Multiple Interactions in Sherpa
MC Results vs. Data

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- Brief Model review
- Combining MIs and the CKKW Merging
- Preliminary Results
- Outlook

Brief MI Model Review

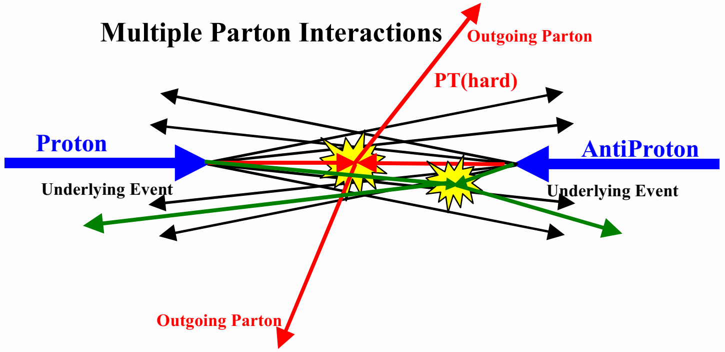
Multiple Interactions (MI) in Sherpa ⟷ formalism invented by T. Sjöstrand[1]

Basic:
- distribute hard scatterings like

$$p(p_\perp) = \frac{1}{\sigma_{\rm ND}} \frac{d\sigma_{\rm hard}(p_\perp)}{dp_\perp}$$

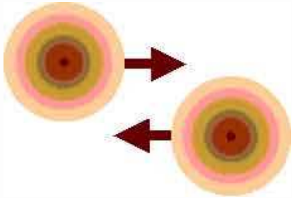
- model proton profile in b-space

  e.g. $f(\mathrm{b}) \propto exp\{-\mathrm{b}^2\}$



Sherpa implementation:

→ enable Parton Showers (PS) for multiple scatterings



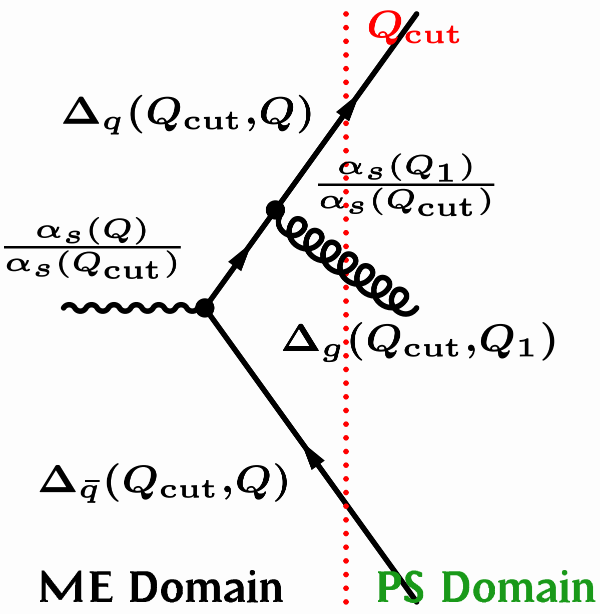
→ combine the MI approach and the CKKW merging procedure

[1] Phys. Rev. D36 (1987)

Brief Review of CKKW

CKKW → General approach to combine Matrix Elements (ME) and Parton Showers, implemented in Sherpa[1]

Example: $e^+e^- \rightarrow hadrons$



- Define phase space cut $Q_{\rm cut}$
- Apply Sudakov weight to ME

  $$\Delta_{\bar{q}}(Q_{\rm cut}, Q)\Delta_q(Q_{\rm cut}, Q)\Delta_g(Q_{\rm cut}, Q_1)$$

- Apply coupling weight to ME

  $$\frac{\alpha_s(Q)}{\alpha_s(Q_{\rm cut})}\frac{\alpha_s(Q_1)}{\alpha_s(Q_{\rm cut})}$$

- Start PS at $scale Q$
- Veto PS emissions above $Q_{\rm cut}$

[1] hep-ph/0409106, hep-ph/0311263

Combining MIs and the CKKW Merging

- Original ordering parameter for MI evolution is $p_{\perp \mathrm{out}}^{2\to2}$
- Need similar ordering parameter, μ_{MI}, in hard processes with higher multiplicity
  - μ_{MI} must reduce to $p_{\perp \mathrm{out}}^{2\to2}$ for pure QCD $2 \to 2$ scattering
  - μ_{MI} must be a QCD scale in electroweak boson production (e.g. W/Z+jets)
- Solution:
  - Employ k_T-algorithm to define core process
    - $2 \to 2$ QCD process in pure QCD
    - $V + 1jet$ process in EW boson production
  - Set starting scale for MI evolution to $p_{\perp \mathrm{out}}$ of the QCD partons from this core process

Combining MIs and the CKKW Merging

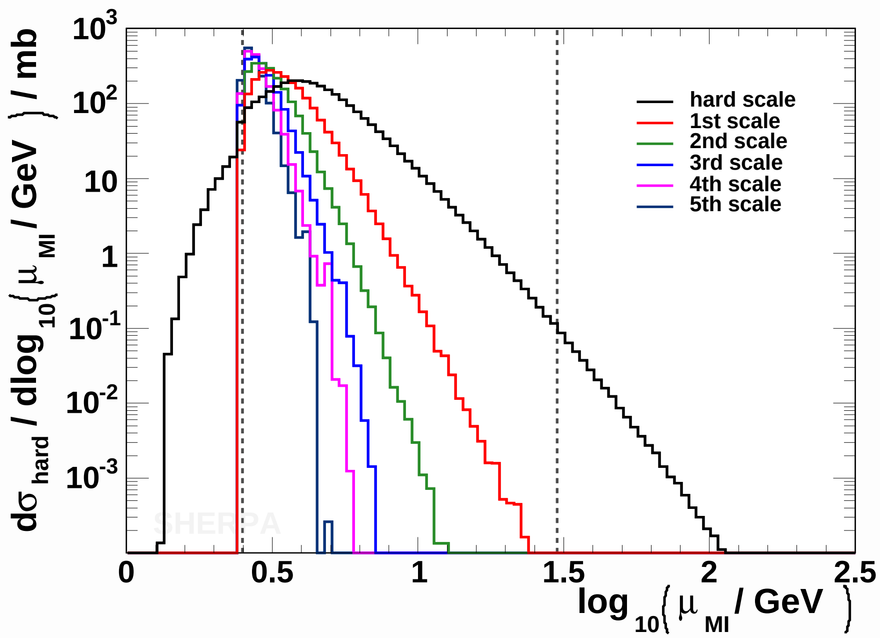
- Original MI algorithm does not allow parton radiation except for the hard scattering
- Need to define starting conditions for PS which do not spoil the MI evolution
- Solution:
  - Set PS starting scale to QCD scale

$$\frac{2\,s\,t\,u}{s^2 + t^2 + u^2}$$

  - Veto on parton shower emissions harder than $p_{\perp \mathrm{out\,MI}}$

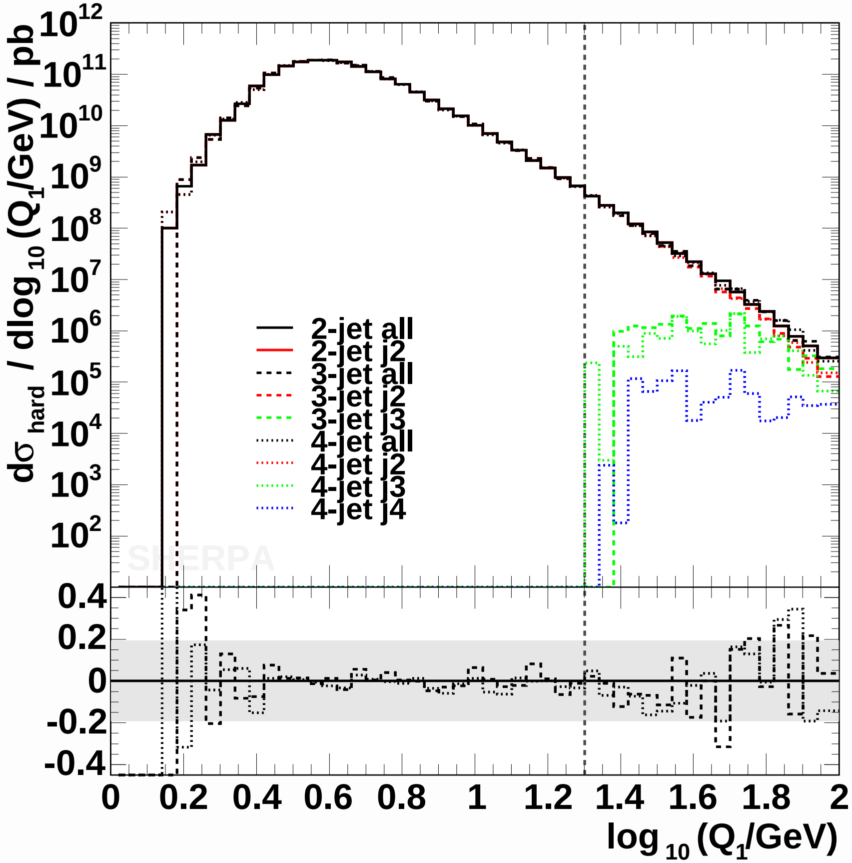
➔ Yields the Highest Multiplicity Treatment in the CKKW approach

