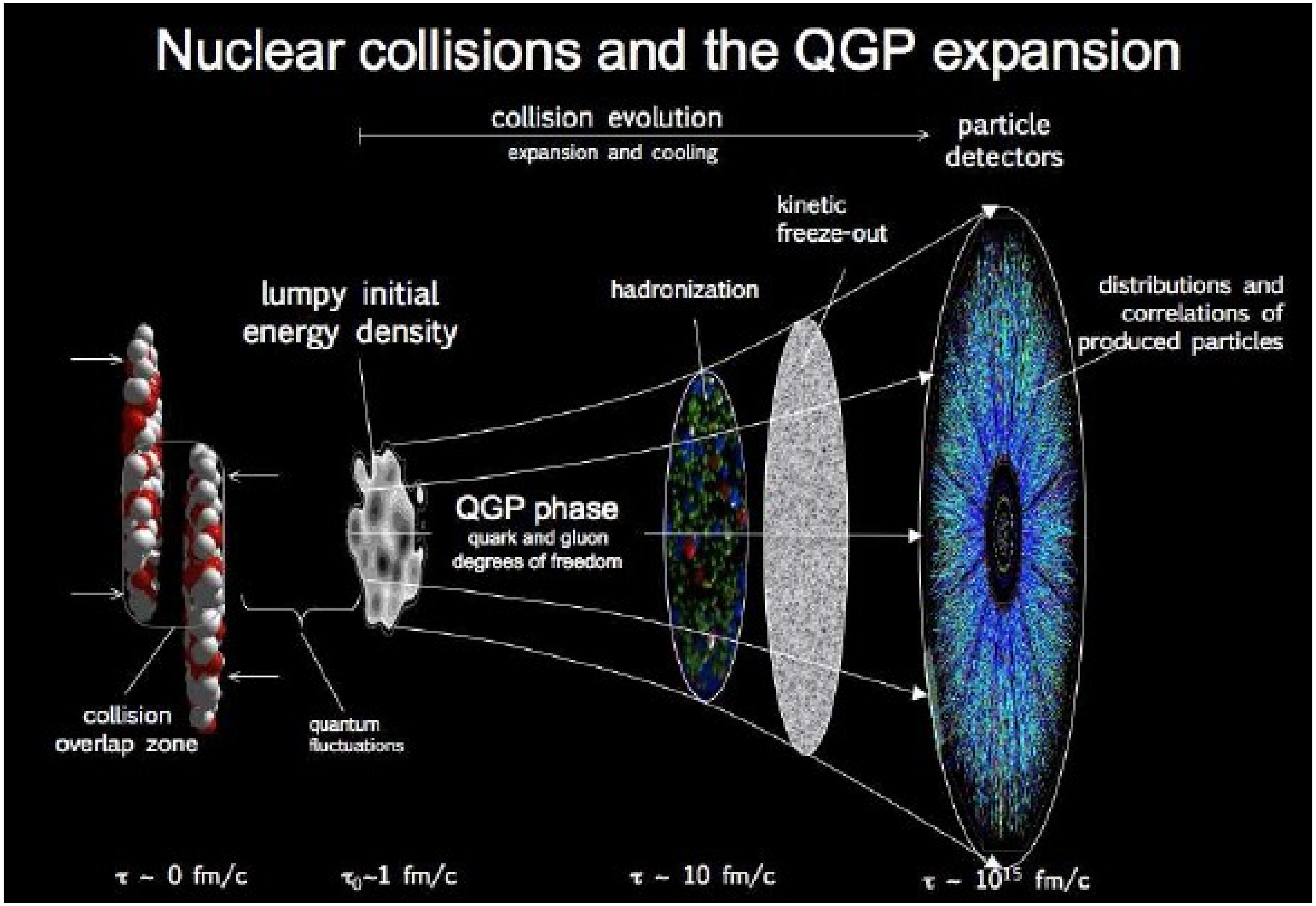
Vladimir Korotkikh
(for CMS Collaboration**)**

Elliptic flow studies in heavy-ion collisions using the CMS detector at the LHC

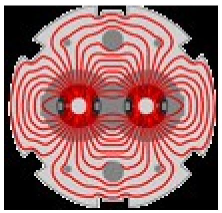
QFTHEP-2010, The XIXth International Workshop High Energy Physics and Quantum Field Theory
8-15 September 2010, Golitsyno (Russian Federation)

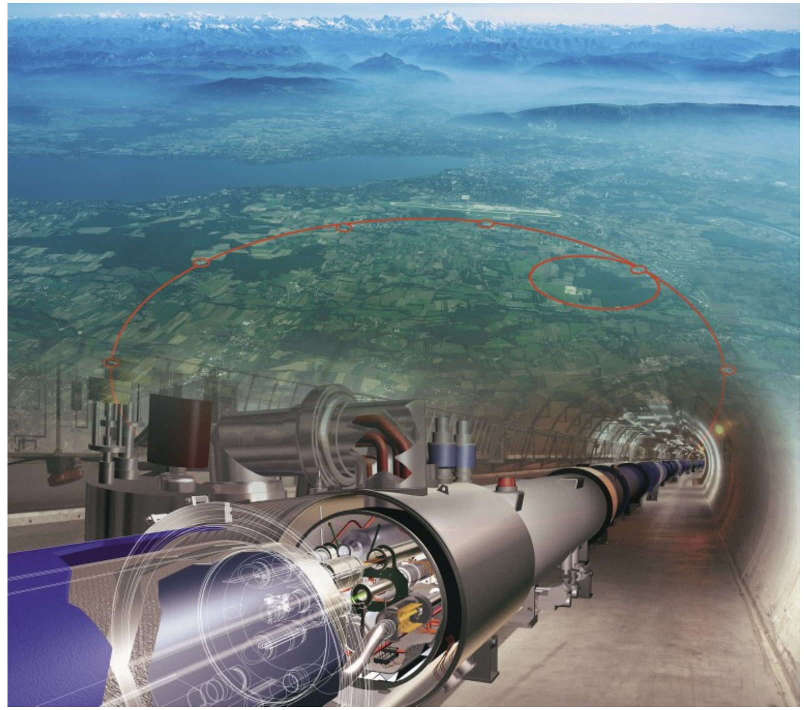
QGP in Heavy Ion collisions



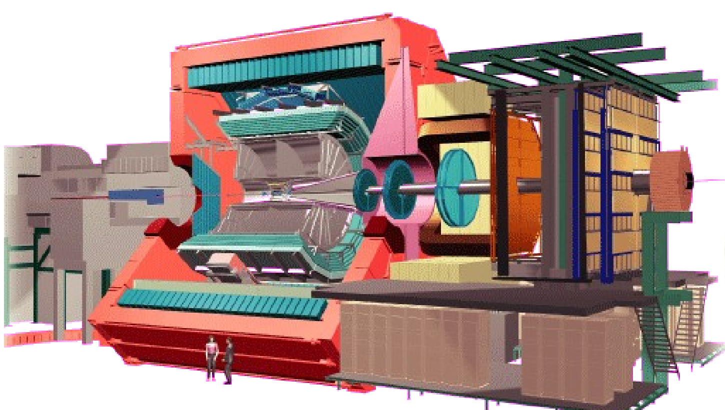
P. Sorensen, International J.M.P.E. 2009. arXiv:0905.0174.

