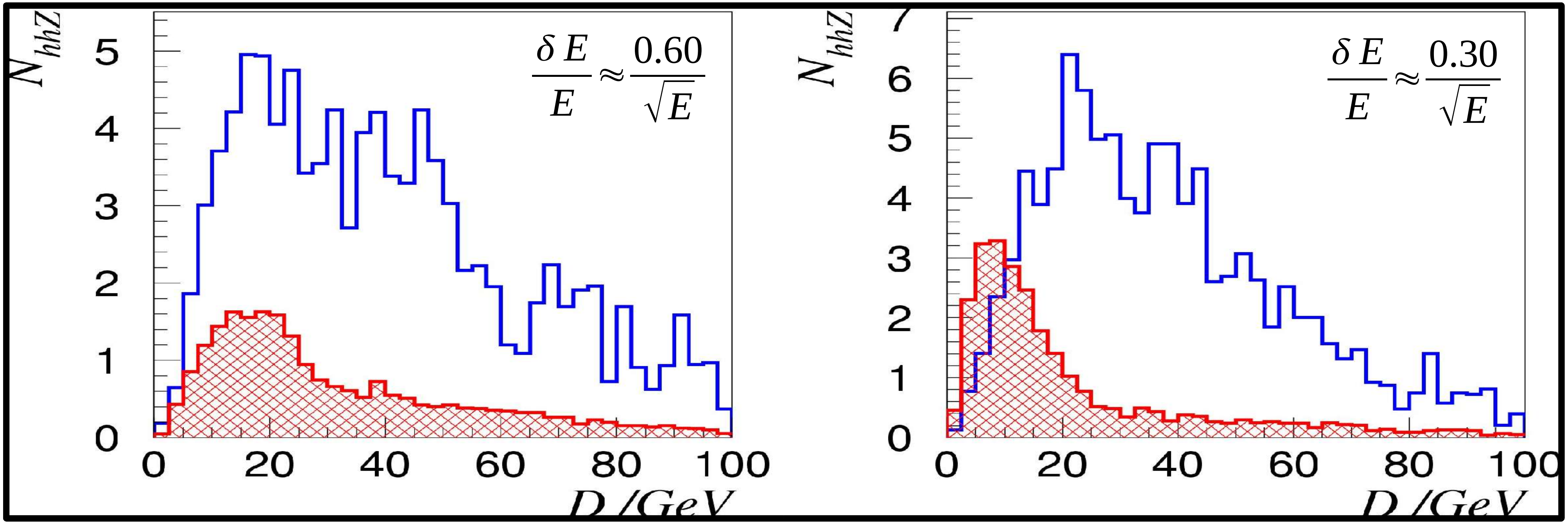
CALICE and LC-ABD

Stewart Boogert (UCL) for CALICE UK

- CALICE overview
  - Physics case
  - ECAL and HCAL design
  - UK activities
    - test beam electronics
    - Simulation (Geant 3&4 and Fluka)
- Synergy
  - Backgrounds
  - Simulation
    - BDSIM, Mokka, Fluka
  - Luminosity spectrum
- UK collaboration
  - Birmingham
  - Cambridge
  - Imperial
  - Manchester
  - UCL
  - RAL
- International collaboration
  - 9 countries (3 regions -US, Asia, Europe)
  - 26 institutes
  - ~150 physicists

Physics case (Higgs self-coupling)

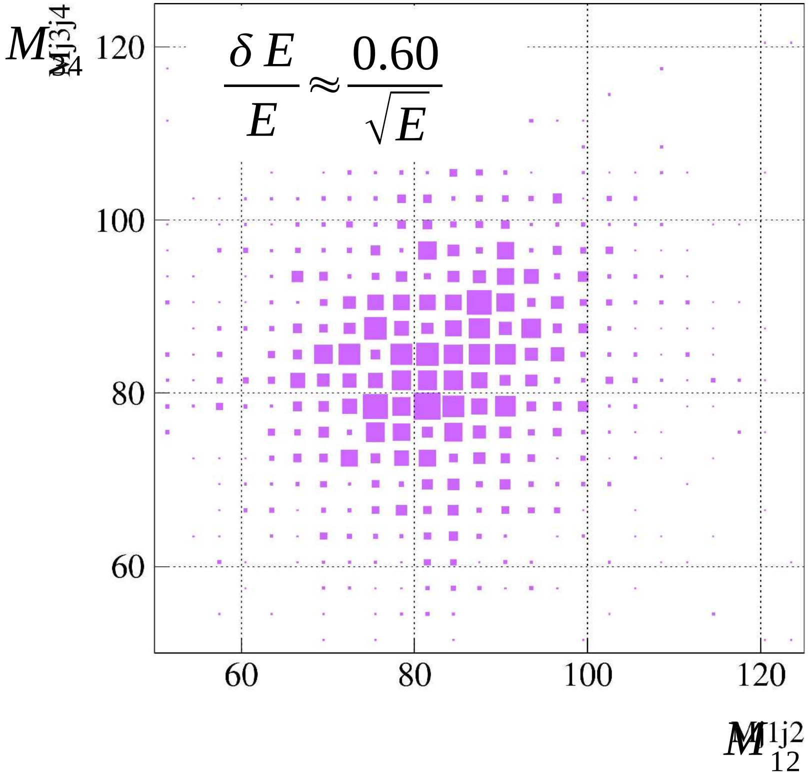


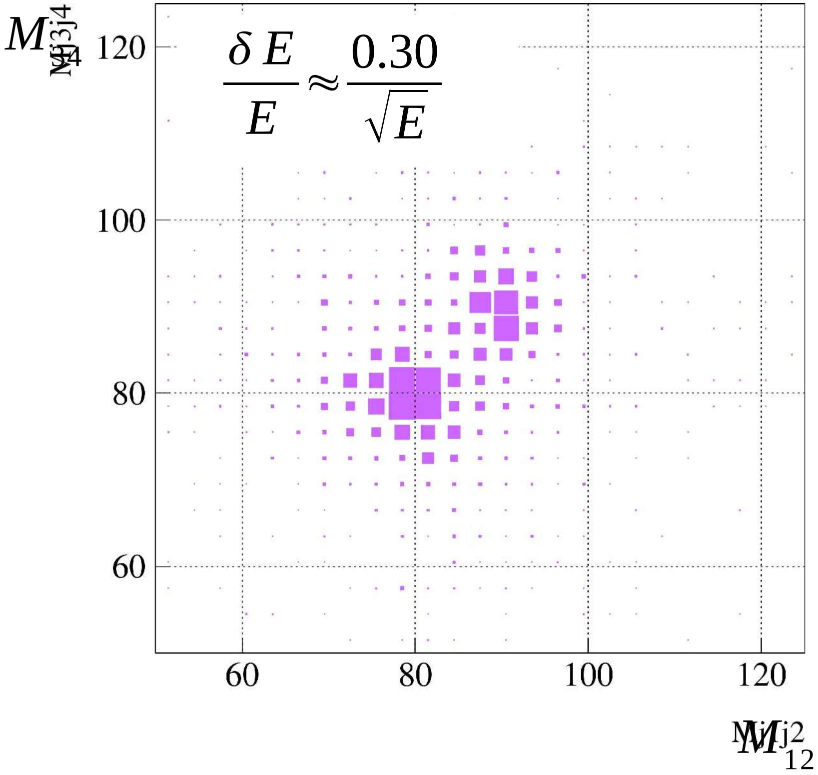
- Higgs self-coupling
  - hhZ events
  - 6 jet topology
- Construct D for 6 jet events

$$D=\sqrt{(m_{12}-m_h)^2+(m_{34}-m_h)^2+(m_{56}-m_z)^2}$$

Physics case (no Higgs)

- No Higgs
  - Standard model unitarity violated without Higgs
  - WW scattering most interesting channel



