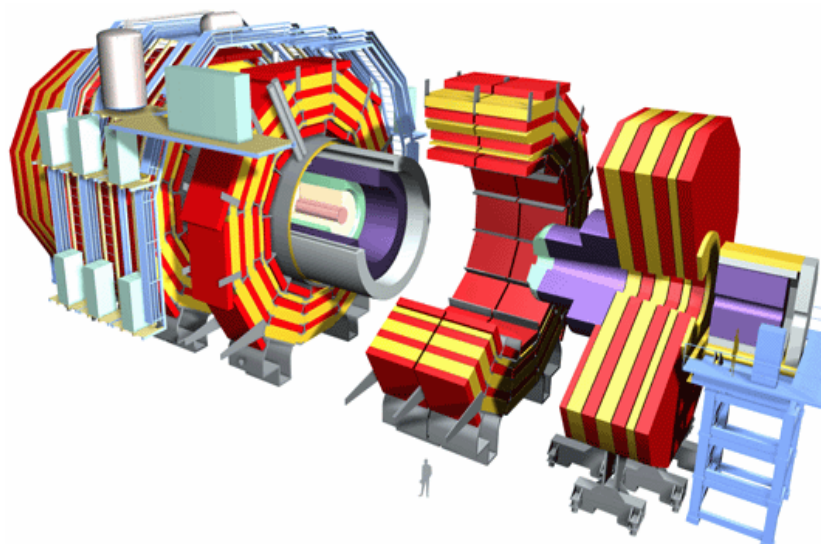


Jet Finding in the CMS Heavy Ion Programs



APCTP Workshop
POSTECH, Pohang, Feb. 27, 2006

Inkyu PARK
Dept. of Physics, University of Seoul

Athens, Auckland, Budapest, CERN, **Chonbuk Univ.**, Colorado, Cukurova, Iowa, Kansas, **Korea Univ.**, Los Alamos, Lyon, Maryland, Minnesota, MIT, Moscow, Mumbai, Rice, **Univ. of Seoul**, Vanderbilt, UC Davis, UI Chicago, **Yonsei Univ.**, Zagreb



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1. LHC as a new tool for HI Physics (5 pages)
2. CMS as detectors for HI physics (10 pages)
3. CMS-HI Physics capability (6 pages)
4. Introduction to Jet and Jet finders (12 pages)
5. CMS-HI Korean Physicists lead... (6 pages)
6. Jet finding at CMS-HI (4 pages)
7. Remarks and Summary (3 pages)

total of 55 pages → So let's move fast...

LHC
as a new tool
for HI Physics



LHC as a new tool for HIP



- **Once again a big energy jump! LHC will accelerate and collide heavy ions at energies far exceeding the range of existing accelerators. It means**
 - Extended kinematic reach for pp, pA, AA
 - New properties of the initial state, possible gluon saturation at mid-rapidity
 - A hotter and longer lived partonic phase
 - Increased cross sections and availability of new hard probes

	AGS	SPS	RHIC	LHC
$\sqrt{s_{NN}}$ [GeV]	5	20	200	5500
E increase		x4	x10	x28
y range	± 1.6	± 3.0	± 6	± 8.6



Quark Gluon Plasma



- **Data from SPS & RHIC show new and unexpected properties of hot nuclear matter**
 - **Jet quenching, strong elliptical flow, d+Au- control data indicate that we have produced strongly interacting color liquid**
- **LHC will significantly increase energy density**
 - **new properties of the QGP**
 - **Continuation of strong coupling regime?**
 - **Weakly interacting Plasma?**
 - **New discoveries guaranteed!**

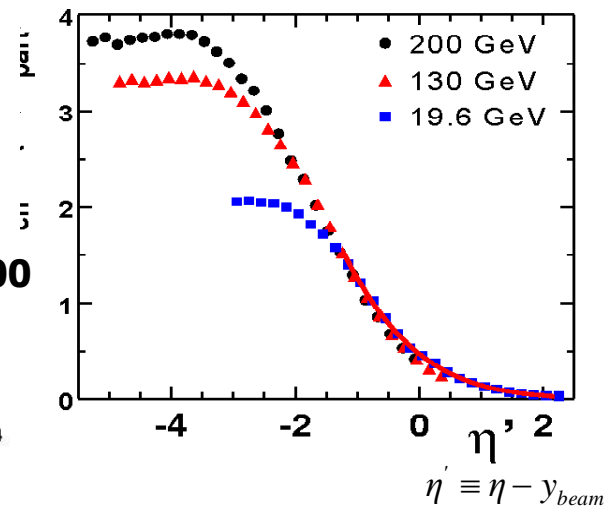
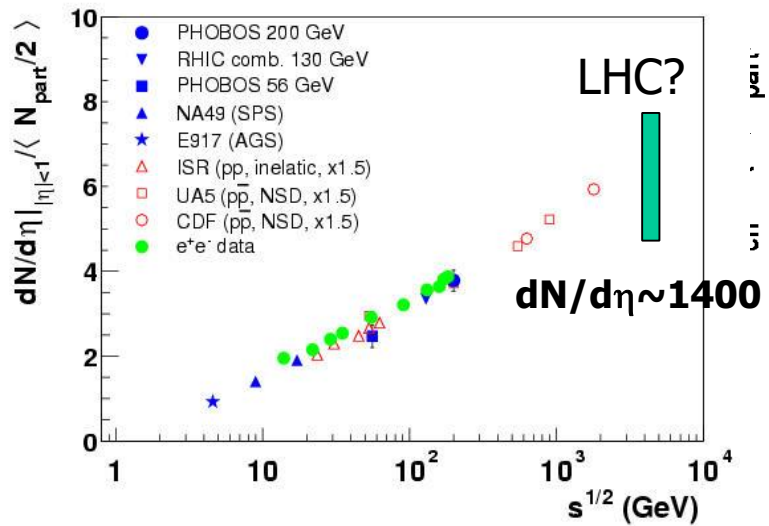


Soft observables: RHIC → LHC



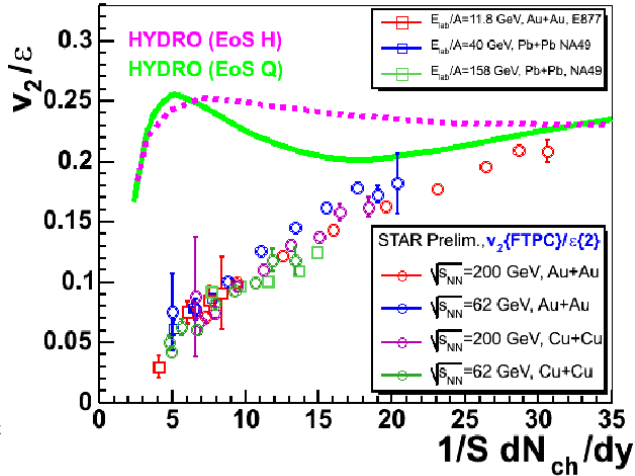
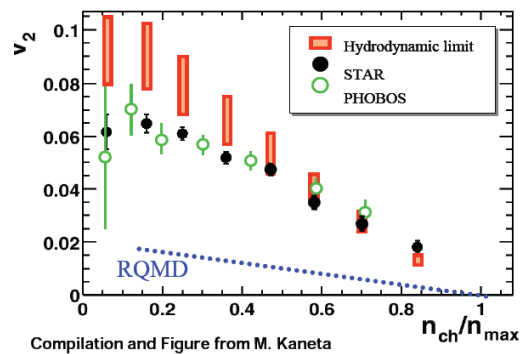
RHIC shows a simple energy dependence. How about at the LHC?

Charged particle multiplicity, limited fragmentation

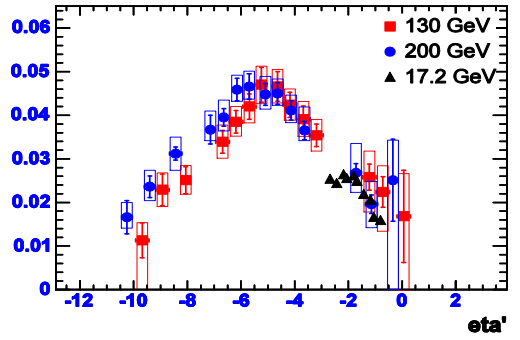


• RHIC prefers Hydrodynamic limit. How about at the LHC?

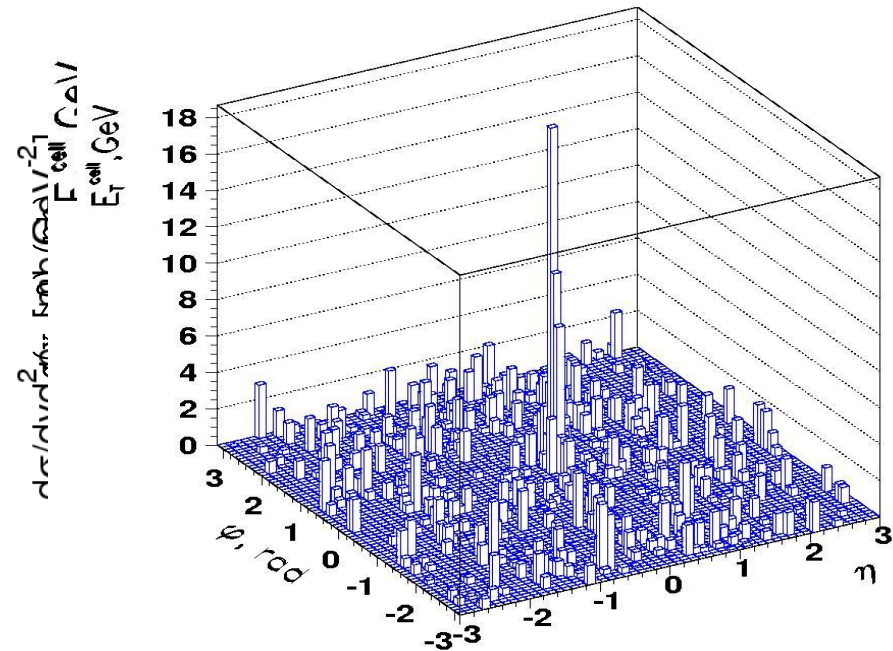
PHOBOS: Phys. Rev. Lett. **89**, 222301 (2002)
 STAR: Phys. Rev. Lett. **86**, 402 (2001)



Flow



- Copious production of high p_T , high-mass particles
- Large production cross section for the J/ψ and ψ' family
- Jets are fully reconstructed for the first time in heavy ion collisions.



After background subtraction



LHC accelerator schedule



Calendar Year	p+p	Heavy Ions
2007	450+450 GeV, $5 \cdot 10^{30}$ Short engineering run	none
2008	14 TeV, $0.5 \cdot 10^{33}$	5.5 TeV, $5 \cdot 10^{25}$ Pb+Pb
2009	14 TeV, $1 \cdot 10^{33}$	5.5 TeV, $1 \cdot 10^{27}$ Pb+Pb
2010	14 TeV, $1 \cdot 10^{34}$	5.5 TeV, $1 \cdot 10^{27}$ Pb+Pb
2011	14 TeV, $1 \cdot 10^{34}$	5.5 TeV, $1 \cdot 10^{27}$ Pb+Pb, other ions

- Heavy Ion runs always follow p+p runs, at the end of calendar year
- Nominal data taking time:
 - p+p: 10^7 seconds/year
 - Heavy ions: 10^6 seconds/year: 0.5 nb^{-1}
- Heavy Ion nominal luminosity is likely to be reached earlier than for p+p

CMS
as detectors
for HI Physics

➤ Calorimeters: high resolution and segmentation

- ▶ Hermetic coverage up to $|\eta| < 5$
- ▶ $|\eta| < 6.6$ with CASTOR
- ▶ Zero Degree Calorimeter

➤ Muon tracking: μ from Z^0 , J/ψ , Υ

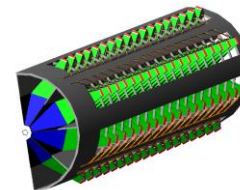
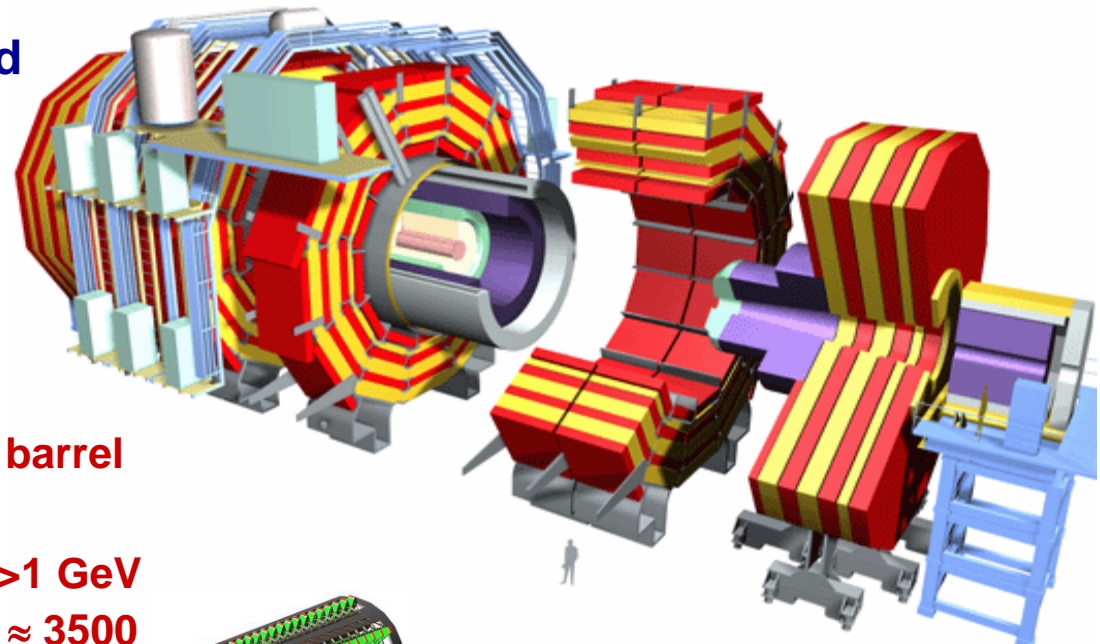
- ▶ Wide rapidity coverage: $|\eta| < 2.4$
- ▶ $\sigma_m \approx 50$ MeV at the Υ mass in the barrel

➤ Silicon Tracker

- ▶ Good efficiency and purity for $p_T > 1$ GeV
- ▶ Pixel occupancy: $< 2\%$ at $dN_{ch}/d\eta \approx 3500$
- ▶ $\Delta p/p \approx 1-2\%$ for $p_T < 100$ GeV
- ▶ Good low p_T reach using pixels

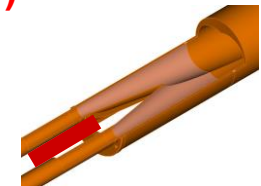
➤ DAQ and Trigger

- ▶ High rate capability for A+A, p+A, p+p
- ▶ High Level Trigger: real time HI event reconstruction



CASTOR

$(5.2 < |\eta| < 6.6)$

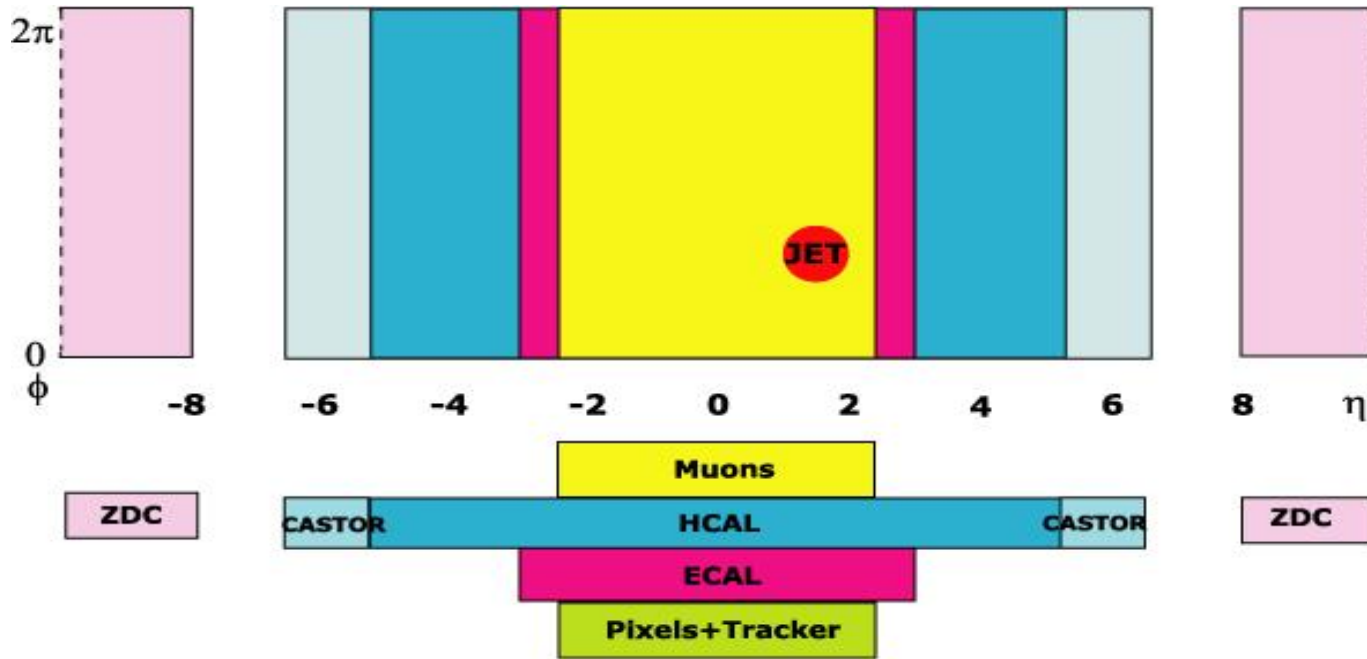


ZDC

$(z = \pm 140 \text{ m}, |\eta| > 8.2 \text{ neutrals})$

Functional at the highest expected multiplicities:

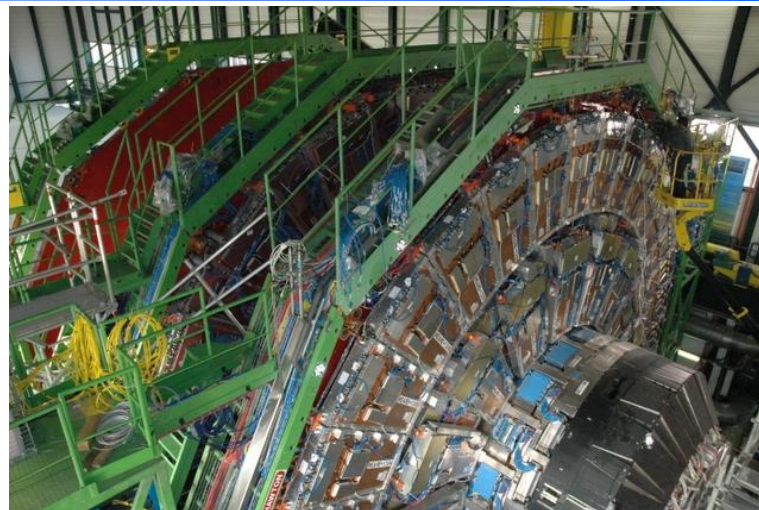
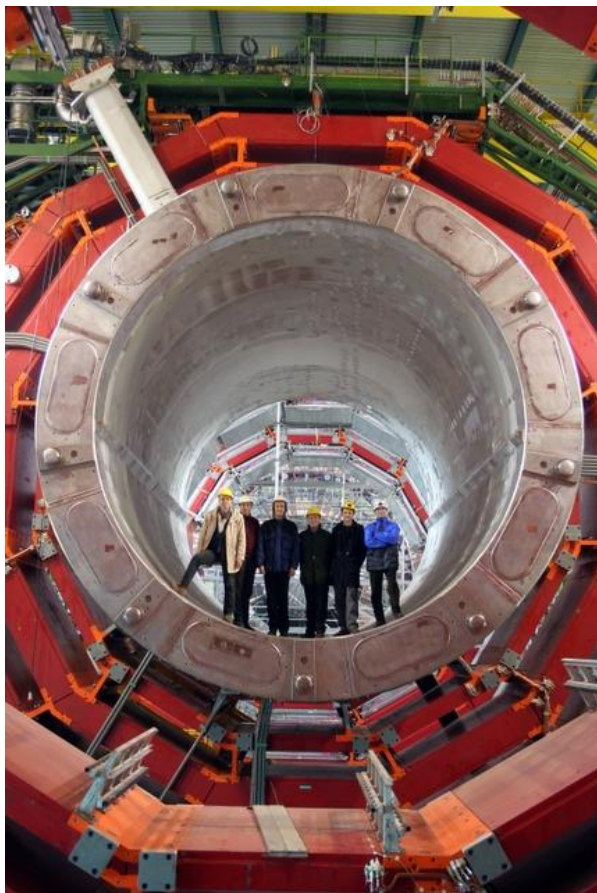
studied in detail at $dN_{ch}/d\eta \approx 3000-5000$ and cross-checked at 7000-8000



- Hermeticity, Resolution, Granularity
 - Central region $\Delta\eta \sim 5$ equipped with tracker, electromagnetic and hadronic calorimeters and muon detector
- Forward coverage
 - Calorimetric coverage of $\Delta\eta \sim 10$
 - Additional calorimeters proposed to extend the coverage: CASTOR $\Delta\eta \sim 14$
 - Zero Degree Calorimeter (ZDC)
- High data taking speed and trigger versatility

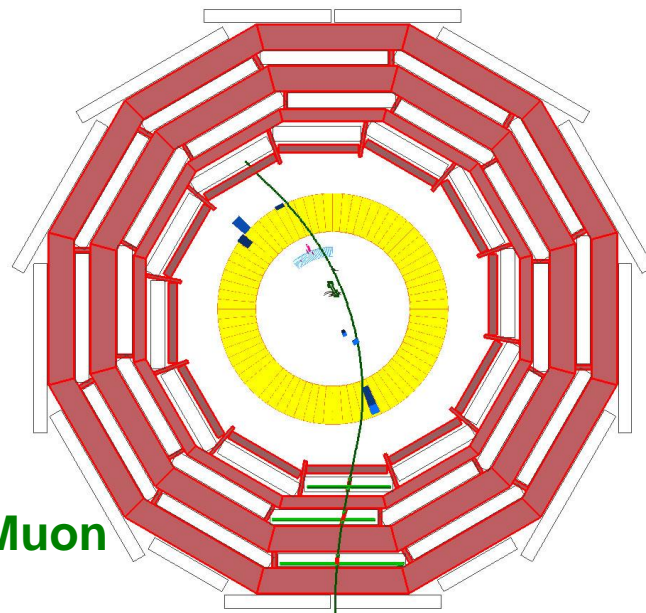
Sub detector	Coverage
Tracker, muons	$ \eta < 2.4$
ECAL + HCAL	$ \eta < 3.0$
Forward HCAL	$3.0 < \eta < 5.2$
CASTOR	$5.2 < \eta < 6.6$
ZDC (neutrals)	$8.2 < \eta $

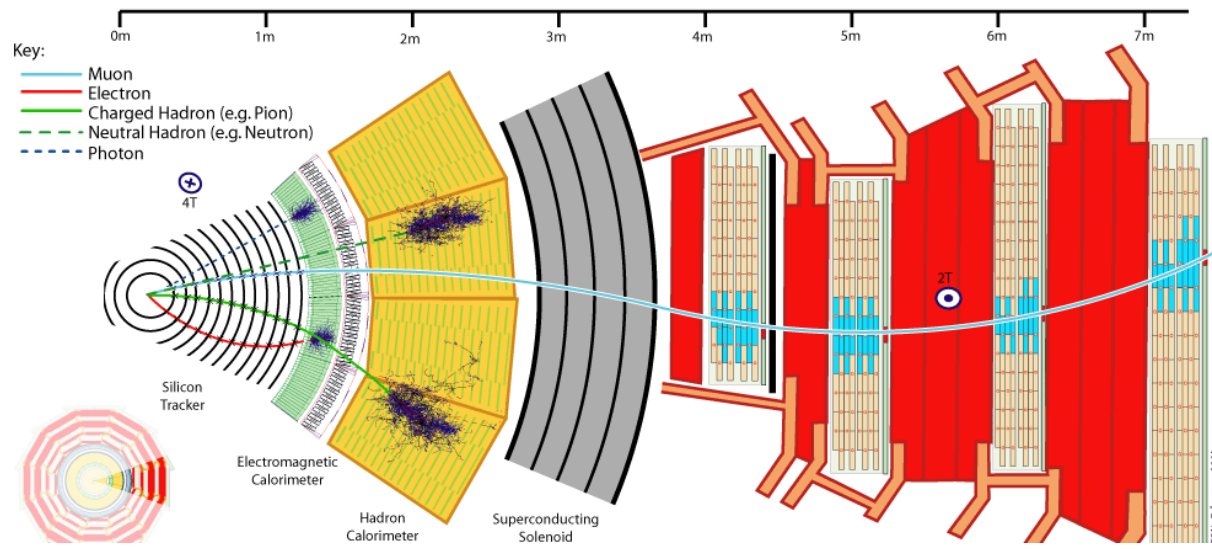
CMS getting ready for beam



**2006 Magnet operation, CMS
Magnet operated at 4T, the nominal
field!**

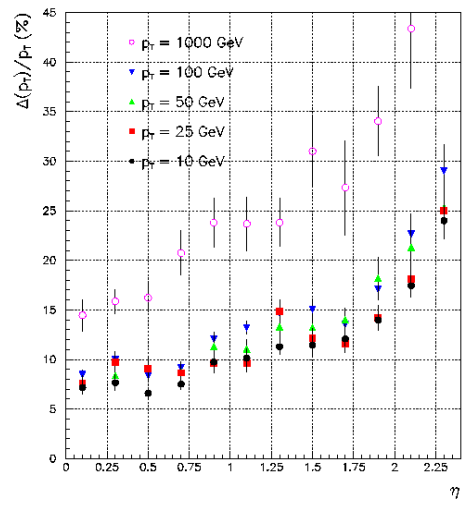
Cosmic Muon



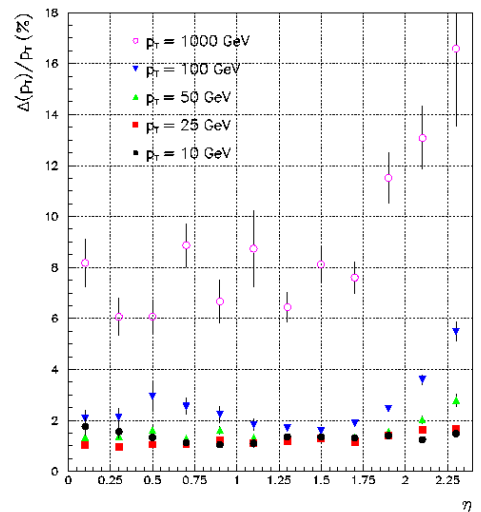


ERN, February 2008

Tracking Resolution—Muon System with Vertex Constraint



Tracking Resolution—Muon System with Inner Tracker



Resolution Standalone

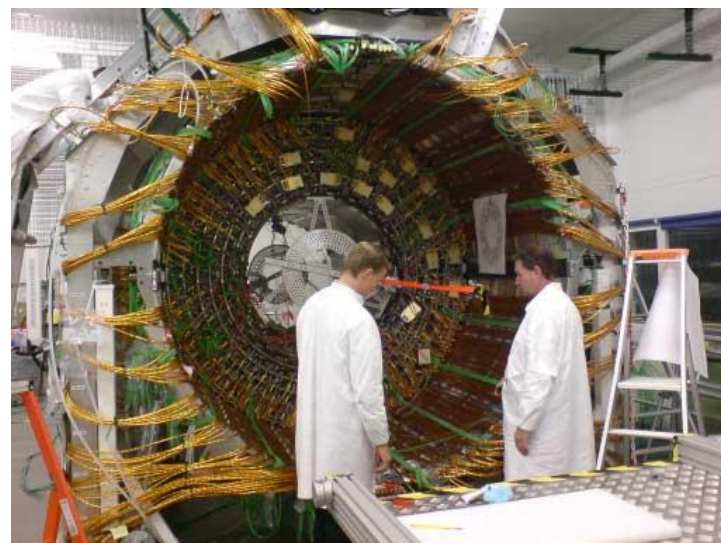
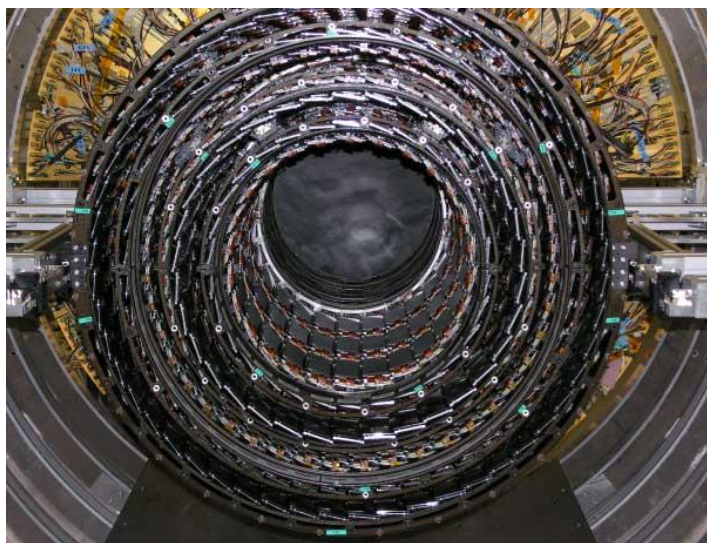
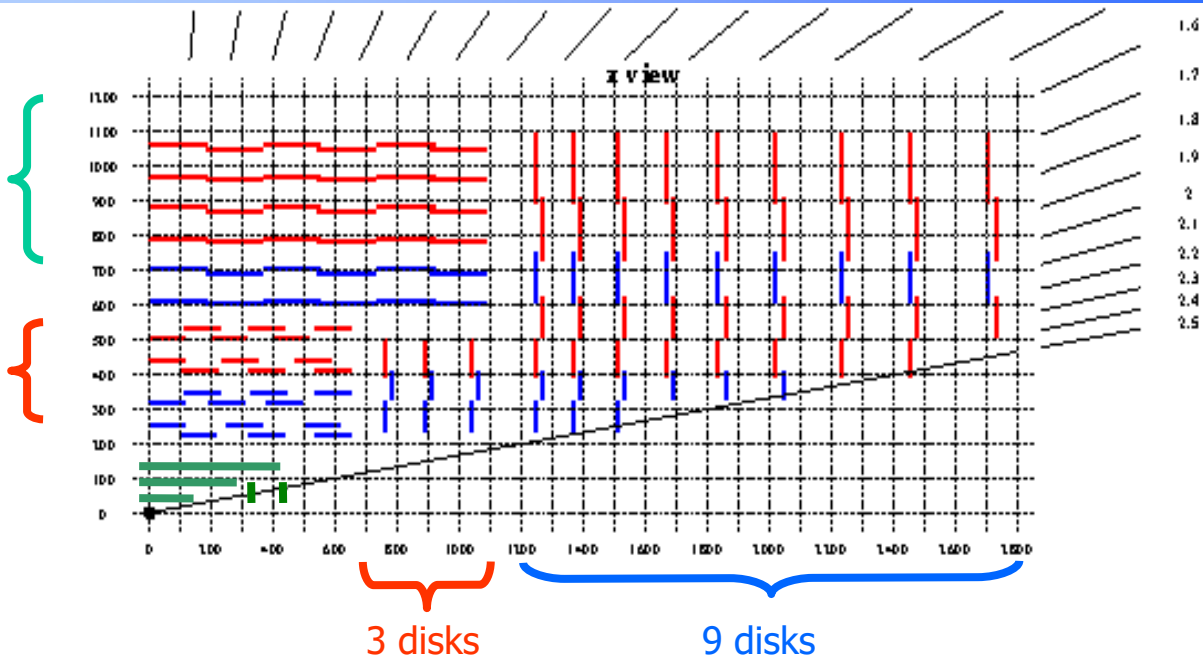
Resolution with tracker

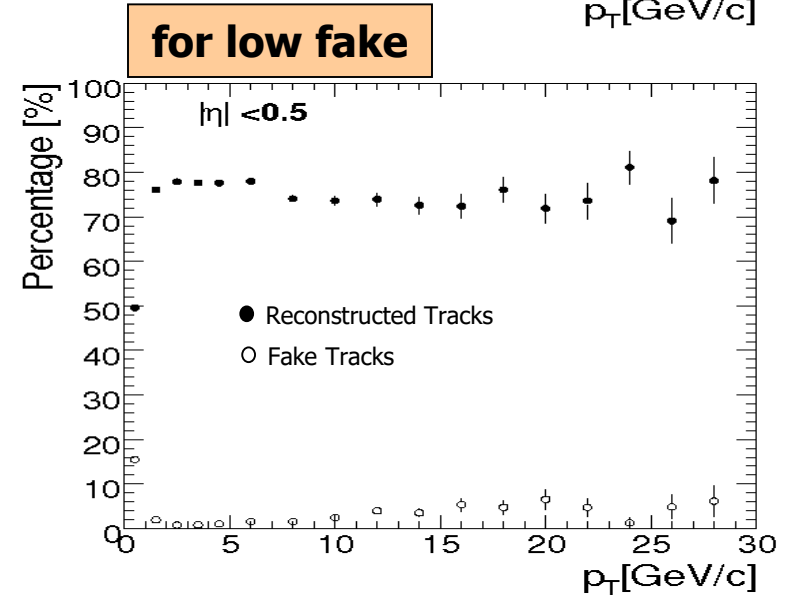
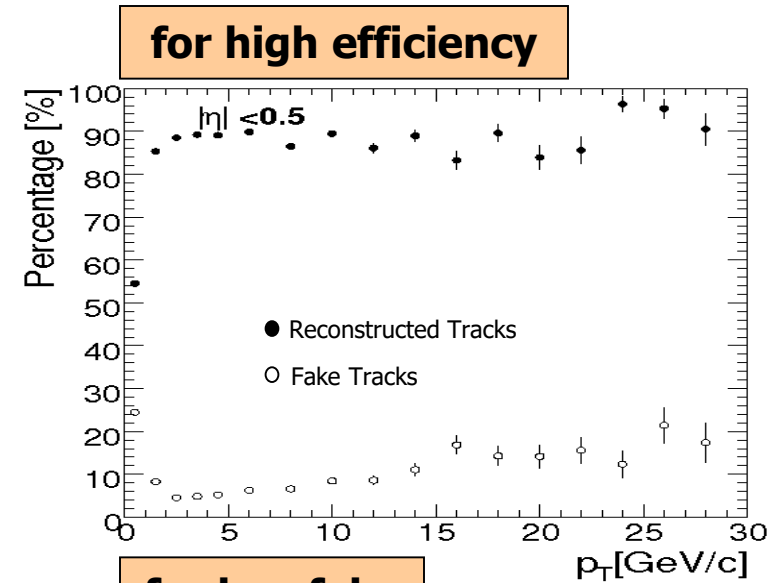
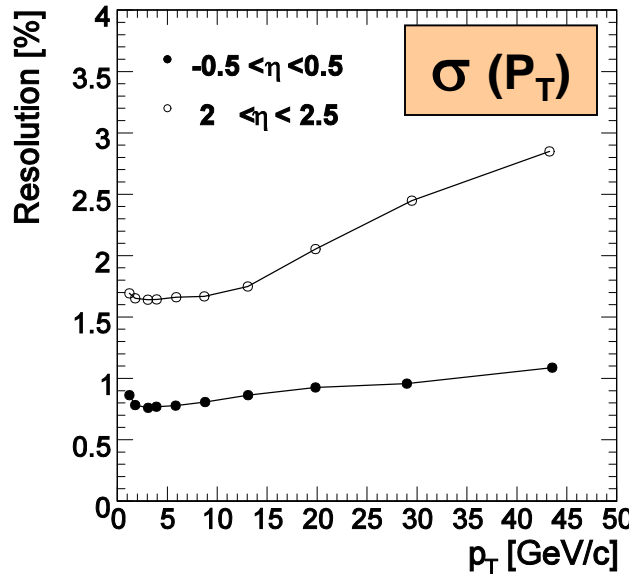
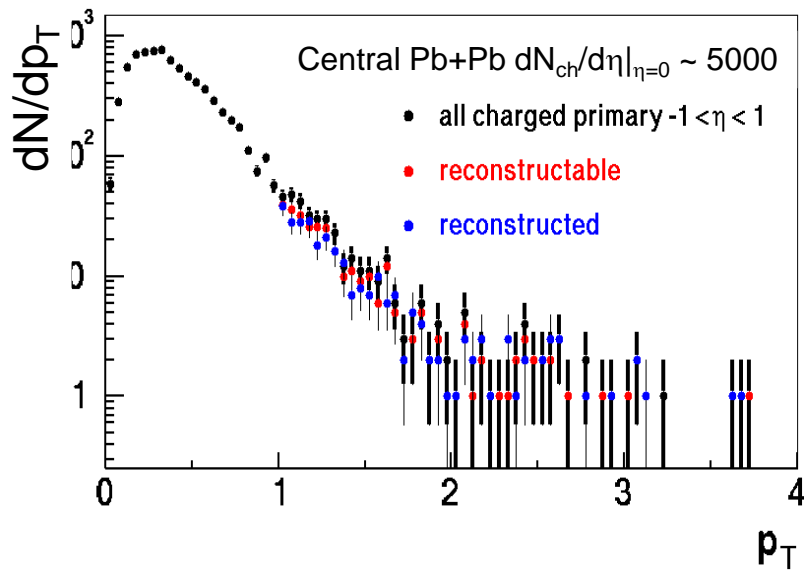
Tracker layout

