b-Jet Tagging Analysis in CMS

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Outline

- Large Hadron Collider (LHC)
- The CMS Experiment
- b-jet Tagging : An Introduction
- Various b tagging techniques
- Preliminary results
- Summary and Conclusions

LHC : The Future (2008)

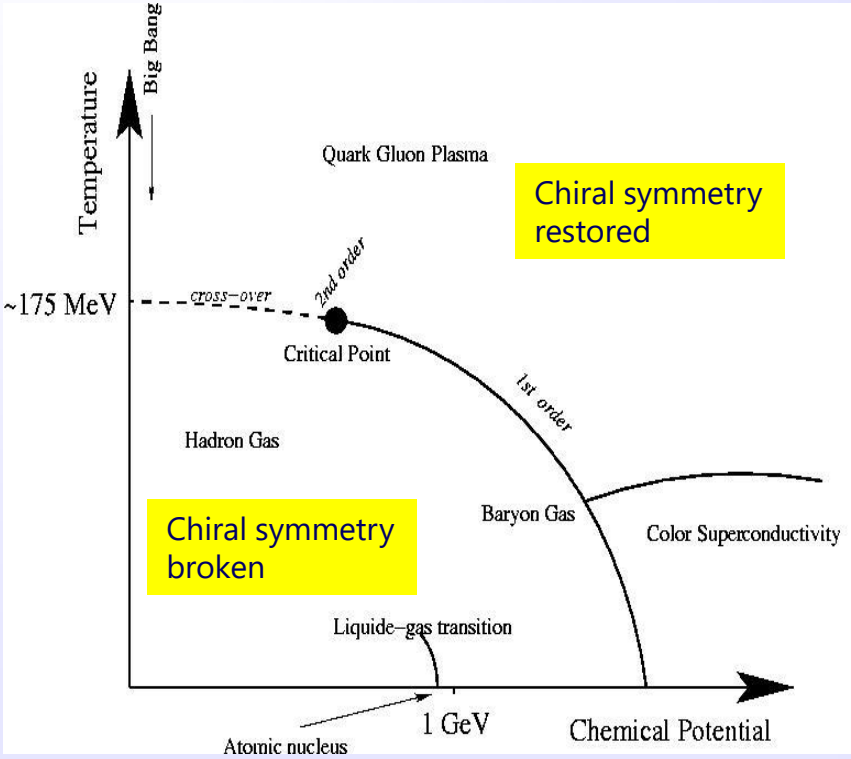
The nucleon-nucleon centre-of-mass energy for collisions of the heaviest ions at the LHC ($\sqrt{s}$ = 5.5 TeV) will exceed that available at RHIC by a factor of about 30, opening a new physics domain.

LHC Energy = 30× RHIC Energy

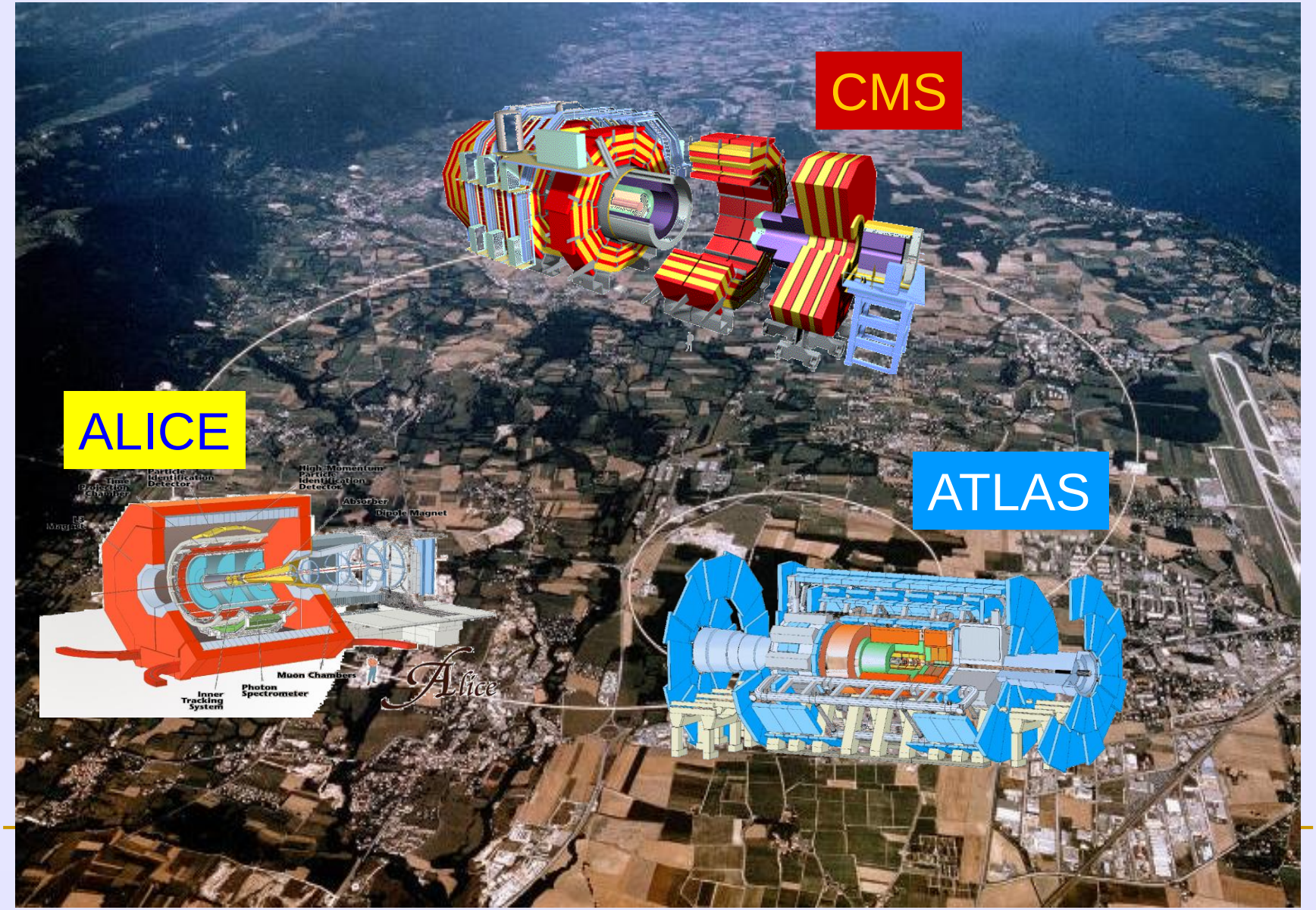
QGP: Longer

Heavy Ion Programme :

