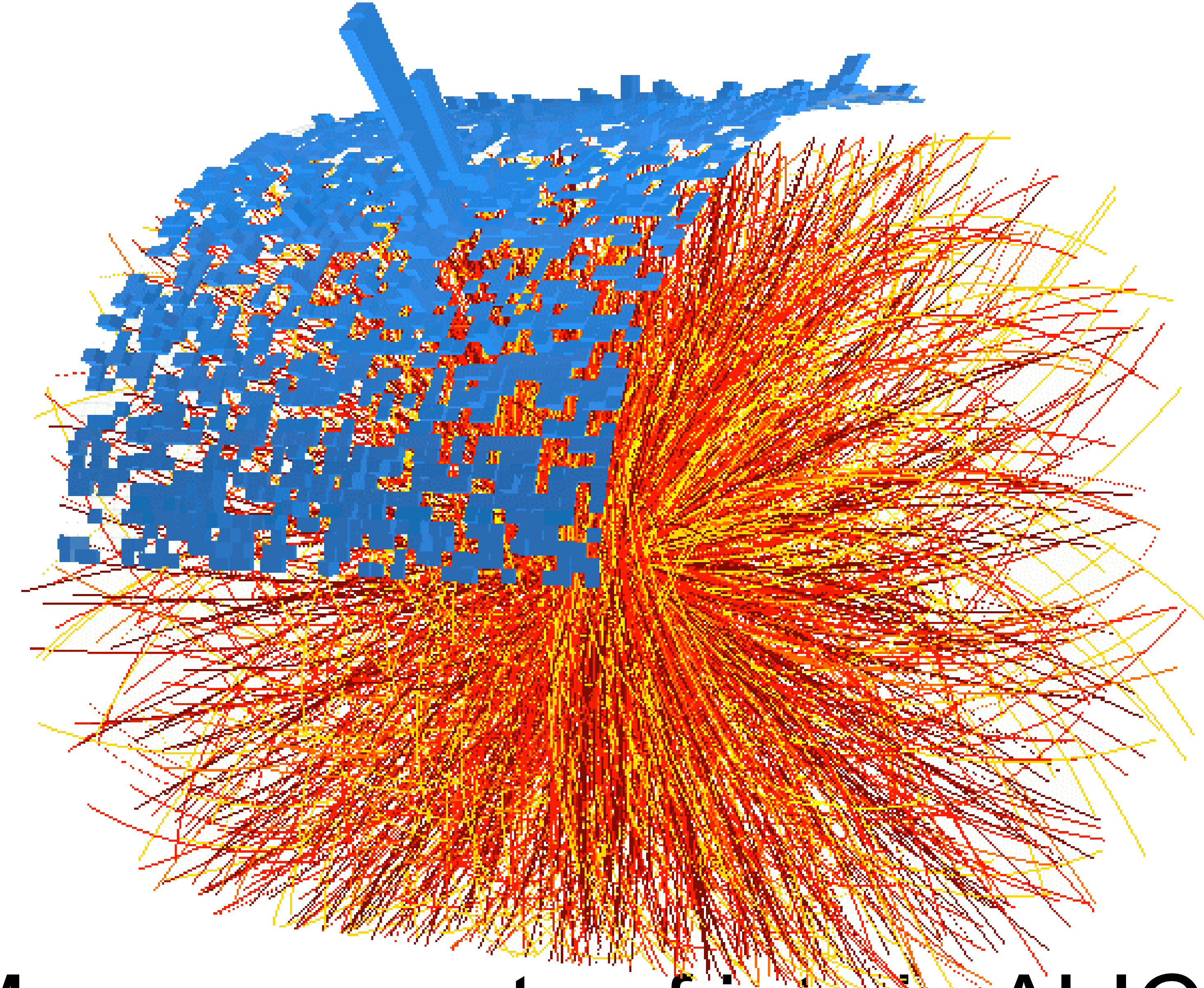


Measurements of jets in ALICE

Christine Nattrass

University of Tennessee, Knoxville

for the ALICE collaboration

Jet formation in a vacuum

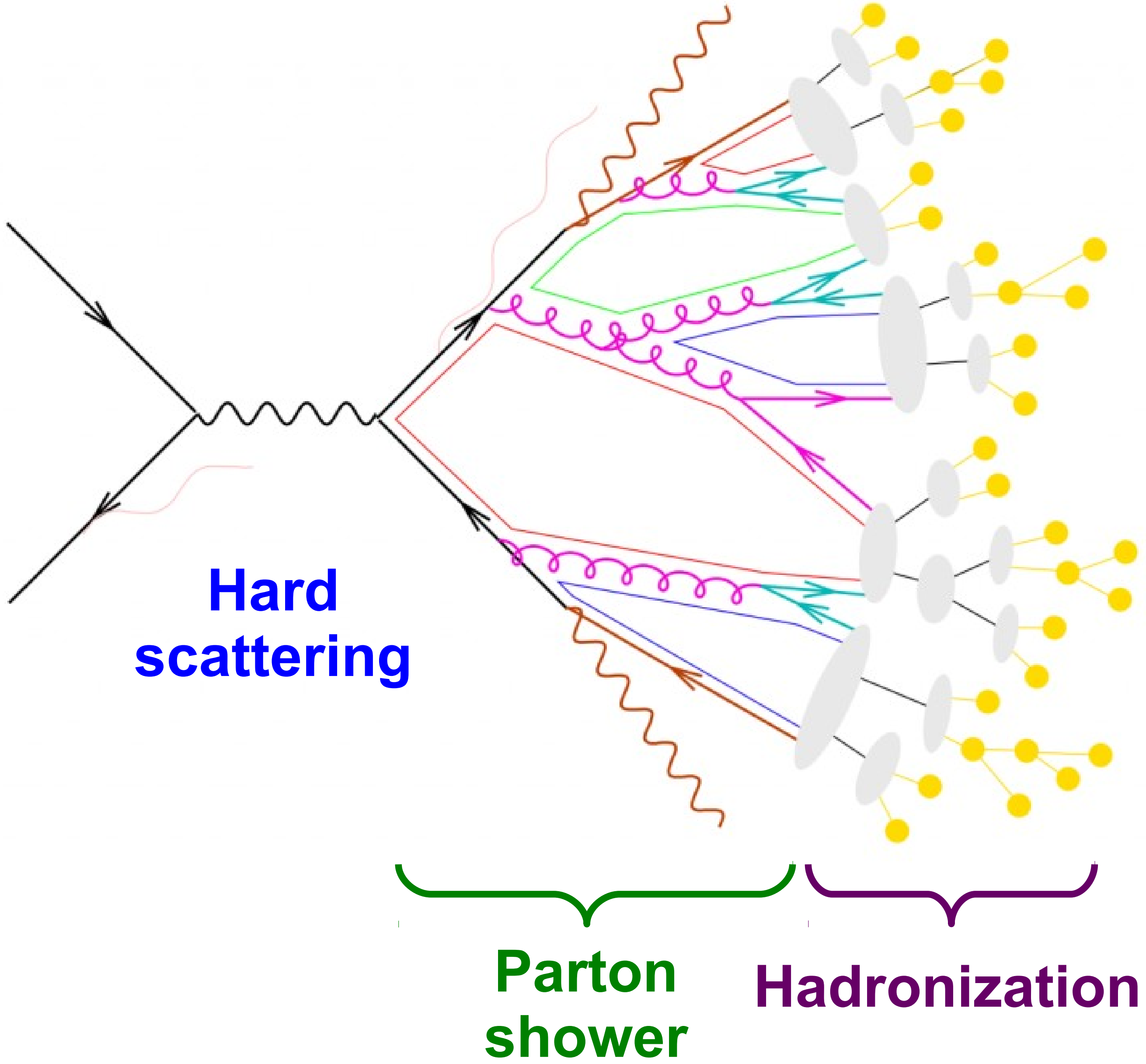


Image from http://www.gk-eichtheorien.physik.uni-mainz.de/Dateien/Zeppenfeld-3.pdf

Jet formation in a vacuum

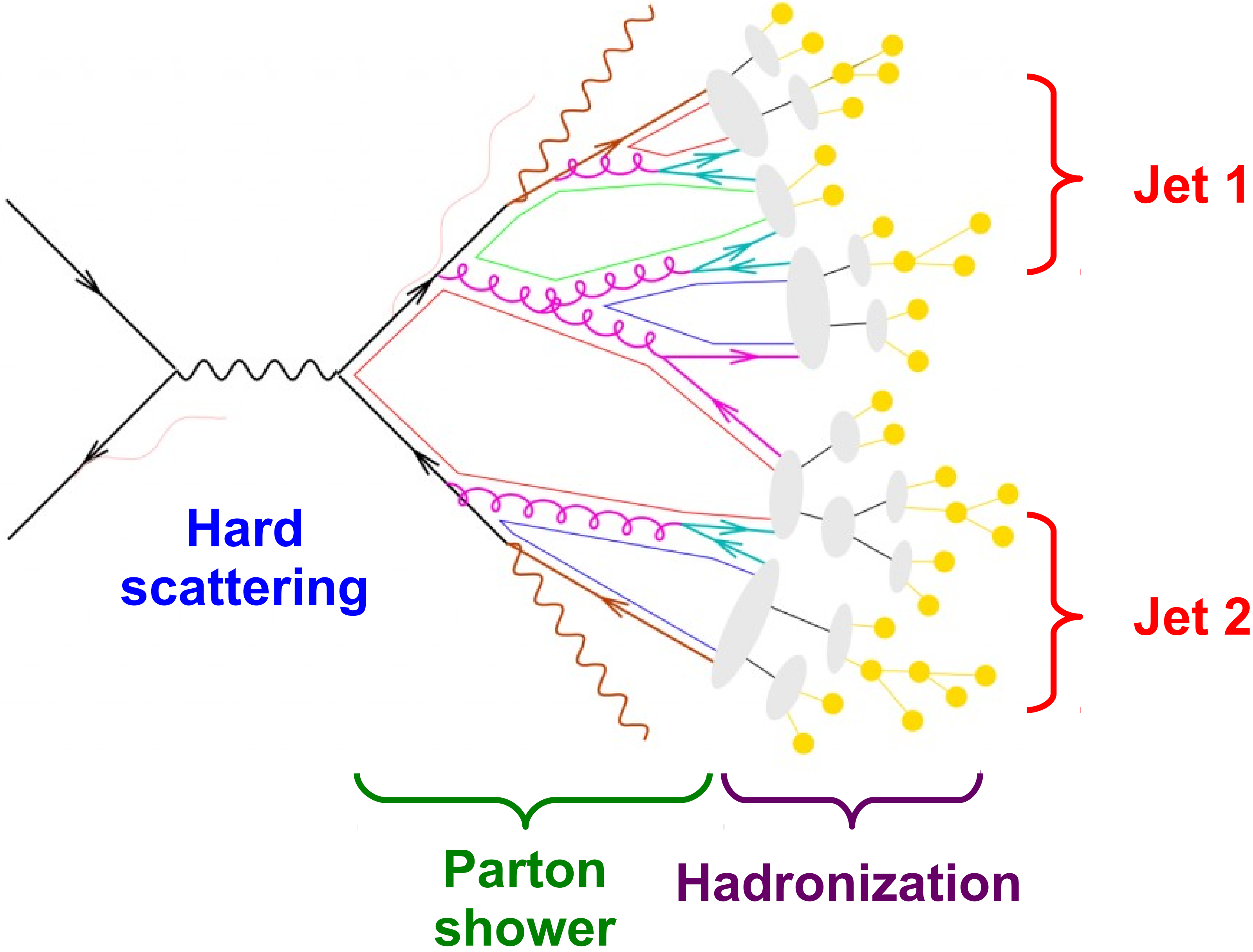


Image from http://www.gk-eichtheorien.physik.uni-mainz.de/Dateien/Zeppenfeld-3.pdf

Jet finding in pp collisions

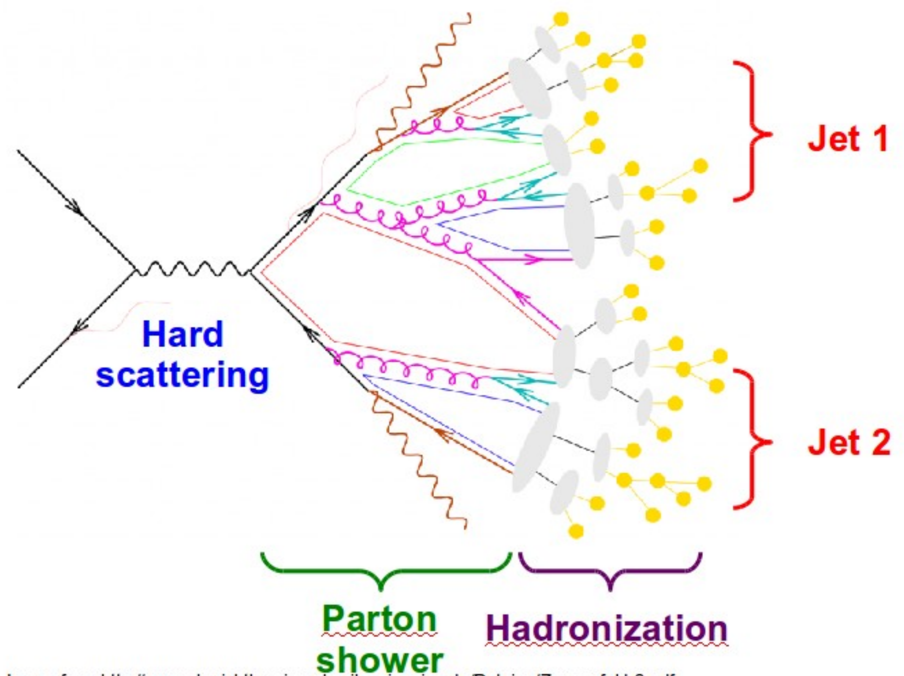


Image from http://www.gk-eichtheorien.physik.uni-mainz.de/Dateien/Zeppenfeld-3.pdf

- No unambiguous definition of a jet
- Jet finder: groups final state particles into jet candidates
  - Anti-k_T algorithm
    JHEP 0804 (2008) 063 [arXiv:0802.1189]
- Depends on hadronization
- Ideally
  - Infrared safe
  - Colinear safe

