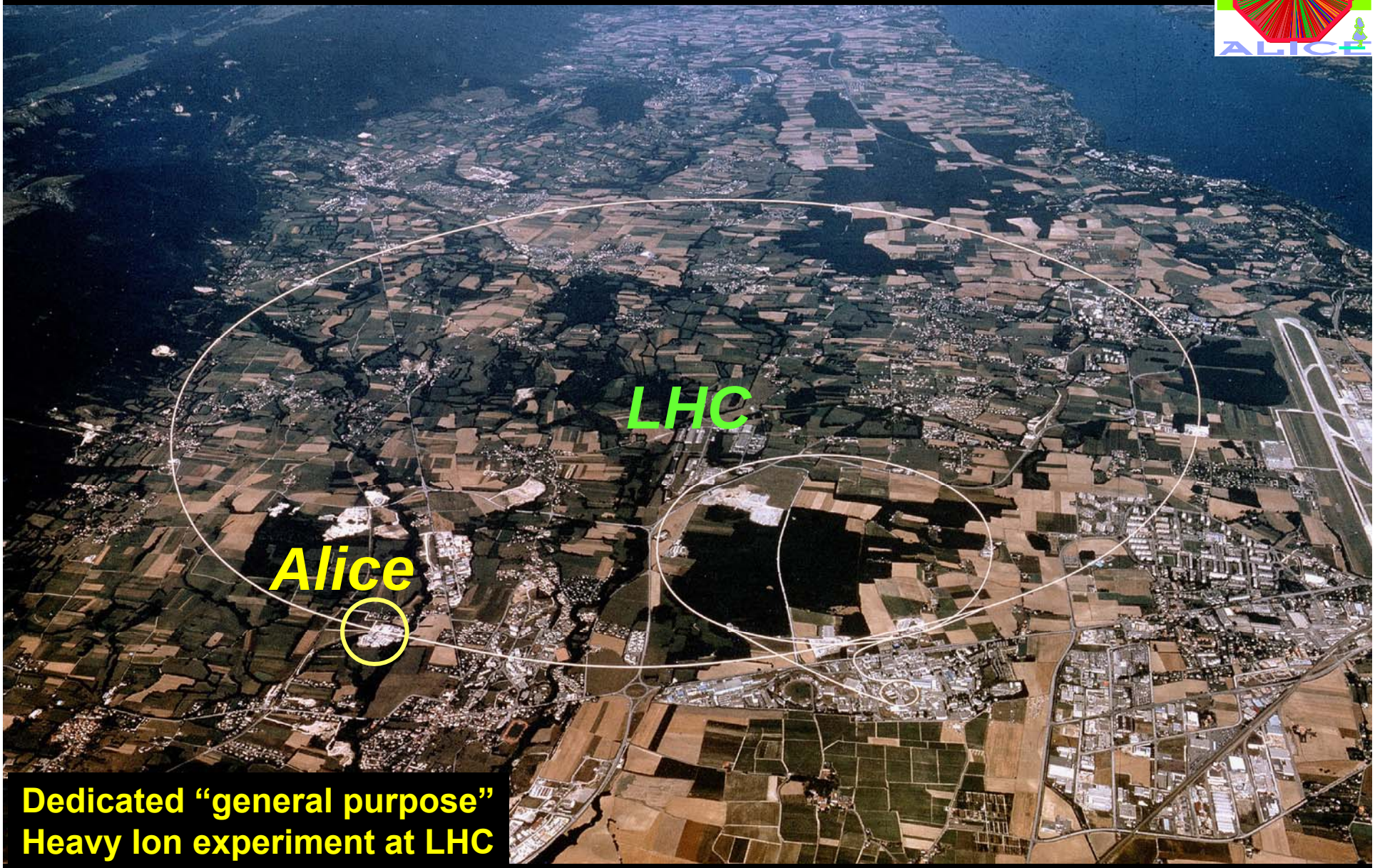
The ALICE Experiment at the LHC



Dedicated "general purpose" Heavy Ion experiment at LHC

ALICE Collaboration

~ 1000 Members

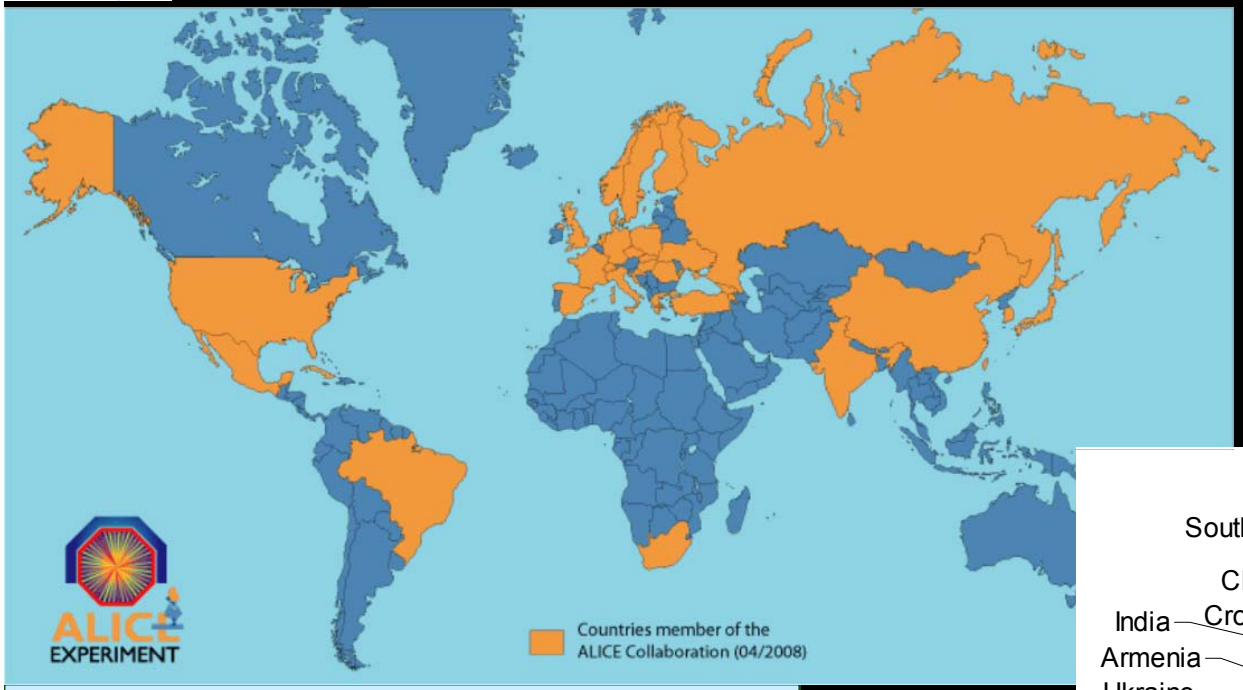
(63% - CERN States)

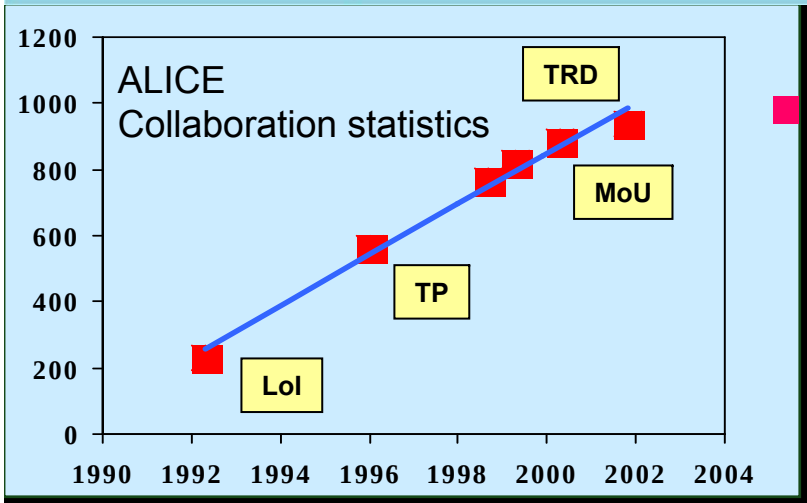
~ 30 Countries

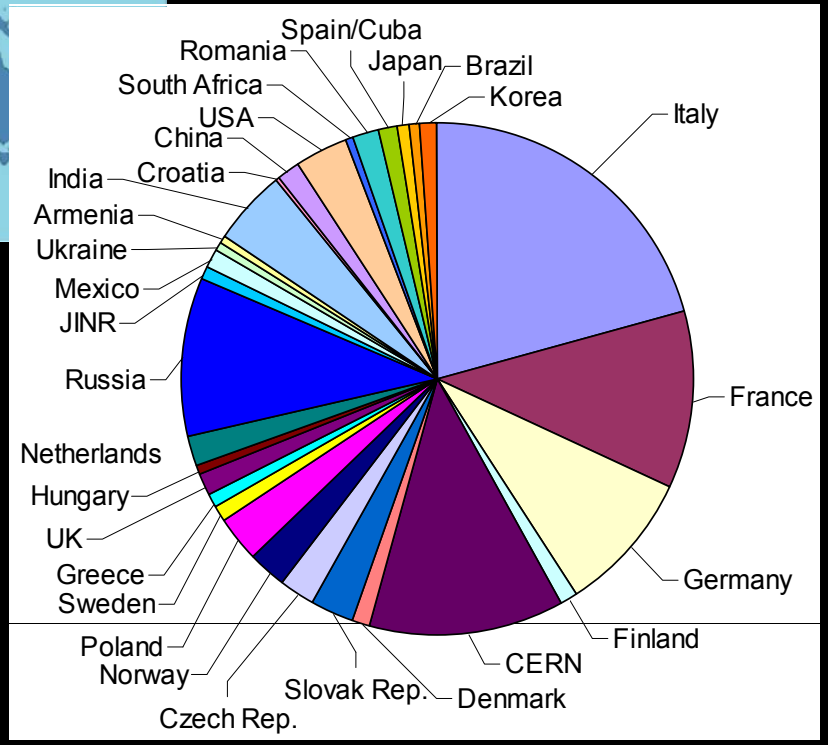
~ 100 Institutes

~ 150 M CHF capital

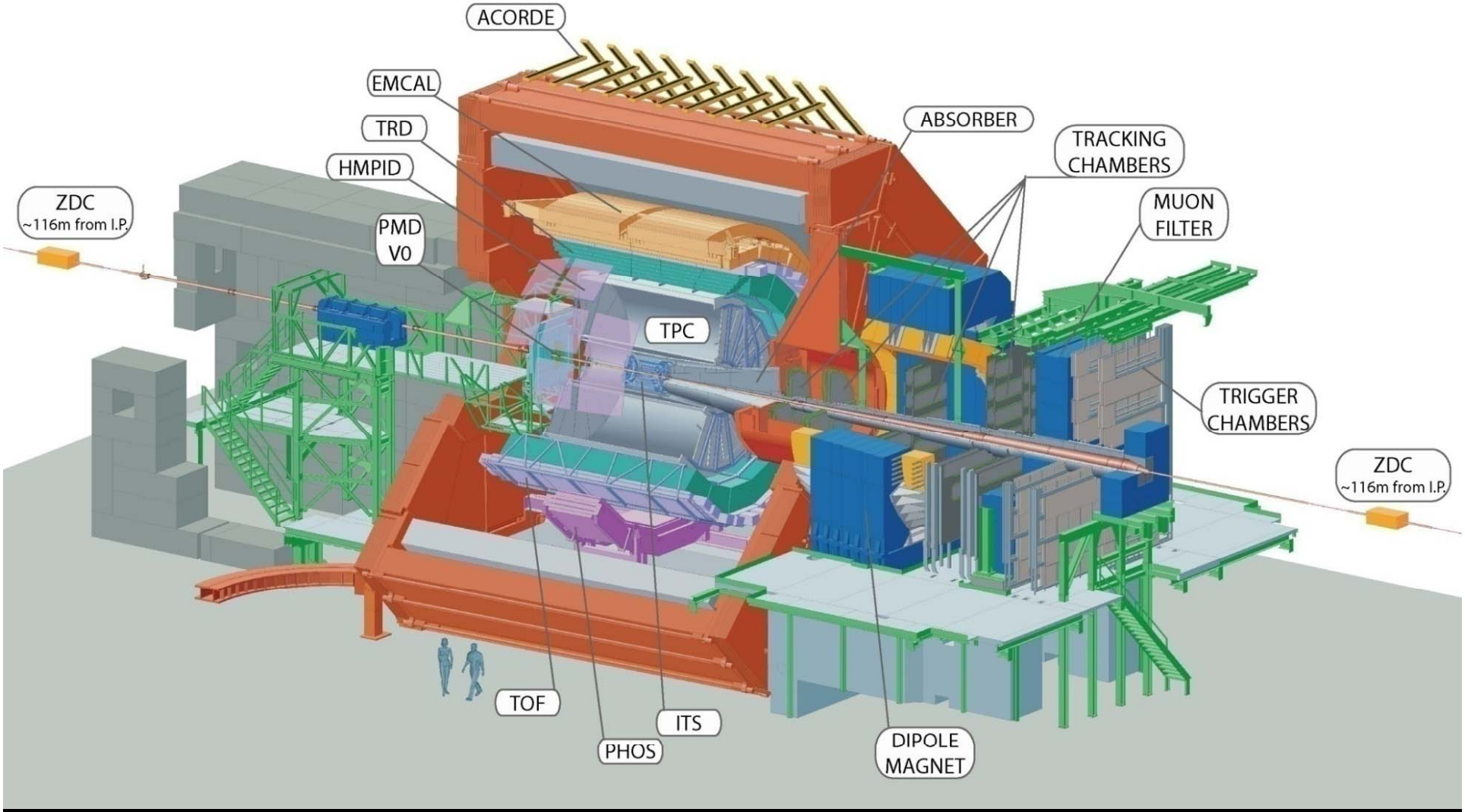
(+ magnet)



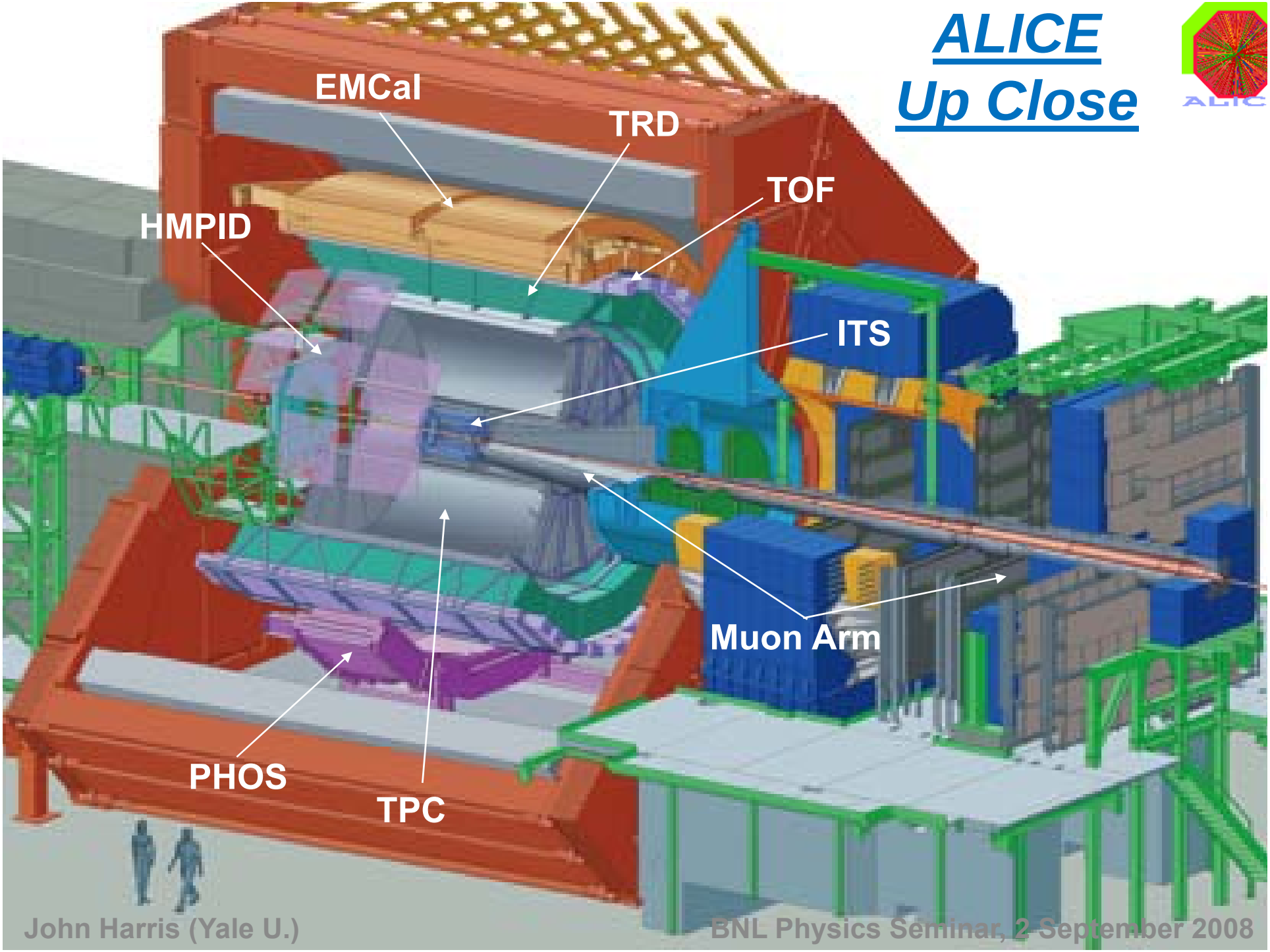




The ALICE Heavy Ion Experiment

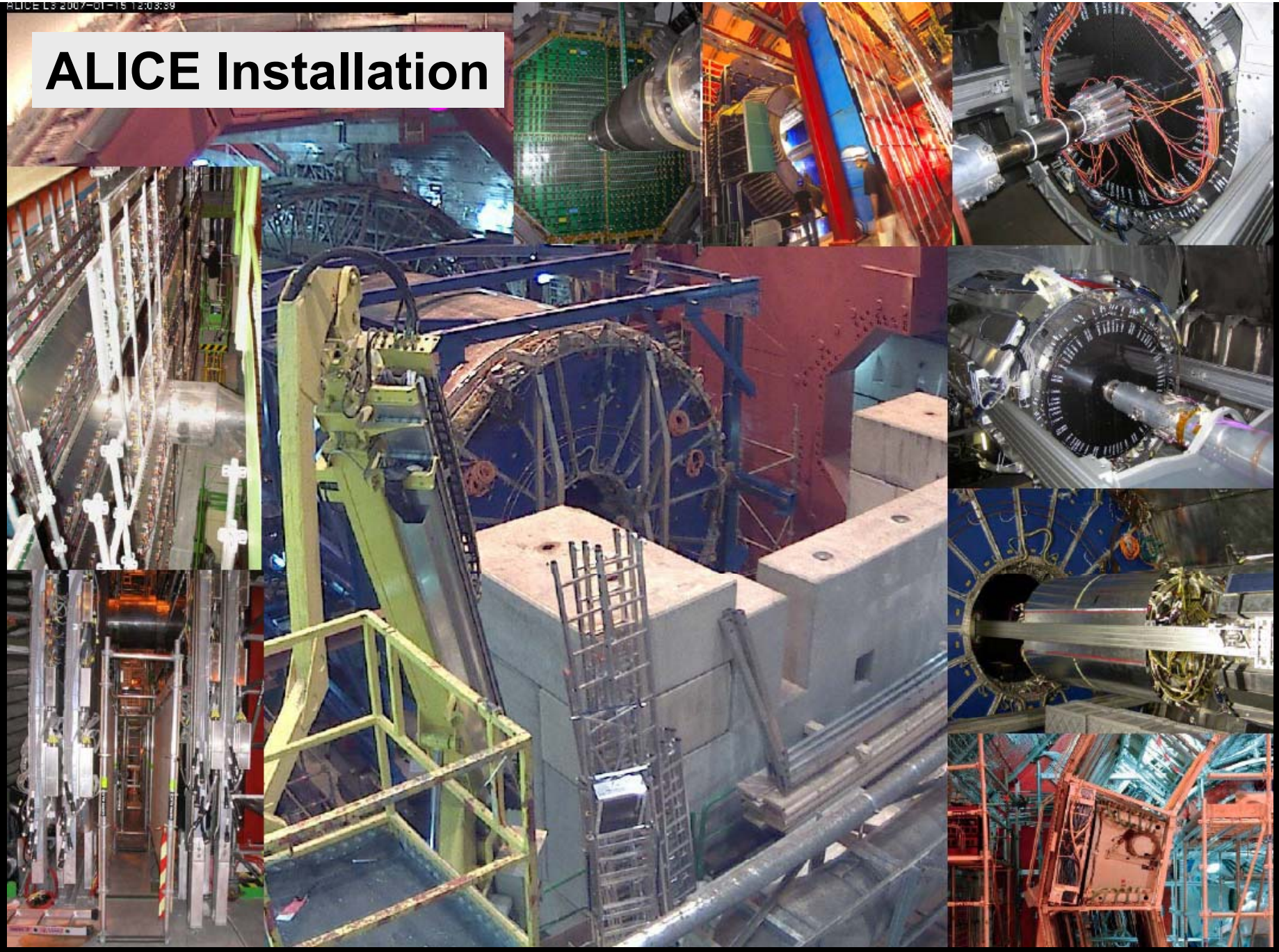


ALICE Up Close

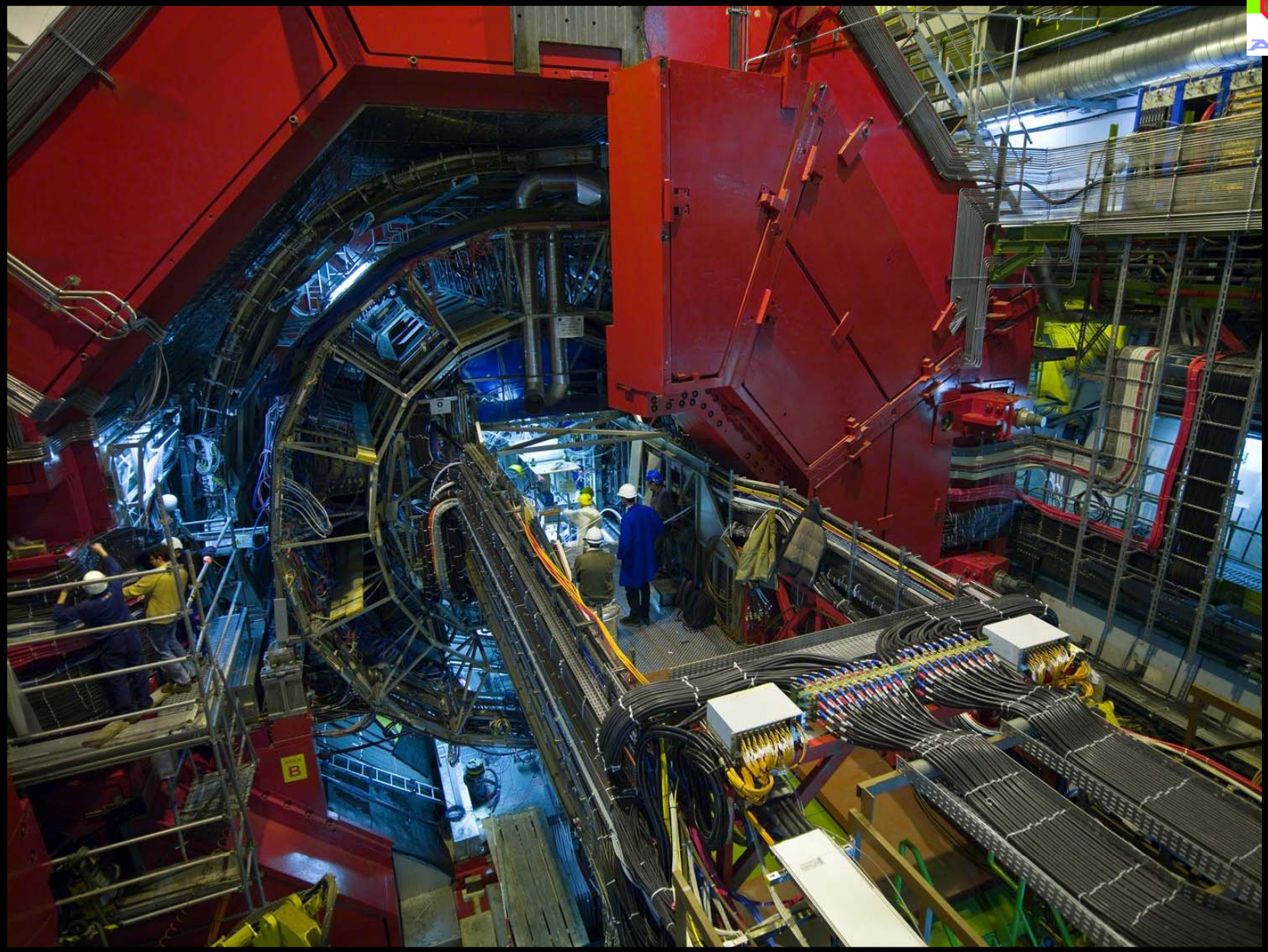


The ALICE Magnet (L3)

