ALICE: The detector and the Physics

T.M. Cormier

For the ALICE-USA Collaboration

ALICE-USA COLLABORATION

T. Awes[9], O. Barannikova[11], H. Bichsel1[14], B. Chapman[5], S. Chattpadhyay[15], M. Cherney[4], V. Cianciolo[9], T. Cormier[15], J. Cramer[14], H. Crawford[1], D. Ferenc[2], V. Ghazikhanian[3], O. Grachov[15], V. Greene[13], A. Hirsch[11], H. Huang[3], T. Humanic[10], P. Jacobs[7], E. Judd[1], L. Johnson[5], D. Keane[6], J. Klay[7], S. Klein[7], I. Kotov[10], A. Lan[5], M. Lisa[10], S. Margetis[6], B. Mayes[5], C. Maguire[13], B. Nilsen[10], G. Odyniec[7], A. Pavlinov[15], L. Pinsky[5], D. Prindle[14], C. Pruneau[15], K. Read[12], J. Riso[15], H.G. Ritter[7], R. Scharenberg[11], J. Seger[4], D. Silvermyr[9], S. Sorensen[12], P. Stankus[9], S. Trentalange[3], D. Truesdale[10], A. VanderMolen[8], M. Van Leeuwen[7], J. Velkowska[13], S. Voloshin[15], G. Westfall[8], C. Whitten[3], F. Wang[11], G. Young[9],

---

[1] University of California- Berkeley
[2] University of California-Davis
[3] University of California-Los Angeles
[4] Creighton University
[5] University of Houston
[6] Kent State University
[7] Lawrence Berkeley National Laboratory
[8] Michigan State University
[9] Oak Ridge National Laboratory
[10] Ohio State University
[11] Purdue University
[12] University of Tennessee
[13] Vanderbilt University
[14] University of Washington
[15] Wayne State University

ALICE-USA:

Significant participation from many who have led the development of the very succesful US heavy ion program.

“LHC is either a confirmation machine or a discovery machine”

Either way, ALICE is the right experiment:

Confirmation must must rely on a common set of observables between the two energy regimes (elliptic flow of identified particles, jet like correlations with strong quenching in the intermediate P_T range, …)

Discovery (e.g. perhaps a weakly coupled plasma at the LHC) will come from the widest possible suite of measurements such as has been provided by the combined capabilities of STAR and PHENIX and the two small experiments at RHIC.

Outline:

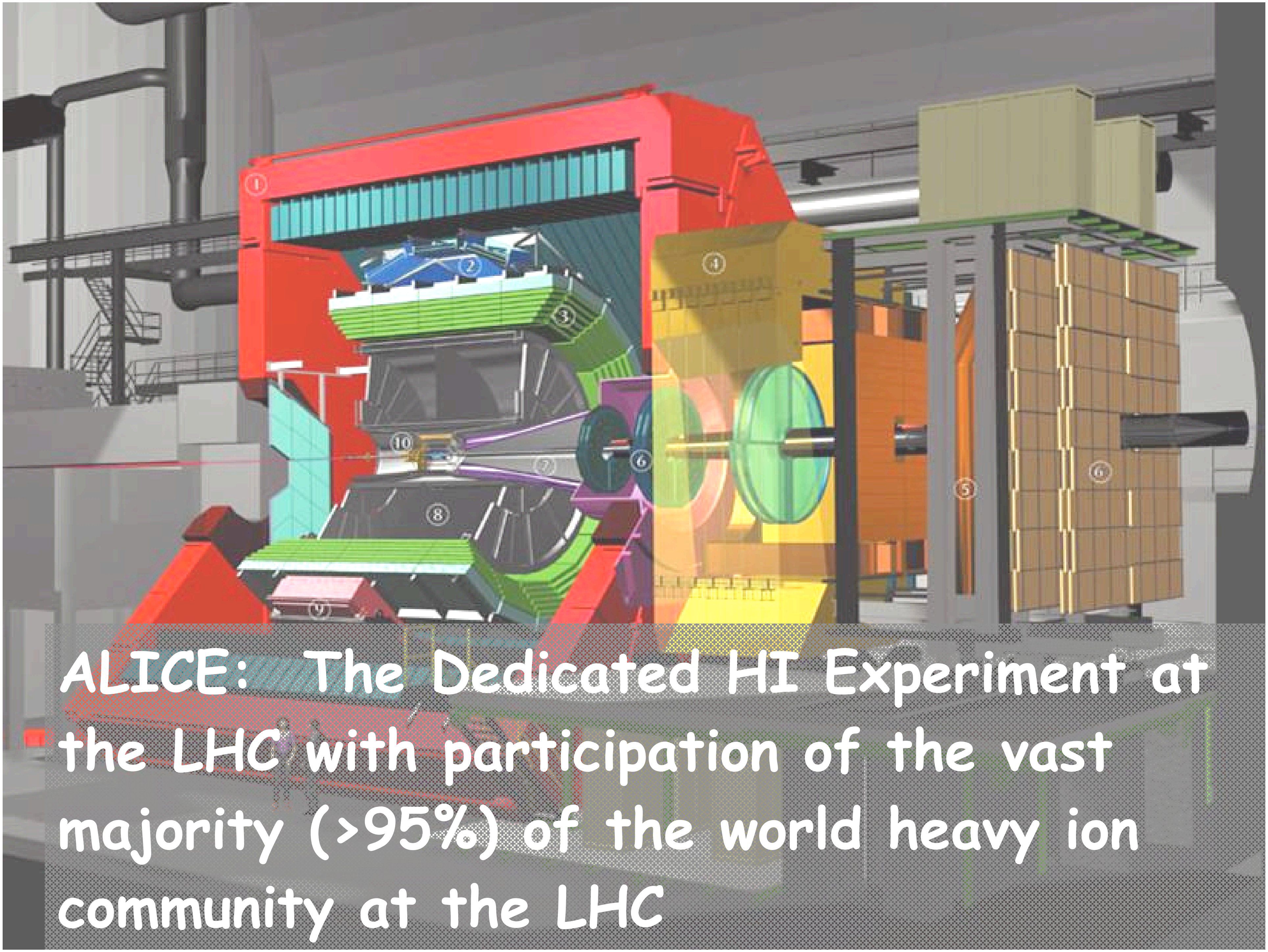
What is ALICE

What is there to measure: The RHIC Plasma and the LHC Plasma

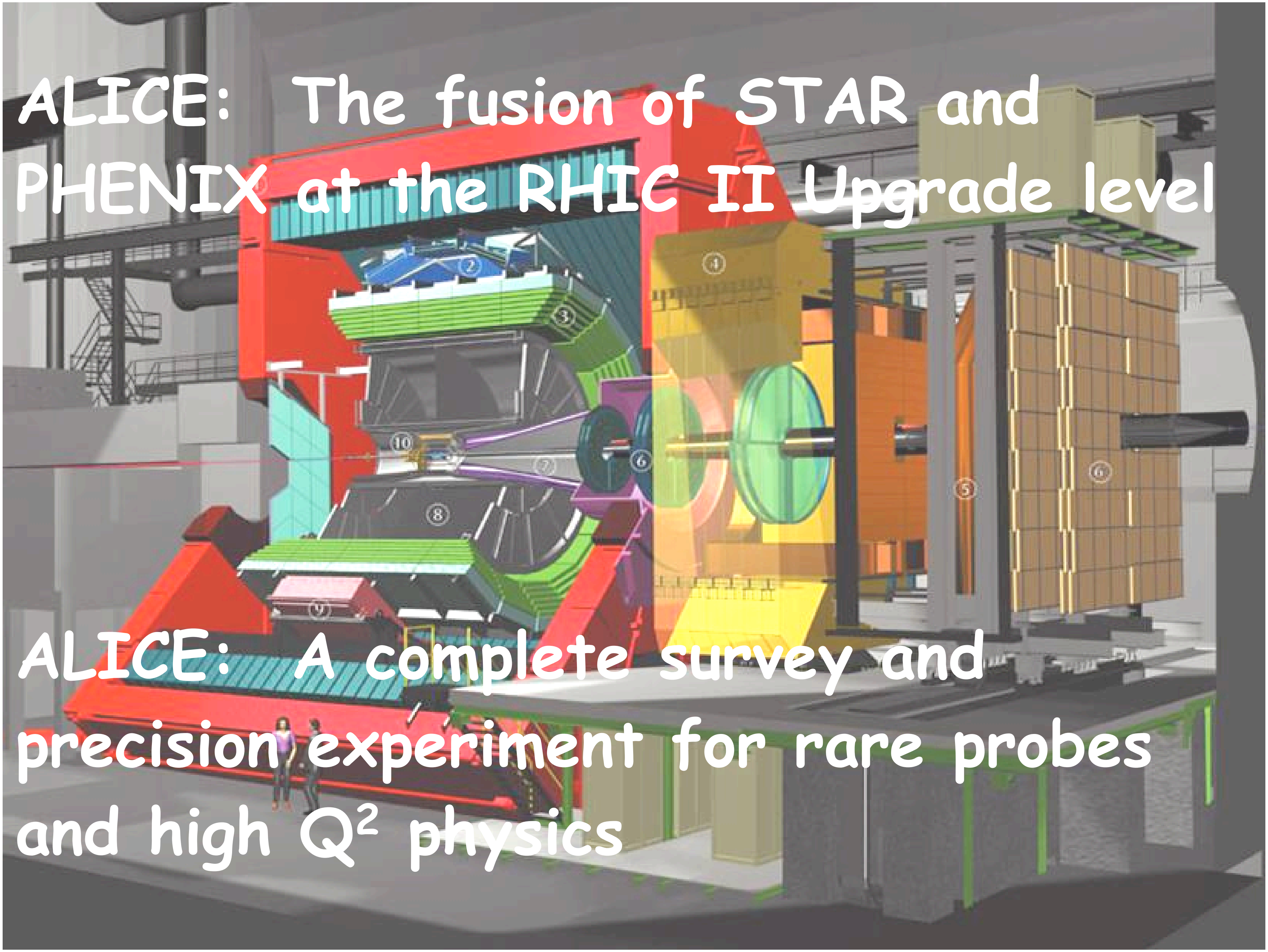
Exploring the LHC Plasma with ALICE

Conclusions

(Committee Questions)



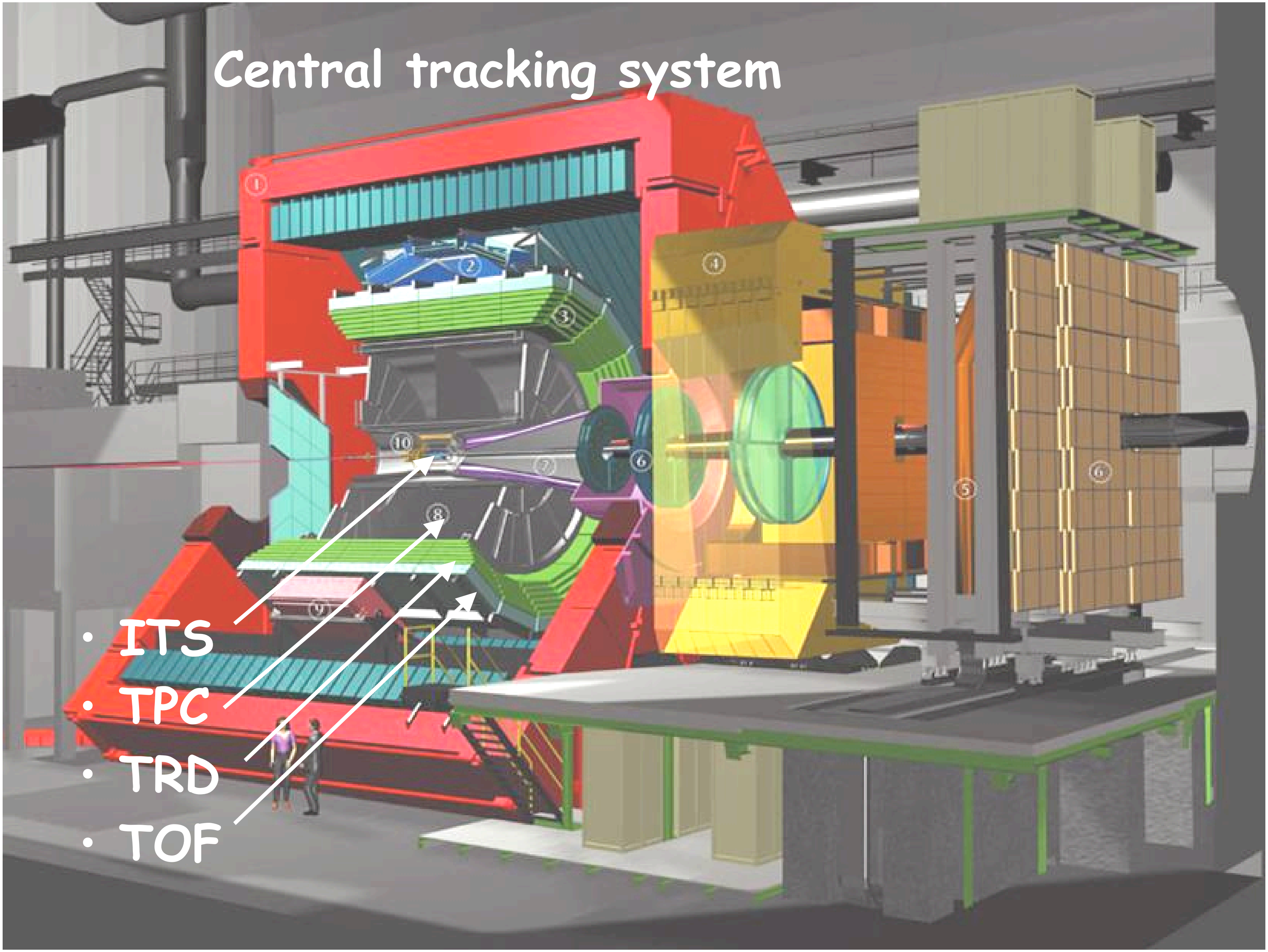
ALICE: The Dedicated HI Experiment at the LHC with participation of the vast majority (>95%) of the world heavy ion community at the LHC



