



Measurement of Jet Quenching in the ALICE Experiment at the LHC

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Outline

- * **Introduction**
 - * Quark-Gluon Plasma and Jet Quenching
 - * LHC-ALICE Experiment
- * **Development and commissioning of the ALICE Calorimeter L1 Trigger system**
- * **Inclusive Charged jet measurement with $\sqrt{s_{NN}} = 5.02$ TeV Pb-Pb collisions**
- * **Summary**

- Introduction
- Development and commissioning of the ALICE Calorimeter L1 Trigger system
- Inclusive Charged jet measurement with $\sqrt{s_{NN}} = 5.02$ TeV Pb-Pb collisions

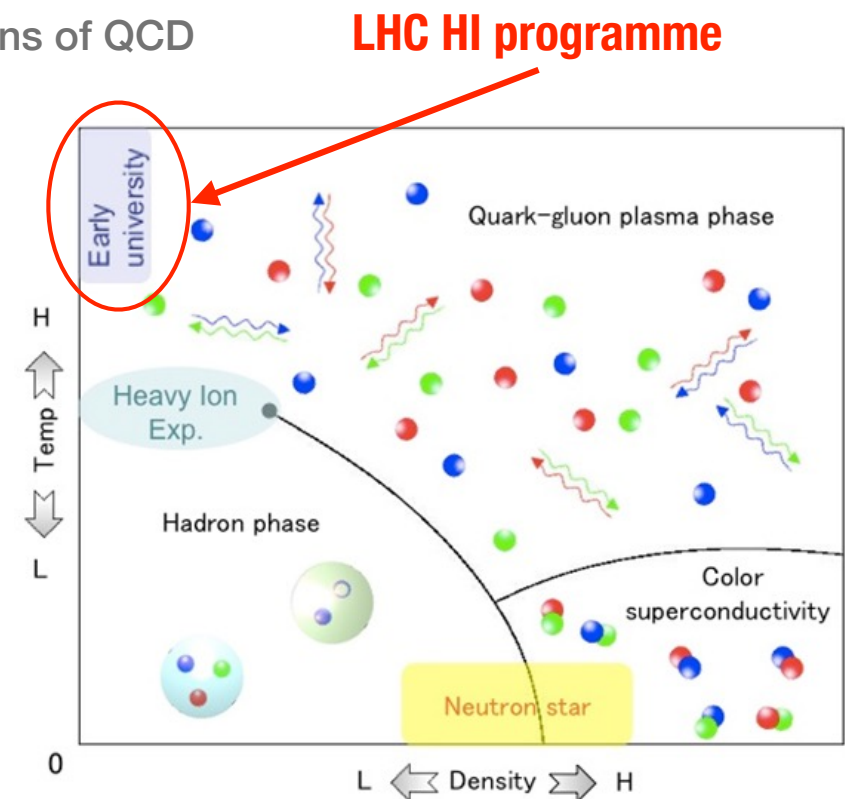
Quark Gluon Plasma

What is QGP ?

- ▶ Quark-Gluon Plasma (QGP)
 - * Hot & dense color thermalized QCD matter prevailing at the early Universe $\sim 1\mu\text{s}$ after big bang
 - * Deconfined state of quarks and gluons
 - * Theoretically inferred through lattice gauge simulations of QCD

How to create ?

- ▶ 'Little Bang'
 - * high-energy head-on nucleus-nucleus collisions at particle accelerators
 - * Recreate QGP droplets for a brief period of time to quantitatively map out the QCD phase diagram



Jets in HI Collisions (Hard Probes of the QGP)

What's a Jet ?

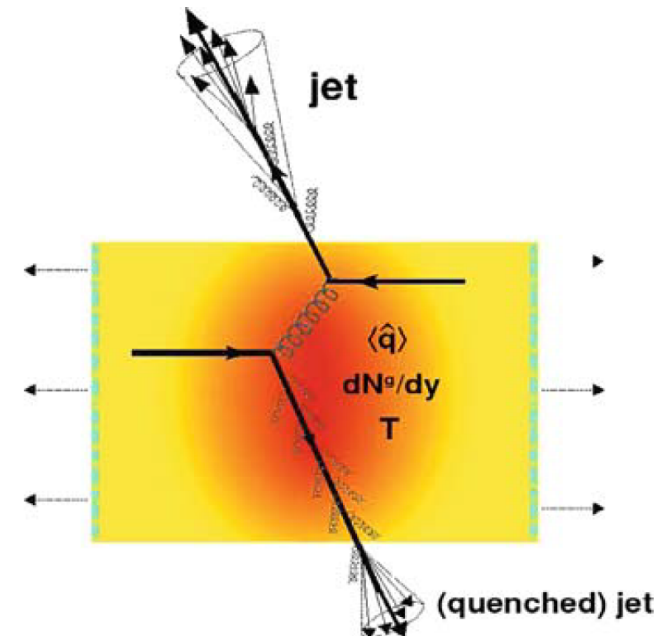
- * Collimated spray of hadrons produced by the hard scattering of partons at the initial stage of the collision
- * high- Q^2 process, $p_T \gtrsim 20$ GeV

Why Jets ?

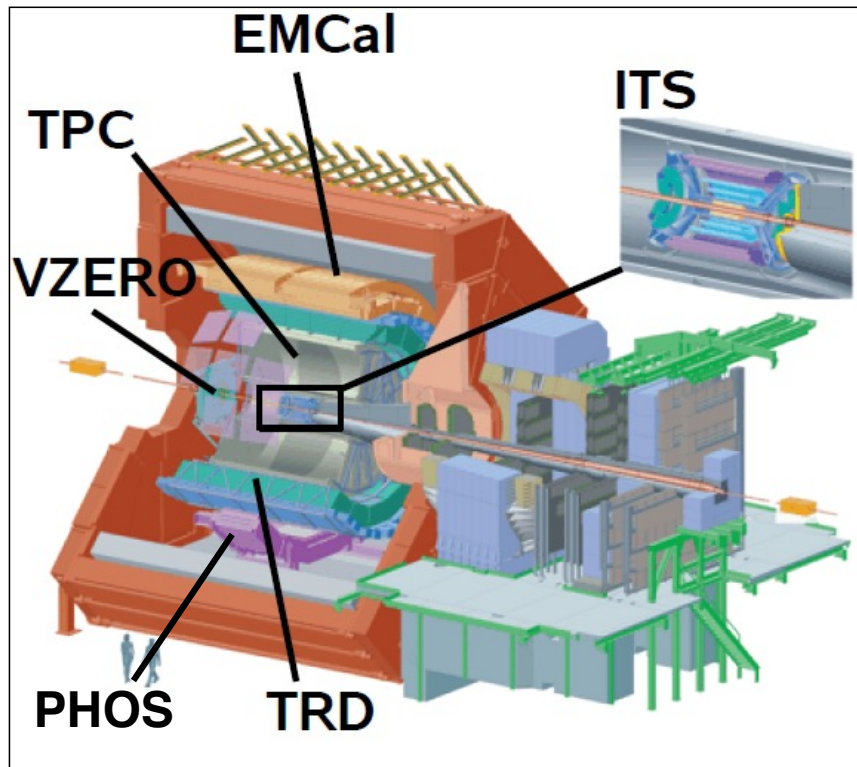
- * The QGP lifetime is so short ($\sim 10^{-23}$ s) that characterisation by external probes is ruled out
 - * **self-produced probes**
- * Occur at early stage : $\tau \sim 1/Q$
 - * **probe the entire medium evolution**
- * Production rate calculable within pQCD
 - * **well calibrated probes**
- * Large cross-section at the LHC
 - * **copious production**
- * Reconstructed jet enables to access
 - * **4-momentum of original parton**
 - * **jet structure (energy re-distribution)**

