

Brief introduction of Simulation tools and Particle Flow Algorithm

1. Performance requirements
2. Tools to optimize detector design and performance
 1. Physics benchmark, and Generators
 2. Detector simulators
3. Particle Flow Algorithm
 1. Key techniques
 2. Examples of current results
4. Summary

Many thanks to Akiya, Ties, Norman, Mark, Tamaki, Junpei,,,,,

For each detector performance, see concept study report tomorrow

Performance Goal of ILC Detectors

The best summarized in World-wide “Linear Collider Detector R&D”

J.Brau et al, <http://blueox.uoregon.edu/~lc/randd.ps>

- VXT: quark flavor tagging - Key for Higgs/top and many physics

Impact Parameter resolution: $\sim 5\mu\text{m} + 10\mu\text{m} / p(\text{GeV}) \sin^{-3/2} \theta$

- Tracker: Higgs recoil, resonances

Momentum resolution: $dp/p \sim 5 \times 10^{-5} \times p(\text{GeV})$ (central region)
 $3 \times 10^{-4} \times p(\text{GeV})$ for forward region

Angular resolution: $d\theta \sim 2 \times 10^{-5} \text{ rad}$ (for $|\cos\theta| < 0.99$)

- For Higgs, SUSY, etc..

Jet energy resolution: $dE/E \sim 0.3 / \sqrt{E(\text{GeV})}$

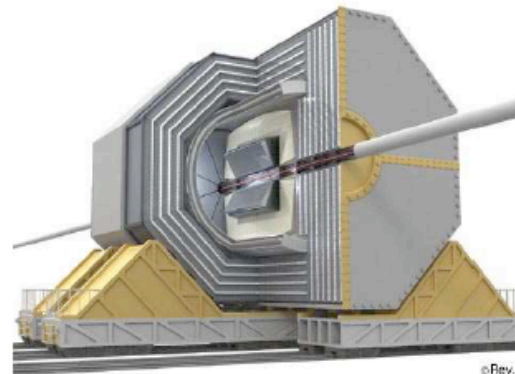
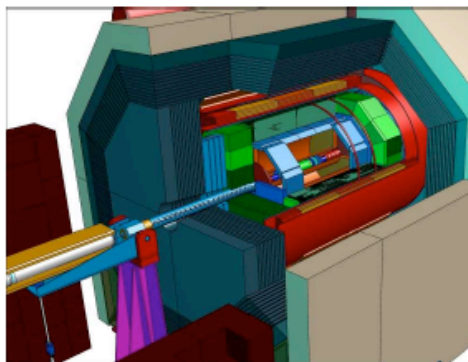
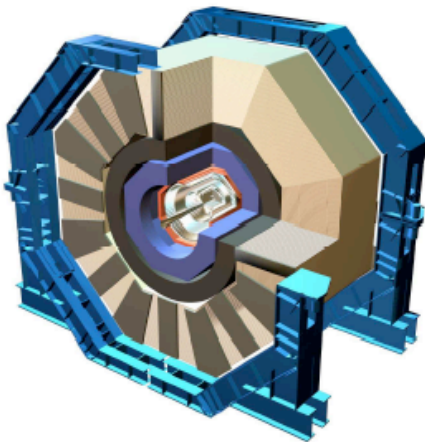
- For background veto, missing energy physics

Excellent **Hermeticity**: down to $\theta \sim 5\text{--}10 \text{ mrad}$ (active mask)

ILC Detector Challenges

With respect to detectors at LHC:

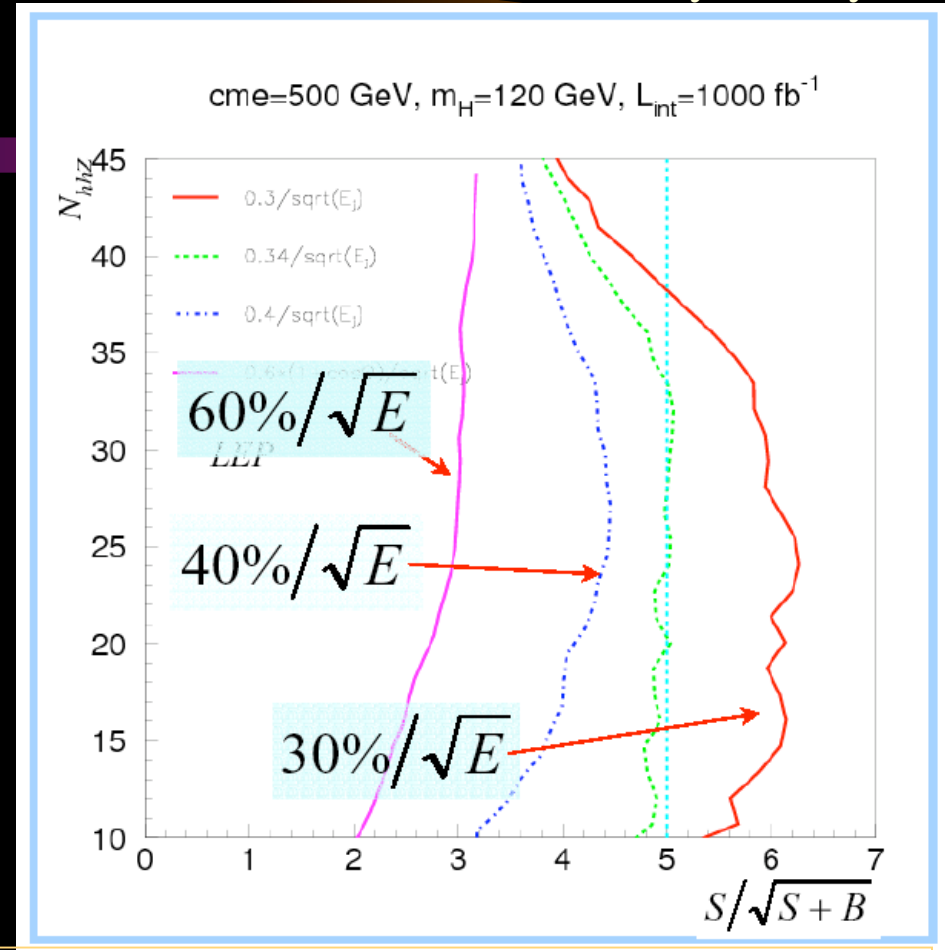
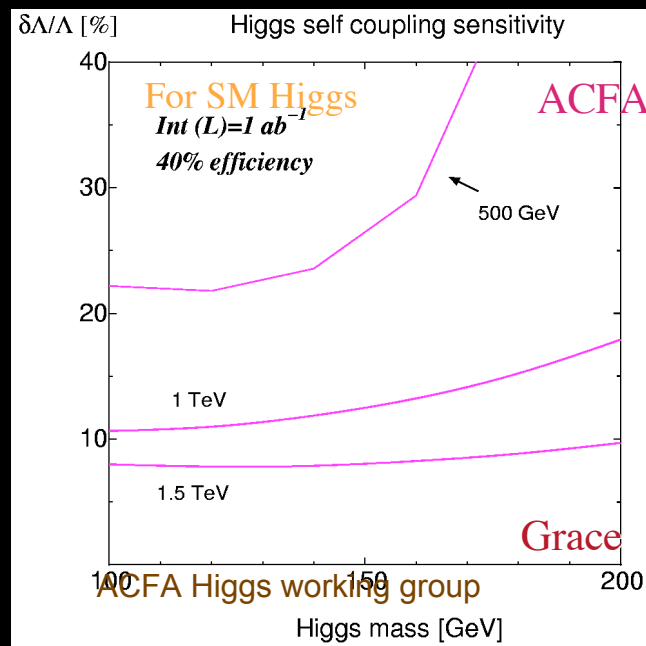
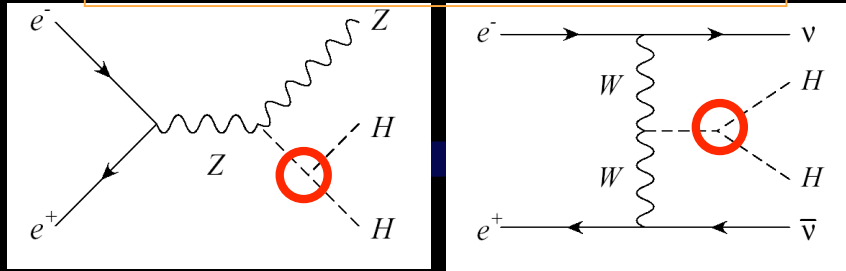
■ Inner VTX layer	3--6 times closer to IP
■ VTX pixel size	1 / 30
■ VTX materials	1 / 30
■ Materials in Tracker	1 / 6
■ Track mom. resolution	1 / 10
■ EM cal granularity	1 / 200 !!



Jet energy resolution is a Key for multi-jets events @ ILC

Higgs self-coupling study

ECFA study - P.Gay et al



60%-->30% improvements is equivalent to
improving the ILC luminosity by factor 4~5 !!

Fast Simulation

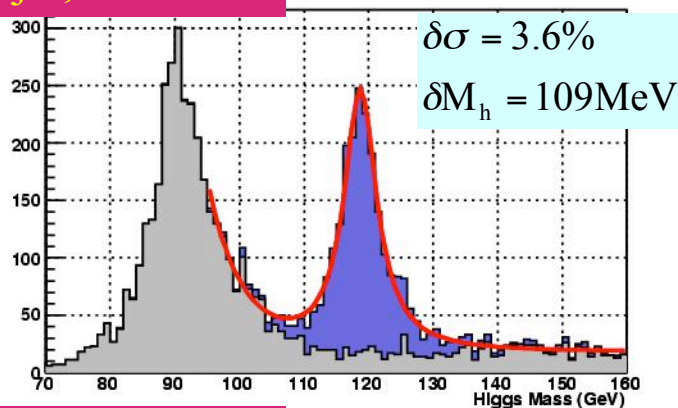
$e^+e^- \rightarrow HZ \rightarrow 2\text{jets} + \nu\nu$

T.Yoshioka et al

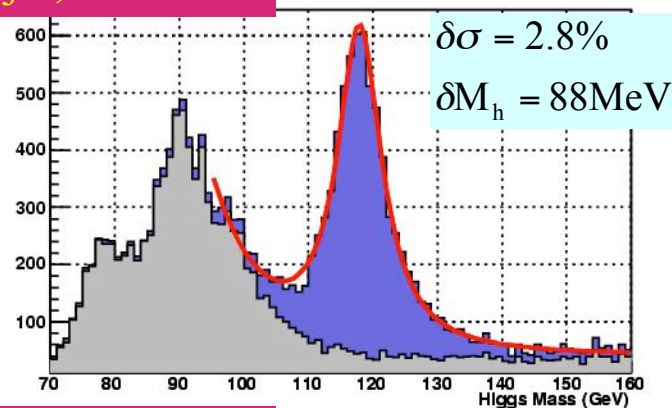
$e^+e^- \rightarrow HZ \rightarrow 4\text{jets}$

