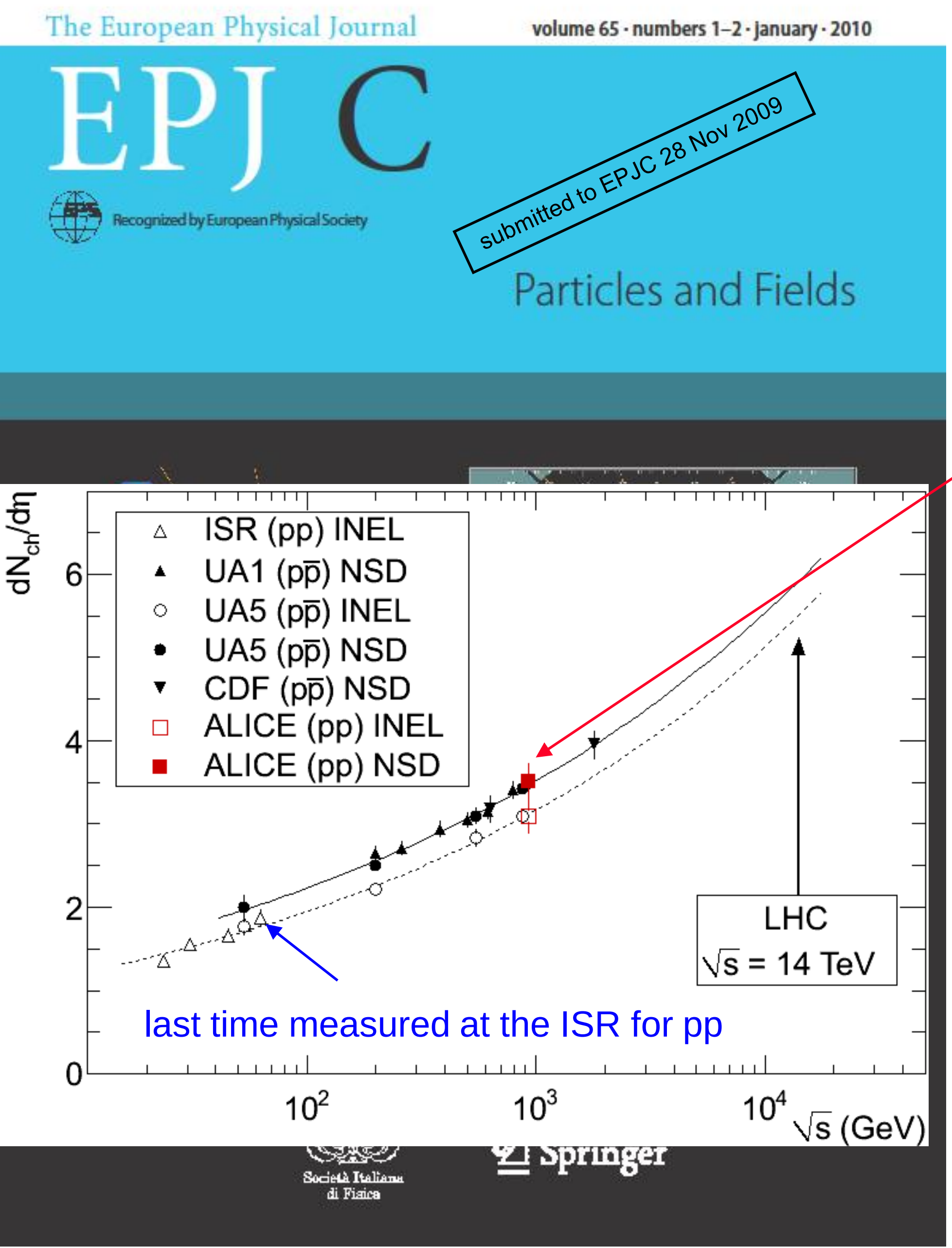
.. and some celebration..

~ 16:42

‘First Physics’ in the making

After years of looking at simulated data, there was no holding back:
First physics results examined,
ca 1 hour after data taking finished (284 events !)..

Physics exploitation of ALICE has started for good !



The **average number of charged particles** created perpendicular to the beam in pp collisions at 900 GeV is:

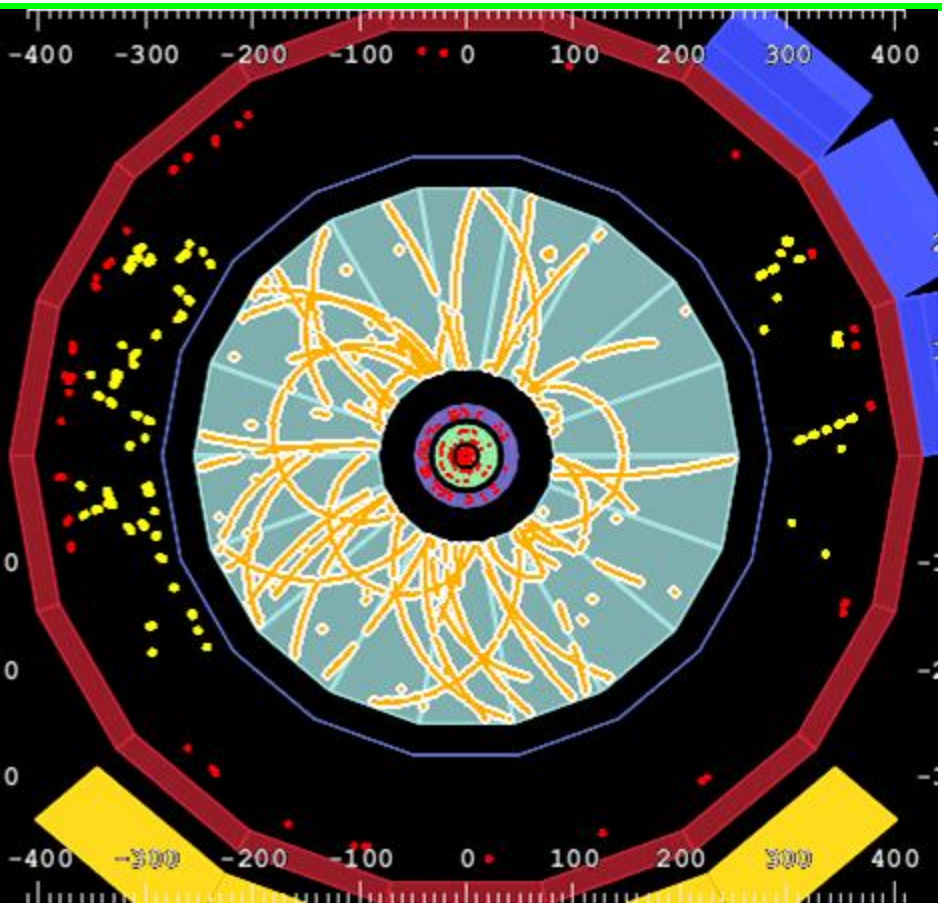
$dN/d\eta = 3.10 \pm 0.13$ (stat) ± 0.22 (syst) $\approx \pi$

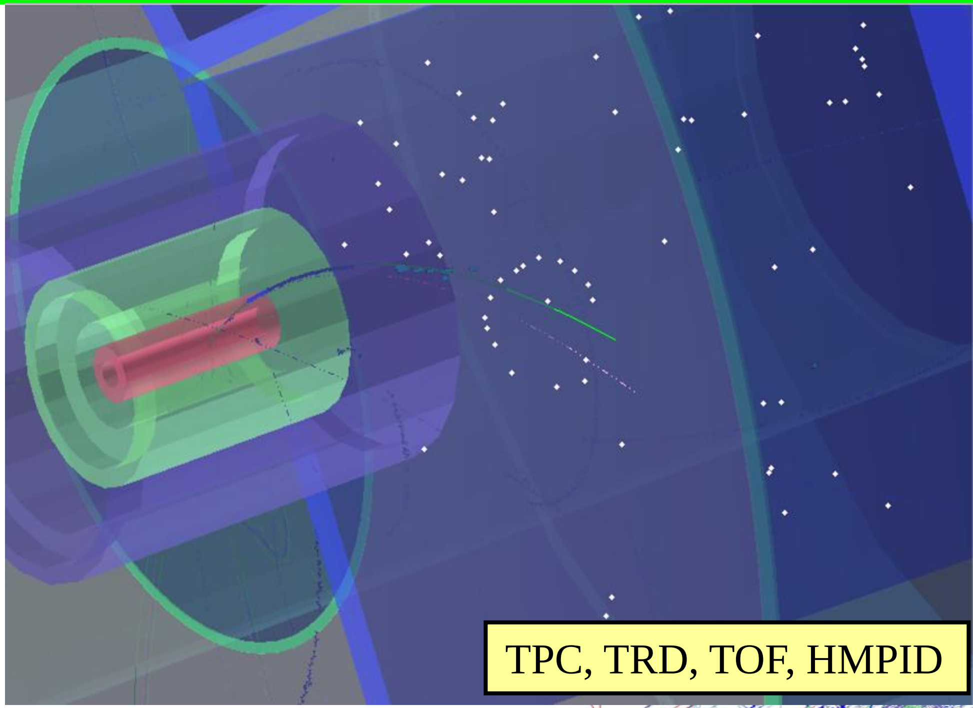
National Geographic News (4 Dec.)

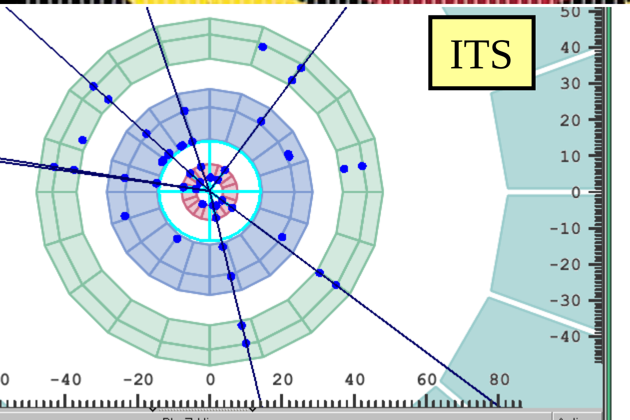
'….a machine called ALICE…. found that **a** (!) proton-proton collision recorded on November 23 **created the precise ratio of matter and antimatter particles predicted from theory..'**

- It took:
  - ⇨ 20 years to built ALICE
  - ⇨ 40 minutes to take the first data
  - ⇨ 1 hour to get the prel. result (±10%)
  - ⇨ 2 days for the final result
  - ⇨ and **3 days** to agree on the Authorlist

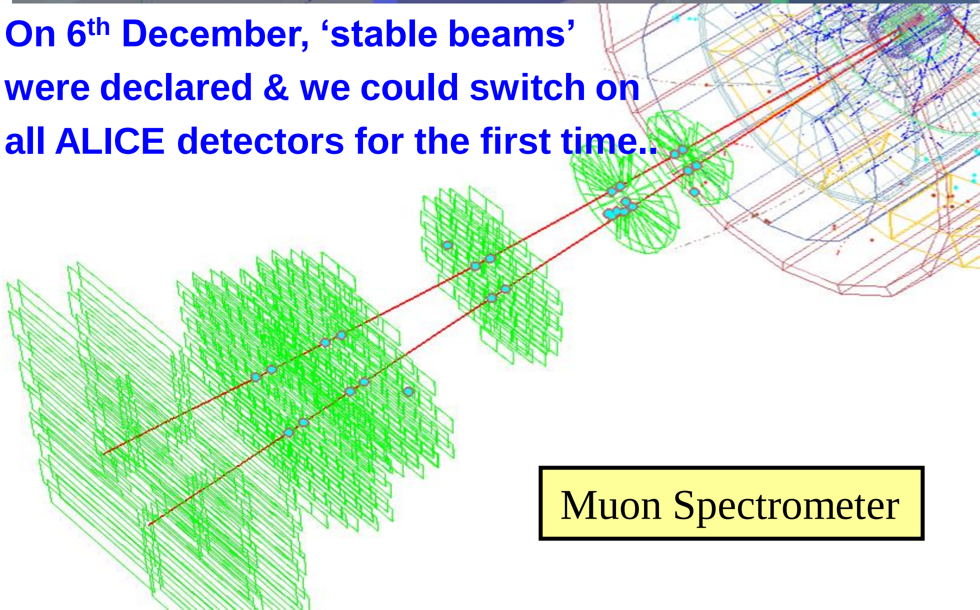
A few days later…



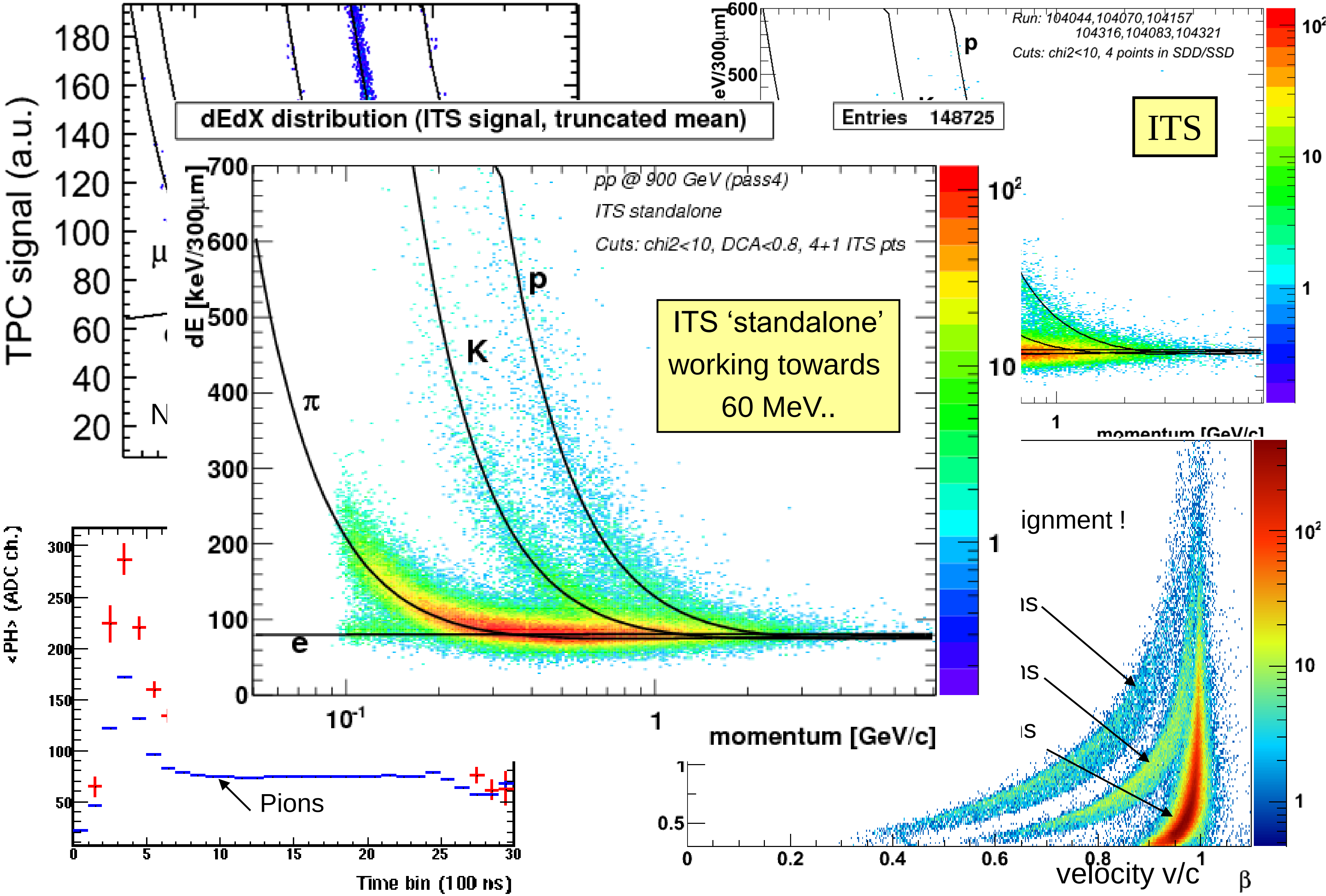




On 6th December, 'stable beams' were declared & we could switch on all ALICE detectors for the first time..

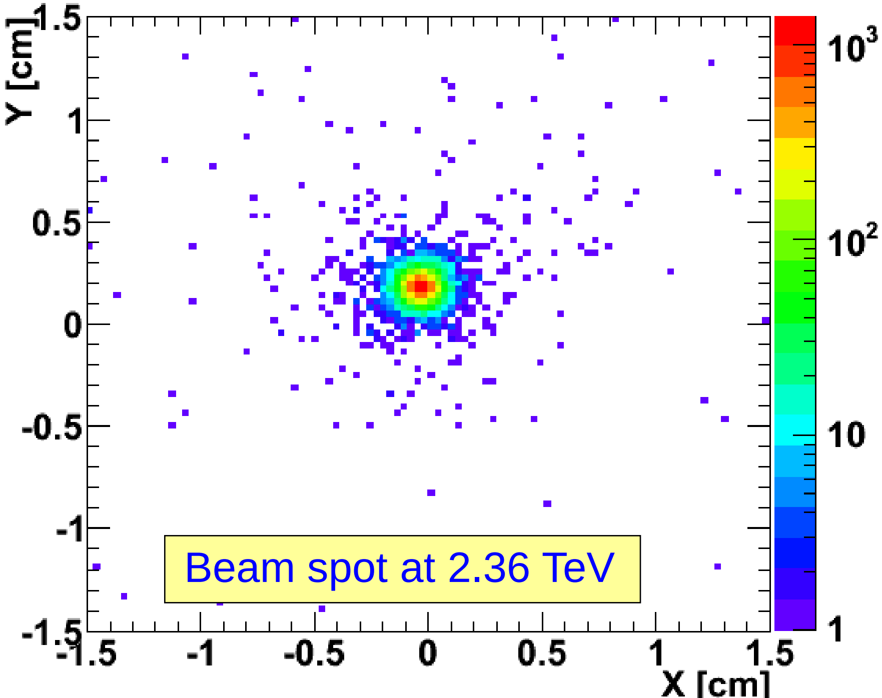


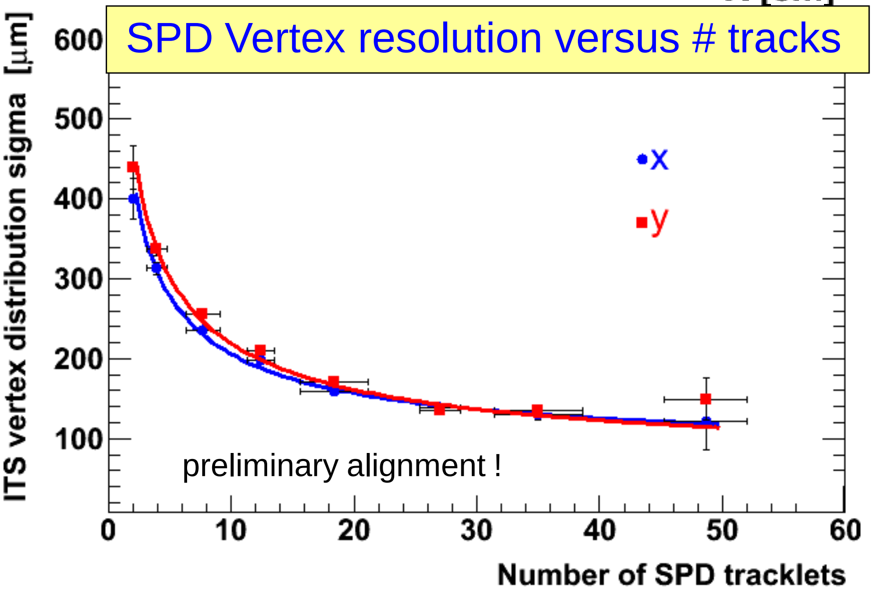
.. ‘lots’ of data..

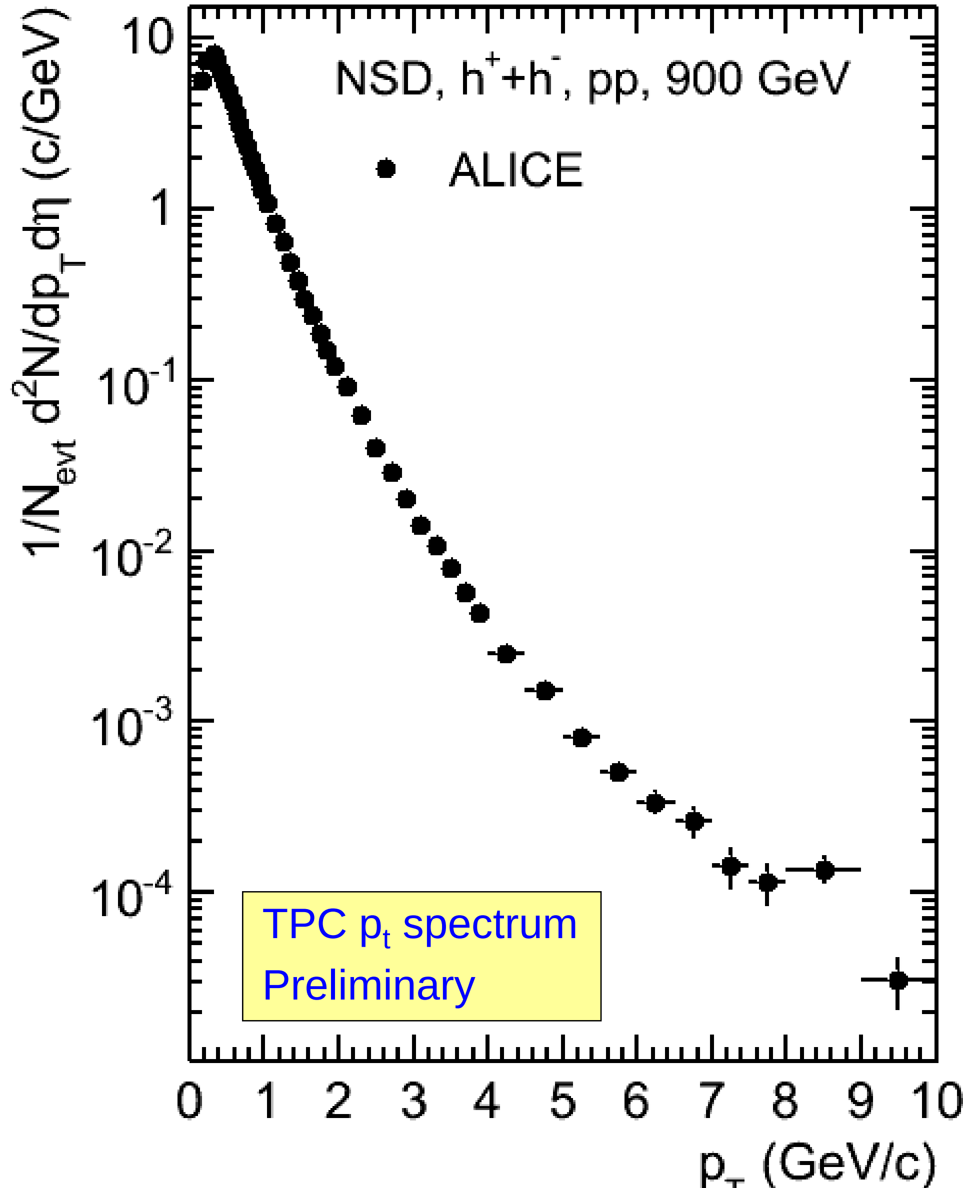


TPC signal (a.u.)
dEdX distribution (ITS signal, truncated mean)
Entries 148725
Run: 104044,104070,104157
104316,104083,104321
Cuts: chi2<10, 4 points in SDD/SSD
ITS
pp @ 900 GeV (pass4)
ITS standalone
Cuts: chi2<10, DCA<0.8, 4+1 ITS pts
dE [keV/300μm]
π
K
p
e
ITS ‘standalone’
working towards
60 MeV..
momentum [GeV/c]
ignment !
<PH> (ADC ch.)
Pions
Time bin (100 ns)
velocity v/c
β

