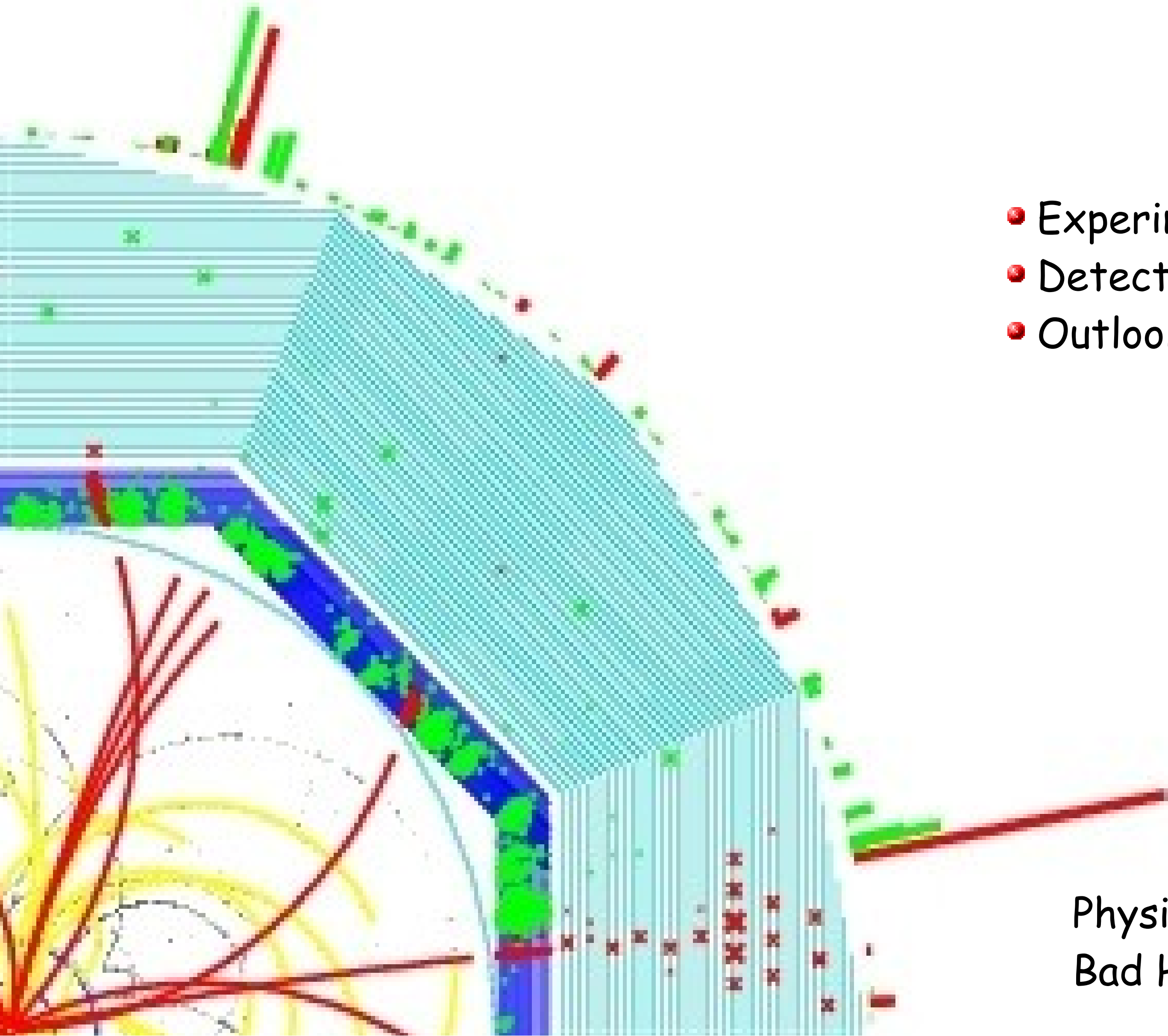
Detector Concepts at the ILC

Ties Behnke, DESY



- Experimentation at the ILC
- Detector Concepts
- Outlook

Physics at the Terascale Seminar,
Bad Honneff, 27.4.2008-30.4.2008

Physics Agenda

Explore the physics at the scale of electroweak symmetry breaking

- Higgs Physics
- Standard Model Physics at "Terascale"

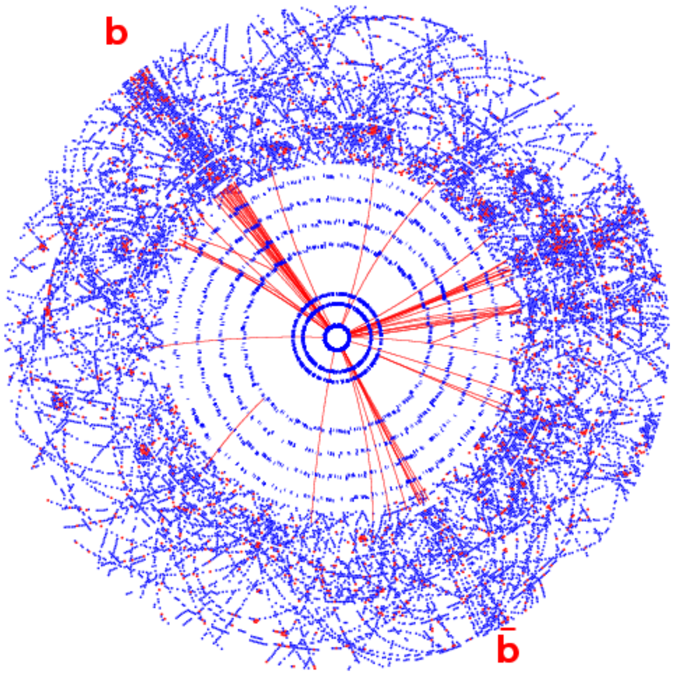
Physics beyond the Standard Model

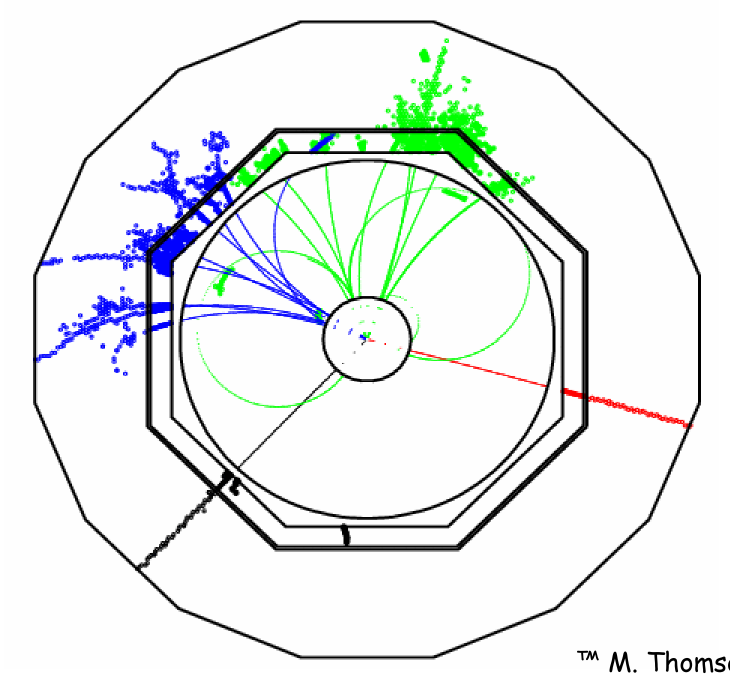
- Search for new physics
- Explore the Terascale

Follow up on any discoveries the LHC might have made

Events at the ILC

- Point like particle collide, few particle per event, clean topologies, ...





™ M. Thomson, Cambridge

Much simpler events than LHC, can focus much more on detailed event properties

Physics at the ILC

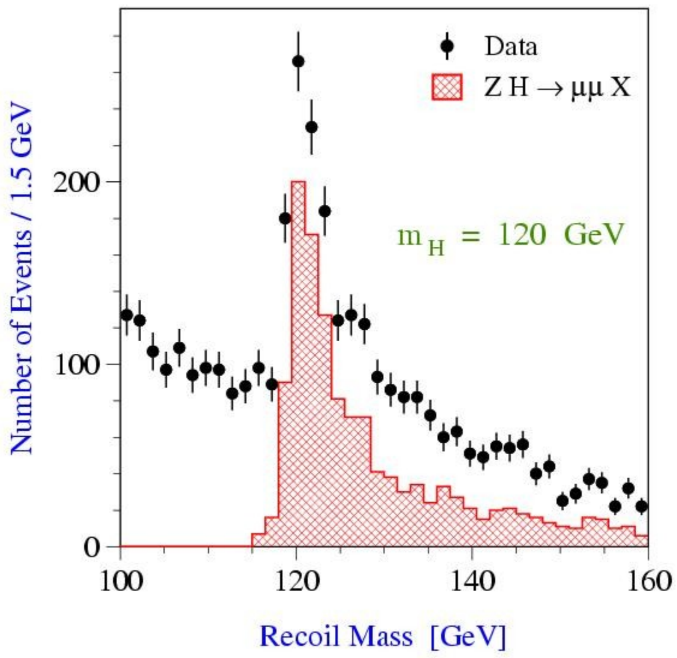
- Stress Precision measurements

  Reconstruct complete event properties
  Do a "full" job: hermeticity

- Be prepared for the unexpected

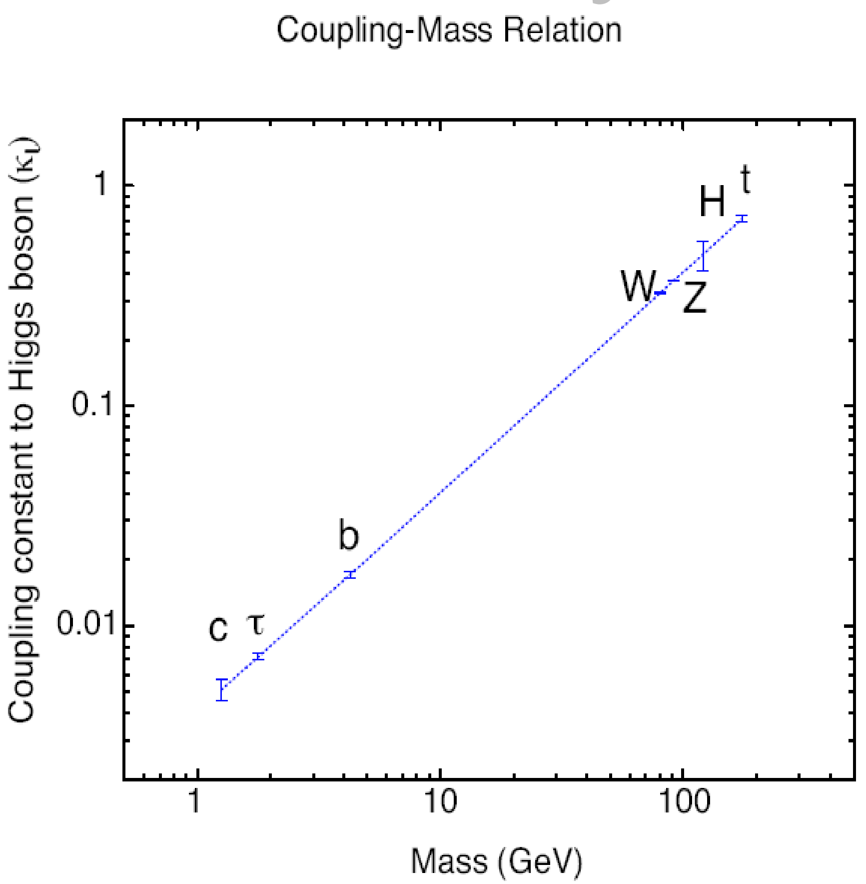
  Dead time free readout
  large acceptance
  "no optimization": very broad program

Higgs recoil spectrum



Goal: "background free" signals

Physics Challenges



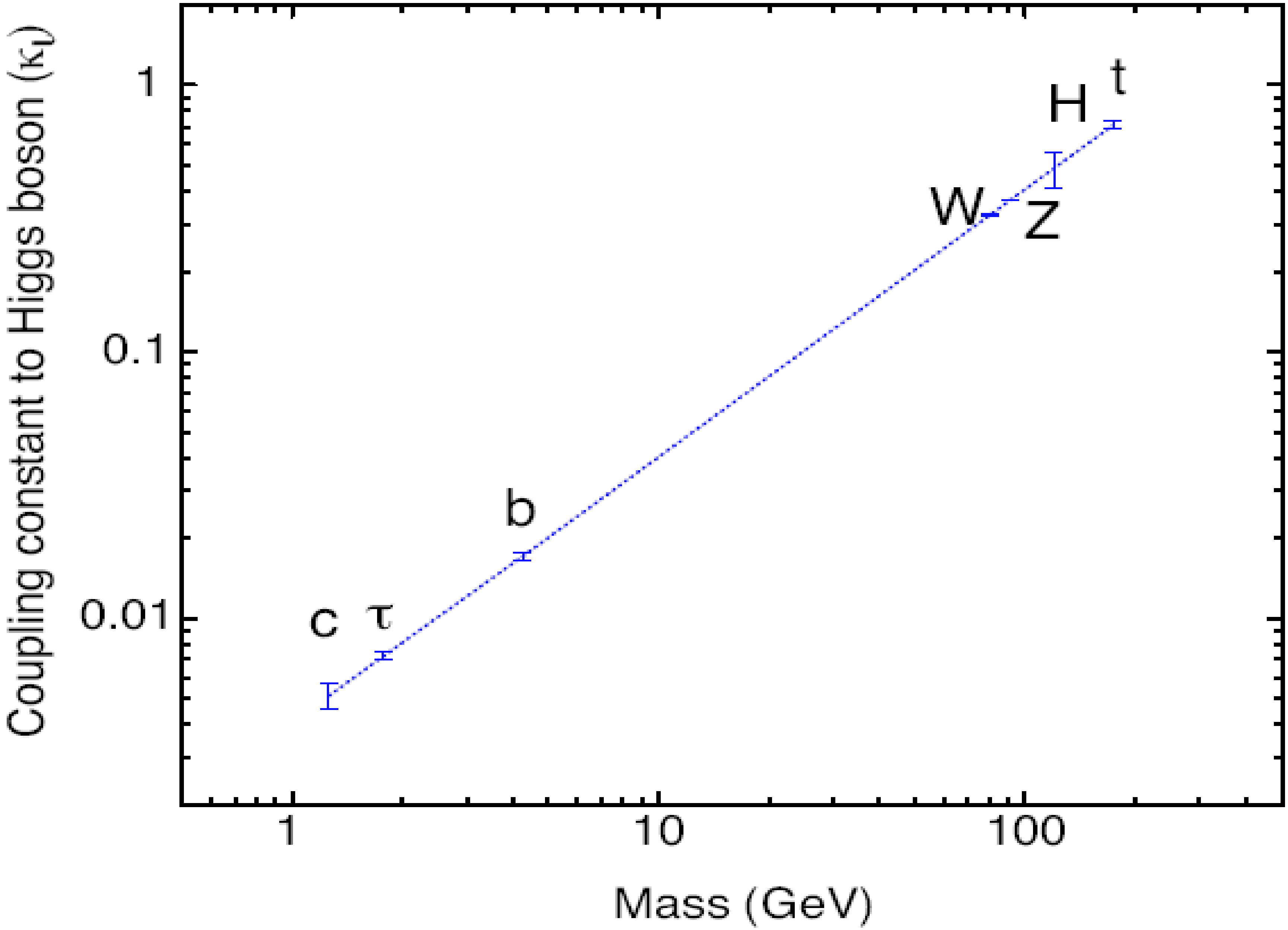
ACFA LC Study

Explore the complete Higgs Sector, including Higgs self coupling

- Multi Jets in the final state
- need excellent jet-energy resolution to get decent measurement