6 layers
Outer
Barrel

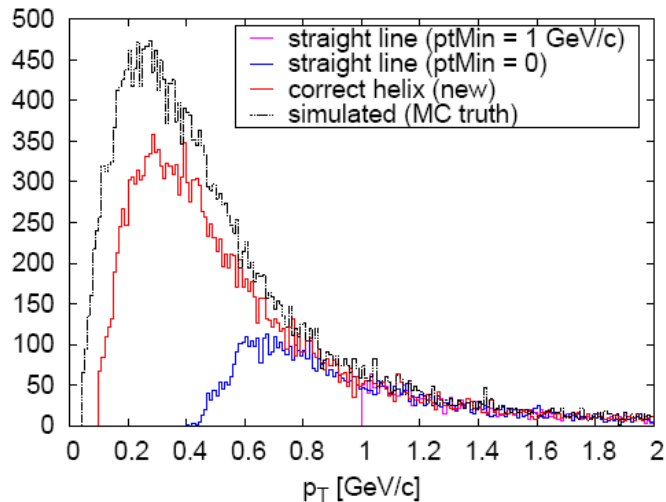
4 layers
Inner
Barrel

3 Pixel Layers

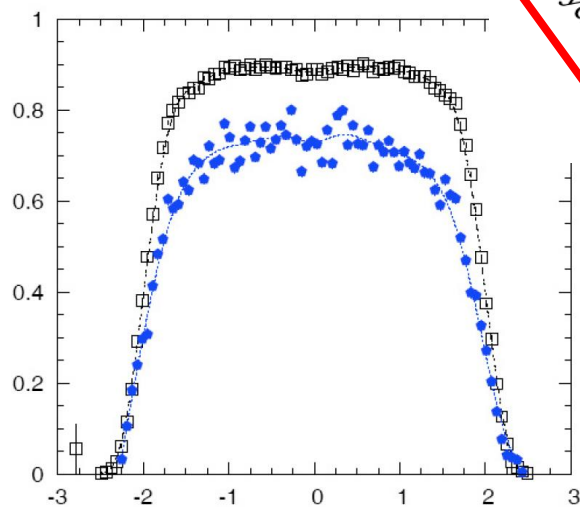
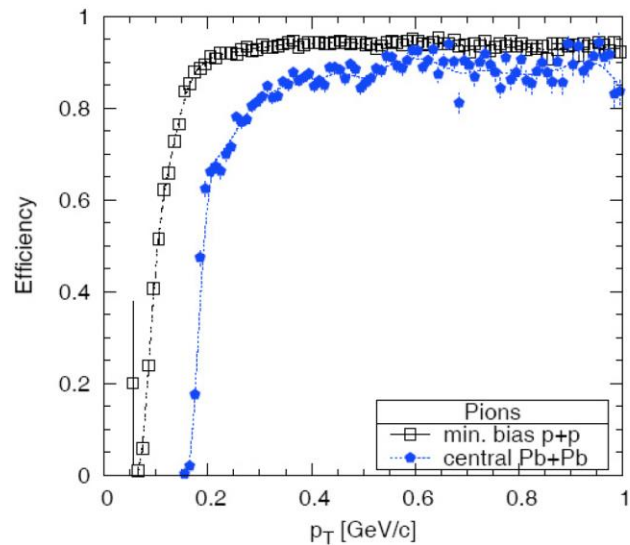
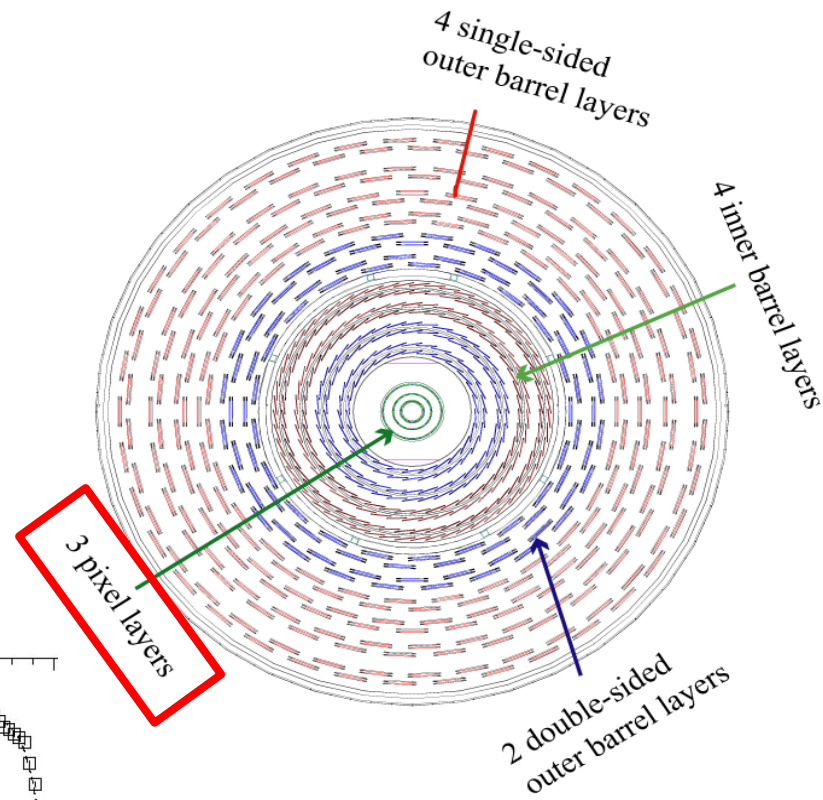


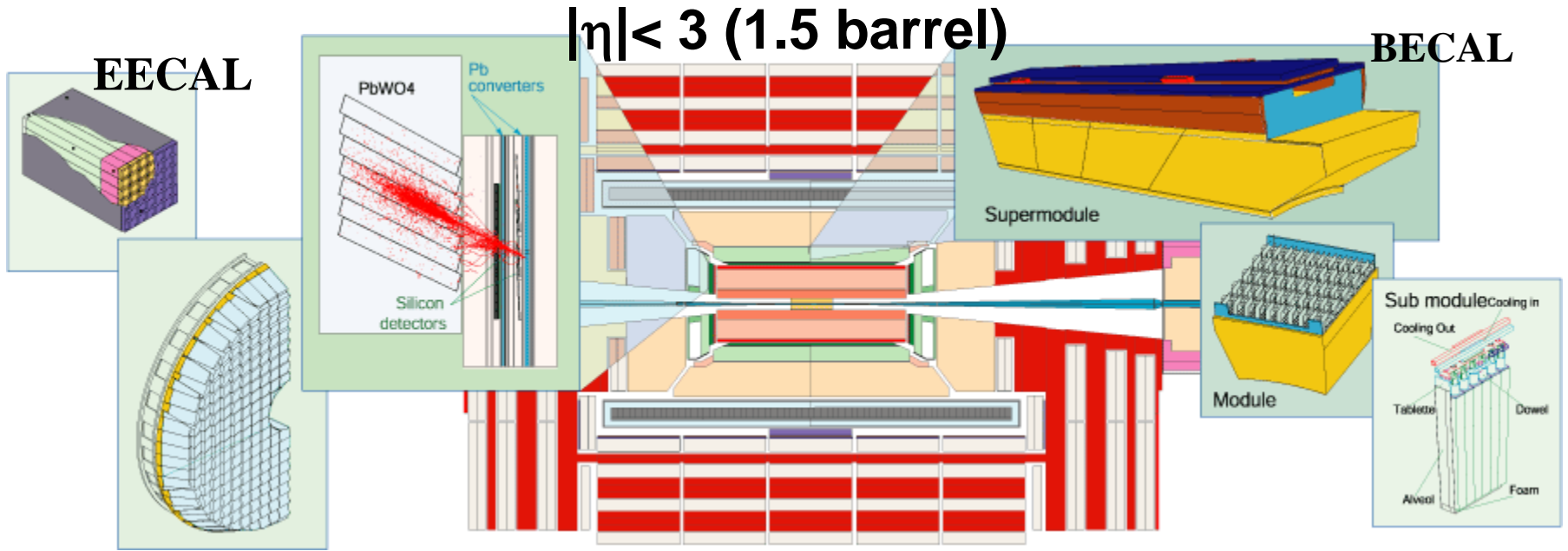


Low p_T tracking using three layers of pixels

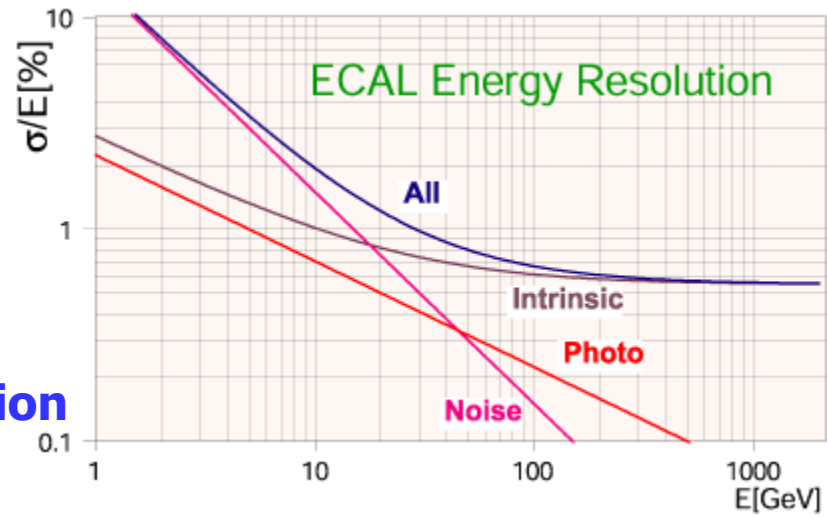


Pixel tracking

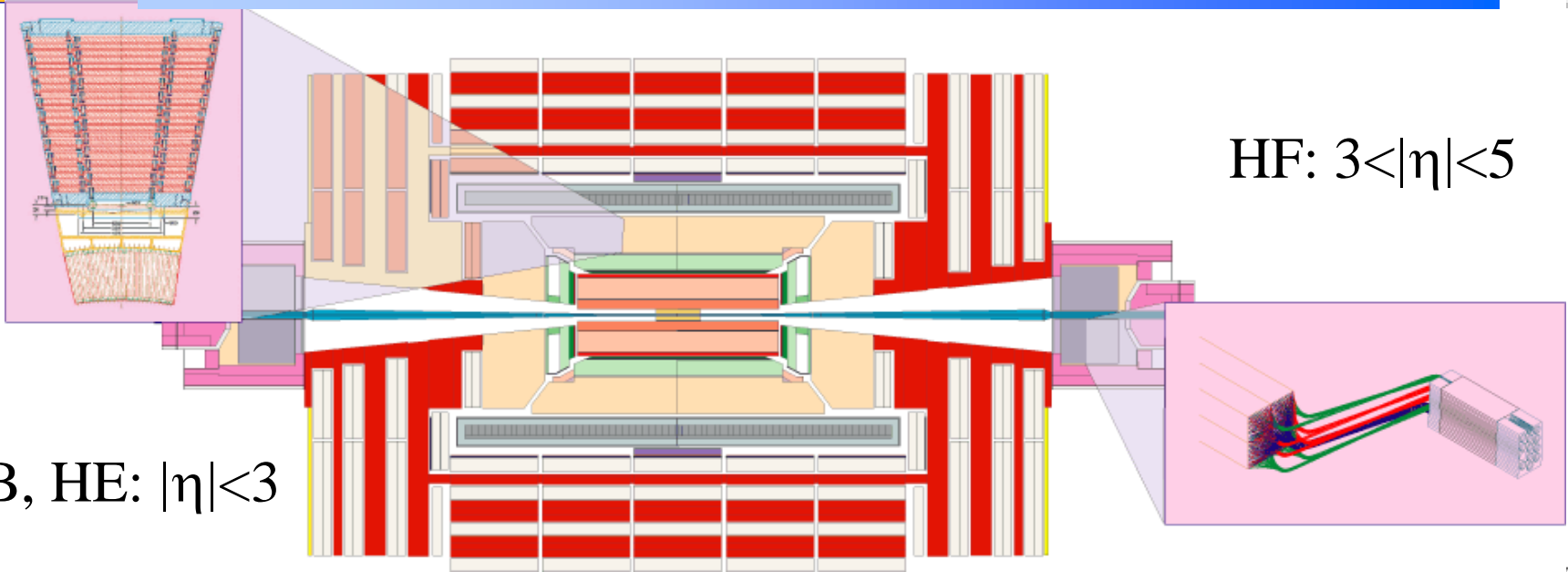




- **76000 PbWO4 crystals**
 - **Granularity in $\Delta\eta \times \Delta\phi$:**
 - **0.0174 x 0.0174 (Barrel) and**
 - **0.0174 x 0.0174 to 0.05x0.05 (Endcap)**
- **Endcap with preshower for γ/p_0 separation**
- **Details in CMS Technical Design Reports**



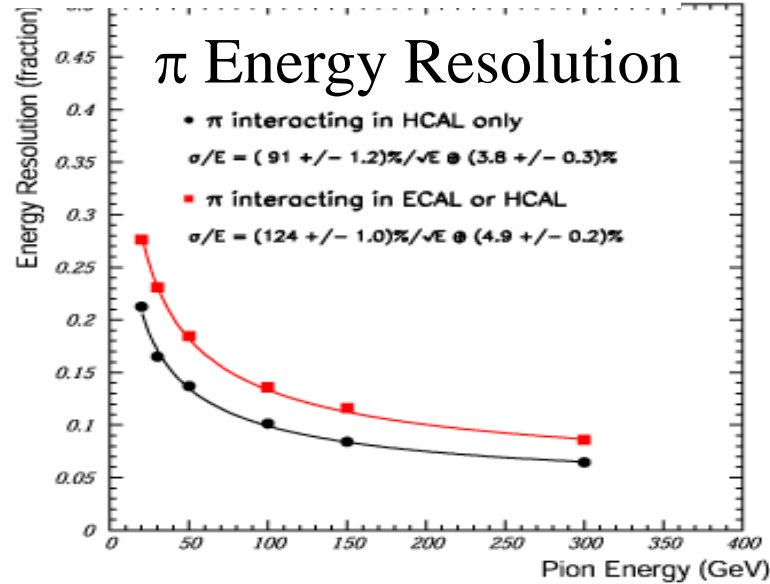
HCAL



HF: $3 < |\eta| < 5$

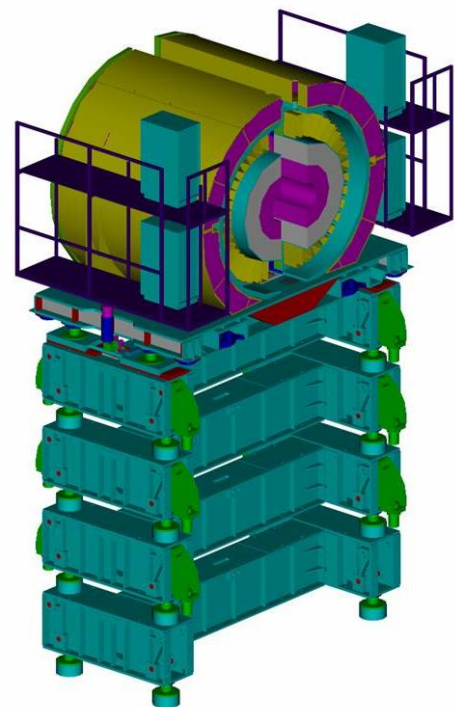
HB, HE: $|\eta| < 3$

- Barrel (HB) and Endcap (HE): Cu/Scintillator
- Forward (HF): Fe/Cerenkov(fiber)
- High granularity: $\Delta\eta \times \Delta\phi$
 - 0.087 x 0.087 (barrel)
 - 0.087 - 0.35 x 0.087 - 0.175 (endcap)
 - 0.152 - 0.3 x 0.175 (HF)
- 5.15 interaction lengths at $\eta=0$
- Dynamic range: 5 MeV-3 TeV

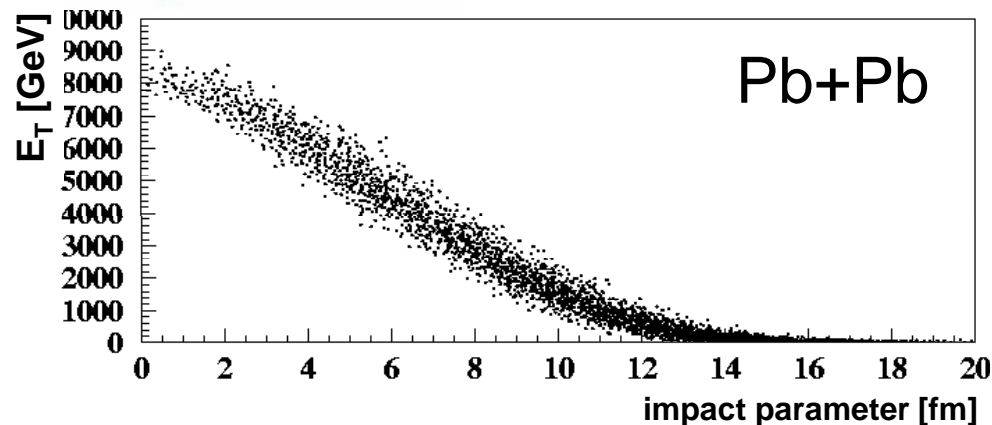


Centrality and forward detectors

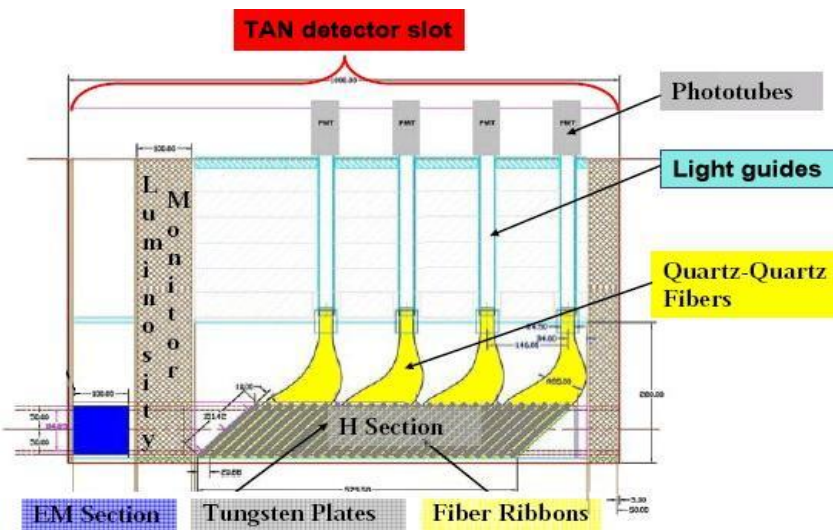
Centrality (impact parameter) determination is needed for physics analysis