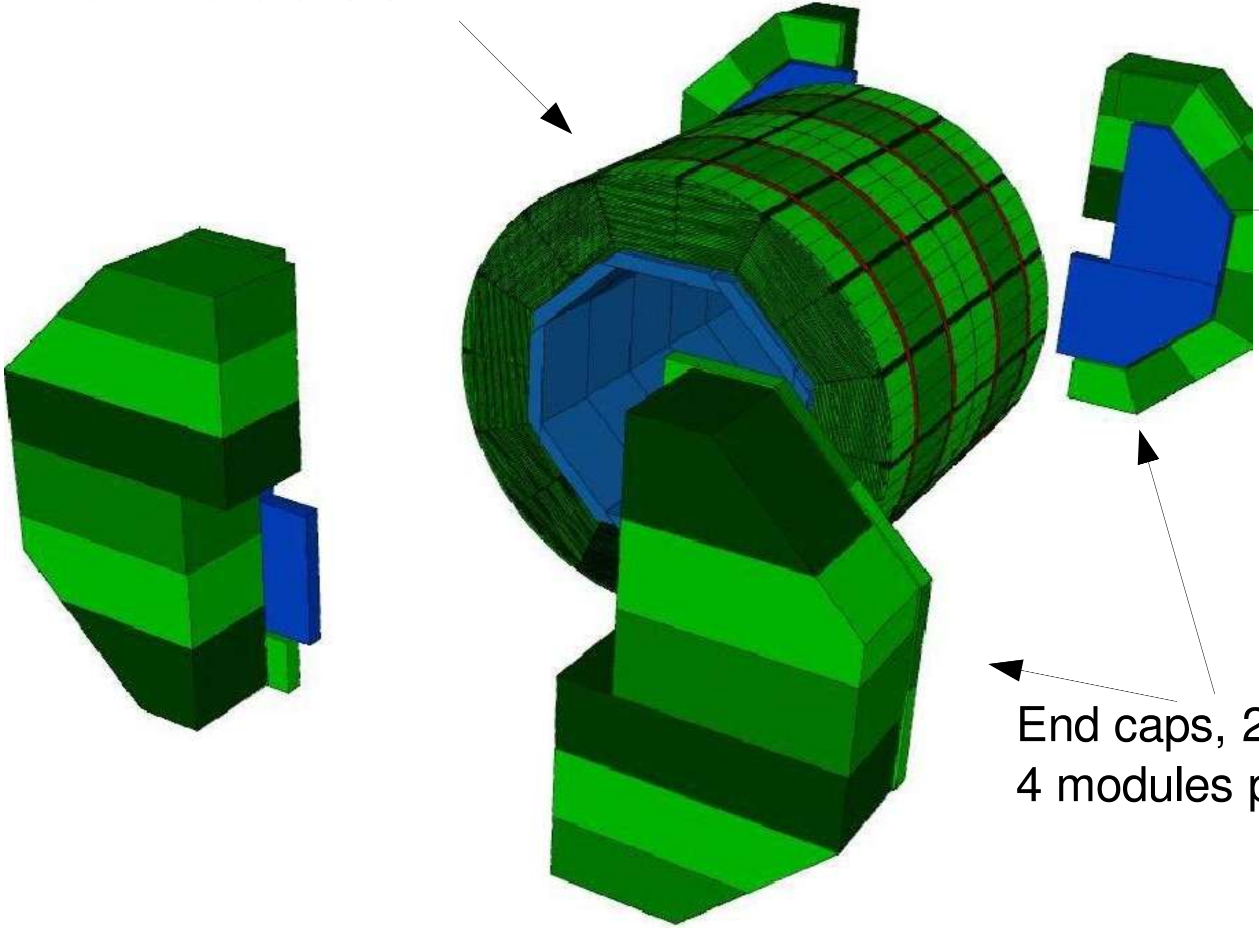


- Separation of
  - $\nu \nu W W \rightarrow 4\ jets$
  - $\nu \nu Z^0 Z^0 \rightarrow 4\ jets$

CALICE introduction

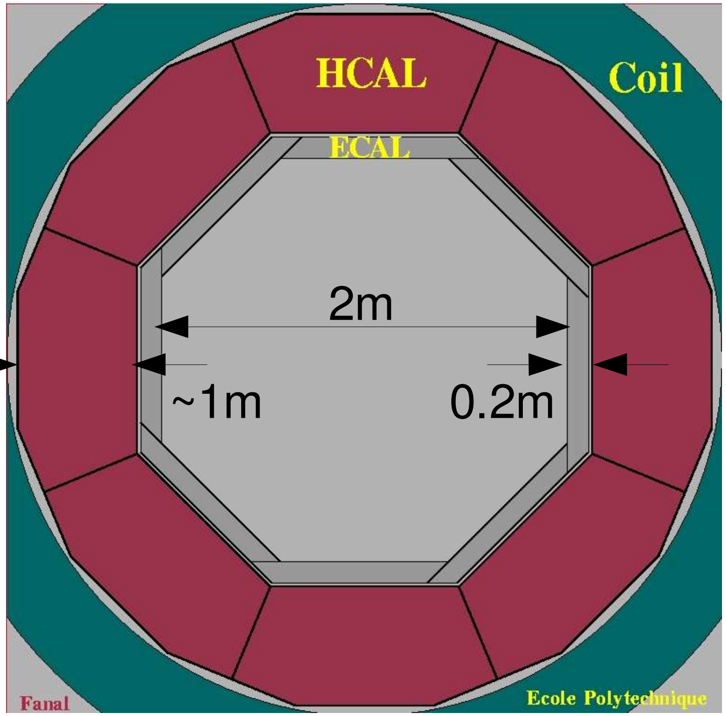
- Calorimeter requirements
  - Calorimeter inside coil to reduce energy loss
  - Thin to reduce cost
  - High B field 3-4T
  - Good solid angle coverage
- Performance
  - ECAL $\frac{\delta E}{E} \approx \frac{0.10}{\sqrt{E}} \oplus 0.01$
  - HCAL $\frac{\delta E}{E} \approx \frac{0.50}{\sqrt{E}} \oplus 0.04$
  - Energy flow measurement $\frac{\delta E}{E} \approx \frac{0.30}{\sqrt{E}}$
- Energy flow
  - Typical jet energies 50 – 200 GeV
    - 62% Charged particles (tracker)
    - 27% Photons (ECAL)
    - 10% Neutral hadrons (HCAL)
  - Combined approach
    - Remove charged deposits by tracking into calorimeter
    - Combine independent calorimeter clusters with tracks
  - Very fine granularity calorimeter
    - “Tracking calorimeter”

TESLA-CALICE geometry

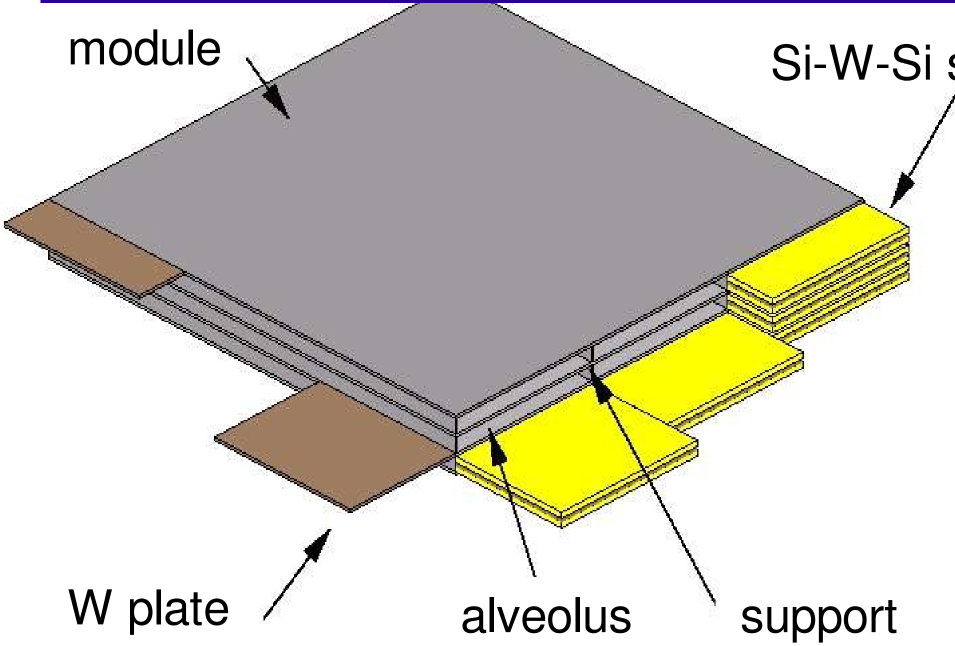


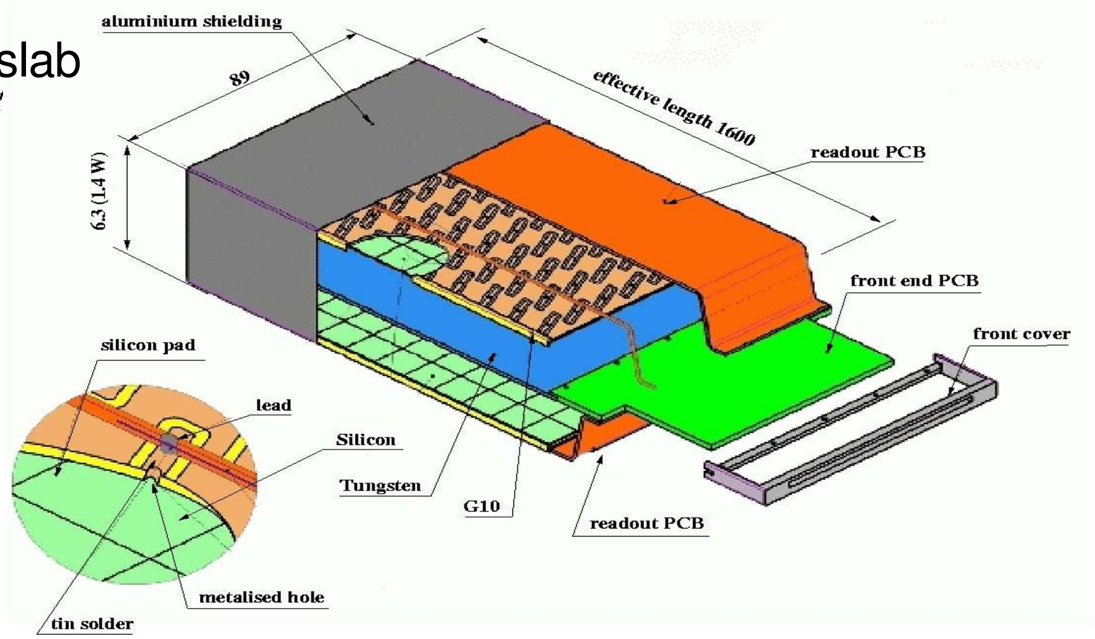
Barrel, 8 fold symmetry
0.2/1.0x0.6x5.5m

