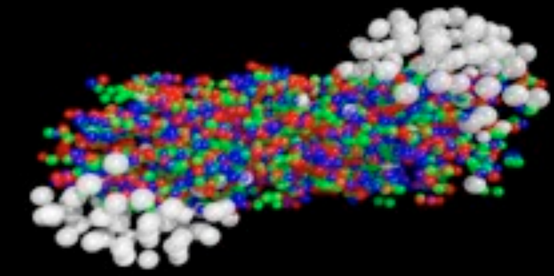


Heavy Ion Physics

Part 2

Raimond Snellings

NIKHEF

Content

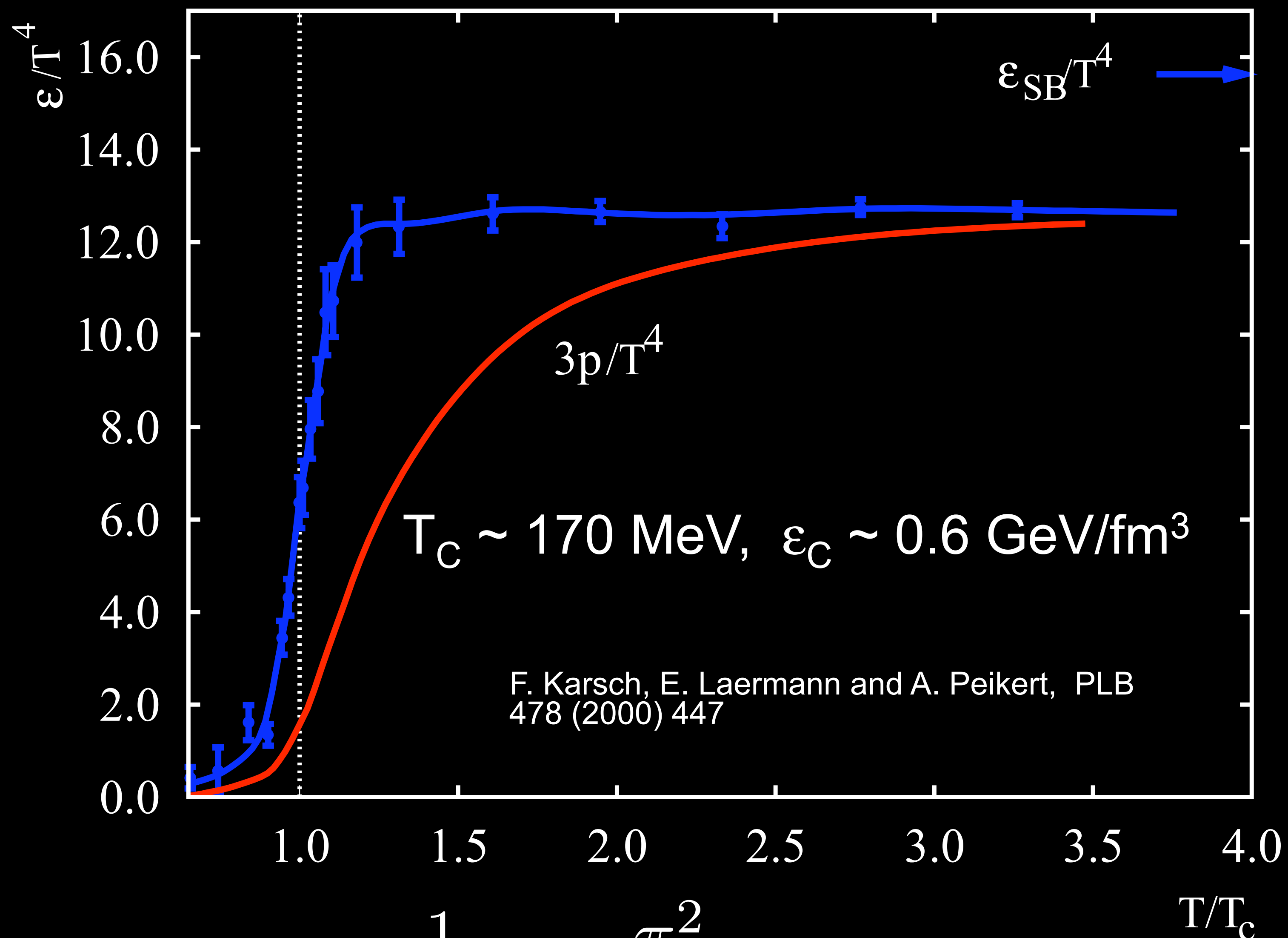
QCD at high density and temperature

heavy-ion accelerators, experiments, global collision characterization

QGP observables and experimental probes

the LHC heavy-ion program and ALICE the dedicated heavy-ion detector

QCD on the Latice



$$
\begin{aligned}
p &= \frac{1}{3}\epsilon = g\frac{\pi^2}{90}T^4 \\
g_{\rm H} &\approx 3 \quad g_{\rm QGP} \approx 37 \\
g &= 2_{\rm spin} \times 8_{\rm gluons} + \frac{7}{8} \times 2_{\rm flavors} \times 2_{q\bar{q}} \times 2_{\rm spin} \times 3_{\rm color}
\end{aligned}
$$

at the critical temperature a strong increase in the degrees of freedom

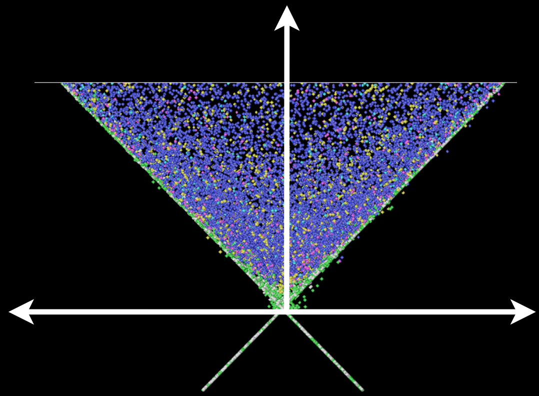
✓ gluons, quarks & color!

not an ideal gas!

✓ residual interactions

at the phase transition dp/dε decreases rapidly

dp/dε drives the collective expansion of the system

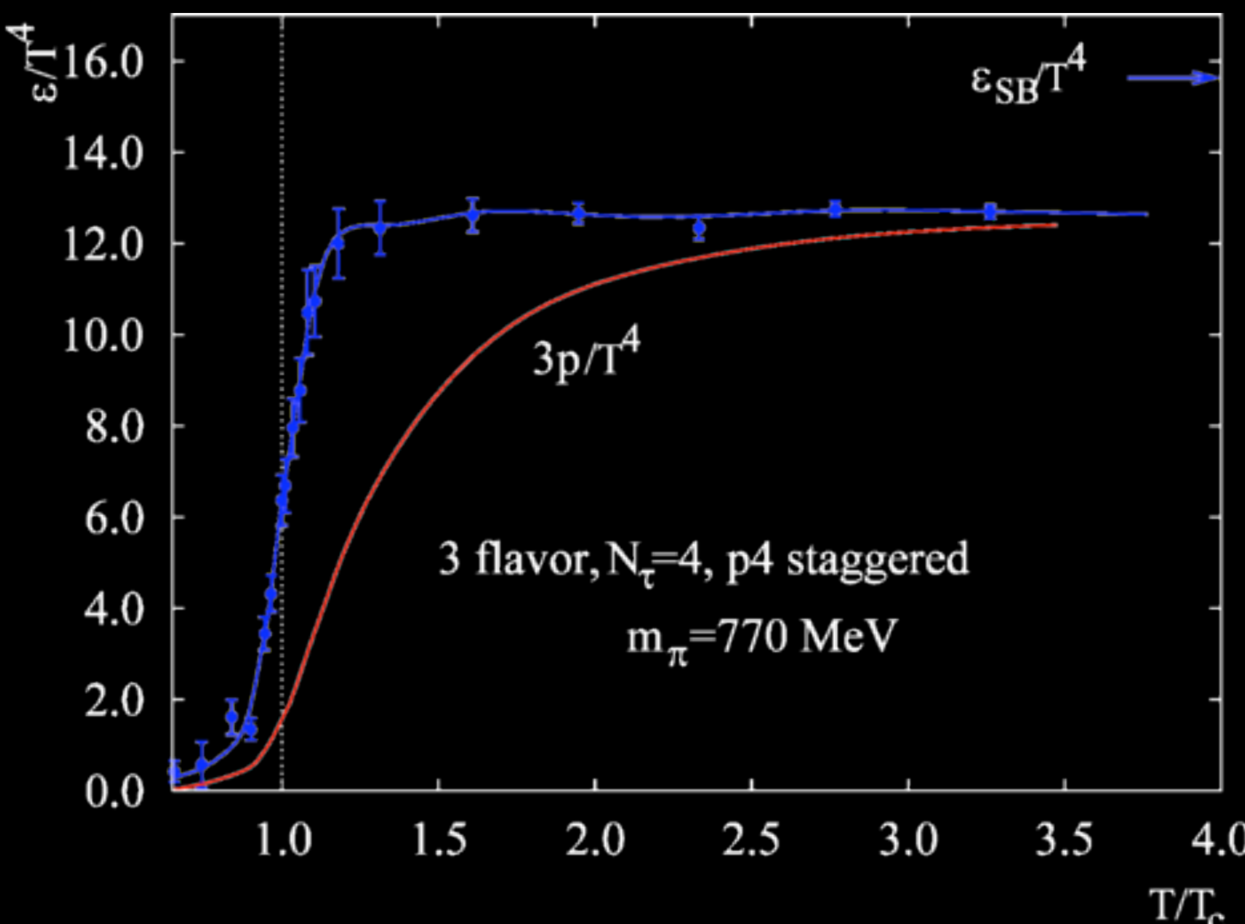


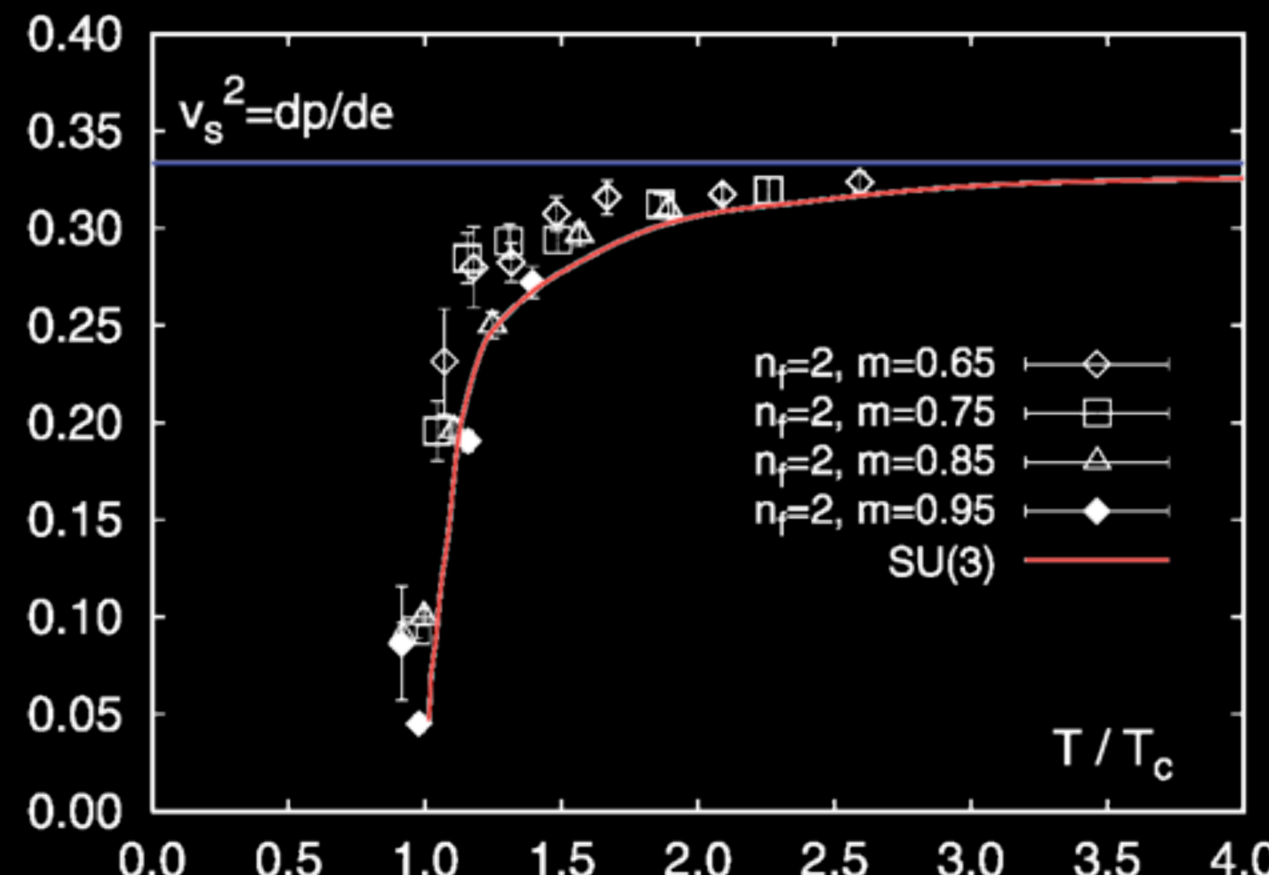
Velocity of Sound

F. Karsch and E. Laermann, arXiv:hep-lat/0305025

$$P_{\mathrm{QGP}} = \frac{1}{3}\varepsilon_{\mathrm{QGP}} = g\frac{\pi^2}{90}T^4$$

velocity of sound $C_s = \sqrt{\dfrac{dP}{d\varepsilon}}$



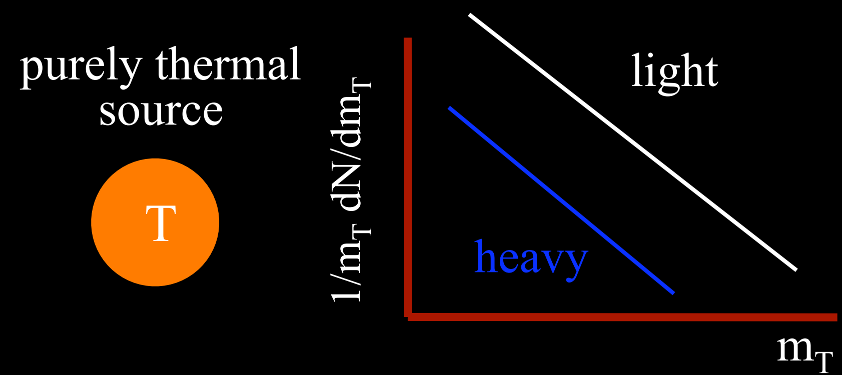


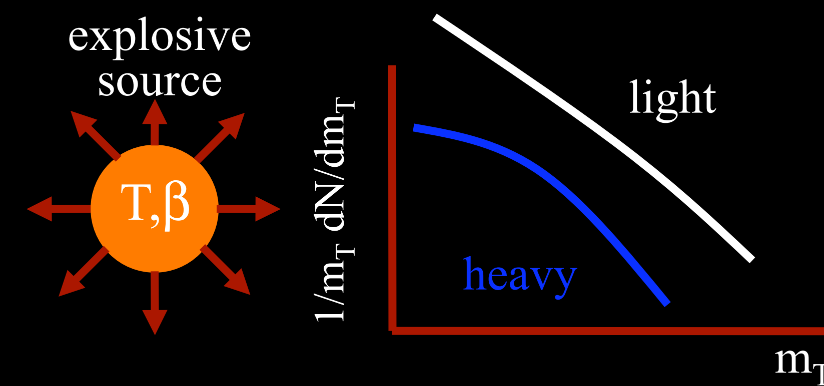
the magnitude of the collective motion is proportional to the velocity of sound

Collective Motion

$$m_T = \sqrt{(m^2 + p_t^2)}$$

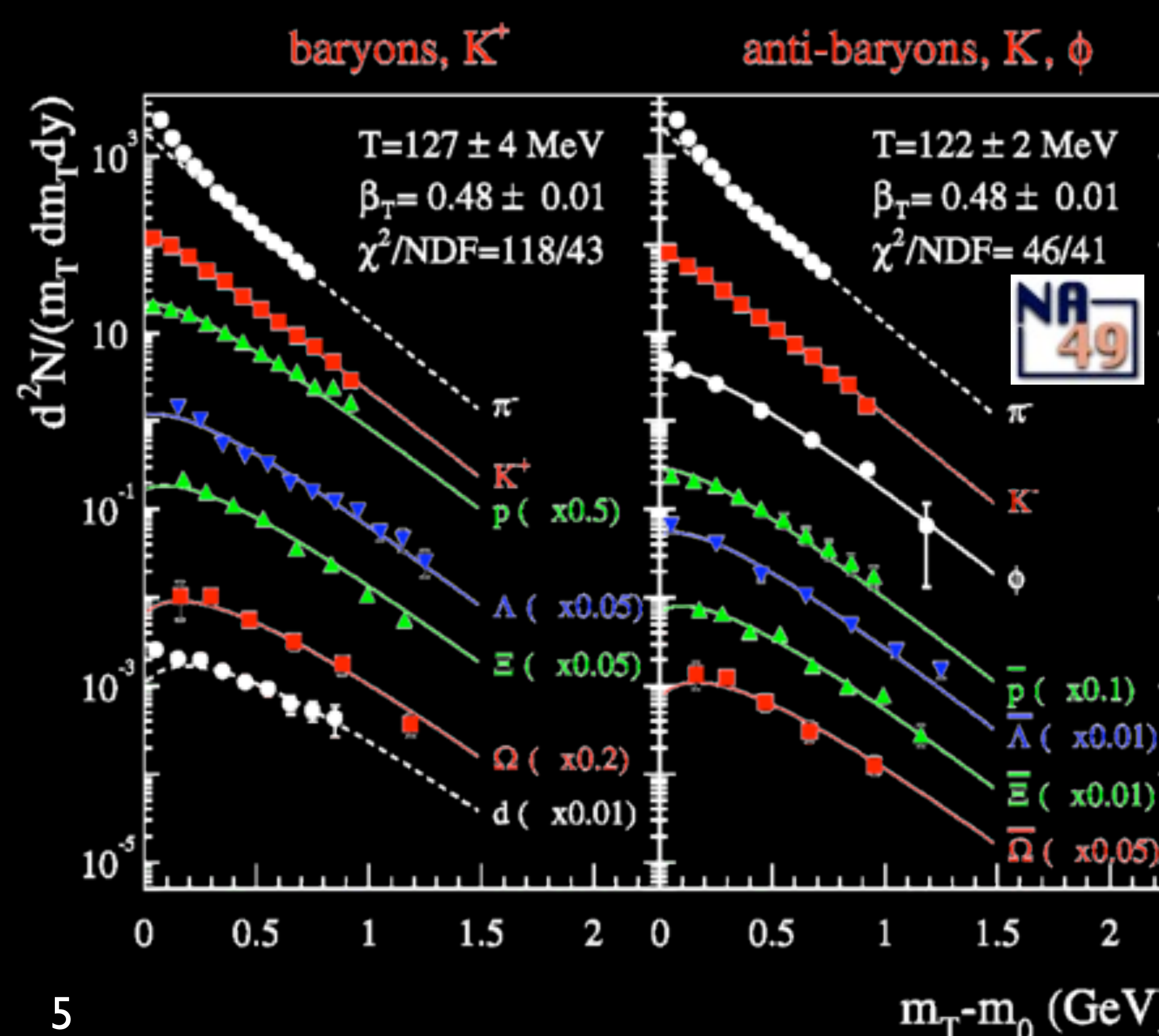
$$\frac{dN}{m_T dm_T} \propto e^{-m_T/T}$$





in p-p at low transverse momenta the particle yields are well described by thermal spectra (m_T scaling)

boosted thermal spectra give a very good description of the particle distributions measured in heavy-ion collisions

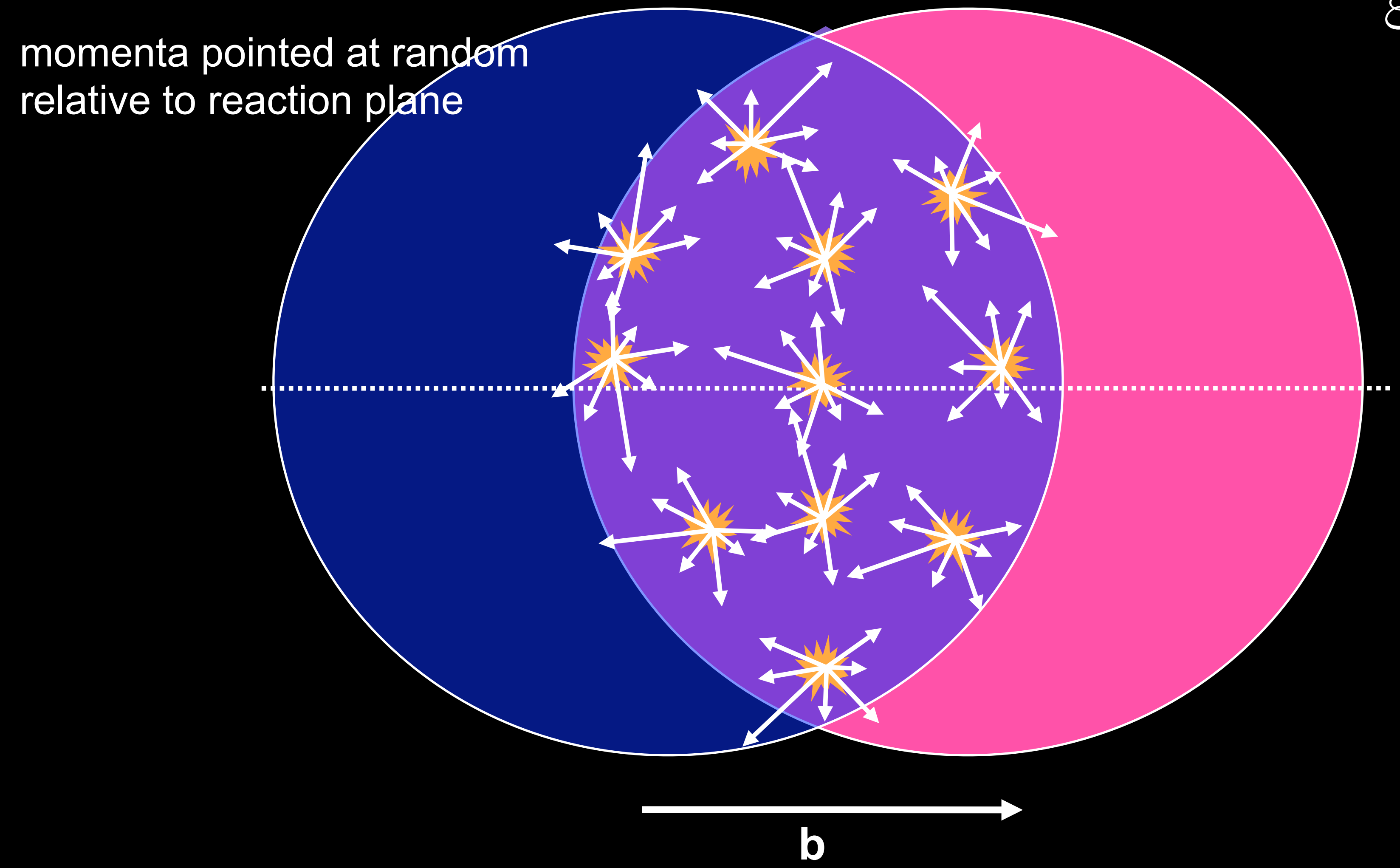


Elliptic Flow

Animation: Mike Lisa

1) superposition of independent p+p:

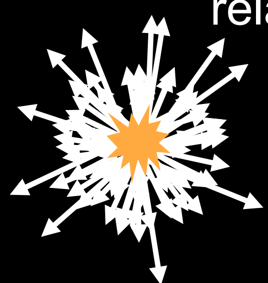
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$



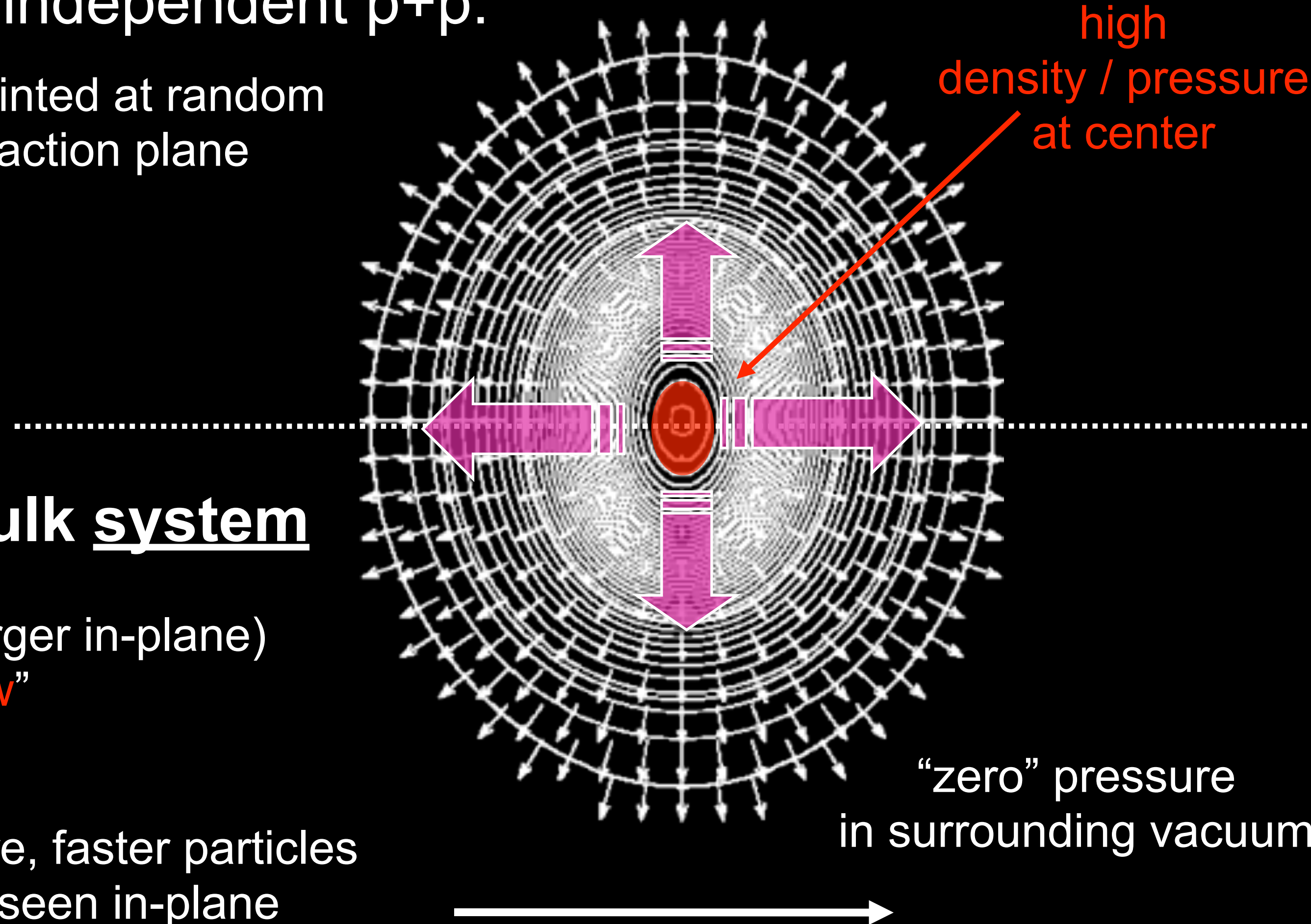
Elliptic Flow

1) superposition of independent p+p:

momenta pointed at random
relative to reaction plane

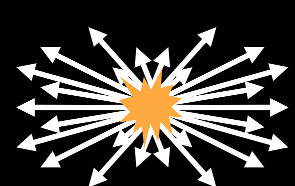


$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$



2) evolution as a **bulk <u>system</u>**

pressure gradients (larger in-plane)
push bulk "out" → "flow"

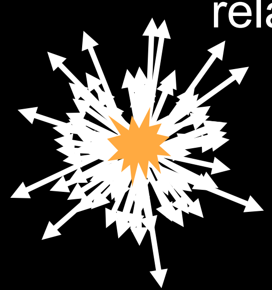


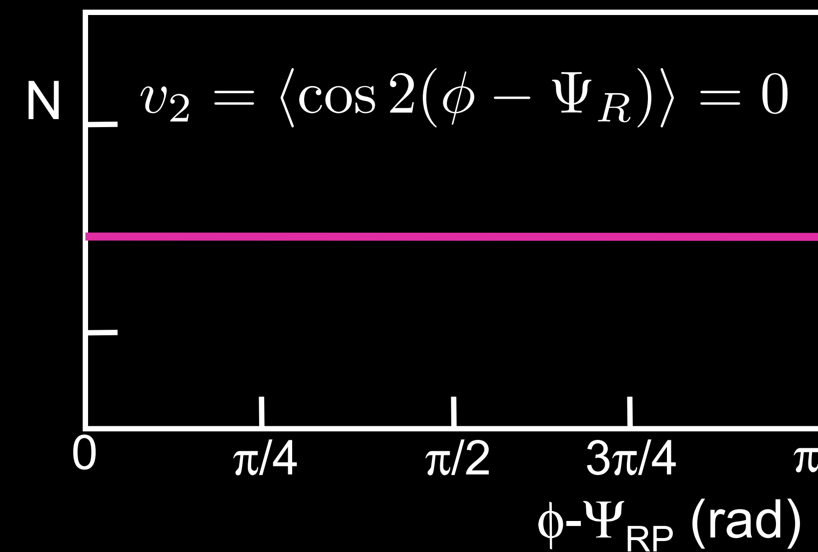
more, faster particles
seen in-plane

Elliptic Flow

1) superposition of independent p+p:

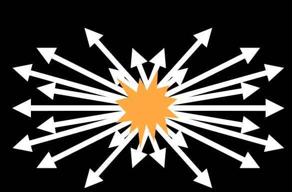
momenta pointed at random
relative to reaction plane



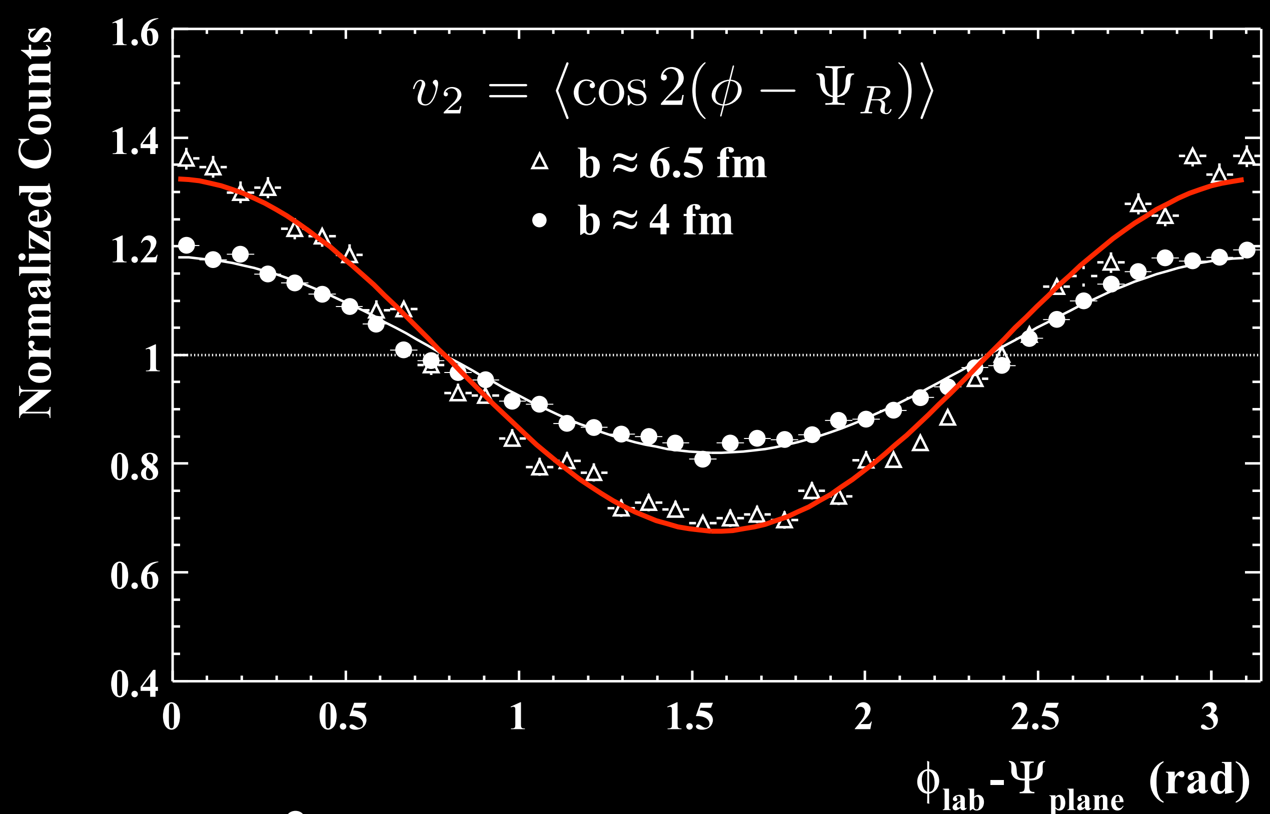


2) evolution as a **bulk** **<u>system</u>**

pressure gradients (larger in-plane)
push bulk “out” → “flow”



