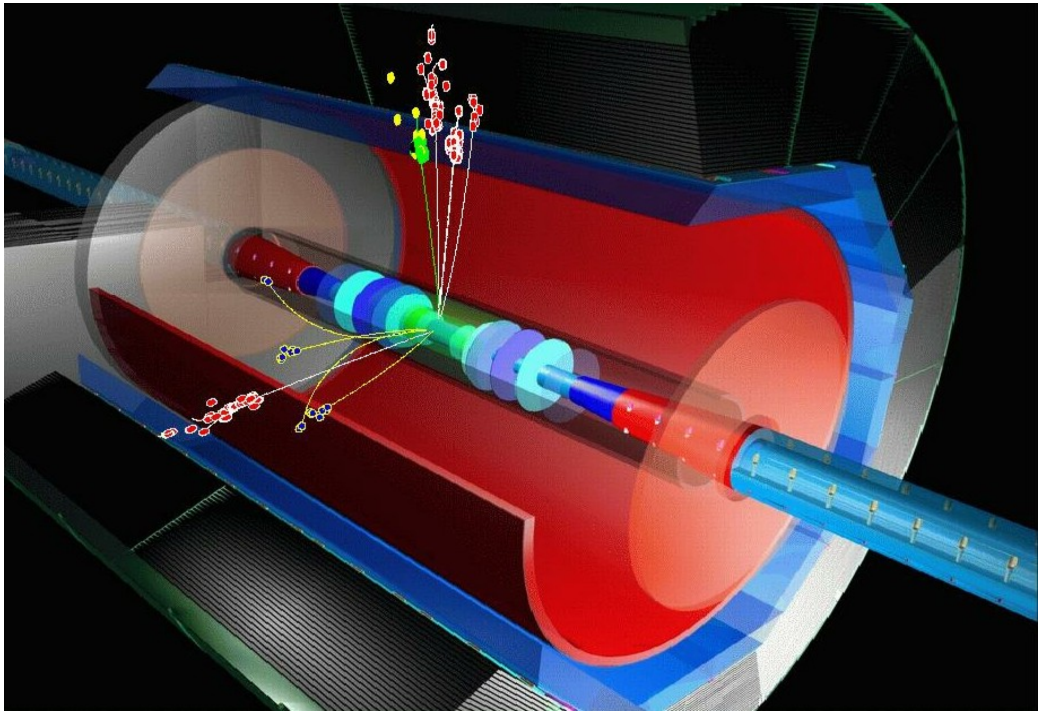
The ILD (LDC) Detector Concept

Ties Behnke, DESY

An of course entirely unbiased review of detector concepts at the ILC
and why it is now the right moment to contribute to the ILD



UK-ILD/ LDC meeting in Cambridge, September 21, 2007

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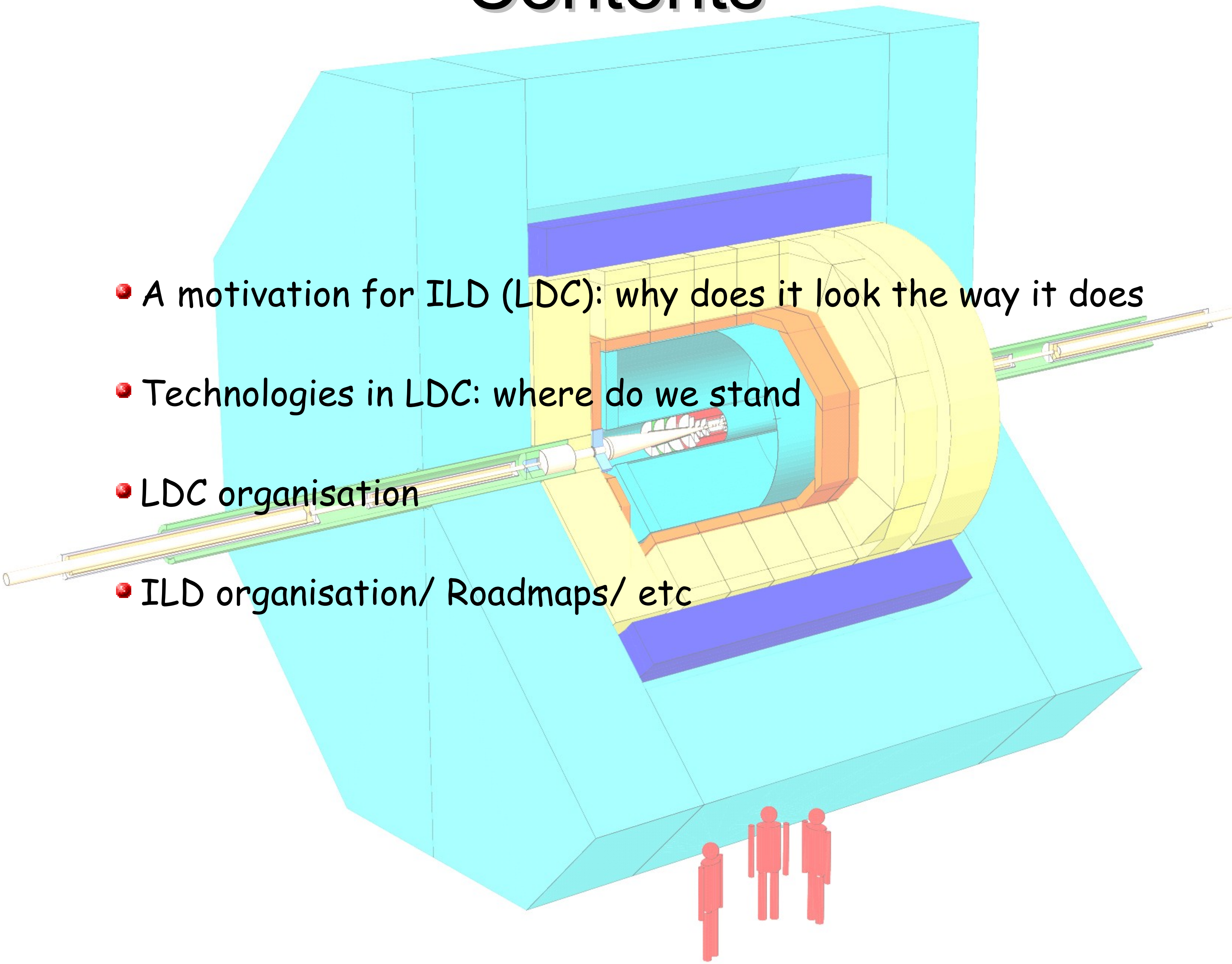
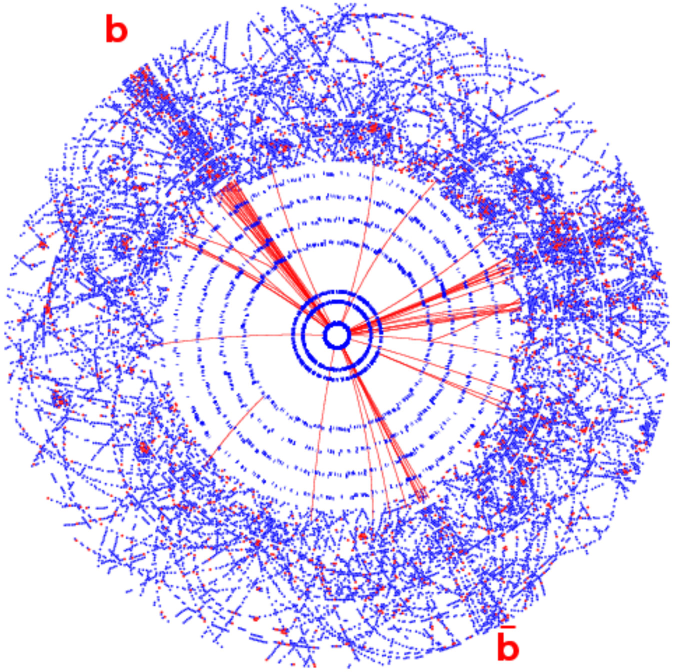
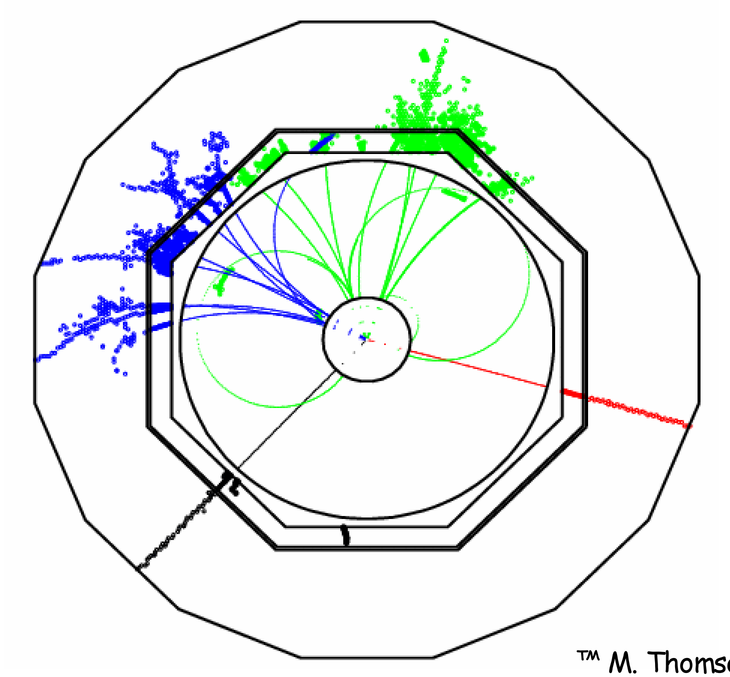


- A motivation for ILD (LDC): why does it look the way it does
- Technologies in LDC: where do we stand
- LDC organisation
- ILD organisation/ Roadmaps/ etc

The Goal

- ILC is precision experiment -> consequences for the detector





™ M. Thomson, Cambridge

Focus on individual particles, focus on detailed reconstruction of particles

Physics at the ILC

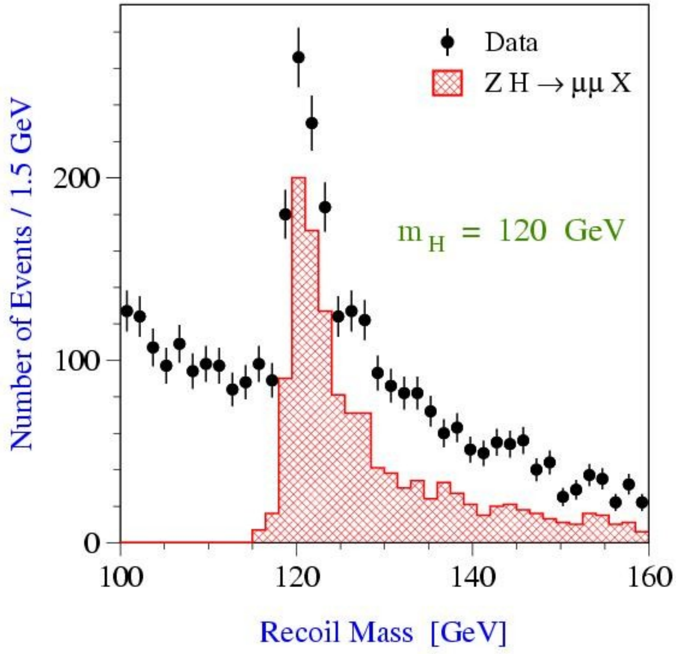
- Stress Precision measurements

  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



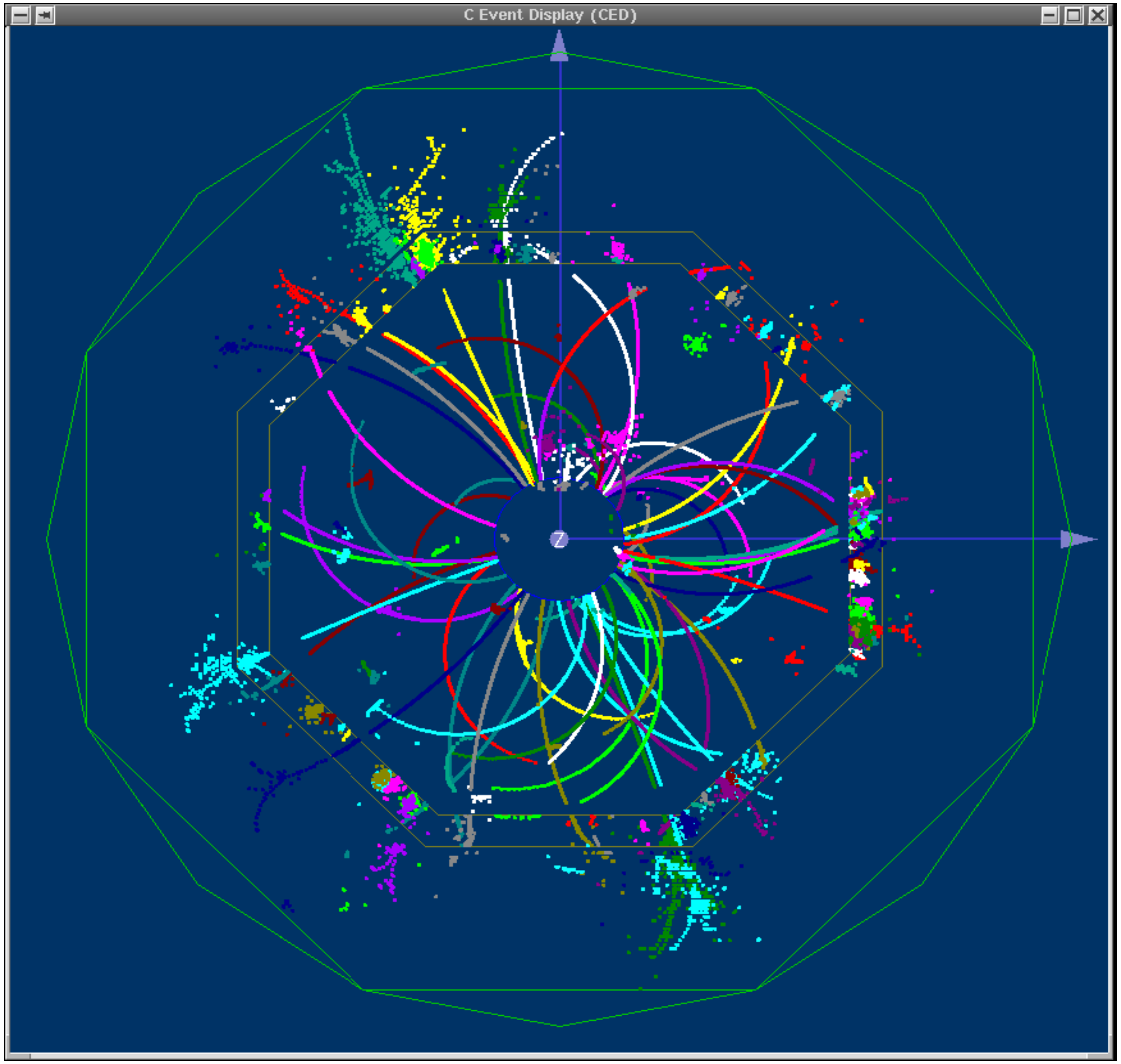
Goal: "background free" signals

The States

Events at the ILC:

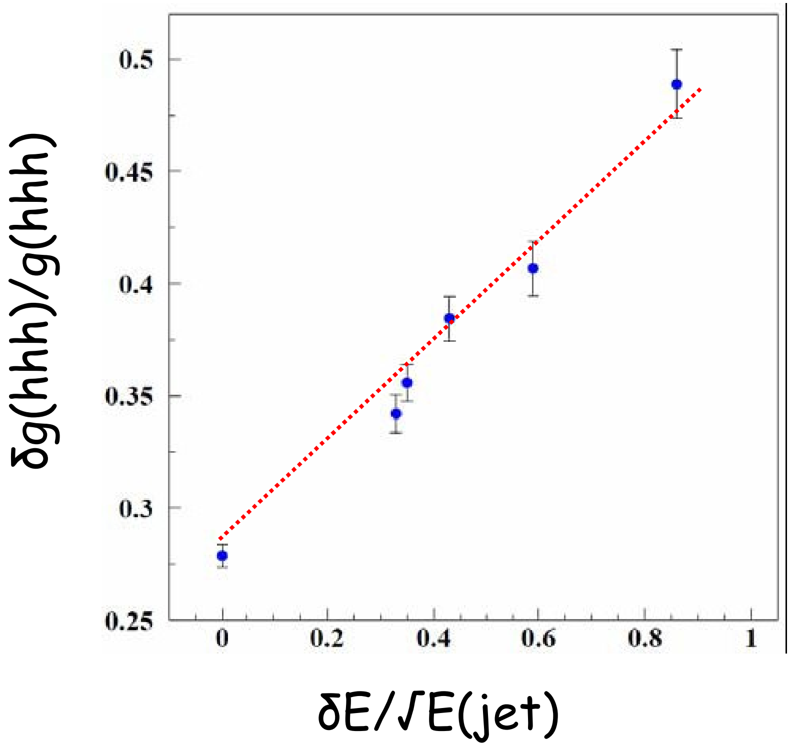
- multi jet final states
- leptons, often in jets
- forward going physics

tt event at the ILC (LDC model)



