# Jet Reconstruction in Heavy Ion Collisions

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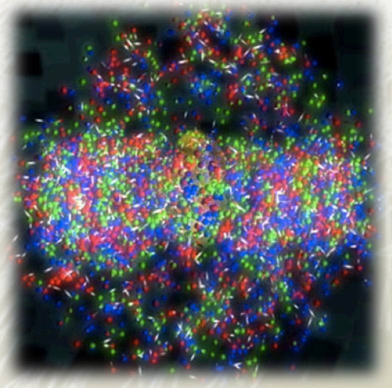
Preliminary: work in progress…

High pT Physics at the LHC
March 26th – March 29th, 2012
Zehntscheune Hanau-Steinheim, Germany

# Introduction

- Ultra-relativistic heavy-ion physics:
  - Main goal: study matter under extreme conditions of temperature and density
    - Quark-Gluon-Plasma (QGP)
  - Collect evidence for the existence of the QGP and to study its properties
    - Need hard probes well controlled by both experiment and theory



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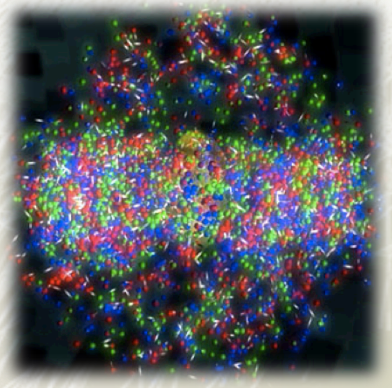
  - Collect evidence for the existence of the QGP and to study its properties
    - Need hard probes well controlled by both experiment and theory
      - Medium-induced modifications to the production of high transverse momentum objects (Jet Quenching)

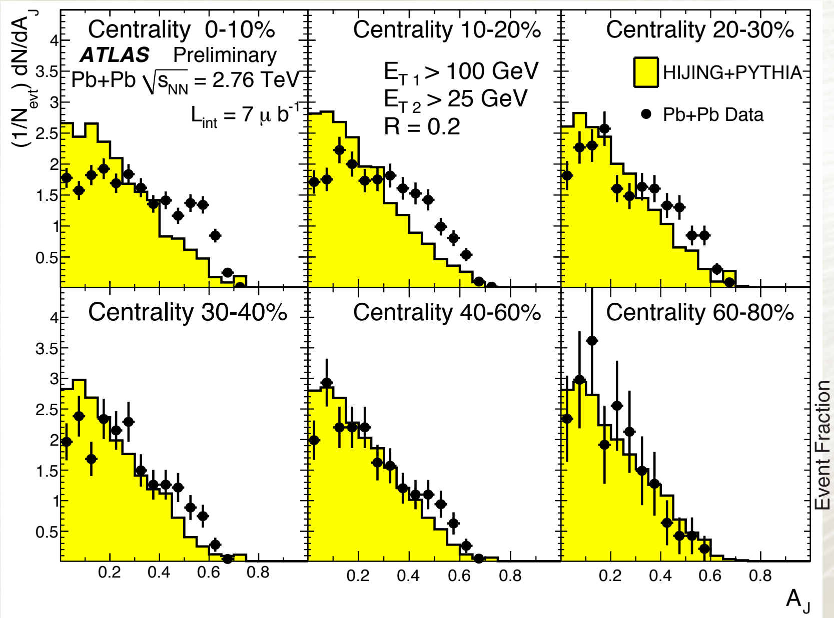
↓ Spectra of high-momentum particles

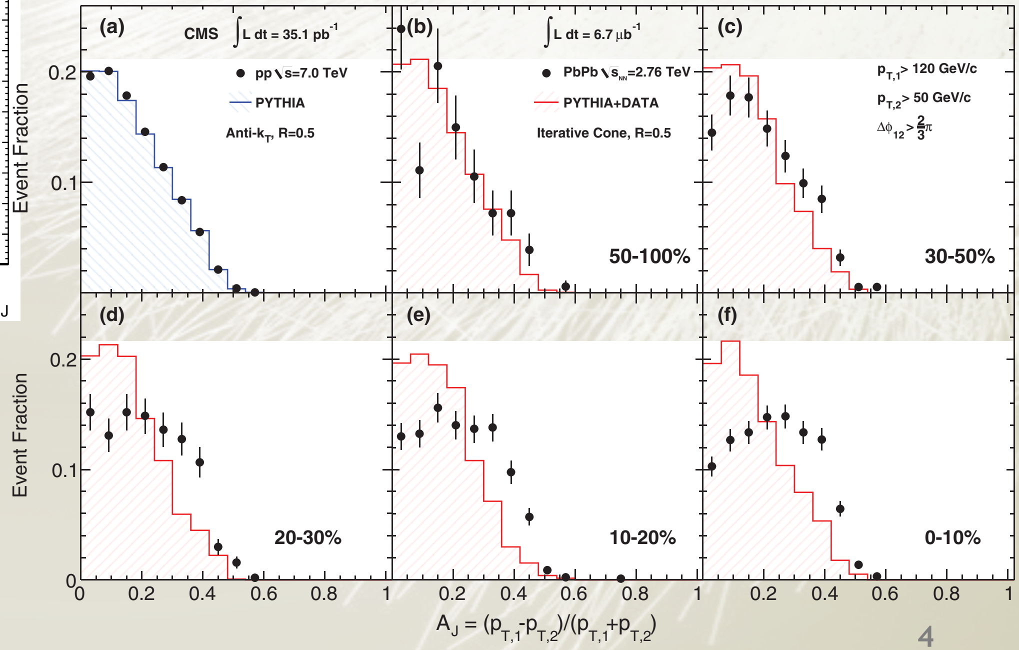
↓ Jets



# Jet Observables

- Dijet Asymmetry ratio $A_J$:




$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

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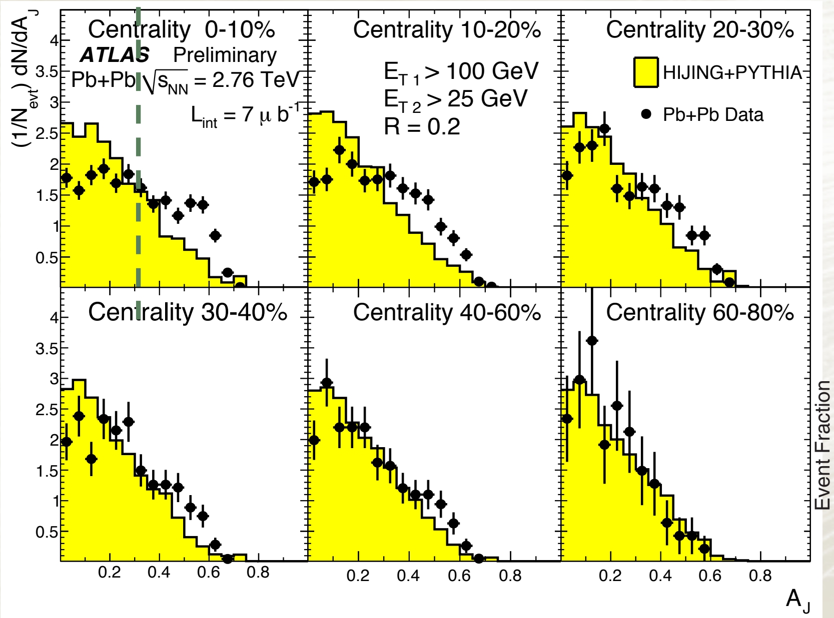


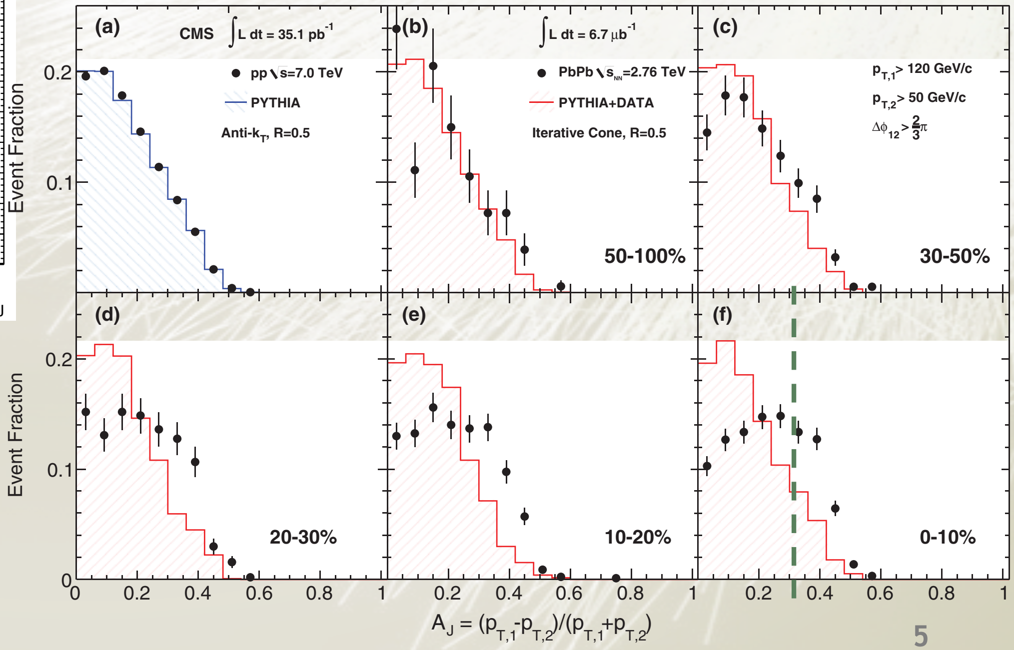


$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

$$E_{T2} = \frac{E_{T1}}{2} \Rightarrow A_J = \frac{1}{3}$$

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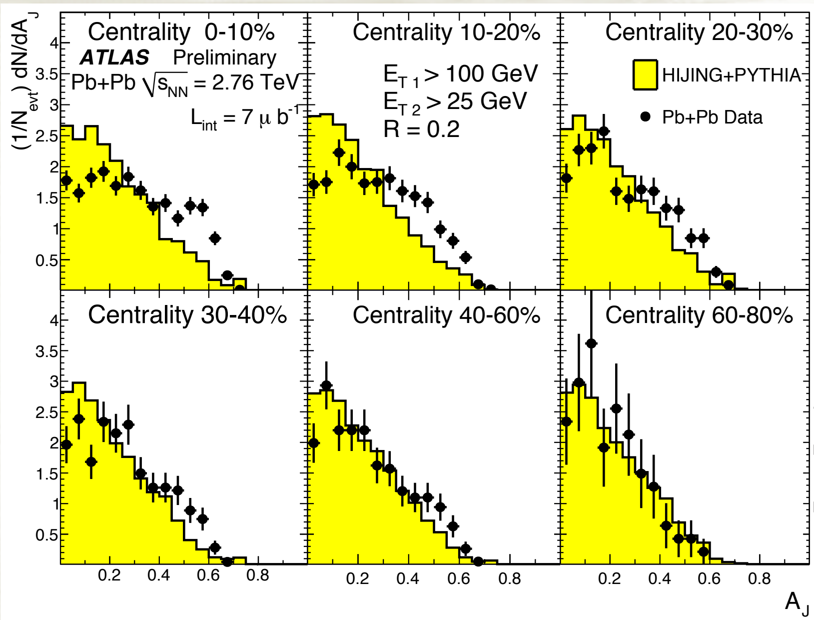