Without Kinematic-fit

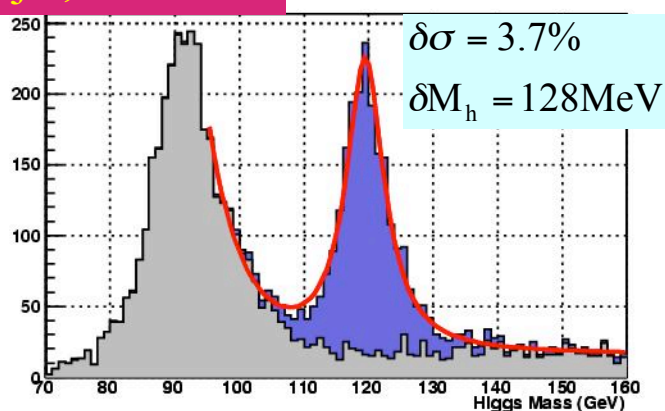
2jet, 30%/√E



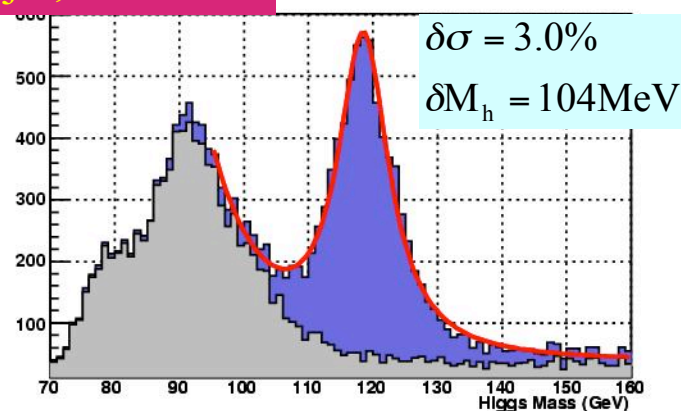
4jet, 30%/√E



2jet, 40%/√E

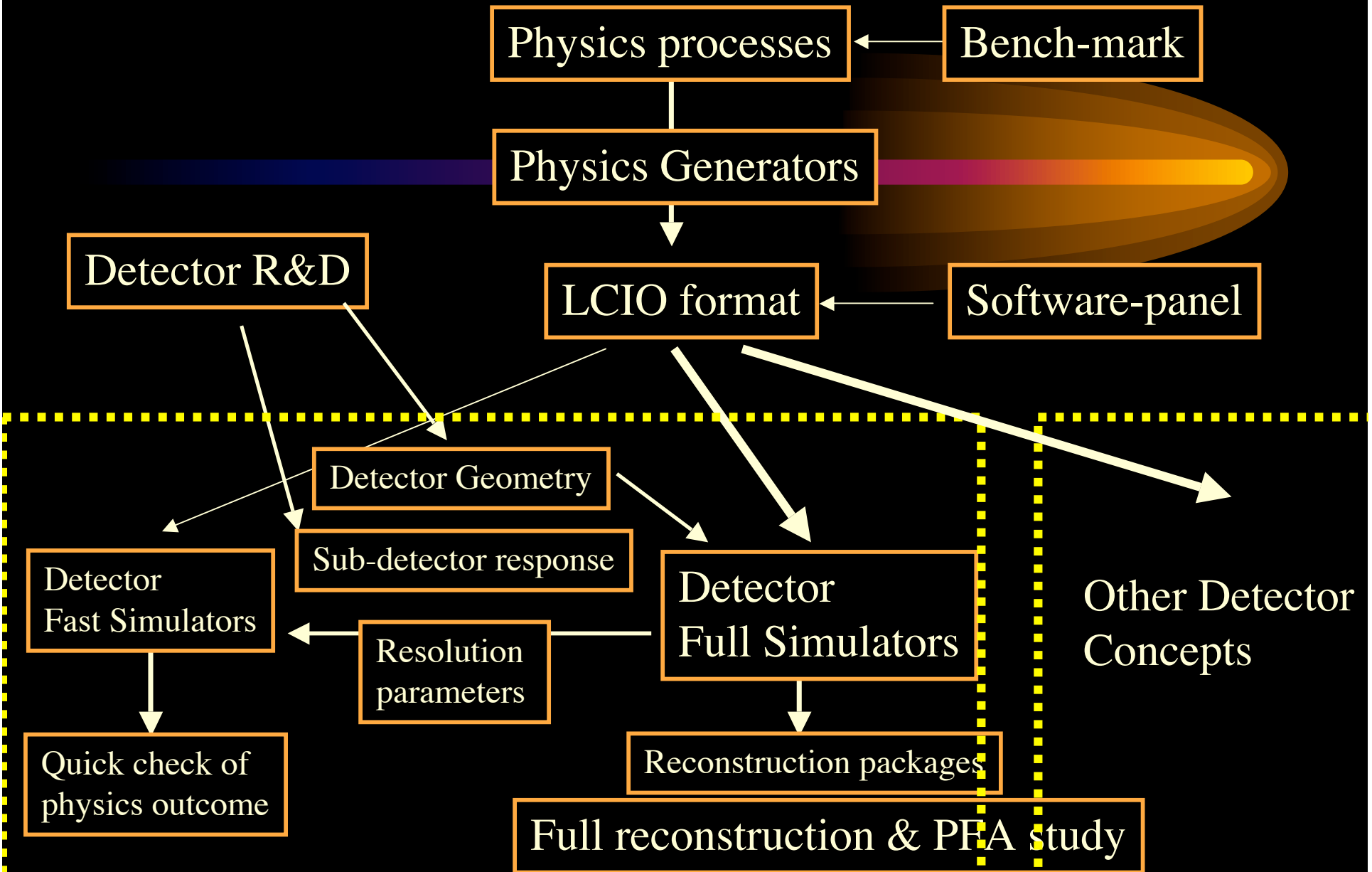



4jet, 40%/√E



Small but significant difference between 30% and 40% resolution

Software tools to optimize detectors



- 
- Physics Benchmark
 - Generators
 - Detector Simulators
 - Reconstruction tools especially PFA

To help detector optimization

Physics Benchmark

Benchmark panel:

T.Barklow, M.Battaglia, Y.Okada, M.Peskin, S.Yamashita, P.Zerwas

Process	Vertex	Tracking		Calorimetry		Fwd		Very Fwd	Integration					Pol.
	σ_{TP}	$\delta p/p^2$	ϵ	δE	$\delta\theta, \delta\phi$	Trk	Cal	θ_{min}^o	δE_{jet}	M_{JJ}	ℓ -Id	V^0 -Id	$Q_{jet/vtx}$	
$ee \rightarrow Zh \rightarrow \ell\ell X$		x									x			
$ee \rightarrow Zh \rightarrow jjbb$	x	x	x			x					x			
$ee \rightarrow Zh, h \rightarrow bb/cc/\tau\tau$	x		x								x			
$ee \rightarrow Zh, h \rightarrow WW$	x		x		x				x		x			
$ee \rightarrow Zh, h \rightarrow \mu\mu$	x	x										x		
$ee \rightarrow Zh, h \rightarrow \gamma\gamma$				x	x		x							
$ee \rightarrow Zh, h \rightarrow invisible$				x		x	x							
$ee \rightarrow \nu\nu h$	x	x	x	x			x				x			
$ee \rightarrow tth$	x	x	x	x	x		x	x				x		
$ee \rightarrow Zh, h \rightarrow \nu\nu$	x	x	x	x	x	x	x		x	x	x	x	x	x
$ee \rightarrow WW$										x				
$ee \rightarrow \nu\nu WW/ZZ$						x	x		x	x	x			
$ee \rightarrow \tilde{e}_R \tilde{e}_R$ (Point 1)		x						x			x			x
$ee \rightarrow \tilde{\tau}_1 \tilde{\tau}_1$	x	x						x						
$ee \rightarrow \tilde{t}_1 \tilde{t}_1$	x	x							x	x		x		
$ee \rightarrow \tilde{\tau}_1 \tilde{\tau}_1$ (Point 3)	x	x			x	x	x	x	x					
$ee \rightarrow \tilde{\chi}_1^0 \tilde{\chi}_1^0$ (Point 5)									x	x				
$ee \rightarrow HA \rightarrow bbbb$	x	x								x	x			
$ee \rightarrow \tilde{\tau}_1 \tilde{\tau}_1$			x											
$\chi_1^0 \rightarrow \gamma + \ell$				x										
$\tilde{\chi}_1^\pm \rightarrow \tilde{\chi}_1^0 + \pi_{soft}^\pm$			x					x						
$ee \rightarrow tt \rightarrow 6 jets$	x		x						x	x	x			
$ee \rightarrow ff [e, \mu, \tau, b, c]$	x		x				x		x		x		x	x
$ee \rightarrow \gamma G$ (ADD)				x	x			x						
$ee \rightarrow KK \rightarrow f\bar{f}$		x									x			
$ee \rightarrow ee f_{vtx}$														
$ee \rightarrow Z\gamma$														

Chosen Characteristic benchmark channels

1. Single Particle, Jet-pair
2. Multi-Jets environments (PFA study etc..)
3. Flavor tagging and tau-ID
4. Small visible energy case (Forward area)

0. Single $e^\pm, \mu^\pm, \pi^\pm, \pi^0, K^\pm, K_s^0, \gamma, u, s, c, b$; $0 < |\cos\theta| < 1, 0 < p < 500$ GeV

1. $e^+e^- \rightarrow f\bar{f}, f = e, c, b$ at $\sqrt{s}=1.0$ TeV;

2. $e^+e^- \rightarrow Zh, \rightarrow \ell^+\ell^- X, m_h = 120$ GeV at $\sqrt{s}=0.35$ TeV;

3. $e^+e^- \rightarrow Zh, h \rightarrow c\bar{c}, \tau^+\tau^-, WW^*, m_h = 120$ GeV at $\sqrt{s}=0.35$ TeV;

4. $e^+e^- \rightarrow Zh, h \rightarrow hh, m_h = 120$ GeV at $\sqrt{s}=0.5$ TeV;

5. $e^+e^- \rightarrow \tilde{e}_R \tilde{e}_R$ at Point 1 at $\sqrt{s}=0.5$ TeV;

6. $e^+e^- \rightarrow \tilde{\tau}_1 \tilde{\tau}_1$, at Point 3 at $\sqrt{s}=0.5$ TeV;

7. $e^+e^- \rightarrow \chi_1^+ \chi_1^- / \chi_2^0 \chi_2^0$ at Point 5 at $\sqrt{s}=0.5$ TeV;

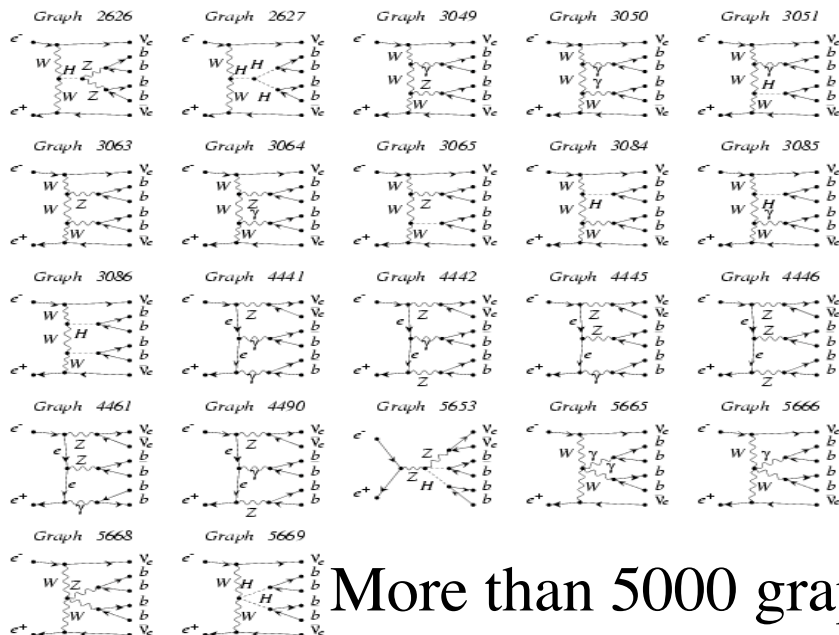
Event generators

Many generators under developments / available

ALPHA, COMPHEP, KORALW(GRACE inside), PYTHIA,
NEXTCALIBUR, WPHACT, WWGENPV, WTO, GRACE,
LUSIFER, WHIZARD, SIXFAP, PHEDAS, EETT6F, AMEGIC++, ...,

Many diagrams must be calculated

Example: $e^+e^- \rightarrow b\bar{b}b\bar{b}v_e\bar{v}_e$



WHIZARD Monte Carlo

All 0,2,4,6-fermion and
top quark (8-fermion processes).
500 fb⁻¹ @ 0.5 TeV all generated.

