



Universiteit Utrecht



Measurement of jet spectra in Pb-Pb collisions at $\sqrt{s}_{\text{NN}}=2.76 \text{ TeV}$ with the ALICE detector at the LHC

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for the ALICE collaboration

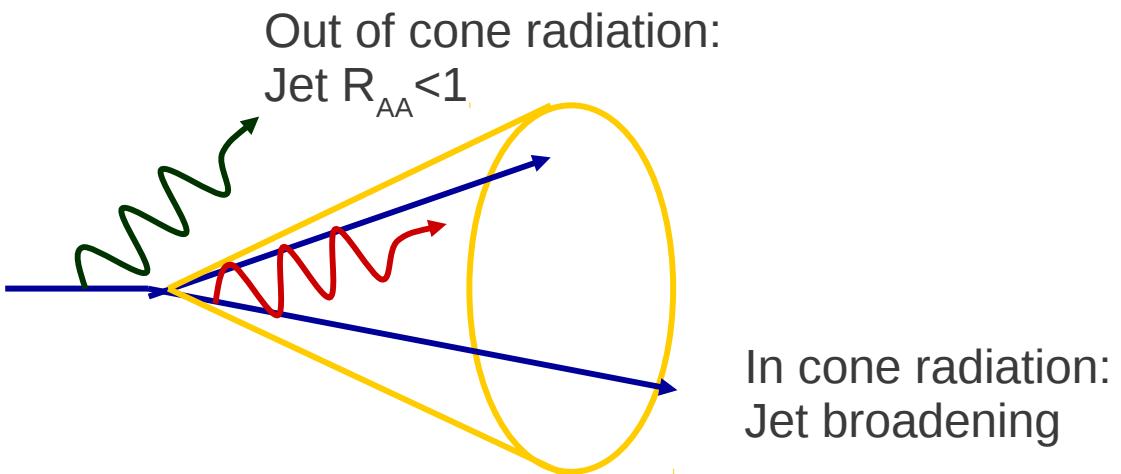
Hard Probes 2012, Cagliari

Jets in Heavy Ion Collisions



- Probes to study properties of medium
- Due to interaction of the jet with the medium, the jet is modified:

Jet Quenching



Experimental challenge in HI collisions:
**Separate jet signal from large soft background
originating from bulk**

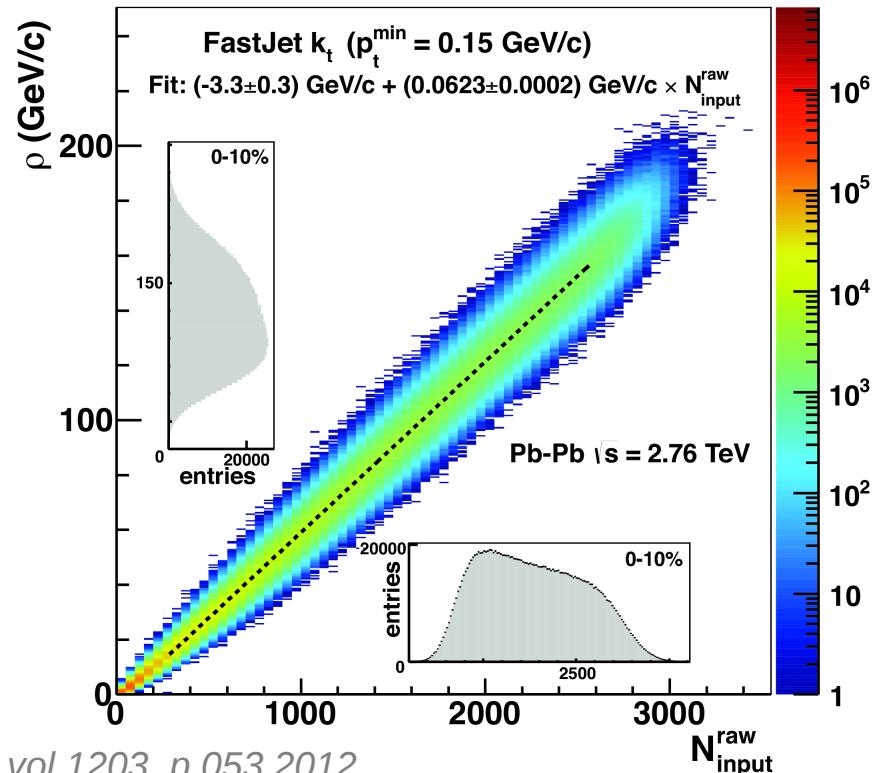
Jet Reconstruction

- ALICE uses sequential recombination algorithms from FastJet package:
 - anti- k_t for signal (stable area)
 - k_t to estimate background density
 - Boost invariant p_t recombination scheme (sets jet mass to zero)
 - **Charged tracks with $p_t > 150 \text{ MeV}/c$**
- Jet reconstruction with charged tracks reconstructed in tracking detectors (ITS + TPC):
 - High precision on particle level
 - Uniform η - φ acceptance: $|\eta| < 0.9$ $0 < \varphi < 2\pi$
 - Neutral energy missing, eg. π^0 , n, γ
measurement not corrected for neutral energy
 - No correction for hadronization effects

Jets in HI events: background

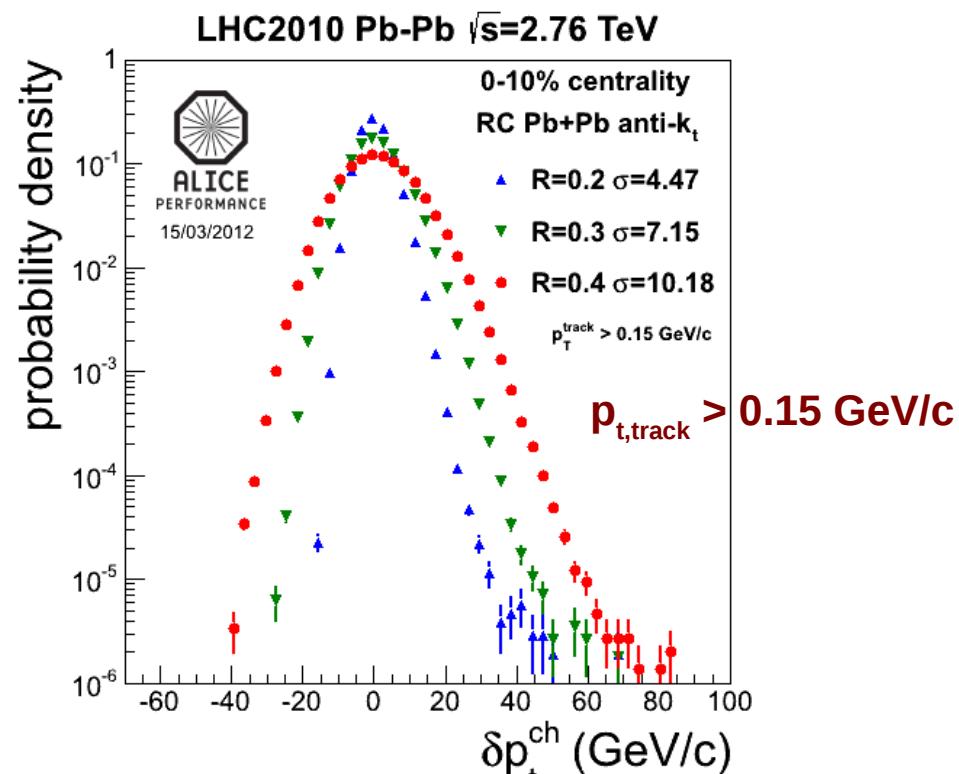
- Two step procedure to correct for UE contaminating the jet:
 - 1) Event-by-event background subtraction:
 - 2) Background fluctuations:

$$\rho = \text{median} \left(\frac{p_T^{jet,i}}{A_i^{\text{jet}}} \right)$$



- Quantified by embedding high p_t probes in measured Pb-Pb events.

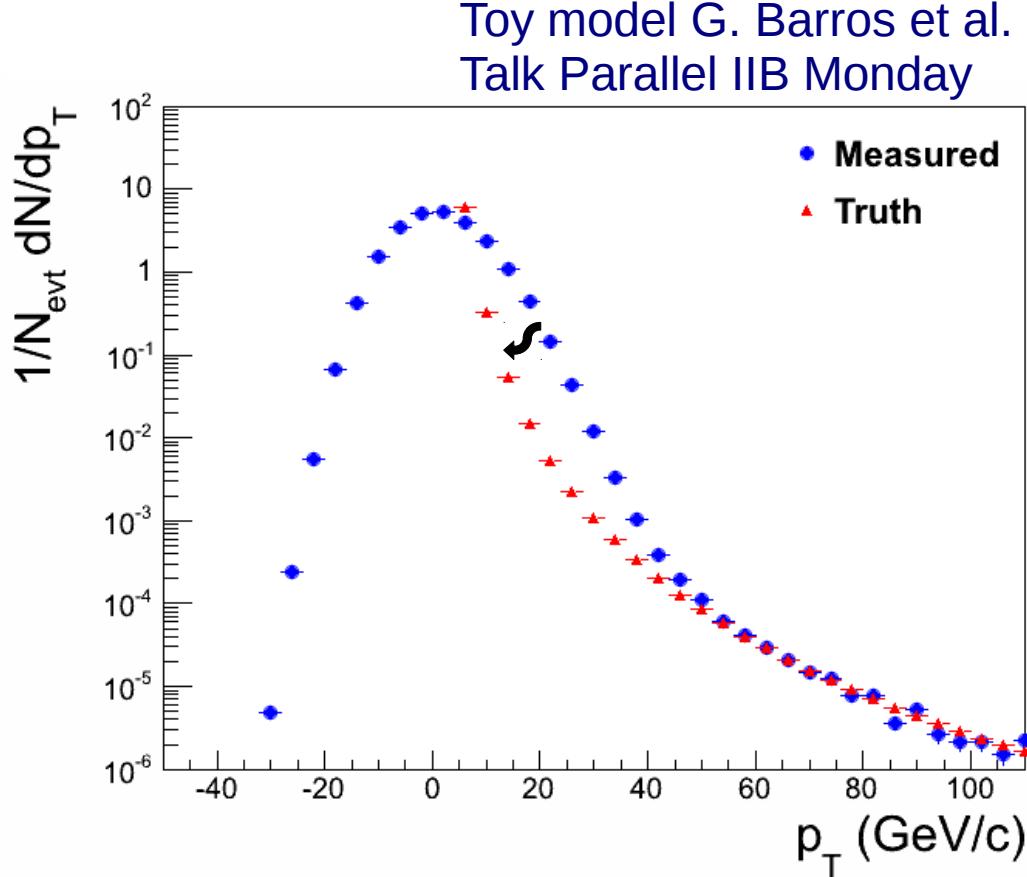
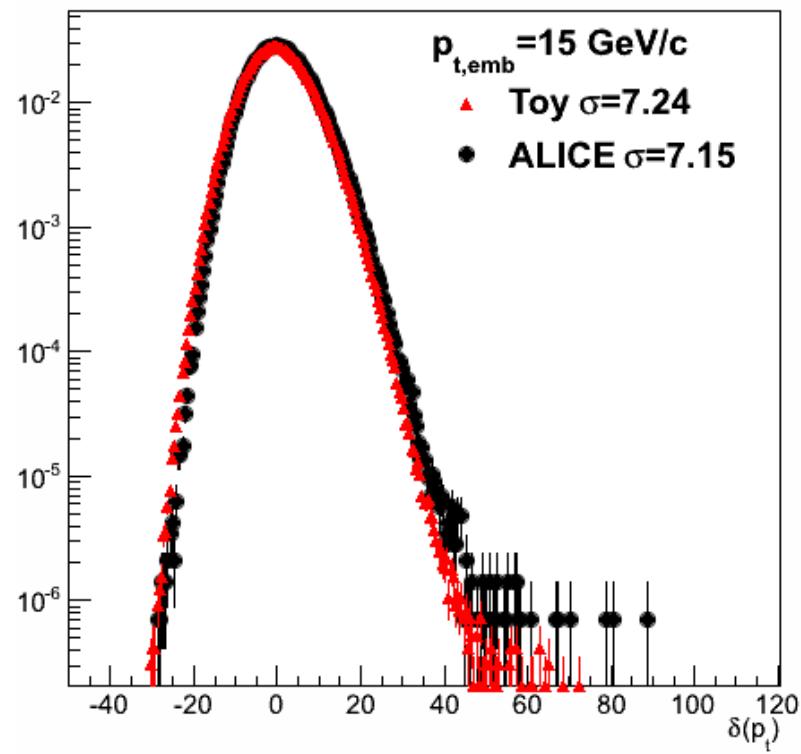
$$\delta_{p_T} = p_{T,jet}^{\text{rec}} - \rho A - p_T^{\text{probe}}$$



