



Physics and Detectors: UK Perspective

Mark Thomson, University of Cambridge



Past, Present and Future



Recent History

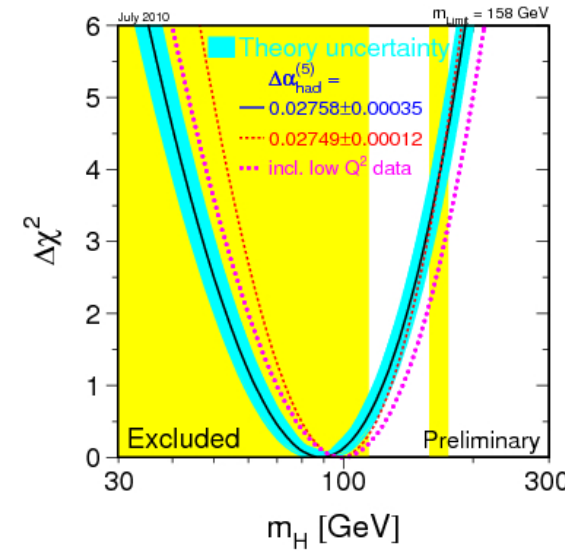


From a slide presented at the September 2011 LCUK meeting:



In the next year results from the LHC **will** change the LC physics landscape

- By end of this year ATLAS/CMS combined may have 8 fb^{-1} of data
- **The noose is closing:** the Higgs will either be discovered or the famous blue band plot will go “all yellow”



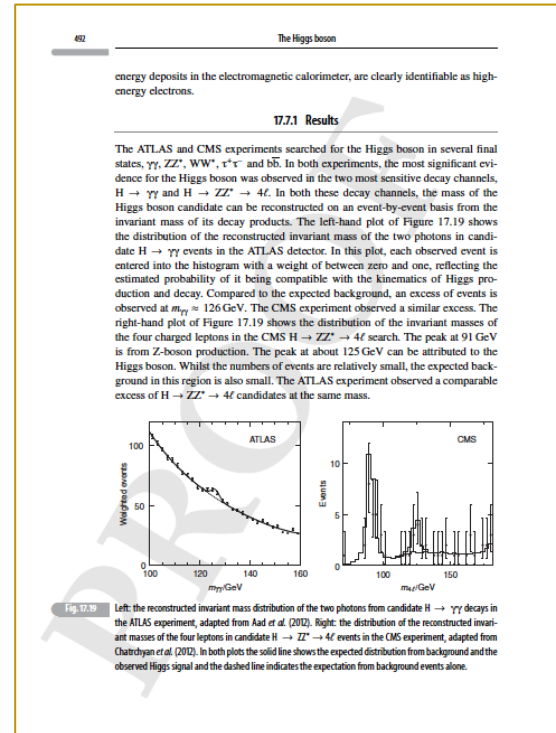
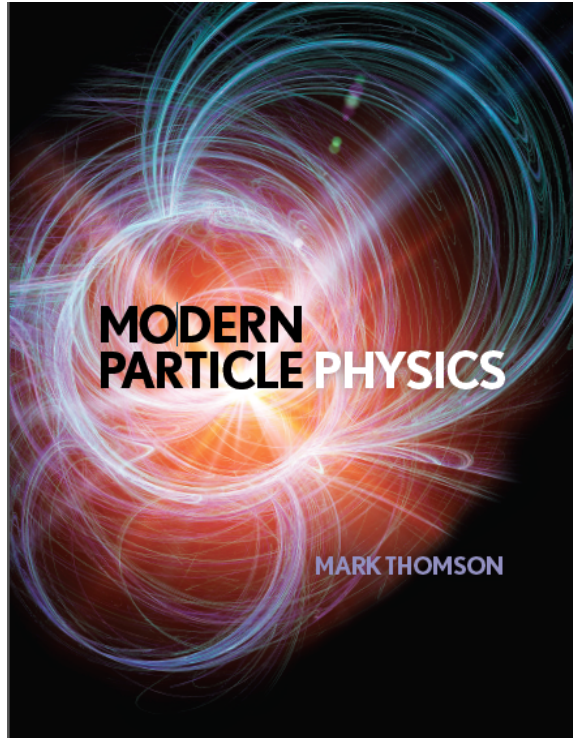
A low mass Higgs would provide strong momentum for the ILC



The Higgs is out there



★ and (from today) coming to all good bookshops near you..



- ★ The ILC is **THE** machine to study the Higgs
- ★ The ILC in Japan is now a very realistic possibility
- ★ The UK needs to consider how to (re)-engage...



This Talk



★ Will cover UK perspective:



Past ILC involvement



Present LC Activities



Future possibilities



★ Will not cover the different R&D topics in great depth
- try to paint the general picture

★ Ultimately touch on:

Next steps for the UK?



The Past

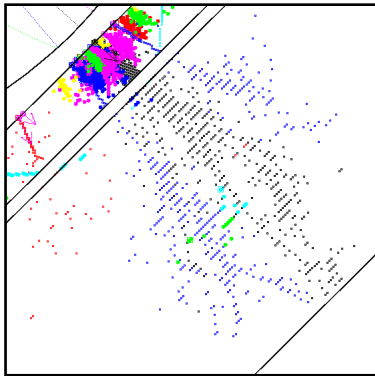


Past UK Activities



- ★ Pre-2007 there was a very active UK LC community
- ★ Focussed on two areas of detector R&D:

i: Calorimetry:



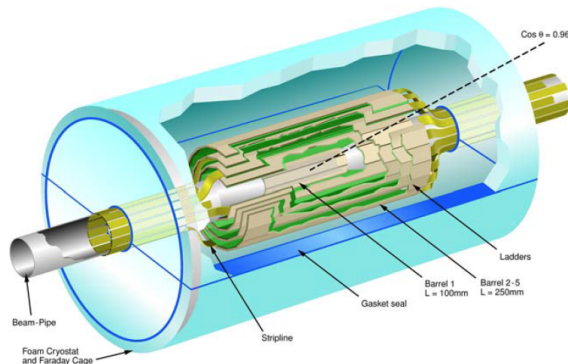
CALICE-UK

Birmingham, Cambridge, Imperial,
Manchester, RHUL, UCL

International R&D programme including:

- DAQ
- MAPS – digital ECAL concept
- Test beam data analysis
- Software: Particle Flow

ii: Vertex Detector:



LCFI

Bristol, Edinburgh, Glasgow,
Lancaster, Liverpool, Oxford, RAL

R&D programme including:

- CCD sensor development – ISIS
- MAPS development
- Mechanics and Support Structures
- Software: flavour tagging