Energy in the forward hadronic calorimeter



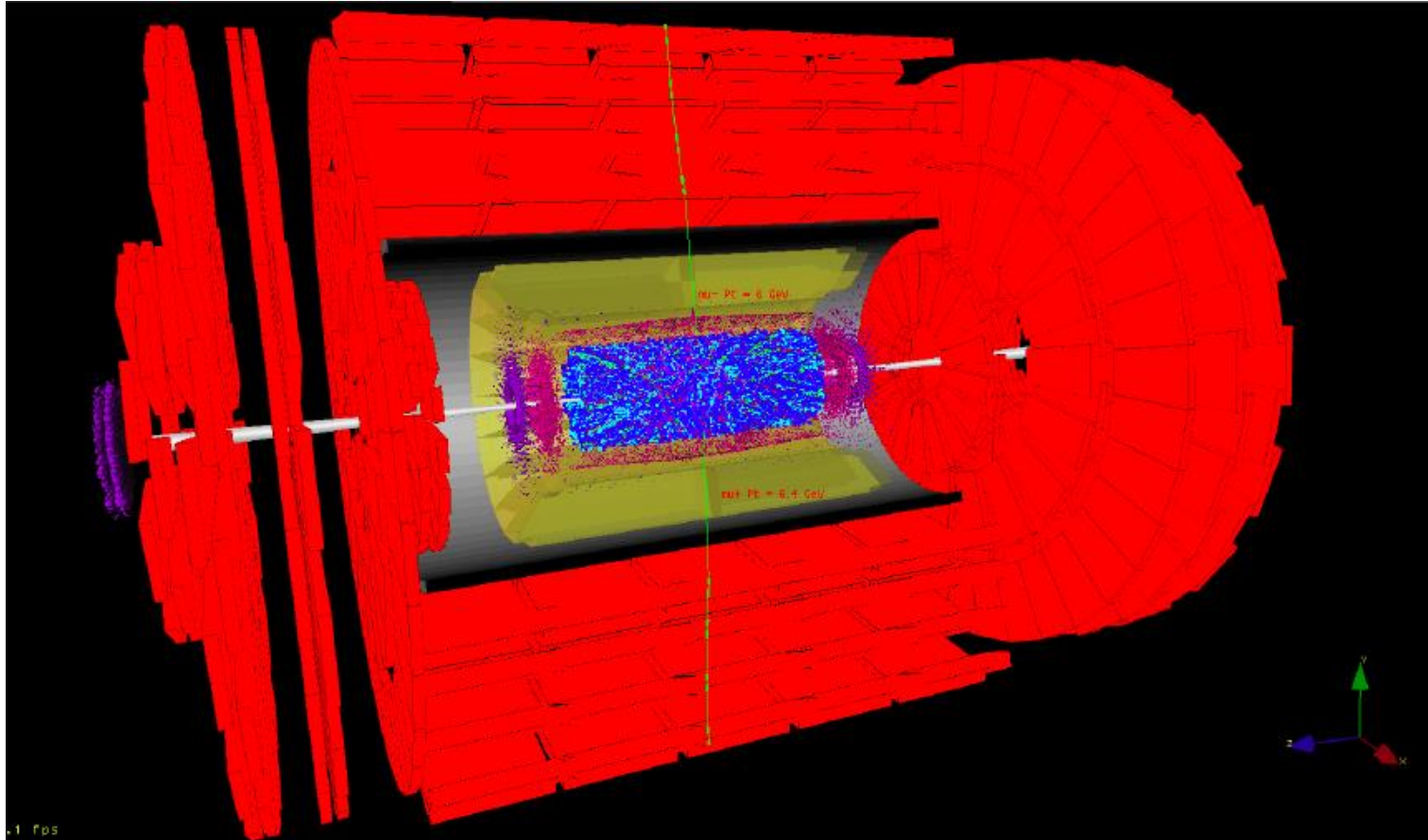
Zero Degree Calorimeter



- ▶ Tungsten-quartz fibre structure
- ▶ electromagnetic section: $19\lambda_0$
- ▶ hadronic section $5.6\lambda_0$
- ▶ Rad. hard to ≈ 20 Grad (AA, pp low lum.)
- ▶ Energy resolution: $\approx 10\%$ at 2.75 TeV
- ▶ Position resolution: ≈ 2 mm (EM sect.)

CMS-HI
Physics capability

Pb+Pb event ($dN/dy = 3500$) with $\Upsilon \rightarrow \mu^+\mu^-$

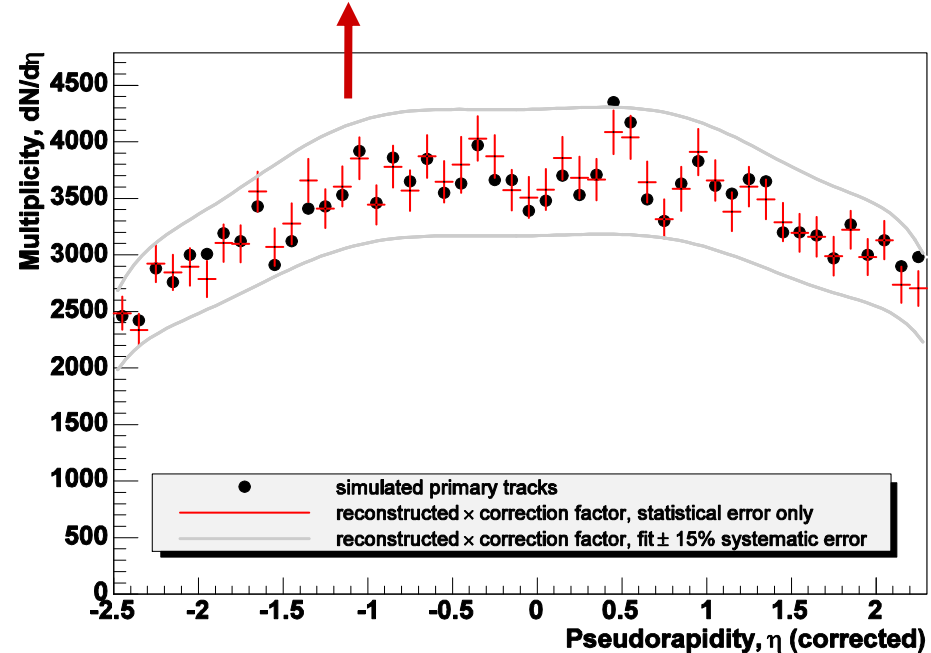
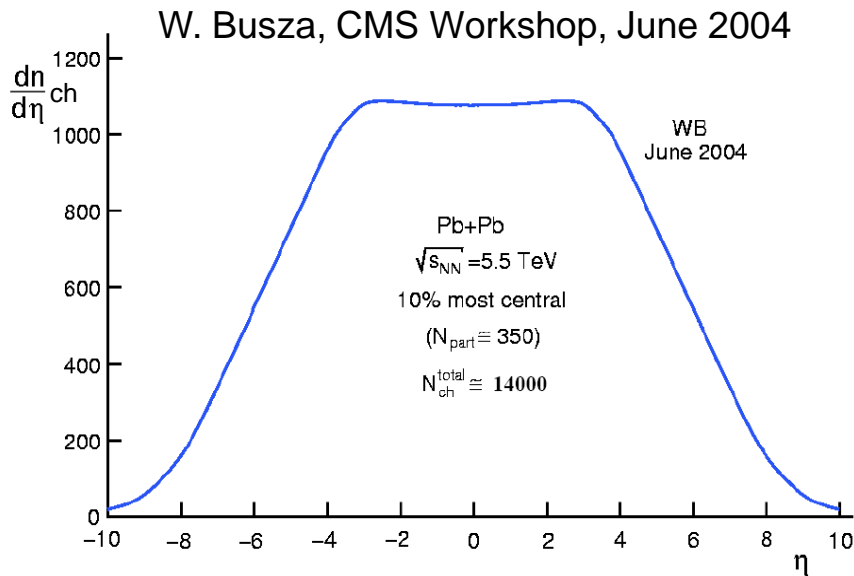


**Pb+Pb event display: Produced in pp software framework
(simulation, data structures, visualization)**

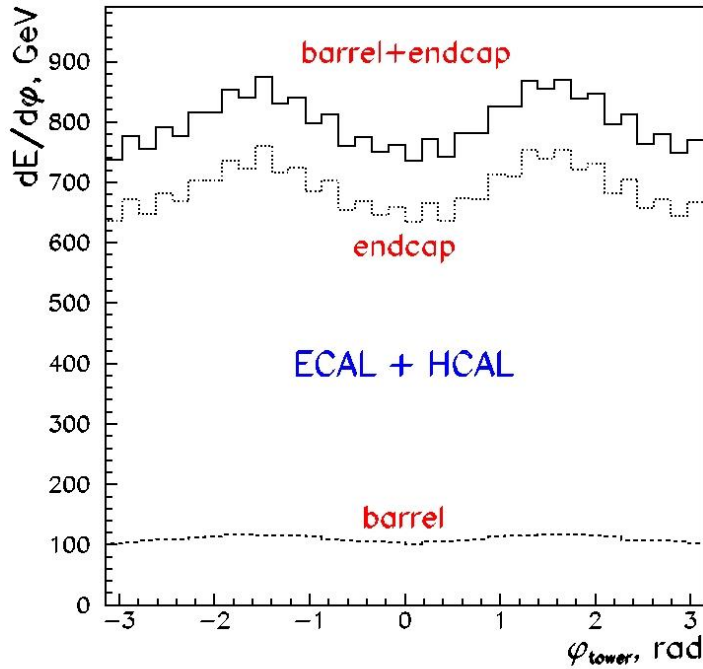
Will be one of the first results, important for initial energy density, saturation, detector performance etc.

- high granularity pixel detectors
- pulse height measurement in each pixel reduces background
- Very low p_T reach, $p_T > 26$ MeV (counting hits)

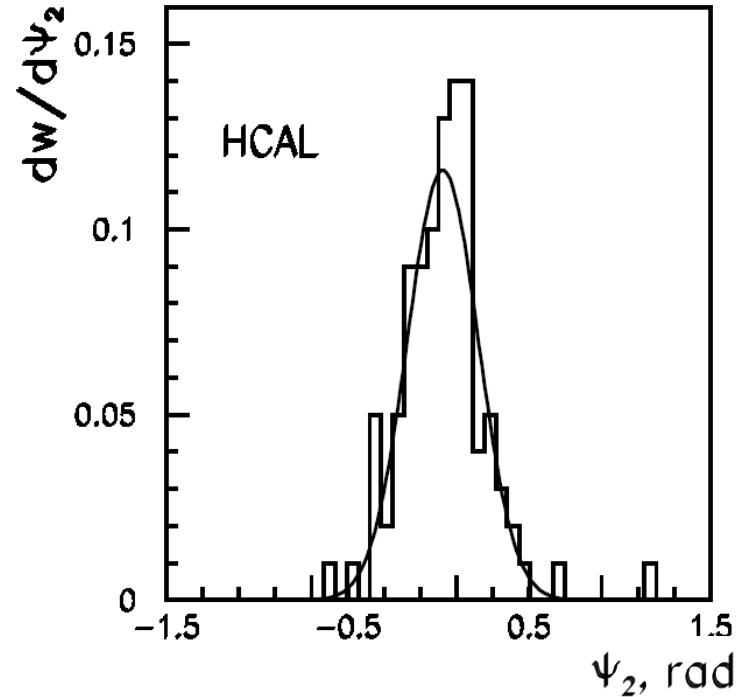
Simple extrapolation from RHIC data



Muon detection, tracking, jet finding performance checked up to $dN_{ch}/d\eta = 5000$



CMS Note 2003-019

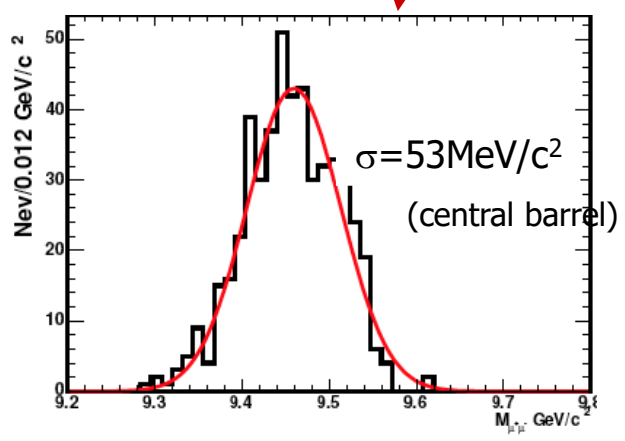
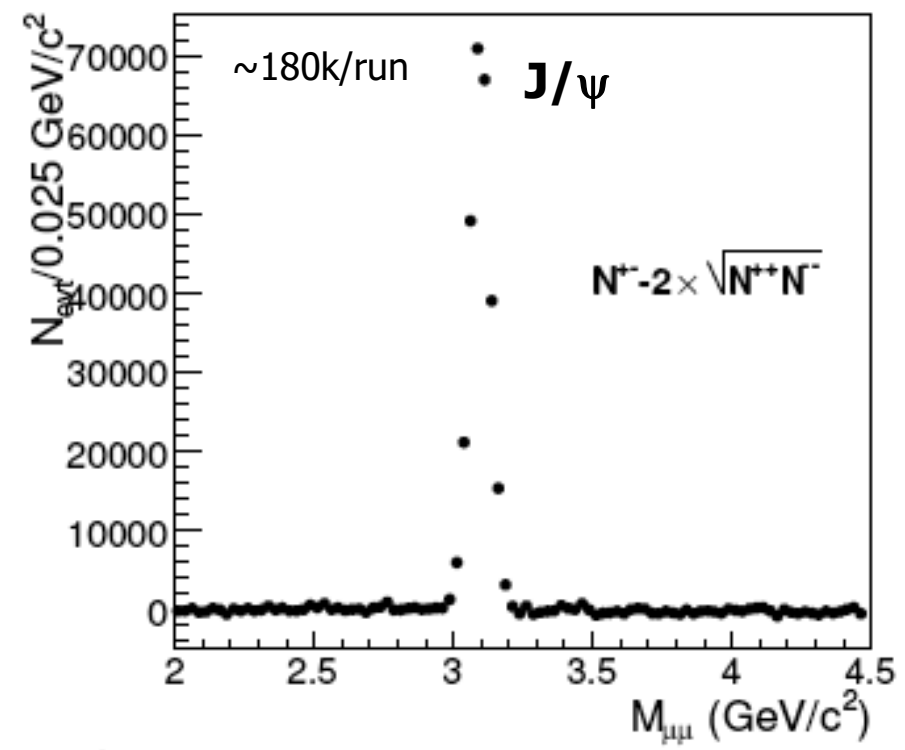
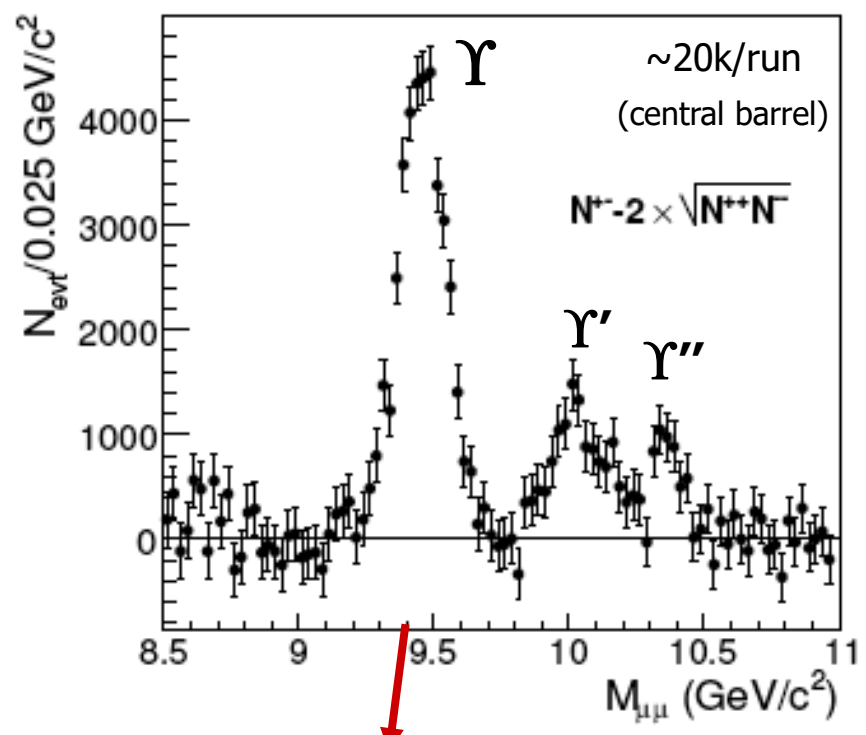


CMS Note 2003-019

- **Reaction plane reconstructed via energy deposited in ECAL+HCAL: $\sigma=0.12$ rad**
- **Left: reconstructed energy deposition in the barrel and endcap regions for electromagnetic and hadronic calorimeters as function of the azimuthal angle for $b = 6$ fm**
- **Right: difference between generated and reconstructed reaction plane angle for Pb+Pb collisions $b = 6$ fm**

