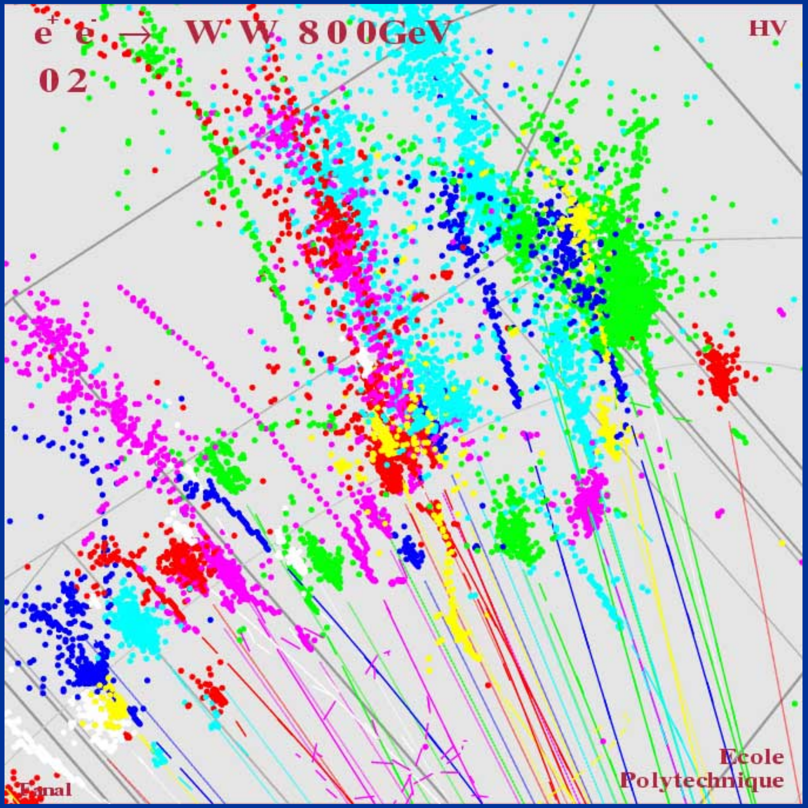
Development of Particle Flow Algorithms (PFA) at Argonne for the Future ILC



Presented by

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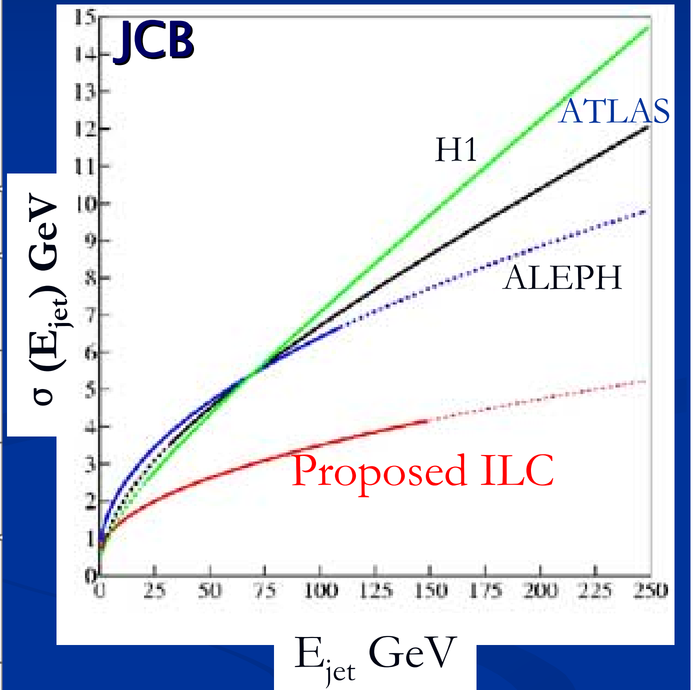
Why do we need PFA for ILC

Process	Vertex	Tracking		Calorimetry		Fwd		Very Fwd	Integration					Pol.
	σ_{IP}	$\delta p/p^2$	ϵ	δE	$\delta\theta,\ \delta\phi$	Trk	Cal	θ^e_{min}	δE_{jet}	M_{jj}	ℓ-Id	V^0-Id	$Q_{jet/vtx}$	
$ee \to Zh \to \ell\ell X$		x									x			
$ee \to Zh \to jjbb$	x	x	x			x				x	x			
$ee \to Zh, h \to bb/cc/\tau\tau$	x		x							x	x			
$ee \to Zh, h \to WW$	x		x		x				x	x	x			
$ee \to Zh,\ h \to \mu\mu$	x	x									x			
$ee \to Zh,\ h \to \gamma\gamma$				x	x		x							
$ee \to Zh, h \to invisible$			x			x	x							
$ee \to \nu\nu h$	x	x	x	x			x			x	x			
$ee \to tth$	x	x	x	x	x		x	x	x		x			
$ee \to Zhh,\ \nu\nu hh$	x	x	x	x	x	x	x		x	x	x	x	x	x
$ee \to WW$										x			x	
$ee \to \nu\nu WW/ZZ$						x	x		x	x	x			
$ee \to \tilde{e}_R\tilde{e}_R$ (Point 1)		x						x			x			x
$ee \to \tilde{\tau}_1\tilde{\tau}_1$	x	x						x						
$ee \to \tilde{t}_1\tilde{t}_1$	x	x							x	x		x		
$ee \to \tilde{\tau}_1\tilde{\tau}_1$ (Point 3)	x	x			x	x	x	x	x					
$ee \to \tilde{\chi}^0_2\tilde{\chi}^0_3$ (Point 5)									x	x				
$ee \to HA \to bbbb$	x	x								x	x			
$ee \to \tilde{\tau}_1\tilde{\tau}_1$			x											
$\tilde{\chi}^0_1 \to \gamma + \not{E}$					x									
$\tilde{\chi}^\pm_1 \to \tilde{\chi}^0_1 + \pi^\pm_{soft}$			x					x						
$ee \to tt \to 6\ jets$	x		x						x	x	x			
$ee \to ff\ [e,\mu,\tau;b,c]$	x		x				x		x		x		x	x
$ee \to \gamma G$ (ADD)				x	x			x						x
$ee \to KK \to f\bar{f}$		x									x			
$ee \to ee_{fwd}$						x	x	x						
$ee \to Z\gamma$		x		x	x	x	x							



