Jet Measurements with the EMCal of ALICE

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Jet Measurements in HI Collisions

- Motivation: Use particles produced in hard processes of the early phase of the HI collision to probe the produced medium.
- Hard photons
  - Unmodified by the medium
- Hard partons -> Jets
  - Interact strongly with the medium and probe its characteristics (parton energy loss)
    - Quark vs Gluon (coupling) dependence
    - Flavor (mass) dependence
RHIC Results on “Jet Quenching” in A+A

- High $p_T$ $\gamma$’s produced at expected rate
  - No large initial state effects
- Yield of high $p_T$ $\pi^0$’s suppressed
  - Parton energy loss reflected in softer fragmentation products

- Suppression of back-to-back high $p_T$ hadrons
  - Recoil parton “quenched”

$$R_{AA}(p_T, \eta; b) = \frac{1}{d^2 N_{coll}^{AB}} \frac{d^2 N_{hard}^{AB}}{d p_T d \eta} \frac{d^2 N_{hard}^{PP}}{d p_T d \eta}$$
Full Jet Measurements

- **Parton energy loss consequences:**
  - Leading fragmentation hadrons are softer due to parton energy loss
    - Observed high $p_T$ hadrons are dominantly from harder partons emitted from the periphery (surface bias)
  - Additional soft “fragmentation” products due to energy loss (gluon bremsstrahlung)
  - Momentum of jet (parton) is not lost but is redistributed in an apparently modified fragmentation

- If we can identify the jet and reconstruct its energy, then we can remove surface bias and study the medium by its effect on the jet fragmentation
  - Measuring the recoil direct photon from $\gamma+\text{jet}$ processes would provide direct measurement of the parton energy (@LO)
    - “Golden” measurement, but difficult due to low rate and backgrounds
The effect of parton energy loss is to suppress the yield of high $z$ ($=p_T^h/E_T^{jet}$) fragmentation hadrons with enhanced low $z$ yield.

The effect on yields is seen more clearly in Humped-Back Plateau distribution.

- Sensitive to the transport coefficient $q^\hat{v}$ characterizing the stopping power of the medium.

$$zD(z, Q^2) = K \exp \left[ -\frac{1}{2\sigma^2} (\xi - \xi_P)^2 \right]$$

$$\xi_P \approx \frac{1}{4} \ln \left( \frac{s}{\Lambda_{QCD}^2} \right)$$

$$\sigma \propto \left[ \ln \left( \frac{s}{\Lambda_{QCD}^2} \right) \right]^{3/4}$$
ALICE Central Detectors

- **ITS, TPC,**
  - Charged multiplicity $|\Delta \eta|<1.8$
  - Excellent tracking from 100 MeV/c; $\Delta p/p=6\% @ 100$ Ge/c

- **TRD, HMPID, TOF, TPC**
  - Excellent Particle ID

- **EM Calorimetry**
  - **PHOS:** high resolution
    - Coverage $\Delta \eta=0.25$, $\Delta \phi=100^\circ$
    - Granularity $\delta \eta = \delta \phi = 0.004$
    - Resolution $\delta E/E=3\%/\sqrt{E}$
    - $\gamma (\pi^0)$ trigger
  - **EMCal:** large coverage
    - Coverage $\Delta \eta=1.4$, $\Delta \phi=107^\circ$
    - Granularity $\delta \eta = \delta \phi = 0.014$
    - Resolution $\delta E/E=11\%/\sqrt{E}$
    - $\gamma (\pi^0)$ and jet trigger
Hard Probes in ALICE

- Jet yields in ALICE to above 200 GeV
- EMCal needed to:
  - Provide trigger
  - Improve Jet resolution
  - Extend $\gamma$, $\pi^0$, and $e^\pm$ measurements
    - $\gamma$-jet measurements
    - $b$, $c$ tagged jets

Jet yields in ALICE:
- Jet yields above 200 GeV
- $\gamma$-jet measurements
- $b$, $c$ tagged jets

Graph showing annual yields in ALICE:
- $E_\text{T} > E_\text{T}^\text{cut}$ or $p_T > p_T^\text{cut}$
- Pb+Pb minbias
- Binary scaling from p+p
- $L = 0.5/\text{mb/s}$; 1 year $= 10^5$ s
- EMCAL: $\Delta\eta \times \Delta\phi = 1.4 \times 10^3$

