Overview and progress from CALICE

Calorimeter for ILC

On behalf of the Calice-UK collaboration

Valeria Bartsch, University College London
presenting the work of my colleagues

Content:

- Introduction
- UK activities
  - test beams - analysis and data taking
  - DAQ - on the way to a technical prototype
  - MAPS - an interesting detector concept
  - PFA and physics analysis - Higgs strahlung and WW scattering
  - mechanical and thermal studies

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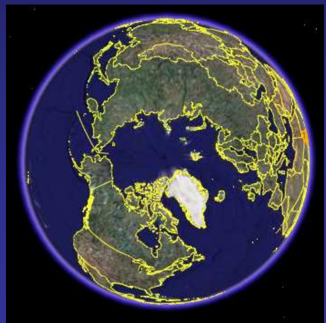
Members of the CALICE Collaboration

Calorimeter for ILC

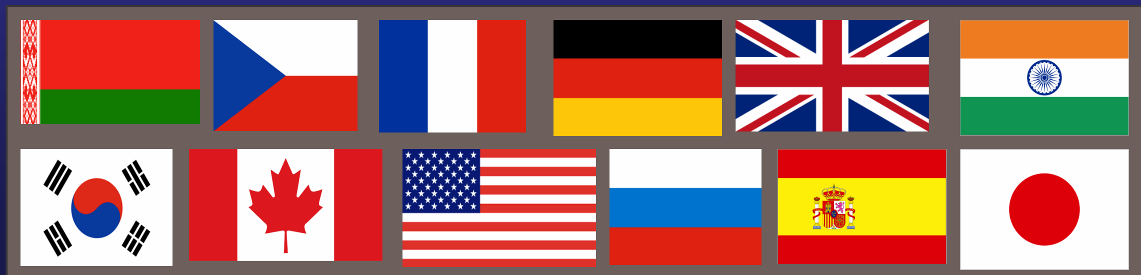


3 regions

12 countries

41 institutes

> 200 physicists



Goals of the Collaboration

To provide a basis for choosing a **calorimeter technology** for the ILC detectors

To **measure** electromagnetic and hadronic showers with unprecedented granularity

Physics prototypes

Various technologies (silicon, scintillator, gas)
Large cubes (1 m^3 HCALs)
Not necessarily optimized for an ILC calorimeter
Detailed test program in particle beams

Technical prototypes

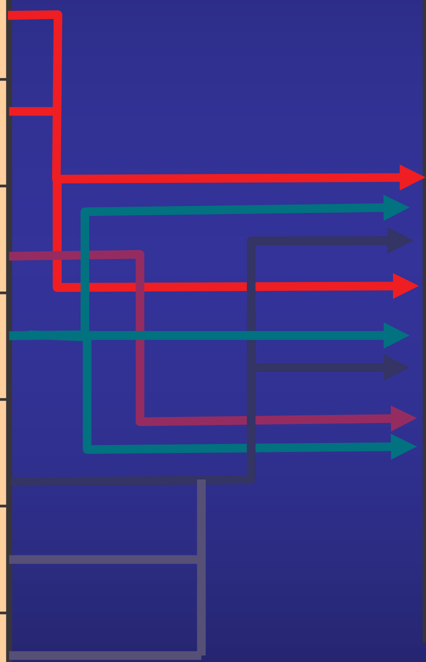
Various technologies
Can be only partially equipped
Appropriate shapes (wedges) for ILC detectors
All bells and whistles (cooling, integrated supplies…)
Detailed test program in particle beams

To **advance** calorimeter technologies and our **understanding** of calorimetry in general

To design, build and test **ILC calorimeter prototypes**

CALICE Projects and the Concepts

CALICE Projects	
ECALs	Silicon - Tungsten
	MAPS - Tungsten
	Scintillator - Lead
HCALs	Scintillator - Steel
	RPCs - Steel
	GEMs- Steel
	MicroMegas - Steel
TCMTs*	Scintillator - Steel



Detector Concept	Optimized for PFA	Compensating Calorimetry (hardware)
SiD	Yes	No
LDC	Yes	No
GLD	Yes	No
4th	No	Yes

All calorimeters with very fine segmentation of the readout

* Tail catcher and Muon Tracker

CALICE Projects and the Concepts

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Detector Concept	Optimized for PFA	Compensating Calorimetry (hardware)
SiD	Yes	No
ILD	Yes	No
4^{th}	No	Yes

CALICE projects on detectors with calorimeters with very fine segmentation of the readout

* Tail catcher and Muon Tracker

PFAs and Calorimetry

Fact

Particle Flow Algorithms improve energy resolution compared to calorimeter measurement alone (see ALEPH, CDF, ZEUS…)

How do they work?

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	0.07^2 E_{jet}
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	0.16^2 E_{jet}
Confusion	The real challenge		**≤ 0.04^2** (goal)

} 18%/√E

Minimize confusion term

Maximize segmentation of the calorimeter readout

High segmentation

O(<1 cm^2) in the ECAL
O(~1 cm^2) in the HCAL
~O(10^7 – 10^8) channels for entire ILC calorimeter

Can PFAs achieve the ILC goal?

YES!

Status of the various projects

Calorimeter	Technology	Detector R&D	Physics Prototype	Technical Prototype
ECALs	Silicon - Tungsten	Well advanced	Exposed to beam	Design started
	MAPS - Tungsten	Started		
	Scintillator - Lead	Well advanced	Exposed to beam	
HCALs	Scintillator - Steel	Well advanced	Exposed to beam	Design started
	RPCs - Steel	Well advanced	Almost ready to be build	(Design started)
	GEMs- Steel	Ongoing		
	MicroMegas - Steel	Started		
TCMTs	Scintillator - Steel	Well advanced	Exposed to beam	

Used in CERN and DESY testbeams

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CALICE Test Beam Activities

DESY electrons 1 – 6 GeV 2006

Silicon-ECAL
Scintillator HCAL

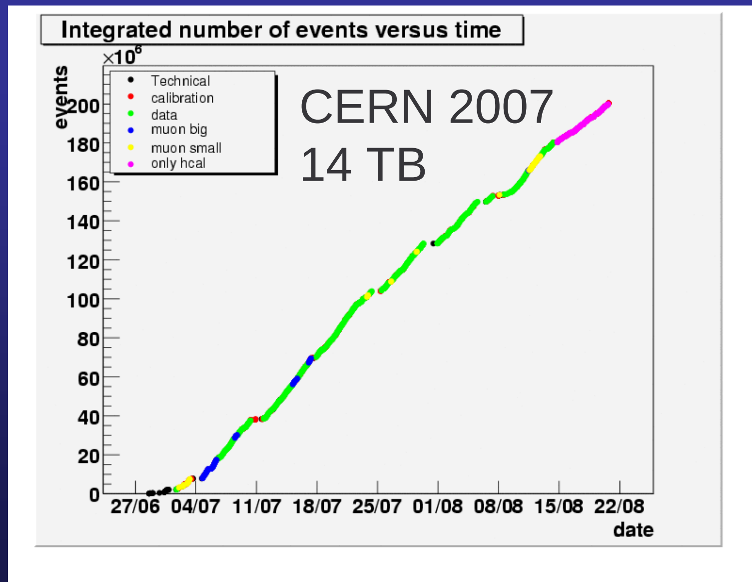
Scintillator ECAL
TCMT

CERN electrons and pions 6 – 120 GeV 2006 and 2007

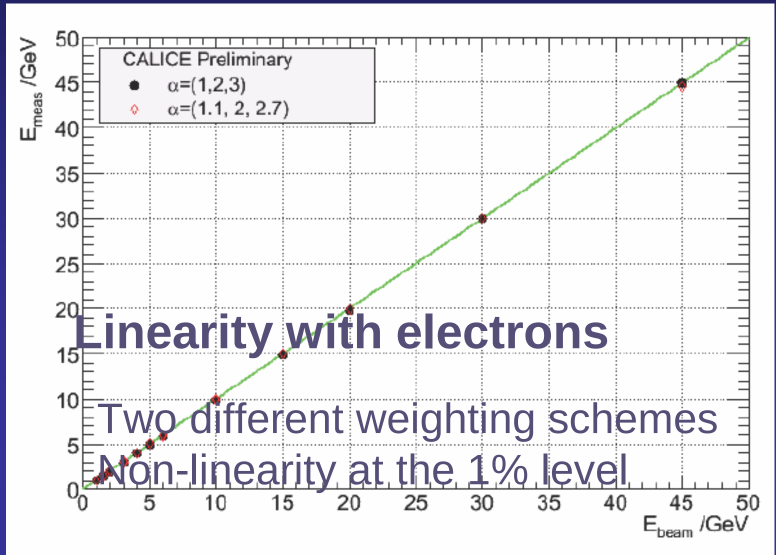
Silicon-ECAL
TCMT (complete)

Scintillator HCAL

UK activities concentrate on test beam operation and ECAL analysis

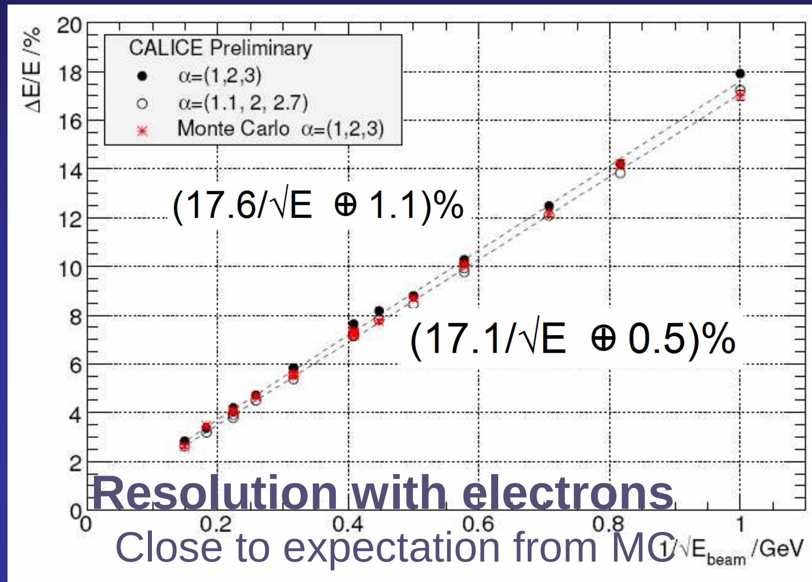


CALICE Test Beam Activities - data analysis 2006: Special emphasis on UK contributions