– Physics Benchmarks for the ILC Detectors

Goal = 30%/ √ E$_{jet}$

Key: Calorimeter

Particle Flow Algorithm

Why do we need PFA for ILC

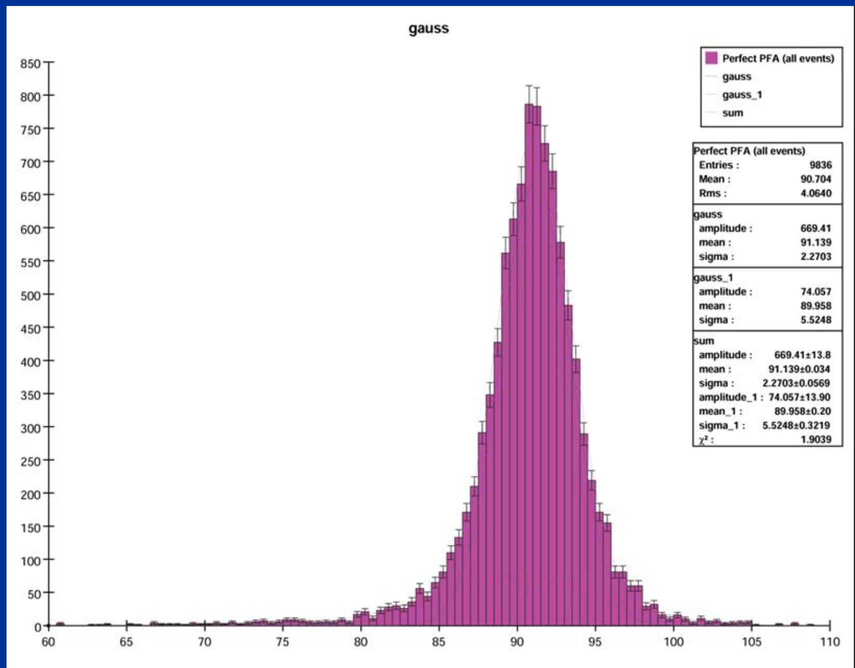
- Measure jets in the PFA way…

Particles in Jets	Fraction of jet energy	Measured with
Charged	65%	Tracker, negligible uncertainty
Photon	25%	ECal, 15%/ $\sqrt{E}$
Neutral hadron	10%	ECal + HCal, ~50-60%/ $\sqrt{E}$

- Clear separation of the 3 parts is the key issue of PFA
  - Charged particle, photon and neutral hadron: all deposit their energy in the calorimeters
  - Maximum segmentation of the calorimeters is needed to make the separation possible
- One Major R&D issue: development of PFA
  - Meets the ILC goal for jet energy resolution
  - Can be used for detector optimization
- Argonne has two parallel efforts on PFA development