Jet finding in AA collisions

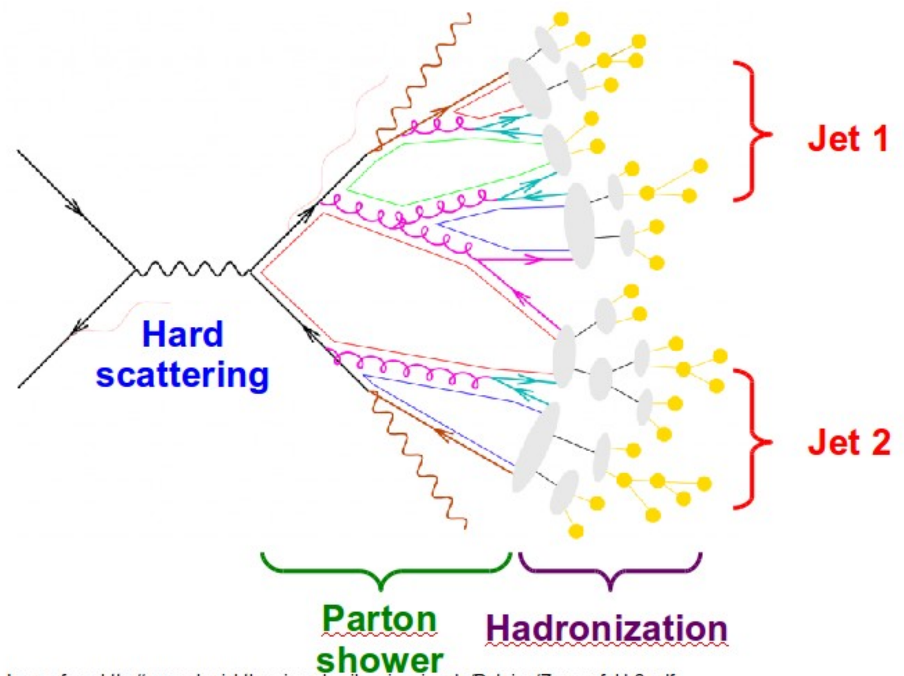
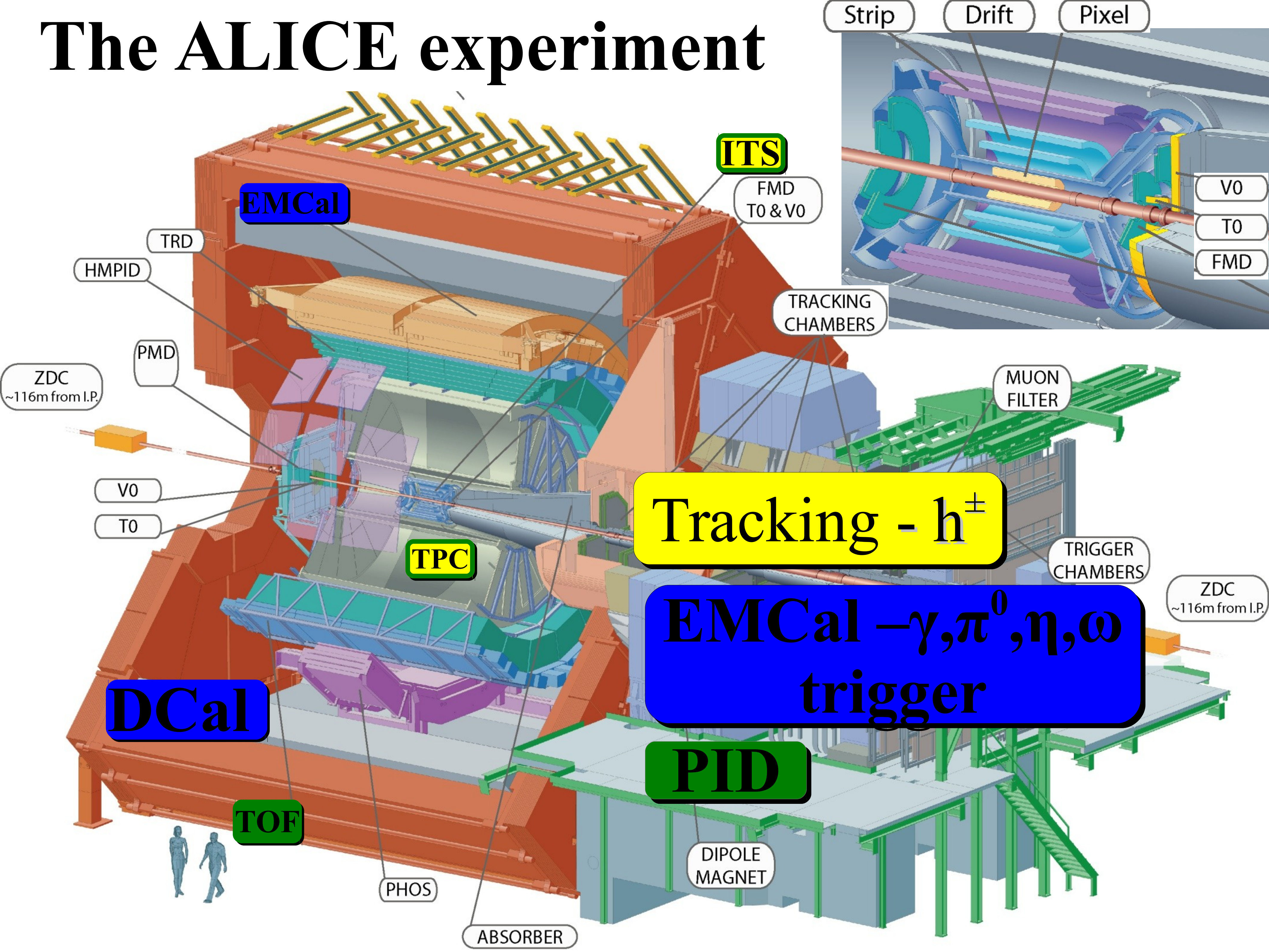


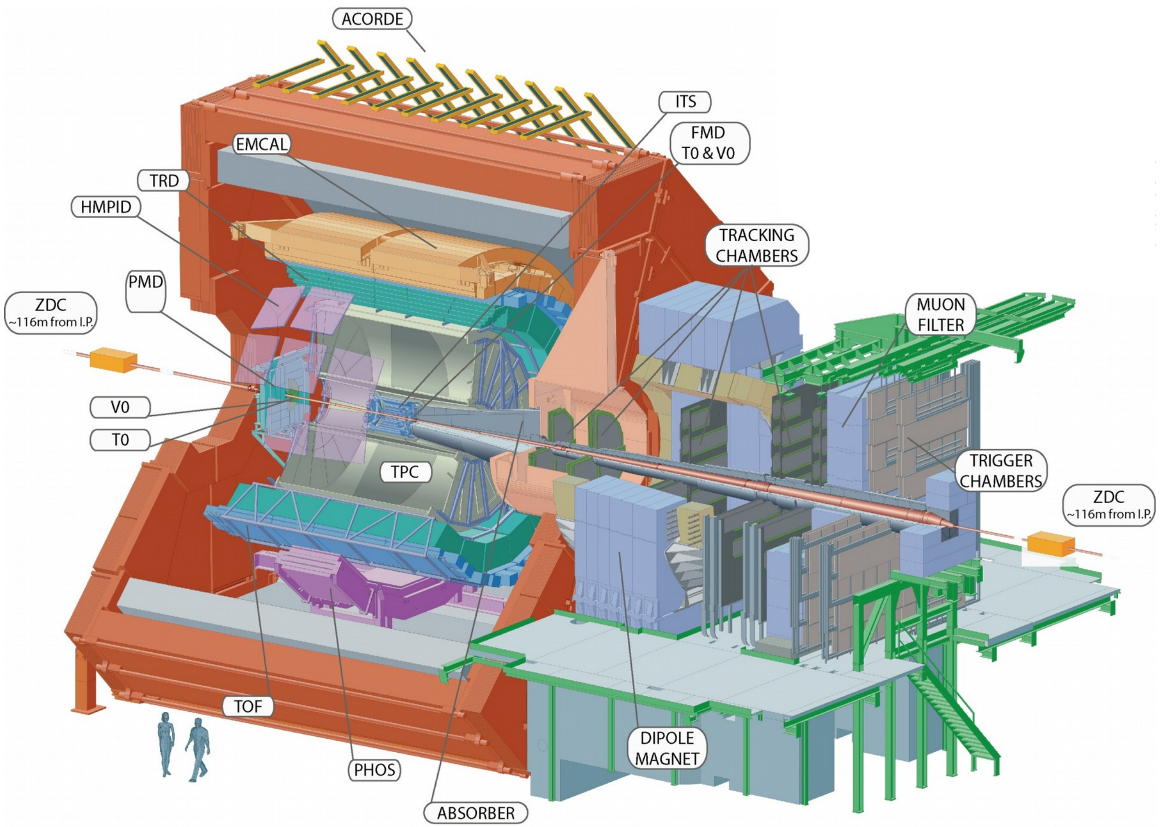
Image from http://www.gk-eichtheorien.physik.uni-mainz.de/Dateien/Zeppenfeld-3.pdf

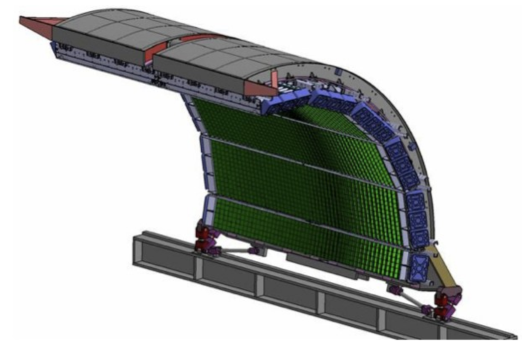
- No unambiguous definition of a jet
- Jet finder: groups final state particles into jet candidates
  - Anti-k_T algorithm
    JHEP 0804 (2008) 063 [arXiv:0802.1189]
- Combinatorial jet candidates
- Sensitive to methods to suppress combinatorial jets

The ALICE experiment



Jets in ALICE





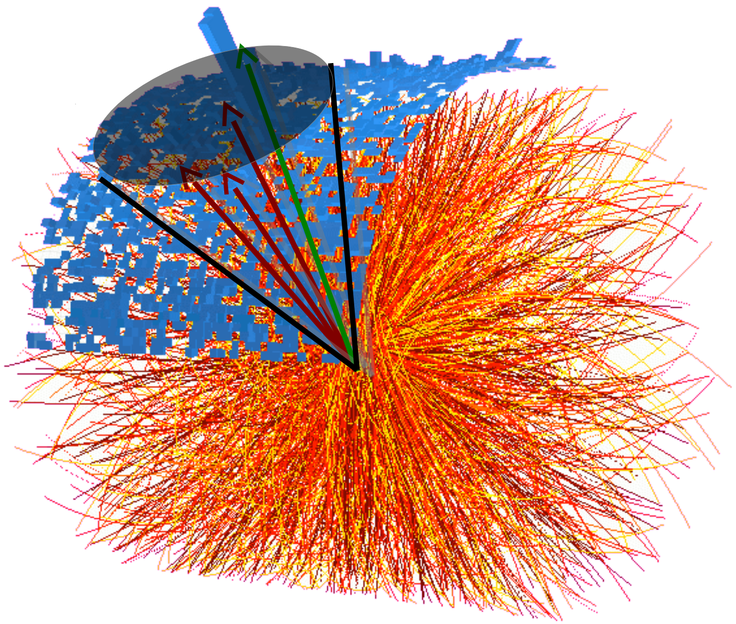
- EMCal Pb-scintillator sampling calorimeter:
  - $|\eta| < 0.7$, $1.4 < \varphi < \pi$
  - tower $\Delta\eta \sim 0.014$, $\Delta\varphi \sim 0.014$

Remove contamination from Charged particles

Neutral constituents

Tracking: $|\eta| < 0.9$, $0 < \varphi < 2\pi$
TPC, ITS → ***Charged constituents*** → **Jet** ← ***Neutral constituents***

Jet reconstruction

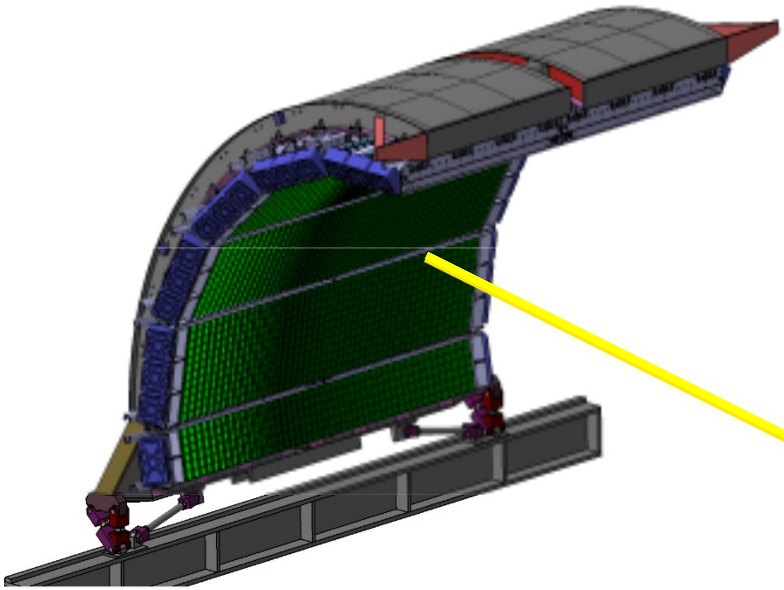


- Input to the jet finder
  - Assumed to be massless
  - Charged tracks (ITS+TPC) with $p_T > 150$ MeV/c
  - Cluster energies $E_{cluster} > 300$ MeV
  - EMCal cluster energies corrected for charged particle contamination with
    f = 100%

$$E^{cor}_{cluster} = E^{orig}_{cluster} - f \sum p^{Matched}, \quad E^{cor}_{cluster} \geq 0$$

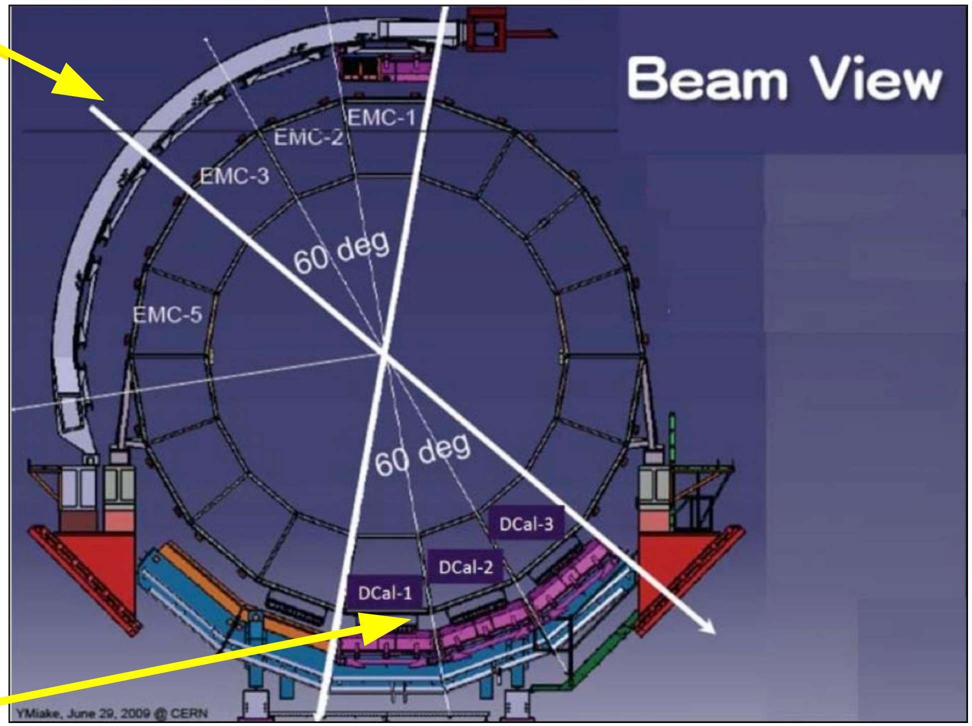
- ALICE measures
  - Full Jets (tracks + clusters) – corrected to include n, K^0_L...
  - Charged jets (tracks only) – corrected to charged particle energy only

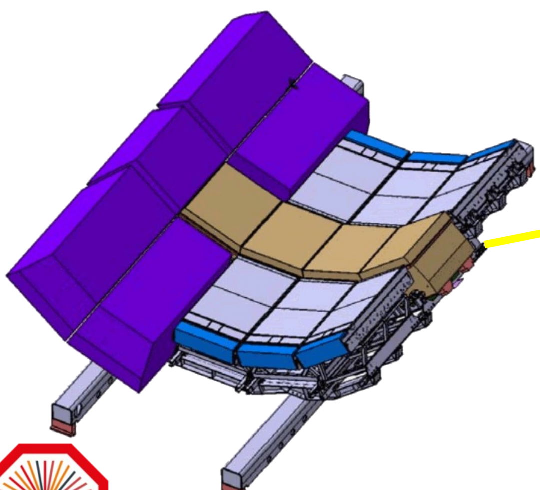
EMCal & DCal



$\Delta\eta$=1.4,$\Delta\varphi$=107°

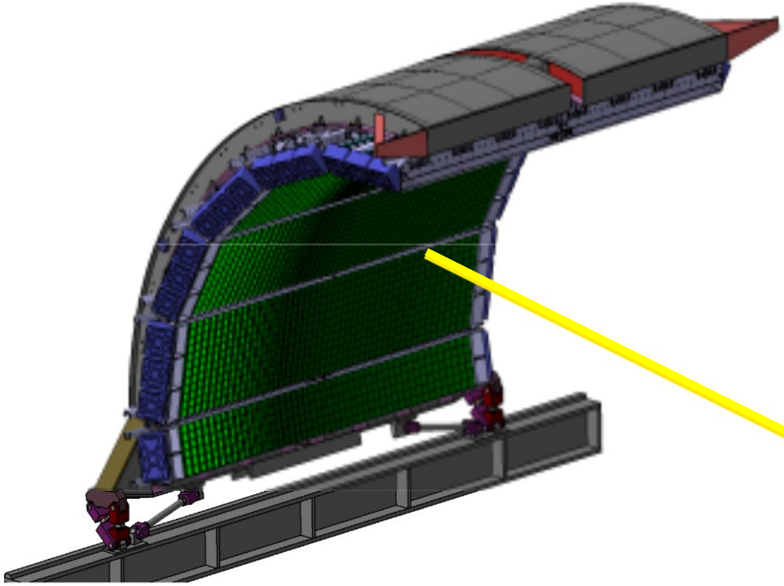
Installed in Fall 2014
$\Delta\eta$=1.4,$\Delta\varphi$=60°



