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Jet Algorithms – Current Thinking & Plans in the JetEtMiss Group

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With thanks to all those from whose presentations I shamelessly extracted material

Disclaimer: the views expressed here are those of the author and may not entirely agree with other views held within ATLAS

JetEtMiss Meeting – January 20, 2009

Introduction to jet algorithms -Jonathan Butterworth

Atlas technicalities on jet algorithms - Pierre-Antoine Delsart

H1-style jet calibration for the SIS-cone and the anti-kt algorithm - Sebastian Eckweiler

Comparision of basic quantitities in dijet and top samples - Sandro De Cecco

Linearity, resolution, efficiency and purity for various jet algorithms - Paolo Francavilla

Data-driven efficiency estimation based on track-jets for various jet algorithms - Stephanie Majewski

Behaviour of jet algorithms in pt-balance studies - Pavel Weber

A study of jet areas and underlying event/pileup subtraction in ATLAS - Brian Martin

Behaviour of jet algorithms under pile-up - David W. Miller

Studies with SIS-cone in SUSY events - Nikola Makovec

Physics requirements from Higgs physics - Ketevi Adikle Assamagan

Summary of feed-back from physics groups and What's next ? - Tancredi Carli

JetEtMiss Meeting on Algorithms – April 27, 2009

Dedicated H1-style calibration for the new jet algorithms - Sebastian Eckweiler

Effects of trigger selection on jet algorithm performance - Kerstin Marie Perez

Jet reconstruction efficiency from track jets using various algorithms - Stephanie Majewski

Flavour dependence of jet reconstruction efficiencies for various jet algorithms - Seth Zenz

Jet reconstruction efficiencies for the nth jets Paolo Francavilla

Performance of jets (finder, size, input) in dijet events with pile-up Eric Feng

Performance of jet algorithm for gamma-jet balance - Georgios Choudalakis

Performance of new jet algorithms for high-pt jet calibration with multi-jet balance - Koji Terashi

Jet algorithm performance on noise in commissioning data - Nikola Makovec

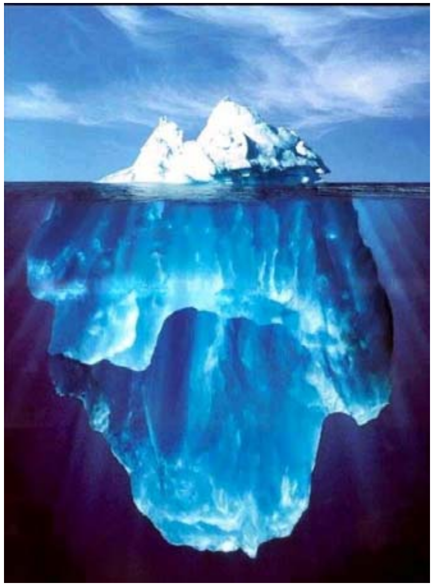
Jet algorithms for top reconstruction - Nabil Ghodbane

Truth jets studies in Z+jets events - David Lopez Mateos

Pile-up subtraction using jet areas - Brian Thomas Martin

Conclusion - Tancredi Carli, Jonathan Butterworth

And this is only the tip of the iceberg



- Les Houches 2007
- Les Houches 2005
- MC4LHC (2006)
- TeV4LHC (2004)
- Tevatron RunII Workshop (2000)
- QCD & Collider Physics,Ellis, Stirling & Webber (1996)
- Tevatron Run I
- e+e- anniihilation (SPEAR, PETRA,PEP,LEP SLC)

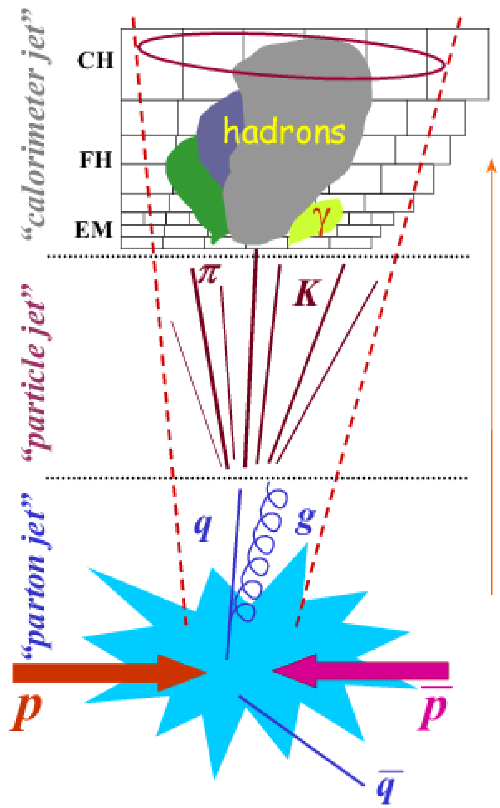
- Photon Hadron Interactions, Feynman (1972)

- Deep inelastic scattering (since 1967 I think)
- And lots of other discourses on related topics with quarks and partons somewhere in there between 1965 & 1970

What is a Jet???

A collection of particles for which the 4-momentum of the reconstructed object follows the momentum and quantum number flow of the primary parton:

- parton fragmentation occurs in longitudinal momentum space (Breit frame)
- in hadronization, the hadron Pt is limited with respect to the parton longitudinal direction
- parton-hadron Duality

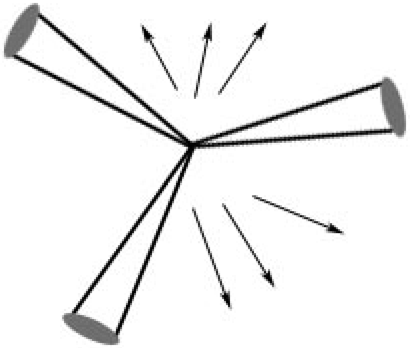


The Answer in Wikipedia

In particle physics, a **three-jet event** is an event with many particles in final state that appear to be clustered in three jets. A single jet consists of particles that fly off in roughly the same direction. One can draw three cones from the interaction point, corresponding to the jets, and most particles created in the reaction will appear to belong to one of these cones. These events are currently the most direct available evidence for the existence of gluons, and were first observed by the TASSO experiment at the PETRA accelerator at the DESY laboratory.[1]

