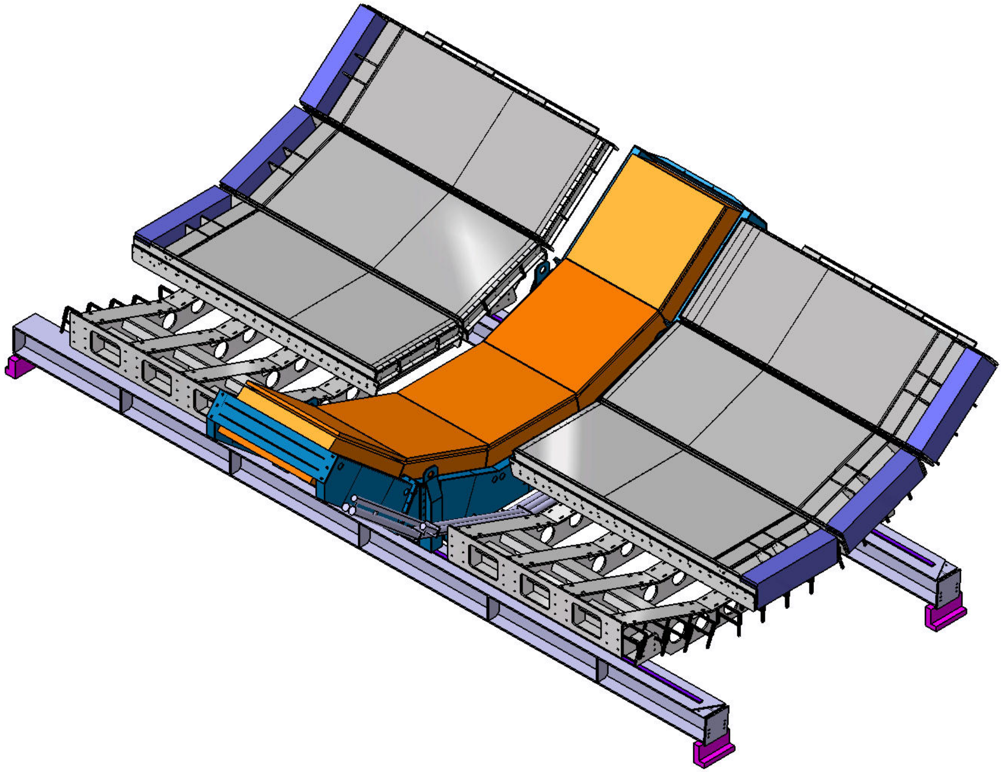


DCal for the ALICE experiment at LHC

Tatsuya Chujo

中條 達也

University of Tsukuba

(for the ALICE D-Cal Project)

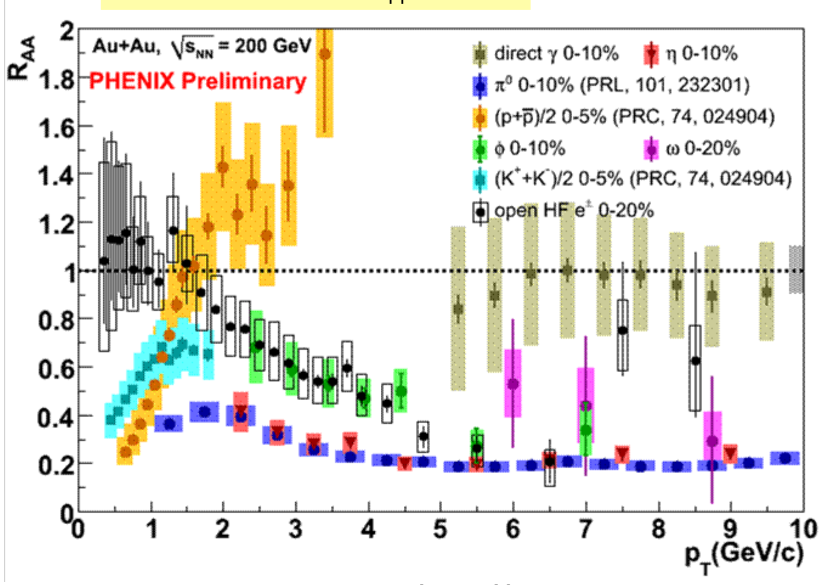
筑波大学
University of Tsukuba

Outline

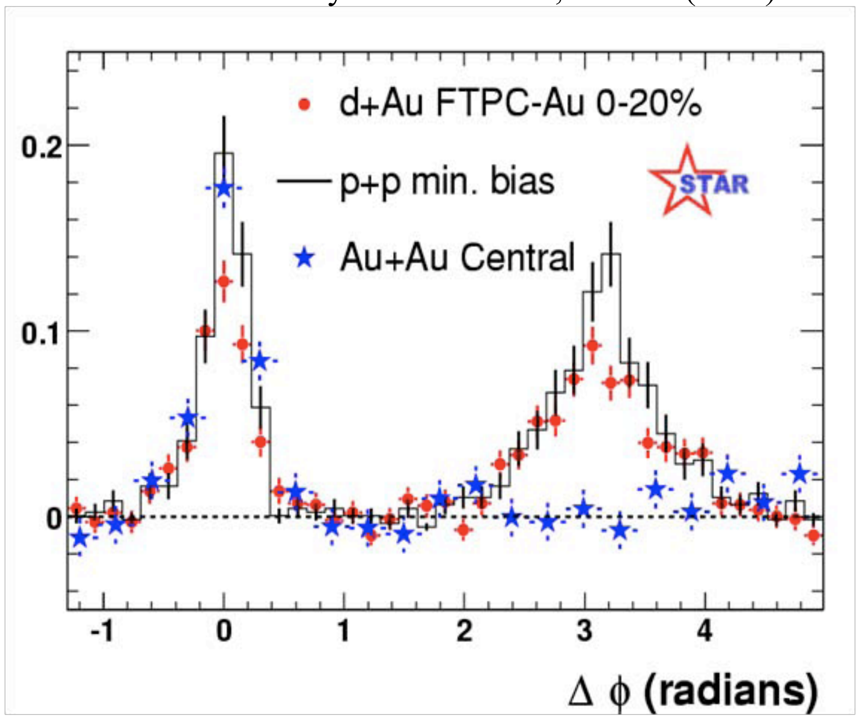
1. Introduction
   - Jet quenching at RHIC and LHC
2. Dijet Calorimeter (=DCal) in LHC-ALICE
3. Physics cases for DCal
4. Current stats and plan
5. Summary

Jet quenching at RHIC

$$R_{AA} = \frac{Yield_{AuAu} / \langle N_{binary} \rangle_{AuAu}}{Yield_{pp}}$$



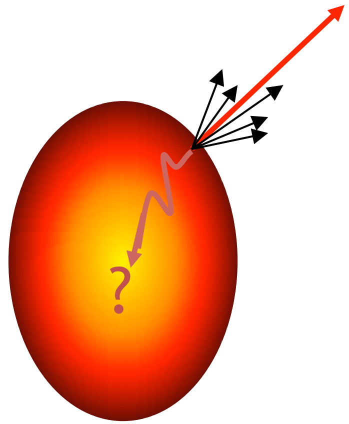
Phys. Rev. Lett. 91, 072304 (2003).



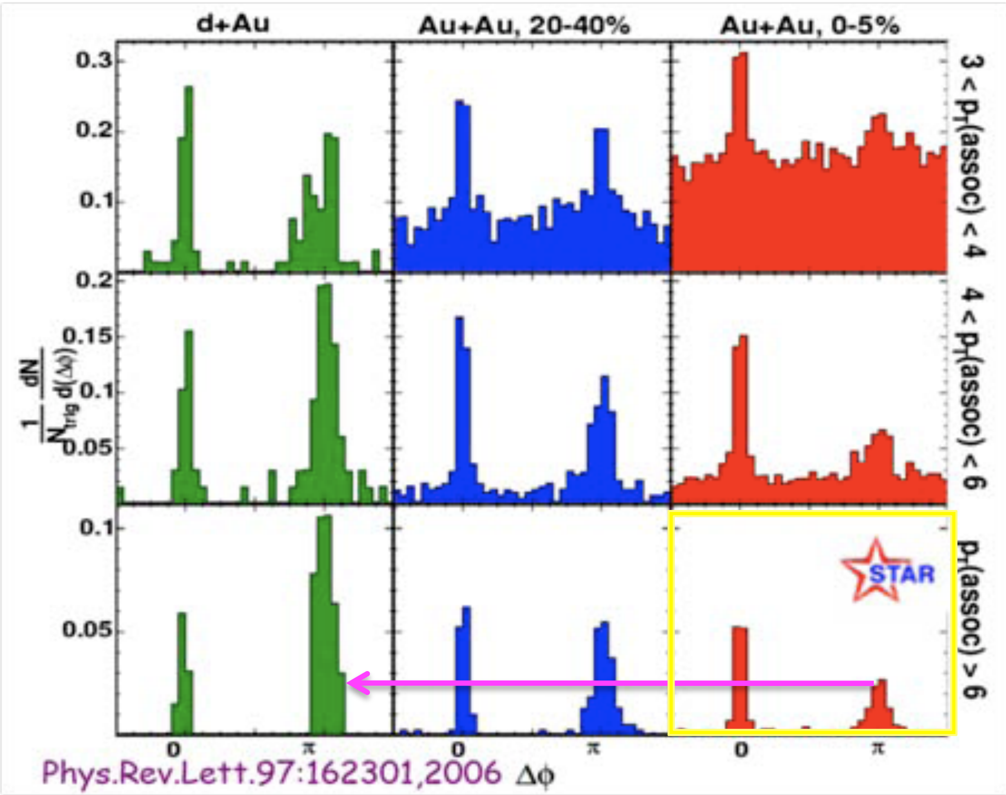
In Au+Au central collisions at RHIC:

- **High p_T yield suppression**
  - Gluon density: dN_g/dy ~ 1100
  - Energy density: **$\varepsilon > 100\ \varepsilon_0$**
  - Precise measurement at very high p_T.
- **Disappearance of away side jet**

Trigger hadron: p_T > 4 GeV/c,
Associated hadron: p_T > 2 GeV/c



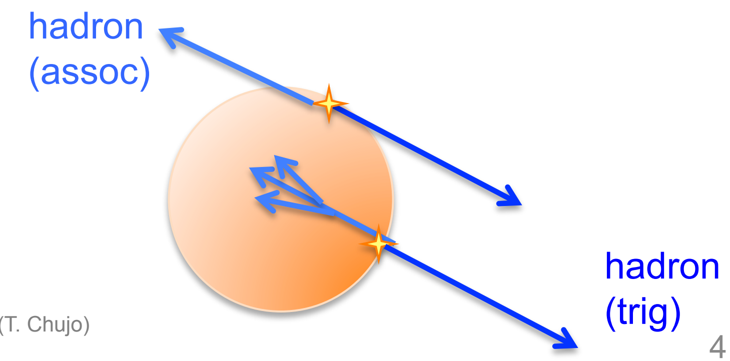
Di-hadron correlation: surface bias



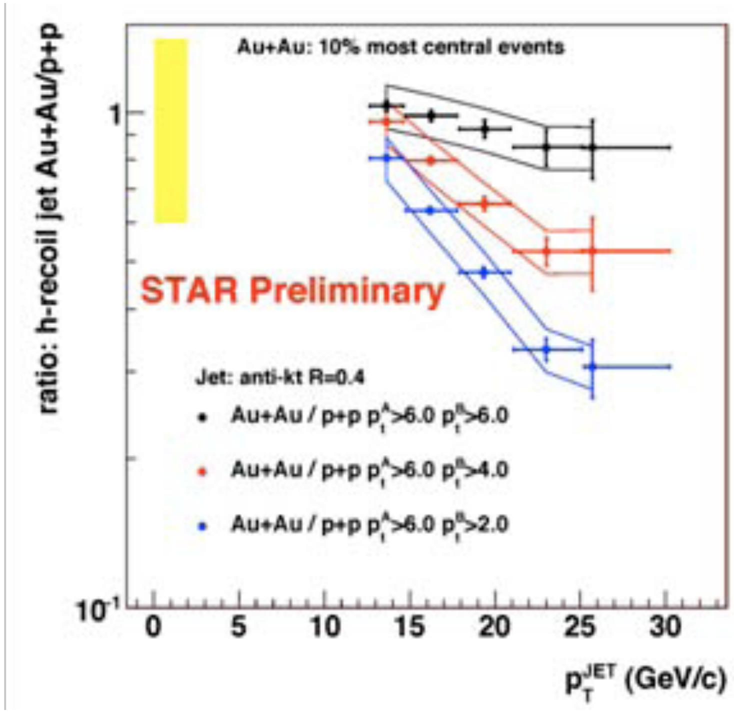
p_T (trig) > 8 GeV/c

- $\Delta\phi$ di-hadron correlations for d+Au, Au+Au at $\sqrt{s_{NN}}$ = 200 GeV (STAR).
- Trigger hadron p_T (trig) > 8 GeV/c, and look at associated hadron in different p_T (assoc) class.