Jet Quenching

- * Attenuation or disappearance of observed Jets in Pb-Pb
- * due to partons' energy loss in the QGP
- * jet shape broadening
- * **evaluation of the degree of the attenuation allows to assess QGP properties**



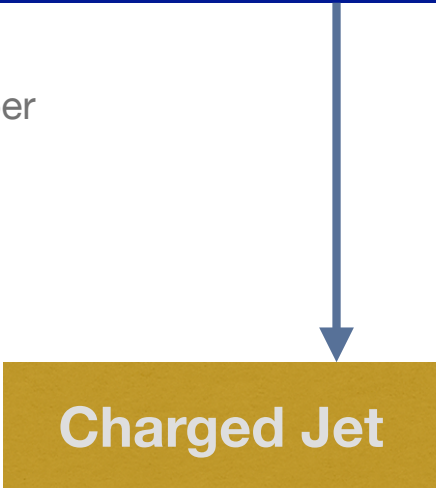
Jet Measurement in LHC-ALICE



- * ALICE detector focus on Heavy Ion Experiment
- * LHC Run2 period started from 2015
 - * $\sqrt{s} = 13 \text{ TeV pp}$
 - * $\sqrt{s_{NN}} = 5.02 \text{ TeV Pb-Pb, pp}$
 - * $\sqrt{s_{NN}} = 8 \text{ TeV p-Pb}$

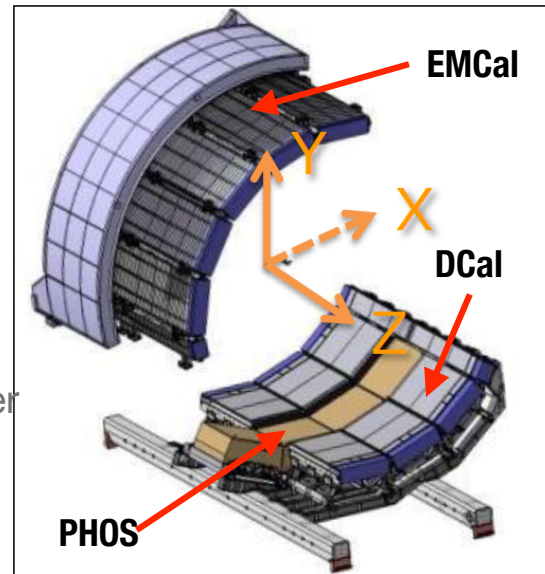
Charged Particles : $|\eta| < 0.9, 0 < \phi < 2\pi$

- * ITS : silicon tracking detector
- * TPC : Time Projection Chamber
- * Charged constituents

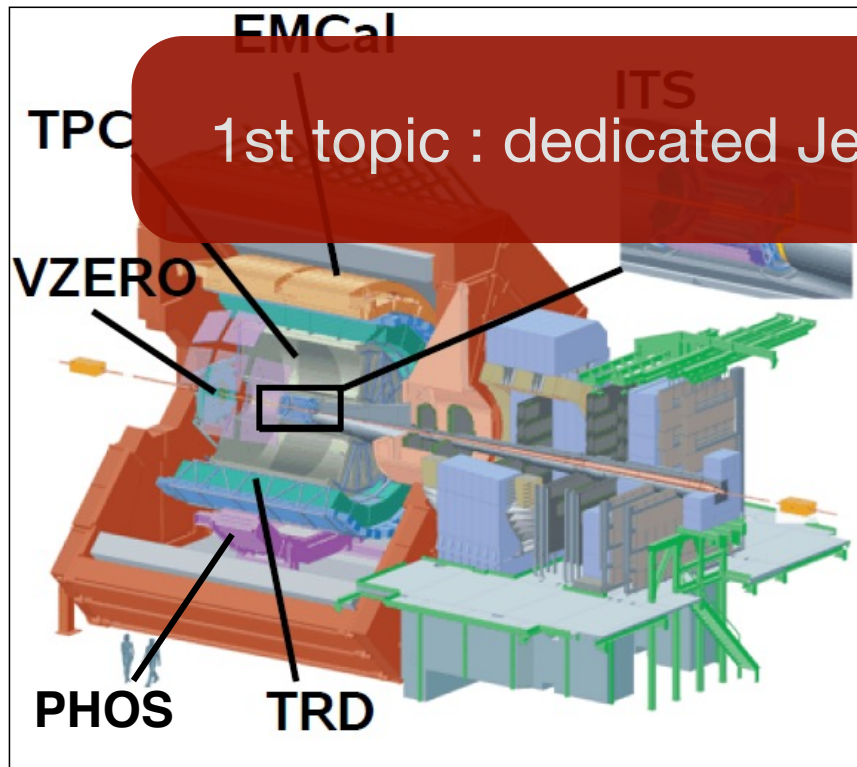


Neutral particles : $|\eta| < 0.7$

- * EMCal, (DCal : Run2 from 2015-)
 - * Pb-Scintillator sampling calorimeter
- * PHOS
 - * lead-tungsten crystal (PWO) based calorimeter
- * Neutral constituents



