Silicon-tungsten Electromagnetic Calorimeter of ILD

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On behalf of the ILD SiW ECAL groups

IN2P3/CNRS
- LLR (École polytechnique)
- LAL (Paris Sud)
- LPSC (Grenoble)
- LPNHE (Paris Diderot, UPMC)
- LPC (Clermont Ferrand)

Kyushu University

The University of Tokyo

Outline

Role of ECAL in International Large Detector (ILD)

Design requirements

Silicon-tungsten ECAL

Optimisation studies

Next talk (T. Frisson) will address status of detector prototypes

More details in ILC Detector Baseline Design (DBD)

Role of ECAL and photon reconstruction in Particle Flow

Hadronic jets on average consist of
- ~65% charged particles
- ~25% photons
- ~10% neutral hadrons
- Large fluctuations in these fractions

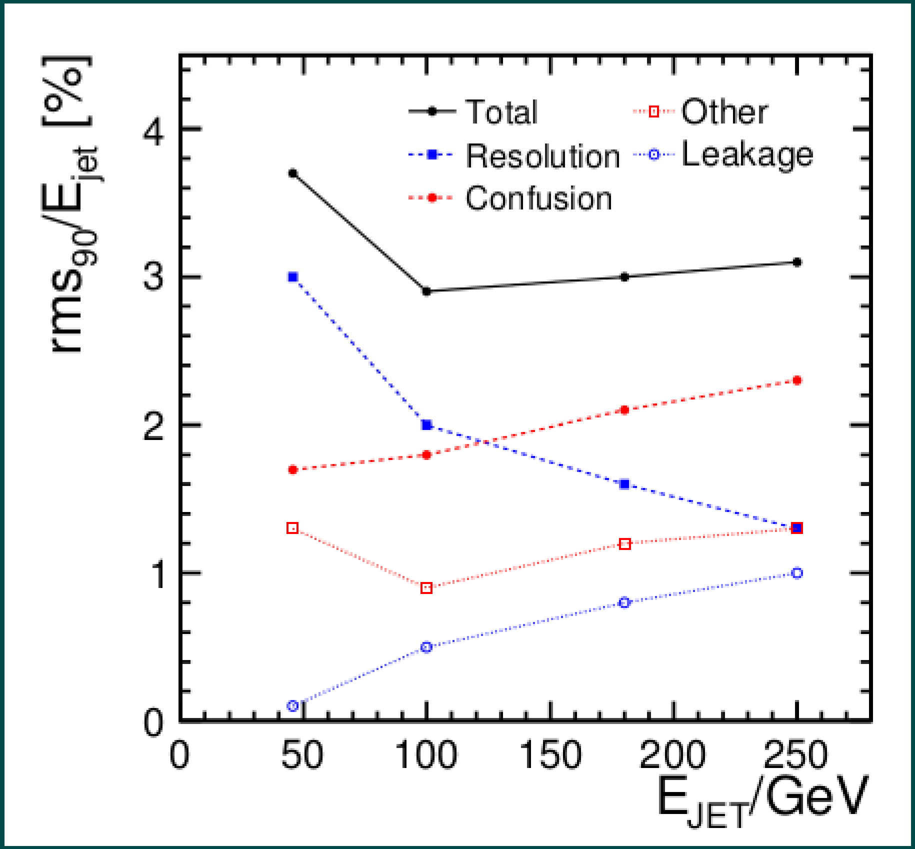
Particle Flow (PF): accurate jet energy measurement

PF relies on (ideally) topologically distinguishing
- Individual particle calorimeter deposits in hadronic jets
- Allows use of tracker measurements to estimate charged energy
- Main limitation: confusion between charged and neutral energy deposits
  - Double counting of energy: charged CALO energy mis-identified as neutral
  - Undercounting: neutral CALO energy mis-identified as charged
  - > “confusion term”

Main role of ECAL:
- Cleanly identify photon energy deposits
  - Measure this photon energy reasonably well
- Identify energy deposits due to charged and neutral hadrons (with HCAL)

At lower jet energies (<~100 GeV),
particles in jet generally well separated
JER dominated by single particle energy resolution
of photons and neutral hadrons

At higher energies (>~100 GeV)
particles in jet no longer well separated
JER dominated by confusion term
Single particle energy resolution has
rather small contribution



M. Thomson, NIMA611 (2009)

ECAL for particle flow

Large distance IP -> ECAL:

- Allow jet to spread, increasing distance between jet particles
  - easier to distinguish particles
- B-field also helps

Small Molière radius

- Smaller single particle showers
  - Easier to distinguish nearby showers
- Fine segmentation of readout in 3-d
  - for accurate topological clustering

~$24X_0$ to contain EM showers

Compact depth: small X0

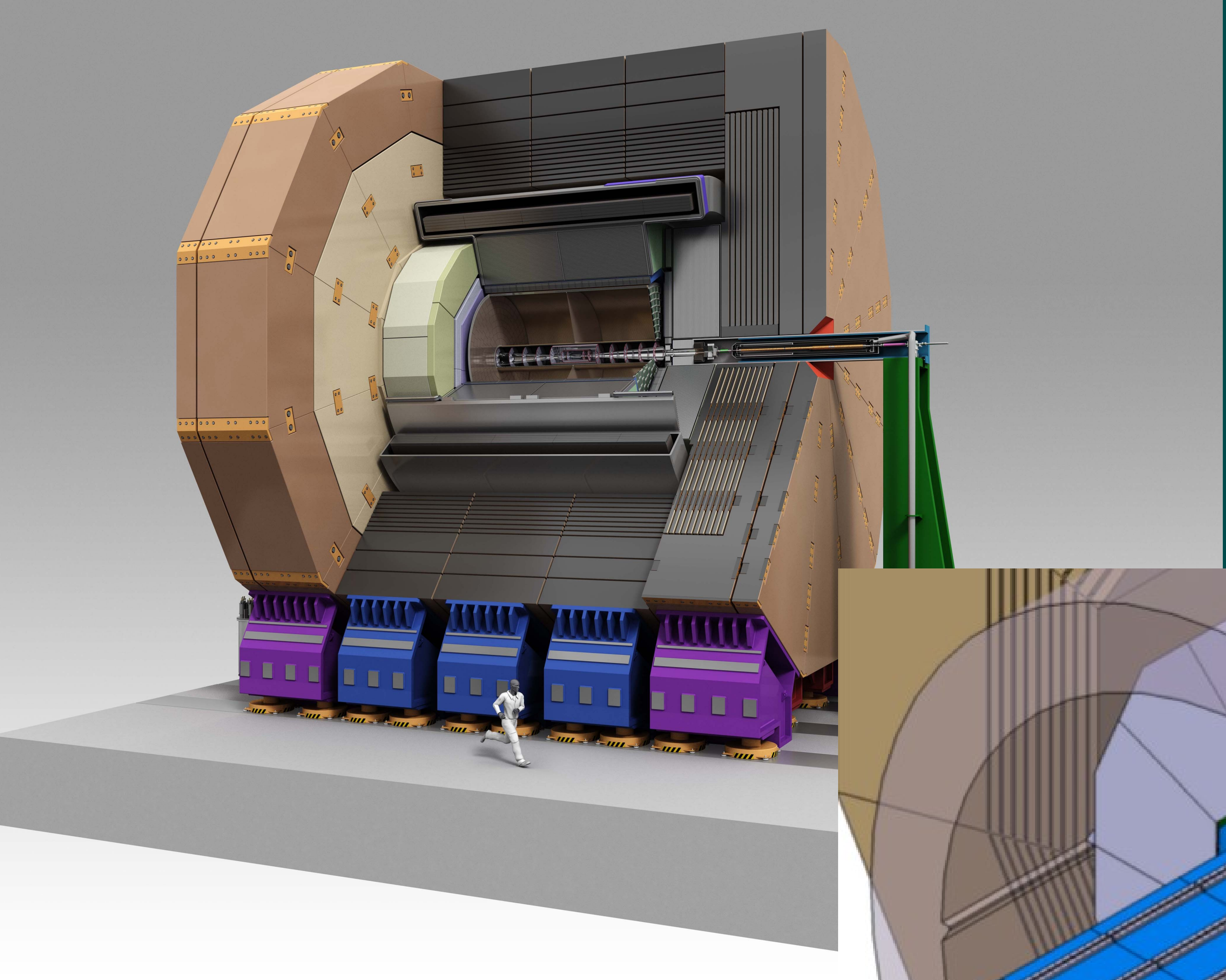
- Constrain size of detector yoke and solenoid

Relatively large hadronic interaction length

- Longitudinal separation between EM and hadronic showers

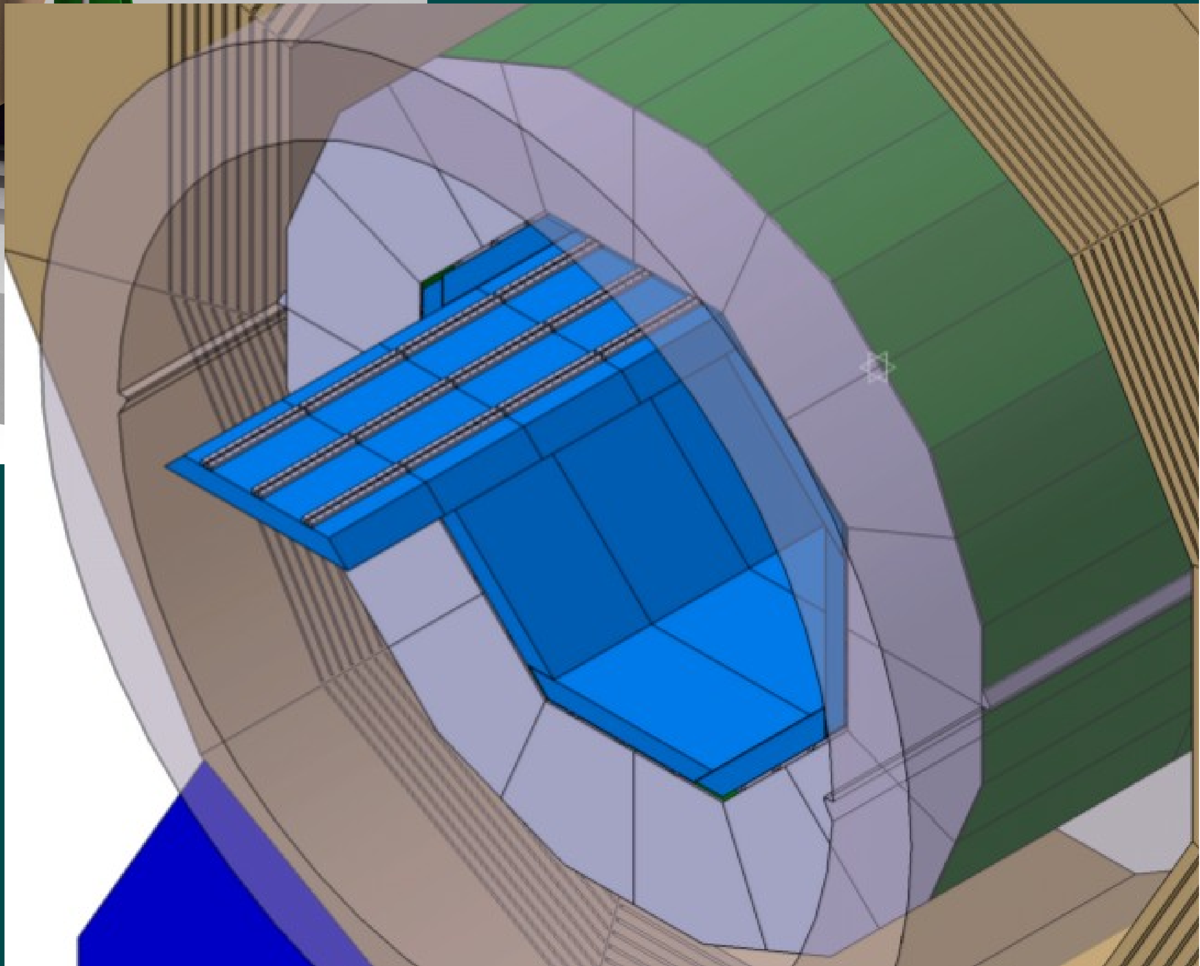
Choose multi-layer sampling calorimeter

- Tungsten is a good choice for absorber material
- In this talk, focus on silicon PIN diodes as actve material
  - scintillator (later talk by Sudo-san),
  - hybrid (Ueno-san in simulation session)



