# Jet Algorithms and the Underlying Event

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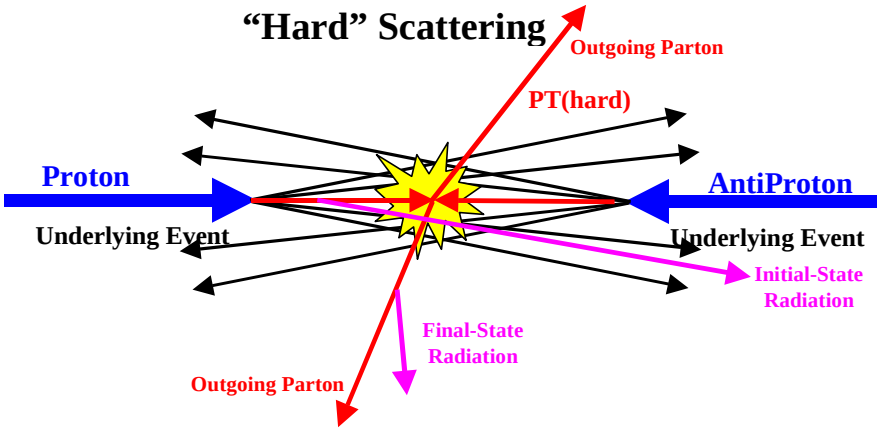



**Fig. 1**. Illustration of a proton-antiproton collision in which a "hard" 2-to-2 parton scattering with transverse momentum, $P_T(\text{hard})$, has occurred. The resulting event contains particles that originate from the two outgoing partons (plus final-state radiation) and particles that come from the breakup of the proton and antiproton (*i.e.* "beam-beam remnants"). The "underlying event" consists of the beam-beam remnants plus initial-state radiation.

# Jet Algorithm

## (1) Jet Definition 0 (seed $P_T$ order)

Jet definition 0 is the simple algorithm we used in our analysis of the "underlying event". Jets are defined as circular regions in η-ϕ space with "radius" given by $R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ . The "seeds" are all charged particles with $P_T > 0.5$ GeV and $|\eta| < 1$ and the algorithm is as follows:

- Order all seeds according to their $P_T$.
- Start with the highest $P_T$ seed and include in the "jet" all particles within the "radius" R = 0.7 seed.
- Go to the next highest $P_T$ seed (*not already included in a "jet"*) and add to the "jet" all particles (*not already included in a "jet"*) within R =0.7.
- Continue until all particles are in a "jet".

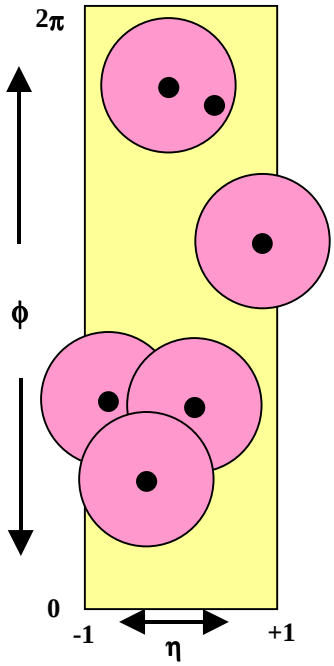



**Fig. 2**. Illustration of an event with six charged particles ($P_T$ > 0.5 GeV and |η| < 1) and five charged "jets" (circular regions in η-ϕ space with R = 0.7).

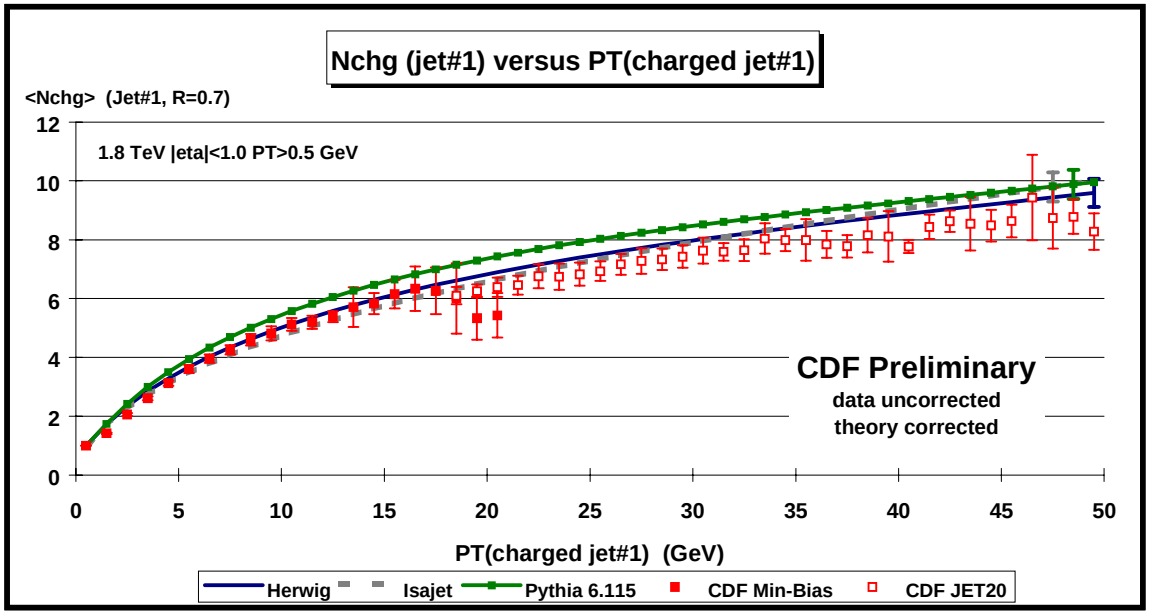



**Fig. 3**. Plot shows the average number of charged particles (PT > 0.5 GeV, |η| < 1) within the leading charged jet (definition 0) as a function of the PT of the leading charged jet. The solid (open) points are Min-Bias (JET20) data. The errors on the (*uncorrected*) data include both statistical and correlated systematic uncertainties. The QCD "hard scattering" theory curves (Herwig 5.9, Isajet 7.32, Pythia 6.115) are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