Combining MIs and the CKKW Merging



➡ Starting scale for MI evolution (nth hard interaction)

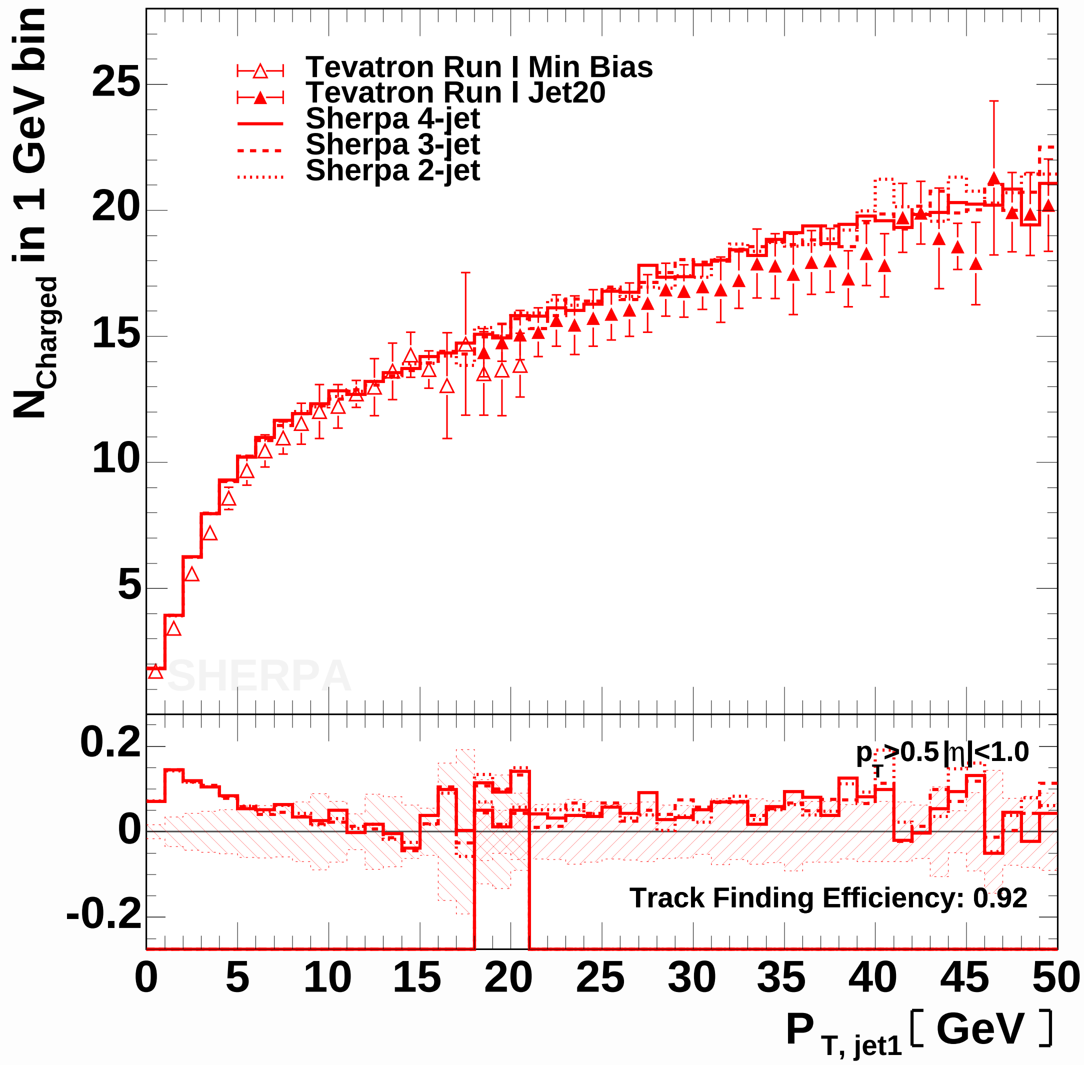
- Hardest scale yields differential 1-jet rate
- Very small dependence on the separation cut Q_{cut}



➡ Differential 1-jet rate

- Very small dependence on the maximal jet number

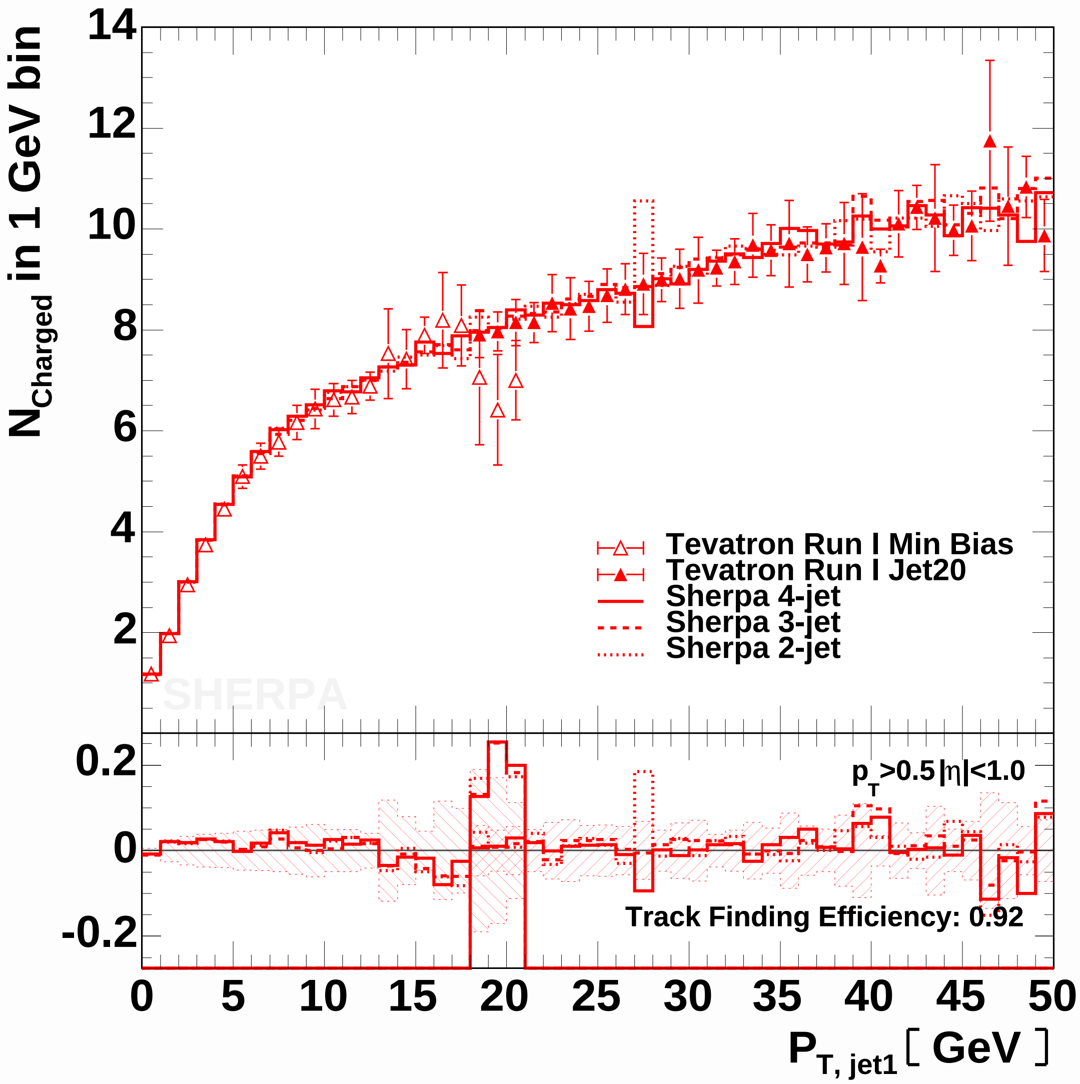
Preliminary Results

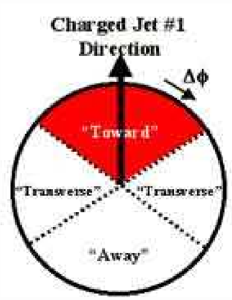


- All MC results corrected for track finding efficiency
- Sherpa MIs produce correct shape
- Total Charged Multiplicity agrees