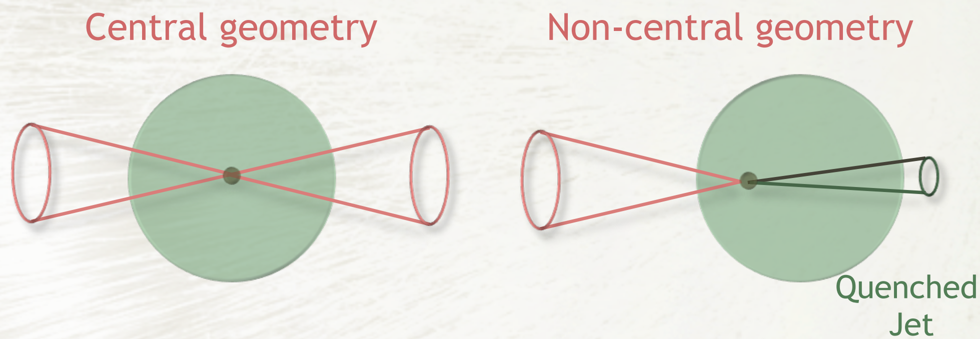


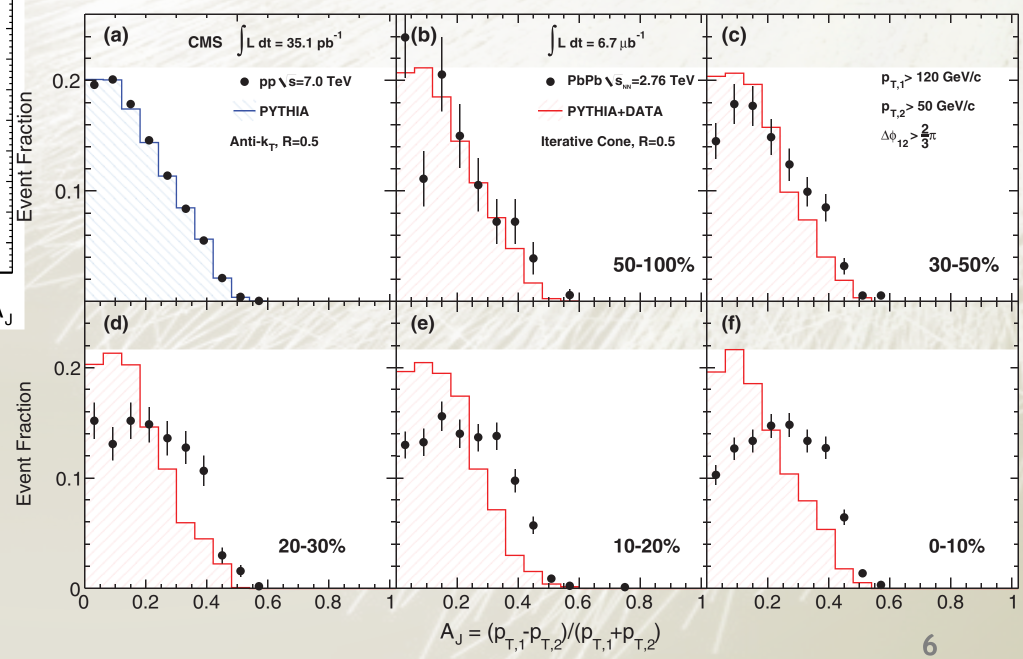


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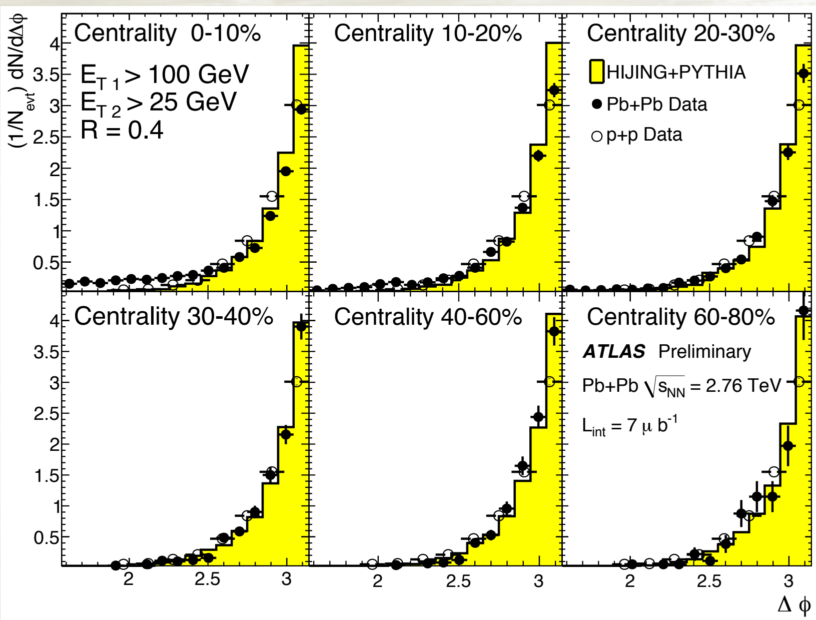
High jet momentum imbalance in dijet events

Asymmetry increases with increasing centrality

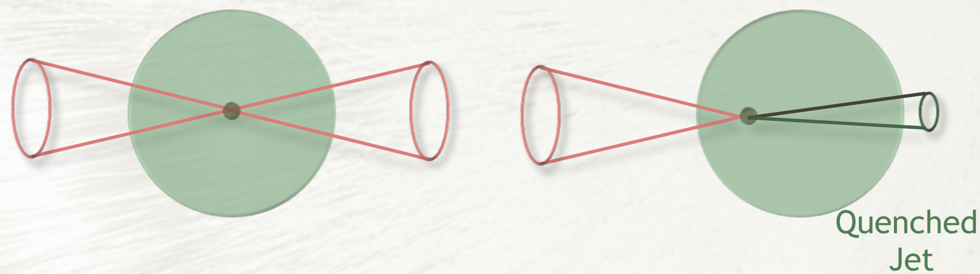
# Jet Observables

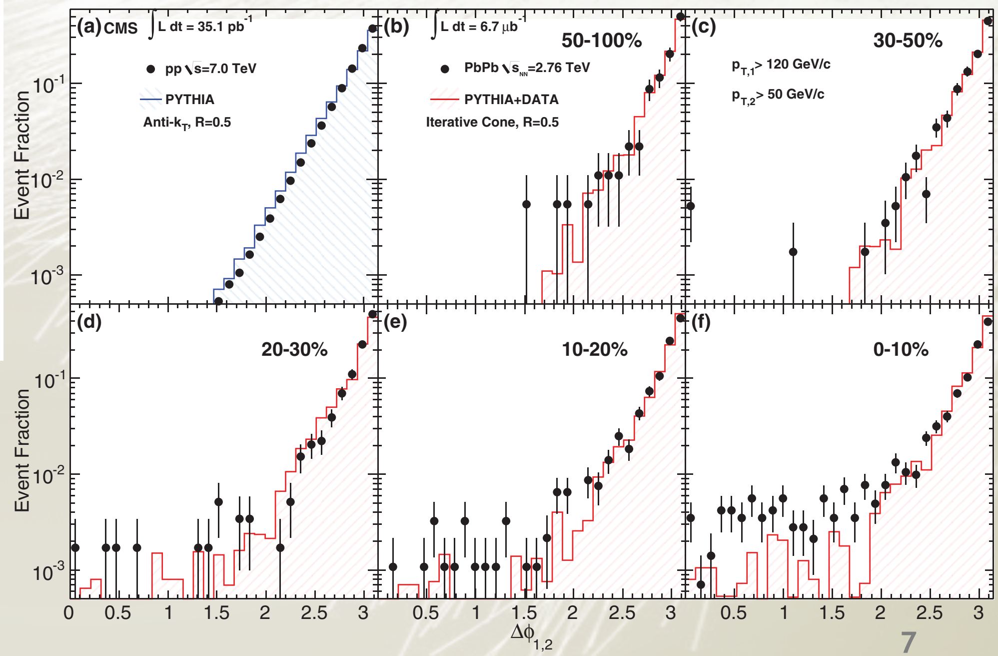
- Dijet Azimuthal correlation:




Central geometry

Non-central geometry



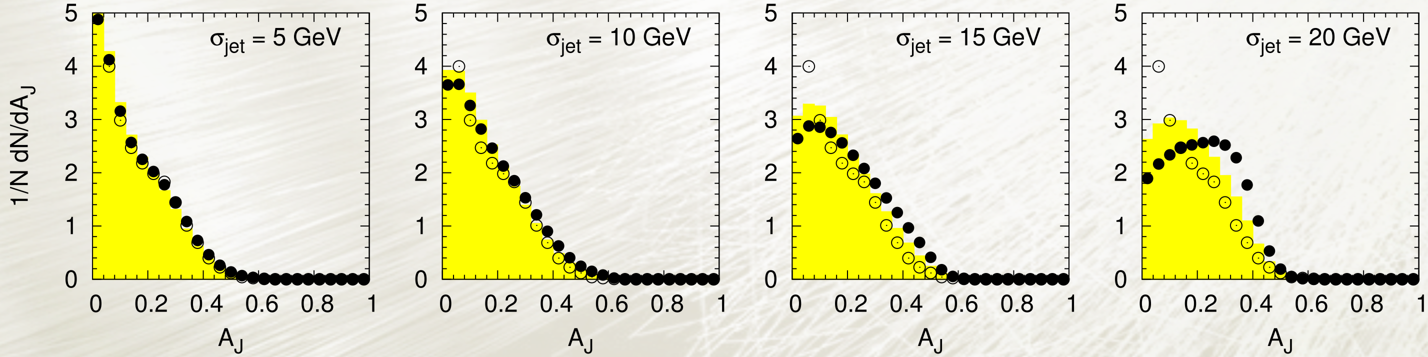




$\Delta\varphi_{12}=|\varphi_1-\varphi_2|$

Angular deviation hardly changes

# Our Analysis

- Main Goal: access the degree of quenching of the data
  - Need to have background parameters (fluctuations) under quantitative control
    - Previous analysis (arXiv:1101.2878) show that fluctuations can play an important role in the dijet momentum imbalance



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  - 1) Parton String Model (PSM) + input spectrum
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    - Background subtraction method (ATLAS- and CMS-like)

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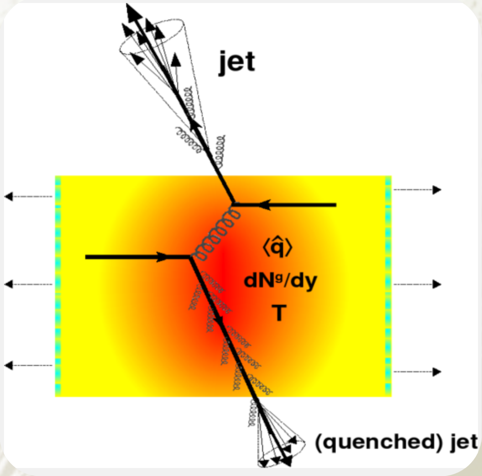

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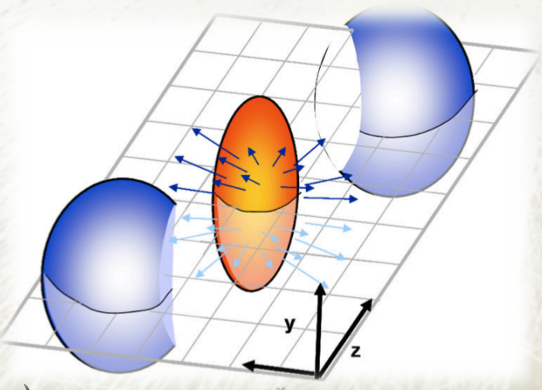


  - Study the impact of:
    - Background fluctuations
    - Background subtraction method (ATLAS- and CMS-like)
    - Quenching (Q-PYTHIA with different qhat parameters)
    - Elliptic Flow $\frac{dN}{d\phi} \propto 1 + \sum_n 2v_n \cos(n\phi)$ $v_2 =< \cos(2\phi) >$

# Procedure

- FastJet (ATLAS-like) subtraction method:
  - Jet finding algorithm:
    - FastJet (anti-kt algorithm with R = 0.4)
  - Background estimation:
    - FastJet (kt algorithm with R = 0.5)
      - Background parameters estimated from the full list of jets except the two hardest ones, using jet areas
      - Full stripe in $|\eta| < 2$

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- CMS-like subtraction method:
  - Same jet finding algorithm
  - Background estimation:
    - Variant of an iterative “noise/pedestal subtraction” technique

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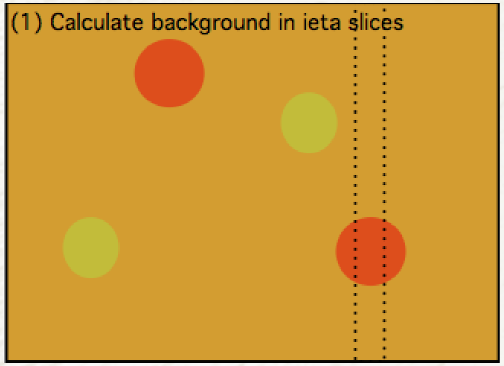
        - $E_T^{tower*} = E_T^{tower} - \langle E_T^{tower}(\eta) \rangle - \sigma_T^{tower}$




[B. Wyslouch]

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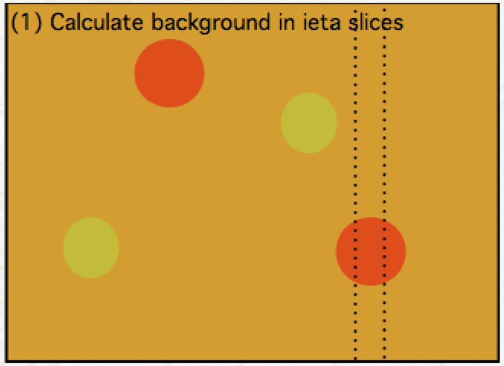


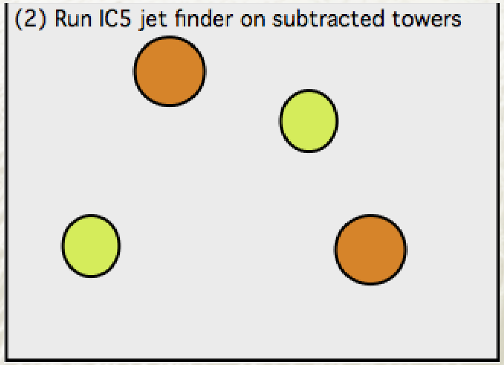


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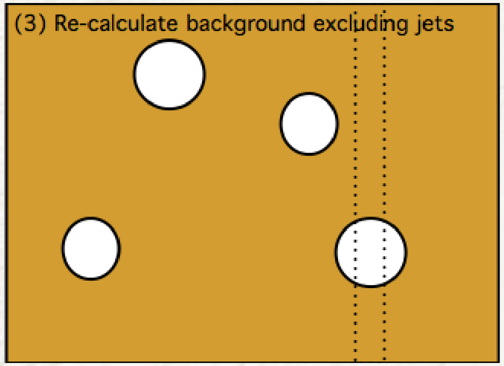


