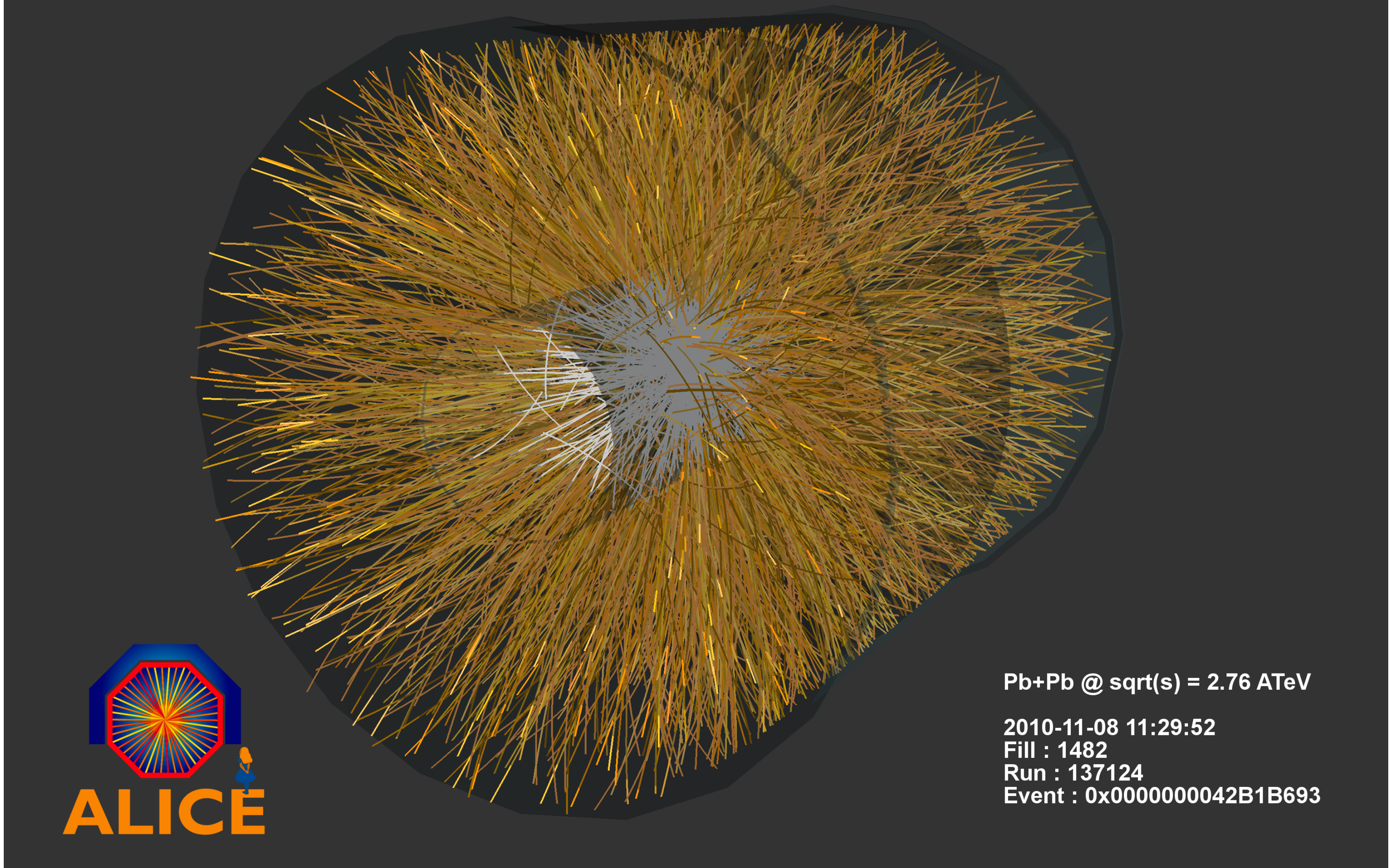
First heavy-ion results from ALICE at the LHC

Les Rencontres de Physique de la Vallée d'Aoste

Andrea Dainese
(INFN Padova, Italy)
on behalf of the ALICE Collaboration

Pb-Pb collisions $\sqrt{s_{NN}}$=2.76 TeV !

→ largest energy jump (×14) in the history of Heavy Ion Physics!

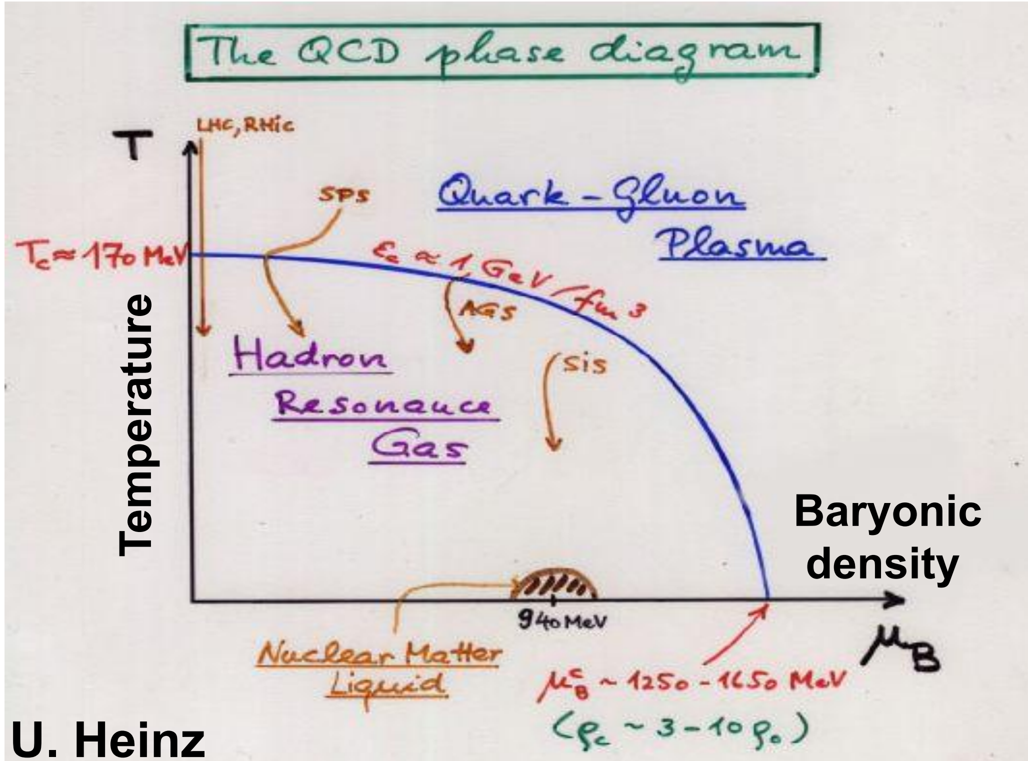


Talk Outline

- QCD matter in extreme conditions at the LHC
- First Pb-Pb run and ALICE
- First characterization of QCD matter *properties*:
  - particle multiplicity ⟷ *energy density*
  - Bose-Einstein particle correlations ⟷ *size and lifetime*
  - collective flow of produced particles ⟷ *viscosity*
  - suppression of hard particles ⟷ *opacity*
- What will come next: outlook
- Conclusions

ALICE Pb-Pb papers so far:
PRL 105, 252301 (2010)
PRL 106, 032301 (2011)
PLB 696, 328 (2011)
PRL 105, 252302 (2010)
PLB 696, 30 (2011)

Heavy Ion Physics at LHC: QCD matter under extreme conditions

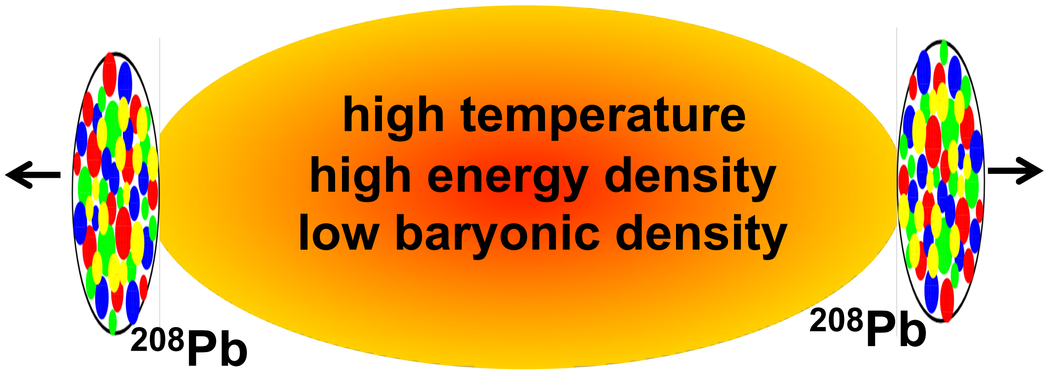


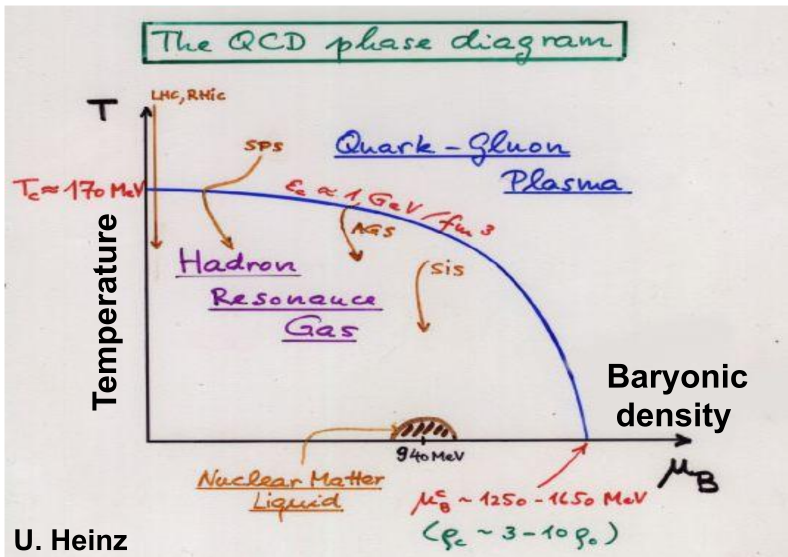
At high energy density (high temperature and/or high density) hadronic matter undergoes a phase transition to the *Quark-Gluon Plasma (QGP)*

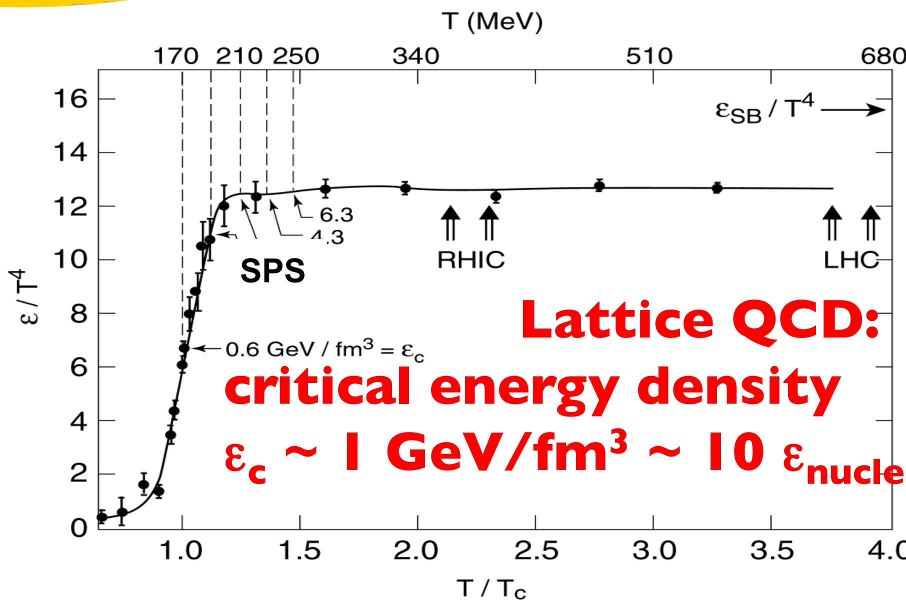
- *a state in which colour confinement is removed*
- *and chiral symmetry is restored*
- *a high-density QCD medium of "free" quarks and gluons*