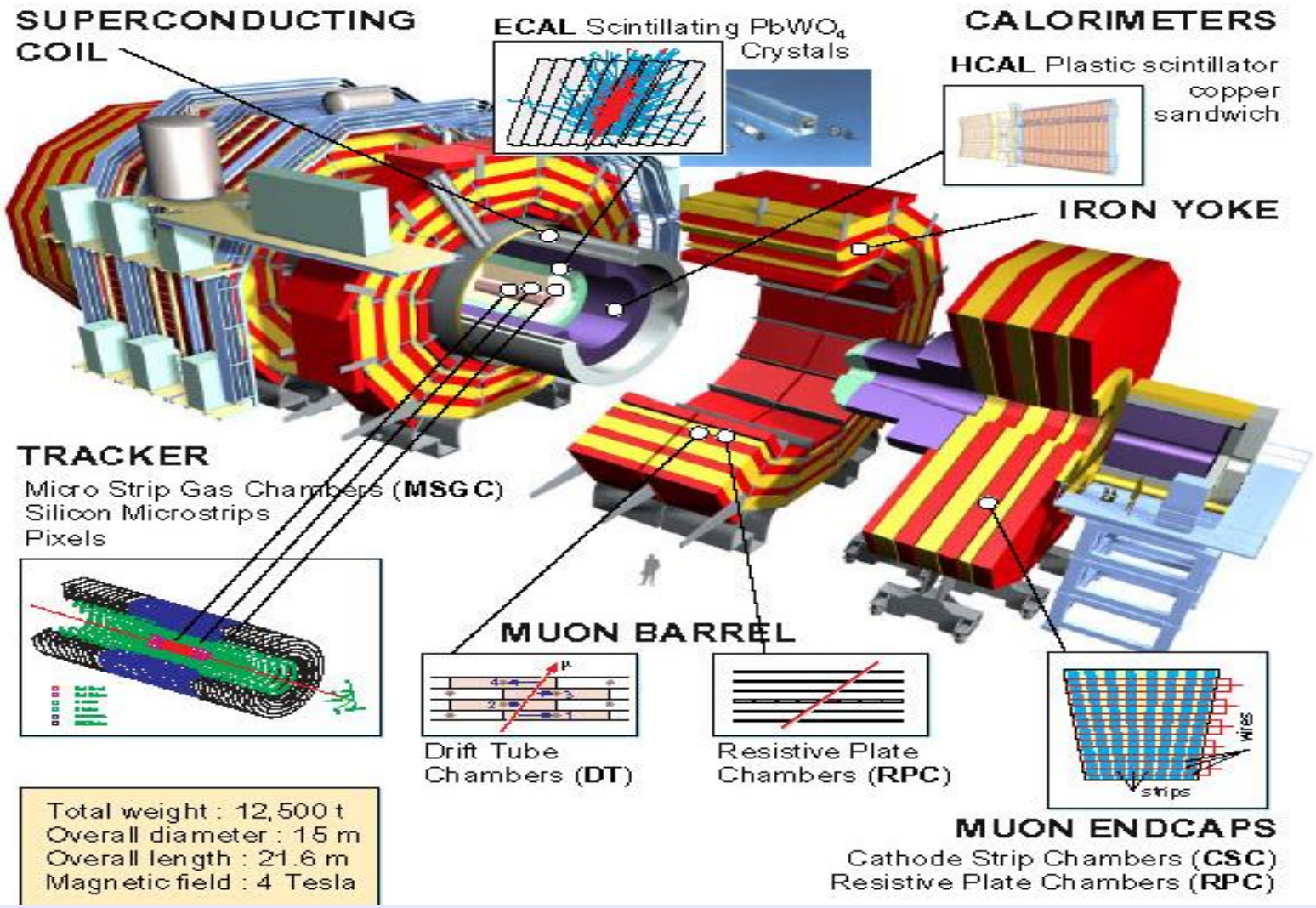
- pp (14 TeV)
- Pb-Pb physics pilot run (5.5 TeV)
- 1-2 yrs Pb-Pb
- 1 yr pPb-ike collisions (pPb,dPb or αPb) (8.8 TeV)
- 1-2 yrs. Ar-Ar (6.3TeV)



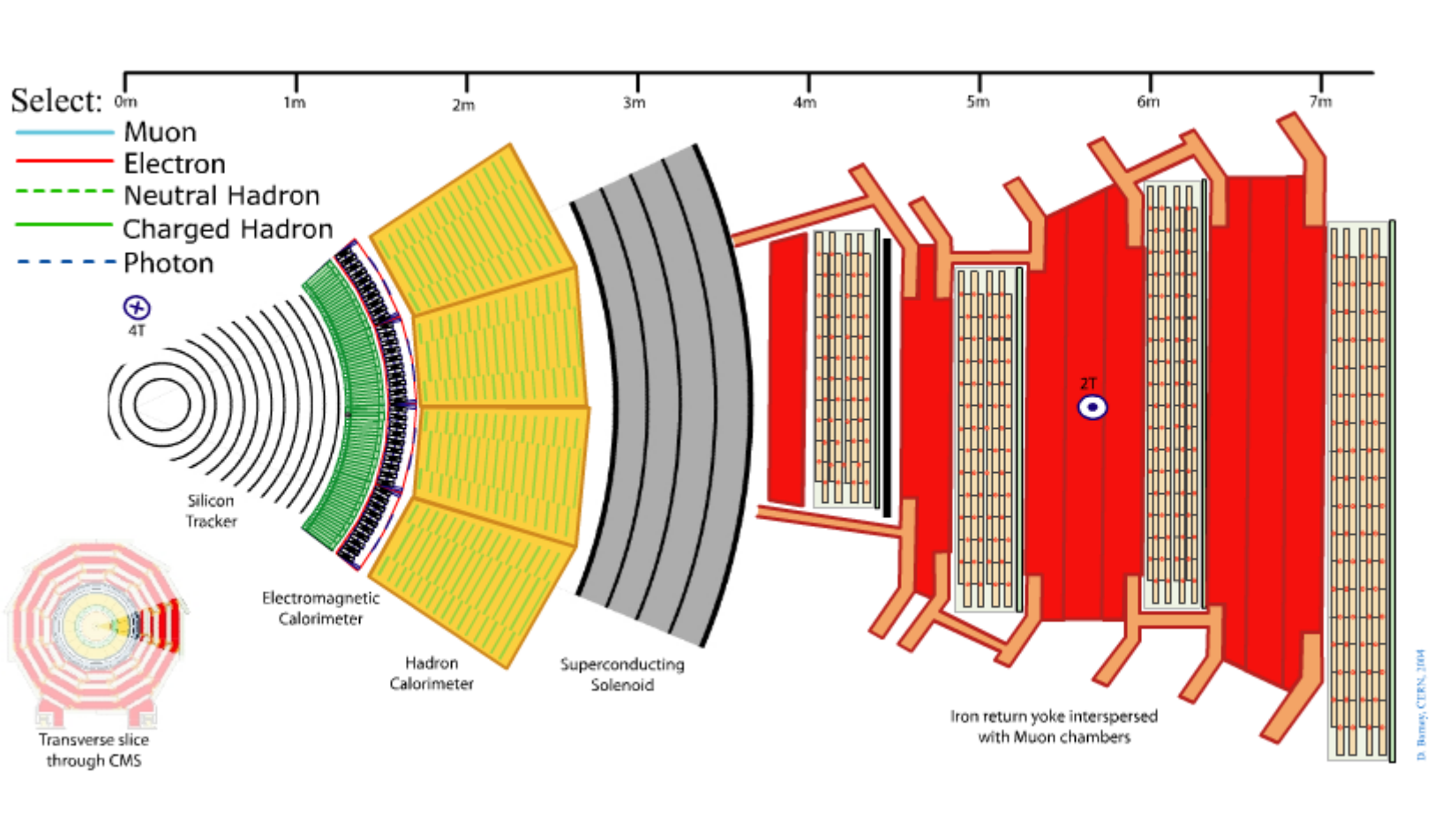
Large Hadron Collider (LHC)