→ Charged Multiplicity vs. P_T of the leading charged particle jet

Preliminary Results

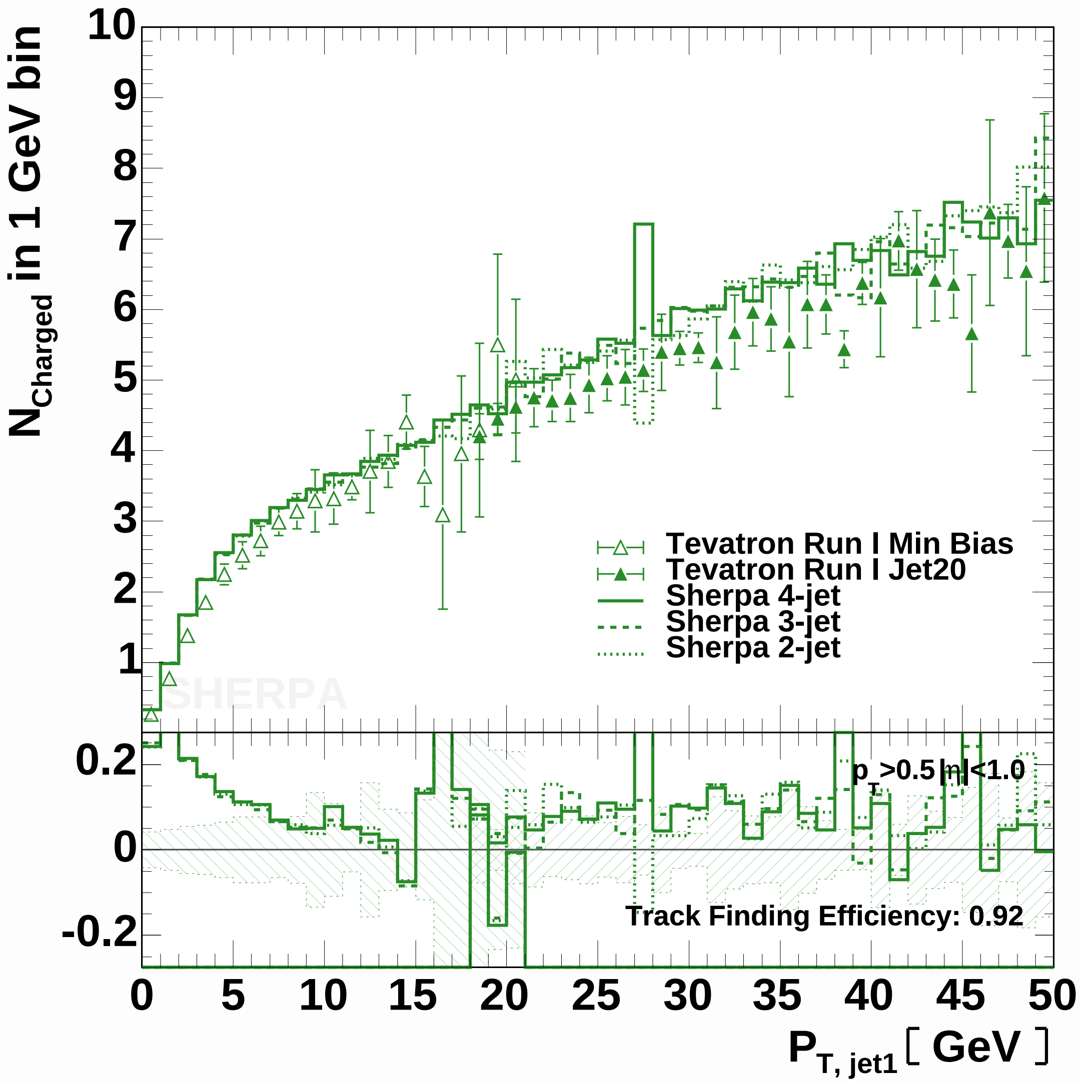


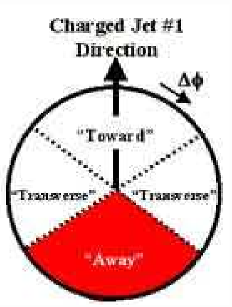


- Shape less influenced by MIs
  - → PS Domain
- MIs slightly increase Multiplicity