The Little Bang in the lab

- QCD phase transition (QGP → hadrons) at $t_{Universe}$~ 10 μs at μ_B=0
- In **high-energy heavy-ion** collisions **large energy densities** (> 2–3 GeV/fm³) are reached over **large volumes** (>> 100 fm³)







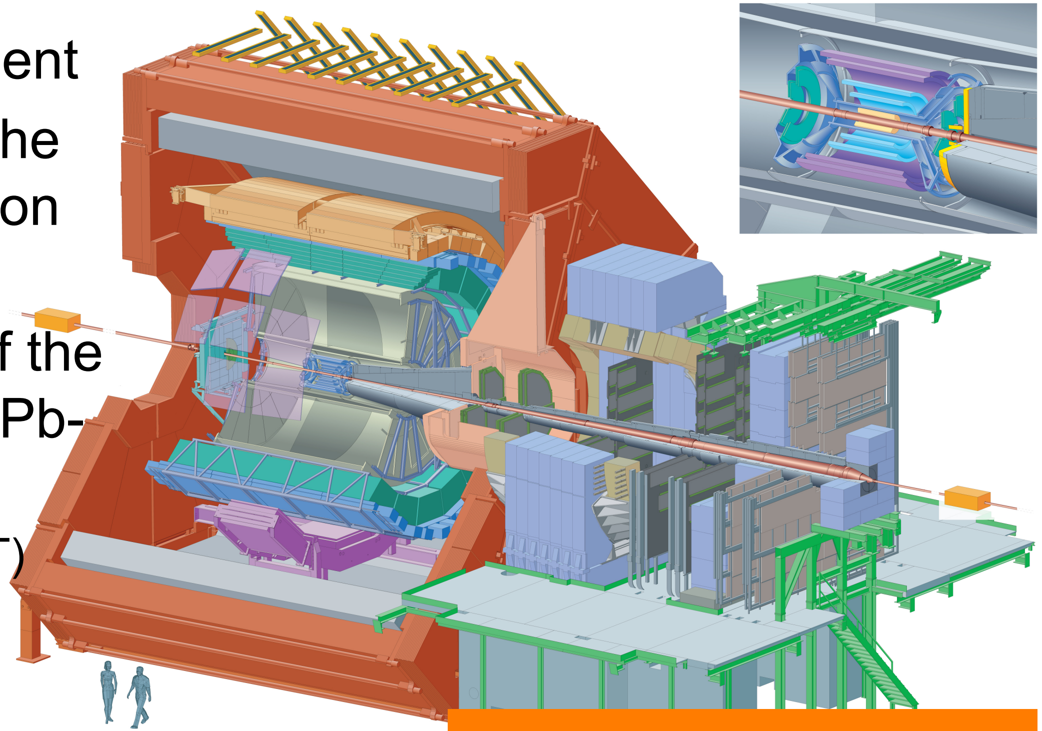
Lattice QCD: critical energy density ε_c ~ 1 GeV/fm³ ~ 10 $\varepsilon_{nucleus}$

The Little Bang in the lab

- QGP hints at **CERN-SPS**, $\sqrt{s_{NN}} = 17\ \text{GeV}$
  - energy density ~ 1 × critical value ε_c
- First QGP properties at **BNL-RHIC**, $\sqrt{s_{NN}} = 200\ \text{GeV}$
  - energy density ~ 10 × critical value ε_c
- Ultimate QGP machine: **CERN-LHC**, $\sqrt{s_{NN}} = 2.76 - 5.5\ \text{TeV}$
  - energy density ~ 30-50 (??) × critical value ε_c
  - ***much higher initial temperature***
  - ***also very important: more physis tools to study the system produced***
    - ***high-energy jets***
    - ***heavy quarks***
    - ***photons and vector bosons (W, Z^0)***

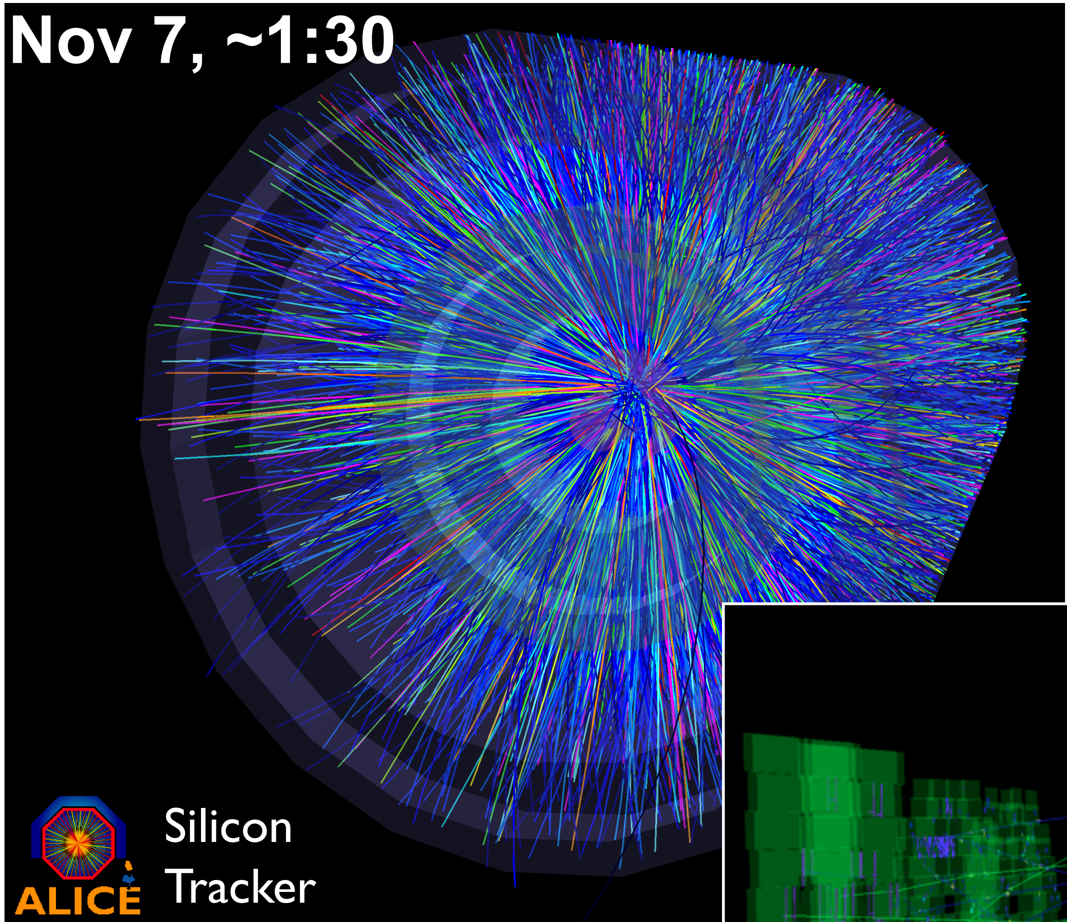
ALICE Heavy Ion Program

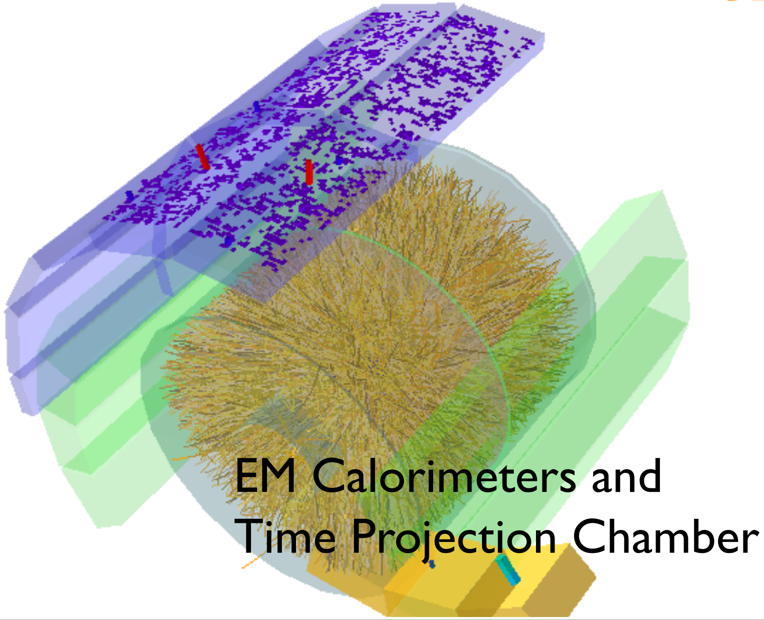
- ALICE is a multi-purpose experiment
- Reconstruct and identify most of the particles emerging from the collision in order to:
- Determine the global properties of the extended QCD state produced in Pb-Pb collisions
  - redundant tracking with low field (0.5T) and material budget
    → sensitivity to the bulk of particles
  - extensive particle identification
    → hadrochemical properties at freeze out
- Assess its temperature and density by studying rare probes
  - high-momentum, jets
  - heavy flavour, quarkonia
  - photons

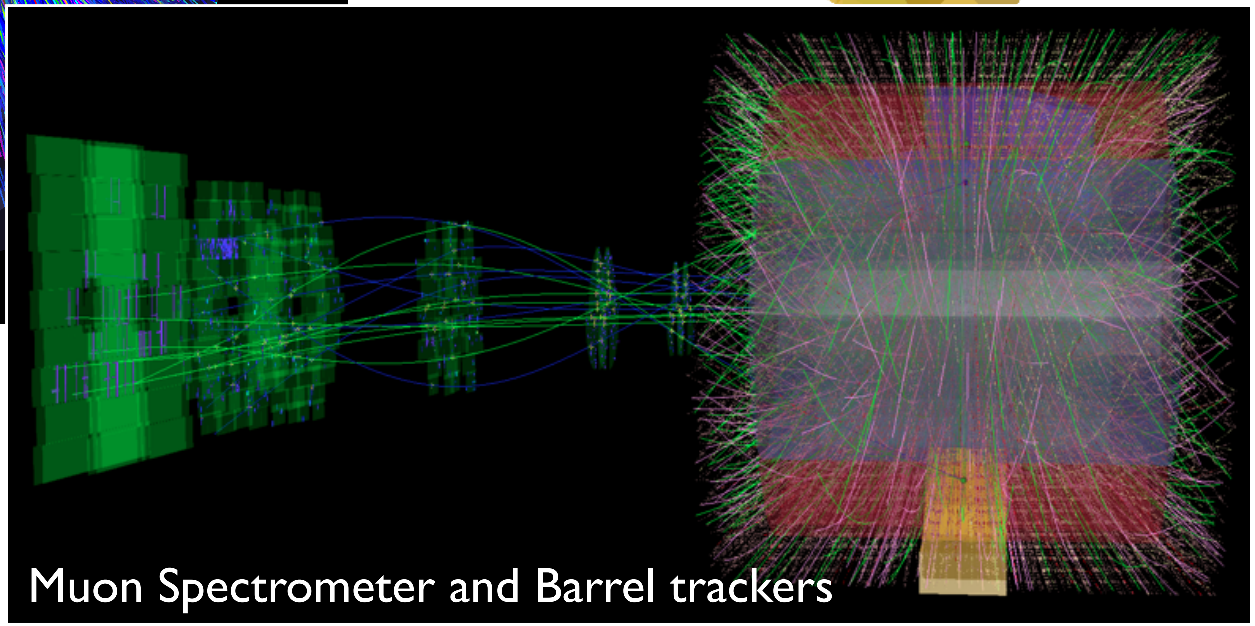


→ see E. Scomparin

November 7, 2010: Start!