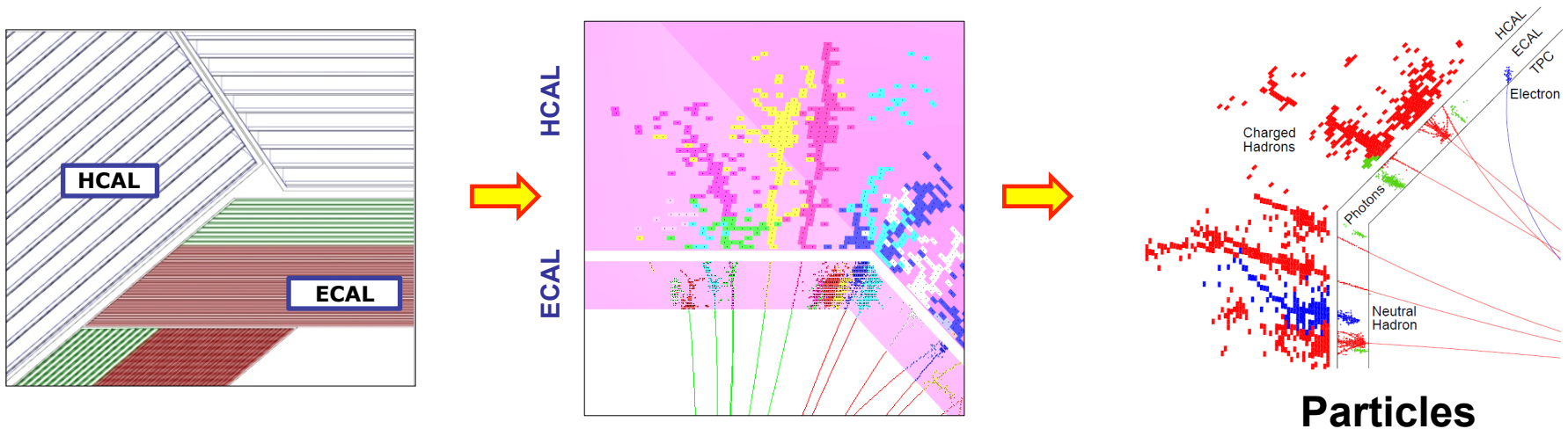
i) Calorimetry



CALICE



- ★ **CALICE** is the umbrella R&D collab. for almost all LC calorimetry R&D
 - ★ ILC jet-energy goals → High-granularity Particle Flow Calorimetry
 - ★ **Idealised** Particle Flow Calorimetry paradigm:
 - ◆ charged particles measured in tracker (essentially perfectly)
 - ◆ Photons in **ECAL**
 - ◆ Neutral hadrons (and **ONLY** neutral hadrons) in **HCAL**
 - ◆ **Only 10 % of jet energy from HCAL**
- **Separate individual energy deposits from different particles**
- ★ **Highly segmented calorimeters + “Particle Flow reconstruction”**

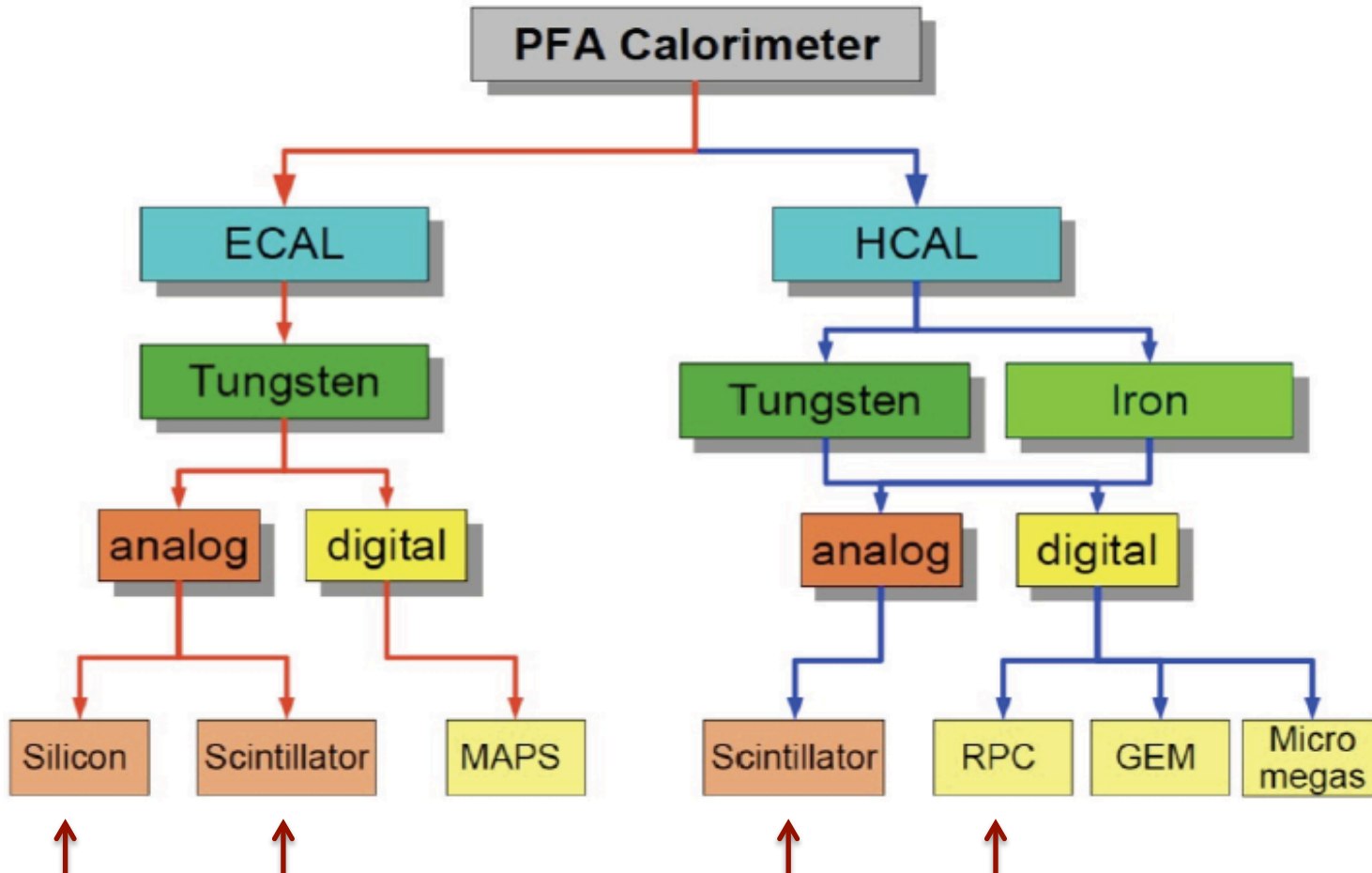




CALICE Activities



- ★ **CALICE** studies encompass a number of technological options
 - with significant scale test beam campaigns