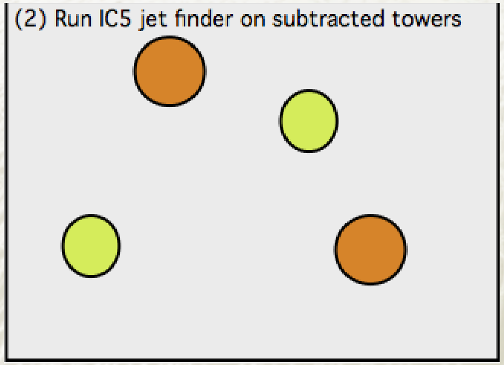


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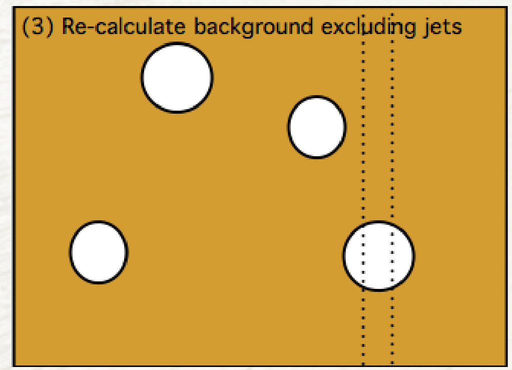


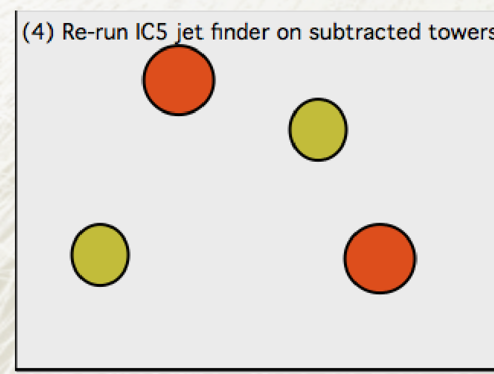


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# Procedure

Results presented with FastJet subtraction

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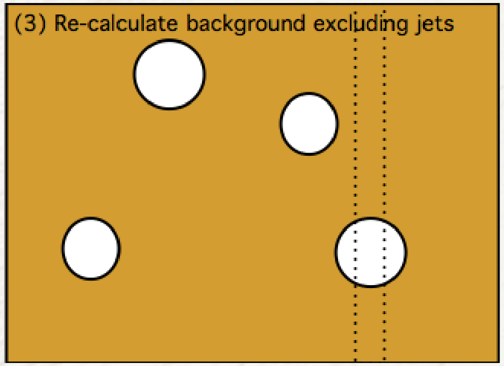
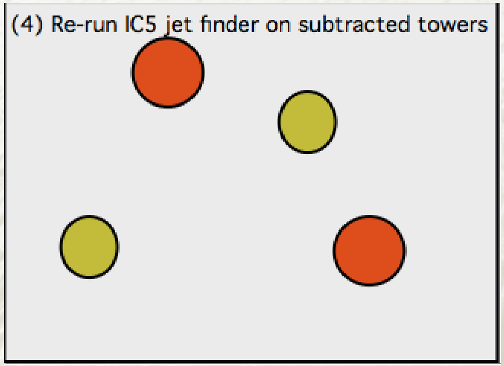


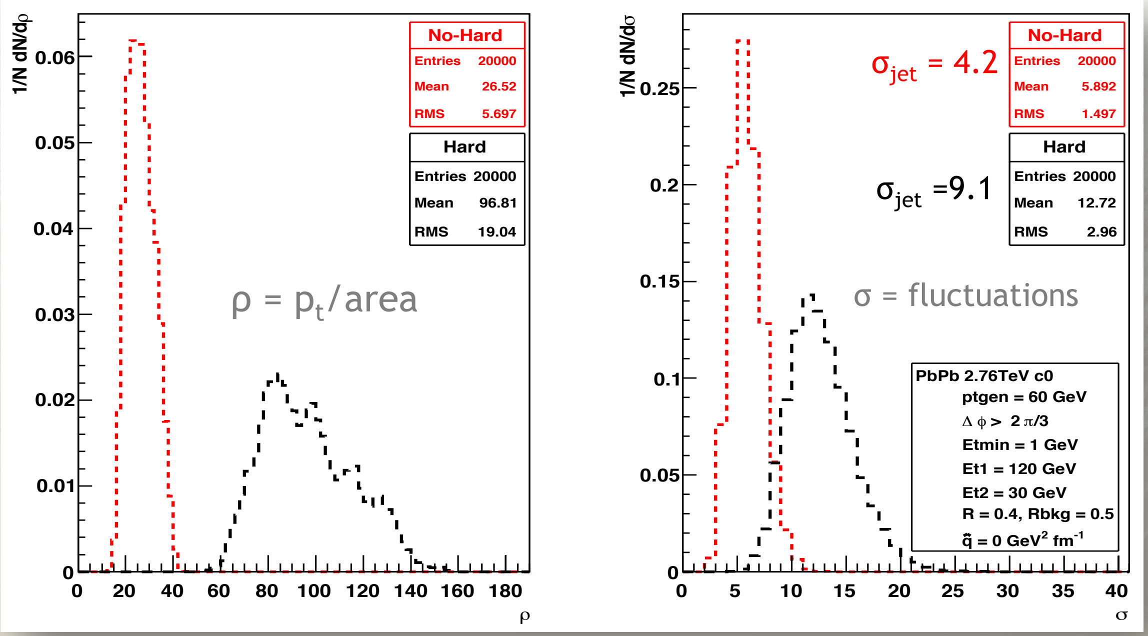

[B. Wyslouch]

CMS-like subtraction method: Work in progress…

# 1) Q-PYTHIA + PSM

- Input spectra + Heavy ion background
  - Input spectra= Q-PYTHIA pp events ($\sqrt{s}$ = 2.76 TeV)
  - Heavy ion background = PSM events (arXiv:hep-ph/0103060v1)
    - 2 types of background:
      - No-hard: without mini-jets ($dN_{ch}/d\eta$ ~ 800)
      - Hard: with mini-jets ($dN_{ch}/d\eta$ ~ 1600)

ALICE: $dN_{ch}/d\eta$ ~ 1600



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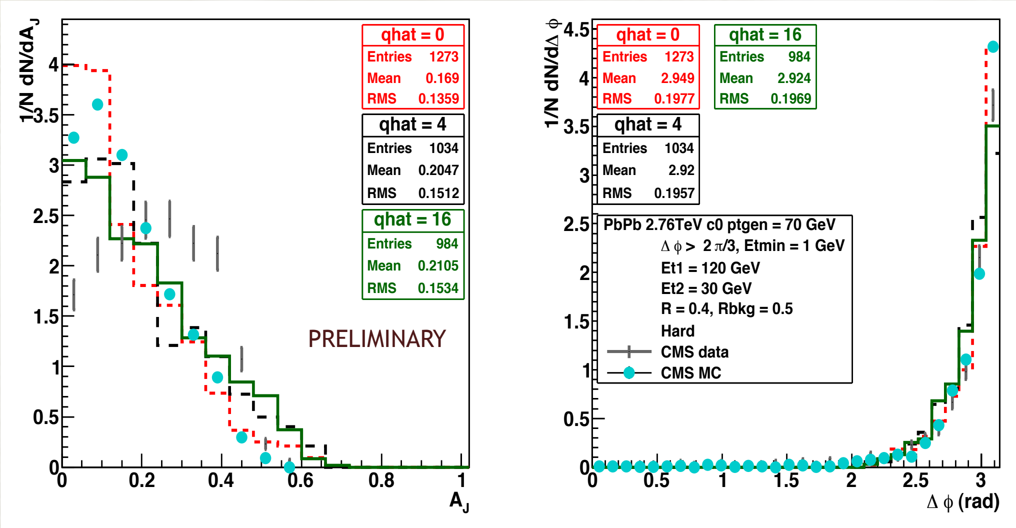
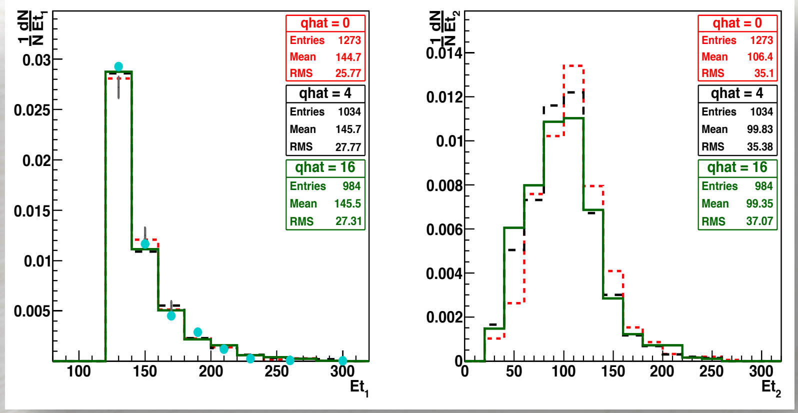
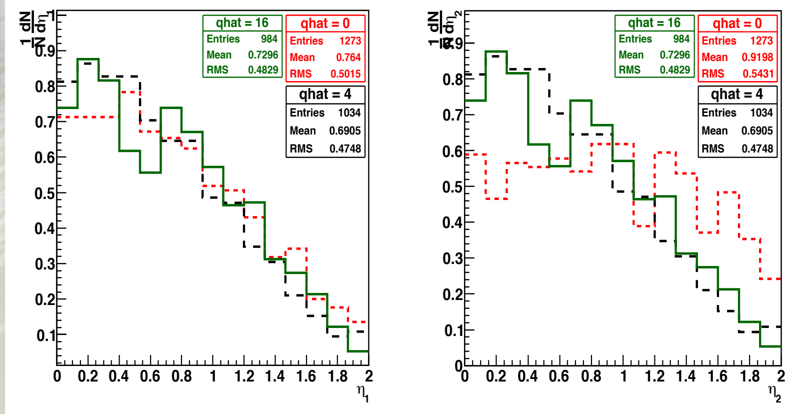
- Results (different qhat):




Quenching makes the distribution flatter



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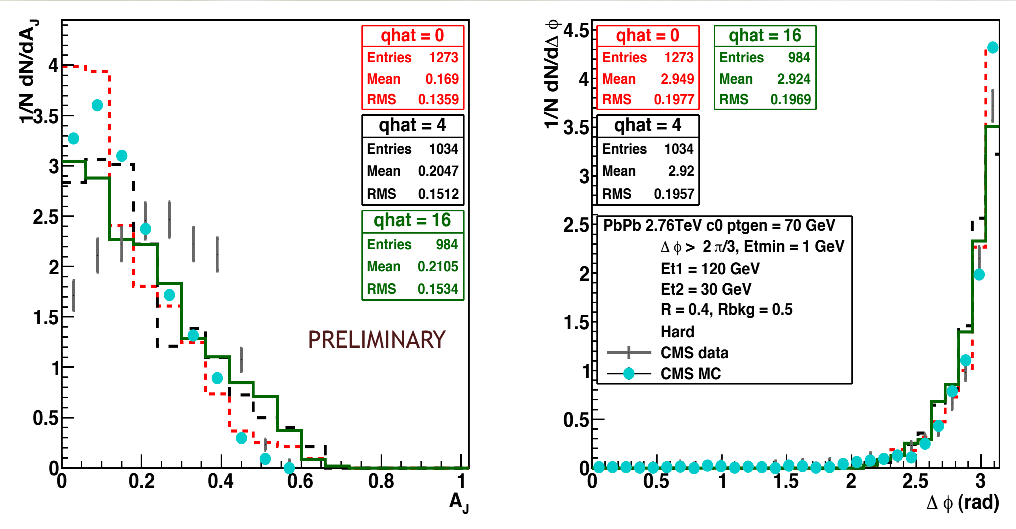