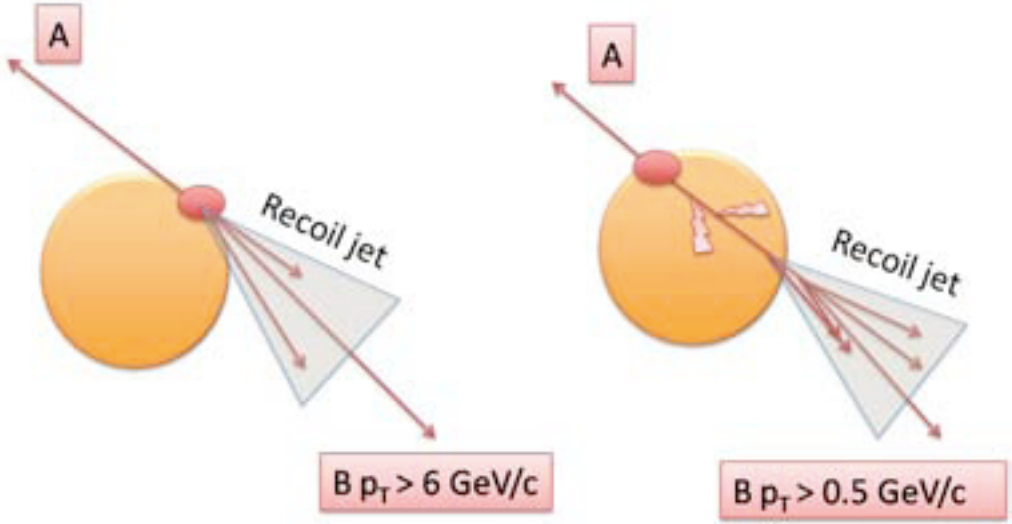
- Away side peak at highest p_T (assoc) > 6 GeV/c.
- **Punch through jets** at high p_T
  - Away side yield: suppressed by factor ~5, compared to d+Au.
  - B-to-B, but tangentially emission.
  - **h-h correlations: strong bias towards surface.**



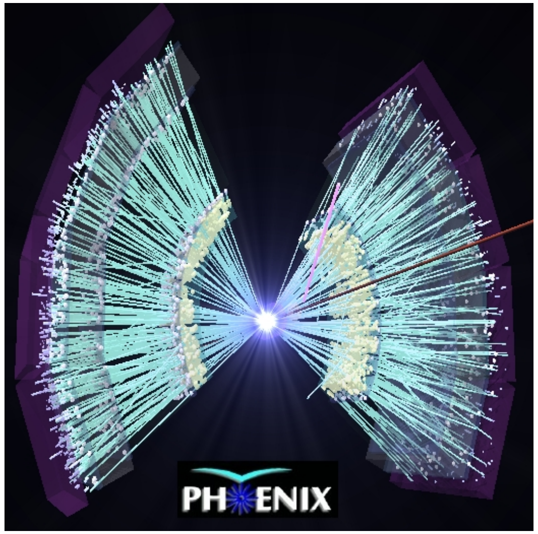
Full jet reconstruction, and h-jet correlations at RHIC



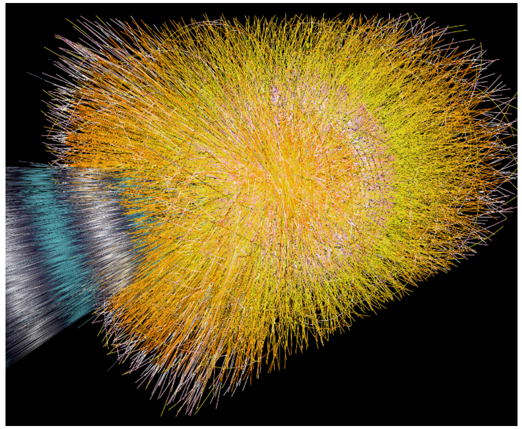
Key to understand jet in HI collisions:
(1) correlations, (2) fully reconstructed jet.



- Used fully reconstructed jet (by STAR TPC & EMC).
- Trigger high p_T hadron, and look at **recoil jet** in away side, measure conditional yield in (Au+Au / p+p).
- **Stronger suppression for lower recoil jet energy.**
  - indicating broadening of recoil jet cone size.
- **"Controlled" surface bias.**



RHIC vs. LHC

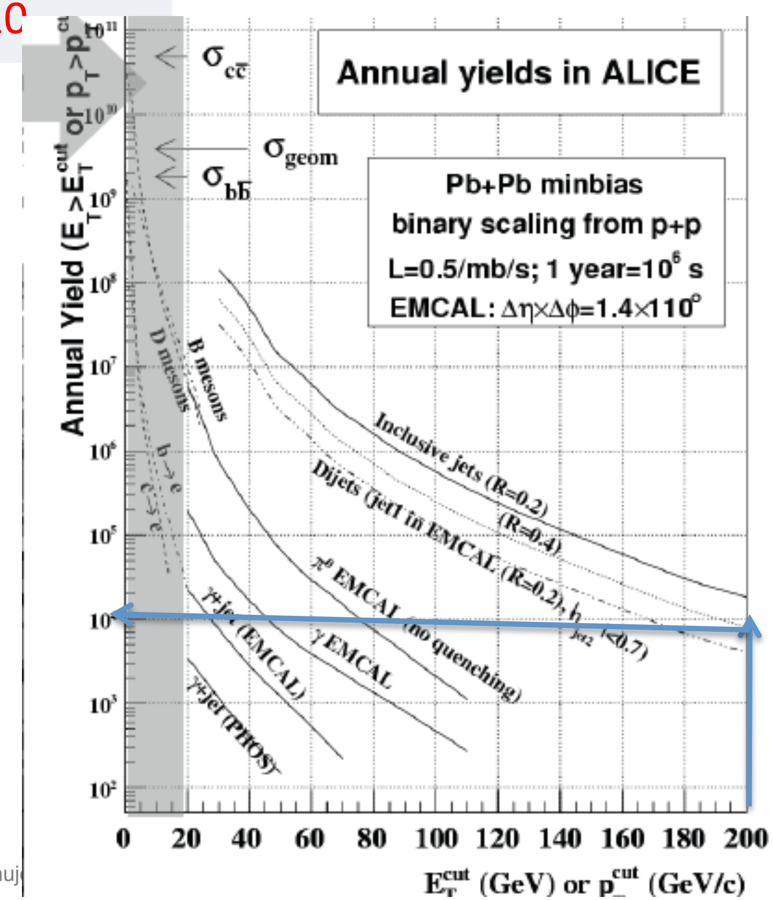


	RHIC	LHC
$\sqrt{s_{NN}}$ (GeV)	200	5500
T/T_c	1.9	3.5-4.0
ε (GeV/fm^3)	5	15-60
τ_{QGP} (fm/c)	2-4	> 10

RHIC

- **LHC: Jet production dominant.**
  - **Study the matter by clean many hard probes, and look at response of bulk matter in HI collisions.**

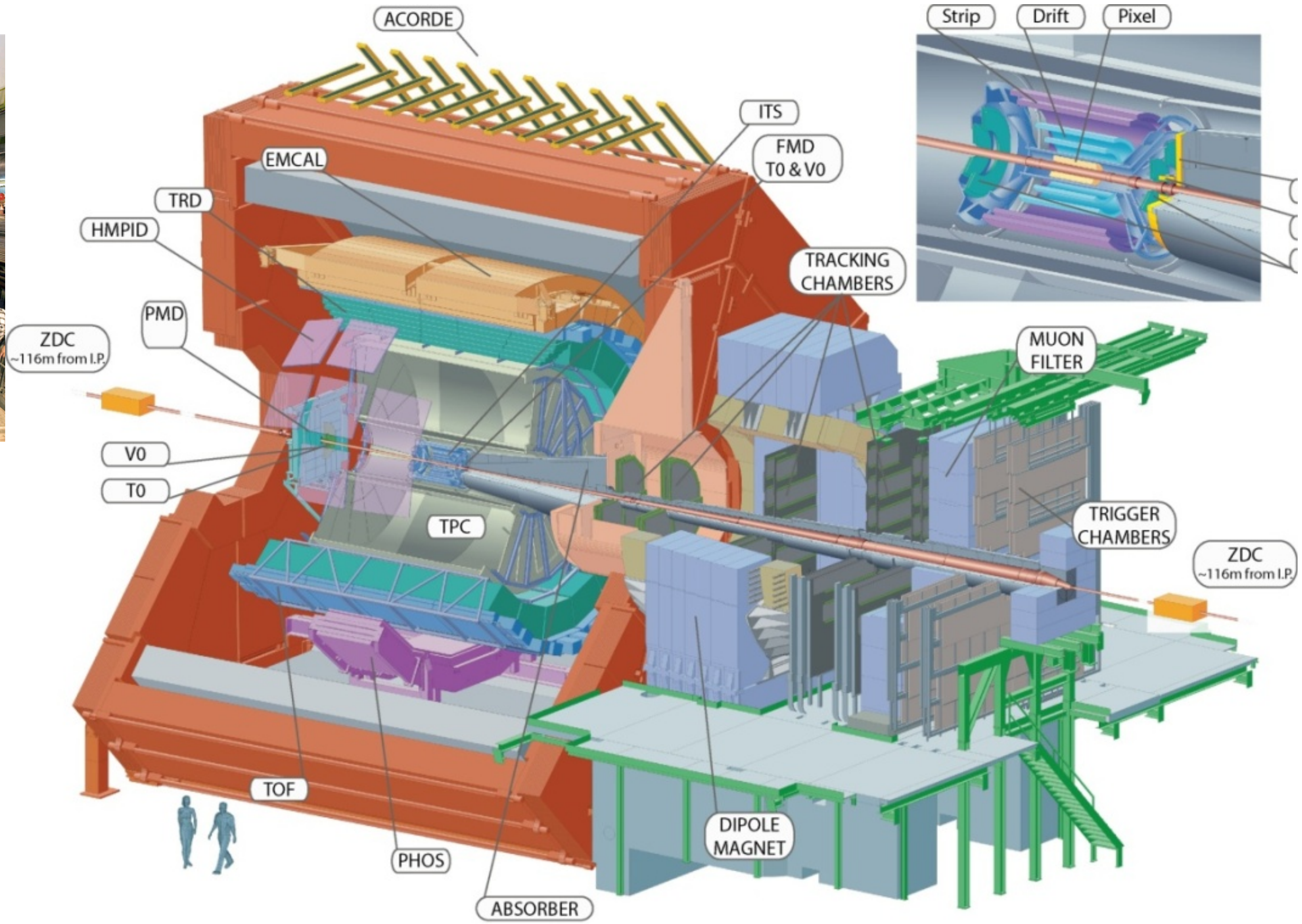
LHC:
Inclusive jets (R=0.4), annual yield; 10^4 @ p_T = 200 GeV/c (5.5 TeV, Year-1)