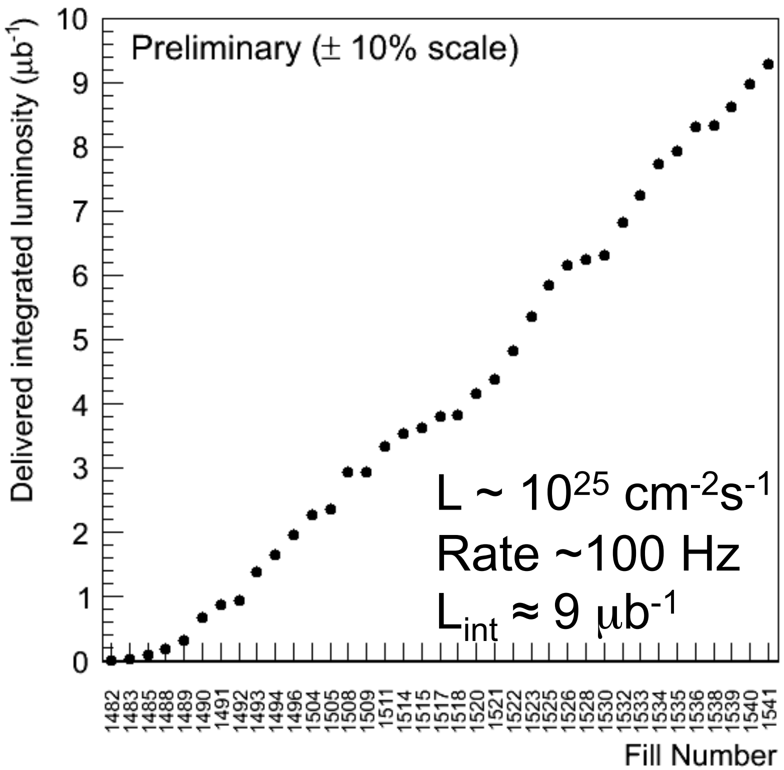


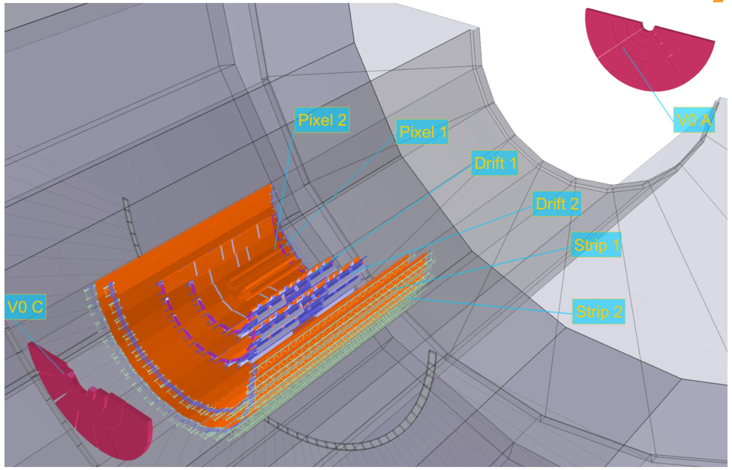




… first ALICE Pb-Pb data taking …

- Loose trigger based on minimum bias interaction
- Catches ≈98% of Pb-Pb inelastic cross section





MB Triggers: combinations of the following detectors

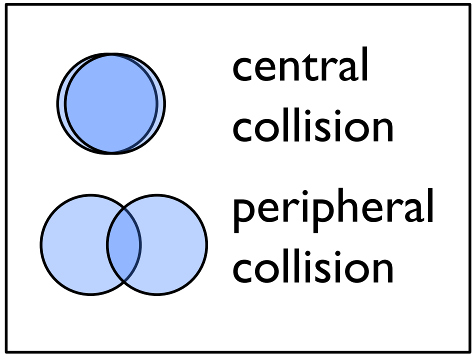
1. **SPD** Fast-Or (1 or 2 hits)
2. **V0** (A side)
3. **V0** (C side)

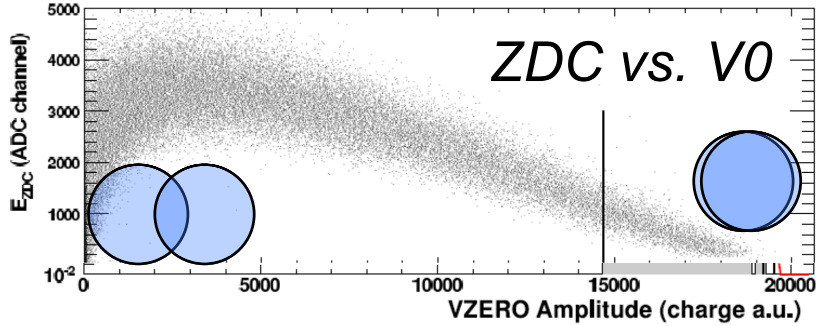
High Multiplicity, Zero Bias and ultraperipheral triggers also used

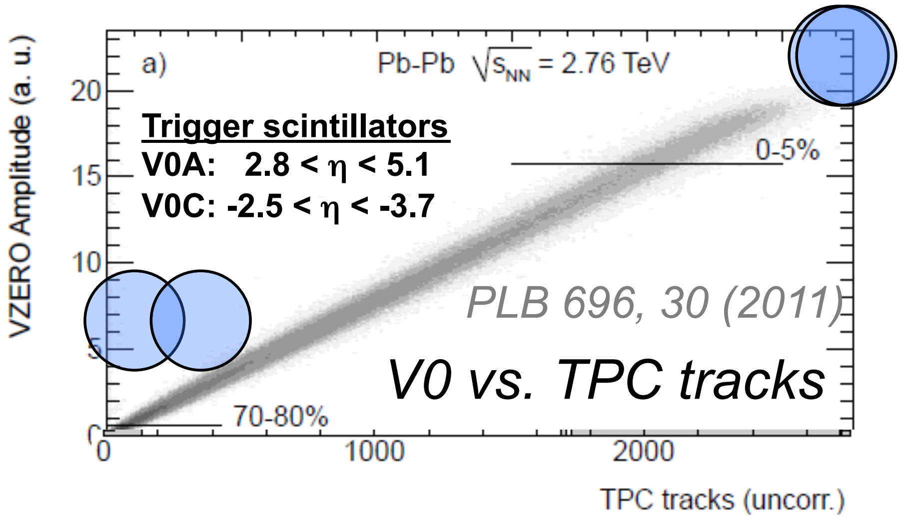
TOTAL of over 90 M recorded triggers

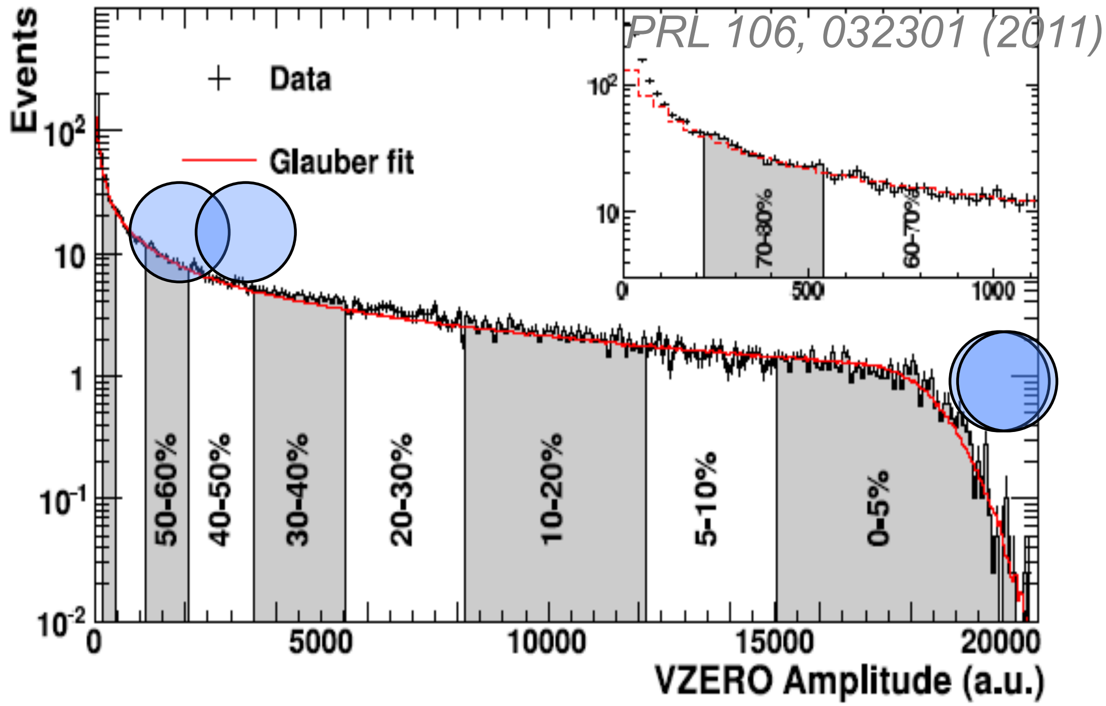
… collision centrality …

- Pb-Pb collisions are classified in centrality classes, corresponding to percentiles of the inelastic cross section
- Glauber-model fits to several estimators (hit/track multiplicities + zero degree calorimeter signals)
  - Glauber fit: $N_{ch} \sim f \times N_{part} + (1-f) \times N_{coll}$









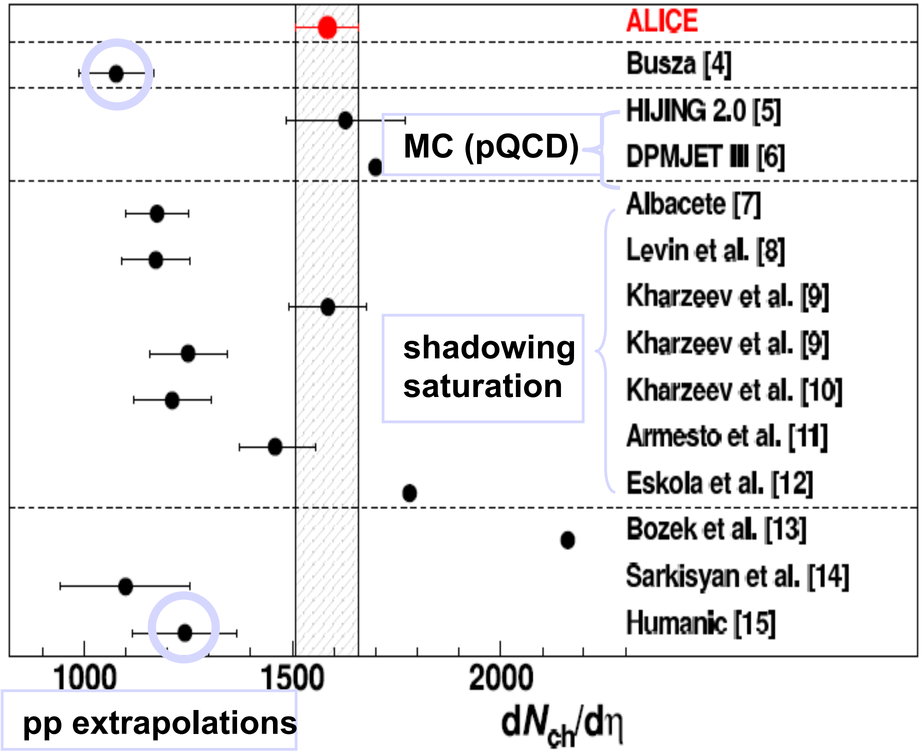
November 17: First Results on Charged Particle Multiplicity

