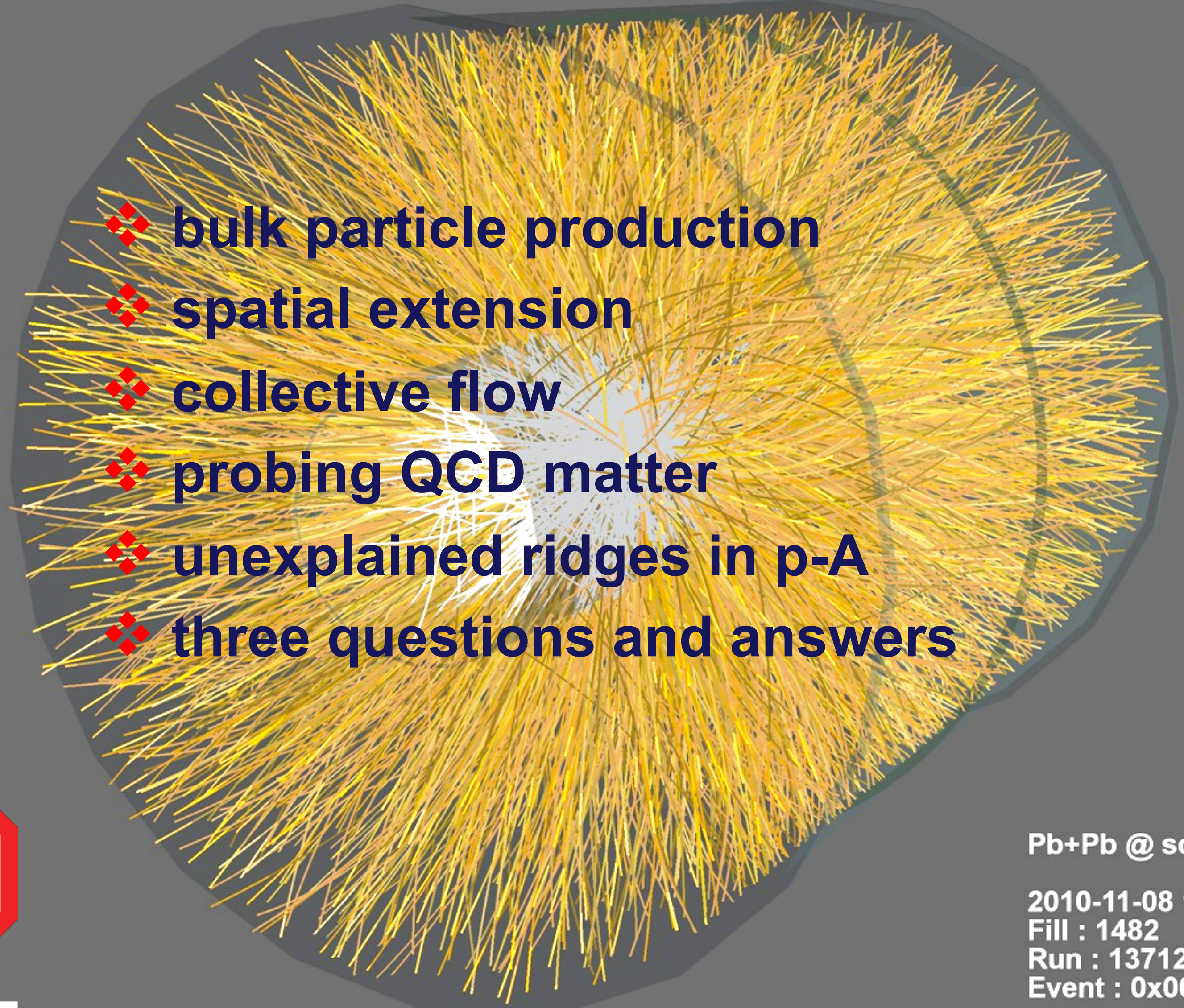
ALICE Pb-Pb and p-Pb results

Dariusz Miskowiec, GSI / EMMI Darmstadt

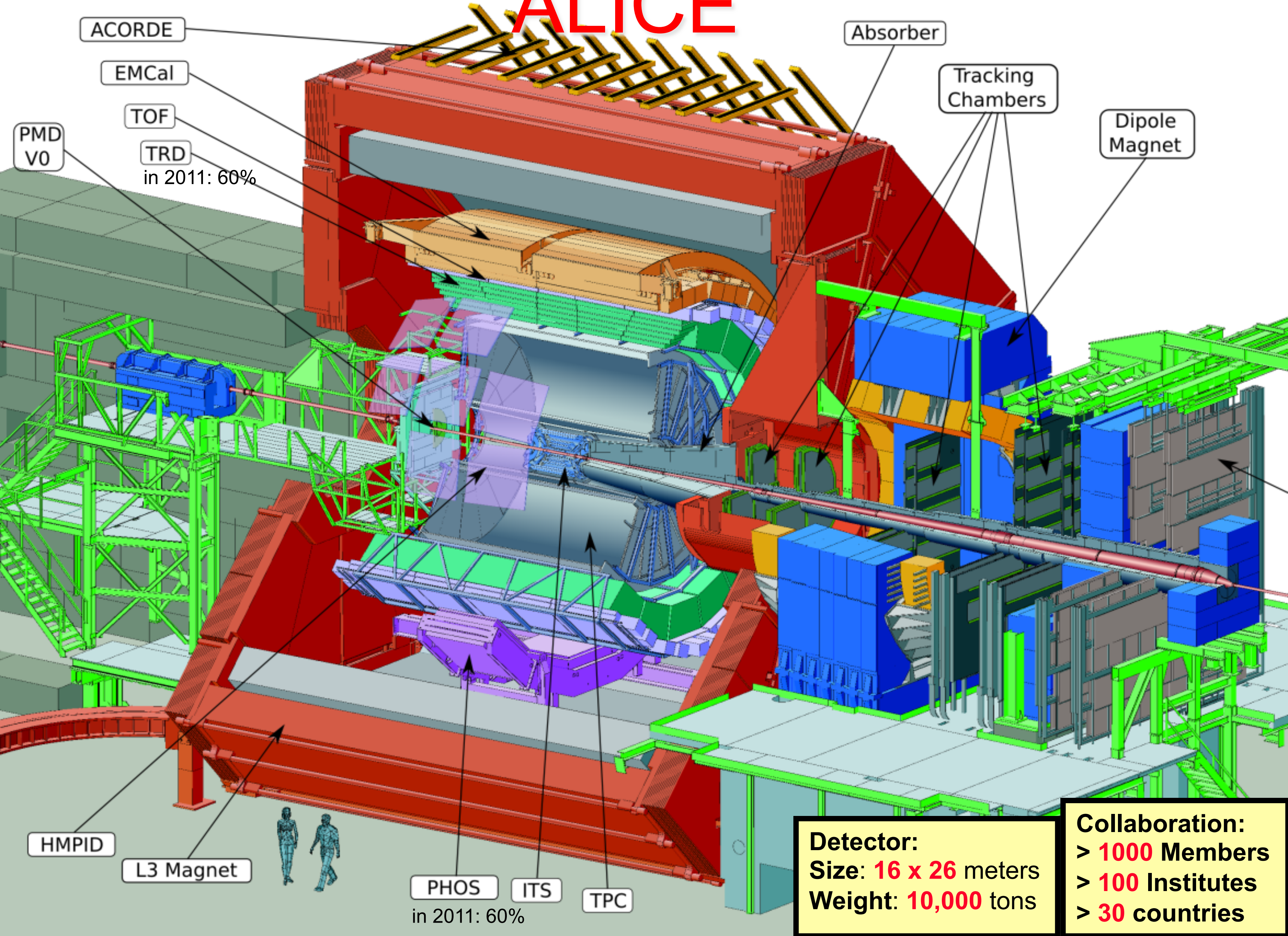


- bulk particle production
- spatial extension
- collective flow
- probing QCD matter
- unexplained ridges in p-A
- three questions and answers

Pb+Pb @ sqrt(s) = 2.76 ATeV

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

ALICE



Detector:
Size: **16 x 26** meters
Weight: **10,000** tons

Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

ALICE measurements

	**pp**	**0.9, 2.36, 2.76, 7.0, 8.0 TeV**	**3 years***
	**Pb-Pb**	**2.76 TeV**	**8 weeks**
	**p-Pb**	**5.02 TeV**	**8 hours****

* at reduced luminosity
** longer run starting next week

	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 pt spectra	PLB 693(2010)53
7	1011.3914	Pb-Pb	2.76	charged particle dN/deta	PRL 105(2010)252301
8	1011.3916	Pb-Pb	2.76	charged particle v2	PRL 105(2010)252302
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/Psi 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

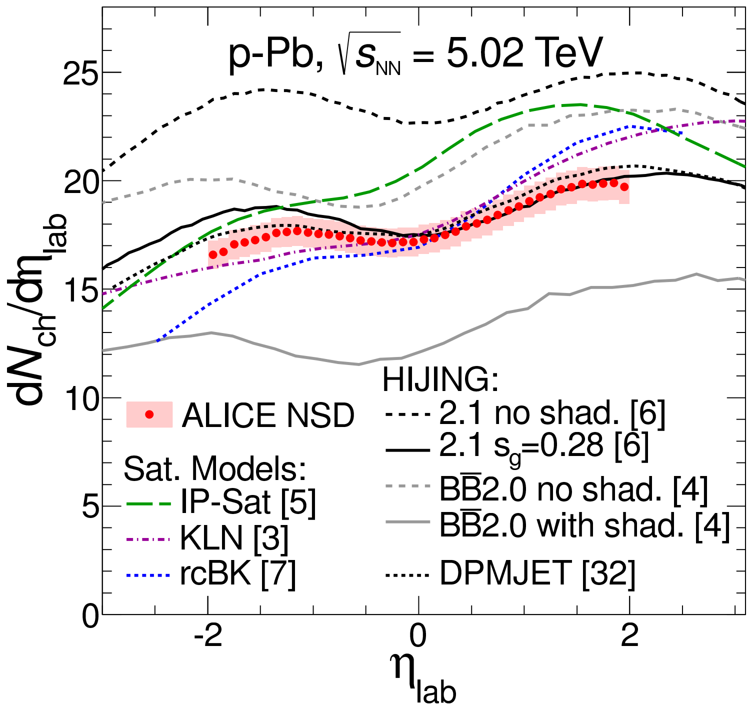
	arxiv	system	energy (TeV)	observable	published in
18	1110.0121	Pb-Pb	2.76	angular correlations	PRL 108 (2012) 092301
19	1111.1553	pp	7.0	D production	JHEP 1201 (2012) 128
20	1111.1630	pp	7.0	J/Psi polarization	PRL 108 (2012) 082001
21	1112.2082	pp	0.9, 7.0	underlying event	JHEP 7 (2012) 116
22	1112.2222	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/Psi suppression	PRL 109 (2012) 072301
26	1202.2816	pp	7.0	Nch dependence of J/Psi 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	
29	1203.3641	pp	2.76	J/Psi 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	
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-pt hadrons pions protons	
36	1205.5880	pp	7.0	J/Psi production	JHEP 11 (2012) 065
37	1205.6443	pp PbPb	2.76	heavy-flavor muons	
38	1206.2056	pp	7.0	K0 HBT	PLB 717 (2012) 151
39	1207.0900	Pb-Pb	2.76	azimuthal charge separation	
40	1207.6068	Pb-Pb	2.76	net-charge fluctuations	
41	1208.1902	pp	7.0	beauty decay electrons	
42	1208.1948	pp	7.0	Ds production	PLB 718 (2012) 279
43	1208.1974	Pb-Pb	2.76	pion, kaon, proton production	
44	1208.2711	Pb-Pb	2.76	charged particle RAA	
45	1208.4968	pp	0.9, 2.76, 7.0	pp cross section	
46	1208.5717	pp	7.0	K*, phi production	EPJ C72 (2012) 2183
47	1209.3715	Pb-Pb	2.76	coherent J/Psi in ultraperipheral	
48	1210.3615	p-Pb	5.02	dNch/deta	
49	1210.4520	p-Pb	5.02	charged particle RAA	
50	1212.2001	p-Pb	5.02	ridges in p-Pb	
51	1212.5958	pp	7.0	kaon HBT	

bulk particle production

charged-particle production: pseudorapidity distributions

p-Pb

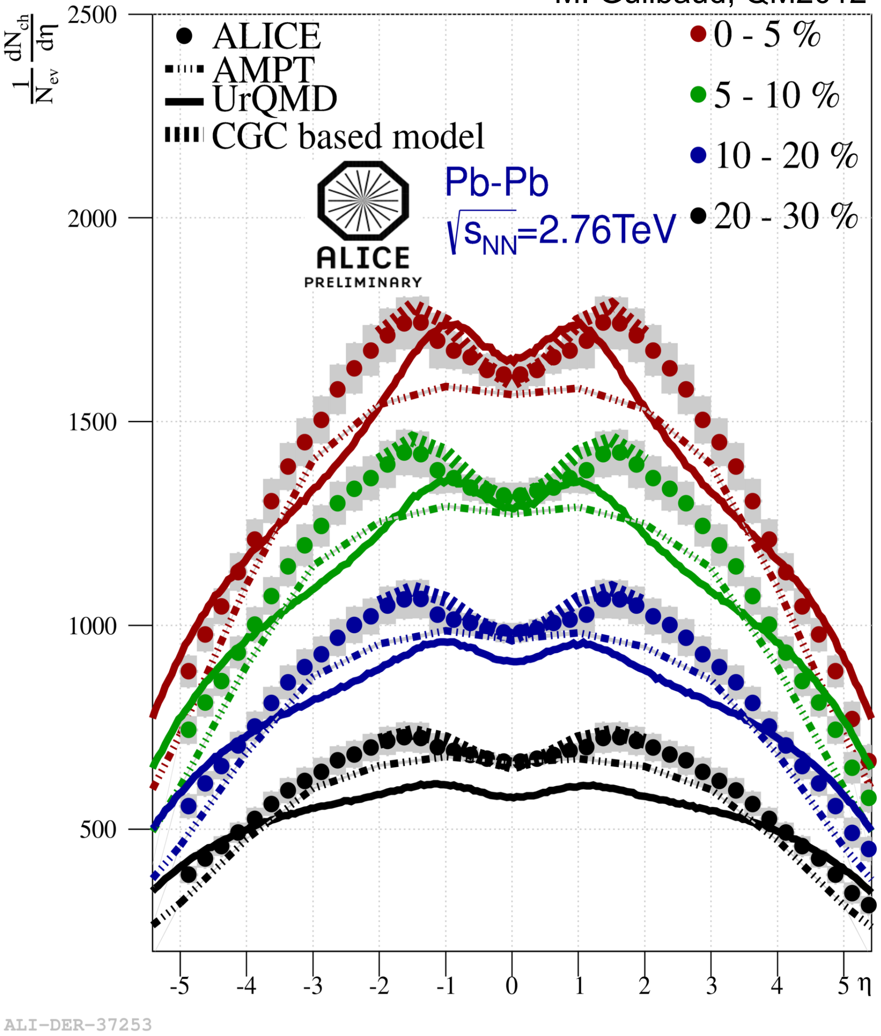

arXiv:1210.3615

constrains initial conditions of heavy-ion collision

models with shadowing or saturation describe the measurement within 20%

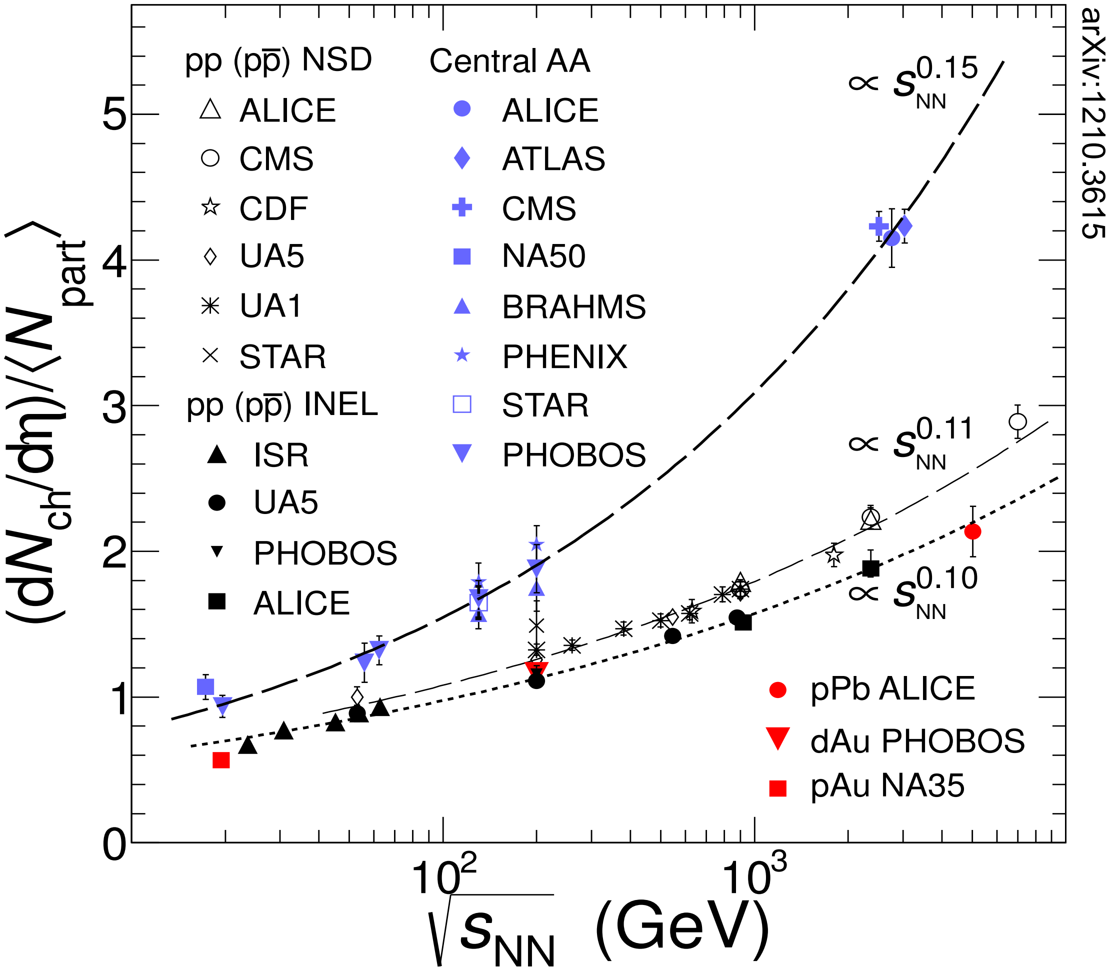
saturation models too steep

Pb-Pb


M. Guilbaud, QM2012

constrains description of dynamics of heavy-ion collision

charged-particle production: collision energy dependence



LHC 2 times higher than RHIC

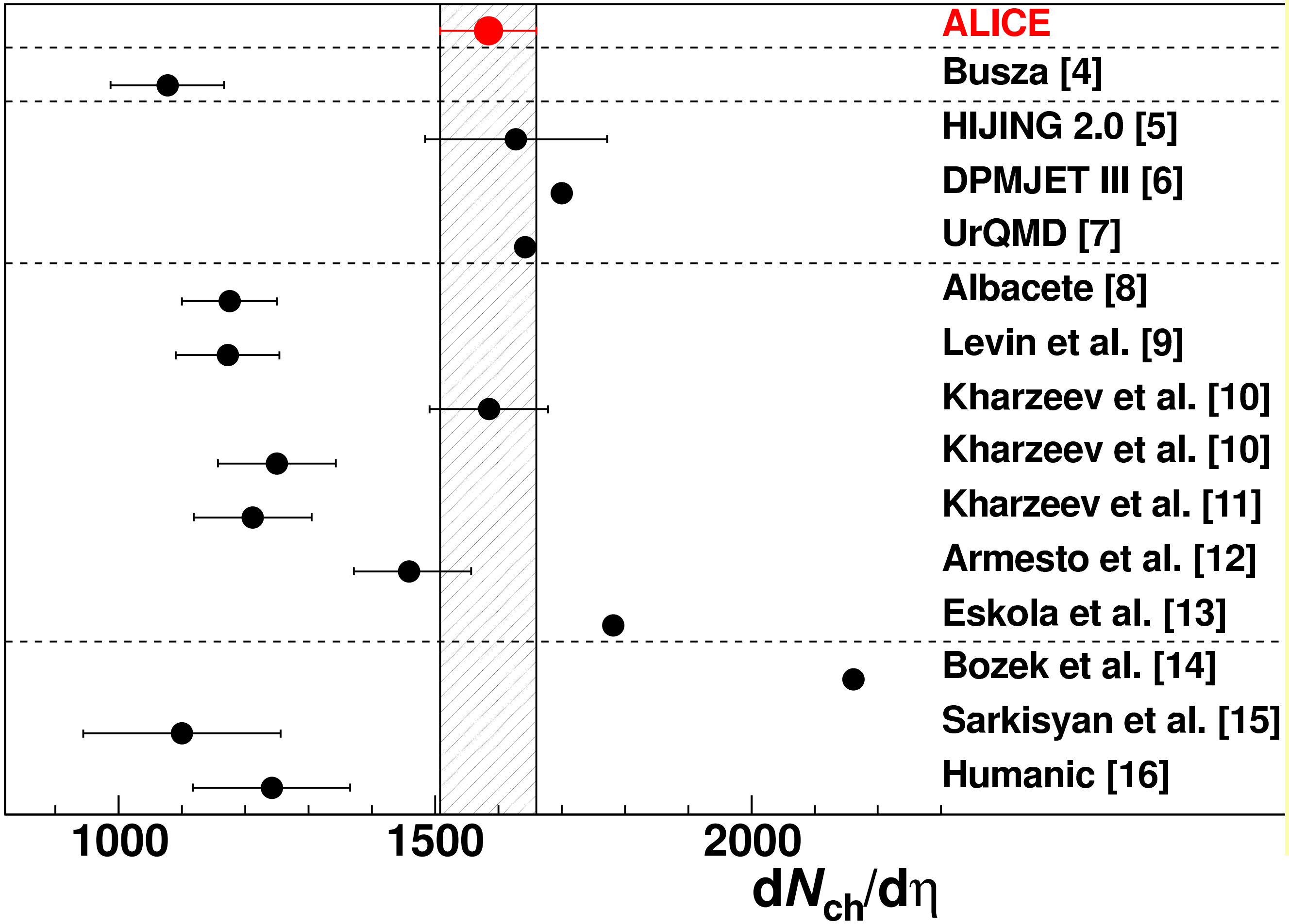
Pb-Pb 2 times higher than pp

p-Pb like INEL pp

steeper growth in AA than in pp and p-A

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.