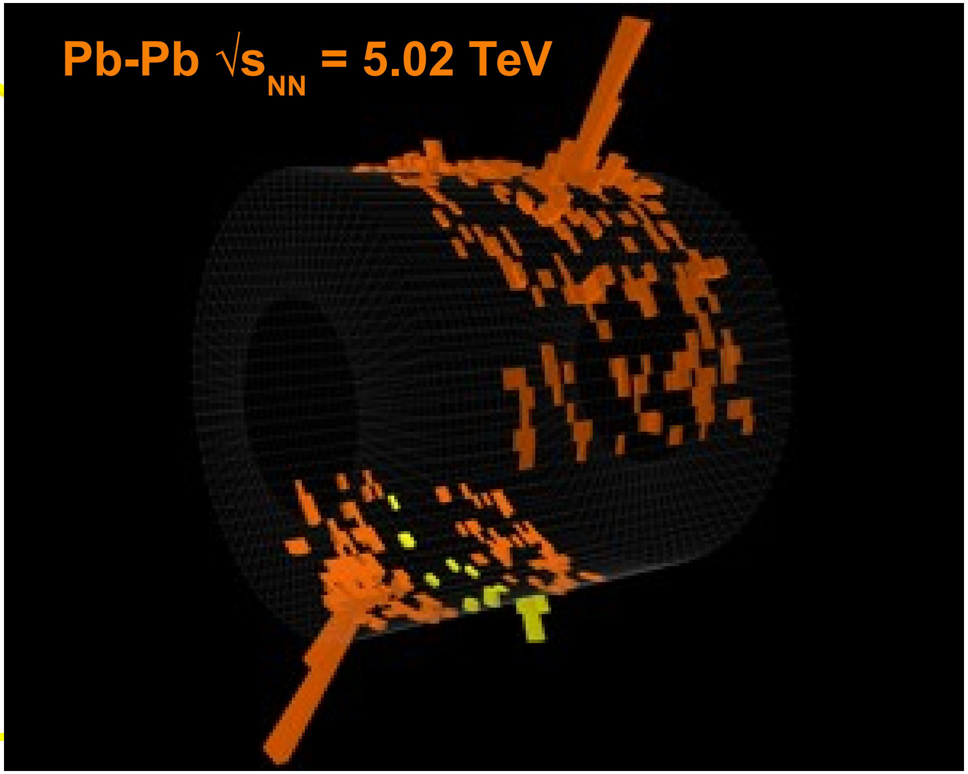


- Lead-scintillator sampling calorimeter
- 13 k towers
- Each tower $\Delta\eta$ X $\Delta\varphi$= 0.014 x 0.014
- $\sigma(E)/E=0.12/\sqrt{E} + 0.02$

EMCal & DCal



$\Delta\eta$=1.4,$\Delta\varphi$=107°



Installed in Fall 2014
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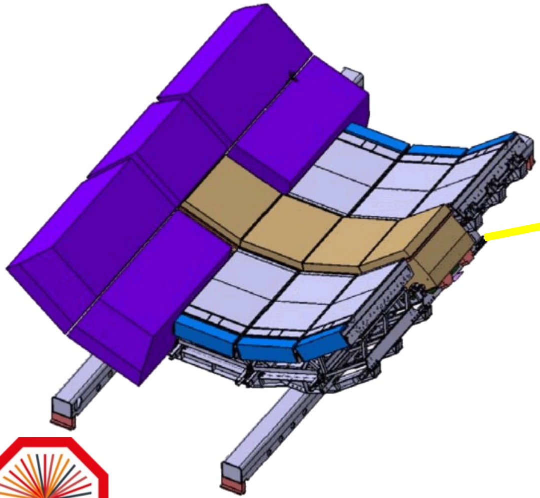

- Lead-scintillator sampling calorimeter
- 13 k towers
- Each tower $\Delta\eta$ x $\Delta\varphi$= 0.014 x 0.014
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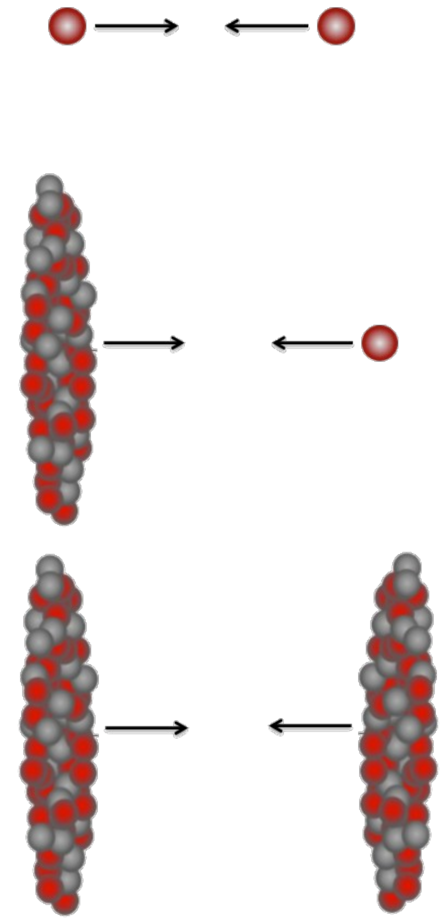
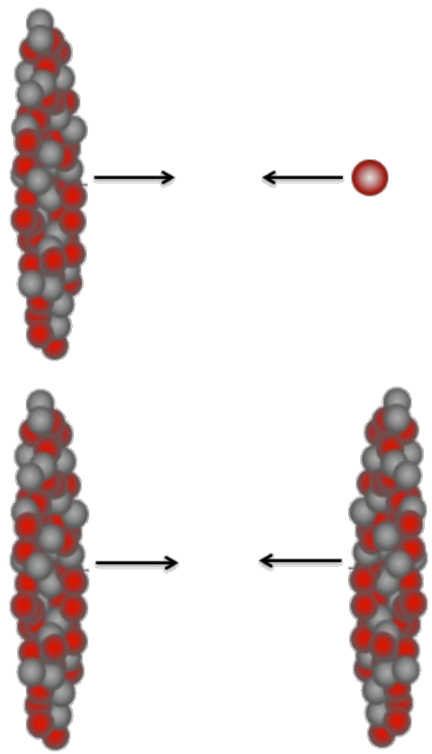
Measurements of jets

- In pp collisions
  - Test QCD
- In pPb collisions
  - Cold nuclear matter effects
- In Pb-Pb collisions
  - Hot QCD effects



Measurements of jets

- In pp collisions
  - Test QCD
  - Consistent with QCD
- In pPb collisions
  - Cold nuclear matter effects
  - No significant effects for jets
- In Pb-Pb collisions
  - Hot QCD effects
  - Significant medium effects

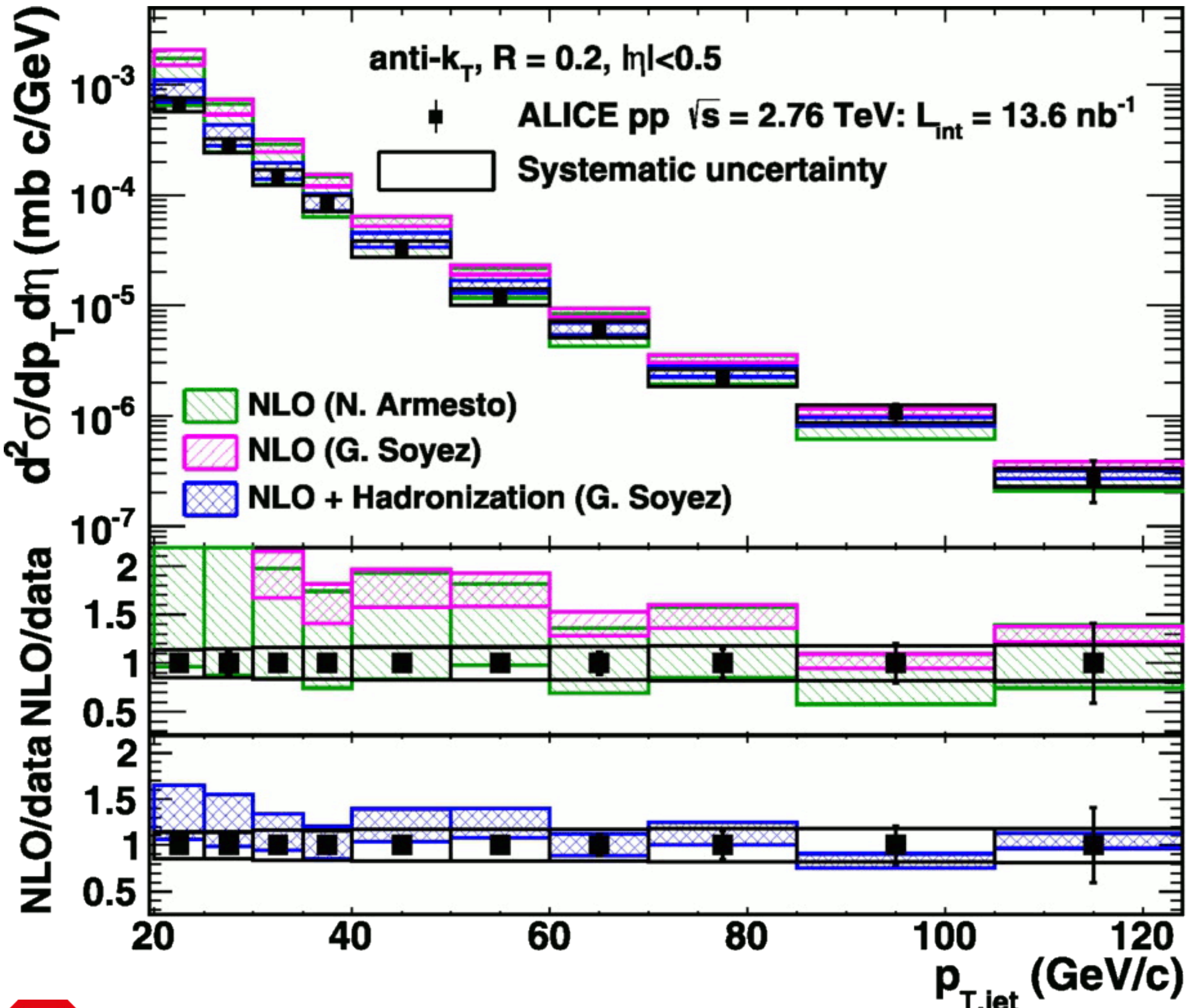


pp collisions

Full jet cross-section in pp

$\sqrt{s} = 2.76$ TeV, R = 0.2 Inclusive

arXiv:1301.3475
PLB: 10.1016/j.physletb.2013.04.026



- f_{hadcor} = 100%,
- p_T > 150 MeV/c
- E_T > 300 MeV
- Green and magenta bands: NLO on Parton level
- Blue band: NLO + hadronization
- Hadronization calculations necessary to describe data

Full jet cross-section in pp

$\sqrt{s}$ = 2.76 TeV, R = 0.2, 0.4 Inclusive

arXiv:1301.3475
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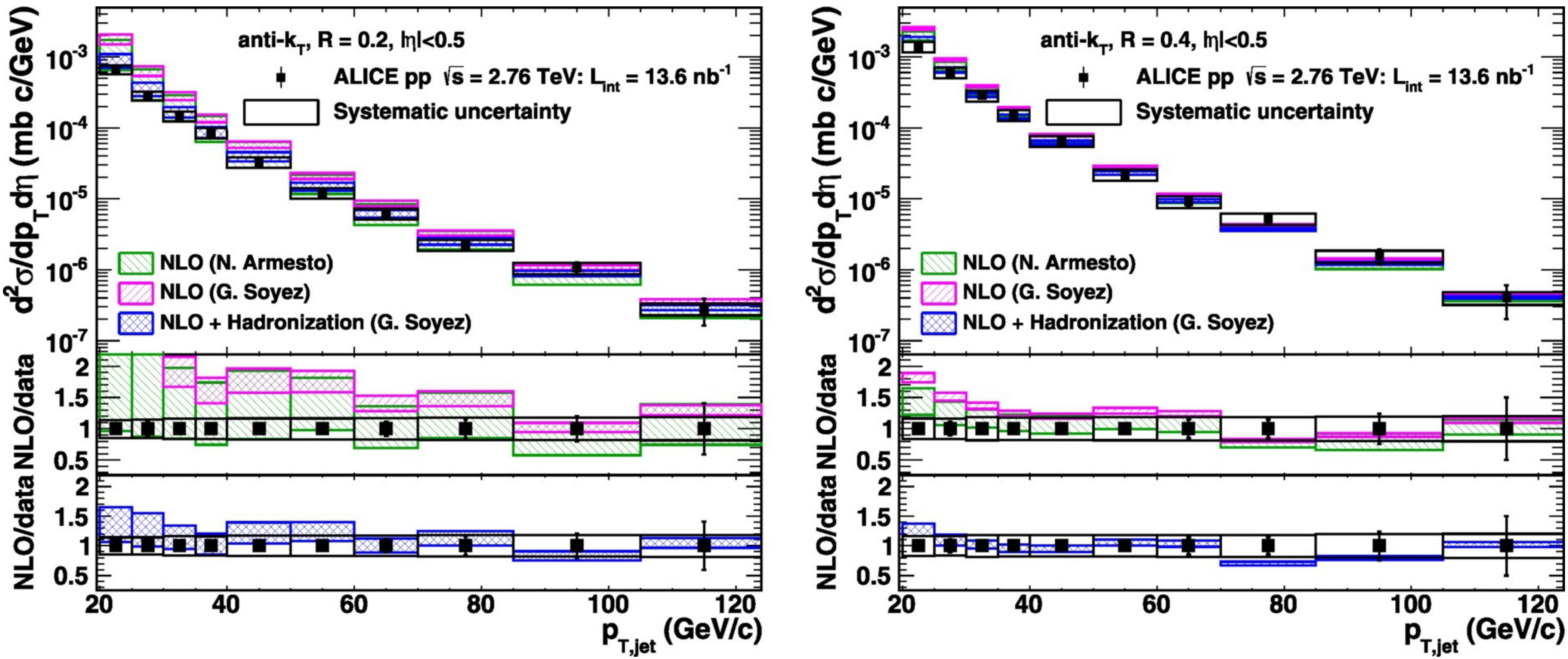
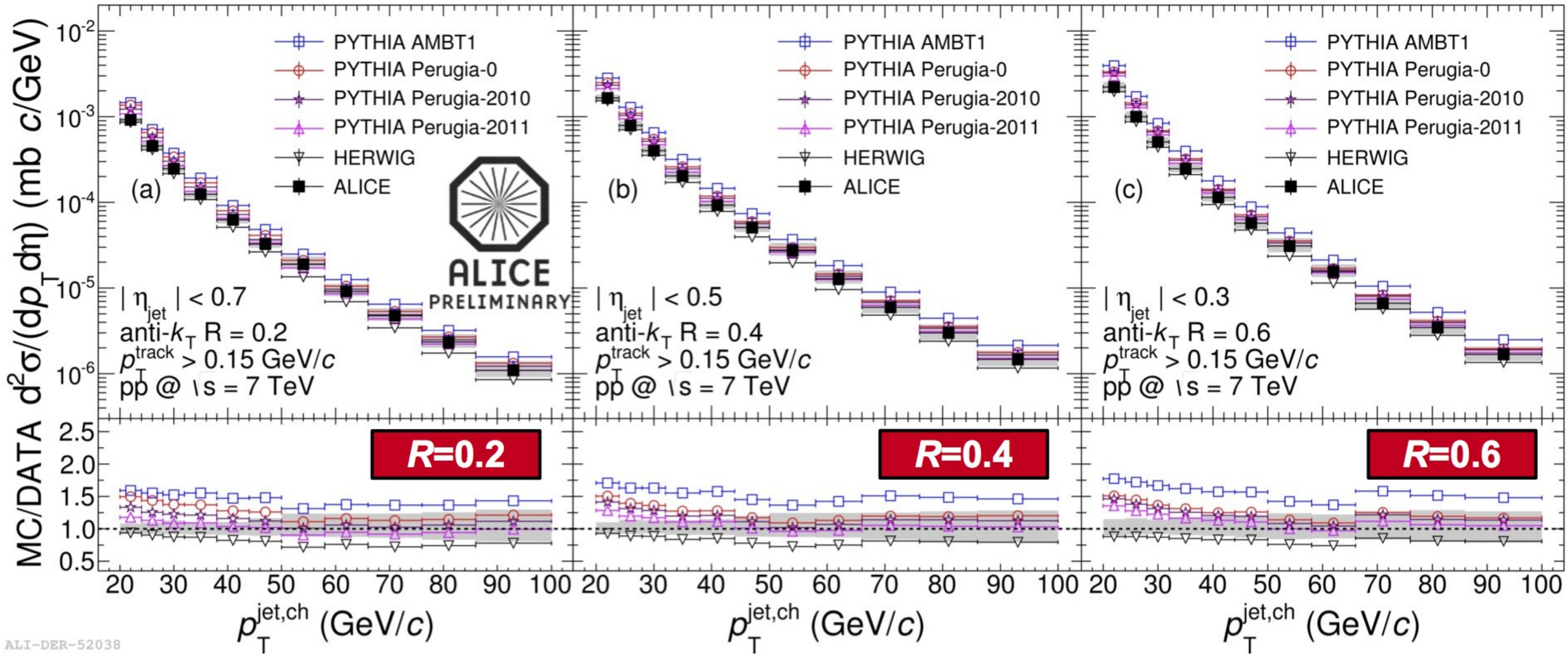