→ "Torward" Charged Multiplicity vs. P_T of the leading charged particle jet

Preliminary Results

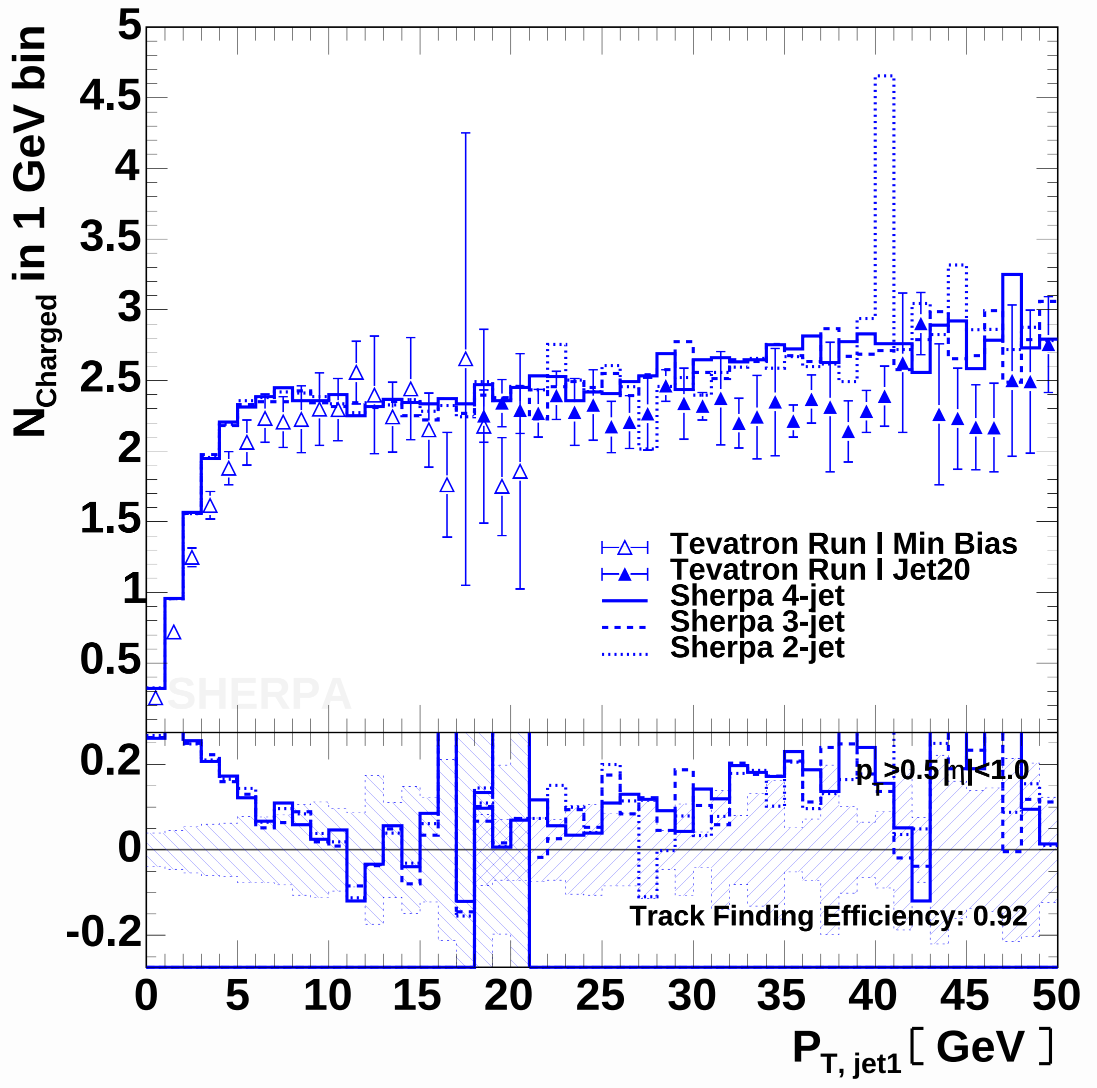


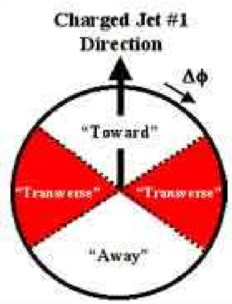


- Shape dominated by $2 \rightarrow 2$ MEs
- MIs increase Multiplicity

➡ "Away" Charged Multiplicity vs. P_T of the leading charged particle jet

Preliminary Results

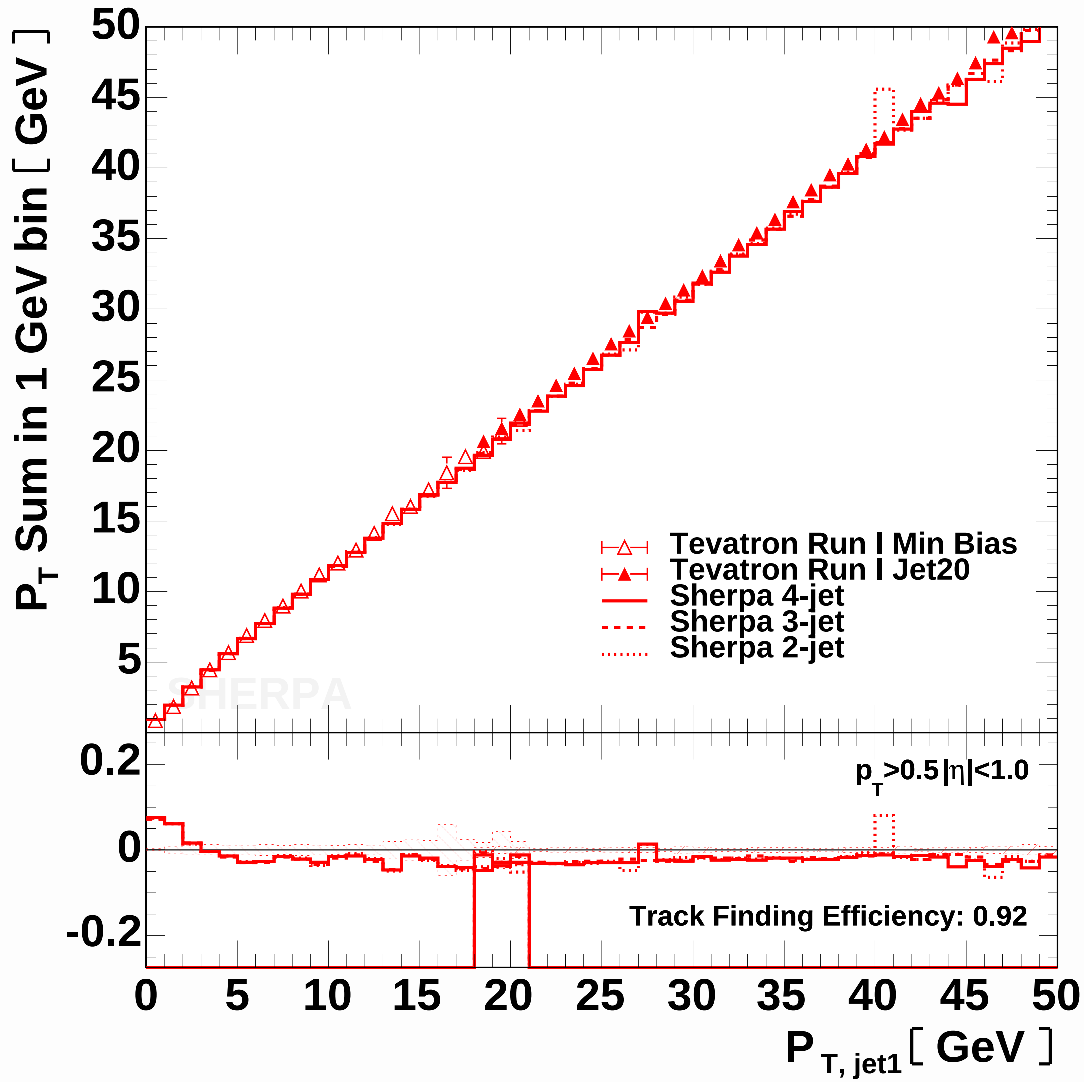


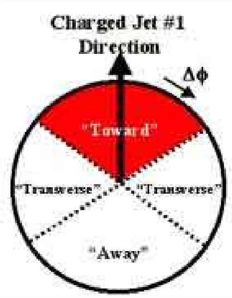


- Shape without MIs given by PS & n-jet MEs (n>2)
- Shape with MIs dominated by MIs
- MIs increase Multiplicity by a factor of ≈2 !

➡ "Transverse" Charged Multiplicity vs. P_T of the leading charged particle jet

Preliminary Results





- Shape less influenced by MIs

  ➡ PS Domain

- MIs slightly increase scalar P_T sum (increased Multiplicity)

➡ “Torward” scalar P_T sum vs. P_T of the leading charged particle jet

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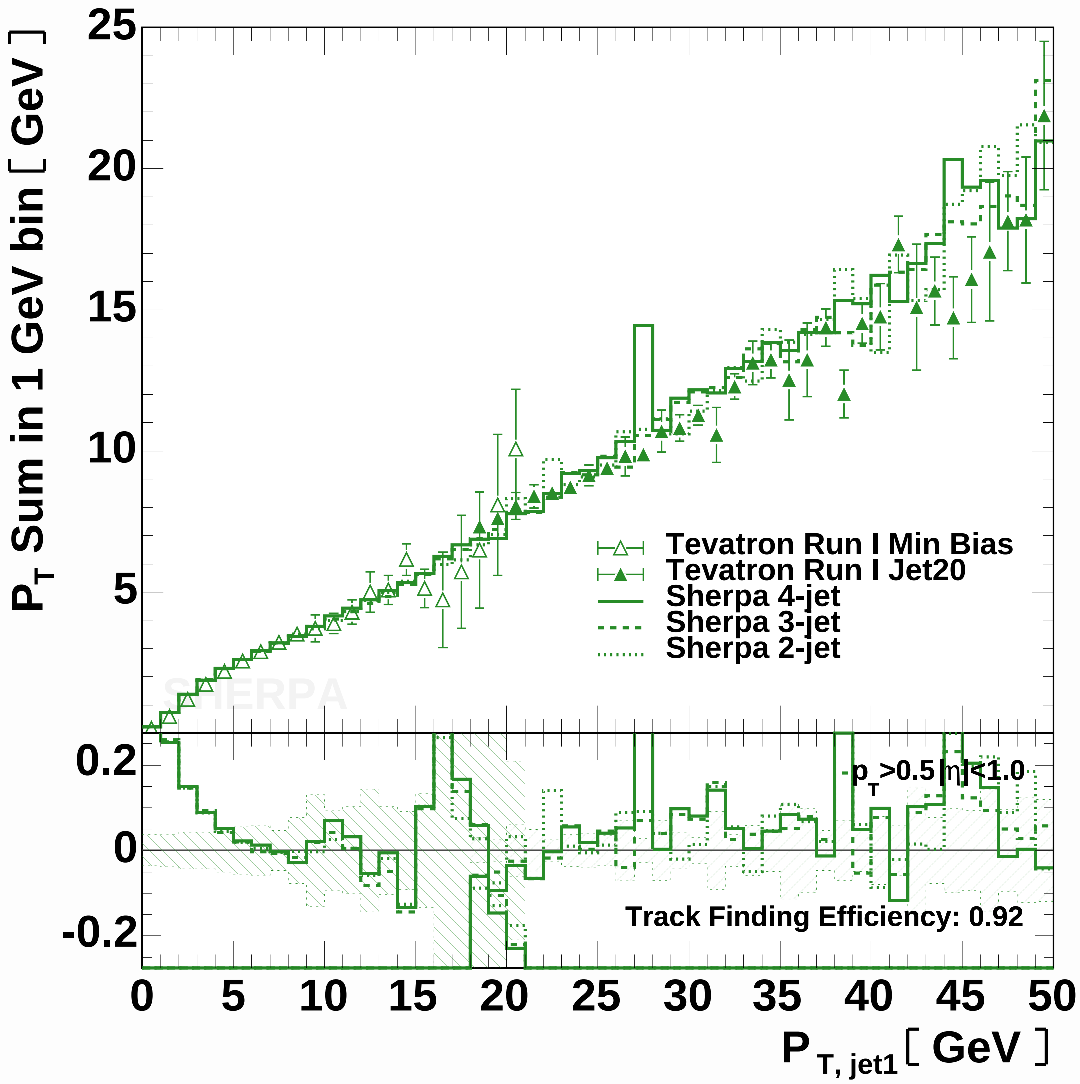