CMS layout and detectors



Transverse slice through CMS detector



Heavy Ion Physics prospects with CMS@LHC

Soft Physics and Global Event Characterization

- Centrality and good Event Selection – Scaling with N_{part}, N_{coll}
- Charged Particle Multiplicity – Initial State Gluon Densities
- Azimuthal Asymmetry (Flow) – Equation of State
- Disoriented Chiral Condensates – Centauro-Anticentauro events
- Fluctuations in particle species
- Spectra + Correlations – Sources, Radial Flow, dE/dx and Quenching

High p_T Probes

- High p_T Particles and studies of Jet Fragmentation – Energy Loss and Modification of Fragmentation Functions. Flavor and Geometry Dependence.
- Quarkonia (J/ψ, Υ) and Heavy Quarks – Suppression and Recombination
- High Energy Photons, Z^0, Jet-γ, Jet-Z^0, Multijet Events – Calibrated Measure of dE/dx

Forward Physics

- Limiting Fragmentation – Color Glass Condensate
- Ultra Peripheral Collisions – PDF in New Regions of x and Q^2

b-jet Tagging : An Introduction

B-tagging is an example of a jet flavor tagging method used in HEP experiments, i.e., it is the identification of jets originating from b-quarks.

Why b-tagging is important …

- It sheds light on CP violation
- Higgs boson is expected to decay into b-quarks more than any other particle if it is very light, thus identifying b-quarks helps studying Higgs Physics

(e.g., H → bb, tt → lepton + undetected neutrino + four high pt b-jets)

-For Heavy Ion Physics : To study b-jets

Unique features of b-jets

- b-quark is much more massive than anything it decays into, so the decay products have higher momentum in the direction perpendicular to the direction of b-quark (b-jet)is going. This causes,

  A) b-jets to be wider and

  B) have higher multiplicities and invariant masses

- b-quark decay inside the detector rather then escape, with the precision silicon detectors, it is possible to identify the particles that originate from a different place where the b-quark was formed.

Traditional Methods for b tagging

- Track Impact Parameter based tag (ALEPH)
  - Track counting b tagging
  - Probability b tagging (DELPHI, CDF)
- Combined secondary vertex tag
- LogL ratio used by ATLAS
- Soft lepton tag
- Method used by CMS

Basic Jet Physics

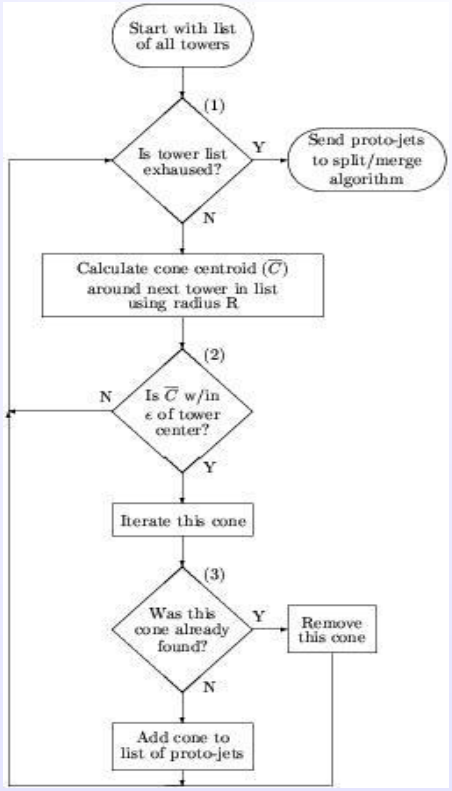
Jets are the experimental signature of the production of high momentum gluons and quarks which hadronize into several collimated particles that deposit energy in e-m and hadronic calorimeter towers