Data and NLO+ hadronization calculations agree well

for both R = 0.2 and 0.4

Charged jet cross-section pp

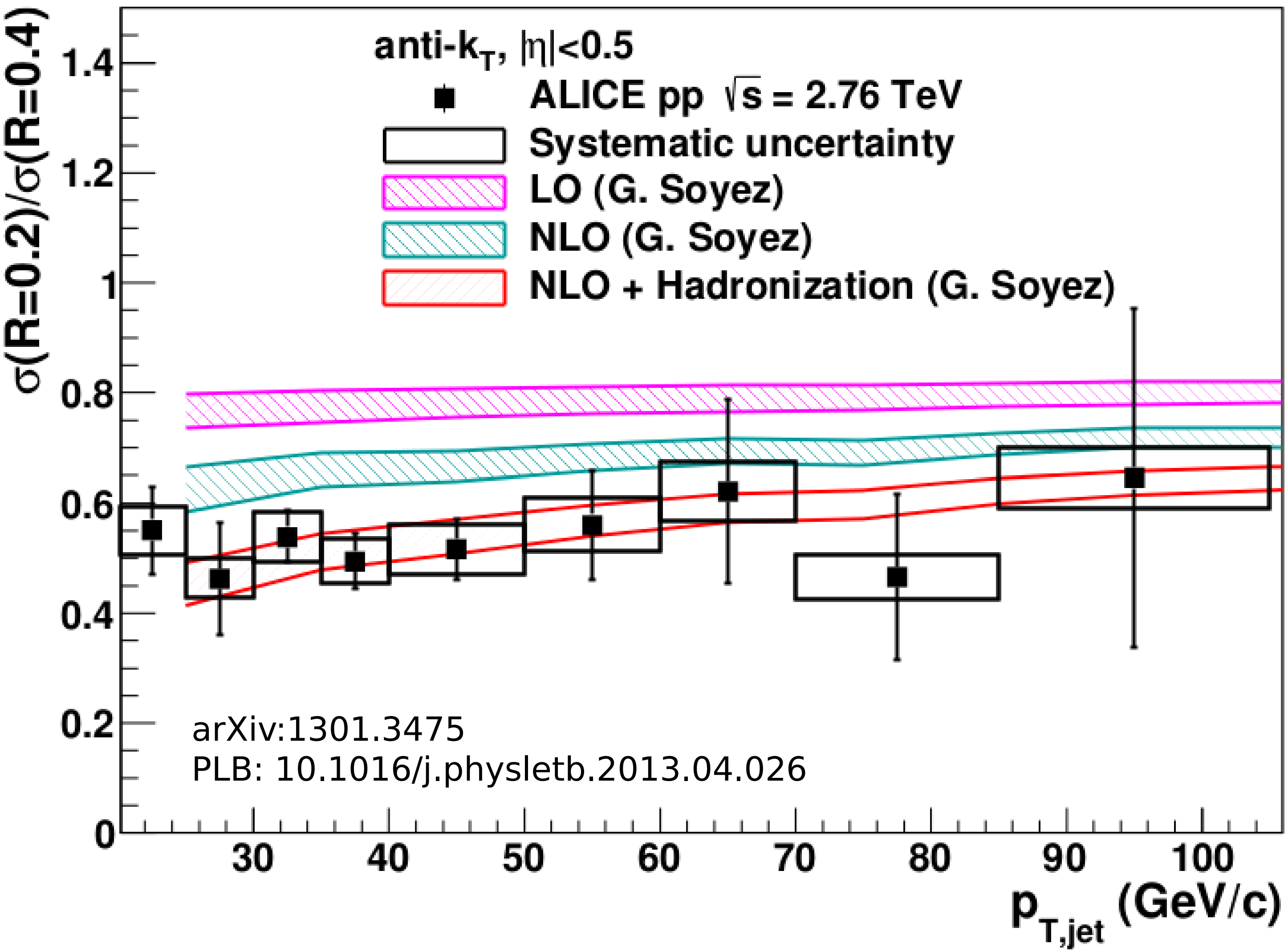
Charged √s = 7 TeV Inclusive

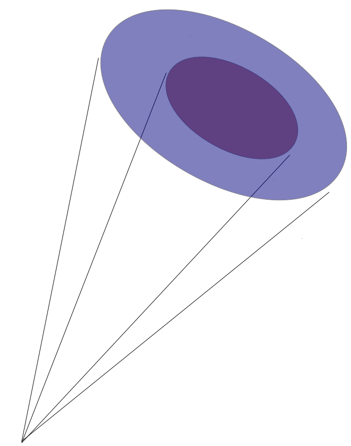


- Data agree well with: PYTHIA Perugia 2011 & HERWIG

Full jet ratios in pp

$\sqrt{s}$ = 2.76 TeV, R = 0.2, 0.4 Inclusive

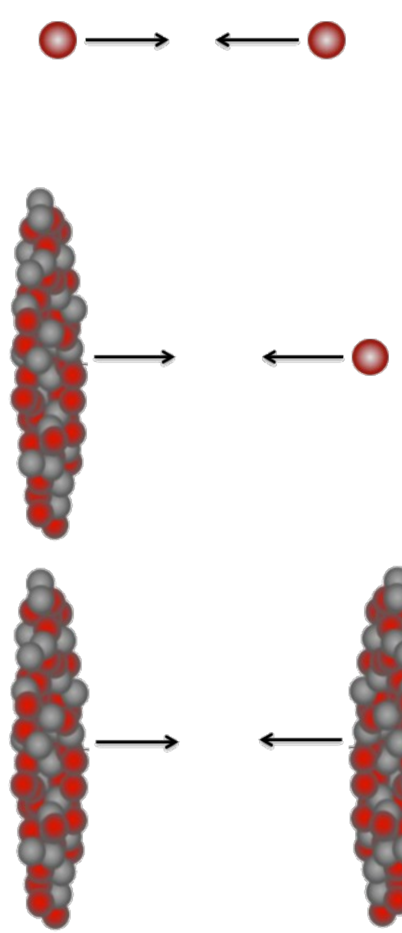




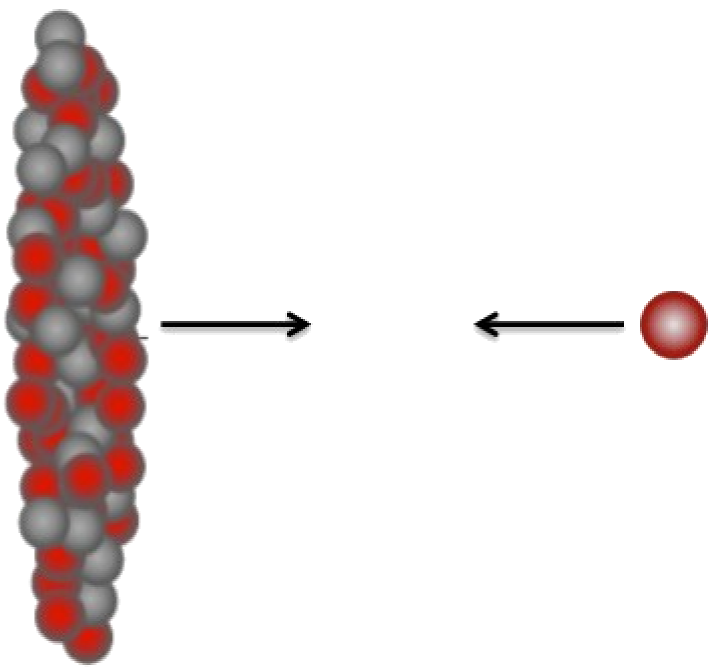
Data and NLO+ hadronization calculations agree well

Measurements of jets

- In pp collisions
  - Test QCD
  - Consistent with QCD
- In pPb collisions
  - Cold nuclear matter effects
- In Pb-Pb collisions
  - Hot QCD effects