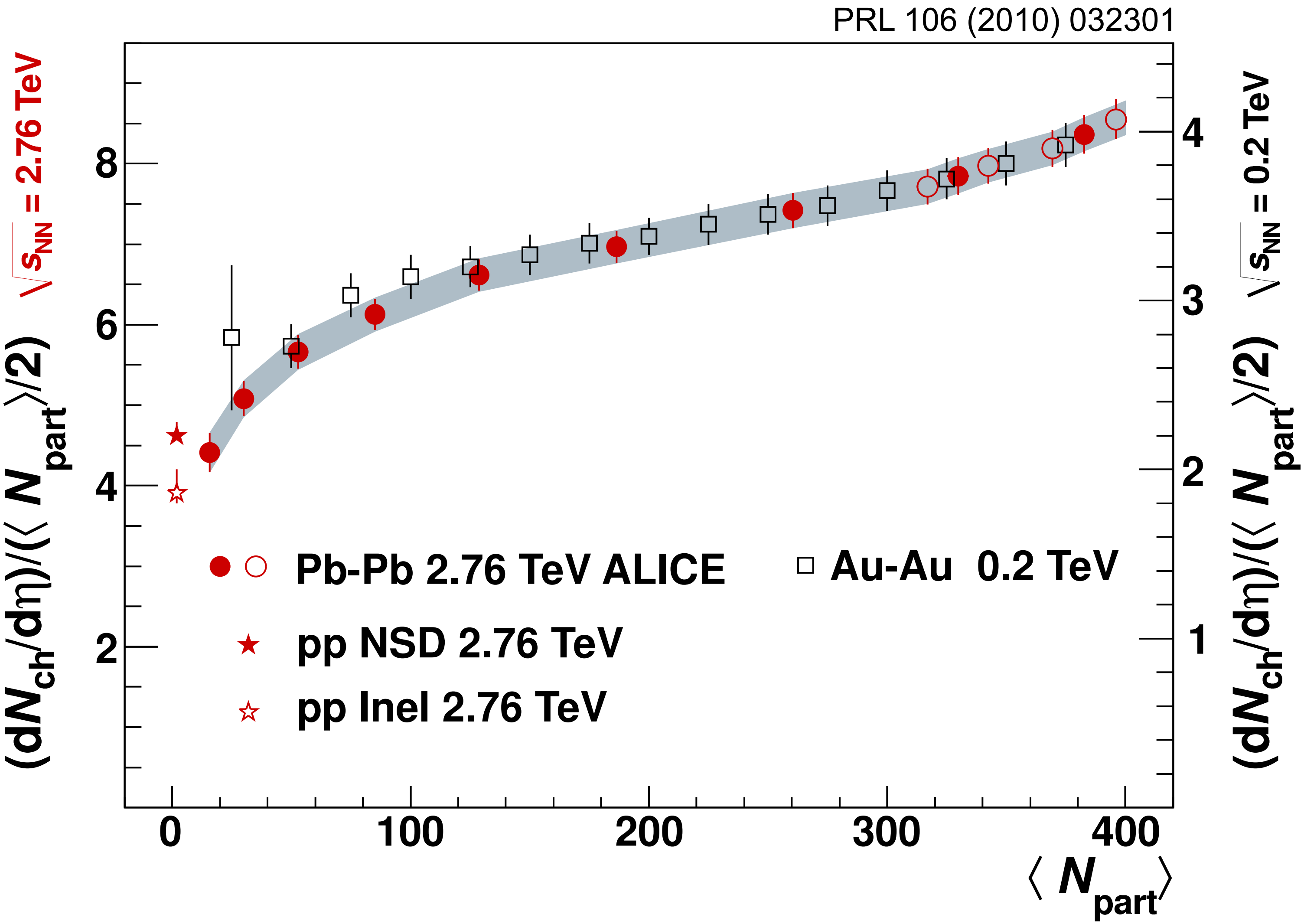
extrapolation from pp

Landau hydro

Pythia+ rescattering

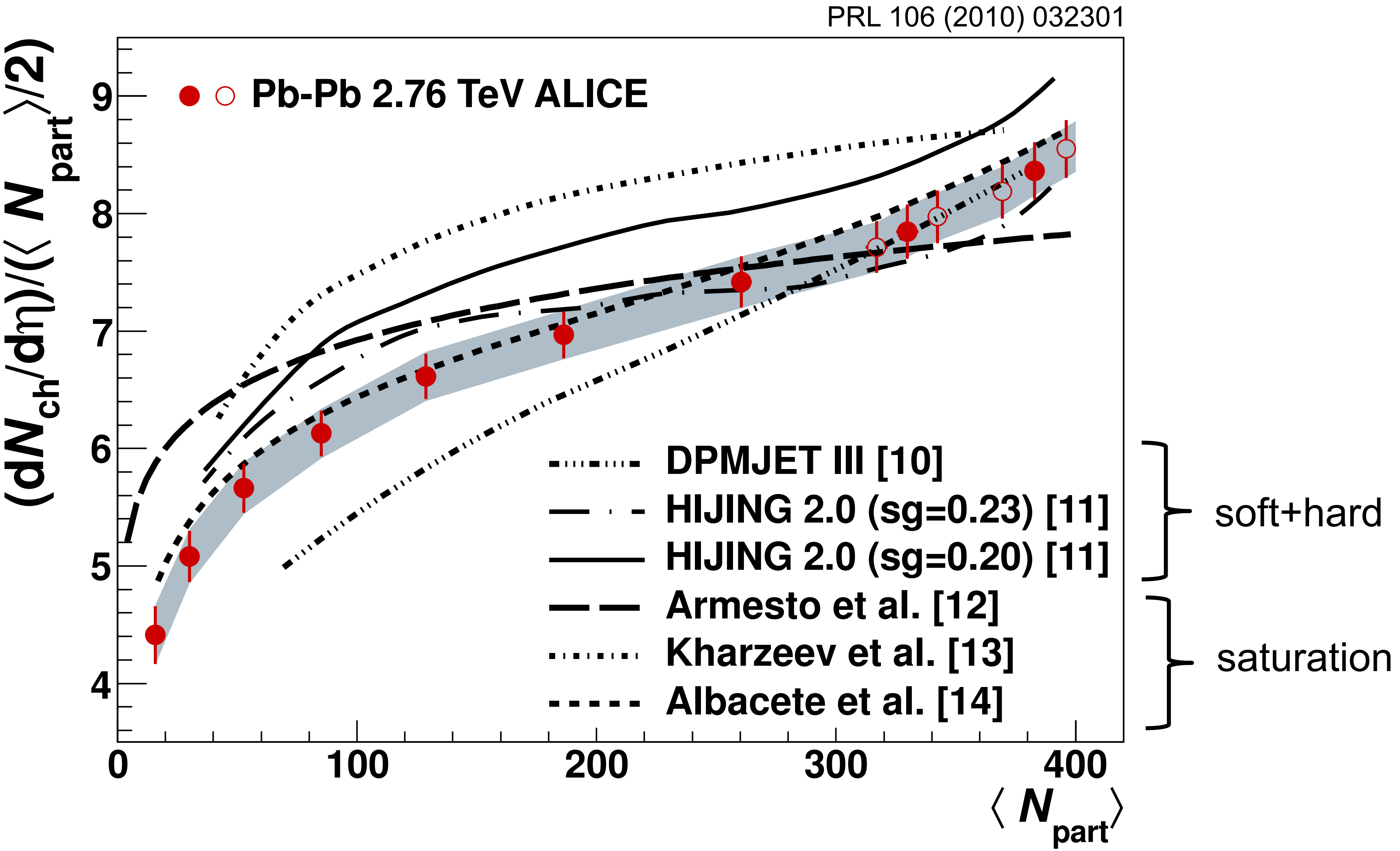
higher yield than expected (by most)

charged-particle production: centrality dependence



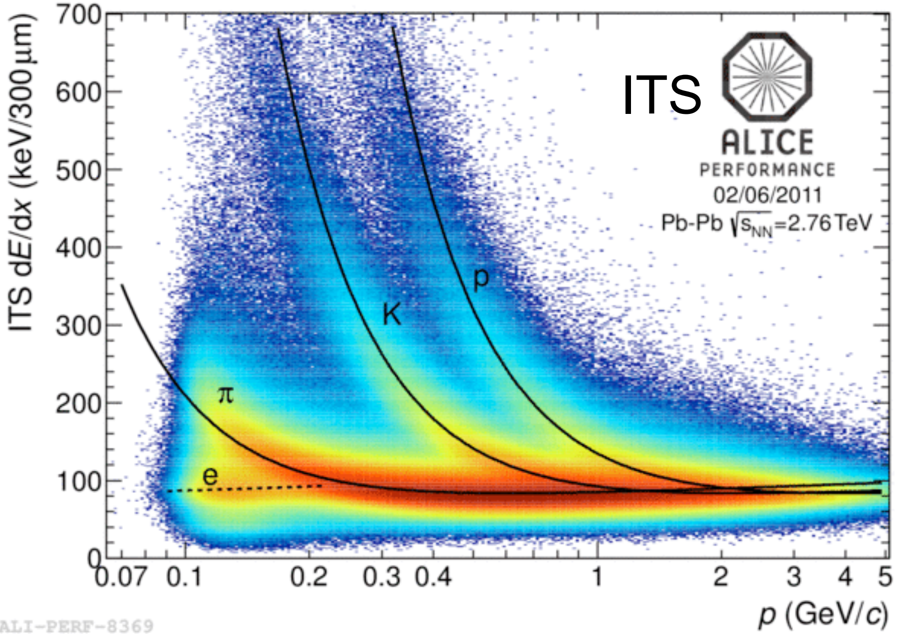
~2 times more particles than at RHIC, same centrality dependence

charged-particle production: centrality dependence

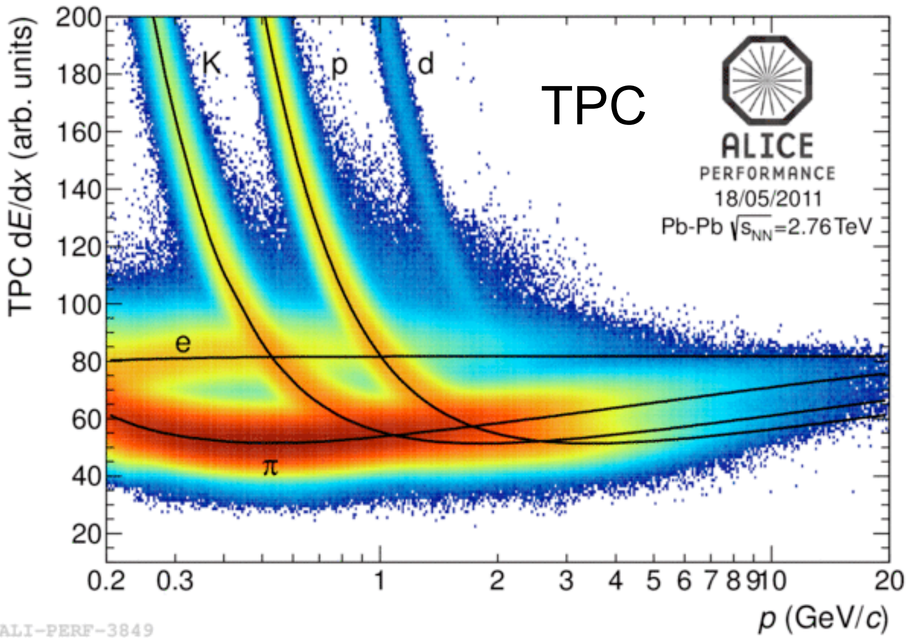


general trend reasonably reproduced by majority of the models
individual differences larger than the difference between the two groups