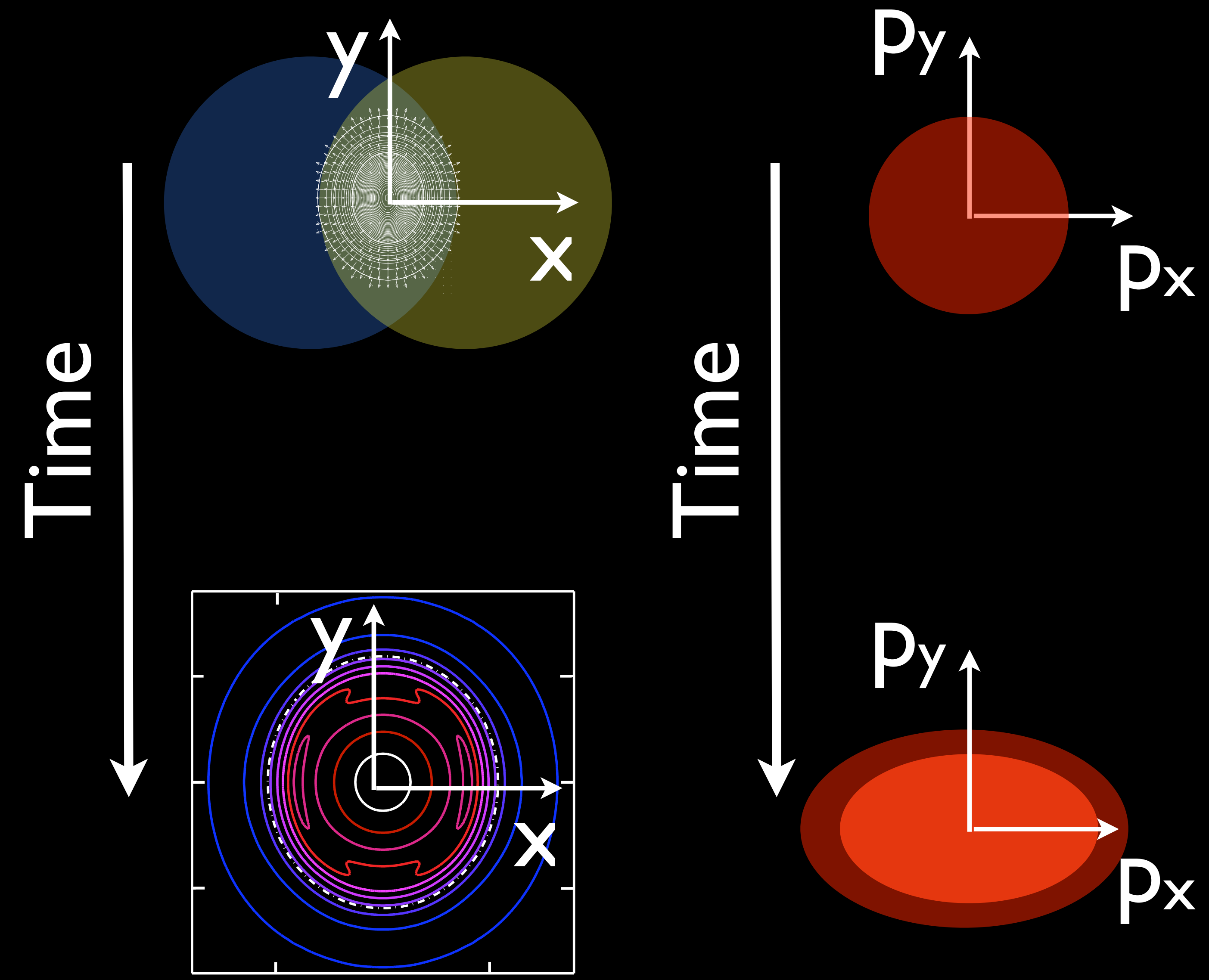
more, faster particles
seen in-plane



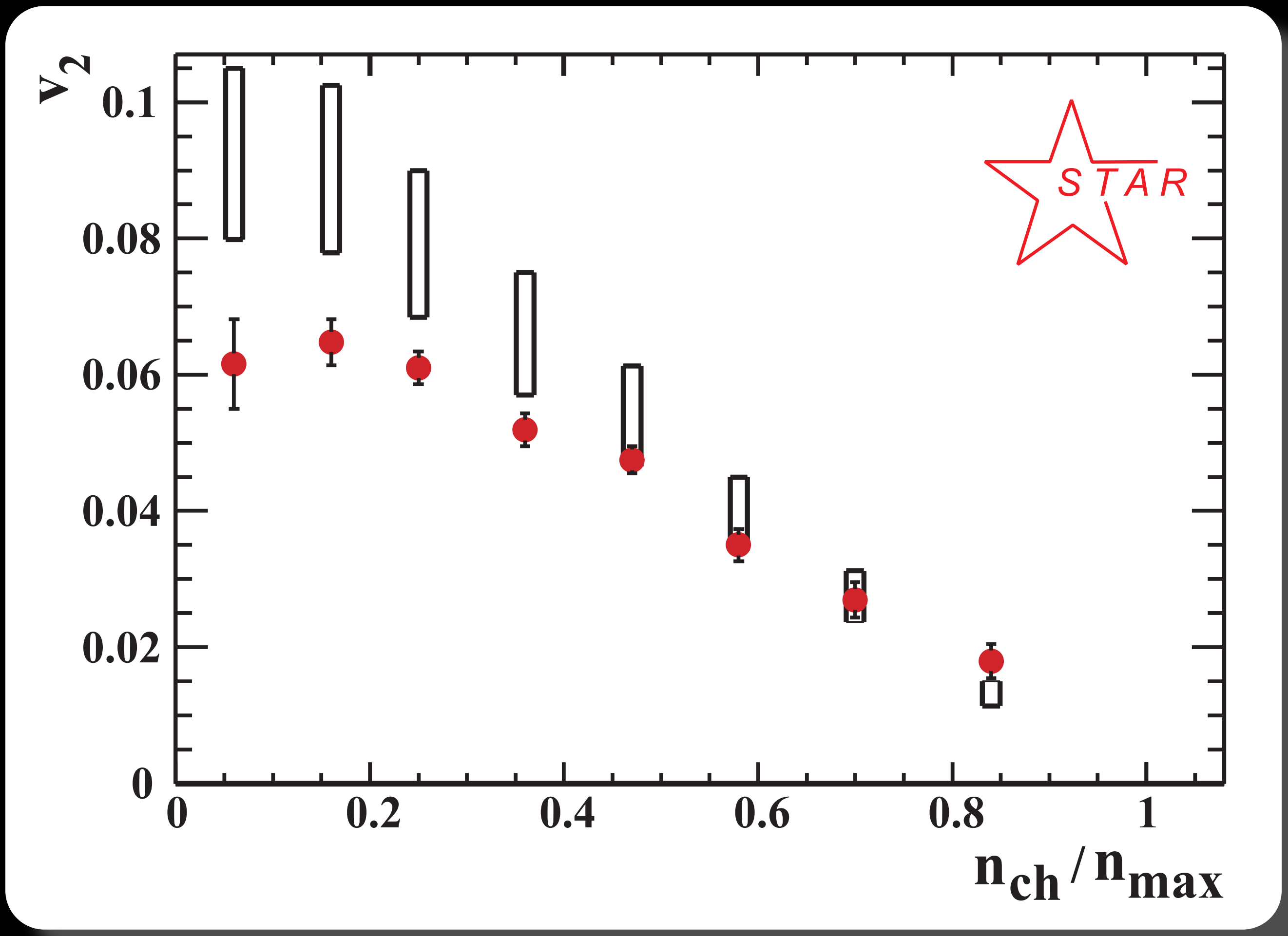
Elliptic Flow

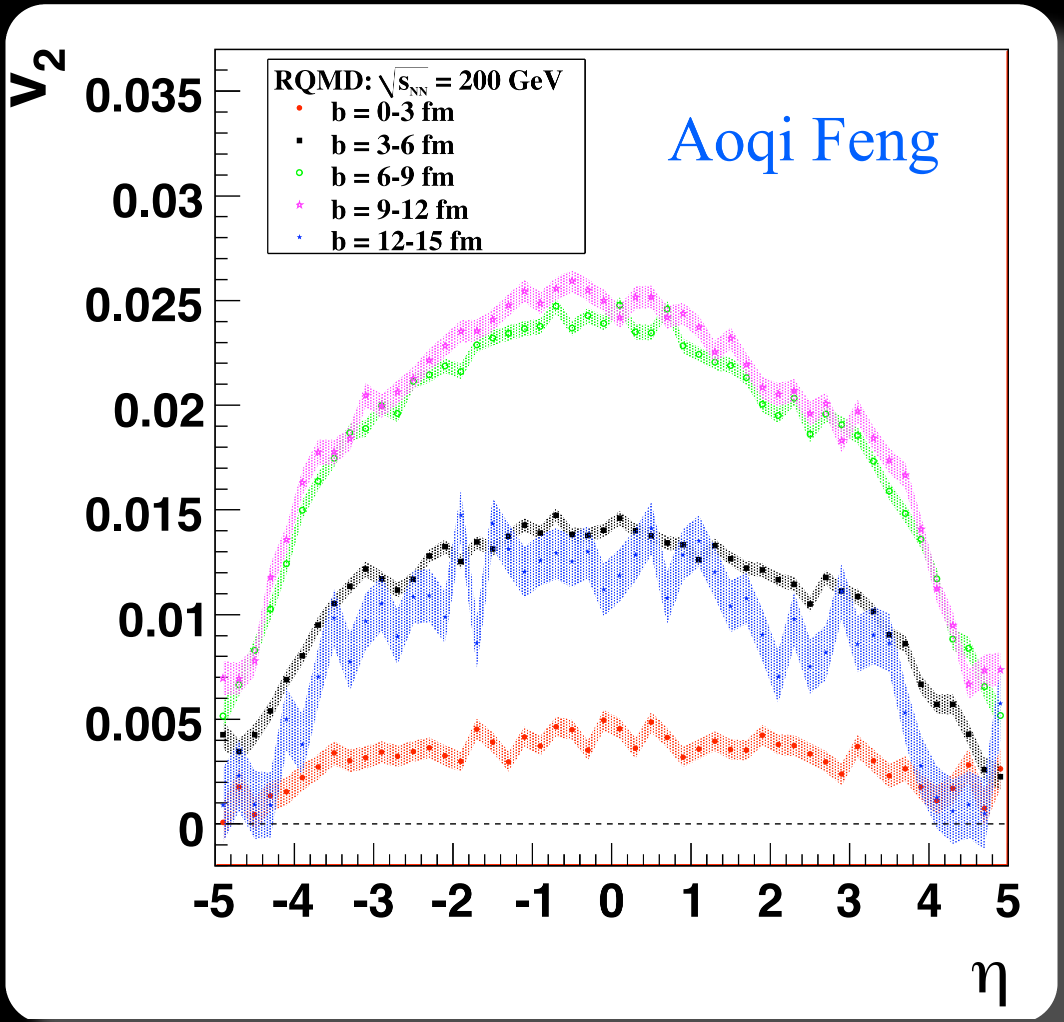
$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle} \qquad v_2 = \langle \cos 2\phi \rangle$$

- in non central collisions coordinate space configuration is anisotropic (almond shape). However, initial momentum distribution isotropic (spherically symmetric)
- interactions among constituents generate a pressure gradient which transforms the initial coordinate space anisotropy into the observed momentum space anisotropy → anisotropic flow
- self-quenching → sensitive to early stage
- **a unique hadronic probe of the early stage**



Flow at RHIC





STAR Phys. Rev. Lett. 86, 402–407 (2001)

ideal hydro gets the magnitude for more central collisions

hadron transport calculations are factors 2-3 off

Hydro Motivated Fit

$$v_2(p_t) = \frac{\int_0^{2\pi} d\phi_b \cos(2\phi_b) I_2(\alpha_t) K_1(\beta_t)(1 + 2s_2 \cos(2\phi_b))}{\int_0^{2\pi} d\phi_b I_0(\alpha_t) K_1(\beta_t)(1 + 2s_2 \cos(2\phi_b))}$$

$$\alpha_t(\phi_b) = (\frac{p_t}{T_f}) \sinh(\rho(\phi_b)) \quad \beta_t(\phi_b) = (\frac{m_t}{T_f}) \cosh(\rho(\phi_b))$$

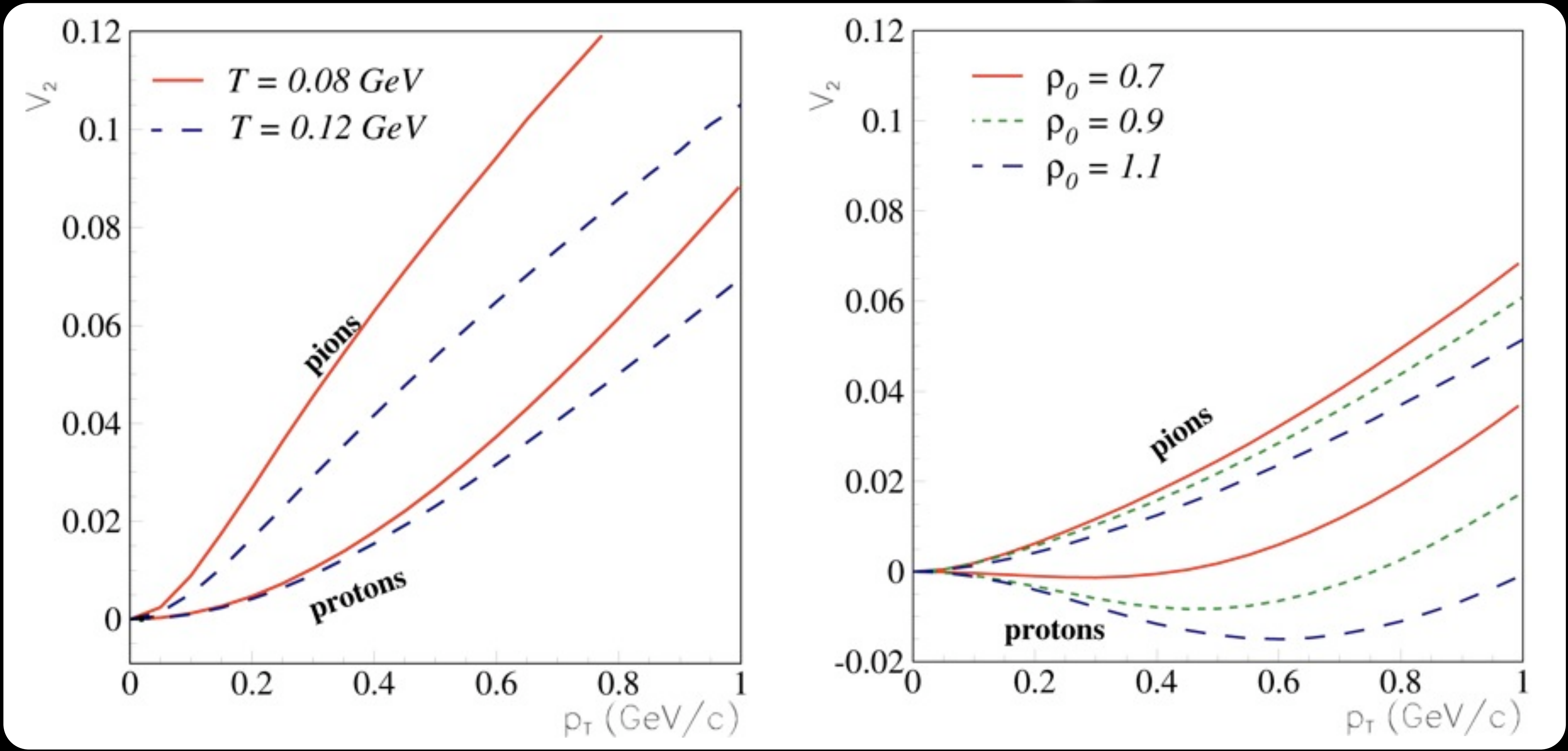
$$\rho(\phi_b) = \rho_0 + \rho_a \cos(2\phi_b)$$

STAR Phys. Rev. Lett. 87, 182301 (2001)

$v_2(p_t)$ and particle mass

- on what freeze-out variables does it depend (simplification)?
  - the average velocity difference in and out of plane (due to Δp)
  - but also
    - the average freeze-out temperature
    - the average transverse flow
    - the average spatial eccentricity

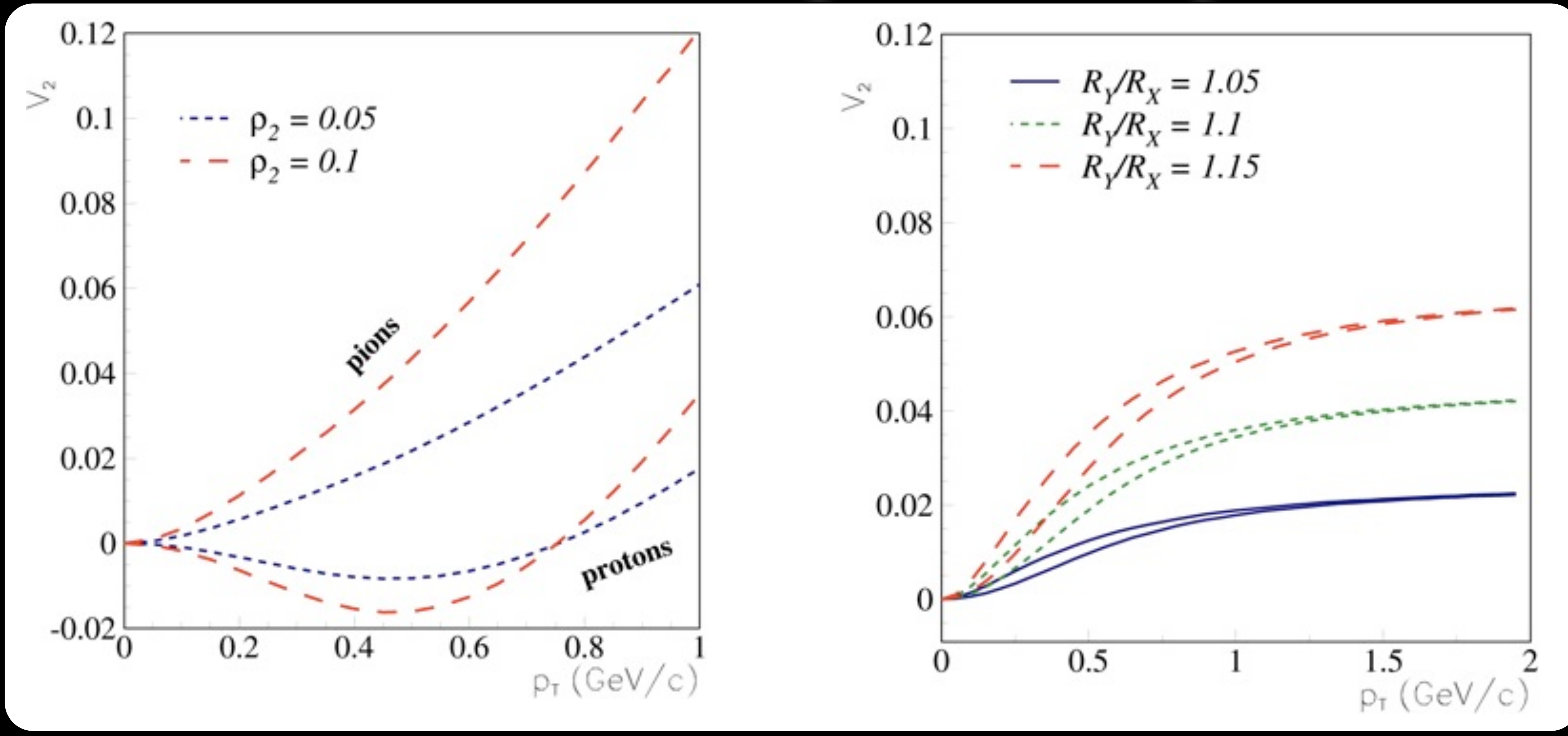
The effect of freeze-out temperature and radial flow on v_2



F. Retiere and M.A. Lisa, Phys.Rev.C70:044907,2004

- **light particle $v_2(p_t)$ very sensitive to temperature**
- **heavier particles $v_2(p_t)$ more sensitive to transverse flow**

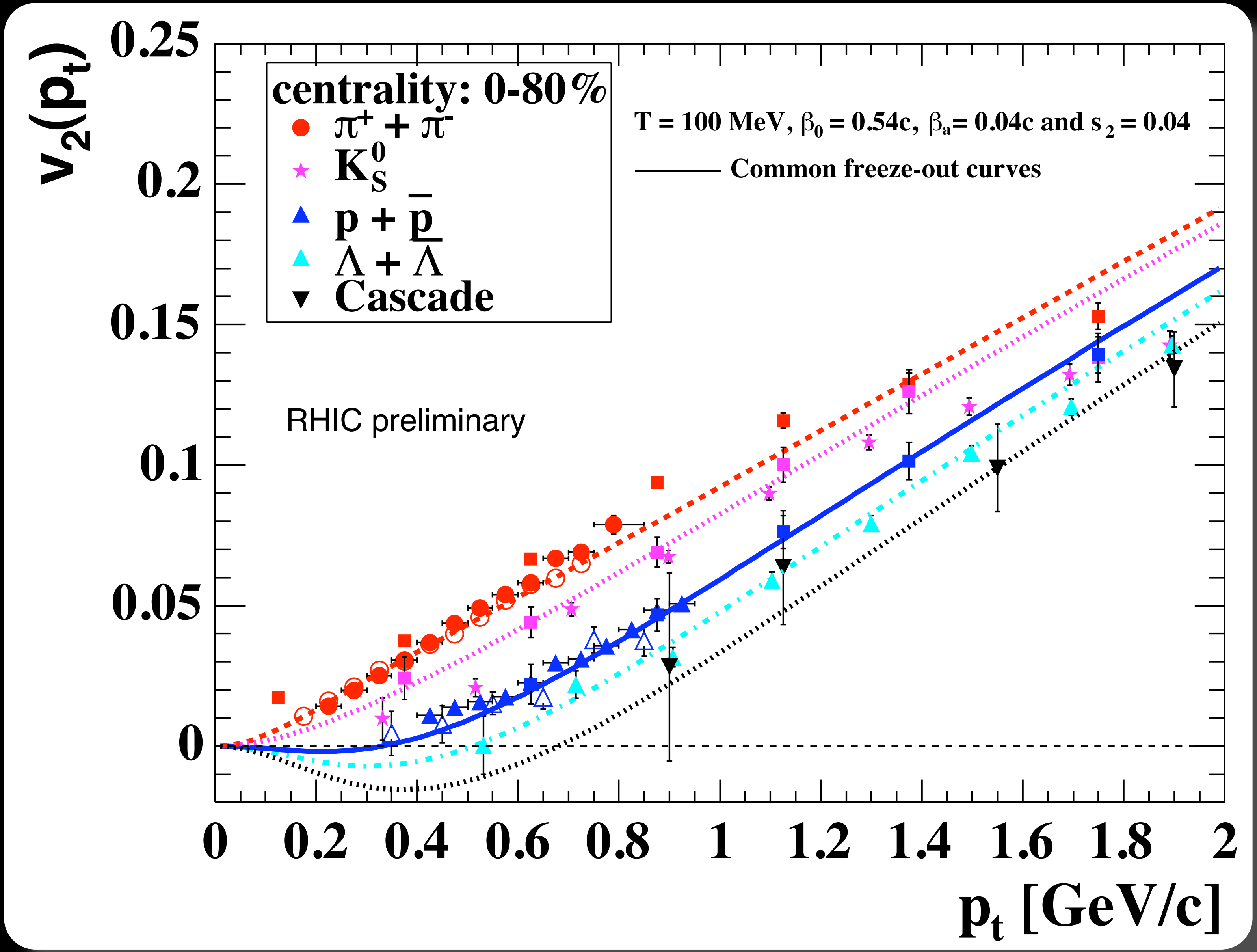
The effect of the azimuthal asymmetric flow velocity and shape



- larger value of the difference in collective velocity in and out of the reaction plane leads to larger slope of $v_2(p_t)$ above ~ $\langle p_t \rangle$ of the particle
- larger spatial anisotropy leads to larger v_2 with little mass dependence (transverse flow boosts more particles in the reaction plane)

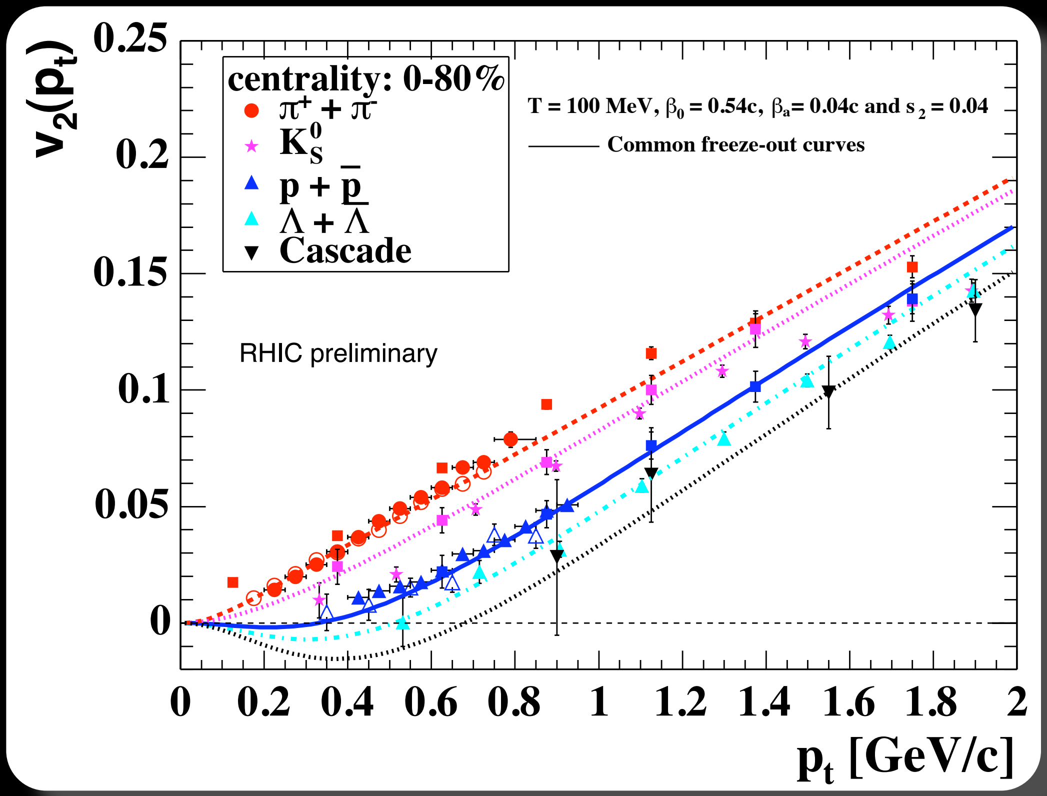
boosted thermal spectra

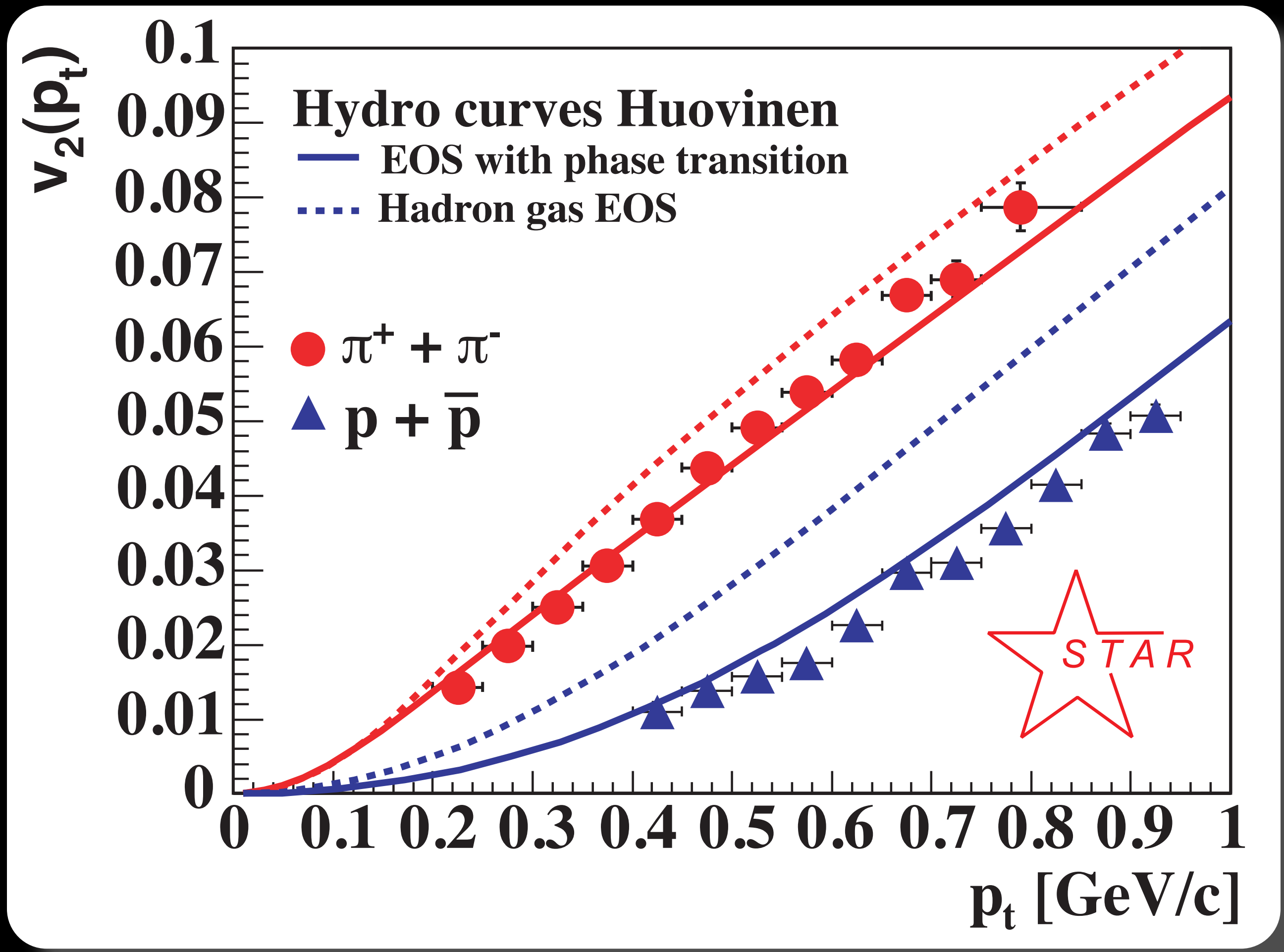
the observed particles are characterized by a single freeze-out temperature and a common azimuthal dependent boost velocity



Fits from STAR Phys. Rev. Lett. 87, 182301 (2001)

The EoS



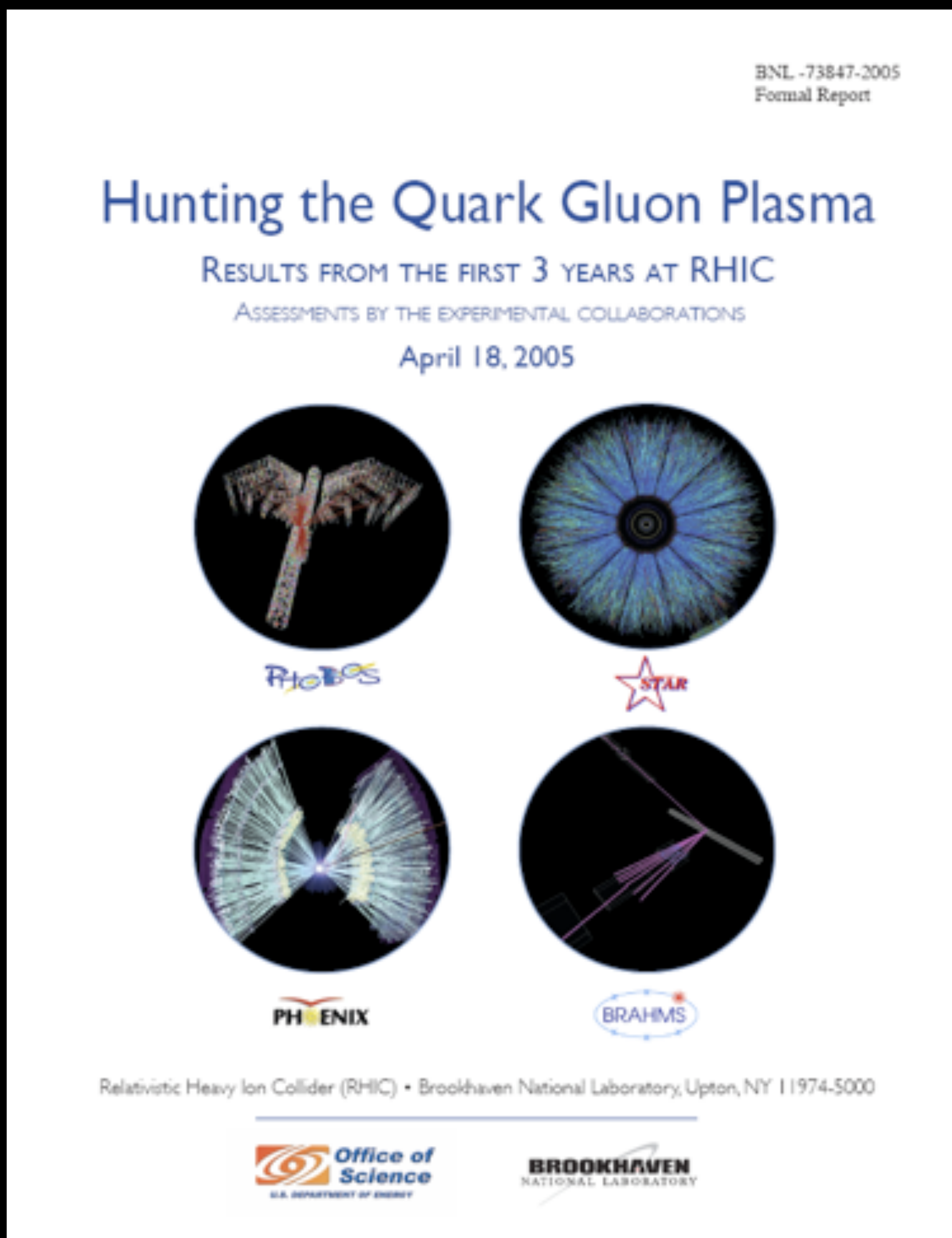


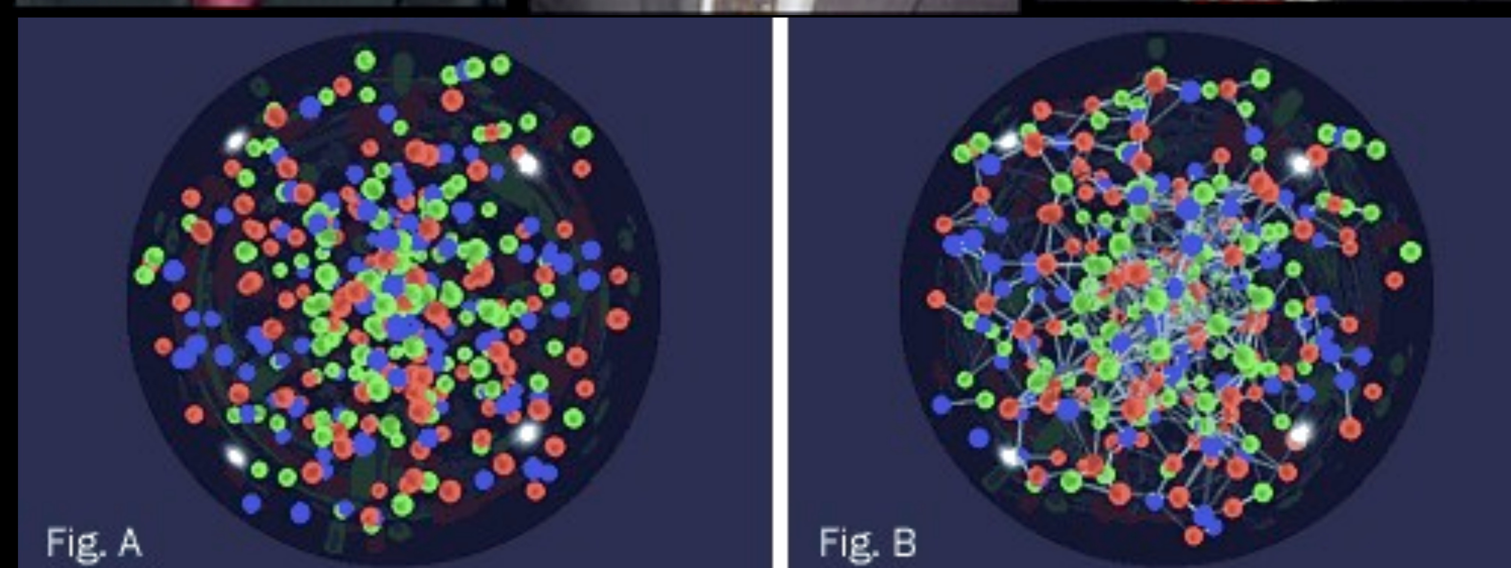
STAR Phys. Rev. Lett. 87, 182301 (2001)

The species dependence is sensitive to the EoS

RHIC Scientists Serve Up “Perfect” Liquid

New state of matter more remarkable than predicted -- raising many new questions
April 18, 2005





RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remarkable than predicted -- raising many new questions

April 18, 2005

Early Universe Went With the Flow

Posted April 18, 2005 5:57PM

Between 2000 and 2003 the lab's Relativistic Heavy Ion Collider repeatedly smashed the nuclei of gold atoms together with such force that their energy briefly generated trillion-degree temperatures. Physicists think of the collider as a time machine, because those extreme temperature conditions last prevailed in the universe less than 100 millionths of a second after the big bang.

Universe May Have Begun as Liquid, Not Gas

Associated Press
Tuesday, April 19, 2005; Page A05

The Washington Post

New results from a particle collider suggest that the universe behaved like a liquid in its earliest moments, not the fiery gas that was thought to have pervaded the first microseconds of existence.

Early Universe was a liquid

Quark-gluon blob surprises particle physicists.

by Mark Peplow
news@nature.com

nature

The Universe consisted of a perfect liquid in its first moments, according to results from an atom-smashing experiment.

Scientists at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory on Long Island, New York, have spent five years searching for the quark-gluon plasma that is thought to have filled our Universe in the first microseconds of its existence. Most of them are now convinced they have found it. But, strangely, it seems to be a liquid rather than the expected hot gas.

New State of Matter Is 'Nearly Perfect' Liquid

Physicists working at Brookhaven National Laboratory announced today that they have created what appears to be a new state of matter out of the building blocks of atomic nuclei, quarks and gluons. The researchers unveiled their findings--which could provide new insight into the composition of the universe just moments after the big bang--today in Florida at a meeting of the American Physical Society.

SCIENTIFIC AMERICAN

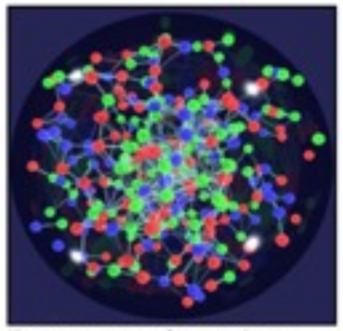
Image: BNL

There are four collaborations, dubbed BRAHMS, PHENIX, PHOBOS and STAR, working at Brookhaven's Relativistic Heavy Ion Collider (RHIC). All of them study what happens when two interacting beams of gold ions smash into one another at great velocities, resulting in thousands of subatomic collisions every second. When the researchers analyzed the patterns of the atoms' trajectories after these collisions, they found that the particles produced in the collisions tended to move collectively, much like a school of fish does. Brookhaven's associate laboratory director for high energy and nuclear physics, Sam Aronson, remarks that "the degree of collective interaction, rapid thermalization and extremely low viscosity of the matter being formed at RHIC make this the most nearly perfect liquid ever observed."

Early Universe was 'liquid-like'

Physicists say they have created a new state of hot, dense matter by crashing together the nuclei of gold atoms.