ALICE: The fusion of STAR and PHENIX at the RHIC II Upgrade level

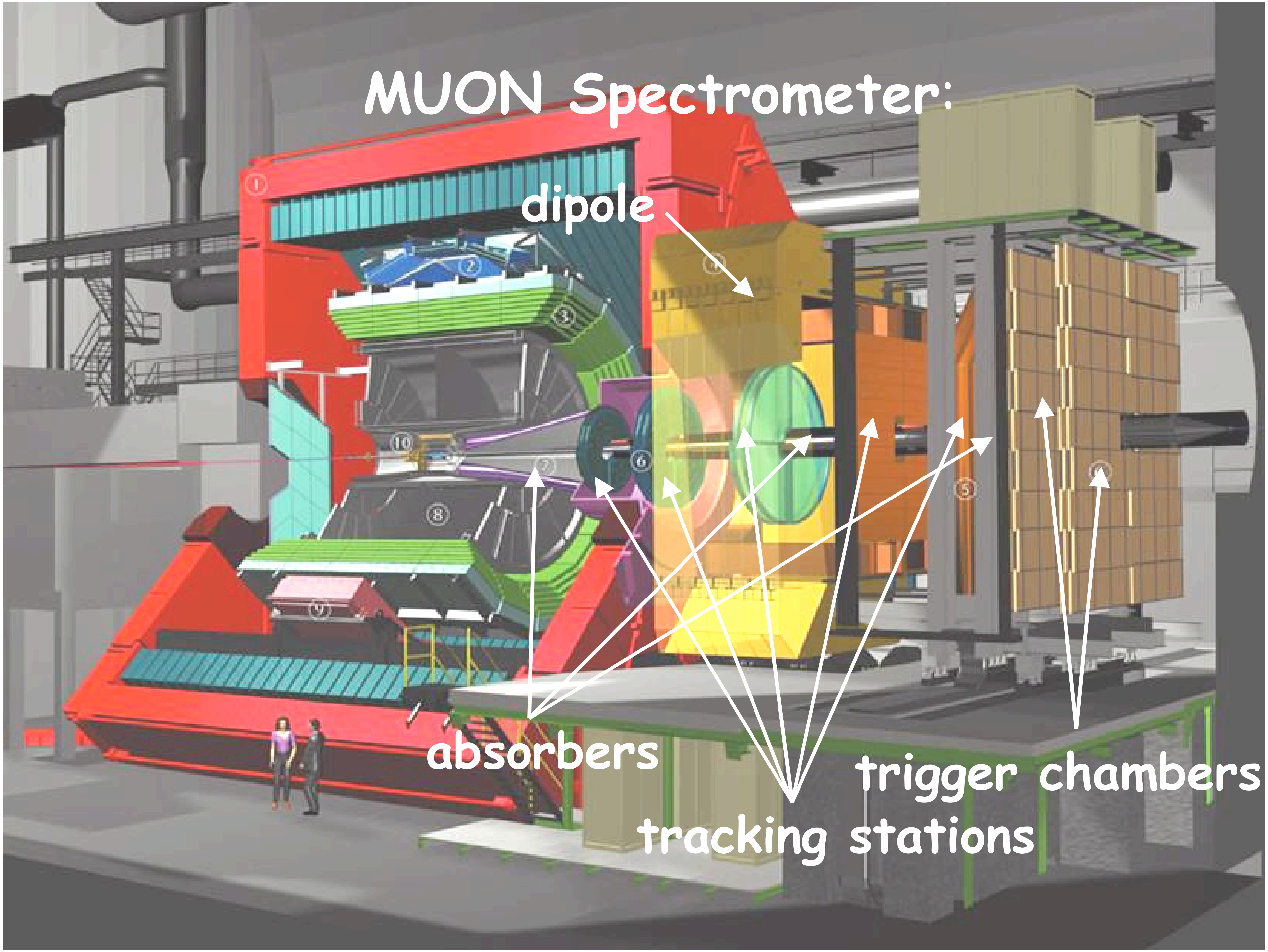
ALICE: A complete survey and precision experiment for rare probes and high Q^2 physics

Central tracking system

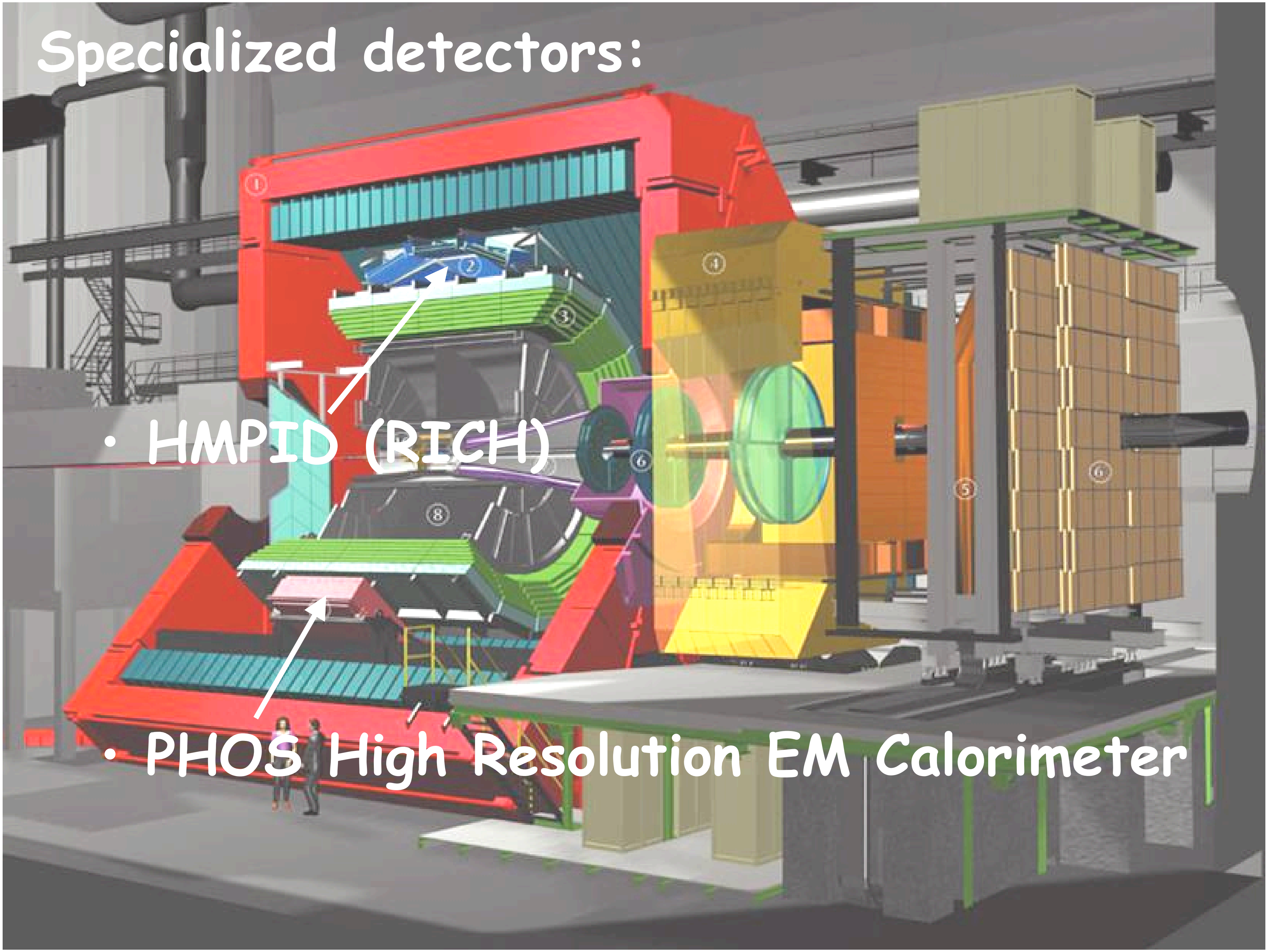


- ITS
- TPC
- TRD
- TOF

MUON Spectrometer:

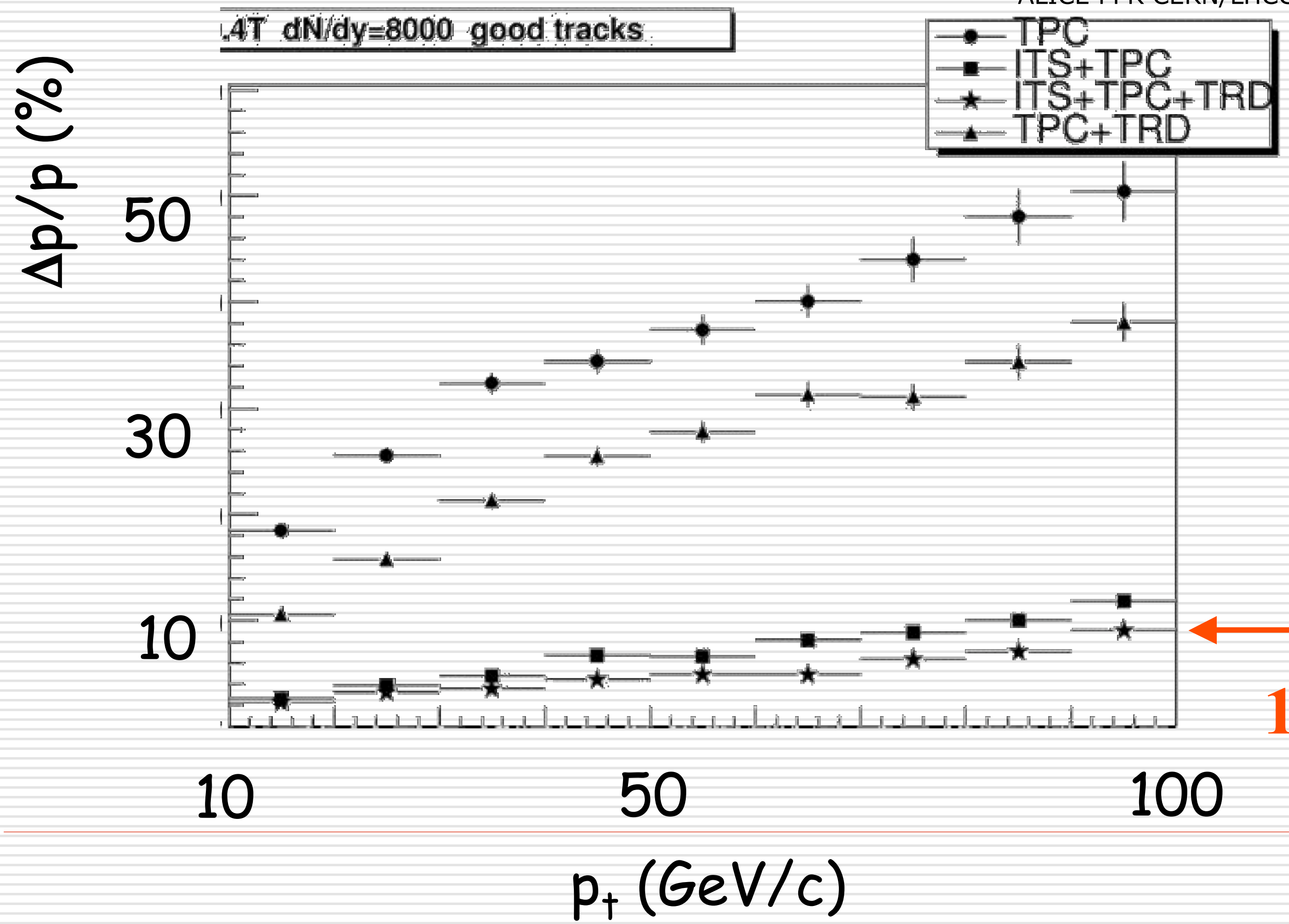


Specialized detectors:



- HMPID (RICH)
- PHOS High Resolution EM Calorimeter

ALICE track resolution at high p_t



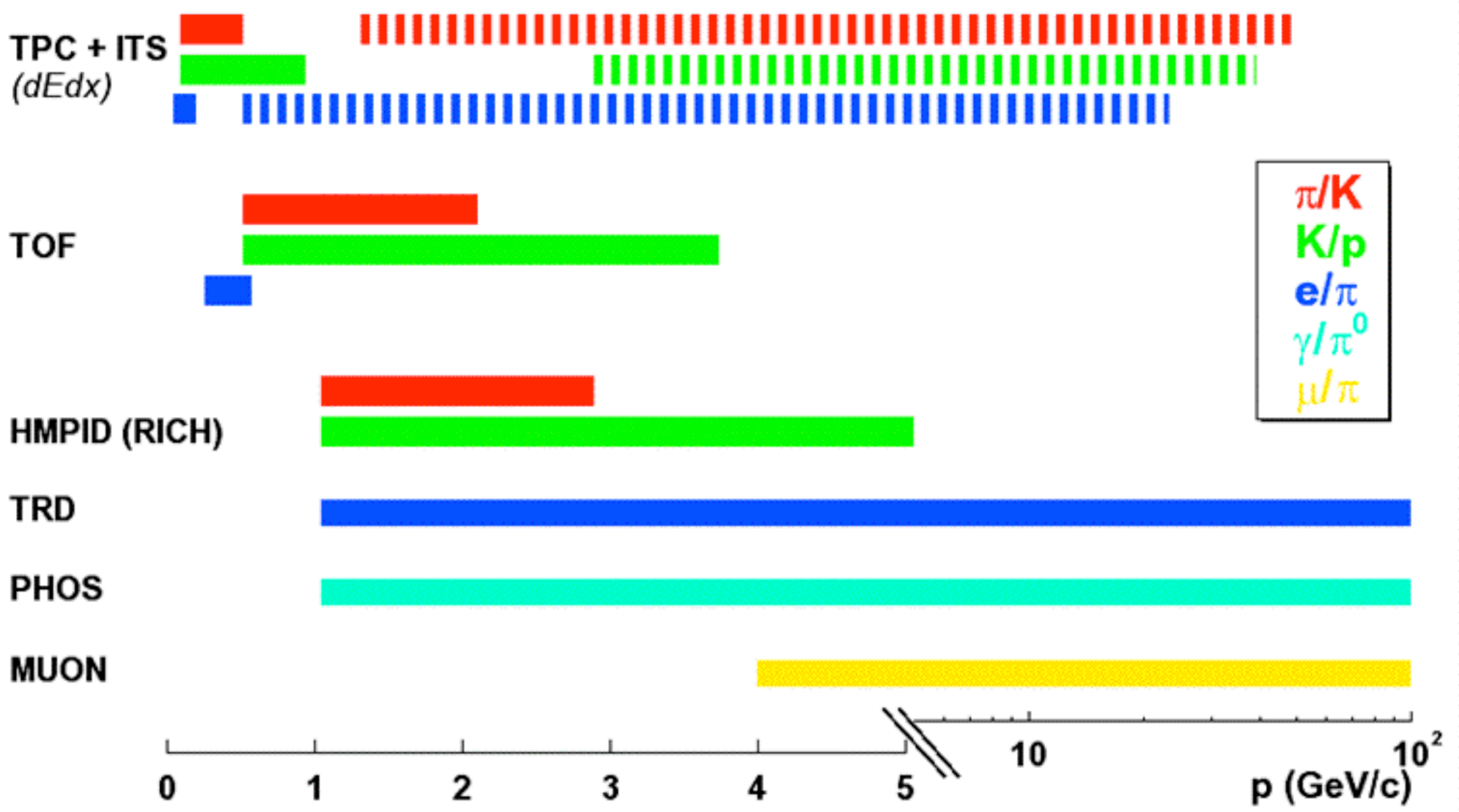
ALICE PPR CERN/LHCC 2003-049

8%

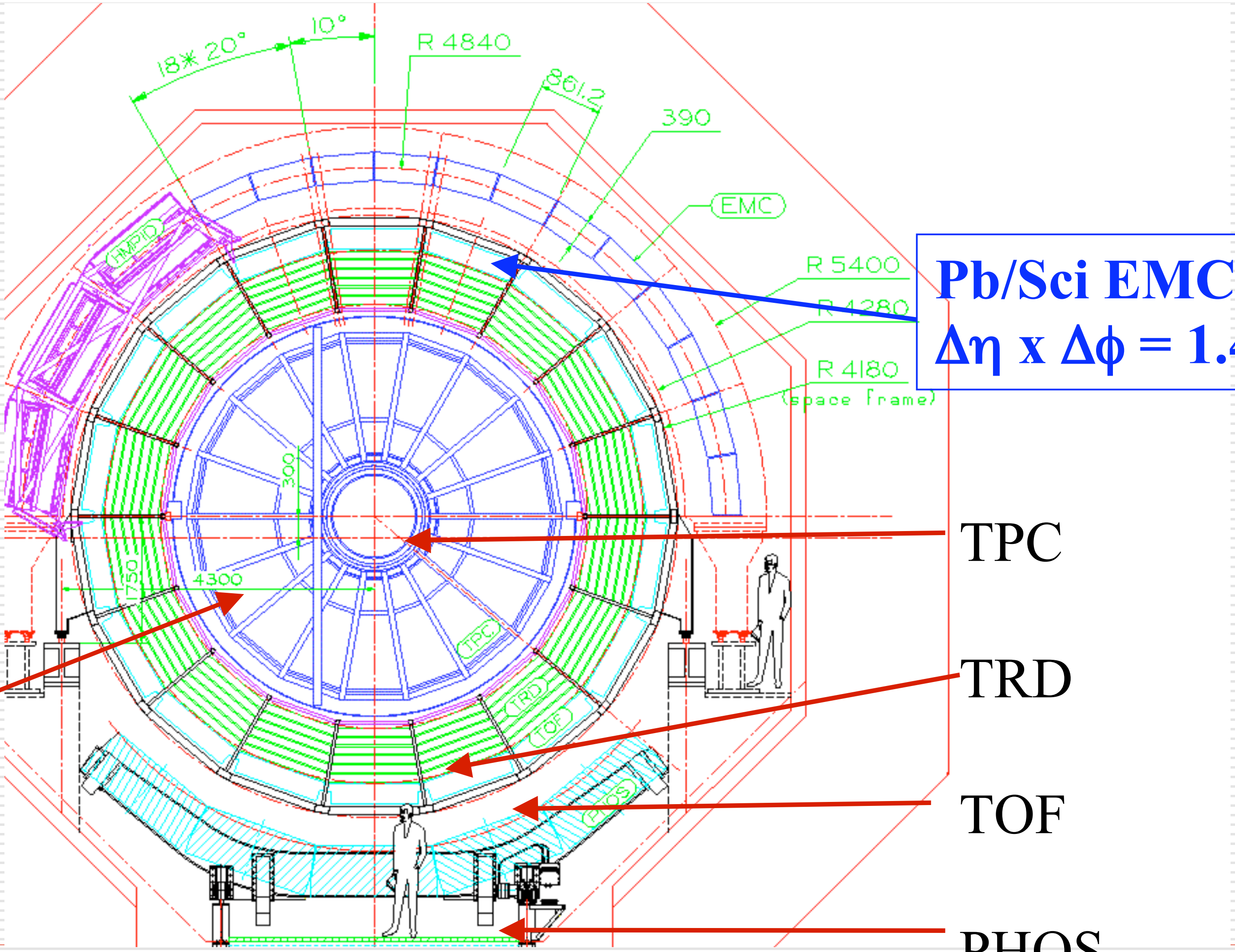
100 GeV/c

ALICE PID performances

ALICE PPR CERN/LHCC 2003-049



ALICE-USA EMCaL



RICH

Pb/Sci EMCal

$\Delta\eta \times \Delta\phi = 1.4 \times 2\pi/3$

TPC

TRD

ITS

TOF

PHOS

Why Study the QGP at the LHC?

Estimated LHC plasma conditions vs RHIC

	RHIC	LHC
T/T_c	1.9	3.0 - 4.2
ε(GeV/fm^3)	5	15 - 60

Given our limited knowledge of the equation of state of QGP, we have no basis from which to assume that the LHC plasma is the same state as found at RHIC. (e.g. Maybe sQGP -> wQGP)

LHC = possibly quite different plasma state + CGC initial conditions

CGC at the LHC = Plasma initial conditions quantifiable in terms of classical QCD fields.

This is a very exciting possibility both theoretically and experimentally

But..... Maybe, the QGP at LHC is an exact copy of the RHIC QGP.

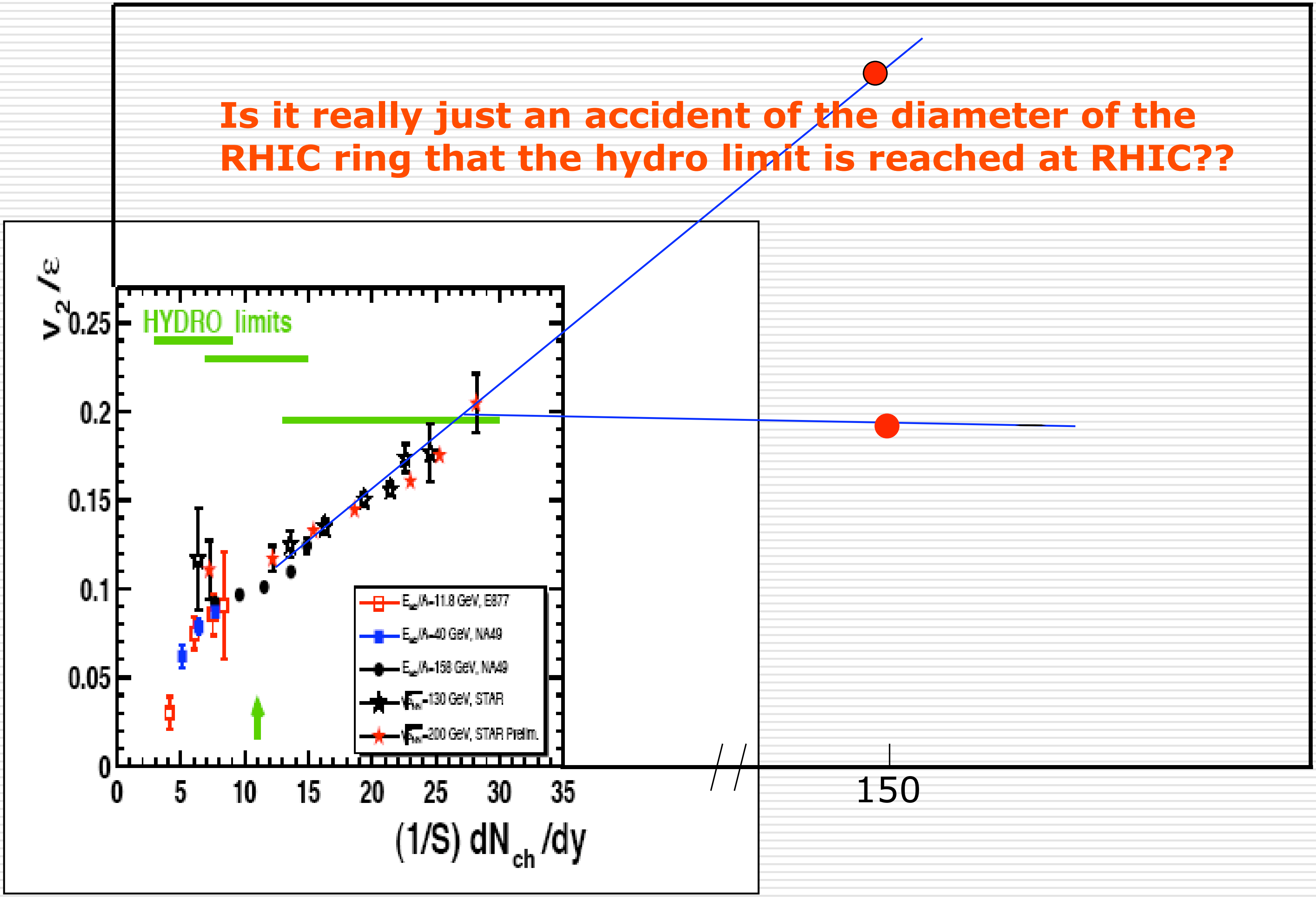
This discovery would be astounding! It would constitute a major increase in our knowledge of the QGP by revealing the stability of the QGP properties over factors of 2 in temperature and factors of 5-12 in energy density!

In either the discovery mode, or the confirmation mode, it will be essential to cover the full suite of RHIC measurements at the LHC.

This can only be done with the ALICE detector

Some example **ALICE measurements** needed to extend and amplify RHIC measurements and explore the LHC plasma properties ….

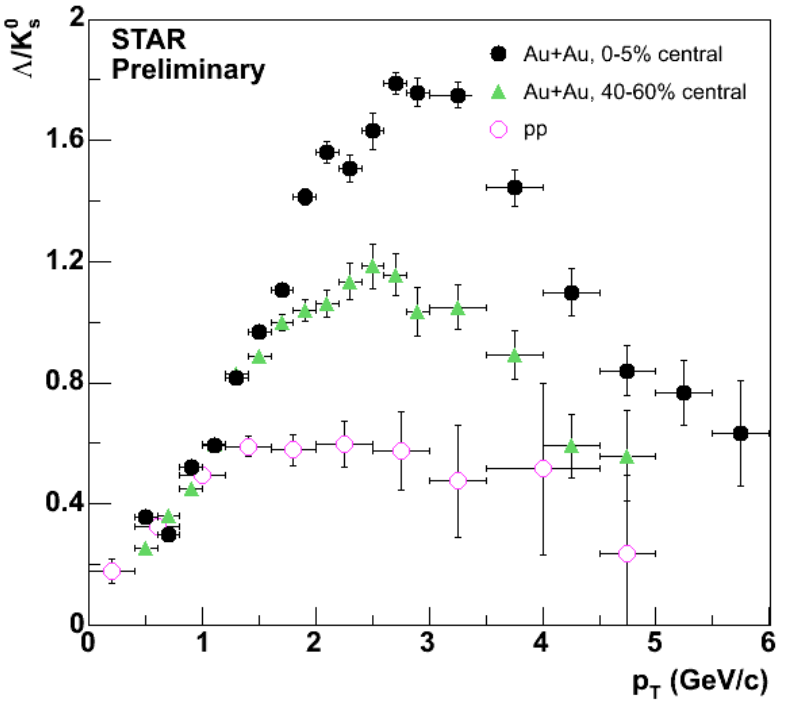
Is it really just an accident of the diameter of the RHIC ring that the hydro limit is reached at RHIC??