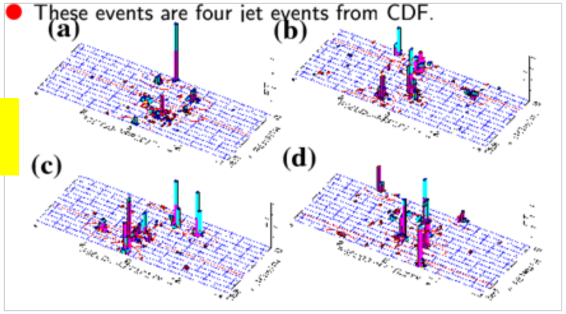
2-Jet Event

3-Jet Event



The Jet Algorithm Paradigm circa 2001

Keith Ellis



- From previous plots we see that jets exist as localized clusters of energy.
- There is no 'best' jet definition, although there are better and worse.
- Good jet definitions are
  - Fully specified
  - Theoretically well-behaved
  - Detector independent
  - Order independent
- For hadron-hadron collisions, the most commonly used definition is of the cone type: a jet is defined to be in the directions which maximizes the transverse energy E_T in a 'cone' of radius R, where

Tevatron RunII Workshop

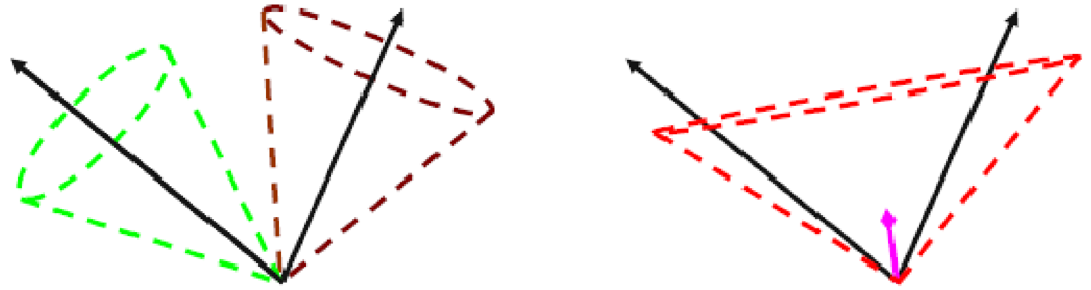
2. Attributes of the Ideal Algorithm
Although it provided a good start, the Snowmass algorithm has proved to be incomplete. It does not address either the phenomena of merging and splitting or the role of the seed towers with the related soft gluon sensitivity. Also, jet energy and angle definitions have varied between experiments. To treat these issues, the group began discussions with the following four general criteria:
1. *Fully Specified*: The jet selection process, the jet kinematic variables and the various corrections (*e.g.*, the role of the underlying event) should be clearly and completely defined. If necessary, preclustering, merging, and splitting algorithms must be completely described.
2. *Theoretically Well Behaved*: The algorithm should be infrared and collinear safe with no ad hoc clustering parameters.
3. *Detector Independence*: There should be no dependence on cell type, numbers, or size.
4. *Order Independence*: The algorithms should behave equally at the parton, particle, and detector levels.
The first two criteria should be satisfied by every algorithm; however, the last two can probably never be exactly true, but should be approximately correct.

The "Modern" Paradigm

- Jets are defined (specified) by the algorithm used to reconstruct them
- **infrared and collinear safety is a "must"**
- sensitivity to noise and pileup should be mimized or at least well controlled
- High efficiency
- ease of calibration – aiming for energy scale uncertainty O[few %]
- Low cpu and memory consumption are operational requirements

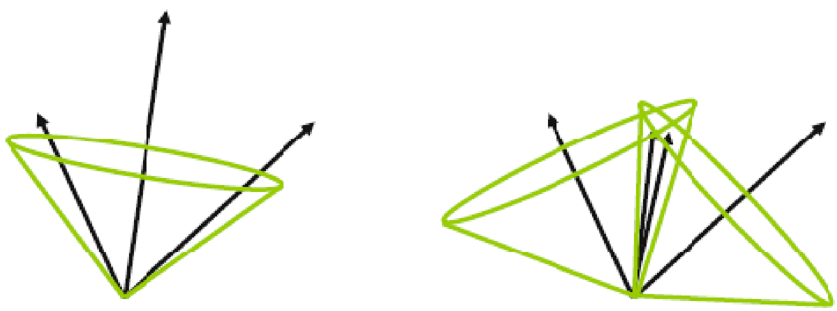
E. Fullana

Infrared safety



The presence of a soft gluon (pink arrow) between two jets (black arrows) cause a merging of the jets that would not occur in the absence of the radiated gluon

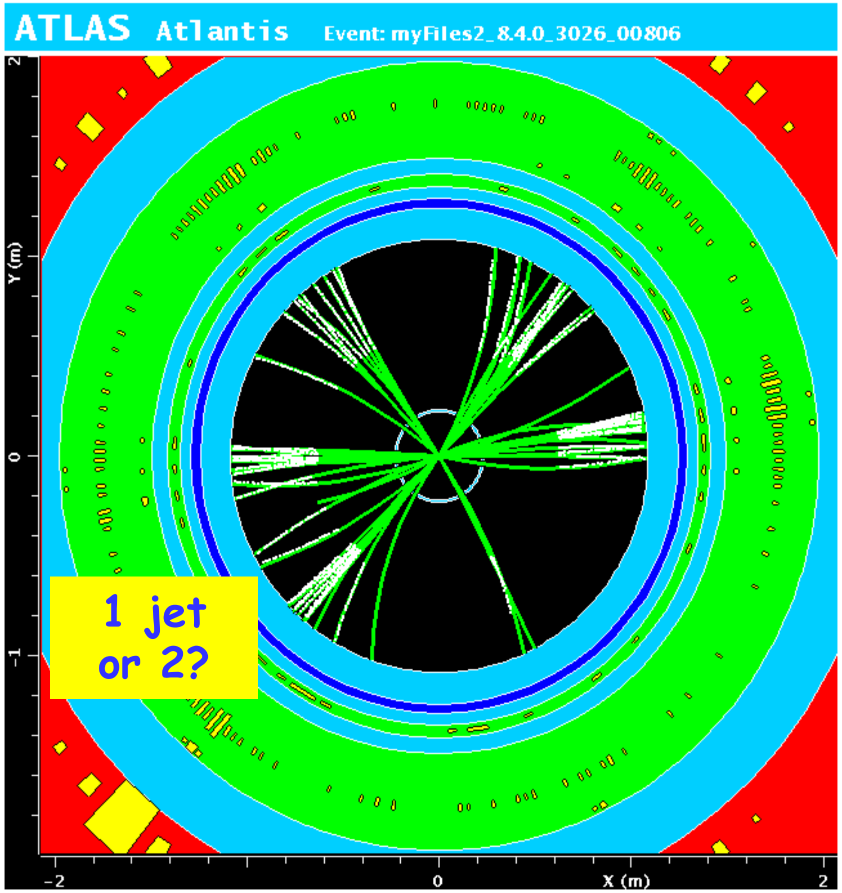
Collinear safety (II)