Background fluctuations are asymmetric (high p_t tail)

Unfolding the background

- Need to **unfold** measured jet spectrum to obtain 'real' jet spectrum (**Truth**)
- Low p_t jets are dominated by random collections of particles → background jets. These appear up to very high p_t .



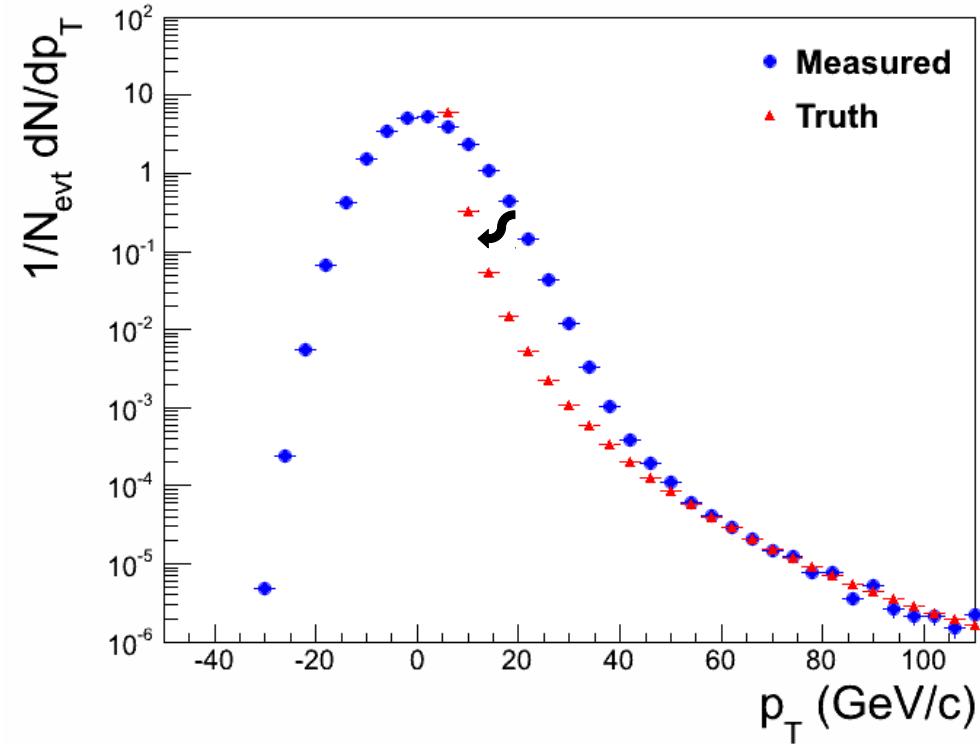
Unfolding the background

- Need to **unfold** measured jet spectrum to obtain 'real' jet spectrum (**Truth**)
- **Refolded** = unfolded jet spectrum smeared with background fluctuations

Assume:

$$\frac{dN}{dp_T} \Big|_{meas} = P(\delta p_T) \otimes \frac{dN}{dp_T} \Big|_{jet}$$

Unfolding done with χ^2 minimization

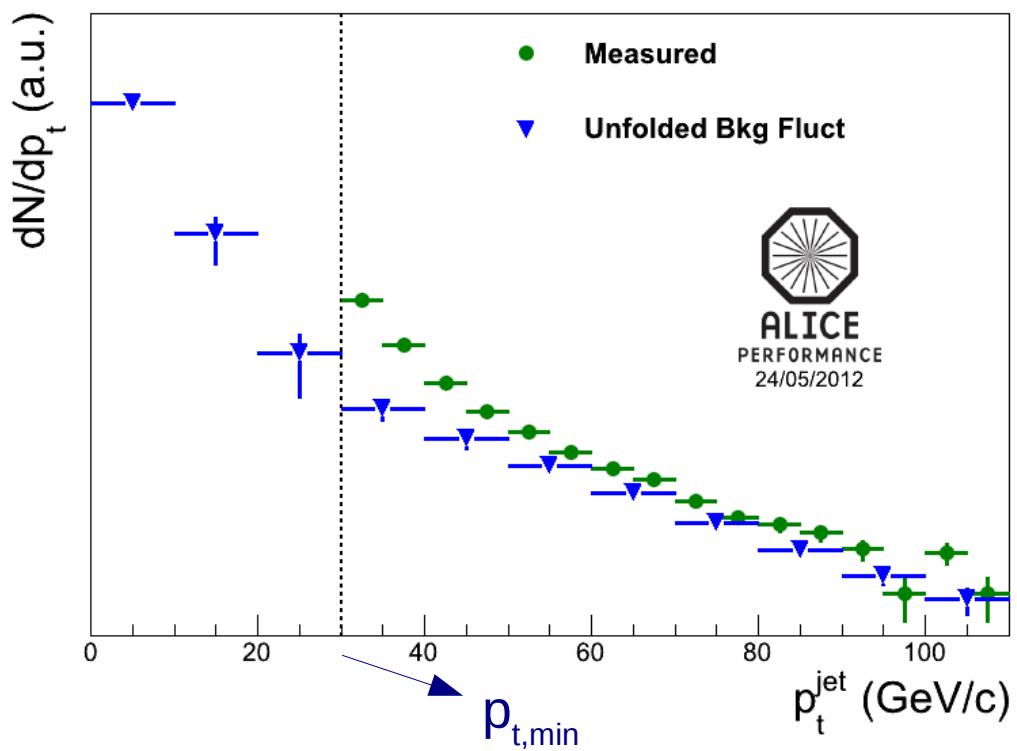


$$\chi^2 = \sum_{refolded} \left(\frac{y_{refolded} - y_{measured}}{\sigma_{measured}} \right)^2 + \beta \sum_{unfolded} \left(\frac{d^2 \log y_{unfolded}}{d \log p_T^2} \right)^2$$

χ^2 -term Regularization/penalty

Unfolding: p_t ranges & systematics

- Measured spectrum: $p_{t,\min} - p_{t,\max}$
 - $p_{t,\min} \sim 5\sigma(\delta p_t) \rightarrow$ Suppression of background jets. Estimated from various toy model studies
- Feed in from low p_t
 - Unfolded starts at $p_t=0$ GeV/c
- Feed in from high p_t



Systematic uncertainty from unfolding procedure
'Shape uncertainty'

Main contributions

- Regularization strength
- p_t cut-off in measured spectrum
- Feed in of low p_t bins in unfolded spectrum

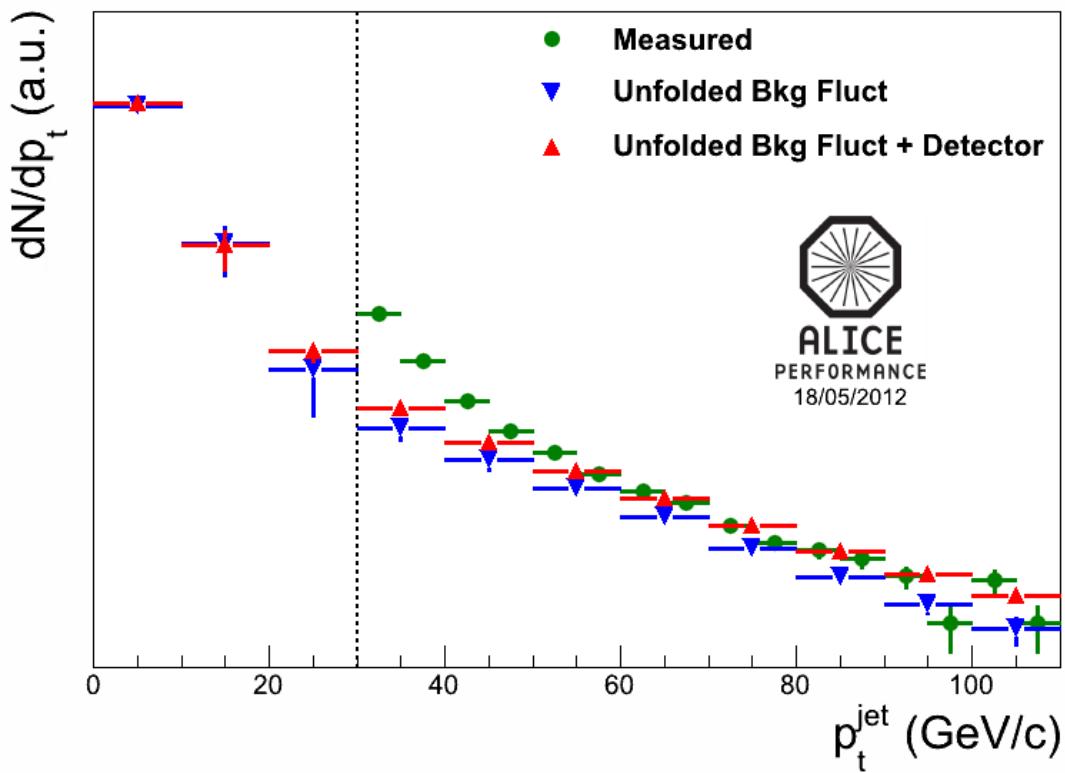
Including detector effects

Response matrix includes background fluctuations and detector effects (tracking efficiency and track p_t resolution).
 No correction for missing neutral particles

