QCD matter studies with ALICE

Dariusz Miskowiec, GSI Darmstadt
for the ALICE Collaboration

- introduction
- bulk particle production
- spatial extension
- collective flow
- hard probes
- collectivity in small systems?
- summary

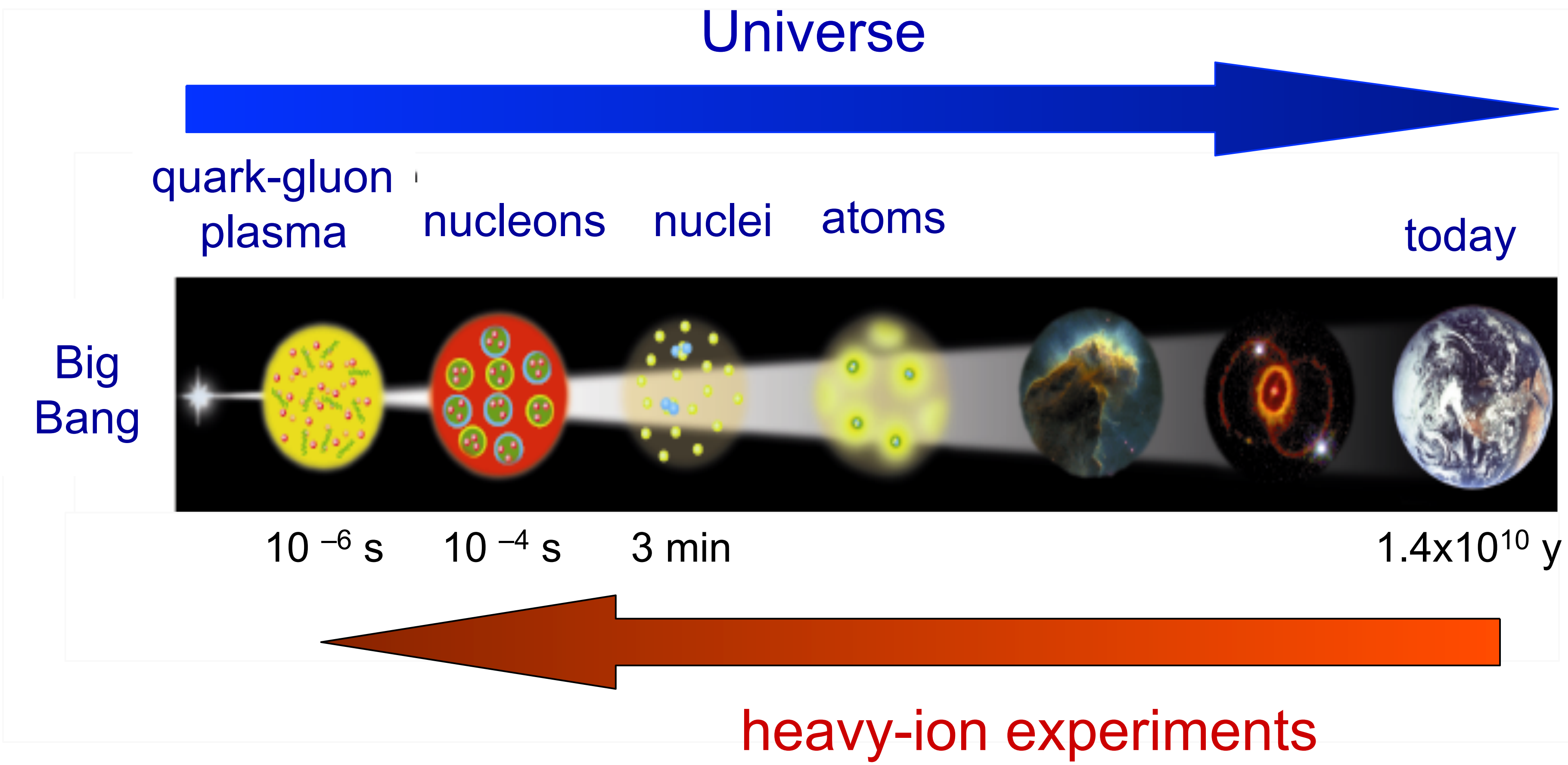
ALICE

Pb+Pb @ sqrt(s) = 2.76 ATeV

2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

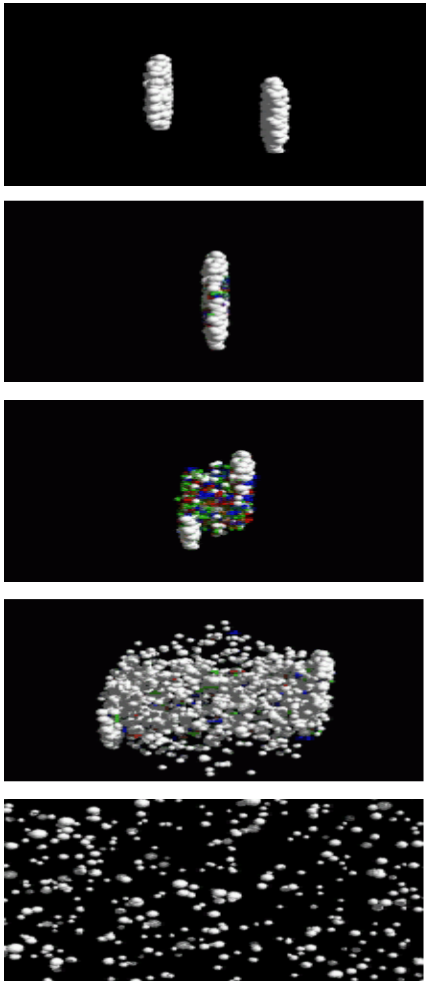
introduction

From the Big Bang to hadrons and nuclei



heavy-ion collisions

UrQMD 160 GeV Au+Au



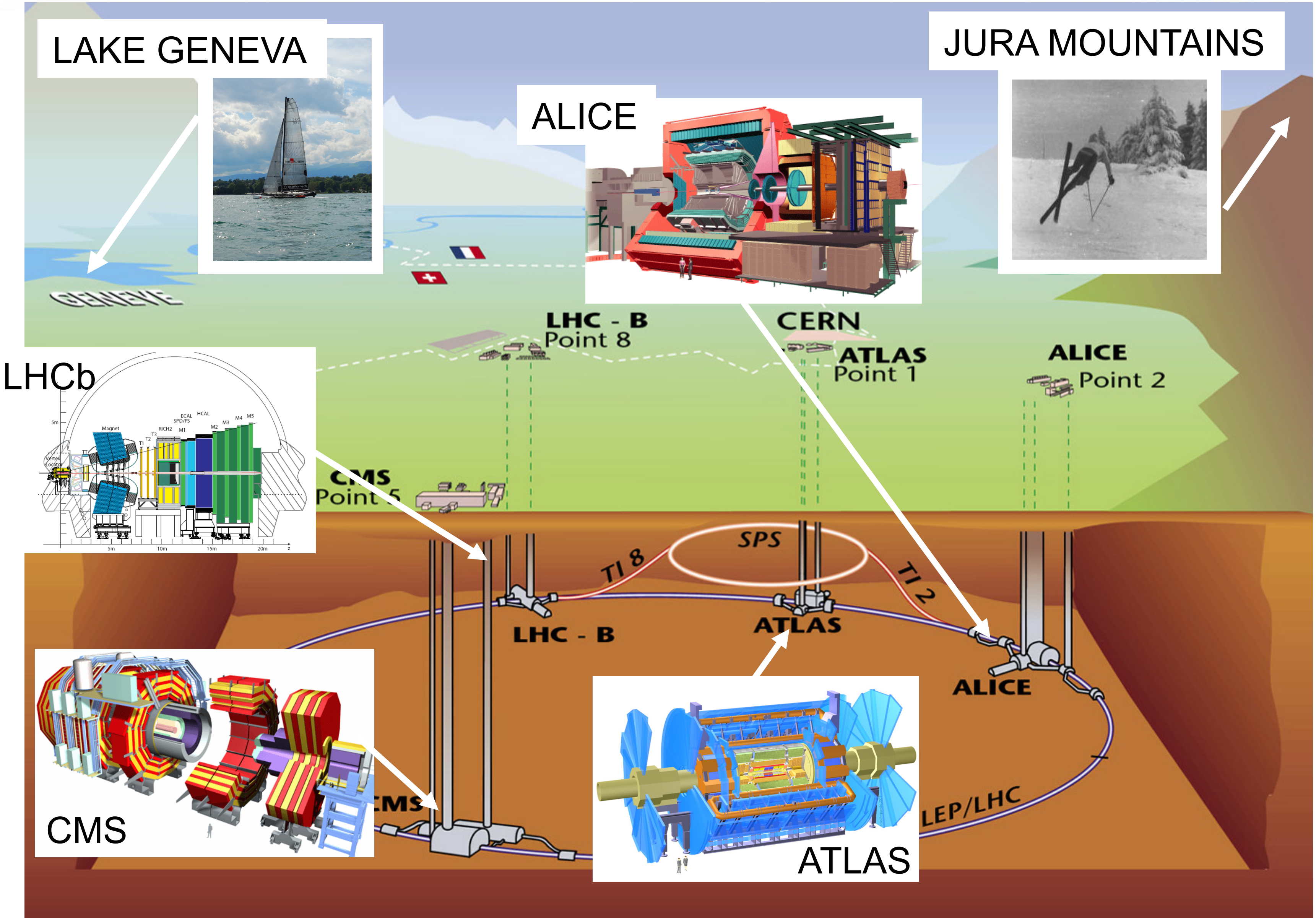
- before collision
- parton collisions
- thermalization
- hadronization
- chemical freezeout (number of particles frozen)
- kinetic freezeout (particle momenta frozen)

normal nuclear matter
$\rho_0 = 0.17\ /\text{fm}^3$
$\varepsilon_0 = 0.16\ \text{GeV/fm}^3$

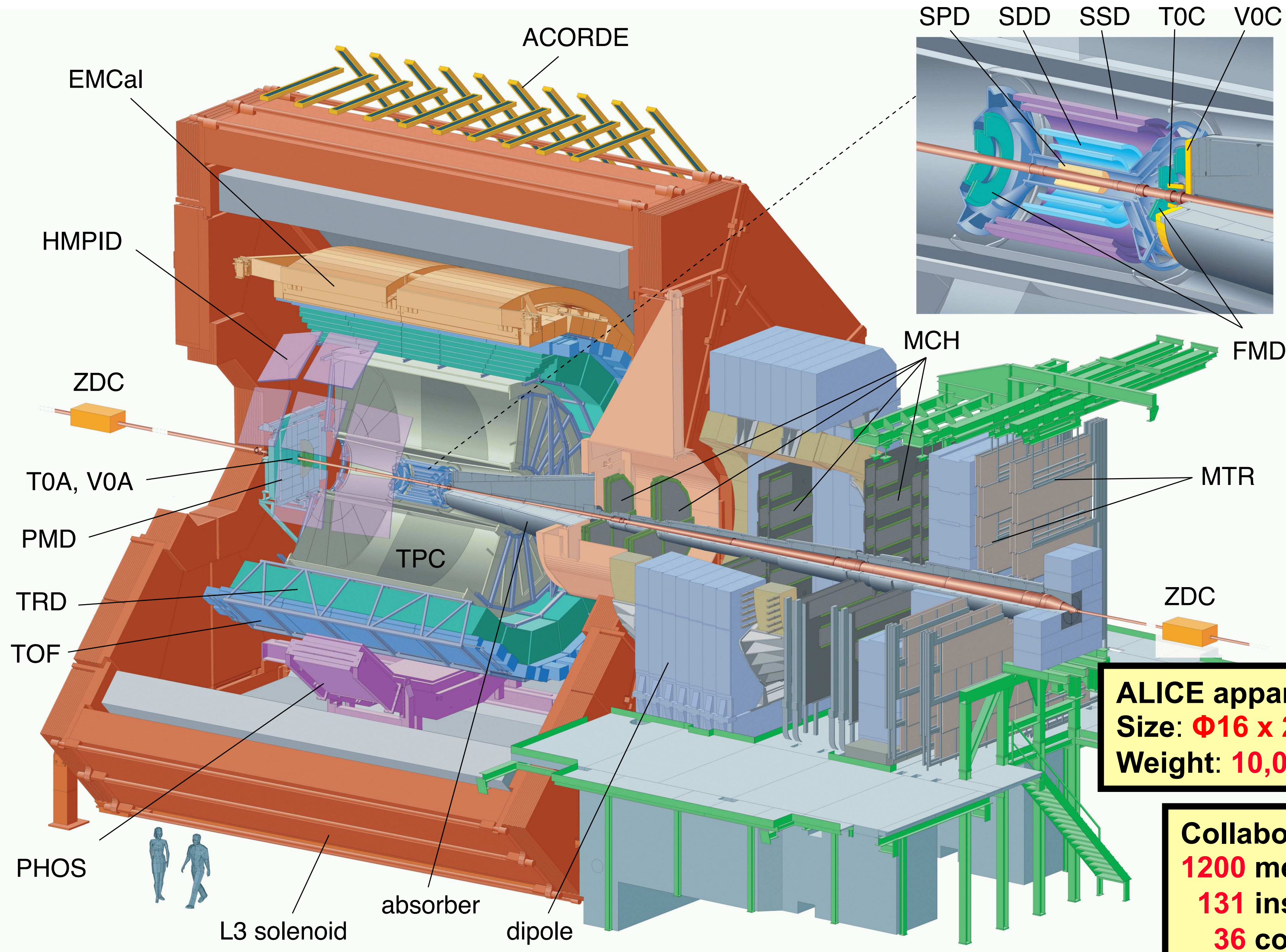
initial-state effects

quark-gluon plasma
$\varepsilon > 0.5\ \text{GeV/fm}^3$

LHC experiments



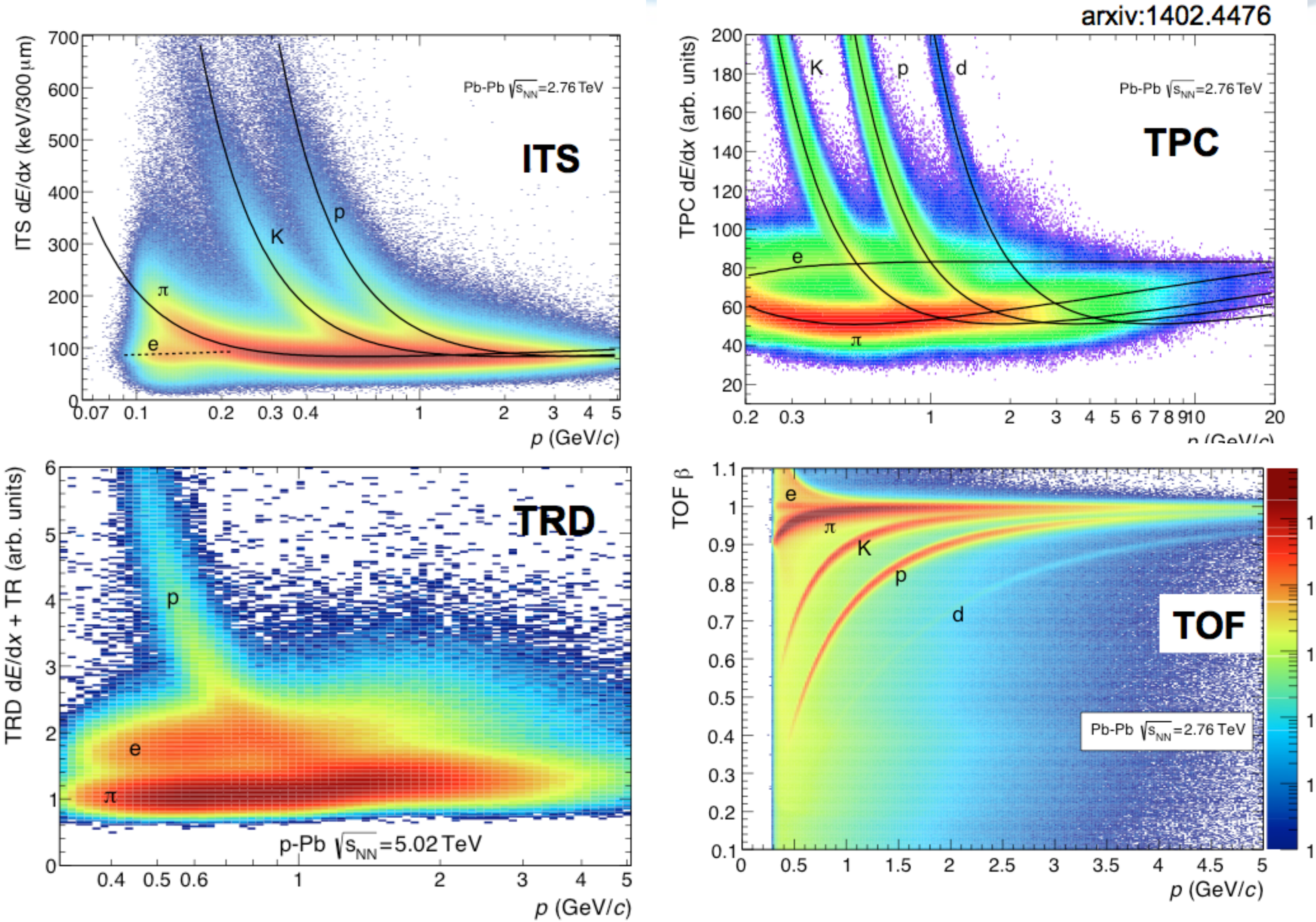
ALICE apparatus



ALICE apparatus:
Size: **Φ16 x 26** m
Weight: **10,000** tons

Collaboration:
1200 members
131 institutes
36 countries

hadron identification



ALICE performance 2009-2013

arxiv:1402.4476

CERN-PH-EP-2014-031
February 20, 2014

Performance of the ALICE Experiment at the CERN LHC

The ALICE Collaboration*

Abstract

ALICE is the heavy-ion experiment at the CERN Large Hadron Collider. The experiment continuously took data during the first physics campaign of the machine from fall 2009 until early 2013, using proton and lead-ion beams. In this paper we describe the running environment and the data handling procedures, and discuss the performance of the ALICE detectors and analysis methods for various physics observables.

google for "alice performance"

ALICE measurements in LHC Run 1 (2009-2013)

	system	$\mathrm{sqrt}(s_{NN})$	data taking time
	pp	0.9, 2.36, 2.76, 7, 8 TeV	21 months*
	Pb-Pb	2.76 TeV	2 x 1 month
	p-Pb	5.02 TeV	1 month

* at a reduced luminosity

tour through major ALICE results 2009-2013

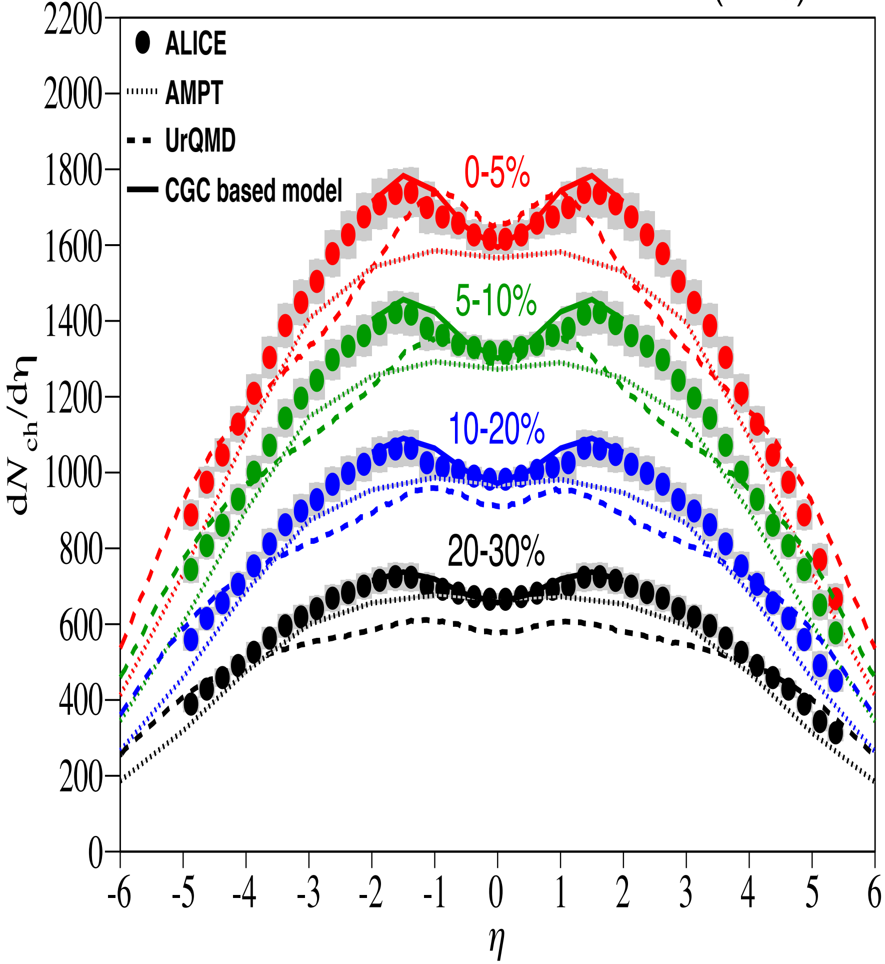
- **selected highlights only**
- **biased towards soft physics**
- **comparison to RHIC ($\sqrt{s_{NN}} \leq 200$ GeV, STAR and PHENIX data)**

bulk particle production

charged-particle production: pseudorapidity distributions

Pb-Pb

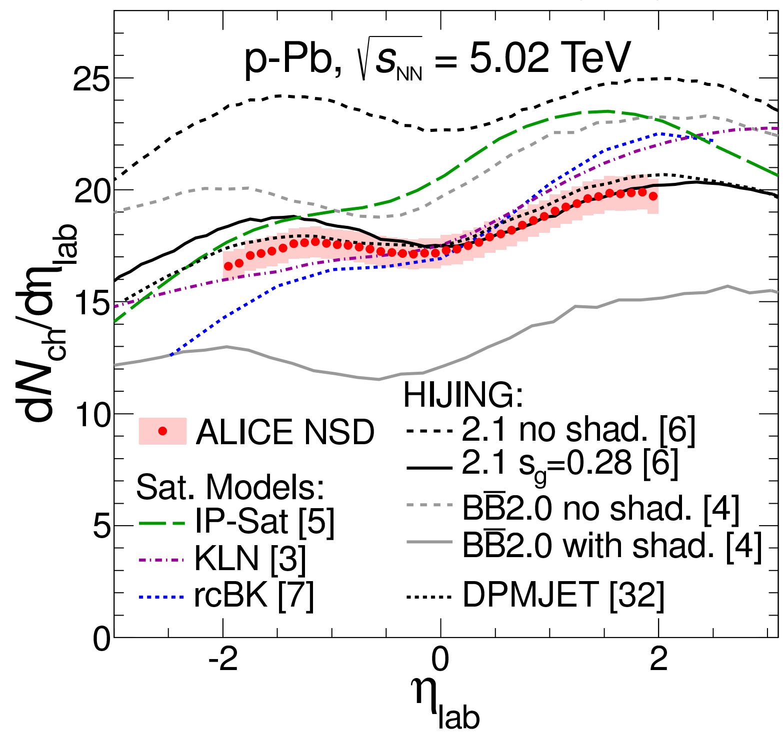
PLB 726 (2013) 610



constrains description of dynamics of heavy-ion collisions

p-Pb

PRL 110 (2013) 032301



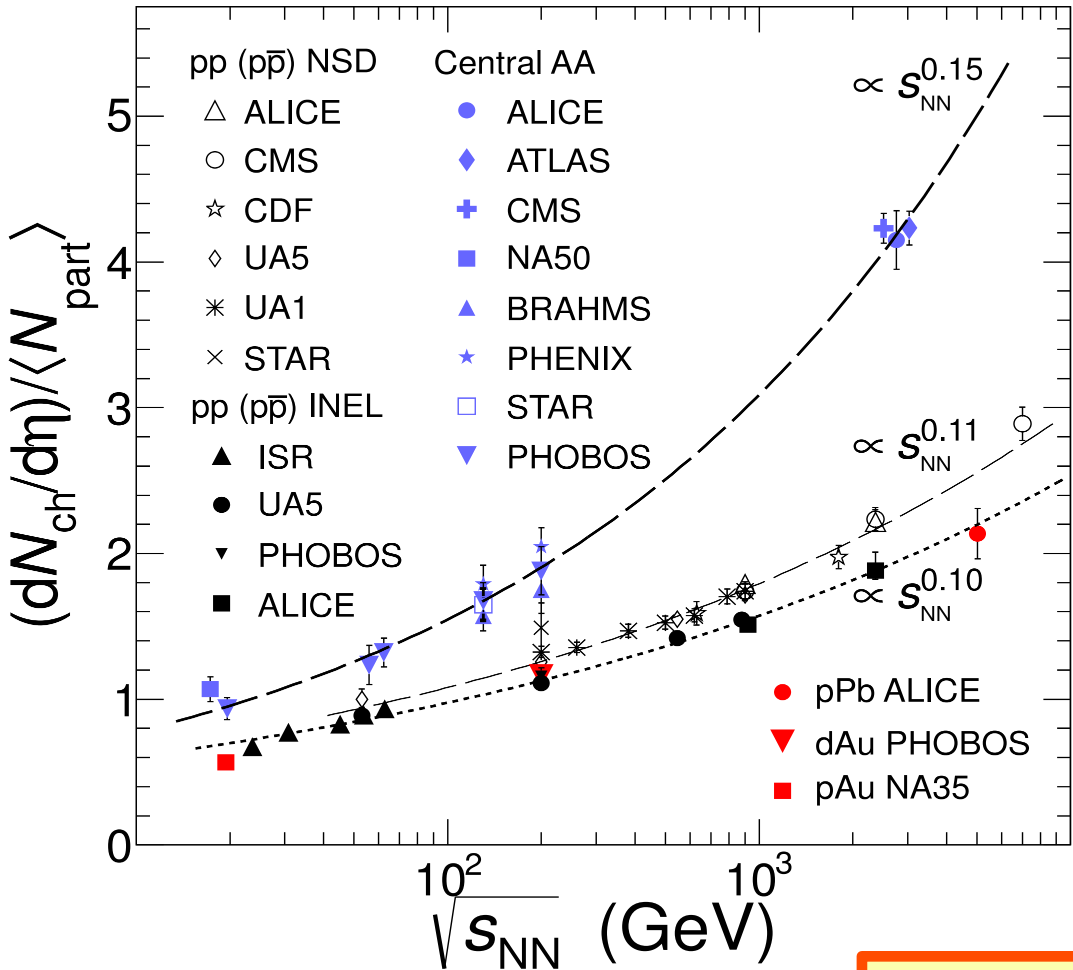
constrains initial conditions of heavy-ion collisions

models with shadowing or saturation describe the measurement within 20%

saturation models too steep

charged-particle production: collision energy dependence

PRL 110 (2013) 032301



← Pb-Pb

← pp, p-Pb

p-Pb comparable to pp
Pb-Pb about 2 times higher
faster growth with collision energy

Wounded Nucleon Model aka Glauber model
aka nuclear overlap calculation → Npart(b), Ncoll(b), dσ/db