ALICE Installation



The ALICE Experiment



ALICE Detectors & Acceptance

central barrel ***-0.9 < η < 0.9***

- $\Delta\phi = 2\pi$ tracking, PID **(TPC/ITS/ToF)**
- single arm RICH **(HMPID)**
- single arm e.m. cal **(PHOS)**
- jet calorimeter **(proposed EMCal)**

forward muon arm ***2.4 < η < 4***

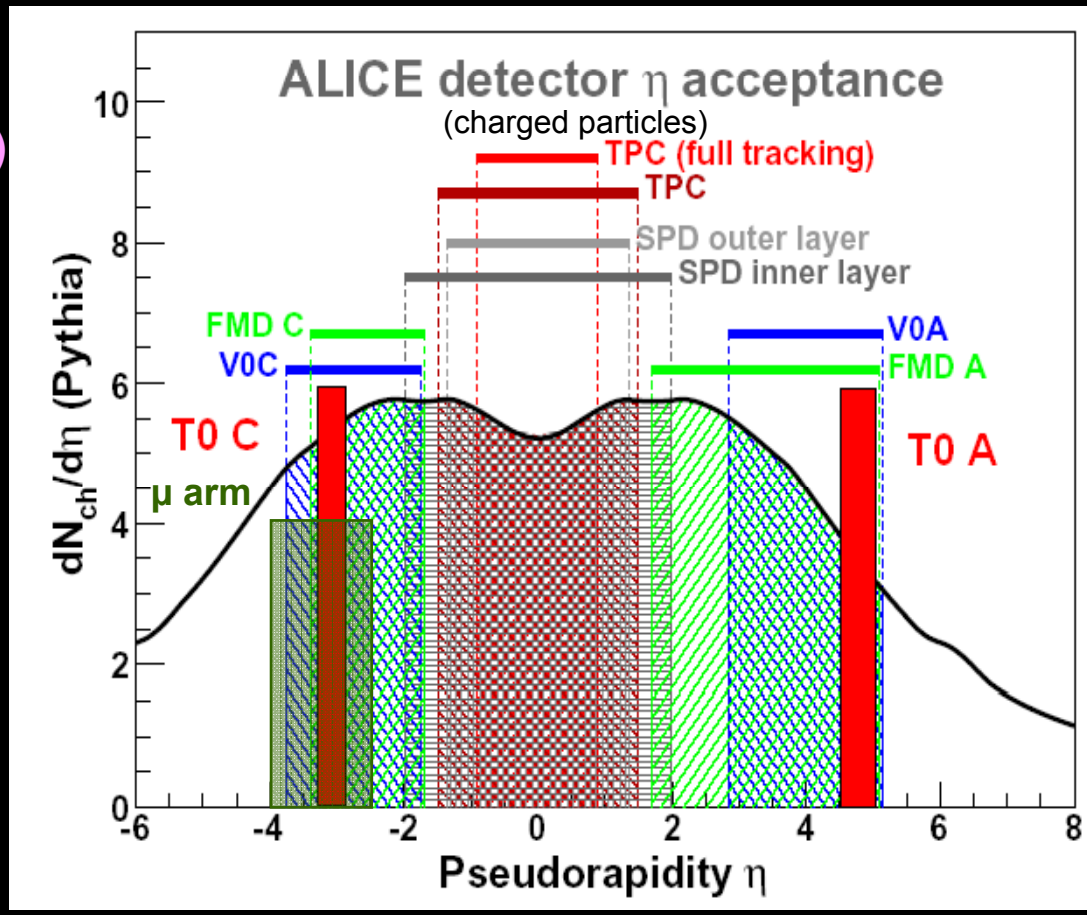
- absorber, 3 T-m dipole magnet
  10 tracking + 4 trigger chambers

multiplicity detectors ***-5.4 < η < 3***

- including photon counting in **PMD**

trigger & timing detectors

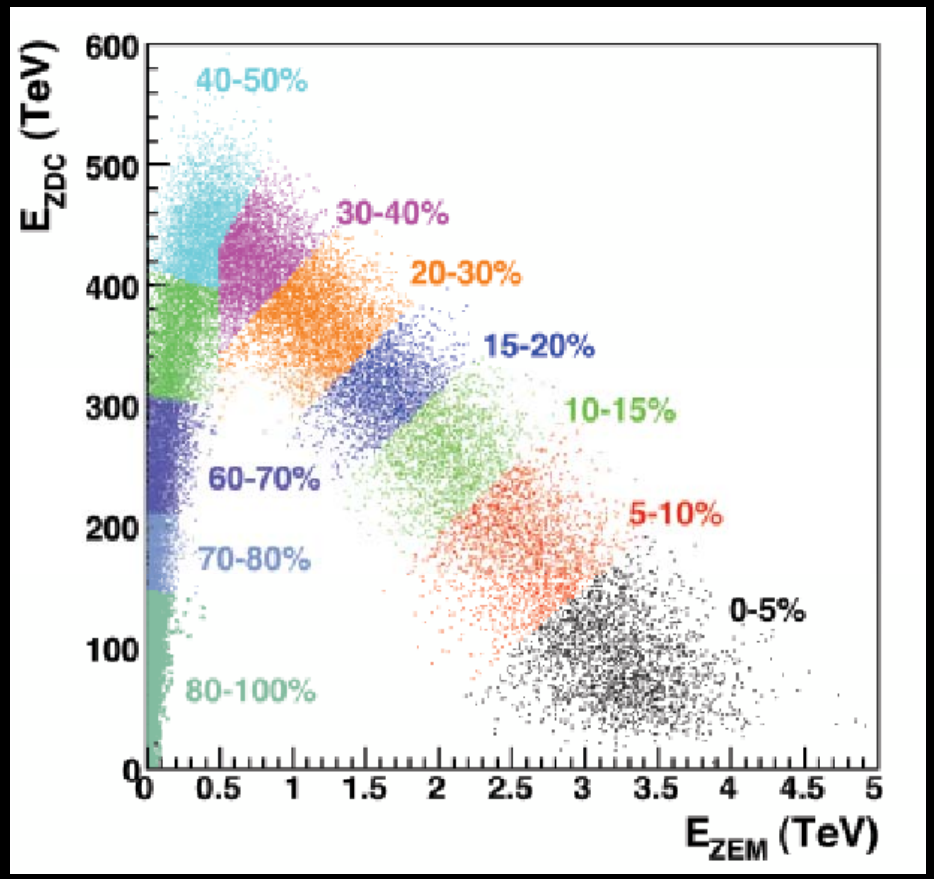
- 6 **Zero Degree Calorimeters**
- **T0:** ring of quartz window PMT's
- **V0:** ring of scint. Paddles

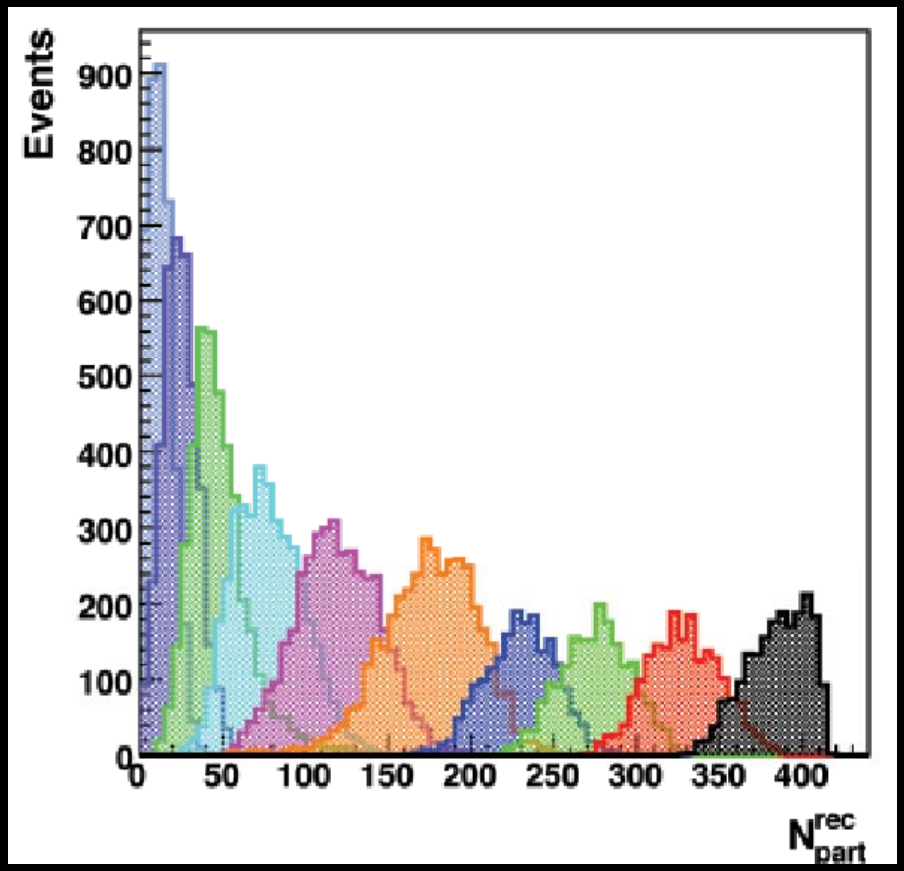


Centrality Determination in ALICE

Event by event determination of centrality:
Zero Degree Calorimeters (ZDC) +
Z Electro-Magnetic calorimeters (ZEM)

E(ZDC) , E(ZEM) → N_{spec} → N_{part} → Impact parameter (b)



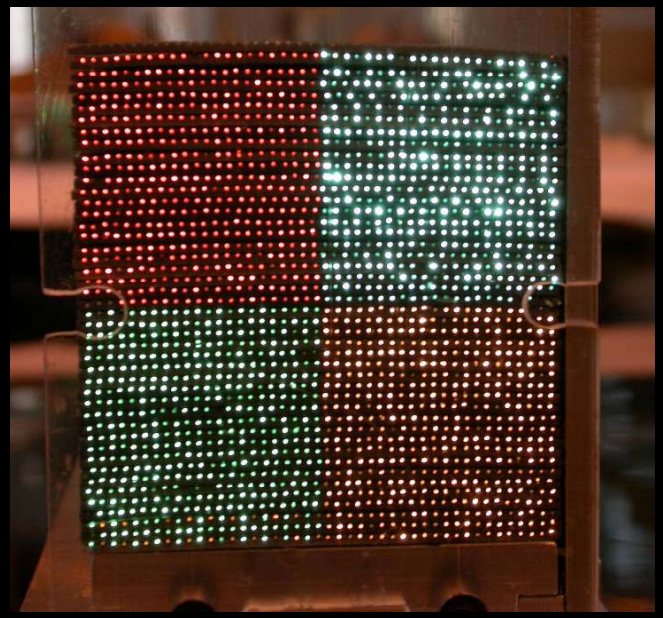


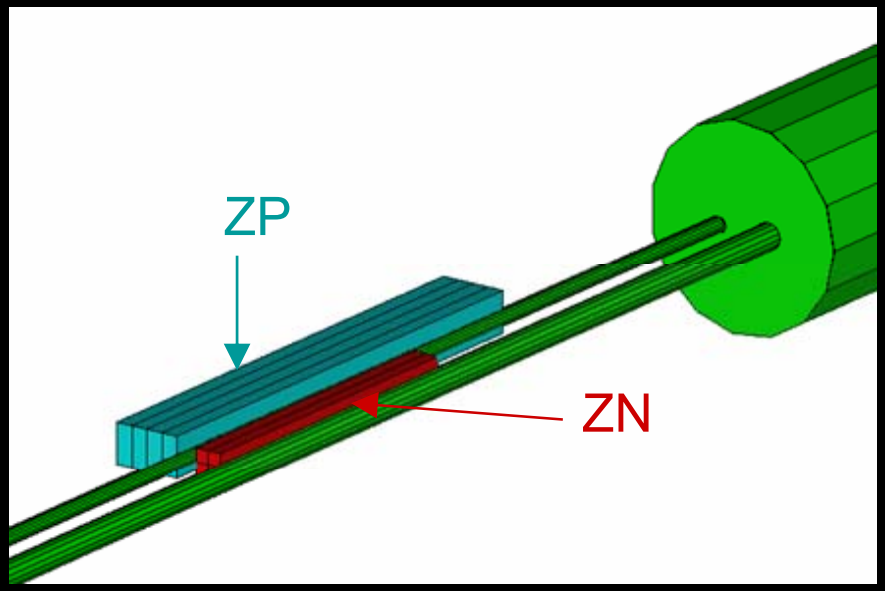
Zero Degree Calorimeters (ZDC)

- **Forward calorimeters**
  - 8 m (ZEM cal.) and 116 m (ZP, ZN) from IP
  - trigger on impact parameter (spectators)
  - v_1 measurement
    - event plane
  - impact parameter in pA
    - effective A^{α} dependence

	Proton ZDC (ZP)	Neutron ZDC (ZN)	EM ZDC
Dimensions (cm^3)	12x21x150	7x7x100	7x7x21
Absorber	brass	W-alloy	lead
Fibre angle wrt LHC axis	0°	0°	45°
Fibre ∅ (μm)	550	365	550

ZDC (ZN)



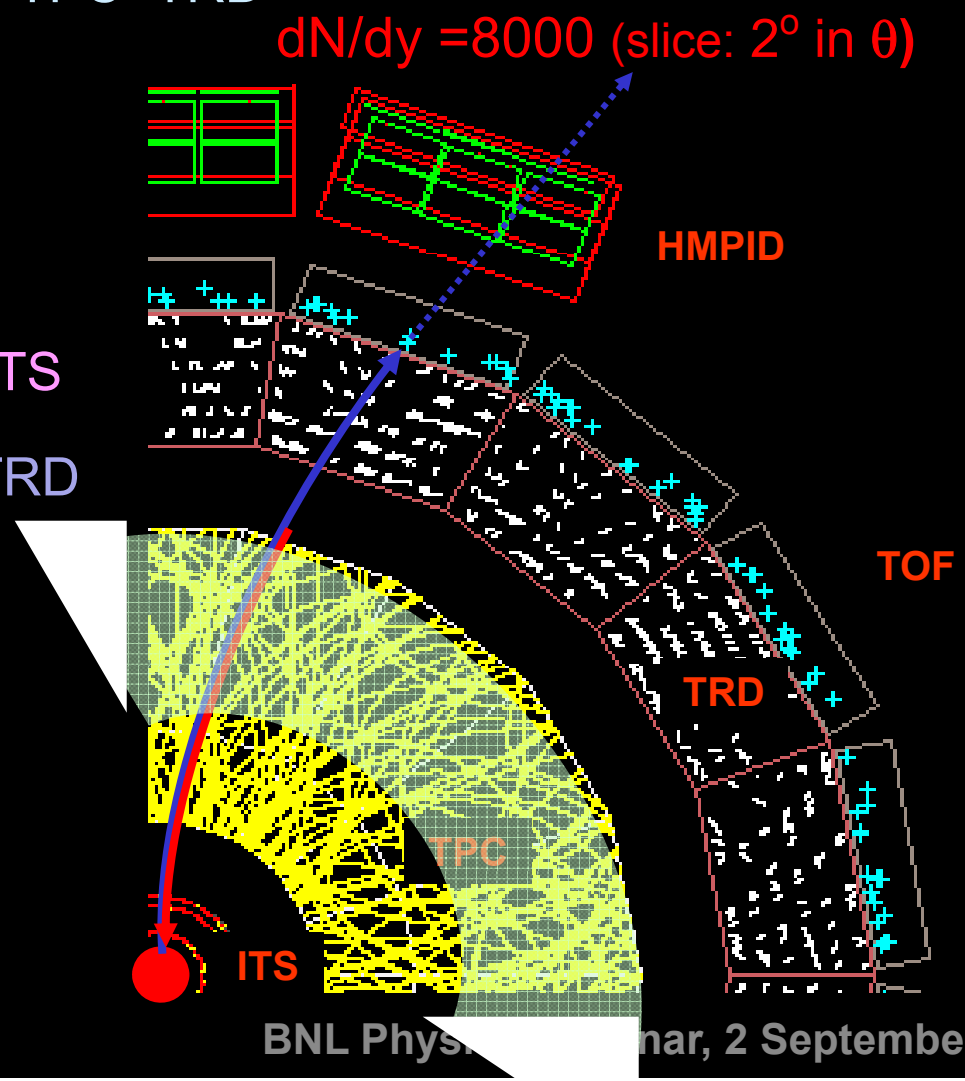


ALICE - Global Tracking

Parallel Kalman Filtering

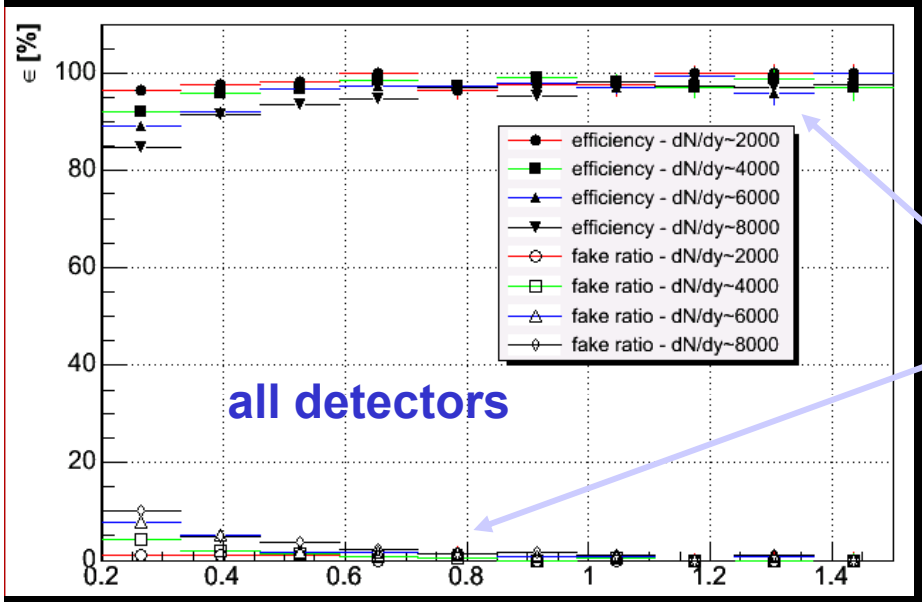
After cluster finding, start iterative process through central tracking detectors, ITS+TPC+TRD

- Primary Vertex from ITS
- Track seed in outer TPC
- Propagate to vertex, track in ITS
- Back-propagate in TPC and TRD
- Extrapolate and connect to outer PID detectors
- Final refit inwards (for V0, 1-prong decays)

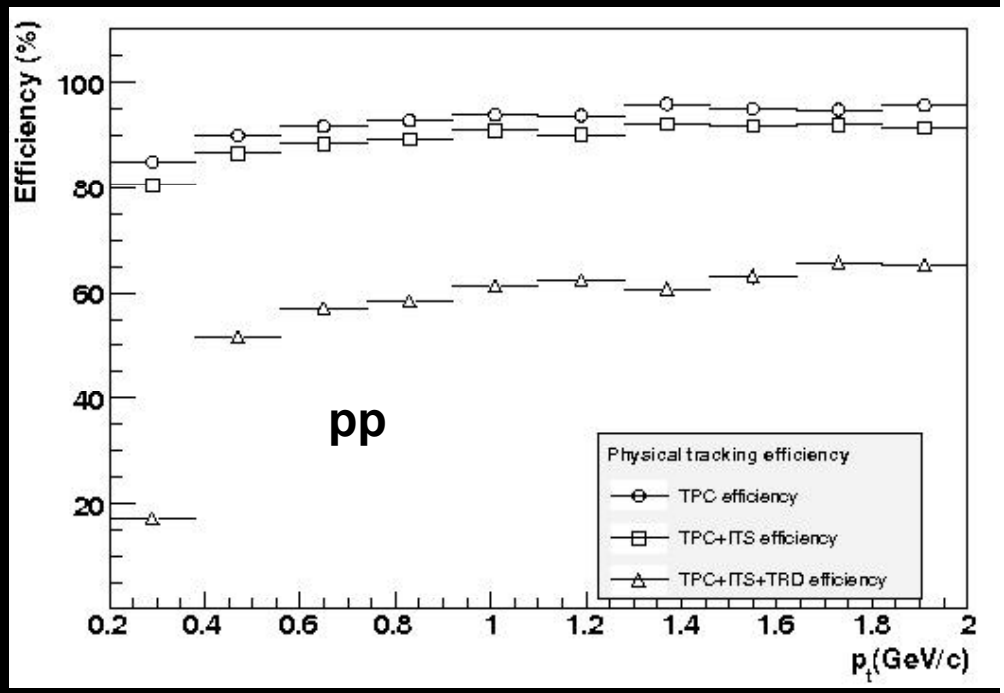


Track Efficiency

Challenge in high-particle density environment



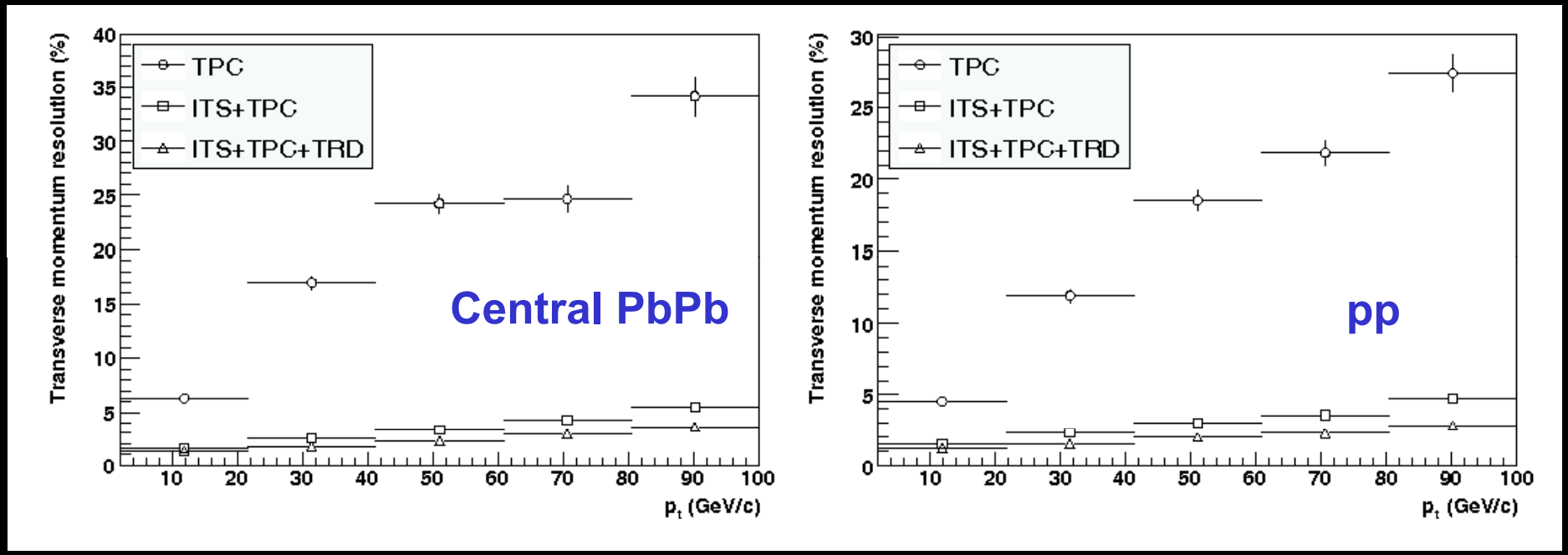
For realistic particle densities
dN/dy = 2000 – 4000
- combined efficiency well above 90%
- and fake track probability below 5%



Efficiency normalized to number of generated particles at primary vertex within the central acceptance |η|<0.9
protons – large absorption
kaons – decays on flight