Perfect PFA: NO algorithm effect

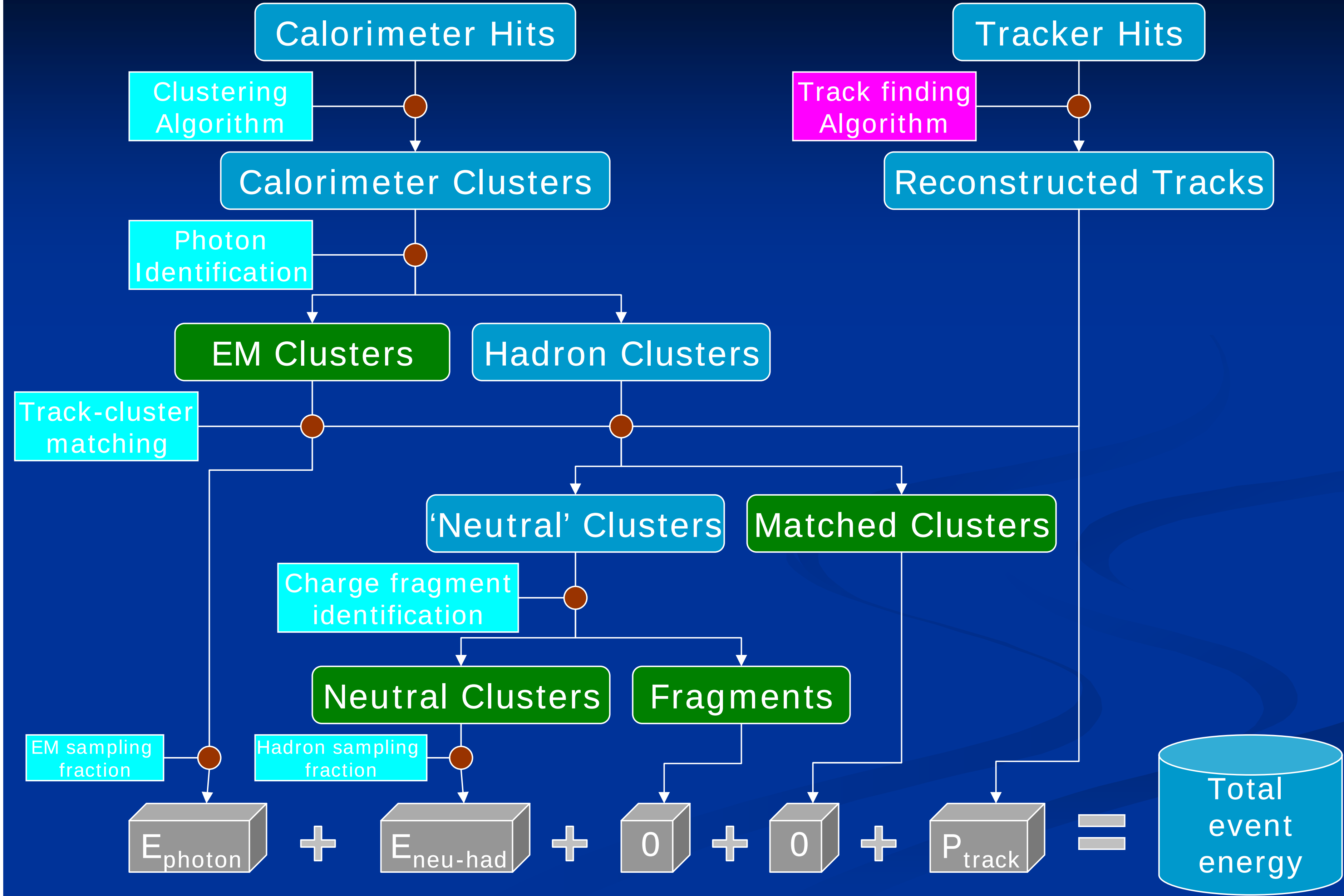
- Take MC track momentum as the energy of charged particles
- Remove calorimeter hits associated with charged particles
- Sum up everything else in the calorimeter as neutral energy
  - Apply appropriate sampling fractions for photon hits and neutral hadron hits
- Z-pole events, no jet algorithm applied



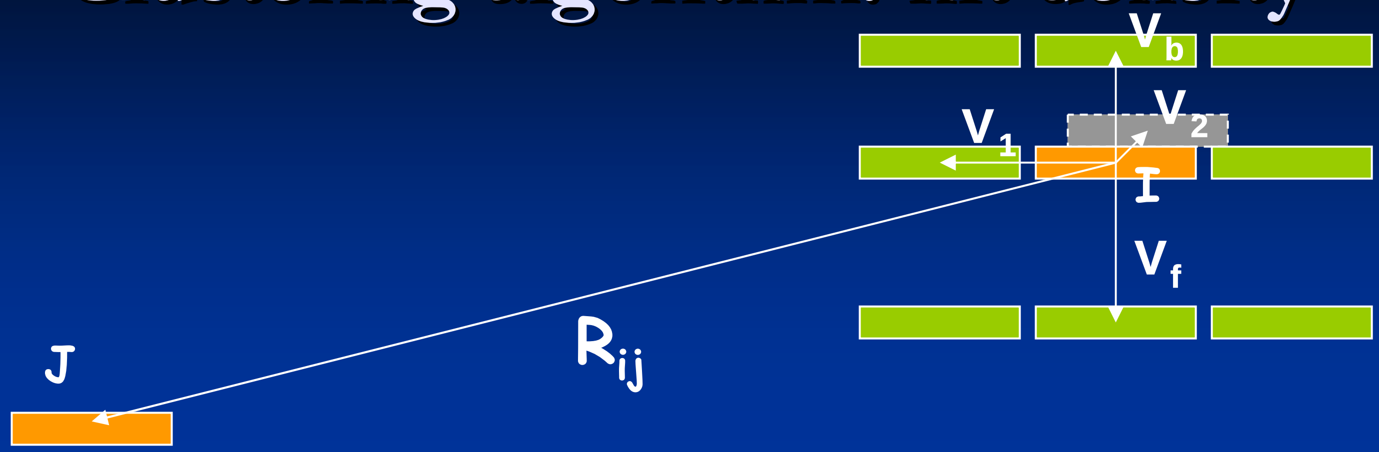
Example: SiD aug05_np

central peak
~2.3 GeV
(no event selection)