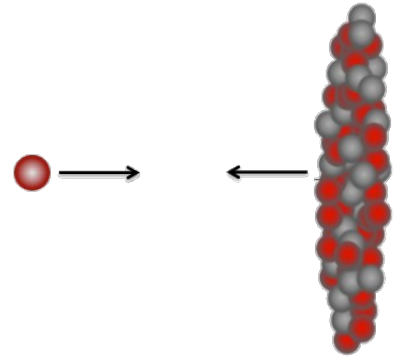


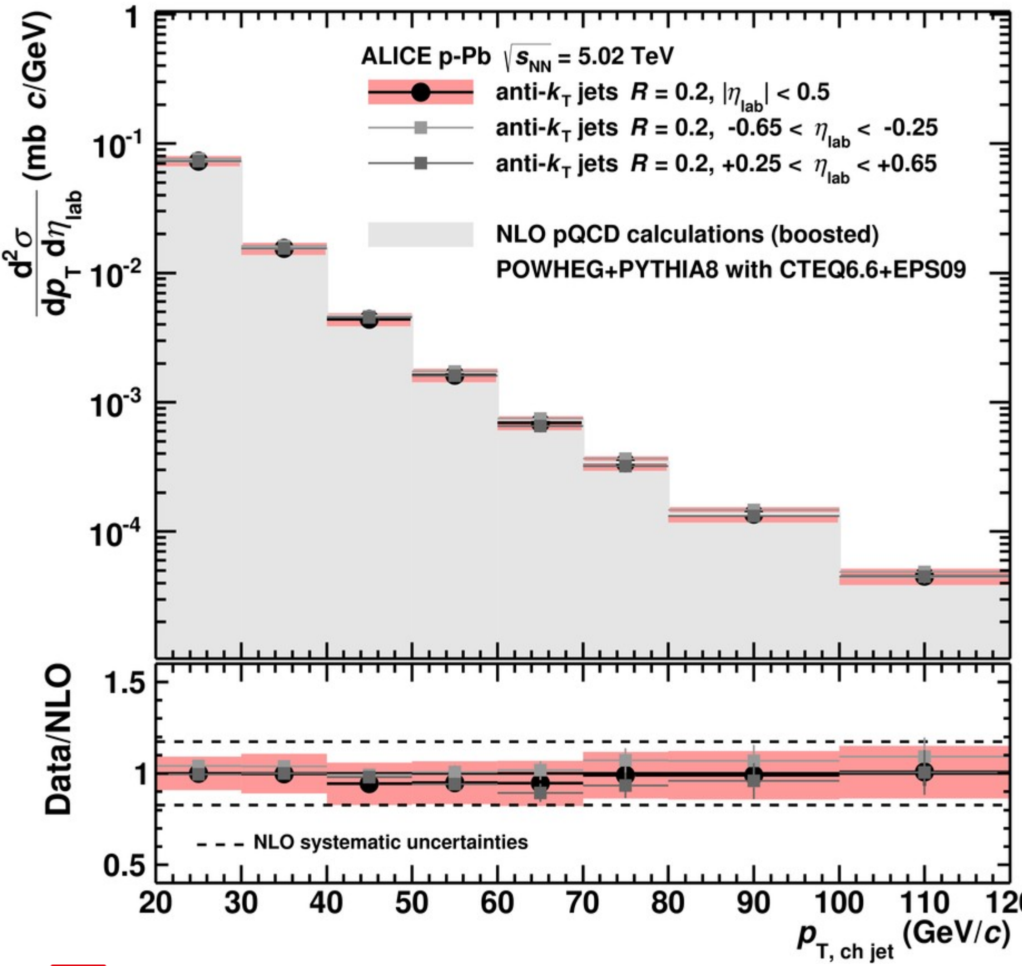
pPb collisions

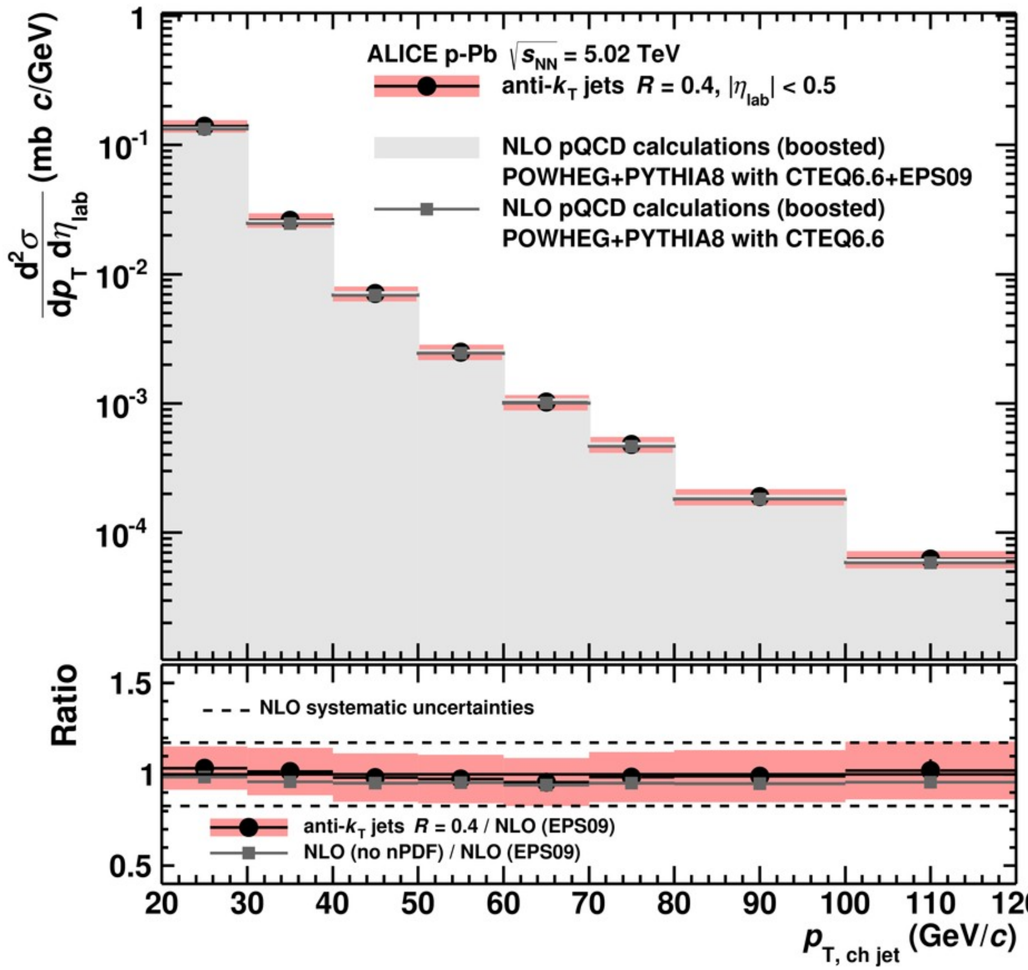


Charged jet cross-section in pPb

$\sqrt{s_{NN}}$ = 5.02 TeV, R = 0.2, 0.4 Inclusive

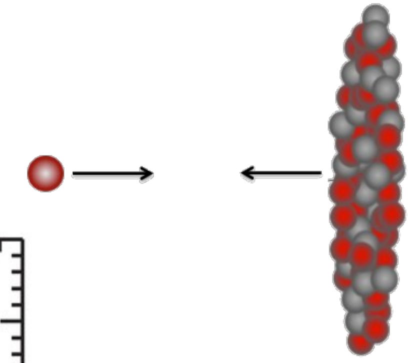


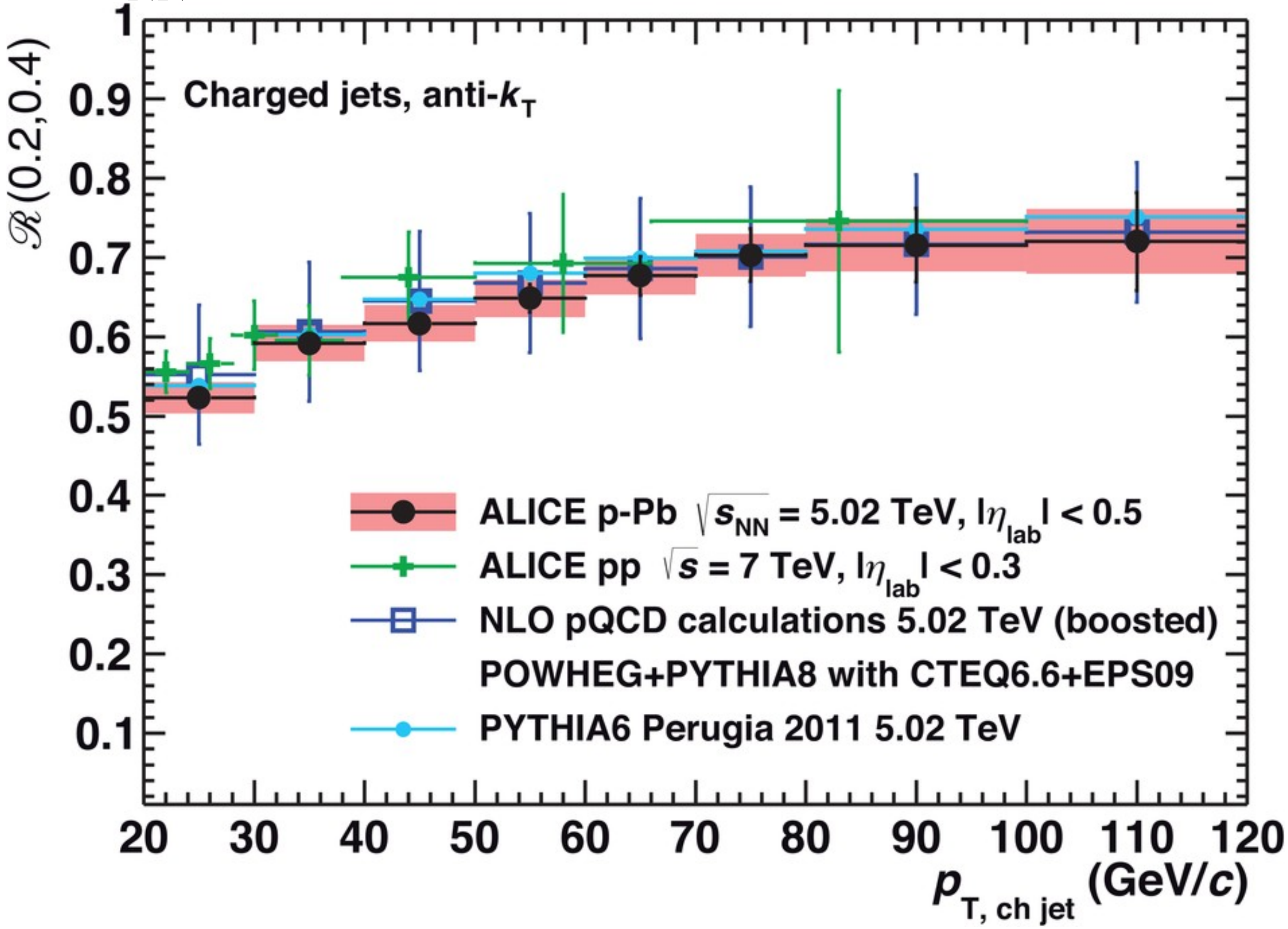




Charged jet ratios in pPb

$\sqrt{s_{NN}}$ = 5.02 TeV, R = 0.2, 0.4 Inclusive

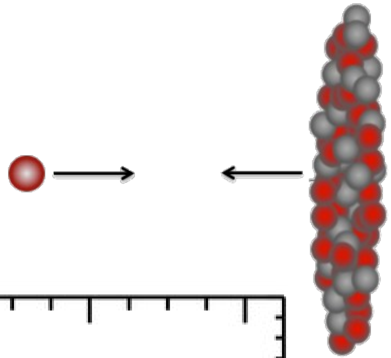


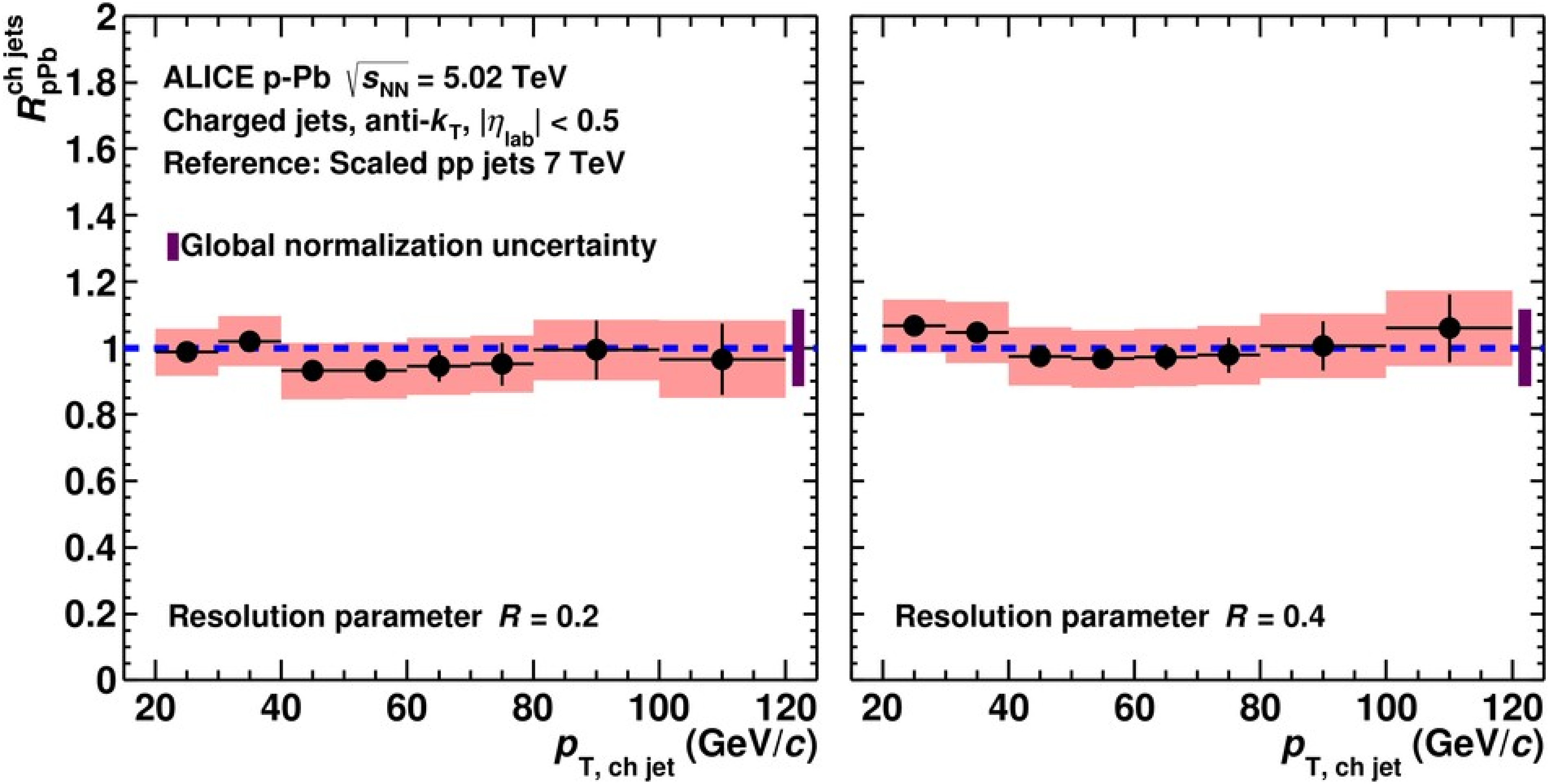


- Comparing to pp simulations, no differences observed within error bars.
- Collimation increases with jet p_T as in pp.
- No significant energy dependence or change with collision species is observed.

Charged jet R_{pPb}

$\sqrt{s_{NN}}$ = 5.02 TeV, R = 0.2, 0.4 Inclusive

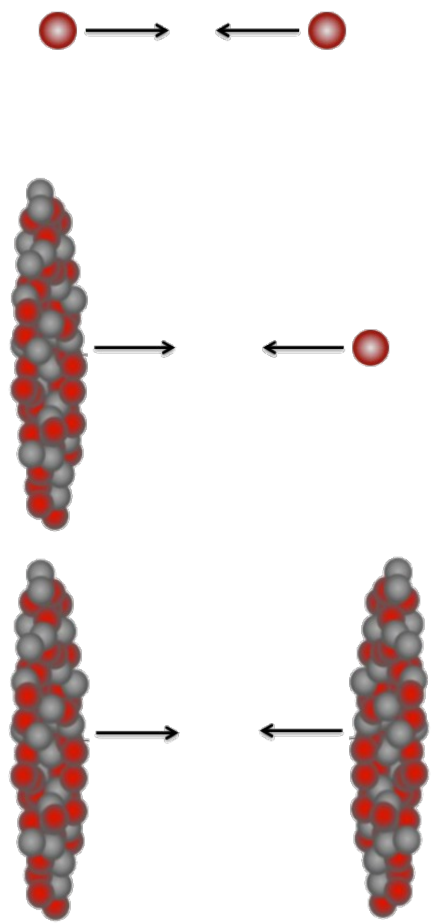




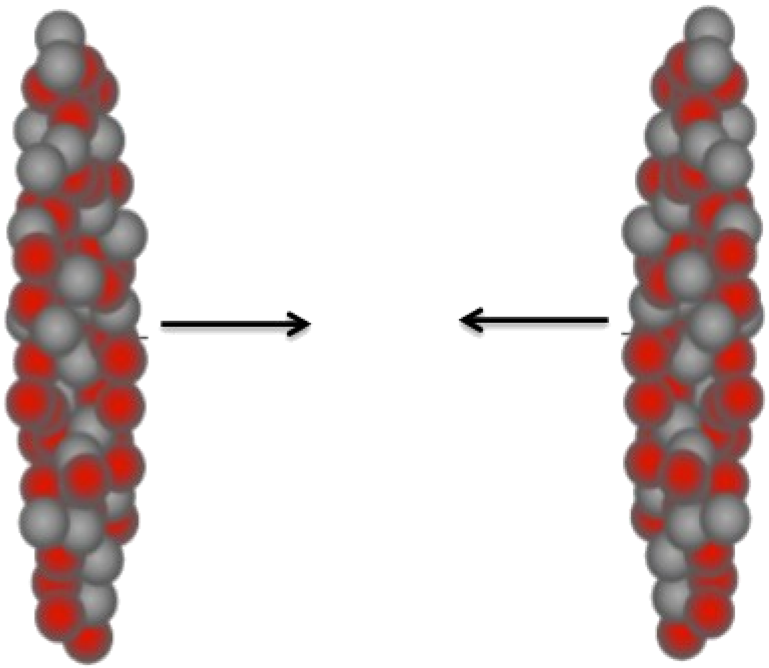
- R_{pPb} consistent with unity
- No cold nuclear matter effects observed for jets

Measurements of jets

- In pp collisions
  - Test QCD
  - Consistent with QCD
- In pPb collisions
  - Cold nuclear matter effects
  - No significant effects for jets
- In Pb-Pb collisions
  - Hot QCD effects

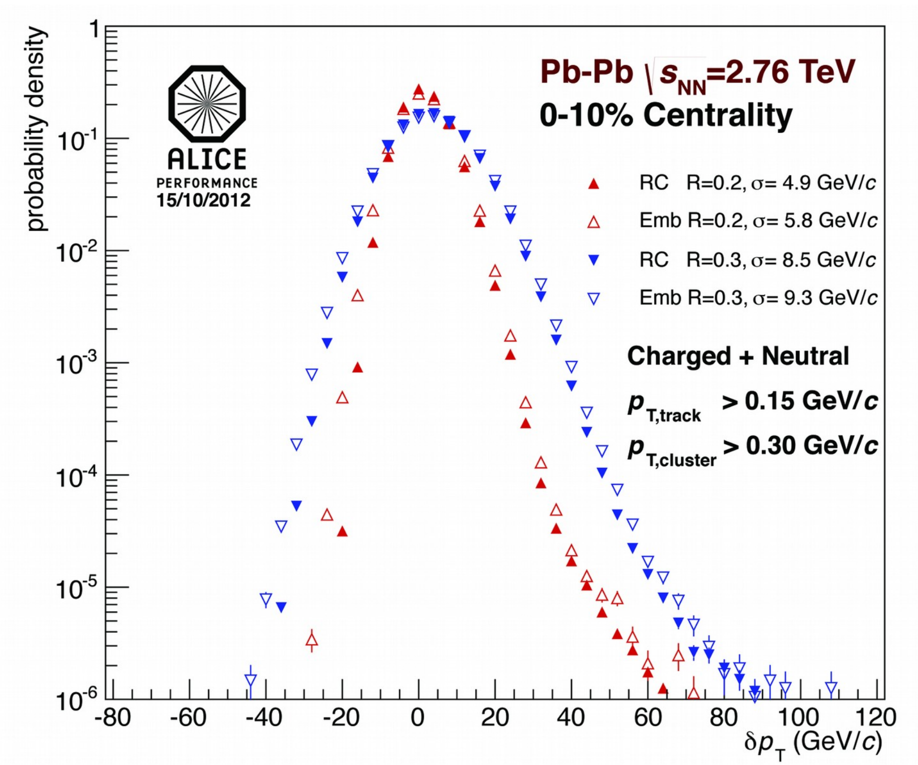


Pb-Pb collisions



Background fluctuations

Full Jets in Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV

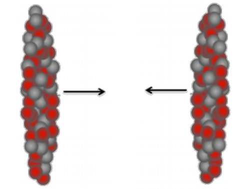


- Fluctuations in the background determined via δp_T
  - Random cones (RC)
  - Depends on
    - Constituent cut R
    - Centrality
    - Event plane
    - Detector

$$\delta p_T = p_T^{rec} - \rho \pi R^2$$

δp_T is not corrected for detector effects – Experiment specific

δp_T is used to construct unfolding response matrix



Leading track jet bias

$\sqrt{s_{NN}}$ = 2.76 TeV Pb-Pb, R=0.2

Combinatorial "jets"

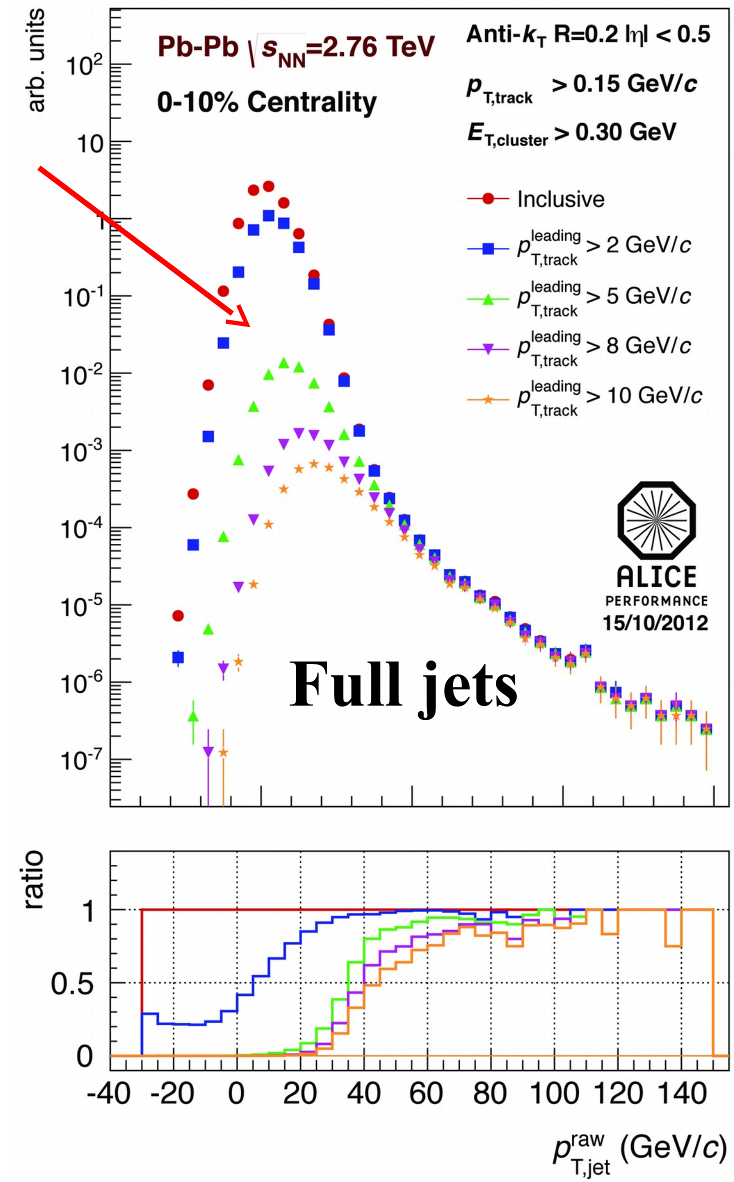
- Combinatorial jets a challenge in HI collisions
  - Require leading track p_T > 5 GeV/c
  - Suppresses combinatorial "jets"
  - Biases fragmentation