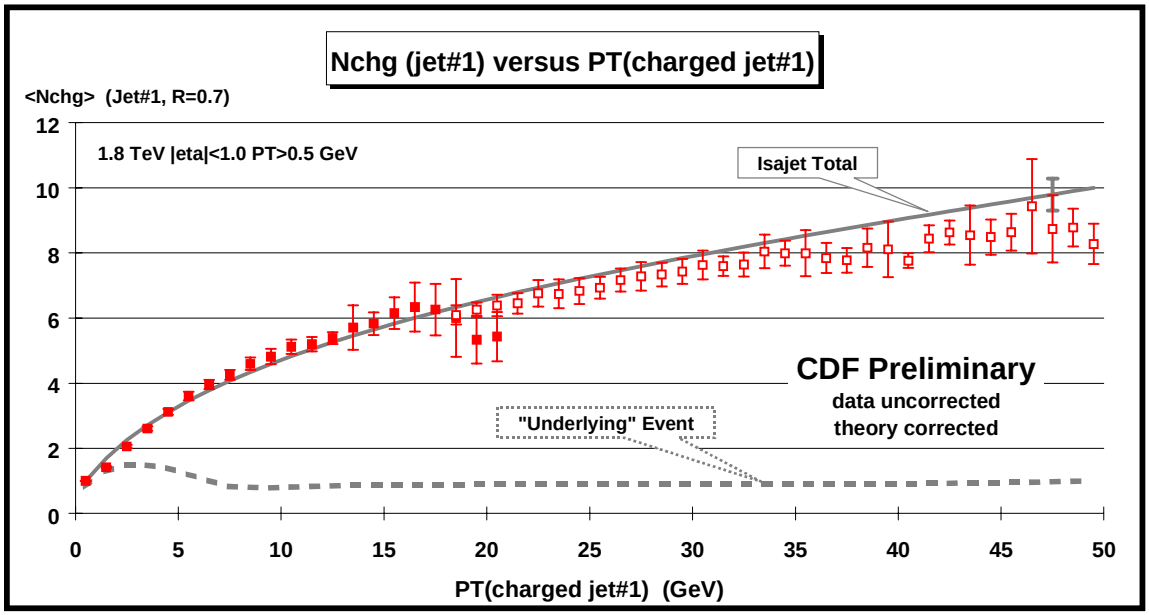



**Fig. 4**. Data from Fig. 3 on the average number of charged particles (PT > 0.5 GeV, $|\eta| < 1$) within the leading charged jet (definition 0) as a function of the PT of the leading charged jet compared with the QCD "hard scatteriing" predictions of Isajet 7.32. Also shown is the contribution from the underlying event (*beam-beam remnants plus initial-state radiation*) predicted by Isajet (see Fig. 1). The errors on the (*uncorrected*) data include both statistical and correlated systematic uncertainties. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

# Other Jet Algorithms

## (2) Jet Definition 10 (seed PTsum order)

Jet definition 10 is very similar to definition 0 except that the seeds are ordered according to the *scalar* $P_T$ sum within R = 0.7 of the seed (*double counting of particles is allowed*). The "seeds" are all charged particles with $P_T > 0.5$ GeV and $|\eta| < 1$ and the algorithm is as follows:

- Order all seeds according to the *scalar* $P_T$ sum of all charged particles within R = 0.7 of the seed.
- Start with the highest PTsum seed and include in the "jet" all particles within the "radius" R = 0.7 of the seed.
- Go to the next highest PTsum seed (*not already included in a "jet"*) and add to the "jet" all particles (*not already included in a "jet"*) within R =0.7.
- Continue until all particles are in a "jet".

# Other Jet Algorithms

## (3) Jet Definition 12A and 12B (midpoint algorithm)

Jet definition 12 is the same as definition 10 except that one adds additional "pseudo-seeds" corresponding to the midpoints of certain seed pairs. In version 12A we include the midpoints of all seed pairs (*unweighted*). In version 12B we include the pseudo-seed only if the distance $\eta$-$\phi$ space between the seed pair, $\Delta R$, satisfies $0.7 < \Delta R < 1.4$ and the midpoint is determined by $P_T$ weighting. The seeds and pseudo-seeds are then ordered according the *scalar* $P_T$ sum of particles within $R = 0.7$ of the seed or pseudo-seed and one proceeds as in definition 10.

## (4) Jet Definition 20 ($k_T$ algorithm)

The initial "seeds" are all charged particles with $P_T > 0.5$ GeV and $|\eta| < 1$. At the start each seed is labeled a "prejet" and a "measure" M is defined for each prejet and pair of prejets as follows:

$$M(\textit{single prejet}) = P_T^2(\textit{prejet})$$

$$M(\textit{prejet pair}) = \min(P_{T1}^2, P_{T2}^2)\,((\eta_2-\eta_1)^2 + (\phi_2-\phi_1)^2))/R^2$$

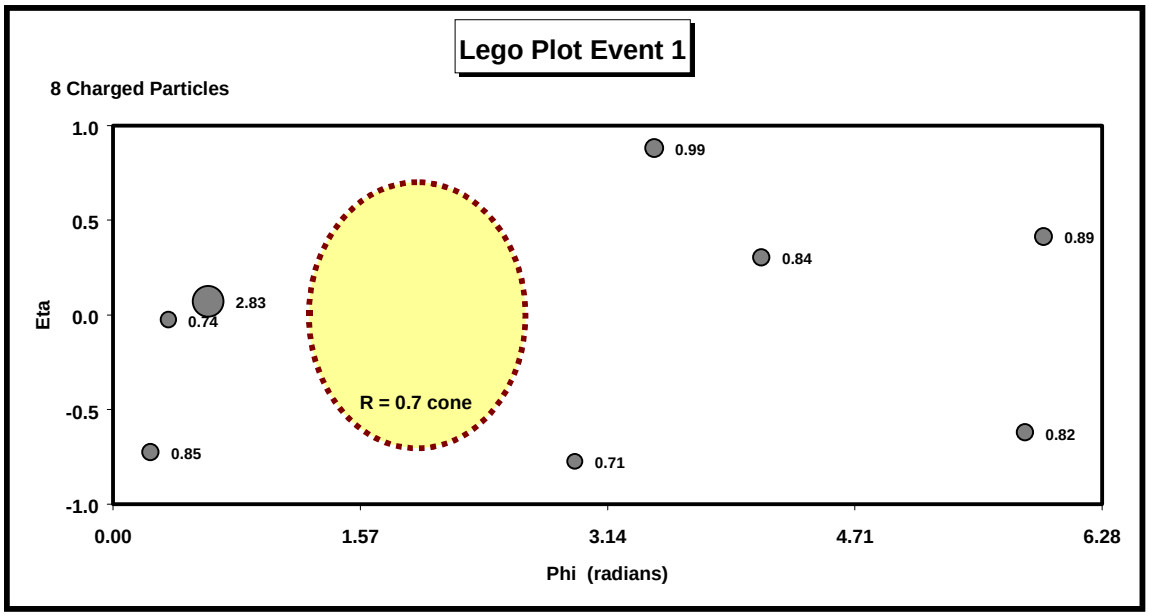
where we define the $P_T$ of a prejet to be the *scalar* $P_T$ sum of the particles within the prejet and we take the radius $R = 0.7$. The algorithm then proceeds as follows:

- Compute the "measure", M, of all prejets and all pairs of prejets.
- Find the prejet or pair of prejets with the smallest "measure", $M_{min}$.
- If $M_{min}$ arises from a single prejet then promote it to a "jet" and remove its particles from consideration.
- If $M_{min}$ arises from a pair of prejets then combine the pair into a new prejet and recompute M for all prejets and pairs of prejets.
- Continue until all prejets have been promoted to "jets".

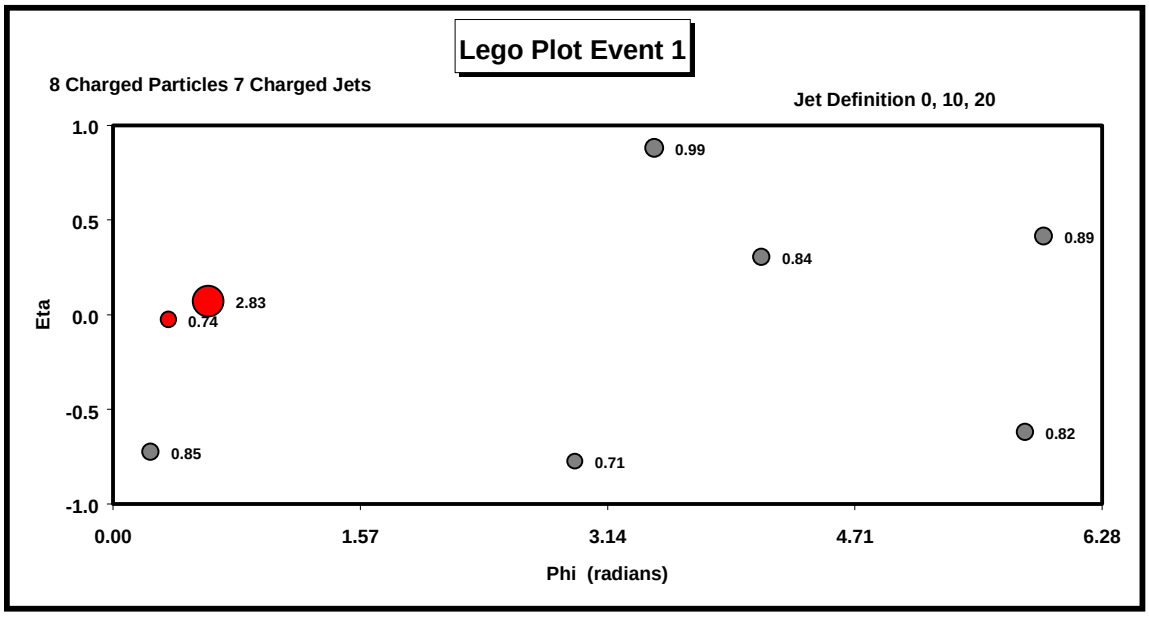
## Summary of Jet Algorithms

| ID | Seeds | Seed Order | Comment |
|---|---|---|---|
| 0 | Charged Particles ($P_T > 0.5$ GeV, $\|\eta\| < 1$) | PT seed | Simple algorithm used in Ref. [1] |
| 10 | Charged Particles ($P_T > 0.5$ GeV, $\|\eta\| < 1$) | PTsum (R = 0.7) | Same as ID=0 but different order |
| 12A | Charged Particles ($P_T > 0.5$ GeV, $\|\eta\| < 1$) plus "pseudo-seeds" | PTsum (R = 0.7) | Midpoint Algorithm: all midpoints included (unweighted) |
| 12B | Charged Particles ($P_T > 0.5$ GeV, $\|\eta\| < 1$) plus "pseudo-seeds" | PTsum (R = 0.7) | Midpoint Algorithm: pseudo-seeds ($0.7 < \Delta R < 1.4$) (PT weighted) |
| 20 | Charged Particles $P_T > 0.5$ GeV, $\|\eta\| < 1$ | none | kT Algorithm: PTsum and $\eta$ |