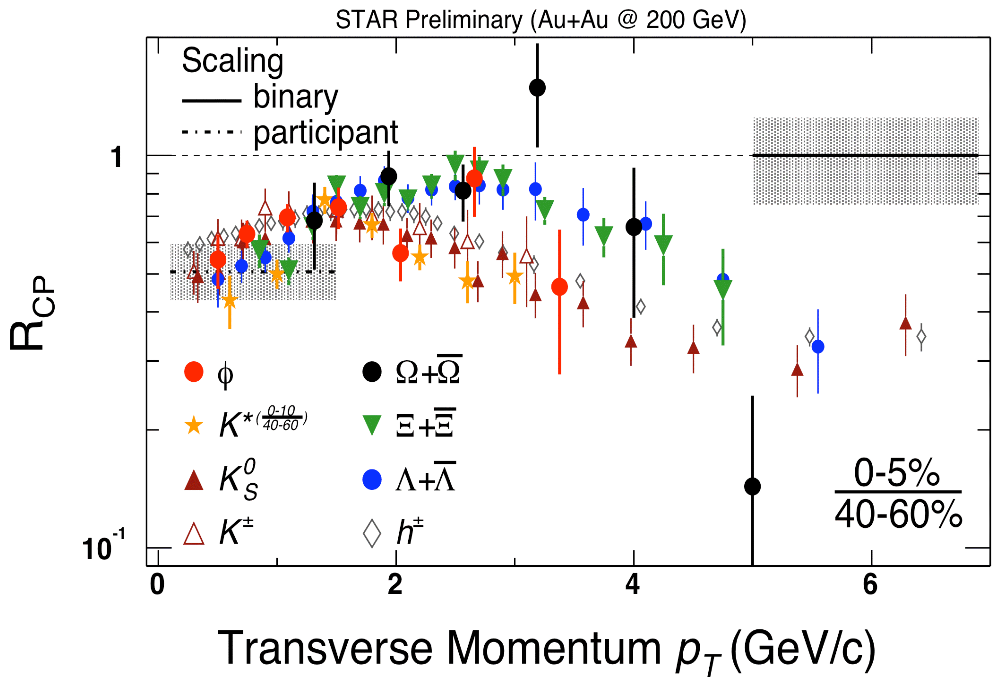


ALICE will study elliptic flow for identified particles from charged and neutral pions through Ω in the cumulant expansion*.

* Given the jetty nature of LHC events, this is probably essential. It requires flawless low P_T tracking of identified particles - unique to ALICE at the LHC

Why worry about particle ID at the LHC?

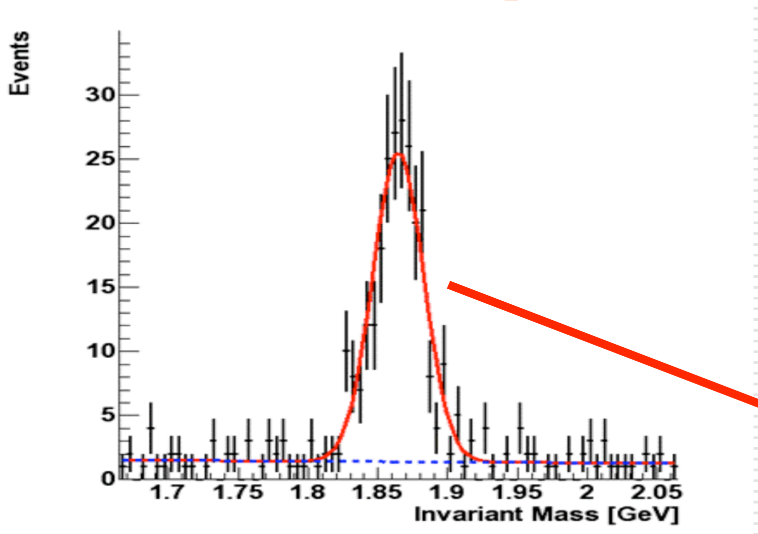


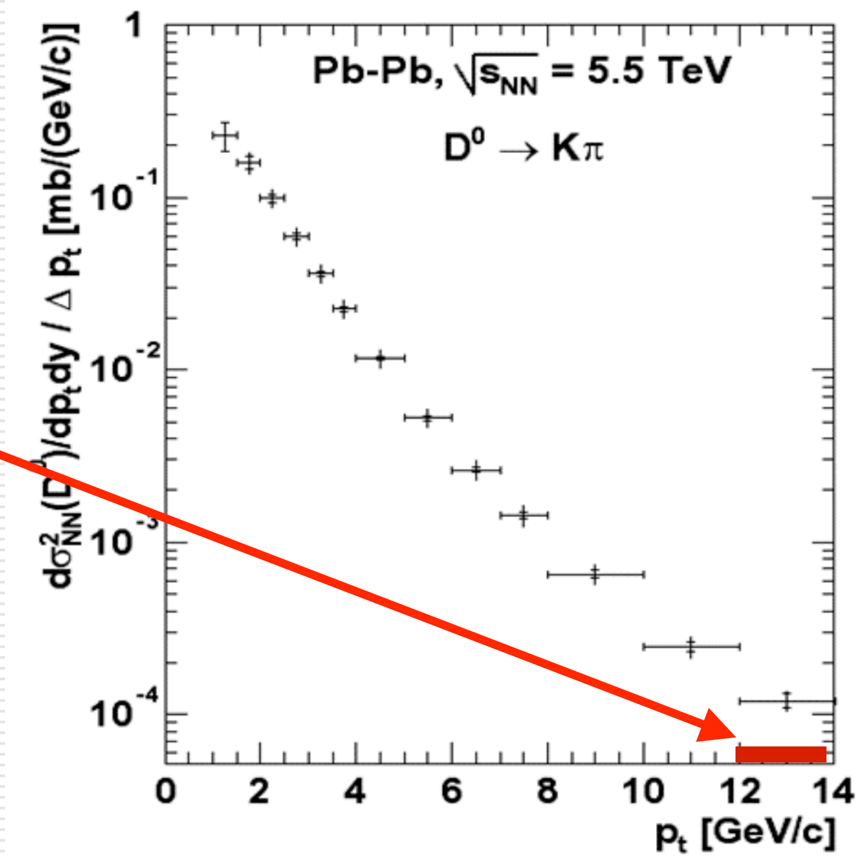


The evolution of the complete physics picture between 200 MeV and 5 GeV at RHIC has required PID, Baryon anomaly, HBT, radial flow, elliptic flow, species dependence of quenching, …

These measurements are fundamental to our current understanding of the new state of matter produced at RHIC. Do we really want to be be part of the LHC program and ignore the importance of particle ID?

Open Charm in ALICE

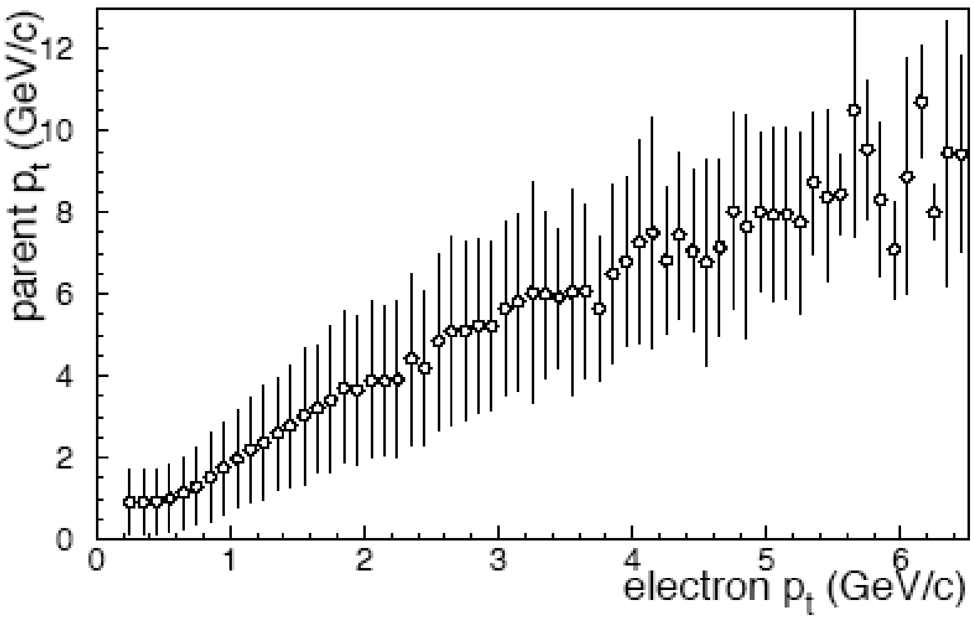


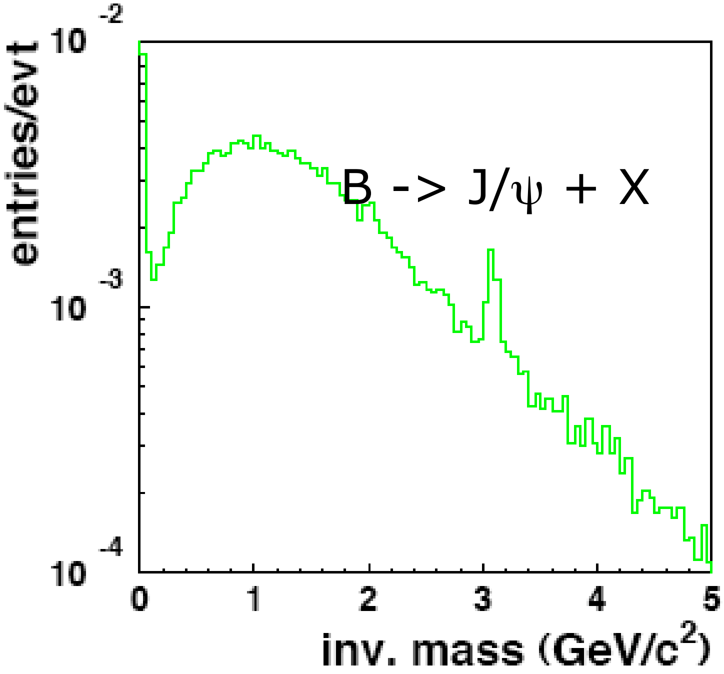


$D^0 \rightarrow K\pi$ reconstruction in ALICE

Search for thermal charm production and equilibration, charm flow, dead cone, …

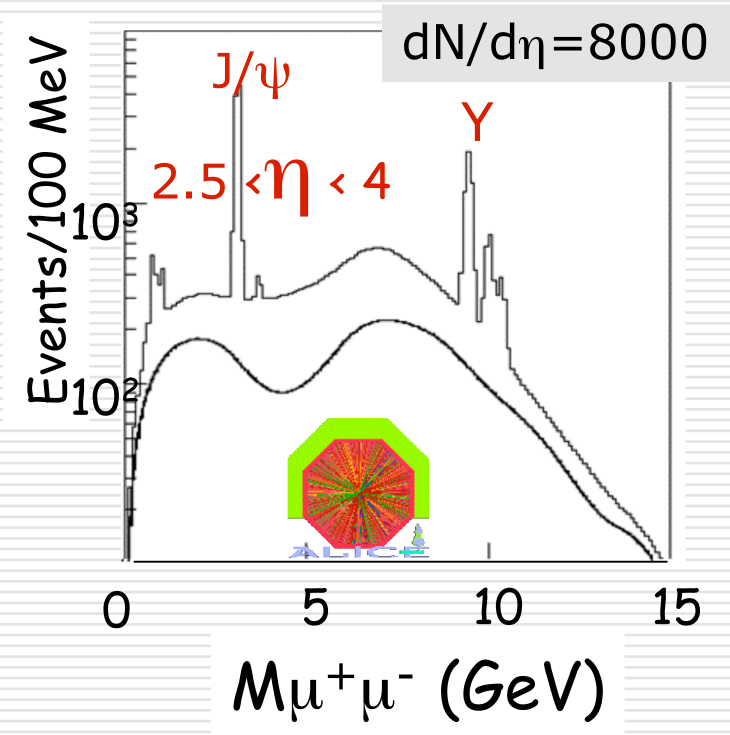
Open Beauty in ALICE- two examples





Inclusive electrons and delayed J/ψ production

c/b Quarkonia in ALICE



Quarkonium Phase Space

J/ψ P_T = 0 to ~20-25 GeV/c

Υ P_T = 0 to ~10-15 GeV/c

η= 4 to -1

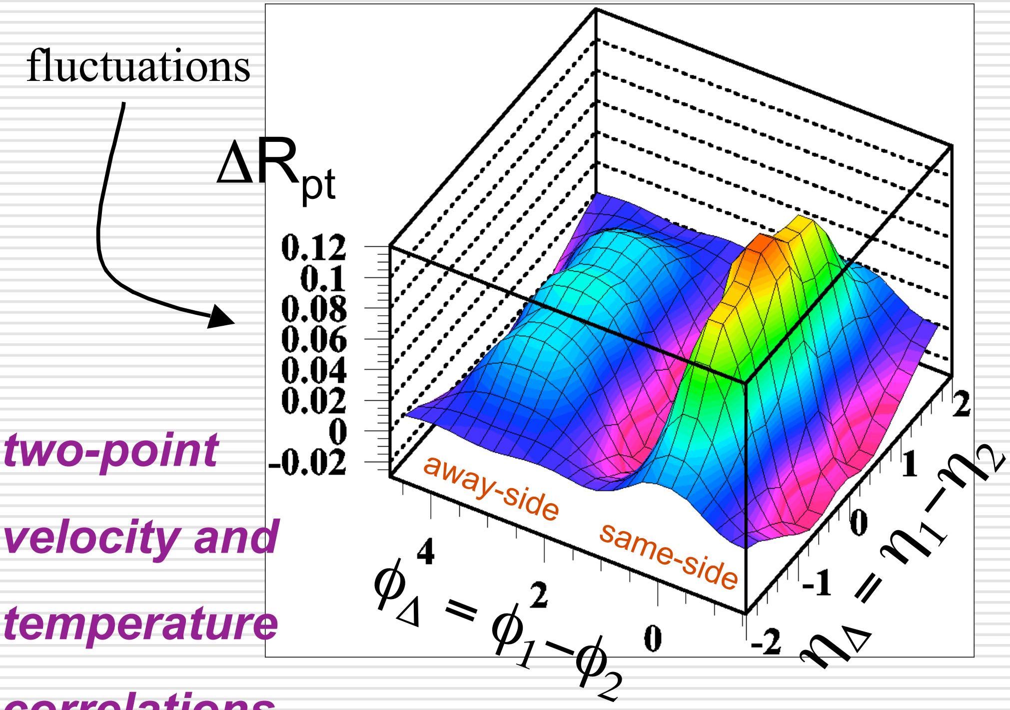
Normalization of quarkoniun suppression to heavy quark production is possible in ALICE!