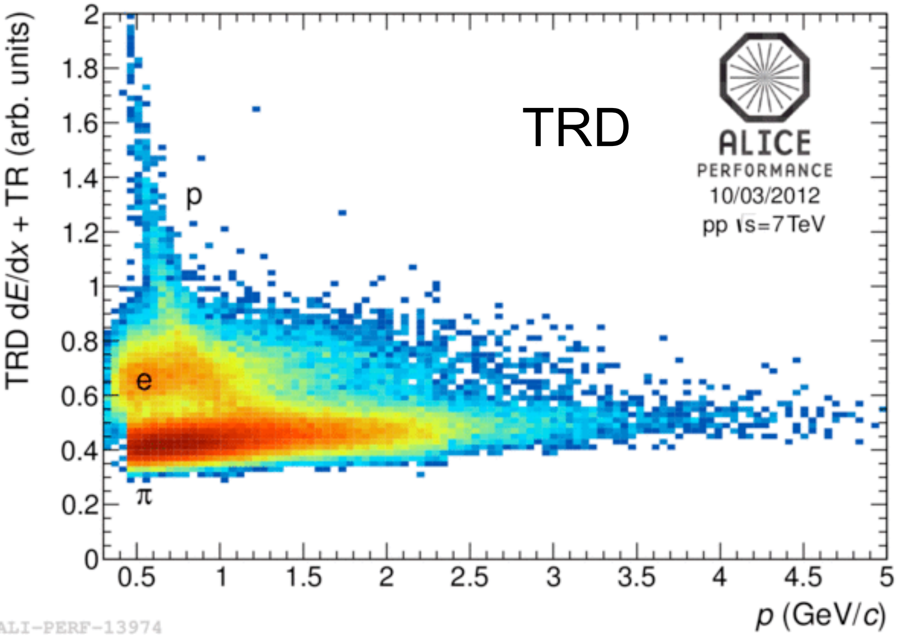
hadron identification



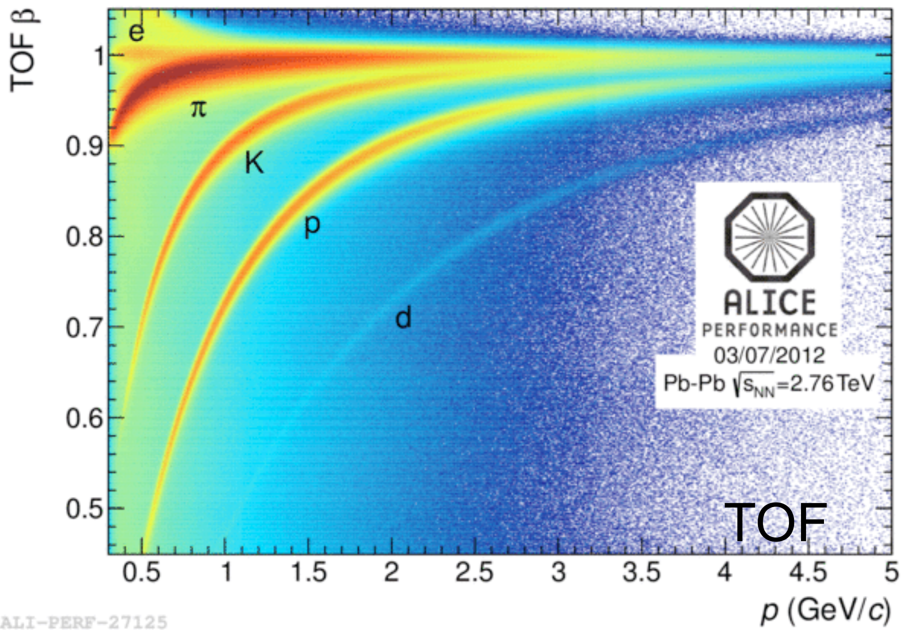
ALI-PERF-8369



ALI-PERF-3849

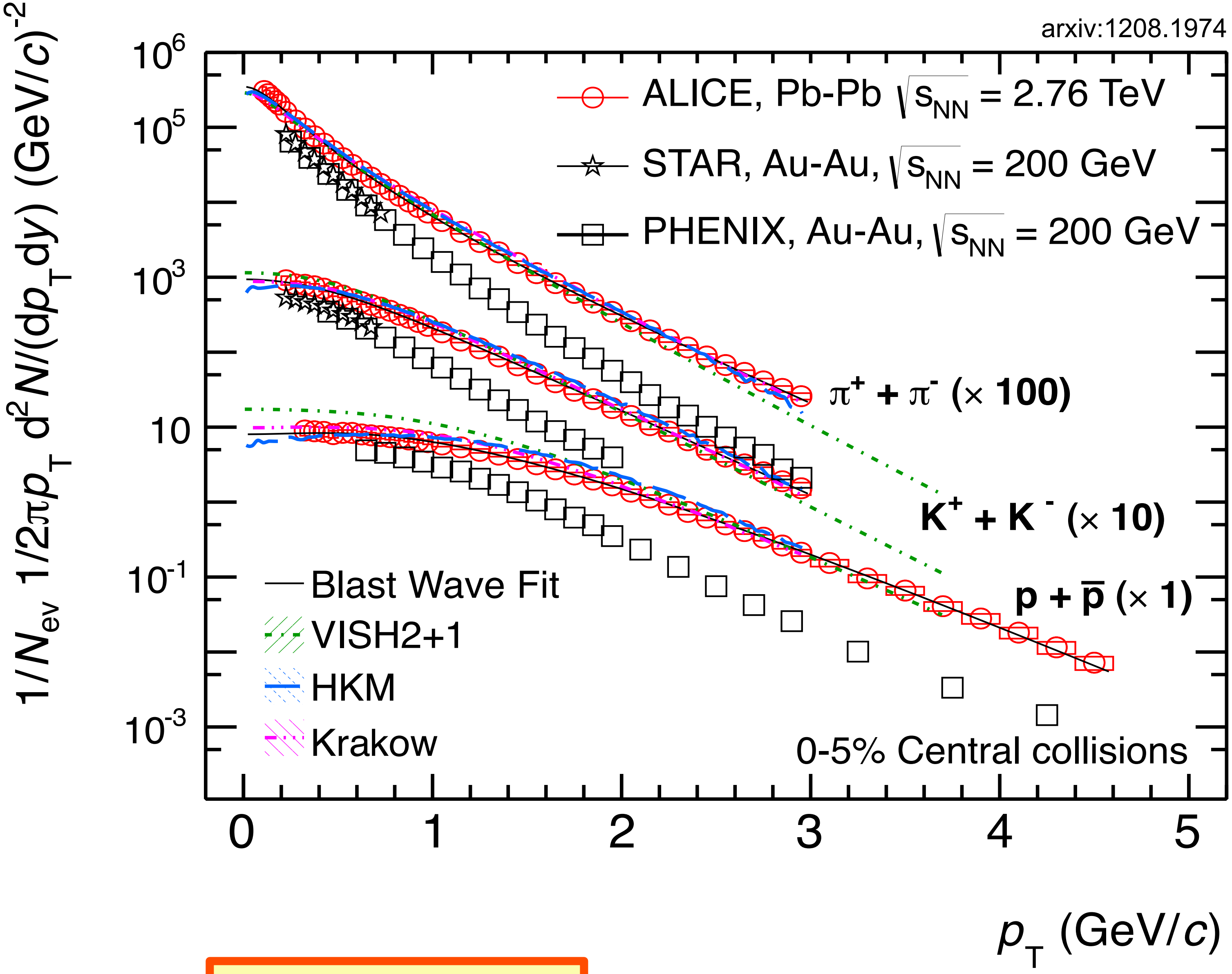


ALI-PERF-13974



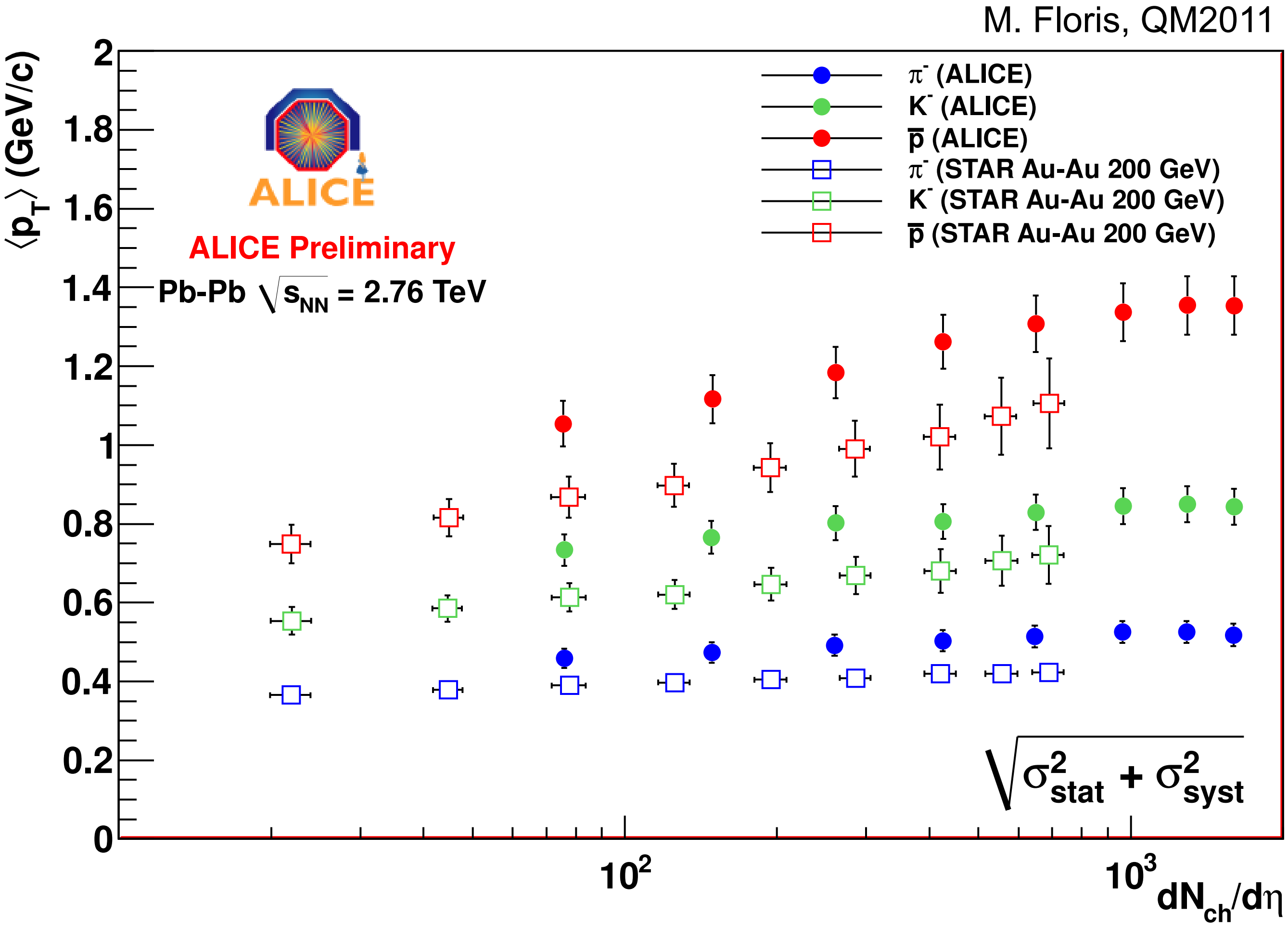
ALI-PERF-27125

identified hadron spectra - comparison to RHIC



harder than at RHIC

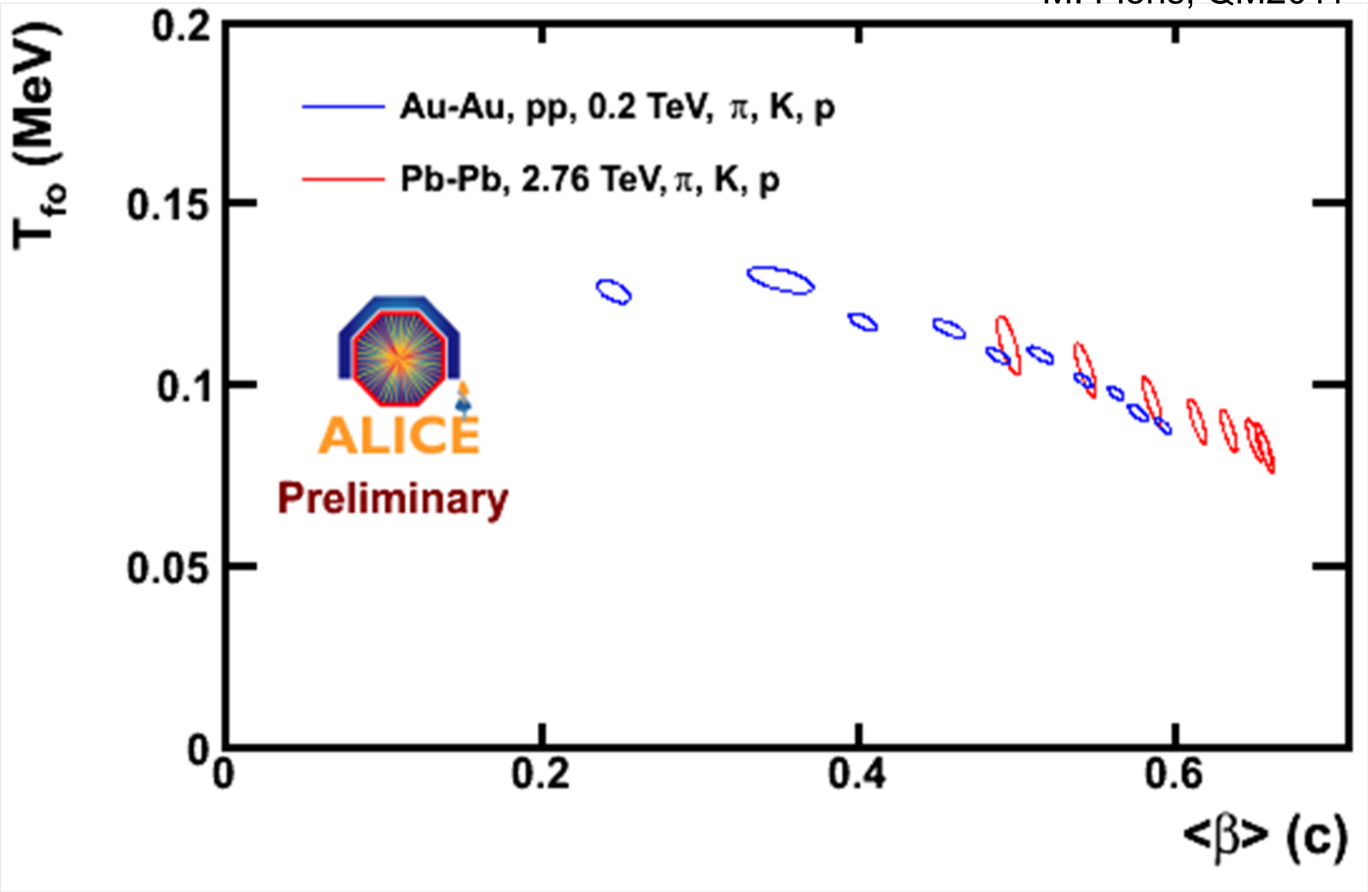
mean p_T of identified hadrons



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

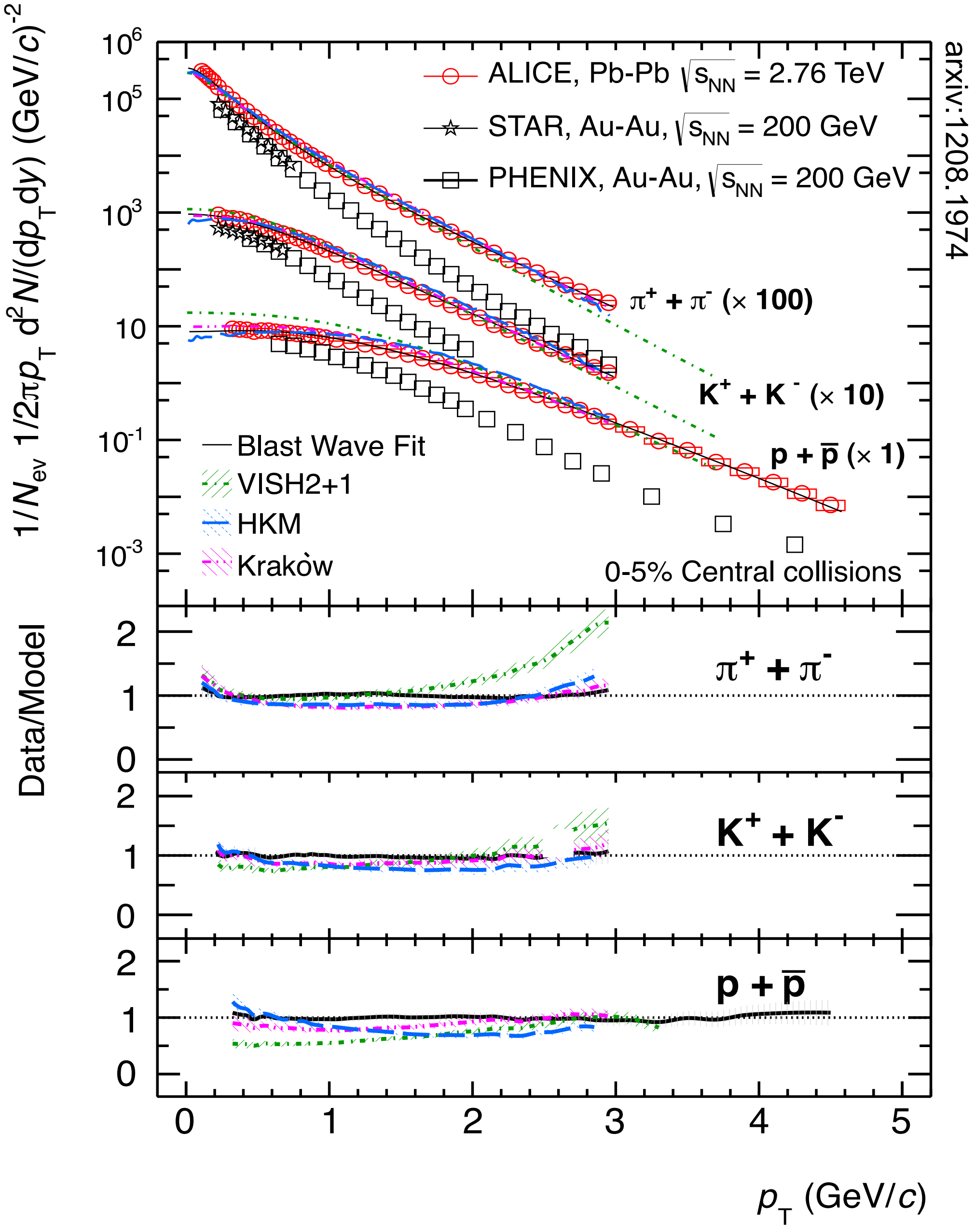
identified hadron spectra: blast wave fit

M. Floris, QM2011



10% more transverse flow than at RHIC

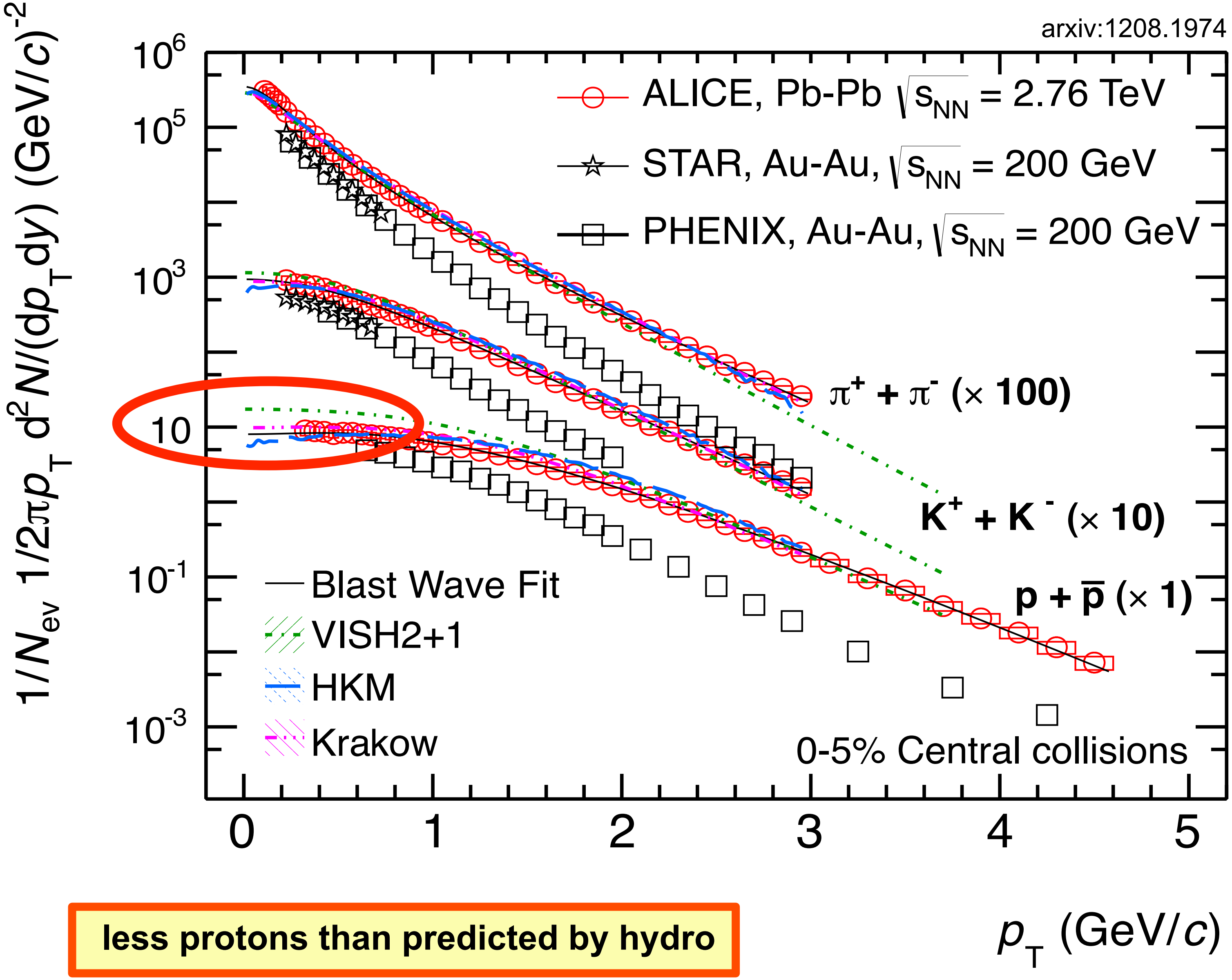
identified hadron spectra - comparison to models



harder than VISH2+1

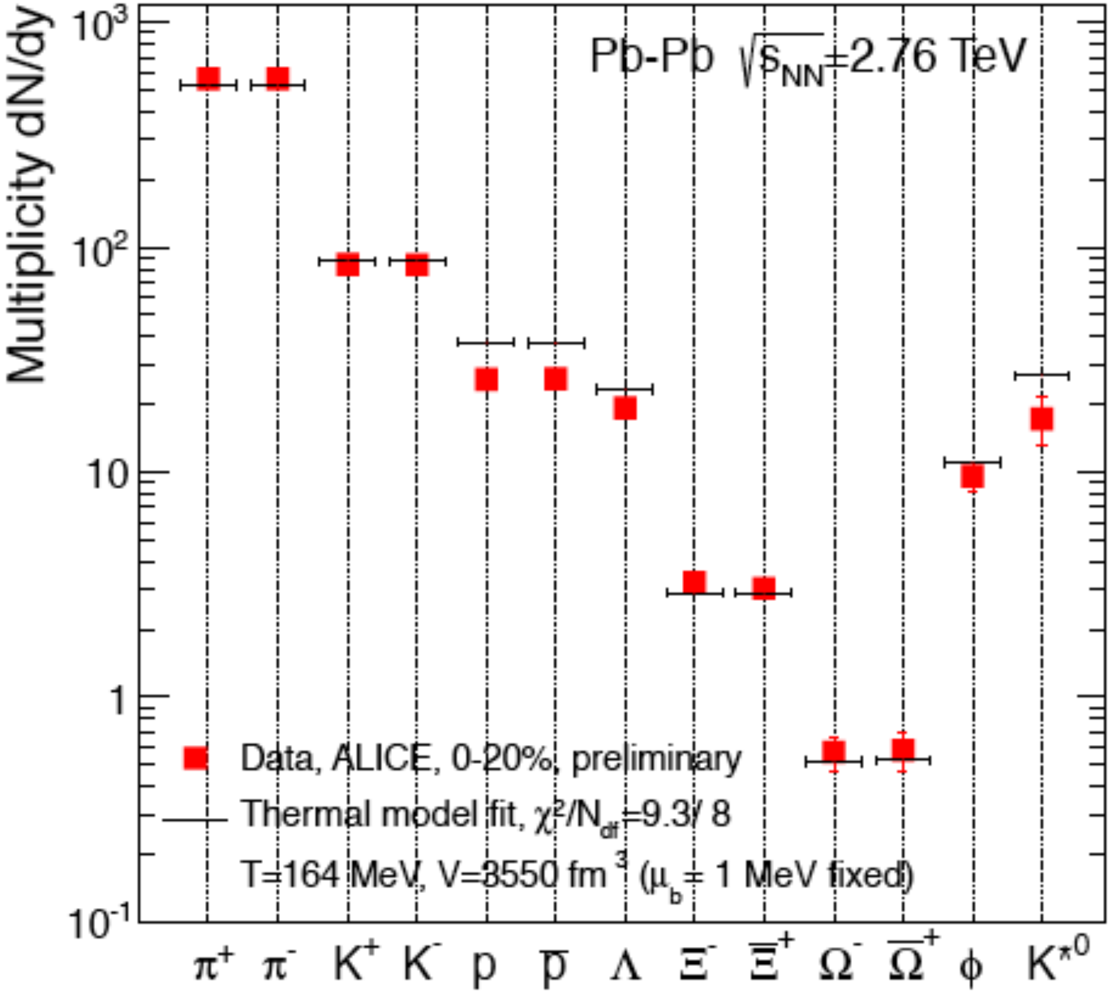
described by Krakow and HKM (early flow, cross-over, realistic EOS, resonances)

proton deficit in Pb-Pb collisions



less protons than predicted by hydro

proton deficit in Pb-Pb collisions



protons not included
in the fit

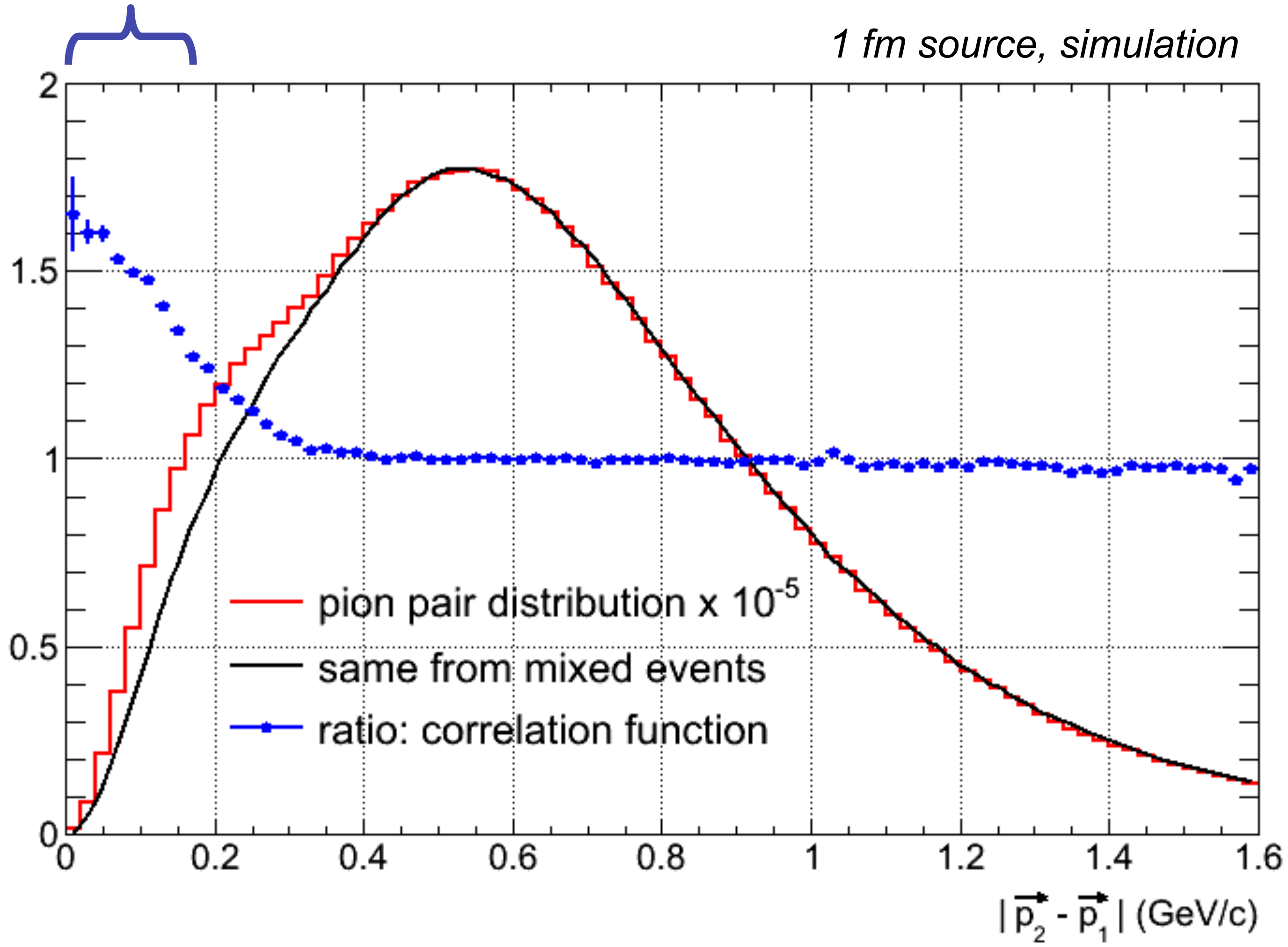
less protons than predicted by thermal model
suggesting a lower chemical freeze-out temperature T_{ch}
...but a lower T_{ch} excluded by Ξ and Ω

spatial extension

more on this subject: M. Szymanski, overview of ALICE femtoscopy, this conference

identical-pion correlation analysis technique (HBT)

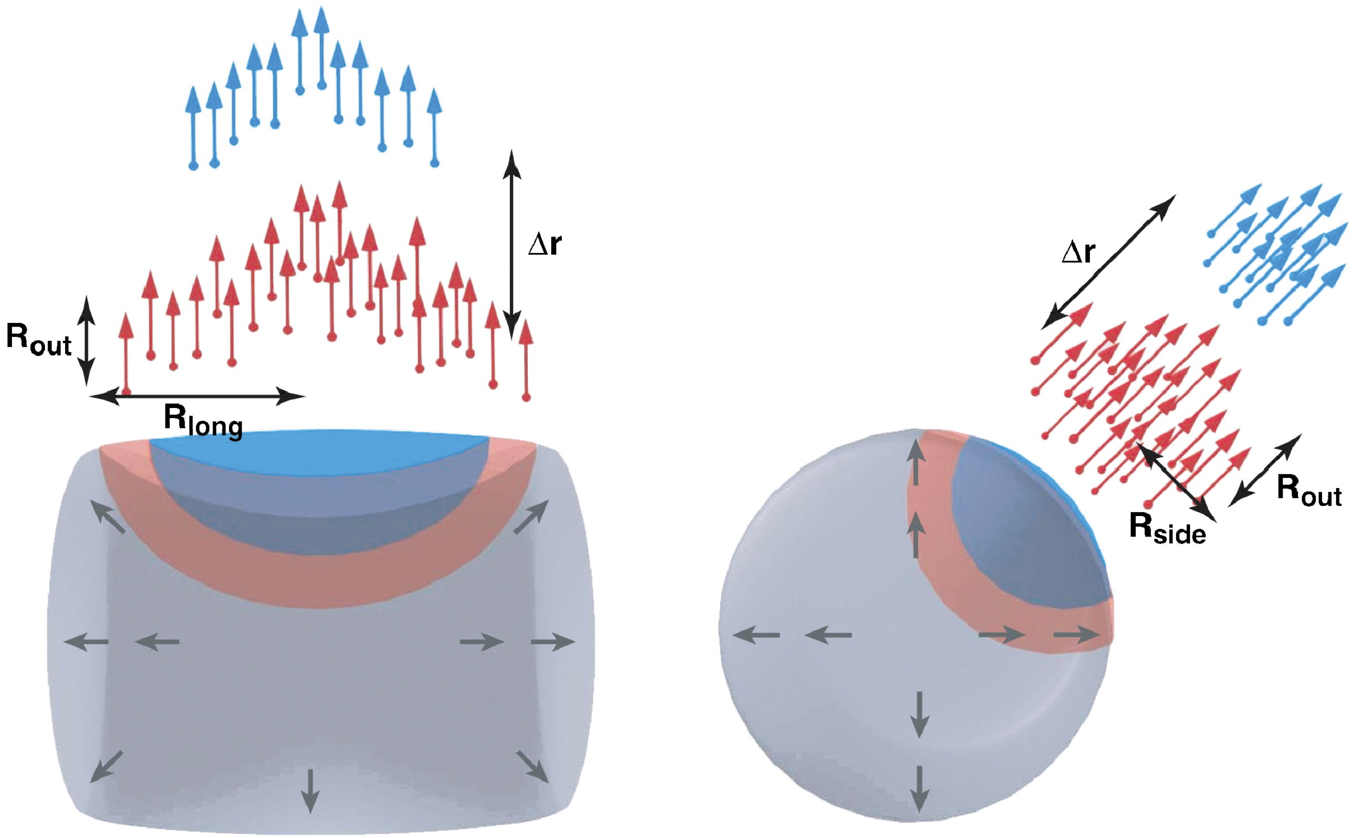
peak width ~ 1 / source size



1 fm source, simulation

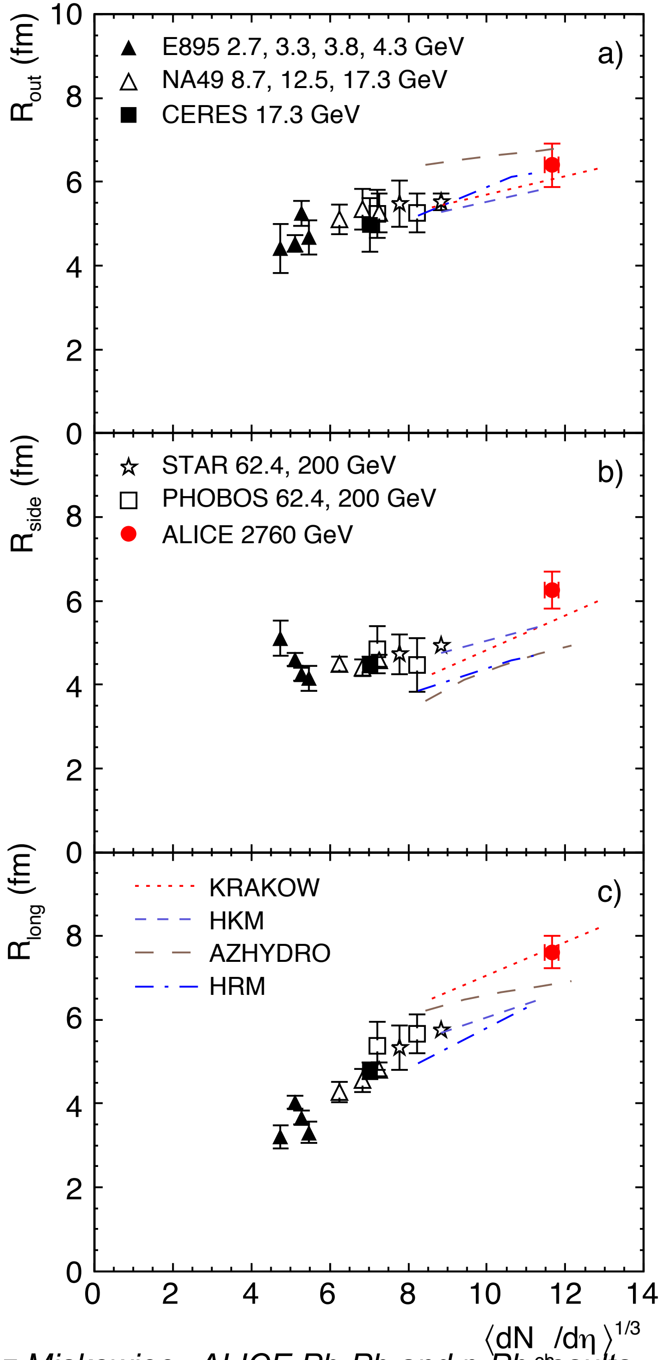
pion source size accessible experimentally