Tracking works beautifully



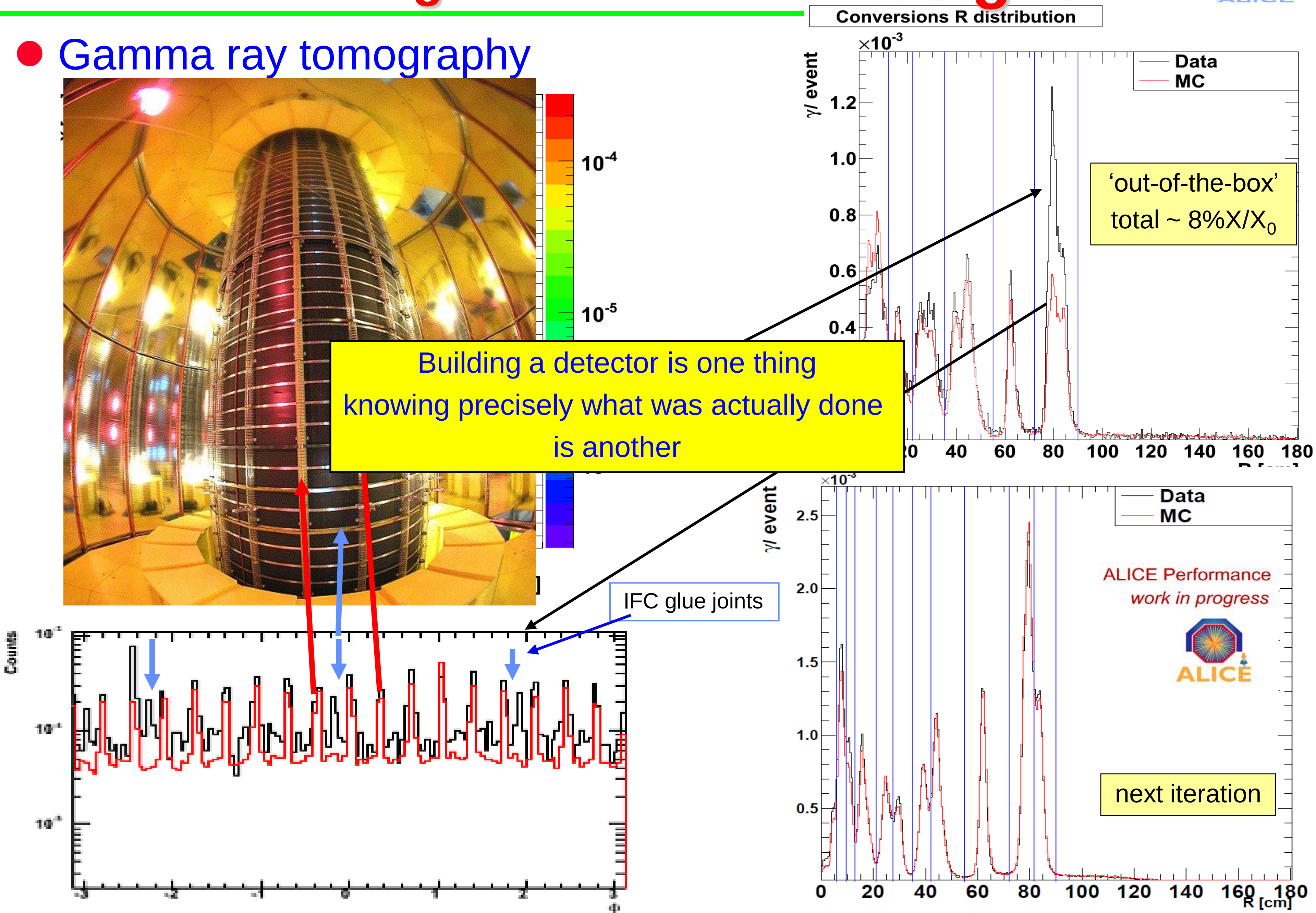




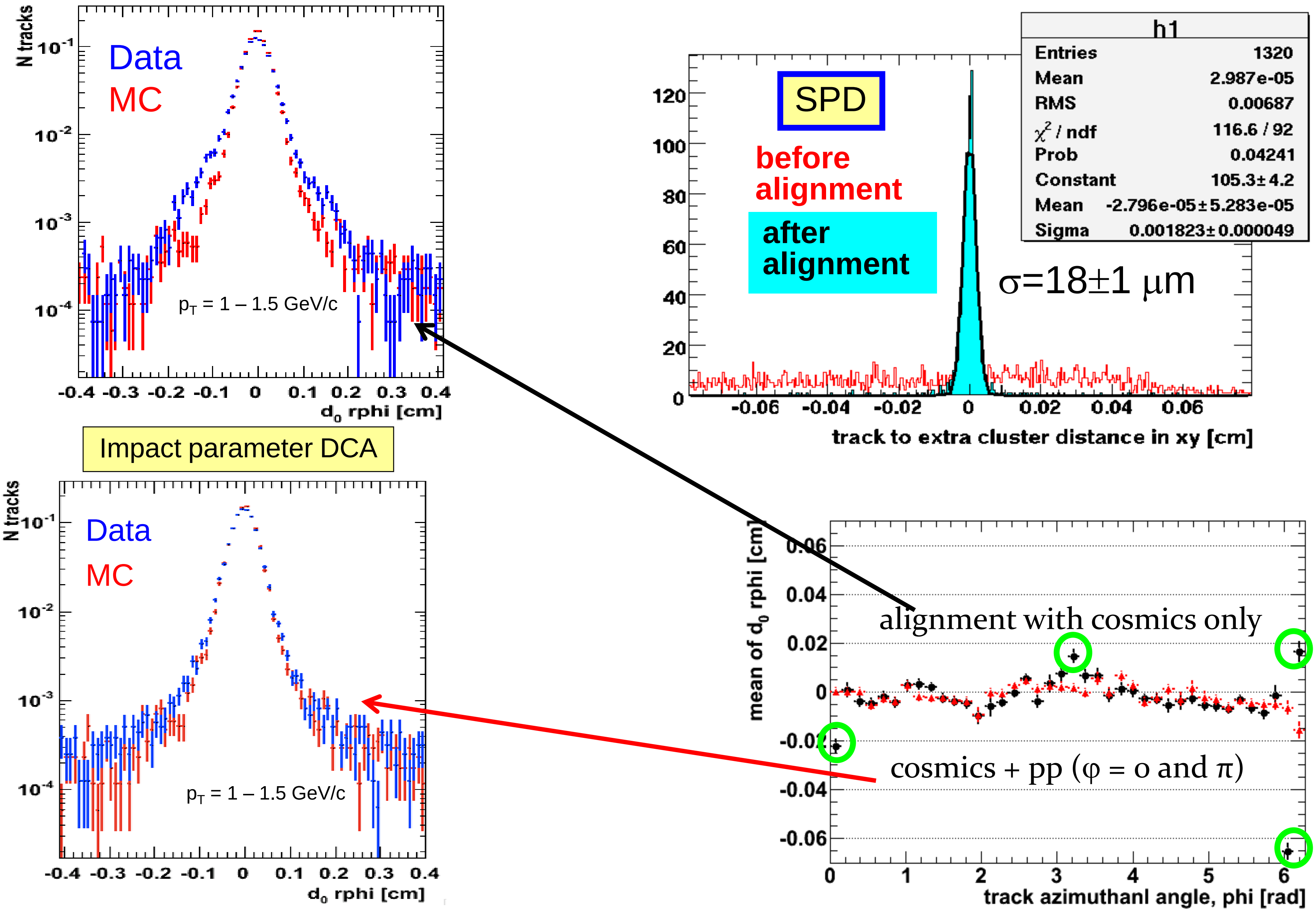
Plots as shown on 18 Dec ‘LHC’ jamboree

Getting to know ALICE: Weight

- Gamma ray tomography

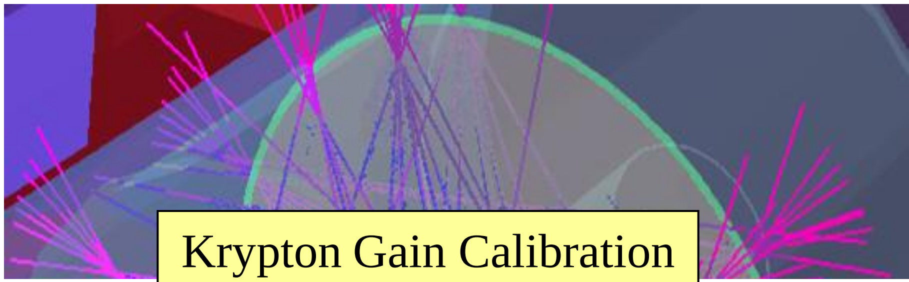


Getting to know ALICE: Shape

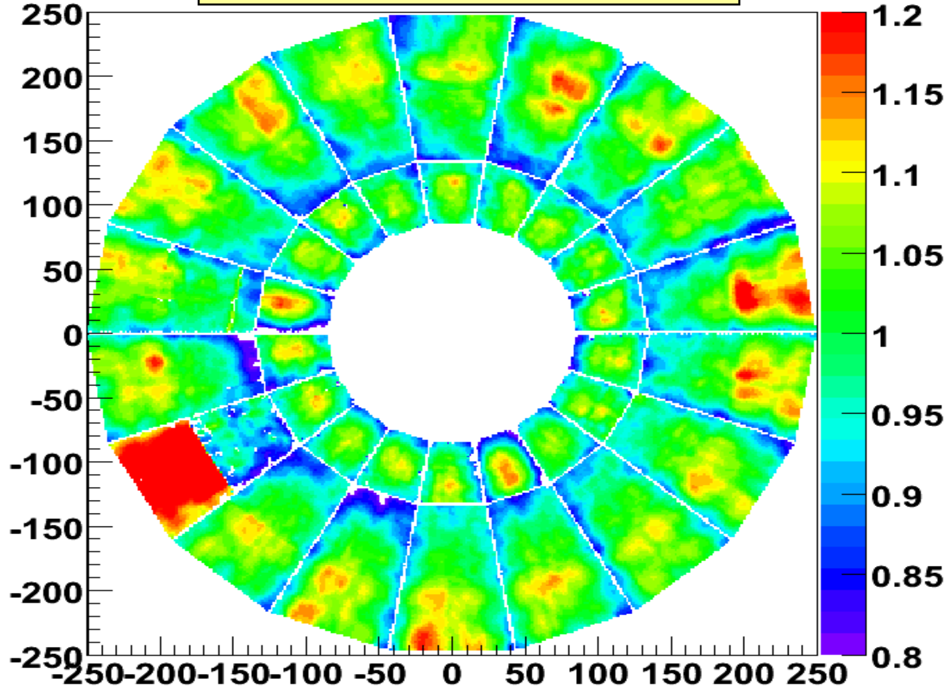


Getting to know : Calibration (non)constants

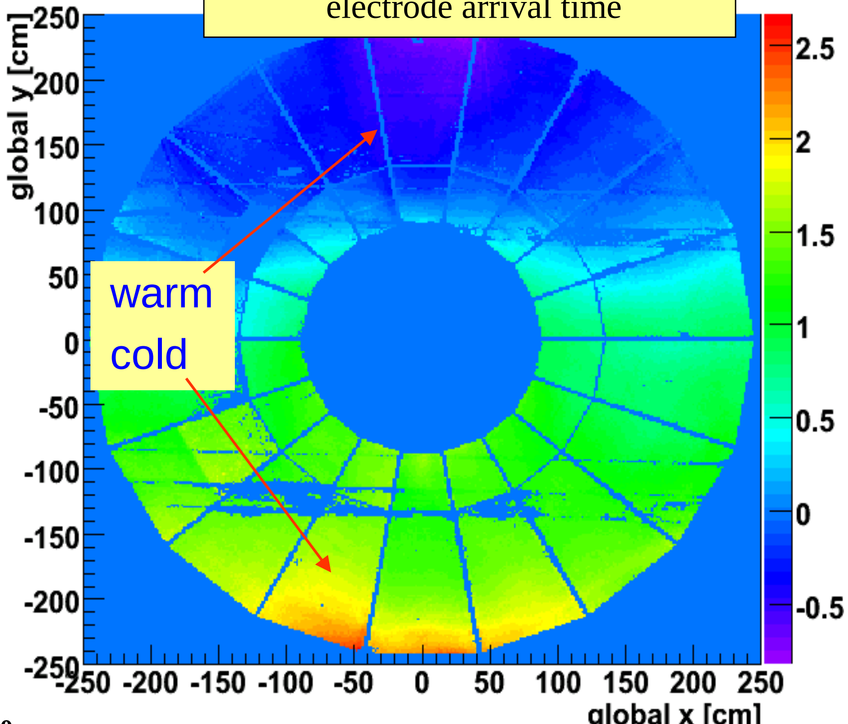
- TPC: concept simple, devil is in the details..
  - ⇨ v_drift = f(T, P, gas, ..), $\Delta v/v < 10^{-4}$, => 4 different methods used
  - ⇨ geometry, planarity (200μm/2m), ..
  - ⇨ Field distortions, ExB effect, $\omega\tau$, …
  - ⇨ pad-by-pad gain calibration (dE/dx < 5.5%



Krypton Gain Calibration



Laser Photo electrons from central electrode arrival time



Detector Status

Complete:

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

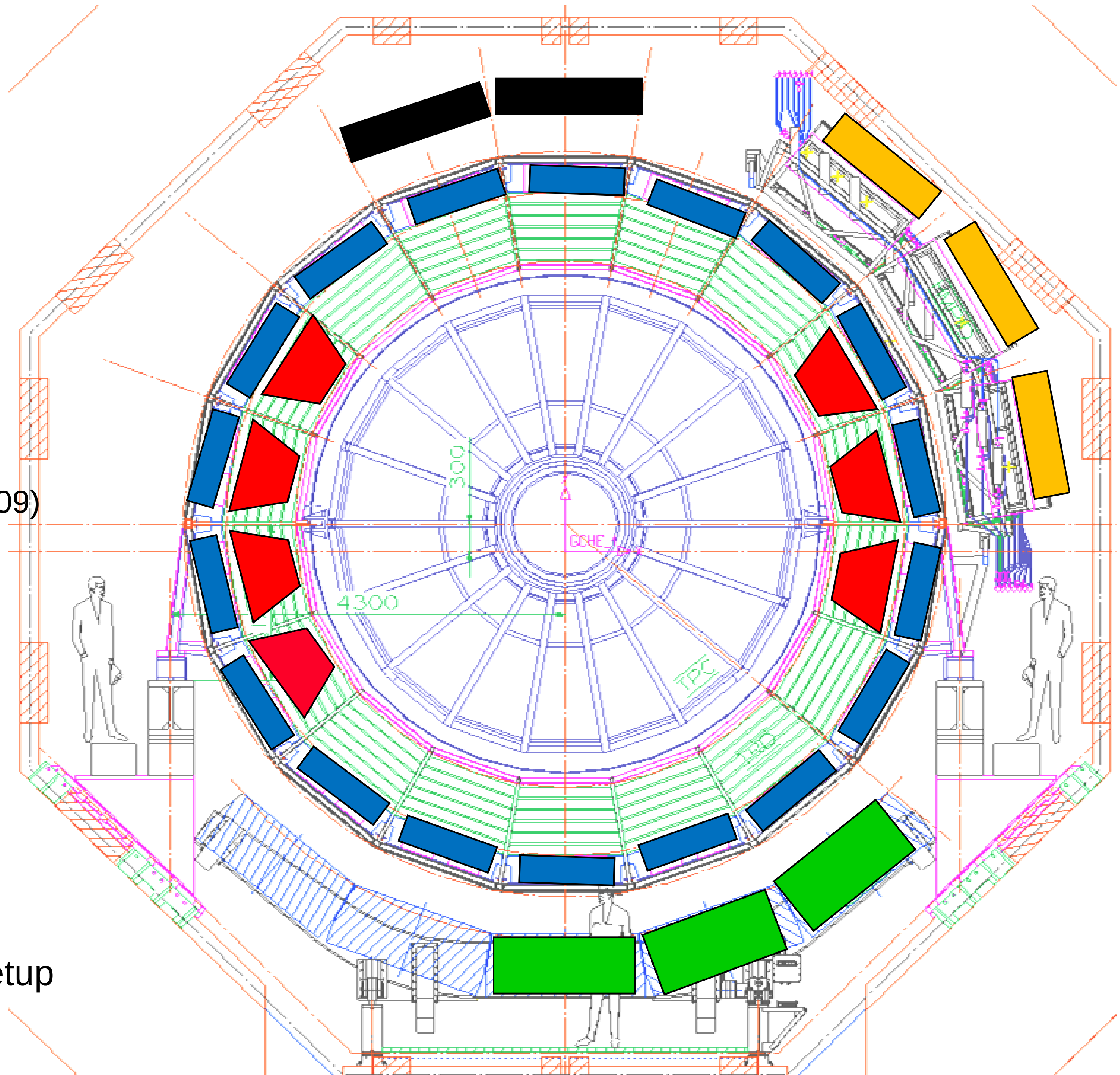
Partial installation:

3/5 PHOS (funding)

7/18 TRD* (approved 2002)

4/10 EMCAL* (approved 2009)

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



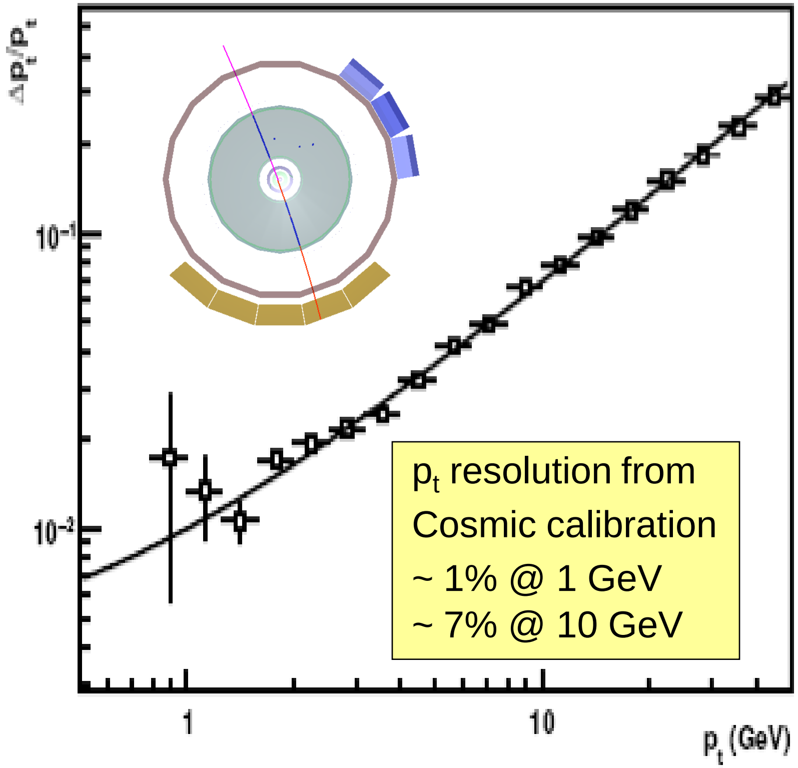
All systems fully operational

*upgrade to the original setup

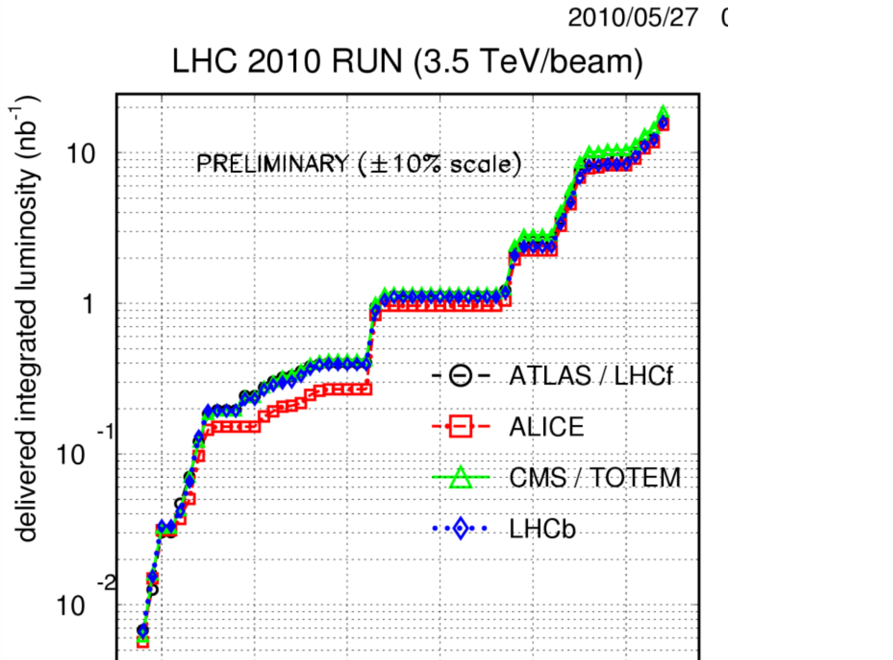
Commissioning Status

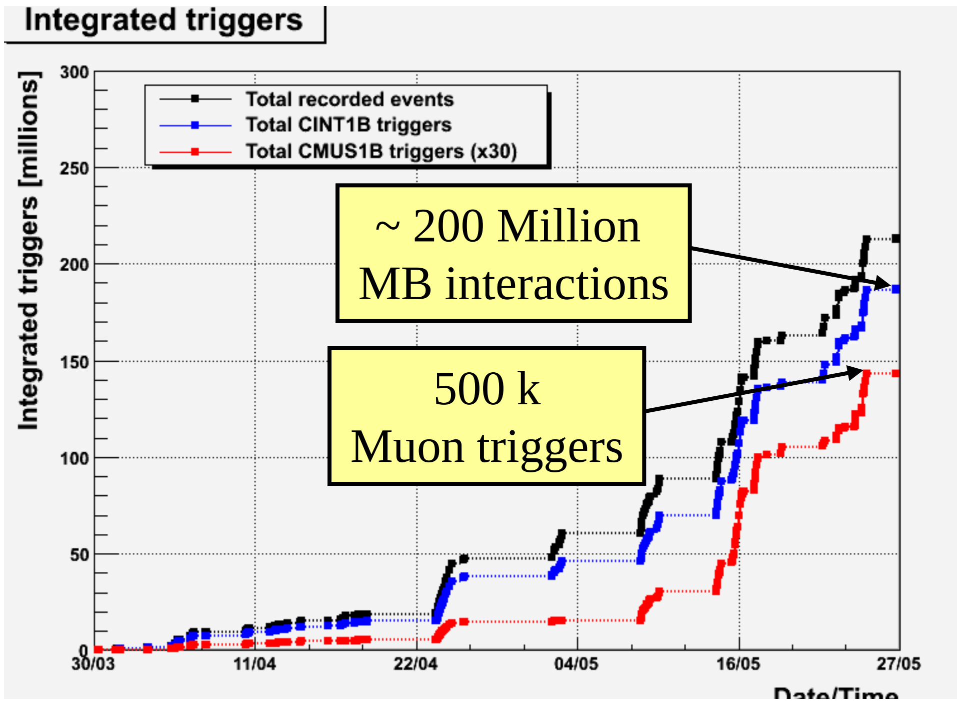
- Alignment (cosmics, collisions)
  - ⇨ SPD/SSD **< 10 μm** (~ final), SDD: **~100 μm**
  - ⇨ TPC: **200-300 μm** outer detectors: **~mm**
  - ⇨ Muon spectrometer: **~mm** (no cosmics !, design < 40 μm)

- Calibration:
  - ⇨ ITS: pulse height **~final**; SDD v_{drift} **ongoing**
  - ⇨ TPC: dE/dx **< 5.5%** (design), V_{drift} **< 10^{-4}**
    - ✪ field distortions: ~ 1mm, locally up to 3 mm
      momenta currently up to 10-20 GeV
      design resolution ITS+TPC: ~7% @100 GeV
  - ⇨ TOF: **~ 90 ps** (close to design)
  - ⇨ em calo: just **starting** (no test beam calibr.)
    - ✪ PHOS: <3%/√E + 1%
    - ✪ EMCAL: <10%/√E + 2%

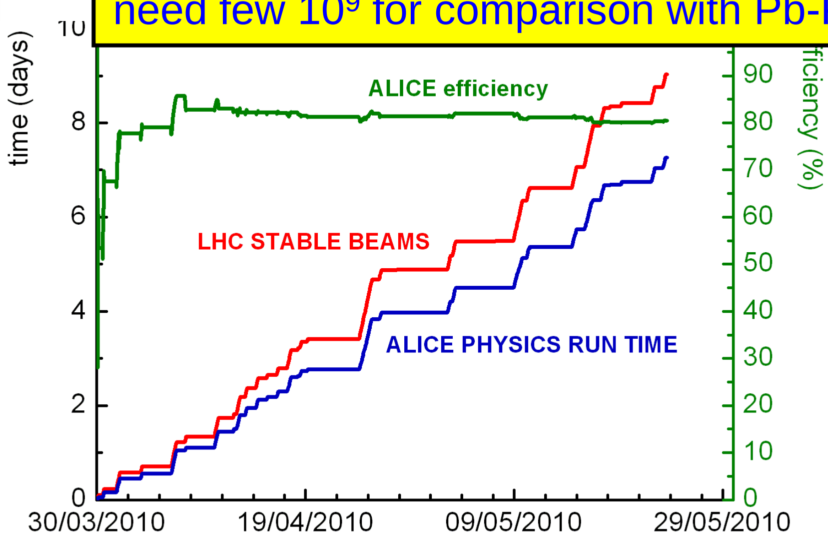


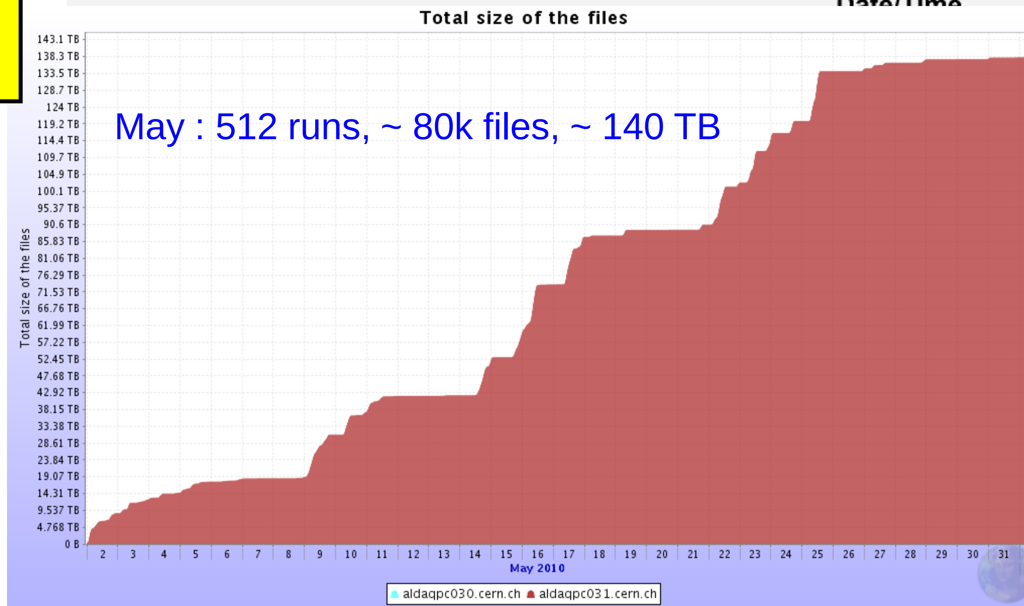
Data Taking



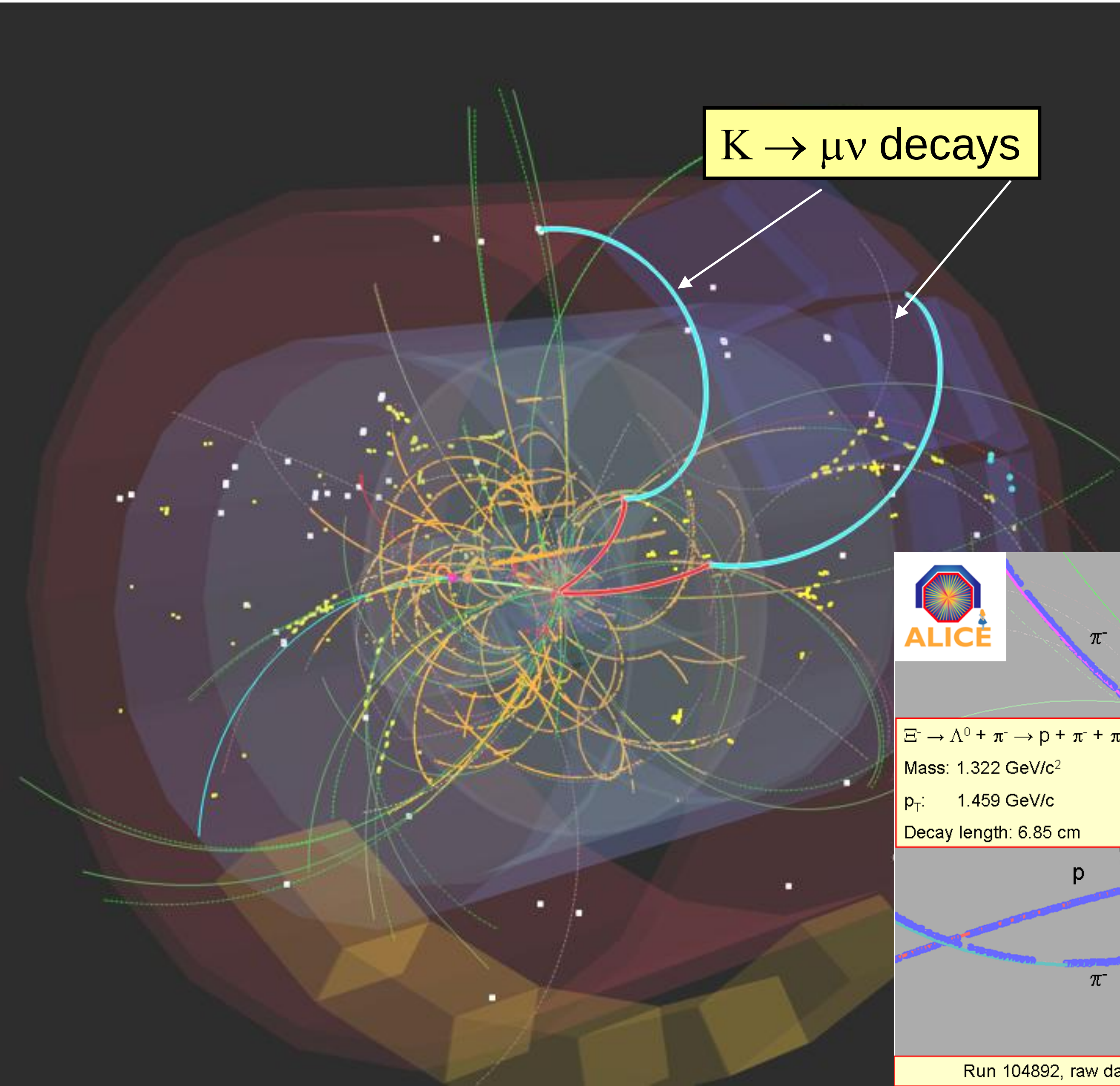


Emphasis so far on MinBias triggers need few 10^9 for comparison with Pb-Pb

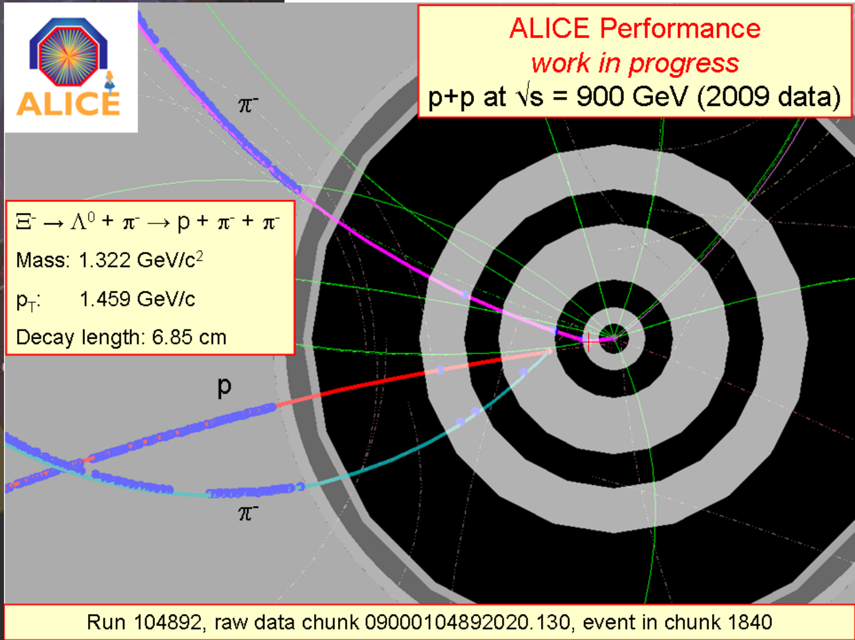




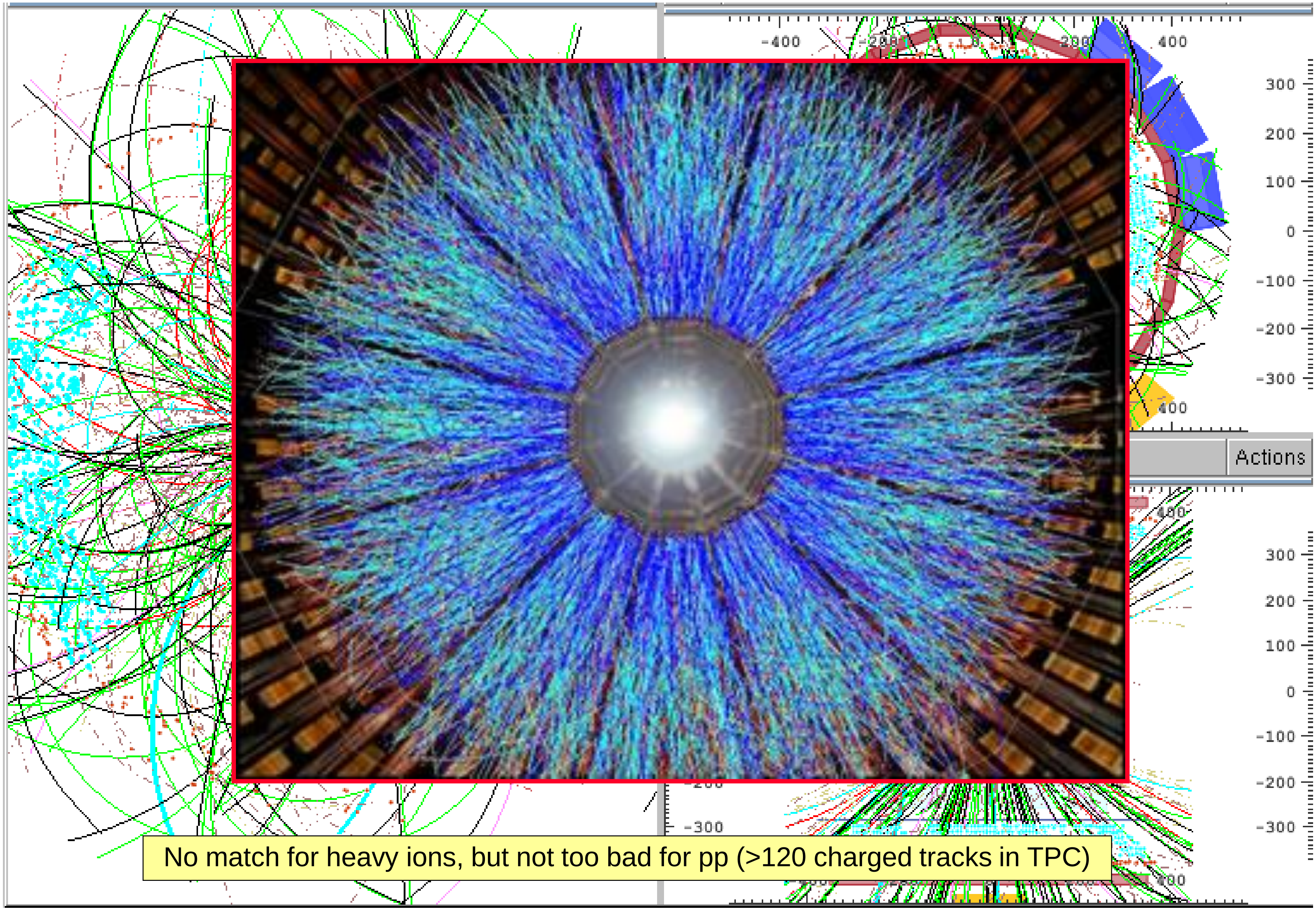
Events of all kinds



Ξ → Λπ → πp π



High Multiplicity Event



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

PHYSICS WITH ALICE

Outline

- Particle multiplicity
  - $dN_{ch}/d\eta$ and dN/dN_{ch} measurements at 0.9, 2.36, and 7 TeV
- Momentum spectra
  - Charged particle p_t spectra at 0.9 TeV
- Baryon production
  - Anti-proton/proton ratio at 0.9 and 7 TeV
- Particle emitting source
  - Femtoscopy (HBT) at 0.9 TeV
- Momentum spectra, outlook
  - Identified charged p_t spectra at 0.9 TeV
  - Strangeness at 0.9 and 7 TeV
  - π^0 and jet reconstruction at 7 TeV
- Event topology
  - Event shape and underlying event at 7 TeV
- Heavy Flavour production
  - Charm and J/ψ production at 7 TeV