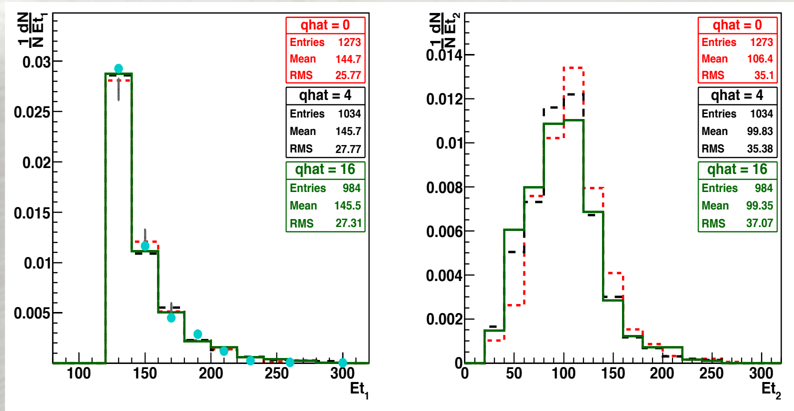


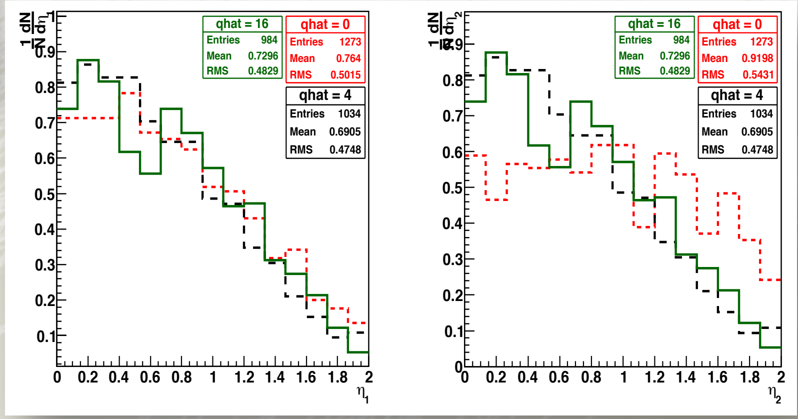


Quenching makes the distribution flatter ✔
Angular deviation slightly broader

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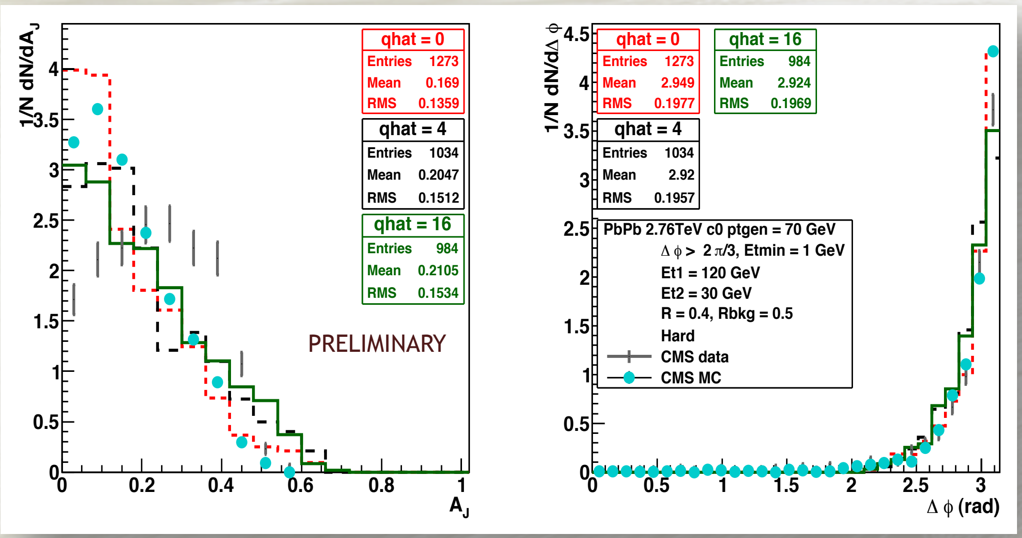


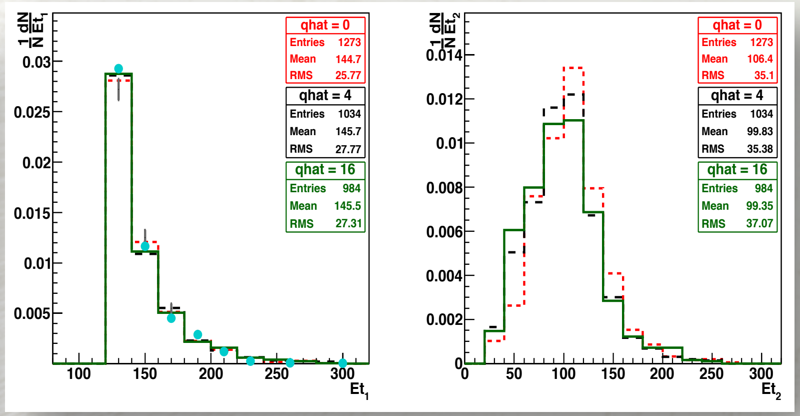


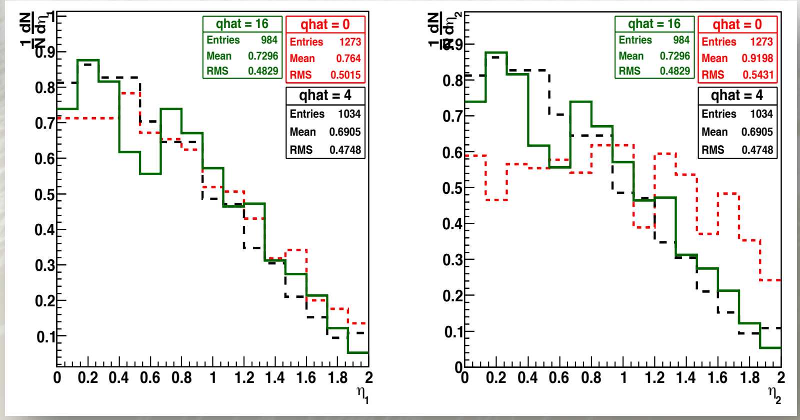


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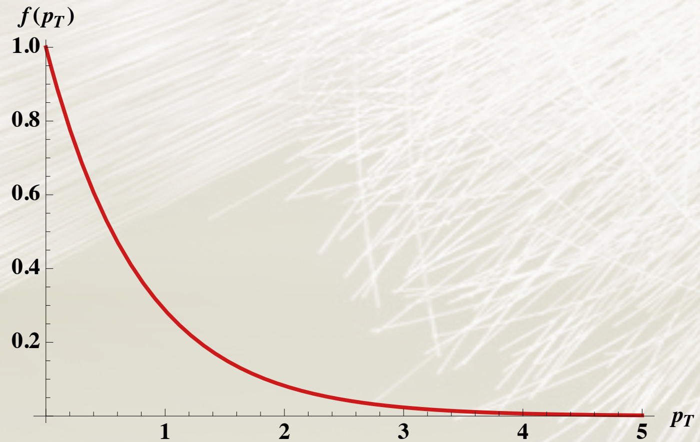
Not enough to describe the data…

# 2) Toy Model

- Input Spectra
  - Q-PYTHIA pp events ($N_{coll}$+HYDJET profile; qhat=0 standard PYTHIA)
- HIC Background
  - Simulate particles according to a thermal spectrum



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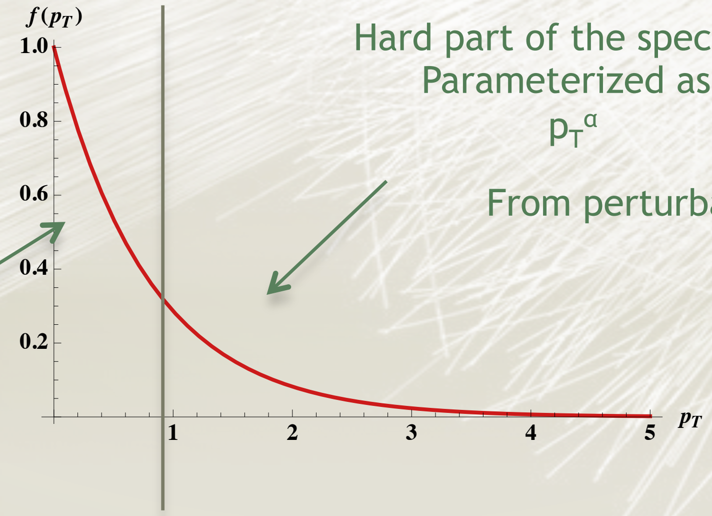
Hard part of the spectrum
Parameterized as:
$p_T^{\alpha}$

From perturbative QCD: α=-6

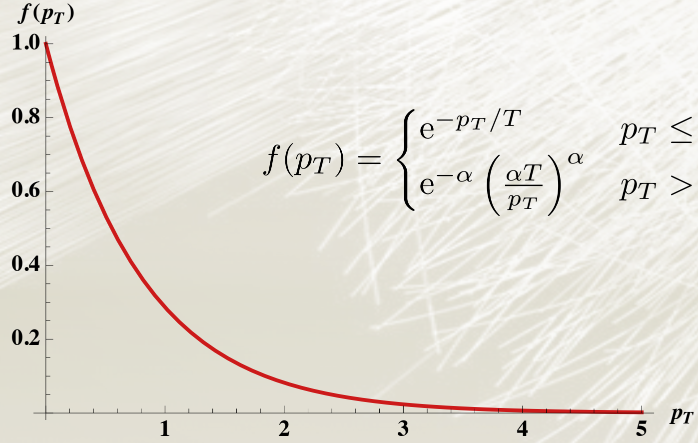



Soft part of the spectrum
Parameterized as:
$e^{-p_T/T}$

T=Temperature
α=QCD exponent

# 2) Toy Model

- Input Spectra
  - Q-PYTHIA pp events ($N_{coll}$+HYDJET profile; qhat=0 standard PYTHIA)
- HIC Background
  - Simulate particles according to a thermal spectrum
- By continuity, the spectrum can be parameterized as $f(p_T)$:
  - Can control the number of background particles (n)




$$f(p_T) = \begin{cases} e^{-p_T/T} & p_T \le \alpha T \\ e^{-\alpha}\left(\frac{\alpha T}{p_T}\right)^{\alpha} & p_T > \alpha T \end{cases}$$

T=Temperature
α=QCD exponent
n=Number of particles

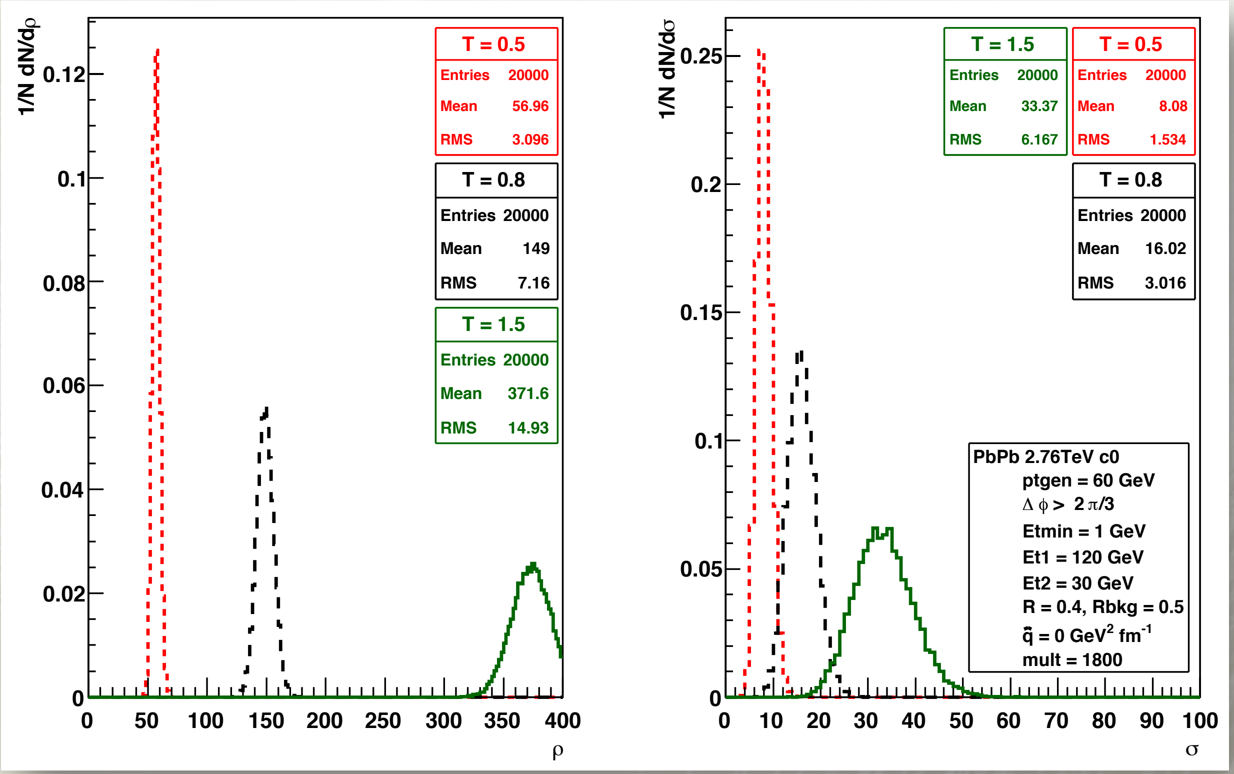
# 2) Toy Model

- Thermal Model:
  - Map between (T, n) ⟷ (ρ, σ)