Jet Measurement in LHC-ALICE



1st topic : dedicated Jet/photon trigger implementation

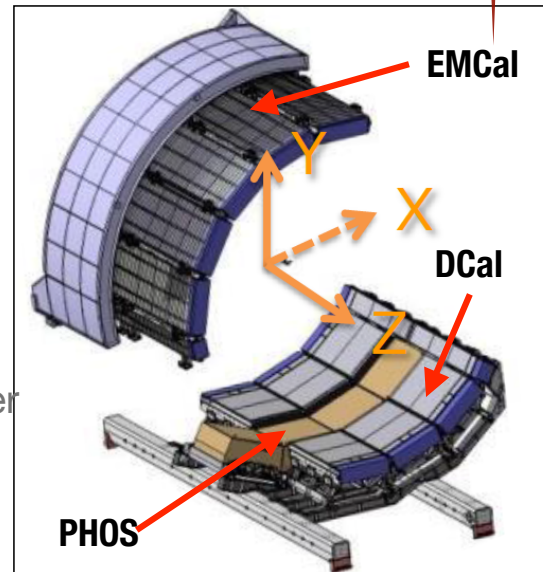
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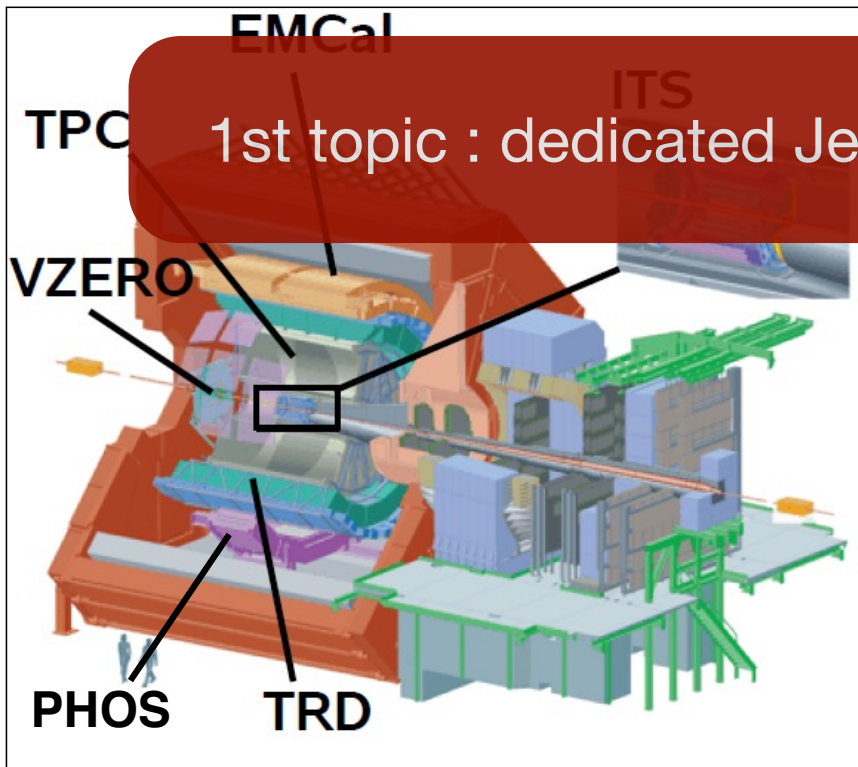
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Charged Jet

Jet Measurement in LHC-ALICE



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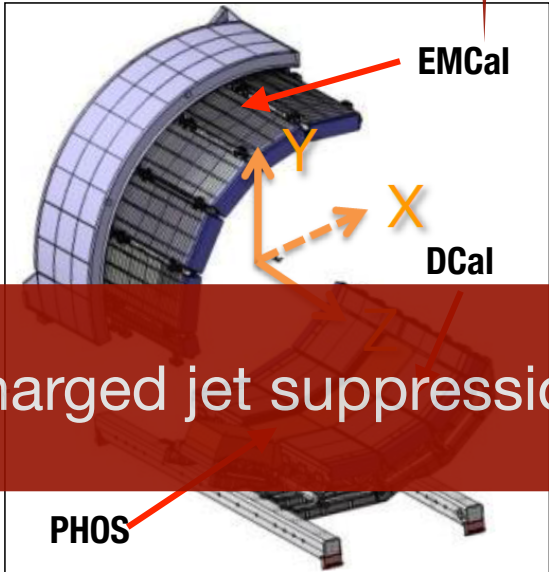
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Charged Jet

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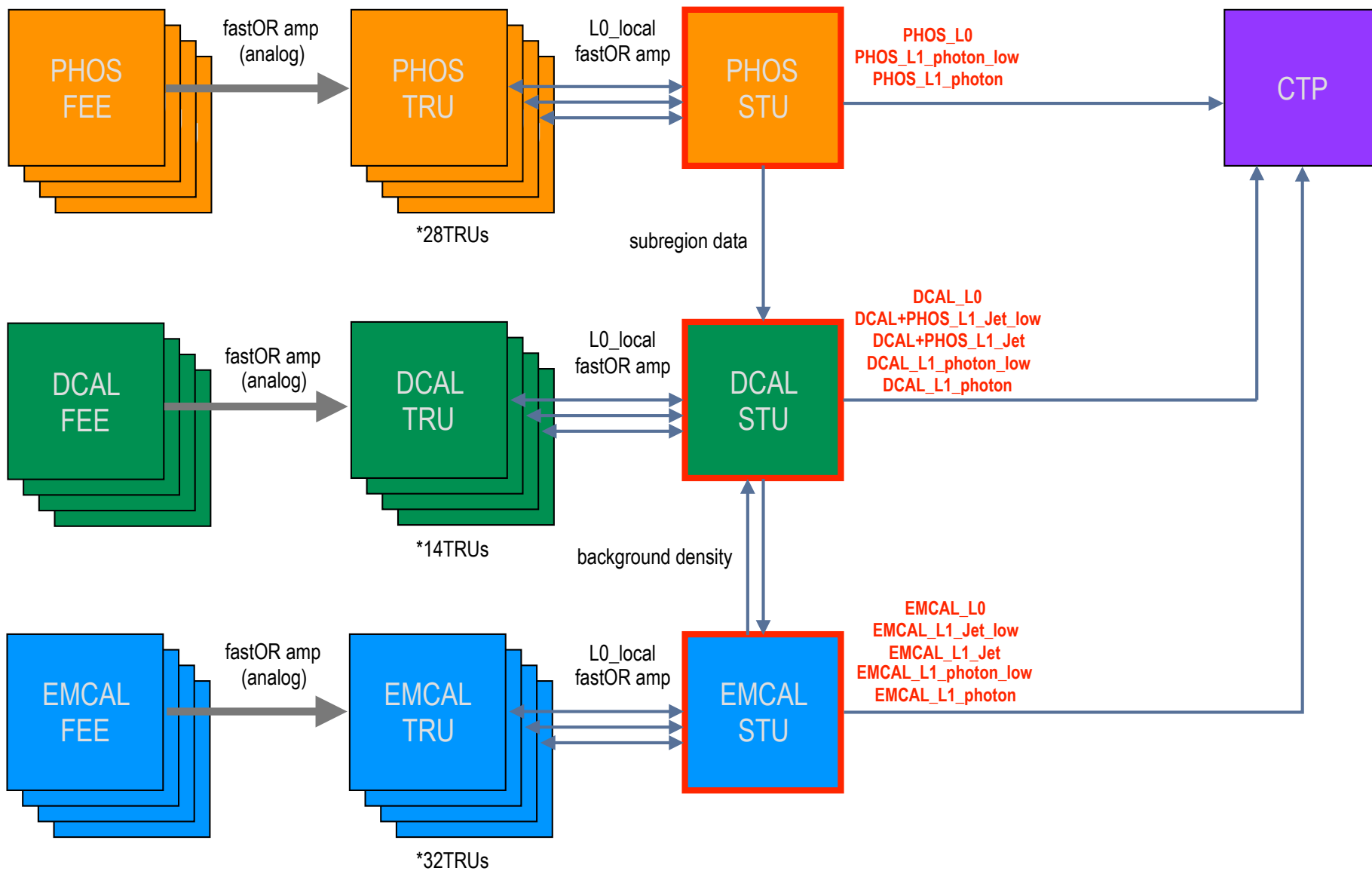
- * EMCal, (DCal : Run2 from 2015-)
- * Pb-Scintillator sampling calorimeter
- * PHOS
- * lead nucleus
- * Neutral constituents