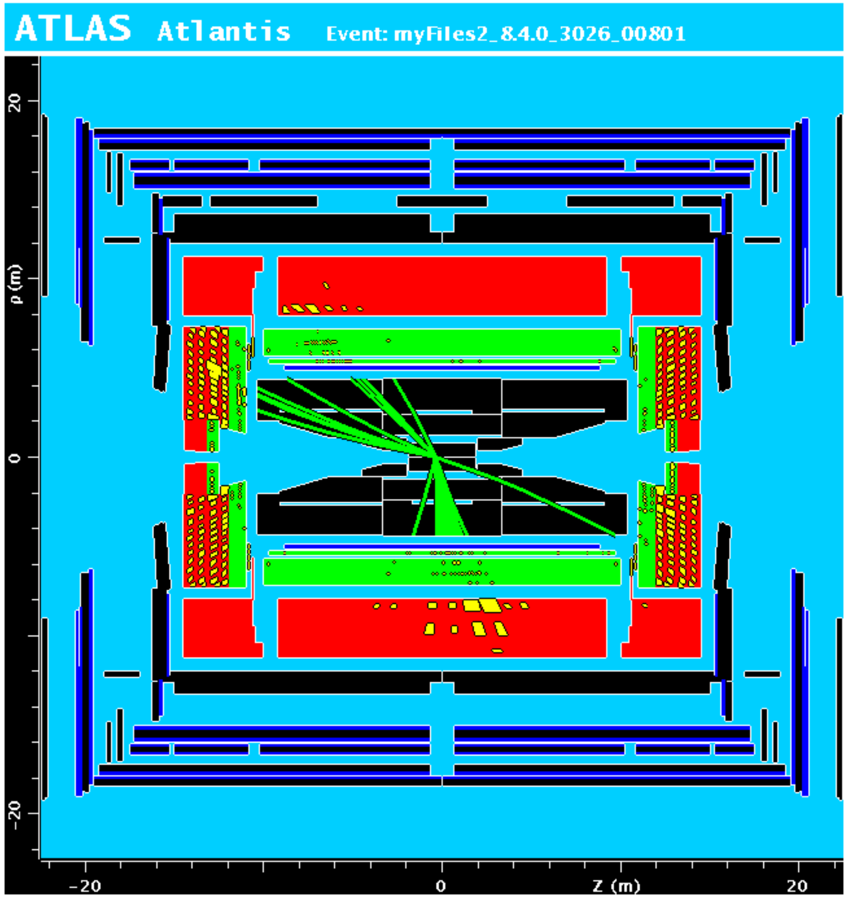


The E_T ordering of the seeds may cause a different final jet configuration due to a collinear effect

Atlantis top event vintage 2004

How Many Jets Do We See?





Gavin Salam: ATLAS Hadronic Calibration Workshop, Tucson 2008

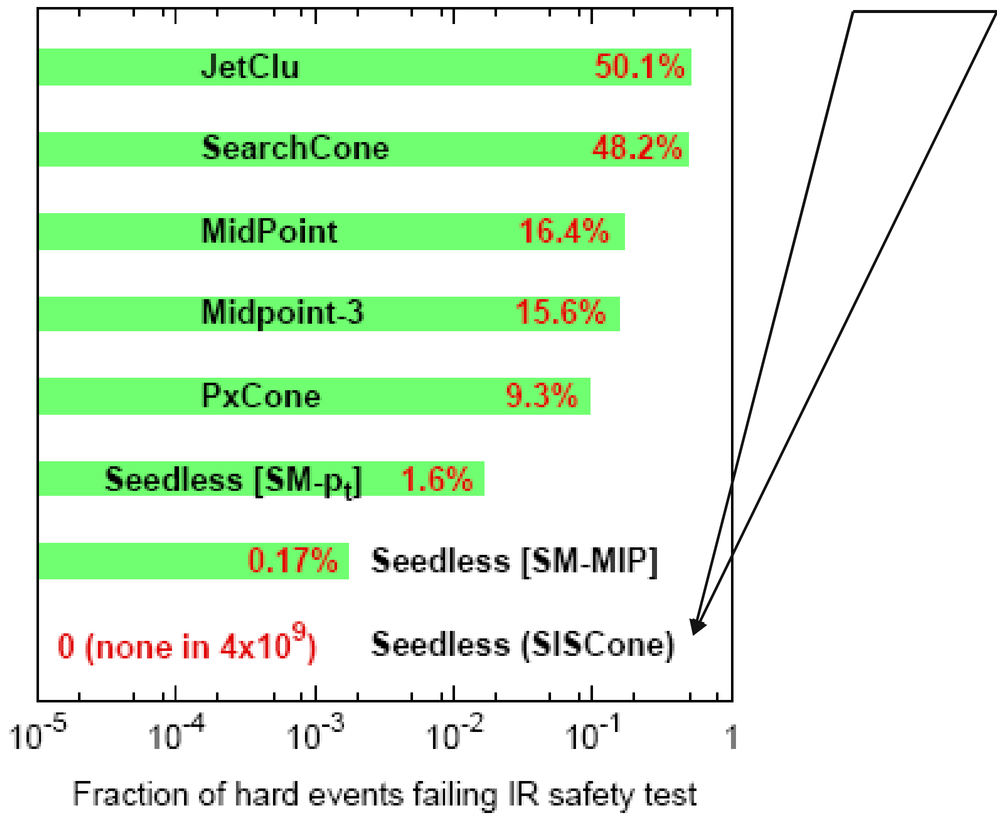
Jets theory, G. Salam (p. 18)
└ Mainstream jet algorithms
  └ Cone

Is it truly IR safe?