definition of out-side-long axes

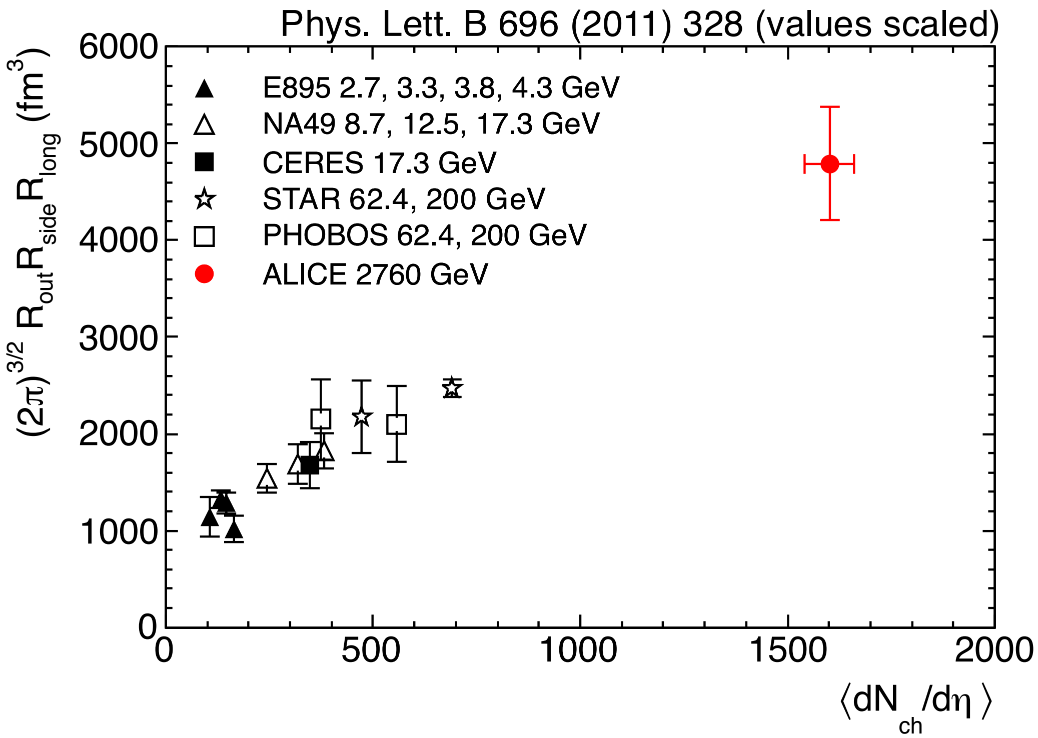


Lisa MA, et al. 2005.
Annu. Rev. Nucl. Part. Sci. 55:357–402

standard way to parametrize source size in 3-dim



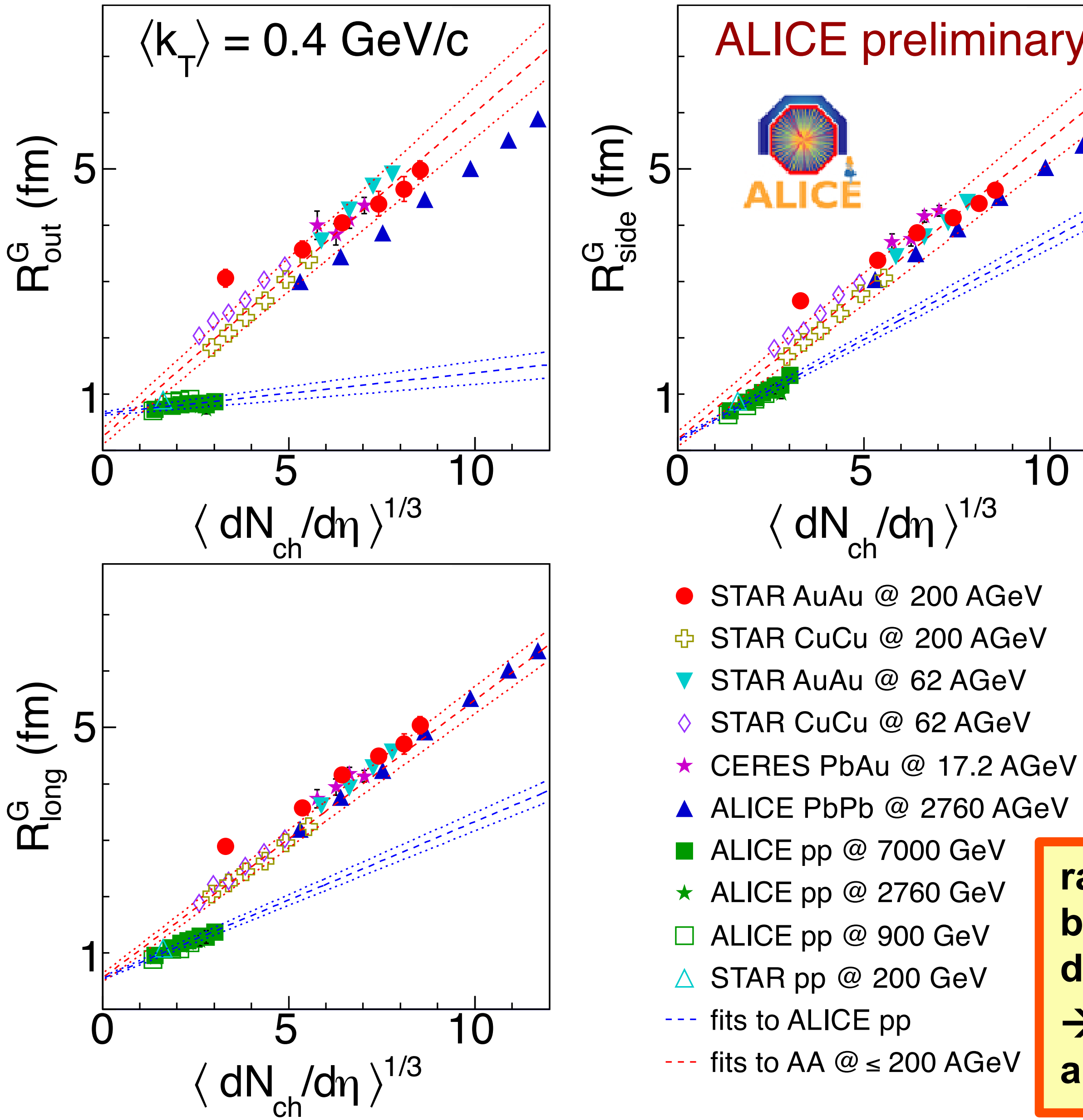
pion HBT


Phys. Lett. B 696 (2011) 328 (values scaled)

homogeneity volume 2 x larger than at RHIC

growth with energy reasonably well described by models tuned to RHIC data, containing early flow, cross-over, realistic EOS, and resonances

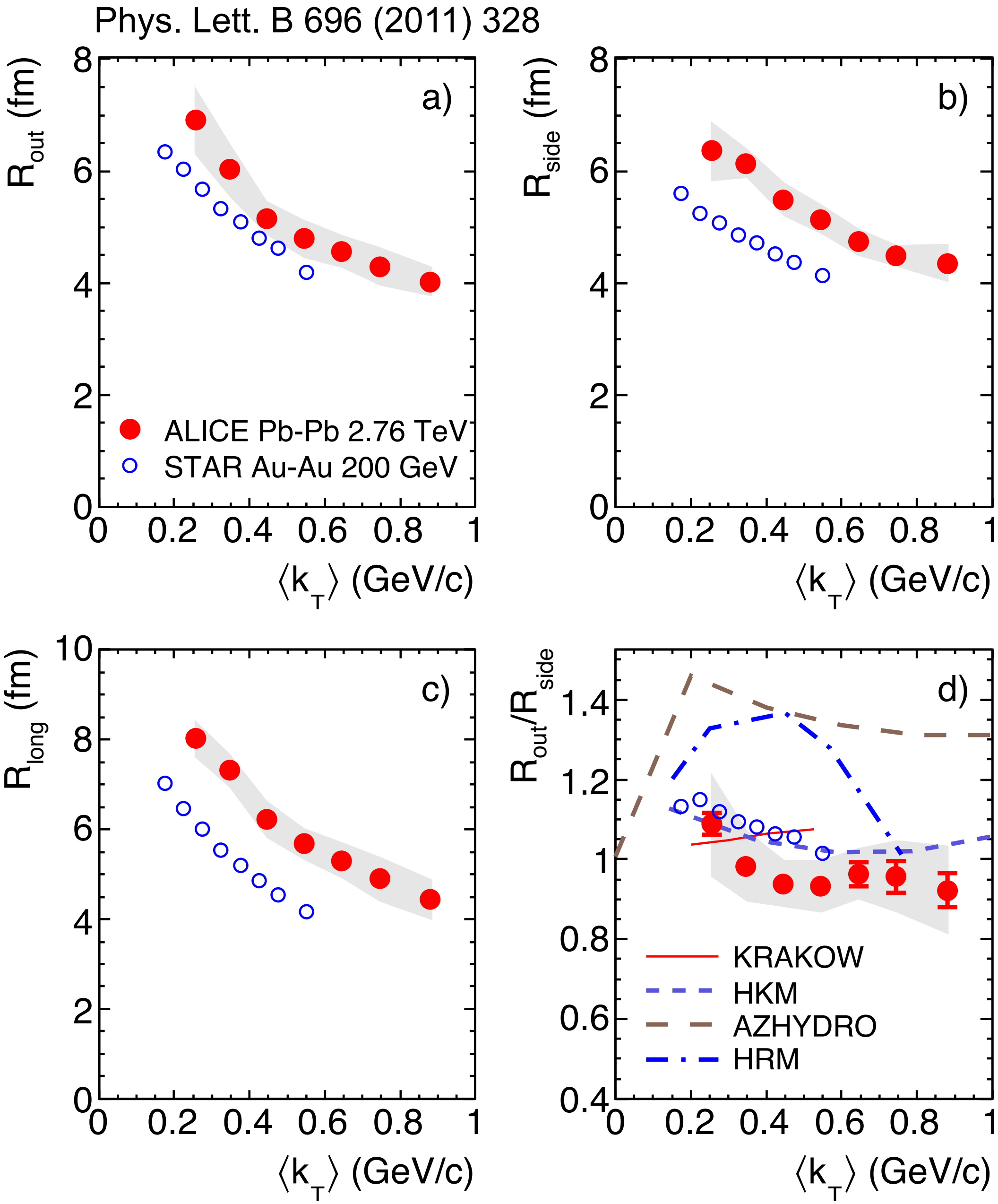
pion HBT



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

→ not only final multiplicity but also initial geometry matters

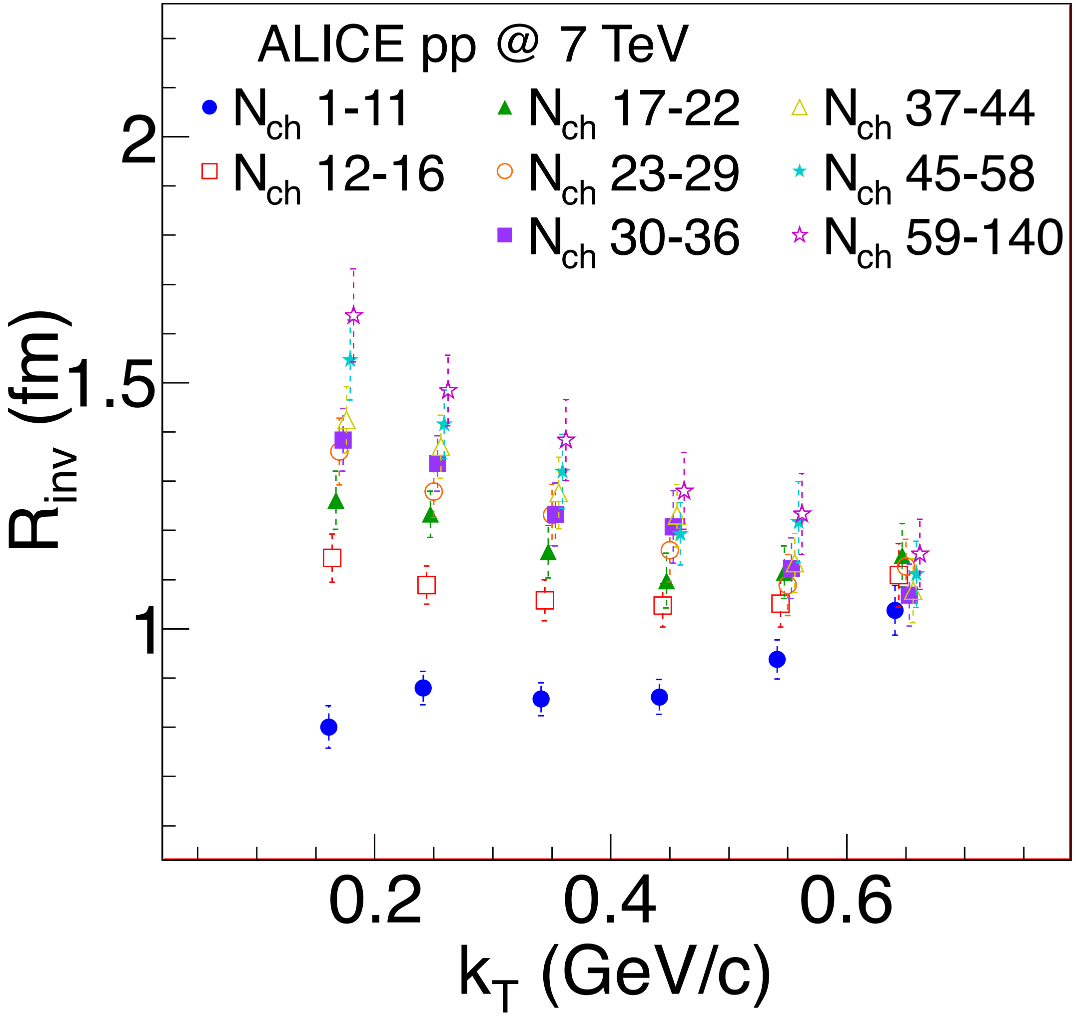
pion HBT



k_T dependence – sign of transverse flow

pion HBT

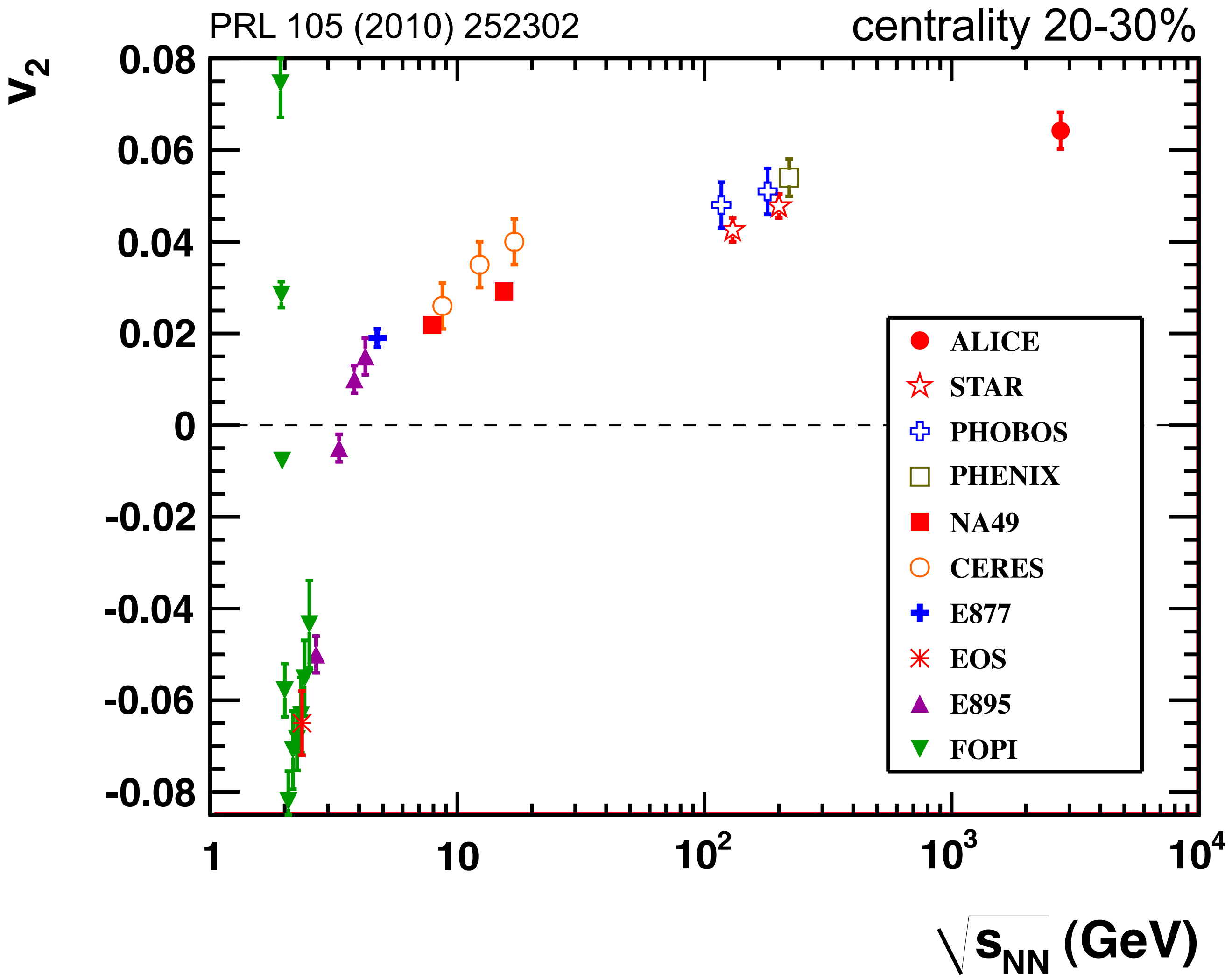
arXiv:1101.3665v1 [hep-ex]

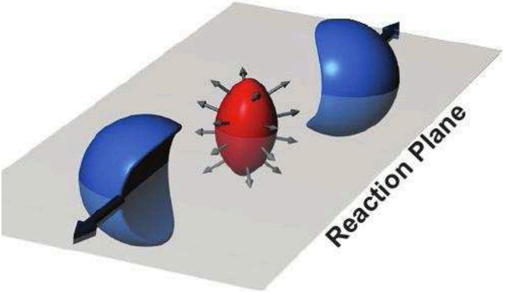


in pp, a similar k_T dependence develops with increasing multiplicity
→ flow in high-multiplicity pp?

flow

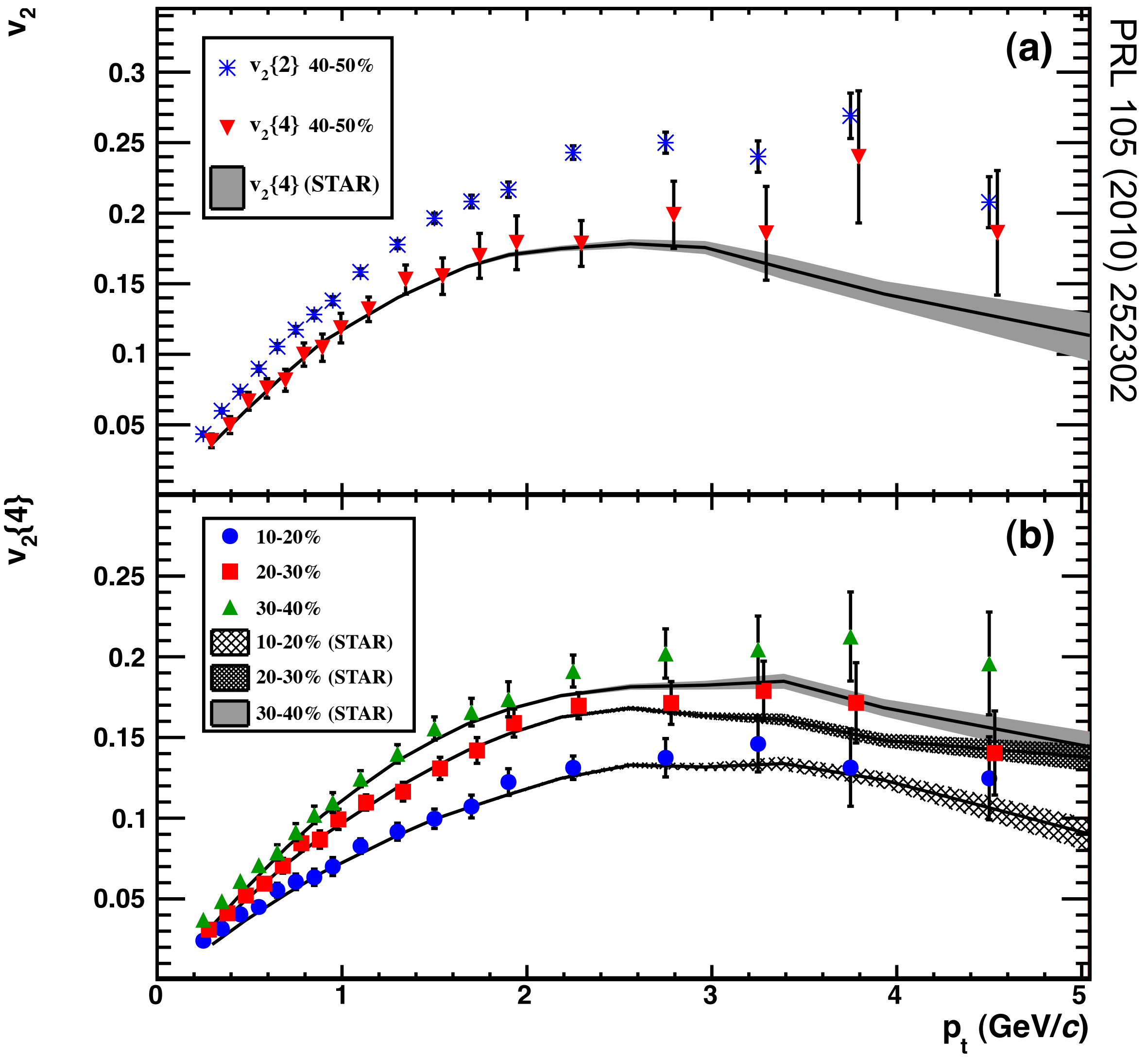
elliptic flow in Au and Pb collisions





hydrodynamic behavior continues at LHC energies

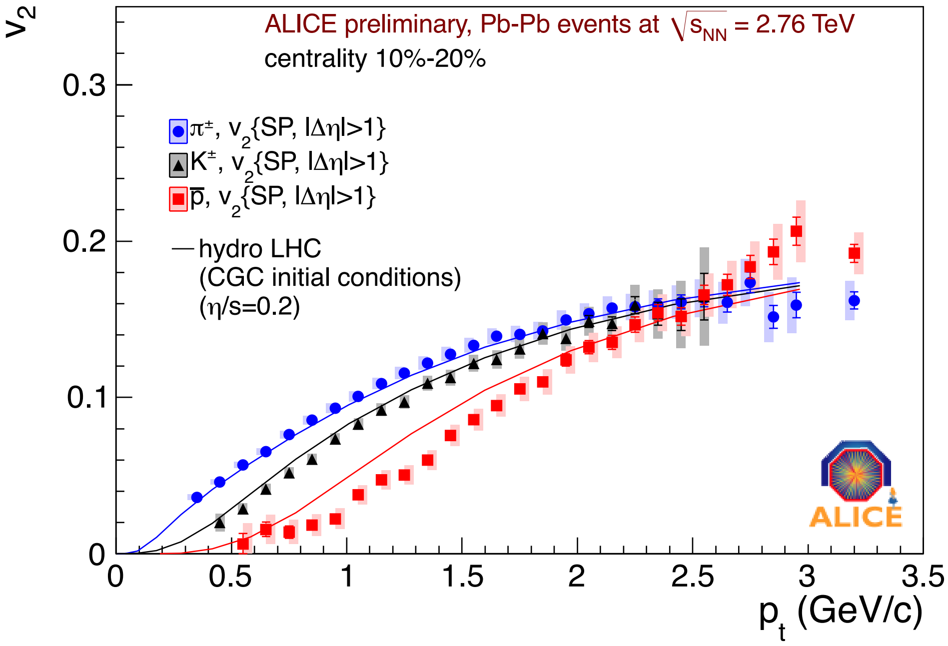
elliptic flow

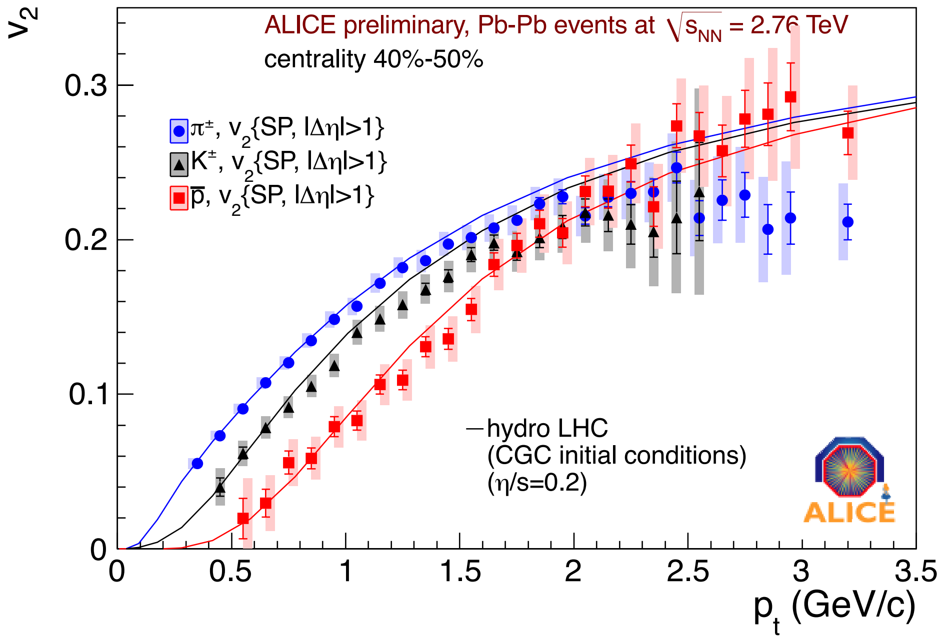


same pt dependence as at RHIC (and below, down to 40 GeV!)
inclusive v$_2$ at LHC higher only because <pt> higher