A news from GRACE

A new version of GRACE
grcft: much faster than old grc

More than 5000 graphs CWS06

Event Samples

From Norman. G

- Have generated canonical data samples and have processed them through full detector simulations.
- simple single particles: γ , μ , e , $\pi^{+/-}$, n , ...
- composite single particles: π^0 , ρ , K_S^0 , τ , ψ
- Z Pole events: 30k/detector, 240,000 events
- WW, ZZ, tt, qq, tau pairs, mu pairs, $Z\gamma$, Zh: with beam pol
 - 10-30k/detector, 960,000 events
- Web accessible:

<http://www.lcsim.org/datasets/ftp.html>

Exiting amplitude using **GRACE/grcft**

processes	# of graphs	Accelerataed factor to old GRACE
$e^+e^- \rightarrow (e^+e^-)^2$	654	3.60
$e^+e^- \rightarrow (e^+e^-)^3$	145128	83.70
$e^+e^- \rightarrow e^+e^-\mu^+\mu^-\tau^+\tau^-$	12094	15.14
$e^+e^- \rightarrow e^+e^-\mu^+\mu^-\tau^+\tau^-\gamma$	117680	142.86

Kinematics is complicated to construct a realistic generator.
 → we need further study.

Plan: systematic study of
 tree level : $e^+e^- \rightarrow 7, 8$: 1-loop effects for $e^+e^- \rightarrow 4f$

- **MSSM**

$e^+e^- \rightarrow 2,3$;

SUSY23(23 processes)

SPA scheme should be introduced.

1-loop effects should be discussed. → see Yasui's talk

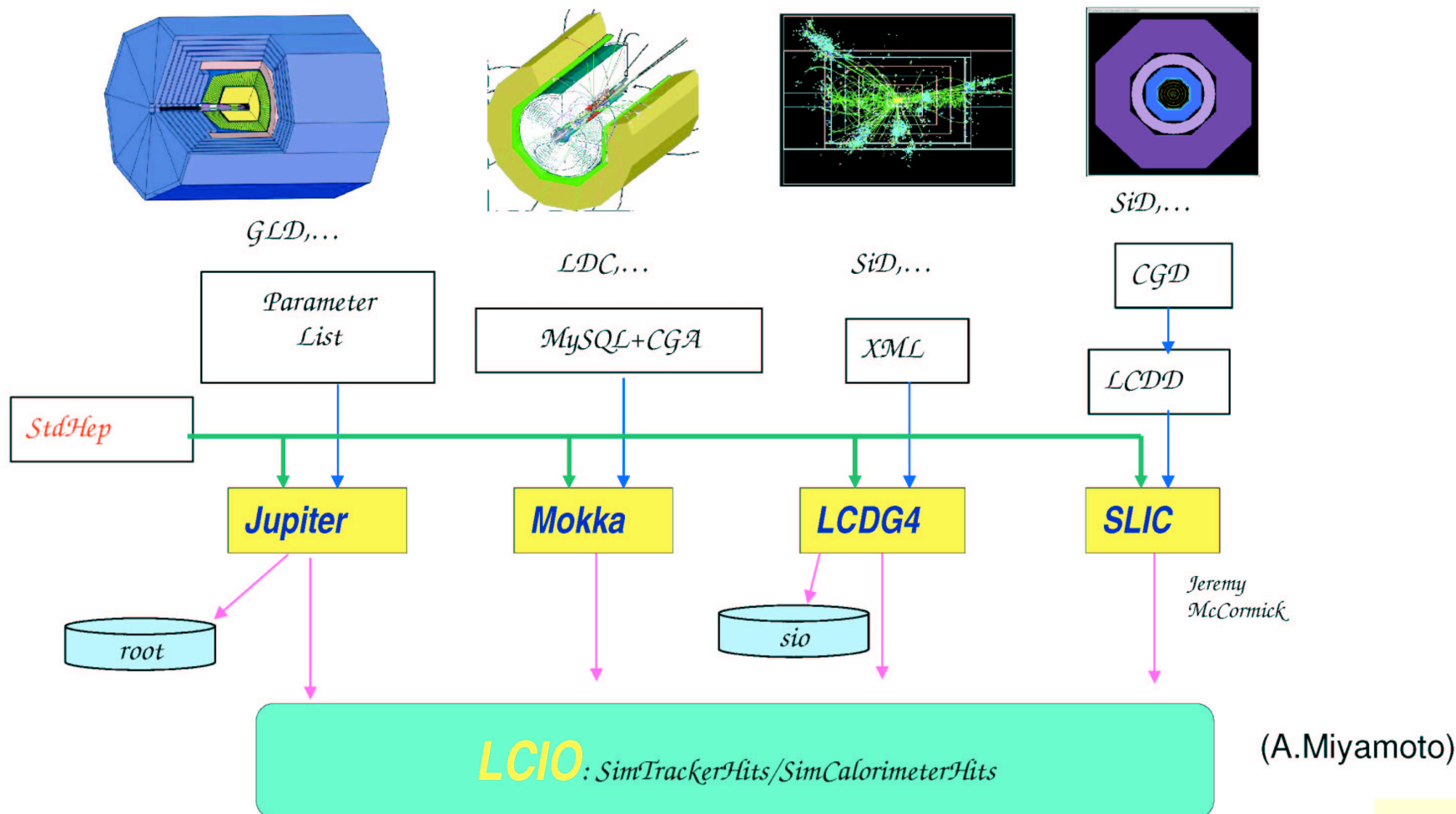
Software / frameworks for Detector Performance study

	Usage	Detector (birth)	Language	I/O-format
Simdet	fast MC	Tesla TDR	Fortran	StdHep/LCIO
JSF-Quicksim	fast MC	ACFA study / GLD	C++	LCIO / internal
SGV	fast MC	flexible	Fortran	(LCIO)
Lelaps	fast MC	SiD	C++	SIO/LCIO
Mokka	full MC - Geant4	LDC	C++	ASCL/LCIO
Brahms-Sim	full MC - Geant3	Tesla TDR	Fortran	LCIO
SLIC	full MC - Geant4	SiD	C++	LCIO
LCDG4	full MC - Geant4	SiD	C++	SIO/LCIO
JUPITER	full MC - Geant4	GLD	C++	LCIO
Brahms-Reco	reconstruction framework	Tesla TDR	Fortran	LCIO
Marlin	reconstruction and analysis	Flexible	C++	LCIO
hep.lcd	reconstruction framework	SiD	Java	SIO
org.lcsim	reconstruction framework	SiD	Java	LCIO
JUPITER-Satelite	reconstruction and analysis	GLD	C++	LCIO/root
URANUS	analyses utilities	ACFA-study / GLD	C++	
LCCD	Conditions Data toolkit	any	C++	
GEAR	Geometry description	any	C++/Java	
JAS3/WIRED	Analyses tool/event display	SiD, LDC	Java	
JSF-framework	Analyses tool/event display	GLD	C++	
LCIO	I/O common data format	common	C++/Fortran/Java	

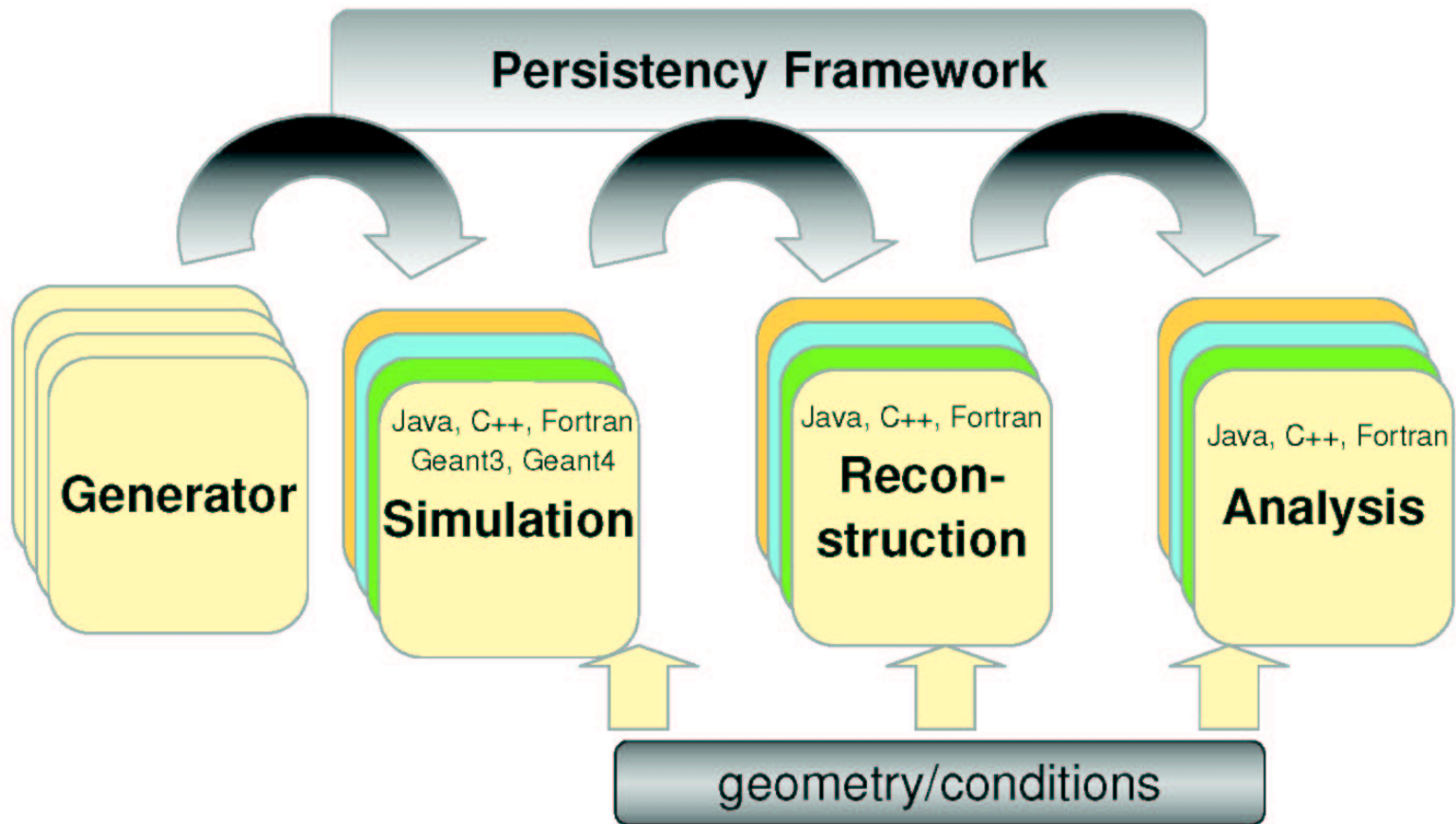
Many are under developments and many others as well.