Linearity with electrons

Two different weighting schemes
Non-linearity at the 1% level



Resolution with electrons

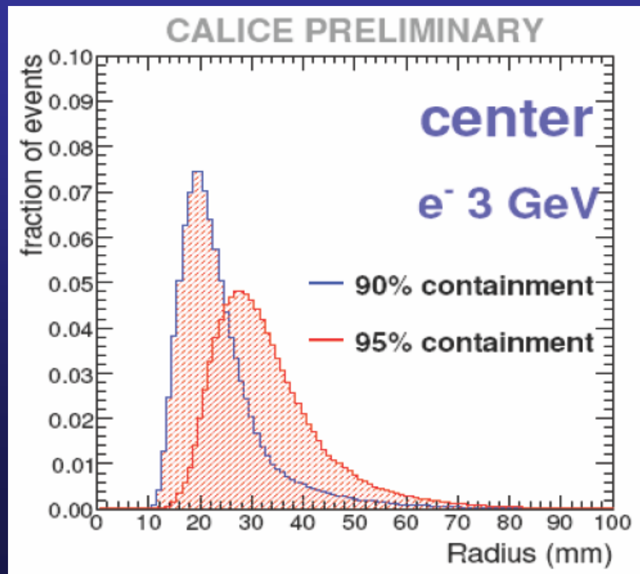
Close to expectation from MC

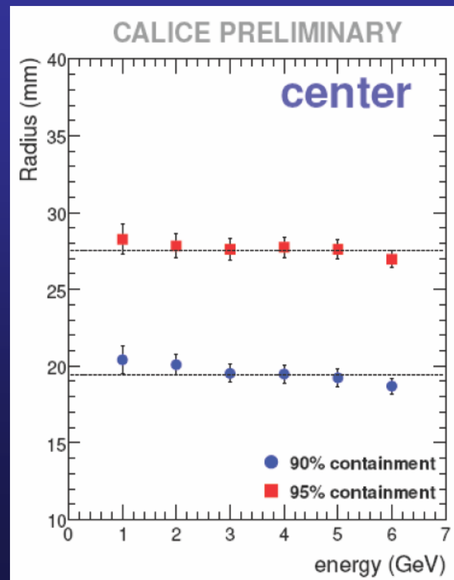
Transverse shower profile

Moliere radius R_M contains 90% of EM shower energy independently of energy

R_M (W) = 9 mm

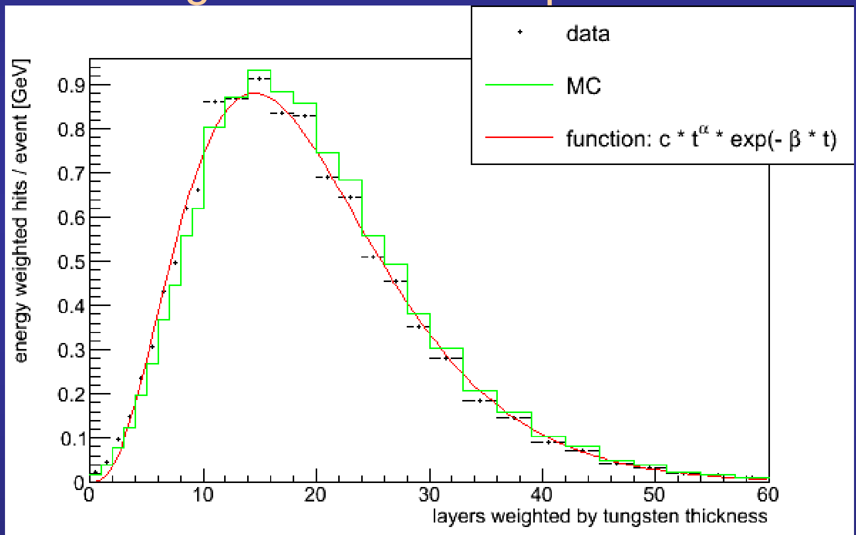
Gap will increase $R_M(W) \rightarrow R_M^{eff}$





CALICE Test Beam Activities - analysis of 2006 data: detailed look

Example:
longitudinal shower profile



- data suggest that more preshowering happens than MC
- leakage energy is not consistent with estimates from beam energy

discrepancy between MC and data:

- low pulse height hits
- interwafer gaps
- shower depth
- number of hits
- transverse shower shape
- mismatch of energy scale between CERN and DESY

Ideas to investigate:

- understand beam line better
- optimise alignment and rotation of detector
- understand passive material in front of calo better
- optimise calibration

CALICE Test Beam Activities - 2007

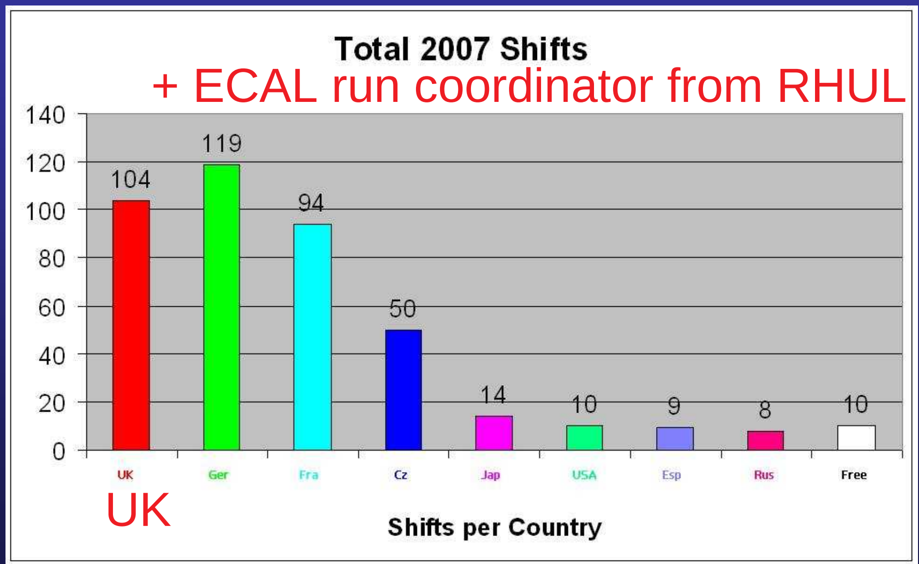
Physics prototype

3 structures with different W thicknesses

30 layers; 1 x 1 cm^2 pads

12 x 18 cm^2 instrumented in 2006 CERN tests

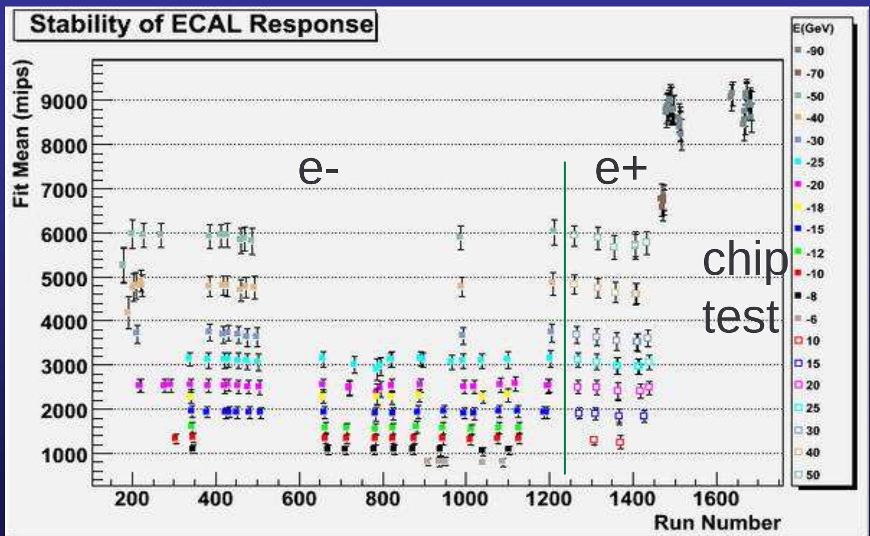
about 6480 readout channels

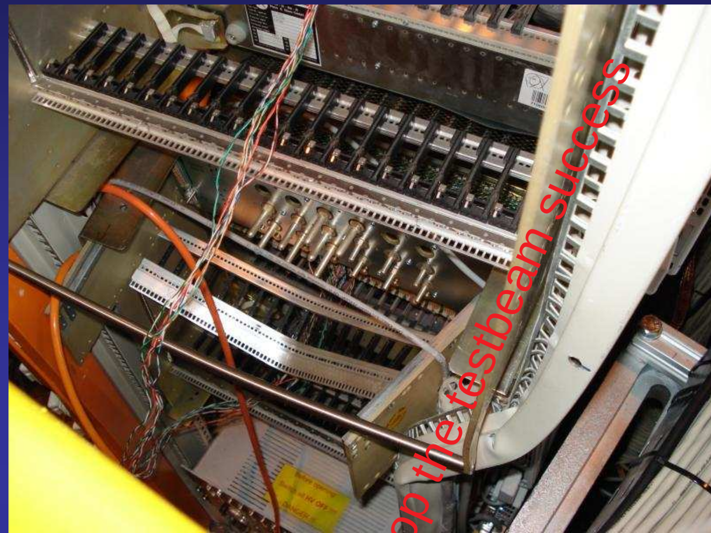


CALICE Test Beam Activities - 2007

summary of data taking:

- π^+, π^-, e^+, e^-, p:
- 6-180 GeV
- with position scans
- angles from 0^0 - 30^0





even accidents could not stop the testbeam success

Test beam activities with physics prototypes

	Project	2007b	2008a	2008b	2009a	2009b
ECAL	**Si-W**	CERN test beam	FNAL test beam			
	MAPS	1^{st} prototype chip		2^{nd} prototype chip	DESY test beam	
	Scintillator			FNAL test beam		
HCAL	**Scintillator**	CERN test beam	FNAL test beam			
	RPC	Vertical slice test in FNAL test beam	Physics prototype construction	FNAL test beam		
	GEM	Vertical slice test In FNAL test beam	Further R&D on GEMs		Physics prototype construction	FNAL test beam
	MicroMegas		1 plane			
TCMT	**Scintllator**	CERN test beam	FNAL test beam			