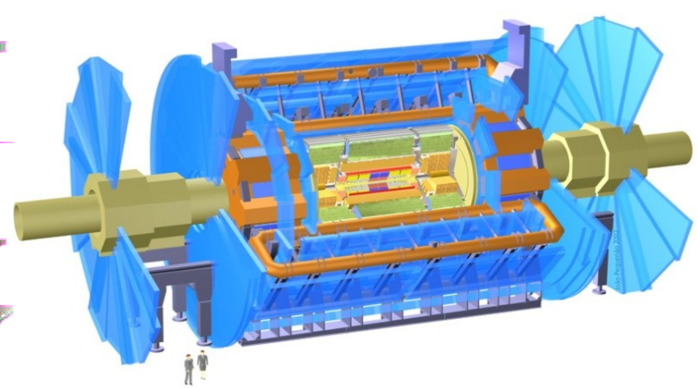
LHC experiments

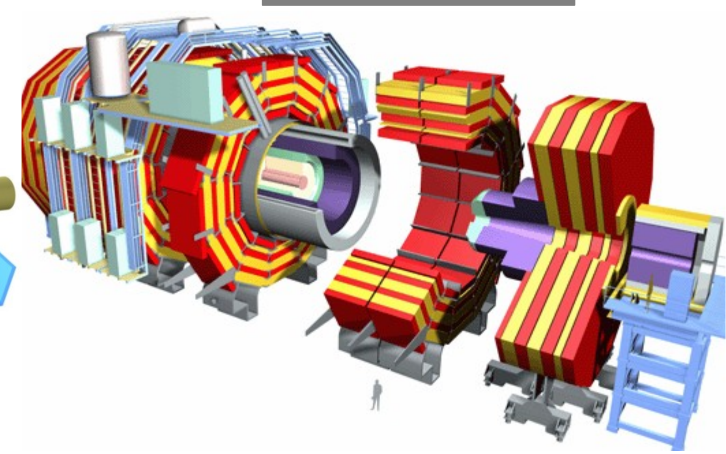




ALICE **ATLAS** **CMS**

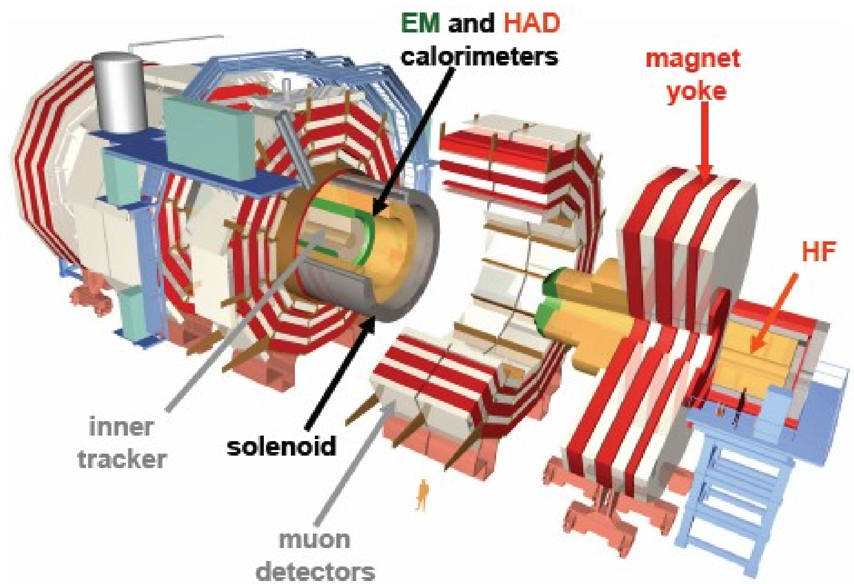






CMS experiment at the LHC

CMS Detector



3

Magnetic field: 3.8 Tesla

- Hit reconstruction efficiency above 99%
- >97% of channels operational
- Coverage over $|\eta| < 2.4$ with ≥ 3 pixel and ≥ 10 strip hits

- **Silicon Tracker**
  $|\eta| < 2.4$
- **Electromagnetic Calorimeter**
  $|\eta| < 3.0$
- **Hadron Calorimeter**
  barrel and endcap
  $|\eta| < 3.0$
  with HF-calorimeter up to
  $|\eta| < 5.2$
- **Muon Chambers**
  $|\eta| < 2.4$

+ CASTOR detector
$5.3 < |\eta| < 6.4$
+ TOTEM
$5.3 < |\eta| < 6.7$
+ Zero-degree calorimeter
$8.3 < |\eta|$

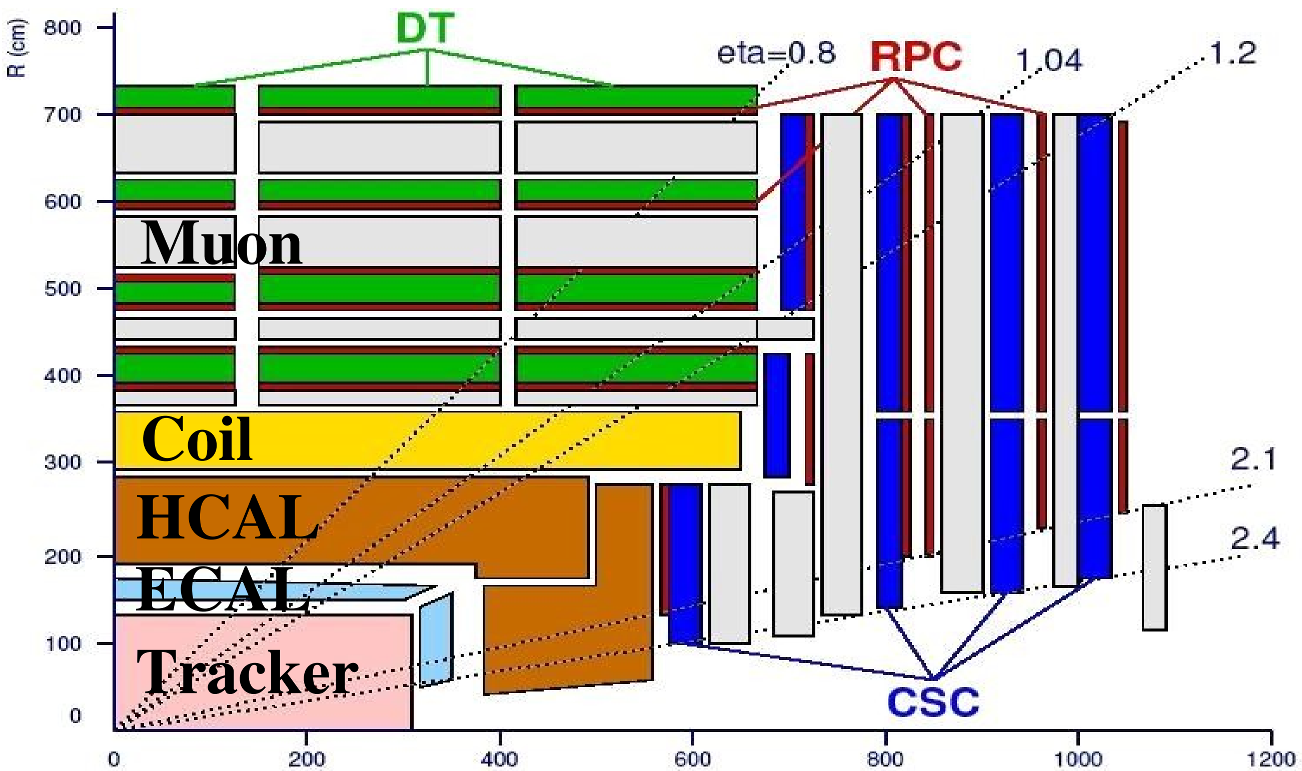
CMS experiment at the LHC

Tracker system:

- Silicon pixel layers (3 in barrel |η| < 1.5, 2 in endcap 1.5 < |η| < 2.4)
- Silicon strips layers (10 in barrel |η| < 1.5, 12 in endcap 1.5 < |η| < 2.4)

Calorimeter system:

- ECAL – electromagnetic (crystals of lead tungstate $PbWO_4$) |η| < 3.0
- HCAL – hadronic (active plastic scintillator tiles interspersed between stainless steel and brass absorber plates) |η| < 3.0
- HF – hadron forward (steel absorbers and embedded radiation hard quartz fibers) 3.0< |η| < 5.2



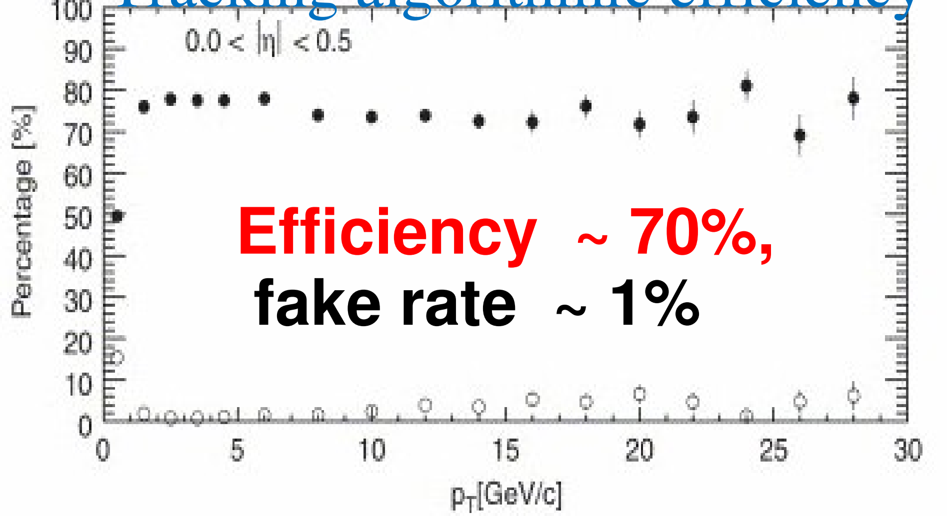
- **Excellent coverage:**
  Tracker
  ~ 5 units in rapidity and 2π in azimuthal angle
  Calorimeter
  > 10 units in rapidity and 2π in azimuthal angle