Momentum Resolution

Robust, redundant tracking from < 100 MeV/c to > 100 GeV/c
Little dependence on dN/dy to dN/dy ≈ 8000



at low momentum dominated by

- ionization-loss fluctuations
- multiple scattering

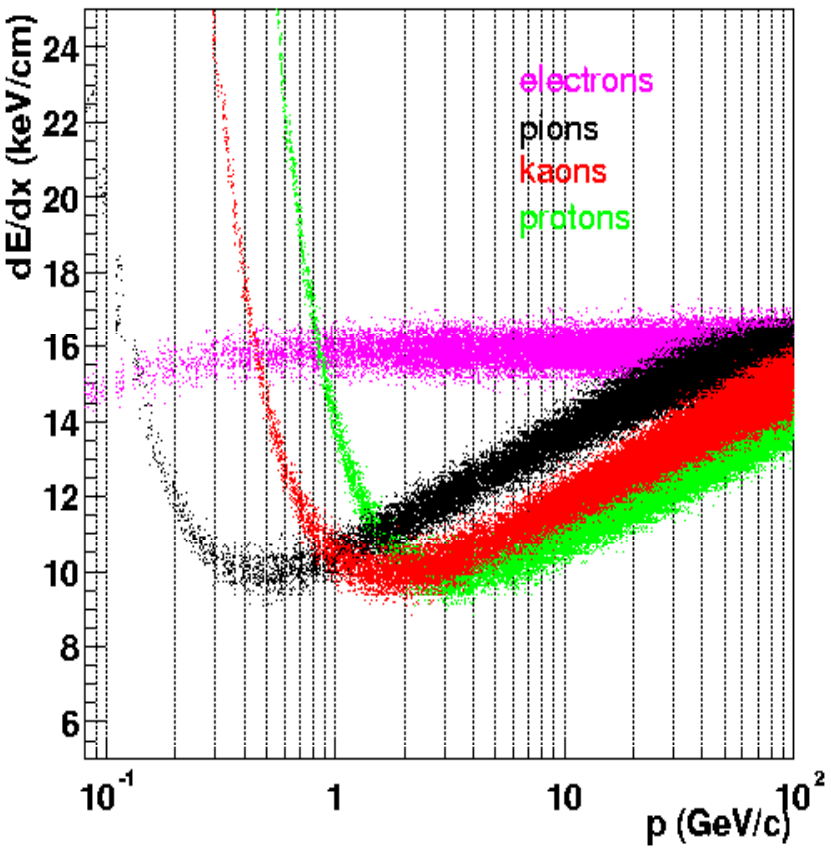
at high momentum determined by

- point measurement precision
- and the alignment & calibration

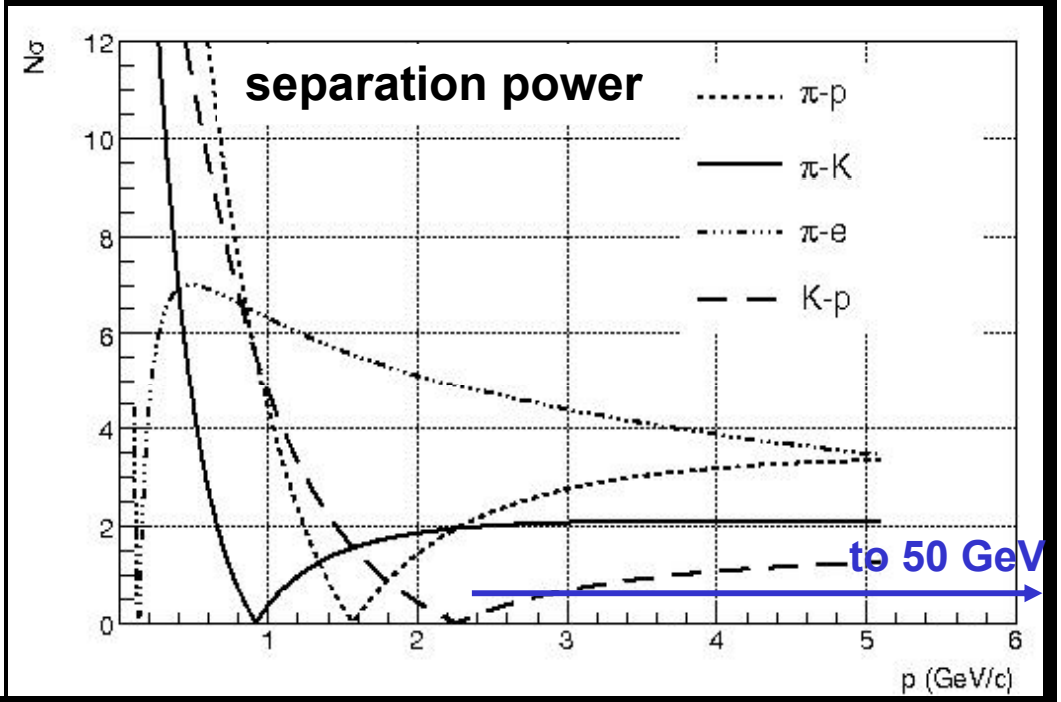
Energy Loss (dE/dx) and PID in the TPC

Bethe-Bloch formula

$$\frac{\overline{\Delta E}}{\Delta x} = 2C\frac{m_e c^2}{\beta^2}\frac{Zz^2}{A}\rho\left[\frac{1}{2}\ln\left(\frac{2\gamma^2\beta^2 m_e c^2 E_{\max}}{I_0^2}\right) - \beta^2 - \frac{\varepsilon}{2} - \frac{\delta(\beta)}{2}\right]$$



~6.5% resolution in central Pb+Pb



Identified Particle Spectra

Particle reconstruction and identification capabilities: unique to ALICE

Global tracking (ITS-TPC-TRD) + dE/dx (low p_T + relativ. rise), TOF, HMPID, PHOS, …

Invariant mass, topological reconstruction

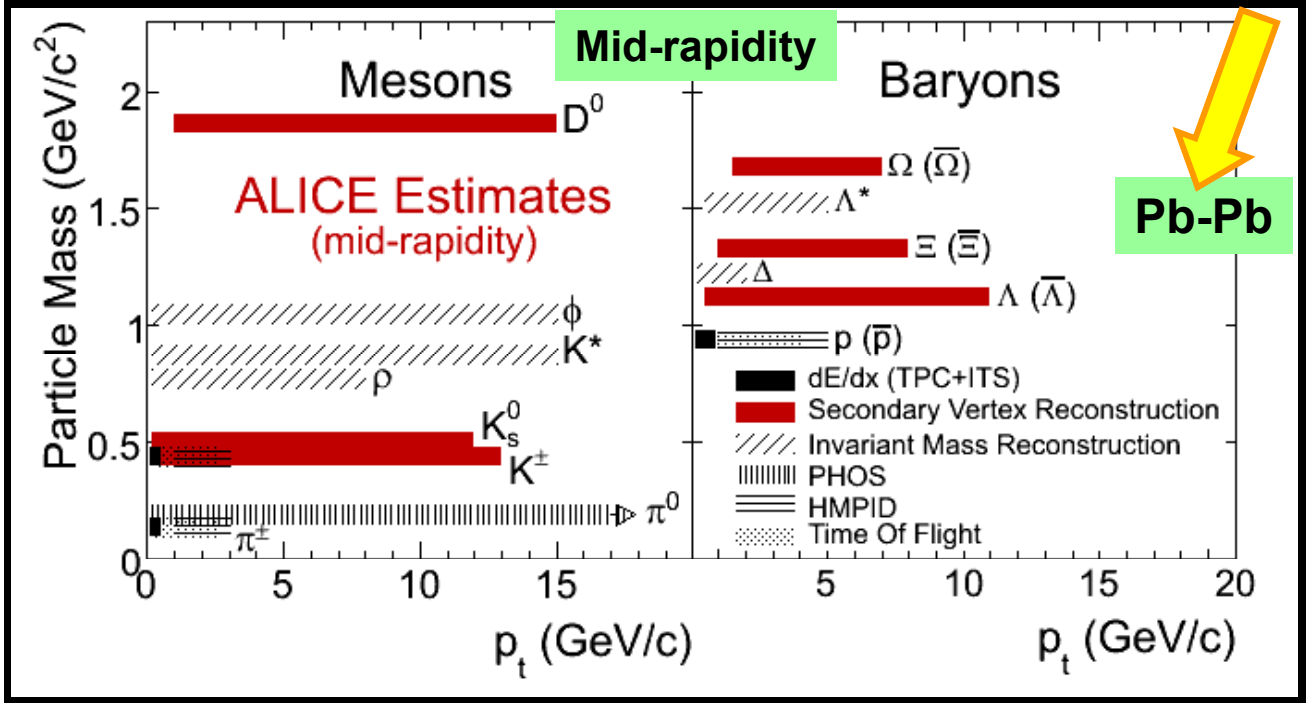
Acceptance / efficiency / reconstruction rate (ε) / contamination

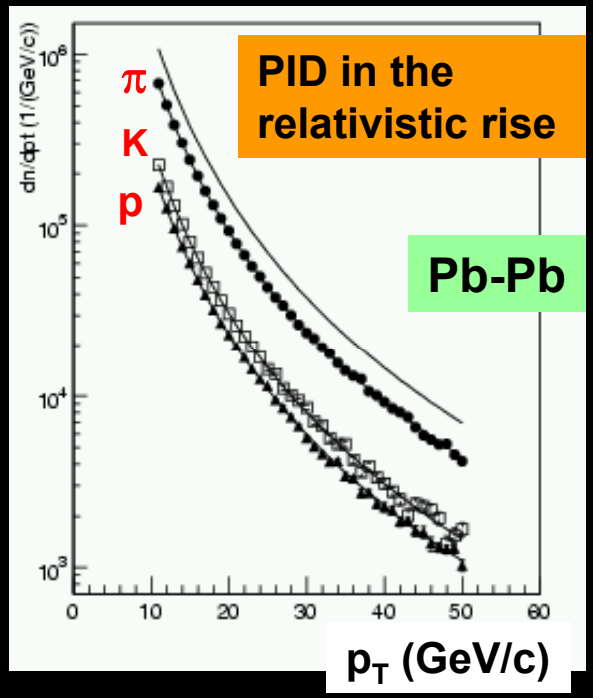
p_T range (PID or stat. limits) for 10^7 central Pb-Pb and 10^9 min. bias pp

For ~ 20 particle species for -1 < y < +1 and -4 < y < +2.5

π, K, p: 0.1- 0.15 to 50 GeV

Weak or strong decaying particles: to 10-15 GeV

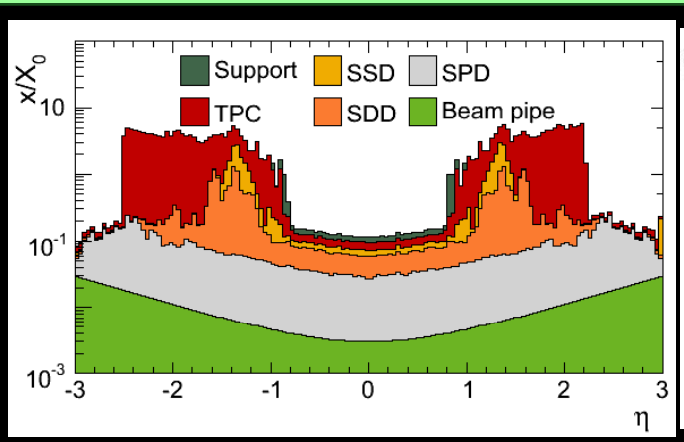


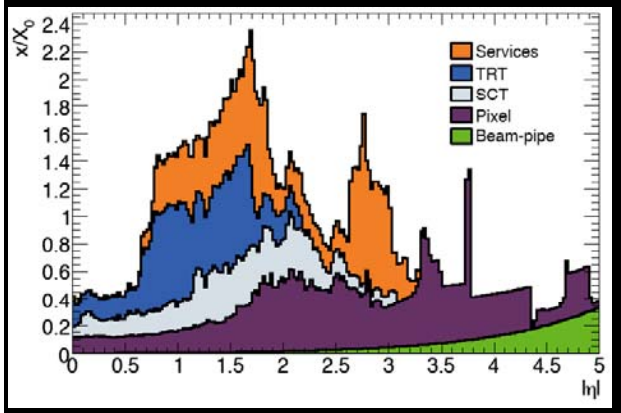


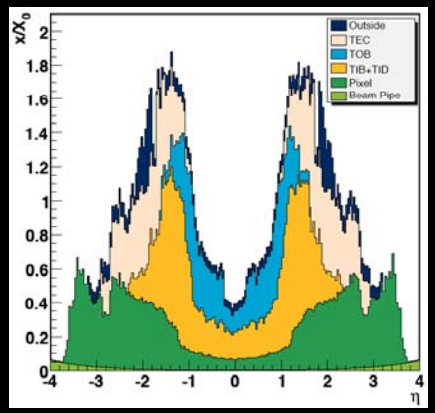
Material Budget

Cumulative mid-rapidity material budget for ALICE, ATLAS and CMS

ALICE	x/X_0 (%)	ATLAS	x/X_0 (%)	CMS	x/X_0 (%)
Beam pipe	0.26	Beam pipe	0.45	Beam pipe	0.23
Pixels (7.6 cm)	2.73	Pixels (12 cm)	4.45	Pixels (10.2 cm)	7.23
ITS (50 cm)	7.43	SCT (52 cm)	14.45	TIB (50 cm)	22.23
TPC (2.6 m)	13	TRT (1.07 m)	32.45	TOB (1.1 m)	35.23







⇨ Ideal Reconstruction and identification low p_T : lowest material budget

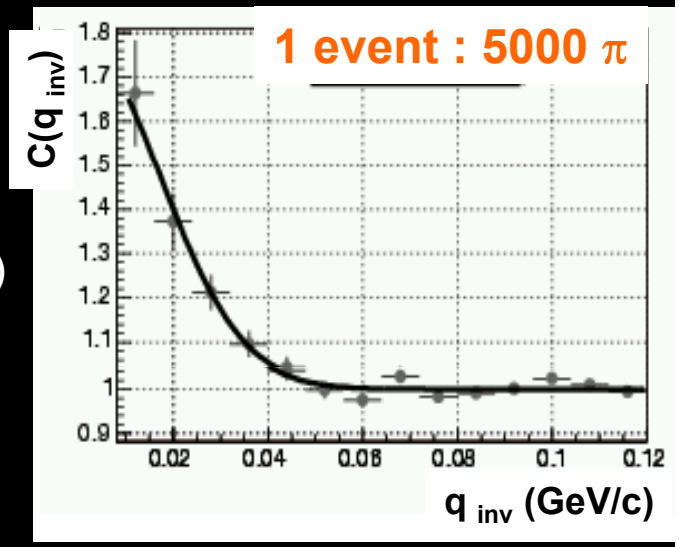
Heavy Ion Physics at the LHC

LHC Heavy Ions –

- guided by pQCD predictions
- expectations (detector simulations) based on RHIC extrapolations and theory
- lesson from RHIC – guided by theory + versatility + **"expect the unexpected"**

Soft Physics at LHC –

- smooth extrapolation from **SPS → RHIC → LHC?**
- expansion will be different (v_2, HBT, T_{chem} & T_{kin}, strange/charm particles & resonances)



Soft Physics in ALICE

"ala RHIC"

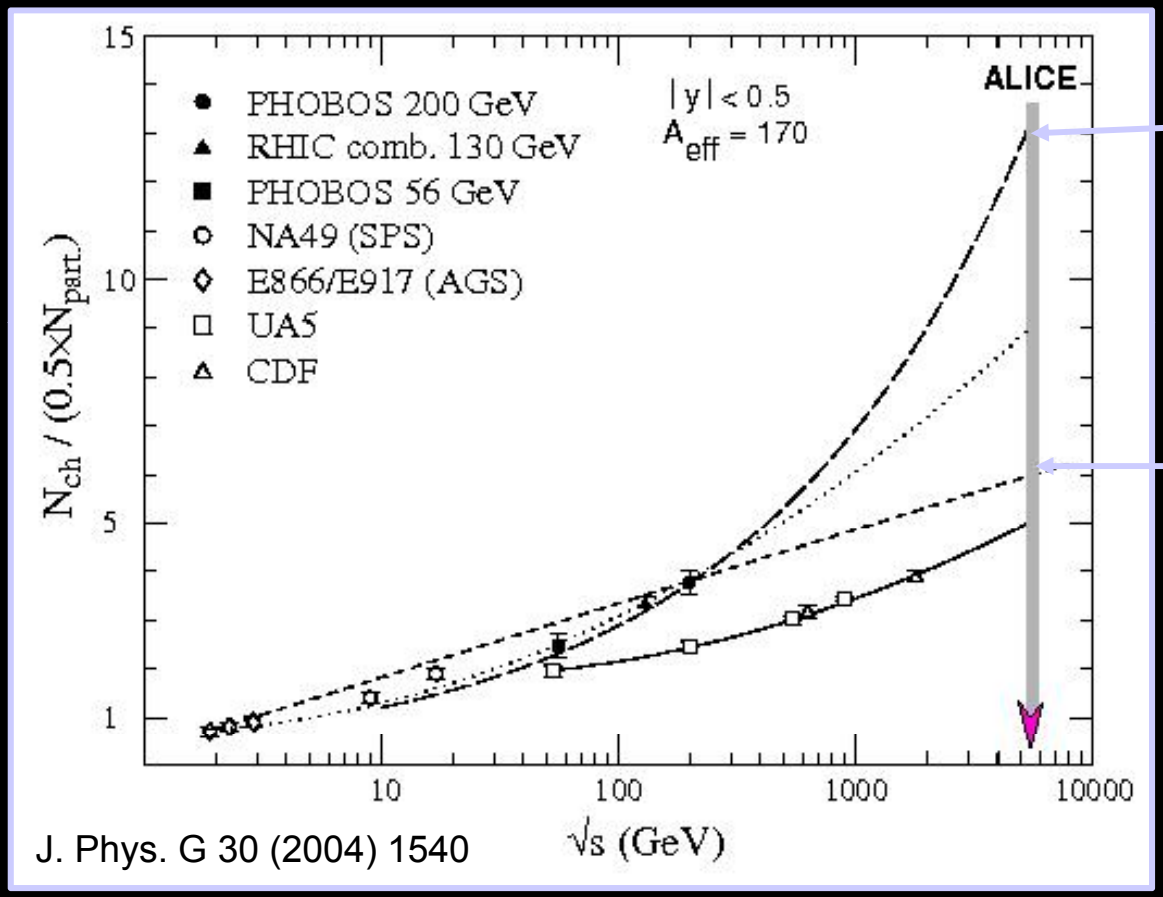
- Expansion dynamics different from RHIC due to timescales, densities
- All soft physics measurements as at RHIC so far (+ extended PID)
- Day 1 physics +

Event Characterization (baseline, shadowing, CGC, ….)

- Multiplicity, centrality, transverse momentum and pseudo-rapidity distributions

Charged-Particle Multiplicity Density

Integrated multiplicity distributions from Au-Au/Pb-Pb collisions and scaled pp collisions



J. Phys. G 30 (2004) 1540

$dN_{ch}/dy = 2600$

saturation model

Eskola hep-ph/050649

$dN_{ch}/dy = 1200$

ln(√s) extrapolation

ALICE designed (before RHIC) for $dN_{ch}/dy = 3500$
design checked up to $dN_{ch}/dy = 7000$

Soft Physics in ALICE

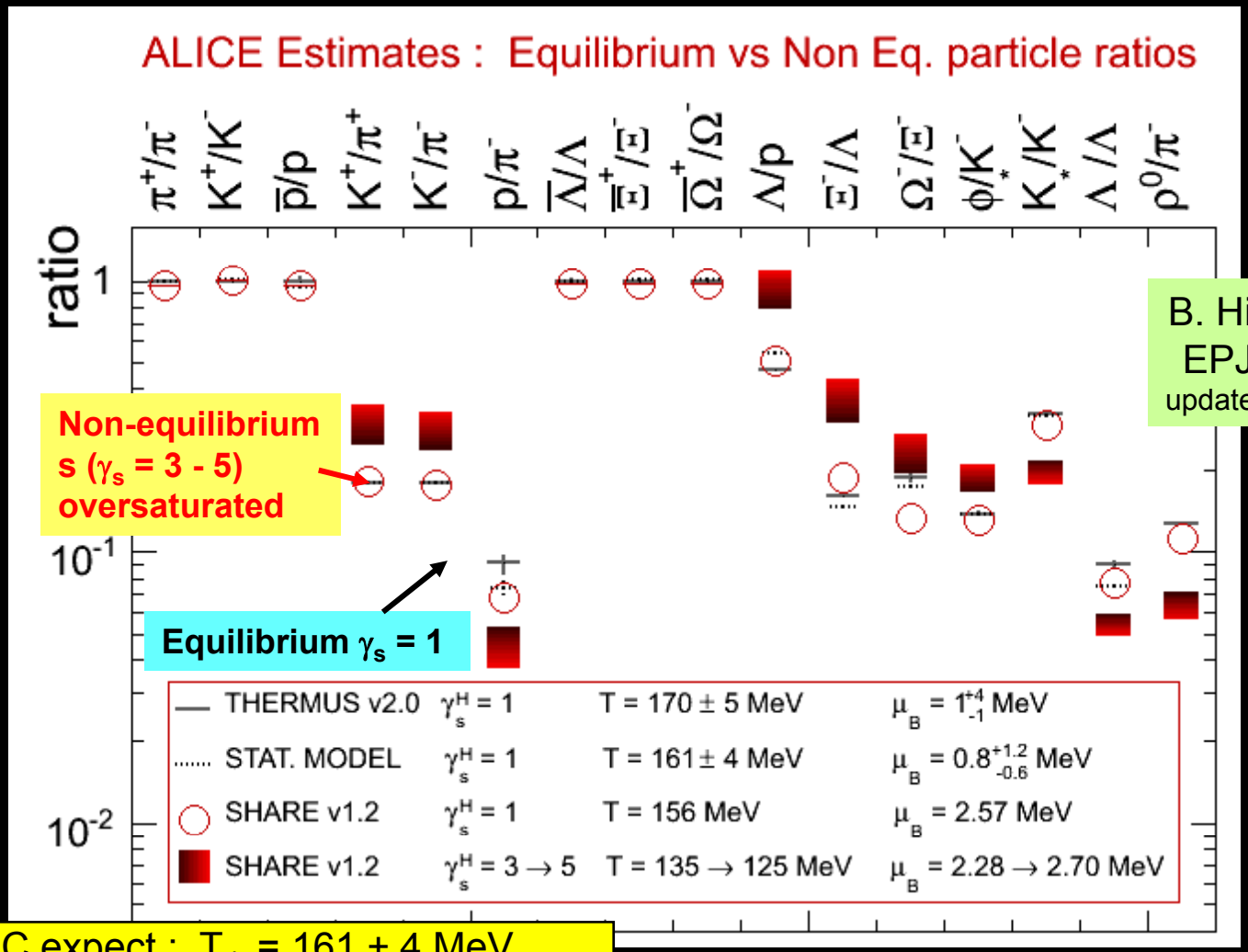
Event Characterization (baseline, shadowing, CGC, ….)

- Multiplicity, centrality, transverse momentum and pseudo-rapidity distributions

Bulk Properties of the Medium (T, μ, …)

- Particle ratios, hadronic resonances

Equilibrium / Non-Equilibrium at LHC?



B. Hippolyte et al.
EPJ C49 (2007)
updated with 0707.4154

⇨ at LHC expect : T_{ch} = 161 ± 4 MeV
μ_B = 0.8+1.2-0.6 MeV

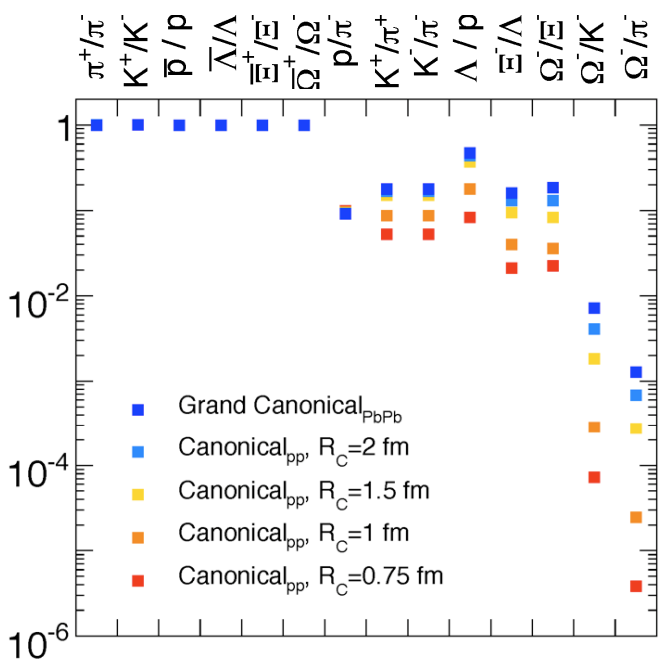
Many additional questions: strangeness enhancement? Correlation volume? Evolution in pp & PbPb?

Hadro-production: equilibrium vs. non equilibrium

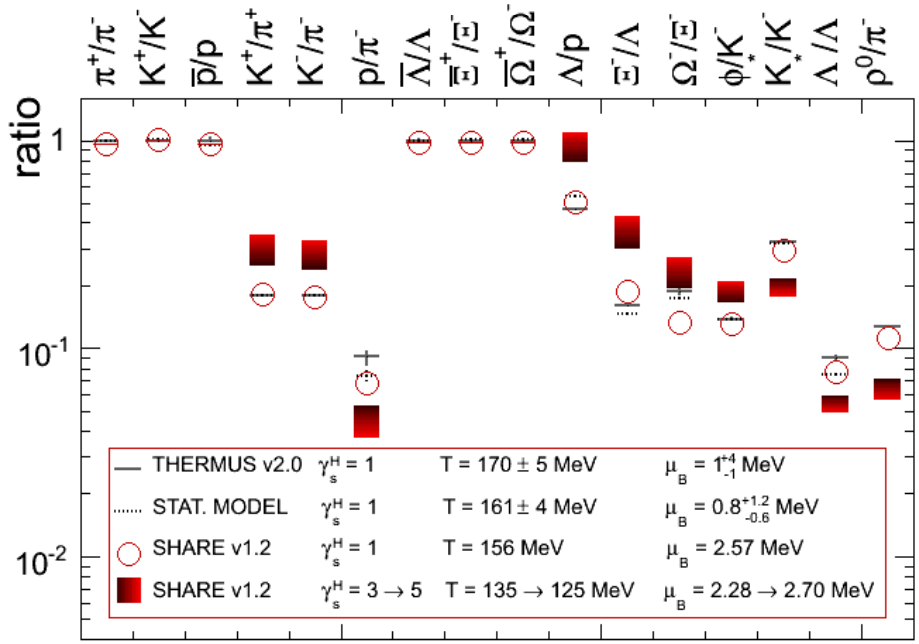
Statistical thermal models describe mid-rapidity p_T-integrated production of baryons and mesons over a large energy range.