"Fully" explore the physics at the Terascale, establish the models and mechanisms

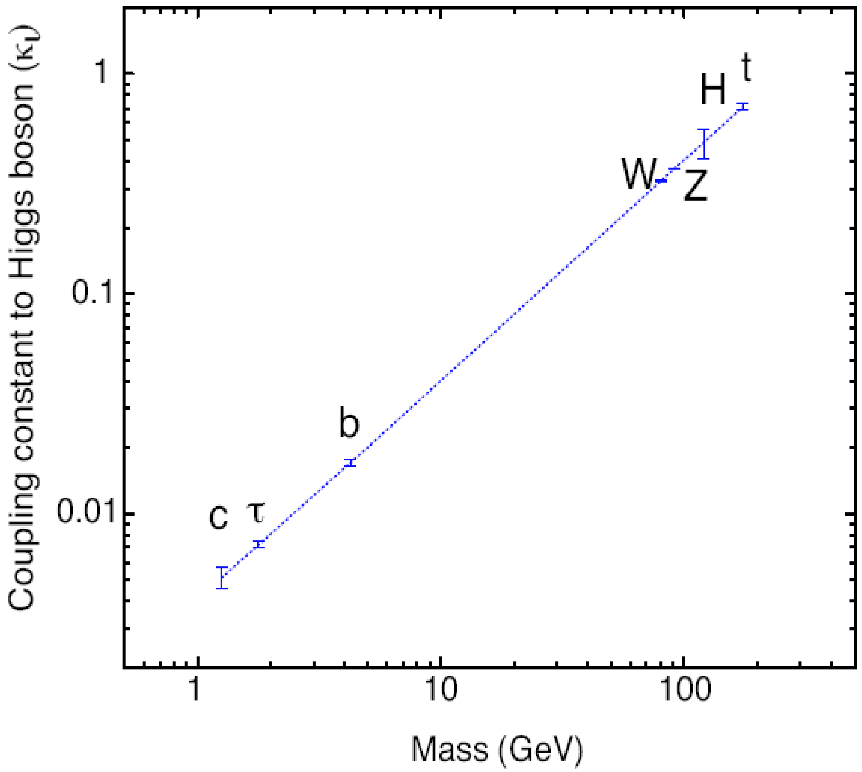
Coupling-Mass Relation



ACFA LC Study

Physics Challenges

Coupling-Mass Relation



ACFA LC Study

The "ultimate" in precision requirements:

Measurement of the Higgs Self Coupling

- Multi Jets in the final state
- need excellent jet-energy resolution to get decent measurement

"Fully" explore the physics at the Terascale, establish the models and mechanisms

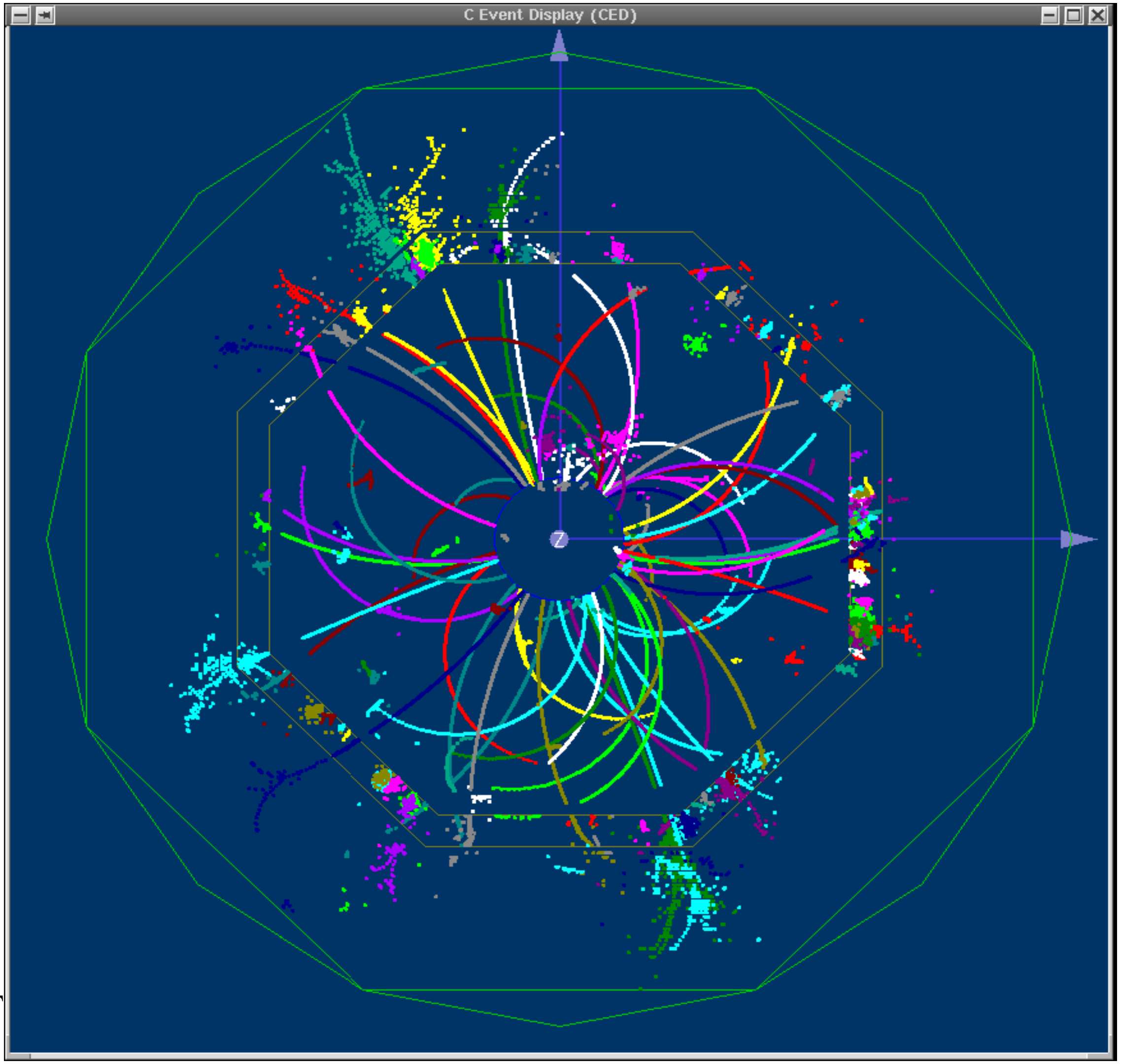
The States

Events at the ILC:

- multi jet final states
- leptons, often in jets
- forward going physics

Jet energy reconstruction plays a central role at the ILC

tt event at the ILC (LDC model)



C: V. Morgunov, A. Raspereza

The Backgrounds

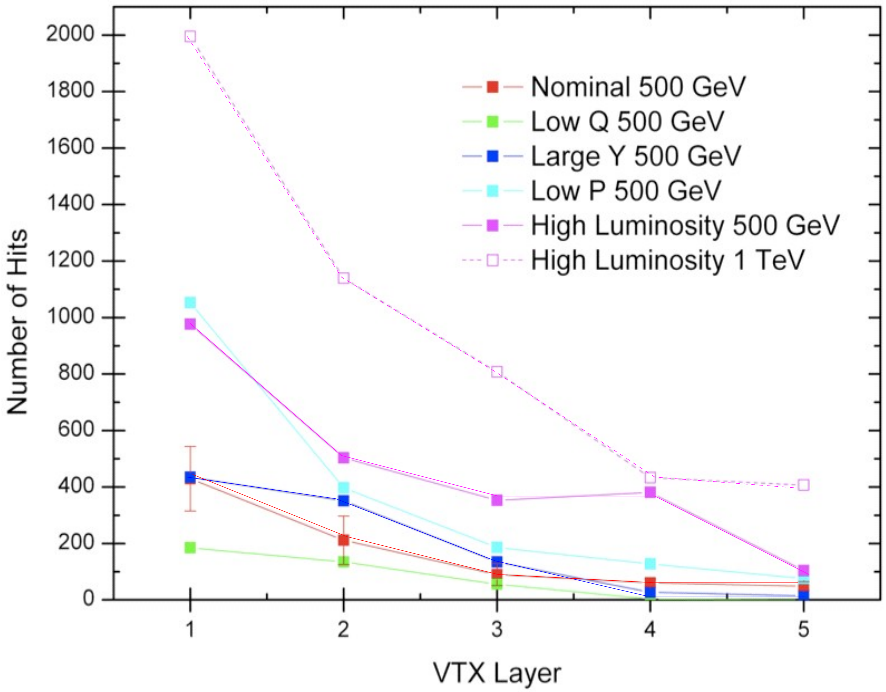
Physics and the beam itself are the main background

Most challenges from beamstrahlung

- Vertex detector occupancy
- Very forward direction

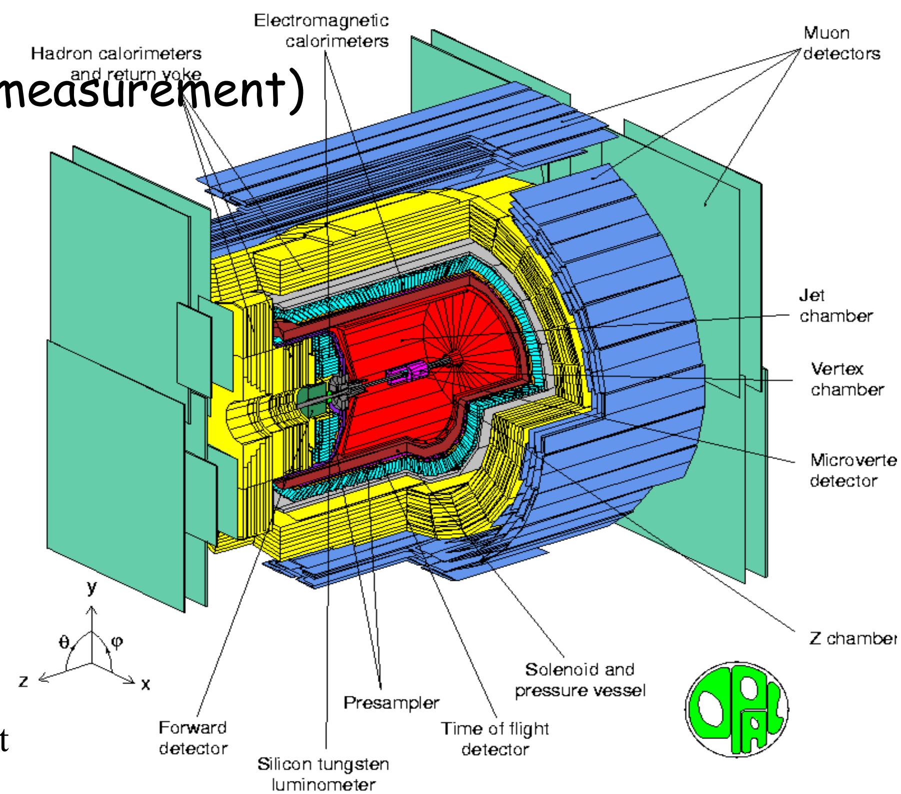
Significant work done, seem to be manageable

Number of background induced hits in VTX vs. radius



The Past: Lessons learned

- Last generation of e+e- detectors: LEP detectors/ SLD
- Lots of know-how/ experience in building LHC detectors
- Be prepared for the unexpected (lifetime measurements, ultimate precision)
- Material hurts and is very important
  (example: vertexing at LEP, luminosity measurement)
- Three dimensional event reconstruction
  is very important for precision
- For ultimate precision:
  - need good hadronic calorimetry
- Reality will be different from simulation..



Detector Requirements

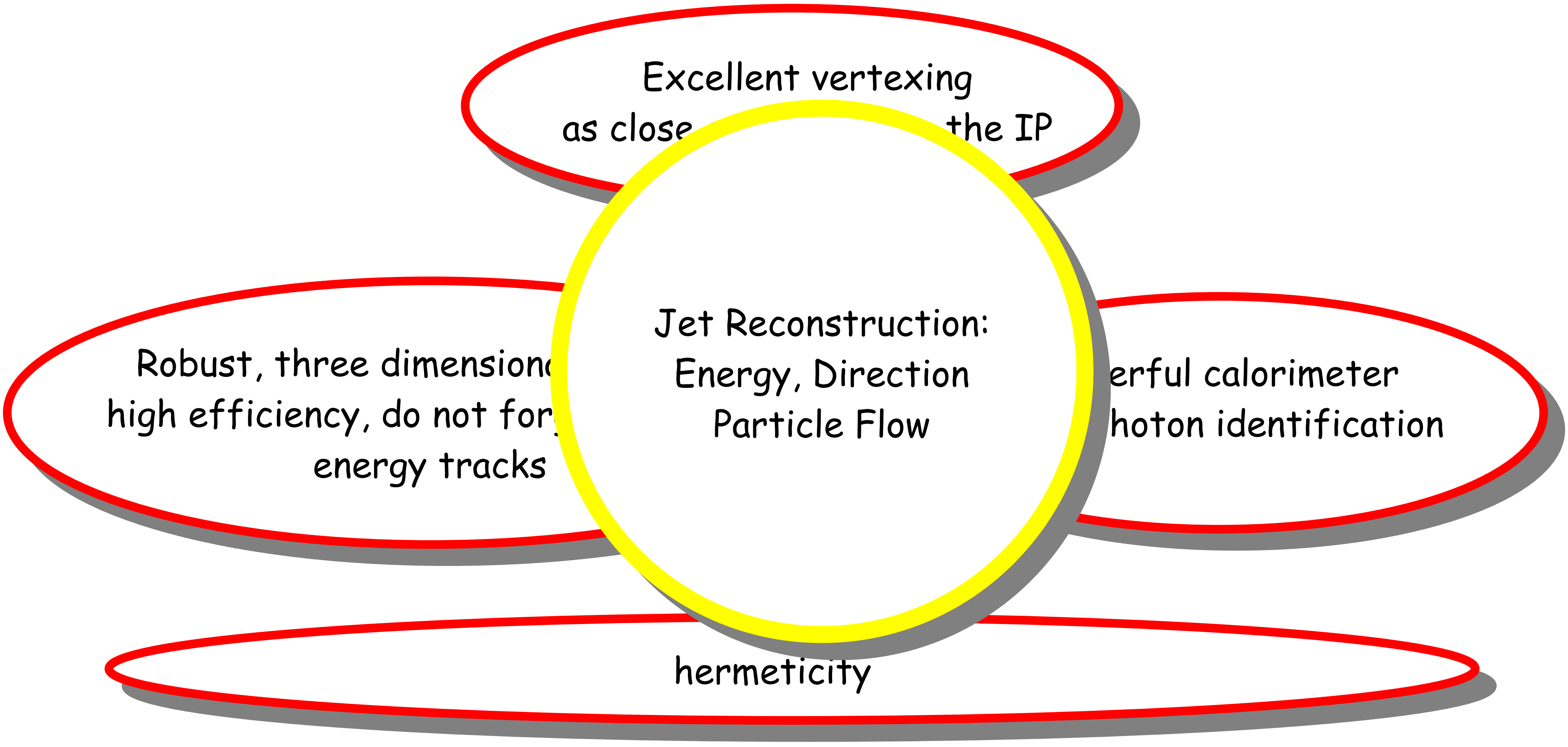
Excellent vertexing
as close as possible to the IP