BBC NEWS



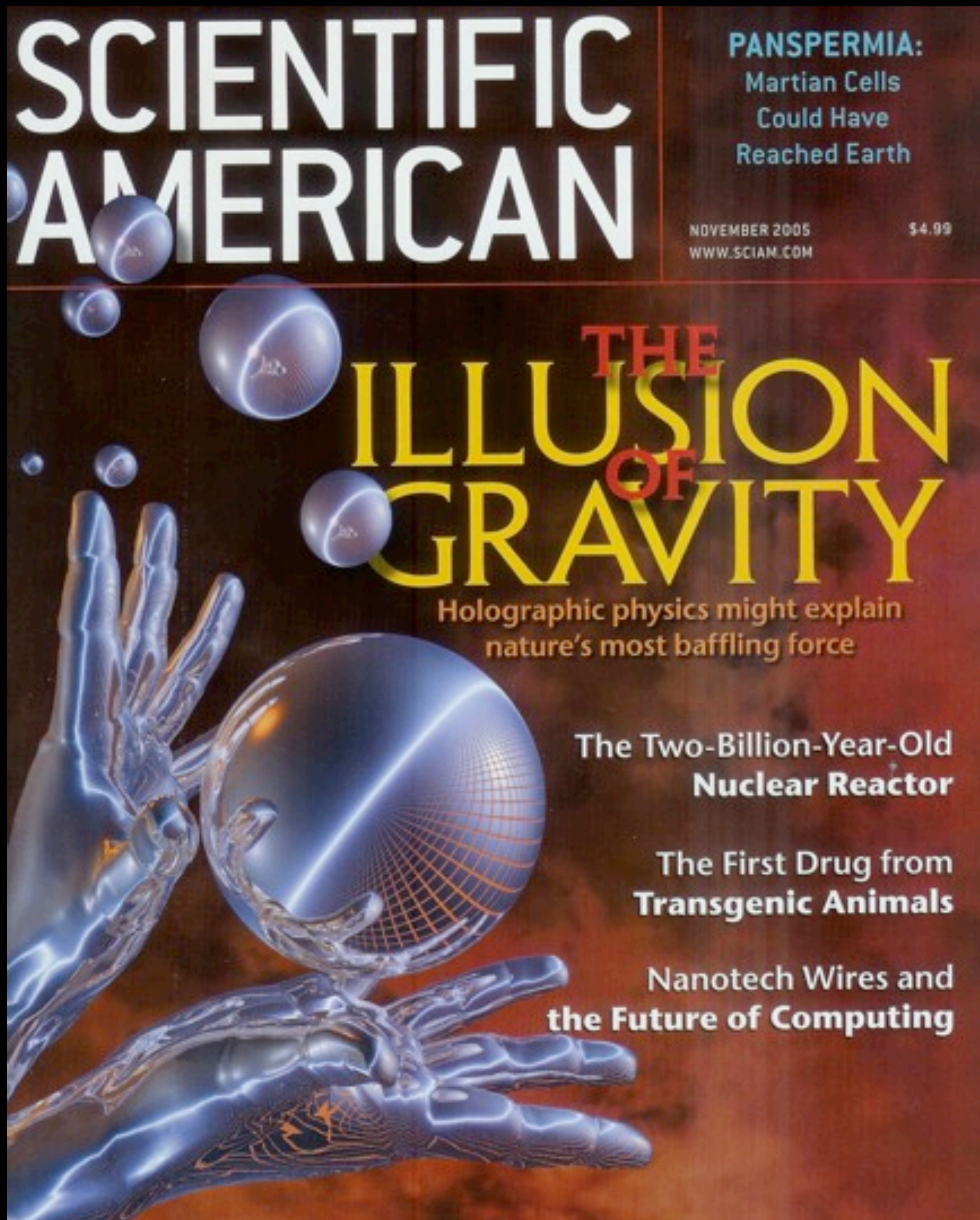
The impression is of matter that is more strongly interacting than predicted

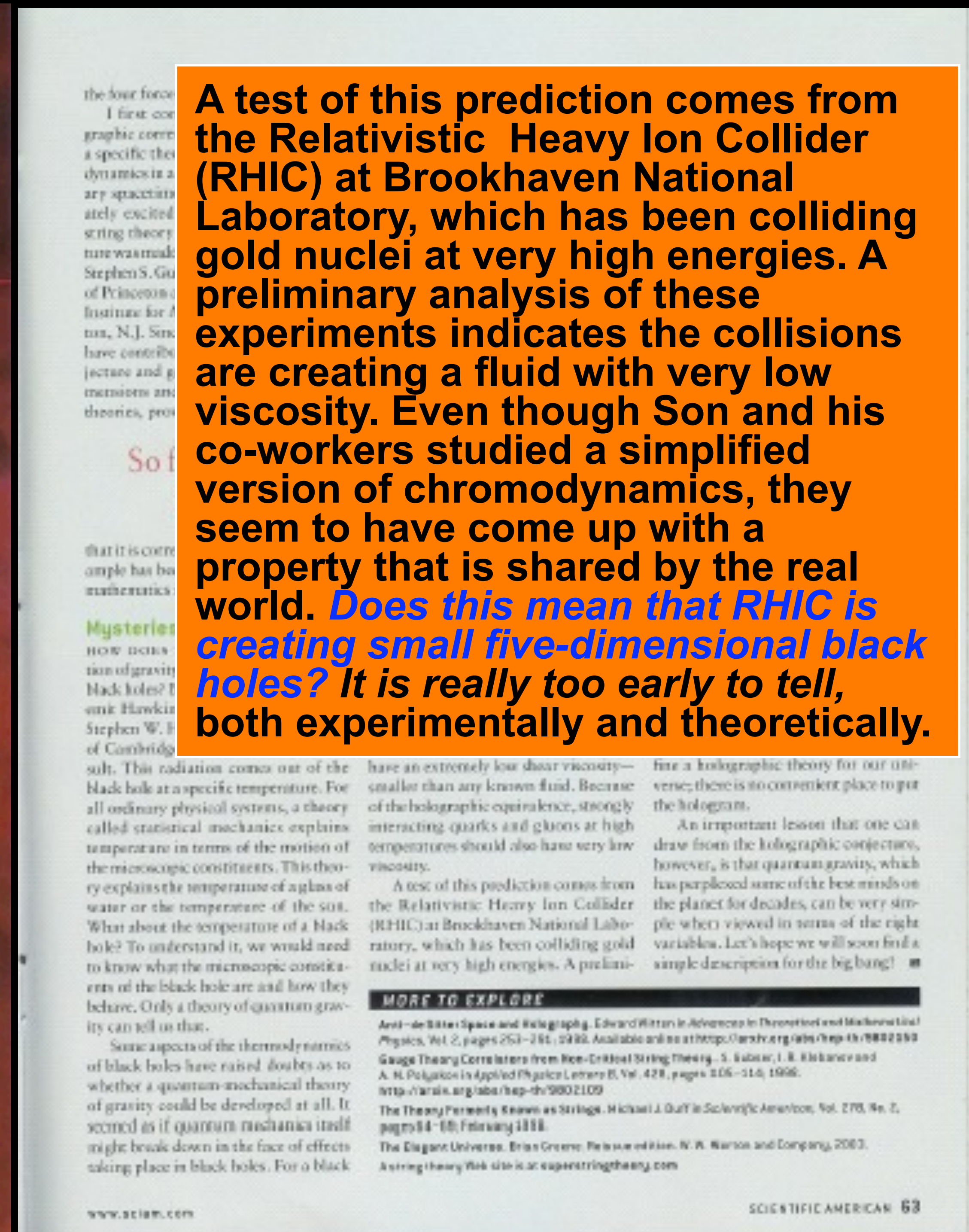
The high-energy collisions prised open the nuclei to reveal their most basic particles, known as quarks and gluons.

The researchers, at the US Brookhaven National Laboratory, say these particles were seen to behave as an almost perfect "liquid".

The work is expected to help scientists explain the conditions that existed just milliseconds after the Big Bang.

AdS/CFT

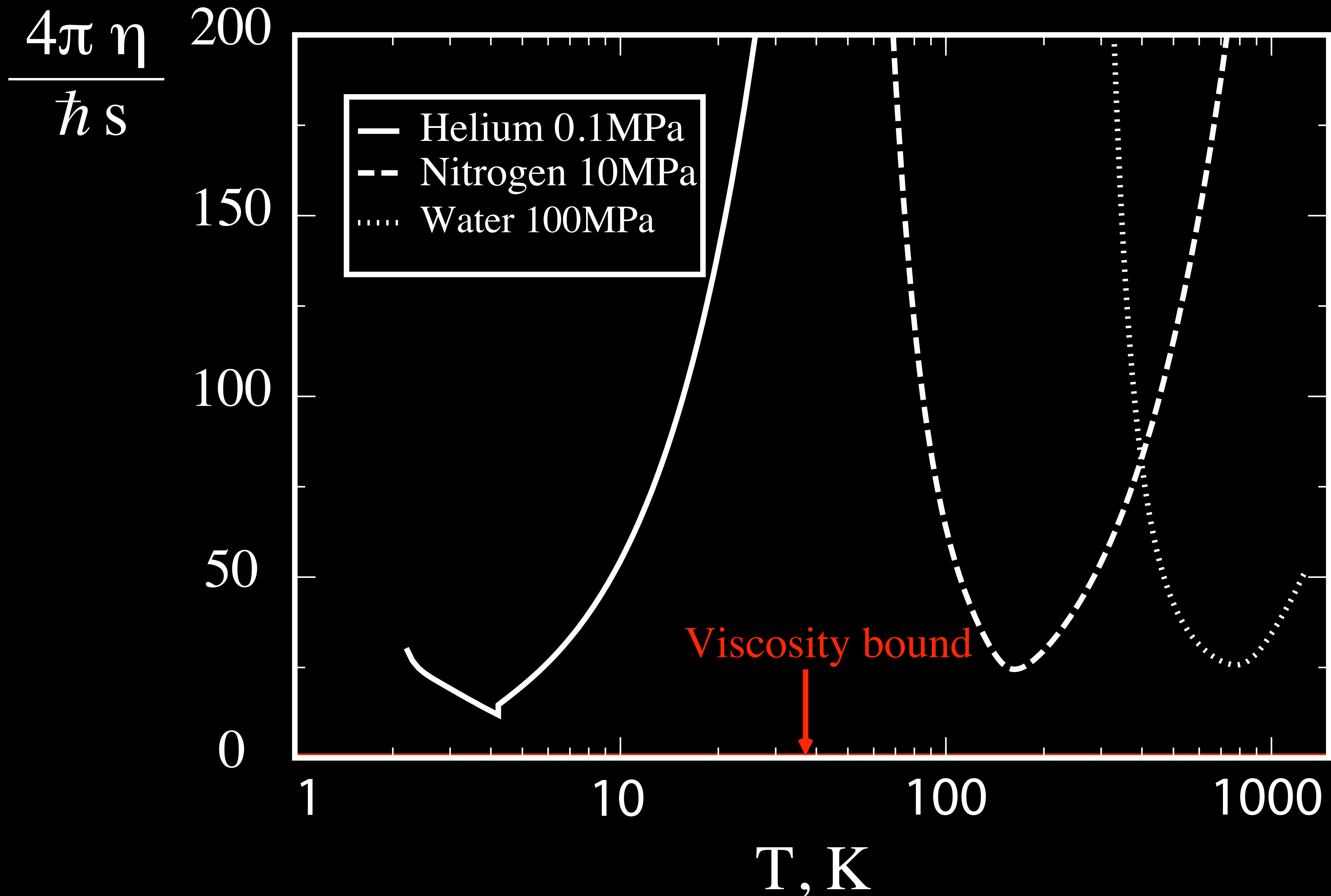




A test of this prediction comes from the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, which has been colliding gold nuclei at very high energies. A preliminary analysis of these experiments indicates the collisions are creating a fluid with very low viscosity. Even though Son and his co-workers studied a simplified version of chromodynamics, they seem to have come up with a property that is shared by the real world. *Does this mean that RHIC is creating small five-dimensional black holes? It is really too early to tell,* both experimentally and theoretically.

November, 2005 Scientific American “The Illusion of Gravity” J. Maldacena

AdS/CFT



Kovtun, Son, Starinets, PRL 94 (2005) 111601

quantifying the viscosity

NA49: C. Alt et al., Phys. Rev. C68, 034903 (2003)

for ideal hydrodynamics:

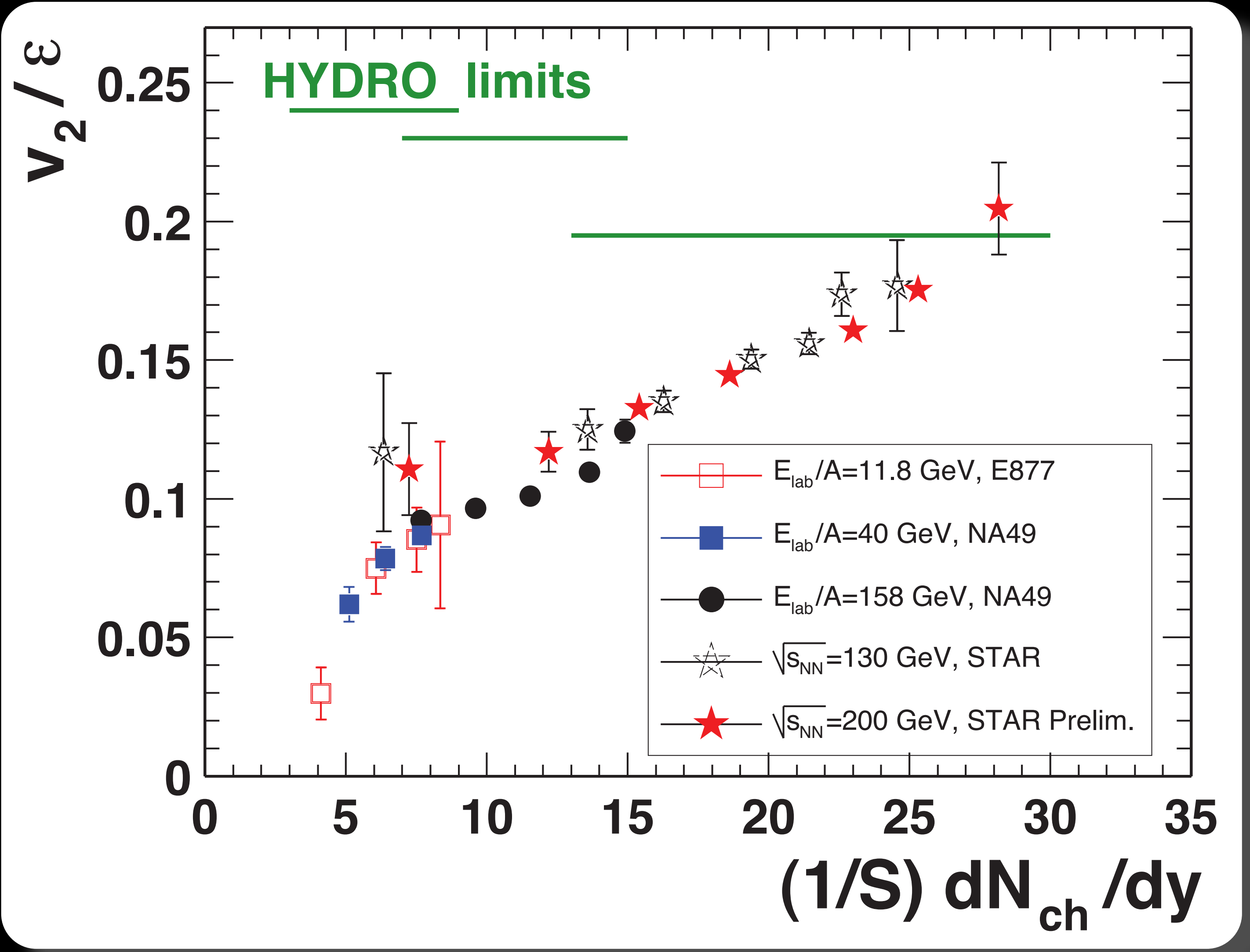
$$\frac{v_2}{\epsilon} = h$$

in the Low Density Limit (LDL):

$$\frac{v_2}{\epsilon} \propto \sigma \frac{1}{S} \frac{\mathrm{d}N}{\mathrm{d}y}$$

H. Heiselberg and A. M. Levy, Phys. Rev. C 59, 2716 (1999)

S. A. Voloshin and A. M. Poskanzer, Phys. Lett. B 474, 27 (2000)



Hydro limits from P.F. Kolb, J. Sollfrank, U.W. Heinz; Phys.Rev.C62:054909,2000.

data <u>not</u> understood in ideal hydrodynamics alone!

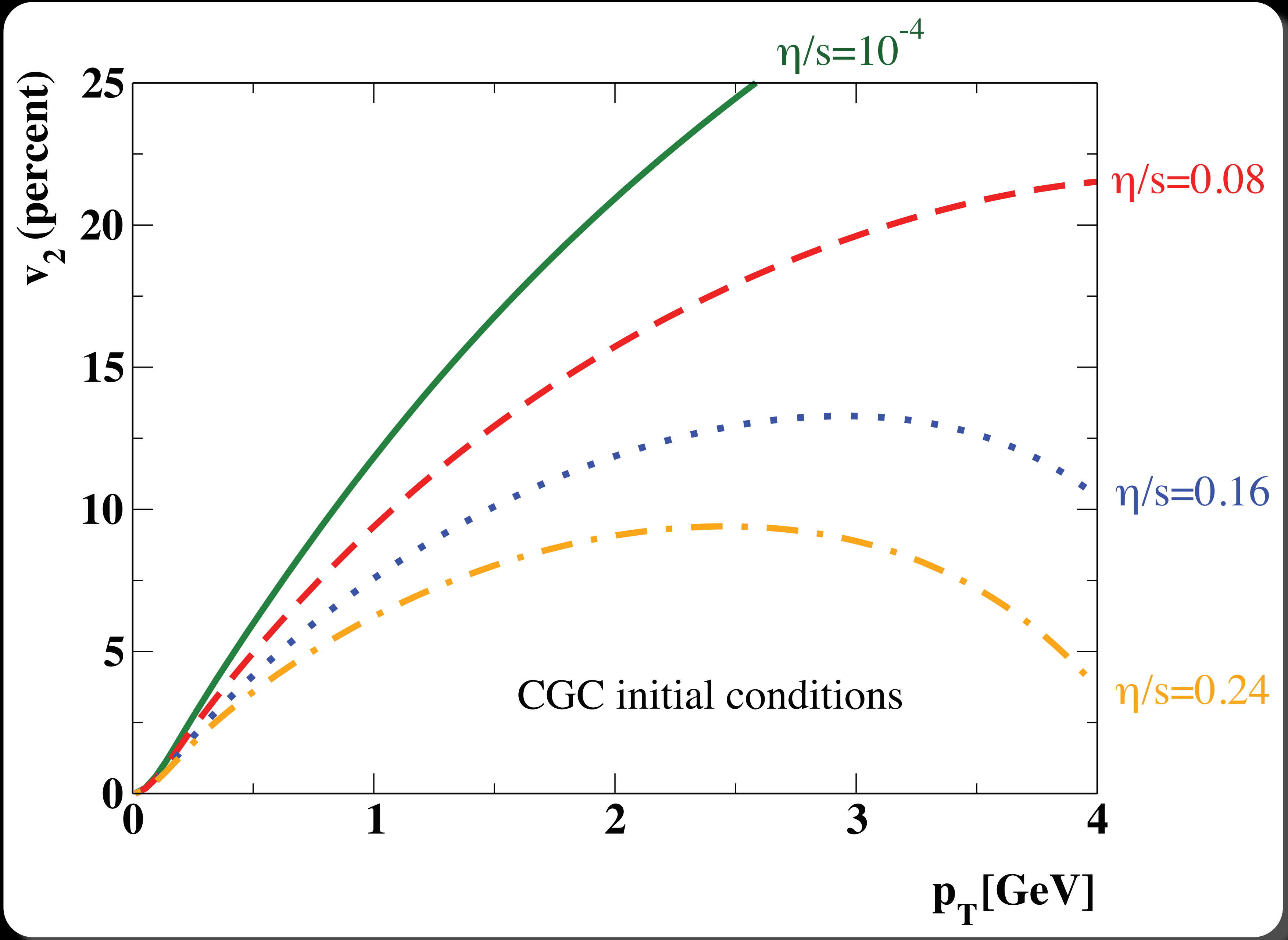
corrections needed: parton cascade, viscous hydro, hadron cascade ......

hydro Calculations of $v_2(p_t)$

small shear viscosity (close to the conjectured lower bound) leads to a significant reduction of the predicted elliptic flow

D.Teaney PRC68 034913 (2003)

in recent years strong theoretical effort to incorporate viscous corrections in the hydro calculations



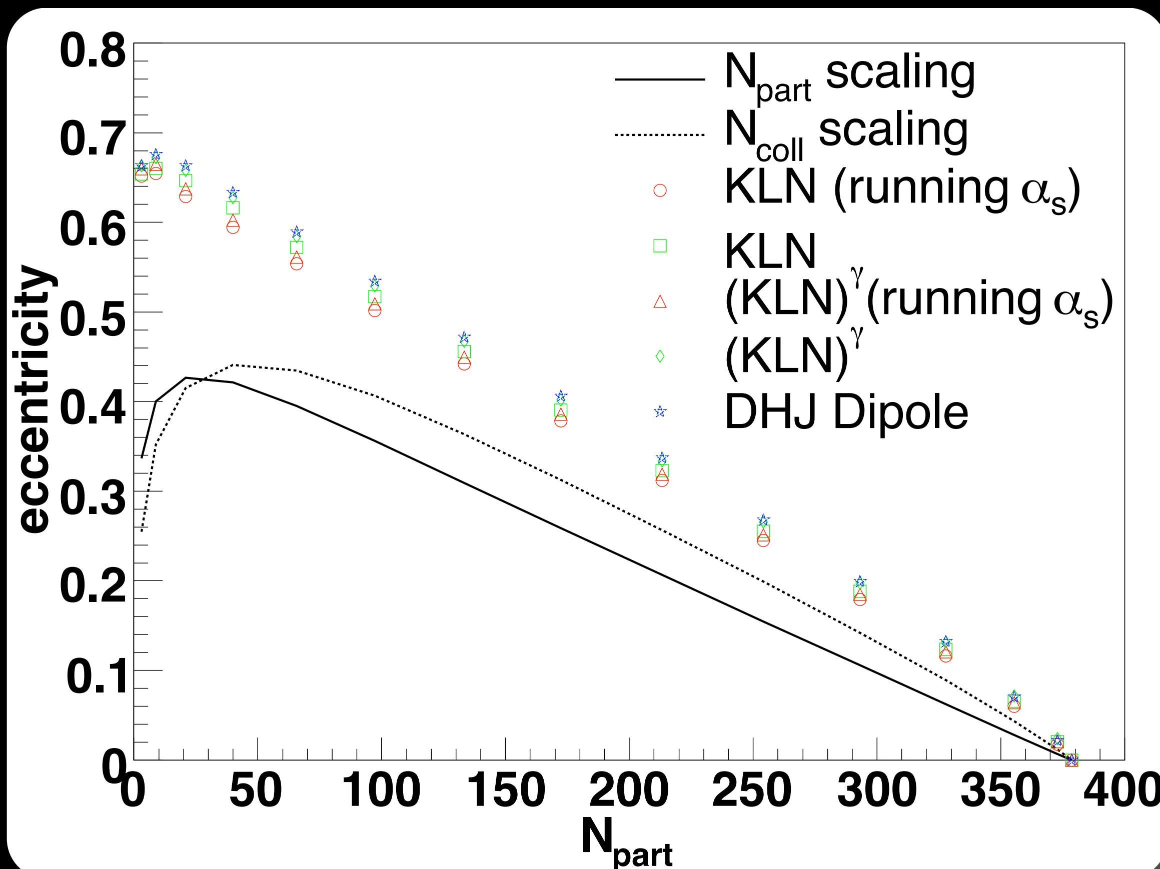
Matthew Luzum, Paul Romatschke arXiv:0804.4015

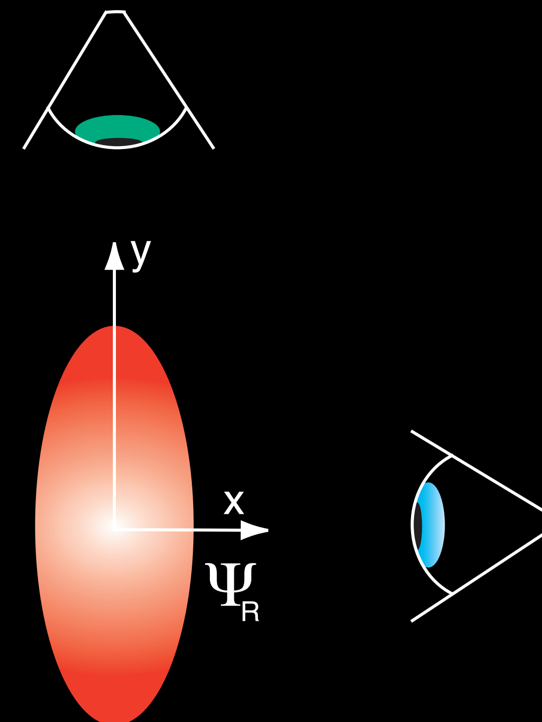
viscous corrections go as p_t^2 → shift of maximum v_2 vs p_t

towards estimates of η/s

- strong experimental/theoretical effort to understand better the uncertainties for the determination of v_2 for the most central and peripheral collisions, and at higher transverse momenta
- strong theoretical/experimental effort to quantify the uncertainties in the initial conditions (main contribution is the eccentricity, mean magnitude and its fluctuation)
- uncertainties are now beter understood (next slides)

initial conditions: ε





$$\varepsilon = \frac{\langle y^2 - x^2 \rangle}{\langle y^2 + x^2 \rangle}$$

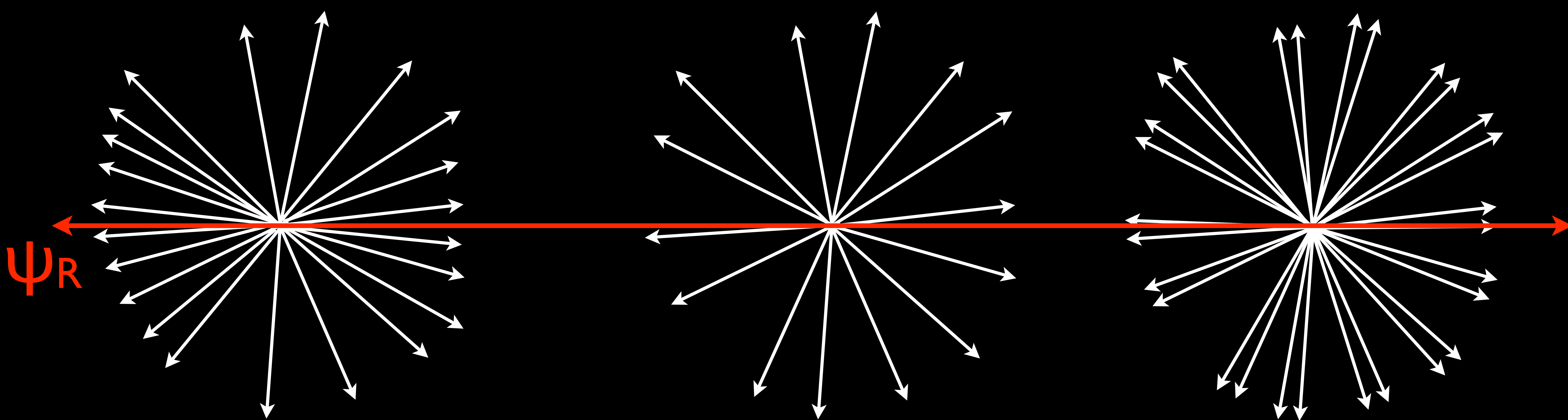
H-J. Drescher et al., Phys.Rev.C74:044905,2006

- estimates of the eccentricity vary significantly ~ 30%!
- difference between CGC and Glauber N_{part} scaling largest
- v_2 follows ε

measure elliptic flow

$$v_n = \langle \cos(n(\phi - \Psi_R)) \rangle = \left\langle e^{in(\phi - \Psi_R)} \right\rangle$$

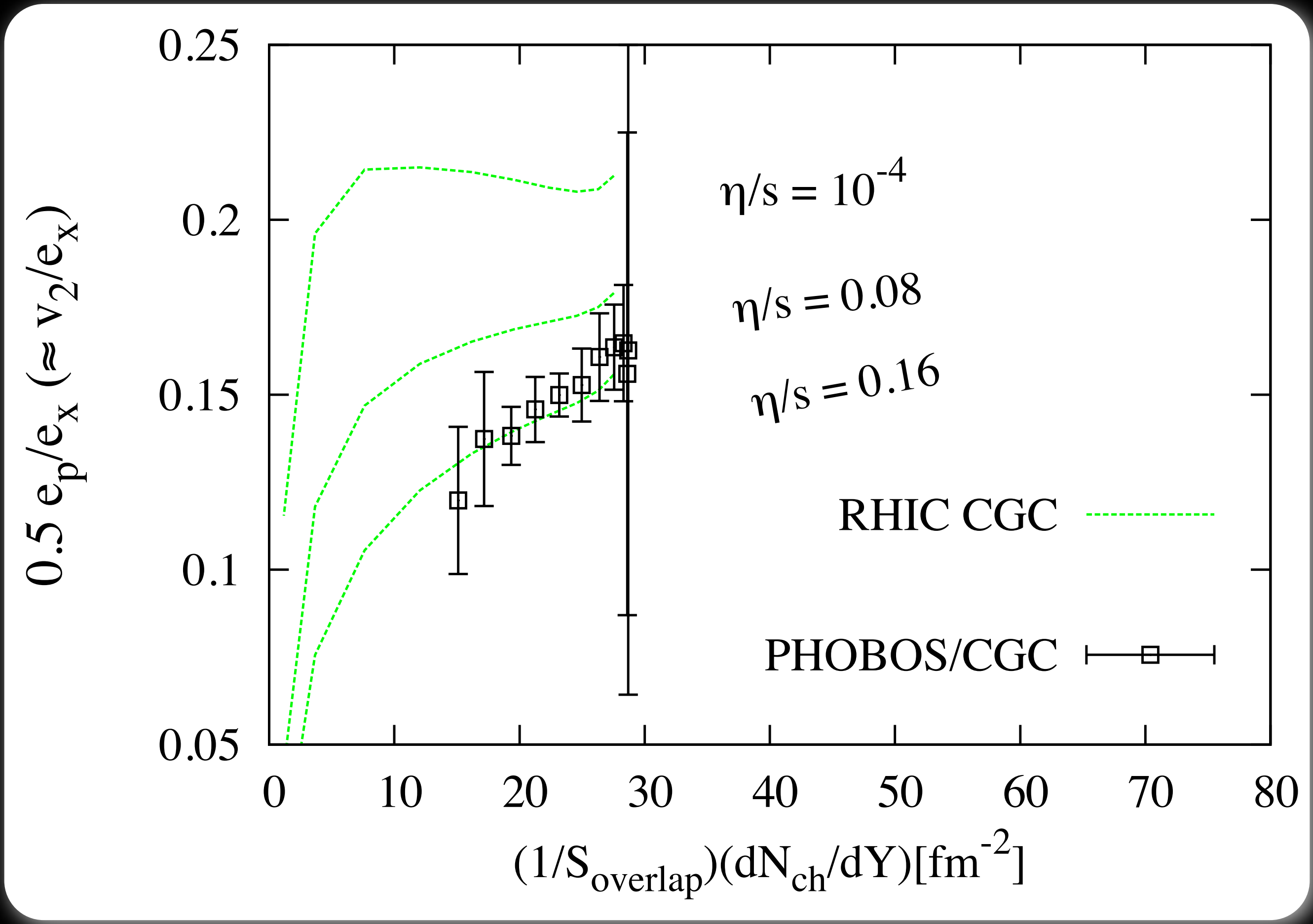
$$\left\langle e^{in(\phi_i - \phi_j)} \right\rangle = \left\langle e^{in(\phi_i - \Psi_R)} e^{in(\Psi_R - \phi_j)} \right\rangle \approx \left\langle e^{in(\phi_i - \Psi_R)} \right\rangle \left\langle e^{in(\Psi_R - \phi_j)} \right\rangle = \left(v_n\{2\} \right)^2$$



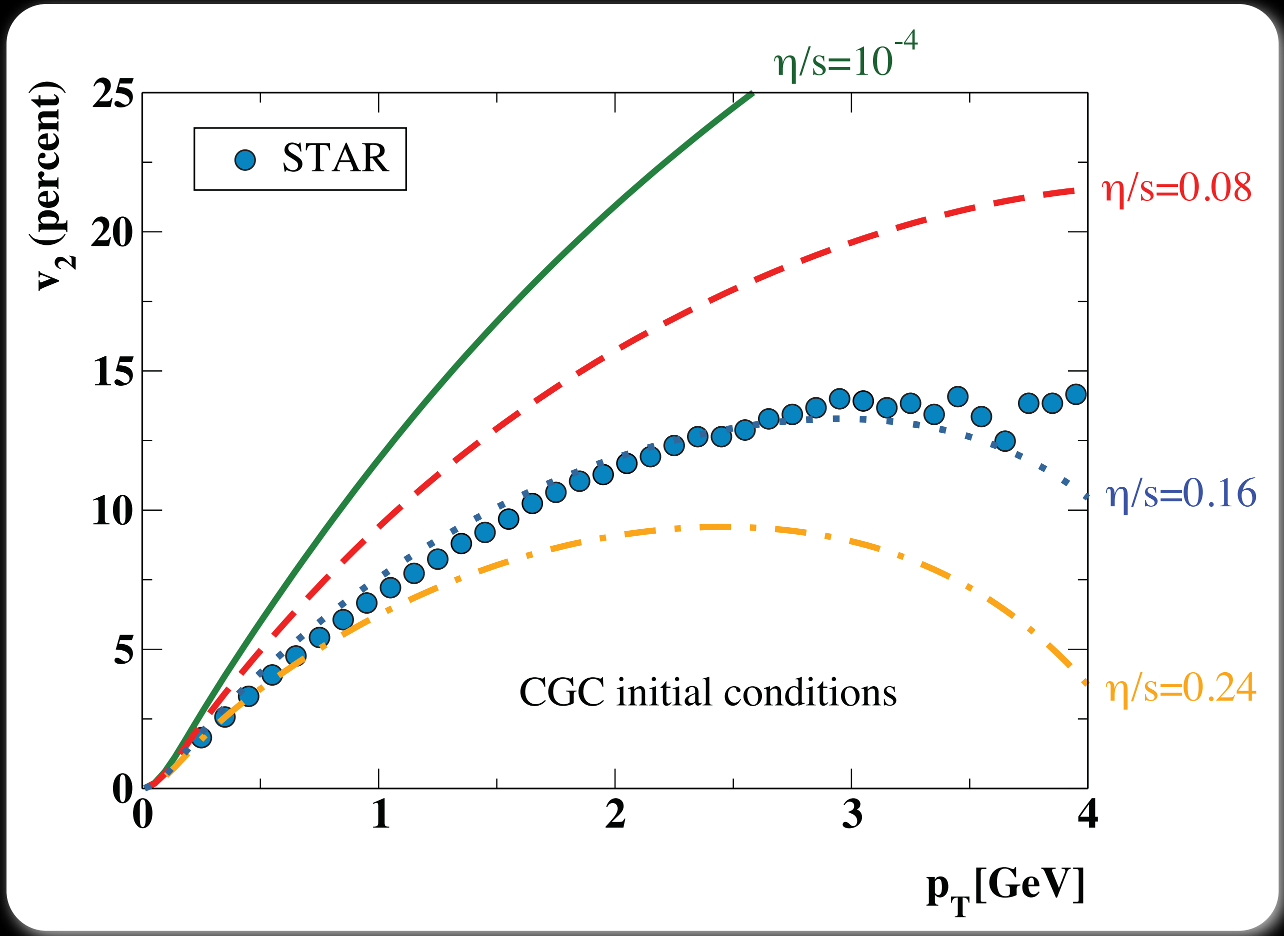
$v_2 > 0$, $v_2\{2\} > 0$ $v_2 = 0$, $v_2\{2\} = 0$ $v_2 = 0$, $v_2\{2\} > 0$

use more sophisticated multiparticle correlation methods

viscous hydro CGC



Matthew Luzum and Paul Romatschke; arXiv: 0901.4588 [nucl-th]



