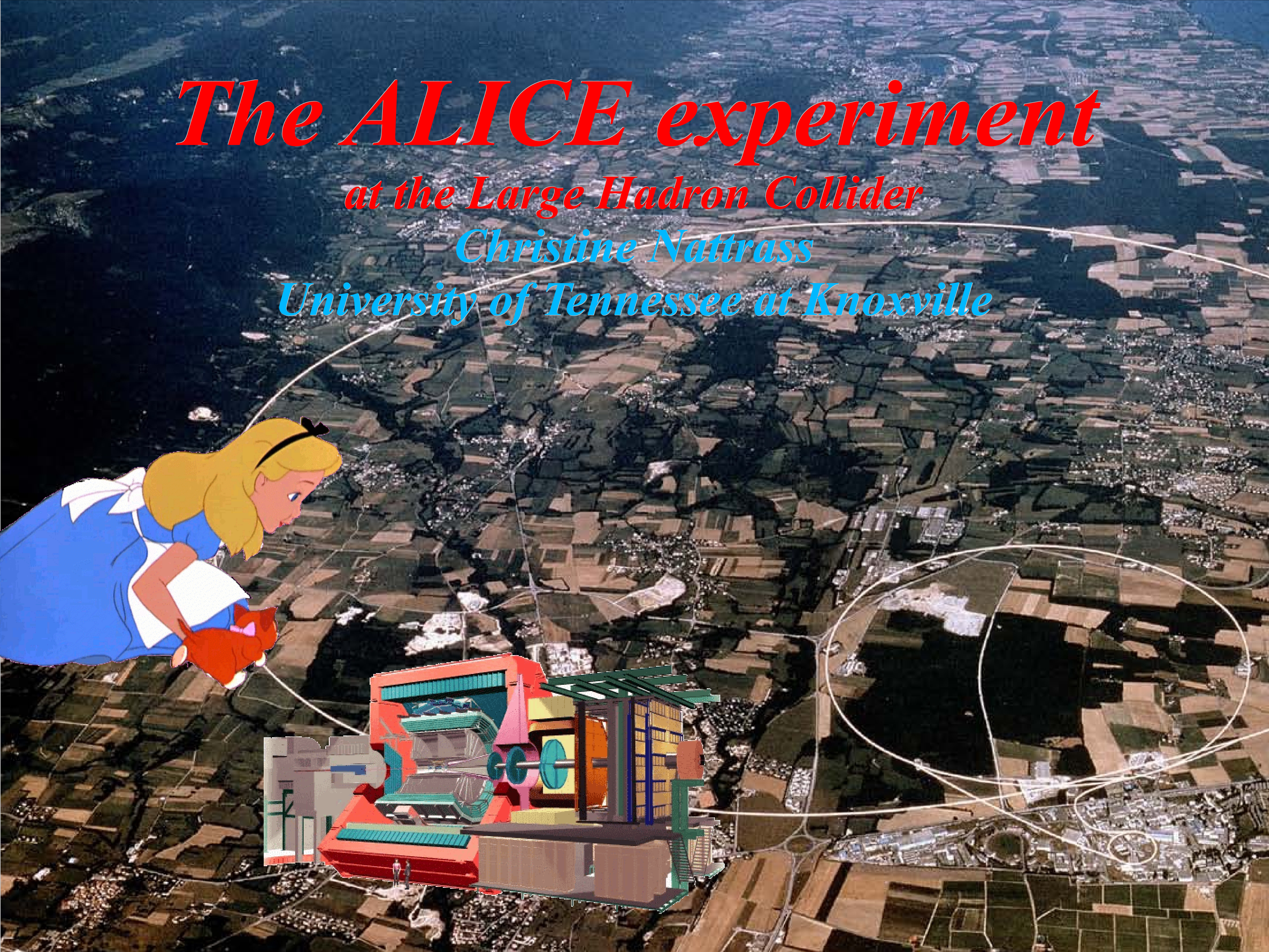
The ALICE experiment

at the Large Hadron Collider

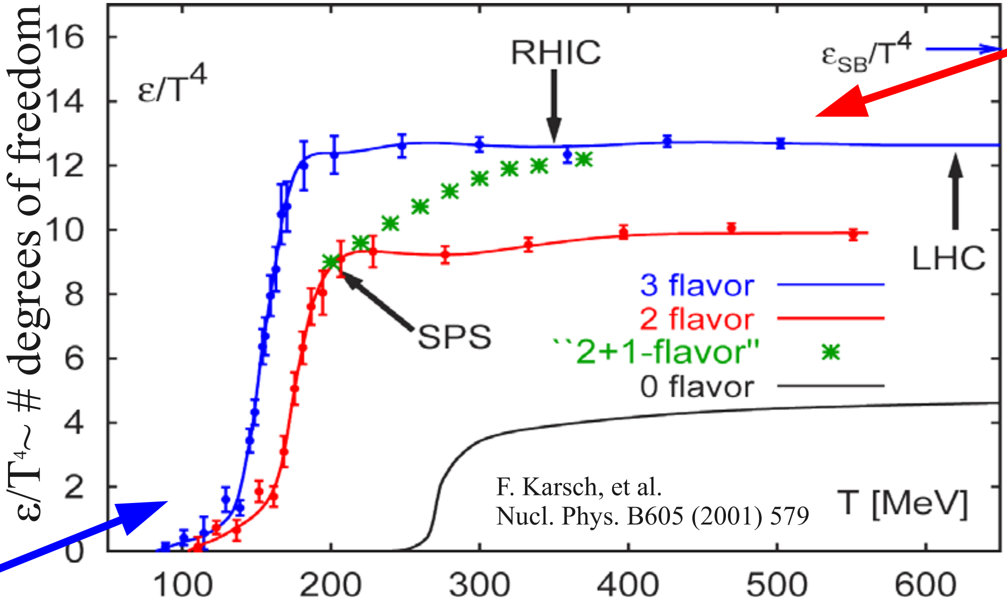
Christine Nattrass

University of Tennessee at Knoxville



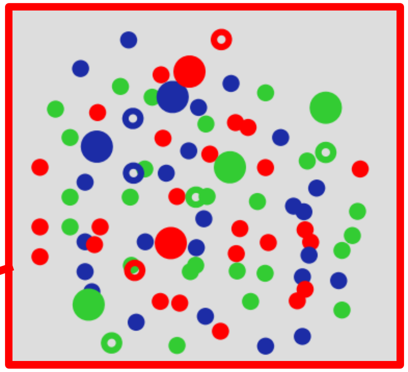
Exploring QCD at high temperatures

$T_c \sim 175 \pm 8$ MeV $\rightarrow \varepsilon_c \sim 0.3$ -1 GeV/fm^3

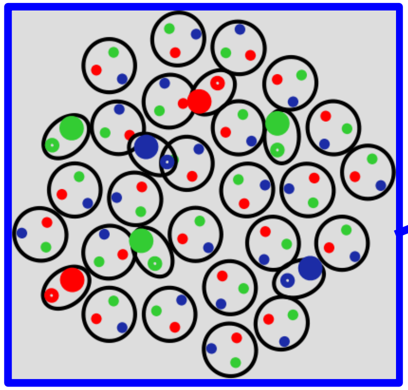


F. Karsch, et al.
Nucl. Phys. B605 (2001) 579

Quark-gluon plasma

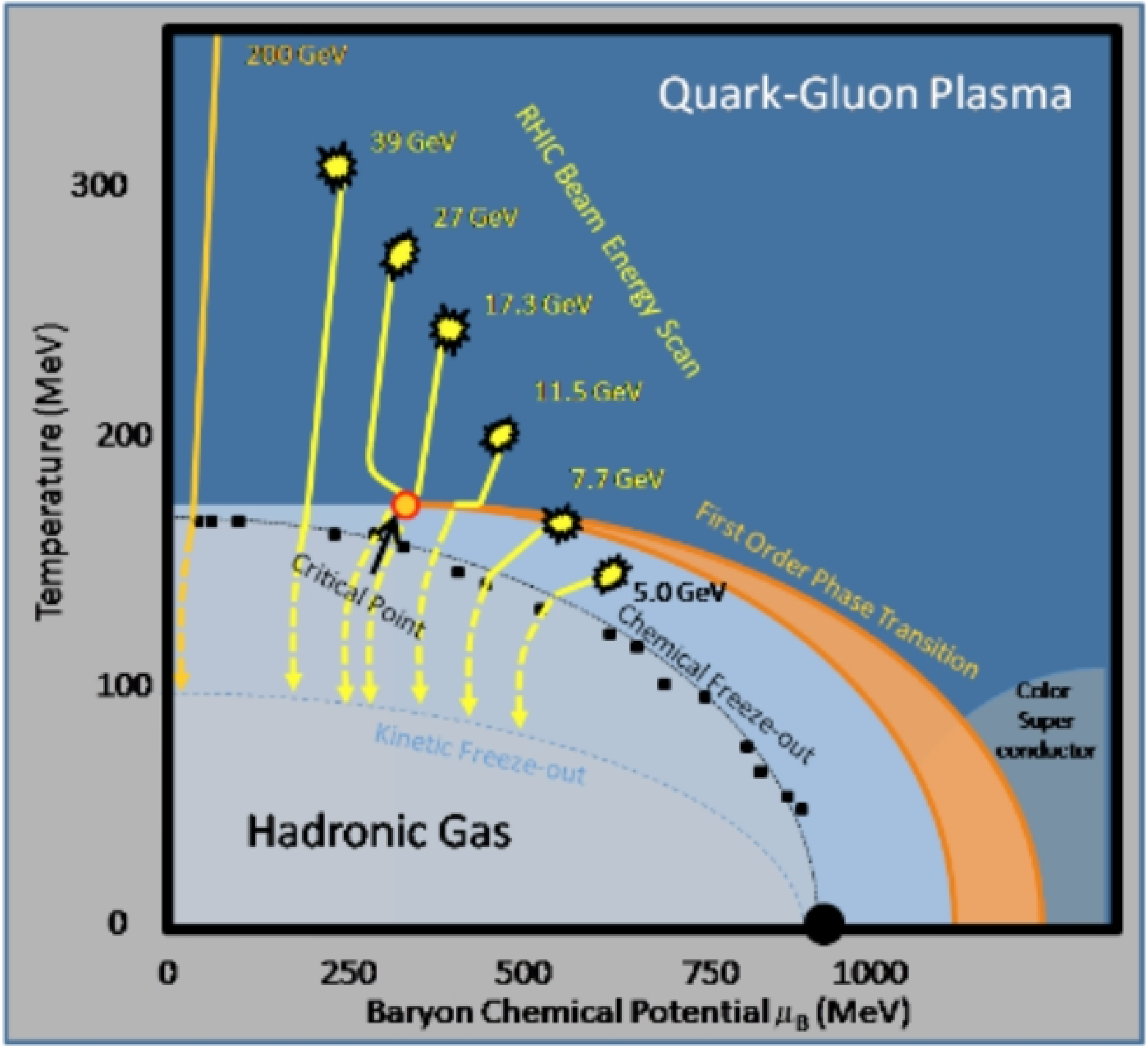


Deconfined - more degrees of freedom



Confined - fewer degrees of freedom

Phase diagram of nuclear matter



Simple Expectations for Heavy Ion Physics at LHC

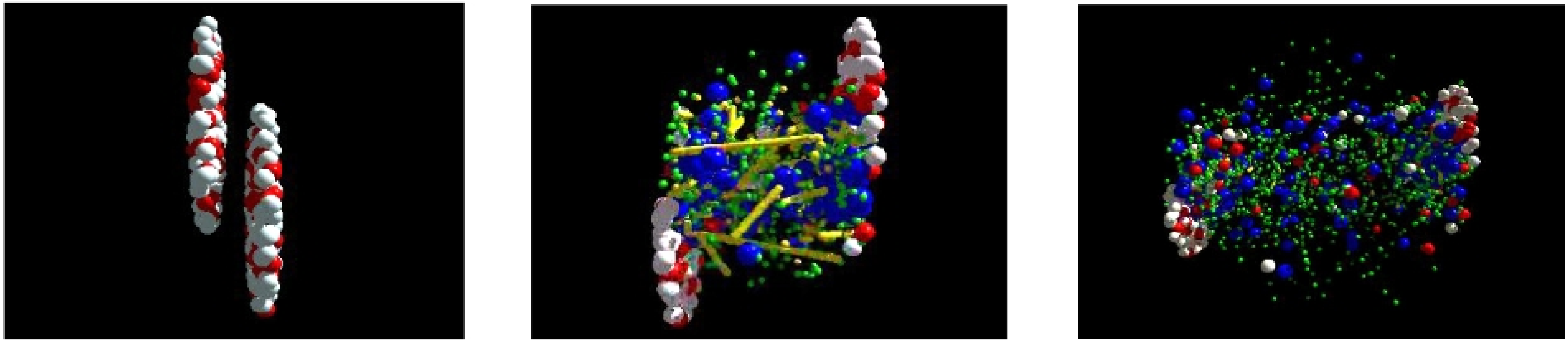
	SPS	**RHIC**	**LHC**	
$\sqrt{s_{NN}}$ (GeV)	17	200	5500	***28x***
$dN_{ch}/d\eta$	~700	~1200	~2000-8000	***2-7x***
T/T_c	1.1	1.9	3.0-4.2	***Hotter***
ε (GeV/fm^3)	3	5	15-60	***Denser***
τ_{QGP} (fm/c)	$\leq$2	2-4	>10	***Longer lived***

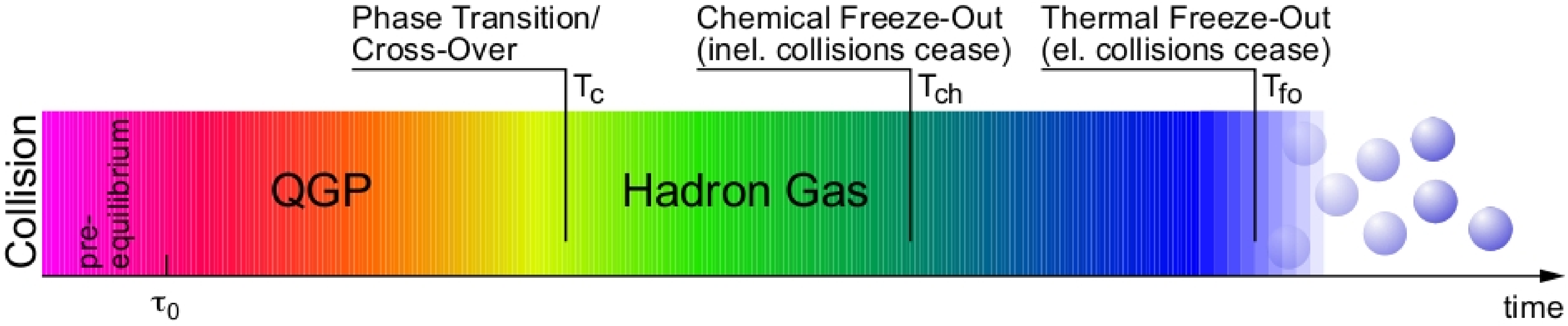
RHIC and LHC:

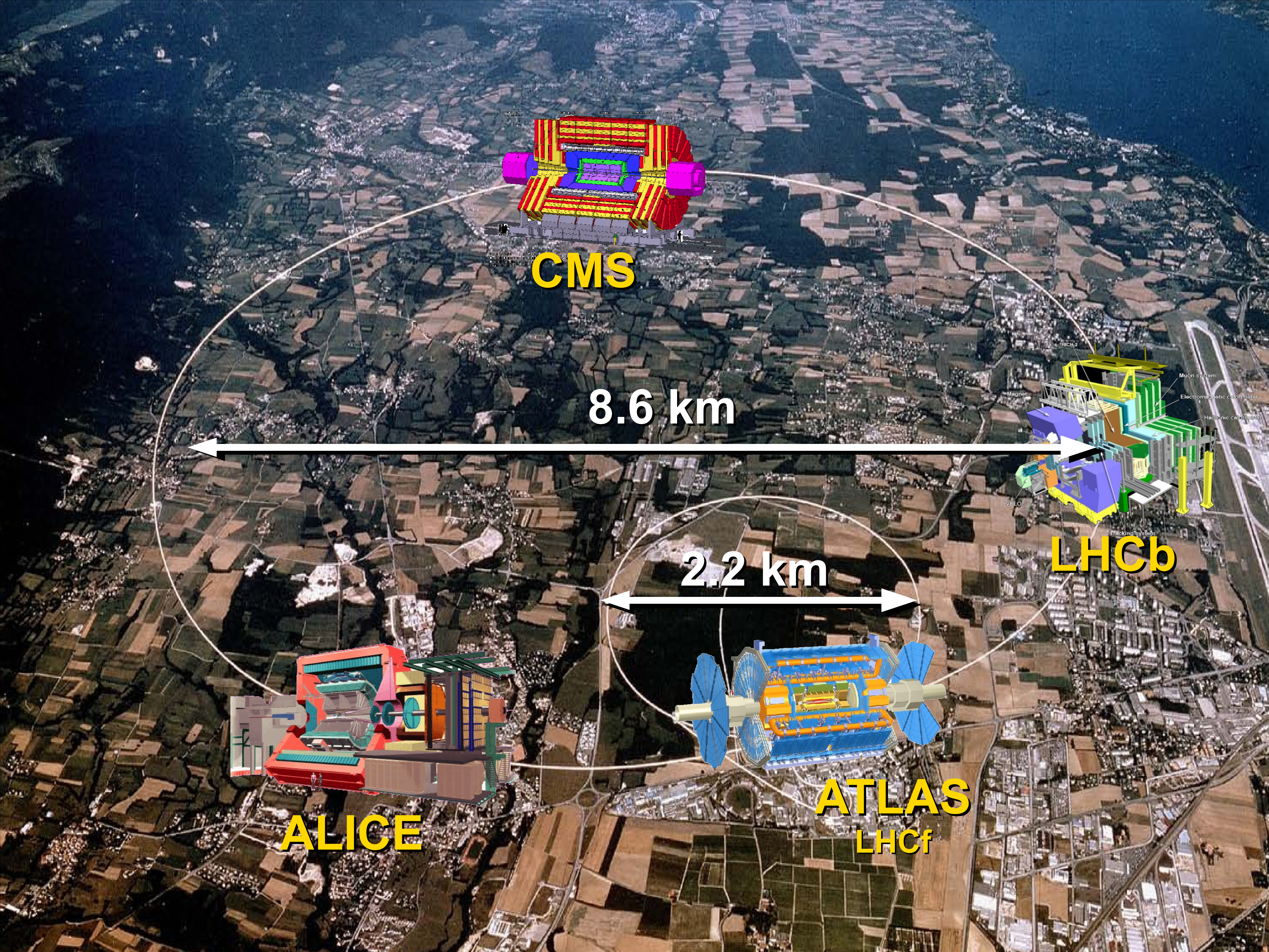
Cover 2 –3 decades of energy ($\sqrt{s_{NN}}$ ~ 20 GeV –5.5 TeV)

To discover the properties of hot QCD at T ~ 150 –600 MeV

The phase transition in the laboratory



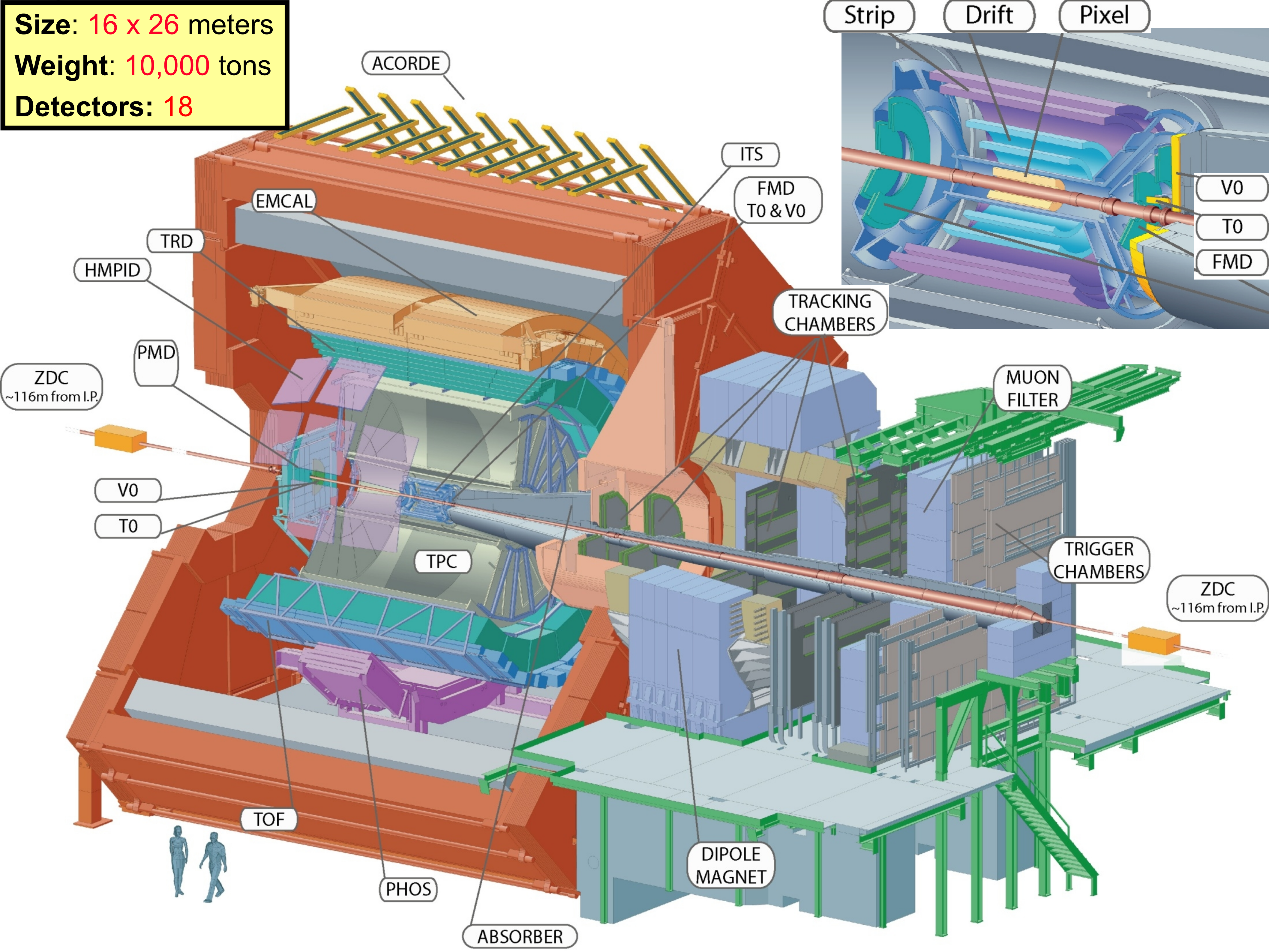



CMS
RICH-2
Muon system
Magnet
Electromagnetic calorimeter
Hadronic calorimeter
8.6 km
VELO
Tracking system
LHCb
2.2 km
ATLAS
LHCf
ALICE