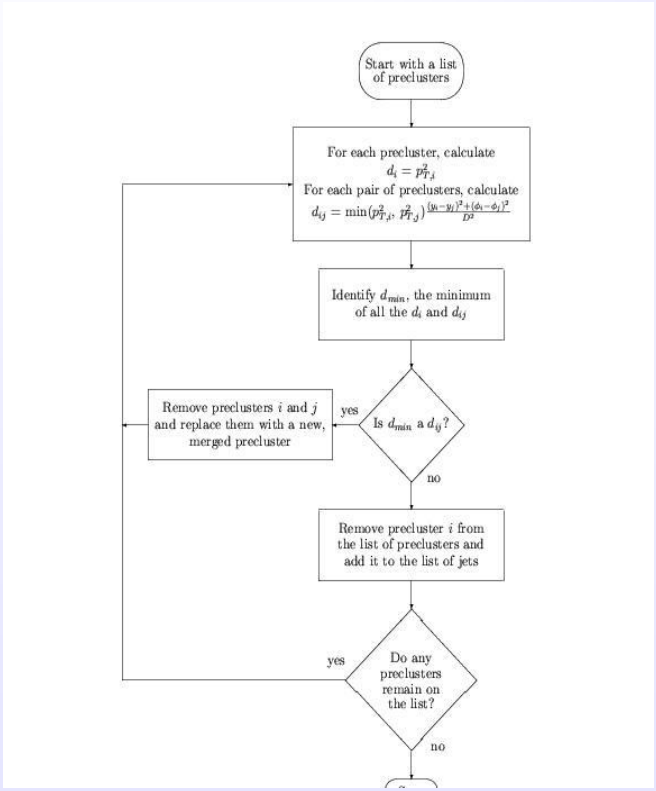
Cone jet Algorithm

K_T jet Algorithm

Association of towers within a cone of radius

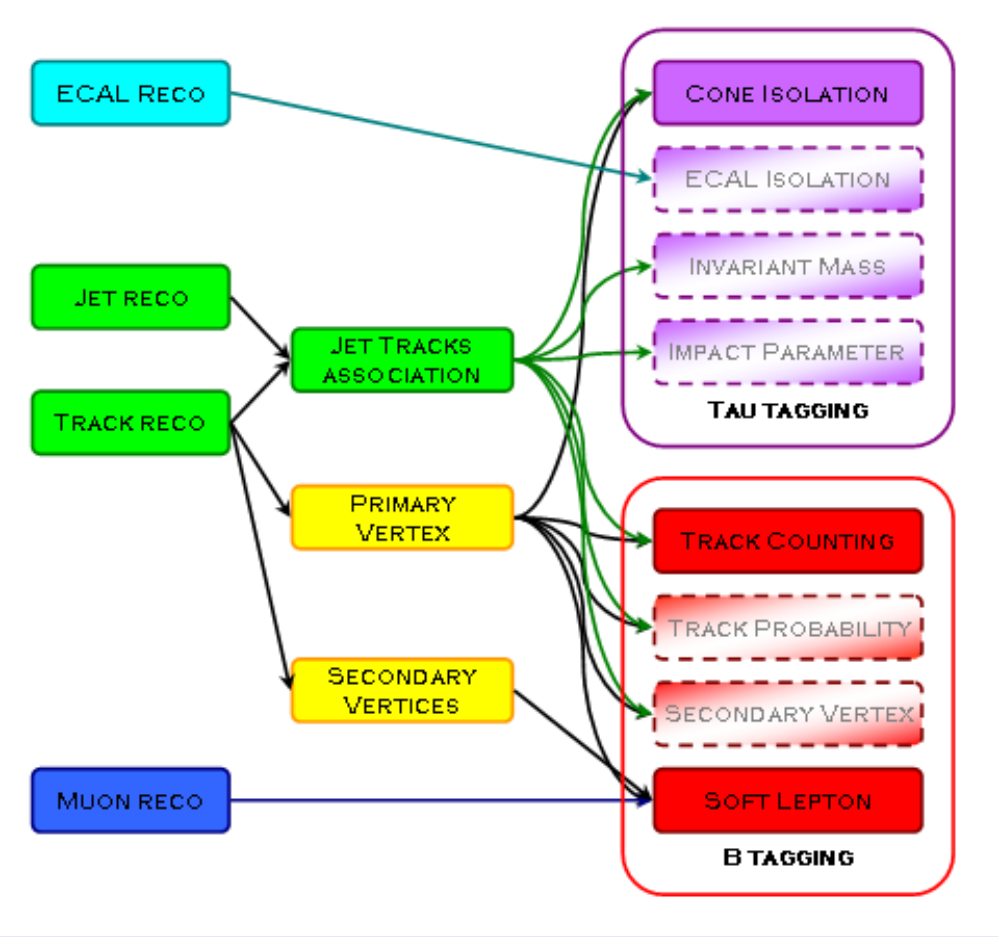
R = $\sqrt{\Delta\eta^2 + \Delta\varphi^2}$



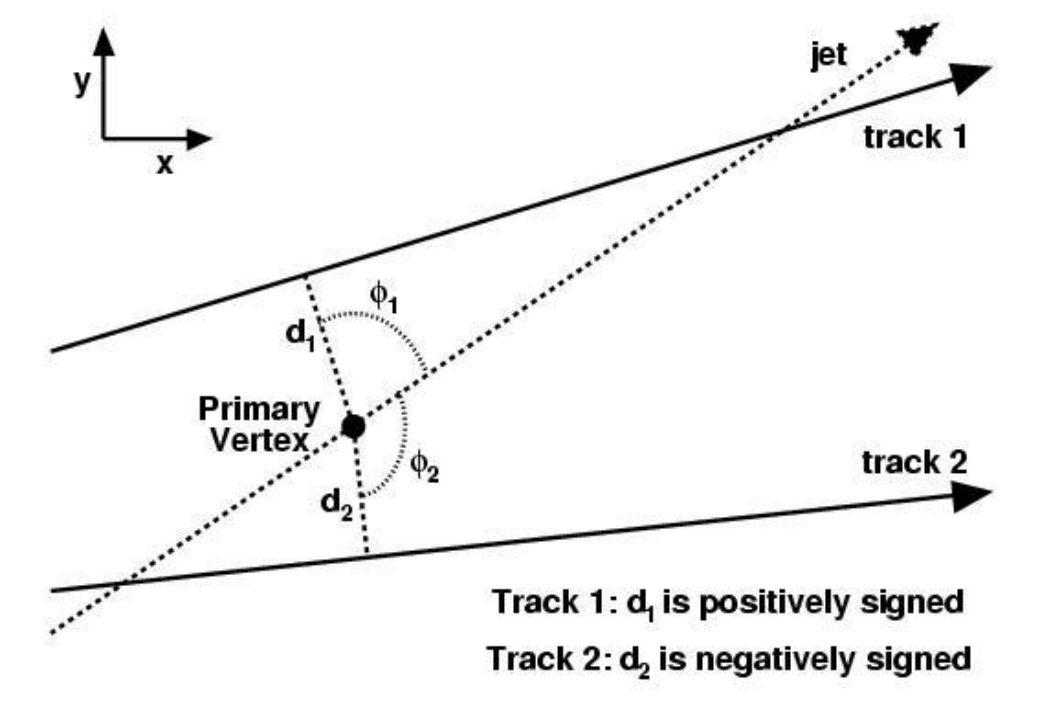


Merge pair of particles with increasing momentum

b-jet tagging Procedure



Impact parameter based tag



ϕ = angle between the jet axis and line connecting the primary vertex and track's point of closest approach to the primary vertex.