# Lego Plots (η-ϕ space)

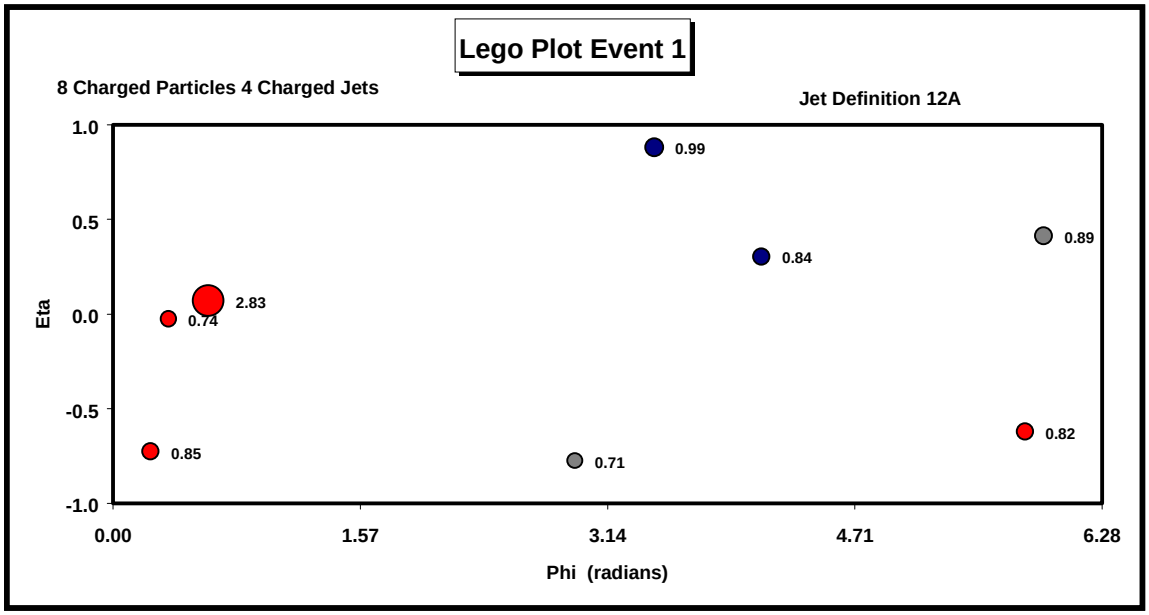



**Lego Fig 1**. Shows the lego plot of event #1 which consists of 8 charged particles. Also shows a cone with radius R = 0.7.

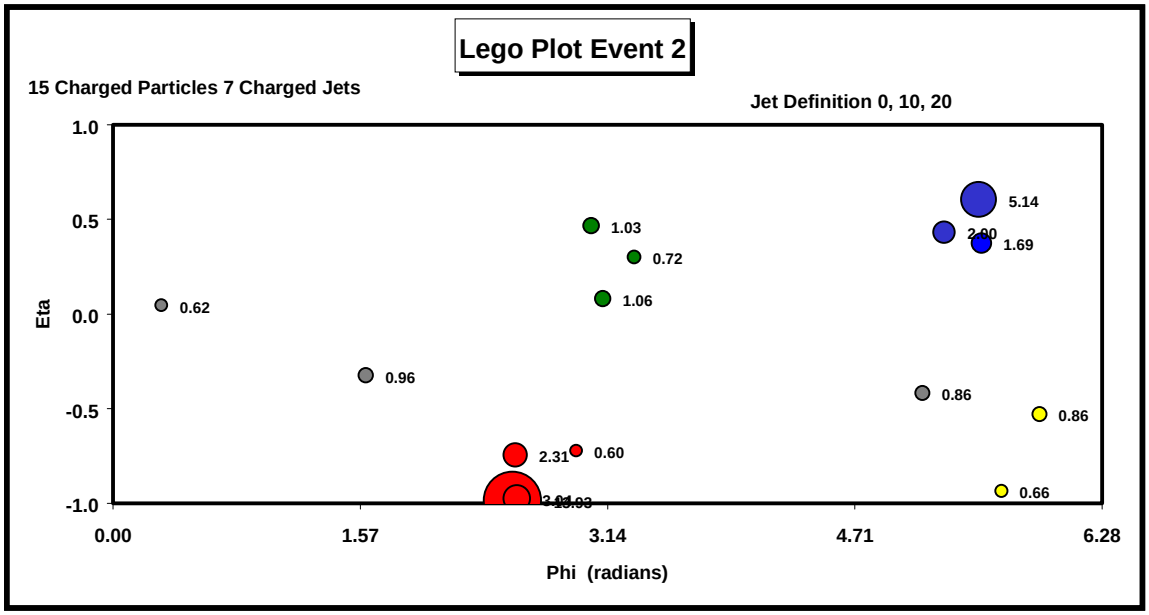



**Lego Fig 2**. Shows the lego plot of event #1 which consists of 8 charged particles plus the 7 jets selected by jet algorithms 0, 10, and 20 with R = 0.7. The leading jet is in red.

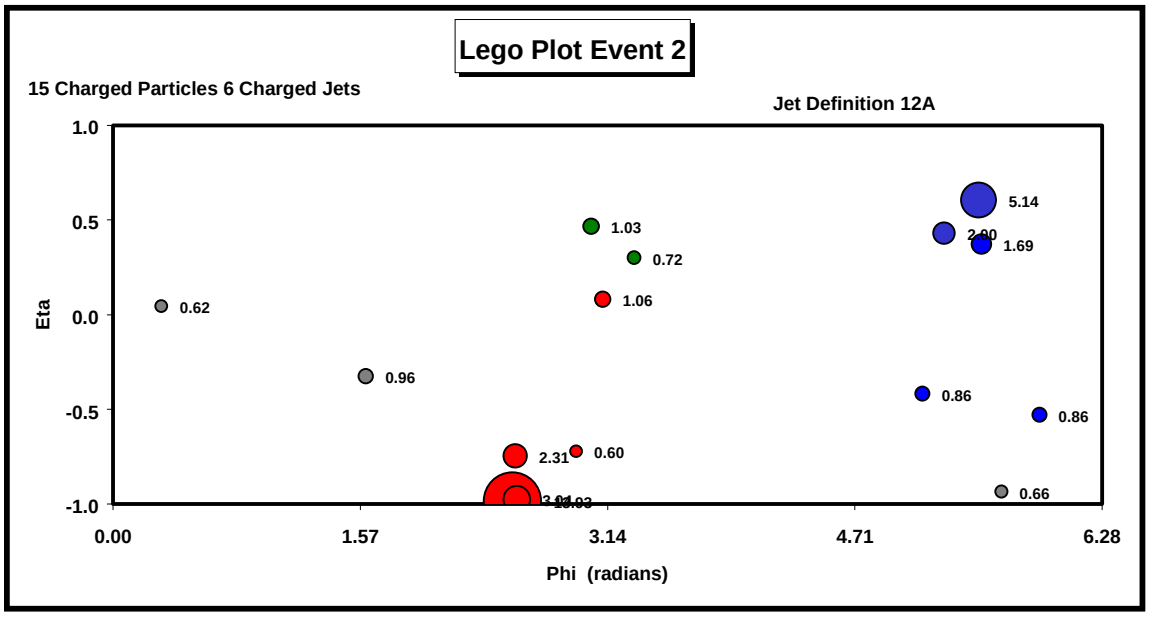
# Lego Plots (η-ϕ space)




**Lego Fig 3**. Shows the lego plot of event #1 which consists of 8 charged particles plus the 4 jets selected by jet algorithm 12A with R = 0.7. The leading jet is in red.