Truth \longrightarrow D \longrightarrow Measured

 RM_{det}
 $RM_{\delta p_t}$

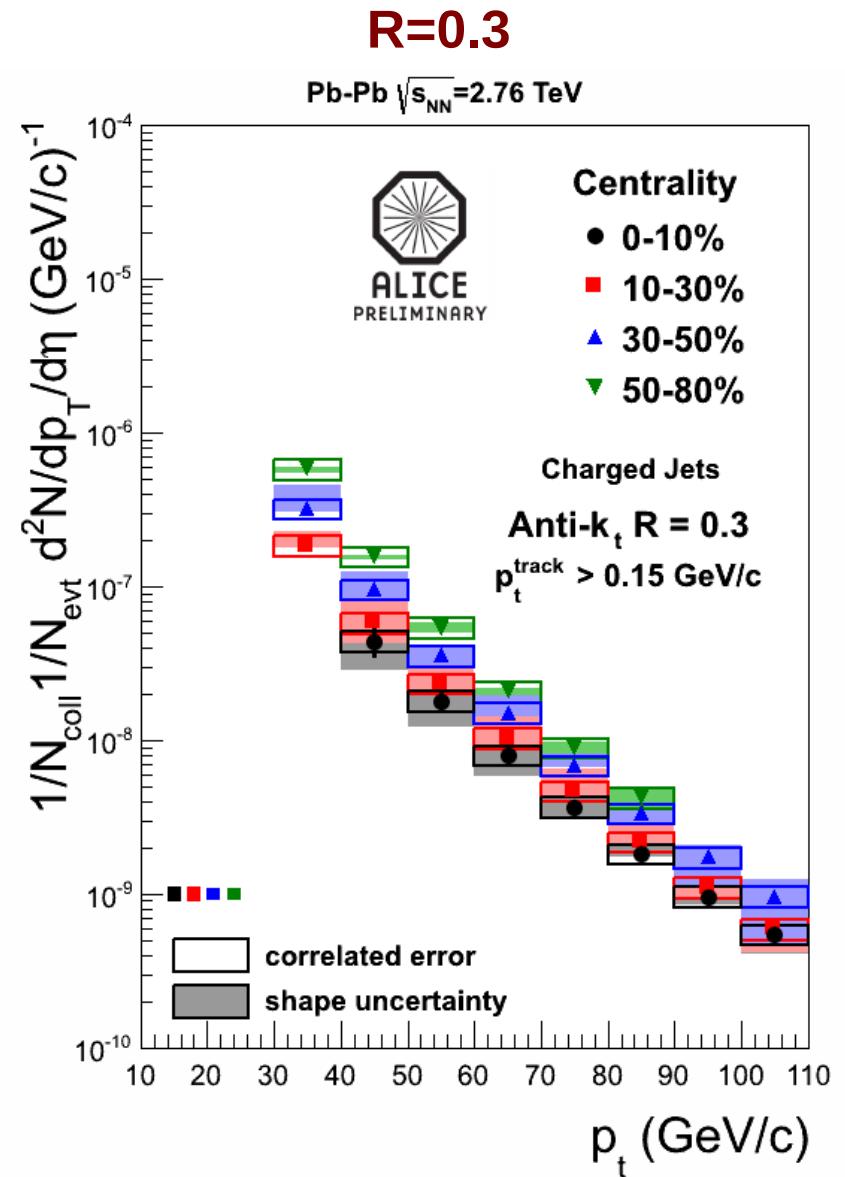
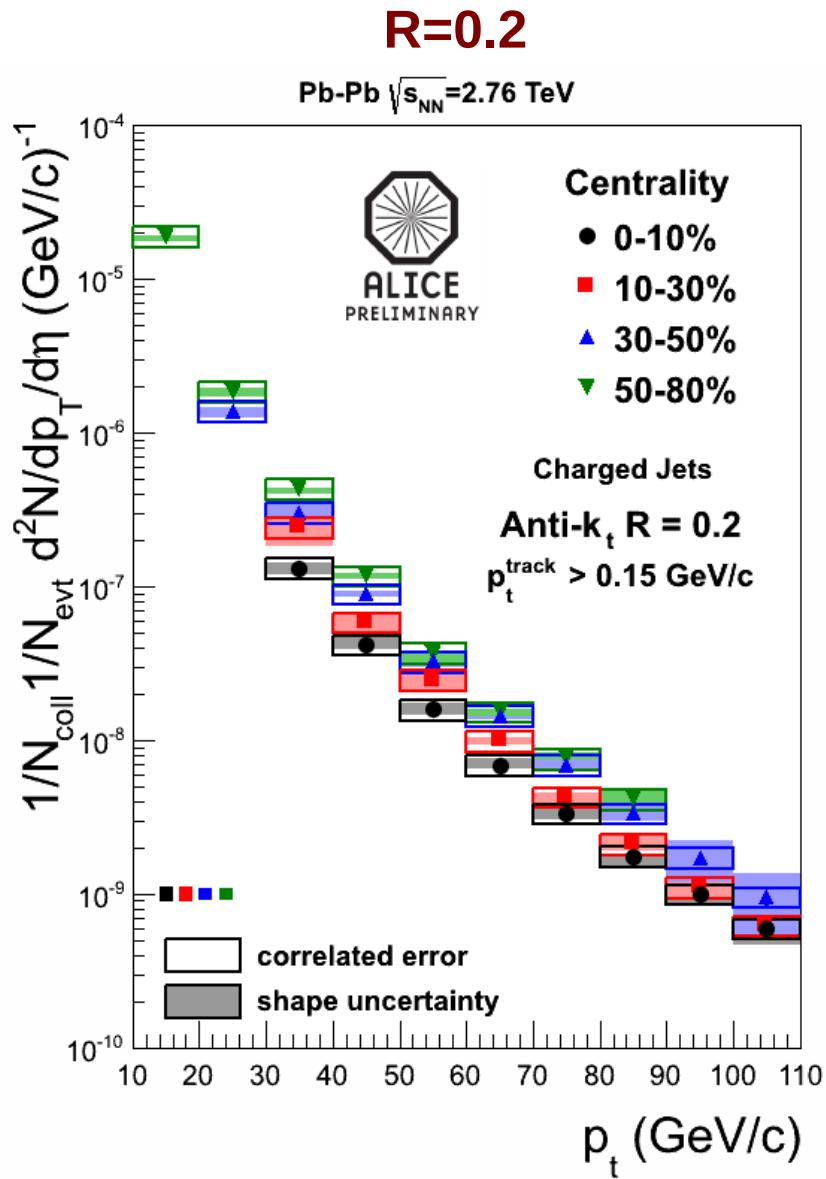
D=jet spectrum after detector effects



$$M = RM_{\delta p_t} \cdot RM_{det} \cdot T$$

$p_t^{\text{jet}} < 60$ GeV/c:
 Dominant correction from
 background fluctuations

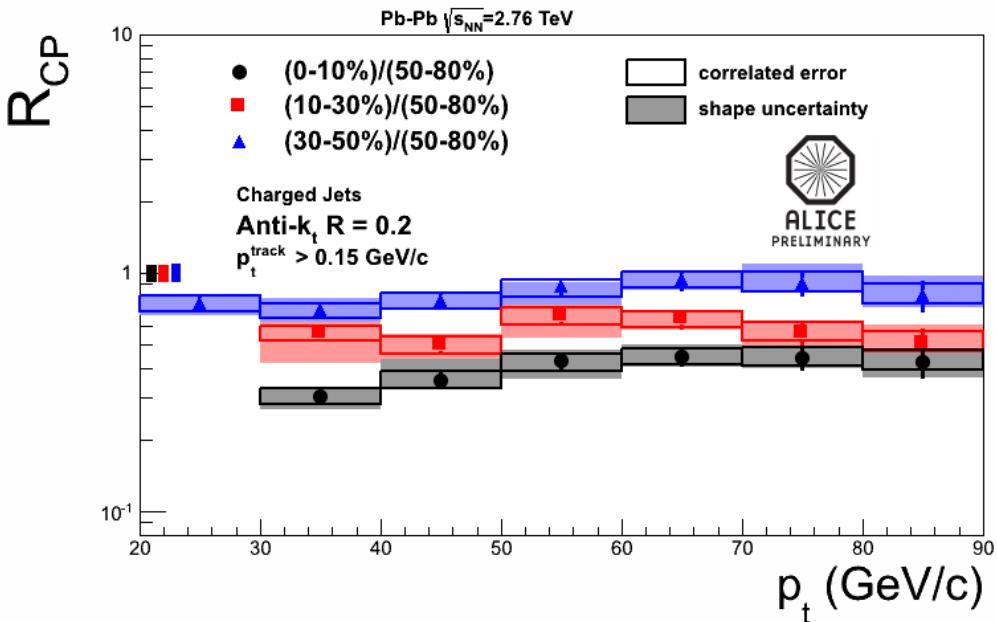
Pb-Pb Jet Spectrum



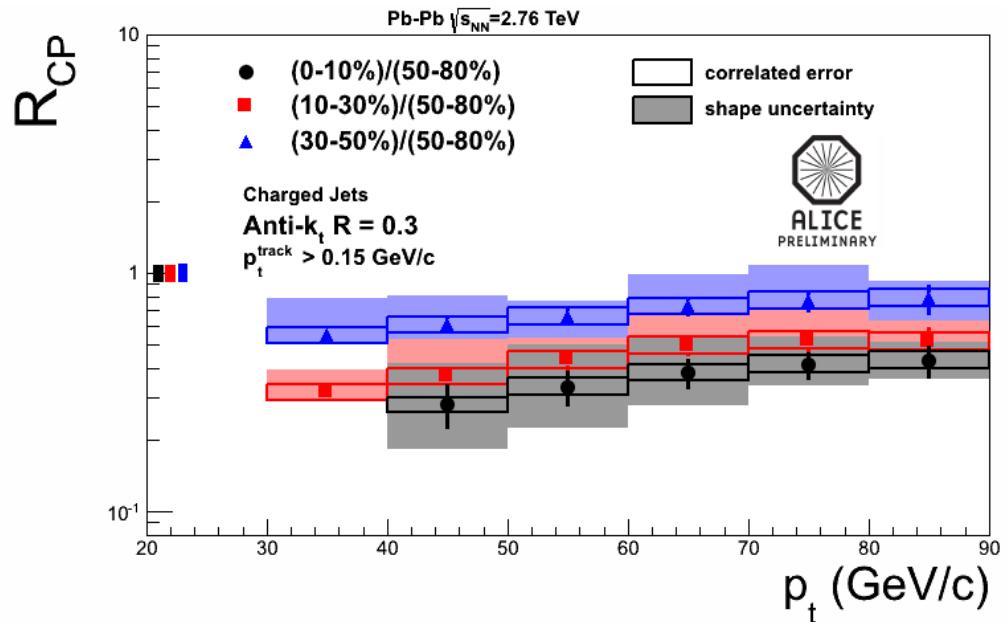
Jet spectra have been measured for 2 cone radii and 4 centrality bins