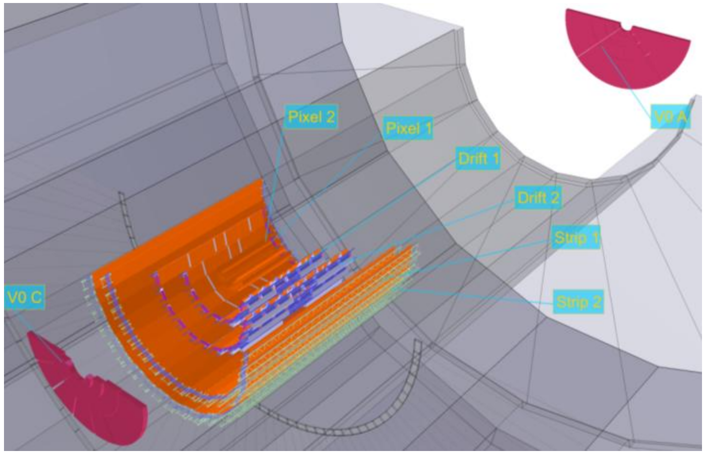
published

preliminary

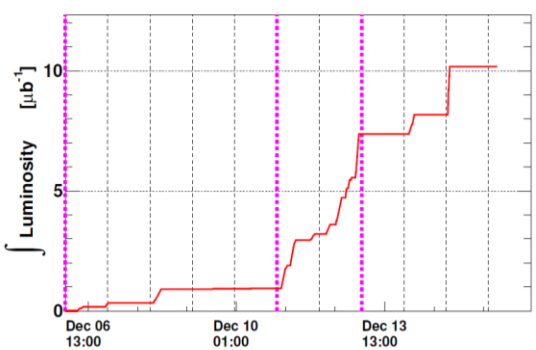
in preparation

Trigger & Data samples

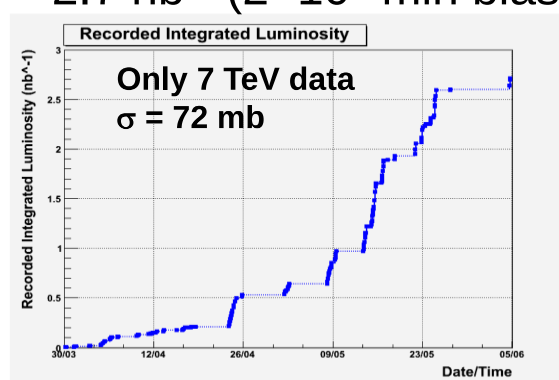
- **"Minimum bias"**, based on interaction trigger:
  - **SPD** **or** **V0-A or V0-C**
    - at least one charged particle in 8 η units
  - read out all ALICE
- **single-muon** trigger:
  - forward muon in coincidence with Min Bias
  - read out MUON, SPD, V0, FMD, ZDC
- Activated in coincidence with the BPTX beam pickups



- 2009 (0.9 and 2.36 TeV)
  - ~10.3 μb^{-1} (5×10^5 min bias)



- 2010, to June 8th (0.9 and 7 TeV)
  - ~2.7 nb^{-1} (2×10^8 min bias)



Outline

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  - Charm and J/ψ production at 7 TeV

published

preliminary

in preparation

Multiplicity Measurement

- Published results
  - $dN_{ch}/d\eta$ at 0.9 TeV. EPJC 65 (2010) 111
- Accepted by EPJC:
  - $dN_{ch}/d\eta$ and dN/dN_{ch} at 0.9 and 2.36 TeV. hep-ex:1004.3034(2010)
  - $dN_{ch}/d\eta$ and dN/dN_{ch} at 7.0 TeV. hep-ex:1004.3514(2010)

Event Classes

0.9 and 2.36 TeV

- Inelastic (INEL) =
  Single-diffractive (SD) +
  Double-diffractive (DD) +
  Non-diffractive (ND);
- Non-single diffractive (NSD)
- Use measured cross sections for diffractive processes
  - Change MC generator fractions (SD/INEL, DD/INEL) such that they match these fractions
  - Use Pythia and Phojet to assess effect of uncertainty in the kinematics of diffractive processes

7 TeV

- Diffraction is quite unknown
- Hadron-level definition of events to minimize model dependence
  - All events that have at least one charged primary particle in $|\eta| < 1$: "INEL>0"

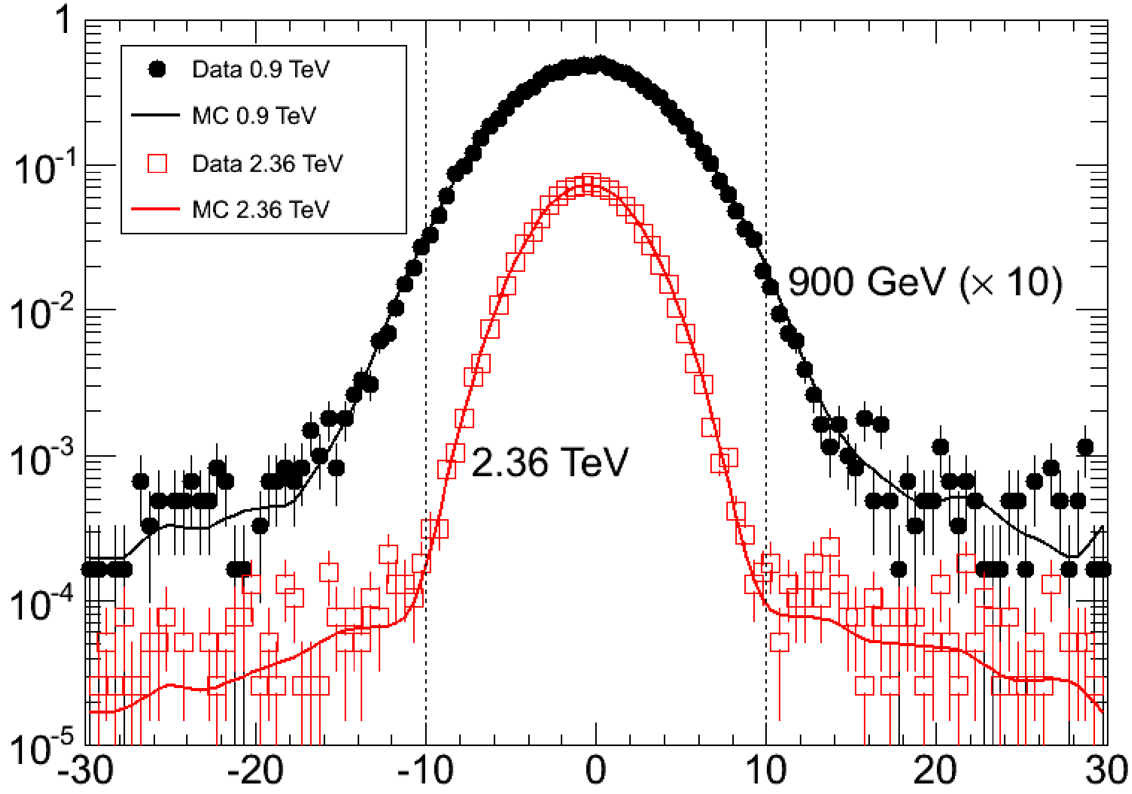
Vertex Reconstruction

The reconstruction correlates the hits in the two pixel layers.
Resolution:

longitudinal 0.1-0.3 mm
transverse 0.2-0.5 mm

Good agreement with MC

More details in the poster of Davide Caffarri



Pseudorapidity Density dN/dη

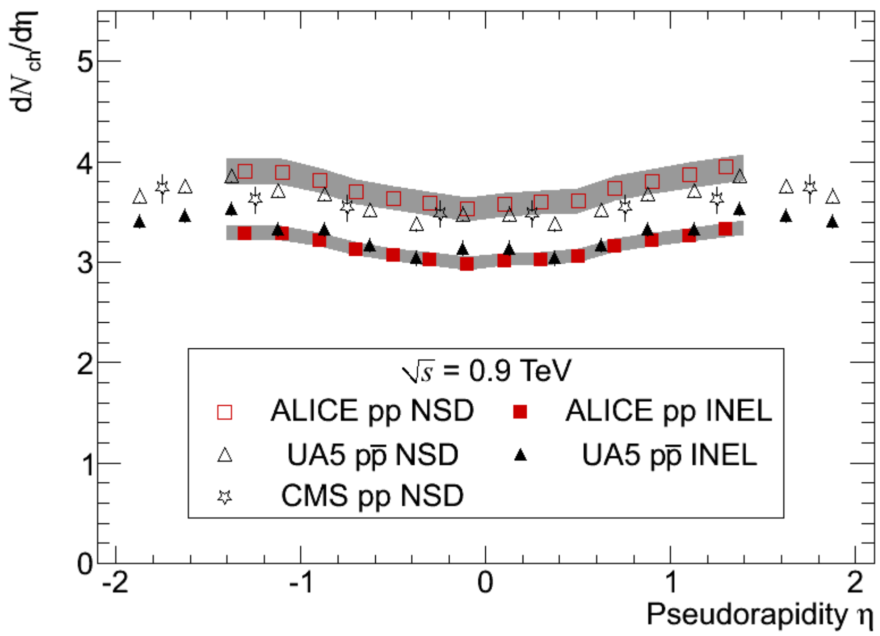
- Analysis:
  - Based on tracklets (hits in the two SPD layers that form short track segments): wider acceptance => smaller corrections
  - Triggered events with vertex
  - Select primary charged particles: matching with the primary vertex, quality cuts
  - Apply multidimensional (η, z_V, p_T) corrections

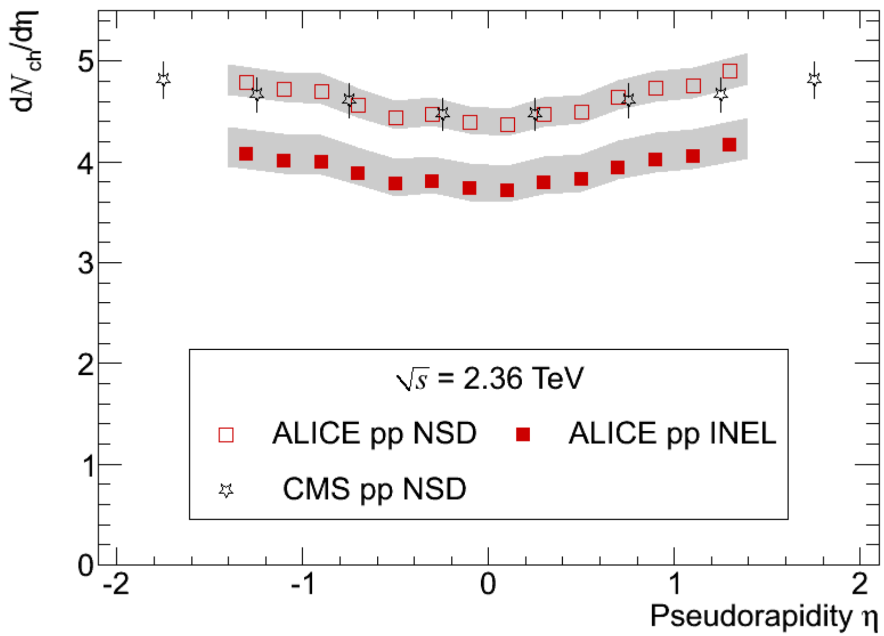
Primary particles = charged particles produced in the collision and their decay products excluding weak decays from strange particles

- Track-to-particle correction
  - Detector acceptance, tracking efficiency
  - Decay, conversions, stopping, etc.
  - Low momentum cut-off ($B \neq 0$)
- Correction for vertex reconstruction efficiency/bias
- Trigger bias correction
  - Using control triggers
  - From MC
- For NSD: remove residual contamination from SD

$dN_{ch}/d\eta$ – Results & Comparison to Other Experiments

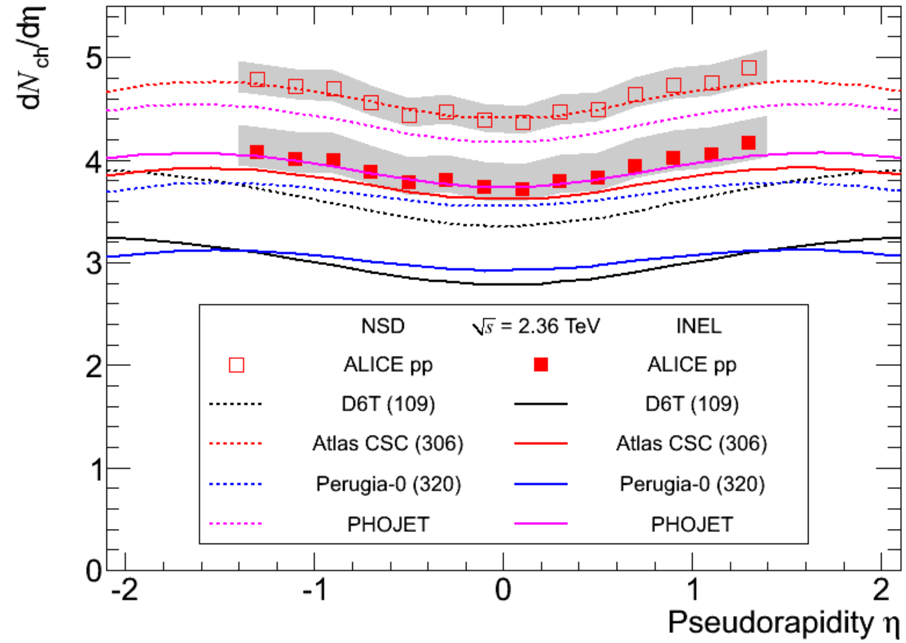
- Good agreement with UA5 (INEL at 0.9 TeV) and CMS (NSD at 0.9 TeV and 2.36 TeV)

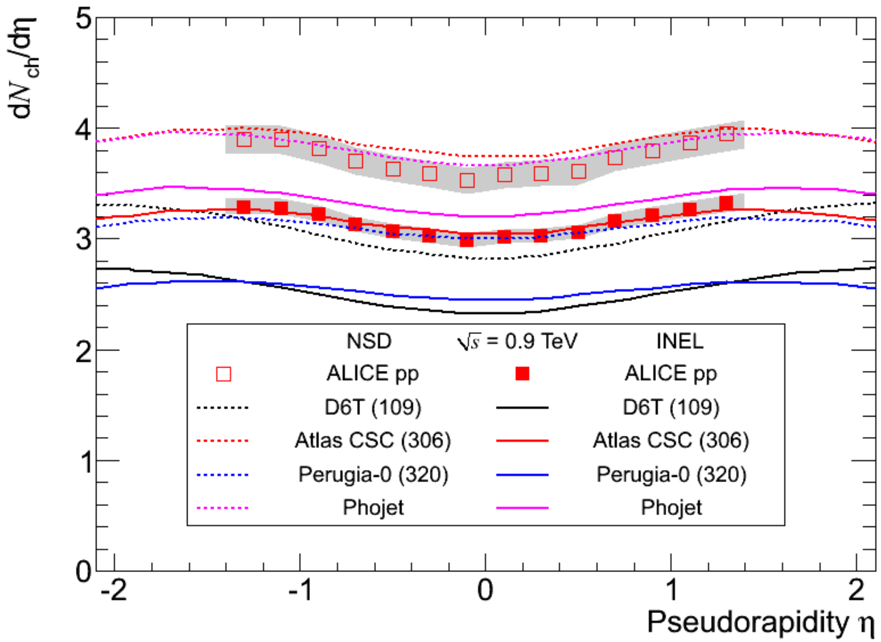


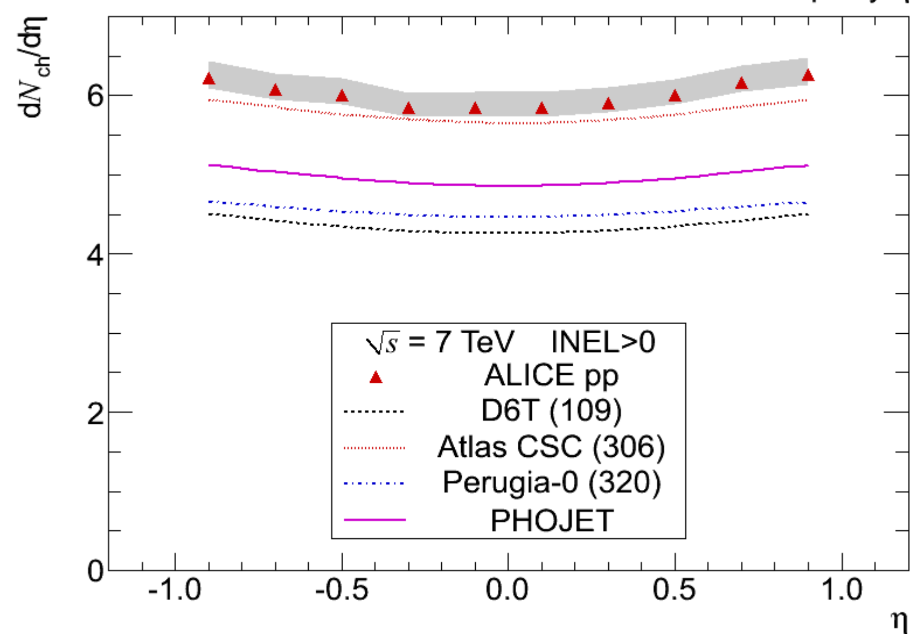


$dN_{ch}/d\eta$ – Comparison to Models

- Pythia D6T and Perugia-0 match neither INEL, NSD, INEL>0 at all three energies
- Pythia Atlas CSC and Phojet reasonably close with some deviations at 0.9 and 2.36 TeV
- Only Atlas CSC close at 7 TeV

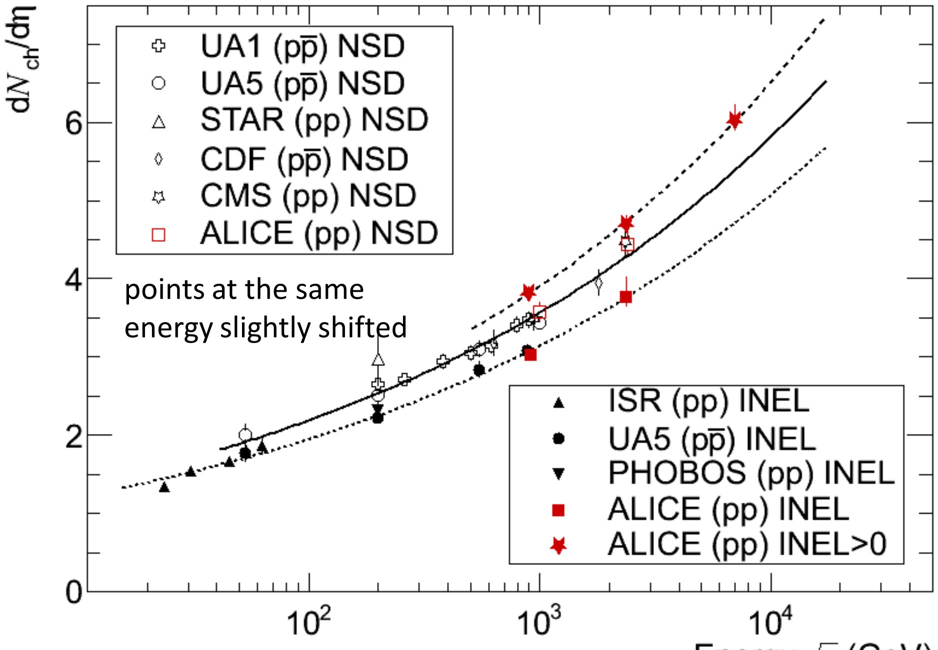


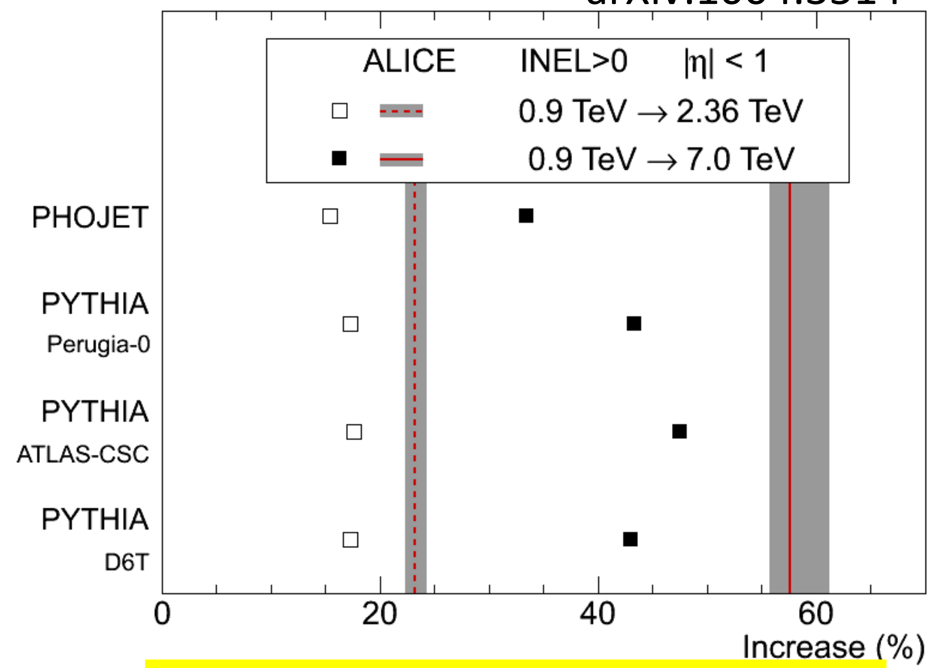




$dN_{ch}/d\eta$ – Energy Dependence

arXiv:1004.3514





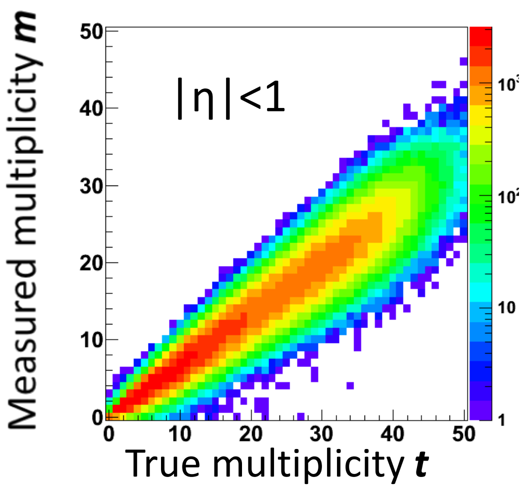
Power law dependence fits well

Significantly larger increase from 0.9 to 7 TeV than in MCs

Increase in $dN_{ch}/d\eta$ in $|\eta| < 1$ for INEL > 0 arXiv:1004.3514	**√s**	**ALICE (%)**	**MCs (%)**
	0.9 → 2.36 TeV	**$23.3 \pm 0.4 {}_{-0.7}^{+1.1}$**	**15 – 18**
	0.9 → 7 TeV	**$57.6 \pm 0.4 {}_{-1.8}^{+3.6}$**	**33 – 48**

Multiplicity Distributions

- Analysis:
  - Select z_V interval where the η acceptance is uniform (MC): $|z_V|<5.5$cm
  - Efficiency, acceptance => Detector response function (MC): Probability that a collision with the true multiplicity ***t*** is measured as an event with the multiplicity ***m***



- Unfolding
  - Regularization: $\chi^2(U)$-> min

$$\chi^2(U) = \sum_m \left(\frac{M_m - \sum_t R_{mt} U_t}{e_m} \right)^2 + \beta P(U)$$

  - Bayesian: iterative

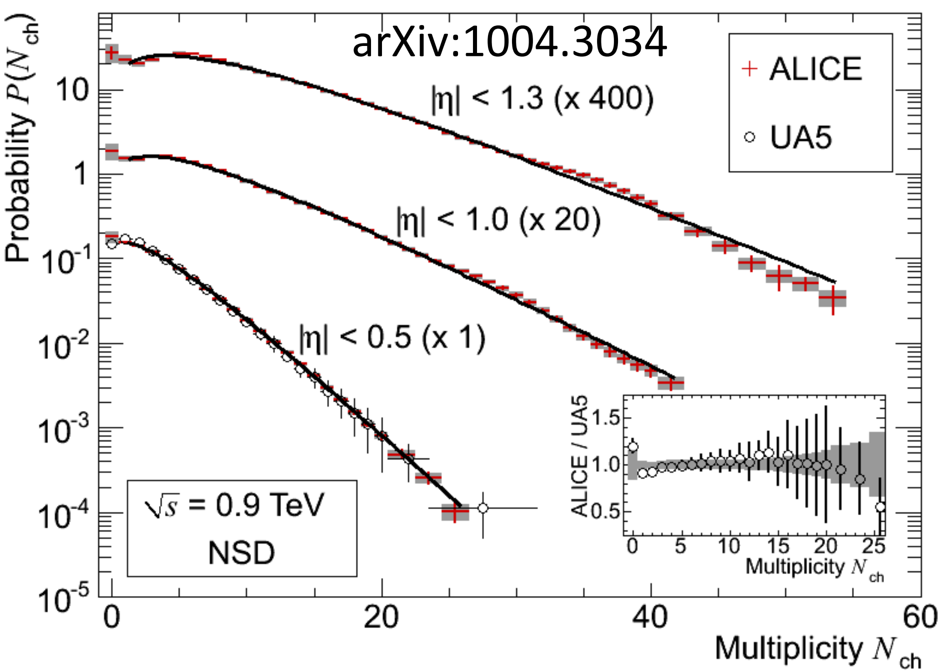
$$\tilde{R}_{tm} = \frac{R_{mt} P_t}{\sum_{t'} R_{mt'} P_{t'}}, \quad U_t = \sum_m \tilde{R}_{tm} M_m$$

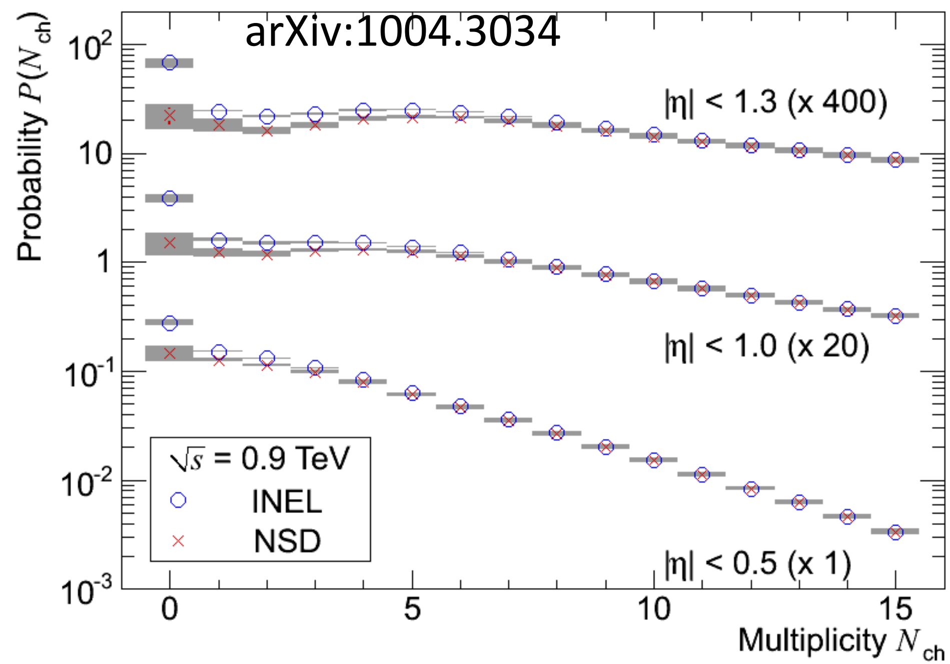
Smooth (or not) U_t and use it as P_t

- Corrections for vertex reconstruction and trigger bias
  - Like for $dN_{ch}/d\eta$, but in unfolded variables (true multiplicity) because it is applied after unfolding