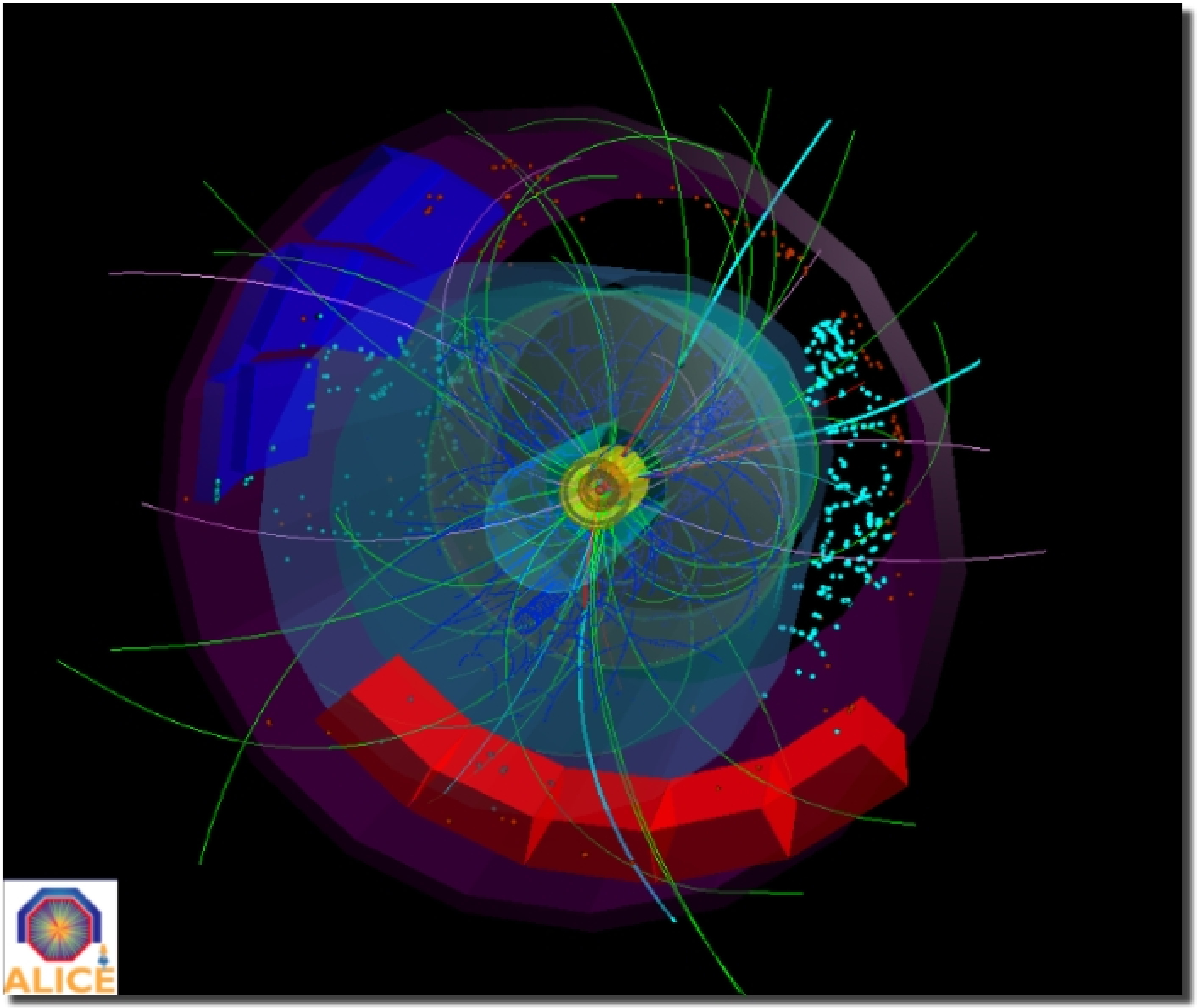
Size: 16 x 26 meters

Weight: 10,000 tons

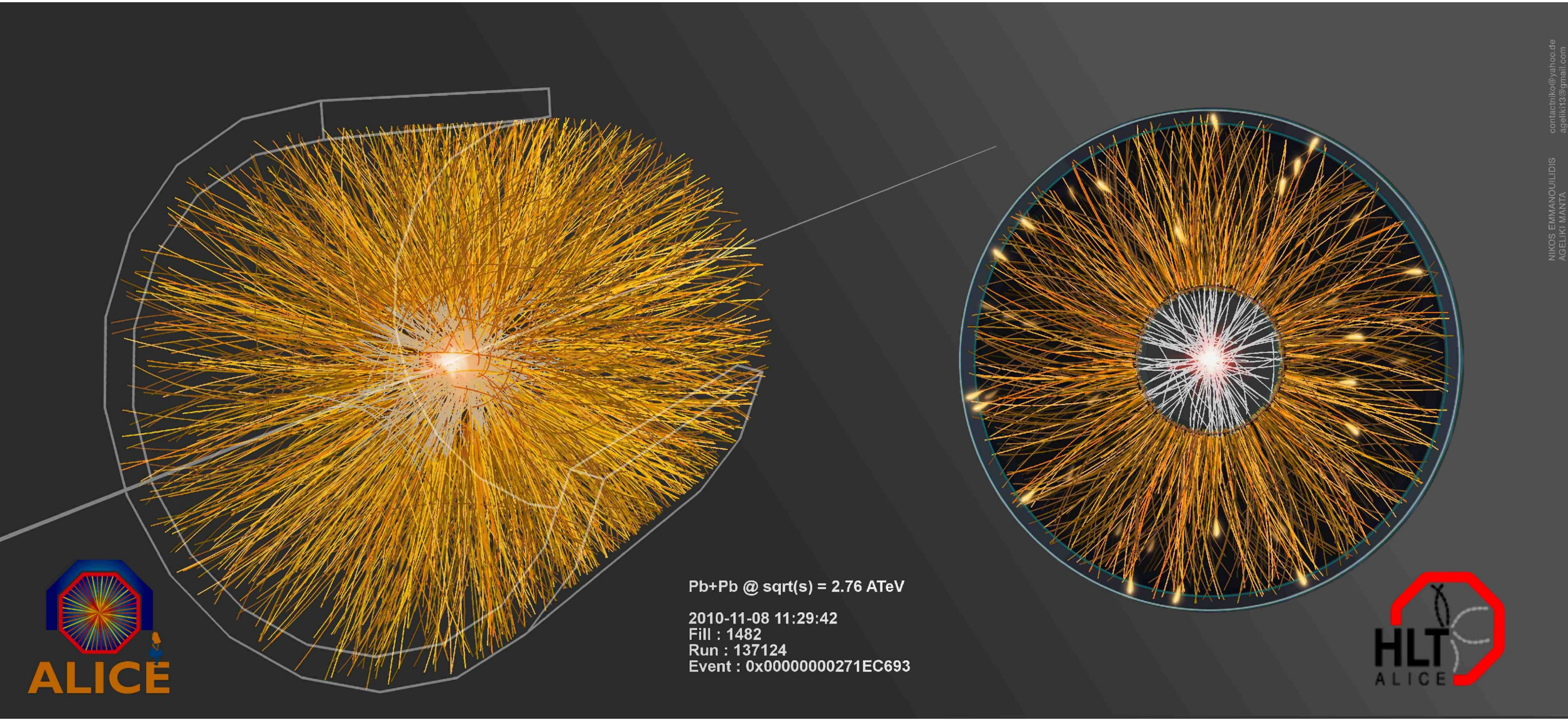
Detectors: 18



p+p collisions



Pb+Pb collisions

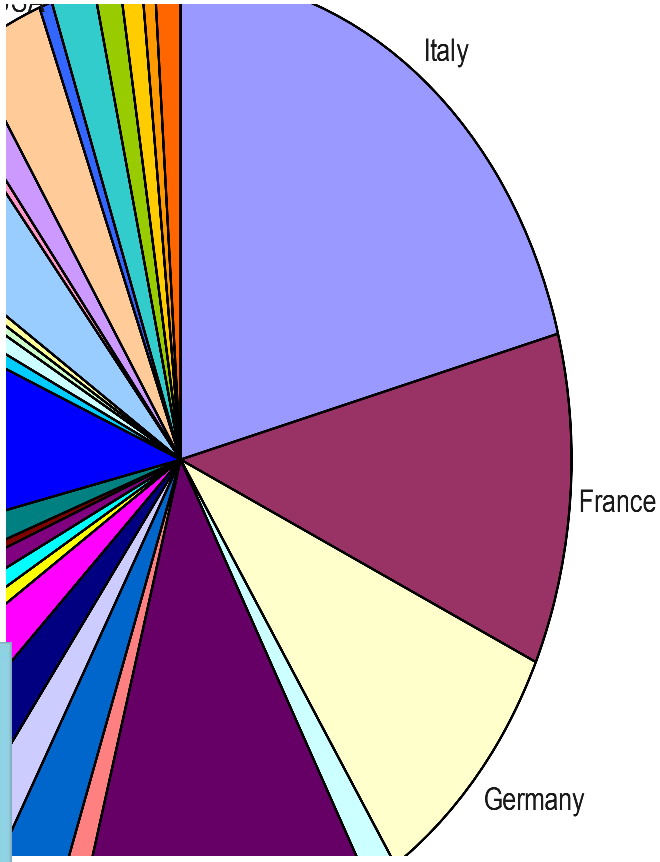


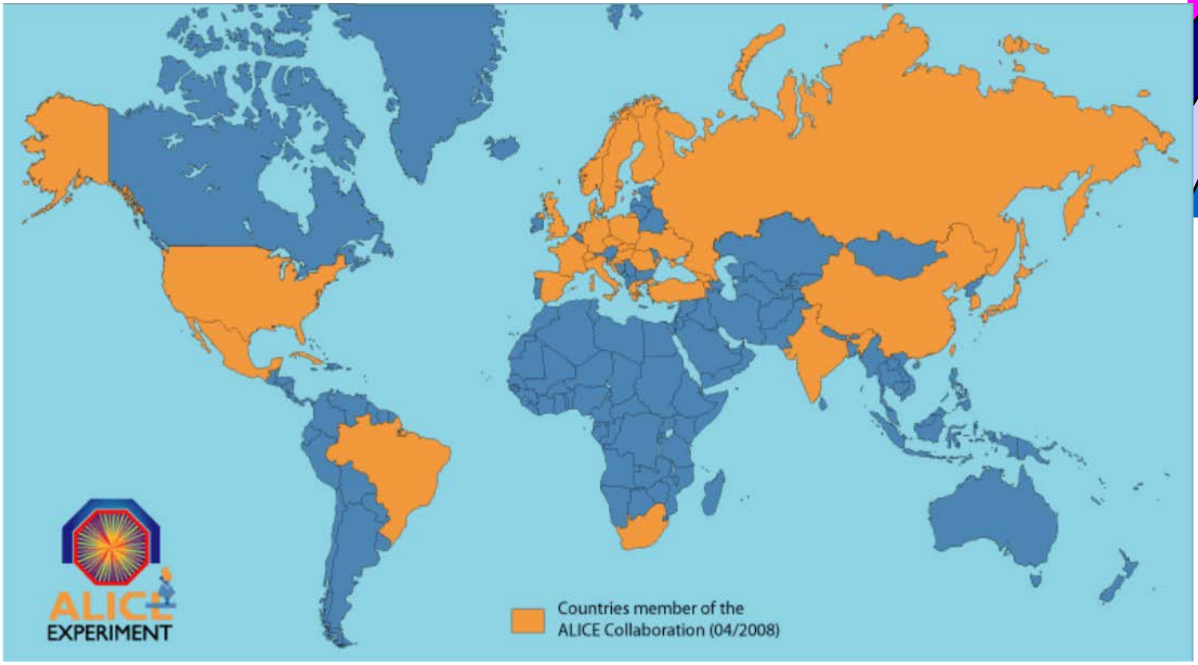
ALICE

- ~1000 members
- ~30 countries
- ~100 institutes

The ALICE Collaboration

~1000	Members 63% from CERN member states
~30	Countries
~100	Institutes
~150	MCHF capital cost (+magnet)



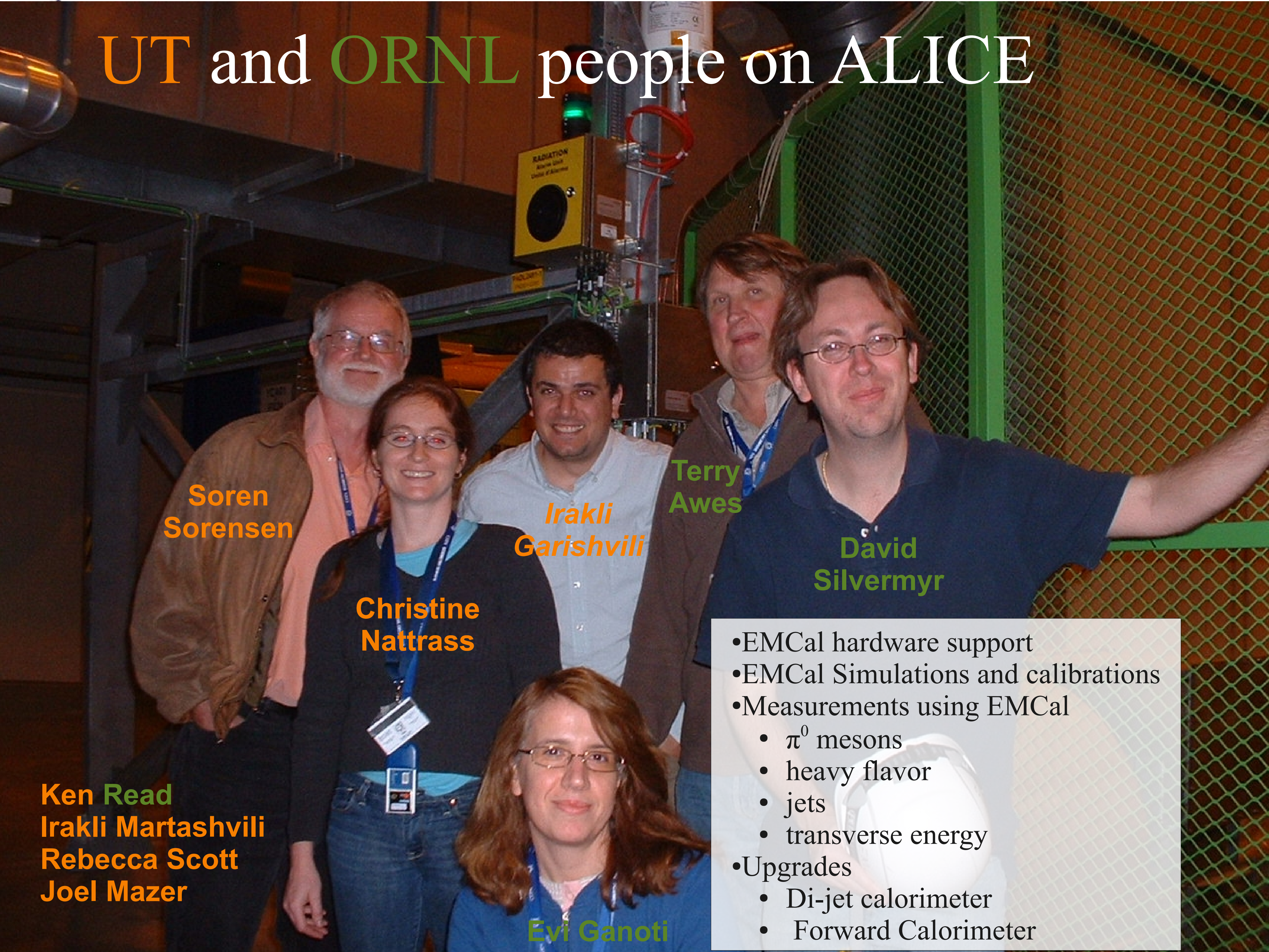


US ALICE

11 Institutions 53 members (inc. 12 grad. Students)

Cal. St. U. –San Luis Obispo, Creighton University, University of Houston, Lawrence Berkeley Nat. Lab, Lawrence Livermore Nat. Lab, Oak Ridge Nat. Lab, Ohio State University, Purdue University, University of Tennessee, Wayne State University, Yale University

UT and ORNL people on ALICE

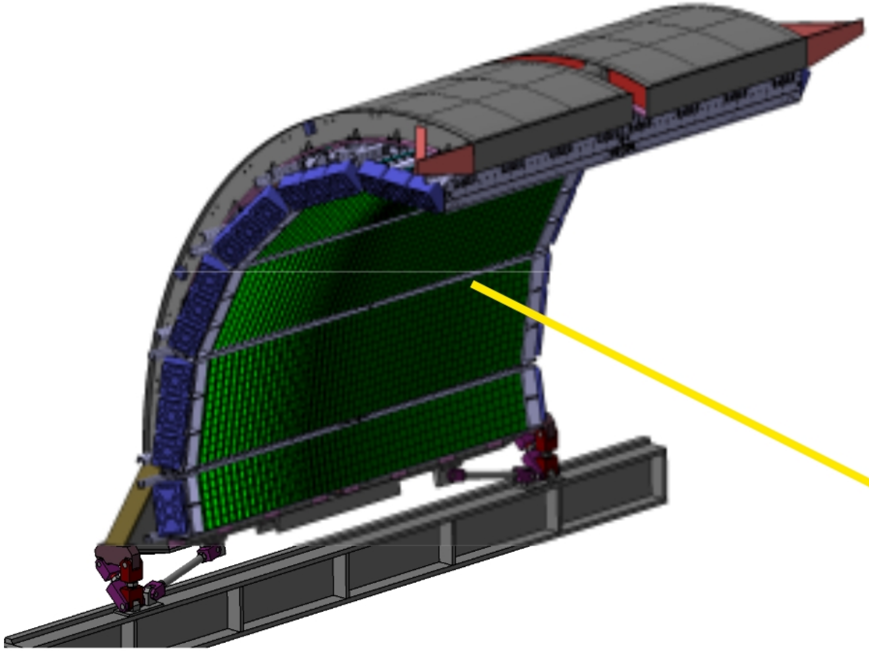


Ken Read
Irakli Martashvili
Rebecca Scott
Joel Mazer

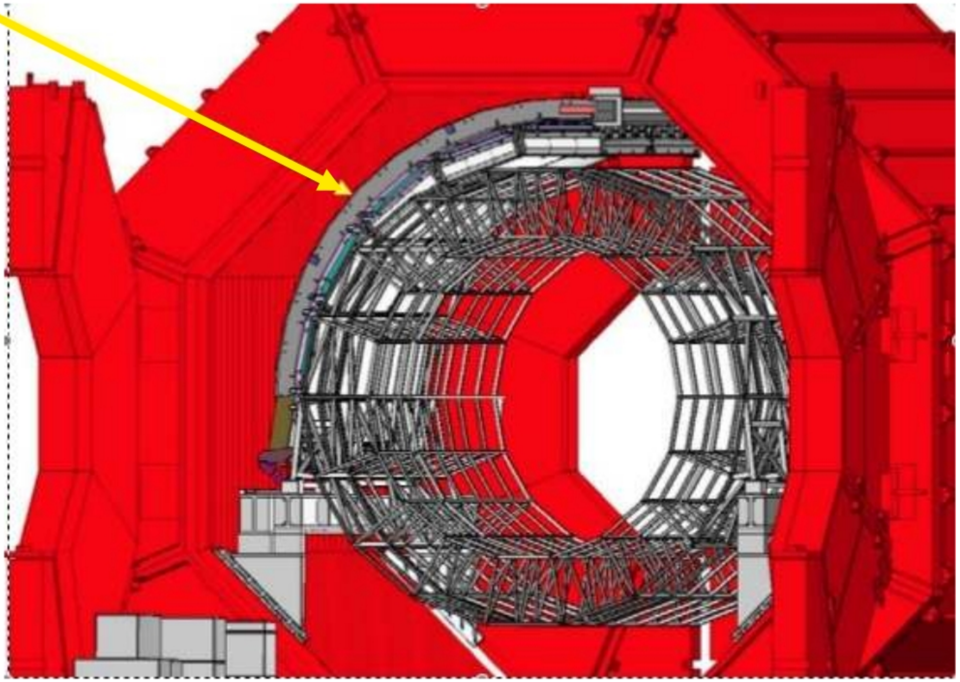
- EMCal hardware support
- EMCal Simulations and calibrations
- Measurements using EMCal
  - π^0 mesons
  - heavy flavor
  - jets
  - transverse energy
- Upgrades
  - Di-jet calorimeter
  - Forward Calorimeter

The Electromagnetic Calorimeter

EMCal



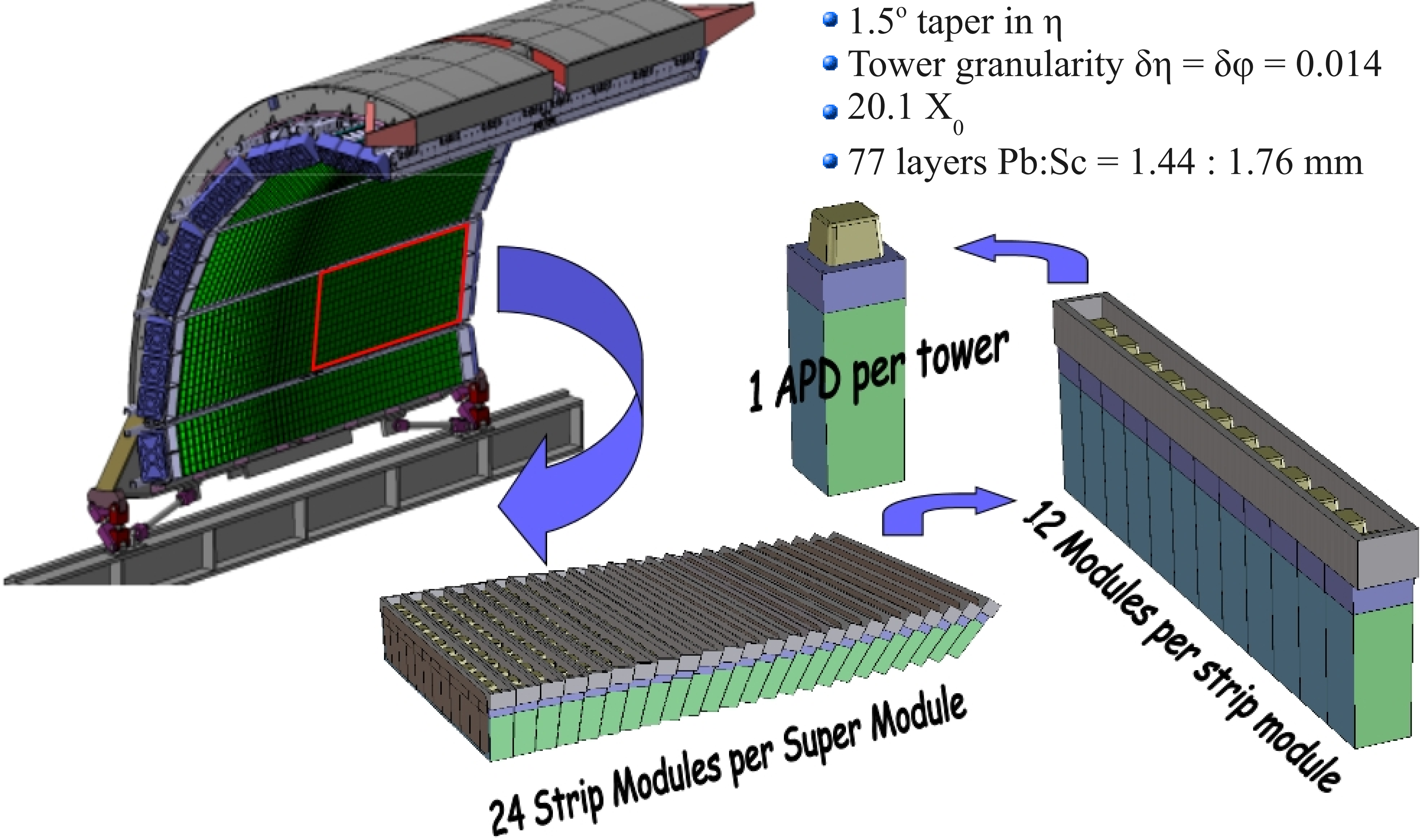
- EMCal: -0.7 <η< 0.7, 80°<φ< 120° in 2010 → 80°<φ< 180° in January 2011
  - – Ahead of schedule!
- DCAL: -0.7 <η< 0.7, 260°<φ< 320° in 2013

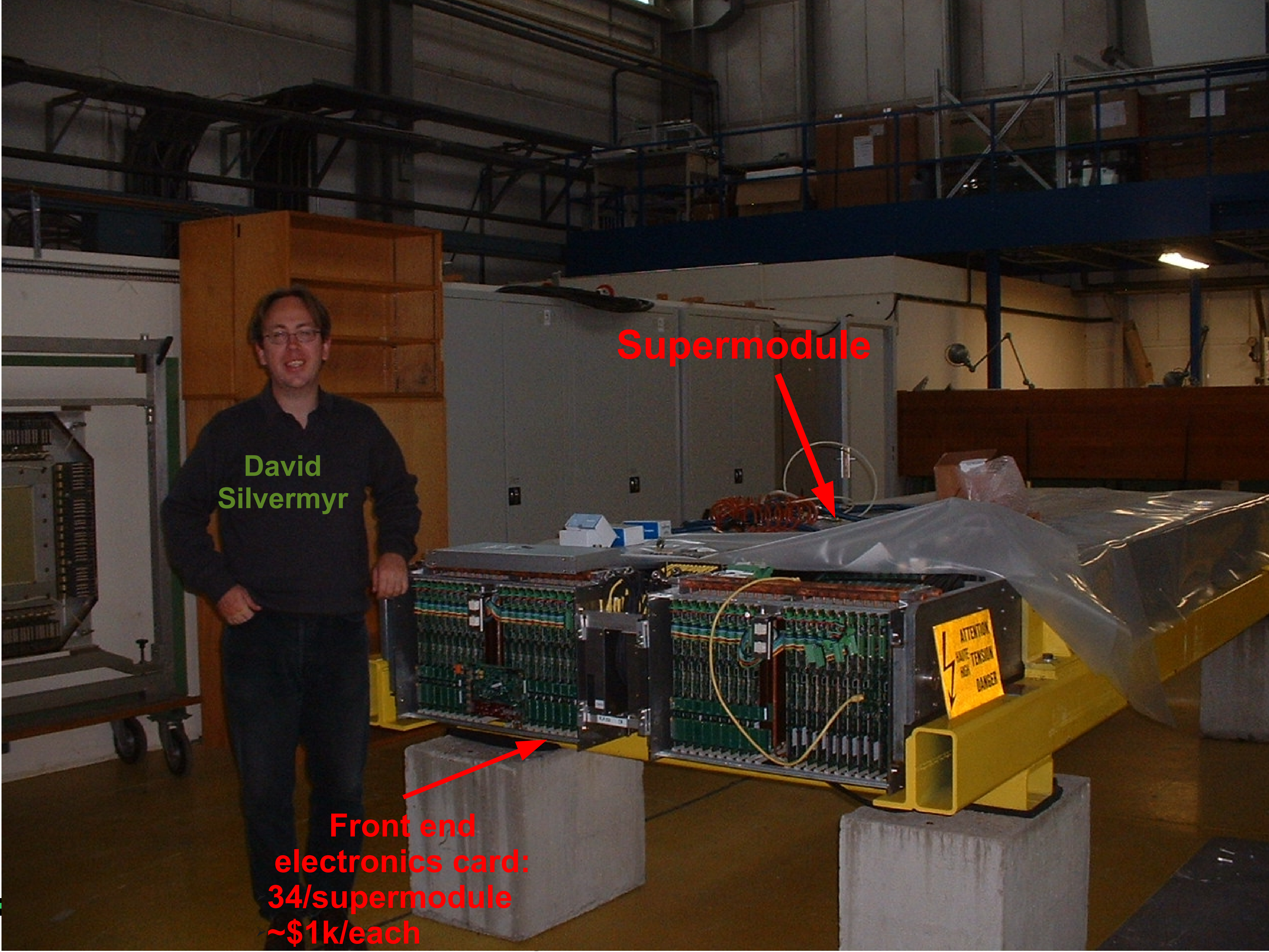


- Lead-scintillator sampling calorimeter
- 13 k towers
- Each tower ΔηXΔφ= 0.014 X 0.014
- Shashlik geometry
- Avalanche photototodiodes
- Δη=1.4,Δφ=107º
- σ(E)/E=0.12/√E + 0.02