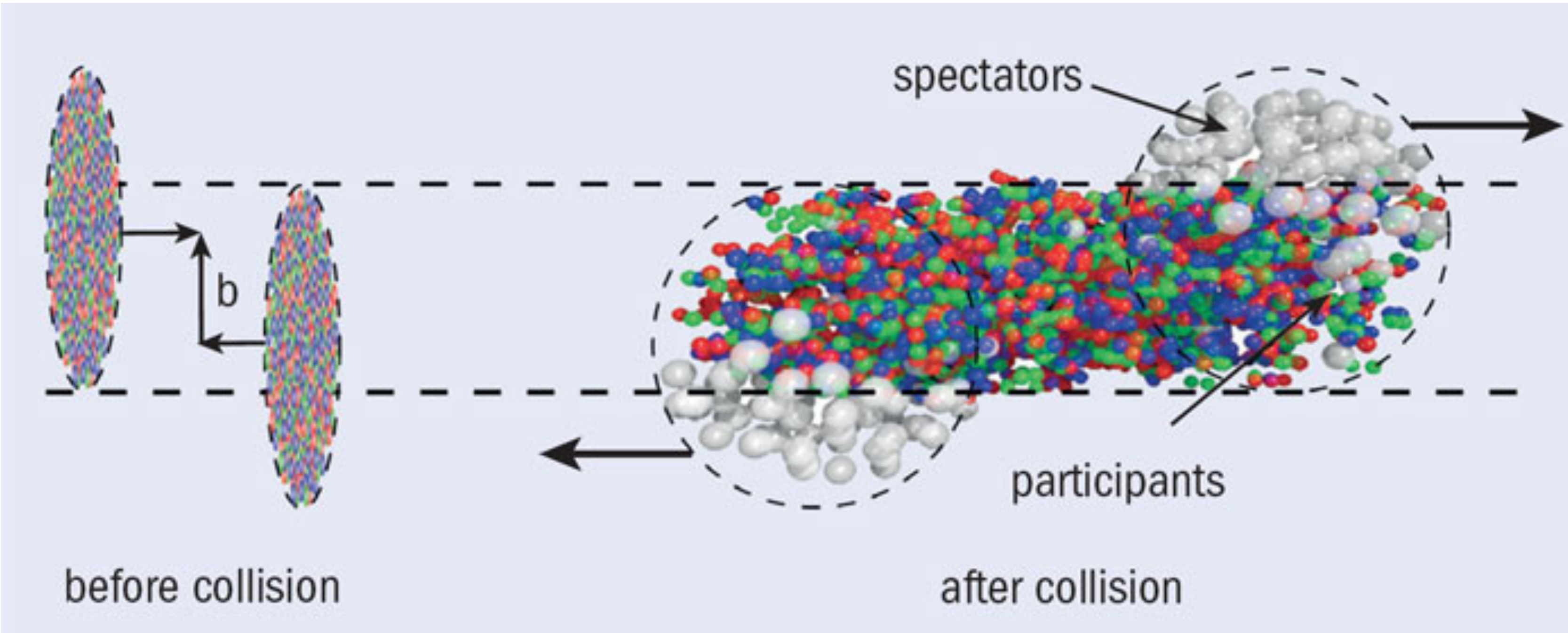
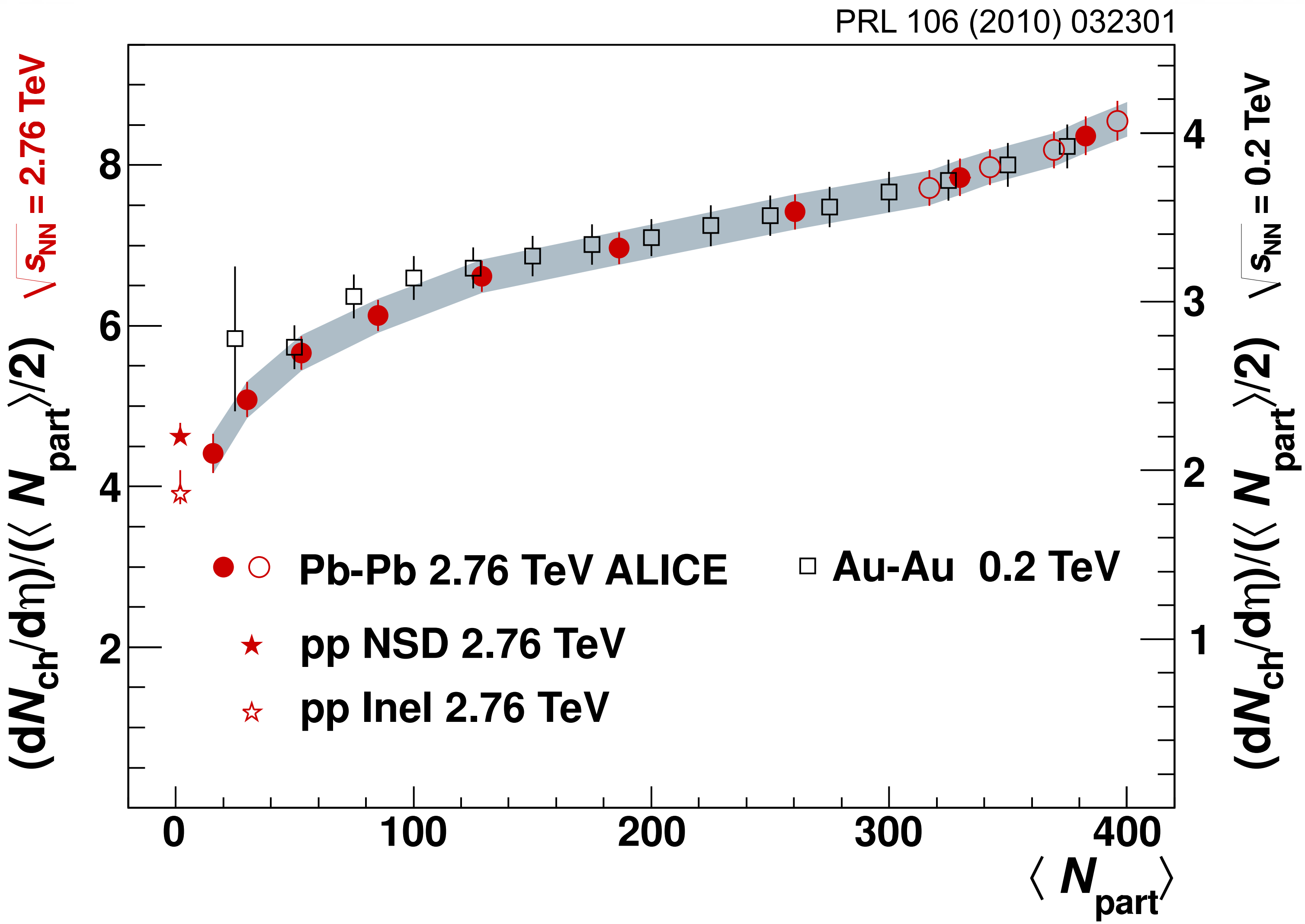


Fig.: A. Toia, CERN Courier 26-Apr-2013

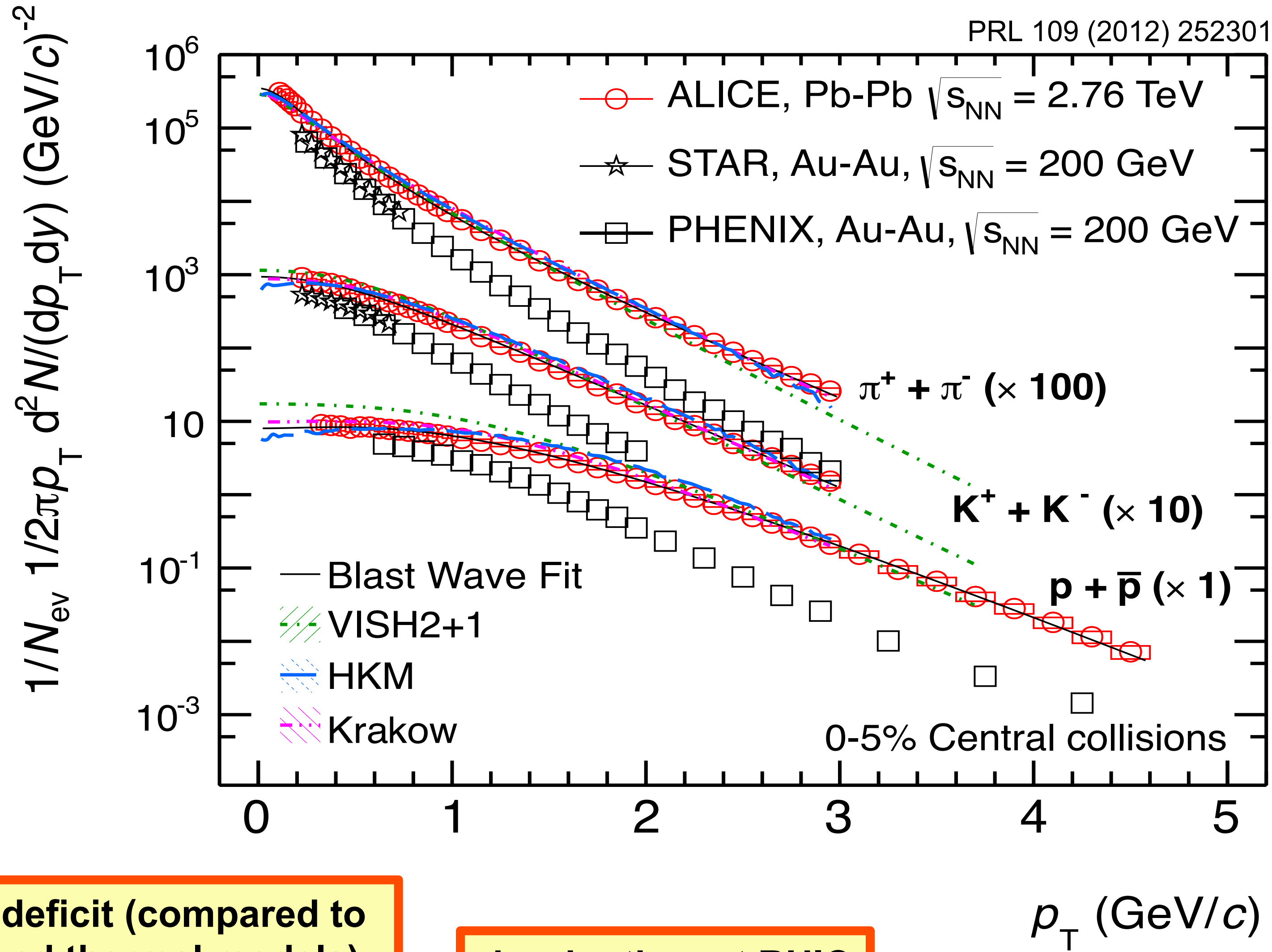
For an online calculation: google for "nuclear overlap"

charged-particle production: centrality dependence



~2 times more particles than at RHIC, same centrality dependence

pion, kaon, proton spectra in Pb-Pb – comparison to RHIC

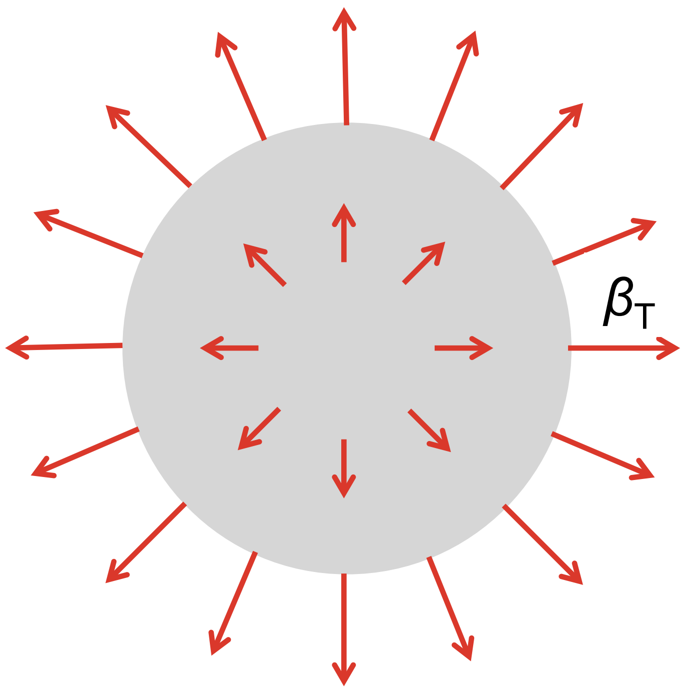


proton deficit (compared to hydro and thermal models)

harder than at RHIC

Blast-wave parametrization of transverse-momentum spectra

Schnedermann, Sollfrank, Heinz, PRC 48(1993)2462



outward collective velocity β_T
+ local kinetic temperature T_{kin}

transverse velocity (flow) profile:

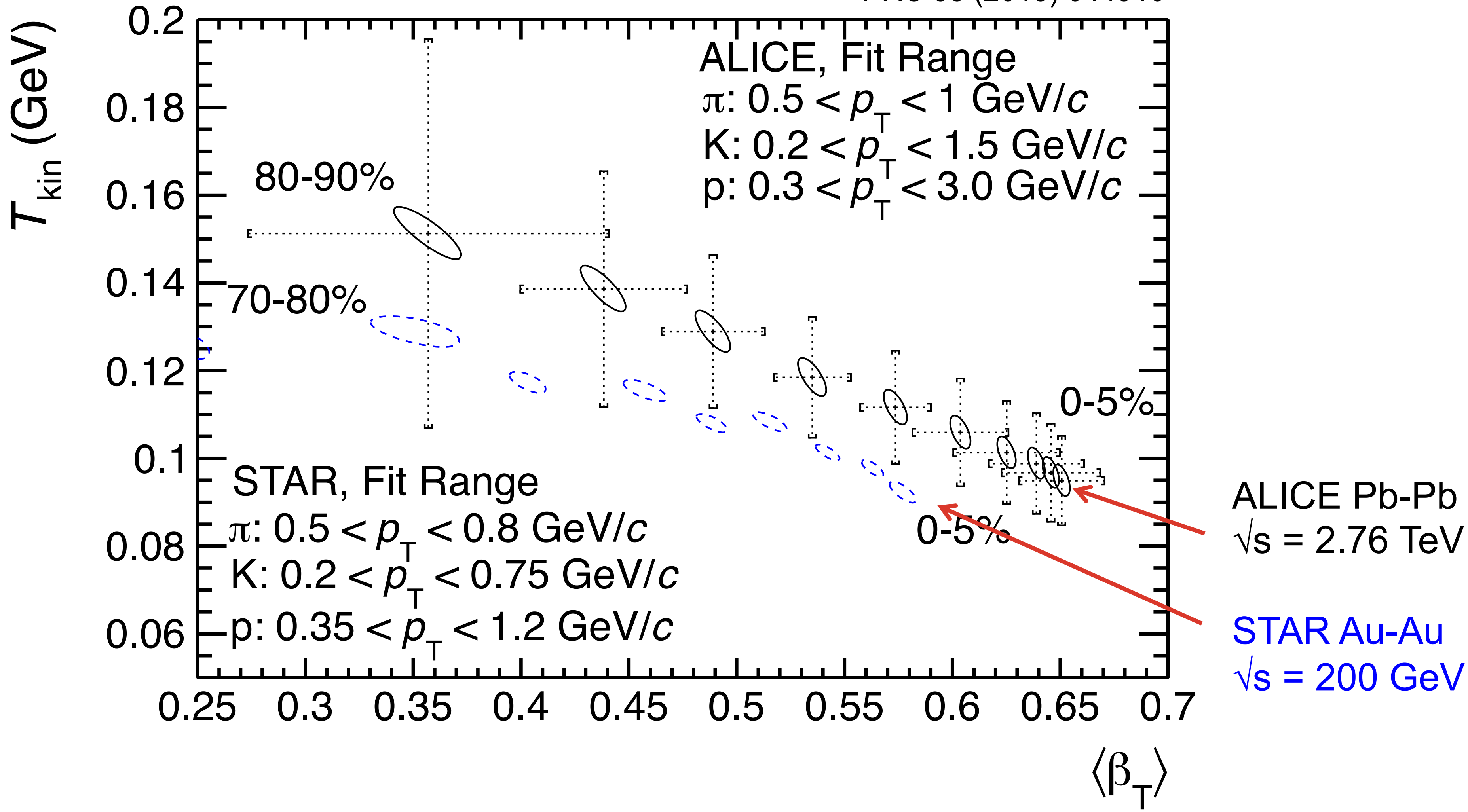
$$\rho = \tanh^{-1}\beta_T = \tanh^{-1}\left(\left(\frac{r}{R}\right)^n \beta_s\right)$$

p_T spectra:

$$\frac{1}{p_T}\frac{dN}{dp_T} \propto \int_0^R r\,dr\, m_T\, I_0\left(\frac{p_T \sinh\rho}{T_{kin}}\right) K_1\left(\frac{m_T \cosh\rho}{T_{kin}}\right)$$

identified-hadron spectra – blast-wave fit

PRC 88 (2013) 044910

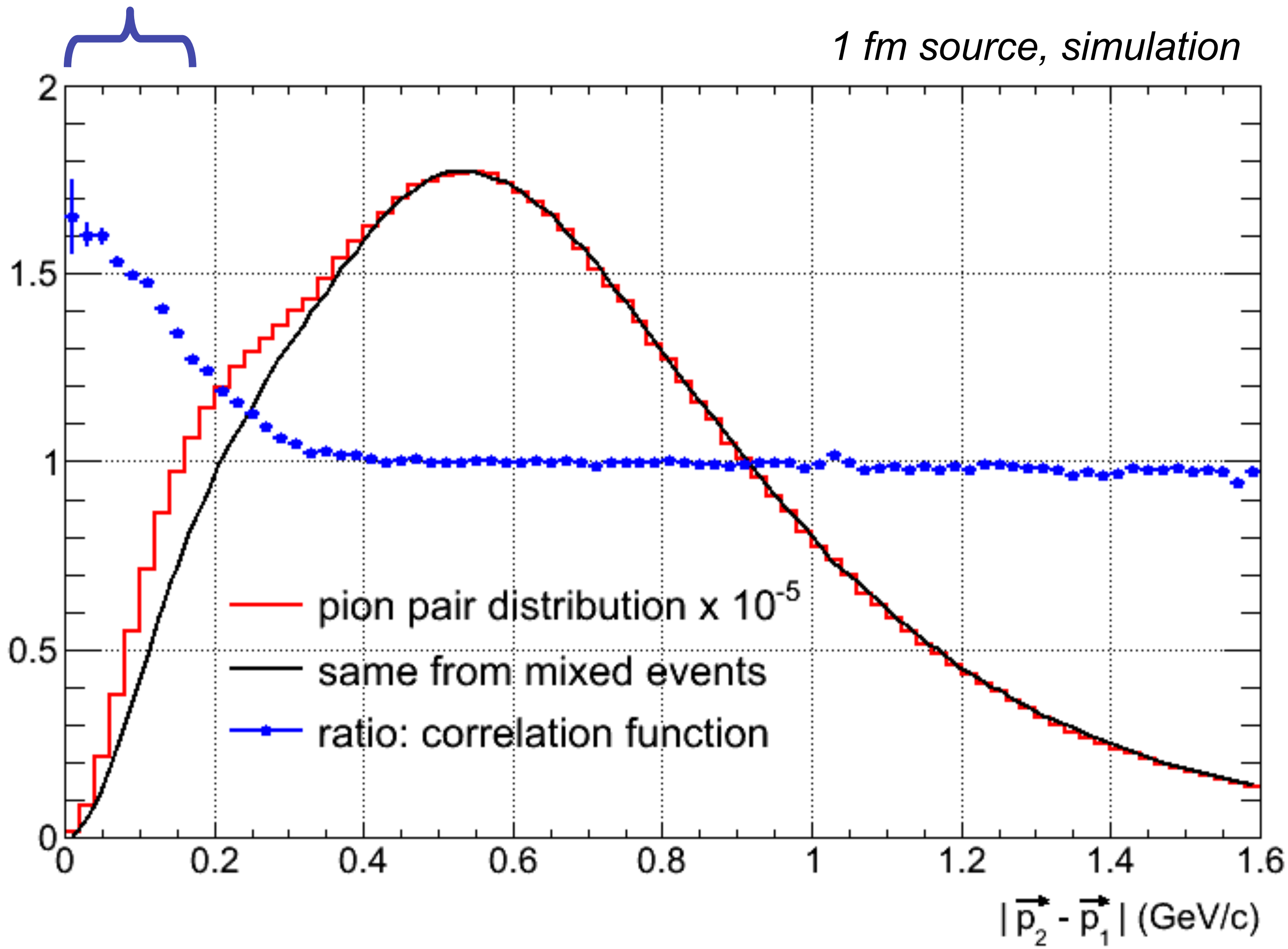


10% more transverse flow than at RHIC

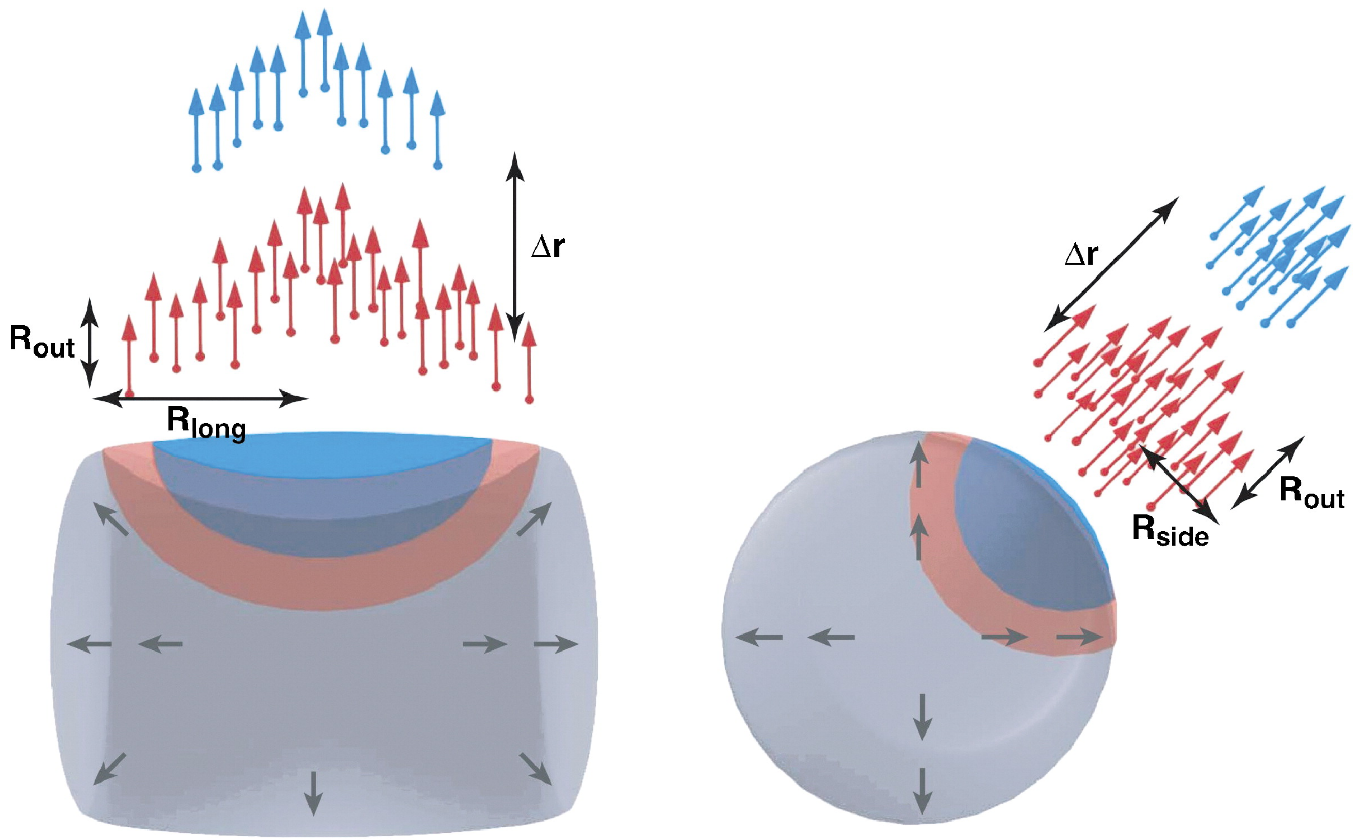
spatial extension

Bose-Einstein correlation analysis technique (HBT)

peak width ~ 1 / source size



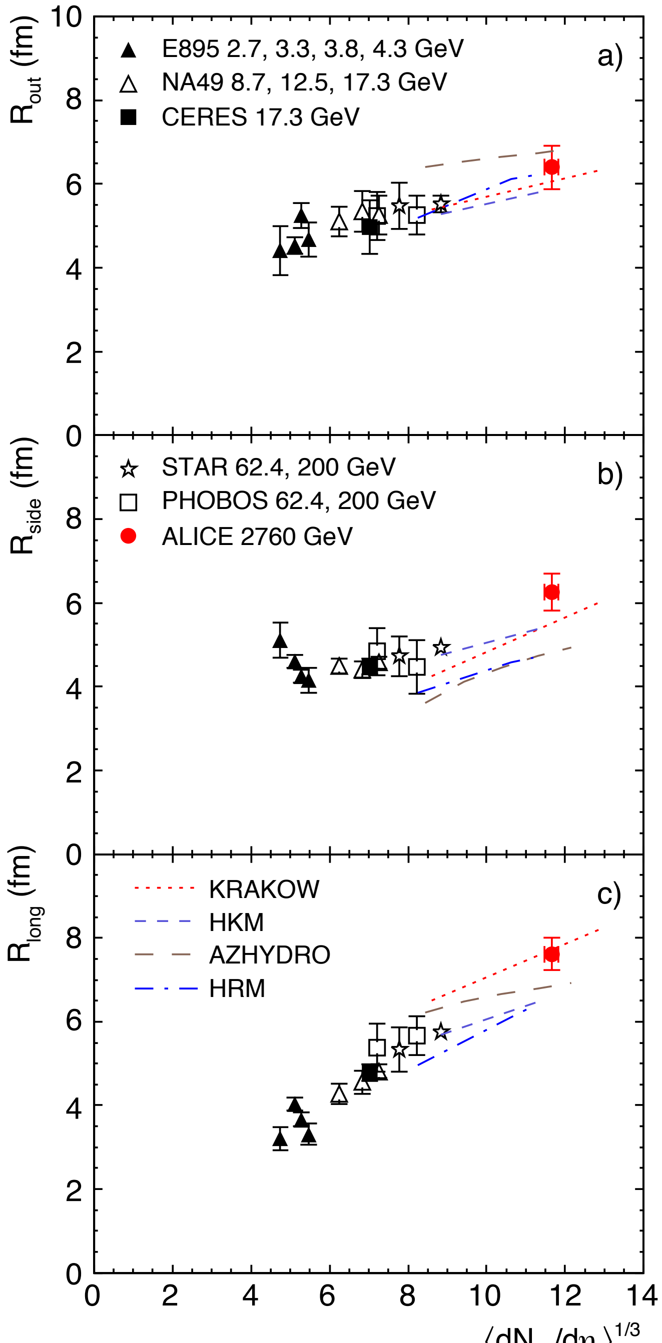
pion source size accessible experimentally