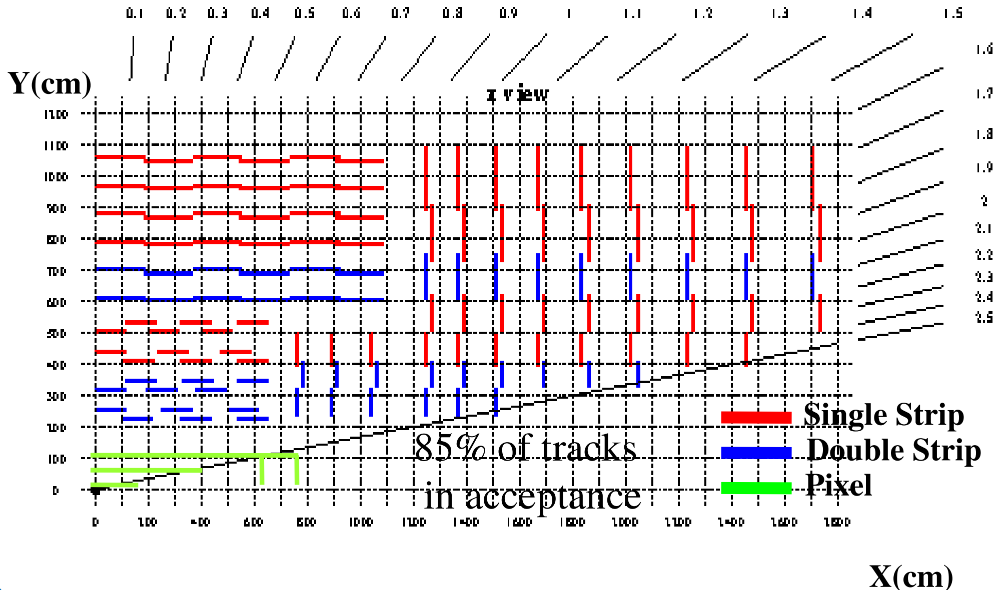
- **Momentum resolution:**
  ~ 2% of momentum resolution for tracks with $p_T < 100$ GeV/c