EMCal Assembly

- 3072 identical modules, 2x2 towers
- 1.5° taper in η
- Tower granularity $\delta\eta = \delta\varphi = 0.014$
- 20.1 X_0
- 77 layers Pb:Sc = 1.44 : 1.76 mm





David Silvermyr

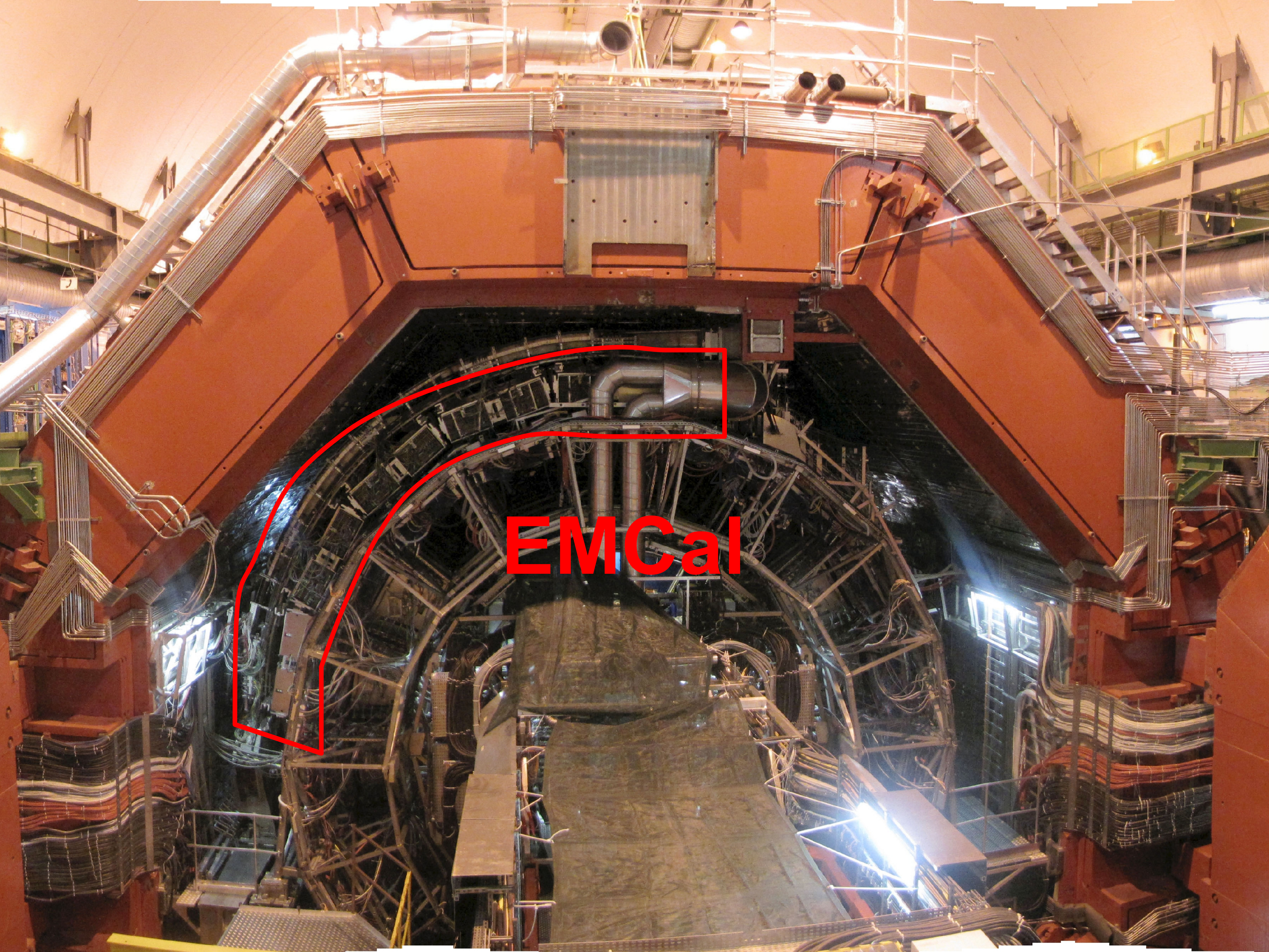
Supermodule

Front end electronics card: 34/supermodule ~$1k/each

Soren Sorensen

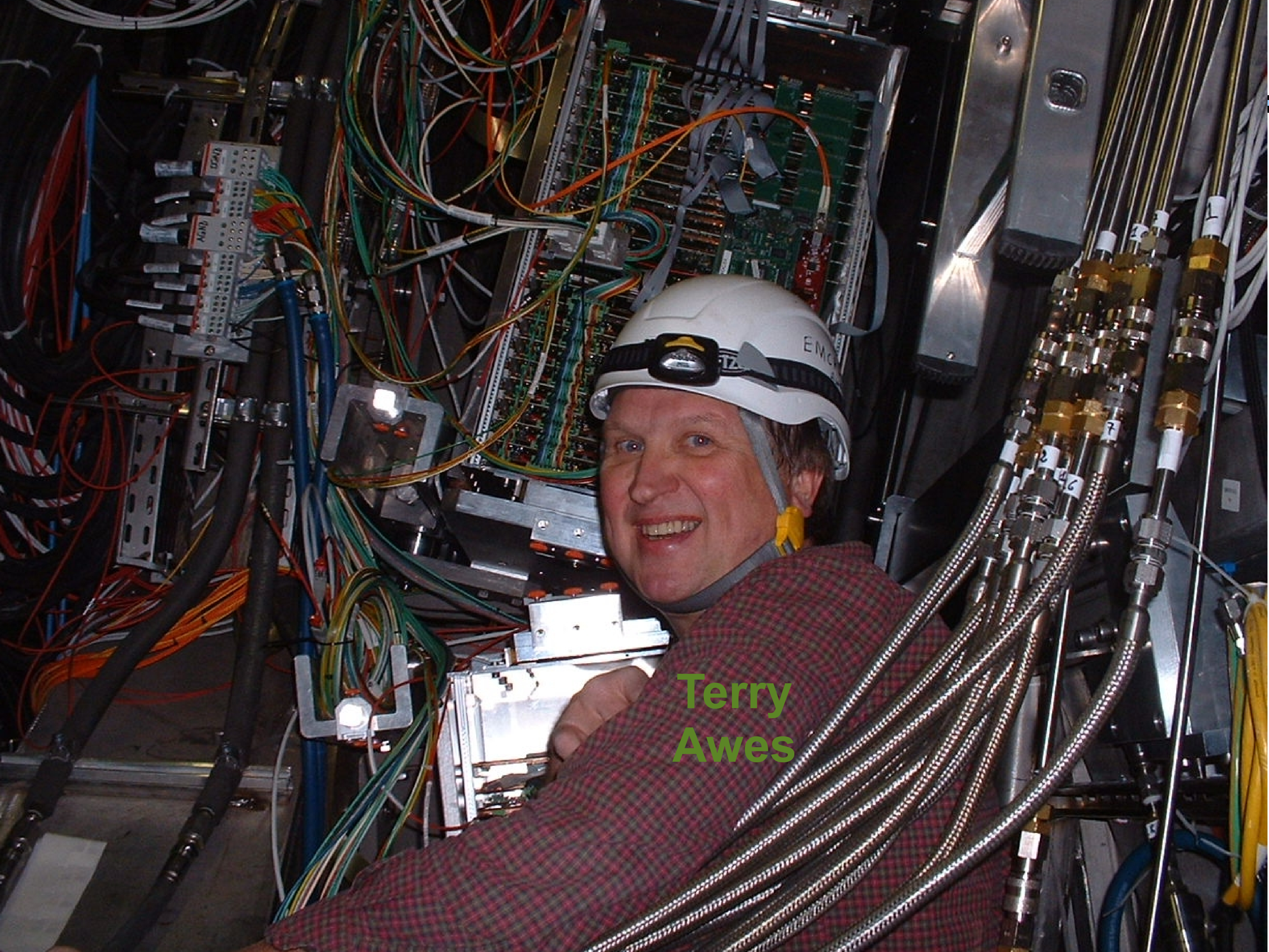
Soren Sorensen

Irakli Martashvili


EMCal

David Silvermyr

Michael Weber



Terry Awes


Evi Ganoti
Christine Nattrass

Christine
Nattrass

Physics goals

Capabilities

- Measurements of γ and π^0

π^0: Single particle energy loss
γ: Thermal photons → temperature

- Heavy flavor measurements
  - Charm and beauty quarks

Flavor-dependent energy loss

- Measurements of jets
  - Access to quark and gluon momenta

Partonic energy loss

Main differences between ATLAS and CMS

- Low momentum tracking (p_T>100 MeV/c vs p_T>900 MeV/c)
- Particle identification

Hard probe rates in ALICE

ALICE hard physics capabilities:

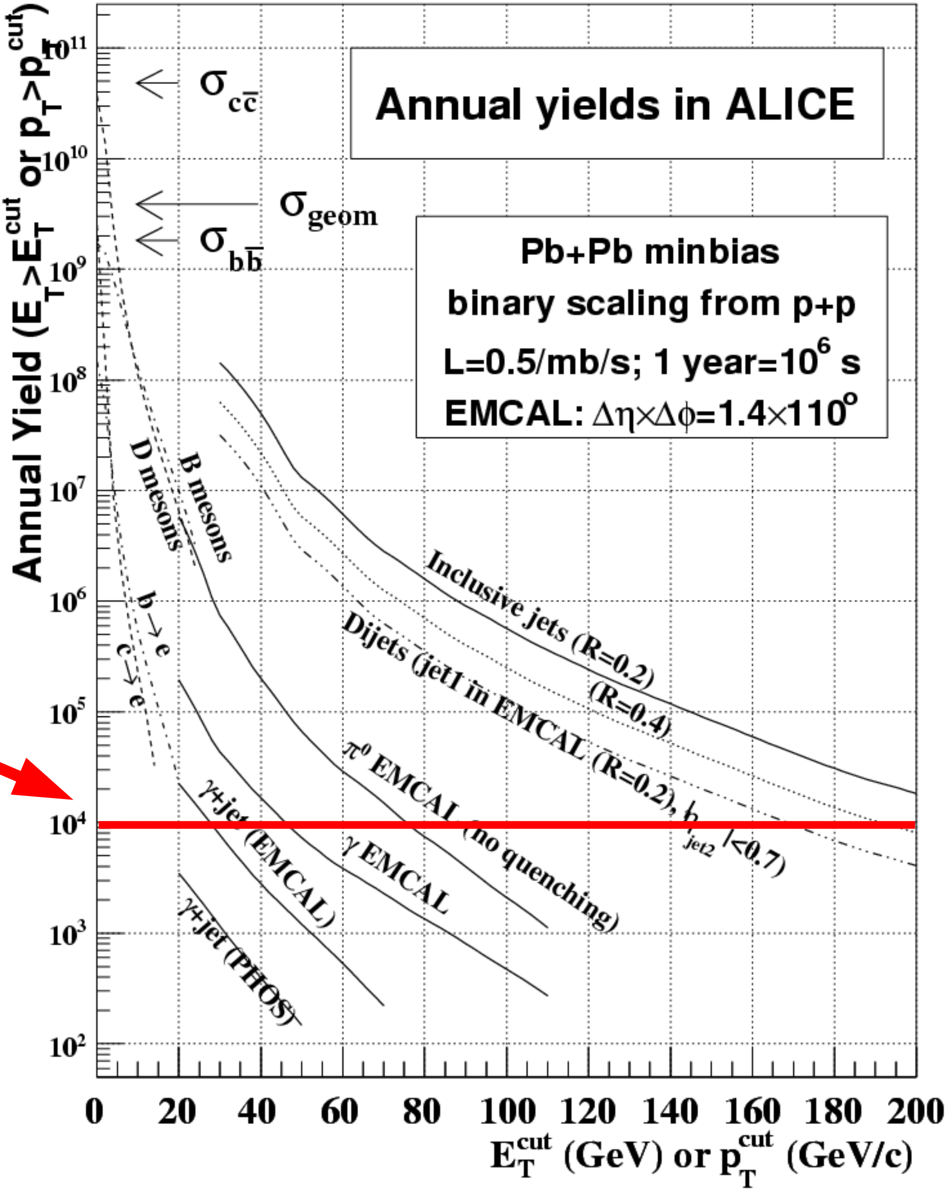
- Electron/hadron discrimination (TRD, EMCal)
- μ measurements(forward muon arm)
- Good γ/π^0 discrimination (EMCal, PHOS)
- Fast trigger on jets(EMCal)

Hard Probes statistics in ALICE:

*10^4/year minbias Pb+Pb at nominal luminosity**

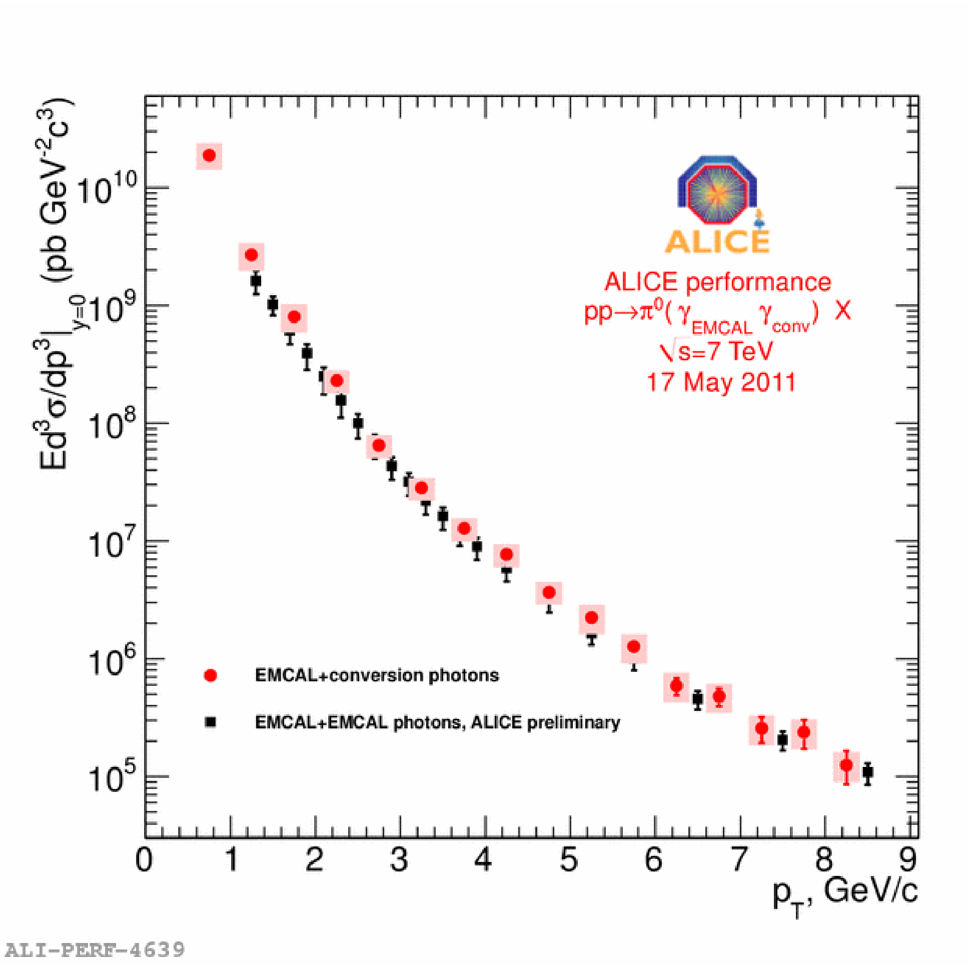
- Inclusive jets: $E_T \sim 200$ GeV
- Dijets: $E_T \sim 170$ GeV
- π^0: $p_T \sim 75$ GeV/c
- Inclusive γ: $p_T \sim 45$ GeV/c
- Inclusive e: $p_T \sim 30$ GeV/c

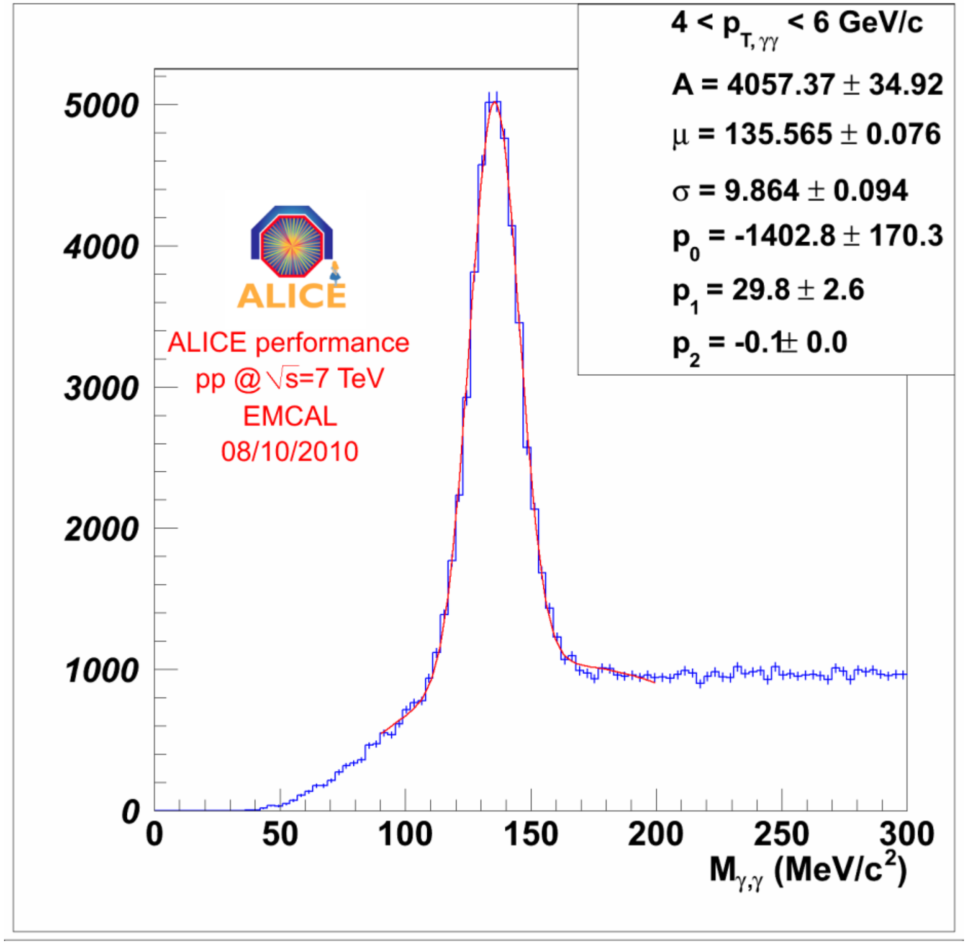
*One year of running = one month of Pb+Pb collisions



Single particle measurements

π^0 measurements

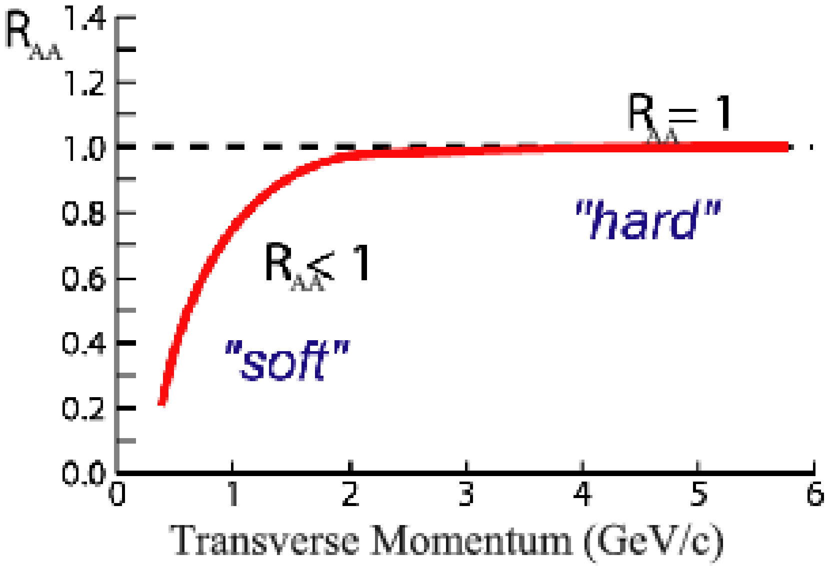




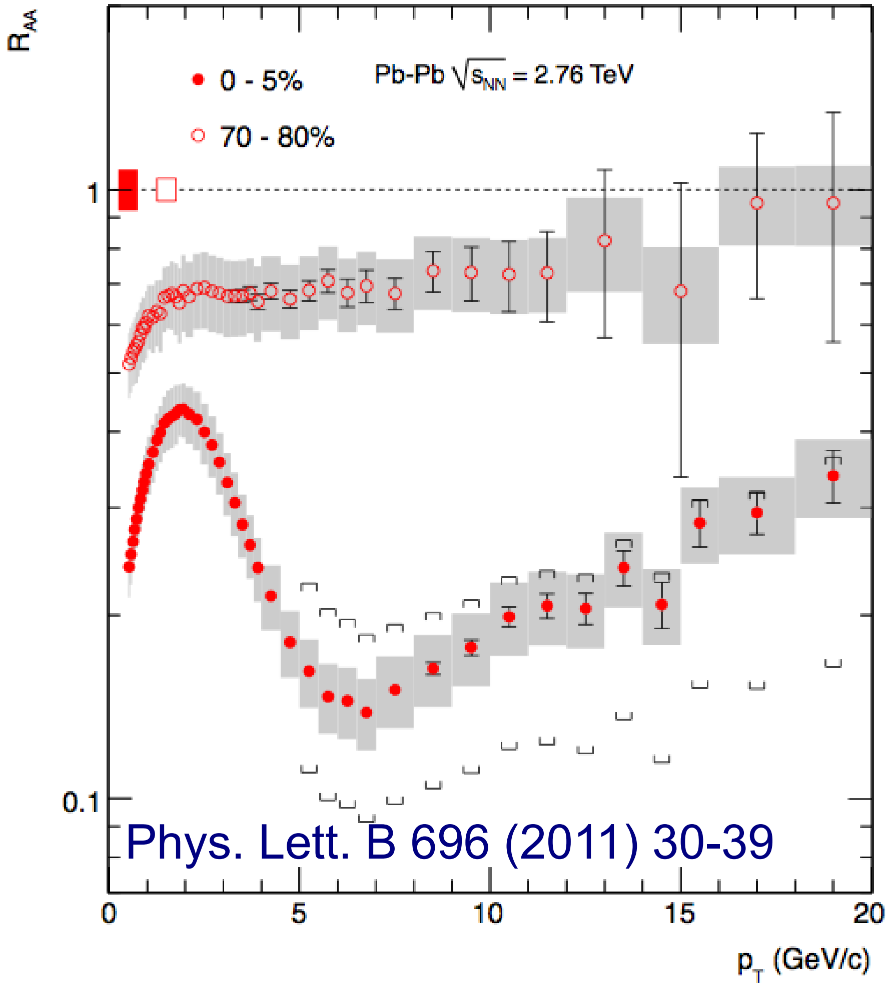
Single particles

- Measure spectra of hadrons and compare to those in p+p collisions or peripheral A+A collisions
- If high-p_T hadrons are suppressed, this is evidence of jet quenching
- Assumption: sufficiently high-p_T hadrons mostly come from jets
- Unmodified spectra:

$$R_{AA} = \frac{d^2N_{AA}/dp_T d\eta}{T_{AA} d^2\sigma^{pp}/dp_T d\eta}$$



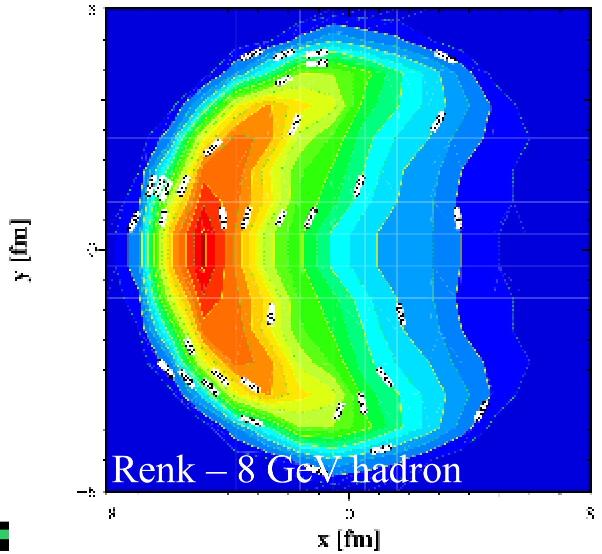
Experimental results



Phys. Lett. B 696 (2011) 30-39

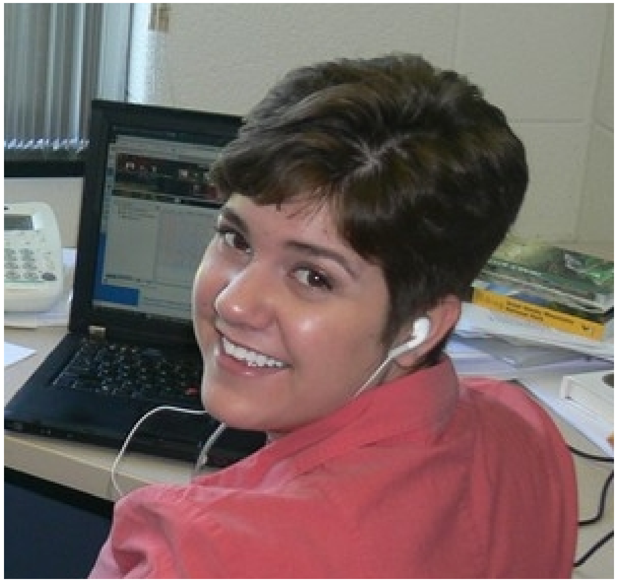
No suppression

Observed



Renk – 8 GeV hadron

Heavy flavor

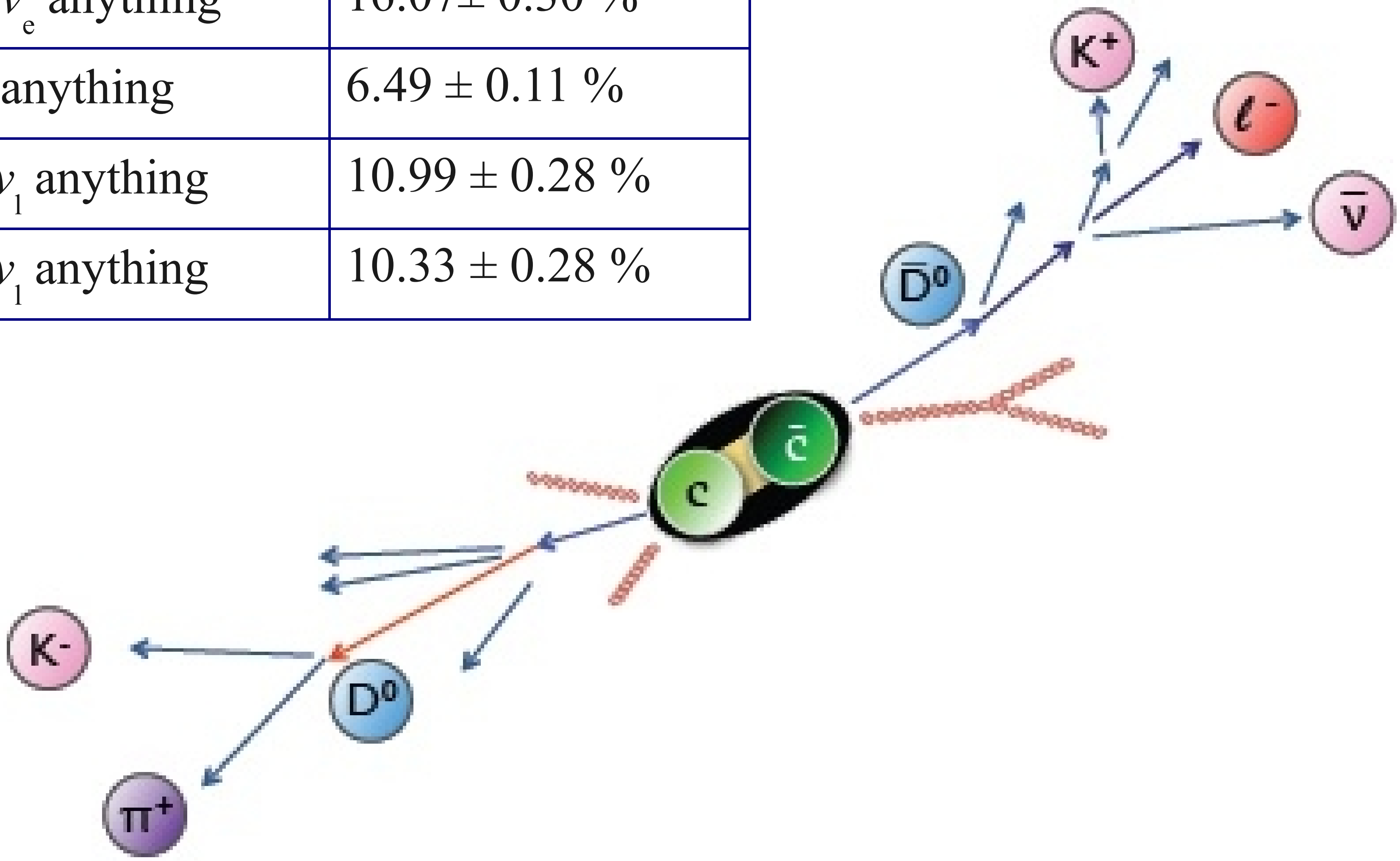


Why study heavy flavor?

- Produced in early stages of the collision
    - Must be from energetic collisions because of mass
- Energy loss and flow are related to the transport properties of the medium in heavy ion collisions
    - Light quark data indicate
        - Medium evolves as if a fluid of quarks at equilibrium
        - Energy loss in medium is large
    - Heavy quarks may propagate through the medium differently

Heavy flavor decay

	Decay	**Fraction**
$D^\pm$	$e^+ \nu_e$ anything	16.07± 0.30 %
D^0	e^+ anything	6.49 ± 0.11 %
$B^\pm$	$l^+ \nu_l$ anything	10.99 ± 0.28 %
B^0	$l^+ \nu_l$ anything	10.33 ± 0.28 %



Measuring electrons from heavy flavor

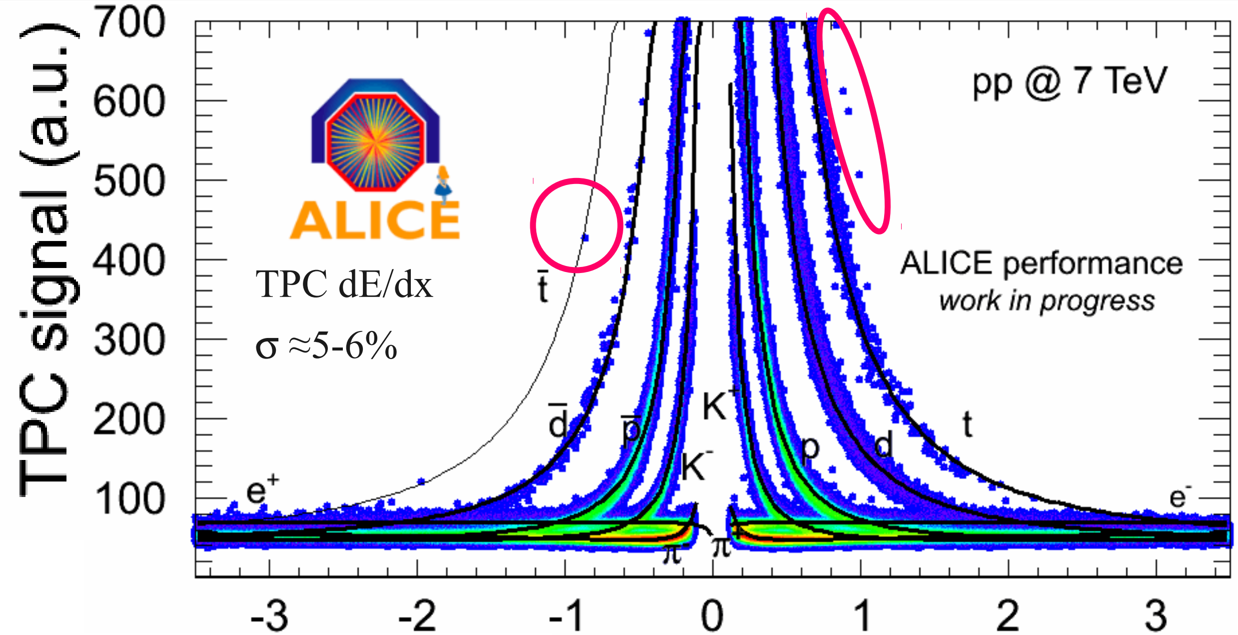
- Identify electrons
- Background subtraction
- Efficiency and acceptance
- Heavy flavor p_T spectrum
- Heavy flavor R_{AA}
- Separate charm and beauty
- Measure angular dependence of electron distribution

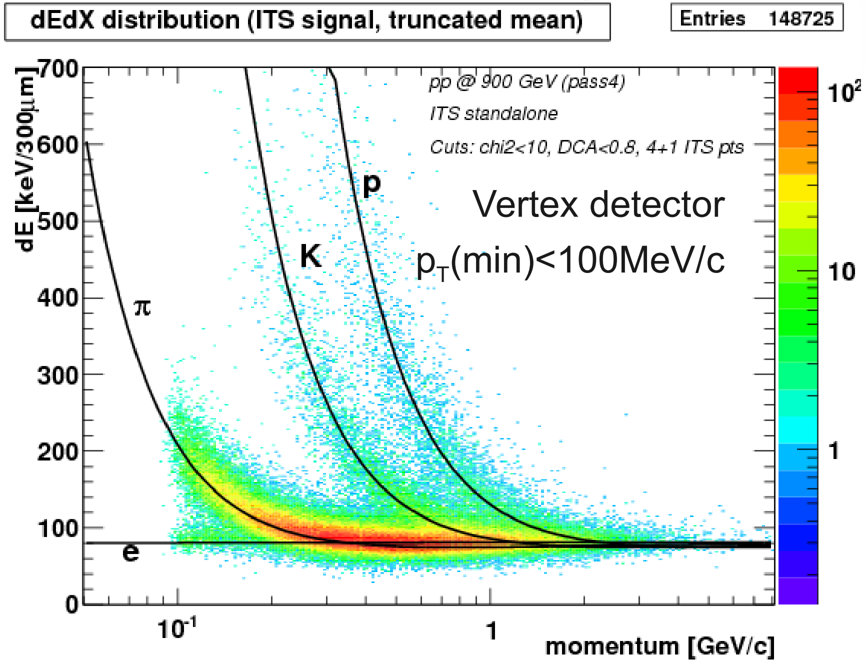
→ Complicated analysis

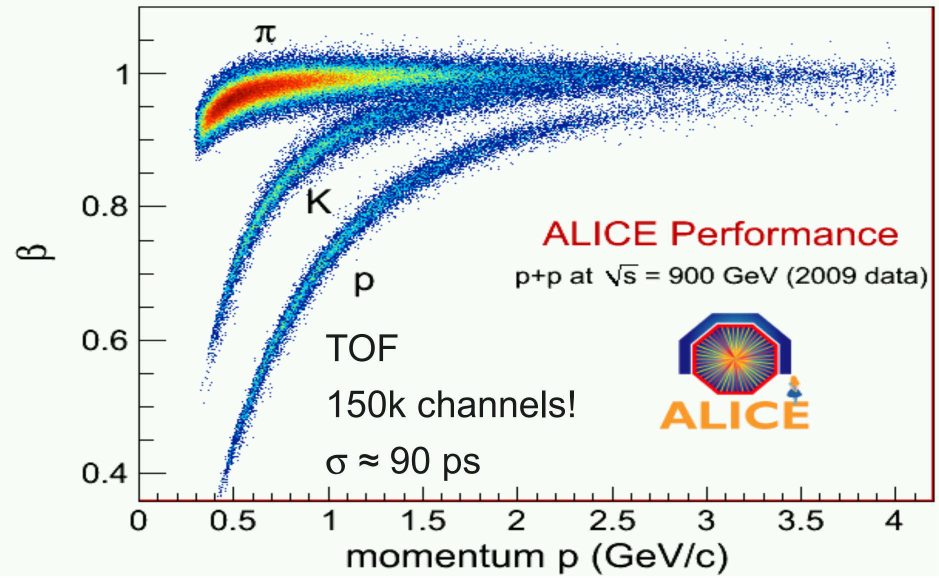
→ Requires identification of electrons at high momentum

Stolen from Rebecca Scott's thesis proposal

Particle identification

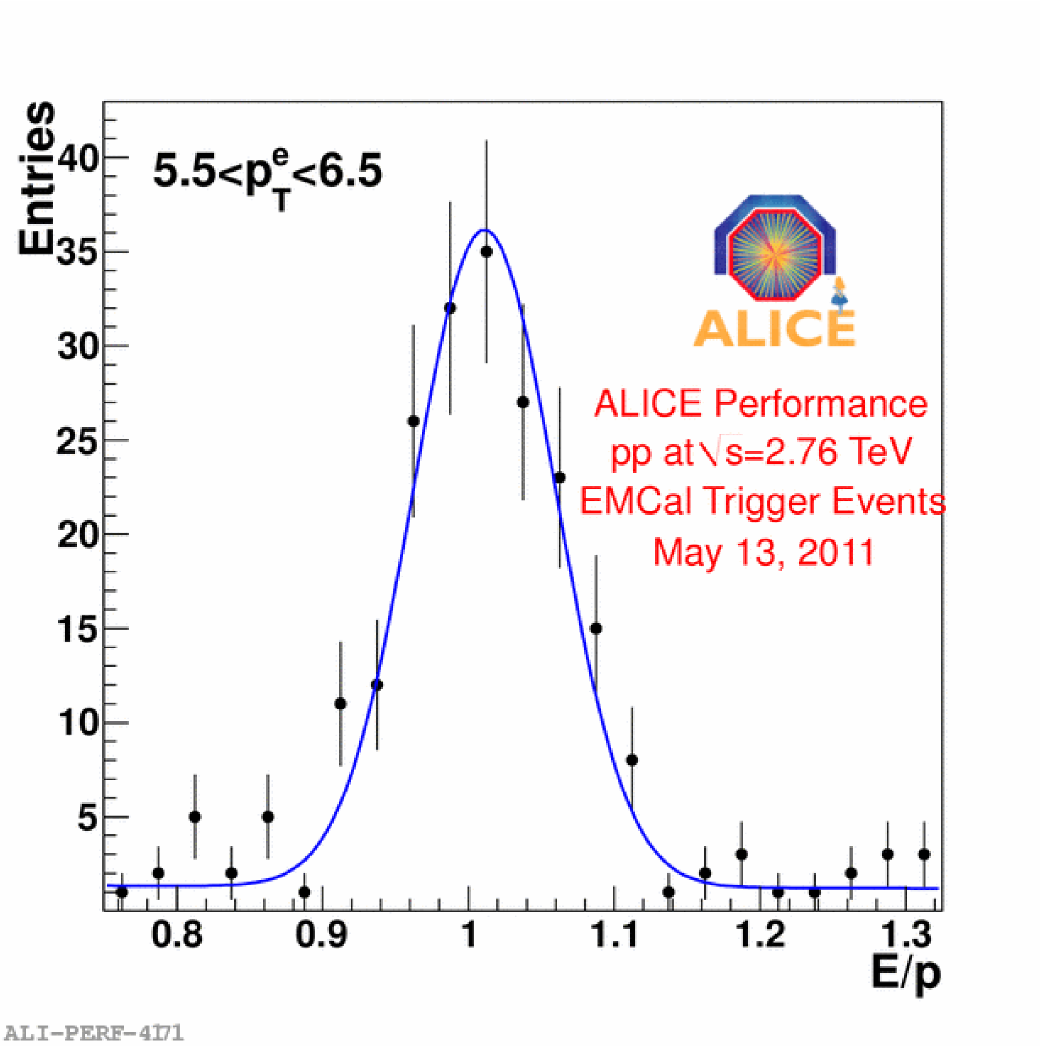






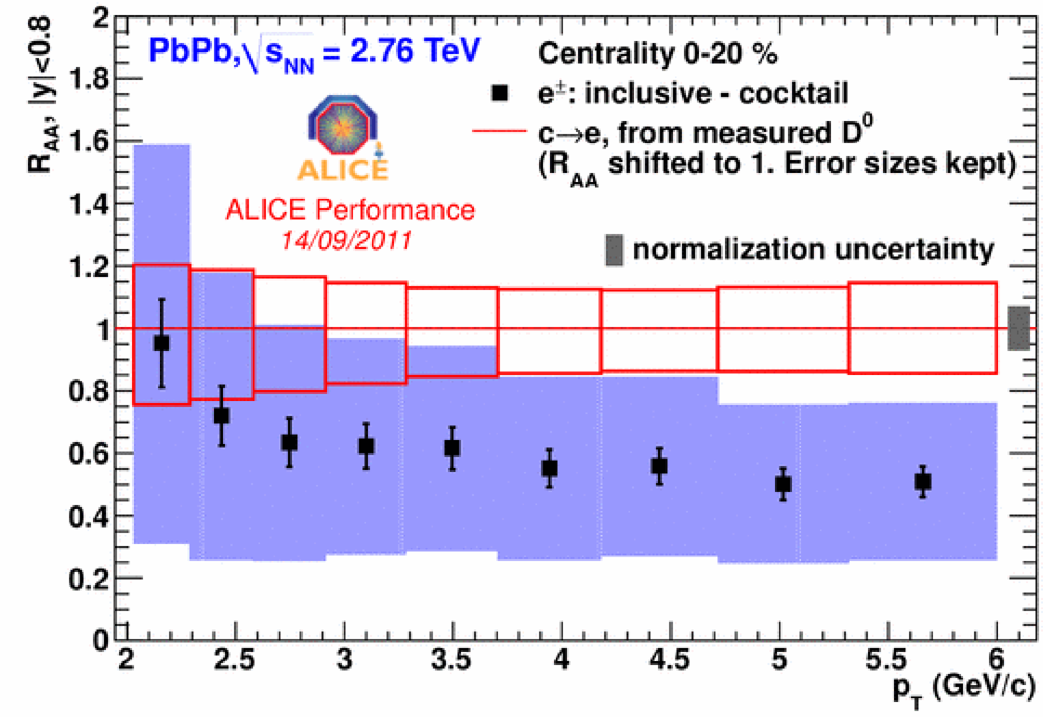
Electron identification

- Electron $m \ll p$
- $E/p \approx 1$ for electrons
- $E/p < 1$ for hadrons
- EMCal can be used to identify electrons even at very high momenta



Non-photonic electrons

Without EMCal



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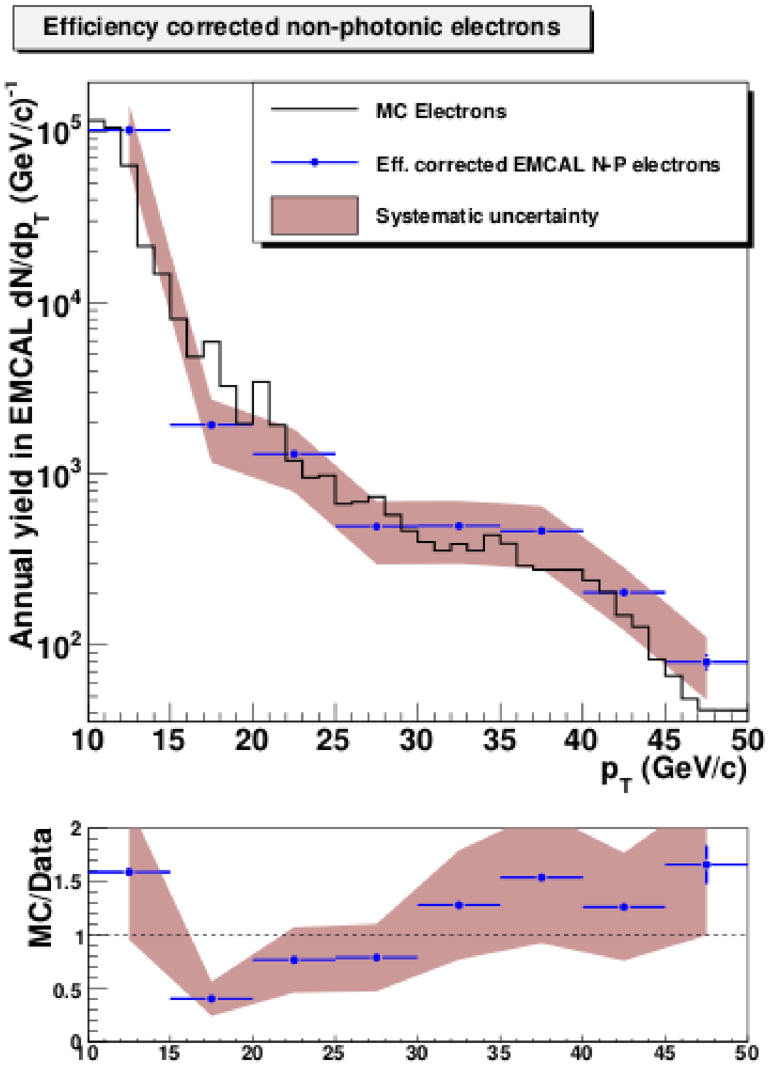
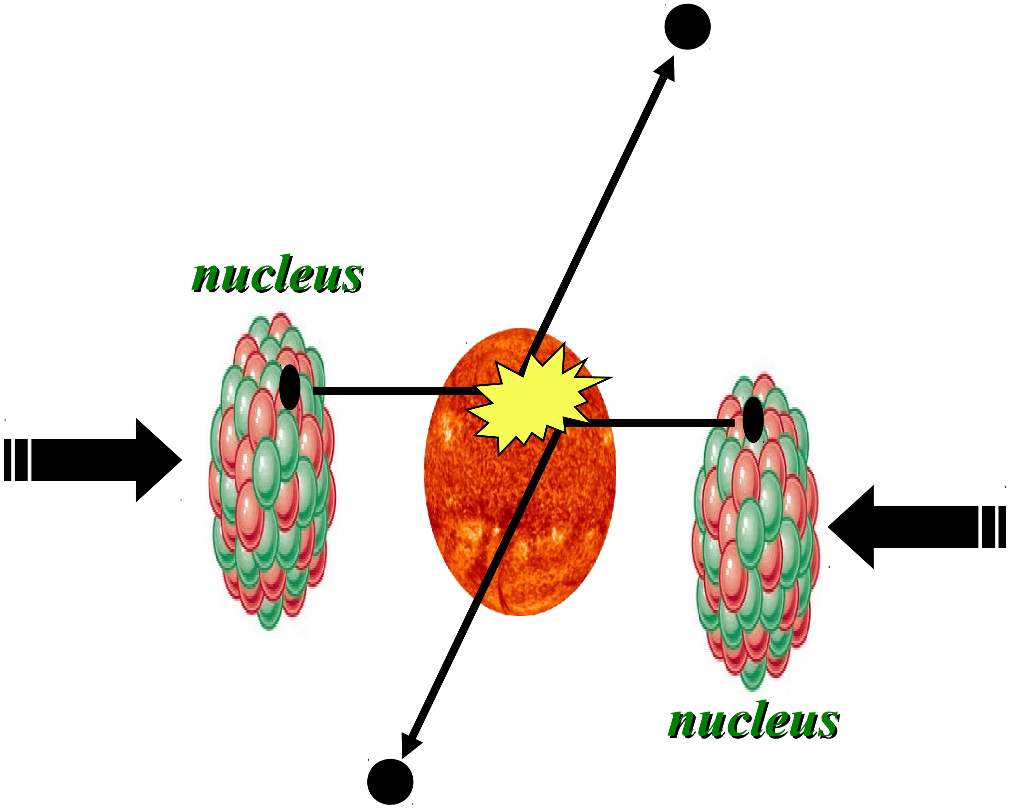
With EMCal