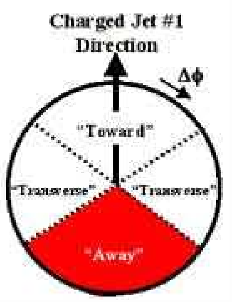

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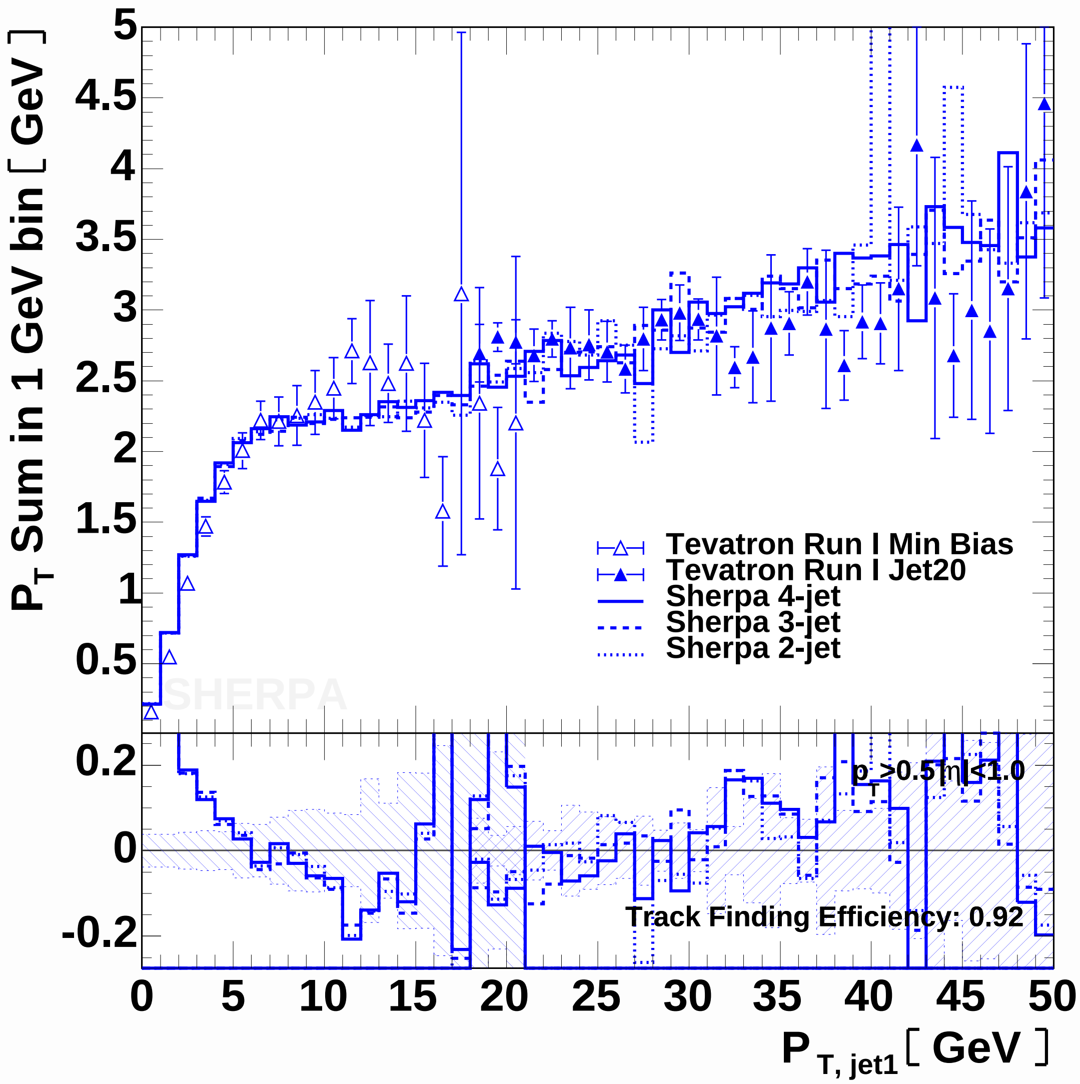

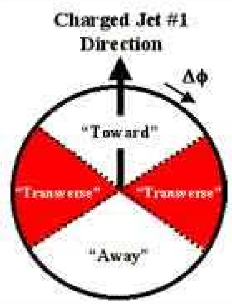

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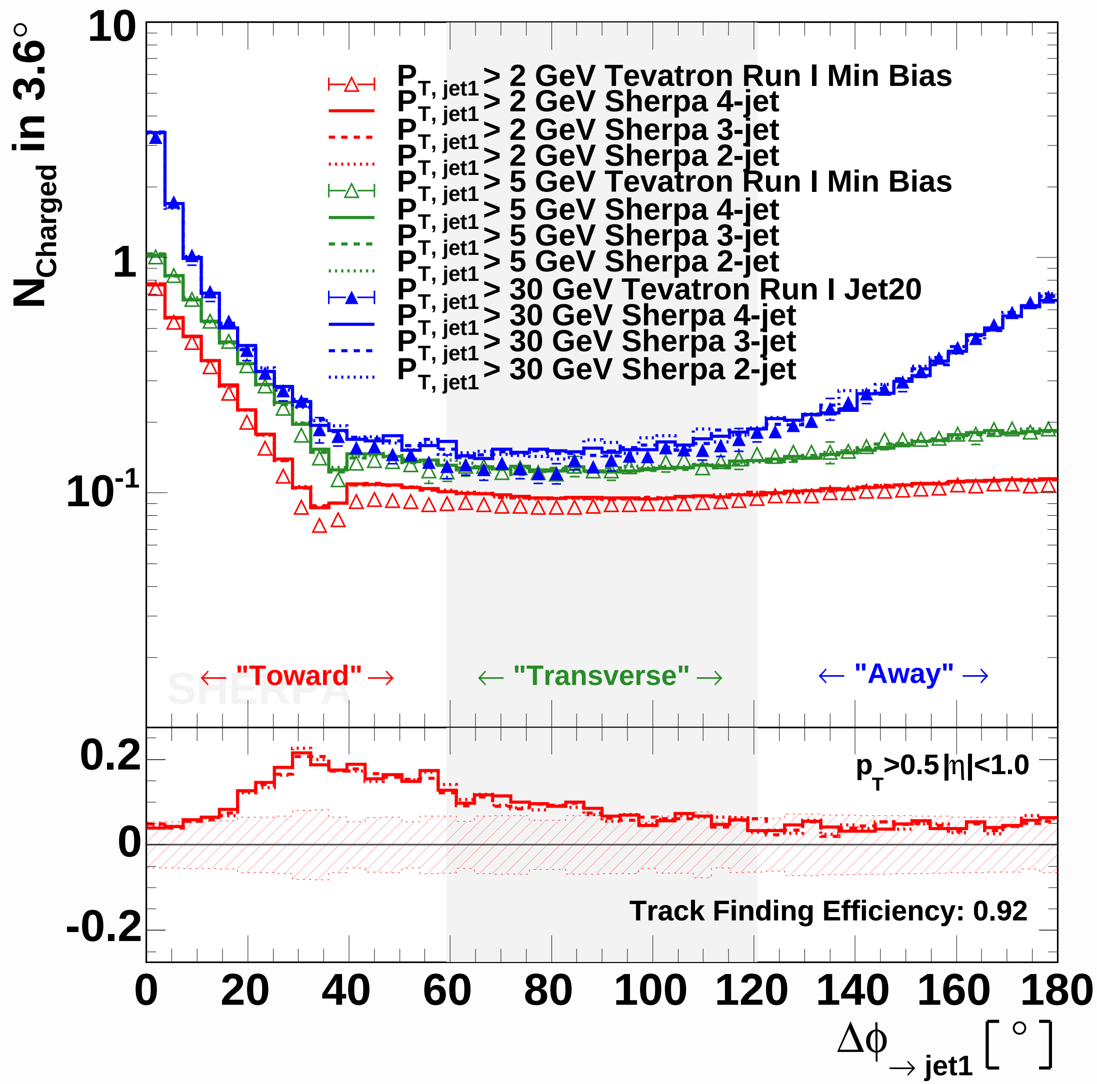
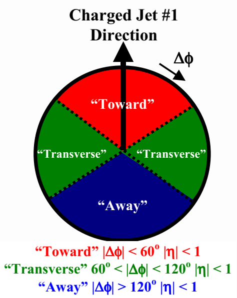
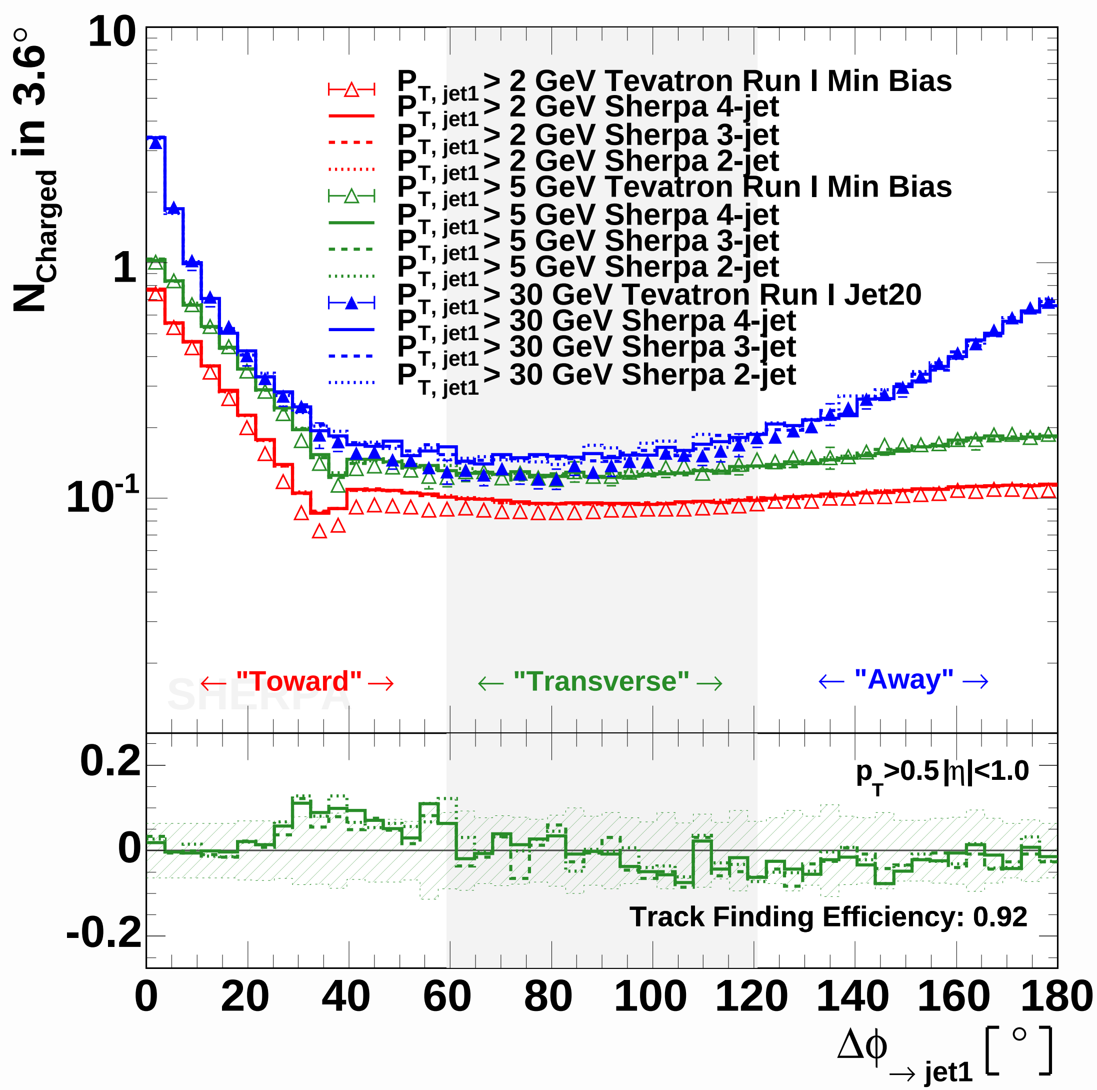