Multiplicity Distributions at 0.9 TeV

- Distributions in limited η-regions
- Consistent with UA5
- Fits with one NBD work well in limited η-regions
- Difference between INEL and NSD in low-multiplicity region

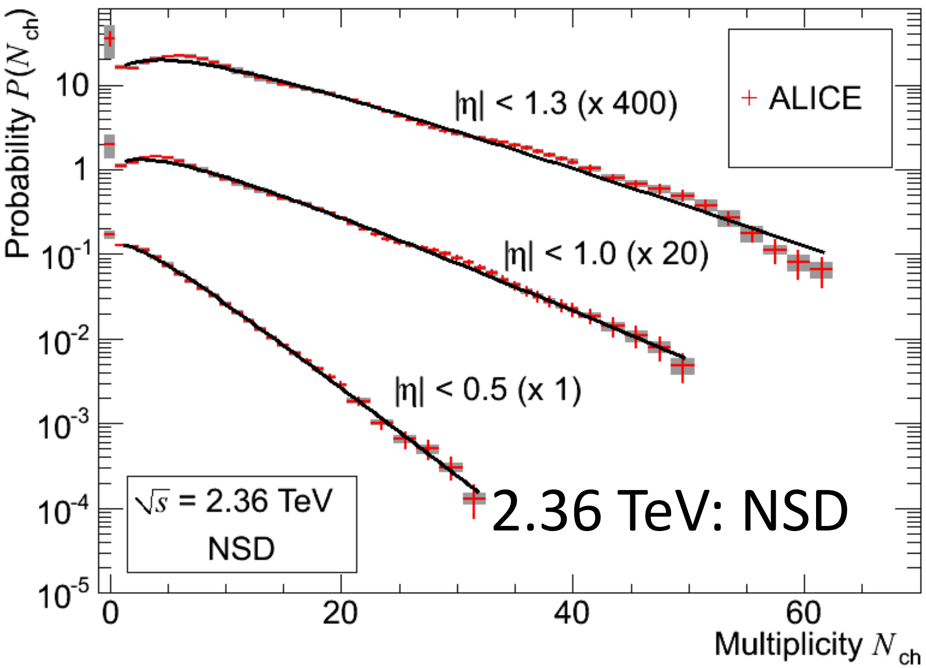




Multiplicity Distributions at 2.36 and 7 TeV

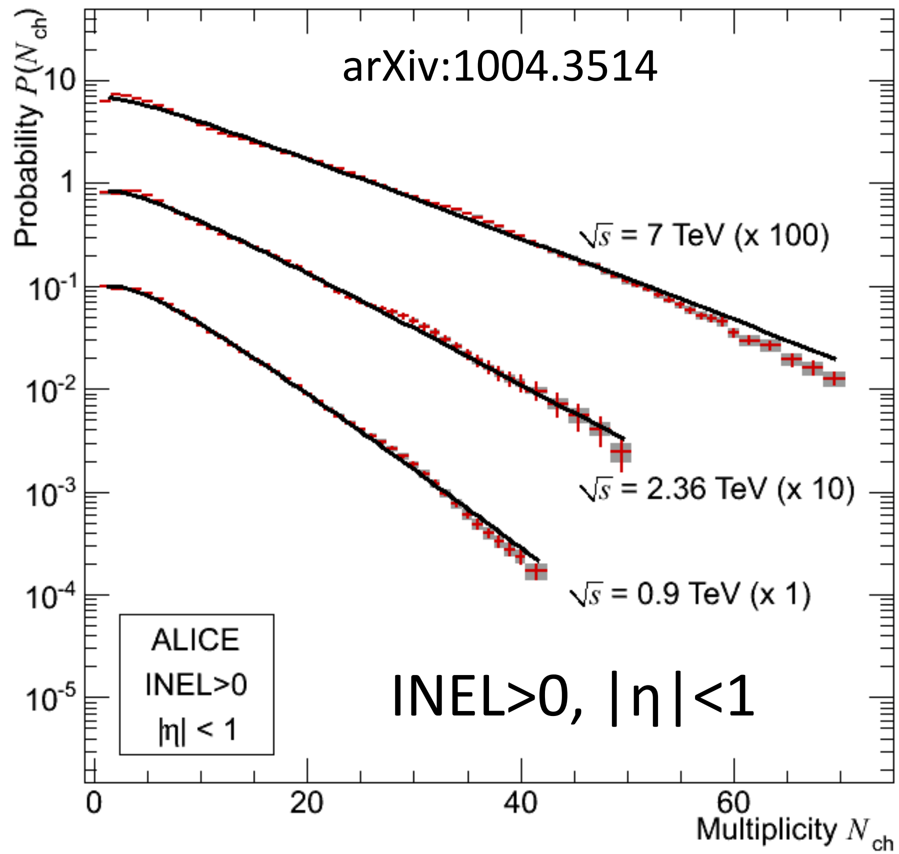
- Fits with one NBD work also at 2.36 and 7 TeV

arXiv:1004.3034



2.36 TeV: NSD

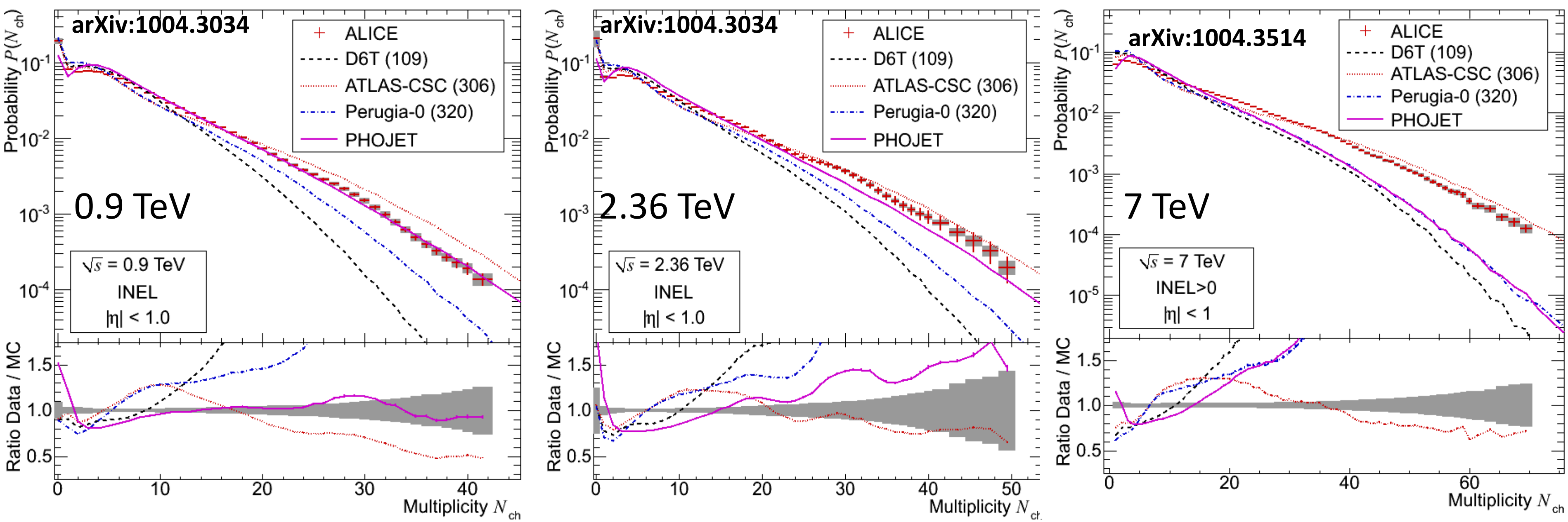
arXiv:1004.3514



INEL>0, |η|<1

Multiplicity Distributions: Comparison to MC

- Phojet
  - provides a good description at 0.9 TeV
  - fails at 2.36 and 7 TeV
- Pythia: Atlas CSC
  - fails at 0.9 TeV
  - reasonably close at 2.36 and 7 TeV but deviations around 10-20
- Pythia: D6T and Perugia-0 far from the distribution at all energies



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- Particle multiplicity
  - $dN_{ch}/d\eta$ and dN/dN_{ch} measurements at 0.9, 2.36, and 7 TeV
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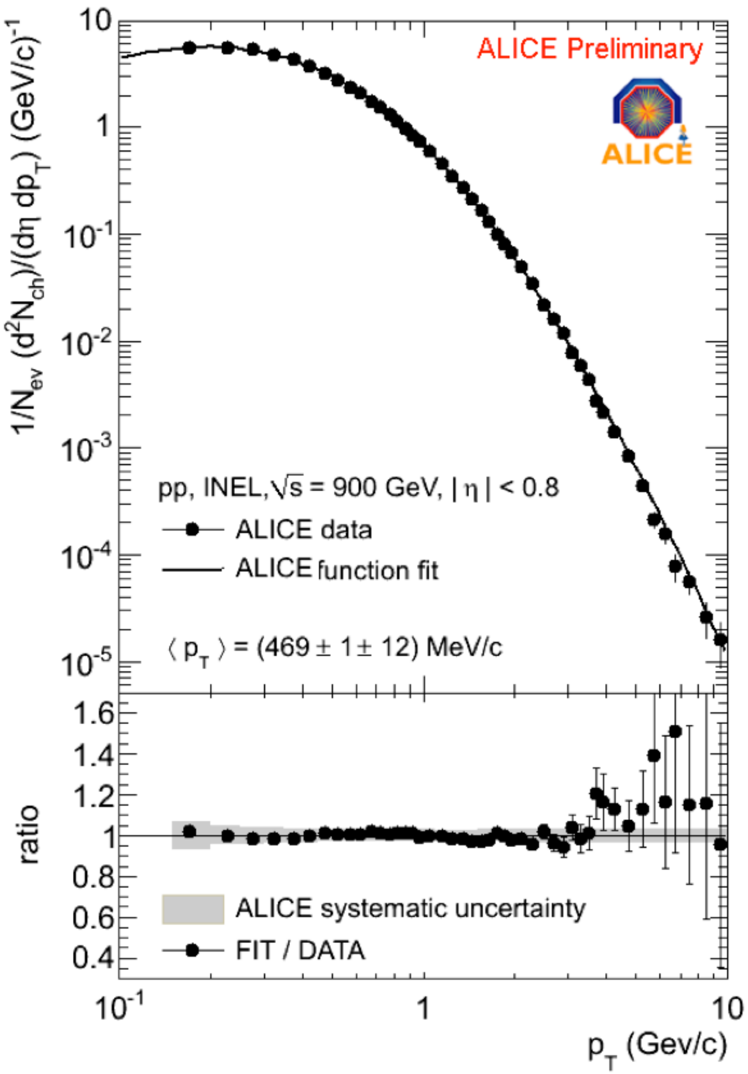
dN_{ch}/dp_T – Results



- The selection of primary tracks is based on the transverse impact parameter from ITS (7σ) + quality criteria in ITS and TPC
- The momentum is estimated by TPC (the ITS-TPC alignment is not final)

$$\sigma(p_T)/p_T = 0.01 \oplus 0.007\, p_T,\ p_T \text{ in } GeV/c$$

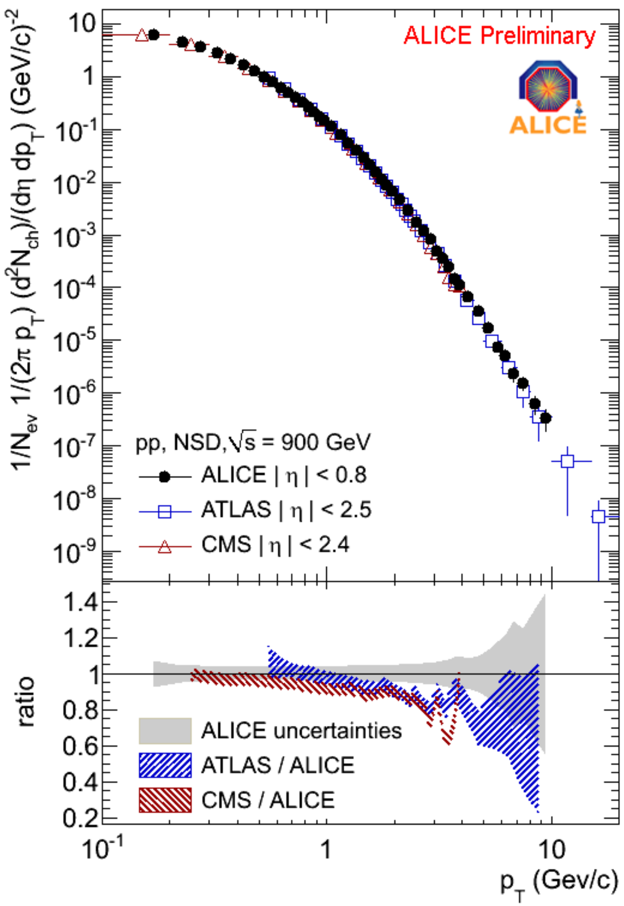
- A fit is used to extrapolate the distribution to p_T=0

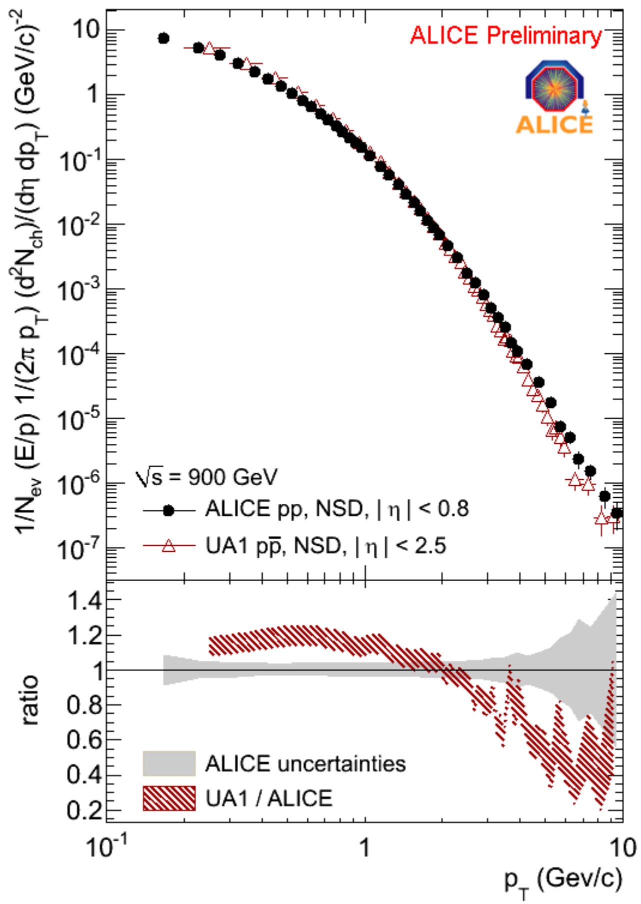
$$\frac{d^2N_{ch}}{d\eta dp_T} \propto p_T\left(1+\frac{E_T}{nT}\right)^{-n}$$

dN_{ch}/dp_T – Comparison to Other Experiments

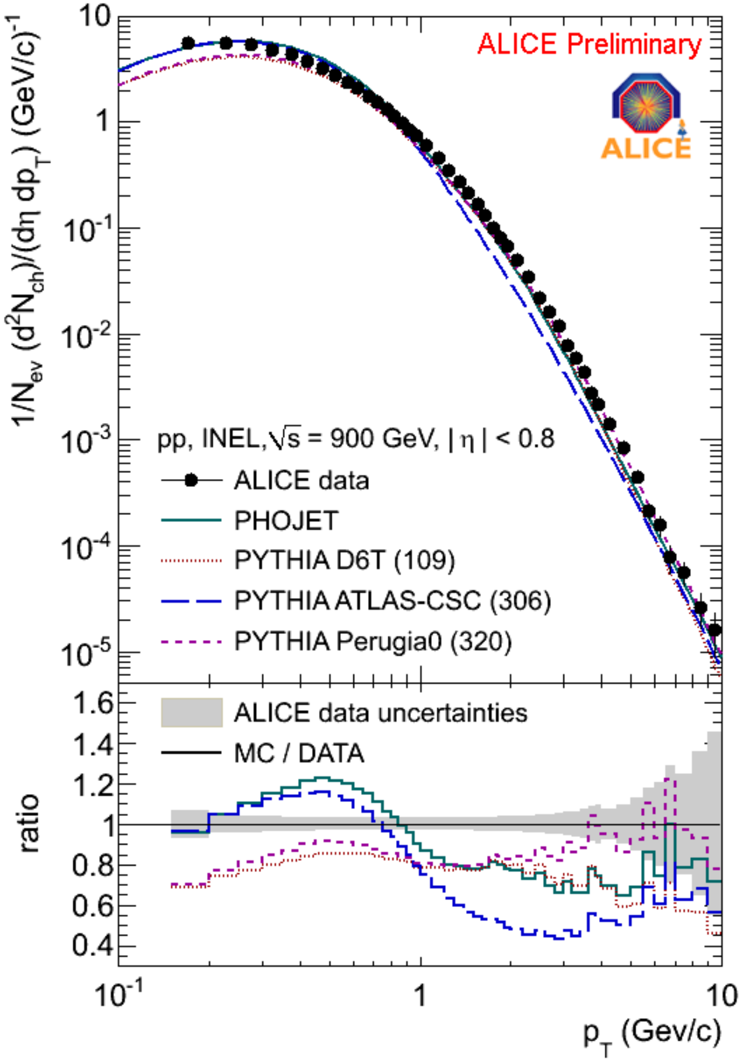
- Good agreement at p_T<1 GeV/c
- ALICE spectrum harder at higher p_T

- UA1 sees higher yield at low p_T – larger η acceptance



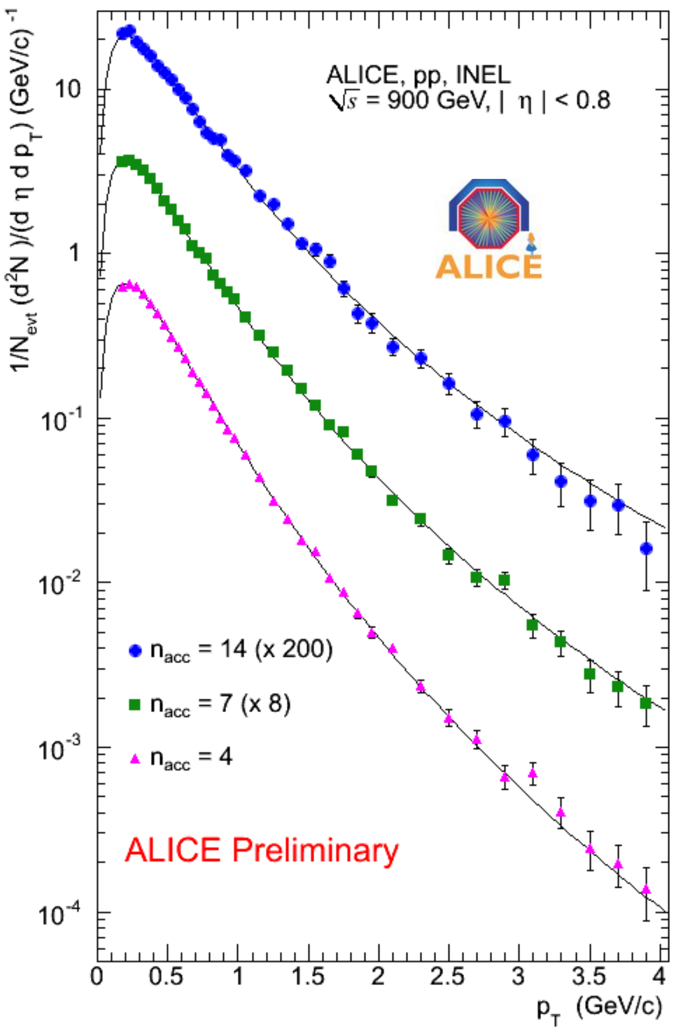


dN_{ch}/dp_T – Comparison to MC



- PYTHIA D6T and Perugia0 describe shape reasonably well but fail in the yield
- PHOJET and ATLAS-CSC are off

$<p_T>$ Dependence on Multiplicity

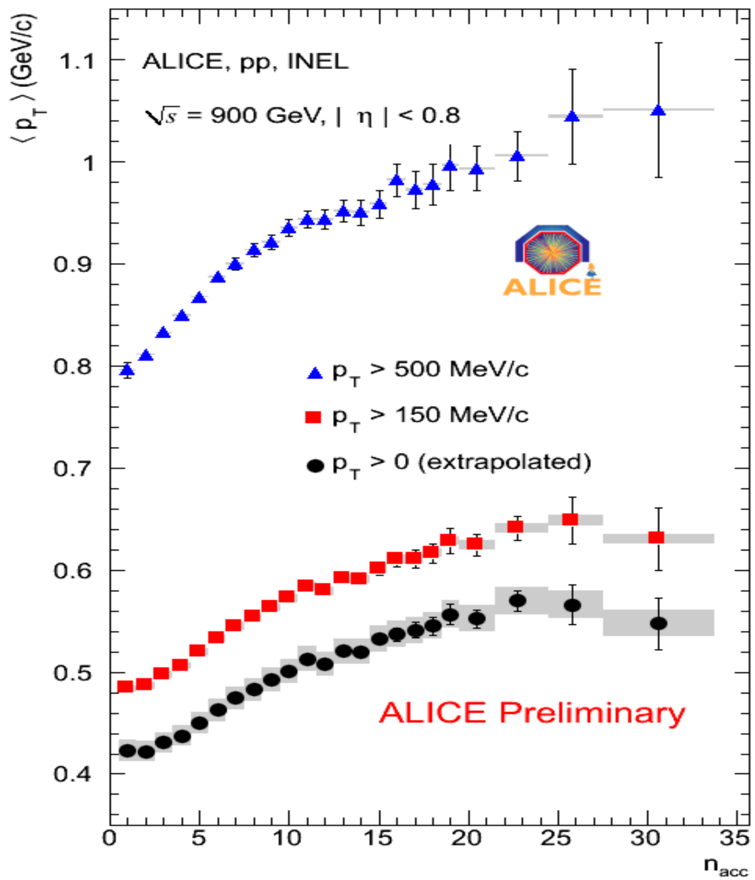


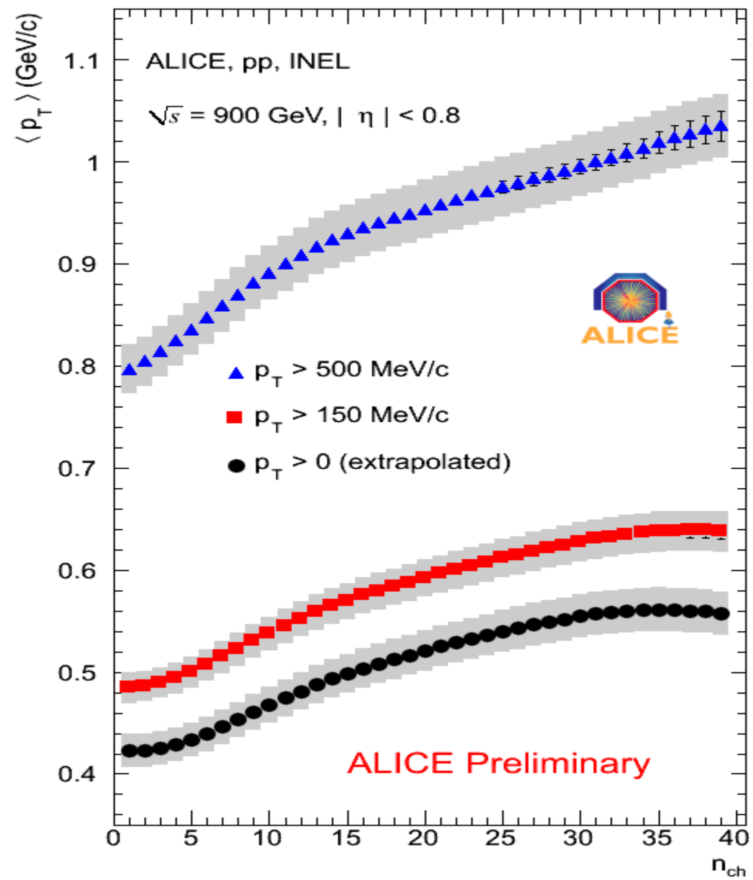
- In bins of observed multiplicity n_{acc}
  - Fits of p_T spectra and calculation of mean
  - Calculation of mean p_T in a "visible" interval: weighted average over data points
  - Calculation of mean p_T in a "visible "interval combined with extrapolation from a fit at low momenta

$\langle p_T \rangle$ vs Multiplicity: from n_{acc} to n_{ch}

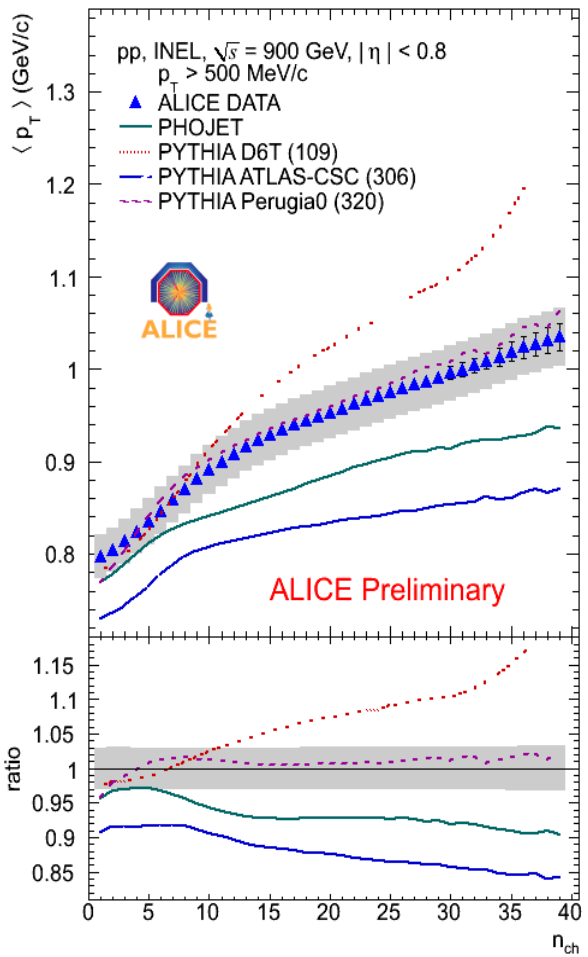
- n_{acc}: number of accepted particles in $|\eta|<0.8$, $p_T>0.15$ GeV/c
- n_{ch}: number of all primaries in $|\eta|<0.8$, $p_T>0$

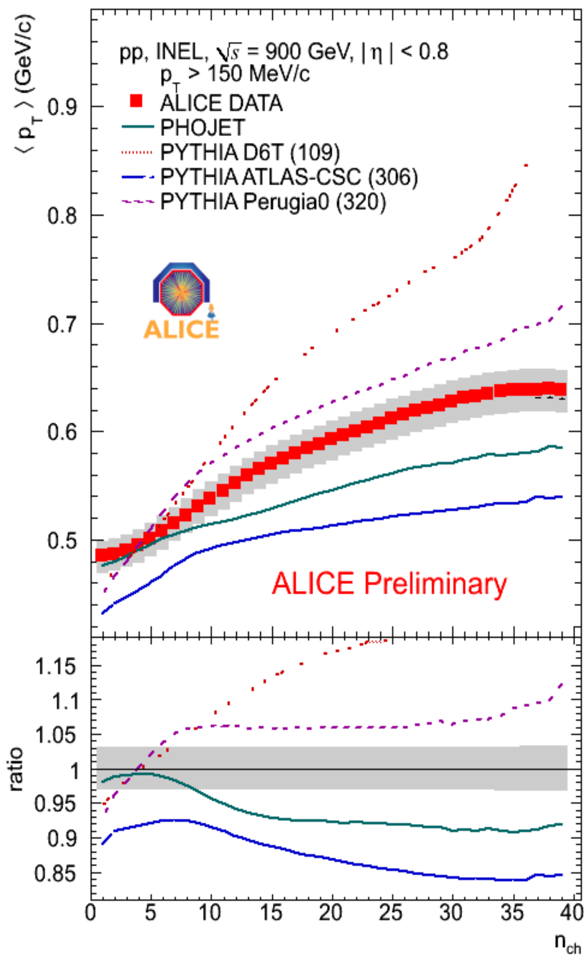
$\langle p_T \rangle(n_{ch}) = \Sigma p_T(n_{acc})R(n_{acc},n_{ch})$, where $R(n_{acc},n_{nch})$: response matrix from MC





$<p_T>$ vs multiplicity – comparison to MC





- p_T>500 MeV/c: PYTHIA Perugia0 gives good description of the data
- p_T>150 MeV/c: all models fail