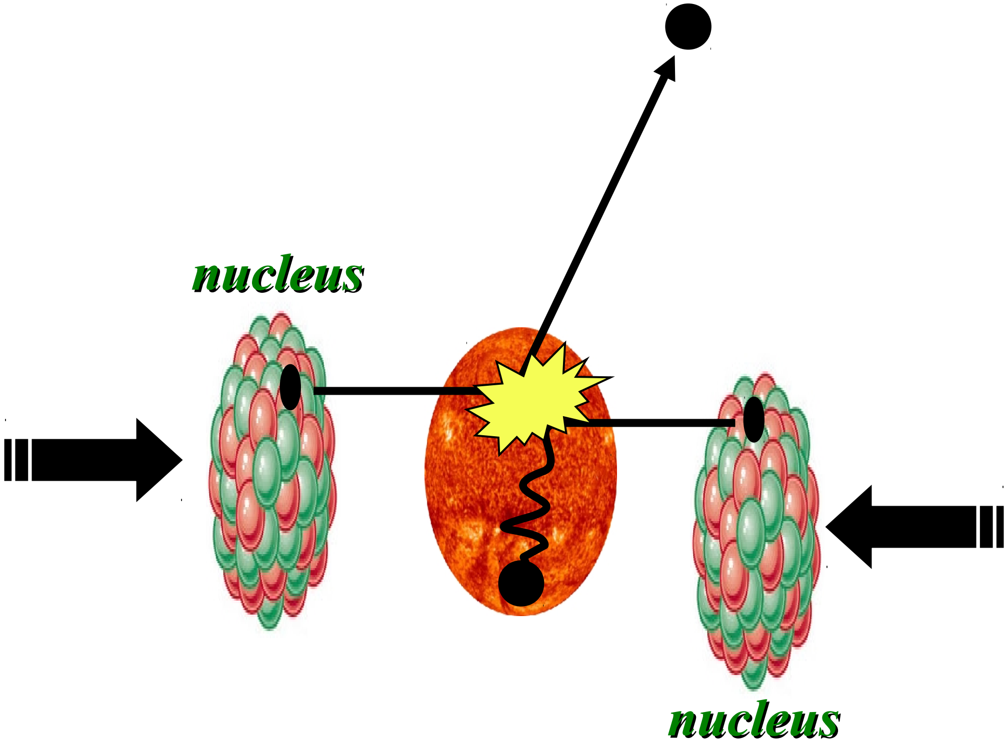
Jets

Probes of the Quark Gluon Plasma



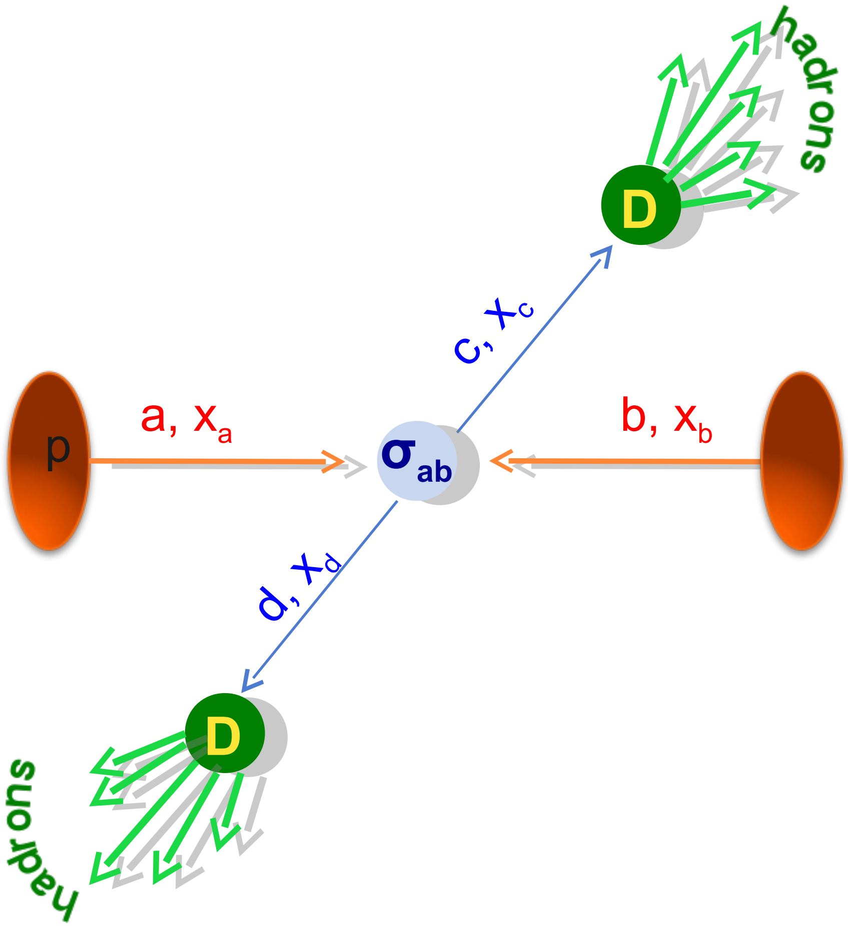
Want a probe which traveled through the collision
QGP is short lived → need a probe created in the collision

Probes of the Quark Gluon Plasma

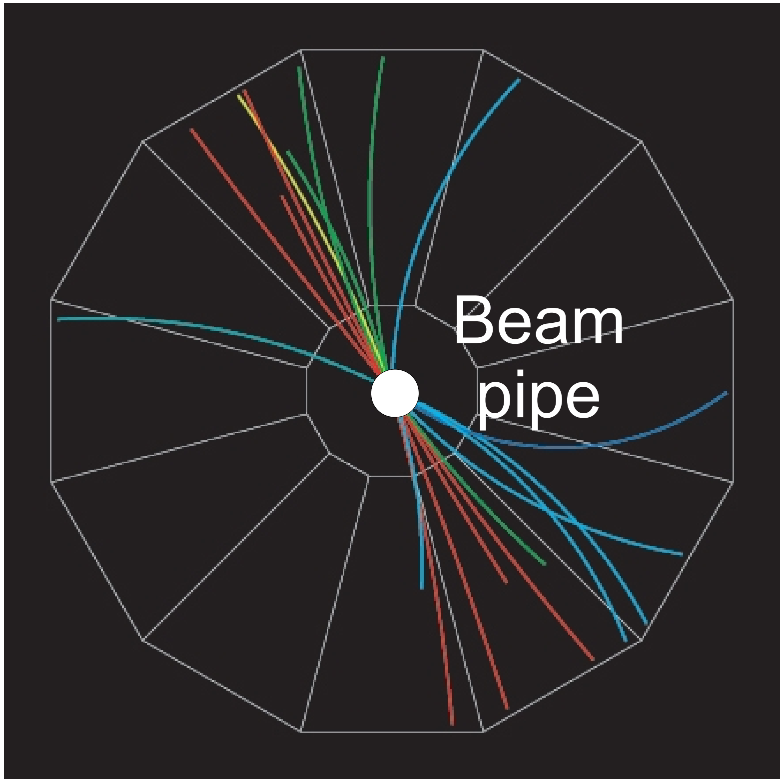


Want a probe which traveled through the medium
QGP is short lived → need a probe created in the collision
We expect the medium to be dense → absorb/modify probe

Jets

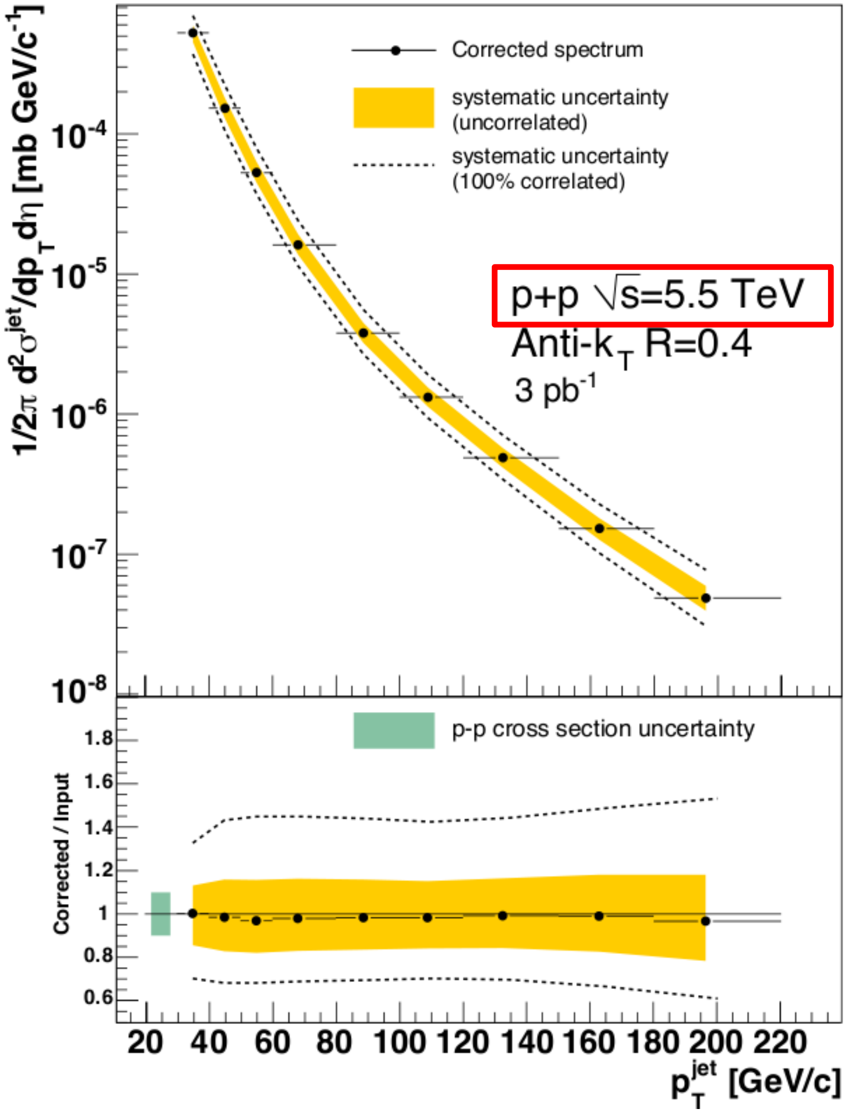


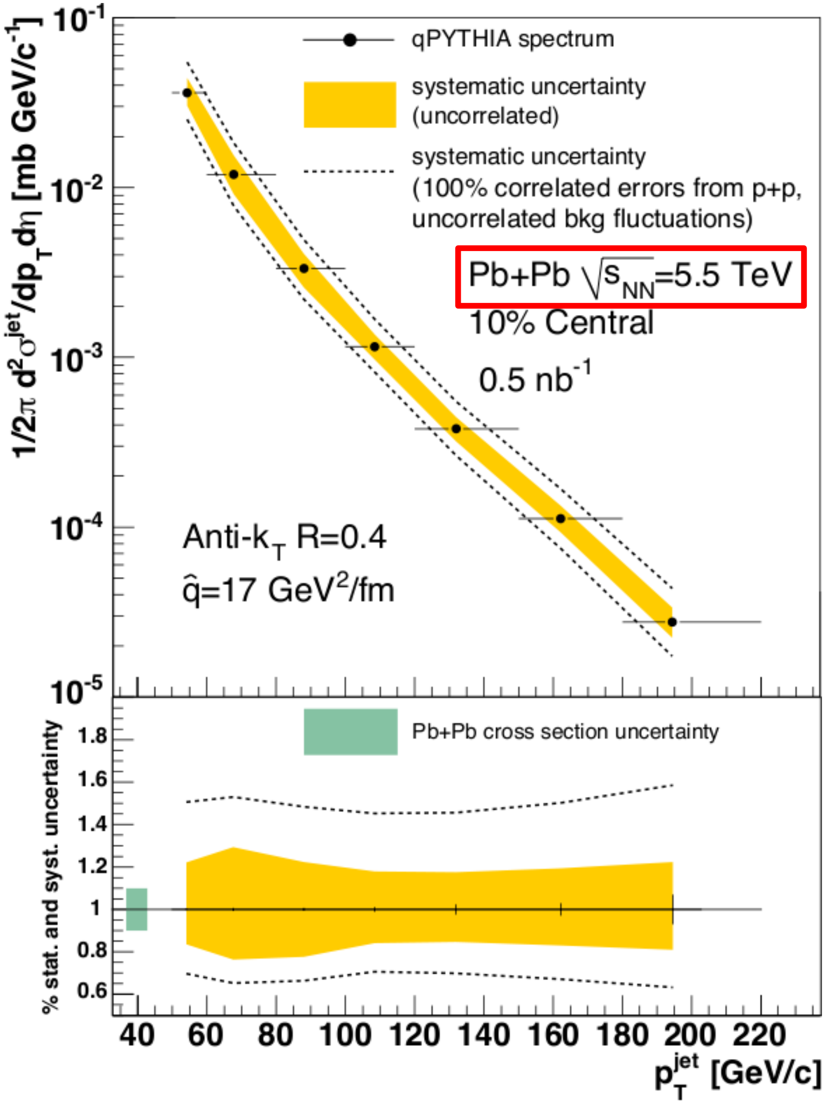
p+p → dijet



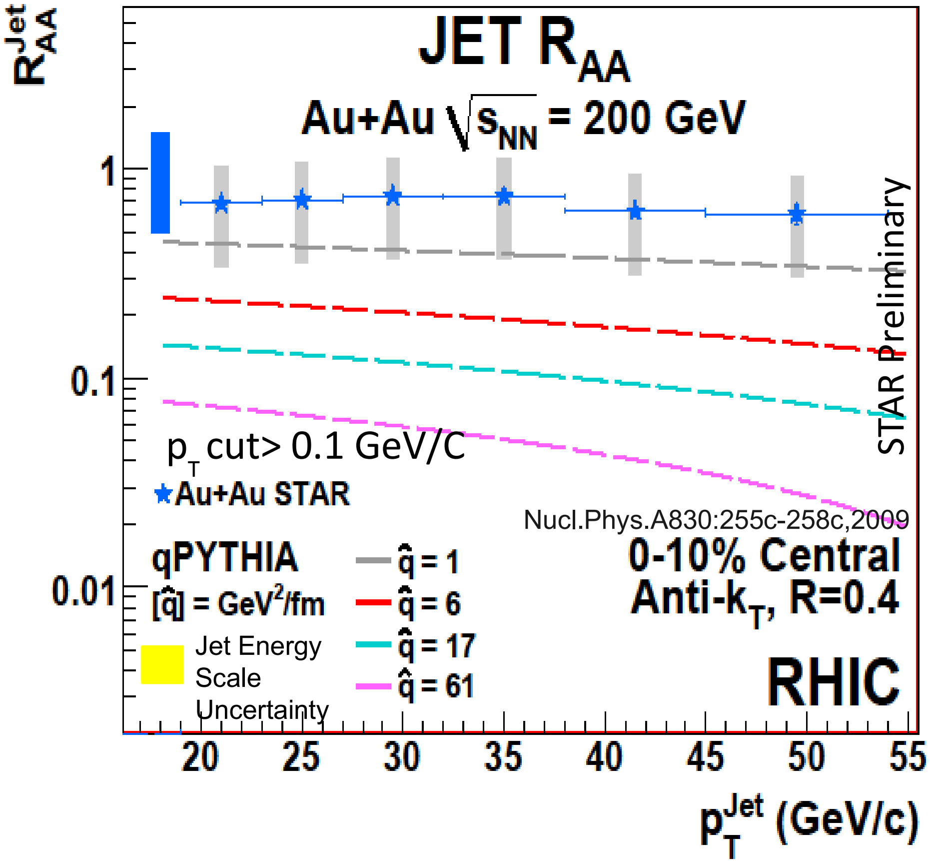
Jets – hard parton scattering leads to back-to-back quarks or gluons, which then fragment as a columnated spray of particles

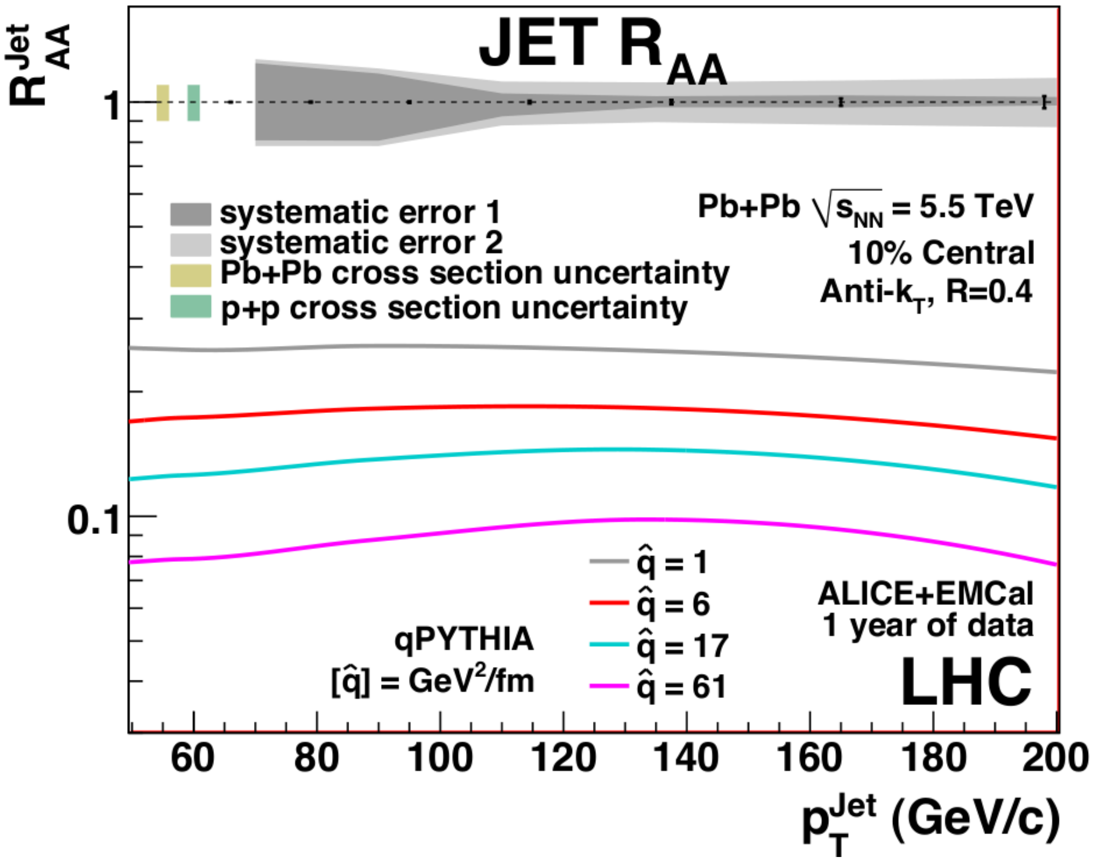
Inclusive spectra





R_{AA}: From RHIC to the LHC





- Much greater kinematic reach at the LHC
- Smaller systematic errors
- Comparison between RHIC and LHC: studies of partonic energy loss at different regions on the phase diagram

Conclusions

Conclusions

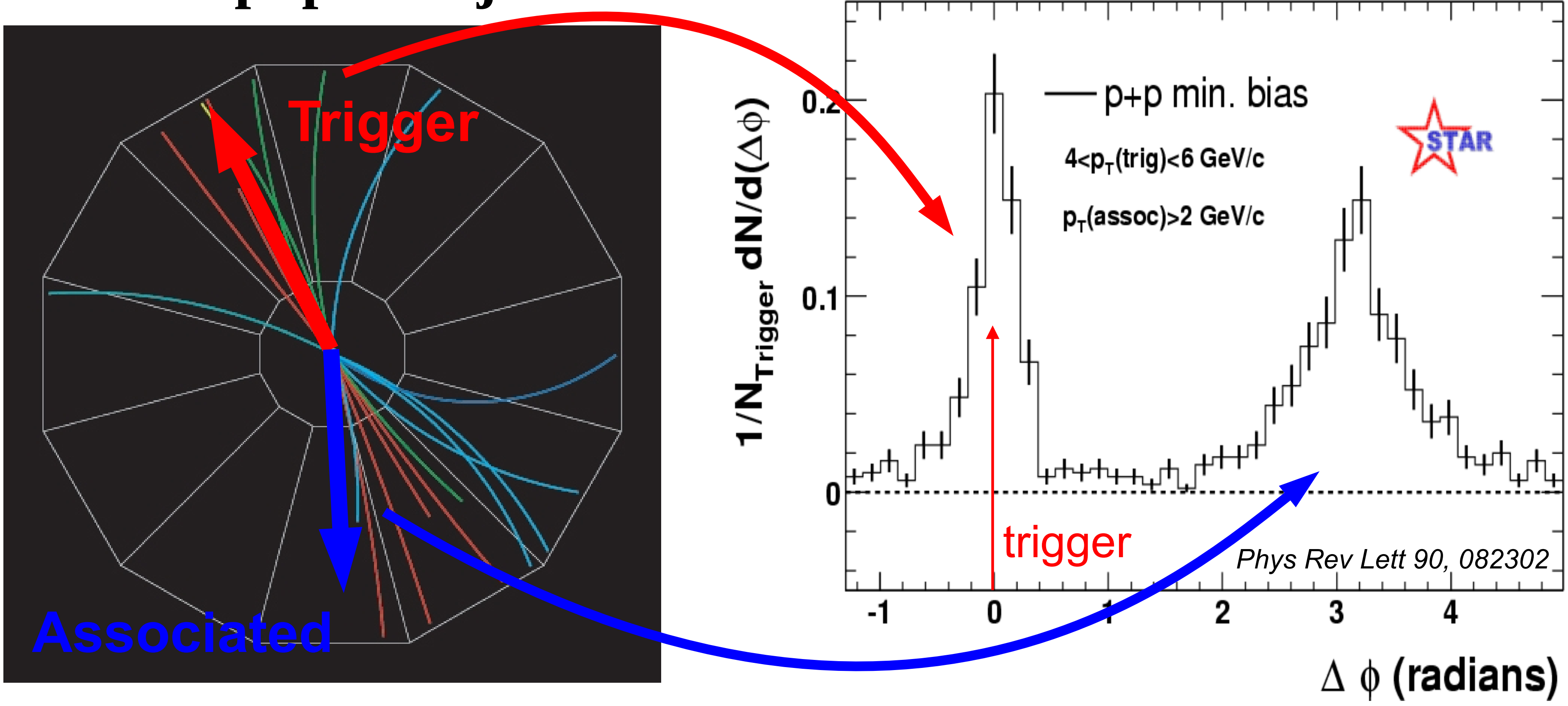
- EMCal useful for measurements of
  - Measurements of γ and π^0
  - Heavy flavor measurements
    - Charm and beauty quarks
  - Measurements of jets
    - Access to quark and gluon momenta

