High Granularity Particle Flow Calorimetry

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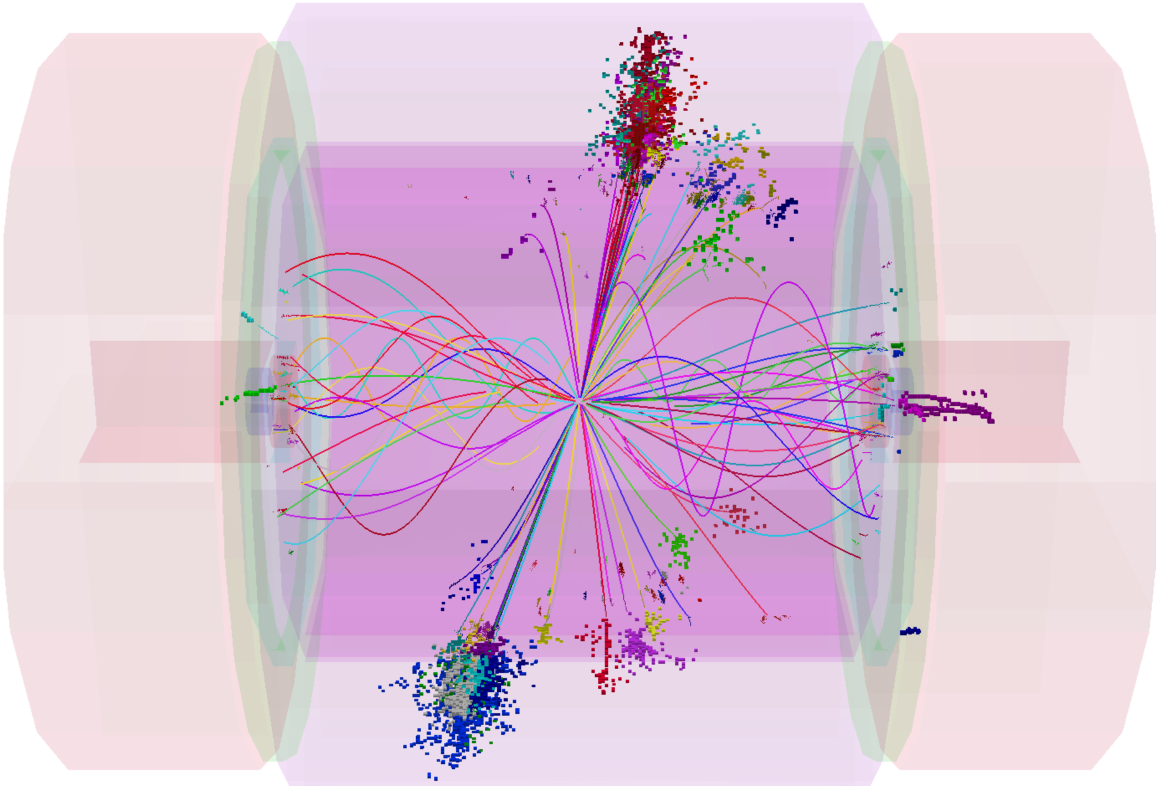


- ★ Part of Task 2.3
- ★ Work package goals described here from two groups:
  University of Cambridge and **CERN**

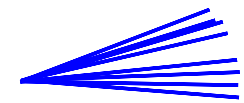
This Talk

- ★ Introduction to Particle Flow Calorimetry
- ★ Status of High Granularity Particle Flow Calorimetry
- ★ PandoraPFA from a physics perspective
- ★ PandoraPFA from a software perspective
- ★ AIDA plans, deliverables, milestones

❶ Particle Flow Calorimetry

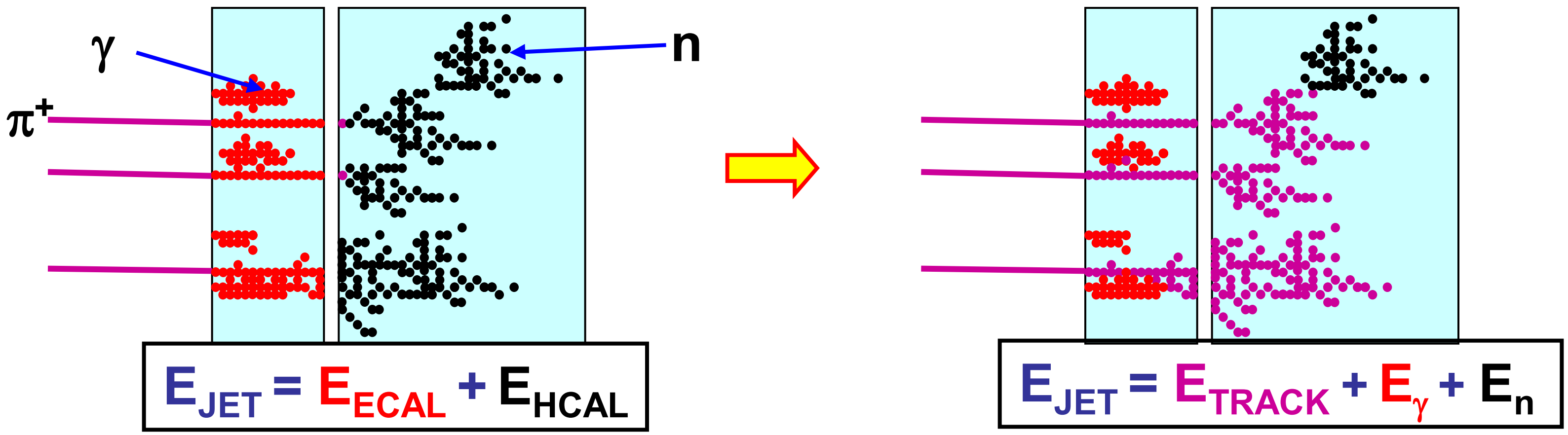
★ **In a typical jet :**

- **60 %** of jet energy in charged hadrons
- **30 %** in photons (mainly from $\pi^0 \rightarrow \gamma\gamma$)
- **10 %** in neutral hadrons (mainly n and K_L)