- Generate event with $2 < N < 10$ hard particles, find jets
- Add $1 < N_{soft} < 5$ soft particles, find jets again [repeatedly]
- If the jets are different, algorithm is IR unsafe.

Unsafety level	failure rate
2 hard + 1 soft	$\sim$ 50%
3 hard + 1 soft	$\sim$ 15%
SISCone	IR safe !

Be careful with split–merge too

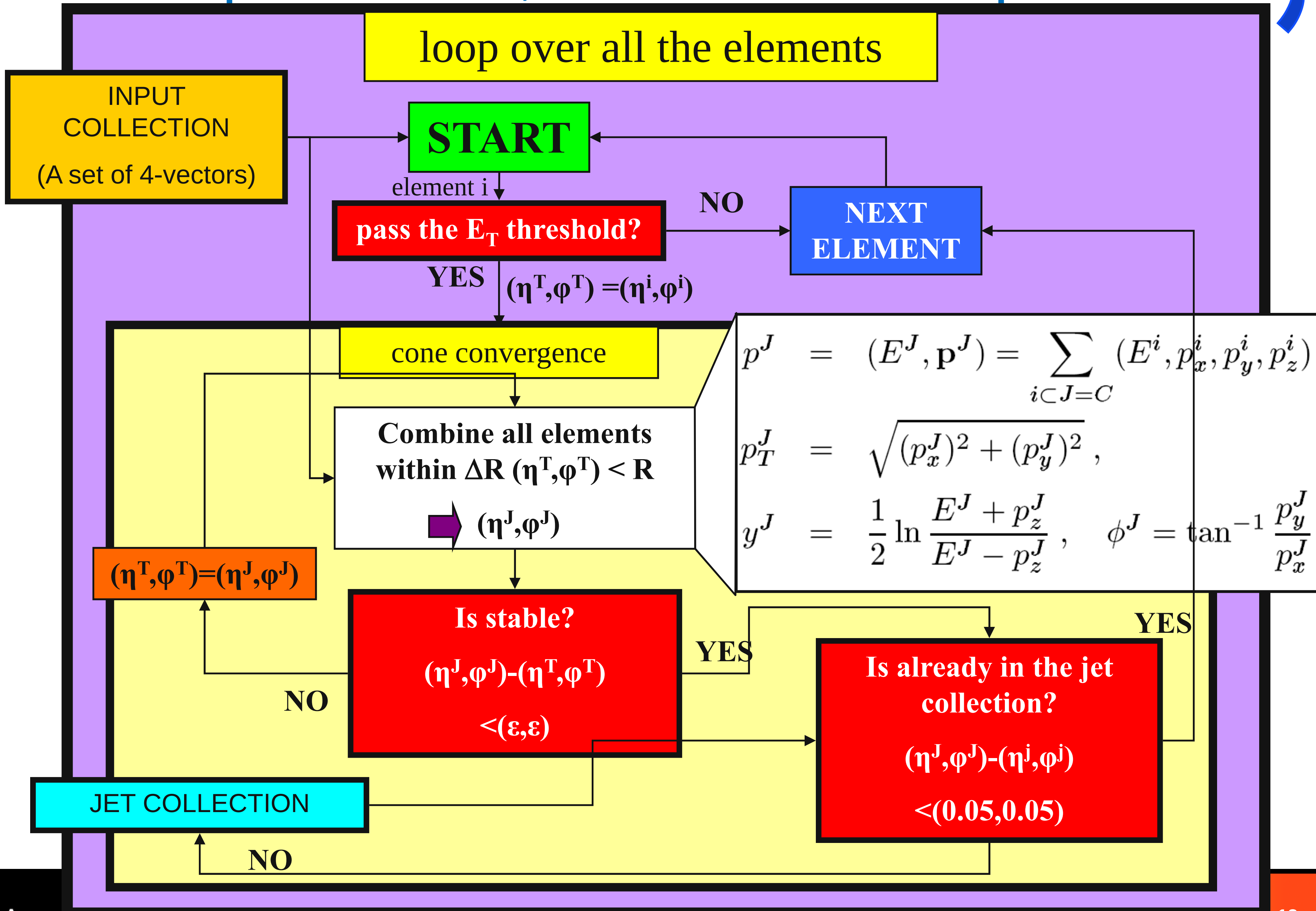


Jet Algorithms in ATLAS

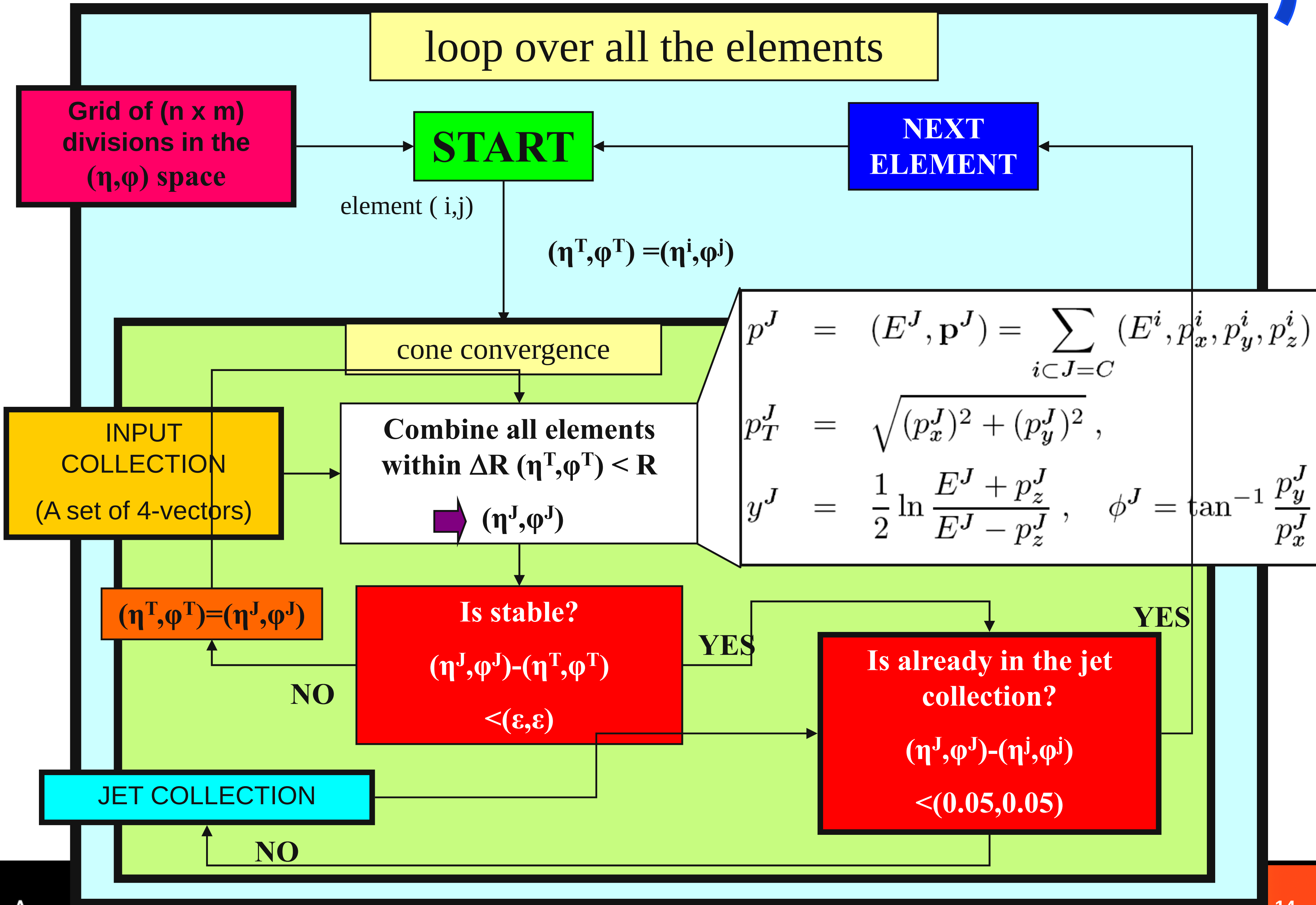
- ATLAS Cone (seeded)
- ATLAS Cone with midpoint
- SIScone (seedless infrared safe)
- K_t
- Anti-K_t

remember too that jets really aren't cones in (η,ϕ) space !

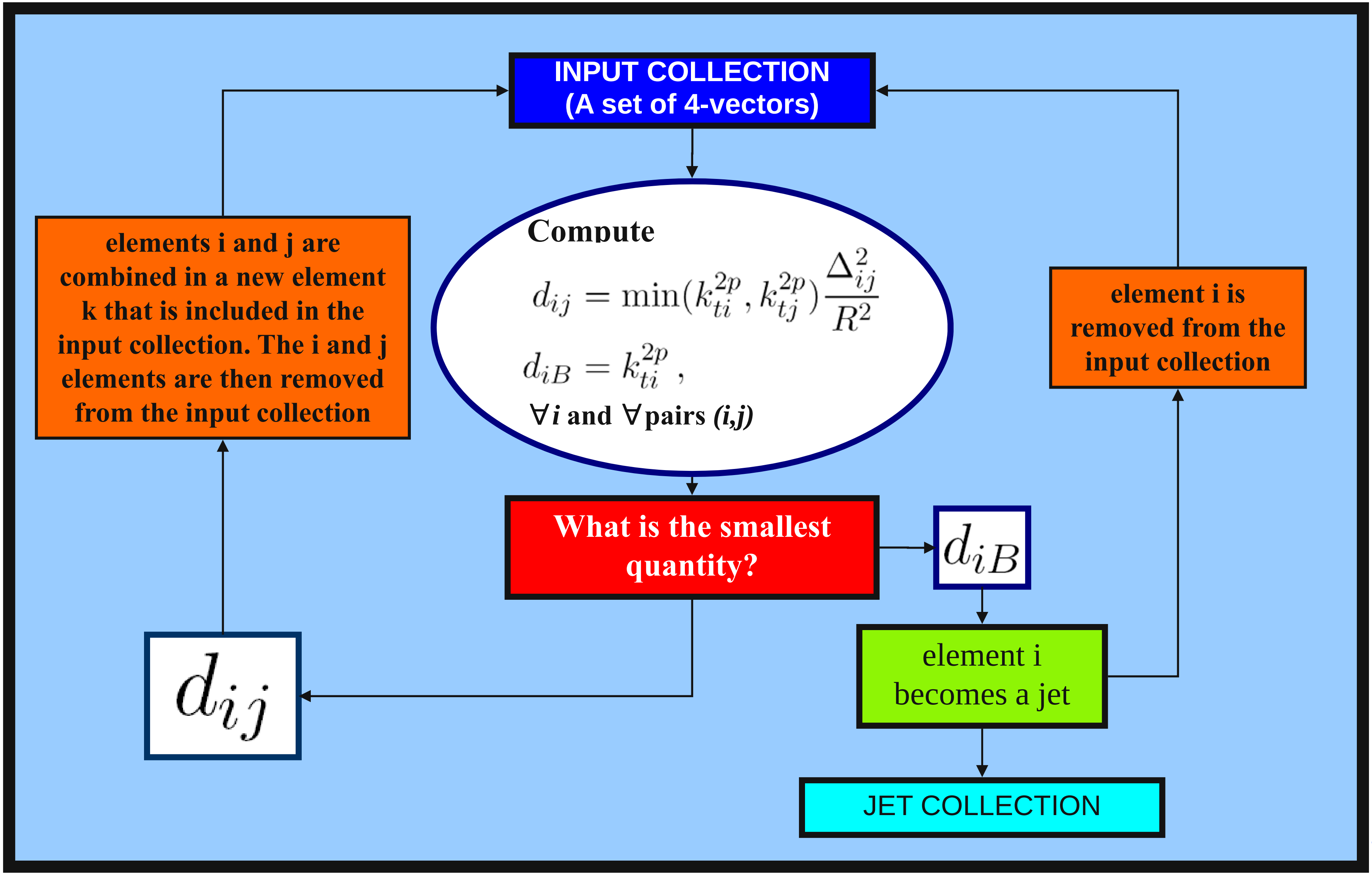
simple cone based, with and without mid-point