End caps, 2 interlocking structures.
4 modules per end cap



ECAL Design

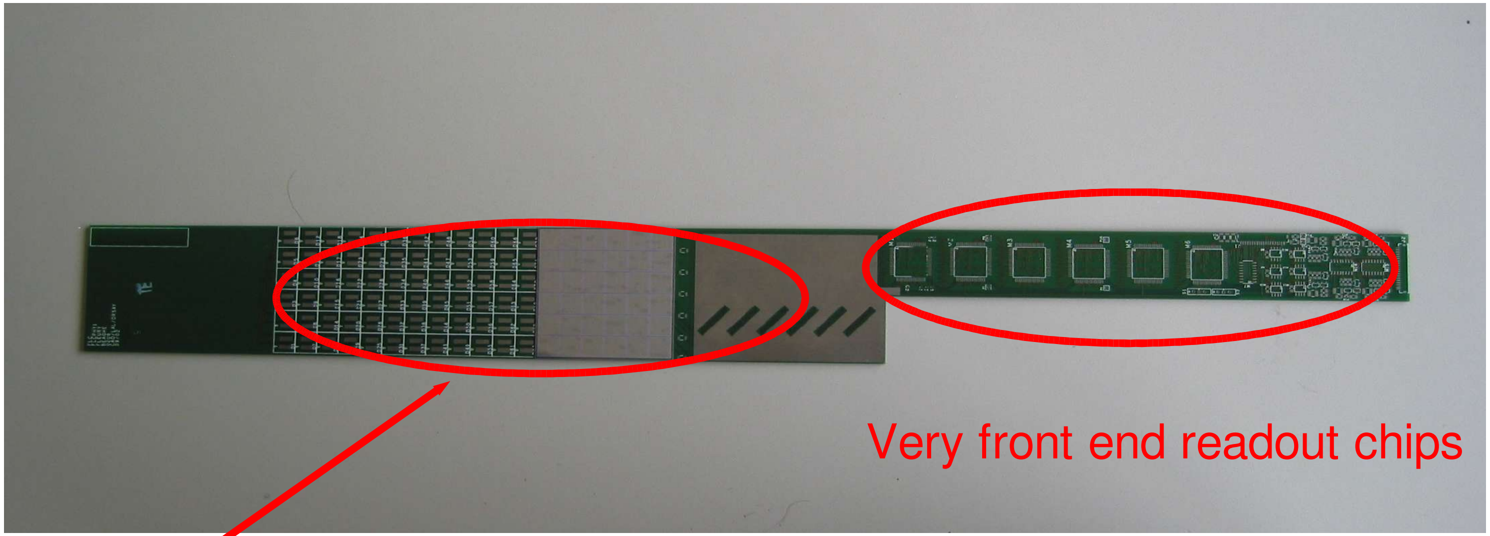




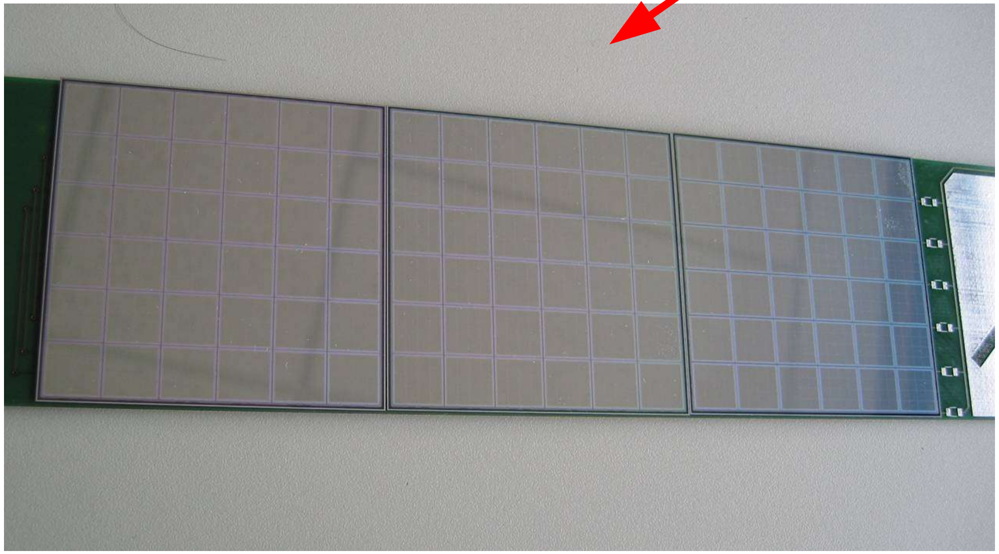
- SiW “tracking” sampling calorimeter
  - 40 layers of Silicon and Tungsten
  - $R_{moliere}$=9mm, X_0~3.5mm and λ_{int}/X_0 large so good em-hadronic separation
  - Silicon pad readout, pad size ~1cm to match $R_{moliere}$
- Mechanics
  - W layers in carbon fiber/epoxy structure

ECAL Design (2)

- ECAL test beam detector layer
  - Si wafers bonded with conductive glue directly to PCB



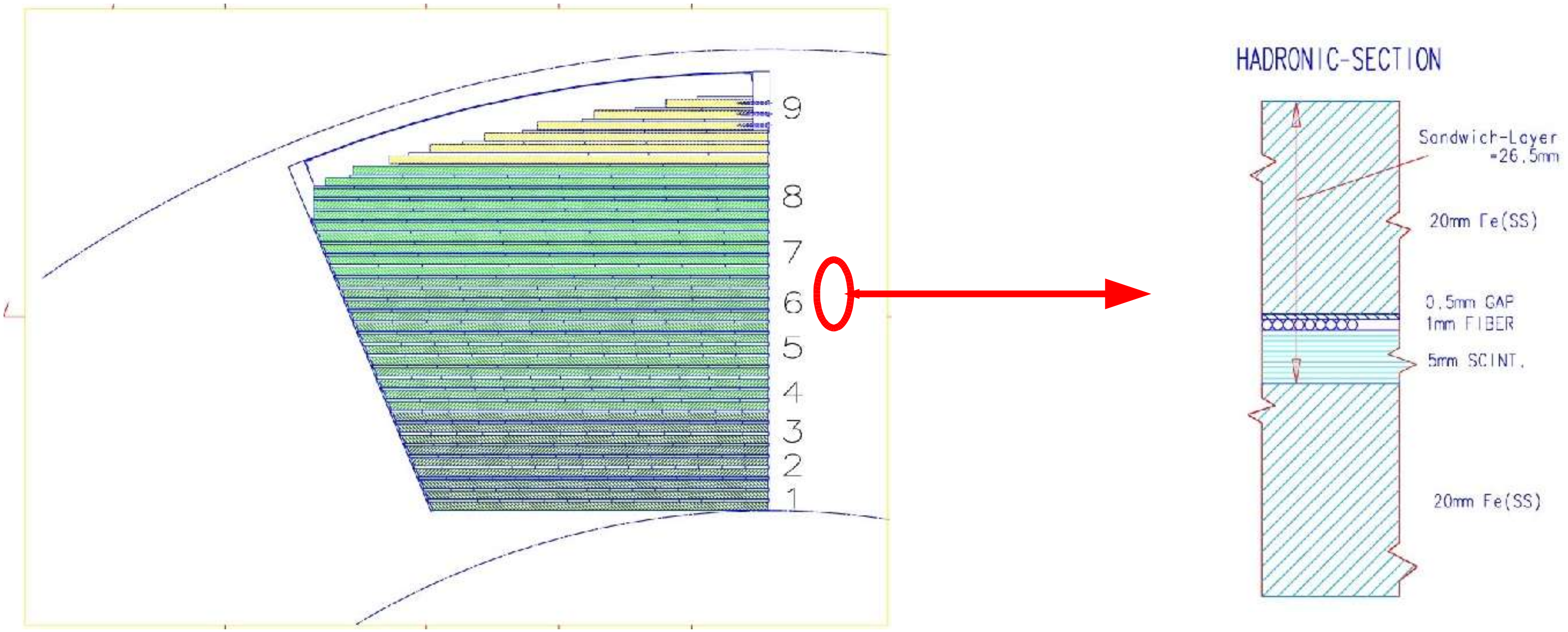
Very front end readout chips



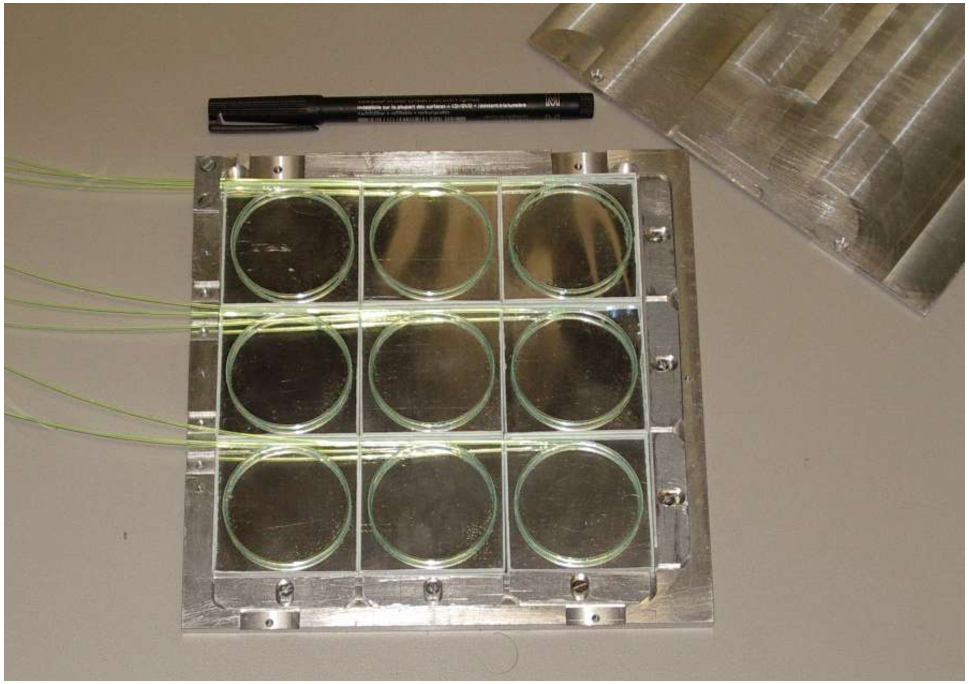
- Si wafers
  - Thickness 0.525mm
  - Capacitance per pad 25 pF
  - Full depletion bias 150V
  - 42,000 e/mip