★ **Traditional calorimetric approach:**

- Measure all components of jet energy in ECAL/HCAL !
- **~70 %** of energy measured in HCAL: $\sigma_E/E \approx 60\,\%/\sqrt{E(\mathrm{GeV})}$
- Intrinsically "poor" HCAL resolution limits jet energy resolution



★ **Particle Flow Calorimetry paradigm:**

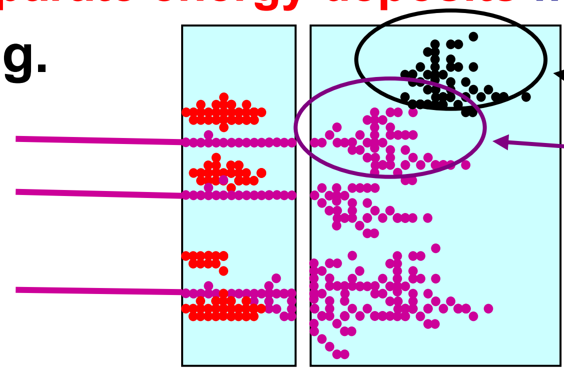
- charged particles measured in tracker (essentially perfectly)
- Photons in ECAL: $\sigma_E/E < 20\,\%/\sqrt{E(\mathrm{GeV})}$
- Neutral hadrons (ONLY) in HCAL
- Only 10 % of jet energy from HCAL ⟹ much improved resolution

Particle Flow Reconstruction

Reconstruction of a Particle Flow Calorimeter:

- ★ **Avoid double counting of energy from same particle**
- ★ **Separate energy deposits from different particles**

e.g.

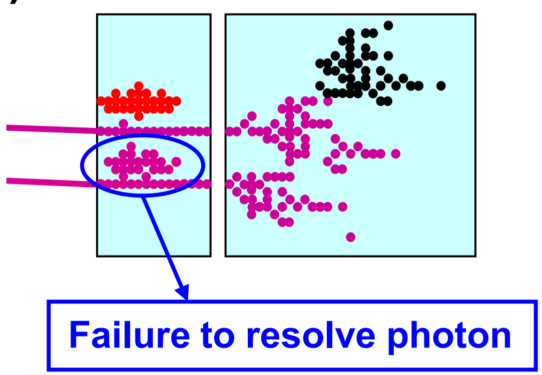


If these hits are clustered together with these, lose energy deposit from this neutral hadron (now part of track particle) and ruin energy measurement for this jet.

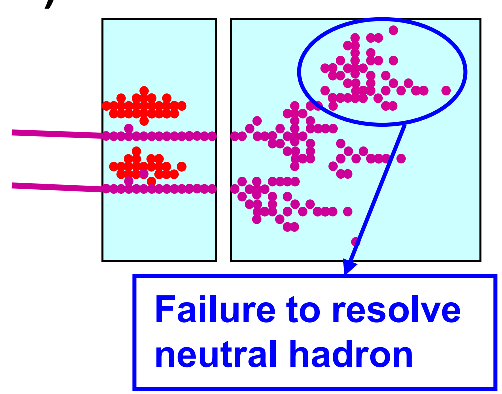
Level of mistakes, "confusion", determines jet energy resolution _not_ the intrinsic calorimetric performance of ECAL/HCAL

Three types of confusion:

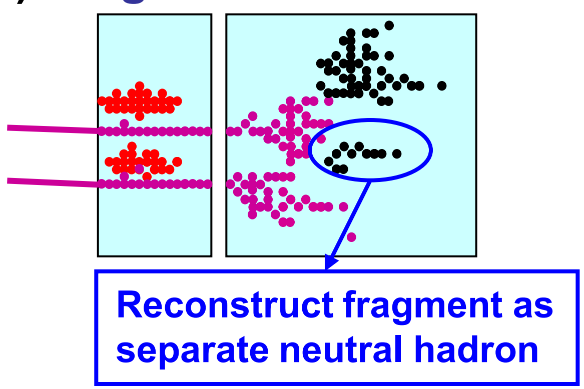
i) Photons



ii) Neutral Hadrons



iii) Fragments

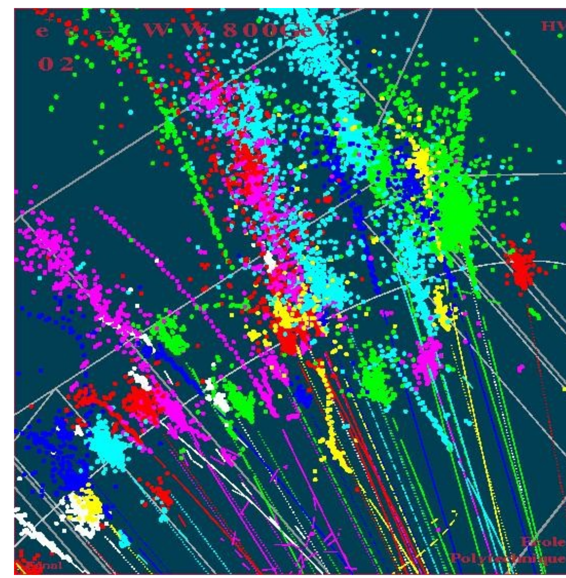


Particle Flow is not new…

- ★ First used by ALEPH
- ★ Major effort in CMS

What's new is…

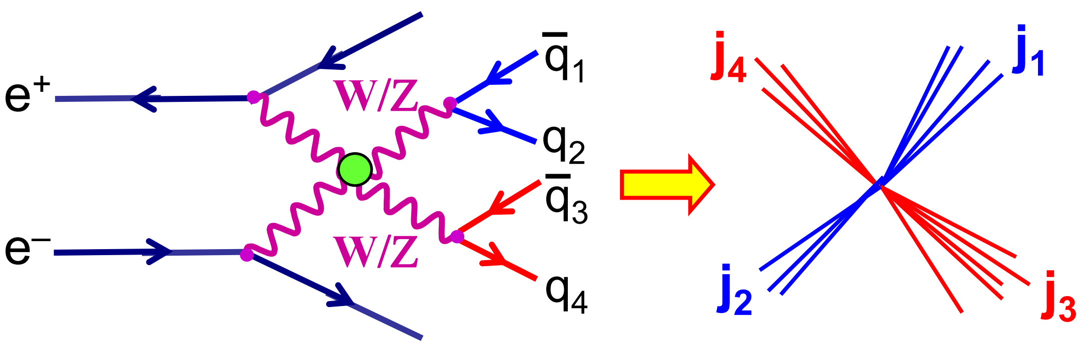
- ★ Application to novel high granularity Collider detectors
- ★ Has driven the design of Linear Collider detectors (ILC and CLIC)

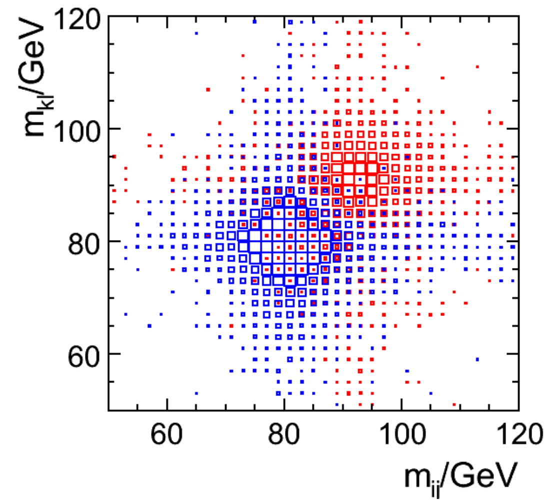


❷ Current Status

- ★ **High Granularity Particle Flow Reconstruction uses information from the entire detector**
- ★ **Complex multistage reconstruction task**
- ★ **Current best performing algorithm in LC-world is “PandoraPFA”**
- ★ **Central to demonstration of ILC/CLIC detector performance goals**

e.g. ability need to separate W/Z hadronic decays





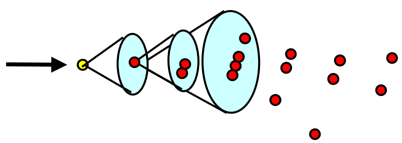
❸ PandoraPFA Algorithm

★ **High granularity Pflow reconstruction is highly non-trivial !**

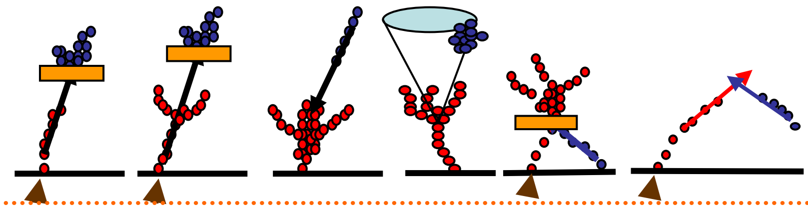
PandoraPFA consists of a many complex steps (not all shown)