2nd topic : evaluation of charged jet suppression in Pb-Pb

- Introduction
- Development and commissioning of the ALICE Calorimeter L1 Trigger system
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L1 System of ALICE Calorimeters

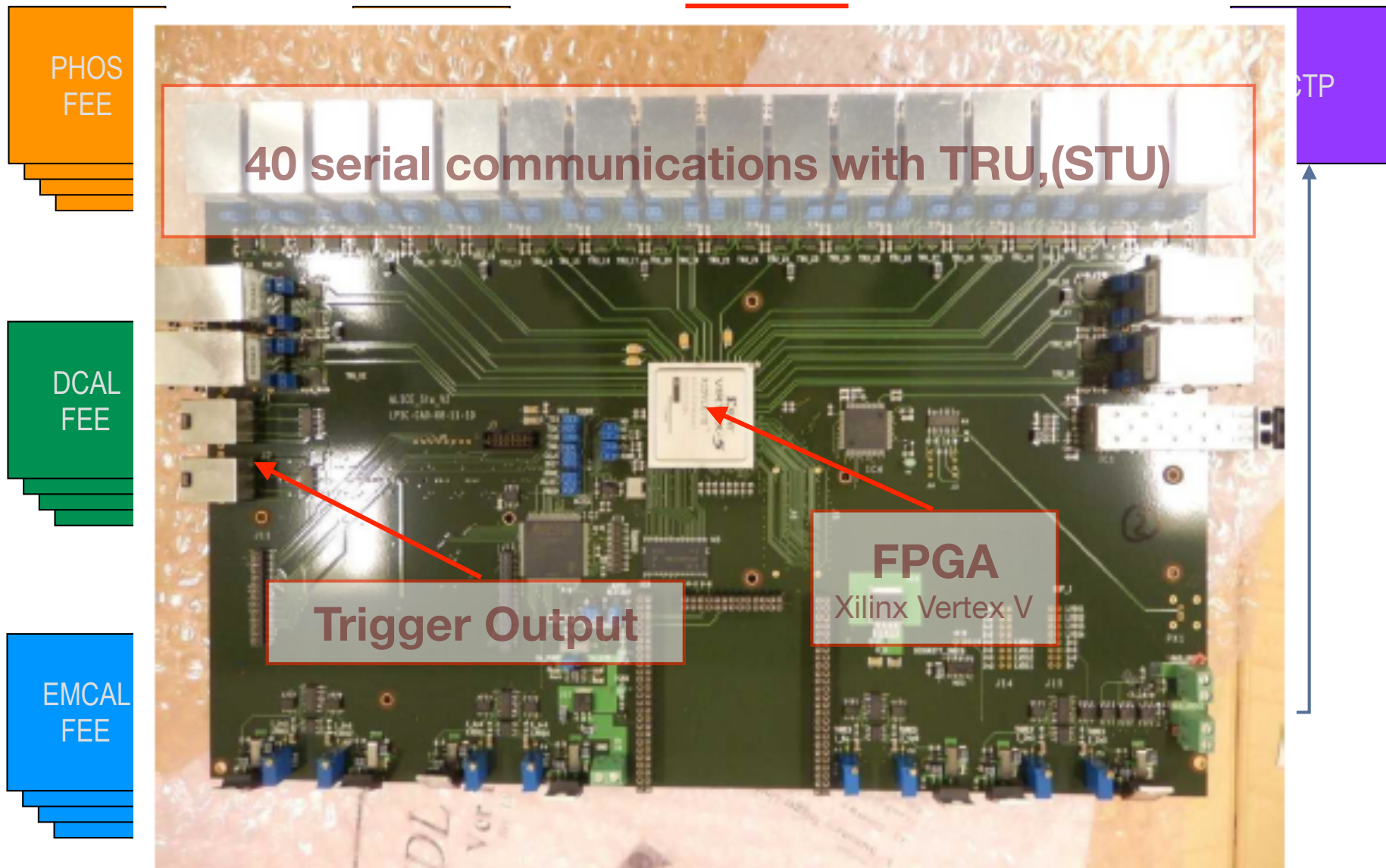


Analog sum
inside 1fastOR

digitise fastOR Amp
L0 trigger calculation

L1 photon/Jet
Trigger calculation

L1 System of ALICE Calorimeters