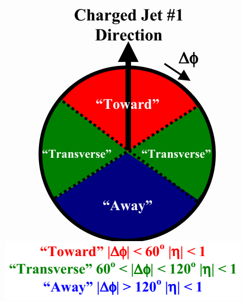


- Shape dominated by MIs ➡ increased "Transverse" Multiplicity
- Shape in "Away" region dominated by interplay between $2 \rightarrow 2$ / multijet MEs and PS effects, resp.

➡ Charged Multiplicity vs. $\Delta\phi_{\rightarrow jet1}$ relative to leading charged particle jet

Preliminary Results





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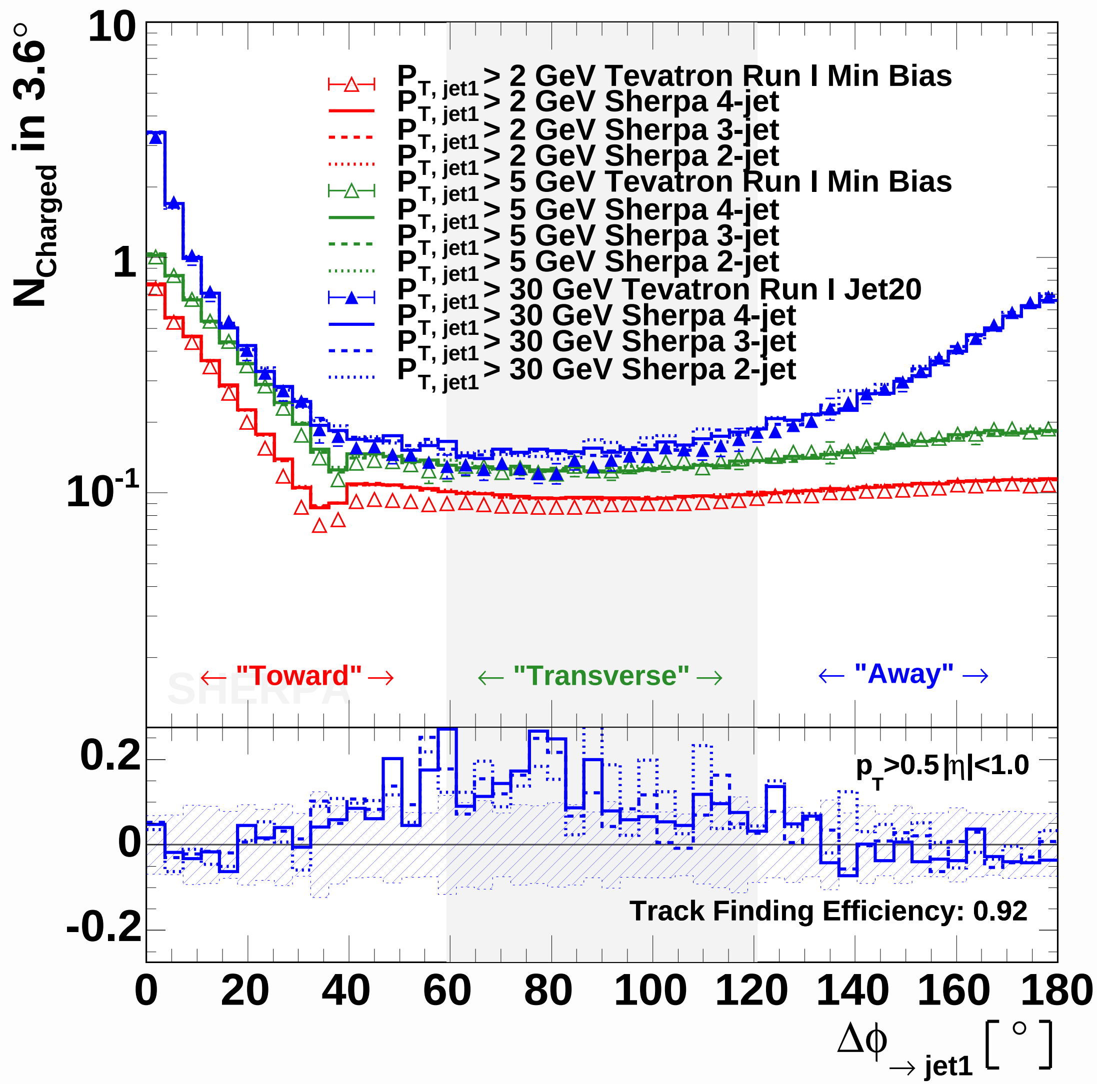