Non-projective geometry
avoid pointing cracks

Hermiticity ECAL
ECAL ring
Forward:
LumiCal, BeamCal
down to 5 mrad



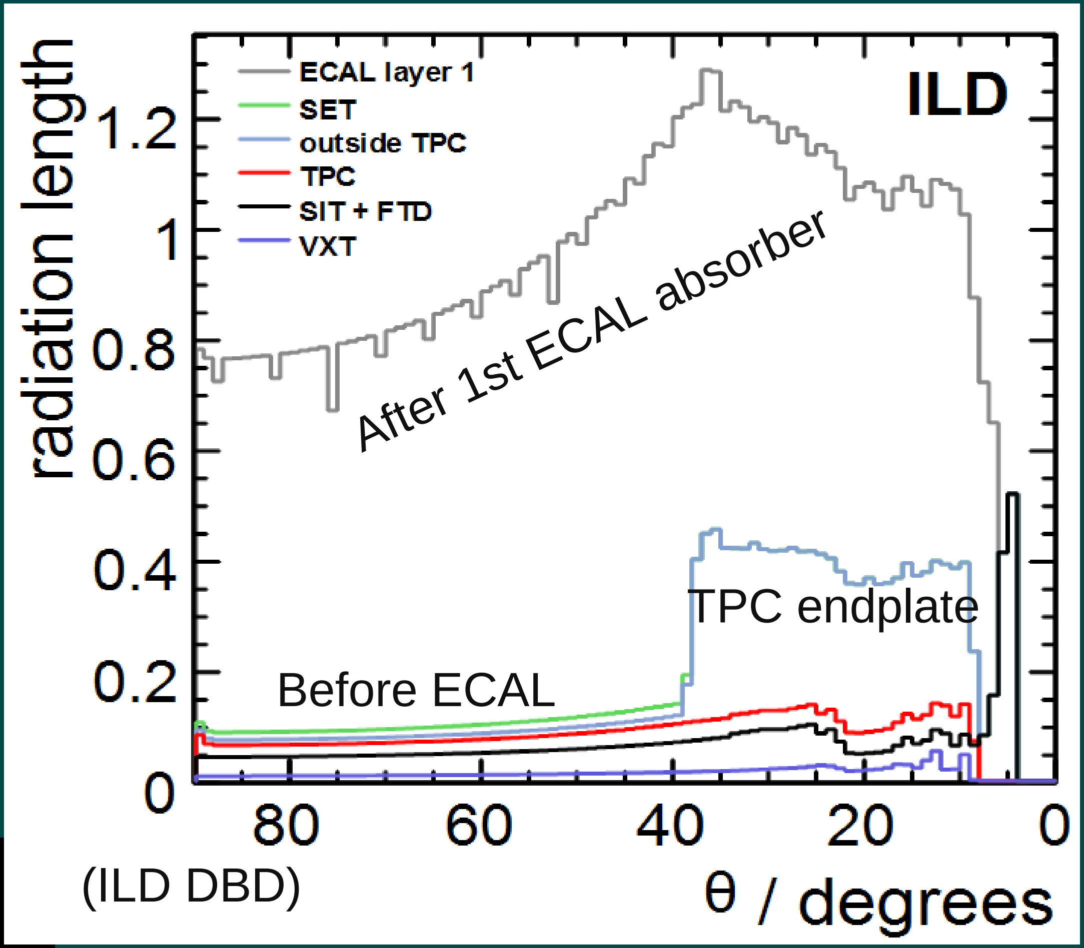
For default 30-layer design:

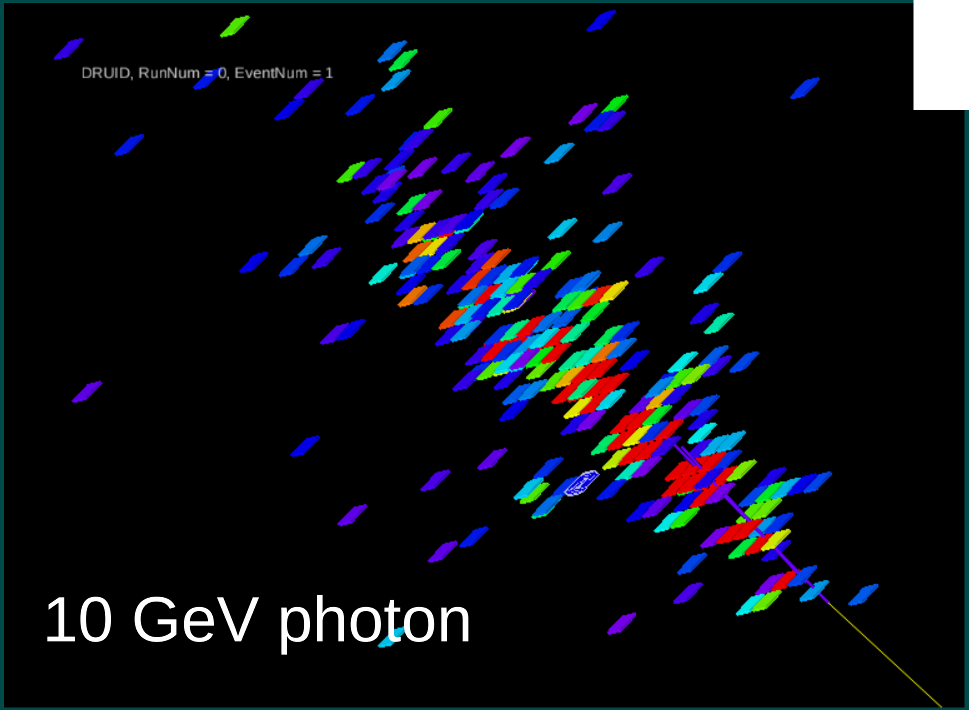
~2400 m^2 of sensors

~10^8 readout channels

Rather small material budget before ECAL

Interactions (particularly hadronic) before ECAL can have severe consequances for PF (~impossible to tag neutrals as not prompt)