+ further R&D, technical prototype designs, construction & testing…

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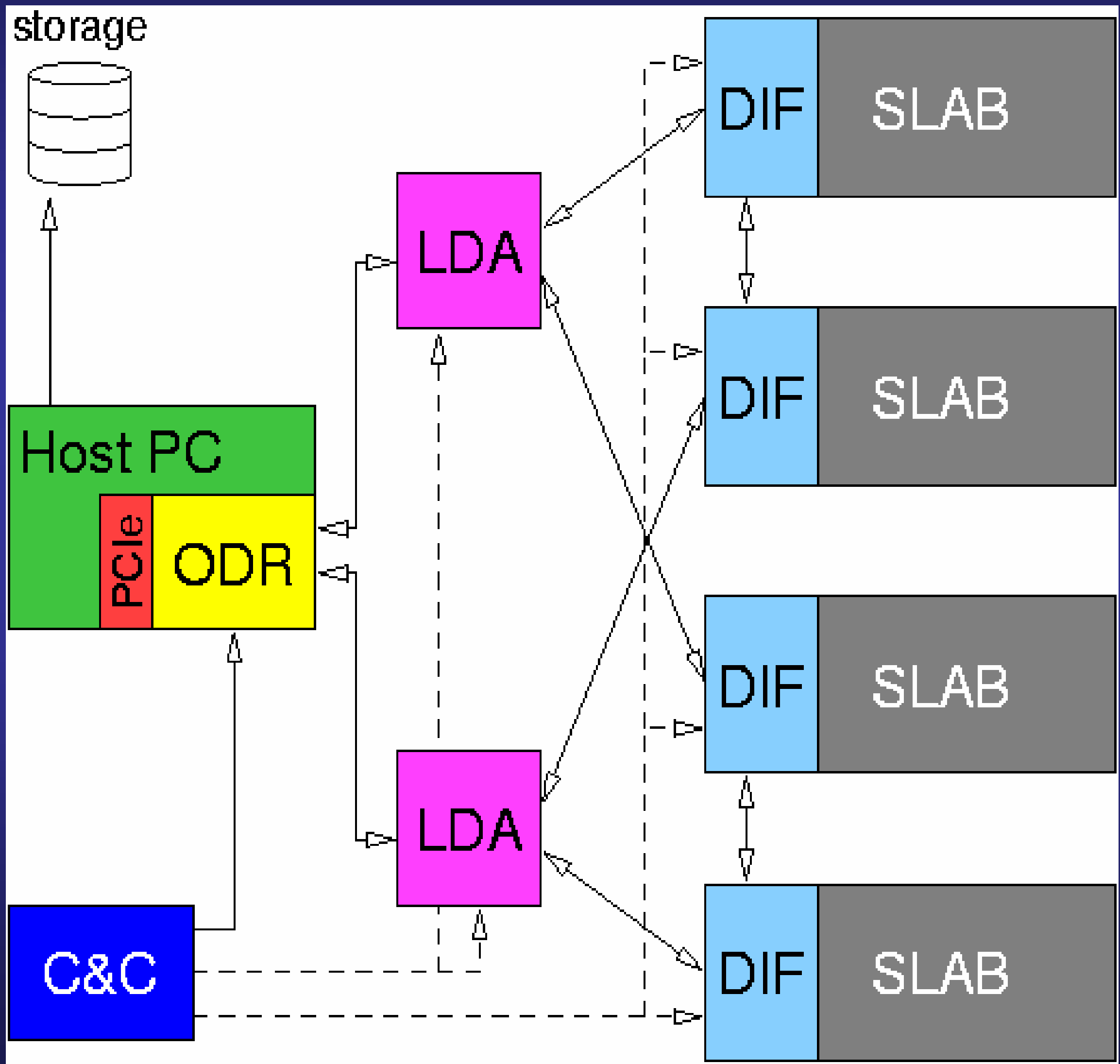
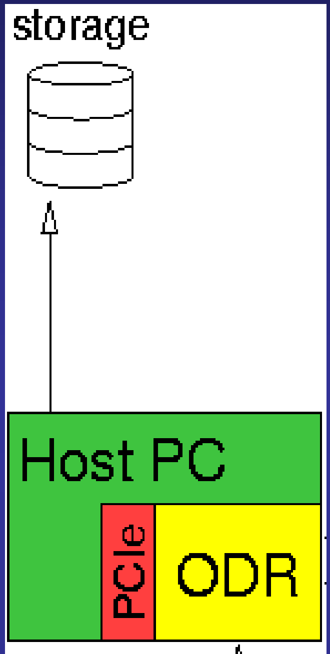
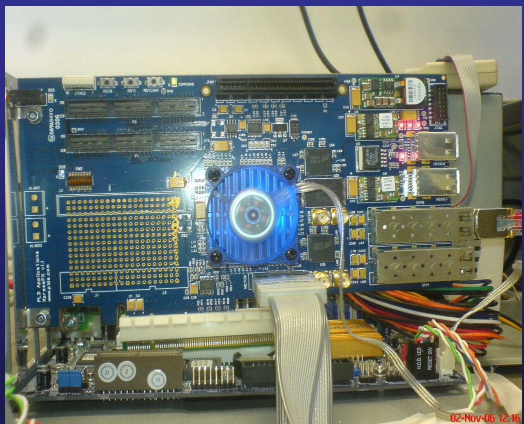
DAQ architecture



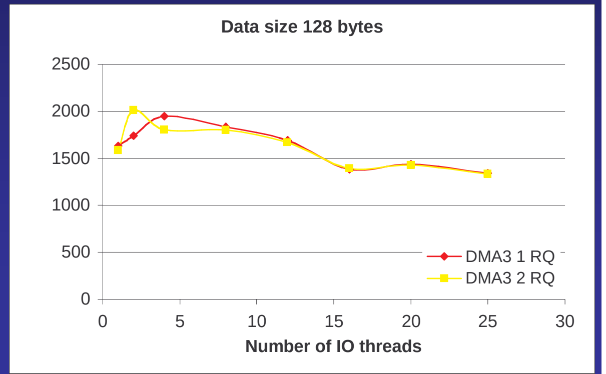
- Slab hosts VFE chips
- DIF connected to Slab
- LDA servicing DIFs
- LDAs read out by ODR
- PC hosts ODR, through PCIexpress
- C&C routes clock, controls

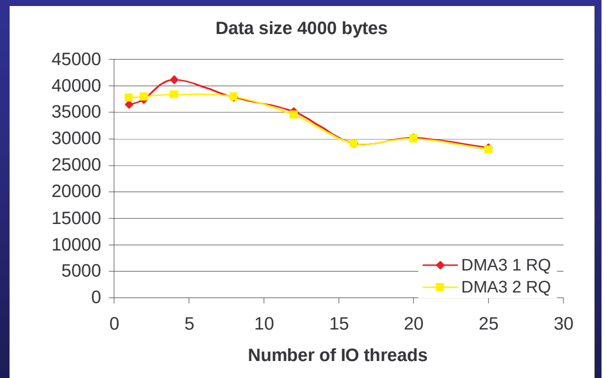
ODR and Data Rates



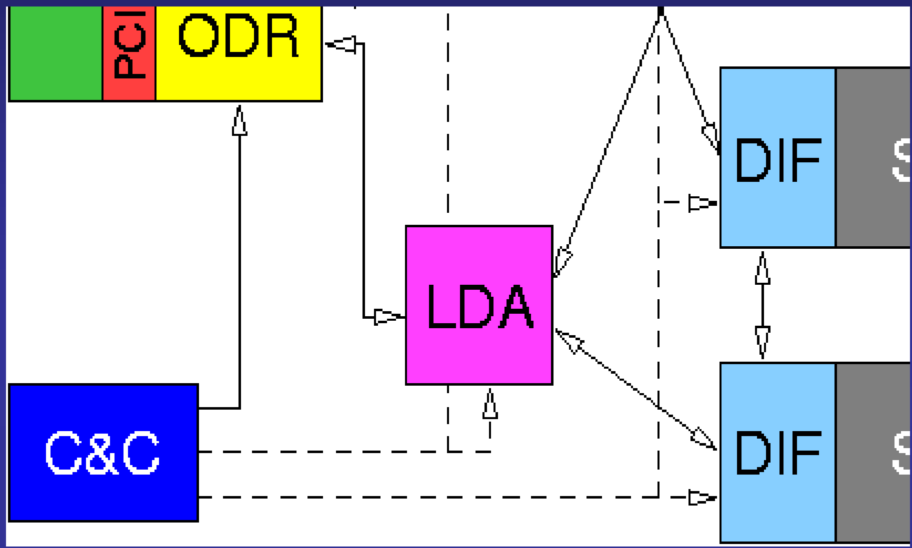


- ODR is a commercial FPGA board with PCIe interface
  (Virtex4-FX100, PCIe 8x, etc.)
- Custom firm- and software
- DMA driver pulls data off the onboard RAM, writes to disk
- Performance studies & optimisation





Clock & Controls Distribution

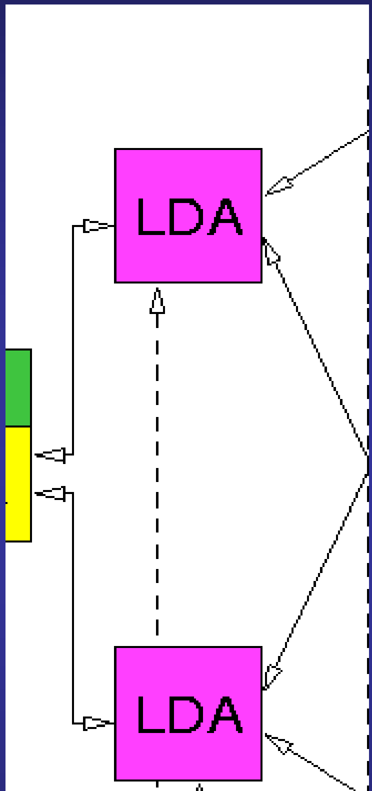


- Fast Controls: encoded through the LDA-DIF link
- Low-latency fast signals: distributed 'directly'

- C&C unit provides machine clock and fast signals to ODR, LDA (and DIF?)
- Clock jitter requirement seems not outrageous

  (at the moment)

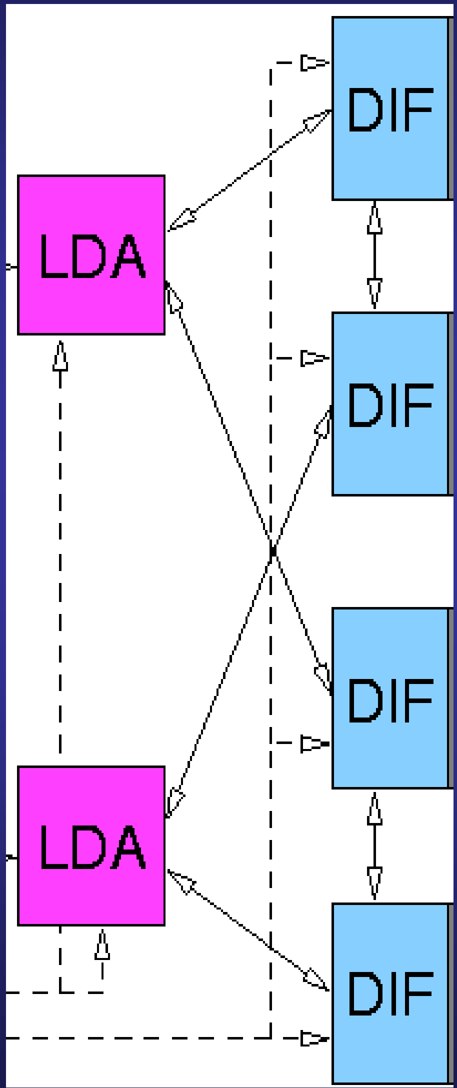
LDA and link to ODR



1st Prototype is again a commercial FPGA board with custom firmware and hardware add-ons:

- Gbit ethernet and Glink Rx/Tx for ODR link - probably optical
- Many links towards DIFs

LDA-DIF link



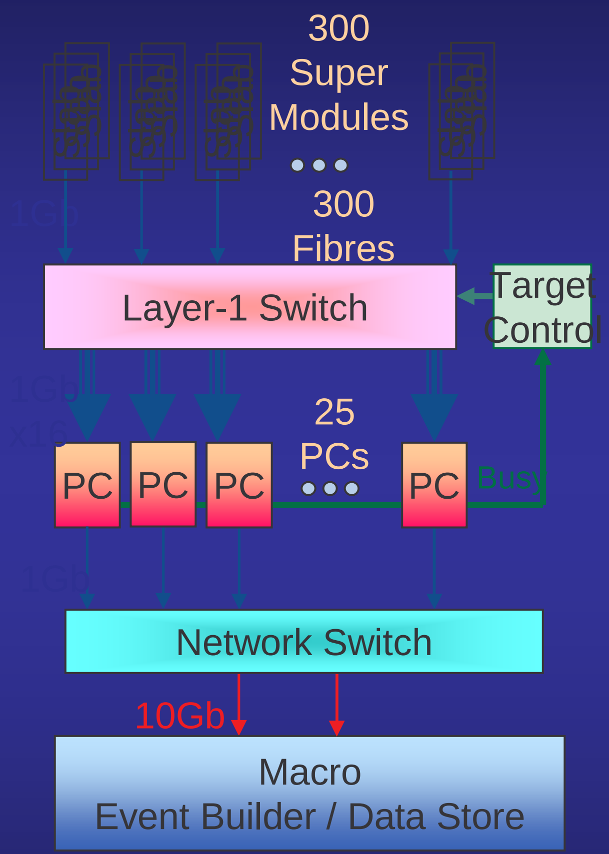
LDA-DIF link:

- Serial link running at multiple of machine clock
- 50Mbps (raw) bandwidth minimum
- robust encoding (8B/10B or alike)
- anticipating 8…16 DIFs on an LDA, bandwidth permitting
- LDAs serve even/odd DIFs for redundancy

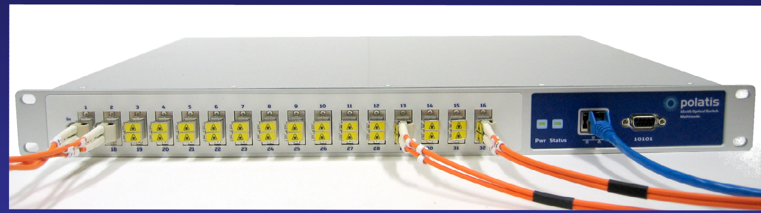
DIF-DIF link:

- Redundancy against loss of LDA link
- Provides differential signals:
  - Clock in both directions
  - Data and Control connections
  - Two spares: one each direction

network



general outline of DAQ design

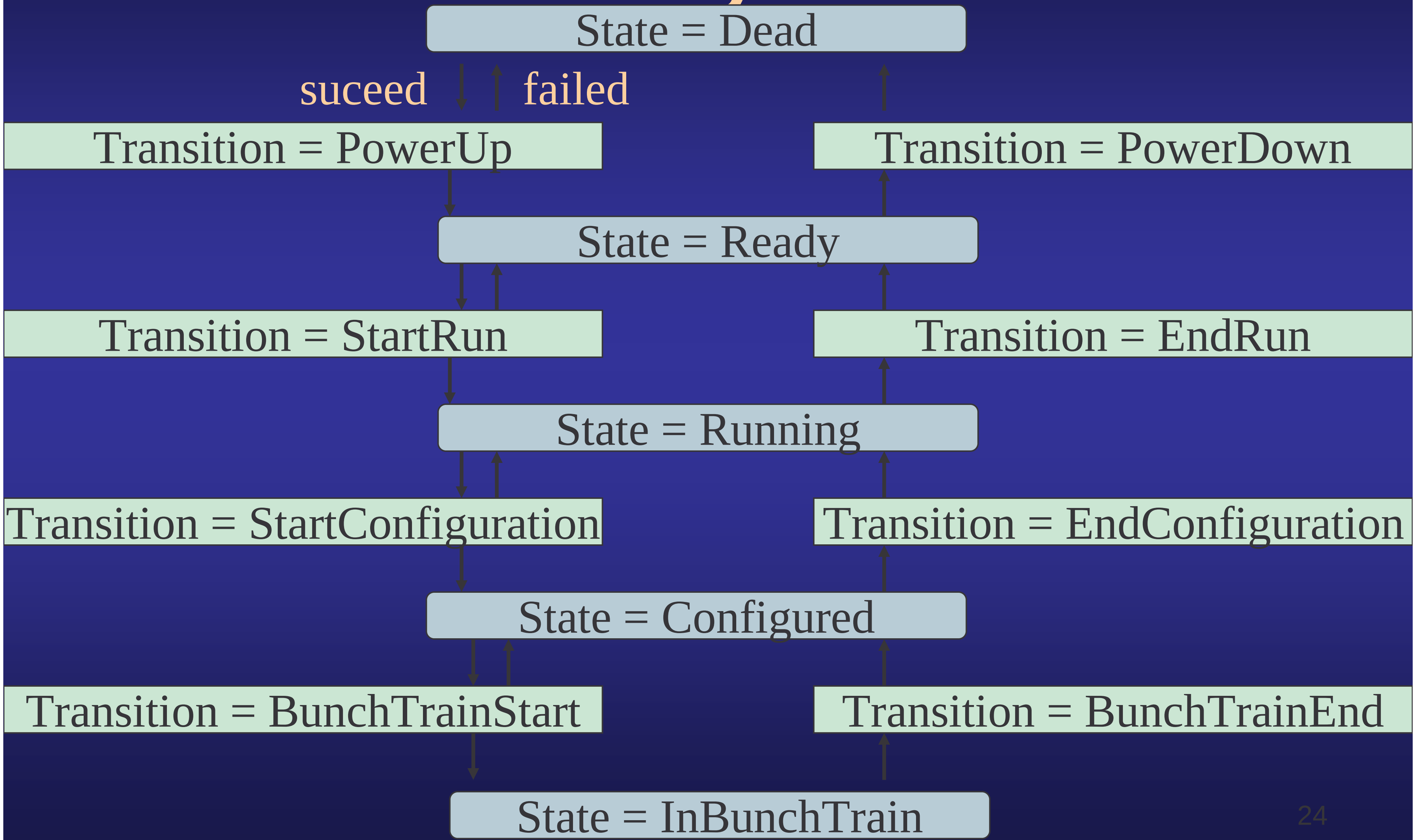


Optical switch to act as Layer-1 Switch

Optical switch:

- fulfills routing and dispatching tasks
- tested that the switch works according to its specification
- needs to be verified within the DAQ framework that it adds additional benefit

DAQ software for Eudet: State Analysis



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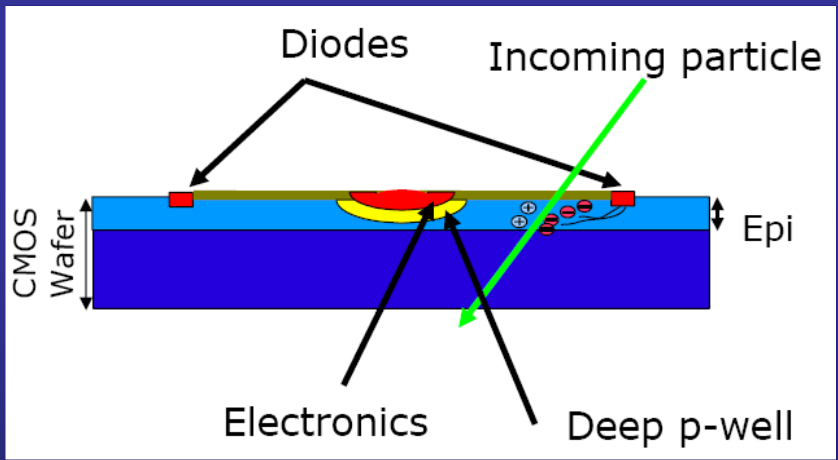
MAPS ECAL

Monolithic Active Pixel Detectors

In-pixel comparator and logic
50 x 50 μm^2 pixels
10^{12} pixels for the ECAL

} Digital (single-bit) readout



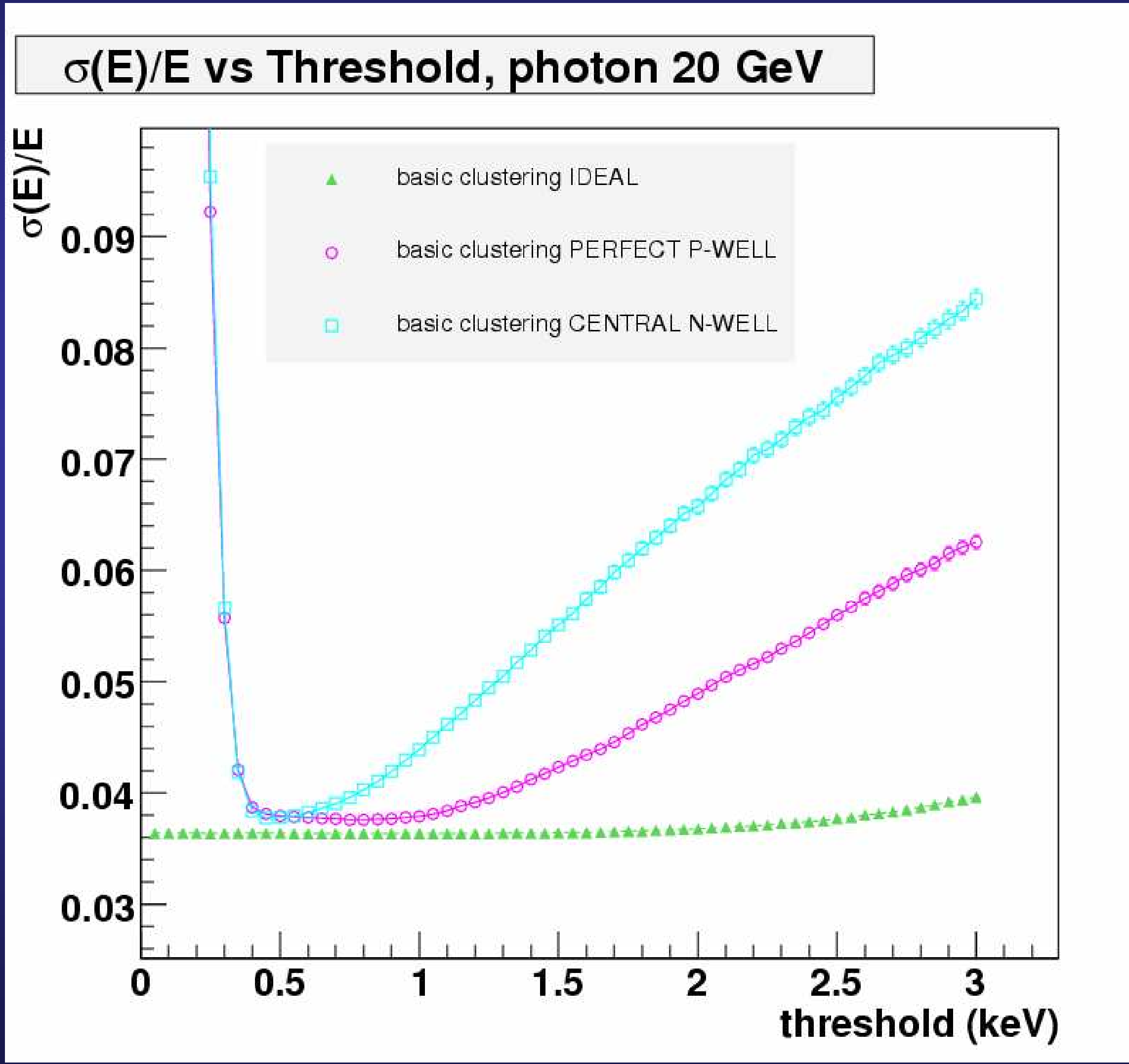
Test Sensor
Area of 1 x 1 cm^2 ~ 28,000 pixels
Testing different architectures n-well or p-well to prevent charge spread

Extensive simulation studies
Charge collection effects
Resolution versus threshold
….

Effect of charge spread model

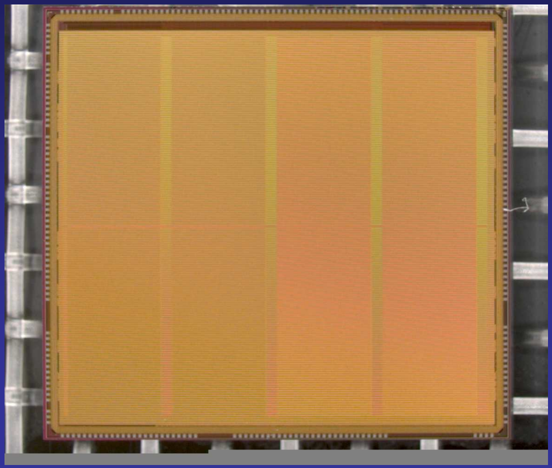
Optimistic scenario:
Perfect P-well after clustering: large minimum plateau Ł large choice for the threshold !!