Robust, three dimensional tracking
high efficiency, do not forget the low energy tracks

Powerful calorimeter
good photon identification

hermeticity

Detector Requirements



Event Reconstruction

Excellent jet reconstruction needed

Individual particles
particle identification
"calculation" of total jet energy/ mass

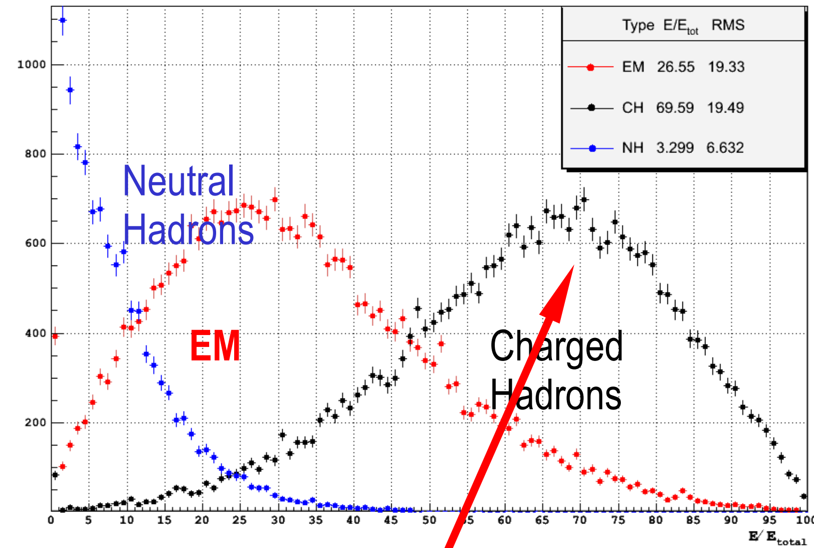
Particle flow

Individual jets
hardware compensation
"measurement" of total jet energy

"compensating" Calorimetry

Particle Flow

- Most precise event reconstruction (measured e.g. in the jet mass)
- Individual particles are reconstructed: charged and neutrals



Fundamental problem: fluctuations in the calorimeter:

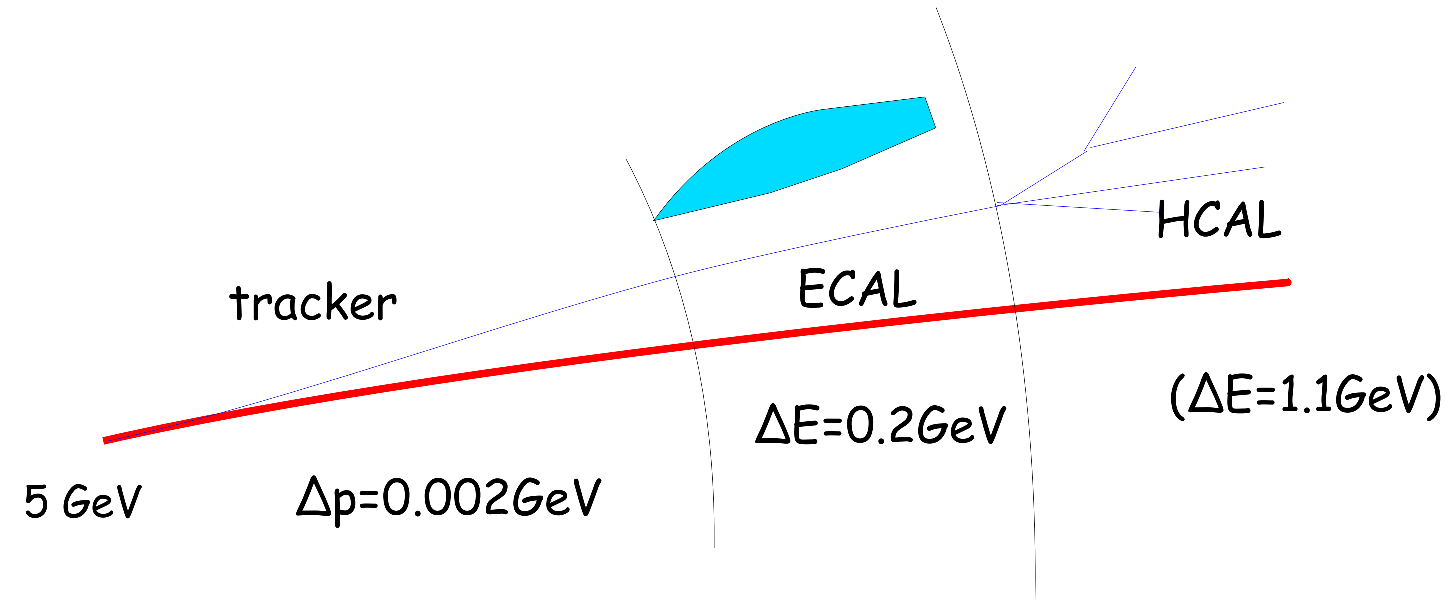
<70%>

use tracker as much as possible
replace information in calorimeter by tracker information
only use calorimeter for neutral particles (photons, neutral hadrons)

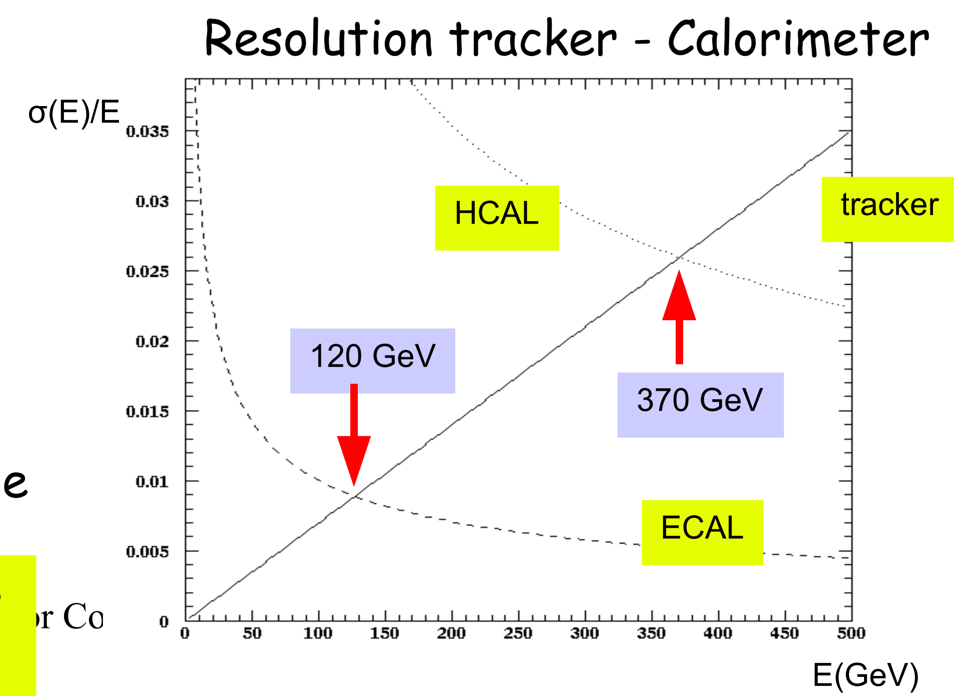
Pushes requirements for calorimeter:
excellent segmentation
energy resolution is of lesser importance

30%/√E (below 100 GeV) is the goal

What is Particle Flow



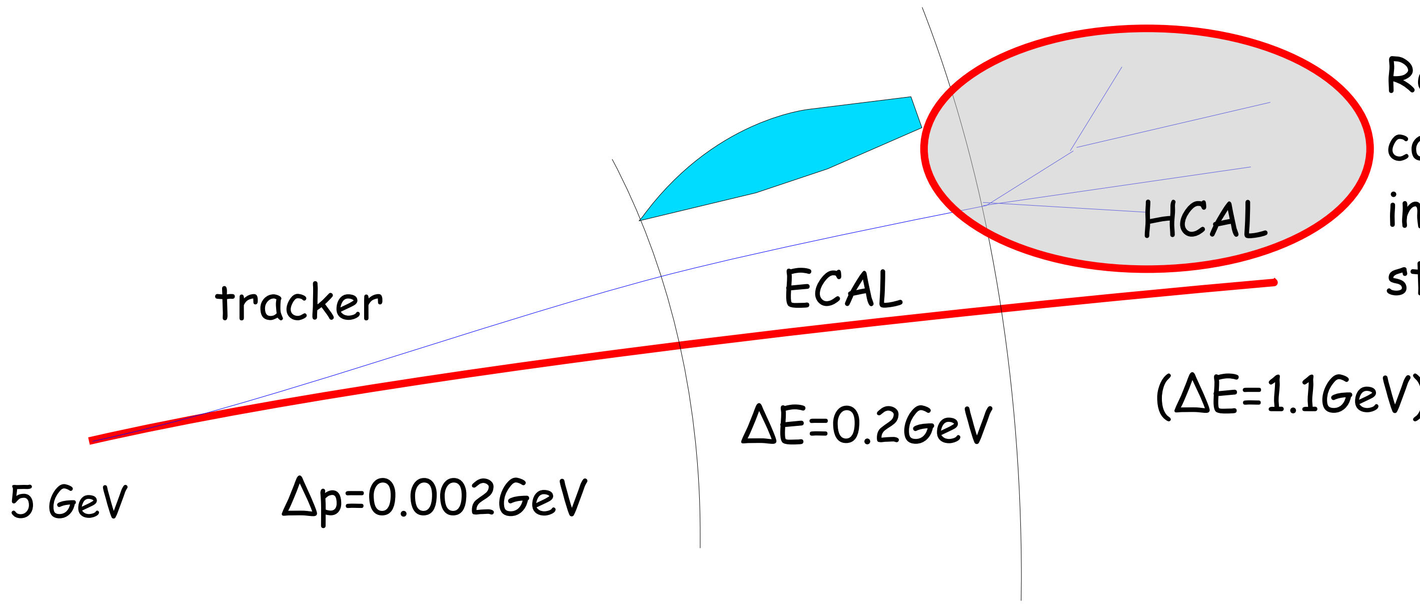
5 GeV electron:	0.002 GeV
photon:	0.2 GeV
neutron:	1.1 GeV



For LC energies: tracker is most precise

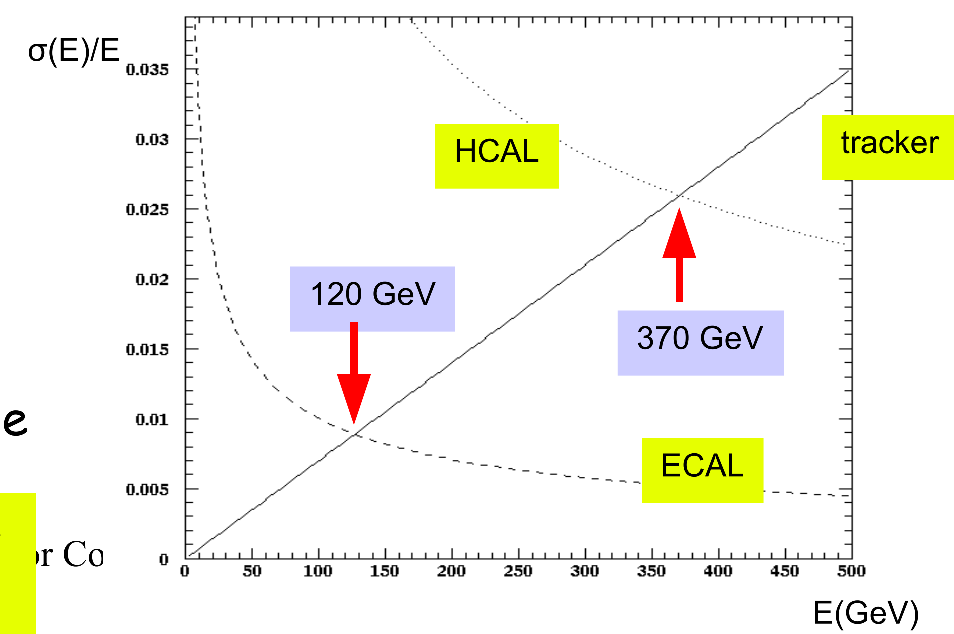
Utilize the precise tracker as much as possible

What is Particle Flow



Remove the calorimeter-based information, stress topology

Resolution tracker - Calorimeter



5 GeV electron:		0.002 GeV
	photon:	0.2 GeV
	neutron:	1.1 GeV

For LC energies: tracker is most precise

Utilize the precise tracker as much as possible

Perfect PFA : What theory predicts

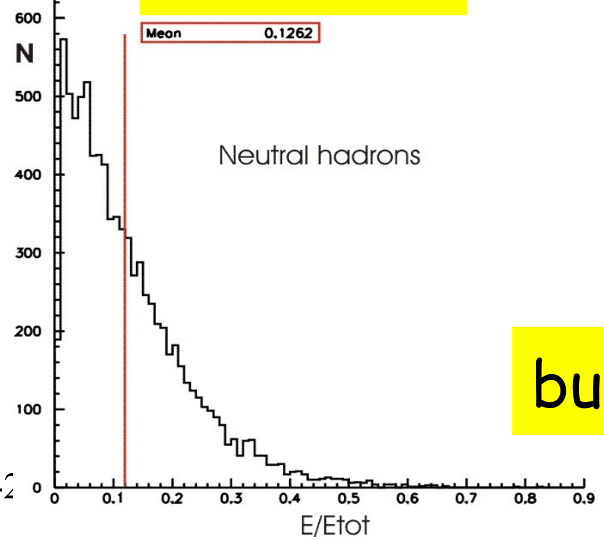
- Jet energy resolution
  $\sigma^2(E_{jet}) = \sigma^2(ch.) + \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(conf.)$
- Excellent tracker :
  $\sigma^2(ch.) \ll \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(conf.)$
- Perfect PFA : $\sigma^2(conf.) = 0$
  $\sigma^2(E_{jet}) = A_\gamma E_\gamma + A_h E_{h0} = w_\gamma A_\gamma E_{jet} + w_{h0} A_h E_{jet}$
  $\sigma(E_{\gamma,h})/E_{\gamma,h} = A_{\gamma,h}/\sqrt{E_{\gamma,h}}$