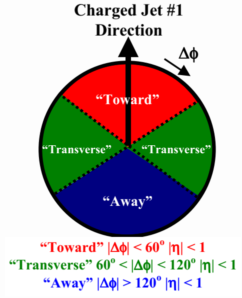

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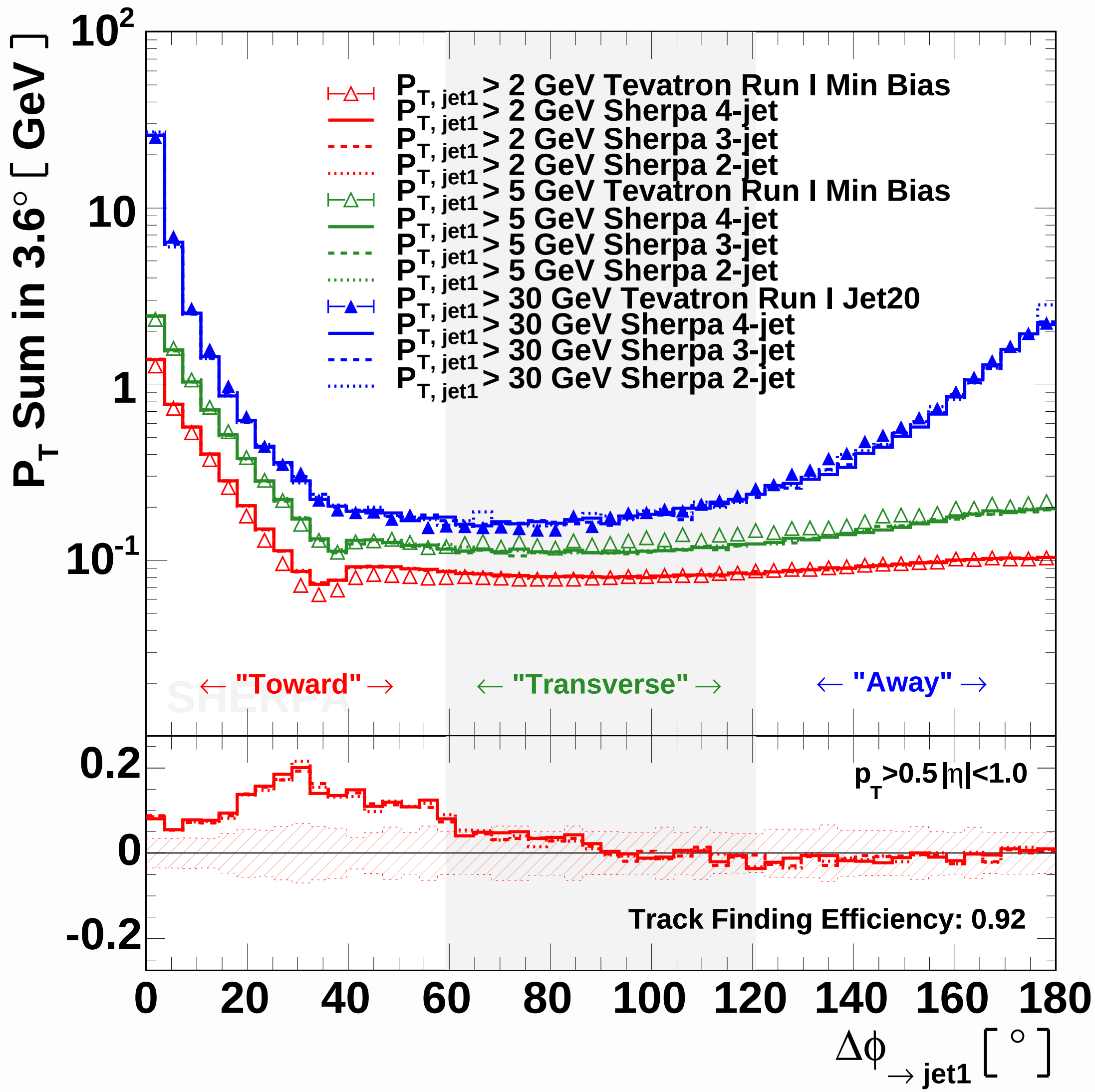

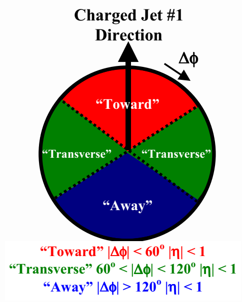

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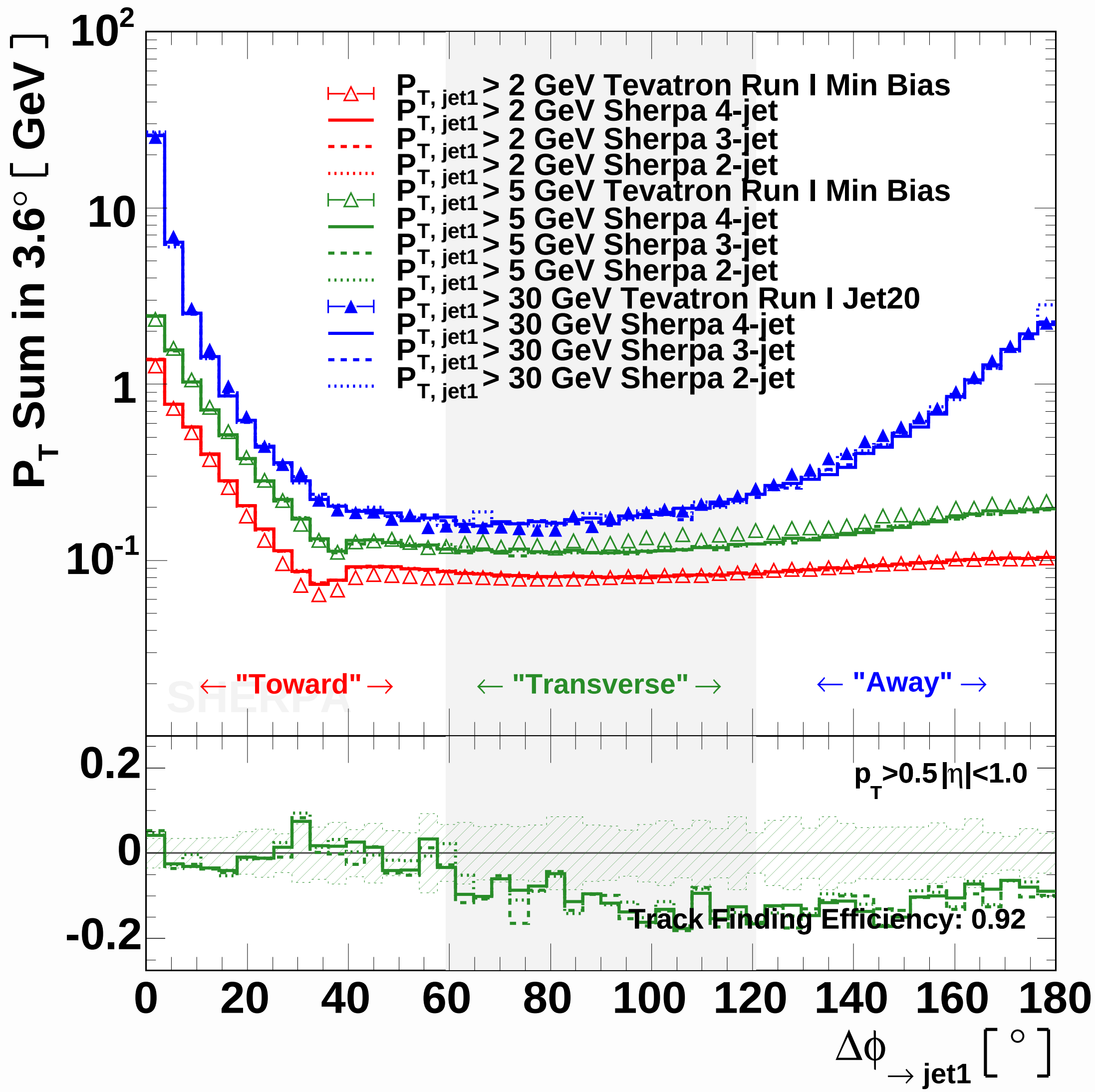

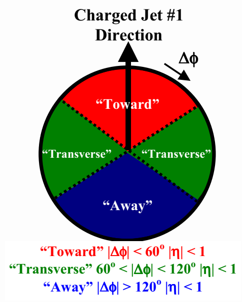

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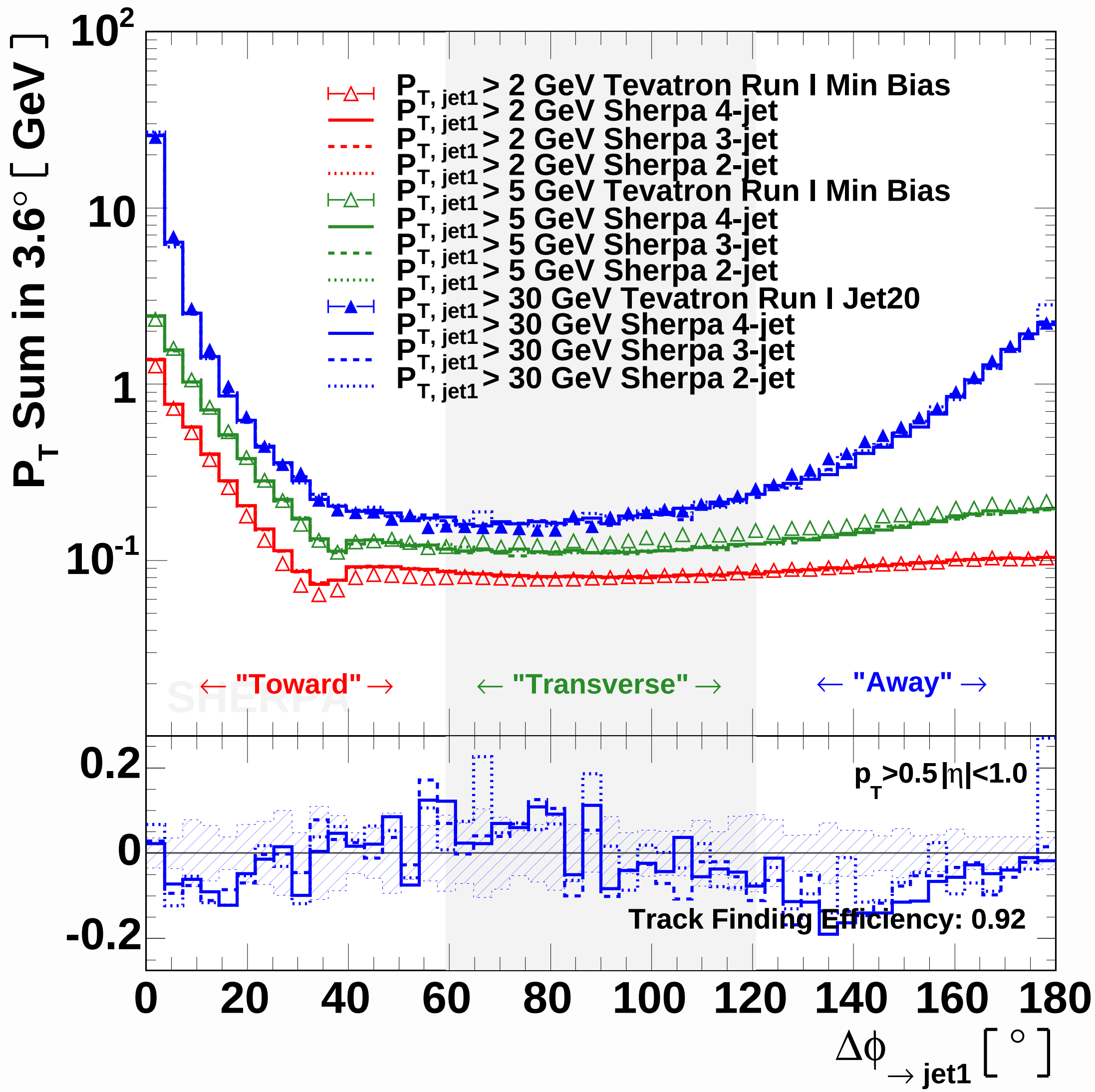