PFA effort: overview



Clustering algorithm: hit density

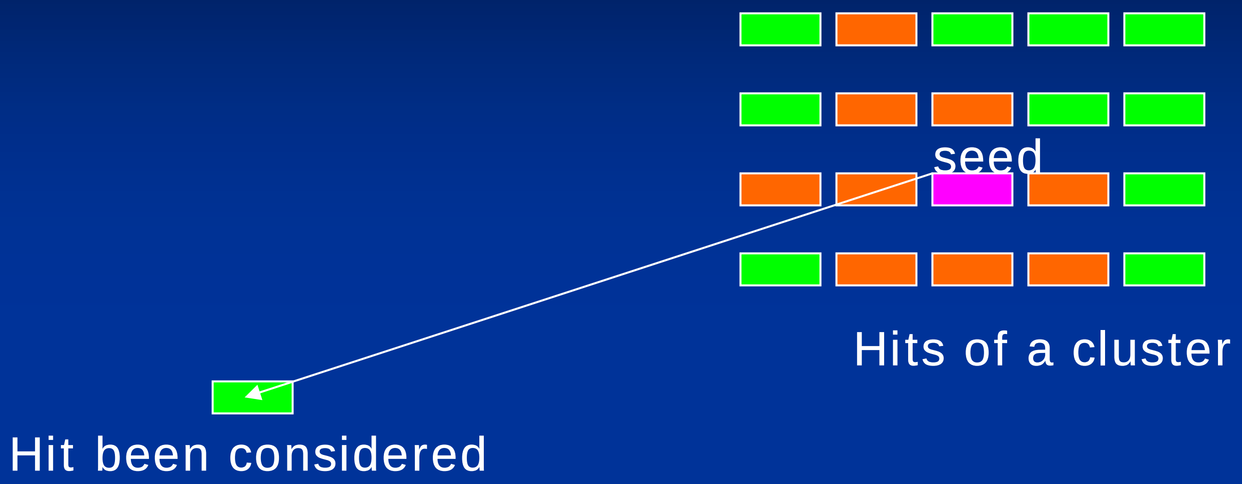


$$D_i = \sum_{\{j \neq i\}} \left(e^{-(|\vec{V}_1 \bullet \vec{R}_{ij}|/|\vec{V}_1|^2)} \times e^{-(|\vec{V}_2 \bullet \vec{R}_{ij}|/|\vec{V}_2|^2)} \times e^{-(|\vec{V}_3 \bullet \vec{R}_{ij}|/|\vec{V}_3|^2)} \right)$$

With $V_3 = V_f$ (if $(V_f \bullet R_{ij}) > 0$) or V_b (if $(V_b \bullet R_{ij}) > 0$)

- Hit density reflects the closeness from one hit i to a group of hits {j}
  - {j} = {all calorimeter hits} to decide if hit i should be a cluster seed
  - {j} = {all hits in a cluster} to decide if hit i should be attached to this cluster
- Consider cell density variation by normalizing distance to local cell separation
  - Density calculation takes care of the detector geometry
  - Clustering algorithm then treat all calorimeter hits in the same way

Clustering algorithm: grow a cluster



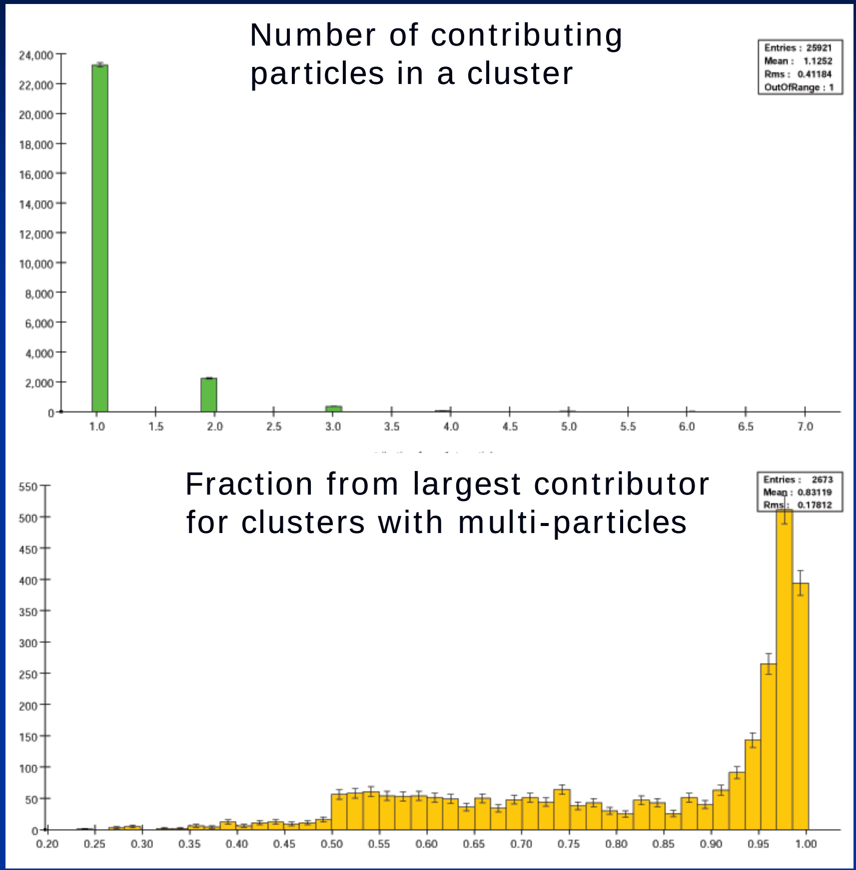
- Find a cluster seed: hit with highest density among remaining hits
- Attach nearby hits to a seed to form a small cluster
- Attach additional hits based on density calculation
  - i = hit been considered, {j} = {existing hits in this cluster}
  - EM hits, $D_i > 0.01$
  - HAD hits, $D_i > 0.001$
  - Grow the cluster until no hits can be attached to it
- Find next cluster seed, until run out of hits