C: V. Morgunov, A. Raspereza

Physics Challenges



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

Jet energy resolution is the (one) key to success at the ILC detector

The Backgrounds

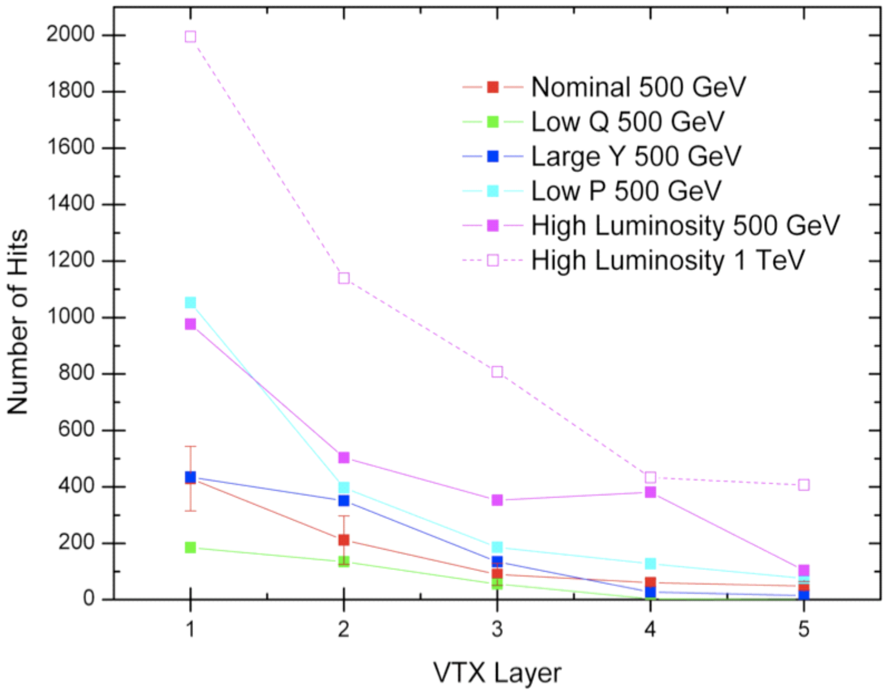
Physics itself is the main background

Though there are
some 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



Detector Requirements

Excellent vertexing
as close as possible to the IP

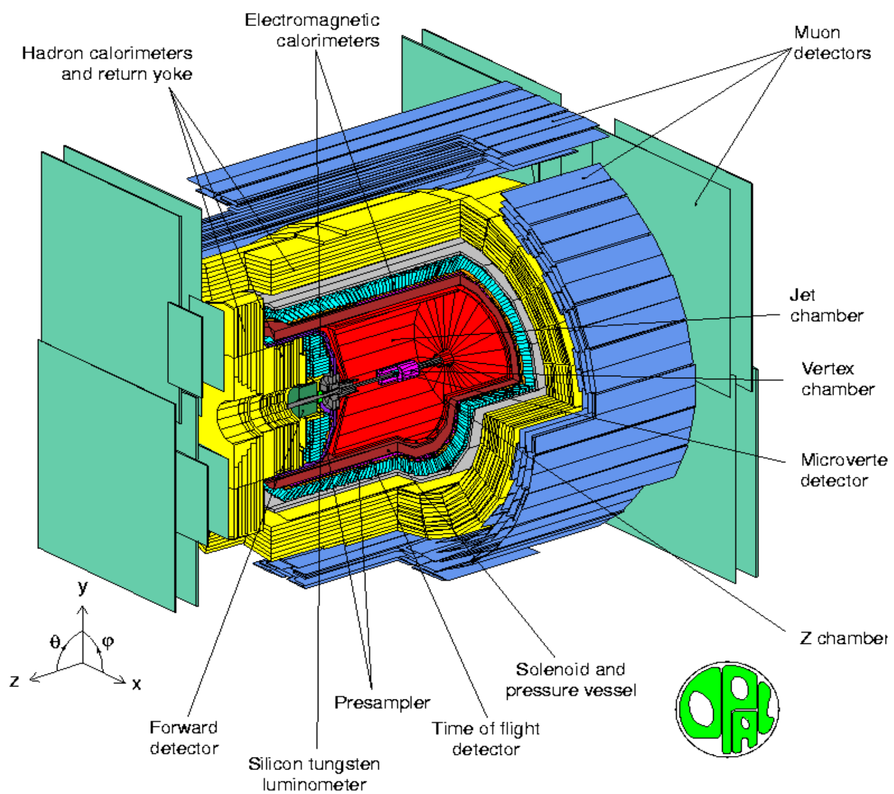
Robust, three dimensional tracking
high efficiency, do not forget the low energy tracks

Powerful calorimeter
good photon identification

hermeticity

Lessons learned

- Last generation of e+e- detectors: LEP detectors/ SLD
- 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 than simulation..
  (see next slide)....

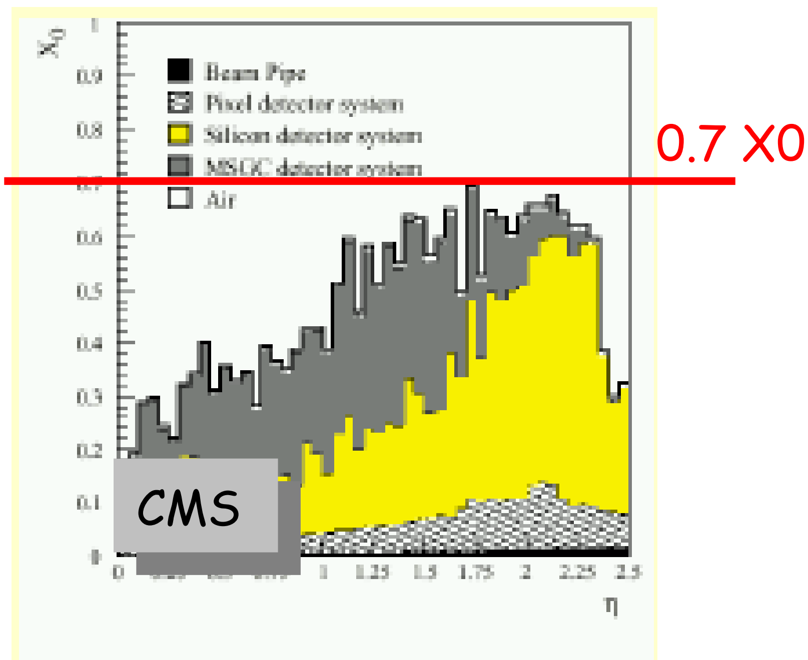


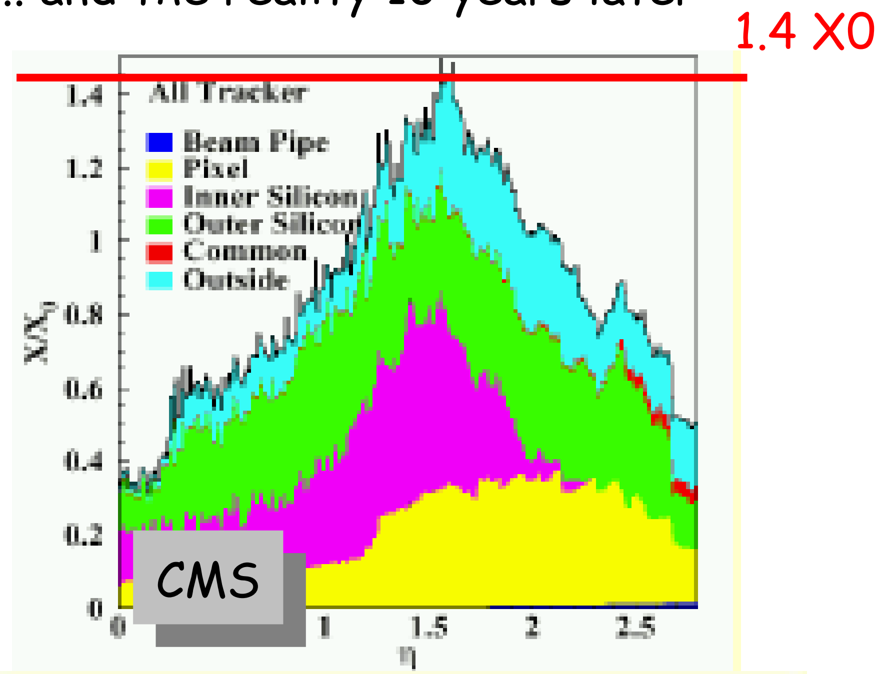
Materials: from Concept to Reality

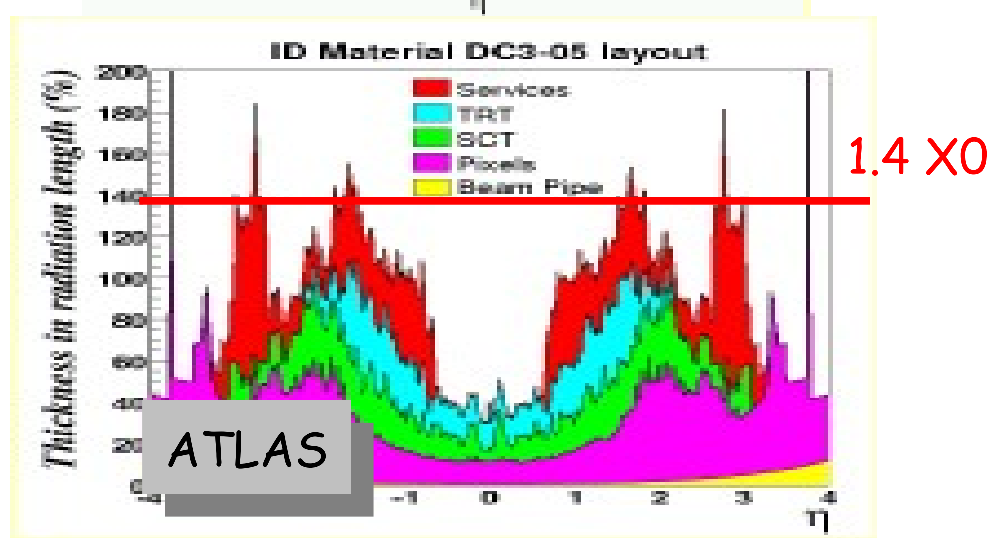
Major difference / advance to LHC detectors is needed:

... and the reality 10 years later

The detector TDR 1996

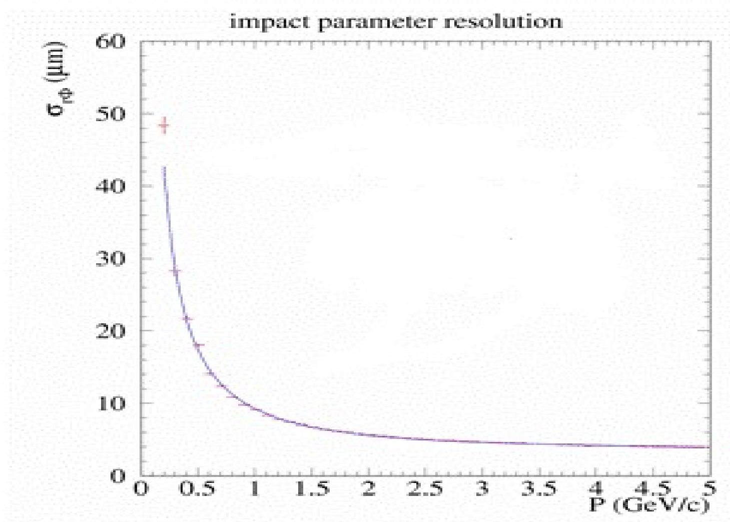






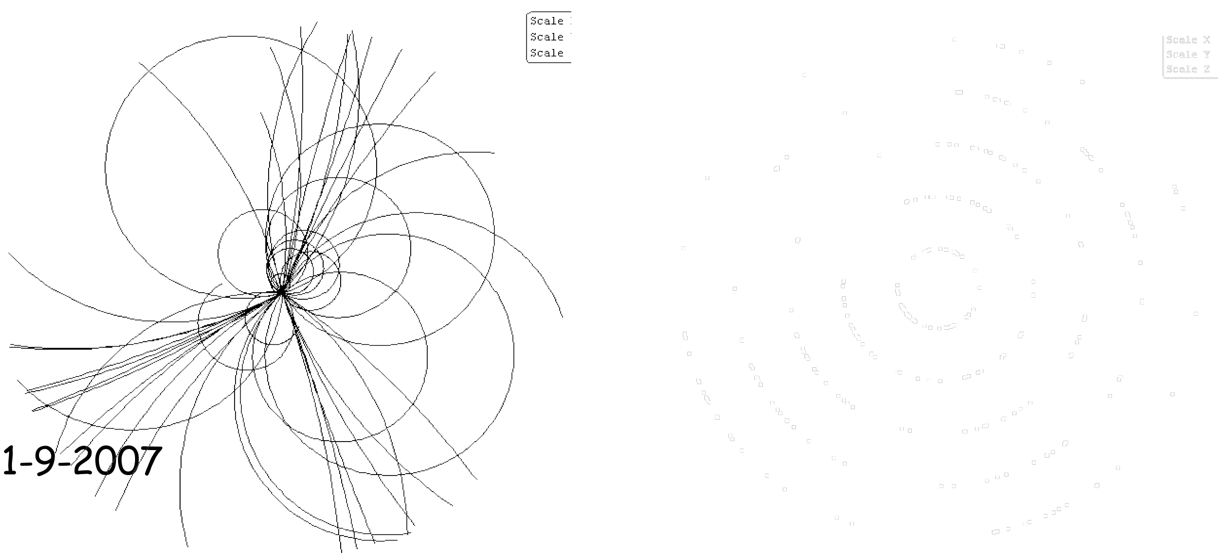
Requirements: Tracking

Vertexing: excellent vertexing capabilities, thin!



- 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

Tracking: High Precision, high efficiency, robust tracking

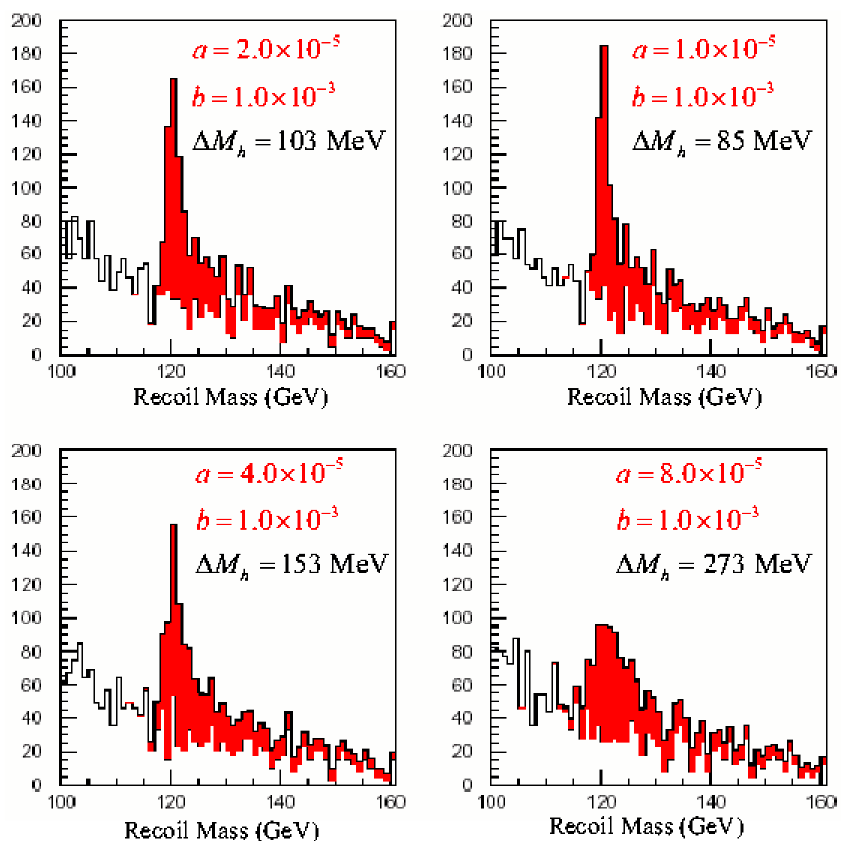


Comparison of TPC (left) and SI based hit pattern at the ILC

goal:

$$\frac{\delta p}{p} = 5 \times 10^{-5}$$

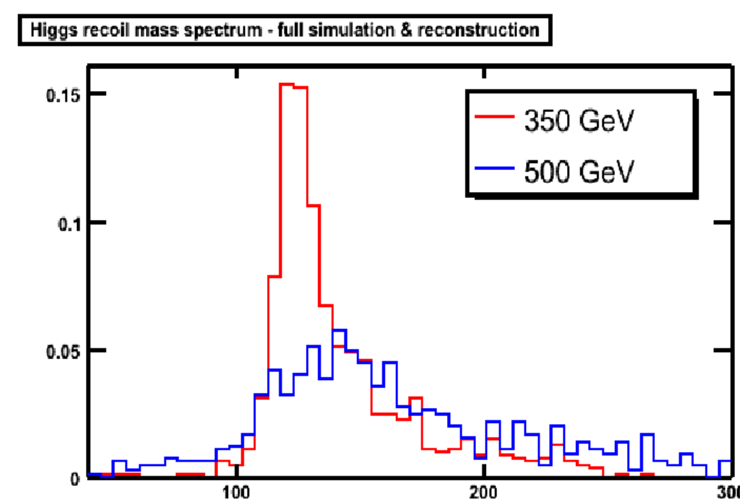
Tracker Benchmarks



Higgs recoil mass measurement:

clear case for excellent momentum resolution (...?)

CMS Energy has much stronger effect



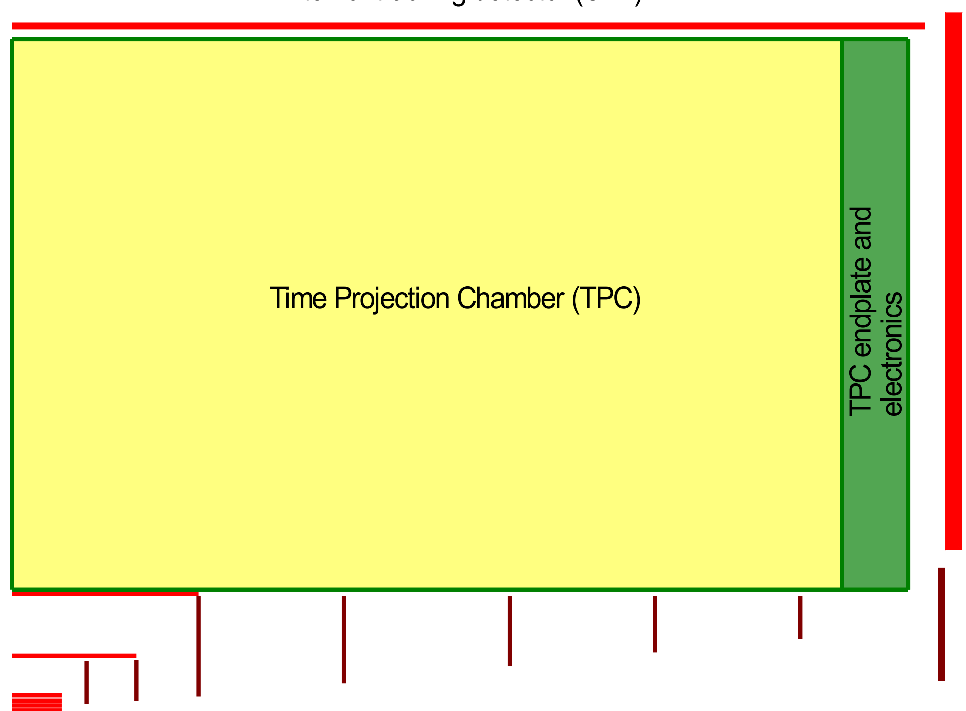
Be aware of single benchmarks -
have to look at the complete system!