T = 0.5:
- <σ> = 8.08
- <ρ> = 56.95
- <σ>/<ρ> = 0.14

T = 0.8:
- <σ> = 16.02
- <ρ> = 148.98
- <σ>/<ρ> = 0.11

T = 1.5:
- <σ> = 33.37
- <ρ> = 371.55
- <σ>/<ρ> = 0.09




Increasing T represents an increase in both ρ and σ

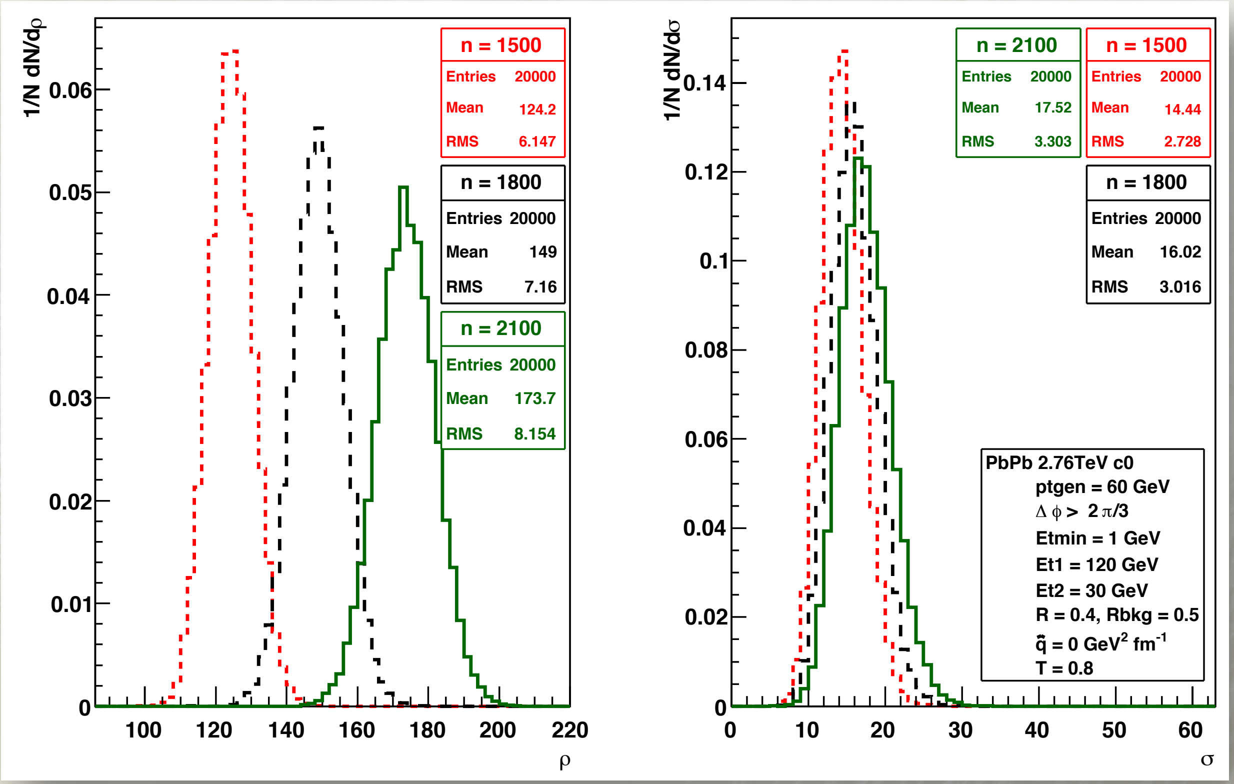
# 2) Toy Model

- Thermal Model:
  - Map between (T, n) ⟷ (ρ, σ)

n = 1500:
$\langle\sigma\rangle = 14.44$
$\langle\rho\rangle = 124.23$
$\langle\sigma\rangle / \langle\rho\rangle = 0.12$

n = 1800:
$\langle\sigma\rangle = 16.02$
$\langle\rho\rangle = 148.98$
$\langle\sigma\rangle / \langle\rho\rangle = 0.11$

n = 2100:
$\langle\sigma\rangle = 17.52$
$\langle\rho\rangle = 173.74$
$\langle\sigma\rangle / \langle\rho\rangle = 0.10$



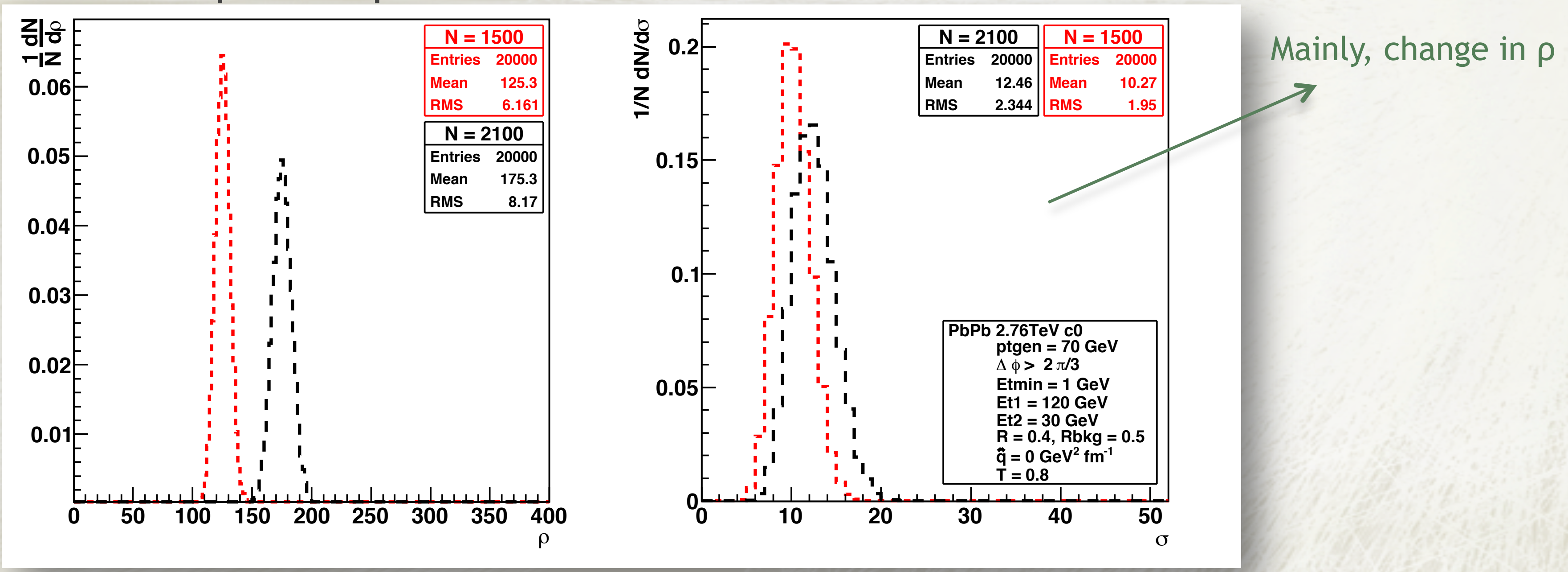

For a fixed T, a change in n accounts for a change in ρ, keeping σ almost constant

# 2) Toy Model

Studying the influence of the background level and fluctuations

# 2) Toy Model

- Impact of ρ:



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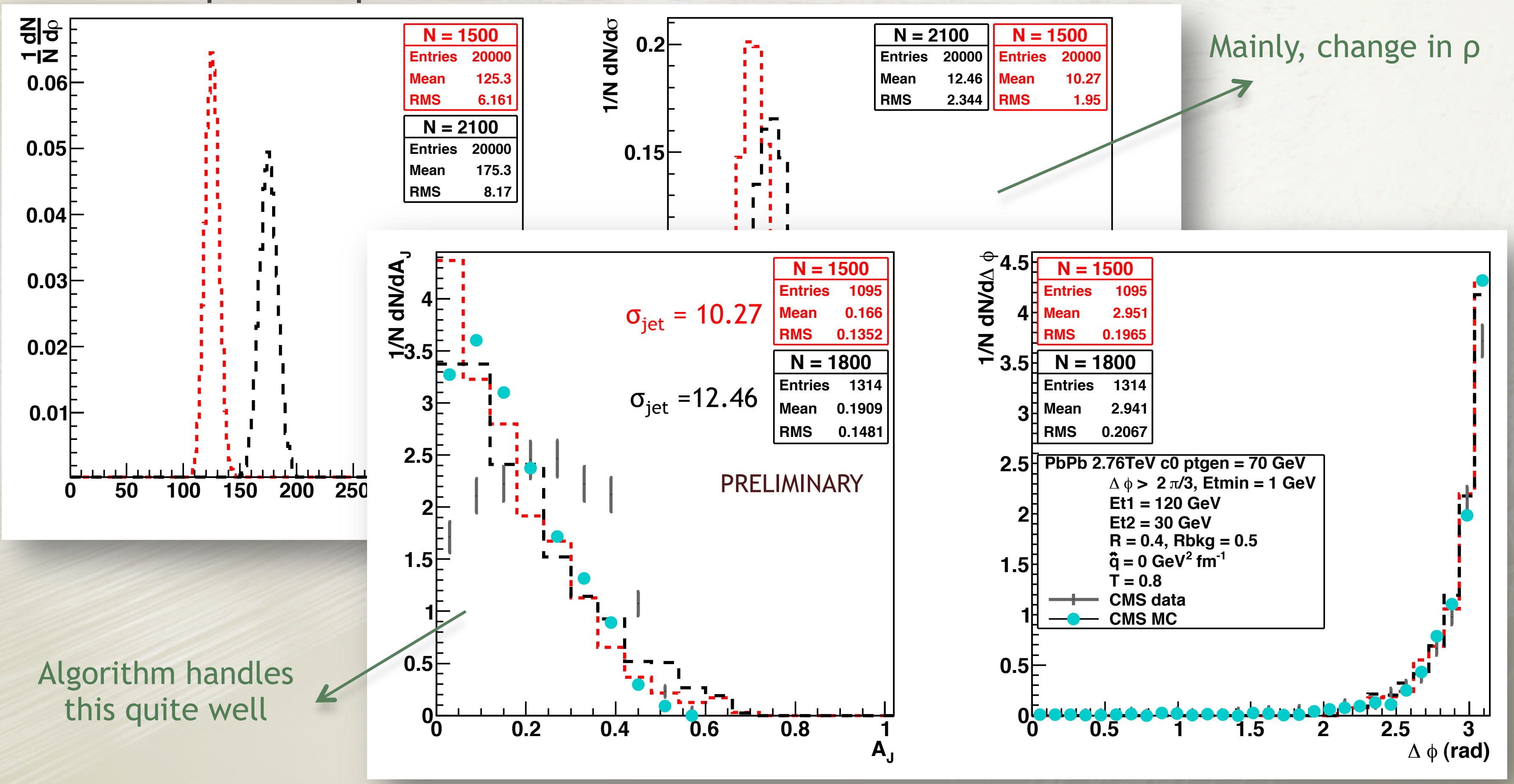

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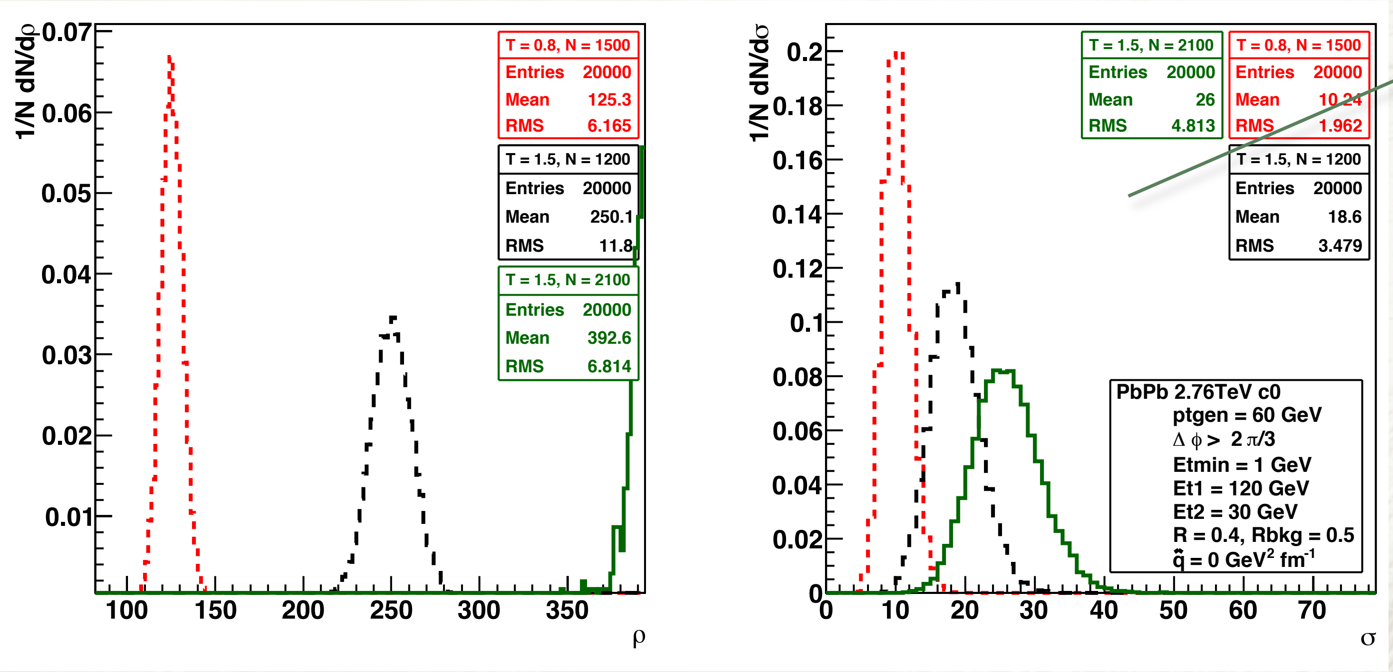