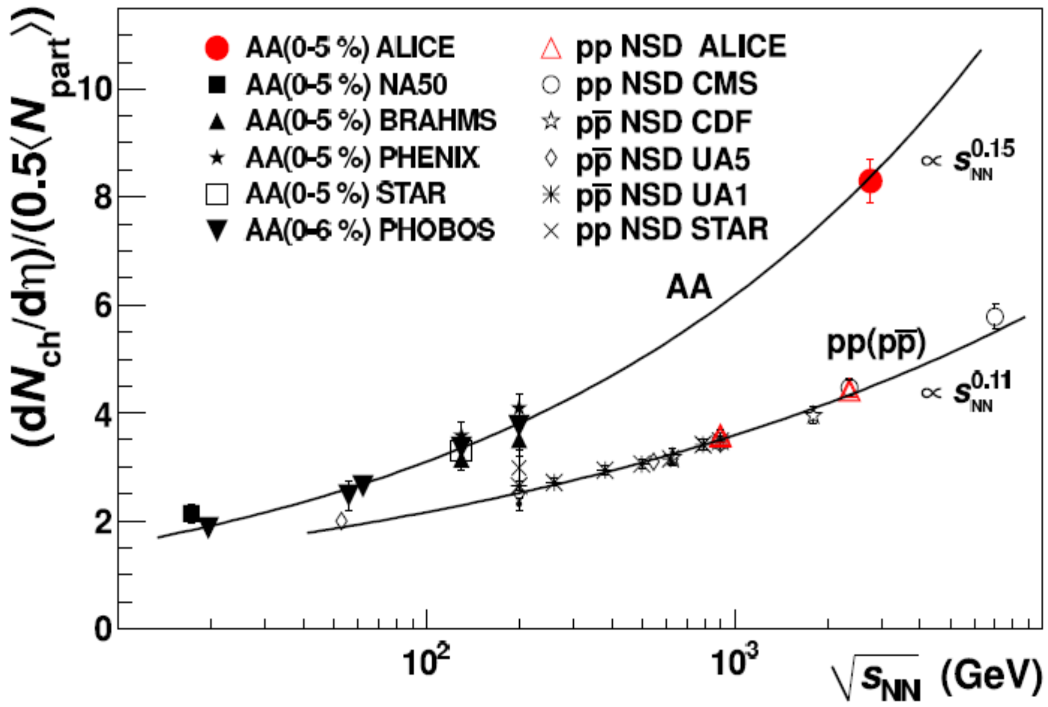
- Central Pb-Pb (from pixels): **$dN_{ch}/d\eta$ = 1584±76** (syst)
  - somewhat on high side of expectations
  - growth with √s faster in AA than pp

$$\varepsilon(\tau_0) = \frac{E}{V} = \frac{1}{\tau_0 A}\frac{dN}{dy} < m_t >$$

- **Energy density ≈ 3×RHIC** (at same time τ_0)
  - lower limit, likely τ_0(LHC) < τ_0(RHIC)

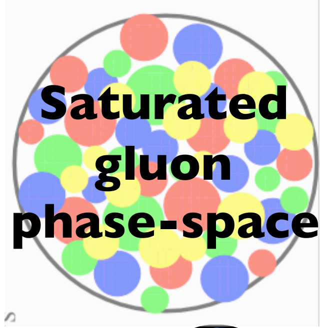
PRL 105, 252301 (2010)

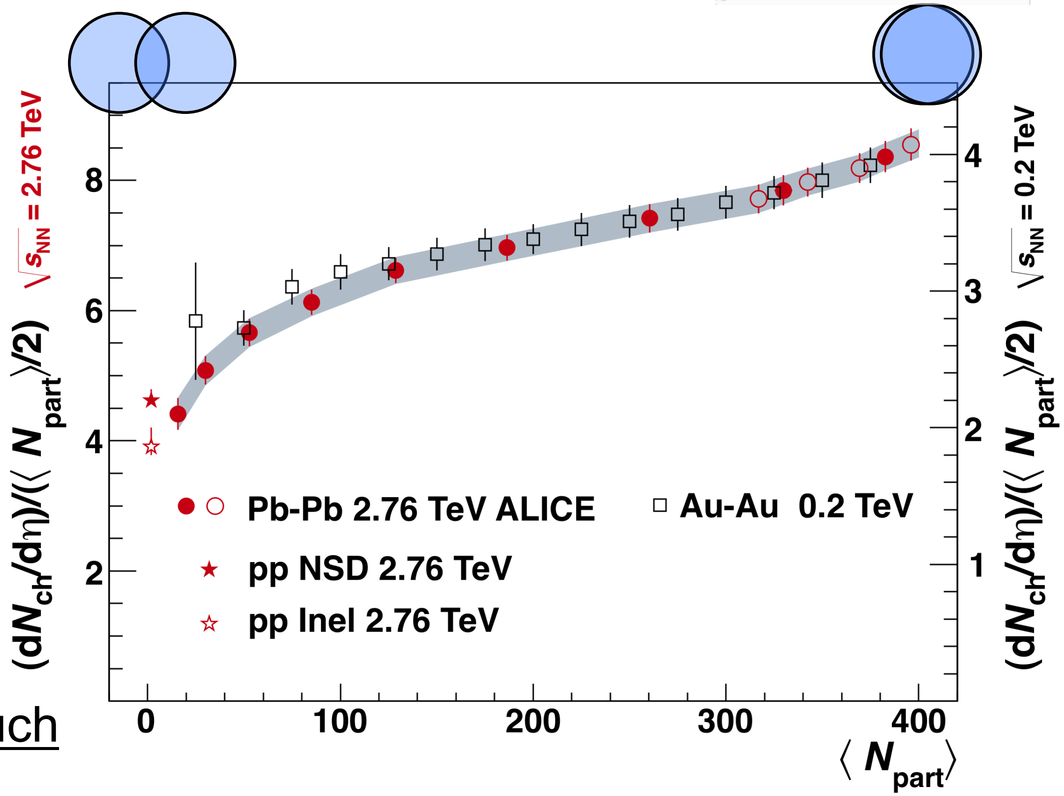




Centrality dependence of $dN_{ch}/d\eta$

- $dN_{ch}/d\eta$ as function of centrality
  - normalized to 'overlap volume' ~ $N_{participants}$
- Sensitive to degree of gluon saturation in the initial state
- Same trend as at RHIC
- Comparison to models:
  - DPMJET MC
    - fails to describe the data
  - HIJING MC
    - strong centr. dependence gluon shadowing
  - Saturation models (Armesto, Kharzeev, Albacete):
    - some tend to saturate too much





PRL 106, 032301 (2011)

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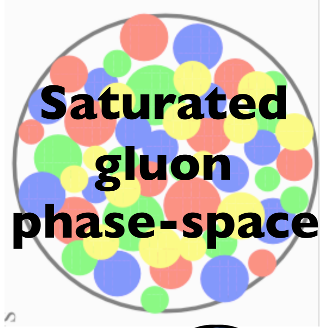
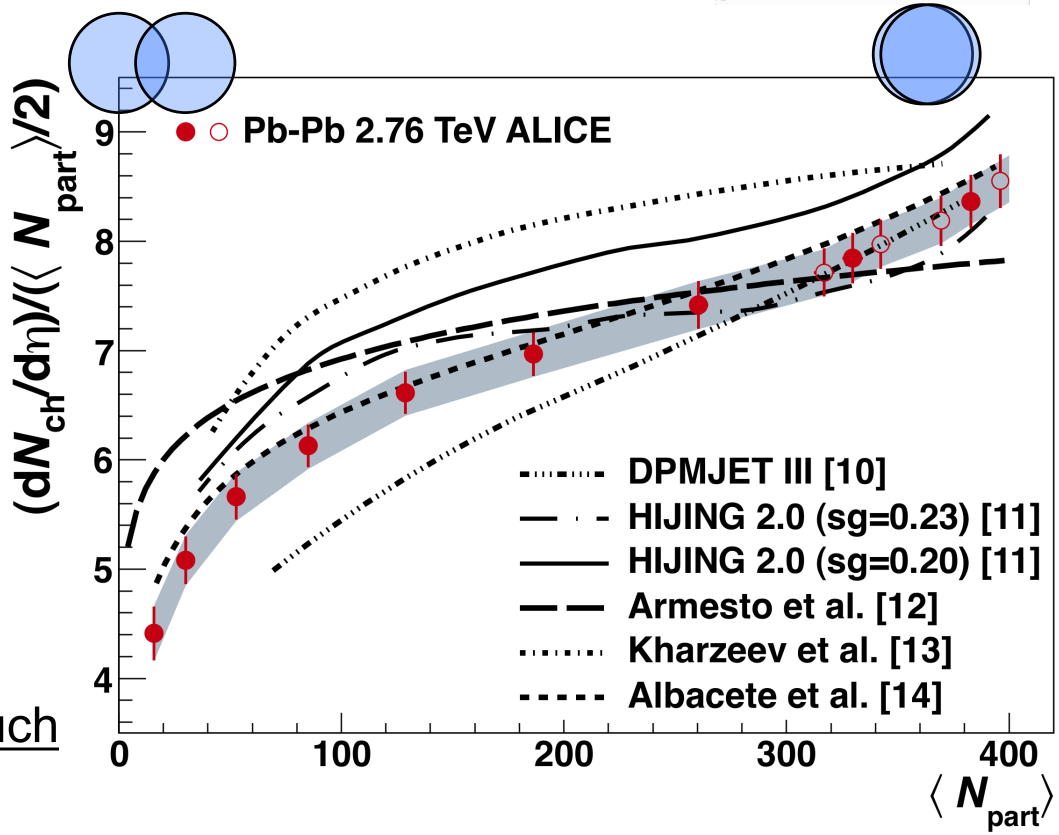


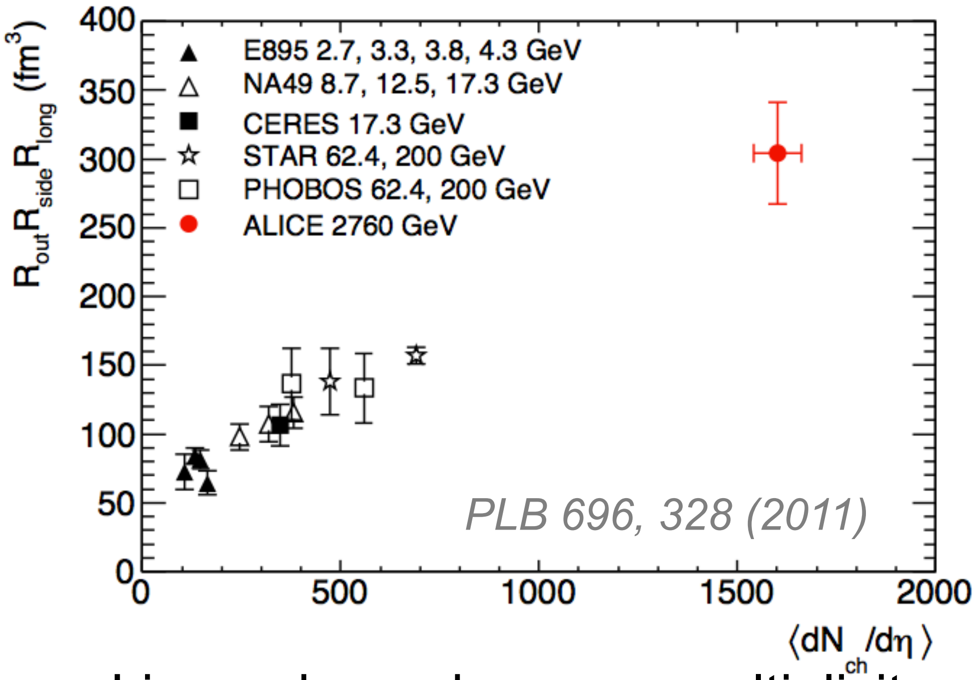


PRL 106, 032301 (2011)