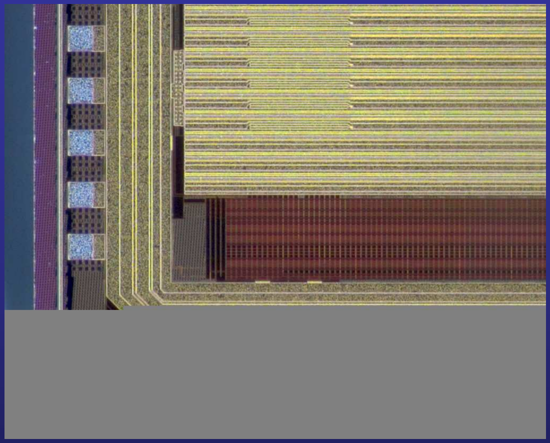
Pessimistic scenario:
Central N-well absorbs half of the charge, but minimum is still in the region where noise only hits are negligible + same resolution !!!



plans for the autumn

- Sensors delivered this summer, tests can go forward
- Charge diffusion studies with a powerful laser setup at RAL :
  - 1064, 532 and 355 nm wavelength,
  - focusing < 2 μm,
  - pulse 4ns, 50 Hz repetition rate,
  - fully automatized
- Cosmics and source setup to provide by Birmingham and Imperial respectively.
- Work ongoing on the set of PCBs holding, controlling and reading the sensor.





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news from the Pandora particle flow algorithm

Eight Main Stages:
- Preparation (MIP hit ID, isolation, tracking)
- Loose clustering in ECAL and HCAL
- Topological linking of clearly associated clusters
- Courser grouping of clusters
- Iterative reclustering
- Photon recovery (new)
- Fragment removal (new)
- Formation of final particle flow objects

E_{jet}	$\sigma_E/E = \alpha/\sqrt{(E/GeV)}$	σ_E/E
45 GeV	0.295	4.4%
100 GeV	0.305	3.0%
180 GeV	0.418	3.1%
250 GeV	0.534	3.3%

Mark Thomson's comment:
Now convinced that PFA can deliver the required ILC jet energy performance

news from the Pandora particle flow algorithm

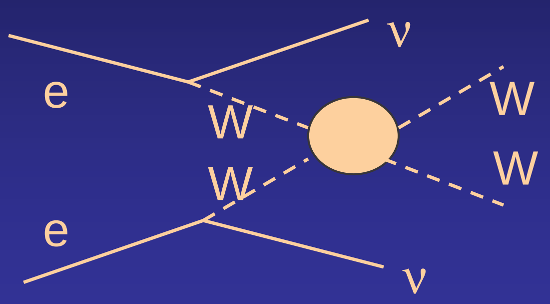
Perfect Pandora added to Pandora which relies on MC information to create the ProtoClusters.

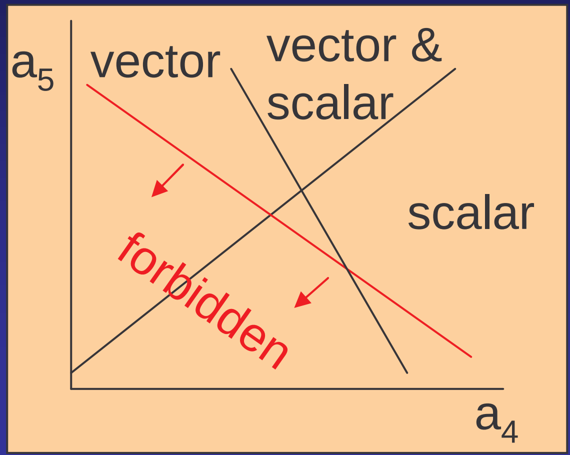
	$\sigma_E/E = \alpha/\sqrt{(E/GeV)}$	
E_{jet}	PerfectPandora	Pandora
100 GeV	0.220	0.305
180 GeV	0.305	0.418

$\Rightarrow$ the current code is not perfect, things will get better

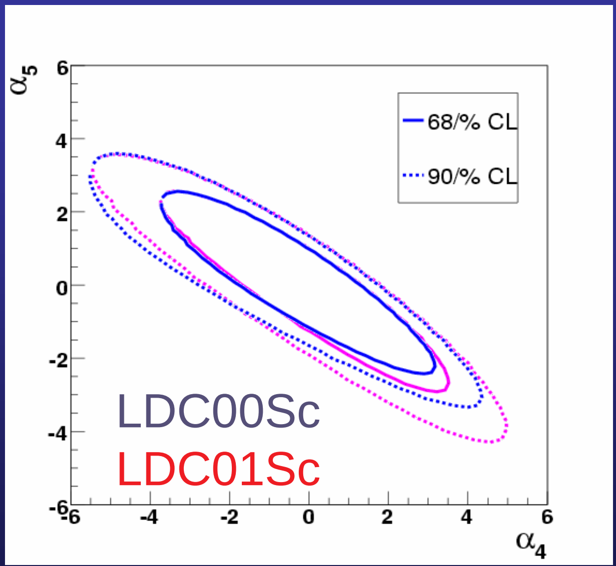
Future developments:
• moving to LDCTracking is highest priorities
• optimisations of newly introduced features

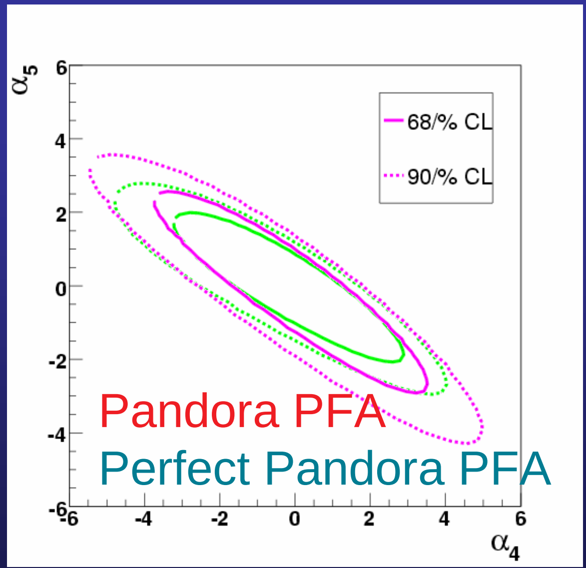
WW scattering





WW scattering model independent way of checking the unitarity breakdown of the standard model





⇒ detector optimization with this study possible

⇒ shows room for improvement within Pandora

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Mechanical and Thermal Studies

- Glue testing now complete
  - Will continue with very-long-term testing using the same samples, checking over ~months timescales.
- Mechanical Work
  - Agreed areas to cover with French groups
    - Attachment of wafers to PCBs
      - Testing of assemblies
    - Mechanical layout of end of modules
      - Full CAD workup of Electrical and Cooling connections

Conclusion:

- **test beams:**

  2006 analysis needs to be finalized,
  2007 analysis not yet started,
  challenging program for 2008/2009

- **DAQ:**

  at the moment only components ready,
  need to be integrated to a whole system until 2009

- **MAPS:**

  on a good way,
  in the phase of prototype design

- **PFA:**

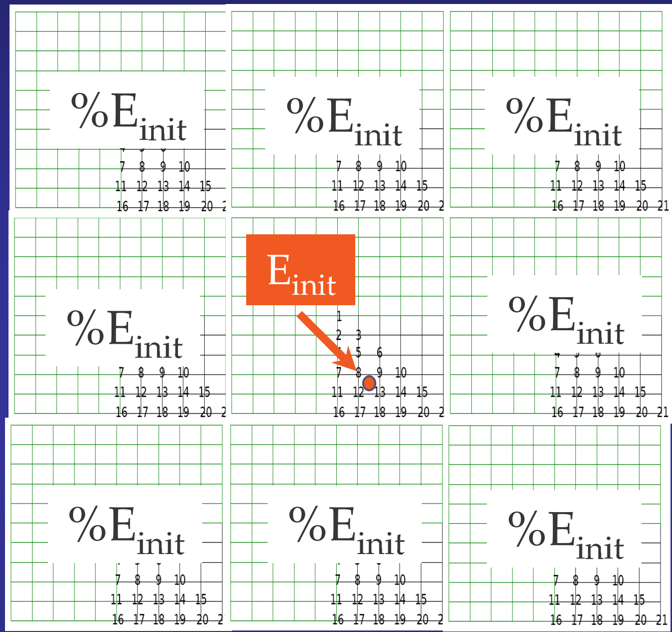
  success story of the UK,
  WW scattering a good testing analysis,
  probably need a few more physics analysis

backup slides

Digitisation procedure

Geant4 E_{init}
in 5x5 µm^2 cells

Apply charge spread
$E_{after\ charge\ spread}$



register the position and the number
of hits above threshold

+ noise only hits :
proba 10^{-6} Ł ~ 10^{6} hits in the whole detector
BUT in
a 1.5*1.5 cm^2 tower : ~3 hits.

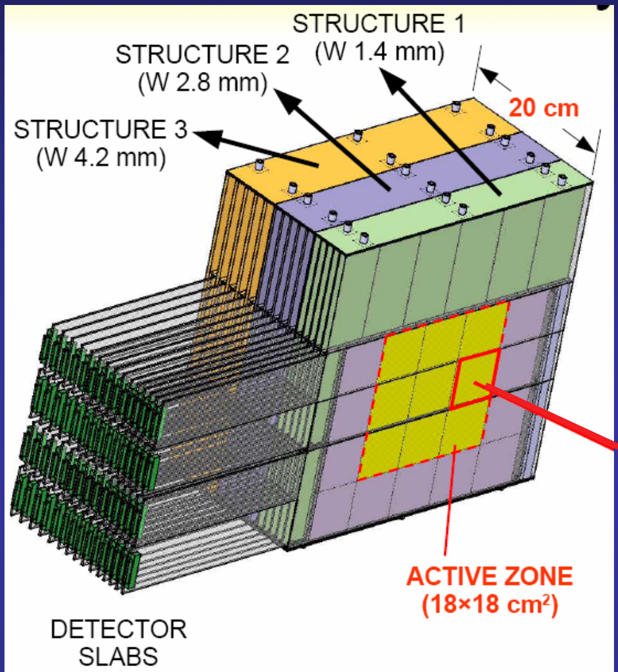
Importance of the charge spread :

$$\sum E_{neighbours} \sim (50\% - 80\%) \times E_{init}$$

Add noise to signal hits

Sum energy in
50x50 µm^2 cells
E_{sum}

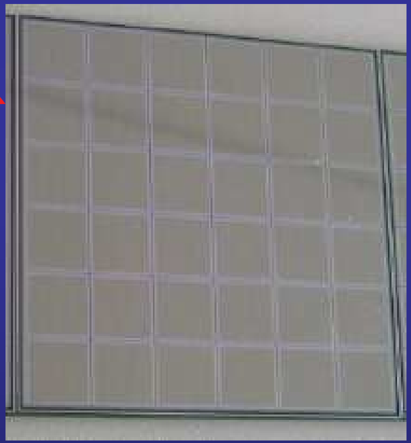
Silicon-Tungsten ECAL



$1\ X_0(W) = 3.5$ mm

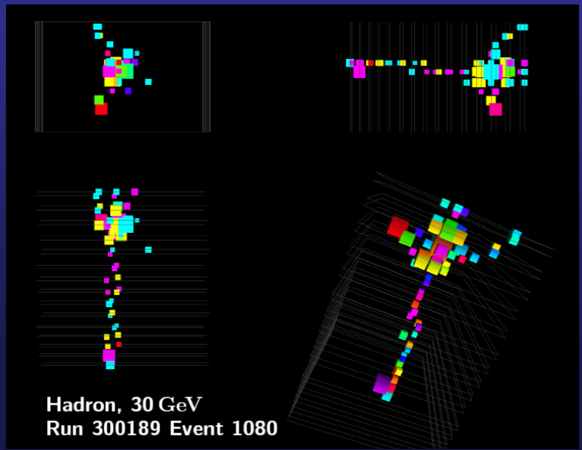
Physics prototype

3 structures with different W thicknesses
30 layers; 1 x 1 cm^2 pads
12 x 18 cm^2 instrumented in 2006 CERN tests
→ 6480 readout channels