elliptic flow of identified hadrons

M. Krzewicki, QM2011

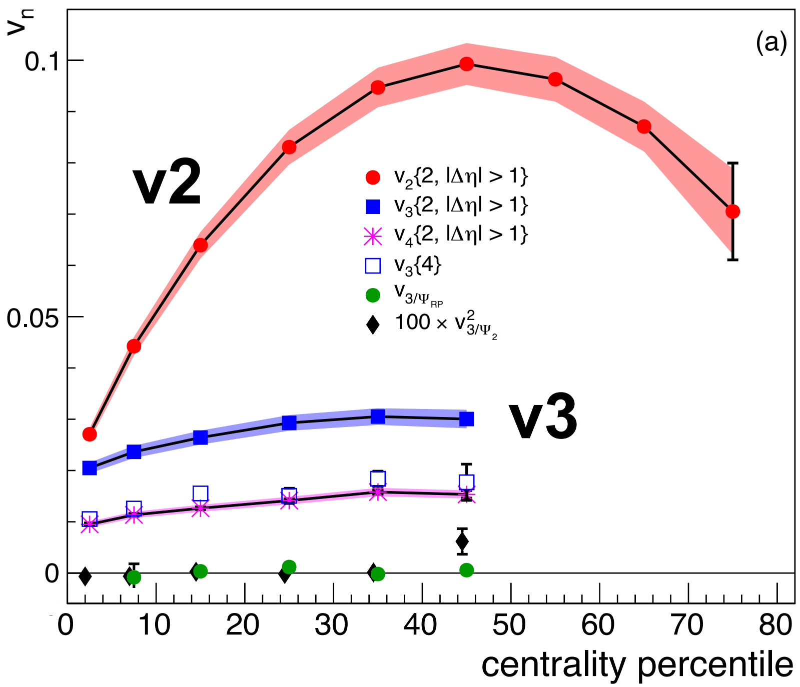


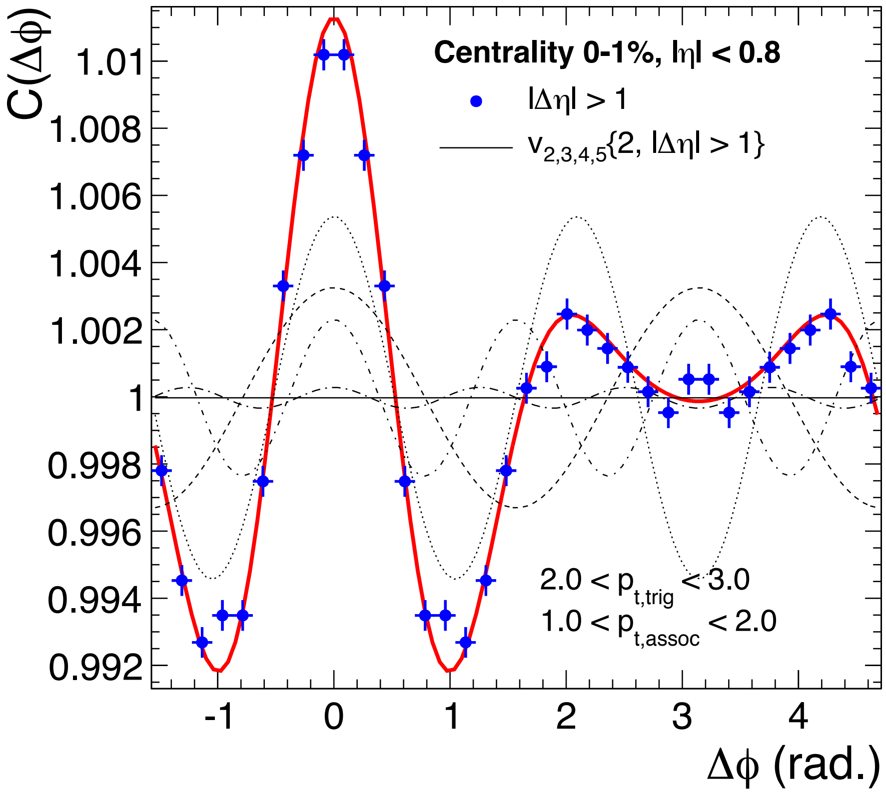


discrepancy for antiprotons – can be fixed by adding rescattering (UrQMD) to hydro (Heinz, Shen, Song, arXiv:1108.5323v1)

higher harmonics of flow

PRL 107 (2011) 032301



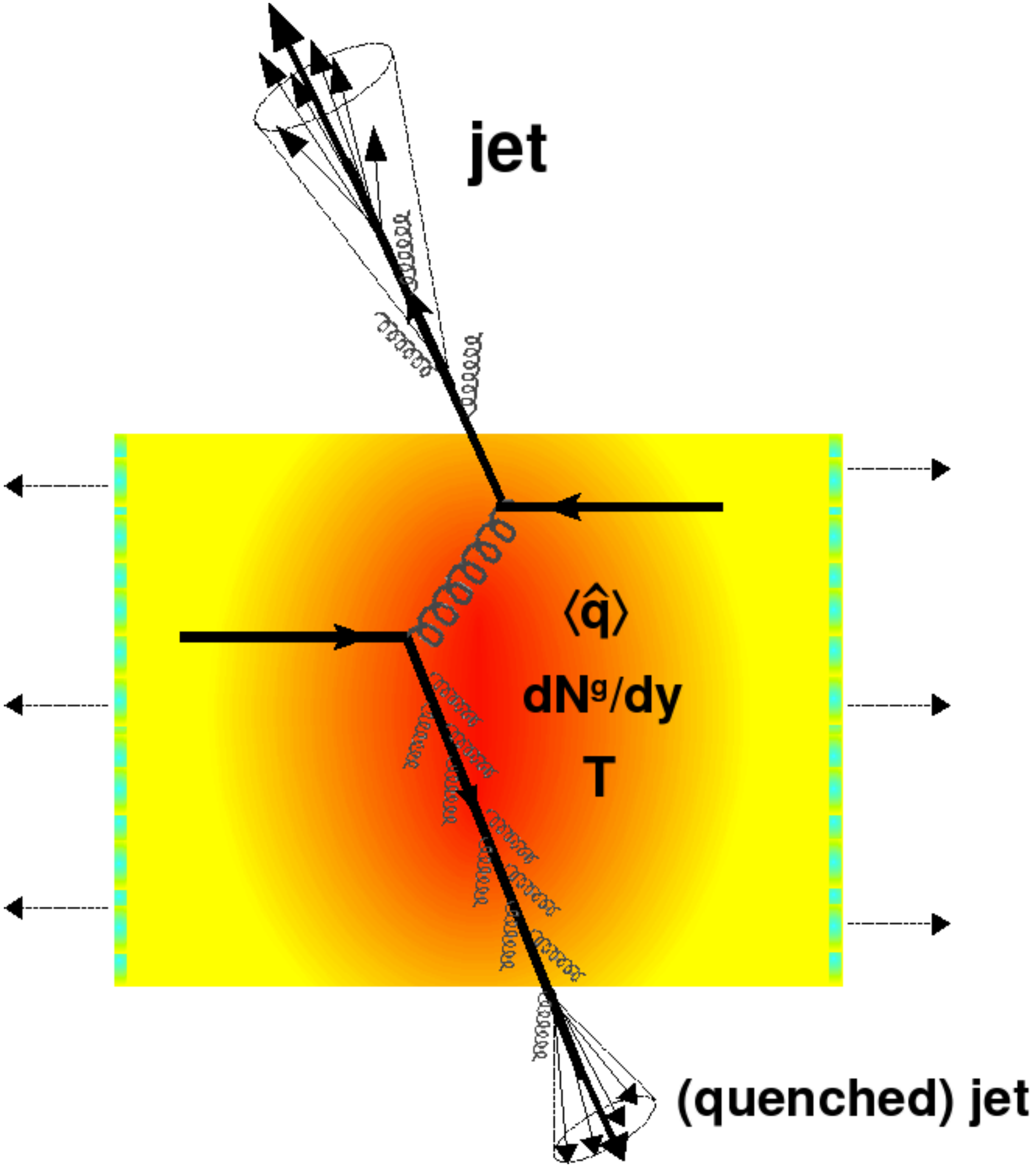


v_3 is not related to reaction plane
v_3 only weakly depends on centrality
v_2 and v_3 magnitudes reasonably well described by hydro
the azimuthal correlations at high p_T fully described by the flow coefficients

the peaks come from hydrodynamic flow

probing QCD matter

nuclear modification factor



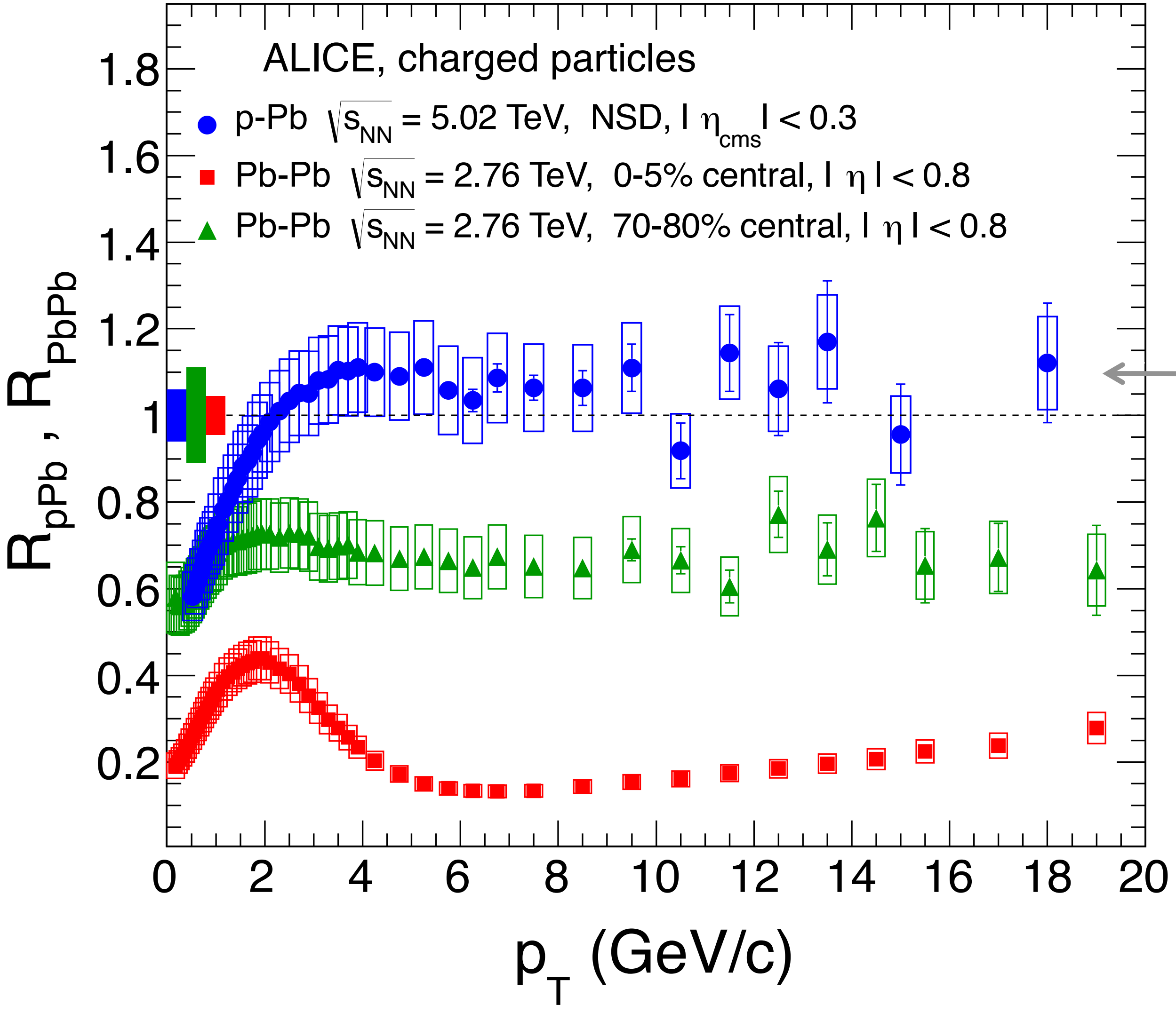
parton energy loss in color medium

manifesting as

suppression of high-pt particles in Pb-Pb

nuclear modification factor

arxiv: 1210.4520

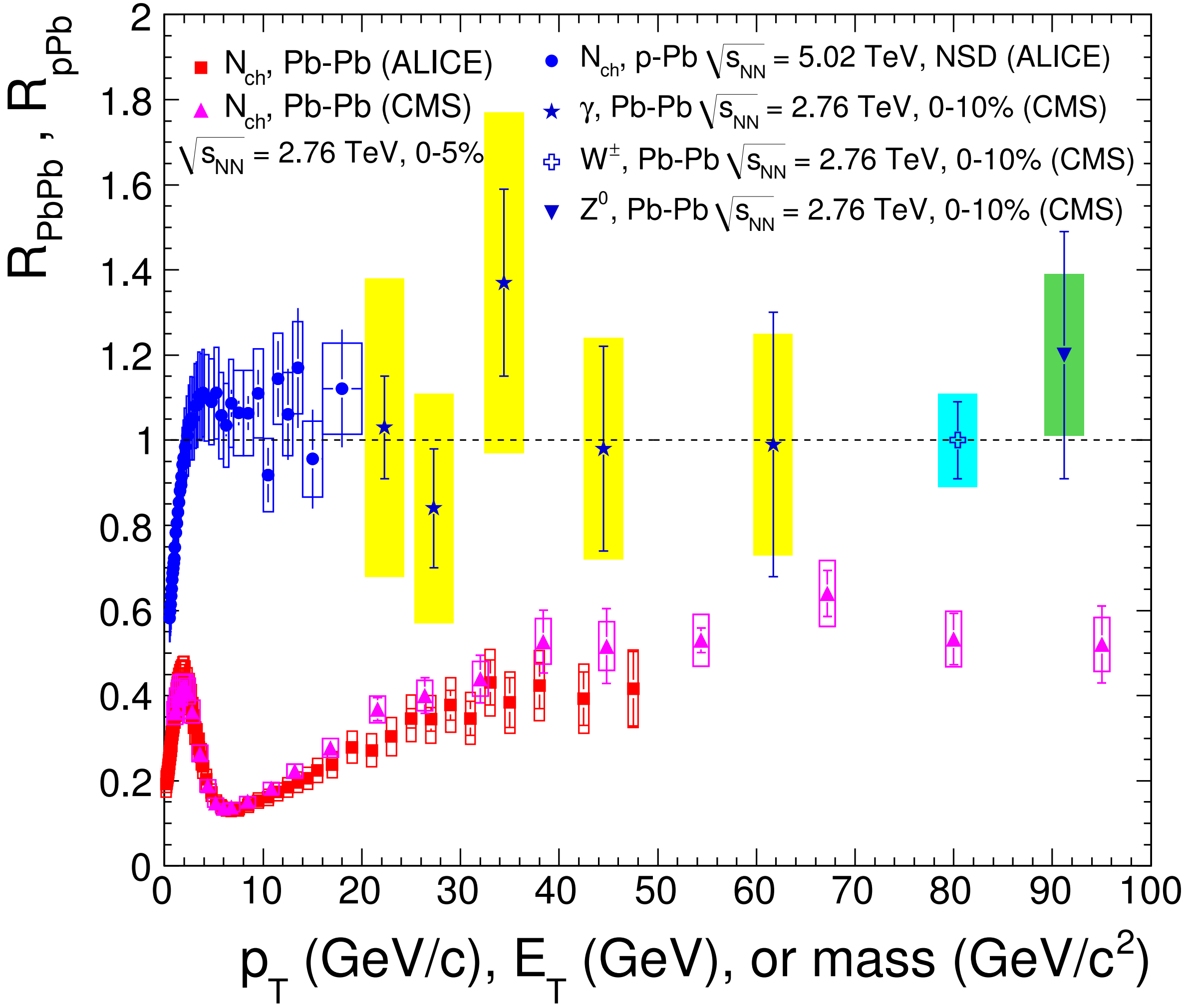


$$R_{AA}(p_T) = \frac{d^2N^{AA}_{ch}/d\eta\, dp_T}{\langle T_{AA}\rangle d^2\sigma^{pp}_{ch}/d\eta\, dp_T}$$

p-Pb is like pp
no suppression

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

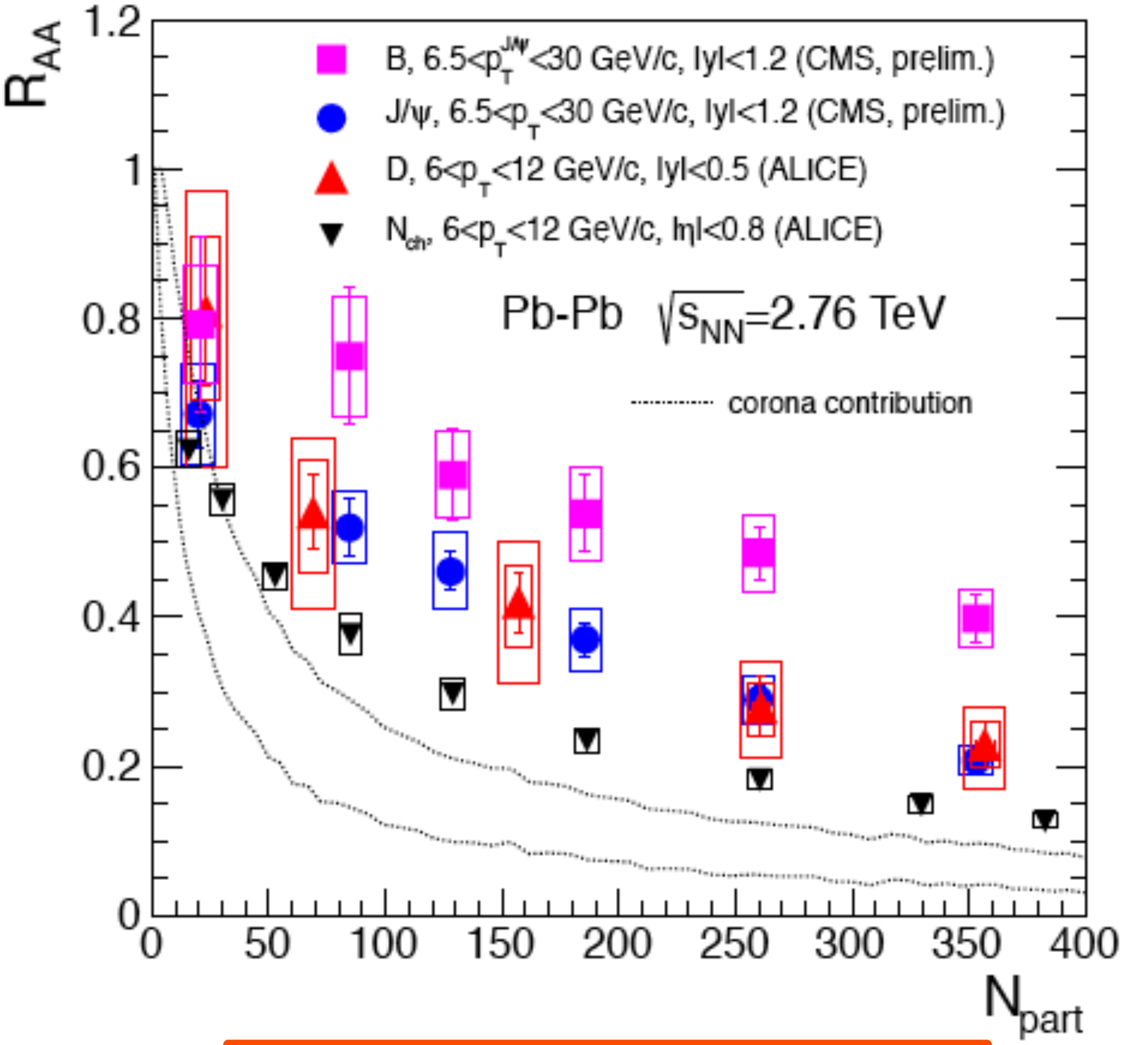
nuclear modification factor



ALI-DER-45646

no suppression of photons, W, Z0 in Pb-Pb

mass dependent energy loss



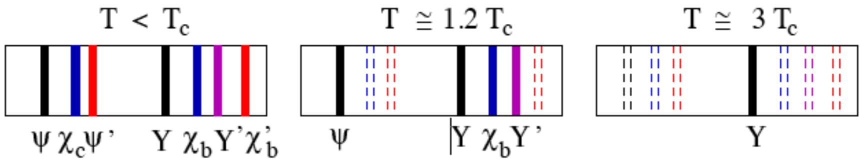
ALICE JHEP 09 (2012) 112
ALICE arxiv:1208.2711
CMS-PAS-HIN-12-014

compilation A. Andronic

less suppression for heavy quarks
B < D, J/Psi < charged particles

J/Psi suppression – or enhancement?