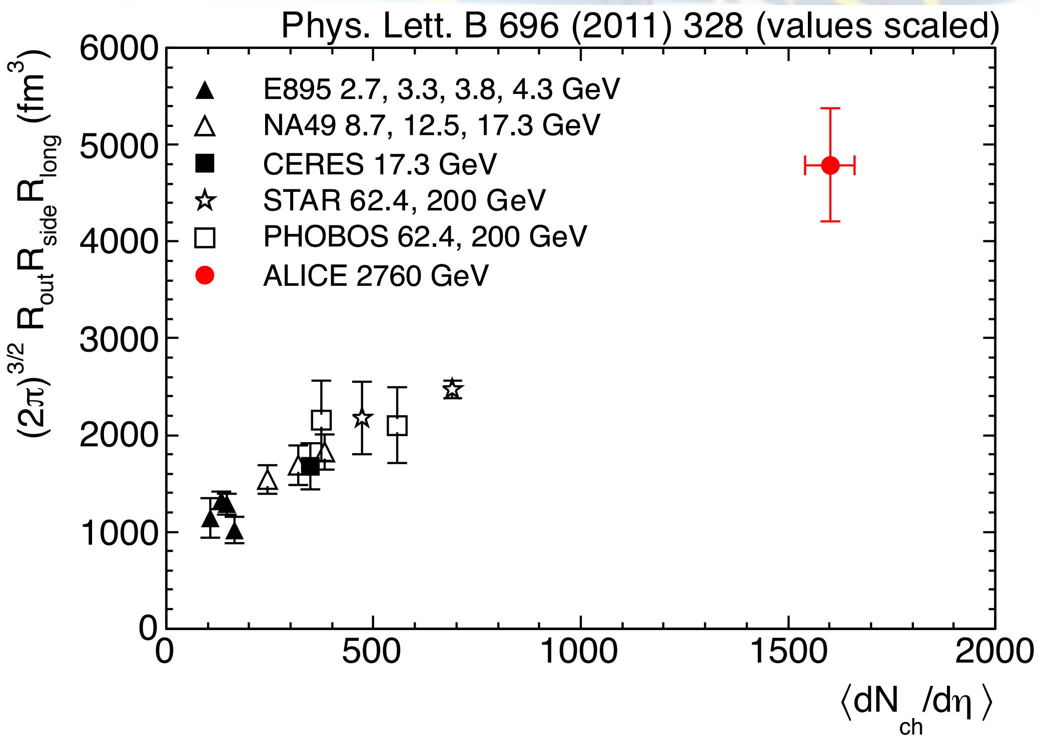


Lisa MA, et al. 2005.
Annu. Rev. Nucl. Part. Sci. 55:357–402

standard way to parametrize source size in 3-dim

pion HBT in central Pb-Pb collisions



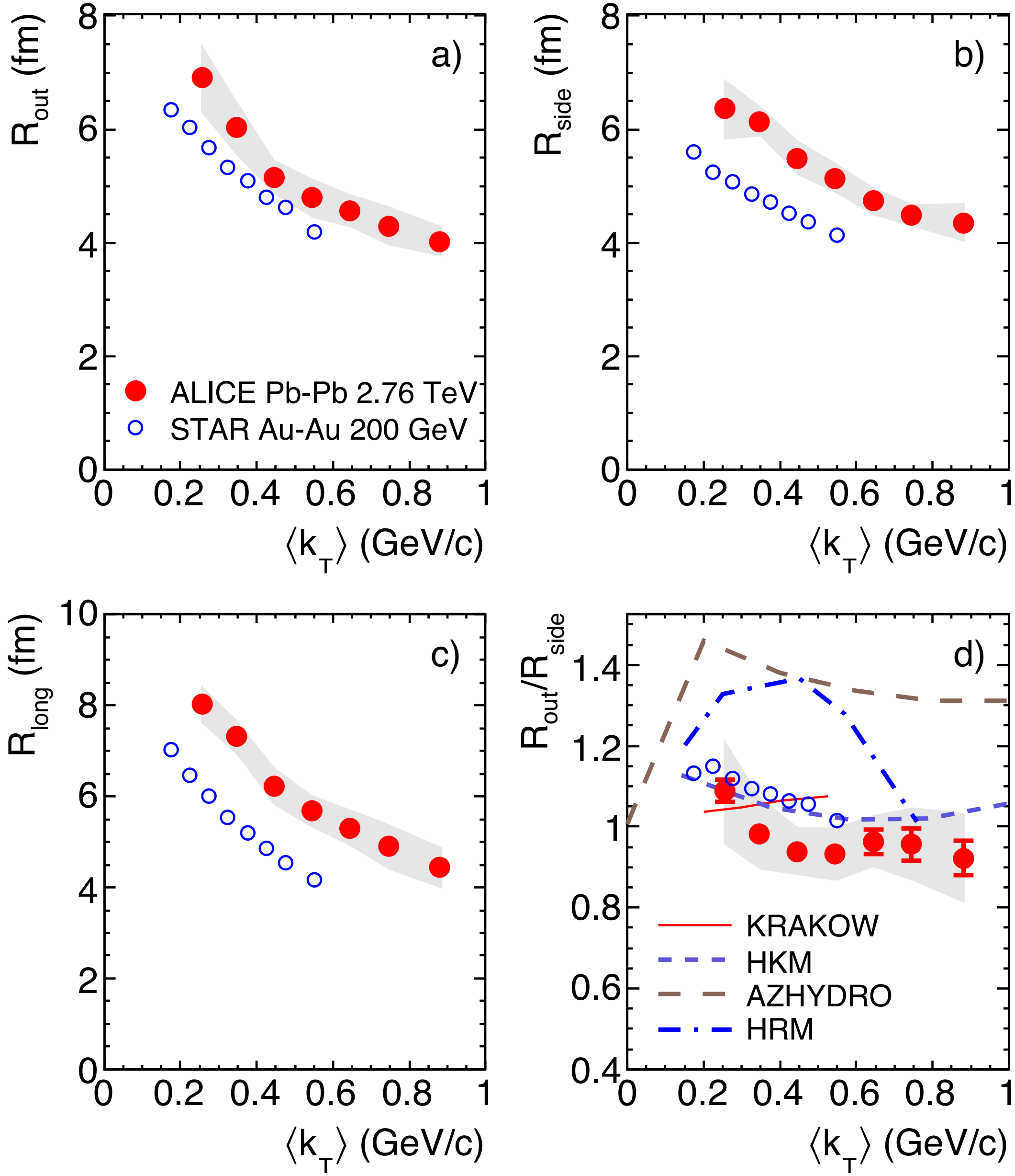


homogeneity volume 2 x larger than at RHIC

growth with energy reasonably well described by hydro-based models tuned to RHIC data, containing early flow, cross-over, realistic EOS, and hadronic rescattering phase

pion HBT in central Pb-Pb collisions

Phys. Lett. B 696 (2011) 328



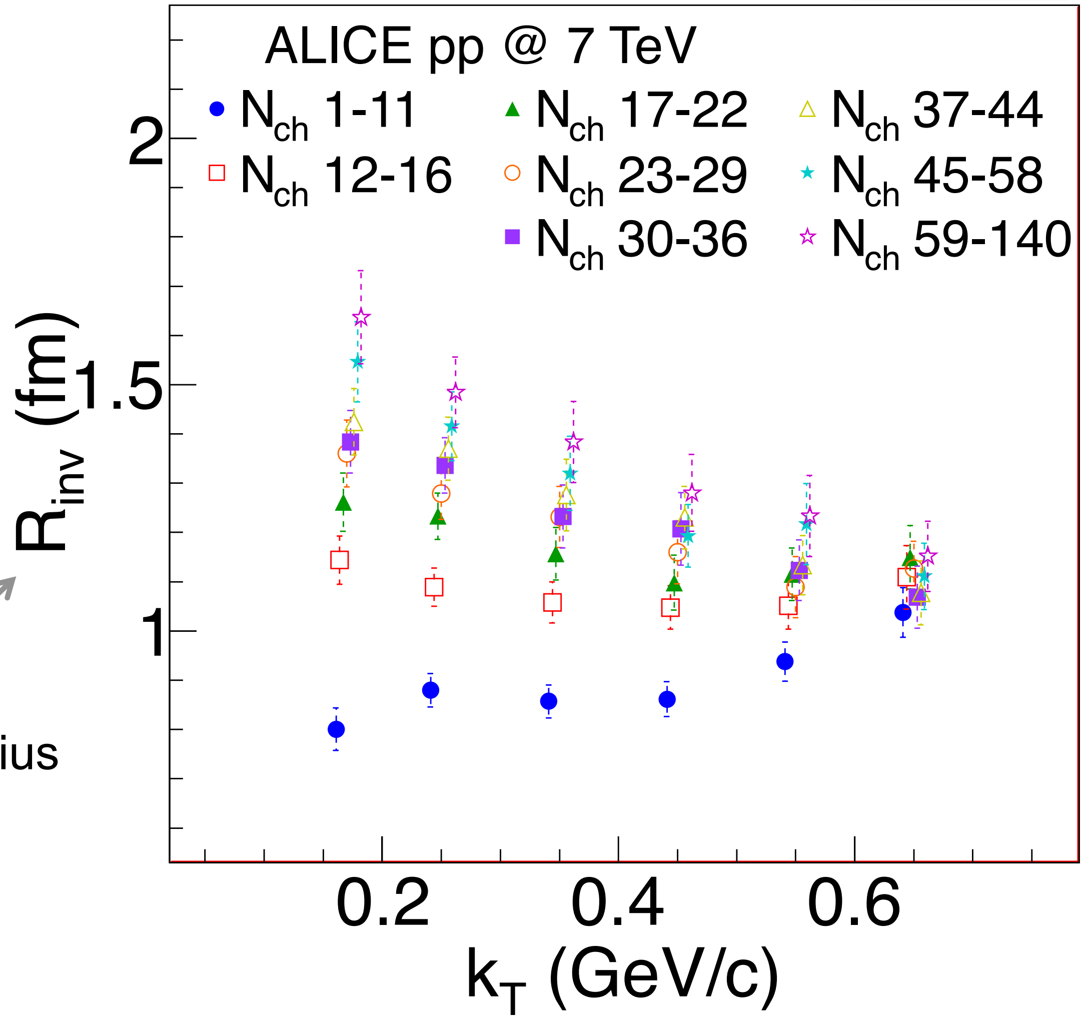
pair transverse momentum

$$k_T = |\mathbf{p}_{T,1} + \mathbf{p}_{T,2}|/2$$

k_T dependence – sign of transverse flow

pion HBT in pp collisions

PRD 84 (2011) 112004

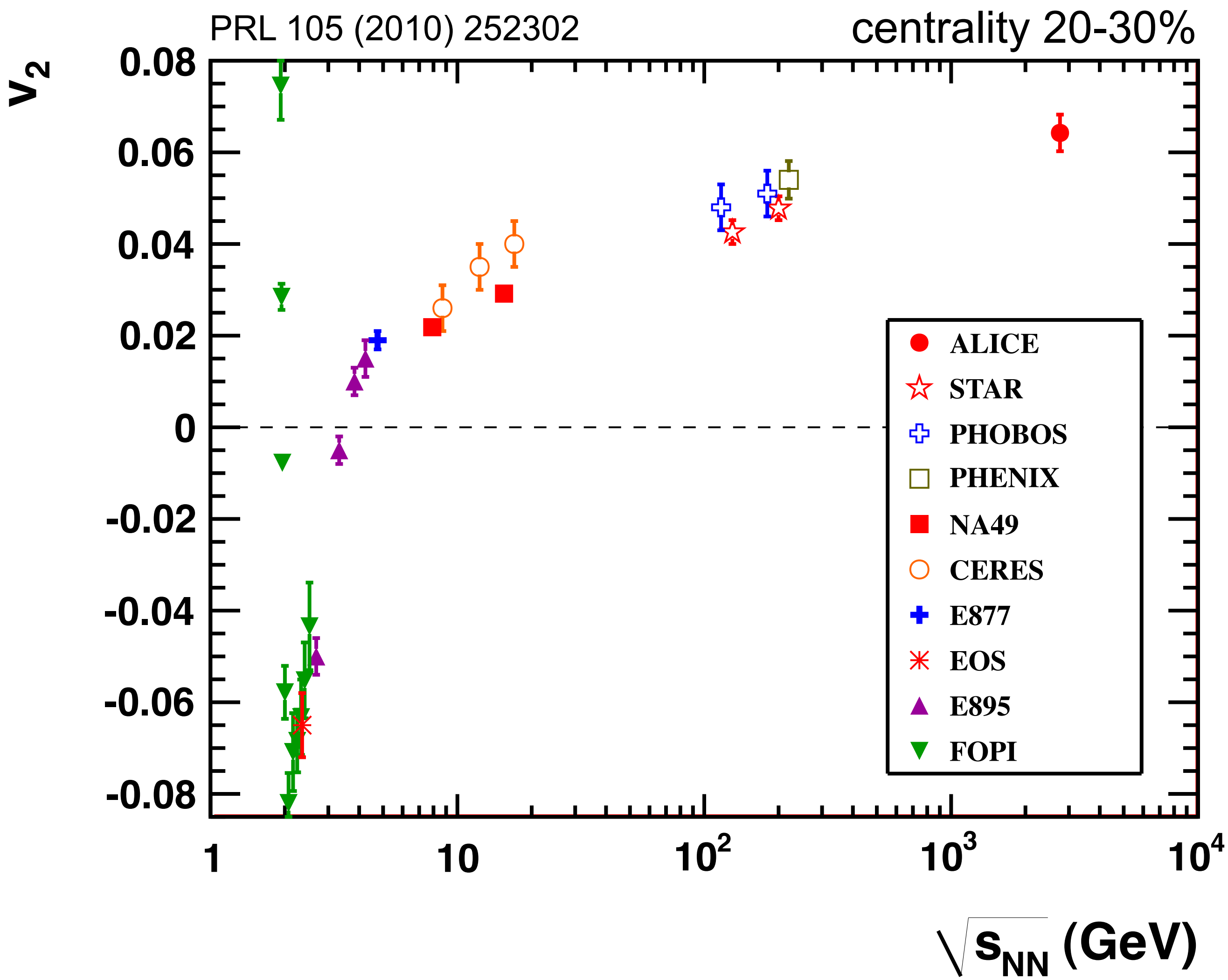


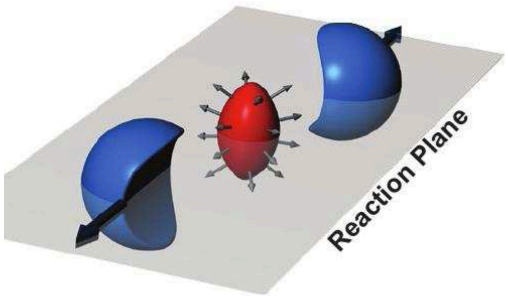
1-dim HBT radius in pair c.m.s.

in pp, a similar k_T dependence develops with increasing multiplicity
→ collective flow in high-multiplicity pp?

flow

elliptic flow in Au and Pb collisions

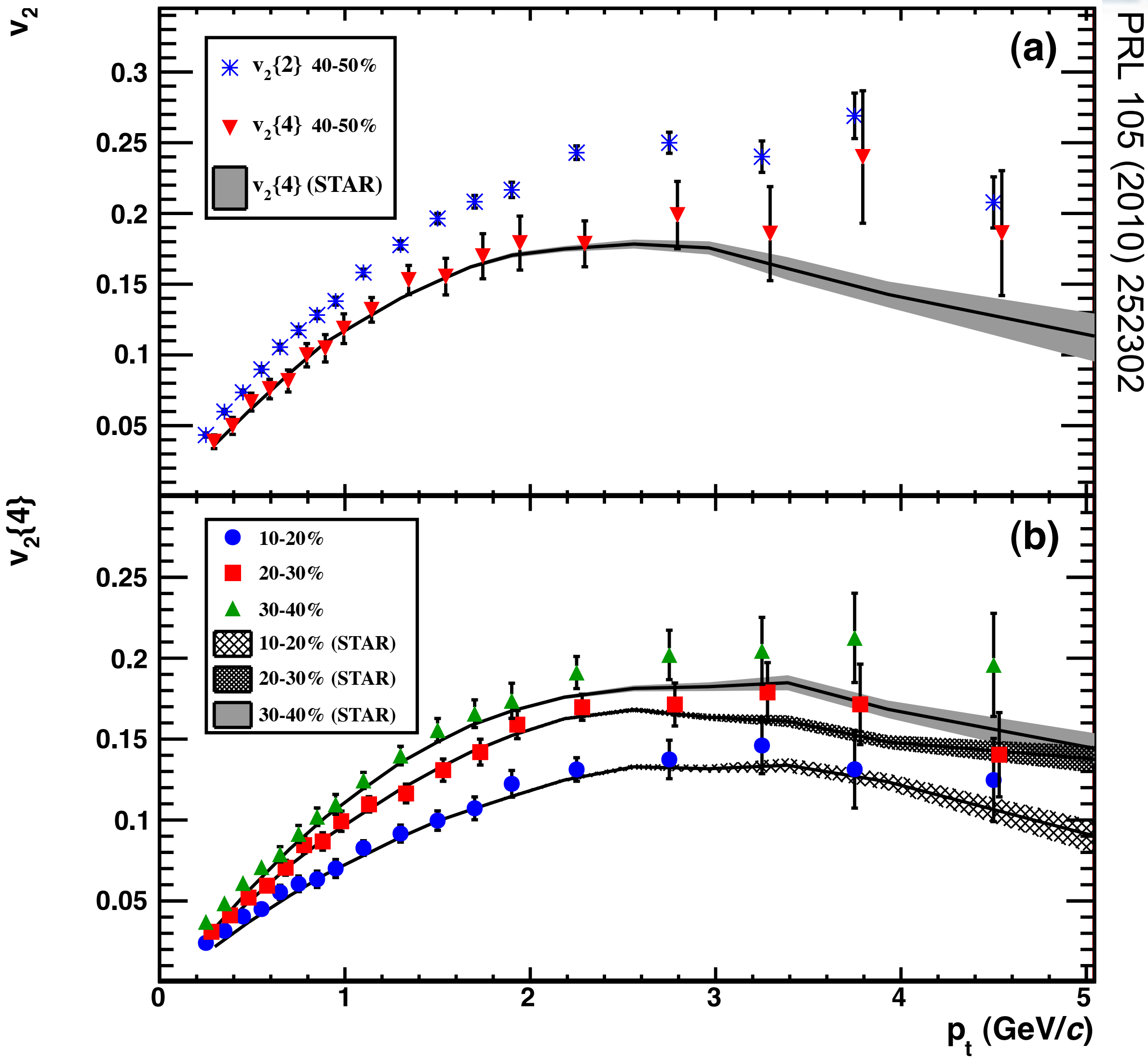




v2
second Fourier coefficient of $dN/d(\varphi-\psi_{RP})$

hydrodynamic behavior continues at LHC energies

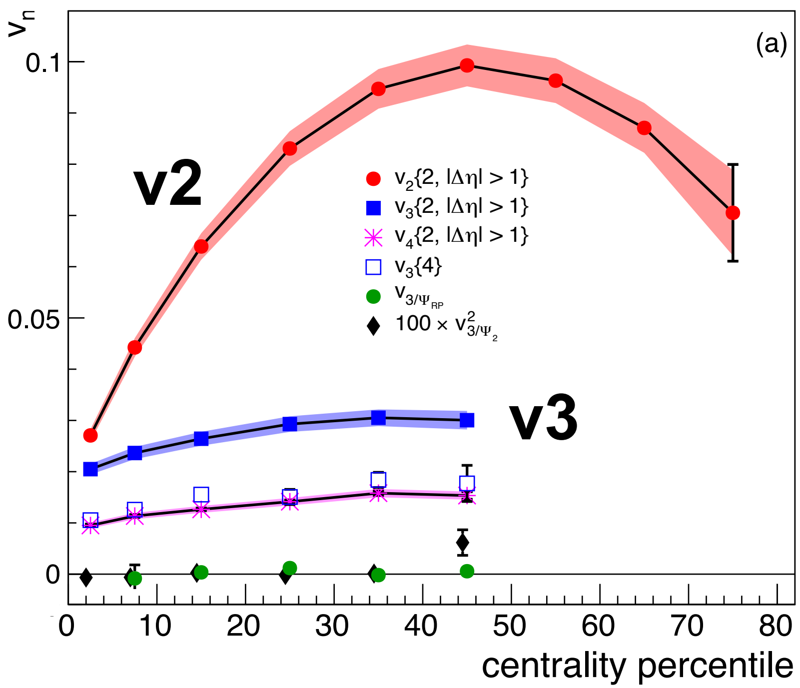
elliptic flow

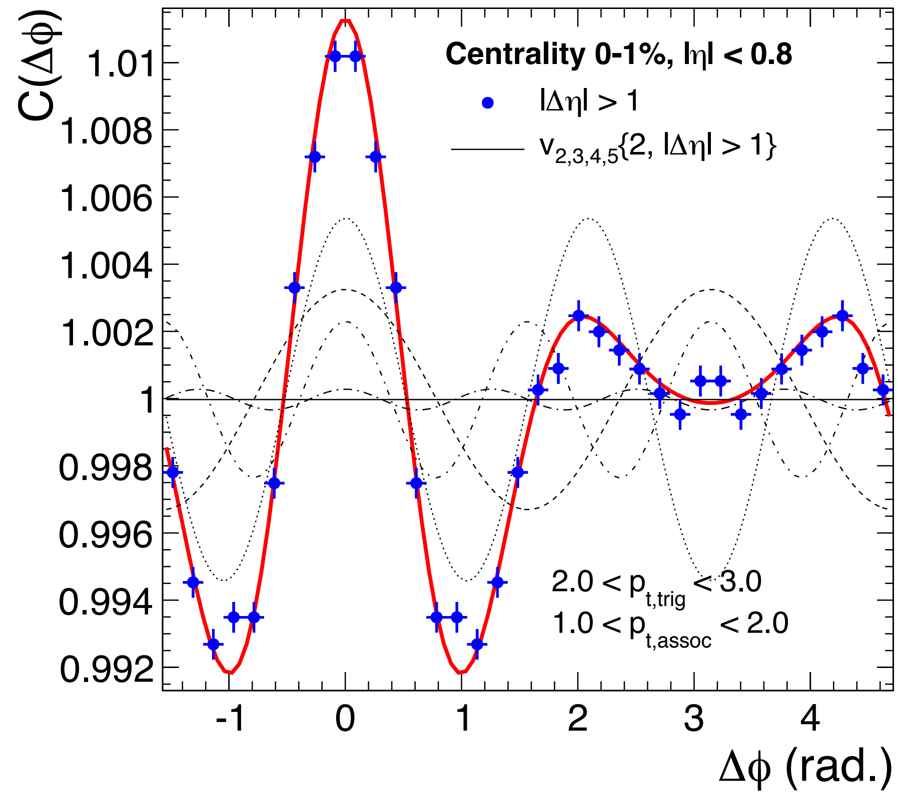


same p_T dependence as at RHIC (and below, down to $\sqrt{s_{NN}}$=40 GeV!)
inclusive v_2 at LHC higher only because $<p_T>$ higher

higher harmonics of flow

PRL 107 (2011) 032301

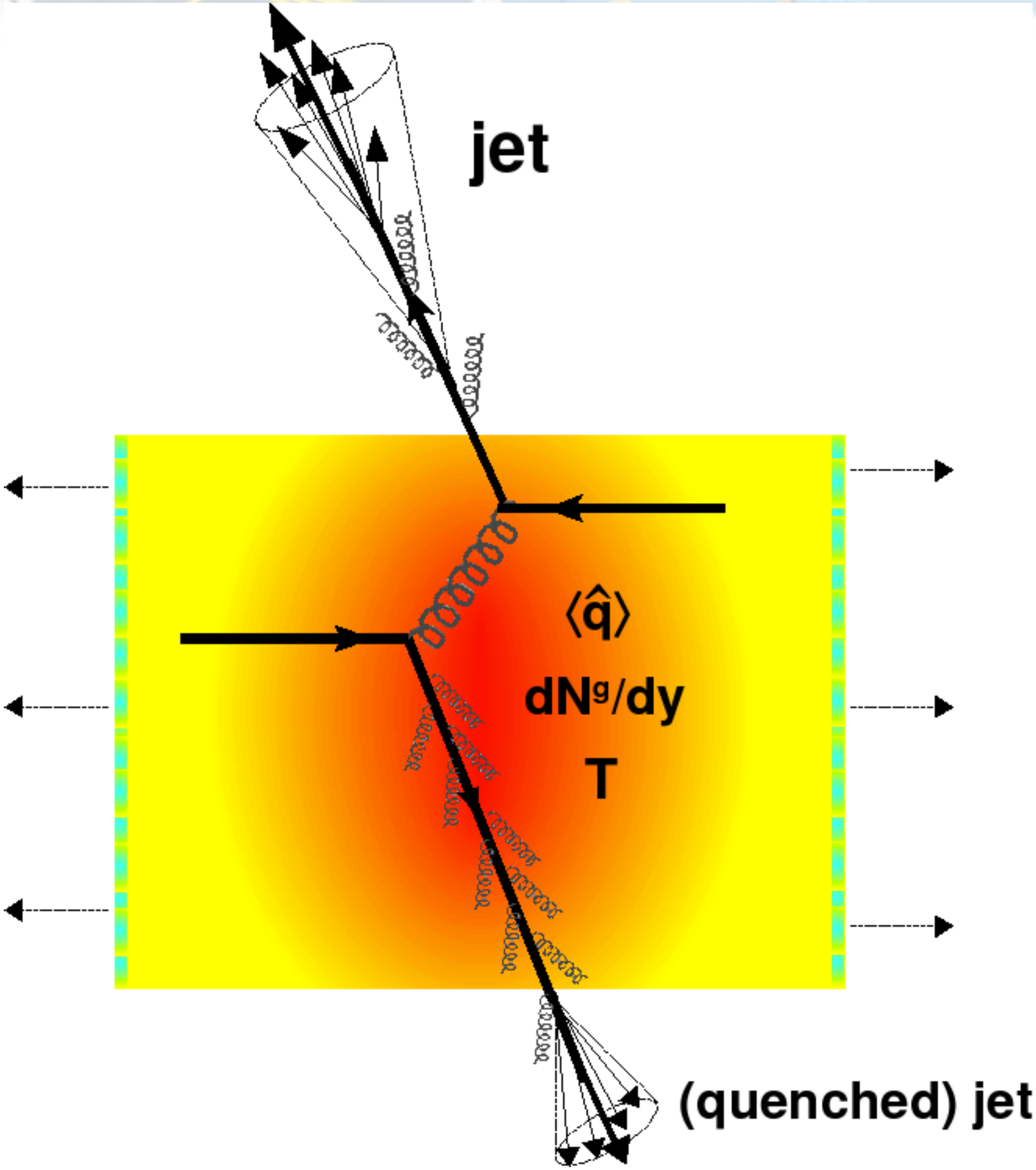




- v_3 is not related to reaction plane
- v_3 only weakly depends on centrality
- v_2 and v_3 magnitudes reasonably well described by hydro
- the azimuthal correlations at high p_T (sometimes interpreted as Mach cone) are fully described by the flow coefficients $v_2 \ldots v_5$

the peaks come from hydrodynamic flow

hard probes of QCD matter



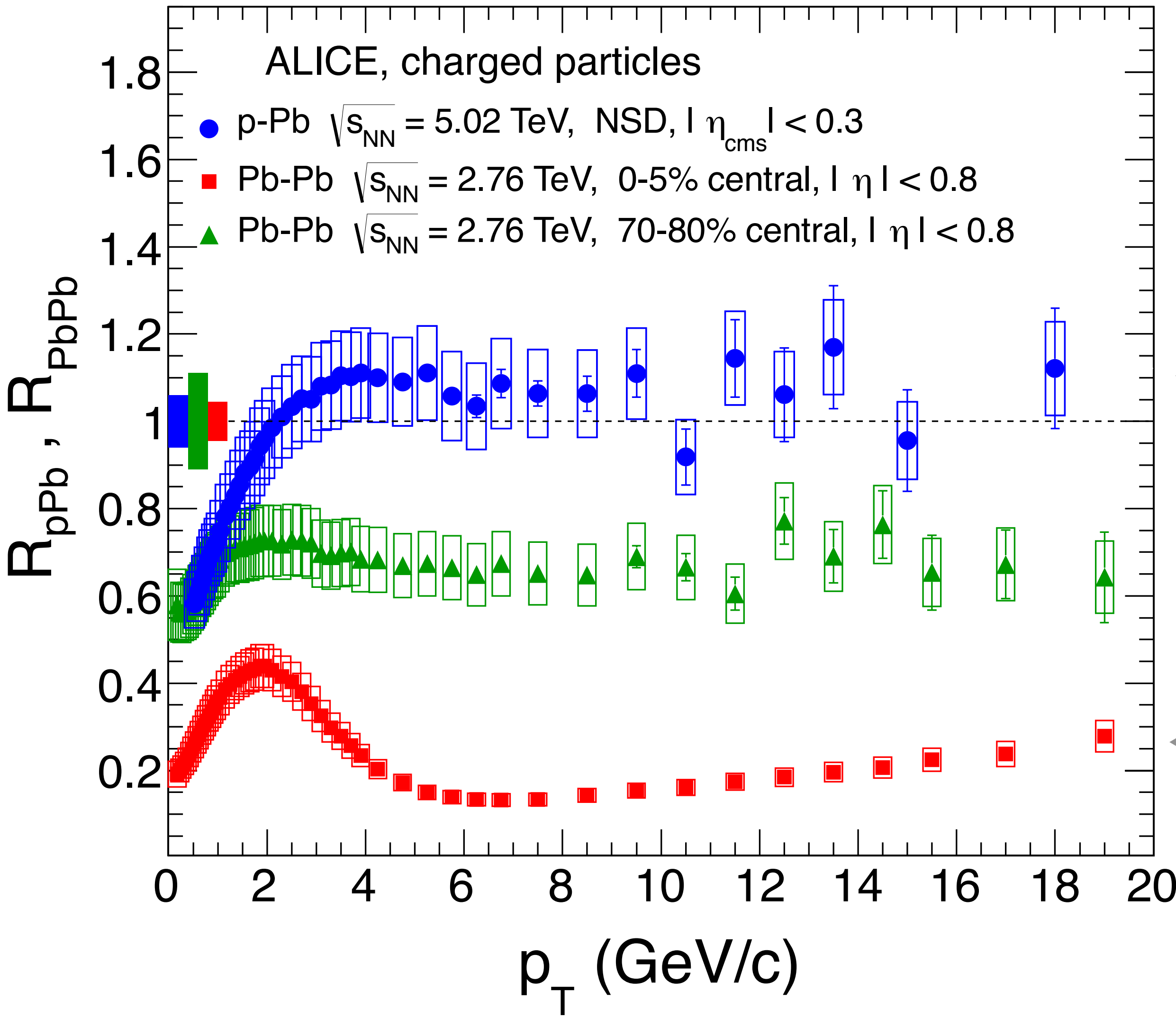
parton energy loss in QCD medium

manifesting as

suppression of high-p_T particles in Pb-Pb

nuclear modification factor for charged particles

PRL 110 (2013) 082302



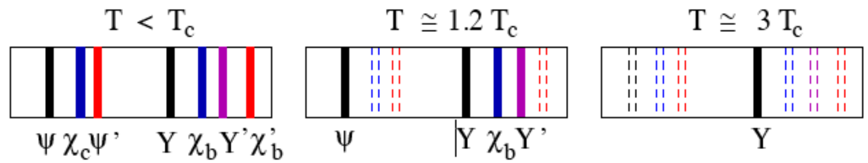
$$R_{AA}(p_T) = \frac{d^2N_{ch}^{AA}/d\eta\, dp_T}{\langle T_{AA}\rangle d^2\sigma_{ch}^{pp}/d\eta\, dp_T}$$

p-Pb is like pp
no suppression

suppression in central Pb-Pb
Parton energy loss in QCD medium
Rise at high p_T: relative energy loss decreasing with p_T

J/ψ suppression – or enhancement?