Matthew Luzum, Paul Romatschke arXiv:0804.4015

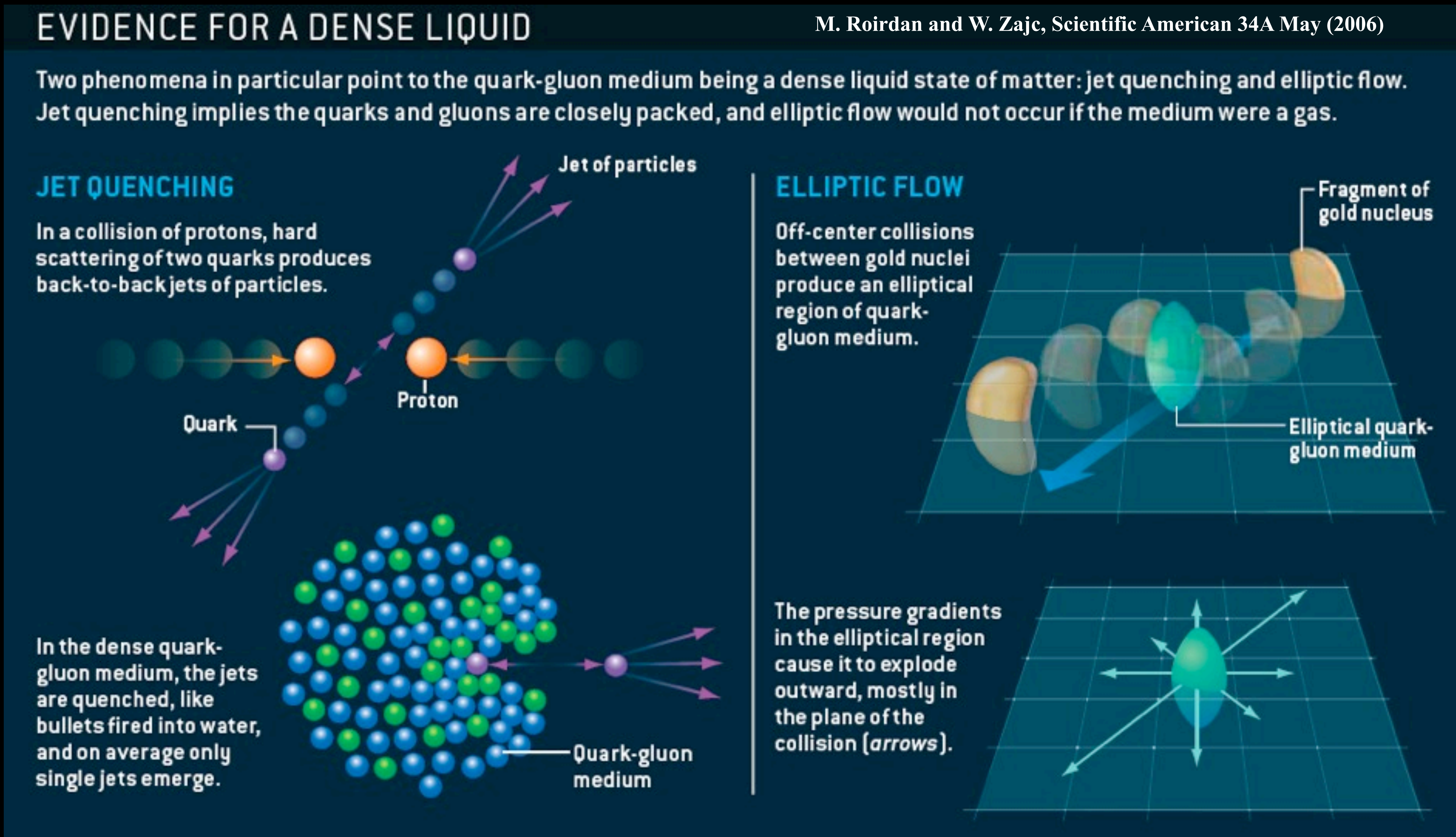
viscous hydro calculations using ~ lattice EoS and CGC ε describe the centrality dependence and p_t dependence using $\eta/s = 2/4\pi$

RHIC Scientists Serve Up "Perfect" Liquid

New state of matter more remarkable than predicted -- raising many new questions
April 18, 2005

- now improved quantitative understanding of the created system at RHIC
- viscous correction are important!
- initial conditions (e.g. ε, initial flow fields) not sufficiently constrained!
- ~ lattice EoS ☺ + ~ CGC ε ☺ → ~ $\eta/s = 2/4\pi$ ☺ describes centrality and transverse momentum dependence of v_2 very well!
    - current estimates of η/s are < 4x the conjectured lower bound from AdS/CFT

highlights at RHIC

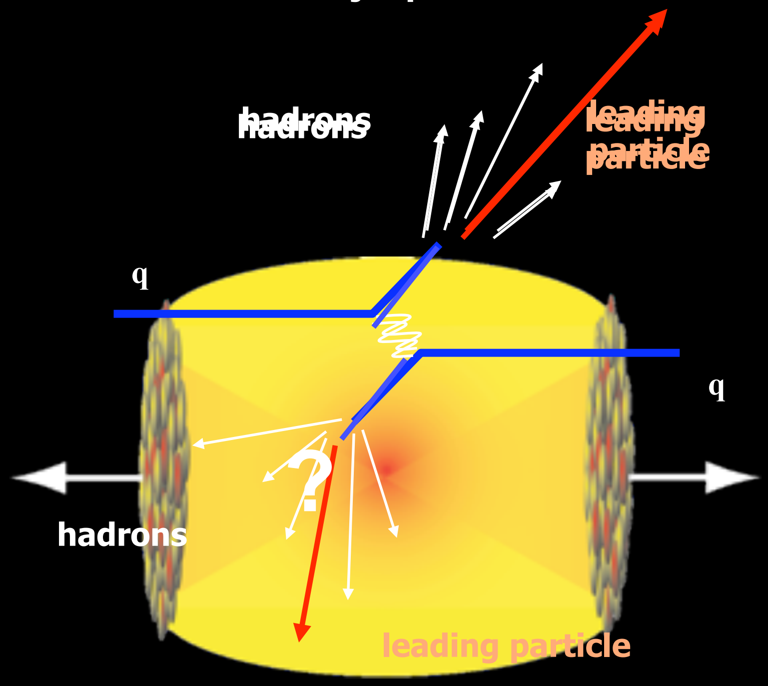


M. Roirdan and W. Zajc, Scientific American 34A May (2006)

parton energy loss

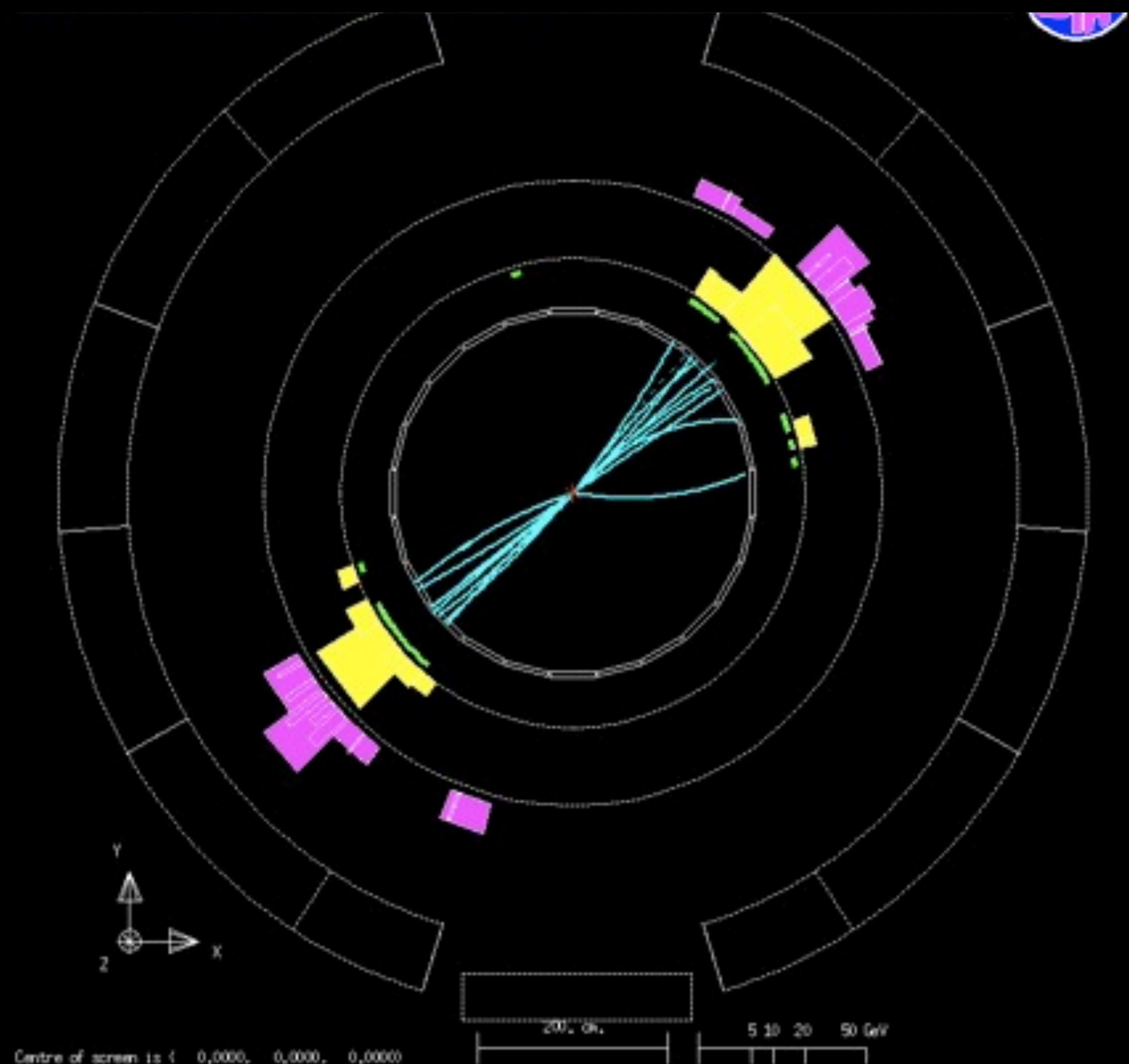
probe the density of the created system

- probe needs to be calibrated
  - ✓high momentum partons
- probe needs to interact with the matter
  - ✓parton energy loss
- interactions should be understood and calculable

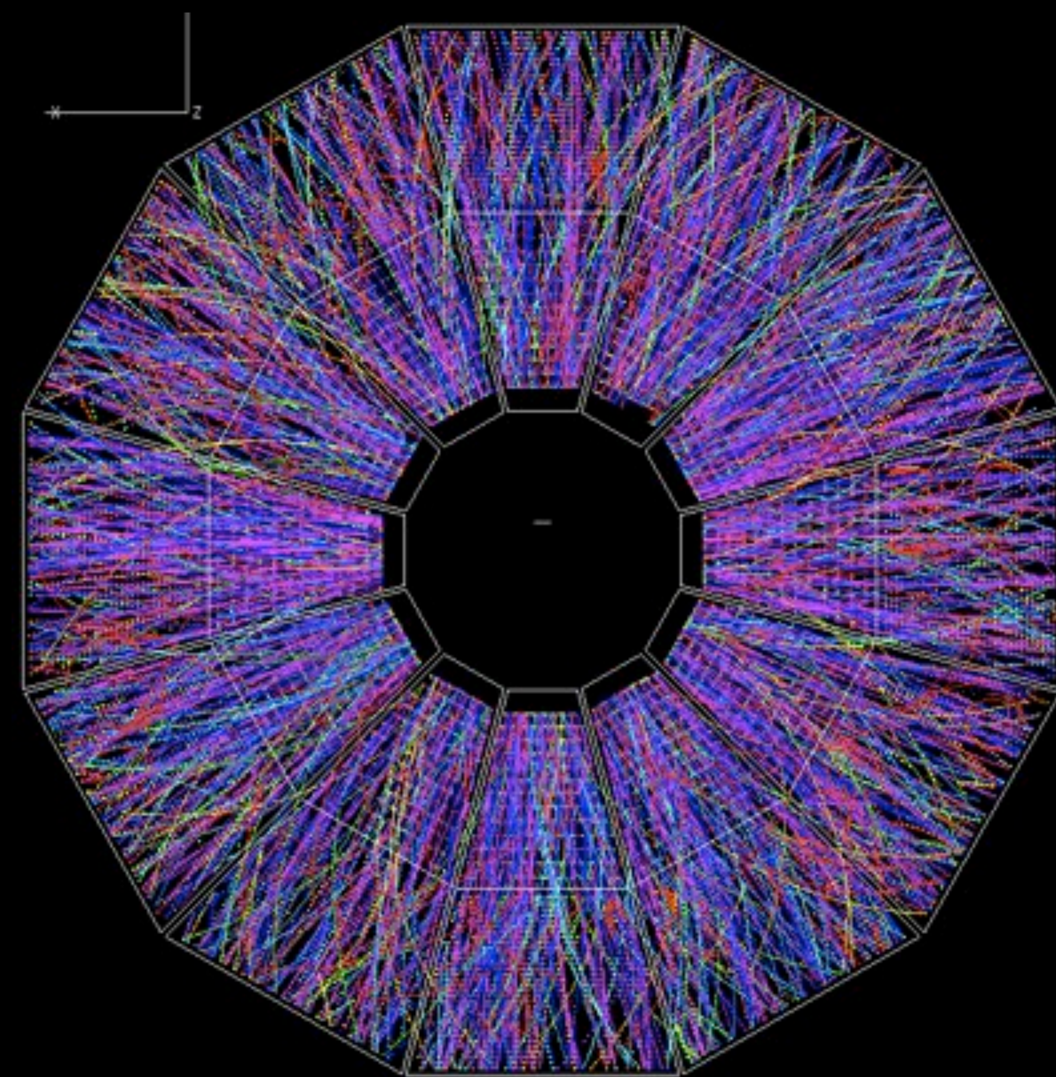


jets in a heavy-ion environment

Jets in e^+e^-



Jets in Au + Au at 200 GeV



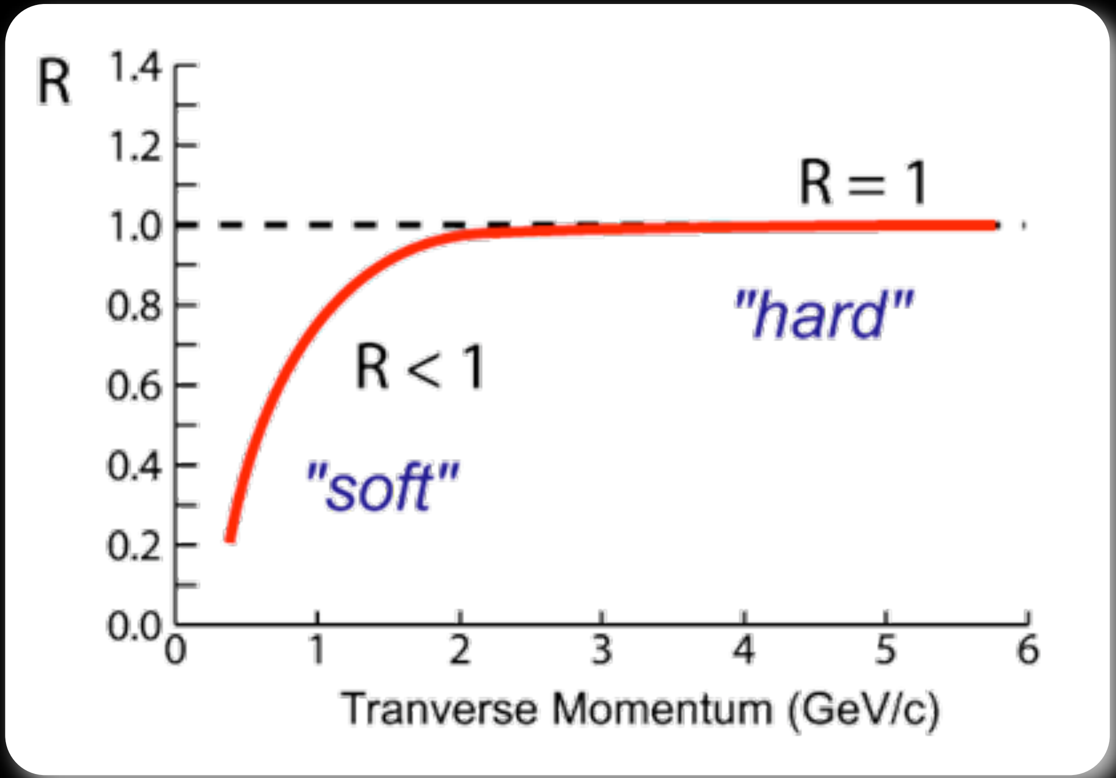
heavy-ion collisions are a complicated environment to do full jet reconstruction!

parton energy loss

we measure the particle yield as function of transverse momentum in nucleus-nucleus and in nucleon+nucleon collisions

we construct the ratio:

$$R = \frac{\mathrm{Yield}_{A+A}/\langle N_{\mathrm{binary}}\rangle}{\mathrm{Yield}_{\mathrm{p+p}}}$$



no “nuclear effects”:
R < 1 in regime of soft physics
R = 1 at high-p_t where hard scattering dominates

suppression:
R < 1 at high-p_t

parton energy loss

$$R = \frac{\mathrm{Yield}_{A+A}/\langle N_{\mathrm{binary}}\rangle}{\mathrm{Yield}_{\mathrm{p+p}}}$$

no “nuclear effects”:
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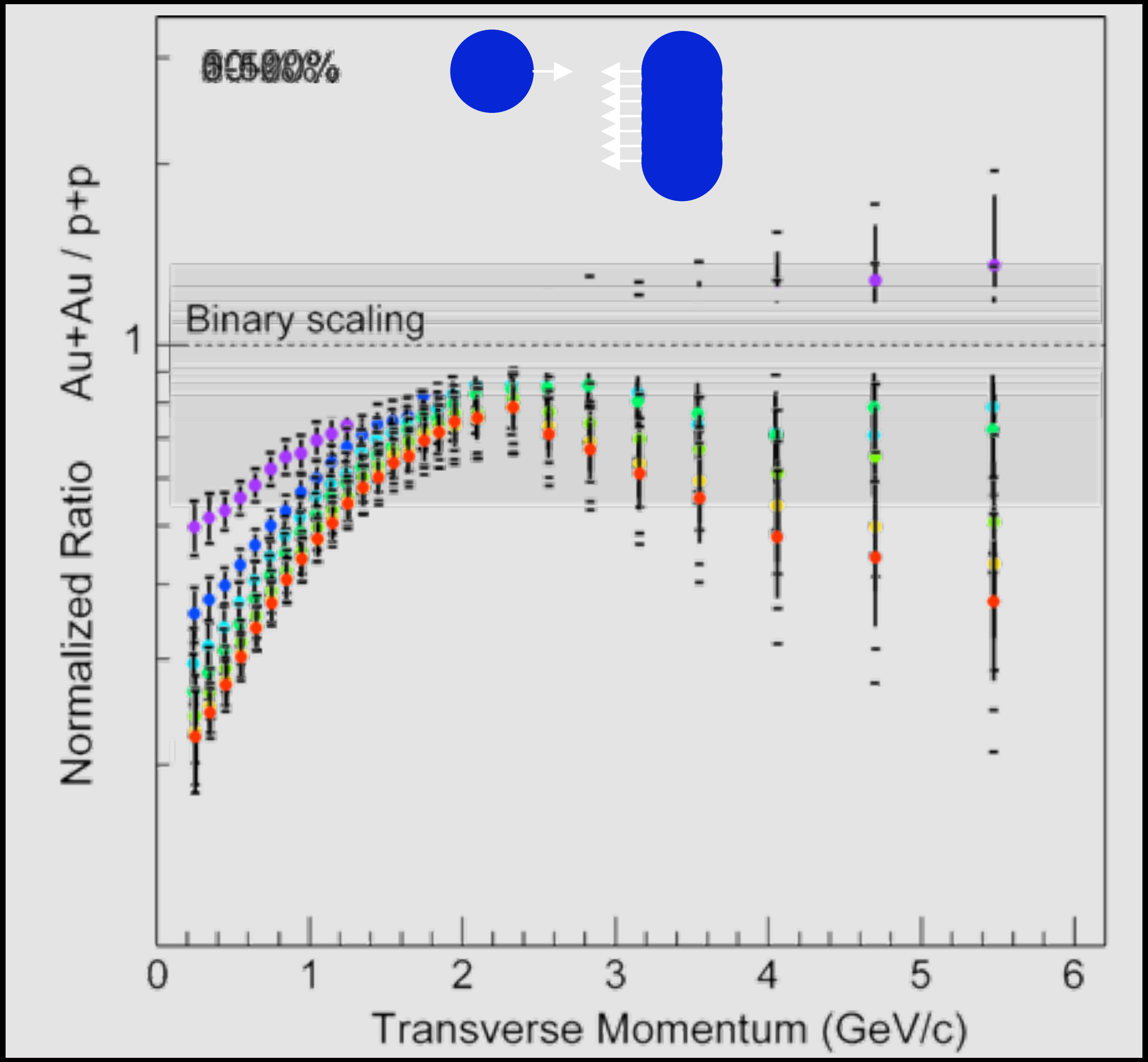
suppression:
$R < 1$ at high-p_t

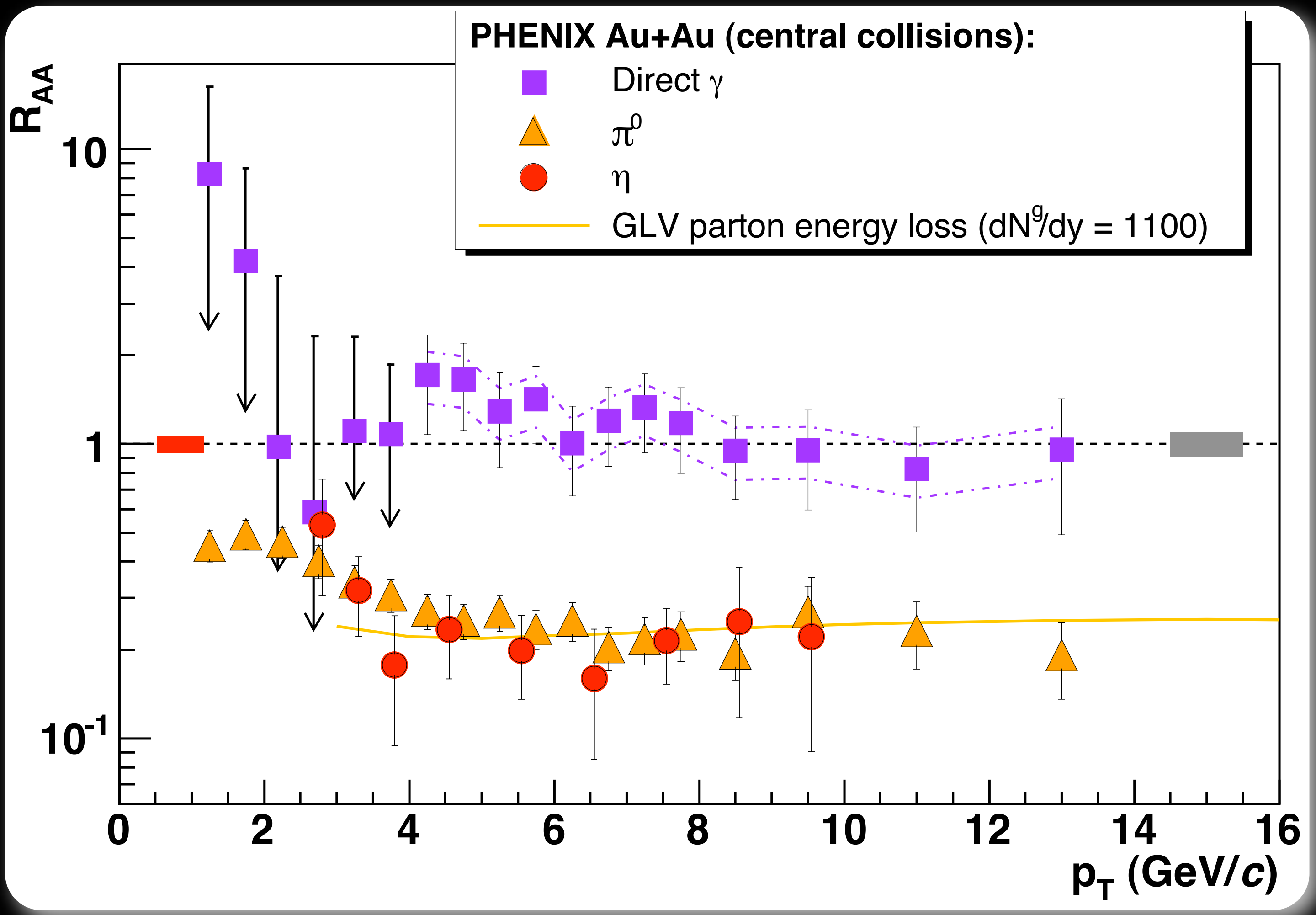


parton energy loss

$$R = \frac{\mathrm{Yield}_{A+A}/\langle N_{\mathrm{binary}}\rangle}{\mathrm{Yield}_{\mathrm{p+p}}}$$

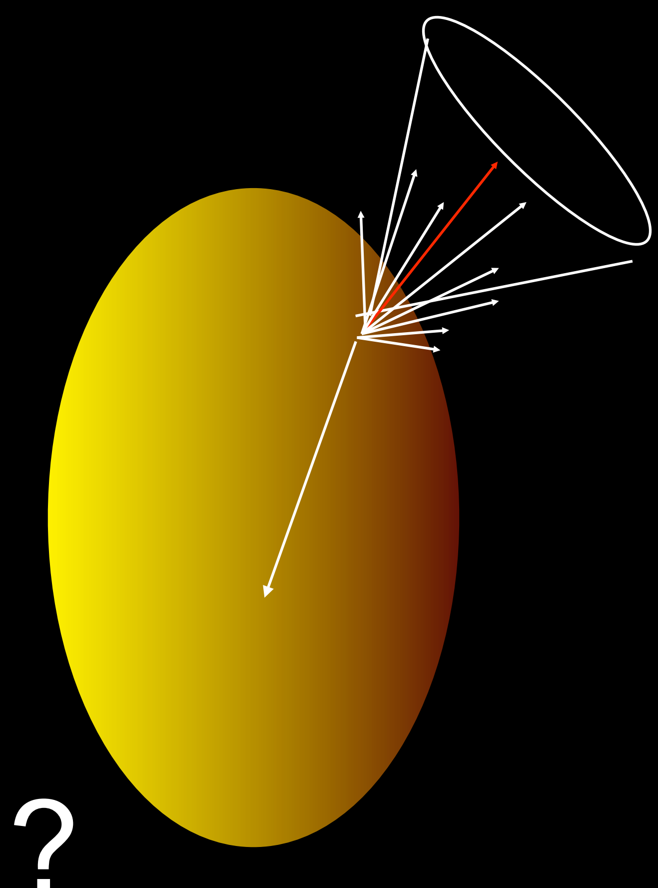
no “nuclear effects”:
$R < 1$ in regime of soft physics
$R = 1$ at high-p_t where hard scattering dominates

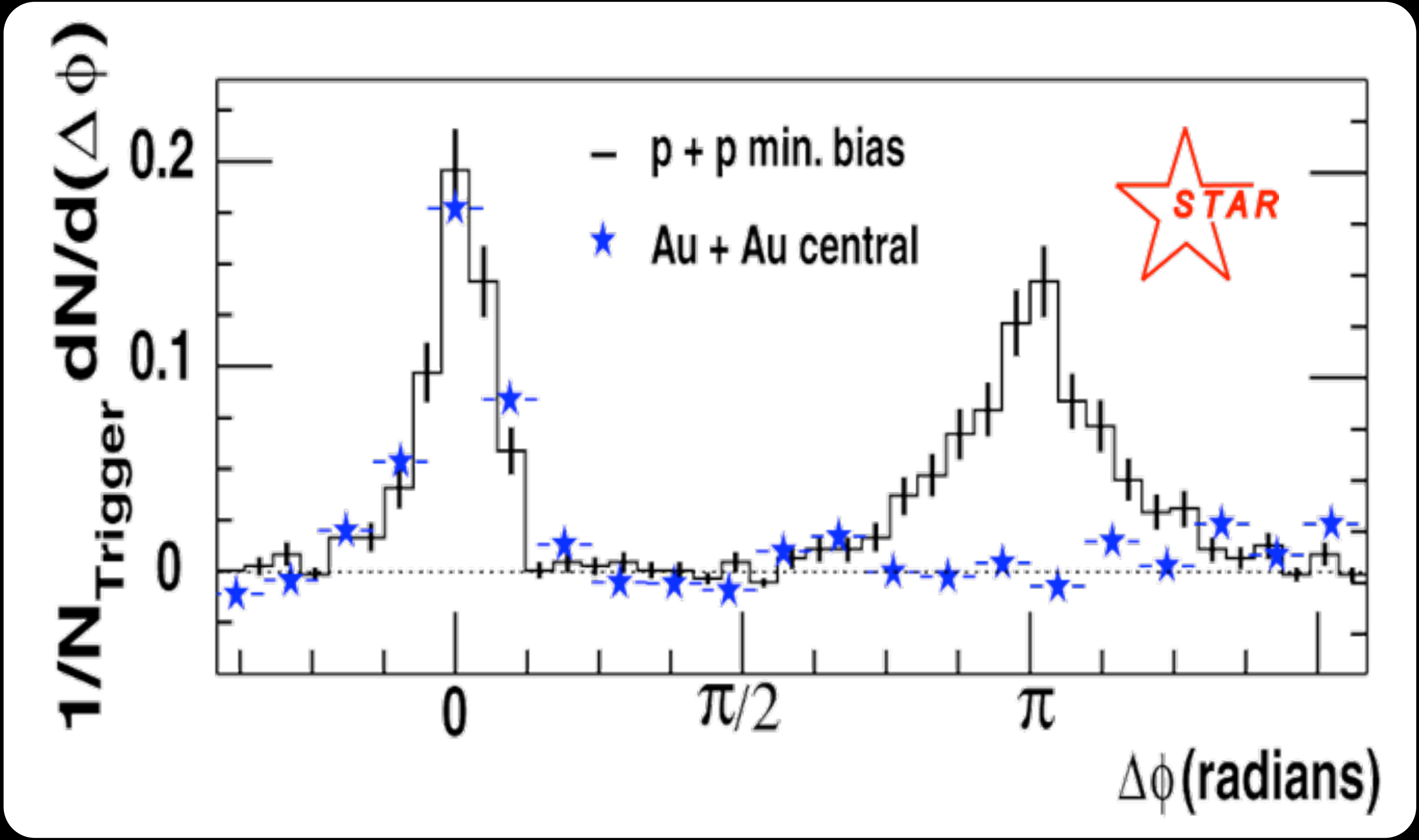
suppression:
$R < 1$ at high-p_t



very strong suppression!
medium density extracted 30-50 times normal nuclear matter density

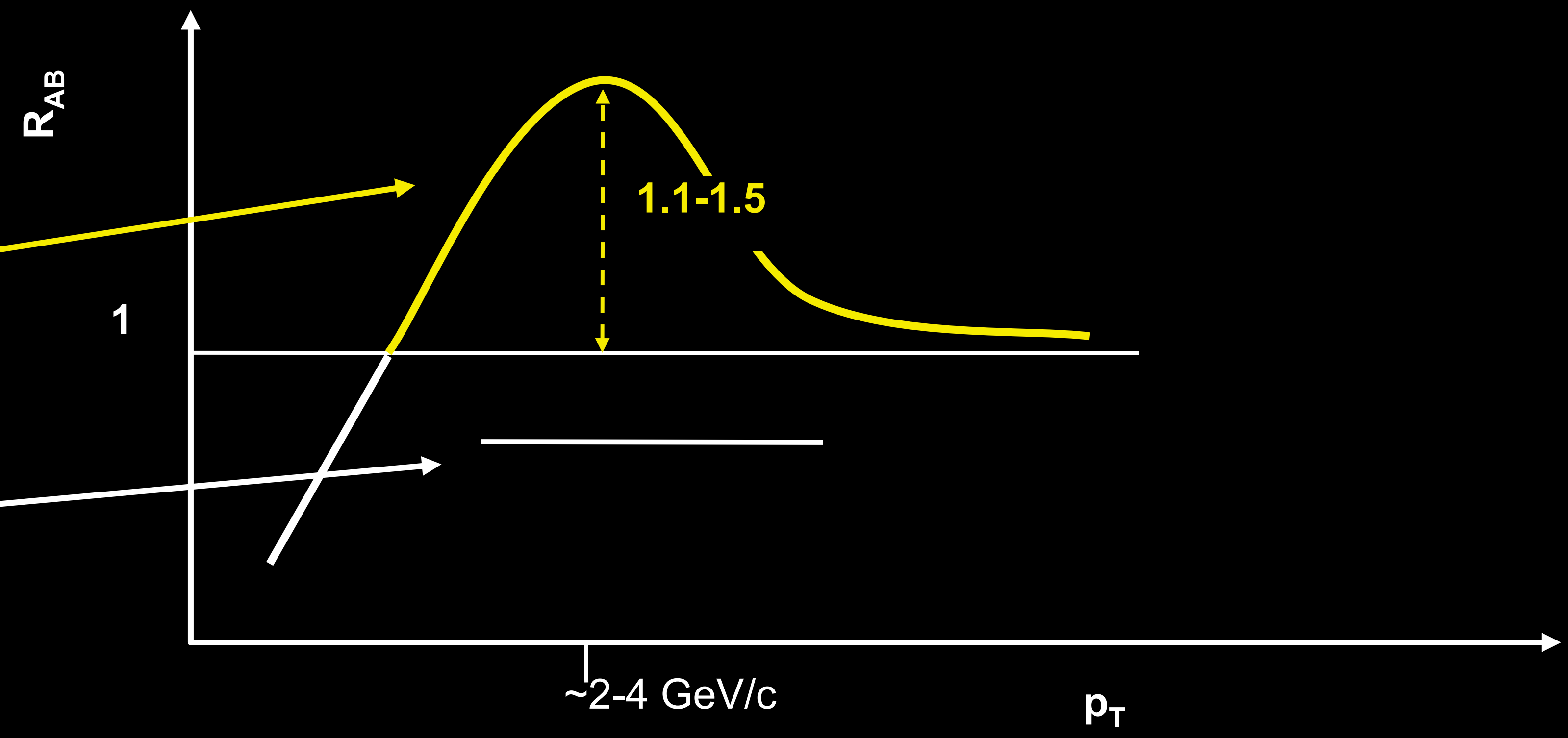
parton energy loss





the away side disappears completely!
medium density extracted 30-50 times normal nuclear matter density

what to expect in d+A?



Inclusive spectra

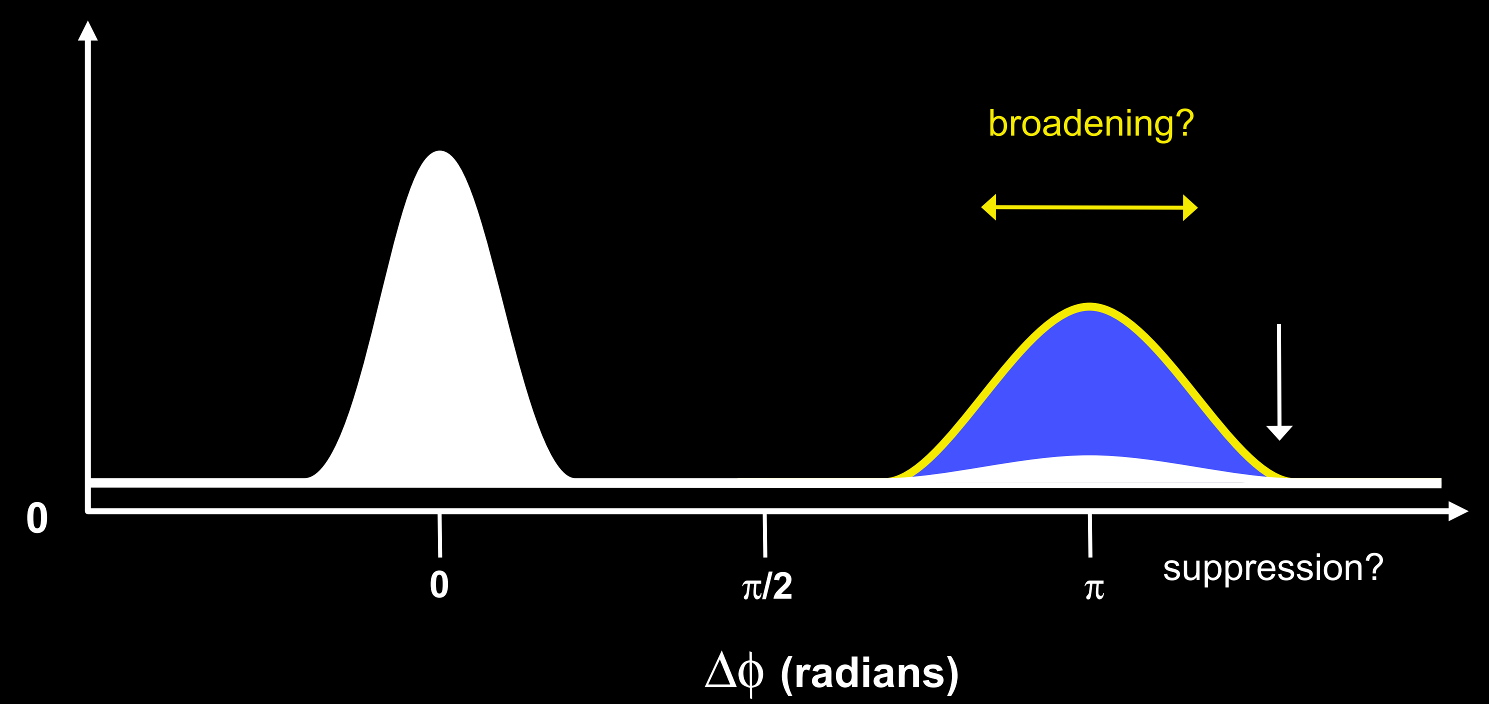
If Au+Au suppression is final state

If Au+Au suppression is initial state (KLM saturation: 0.75)

High p_T hadron pairs

pQCD: no suppression, small broadening due to Cronin effect

saturation models:
suppression due to mono-jet contribution?