sequential suppression

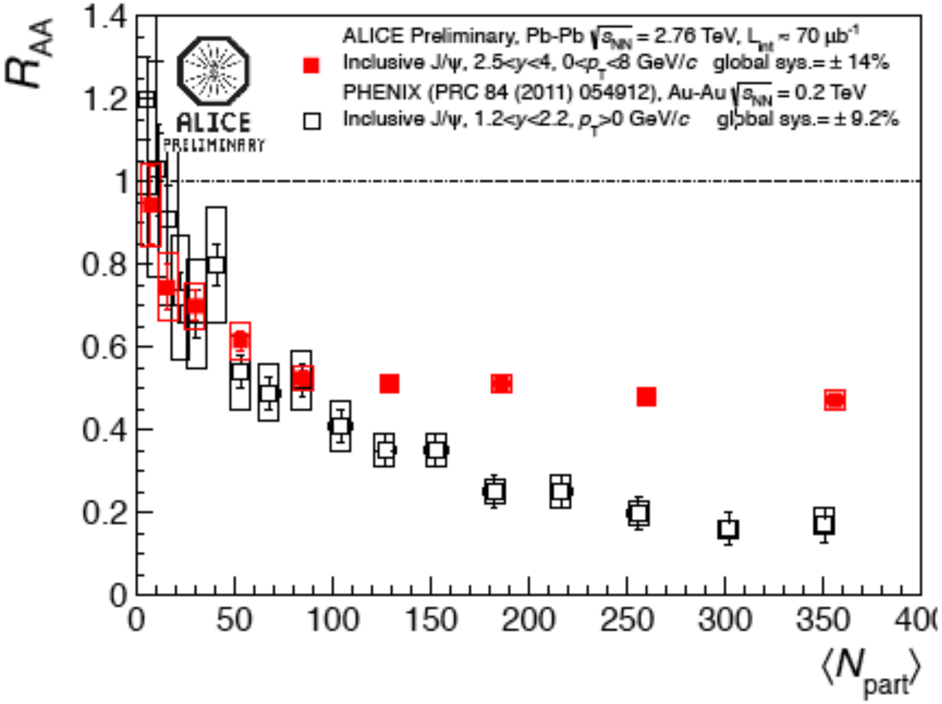


PLB 178 (1986) 416

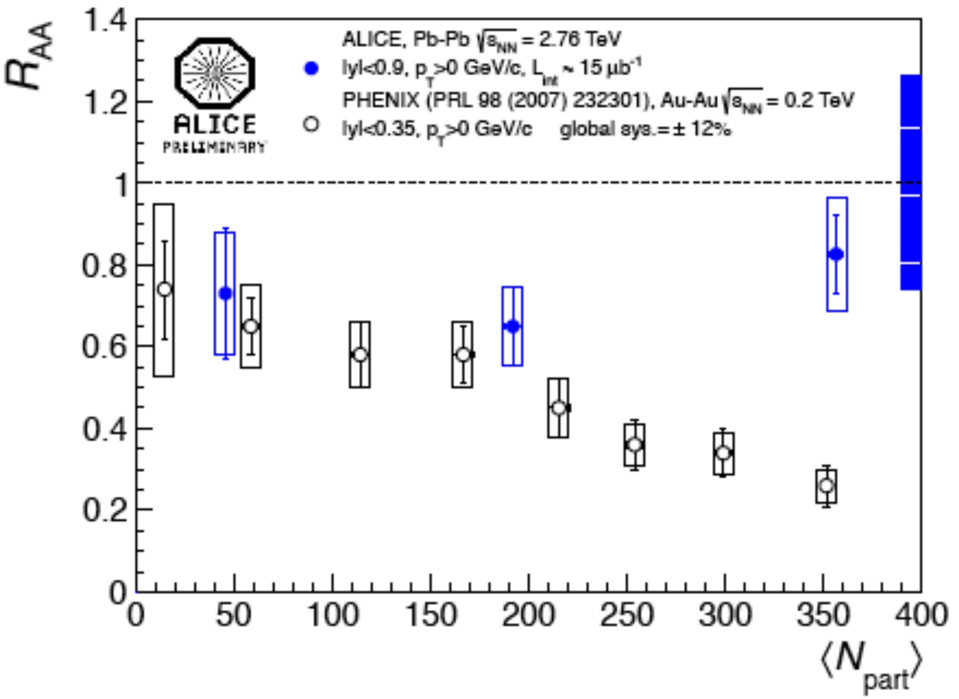
statistical hadronization c+cbar → J/Psi PLB 490 (2000) 196

both effects expected to be stronger at LHC than at RHIC

2.5 < y < 4



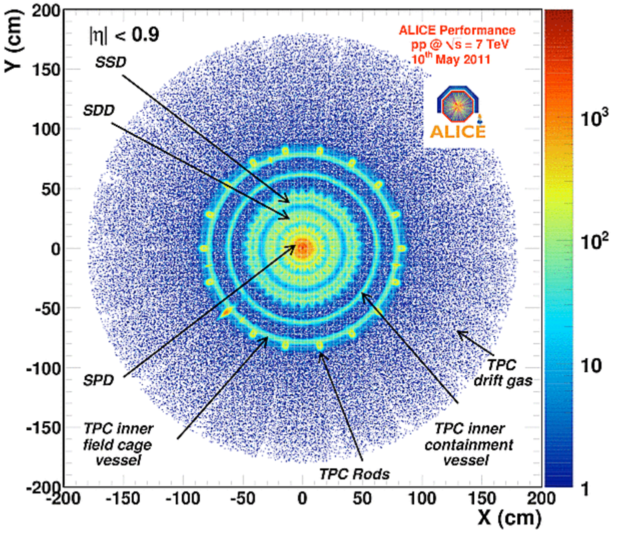
|y| < 0.9



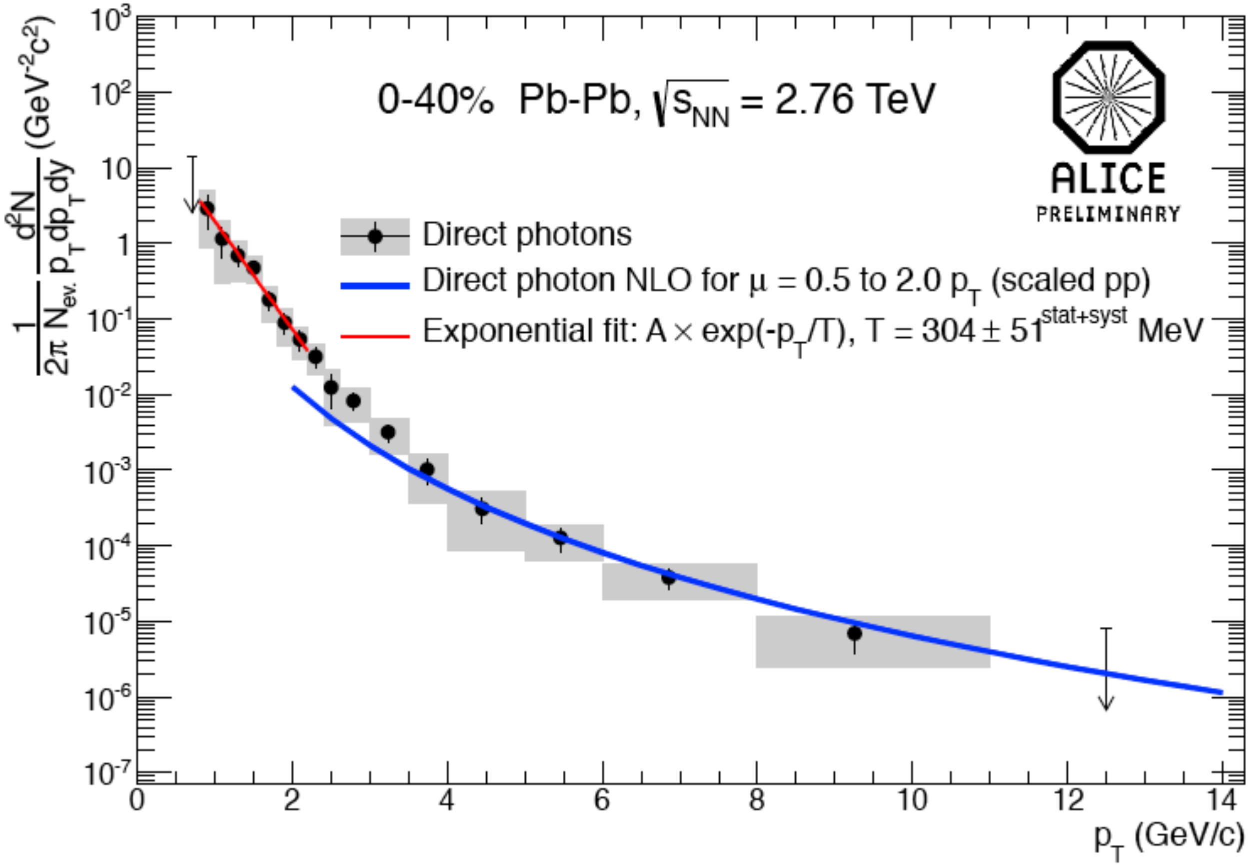
J/Psi production by statistical hadronization

hot photons

photons measured via conversions into e+e-



arXiv:1210.5958

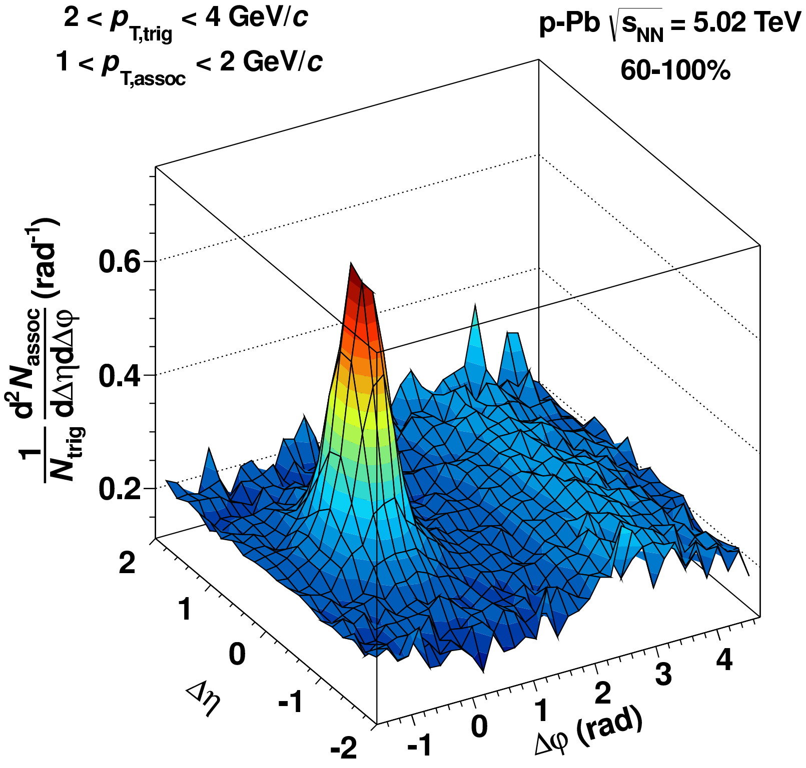


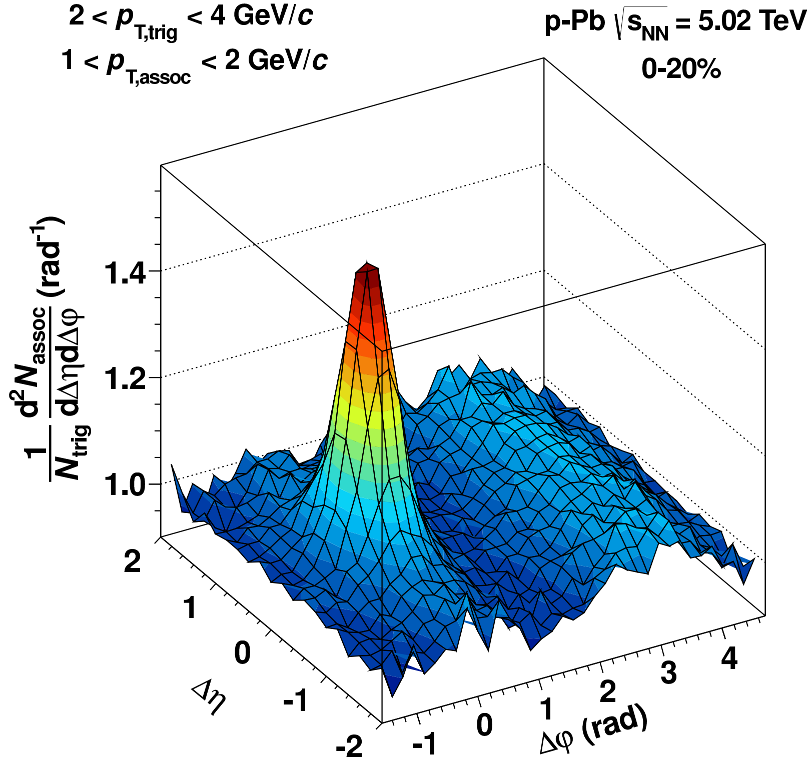
photon temperature higher than T_c

ridges in p-Pb

correlations originating from jets and other sources

arXiv:1212.2001

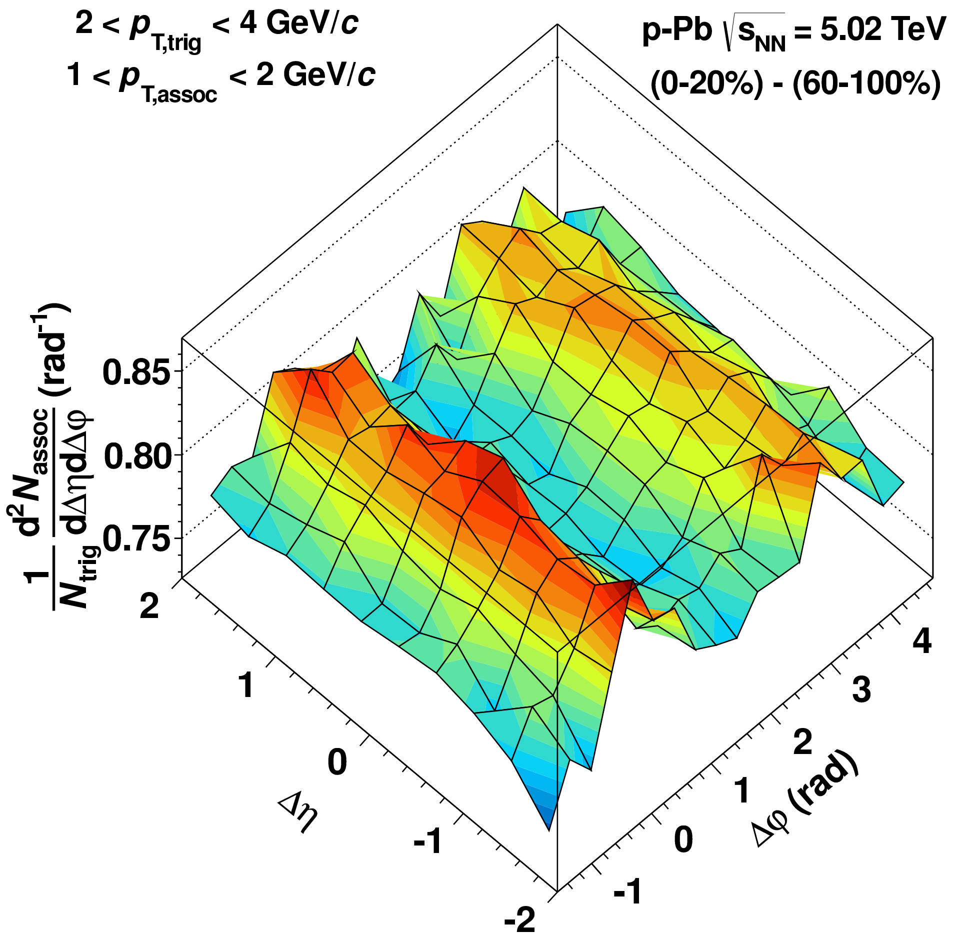




in high-multiplicity p-Pb, a ridge develops (like the one reported by CMS)

difference between central and peripheral

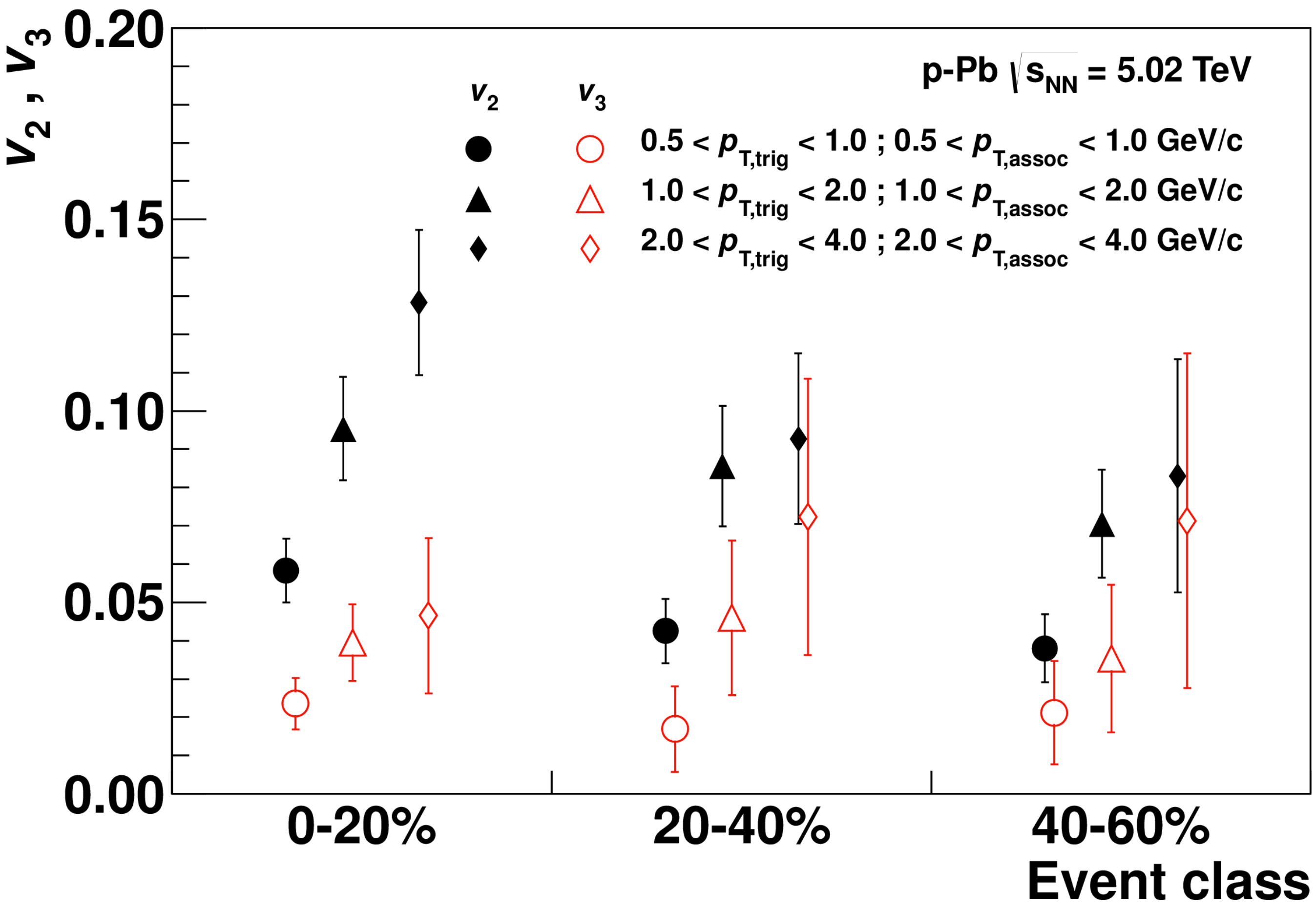
arXiv:1212.2001



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

properties of this double ridge

arXiv:1212.2001



Fourier analysis of the ridge → v2 and v3

like flow: increase with pt

unlike flow: increase with centrality

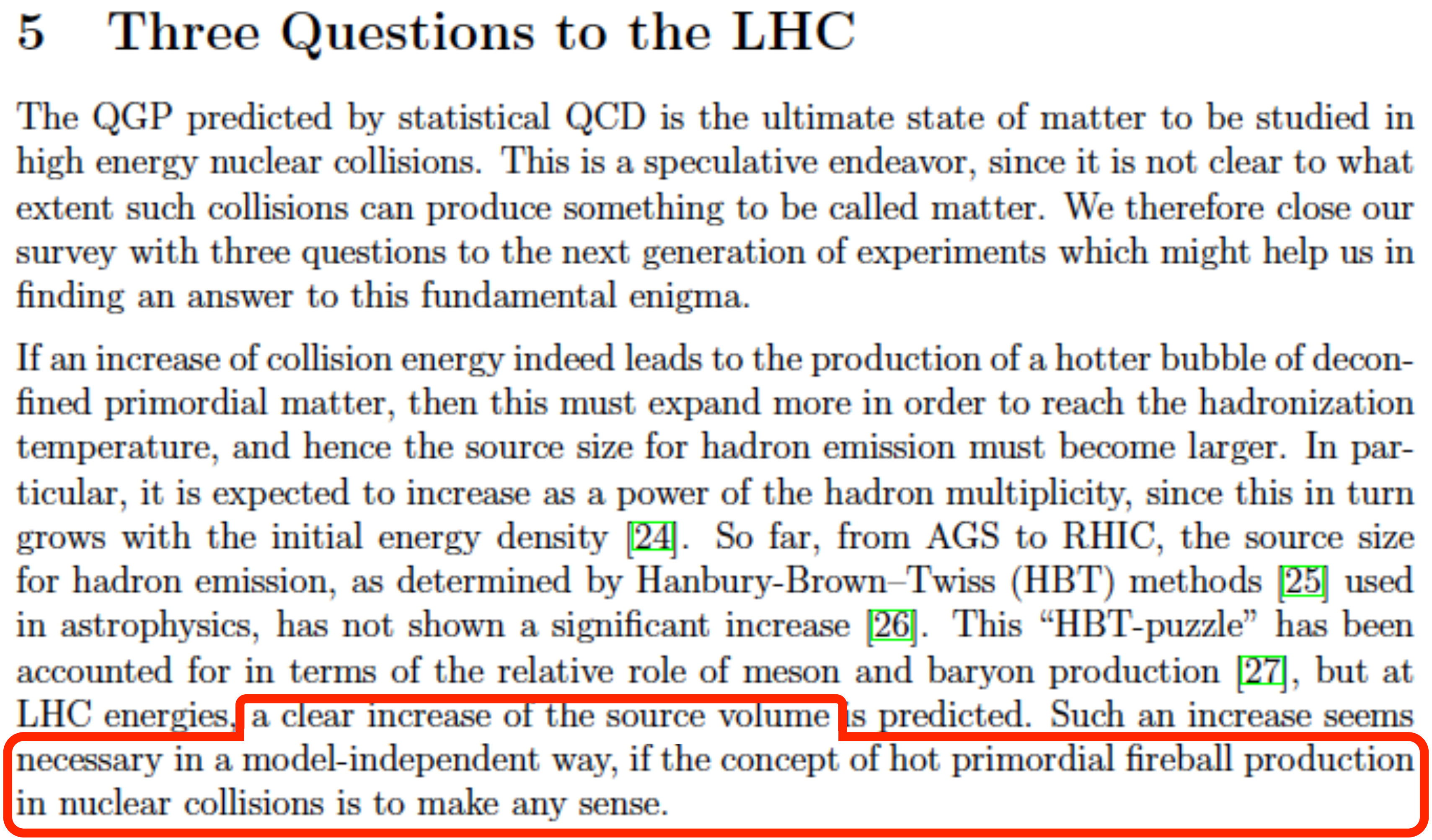
three questions to LHC

Helmut Satz, arXiv:1101.3937 “The Quark-Gluon Plasma”
Student Day Lecture, Goa, Dec 2010

… and three answers

first question to LHC: particle-source size

Helmut Satz, arXiv:1101.3937 “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