Measured spectra:

$$p_{T,jet}^{unc} = p_{T,jet}^{rec} - \rho A$$

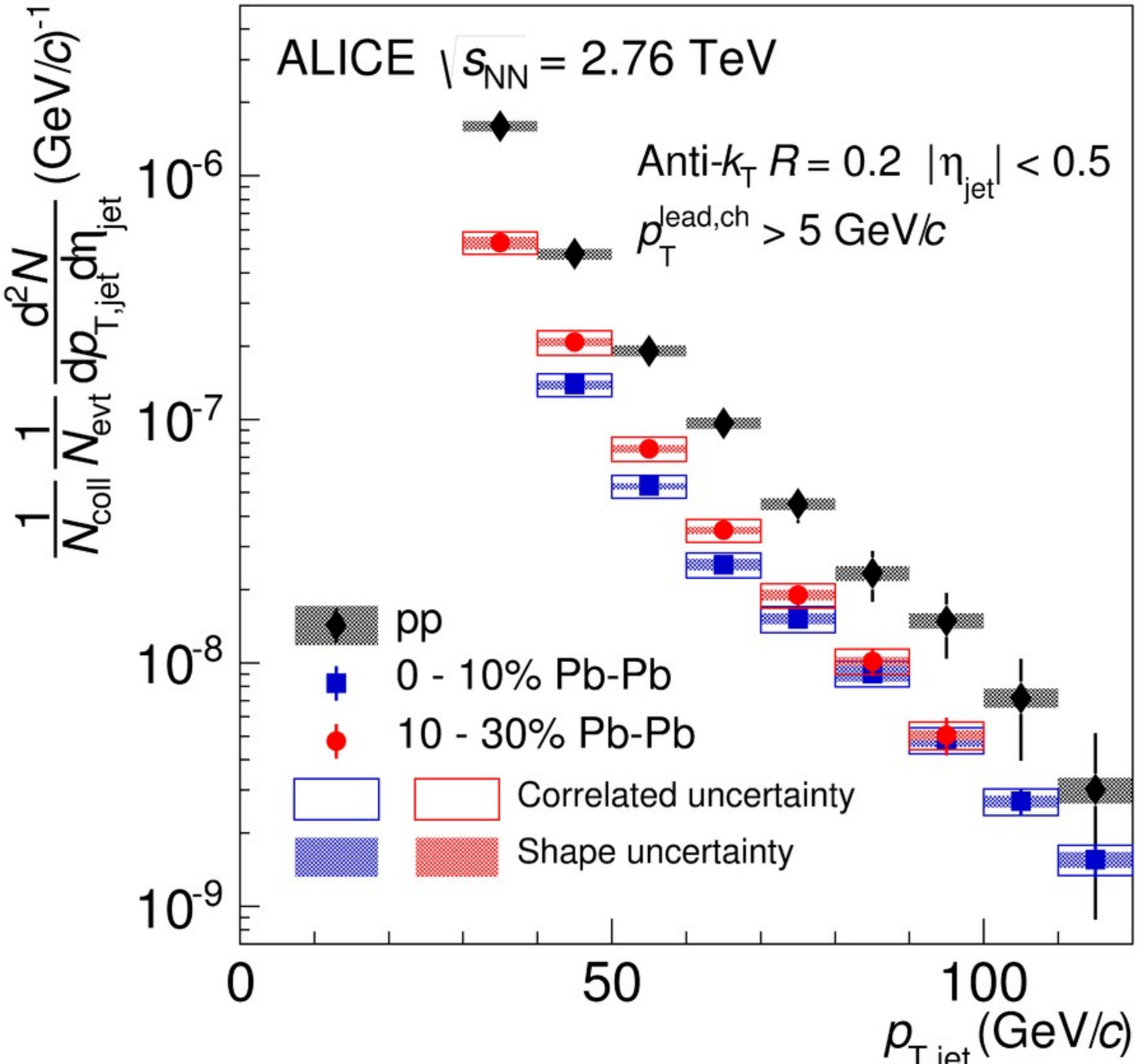
Where $p_{T,jet}^{rec}, A$

comes from FastJet anti-k_T algorithm



Full jet cross-section in Pb-Pb

$\sqrt{s_{NN}} = 2.76$ TeV, R = 0.2 Inclusive

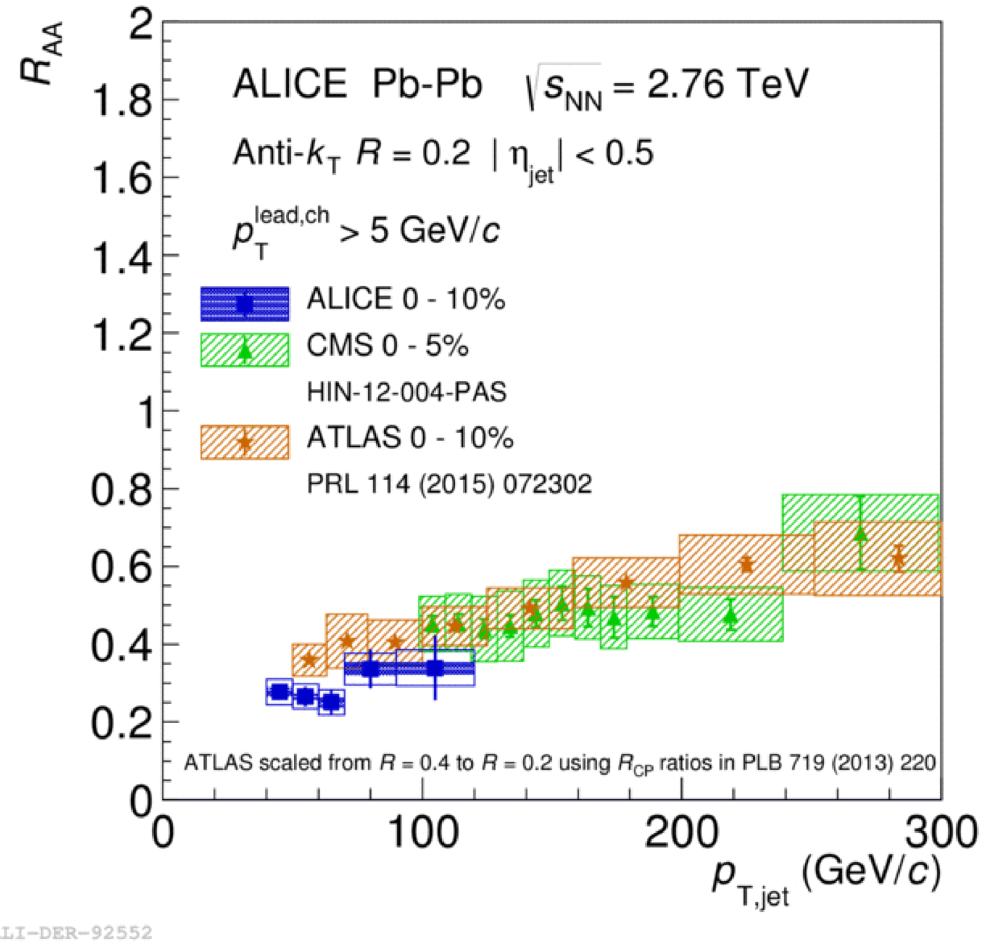


Full jet R_{AA}

$\sqrt{s_{NN}}$ = 2.76 TeV, R = 0.2 Inclusive

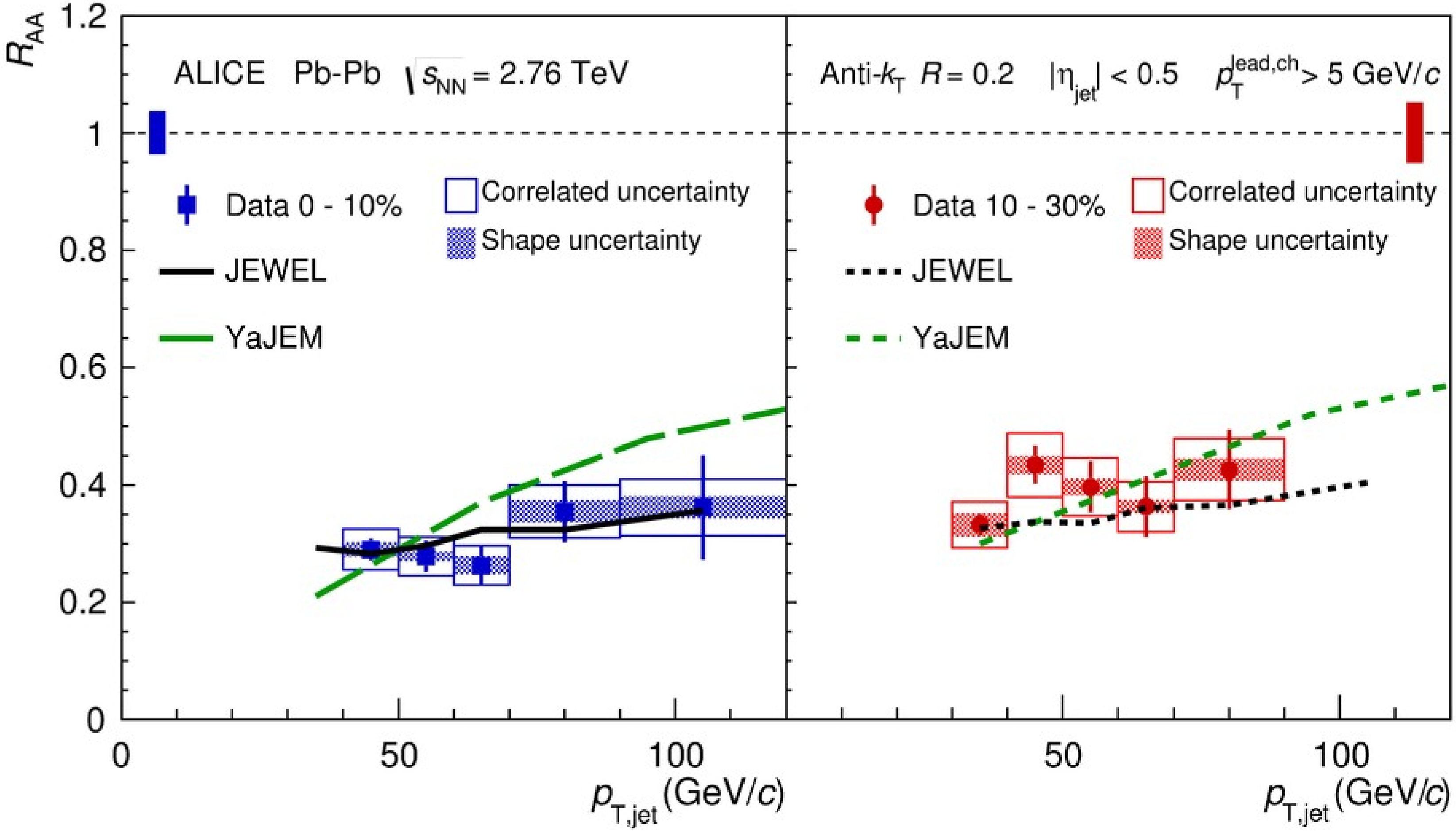
Full jet RAA in central Pb-Pb collisions,

- Different jet reconstruction techniques (ATLAS: Calo Jets, CMS: Particle-Flow Jets, ALICE: Ch+En Jets) used by the different experiments
- R=0.2: ATLAS scaled from R=0.4 to R=0.2



Full jet R_{AA}

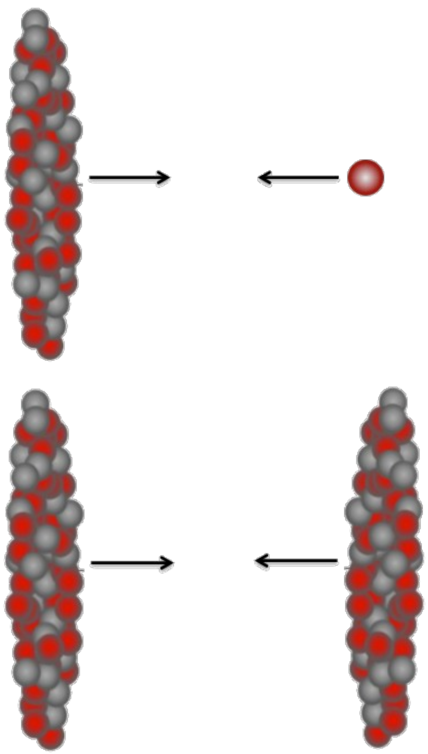
$\sqrt{s_{NN}}$ = 2.76 TeV, R = 0.2 Inclusive



- Both models use a fit to hadron R_{AA} to adjust their parameters
- Both models agree well with data

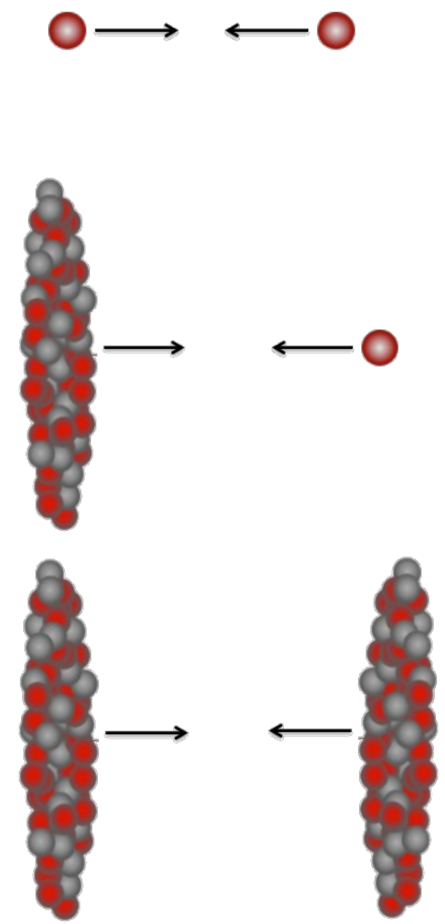
Measurements of jets

- In pp collisions
  - Test QCD
  - Consistent with QCD
- In pPb collisions
  - Cold nuclear matter effects
  - No significant effects for jets
- In Pb-Pb collisions
  - Hot QCD effects
  - Significant medium effects



Conclusions

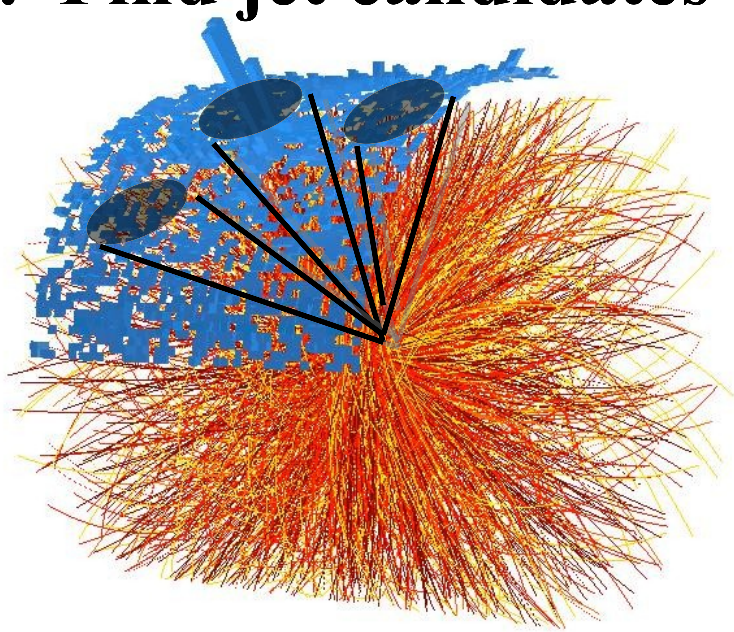
- In pp collisions
  - Data agree with NLO pQCD + hadronization
- In pPb collisions
  - Data agree with NLO pQCD
  - Consistent with no CNM effect
- In Pb-Pb collisions
  - Strong jet suppression