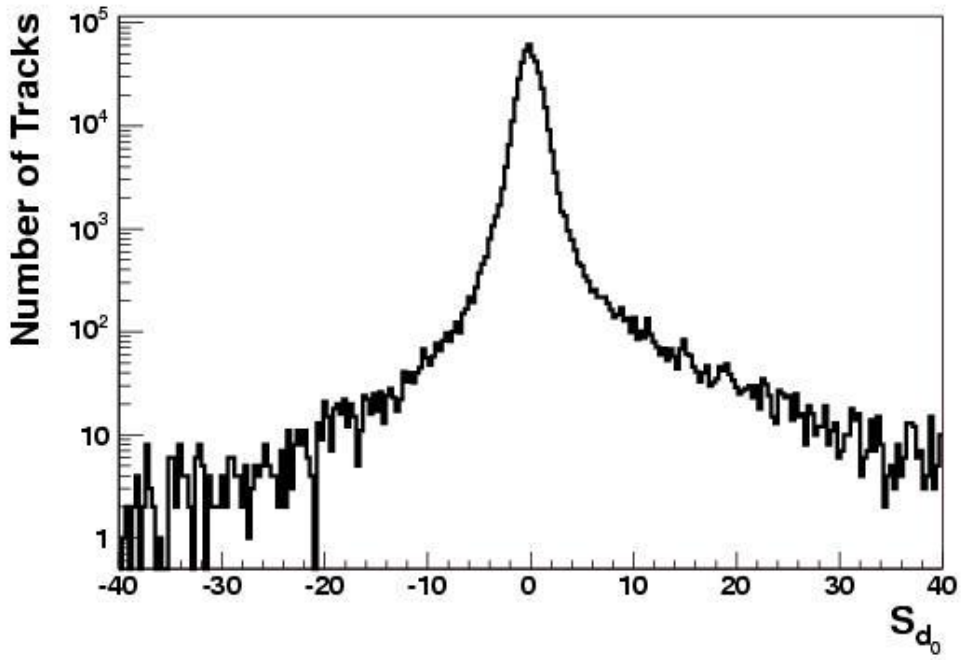
d → +ve if $\phi < \pi/2$

-ve if $\phi > \pi/2$

Impact parameter significance, $S_{do} = d_0/\sigma_{do}$

CDF Collaboration, Phys. Rev.D 74,072006, 2006.

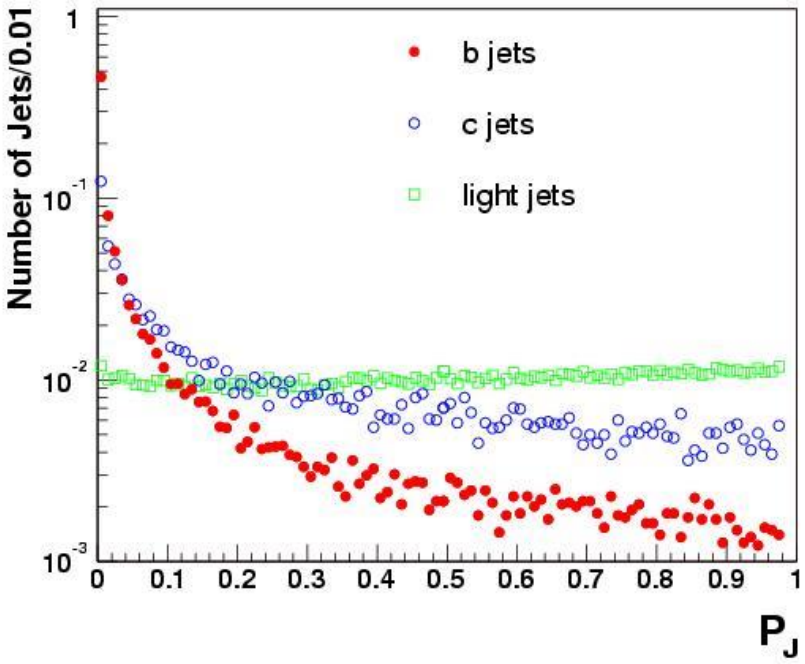
Impact Parameter Significance



Jets which originate from a heavy parton contain long lived hadrons giving rise to tracks displaced in the jet direction, preferentially populate the positive side of the impact parameter.

Simple method : Apply a suitable cut on S_{do} and tag b jets

Probability Method



$$P_{jet} = \Pi \cdot \sum_{j=0}^{N_{tr}-1} \frac{(-\ln \Pi)^j}{j!}, \quad \Pi = \prod_{i=1}^{N_{tr}} P_{tr\,i}$$

Positive tagged jets are expected to be enriched in heavy flavor. The most remarkable feature of this method is that by adjusting P_j cut the jets from heavy flavor (b and c) can be separated.

Secondary Vertex Tag

b-tagging scheme in detail :

1. Find which of the vertices is nearest to the identified e- or muon or find the vertex which has the highest total scalar sum of transverse momentum of the associated tracks

2. Fit the tracks within $\pm \Delta z$ around the vertex $|S_{do}|$, tracks having optimum cuts (for example, $\chi^2 > 10$ (or $\chi^2/NDF > 5$) are removed.

3. **Look for Secondary vertex :** Secondary vertex tagging operates on jet basis

   A. Consider only the tracks within the jet cone.

   B. A set of cuts involving pt, χ^2/NDF are applied to reject the poorly reconstructed tracks

   C. A jet is defined taggable if it has two good tracks

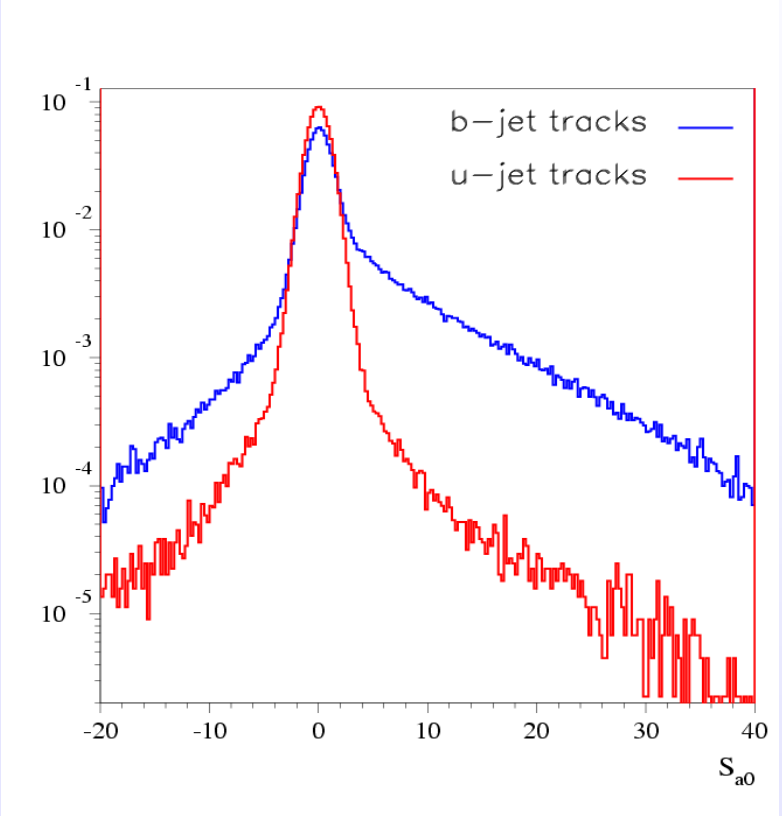
   D. Tracks should pass two checks ($p_t >$ certain threshold, 0.5 and $S_{do} > 2.5$ for the secondary vertex reconstruction