Plus other things I haven't talked about

Backup

Jets – azimuthal correlations

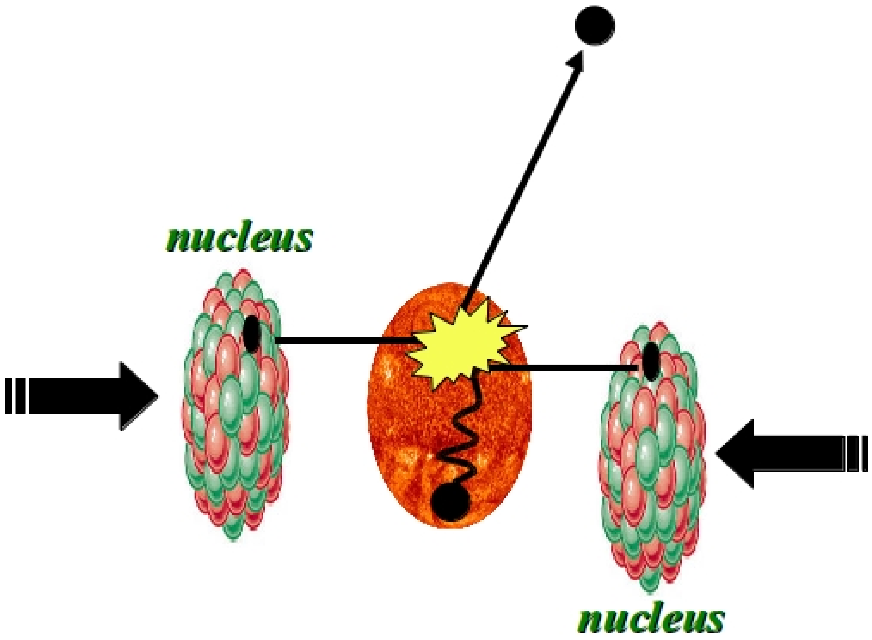
p+p → dijet

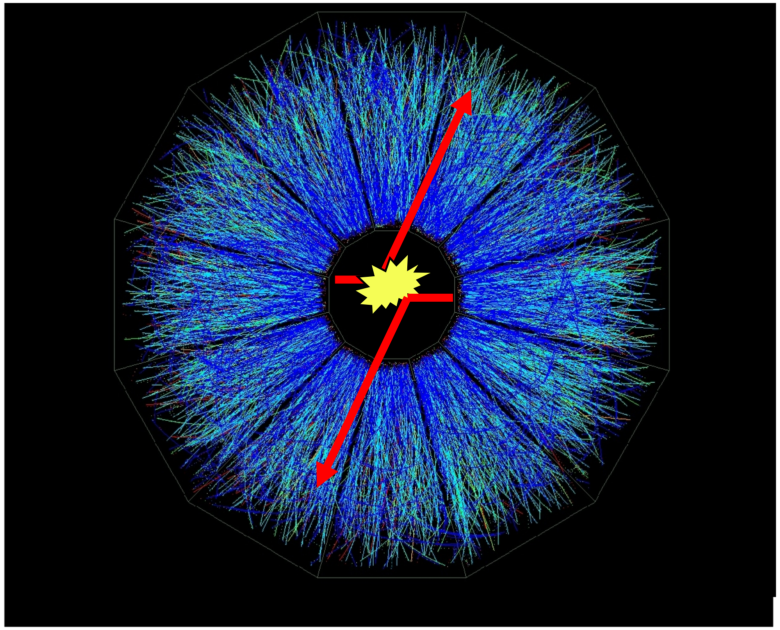


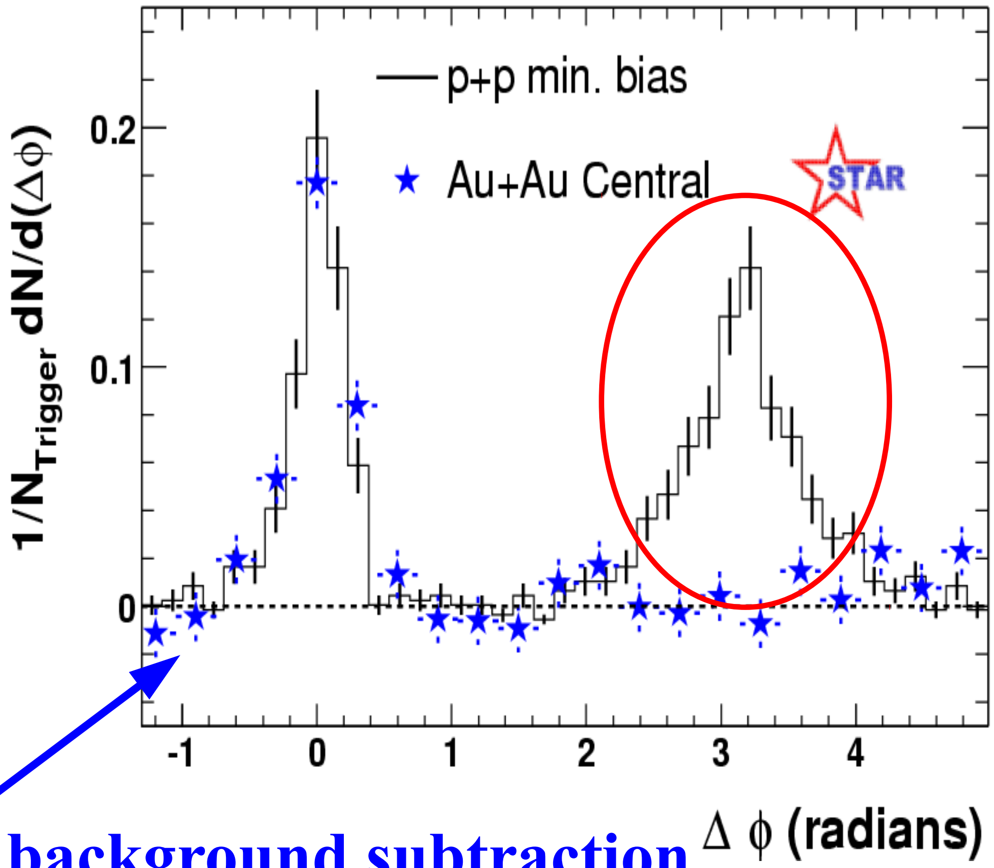
Phys Rev Lett 90, 082302

Select high momentum particles → biased towards jets

Jets – azimuthal correlations



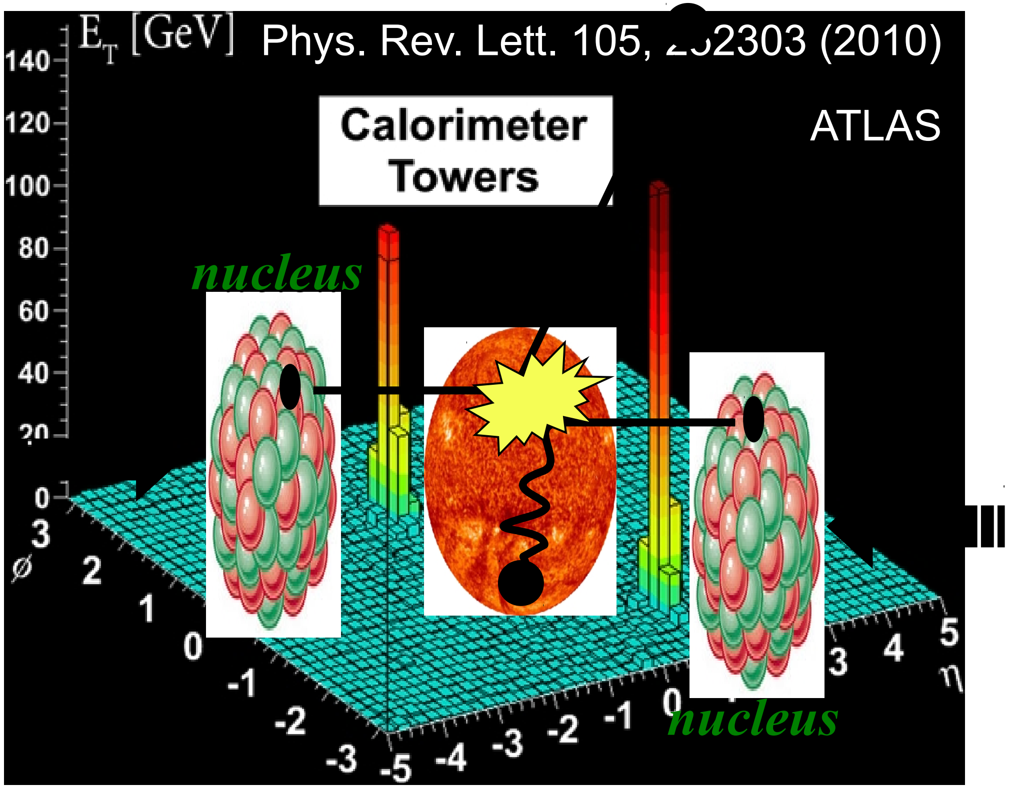




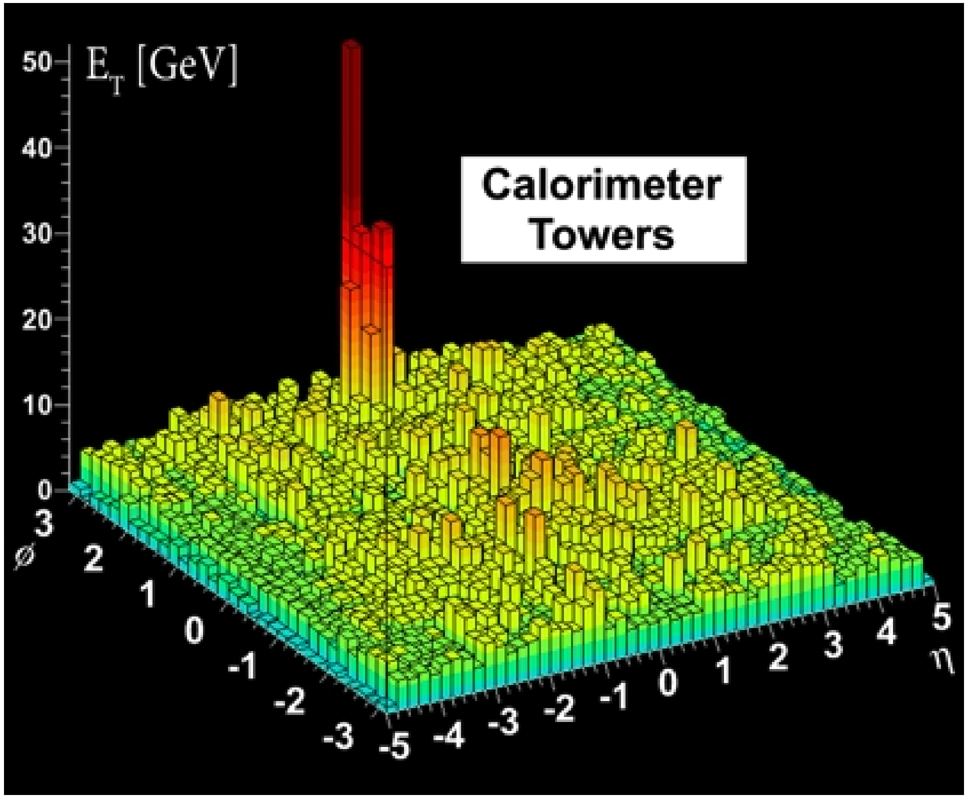
Big background subtraction

Jet quenching – absorption of jets by the medium

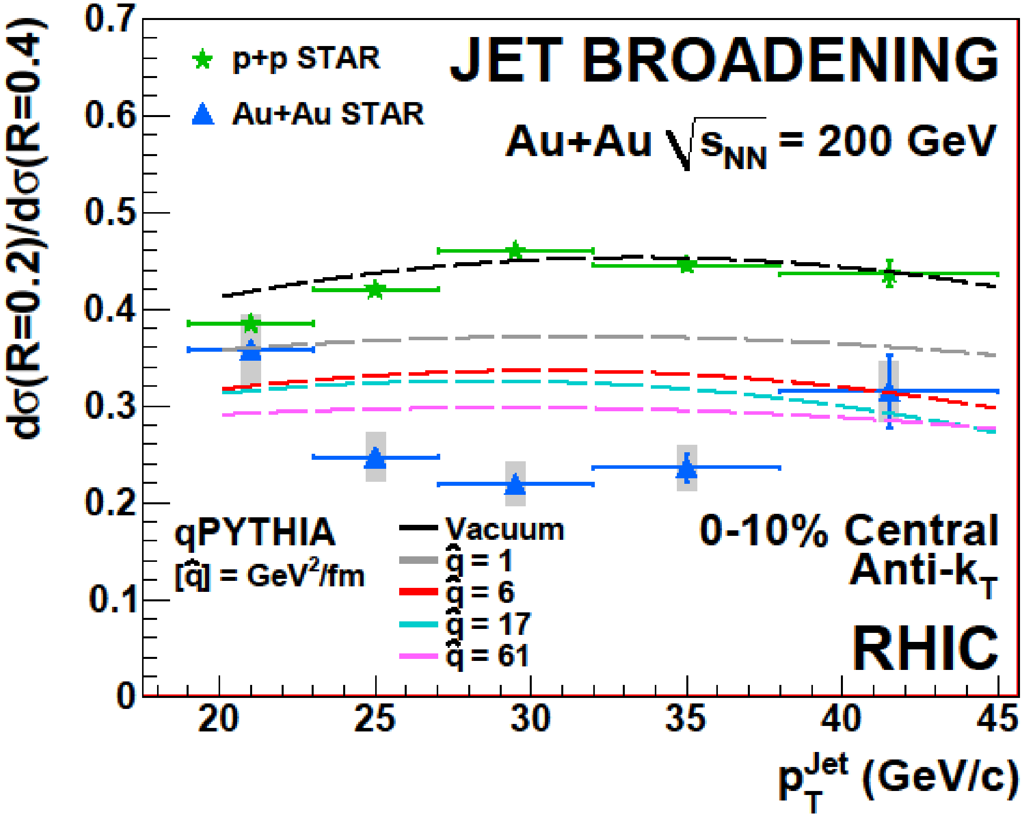
Jets at the LHC

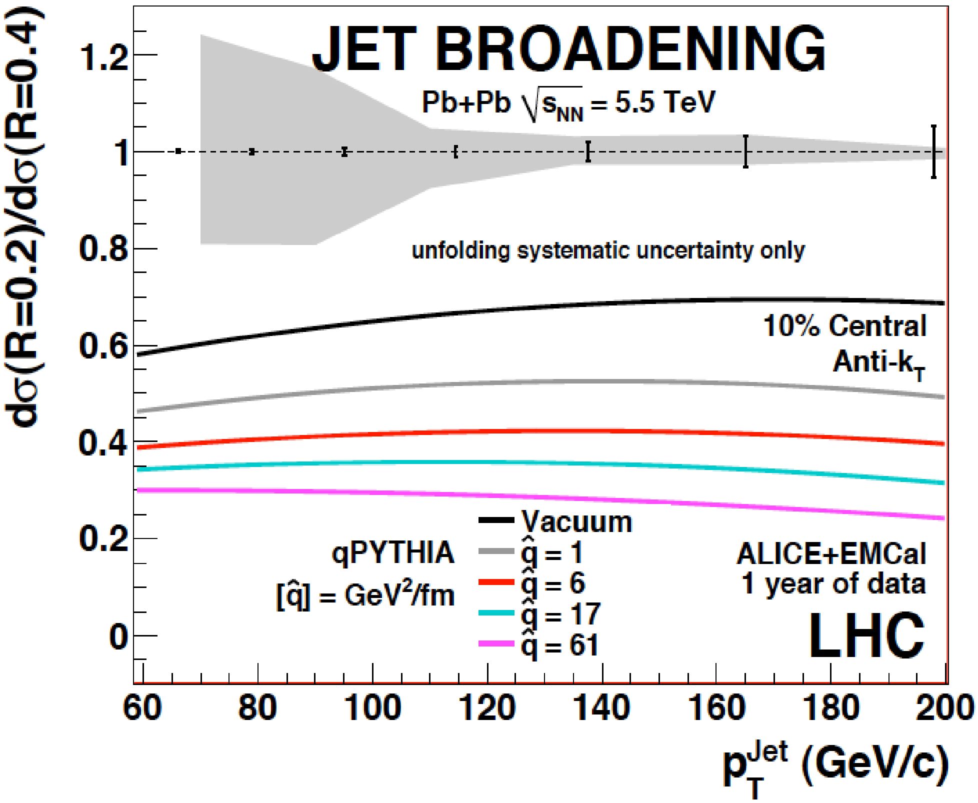


Phys. Rev. Lett. 105, 252303 (2010)



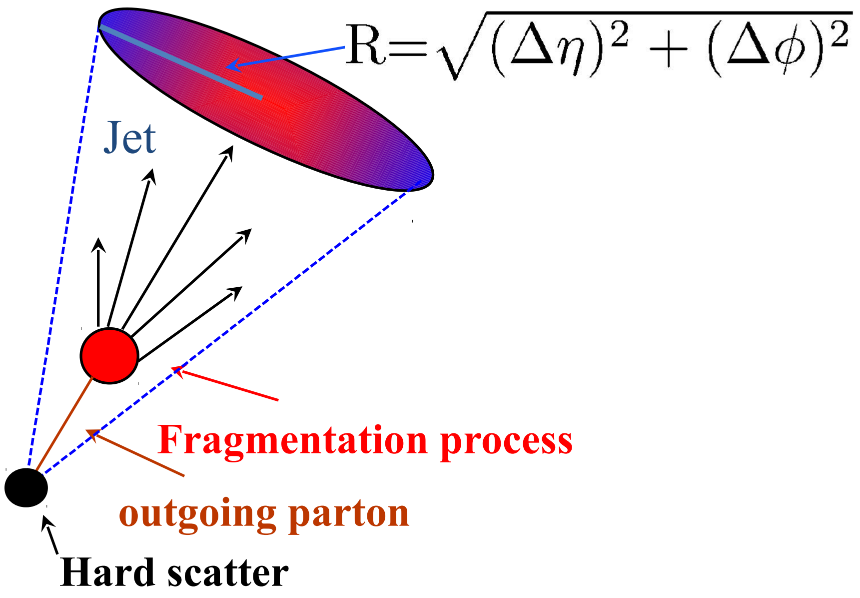
Jet broadening





- QPYTHIA not optimized (yet) –do not draw conclusions from shape differences
- Jet energy profile (Au+Au data) BROADENED indicating JET QUENCHING
- Small experimental systematic uncertainties in measurements (ratios from same data set) →a precision measurement in ALICE

Jet reconstruction algorithms


$$R=\sqrt{(\Delta\eta)^2+(\Delta\phi)^2}$$

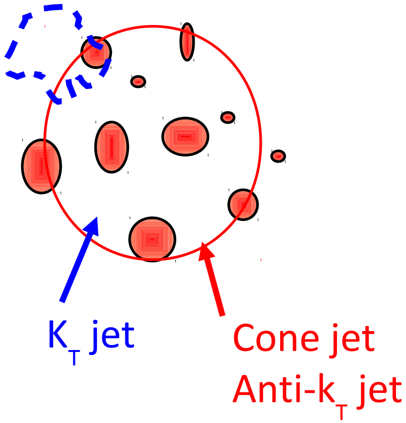
Cone Algorithm:

1. Mid Point Cone: Merging & Splitting
2. SIS CONE
   - Insensitive to “soft” radiation
   - Splitting doesn’t change jets
3. Leading Order High Seed Cone (LOHSC)

Sequential recombination:

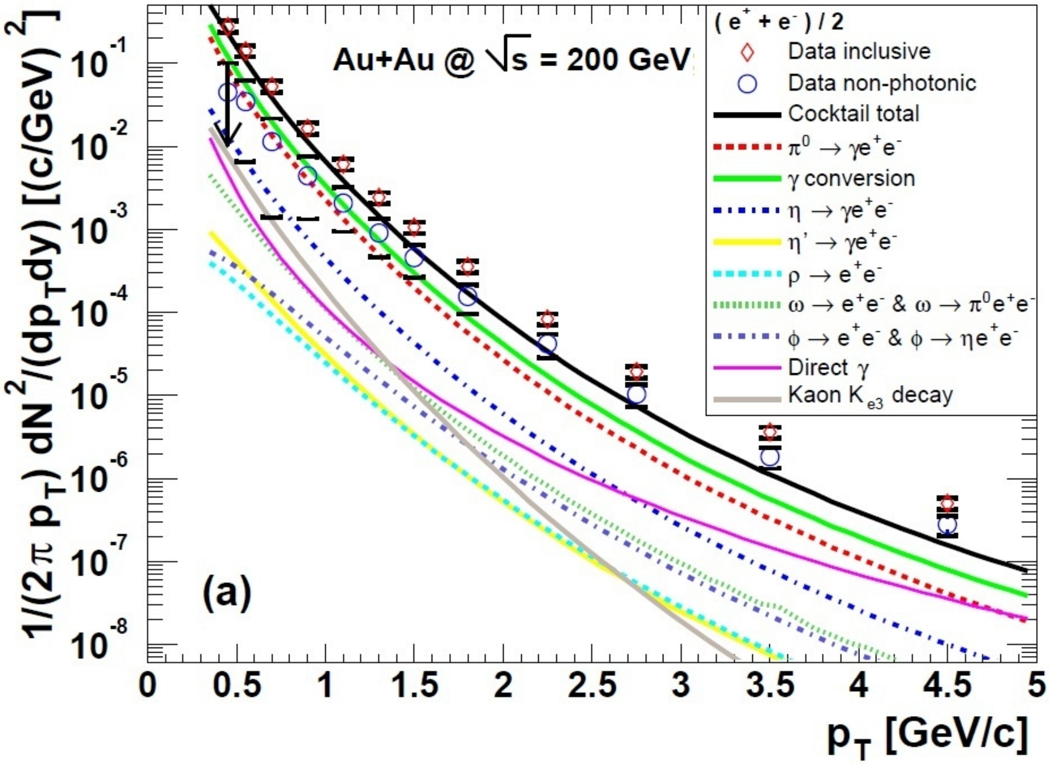
Cluster pairs of objects close in relative p_T

4. K_T (starting point: low p_T particles)
5. Anti-K_T (starting point: high p_T particles)



6. Gaussian filtering. Y. Lai, B. Cole arXiv:0806.1499

Background subtraction: Cocktail Method



Steps for the cocktail method:

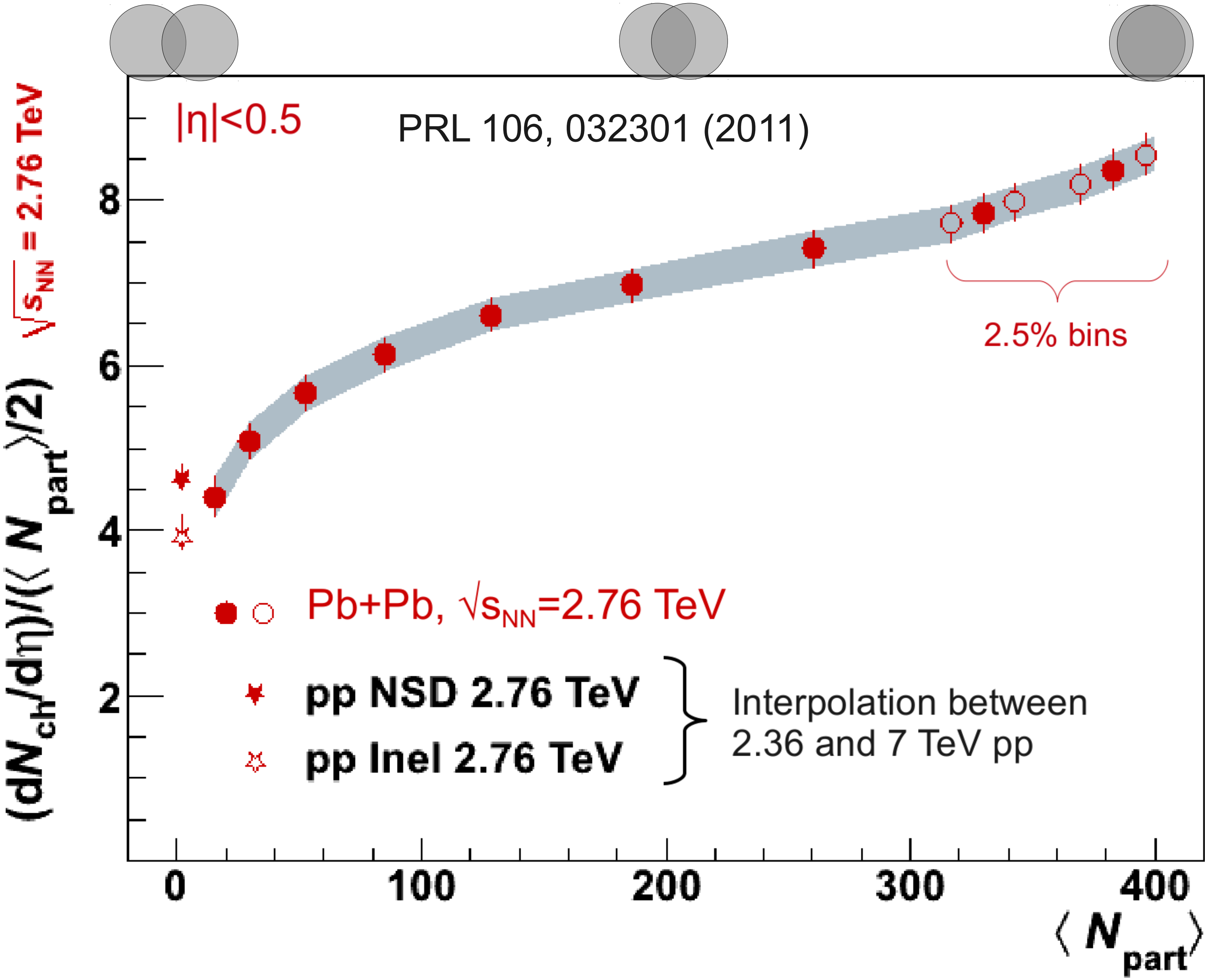
a) determine all other processes producing electrons

b) determine the relative weight

c) determine the momentum and rapidity distribution

Photonic electrons: $\gamma \rightarrow e^+ e^-$, $\pi^0 \rightarrow \gamma e^+ e^-$, $\eta \rightarrow \gamma e^+ e^-$...