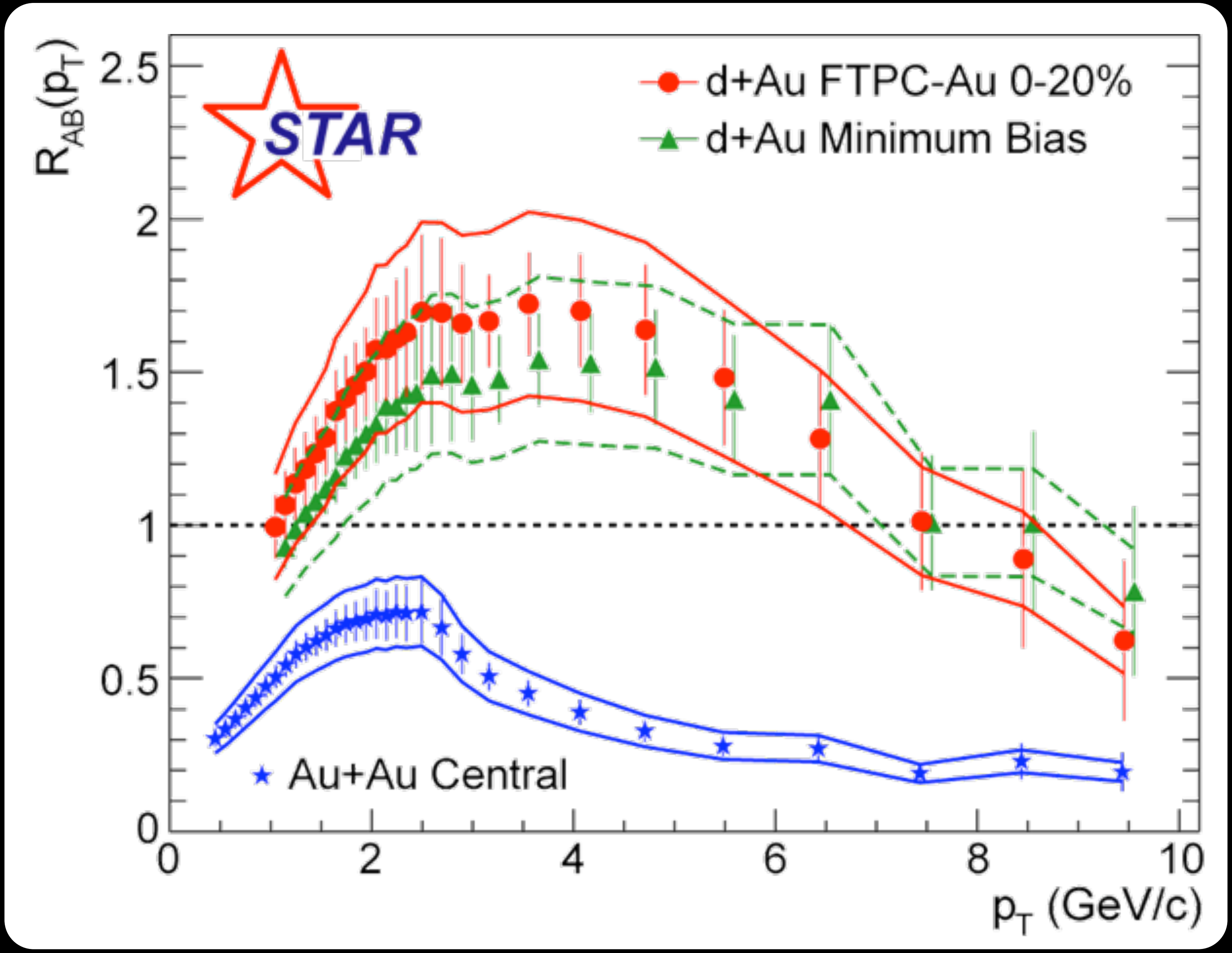


All effects strongest in central d+Au collisions

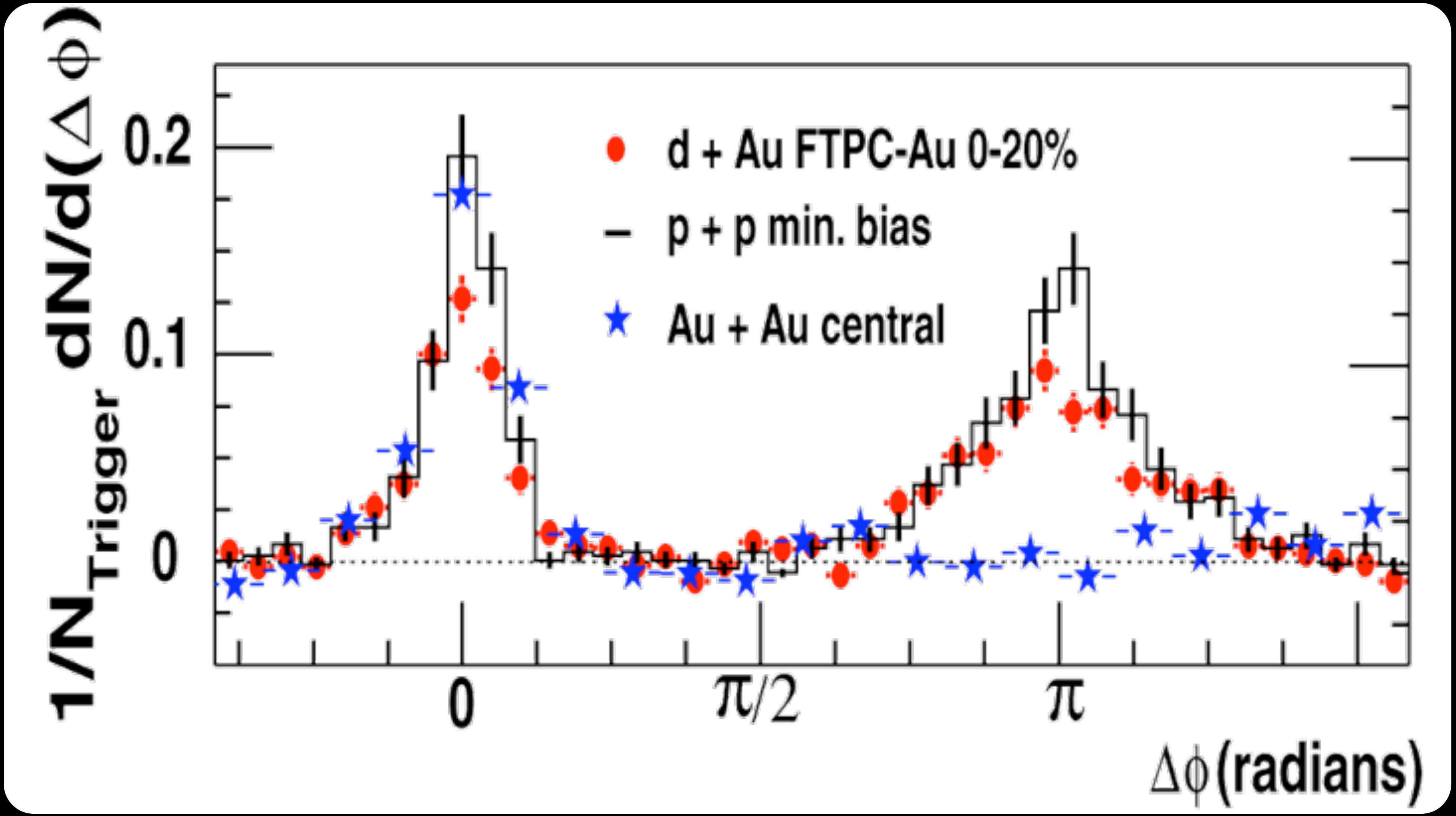
d+Au

ratio is larger than unity in d+Au opposite to Au+Au!

suppression is final state medium effect!

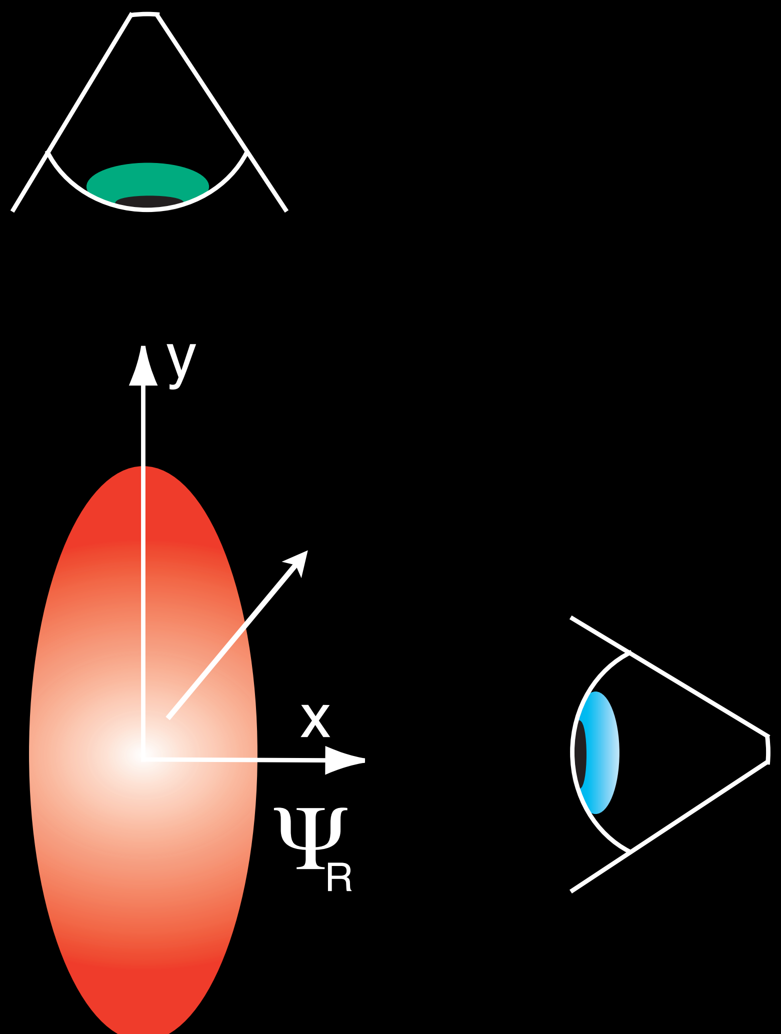


d+Au



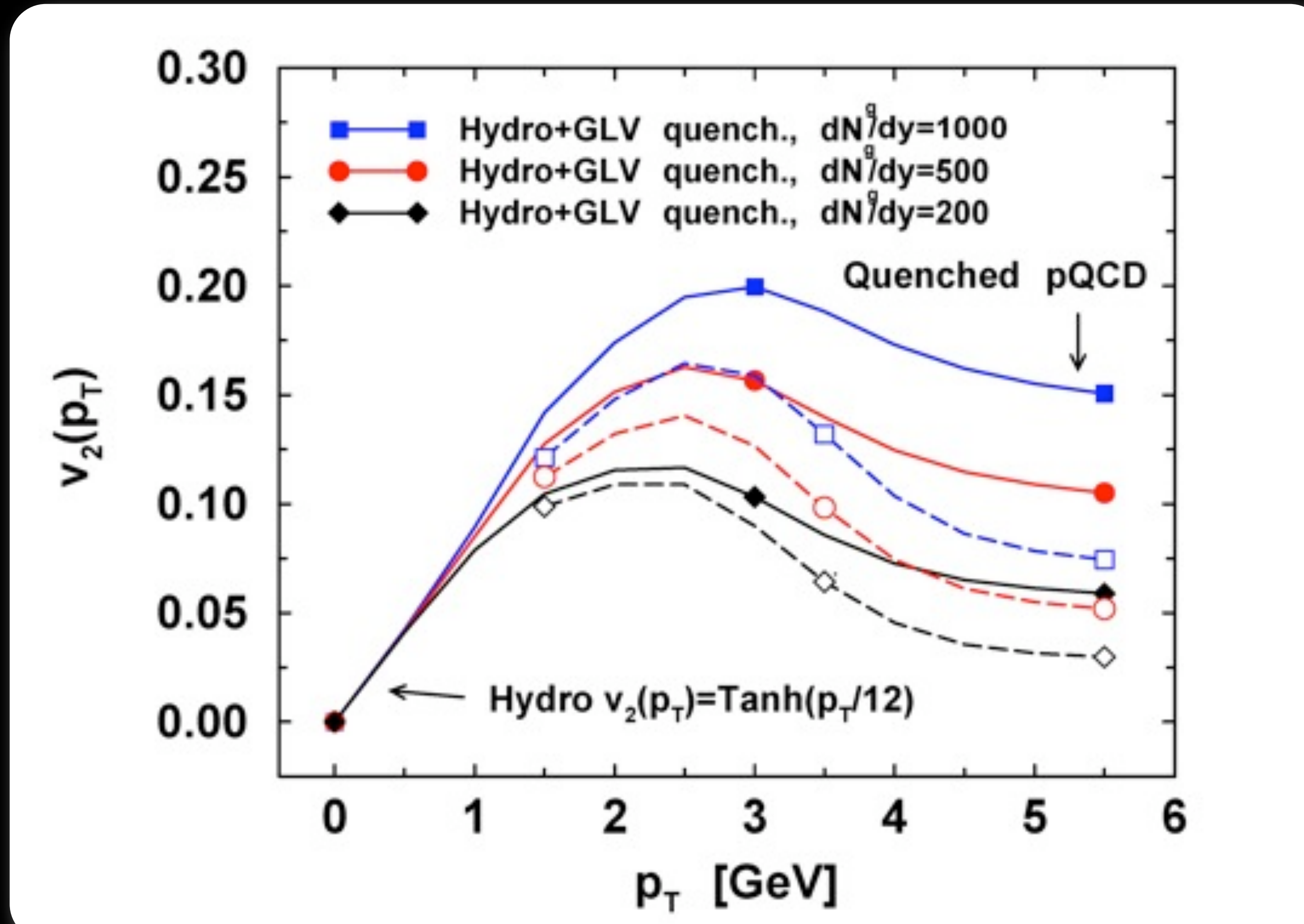
correlation in d+Au resembles pp and very different from Au+Au!
suppression is final state medium effect!

parton energy loss



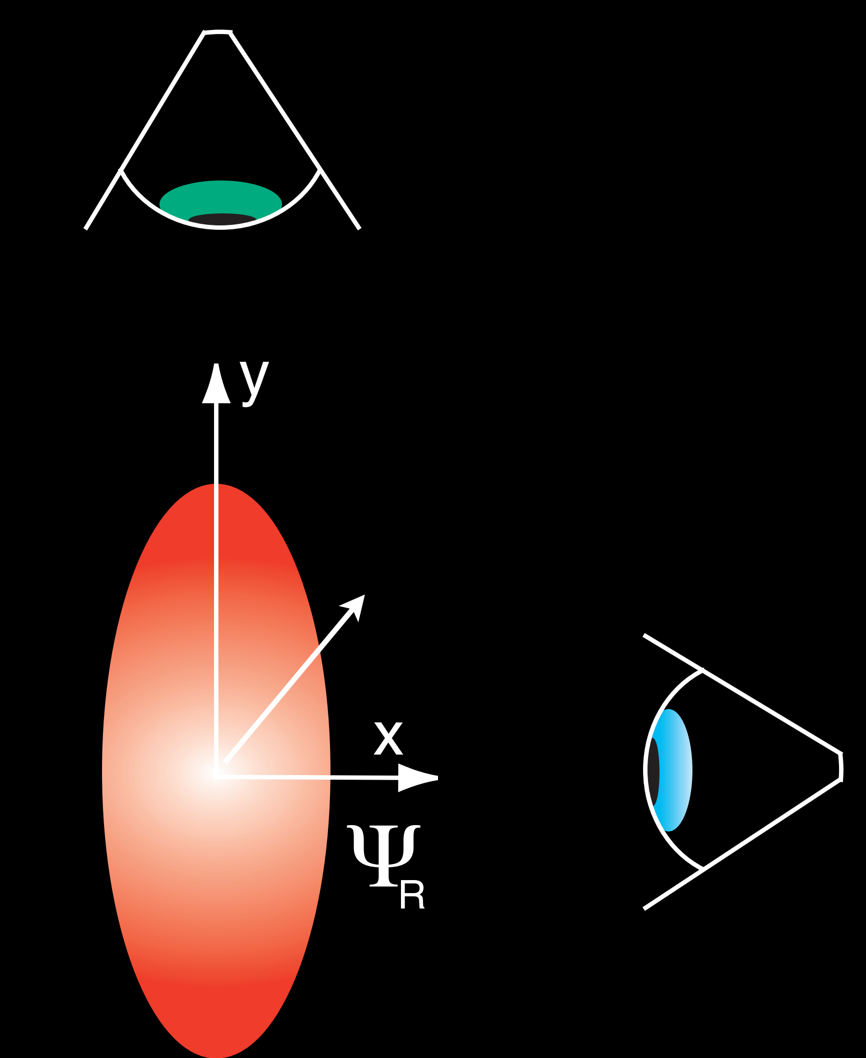
$$v_2 = \langle \cos 2(\phi - \Psi_R) \rangle$$

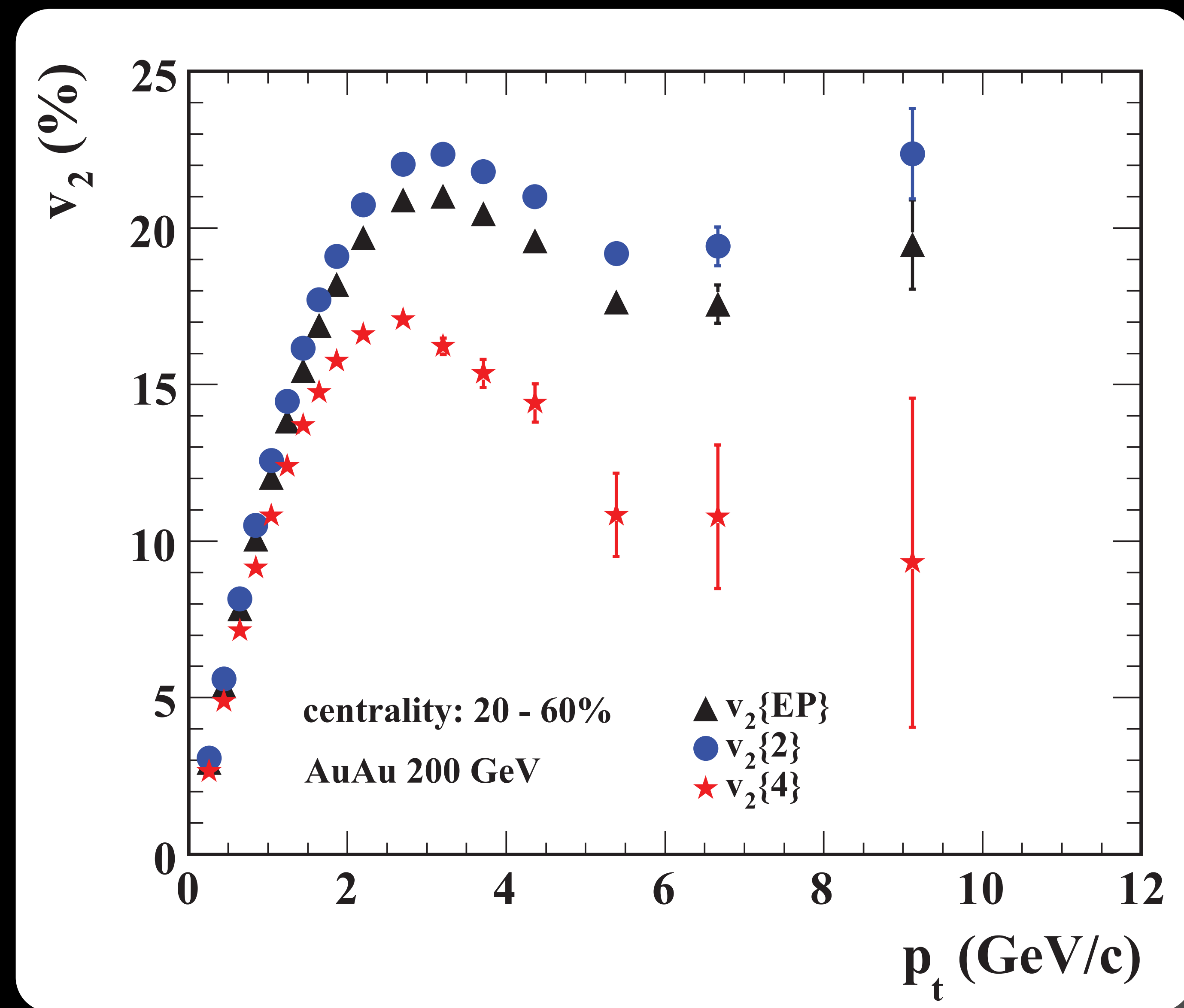
R.S, A.M. Poskanzer, S.A.Voloshin, nucl-ex/9904003



M. Gyulassy, I. Vitev and X.N. Wang PRL 86 (2001) 2537

parton energy loss



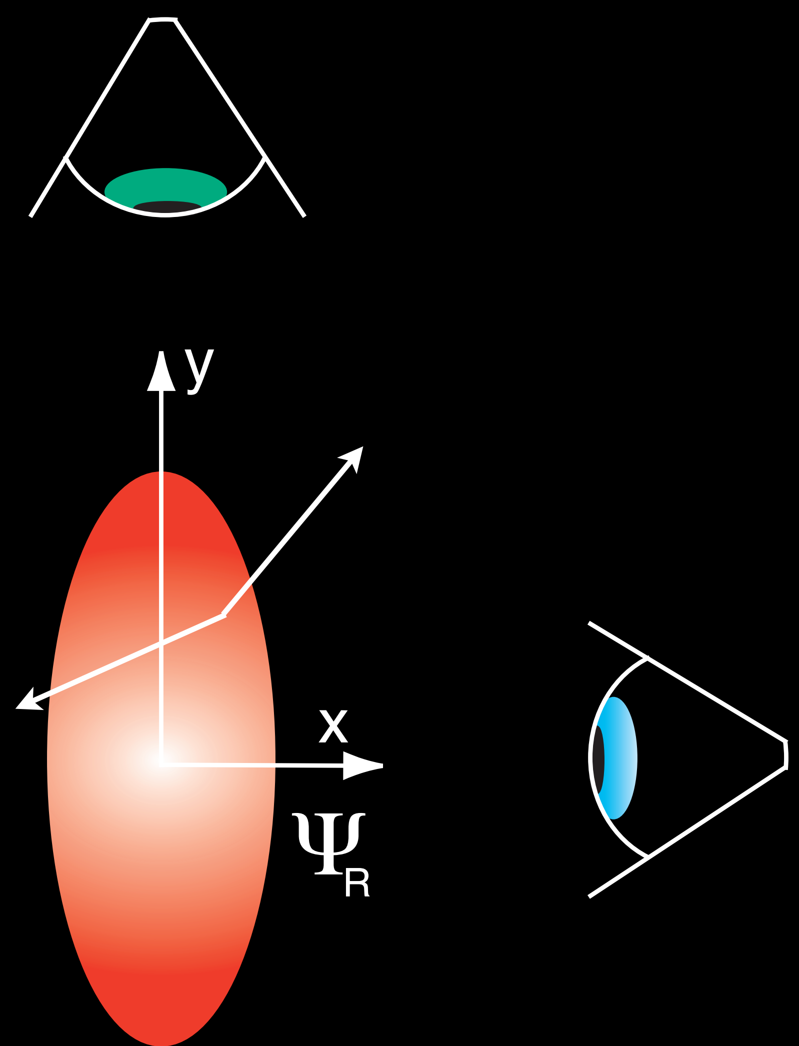


$$v_2 = \langle \cos 2(\phi - \Psi_R) \rangle$$

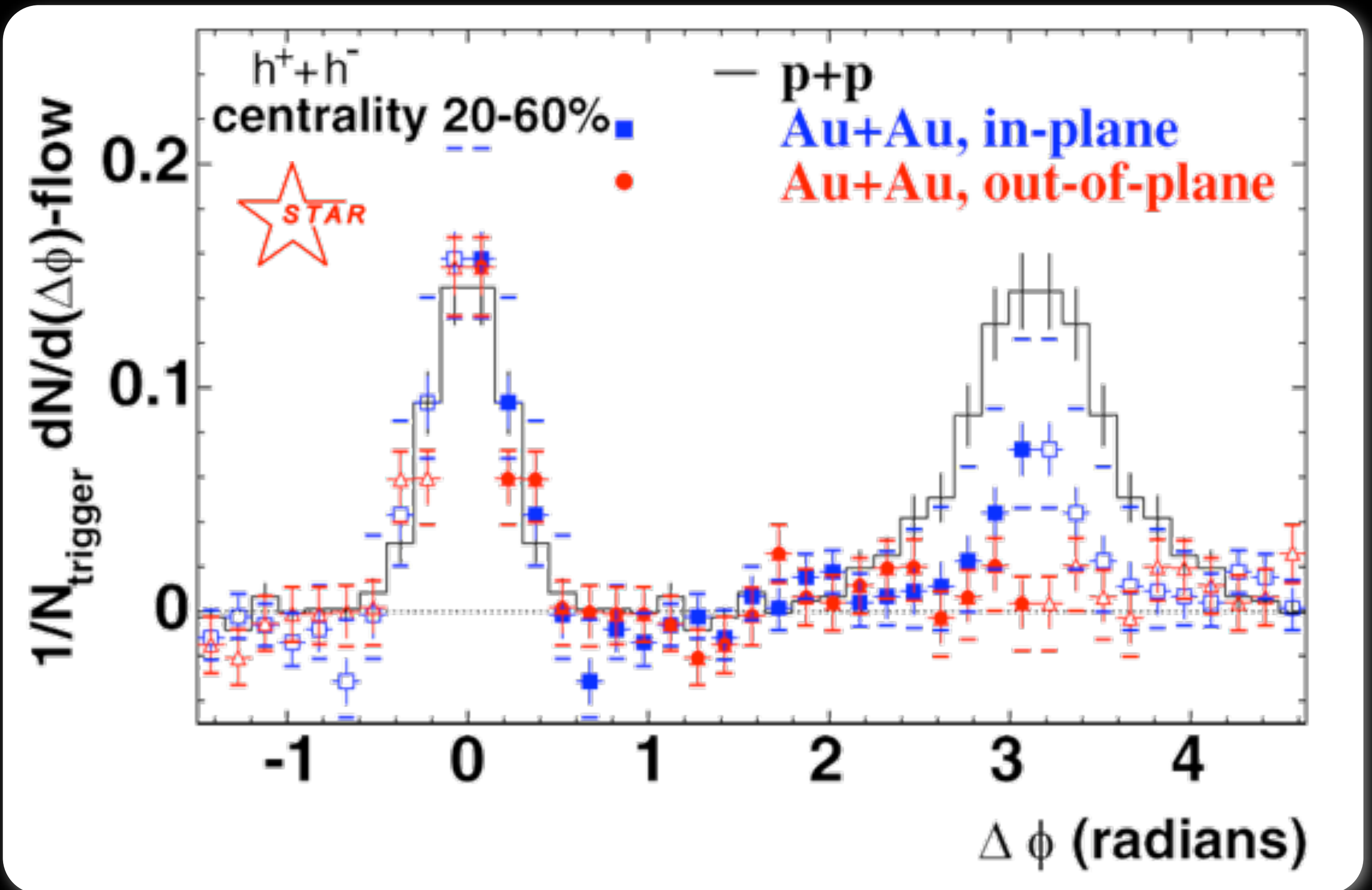
Yuting Bai, Nikhef PhD thesis

strong path length dependence observed!

parton energy loss



$$v_2 = \langle \cos 2(\phi - \Psi_R) \rangle$$

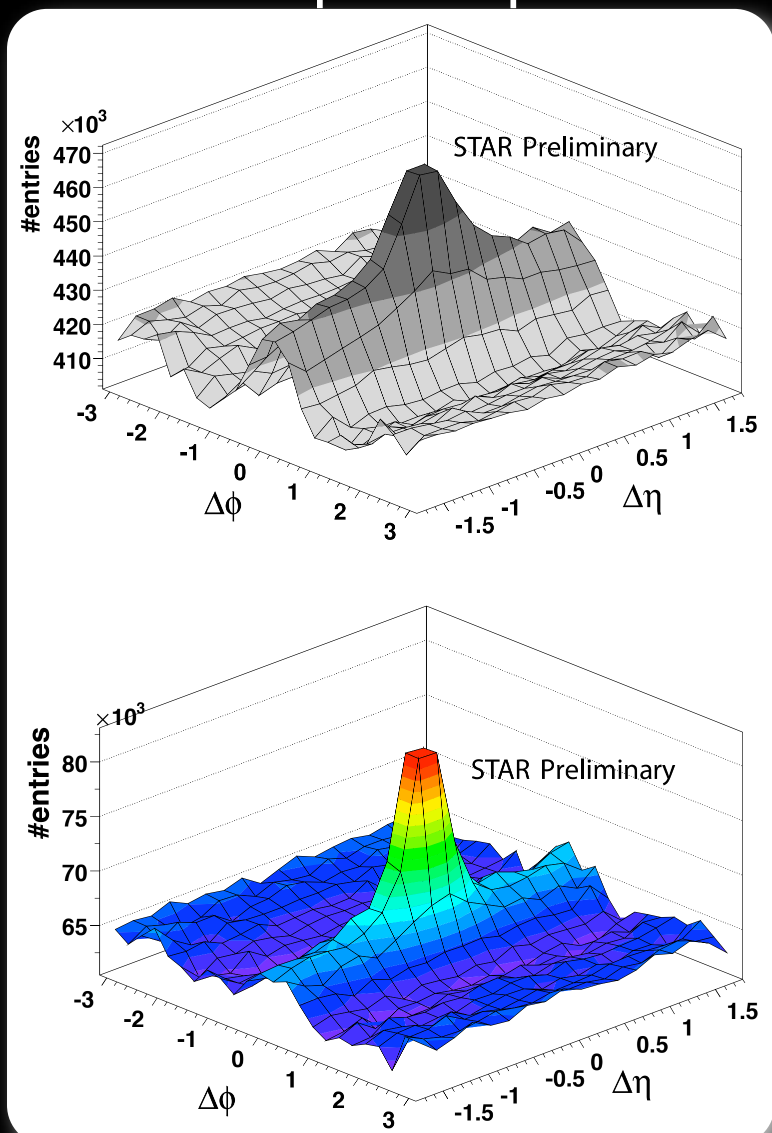


path length dependence observed!

simple? the ridge

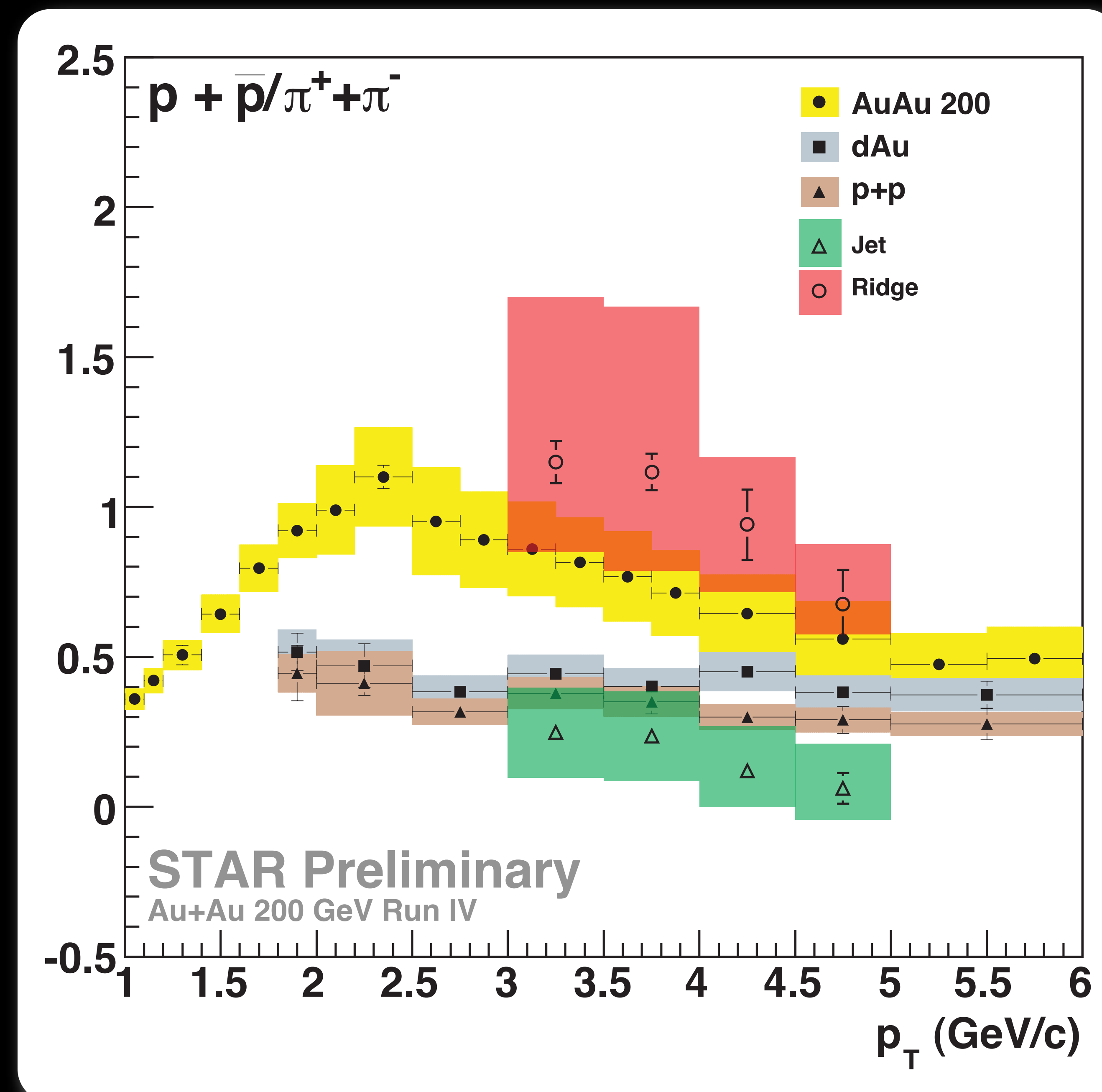
M. van Leeuwen, J. Putschke

$2 < p_t^{asso} < p_t^{trigg}$



$3 < p_t^{trig} < 4$ GeV/c

$4 < p_t^{trig} < 6$ GeV/c

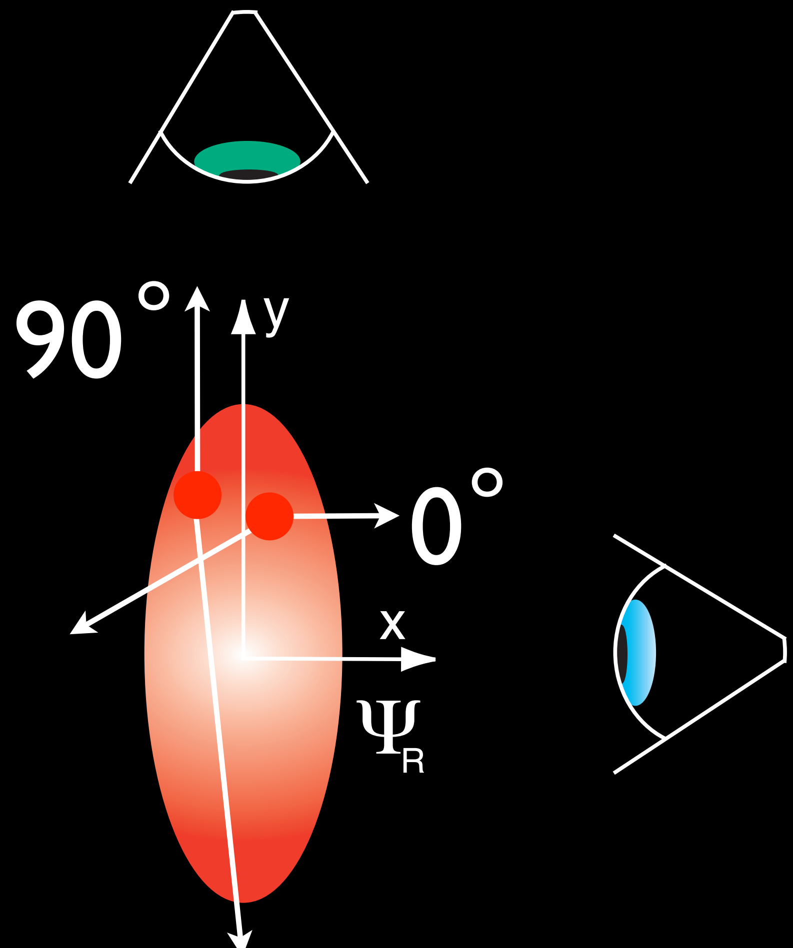


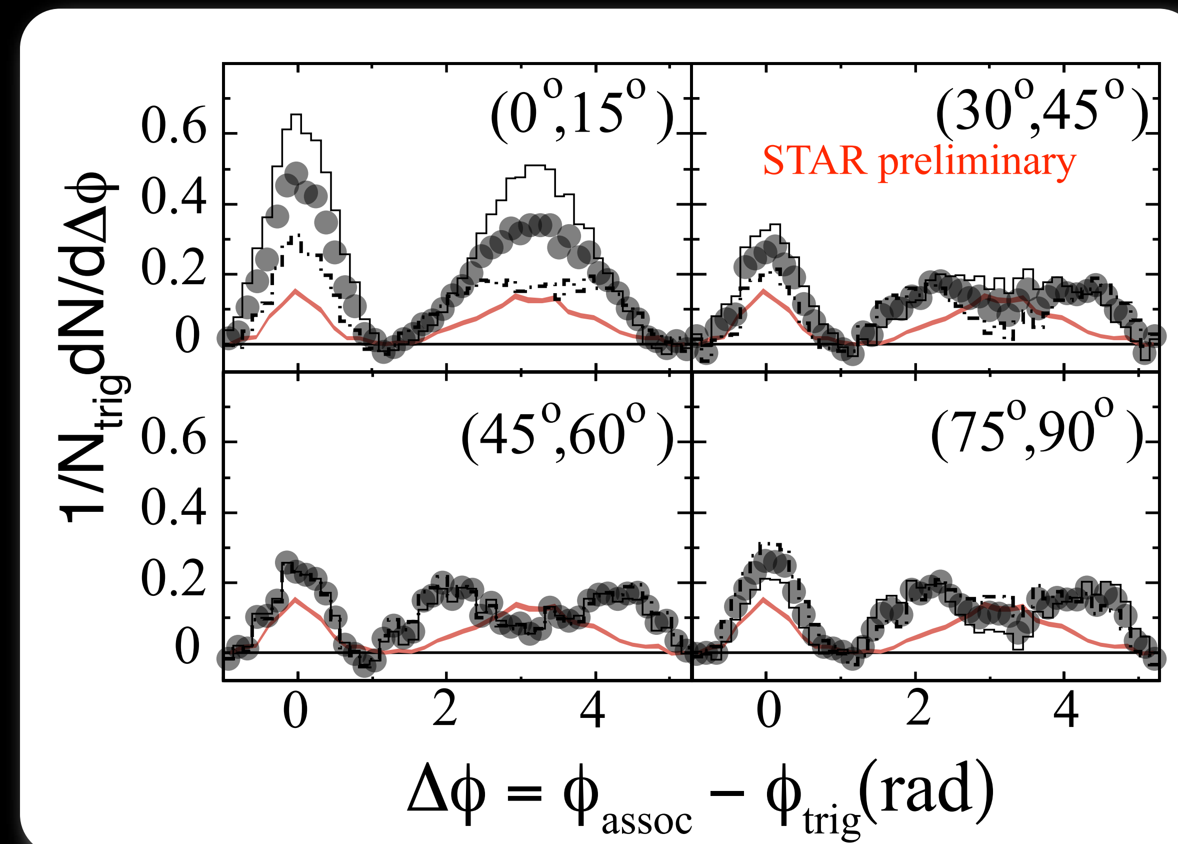
in Au+Au a “ridge” of correlated yield with the trigger particle