ALICE experiment

ALICE = A Large Ion Collider Experiment

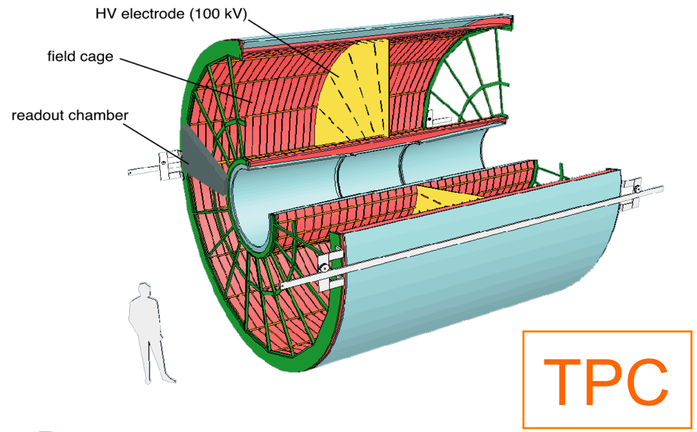
- Dedicated heavy ion experiment at LHC:

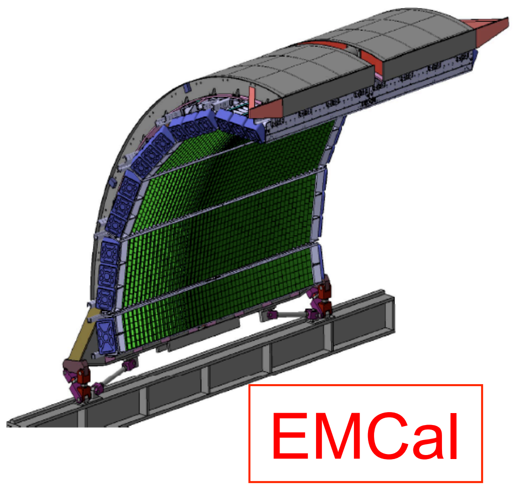


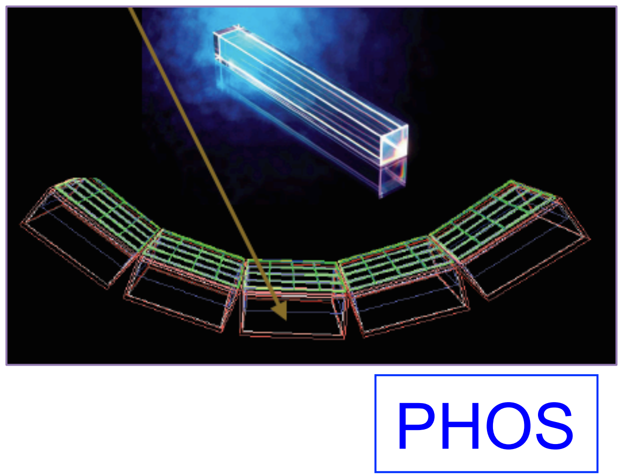
ALICE

Key detectors for jet measurement in ALICE

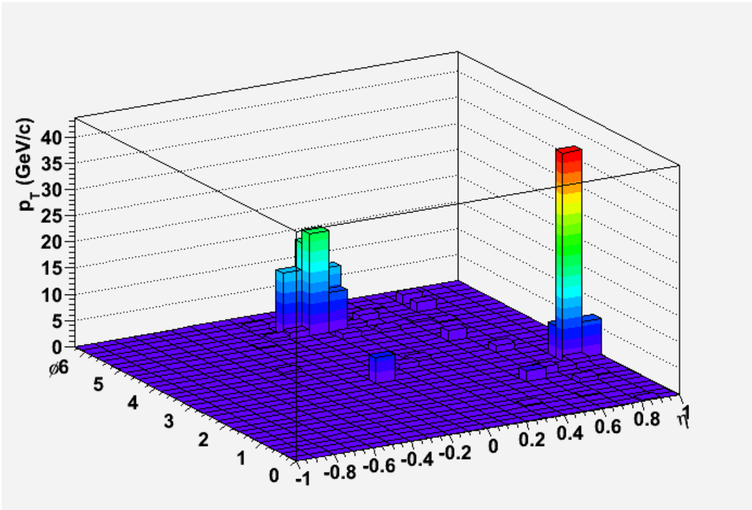
- **TPC (+ITS)**
  - **Charged particles $\Delta\eta$ = 1.8.**
  - Excellent momentum resolution.
  - Excellent PID and heavy flavor tagging.
- **EMCal**
  - Pb-Scint sampling EMC.
  - $\Delta\phi$ = 107°, $\Delta\eta$ = 1.4
  - **Energy resolution ~10%/√E_γ**
  - Jet and γ trigger
- **PHOS**
  - PWO crystal EMC.
  - 220° < ϕ < 320°, $\Delta\eta$ = 0.24
  - **Energy resolution ~3%//√Eγ**
  - γ trigger.



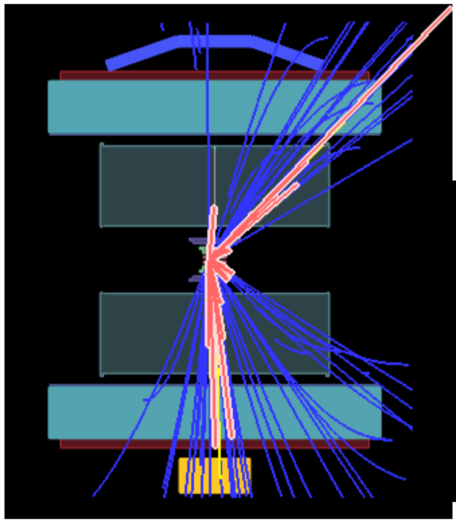


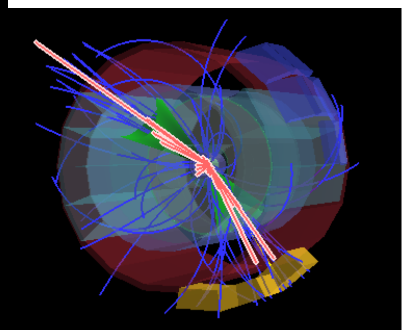


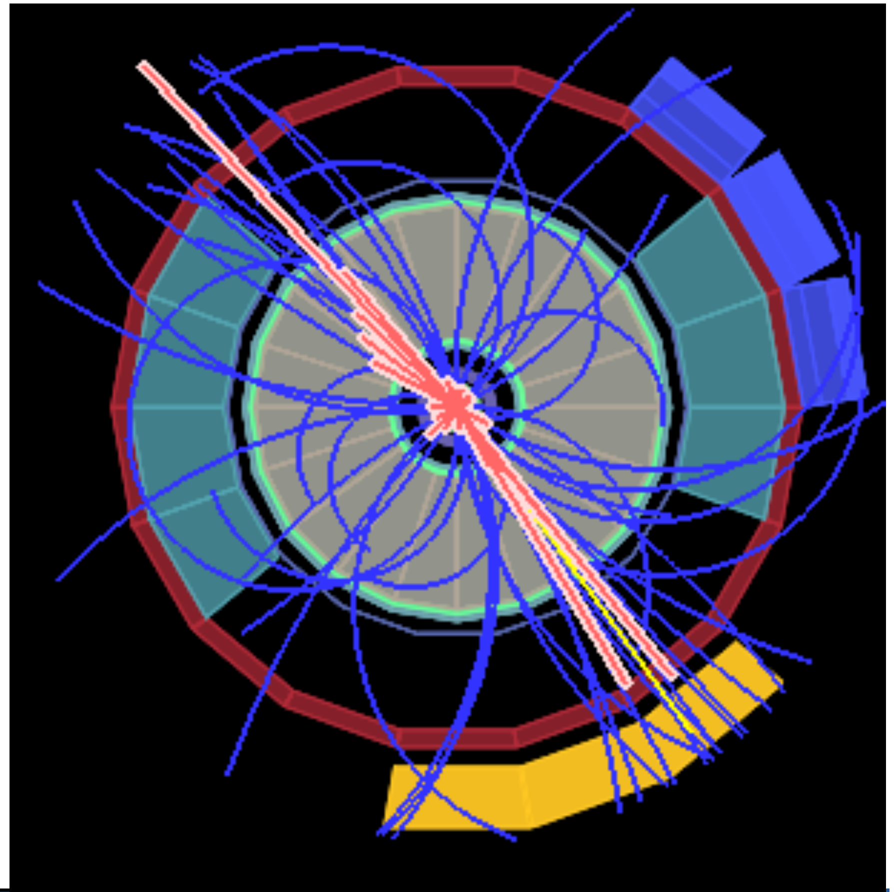
Di-Jet event @ 7 TeV p+p (real data); used only charged tracks (ITS-TPC)



η-φ







Reconstructed Jets UA1 Cone R = 0.4:

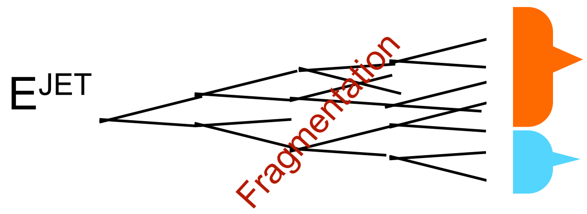
Jet 1: $\eta = 0.02$, $\phi = 306°$, $p_T = 71$ GeV, Tracks 15

Jet 2: $\eta = 0.84$, $\phi = 132$, $p_T = 47$ GeV, Tracks 9

$\Delta\phi = 174°$

Total Tracks 108

But, don't forget the fluctuation by neutral!