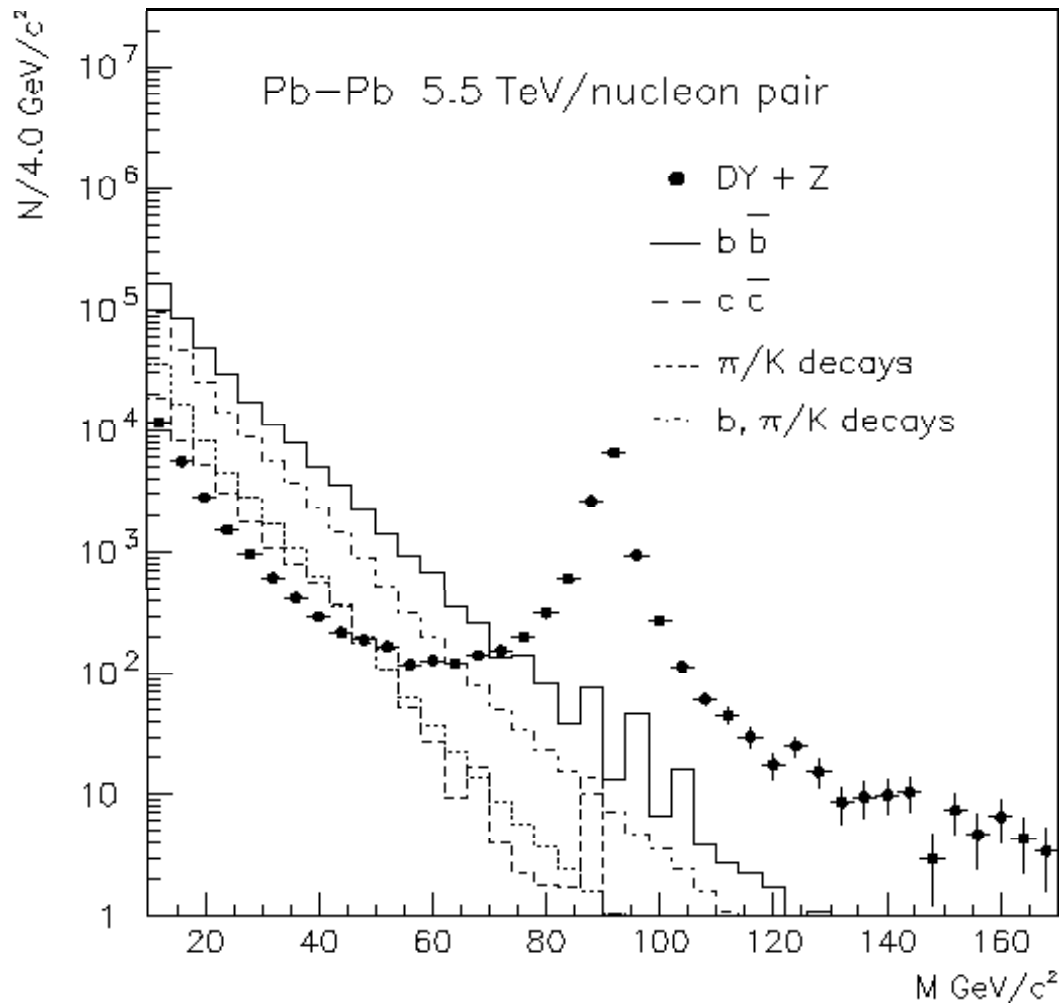
S. Petrushanko, 2003

Quarkonia: Υ and J/ψ



- Best J/ψ , Υ mass resolution at LHC.
- Unique separation of $\Upsilon(1S)$, $(2S)$, $(3S)$ at $|\eta| < 2.5$

Kodolova, Bedjidian, 2006



Kvatadze, 1999

- **Z $\rightarrow \mu\mu$ reconstructed with high efficiency by design**
 - A probe to study nuclear shadowing
 - Unaffected reference for jet-tagging studies
- **Dimuon continuum dominated by b decays**
 - Heavy quark energy loss
- **High statistics**
 - $O(10^4)$ Z per nominal HI run

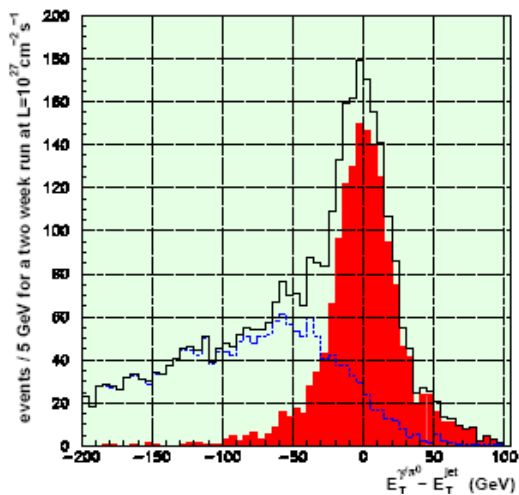
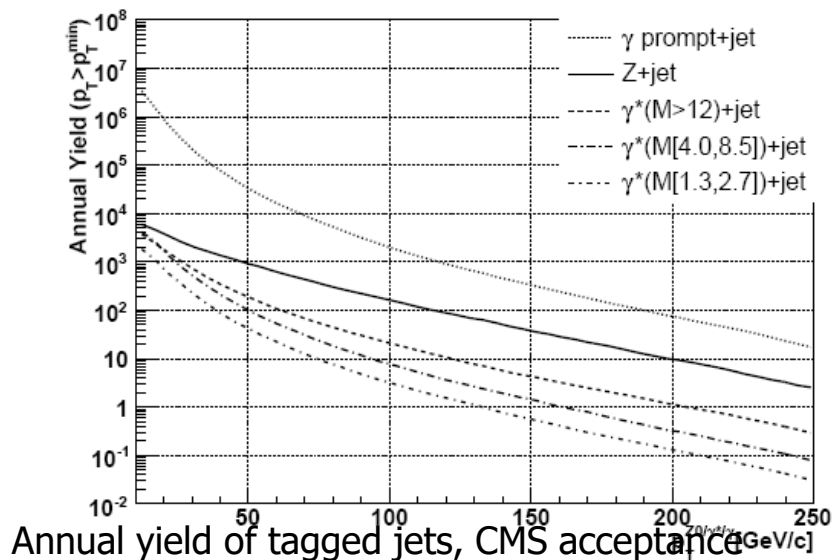
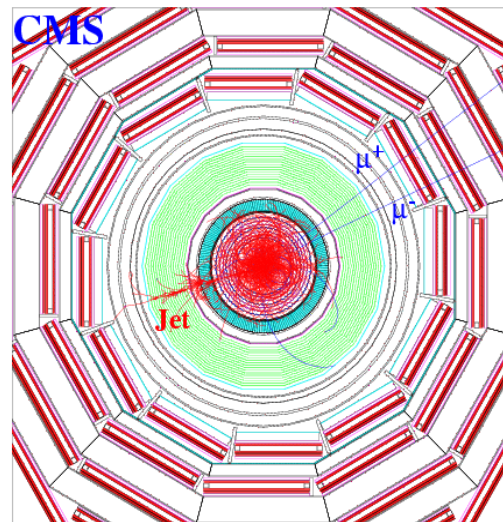


Tagged jets: jet+ γ , Z/ γ^* - $\mu\mu$

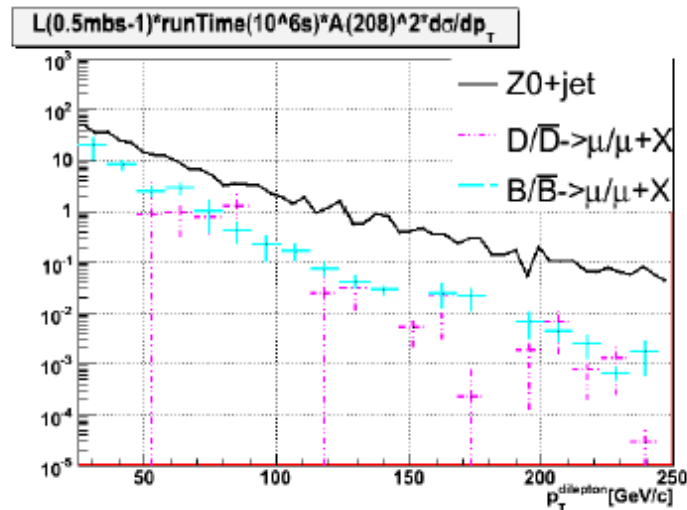


Z+jet event in the Heavy Ion collision

$dN_{ch} / dY = 5000$



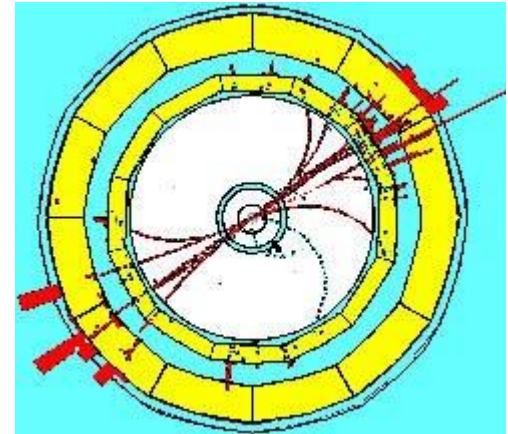
Jet+ γ $E_{Tjet} > 120 \text{ GeV}/c^2$



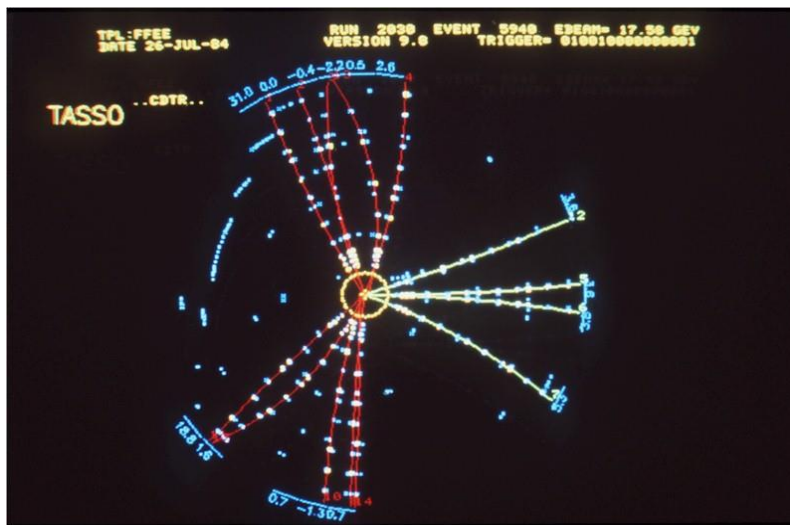
Jet+ $\mu^+\mu^-$ $81 \text{ GeV}/c^2 < M_{\mu\mu} < 101 \text{ GeV}/c^2$

***Introduction to Jet
and Jet finders***

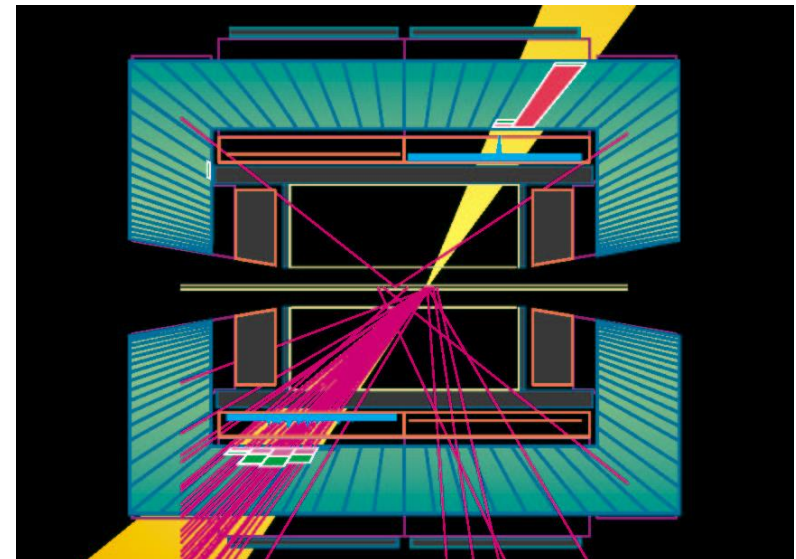
- Collimation of final state particles in a certain direction in collision events
- Particle in a jet has little transverse momentum along with the jet direction.



LEP/ALEPH

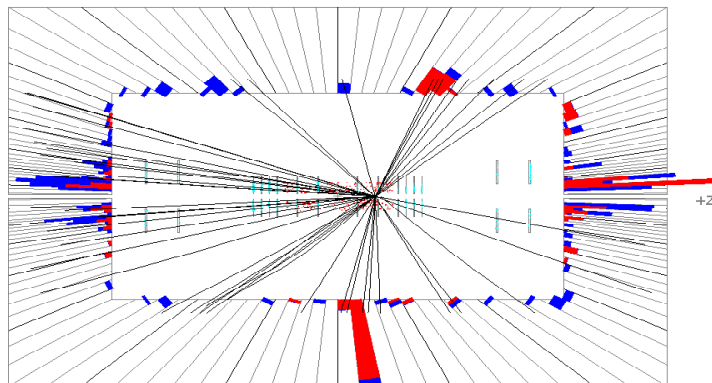
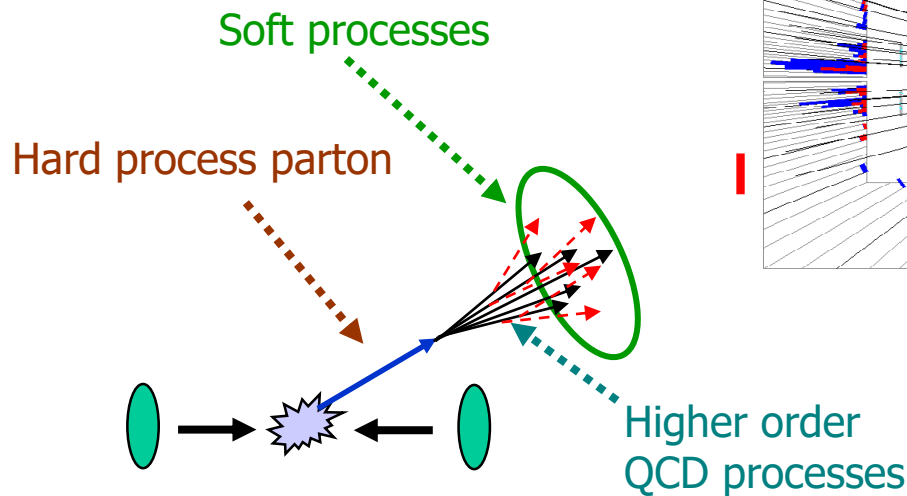


PETRA/TASSO

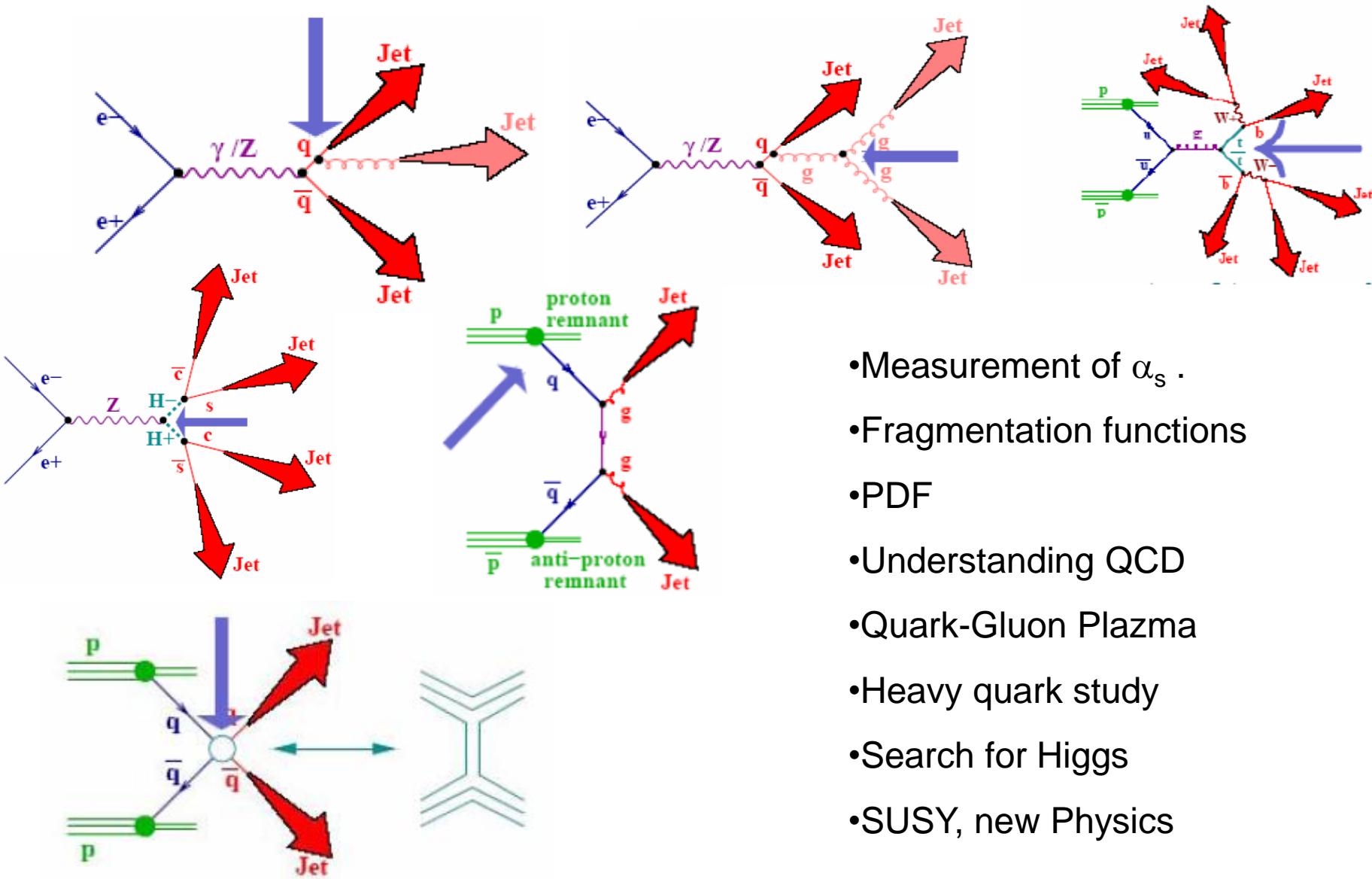


Tevatron/CDF

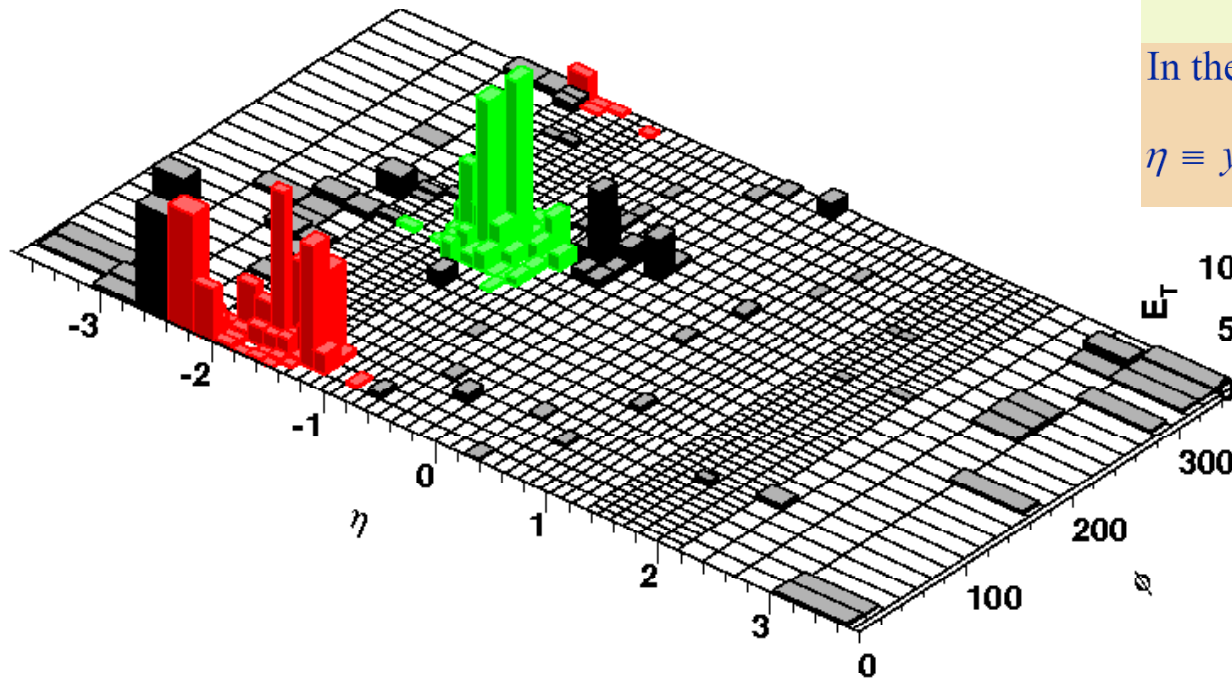
- Parton \rightarrow fragmentation / hadronization
- Charged particles \rightarrow Trackers
- Charged and Neutrals \rightarrow ECAL & HCAL