Centrality dependence of $dN_{ch}/d\eta$



PRL 106, 032301 (2011)

2.5% bins

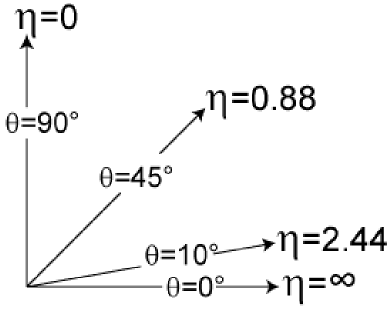
Interpolation between 2.36 and 7 TeV pp

RHIC data scaled by 2.1

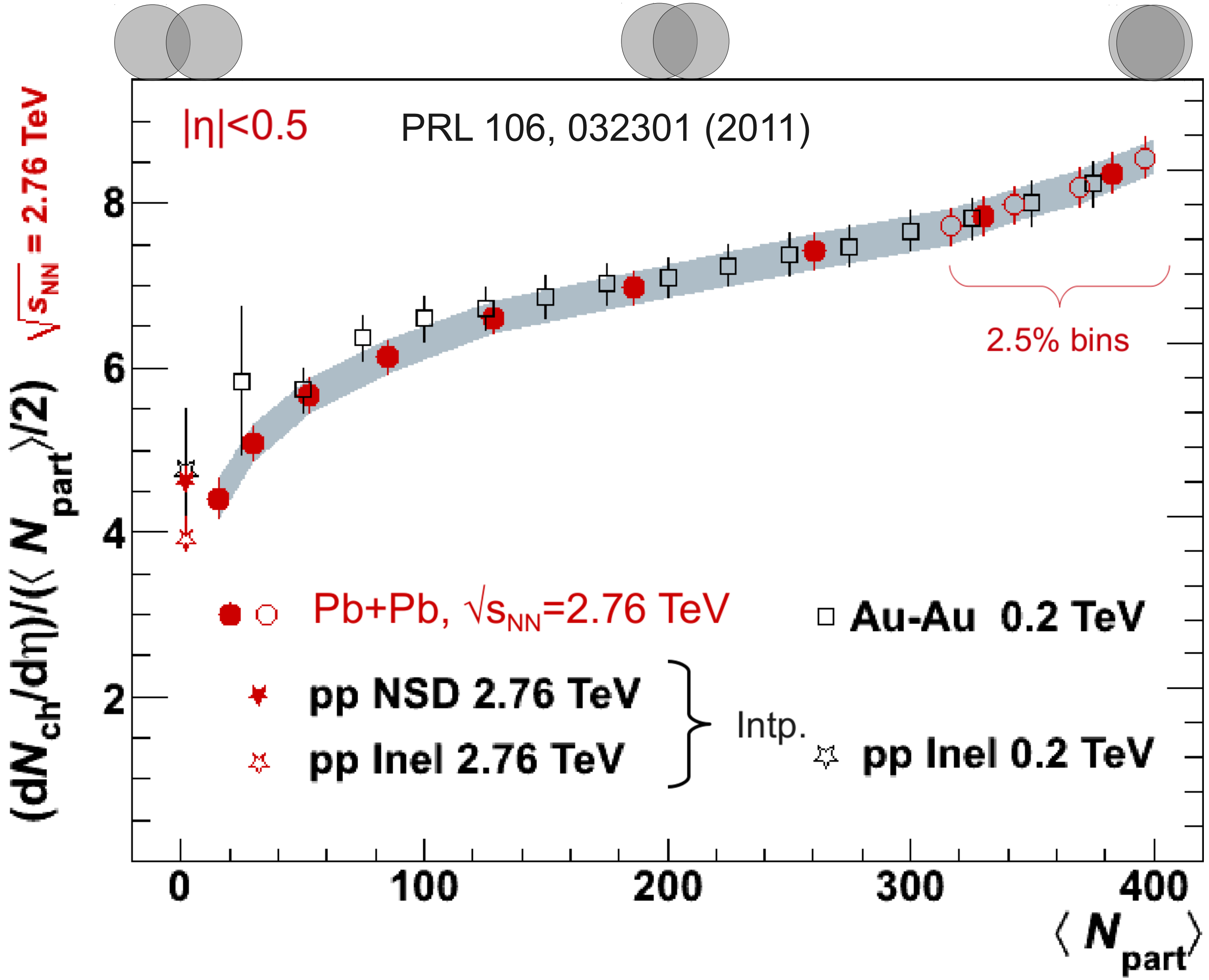
PHENIX
PRC 71, 034908 (2005)

$dN_{ch}/d\eta$ = Number of charged tracks per unit pseudorapidity

η = pseudorapidity
= - ln[tan(θ/2)]



Centrality dependence of $dN_{ch}/d\eta$



RHIC data scaled by 2.1

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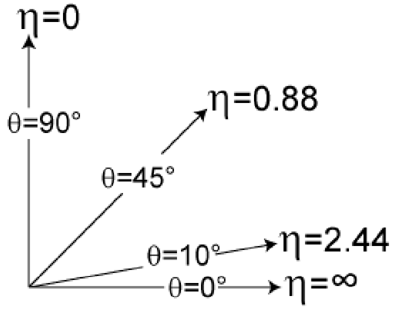
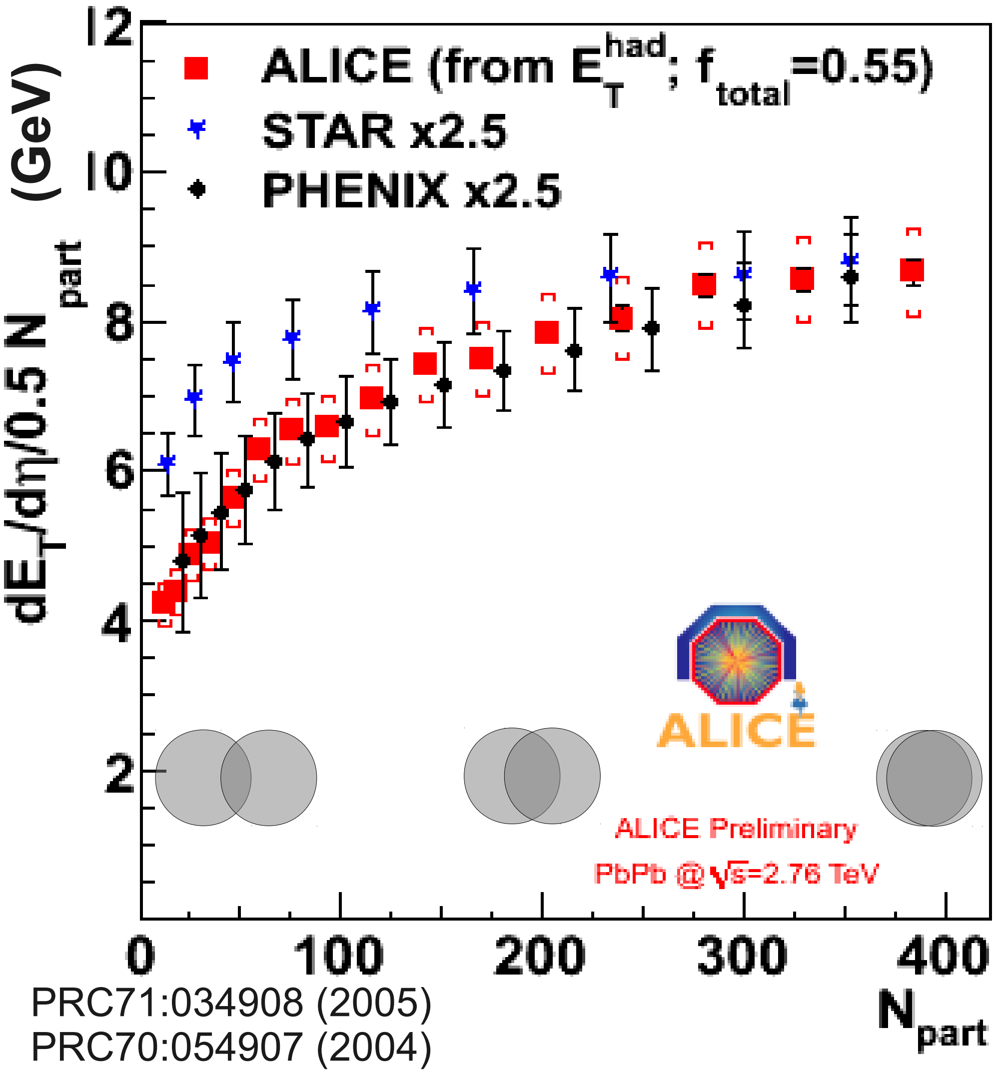


N_{part} = number of participating nucleons

Transverse Energy



PRC71:034908 (2005)
PRC70:054907 (2004)

Centrality dependence similar to RHIC (PHENIX)

- E_T^{had} from charged hadrons directly measured by the tracking detectors
- f_{total} from MC to convert into total E_T
- From RHIC to LHC
  - ~2.5 increase $dE_T/d\eta/\,(0.5{*}N_{part})$
- Energy density (Bjorken)

$$\varepsilon = \frac{1}{\pi R^2 \tau}\frac{dE_t}{dy} \qquad R = 1.12\,A^{1/3} fm$$

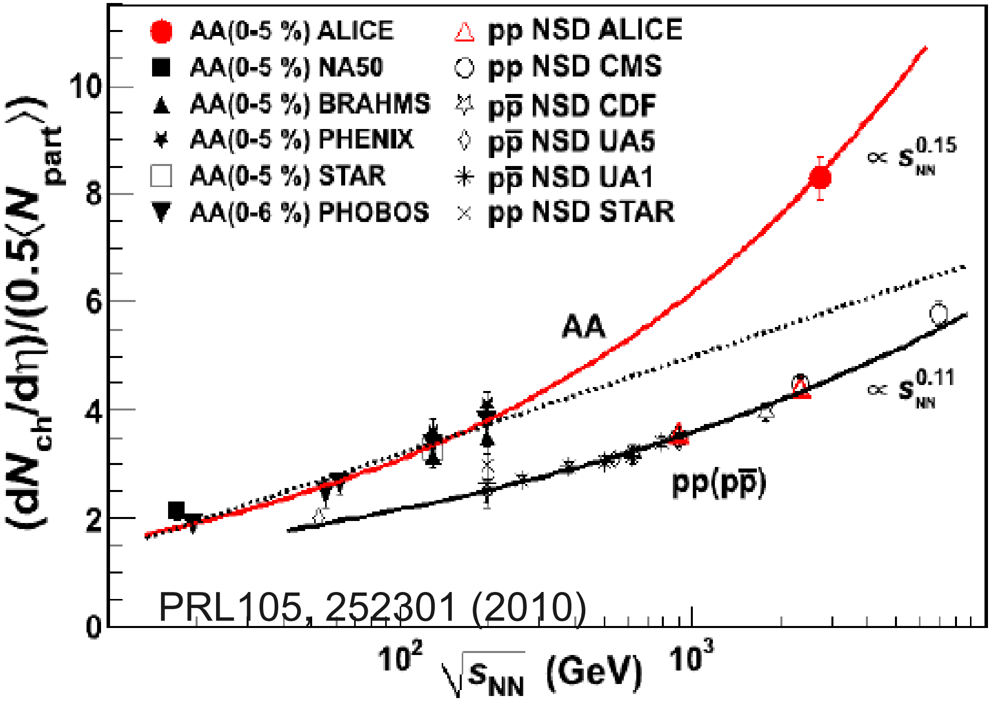
- $\varepsilon\tau \sim 16$ GeV/(fm^{2}c)
  RHIC: $\varepsilon\tau = 5.4 \pm 0.6$ GeV/(fm^{2}c)

$\sqrt{s}_{NN}$ dependence

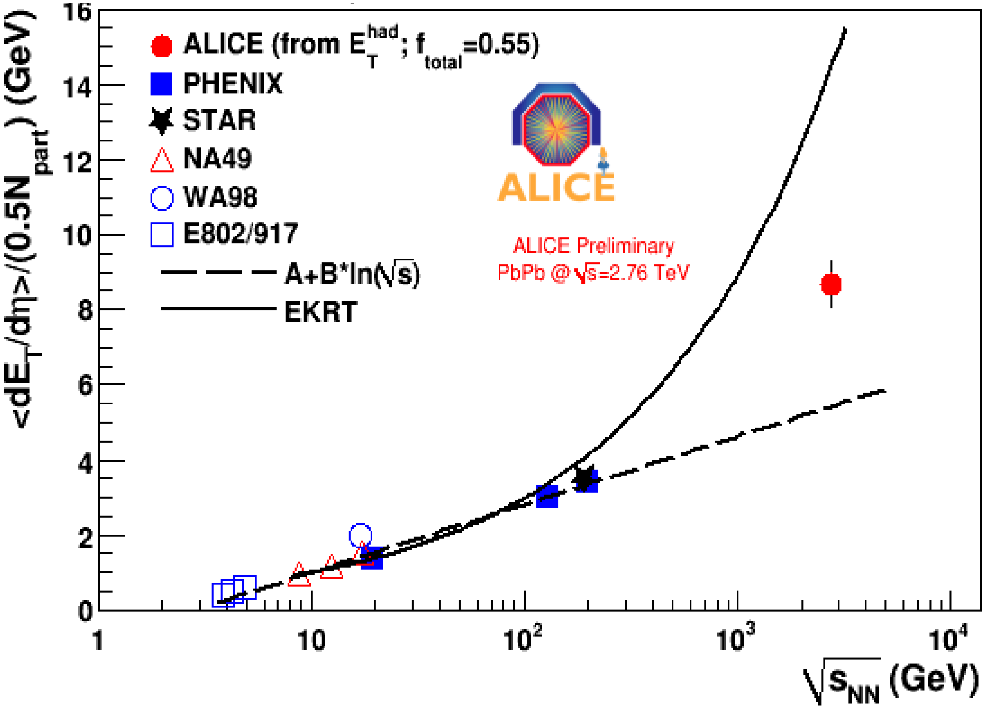
- $dN_{ch}/d\eta/(0.5*N_{part}) \sim 8$
- **2.1 x RHIC**
  1.9 x pp (NSD) at 2.36 TeV
- growth with √s faster in AA than pp

- $dE_T/d\eta/(0.5*N_{part}) \sim 9$ in 0-5%
- ~5% increase of N_{part} (353 → 383)
  → **2.7 x RHIC**
  (consistent with 20% increase of $\langle p_T \rangle$)

Grows faster than simple logarithmic scaling extrapolated from lower energy



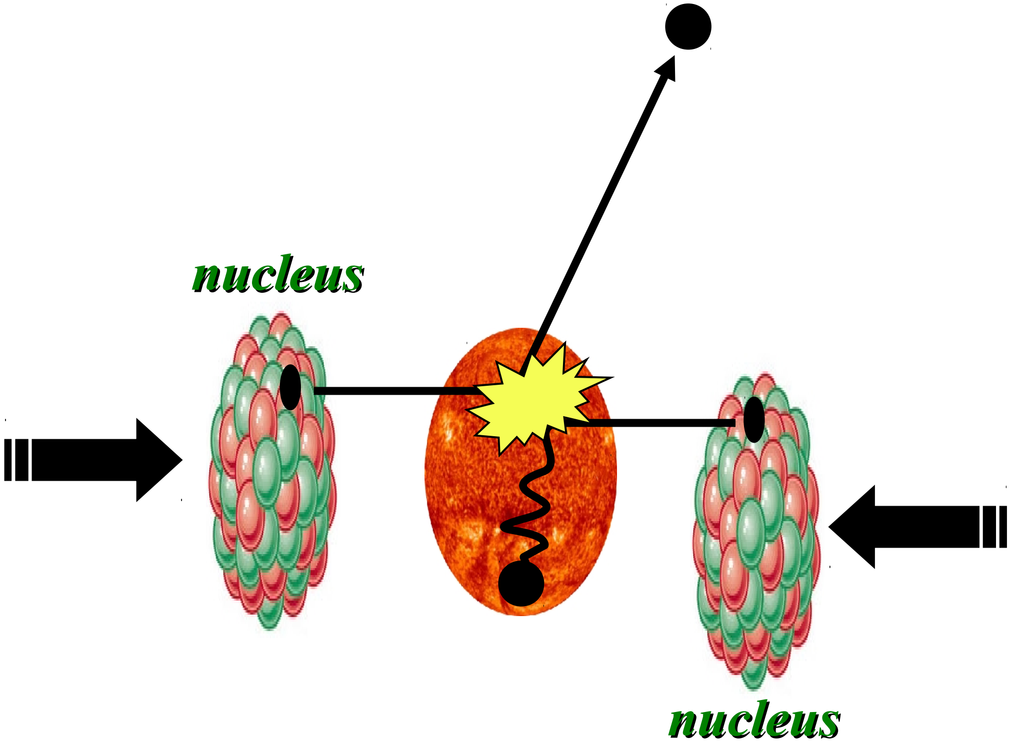
PRL105, 252301 (2010)



$\sqrt{s}_{NN}$ = Center of mass energy per nucleon

Probes of the Quark Gluon Plasma

Probes of the Quark Gluon Plasma



Want a probe which traveled through the collision
QGP is short lived → need a probe created in the collision
We expect the medium to be dense → absorb probe

Single particles

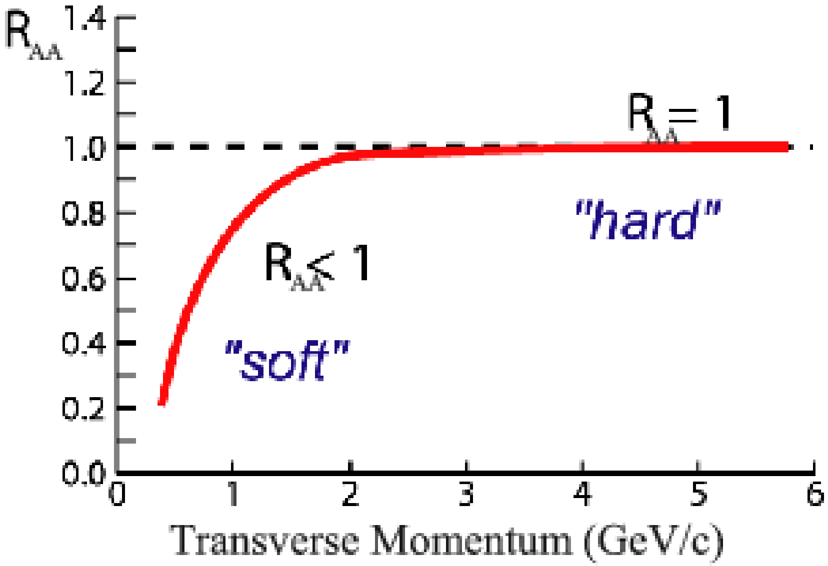
Measure spectra of hadrons and compare to those in p+p collisions or peripheral A+A collisions

If high-p_T hadrons are suppressed, this is evidence of jet quenching

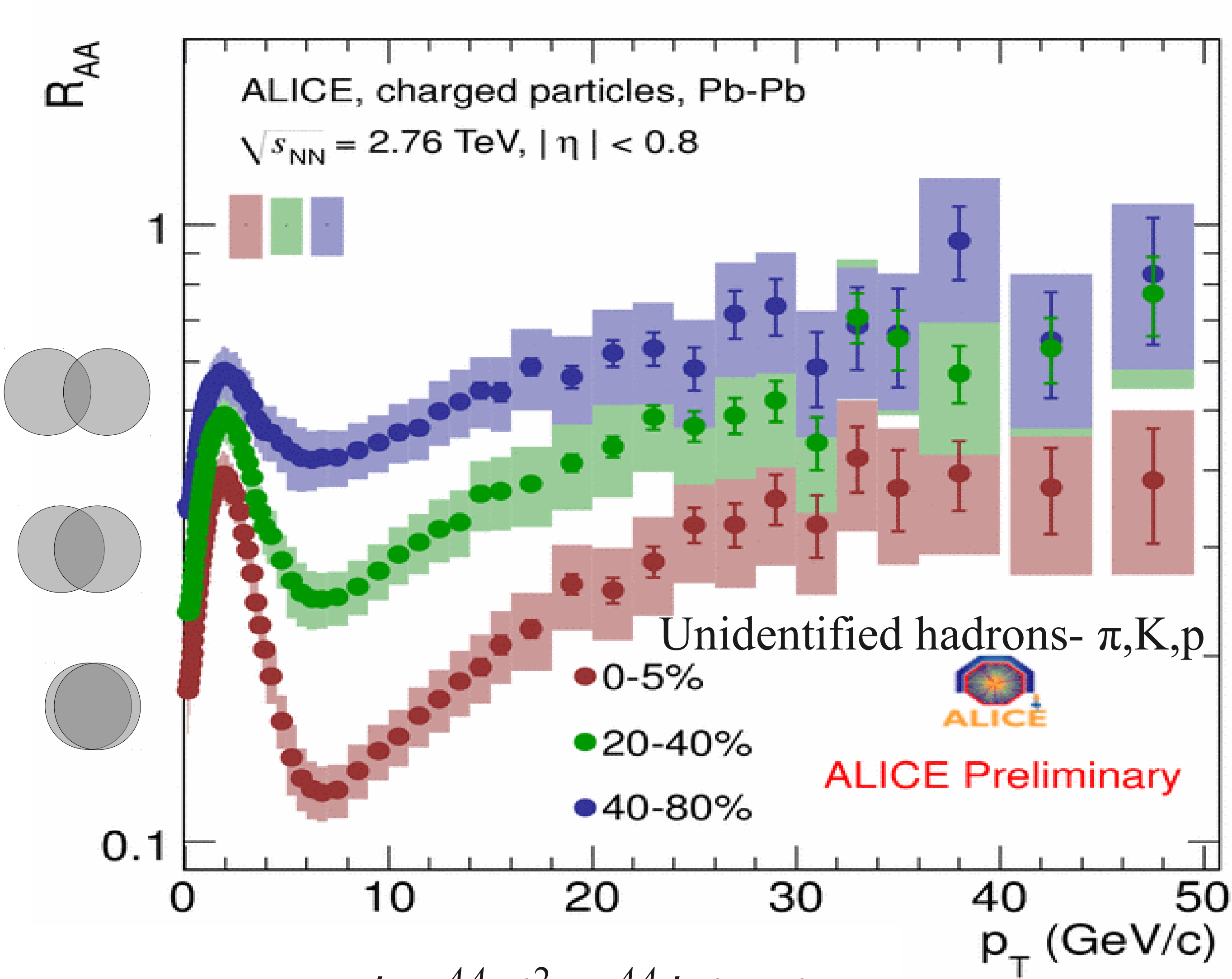
Assumption: sufficiently high-p_T hadrons mostly come from jets

Unmodified spectra:

$$R_{AA} = \frac{1/N_{evt}^{AA}\, d^2N_{ch}^{AA}/d\eta\, dp_T}{\langle N_{coll}\rangle (1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta\, dp_T}$$



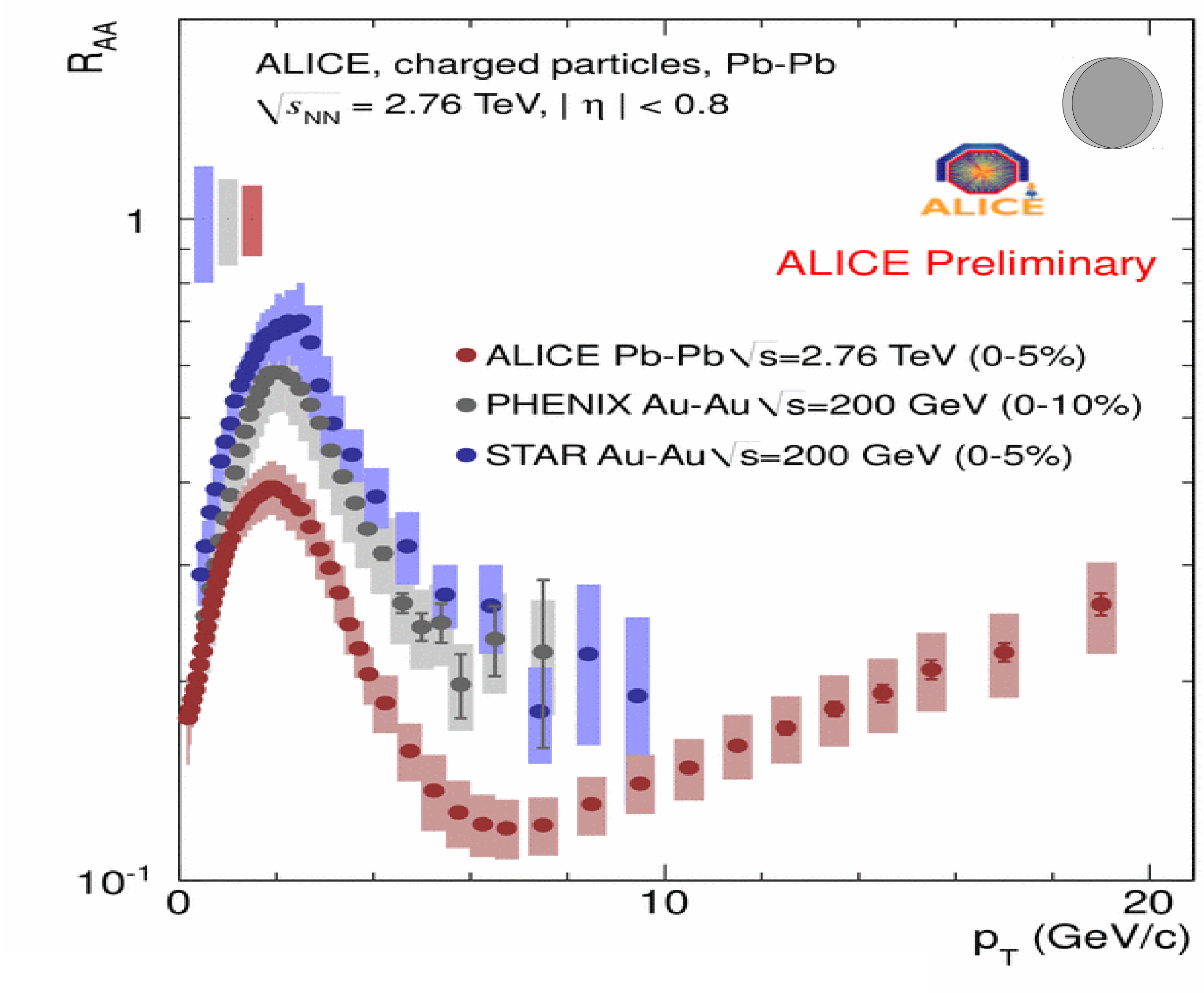
Nuclear modification factor (R_{AA})