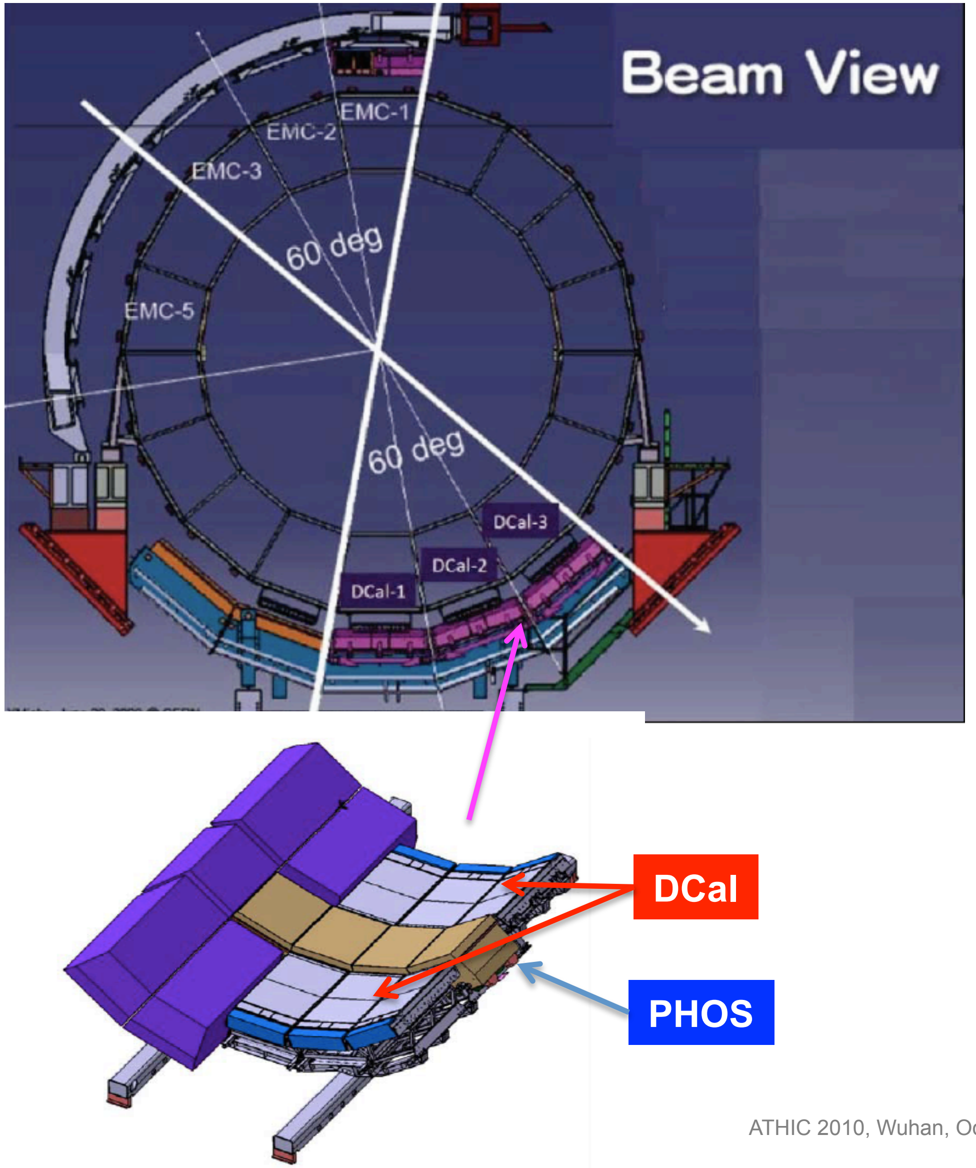


$$E^{JET}=E^{CHARGED}+E^{NEUTRAL}$$

$$dE^{CHARGED} = -dE^{NEUTRAL}$$

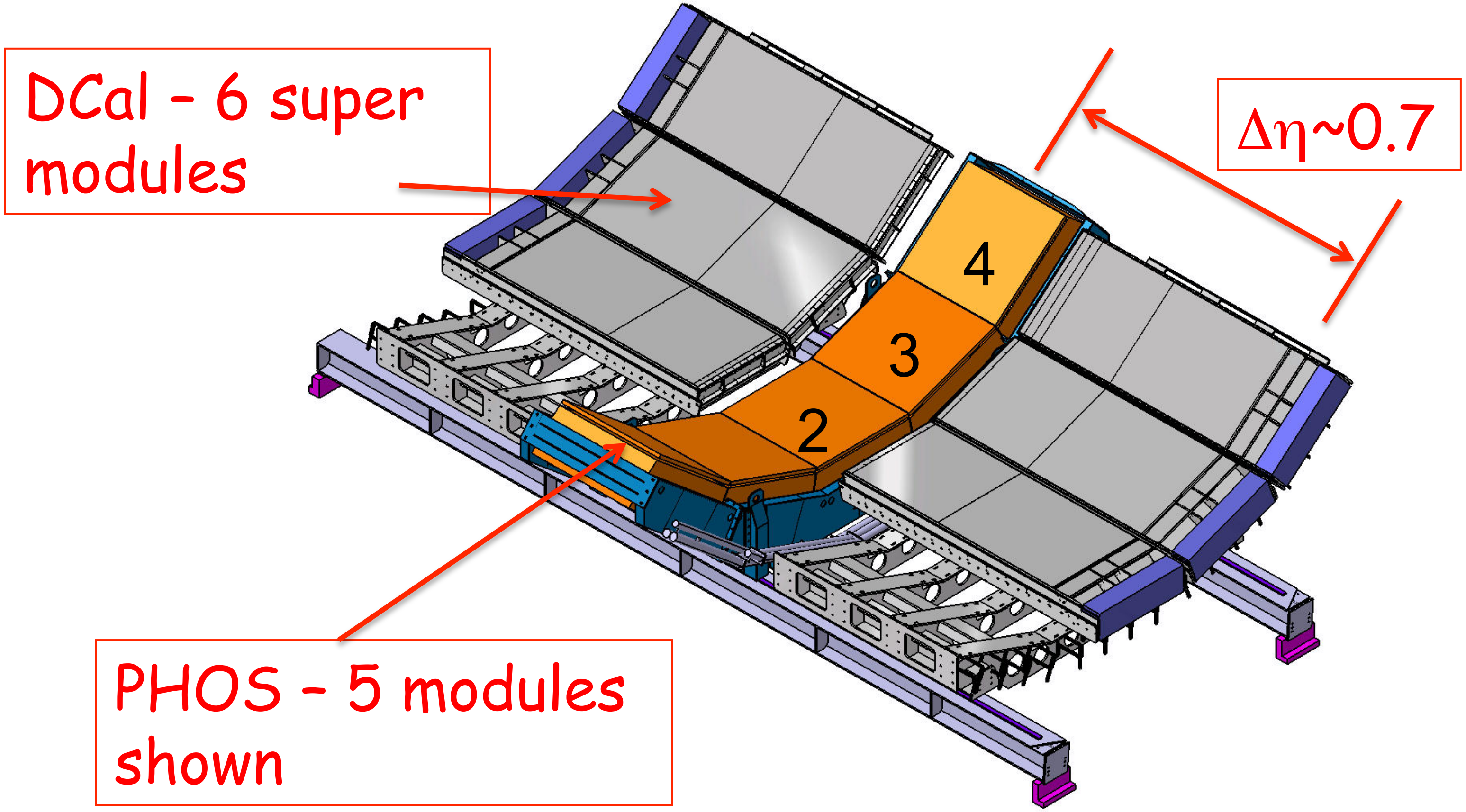
- **Statistical fluctuation with total energy limitation**
  - **Total jet energy is fixed.**
    - **fluctuation of neutral play significant role**
    - **Need larger acceptance EMC on opposite side of EMCal in ALICE.**

ALICE Dijet Calorimeter (DCal)



- *Extension of the acceptance of EMCal .*
- *Lead-scintillator sampling type EMC with APD readout.*
  - *EMCal: $\Delta\phi$ = 110°*
  - *DCal: $\Delta\phi$ = 60° (on opposite side of EMCal)*
  - *$\Delta\eta$ = 0.7 for both EMCal and DCal + PHOS*
  - *~10%/√E*
- *Allow back-to-back hadron-jet, di-jet measurements in ALICE, with R = 0.4, up to p_T ~ 150 GeV/c.*
- *Enhance jet, γ trigger capability.*

D-Cal Design



6 Super Module configuration was chosen to have a largest possible jet radii in DCal, together with PHOS, i.e. R=0.4

ALICE-DCal Collaboration

China
Huazhong Normal University

Finland
University of Jyvaskyla

France
LPSC Grenoble, Subatech Nantes, IPHC Strasbourg

Italy
INFN Catania, LNF Frascati,

Japan
Hiroshima University, University of Tokyo, University of Tsukuba,

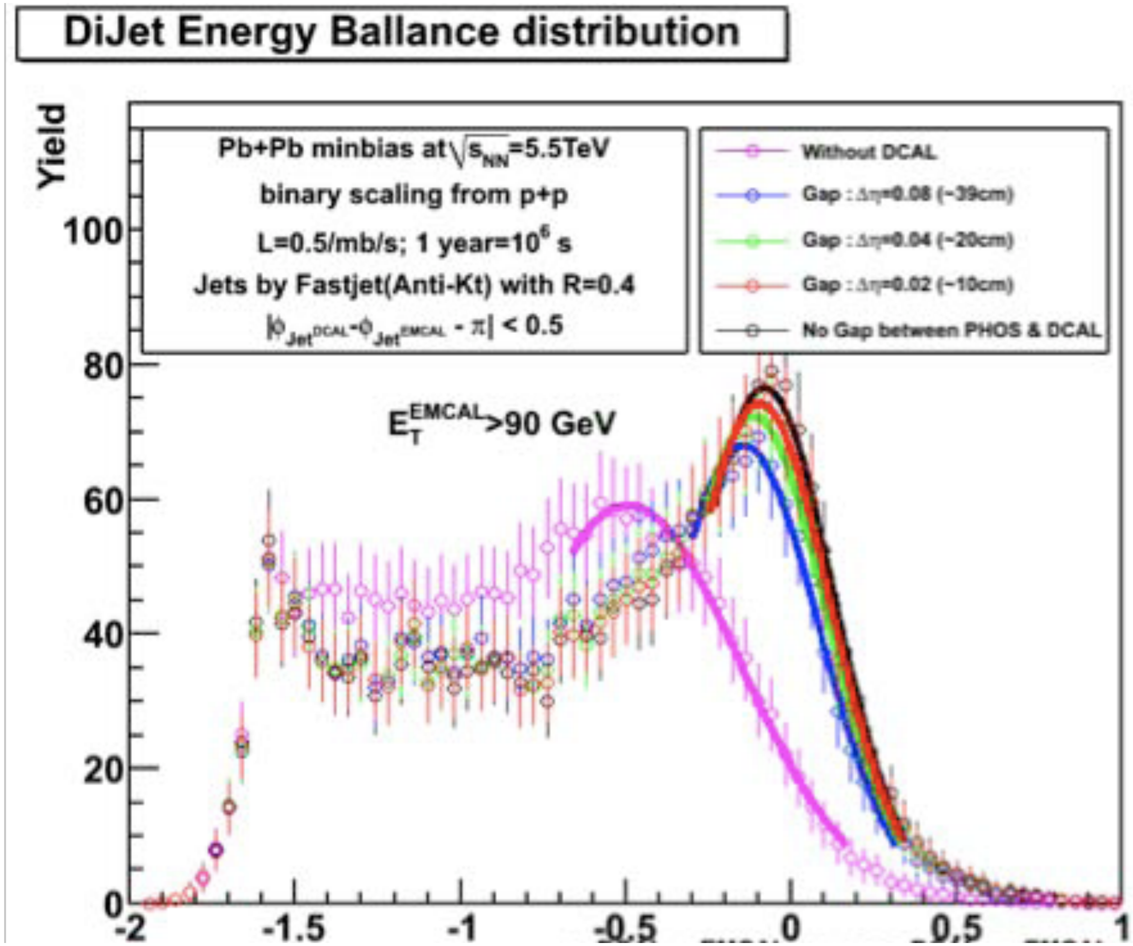
Switzerland
CERN

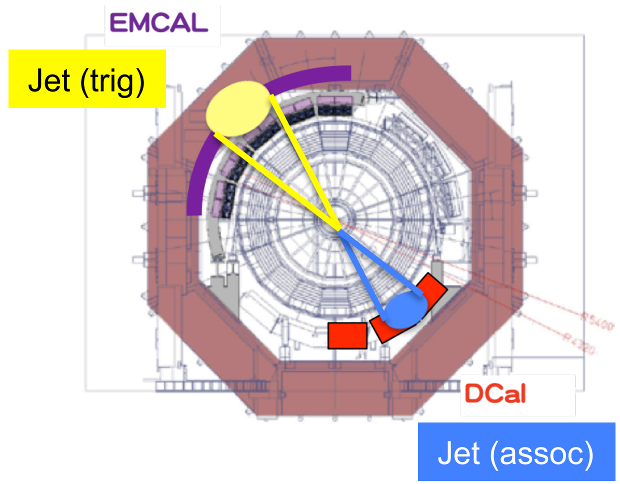
USA
Lawrence Berkeley National Laboratory, Wayne State University, University of Houston, University of Tennessee, Lawrence Livermore National Laboratory, Yale University, Oak Ridge National Laboratory, Creighton University, Cal Poly San Luis Obispo, Purdue University