With major technological prototypes in beam tests in 2011-2012



e.g. Si-ECAL prototype

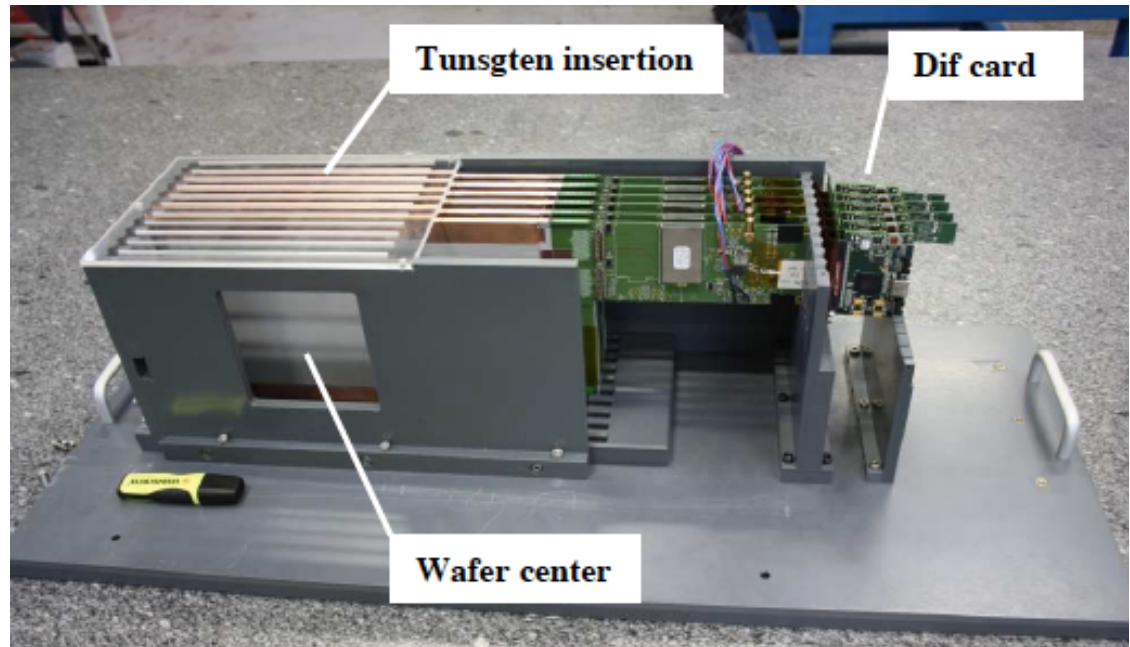


★ Technological Si-ECAL prototype:

- Real-scale detector integration model
- Large Si sensors with small $5 \times 5 \text{ mm}^2$ PADs
- System with 1200 cells in DESY test beam in 2012



Full-scale mechanical structure



Test beam characterisation of technology

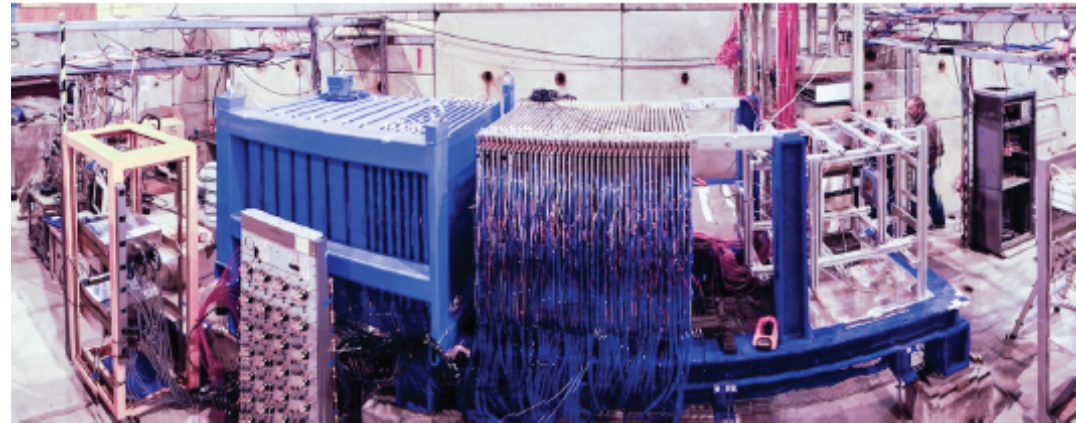


e.g. Digital HCAL



54 glass RPC chambers, 1m² each

- PAD size 1×1 cm²
- Digital readout (1 threshold)
- Fully integrated electronics
- Total: 500000 readout channels



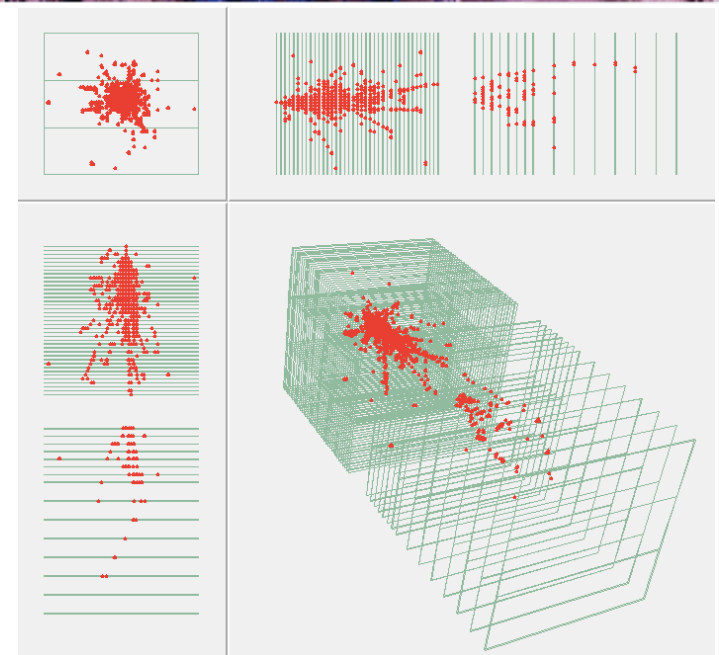
➔ Detailed 3D images of hadronic showers

Test beam campaigns:

- Demonstrate technology
- Provide high quality physics data
 - ➔ test GEANT4 models
- Many CALICE publications



Many important UK contributions in this large international collaboration



W-DHCAL π^- at 210 GeV (SPS)



ii) Vertex Detectors + Si Sensors



Past: LCFI

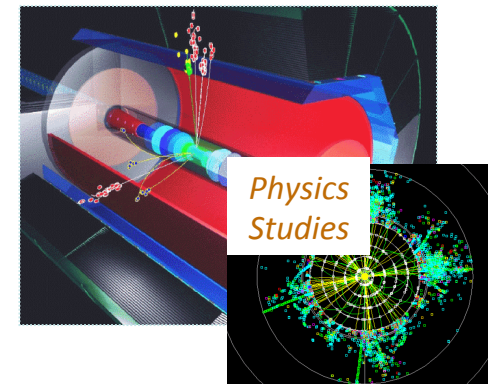
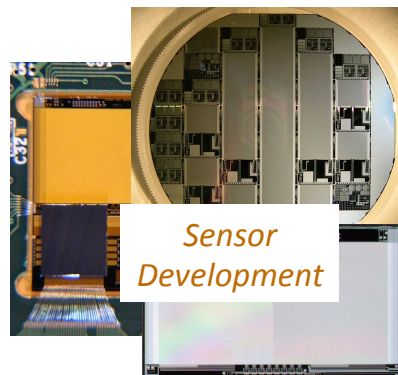
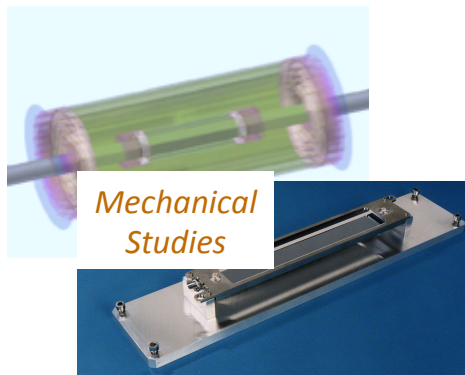