Bose-Einstein correlations: extended system of QCD matter

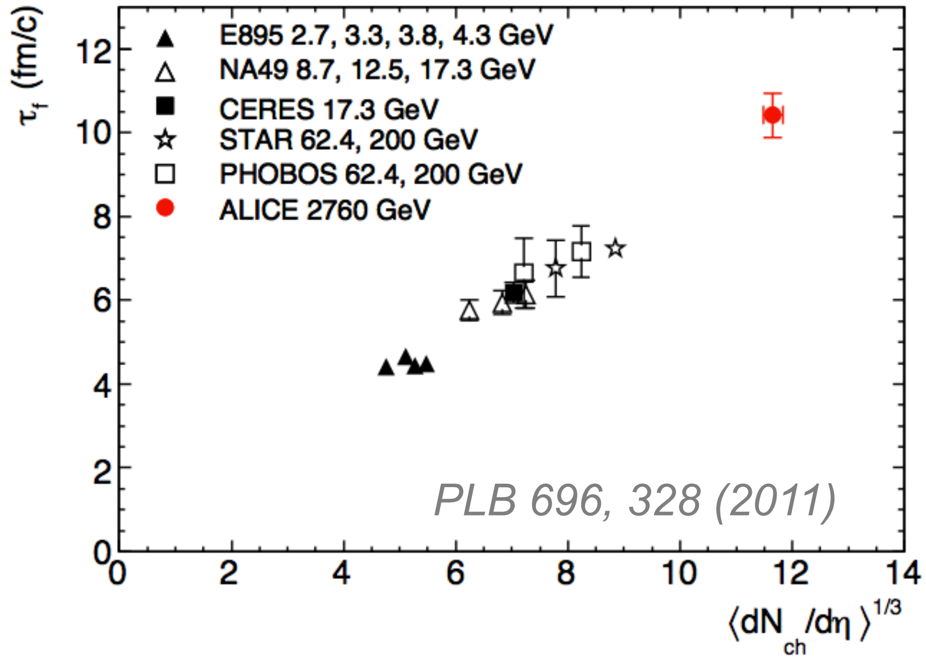
- Measure the Bose-Einstein enhancement for pairs of pions (identical bosons) at low momentum difference $q_{inv}=|\mathbf{p}_1-\mathbf{p}_2|$, vs. multiplicity
- Assess the space-time extension of the system that emits particles in Pb-PB collisions (homogeneity volume)

Homogeneity volume



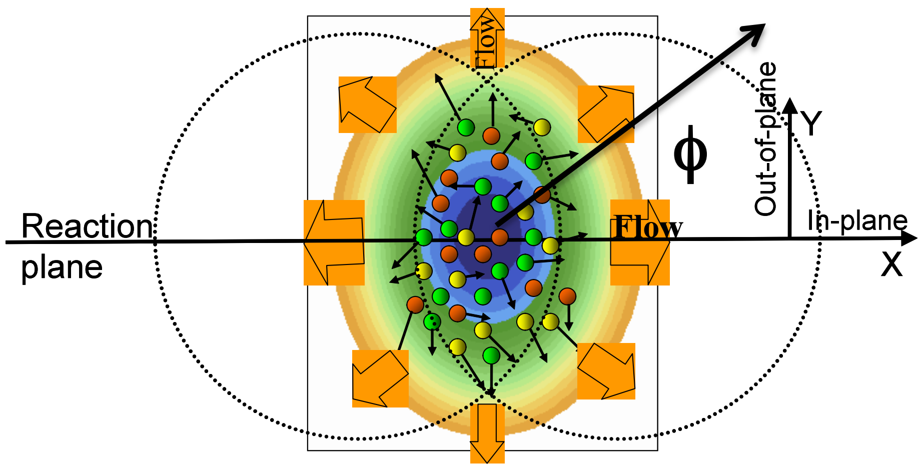
- Linear dependence on multiplicity
- V≈300 fm^3 ~ ×2 as at RHIC

Decoupling time **(from collision to hadron freeze-out)**



- 10-11 fm/c ~ ×1.4 as at RHIC

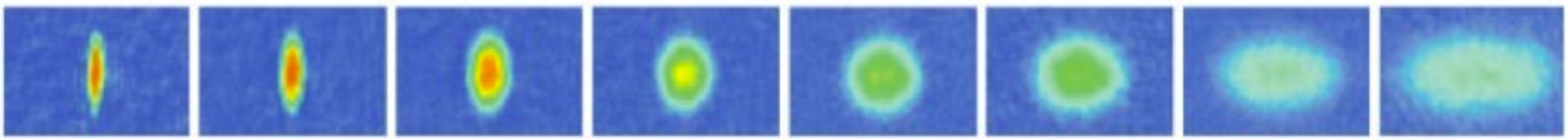
November 17: Collectivity! First Results on Elliptic Flow



- System geometry asymmetric in non-central collisions
- Hydro-dynamic models:
  - expansion under azimuth-dep. pressure gradient
  - results in azimuth-dep. momentum distributions
- Measured by the elliptic flow

parameter $v_2(p_t) = \langle\cos(2\phi)\rangle(p_t)$

- Size of v_2 provides a measure of strength of collectivity (mean free path of gluons)
  - Extreme: perfect liquid (zero mean free path) → liquid He, QGP at RHIC?
  - What about LHC? can it be more perfect than at RHIC?

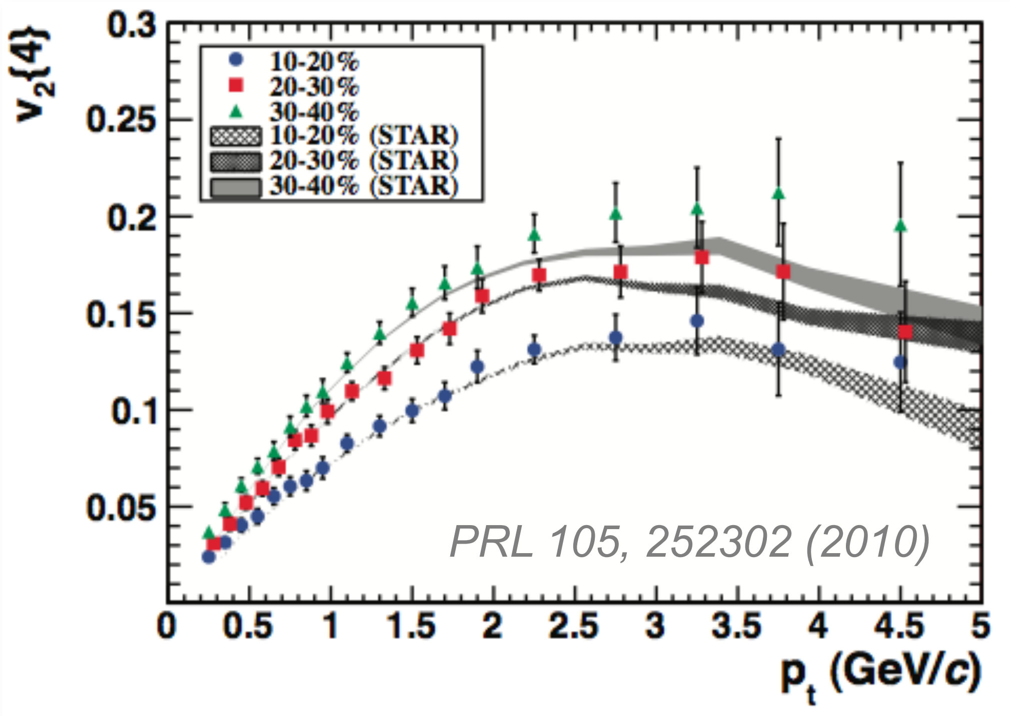


An atomic analogue: Liquid Helium explodes in vacuum

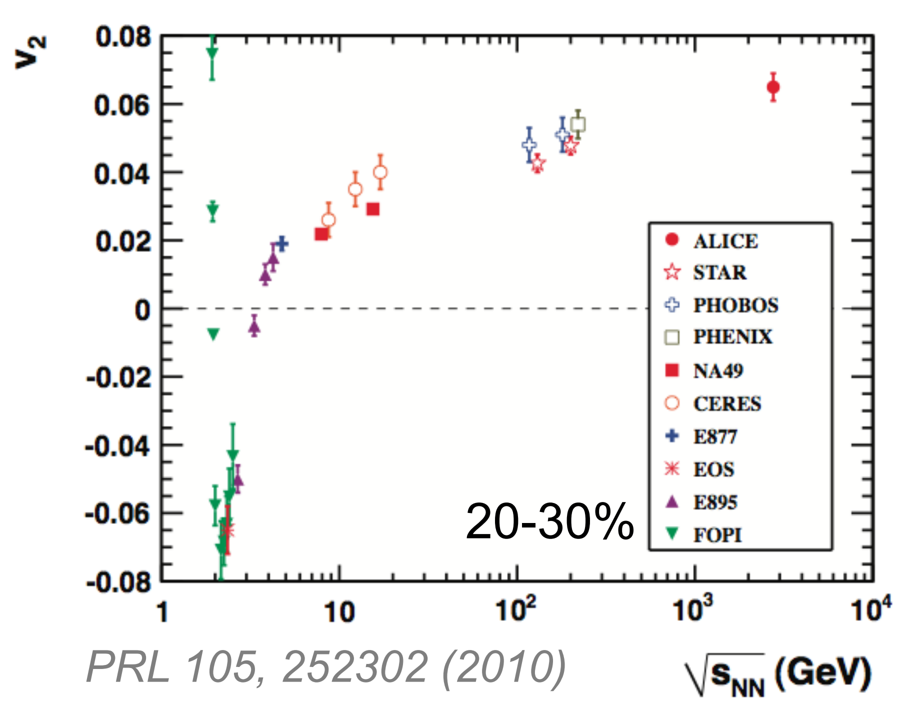
Elliptic flow (v_2) of charged particles

- v_2 extracted based on 2 and 4 particle cumulants
  - methods well established based on RHIC experience

p_t dependence very close to RHIC measurements (in centrality classes)
→ expected based on hydrodynamic models



Elliptic Flow and the Perfect-Liquid QGP



p_t-integrated v_2 in semi-central increases by 30% wrt RHIC

- Large elliptic flow reaches hydro-dynamical limit
  - strong pressure gradient, system close to full thermalization
- Increase with energy larger than predicted for perfect liquid (zero viscosity)
  - need viscous corrections (more important at RHIC than LHC)
  - closer to perfect liquid at LHC than at RHIC?

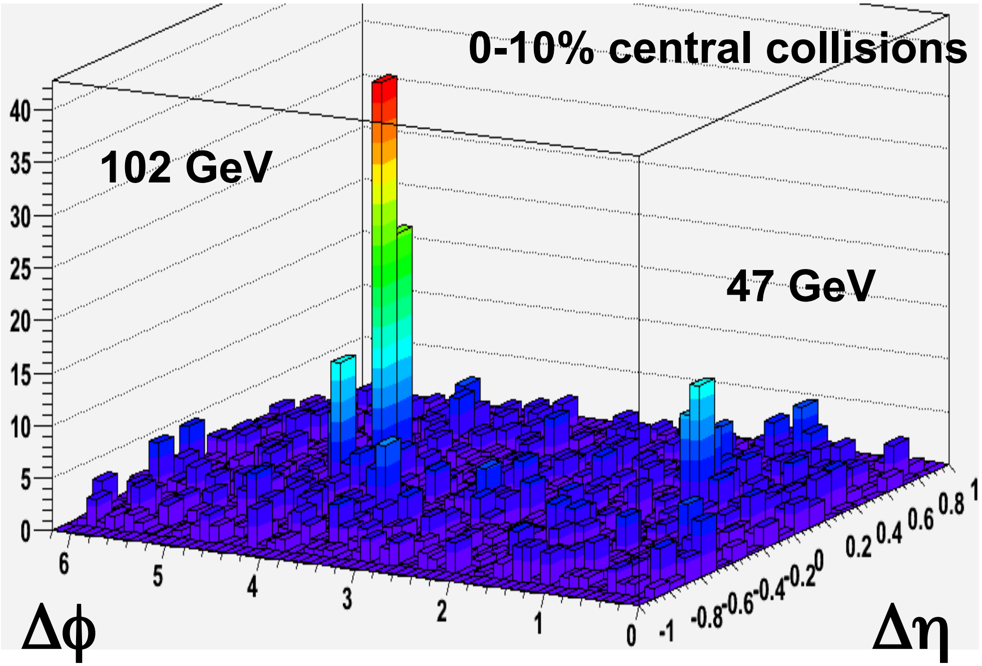
Global properties of QCD matter at the LHC