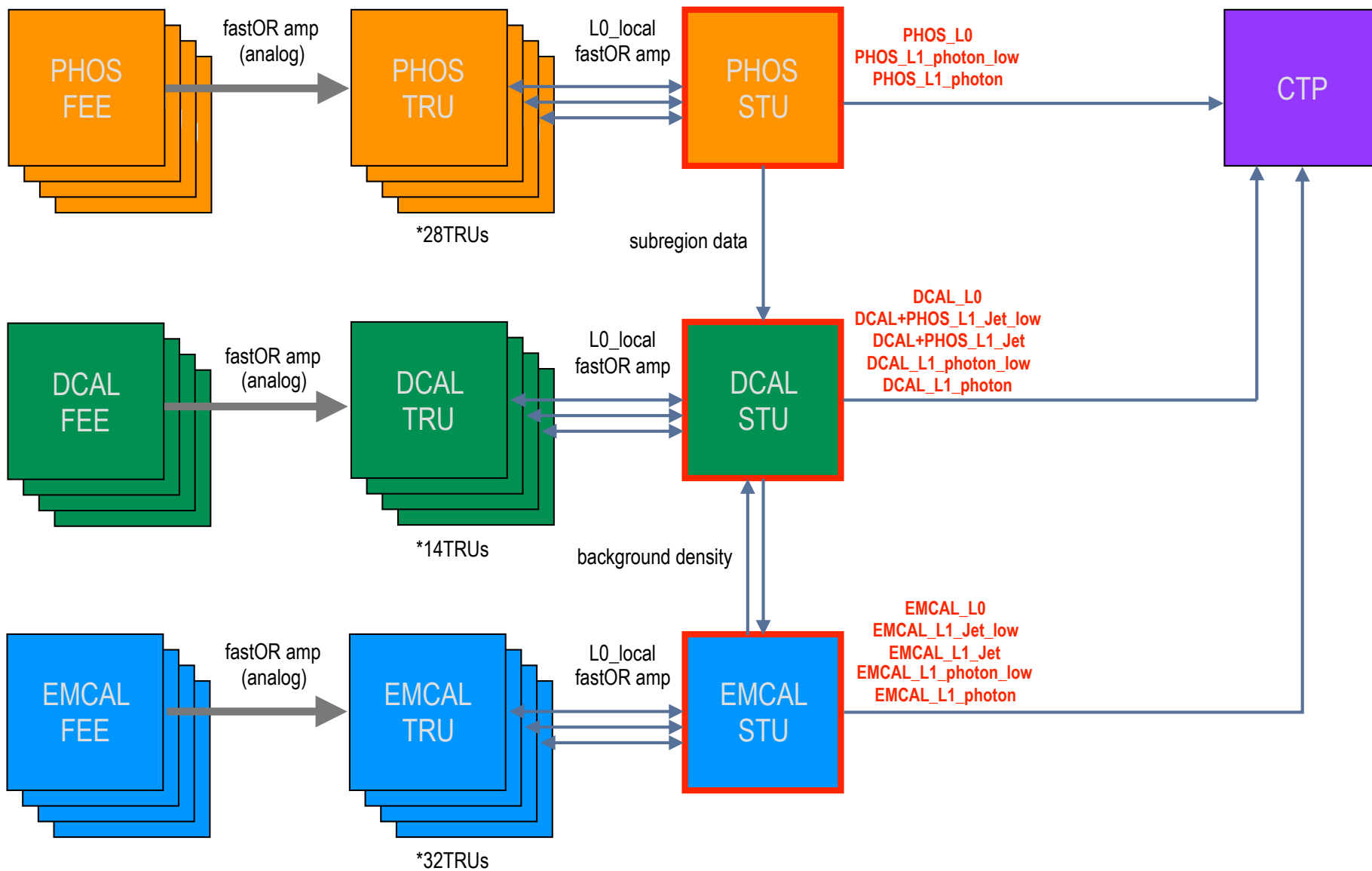


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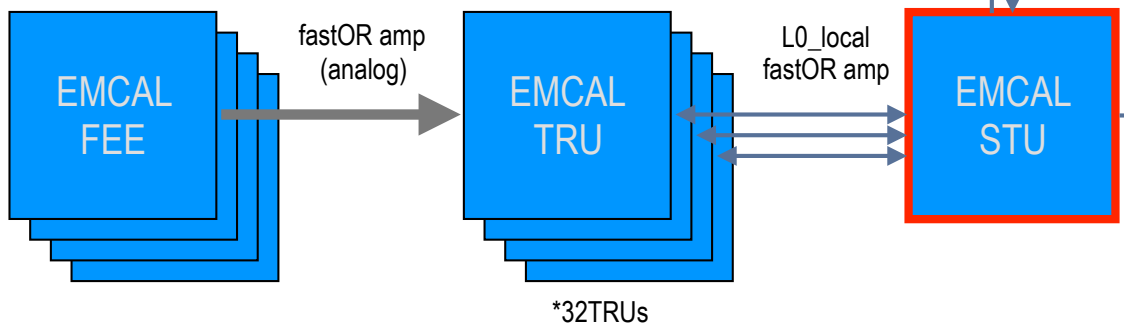
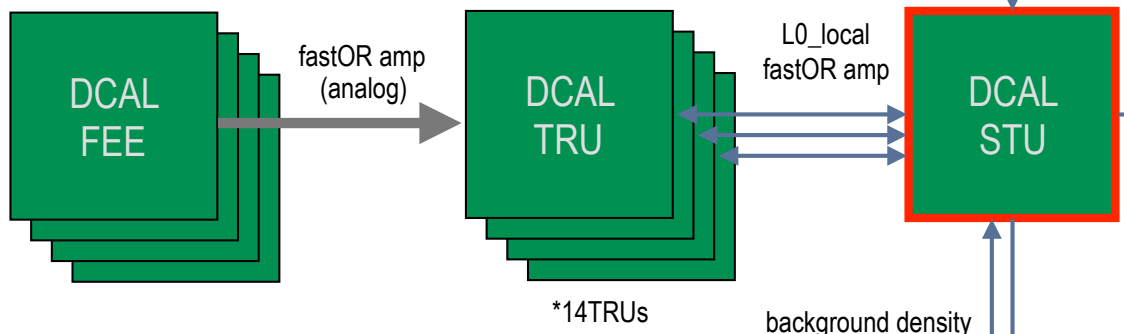
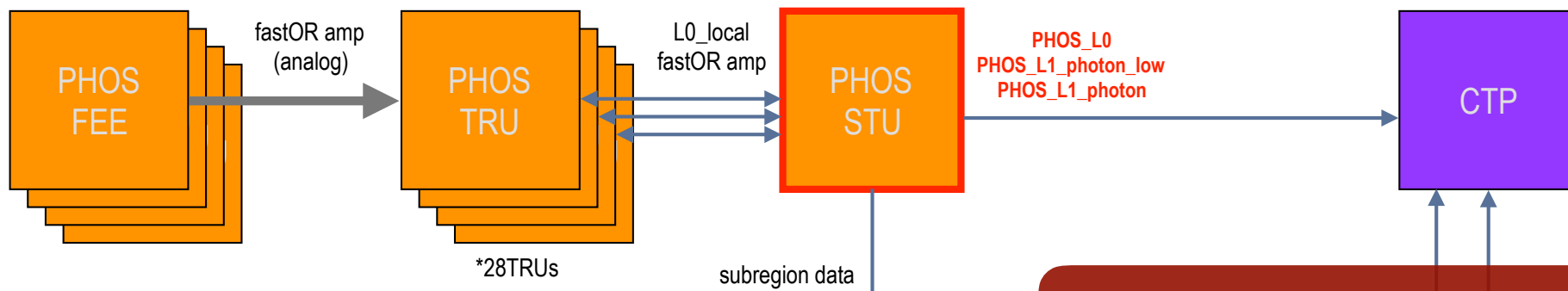


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L1 System of ALICE Calorimeters



Contribution of Grenoble Group :
Design / Production of the STU (Summary Trigger Unit)
FPGA FW development on STU at period of Run1 (2010-)