Jet R_{CP}

R=0.2



R=0.3

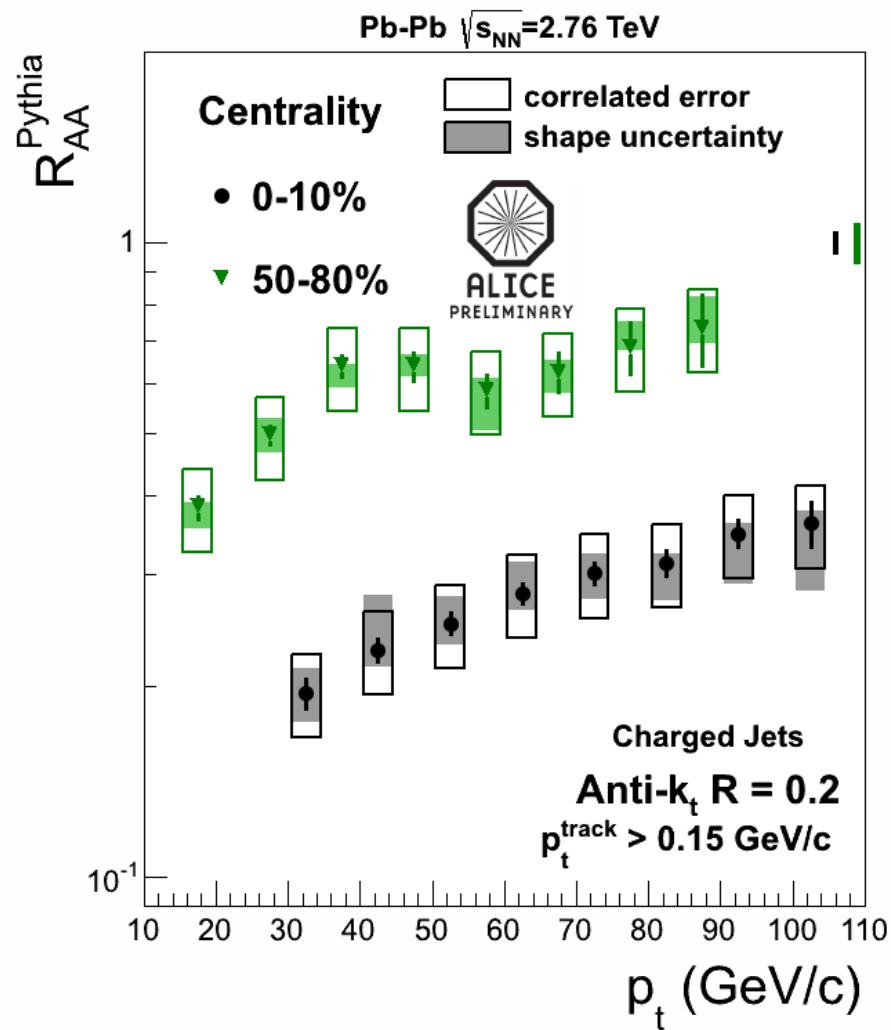


Strong suppression for jets
No strong p_t dependence

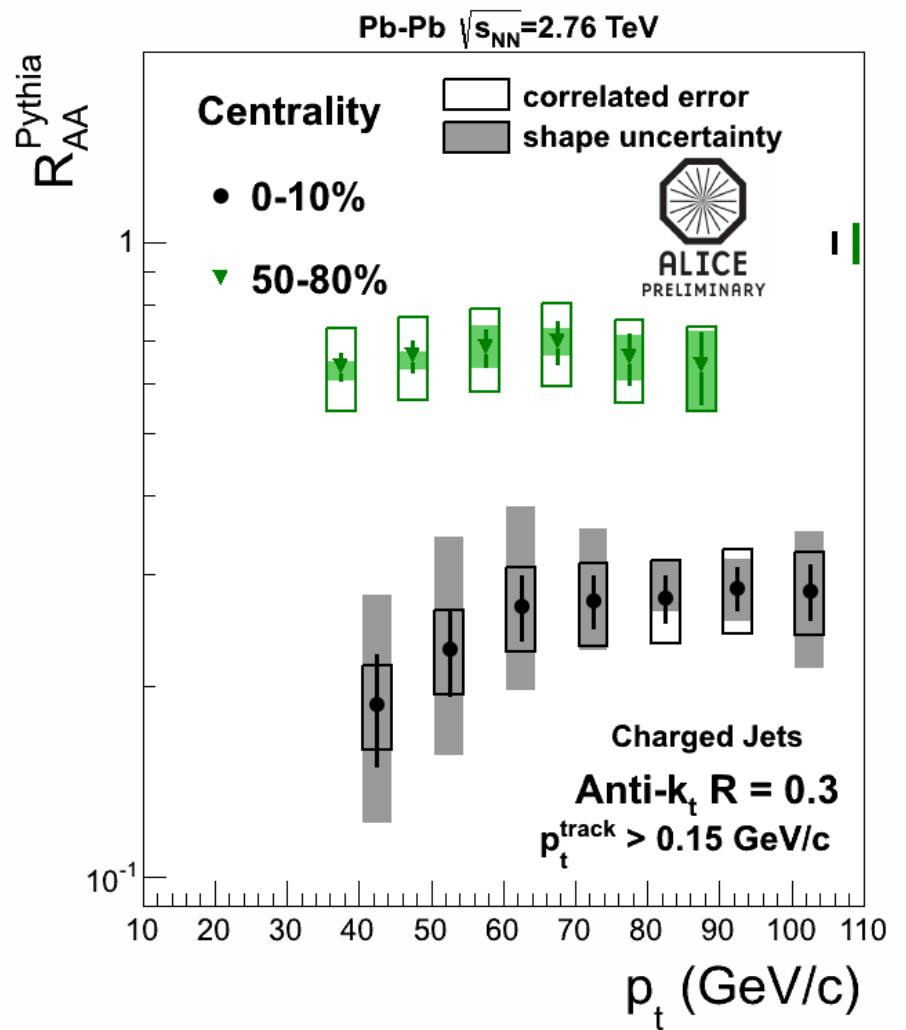
Central events jet $R_{CP} \sim 0.5$
Peripheral closer to 1