Analogue HCAL Design

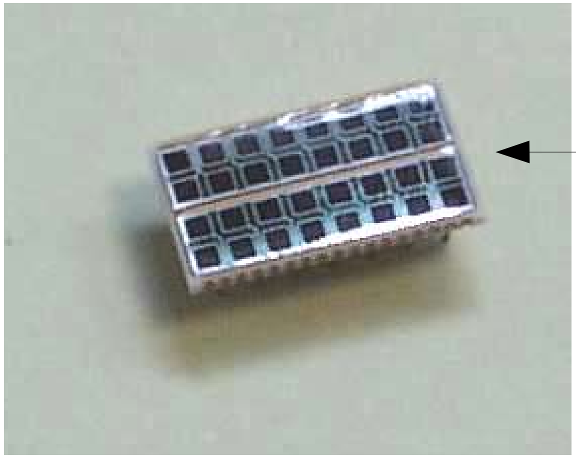
- Sampling Fe-Scint calorimeter
  - Barrel 38 layers of Fe/scint
    - 32 modules of ~1.1x1.1x2.7m
  - End cap 53 layers
    - 8 modules 3.1x2.5x1.4



Analogue-HCAL Design (2)



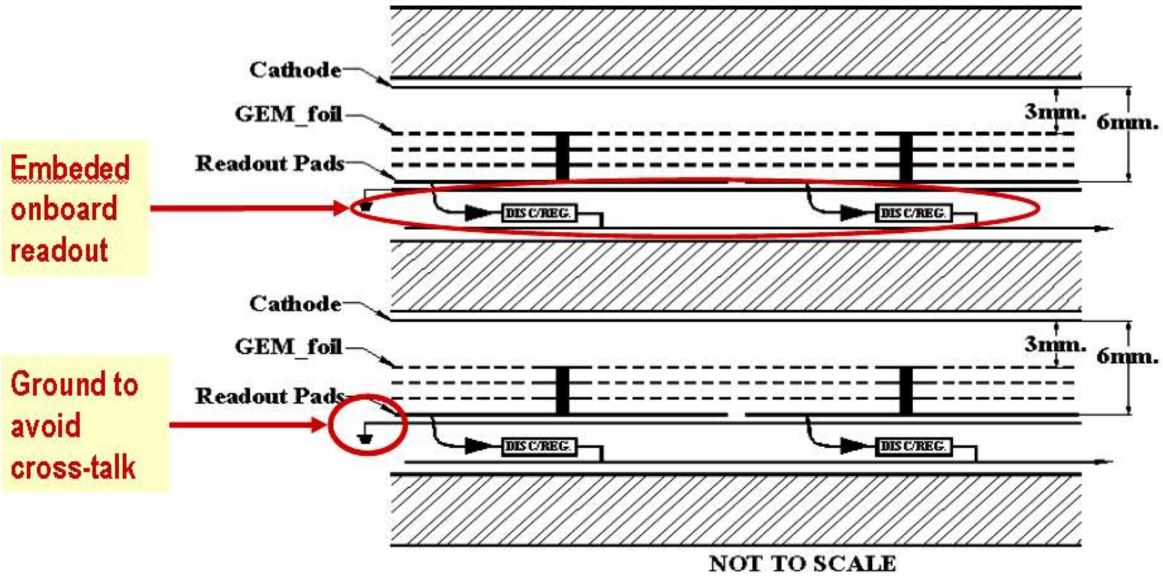
- Sampling calorimeter
  - Tiles coupled to wavelength shifting (WLS) fibers
  - Optimising
    - WLS fiber groove
    - Fiber end reflector
    - Readout



- Readout options
  - APDs
  - Si-PMs
    - Cheap
    - Saturation problems

Digital-HCAL Design

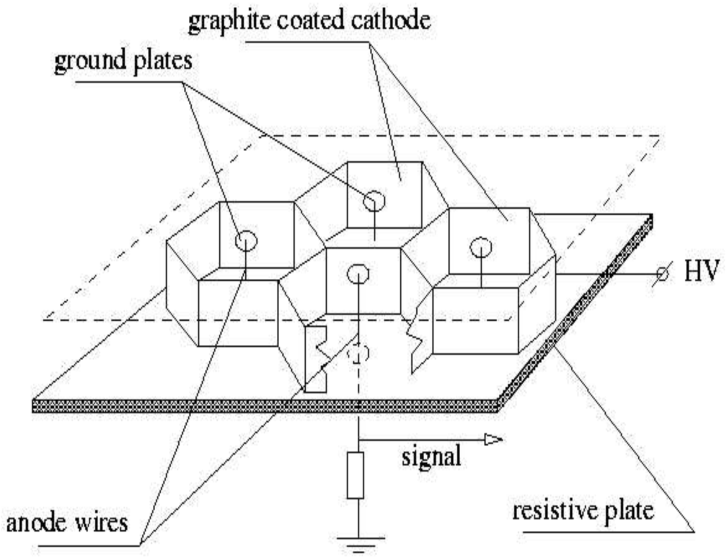
- "Digital calorimetry"
  - High segmentation – cells 1cm^3
  - 50x10^6 channels
  - Analogue readout very difficult
  - Landau fluctuations in small cells
- Digital readout
  - Deposited energy proportional to number of fired cells in cluster
- Possible to use scint tiles as in AHCAL design
  - Many other digital detector/readout options
- Gas electron multiplier (GEMS)
  - Q~5fC
  - I~5fC/20ns = 0.25 A
  - V~5mV
- Test chamber assembled



Embeded onboard readout

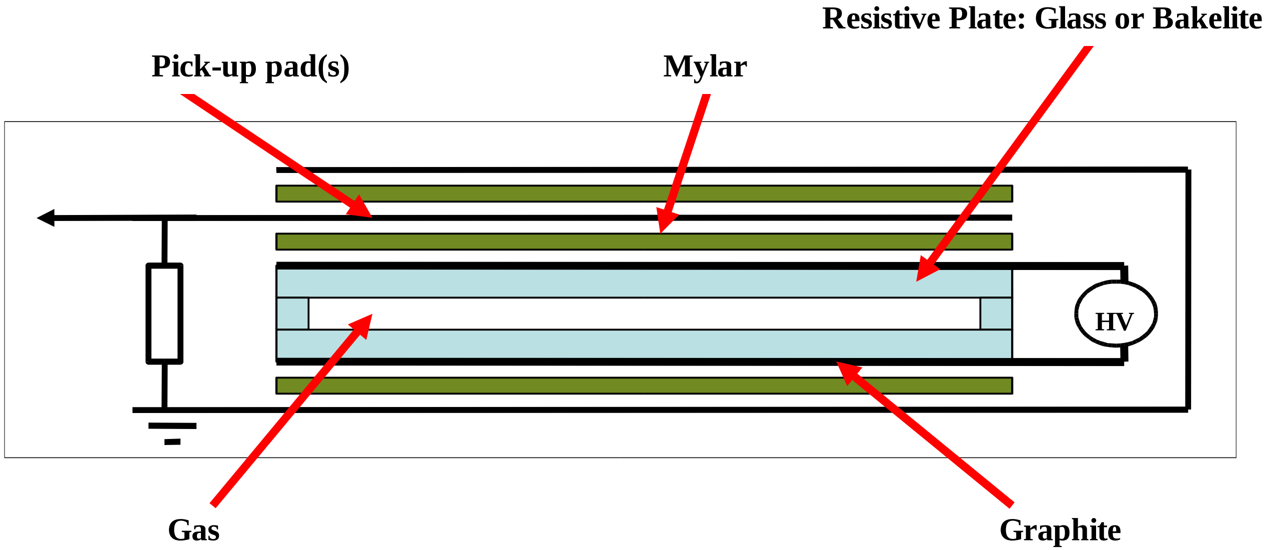
Ground to avoid cross-talk

Digital-HCAL Design (2)



- Short drift tubes
  - Hexagonal cells 1cm^{2}x3mm
  - Gas mix IB:Ar:TFE
  - Testing : efficiency, multiplicity as function of HV

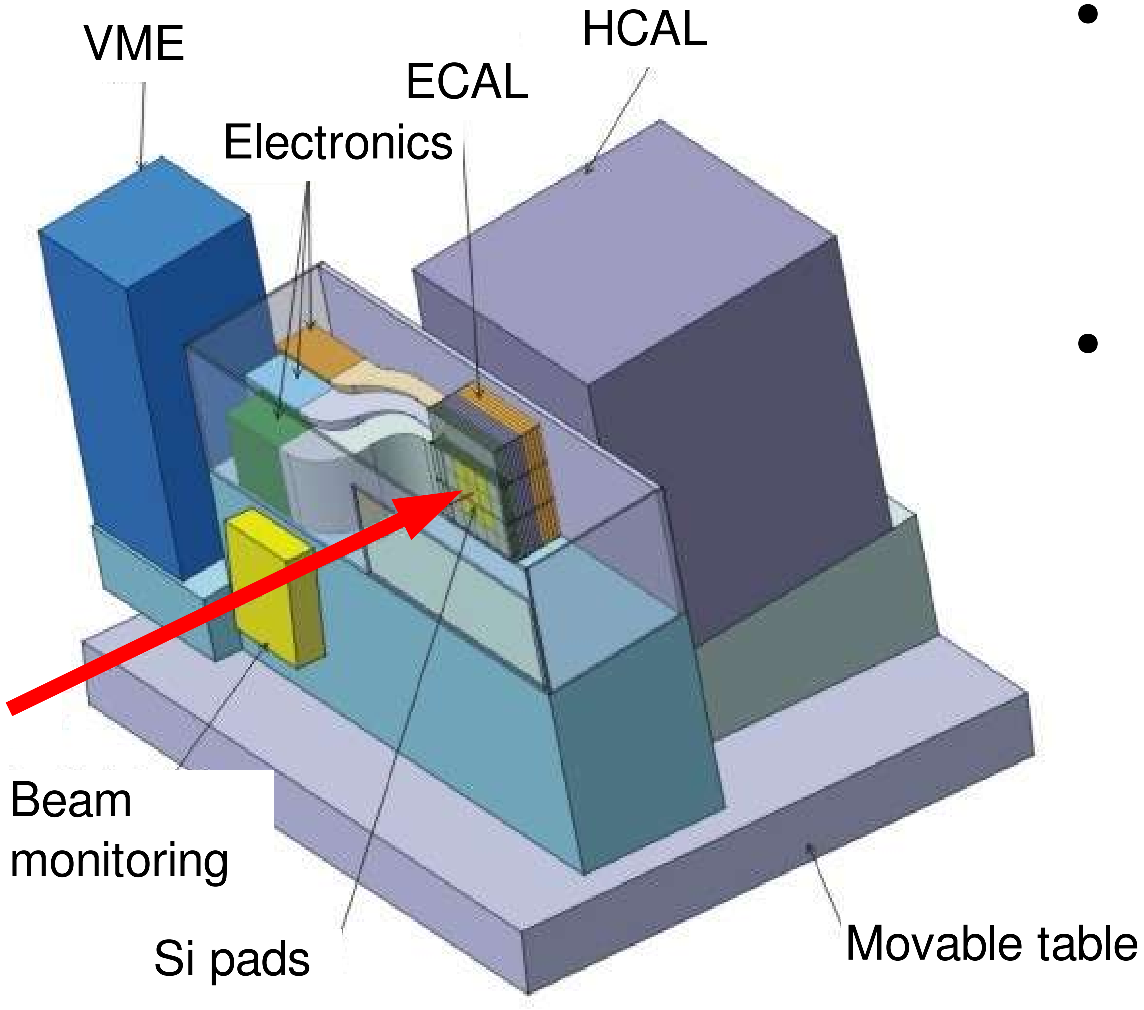
- Resistive plate chambers (RPCs)
  - Most promising DHCAL option
  - Testing: efficiency, cross-talk
  - Design optimisation