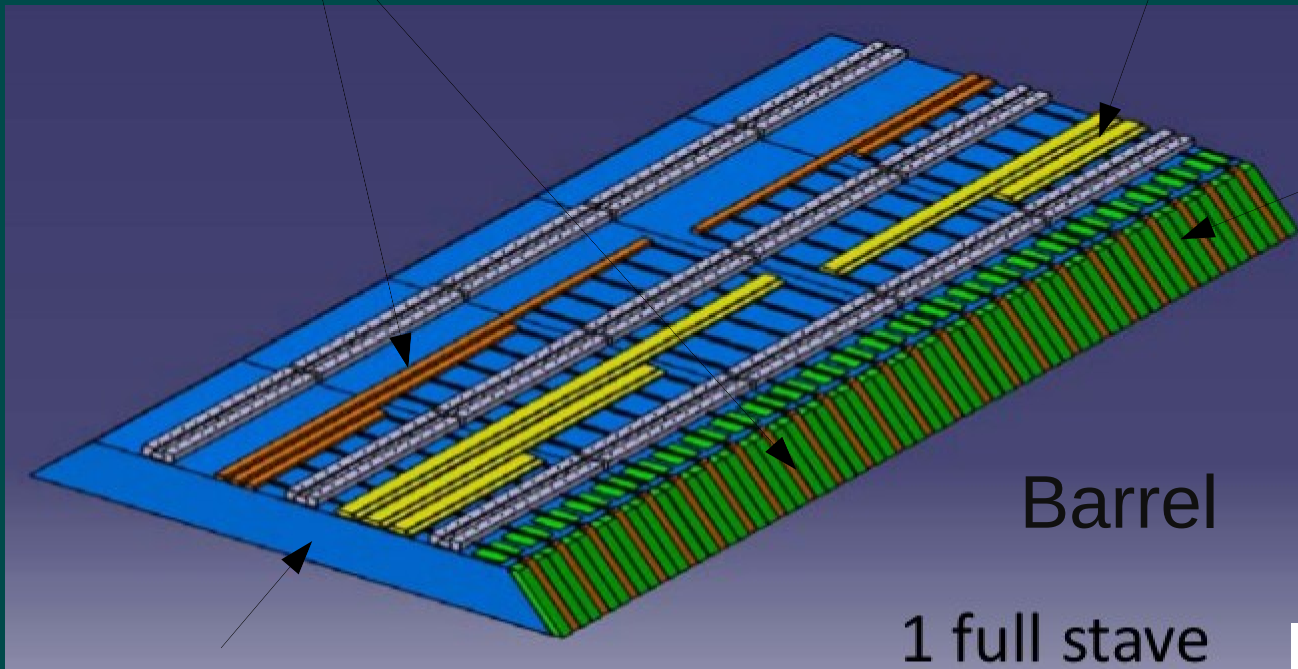


Particles typically measured by many detector cells

Water-based cooling

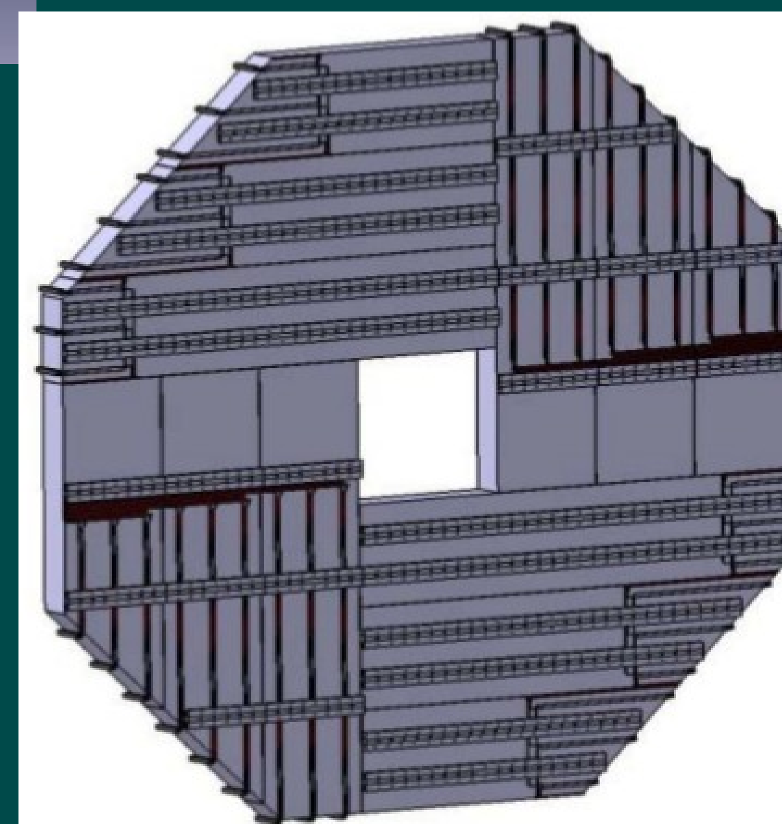
HV, LV, signal cables

DAQ interface cards



Carbon-fibre / tungsten
mechanical modules

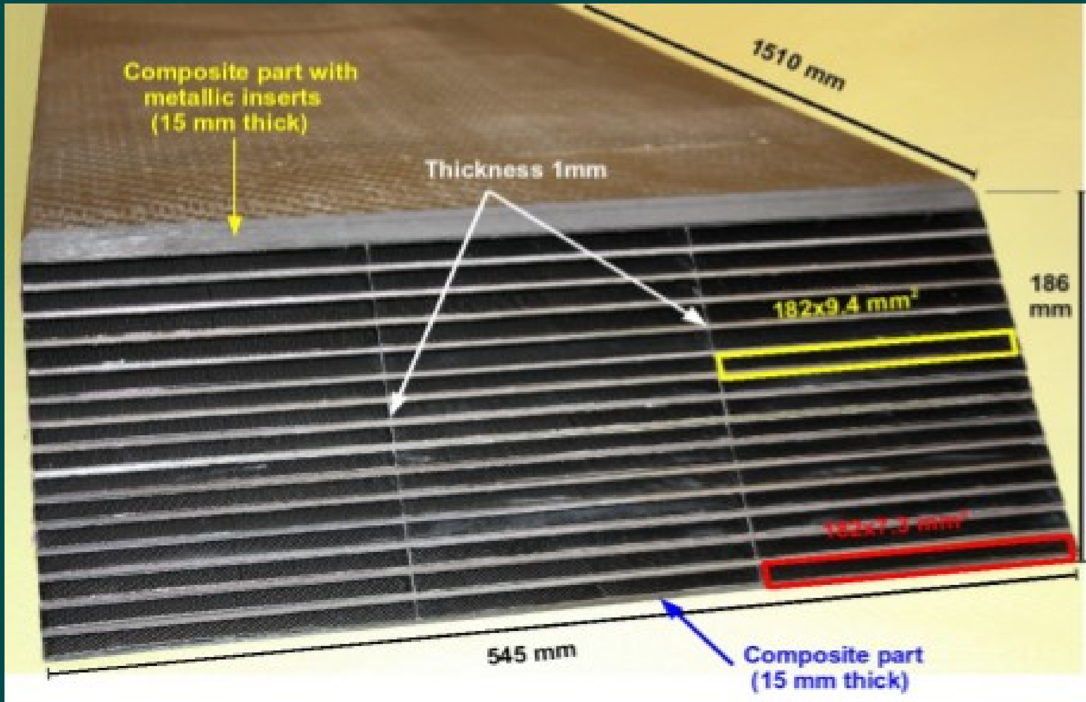
Endcap: similar design
somewhat longer modules



Digitization, data concentration performed inside detector

Services run in 3cm gap between ECAL and HCAL

Exit detector between barrel and endcap

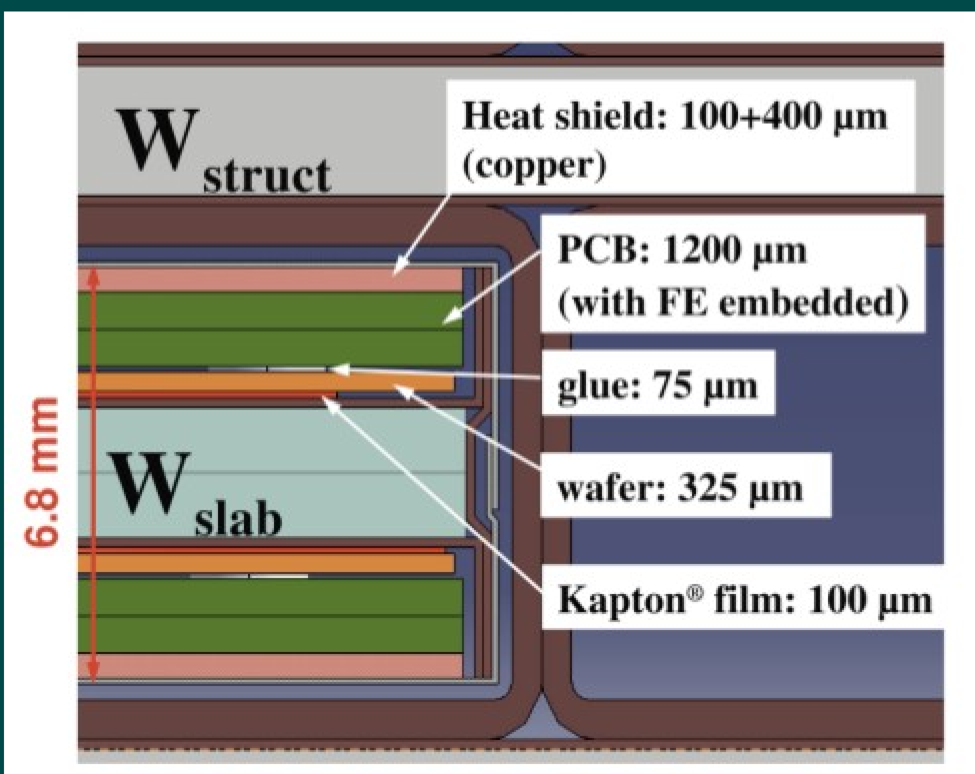


Carbon-fibre/tungsten mechanical strcuture

Active Sensor Unit (1024 readout channels)
- 18X18 cm^2 PCB
- 16 readout ASICs
- 4 silicon sensors
  - (each with 256 5x5mm^2 pads)

Dynamic range: single MIP to
EM shower core @ 100s GeV

Details of technical realisation in next talk



Power and cooling

To reduce power consumption,
- take advantage of ILC beam structure: 1ms bunch train every 200 ms
  - switch off front end electronics in inter-train interval

Then ~25 microW per channel -> ~2.5kW in total within structure
- Additional power consumption in ECAL-HCAL gap (mostly DAQ)

Designed water-based cooling system
- Sub atmospheric pressure -> “leak-less”
  - Remove heat at edge of every detector slab

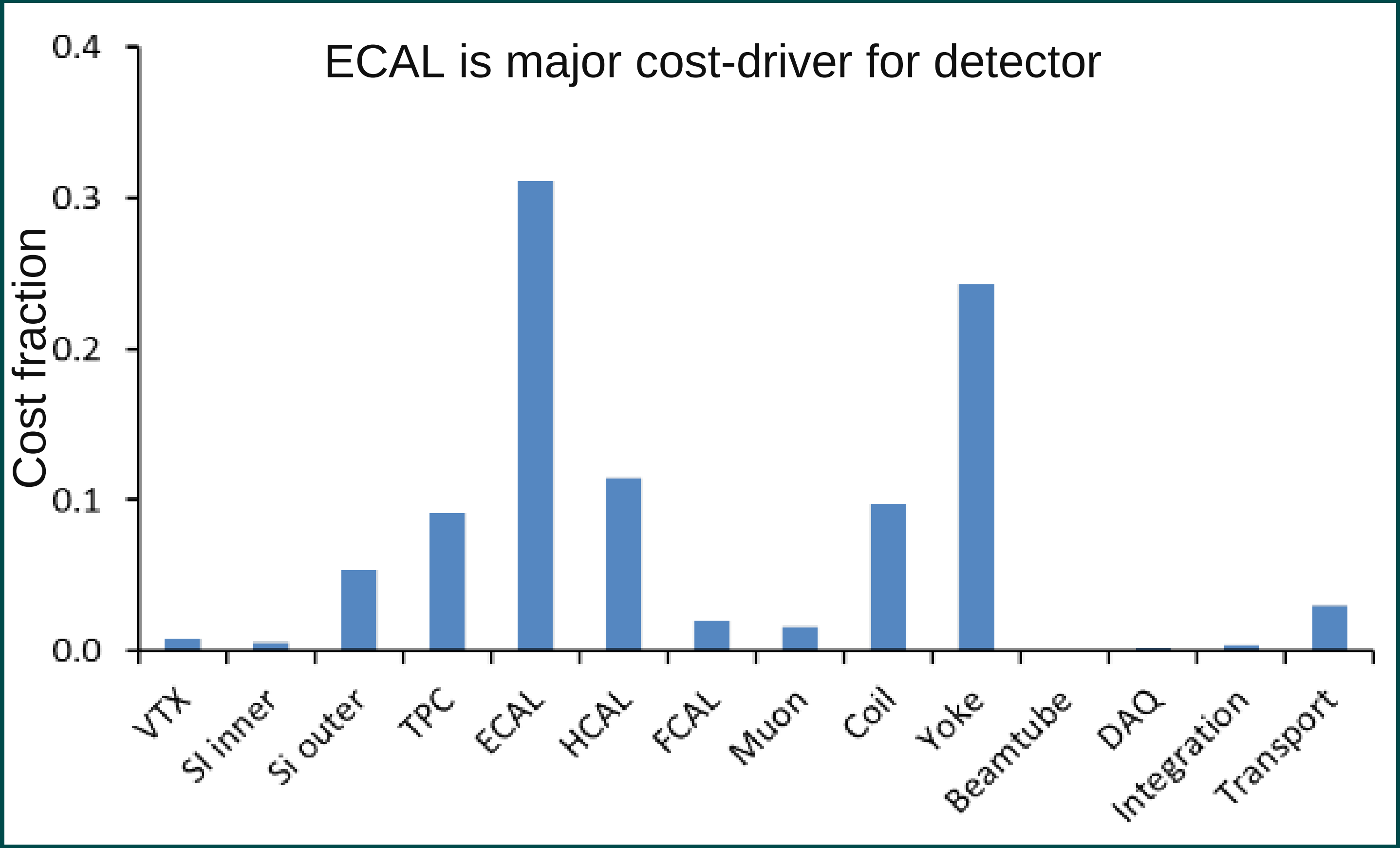
Construction industrialisation

Highly modular design, large numbers of identical pieces
- industrialised manufacture
- Simpler testing and quality control