❹

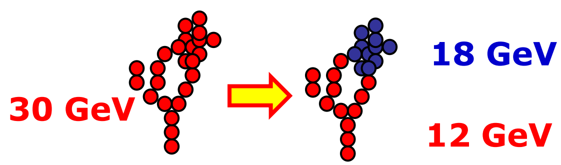
Clustering



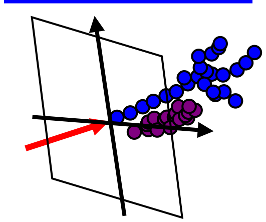
Topological Association



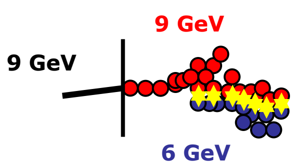
Iterative Reclustering

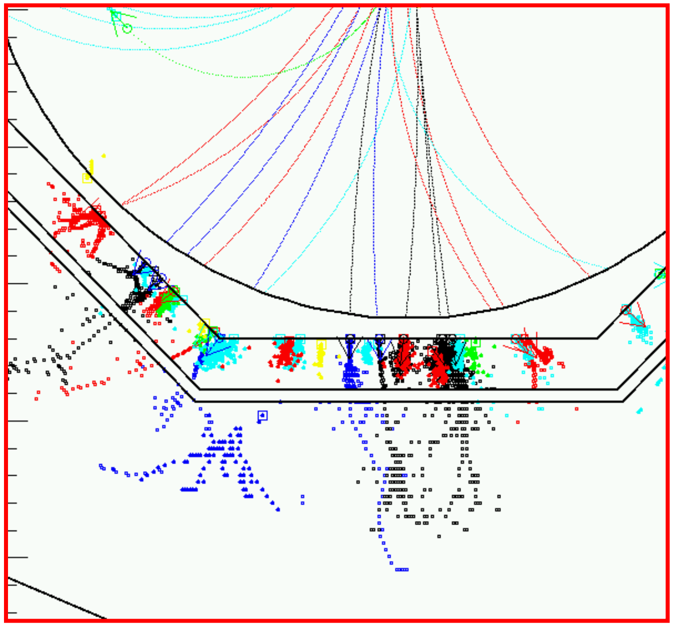


Photon ID



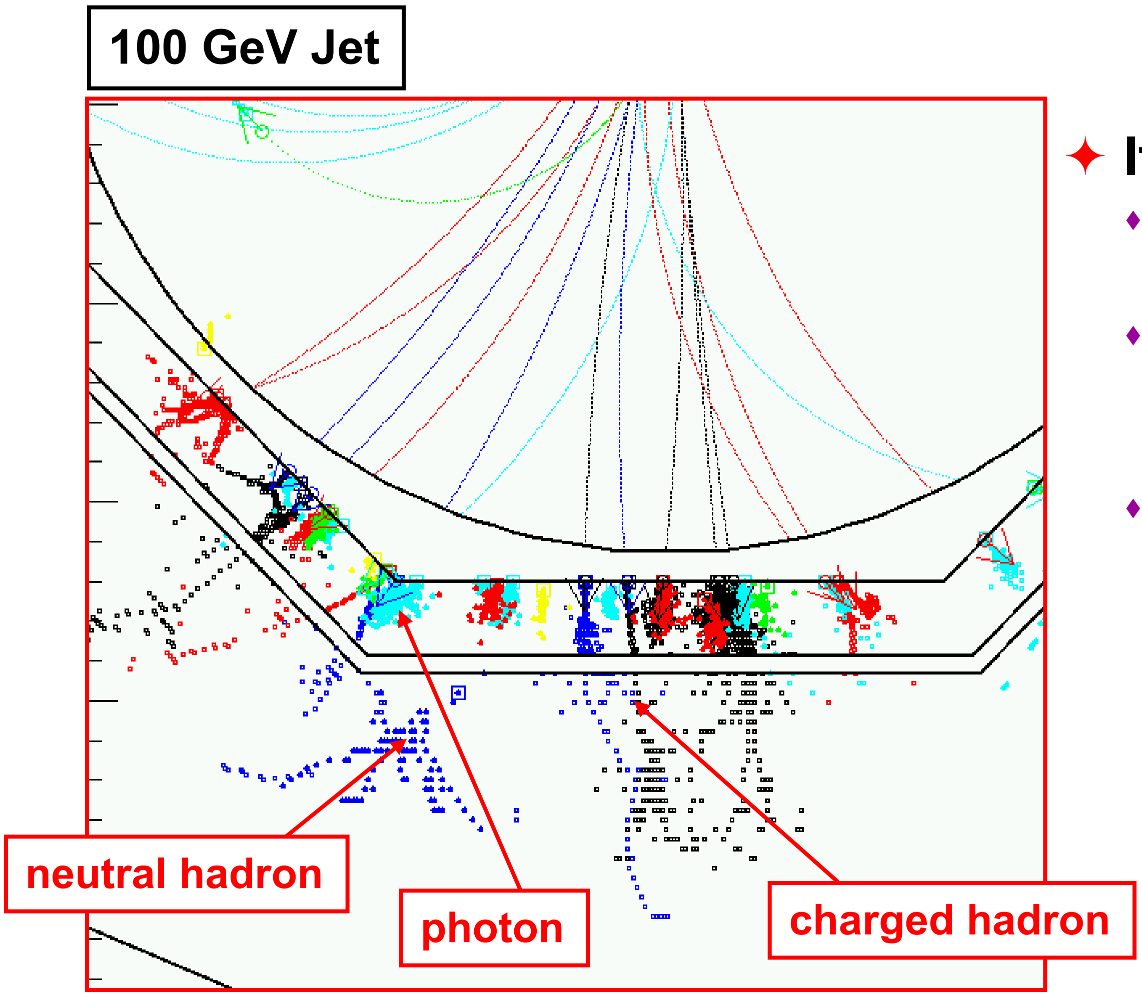
Fragment ID





For more details: MT, NIM 611 (2009) 24-40

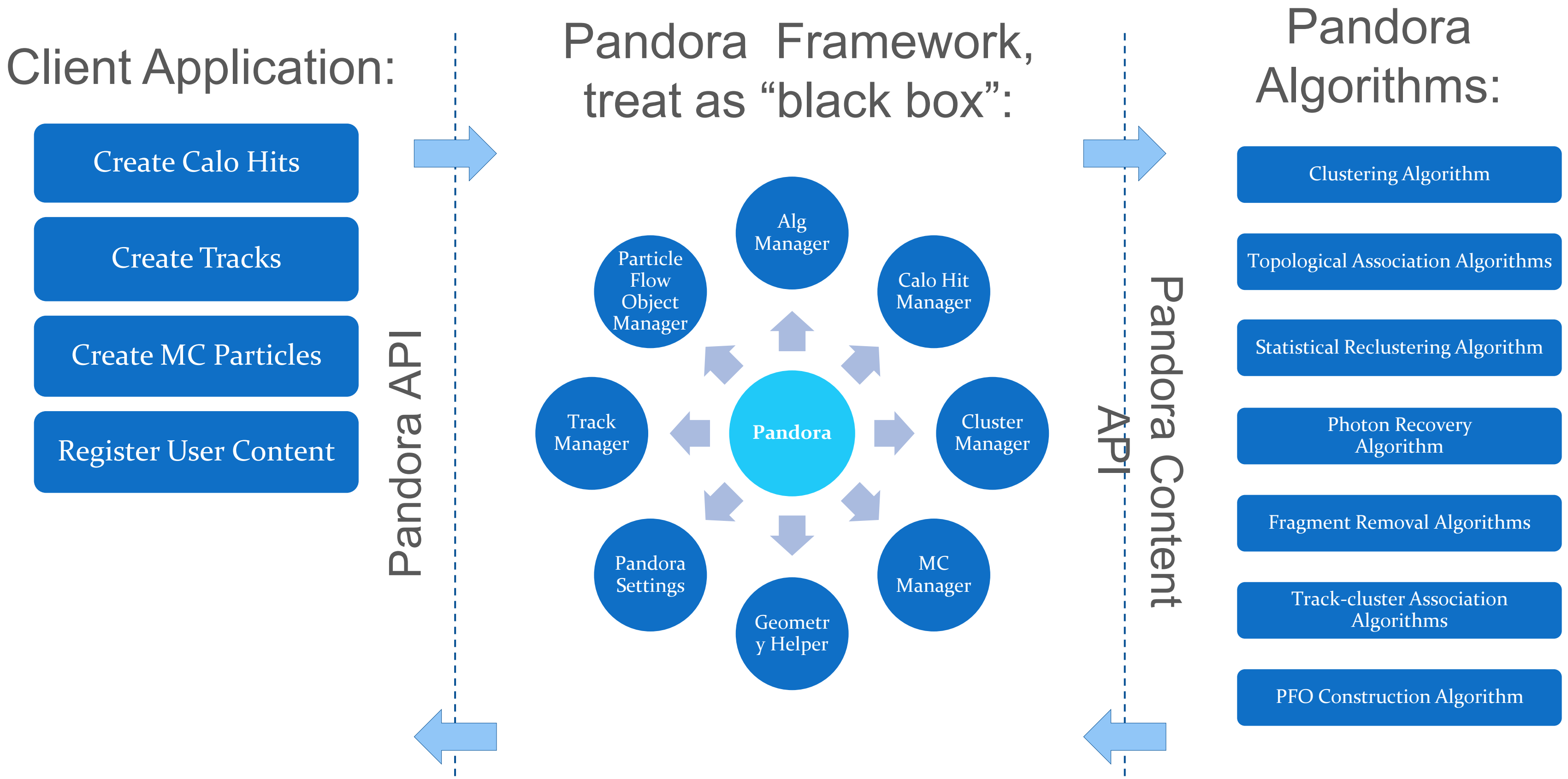
The output… reconstructed particles



- If it all works…
  - Reconstruct the individual particles in the event.
  - Calorimeter energy resolution not critical: most energy in form of tracks.
  - Level of mistakes in associating hits with particles, dominates jet energy resolution.

❸ PandoraPFA: Software

- ★ PandoraPFA initially very focussed on ILC reconstruction
- ★ Code developed in "physicist style"
  - resulted in single use-case unmanagable "rat's nest"
- ★ Recently re-design from scratch