ILC Simulation Frameworks (Geant4)

- *Geant4*, *StdHep* and *LCIO* are common feature
- Each trying to be generic with different approach
different ways to define geometries



ILC software chain

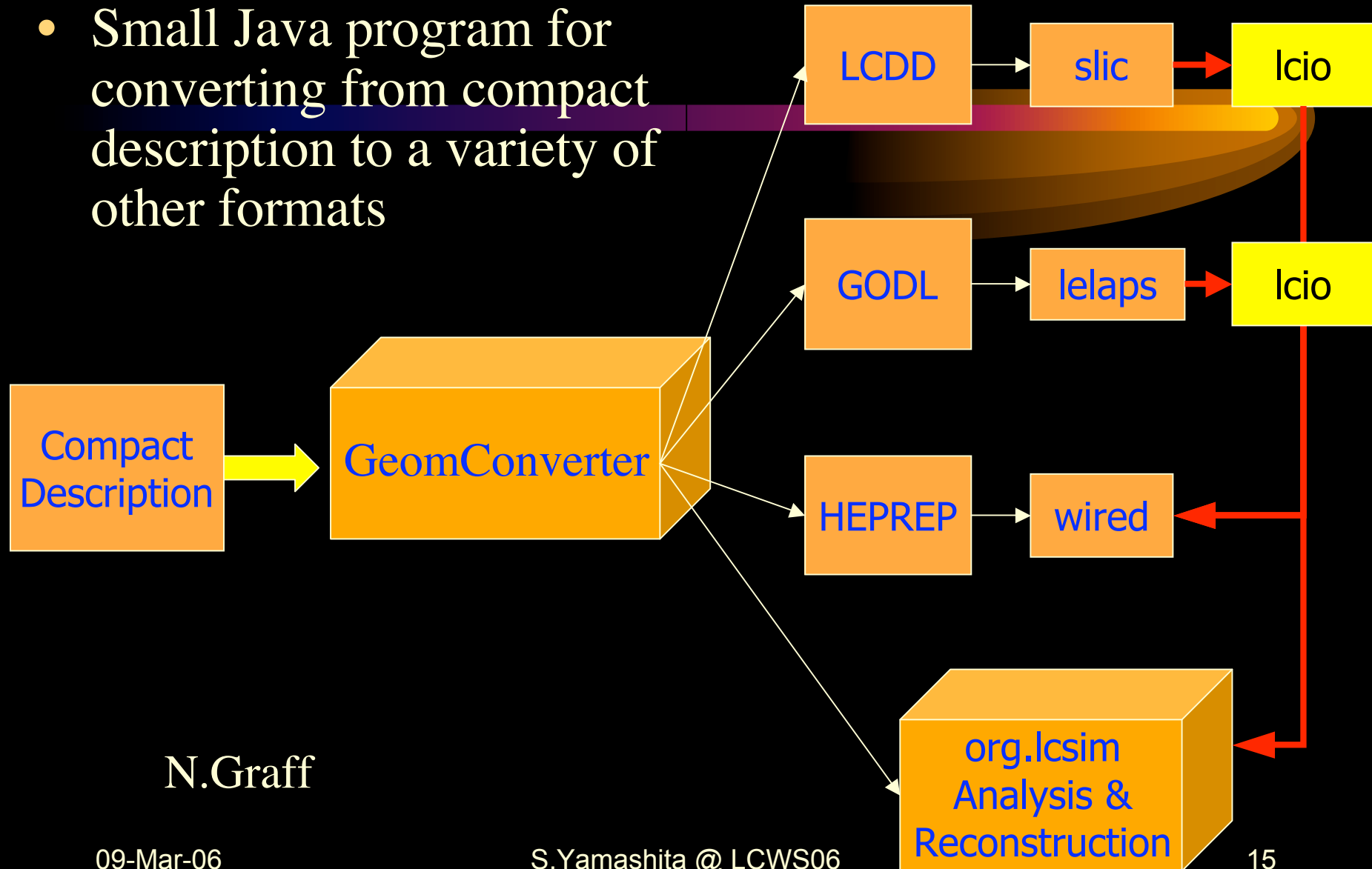


Frank Gaede, ECFA ILC Workshop, Vienna, Nov 14-17, 2005

Example: Geometry Converter

- Small Java program for converting from compact description to a variety of other formats

GeomConverter



N.Graff

09-Mar-06

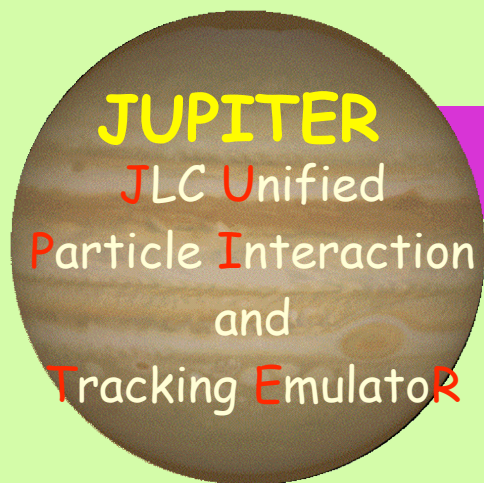
S.Yamashita @ LCWS06

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Jupiter/Satellites Concepts

Tools for simulation Tools

For real data



Geant4 based
Simulator

MC truth generator

Satellites



Input/Output
module set

METIS



Monte-Carlo Exact hits To
Intermediate Simulated output

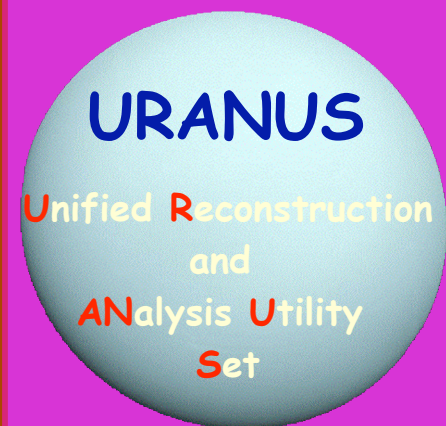
LEDA



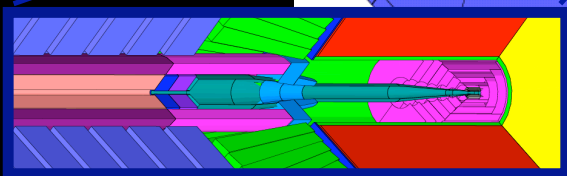
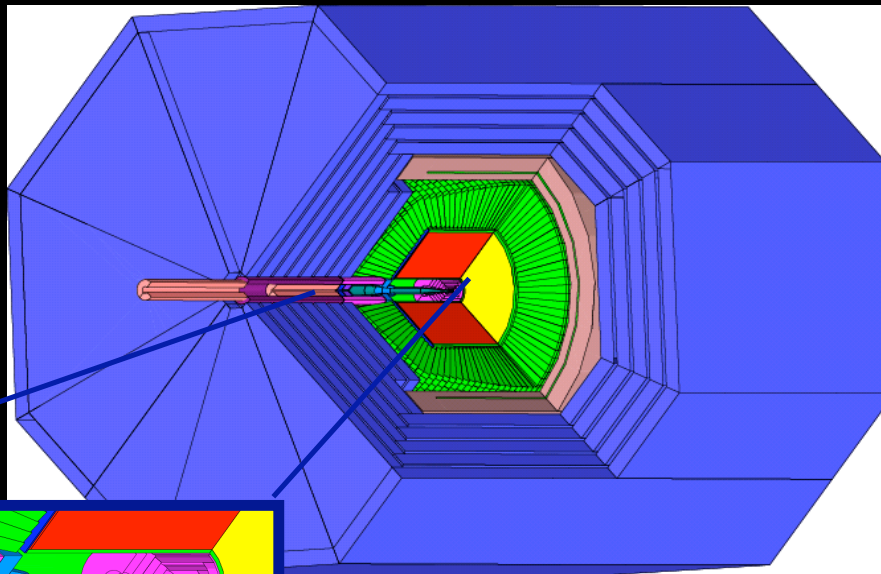
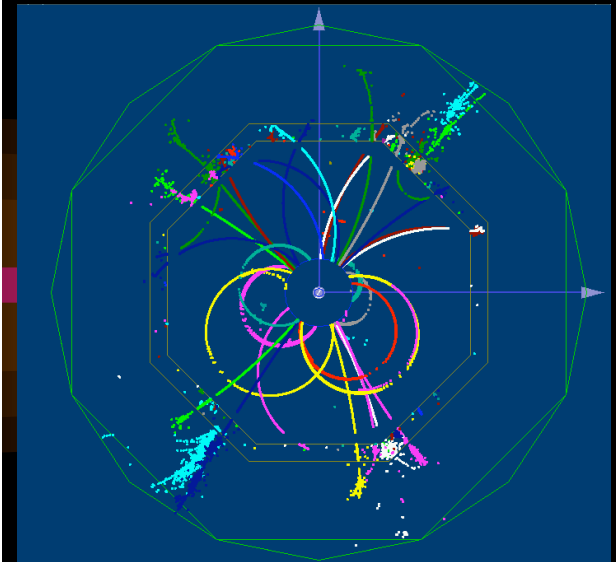
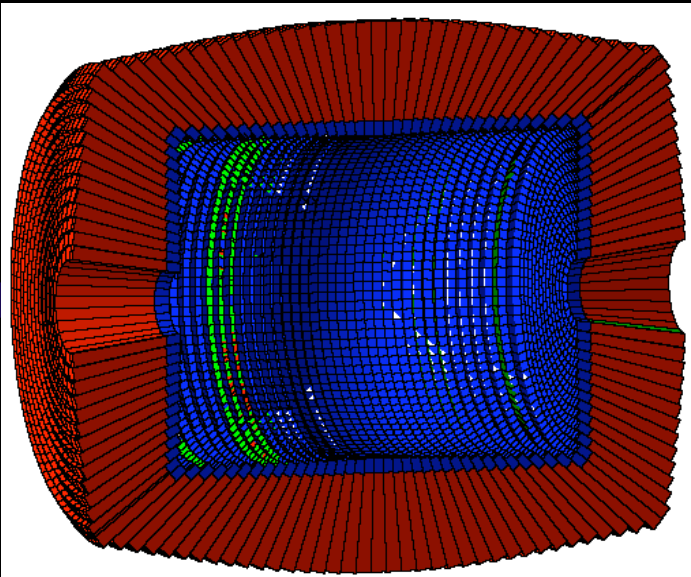
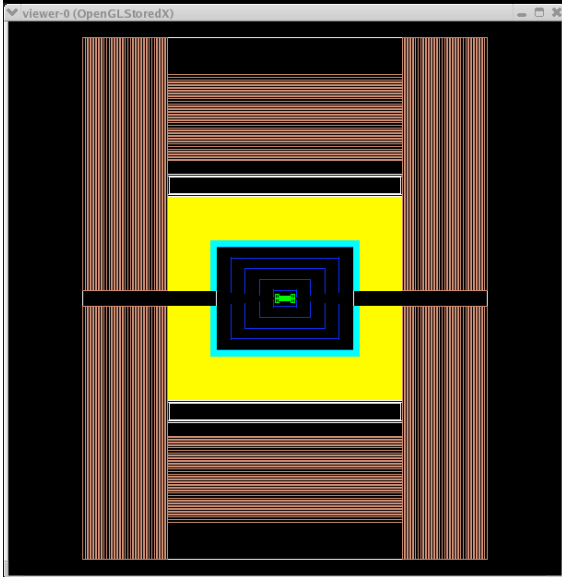
Library Extension
for
Data Analysis