CMS HI Tracking

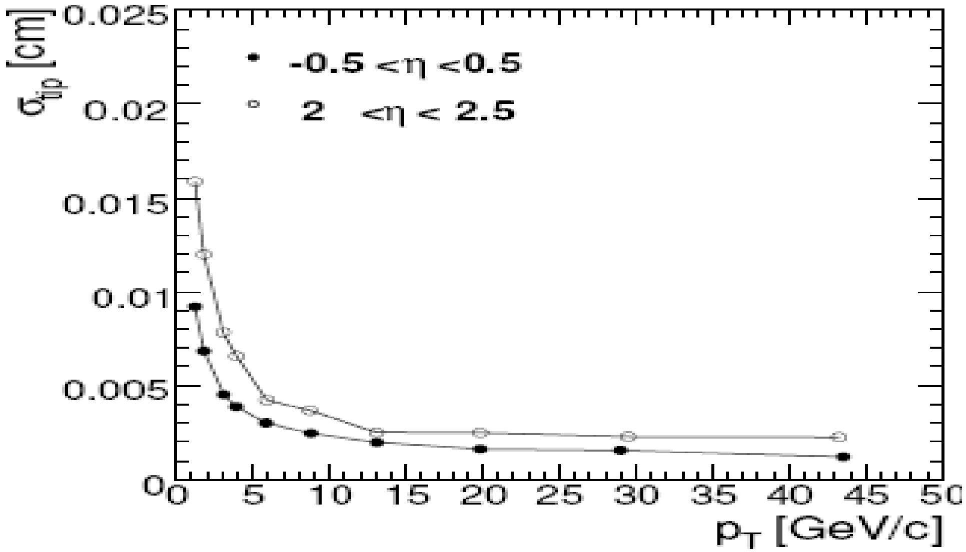
- Based on standard pp tracking modules

Tracking algorithmic efficiency

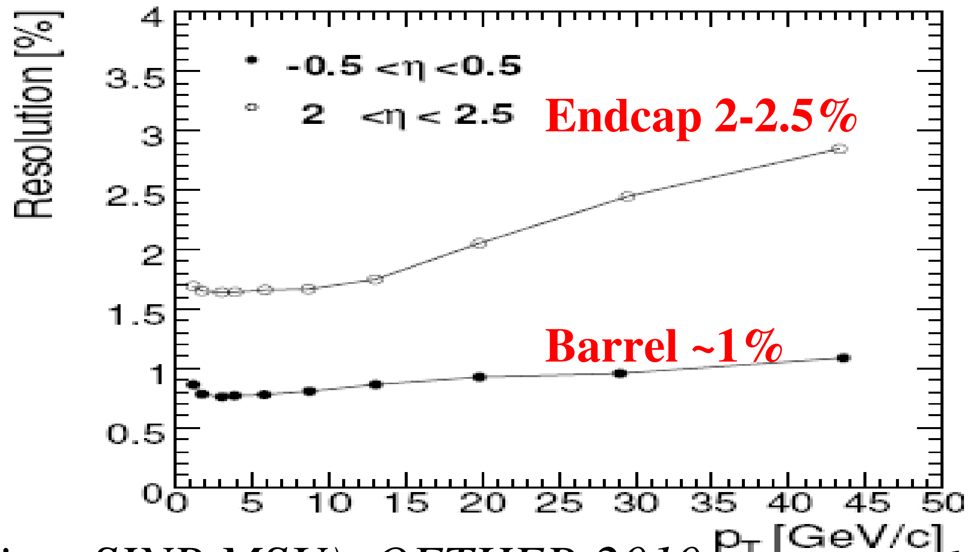




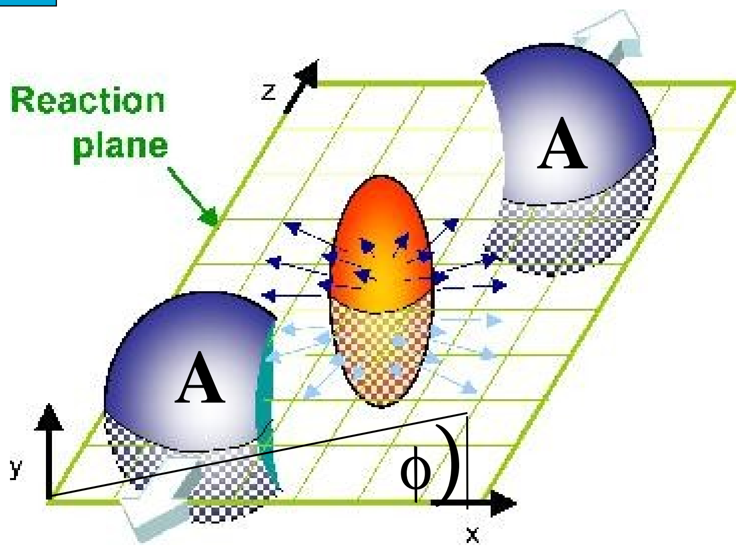
Transverse impact parameter resolution

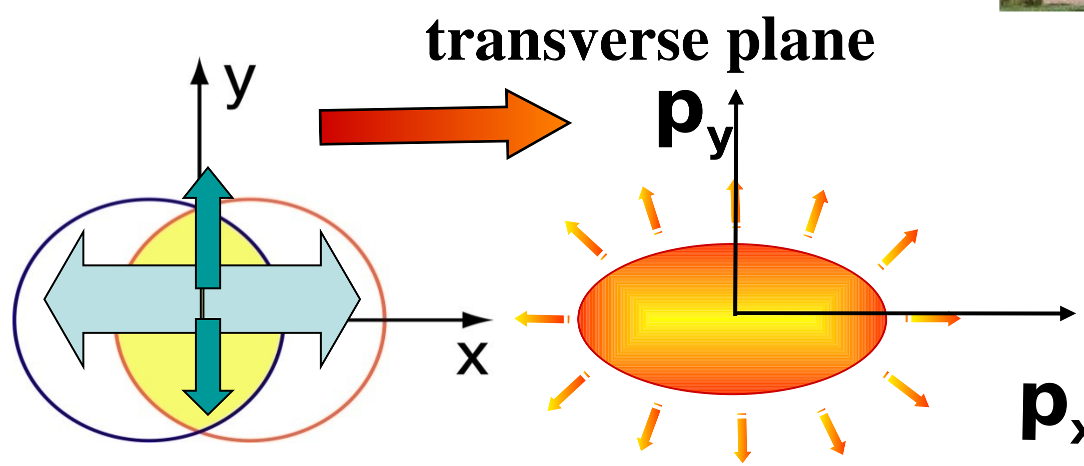


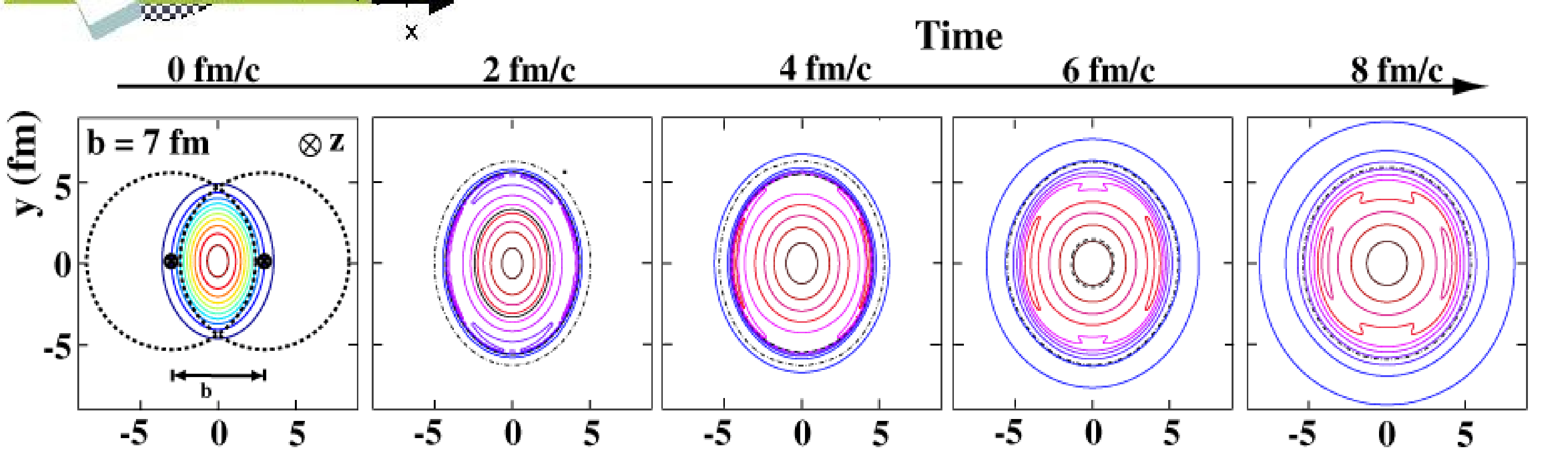
Momentum resolution



Elliptic flow in non-central heavy-ion events







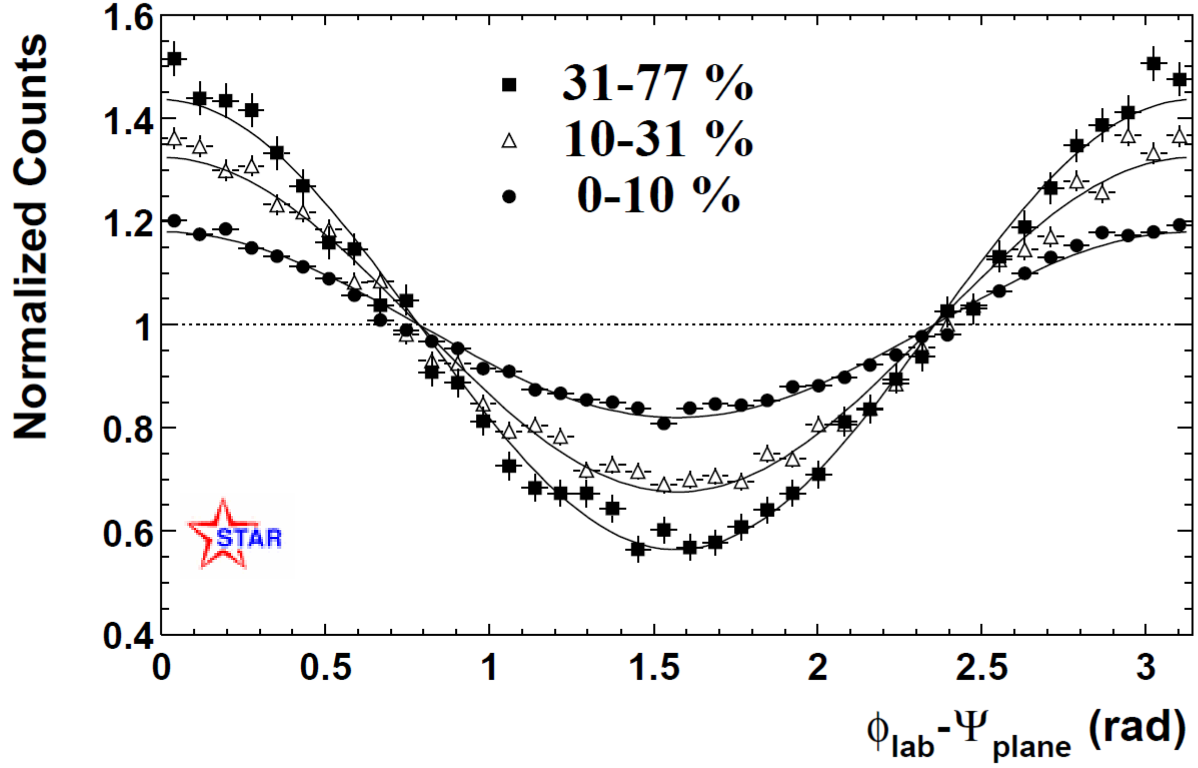
Kolb P.F., Heinz U., nucl-th/0305084

Initial spatial anisotropy results in elliptic flow of final particles.
Azimuthal anisotropy of particles is a signature of thermalization.

Azimuthal distribution at the RHIC

Ψ_R – azimuthal angle of the reaction plane

STAR Collaboration, Phys.Rev.Lett.90:032301,2003.

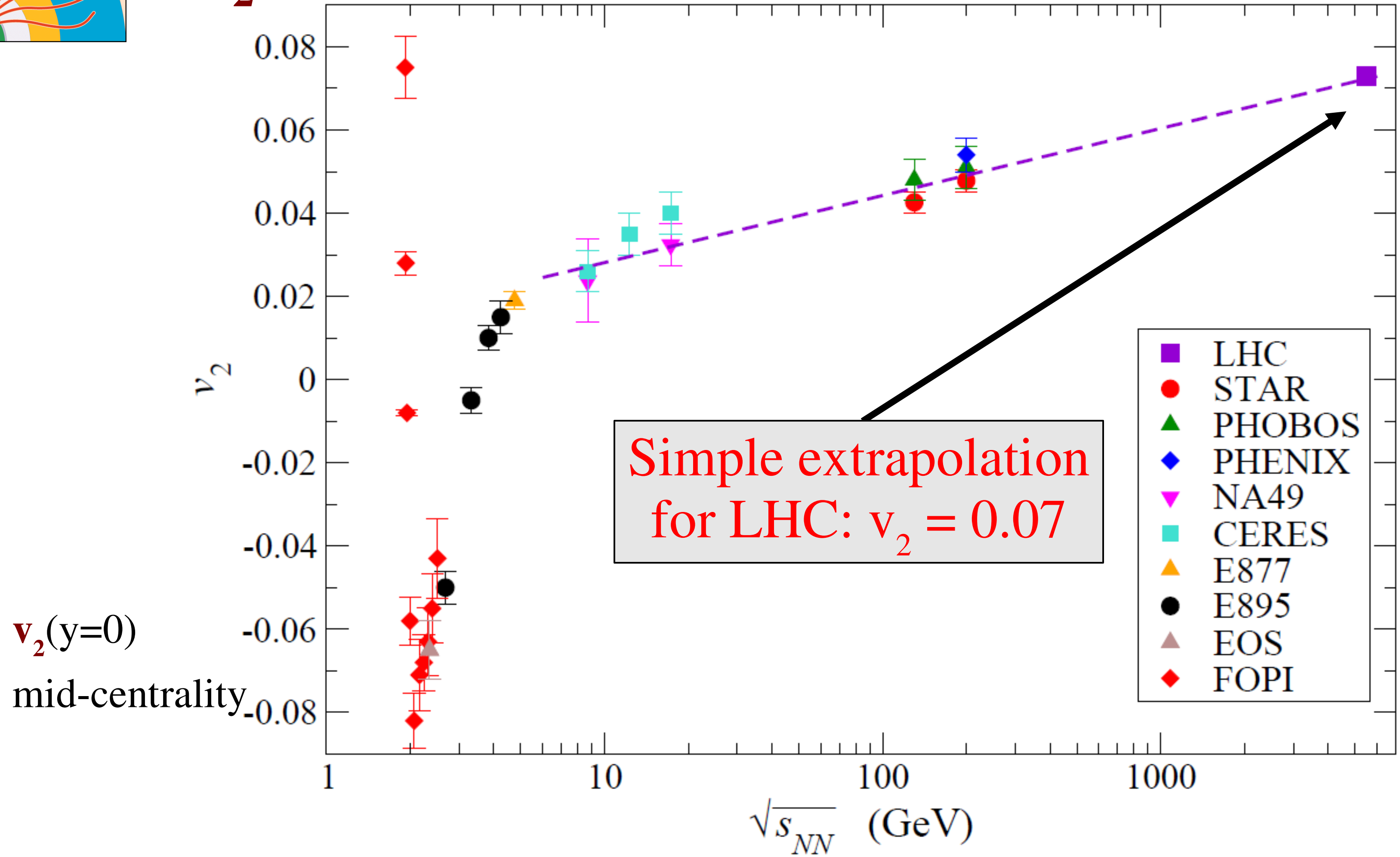


$$\frac{dN}{d\varphi}(\varphi_p) = N_0(1 + 2v_1\cos(\varphi_p - \Psi_R) + 2v_2\cos 2(\varphi_p - \Psi_R) + \ldots)$$