SIScone


loop over all the elements
Grid of (n x m) divisions in the (η,φ) space
START
NEXT ELEMENT
element (i,j)
$(\eta^T,\varphi^T) = (\eta^i,\varphi^j)$
cone convergence
INPUT COLLECTION
(A set of 4-vectors)
Combine all elements within $\Delta R\,(\eta^T,\varphi^T) < R$
(η^J,φ^J)
$p^J = (E^J, \mathbf{p}^J) = \sum_{i \subset J = C} (E^i, p^i_x, p^i_y, p^i_z)$
$p^J_T = \sqrt{(p^J_x)^2 + (p^J_y)^2}\,,$
$y^J = \frac{1}{2} \ln \frac{E^J + p^J_z}{E^J - p^J_z}\,, \quad \phi^J = \tan^{-1} \frac{p^J_y}{p^J_x}$
$(\eta^T,\varphi^T)=(\eta^J,\varphi^J)$
Is stable?
$(\eta^J,\varphi^J)-(\eta^T,\varphi^T) < (\varepsilon,\varepsilon)$
NO
YES
YES
Is already in the jet collection?
$(\eta^J,\varphi^J)-(\eta^i,\varphi^j) < (0.05,0.05)$
JET COLLECTION
NO

The K_T algorithm



The K_T algorithm: p = -1,0,1

where:

$\Delta_{ij}^2 = (y_i - y_j)^2 + (\phi_i - \phi_j)^2$ the distance in the rapidity-azimuth space

k_{ti} is the P_T of the element I and R is a parameter of the algorithm.

Now, according to ***p***

p = 1 **it is the traditional K_T algorithm**

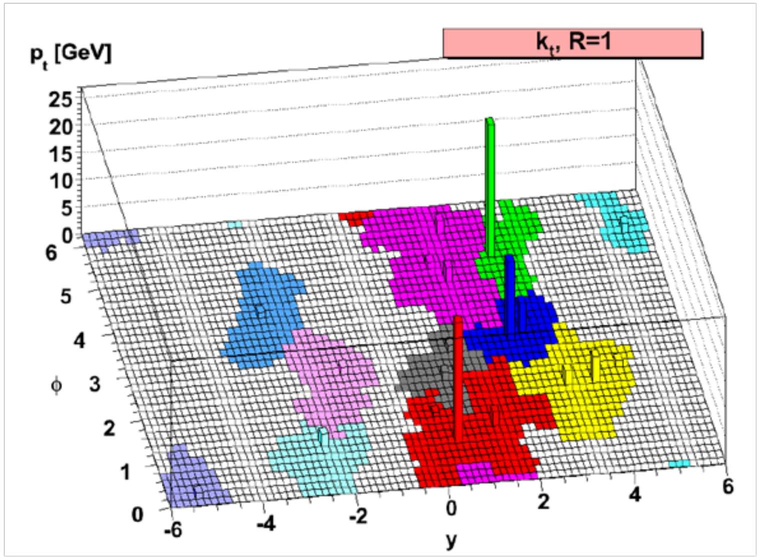
p = 0 **it is the Cambridge/Aachen algorithm**

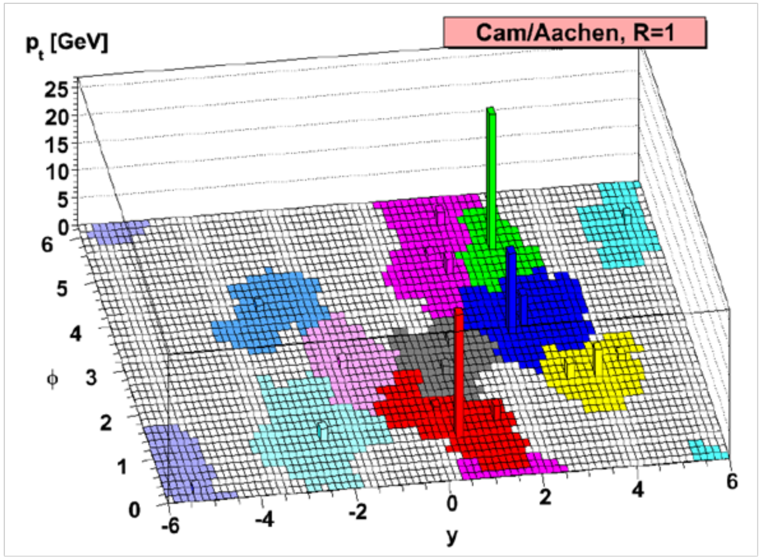
p = -1 **it is the anti-K_T algorithm or reversed K_T**

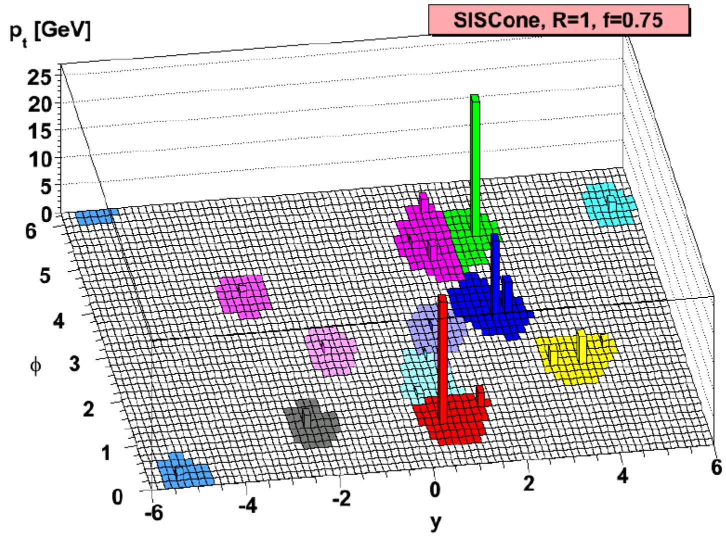
this is for the **inclusive version**.