Jet R_{AA}

R=0.2



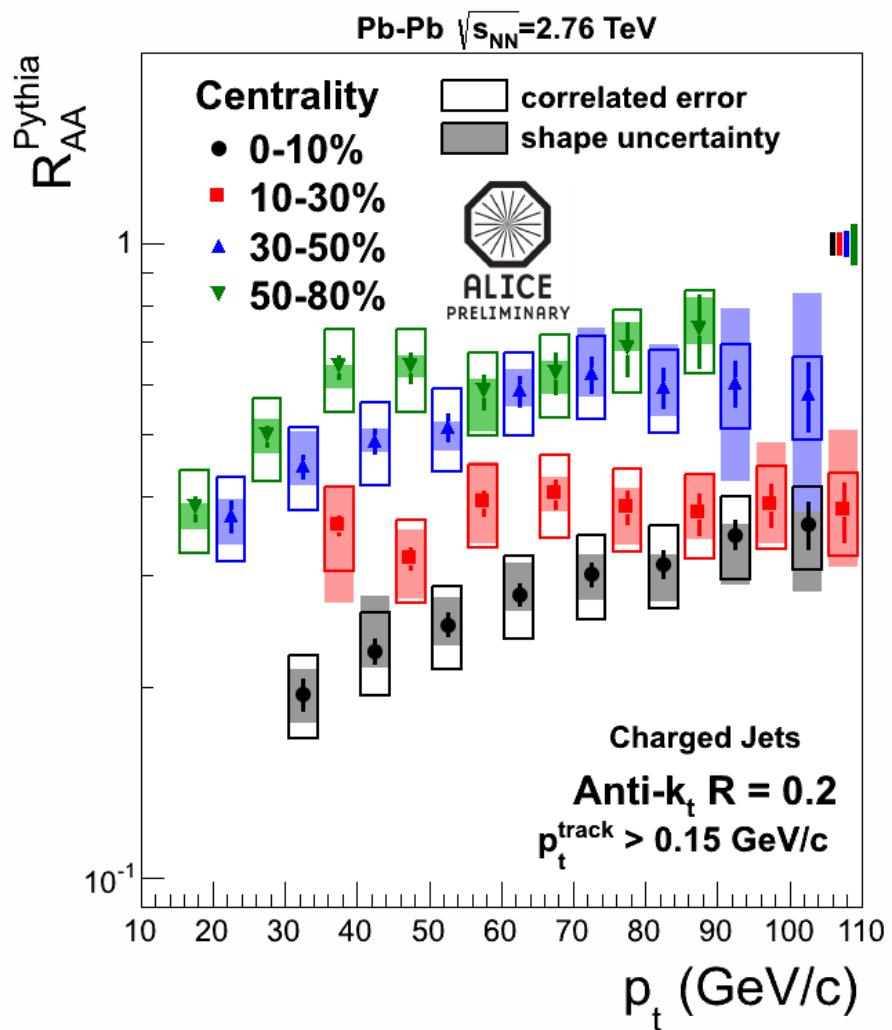
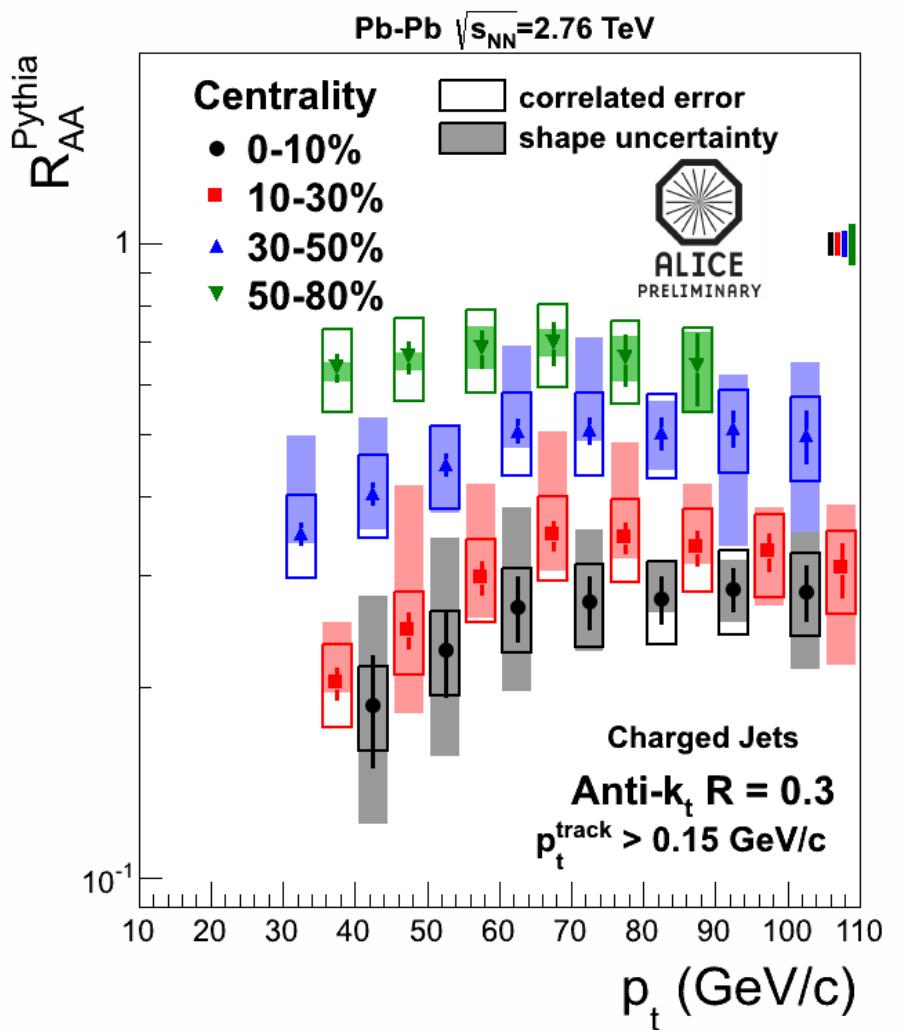
R=0.3



Larger jet suppression for central than peripheral events.

Full jet energy is not captured in heavy ion events for jets with radii R=0.2 and 0.3.

Jet R_{AA}

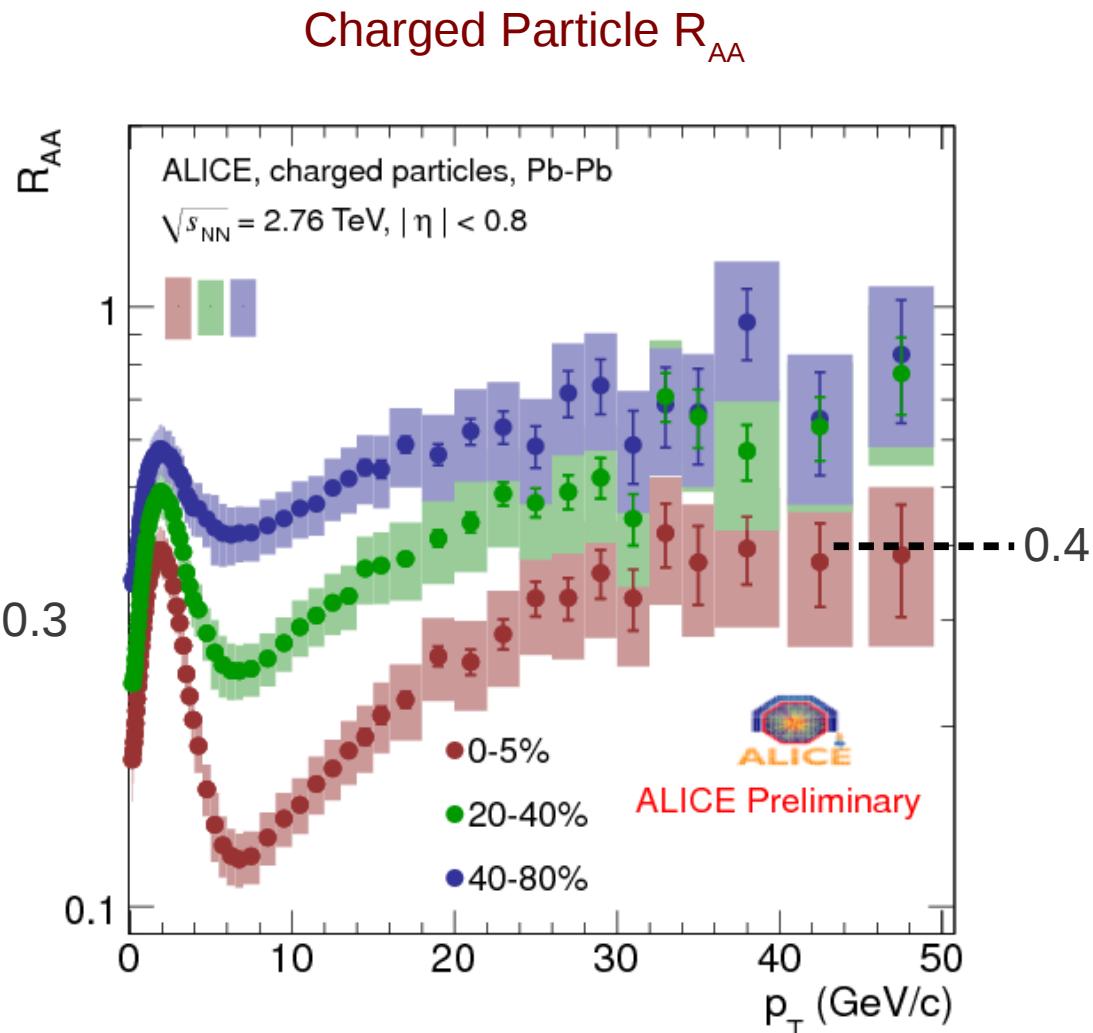
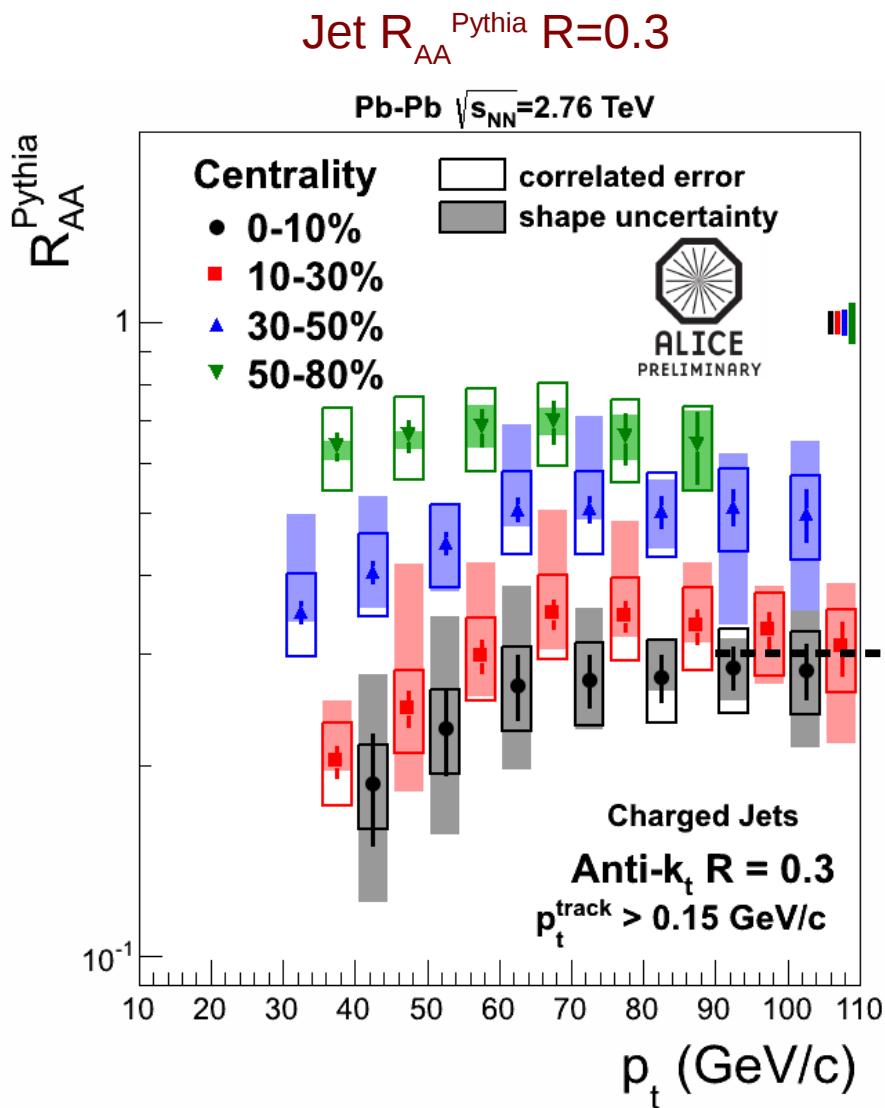
R=0.2

R=0.3


Larger jet suppression for central than for peripheral events.

Full jet energy is not recovered in heavy ion events for jets with radii R=0.2 and 0.3.