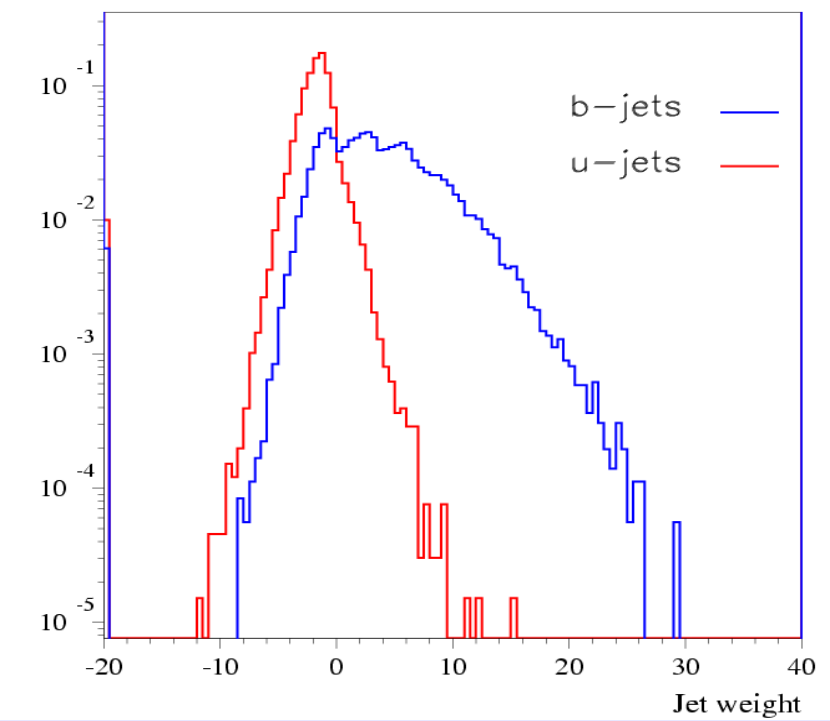
4. Once the secondary vertex is detected, 2-dim decay length of secondary vertex, L2D is calculated as the projection on to the jet axis in the r-phi region

5. A secondary vertex corresponding to the b and c decay hadrons are expected to have large positive L2D

LogL ratio method (basic ATLAS)

$$W_{jet} = \sum_{i=1}^{N_{tr}} \ln \frac{b(S_i)}{u(S_i)}$$

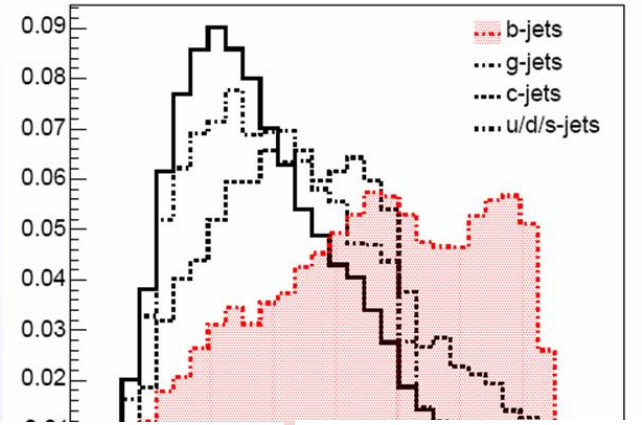


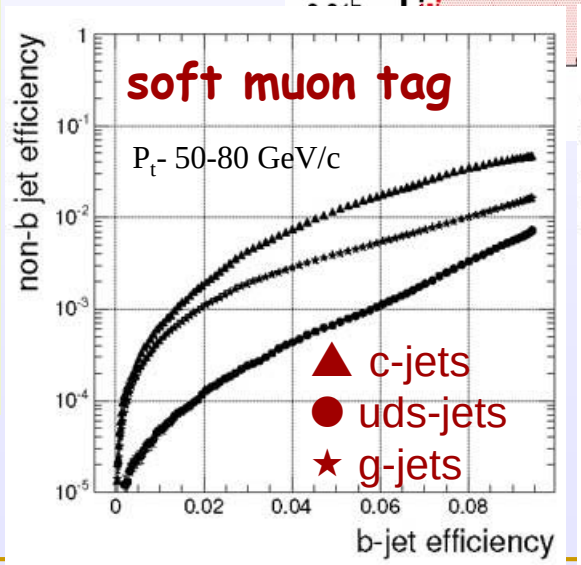


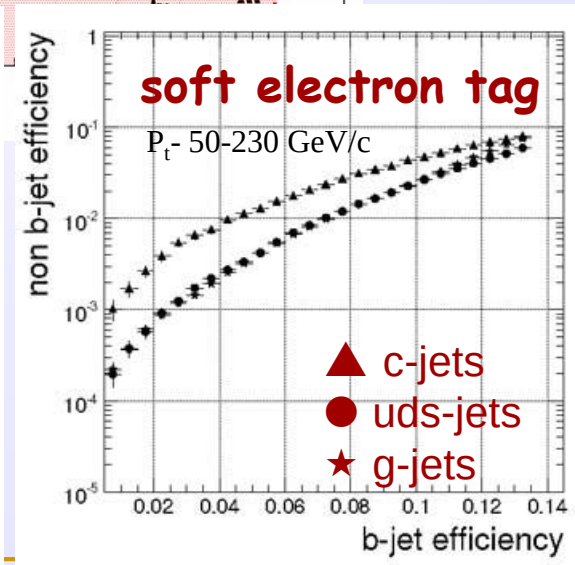
Soft Lepton Tag

A.Bocci, P.Demin, et al., CMS Note 2006/043

- The principle:
  - use the fact, that ~19 % of b-quarks decay inclusively into electrons and muons
- The algorithm:
  - e: propagate tracks to ECAL and match tracks to ECAL cells
  - e: use neural net with covariance of cluster energy distribution, repartition of cluster energy and cluster energy over track
  - mu: require > 70 momentum ratio % of common hits for track and reconstructed muon