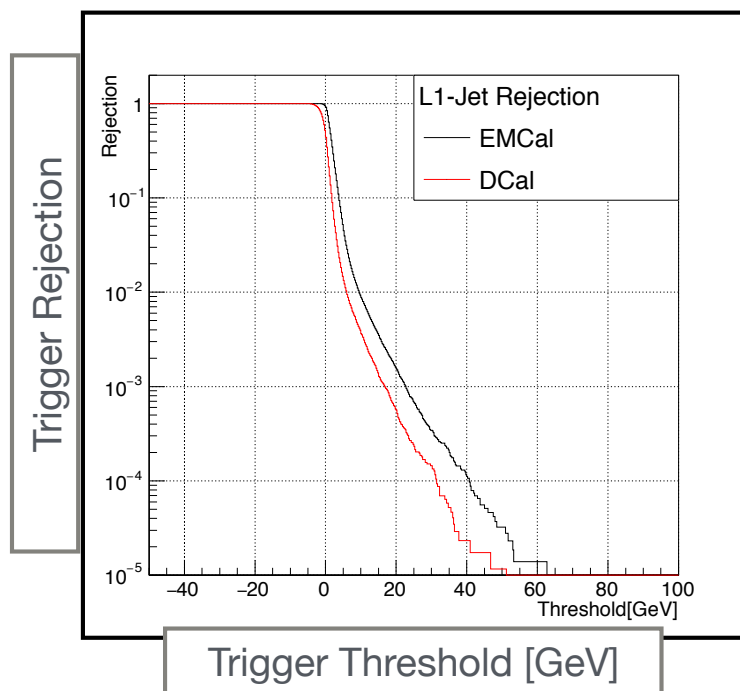
MY ACTIVITY :
FPGA FW development on STU for Run2 period (2015-)
Trigger system commissioning

Analog sum inside 1fastOR digitise fastOR Amp L0 trigger calculation L1 photon/Jet Trigger calculation

Trigger Performance

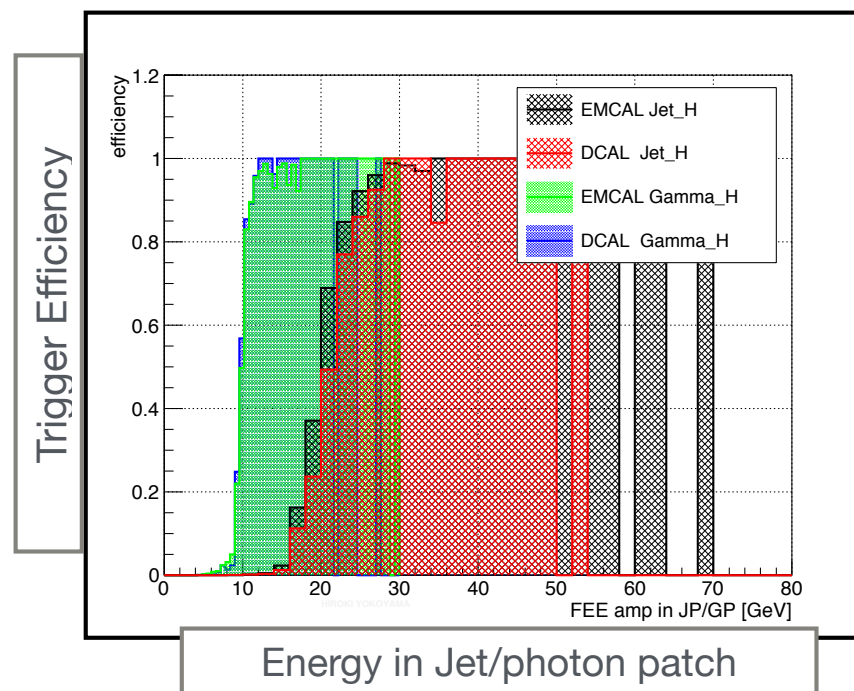
* Trigger rejection

- * To define threshold which satisfy the BandWidth restriction of the data taking
- * ~1000 for L1-Jet @20GeV threshold



* Trigger efficiency

- * clear turn-on at set values of 10 GeV (L1-photon) and 20 GeV (L1_Jet)



All L1-Jet/photon Triggers by Calorimeters Worked Well in 2015 Pb-Pb Runs!

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Analysis Flow (Pb-Pb collisions)

* Dataset

- * $\sqrt{s_{NN}} = 5.02$ TeV, Pb-Pb collisions
- * MB triggered events
(3.36M events, ~5% of full statistics)

* Charged track selection

- * $|\eta| < 0.9$, $p_T^{\text{track}} > 0.15$ GeV/c

* Jet reconstruction

- * anti- k_T jet reconstruction algorithm
- * $R = 0.2$
- * $|\eta| < 0.7$, $p_T^{\text{lead}} > 5$ GeV/c