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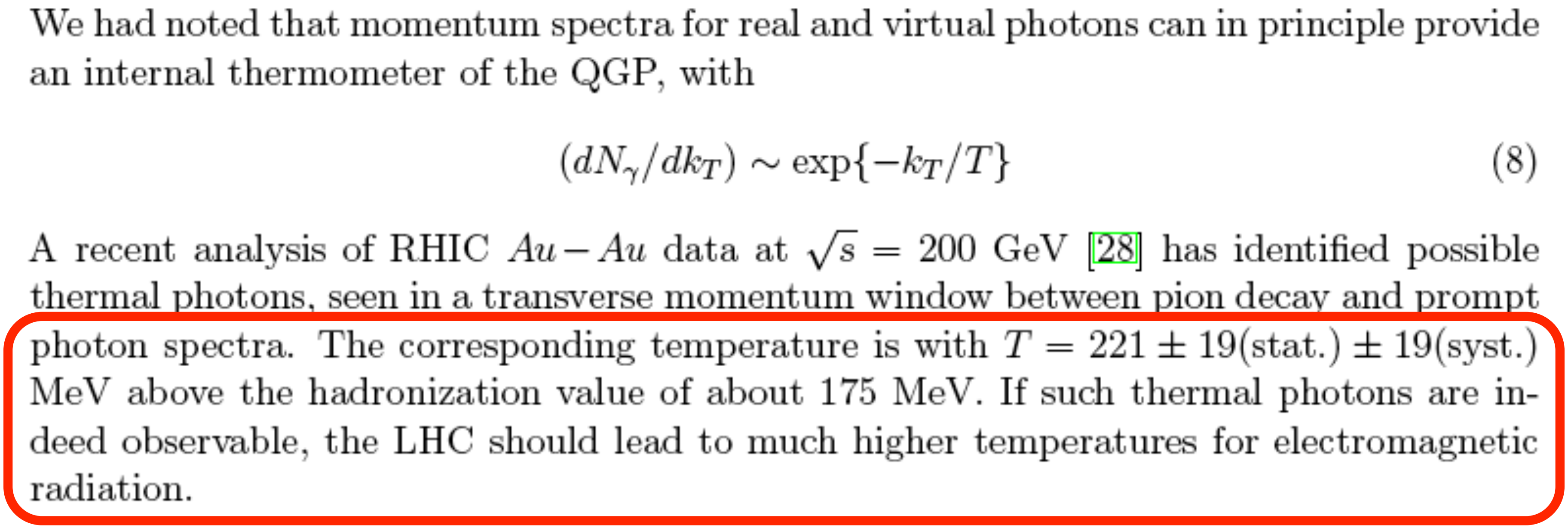

We had noted that momentum spectra for real and virtual photons can in principle provide an internal thermometer of the QGP, with

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

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/Psi suppression or regeneration

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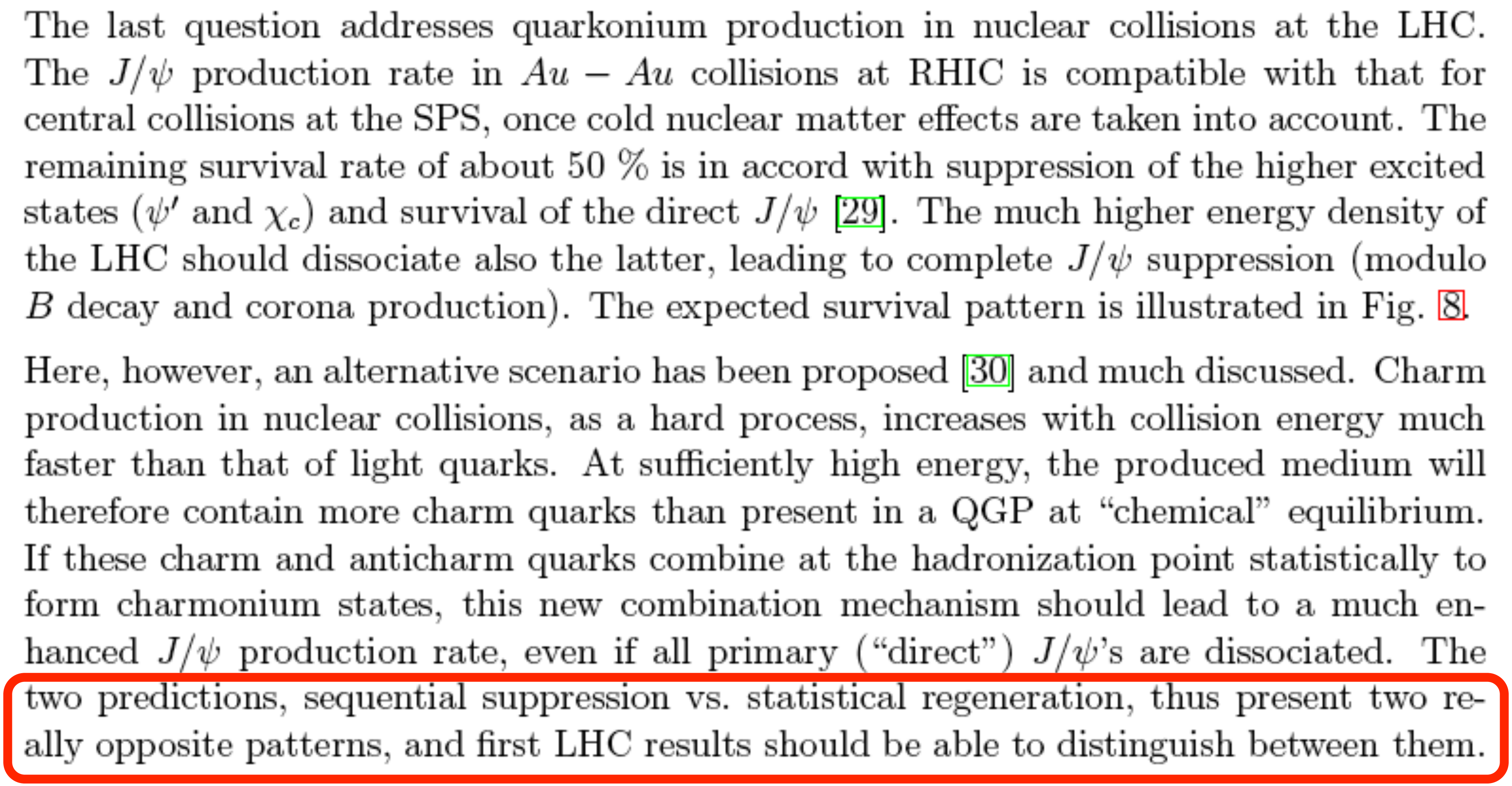


The last question addresses quarkonium production in nuclear collisions at the LHC. The J/ψ production rate in $Au - Au$ collisions at RHIC is compatible with that for central collisions at the SPS, once cold nuclear matter effects are taken into account. The remaining survival rate of about 50 % is 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

summary

new insight into the reaction dynamics from LHC

- Mach cone and ridge challenged
- HBT $R(k_T)$ dependence developing with multiplicity in pp
- proton puzzle: lower yield, lower v_2 than expected
- nuclear suppression decreasing at very high pt (R_{AA} increasing)
- J/Psi production via statistical regeneration
- ridges 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

working at CERN - requirements

always wear safety equipment

stay concentrated

handle properly
the Unexpected

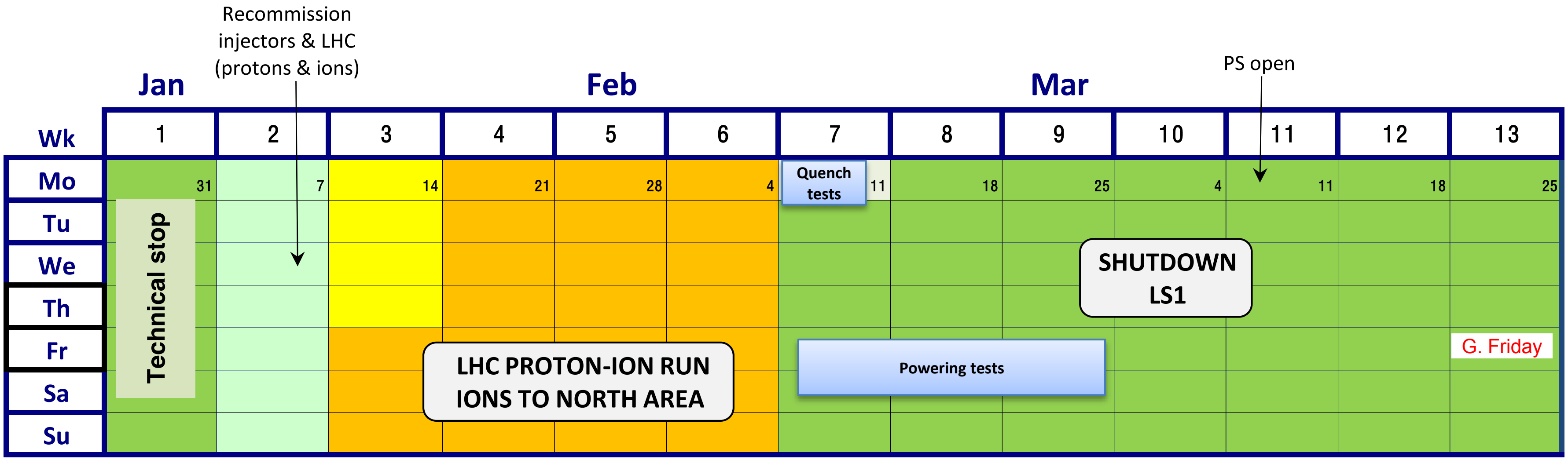
ML

July 31, 2012

V1.1

2013 LHC & Injector Schedule

Draft



Recommission injectors & LHC (protons & ions)

PS open

	Jan				Feb				Mar				
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13
Mo	31	7	14	21	28	4	11	18	25	4	11	18	25
Tu													
We													
Th													
Fr													G. Friday
Sa													
Su													

Technical stop

Quench tests

LHC PROTON-ION RUN
IONS TO NORTH AREA

Powering tests

SHUTDOWN
LS1

ALICE plans

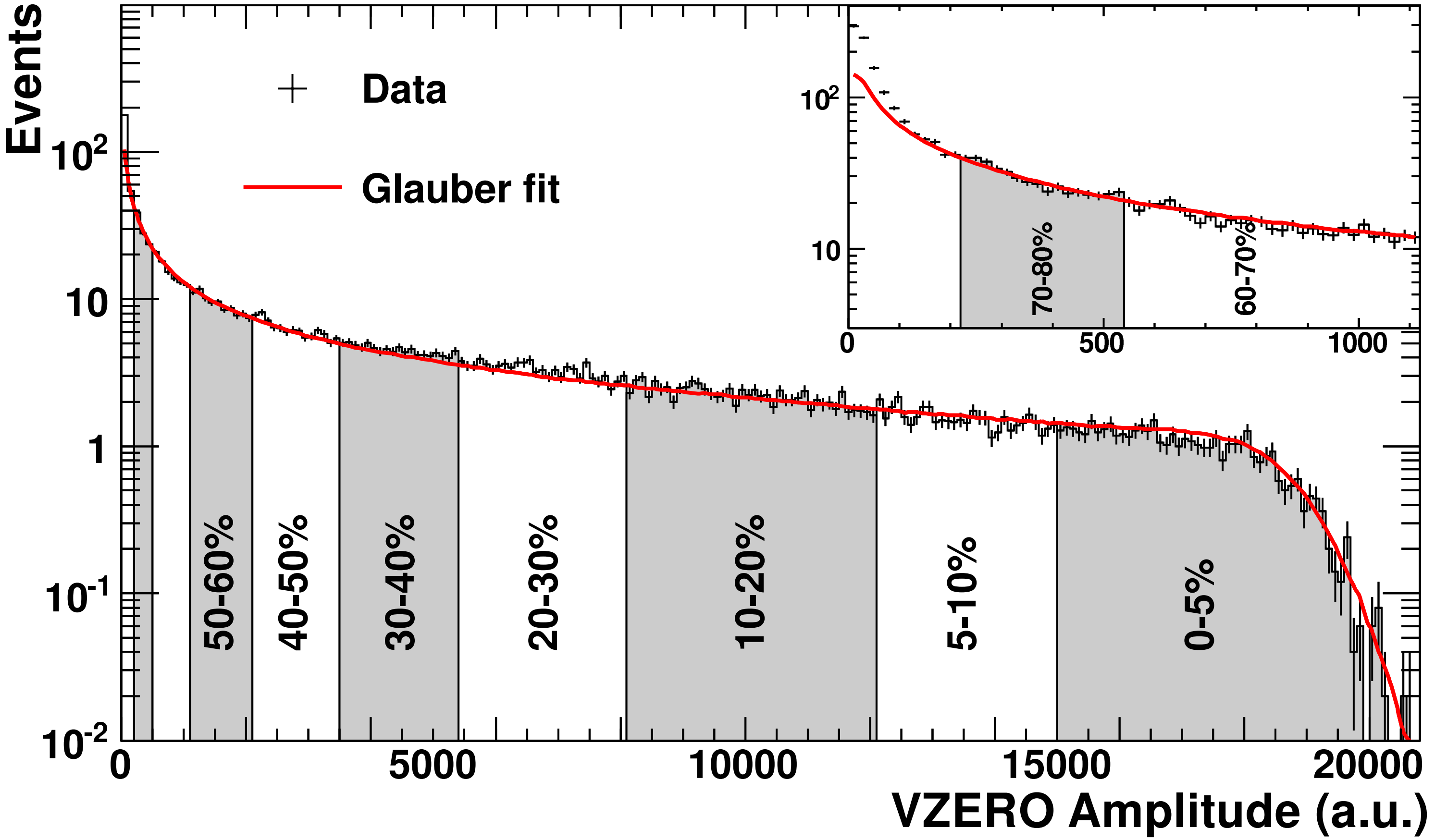
2013	LS1: completion of TRD,
2014	PHOS, and DCAL
2015	Pb-Pb at sqrt(s)=5.1 TeV
2016	Pb-Pb at sqrt(s)=5.5 TeV
2017	Pb-Pb at sqrt(s)=5.5 TeV
2018	LS2: lumi upgrade from 0.5 to 50 kHz Pb-Pb, 3 x better vertexing
2019	possibly Ar-Ar
2020	possibly p-Pb at full energy
2021	possibly Pb-Pb - reach 1 nb^{-1}
2022	LS3
later	reach 10 nb^{-1} Pb-Pb

ongoing upgrade studies

MFT	Muon Forward Tracker	pixel Si -4<eta<-2.5, better res. and S/B, c/b
VHMPID	Very High Momentum PID	gas Cher., pi/K/p separation in 5<p<25 GeV
FoCal	Forward EM Calorimeter	W+Si 2.5<eta<4.5

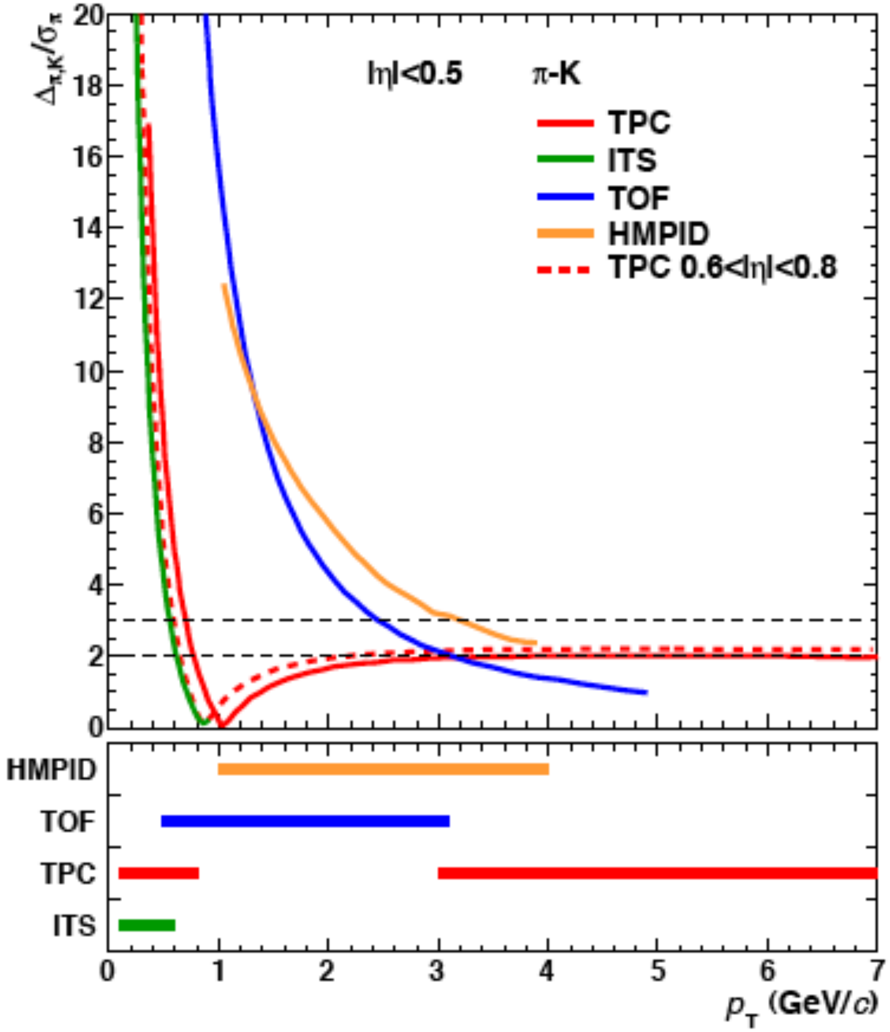
centrality determination

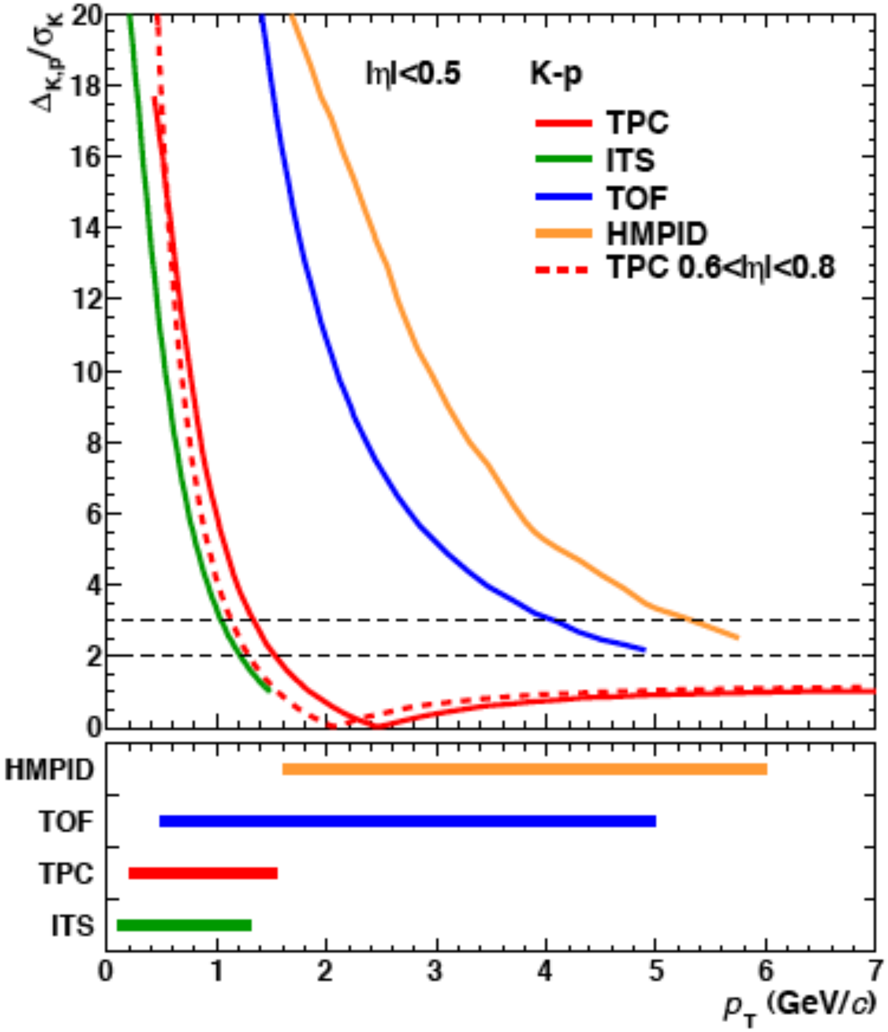
PRL 106 (2010) 032301



- VZERO covers $-3.7 < \eta < -1.7$ and $2.8 < \eta < 5.1$, signal ~ multiplicity
- fit function: a Ncoll + b Npart sources, each source producing particles following a negative binomial distribution
- centrality resolution better than 1%