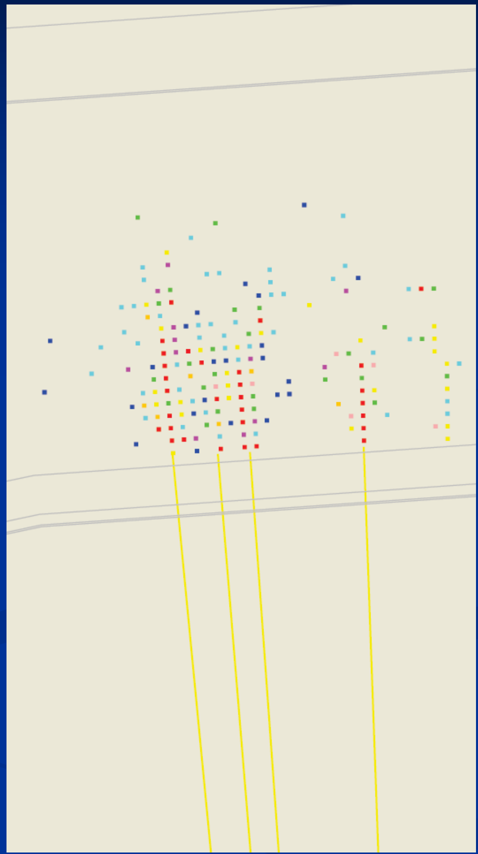
Density driven clustering

Particle	ECal hit efficiency	HCal hit efficiency	Overall hit efficiency	Overall energy efficiency
Photon (1GeV)	89%	43%	89%	91%
Photon (5GeV)	92%	54%	92%	96%
Photon (10GeV)	92%	61%	92%	97%
Photon (100GeV)	95%	82%	95%	>99%
Pion (2 GeV)	78%	59%	75%	71%
Pion (5 GeV)	81%	70%	79%	80%
Pion (10GeV)	84%	80%	83%	85%
Pion (20GeV)	85%	87%	88%	91%

- Typical electron cluster energy resolution ~ 21%/sqrt(E)
- Typical pion cluster energy resolution ~70%/sqrt(E)
- All numbers are for one main cluster (no other fragments are included)