JSF/ROOT based
Framework

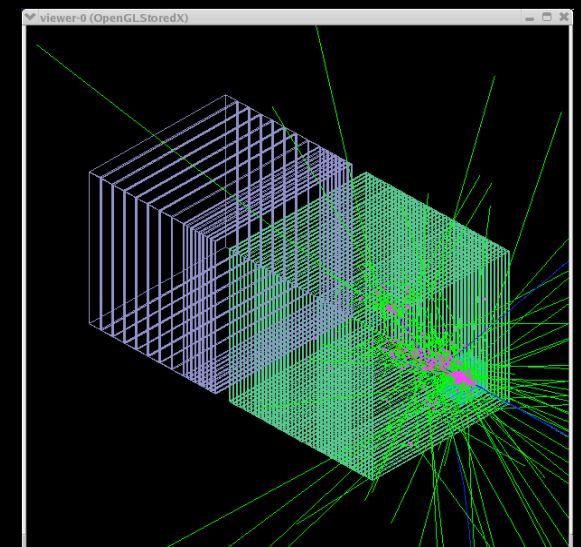
Event Reconstruction



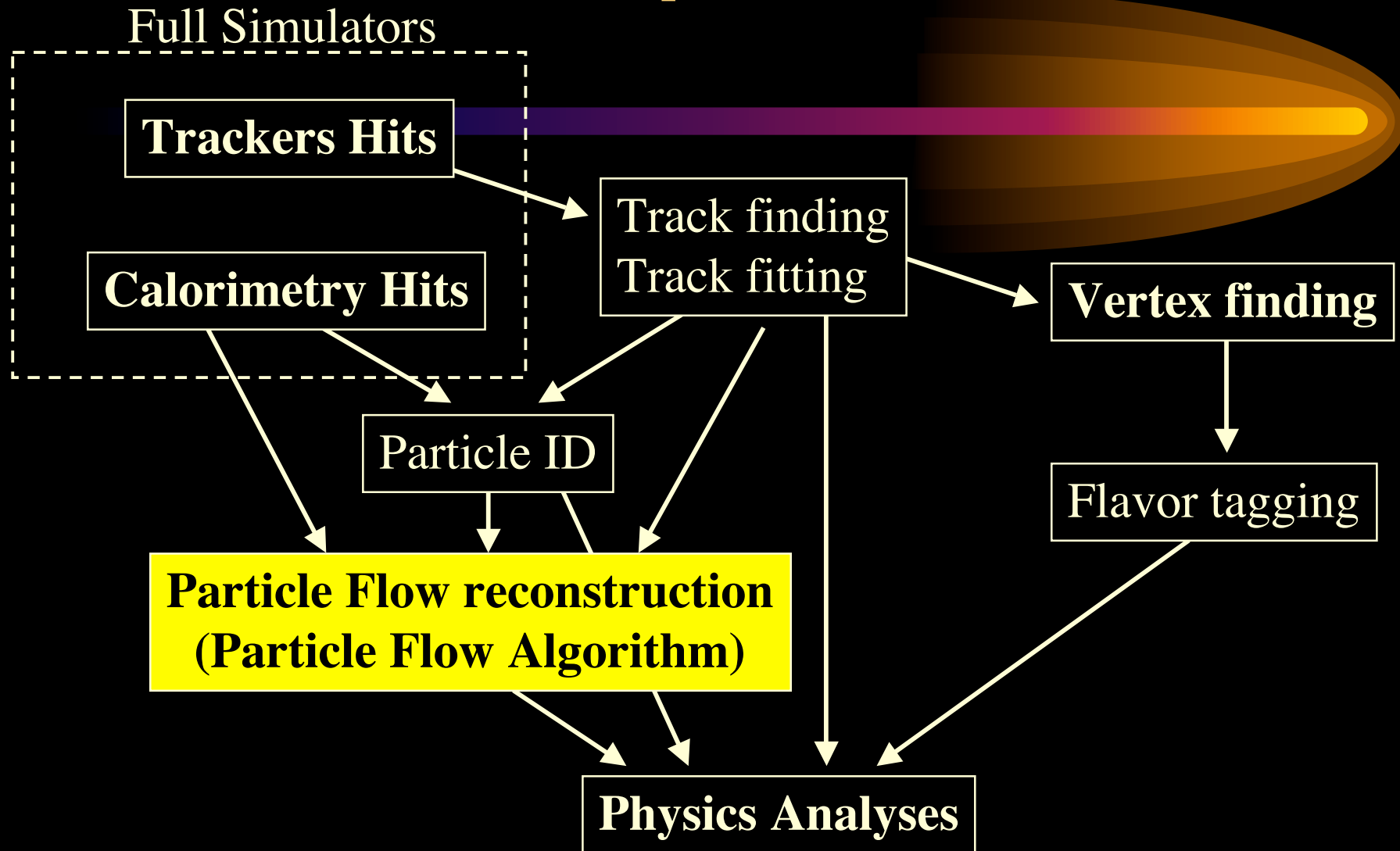
JSF: the analysis flow controller based on ROOT: I/O=LCIO
The package includes event generators, Quick Simulator,
and event display



S.Yamashita @ LCWS06



Generators / Simulators are prepared...
Next step is the reconstruction



Jet energy reconstruction

Typical event **30% electro-magnetic(γ)**, **70% hadronic**.

- Typical resolution: $\delta E/E = 10 \sim 15\% / \sqrt{E(\text{GeV})}$ for EM-CAL, $\delta E/E = 40 \sim 60\% / \sqrt{E}$ for Hadron-CAL

→ Ultimate resolution only with Calorimeters
 $\delta E/E = \sim 45\% / \sqrt{E(\text{GeV})}$ (perfect calibration case)

Particle Flow Algorithm (Energy flow): widely used at LEP.

-- powerful & simple philosophy, but not easy technically.

- 70% hadronic ~ **60% charged hadron** + 10% neutral hadron
- Tracker's resolution is much better : $\delta P/P = 5 \times 10^{-5} \times P(\text{GeV})$
- **Try to remove CAL-hits caused by charged hadron and use tracker Energy instead: (Technical challenge).**

→
09-Mar-06

Ultimate Resolution $\delta E/E = \sim 20\% / \sqrt{E(\text{GeV})}$

“Perfect (cheated) PFA” to know the ultimate performance

- Full simulation
- Sub-detector (CAL/Trackers) resolution same as reality.
- **Perfect Track - CAL association** looking into MC info (cheating).