Optimisation studies

to justify or reduce cost

ECAL cost driven by
- large sensitive area
- number of readout channels



(ILD Detector Baseline Document)

Optimisation of ECAL

Overall dimensions

Readout granularity

Number of sampling layers

PCB thickness

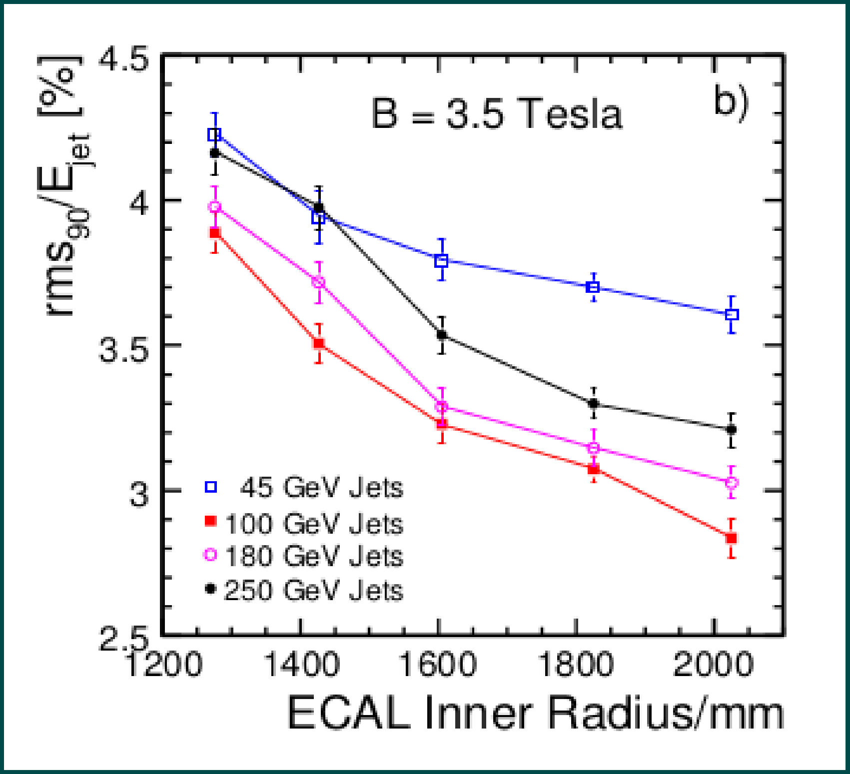
Silicon sensor guard ring width

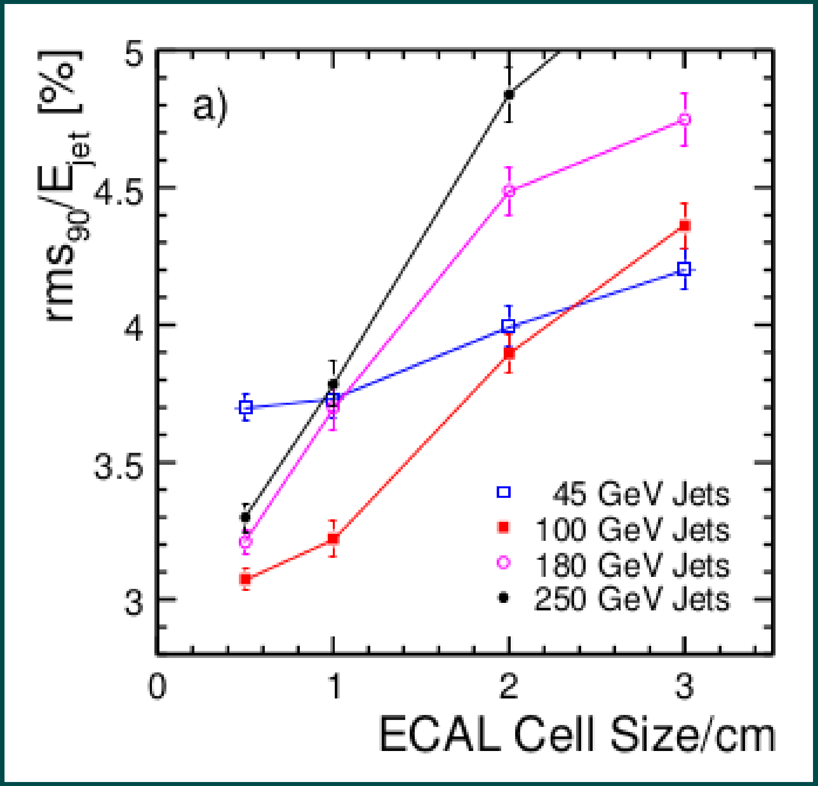
Robustness against failures

Optimisation metric:
- single photon energy resolution,
- PF jet energy resolution (RMS_{90}) in 2-light quark events at various energies

Attempt to reduce cost, technical “aggressiveness”

ECAL inner radius, readout granularity





ILD letter of Intent (2010)
M. Thomson

Large radius clearly improves performance
however also has large influence on cost of HCAL, solenoid and yoke

Cell sizes below 1cm useful for higher energy (>100 GeV) jets
(higher particle density in higher energy jets)

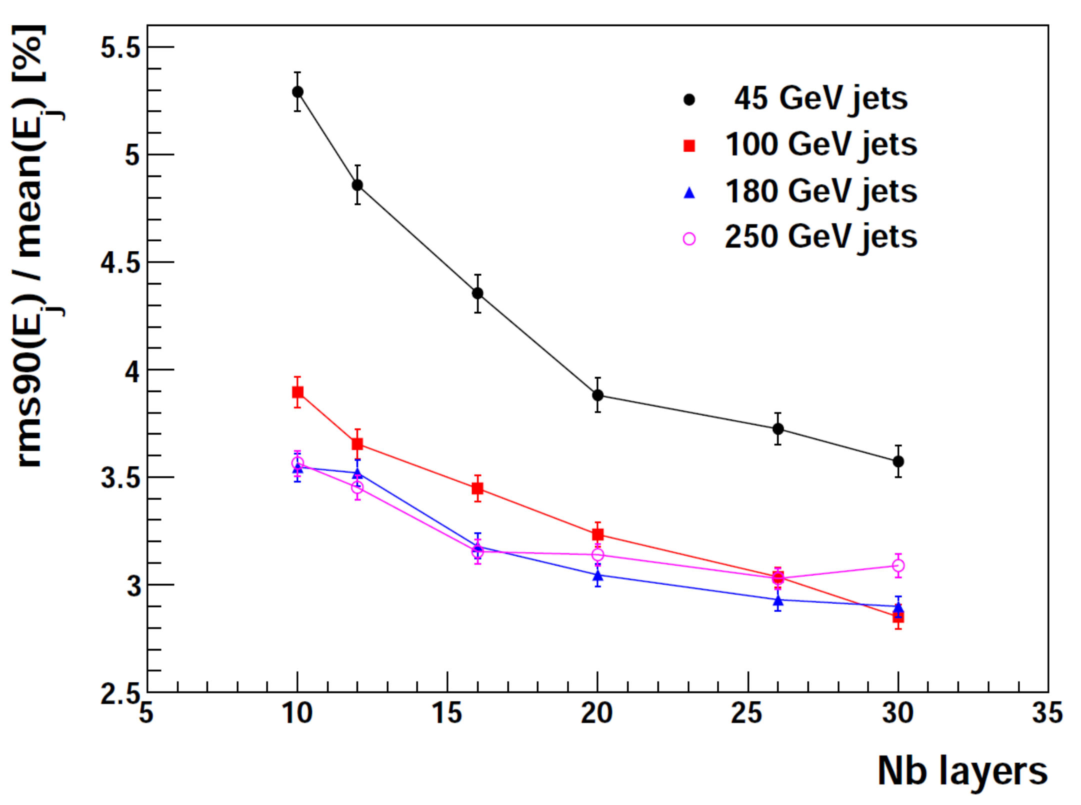
Number of sampling layers

Constant absorber thickness,
vary number of sampling layers

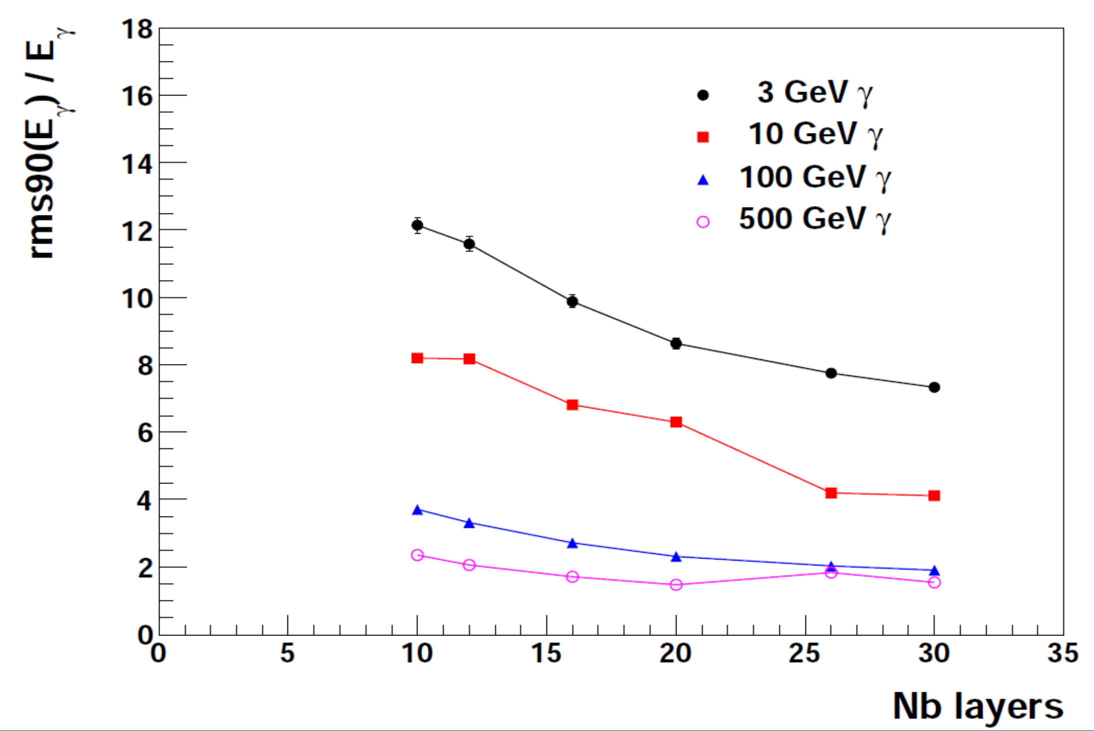
Effect on photon and
jet energy resolution