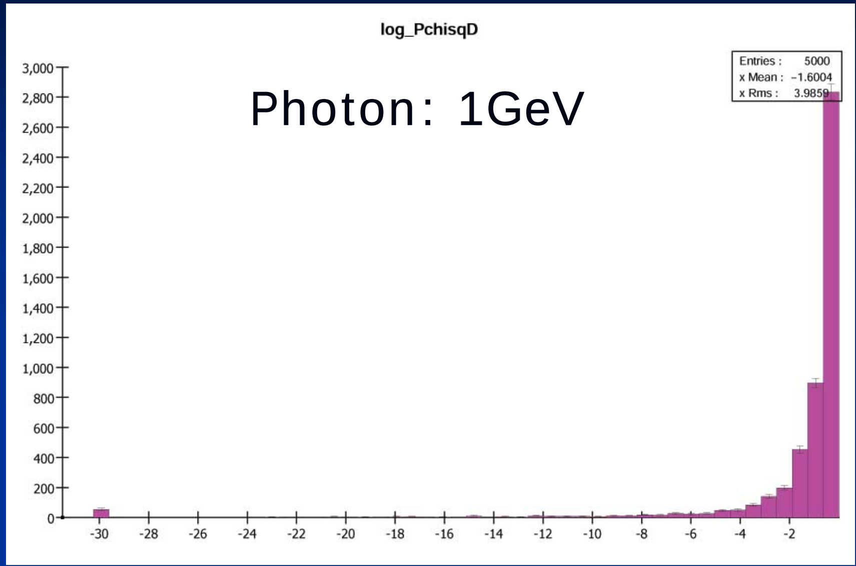
Cluster purity : Z pole (uds) events

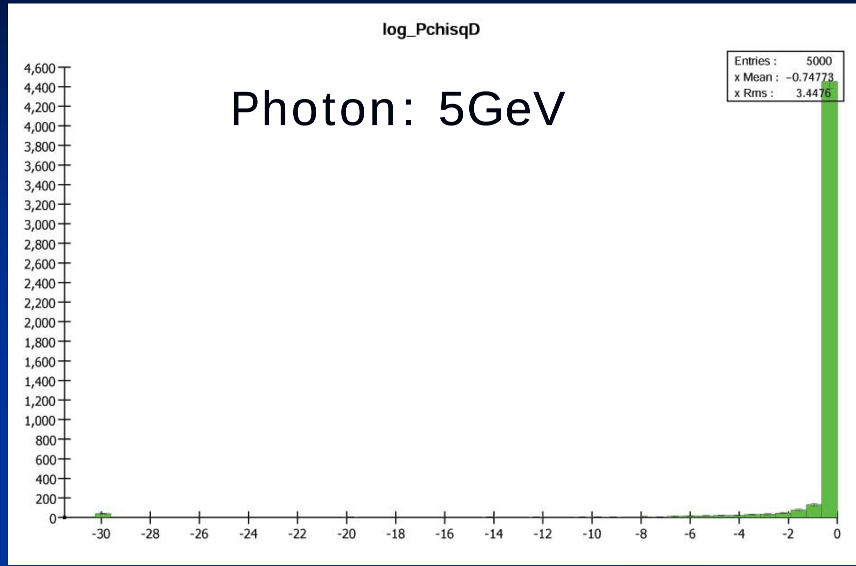


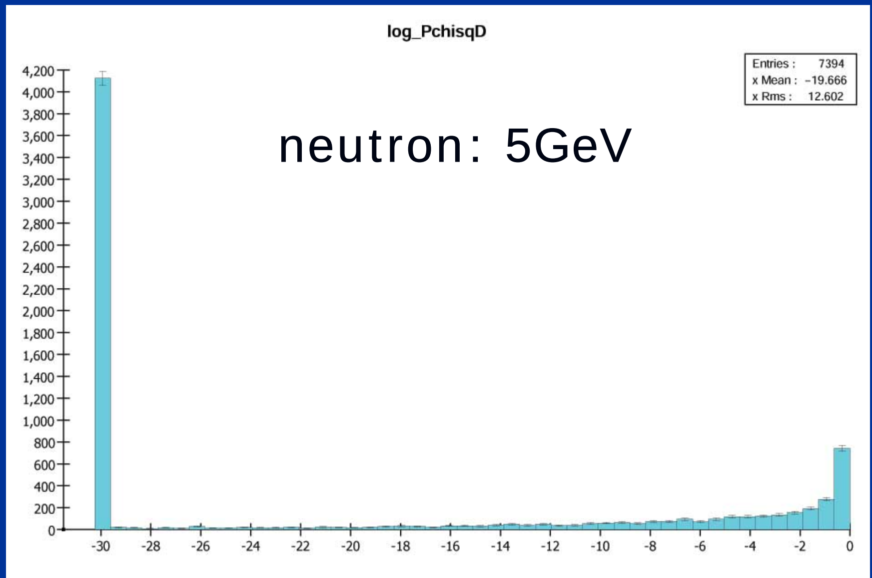


- Most of the clusters (89.7%) are pure (only one particle contributes)
- For the remaining 10.3% clusters
  - 55% are almost pure (more than 90% hits are from one particle)
  - The remaining clusters contain merged showers, some of them are 'trouble makers'
- On average, 1.2 merged shower clusters/Z pole event

Photon id – longitudinal H-matrix



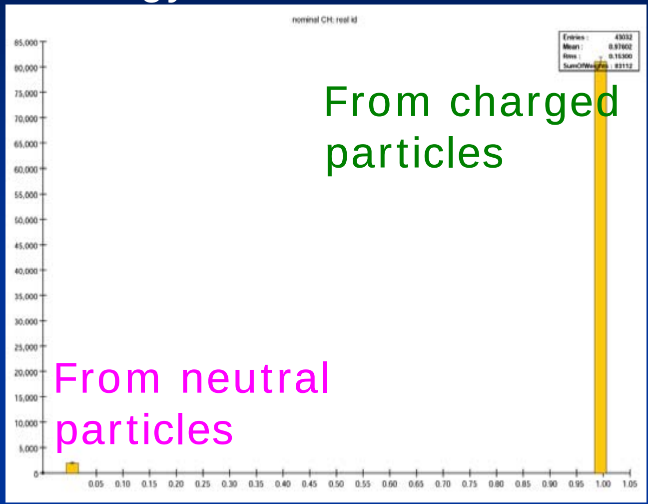




Still need more tuning to optimize the performance

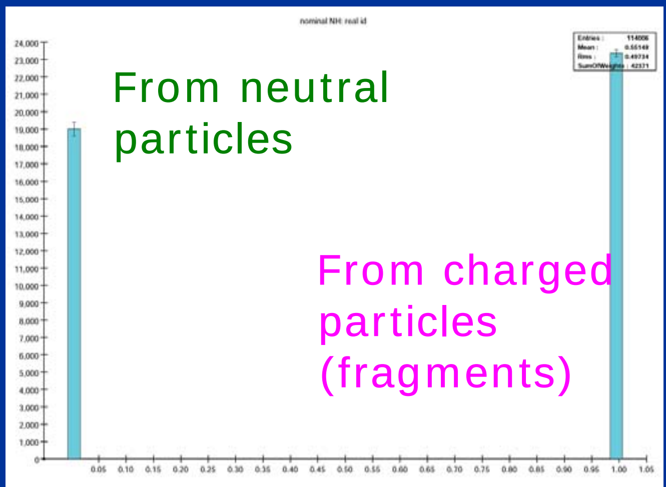
Charge fragment identification/reduction