Tracking Layout

The real challenge:

design an integrated system,
which is powerful and thin at the same time!

Proposed layout of the LDC central tracking system



Special Focus on:

Robustness/ Redundancy

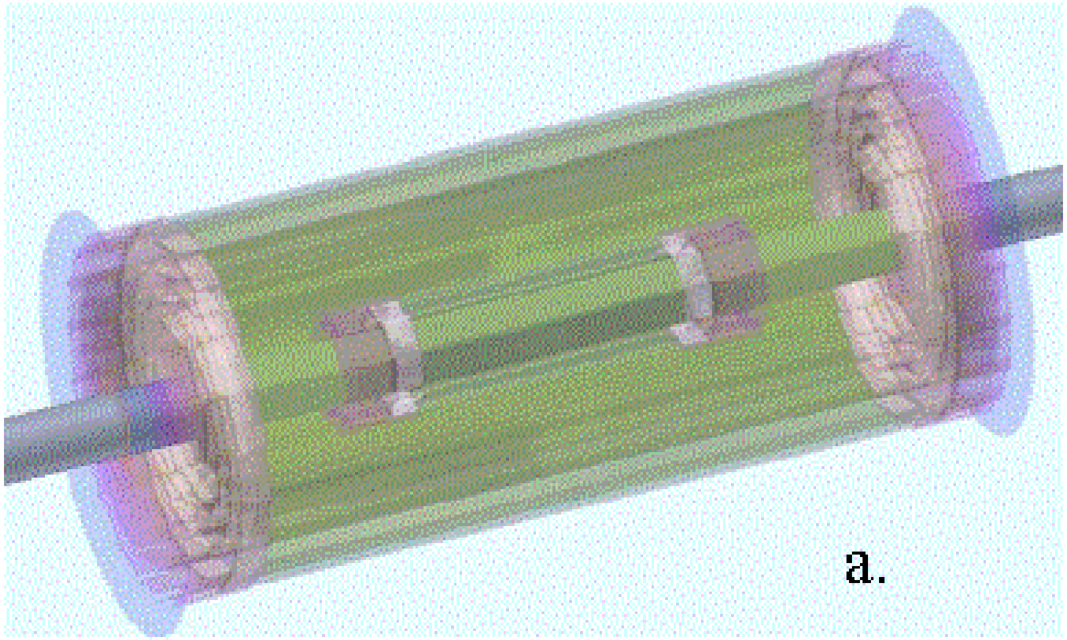
Excellent precision

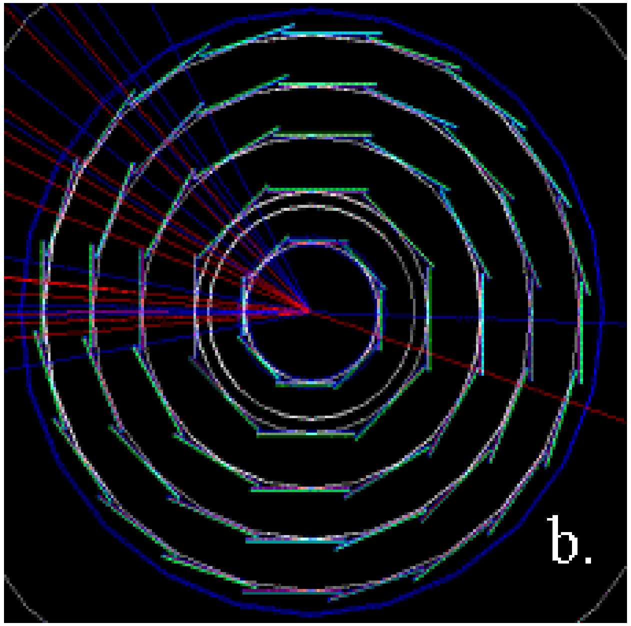
Vertexing

Pixel detector:

Low occupancy needed
Challenge in the ILC environment

Many different technologies under discussion
UK is very active in this area (Rutherford, others, LCFI etc)



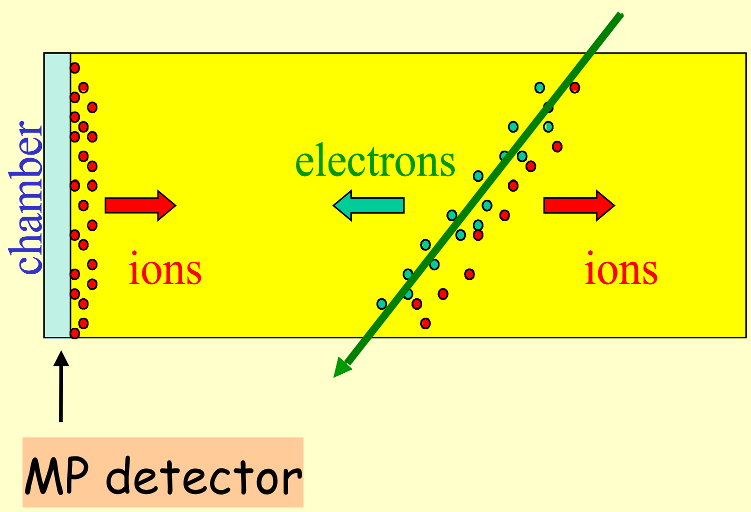


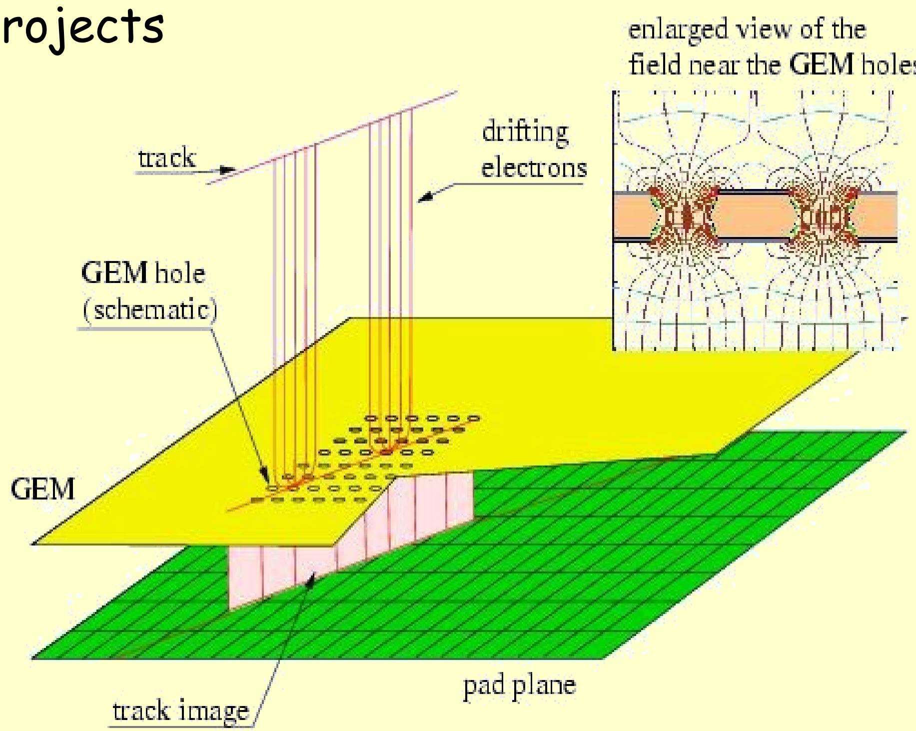
A TPC tracker for the ILC

Proposed solution:

- Based on micro-pattern (MP) gas detectors
- GEM/ micromegas
- Mechanically potentially simpler
- Less material
- Less systematic effects (potentially)
- Not yet proven in large scale projects

- Many space point
- true 3D points
- Excellent Pattern Recognition
- Large volume coverage

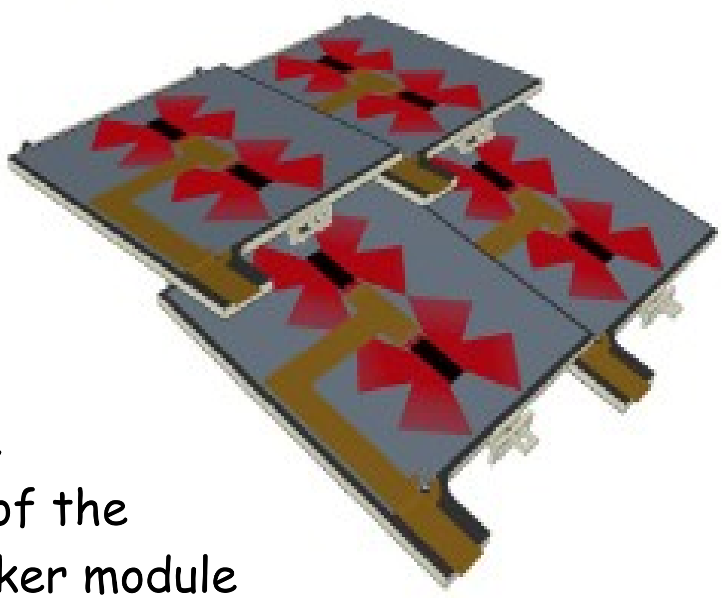




Silicon based tracking

Addition to the TPC based tracking:

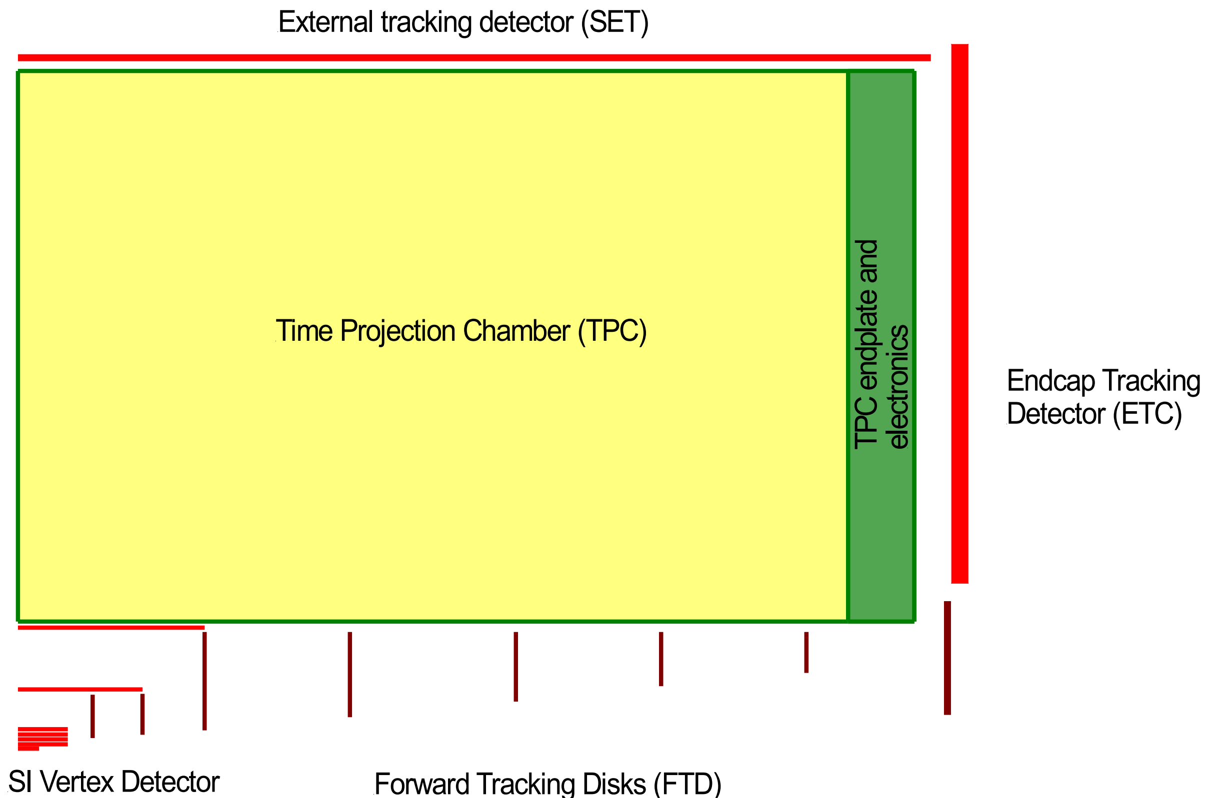
- SI strip detectors to complement the TPC
- A few high precision points replace inside (and outside)



- Improved momentum resolution
- Impact on material budget
  needs to be studied

Possible
Layout of the
SI tracker module

Forward Tracking/ Event Reconstruction

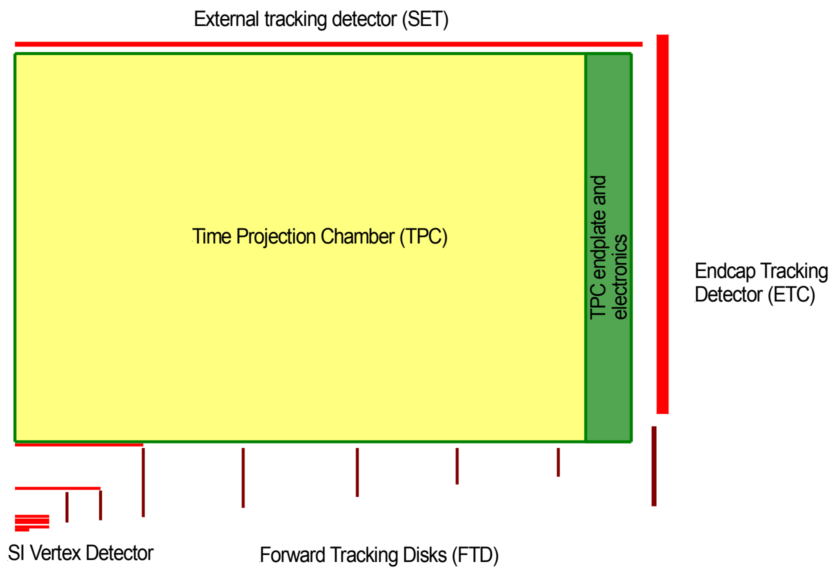


Tracking behind the TPC is an issue:

- Needed?
- How good?
- Where?
- Impact on calorimetry?
- technology

Potentially very powerful forward tracking system but careful evaluation of performance is missing

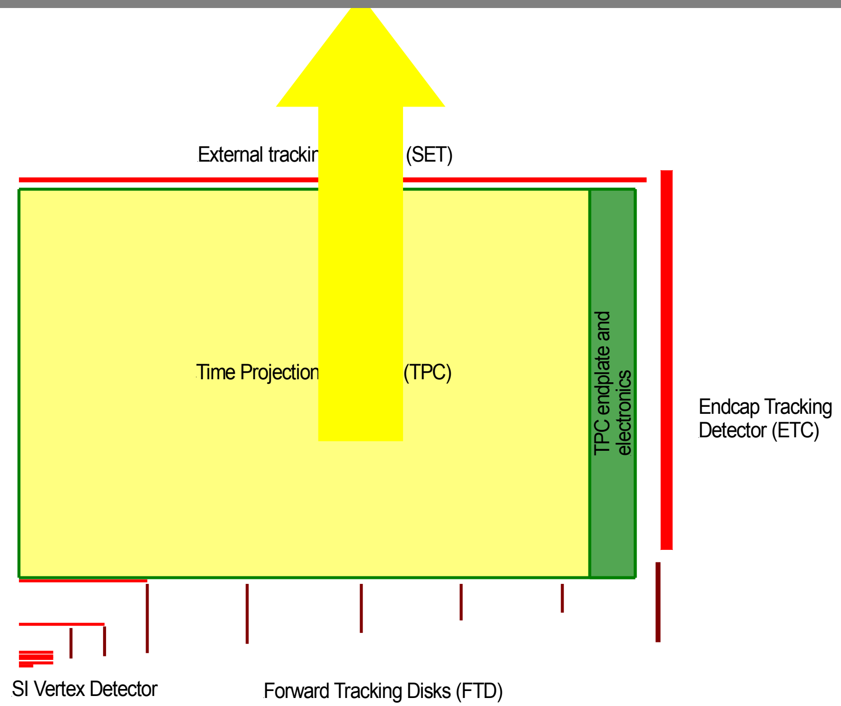
Open Issues in Tracking



Open Issues

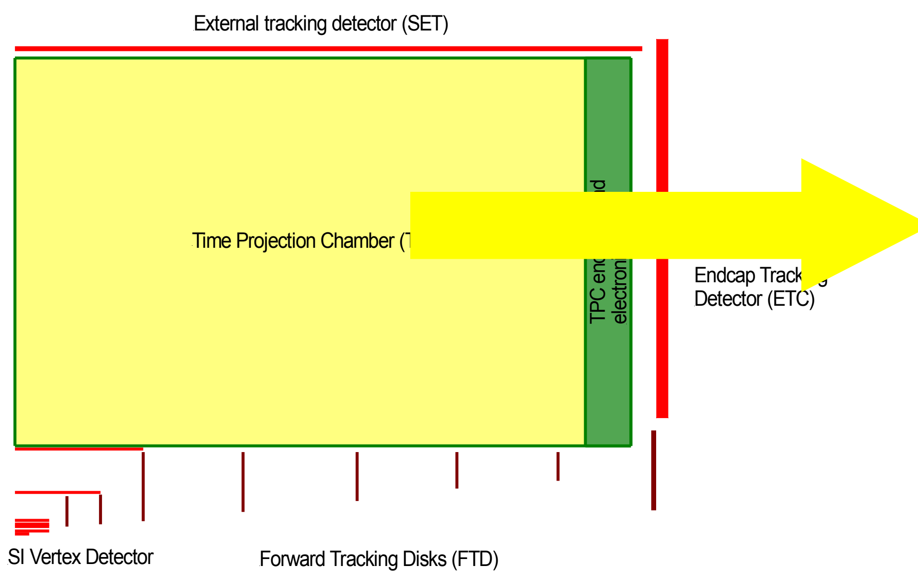
… many …

Final resolution? Control of systematics



Open Issues

... many ...