Test beam aims

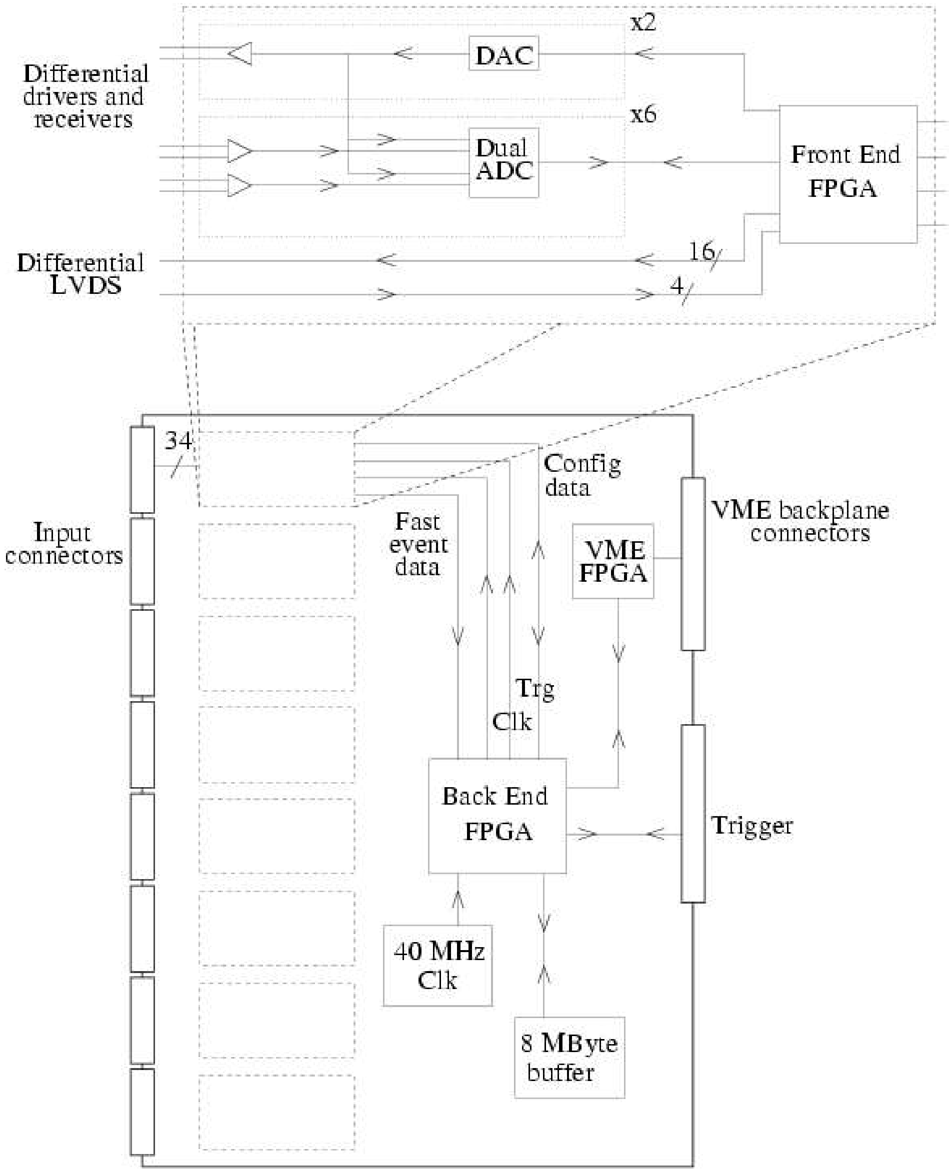
- Test beam motivation
  - Validate electronic and mechanical design
  - Tune simulation, particularly important for hadronic showers
- Configurations
  - Particle beams (e, π and hadron) with energies (1-100GeV)
  - Want ~100 configurations with high statistics 10^6 events
  - Total event sample ~10^8 events
  - ~40kBytes/event, terabytes of data.
- Readout, ECAL + (A/D)HCAL, plus
  - Beam monitoring
  - "Tail catchers" for shower containment

CALICE test beam



- ECAL
  - 30 layers of tungsten
  - $10 \times 0.4X_0 + 10 \times 0.8X_0 + 10 \times 1.2X_0$
- HCAL
  - 38 layers of Fe
  - 5000 5x5cm^2 scintillator tiles with analogue readout
  - Or 350k 1x1cm^2 RPC, GEM or scintillator tiles with digital readout

Test beam electronics



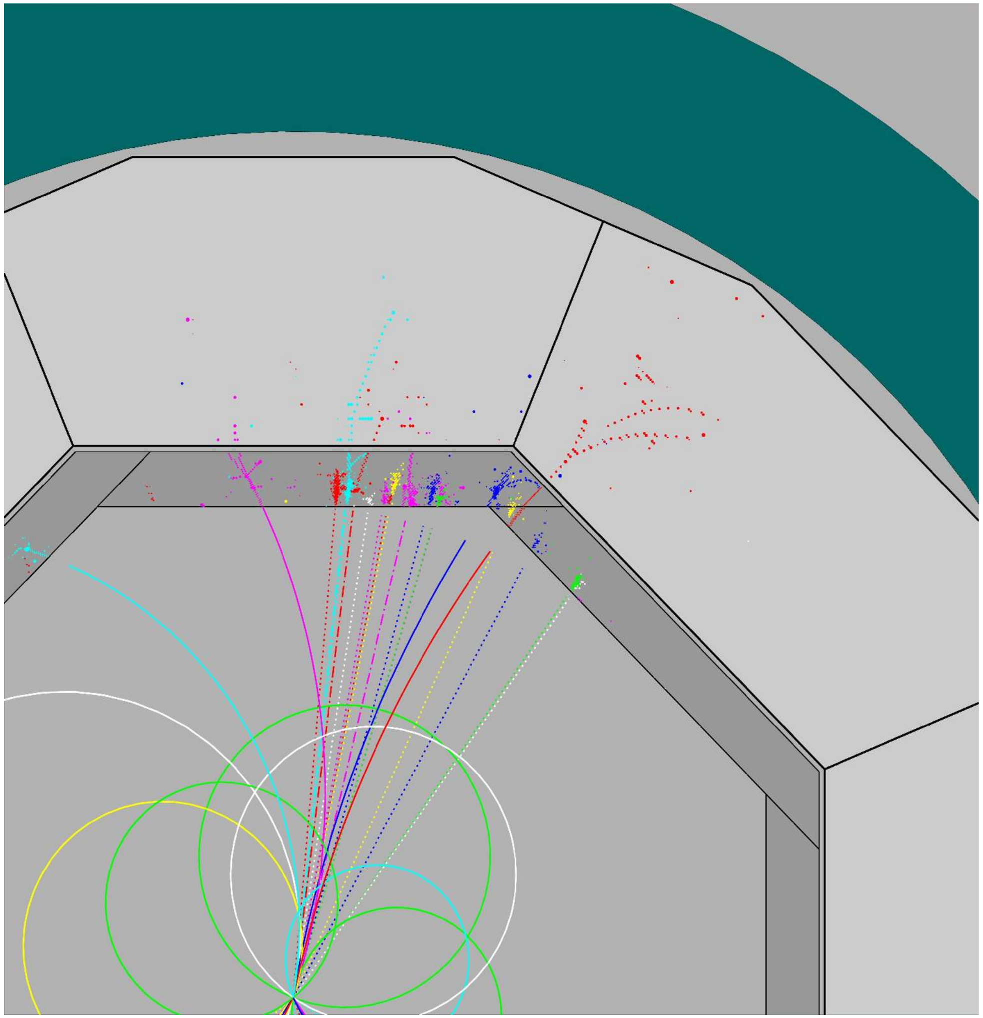
- Front end (FE) FGA controls signals to ADC, DAC LVDS
- Back end (BE)
  - FPGA gathers data from FE and provides interface to VME backplane
  - Trigger logic in BE (active only in one readout board) and trigger information distributed via backplane
- Schedule
  - VFE chips produced by December 2003
  - Readout boards ready February 2004