**Lego Fig 4**. Shows the lego plot of event #2 which consists of 15 charged particles plus the 7 jets selected by jet algorithms 0, 10, and 20 with R = 0.7. The leading jet is in red.




**Lego Fig 5**. Shows the lego plot of event #1 which consists of 15 charged particles plus the 6 jets selected by jet algorithm 12A with R = 0.7. The leading jet is in red.

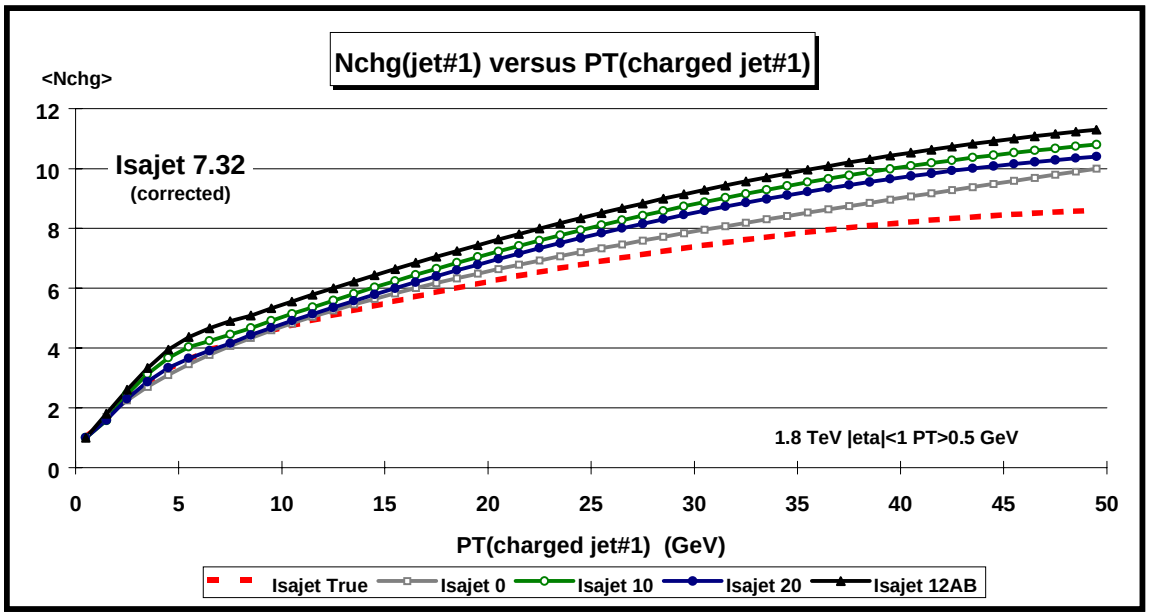



**Fig. 5**. Shows the average number of charged particles (PT > 0.5 GeV, |η| < 1) within the leading charged jet as a function of the PT of the leading charged jet resulting from the five jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. Note that the five jet algorithms are applied to the *same* set of Isajet events. Also shown are the "true" particles belonging to the leading jet (*Isajet True*) plotted versus the "true" jet PT. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

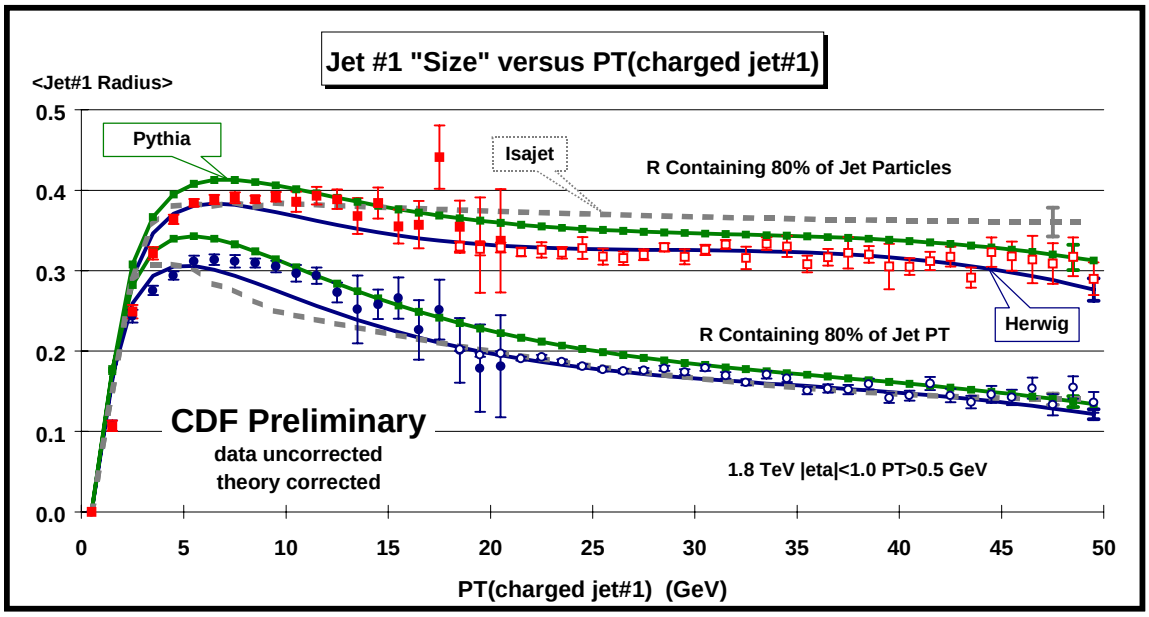



**Fig. 6**. Plot shows the average radius in η-ϕ space containing 80% of the charged particles (and 80% of the charged $P_T$) as a function of the transverse momentum of the leading charged jet (definition 0). The errors on the (*uncorrected*) data include both statistical and correlated systematic uncertainties. The QCD "hard scattering" theory curves (Herwig 5.9, Isajet 7.32, Pythia 6.115) are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