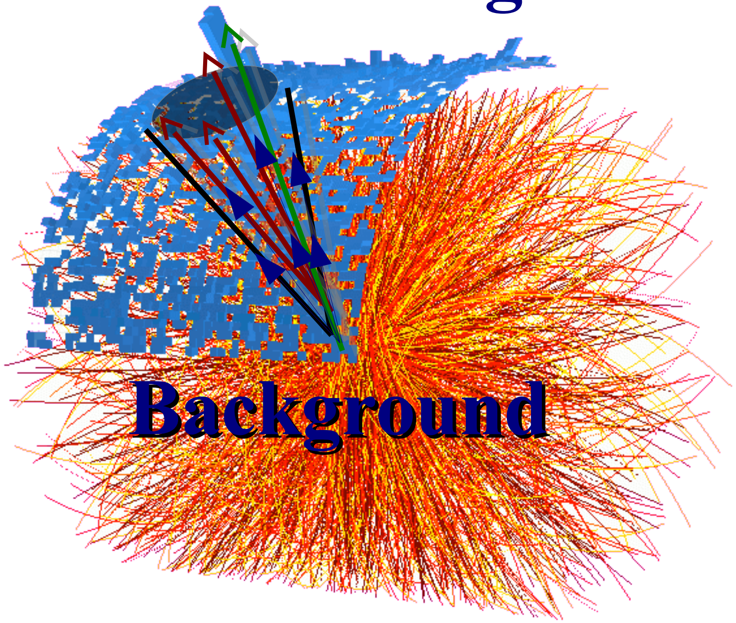
Backup

Method

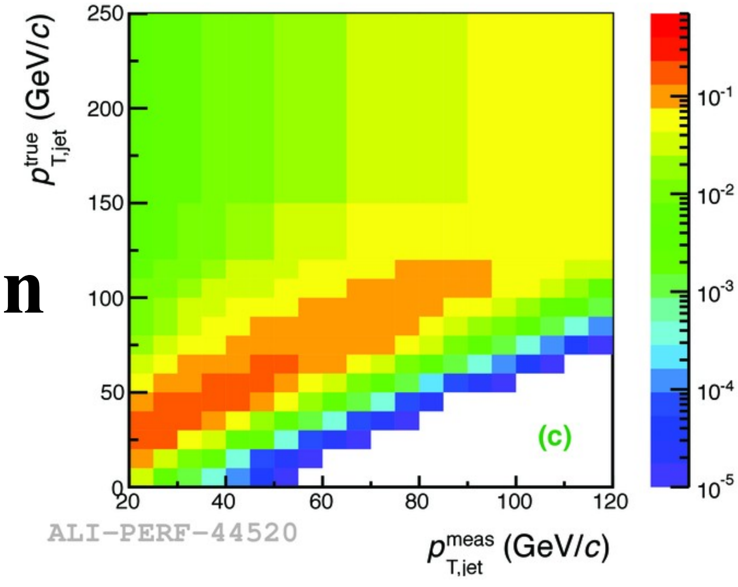
1. **Find jet candidates**



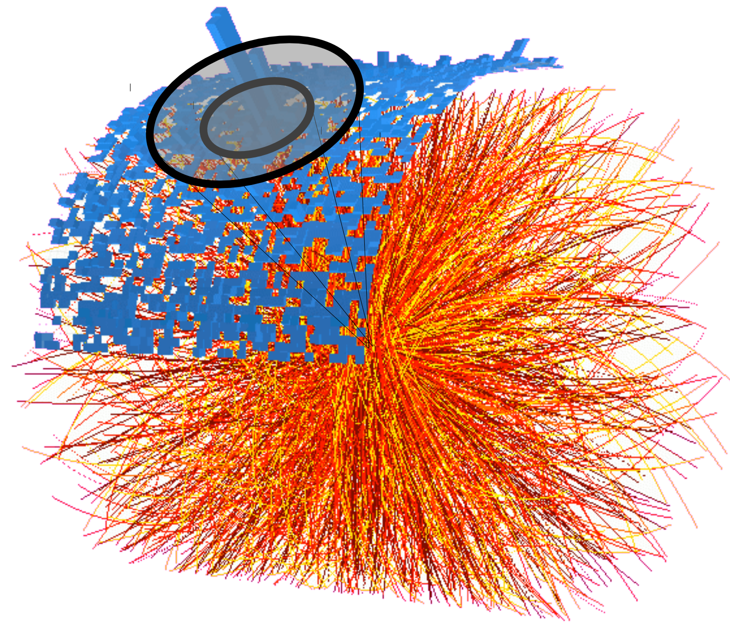
2. **Subtract background**



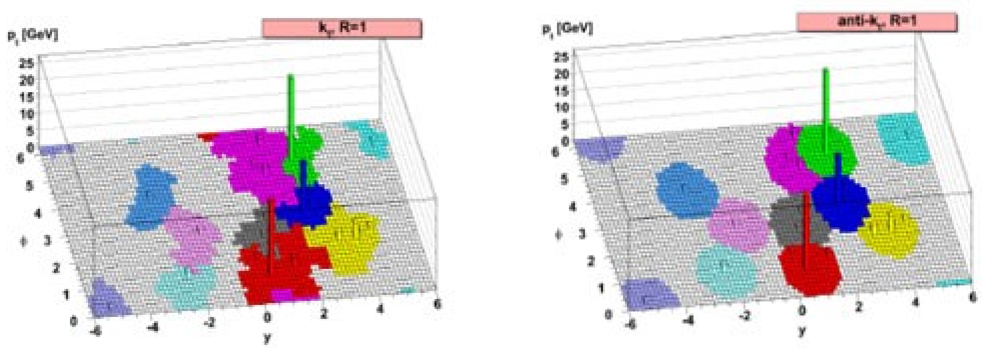
3. **Correct for resolution**



Jet Reconstruction



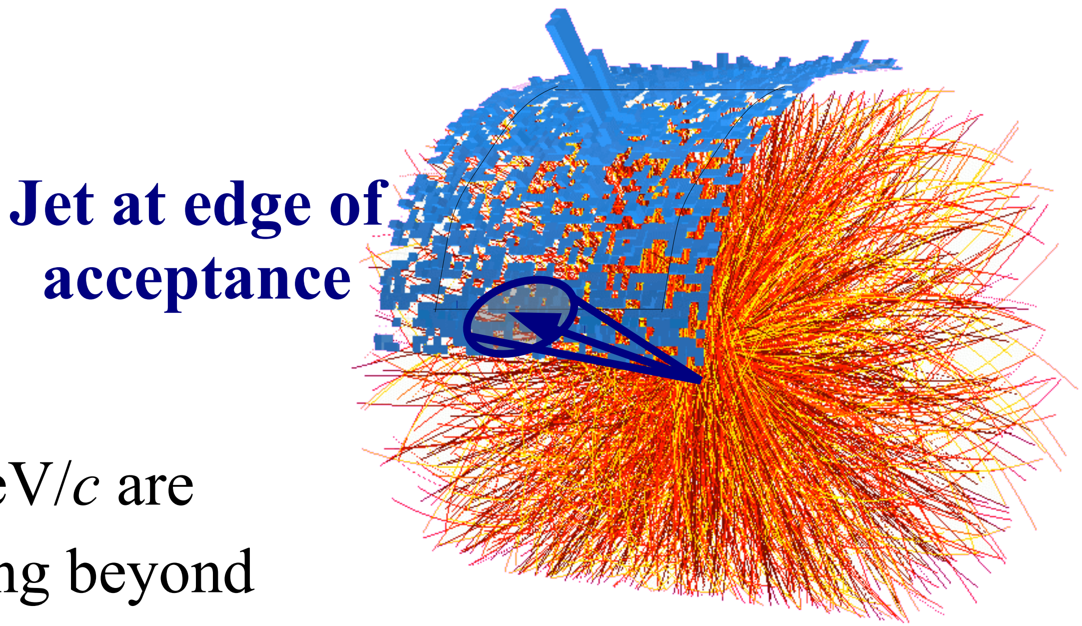
- Jets reconstructed using FastJet package
  - $R = 0.2 - 0.4$
  - Anti-k_T – Used for signal determination
  - k_T – Used for background determination
- Correct for detector effects using unfolding
  - Momentum resolution
  - Energy resolution
  - Track Matching



M. Cacciari, G. P. Salam, G.Soyez, JHEP 0804:063,2008

Full Jet Selection Requirements

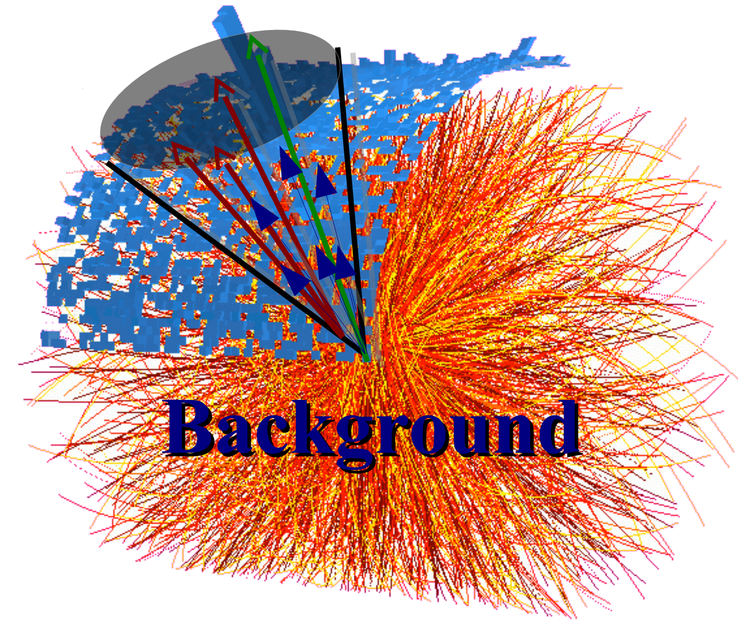
- EMCal fiducial acceptance cut
  - *R* away from EMCal boundaries
  - *R*=0.2:
    - $|\eta_{jet}| < 0.5$
    - $1.60 < \varphi_{jet} < 2.94$
- Jets with leading track $p_T > 100$ GeV/*c* are rejected due to limitations of tracking beyond 100 GeV/c



Jets in Heavy Ion Collisions

Experimental Challenges

- Need to remove underlying event (UE) contribution
  - $p_{T,Jet} = p_{T,Jet}^{rec} - \rho A + B_{\sigma}$
  - A = Jet area, ρ = median UE momentum density
  - $p_{T,\,Jet}$ = Jet p_T from jet finder
  - We can only remove the average background contribution



- B_{σ} from UE fluctuations
- Combinatorial (fake) jets can be reconstructed from UE
- Detector effect corrections depend on fragmentation
- Both background and detector effects are corrected in unfolding
  - Corrects spectra for the B_{σ} term
  - Quantified in Response Matrix (RM)

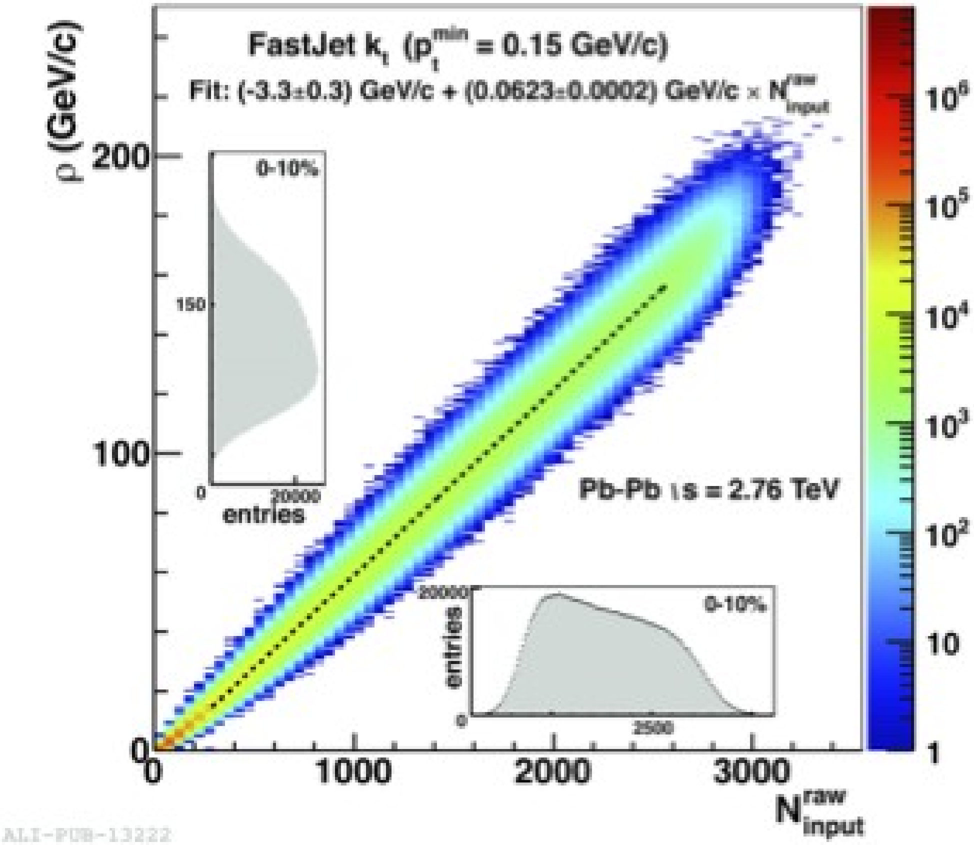
HI Background Determination

Charged Jets $\sqrt{s_{NN}} = 2.76$ TeV

- ρ_{ch} : **median** of $p^{ch}_{T,kTjet} / A_{kTjet}$
  - 2 leading jets removed
  - May be sensitive to jet fragments outside k_T jet cone
  - Determined event-by-event
- ρ_{ch} is not corrected for detector effects or missing energy
- Subtracted from signal jets on a jet-by-jet basis

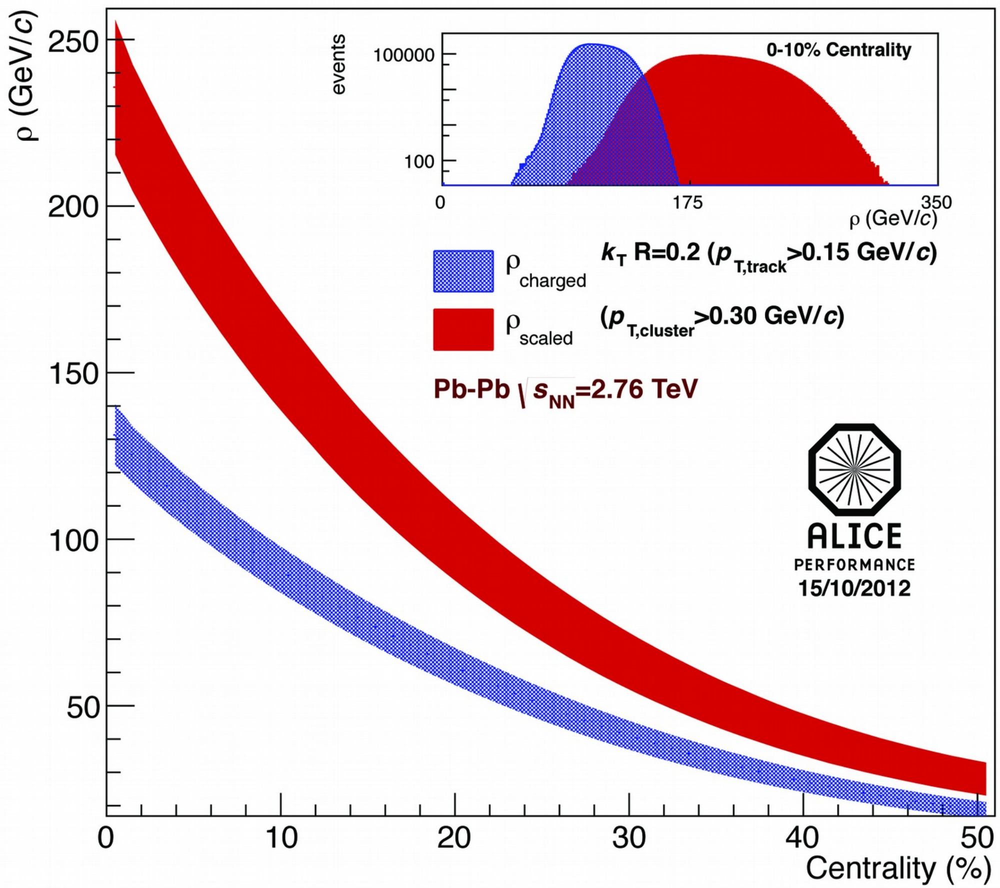
$$p^{ch,unc}_{T,jet} = p^{rec}_{\mathrm{T,jet}} - \rho_{ch} A$$

JHEP 1203:053, 2012
(arxiv:1201.2423)