Test beam schedule

- Schedule still rather flexible, dependent on
  - Development of prototypes (D/AHCAL)
  - Available beam lines
- Approximate schedule
  - Spring 2004 Cosmic tests on ECAL prototype
  - Summer 2004 ECAL tests at DESY electron test beam
  - Summer 2004 AHCAL tests at DESY electron beam
  - Autumn 2004 ECAL+AHCAL
  - Winter 2004 ECAL+RPC DHCAL
  - Summer 2005 ECAL +(RPC/GEM/Scintillator)HCAL

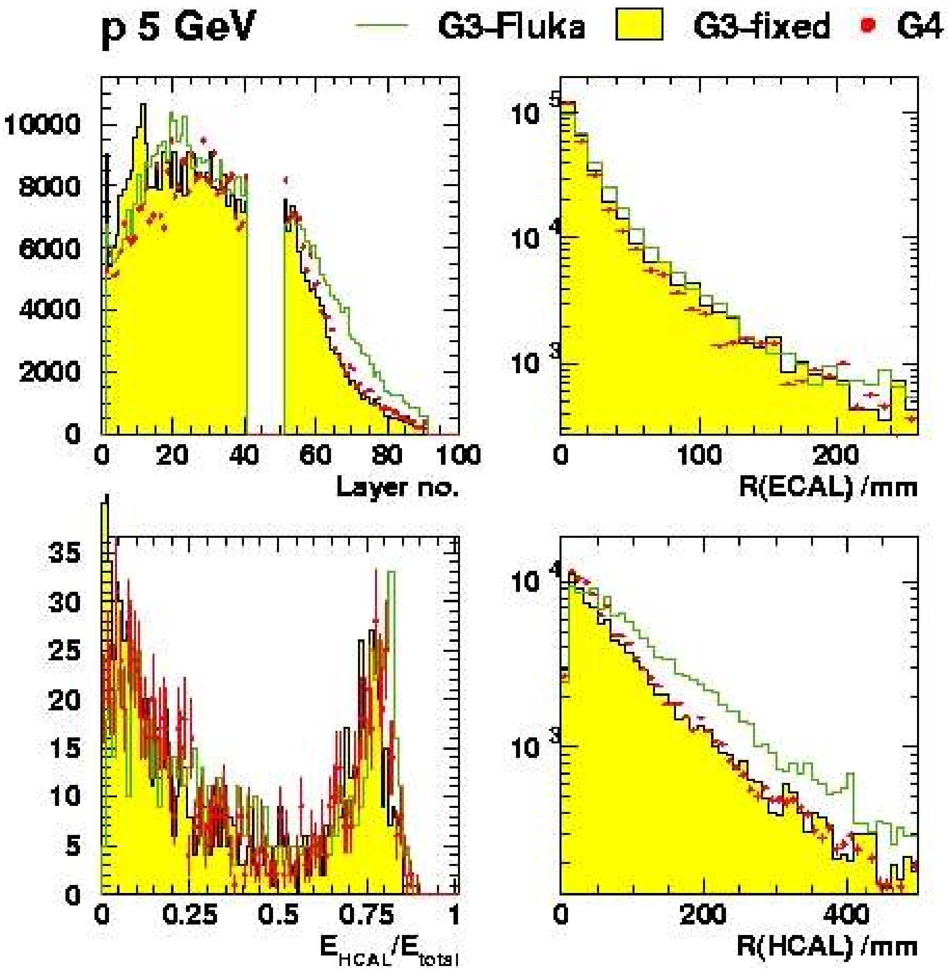
CALICE simulation

- Current simulation tools
  - Brahms (Geant 3) TESLA TDR
    - Full detector
    - Difficult to modify
  - Mokka (Geant 4)
    - Mainly calorimeter
    - Other components simply implemented
    - Geometry database (MySQL)
- Additionally
  - Mokka Geometry in Geant 3
  - Mokka Geometry in Fluka
  - Hit data stored in generic LCIO files



Geant-3 and Fluka comparisons

- Comparisons between
  - Geant 4
  - Geant 3
  - Fluka (deprecated version, within Geant 3)
  - All using the same Geant 4 defined geometry, SiW ECAL and Scint AHCAL
- Bug fixed in G3
  - Good agreement between G3 and G4
  - Fluka differences significant



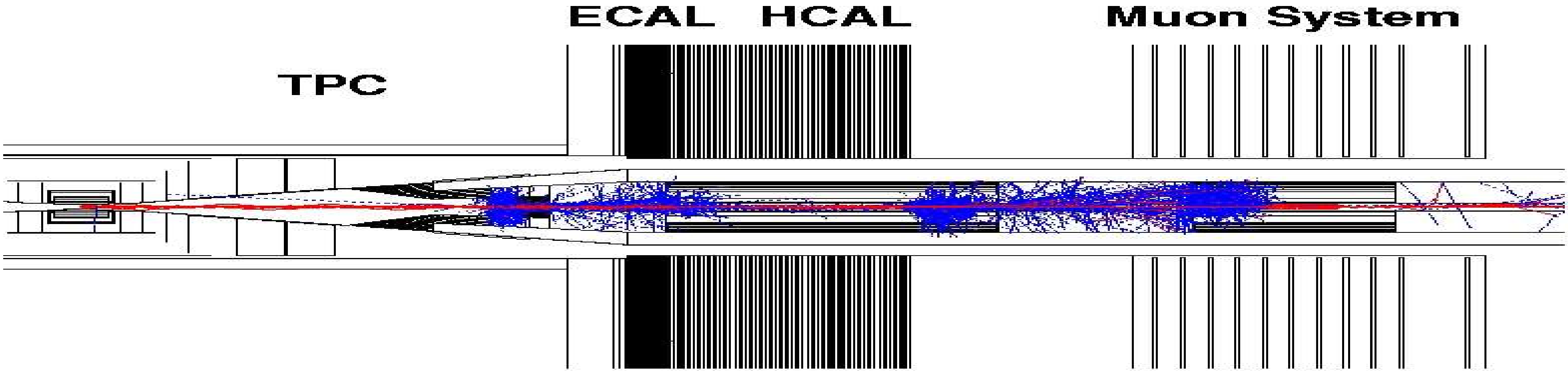
CALICE background

- Beam-beam interaction
  - Beamstrahlung
  - Pairs (e^+e^-)
  - Hadrons (from interactions)
- Neutrons
  - Radiative Bhabhas
  - Pairs
- BDS
  - Muons
  - Sync. Radiation
  - Beam gas

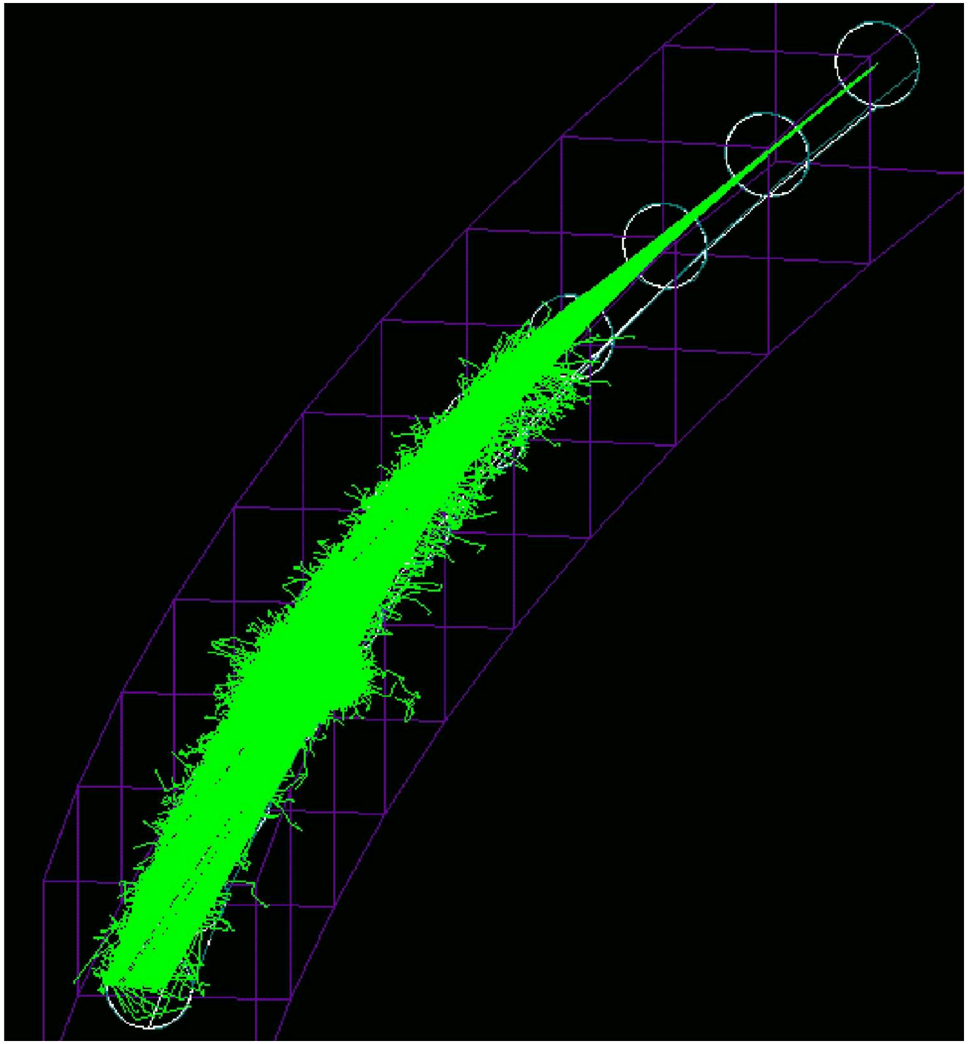
- TESLA @ 500GeV TDR results
  - Leakage from mask ~1GeV/BX
  - Pairs ~5GeV/BX (1GeV Barrel + 4GeV End caps)
  - Hadrons from ~2GeV/BX
  - Neutrons ~6GeV (ECAL) ~8GeV(HCAL)
  - Muons 0.3/BX (whole detector)
  - Sync. radiation and beam gas negligible