Comparison to MCs: summary

- MC << data
- MC >> data
- MC ≈ data

$\sqrt{s}$ = 0.9 TeV

MC/TUNE	D6T	Perugia0	CSC	PHOJET
η	-20%	-17%	+3%	-2%
N_{ch}	N_{ch}>10	N_{ch}>5	N_{ch}>15	N_{ch}>10
p_t		p_t>4GeV	p_t>1GeV	p_t>1GeV
$\langle p_t \rangle$				

→ 0.9 TeV: PHOJET better for N_{ch}, Perugia-0 for p_t

$\sqrt{s}$ = 2.36 TeV

	D6T	Perugia0	CSC	PHOJET
η	-24%	-21%	-2%	-8%
N_{ch}	N_{ch}>10	N_{ch}>5	N_{ch} >20	N_{ch}>15

$\sqrt{s}$ = 7 TeV

	D6T	Perugia0	CSC	PHOJET
η	-27%	-24%	-4%	-17%
N_{ch}			N_{ch} >30	

→ 2.36, 7 TeV: CSC better for N_{ch}

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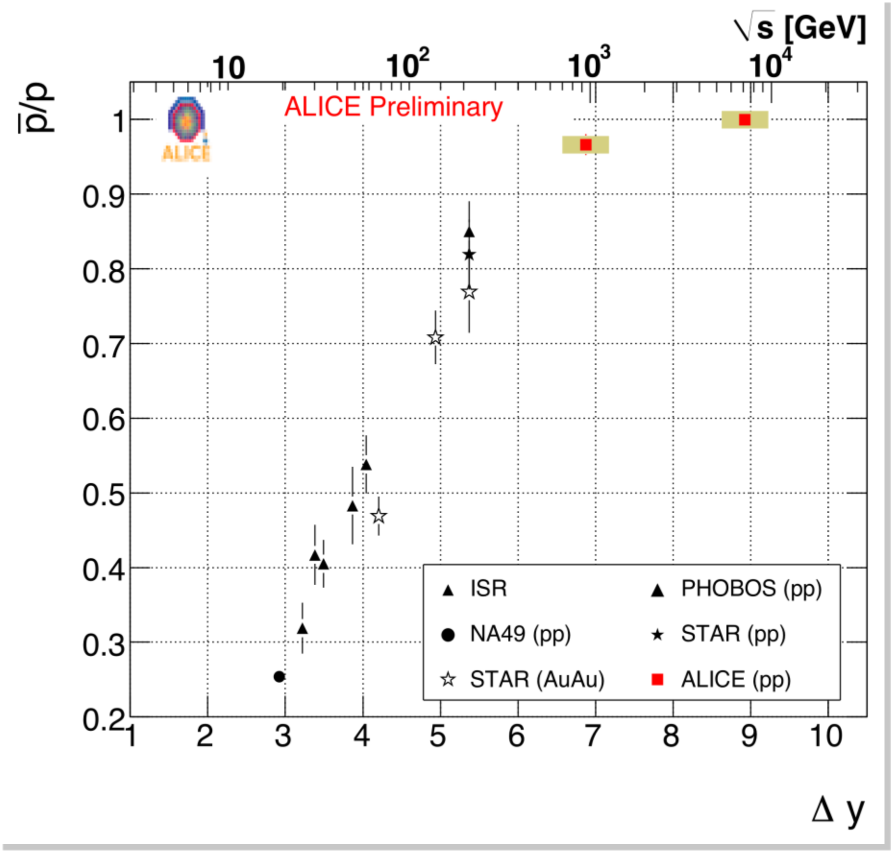
$p/\bar{p}$ measurement at mid-rapidity

- Proton identification with TPC dE/dx
- Special care for secondaries and absorption corrections
- pbar/p at |y| < 0.5 and 0.45 < p_t < 1.05 GeV/c

- Baryon-stopping at low

  $\Delta y = y_{beam} - y_{CM}$

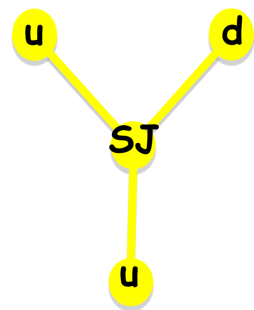
Vanishes at high LHC energy



→ M.Broz

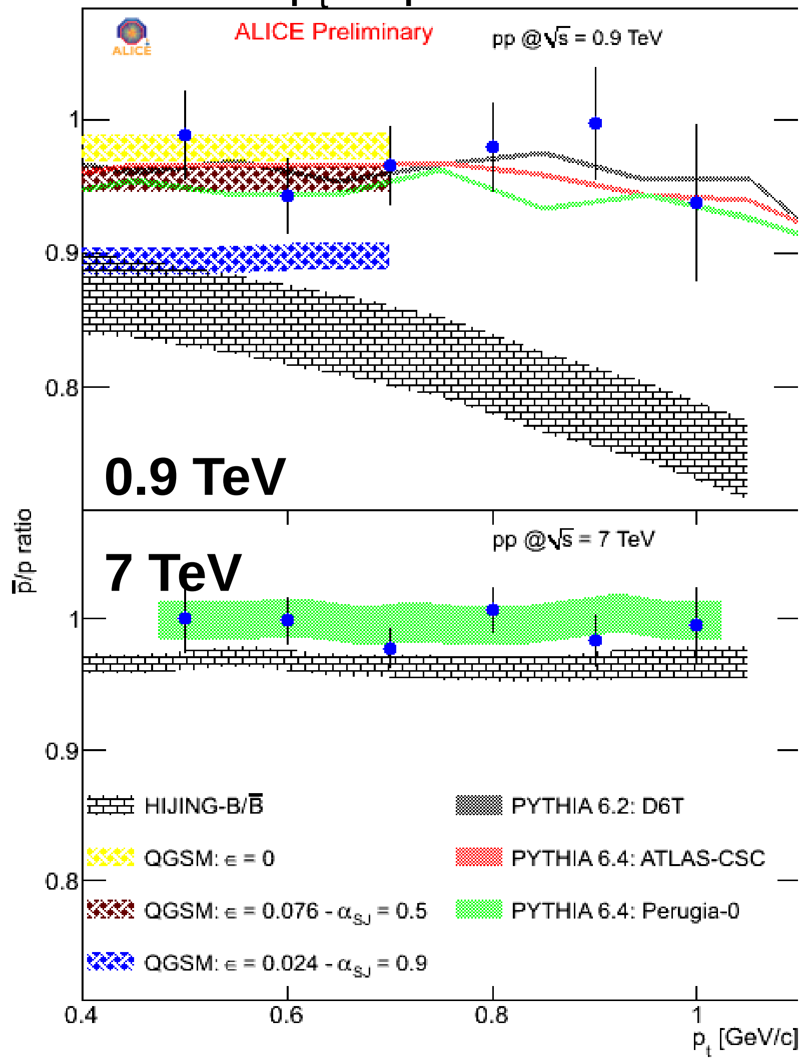
$p/\bar{p}$ measurement vs. MCs

- Baryon number transport is usually explained by a String Junction transfer (gluon field)



- What is the intercept of the corresponding Regge trajectory
  - (α_{SJ} = ½ or 1?)
- Data described well by PYTHIA tunes
- Other models (HIJING-B, QGSM with α_{SJ} ~ 1) underestimate the data
- **Data show suppression baryon transport over large rapidity gaps in pp collisions**

No p_t dependence



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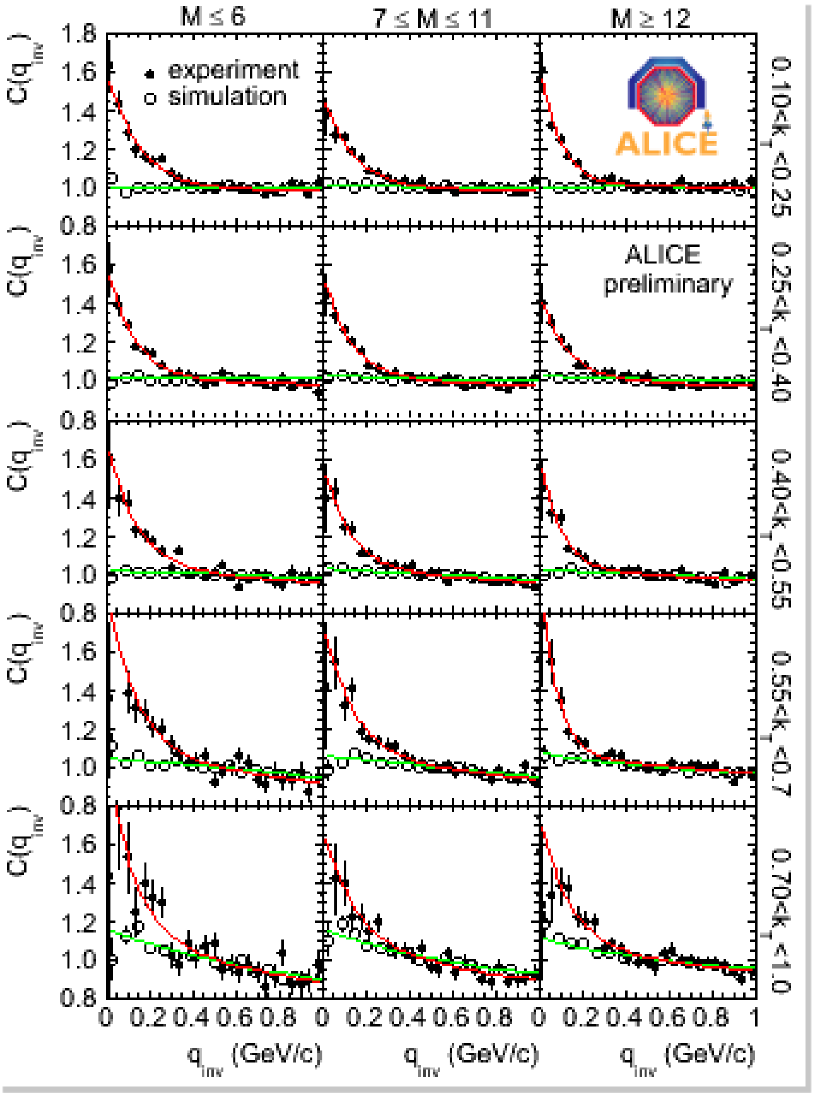
Femtoscopy: particle emitting source

0.9 TeV

- Assess the space-time evolution of the system that emits particles in pp collisions
- Measure the Bose-Einstein enhancement for pairs of pions (identical bosons) at low momentum difference $q_{inv}=|\mathbf{p}_1-\mathbf{p}_2|$, vs. event multiplicity and pair $k_t = |\mathbf{p}_{t1}+\mathbf{p}_{t2}|/2$
- Fit with a Gaussian

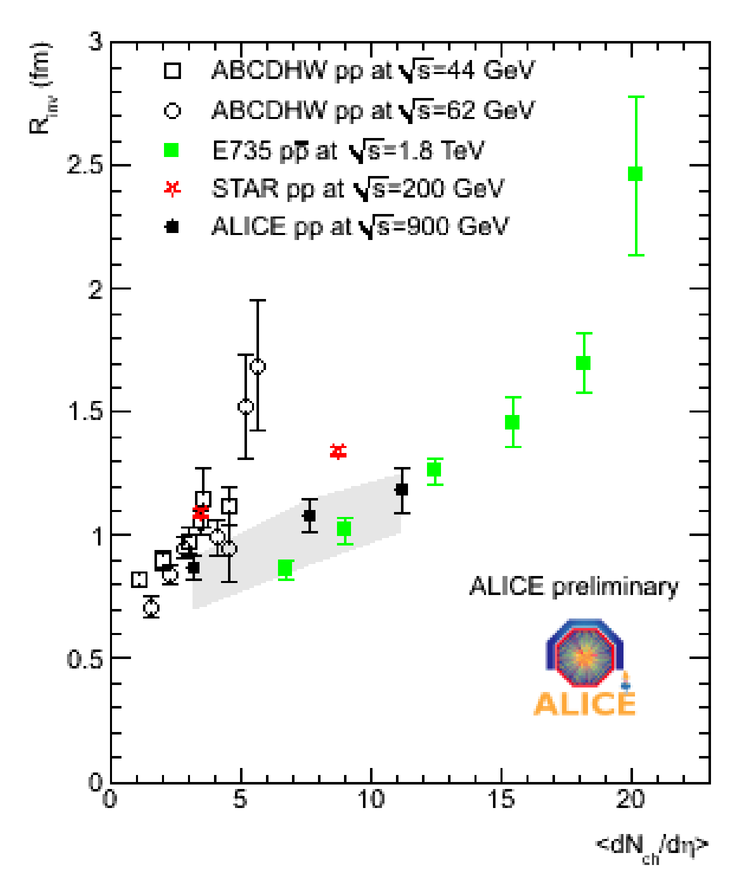
$$C(q_{inv}) = 1 + \lambda \exp(-q_{inv}^2 R^2)$$

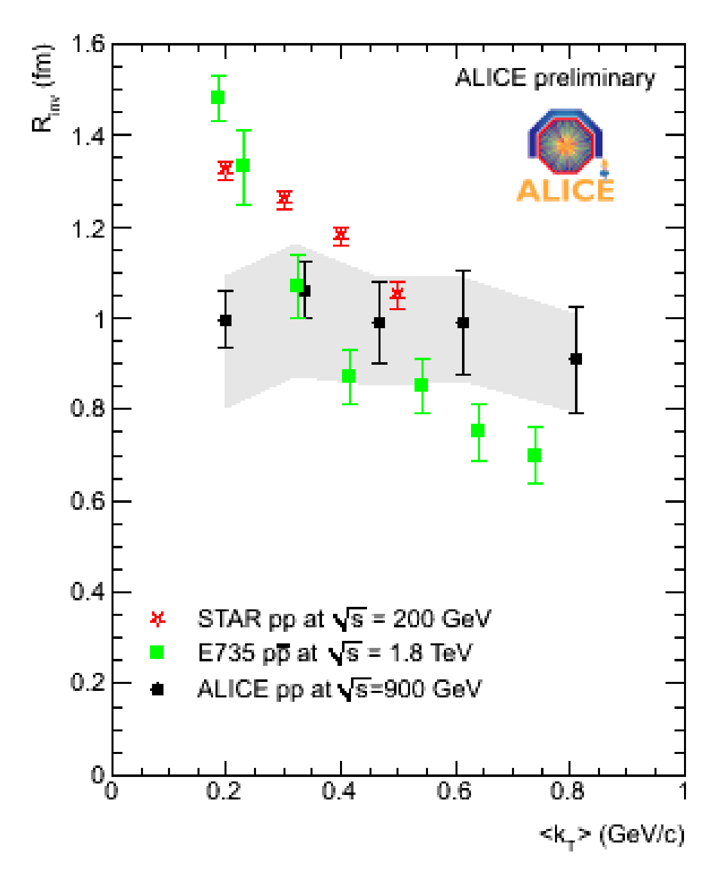
→ D.Miskowiec



Femtoscopy results at 0.9 TeV

- Radius grows with $dN_{ch}/d\eta$: consistent with other data and expectations (larger correlation volume at large multiplicities)
- No visible k_t dependence





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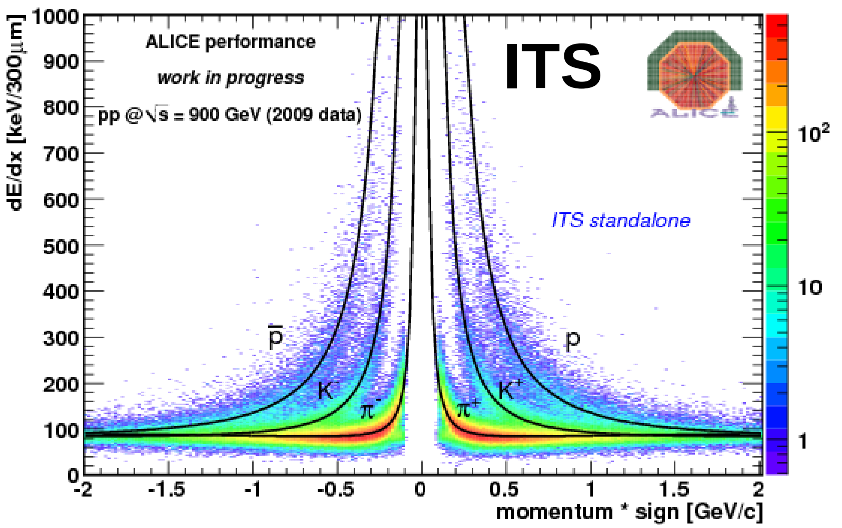
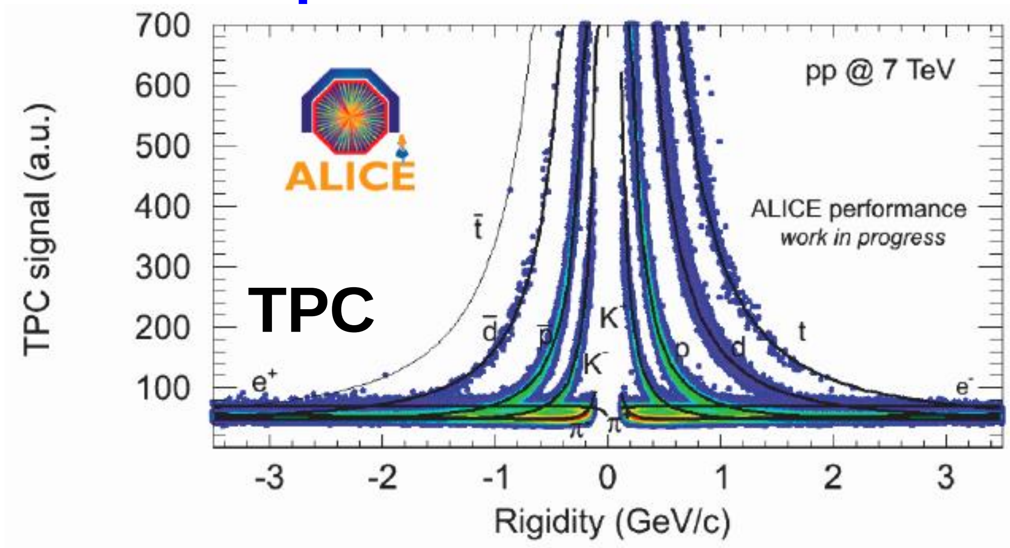
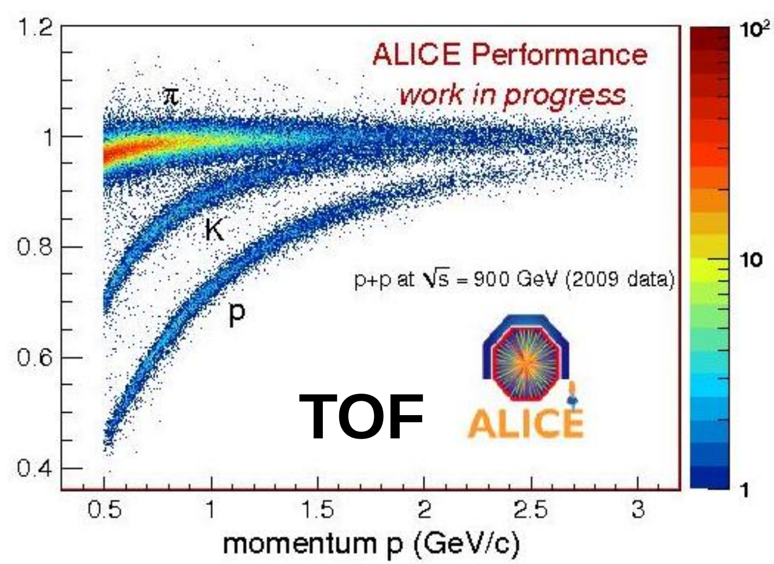
Identified spectra: one of ALICE's specials

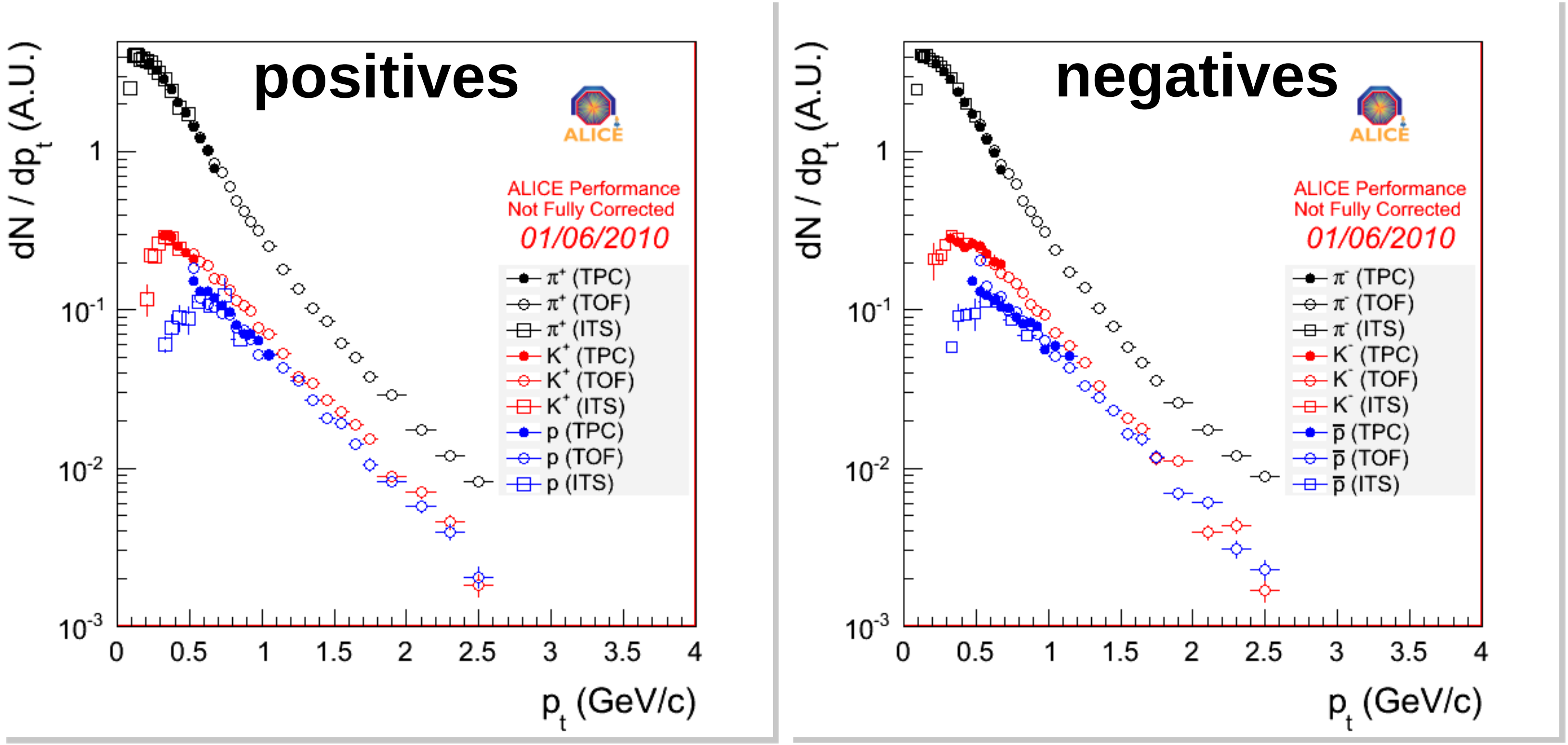






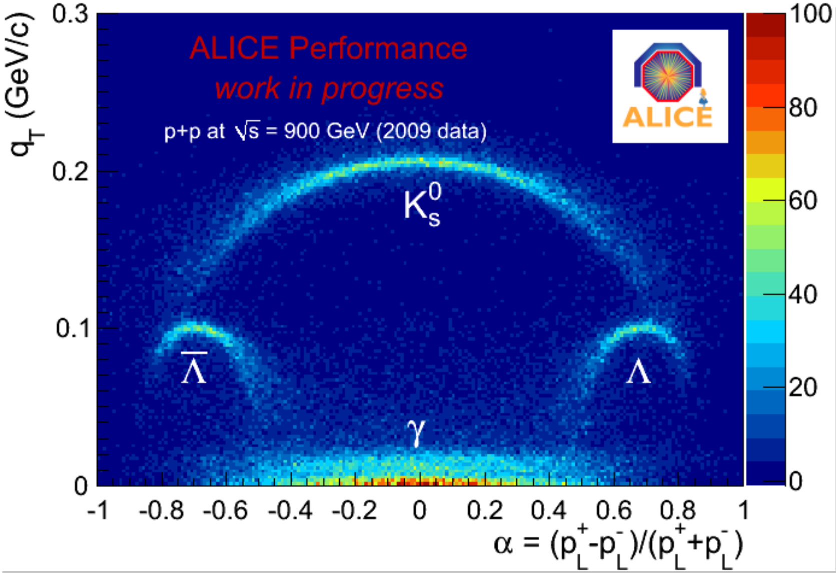
Identified spectra at 0.9 TeV

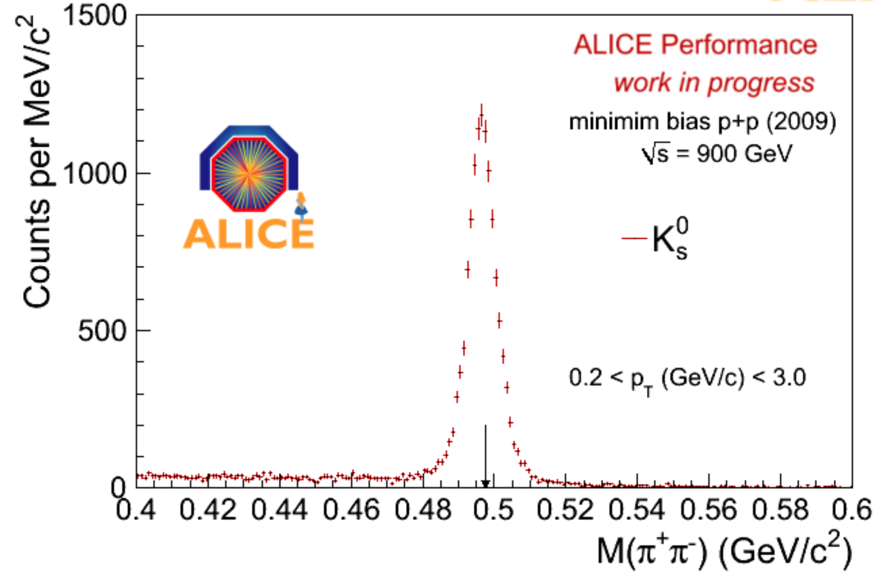
- Analysis in progress (spectra not fully corrected yet)
- Good agreement between the 3 detectors (ITS, TPC, TOF)
- Shows that detectors' calibration/understanding is OK