Elliptic flow $v_2 = \langle \cos 2(\varphi - \Psi_R) \rangle$

$\varphi = \tan^{-1}(p_y/p_x)$

v_2 – current data and prediction for LHC



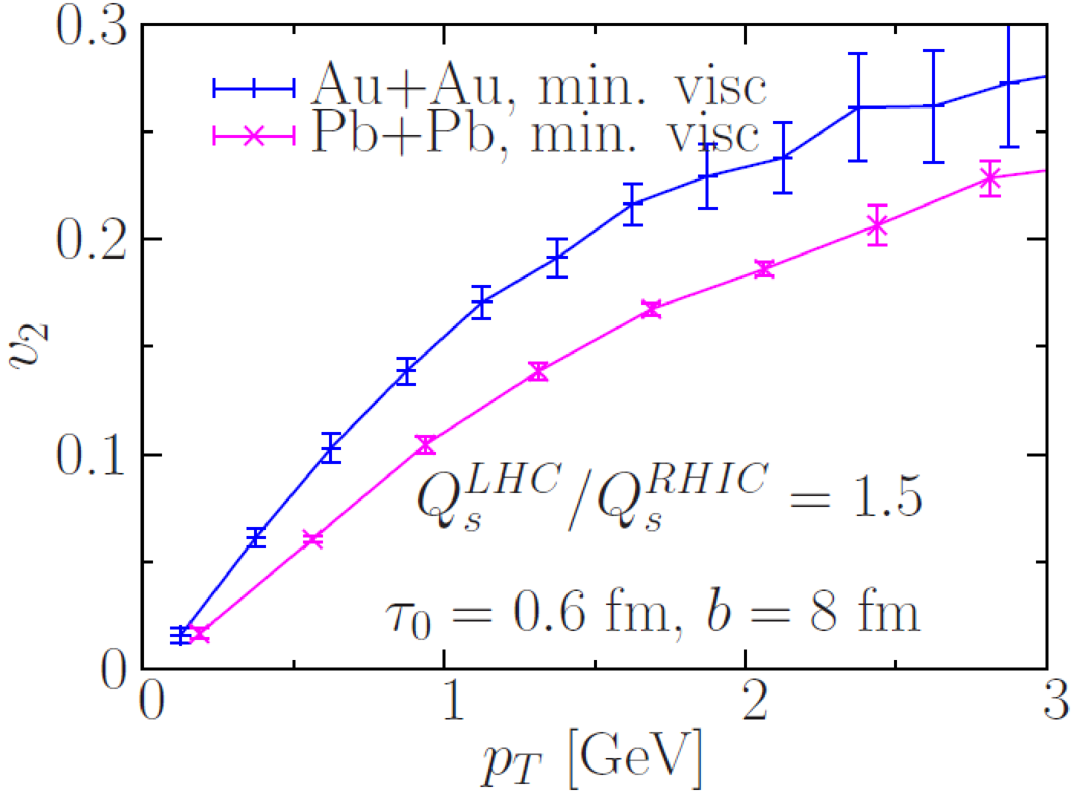
Alessandro B et al., 2006 J. Phys. G: Nucl. Part. Phys. 32 1295

Simple extrapolation gives slight increasing of v_2 for LHC energy

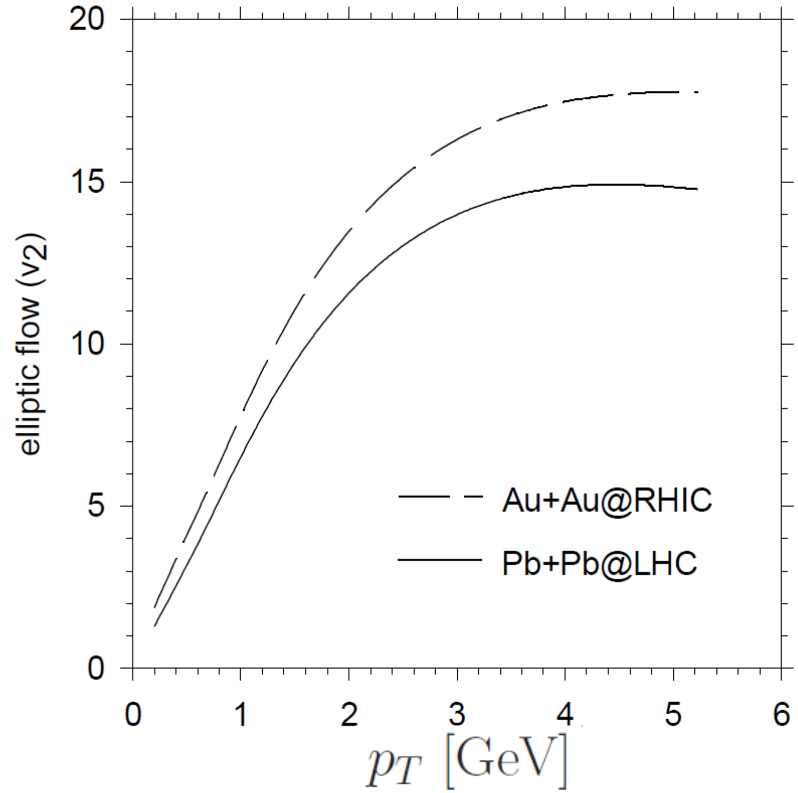
The models predict for v_2(if compare with RHIC):

1) decrease 2) increase 3) saturation

v_2 vs. p_T – RHIC and LHC (two predictions)



N. Armesto et al., J. Phys. G 35 (2008) 054001.



A. K. Chaudhuri, Phys. Lett. B 672 (2009) 126

MPC parton cascade of Molnar for RHIC and LHC, b = 8 fm.

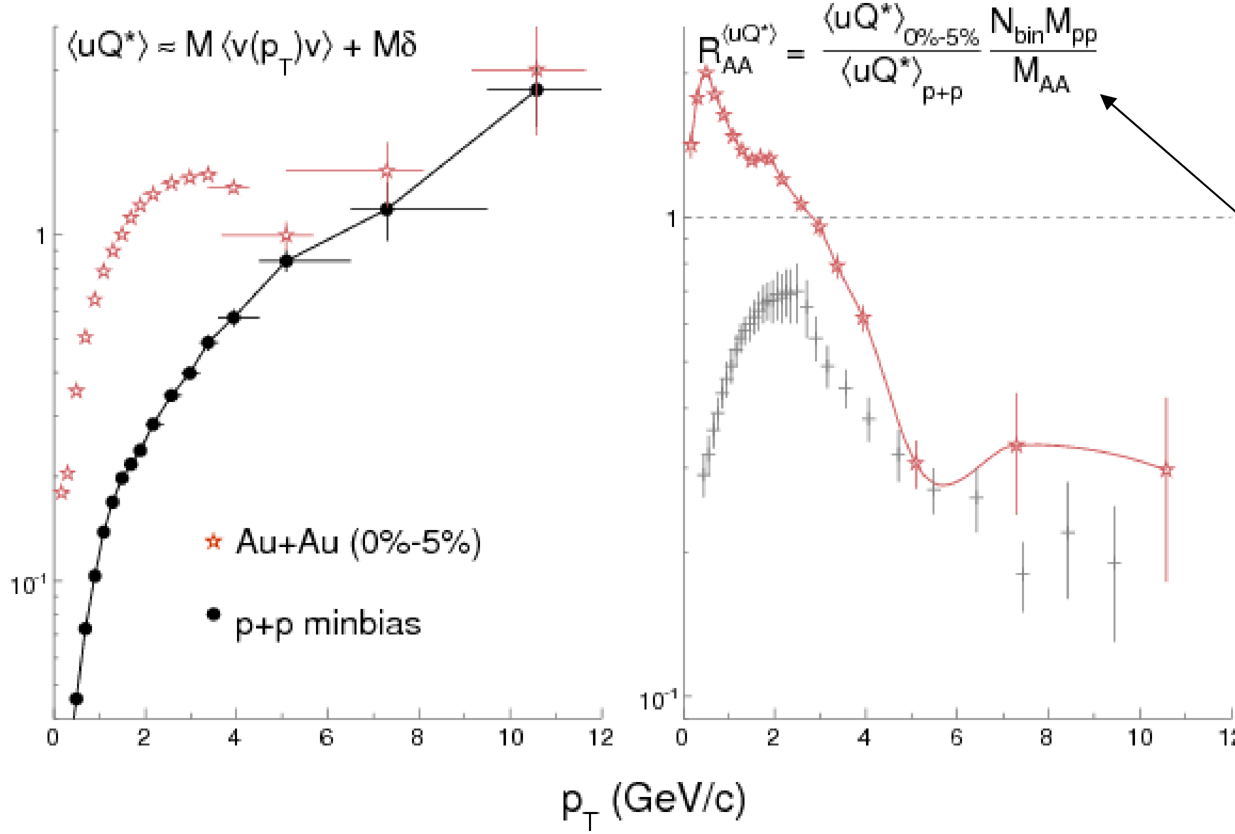
Viscous hydrodynamical calculations for RHIC and LHC, minimum bias collisions.

