Exploring Jet Properties in p+p Collisions at 200 GeV with STAR

Helen Caines - Yale University - for the STAR Collaboration

Outline

• What we know already
• Jets and our data set
• $z$ and $\xi$ distributions
• The underlying event
• Summary and outlook
Jets – a calibrated probe

- Jet cross-section in p+p is well described in pQCD framework over 7 orders of magnitude.
- Minimum bias particle production in p+p also well modeled.

What about fragmentation?
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Fragmentation functions (FF)

- No previous comparisons at RHIC energies available.
- Measurements at higher $\sqrt{s}$ agree well with theory.

Test energy scaling of fragmentation functions.

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- FF are particle species dependent.

Need to study composition of jets and complete event.

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The p+p data set

- TPC tracks to identify charged particles contribution.
- Barrel EMCal for neutral energy contribution.

2006 Run
Sampled luminosity for Jet-Patch triggers:
~8.7 pb$^{-1}$
(~8 M events)

Jet-Patch Trigger:
BBC coincidence + EMCal Jet-Patch

Jet-Patch:
$E_T > 8$ GeV in
$\Delta \eta \times \Delta \phi = 1 \times 1$
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Jet-Patch - NEF FF bias - use non-triggered jet for studies.
Jet reconstruction - algorithms

Seedless Cone - SISCones

- $R_{\text{cone}} = \sqrt{(\Delta \varphi^2 + \Delta \eta^2)}$
- all particles used.
- Splitting/Merging destroys cone shape.

Fastjet package - [Cacciari, Soyez, arXiv:0704.0292]
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- \( k_T \) starts from lowest \( p_T \).
- merges weighted by \( 1/p_T \) i.e. high \( p_T \) is dis-favored.

Anti-\( k_T \)

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Compare results to explore systematics.

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Jet reconstruction - the resolution parameter

\[ \frac{\text{Energy within resolution parameter } R}{R < 0.3} \]

- Consistent with CDF

> 80% within R~0.3.

- Larger energy $\rightarrow$ more focused jet.

Compare FF using different radii.

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Energy resolution - the jet energy scale

Calculated in two way:

- Simulation
  - MC input compared to reconstructed output.

- Offset due to missing energy:
  - Detector efficiencies.
  - Undetected particles (n, K$_{0L}$).

- Resolution $\sim$15-20% for $p_{TJet} > 15$GeV/c.
Energy resolution - the jet energy scale

Calculated in two way:

- Simulation
  - MC input compared to reconstructed output.
- Real data

Offset due to missing energy:
- Detector efficiencies.
- Undetected particles (n, K$^0_L$).

Resolution $\sim$15-20% for $p_{T\text{Jet}}$>15GeV/c.
ξ and Z distributions for charged hadrons

20 < Jet p_{T_{reco}} < 30 GeV/c

R = 0.4

30 < Jet p_{T_{reco}} < 40 GeV/c

Data not corrected to particle level.

"PYTHIA" = PYTHIA + GEANT

Reasonable agreement between data and PYTHIA+GEANT.
Charged hadrons $\xi$ for different $R$ and jet $p_T$

$20 < p_T^{\text{reco}} < 30$ GeV/c

$30 < p_T^{\text{reco}} < 40$ GeV/c

Data not corrected to particle level.

"PYTHIA" = PYTHIA + GEANT

Agreement similar between PYTHIA and data for both radii.
What about the Underlying Event?

- p-p events are complicated. More than just hard scattering.

- Underlying Event: soft or semi-hard multiple parton interactions, initial & final state radiation, beam-beam remnants

The Underlying Event is everything BUT the hard scattering

Figure from Rick Field
Define:

- $|\Delta \phi|$ – Angle relative to leading jet

- “Toward” $|\Delta \phi| < 60^\circ$

- “Away” $|\Delta \phi| > 120^\circ$

- “Transverse” $60^\circ < |\Delta \phi| < 120^\circ$
  
  - **TransMax** - Trans. region with highest $\Sigma p_T$ or $\Sigma N_{\text{track}}$
  
  - **TransMin** Trans. region with least $\Sigma p_T$ or $\Sigma N_{\text{track}}$

Underlying Event is the data in the Transverse regions.
Sensitivities of the variables

**leading** : Most basic jet cut, one jet in our acceptance.

**back-to-back** : Sub-set of *leading* jet collection.
   Require $|\Delta \phi| > 150$, $p_{T\text{Away}}/p_{T\text{Lead}} > 0.7$
   Suppresses hard initial and final state radiation.

**TransMin** : Sensitive to beam-beam remnants and soft multiple parton interactions.

**TransMax** : Enhanced probability of containing hard initial and/or final state radiation component.
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Compare **TransMin** and **TransMax** data from leading and back-to-back jet samples →

Information about large angle initial/final state radiation.
TransMin vs TransMax regions of UE

CDF $\sqrt{s}=1.96$ TeV
- leading TransMax > back-to-back TransMax

Significant initial/final state radiation at large angles.

CDF Run 2 Preliminary
- data corrected to particle level
- "Leading Jet"
- "Back-to-Back"

MidPoint R = 0.7 $|\eta|$(jet#1) < 2

Charged Particles ($|\eta|<1.0$, PT>0.5 GeV/c)

$\text{TransMAX} \text{ Charged Particle Density: } dN/d^2d^0$

0 50 100 150 200 250 300 350 400 450

PT(jet#1) (GeV/c)
TransMin vs TransMax regions of UE

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STAR $\sqrt{s}=200$ GeV
- leading TransMax $\sim$ back-to-back TransMax
  Small initial/final state radiation at large angles.

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  - TransMax $>$ TransMin

Poisson distribution with average $dN_{ch}/d\eta d\phi = 0.36$
- UE $\sim$ independent of jet $p_T$.!
$p_T$ spectra in jet, UE, Min-Bias event

$15 < p_{T_{\text{jet}}} < 20 \text{ GeV/c}, |\eta_{\text{jet}}| < 1-R$

**Charged particles**

**$K^0_s$**

**All data raw**

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Summary & outlook

- Charged hadron $\xi$ and $z$ distributions at $\sqrt{s}=200$ GeV similar to PYTHIA 6.4.
- Underlying Event largely decoupled from hard scattering.
- Large angle initial/final state radiation is small.
- Particle $p_T$ spectra are significantly softer out of the jet cone compared to in the jet.
- $p_T$ spectra of Underlying Event close to that of Min-Bias triggered events.

Outlook

- Compare more jet-variables ($k_T, j_T$, etc) to pQCD models.
- Use relativistic rise and newly installed ToF to identify $\pi, K, p$.
- Repeat measurements at $\sqrt{s}=500$ GeV.
- Measure PID FF in heavy ion collisions.

See posters: 2-Hadron FF (M. Elnimr), d-Au (J. Kapitan), UE (HC)