	ALICE e^+e^-	ALICE $\mu^+\mu^-$	CMS $\mu^+\mu^-$
$\epsilon^{\Upsilon}_{\rm det}$ (%)	1	3.24	5.2
$N^{\Upsilon}_{\rm tape}$	2600	8400	13500
$S/\sqrt{S+B}\ \Upsilon:\Upsilon':\Upsilon''$	—	71:36:23	80:32:17

L =0.5x10^{26}

E-by-E Two-Particle p_t Correlations as a plasma diagnostic

STAR Data



two-point velocity and temperature correlations

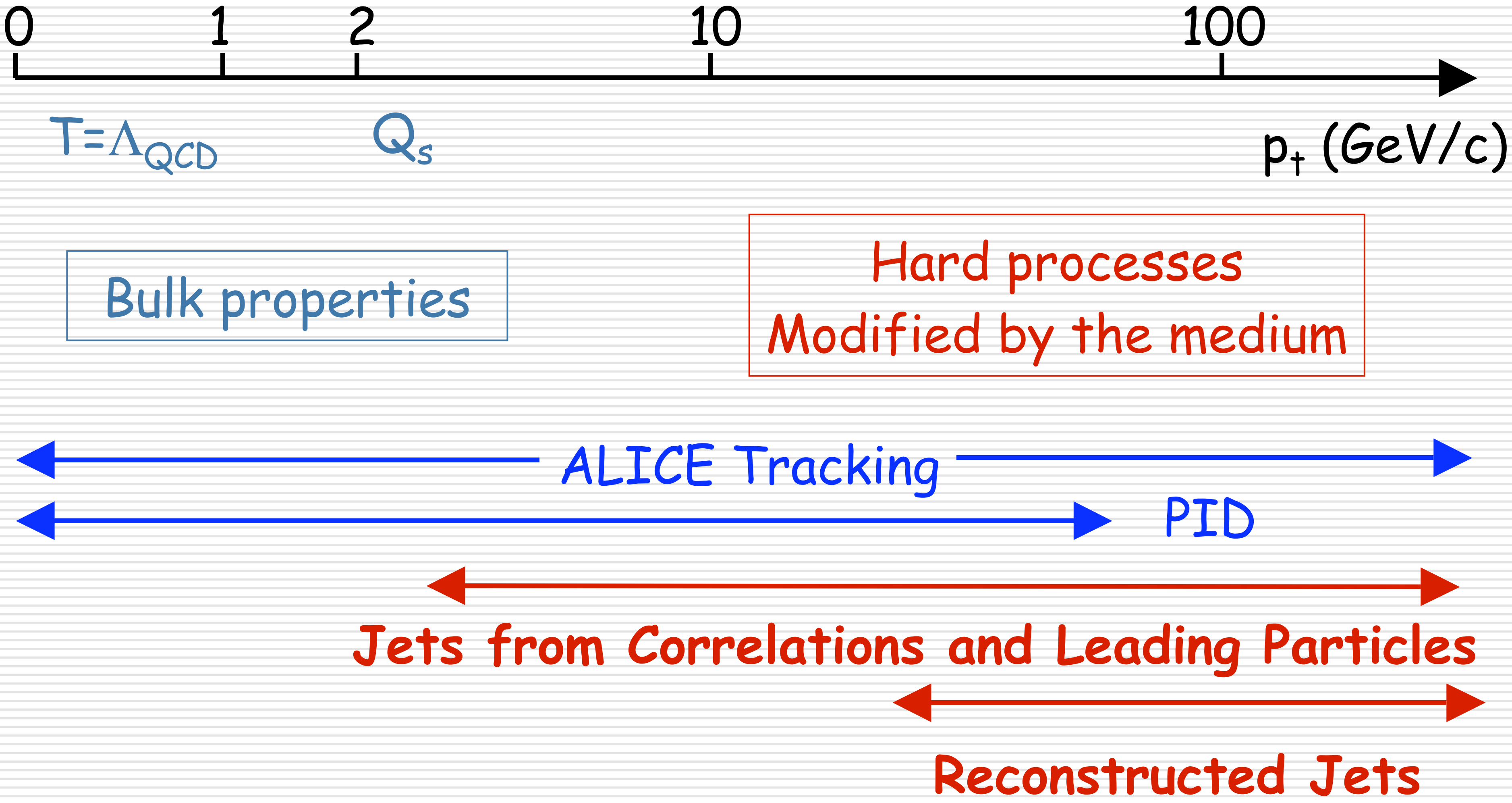
Observation, with centrality $p_t = 0.15 – 2.00$ GeV/c

- ☐ Suppression of away/same-side amplitude ratio
- ☐ Elongation of same-side peak on η_Δ (possibly related to longitudinal expansion)
- ☐ Narrowing of same-side peak on ϕ_Δ

Au+Au @200GeV, 20 – 30% central, $|\eta| < 1$

Dipole and quadrupole terms removed.

ALICE Jet Phase Space



0 1 2 10 100

$T=\Lambda_{QCD}$

Q_s

p_t (GeV/c)

Bulk properties

Hard processes
Modified by the medium

ALICE Tracking

PID

Jets from Correlations and Leading Particles

Reconstructed Jets

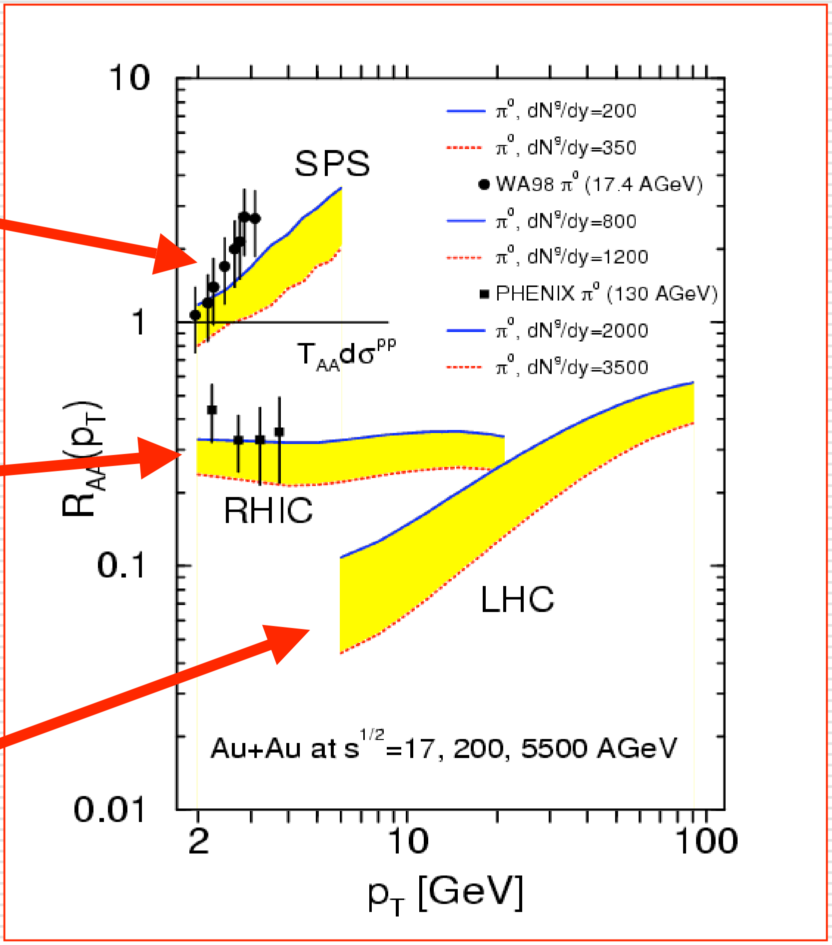
Jets from Correlations and Leading Particles

Jet quenching in inclusive single particle spectra

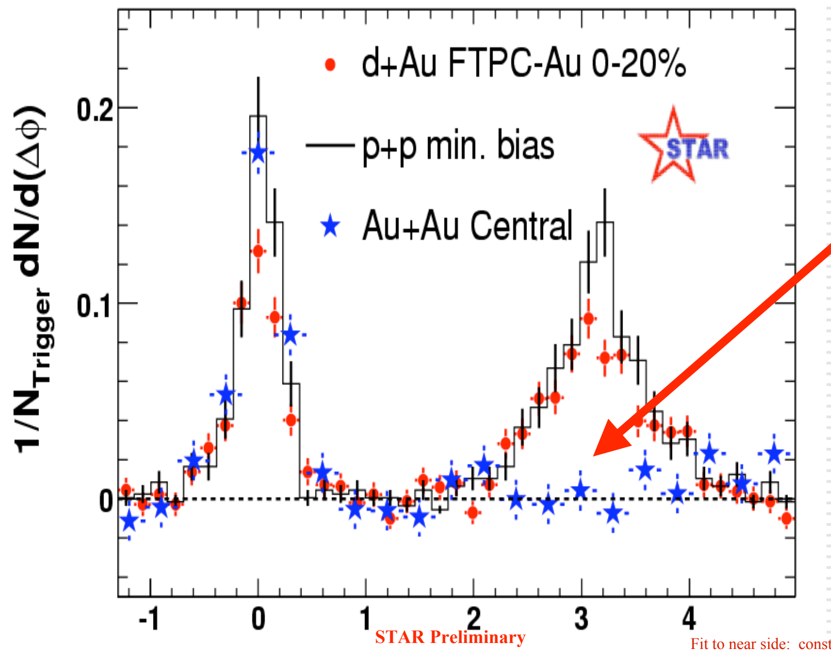
SPS
Cronin dominates

RHIC
Cronin ~ Quenching

LHC
Quenching dominates



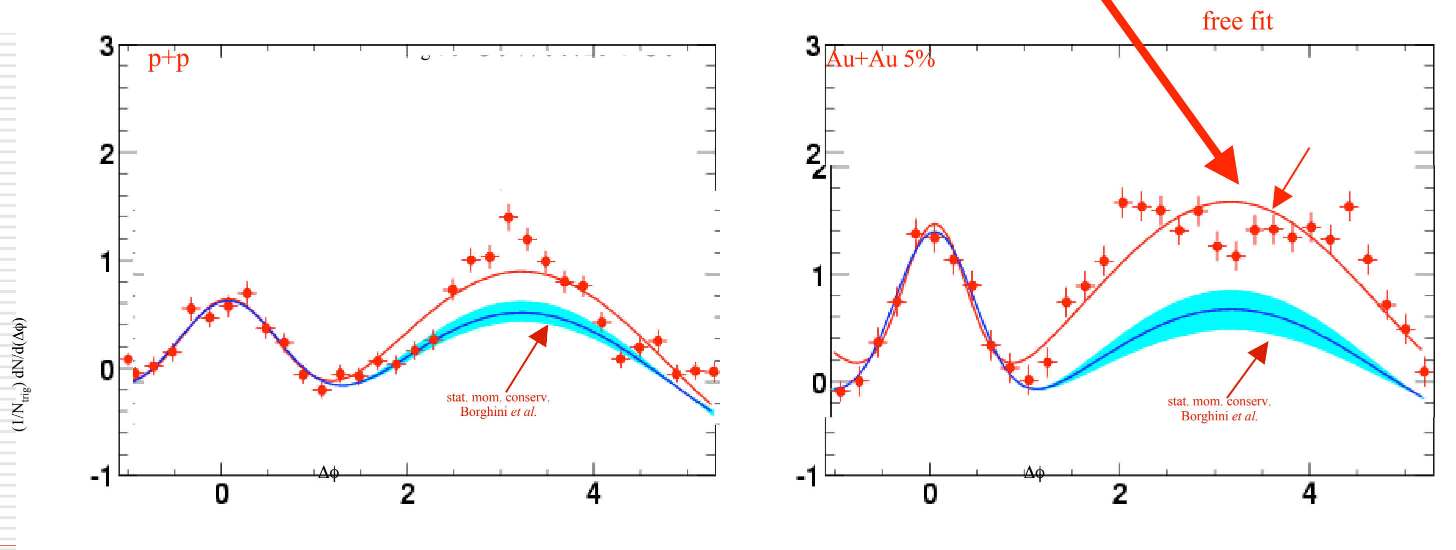
Vitev, Gyulassy, Phys.Rev.Lett. 89 (2002)



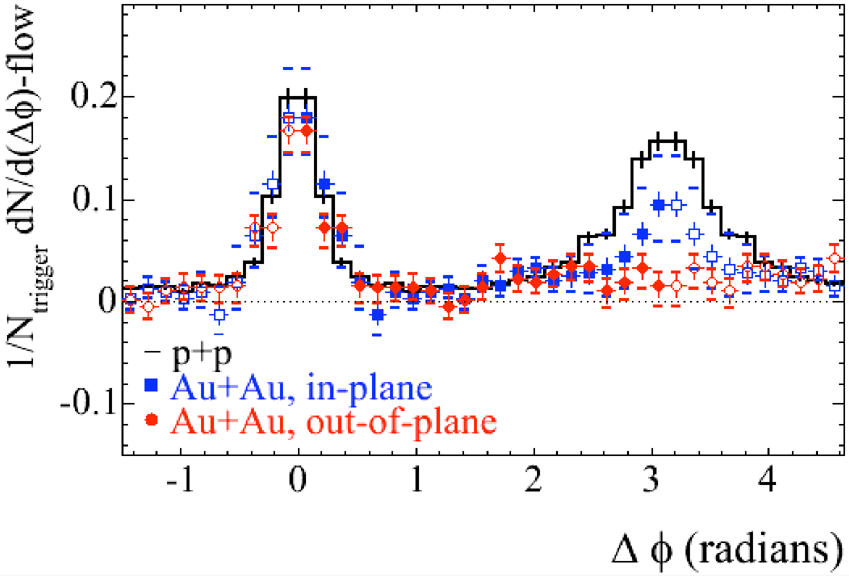
Disappearance of away side jet in central AuAu