Physics case of DCal

- **Case1: Jet-Jet in p+p**
- **Case2: Jet-Jet in Pb+Pb (quenching effect)**
- **Case3: π^0-Jet in Pb+Pb**
  - Notes:
    - MC simulation study using qPYTHIA.
    - "DCal" means including PHOS acceptance, i.e. DCal+PHOS.
    - Uncertainty on data points: Pb+Pb (central 0-10%) @ 5.5 TeV one year running statistical uncertainty (= 0.5 nb^{-1}).
    - Jet reconstruction: FAST jet anti-kT algorithm, R=0.4.

Case1: Dijet in p+p

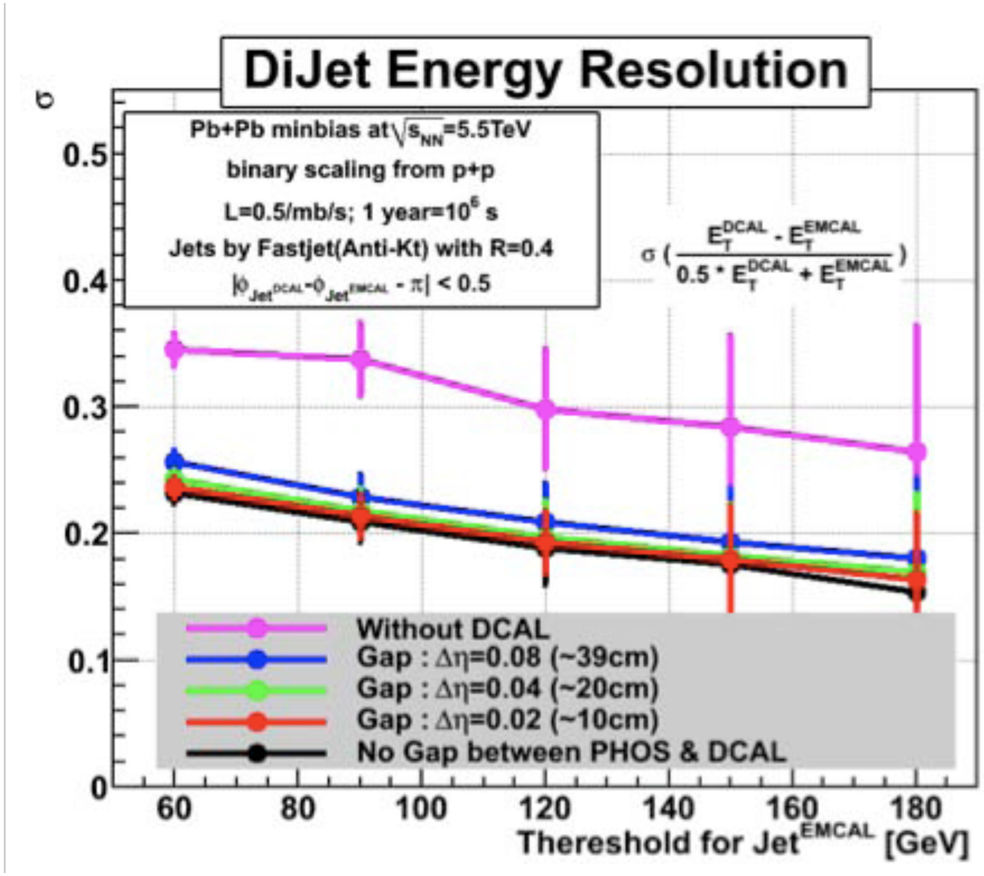


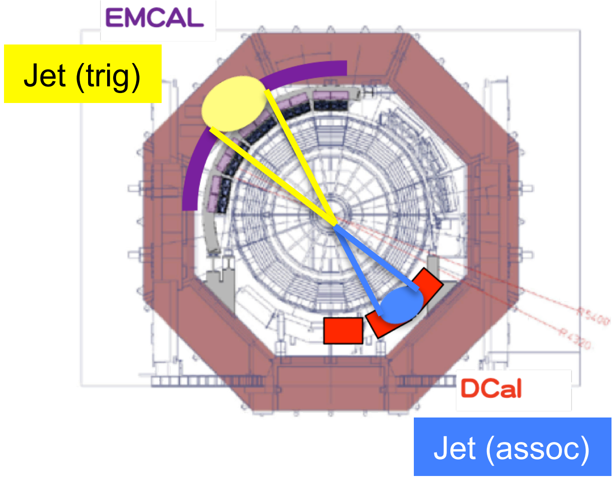


- Dijet energy balance, Δ.
- No quenching (p+p)
- **True dijet peak Δ~0, except without DCal.**
- **No clear peak EMC-TPC (no DCal).**
- Asymmetric shape due to recoil jet escape the acceptance of DCal, and jet from BG.
- **DCal is essential for better Δ resolution.**

$$\Delta = \frac{(E_T^{DCal} - E_T^{EMCal})}{(E_T^{DCal} + E_T^{EMCal})/2}$$

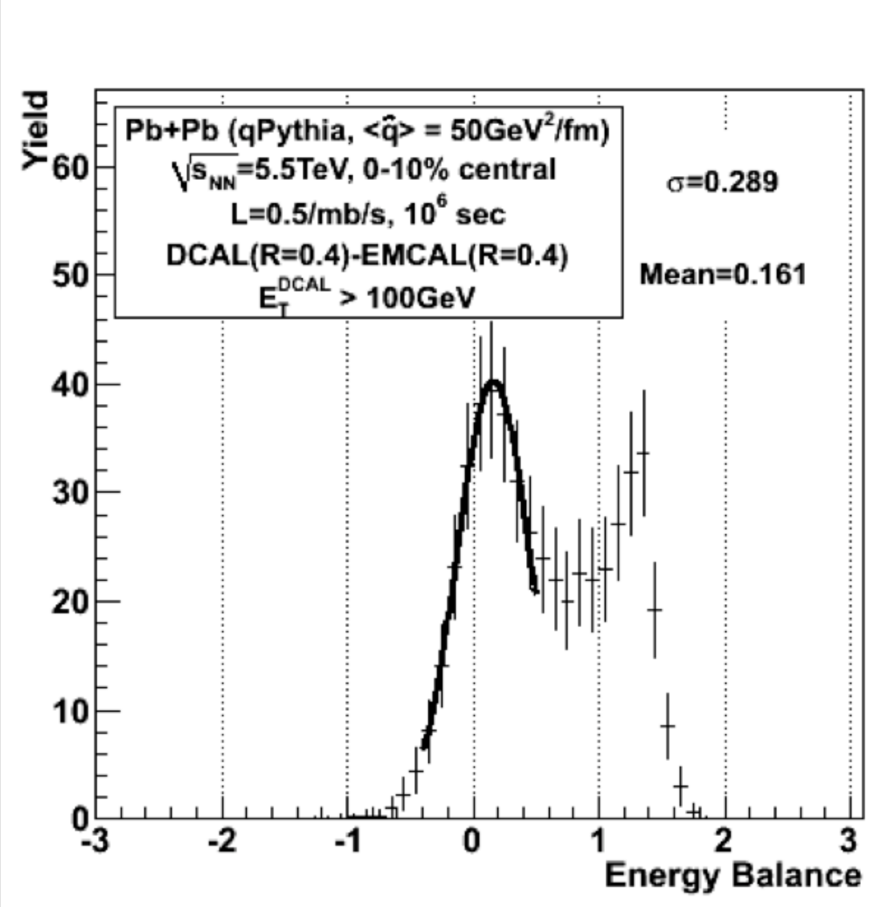
Case1: Dijet in p+p



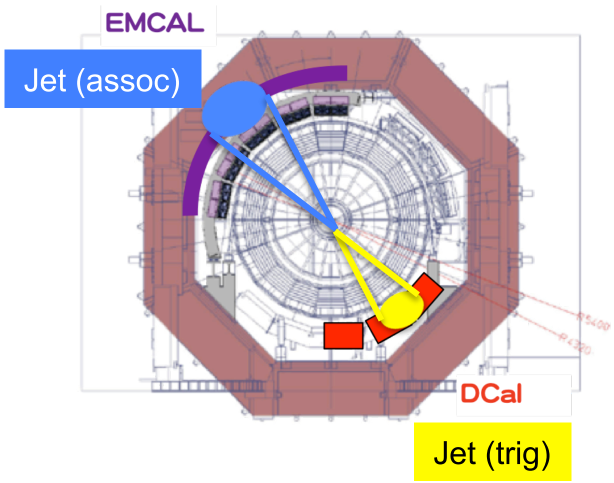


- DCal improves the energy balance resolution from ~35% to ~25% @ E_T^{EMCal} = 60 GeV, down to <20% for higher E_T^{EMCal}.
- Small effect by gap between PHOS and DCal.

Case2: Dijet in Pb+Pb, quenched jet



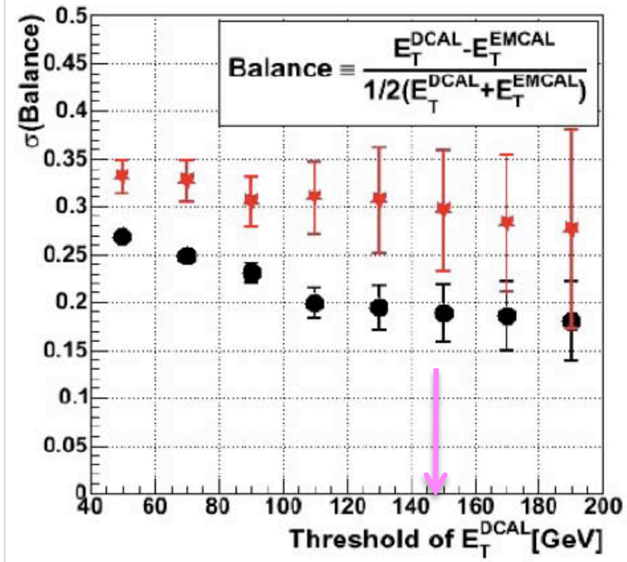
$$\Delta = \frac{(E_T^{DCal} - E_T^{EMCal})}{(E_T^{DCal} + E_T^{EMCal})/2}$$



- Same as “Case1” but, **required trigger jet in DCal side** instead.
- “Tail” on positive side due to trigger for DCal in this case.
- In this case, <qhat> = 50 GeV^2/fm, and DCal jet energy threshold of 100 GeV.
- Peak: true dijet with quencing.
  - look at sigma, and centroid to quantify the jet quenching effect (see next slide).
- Tail: recoil jet out of acceptance, BG.