u,d,s quark pair Events at Z pole

Breakdown of Error Source

Neutrino 0.30 GeV

5mrad cut 0.62

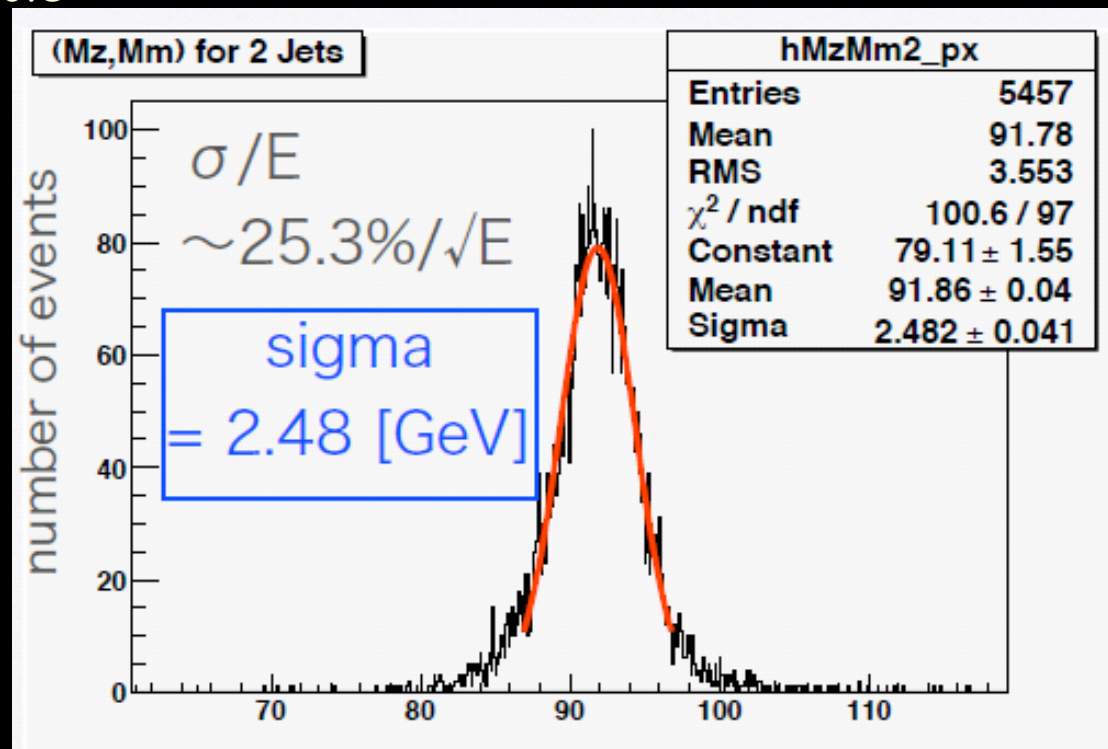
Low Pt track 0.83

Track Resol. 0.0

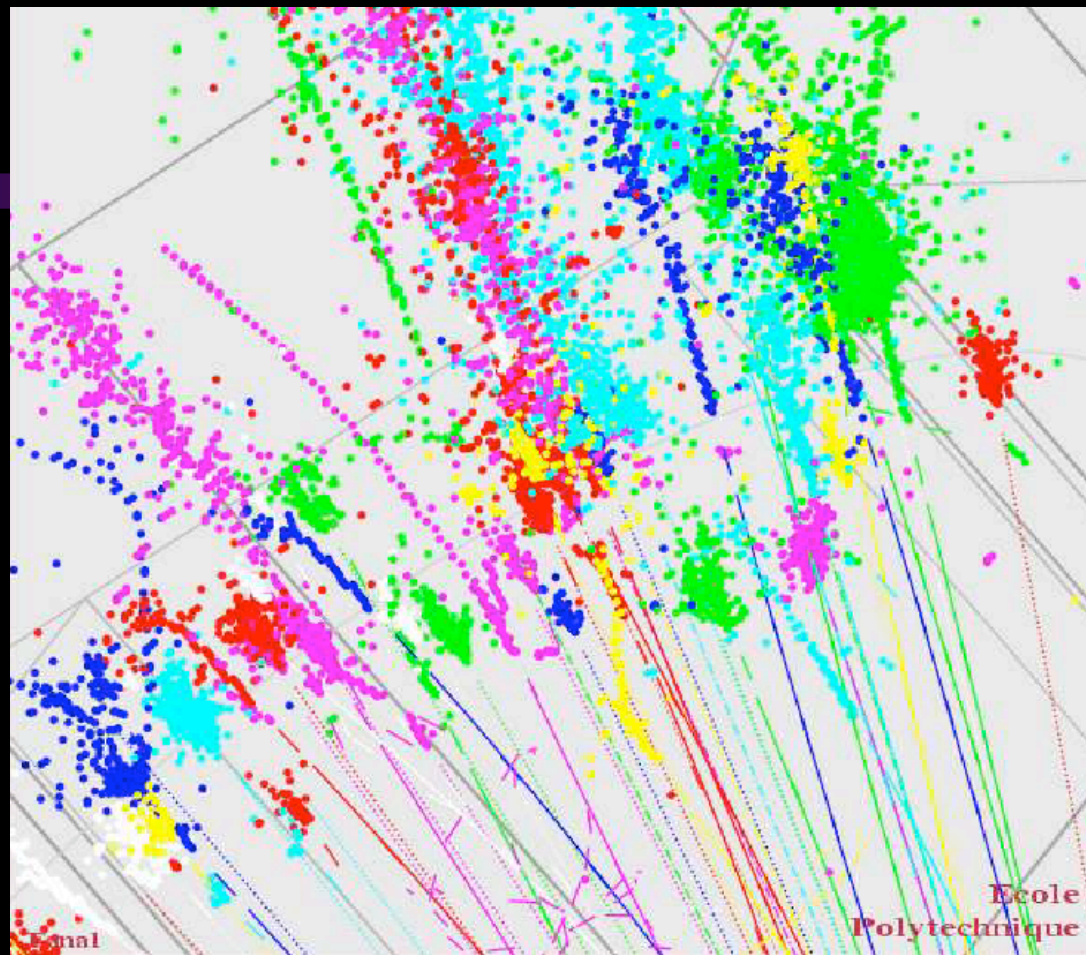
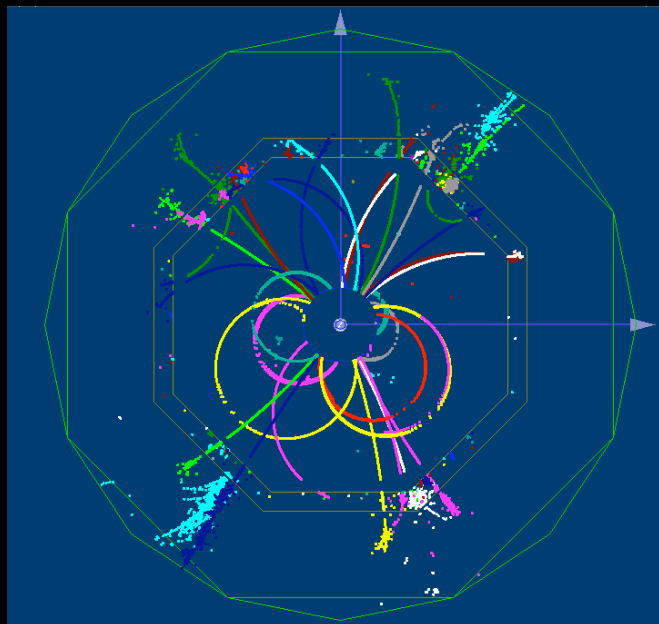
EM Cal Resol. 1.36

HD Cal Resol. 1.70

Total 2.48



Challenges of PFA in reality



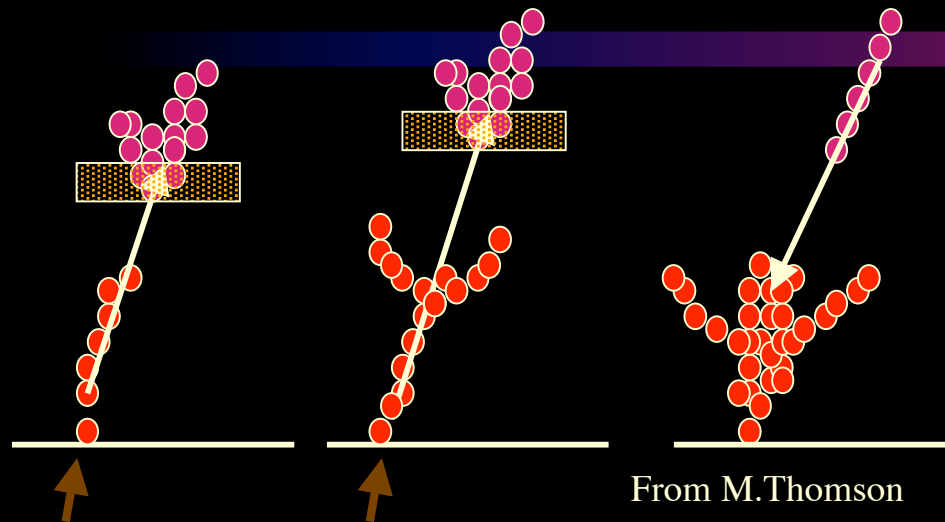
Track - CALhits association is not easy in real world...

PFA in reality

- From Detector Concepts
 - How to reduce particle density in CAL to make track-CAL association easy? How to improve overlap of hits in CAL?
 - --> High magnetic field and/or
 - --> Large volume detector and/or
 - --> High granularity (~must)
- Most important key is the pattern recognition (clustering/tracking) in EM CAL:
 - Very high hit density
 - Mixture of different particles (γ , h^{+-} , h^0) -- different calibration factors
- How to clusterize/connects hits (**clustering techniques**)
- How to discriminate γ and hadron in EM-CAL (**shower shape analyses**)
- How to remove satellite (daughter) clusters far from original tracks (**time analyses / shape analyses**)

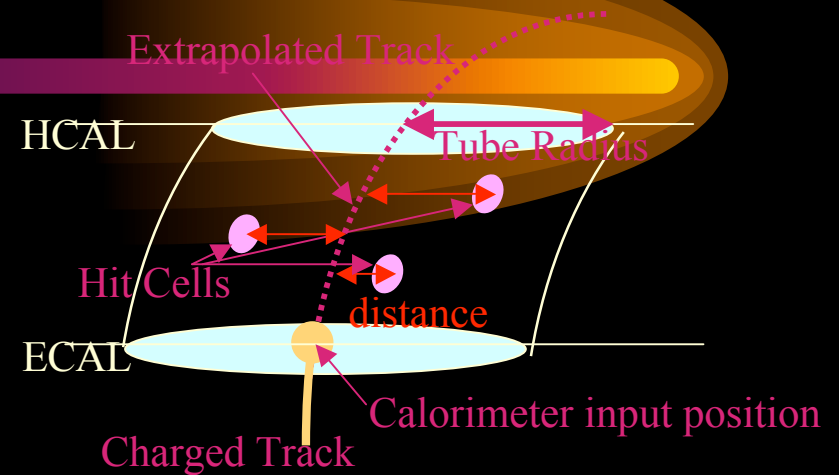
Two directions of PFA under developments

Full pattern recognition in CAL



- can be ~ultimate PFA
- Need to consider many patterns

Simple Track-hit association



- Simple, fast and robust
- Weak for very high density case

Combination of these may be the best

What is suitable depends on detector configuration,
granularity, size, e/π ratio (compensation type or not),,,

Example of shower shape analyses etc..

Cluster shape fit

gamma

hadrons

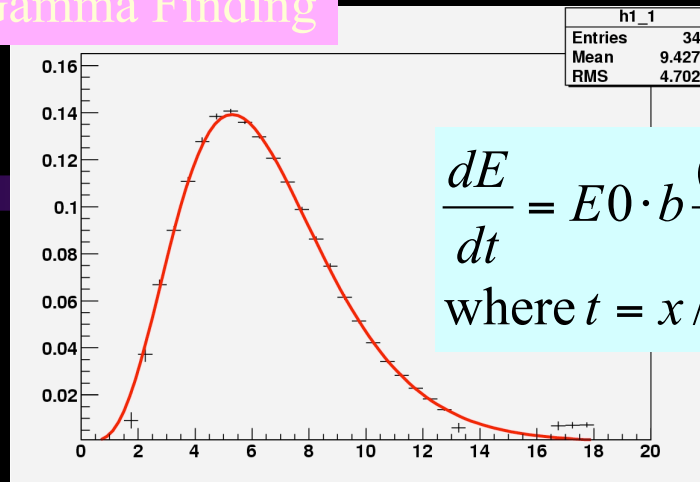
Other techniques

- MIP track finding in CAL
- Neutral cluster finding
- Satellite cluster rejection
- Reconstruction of π^0

Many developments on going
WOLF/MAGIC
PandraPFA
Jupiter-Satellite

,,, 09-Mar-06

Gamma Finding



$$\frac{dE}{dt} = E0 \cdot b \frac{(bt)^{a-1} \exp(-bt)}{\Gamma(a)}$$

where $t = x / X_0, b \approx 0.5$

Fujikawa et al

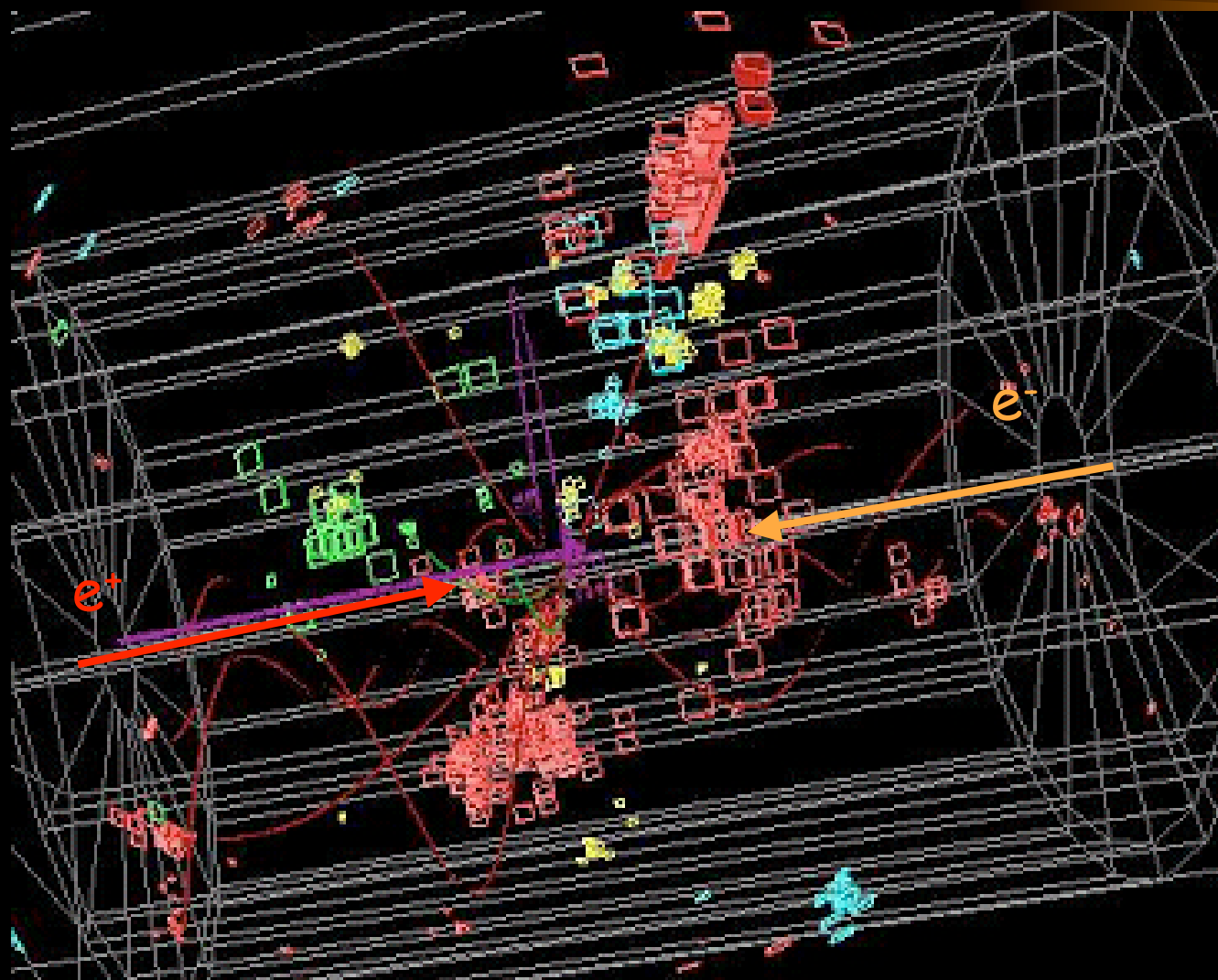
Efficiency and Purity (Energy Weighted)
@ usd jets @ Z (GLD study)

- Charged Hadron finding
Efficiency = 94.9%, Purity = 89.0%
- Gamma Finding
Efficiency = 85.2%, Purity = 92.2%

Still big room to improve !