- ★ Re-implementation gives (almost) identical performance

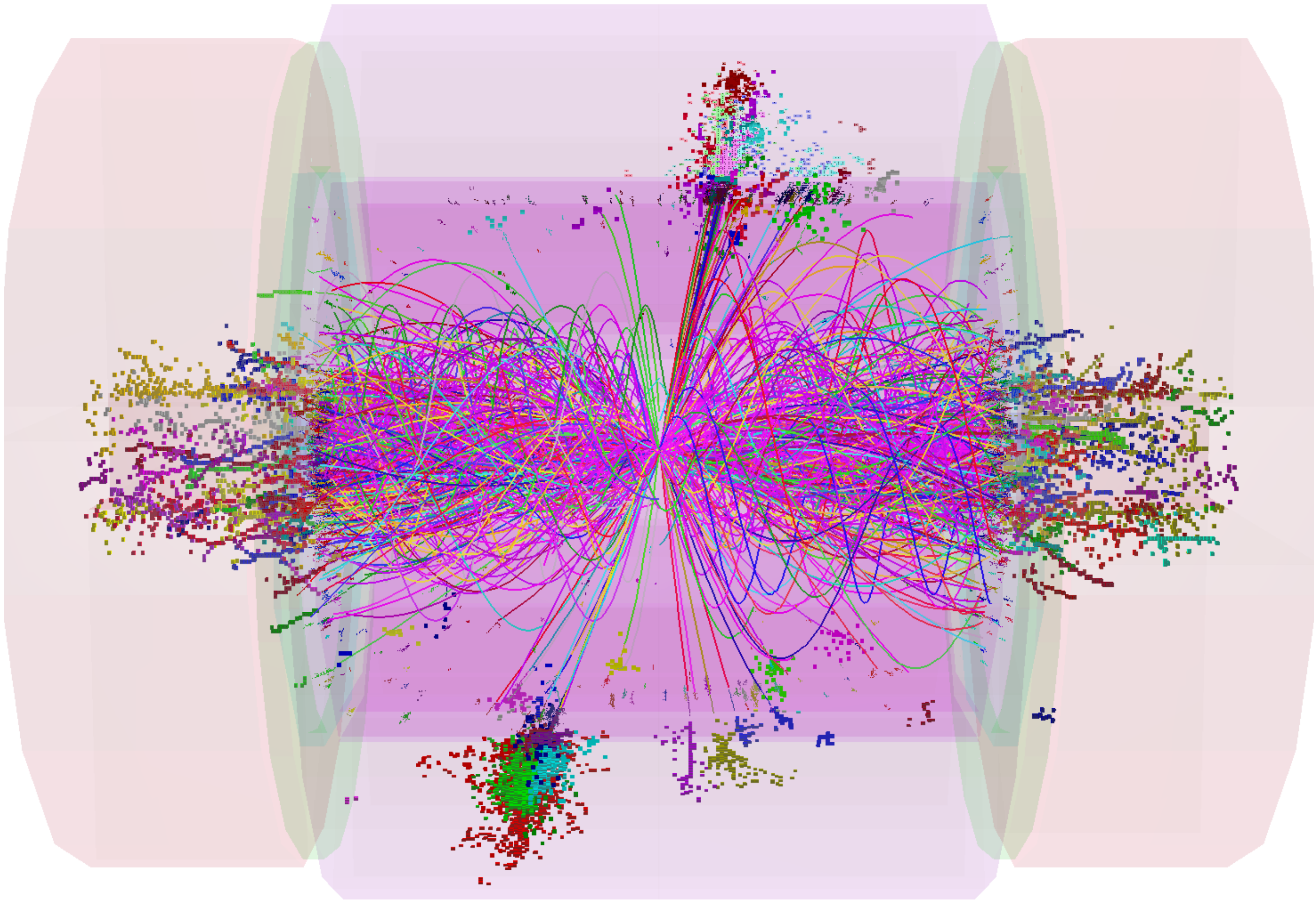
❹ WP Goals/Deliverables

Goals: High Level

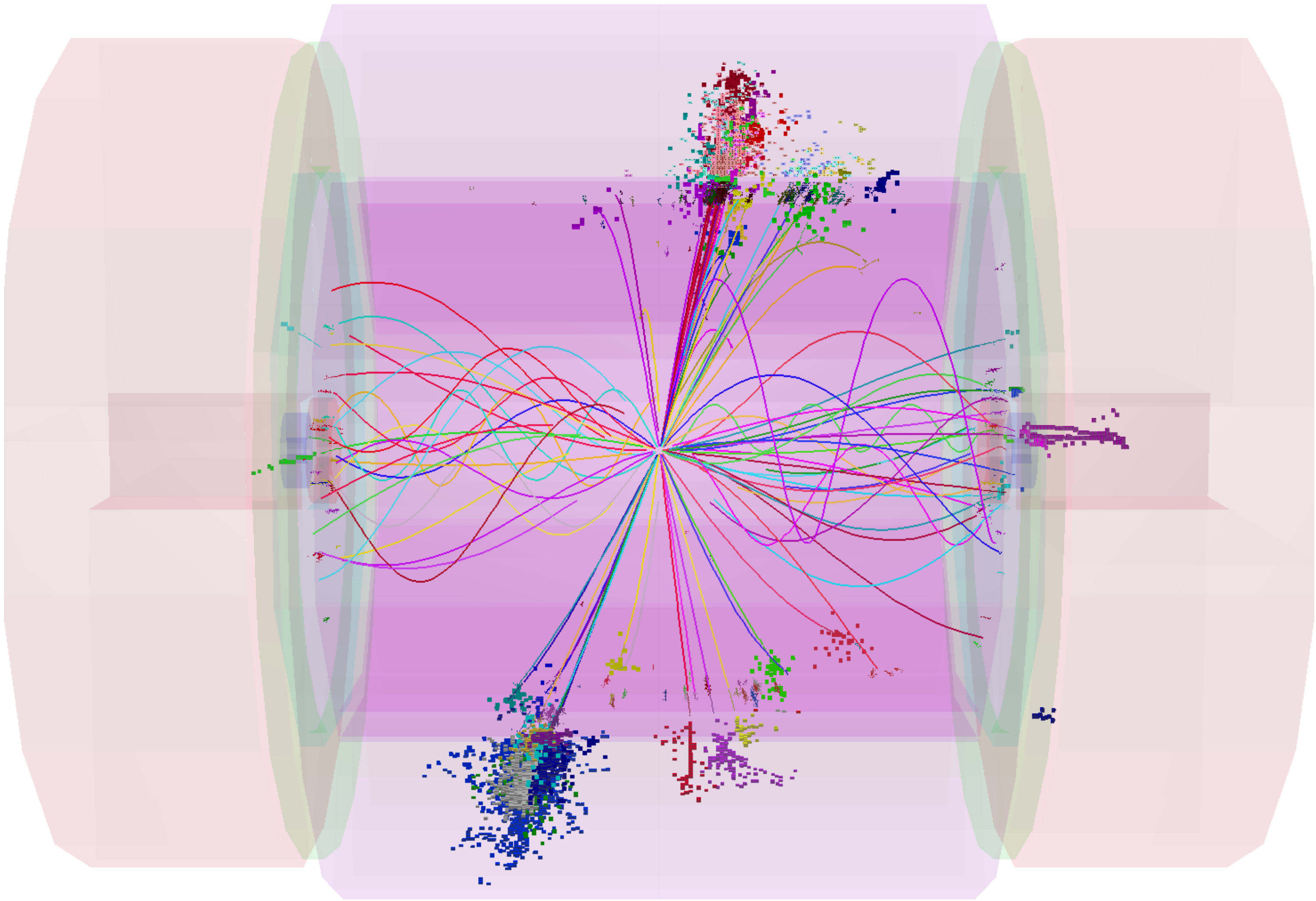
- ★ Continue to support Particle Flow Algorithm development for LC
- ★ Develop PandoraPFA into a generic clustering toolkit
  - Is this possible?
  - Yes, because…
  - Decoupling from "ILC framework" into standalone package
  - Decoupling from geometry via API design
- ★ Apply Pandora infrastructure to specific use-cases (i.e. experiments)
  - (hopefully) real benefit to wider HEP community
  - + push algorithm development in "useful" direction