★ Linear Collider Flavour Identification: *LCFI*

- Born in the UK: grew to 9 institutes including international partners
- >£2M/year in grants
- Work packages developing all aspects of vertex detector
- Led international **pixel vertex detector development** for ILC

★ *LCFI* Accomplishments

- Several generations of fast CCDs, readout ASICs, bump bonding, ultra-light mechanics (foams), vertexing code, CMOS ISIS sensors, etc.
- UK expertise in all areas needed for detector construction!
- Well-placed in both of the two ILC detector concepts
- Many successful “spin-offs” – see later





Past: LCFI



- ★ Silicon sensor development covered in detail in next talk
 - + will cover the **ongoing** MAPS developments shortly
- ★ Here, just note that LCFI left strong legacy in ILC/CLIC **physics studies**

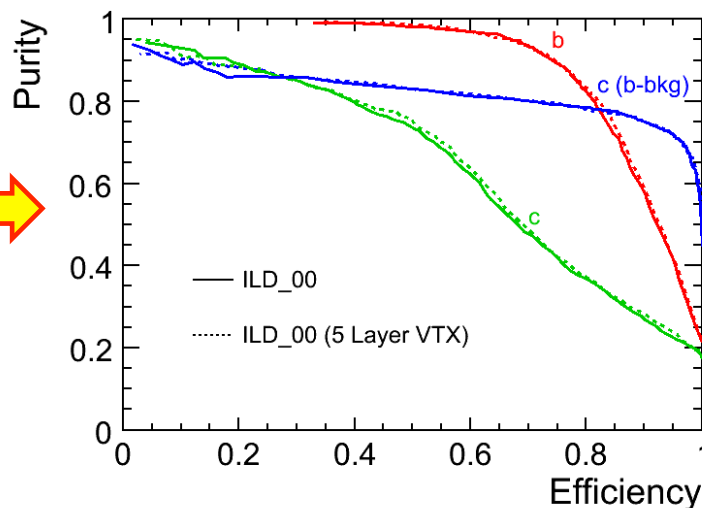
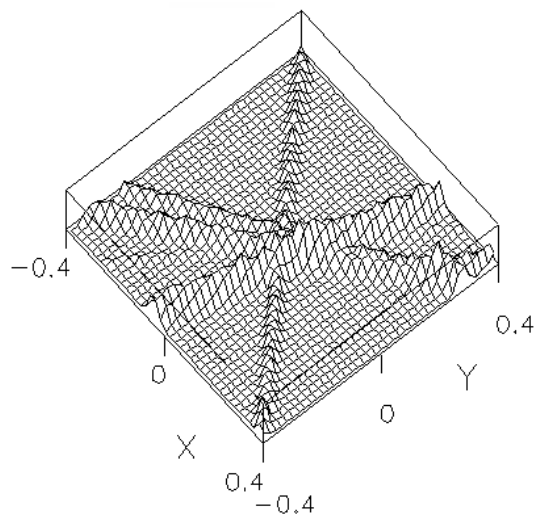
LCFIVertex



- ★ Sophisticated flavour tagging software
 - used in **almost all** ILC and CLIC physics studies
 - C++ implementation of SLD **ZVTOP** algorithm



Google images: ZVTOP



- ★ Now supported and developed by Japanese groups



Then... December 2007



- ★ UK built a vibrant LC Detector R&D community...
- ★ But then came, “Black December”:
 - STFC: due to lack of finance, STFC “withdraws from ILC”
 - USA budgetary crisis means large cuts to ILC (and other project funding) – impact beyond US

Somewhat negative effect
on LC R&D in UK






The Present



Current Activities



- ★ 2007: more than a flesh wound...
- ★ But (thanks *in part* to support from STFC) some generic R&D survived
- ★ Continuing  activities:
 - MAPS
 - Low mass structures
 - Particle Flow
 - Calorimeter Optimisation – next talk
 - Physics studies – not covered here, but a number of UK groups still active



MAPS for LC



Monolithic Active Pixel Sensors

Some History

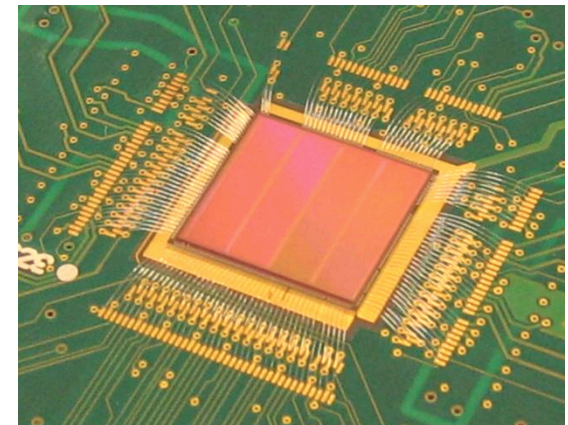
UK developed MAPS as technology with potential for vertexing, tracking and digital calorimetry

- CALICE-UK (ILC calorimetry, MAPS)
- SPiDer (adds **vertexing/tracking** at LC)
- Arachnid (generic detector + ALICE ITS)



Potential Advantages:

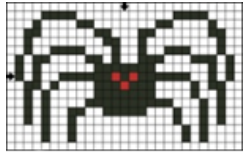
- Mature, high volume industrial CMOS devices
lower costs, no proprietary processes
- Low(ish) power, depends on duty cycle
- Low material budget, can be very thin
- Radiation hard (few >Mrad)
- Very granular (pixels $\sim 10\mu\text{m}$)



See [Fergus Wilson's talk](#), ECFA LC 2013, DESY, for generic MAPS/silicon R&D in UK