Observation of centrality dependent jet suppression

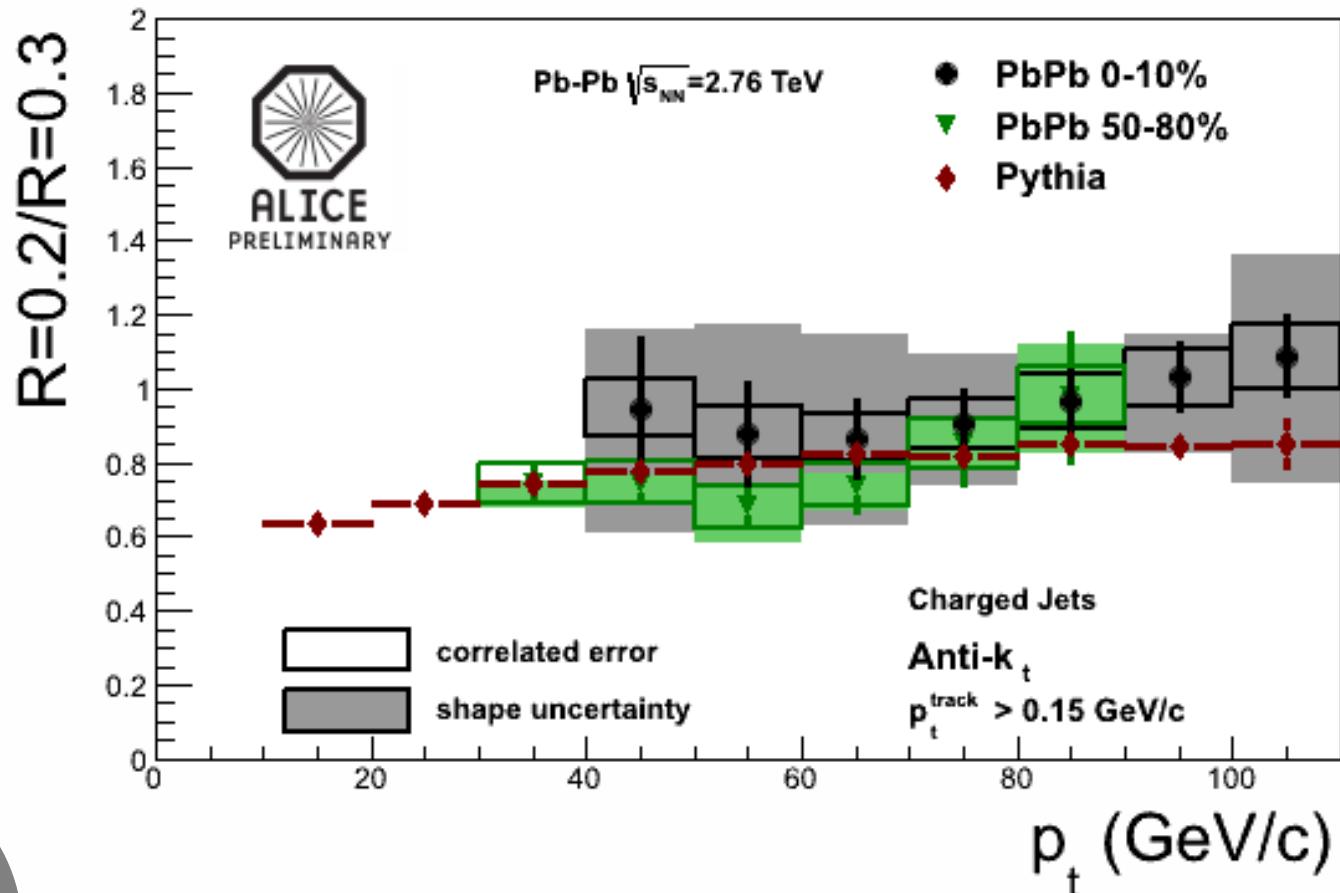
Jet R_{AA} vs Hadron R_{AA}



Jet $R_{AA}^{\text{Pythia}} \leq \text{Hadron } R_{AA}$

Ratio of jet cross sections

$$R=0.2/R=0.3$$



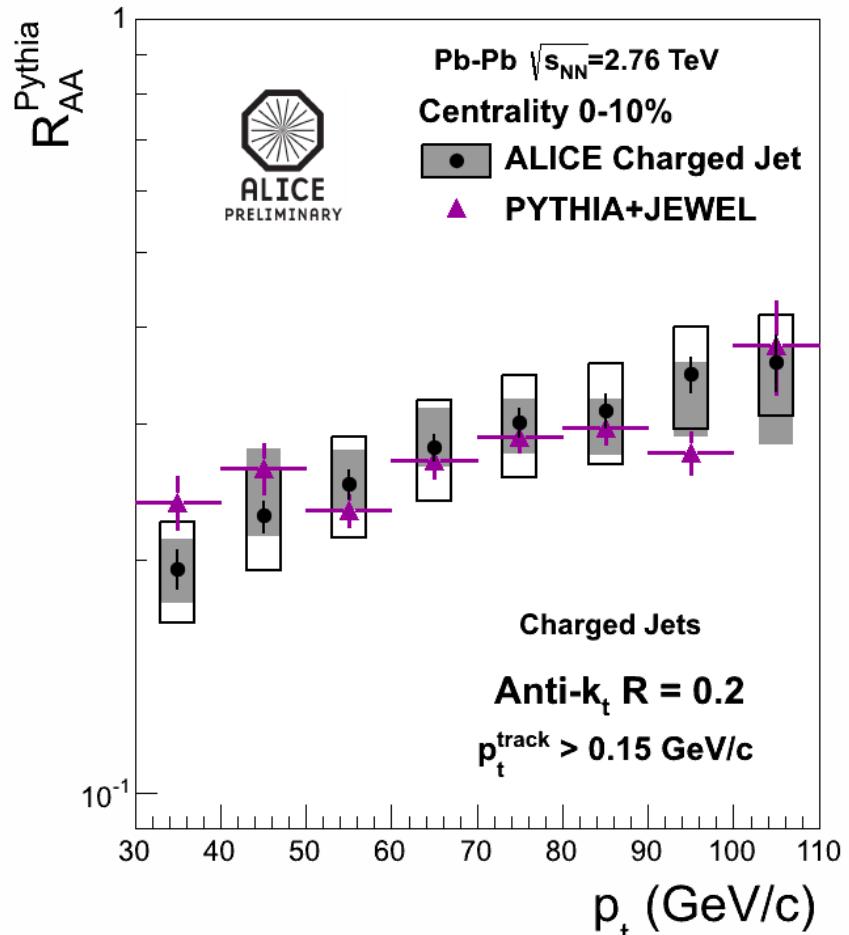
R=0.2

R=0.3

Ratio R=0.2/R=0.3 consistent with vacuum jets
for **peripheral** and **central** collisions