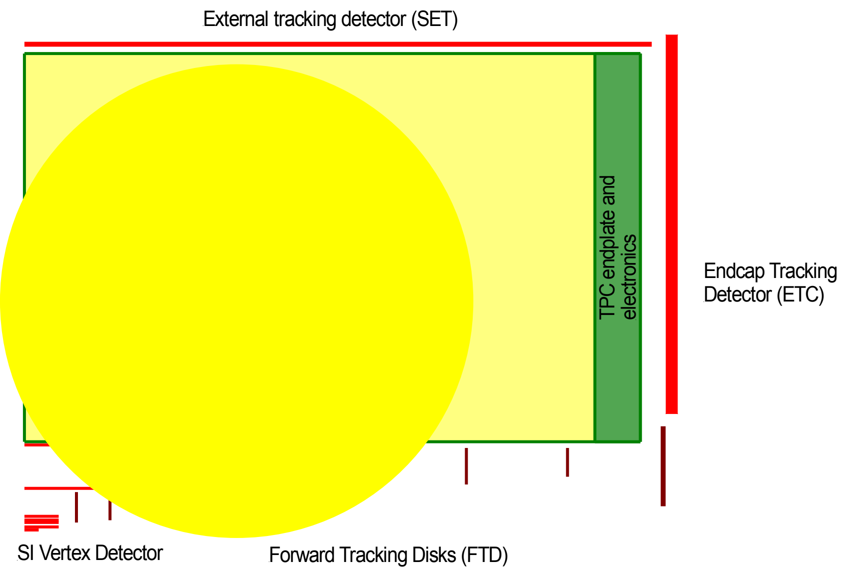
Endcap design, interference with the calorimeter

material in endcap?

Open Issues

... many ...

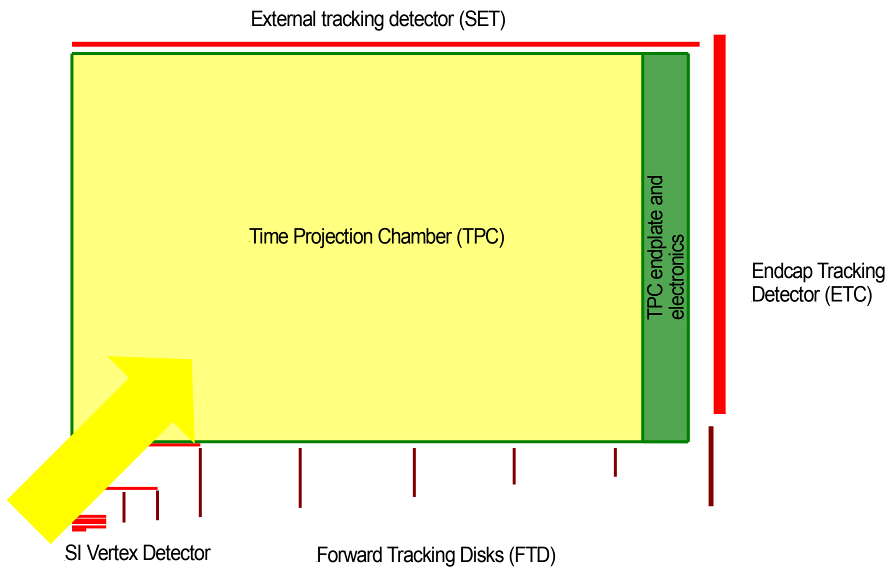
TPC or SI tracking?



Even though ILD has decided to use a TPC, we should understand and justify this decision

Open Issues

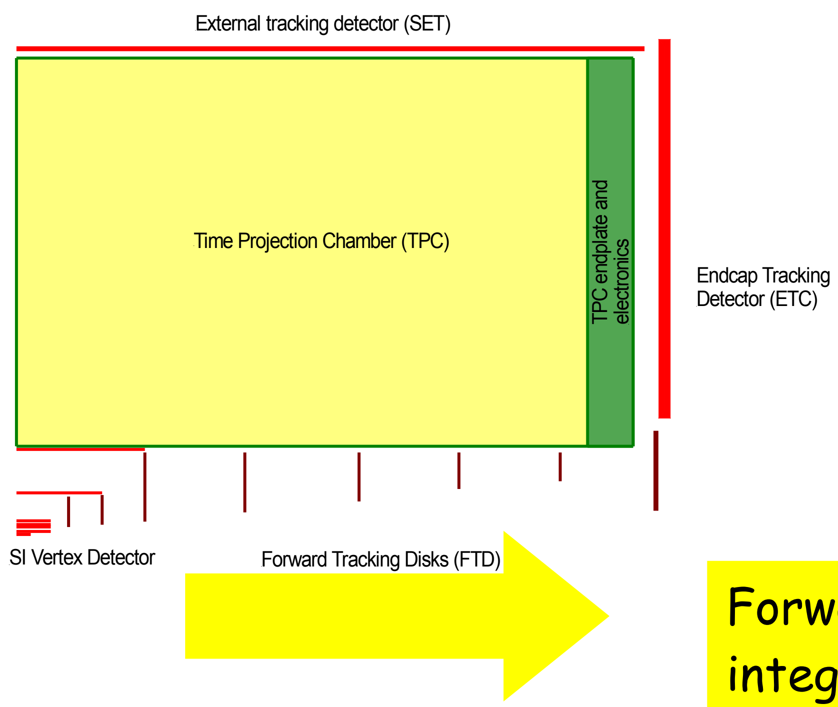
... many ...



VTX detector layout integration into the rest?

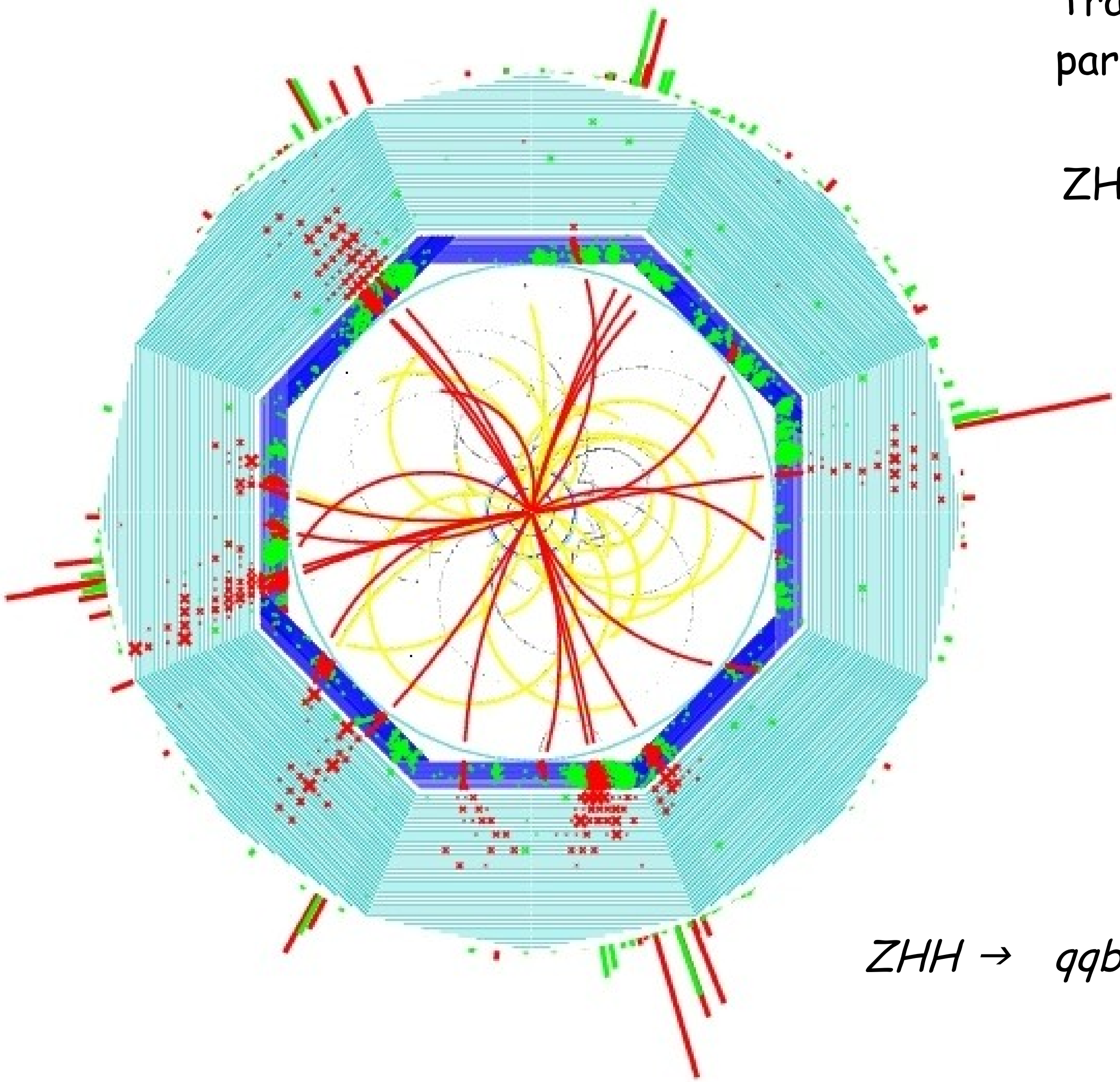
Open Issues

... many ...



Forward tracking integration into the rest?

A ZHH event at the ILC



Track reconstruction is only part of the story

ZHH->qqbbbb event at 500 GeV

many jets (6)

lots of tracks

but still much cleaner than any hadron collider can dream of

ZHH → qqbbbb

Event Reconstruction

Excellent jet reconstruction needed

SiD/ LDC/ GLD

Individual particles
particle identification
“calculation” of total jet energy/ mass

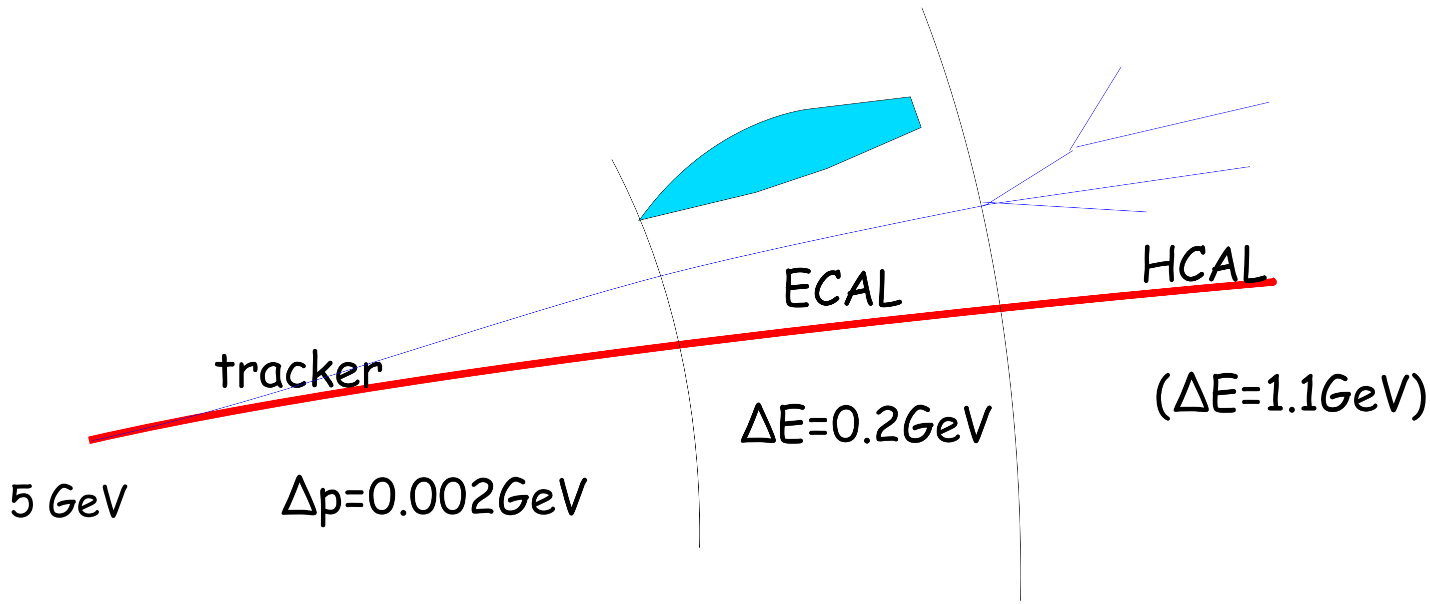
→ **Particle flow**

4th

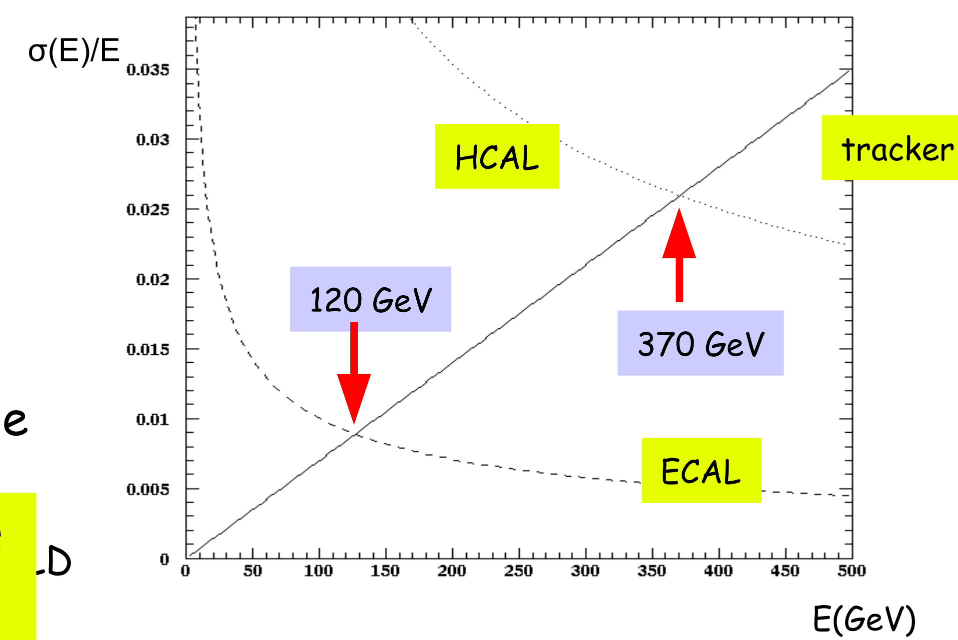
Individual jets
hardware compensation
“measurement” of total jet energy

ILD is very much concentrated on particle flow!

What is Particle Flow



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

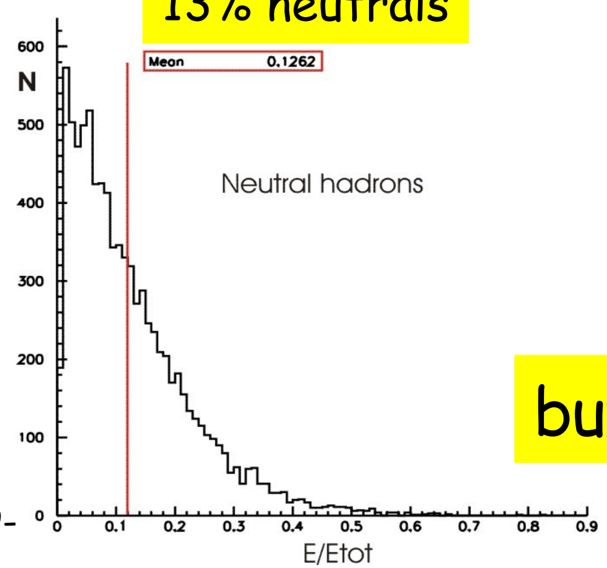
- Jet energy resolution
  $\sigma^2(E_{jet}) = \sigma^2(ch.) + \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(conf.)$
- Excellent tracker :
  $\sigma^2(ch.) \ll \sigma^2(\gamma) + \sigma^2(h^0) + \sigma^2(conf.)$
- Perfect PFA : $\sigma^2(conf.) = 0$
  $\sigma^2(E_{jet}) = A_\gamma E_\gamma + A_h E_{h0}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

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

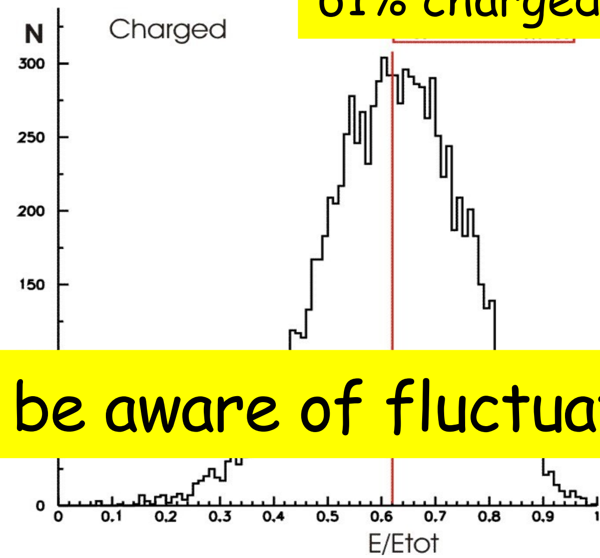
$A_g = 11\%$; $A_{h0} = 34\%$
=> $s(E_{jet})/E_{jet} = 14\%/\sqrt{E_{jet}}$

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

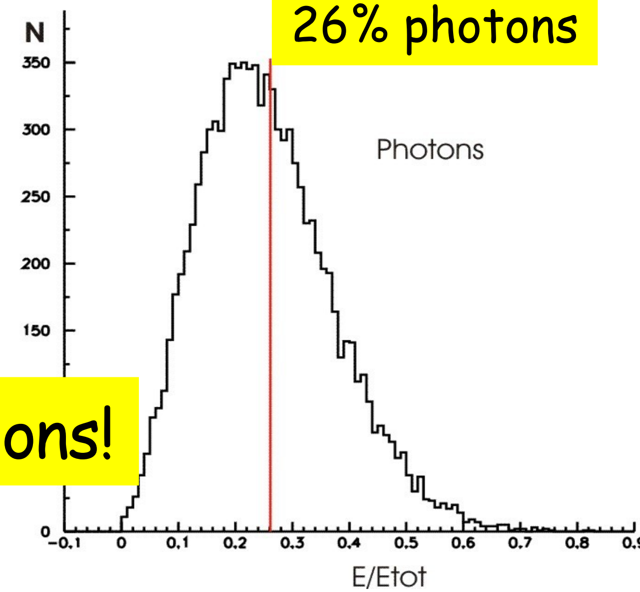
13% neutrals



61% charged



26% photons



but be aware of fluctuations!