Arachnid



Arachnid



UNIVERSITY OF
BIRMINGHAM



University of
BRISTOL



Queen Mary
University of London



Science & Technology Facilities Council
Daresbury Laboratory

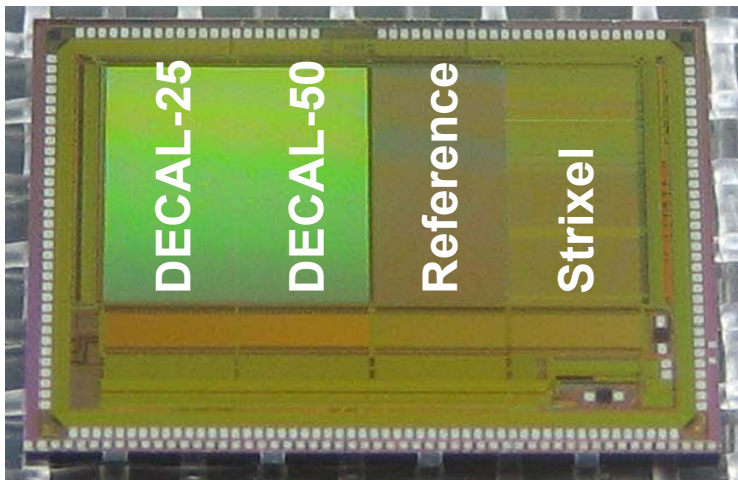


Science & Technology Facilities Council
Rutherford Appleton Laboratory

Arachnid CMOS MAPS programme:

- Cherwell chip has 4T pixels – validated strixel technology being used for ALICE prototype
- Enabled 4 MCHF programme between CERN and TowerJazz Foundary
- Performed numerous benchtests and test beam studies at CERN in 2012

4 main pixel types:



Chip characteristics

- noise 8-12e⁻ RMS
- Efficiency >99.7%
- S/N for a MIP ~150
- Hit resolution ~ 4µm



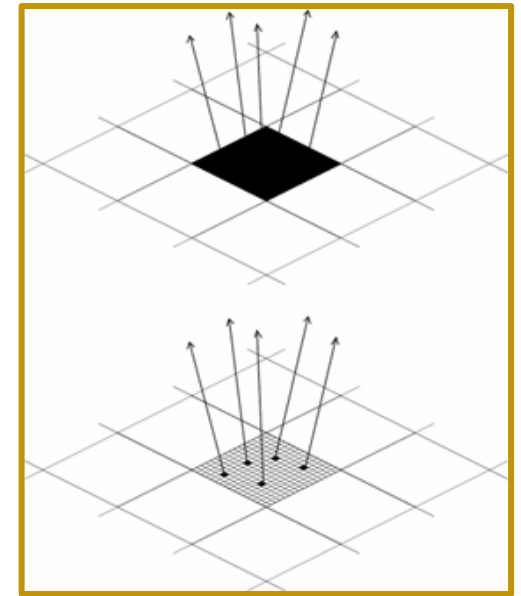
UK is a world-leader in this area



MAPS Digital ECAL Concept

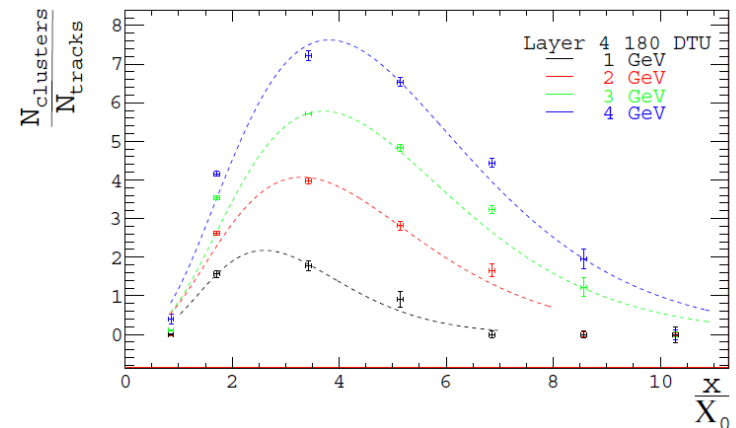


- ★ More on MAPS for vertexing/tracking in next talk – but also potential ECAL applications
- ★ **MAPS DECAL Concept**
 - UK idea with potential cost savings
 - Swap “large” $0.5 \times 0.5 \text{ cm}^2$ Si pads with **small** pixels
 - With **small** enough pixels can count MIPs
 - How small?
 - EM shower core density at 500GeV is $\sim 100/\text{mm}^2$
 $\Rightarrow \sim 50 \times 50 \mu\text{m}^2$
 - Gives $\sim 10^{12}$ pixels for ECAL – “Tera-pixel APS”
 - Mandatory to integrate electronics on sensor



Studied TPAC sensors as “calorimeter” layer
 Peak of sensor activity vs. depth of material

[see T. Price, PhD thesis, Aug. 2013, Univ. Birmingham]



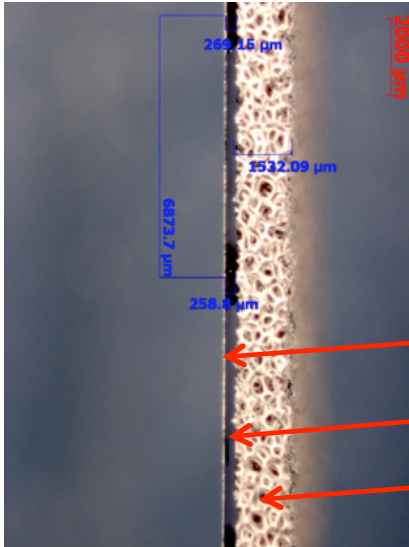
- ★ Interesting concept – but would requires serious R&D to raise TRL for ILC



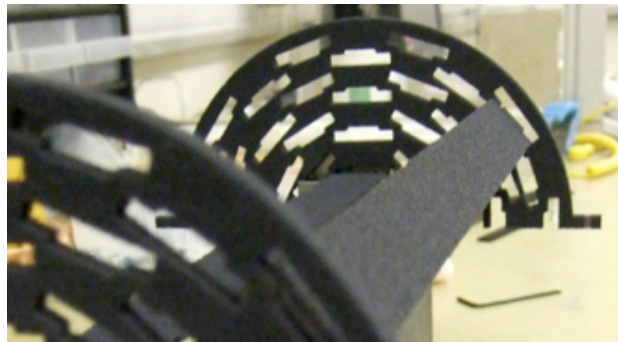
Low Mass and PLUME



- ★ Ultra-high precision tracking → very low material budget
- ★ Low-mass (STFC funded) investigated SiC foam structures



- ★ Open-cell foam
- ★ Commercially available at 8%
 - Can get 2-3%
- ★ Baseline ladder:
 - 20μm silicon sensor
 - Silicone glue/gap
 - 1.5 mm foam