QCD partons \rightarrow jets of hadrons \rightarrow detector signals



- Measurement of α_s .
- Fragmentation functions
- PDF
- Understanding QCD
- Quark-Gluon Plazma
- Heavy quark study
- Search for Higgs
- SUSY, new Physics



$$y \equiv \frac{1}{2} \ln \frac{E + p_z}{E - p_z} = \frac{1}{2} \ln \frac{1 + \beta \cos \theta}{1 - \beta \cos \theta}$$

In the limit $\beta \rightarrow 1$ (or $m \ll p_T$) then

$$\eta \equiv y|_{m=0} = \frac{1}{2} \ln \frac{1 + \cos \theta}{1 - \cos \theta} = -\ln \tan \frac{\theta}{2}$$

- **The best jet finder is human eyes**
- **Computational approach is natural and mandatory**



Various jet finding algorithms



- **Cone algorithm**
 - **Iterative cone algorithm**
 - **Sliding window algorithm**
 - **Mid-point cone algorithm**
 - **K_T algorithm**
 - **FastJet algorithm (K_T with CGAL)**
 - **Mulguisin algorithm (ATLAS JetFinder Library)**
 - **proposed and by the man you are looking at**
- **Systematic study on various jet-finders at the LHC energy is important**

- Simple and intuitive.
- Cone seed starts with the maximum E_T cell
- consider all cells within R

- Cone center $\rightarrow (\eta^C, \phi^C)$

- Cell i is

$$\sqrt{(\eta^i - \eta^C)^2 + (\phi^i - \phi^C)^2} \leq R$$

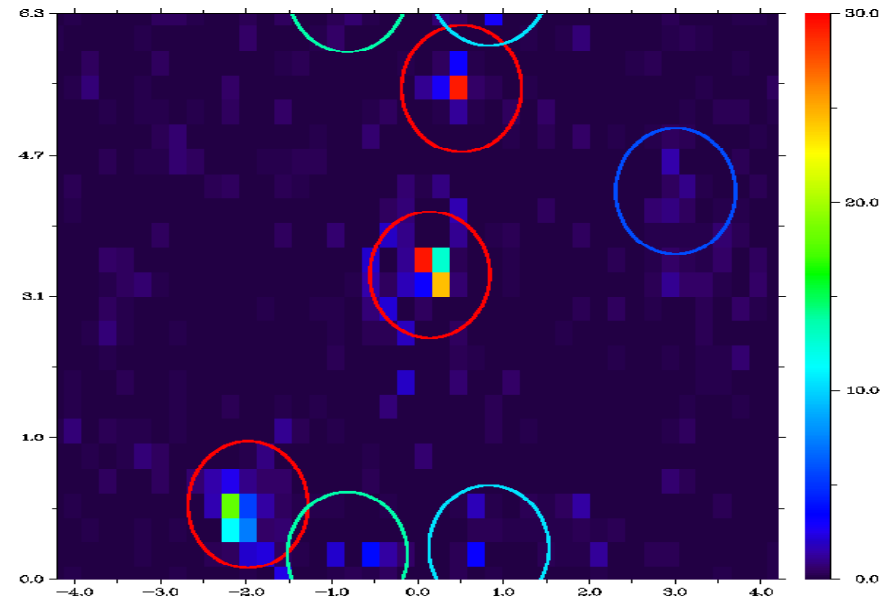
- Energy of cone

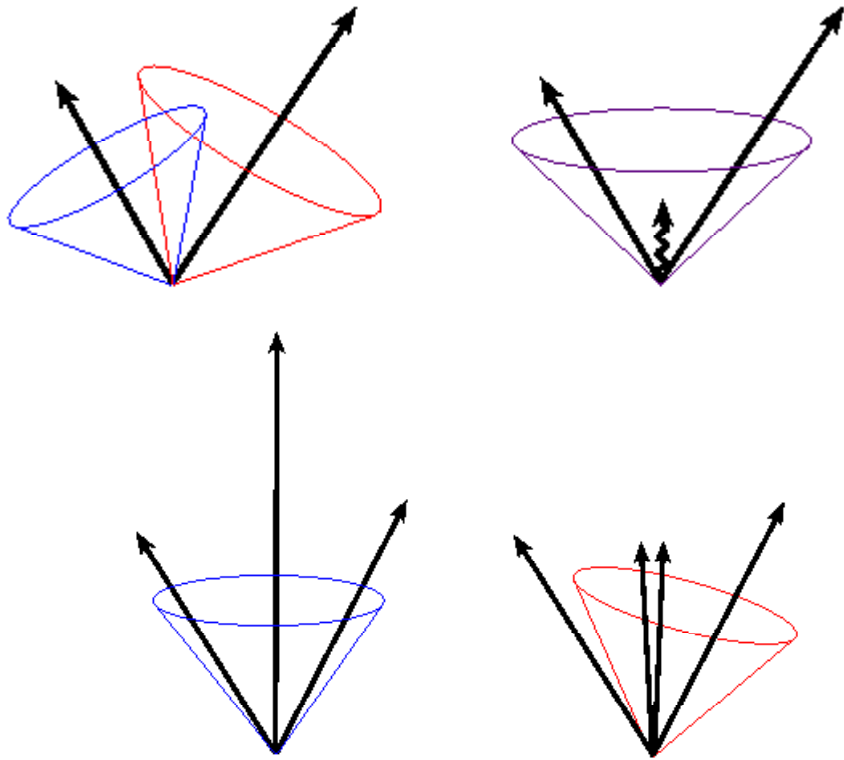
$$E_T^C = \sum_{i \in C} E_T^i$$

- Energy weighted center of jet

$$\bar{\eta}^C = \sum_{i \in C} E_T^i * \eta^i / E_T^C ; \bar{\phi}^C = \sum_{i \in C} E_T^i * \phi^i / E_T^C$$

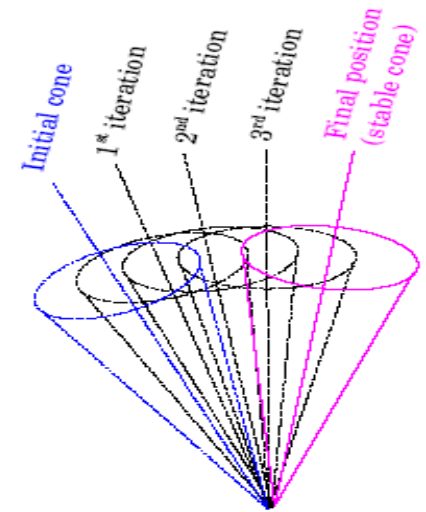
- overlapping jet, sharing, etc.



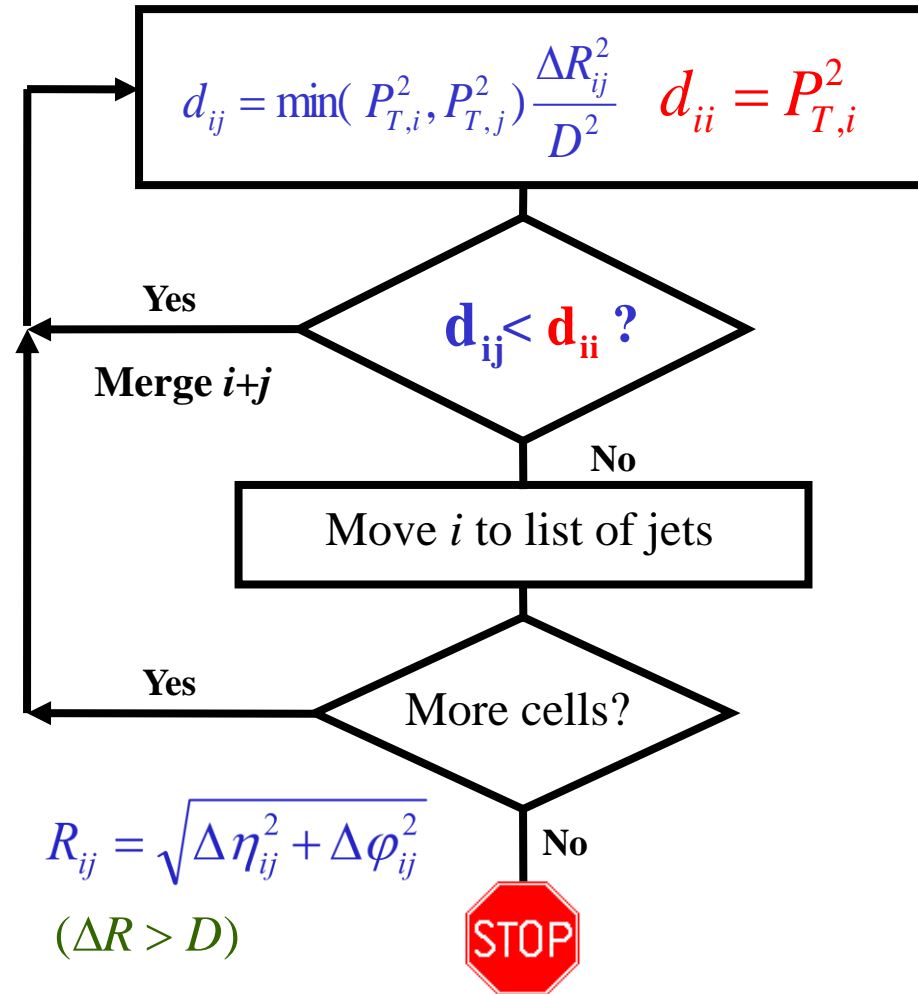


- Cone algorithm → infrared unsafe, collinear unsafe
- Most of time cone center is not jet center (E_T weighted) → Re-center cone, and update cell list
- CPU $\sim O(N^2)$

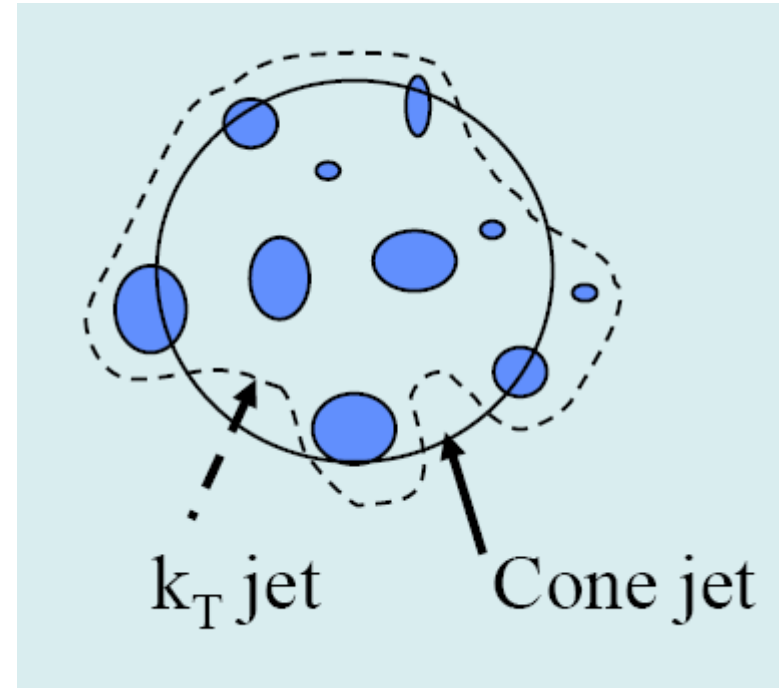
- Cone merge, separation, recalculating the jet center, etc. are necessary → various cone variants, such as Mid-point, Iterative, Double cone, etc..



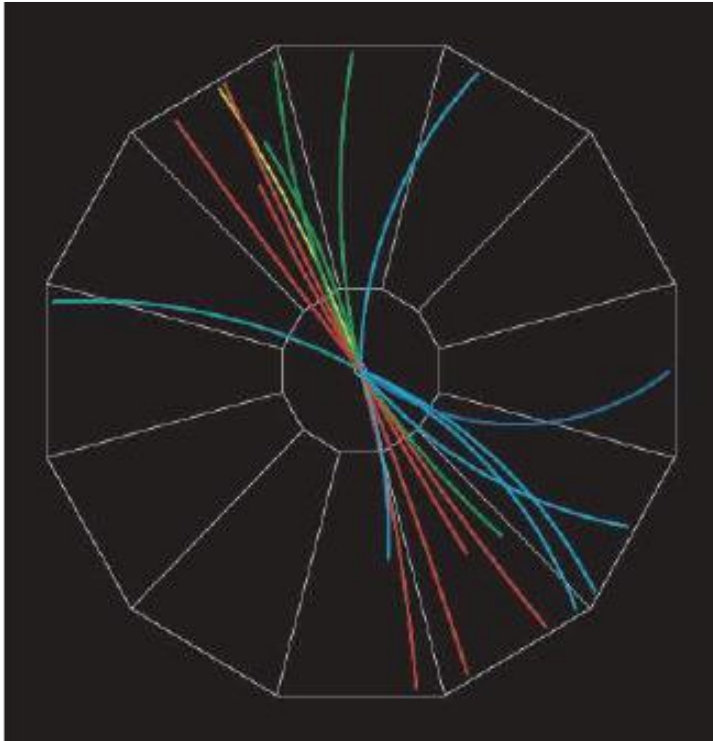
- **Minimize Invariant mass \rightarrow Looks like to have theoretical basis, but not really.**
- **No overlapped jets, every parton, particle, or detector cell is assigned to a jet**



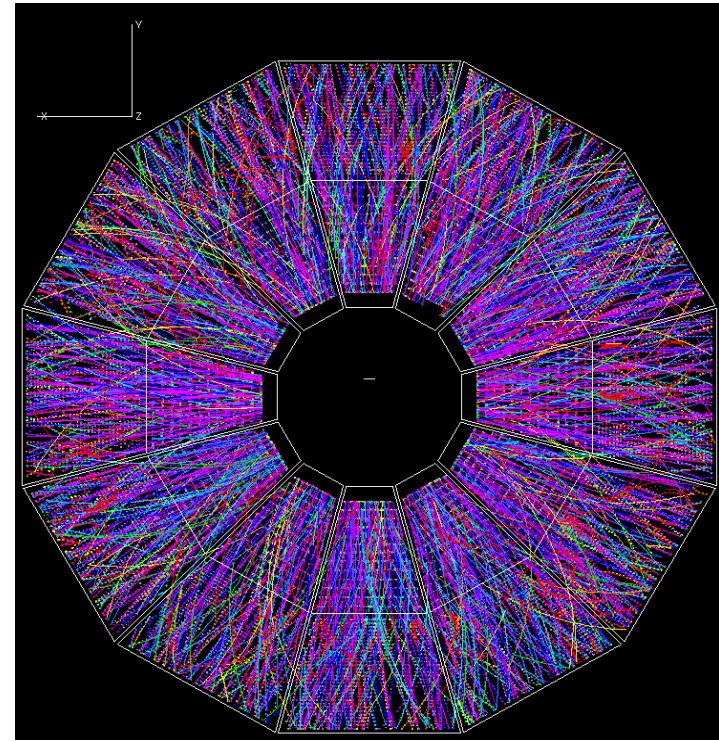
- **Infrared, Collinear safe!**
- **Less sensitive to hadronization effects**
- **Not easy to calibrate jet energy compared with Cone jet**
- **Big CPU consumption**
- **CPU $\sim O(N^3)$**
- **No way in the case of trackers with LHC HI program**



p+p @ $\sqrt{s} = 200$ GeV



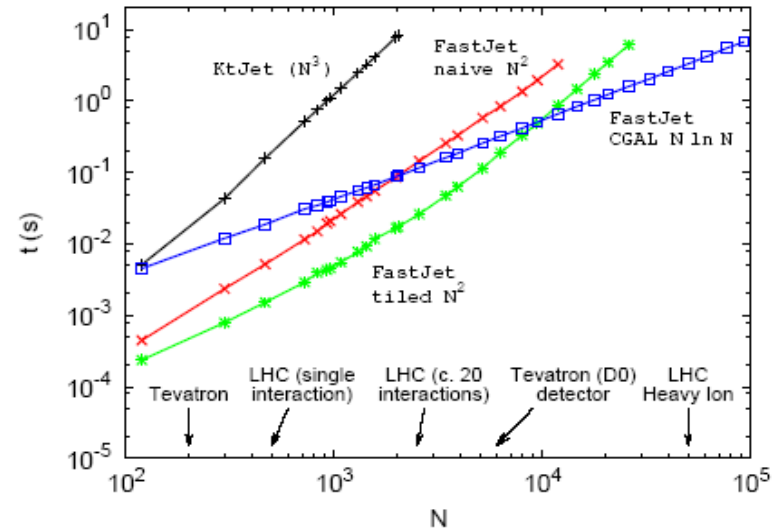
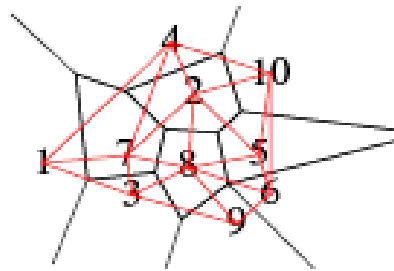
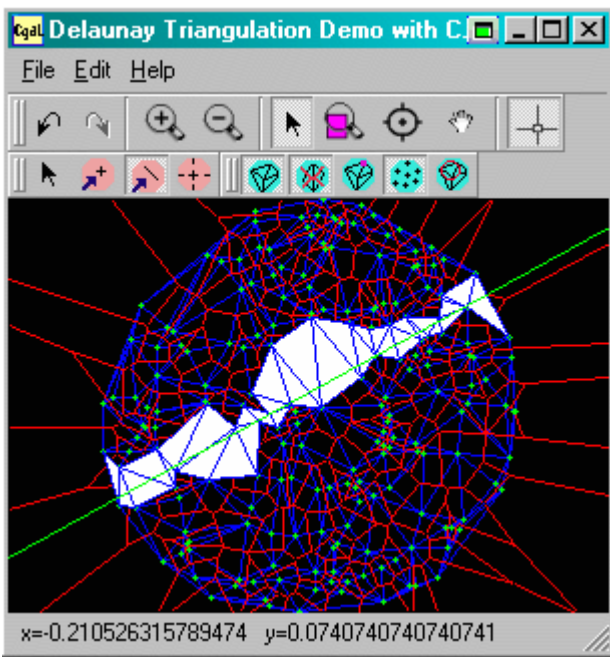
STAR Au+Au @ $\sqrt{s_{NN}} = 200$ GeV



Special care is needed to find jet in HI program

Leading particle was considered as the Jet signal at RHIC

- M. Cacciari, G. Salaam hep-ph/0512210
- CGAL geometry package is used
- Extracting 3D model from point clouds using Delaunay triangulation algorithm



The only solution for LHC Heavy Ion ?