Baryo-chemical potential μ_B and Chemical freeze-out Temperature T_{ch}

I.Kraus et al., in arXiv0711.0974 [hep-ph]



ALICE Estimates : Equilibrium vs Non Eq. particle ratios



⇨ Expectations at LHC: T_{ch} =161±4 MeV
μ_B =0.8+1.2-0.6 MeV

Eq. [I.Kraus *et al.*, J.Phys.G32 (2006) S495]
[A.Andronic *et al.*, Nucl. Phys. A772 (2006) 167]
Non Eq. [J.Rafelski *et al.*, Eur. J. Phys. C45 (2006) 61]

Note: Anti-particle/particle ~ unity will be difficult to constrain but can be used for addressing baryon transport

Soft Physics in ALICE

Event Characterization (baseline, shadowing, CGC, ...)

- Multiplicity, centrality, transverse momentum and pseudo-rapidity distributions

Bulk Properties of the Medium (T, μ, …)

- Particle ratios, hadronic resonances

Chiral Symmetry Restoration

- Short-lived resonances & medium-modified masses

Collision Dynamics (space-time evolution, transport properties)

- Momentum correlations (HBT)
- Collective Flow (radial, anisotropic)
- Baryon number transport

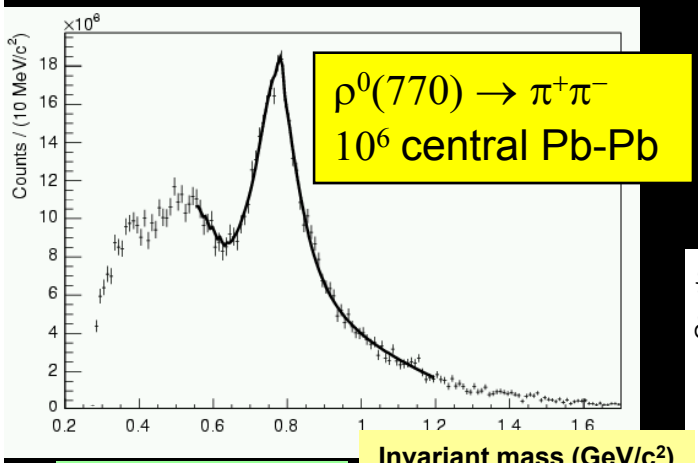
Fluctuations

- Event-by-event – particles, momentum, …

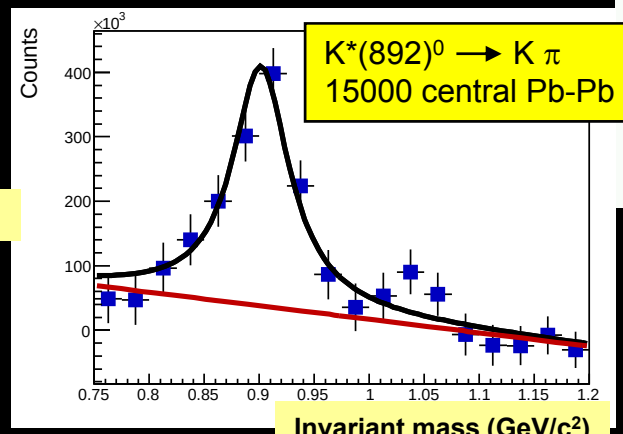
Resonances (ρ, φ, K*, ...) → Hadrons

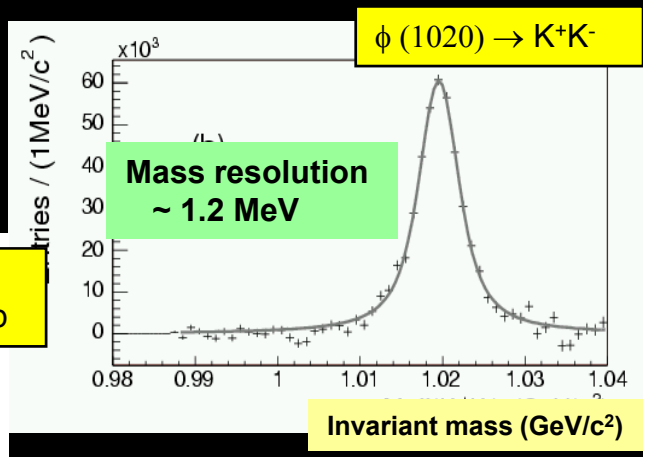
- Time difference between chemical and kinetic freeze-out
- In medium modifications of mass, width, comparison of hadronic and leptonic channels → partial chiral symmetry restoration?

- **Reconst invariant mass spectrum, background subtract (like-sign method).**
- **Mass resolutions ~ 1.5 - 3 MeV . p_T statistical limits: 8 (ρ) to 15 GeV/c (φ,K*)**



Mass resolution ~ 2-3 MeV





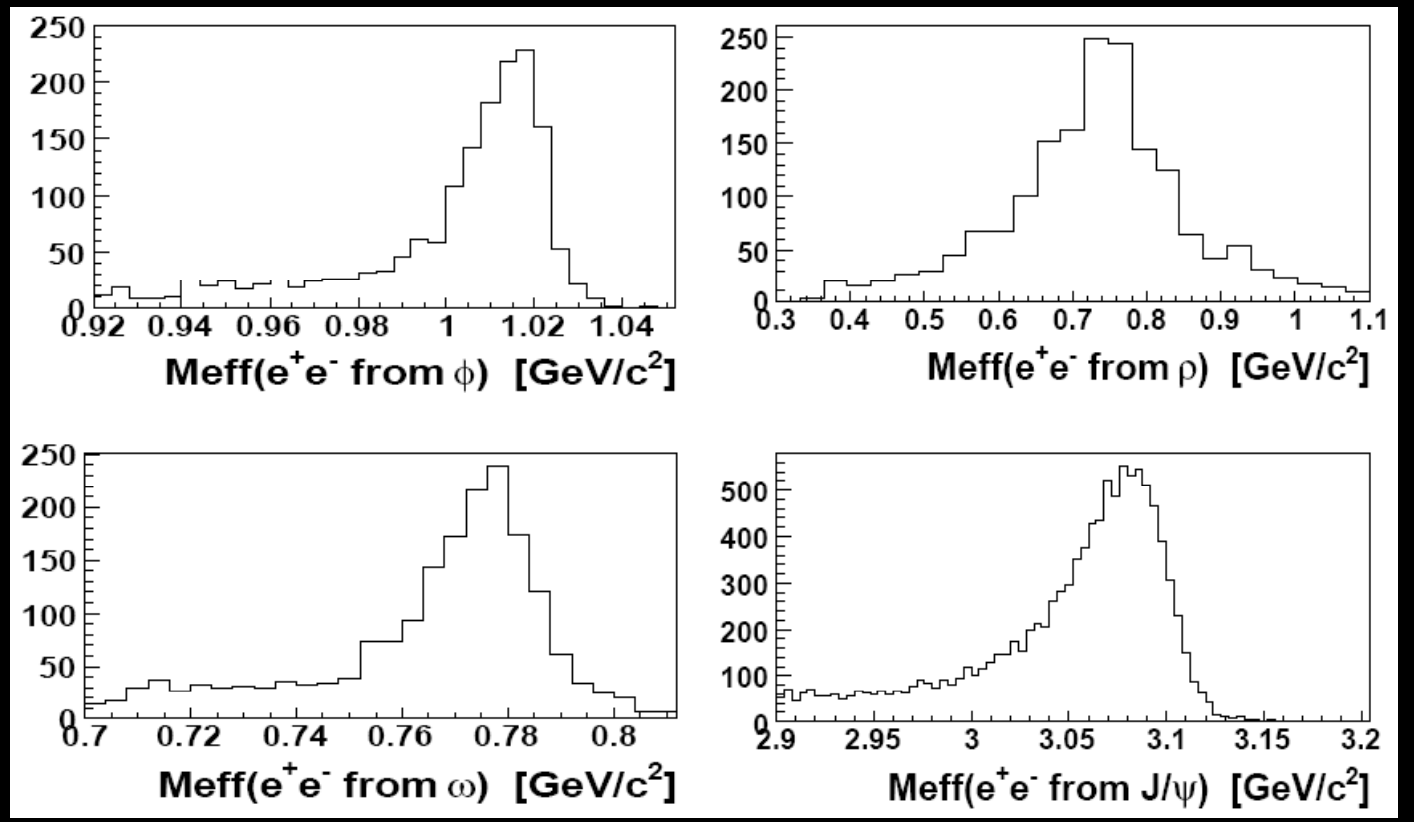
Resonances (ρ, φ, ω, J/ψ) $\rightarrow e^+e^-$

- In medium modifications of mass, width, comparison of hadronic and leptonic channels → partial chiral symmetry restoration?

p [GeV/c]	1.5	2.0	4.0	6.0	8.0	10.0
Rejection in the TPC	2500	2000	400	50	25	12
Rejection in the TRD	40	30	25	10	8	5
Rejection in the TPC+TRD	10^5	6×10^4	10^4	500	200	60

2 x 10^7 Pb+Pb events

ω, ϕ: S/B ~ 0.10 – 0.15
J/ψ: S/B 0.4 – 0.6



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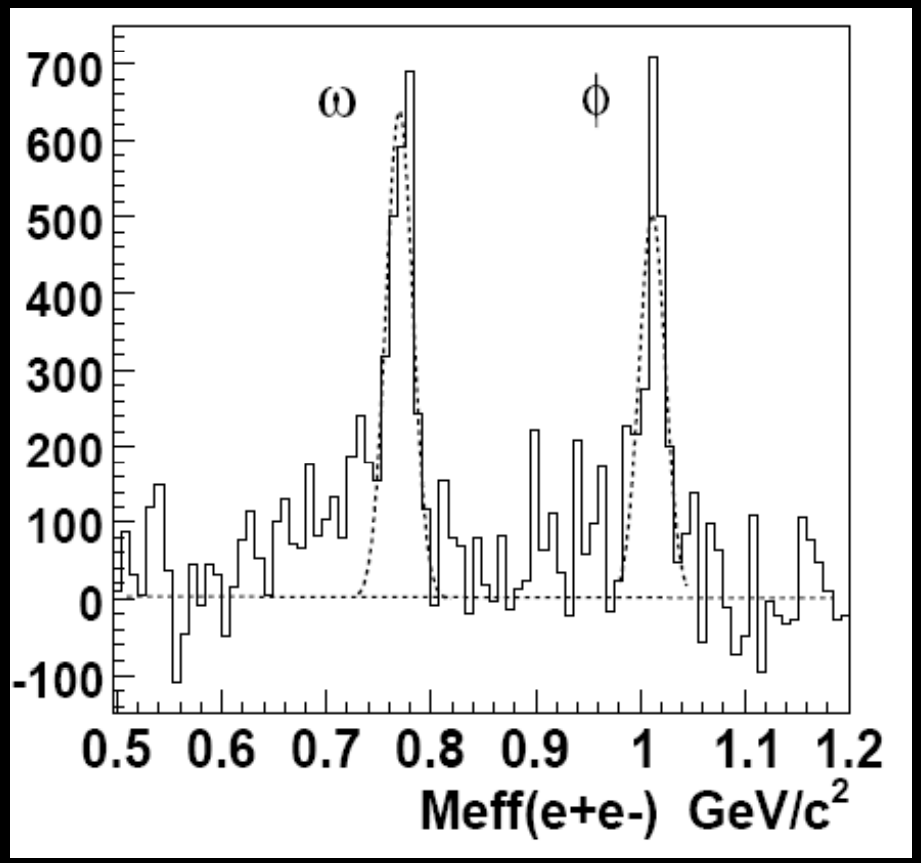
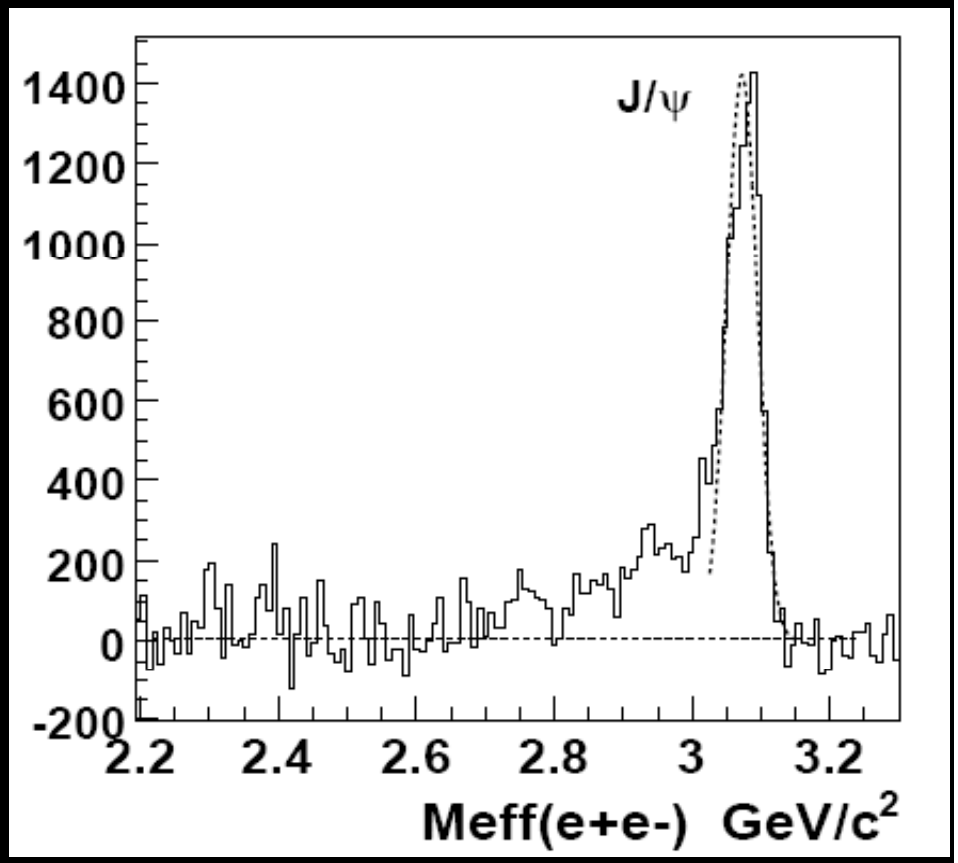
2 x 10^7 Pb+Pb events





2 x 10^7 Pb+Pb events -

ω, ϕ: significance = 12 - 15

J/ψ: significance = 40 - 50

Soft Physics in ALICE

Event Characterization (baseline, shadowing, CGC, ...)

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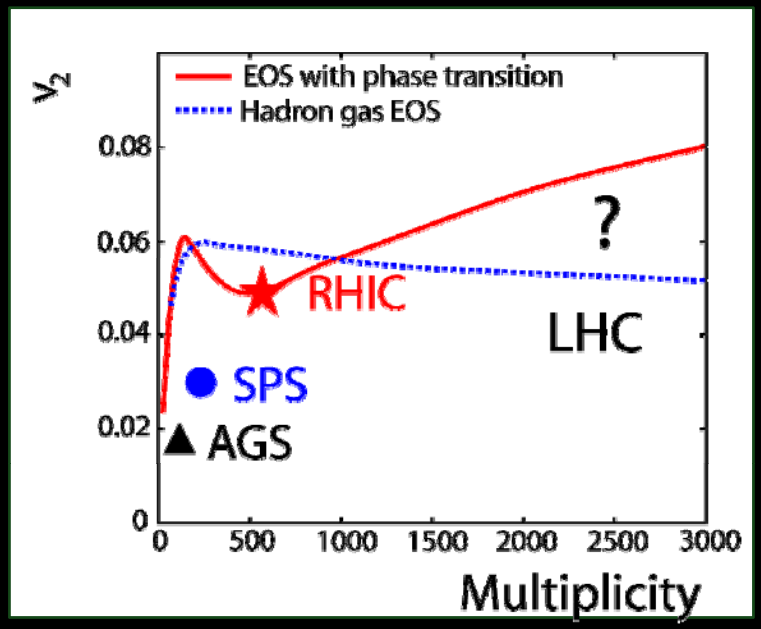
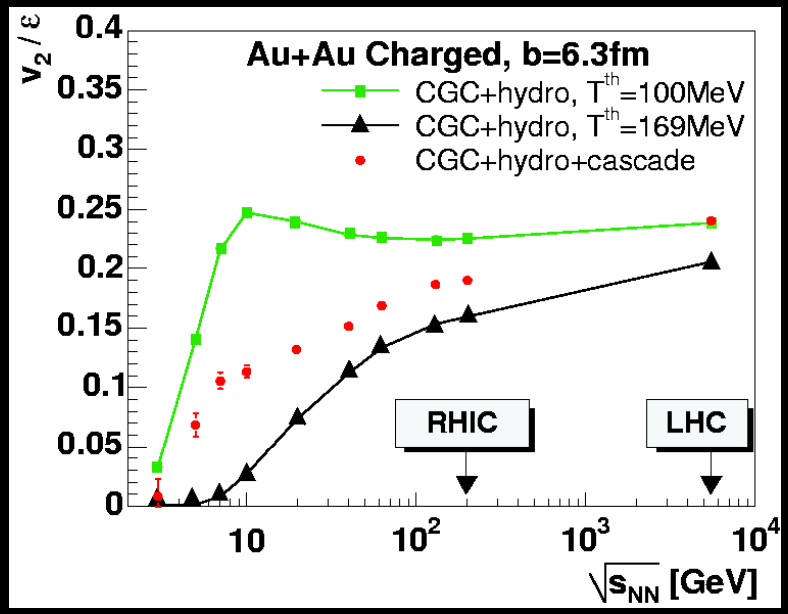
Fluctuations

- Event-by-event – particles, momentum, …

v_2 Predictions for the LHC

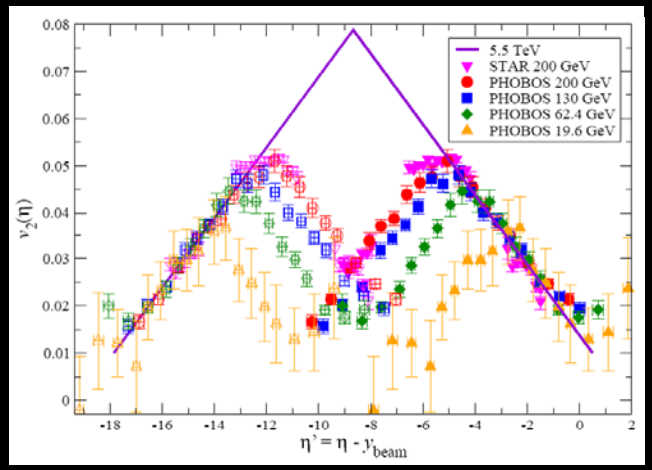
Heinz, Kolb, Sollfrank

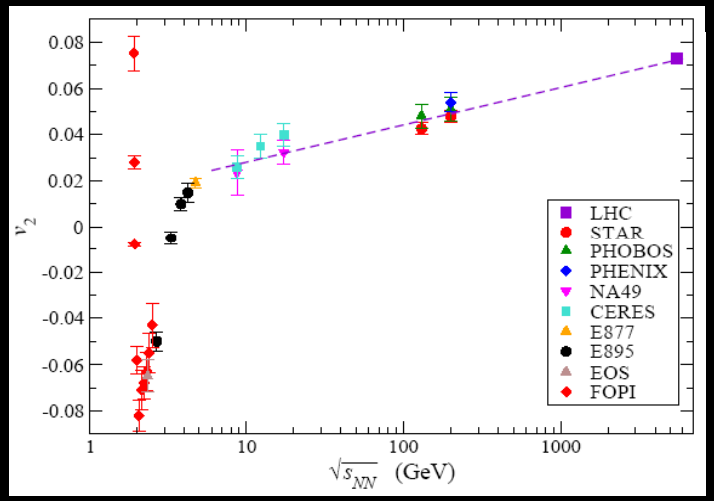




Hirano et al , nucl-th/0701075v2

N.Borghini and U.A.Weidemann, J.Phy.G 35 (2008) 023001





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LHC Heavy Ions –

- guided by pQCD predictions
- expectations (detector simulations) based on RHIC extrapolations and theory
- lesson from RHIC – **"expect the unexpected"**

Soft Physics at LHC –

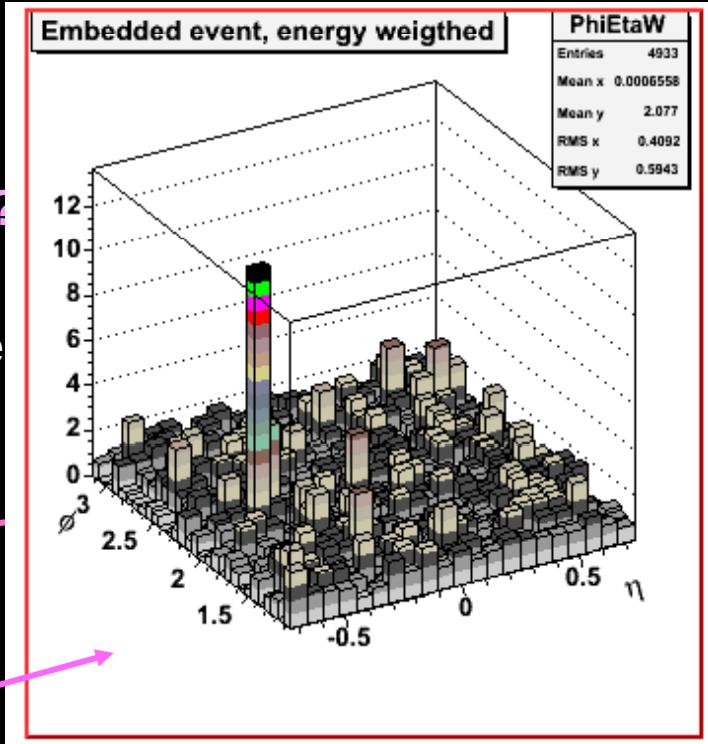
- smooth extrapolation from **SPS → RHIC → LHC?**
- expansion will be different (v_2, HBT, T_{chem} & T_{kin}, strange/charm particles & resonance

Hard Probes at LHC –

- **significant increase in hard cross sections**

  → $\sigma_{hard} / \sigma_{total}$ ~ 2% at SPS
  50% at RHIC
  98% at LHC

- "real" jets, large p_T processes
- abundance of heavy flavors
- probe early times, calculable → **precision studies!**



σ_{bb} (LHC) ~ 100 σ_{bb} (RHIC)

σ_{cc} (LHC) ~ 10 σ_{cc} (RHIC)

Hard Probes in ALICE

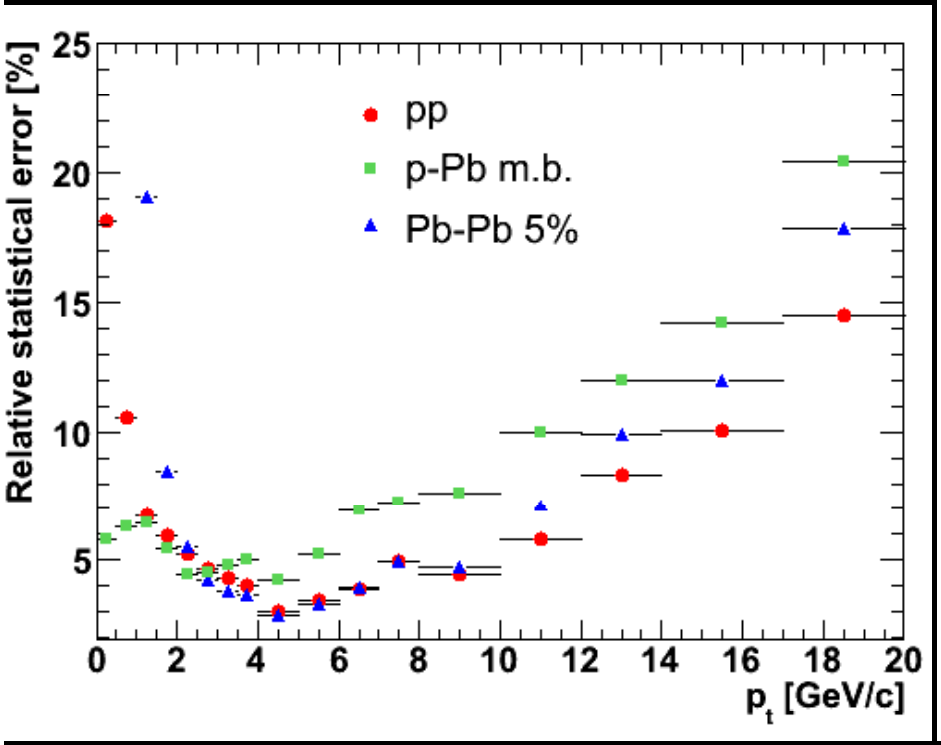
Heavy Quarks

(mass/color dep. of parton E-loss)