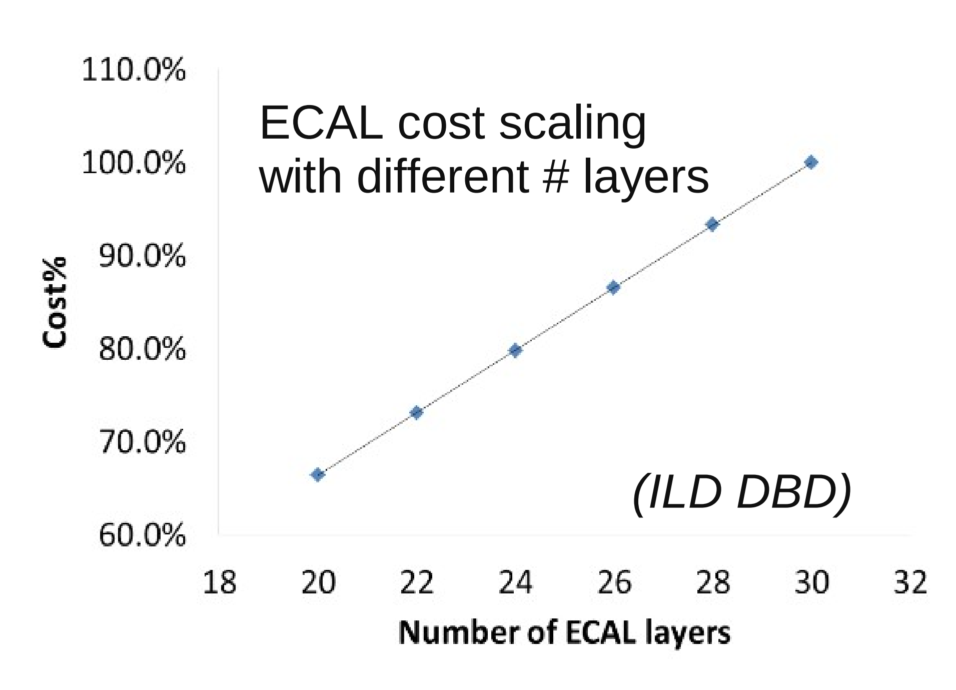
Degrades photon stochastic term
-> effects lower energy photons and
lower energy jets

Performance with 20 layers
may be acceptable

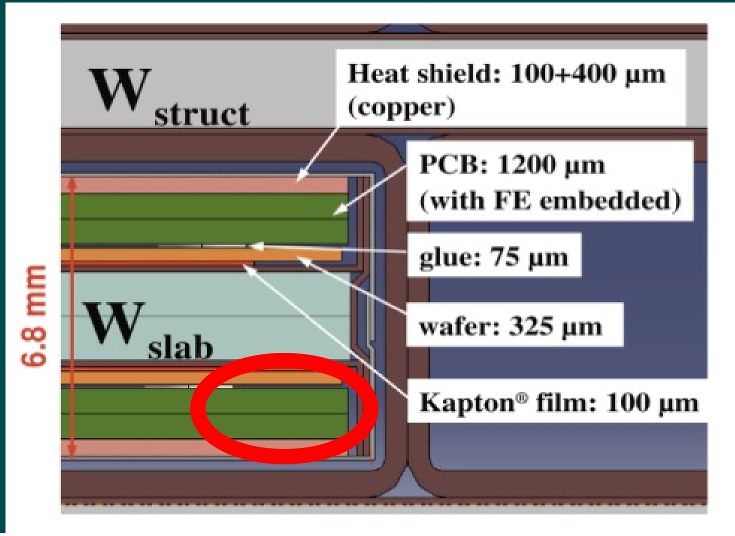


T H Tran, LLR





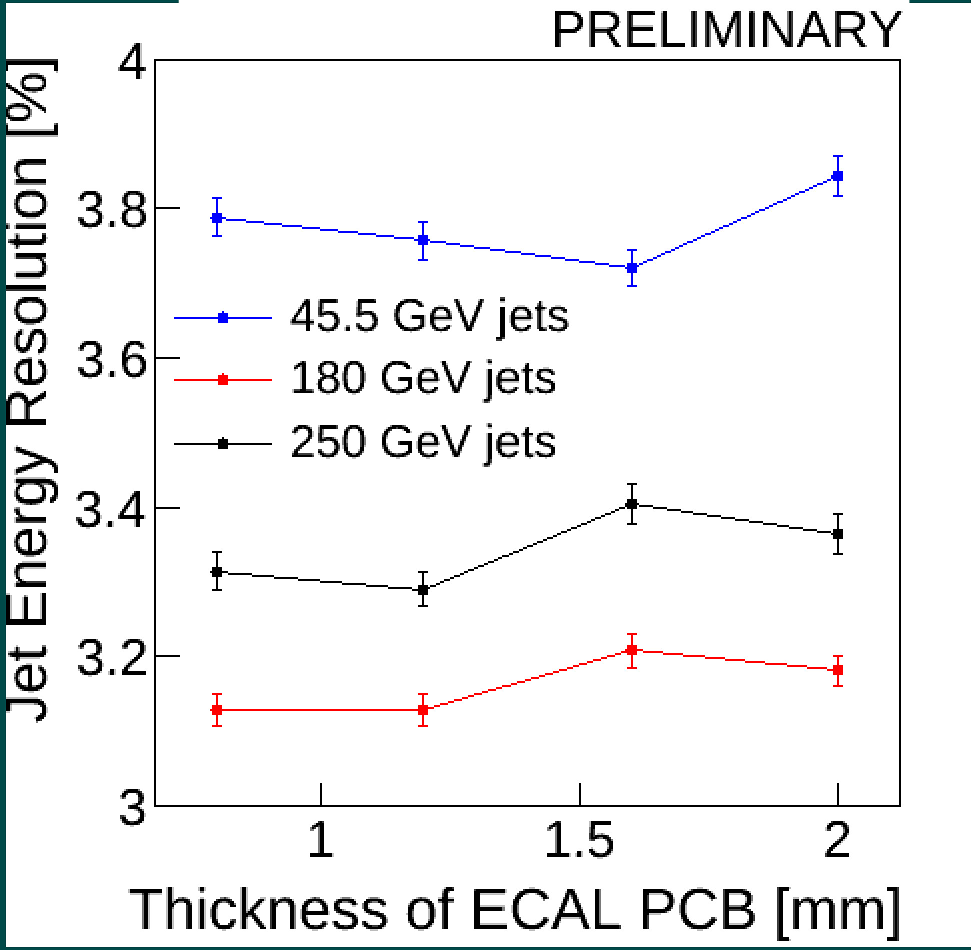
PCB of Active Sensor Unit (ASU)



18x18 cm^2, multilayer
Si sensors glued on one side
Host the front end readout ASIC
DAQ, power lines

Minimise thickness
-> reduce Molière radius, total thickness
...but preserve flatness

Technologically challenging
Current prototypes ~1.2 mm: difficult
Optimistic hope ~ 0.8mm: not yet demonstrated



Assess effect of increasing thickness:
JER for different PCB thicknesses

No strong effect on performance
Can relax beyond 1.2 mm
However: has effect on overall ECAL thickness
and size of HCAL, coil, yoke...