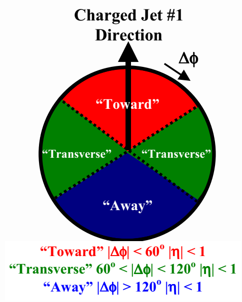

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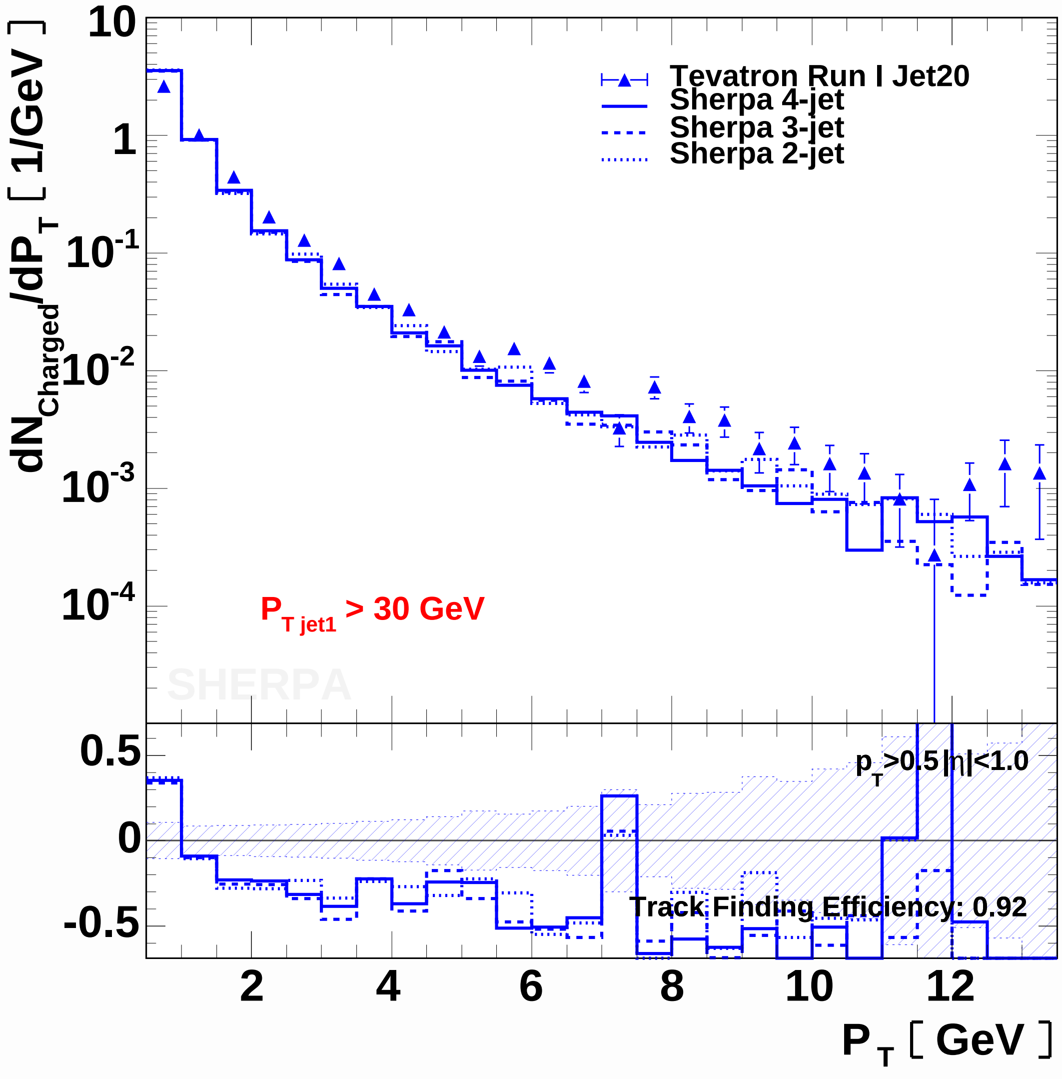
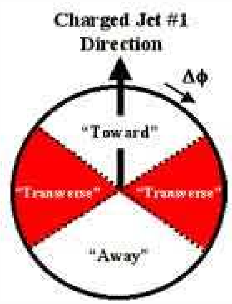




- High P_T Shape dominated by MEs
- Low P_T Shape dominated by MIs
  - ➡ Increased Multiplicity

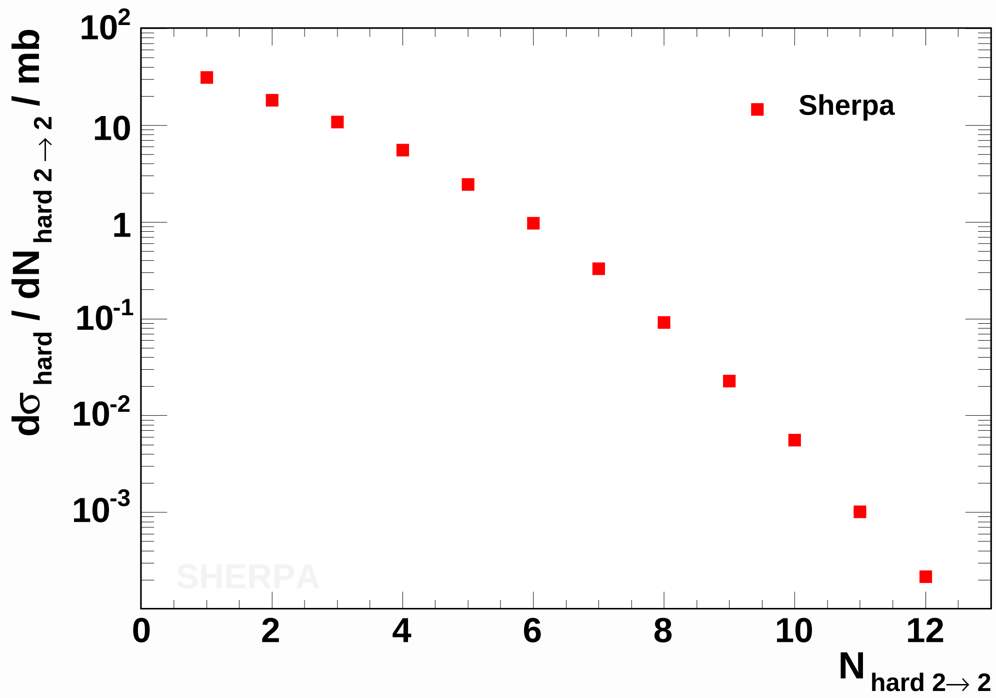
➡ "Transverse" $\frac{\mathrm{d}N_{charged}}{\mathrm{d}P_T}$

Preliminary Results

Current "Best Fit" Parameters:

- $p_{\perp \mathrm{out\ min}}^{2\to 2}$ = 2.5 GeV
- Gaussian matter distribution

PDF set has been CTEQ6L to have consistent PS evolution



→ MI Distribution

- moderate interaction number $< N_{\mathrm{hard}}^{2\to 2} >= 1.56$

Outlook

Done:

- MIs included in Sherpa ✓
- MIs combined consistently with CKKW

Now:

- Test MI treatment for Vector boson production
- Check MC results vs. Tevatron Run II data
- Examine energy dependence of MI parameters

The Sherpa group are:

Tanju Gleisberg, S.H., Frank Krauss, Caroline Semmling, Thomas Laubrich, Andreas Schälicke, Steffen Schumann and Jan Winter