Background simulation

- Current detector background simulation
  - Based on Geant 3 (Brahms)
  - Geometry updating difficult
  - No accelerator tracking
  - Updates from TDR?
    - L^*=5m
    - Crossing angle (TESLA)



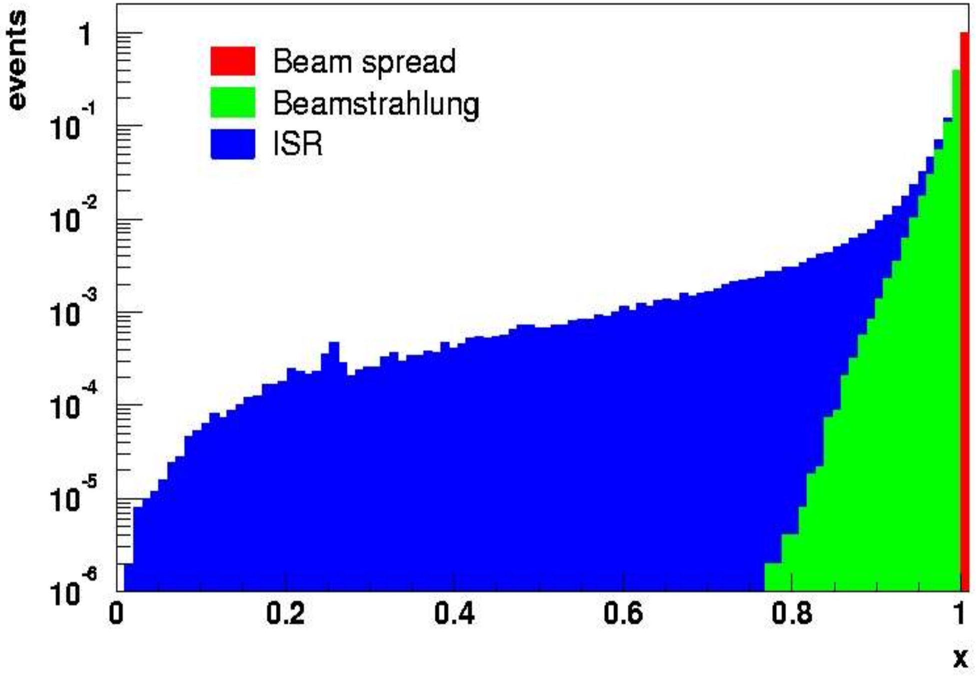
Mokka + BDSIM?

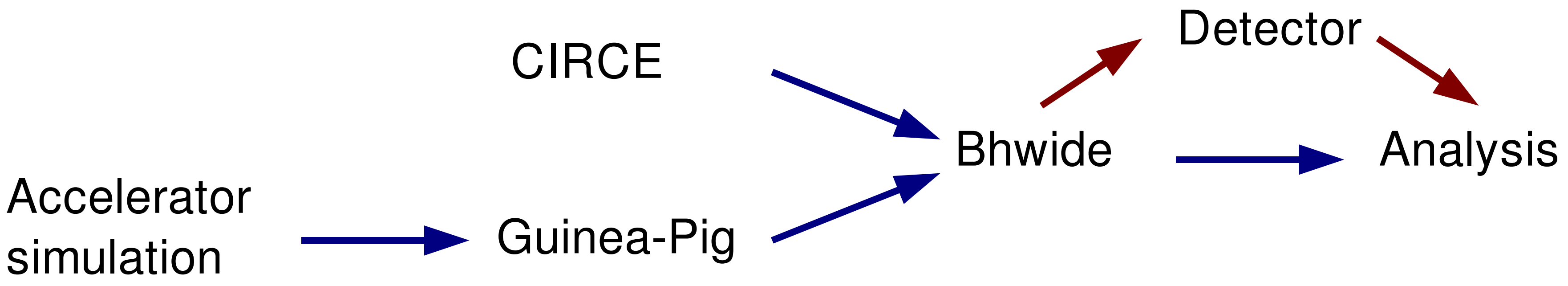


- BDSIM
  - Accelerator tracking code based on Geant 4 (Grahame Blair)
    - Many physics processes implemented via Geant for wide range of energies
    - Track particles to interaction region and simulate detector response
  - Geant 4 basis
    - LCFI, CALICE, MDI all benefit
    - Neutron transport from Fluka

Luminosity spectrum

- Beam-beam interaction
  - Significantly reduces the center of mass energy, due to beamstrahlung losses
  - No beam line constraint
  - Measure luminosity spectrum
  - Most significant systematic error on threshold mass measurements





CIRCE

Accelerator simulation

Guinea-Pig

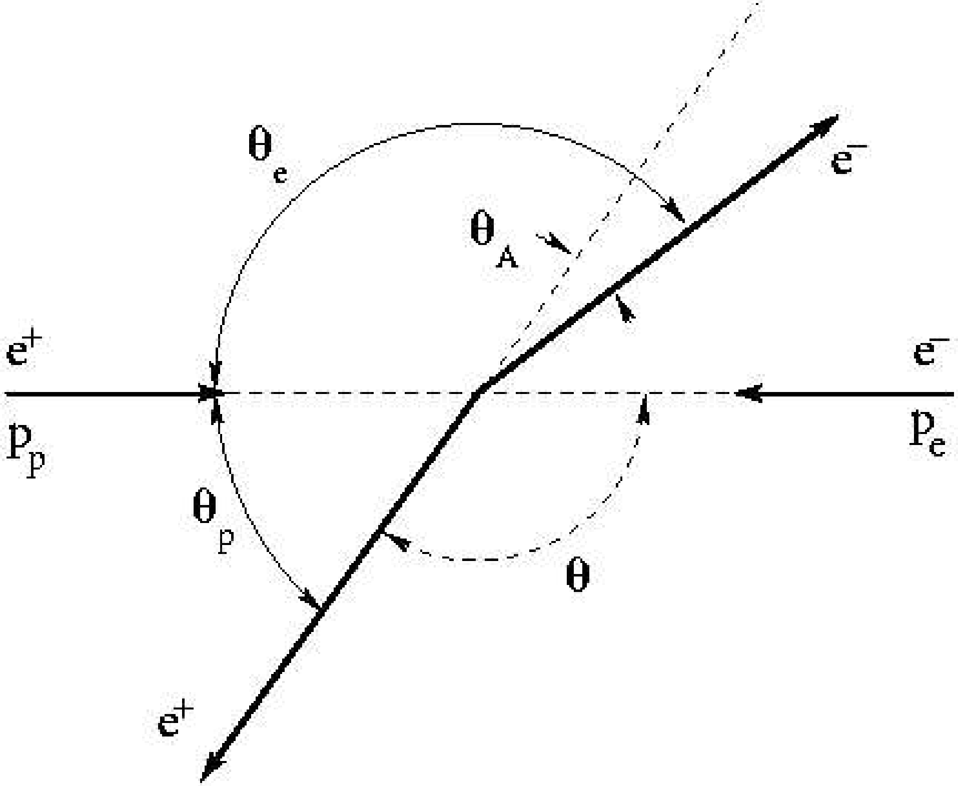
Bhwide

Detector

Analysis

Bhabha acolinearity

- $e^+e^- \to e^+e$
  - High rate $\sigma_{\text{Bhabha}} >> \sigma$
  - Clean events
- x reconstruction
  - Can not use calorimeter energy, due to energy resolution
  - Use scattered particle angular variables only



- Frary-Miller (angle approx.)

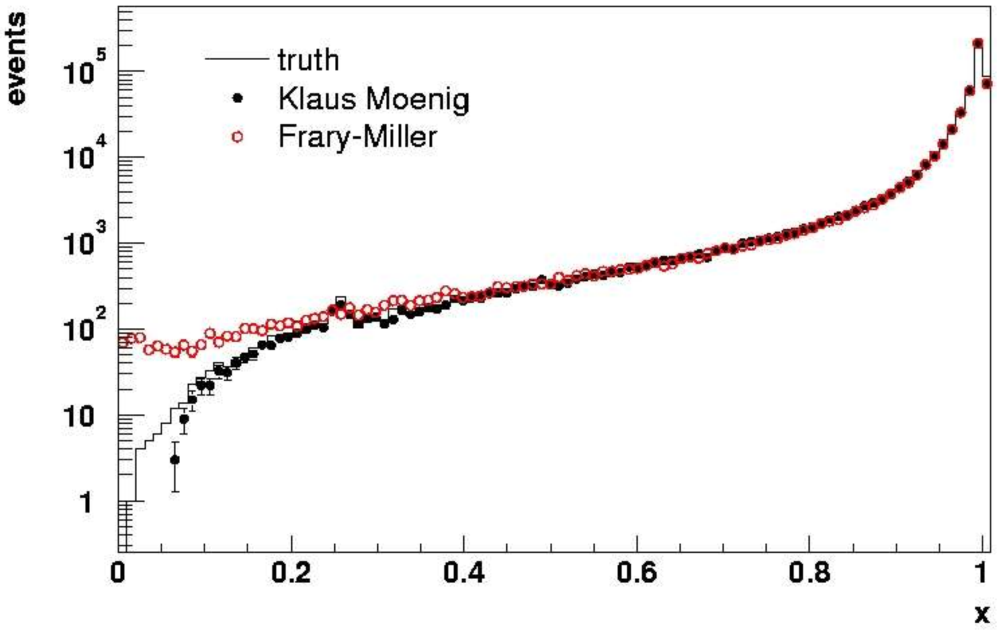
$$x = \frac{\sqrt{s'}}{\sqrt{s}} = 1 - \frac{\theta_A}{\sin(\overline{\theta})}$$