Prototype SiC vertex detector

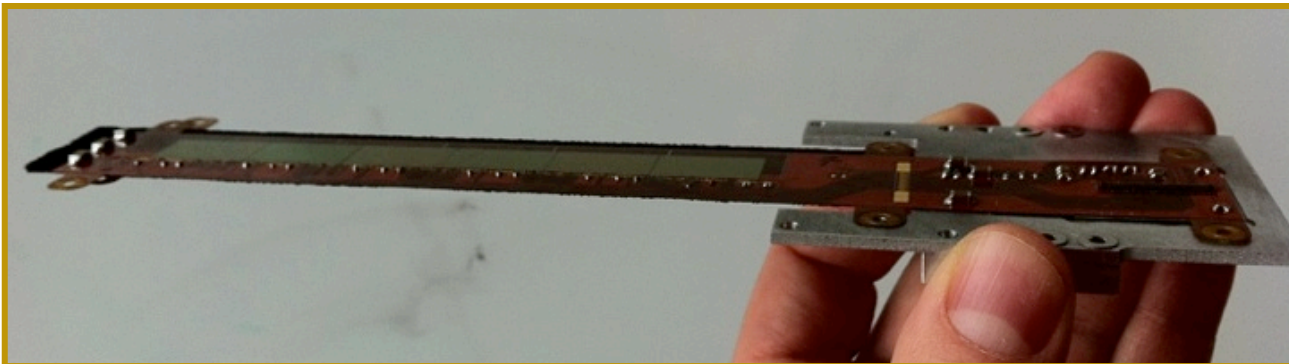


Low Mass and PLUME



PLUME = European R&D for ILC VXD ladders

- **Strasbourg, DESY, (Oxford), Bristol**
 - **Double-sided with Mimosa (MAPS)**
 - **Kapton flex on SiC foam**
- **Oxford were responsible for flex circuits**
- **Bristol responsible for foam and mechanics**



Version 0: prototypes tested in beam in 2009

Version 1: (6 chips/side) tested in beam in 2011

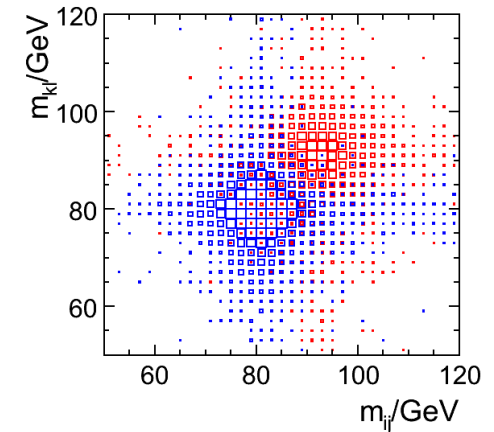
Version 2: (lower material) under development



Particle Flow Calorimetry



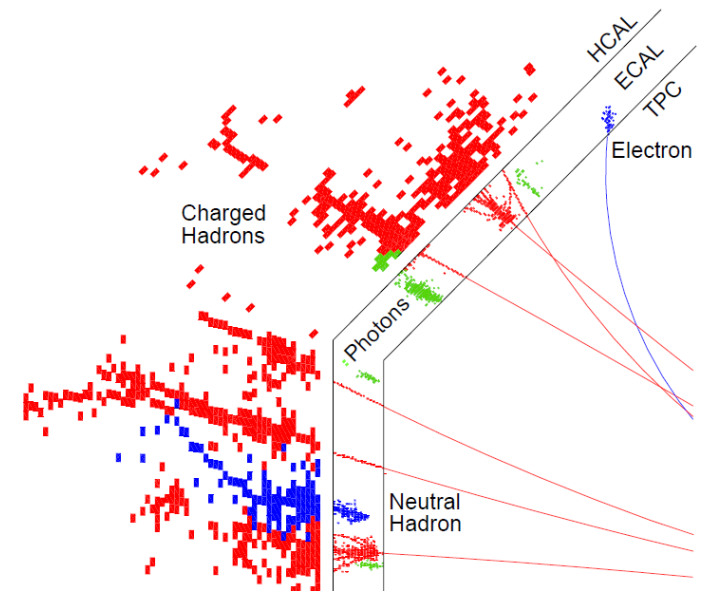
- ★ **Baseline calorimetry at LC = High granularity PFlow**
➡ **Factor 2-3 better jet energy resolution**
- ★ **Lives or dies** on the quality of the reconstruction
- ★ **Requires high-performance software:**
 - **algorithmic sophistication**
 - **CPU/memory usage** – these are complex events with many hits



PandoraPFA



- ★ **Almost all ILC/CLIC studies based on Pandora C++ software development kit**
- ★ **Initial funding from STFC now EU**  **AIDA**
- ★ **Provides highly sophisticated PFlow reconstruction for LC-style detectors**
 - **Provided the proof-of-principle of PFA at ILC**



Typical topology of a simulated 250GeV jet in CLIC ILD



PandoraPFA Framework



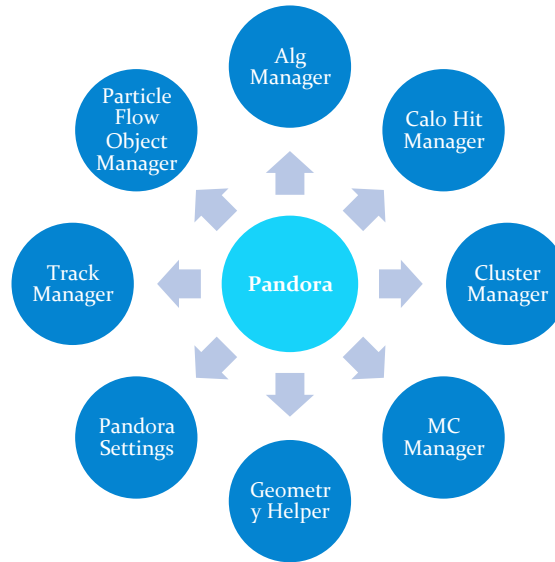
★ PandoraPFA = sophisticated framework + algorithms

Client Application:

- Create Calo Hits
- Create Tracks
- Create MC Particles
- Register User Content

Pandora API

Pandora Framework:



Pandora Content API

Pandora Algorithms:

- Clustering Algorithm
- Topological Association Algorithms
- Statistical Reclustering Algorithm
- Photon Recovery Algorithm
- Fragment Removal Algorithms
- Track-cluster Association Algorithms
- PFO Construction Algorithm

Get Particle Flow Objects

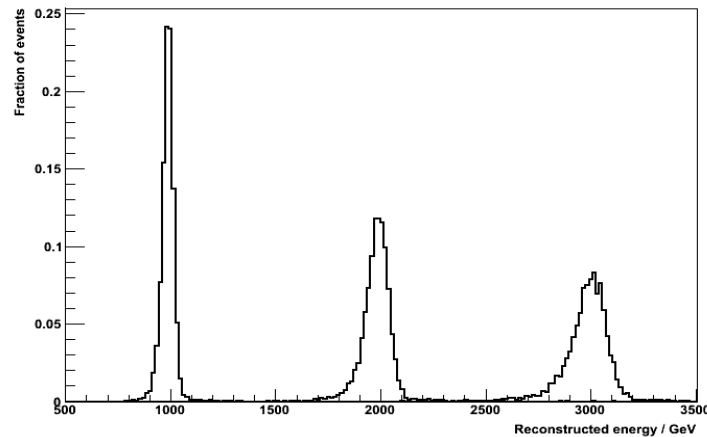
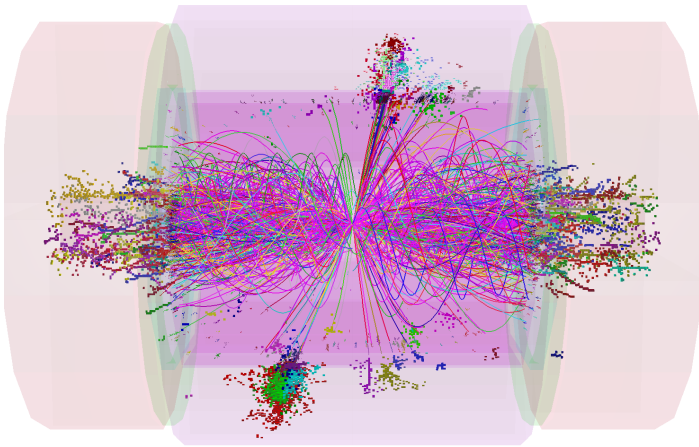
- ★ Highly optimised (CPU/memory footprint) framework
- ★ User code “Algorithms” separated from Framework code
- ★ Genuinely reusable (just different client apps):
 - ILD, SiD, CLIC, **neutrinos (LAr) + CMS upgrade interest**