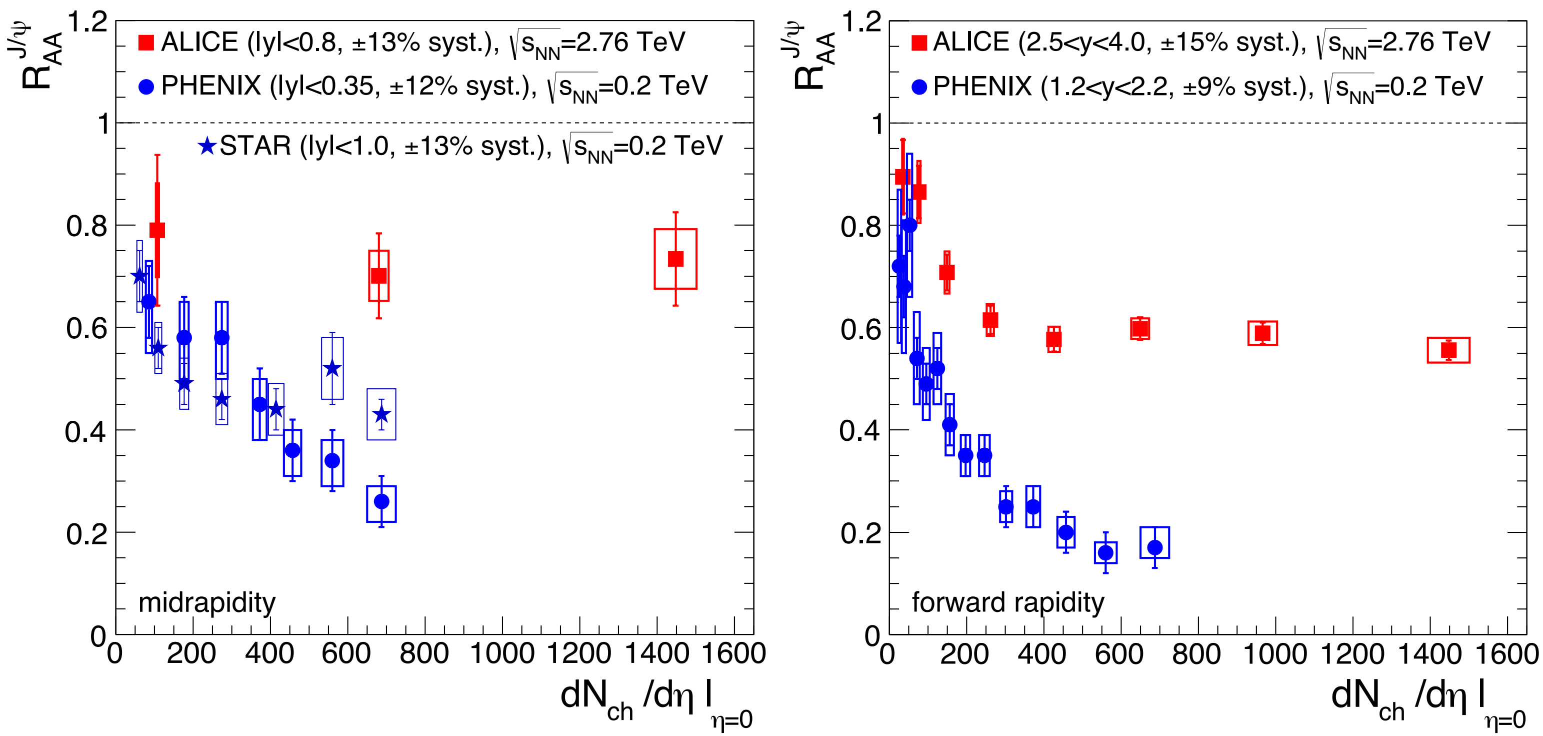
sequential suppression



PLB 178 (1986) 416

statistical hadronization $c + \overline{c} \rightarrow J/\psi$ PLB 490 (2000) 196

both effects expected to be stronger at LHC than at RHIC



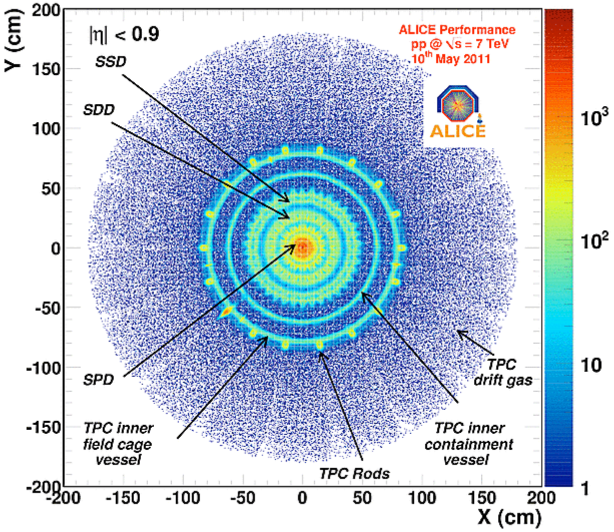
A. Andronic
NPA 931(2014)135
arxiv:1409.5778

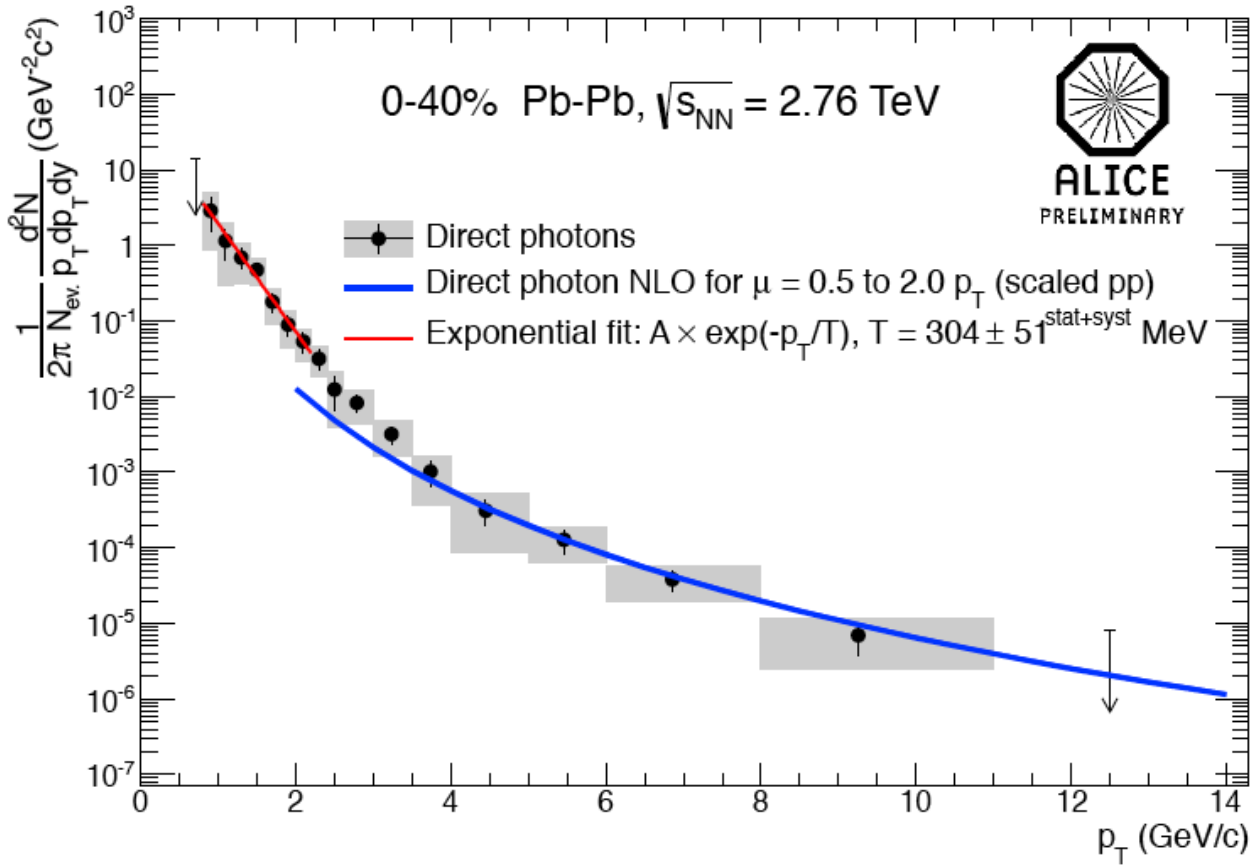
ALICE data from
PLB 743(2014)314

J/ψ enhanced in central collisions → production by statistical hadronization

hot photons

photons measured via
conversions into e+e-





photon temperature higher than T_c

However:
R. Rapp arxiv:1306.6394: most photons are emitted around the phase transition and are subject to blueshift by radial flow…

matter?
QCD matter?

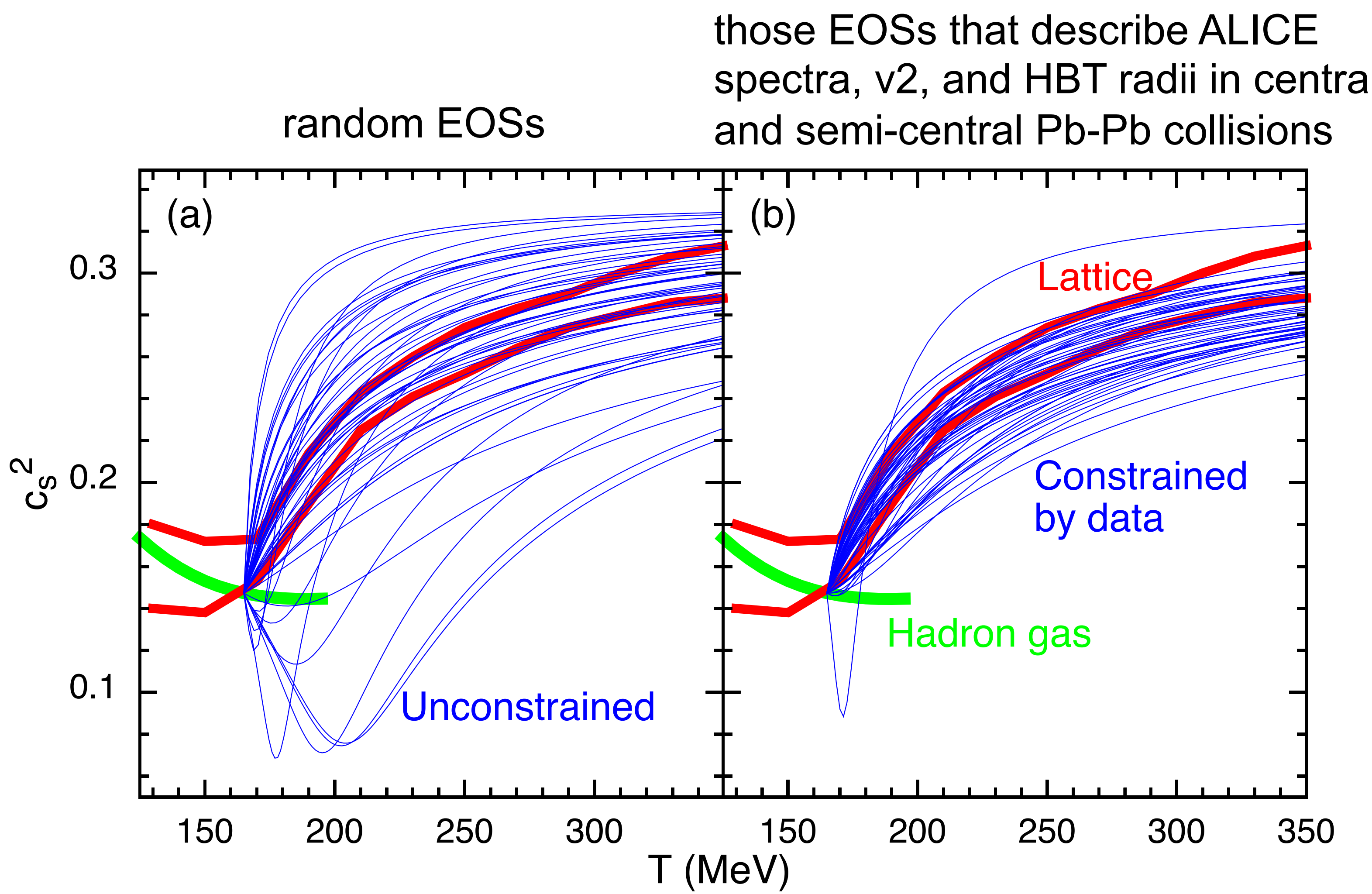
central Pb-Pb collisions: can we talk about QCD "matter"?

"Three questions to LHC" H. Satz, Nucl. Phys. A862-863 (2011) 4 When going from RHIC to LHC, do we see…	**ALICE results 2009-2013**
Increase of source volume?	Yes, by a factor of 2
Increase of photon spectral temperature?	Yes, from 221(27) to 304(51) MeV (But: blueshift?)
J/ψ production: sequential suppression or statistical regeneration?	Visible contribution of (re)generation

Yes, we can!

Equation of State of quark-gluon plasma

Pratt et al., arxiv:1501.04042



soft-physics observables from ALICE are consistent with the lattice EOS

collectivity in pp and p-Pb collisions?

definition

collectivity ⇔ mean velocity depends on position

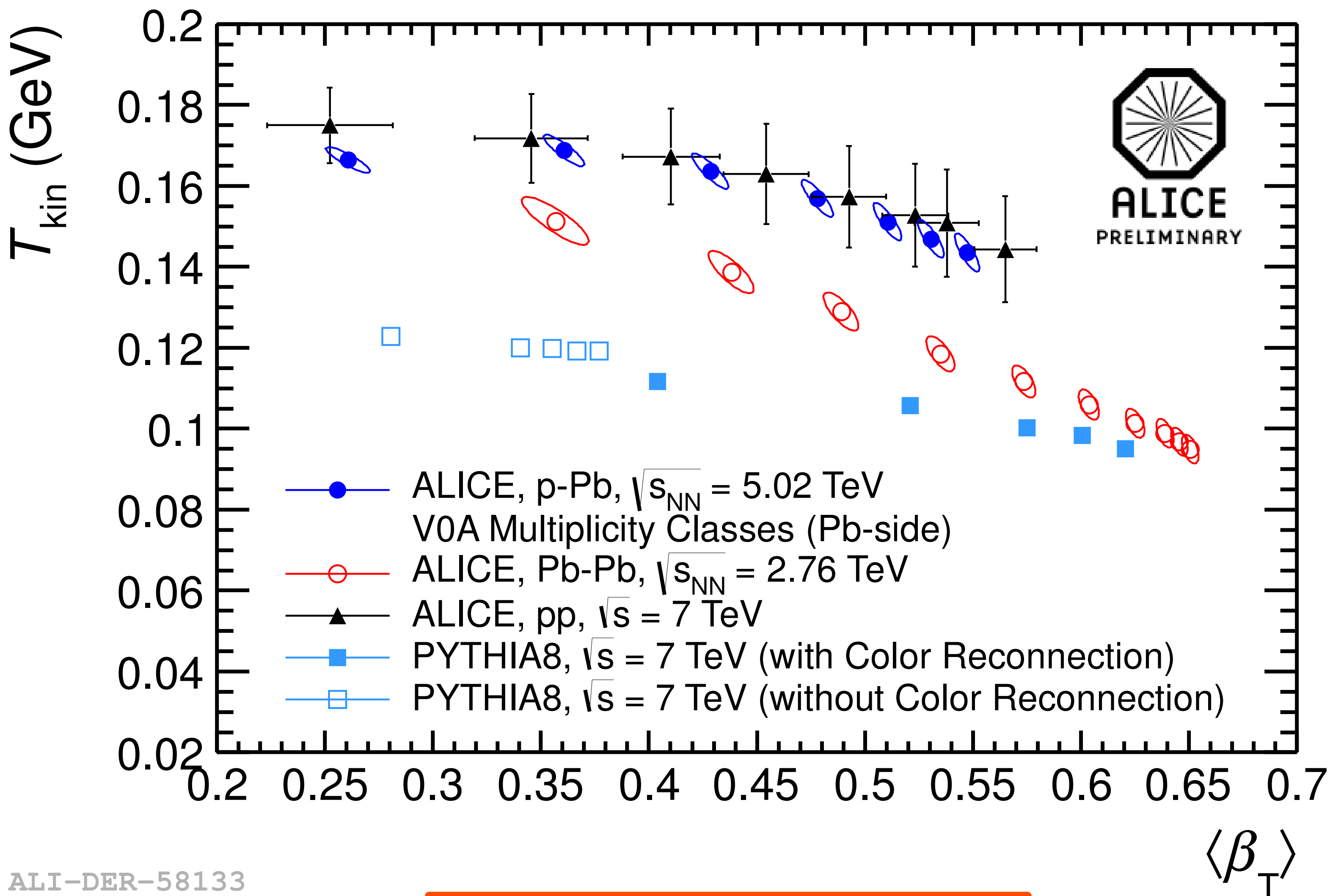
experimental manifestation of collectivity in Pb-Pb

transverse flow via p_T spectra

flow via particle correlations

p_T dependence of HBT radii

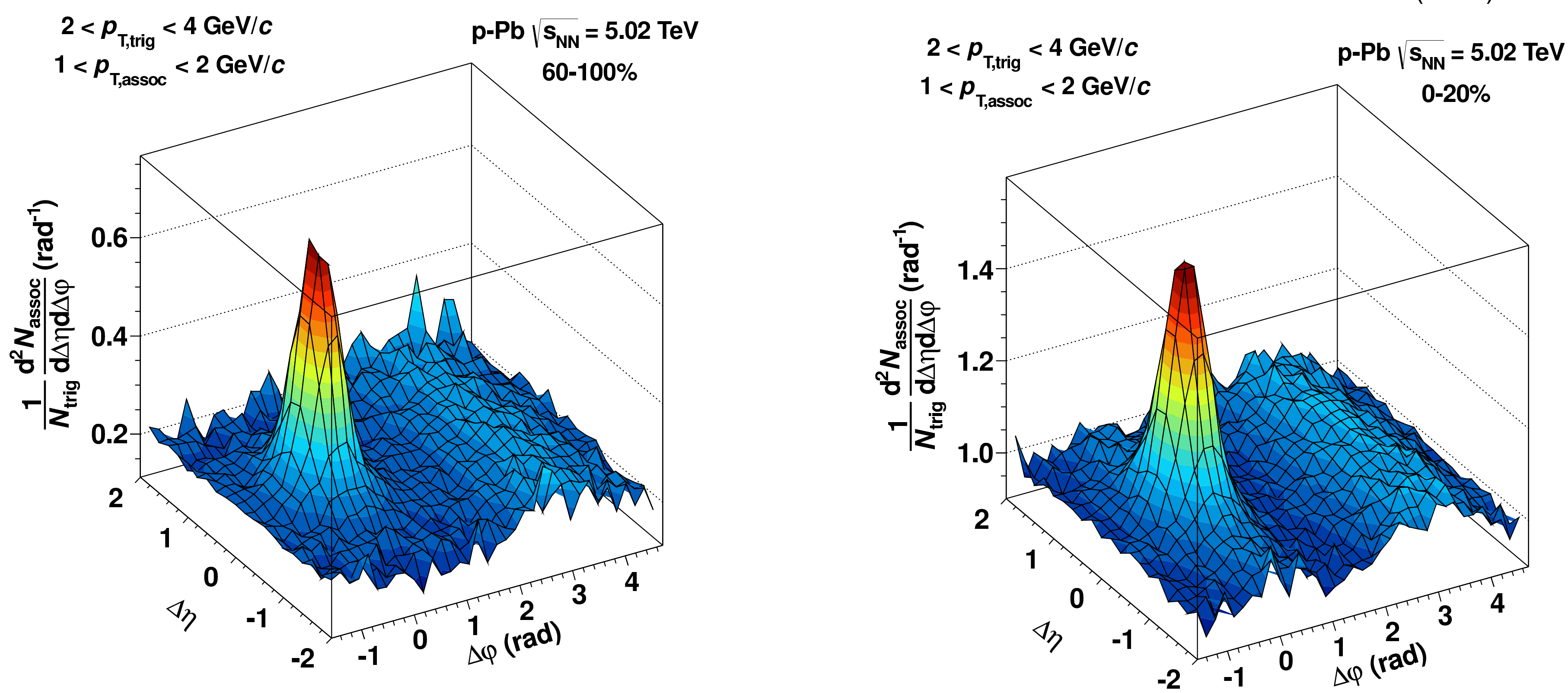
Blast-wave fit to pT spectra of pions, kaons, protons, lambda



transverse flow in pp and p-Pb?