Azimuthal correlations in pp and AuAu at 200 GeV

200 GeV, Au-Au - 2M events, p-p - 11 M events minbias

, P. Sorensen, International J.M.P.E. 2009. arXiv:0905.0174.

J. Adams et al (STAR), PRL 93, 252301



STAR (RHIC) resume:

(AA -pp) = flow

Relative degree of nonflow contribution

A nature of non-flow effects in pp collisions is not clear

$$\left\langle uQ^* \right\rangle_{evnt} = \left\langle \sum_i \cos[n(\varphi - \varphi_{p_T})] \right\rangle_{evnt} \cong \overline{M} v_2(p_t) < v_2 >$$

Predictions of the elliptic flow in p+p collisions

1. **D. d'Enterria , G.Eyyubova, V.Korotkikh, I.Lokhtin, S.Petrushanko, L.Sarycheva, A.Snigirev.**
Estimates of hadron azimuthal anisotropy from multiparton interactions in proton-proton collisions at sqrt(s) = 14 TeV
Eur.Phys.J. C66:173(2010), e-Print: **arXiv:0910.3029**

Incomplete thermalization model

2. **S.K. Prasad et al., Elliptic flow (v_2) in pp collisions at LHC energy : A hydrodynamical approach.**
e-Print: **arXiv:0910.4844**

HYDRO model

3. **P. Bozek, Observation of the collective flow in proton-proton collisions.**
Acta Phys. Pol. B41 (2010) 837,,e-Print: **arXiv:0911.2392**

HYDRO model

4. **J.Casalderrey-Solana, U.A. Wiedemann. Eccentricity fluctuations make flow measurable in high multiplicity p-p collisions**.
PRL 104,102301(2010) , e-Print: **arXiv:0911.4400** [hep-ph]

Hot spots MC model

5. **G. Ortona, et al., Elliptic flow in high multiplicity proton-proton collisions at $\sqrt s$ = 14 TeV as a signature of deconfinement and quantum energy density fluctuations**
e-Print: **arXiv:0911.5158v1** [hep-ph]

3+1D HYDRO model

6. **A.K. Chaudhuri, Phys.Lett. B692, 15, 2010**
e-Print: **arXiv:0912.2578v1** [hep-ph],

HYDRO model with hot spots

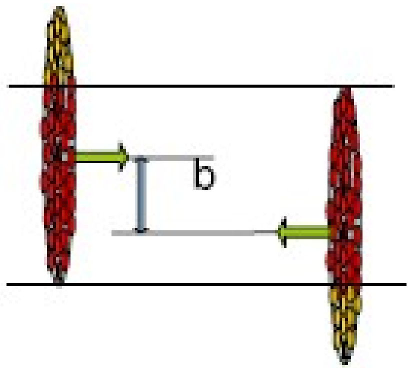
7. **M.Luzum, P.Romatschke, Phys.Rev.Lett.103: 262302, 2009**
e-Print: **arXiv:0912.2578v1** [hep-ph]

HYDRO model

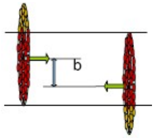
V_2 from 0.03 till 0.15 in various models

From A+A to p+p at LHC

A+A $R_A \approx 6$ fm → p+p **$R_p \approx 0.56$ fm**

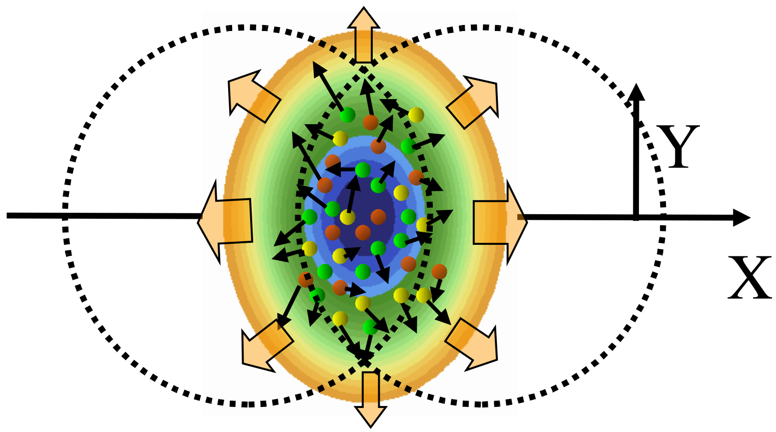


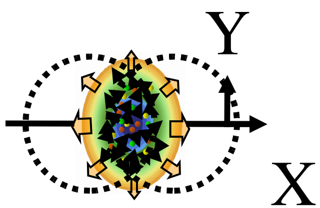
1. Transition to small spatial scale
2. Change multiplicity dN/dy≈1000 to dN/dy ≈ 10
3. Transverse overlap area



$A_T \approx 85\, fm^2 \;\; at\; b = 0$

$A_T \approx 0.85\, fm^2 \;\; at\; b = 0$





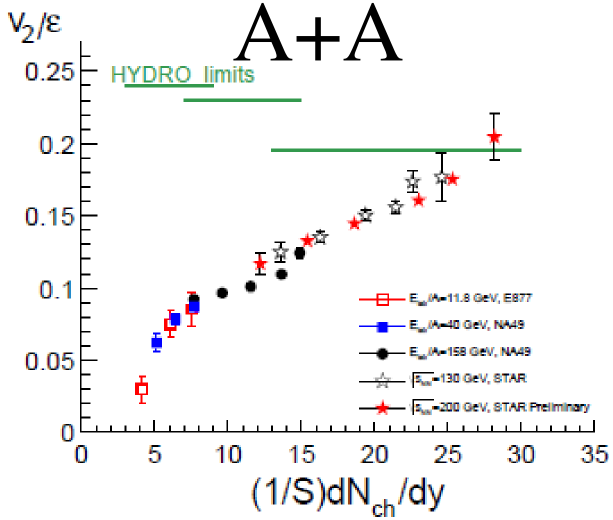
Particle density on unit overlap area is the same order in A+A and in p+p collisions

$$\left(\frac{dN\;/dy}{A_T}\right)_{AA} = \left(\frac{dN\;/dy}{A_T}\right)_{pp} \approx 1\, mb^{-1}$$