- Energy density ×3 wrt RHIC → > 15 GeV/fm^3 **Hotter**
- Freeze-out volume ~ 300 fm^3 → ×2 wrt RHIC **Larger**
- Decoupling time ~11 fm/c → ×1.4 wrt RHIC **Longer-lived**
- Elliptic flow as expected for close-to-perfect liquid
- Initial state gluon saturation less strong than expected

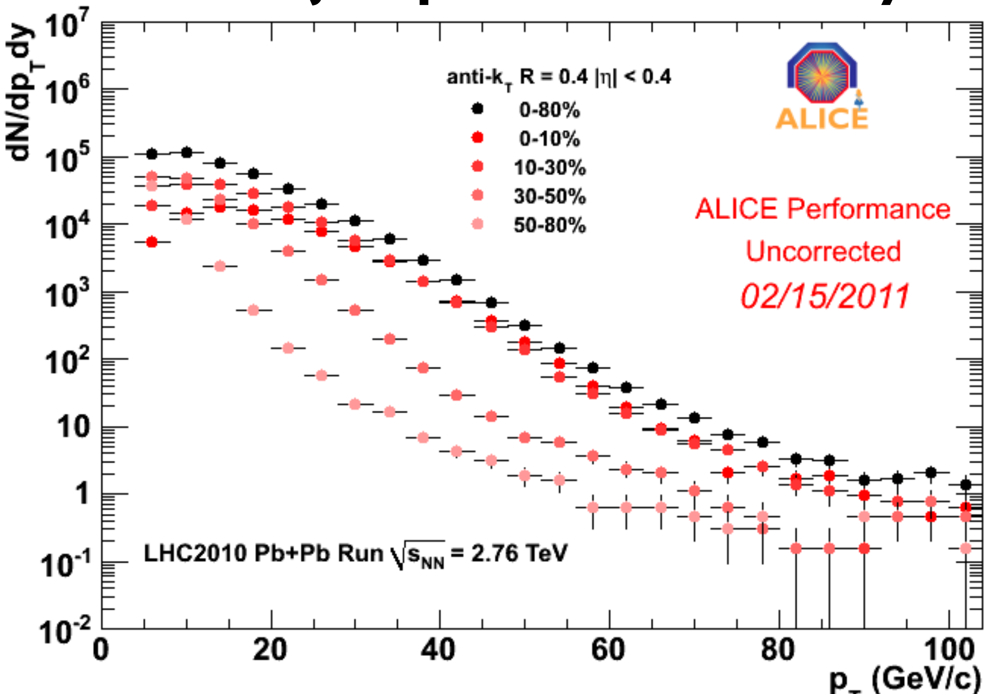
What about Jet Quenching?

- Striking di-jet imbalance observed by ATLAS and CMS
- ALICE EMCal coverage limited in 2010
- Jet reconstruction with charged tracks from TPC (|η|<1)
  - we see qualitatively a similar effect
  - goal: study effect down to low p_t, study onset of di-jet imbalance

→see P. Steinberg, G. Tonelli



Raw jet spectra vs centrality

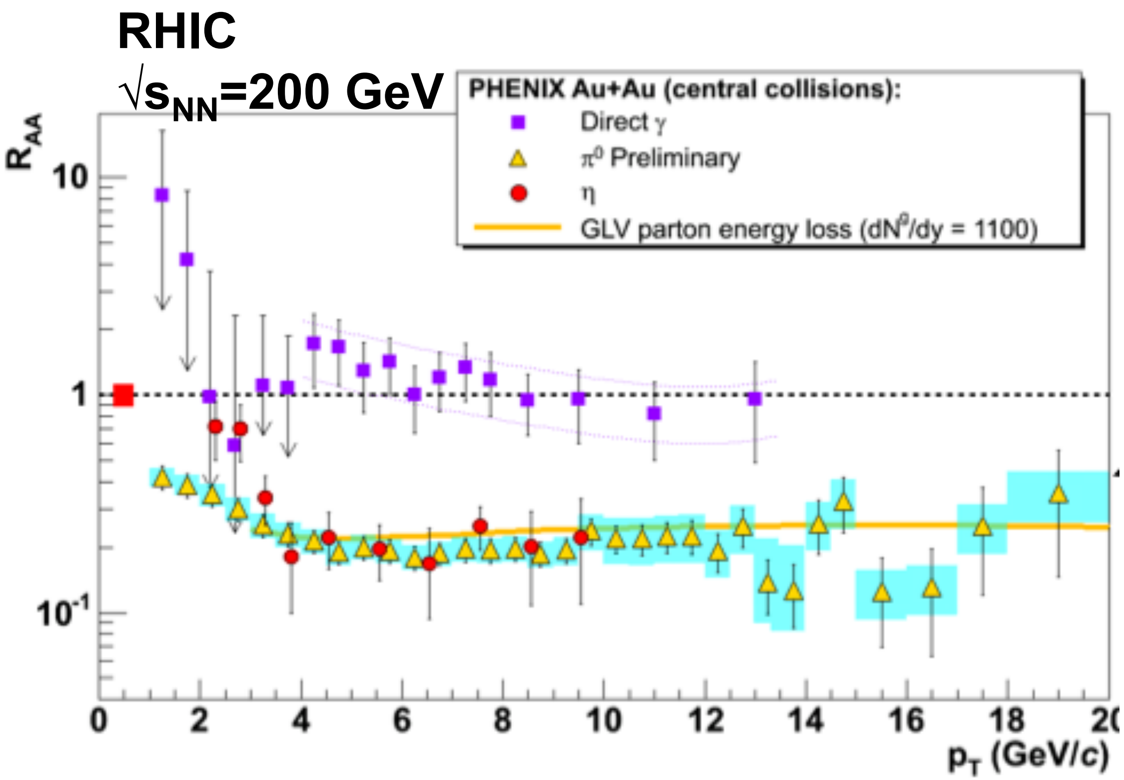


High-momentum particle suppression

- Nuclear modification factor of p_t spectra

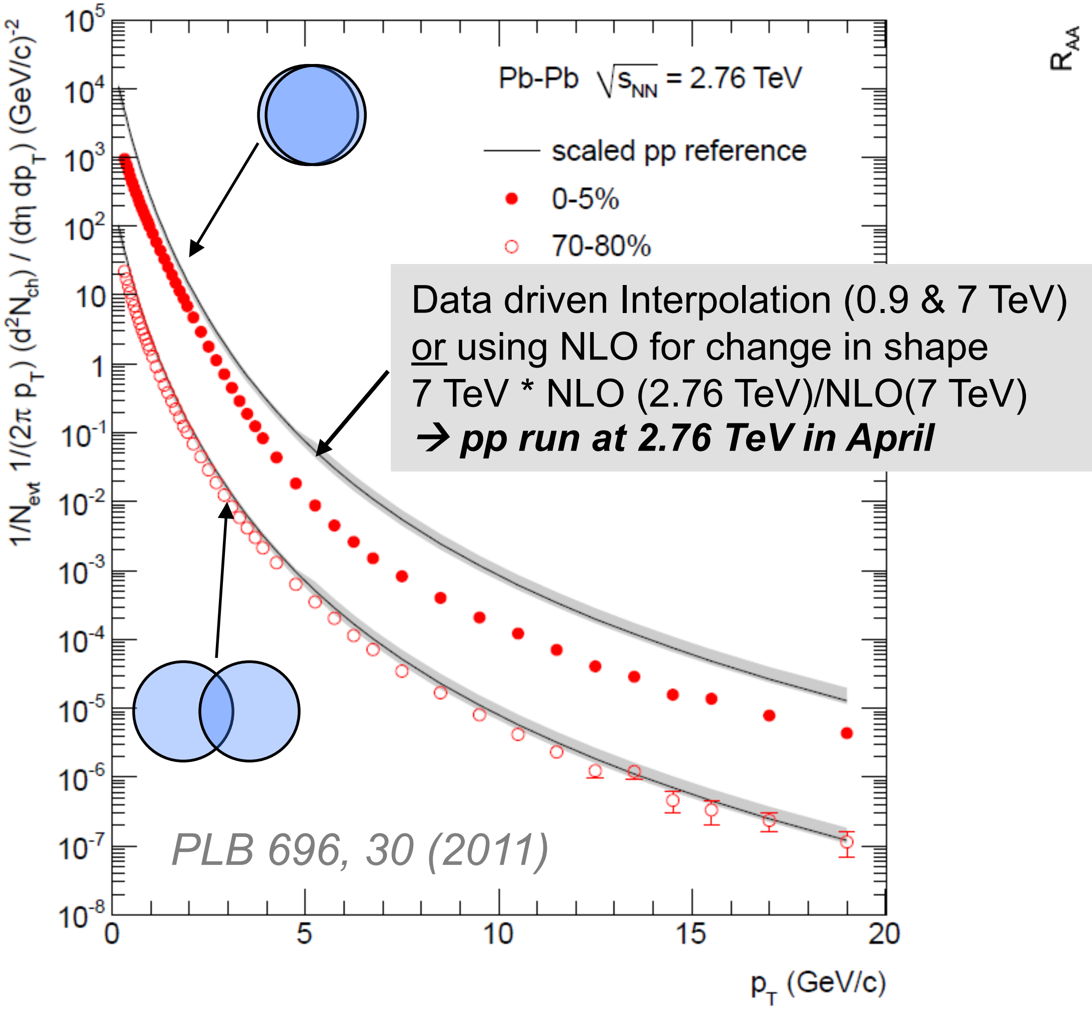
$$R_{AA} = \frac{Yield\ in\ Pb+Pb}{N_{coll} \times Yield\ in\ p+p}$$

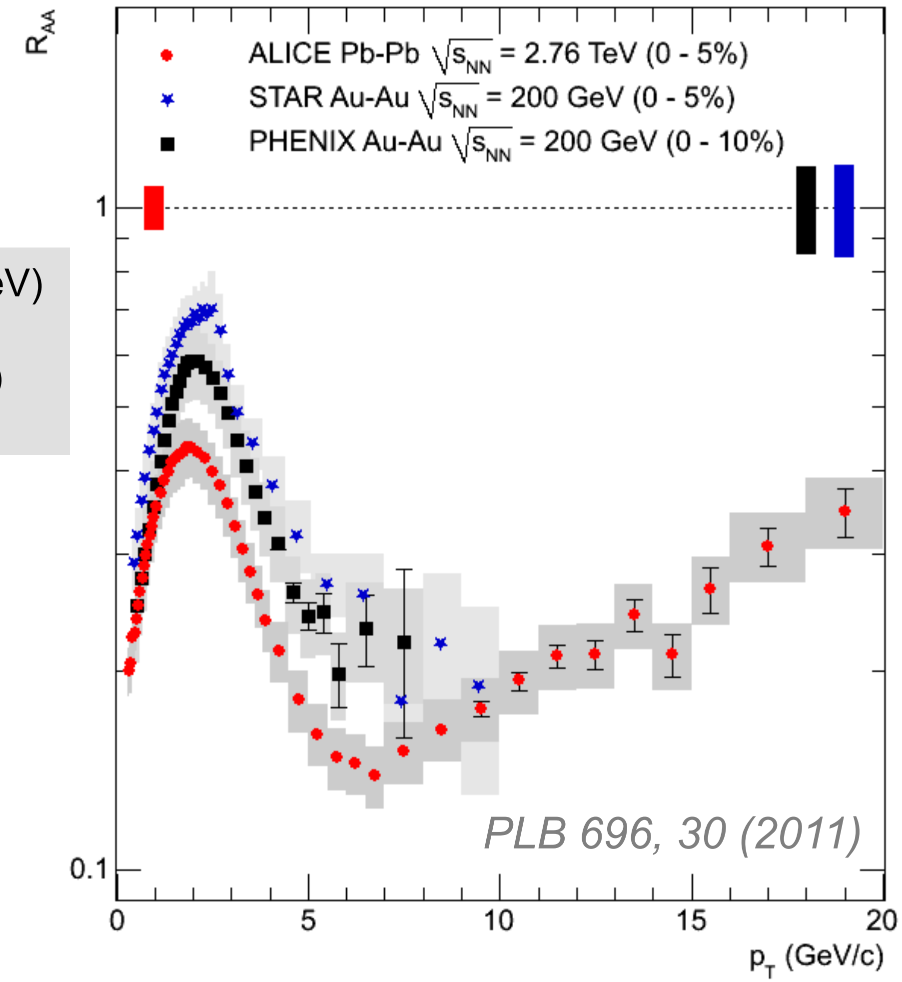
- Factor 4-5 suppression at RHIC, p_t-indep?
- No suppression for γ's (blind to strong inter.)
- Parton energy loss in dense QCD medium