Typically $w_g = 25\%$; $w_{h0} = 13\%$

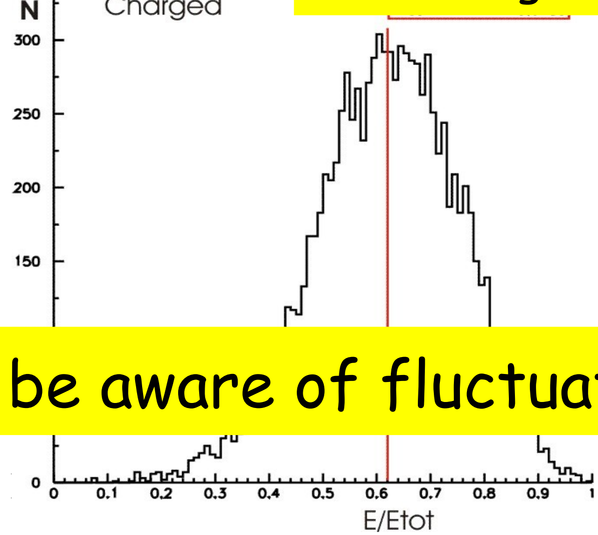
$A_g = 11\%$; $A_{h0} = 34\%$
$\Rightarrow s(E_{jet})/E_{jet} = 14\%/\sqrt{E_{jet}}$

$A_g = 11\%$; $A_{h0} = 50\%$
$\Rightarrow s(E_{jet})/E_{jet} = 17\%/\sqrt{E_{jet}}$

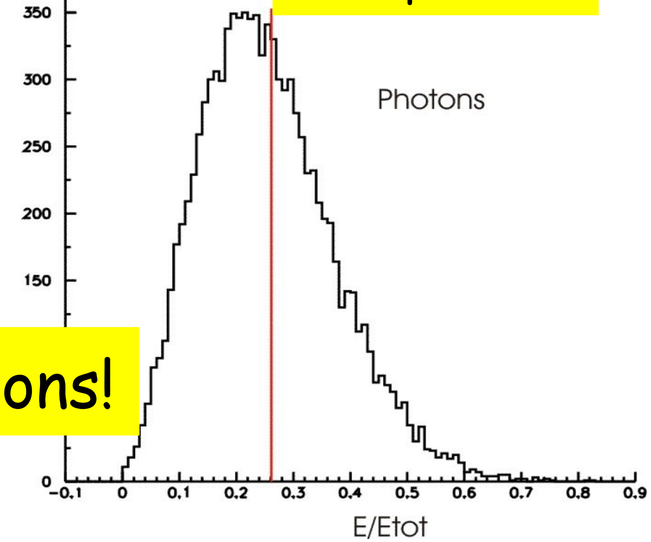
13% neutrals



61% charged



26% photons



but be aware of fluctuations!

Factors Contributing to Jet mass resolution

$$e^+ e^- \rightarrow Z^0 \rightarrow q\bar{q} \text{ at } 91.2\text{GeV}$$

Studies by P. Krstonosic

Effect	σ [GeV] separate	σ [GeV] not joined	σ [GeV] total ($\%/\sqrt{E}$)	σ to total
$E_\nu > 0$	0.84	0.84	0.84 (8.80%)	12.28
$Cone < 5^o$	0.73	1.11	1.11(11.65%)	9.28
$P_t < 0.36$	1.36	1.76	1.76(18.40%)	32.20
σ_{HCAL}	1.40	1.40	2.25(23.53%)	34.12
σ_{ECAL}	0.57	1.51	2.32(24.27%)	5.66
M_{neutral}	0.53	1.60	2.38(24.90%)	4.89
M_{charged}	0.30	1.63	2.40(25.10%)	1.57

HCAL becomes very important for ultimate precision

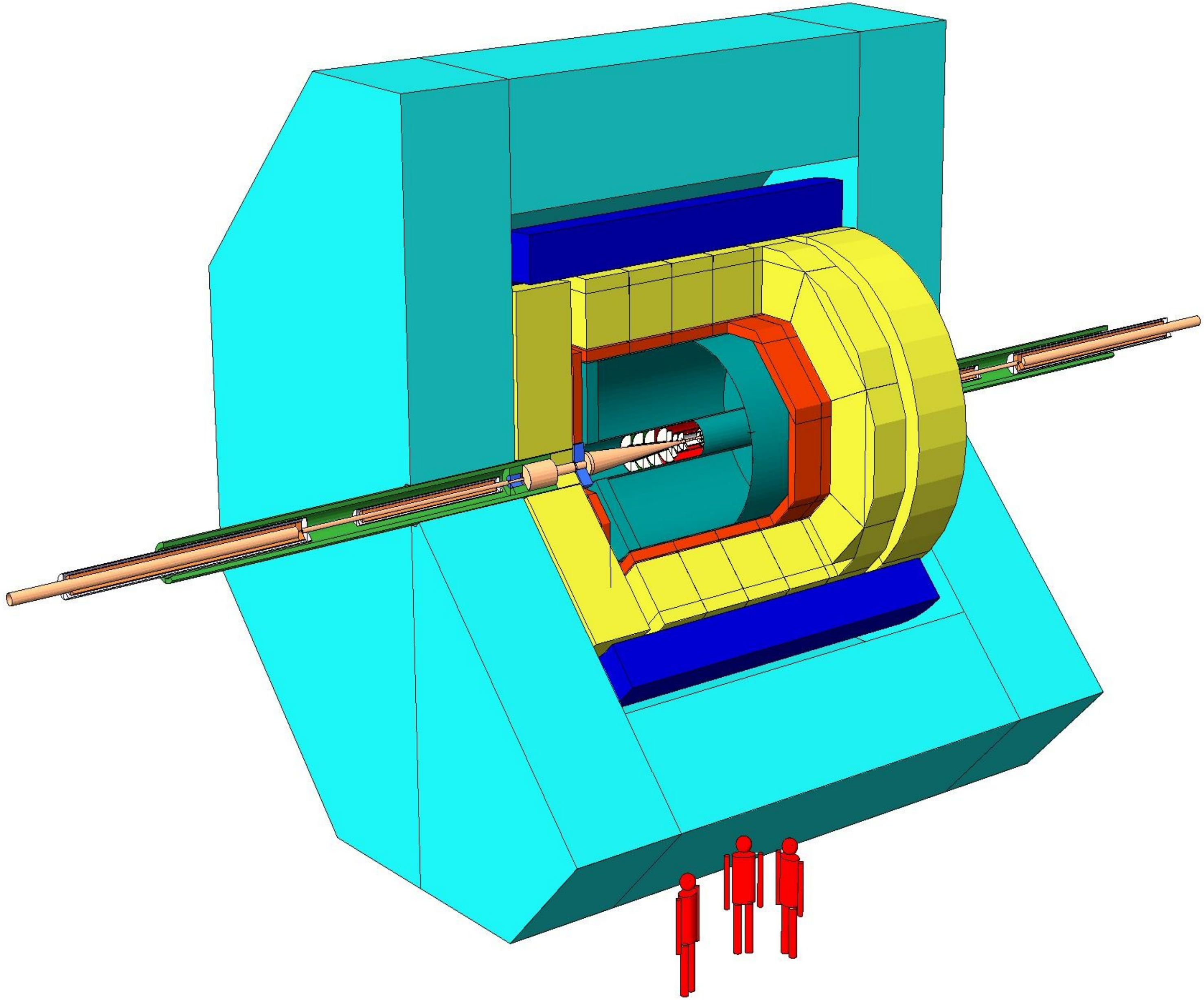
Detector Requirements

Excellent vertexing
as close as possible to the IP

Robust, three dimensional tracking
high efficiency, do not forget the low energy tracks

Powerful calorimeter
good photon identification

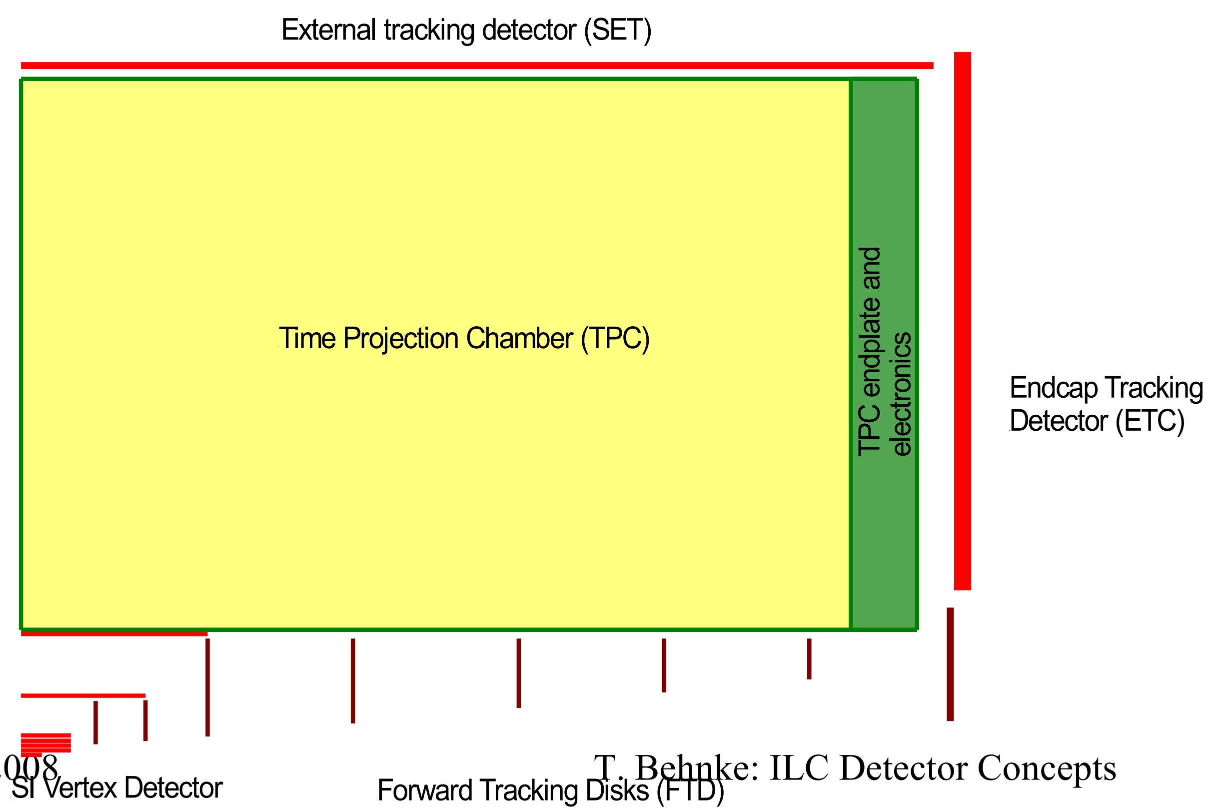
hermeticity



Tracking Layout

Powerful tracking / vertexing system

excellent vertexing capability
high precision tracking



Proposed layout of the LDC central tracking system

Special Focus on:

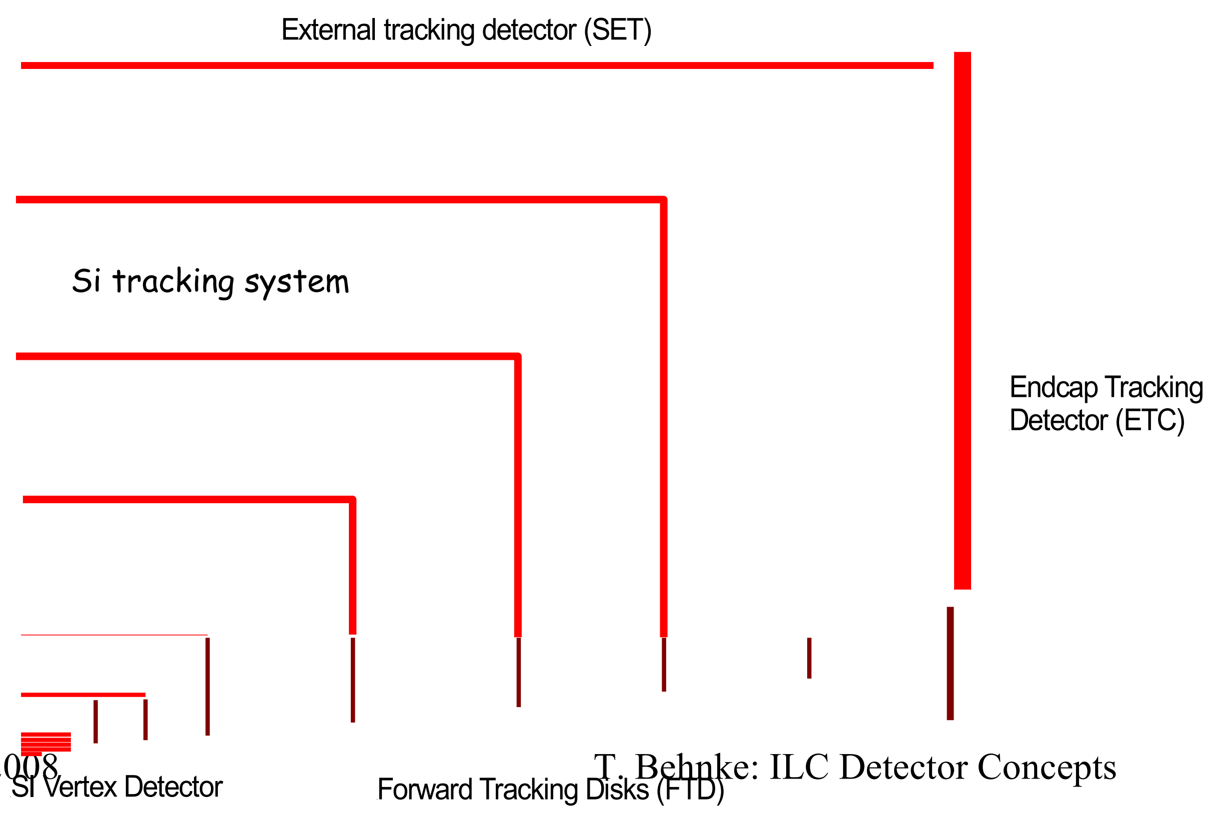
Robustness/ Redundancy

Excellent precision

Tracking Layout

Powerful tracking / vertexing system

excellent vertexing capability
high precision tracking



Proposed layout of the LDC central tracking system

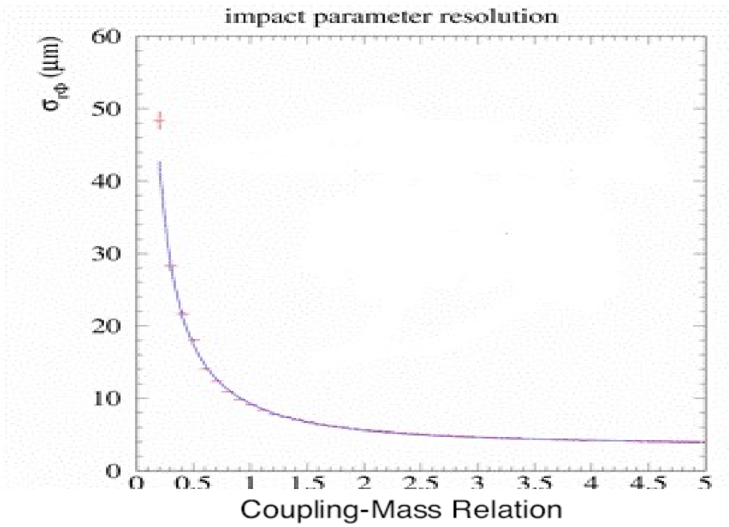
Special Focus on:

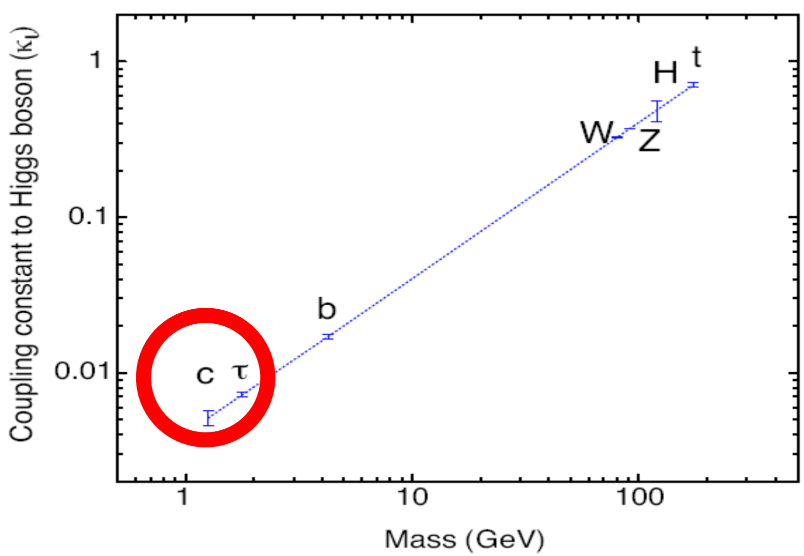
Robustness/ Redundancy

Excellent precision

Vertexing/ Tracking

Vertexing: excellent vertexing capabilities, thin!





ACFA LC Study

- Key issuses:
  - measure impact parameter for each track
  - space point resolution < 5 μm
  - smallest possible inner radius $r_i \approx 15$ mm
  - **transparency: ≈ 0.1% X_0 per layer**
    = 100 μm of silicon for 5 layers
  - stand alone tracking capability
  - full coverage |cos Θ| < 0.98
  - modest power consumption < 100 W

Momentum resolution goal: $$\frac{\delta p}{p} = 5 \times 10^{-5}$$

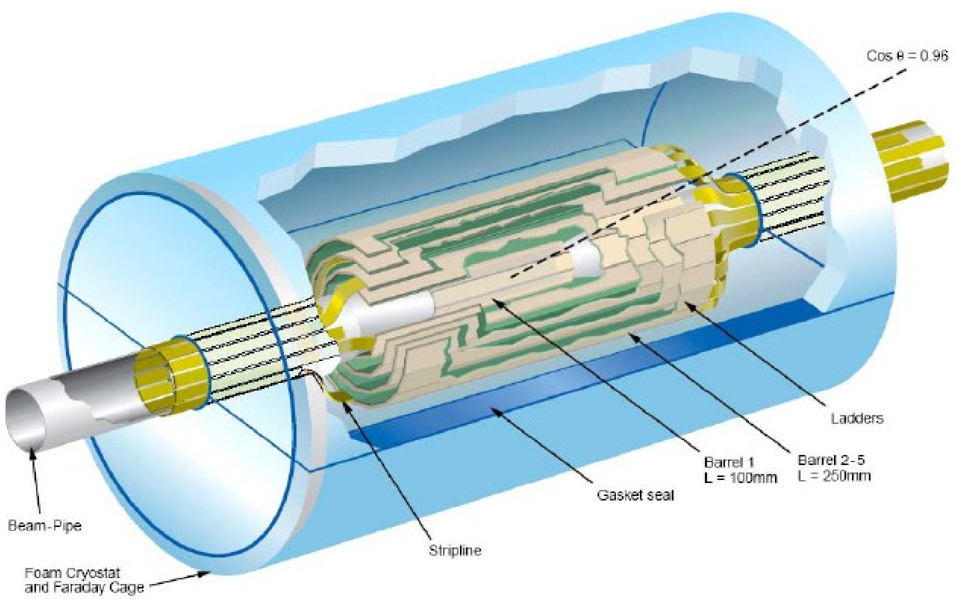
Vertexing

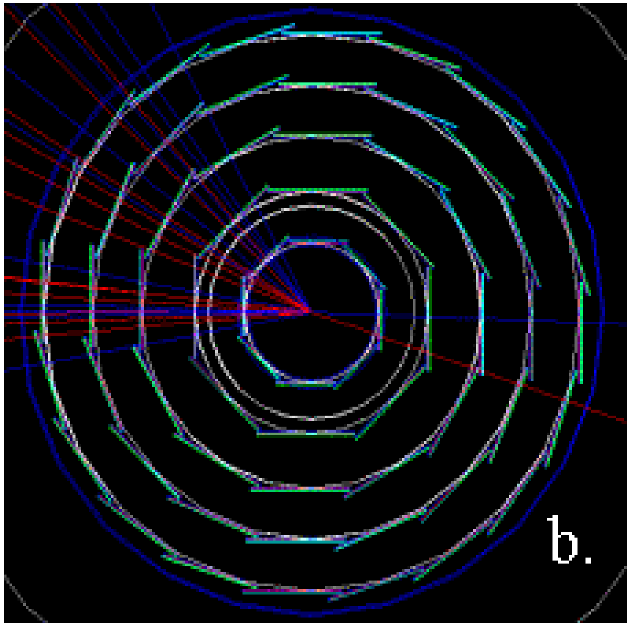
Pixel detector:

Many different technologies under discussion
Resolution – dead area – material - speed

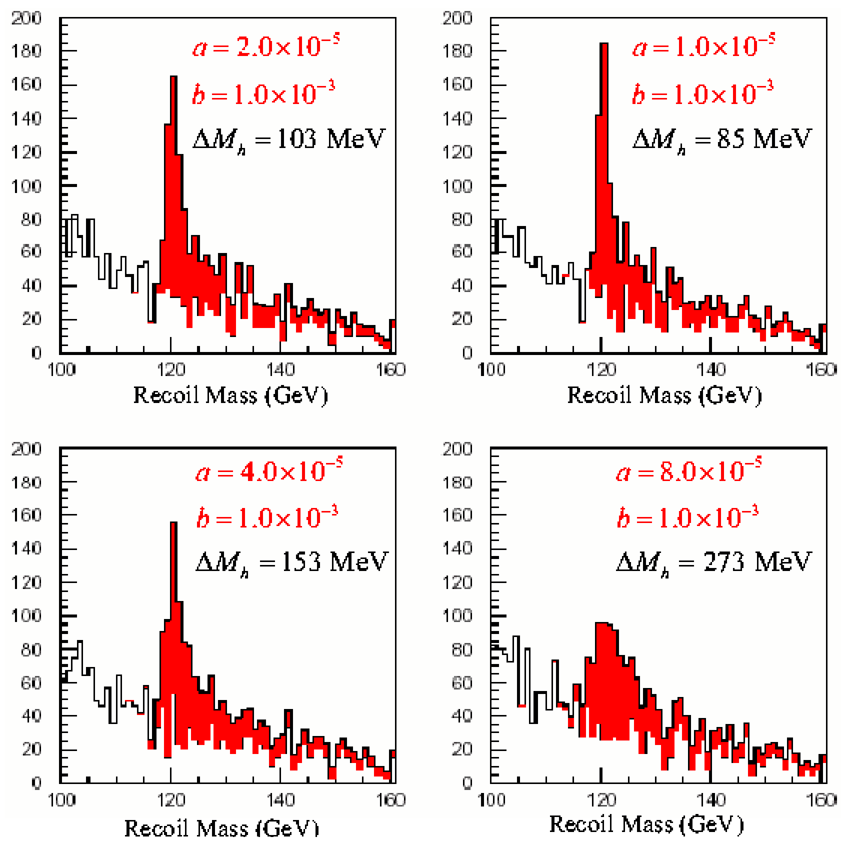
Low mass structure
readout speed

5 pixel layers, as small inner radius as possible, low material





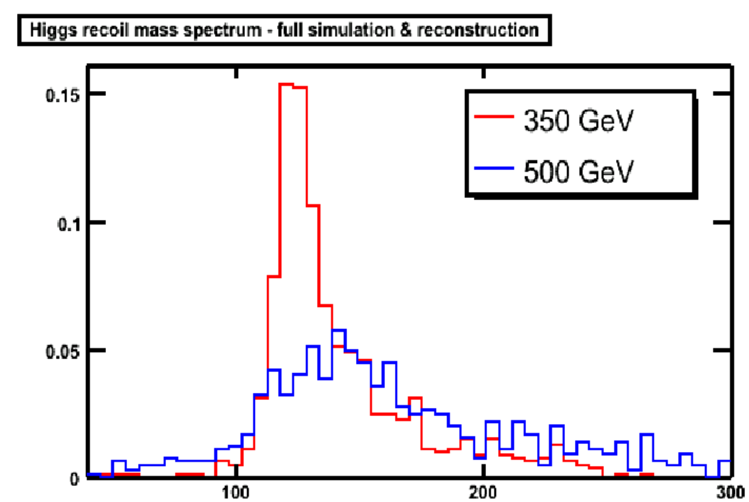
Tracker Benchmarks



Higgs recoil mass measurement:

clear case for excellent momentum resolution

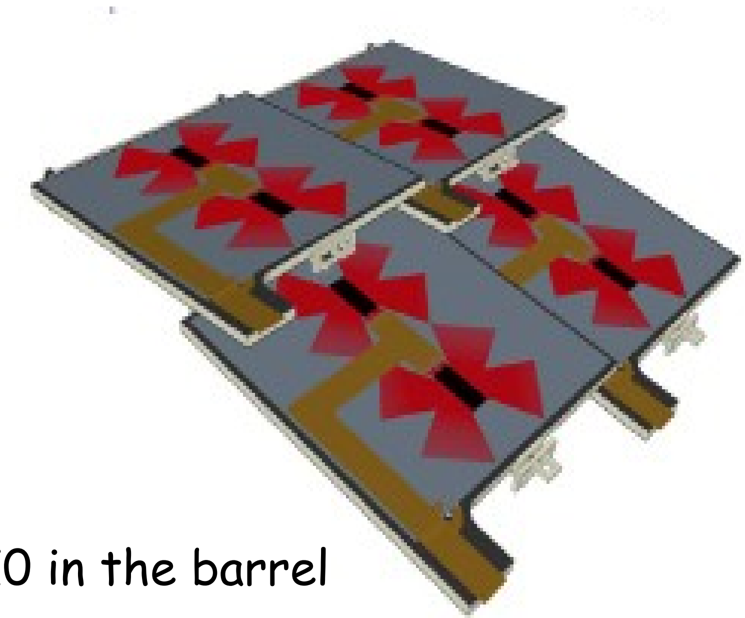
But be aware:
proper choice of
CMS Energy may have strong effect



Be aware of single benchmarks -
have to look at the complete system!

Material in the Tracker

All SI tracker
TPC based tracker:



Goal: very light tracking system:

total material before calorimeter < 3% X0 in the barrel
<15% in the endcap

including all services, all support structures, cables, etc.

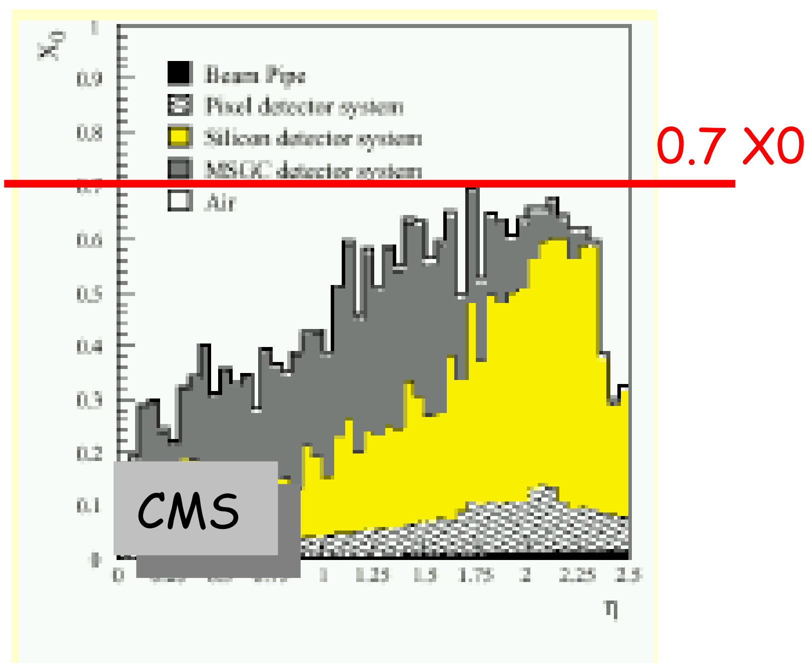
Realistic (but optimistic) estimates make this believable...