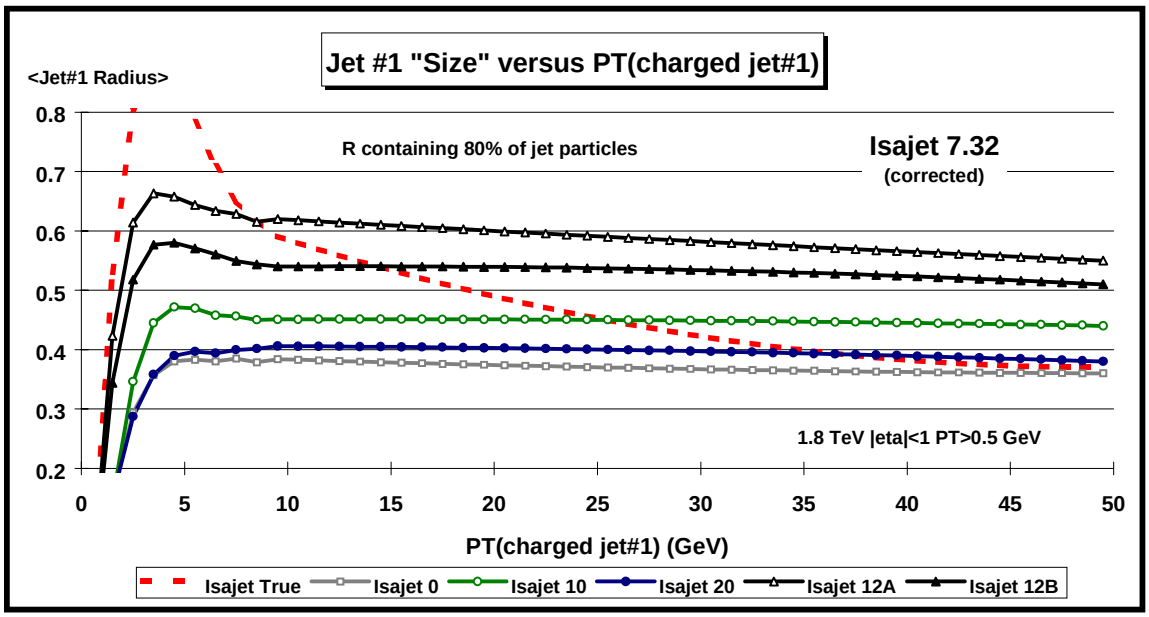



**Fig. 7**. Plot shows the average radius in η-ϕ space containing 80% of the charged particles as a function of the transverse momentum of the leading charged jet resulting from the five jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. Note that the five jet algorithms are applied to the *same* set of Isajet events. Also shown are the "true" particles belonging to the leading jet (*Isajet True*) plotted versus the "true" jet PT. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

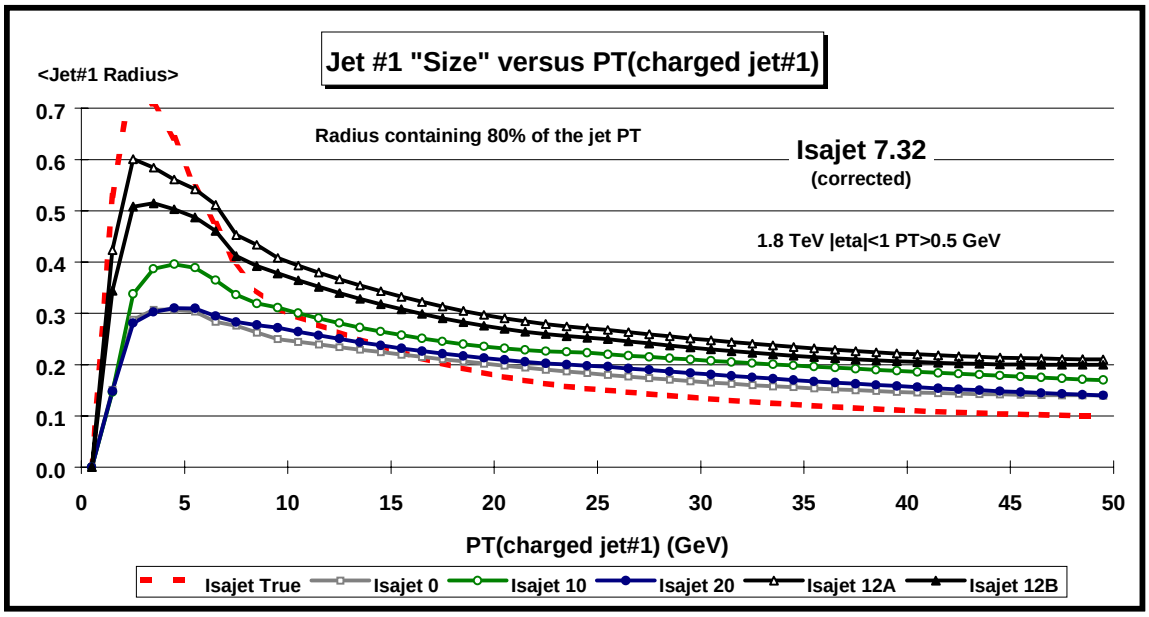



**Fig. 8**. Plot shows the average radius in η-ϕ space containing 80% of the charged particle *scalar* PT sum as a function of the transverse momentum of the leading charged jet resulting from the five jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. Note that the five jet algorithms are applied to the *same* set of Isajet events. Also shown are the "true" particles belonging to the leading jet (*Isajet True*) plotted versus the "true" jet PT. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