Mulguisin algorithm

Some successful stories, now resurrect with C++

ATLAS Internal Note
PHY/2012
23rd April

Consequences of Baryonic R-parity Violation for Measurements of SUSY Particles using the ATLAS Detector



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Abstract

The discrete R-parity symmetry in SUSY models makes the lightest supersymmetric particle (LSP) stable. It therefore escapes detection and gives the traditional SUSY signature of missing transverse energy. There is, however, no fundamental symmetry to protect R-parity and it may, therefore, be violated naturally. If R-parity is violated, the LSP decays and the missing transverse energy signal decreases significantly or disappears. The final state signatures for SUSY change drastically in such scenarios. This note investigates the experimental consequences of baryonic R-parity violation that lead to the decay of the LSP into three jets. We examine the phenomenology defined by the minimal supersymmetric SU(5) (mSUGRA) model, with the values of the fundamental parameters $m_0 = 100$ GeV, $m_{1/2} = 200$ GeV, $A_0 = 0$ GeV, $\mu > 0$ and $\tan\beta = 2.1$ (this is the so-called Point 5). The possibility to observe SUSY and reconstruct the LSP and other SUSY particles is demonstrated. It is shown that for this model several precise measurements can be performed that greatly constrain the fundamental parameters of the SUSY model. Potential SUSY discovery and reconstruction of the LSP are also discussed for a few other SUSY models (Points 1.2,3 and 4).

¹jesper@particle.kth.se

Figure 2: A calorimeter map in $\eta - \phi$ where the size of the boxes are proportional to the energy in the cell. Circles are jets reconstructed with the 'cone' algorithm and isolated leptons. The numbers in the circles are the reconstructed transverse jet momenta in GeV. The larger digits are for jets that are used in the χ^2 reconstruction (discussed in section 8.2). Note that the forward calorimeters, $|\eta| > 3.2$, are not included. The calorimeter cells in the dashed square are shown zoomed in figure 4.

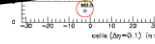


Figure 3: The 'cone' algorithm reconstructs jets by forming a cone of fixed size, around an initiator cell containing the maximum energy. The procedure for finding jets is as follows. Cells with transverse energy greater than a threshold ($E_{T,cell} > 1.5$ GeV), in order of decreasing E_T , are taken as possible initiators of clusters and cells within ΔR are included in the cluster. Clusters are formed until there are no initiator cells left. If two jets are overlapping, the energy in shared cells is divided between the two clusters weighted by the jet energy. After this sharing the jet directions are not recomputed in the analysis presented here.

Figure 4: The 'mulguisin' algorithm [24] has a flexible cone size with a minimum size here called resolution (R_0). For this analysis $R_0=0.25$ is used. Reconstruction of jets is an iterative procedure:

1. Find the maximum E_T cell and define it as the first cluster. Set initial cluster size to R_0 .
2. Find the next cell in order of decreasing E_T .

¹Many of these files have been included in later releases of ATLASFT. ²Implemented in software package BADCORE. ³The name originates from an old Korean tale about ghosts living in a sea. (mulgu=monster, sin=ghost)

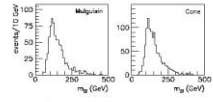


Figure 19: The χ^2 reconstructed with the cone and 'mulguisin' jet finder.

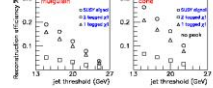


Figure 20: The reconstruction efficiency for $\chi^2 \rightarrow jjj$ decays as a function of the jet threshold for the 'mulguisin' and 'cone' jet finder.

mass distribution of the 3-jet combinations of the SUSY for a threshold above 20 GeV for the 'cone' algorithm. The 'mulguisin' algorithm is less sensitive to the jet threshold and was therefore chosen for the results presented in this note. It is interesting to note that if a stricter cut, $\Delta R_{j,j} < 10$ GeV, is used the reconstruction efficiency is better for a jet threshold of 17.5 GeV than for 15.0 GeV. The nominal jet threshold used in this analysis is 17.5 GeV. Reconstruction of jets as soft as this should not be a problem during low luminosity operation, but, if for any reason the jet threshold needs to be raised, the rate would be altered accordingly. The loss of signal events ≥ 20 . Clearly, a more detailed study, beyond the scope of this reconstruction efficiency for $\chi^2 \rightarrow jjj$ decays. In particular, need for reconstruction of high $p_T \rightarrow jj$ decays [24, 25], to reconstruct the χ^2 decay without explicitly require three jets.

Less sensitive to Jet threshold cut

Searching for Graviton Resonances at the LHC

M. Palmer, Cambridge

- Extra dimension models can contain massive graviton resonances
- In some models, these resonances are well spaced in mass
- With universal couplings, the resonance could be detected in many channels (jet-jet, lepton-lepton, ZZ, WW etc)
- Model independent analysis: R-S type model used as test case.
- Graviton mass given by:

$$m_1 = kv_1 \exp(-k r_c \pi) = 3.83 \frac{k}{M_{Pl}} \Lambda_{*}$$

Where: $0.01 \leq \frac{k}{M_{Pl}} \leq 1$

- Cross-section $\propto (k/M_{Pl})^2$

Reconstruction Method

Require 1e or 1 μ and 2 or more jets with $|\eta| < 2$

Pt cuts:

- Pt miss > 50 GeV
- Pt lepton > 100 GeV
- Pt jets > 50 GeV

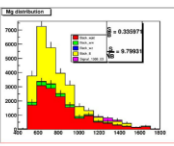
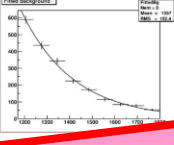
Pz v:

- Find by M_W constraint
- Gives 2 solutions
- Take average
- Require Pt W from 1 and v > 200 GeV

Reconstruct W from jets:

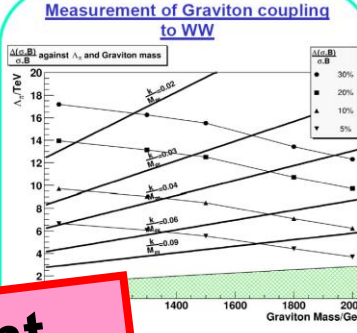
- Use Mulguisin algorithm to find jets
- Require high p_T jets

Results

- Background subtraction result shown.
- Will generate more background to check this.

Measurement of Graviton coupling to WW



Green hatched region is where width \geq resolution (Analysis assumes width $<$ resolution)

***CMS-HI Korean Physicists
lead the jet finder activity***



Brief history and now



- **2006 summer:** We have visited CERN and started **implementation of Jet Finding Library** in HIROOT.
- **FastJet** (M. Cacciari et al), a promising Kt substitute, was needed to be implemented.
- **2006 fall:** CMS-KR Heavy-Ion team was formed. ~5 PhDs and ~10 graduate students from 4 institutions
 - **Univ of Seoul, Chonbuk Nat'l Univ, Korea Univ. Yonsei Univ.**
- CMS-HI convener made a visit to Korea to promote CMS-KR.
- **2007 now:** 6 graduate students are working with HIROOT/CMSSW
 - 2 are writing their theses for Master degree with Jet finding
 - 2 are working with MC/muon for their PhD degree
 - 2 are doing more computing/grid elaborated work

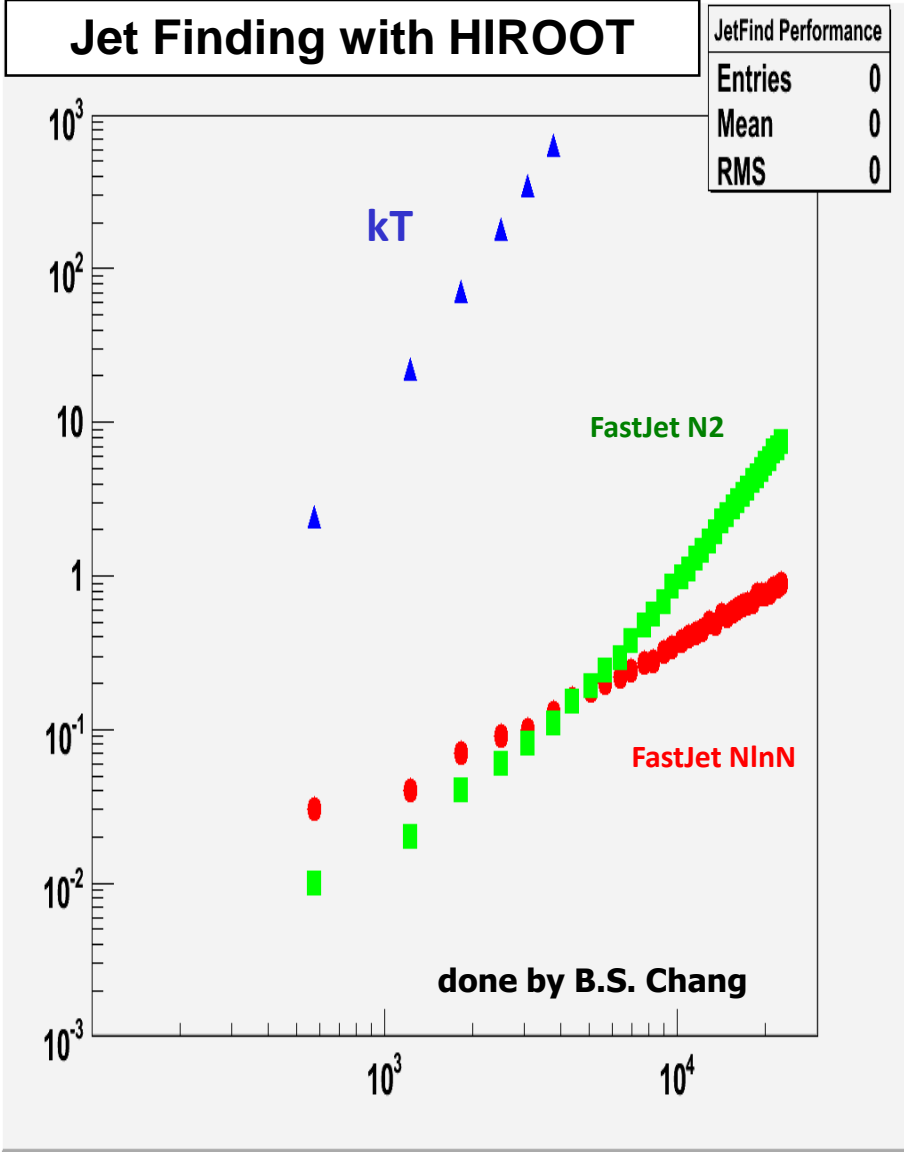
- **3 Jet algorithms were implemented and tested**
- **THISimpleKtJetFinder** → from a historical FORTRAN version
- **THIFastJetFinder** → from M. Cacciari's release
- **THIMulguisinJetFinder** → MGS algorithm from ATLAS Jet library
- **Job assignment:**
 - **Inkyu** → hiroot coding, library implementation
 - **BS Chang, KS Kim** → Jet study, benchmark
 - **DH Moon, JH Kim** → MC generation (HIJING, HYDJET)
 - **JW Park** → Heavy-Ion Data Grid preparation



Benchmark test with HIROOT



- **Use CMS-HI Tier2 of UoS**
- ***HIROOT + CGAL 3.2.1 patch, fastjet 2.0.0***
- ***DATA : generated with HYDJET / HIROOT***
 - **Multiplicity $\sim E^n$ where $n=1,2,3,4$**
 - **4 Hydjet Type(THIHydjet::EydjetSel)**
 - **25 Energy Level (100~14000)**
 - **400 runs each 100 events**
- ***Jet Finders for benchmark : 6 finders (JetTh=30GeV)***
 - **IterativeCone with/without Seed Threshold**
 - **SimpleKt**
 - **FastJet(N2), FastJet(NlnN)**
 - **Mulguisin**



M. Cacciari's publication

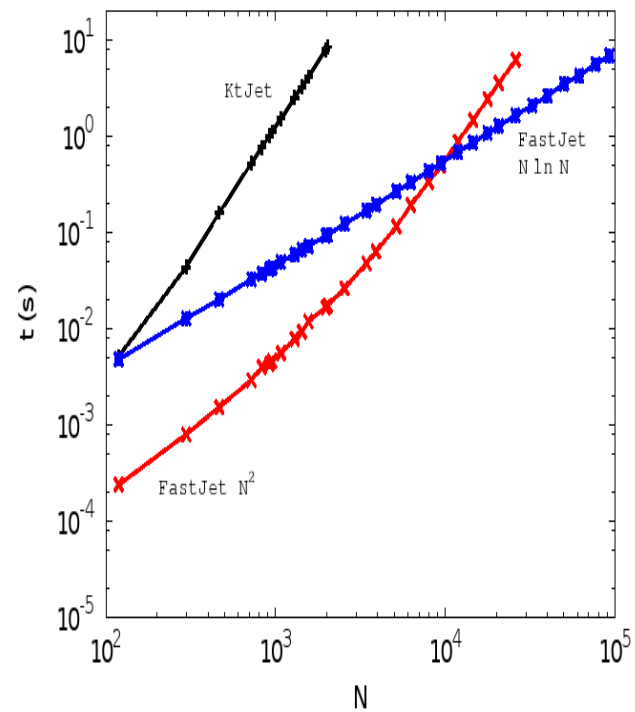


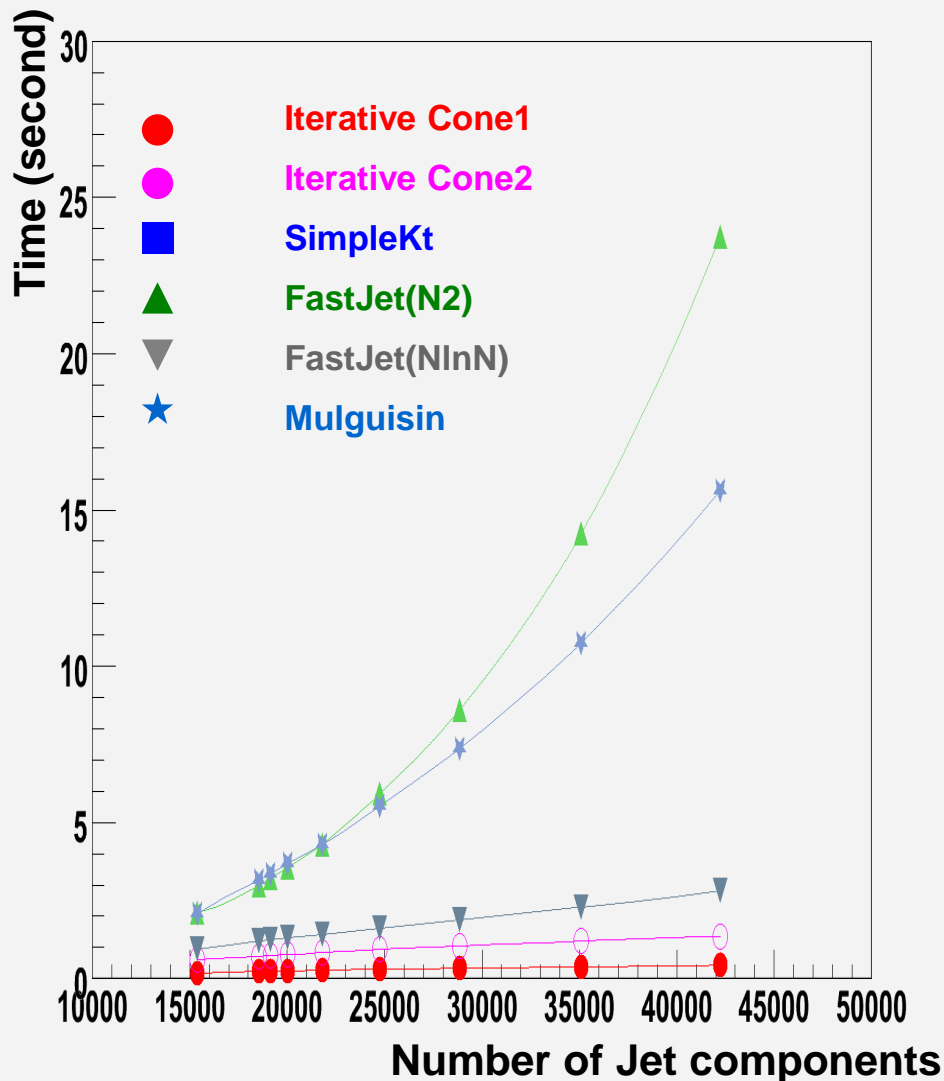
Figure 2: The running times (on a 3 GHz Pentium 4 processor with 1 GB of memory, 512 kB of cache, and version 3.4 of the GNU g++ compiler) of the KtJet [22] and FastJet implementations of the k_t -clustering jet-finder versus the number of initial particles. Different values of N have been obtained by taking a LHC dijet event with $p_t \simeq 60$ GeV and adding on variable numbers of minimum bias events. Both kinds of events have been simulated with Pythia 6.3 [28].