Factors Contributing to Z Mass Resolution

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

Studies by
P. Krstonosic

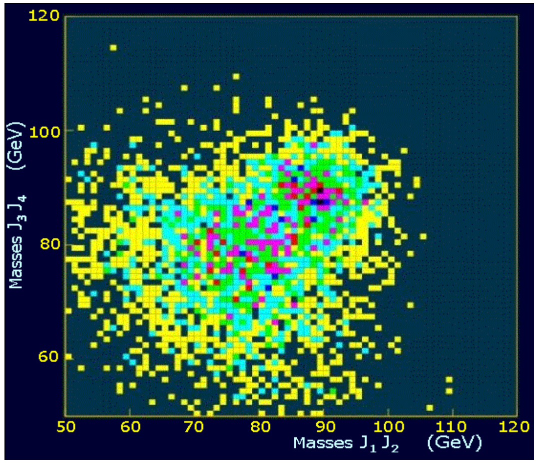
Effect	σ [GeV] separate	σ [GeV] not joined	σ [GeV] total ($\%/\sqrt{E}$)	σ to total
$E_\nu > 0$	0.84	0.84	0.84 (8.80%)	12.28
$Cone < 5^o$	0.73	1.11	1.11(11.65%)	9.28
$P_t < 0.36$	1.36	1.76	1.76(18.40%)	32.20
σ_{HCAL}	1.40	1.40	2.25(23.53%)	34.12
σ_{ECAL}	0.57	1.51	2.32(24.27%)	5.66
M_{neutral}	0.53	1.60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

What do we want?

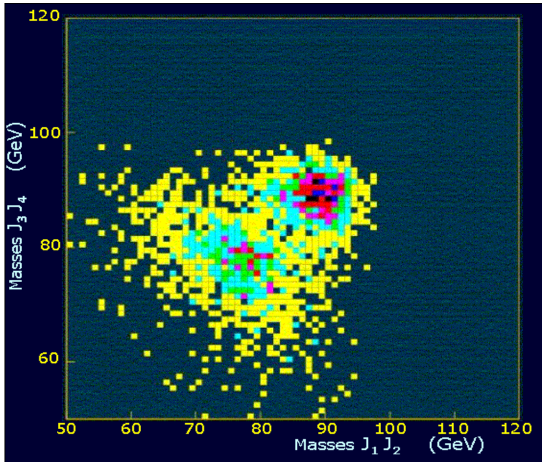
Traditional ILC goal: 30%/√E

Derived from physics studies, but needs to be interpreted with care

60%/√E



30%/√E



WW/ ZZ separation studies

Clearly a too simplistic view:

- Constant term becomes dominant at high energies
- Simple scaling produces unrealistic resolutions

To be understood

More realistic goal: 30%/√E (√GeV) ⊕ C(%) with C=2-4%

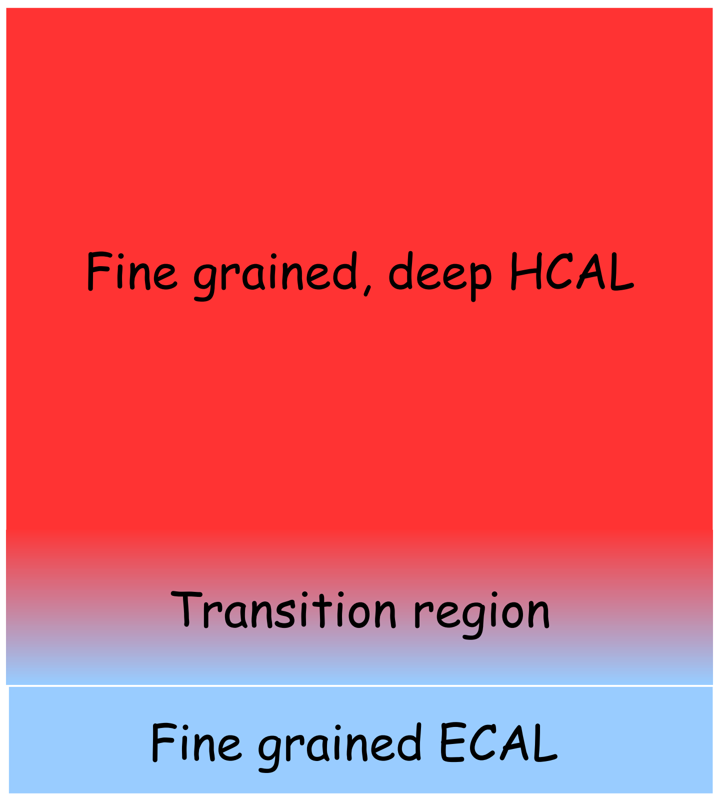
see work by Mark

The ideal PFLOW calorimeter

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

Traditional energy resolution is important

but not so critically



containment

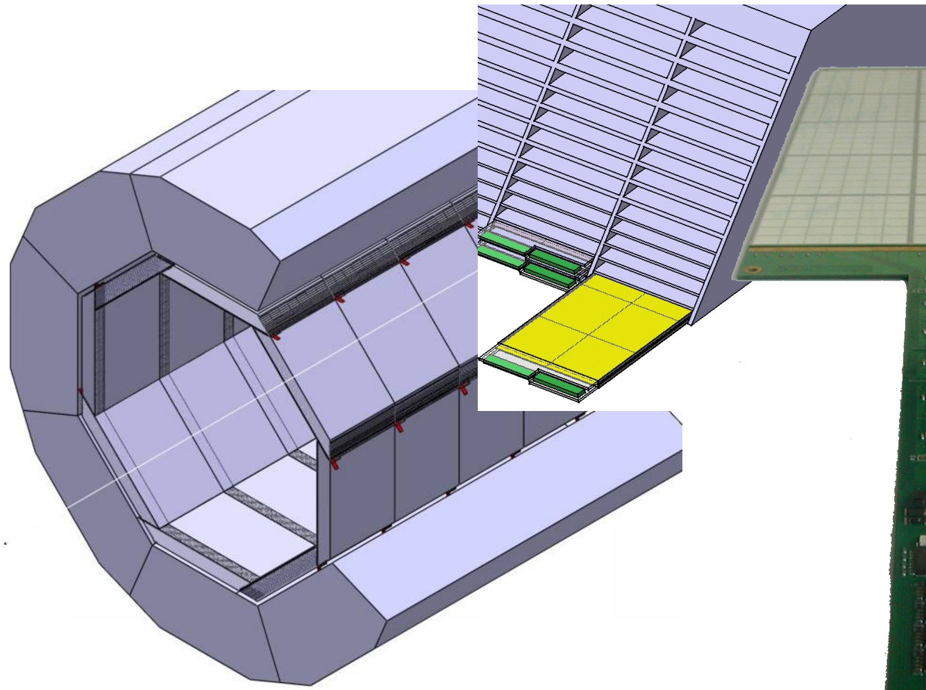
Granularity and longitudinal sampling

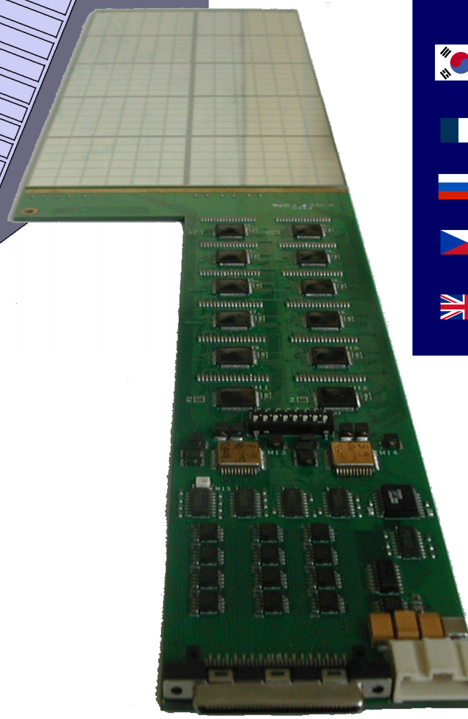
As deep as possible

Granularity: “tracking”

HCAL becomes very important for ultimate precision

SiW ECAL





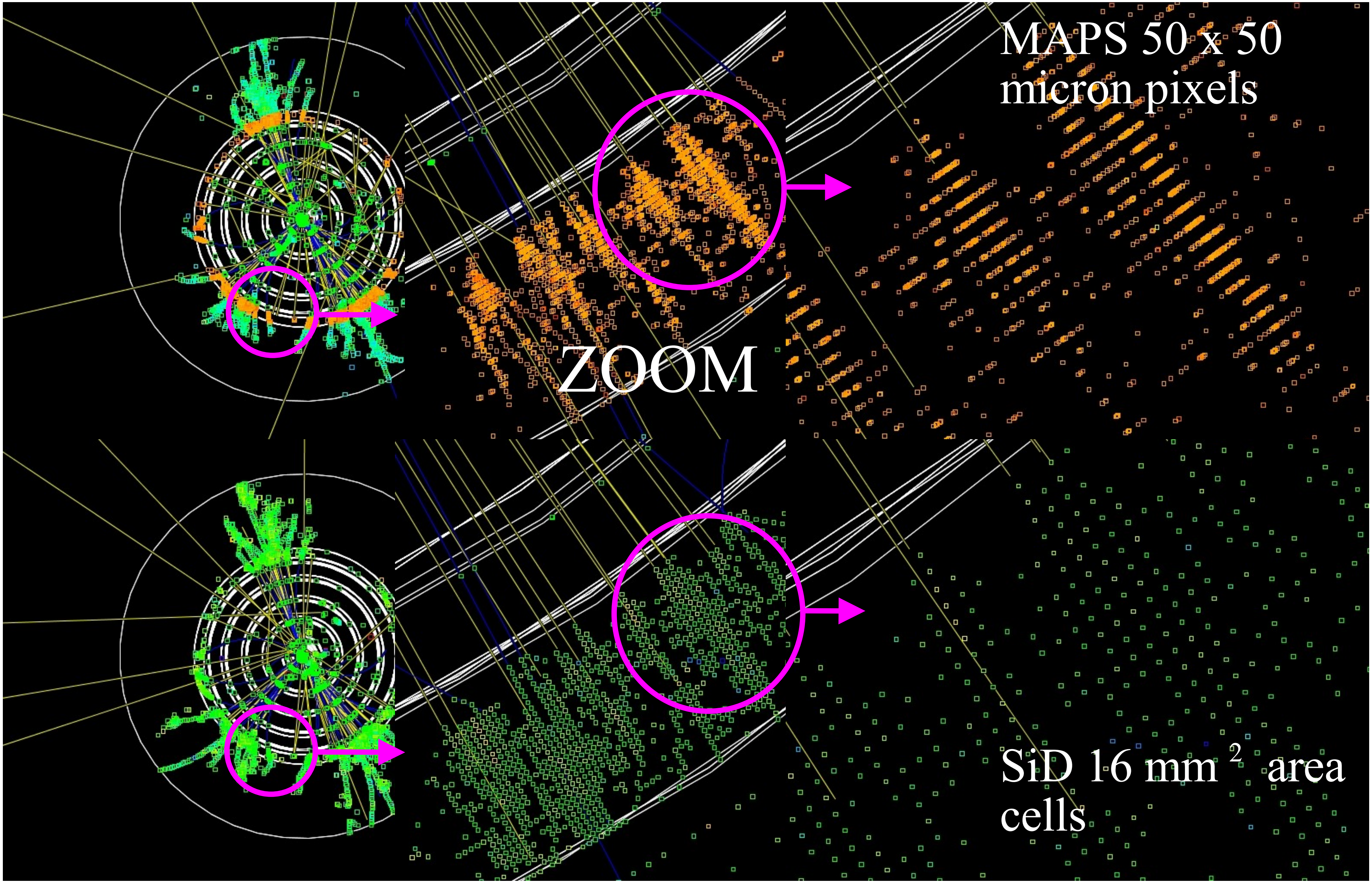
CALICE - ECAL

- Ewha Univ., Sungyunkwan Univ., Kangnung NU , Yonsei Univ.
- LAL,LLR,LPC-Ct, LPSC, PICM
- ITEP,IHEP, MSU
- Prague(iop-ascr)
- Imp. Coll, UCL, Cambridge Birmingham, Manchester,RAL, RHUL

1 x 1 cm granularity

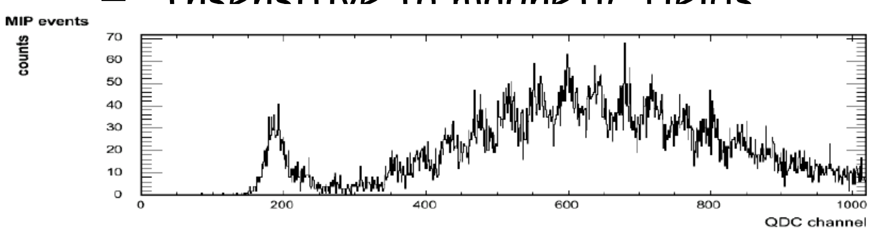
- W is absorber material
- SI detectors as active medium
- 30 layers, 24 X_0 (20 cm), 1x1 cm^2 cells
- Alveolar structure, carbon wrapped W
- 9720 channels – in an $(18\ cm)^3$ cube

Extreme Segmentation?

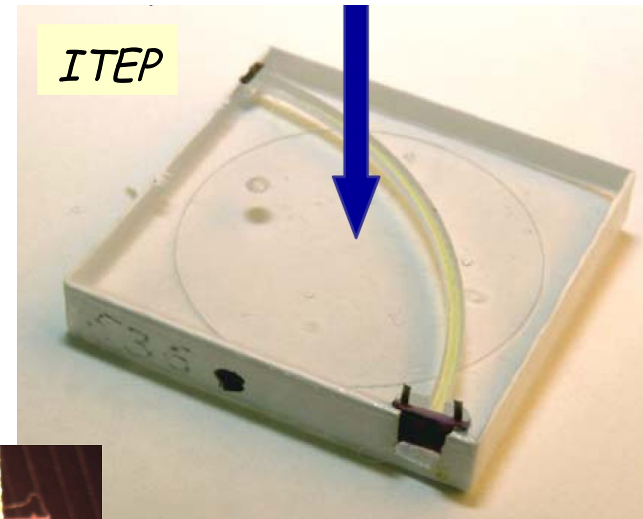


Silicon based photon detectors for the HCAL

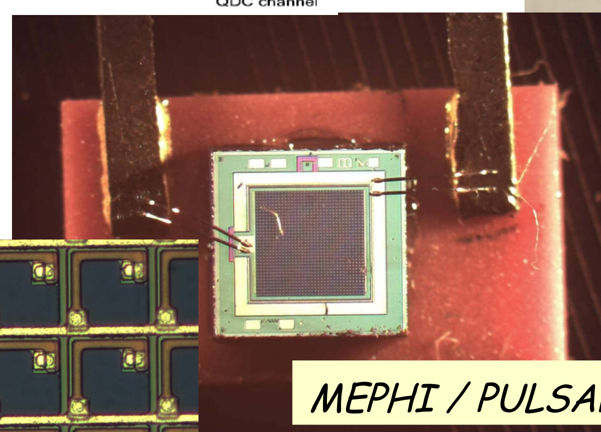
- Multipixel Geiger Mode APDs
  - Gain 10^6, bias ~ 50 V, size 1 mm^2
  - Insensitive to magnetic fields

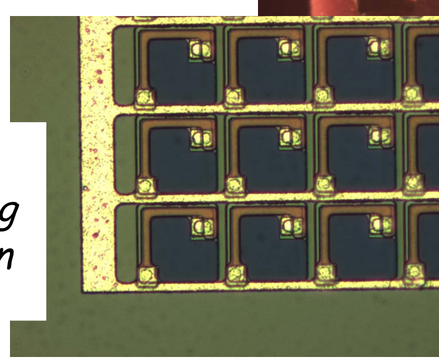


Auto-calibrating but non-linear



3x3 cm scintillator tile with WLS fibre





1156 pixels with individual quenching resistor on common substrate

New era for scintillator-based detectors:
High granularity** at relatively **low cost

HCAL sensor technologies

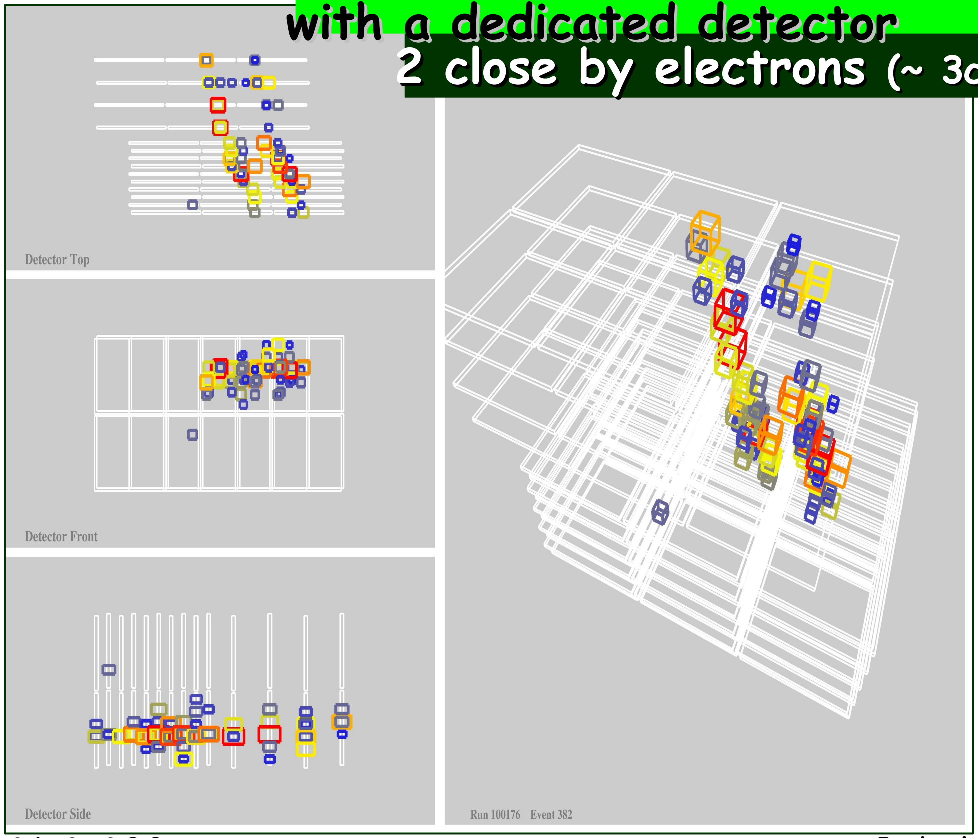
- Scintillators
  - Trade amplitude resolution against granularity: analogue or semi-digital readout
  - Goal: Detector architecture with embedded sensors and electronics