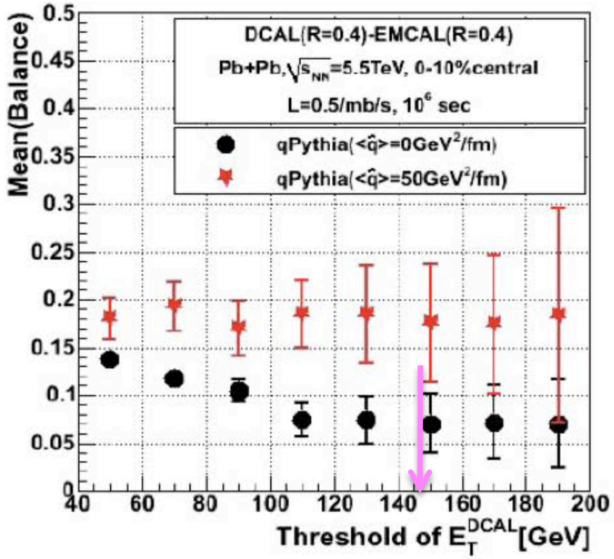
Case2: Dijet in Pb+Pb, quenched jet

Width

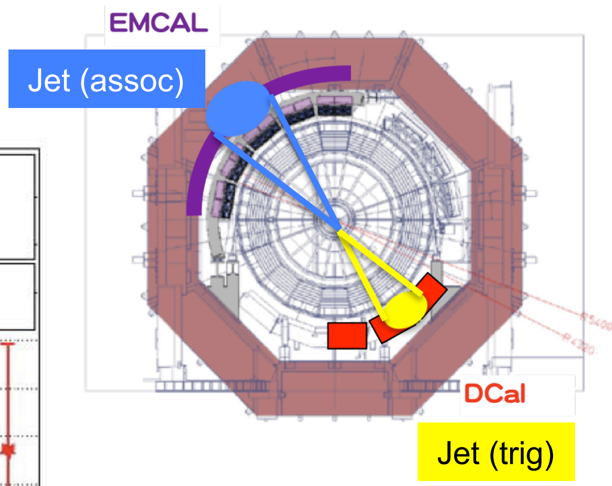


150 GeV

Centroid



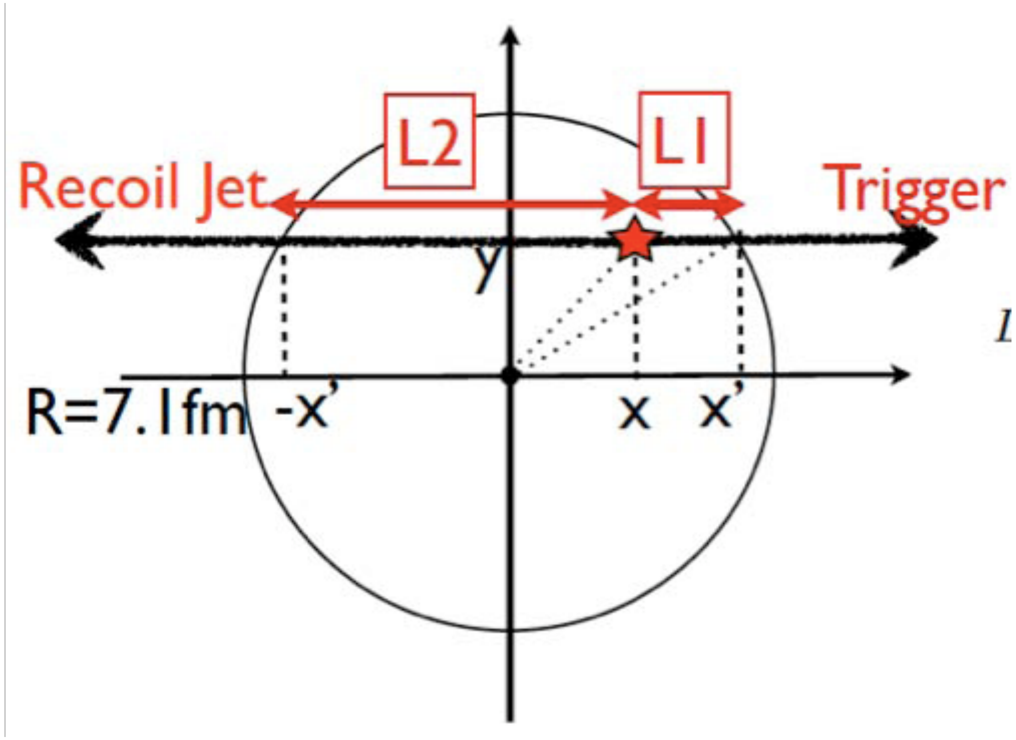
150 GeV

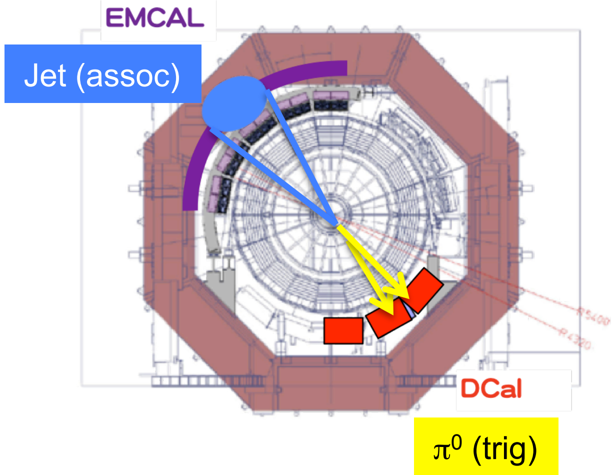


- **Red: <qhat> = 50 GeV^2/fm**, **Black: <qhat> = 0 GeV^2/fm.**
- Broadening of peak is seen for jet quenching.
- Shift of centroid -> energy loss.
- Using one year Pb+Pb running (in this model & parameter set), possible to study jet quenching effect up to E_T^{DCal} ~ 150 GeV.

Case 3: π^0-jet, control path length

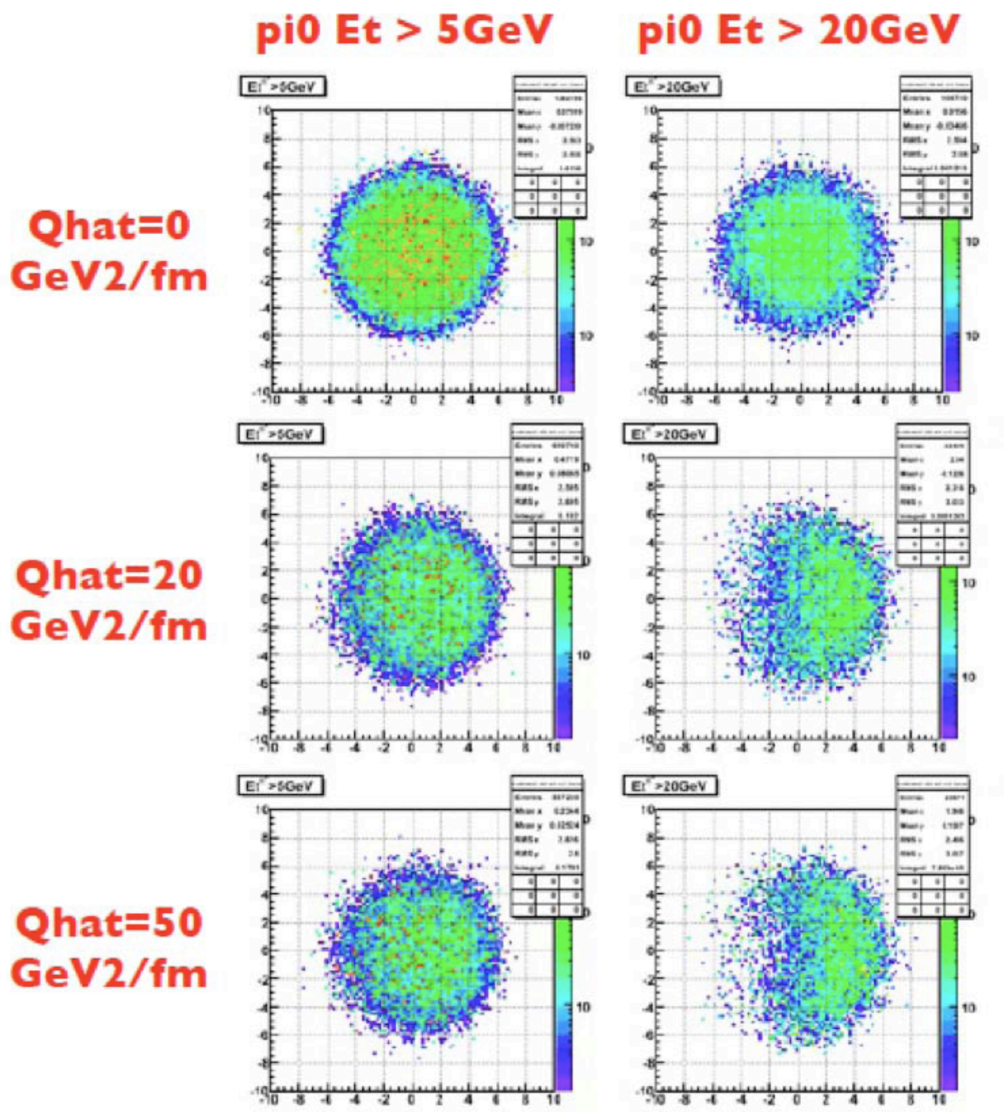
Geometry of π^0 trigger and associated recoil jet

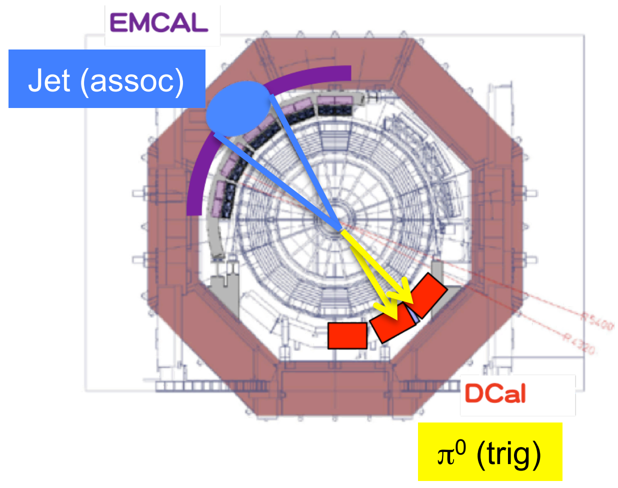




- Trigger π^0 in DCal, requiring jet in EMCal.
- Producing strong geometry bias by hand, i.e. “control” the path length of jet.