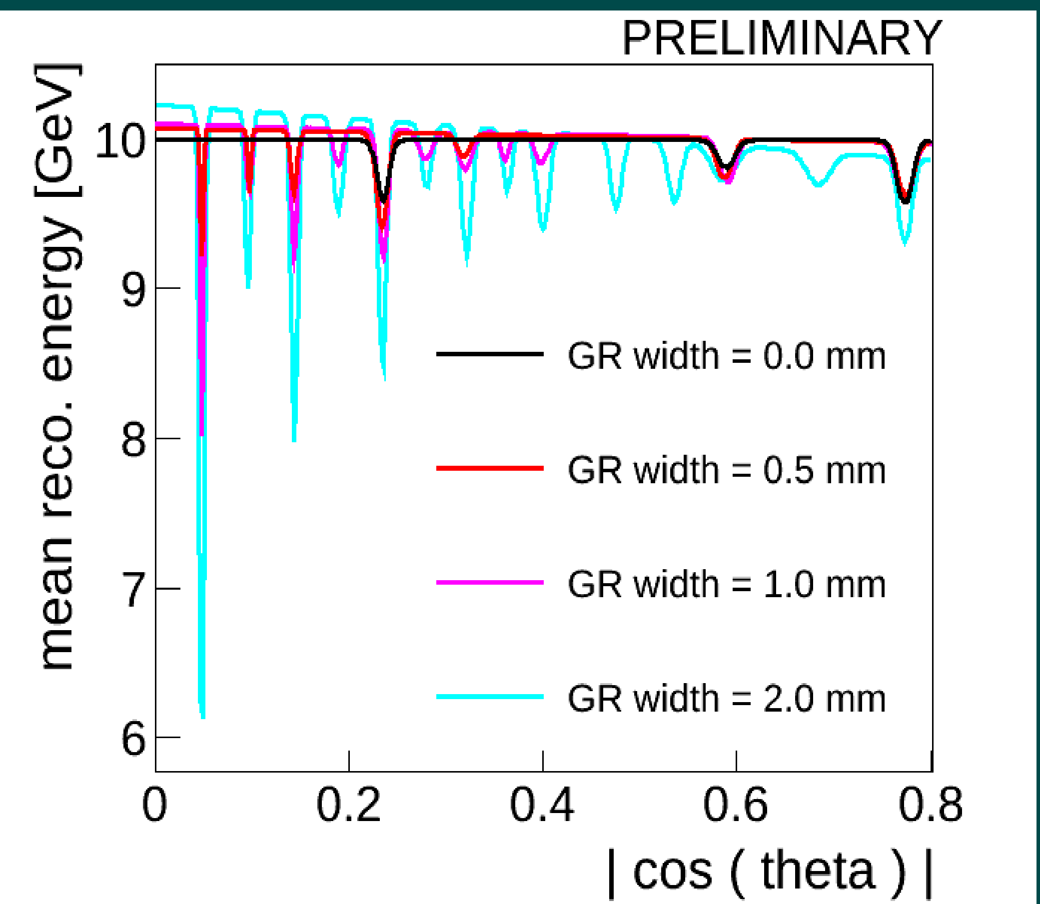
C Kozakai, Tokyo

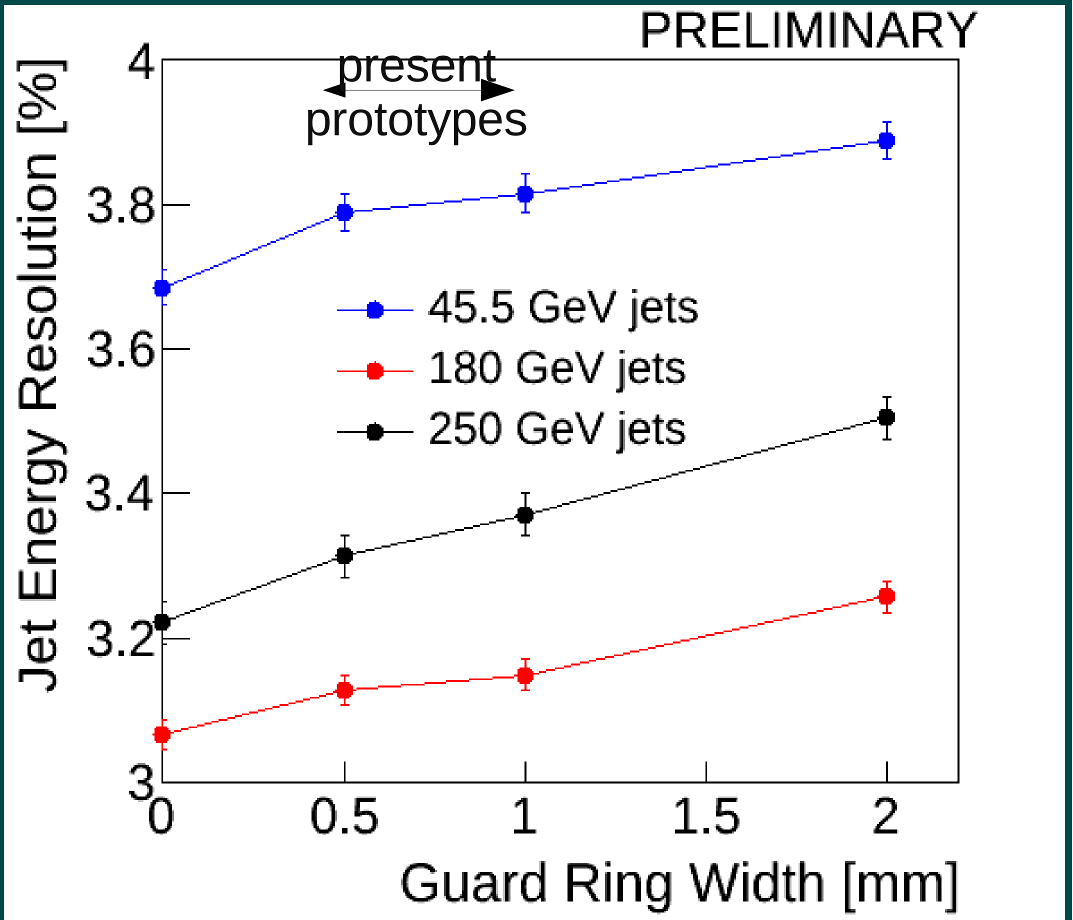
Dead area at edge of silicon sensor
due to guard ring, mechanical tolerances

Simulation study to understand effects of this region
How carefully do we need to minimize?

These dead zones are projective only at theta = 90 degrees

Simple average energy correction function





Small (but non-negligible) effect

C Kozakai, Tokyo

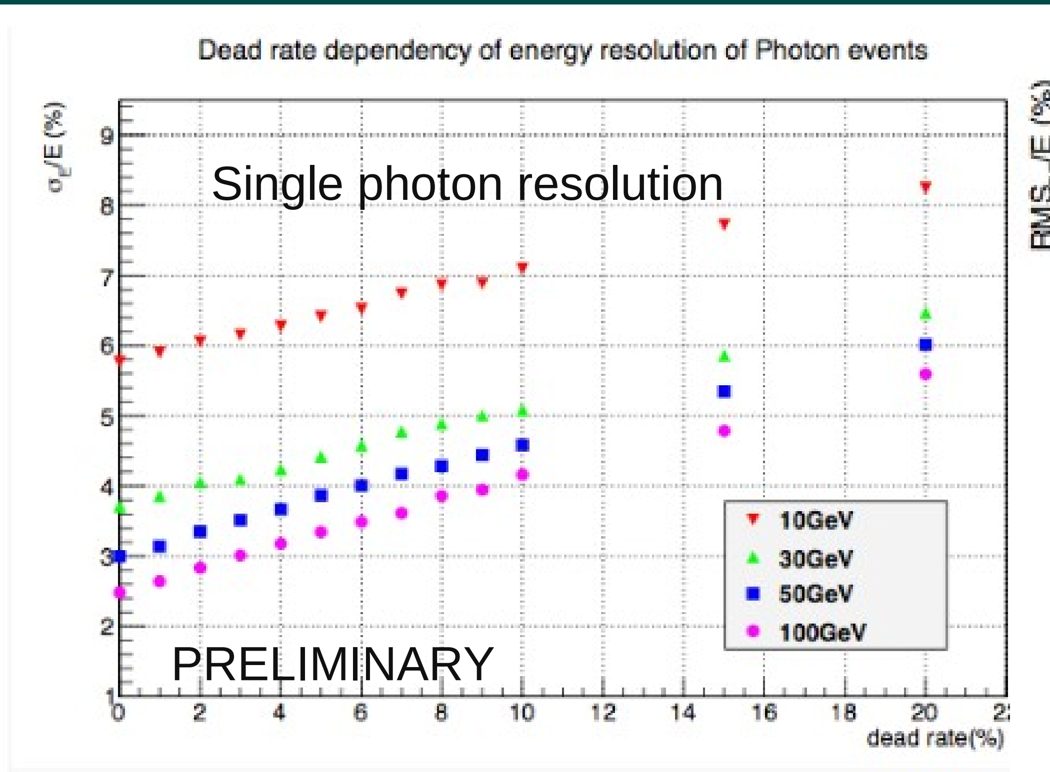
Silicon sensor quality/defects

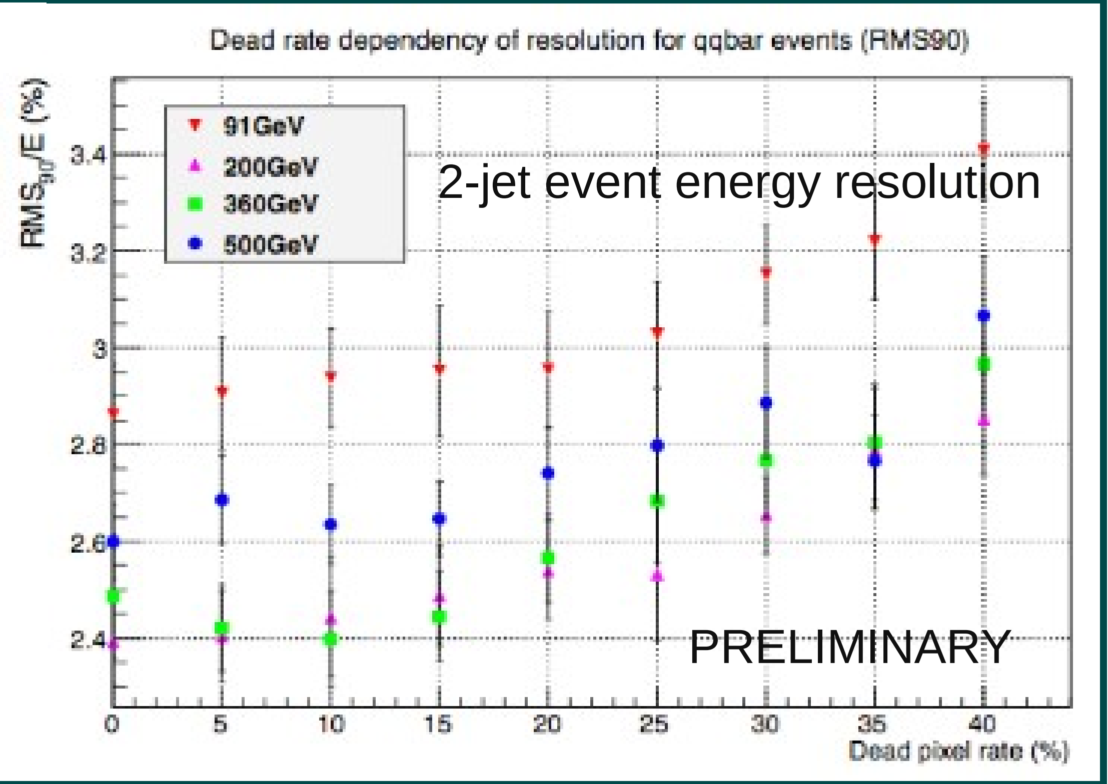
How robust are the ECAL design and PFA reconstruction against sensor imperfections?

Every particle is measured by 10s -> 1000s of detector cells

Are "perfect" sensors required?

- Can we accept sensors with a small number of "randomly" distributed defective cells?
  - Improve industrial yield, reduce cost