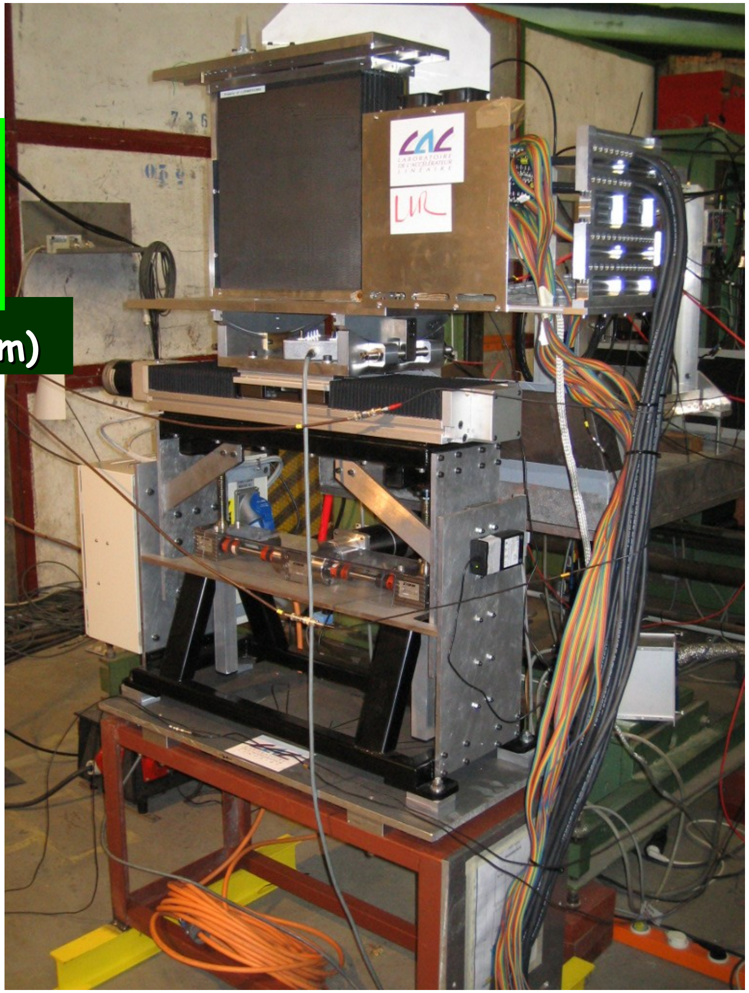
- Gaseous: Glass RPC or GEM foils
  - Natural choice for finest granularity
  - Digital readout for 50 million channels?

ECAL Test Beam (CALICE)

First real test versus
the « Particle Flow » method
with a dedicated detector

2 close by electrons (~ 3cm)



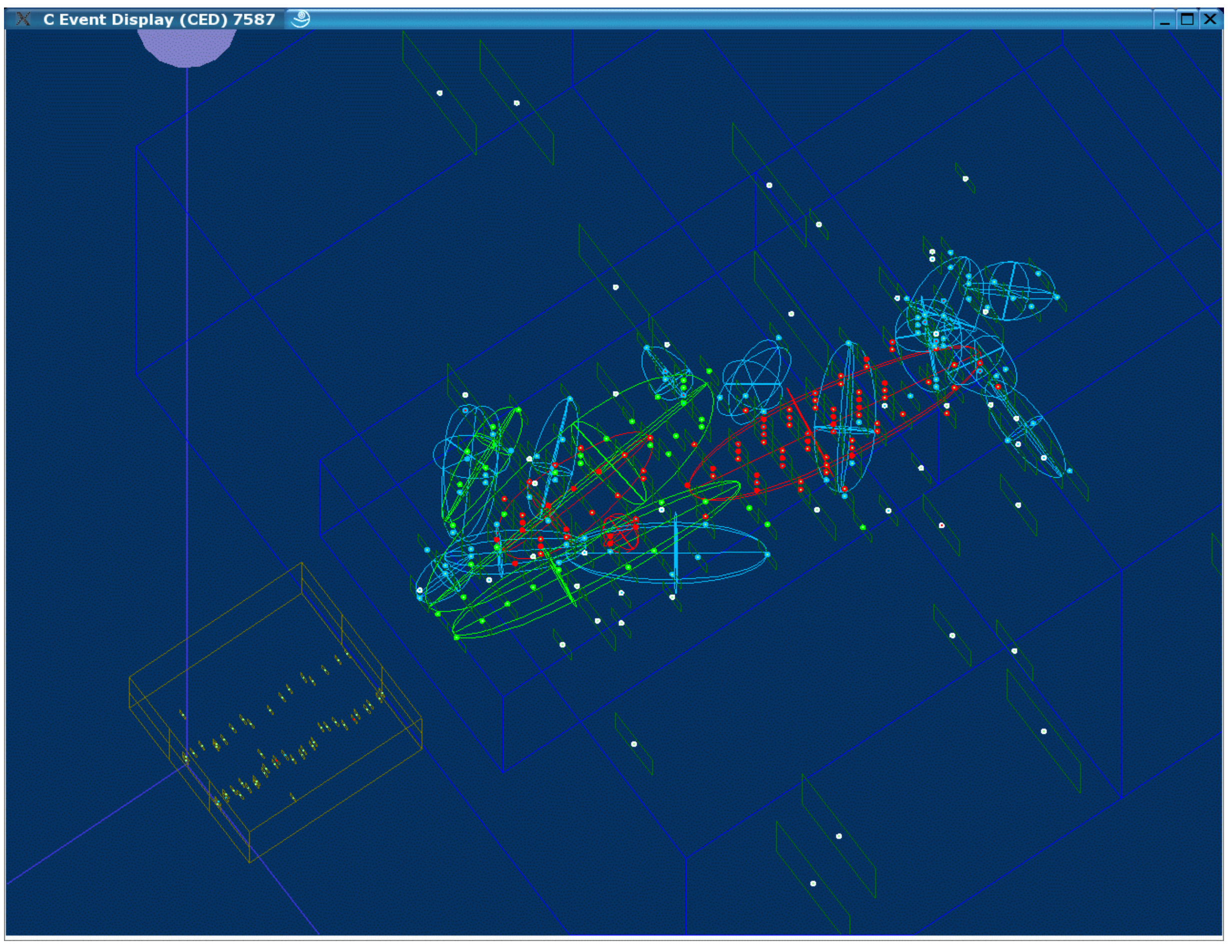


ECAL/ HCAL Test Beam (CALICE)

Major effort to test

- Technologies
- Shower physics

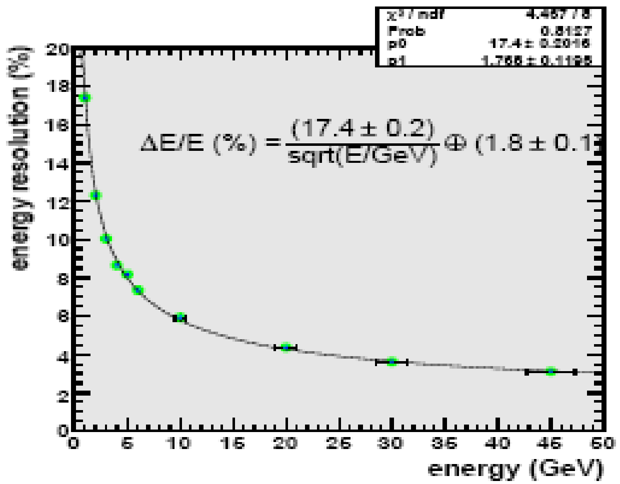
Combined ECAL/ HCAL/ Tailcatcher
test beam at CERN (2006/7) FNAL (2007/8)



2 track event
recorded at the CERN
test beam

with reconstruction
run on the data

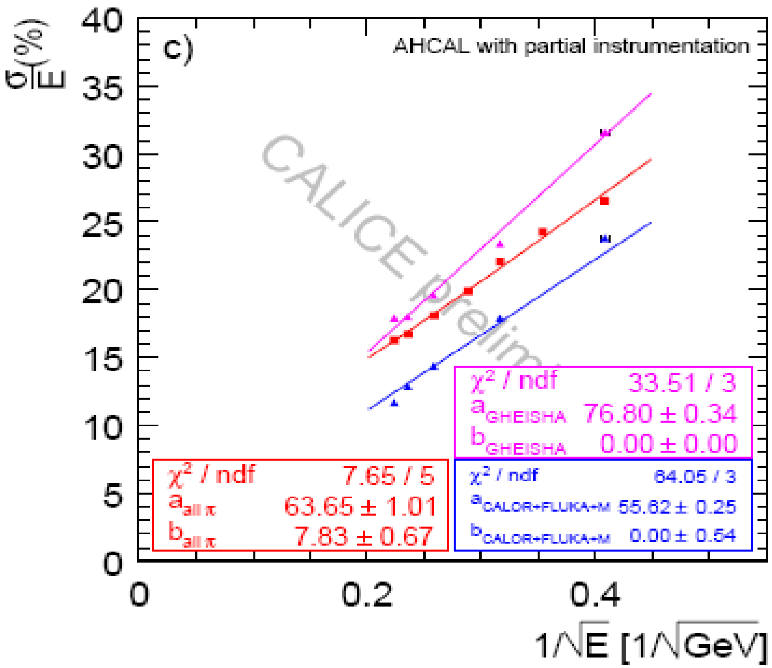
Results



Measured energy resolution in the ECAL

Not fully corrected data
(work ongoing in UK and elsewhere)

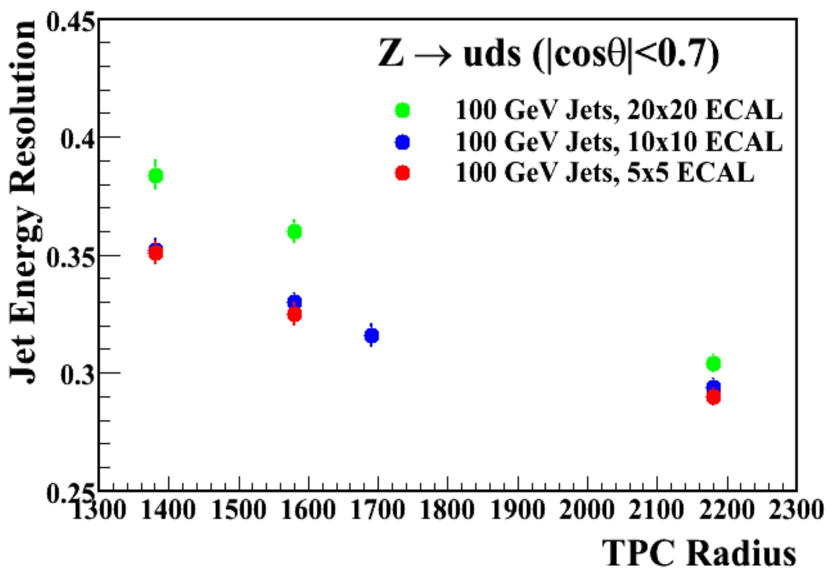
Energy resolution HCAL
with partial instrumentation
($\frac{1}{2}$ number of layers)



Lots of data accumulated, analyses are very preliminary
Expect many new and interesting results in the near future

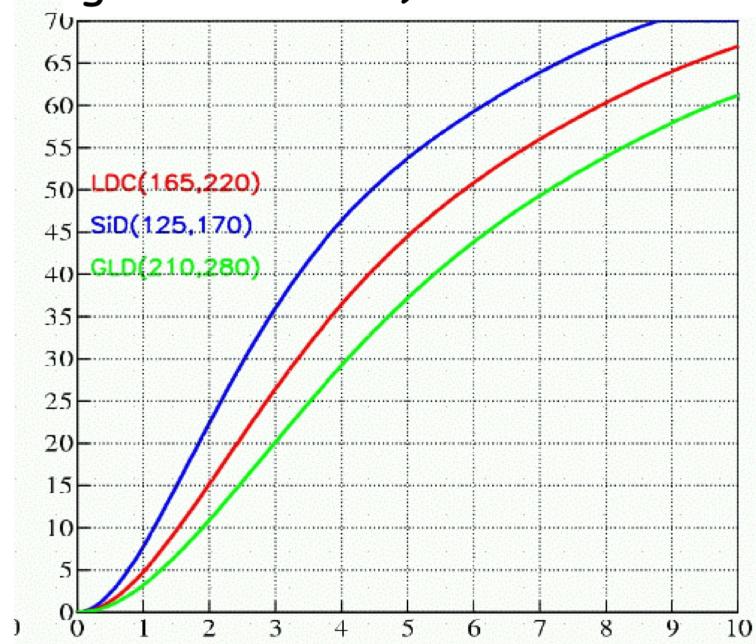
Detector Optimization: ECAL

Brient 2004
Thomson 2007



First full reconstruction results

Photon separation
(fraction of second photon within given distance)



Cell size in cm

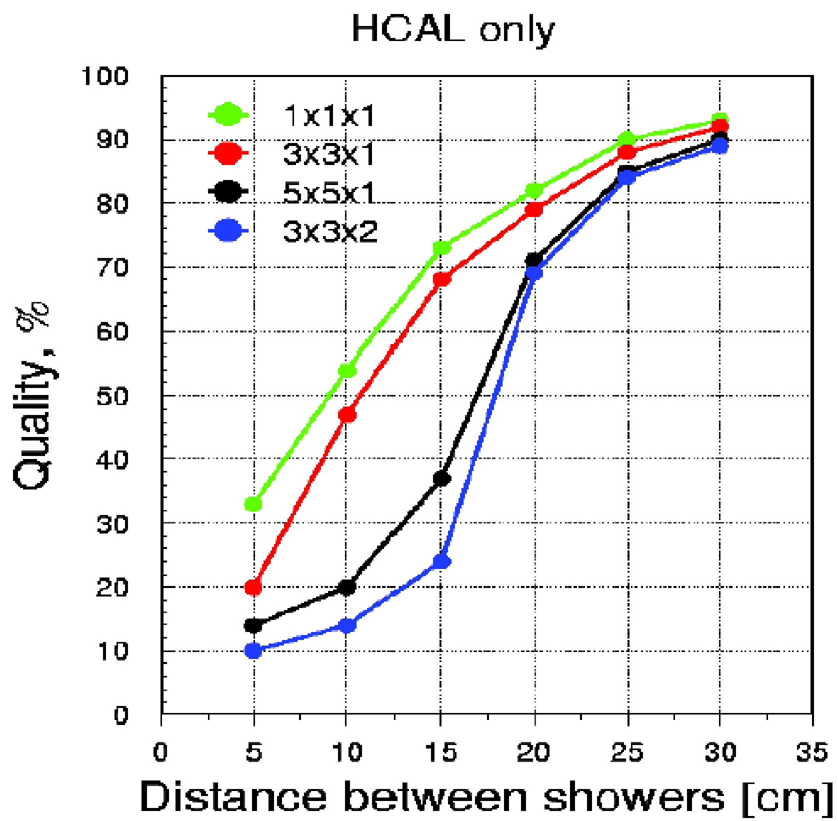
1x1 cm^2 cell sizes seem reasonable

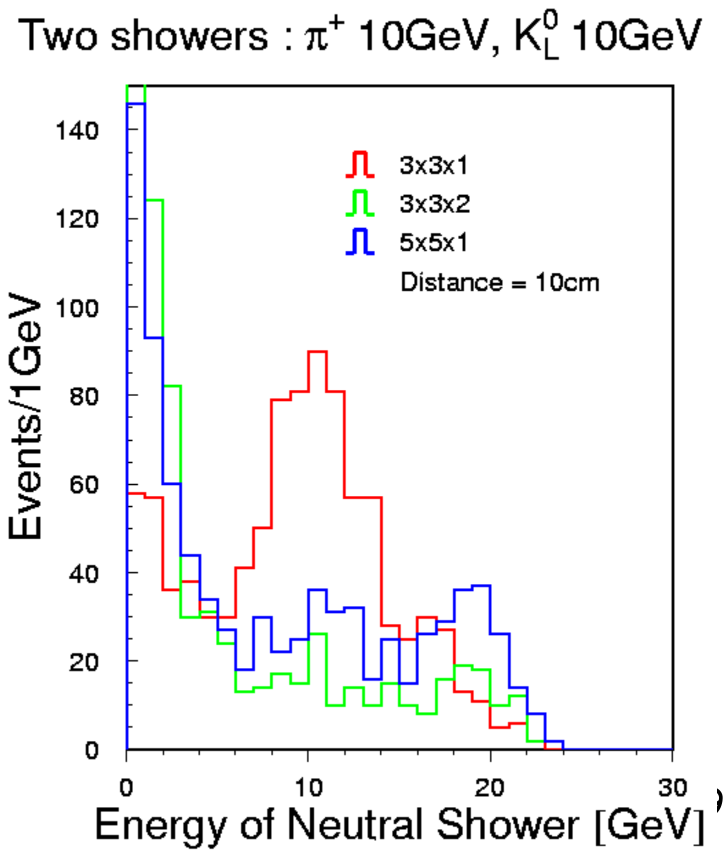
not a huge gain by smaller cells seen at the moment