PandoraPFA Jet Reco



- ★ PandoraPFA is workhorse for recent CLIC CDR and ILC TDR
- ★ **All** recent full simulation physics studies based on PandoraPFA reconstruction



E_{JET}	RMS_{90}/E_J
45 GeV	3.6 %
100 GeV	2.9 %
250 GeV	2.8 %
500 GeV	3.0 %
1 TeV	3.2 %
1.5 TeV	3.2 %

- ★ High-G Pflow is a **new** approach to calorimetry:
 - Drives ILC detector design
 - Will deliver unprecedented jet energy resolution
 - **PandoraPFA** central to Calorimeter design studies, e.g.
 - Recent collaboration with CERN on ECAL optimisation (next talk)



Bottom line:

Despite difficulties, UK has retained *some* leadership...



Time to look forward and (re)build...



SPECIAL REPORT

The Des Moines Register

WEDNESDAY
December 21, 2012

The Newspaper Iowa Depends Upon ■ DesMoinesRegister.com ■ Price 40 Cents in Stores / 50 Cents in Coin Racks

U.S. Government declares public state of emergency

Poll: Christians bemoan end of world 'at hand'

Mercy Medical Centers 'completely overwhelmed'

Citizens urged to stay indoors, remain calm

DEAD RISING FROM GRAVE



New York, N.Y. — In the past several days, thousands of people have been killed in a series of attacks that have been described as the worst in the history of the United States. The attacks, which began on Tuesday, have killed more than 1,000 people and injured thousands more. The attacks have been described as a "fourth great war" and a "fourth great calamity."

"They are not just random acts of violence," said a senior administration official. "They are a coordinated effort to bring down the United States and to bring about the end of the world as we know it."

President Bush said in a speech to Congress on Tuesday that the attacks were "an act of war" and that the United States was now in a state of emergency. He said that the United States would take all necessary steps to protect itself and its citizens.

Sen. Robert J. White, a Republican from Missouri, said that the attacks were "an act of war" and that the United States was now in a state of emergency. He said that the United States would take all necessary steps to protect itself and its citizens.

Establishing the death toll could take weeks. The four airliners that had 295 people aboard, and those...

See B9B9B9, Page 24

'Our nation saw evil,' Bush says

President Bush spoke from the Oval Office late Tuesday after heading to Florida and on home to Louisiana and Nevada for security reasons.

"There are already a lot of people out there who are afraid of America and our way of life," Bush said. "We have been attacked and we have been attacked in a way that we have never seen before."

President Bush condemned the attacks on Washington and New York and vowed to "lead the world in the fight against terrorism."

Full coverage inside

The Future

or how does the UK reengage with the ILC?



Planning for the future

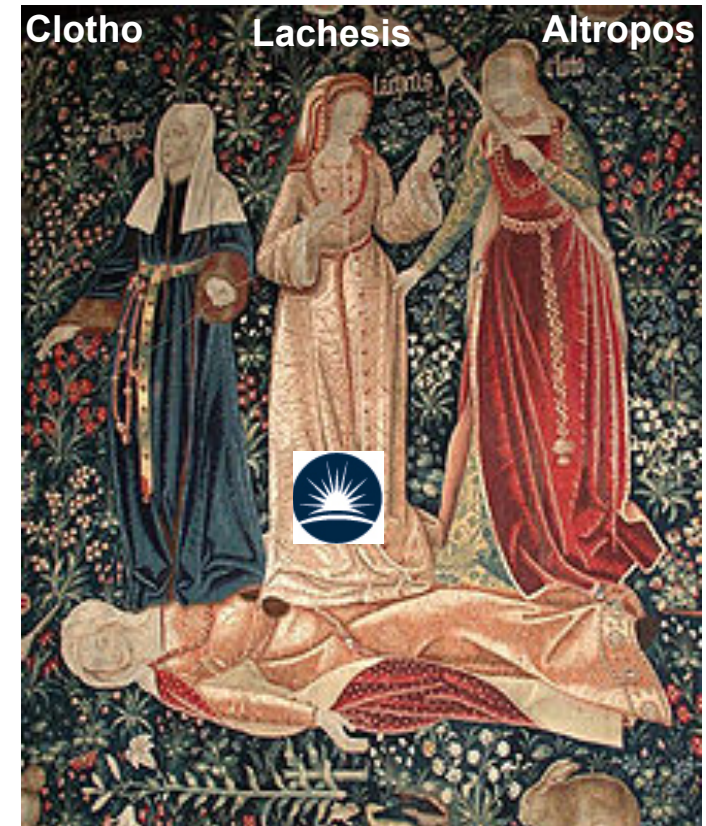


- ★ **A simple plan:**
 - Japan hosts ILC
 - Major UK contribution to detector



- ★ **Despite difficulties, UK still has leadership within ILC !**
- ★ **There a lot of interest in the ILC**
 - just lack of funds at the moment...
- ★ **Need to rebuild UK effort**
- ★ **Three steps to UK ILC heaven:**
 - Decide on future UK focus
 - **Need to reengage with LC**
 - **Ultimately bid for detector construction**
- ★ **Must be realistic:**
 - At moment, funds are tight...

Funding →





What if...?