Reappearance of away side jet in higher multiplicity flow at low P_T

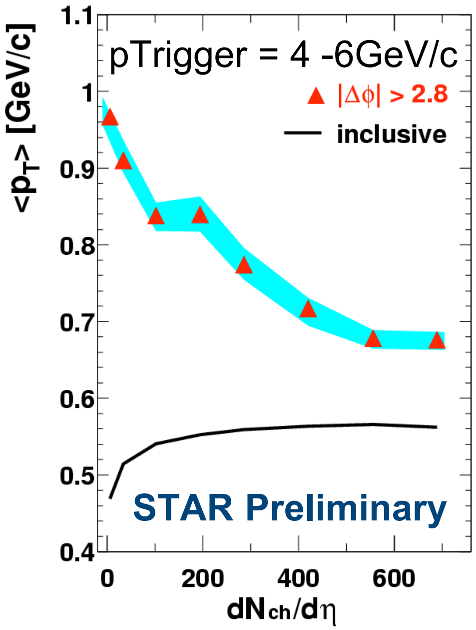
Fit to near side: const. + gaussian + Borghini-cos(fixed)



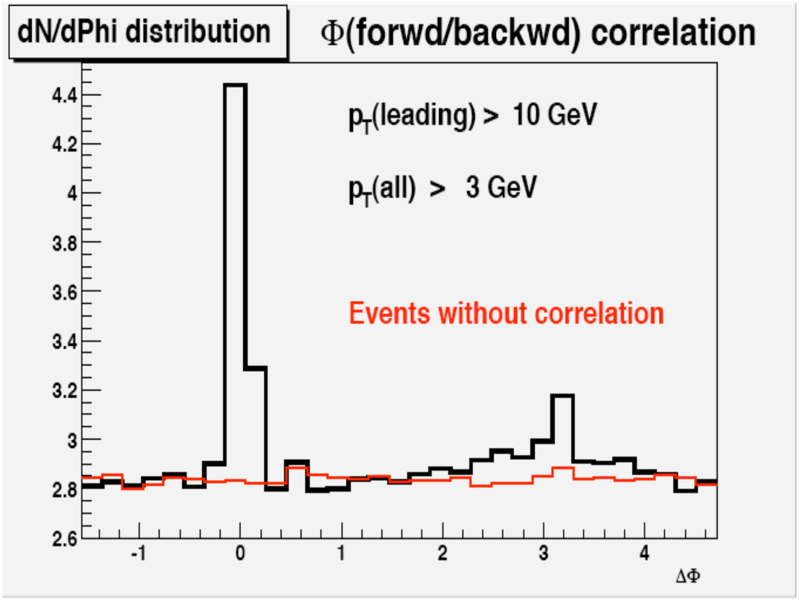
How will low P_T jets quench in the very dense LHC plasma?



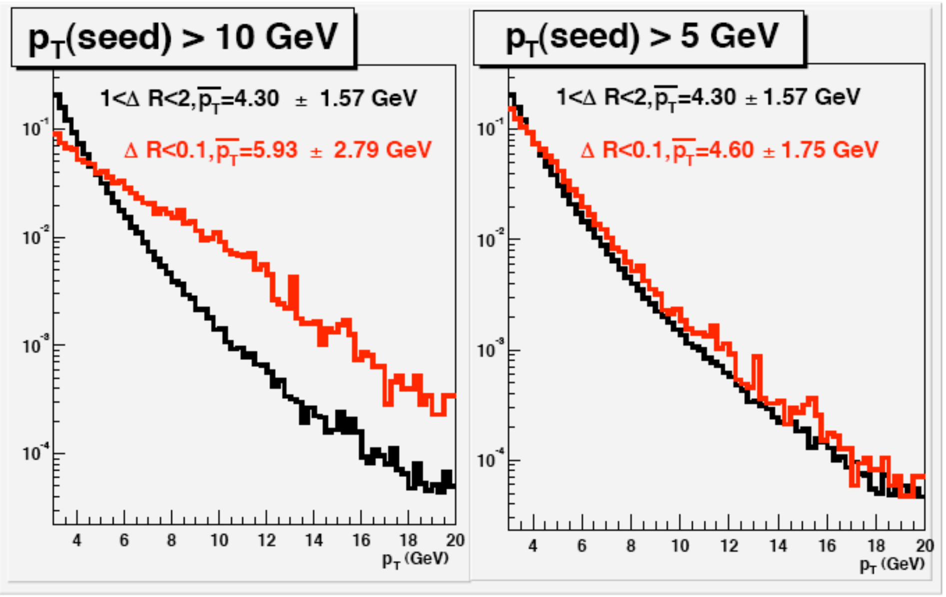
$1/N_{trigger}$ dN/d(Δφ)-flow
0.2
0.1
0
-0.1
-1
0
1
2
3
4
Δ φ (radians)
p+p
Au+Au, in-plane
Au+Au, out-of-plane



<p_T> [GeV/c]
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0
200
400
600
$dN_{ch}/d\eta$
pTrigger = 4 -6GeV/c
▲ |Δφ| > 2.8
— inclusive
STAR Preliminary



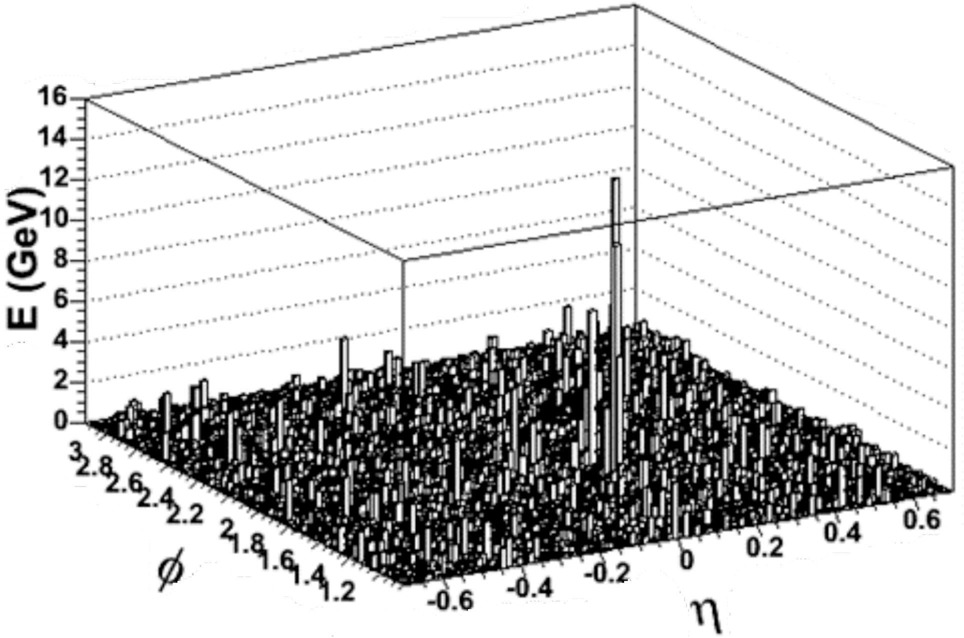
dN/dPhi distribution
Φ(forwd/backwd) correlation
p_T(leading) > 10 GeV
p_T(all) > 3 GeV
Events without correlation
4.4
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
-1
0
1
2
3
4
ΔΦ



p_T(seed) > 10 GeV
1<Δ R<2,$\overline{p_T}$=4.30 ± 1.57 GeV
Δ R<0.1,$\overline{p_T}$=5.93 ± 2.79 GeV
p_T(seed) > 5 GeV
1<Δ R<2,$\overline{p_T}$=4.30 ± 1.57 GeV
Δ R<0.1,$\overline{p_T}$=4.60 ± 1.75 GeV
10^{-1}
10^{-2}
10^{-3}
10^{-4}
4
6
8
10
12
14
16
18
20
p_T (GeV)