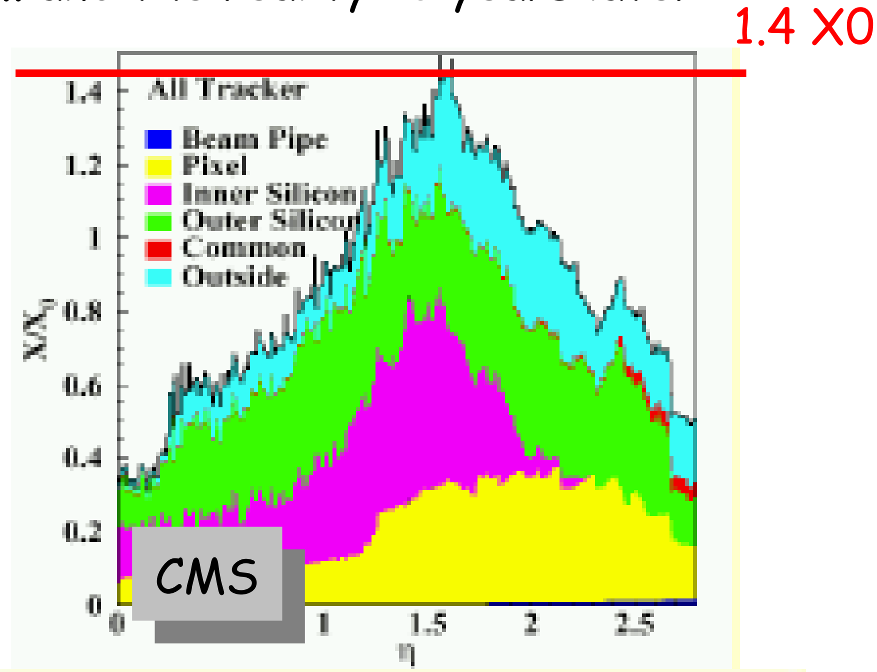
Materials: from Concept to Reality

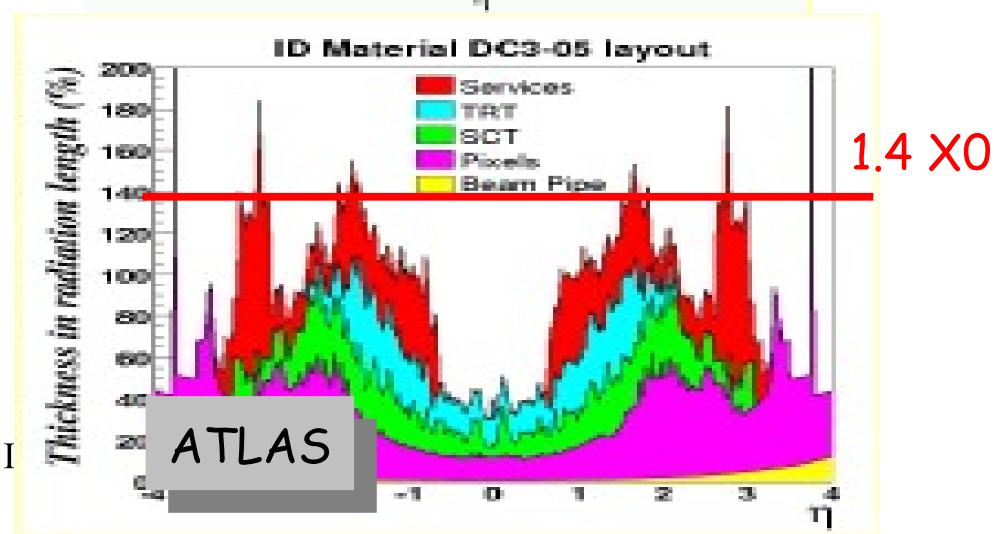
Major difference / advance to LHC detectors is needed:

... and the reality 10 years later

The detector TDR 1996





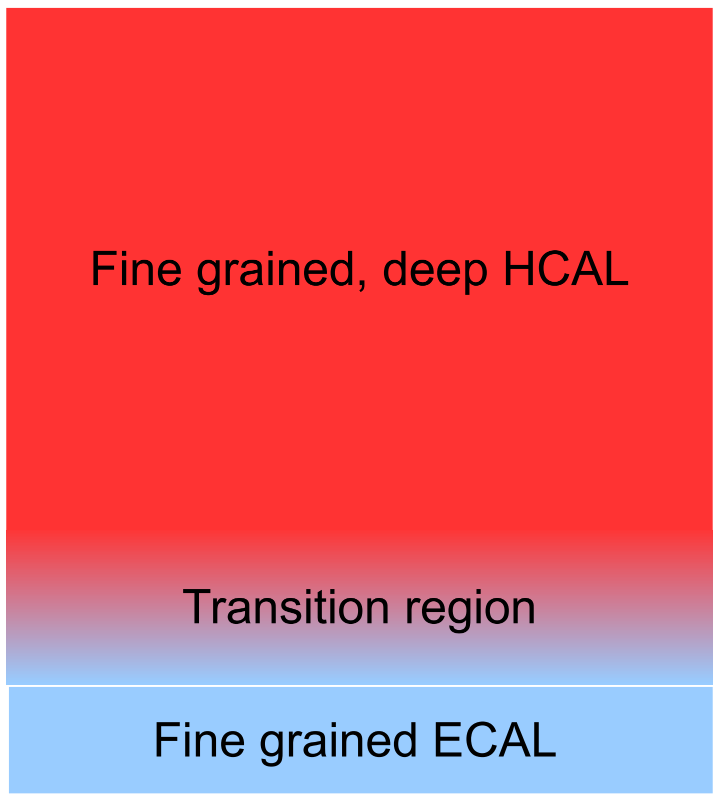


The ideal PFLOW calorimeter

Traditional energy resolution is important

but not so critically

- Extremely dense (small Moliere Radius)
- Extremely granular (particle separation)



containment

Granularity and longitudinal sampling

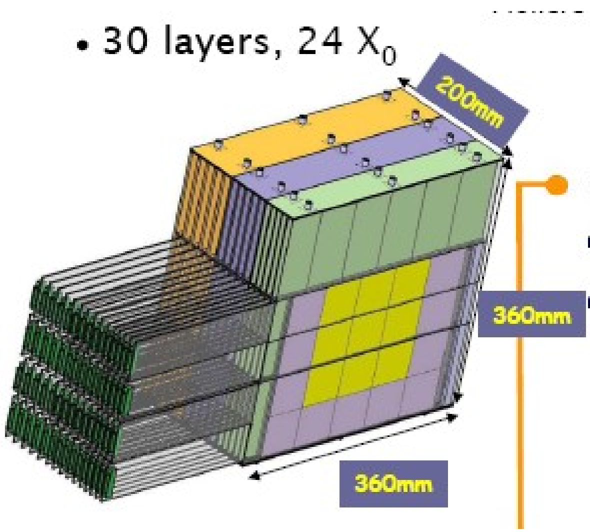
As deep as possible

Granularity: “tracking”

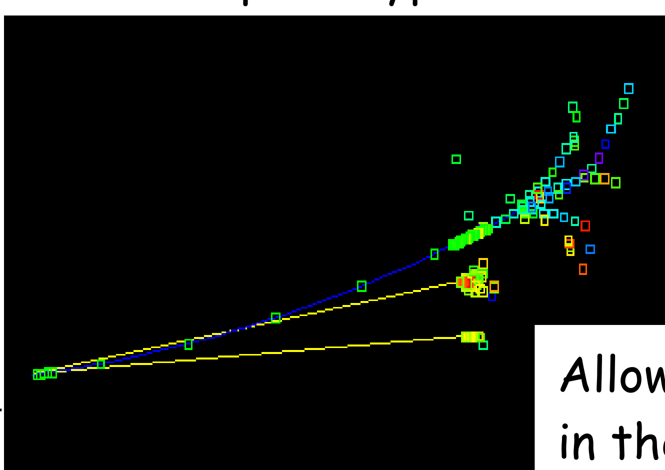
PFLOW ECAL

Typical granularity for ECAL: 0.5cmx0.5cm to 1cmx1cm,
SI detectors, Tungsten absorbers

See lecture
by A. Frey

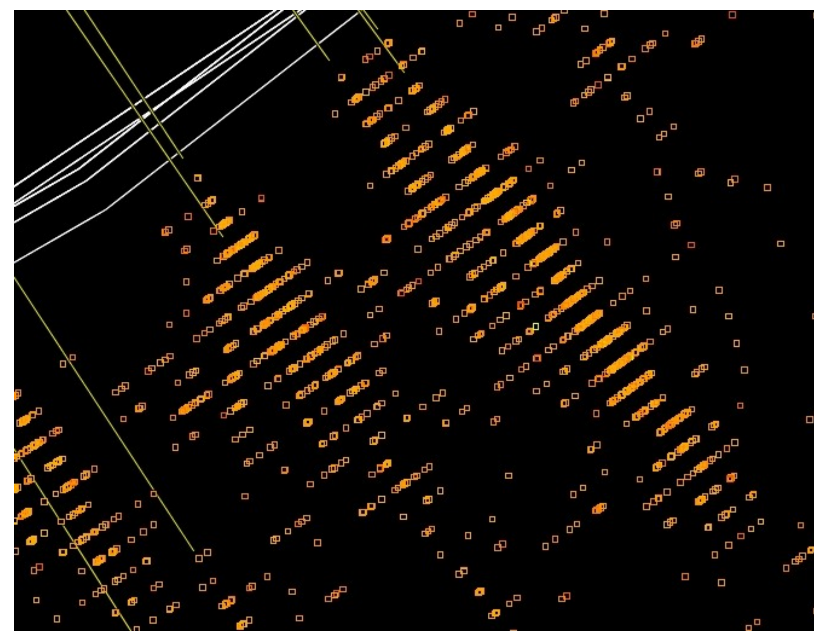


CALICE prototype



Allows "tracking"
in the calorimeter

Extreme direction:
MAPS sensors in the ECAL



Very detailed shower images

PFLOW HCAL

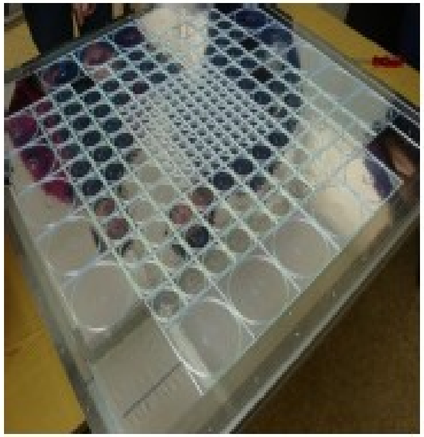
See lecture by A. Frey

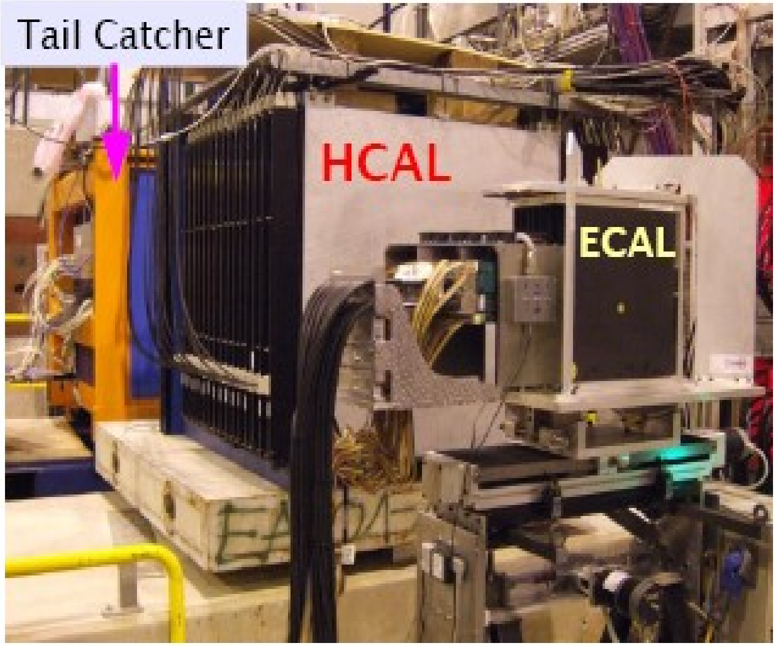
HCAL plays crucial role in a particle flow calorimeter

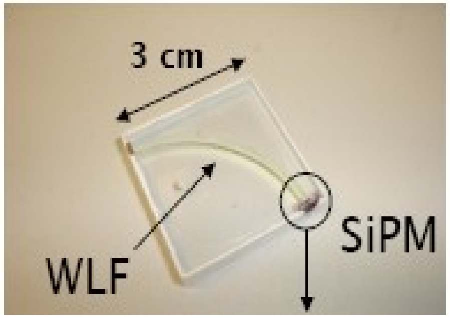
Simulation of hadronic shower is problematic

Typical cell sizes 3x3 cm² with analogue readout

Digital option investigated (smaller cells, 1bit readout)







Major effort (CALICE) to protoype such a calorimeter for the ILC

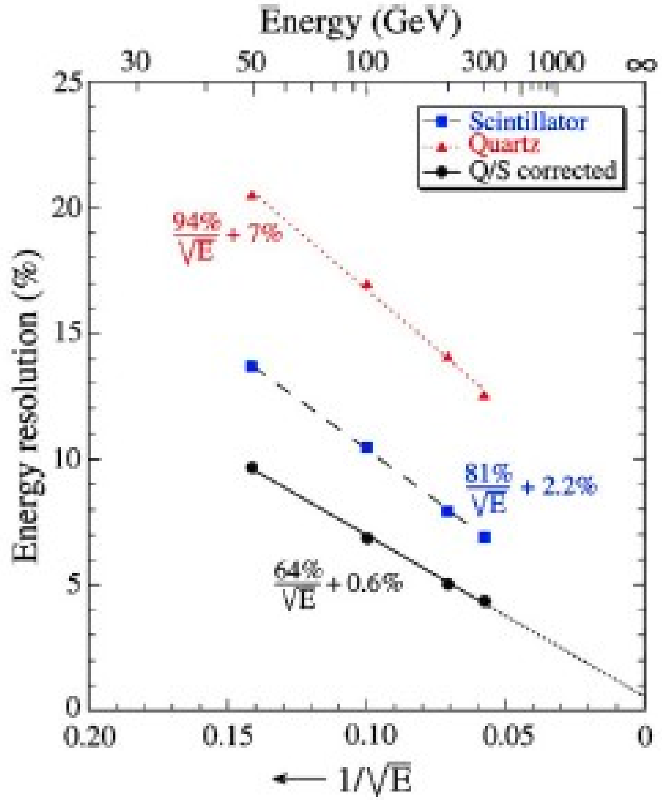
Non-PFLOW: DREAM

Dual readout calorimeter (DREAM):

- Scintillator and Cerenkov fibers
- Sensitivities to EM and had part are different

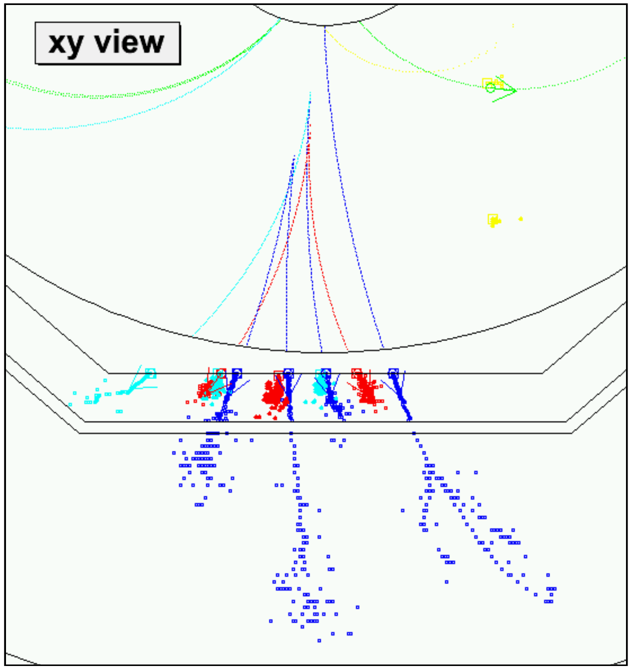
Measure individually the EM and the EM+HAD component of a shower

Good energy resolution possible
compensation by software “easy”
segmentation is difficult, in particular in depth

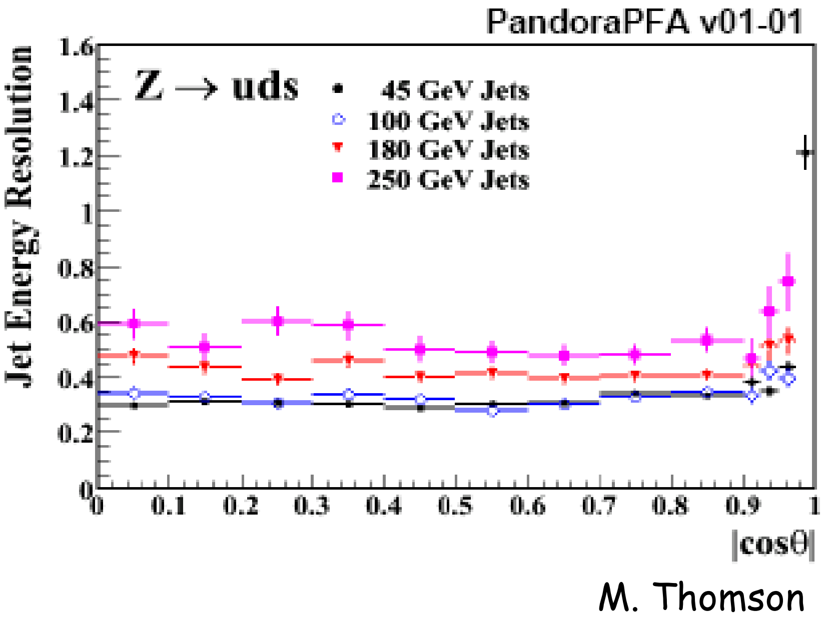


Is this an alternative to the “particle flow” calorimeters?