Case 3: π^0-jet, control path length



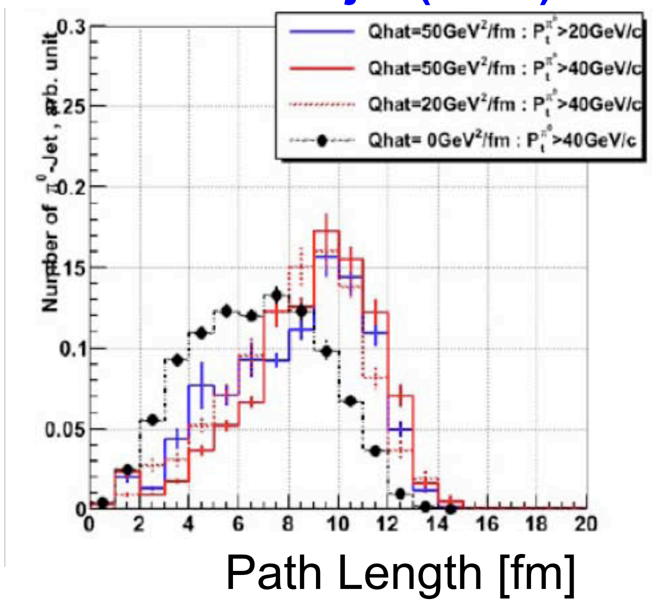


- Hard scattering point (in x-y plane) of trigger π^0 with associate recoil jet.
- **The higher E_T π^0, the stronger surface bias.**
- <qhat> = 20 & 50 GeV^2/fm
  - small difference.

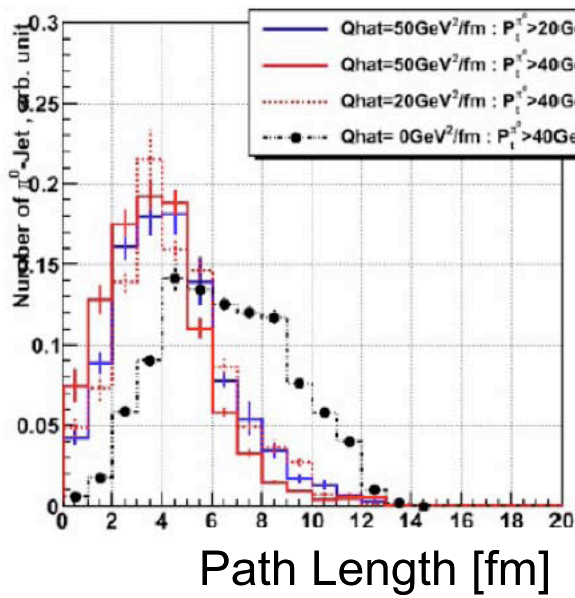
    → can be used as geometry measure of emission point, without knowing the quench parameters.

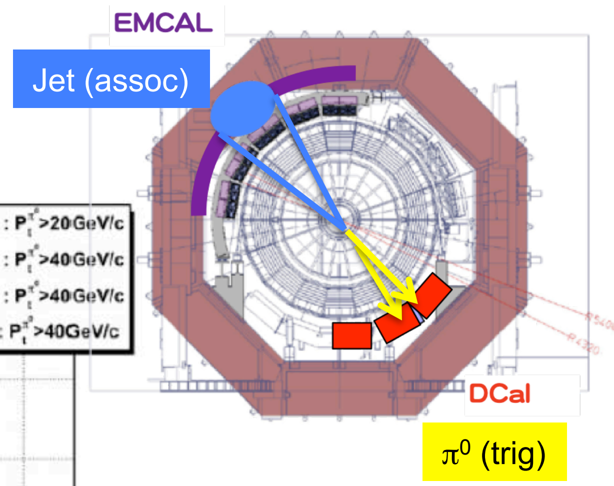
Case 3: π^0-jet, control path length

Recoil jet (EMC)



Trig π^0 (DCal)

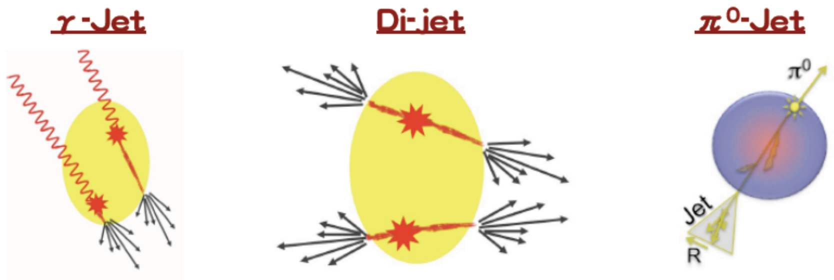


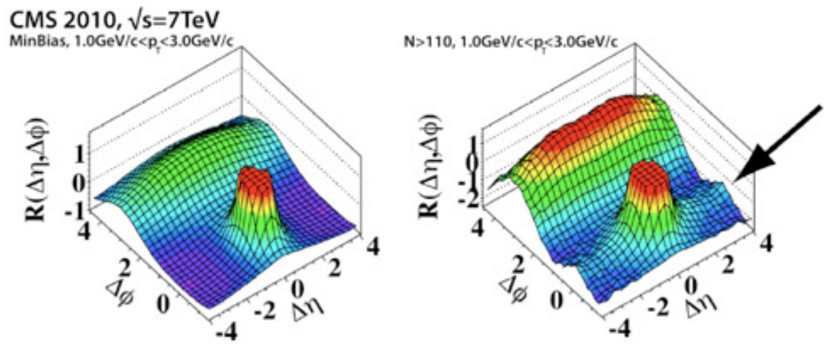


- **Trigger π^0 (right): Minimizing path length.**
- **Recoil jet (left): Maximizing path length.**
- **Path length of jet medium, "control" experiment.**
- Efficient trigger of π^0 (Level 1) is the key, and it is capable by utilizing existing level 1 readout for EMC.

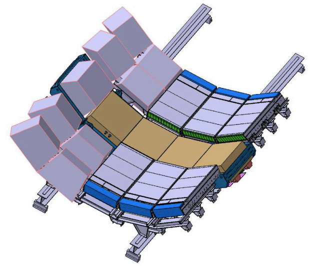
Other interesting measurements with DCal

- **γ-jet:**
  - Golden channel !!
  - Complementally to h (π^0) -jet, jet-jet.
- **Ridge study with di-jet & π^0 - jet**
- **Reaction plane dependence of:**
  - di-jet energy balance
  - π^0-jet
- **Discrimination of quark jet, gluon jet**
  - Study of energy loss mechanism.
  - Multiplicity and other observables can be used.



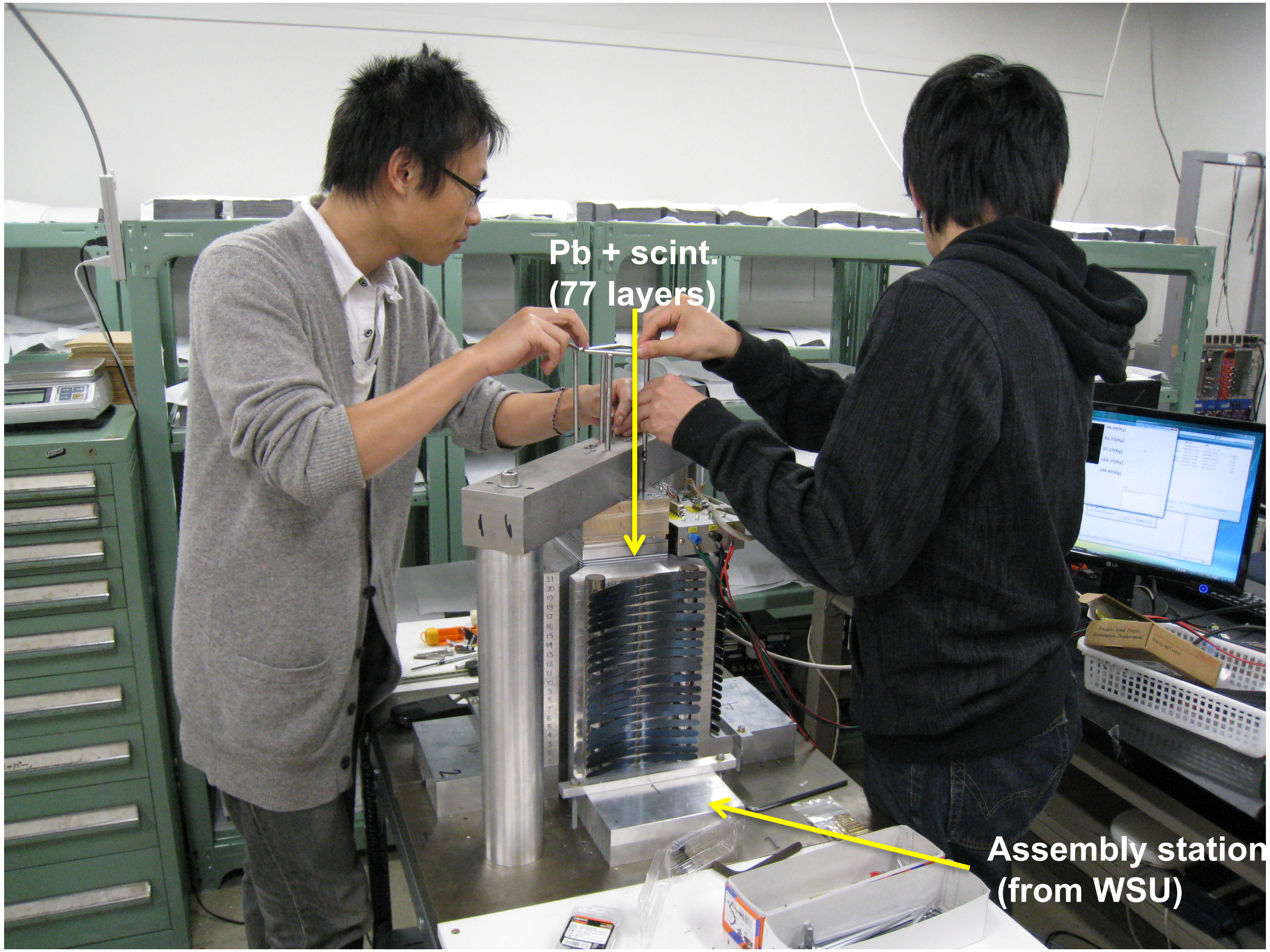


Current status and schedule

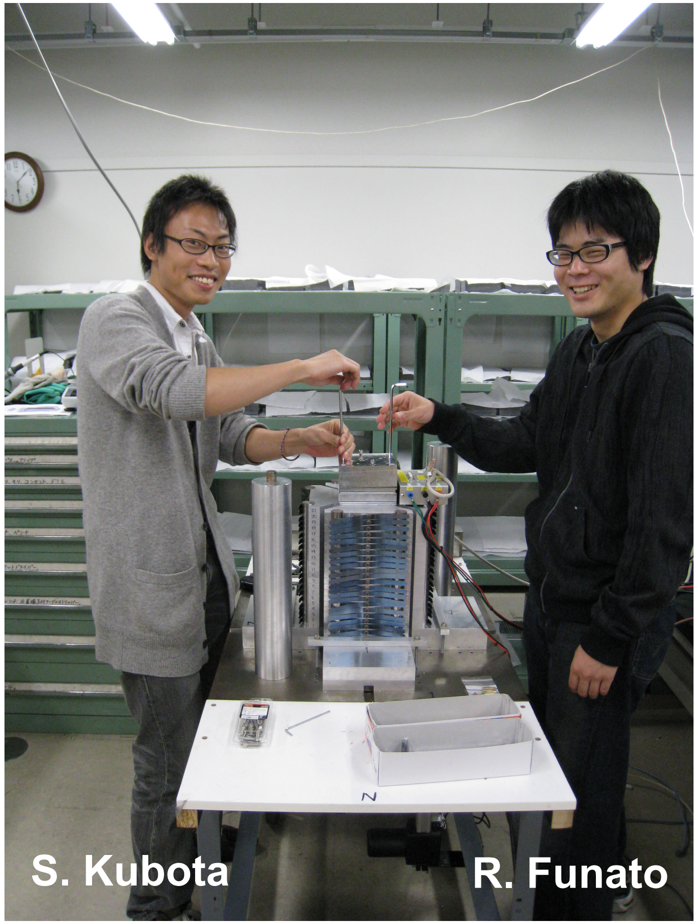


- DCal has been approved by the ALICE collaboration, Oct. 2009.
- Finished parts order. Now (almost) all parts have been delivered.
- **Module production starts in Oct. 2010, and will continue until early next year.**
  - 3.0 SM from Wayne State Univ. (USA)
  - **1.5 SM from Tsukuba (Japan)**
  - **1.0 SM from Wuhan (China)**
  - 0.5 SM from Nantes (France)
    - Total: 6 SM (192 x 6 = 1152 modules) for DCal.
- Integrated SM in Nantes, Grenoble.
- **Installed in the ALICE experimental area during the long LHC shutdown in 2011-2012.**
- **Ready to take the first 5.5 TeV Pb+Pb run, expected in 2012-2013.**