Tests at DESY/CERN in 2006

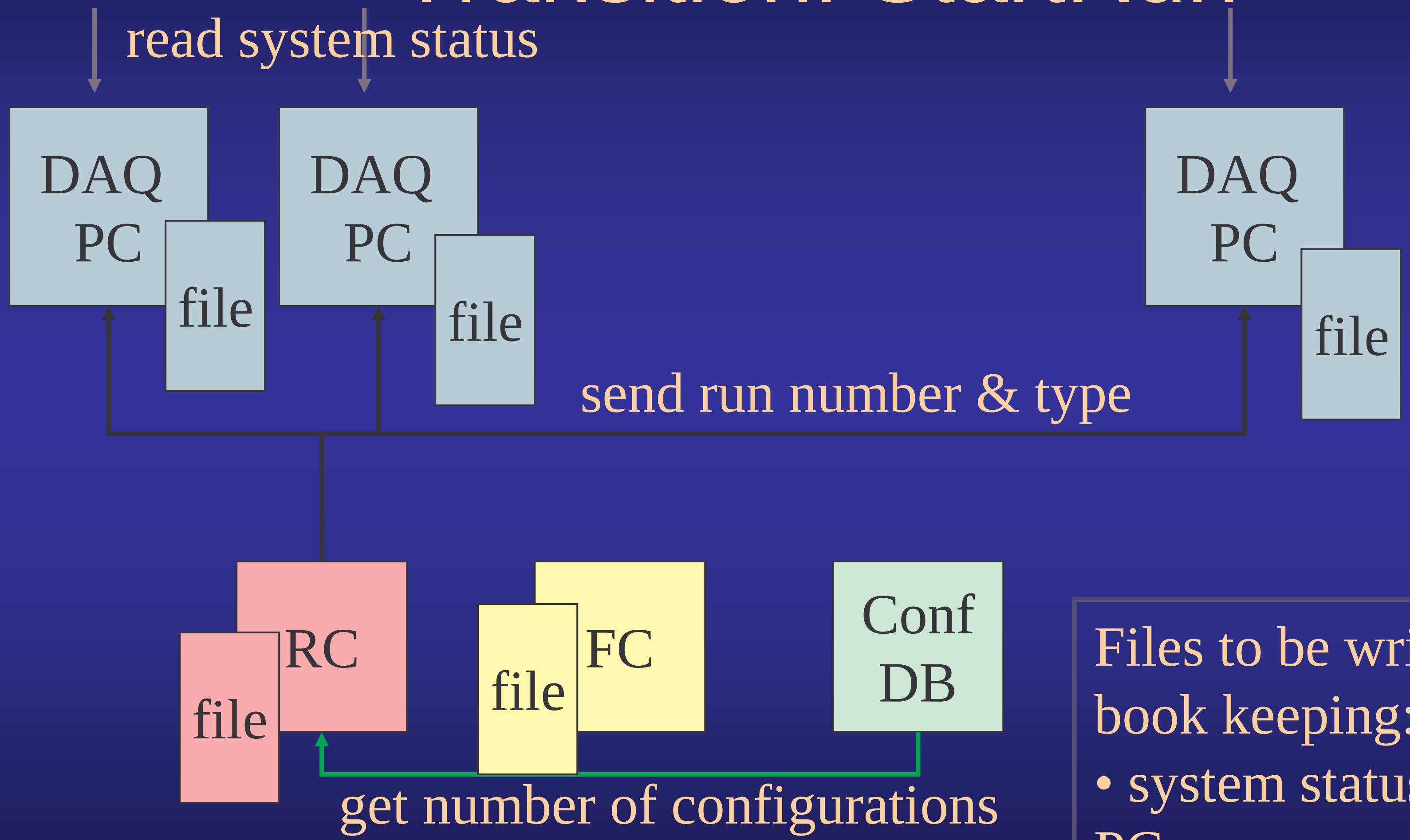
Electrons 1 – 45 GeV
Pions 6 – 120 GeV



Electronic Readout

Front-end boards located outside of module
Digitization with VME – based system (off detector)

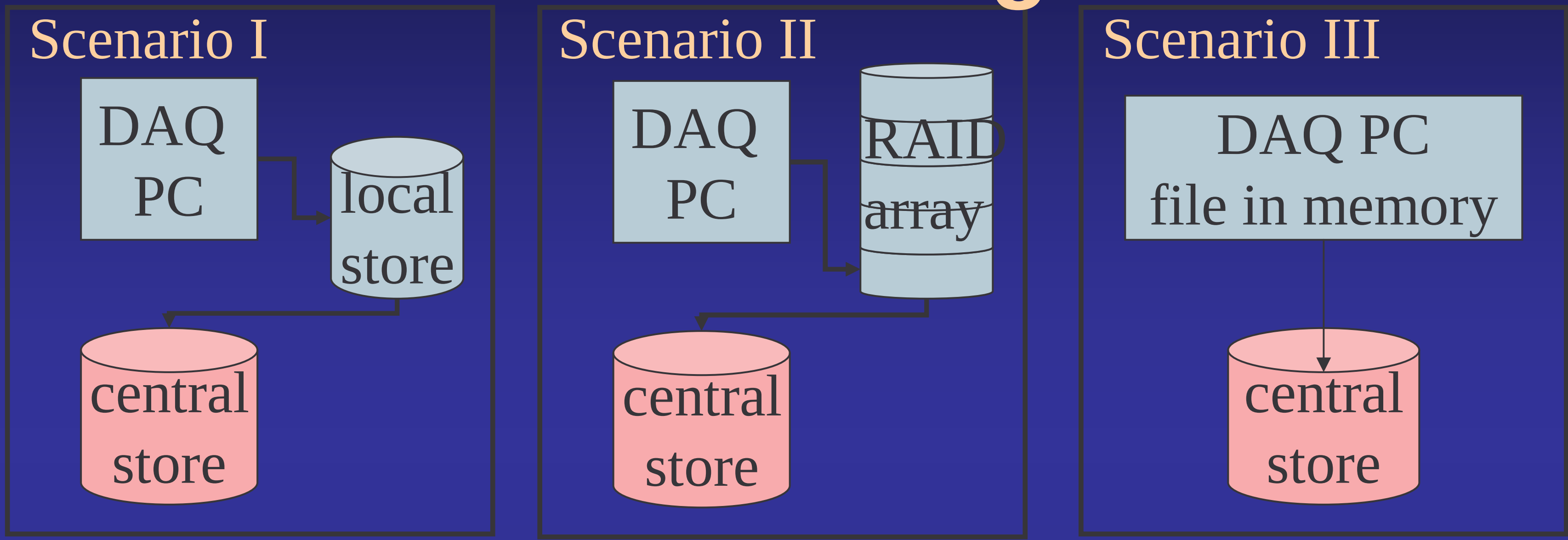
DAQ software for EUDET: Transition: StartRun



Files to be written for book keeping:

- system status by DAQ PC
- run info by RC PC
- system status by FC

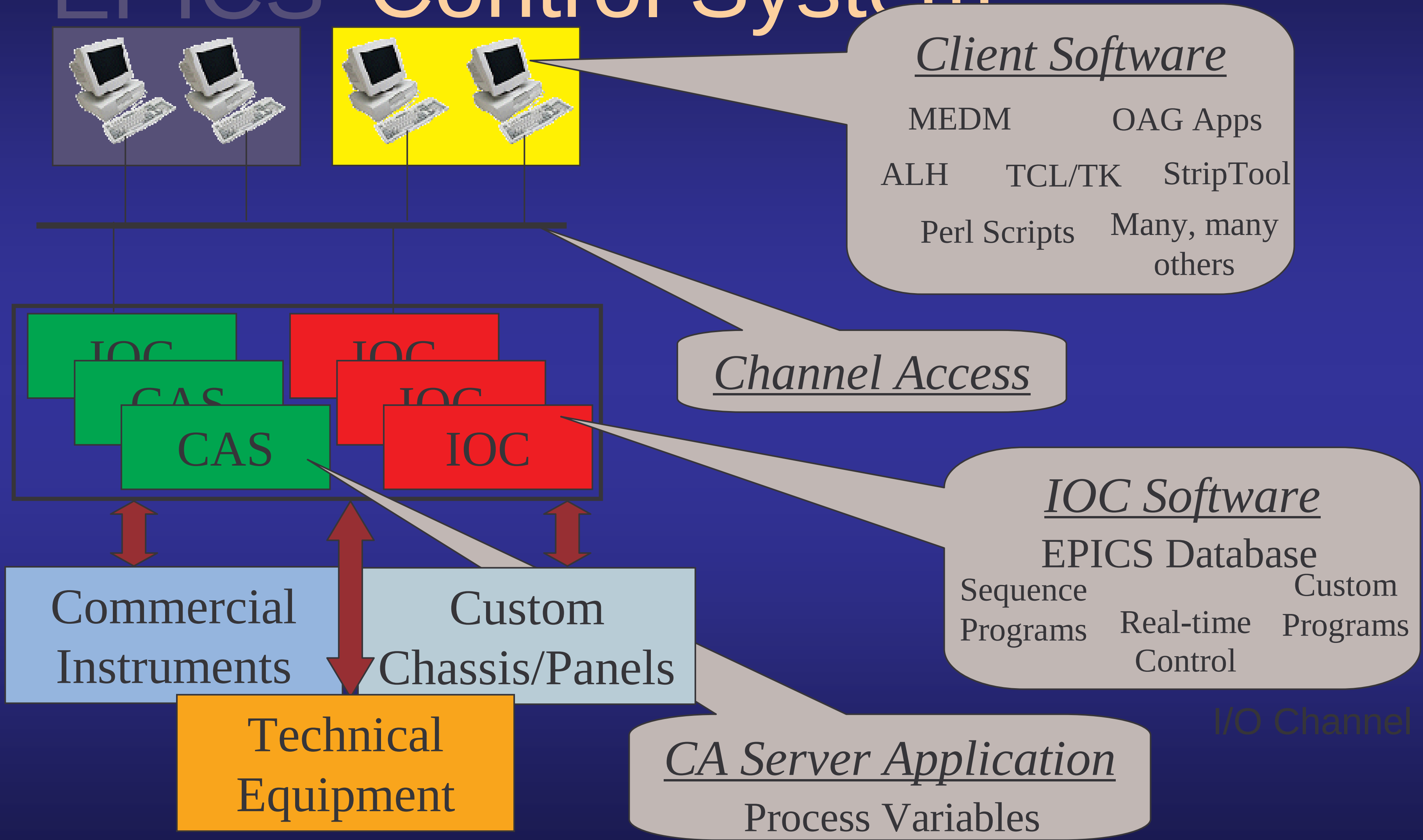
DAQ software for EUDET: Data Storage



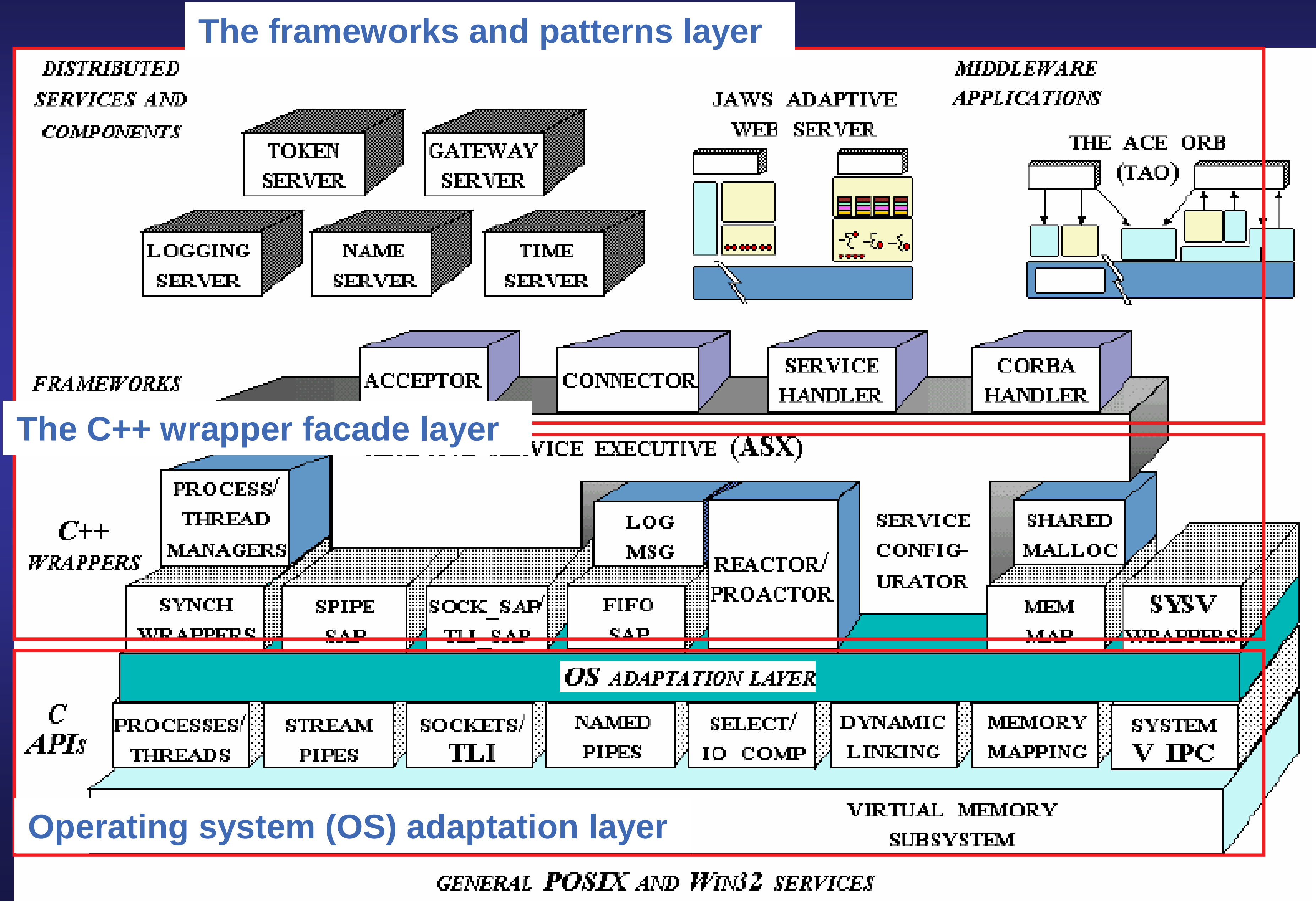
- which scenario to choose depending on the bandwidth with which the data gets produced: (I) up to 200Mbit/sec, (II) up to ~1600Mbit/sec, (III) from there on

- desirable to have files because transfer is easier and in case of timing problems error handling is easier, but keep system flexible for now

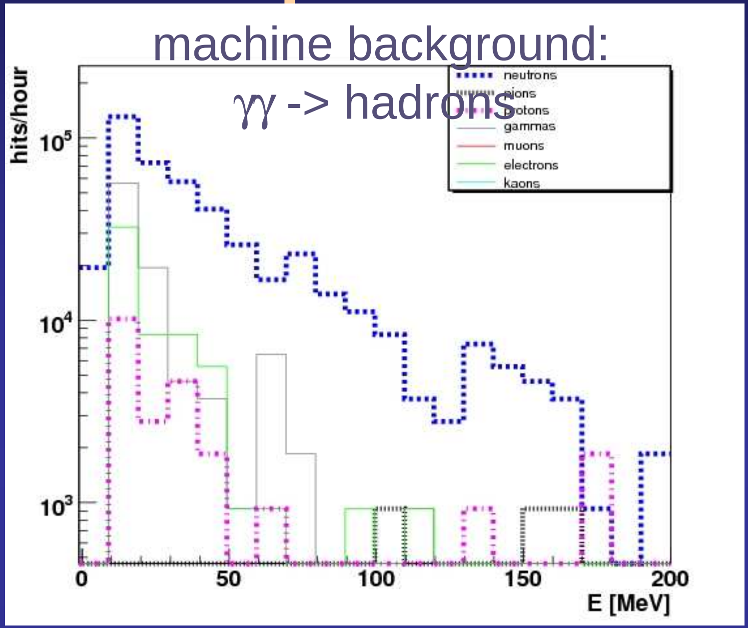
Canonical Form of an EPICS Control System

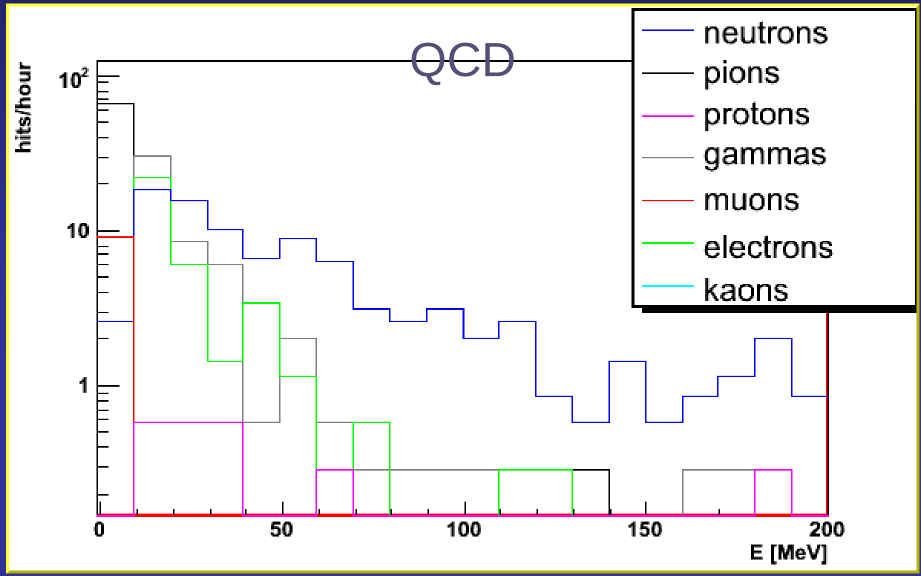


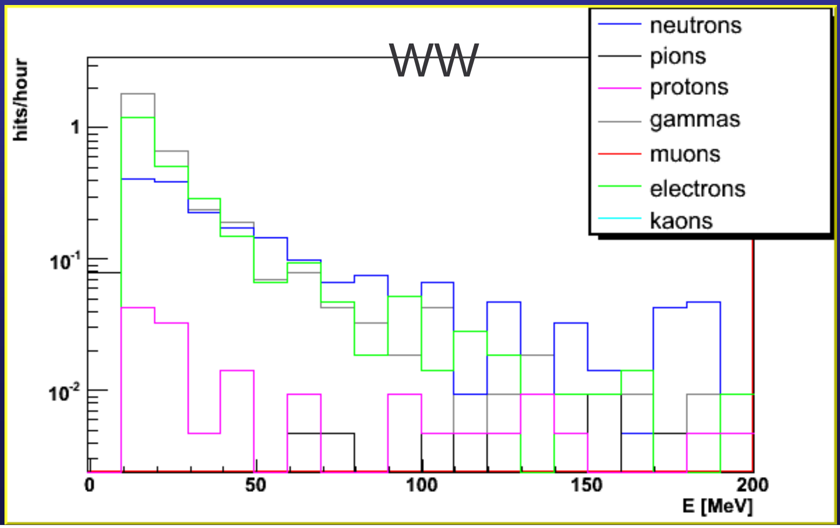
ACE Architecture

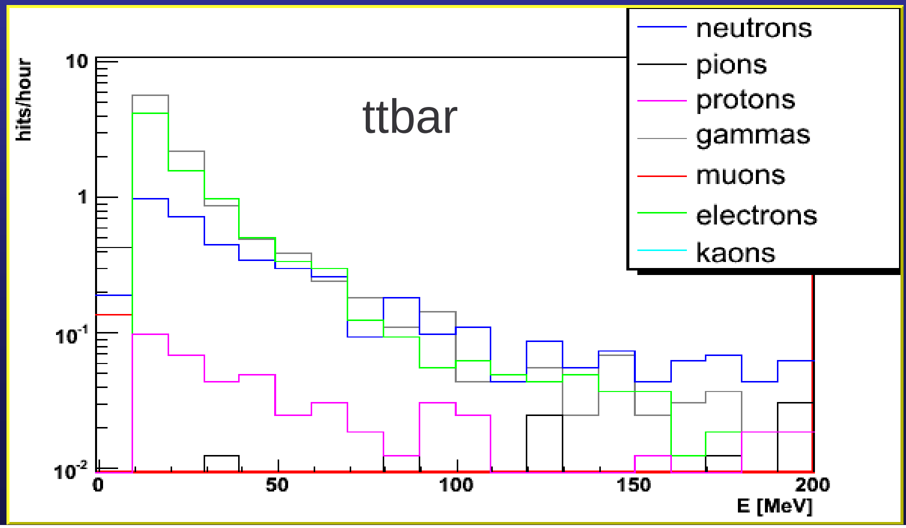


energy spectrum of particles in the FPGAs









Other FPGAs

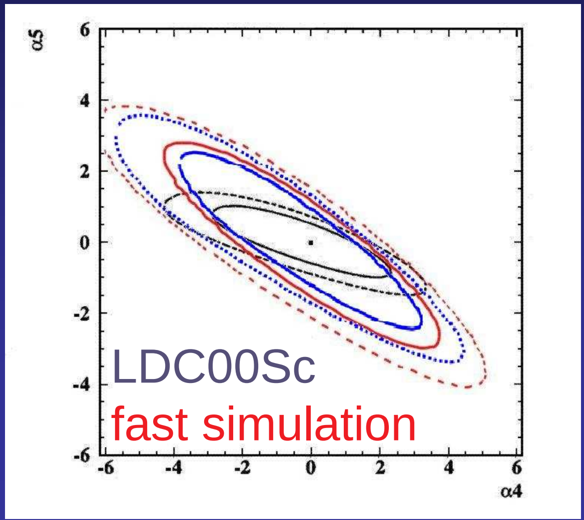
Virtex II X-2V100 Virtex II X-2V6000	0.05 SEUs/h
Altera Stratix	0.61 SEUs/h
Xilinx XC4036XLA	**0.01 SEUs/h**
Virtex XQVR300	0.12 SEUs/h
9804RP	0.04 SEUs/h