Particle Flow in Simulation



Simulation of an event



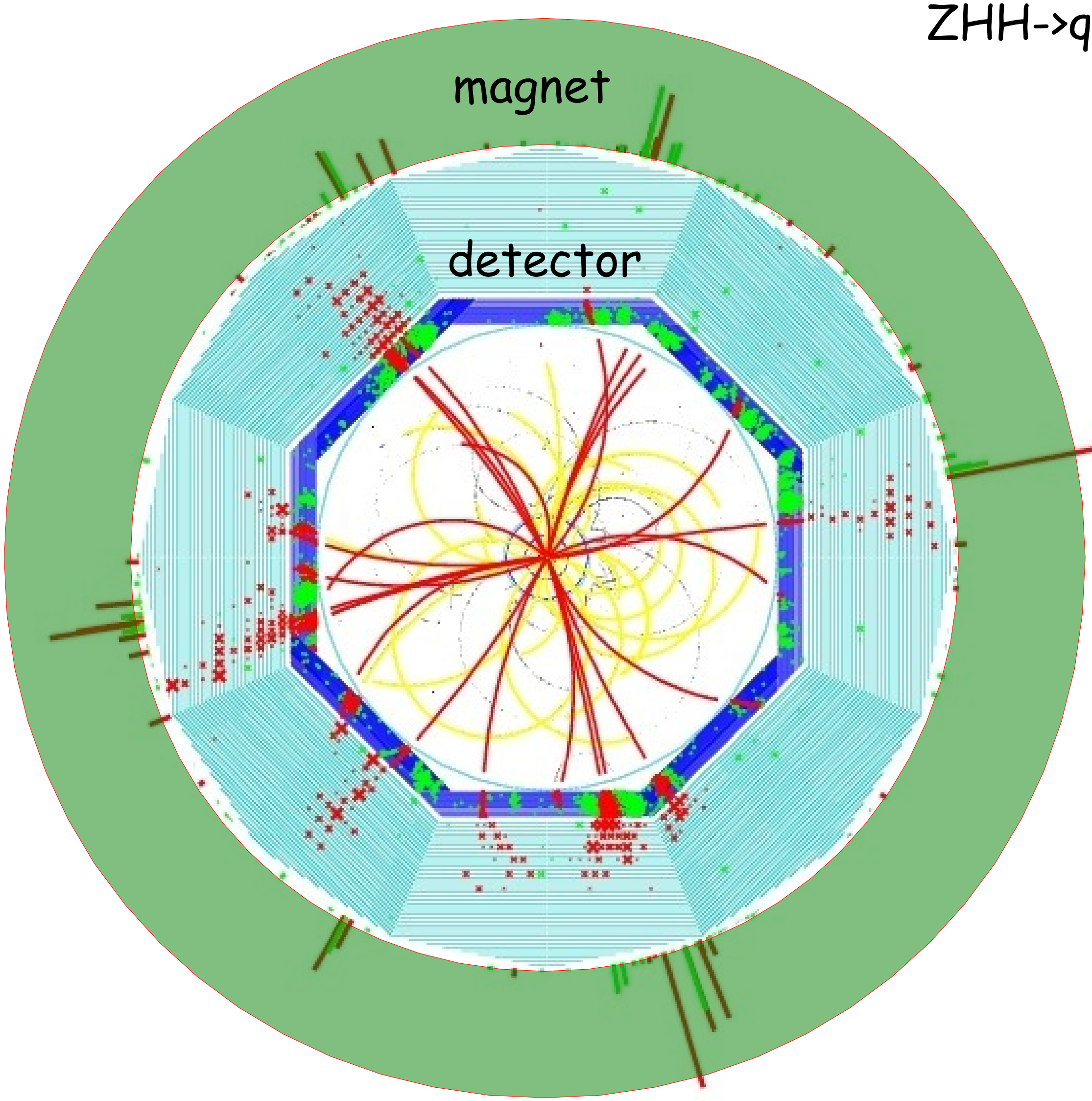
Resolution close to 30%/√E for jets below 100 GeV

Particle flow gives ~2x better performance than traditional approach (<100 GeV jets)

Software is an important part of the detector optimization and development

Putting it together

ZHH->qqbbbb event at 500 GeV



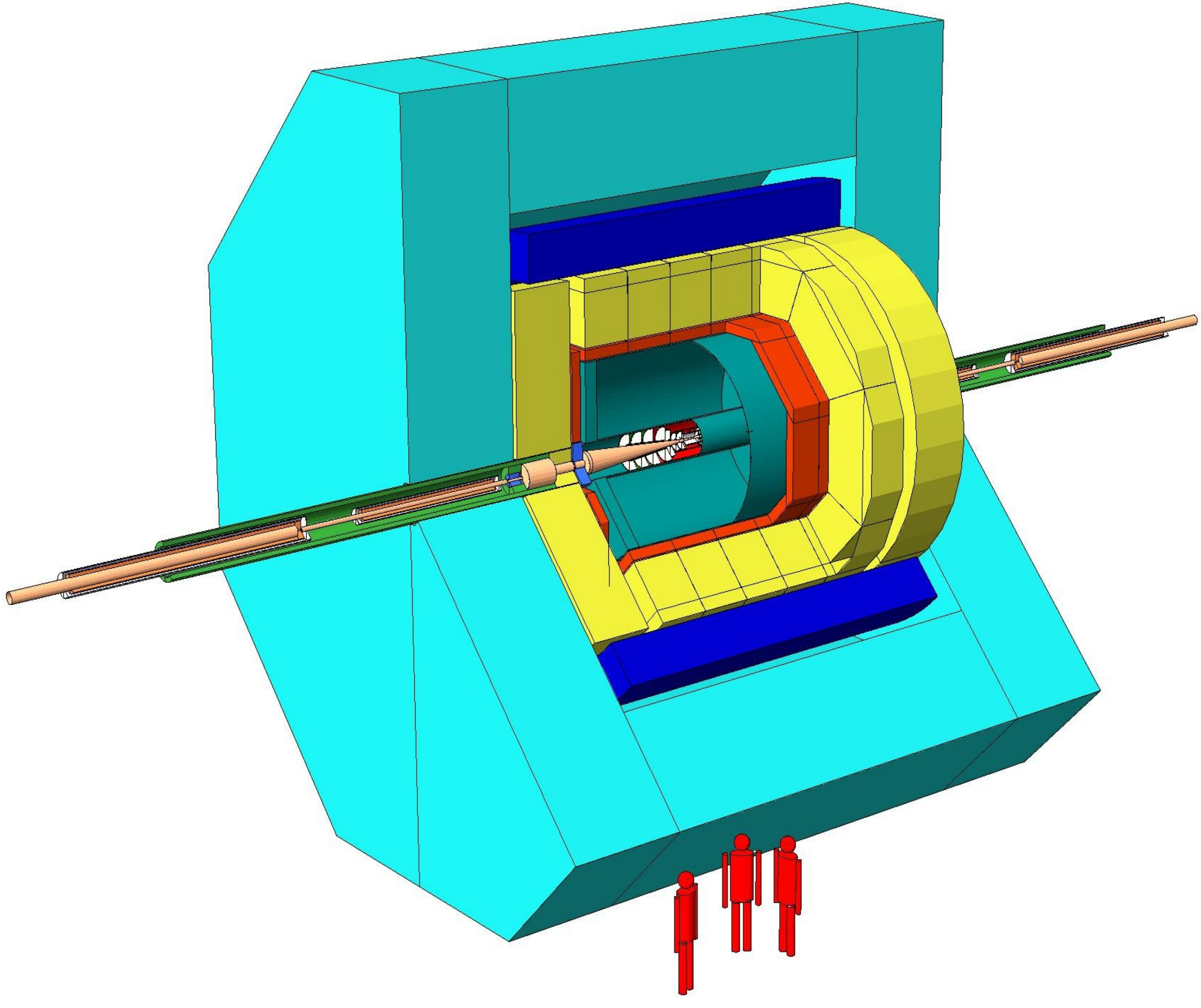
Powerful vertex/ tracking/ calorimeter

put all this into a strong B field

incidentially have some muon ID on the outside

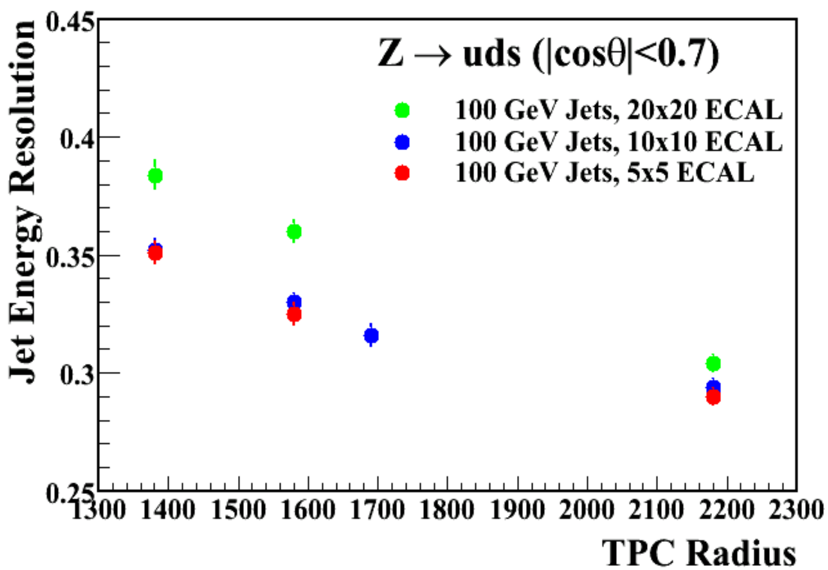
I have not talked about the forward region etc.. sorry

HH → qqbbbb



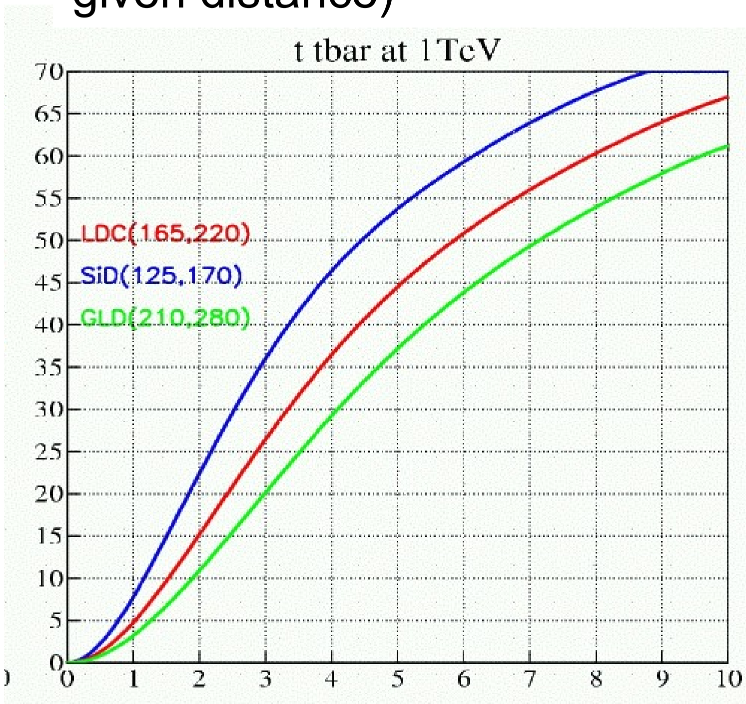
Detector Optimization: ECAL

Brient 2004
Thomson 2007



First full reconstruction results

Photon separation
(fraction of second photon within
given distance)