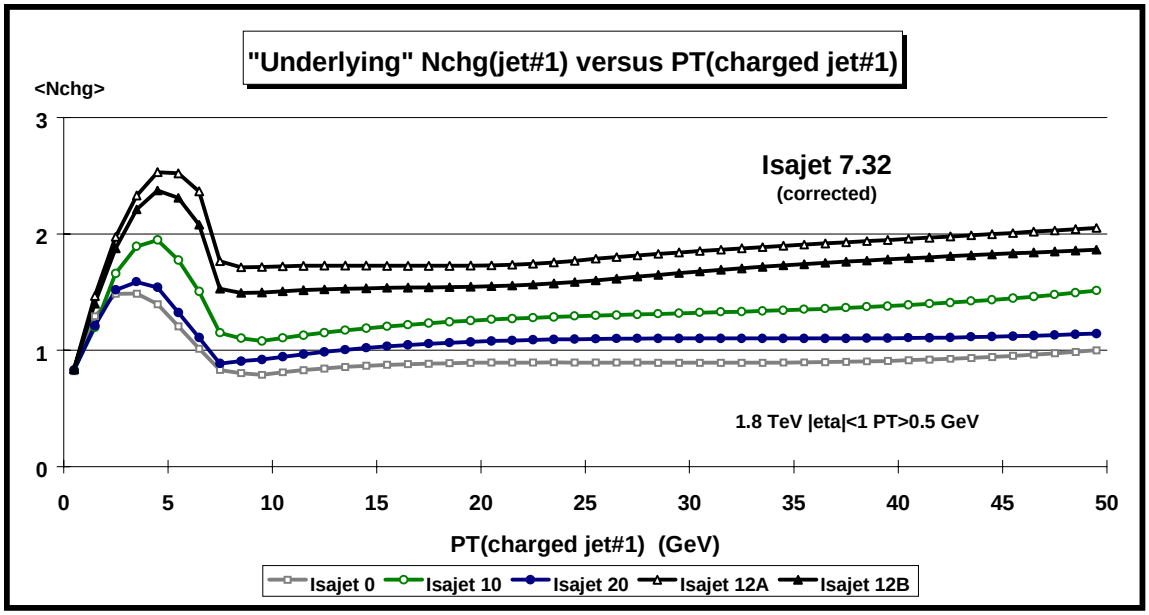



**Fig. 9**. Shows the contribution to the number of charged particles (PT > 0.5 GeV, |η| < 1) within the leading charged jet arising from the underlying event (*beam-beam remnants plus initial-state radiation*, see Fig.1) as a function of the PT of the leading charged jet resulting from the five jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. Note that the five jet algorithms are applied to the *same* set of Isajet events. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

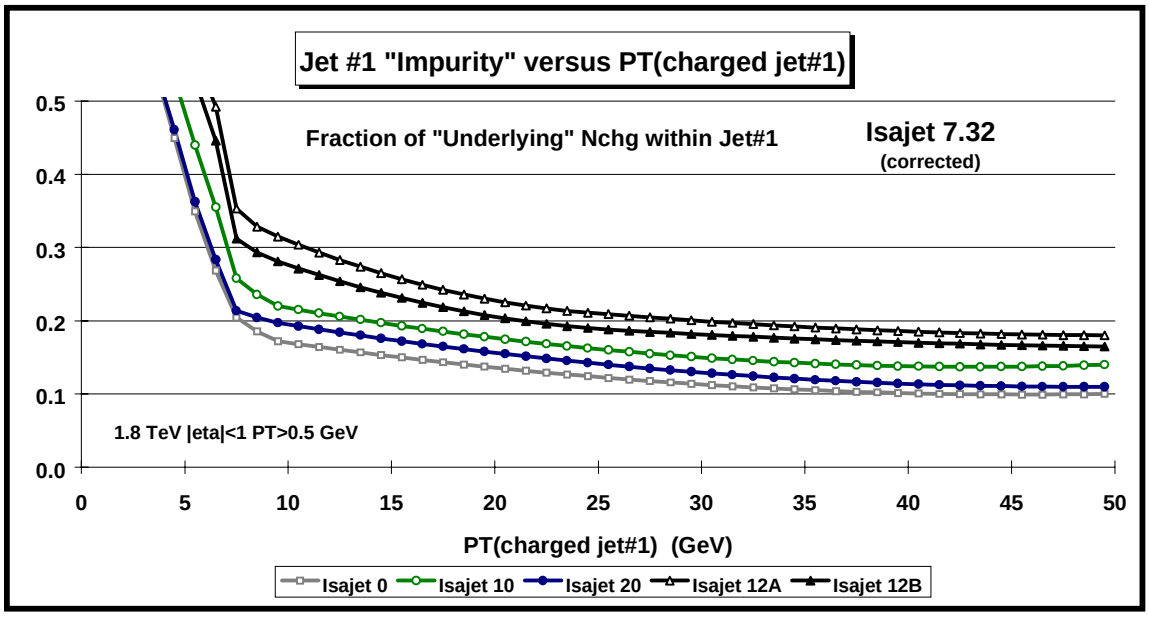



**Fig. 10**. Shows the fraction of charged particles (PT > 0.5 GeV, |η| < 1) within the leading charged jet arising from the underlying event (*beam-beam remnants plus initial-state radiation*, see Fig.1) as a function of the PT of the leading charged jet resulting from the five jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. Note that the five jet algorithms are applied to the *same* set of Isajet events. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

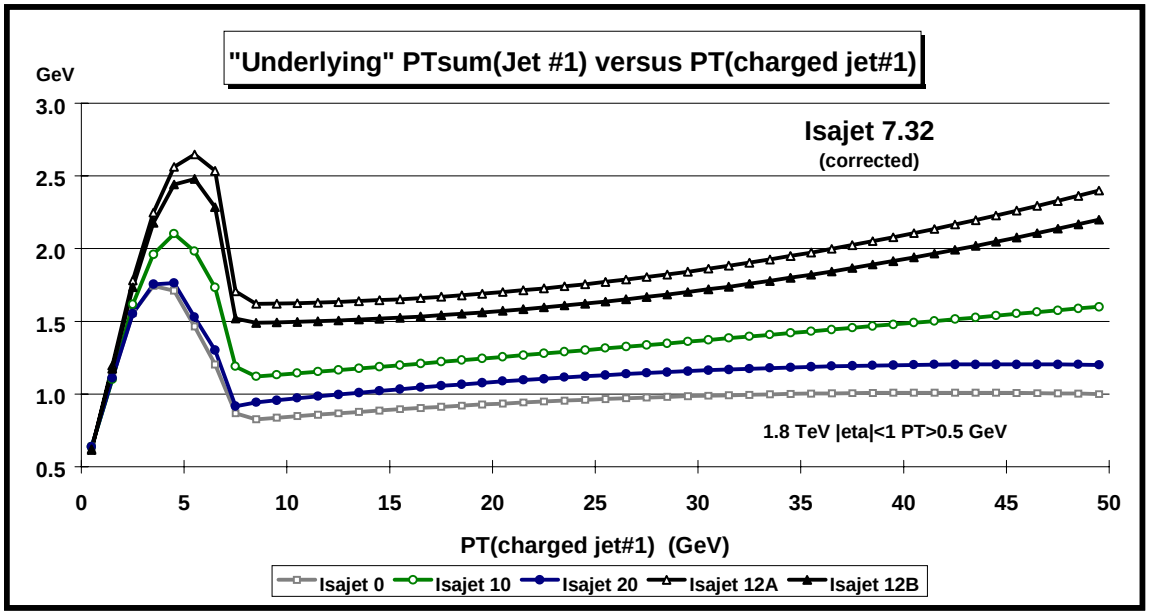



**Fig. 11**. Shows the contribution to the charged particle scalar PT sum (PT > 0.5 GeV, |η| < 1) within the leading charged jet arising from the underlying event (*beam-beam remnants plus initial-state radiation*, see Fig.1) as a function of the PT of the leading charged jet resulting from the five jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. Note that the five jet algorithms are applied to the *same* set of Isajet events. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