The generic aspects are realistic

e.g. CLIC “pile-up”



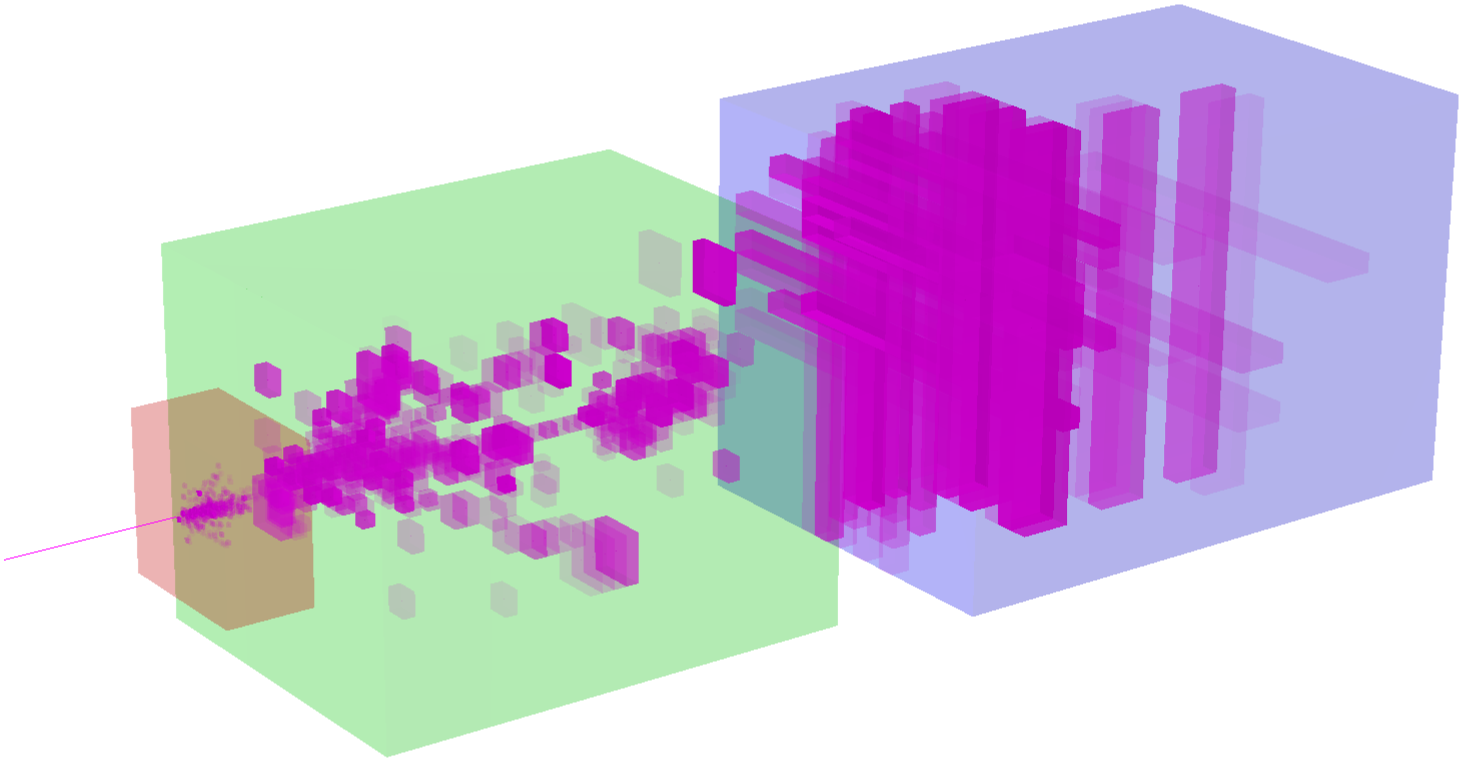
with “4D reconstruction”