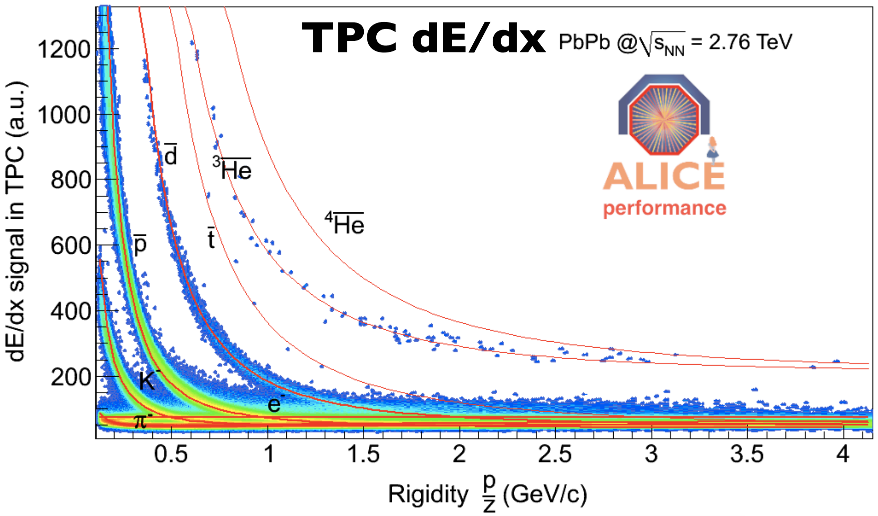
High-momentum particle suppression

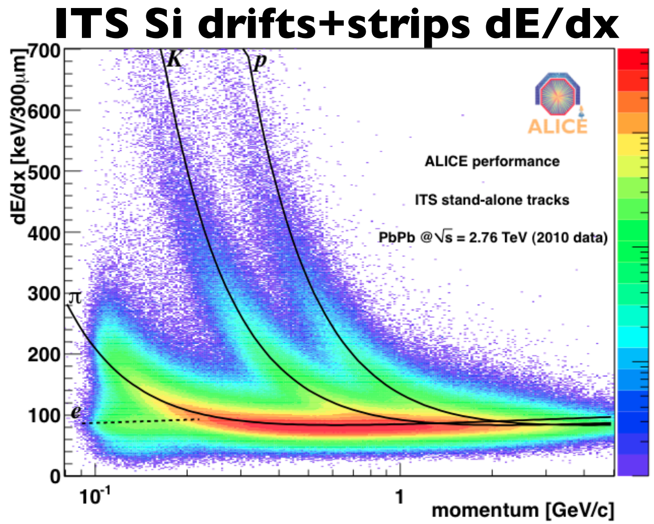
- Charged hadron R_{AA} down to 0.13 (x2 smaller than at RHIC!)
- Steep rise with p_t, to reach 50 GeV/c with full 2010 statistics

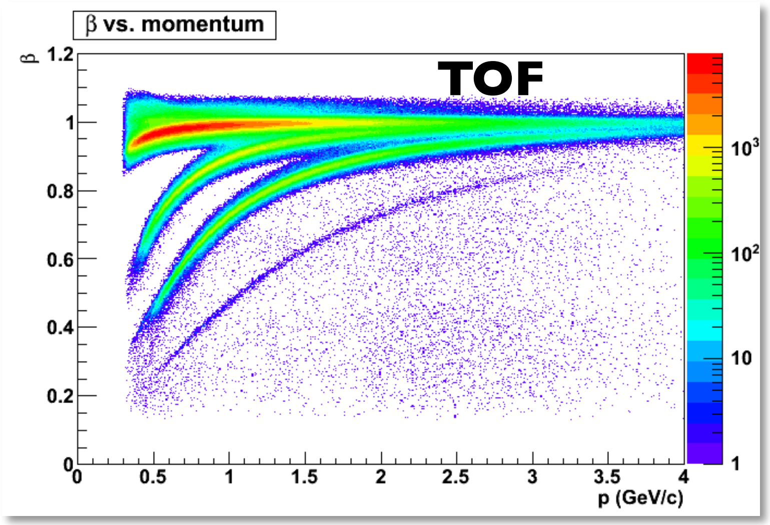


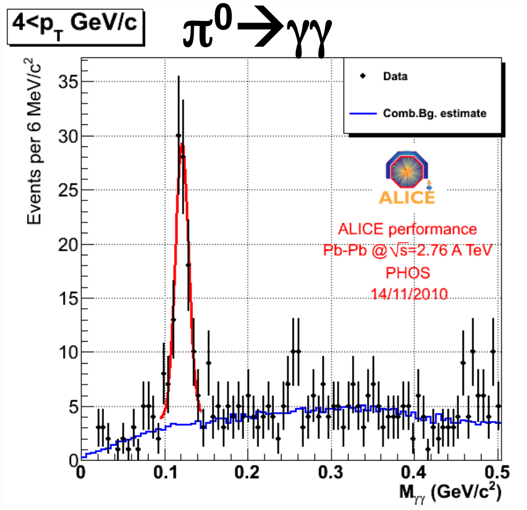


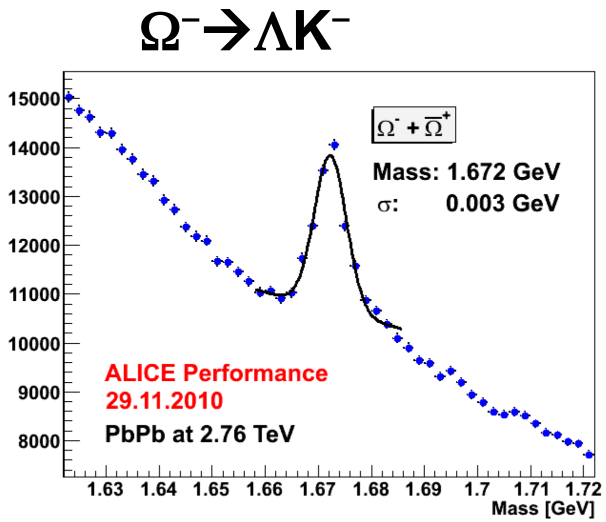
Outlook: particle-type dependence











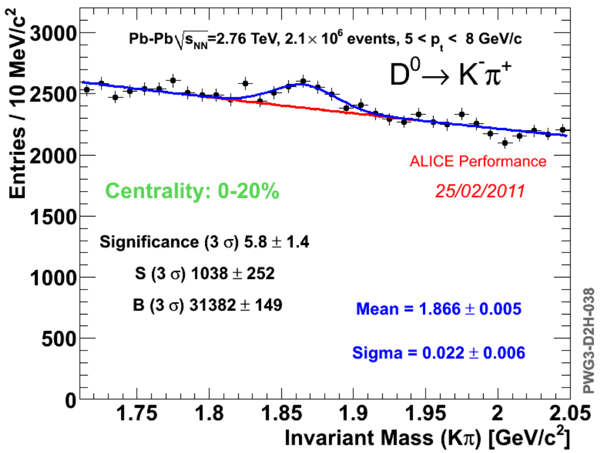
Outlook: heavy quarks

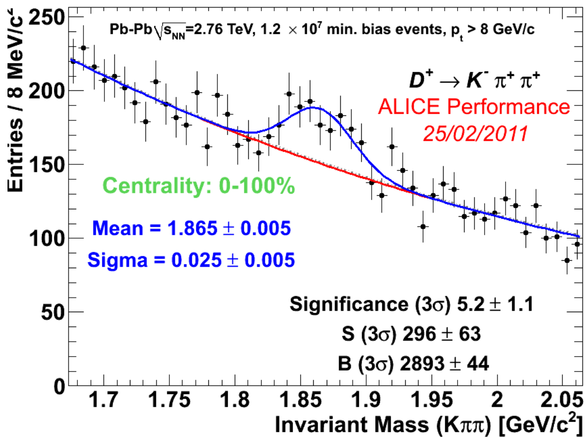
- Charm via D mesons, beauty via leptons (e, μ):

  colour charge and mass dependence of energy loss

- Quarkonia: suppression or regeneration?

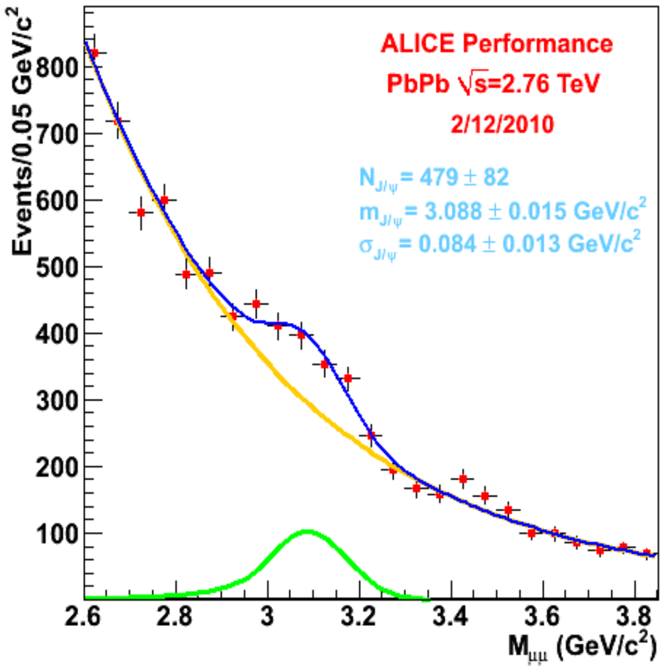
$D^0 \to K\pi$, $D^+ \to K\pi\pi$ via secondary vertex reconstruction





Expect coverage $5<p_t<15$ GeV/c

J/ψ→μμ at forward rapidity



Expect few 1000 J/ψ from full 2010 statistics

Conclusions

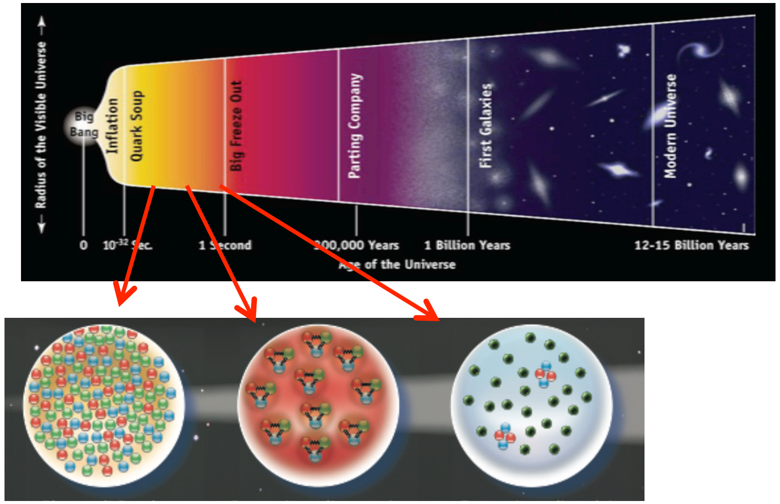
- LHC and ALICE performed well in the first Pb-Pb run
- Global properties of QCD matter at LHC from analysis of partial statistics
  - Highest charged particle density ever reached
  - Its centrality dependence saturates
  - Very large volume of particle emitting source
  - Hadrons flow close to hydro limit
  - High p_t suppression stronger than at RHIC and rises with p_t
- Many more analyses in progress
  - particle type dependencies
  - charmonium
  - heavy quarks
  - jets
  - …