Difference in ρ but also in σ

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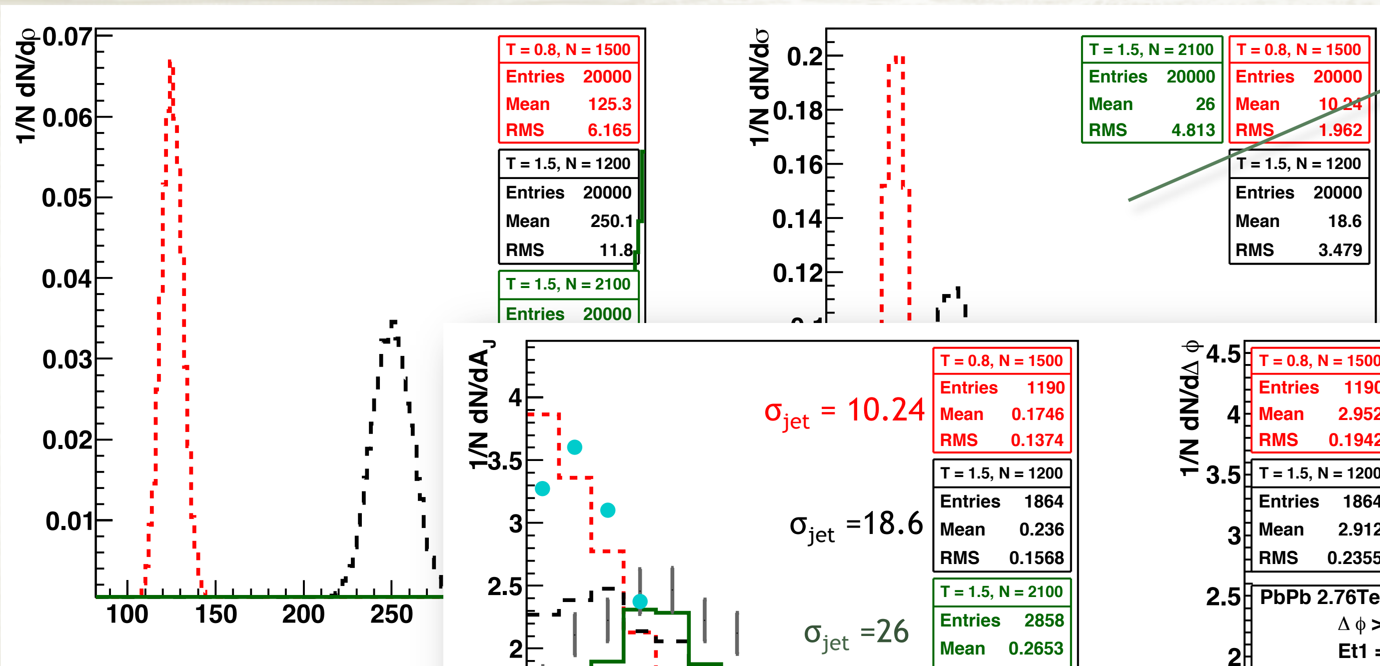
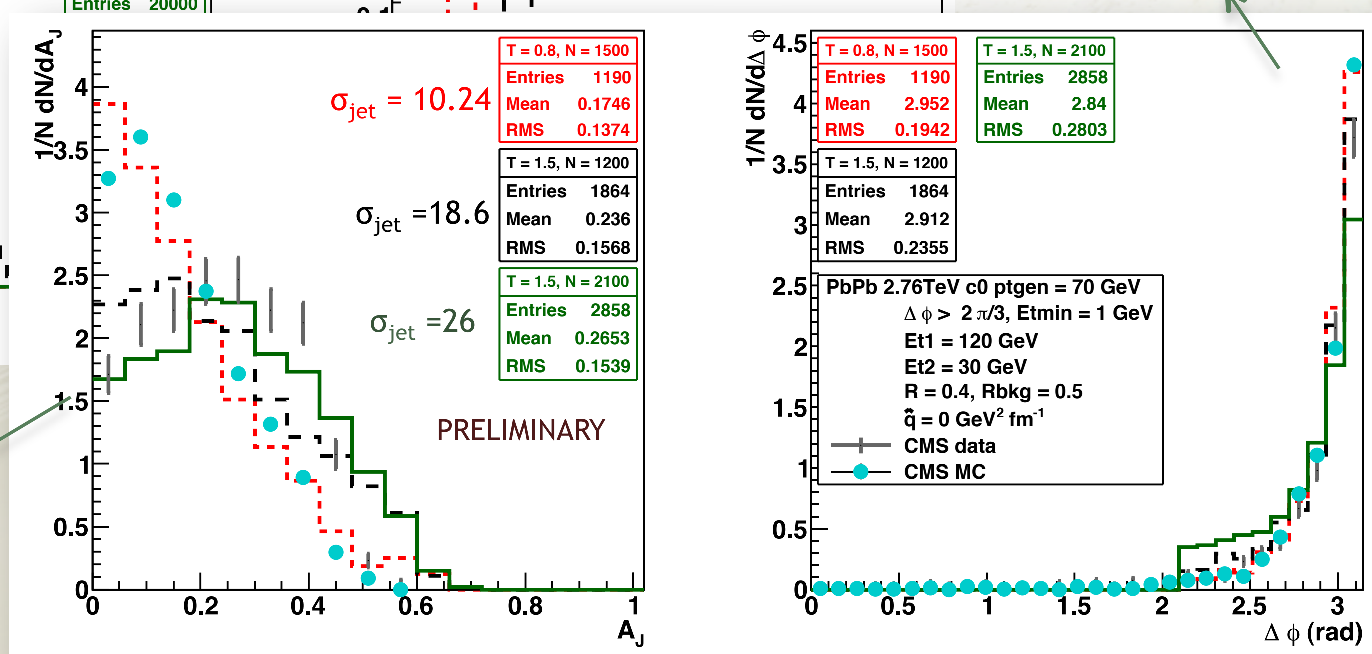
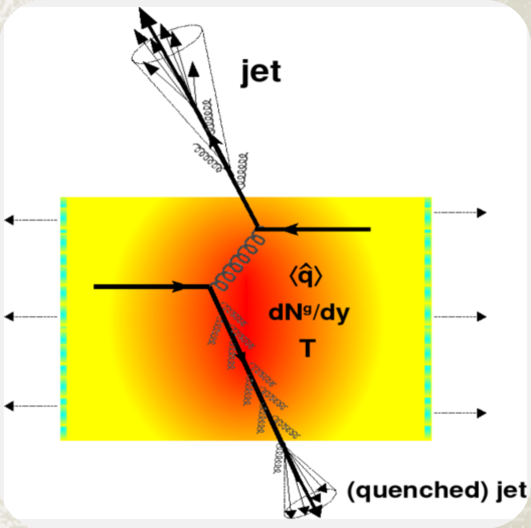



Difference in ρ but also in σ

Very high fluctuations also affect the azimuthal correlation




Affect the asymmetry in the same direction than data

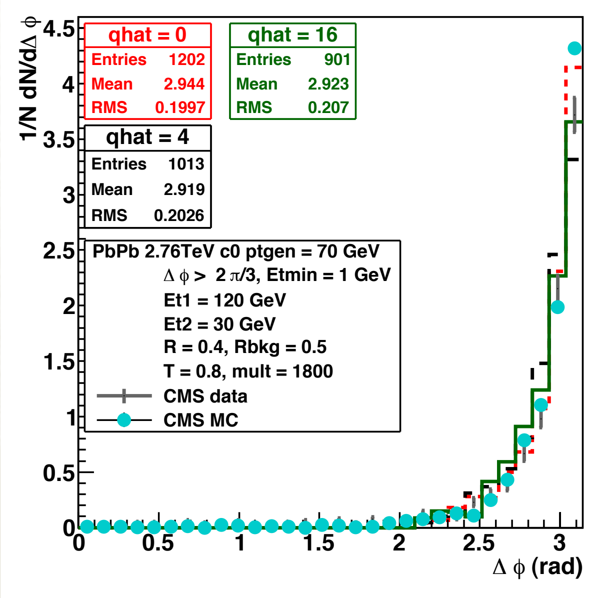



# 2) Toy Model

## Influence of quenching

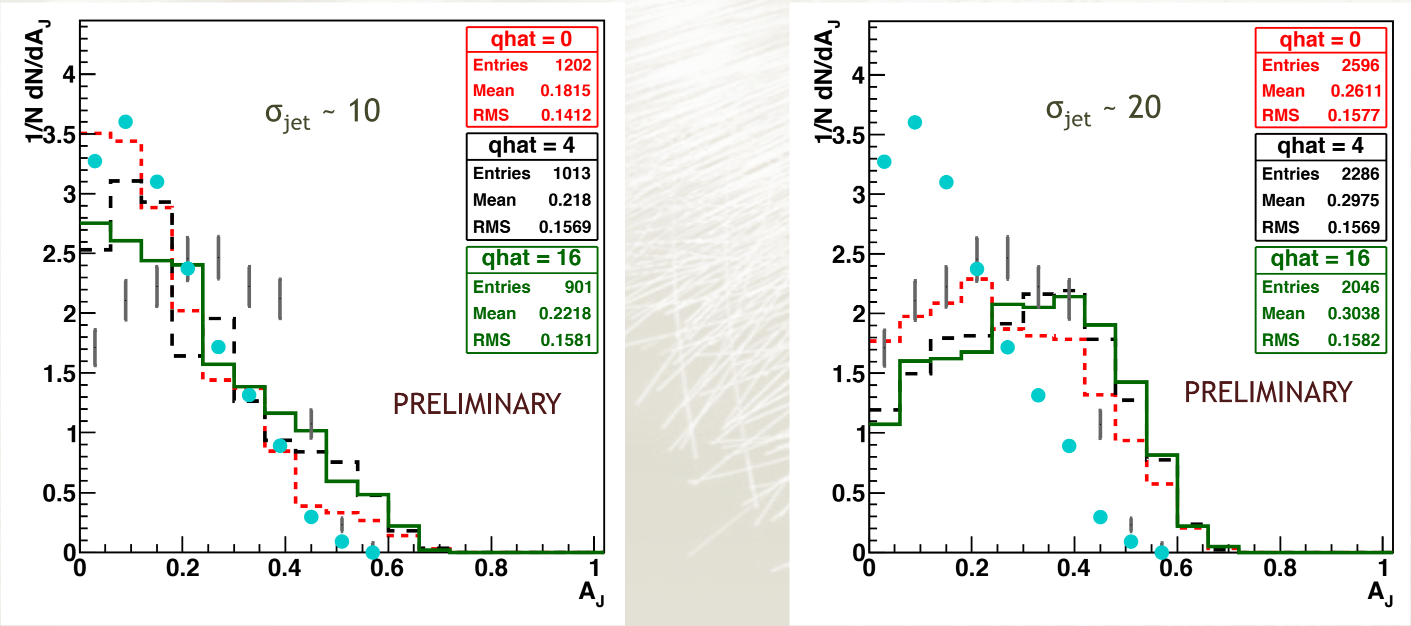
# 2) Toy Model

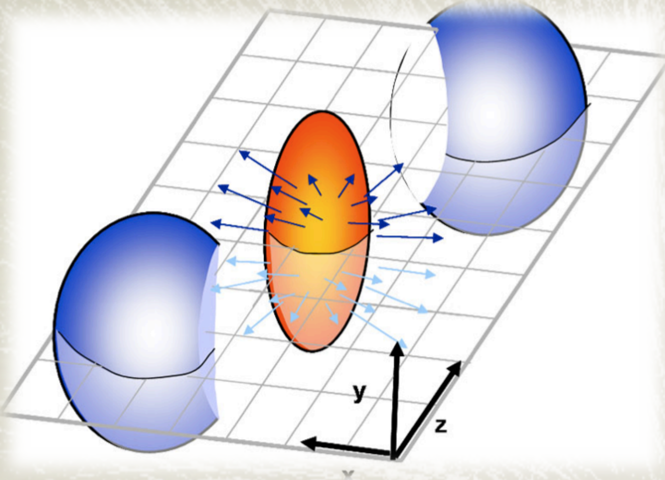
- Impact of qhat:
  - Relatively small effect in the angular correlation:



# 2) Toy Model

- Impact of qhat:
  - Relatively small effect in the angular correlation:
  - Higher effect in the dijet momentum asymmetry with increasing medium fluctuations:






$$\frac{dN}{d\phi} \propto 1 + \sum_n 2v_n \cos(n\phi)$$

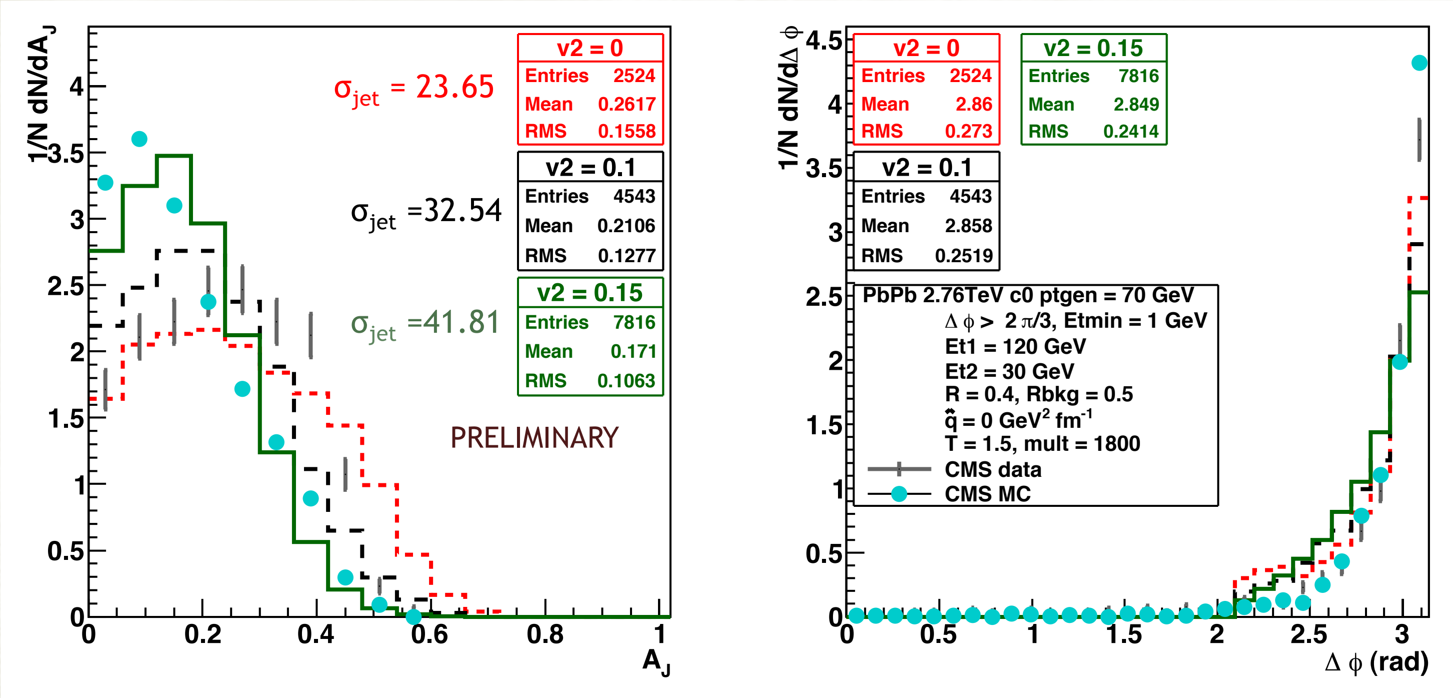
$$v_2 =< \cos(2\phi) >$$

# 2) Toy Model

## Dependency with an elliptic flow component

# 2) Toy Model

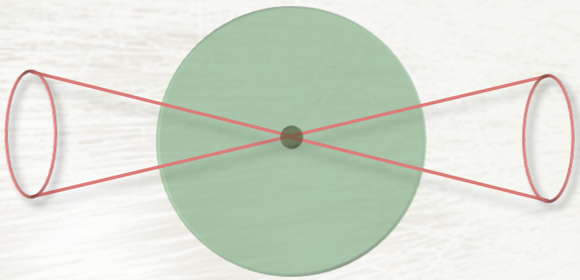
- Impact of $v_2$ (in a high fluctuating medium):