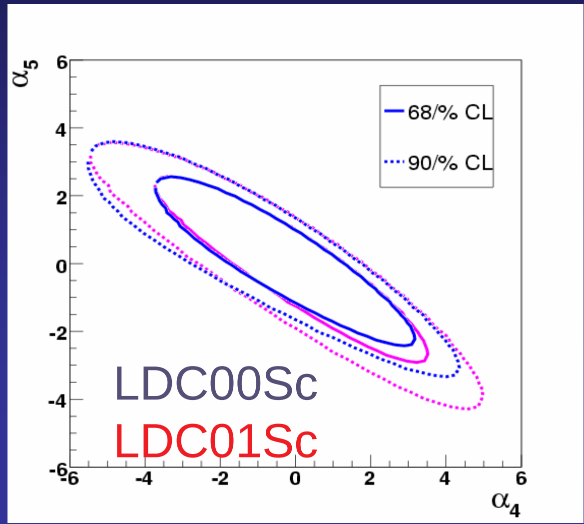
1 SEU between 0.5 hours and 12 days depending on FPGA chosen

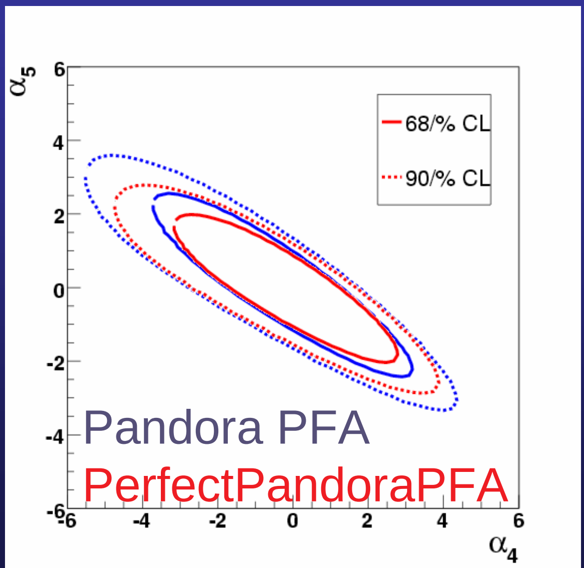
DIF Functionality

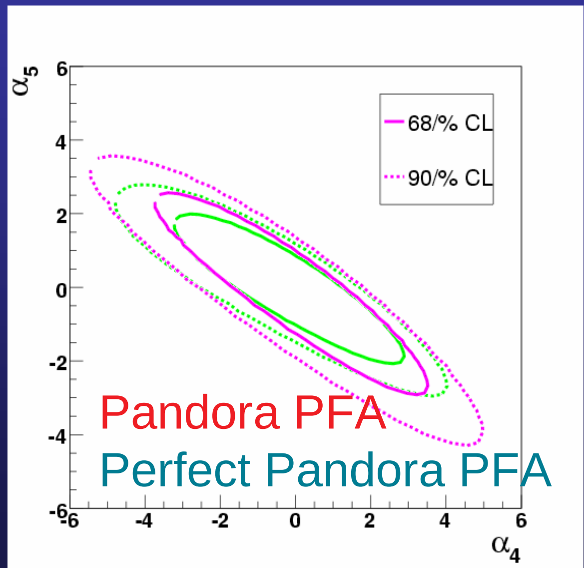
- Receive, regenerate and distribute clocks
- Receive, buffer, package and send data from VFE to LDA
- Receive and decode incoming commands and issue corresponding signals
- Control the DIF-DIF redundancy connection
- Receive, decode and distribute slow control commands
- Control power pulsing and provide watchdog functionality
- Provide an USB interface for stand-alone running and debugging
- …..on top of that: all the things we did not think of so far

WW scattering









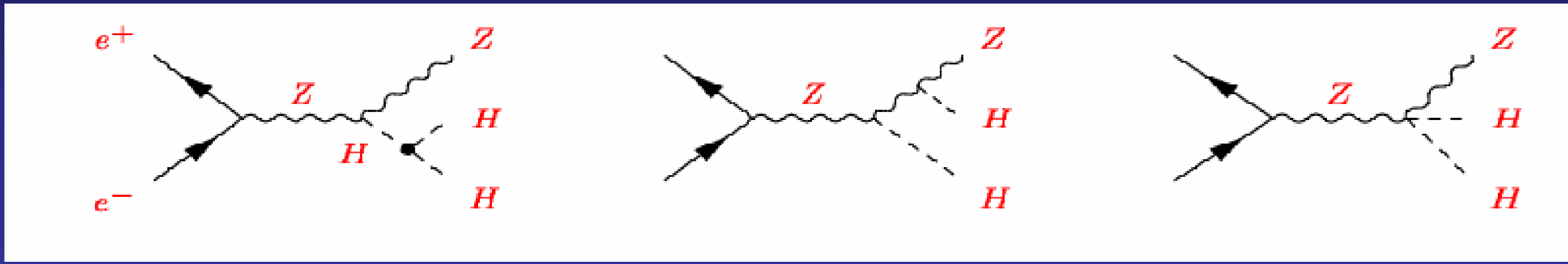
$\Rightarrow$ simulation consistent with older simu

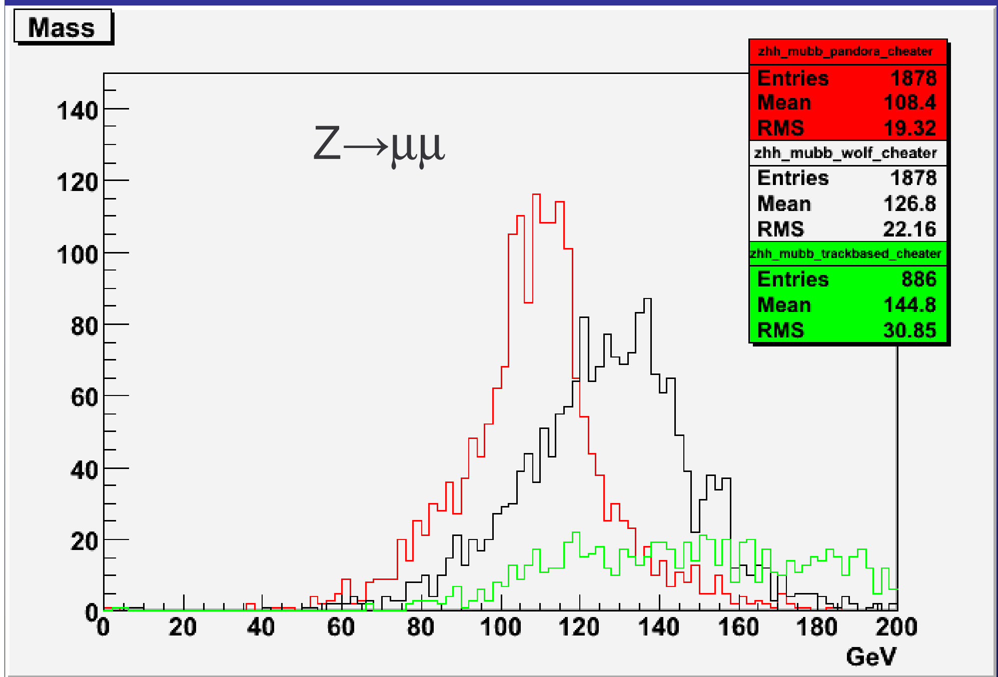
$\Rightarrow$ detector optimization with this study possible

$\Rightarrow$ shows room for improvement within Pandora

Higgsstrahlung

study of the Higgs self coupling constant

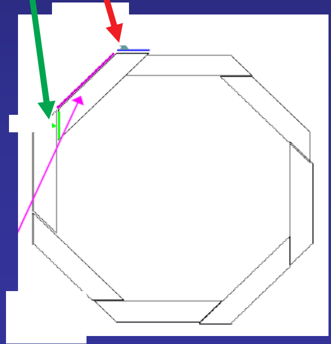




- Pandora has very good RMS
- Wolf reconstructs too high mass
- Problem with muon id affects the higgs reconstruction in TrackbasedPFA

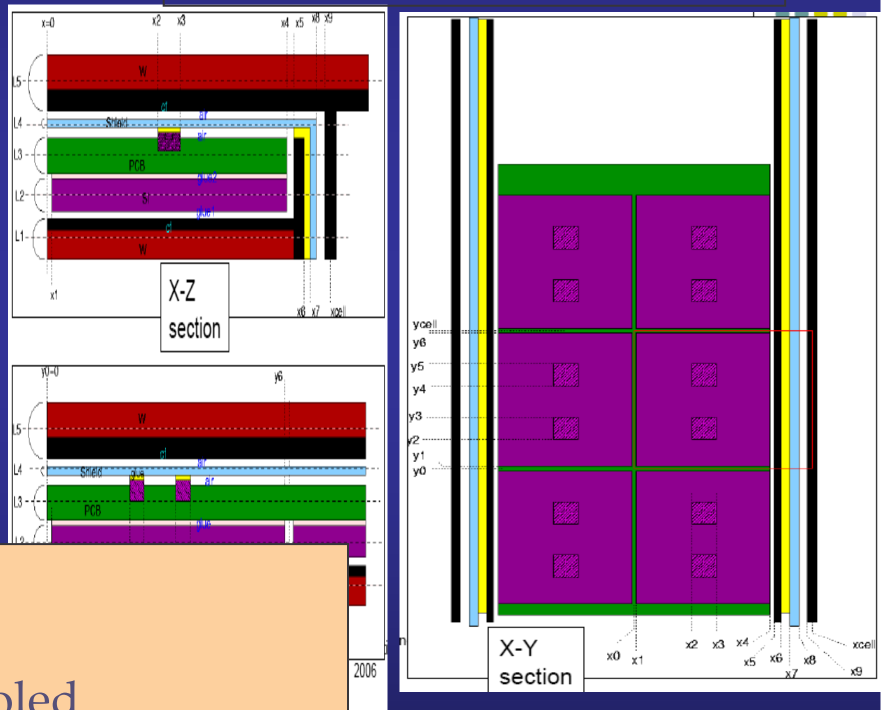
Thermal studies in ECAL Barrel

- A CALICE module will dissipate at least 300 W Ł active cooling required
- Obvious places : this end. Problem : already busy with slab readout.
- Alternatively : this end. Disadvantage : dead area.



- Or this face.
  Disadvantage :
  poor conductivity in the perpendicular direction.

Implementation in the simulation



RESULTS :

Ł Assuming a module is 26 cells long :

$\Delta T_{bothEnds}$ = 10.3 °C only one end cooled

$\Delta T_{middleEnds}$ = 2.6 °C both ends cooled

Ł Manchester will build a cooling test setup to verify simulation

Ł environment for active cooling tests