Global correction factor applied
- more sophistical approaches possible

Negligible effect on Jet measurement, even up to ~15%

S. Chen, Tokyo

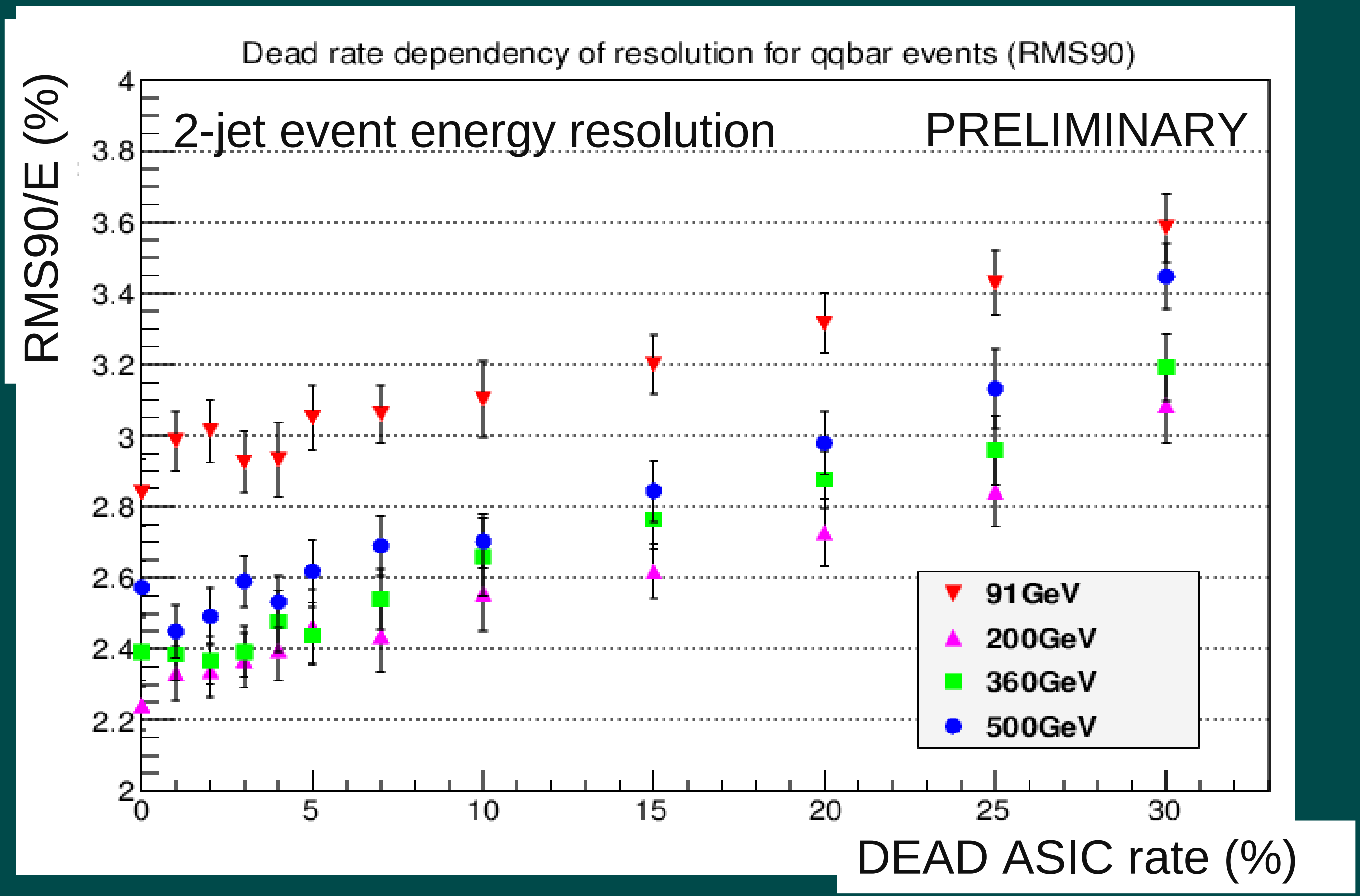
What if an entire readout ASIC fails ?

(e.g. bonding failure during assembly)

Lose block of 64 readout cells

Do we reject entire ASU?

(1 ASU = 16 ASICS,
1 ASIC = 64 channels)



Loss of large areas of pixels has more serious effect than random pixels

A few % is still acceptable

Expect these to be identified before final assembly

can be installed in less critical regions of detector (e.g. later layers)

S. Chen, Tokyo

Summary

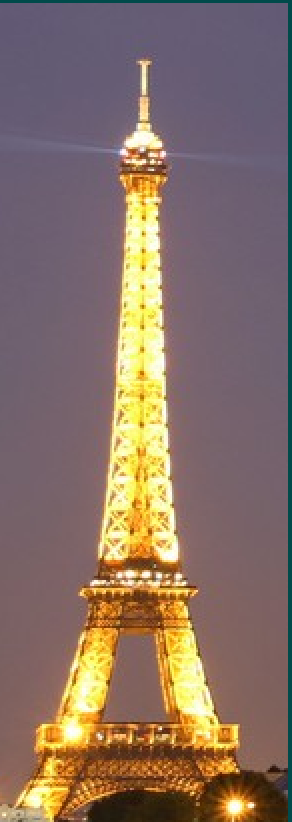
Si-W ECAL for ILD
    optimised for Particle Flow reconstruction

3-d readout granularity is central

Compact design based on
    tungsten absorber and
        silicon sensors

Effects of “downgraded” designs to
    ease manufacture, reduce cost
        Number of layers,
            PCB thickness,
                Si sensor dead area

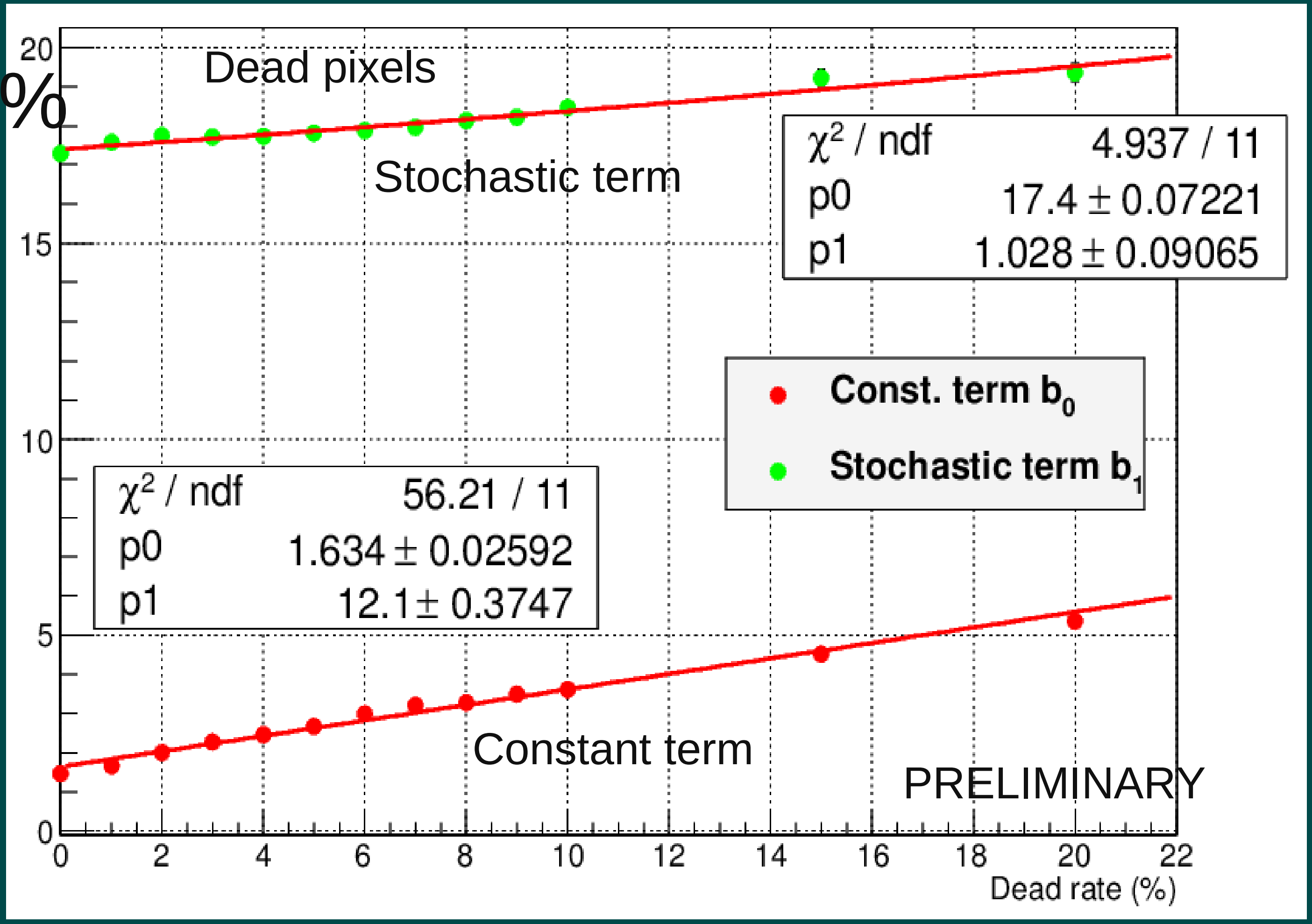
Jet Energy Resolution seems robust against up to
    several % pixel and readout ASIC failures