New feature at the LHC

Fully reconstructed jets



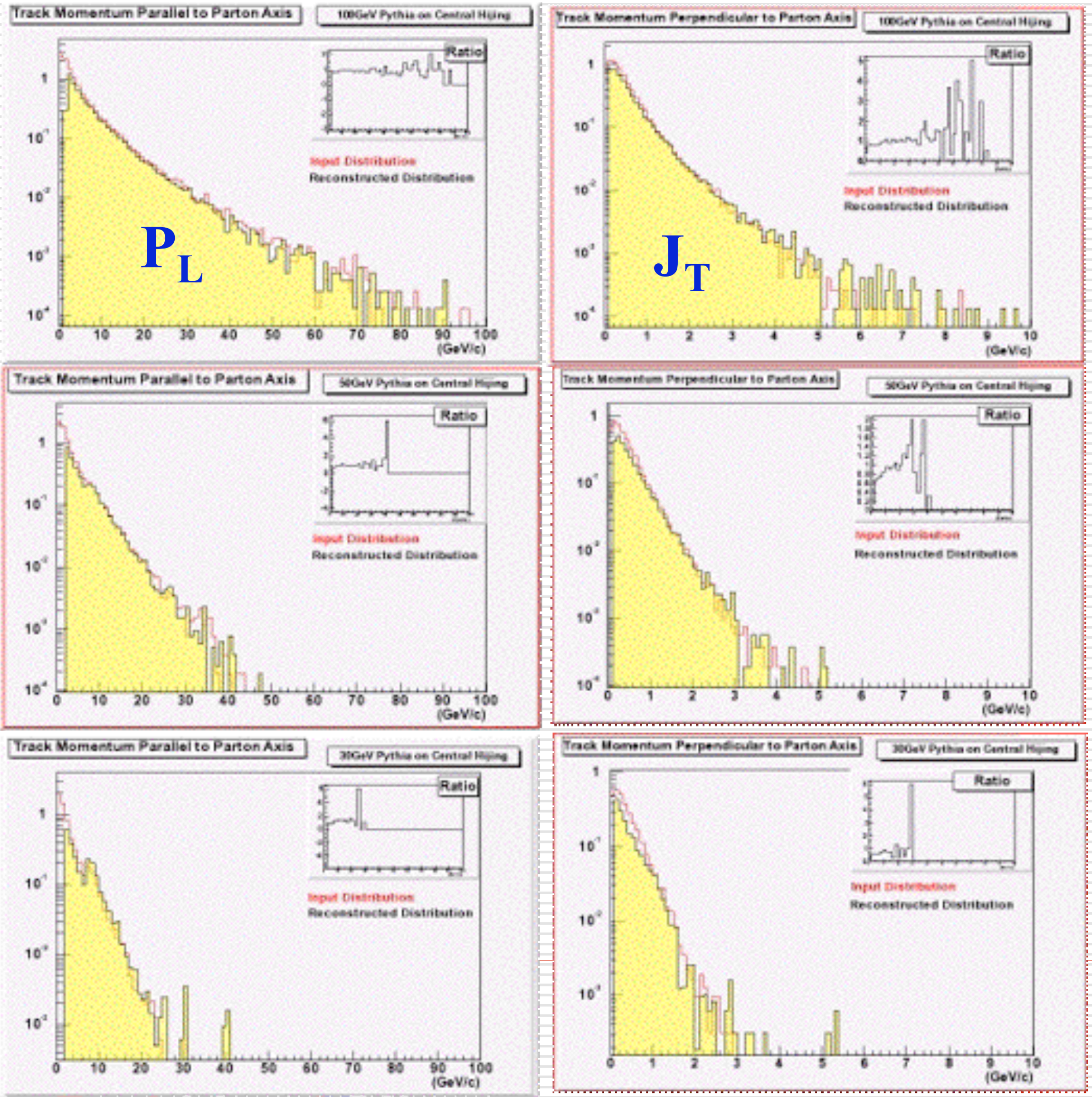
Fragmentation P_L and J_T Distributions

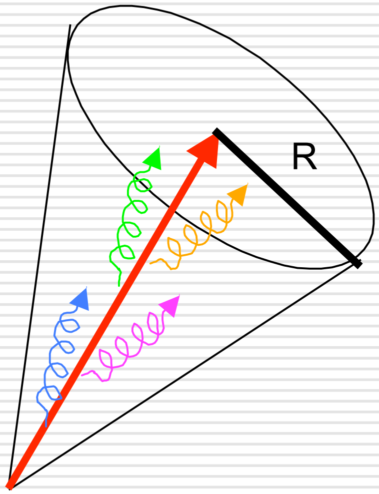
Input versus reconstructed output

100 GeV/c

50 GeV/c

30 GeV/c

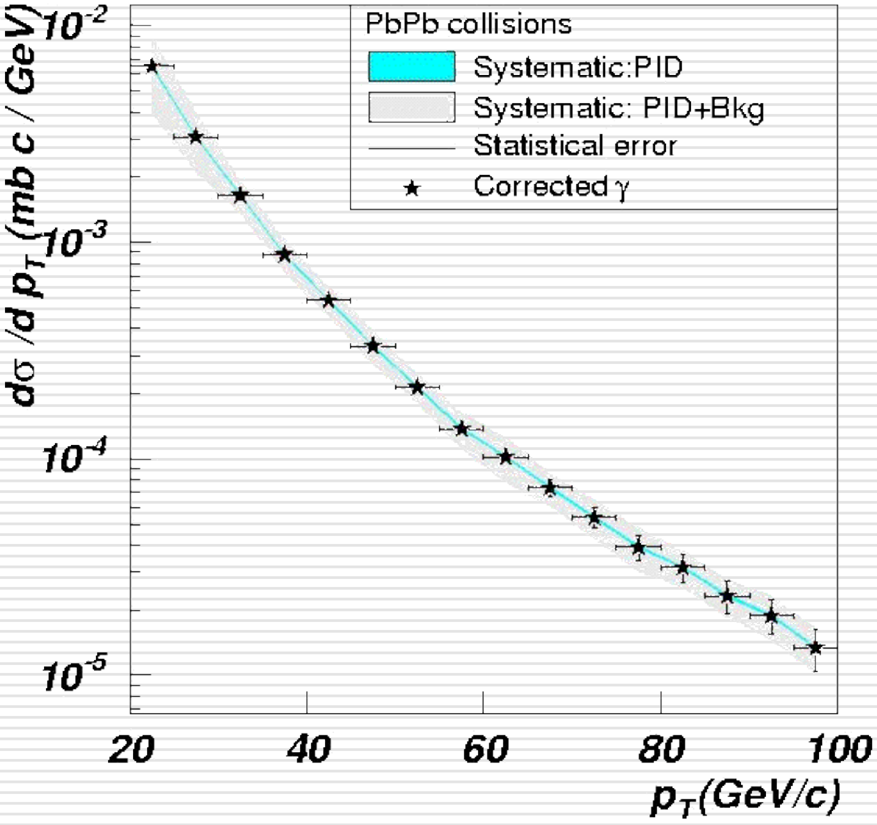


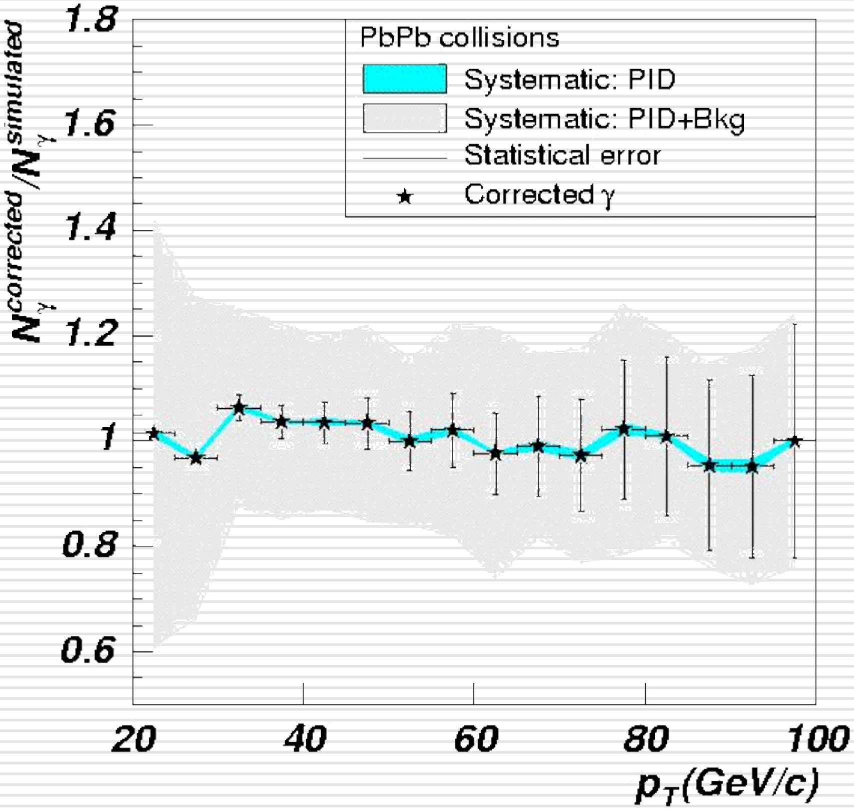


P_L -> Jet Quenching

J_T -> Transverse Heating

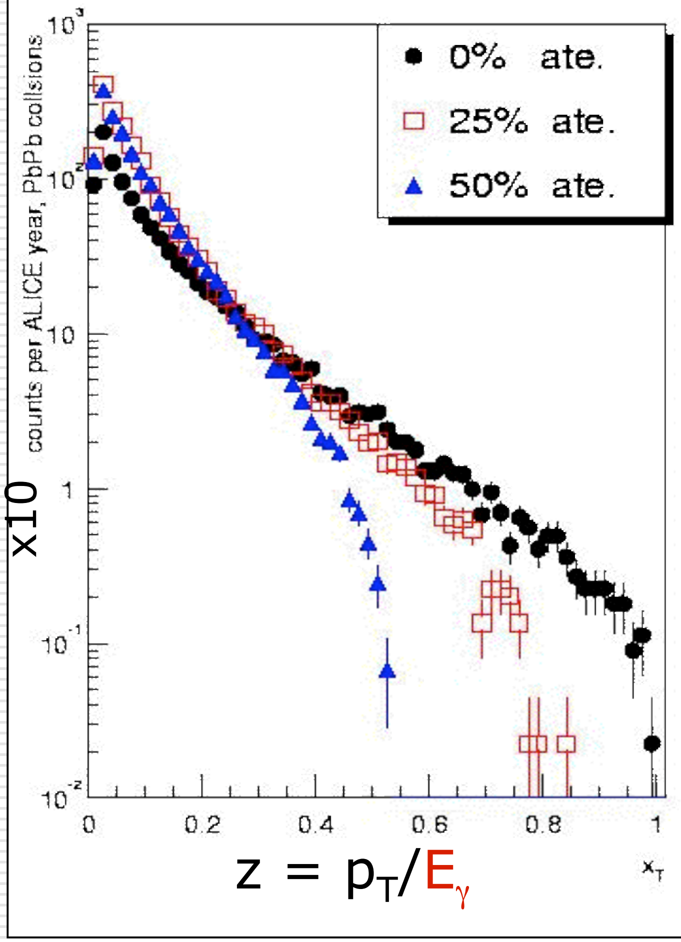
Direct Photons in Central PbPb in ALICE





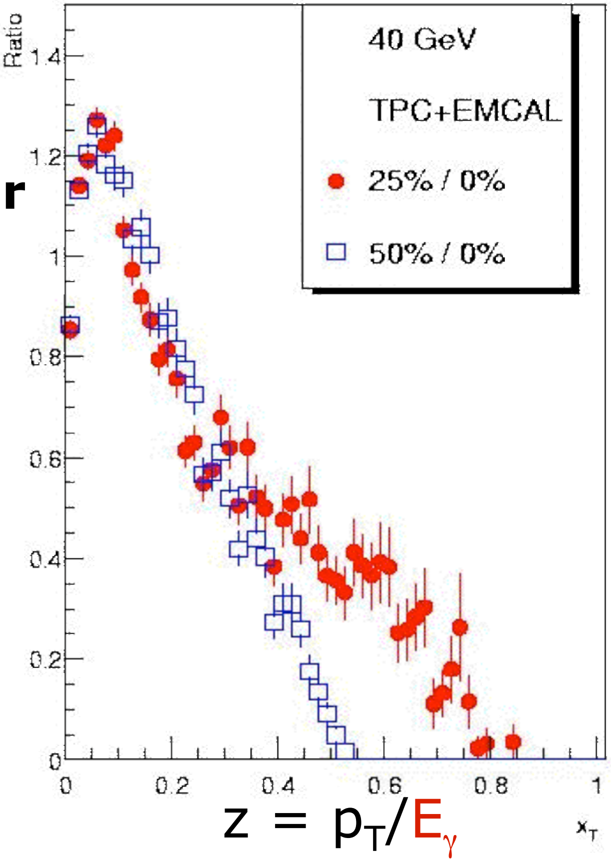
Exclusive jets in central PbPb: γ-Tagging

Direct measurement of jet energy: γ, γ*, Z^0



E_γ = 40 GeV

~ 50k events per LHC year



Conclusions

1. **LHC is a new environment with completely new plasma conditions which must be studied in parallel with RHIC. This is not a competition but rather a complimentary study of different but related systems. e.g. sQGP -> wQGP @ LHC??**
2. **Initial plasma conditions at LHC may be completely defined by classical QCD fields.**
3. **LHC is a new discovery frontier. ALICE is has ~ the combined capabilities of STAR + PHENIX at the RHIC-II upgrade level. ALICE is a survey experiment with sufficient acceptance to study all the high Q^2 probes. To avoid a key-hole approach to LHC physics, the US must participate in the ALICE experiment.**
4. **RHIC upgrades and LHC will run simultaneously, but…The physics is almost certainly different. Both RHIC and ALICE are needed to complete the picture of quark matter**

Questions from the Committee

8. *What are the most important and unique measurements which can only be performed by your experiment for central Pb+Pb and for pp collisions?*

- Charged Particle ID over wide p_t range
- Very low momentum charged particles
- R_{AA} and jet quenching and correlations with identified particles in intermediate P_T region
- Elliptic flow of identified particles (Cumulant expansion)
- Soft physics with identified particles (HBT, correlations, fluctuations, strangeness,…)
- Thermal photons
- γ + jet fragmentation function from E_γ ~10 GeV
- Quarkonium down to p_t ~0 from $\eta = 4$ to $\eta = -1$
- Open charm and beauty down to p_t ~0
- Quarkonium suppression measured relative to heavy quark production
- QCD in low p_t pp

Questions from the Committee

1. *Comment on the PID capabilities vs. p_t of your experiment*
   - ALICE is designed as a dedicated heavy-ion experiment to survey both expected and unexpected novel features from the bulk matter to the fragmentation of high p_t jets. As such, ALICE will measure the favor content and the phase-space distribution event by event
   - Long lived hadrons are identified through dE/dx (ITS, TPC), transition radiation (TRD), time of flight (TOF), Cerenkov (HMPID) :
     - π/K from 0.1 GeV/c to 40-50(2.3-3) GeV/c on statistic basis (at 3σ)
     - K/p from 0.1 GeV/c to 40(4-5) GeV/c
     - e/π from 1 GeV/c to 100 GeV/c

Questions from the Committee

1. *Comment on the PID capabilities vs. p_t of your experiment*
   - **Weak decay Hyperons, mesons and resonances** are identified via decay topology: Λ, Ξ, Ω, K_s, Λ^*, K^*, …
     - ~0.1 GeV/c to statistics limit (e.g. ~15-20 GeV/c for Λ in central events)
   - π^0 are identified through EM calorimetry (PHOS, EMCAL)
     - from ~2 GeV/c to ~30 GeV/c on statistic basis
     - from ~30 GeV/c to ~100 GeV/c on event by event basis
   - **Direct photons** are identified through EM calorimetry (PHOS, EMCAL)
     - from ~1 GeV/c to ~30 GeV/c on statistic basis
     - from ~30 GeV/c to ~100 GeV/c on event by event basis

Questions from the Committee

1. *Comment on the PID capabilities vs. p_t of your experiment*
   - **Open charm/beauty** are identified through hadronic or semi-leptonic decay and displaced vertex
     - ~0 GeV/c to statistics limit (e.g. ~15 GeV/c for D^0 and ~10 GeV/c for B^0 in central events)
   - **Quarkonia** bound states (J/ψ, ψ', Υ, Υ', Υ'') are identified through di-lepton decay (e^+e^- and $\mu^+\mu^-$)
     - from ~0 GeV/c to statistics limit

Questions from the Committee

2. *What are the capabilities for a soft physics program in your experiment ? Comment on the strengths and weaknesses*
    - ALICE is designed to fully explore all of the soft observables and thereby most fully diagnose the bulk properties of the matter formed at LHC and assess differences with the RHIC plasma. For example, ALICE will address flow via the cumulant expansion with identified particles, the RHIC HBT puzzle with identified particles, the apparent coalescence of constituent quarks into identified baryons and mesons, measure the thermal direct photon spectrum,etc. …
    - The strength of ALICE is its PID capabilities and its very low p_t cutoff.
    - The weakness of ALICE is its small acceptance in pseudo rapidity (i.e. equivalent to STAR and PHENIX)

Questions from the Committee

3. Which measurements used at SPS and RHIC to test the microscopic description of RHI collisions can your experiment contribute? What typical measurement cannot be done?

- ALICE has been deliberately designed to perform the full suite of measurements performed at both the SPS and RHIC.
- The exception is the low mass dilepton continuum which has been studied in CERES at the SPS and could potentially be performed in RHIC if a hadron blind detector is included in the upgrade mix.

Questions from the Committee

4. Over which p_t range can direct photon be measured in central Pb-Pb collisions?

- ALICE identifies direct photon from the thermal range well into the hard regime:
  - from ~1 GeV/c up to ~30 GeV/c on a statistic basis
  - from ~20 GeV/c to statistics limit (a few hundred GeV/c) on event by event basis
- ALICE identifies photon tagged jet events and the associated jet fragmentation function
  - from E_γ~20 GeV/c up to the statistics limit (E_γ~100 GeV/c)

Questions from the Committee

5. *Over which p_t range can J/ψ and Y be measured in central Pb-Pb collisions?*
    - ALICE measures quarkonia bound states from ~0 GeV/c up to the statistics limit:
        - ~20-25 GeV/c for J/ψ
        - ~10-15 GeV/c for Y

6. *Over which p_t range can jets be measured in central Pb-Pb collisions?*
    - ALICE measures jets from ~10 GeV/c up to the statistics limit ~200 GeV/c

Questions from the Committee

7. In what level of detail can the jet studies be performed? - e.g. fragmentation functions, f(z) and j_T, with/without PID?

- The excellent tracking capabilities of ALICE enables to measure the fragmentation function of identified particles down to very low z, with and without photon-tagging.
- The same statement holds for the measurement of transverse momentum distribution with respect to the jet axis, the jet fragments multiplicity and the jet width.