Detector Optimization: HCAL

A. Raspereza,
V. Morgunov,
Snowmass 2005

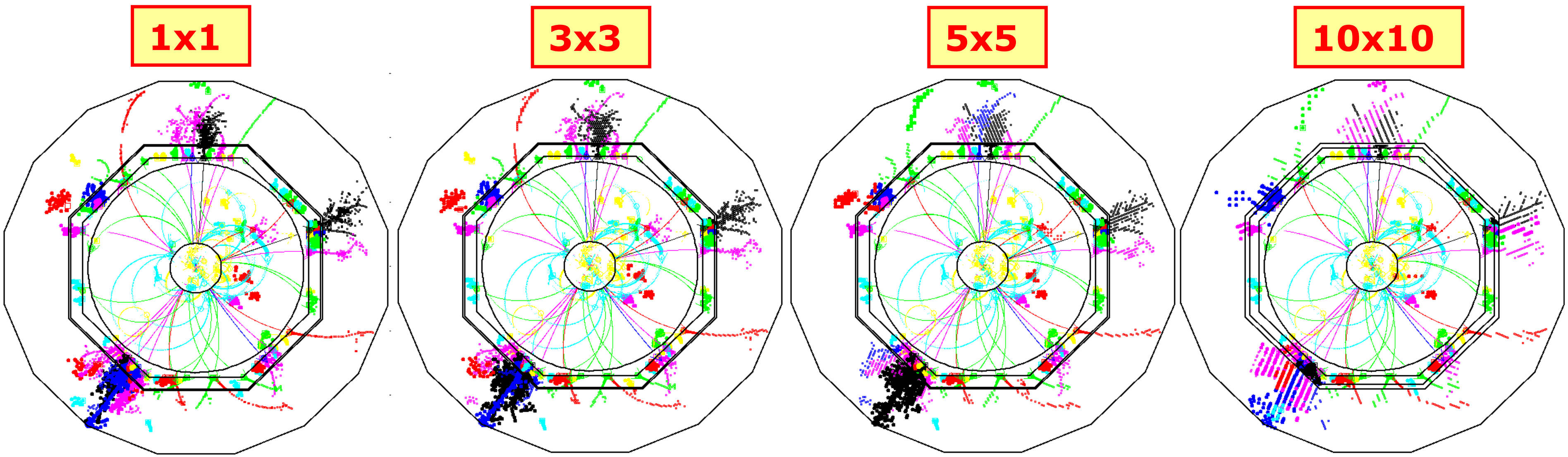
HCAL optimization:
reconstruction of overlapping hadronic showers

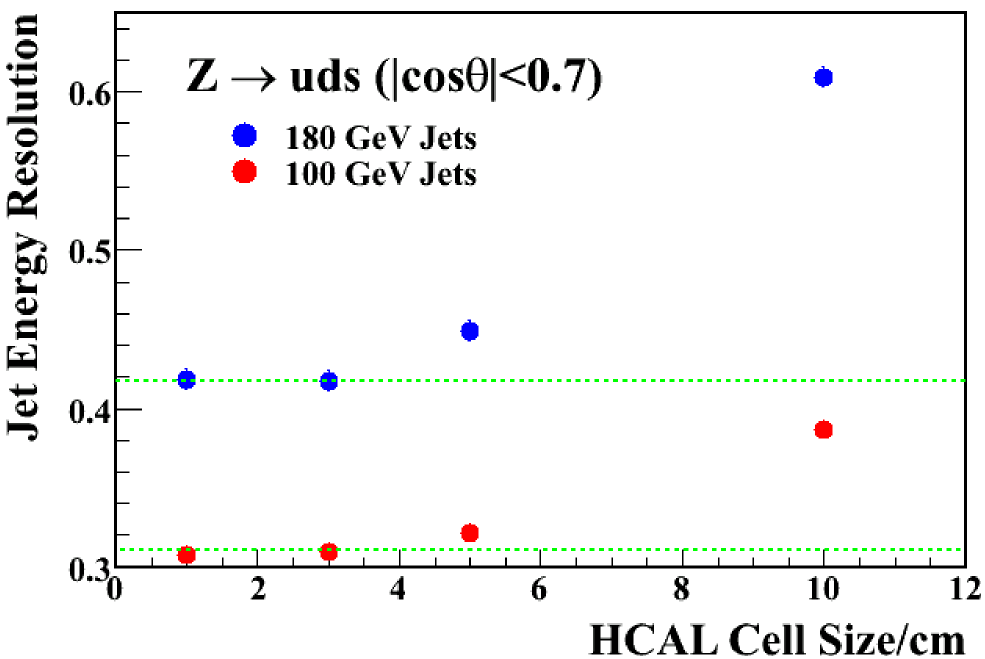




Detector Optimization: HCAL

M. Thomson, Paris 2007



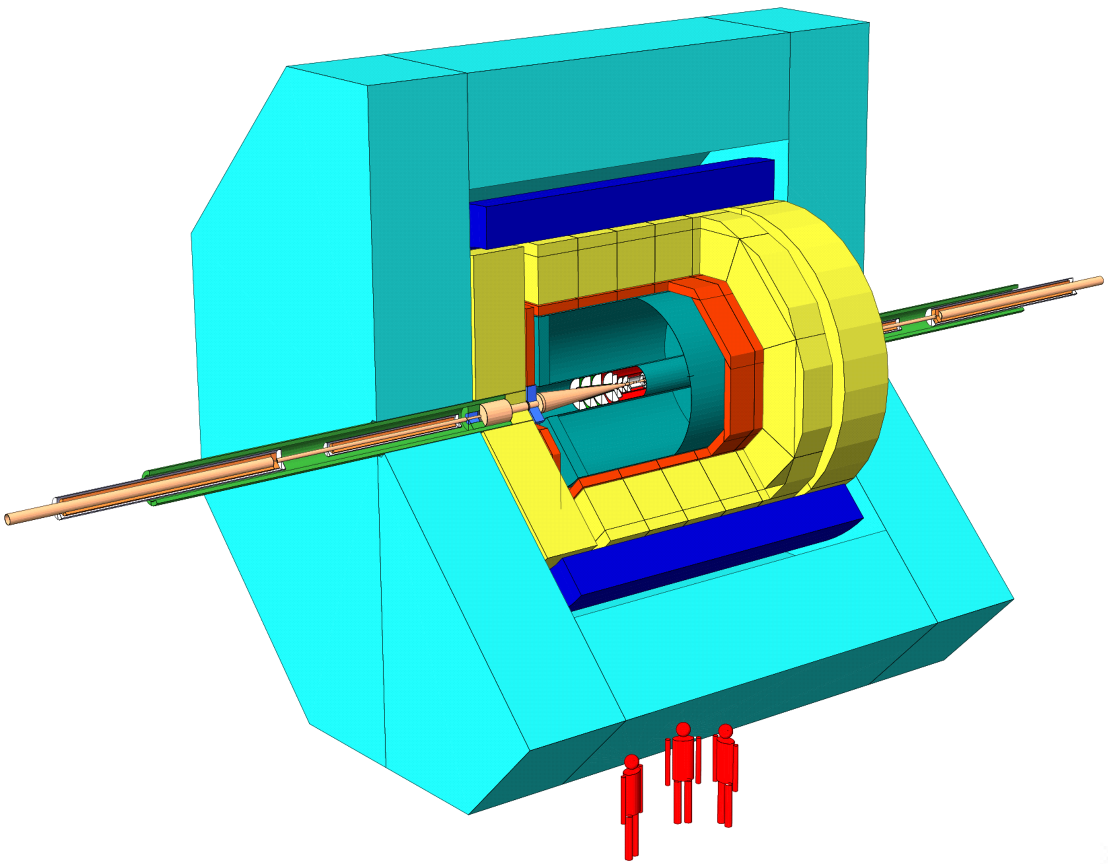


"Preliminary Conclusions"

- 3x3 cm² cell size ok
- No advantage → 1x1 cm²
  - physics ?
  - algorithm artefact ?
- 5x5 cm² degrades PFA

Update today

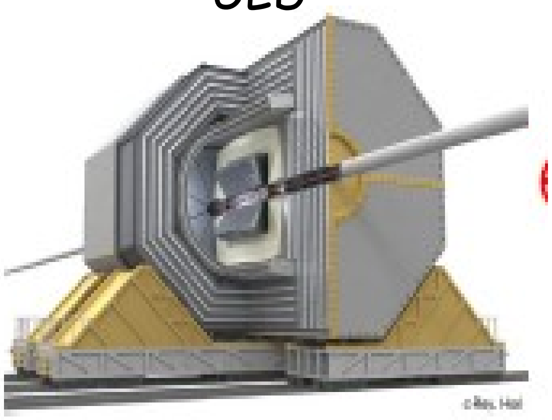
The real thing



The LDC concept

small by LHC standards, but still pretty sizable objects

And our new "cousin", GLD

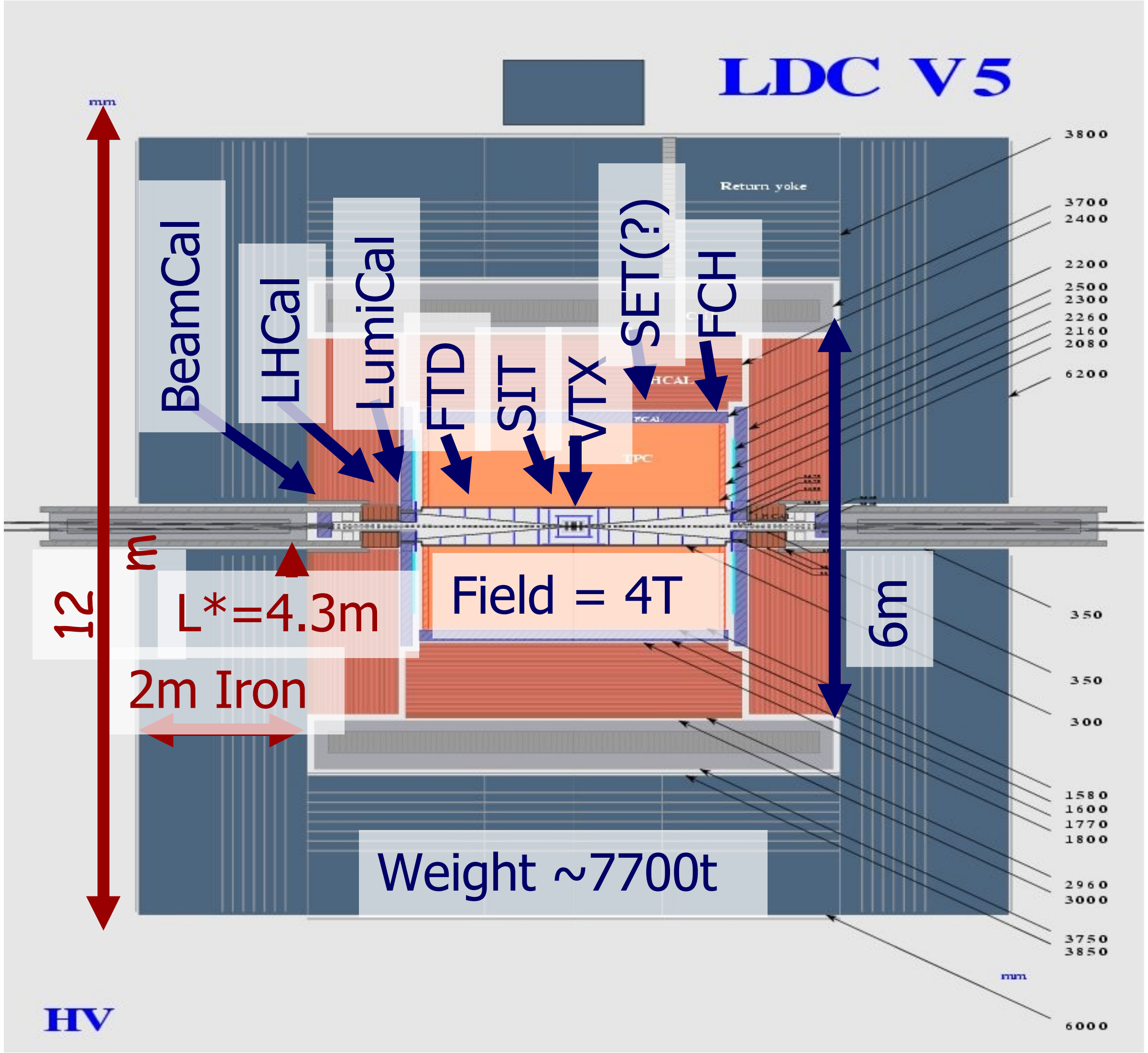


The latest LDC

LDC starting point
for the ILD design

but

ILD will look different
in a few months time

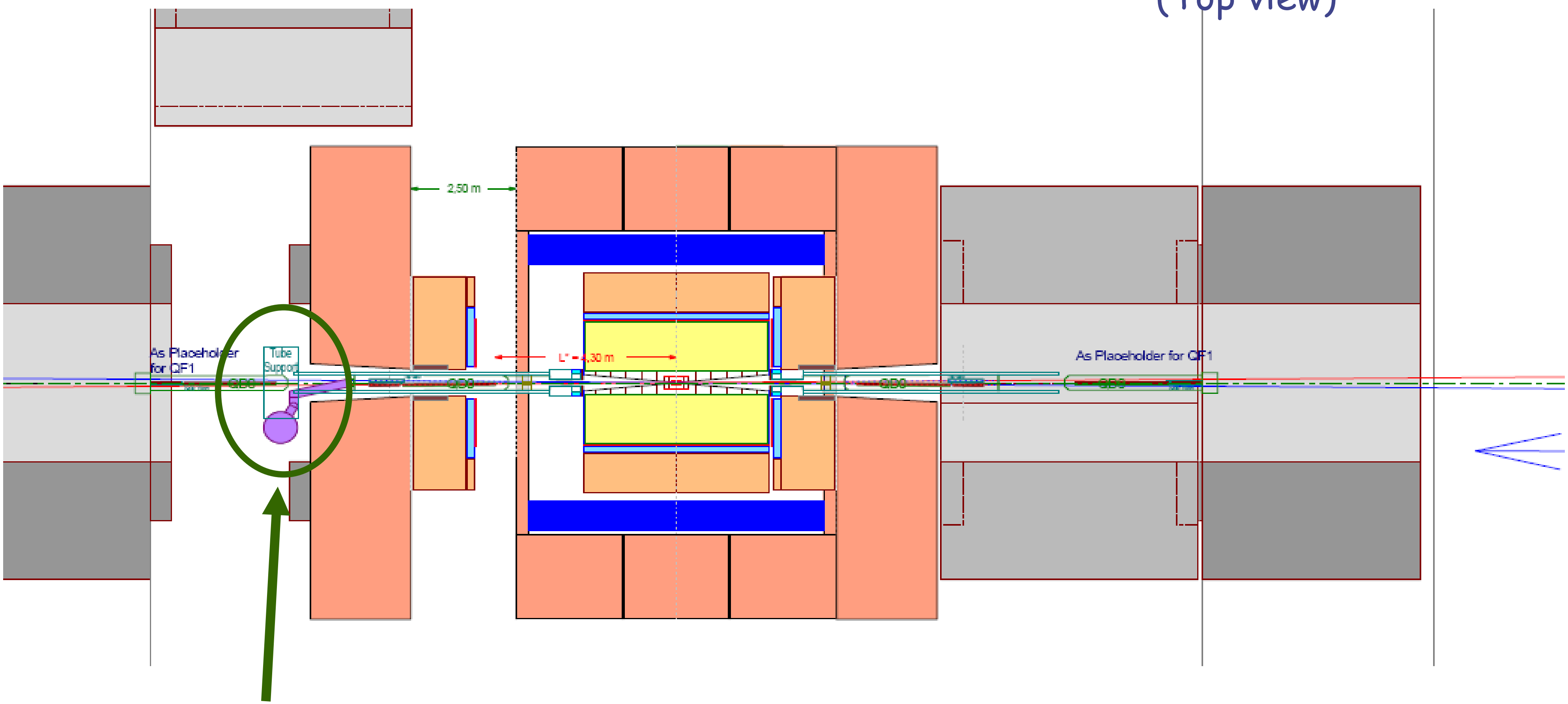


Opening the Detector

Key issue at the moment: place needed for the detetor opening of the detector

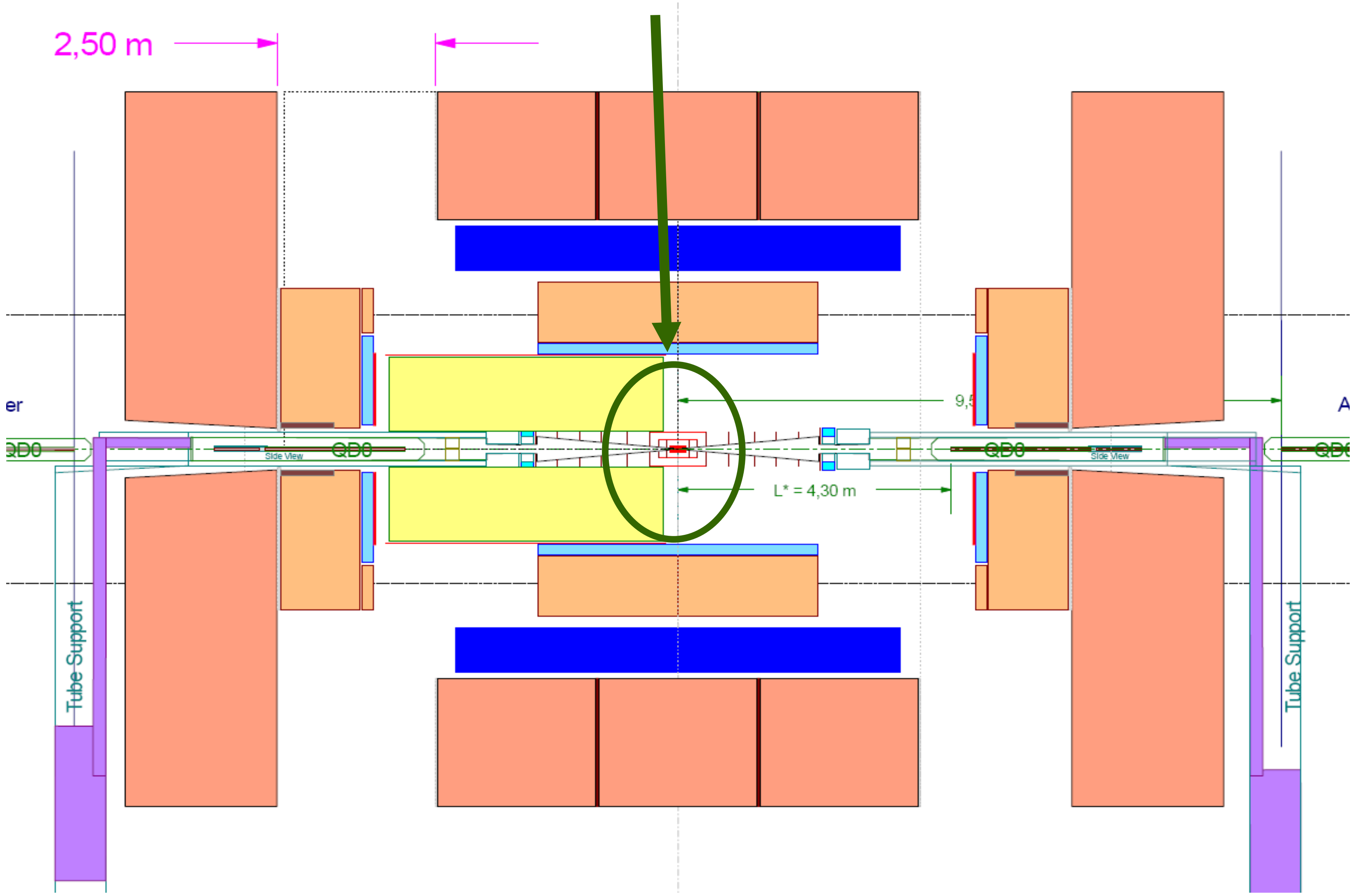
Need 2.5-3m to access the detector

(Top view)