Introduction of a $v_2$ component increase the fluctuations by a large amount!
But the dijet momentum asymmetry decreases…
Angular correlation becomes broader

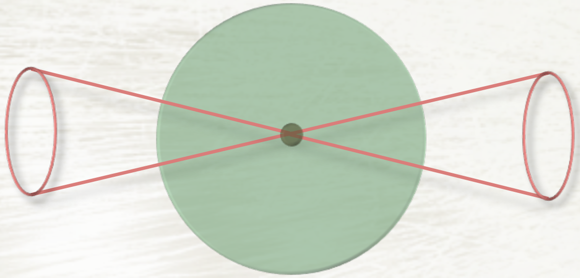
# 2) Toy Model

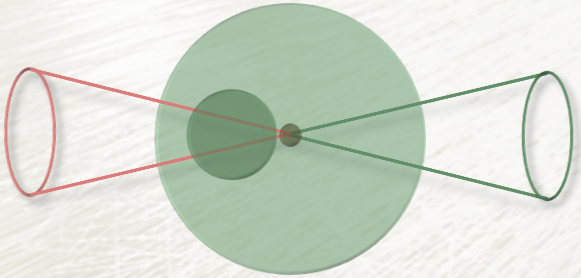
- Impact of $v_2$:
  - Homogenous medium:
    - Aj ~ 0



# 2) Toy Model

- Impact of $v_2$:
  - Homogenous medium:
    - Aj ~ 0
  - Fluctuating medium:
    - Random fluctuations
    - Aj increases





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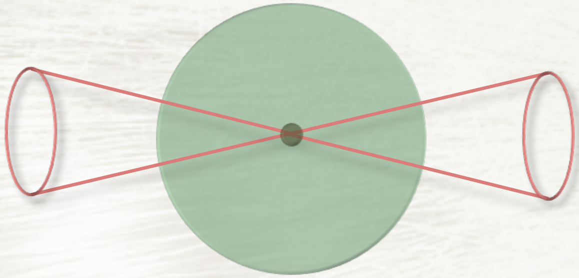

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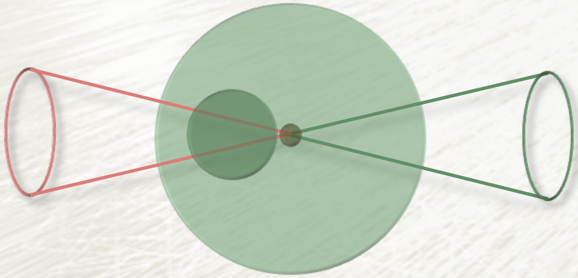
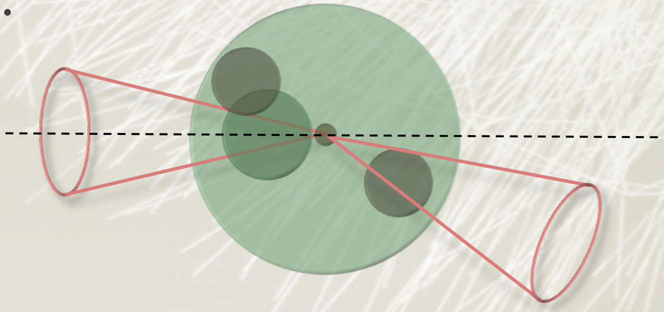
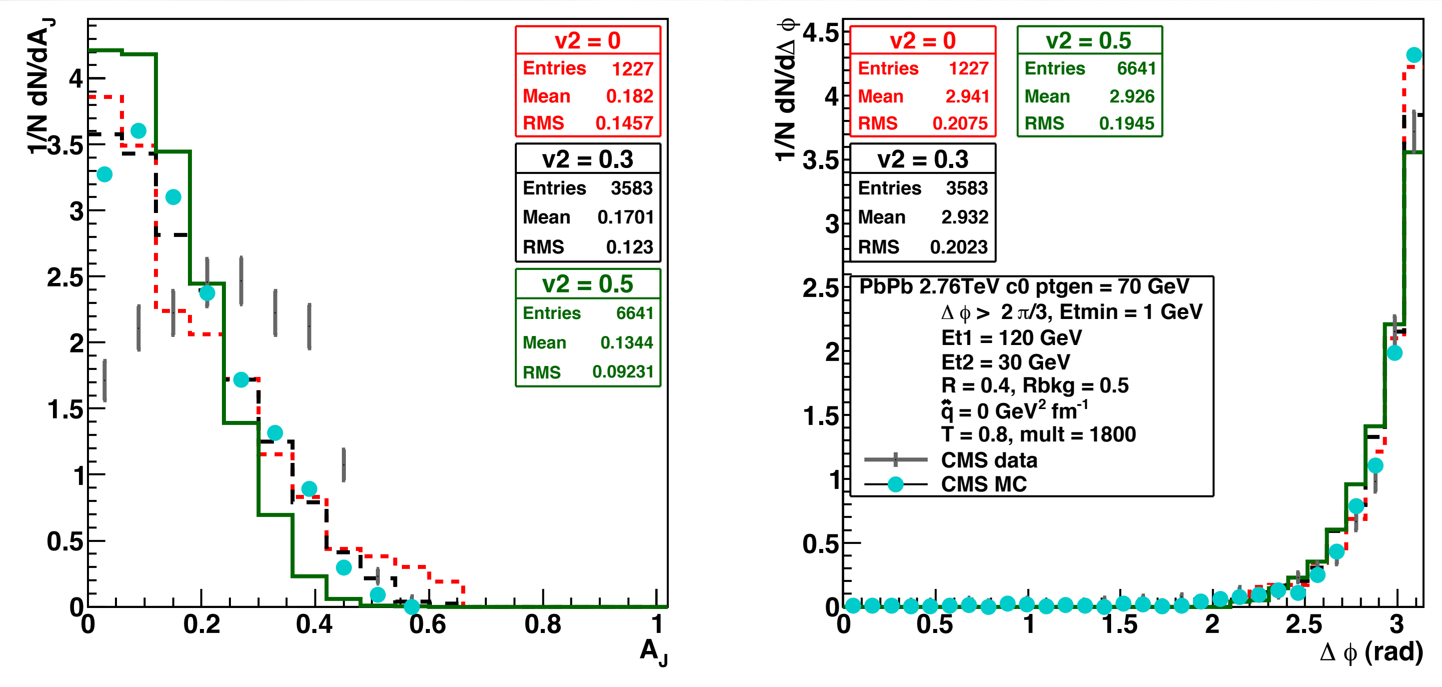


  - Fluctuating medium with flow:
    - Fluctuations are symmetric!
    - Aj decreaases
    - Angular deviation change



# 2) Toy Model

- Impact of $v_2$ (in a moderate fluctuating medium):




Need more $v_2$ to get the same effect…

# Conclusions

- Dijet energy-momentum imbalance seems to indicate strong medium effects
  - Softer modification of the angular correlation

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  - Softer modification of the angular correlation
- Background fluctuations seems to play an important role on the modification of the observables features:

  (arXiv:1112.6021, 1101.2878, 1103.1853):
  - Local fluctuations may change the distribution in the same direction than data
  - Quenching effects are more visible with increasing fluctuations
  - $v_2$ seems to have a strong effect on Aj and angular distributions

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# Conclusions

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  - Softer modification of the angular correlation
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  - $v_2$ seems to have a strong effect on Aj and angular distributions
  - Need to understand what part of the observed effect is related to background fluctuations and what is caused by quenching (other energy loss mechanism?)
- On-going work…

# Thank You!

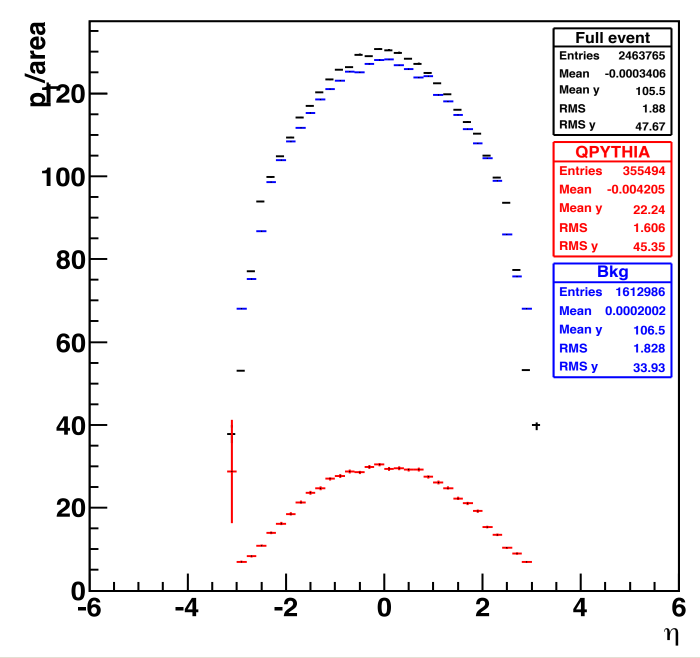
# Backup Slides

# 1) Q-PYTHIA + PSM

- Input spectra + Heavy ion background
  - Input spectra= Q-PYTHIA pp events (√s = 2.76 TeV)
  - Heavy ion background = PSM events (arXiv:hep-ph/0103060v1)
    - 2 types of background:
      - No-hard: without mini-jets ($dN_{ch}/d\eta$ ~ 800)
      - Hard: with mini-jets ($dN_{ch}/d\eta$ ~ 1600)

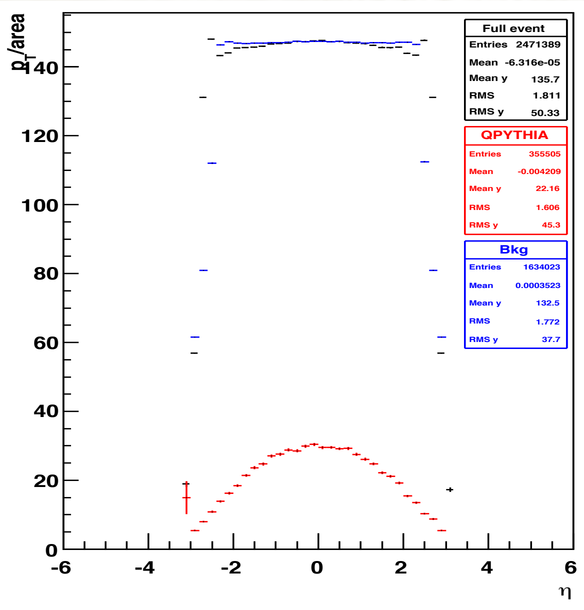
ALICE: $dN_{ch}/d\eta$ ~ 1600

- Jet Profile:



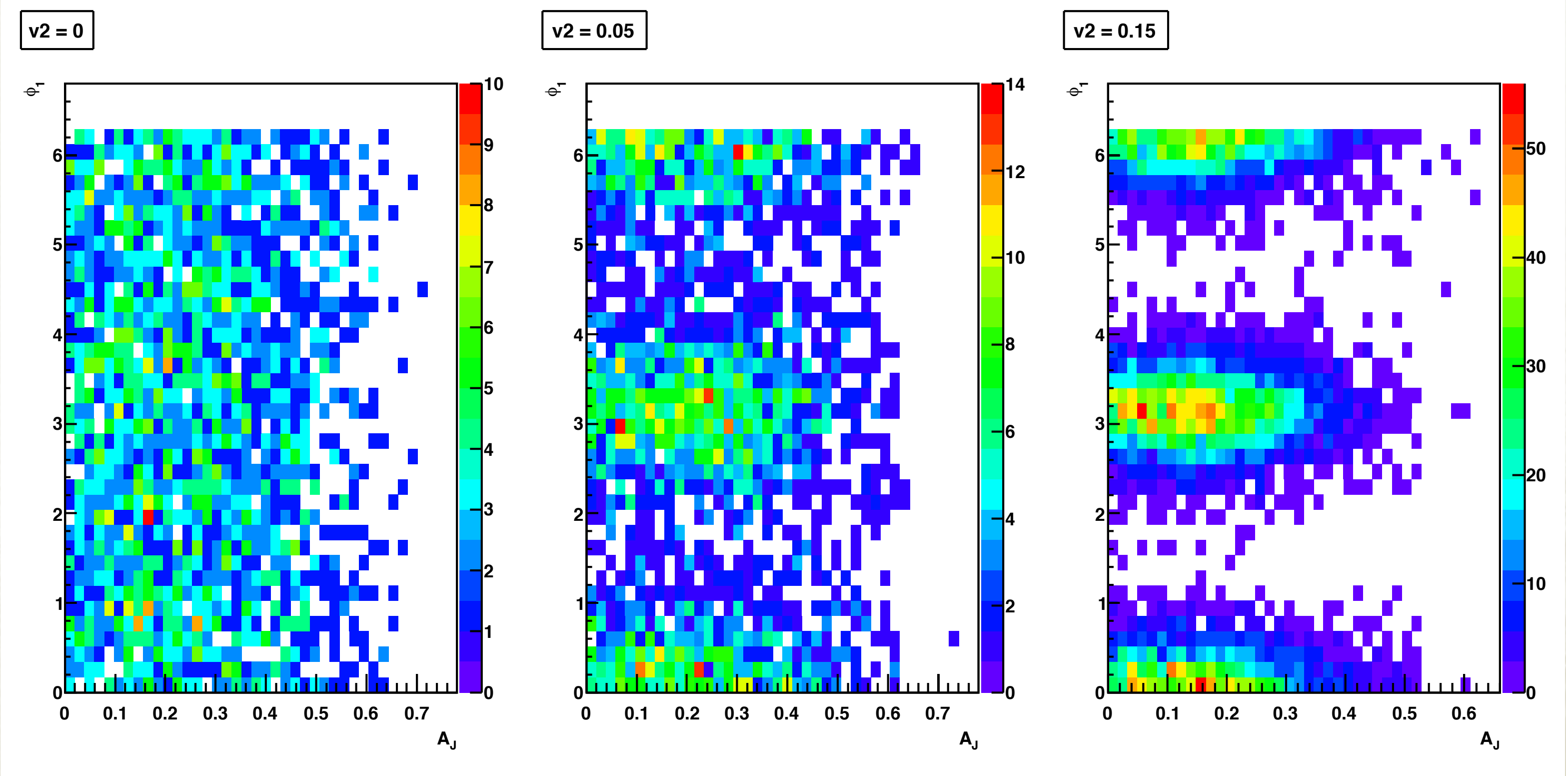
# 2) Toy Model

- Input Spectra
  - Q-PYTHIA pp events ($N_{coll}$+HYDJET profile; qhat=0 standard PYTHIA)
- HIC Background
  - Simulate particles according to a thermal spectrum
- By continuity, the spectrum can be parameterized as $f(p_T)$:
  - Can control the number of background particles (n)
- Jet Profile:



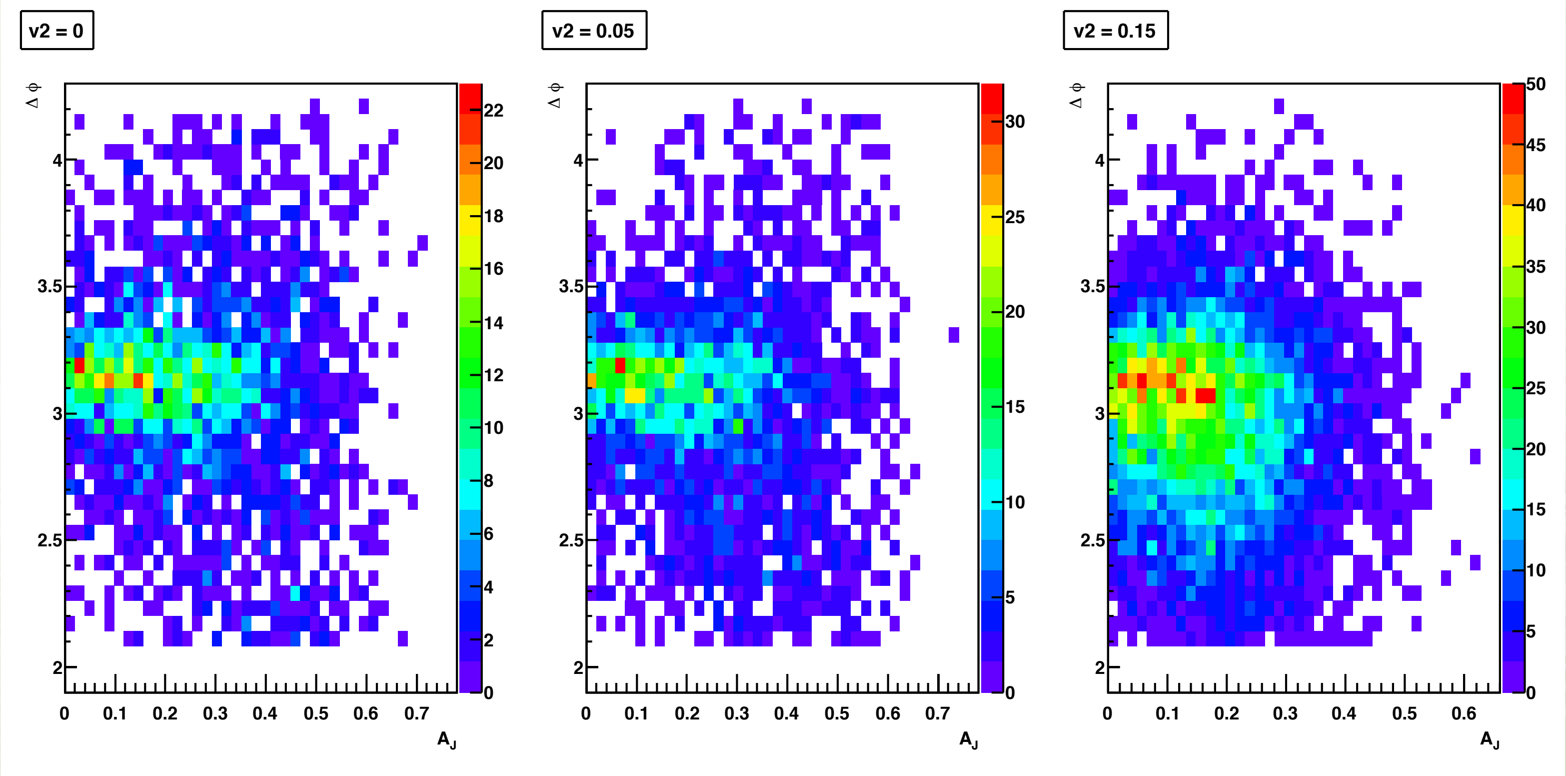
# 2) Toy Model

- Impact of $v_2$:
  - Correlation between $A_j$ and jet angles:



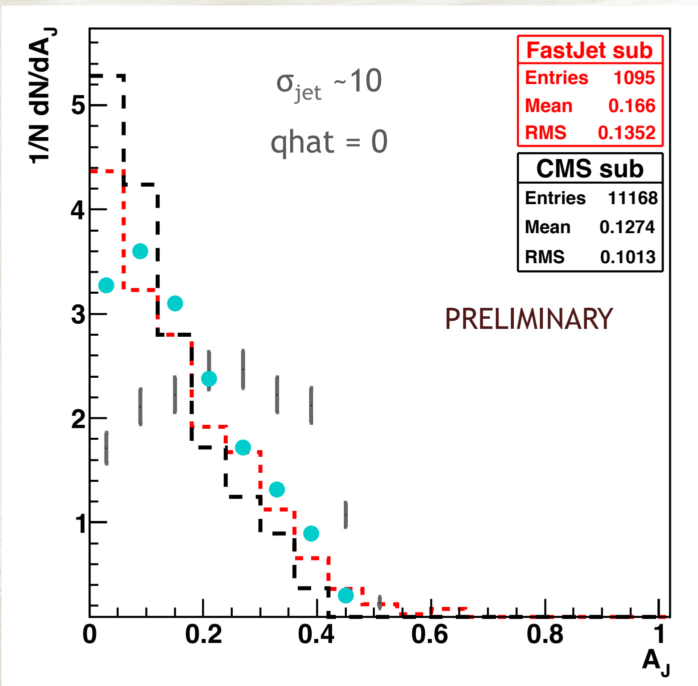
# 2) Toy Model

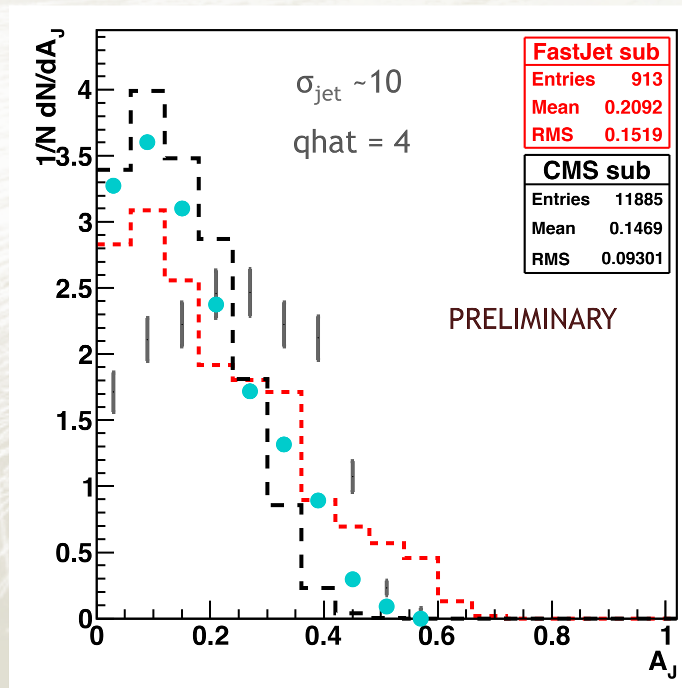
- Impact of $v_2$:
  - Correlation between $A_j$ and angular deviation:



# On-going work

- Testing differences in background subtraction methods:
  - Moderate fluctuating background

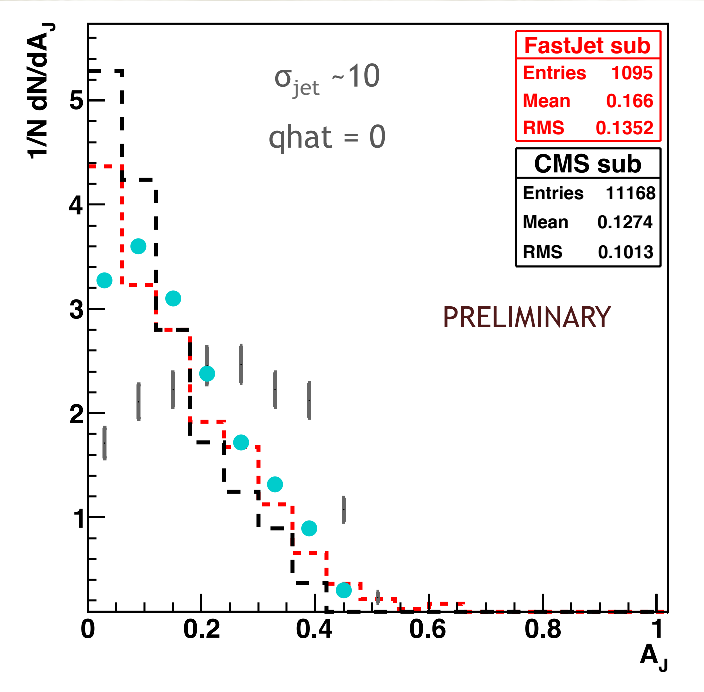


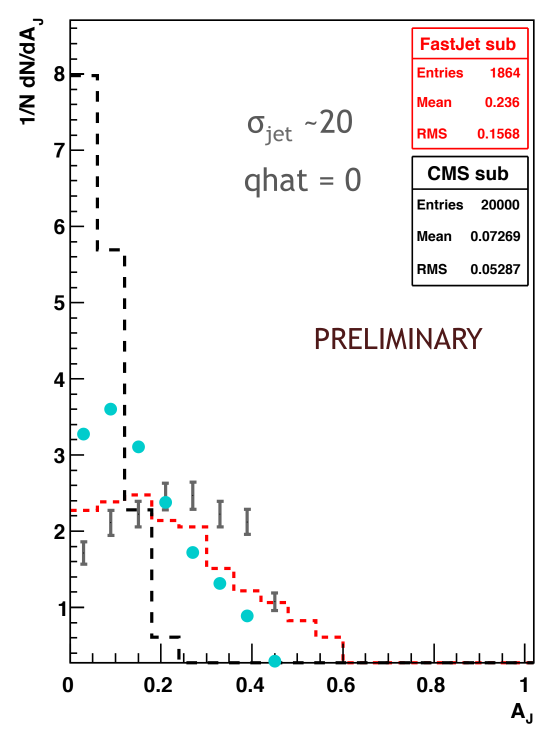




Both methods react in the same way to quenching

# On-going work

- Testing differences in background subtraction methods:
  - Moderate fluctuating scenario




But has an opposite behavior to fluctuations…