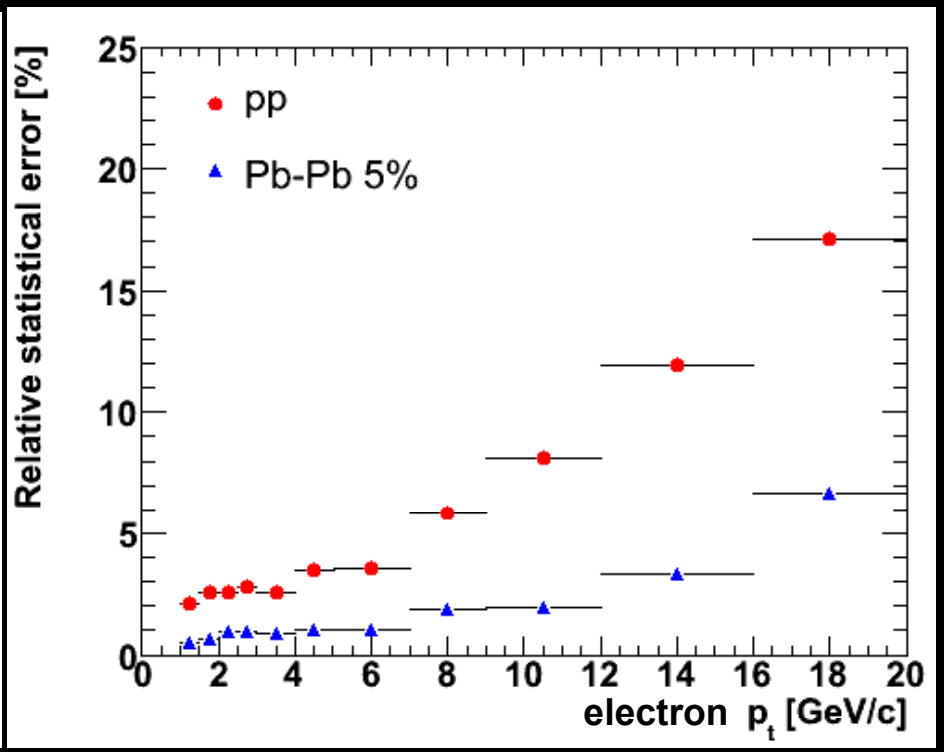
- Displaced vertices ($D^o \rightarrow K^- \pi+$) from TPC/ITS
- Electrons in Transition Radiation Detector (TRD)

Heavy Quarks in ALICE - p_t Coverage

$D^0 \rightarrow K\pi$

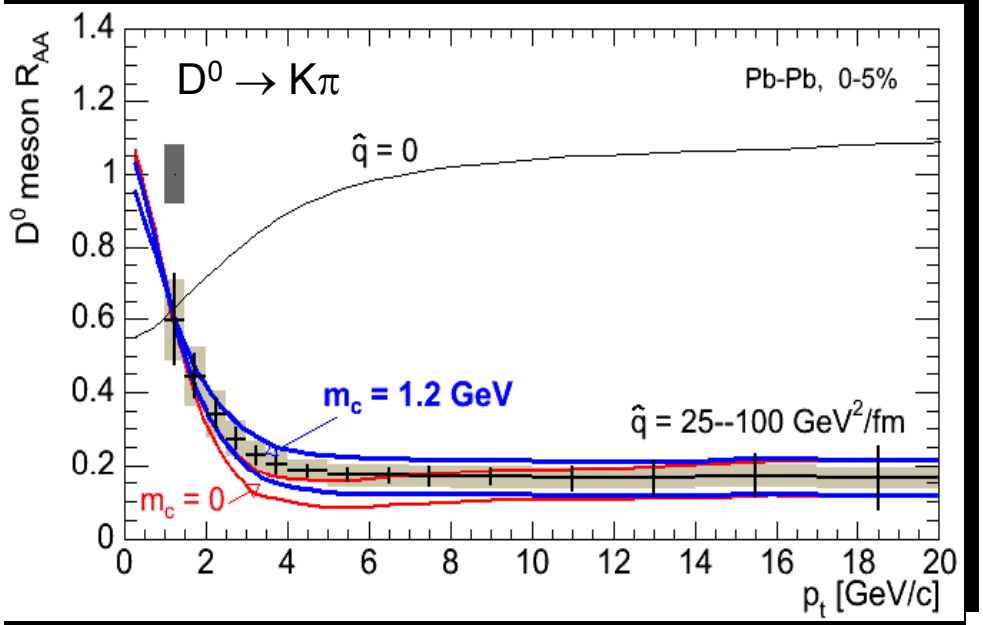


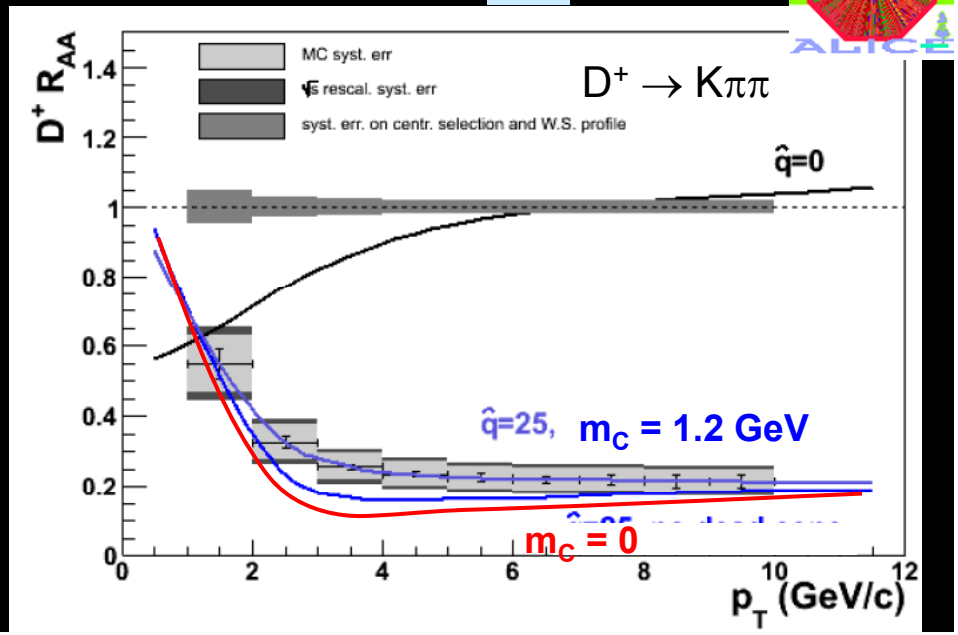
$B \rightarrow e + X$



1 year at nominal luminosity
(10^7 central Pb-Pb events, 10^9 pp events)

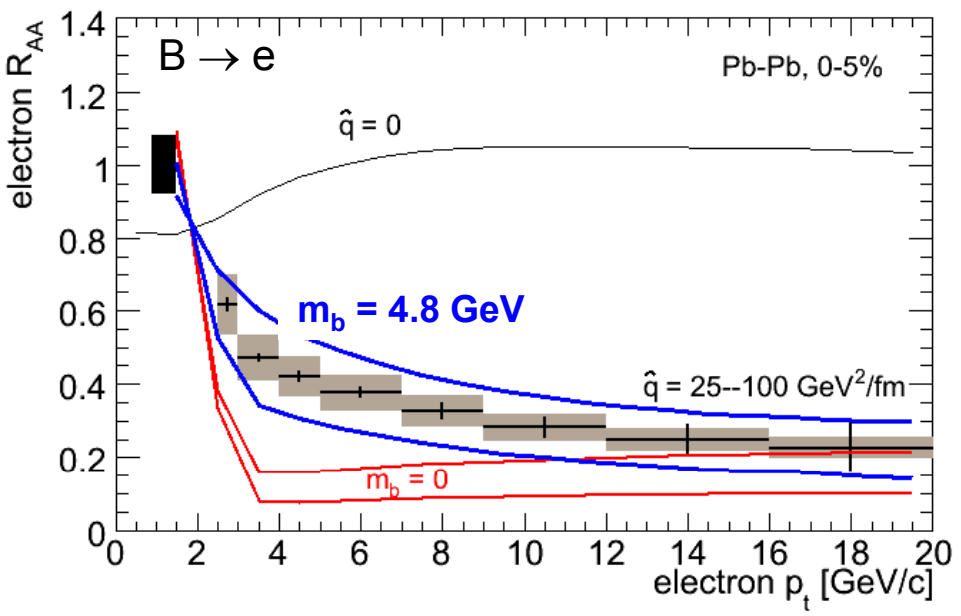
Charm and Beauty E-Loss : R_{AA}





E-loss calc.: Armesto, Dainese, Salgado, Wiedemann

1 year at nominal luminosity
(10^7 central Pb-Pb events, 10^9 pp events



Hard Probes in ALICE

Heavy Quarks

(mass/color dep. of parton E-loss)

- Displaced vertices ($D^o \rightarrow K^- \pi+$) from TPC/ITS
- Electrons in Transition Radiation Detector (TRD)

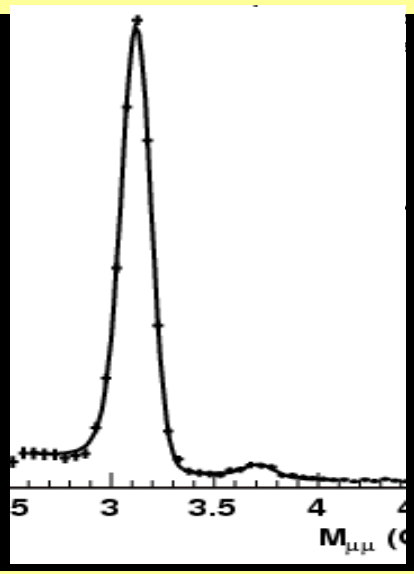
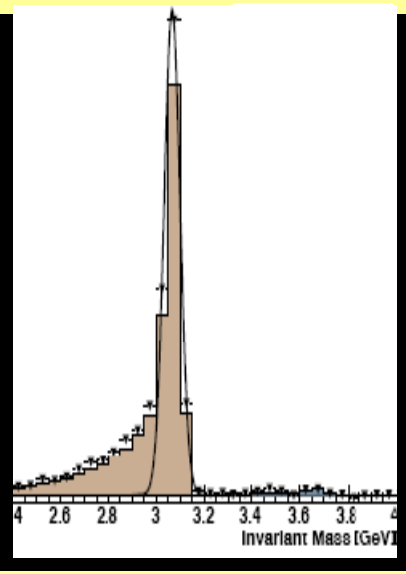
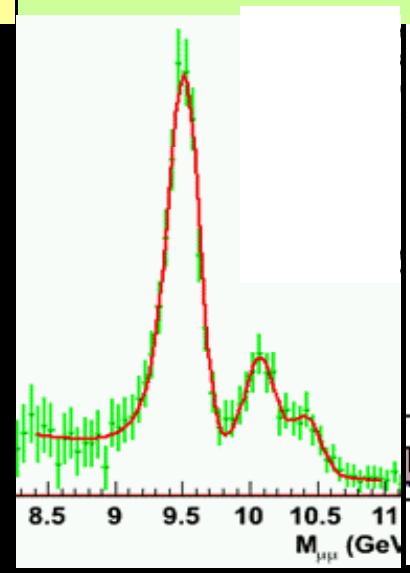
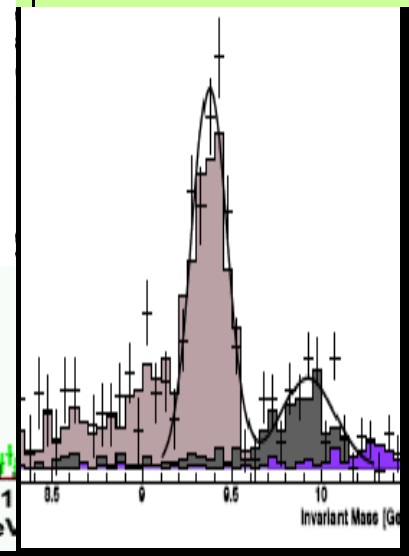
Quarkonia

(Initial T, Debye screening, recombination,..)

- J/ψ, Υ, Υ' (excellent), Υ''(2-3 yrs), ψ' (very difficult)

Quarkonia Performance

dN_{ch}/dy = 4000 in central Pb-Pb

Particle	Charmonia $\mu^+\mu^-$	Charmonia e^+e^-	Bottonia $\mu^+\mu^-$	Bottonia e^+e^-
Bkg-subtr. mass plot				
acc. η	$-4 < \eta < -2.5$	$\lvert\eta\rvert < 0.9$	$-4 < \eta < -2.5$	$\lvert\eta\rvert < 0.9$
M res.	65 MeV	35 MeV	90 MeV	90 MeV
S / $\sqrt{(S+B)}$ (1 mo.)	J/ψ 150, ψ' 7	J/ψ 245	Υ 30, Υ' 12, Υ'' 8	Υ 21, Υ' 8
Perf.	ψ, ψ'	ψ, ψ'	Υ, Υ', Υ''	Υ, Υ', no Υ''
p_t	J/ψ 0-20 GeV	J/ψ 0-10 GeV	Υ 0-8 GeV	--

Hard Probes in ALICE

Heavy Quarks

(mass/color dep. of parton E-loss)

- Displaced vertices ($D^o \rightarrow K^- \pi+$) from TPC/ITS
- Electrons in Transition Radiation Detector (TRD)

Quarkonia

(Initial T, Debye screening, recombination,..)

- J/ψ, Υ, Υ' (excellent), Υ''(2-3 yrs), ψ' (very difficult)

Jet Quenching

(E-loss, parton density, fragmentation, medium response)

- Jets, γ , pi-zeros, leading particles to large p_T
- Modification of fragmentation
- Medium response to E deposition - dissipation on near- and away-side

Detectors Utilized for High p_T Jet, γ, e Physics

Tracking - PID: ITS+TPC+(TOF, TRD)

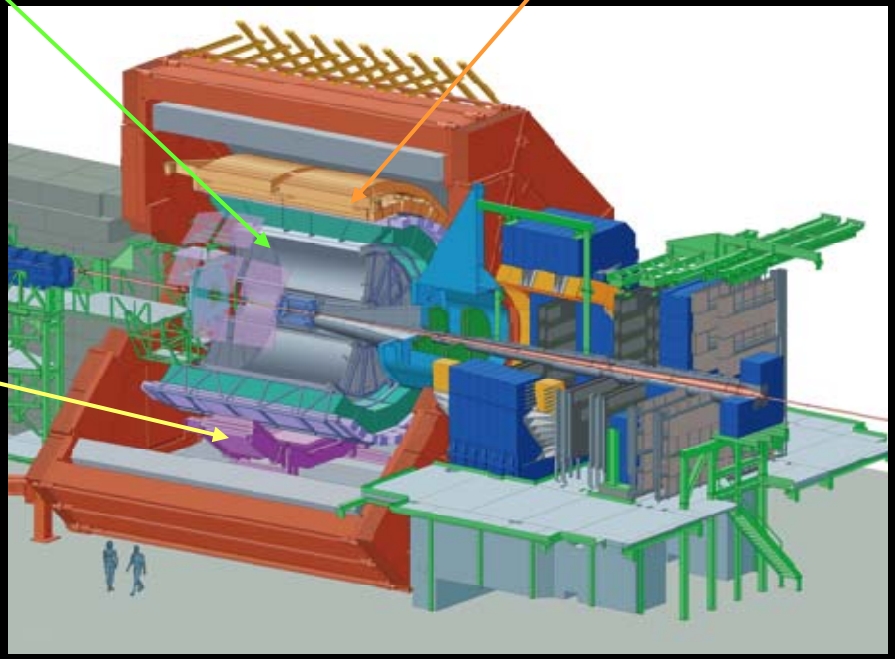
- Charged particles $|\eta| < 0.9$
- Momentum resolution ($\Delta p/p < 6\%$) to 100 GeV/*c*
- Tracking down to 100 MeV/*c*
- Particle ID & heavy flavor tagging

EMCal

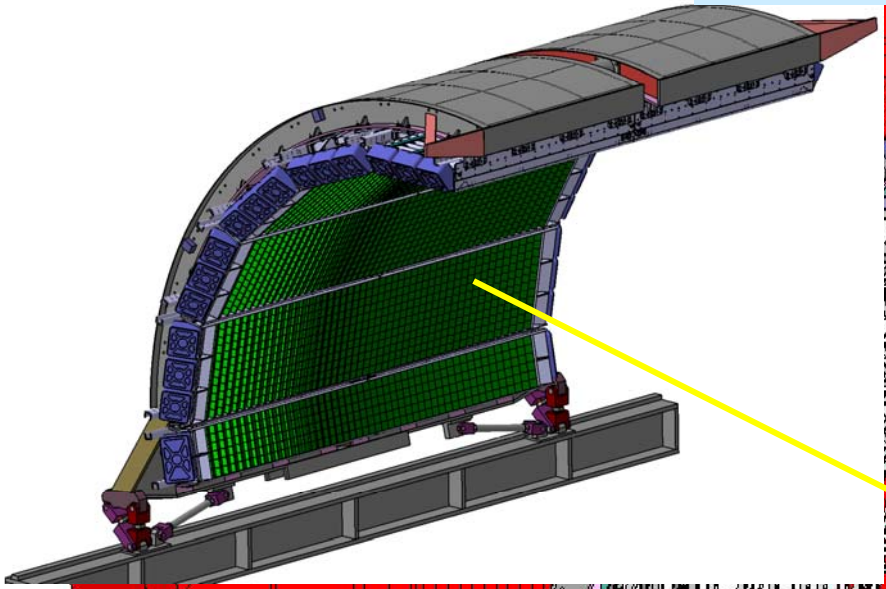
- Energy from neutral particles
- Pb-scintillator, 13,000 towers
- $\Delta\phi = 107°$, $|\eta| < 0.7$
- Energy resolution = $10.6\%/\sqrt{E} + 2.1\%$
- Trigger capabilities

PHOS

- Hi-res electromagnetic spectrometer ($PbWO_4$ crystals)
- γ–Trigger
- $|\eta| < 0.1$, $220° < \phi < 320°$
- $\Delta E_\gamma/E_\gamma = 3\%/\sqrt{E_\gamma}$
- $\Delta x/x = 23\%/\sqrt{E_\gamma}$



ALICE EMCal



Approved for funding Jan. 2008

10 ½ Super Modules
7 ½ SM from US
3 SM from France, Italy

Construct / Install: 2009 → 2011

ead-scintillator sampling calorimeter
$\Delta\eta = 1.4, \quad \Delta\phi = 110°$

hashlik geometry, APD photosensor
~13K towers ($\Delta\eta$ x $\Delta\phi$ ~ 0.014 x 0.014)

Energy resolution = 10.6%/√E + 2.1%
over-takes tracking above ~ 30 GeV

π^o/γ discrimination to p_T ~ 30 GeV

EMCal Space Frame

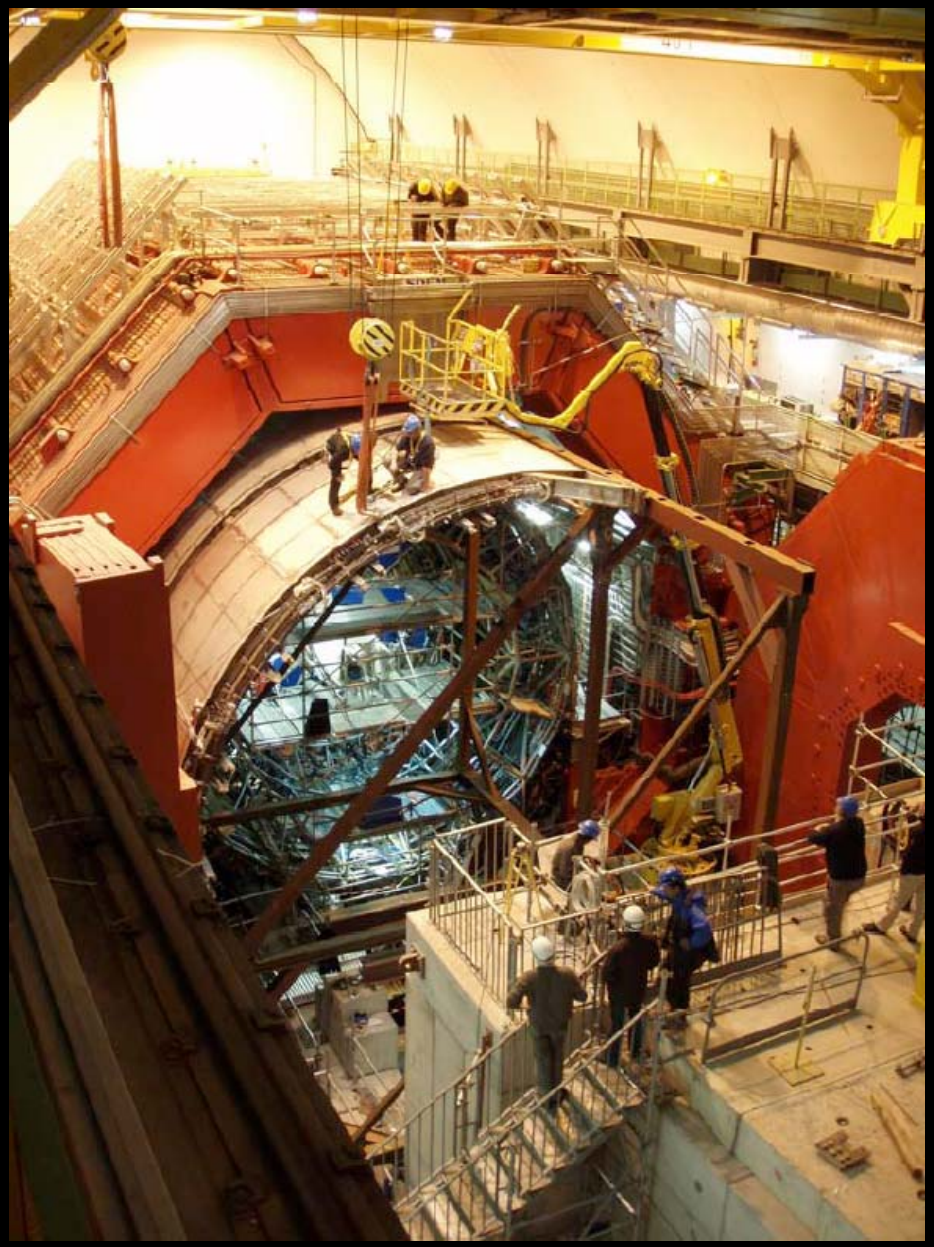
1 Year Ago:

Delivered to CERN

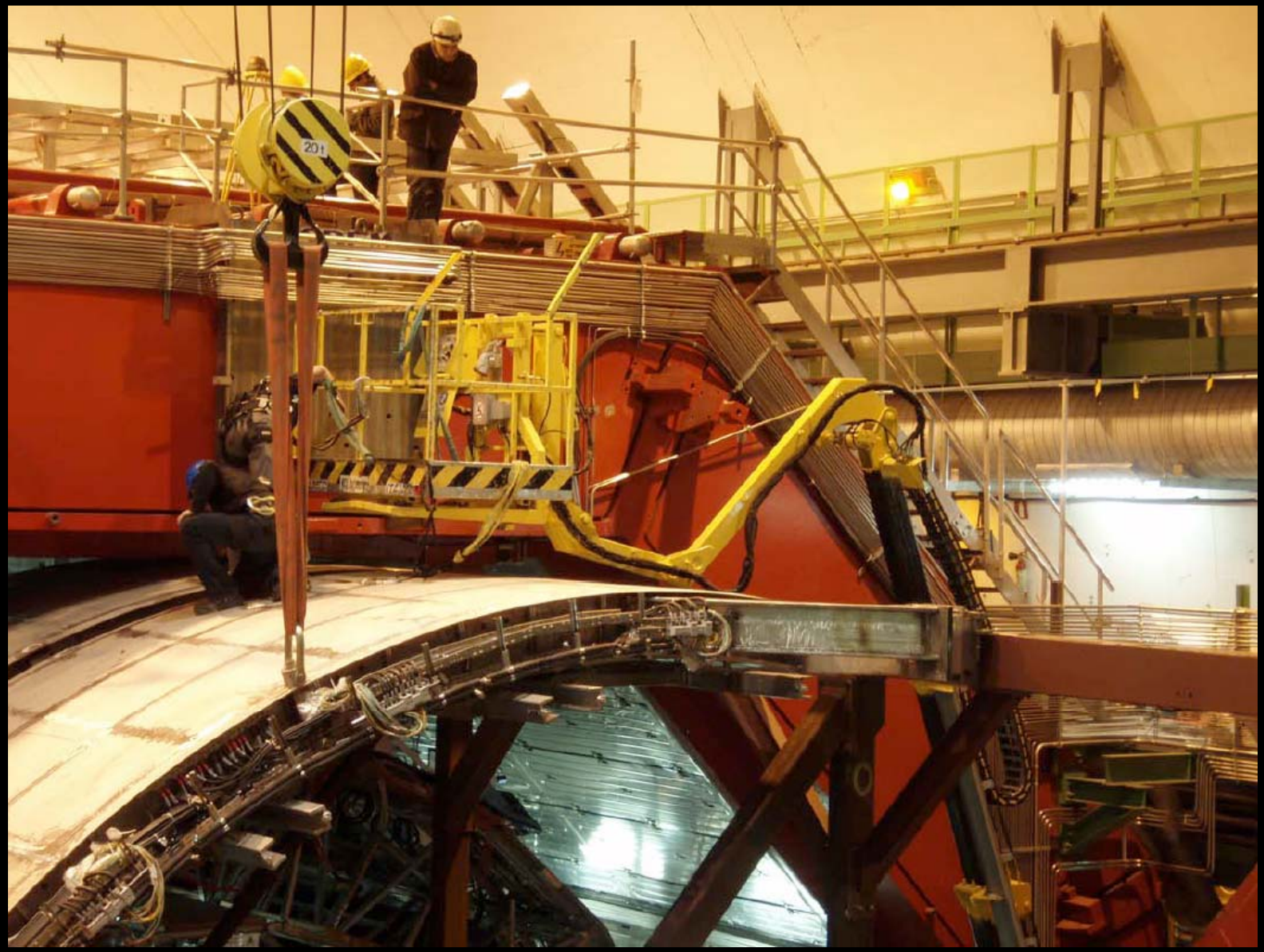
EMCal Space Frame above ALICE

Lowering EMCal Space Frame down ALICE Shaft

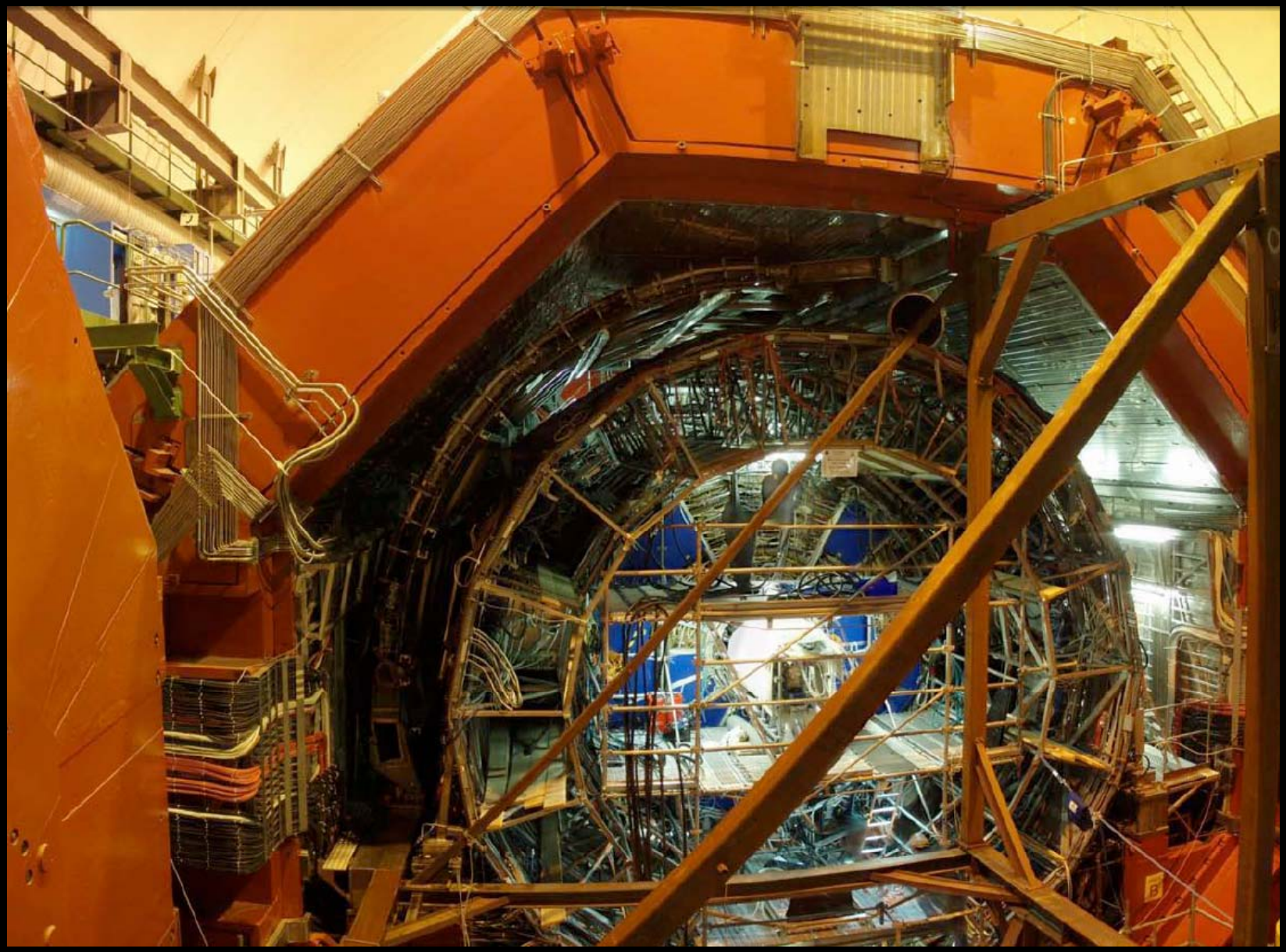
EMCal Space Frame at Bottom of Shaft / into ALICE



EMCal Space Frame Being Inserted into ALICE



EMCal Space Frame in Place in ALICE



Physics with the ALICE EMCal

Utilize Initial Hard Parton Scattering

- High energy jets, photons and heavy flavors → requires EMCal and triggering

  Exploit large kinematic range of jets at LHC

  Measure jet structure & medium-induced jet modification

  Investigate energy loss mechanism with

  quark-tagged jets (heavy flavor decays)

  gluon jets (light hadron leading)

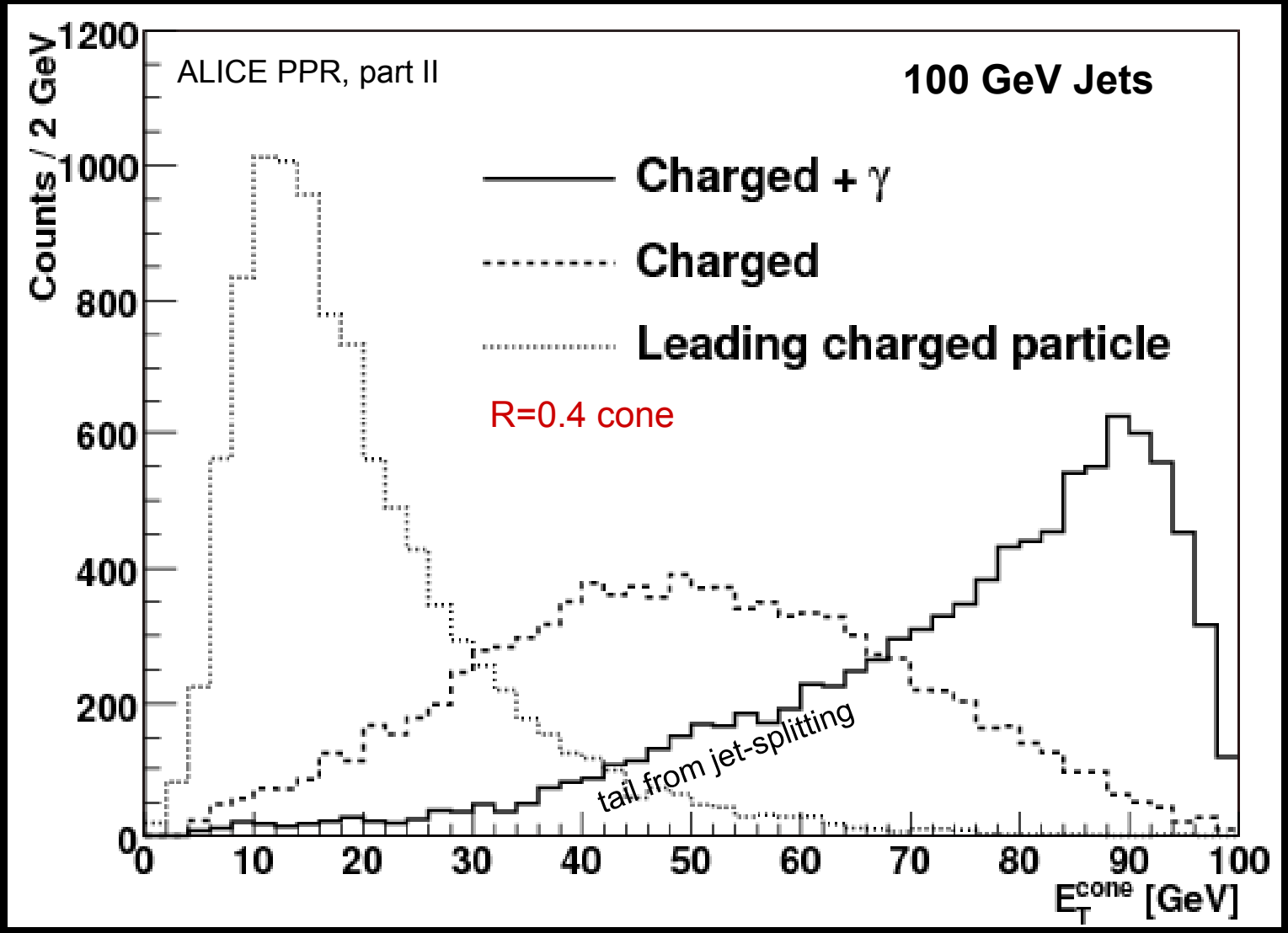
  γ – jet coincidences

- Low energy particles correlated with trigger or quenched jet

  → requires ALICE acceptance, robust tracking, & PID to low/high p_T

  Investigate energy propagation in medium to determine medium properties

"Simple" Jet Energy Response in ALICE



EMCal significantly improves ALICE jet capabilities

Anticipated Capabilities of ALICE with EMCal

EMCal improves detector capabilities:

- Fast trigger ~10 -100 enhancement of jets
- Improves jet reconstruction (plus TPC)
- Good γ/π^0 discrimination

  increases coverage
- Good electron/hadron discrimination

EMCal extends the physics of ALICE:

10^4 / year in minbias Pb+Pb:

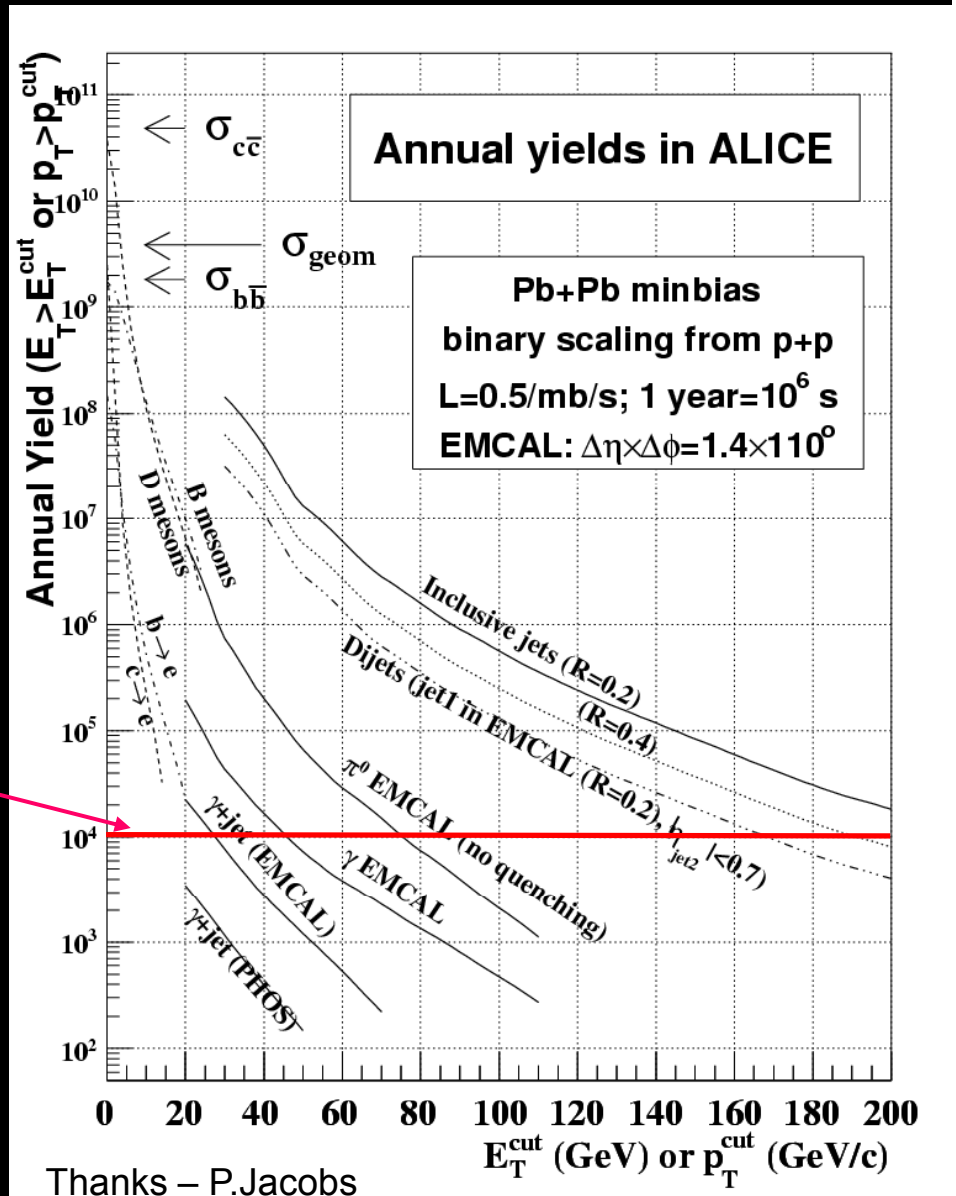
inclusive jets: $E_T \sim 200$ GeV

dijets: $E_T \sim 170$ GeV

π^0: $p_T \sim 75$ GeV

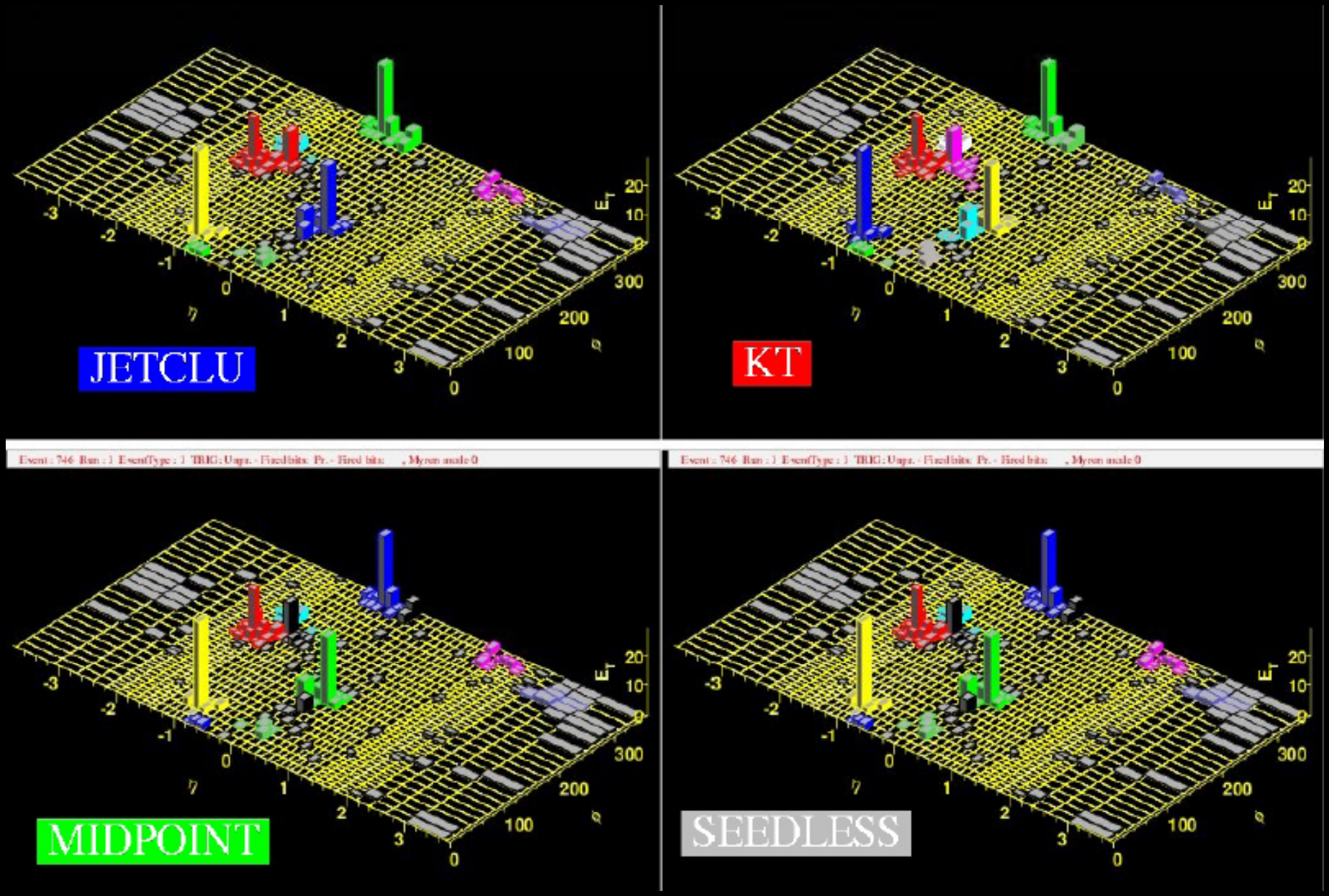
inclusive γ: $p_T \sim 45$ GeV

inclusive e: $p_T \sim 30$ GeV



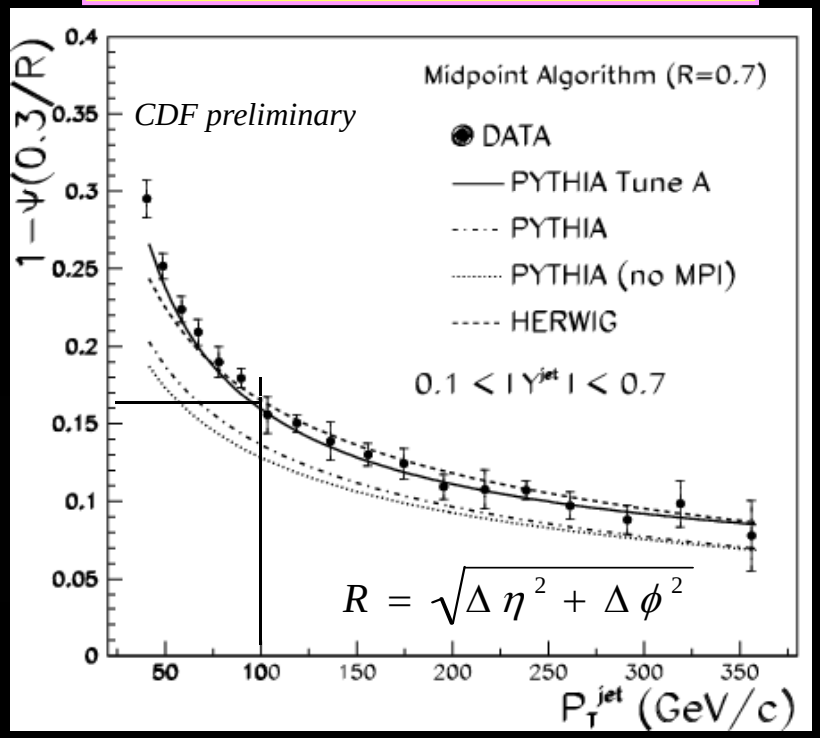
Thanks – P.Jacobs

Jet-finding – Much Work Already at LEP & Tevatron



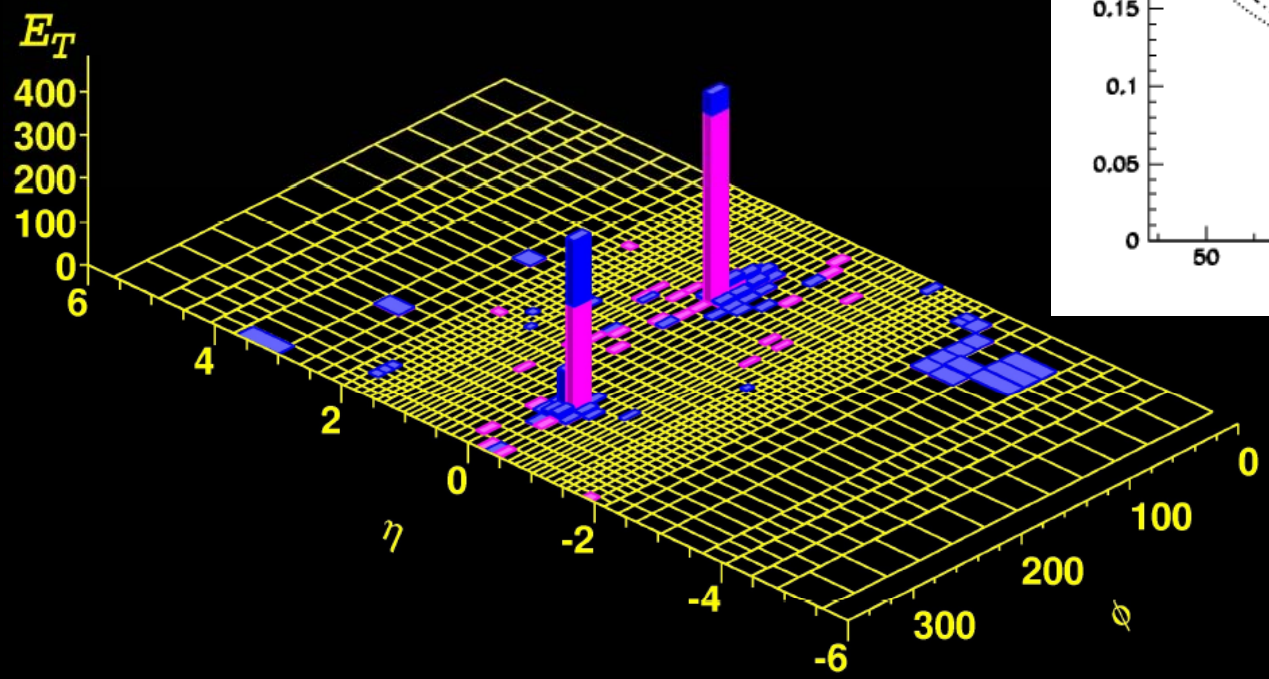
Jet-finding - Learning from the Tevatron

fraction of energy outside R = 0.3



p + p experience (CDF)

- most of energy within R = 0.3



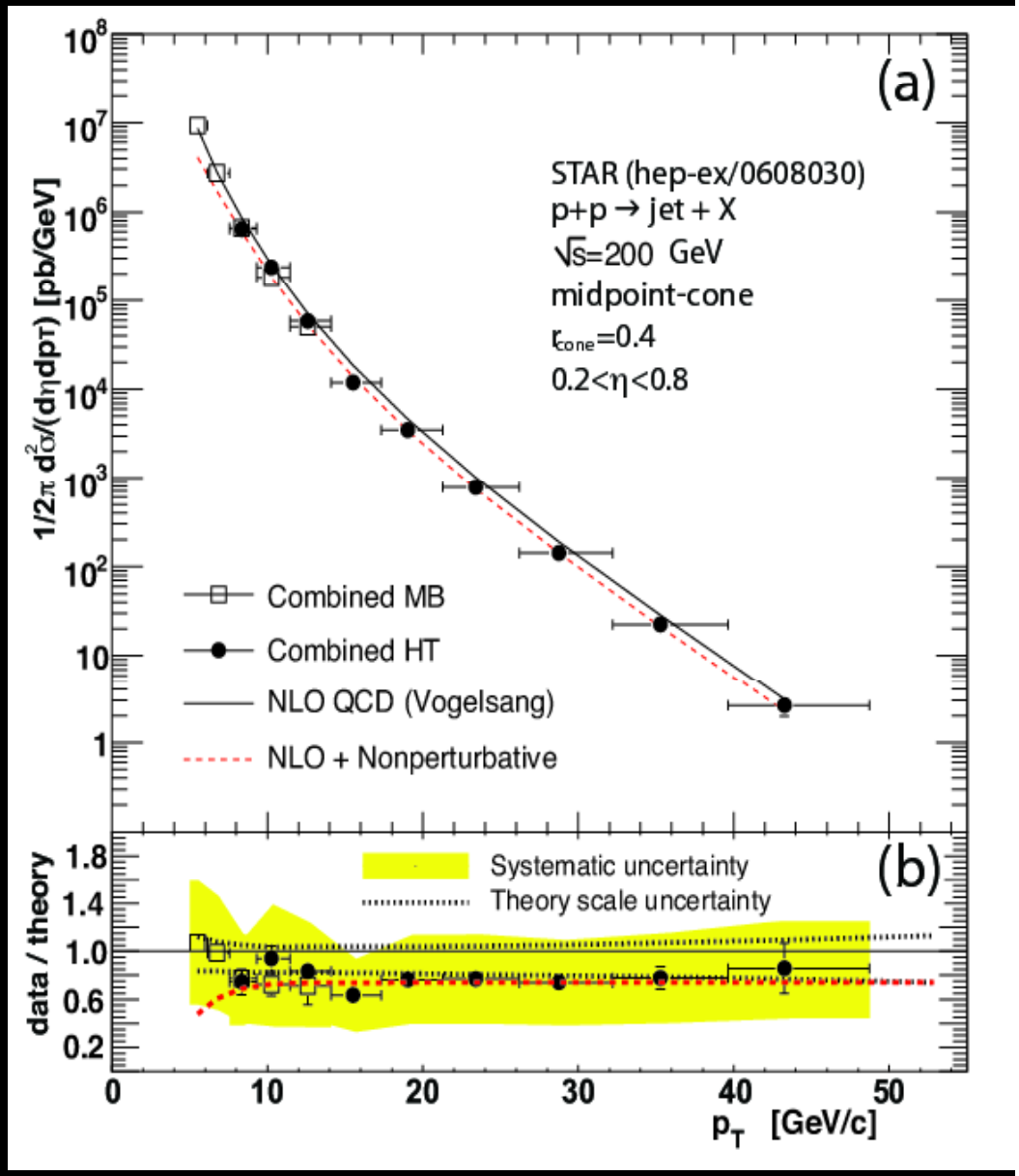
Start of Jet-finding at RHIC and LHC

Experience from STAR

- p + p at 200 GeV
- Mid-point jet cone algorithm, R = 0.4
- note uncertainty on jet p_T scale
- extension of techniques to Au + Au