the ridge has the same properties as the bulk

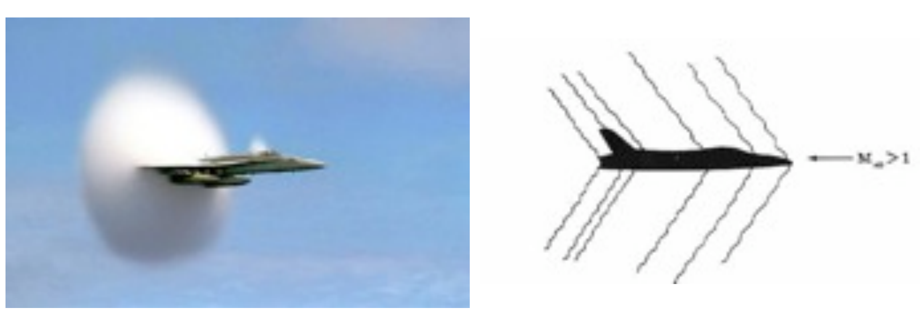
simple? the away side

$3 < p_t^{trig} < 4$ GeV/c $1.0 < p_t^{asso} < 1.5$ GeV/c





Aoki Feng



The away side changes from single peak (in plane) to double peak (out of plane)

strongly debated measurement and interpretation could provide additional acces to the sound speed

high p_t probes in A+A

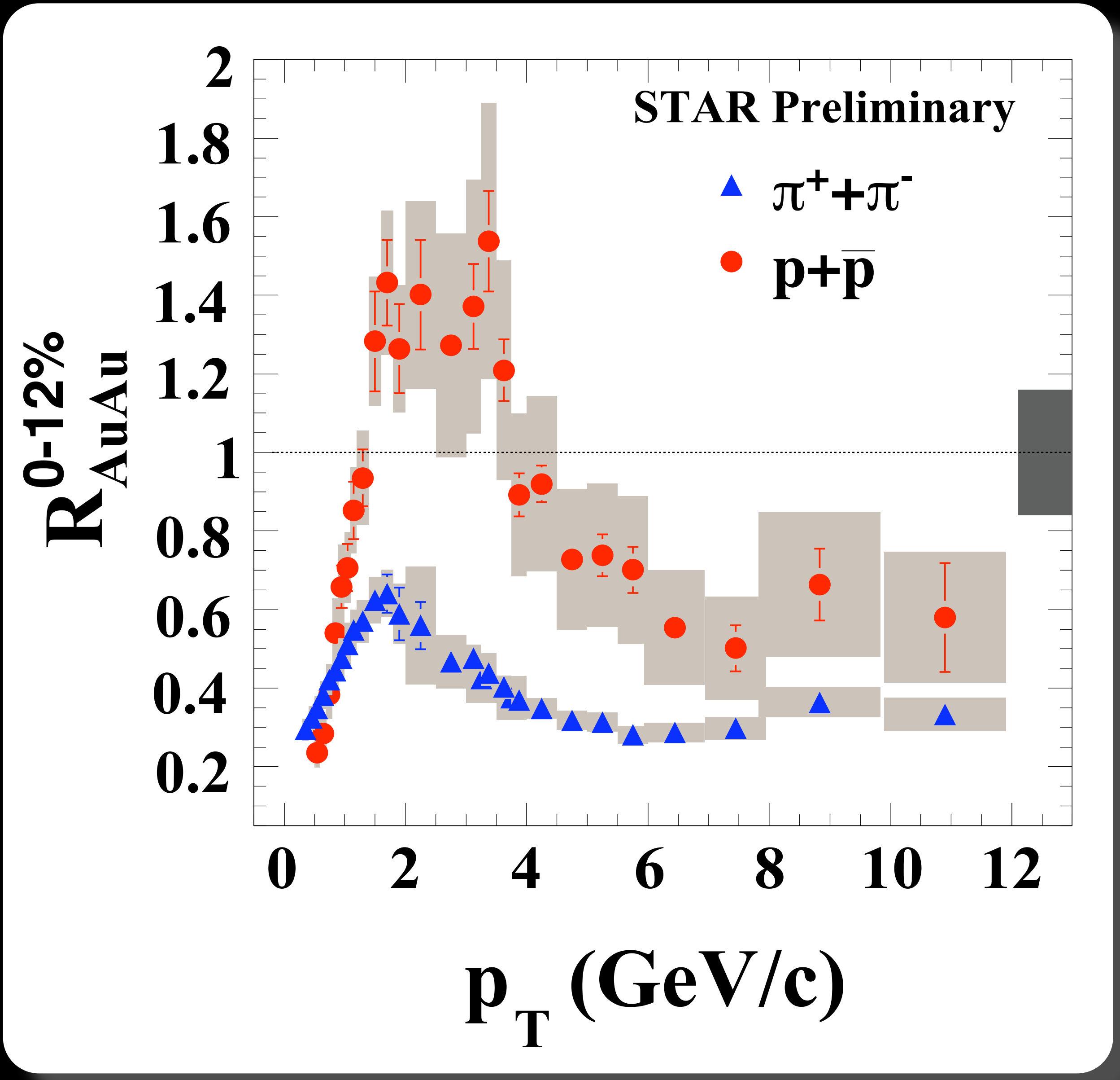
- source rather well understood (with p+p and p+A data available at the same energy)
- the probes clearly strongly interact with the medium
- to calibrate the interaction of the probes with the medium is the main part of the ongoing research
  - color factors
  - heavy quarks

Color Factors?

$$\langle \Delta E \rangle \propto \alpha_s C \langle \hat{q} \rangle L^2$$

$$\frac{\Delta E_g}{\Delta E_q} \approx \frac{9}{4}$$

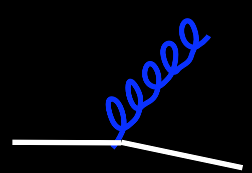
protons produced more from gluons, pions produced more from quarks: expect stronger suppression protons



color factor effects of the magnitude 9/4 are not observed!

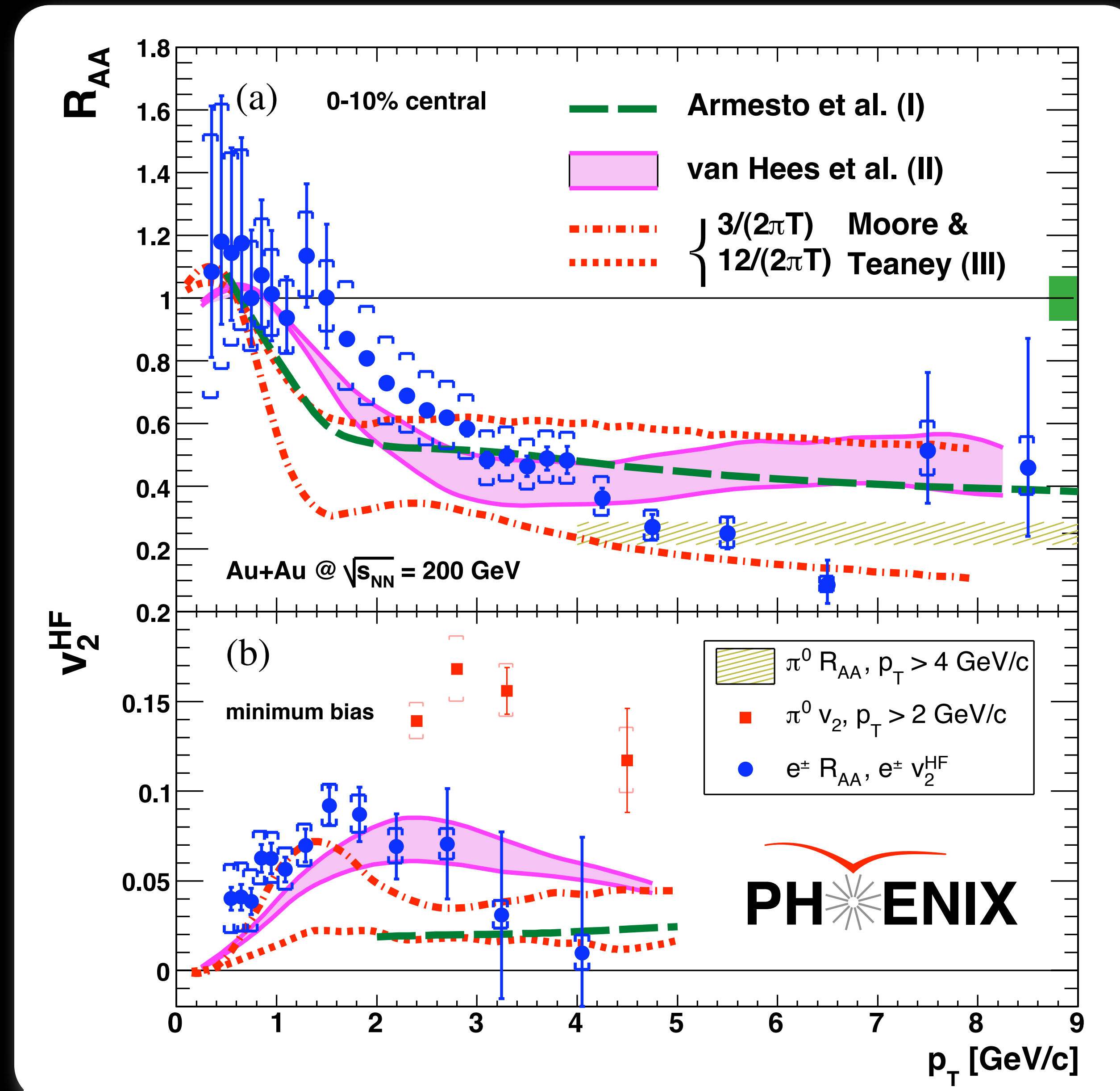
Dead Cone?

probability



$$\propto \frac{1}{[\Theta^2 + (m_Q/E_Q)^2]^2}$$

in medium dead cone implies less energy loss for heavy quarks



PHENIX Phys. Rev. Lett. 98, 172301 (2007)

heavy quarks show similar suppression as light quarks!

RHIC: current summary

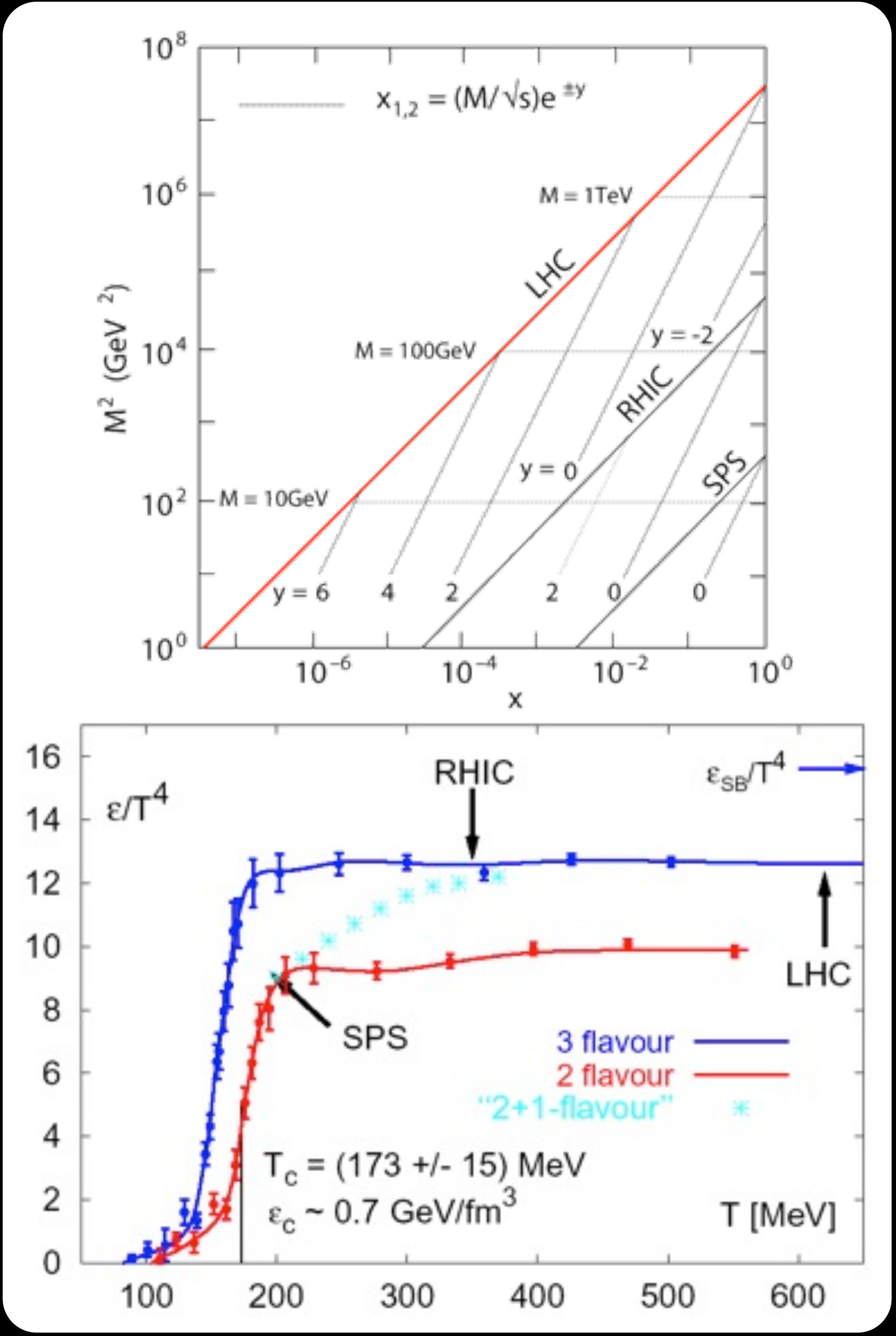
- A tremendous amount of striking observables at RHIC
- Leading to surprising conclusions about the matter created at RHIC
  - sQGP, perfect liquid
- Measurements and theory becoming more quantitative
  - flow: viscous corrections are adressed
  - high-p_t: testing energy loss mechanism, starting full jet reconstruction

From SPS, RHIC to the LHC

	SPS	RHIC	LHC	
$\sqrt{s_{NN}}$ (GeV)	17	200	5500	
dN/dy	500	850	1500-4000	
τ^0_{QGP} (fm/c)	1	0.2	0.1	
T/T_c	1.1	1.9	3-4	Hotter
ε (GeV/fm^3)	3	5	15-60	Denser
τ_{QGP} (fm/c)	≤ 2	2-4	≥ 10	Longer
τ_f (fm/c)	~10	20-30	30-40	
V_f(fm^3)	few 10^3	few 10^4	Few 10^5	Bigger

From SPS, RHIC to the LHC

- not just super sized, a new regime!
    - high density pdf's (saturized) determine particle production
    - parton dynamics dominate the fireball expansion
- new tools!
    - hard processes contribute significantly to the cros section
    - weakly interacting hard probes become available
- detailed understanding of QGP
- possible surprises!



Jets at the LHC

- At LHC >90% of the particle production from hard collisions, jet rates are high at energies at which jets can be reconstructed over the large background from the underlying event
- More than 1 jet > 20 GeV per central collision (more than 100 > 2 GeV!)
- Reach to about 200 GeV
- Provides lever arm to measure the energy dependence of the medium induced energy loss

1 month of running	
E_T >	N_{jets}
50 GeV	2.0×10^7
100 GeV	1.1×10^6
150 GeV	1.6×10^5
200 GeV	4.0×10^4

penetrading probes: heavy quarks

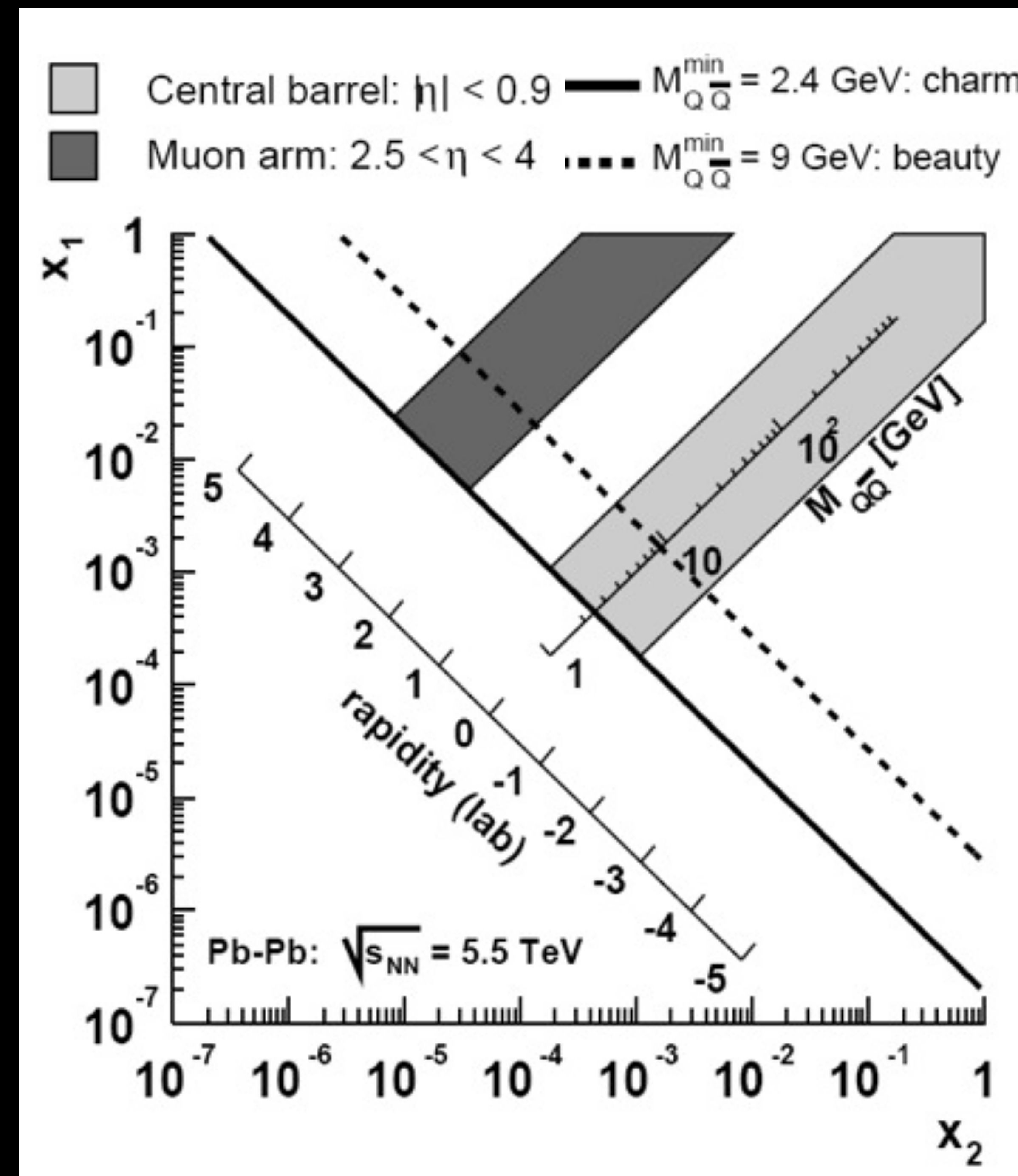
	SPS PbPb Cent	RHIC AuAu Cent	LHC pp	LHC pPb	**LHC PbPb Cent**
N_{cc}/evt	0.2	10	0.2	1	**115**
N_{bb}/evt	-	0.05	0.007	0.03	**5**

- produced early and calculable: $\tau \propto 1/m_C$
- Relatively long lifetime: $\tau_{decay} \gg \tau_{QGP}$
- detailed test of parton energy loss
  - dead cone effect

Probability:

$$\propto \frac{1}{[\theta^2 + (m_Q / E_Q)^2]^2}$$

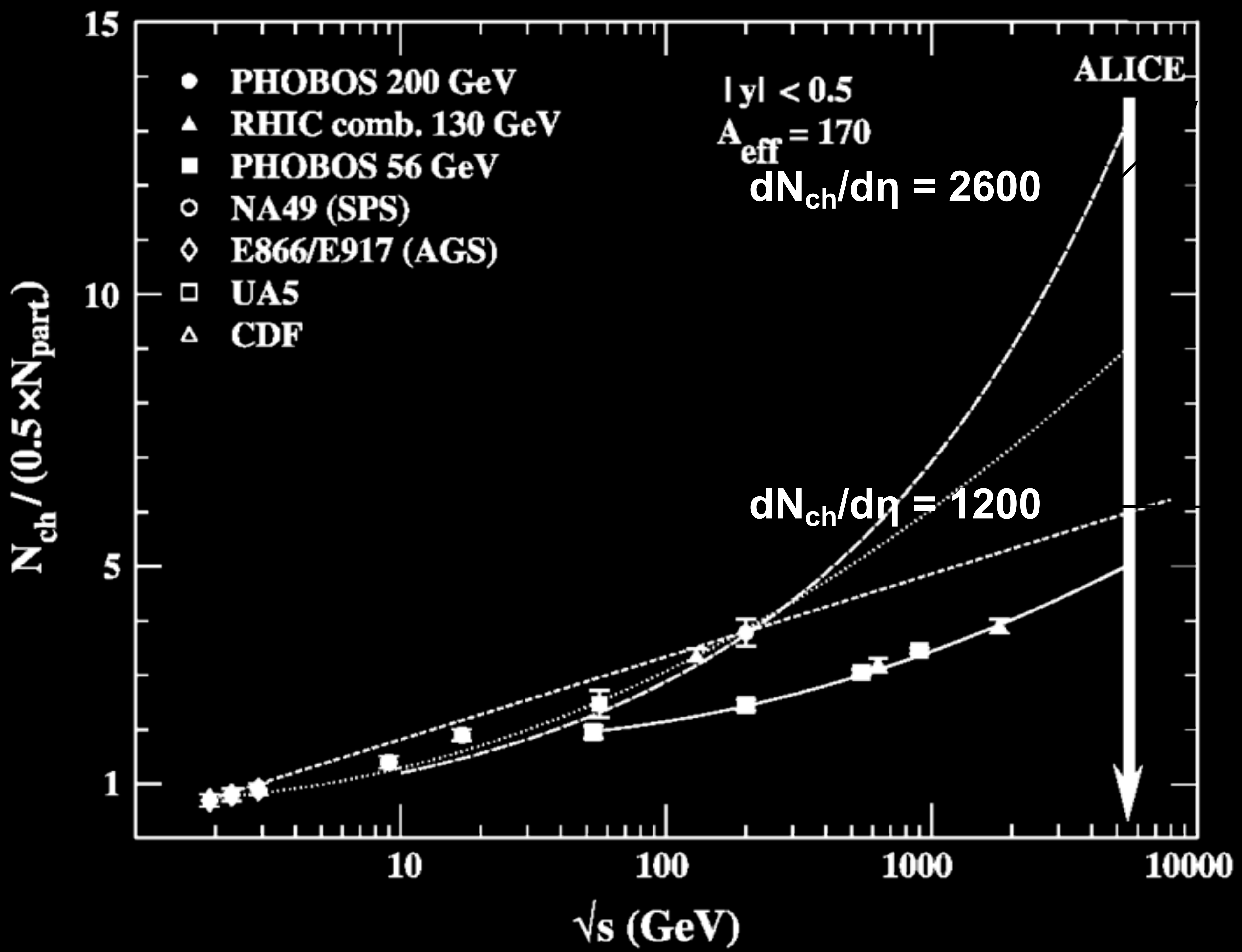
  - In medium dead cone implies less energy loss
- probes small x (10^{-3} – 10^{-5})



particle multiplicities

large uncertainty in predicted multiplicities at the LHC

complicates designing a detector!

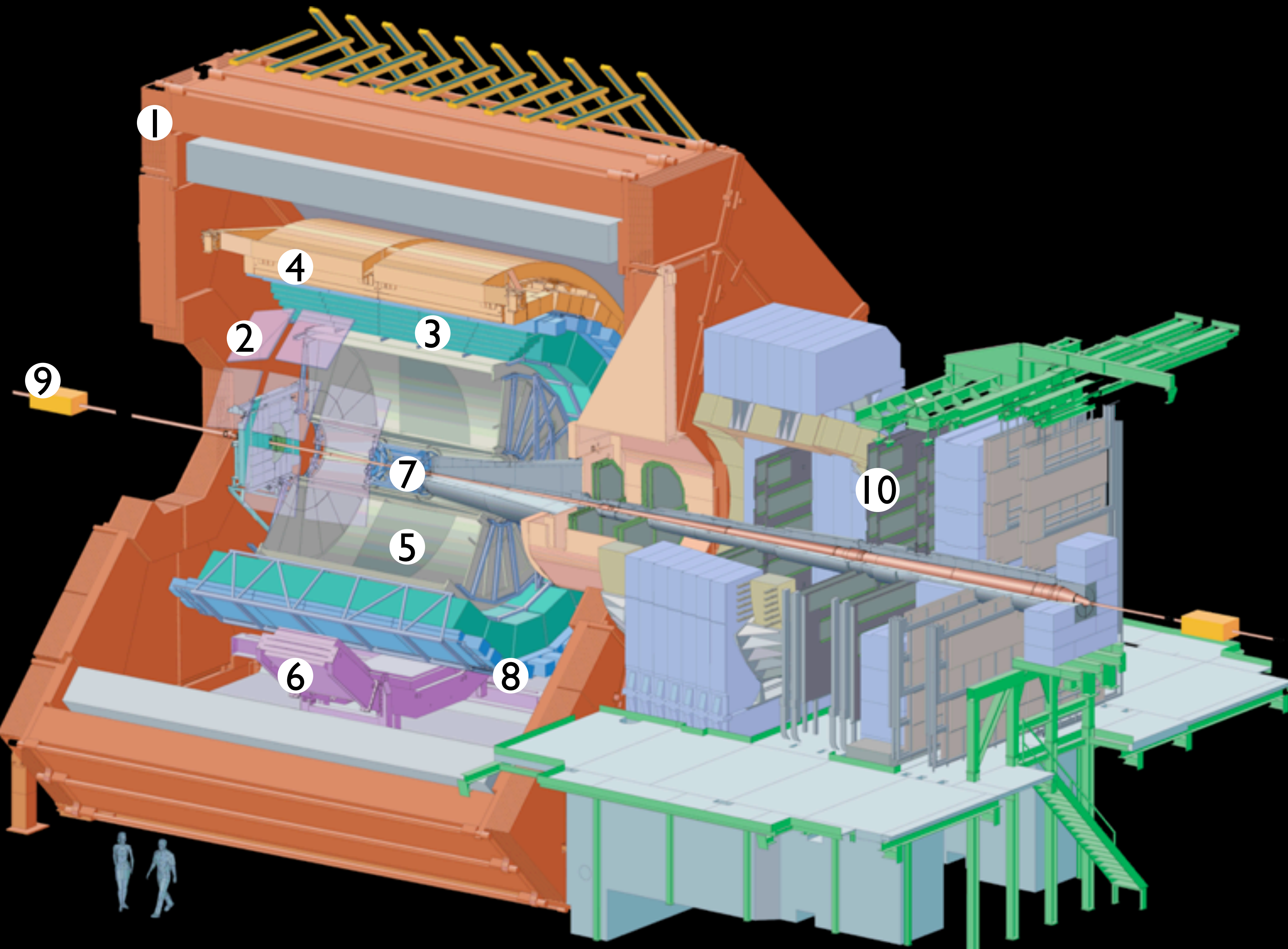


Alice Detector

- measure low-p_t particles (<100 MeV/c)
- measure high-p_t tracks (100 GeV/c)
- particle identification over this range
- able to measure large multiplicities (4000 per unit rapidity)
- measure rare probes (direct γ, charm, bottom)

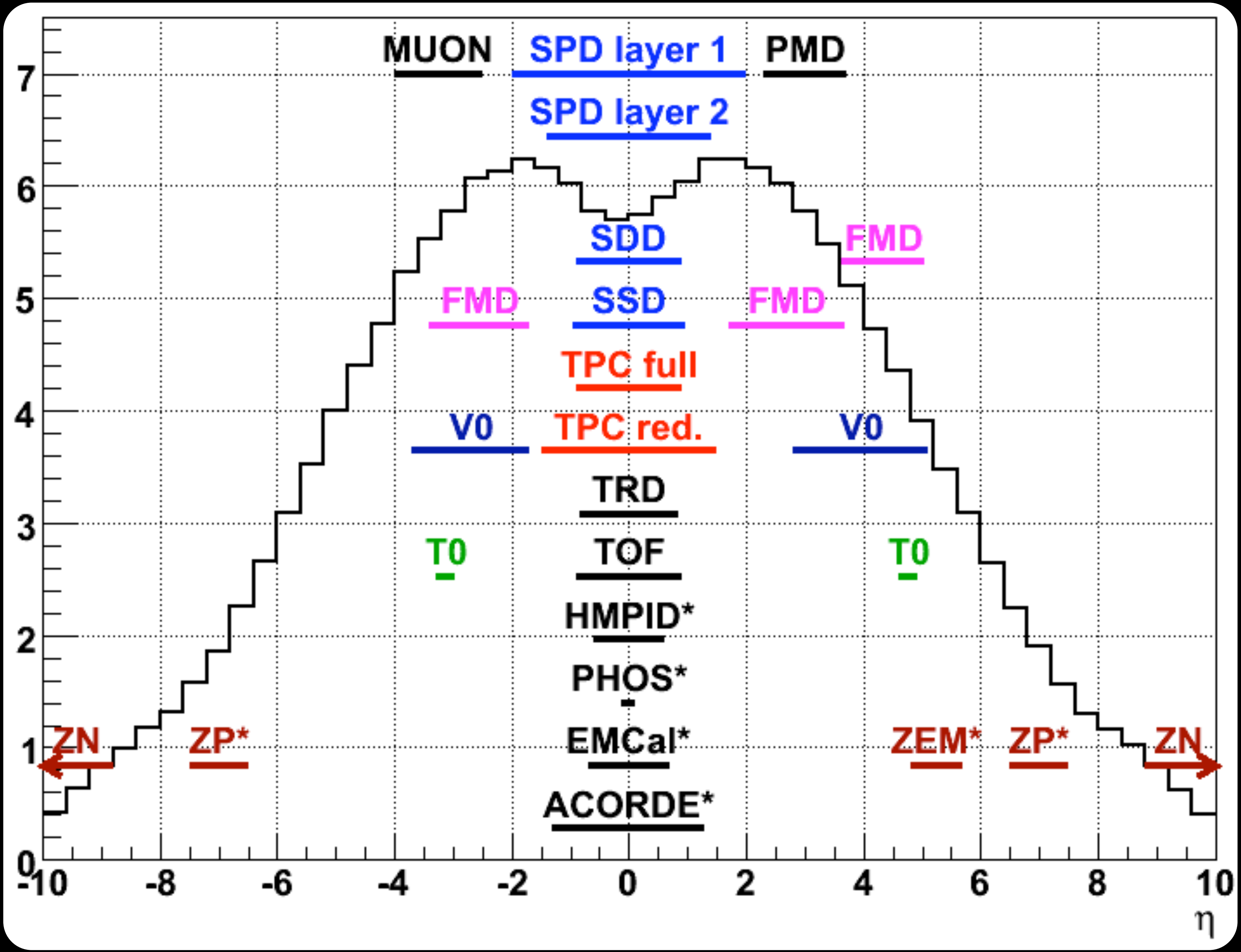
ALICE at the LHC

1. L3 magnet
2. HMPID
3. TRD
4. EMCAL
5. TPC
6. PHOS
7. ITS
8. TOF
9. ZDC
10. Muon system



~1000 collaborators from 109 institutes in 31 countries

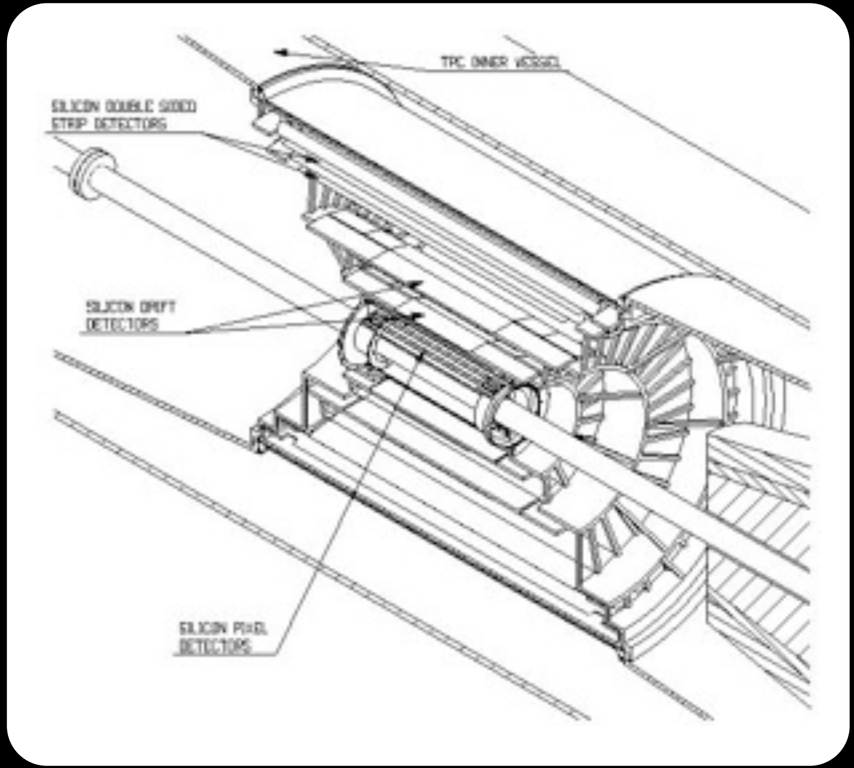
Alice Detector



Inner Tracker System

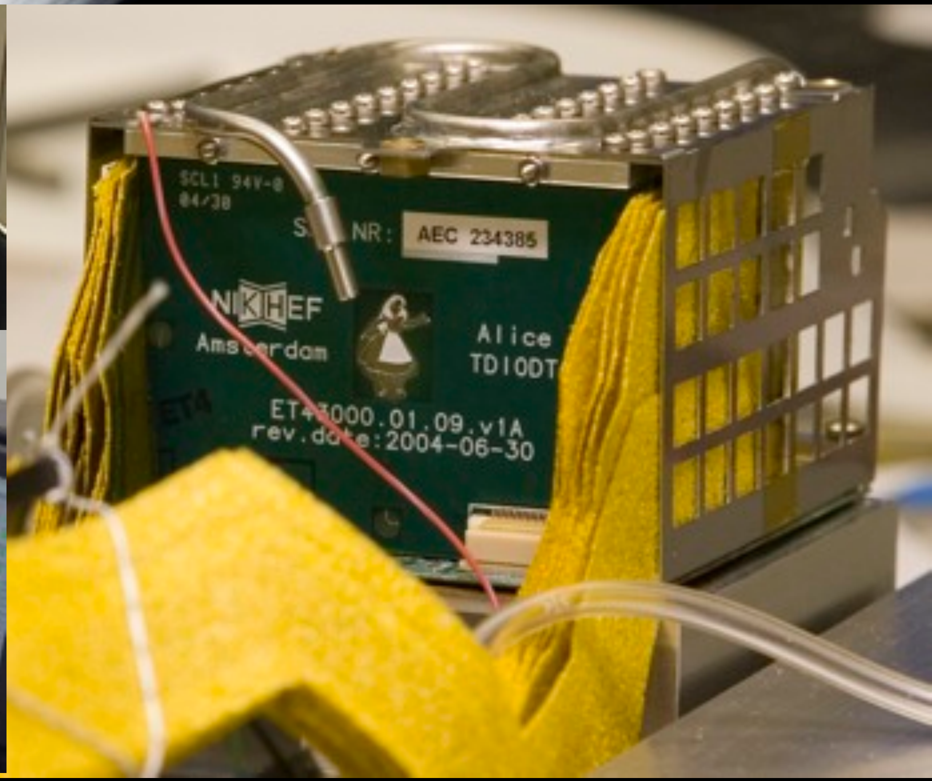
low mass: 8 % X_0

6 layers		R	σ rϕ	σ Z
Layer 1	pixels	4 cm	12 μm	100 μm
Layer 2	pixels	8 cm	12 μm	100 μm
Layer 3	drift	15 cm	38 μm	28 μm
Layer 4	drift	24 cm	38 μm	28 μm
Layer 5	double sided strip	38 cm	17 μm	800 μm
Layer 6	double sided strip	43 cm	17 μm	800 μm