Questions from the Committee

9. *What fraction of the operating cost (data taking, recording, analyzing) for the PbPb operation of your experiment will the US be expected to cover?*
    - We will pay ALICE maintenance and operation (M&O) costs for non-member states. ALICE operating costs are amortized over the full 1000 person collaboration: 3.5 kSF (2005) to 10k SF (>2008) per Ph.D. collaborator per year
    - Estimated DOE annual cost: 440k SF ≈ 350k US$
    - Estimated NSF annual cost: 60k SF ≈ 50k US$

Questions from the Committee

10. *What are the estimated annual operating costs to the US? Comments on the numbers in some details.*
    - ALICE M&O Costs (question #9)
        - Estimated DOE annual cost: 440k SF ≈ 350k US$
        - Estimated NSF annual cost: 60k SF ≈ 50k US$
    - Computing costs - PDSF Model
        - 150k US$ personnel costs per year (1.5 FTE@PDSF)
    - ALICE-USA detector operations
        - 150k US$ personnel costs per year (1.5 FTE@CERN)

    - Significant of the above fraction may come from redirected base

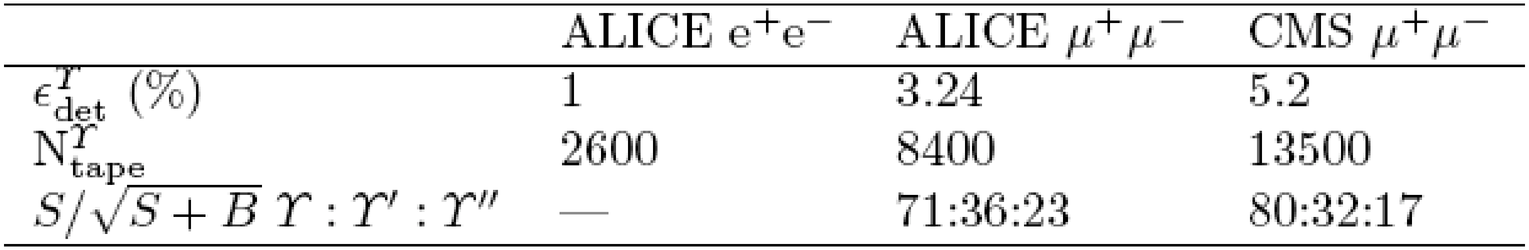
Questions from the Committee

11. Comment on the momentum resolution, angular resolution, S/N, backgrounds in the measurements of jets, J/ψ, Y,…

- Jets
  - p_t resolution: it is ~25%. This is completely dominated by non-instrumental effects. The need to operate with small jet cones to minimize influence of soft background results in increased out-of -cone fluctuations. The resolution is optimum for R~0.3
  - Angular resolution: $\Delta\eta$, $\Delta\phi \sim$ 0.1- 0.05R
  - Backgrounds: Soft hadrons in the jet cone common to all experiments. For R ~ 0.3, S/N >10 for leading hadron and S/N ~1 for integrated jet energy.

Questions from the Committee

11. *Comment on the momentum resolution, angular resolution, S/N, backgrounds in the measurements of jets, J/ψ, Y,…*
    - J/ψ and Y
        - ☐ Mass resolution: with electrons in the central region, integrated over the full p_t range is ~90 MeV/c^2 for Y with B=0.4T.
        - ☐ Mass resolution with muons in the forward region, integrated over the full p_t range is ~60 MeV/c^2 for J/ψ and ~90MeV/c^2 for Y.
        - ☐ Comparison of statistical significance on the Y measurement in ALICE and CMS



	ALICE e^+e^-	ALICE $\mu^+\mu^-$	CMS $\mu^+\mu^-$
$\epsilon^{\Upsilon}_{\mathrm{det}}$ (%)	1	3.24	5.2
$\mathrm{N}^{\Upsilon}_{\mathrm{tape}}$	2600	8400	13500
$S/\sqrt{S+B}$ $\Upsilon:\Upsilon':\Upsilon''$	—	71:36:23	80:32:17

Questions from the Committee

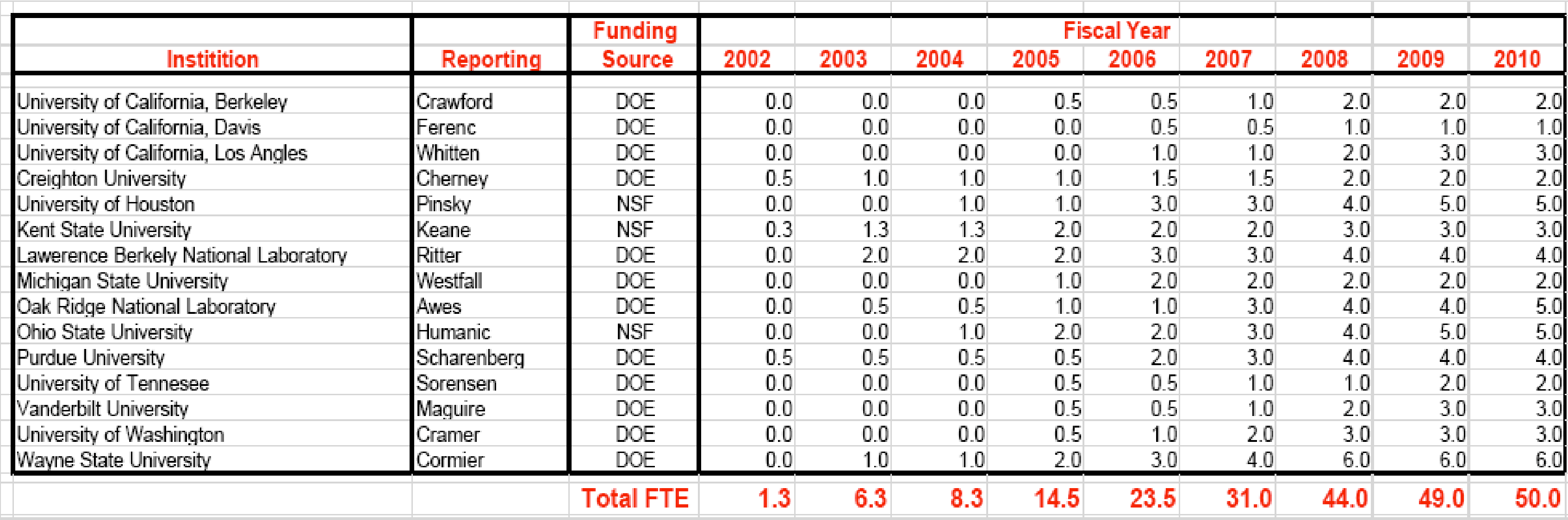
11. *Comment on the momentum resolution, angular resolution, S/N, backgrounds in the measurements of jets, J/ψ, Y,…*

- J/ψ and Y
  - ☐ Background: The irreducible background is physics dominated - heavy quark semi-leptonic decay. The background is an interesting physics signal. Non-physics backgrounds include decay muons in the forward spectrometer. The residual non physics background is known from a like sign subtraction. The significance $S/\sqrt{(S+B)}$ is 310 at J/ψ and 39 at Y
  - ☐ In the central spectrometer, the non-physics background is predominantly photon conversion electrons and π^{o} Dalitz decay electrons. The significance $S/\sqrt{(S+B)}$ is 230 at J/ψ and 15 at Y for p_t 2-5 GeV/c. J/ψ from B decay are identified through displaced vertex.

Questions from the Committee

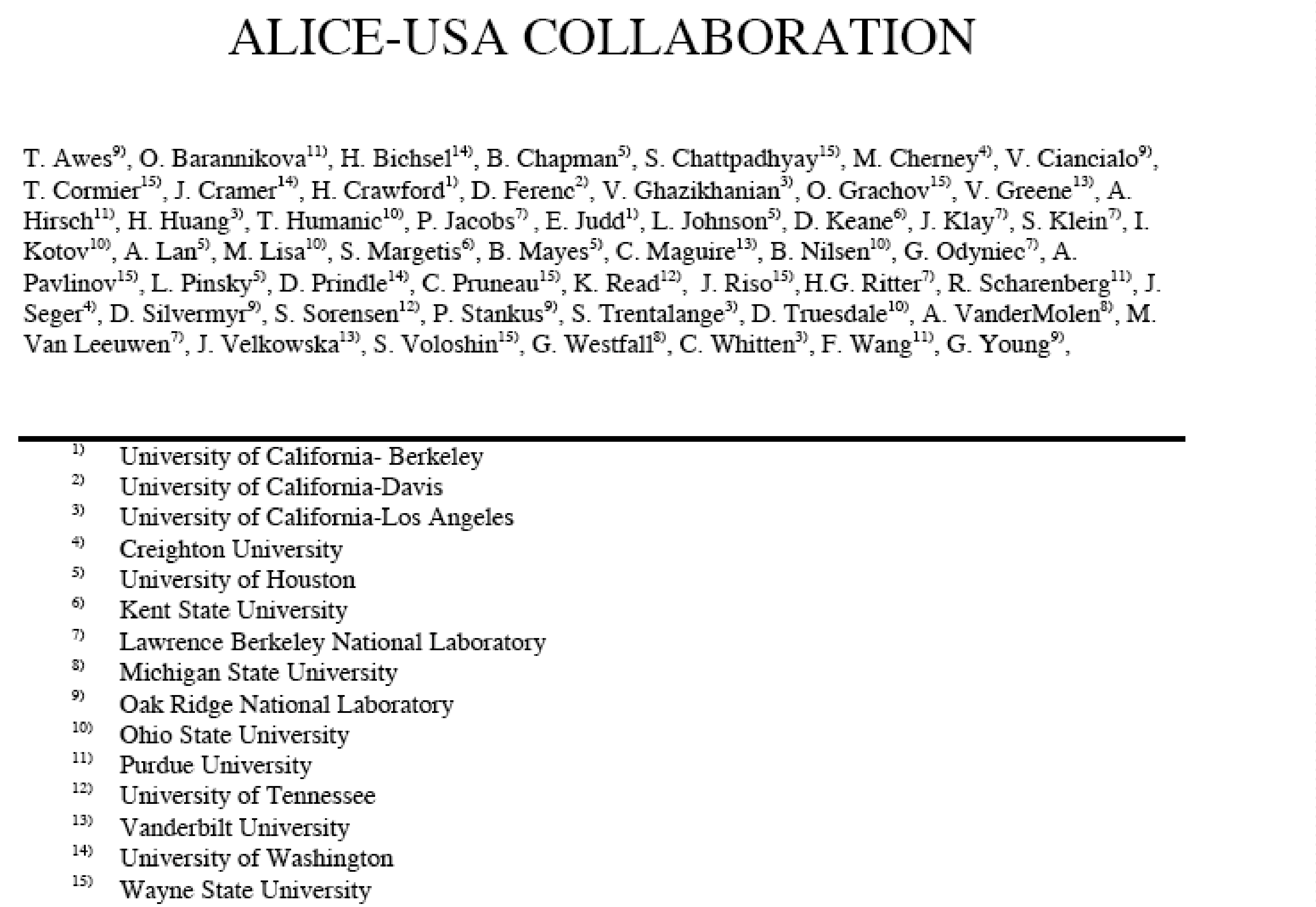
12. What is the number of US physicists who are currently committed to participate in this HI program at your detector?

- ALICE-USA manpower commitment: 50 PhD FTE's in steady state operation mostly from STAR and PHENIX



		Funding					Fiscal Year				
Institition	**Reporting**	**Source**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
University of California, Berkeley	Crawford	DOE	0.0	0.0	0.0	0.5	0.5	1.0	2.0	2.0	2.0
University of California, Davis	Ferenc	DOE	0.0	0.0	0.0	0.0	0.5	0.5	1.0	1.0	1.0
University of California, Los Angles	Whitten	DOE	0.0	0.0	0.0	0.0	1.0	1.0	2.0	3.0	3.0
Creighton University	Cherney	DOE	0.5	1.0	1.0	1.0	1.5	1.5	2.0	2.0	2.0
University of Houston	Pinsky	NSF	0.0	0.0	1.0	1.0	3.0	3.0	4.0	5.0	5.0
Kent State University	Keane	NSF	0.3	1.3	1.3	2.0	2.0	2.0	3.0	3.0	3.0
Lawerence Berkely National Laboratory	Ritter	DOE	0.0	2.0	2.0	2.0	3.0	3.0	4.0	4.0	4.0
Michigan State University	Westfall	DOE	0.0	0.0	0.0	1.0	2.0	2.0	2.0	2.0	2.0
Oak Ridge National Laboratory	Awes	DOE	0.0	0.5	0.5	1.0	1.0	3.0	4.0	4.0	5.0
Ohio State University	Humanic	NSF	0.0	0.0	1.0	2.0	2.0	3.0	4.0	5.0	5.0
Purdue University	Scharenberg	DOE	0.5	0.5	0.5	0.5	2.0	3.0	4.0	4.0	4.0
University of Tennesee	Sorensen	DOE	0.0	0.0	0.0	0.5	0.5	1.0	1.0	2.0	2.0
Vanderbilt University	Maguire	DOE	0.0	0.0	0.0	0.5	0.5	1.0	2.0	3.0	3.0
University of Washington	Cramer	DOE	0.0	0.0	0.0	0.5	1.0	2.0	3.0	3.0	3.0
Wayne State University	Cormier	DOE	0.0	1.0	1.0	2.0	3.0	4.0	6.0	6.0	6.0
		Total FTE	**1.3**	**6.3**	**8.3**	**14.5**	**23.5**	**31.0**	**44.0**	**49.0**	**50.0**

Questions from the Committee



ALICE-USA COLLABORATION

T. Awes[9], O. Barannikova[11], H. Bichsel[14], B. Chapman[5], S. Chattpadhyay[15], M. Cherney[4], V. Ciancialo[9], T. Cormier[15], J. Cramer[14], H. Crawford[1], D. Ferenc[2], V. Ghazikhanian[3], O. Grachov[15], V. Greene[13], A. Hirsch[11], H. Huang[3], T. Humanic[10], P. Jacobs[7], E. Judd[1], L. Johnson[5], D. Keane[6], J. Klay[7], S. Klein[7], I. Kotov[10], A. Lan[5], M. Lisa[10], S. Margetis[6], B. Mayes[5], C. Maguire[13], B. Nilsen[10], G. Odyniec[7], A. Pavlinov[15], L. Pinsky[5], D. Prindle[14], C. Pruneau[15], K. Read[12], J. Riso[15], H.G. Ritter[7], R. Scharenberg[11], J. Seger[4], D. Silvermyr[9], S. Sorensen[12], P. Stankus[9], S. Trentalange[3], D. Truesdale[10], A. VanderMolen[8], M. Van Leeuwen[7], J. Velkowska[13], S. Voloshin[15], G. Westfall[8], C. Whitten[3], F. Wang[11], G. Young[9],

---

[1] University of California- Berkeley
[2] University of California-Davis
[3] University of California-Los Angeles
[4] Creighton University
[5] University of Houston
[6] Kent State University
[7] Lawrence Berkeley National Laboratory
[8] Michigan State University
[9] Oak Ridge National Laboratory
[10] Ohio State University
[11] Purdue University
[12] University of Tennessee
[13] Vanderbilt University
[14] University of Washington
[15] Wayne State University

ALICE-USA EMCal “under construction” in the L3 Magnet