p-Pb collisions: correlations originating from jets and other sources

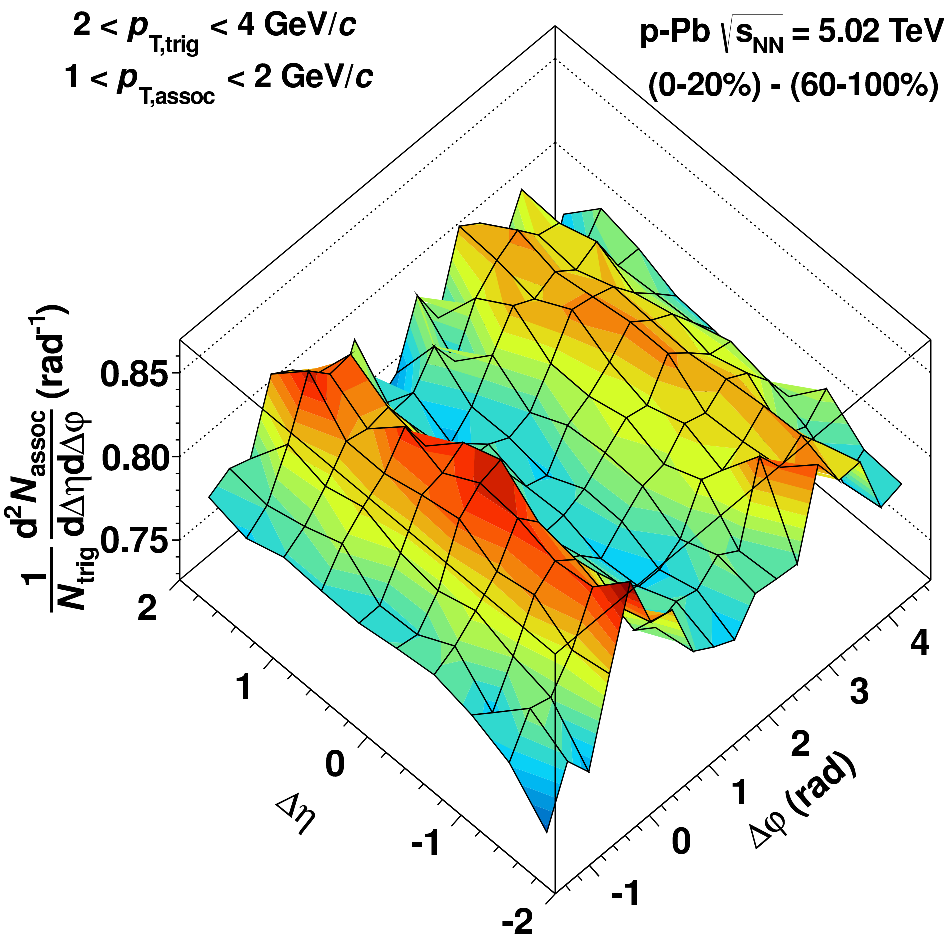
PLB 719 (2013) 29



in high-multiplicity p-Pb, a near-side ridge develops (like the one reported by CMS)

difference between central and peripheral

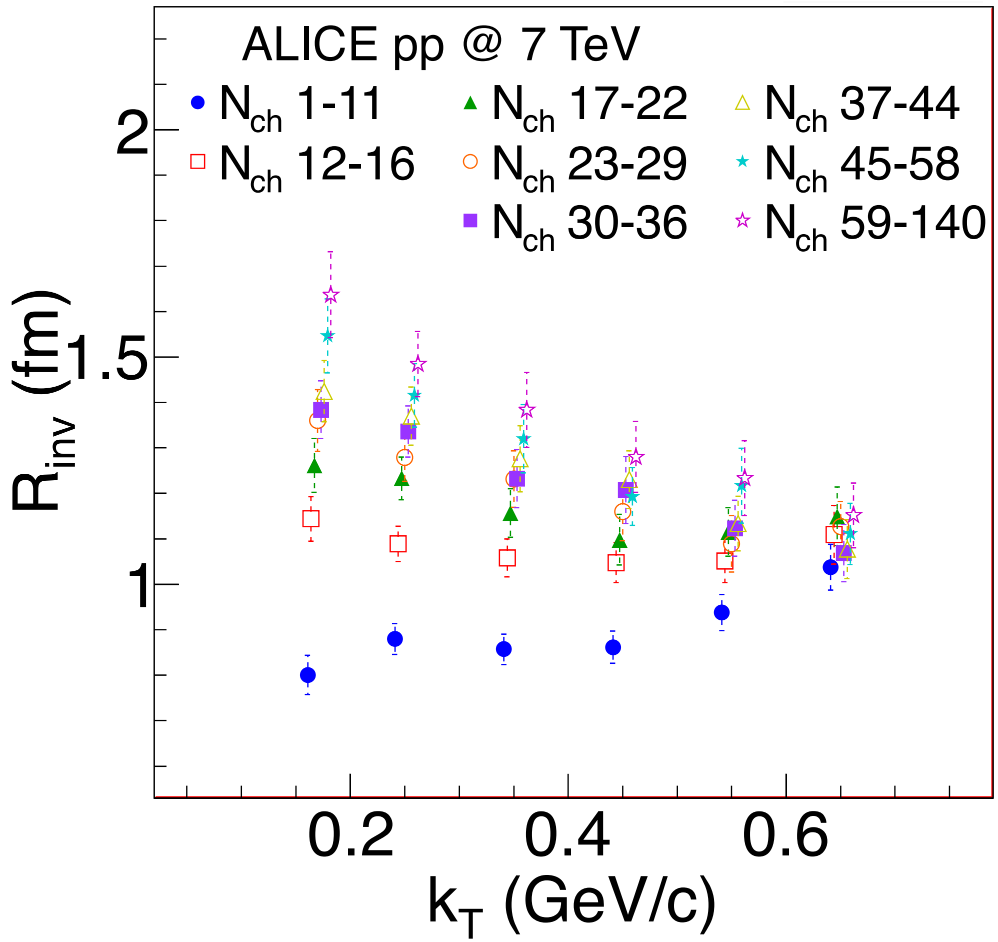
PLB 719 (2013) 29



near-side ridge arising in high-multiplicity collisions is accompanied by a similar ridge on the away side → elliptic flow?

dependence of HBT radii on transverse momentum in high-multiplicity pp collisions

PRD 84 (2011) 112004



indication of collectivity in violent pp collisions

summary

summary

new insight into the reaction dynamics from LHC

- proton puzzle: lower yield, lower v_2 than expected
- flow rather than Mach cone
- nuclear suppression decreasing at very high p_T (R_{AA} increasing)
- J/ψ production via statistical regeneration
- indications of collectivity in high-multiplicity pp and p-Pb collisions

~2 x higher than at RHIC

- particle production
- homogeneity volume

~10-30% higher than at RHIC

- transverse flow
- mean transverse momentum
- integrated elliptic flow
- mass-splitting of v_2

like at RHIC

- centrality dependence of particle production
- centrality dependence of v_2
- multiplicity dependence of HBT radii
- transverse momentum dependence of v_2
- charge and p_T fluctuations
- charge dependent azimuthal correlations

thank you for your attention

Appendix: working in CERN environment

always wear safety equipment

stay concentrated

handle properly the Unexpected

…and outlook

ALICE outlook

- 2014 LS1: completion of TRD, PHOS, and DCAL; consolidation
- 2015
- 2016 } Run 2 (full energy)
- 2017
- 2018 LS2: ALICE upgrade
- 2019 LS2
- 2020
- 2021 } Run 3 (full luminosity)
- 2022
- 2023 LS3
- 2024 LS3
- 2025 LS3

detector objectives

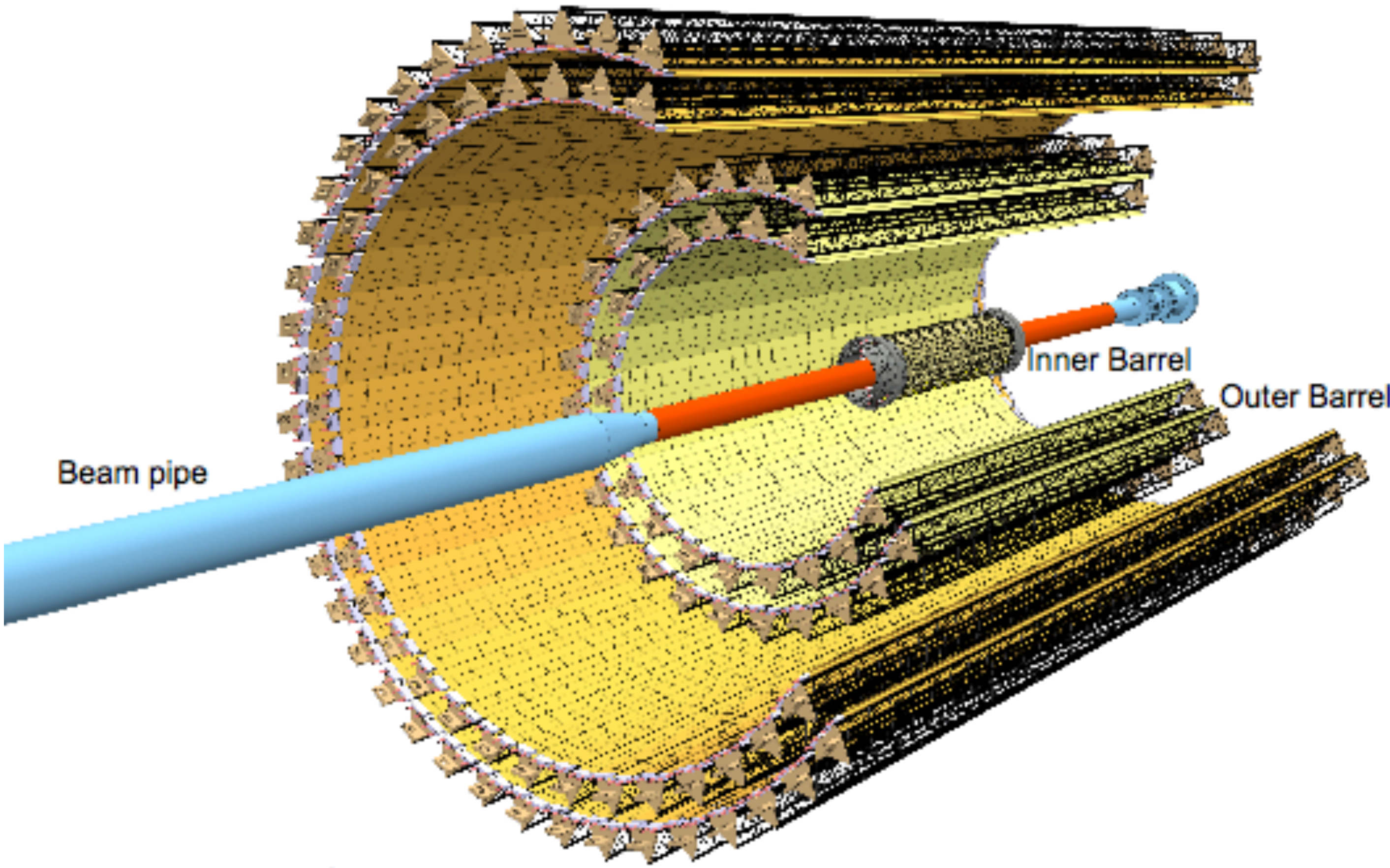
- cope with 50 kHz Pb-Pb
- inspect all collision events
- improve or preserve the resolution

physics objectives

- charm and beauty
- low-mass dileptons
- jets
- search for exotica

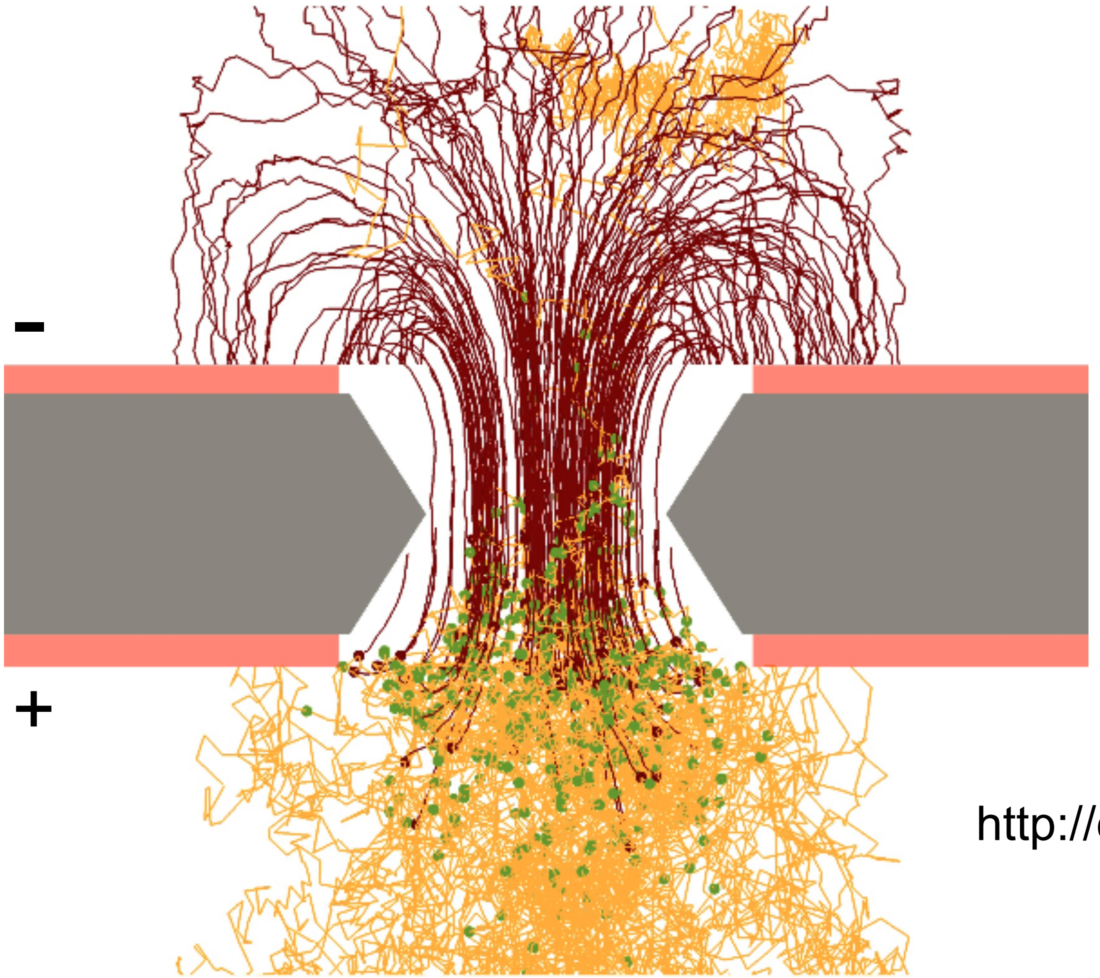
ALICE Upgrade Letter of Intent
http://cds.cern.ch/record/1475243

7 layers of pixel Si, reduced material, 3 x better resolution, lower momentum cutoff, topological trigger at L2 for charm and beauty, low-mass dielectrons



http://cds.cern.ch/record/1625842

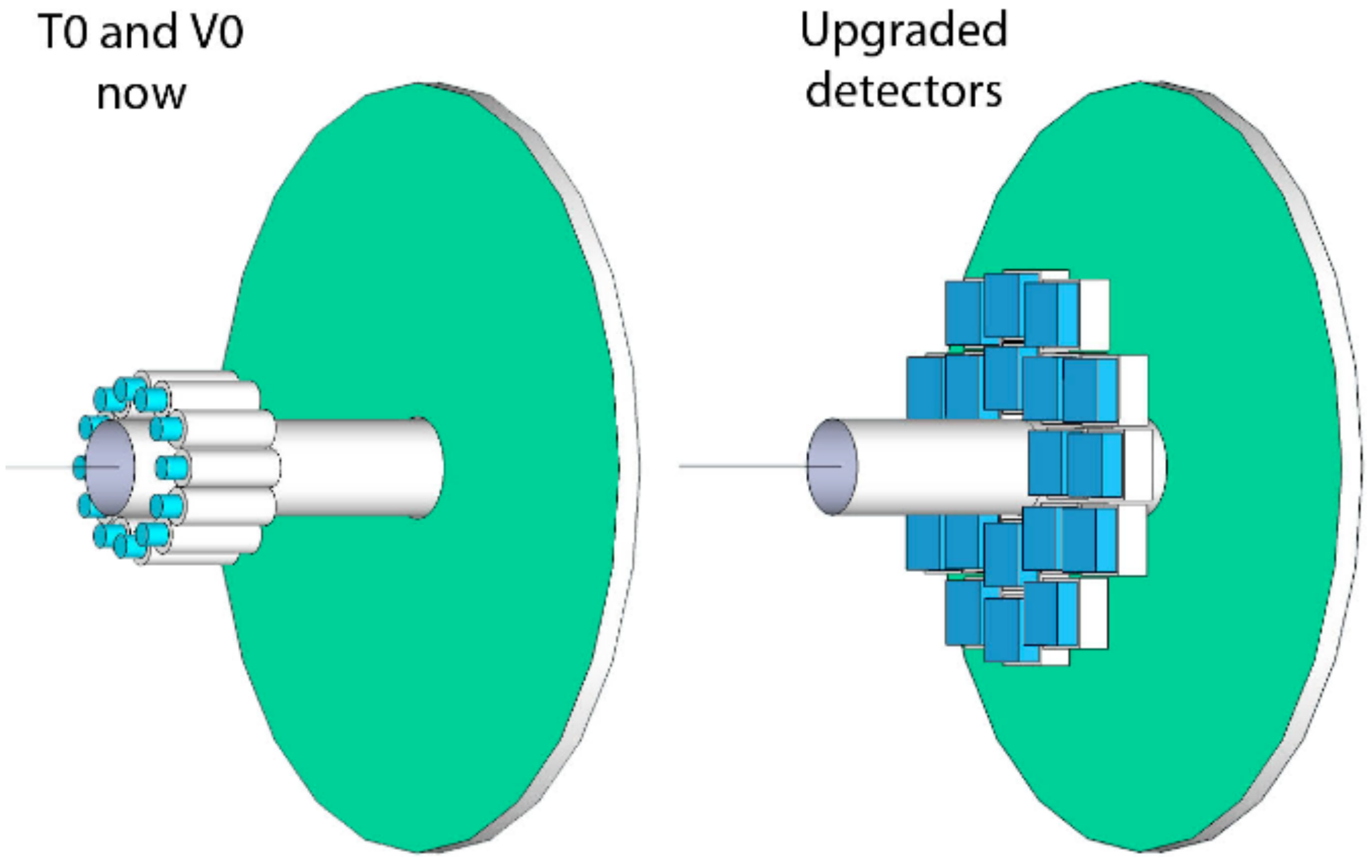
faster gas, 3-4 GEM foils instead of the gating grid (suppression of ion backflow by a factor of 100), faster and continuous readout for heavy flavors, low-mass dielectrons, jets, exotica



GEM foil simulation
50-70 μm holes

http://cds.cern.ch/record/1622286

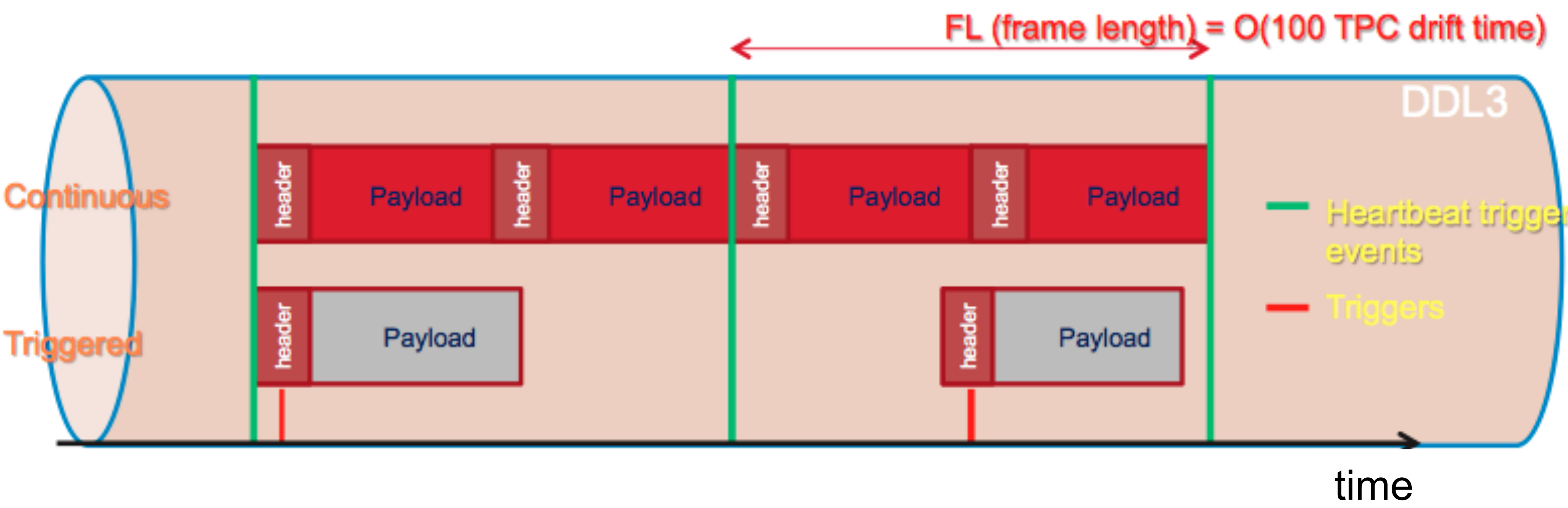
fast readout, replacing T0/V0/FMT with new detector FIT
for increased interaction and event rates



http://cds.cern.ch/record/1603472

new combined DAQ/HLT/offline system for high-rate and continuous readout; online processing and compression; for increased event rates

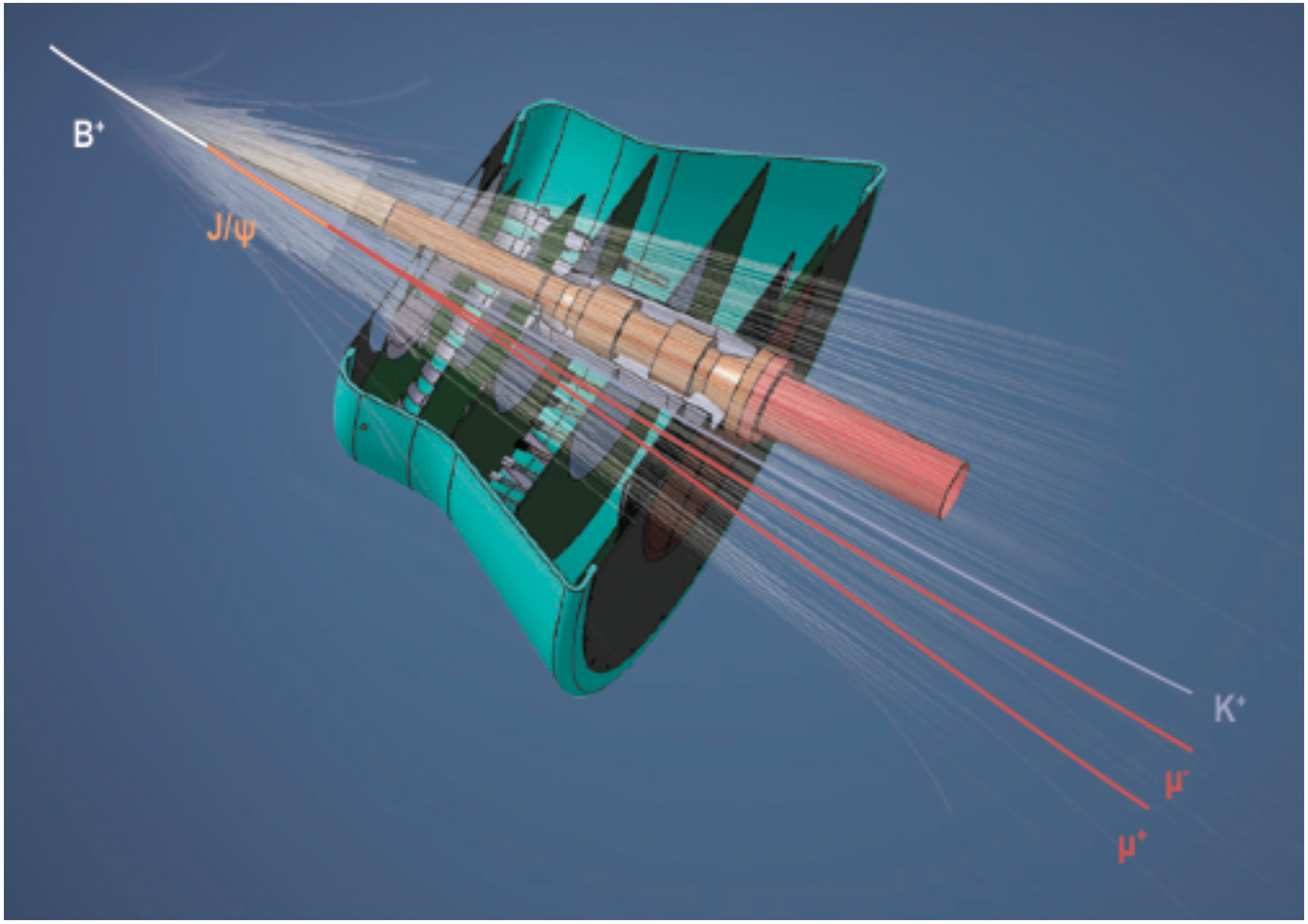
http://cds.cern.ch/record/1475243



Muon Forward Tracker (MFT) addition 2018

pixel Si, $-4<\eta<-2.5$ before the absorber, same technology as the upgraded ITS; improved momentum resolution, separation of prompt and secondary charmonia

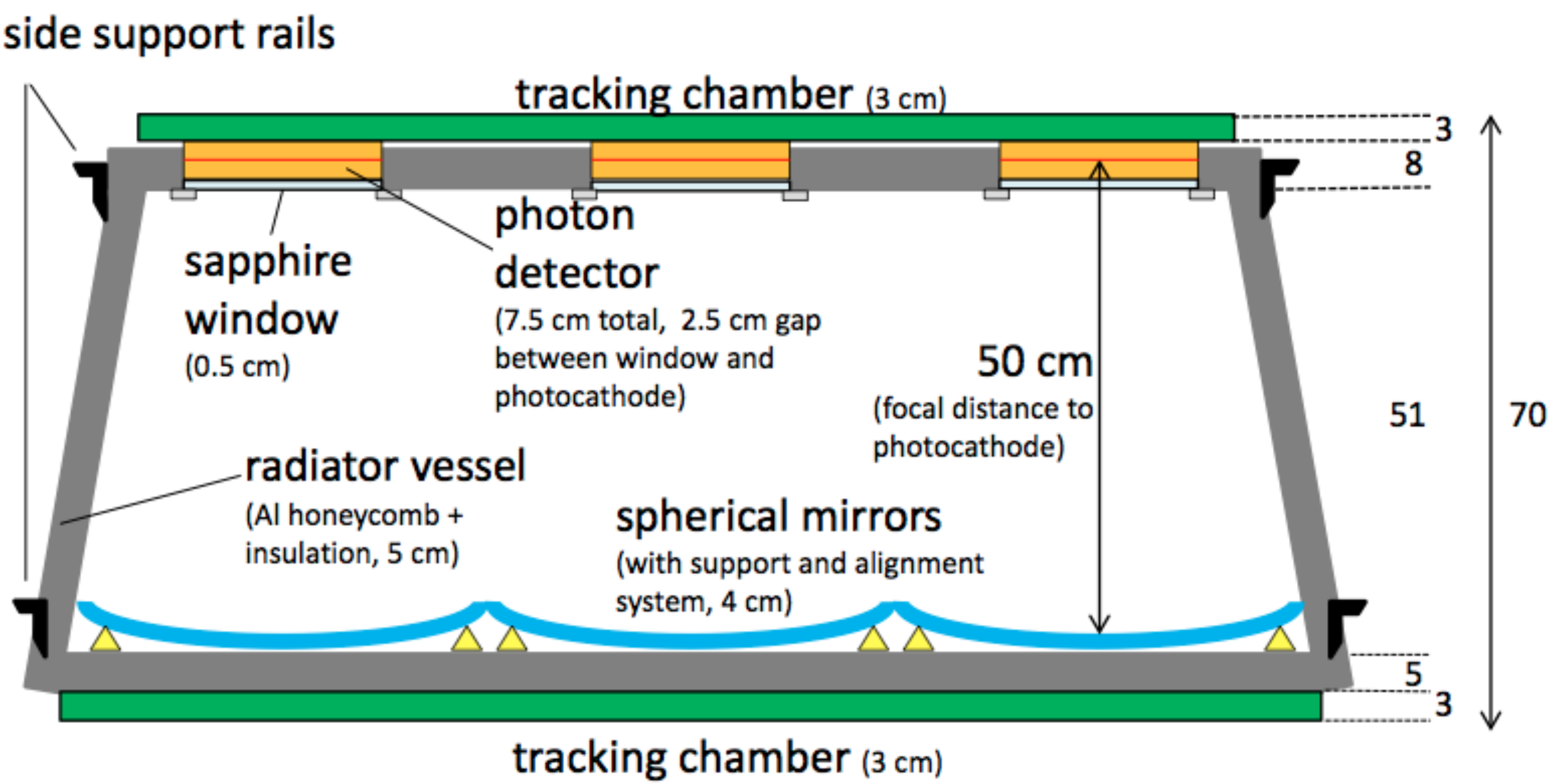
https://cds.cern.ch/record/1592659



Very High Momentum Particle Identification Detector (VHMPID) not scheduled

large-volume gas (3.5 atm, 46° C) Cherenkov detector between TOF and the calorimeters, π/K/p separation in 5<p<25 GeV/c for jet and fragmentation studies