* Underlying Event subtraction

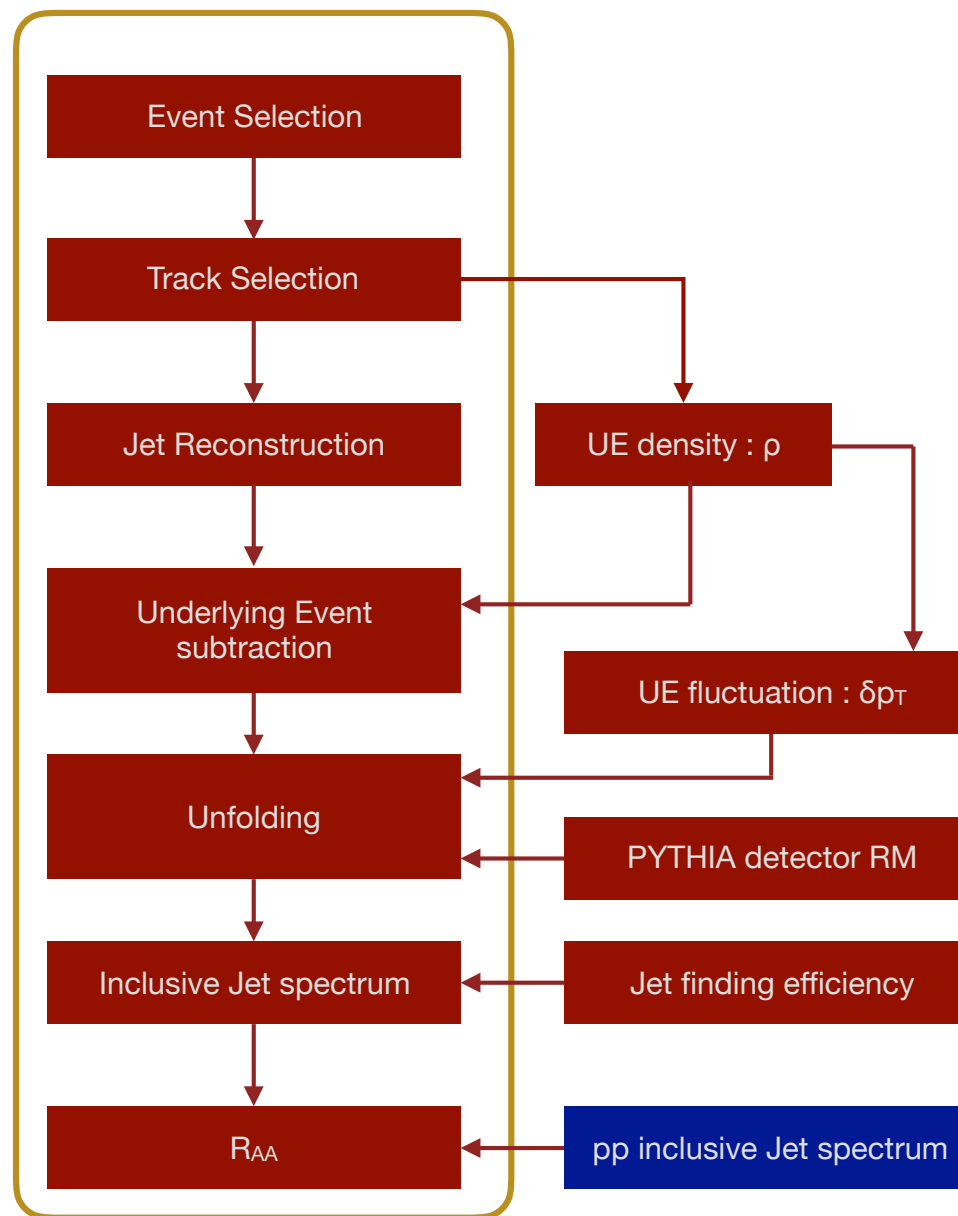
- * background is subtracted from reconstructed jet

* Unfolding

- * to correct for detector effects and background fluctuations

* Inclusive jet spectrum, R_{AA}

- * fully corrected to charged particle level, assess nuclear modification



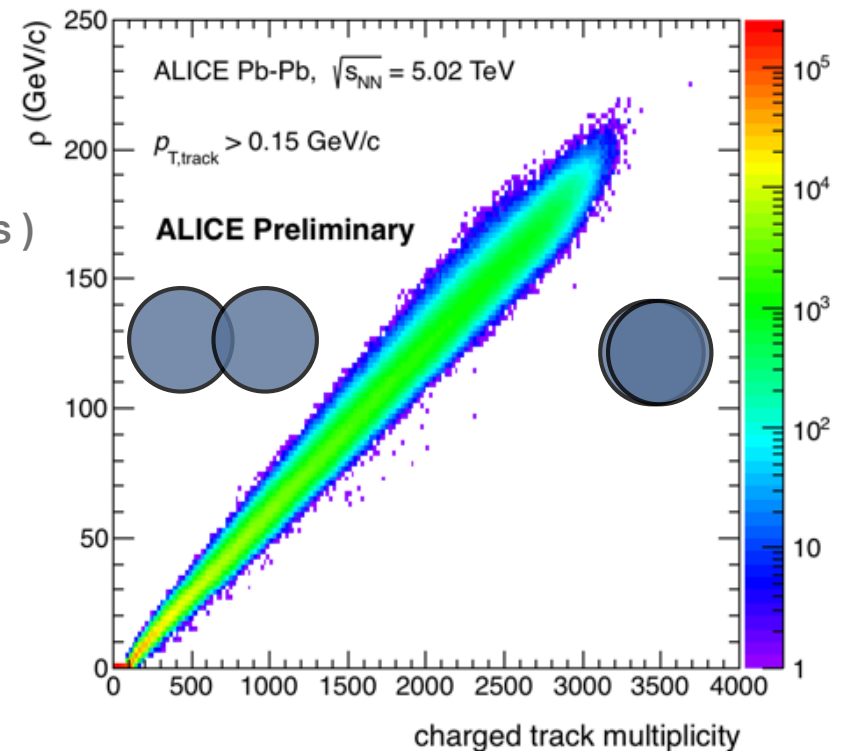
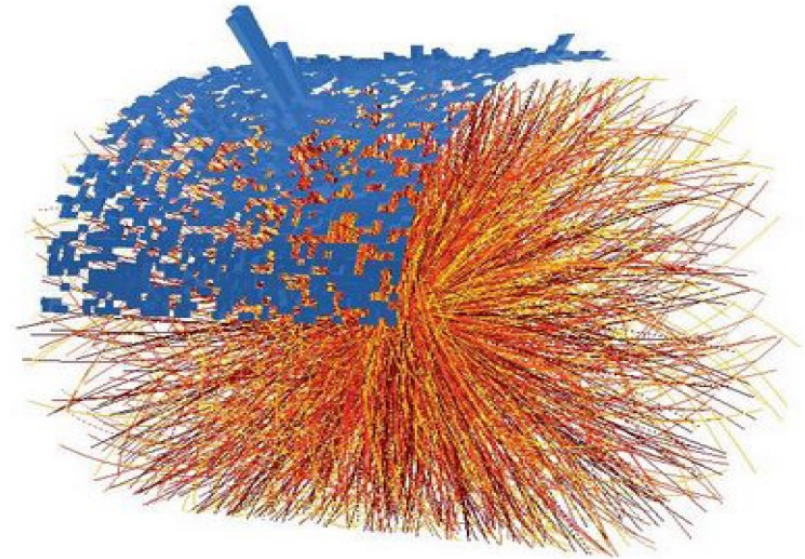
Underlying Event Density

Challenge in Heavy-Ion Collisions

- * large background contribution to jet energy
- * $dN_{ch}/d\eta \sim 1300$ (0-10% centrality)

Underlying Event Density

- * **background density : ρ**
 - * median of k_T clusters except largest two
- $$\rho = \text{median} \left\{ \frac{p_{T,i}}{A_i} \right\}$$
- * $\rho \sim 145$ GeV/c for 0-10% (~ 18 GeV/c for $R=0.2$ jets)
 - * The average background energy density ρ scales linearly with track multiplicity.