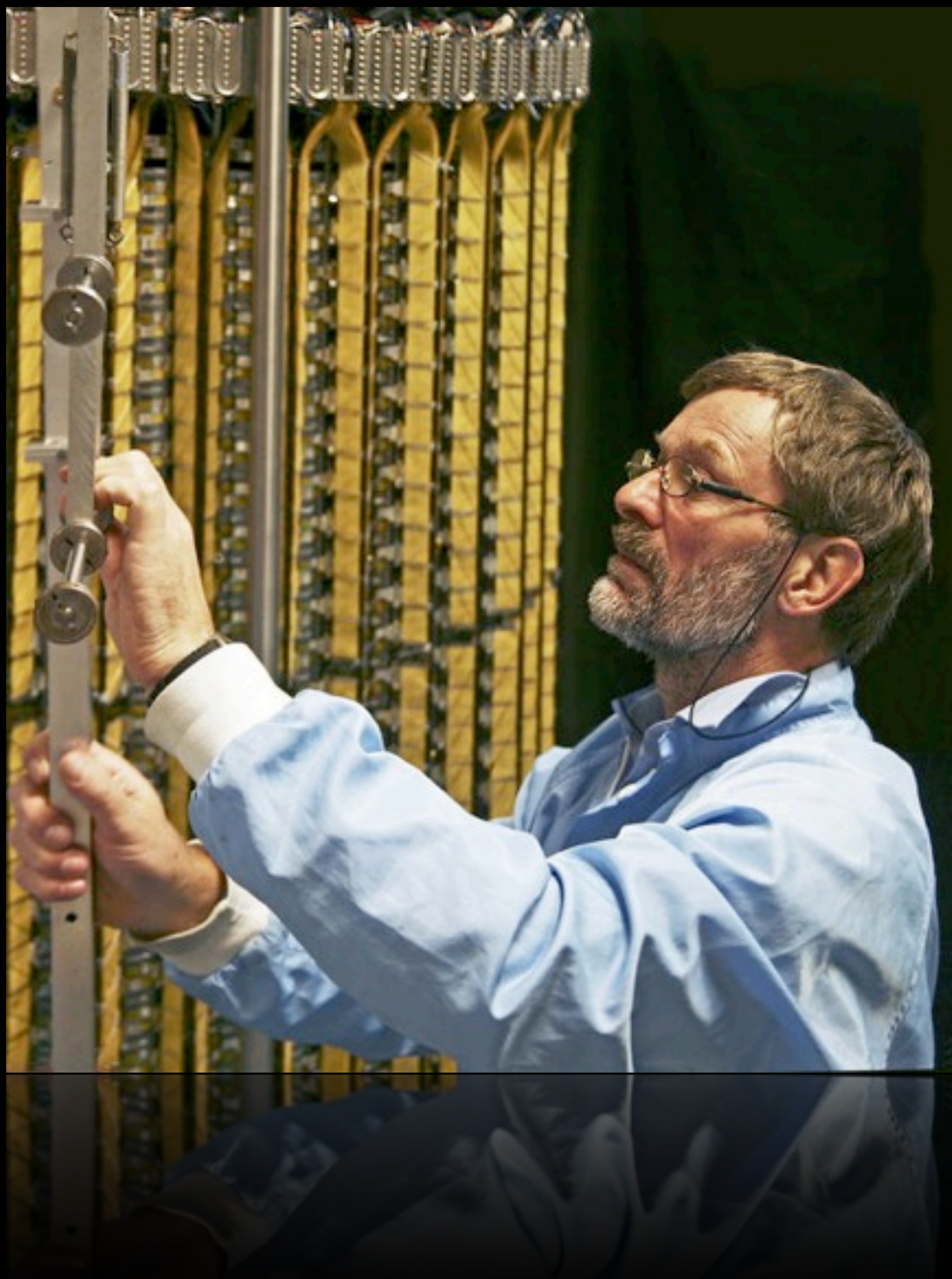


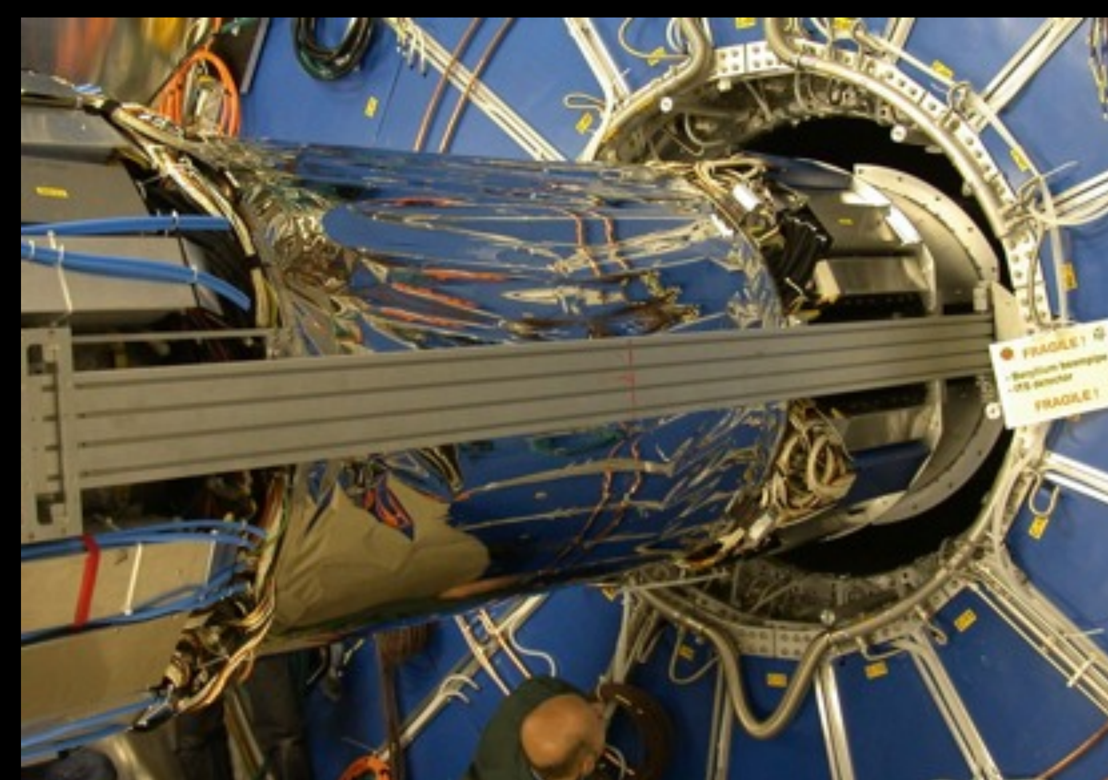
- needed to reconstruct secondary vertices
- needed to track very low momenta particles

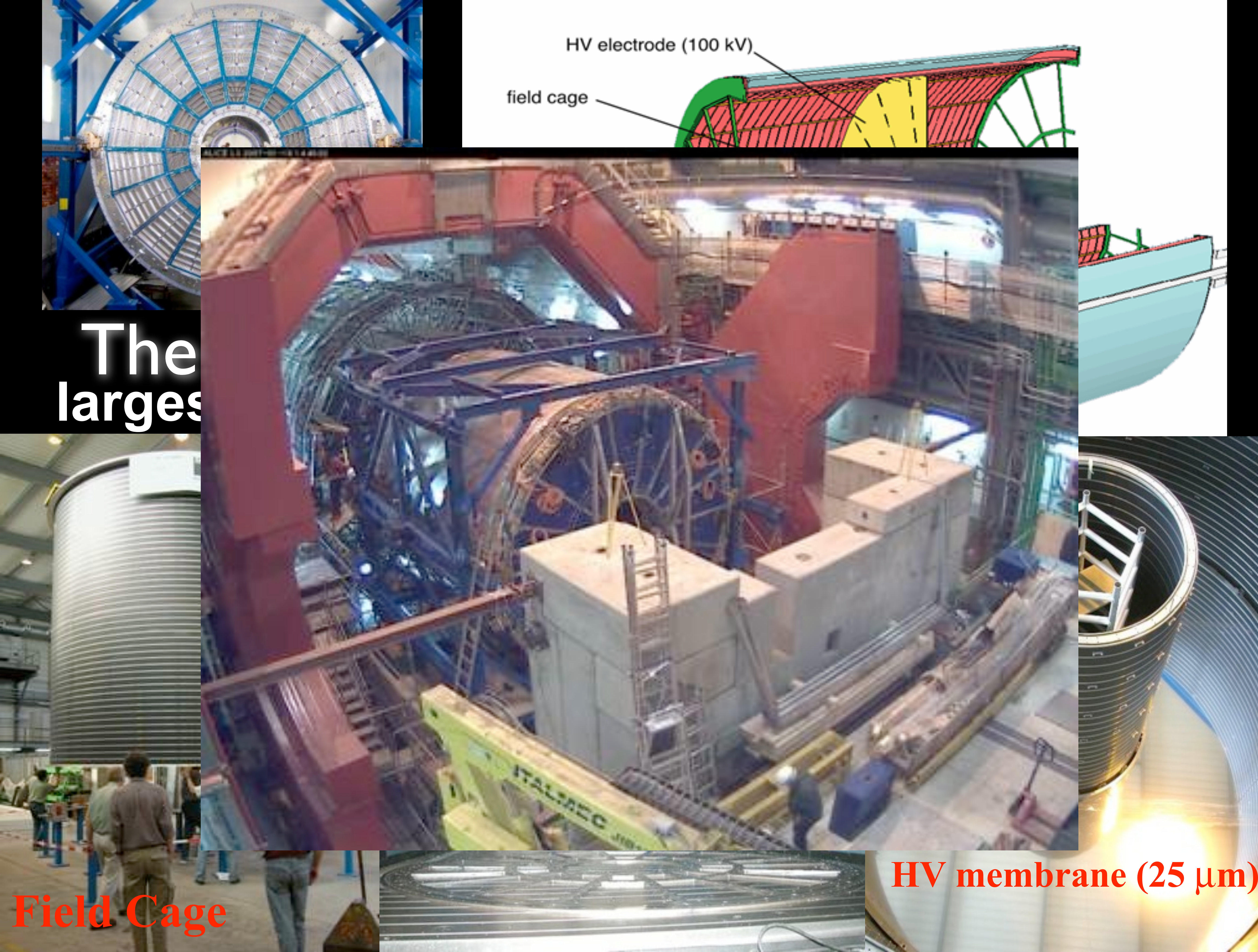
Completed SSD Ladder



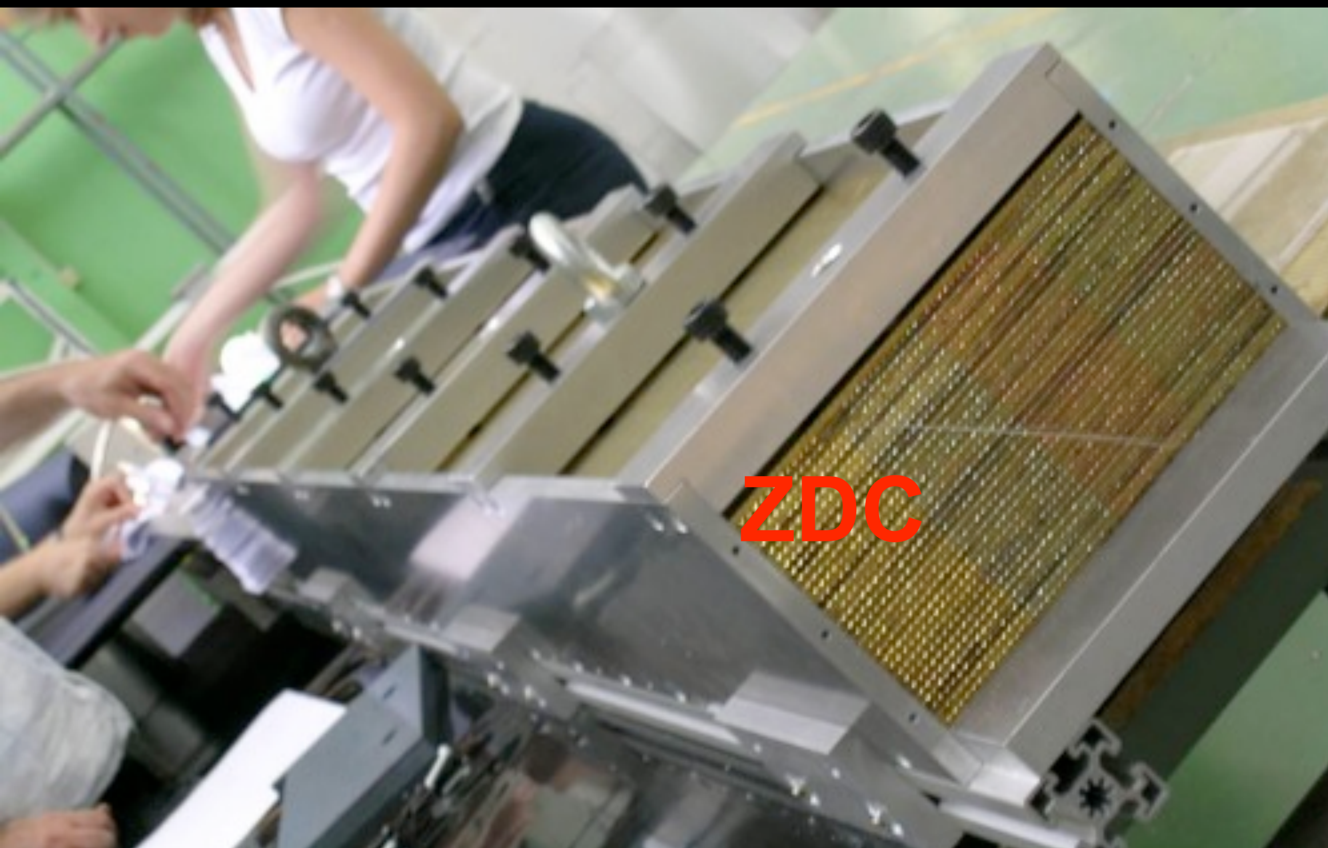
Full SSD

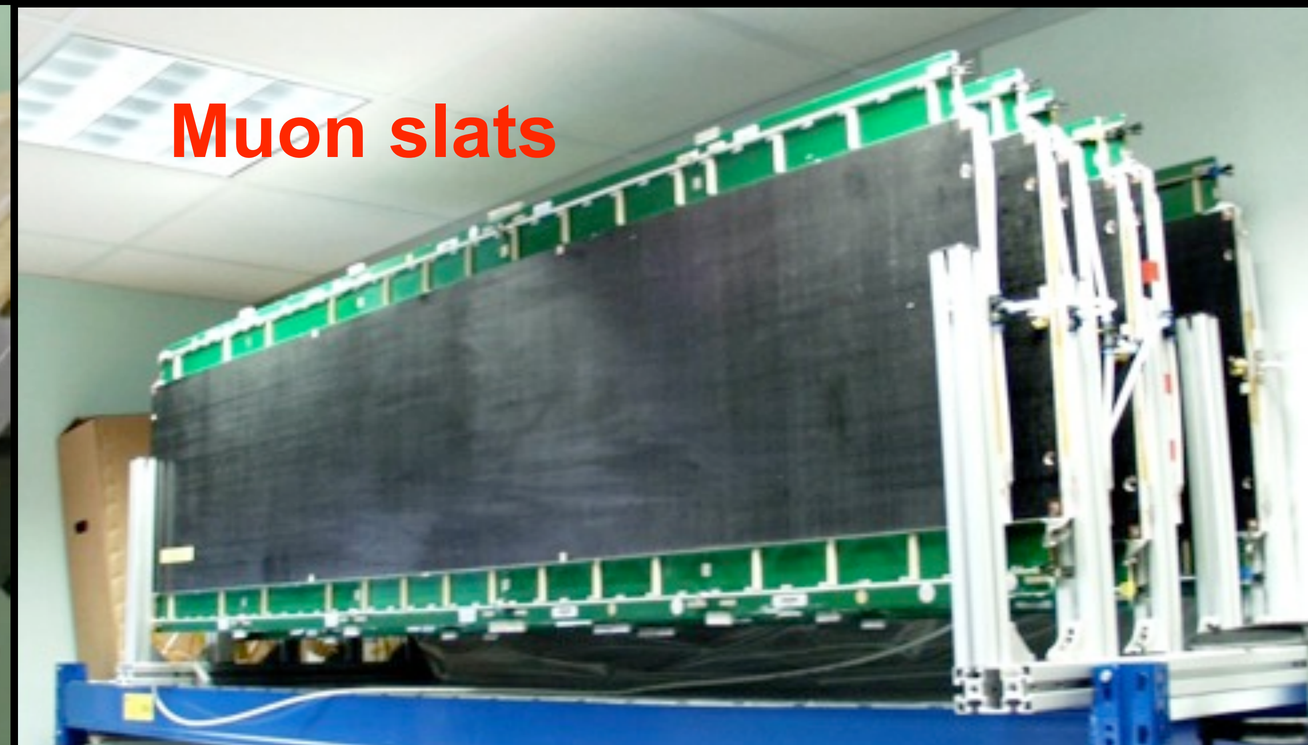





HV electrode (100 kV)
field cage
The
larges
ITALMEC
Field Cage
HV membrane (25 μm)

A few other detectors



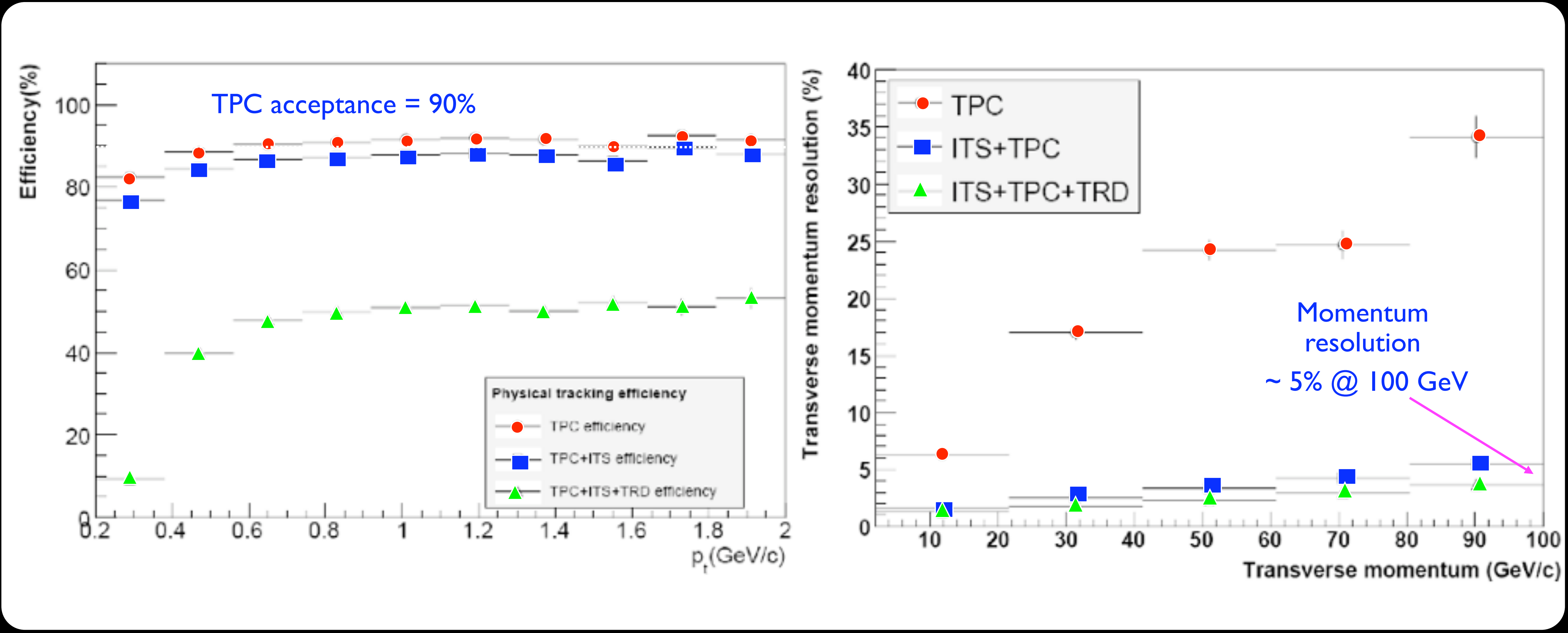


Tracking

- robust, redundant tracking from 0.1 to 100 GeV/c
  - modest solenoidal field (0.5 T) ⇒ easy patern recognition
  - long lever arm ⇒ good momentum resolution
    - BL^2: ALICE ~ CMS > ATLAS
  - small material budget ~ 10% X_0 vertex to end TPC
  - Silicon Vertex Detector: 4-44 cm, 6 layers
  - Time Projection chamber: 85-245 cm, 159 pad rows
  - Transition Radiation Detector: 290-370 cm, 6x3 cm tracks

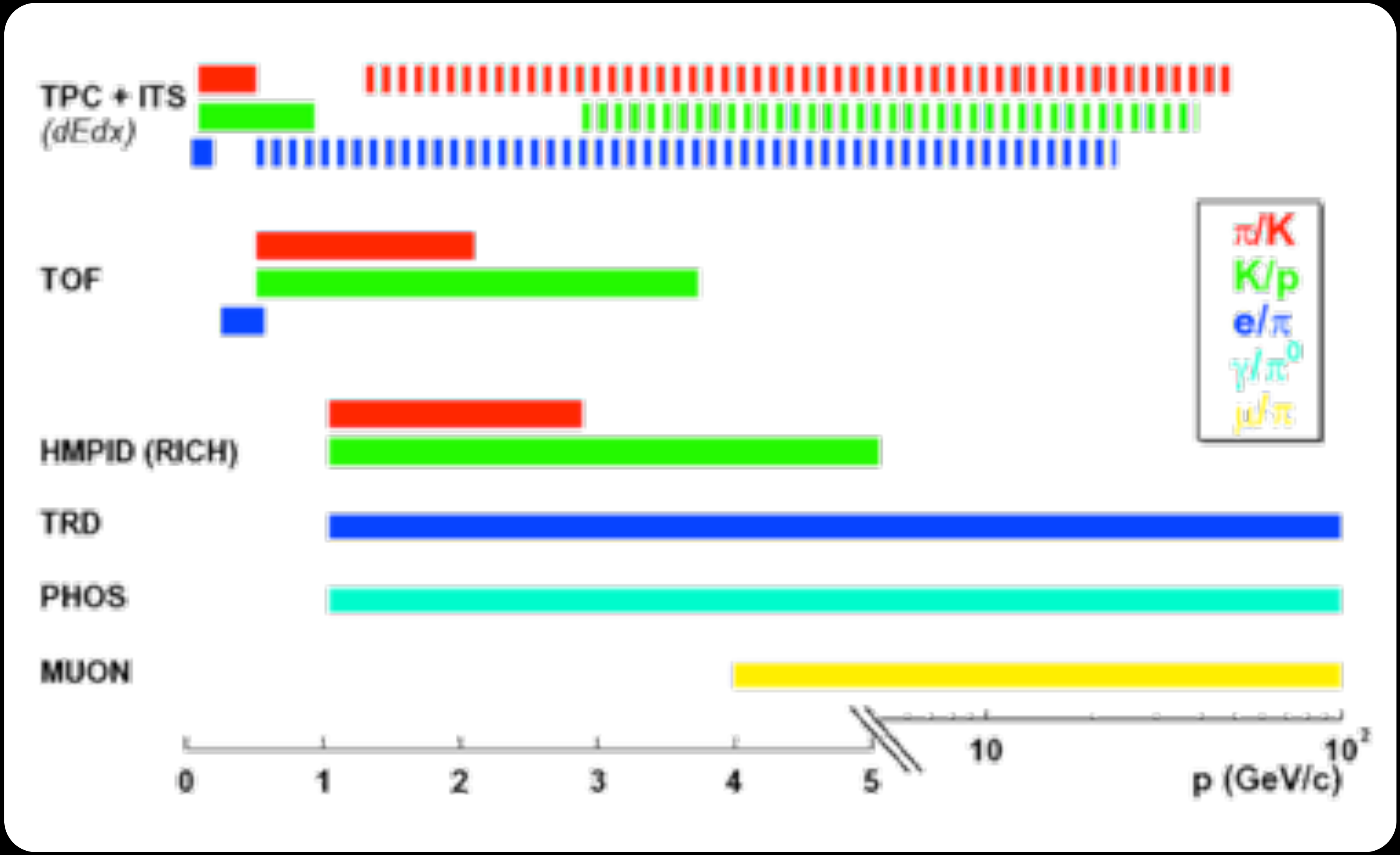
Tracking

- full GEANT simulation: central Pb-Pb, **dN_{ch}/dy = 6000**
  - very little dependence on dN_{ch}/dy up to 8000 (important for systematics !)



particle identification

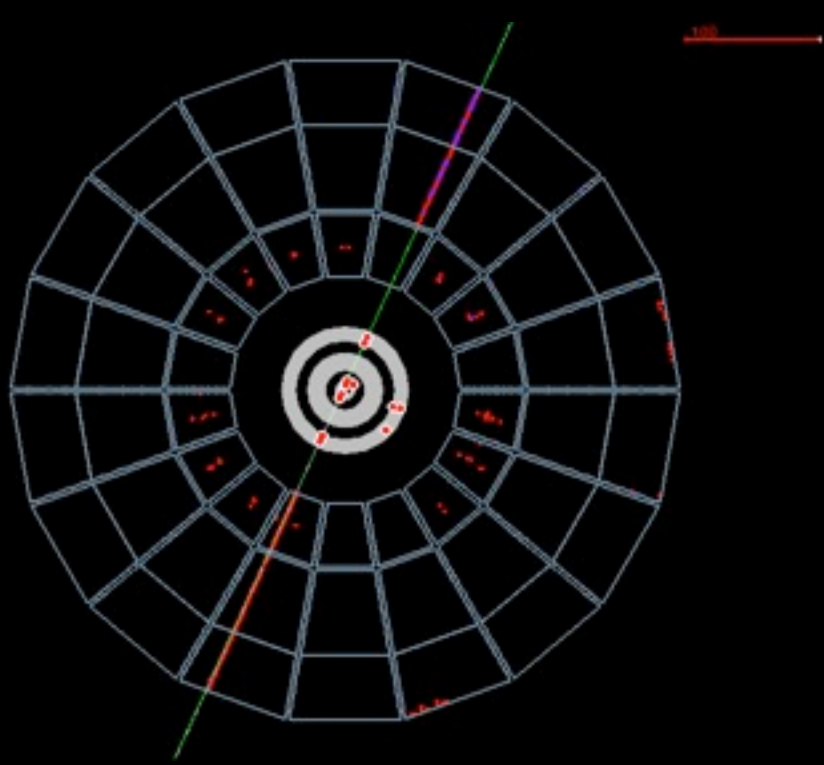
- techniques
  - dE/dx
  - time-of-flight
  - Cerenkov
  - transition radiation
  - calorimeter
  - spectometer

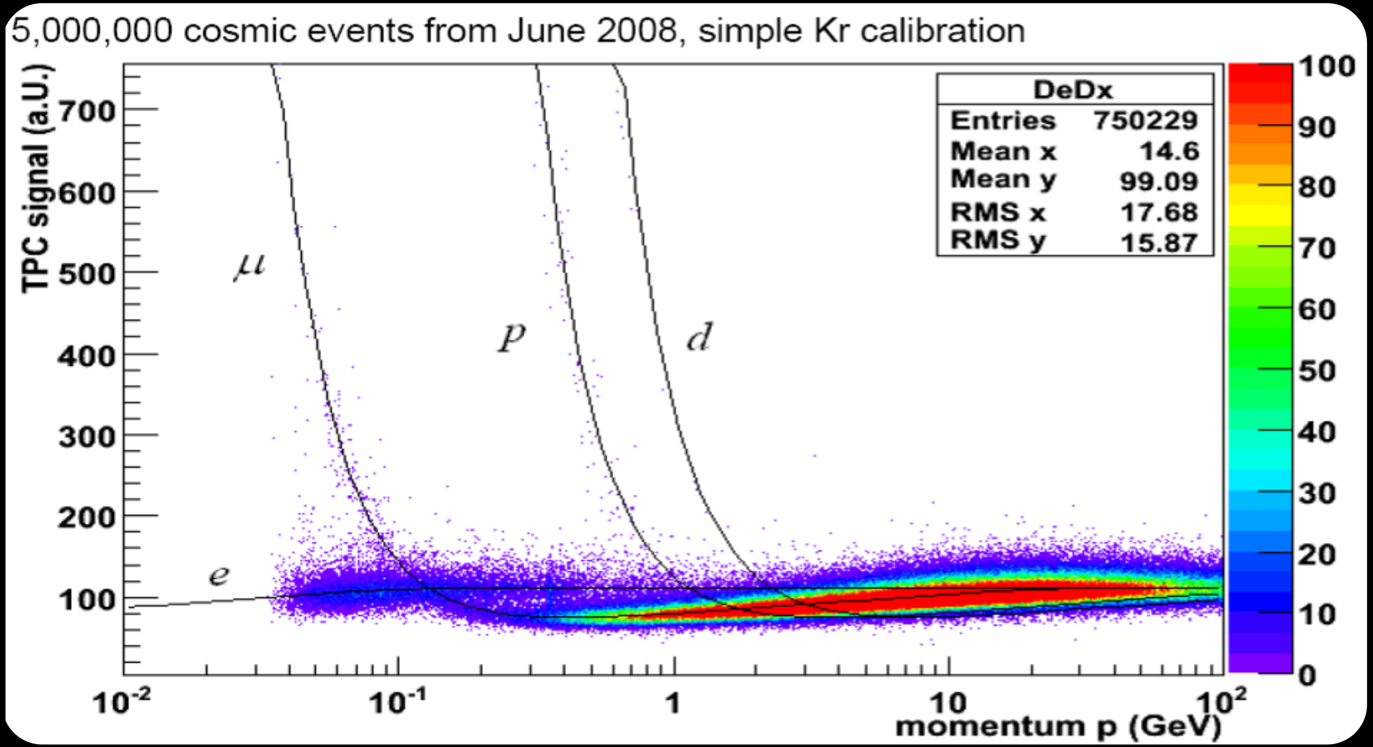


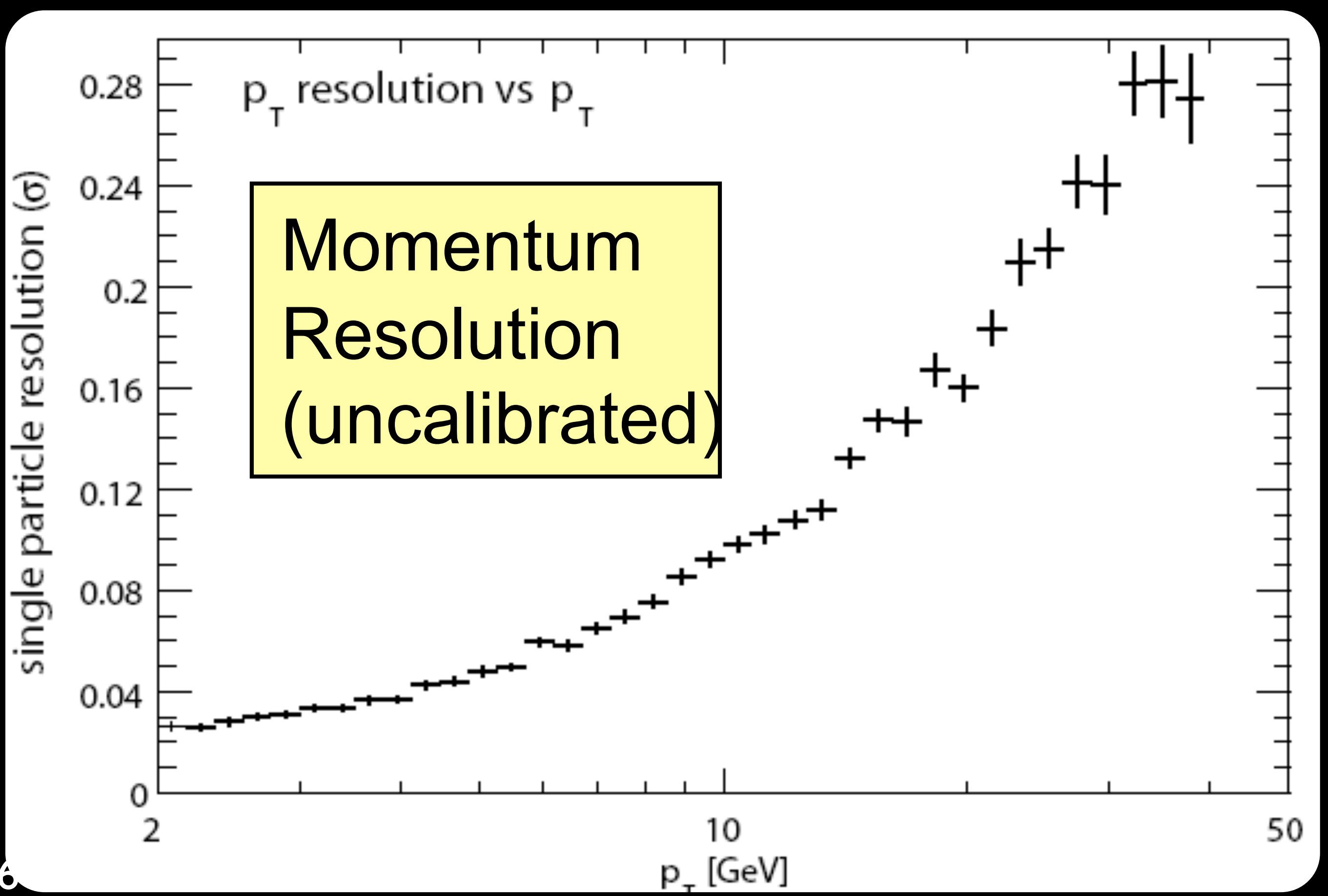
End of ALICE Installation 2008

TPC Performance

- from cosmic data
    - dE/dx resolution < 6% (PPR goal 5.5%)
    - transverse momentum resolution 10% at 10 GeV/c, no calibration (PPR 5%)