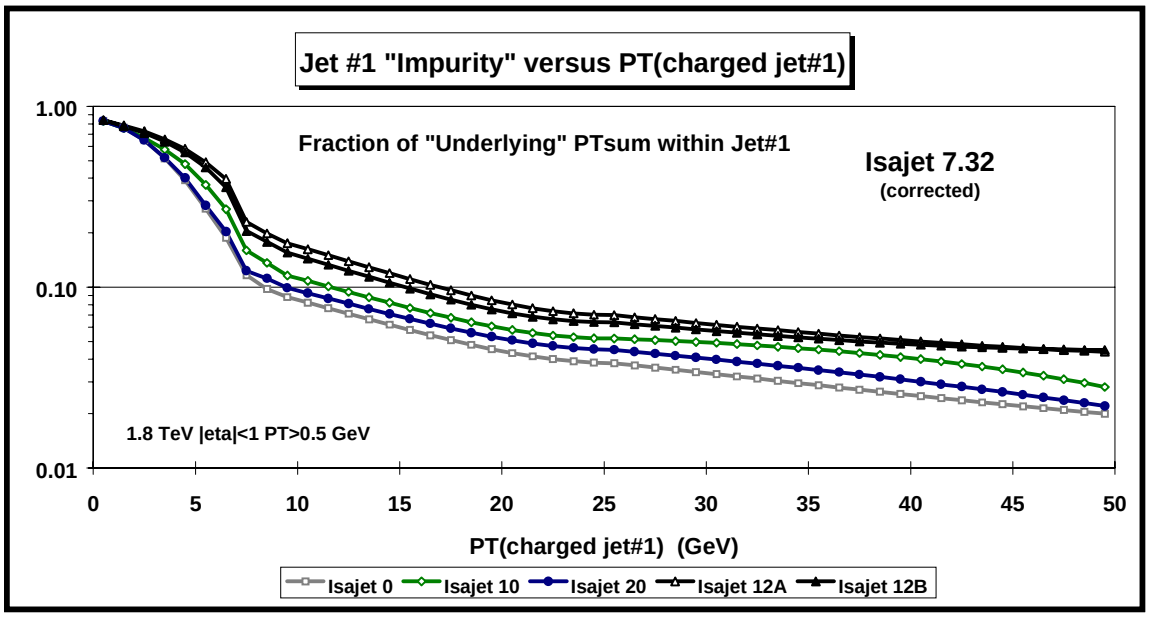



**Fig. 12**. Shows the fraction of charged particle scalar PT sum (PT > 0.5 GeV, $|\eta| < 1$) within the leading charged jet arising from the underlying event (*beam-beam remnants plus initial-state radiation*, see Fig.1) as a function of the PT of the leading charged jet resulting from the five jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. Note that the five jet algorithms are applied to the *same* set of Isajet events. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.

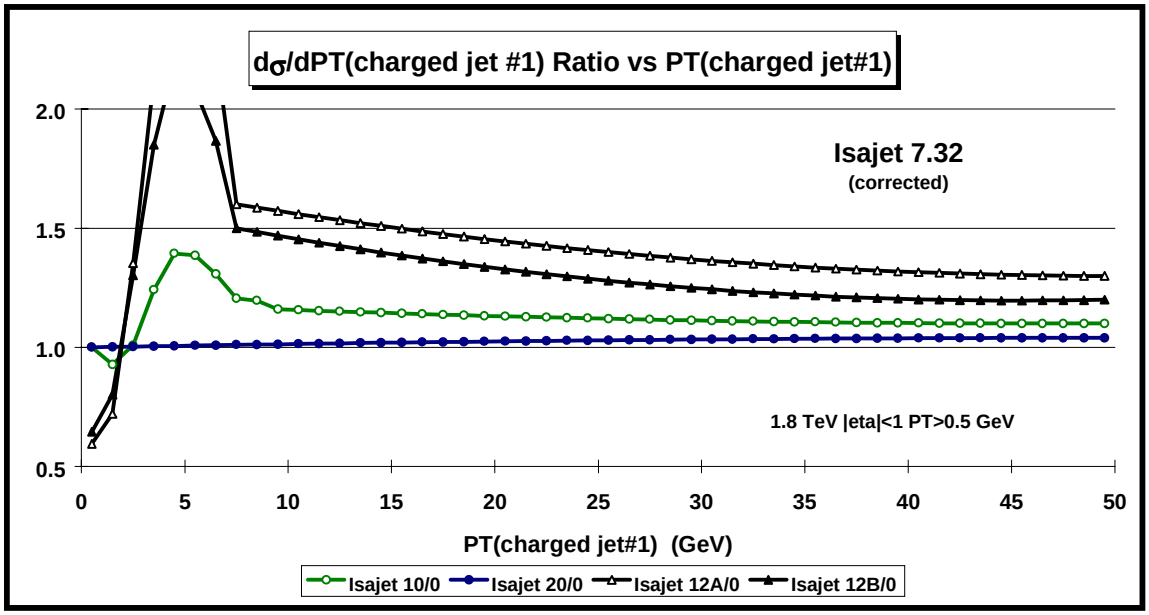



**Fig. 13**. Shows the charged particle jet cross section, dσ/dPT(jet#1), ratio resulting from the jet algorithms in Table 1 applied to QCD "hard scattering" events generated by Isajet 7.32. The ratios correspond to the leading jet cross sections from definitions 10, 20, 12A, and 12B divided by the leading jet cross section from definition 0. Note that the five jet algorithms are applied to the *same* set of Isajet events. The theory curves are corrected for the track finding efficiency and have an error (*statistical plus systematic*) of around 5%.