★ **Not Generic (still an LC detector) but very challenging environment**

CALICE reconstruction

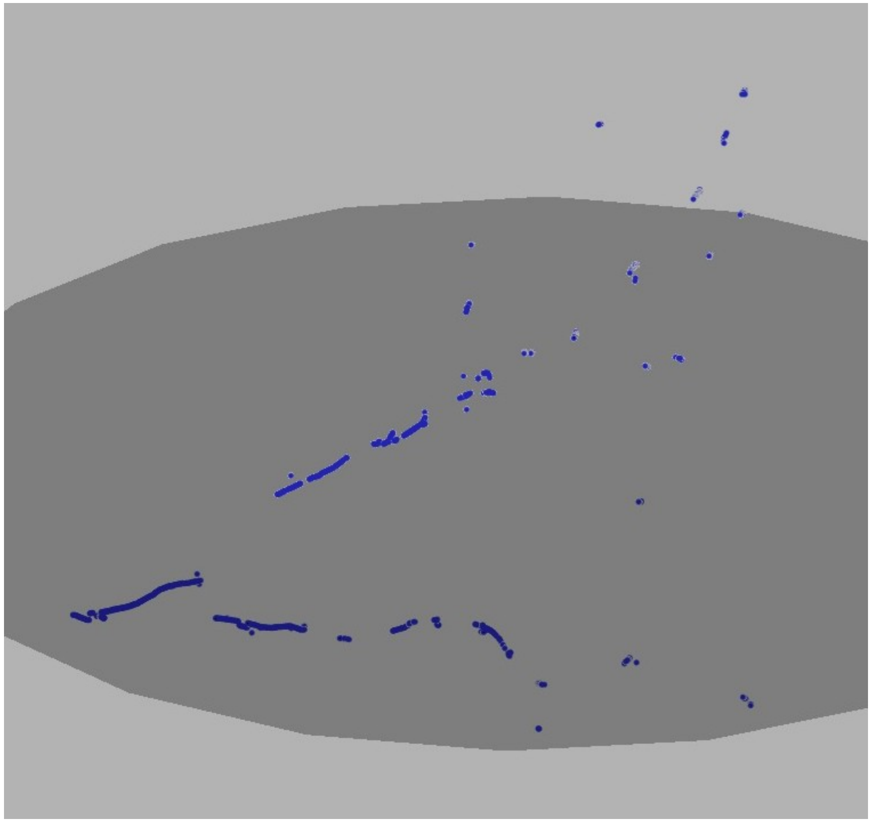
★ CALICE interface to PandoraPFA (P. Speckmayer, CERN)
e.g. 80 GeV pion test beam



★ Worked out of the box…

★ "Generic" but this is an LC calorimeter prototype…

Liquid Argon TPC Reconstruction



Simulated 500 MeV π^0 from NC neutrino interaction

- ★ Interface worked out of the box…
- ★ "Tracking-like" algorithms worked
- ★ Proof of principle
- ★ However, needs development algorithm

❺ WP Plans

Plans:

- ★ Continued development of PandoraPFA "framework"
- ★ Development of PandoraPFA as a particle flow clustering toolkit
  - Bring in modern clustering approaches from Comp. Sci.
- ★ PandoraPFA algorithm development
  - geared to specific use-cases (ILC, CLIC, LAr, …)
  - Kalman filtering in a calorimeter
- ★ Investigation of application of PFlow techniques to current detectors

Manpower:

- ★ Cambridge/CERN combined effort ~55 FTE-months
- ★ Cambridge will work all aspect, core "framework" development central
- ★ CERN will work on algorithm development, + strong connection to ongoing CLIC studies

Final words:

- ★ This is an **ambitious** project
- ★ But, building on strength
- ★ Believe we have the expertise and effort to succeed

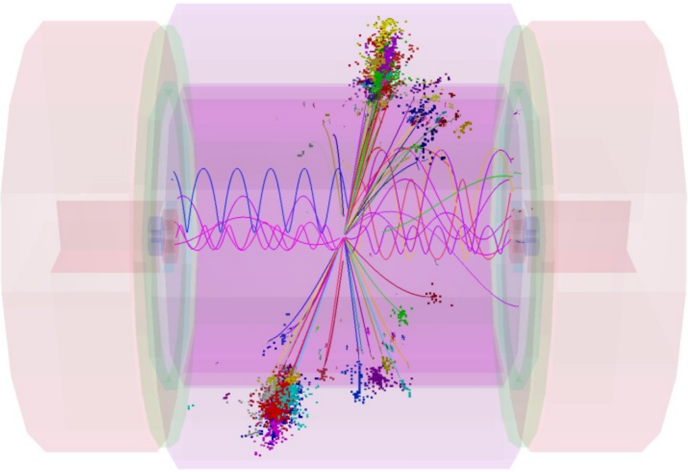
"ILC" Jet Energy Resolution

★ For ILC/CLIC calorimetry goal is:

Jet energy resolution: $\sigma_E / E < 3.5\%$

★ Benchmark performance using jet energy resolution in Z decays to light quarks

★ Use total energy to avoid complication of jet finding (mass resolutions later)



★ Current Pflow performance (PandoraPFA + ILD)

- uds jets (full GEANT 4 simulations)

rms$_{90}$

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\lvert\cos\theta\rvert<0.7$	σ_E/E_j
45 GeV	25.2 %	3.7 %
100 GeV	29.2 %	2.9 %
180 GeV	40.3 %	3.0 %
250 GeV	49.3 %	3.1 %

Factor 2-3 improvement c,f traditional methods