Cell size in cm

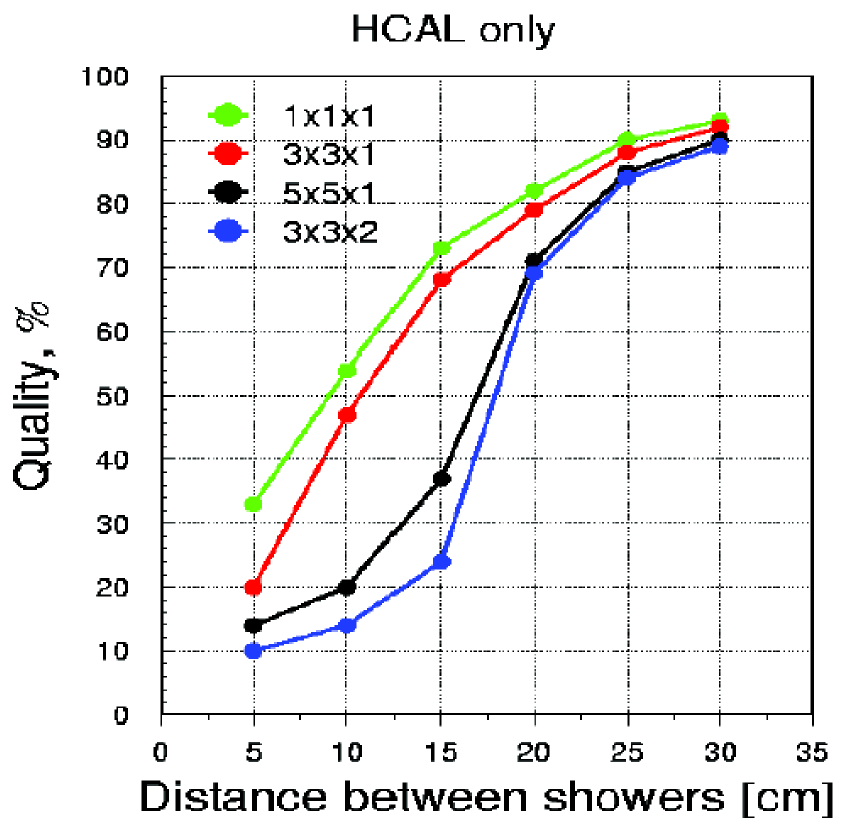
1x1 cm^2 cell sizes seem reasonable

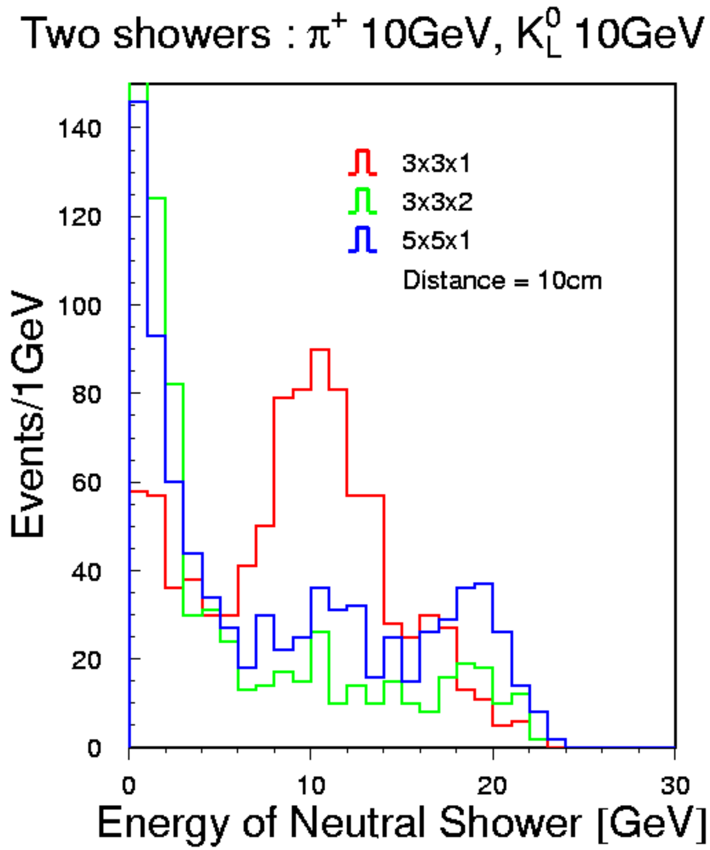
not a huge gain by smaller cells seen at the moment

Detector Optimization: HCAL

A. Raspereza,
V. Morgunov,
Snowmass 2005

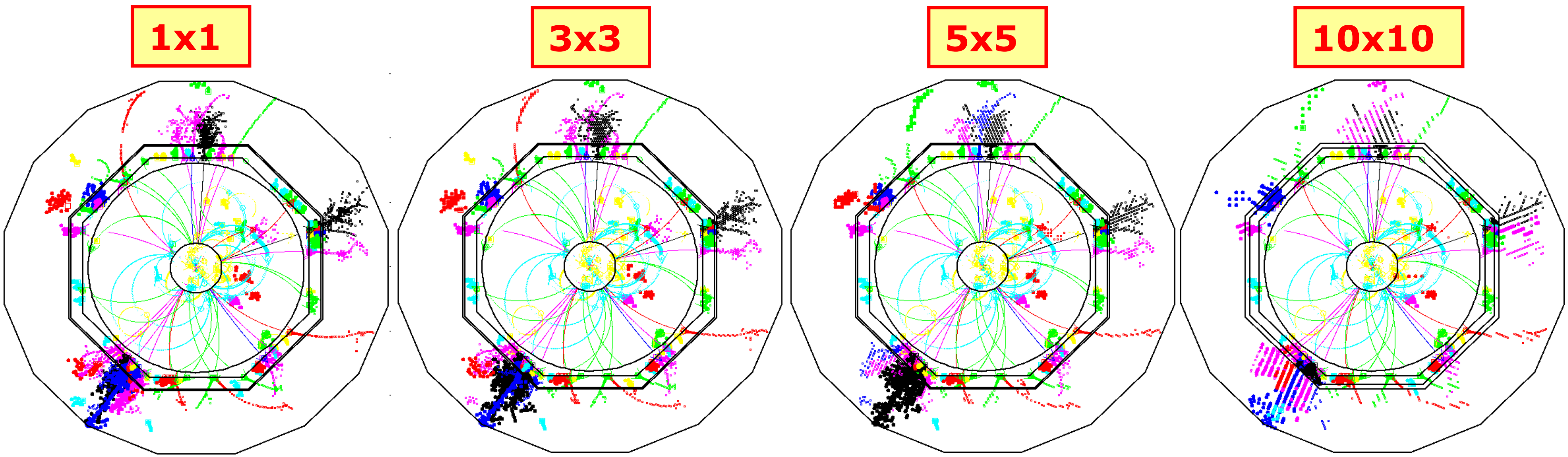
HCAL optimization:
reconstruction of overlapping hadronic showers

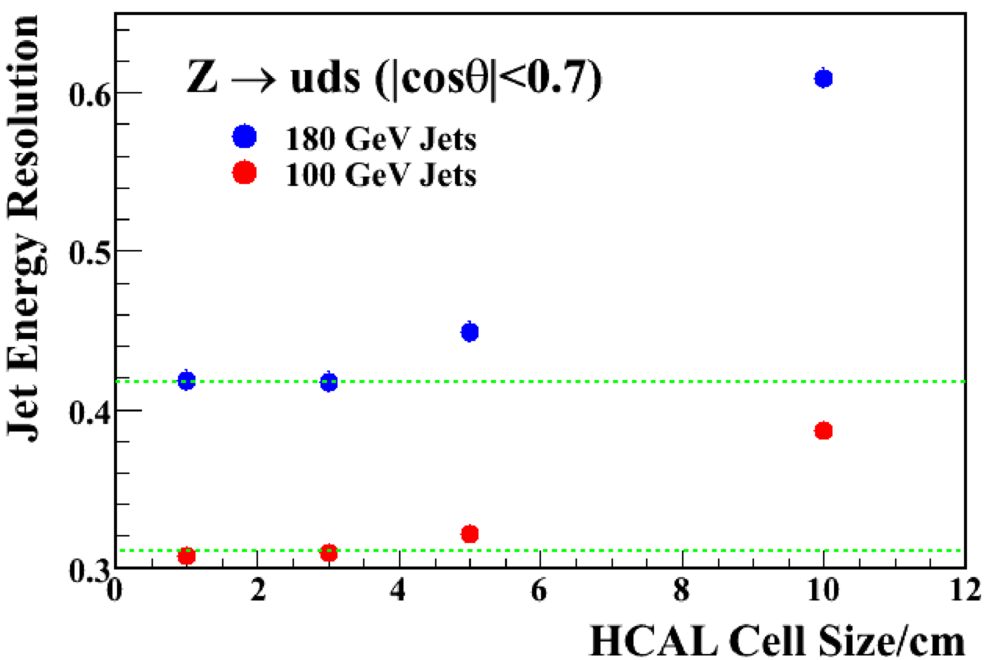




Detector Optimization: HCAL

M. Thomson, Paris 2007





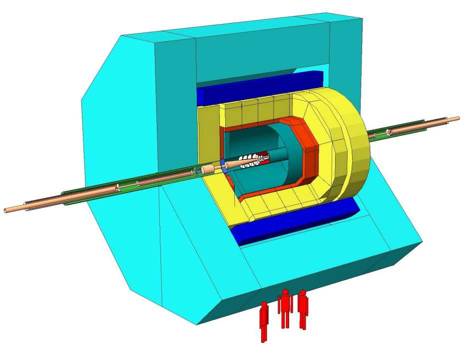
"Preliminary Conclusions"

- 3x3 cm^2 cell size ok
- No advantage -> 1x1 cm^2
  - physics ?
  - algorithm artefact ?
- 5x5 cm^2 degrades PFA

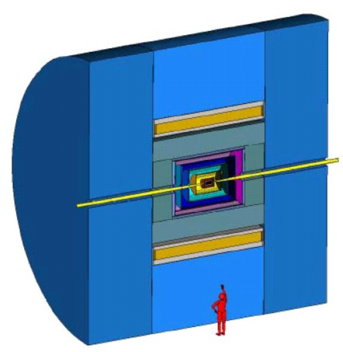
Detector Concepts at the ILC

Develop an integrated design of a possible detector at the ILC;

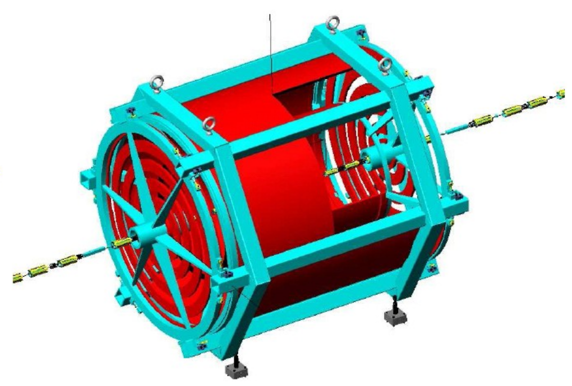
- Research into technologies: R&D collaborations
- Combine things into one detector: Concept Groups



ILD



SiD



4th

Detector Concepts at the ILC

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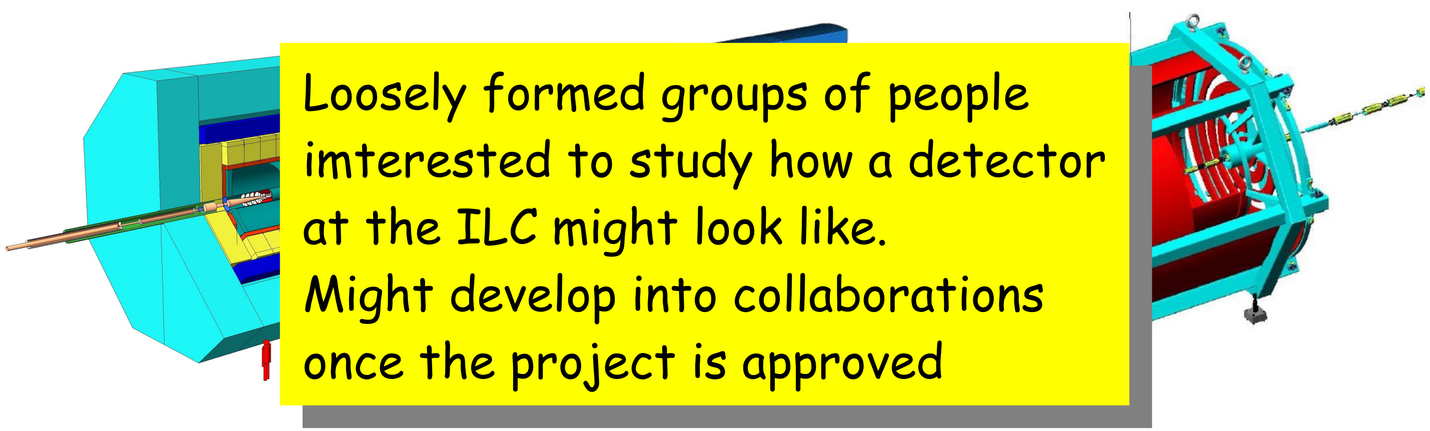


Loosely formed groups of people interested to study how a detector at the ILC might look like.
Might develop into collaborations once the project is approved

ILD SiD 4th

A Comparison

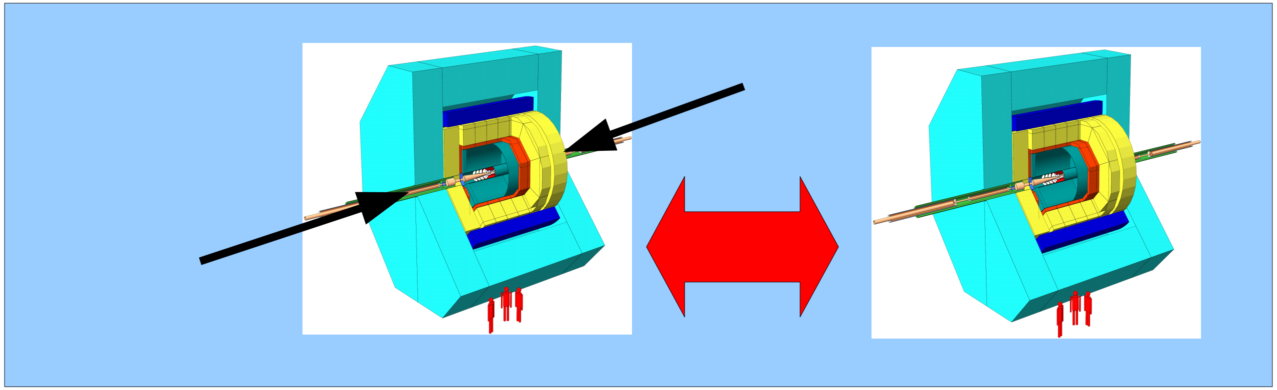
	SiD	ILD	4th
Vertex	Si-pixel	Si-pixel	Si-pixel
Tracker	Silicon strip	TPC	TPC or drift
ECAL	Si-W	Si-W	DREAM
HCAL	RPC digital	Fe-Scint	open
Field	5T	3.5-4T	4T
Event Reco	PFLOW	PFLOW	Compensating
main base	US	Europe/ Asia	US/ Europe
# of subscribers	38	174	ca 20

Experiments at the ILC

One collider, one beam, two experiments:

- Two beam lines, switching beam from experiment to experiment
- One beam line, switching experiments from in-beam to standby

Push-Pull configuration favored because of cost considerations



Can this be done?
How quickly?
Loss of efficiency?
Alignment?

Highly non trivial

Detector Roadmap

The roadmap for detectors at the ILC;

2007	2009	2012
Call for letters of intend	Letters of intend collect groups willing to contribute to a EDR for the concept	Prepare an engineering design report (light) in step with the collider

Research Director

A complete concept
some engineering support of the concept
a reliable costing
demonstration: we can start if we may

R&D at the ILC - NOW

Organized in two complementary ways:

Technology R&D collaborations

Look primarily at technologies
concentrate on sub-detectors

horizontal

LCFI, MAPS, ...
CALICE, LC-TPC,
FCAL, ...

Detector Concept groups

vertical

Look at the overall concept
optimize the interfaces between sub-detectors
Look at integration issues

SiD, ILD, 4th

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SiD, ILD, 4th

The Next Years

Lots of detector R&D remains to be done:

see lecture by A. Frey after this.

Many great opportunities for interesting work and novel technological developments:

e.g. SiPM, SI readout for TPC, Timepix, new pixel detectors, low mass mechanics, etc etc etc

Have to face the challenge of preparing a coherent design without cutting technological developments off at the wrong moment

Conclusion and Outlook

The ILC physics program remains as interesting as ever

The ILC faces many interesting technological challenges:

- great progress has been made over the last few years to meet them
- much progress still needs to be done before we can built these detectors

Concept groups (“Proto”-Collaborations) are forming to design and push specific detector concepts in a friendly but competitive environment

The ILC remains an exciting project, even after the recent political problems.
Experimentation at the ILC is as challenging as experimentation at the LHC!