arXiv:1309.5880

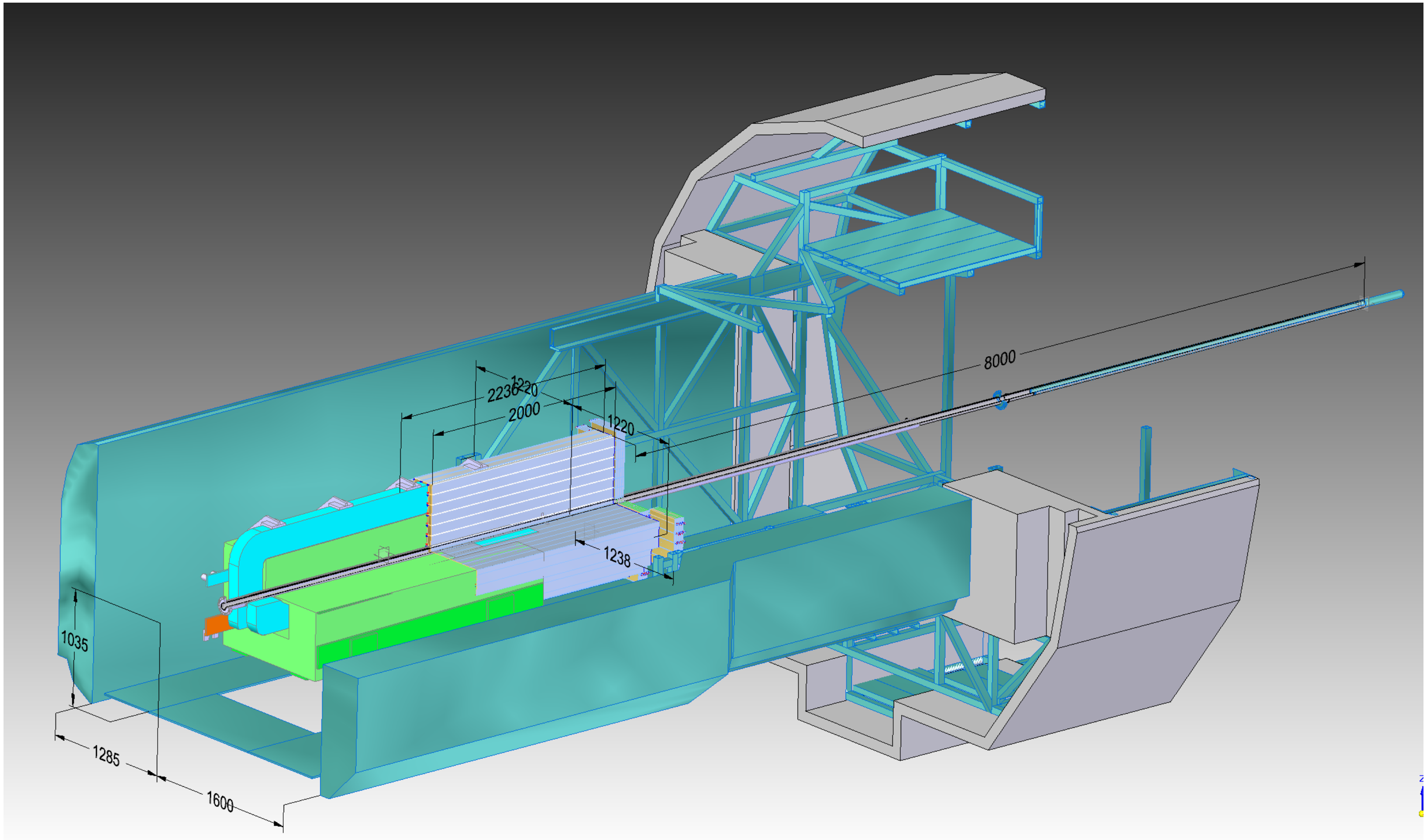


Forward Calorimeter (FoCal) possibly after Run 3

WSi (EM) + Pb-scint. (hadronic) calorimeter 2.5<η<4.5 or 3.3<η<5.3

for studies of initial-state effects

arXiv:1309.5880

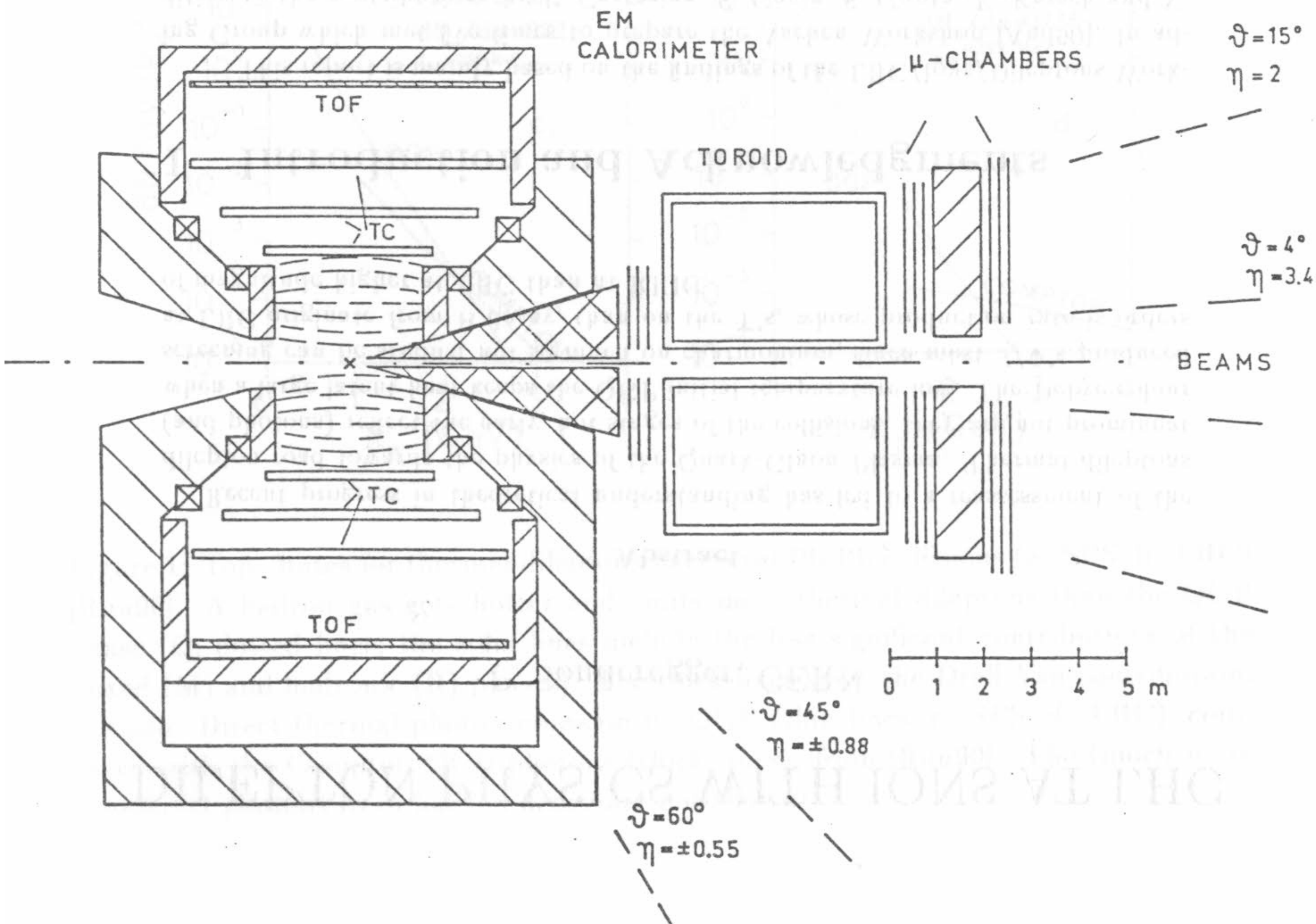


ALICE upgrades considered for the time after Run 2

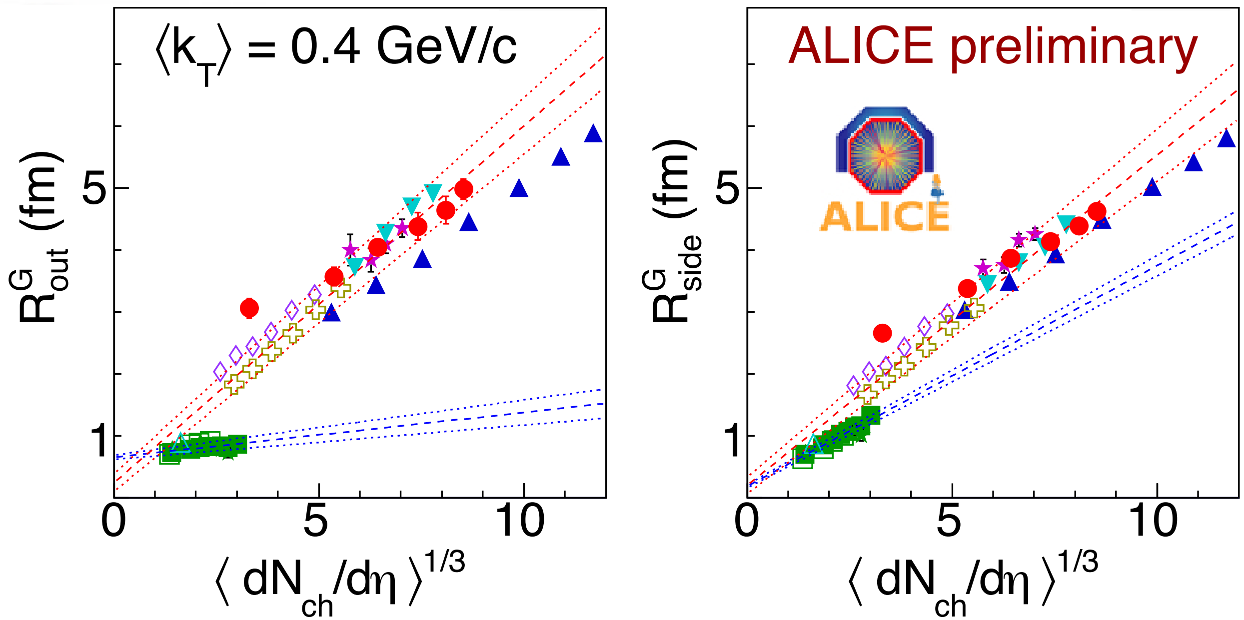
system	upgrade	scheduled installation
ITS	reduced material, improved resolution, topological trigger at L2	2018
TPC	faster gas, GEM readout, faster and continuous readout	2018
trigger/ readout	fast readout, replacing T0/V0/FMT with new detector FIT	2018
O^2	new combined DAQ/HLT/offline system for high-rate and continuous readout	2018
MFT	Muon Forward Tracker, pixel Si, $-4<\eta<-2.5$	2018
VHMPID	Very High Momentum PID, gas Cherenkov, π/K/p separation in $5<p<25$ GeV/c	not scheduled
FoCal	Forward Calorimeter, WSi+Pb-scint, photon/ electron/π^0/jet	after Run 3

backup

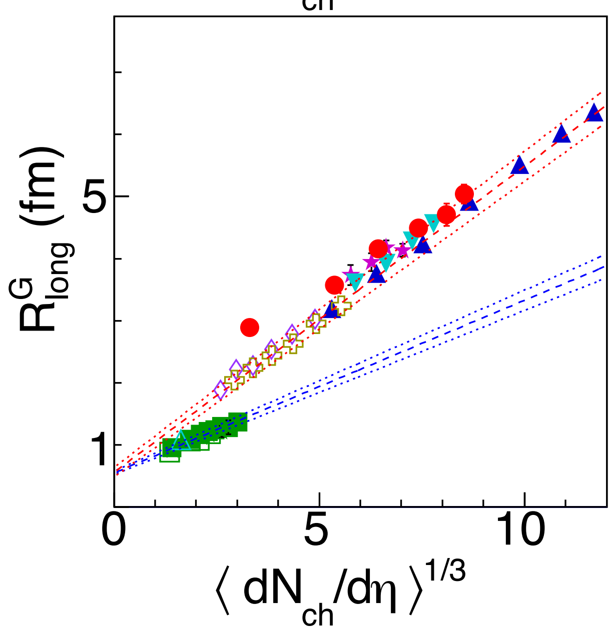
an early idea for ALICE, 1990



object of a similar age and shape



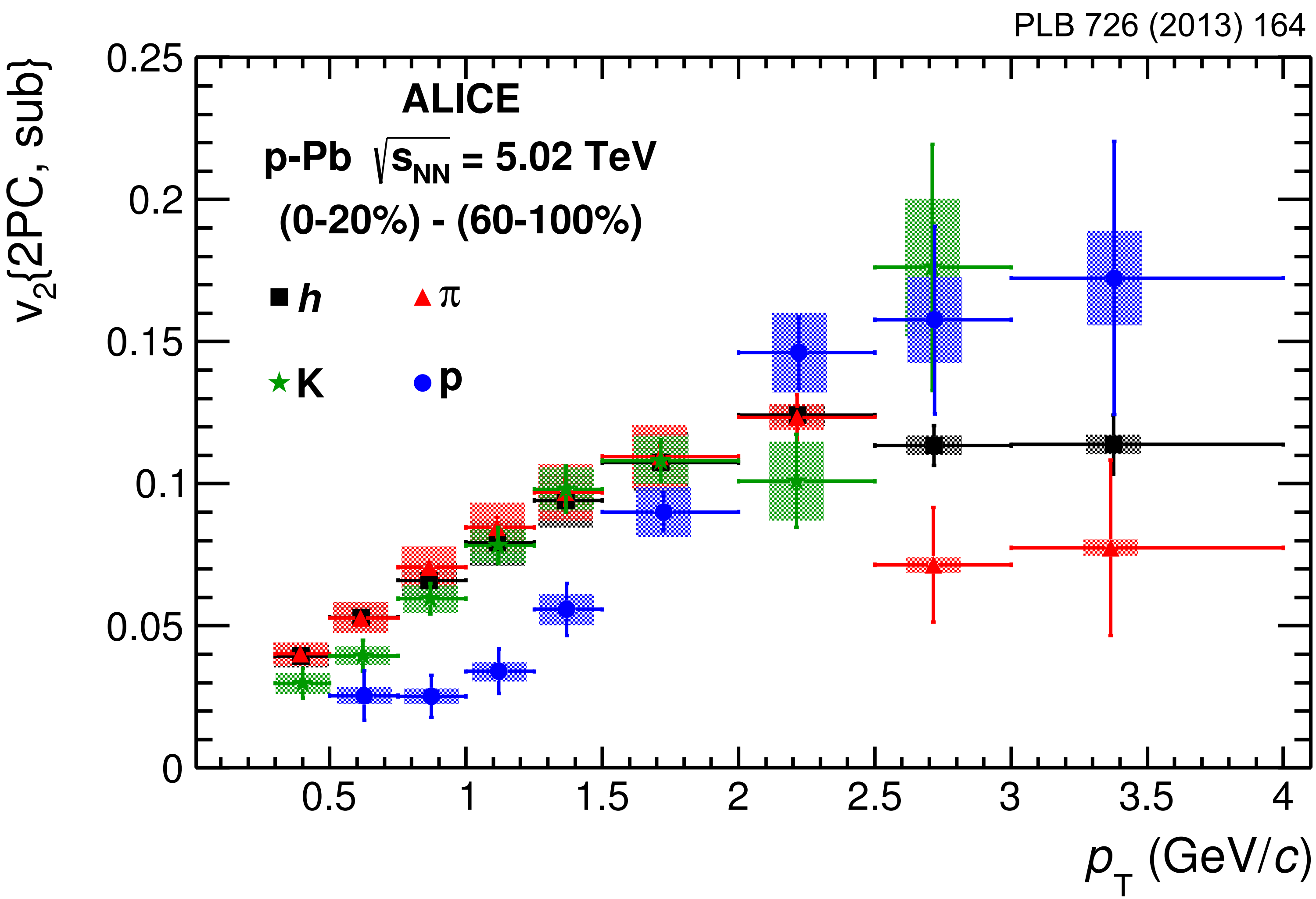
data published in
PRD 84 (2011) 112004



radii increase with multiplicity both in pp and Pb-Pb but with different slopes

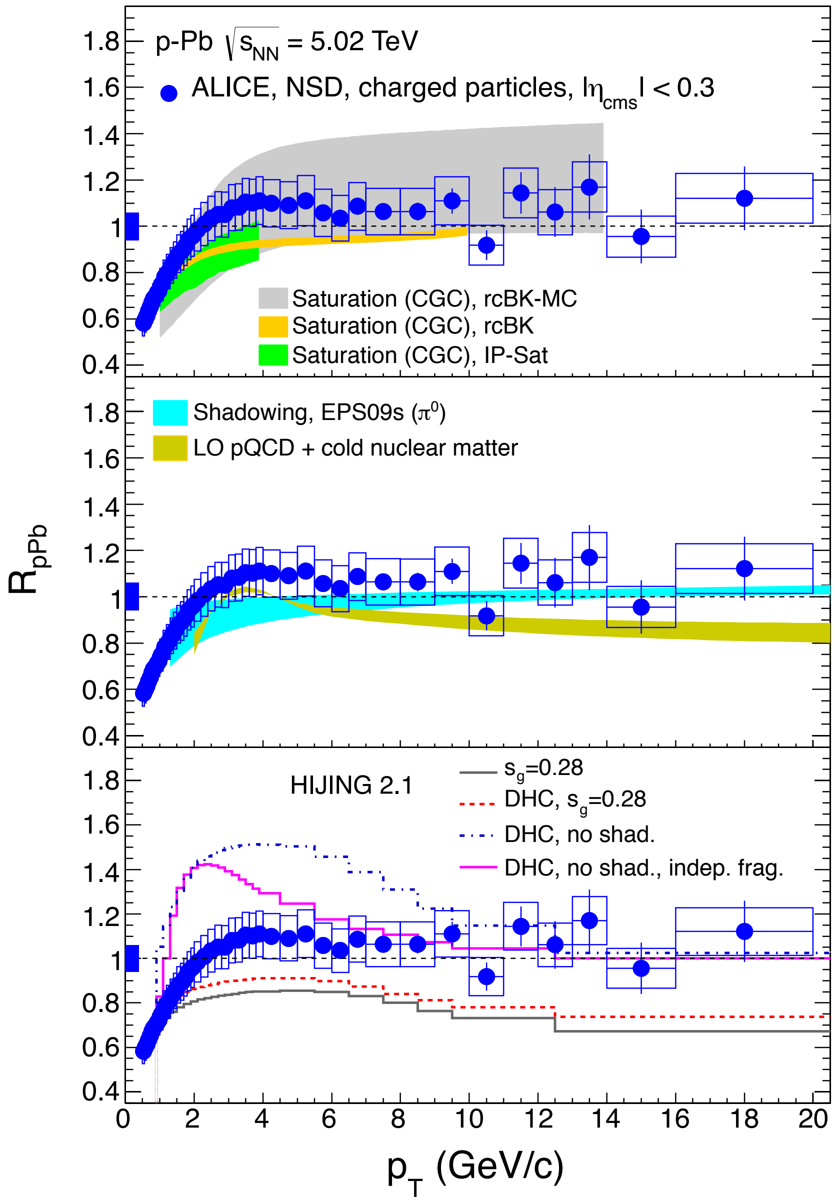
→ not only final multiplicity but also initial geometry matters

v2 of pions, kaons, protons in p-Pb collisions



mass splitting like in Pb-Pb → further support for the collective flow picture

nuclear modification factor in p-Pb – comparison to models

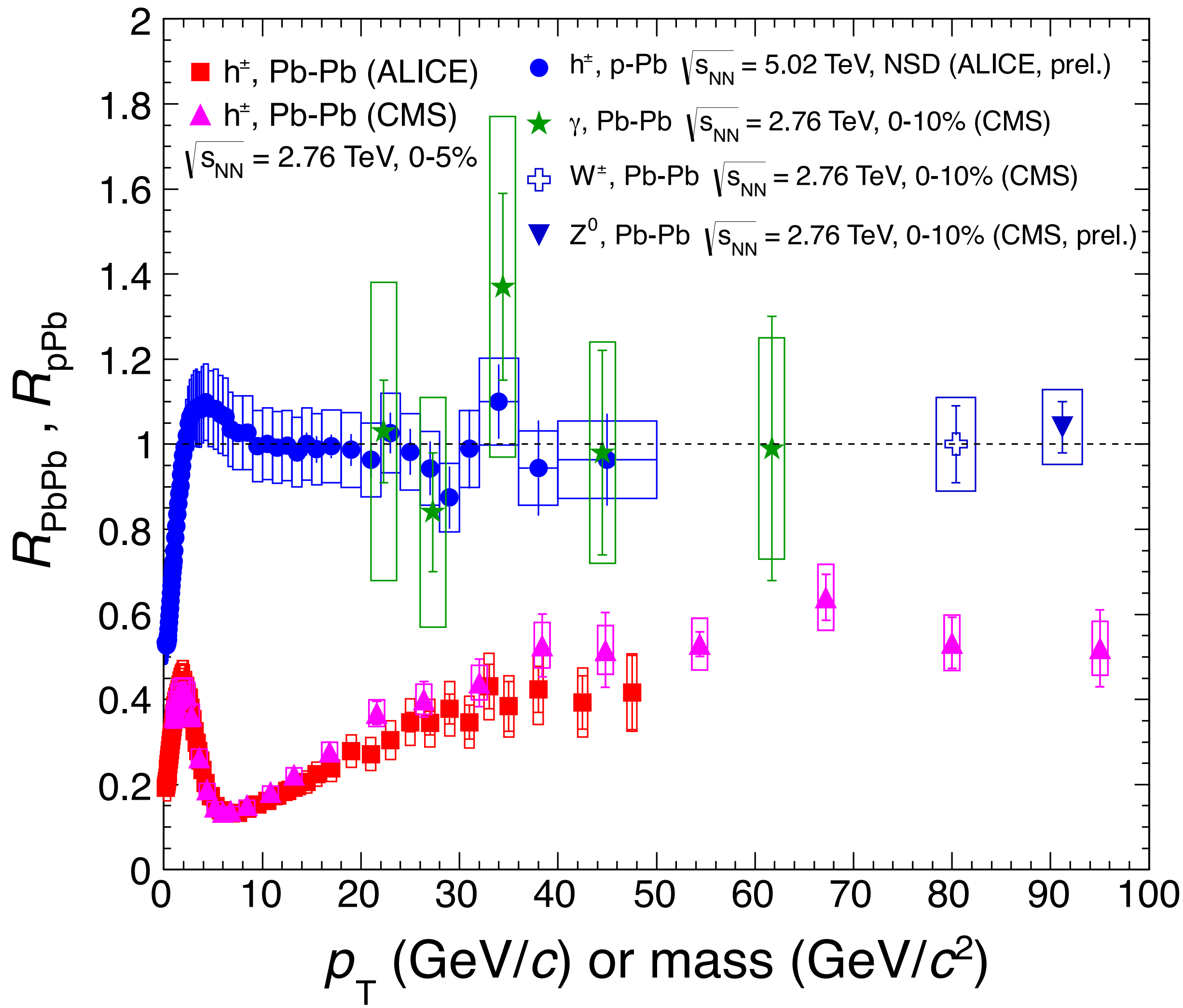


saturation models OK

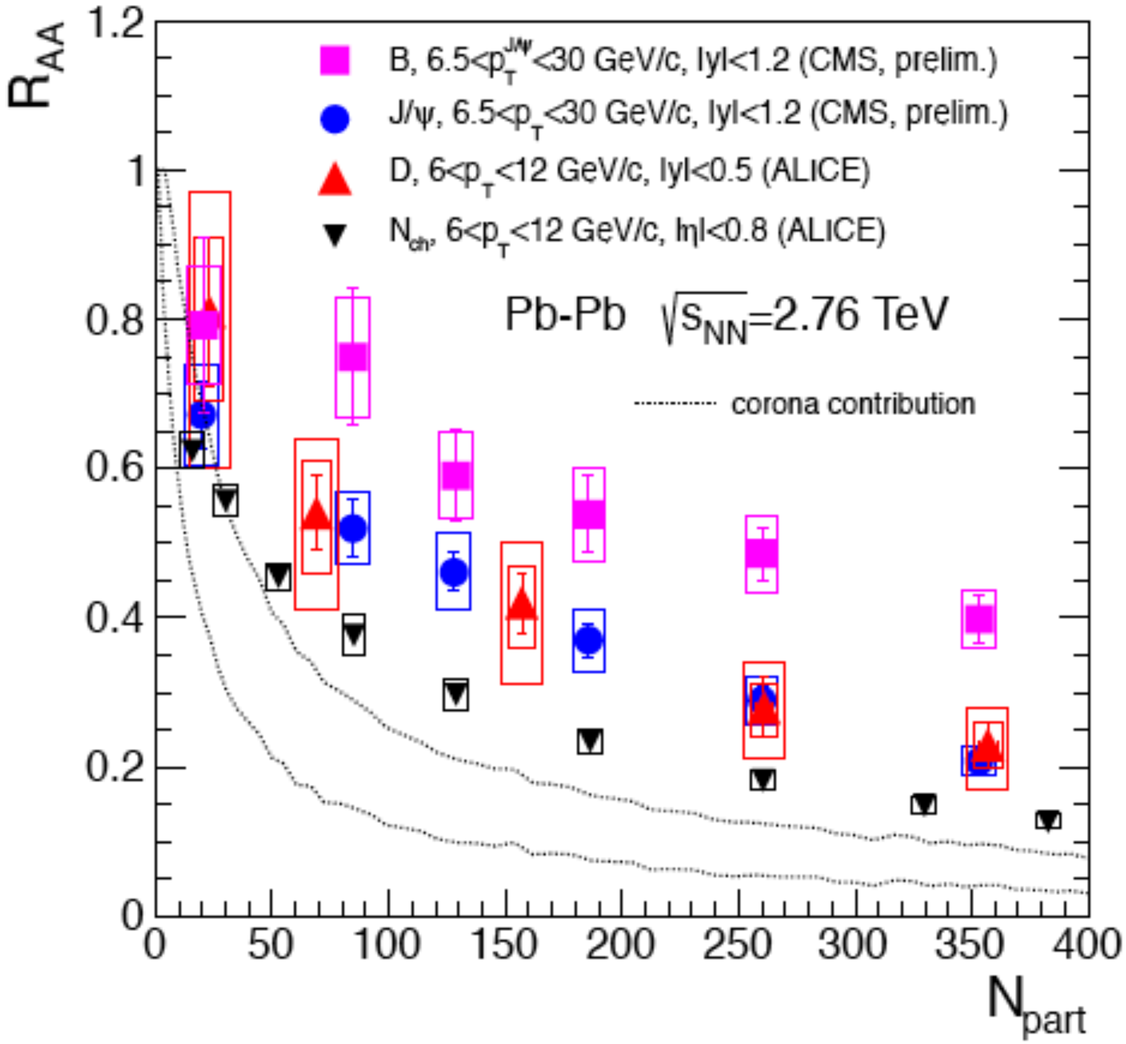
shadowing OK

Hijing, DPMJET – problems in describing the data

nuclear modification factor for gauge bosons



no suppression of photons, W, Z^0 in Pb-Pb



ALICE JHEP 09 (2012) 112

ALICE PLB 720 (2013) 52

CMS-PAS-HIN-12-014

compilation A. Andronic

← b quarks

← c quarks

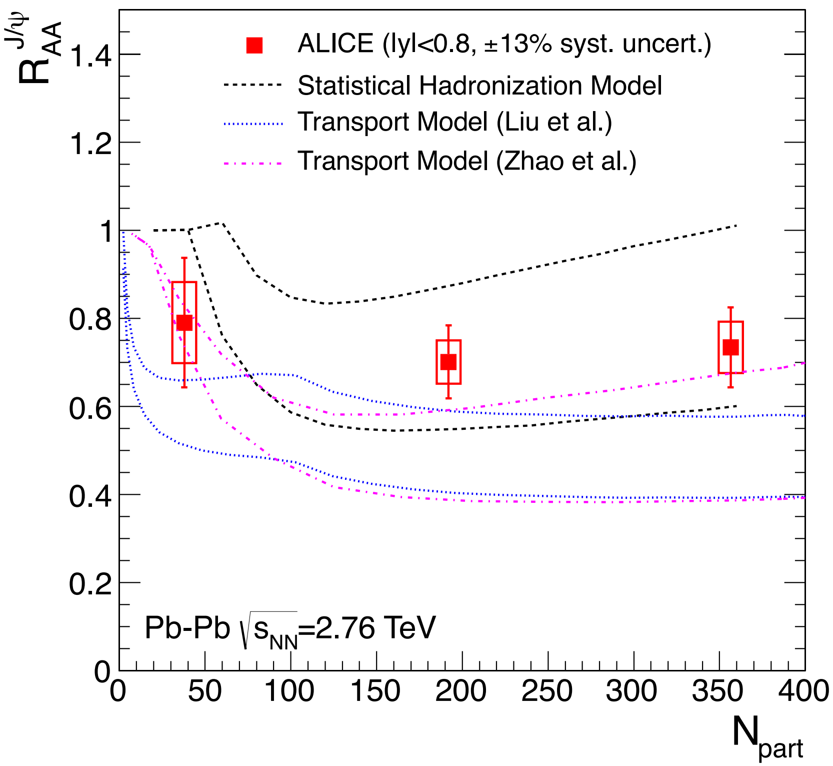
← light quarks and gluons

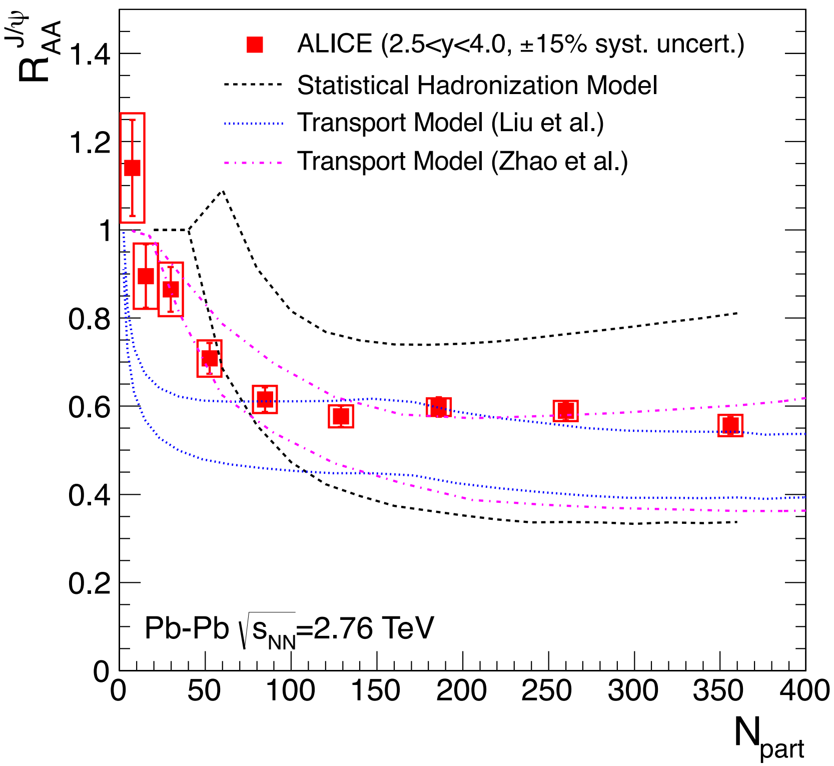
less suppression for heavy quarks

B < D, J/ψ < charged particles

nuclear modification factor for J/ψ prediction from models which include (re)generation

statistical hadronization	PLB 490 (2000) 196
transport model (Liu et al.)	PLB 678 (2009) 72
transport model (Zhao and Rapp)	NuPhA 859 (2011) 114