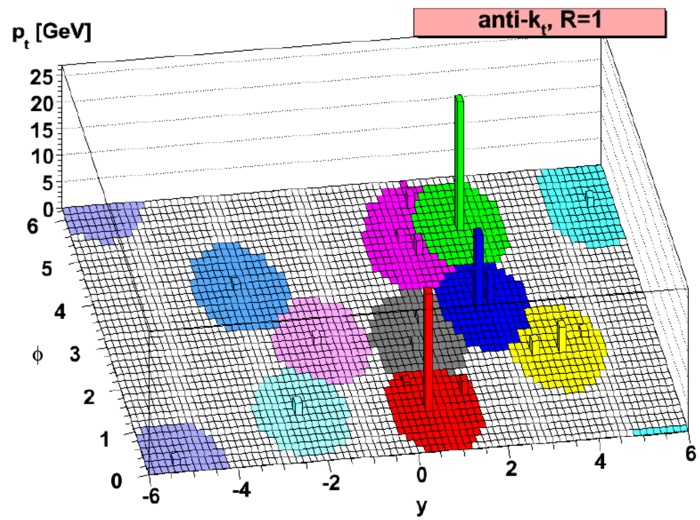
The D **exclusive version** introduces a new parameter $\boldsymbol{d_{cut}}$ where merging stops when all the remaining d_{iB} and d_{ij} exceeds $\boldsymbol{d_{cut}}$ and the remaining d_{iB} define the jets. The N exclusive version limits the number of jets. These exclusives versions are only available for the traditional version