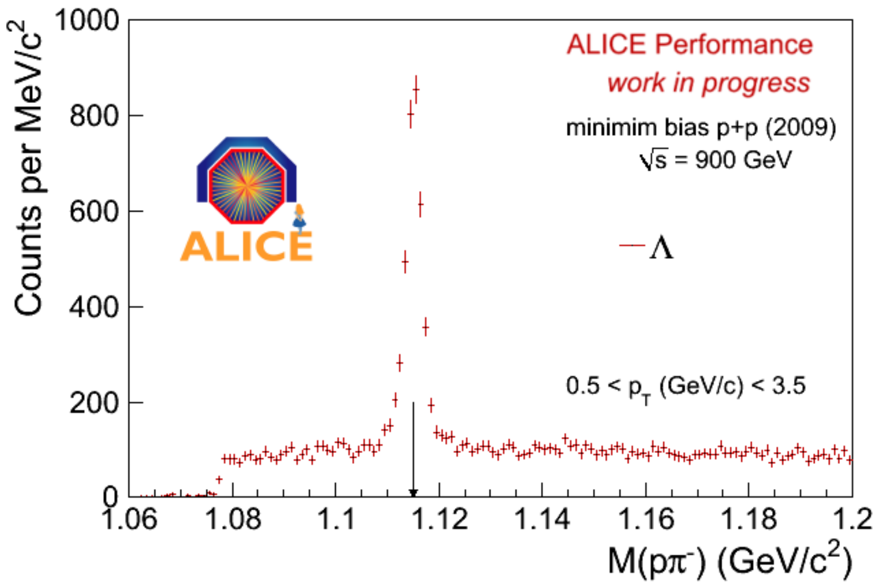


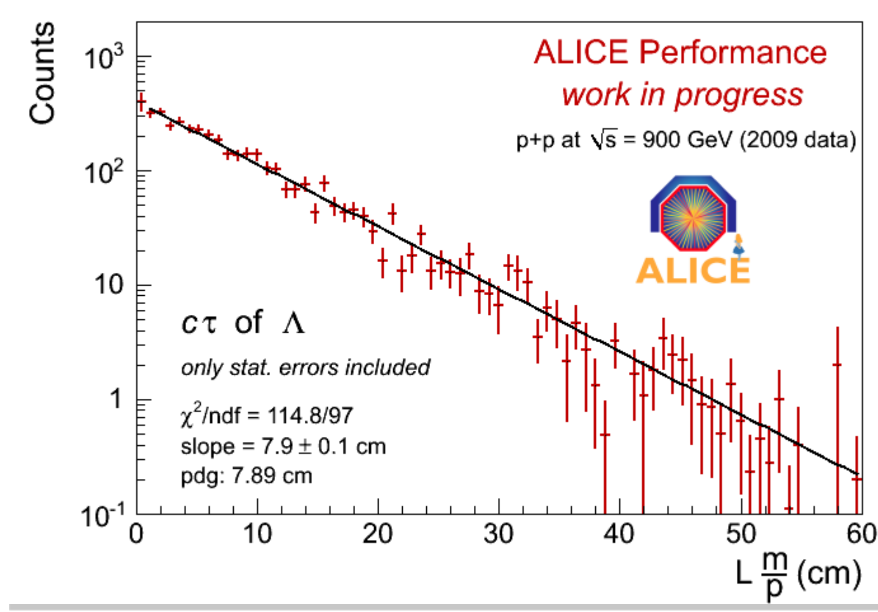
Strangeness at 0.9 TeV

→A.Maire

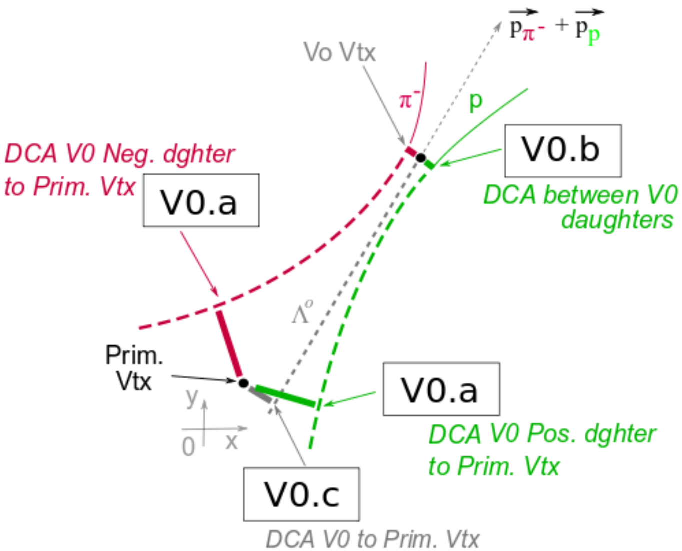




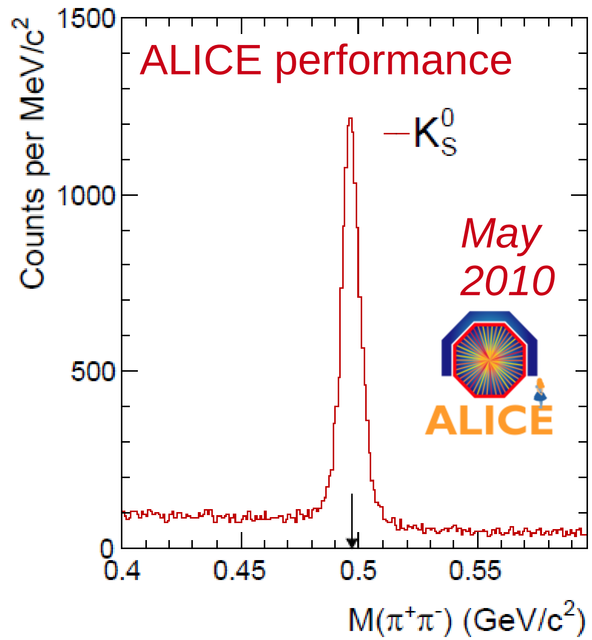


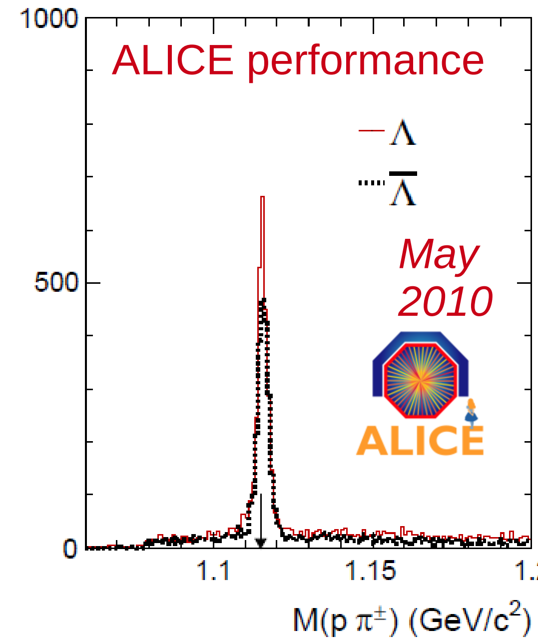


K^0s, Λ^0, Λ^0 : reconstruction



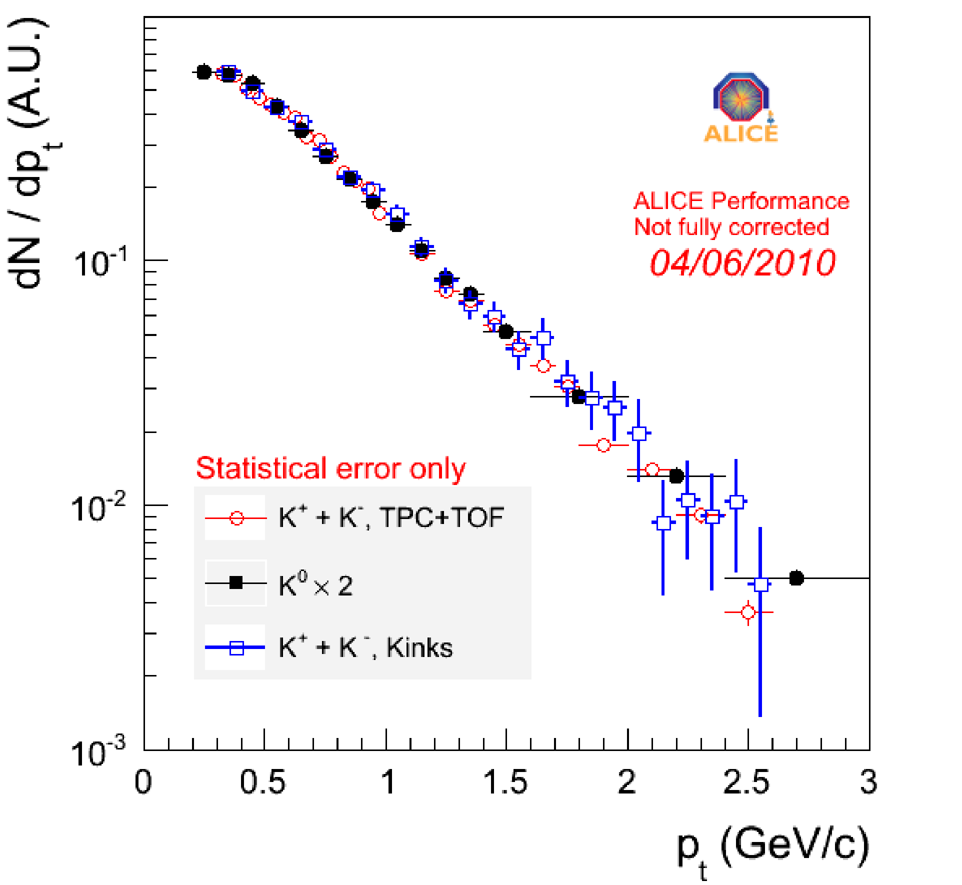
- Decay channel : $K^0s\ (ds) \rightarrow \pi^+ + \pi^-$ ($c\tau$ = 2,68 cm)
  $\Lambda^0(uds) \rightarrow p^+ +$





- Reconstruction based on 2*dary*
  tracks, with opposite charges,
  within a fiducial volume,
  + "*V0 topology*"
  + protons identified via *TPC PID*

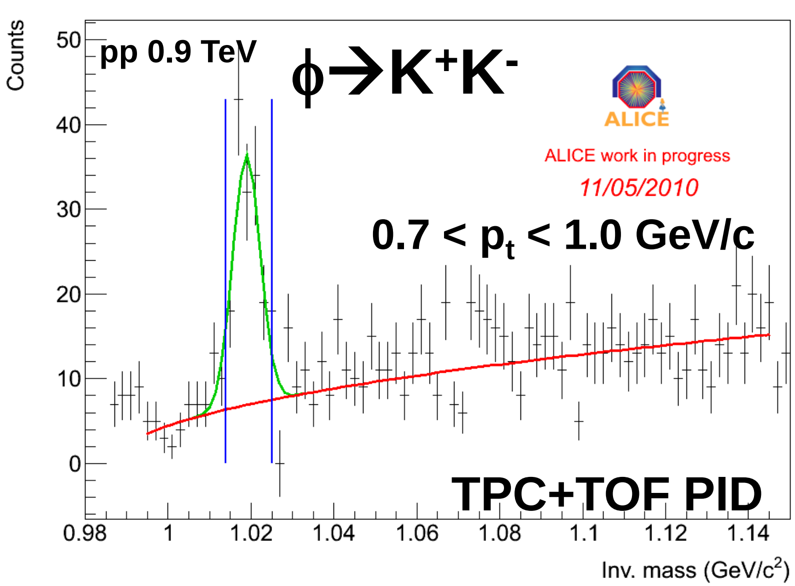
The three ways to kaons

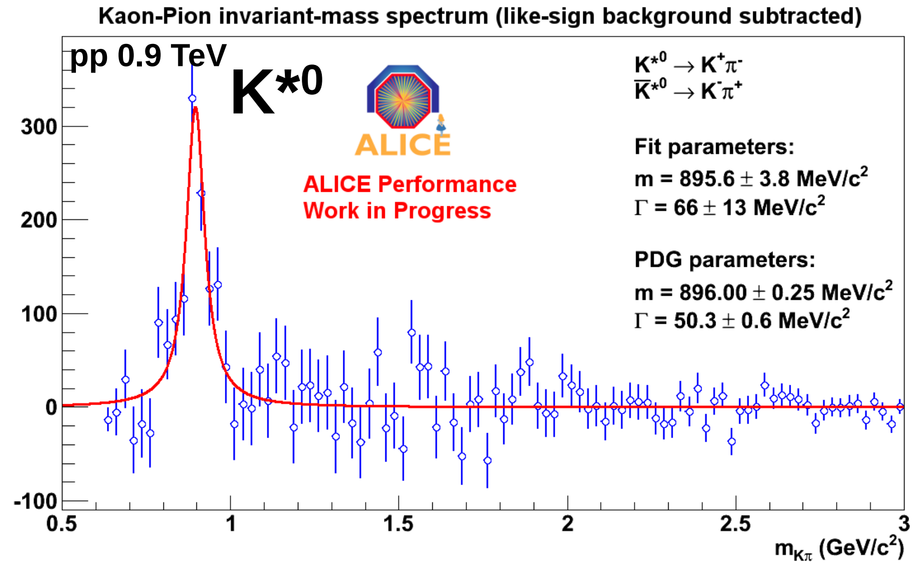


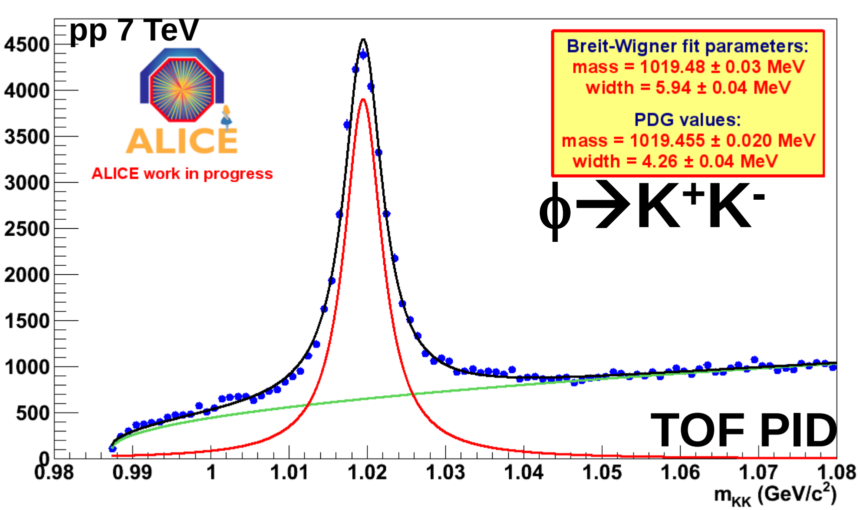
- $K^{\pm}$ TPC+TOF PID
- K^0_S vertex reconstruction
- $K^{\pm} \rightarrow \mu^{\pm}\nu$ kink reconstruction

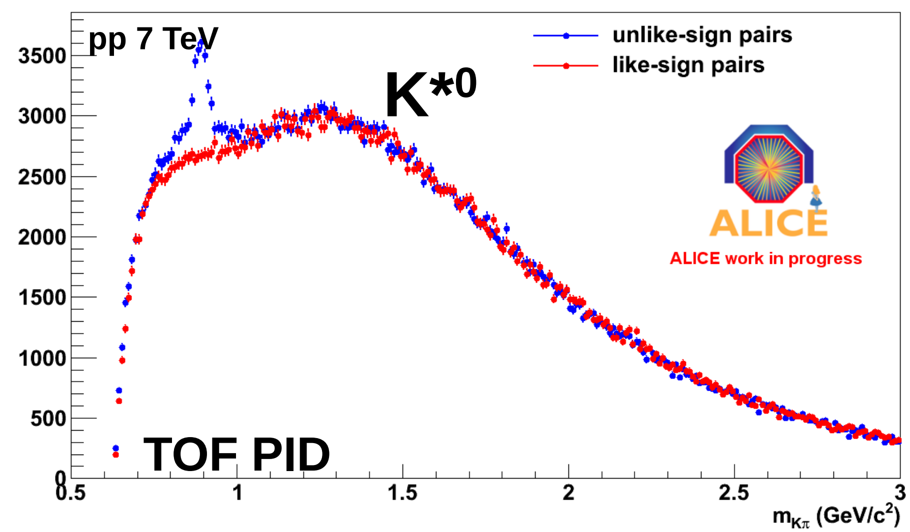
- Spectra not fully corrected
- Good internal constency

ϕ and K^{*0} at 0.9 and 7 TeV

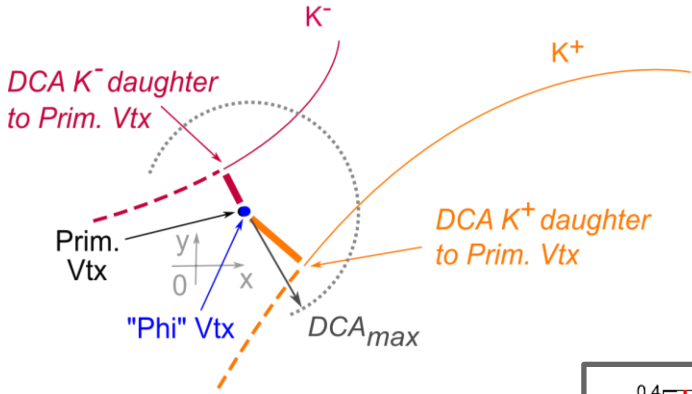




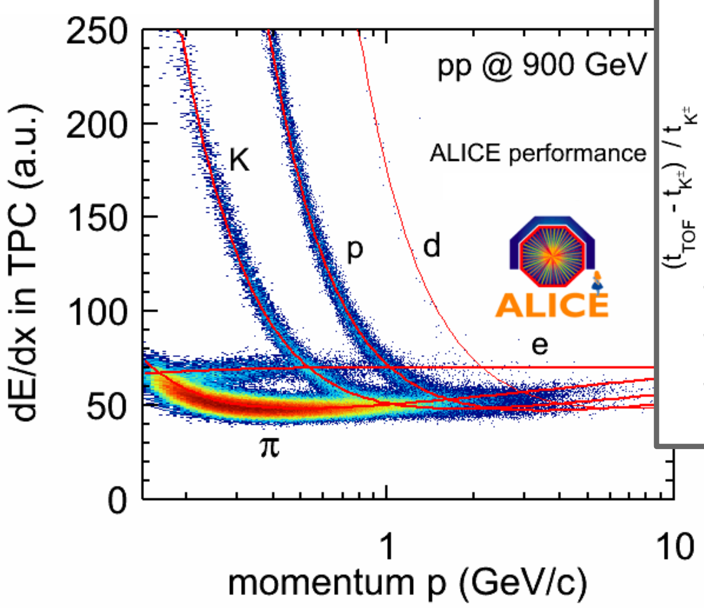


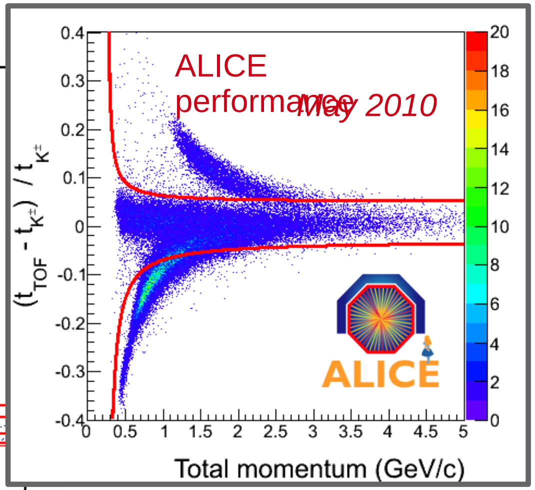


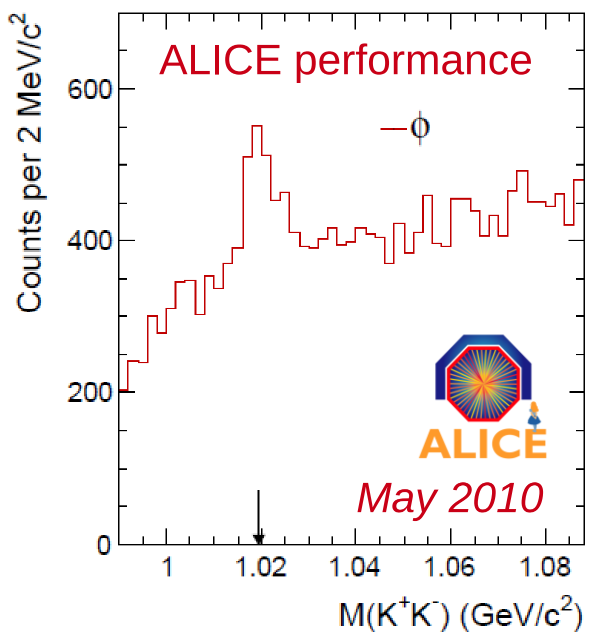
φ(1020) : reconstruction



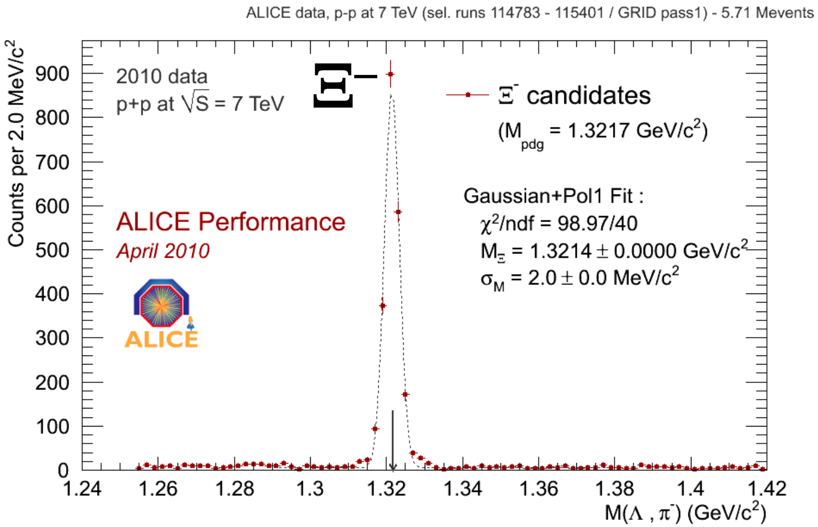
- **Decay channel :** φ(1020) (ss) → $K^+ + K^-$
- **Reconstruction** based *primary* tracks,
  with opposite charges,
  + Kaons identified via *TPC+TOF PID*

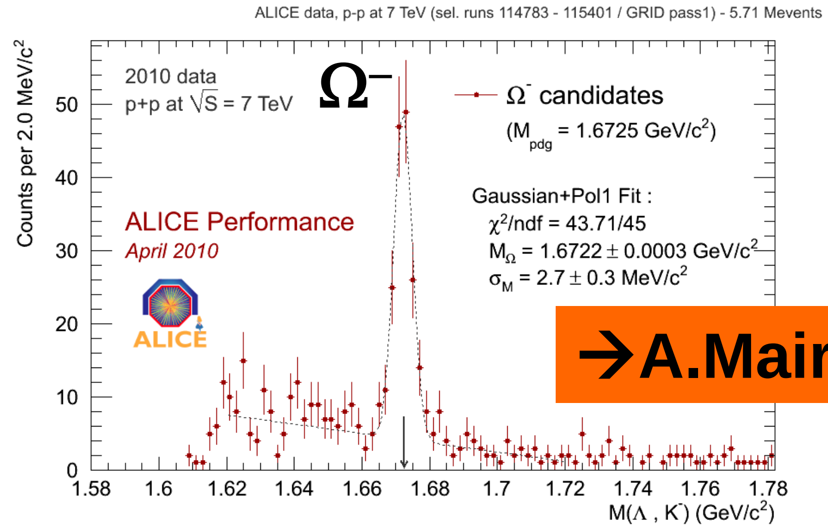






Multi-strange baryons at 7 TeV



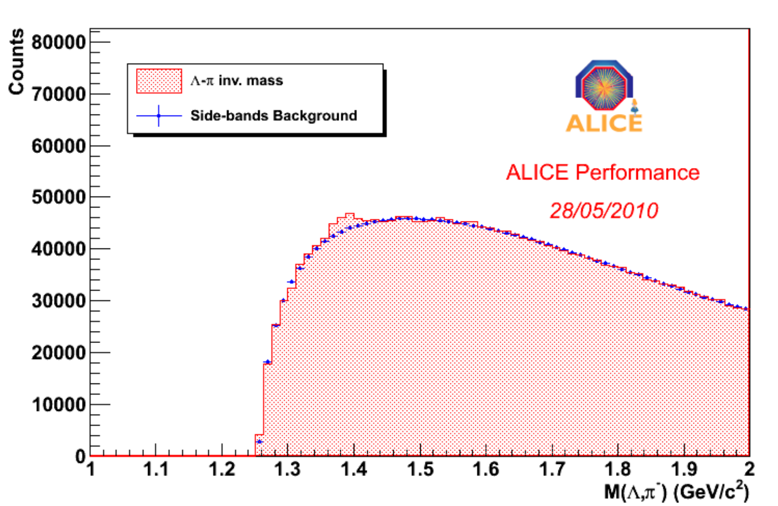


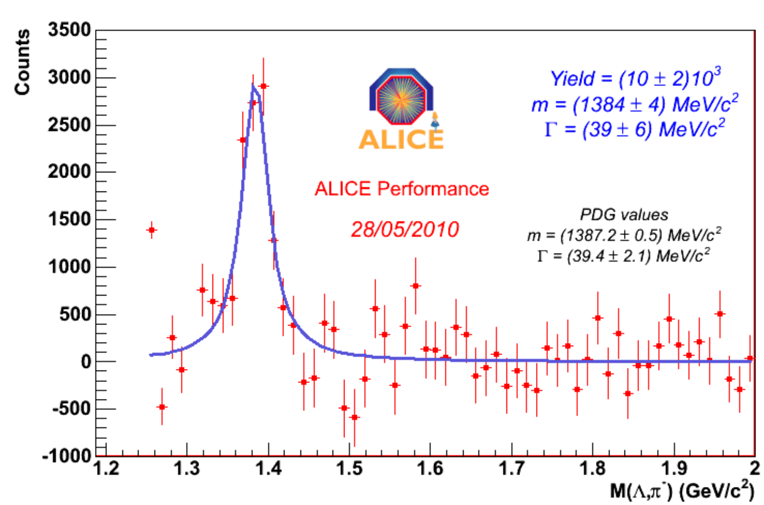
→A.Maire

$\Lambda\,\pi^-$ *invariant mass spectrum with side-bands background*

$\Sigma^{*-} \rightarrow \Lambda\pi^-$

$\Lambda\,\pi^-$ *invariant mass spectrum (side-bands background subtracted)*



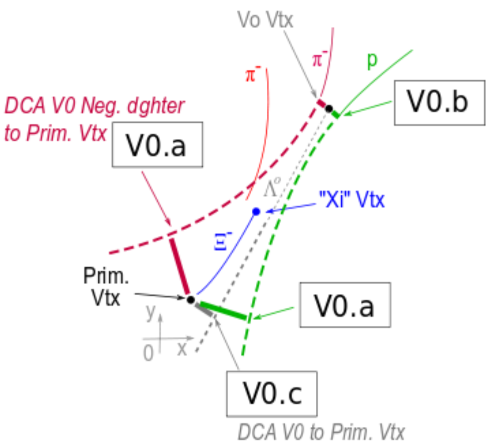


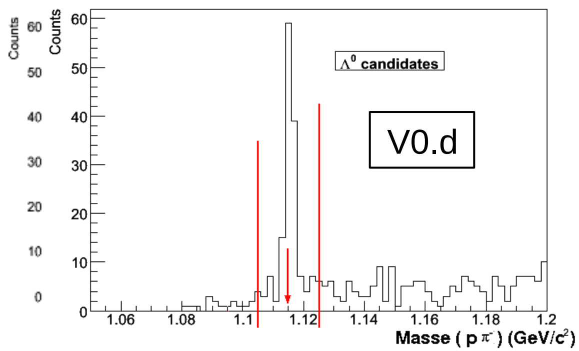
$\Xi^{\pm}$: reconstruction

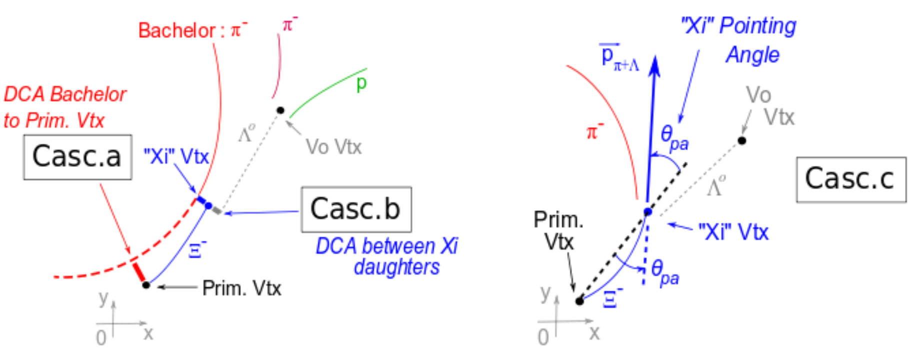
- **Decay channel :** Ξ^{-} (dss) $\rightarrow \Lambda^{0}$(uds) + $\pi^{-} \rightarrow$ p + π^{-} + π^{-} ($c\tau$ = 4,91 cm)

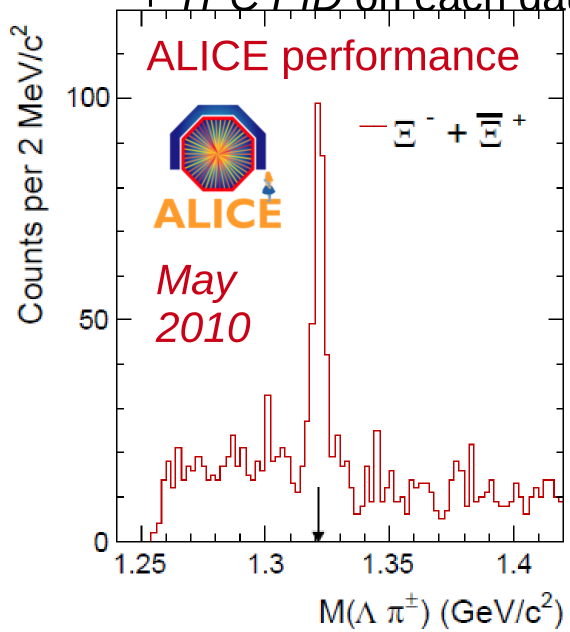
  Ξ^{+} (dss) $\rightarrow \Lambda^{0}$(uds) + $\pi^{+} \rightarrow$ p + π^{+} + π^{+} ($c\tau$ = 4,91 cm)

- Reconstruction based on three 2^{dary} tracks, within a fiducial volume,
  + "Cascade *topology*"
  + *TPC PID* on each daughter