  (see Hard Probes talks

  of Joern Putschke & Sevil Salur)



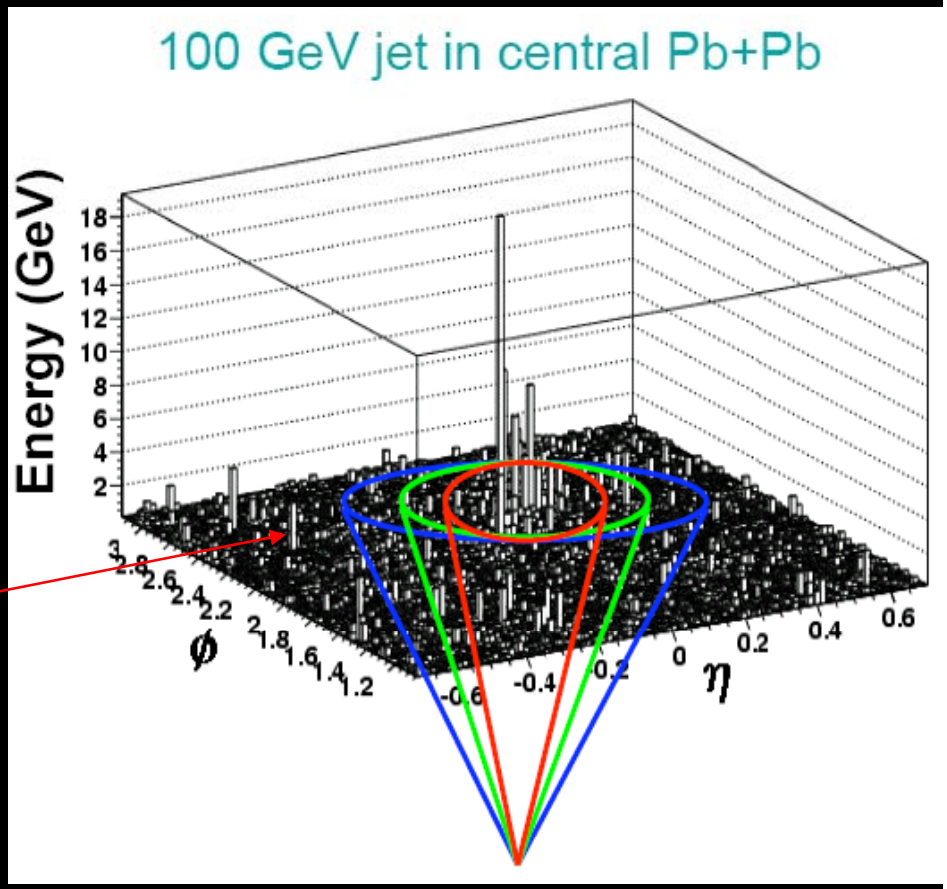
Jet-finding Approach with Heavy Ions

p + p experience (CDF)

- most of energy within R = 0.3

A + A approach (current attempts)

- suppress "soft" heavy ion background by
  - p_T cut: $p_T > 1 – 2$ GeV/c
  - use small jet cones R = 0.3 – 0.4
- estimate remaining background by
  - EbyE out-of-cone background energy



Issues to understand:
- effects of acceptance
- event-by-event fluctuations
- elliptic flow
- other effects of real data!

J. Putschke (ECT Workshop 2008)

Using Jet Cone Algorithm

Comparing Pb + Pb to p + p

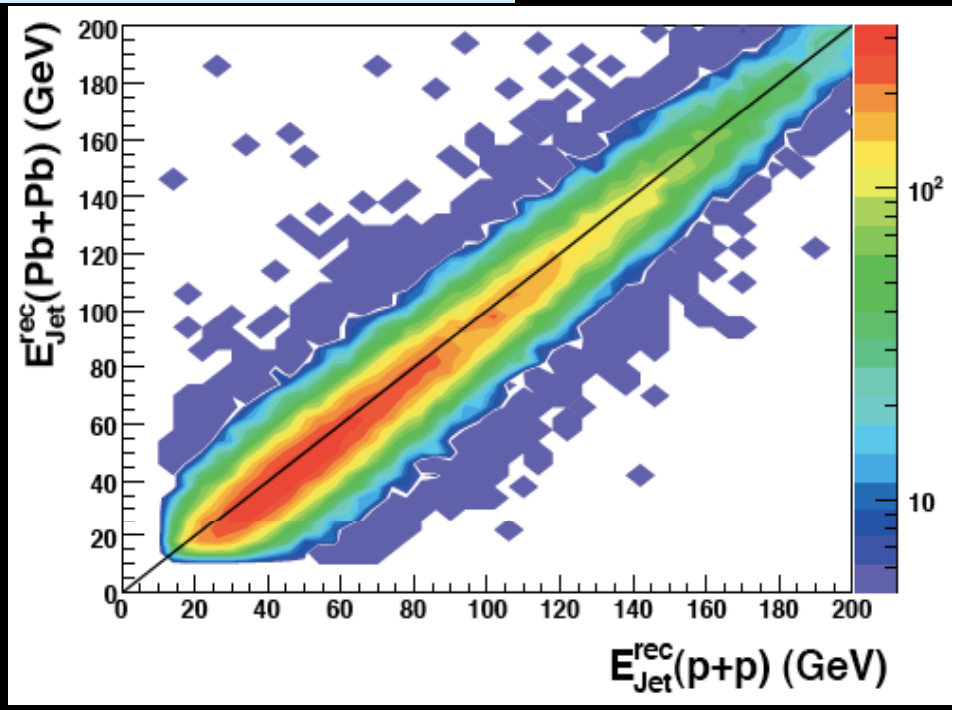
- Jet energy determination from

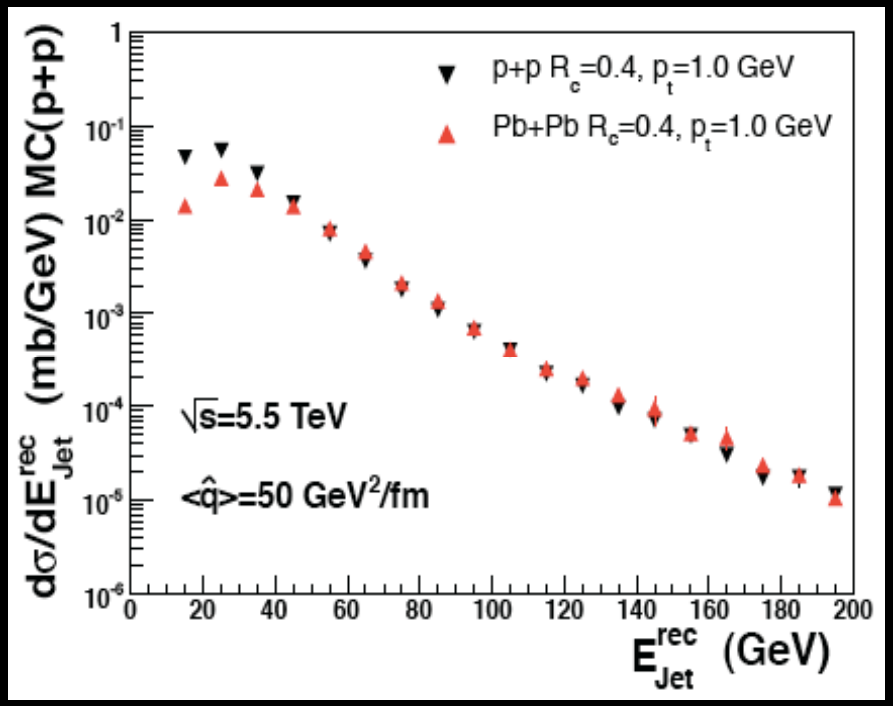
  R_c=0.4 p_T > 1 GeV/c

- Subtract EbyE out-of-cone background E

- Minor influence of background

  < 10% E difference for E_{jet} > 100 GeV





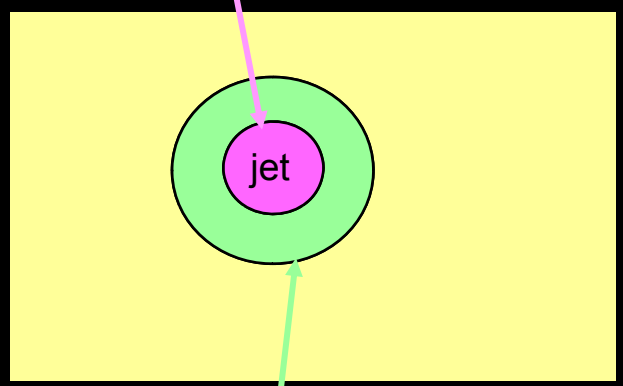
Pb + Pb spectra = p + p spectra

- for p_T > 50 GeV/c

Getting to the Fragmentation Function in PbPb

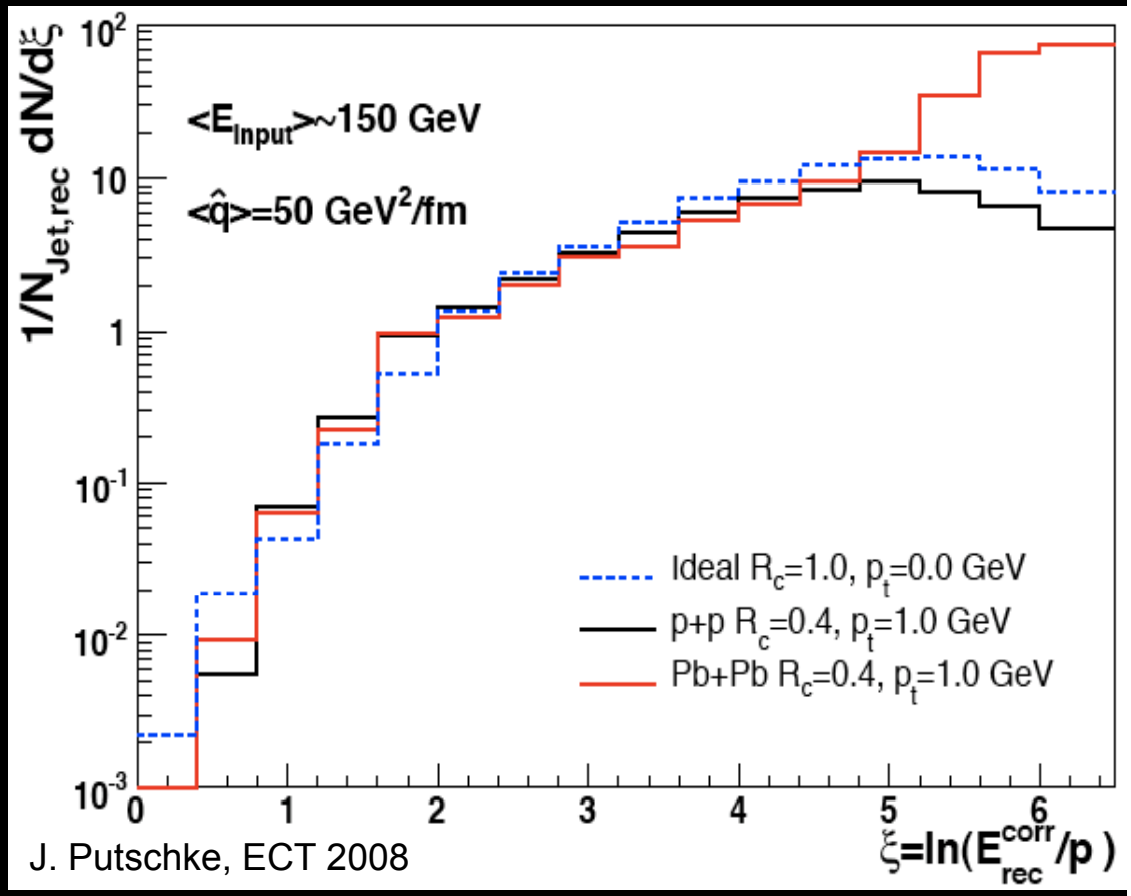
Jet energy determination from

R_c=0.4 p_T > 1 GeV/c



Charged particles for FF ξ from

R_c=0.7 p_T > 0 GeV/c



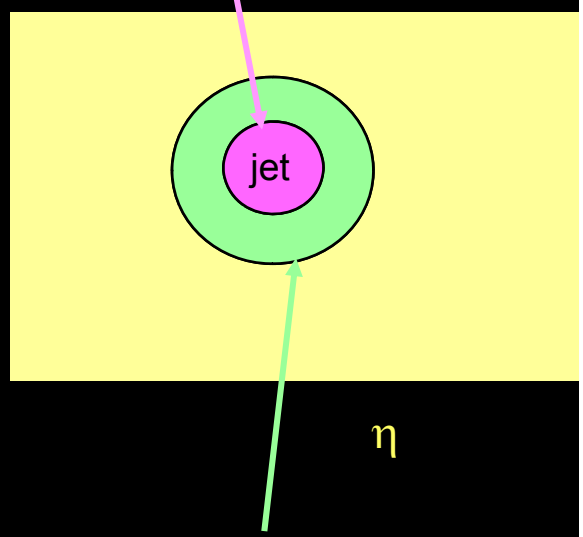
J. Putschke, ECT 2008

Fragmentation function measurement up to ξ ~ 4.5 - 5
Influence of heavy-ion background at ξ > 4.5

Measuring the PbPb Fragmentation Function

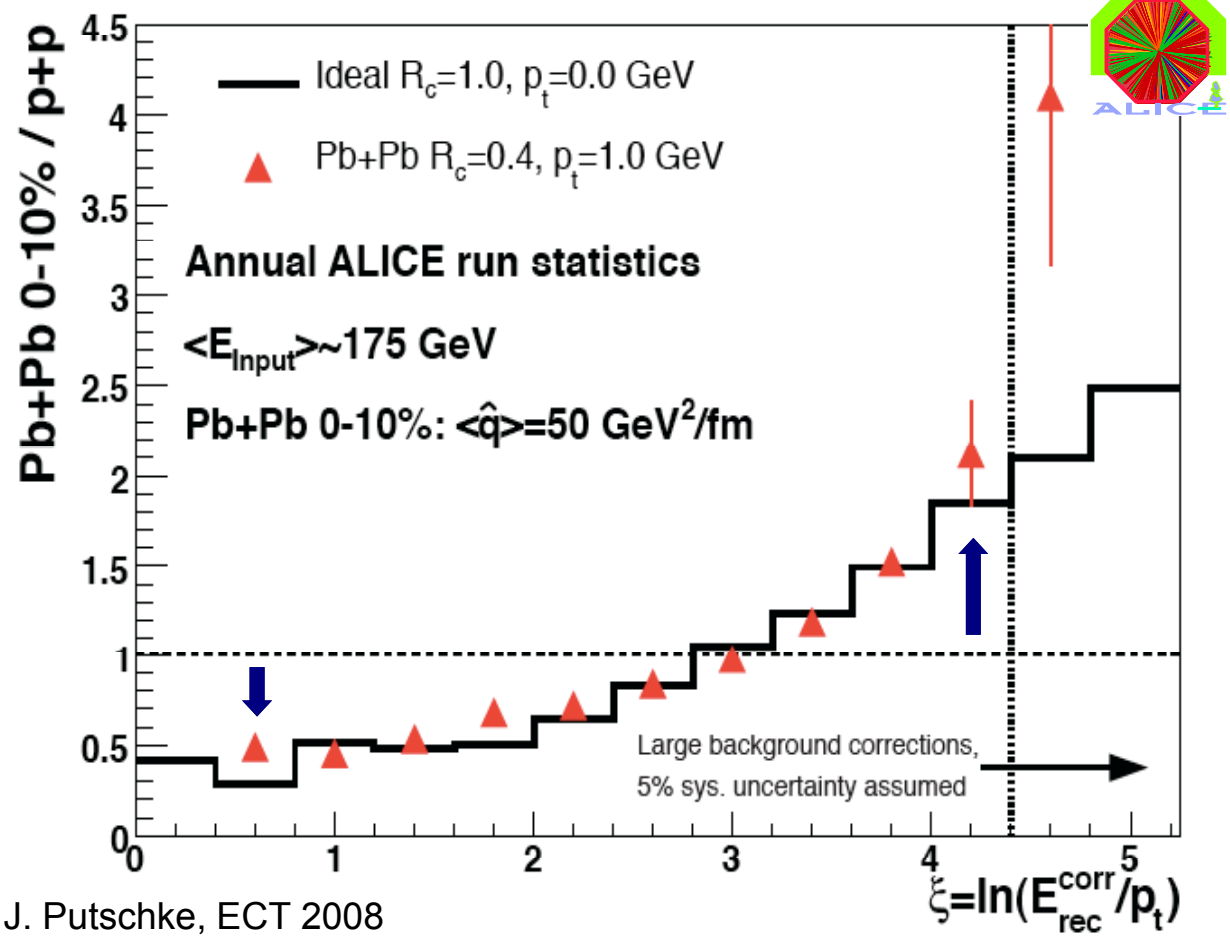
Jet energy determination:

R_c=0.4 p_T > 1 GeV/c



Charged particles for FF ξ:

R_c=0.7 p_T > 0 GeV/c



J. Putschke, ECT 2008

More studies of background are needed & underway!

ALICE Jet Trigger Yields in an LHC Pb + Pb Year

Jet yield in 20 GeV bin

System	jet trigger?	N_{jets} (125 GeV)	N_{jets} (175 GeV)
Pb+Pb cent	y	1.1×10^4	1700
	n	2100	320
Pb+Pb periph	y	410	62
	n	8	1
p+Pb 8.8 TeV	y	2.7×10^4	4200
	n	250	40
p+p 14 TeV	y	6.9×10^5	1.0×10^5
	n	1200	190

Includes acceptance, efficiency, dead time, energy resolution

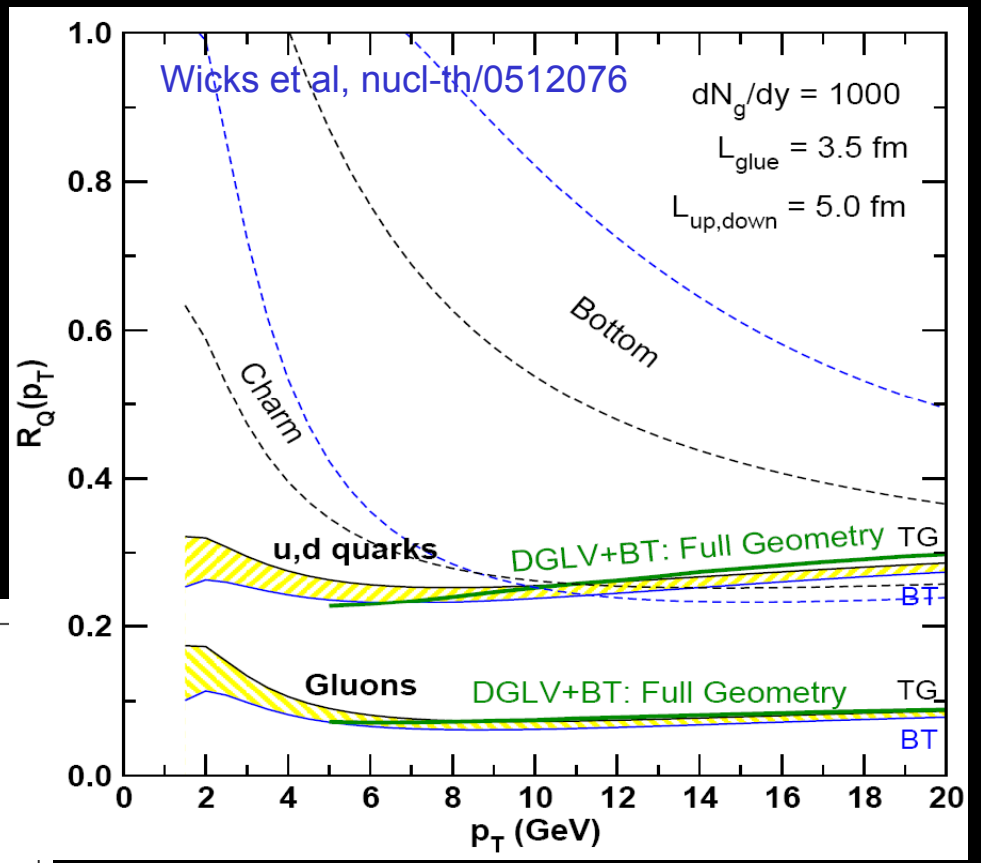
Large gains due to jet trigger

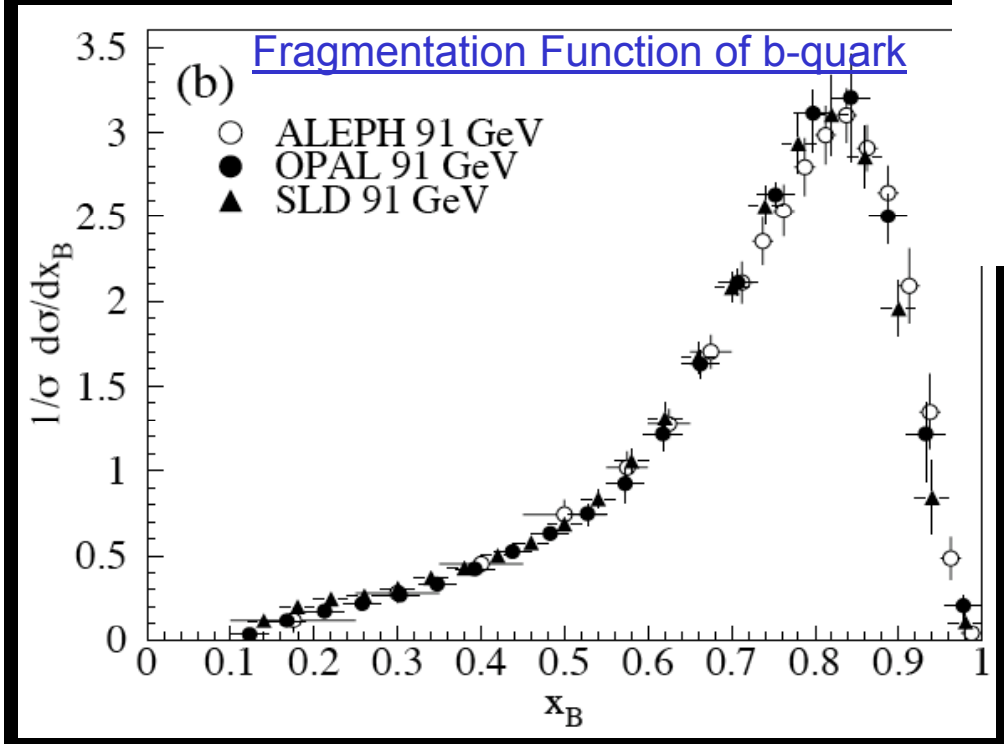
Large variation in statistical reach for different reference systems