Energy of matched clusters



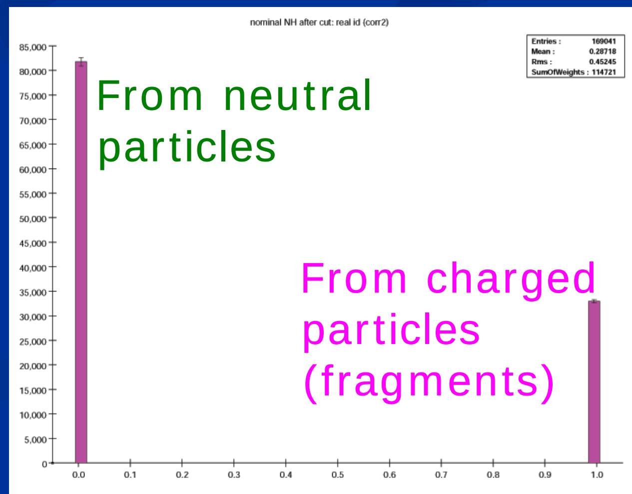
- Use geometrical parameters to distinguish real neutral hadron clusters and charge hadron fracments

Energy of clusters not matched to any track: neutral candidate



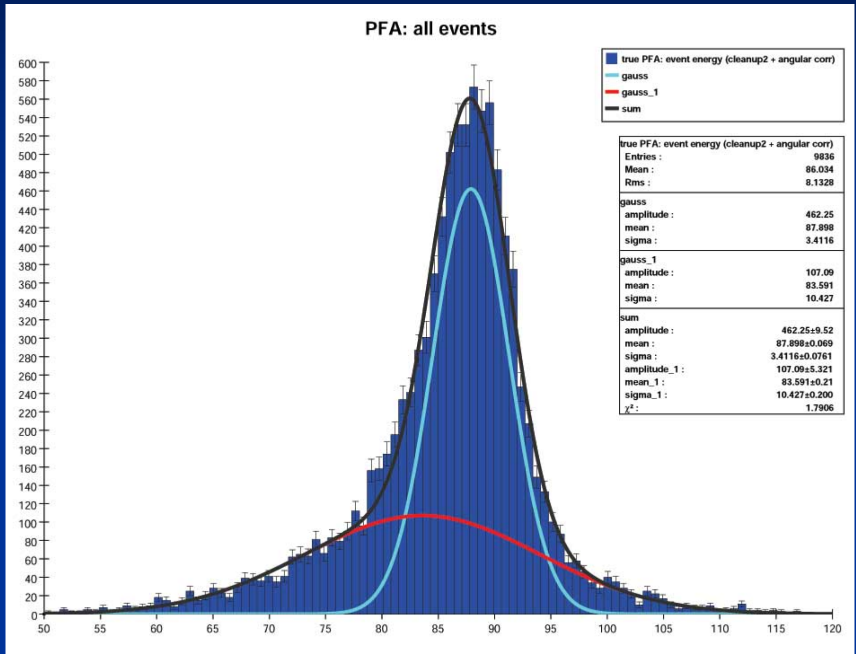
1 : 1.24

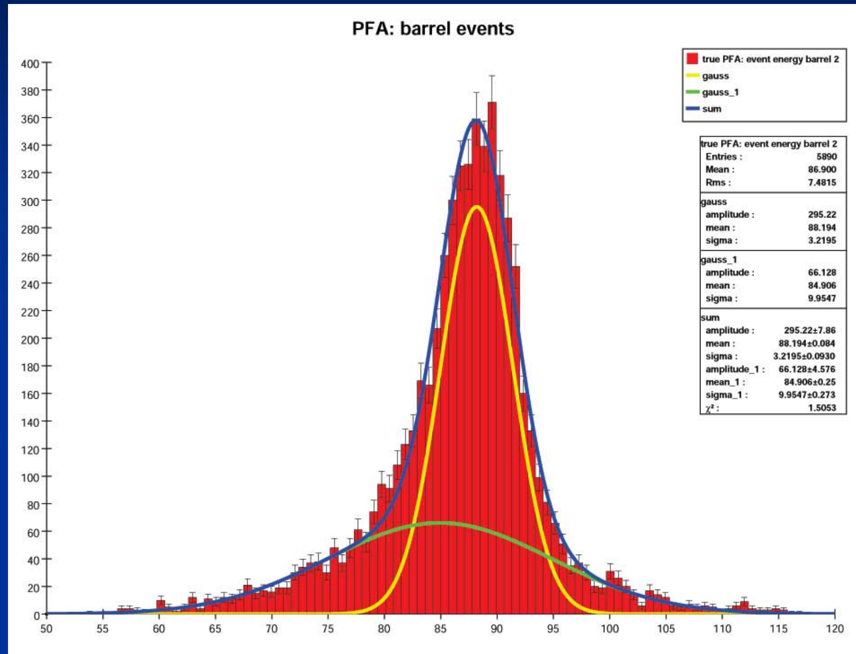
After charge fragment identification/reduction