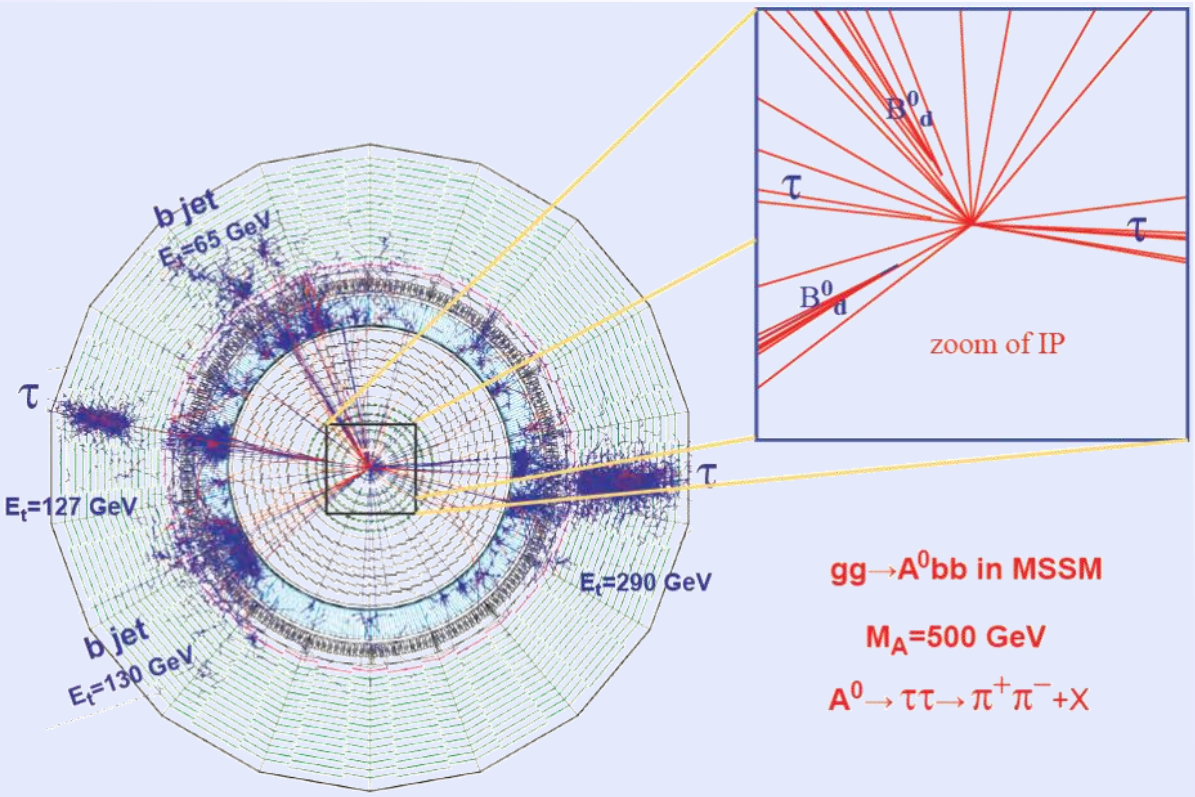




Cuts for b tagging in CMS

CMS PTDR vol.I chap.12.2

- **track selection cone**
  - tracks selected in a cone of 0.3 or 0.4 around jet direction
- **minimum pT cut**, pT > 1 GeV/c
- **quality cuts for the leading track**
  - at least 8 hits, c2 at most 10
- **upper limit on impact parameter**
  - IPT < 2.0 mm
- **IP sign**
  - IP needs to be going downstream from PV



CMS Software : CMSSW

CMSSW is built around EDM (Event data Model) i.e., it believes in the concept of an event and is directly observable in root.

CMSSW has a modular architecture i.e.,any module can be run in isolation

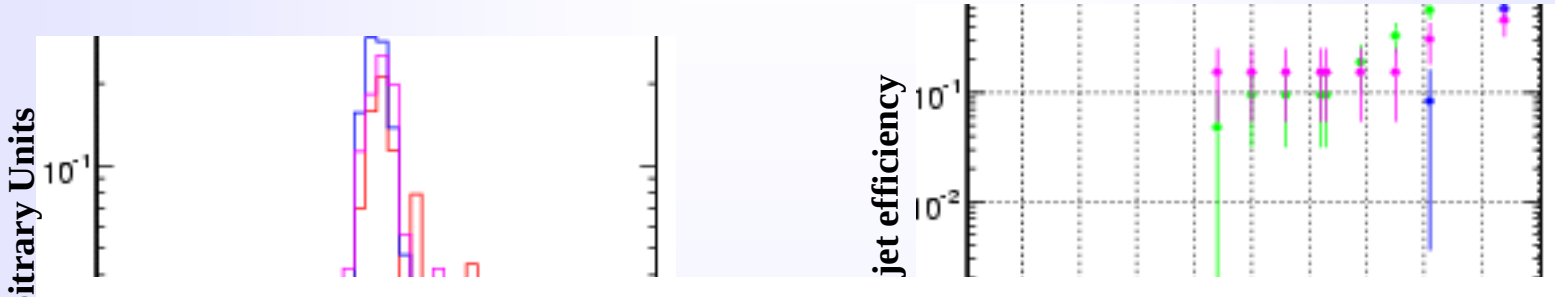
The main executable is cmsRun and it works on users job specific configuration file (.cfg file)

The same executable is used for both real and MC data

The analysis tool for b-jets is provided in the package **RecoBTag/Analysis** (in CMSSW) with the EDAnalyzer named **BTagPerformanceAnalyzer.**

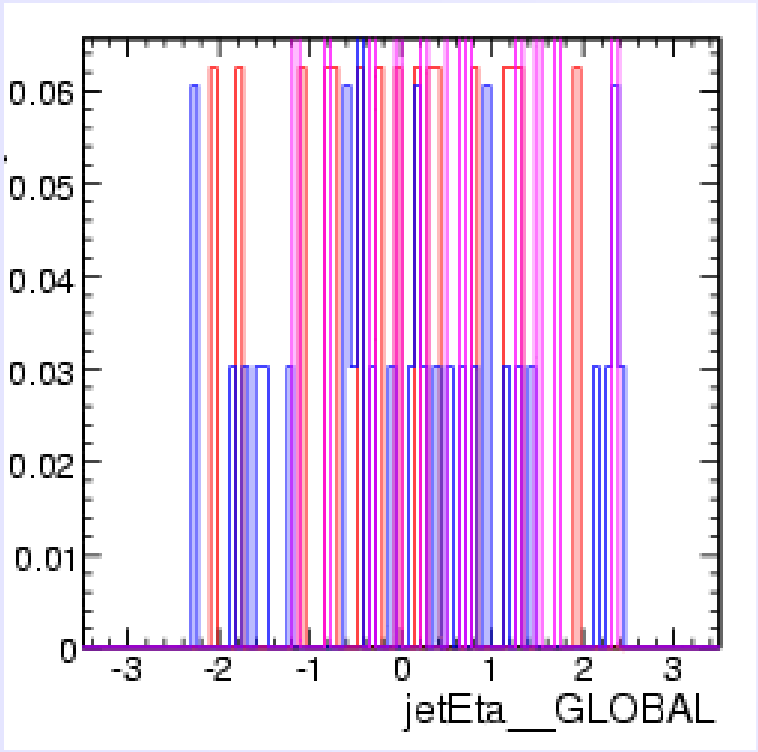
All the methods : Track Counting, Track Probability, Secondary Vertex and Soft Lepton exist in CMSSW, but, needs tuning for Heavy Ion Physics