Flow prediction in p-p collisions

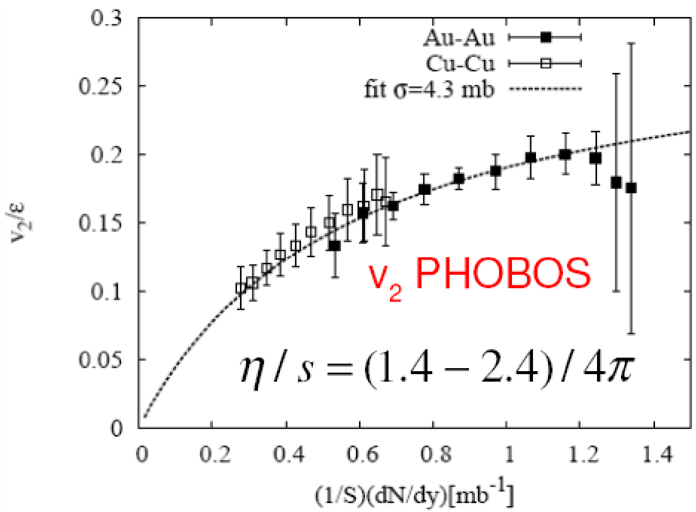
A+A

P. Sorensen, International J.M.P.E. 2009. arXiv:0905.0174.

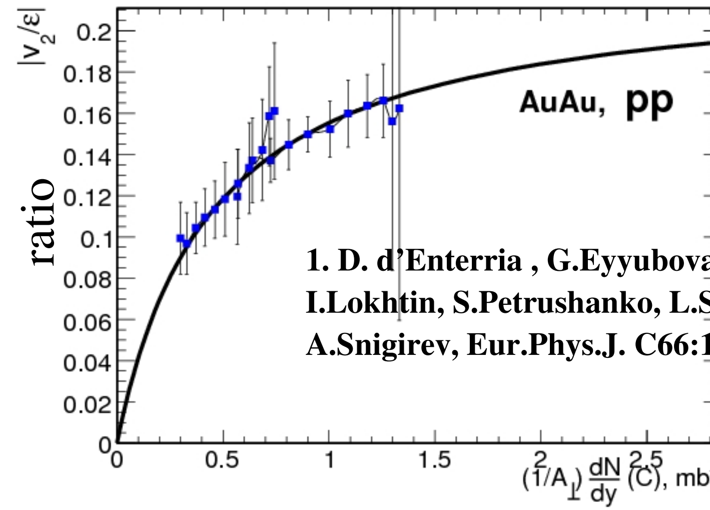


Eccentricity scaling and incomplete thermalisation model

H.J.Drescher et al., PRC76(07)024905

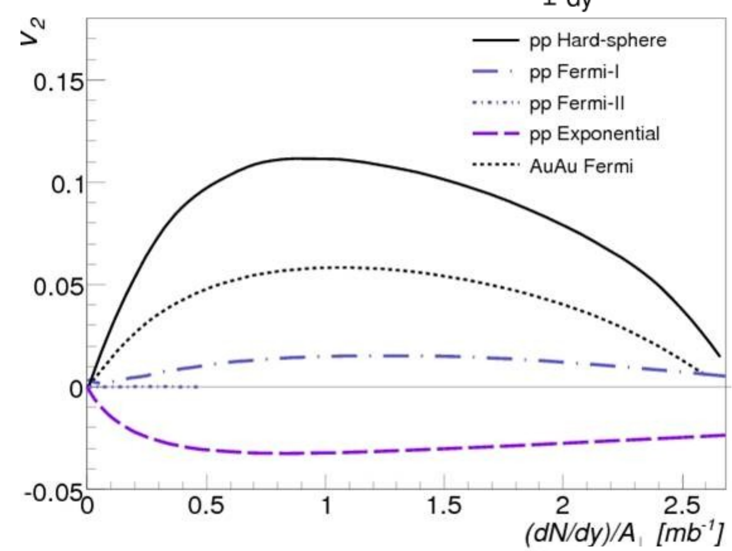


p+p



1. D. d'Enterria , G.Eyyubova, V.Korotkikh, I.Lokhtin, S.Petrushanko, L.Sarycheva, A.Snigirev, Eur.Phys.J. C66:173(2010)

$A_T = 4S$



$$\left(\frac{v_2}{\varepsilon}\right) = \left(\frac{v_2^{hydro}}{\varepsilon}\right)\frac{1}{(1+K/K_0)}$$

$$\rho(r) = \frac{\rho_0}{e^{(r-R)/a}+1} \quad \rho(r) = \frac{1}{4/3\,\pi R^3}\Theta(r-R) \quad \rho(r) = \frac{1}{8\pi R^3}e^{-r/R}$$

R_{rms}(ep)=0.89fm

From RHIC to LHC: time and statistics for first heavy-ion run

Physics proton-proton run at the LHC has started in November 2009 at $\sqrt{s}$ = 0.9, 2.36, 7 TeV.

The heavy-ion run is expected in the November-December 2010

Pb+Pb collisions at **$\sqrt{s}$ = 2.76 TeV** per nucleon pair

CMS expected integrated luminosity **L=10 µb $^{-1}$ ~ 40-80M events**

- Possible CM Energy per nucleon pair
  - 2.75 TeV corresponding to 7 TeV for pp
  - 3.9 TeV corresponding to 10 TeV for pp

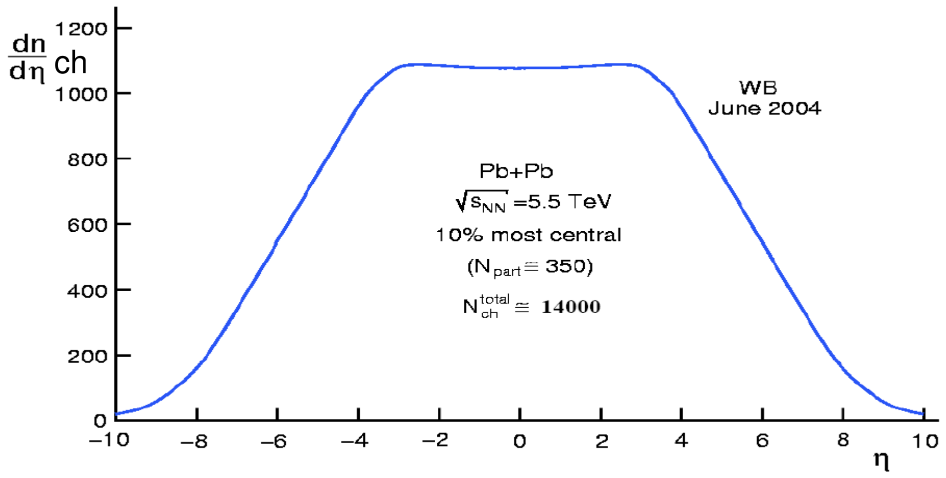
Statistical reach at CMS will be better or comparable with the RHIC results

Elliptic flow – one of the priorities of the CMS heavy-ion group for the first heavy-ion run at the LHC

Central Pb+Pb Events on LHC

Extrapolation from RHIC data:

WHEN CMS STARTS TAKING DATA WITH HEAVY IONS
THIS IS THE FIRST RESULT THAT WE WILL OBTAIN



Mean of predictions :
about $dN_{ch}/d\eta \approx 1500$

ε (Bjorken)~ 15-60 GeV/fm^3

T/T_c ~ 2 - 4

- Simple extrapolation of RHIC results suggests dN/dy_{ch} <1500
- Use HYDJET tuned to dN/dy (charged) ~ 3000
  - **Wide multiplicity distribution**
  - **Contains a significant amount of “mini” Jets.**

Reconstruction of the reaction plane in CMS

CMS Tracker

Reconstructed Tracks (|η|<2.4)

The reaction plane at the CMS can be determined independently by different detector subsystems and in different pseudorapidity windows.

$$tan(2\varphi_{rec}) = \frac{\sum_i \omega_i \sin 2\varphi_i}{\sum_i \omega_i \cos 2\varphi_i}$$

$$\omega_i = 1, p_T^i, (p_T^i)^2$$

CMS Calorimeters

ECAL (|η|<3) and HCAL (|η|<5.2)

$$tan(2\varphi_{rec}) = \frac{\sum_{towers} \omega_{tower} \sin 2\varphi_{tower}}{\sum_{towers} \omega_{tower} \cos 2\varphi_{tower}}$$

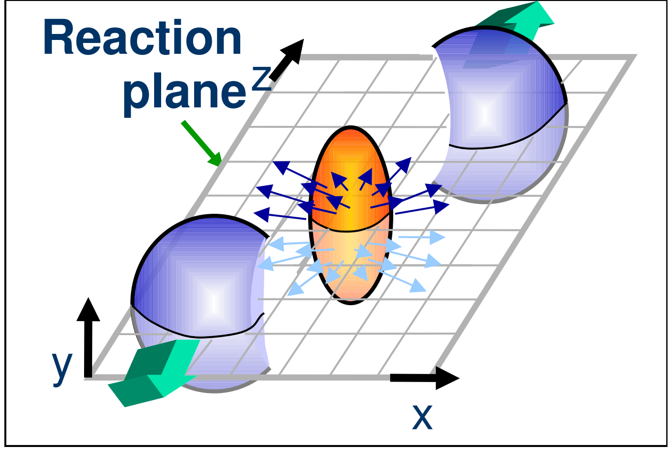
$$\omega_{tower} = E^{tower}, E_T^{tower}$$

HYDJET generator was used to simulate PbPb events at the LHC.

I.P. Lokhtin and A.M. Snigirev, Eur. Phys. J. C 46 (2006) 211, http://lokhtin.web.cern.ch/lokhtin/hydro/hydjet.html

GEANT-based software was used to simulate CMS responses.