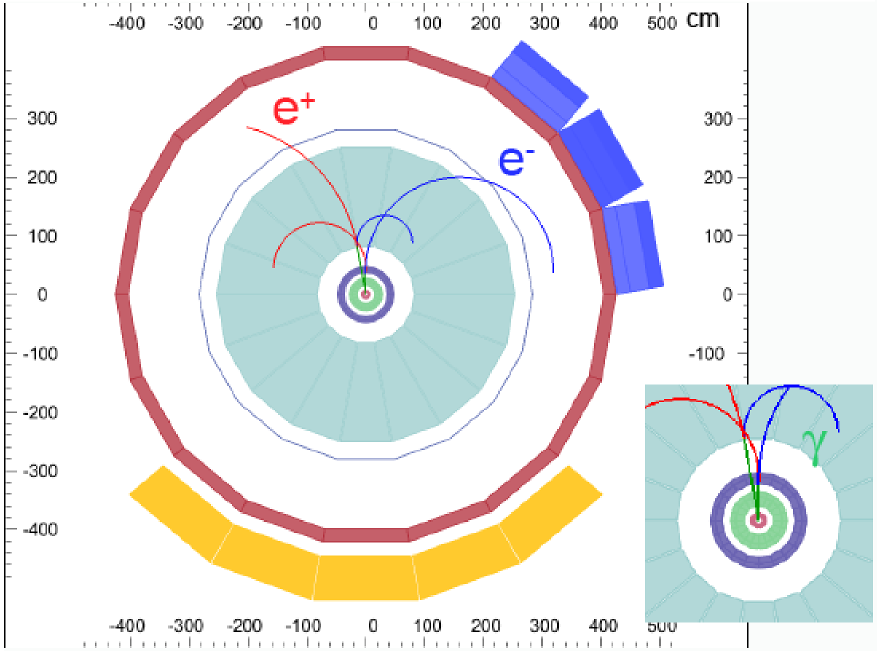


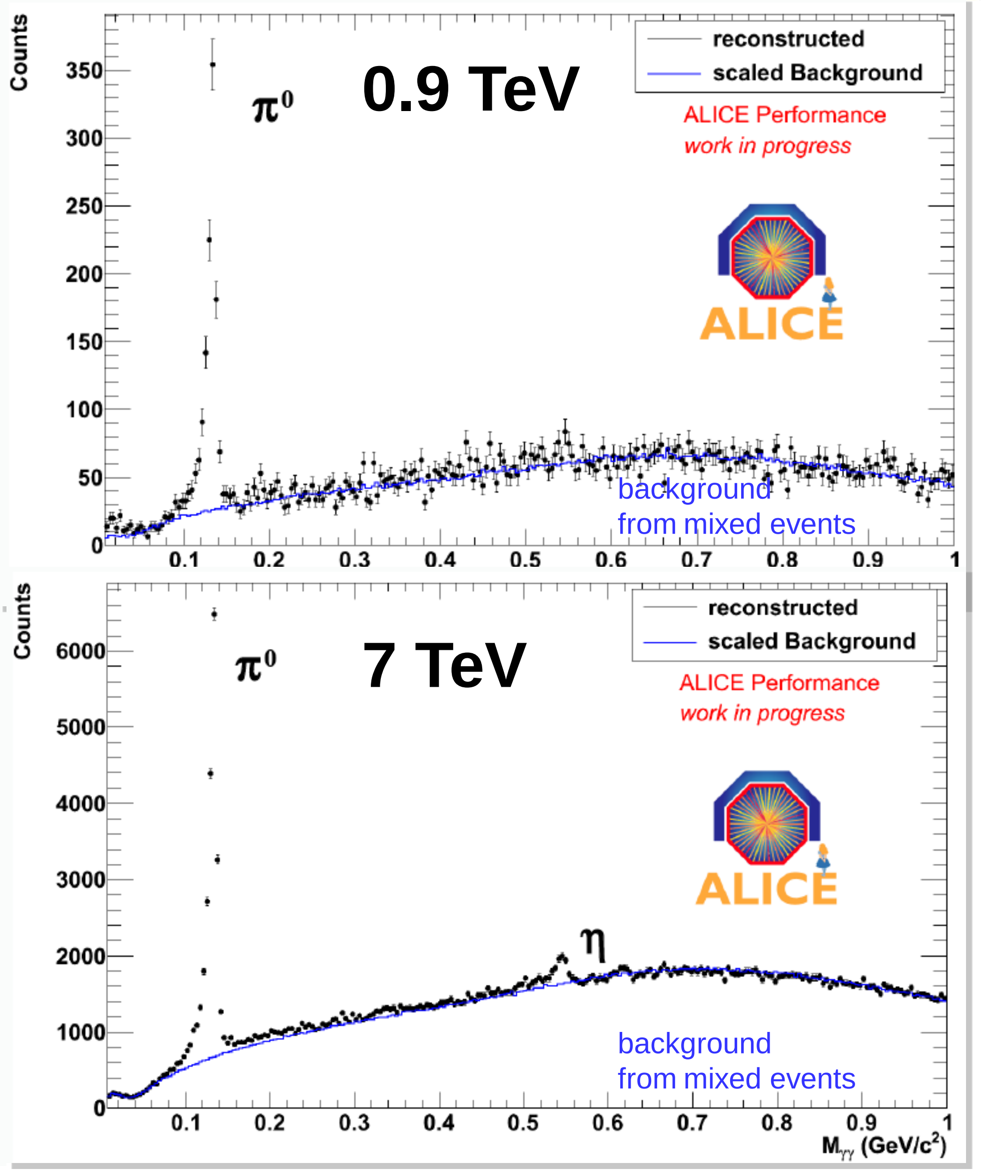




Prospects for π^0: conversions

- Electron ID in TPC
  - TRD to join soon
- Conversion reconstruction in TPC+ITS
  - also very important for material budget scan
- For π^0 and η: double conversion





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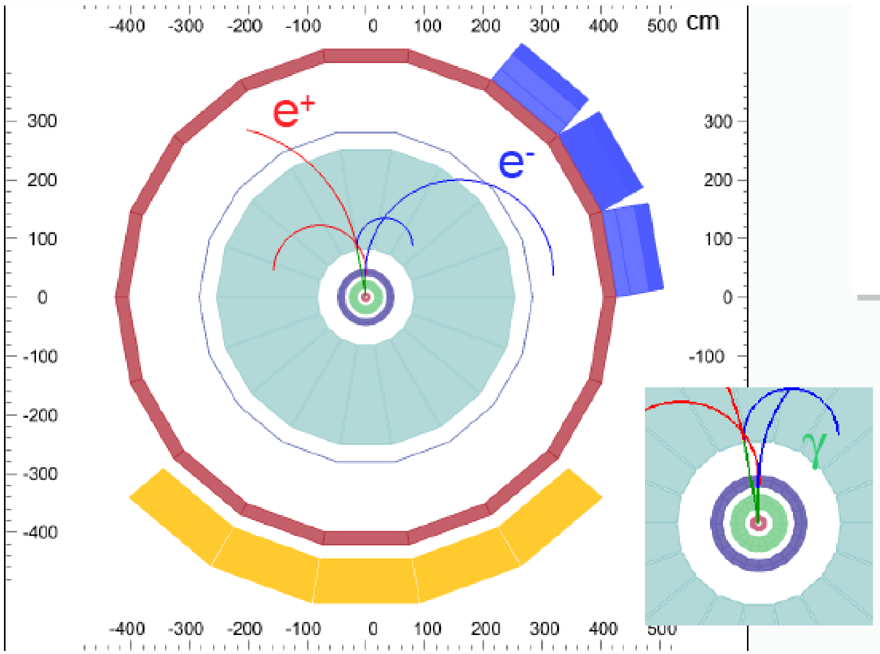
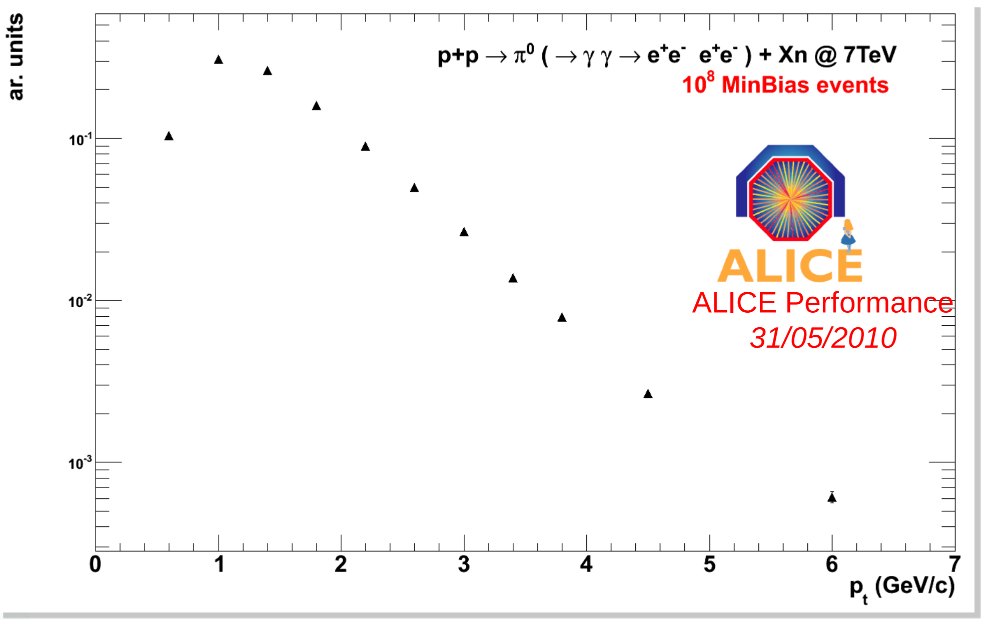


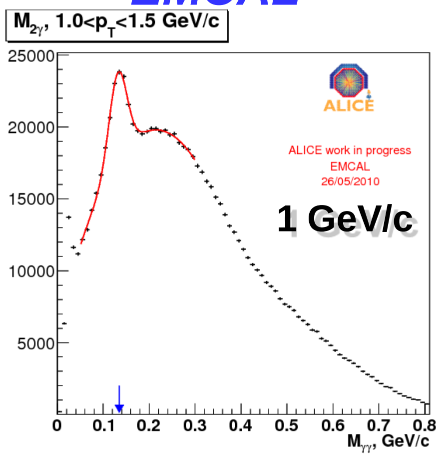
Raw π^0 dN/dp_t



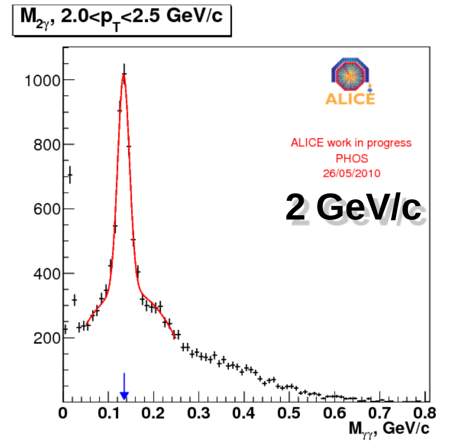
Prospects for π^0: EM calorimeters

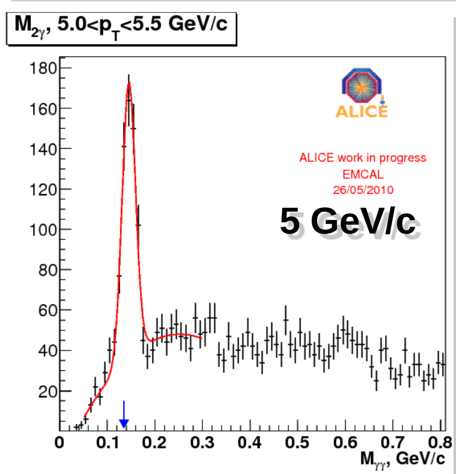
- Two EM calorimeters (back-to-back): EMCAL, PHOS
- Calibration ongoing, but already nice π^0 signals

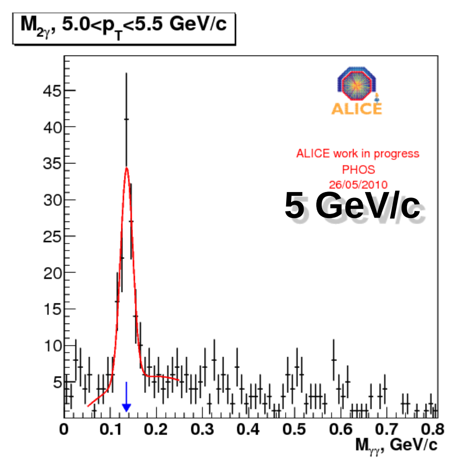
EMCAL



PHOS

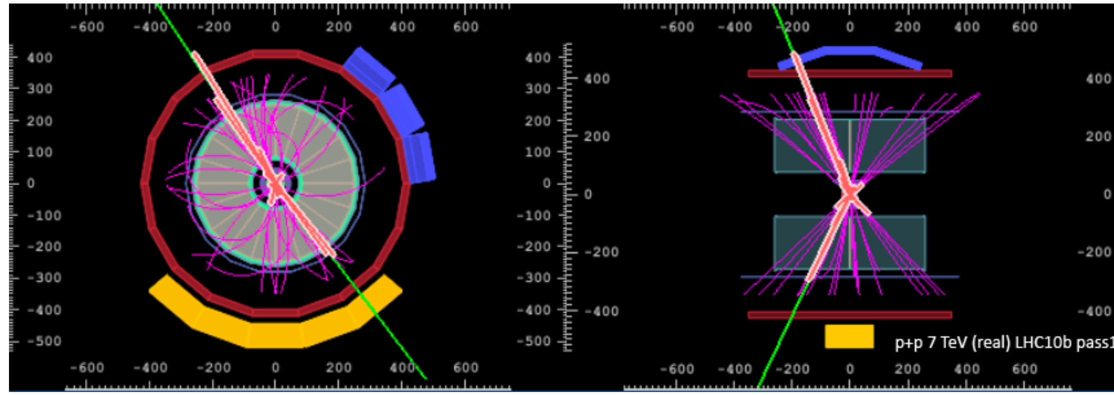


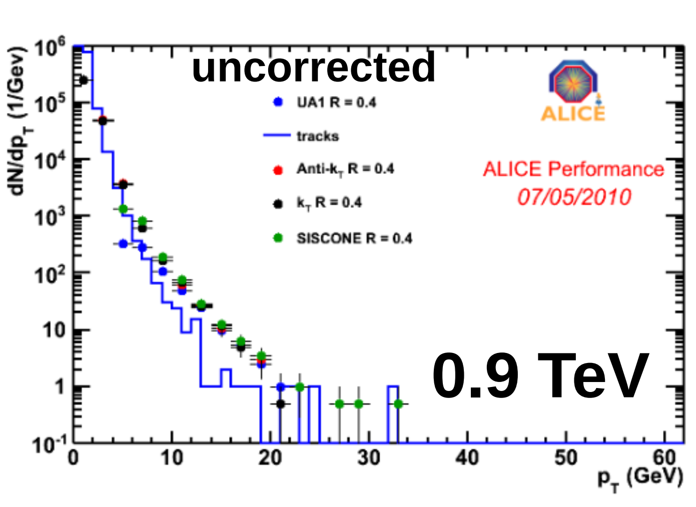


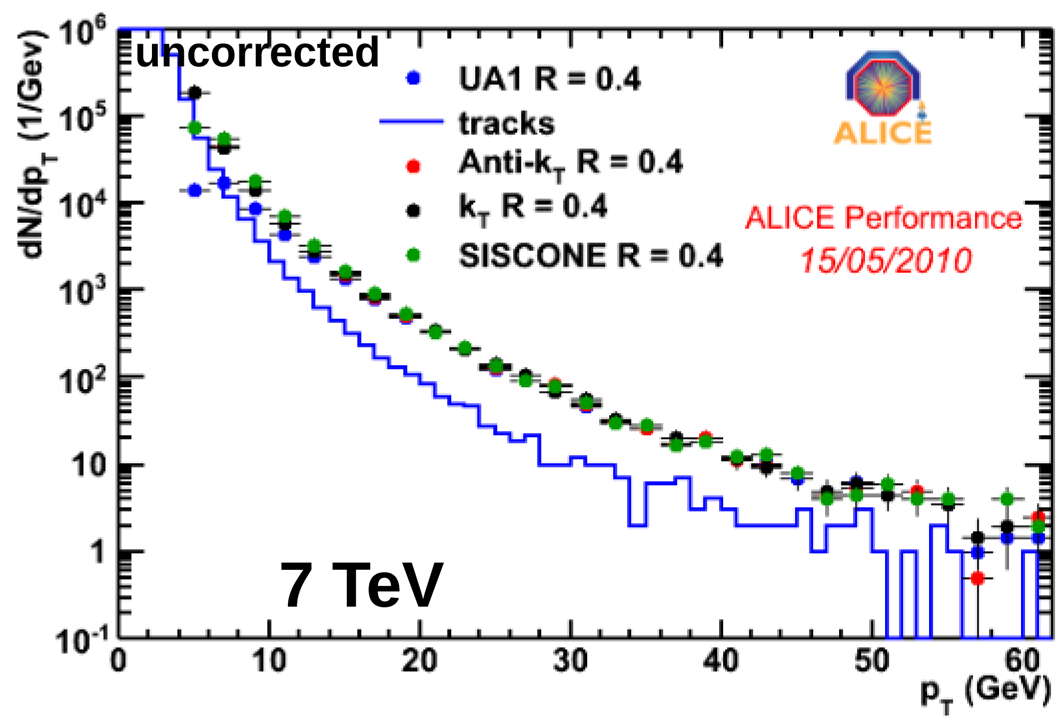


Jet reconstruction

- Charged-track jets raw spectra 0.9 and 7 TeV
  - $|\eta|<0.5$
  - Four jets algos compared
  - uncorrected







Outline

- Particle multiplicity
  - $dN_{ch}/d\eta$ and dN/dN_{ch} measurements at 0.9, 2.36, and 7 TeV
- Momentum spectra
  - Charged particle p_t spectra at 0.9 TeV
- Baryon production
  - Anti-proton/proton ratio at 0.9 and 7 TeV
- Particle emitting source
  - Femtoscopy (HBT) at 0.9 TeV
- Momentum spectra, outlook
  - Identified charged p_t spectra at 0.9 TeV
  - Strangeness at 0.9 and 7 TeV
  - π^0 and jet reconstruction at 7 TeV
- Event topology
  - Event shape and underlying event at 7 TeV
- Heavy Flavour production
  - Charm and J/ψ production at 7 TeV

published

preliminary

in preparation

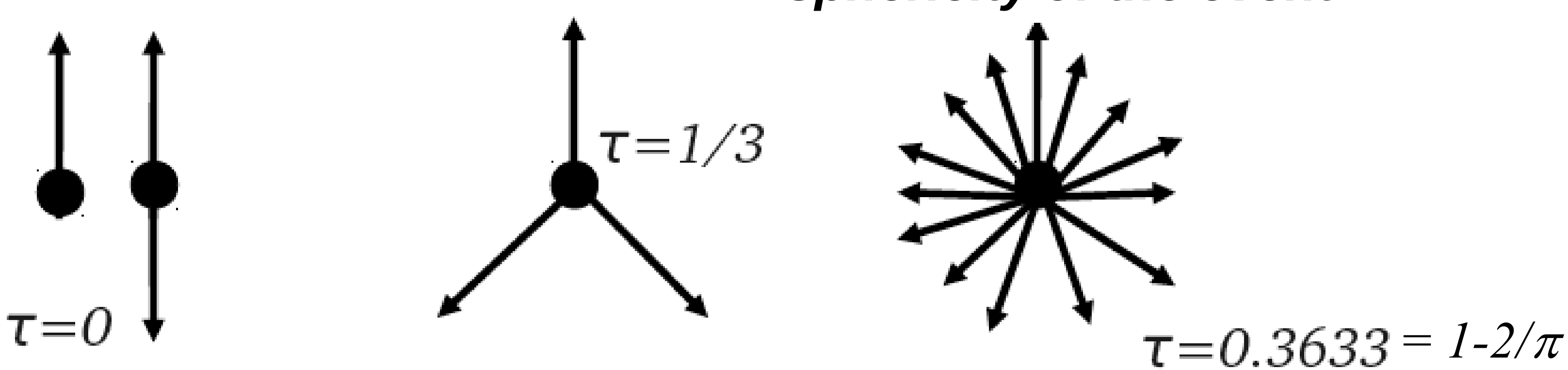
Event shape studies

- Event shapes are sensitive to underlying event properties
  - multiple interactions mechanism
  - tuning of MC generators
- Can be used to classify events as “soft” or “hard”
- Look for unusual topologies
- Transverse thrust (hard scattering frame moves longitudinally)

$$T \equiv \underbrace{max}_{\vec{n}_t} \frac{\sum_i |\vec{p}_{t,i} \cdot \vec{n}_t|}{\sum_i |\vec{p}_{t,i}|}$$

$$\tau \equiv 1 - T$$

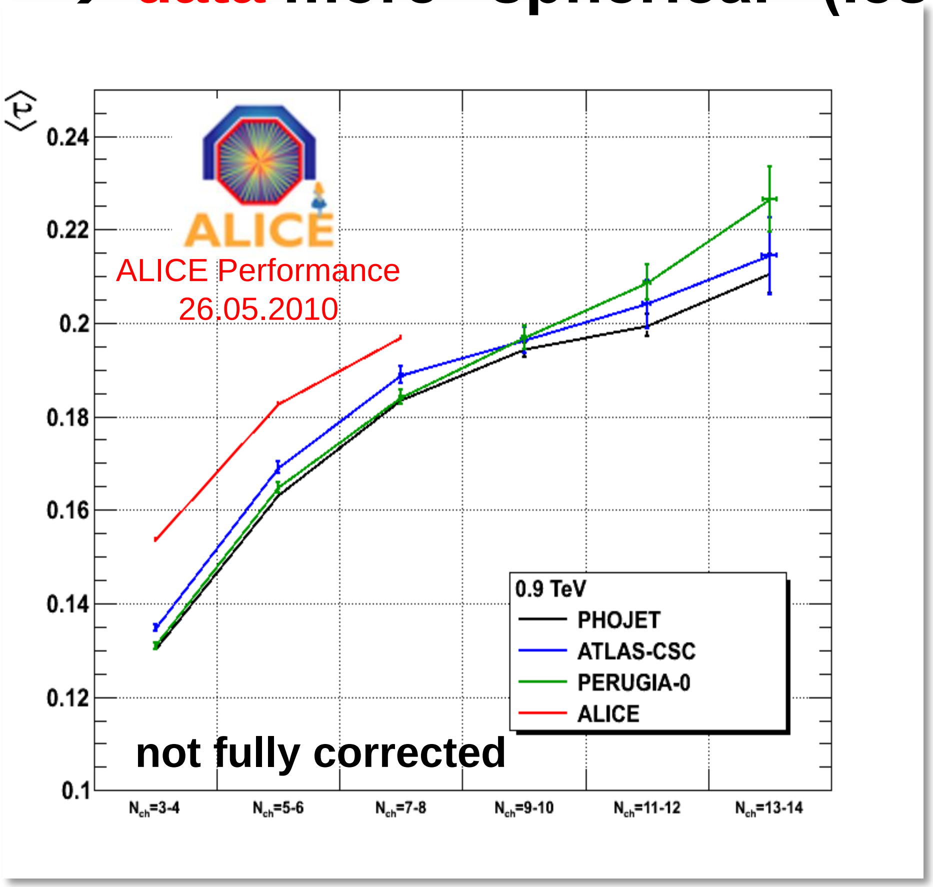
→ ***measures the transverse sphericity of the event***

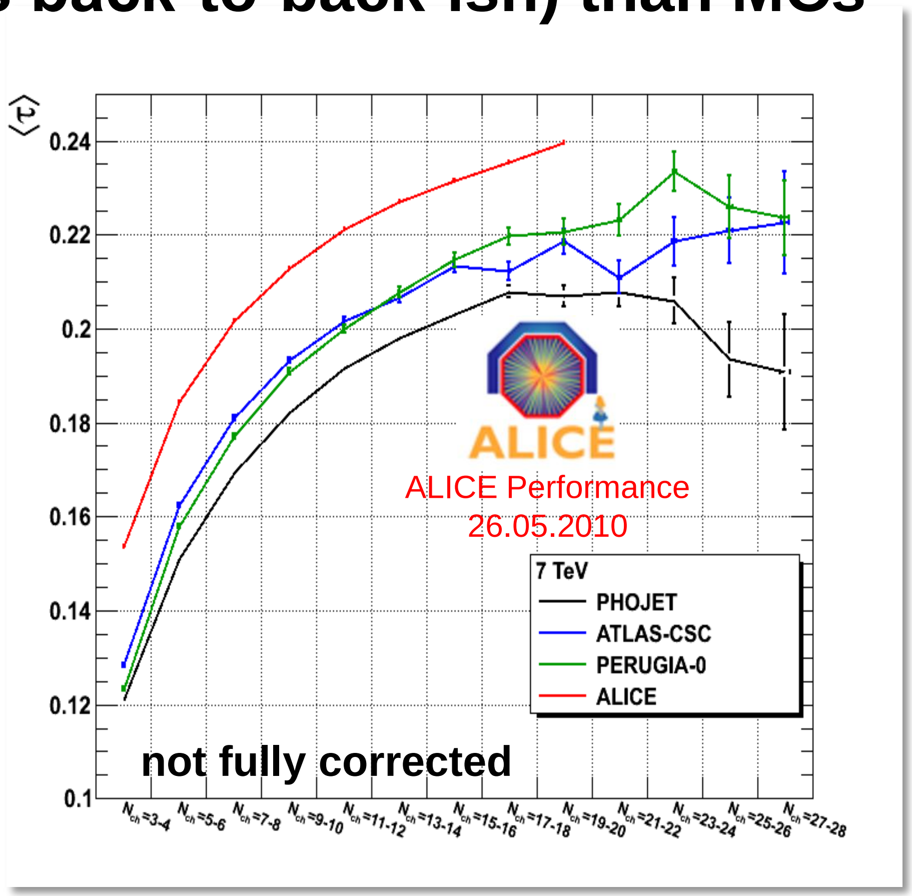


Event shape: Thrust

- $\langle\tau\rangle$ (= <1-T>) vs. multiplicity at 0.9 and 7 TeV
- Thrust spectrum is unfolded based on MC (χ^2 minimization)

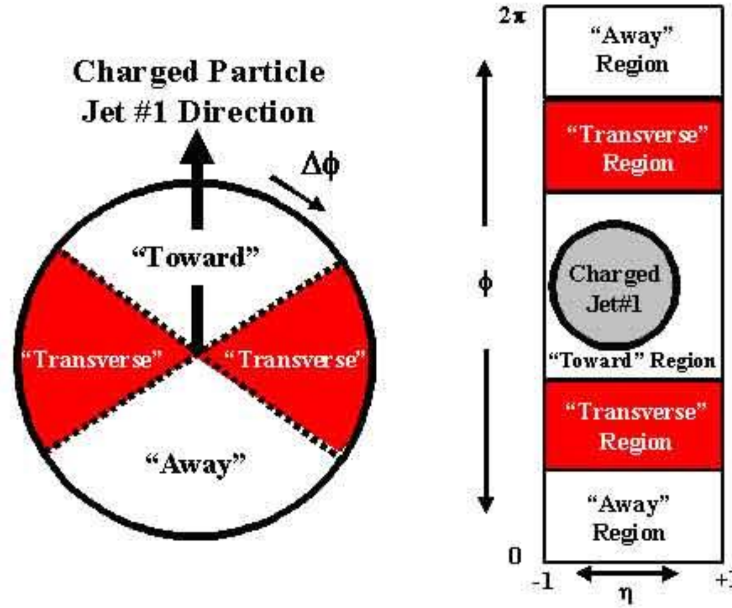
→ **data more "spherical" (less back-to-back-ish) than MCs**

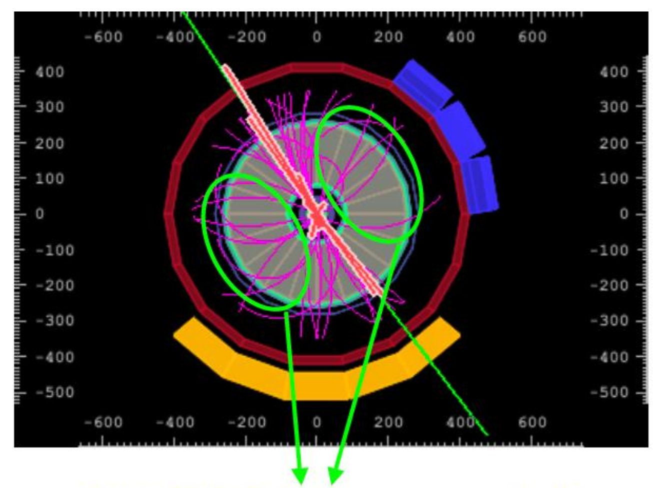




Event structure: Underlying Event

- Event-by-event analysis:
  - identify leading hadron
  - define transverse regions
  - Σp_t in the two regions
- Region with larger energy (MAX) → sensitive to QCD final-state radiation
- Region wth smaller energy (MIN) → sensitive to soft component (multiple interactions)

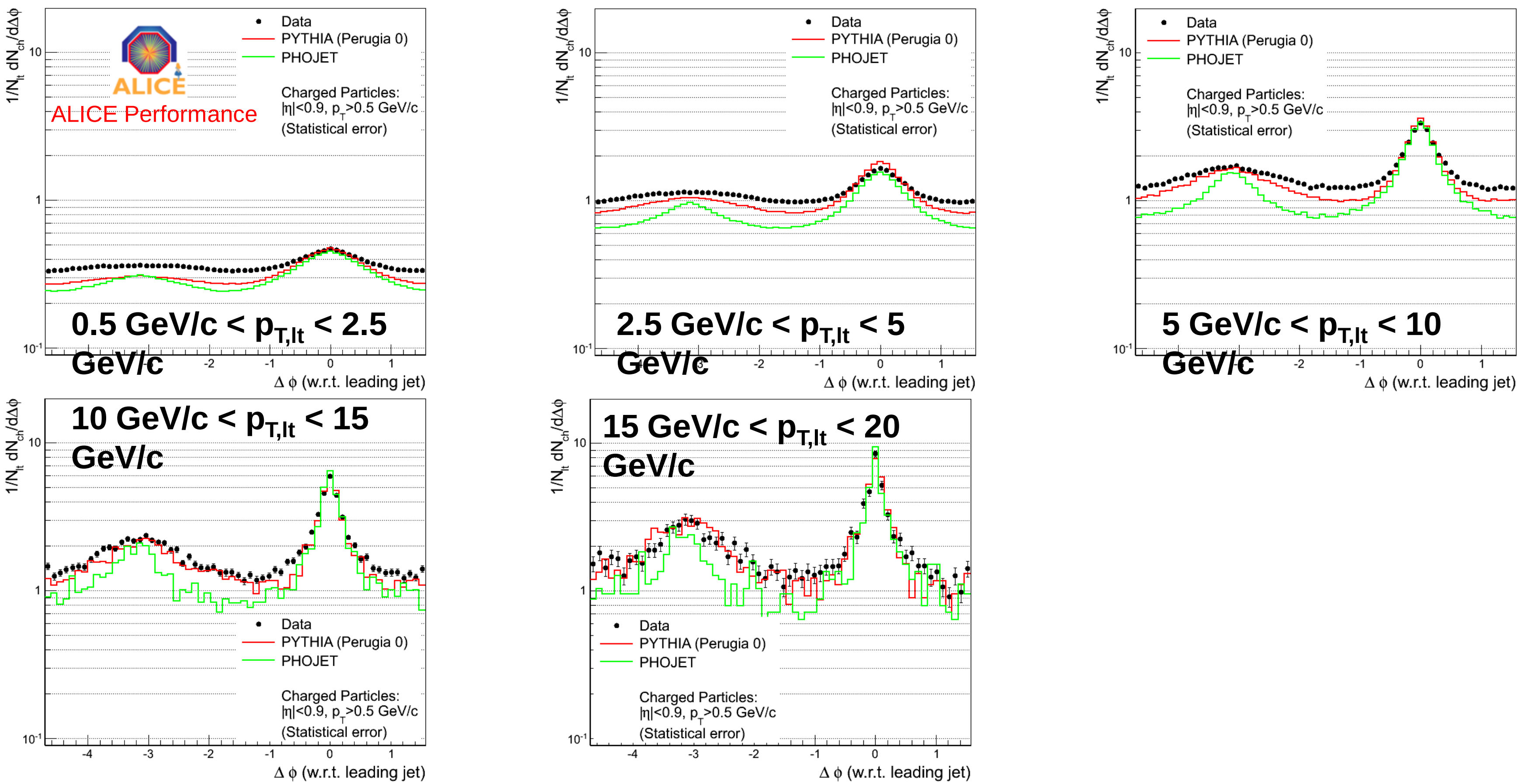




TRANSVERSE REGIONS: here we measure the UE!