Model Comparison

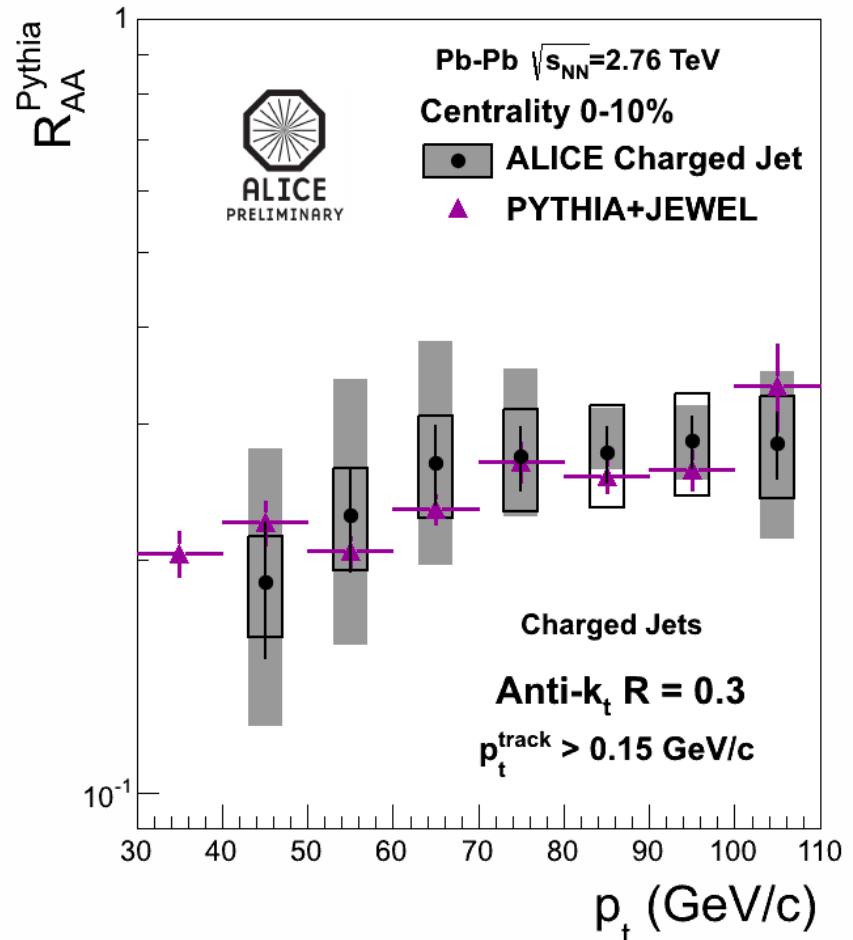
Jet R_{AA} : ALICE vs JEWEL



JEWEL reproduces

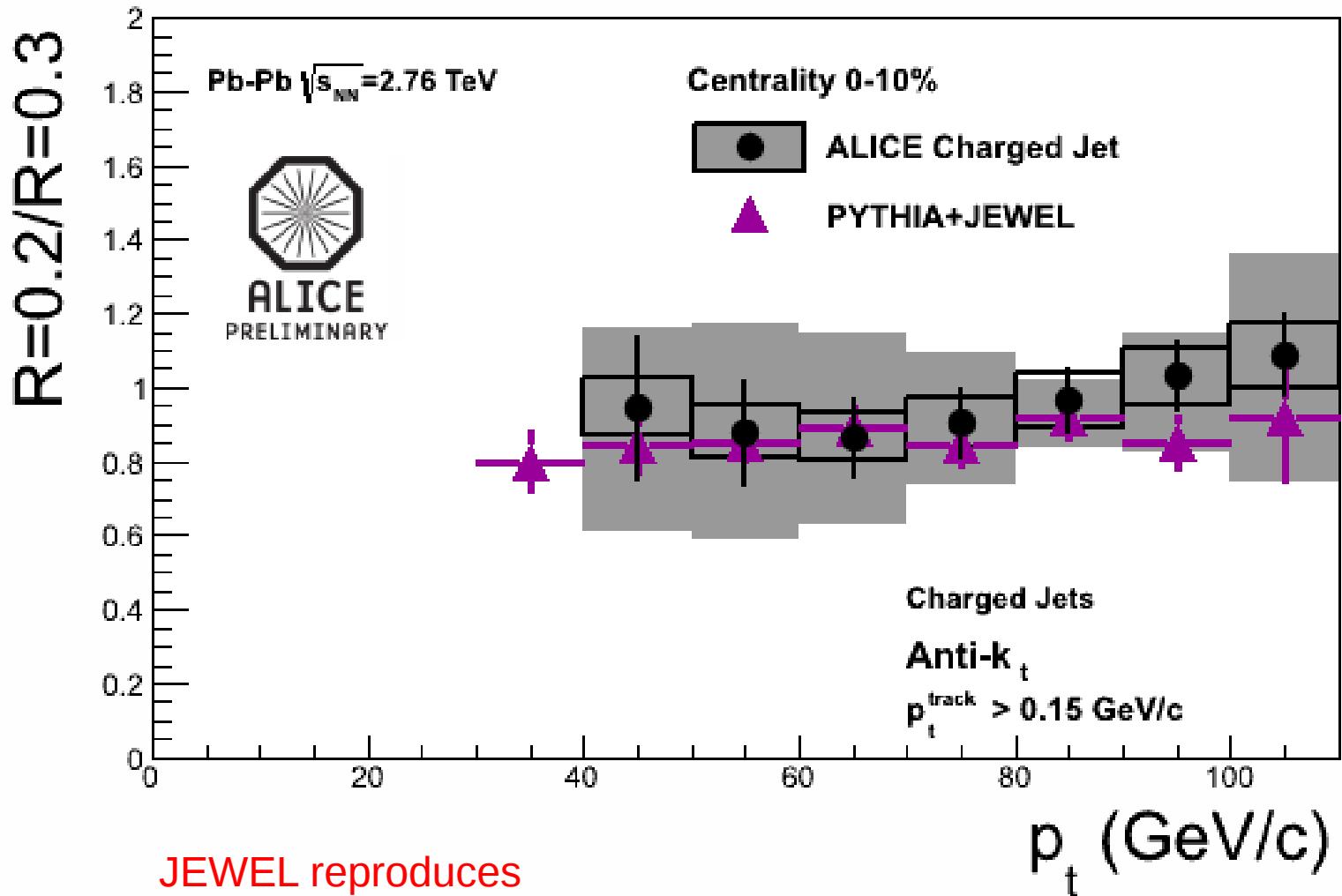
→ Hadron R_{AA} (Zapp, Krauss Wiedemann arXiv:1111.6838)

→ Charged jet R_{AA} for $R=0.2$ and $R=0.3$



JEWEL jet results: private communication

Model Comparison



JEWEL reproduces

- Hadron R_{AA} (Zapp, Krauss Wiedemann arXiv:1111.6838)
- Charged jet R_{AA} for $R=0.2$ and $R=0.3$
- Ratio $R=0.2/R=0.3$

JEWEL jet results: private communication

Summary

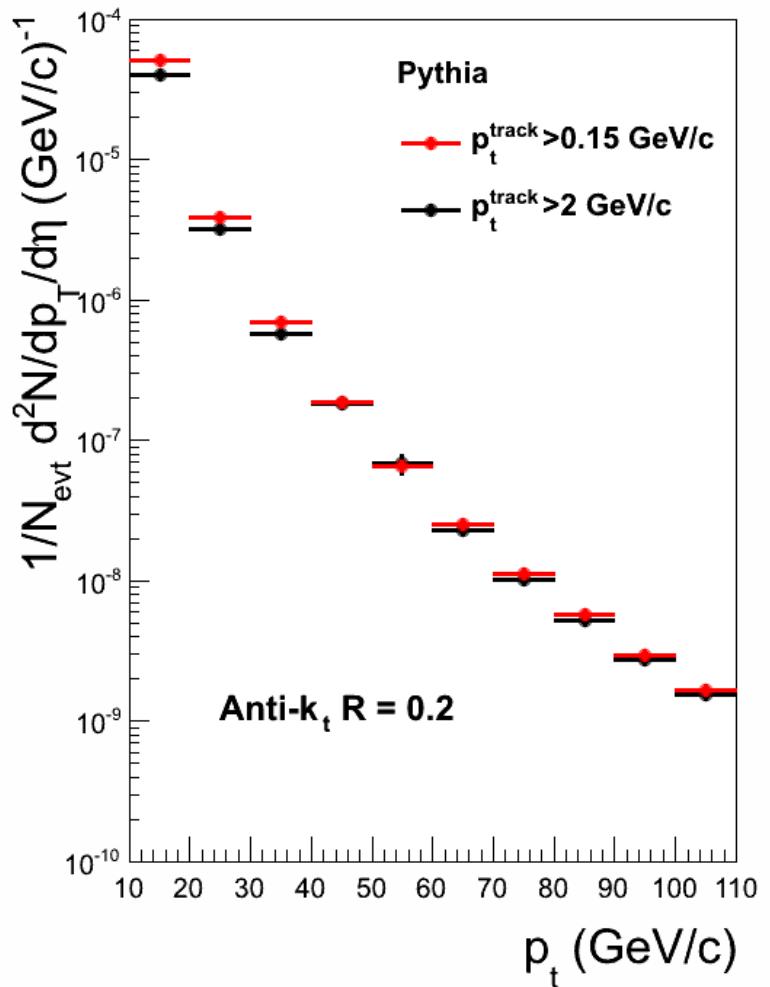
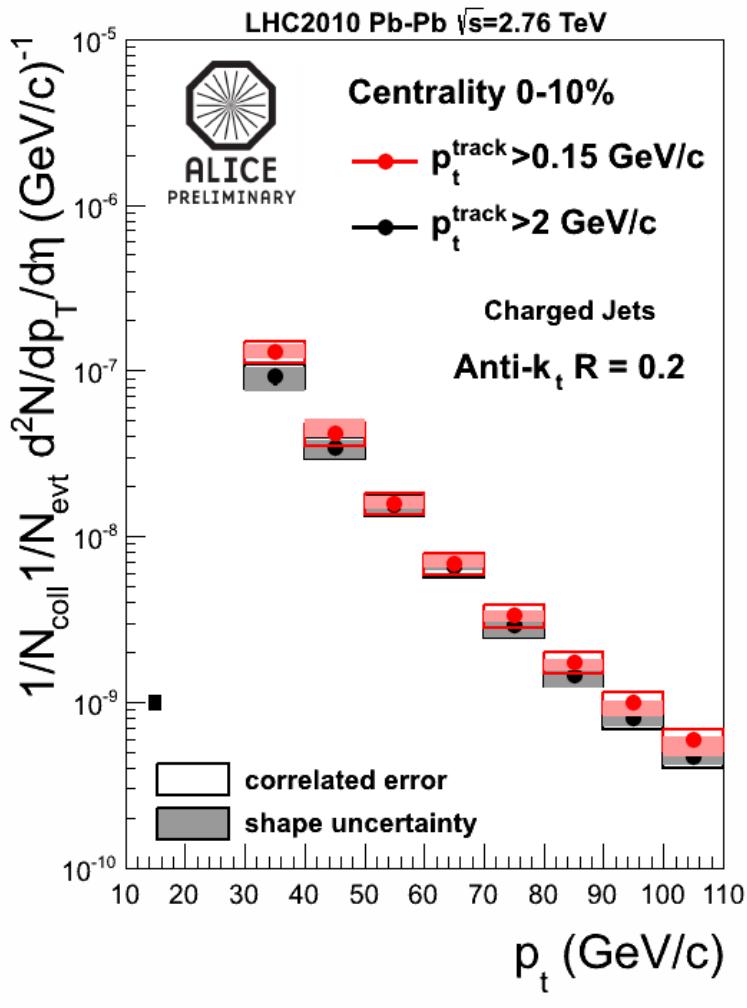
- ALICE measures jets with constituents $p_t > 150 \text{ MeV}$
 - Average HI background is subtracted event-by-event
 - Background fluctuations are unfolded
- Strong jet suppression in central events
- No signs of modified jet structure observed in ratio of jet cross section $R=0.2/R=0.3$
- Jet $R_{AA} \leq$ Hadron R_{AA}

backup

Jet Constituents

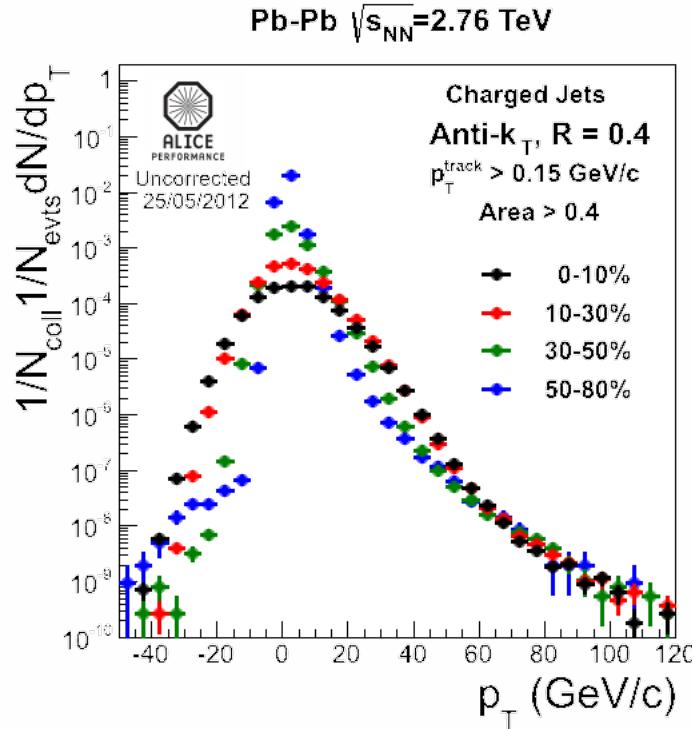
Spectra corrected for detector level effects for particles with $p_t > p_{t,\min,track}$

$R=0.2$: PbPb very similar to Pythia \rightarrow shift of spectrum in p_t for PbPb and Pythia.
 Not many soft particles in small cone of $R=0.2$.