B-jet Physics

Quark vs gluon E-loss in medium

B-jets - pure sample of quark jets

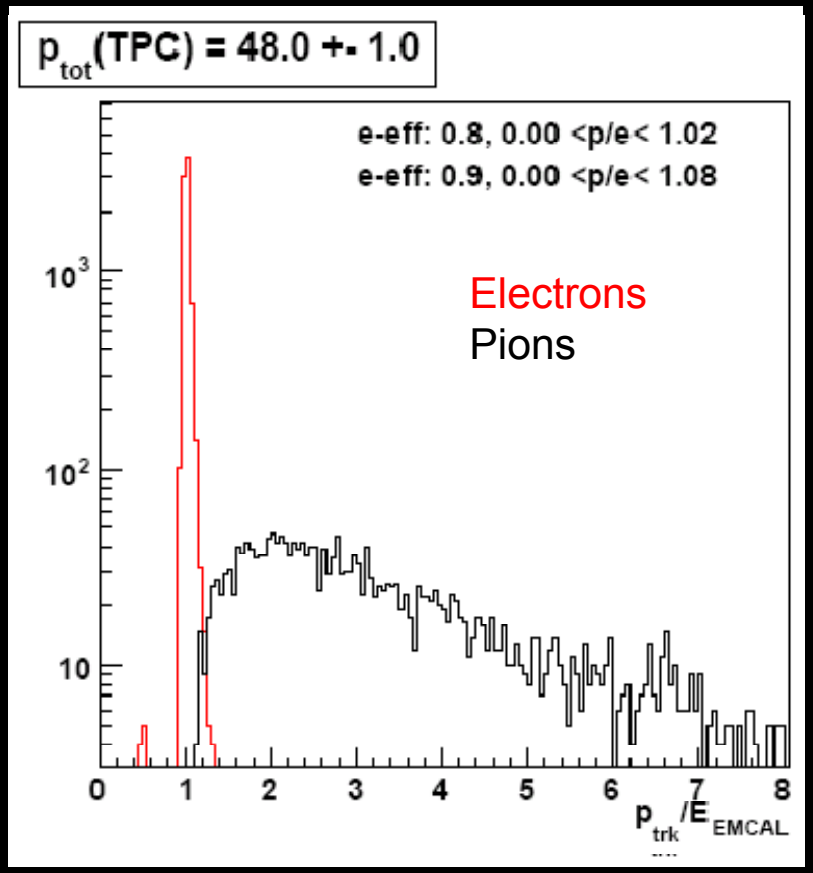




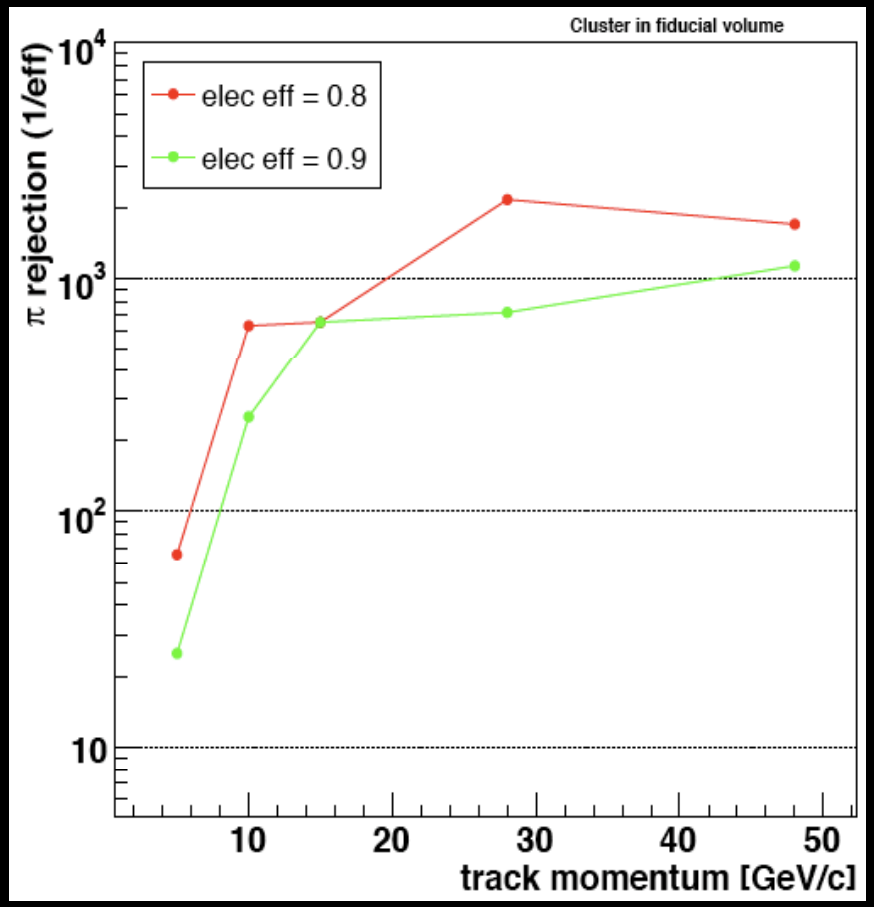
Measure B-jet Fragmentation Fctn

- harder fragmentation of b-quark (higher <z>)
- E_{jet} measured more precisely
- Better measurement of FF

Electron ID for B-jet Tagging in ALICE

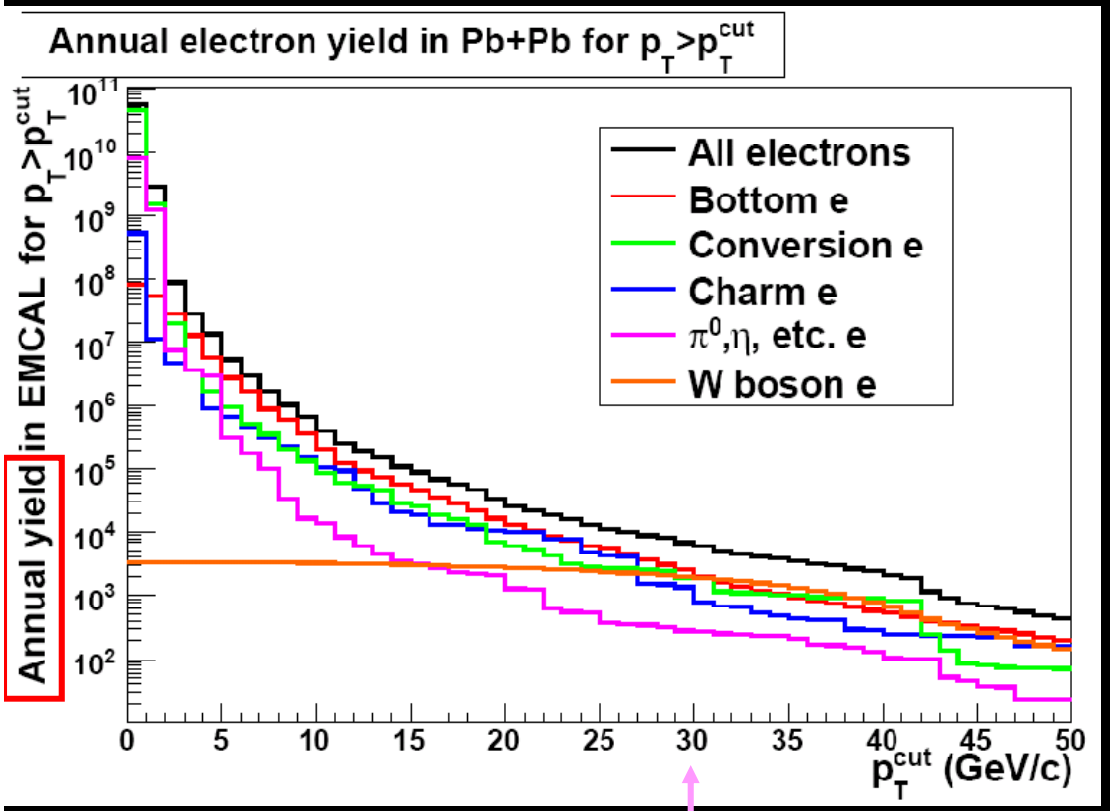


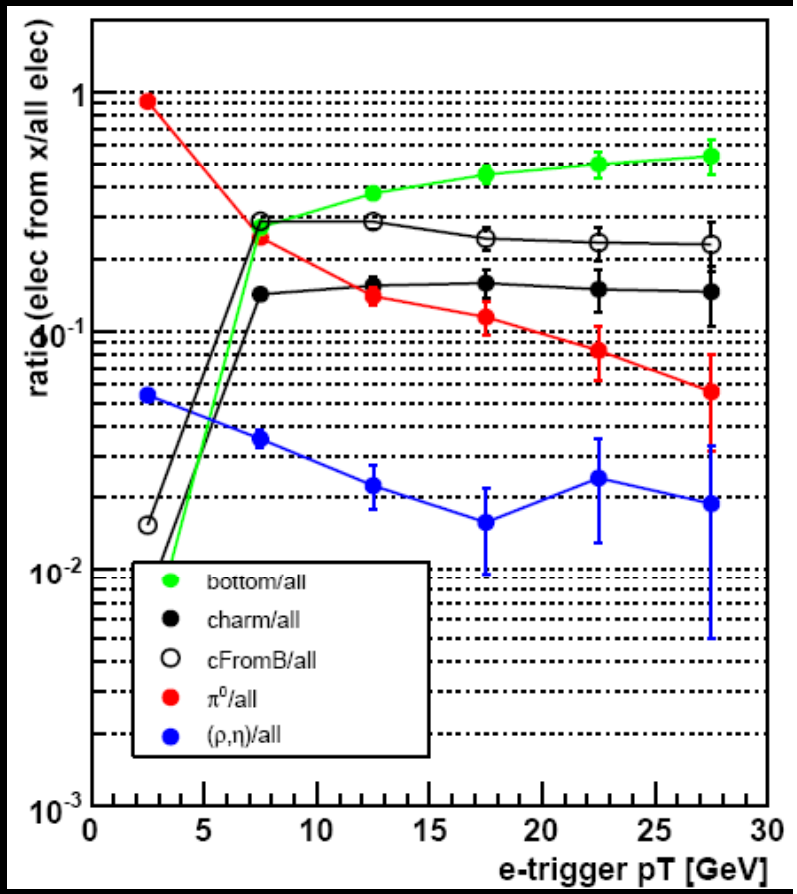
- Electron ID based on p/E
- Track-Cluster matching
- Test-beam data being analyzed



- p/E pion rejection > 1000 with
- electron efficiency of 80%

Semi-leptonic B yields in ALICE EMCal

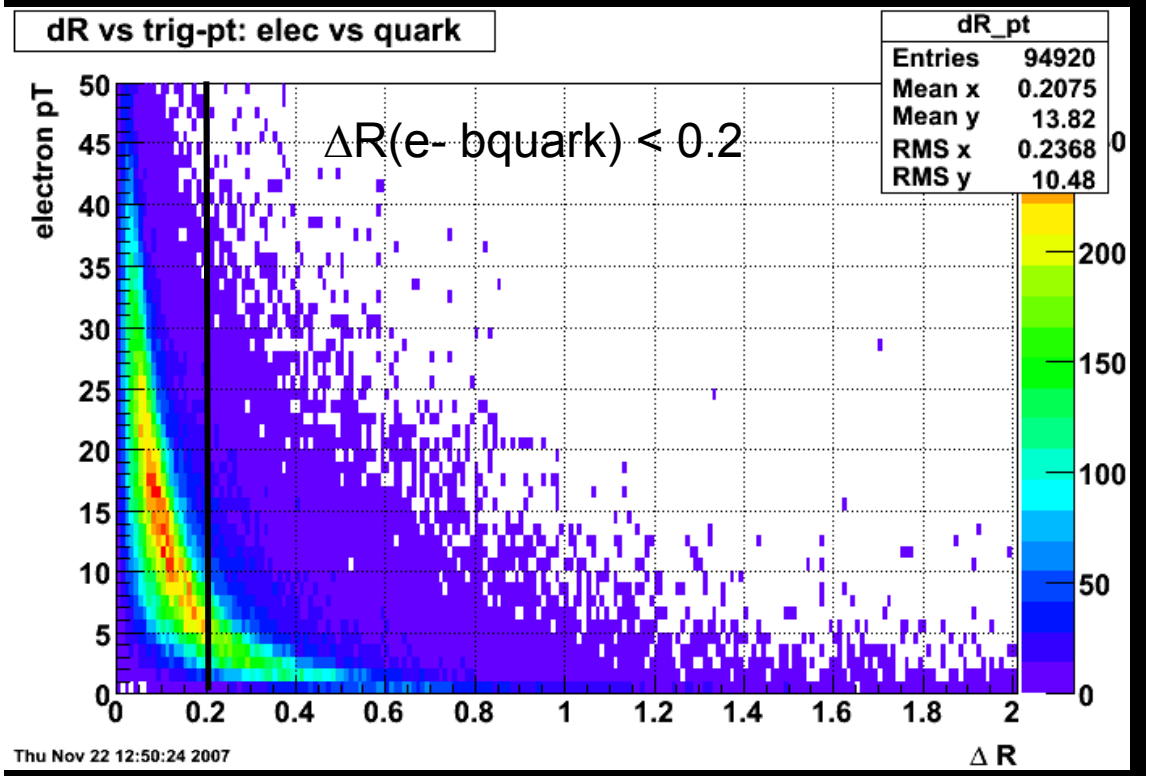


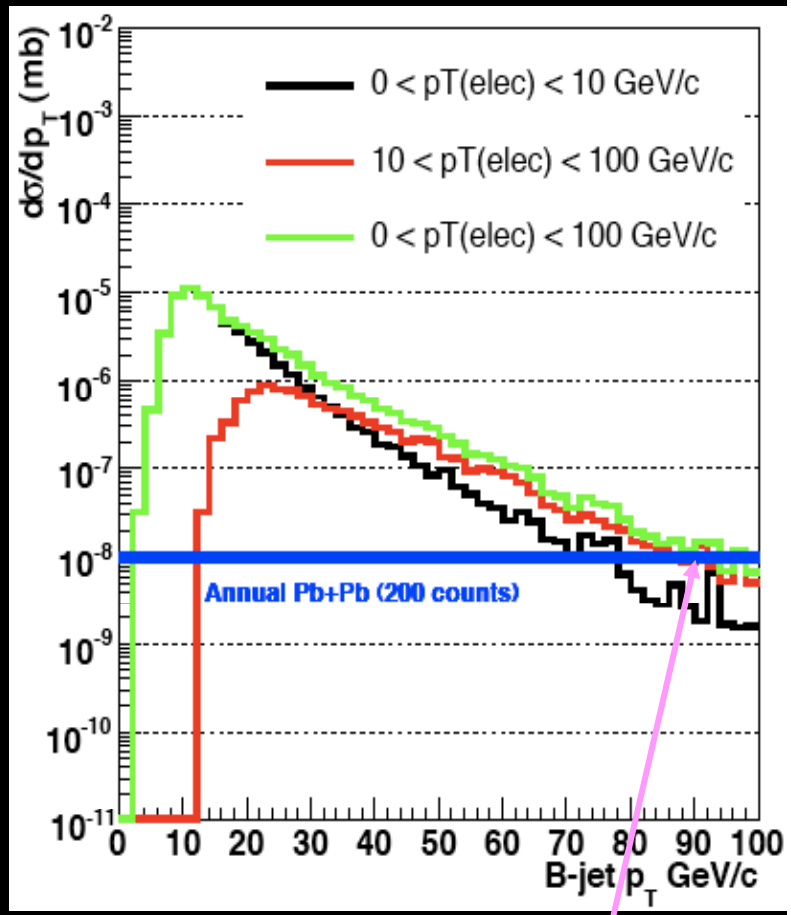


~ 5000 electrons with p_T > 30 GeV/c from B's

Mark Heinz (& Jenn Klay) – ECT 2008

ALICE with EMCal Trigger & Electron ID





B-jet measurements up to ~ 90 GeV

Tagging Jets with Photons

Strategy (event by event):

Search for identified prompt photon (in PHOS) with largest p_T (E_γ > 20 GeV)

Search for leading particle :

$\phi_\gamma - \phi_{leading} \sim 180^o$

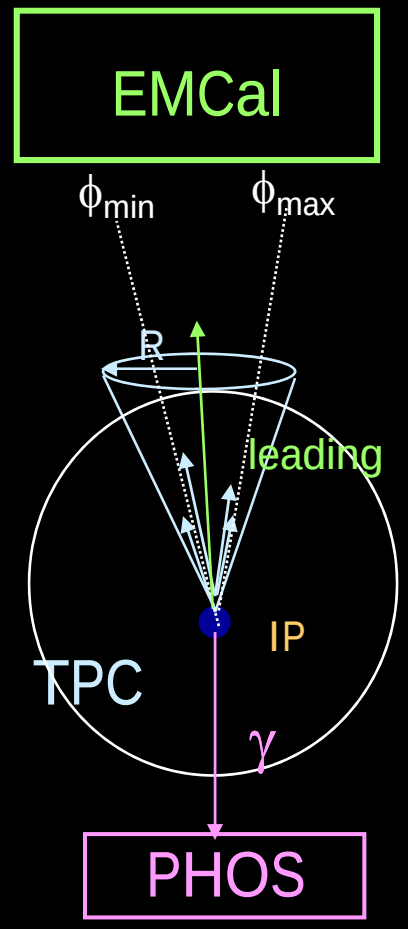
$E_{leading} > 0.1\ E_\gamma$

Reconstruct the jet :

Particles around leading with p_T > 0.5 GeV/c, inside a cone of R = 0.3.

2 configurations:

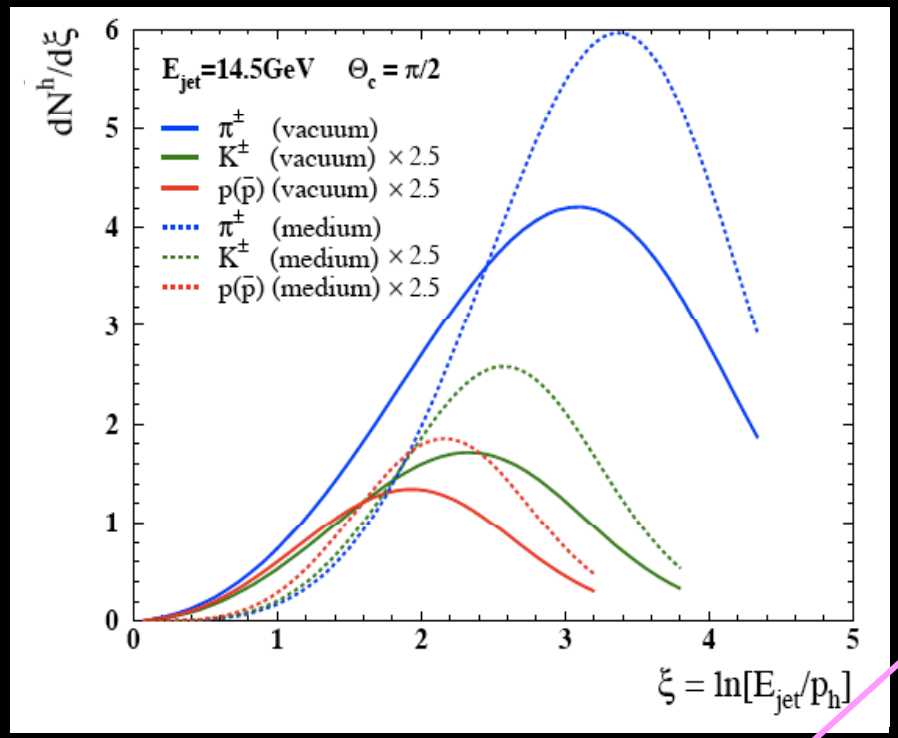
charged and neutral hadrons (TPC+EMCAL) and charged only (TPC).

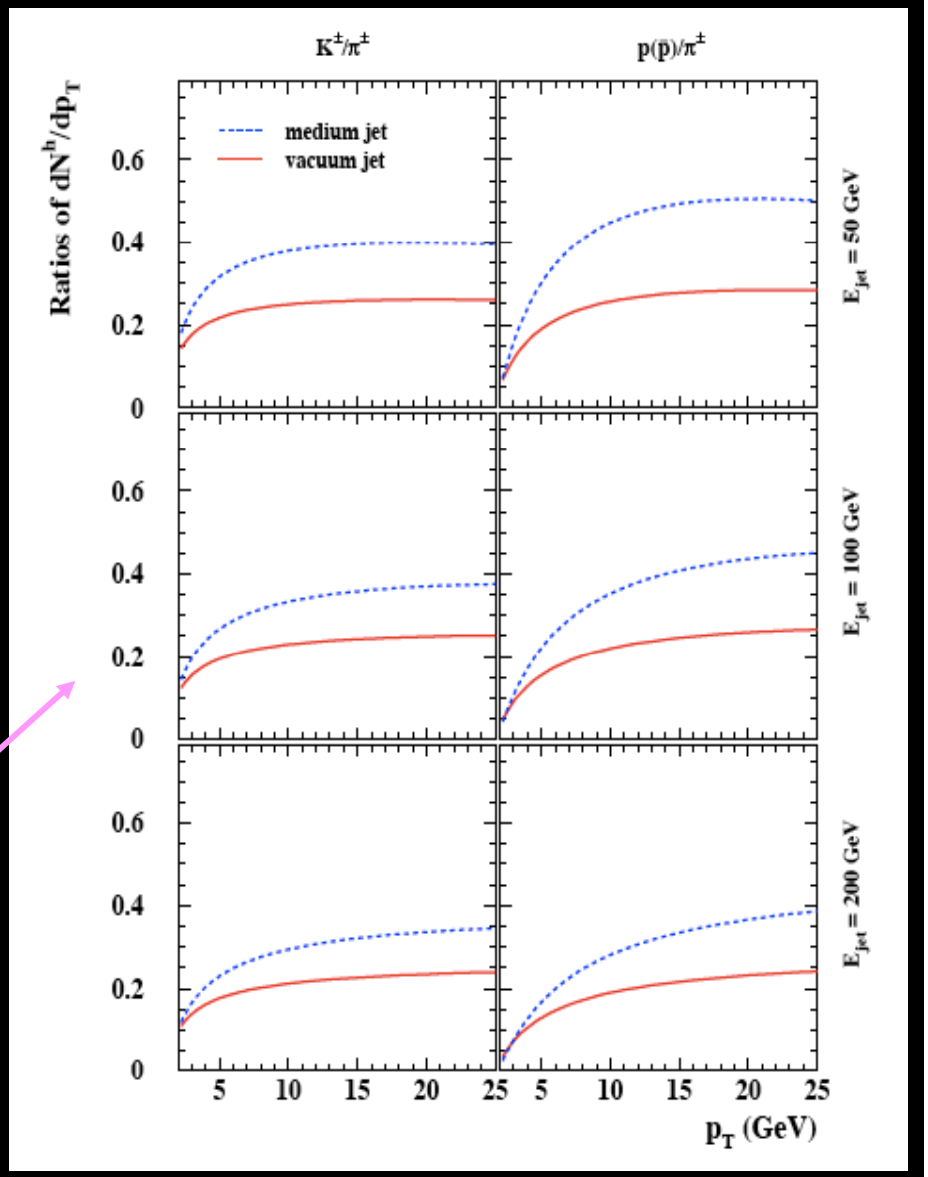


Thanks - Gustavo Conesa Balbastre – INFN Frascati

Particle Identified Fragmentation Functions

MLLA + LPHD *Sapeta, Wiedemann hep-ph/0707.3494*





ALICE PID and EMCal will enable this kind of PID'ed FF measurements

Summary

ALICE - versatile, general purpose heavy ion detector at LHC
will contribute significantly to understanding of (soft & hard) HI physics

ALICE EMCal (construction started) - provides significant high p_T & jet physics
will measure and trigger on jets, γ's, π^0's, electrons
will allow B-jet (quark-jet) tags
jet triggering $\rightarrow$ essential for jets in pp, pPb & peripheral PbPb
triggered jets $\rightarrow$ enable study of response of medium in lower p_T sector

Jet-finding in full simulations
jet reconstruction & fragmentation function mod. studies are possible
jet energies up to ~ 225 GeV possible (stats), 10% sensitivity at $\xi \sim 4$

B-jets from full simulations
measurements possible up to 80 to 90 GeV (stats in one PbPb month)
allows investigation of differences in quark & gluon jet energy loss

Work continues
establish best jet algorithm for heavy ions
deal with background, jet-splitting & jet-merging
develop heavy flavor (quark) tag algorithms
determine γ-jet capabilities through full simulations in ALICE

ALICE in 2008 LHC Run

- Complete – fully installed & commissioned
  - ITS, TPC, TOF, HMPID, MUONS, PMD, V0, T0, FMD, ZDC, ACORDE, TRIGGER, DAQ
- Partially completed
  - TRD (20%) to be completed by 2009
  - PHOS (40%) to be completed by 2010
  - EMCAL (0%) to be completed by 2010/11
- At start-up full hadron and muon capabilities
- Partial electron and photon capabilities

ALICE Goals for Data

- First physics in ALICE will be pp - important reference data for heavy-ions
- Unique pp physics in ALICE - examples
  - multiplicity distribution
  - baryon transport
  - measurement of charm cross section major input to pp QCD physics

- **First 10^5 PbPb events:** global event properties
  - multiplicity, rapidity density
  - elliptic flow
- **First 10^6 PbPb events:** source characteristics and spacetime evolution
  - particle spectra, resonances
  - differential flow analysis
  - interferometry
- **First 10^7 PbPb events:** high-p_t, heavy flavours
  - jet quenching, heavy-flavour energy loss
  - charmonium production
- Eventual goals - bulk properties of medium
  - energy density, temperature, pressure
  - heat capacity/entropy, viscosity, sound velocity, opacity
  - susceptibilities, order of phase transition

Special thanks to contributors:

- Ana Marin
- Boris Hippolyte
- Joern Putschke
- Mark Heinz
- Jennifer Klay
- Peter Jacobs
- Andreas Morsch
- Magali Estienne
- Gustavo Conesa Balbastre