Algorithms – one event – shape comparison

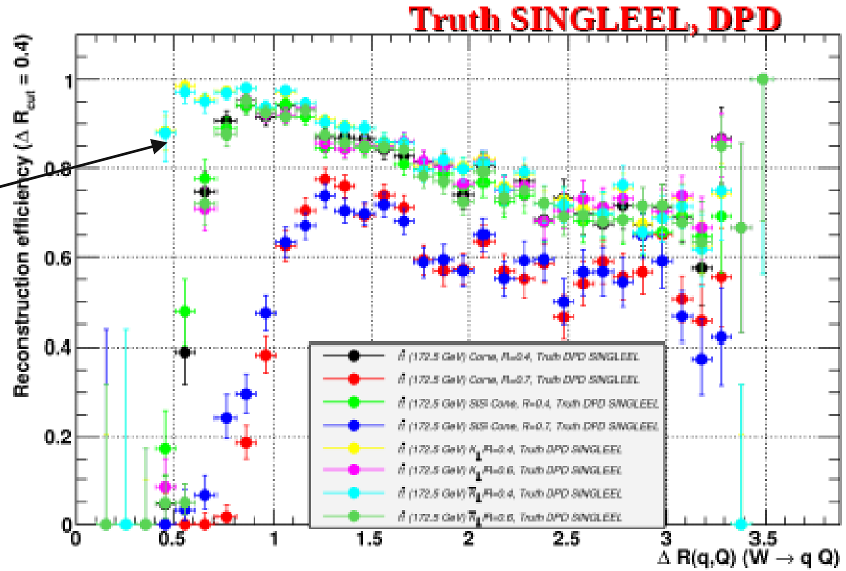




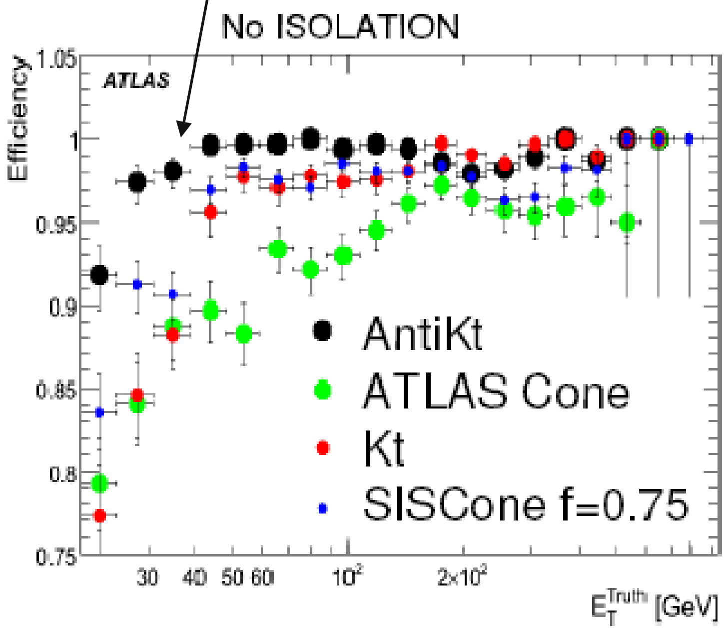




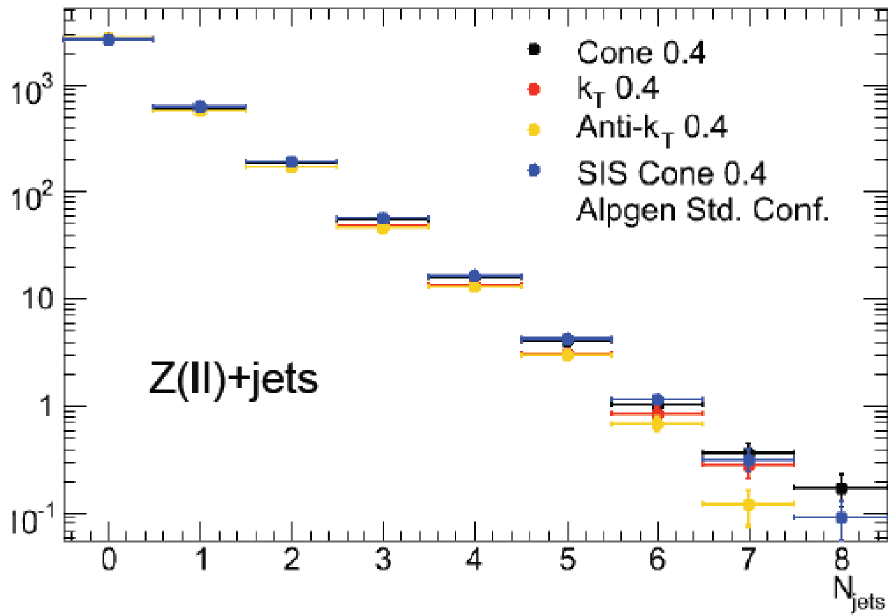
Good match between 4-vectors for truth and Reco



Reconstruction efficiency in Top events



W + Njets: 3rd jet efficiency



Jet Multiplicity for Truth Jets in Z+Jets Events

Sensitivity to Noise

AND

Jet Inputs

		Fraction of evts with at least 1 jet (%) (et>7GeV)		
R	Algo	Towers	Topo towers	Topo clusters
0.4	Cone	>0.01	>0.01	0.05
	SISCone	0.14	0.04	0.05
	Kt	0.09	0.03	0.05
	AntiKt	0.15	0.04	0.05
0.7	Cone	0.01	>0.01	0.06
	SISCone	2.11	0.07	0.06
	Kt	1.54	0.05	0.06
	AntiKt	1.83	0.07	0.06

Conclusions of Jet Algorithm Discussions in March (Tancredi)

Aim of the Jet Algorithm meetings

Theoretical arguments in favour of Kt, Anti-kt and Sis-cone algorithm clear

Goal was to study experimental aspects relevant for jet calibration in a comprehensive way:

- Memory and Timing in off-line and trigger software
- Trigger performance and trigger efficiencies
- H1-style calibration
- Jet reconstruction efficiency and purity
- Sensitivity to noise
- Performance under pile-up
- Linearity and Resolution
- Performance in in-situ calibration studies:
  di-jet balance, gamma-jet balance, multi-jet balance, W→jet jet

→ Most points have been addressed, time to conclude

Also feed-back from physics groups received
(e.g. top mass reconstruction, Z+n jet analysis etc.)

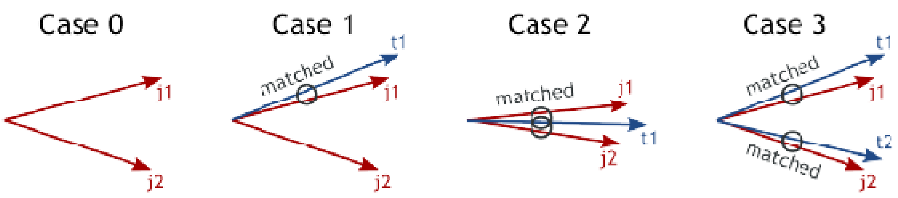
Conclusion

- Comparison not always fair, since Atlas cone (sometimes SIS-cone) with OLP=0.5 (OLP=0.75 seems to be better)
- However, Anti-kt algorithm has no problems:
  -theoretically safe
  -conceptually simple (only one free parameter)
  -fast and low memory consumption (trigger!)
  -well adapted to what is done in trigger
  -high jet reconstruction efficiency and memory
  -stable and cone-like jet area
  -stability under pile-up
- Recommendation Proposal:
  use Anti-kt to concentrate our calibration efforts for 2009/2010 data
  continue to work on SIS-cone
- Next Steps:
  1) put anti-kt on AOD together with Atlas-cone
  → allows more people to give feed-back
  2) Long term: replace Atlas cone with Sis-Cone ?
  ..or just remove Atlas-cone (after everybody agrees?)

It may NOT be that obvious however see yesterdays Jet Calibration Task Force Meeting

Configurations of two close-by jets j1 and j2

For JES correction the following cases must be distinguished:



#jets for different jet algorithms:

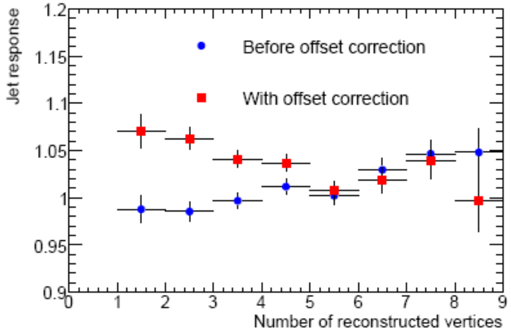
		isolated	case 0	case 1	case 2	case 3
antikt4	topo	1810	0	25.2 %	2.5 %	72.3 %
antikt4	tower	2946	0.1 %	41.0 %	0.4 %	58.5 %
cone4	topo	2865	1.5 %	42.6 %	1.6 %	54.3 %
cone4	tower	2309	1.9 %	36.1 %	1.1 %	60.9 %

⇒ First of all, studying only case 1 and case 3

Dennis Hellmich

Tower-based offset correction closure-test

Di-jet ($J2 - J5$) events at 450ns ($\mathcal{L} = 10^{32} cm^{-2} s^{-1}$)



- Cone tower jets
- Anti-k_T tower jets
- Anti-k_T topo-jets

David Miller

Needs a More Quantitative Comparison

My Conclusion Today

A jet is a collection of particles for which the 4-momentum of the reconstructed object follows the quantum number and 4-momentum of the primary parton

Discriminants:

matching efficiency in momentum space

Fake rate and errors in reconstruction due to for example noise and pileup

Which Algorithm best meets these criteria ?

=>Anti-Kt still comes out pretty well