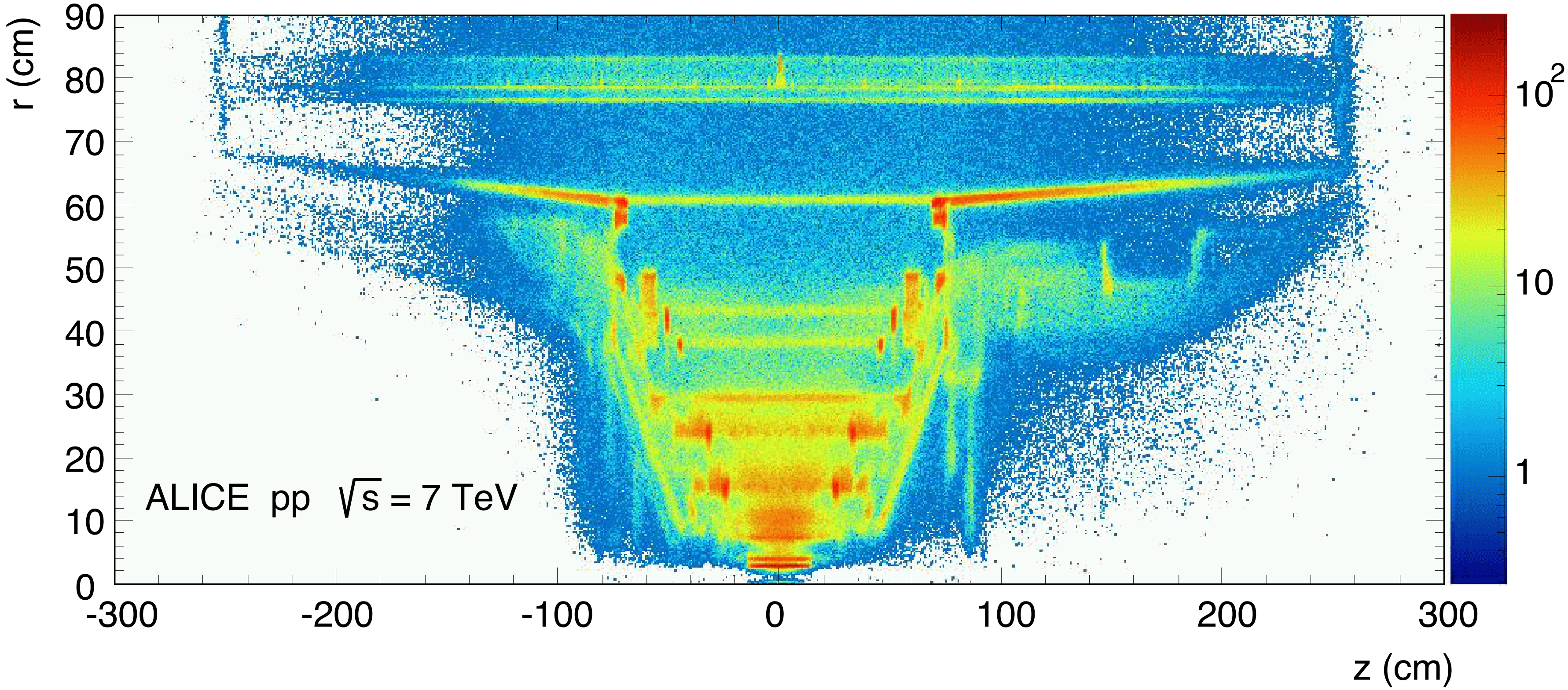




detector	acceptance polar	acceptance azimuthal	position	technology	main purpose
SPD*	$\|\eta\| < 2.0$	full	$r = 3.9$ cm	Si pixel	tracking, vertex
	$\|\eta\| < 1.4$	full	$r = 7.6$ cm	Si pixel	tracking, vertex
SDD	$\|\eta\| < 0.9$	full	$r = 15.0$ cm	Si drift	tracking, $\mathrm{d}E/\mathrm{d}x$
	$\|\eta\| < 0.9$	full	$r = 23.9$ cm	Si drift	tracking, $\mathrm{d}E/\mathrm{d}x$
SSD	$\|\eta\| < 1.0$	full	$r = 38.0$ cm	Si strip	tracking, $\mathrm{d}E/\mathrm{d}x$
	$\|\eta\| < 1.0$	full	$r = 43.0$ cm	Si strip	tracking, $\mathrm{d}E/\mathrm{d}x$
TPC	$\|\eta\| < 0.9$	full	$85 < r/\mathrm{cm} < 247$	Ne drift	tracking, $\mathrm{d}E/\mathrm{d}x$
TRD*	$\|\eta\| < 0.8$	full	$290 < r/\mathrm{cm} < 368$	TR+Xe drift	tracking, $e^{\pm}$ id
TOF*	$\|\eta\| < 0.9$	full	$370 < r/\mathrm{cm} < 399$	MRPC	time of flight
PHOS*	$\|\eta\| < 0.12$	$220^\circ < \phi < 320^\circ$	$460 < r/\mathrm{cm} < 478$	$PbWO_4$	photons
EMCal*	$\|\eta\| < 0.7$	$80^\circ < \phi < 187^\circ$	$430 < r/\mathrm{cm} < 455$	Pb+scint.	photons and jets
HMPID	$\|\eta\| < 0.6$	$1^\circ < \phi < 59^\circ$	$r = 490$ cm	C_6F_{14} RICH	charged kaon id
ACORDE*	$\|\eta\| < 1.3$	$30^\circ < \phi < 150^\circ$	$r = 850$ cm	scint.	cosmics
PMD	$2.3 < \eta < 3.7$	full	$z = 364$ cm	Pb+PC	photons
FMD	$3.6 < \eta < 5.0$	full	$z = 320$ cm	Si strip	charged particles
	$1.7 < \eta < 3.7$	full	$z = 80$ cm	Si strip	charged particles
	$-3.4 < \eta < -1.7$	full	$z = -70$ cm	Si strip	charged particles
V0*	$2.8 < \eta < 5.1$	full	$z = 340$ cm	scint.	charged particles
	$-3.7 < \eta < -1.7$	full	$z = -90$ cm	scint.	charged particles
T0	$4.6 < \eta < 4.9$	full	$z = 375$ cm	quartz	time, vertex
	$-3.3 < \eta < -3.0$	full	$z = -73$ cm	quartz	time, vertex
ZDC*	$\|\eta\| > 8.8$	full	$z = \pm 116$ m	W+quartz	forward neutrons
	$6.5 < \|\eta\| < 7.5$	$\|\phi\| < 10^\circ$	$z = \pm 116$ m	brass+quartz	forward protons
	$4.8 < \eta < 5.7$	$\|2\phi\| < 32^\circ$	$z = 7.3$ m	Pb+quartz	photons
MCH	$-4.0 < \eta < -2.5$	full	$-14.2 < z/\mathrm{m} < -5.4$	MWPC	muon tracking
MTR*	$-4.0 < \eta < -2.5$	full	$-17.1 < z/\mathrm{m} < -16.1$	RPC	muon trigger

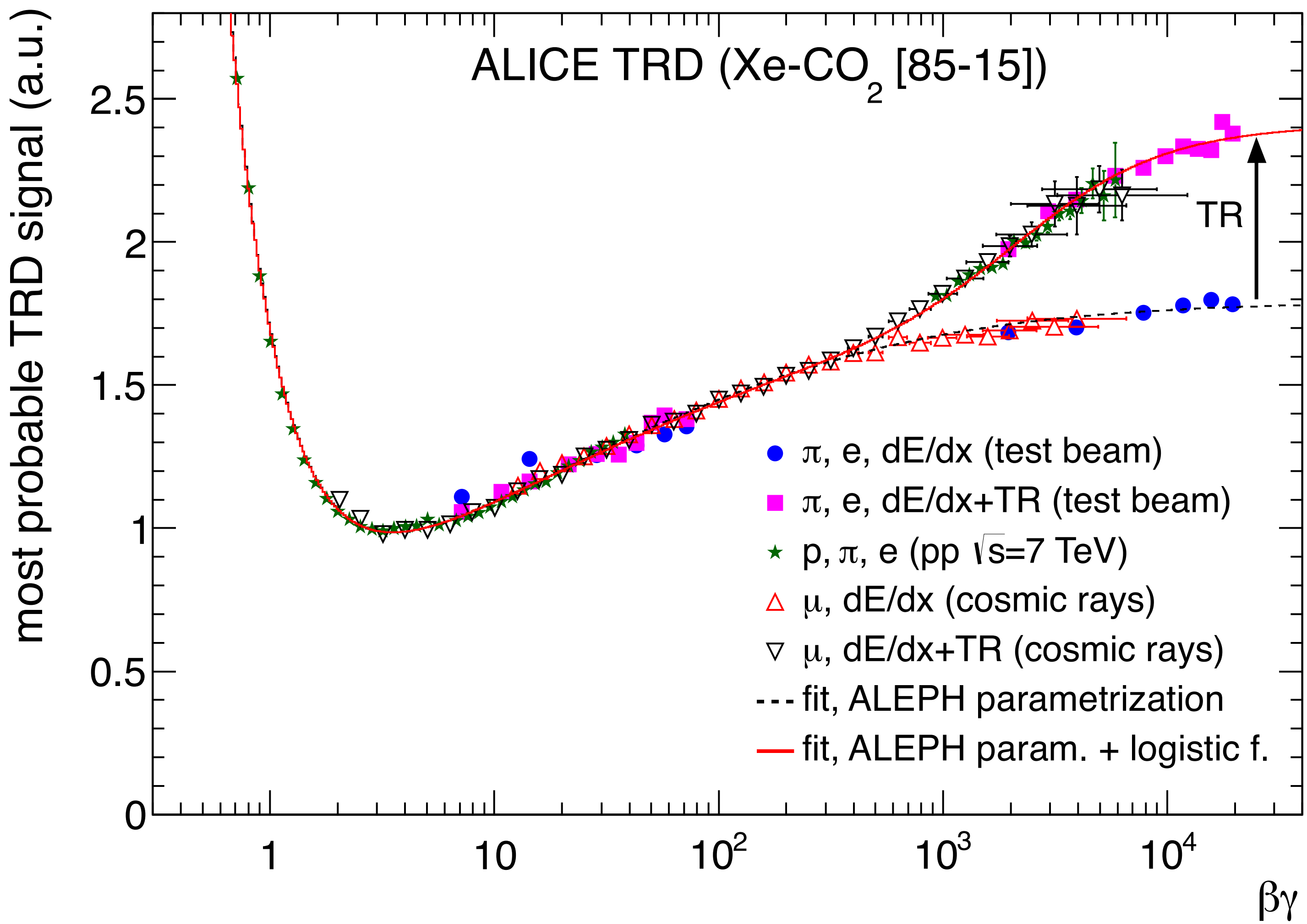
Verification of experiment's material

arxiv:1402.4476



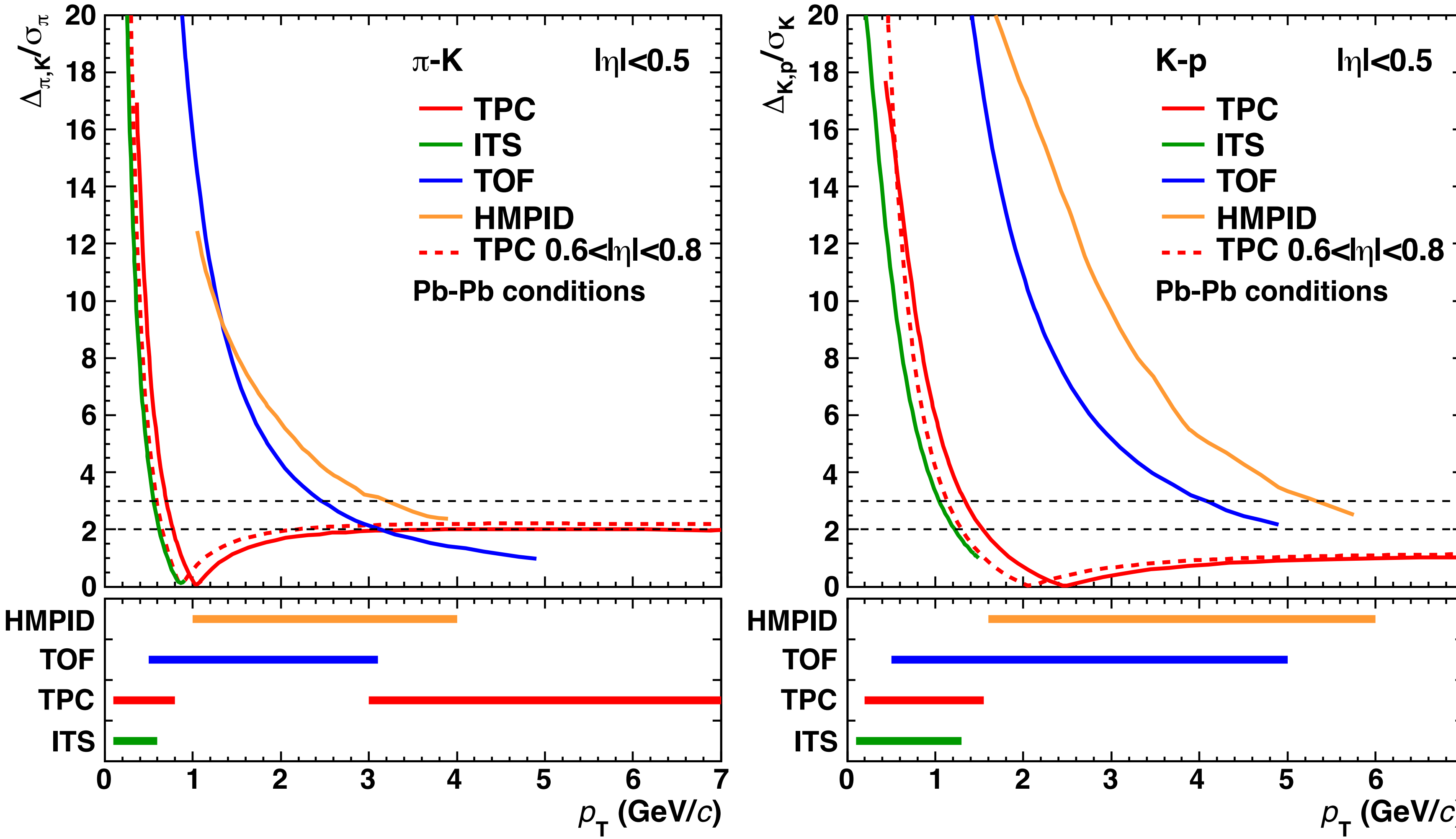
TRD performance

arxiv:1402.4476



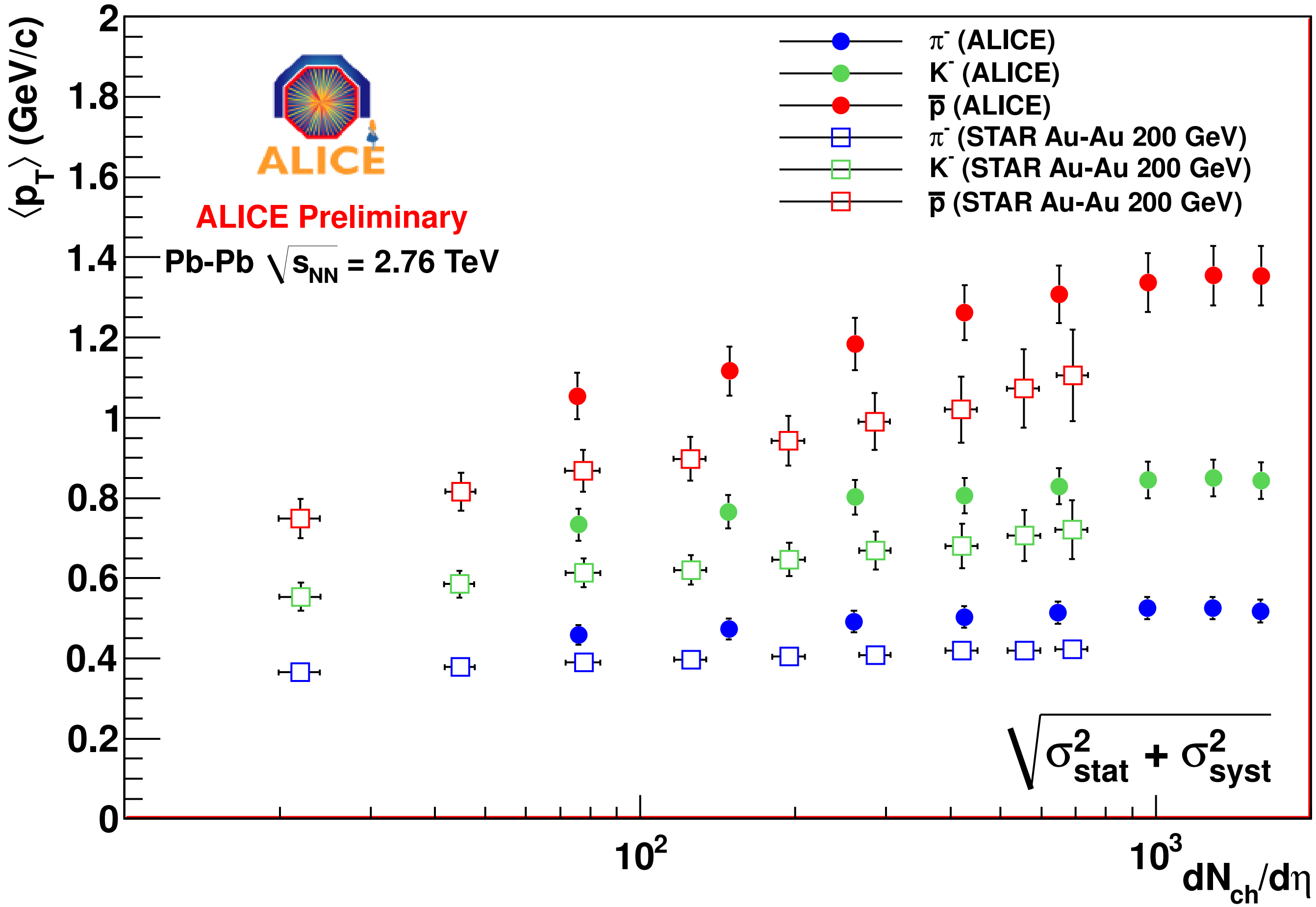
Combined particle-identification power

arxiv:1402.4476



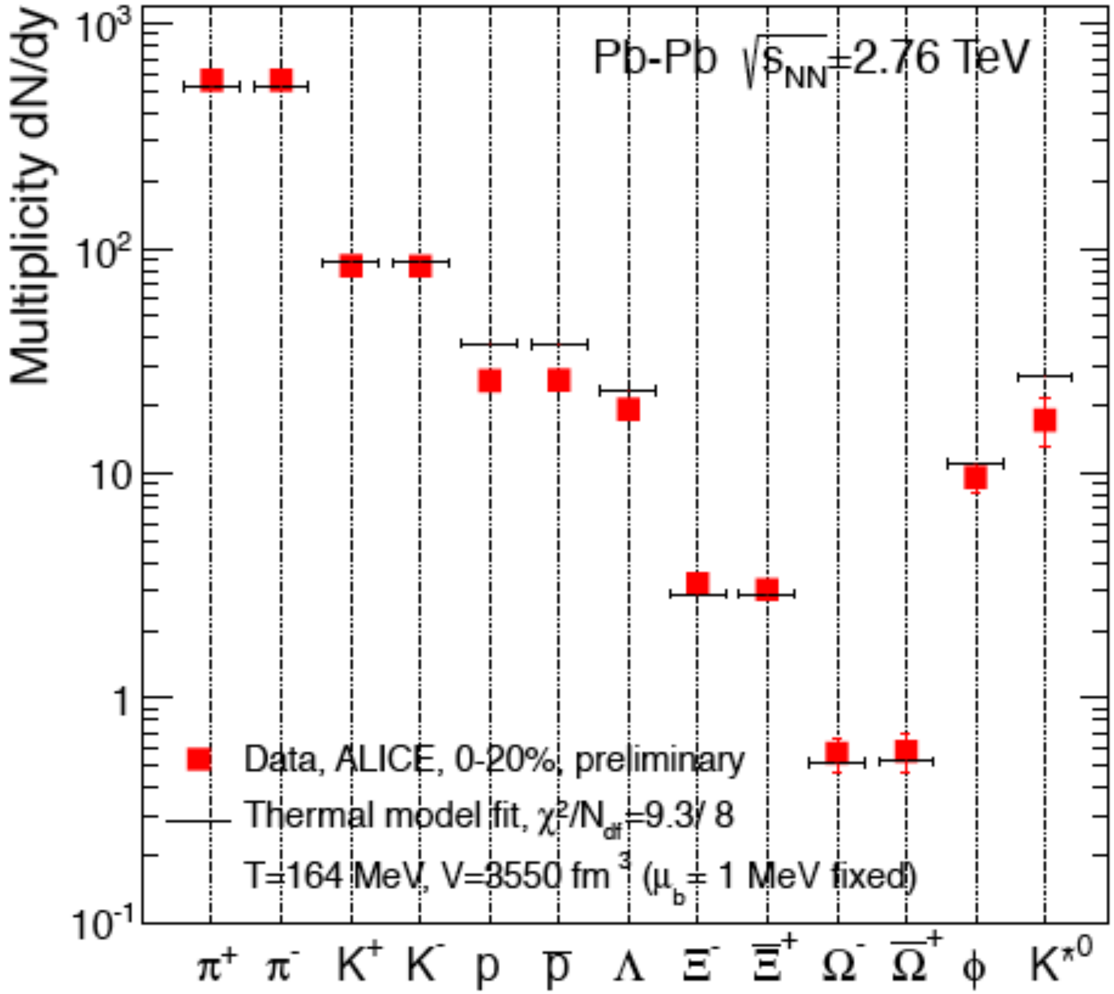
mean pT of identified hadrons

M. Floris, QM2011 (see also PRC 88 (2013) 044910)



$<p_T>$ ~20% higher than at RHIC at the same multiplicity

proton deficit in Pb-Pb collisions



protons not included in the fit

less protons than predicted by thermal model
suggesting a lower chemical freeze-out temperature T_{ch}
...but a lower T_{ch} leads to a worse description of Ξ and Ω