Uncorrected Jet Spectra

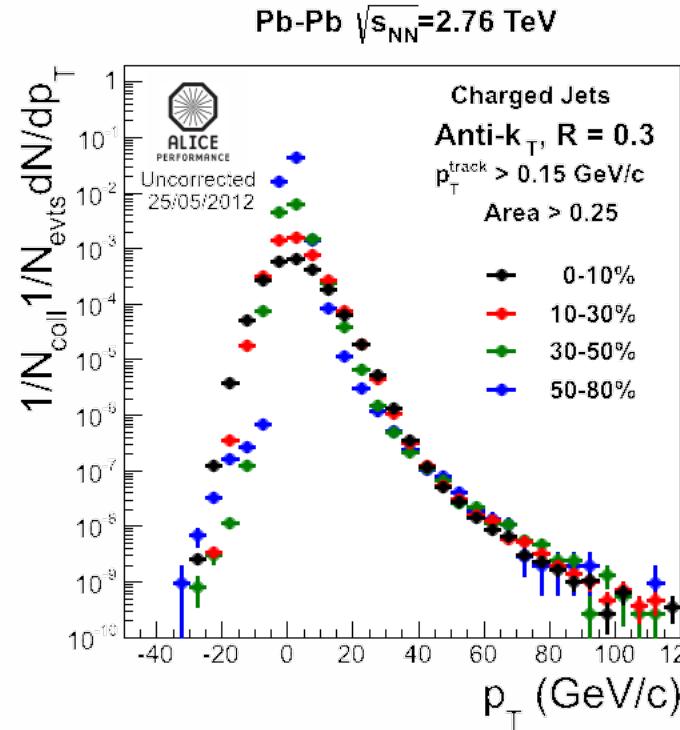
R=0.4



$$\sigma(\delta p_t) \sim 11 \text{ GeV}$$

$\sigma(\delta p_t)$ values for central events

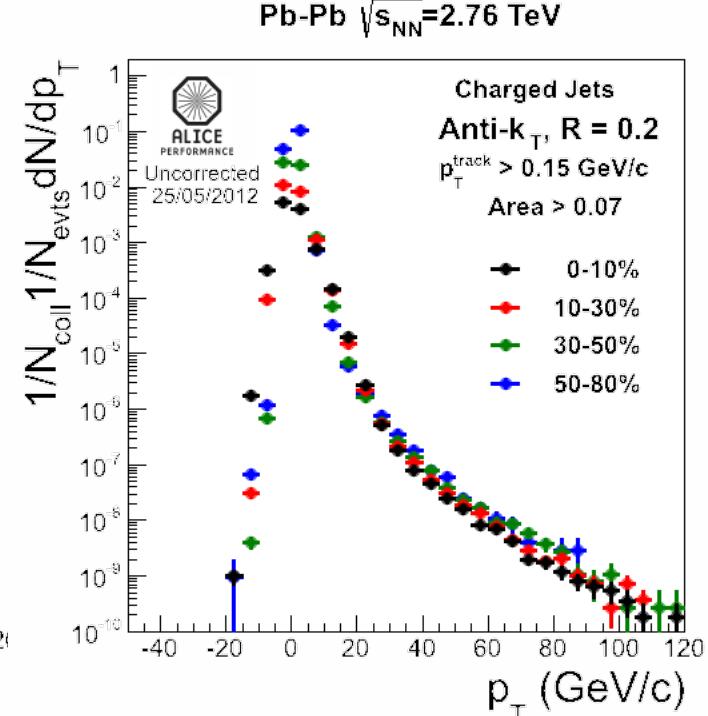
R=0.3



$$\sigma(\delta p_t) \sim 7 \text{ GeV}$$

$$\sigma(\delta p_t) \sim 7 \text{ GeV}$$

R=0.2



$$\sigma(\delta p_t) \sim 4.5 \text{ GeV}$$

$p_{t,\text{track}} > 0.15 \text{ GeV}/c$

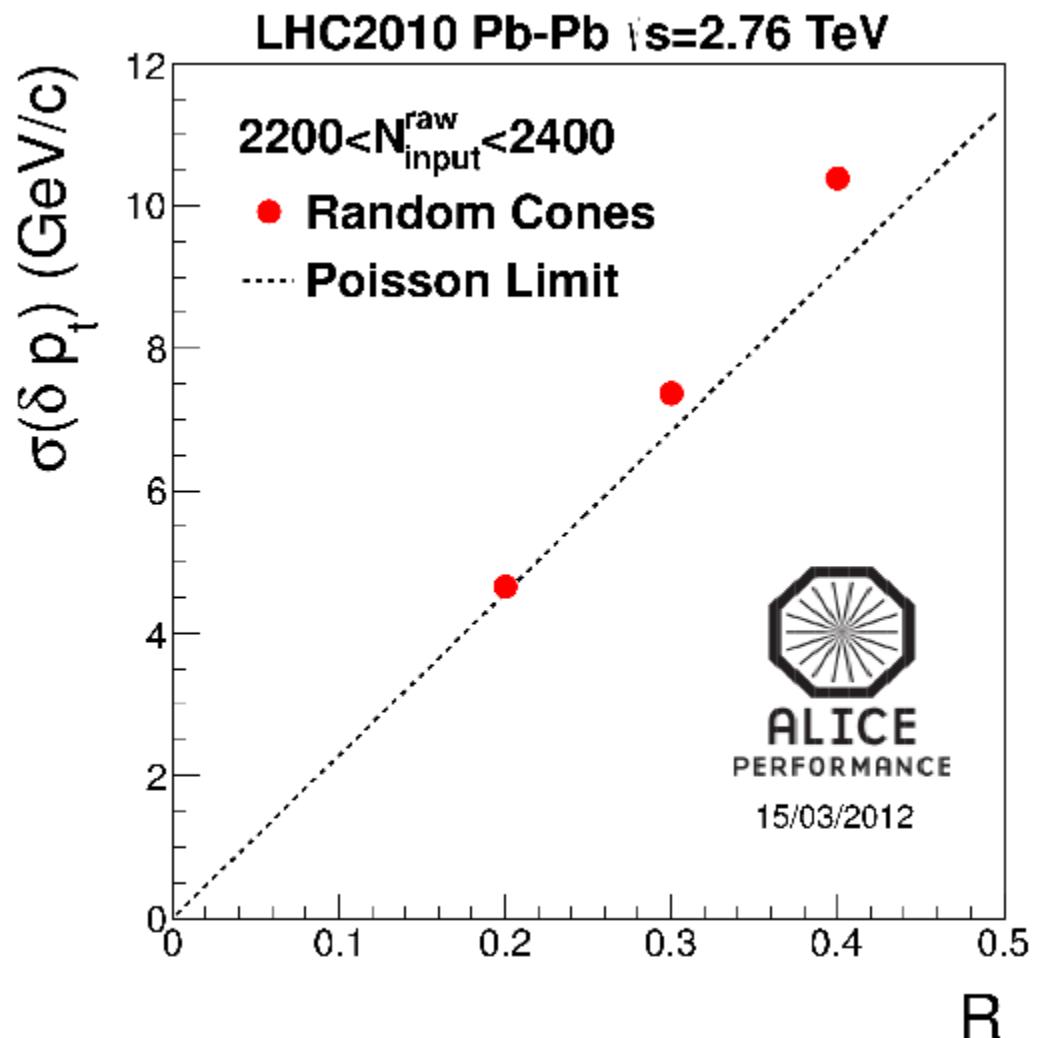
Smaller Jets \rightarrow Less Background Fluctuations

Area dependence

- Multiplicity bin typical for 10% most central events
- Reduced background fluctuations for smaller jet areas
-

$$\sigma(\delta p_t) = \sqrt{N_A \cdot \sigma^2(p_t) + N_A \cdot \langle p_t \rangle^2}.$$

- Measured $\sigma(\delta p_T)$ larger than naive expectation from only statistical fluctuations
 - flow and hard jets



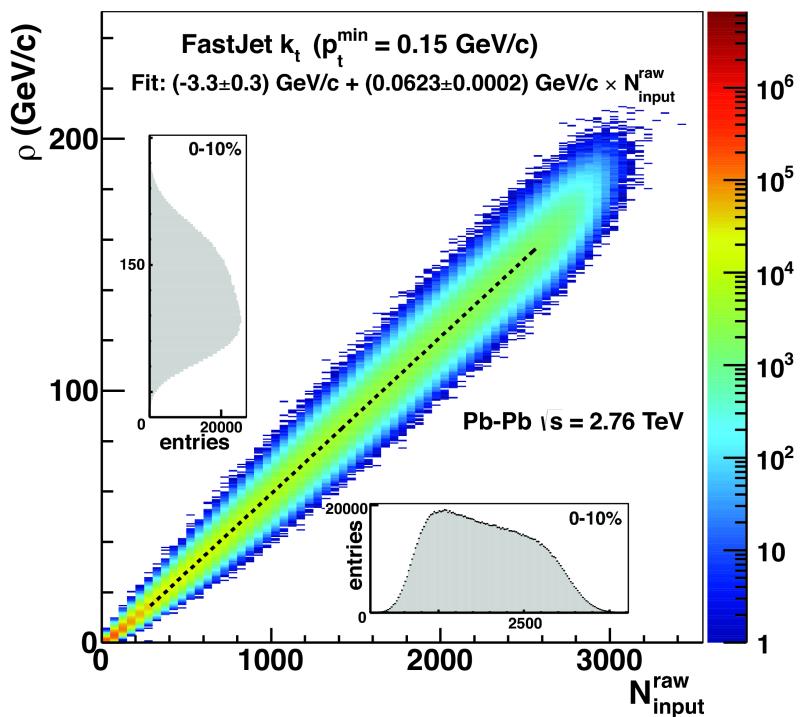
Background Fluctuations

- Background fluctuations estimated by studying the response of embedded high p_T probe in heavy ion event.
- Data driven approach to estimate influence of background fluctuations on jet reconstruction.
- We embed different kind of probes:
 - Random cones
 - Single tracks
 - Jets from full detector simulation pp @ 2.76 TeV
- Response is quantified by comparing the reconstructed jet to the embedded probe:

$$\delta_{p_T} = p_{T,jet}^{rec} - \rho A - p_T^{probe}$$

Event Background

- Event-by-event background subtraction



$$\rho = \text{median} \left(\frac{p_T^{jet,i}}{A_i^{\text{jet}}} \right)$$

- Background density scales with event multiplicity:
 $\rho \sim N \langle p_T \rangle$
- 0-10% centrality:
 $\langle \rho \rangle \sim 140$ GeV/area
 $\rightarrow 70$ GeV/c for $R=0.4$ cone
- Event-by-event fluctuations of ρ for fixed multiplicity.

Jet analysis with ALICE

- In this analysis jet reconstruction with charged particles:
 - Central tracking system: Time Projection Chamber (TPC) + Inner Tracking System (ITS)
 - Uniform acceptance: $|\eta| < 0.9$ and $0 < \phi < 2\pi$
- 15M events from 2010 PbPb run