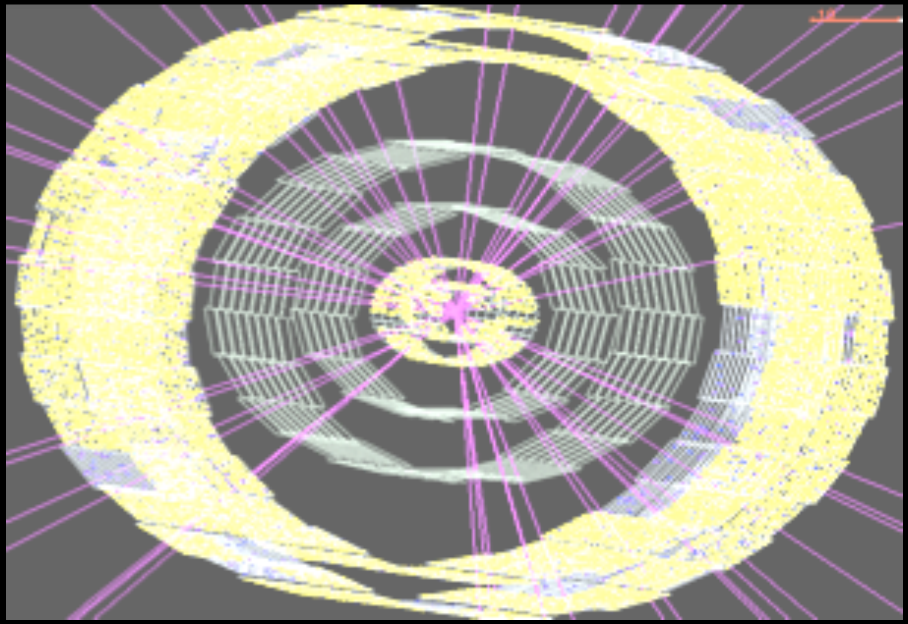






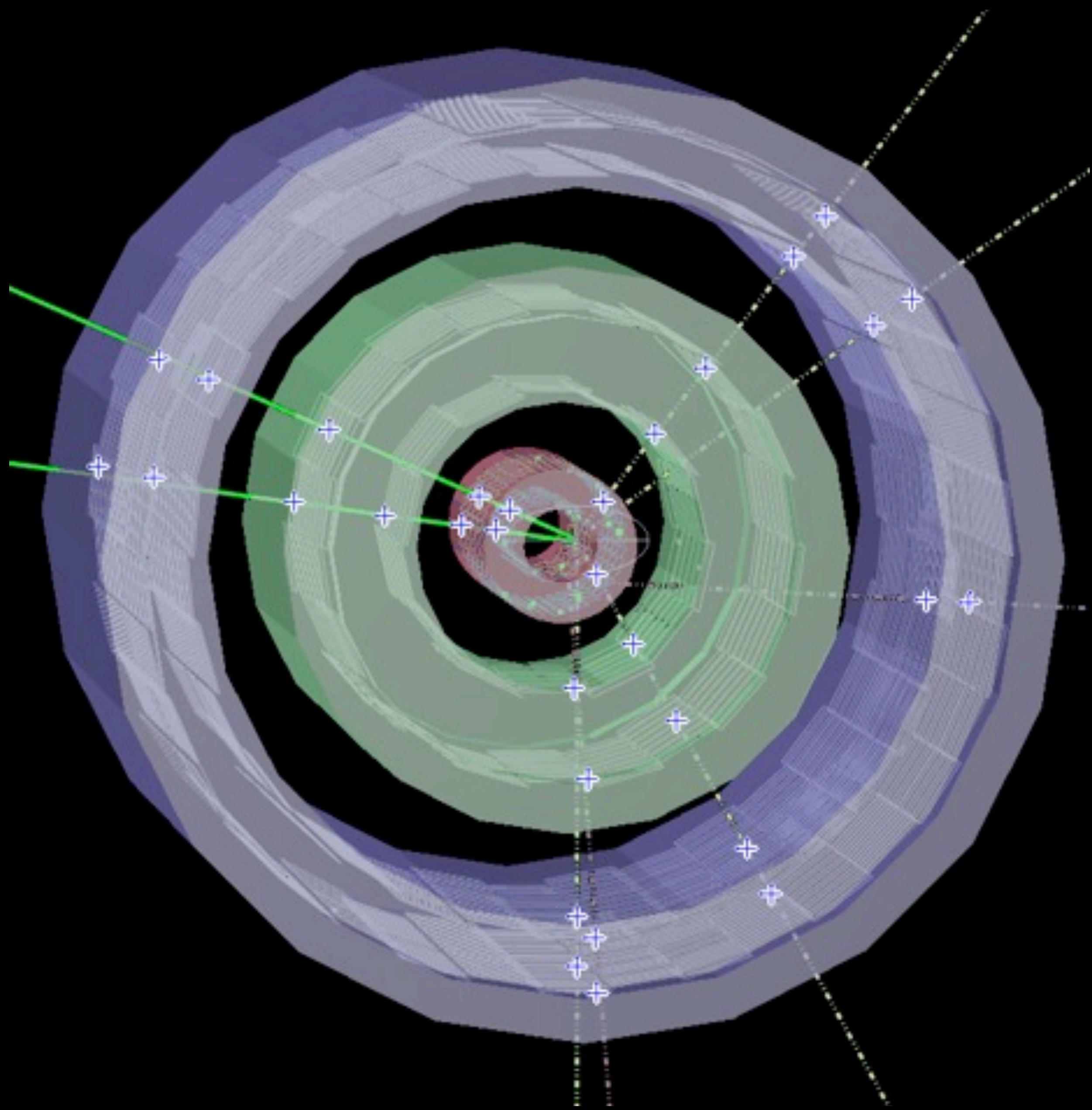
Injection Test

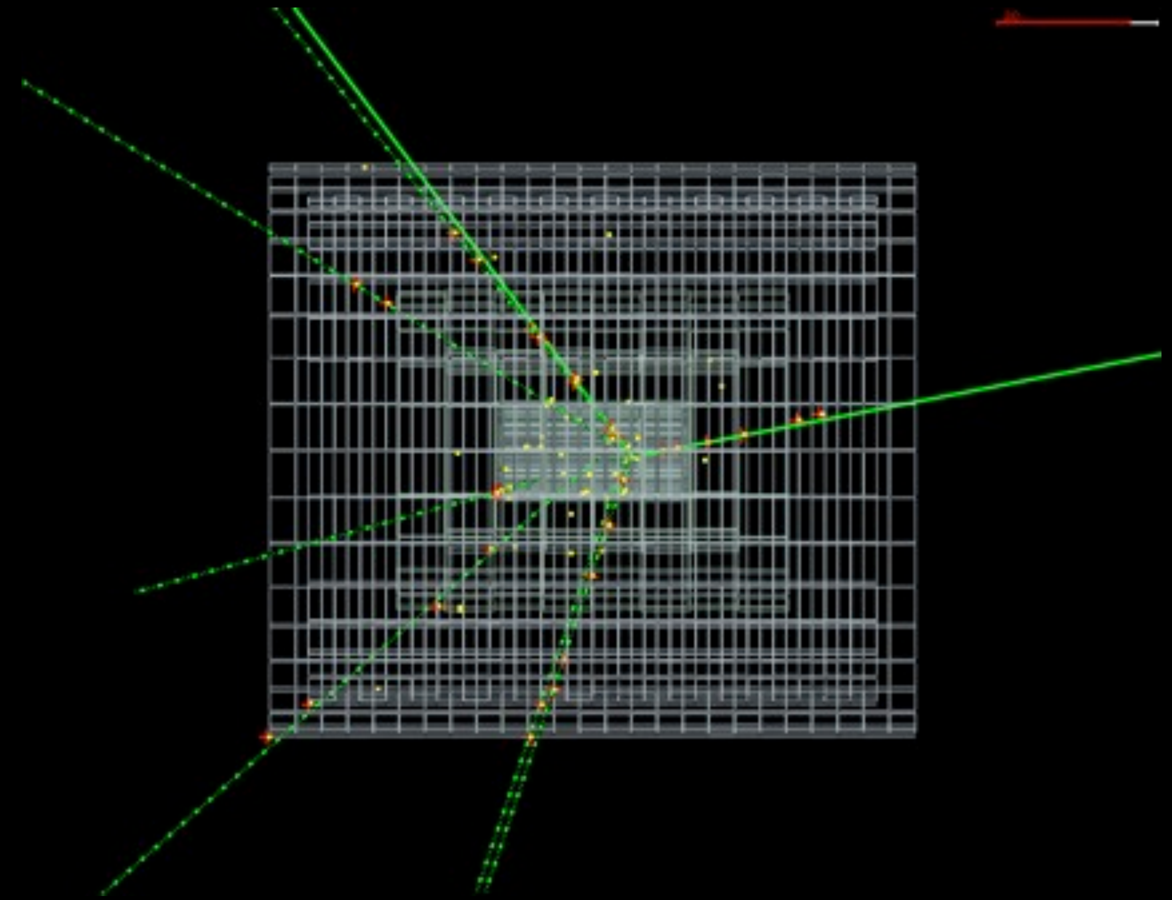
- Events in ALICE
  - TI2 dump June 15
  - Injection test August
  - Circulating beam September

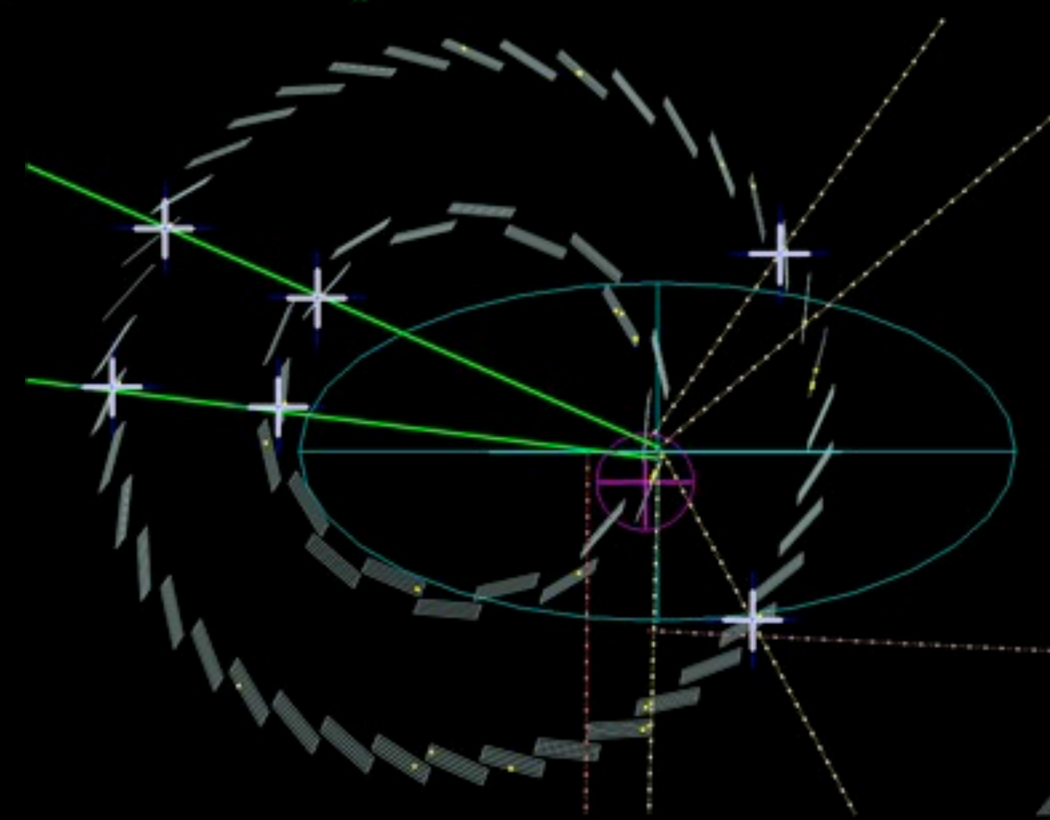


- Observed very high particle densities
  - 10s - 1000s of particles per cm2
  - sensitive detectors turned off
  - SPD and V0 always on
  - SDD, SSD, T0 and FMD sometimes

First Interaction 12-9



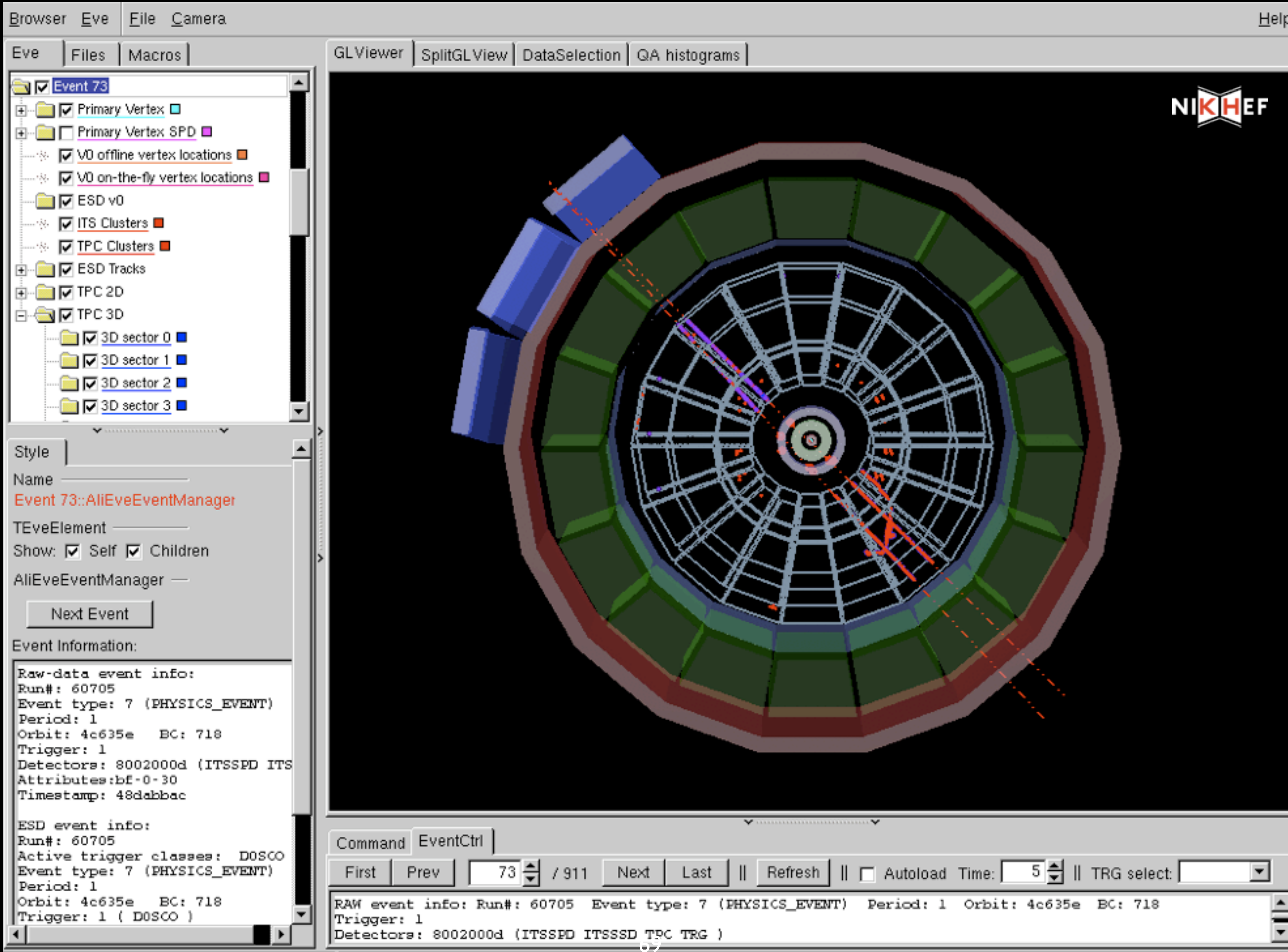




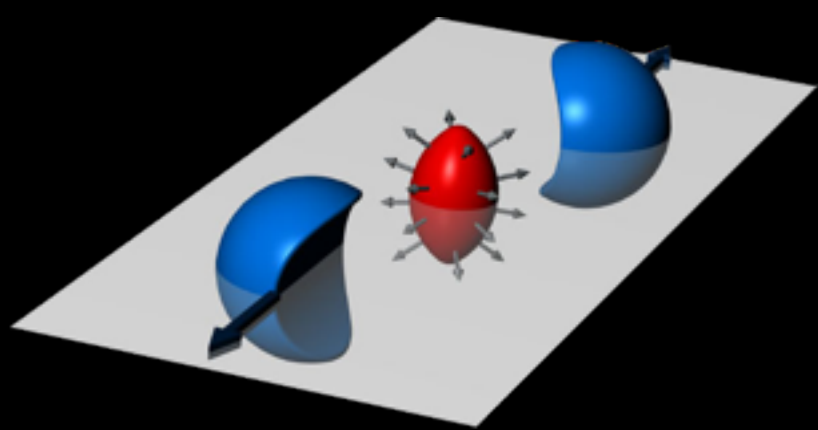
Summary

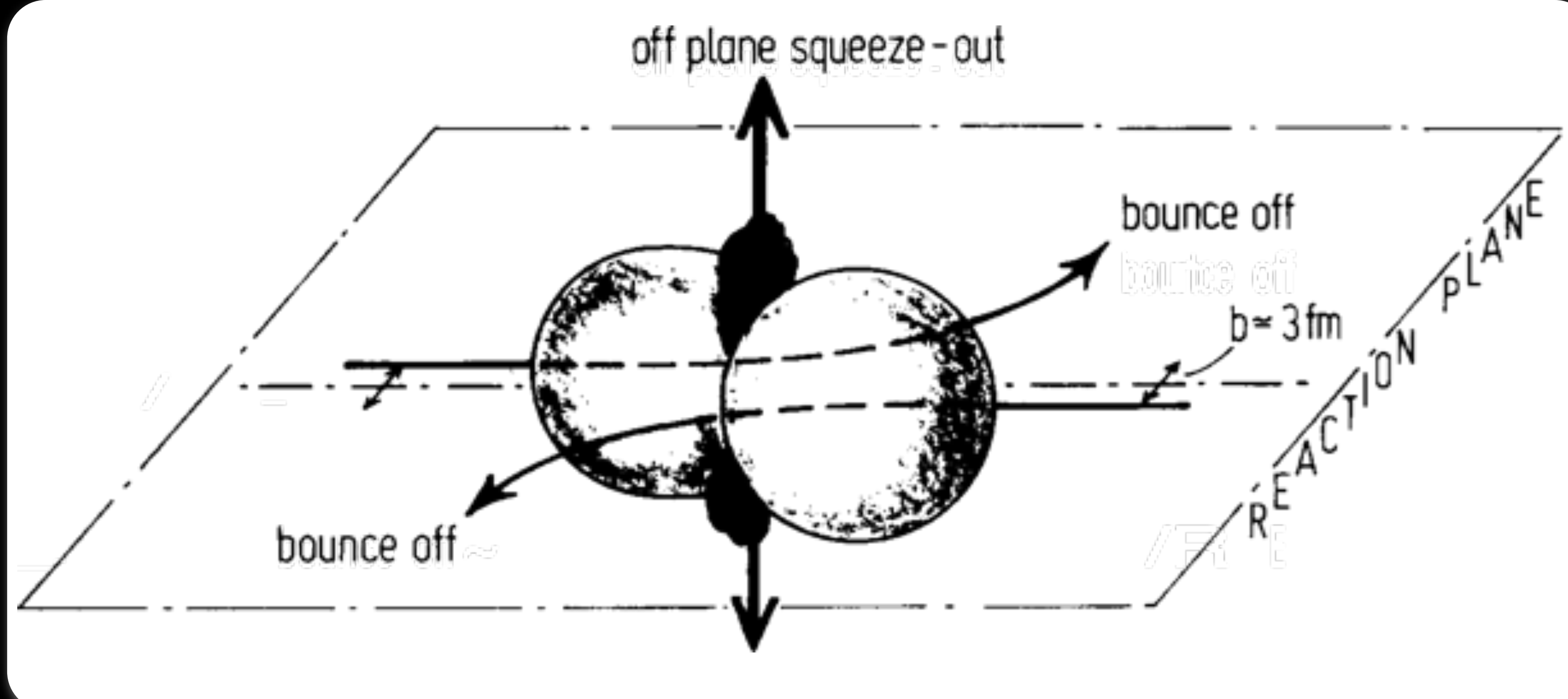
- heavy-ion experiments provide us acces to the properties of matter at extreme temperatures and densities
- the LHC is the next chapter and a step above and beyond existing facilities
- ALICE is ready

Backup

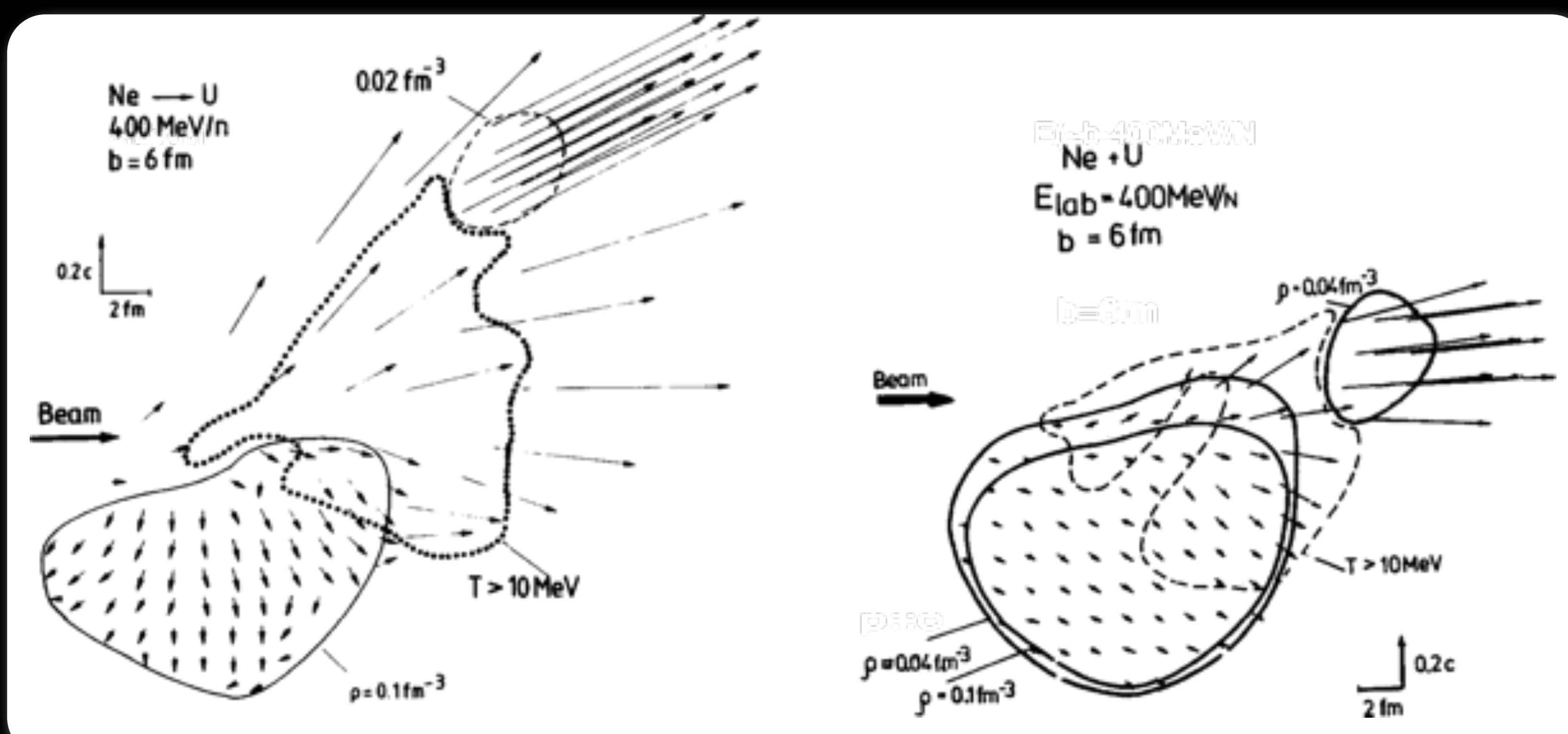

Browser Eve File Camera Help
Eve Files Macros
GL Viewer SplitGL View DataSelection QA histograms
Event 73
Primary Vertex
Primary Vertex SPD
V0 offline vertex locations
V0 on-the-fly vertex locations
ESD v0
ITS Clusters
TPC Clusters
ESD Tracks
TPC 2D
TPC 3D
3D sector 0
3D sector 1
3D sector 2
3D sector 3
Style
Name
Event 73::AliEveEventManager
TEveElement
Show: Self Children
AliEveEventManager
Next Event
Event Information:
Raw-data event info:
Run#: 60705
Event type: 7 (PHYSICS_EVENT)
Period: 1
Orbit: 4c635e BC: 718
Trigger: 1
Detectors: 8002000d (ITSSPD ITS
Attributes:bf-0-30
Timestamp: 48dabbac
ESD event info:
Run#: 60705
Active trigger classes: D0SCO
Event type: 7 (PHYSICS_EVENT)
Period: 1
Orbit: 4c635e BC: 718
Trigger: 1 (D0SCO)
NIKHEF
Command EventCtrl
First Prev 73 / 911 Next Last Refresh Autoload Time: 5 TRG select:
RAW event info: Run#: 60705 Event type: 7 (PHYSICS_EVENT) Period: 1 Orbit: 4c635e BC: 718
Trigger: 1
Detectors: 8002000d (ITSSPD ITSSSD TPC TRG)

Collective Motion





H. Stöcker and W. Greiner,
Phys. Rep. 137 (1986) 277



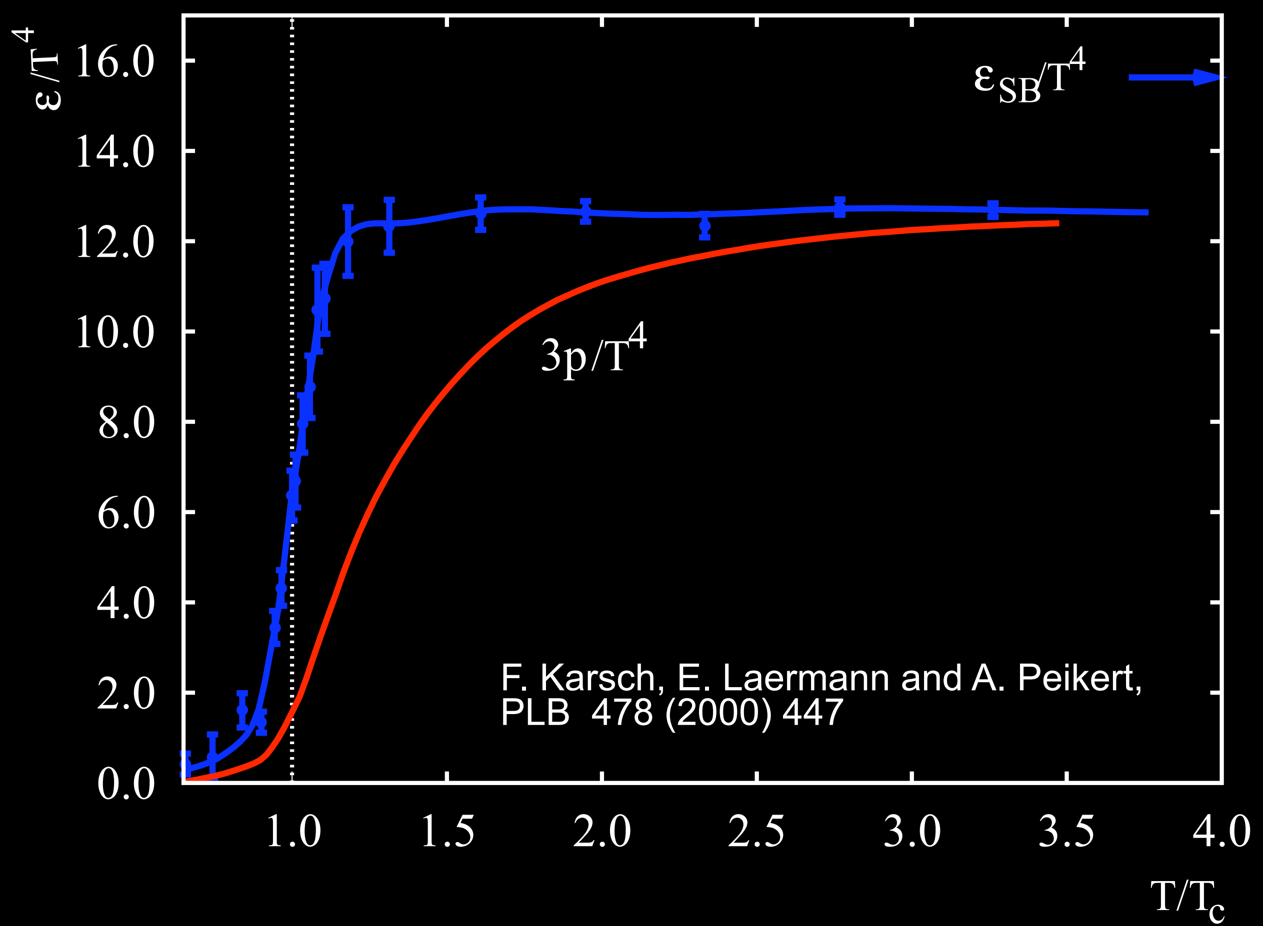
quickly recognized as important probe

QCD and QGP

It would be interesting to explore new phenomena by distributing high energy or high nuclear density over a relatively large volume

T.D. Lee (1978)

Lattice QCD predicts a sharp rise in the number of degrees of freedom near Tc



The LHC

Running parameters

Collision system	$\sqrt{s_{NN}}$(TeV)	$\mathcal{L}_0$ (cm^{-2}s^{-1})	$<\mathcal{L}>/\mathcal{L}_0$(%)	Run time (s/year)
pp	14.0	10^{34} *		10^7
PbPb	5.5	10^{27}	50	10^6 **
pPb	8.8	10^{29}		10^6
ArAr	6.3	10^{29}	65	10^6

*$\mathcal{L}_{max}$(ALICE) = 10^{31} ** $\mathcal{L}_{int}$(ALICE) ~ 0.5 nb^{-1}/year

The Standard Model

(matter)

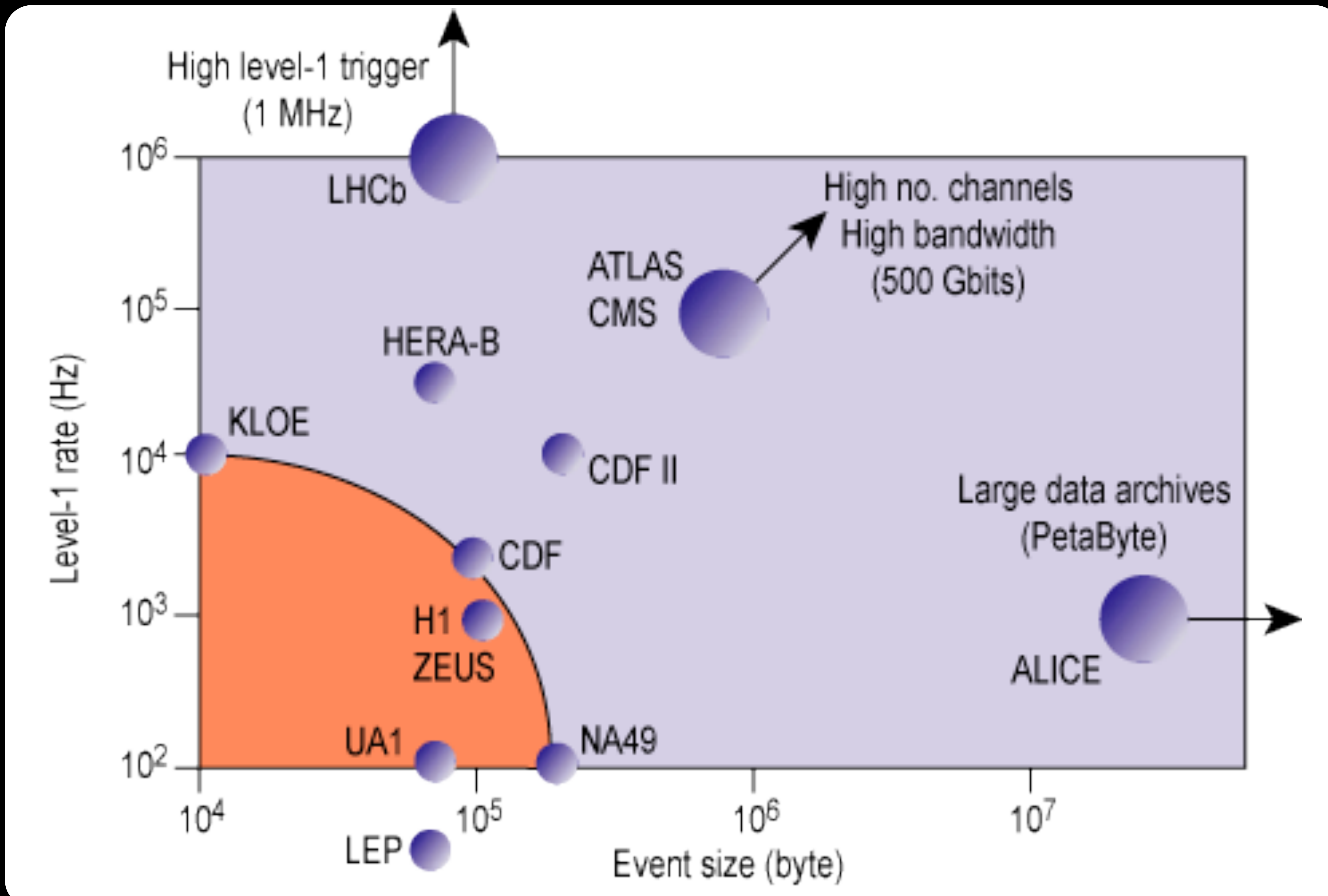
	1st generation	mass	2nd generation	mass	3rd generation	mass	charge
quarks	u u u	~3	c c c	1250	t t t	174300	2/3
	d d d	~6	s s s	120	b b b	4200	-1/3
leptons	ν_e	~0	ν_μ	~0	ν_τ	~0	0
	e	0.511	μ	106	τ	1770	-1

The Standard Model

(anti-matter)

	1st generation	mass	2nd generation	mass	3rd generation	mass	charge
anti-quarks	$\bar{u}$ $\bar{u}$ $\bar{u}$	~3	$\bar{c}$ $\bar{c}$ $\bar{c}$	1250	$\bar{t}$ $\bar{t}$ $\bar{t}$	174300	-2/3
	$\bar{d}$ $\bar{d}$ $\bar{d}$	~6	$\bar{s}$ $\bar{s}$ $\bar{s}$	120	$\bar{b}$ $\bar{b}$ $\bar{b}$	4200	1/3
anti-leptons	$\bar{\nu}_e$	~0	$\bar{\nu}_\mu$	~0	$\bar{\nu}_\tau$	~0	0
	e	0.511	μ	106	τ	1770	+1

Alice DAQ



High level-1 trigger
(1 MHz)
LHCb
High no. channels
High bandwidth
(500 Gbits)
ATLAS
CMS
HERA-B
KLOE
CDF II
Large data archives
(PetaByte)
CDF
H1
ZEUS
ALICE
UA1
NA49
LEP
Level-1 rate (Hz)
Event size (byte)
10^2
10^3
10^4
10^5
10^6
10^4
10^5
10^6
10^7

Proton-proton physics with ALICE

- The ALICE detector works even better for pp collisions, because of the low occupancy (10^{-4} to 10^{-3}), even if there is a significant number of events overlapping.
- The first physics with ALICE will be proton-proton collisions, which correspond to a major part of the ALICE programme for several reasons:
  - to provide **"reference" data** to understand heavy ion collisions. In a new energy domain, each signal in HI has to be compared to pp;
  - For **genuine proton-proton physics** whenever ALICE is unique or competitive; note that ALICE can reach rather "high" p_T, up to ~ 100 GeV/c, ensuring overlap with other LHC experiments.
  - The **possibility of taking proton data at several center of mass energies** (**0.9 TeV, 2.4 TeV, perhaps 5.5 TeV, and 14 TeV**), will provide ALICE with the possibility to understand the evolution of many of the properties of pp collisions as a function of the center of mass energy, and also to add to the measurements from previous experiments using proton-antiprotons.