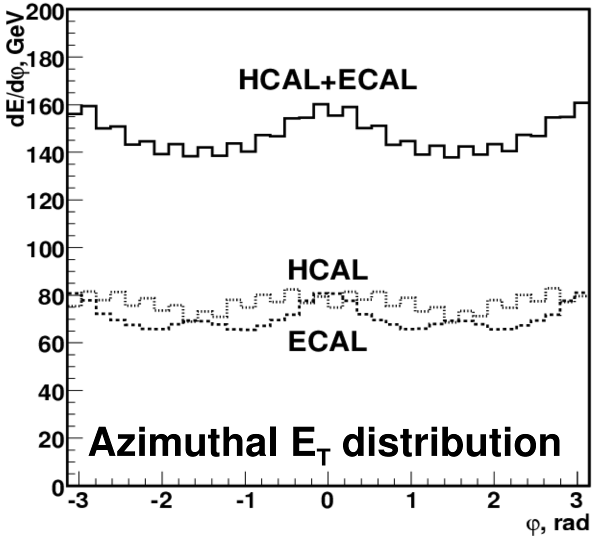
Elliptic Flow V_2

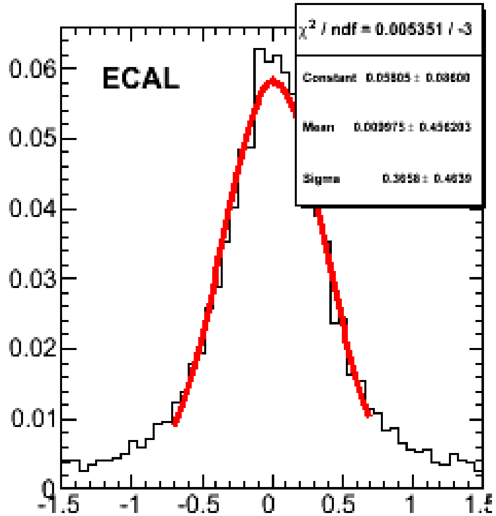


Methods:

- **Event plane, Ψ_{RP}**
- **Two and more particle correlation**

Find the reaction plane with calorimeters and tracker





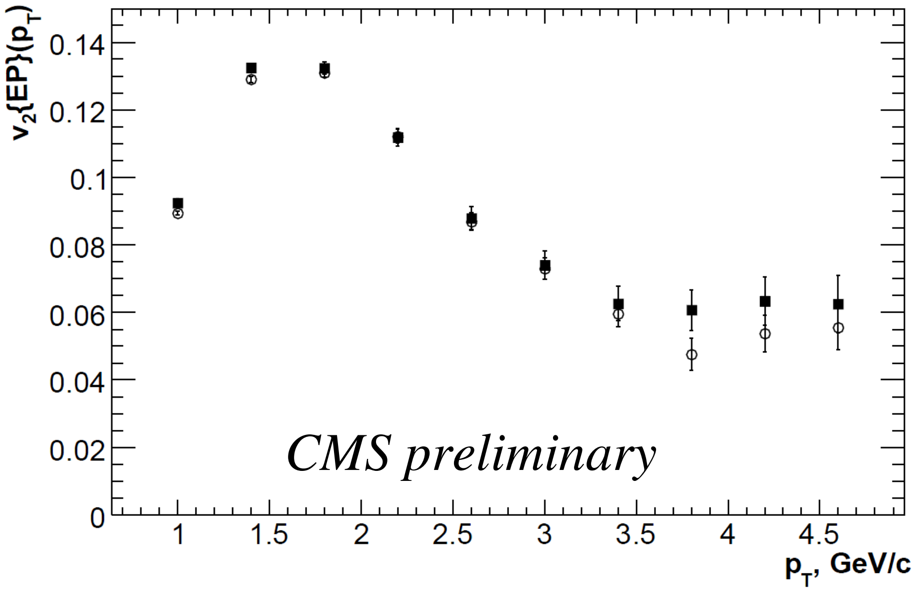
HYDJET, PbPb, b=9 fm

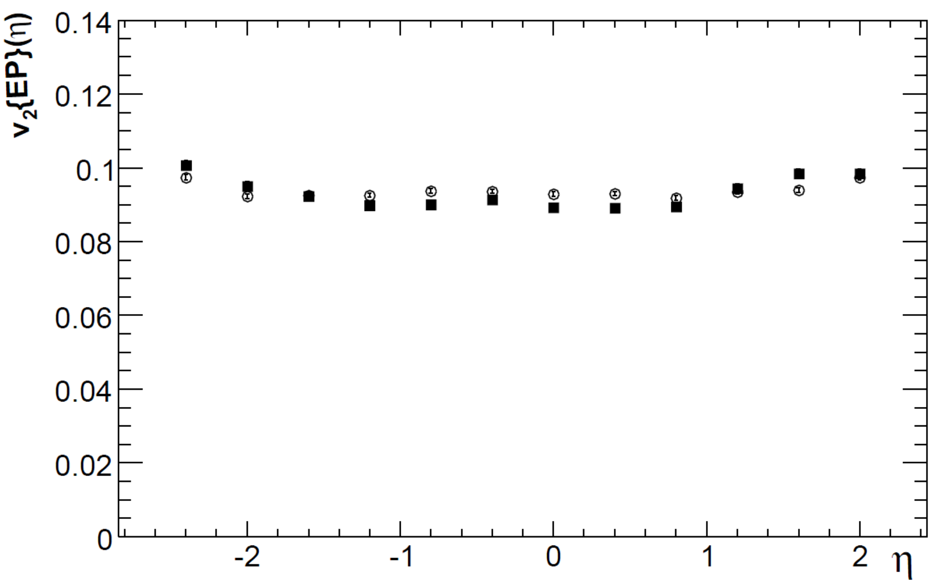
Event plane resolution with ECAL: 0.37 radian

Perspective experimental HI CMS studies:

1. V_2 with particle identification (ligth and heavy quarks)
2. Ψ_{RP} - dependence of Nuclear modification factor
3. Ψ_{RP} - dependence of backward peak in two particle correlations

v_2 vs. p_t and η– CMS tracker, PbPb b=9 fm





Tracks with p_T >0.9 GeV/*c*

(by Event Plane method)

The uncertainties of the CMS Tracker detector is not higher than 3%

○ - v2{EP} in generated events

■ - reconstructed

G.Kh.Eyyubova, V.L. Korotkikh, I.P. Lokhtin, S.V. Petrushanko, L.I. Sarycheva, A.M. Snigirev ,David Krofcheck , CMS AN-2007/004

Further study with LYZ method in

G.Kh.Eyyubova, V.L. Korotkikh, I.P. Lokhtin, S.V. Petrushanko, L.I. Sarycheva, A.M. Snigirev , , Phys.Atom.Nucl.71:2142, 2008

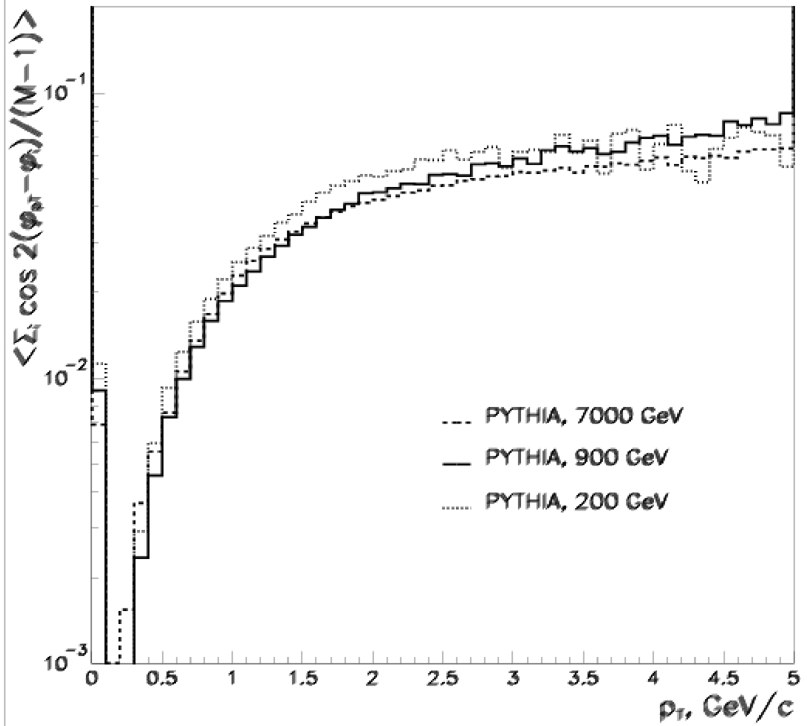
Energy independence of correlator in pp

$$<\sum_i \cos[2(\varphi_i - \varphi_{p_T})]>_{RHIC} \Rightarrow \left\langle \frac{\sum_i \cos[2(\varphi_i - \varphi_{p_T})]}{M-1} \right\rangle$$

For particles relatively to direction of leading particle

$$\left\langle \frac{\sum_i \cos[2(\varphi_i - \varphi_{p_T}^{lead})]}{M-1} \right\rangle_{evnt} = v_2^{jet}(p_T) < v_2^{jet} >$$

PYTHIA pp 200 - 7000 GeV



The correlator in pp collisions describes an angular form of particle azimuthal distribution relatively to leading particle direction.

v_2^{jet} (p_T) is anisotropy parameter for string fragmentation particles, which may be independent on energy.

Quasi-scaling on energy? It may be interesting effect in pp collisions.

Paper **in preparation**

Summary

- CMS is an excellent detector for studying minimum bias QCD and heavy-ion physics.

- Azimuthal correlations in pp is important reference for HI and can give unique information on jet fragmentation.

- v_2 study in HI collisions at LHC energy can give new information on collective phenomena of QGM.

- Pb-Pb collisions are expected at the LHC in November- in Run-1 at 2.76 TeV with the most early publication in 2011 year.

- CMS detector at the LHC is ready to study elliptic flow by different detector subsystems, in different pseudorapidity windows and by different methods.