Unidentified hadrons- π,K,p

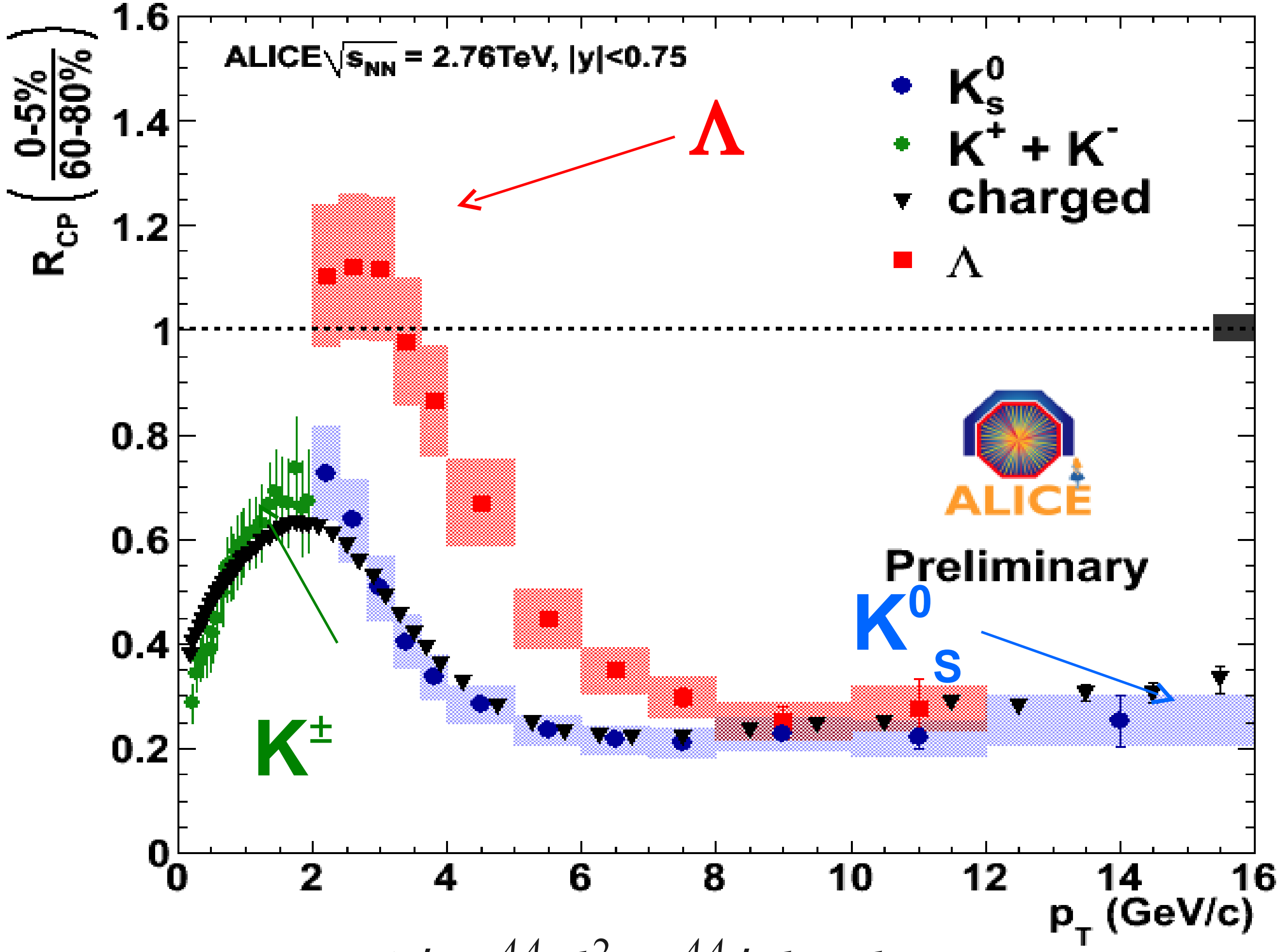
$$R_{AA} = \frac{1/N_{evt}^{AA}\, d^2 N_{ch}^{AA} / d\eta\, dp_T}{\langle N_{coll} \rangle (1/N_{evt}^{pp})\, d^2 N_{ch}^{pp} / d\eta\, dp_T}$$

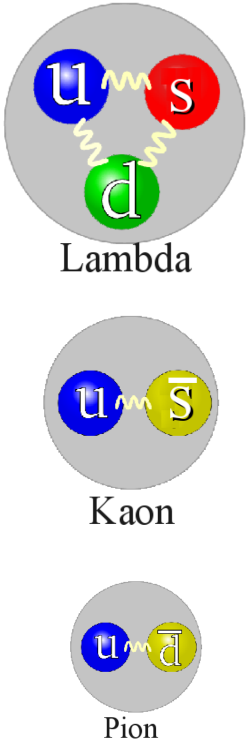
Nuclear modification factor (R_{AA})



$$R_{AA} = \frac{1/N_{evt}^{AA}\, d^2 N_{ch}^{AA} / d\eta\, dp_T}{\langle N_{coll} \rangle (1/N_{evt}^{pp})\, d^2 N_{ch}^{pp} / d\eta\, dp_T}$$

Nuclear modification factor (R_{AA})

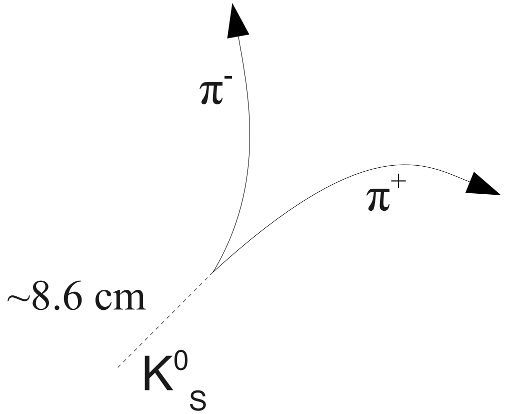




~1116 MeV/c^2

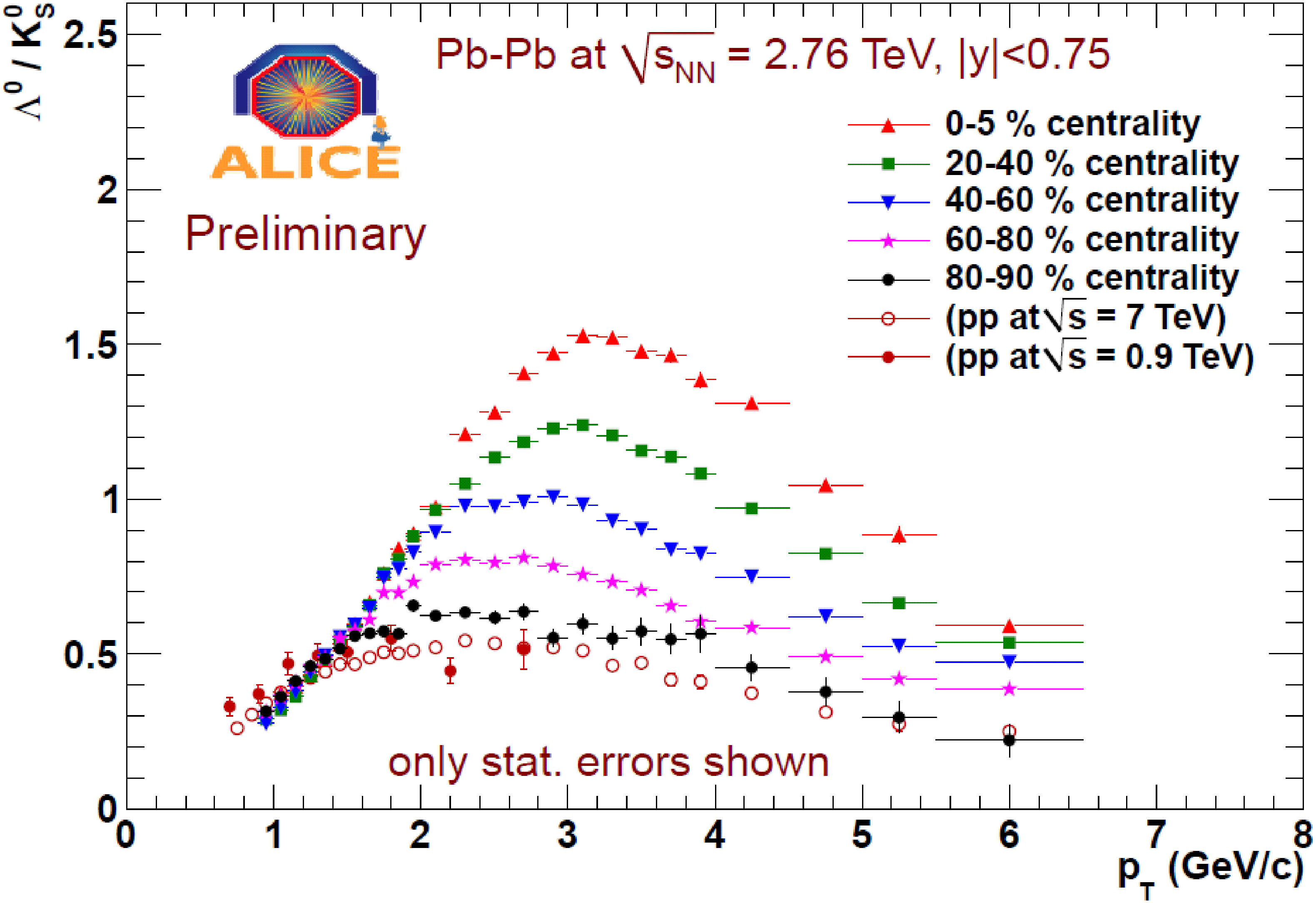
~494 MeV/c^2

~140 MeV/c^2

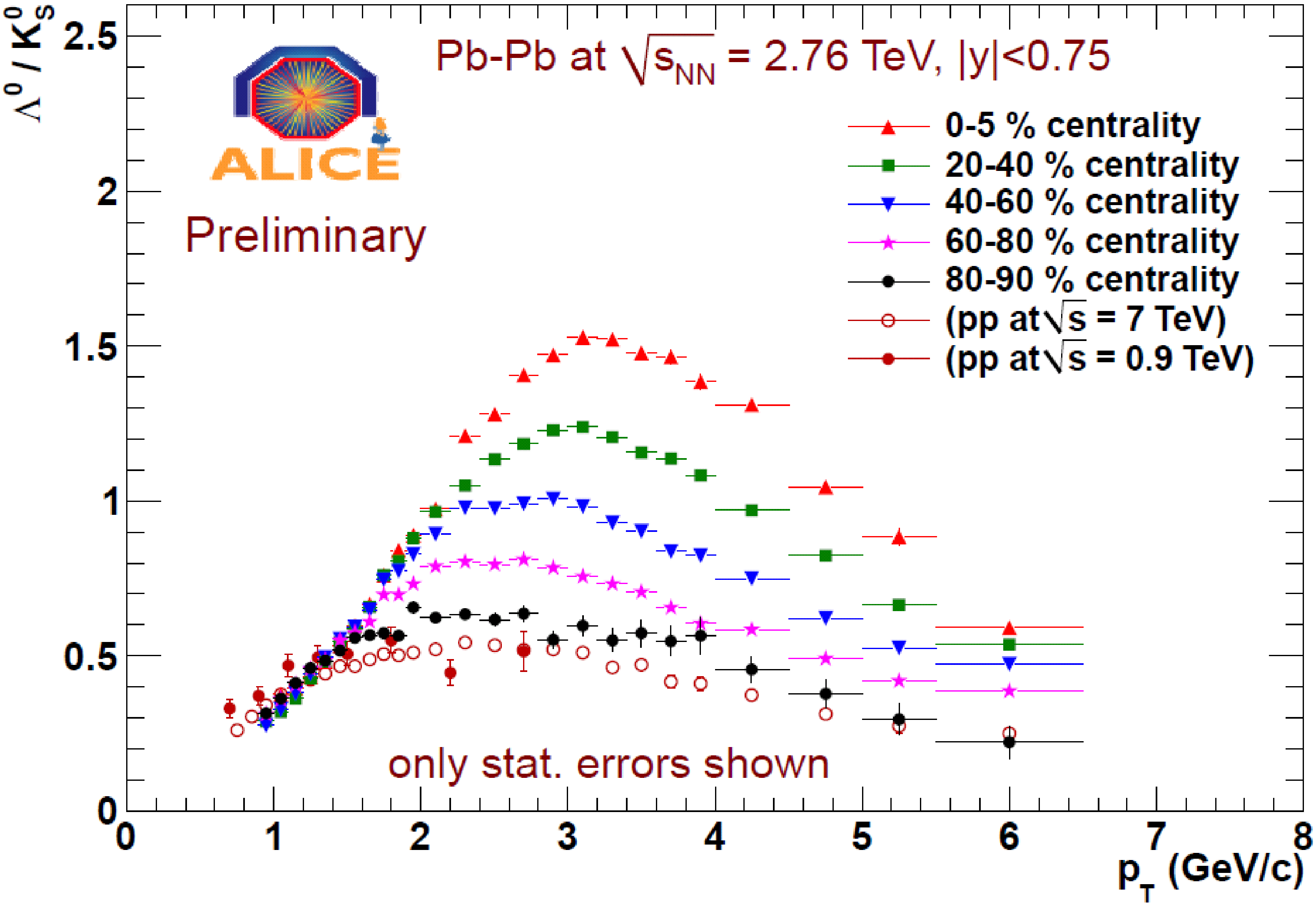


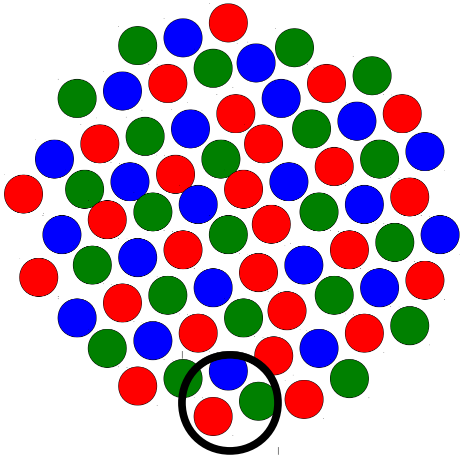
$$R_{AA} = \frac{1/N^{AA}_{evt}\, d^2 N^{AA}_{ch}/d\eta\, dp_T}{\langle N_{coll}\rangle (1/N^{pp}_{evt})\, d^2 N^{pp}_{ch}/d\eta\, dp_T}$$

Baryon anomaly: Λ/K^0_S



Baryon anomaly: Λ/K^0_S

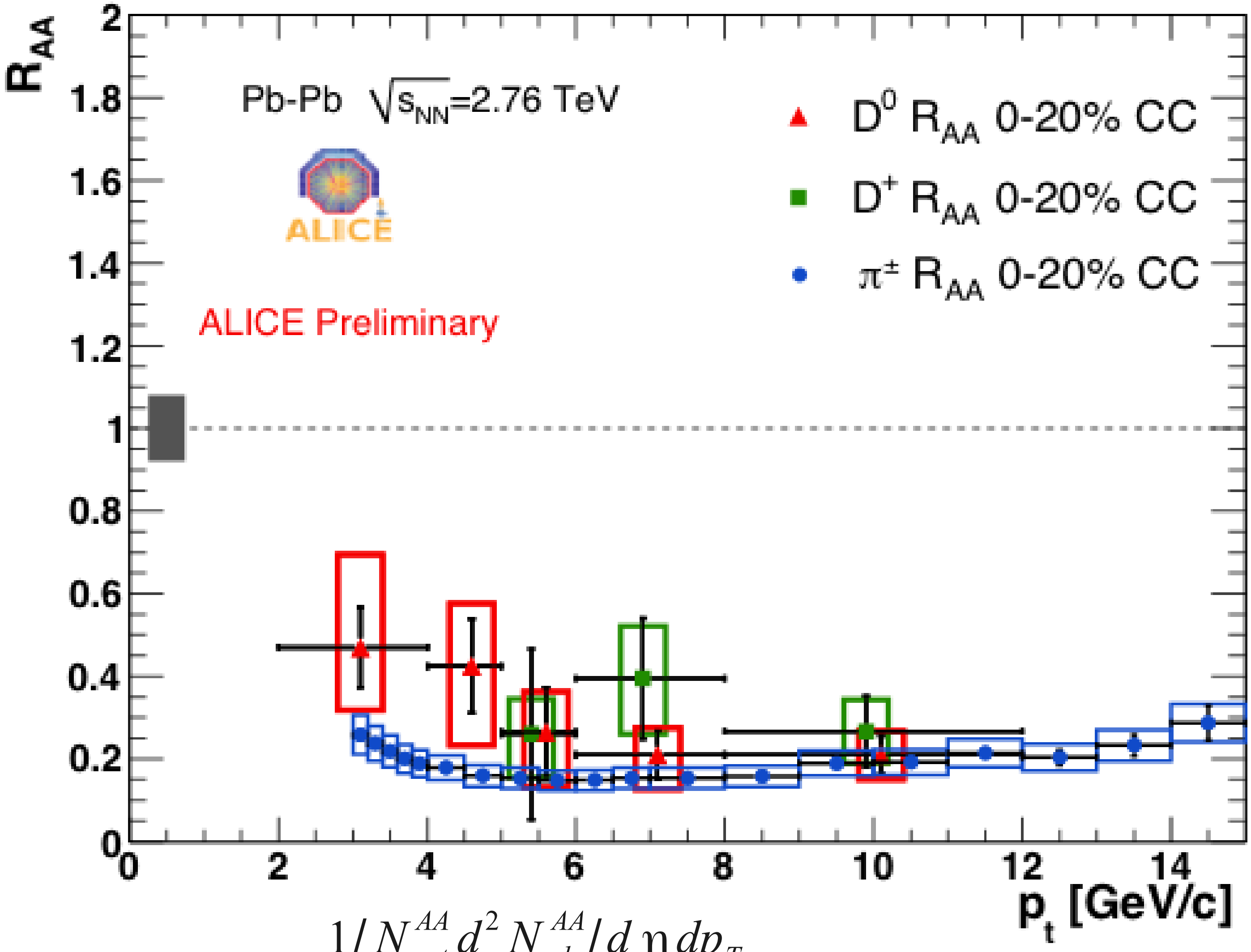




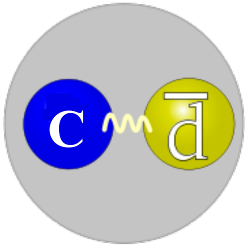
Recombination

Ann.Rev.Nucl.Part.Sci.58:177-205,2008

Charm nuclear modification factor

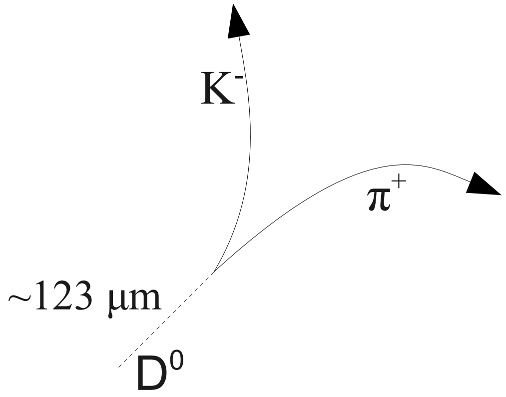


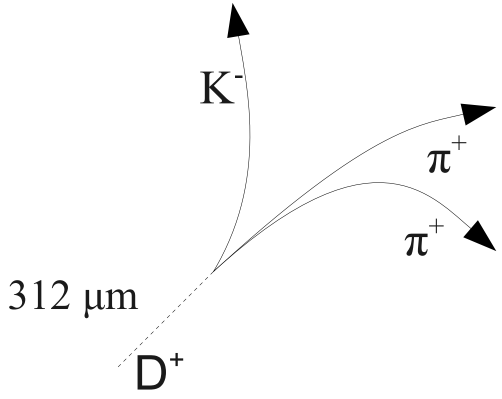
$$R_{AA}=\frac{1/N_{evt}^{AA}\,d^2N_{ch}^{AA}/d\eta\,dp_T}{\langle N_{coll}\rangle(1/N_{evt}^{pp})\,d^2N_{ch}^{pp}/d\eta\,dp_T}$$



D meson

~1865 MeV/c^2



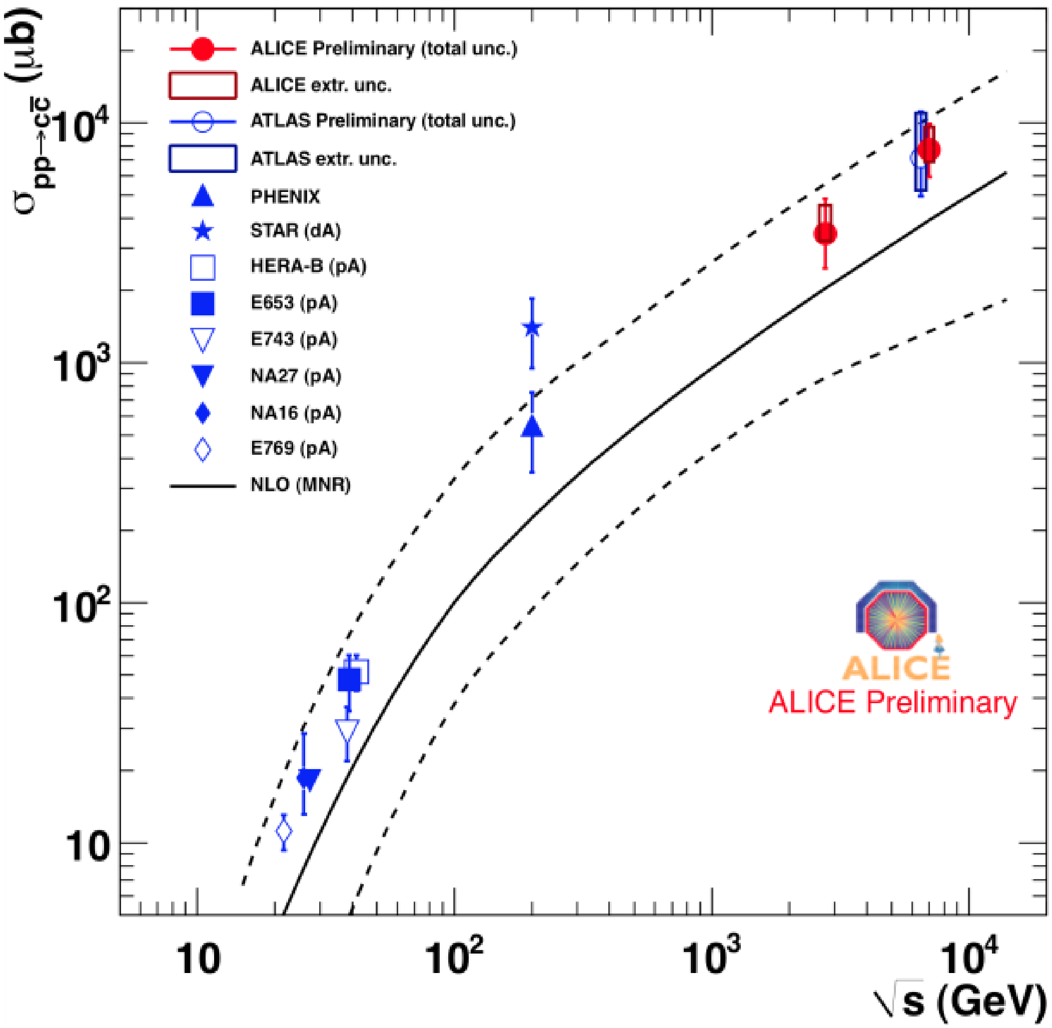


Conclusions

- Charged particle production and transverse energy follow same trends as seen at RHIC
- Energy higher than experimental extrapolation, lower than many models
- High p_T particle production suppressed to ~0.15 of what we would expect from scaling p+p collisions → hot, dense medium produced
- Significant suppression observed even for heavy quarks

Backup slides

Charm cross section



pp