Some big questions:

- ⊙ **What if Japan makes **firm commitment** to build ILC...**
 - ★ **What are our aspirations in the experiment(s) ?**
- ⊙ **Collaborations could form quickly...**
 - ★ **proto-collaborations already in place (ILD and SiD)**
 - **but can't assume there will be two detectors...**
 - **if there are two, STFC is unlikely to invest in more than one**
 - **+ there will be new players...**
 - ★ **how does UK position itself **prior** to a firm ILC commitment ?**
- ⊙ **Interaction with STFC – needs realism**
 - ★ **may be little headroom in foreseeable future**
 - **ILC will compete with LHC upgrades + ...**
 - **Unlikely to be very significant funding prior to **funded ILC project****
 - ★ **when to approach STFC with Sol + funding request ?**
 - **Programmatic review will soon be announced...**
 - ★ **start to think about short term priorities**
 - **Re-engage and build UK leadership**



UK Future directions



- ★ UK has expertise in a number of areas
 - Can gain leading roles in a number of areas

★ Possibilities (include):

Calorimetry

Si

DAQ

Software



Possible Opportunities



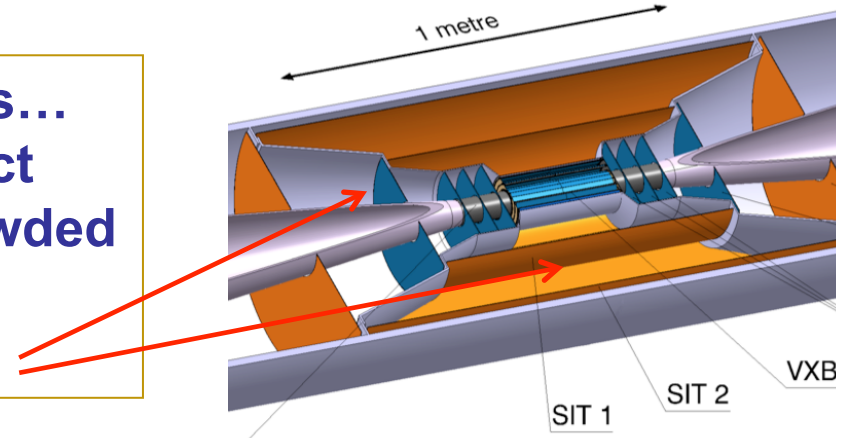
Calorimetry:

Just a few first thoughts...

- ⊙ Re-engage with CALICE with aim of contributing to LC calorimeter
 - ★ Hardware: work with CERN, already good contacts
 - ★ Design studies – UK can lead calorimeter design/optimisation

Silicon:

- ⊙ UK has strong heritage in Si sensors...
 - ★ Central Si tracker is a large project
 - ★ Vertex detector already quite crowded
 - ★ But ILC detectors have a lot of Si
 - forward/intermediate trackers?



DAQ:

- ⊙ UK has strong heritage in trigger/DAQ
 - ★ there is an opportunity here...

Software/Physics:

- ⊙ Strong UK heritage in ILC software – build on this



other ideas?



- ★ Previous page gives a few ideas
- ★ Apologies if missed something
 - ...

- ★ **SEMI-SERIOUS POINT:**
 - Need to be ambitious...
 - ...but, need a clear route from the present to our future aspiration
 - Will need to collaborate with:
 - International partners (CERN?)
 - R&D collaborations (CALICE?)





The time is right...

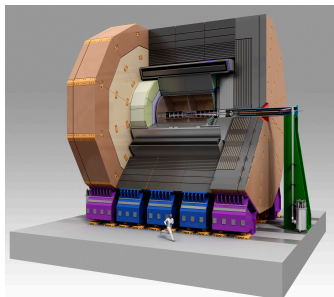


★ Design of ILD and SiD not changed much in last 5 years

- For a real detector: **cost considerations become ever more important**
- ILD (and SiD) now starting to think seriously about cost optimisation
- Opportunity to rethink + new ideas: **UK must be part of this process**



e.g. ILD as of today



★ UK can help with design and optimisation process

- Potential for intellectual input
- Bring our own ideas



The time is right...

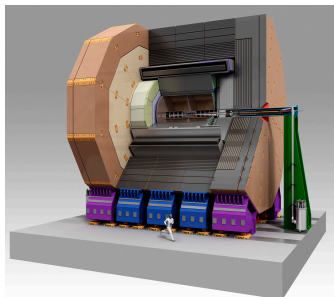


★ Design of ILD and SiD not changed much in last 5 years

- For a real detector: **cost considerations become ever more important**
- ILD (and SiD) now starting to think seriously about cost optimisation
- Opportunity to rethink + new ideas: **UK must be part of this process**



e.g. ILD as of today



★ UK can help with design and optimisation process

- Potential for intellectual input
- Bring our own ideas
- Requires funding...



Concluding Thoughts



★ The **ILC** will be a wonderful machine

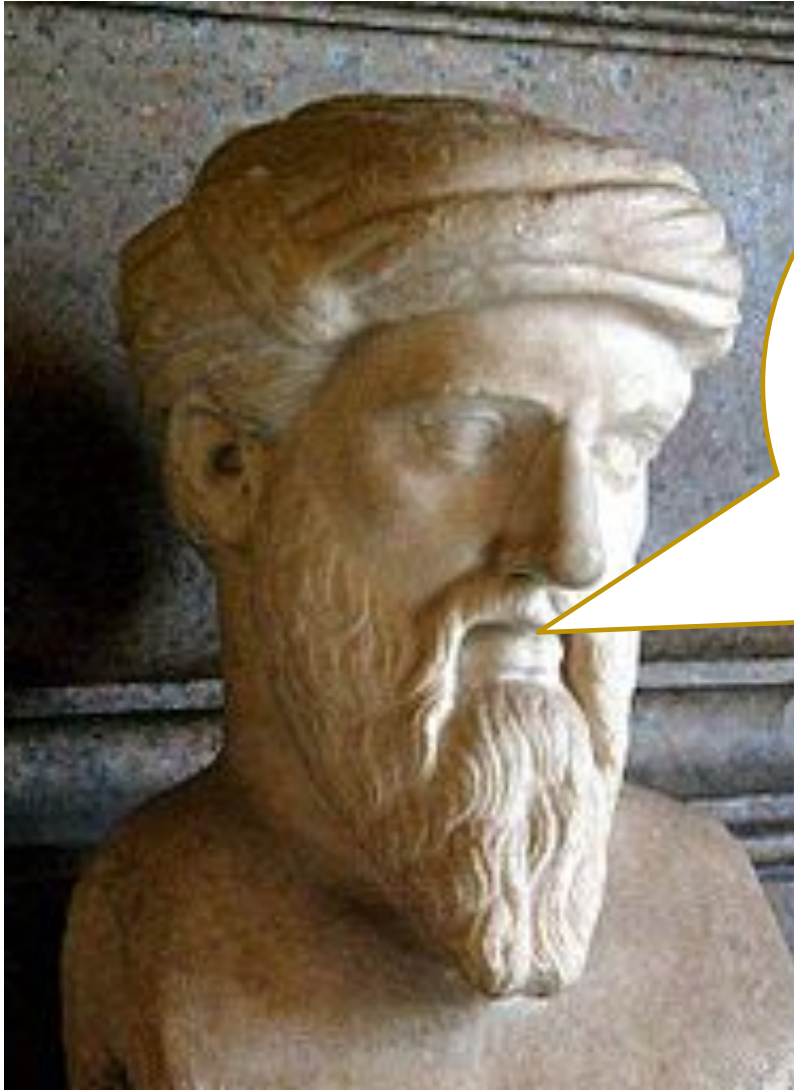
★ Rich and strong physics case, **Higgs and more**

★ The **UK** must be there

★ Don't miss the boat, **need to start preparing now**



Concluding Thoughts



**Carpe
Diem**

* Apologies to Pythagoras for linguistic shear