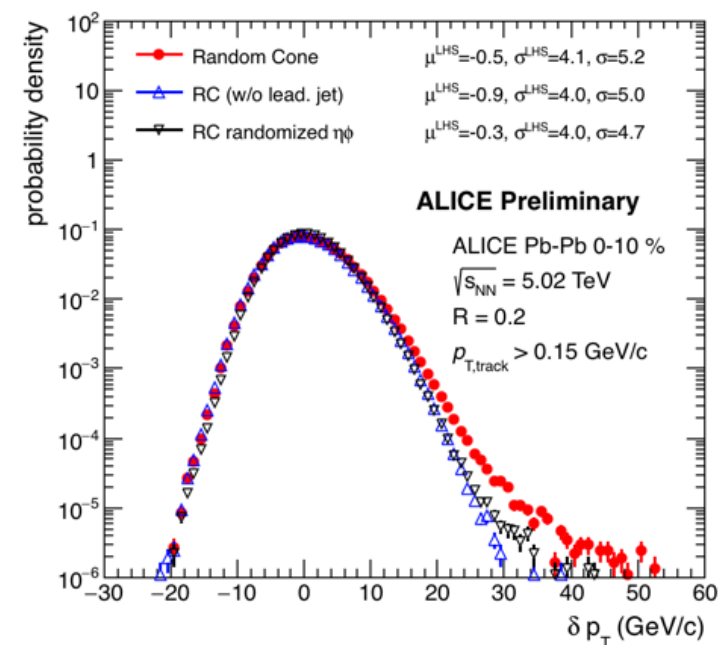
Underlying Event Fluctuation

UE fluctuation : δp_T

- * δp_T is used as a measure for background fluctuation
- * for the correction of measured spectrum

$$\delta p_T = \sum_i^{RC} p_{T,i}^{\text{track}} - A \cdot \rho$$

- * **δp_T width (magnitude of UE fluctuation)**
- * fluctuations larger in central than in peripheral collisions
- * ~ 5 GeV/c for $R=0.2$, 0-10% centrality



Nuclear Modification Factor : R_{AA}

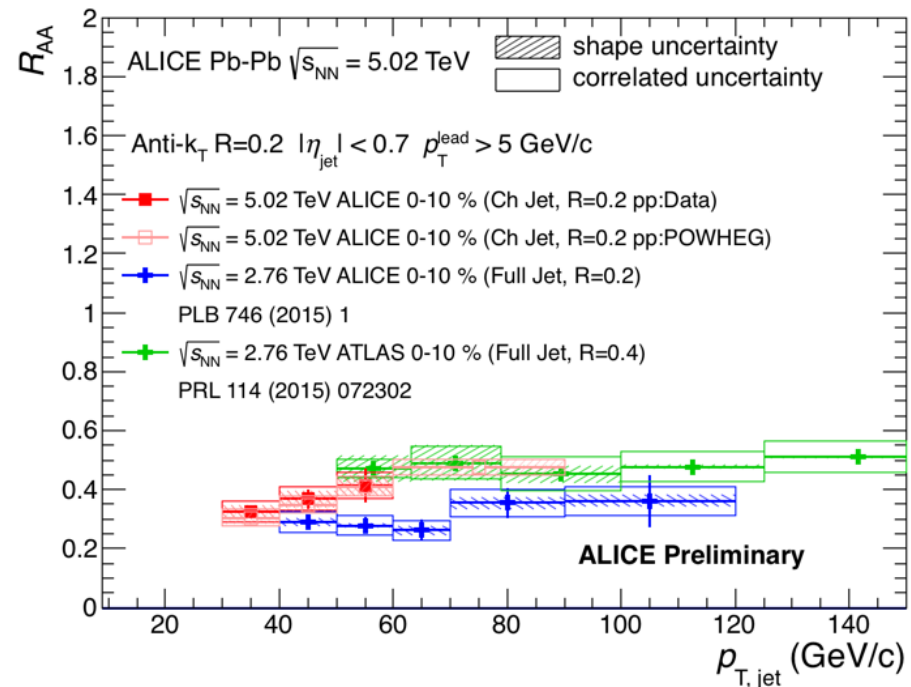
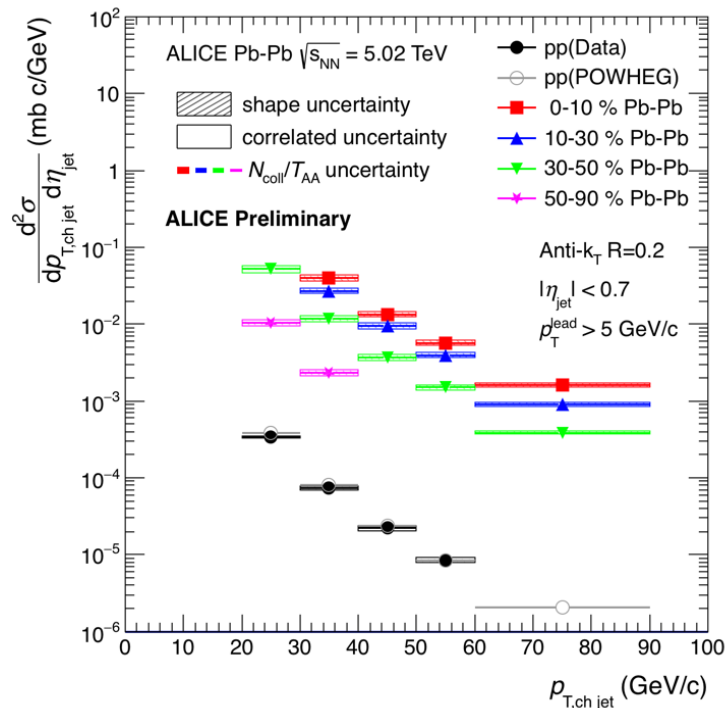
* Nuclear modification factor : R_{AA}

- * $R_{AA} > 1$, enhancement of yield
- * $R_{AA} < 1$, suppression

$$R_{AA} = \frac{\frac{1}{\langle T_{AA} \rangle} \frac{1}{N_{evt}} \frac{dN_{ch\ jet}}{dp_T d\eta}}{\frac{d\sigma_{pp}}{dp_T d\eta}}$$

* R_{AA} (5.02TeV) is comparable to R_{AA} (2.76TeV)

- * denser medium \Rightarrow stronger jet suppression \Rightarrow smaller R_{AA}
- * harder collision \Rightarrow flatter jet spectrum \Rightarrow larger R_{AA}
- effect of flattening of the spectrum compensated by stronger jet suppression ?



Summary

- * **Jet Quenching**
 - * Attenuation of jets in central Heavy-Ion collisions
 - * -> jets are good probe to access QGP property
- * **development & commissioning of ALICE-EMCals' L1 trigger system**
 - * Jet/photon triggers working well in Run2
 - * achieves expected performance
- * **Inclusive charged jets R_{AA} in $\sqrt{s_{NN}} = 5.02$ TeV Pb-Pb Collisions**
 - * strong suppression at central collisions
 - * comparable to R_{AA} in $\sqrt{s_{NN}} = 2.76$ TeV
 - * -> balance b/w spectrum flattening and stronger suppression?