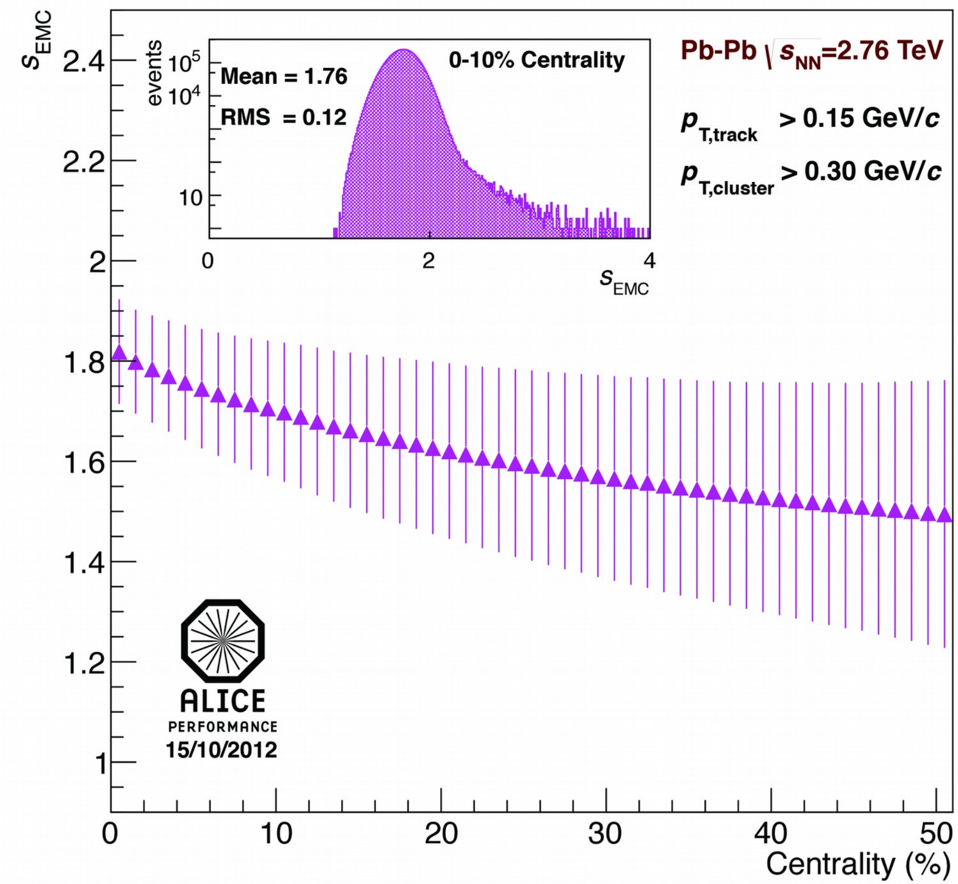


HI Background Determination

Full Jets $\sqrt{s_{NN}} = 2.76$ TeV



ALI-PERF-44505



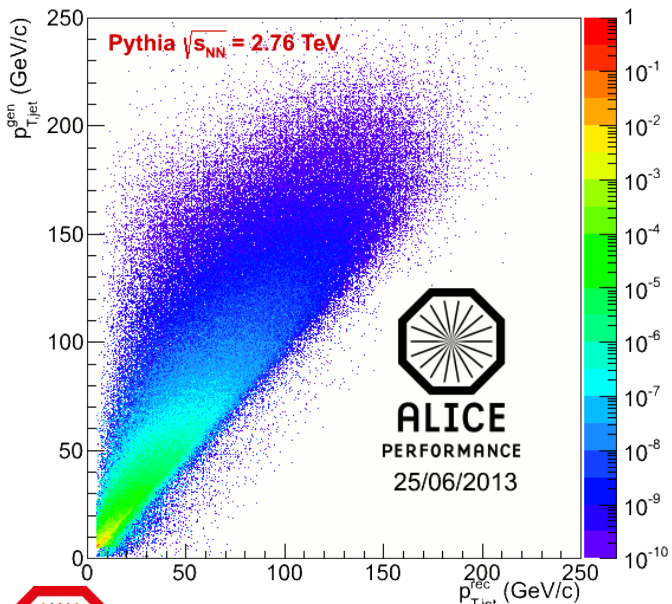
ALI-PERF-44509

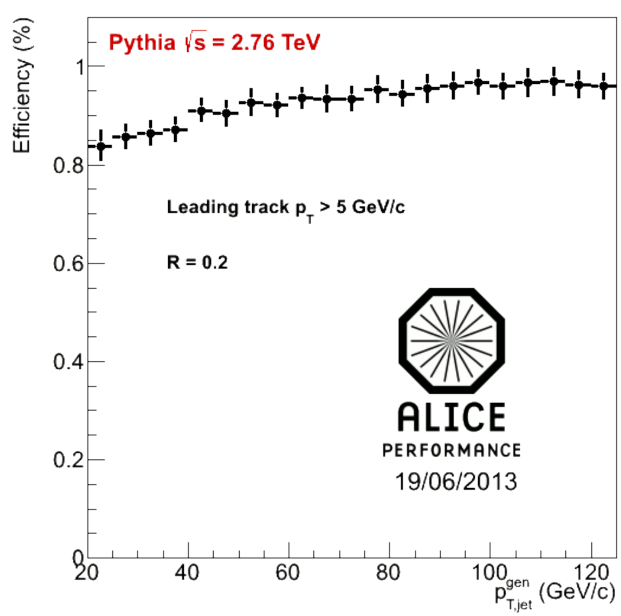
Centrality dependent scale factor accounts for neutral energy

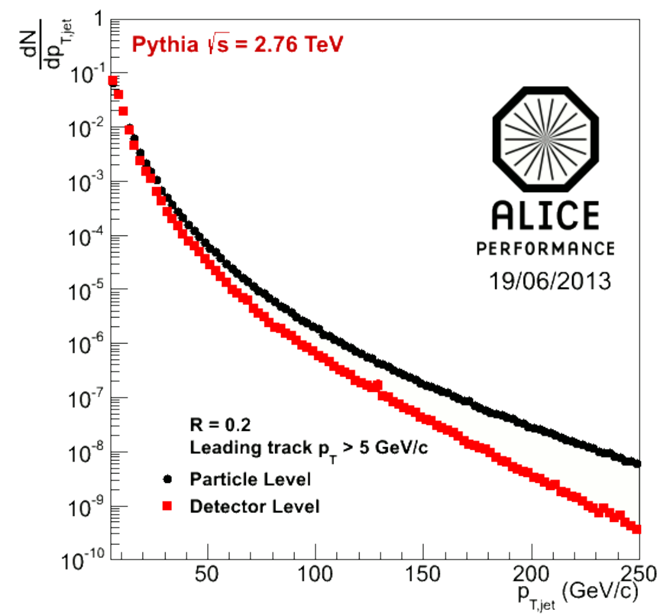
$$\rho_{scaled} = \rho_{ch} \times \rho_{EMC}$$

Response matrix RM_{det}

- RM_{det} quantifies detector response to jets
  - "Particle" level jets – defined by jet finder on MC particles
  - Pythia with Pb-Pb tracking efficiency
  - "Detector" level jets – defined by jet finder after event reconstruction through GEANT
  - Particle level jets are geometrically matched to detector level jets
  - Matrix has a dependence on spectral shape and fragmentation
- Jet-finding efficiency is probability of a matched particle level jet

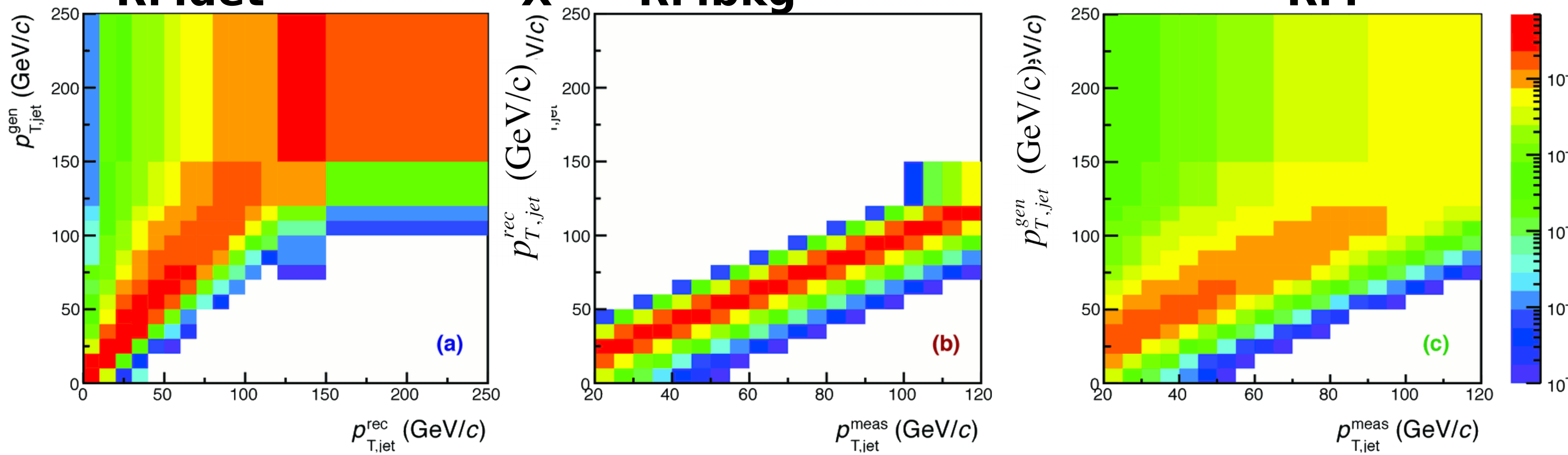


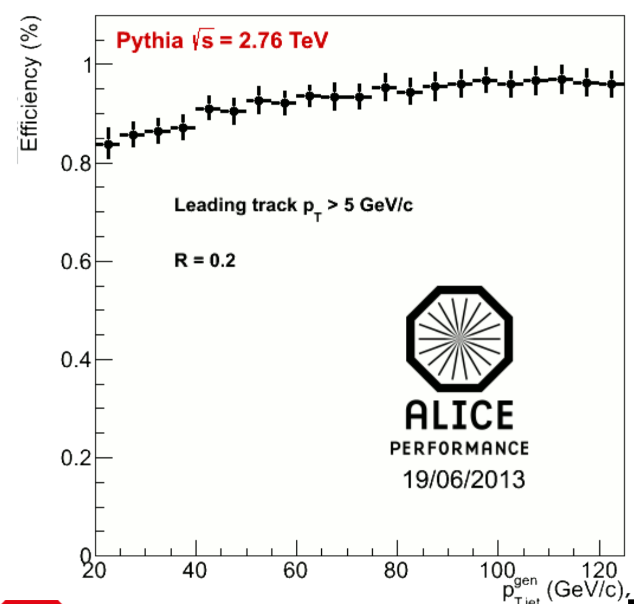




Response Matrix Construction

RMdet X RMbkg = RM





Anti-k_T R=0.2

$p_{T,track}$ > 0.15 GeV/c

$E_{T,cluster}$ > 0.30 GeV

$p_{T,track}^{leading}$ > 5 GeV/c

(a) RM_{det} Detector response matrix

(b) RM_{bkg} Background fluctuation matrix

(c) $RM_{tot} = RM_{bkg} \times RM_{det}$

Pb-Pb $\sqrt{s_{NN}}$=2.76 TeV

0-10% Centrality

ALICE PERFORMANCE

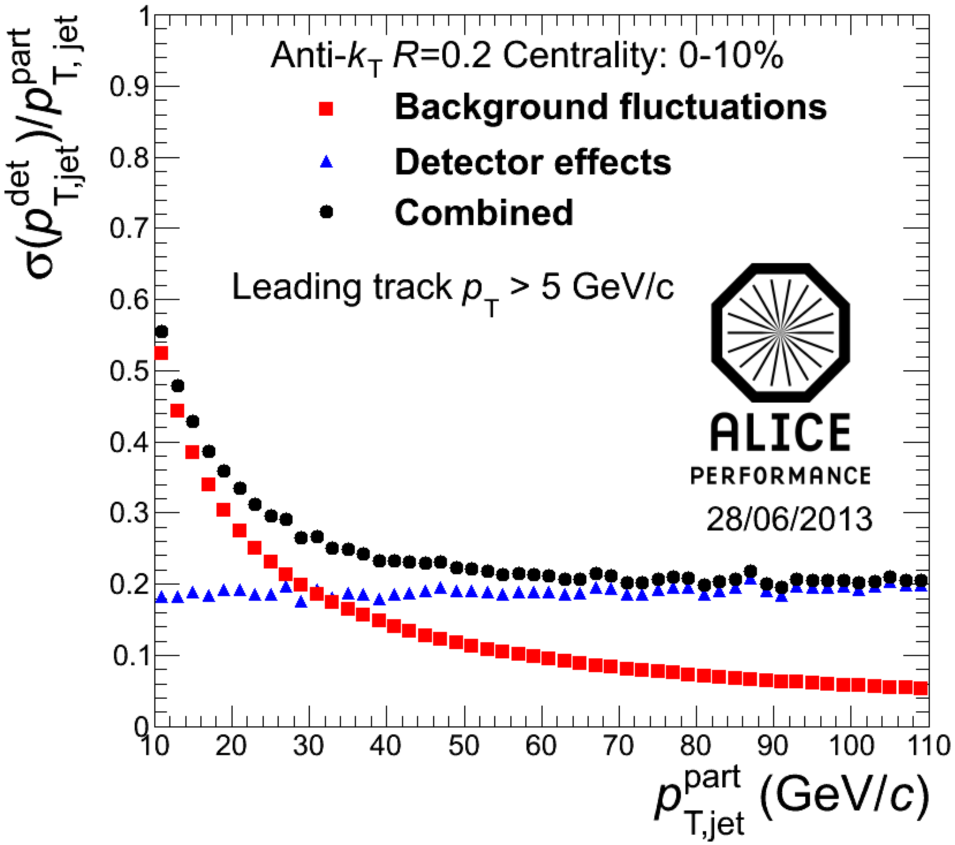
15/10/2012

RM_{bkg} and RM_{det} are approximately factorizable

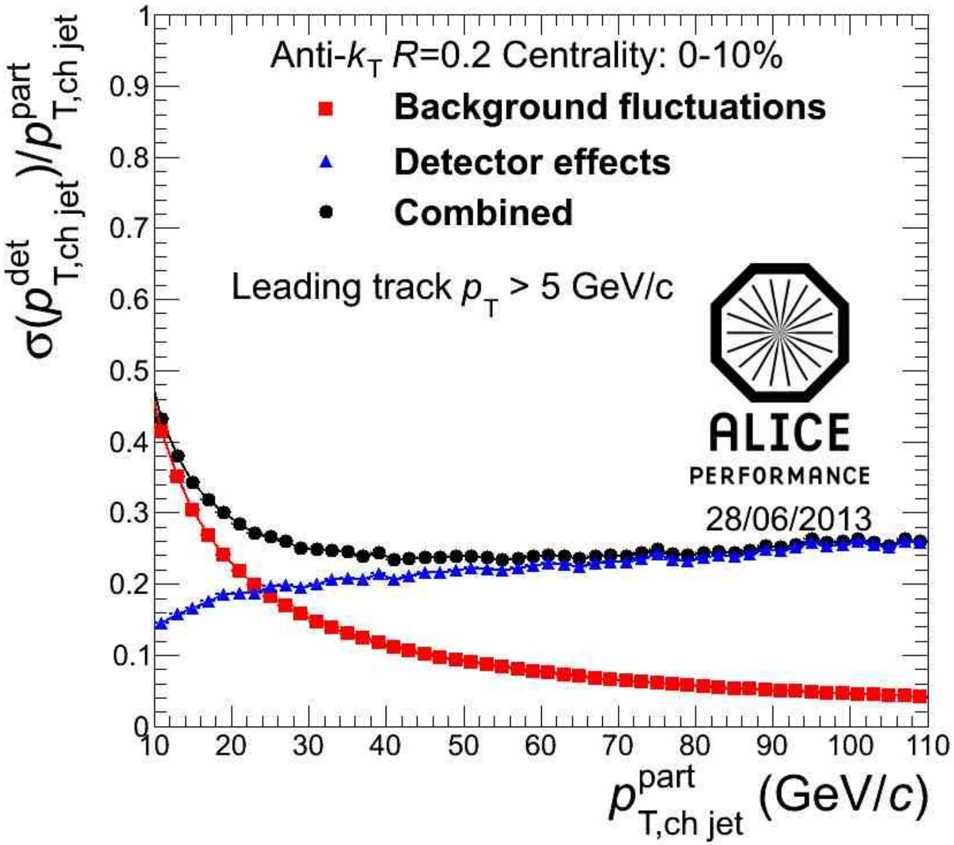
ALI-PERF-44520

Jet Resolution

Full



Charged



- Jet resolution
  - Dominated by background fluctuations at low momentum
  - Dominated by detector effects at high momentum