Graph showing 100 GeV Jet counts:
- Charged
- $\gamma$
- Leading charged particle

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ALICE EMCal

EMCal: Pb/Sc Shashlik
- 10+2/3 Super Modules
- Approved 12/08
- Two SM for 2009 run
- Complete for 2011 run

Module:
2x2 towers

- Coverage $\Delta \eta = 1.4$, $\Delta \phi = 107^\circ$
- Granularity $\delta \eta = \delta \phi = 0.014$
- Resolution $\delta E/E = 11\% / \sqrt{E}$
- $\gamma$ ($\pi^0$) and jet trigger

24 Strip Modules per Super Module
EMCal Trigger

- Level 0 trigger for unbiased $\gamma$, $\pi^0$, and $e^\pm$ measurements
  - Avoid bias of p+p min bias
- L1 $\gamma$ ($\pi^0$, and $e^\pm$) trigger
  - Overlapping 4x4 tower sums (a la PHENIX)
- L1 jet trigger
  - Overlapping jet-patches with multiplicity dependent $E$ threshold
  - Programmable jet-patch size (N x N towers)
- Participate in High Level Trigger to use tracking information to improve jet energy resolution and refine threshold

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Reconstructing Jets in A+A

• The Challenge:
  - To find the jet in the high multiplicity environment of central collisions A+A
  - Aided by angular ordering of fragmentation process
  - To remove the soft background in order to study the modified fragmentation
Reconstructing Jets in A+A

- **Strategy:**
  - To determine jet energy use restricted cone radius $R_c \approx 0.3 - 0.4$ and particle $p_T$ threshold to minimize underlying event contribution
  - Large cones worsen jet energy measurement
  - Estimate and subtract energy of underlying event by measuring energy in equivalent cone area outside jet region
  - Correct jet energy scale for cone acceptance
  - Test by embedding jets in A+A events
- Works well!
**Jet fragmentation modification**

- Use simulations to test and develop algorithms
  - Cone radius, $p_T$ cut, background subtraction

- Results confirm that jet modifications can be extracted reliably and are sensitive to energy loss parameters

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**Annual ALICE run statistics**

$<E_{\text{input}}>$~175 GeV

$\text{Pb+Pb 0-10\%: } <\hat{q}> = 50 \text{ GeV}^2/\text{fm}$

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**Diagram Details**

- Ideal $R_c=1.0$, $p_t=0.0 \text{ GeV}$
- $\text{Pb+Pb } R_c=0.4$, $p_t=1.0 \text{ GeV}$

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**References**

- EMCal + tracking $R=0.4$, $p_t=1.0$
- EMCal + tracking $R=0.4$, $p_t=1.0$, APQ

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**Footnote**

Large background corrections, 5% sys. uncertainty assumed

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**Chart**

- $\frac{1}{N_{\text{jet rec}}}$ vs. $dN/dE$
- $\zeta = \ln(E_{\text{rec}}/p_t)$

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ALICE Jet Measurement Program

- Baseline measurement in p+p
  - Detailed FF measurements with PID to low z
    - Of interest to improve understanding of fragmentation process

- In Pb+Pb measure modifications
  - Extract quenching parameters characterizing the medium
    - Currently model dependences dominate uncertainties
  - Cone radius dependence
    - E.g., suppressed early radiation (high z) due to absorption, but enhanced low z radiation within large cone
  - Other features: Near-side Ridge and away-side Cone

- Investigate HBP for identified particles, especially at low $p_T$
  - Electron tagged b and c jets
    - Quark mass dependence of parton $E_{\text{loss}}$
  - Modifications of the flavor content of jet due to medium
    - Flavor changing interactions during propagation through the medium
Summary

• ALICE will excel at Jet fragmentation measurements
  - Large acceptance EMCal with good resolution and granularity
  - Trigger on Jets (and high $p_T \gamma$’s ($e^\pm$), and $\pi^0$’s)
  - Superb particle identification and tracking to high $p_T$

• Analysis procedures have been developed and are ready for the challenge of Jet measurements in Pb+Pb collisions
Jet Resolution

Resolution (RMS/mean) vs Jet Energy (GeV):
- Pb+Pb + full detector simulation
- p+p + full detector simulation

Energy (rel. to fully reconstructed jets, R = 1)

Direction (η,φ):
- Δη RMS for PbPb
- Δφ RMS for pp
- Δη RMS for pp