0.88 : 0.35

PFA: Z-pole (uds) performance





All events:

3.41 GeV @87.9GeV 58.5%
10.4 GeV 41.5%

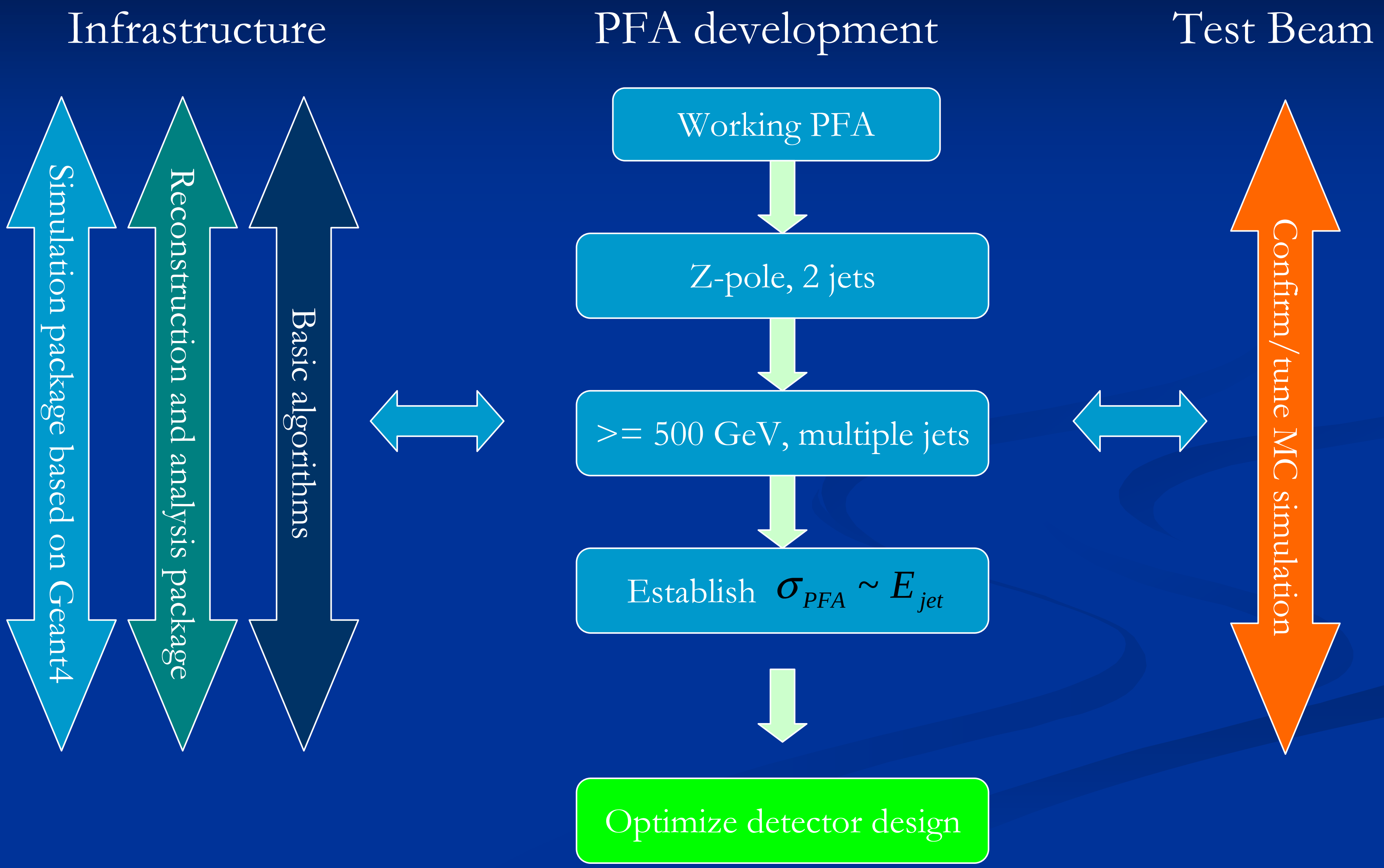
Barrel events: 60%

3.22 GeV @88.2GeV 59%
9.95 GeV 41%

Barrel: -45 deg < Theta (uds quark) < 45 deg

SiD aug05_np

My un-official PFA roadmap



Summery

- Particle Flow Algorithms are being developed at Argonne
  - Two ‘complete’ PFAs are available to play with

- Current PFA performance at Z-pole looks promising
  - Performance at Z-pole will continue to improve
  - Not a problem to achieve ILC goal at this energy range

- Need to study PFA performance over the entire ILC interested jet energy range
  - Prove that PFA is the way to achieve the ILC jet energy resolution goal
  - Use PFA to optimize ILC detector design

- Test beam data need to come in time!