S.Yamashita @ LCWS06

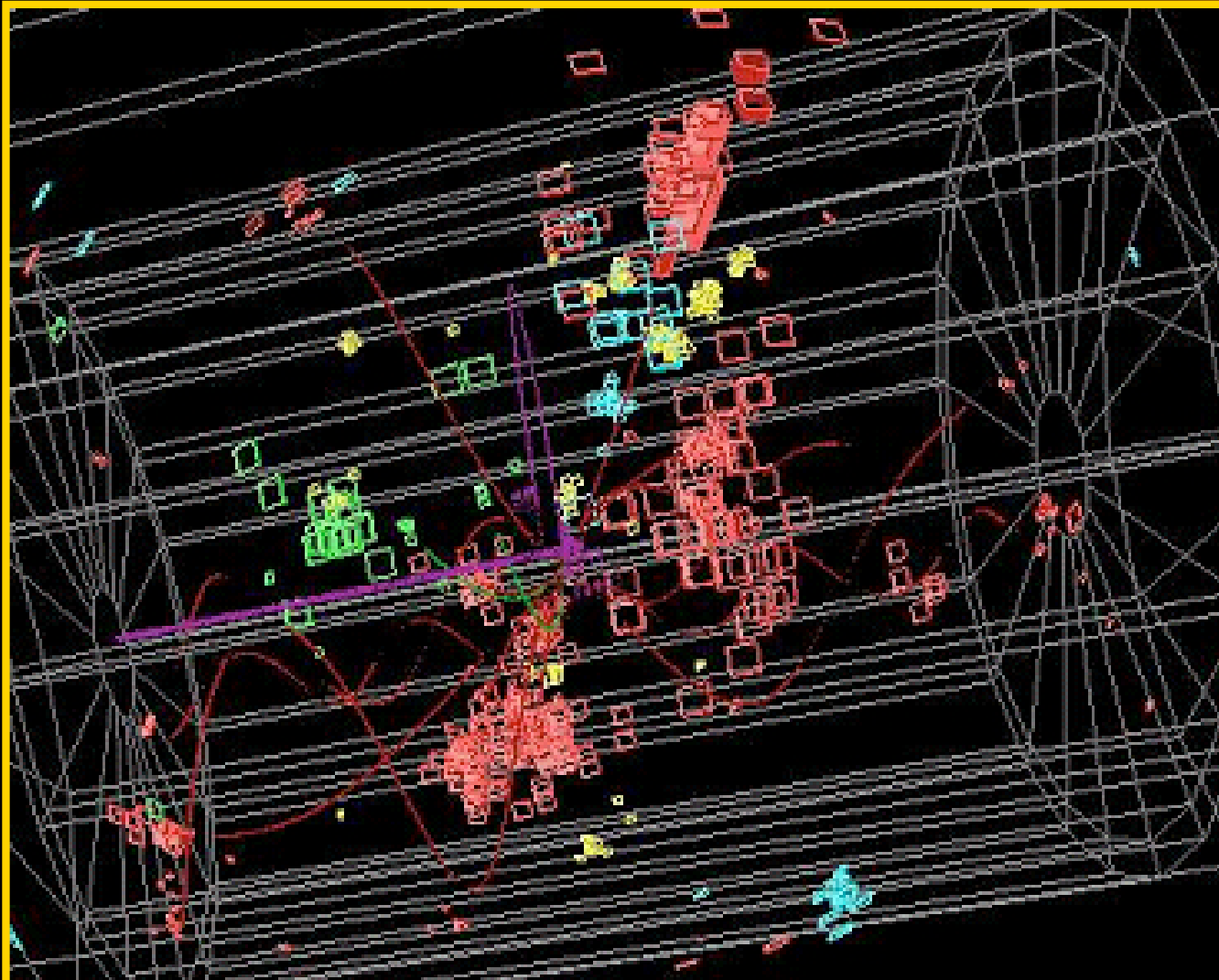
24



Red : charged hadron
Yellow : gamma
Blue : neutron

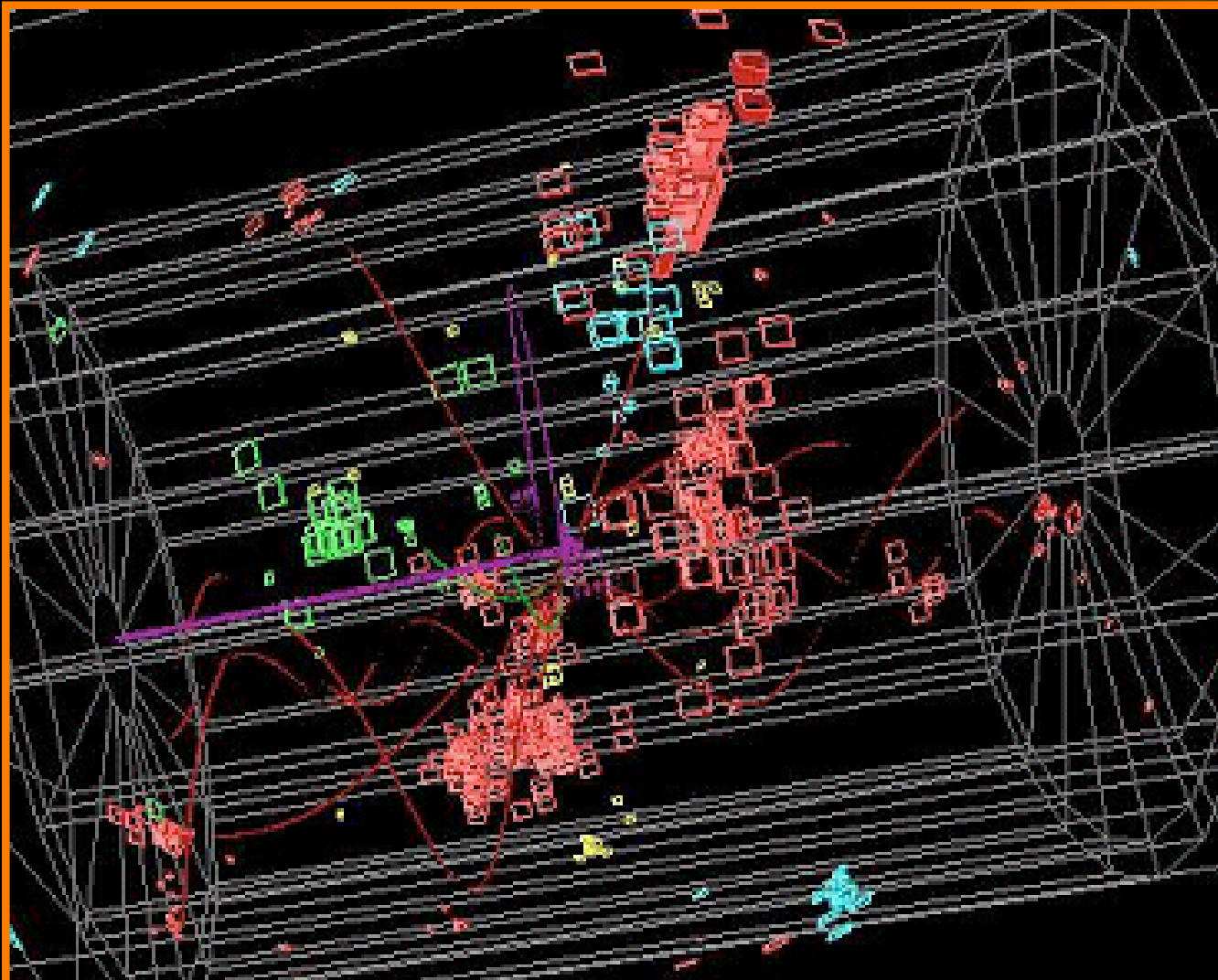
GLD study

Red : charged hadron
Yellow : gamma
Blue : neutron



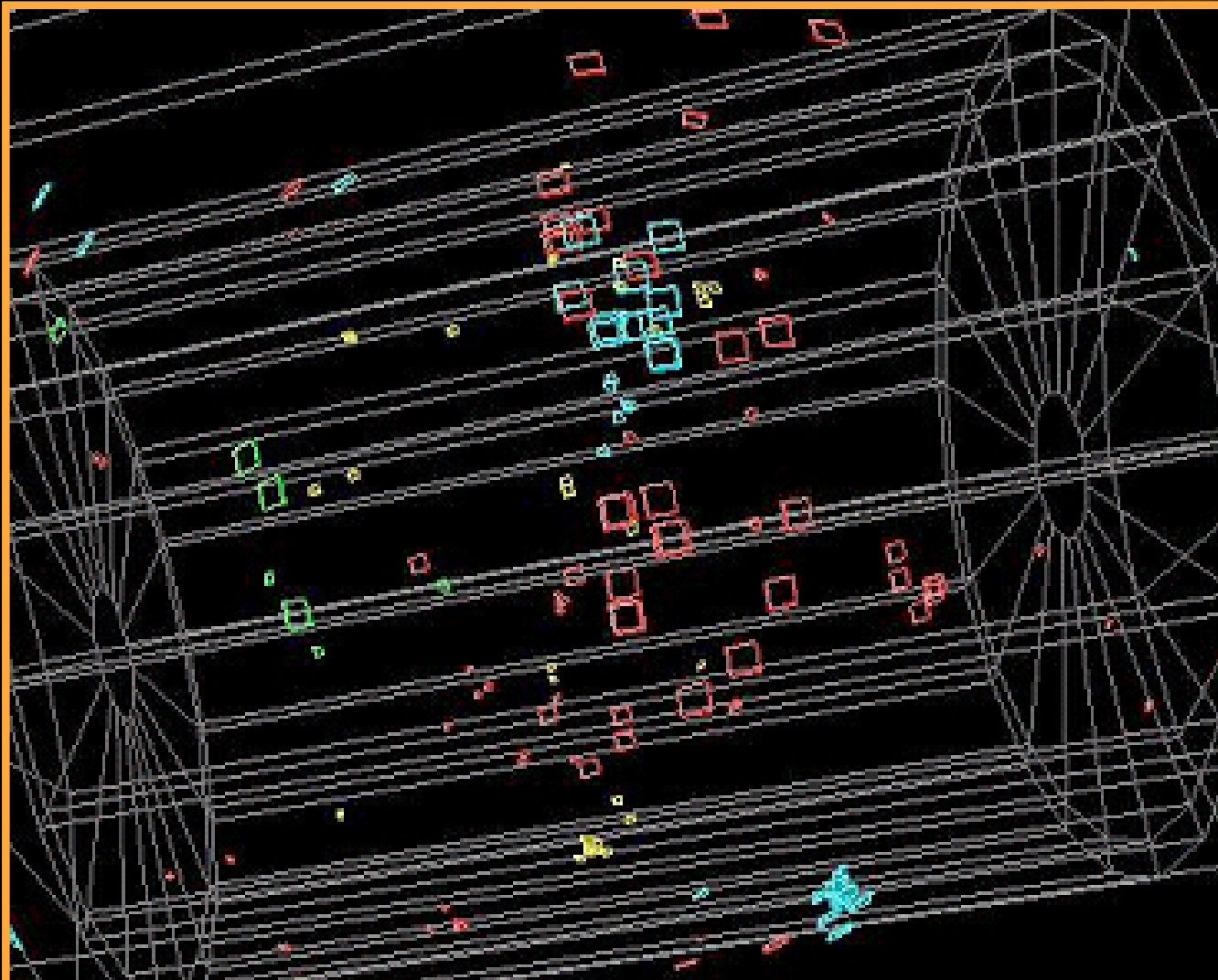
Before PFA

Red : charged hadron
Yellow : gamma
Blue : neutron



After gamma
finding

Red : charged hadron
Yellow : gamma
Blue : neutron



After charged
Hadron tagging

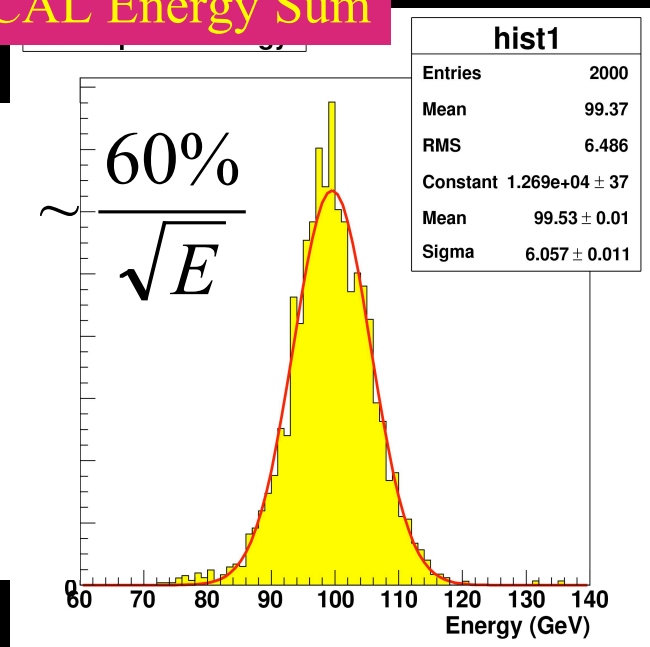
Majority of gamma's
and charged hadrons
are tagged properly

Example of PFA current result

• $Z \rightarrow qq$ @ 91.18 GeV

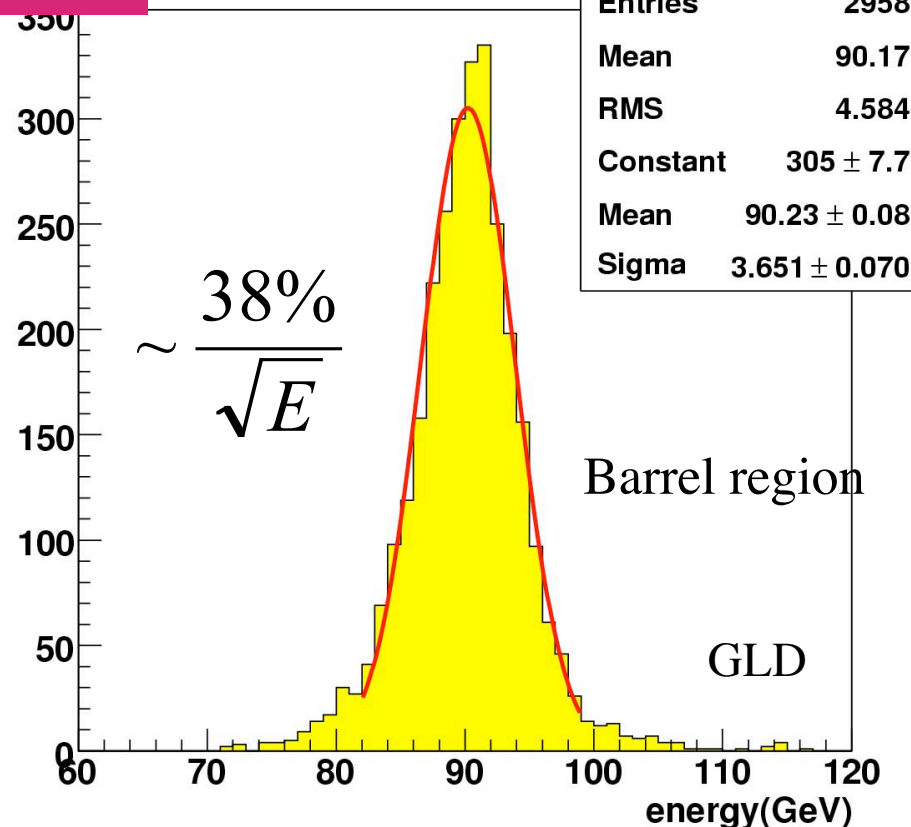
T.Yoshioka et al

CAL Energy Sum



PFA

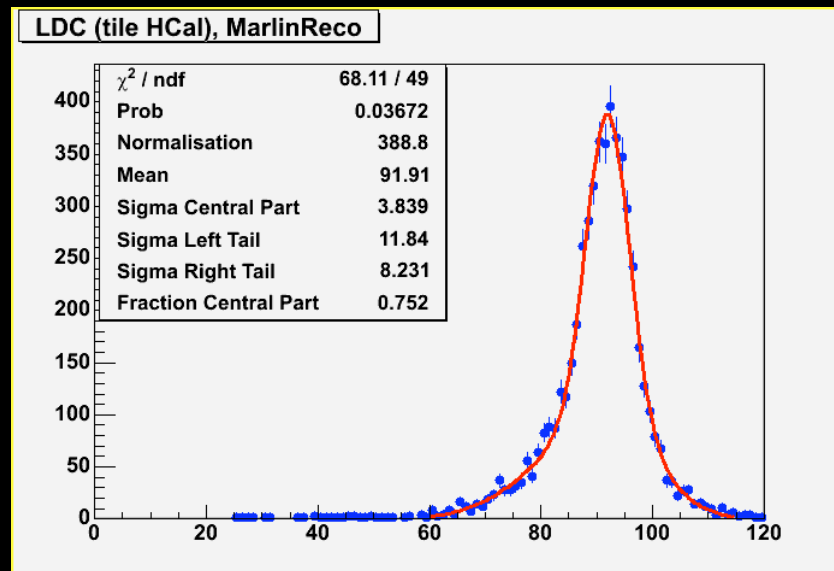
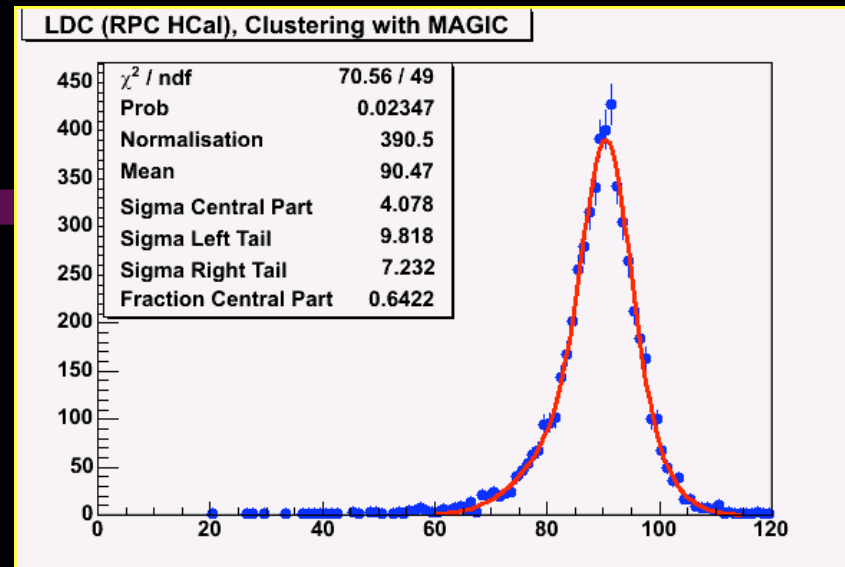
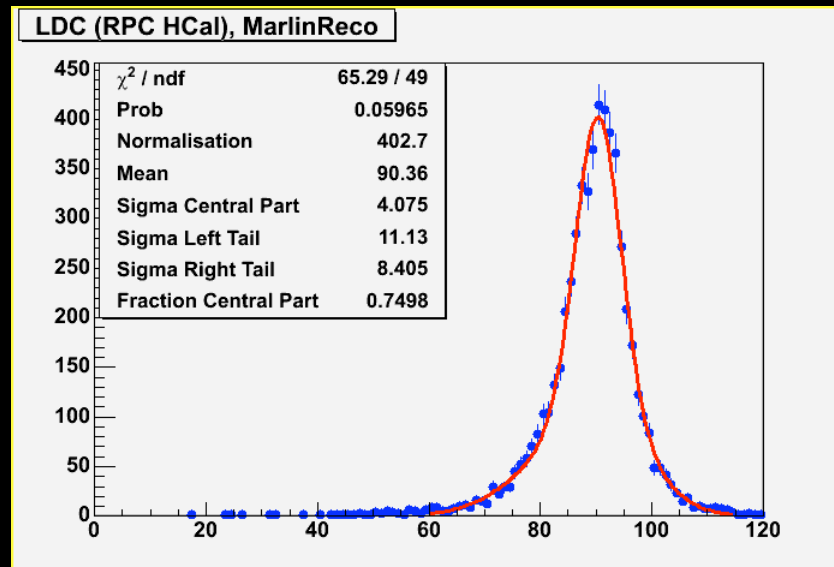
Flow Algorithm



Note: Only for jets towards barrel region,
and effect of neutrino is removed.

Taken from M.Thomson's slides at ECFA study

WOLF Results ($Z \rightarrow uds$ jets)



★ RMS(90%)

★ Find smallest region containing
90 % of events

★ Determine rms in this region

	RMS (90%)
RPC HCal	4.3 GeV
Tile HCal	4.1 GeV
RPC (MAGIC)	4.4 GeV

Summary

- **Various software tools** (Generators, Simulators, reconstruction tools) have been prepared and extensively improved/developed. We are ready for full detector performance study such as PFA.
- **LCIO format** is commonly used for all concepts study, and inter-concepts developments for reconstruction tools have been started.
- Various method of **Particle Flow Algorithm for ILC** is under development. Philosophy is simple and widely used at LEP, but it's not technically straight-forward.
- (Ultimate goal is $\delta E/E \sim 25\%/\sqrt{E}(\text{GeV})$ and target is $30\%/\sqrt{E}(\text{GeV})$)
- Big activity is on-going world-wide for PFA, and nice and similar results have been obtained in different detector configuration with different algorithms.
- While there are still **many rooms for improvements**, current **PFA studies already achieved $\delta E/E < 40\%/\sqrt{E}(\text{GeV})$**
- **For each detector performance, let's watch the concept talks (tomorrow)**