BACKUP

Dead ECAL pixels for single photon resolution

Constant term, stochastic term

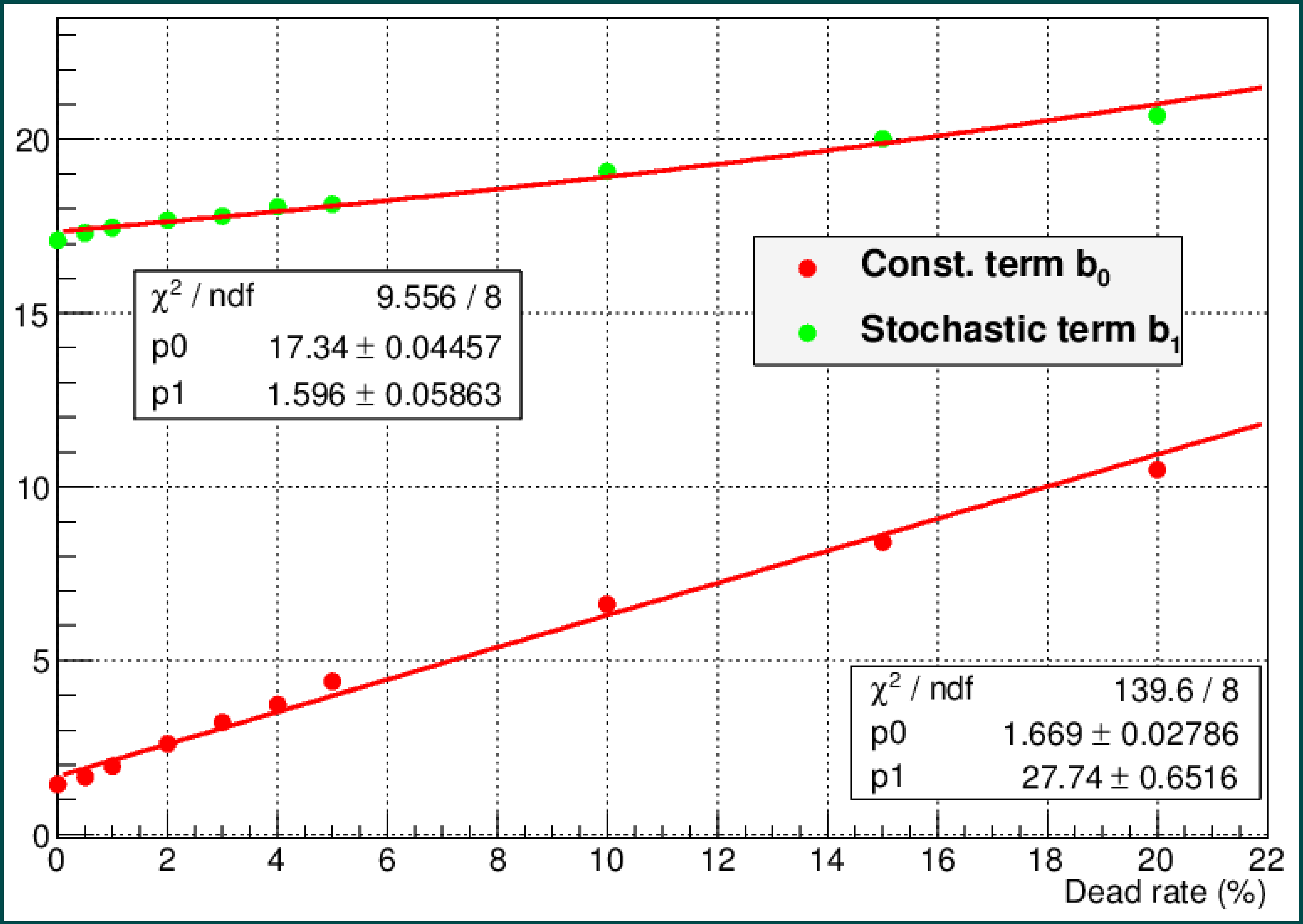


Affects mostly constant term of resolution

Less important for low energy photons

S. Chen, Tokyo

Dead ASIC: single photon



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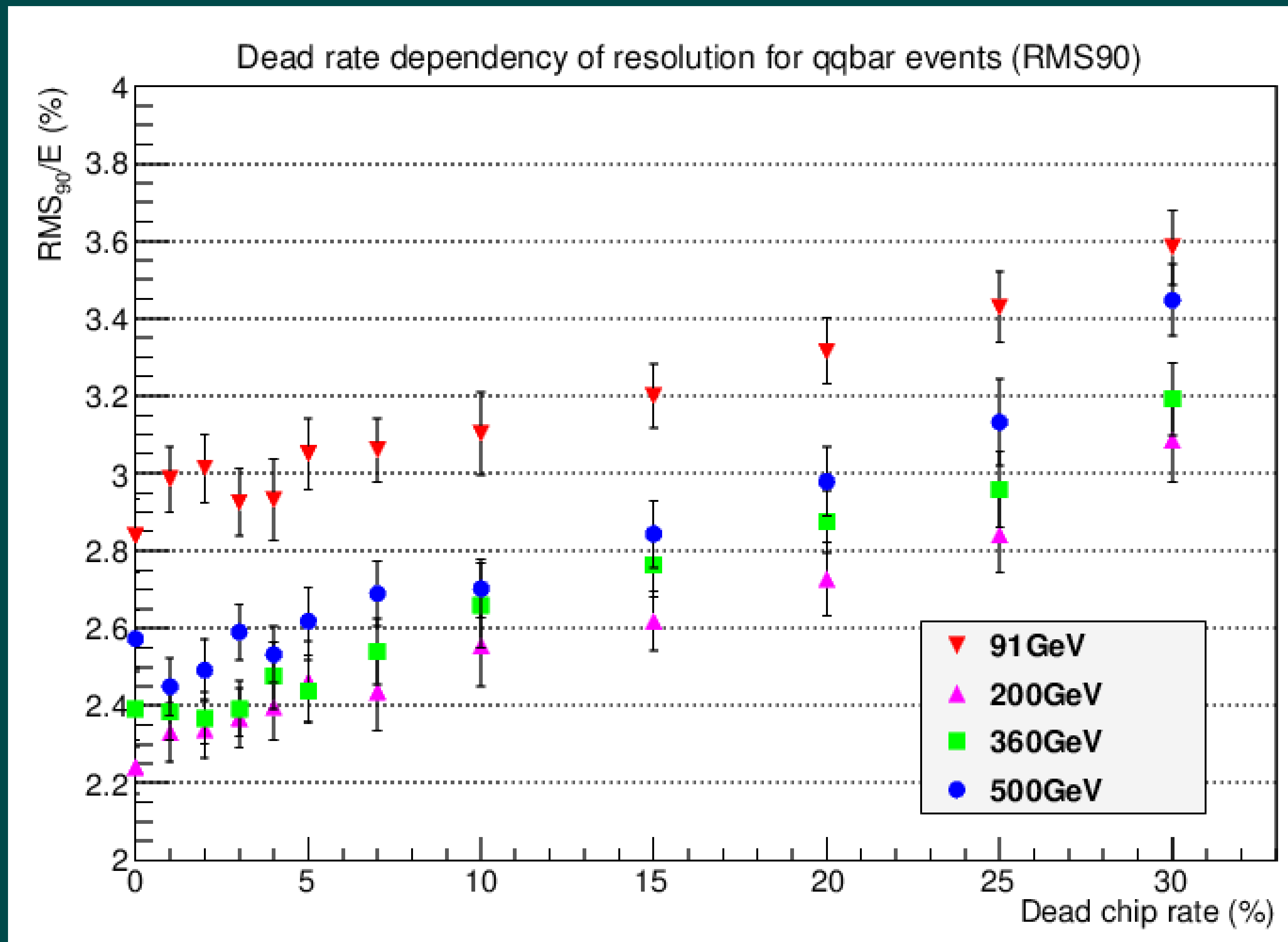
Dead ASIC: 2-q events



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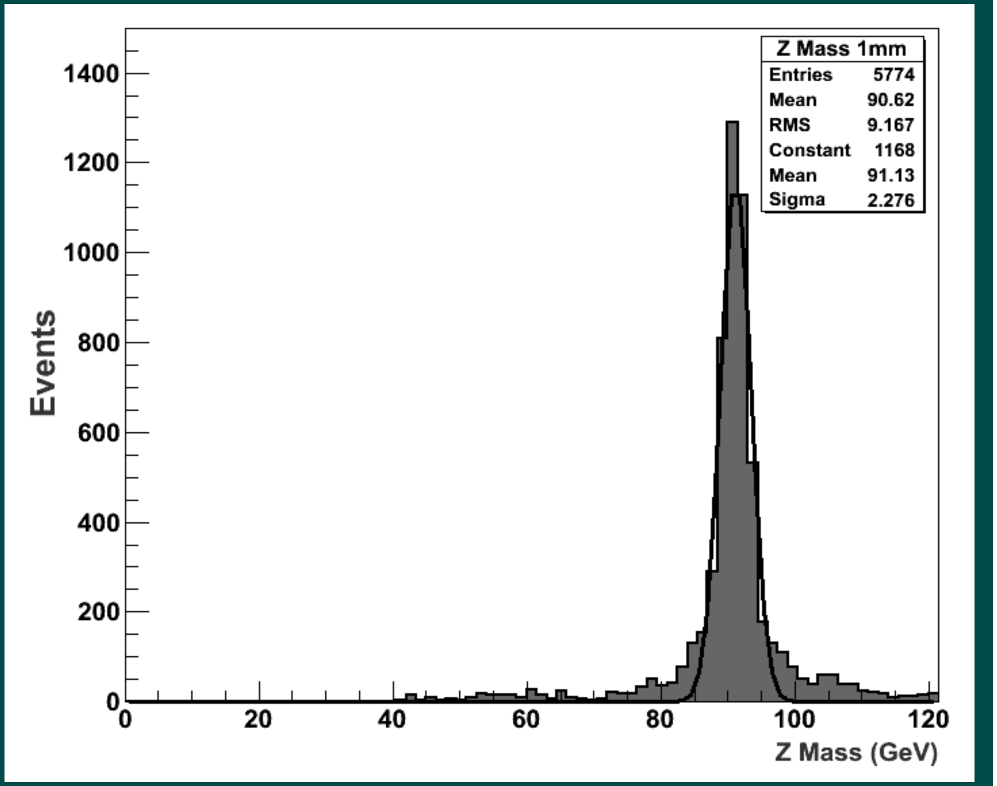
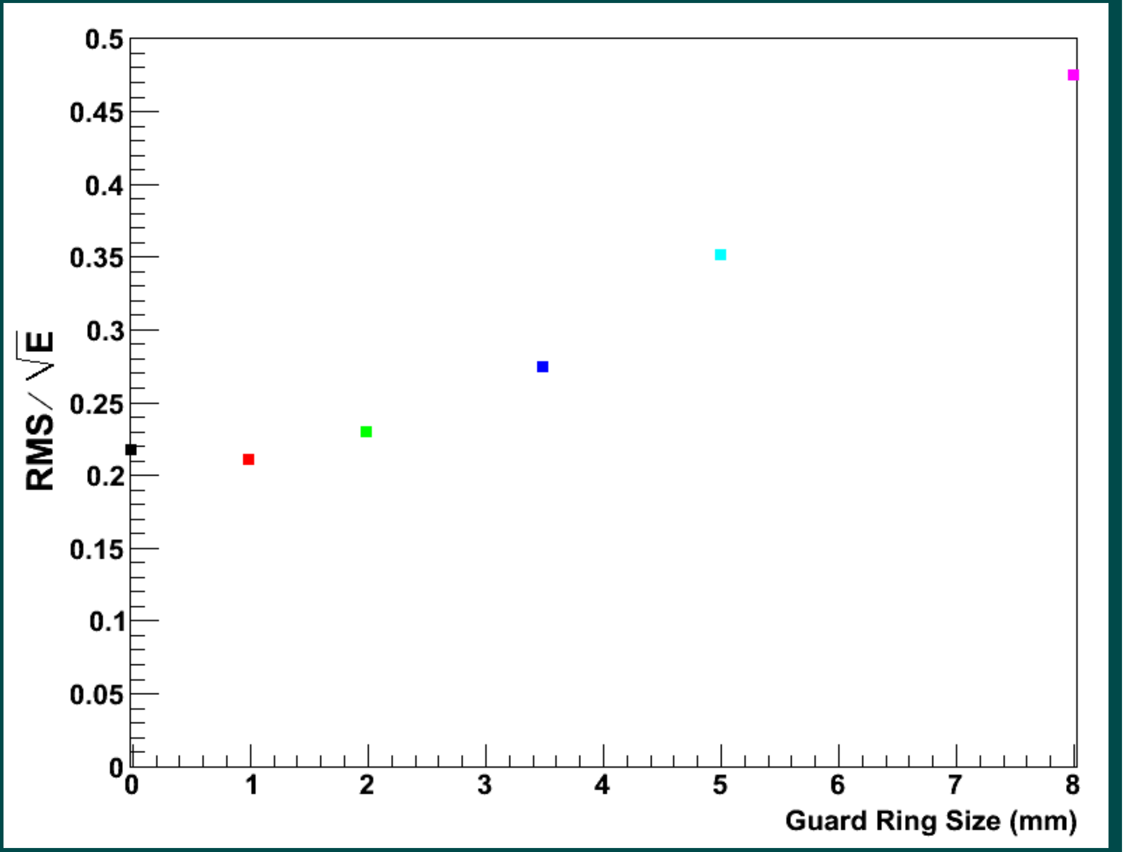
Effect on Z->ee reconstruction of guard ring width

Reconstruction of Z mass in Z->e+e- important for higgs-strahlung measurement

Could be sensitive to effects of large GR





No significant degradation in realistic GR size range (0->2 mm)

S. Amjad (LAL)

Calibration

How can you hope to calibrate 10^8 detector cells?

PIN diode response expected to be very stable
- seen in test beams over ~5 year period

Electrical characterisation of PIN diodes
- width of depletion layer

Calibrate all ASUs before final assembly
- Sensor + front end ASIC
- Muon beam and/or cosmics
- Relative channel-to-channel calibration

Absolute energy scale
- Completed module(s) in test beam

In-situ monitoring
- MIP-like tracks in jets (hadrons, muons)
- Bhabha, Z->e+e-, E/p