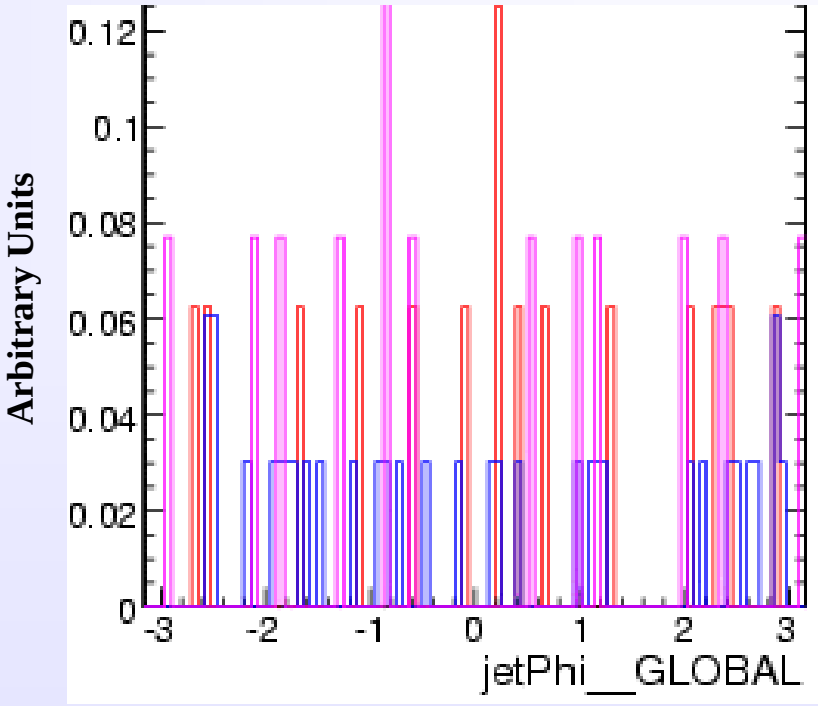
Very Preliminary results



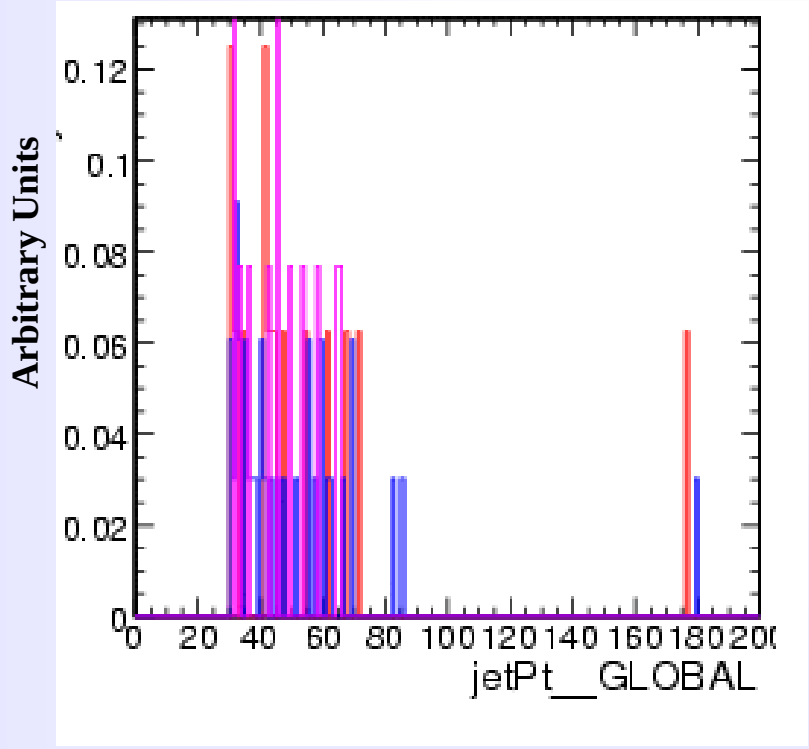
List of tagged jets:
Found 5 B candidates
Tag with discriminator 0.465788 – Associated Parton flavour: 5
  Eta/phi of reconstructed jet: -0.00435638 , 2.14022
  Eta/phi of parton: 0.0431445 , 2.11373
Tag with discriminator 7.55172 – Associated Parton flavour: 5
  Eta/phi of reconstructed jet: 1.26817 , -1.09091
  Eta/phi of parton: 1.30328 , -1.05517
Tag with discriminator -10 – Associated Parton flavour: 21
  Eta/phi of reconstructed jet: -2.46481 , -2.10657
  Eta/phi of parton: -2.28652 , -2.18527
Tag with discriminator -10 – Associated Parton flavour: 21
  Eta/phi of reconstructed jet: 2.38606 , -0.986838
  Eta/phi of parton: 2.48835 , -1.20238
Tag with discriminator -10 – Associated Parton flavour: 21
  Eta/phi of reconstructed jet: 2.252 , 1.48353
  Eta/phi of parton: 2.29099 , 1.31272

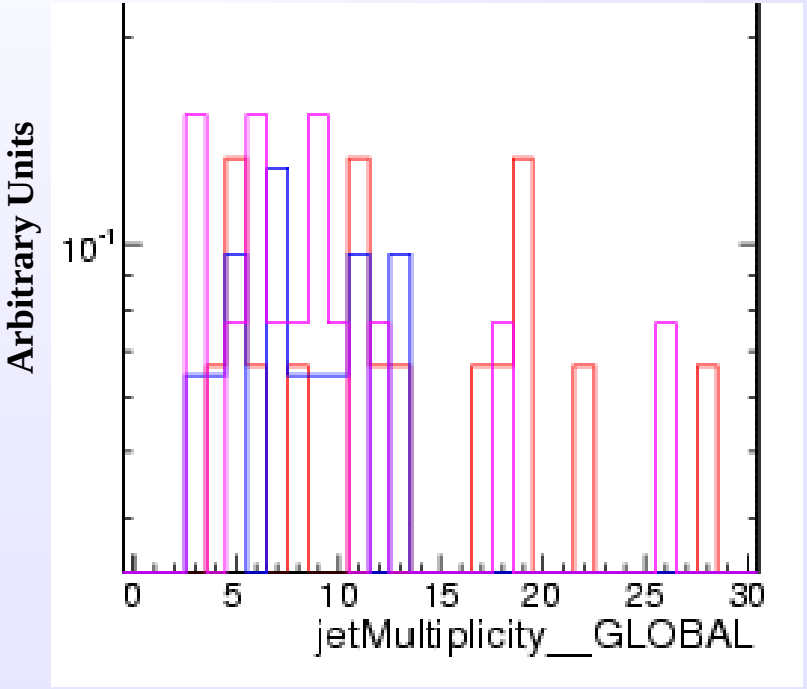
Jet : η and ϕ distributions





Jet Multiplicity and P_t





Summary and Conclusions

- LHC is going to bring lots of new surprises (We'll be entering new high p_t domain, lots of jets and heavy flavor production
- CMSHI group has a planned agenda to explore all the QGP signals at LHC
- Jet flavor tag will be a new and exciting signal
- Various b-tagging techniques exist and we are optimising them according to the heavy ion physics studies

Thank you