EXTRA SLIDES

The Little Bang in the lab

- QCD phase transition (QGP → hadrons) at t_{Universe} ~10 μs
- In **high-energy heavy-ion** collisions, **large energy densities** (> 2–3 GeV/fm³) are reached over **large volumes** (>> 100 fm³)

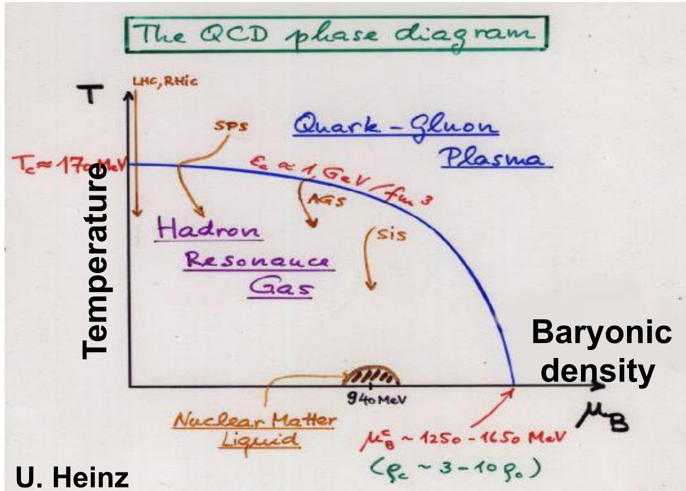
Big Bang



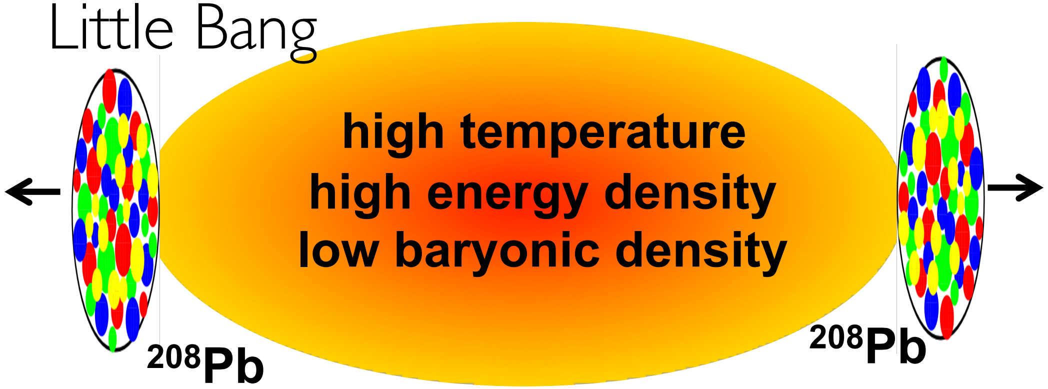
quark-gluon plasma

formation of nucleons

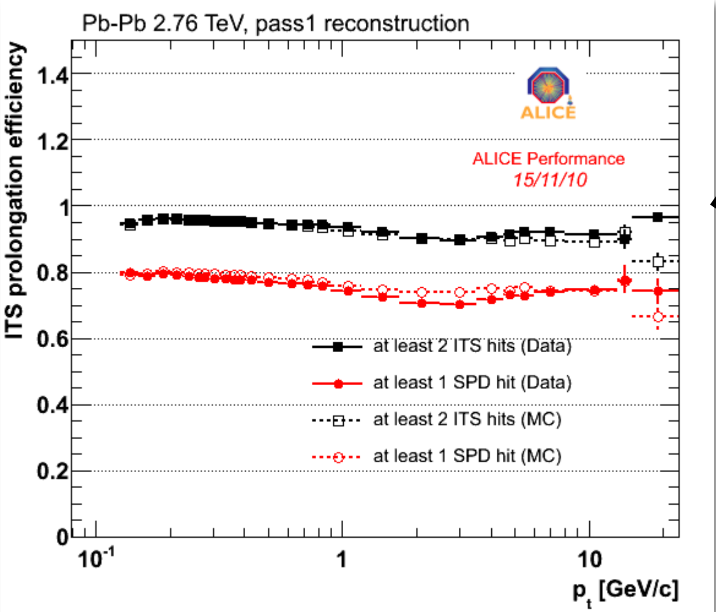
formation of nuclei



Little Bang



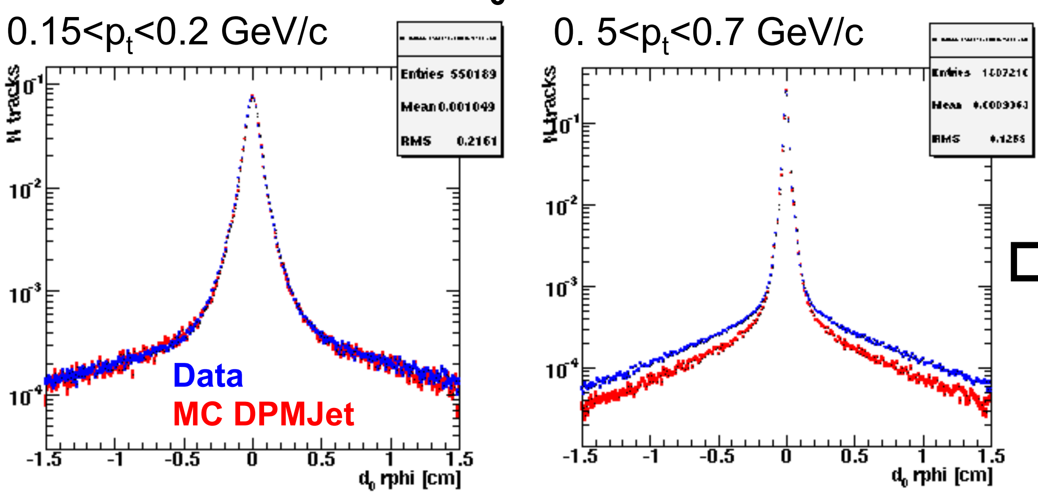
Tracking in Pb-Pb

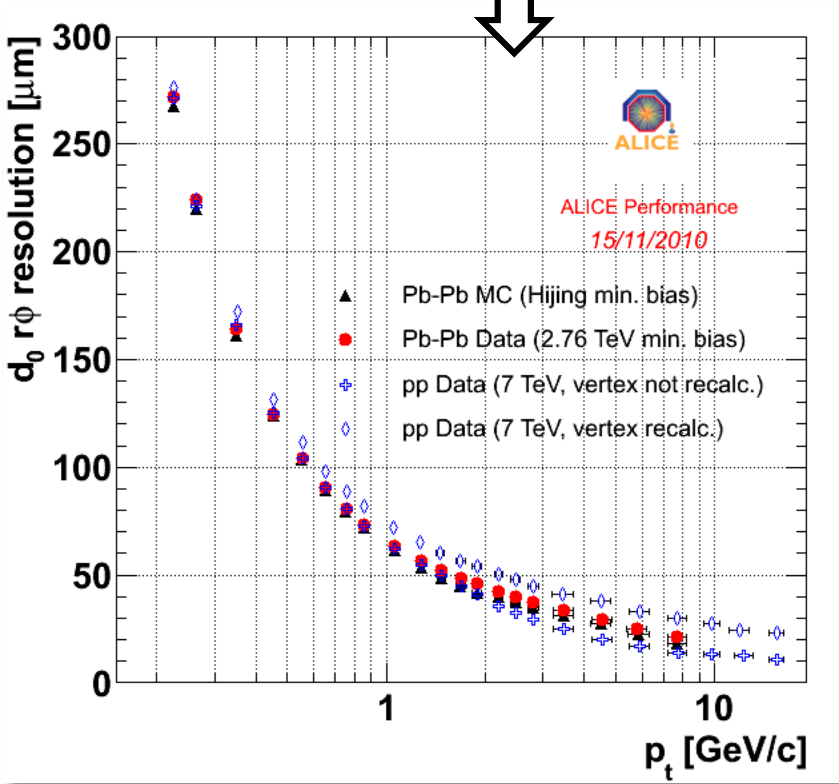


Track prolongation efficiency from TPC to ITS already close to MC

Track impact parameter resolution (TPC+ITS with 2 SPD hits) close to MC and "same" as in pp

Transverse d_0 distributions

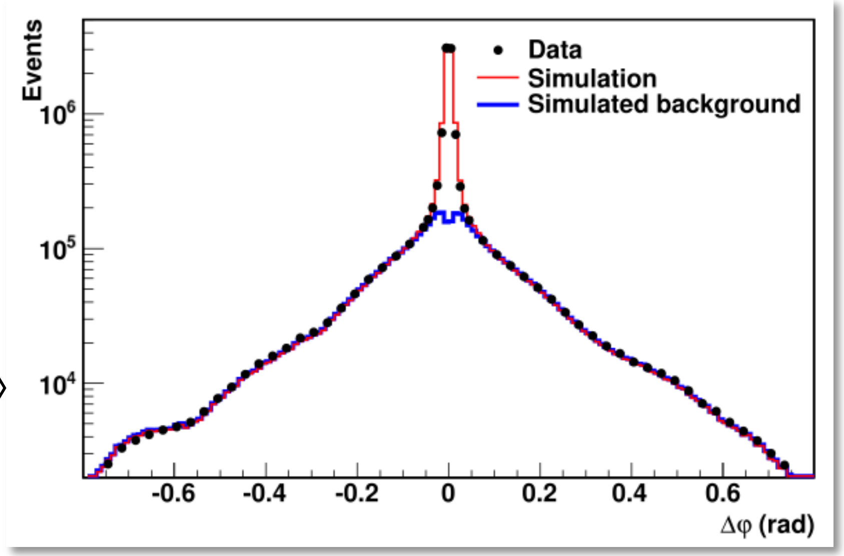




Measurement of $dN_{ch}/d\eta$ in central Pb-Pb at 2.76 TeV

- First glimpse of the features of the high-density QCD state produced in these collisions
  - Related to the energy density and gluon density in the system
  - Strong test/constraint for theoretical models
- Data sample: ~50 000 Pb-Pb m.b. collisions collected on Nov 9
- Select the 5% most central using V0 amplitude (0-5% centrality class)
- Measurement based on pixel tracklets (as for our pp publications)
  - correlate hits on the two layers within a narrow $\Delta\phi$ x $\Delta\theta$ window from the primary vertex
  - cross-checked with global and with TPC-only tracks

Tracklets combinatorial background (14%) Well described by MC (only 1% scaling factor to match tails)



dNch/deta - Backup

- 90% of QED processes in ultra-peripheral collisions give close to 0 mult.
- 1% background in the sample eliminated by
  - V0 timing selection
  - correlation between #TPC tracks and #hits in SPD inner layer
- Three methods for comb. background
  - from MC
  - from data: pixel inner layer rotation by 180deg
  - from data: injection of random hits
- Consistent results
- Measurement cross-checked with TPC-only tracks and with global (TPC +ITS) tracks
- Low p_t cutoff (50 MeV/c)
  - angular window
  - absorption in material
- Particle comp. varied by 50%
- Strangeness by factor 2
- Centrality done also with SPD and varying Glauber fit range

Source	
Background subtraction	2%
Particle composition	1%
Contamination by weak decays	1%
Low-p_t extrapolation	2%
Event generator	2%
Centrality definition	3%
Total (added in quadrature)	5%

v2 - Backup

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos\left(n(\phi-\Psi_R)\right)\right).$$

$v_2\{2\}$ and $v_2\{4\}$:

- $v_2\{4\}$ insensitive to nonflow contributions (BE, resonances, jets)
  - we estimate 5% nonflow contr. to $v_2\{2\}$ by comparing with cumulants with same-charge tracks
- flow fluctuations have increase $v_2\{2\}$ and decrease $v_2\{4\}$