Underlying Event 7 TeV: first look at Δφ

- Start by looking at inclusive Δφ correlations wrt leading track
- Data not corrected, compared to MCs (geant + recon)
- Leading p_t<10 GeV/c → **data** less back-to-back-ish than **MC**s



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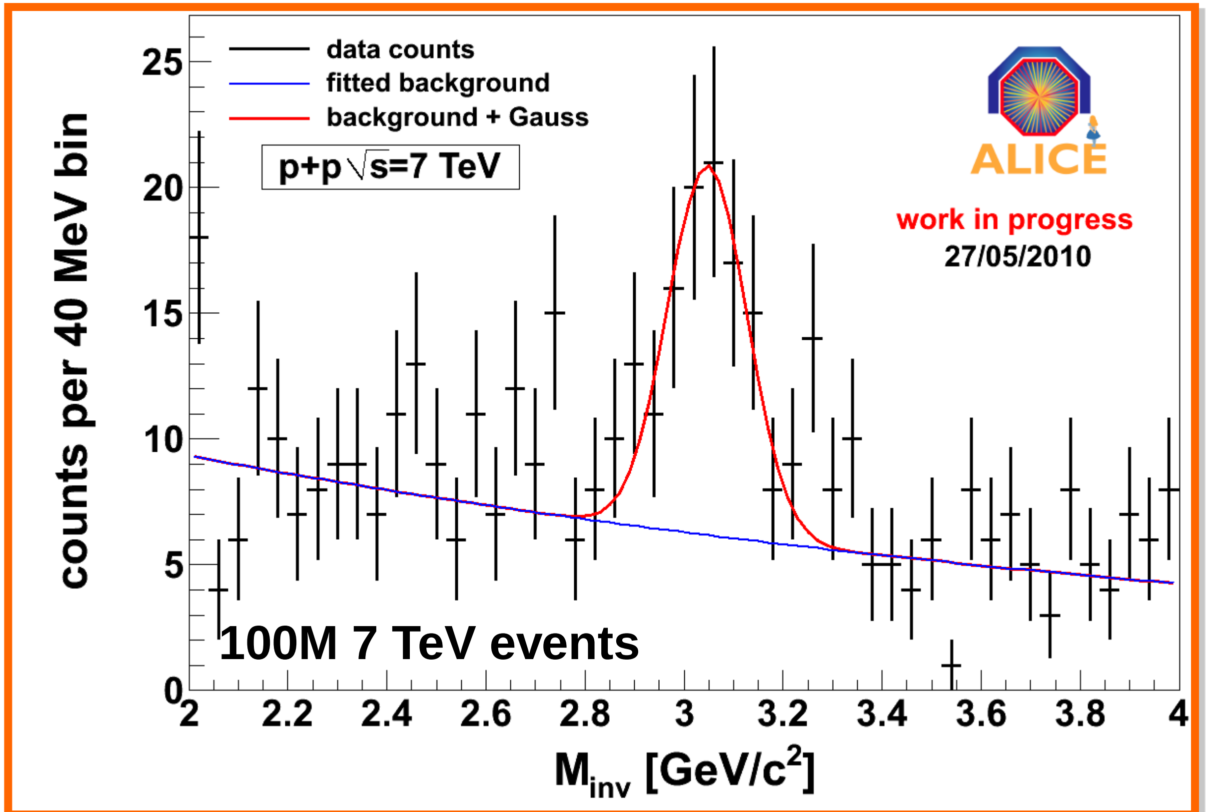
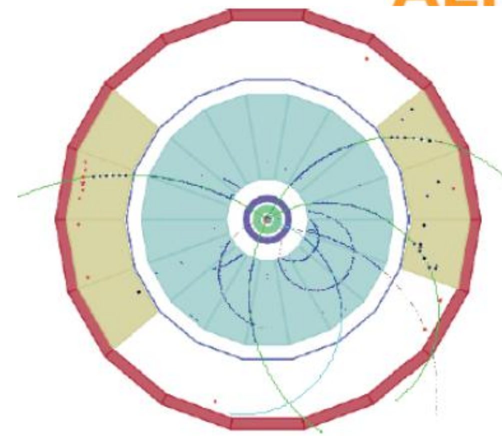
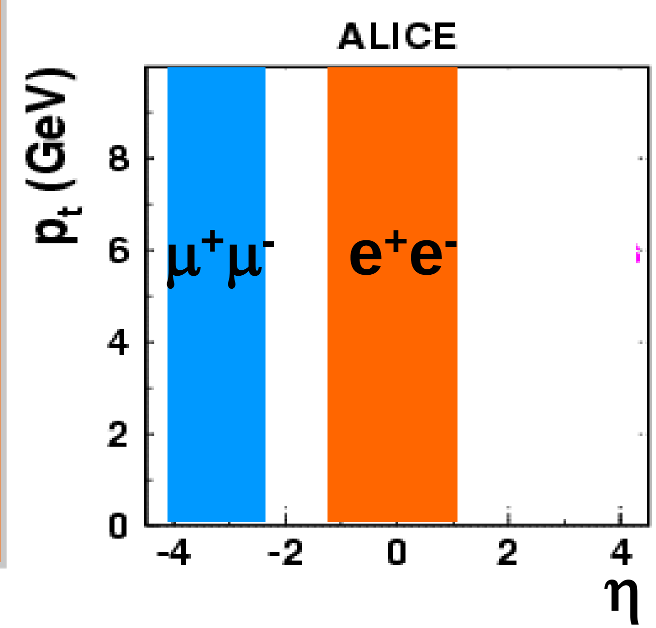
$J/\psi \rightarrow ee$, $|\eta|<0.9$

- e PID from TPC
  - TRD and EMCAL calib. ongoing



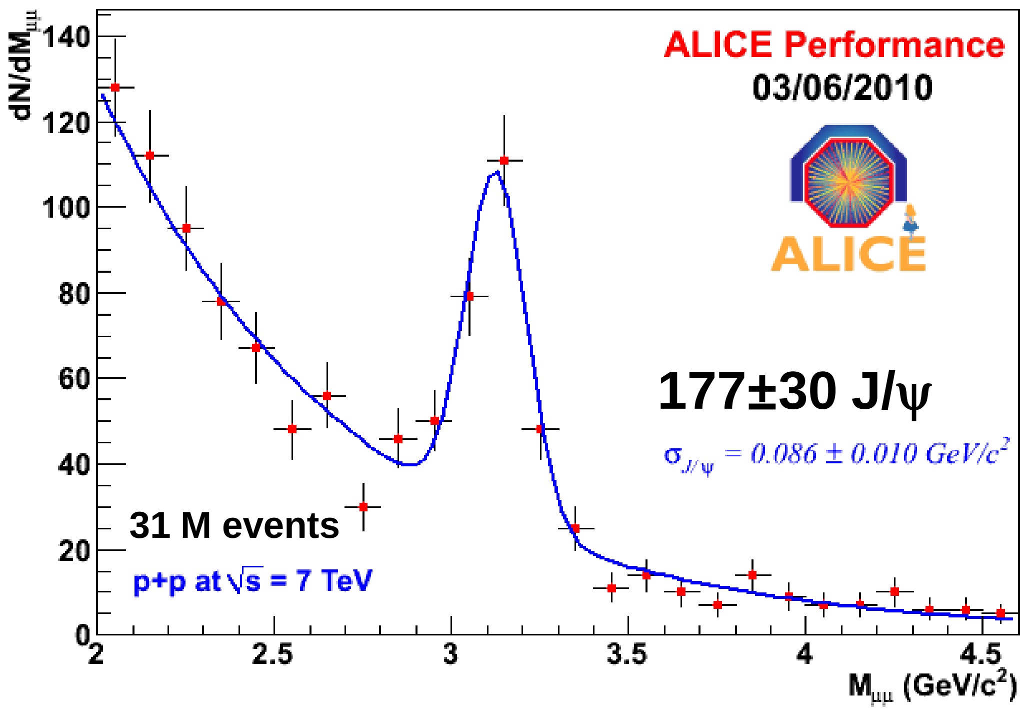


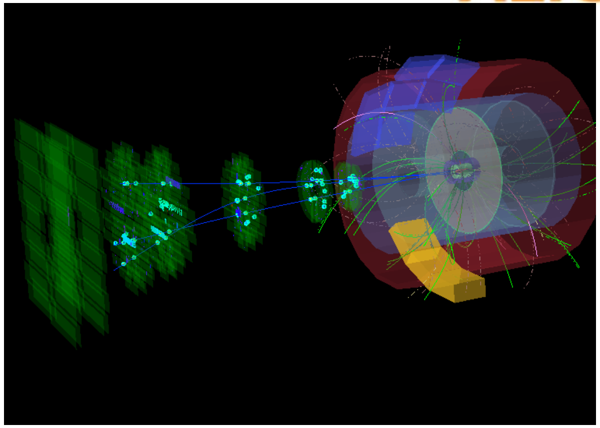
acceptance to $p_t=0$



Forward J/ψ→μμ

- J/ψ→μμ, -4<η<-2.5





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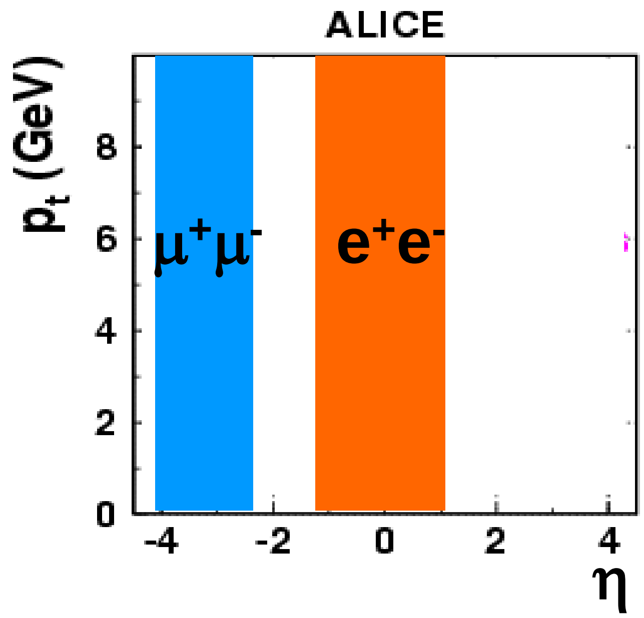
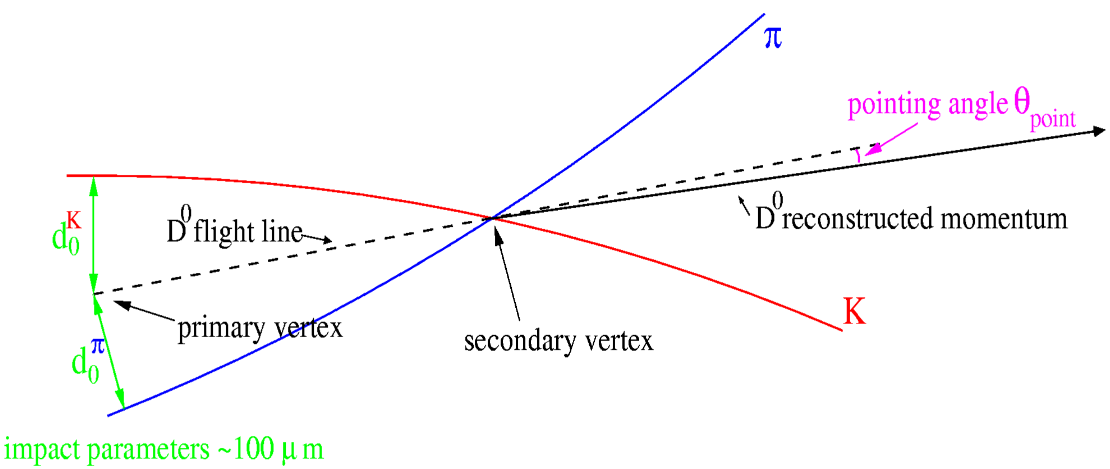
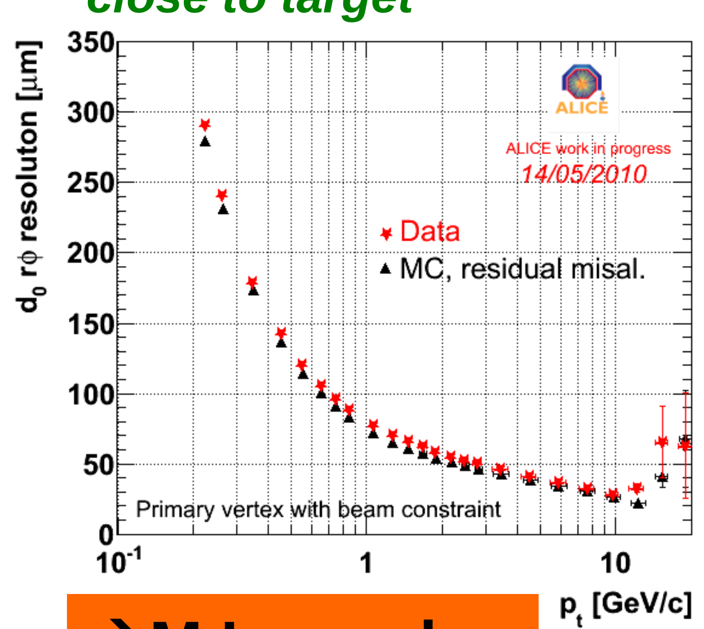


Charm: D meson reconstruction

- Main selection: displaced-vertex topology
- Example: $D^0 \rightarrow K^- \pi^+$
  - good pointing of reconstructed D momentum to the primary vertex
  - ppair of opposite-charge tracks with large impact parameters
- K ID in TPC+TOF helps rejecting background at low p_t



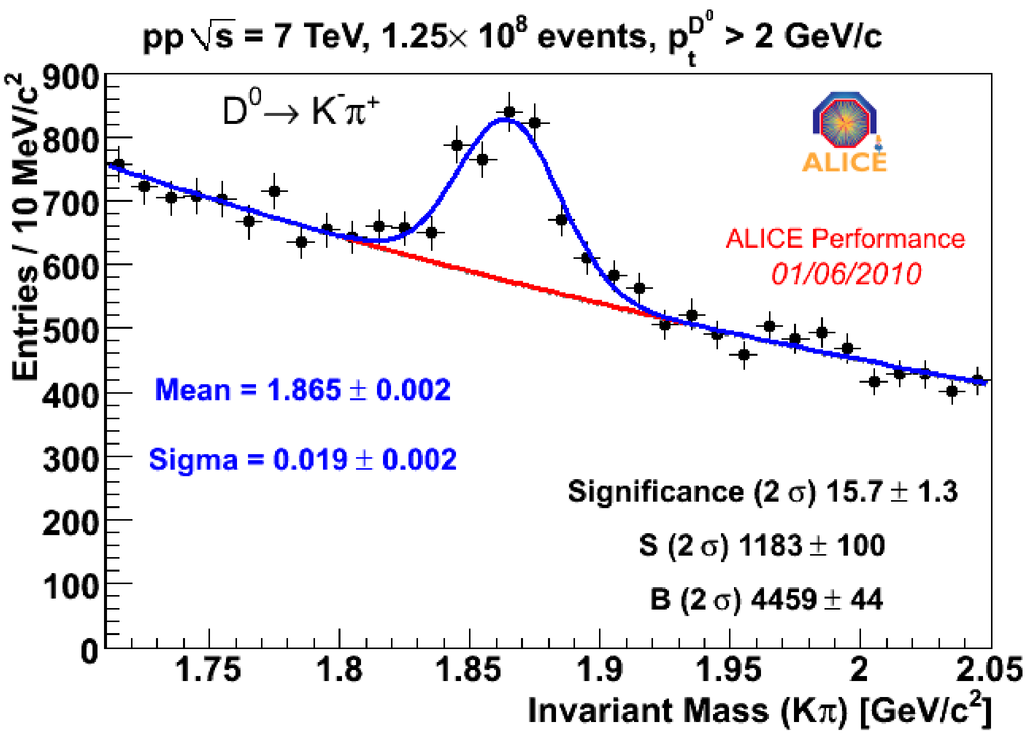
Impact parameter resolution close to target

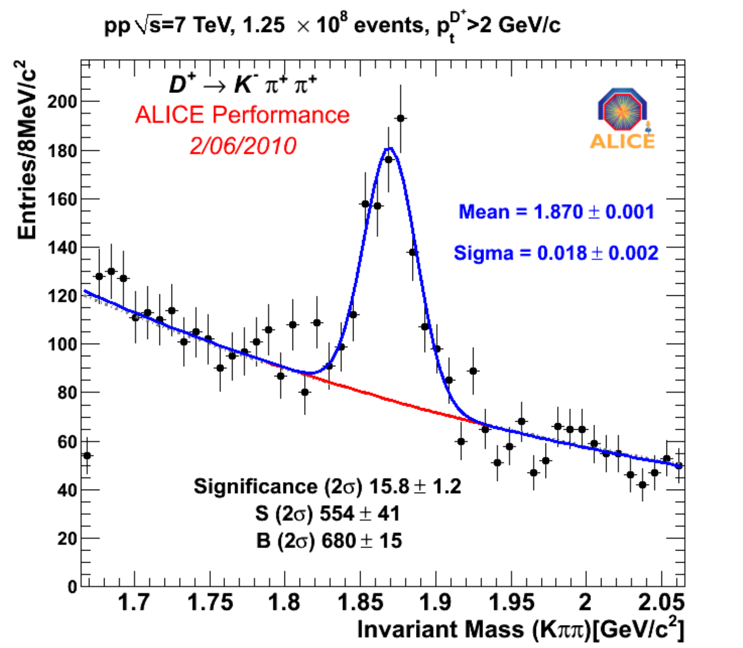


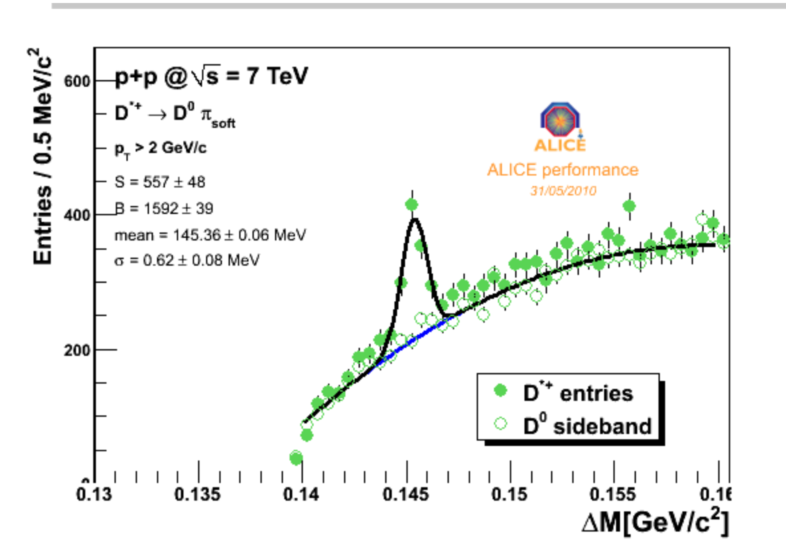
→M.Lunardon

Charm: D^0, D^+, D^{*+}

- 1.25×10^8 pp at 7 TeV
- Signals in 4 p_t bins in 2-10 GeV/c
  - expect to cover 0.5-15 GeV/c with 10^9
  - compare to pQCD (FONLL) at 7 TeV



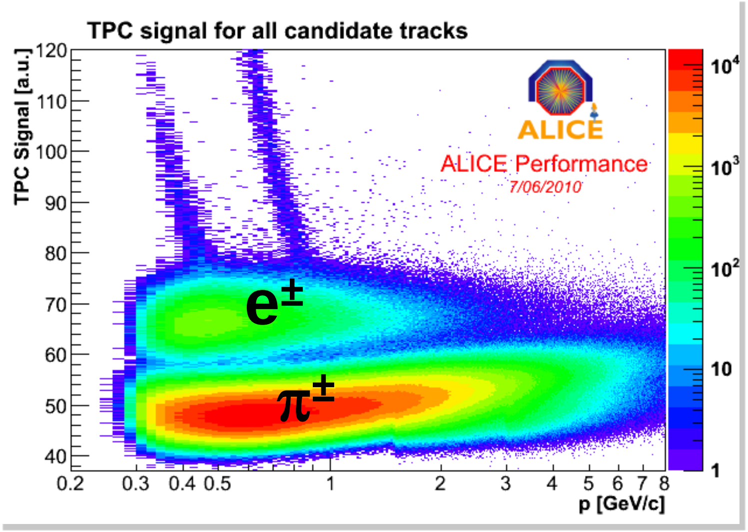


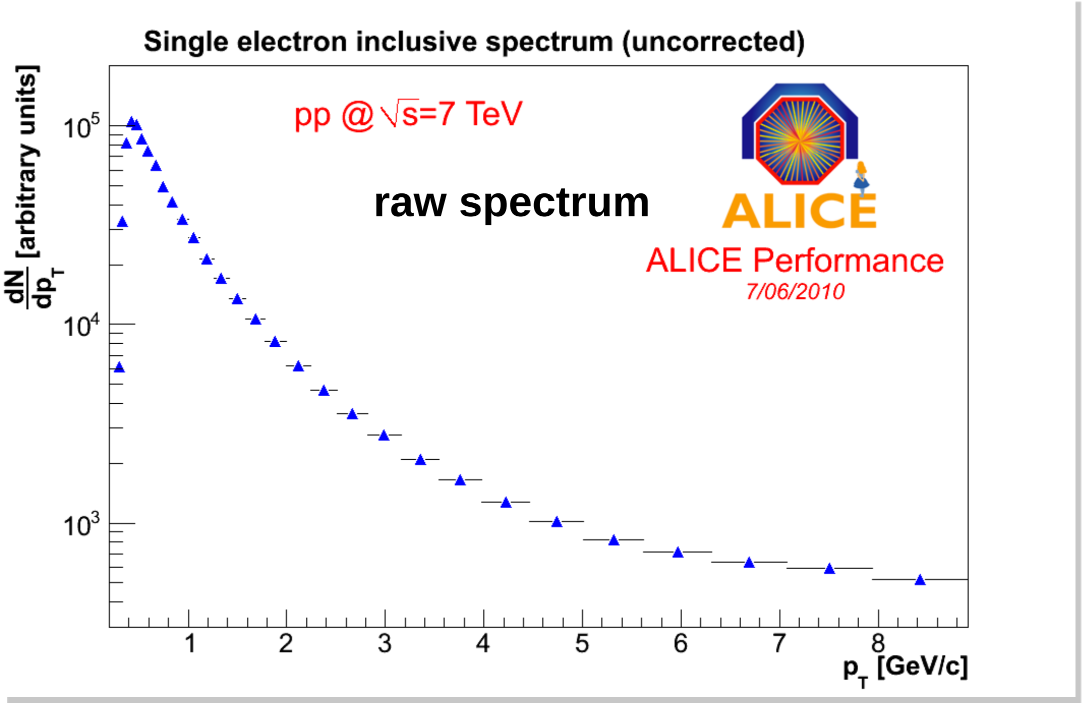


Heavy flavour from single leptons

- c and b production in semi-leptonic channels in preparation

Electrons |η|<0.9:
TPC dE/dx after K and p rejection with TOF. TRD and EMCAL will join soon



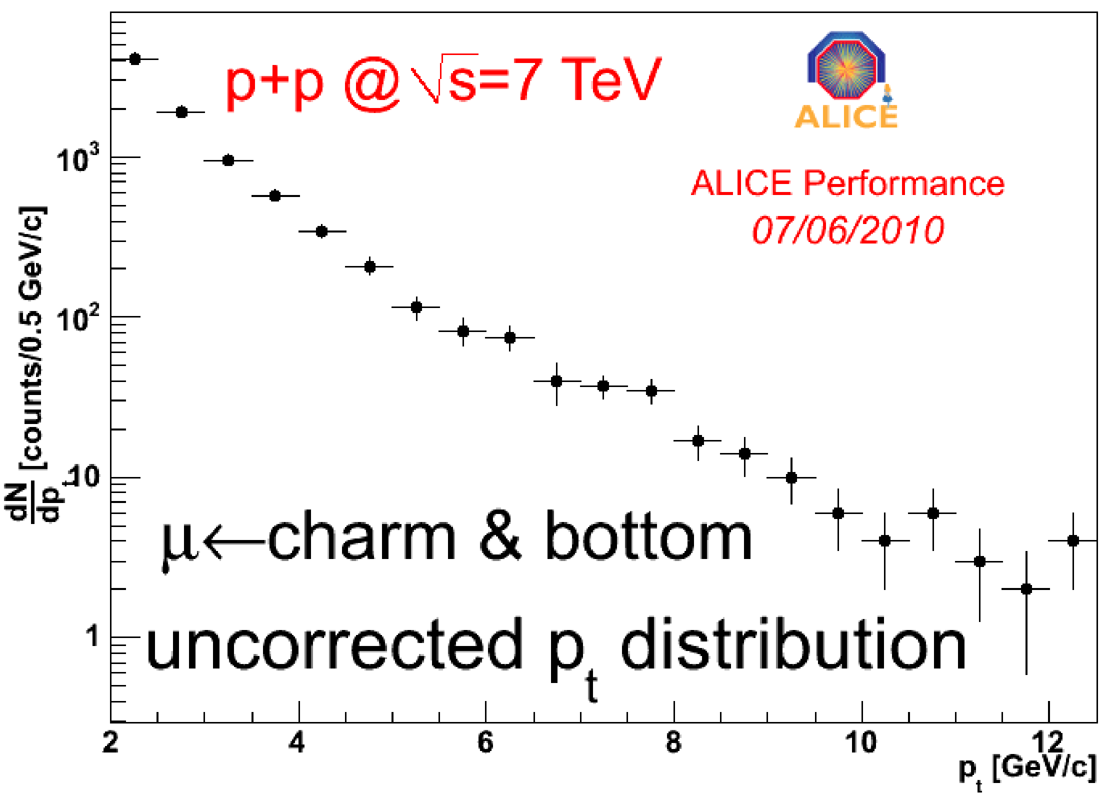


+ displacement selection → beauty

Heavy flavour from single leptons

- c and b production in semi-leptonic channels in preparation

Muons $-4<\eta<-2.5$:
Light quark contribution subtracted with PYTHIA (normalized to data at low p_t).
Not corrected.



→ c (low p_t) & b to be separated by fitting based on pQCD shapes, in progress ...

First Physics Results from ALICE

- Particle multiplicity
  - *increase from 0.9 to 7 TeV significantly larger (>20%) than predicted*
- Momentum spectra
  - *$\langle p_t \rangle$ VS N_{ch} not described by any of the MCs*
- Anti-proton/proton ratio at midrapidity
  - *$\bar{p}/p$ goes to 1 at 7 TeV → baryon number transfer suppressed over large Δy*
- Femtoscopic measurement at 0.9 TeV
  - *particle emitting source "size" increases with multiplicity*
- Event topology
  - *lower "jettiness" than expected in LHC collisions*
- Promising performance for ID spectra, strangeness, charm, charmonium
  - ***ALICE is ready to deliver many more Physics Results***

Outlook

Papers in the pipeline:

- Charged particle p_t distribution
- Baryon-antibaryon asymmetry
- Bose-Einstein correlations
- Strangeness production (K^0, Λ, Ξ, Φ)
- Identified particles p_T (π, K, p)

Analyses in progress:

- dN/dp_t at 7 TeV
- π^0, η
- c and b production
- J/ψ production
- high multiplicity
- jet correlations
- event shape
- underlying events
- reconstructed jets
- b-tagged jets
- …

November 2010: Pb-Pb collisions in ALICE!

→H.Torii