Assembly of 1st DCal module in Tsukuba (Oct. 18, 2010)

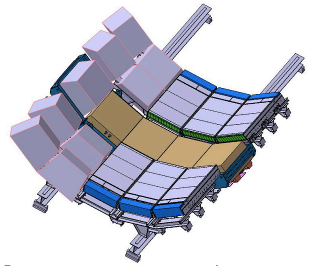


(almost) all parts in hands, ready to start production !



Wuhan team is ready.

Summary



- **Dijet Electromagnetic Calorimeter (DCal) in ALICE experiment provide a powerful & unique tool to investigate hot and dense matter in HI collisions at LHC, through dijet and π^0-jet measurements.**

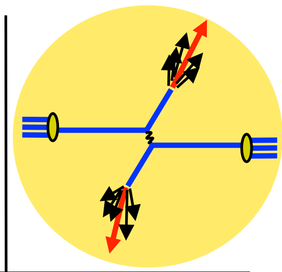
  1. **Di-Jet correlations:**
     - **Energy balance of jet.**
  2. **π^0-Jet correlations:**
     - **Control path length of jet.**

- **DCal has an essential role to make these measurements.**
- **Together with other measurements (e.g. γ-jet, reaction plane dep.), one may obtain a complete understanding of jet quenching mechanism at LHC energy, i.e. "jet tomography".**

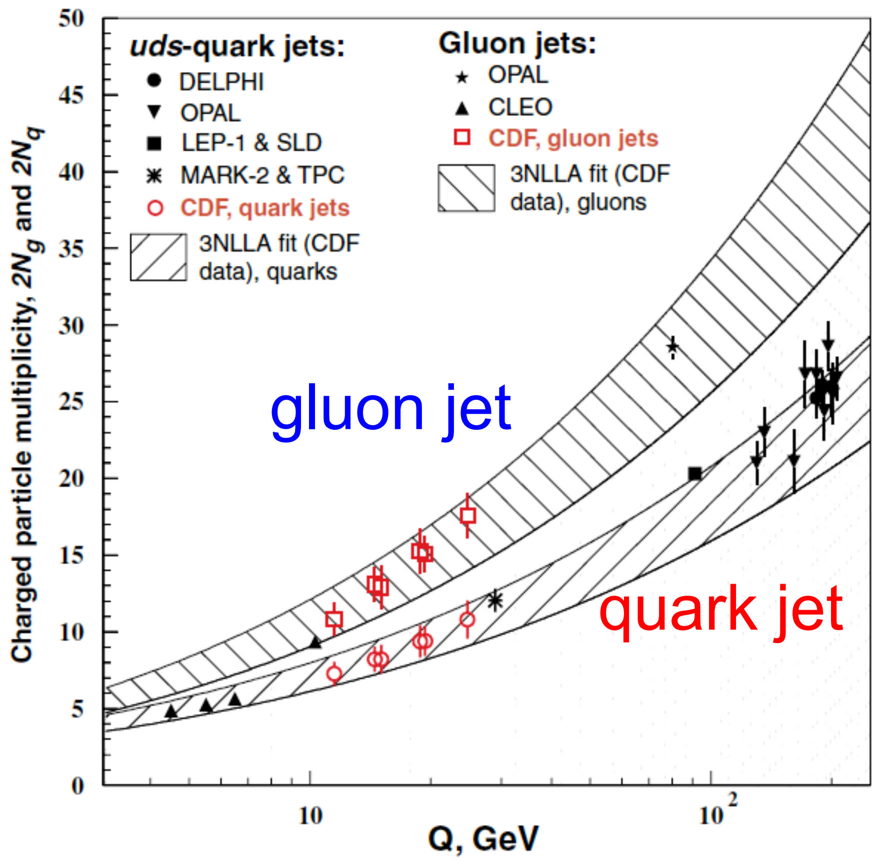
- **DCal will be installed in the next LHC long shutdown (2011-2012), and will be ready to take first 5.5 TeV data in 2012-2013.**

BACKUP

Possibility of Parton ID



CDF, PRL94(2005)171802



- As a new generation exp., from Particle ID to Parton ID !
  - According to CDF exp., charged/neutral works
- Might be very difficult in heavy ion environment
- Nevertheless, challenge!
- It becomes feasible for higher p_t jet

Jet trigger in Pb+Pb

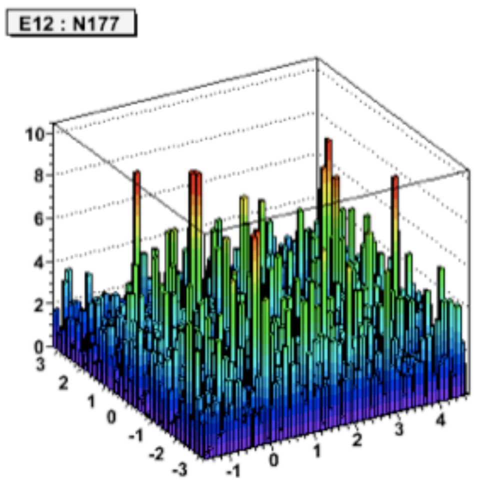
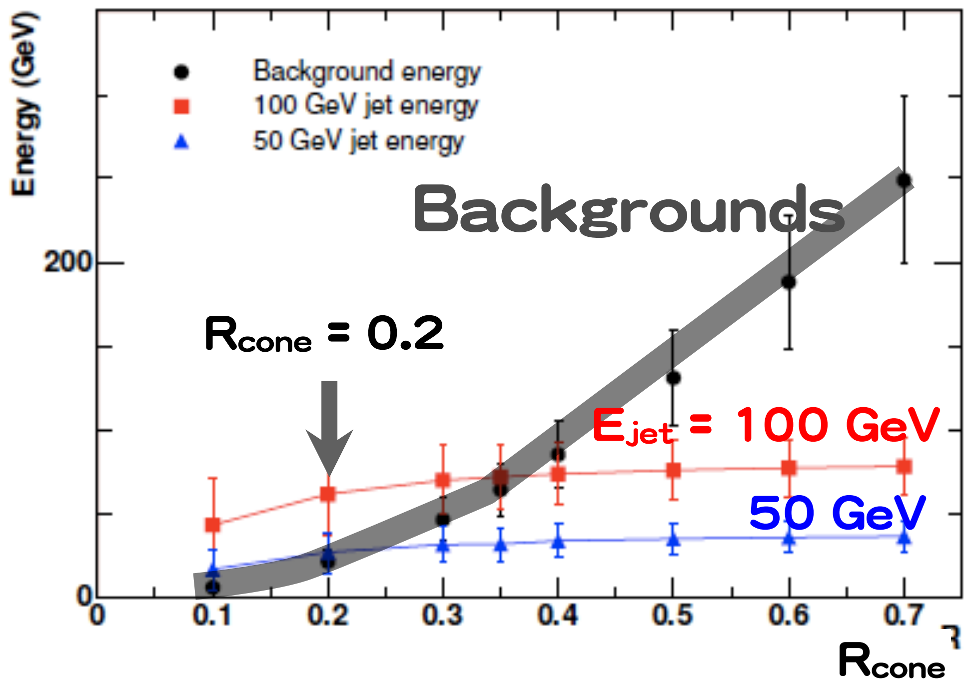
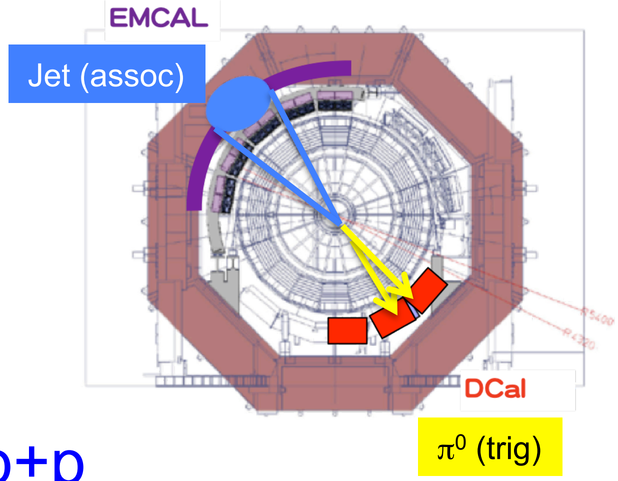


Fig.8.4 of TDR

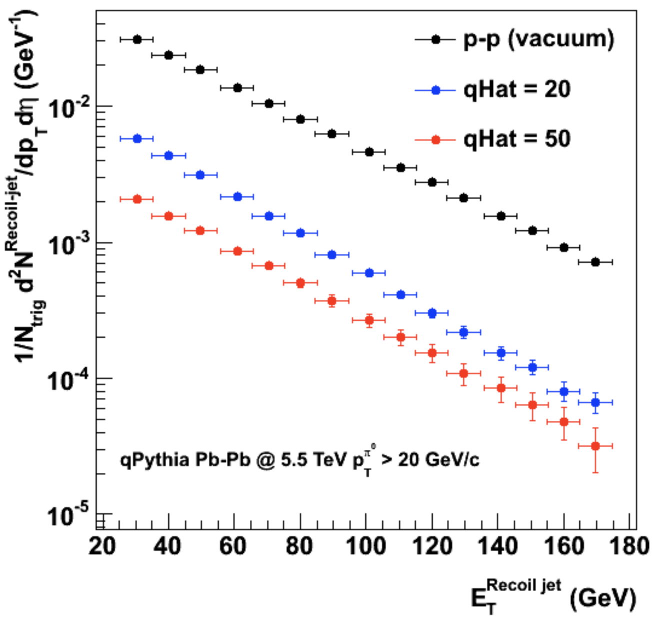


- With R_{cone} = 0.2, triggering jet of < 50 GeV becomes difficult.
- Back-to back

Case 3: π^0-jet, control path length



semi-inclusive jet spectrum (π^0-jet)



Au+Au/p+p