Adding collectivity to pp models

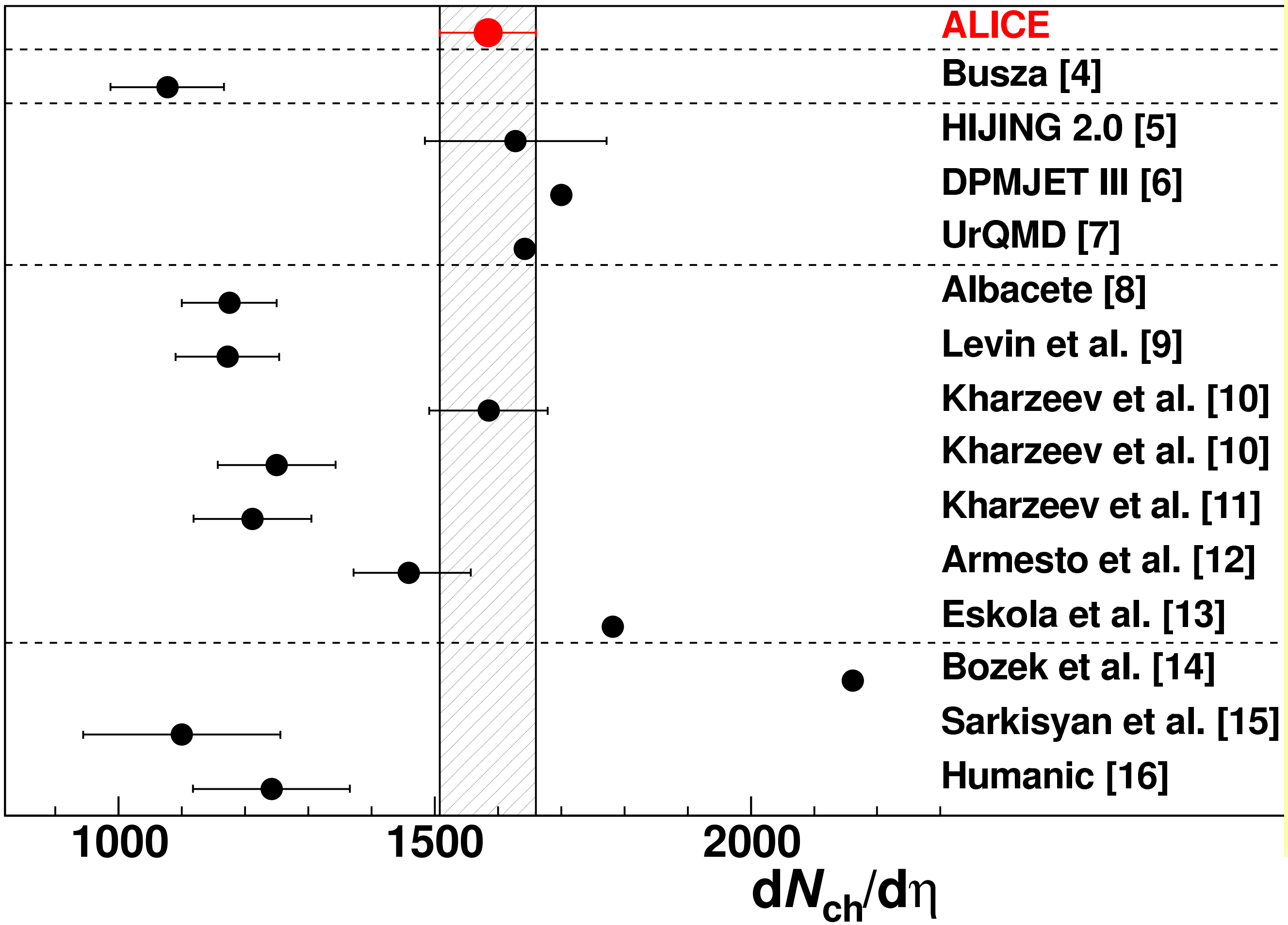
- **AMPT with string melting**
  strings decaying into soft partons rather than Lund fragmentation
  parton-parton interactions
  parton coalescence

- **PYTHIA with color reconnection**
  fewer particles, higher momenta

- **EPOS**
  built in

charged-particle production in Pb-Pb: comparison with models

PRL 105 (2010) 252301



extrapolation in sqrt(s)

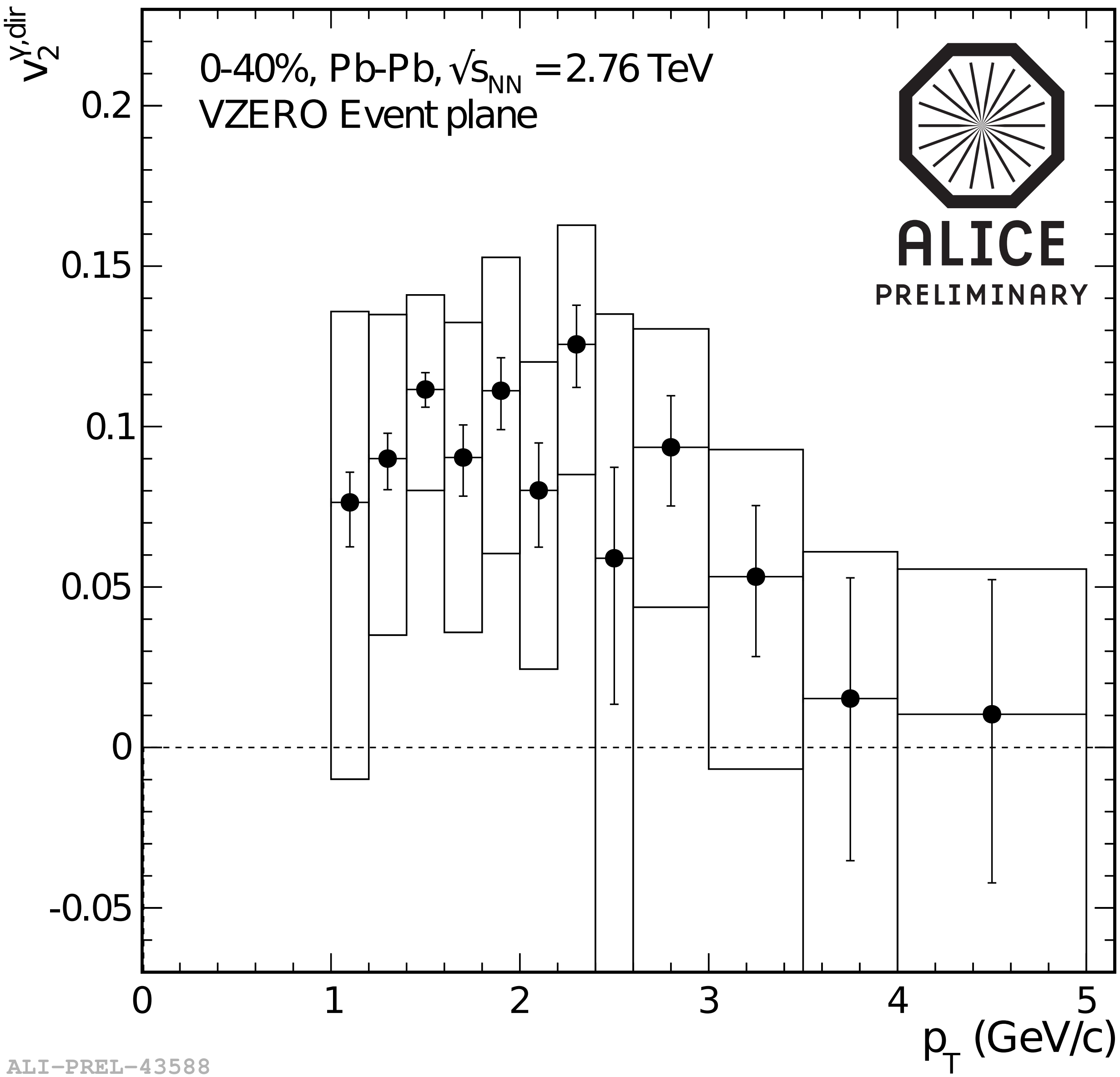
adj. to pp, no jet quench.
pQCD

initial state gluon saturation

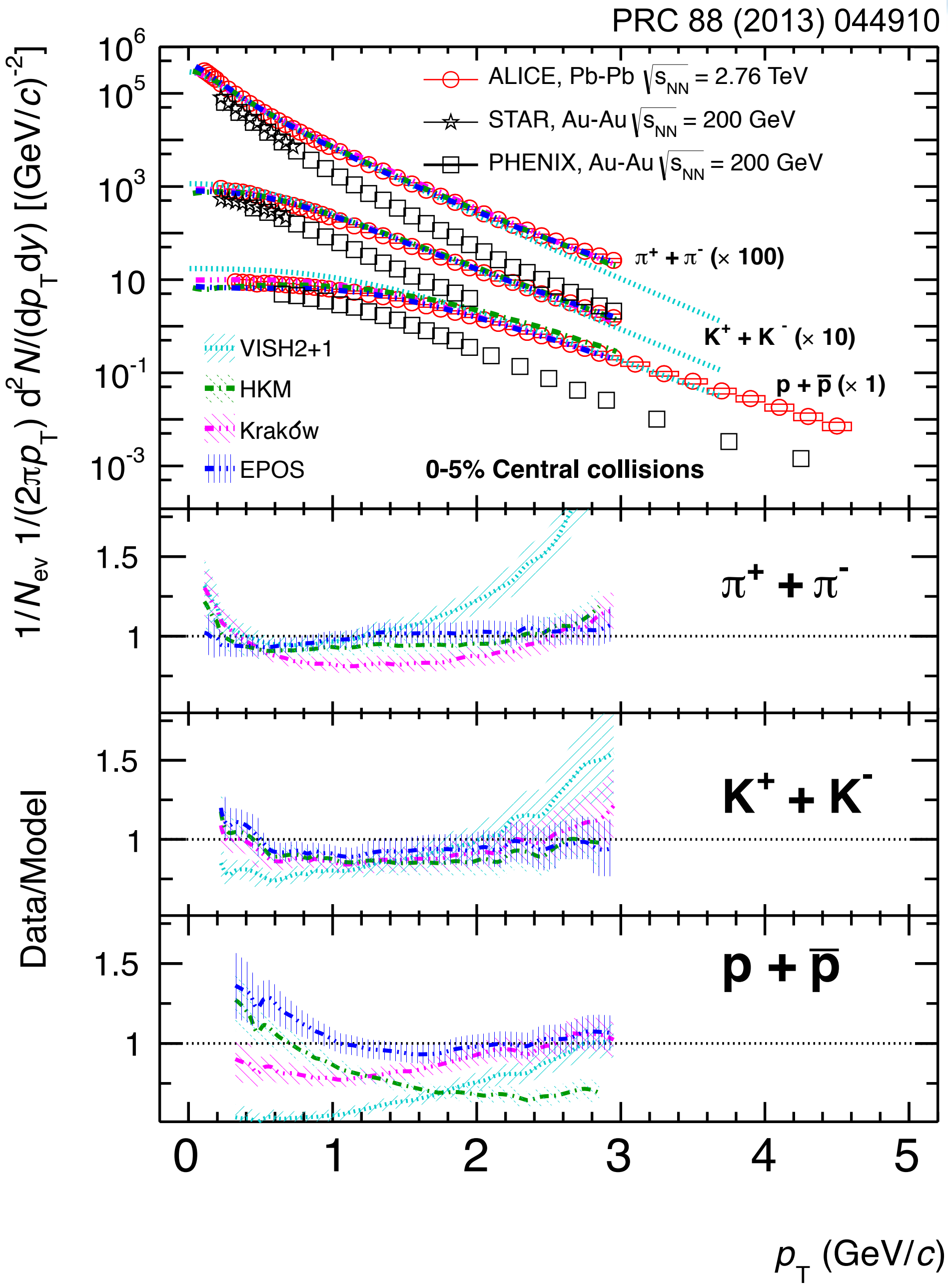
hydro + final parton sat.
extrapolation from pp
Landau hydro
Pythia+ rescattering

higher yield than expected (by most)

elliptic flow of direct photons



identified hadron spectra – comparison to models



fairly good description by hydrodynamics-based models

VISH2+1 (pure hydro) overpredicts protons (fixed by adding a hadronic phase – VISHNU – with baryon annihilation, arXiv:1311.0157)

Krakow, HKM, and EPOS (hydro + hadronic cascade) agree with the measurement

	arxiv	system	energy (TeV)	observable	published in
1	0911.5430	pp	0.9	charged particle dN/deta	EPJ C65 (2010) 111
2	1004.3034	pp	0.9, 2.36	charged particle dN/deta, mult. distr.	EPJC 68(2010)89
3	1004.3514	pp	7.0	same	EPJC 68(2010)345
4	1006.5432	pp	0.9, 7.0	antiproton/proton ratio	PRL 105(2010)072002
5	1007.0516	pp	0.9	pion HBT	PRD 82(2010)052001
6	1007.0719	pp	0.9	charged particle p_T spectra	PLB 693(2010)53
7	1011.3914	Pb-Pb	2.76	charged particle v2	PRL 105(2010)252302
8	1011.3916	Pb-Pb	2.76	charged particle dN/deta	PRL 105(2010)252301
9	1012.1004	Pb-Pb	2.76	charged particle RAA	PLB 696(2011)30
10	1012.1657	Pb-Pb	2.76	centrality dependence of Nch	PRL 106(2011)032301
11	1012.3257	pp	0.9	K0, phi, lambda, cascade	EPJC 71(2011)1594
12	1012.4035	Pb-Pb	2.76	pion HBT	PLB 696(2011)328
13	1101.3665	pp	0.9, 7.0	pion HBT	PRD 84 (2011) 112004
14	1101.4110	pp	0.9	pion, kaon, proton production	EPJC 71(2011)1655
15	1105.0380	pp	7.0	J/ψ production	PLB 704 (2011) 442+E
16	1105.3865	Pb-Pb	2.76	charged particle v3, v4,v5	PRL 107 (2011) 032301
17	1109.2501	Pb-Pb	2.76	angular correlations	PLB 708 (2012) 249

	arxiv	system	energy (TeV)	observable	published in
18	1110.0121	Pb-Pb	2.76	angular correlations	PRL 108 (2012) 092301
19	1111.1553	pp	7.0	D production	JHEP 1201 (2012) 128
20	1111.1630	pp	7.0	J/ψ polarization	PRL 108 (2012) 082001
21	1112.2082	pp	0.9, 7.0	underlying event	JHEP 7 (2012) 116
22	1112.2222	pp	7.0	phi, omega production	PLB 710 (2012) 557
23	1201.2423	Pb-Pb	2.76	jet background	JHEP 1203 (2012) 053
24	1201.3791	pp	7.0	heavy-flavor muons	PLB 708 (2012) 265
25	1202.1383	Pb-Pb	2.76	J/ψ suppression	PRL 109 (2012) 072301
26	1202.2816	pp	7.0	Nch dependence of J/ψ production	PLB 712 (2012) 165
27	1203.2160	Pb-Pb	2.76	D suppression	JHEP 09 (2012) 112
28	1203.2436	Pb-Pb	2.76	electromagnetic dissociation	PRL 109 (2012) 252302
29	1203.3641	pp	2.76	J/ψ production	PLB 718 (2012) 295
30	1204.0282	pp	7.0	cascade, Omega production	PLB 712 (2012) 309
31	1205.3963	pp	0.9, 2.76, 7.0	sphericity	EPJ C72 (2012) 2124
32	1205.4007	pp	2.76	D production	JHEP 1207 (2012) 191
33	1205.5423	pp	7.0	heavy-flavor electrons	PRD 86 (2012) 112007
34	1205.5724	pp	0.9, 7.0	pi0, eta production	PLB 717 (2012) 162

	arxiv	system	energy (TeV)	observable	published in
35	1205.5761	Pb-Pb	2.76	v2 of high-p_T hadrons pions protons	PLB 719 (2013) 18
36	1205.5880	pp	7.0	J/ψ production	JHEP 11 (2012) 065
37	1205.6443	pp PbPb	2.76	heavy-flavor muons	PRL 109 (2012) 112301
38	1206.2056	pp	7.0	K0 HBT	PLB 717 (2012) 151
39	1207.0900	Pb-Pb	2.76	azimuthal charge separation	PRL 110 (2013) 012301
40	1207.6068	Pb-Pb	2.76	net-charge fluctuations	PRL 110 (2013) 152301
41	1208.1902	pp	7.0	beauty decay electrons	PLB 721 (2013) 13
42	1208.1948	pp	7.0	Ds production	PLB 718 (2012) 279
43	1208.1974	Pb-Pb	2.76	pion, kaon, proton production	PRL 109 (2012) 252301
44	1208.2711	Pb-Pb	2.76	charged particle RAA	PLB 720 (2013) 52
45	1208.4968	pp	0.9, 2.76, 7.0	pp cross section	EPJC 73 (2013) 2456
46	1208.5717	pp	7.0	K*, phi production	EPJ C72 (2012) 2183
47	1209.3715	Pb-Pb	2.76	coherent J/ψ in ultraperipheral	PLB 718 (2013) 1273
48	1210.3615	p-Pb	5.02	dNch/deta	PRL 110 (2013) 032301
49	1210.4520	p-Pb	5.02	charged particle RAA	PRL 110 (2013) 082302
50	1212.2001	p-Pb	5.02	ridges in p-Pb	PLB 719 (2013) 29
51	1212.5958	pp	7.0	kaon HBT	PRD 87 (2013) 052016

	arxiv	system	energy (TeV)	observable	published in
52	1301.3475	pp	2.76	jets	PLB 722 (2013) 262
53	1301.3756	Pb-Pb	2.76	balance functions	PLB 723 (2013) 267
54	1301.4361	Pb-Pb	2.76	centrality	PRC 88 (2013) 044909
55	1303.0737	Pb-Pb	2.76	pion, kaon, proton vs centrality	PRC 88 (2013) 044910
56	1303.5880	Pb-Pb	2.76	J/ψ v2	
57	1304.0347	Pb-Pb	2.76	dNch/deta vs centrality	PLB 726 (2013) 610
58	1305.1467	Pb-Pb	2.76	J/ψ in ultraperipheral	EPJC 73 (2013) 2617
59	1305.1562	pp	0.9, 2.76, 7	antibaryon/baryon ratios	EPJC 73 (2013) 2496
60	1305.2707	Pb-Pb	2.76	D meson v2	PRL 111 (2013) 102301
61	1306.4145	Pb-Pb	2.76	v1	PRL 111 (2013) 232302
62	1307.1093	pp	0.9, 2.76, 7	charged particle p_T spectra	EPJC 73 (2013) 2662
63	1307.1094	all three	many	$\langle p_T \rangle$ vs multiplicity	PLB 727 (2013) 371
64	1307.1249	pp	0.9, 2.76, 7	angular correlations	JHEP 1309 (2013) 049
65	1307.3237	p-Pb	5.02	angular correlations of pi, K, p	PLB 726 (2013) 164
66	1307.5530	Pb-Pb	2.76	K0, lambda	PRL 111 (2013) 222301
67	1307.5543	Pb-Pb	2.76	Xi, Omega	PLB 728 (2014) 216
68	1307.6796	p-Pb	5.02	pi, k, p, lambda vs multiplicity	PLB 728 (2014) 25

	arxiv	system	energy (TeV)	observable	published in
69	1308.6726	p-Pb	5.02	J/ψ	
70	1310.7808	Pb-Pb	2.76	three-pion HBT	PRC 89 (2014) 024911
71	1311.0214	Pb-Pb	2.76	J/ψ suppression	
72	1311.0633	Pb-Pb	2.76	jet suppression	
73	1401.1250	Pb-Pb	2.76	pion, kaon, proton suppression	
74	1404.0495	Pb-Pb	2.76	K*(892)0 and phi	
75	1404.1194	all three	7, 5.02, 2.76	three pion HBT	
76	1405.2001	Pb-Pb	2.76	D v2	PRC 90 (2014) 034904
77	1403.3648	pp	7	J/psi, psi, Upsilon via mumu	EPJC 74 (2014) 2974
78	1405.1849	p-Pb	5.02	cross section	JINST 9 (2014) 1100
79	1405.2737	p-Pb	5.02	charged particle RAA	EPJC 74 (2014) 3054
80	1405.4493	Pb-Pb	2.76	Upsilon RAA	PLB 738 (2014) 361
81	1407.5530	pp,PbPb	0.9, 2.76, 7	pt fluctuations	EPJC 74 (2014) 3077
82	1410.2234	p-Pb	5.02	Upsilon	PLB 740 (2015) 105
83	1411.4969	pp	7	jets	
84	1411.4981	pp	0.9, 2.76, 7	photons	
85	1412.6828	p-Pb	5.02	centrality	

Superdense Matter: Neutrons or Asymptotically Free Quarks?

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(Received 6 January 1975)

We note the following: The quark model implies that superdense matter (found in neutron-star cores, exploding black holes, and the early big-bang universe) consists of quarks rather than of hadrons. Bjorken scaling implies that the quarks interact weakly. An asymptotically free gauge theory allows realistic calculations taking full account of strong interactions.

A neutron has a radius[10] of about 0.5–1 fm, and so has a density of about 8×10^{14} g cm^{-3}, whereas the central density of a neutron star[1,2] can be as much as 10^{16}–10^{17} g cm^{-3}. In this case, one must expect the hadrons to overlap, and their individuality to be confused. Therefore, we suggest that matter at such high densities is a quark soup. In such a system, long-range interactions are screened because of many-body effects,[11] and hence no problems will arise for any peculiar infrared behavior of quark binding forces. At short

first question to LHC: particle-source size

Helmut Satz, Nucl. Phys. A862-863 (2011) 4, "The Quark-Gluon Plasma"
Student Day Lecture, Goa, Dec 2010

5 Three Questions to the LHC

The QGP predicted by statistical QCD is the ultimate state of matter to be studied in high energy nuclear collisions. This is a speculative endeavor, since it is not clear to what extent such collisions can produce something to be called matter. We therefore close our survey with three questions to the next generation of experiments which might help us in finding an answer to this fundamental enigma.

If an increase of collision energy indeed leads to the production of a hotter bubble of deconfined primordial matter, then this must expand more in order to reach the hadronization temperature, and hence the source size for hadron emission must become larger. In particular, it is expected to increase as a power of the hadron multiplicity, since this in turn grows with the initial energy density [24]. So far, from AGS to RHIC, the source size for hadron emission, as determined by Hanbury-Brown–Twiss (HBT) methods [25] used in astrophysics, has not shown a significant increase [26]. This "HBT-puzzle" has been accounted for in terms of the relative role of meson and baryon production [27], but at LHC energies, a clear increase of the source volume is predicted. Such an increase seems necessary in a model-independent way, if the concept of hot primordial fireball production in nuclear collisions is to make any sense.

ALICE: homogeneity volume at LHC two times higher than at RHIC

second question to LHC: photon temperature

Helmut Satz, Nucl. Phys. A862-863 (2011) 4, "The Quark-Gluon Plasma"
Student Day Lecture, Goa, Dec 2010

We had noted that momentum spectra for real and virtual photons can in principle provide an internal thermometer of the QGP, with

$$(dN_\gamma/dk_T) \sim \exp\{-k_T/T\} \quad (8)$$

A recent analysis of RHIC $Au-Au$ data at $\sqrt{s} = 200$ GeV [28] has identified possible thermal photons, seen in a transverse momentum window between pion decay and prompt photon spectra. The corresponding temperature is with $T = 221 \pm 19(\text{stat.}) \pm 19(\text{syst.})$ MeV above the hadronization value of about 175 MeV. If such thermal photons are indeed observable, the LHC should lead to much higher temperatures for electromagnetic radiation.

ALICE: T = 304 +- 51 MeV

third question to LHC: J/ψ suppression or regeneration

Helmut Satz, Nucl. Phys. A862-863 (2011) 4, "The Quark-Gluon Plasma"
Student Day Lecture, Goa, Dec 2010

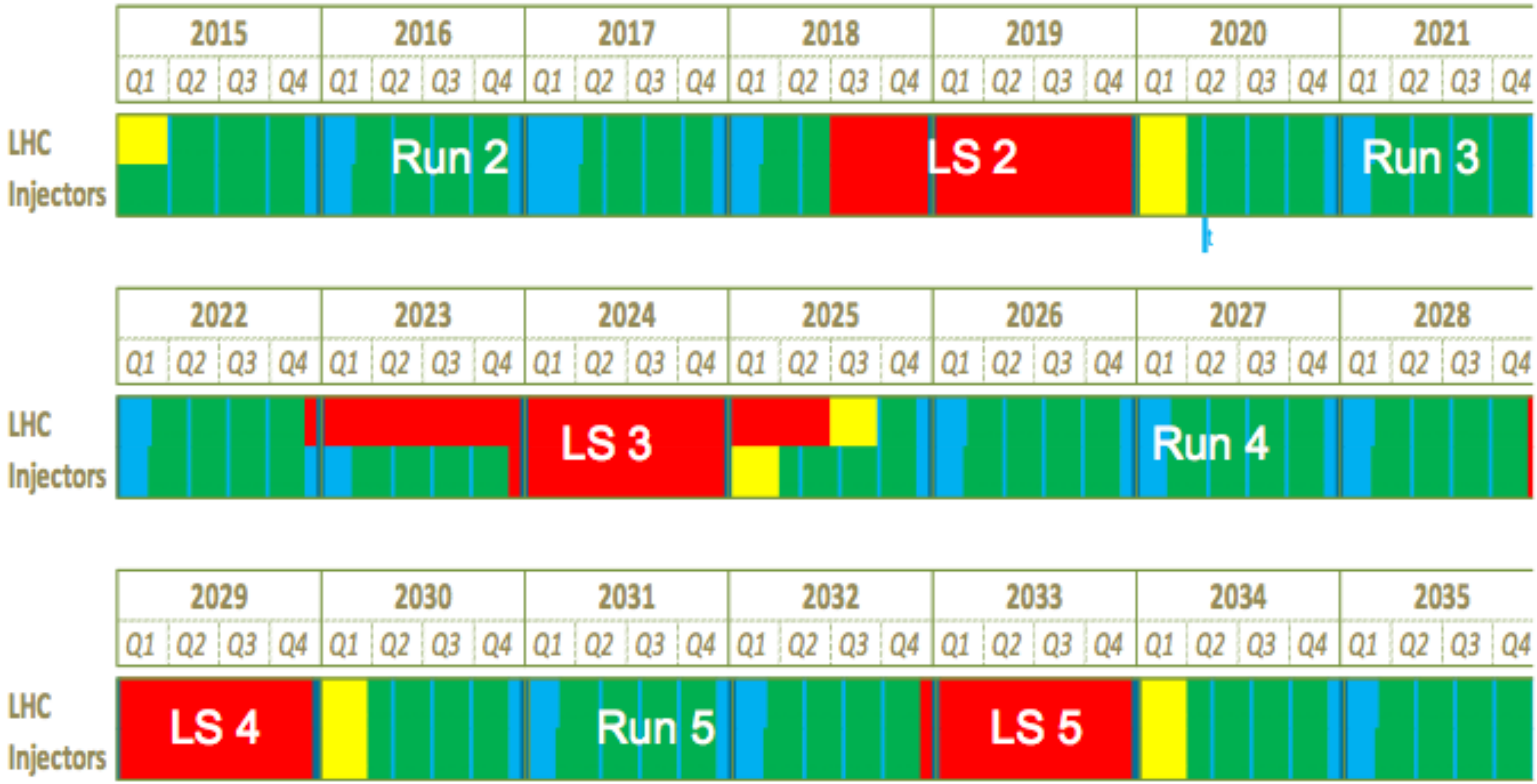
The last question addresses quarkonium production in nuclear collisions at the LHC. The J/ψ production rate in $Au - Au$ collisions at RHIC is compatible with that for central collisions at the SPS, once cold nuclear matter effects are taken into account. The remaining survival rate of about 50 % is in accord with suppression of the higher excited states (ψ' and χ_c) and survival of the direct J/ψ [29]. The much higher energy density of the LHC should dissociate also the latter, leading to complete J/ψ suppression (modulo B decay and corona production). The expected survival pattern is illustrated in Fig. 8.

Here, however, an alternative scenario has been proposed [30] and much discussed. Charm production in nuclear collisions, as a hard process, increases with collision energy much faster than that of light quarks. At sufficiently high energy, the produced medium will therefore contain more charm quarks than present in a QGP at "chemical" equilibrium. If these charm and anticharm quarks combine at the hadronization point statistically to form charmonium states, this new combination mechanism should lead to a much enhanced J/ψ production rate, even if all primary ("direct") J/ψ's are dissociated. The two predictions, sequential suppression vs. statistical regeneration, thus present two really opposite patterns, and first LHC results should be able to distinguish between them.

ALICE: statistical regeneration dominates

LHC schedule beyond LS1

Only EYETS (19 weeks) (no Linac4 connection during Run2)
LS2 starting in 2018 (July) 18 months + 3months BC (Beam Commissioning)
LS3 LHC: starting in 2023 => 30 months + 3 BC
injectors: in 2024 => 13 months + 3 BC



LHC schedule approved by CERN management and LHC experiments spokespersons and technical coordinators
Monday 2nd December 2013

fully liberated quarks would lead to a causality problem during hadronization

(arxiv:0707.0923, or google for "QGP paradox")