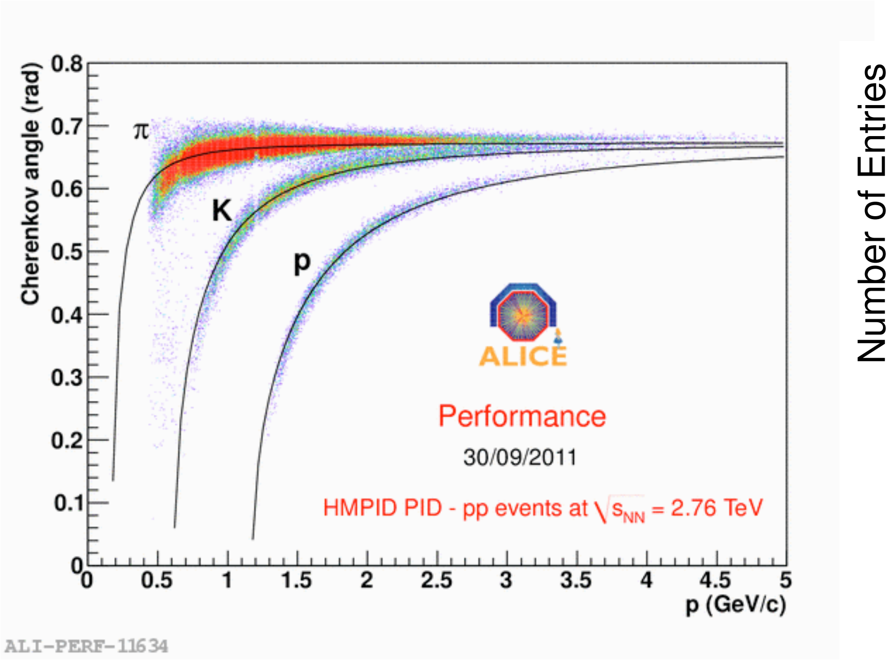
hadron identification

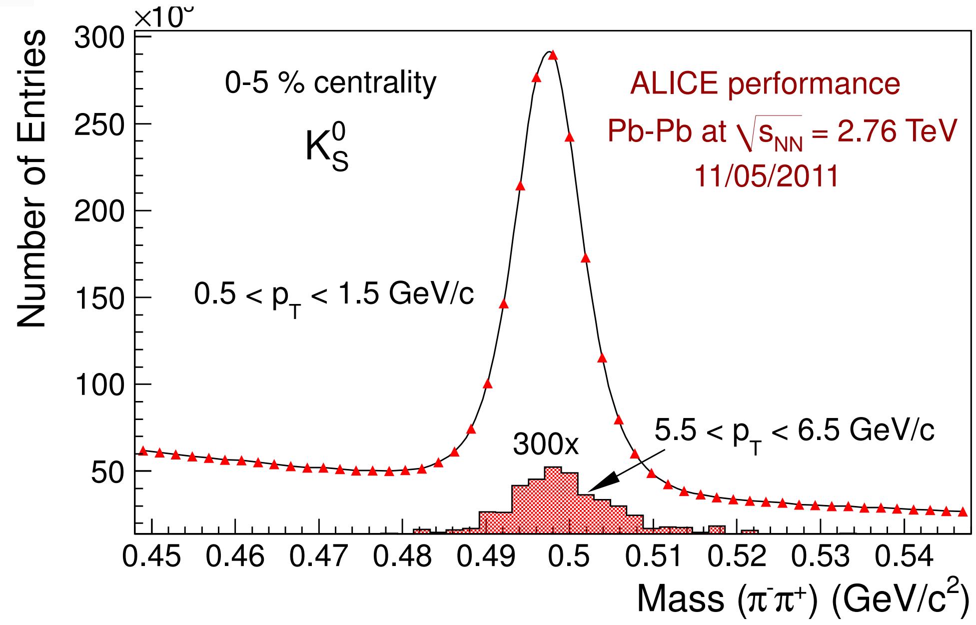

pion-kaon separation


kaon-proton separation

good PID performance over large pt range

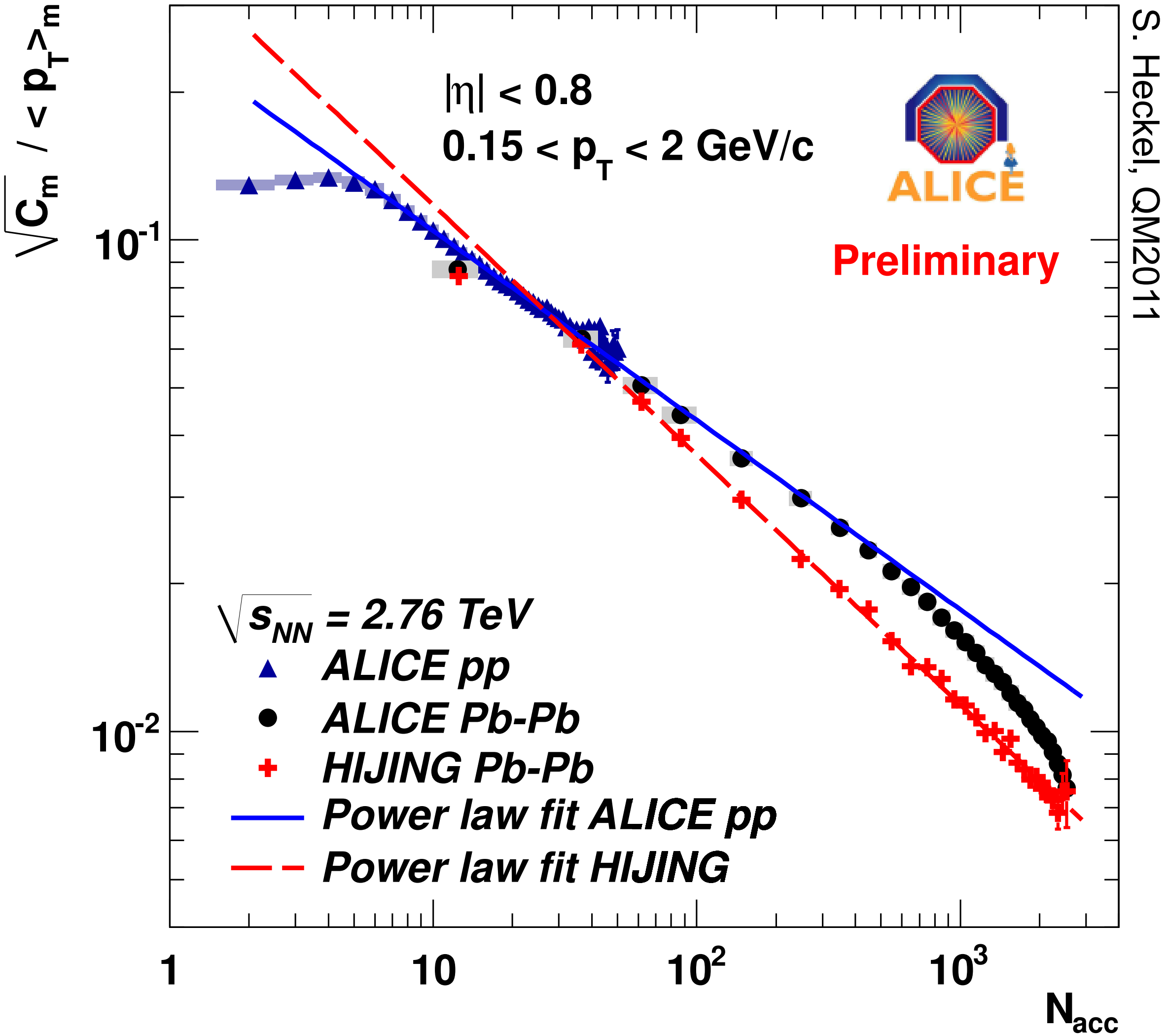
hadron identification





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

pt fluctuations

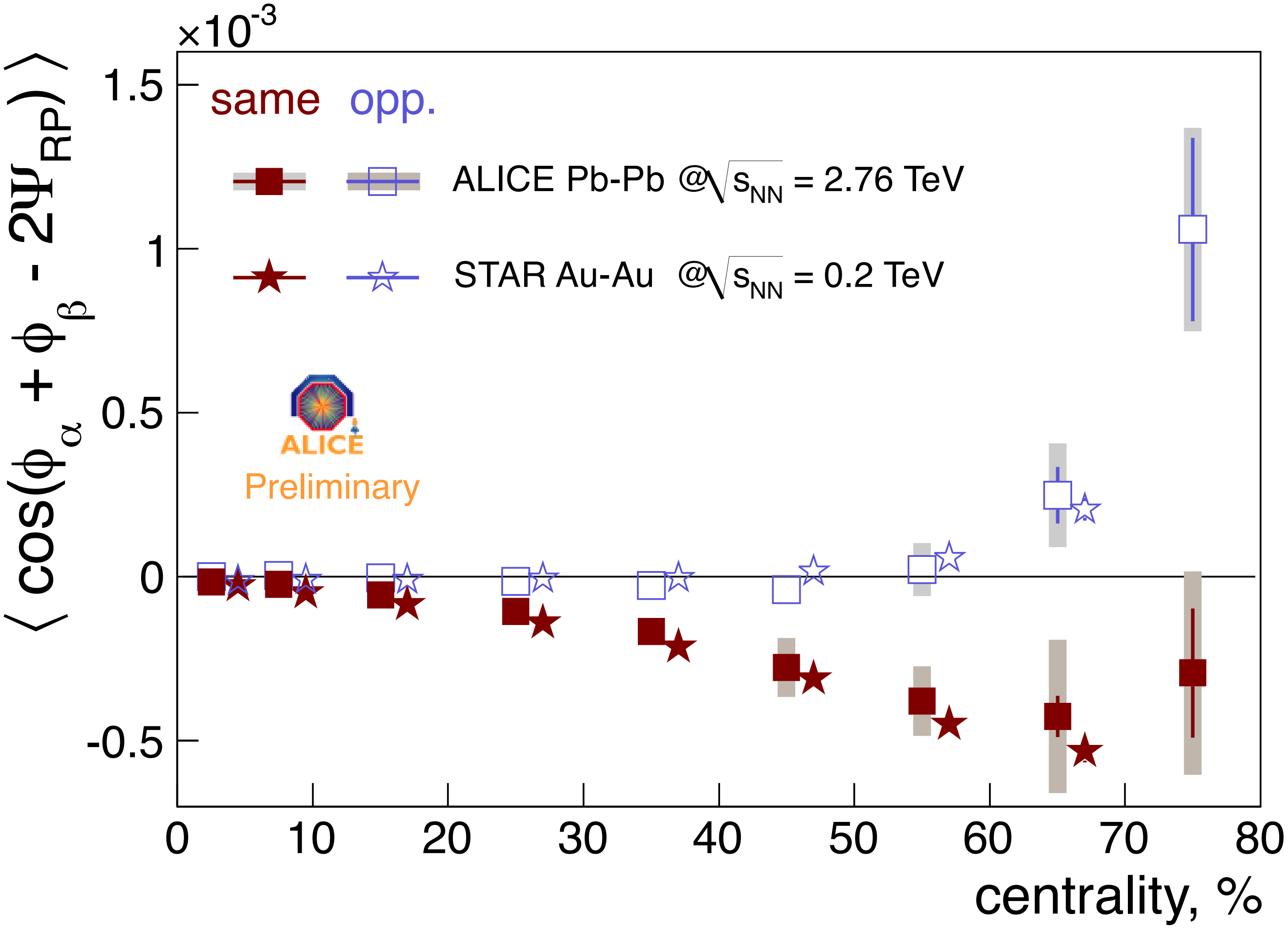


universal scaling

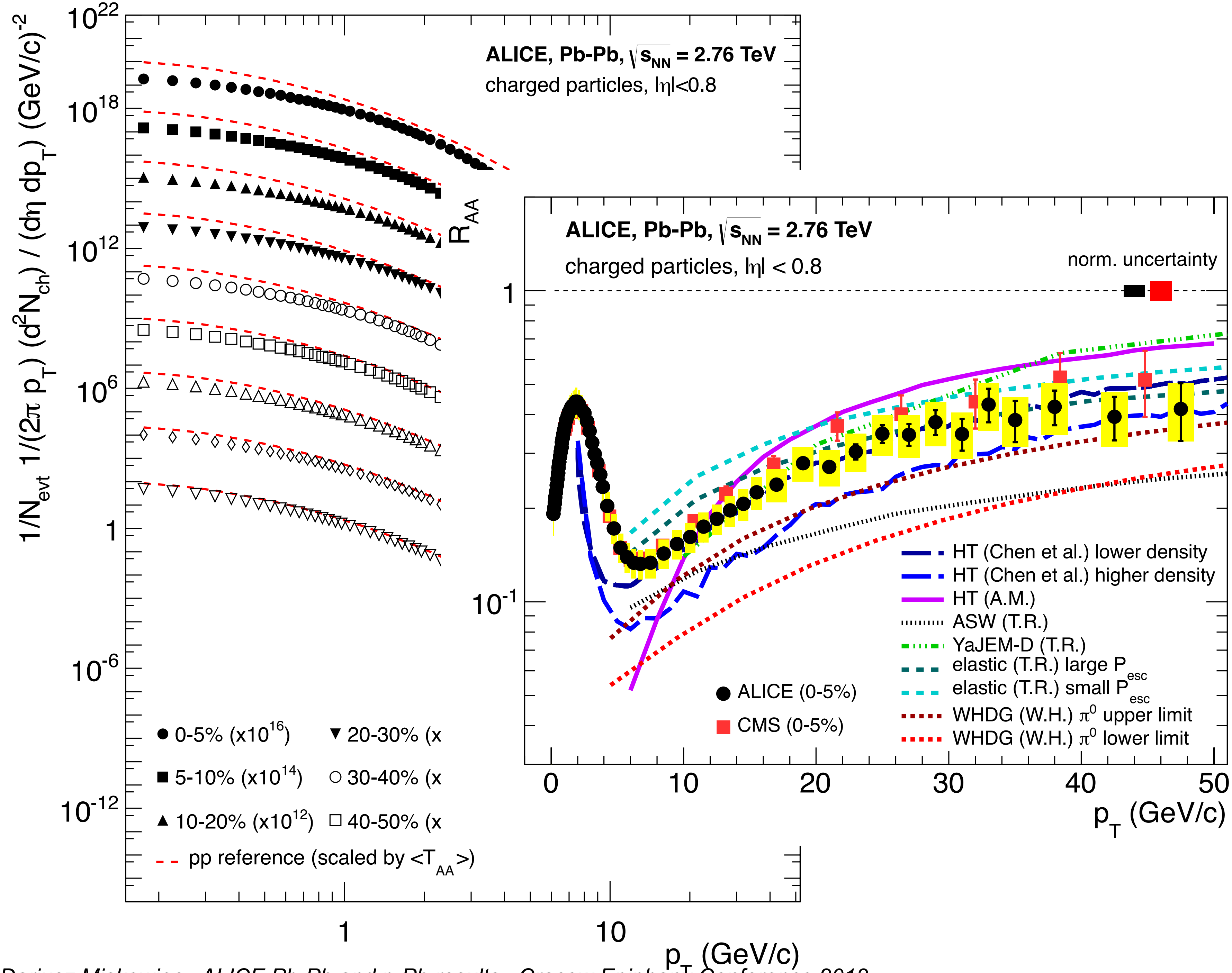
suppression in central collisions

absent in HIJING

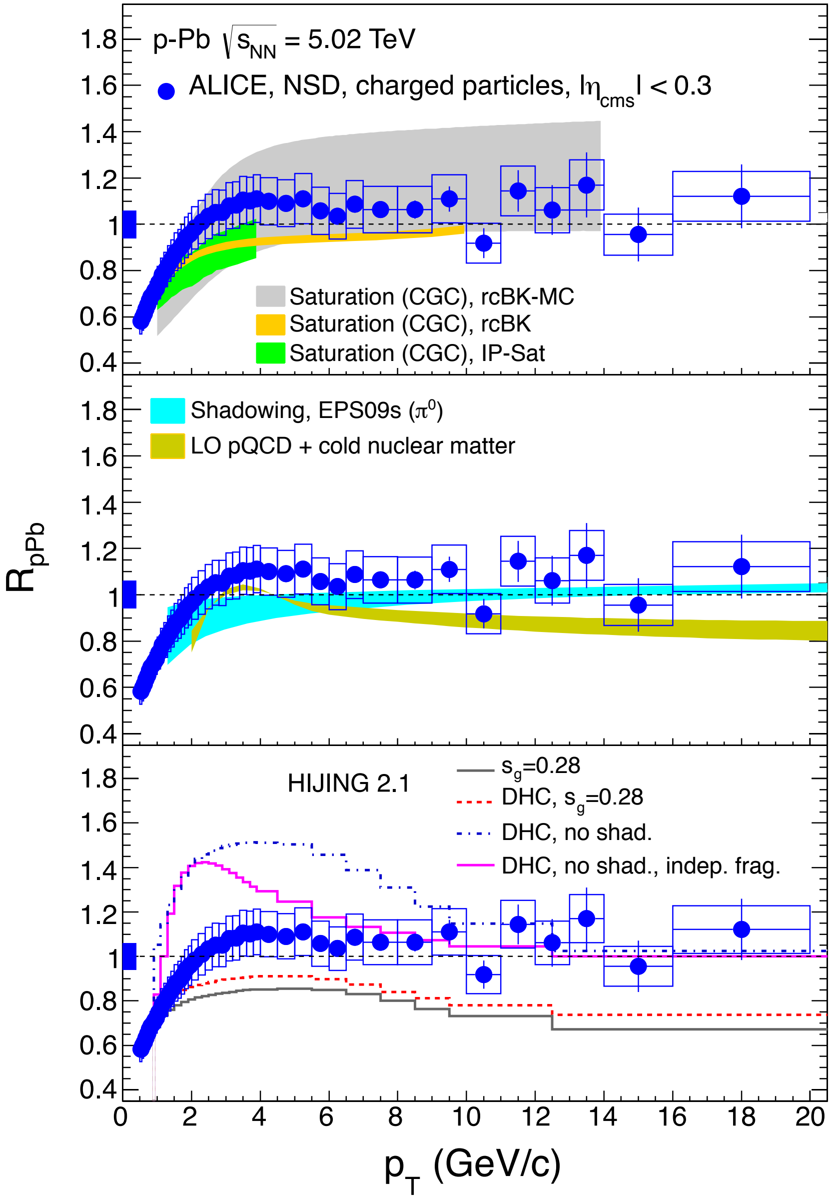
charge dependent azimuthal correlations



similar shape and magnitude as at RHIC


ALICE, Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
charged particles, |η|<0.8
$1/N_{evt}$ $1/(2\pi p_T)$ (d^2N_{ch}) / $(d\eta\, dp_T)$ $(GeV/c)^{-2}$
10^{22}
10^{18}
10^{12}
10^{6}
1
10^{-6}
10^{-12}
1
10
p_T (GeV/c)
● 0-5% (x10^{16})
■ 5-10% (x10^{14})
▲ 10-20% (x10^{12})
▼ 20-30% (x
○ 30-40% (x
□ 40-50% (x
pp reference (scaled by $\langle T_{AA}\rangle$)
ALICE, Pb-Pb, $\sqrt{s_{NN}}$ = 2.76 TeV
charged particles, |η| < 0.8
norm. uncertainty
R_{AA}
1
10^{-1}
0
10
20
30
40
50
p_T (GeV/c)
HT (Chen et al.) lower density
HT (Chen et al.) higher density
HT (A.M.)
ASW (T.R.)
YaJEM-D (T.R.)
elastic (T.R.) large P_{esc}
elastic (T.R.) small P_{esc}
WHDG (W.H.) π^0 upper limit
WHDG (W.H.) π^0 lower limit
ALICE (0-5%)
CMS (0-5%)

nuclear modification factor in p-Pb – comparison to models



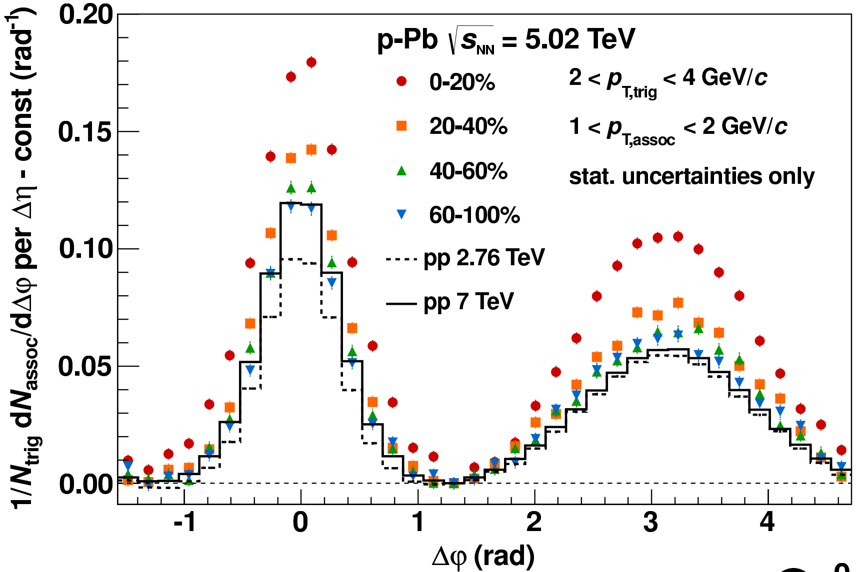
saturation models OK

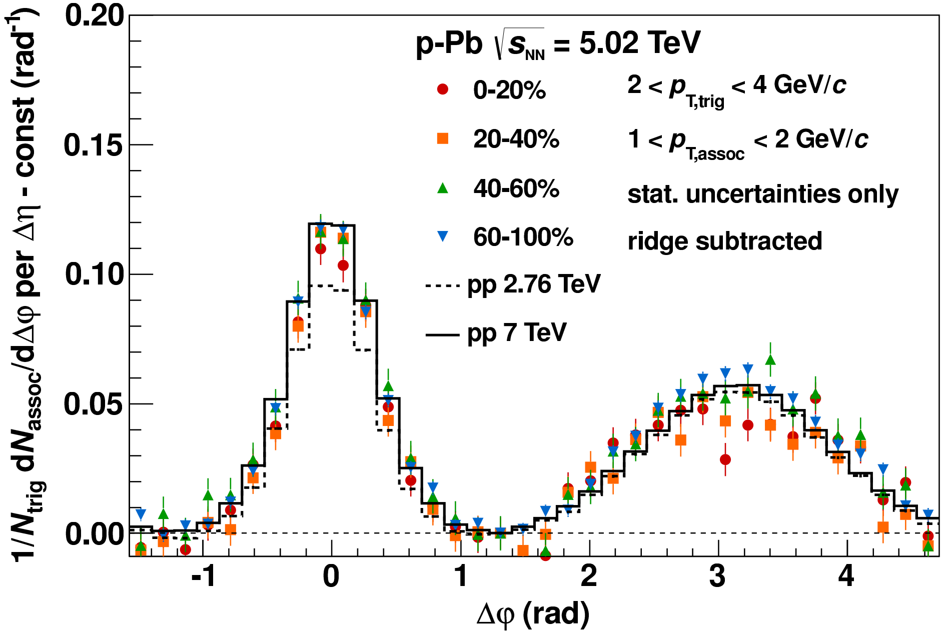
shadowing OK

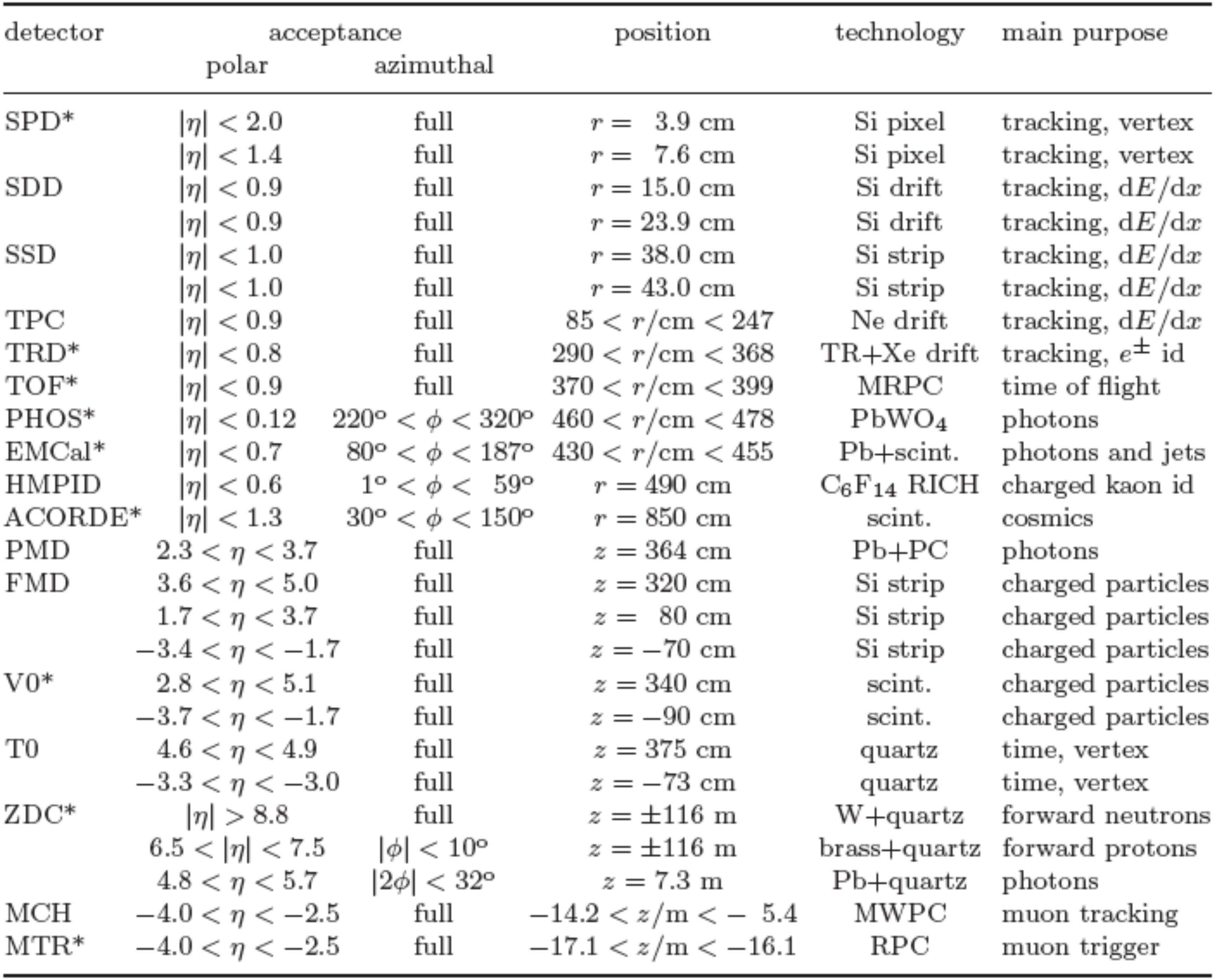
Hijing, DPMJET – problems in describing the data

p+Pb = pp + double ridge

arXiv:1212.2001







detector	acceptance		position	technology	main purpose
	polar	azimuthal			
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*	$\|\eta\| < 0.12$	$220^{\circ} < \phi < 320^{\circ}$	$460 < r/\mathrm{cm} < 478$	$\mathrm{PbWO_4}$	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	$\mathrm{C_6F_{14}}$ 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