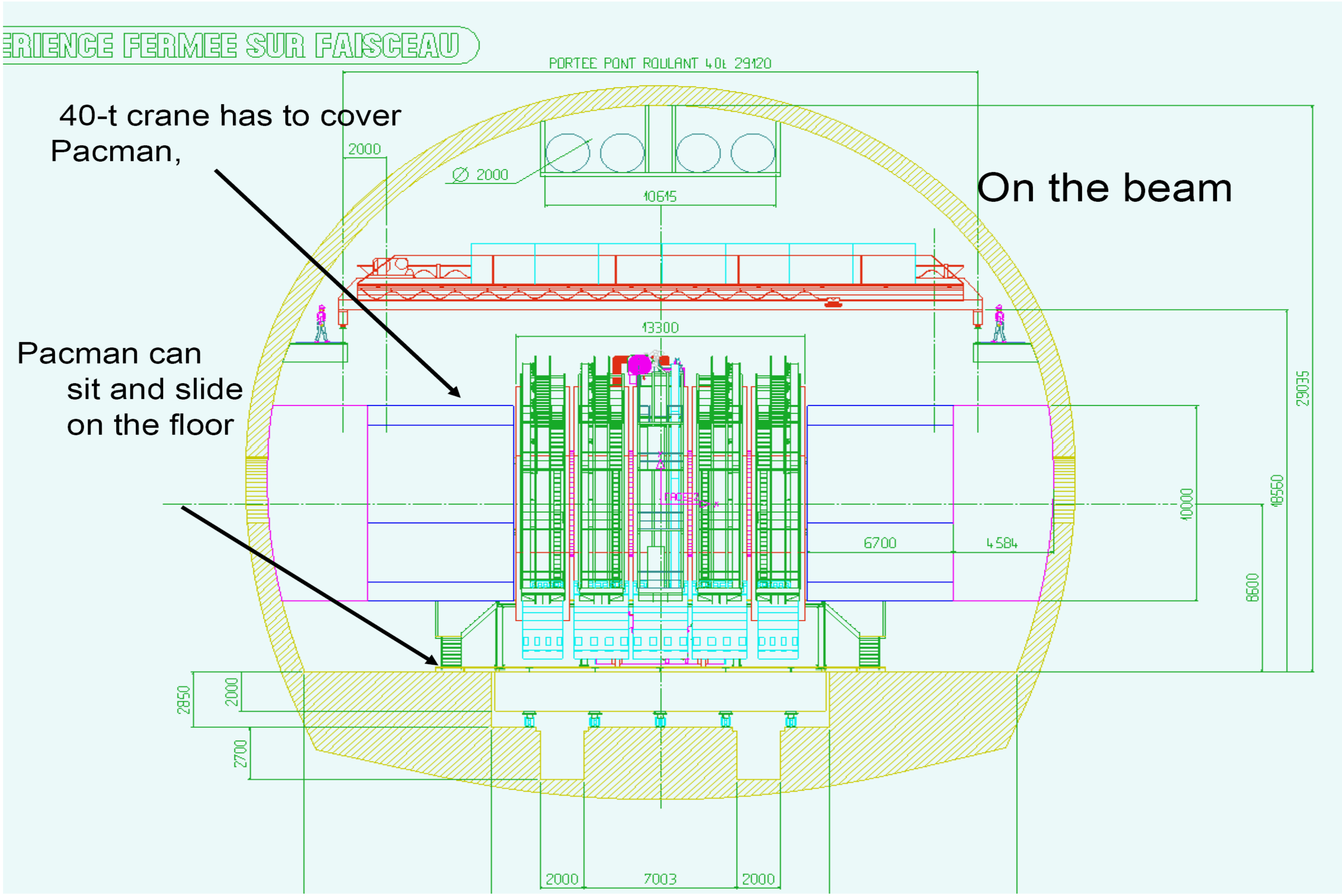


Access to the inner detectors

VTX detector can be serviced



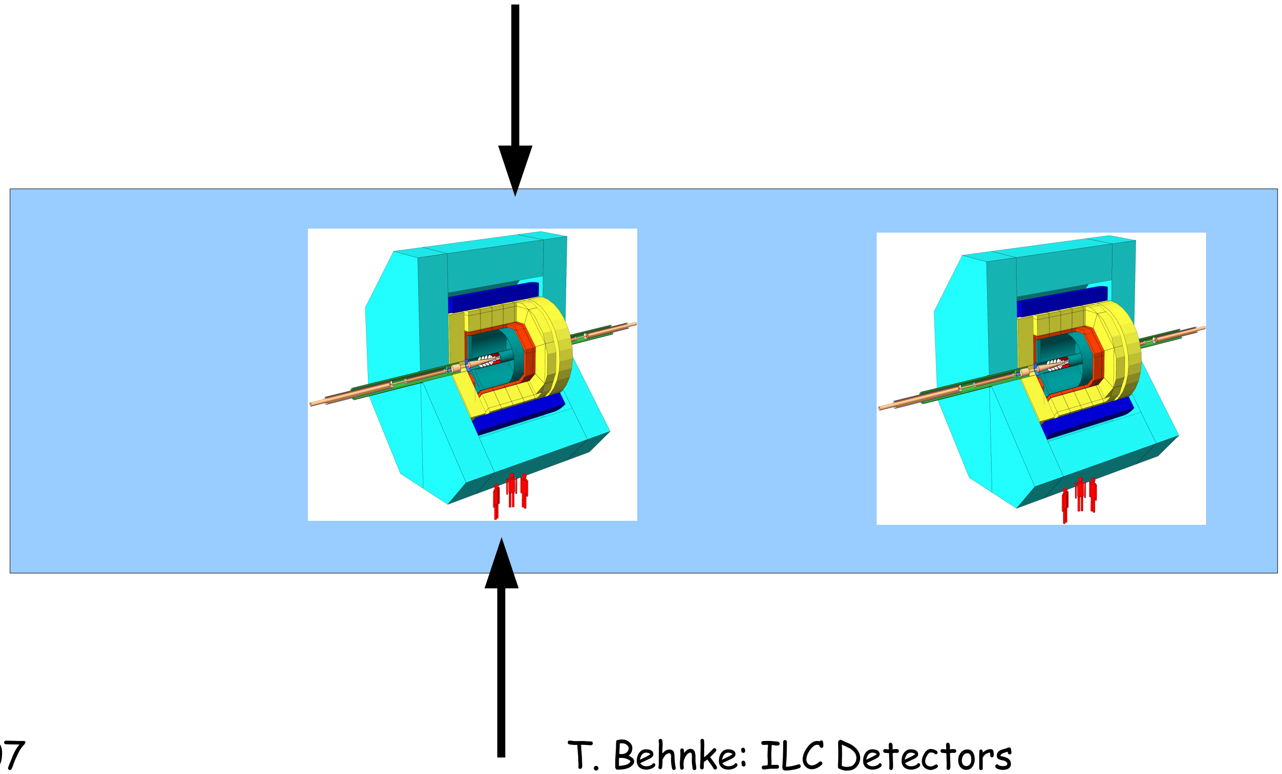
Hall Cross Section



One versus Two? Push-Pull?!

We want two detectors - clear agreement in the community

Cost considerations: 2 IP are too expensive
push pull operation has been proposed



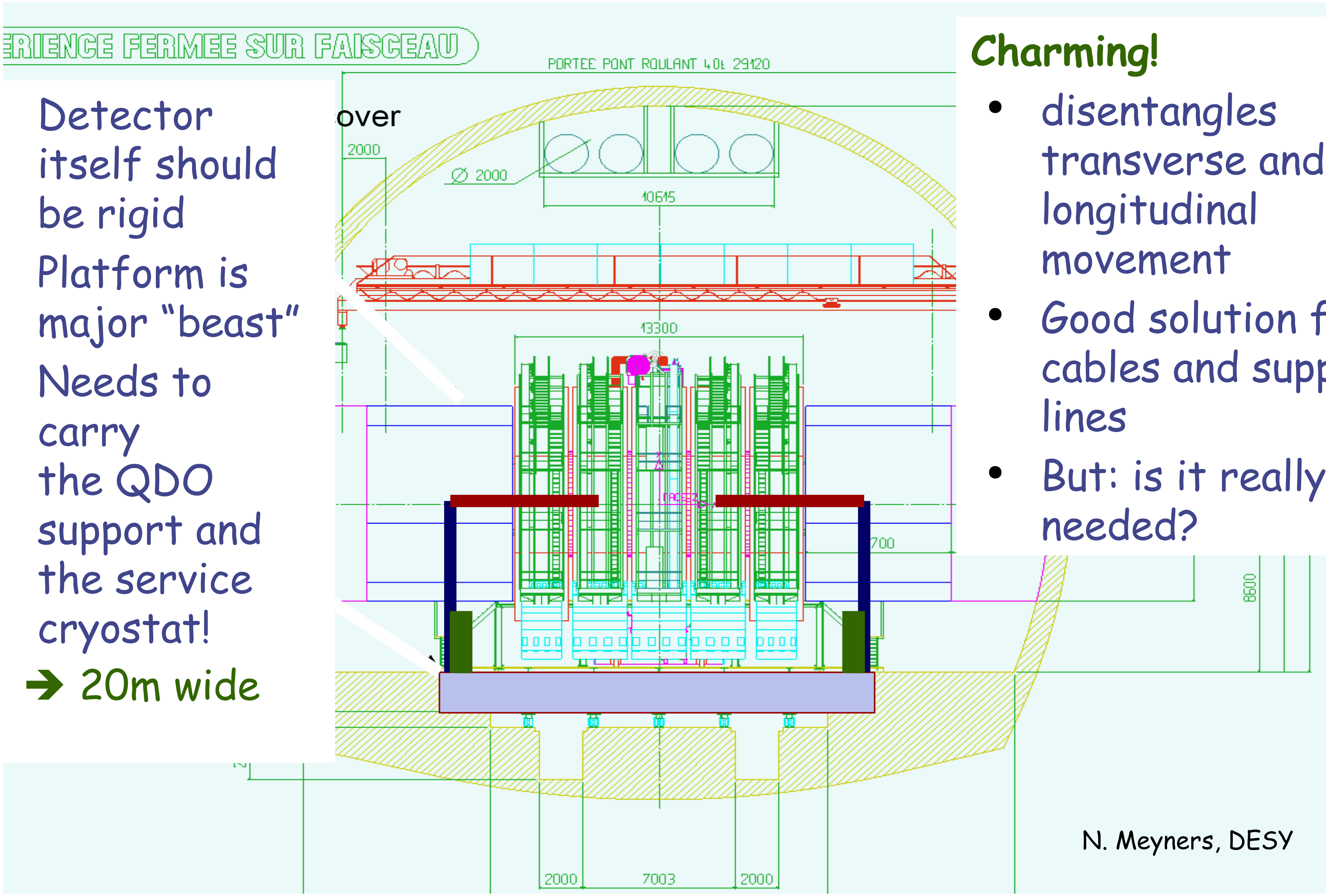
Can this be done?
How quickly?
Loss of efficiency?
Alignment?

Highly non trivial

Detector Platform for Push Pull?

- Detector itself should be rigid
- Platform is major "beast"
- Needs to carry the QDO support and the service cryostat!

➔ 20m wide



Charming!

- disentangles transverse and longitudinal movement
- Good solution for cables and supply lines
- But: is it really needed?

N. Meyners, DESY

Detector Roadmap

The roadmap for detectors at the ILC;

2007	2008	2010
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

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

Detector Roadmap

The roadmap for detectors at the ILC;

2007 2008 2010

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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
example: CALICE, LCFI, LC_TPC, ...

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, LDC,
GLD, 4th,
other?

Towards the LOI

At LCWS2007: LDC and GLD decided to join forces to write a common LOI

- Detectors are similar
- Intense collaboration on R&D level exists already at all levels
- Resources needed to write yet another report (LOI) and to do serious engineering are rather limited

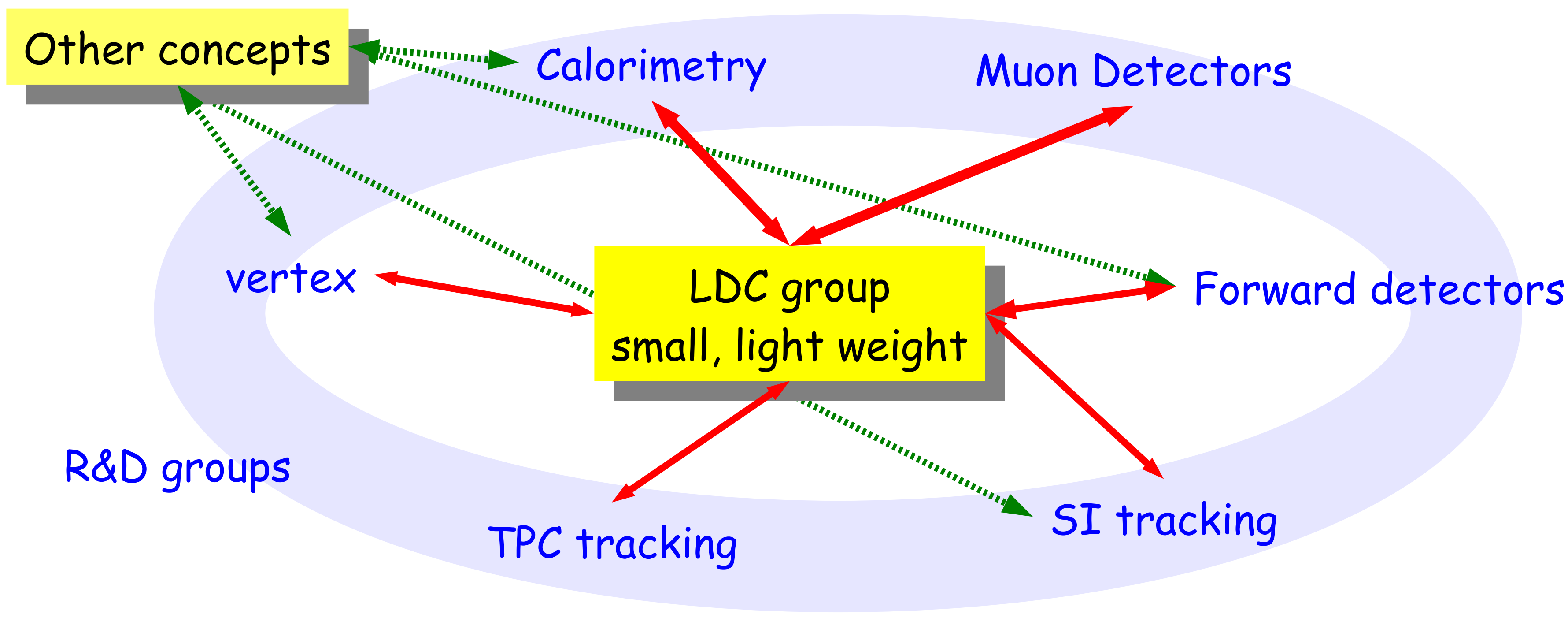
In our understanding:

- The LOI is rather heavy on performance evaluation
- We want to understand the optimum for an LDC like detector (GLD like detector)
- We are convinced we can go much further if we collaborate than if we start a competition

Who does what in LDC

LDC has been a European dominated effort so far

with ILD this will change (but here I restrict myself mostly to LDC)



Main groups in LDC

VTX: UK, Germany, Italy, France, Poland	LCFI MAPS DEPFET ...
TPC: Germany/ France/ USA/ Canada/ Japan/ China	LC-TPC
ECAL: France/ UK and others, Japan	
HCAL: Germany / Russia/ Czech AHCAL, France (dHCAL), Spain (dHCAL), Japan	CALICE
Muon: USA (NIU), Italy (decreasing)	
Forward (Germany, Czech, Poland, ...)	FCAL

LDC efforts

Overall Detector Integration and Engineering	Germany (DESY), France (LLR)
Core Software	DESY LLR UK ...
Detector Optimization	UK Germany France

ILD structures

ILD steering group is the force behind the effort:

Hitoshi Yamamoto, Yasuhiro Sugimoto
Ties Behnke, Henri Videau
Dean Karlen, Graham Wilson

Working groups

detector optimization	Mark Tompson
	Tamaki Yoshioka
MDI	Karsten Buesser
	Toshiaki Tauchi
Costing	Henri Videau
	Akihiro Maki

ILD plans

... are still evolving, but

1) make the working groups work

special emphasis at the moment is put on the optimization group

2) based results from the optimization group, work out an “optimal” set of parameters for ILD, which are not just (LDC+GLD)/2

3) Spring 2008: form sub-system groups, charged with preparing the relevant parts of the LOI

4) submit LOI summer/ fall 2008

Please join the regular Optimization phone/ Video meetings, which are about to start!

Summary and Conclusion

Detectors for the ILC are a very active field

Many interesting technological developments are ongoing

Detector R&D is particularly strong in Europe, but other regions are ramping up their efforts

Many programs have reached the state of first test results, we will need a few more years to come to conclusions

Studies/ understanding of systems reaches a point where a meaningful detector optimization is possible

Summary and Conclusions: ILD

ILD is the new kid around the block

though it is based on “old” and very experienced parents

ILD is very open and democratic, and lightweight in organization

ILD will try to do a real optimization – we want to be a heavyweight in results

ILD will try to make the case for a “large” detector at the ILC with redundant precision tracking and an emphasis on particle flow

ILD offers many exciting and challenging areas where people can contribute even with limited resources

ILD has many of the tools needed to make contributions (see talk by Frank)

ILD will soon even have a WEB page: http://www.ilcild.org