Benchmark: Particle level study



Time vs JetComponents

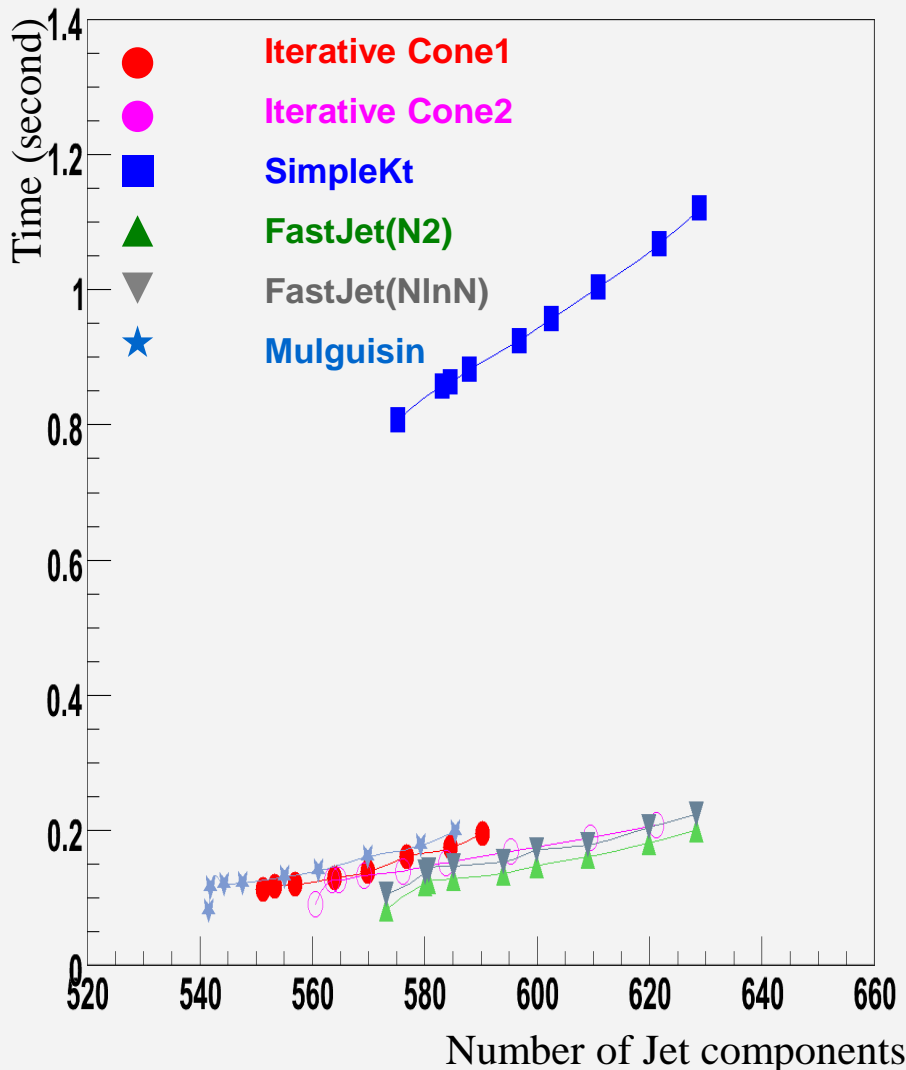


- KT algorithm fails with high multiplicity
- Cone is faster than FastJet
- FastJet (N2) and MGS show $O(N^2)$ behaviour
- FastJet (NlnN), i.e. with CGAL, show fast result, thus can be a substitution of KT
- Not a real case!!

done by B.S. Chang

Benchmark: Calorimeter level study

Time vs JetComponents

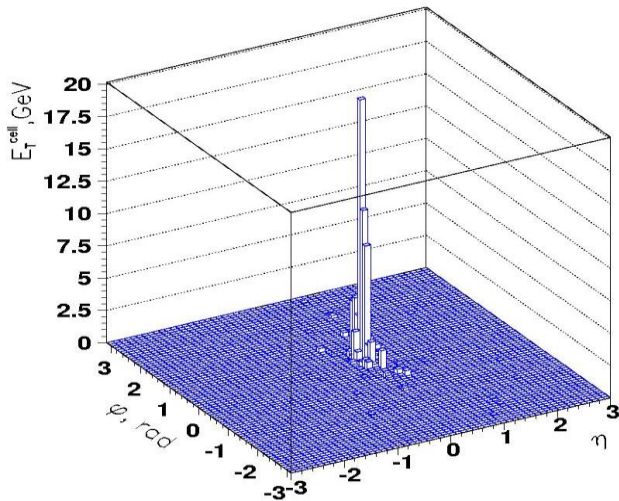


- Calorimeters are applied
- # of cells (or towers) are limited (<2000)
- KT works but still slow $\rightarrow O(N^3)$
- FastJet, Cone, MGS show all very similar speed
- Now it's matter of performance & resolution.

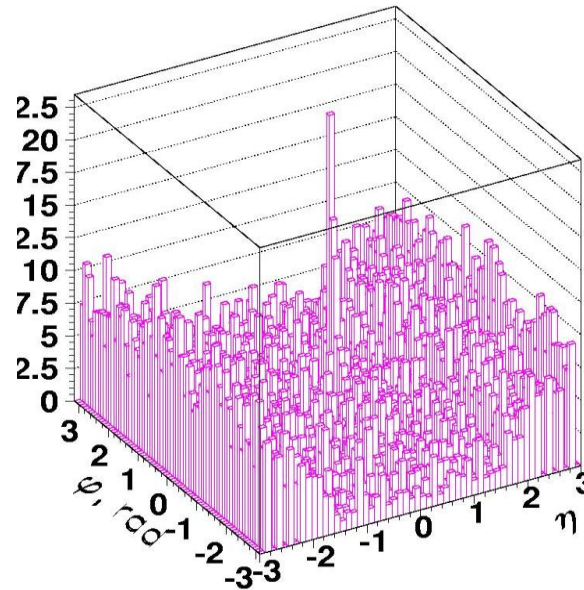
Jet Finding at CMS-HI

Jet $E_T \sim 100\text{GeV}$, Pb Pb background $dN_{ch}/dy \sim 5000$

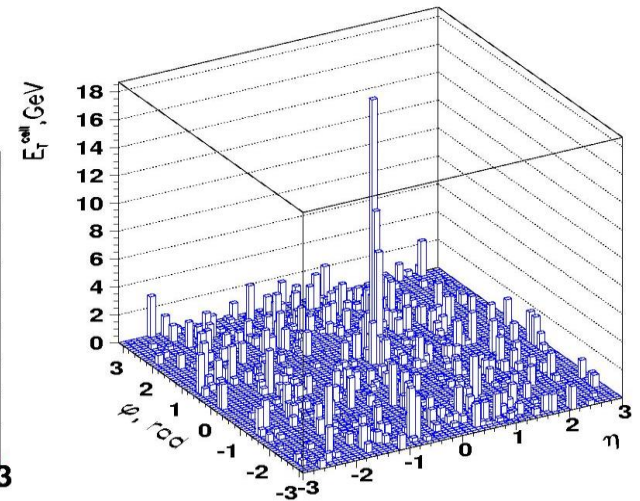
Jet in pp after pileup subtraction

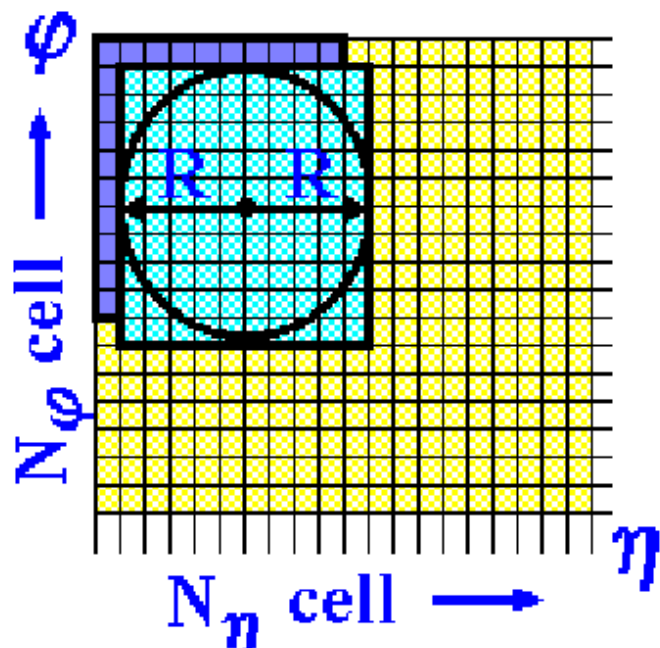


Jet superimposed on Pb Pb background



Jet in Pb-Pb after pileup subtraction





Event-by-event background subtraction:

- Calculate $\langle E_T^{\text{Tower}}(\eta) \rangle$ and $D^{\text{Tower}}(\eta)$ for each η ring

- Recalculate all E_T^{Tower} tower energies:

$$E_T^{\text{Tower}} = E_T^{\text{Tower}} - E_t^{\text{pile-up}}$$

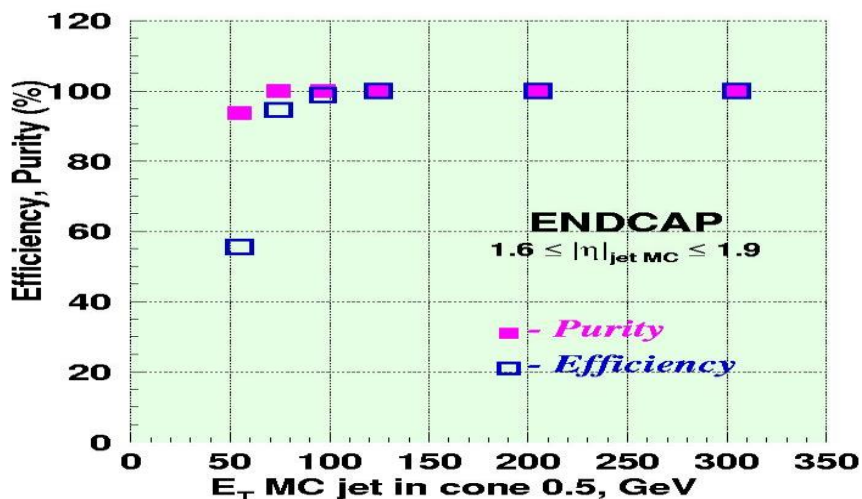
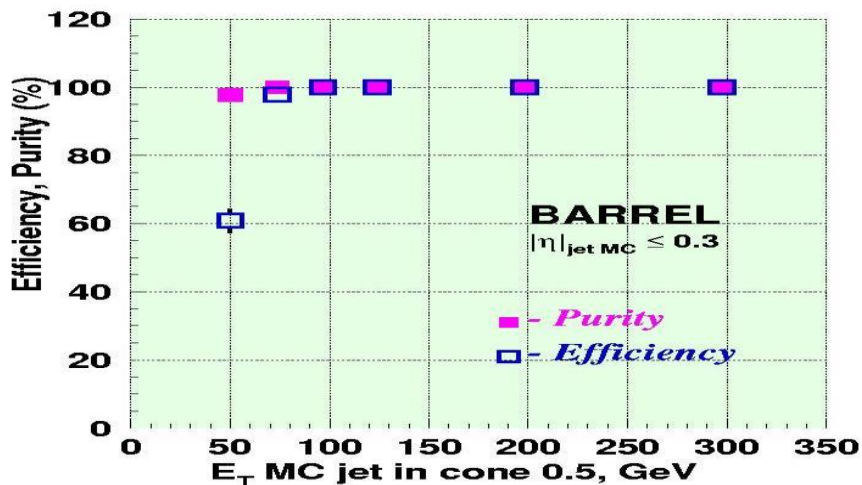
$$E_t^{\text{pile-up}} = \langle E_T^{\text{Tower}}(\eta) \rangle + D^{\text{Tower}}(\eta)$$

- Negative tower energies are replaced by zero

- Find Jets with $E_T^{\text{jet}} > E_t^{\text{cut}}$ using standard iterative cone algorithm using new tower energies
- Recalculate pile-up energy with towers outside of the jet cone
- Recalculate tower energy with new pile up energy
- Final jets are found with the same iterative cone algorithm $E_T^{\text{Jet}} = E_T^{\text{cone}} - E_t^{\text{pile-up new}}$

Efficiency, Purity vs. Jet Energy

Reconstructing 50-300 GeV Jets in Pb-Pb background



- **EFFICIENCY**

- Number of events with true reco. Jets / Number of all generated events

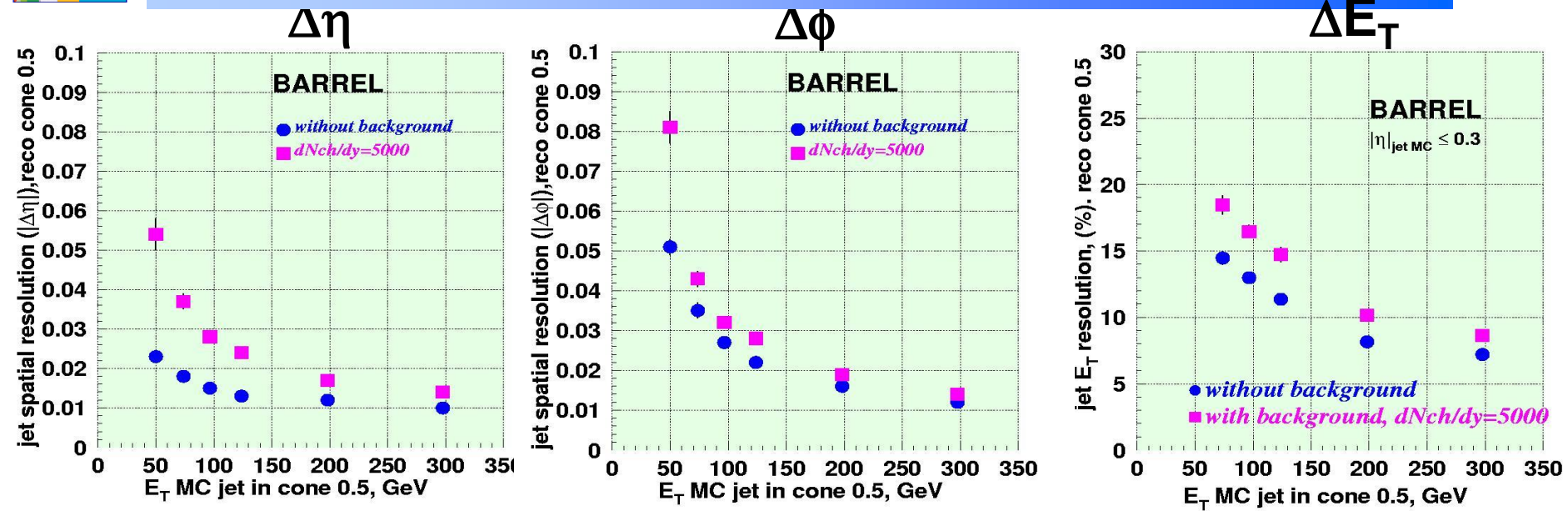
- **PURITY**

- Number of events with true reco. QCD Jets / Number of all reco. Jet events (true+fake).

- **Threshold of jet reco. $E_T > 30$ GeV.**

- **Above 75(100) GeV we achieve**

- 100% efficiency and purity in the barrel (endcap)
 - Unbiased



- The resolutions are degraded in Pb Pb collisions
 - η, ϕ better than size of calorimeter tower (0.087x0.087)
 - E_T resolution $\sim 16\%$ at 100GeV
- Expect further improvement by adding tracker information
 - p_T measurement of tracks is more precise than the response of the calorimeter
 - Recover charged tracks that are bent out of the jet cone by the magnetic field

Remarks & Summary



Heavy Ion Data generation and Grid



- **KU are working with HYDJET, HIJING with HIROOT / CMSSW + Muon package work**
 - **Study HYDJET and CMS MC generation with CMSSW**
- **E.J.Kim et al. have visited MIT in early Feb., and are setting now CMS-HI Tier2/3.**
 - **Learn MIT Tier 2 & d-Cache, operation, etc.**
- **Univ. of Seoul will invest \$0.2M for computing upgrade (2007 budget plan)**
 - **256 machines → Data storage configuration**
 - **64TB (mid 2007) → 128 TB (end 2007) → 256TB (goal)**
- **New CPU 64bit dual core machines are to come**
 - **total of 128 Xeon cluster (TIER2)**



Pure Koreans contributions to CMS



- **Full contribution! KT Jet and FastJet implementations in HIROOT / CMSSW.**
 - **Kt, FastJet, Mulguisin**
- **CMS-HI Tier2 (both Data grid & CPU grid) will be added as a Korean contribution**
 - **both LCG and OSG are available. MC contribution too.**
- **Muon package contribution will be added**
- **We move forward toward CMS JetFinder Library.**
- **Visible contribution to CMS/LHC world.**
- **Strongly hope to do real physics with our jetfinder library.**



Remarks & Summary



- **Understanding jet is crucial in LHC experiments.**
- **The CMS Detector will allow precision jet study**
 - **The combination of large acceptance Calorimeters high precision charged particle tracking and flexible Trigger/DAQ system will allow us to address a wide range of Jet Physics observables**
- **Jet Physics in Heavy Ion Collisions will be an exciting new field of study with jets**
 - **Need to develop many new experimental techniques**
- **New algorithms should be considered due to unprecedented CPU time and better precision**
 - **FastJet, Mulguisin, and hybrid algorithms**
- **KR CMS-HI group will do real contributions and will make real physics outputs**