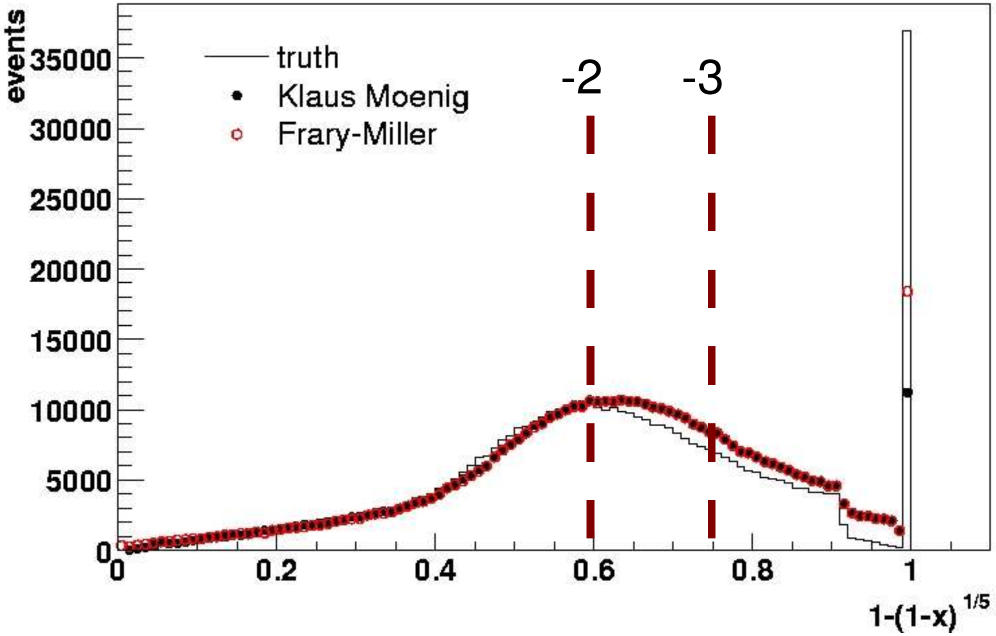
Moenig (1 photon approx)

$$x = \sqrt{\cot\left(\frac{\theta_1}{2}\right)\cot\left(\frac{\theta_2}{2}\right)}$$

Spectrum reconstruction

- Reconstruction performance
  - “Good” agreement seen over important x range
  - Both methods identical in peak region
  - Differences at x<0.2 insignificant





- Transformed x
  - Detail in peak $x>1.10^{-4}$
  - Resolve peak structure with following transformation:

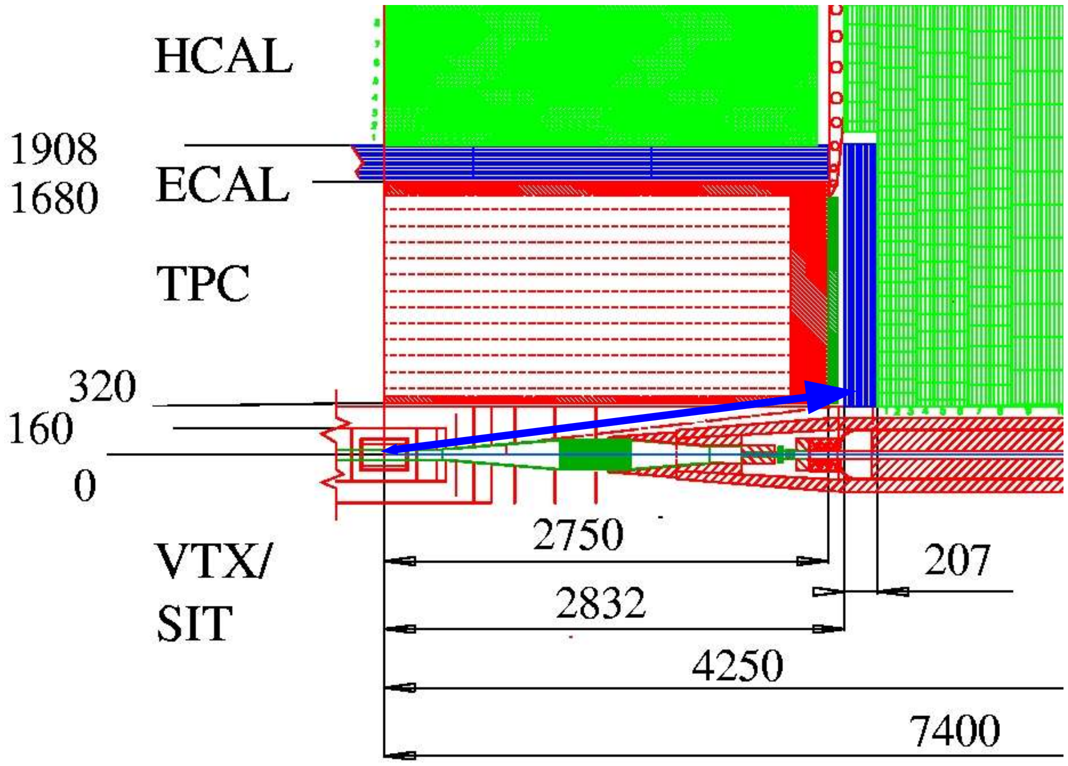
$$x' = 1 - (1-x)^{1/5}$$

Effect of CALICE on spectrum

- Calorimeter resolution

$$\sigma_\theta = 68\,mrad/\sqrt{E} + 8\,mrad$$

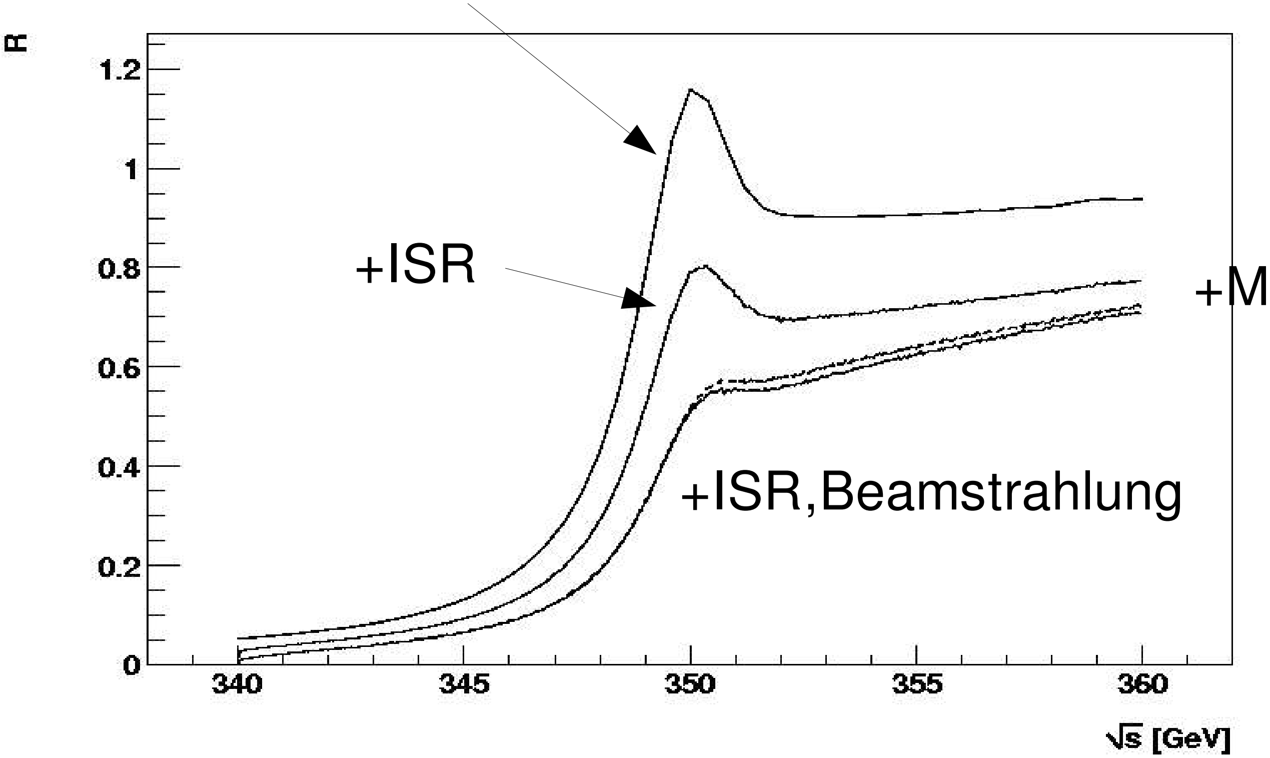
- Tracking resolution
  - Ultimate precision depends on low angle track angular resolution (3.10^{-5}rad)
  - Problem with tracking efficiency
  - CALICE electron efficiency ≈100%
- Energy flow measurement essential with full detector simulation
  - vertex position resolution, jitter?



Effect on top threshold

- True next next to leading order (NNLO) top threshold calculated via TOPPIK
- Smear “true” threshold with x (true/reconstructed) distribution

$$\sigma'(\sqrt{s})=\sum x_i\sigma(x\sqrt{s})$$



“true” threshold1s mass = 350 GeV

+ISR

+Measured luminosity spectrum

+ISR,Beamstrahlung

Summary

- Test beam
  - SiW ECAL prototype well underway
  - HCAL development in many areas and proceeding well
- Simulation
  - Progress being made with Geant 4 comparisons with Geant 3 and Fluka
  - Comparisons to test beam data
  - Hope to have energy flow algorithms for “realistic” physics studies
- Synergy
  - Excellent opportunity to integrate UK simulation activity within Geant 4 framework (background studies)
    - Relation to LC-ABD PPARC bid
  - Luminosity spectrum
    - Inclusion of detector effects (CALICE, but also tracking)