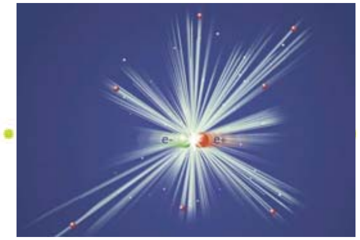
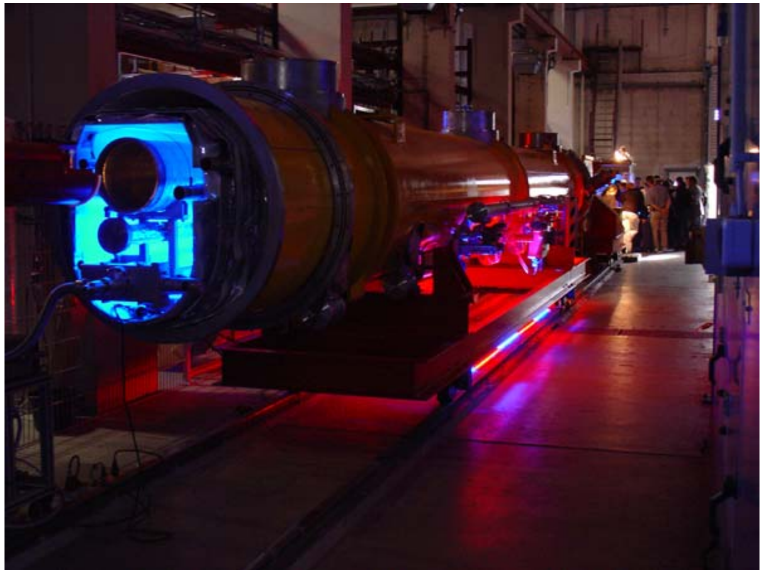
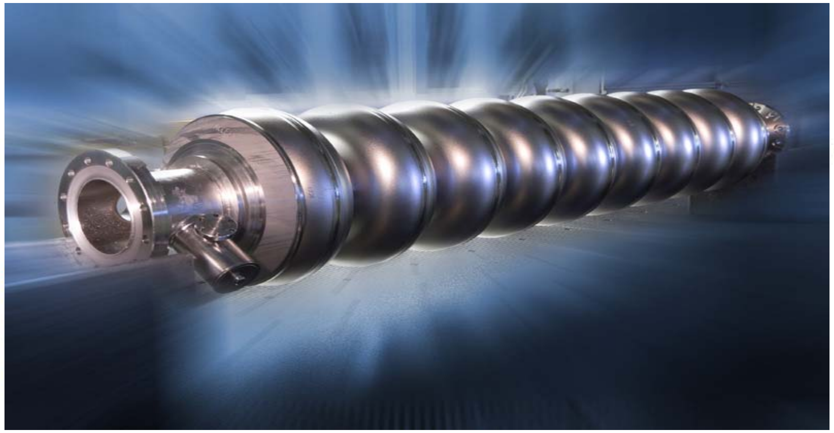


Kalorimetr pro mezinárodní lineární urychlovač (ILC)

1. Co to je ILC?
2. Proč ILC?
3. Detektory pro ILC
4. Kalorimetry
5. Výsledky testů kalorimetrů
6. Pohled do budoucnosti



ilc - co je?



HOW DOES THE ILC WORK?

The Linacs
Scientists will use two main linear accelerators ("linacs"), one for electrons and one for positrons, each 12 kilometers long, to accelerate the bunches of particles toward the collision point. Each linac consists of 8,000 superconducting cavities nestled within a series of cooled vessels to form cryomodules. The modules use liquid helium to cool the cavities to -271°C, only slightly above absolute zero. Scientists will launch traveling electromagnetic waves into the cavities to "push" the particles through, and accelerate them to energies that will total 500 GeV.

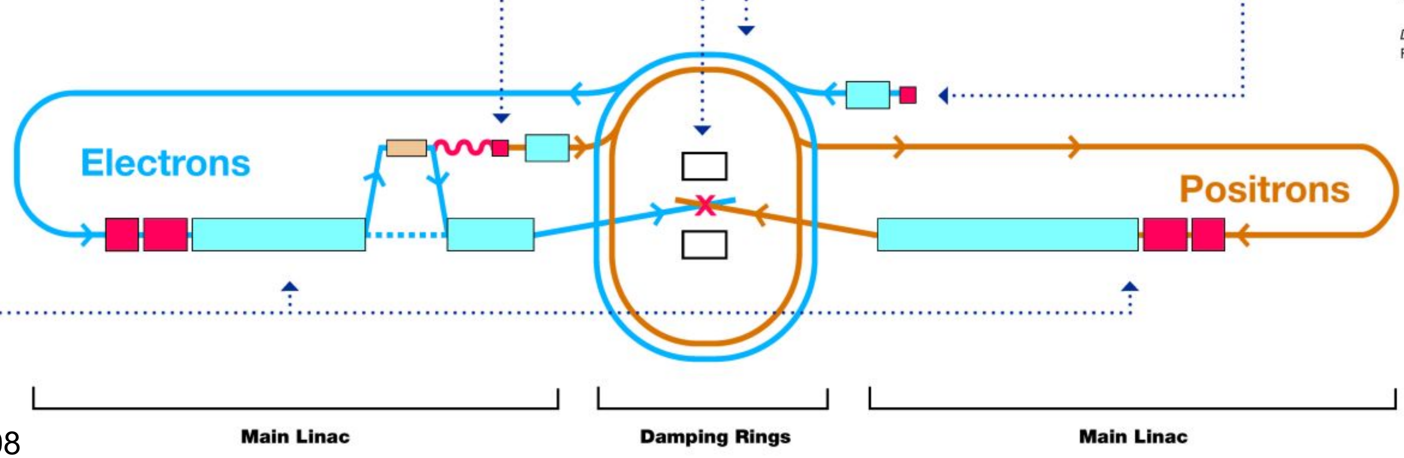
Positrons
Positrons, the antimatter partners of electrons, do not exist naturally on earth. To produce them scientists will send the high-energy electron beam through an undulator, a special arrangement of magnets in which electrons are sent on a "roller-coaster" course. This turbulent motion will cause the electrons to emit a stream of photons. Just beyond the undulator the electrons will return to the main accelerator, while the photons will hit a titanium-alloy target and produce pairs of electrons and positrons. The positrons will be collected and launched into their own 250-meter 5-GeV accelerator.

The Detectors
Traveling towards each other at nearly the speed of light, the electron and positron bunches will collide with a total energy of 500 GeV. Scientists will record the spectacular collisions in two giant particle detectors. These work like gigantic cameras, taking snapshots of the particles produced by the electron-positron annihilations. The two detectors will incorporate different but complementary state-of-the-art technologies to capture information about every particle produced in each collision. Having these two detectors will allow vital cross-checking of the potentially-subtle physics discovery signatures.

The Damping Rings
When created, neither the electron nor the positron bunches are compact enough to yield the high density needed to produce collisions inside the detectors. Scientists will solve this problem by using seven-kilometer-circumference damping rings, one for electrons and one for positrons. In each ring, the bunches will travel through a series of wigglers that literally "wiggle" the beam to emit photons. This process makes the bunches more compact. Each bunch will circle the damping ring roughly 10,000 times in only two tenths of a second. Upon exiting the damping rings, the bunches will be a few millimeters long and thinner than a human hair.

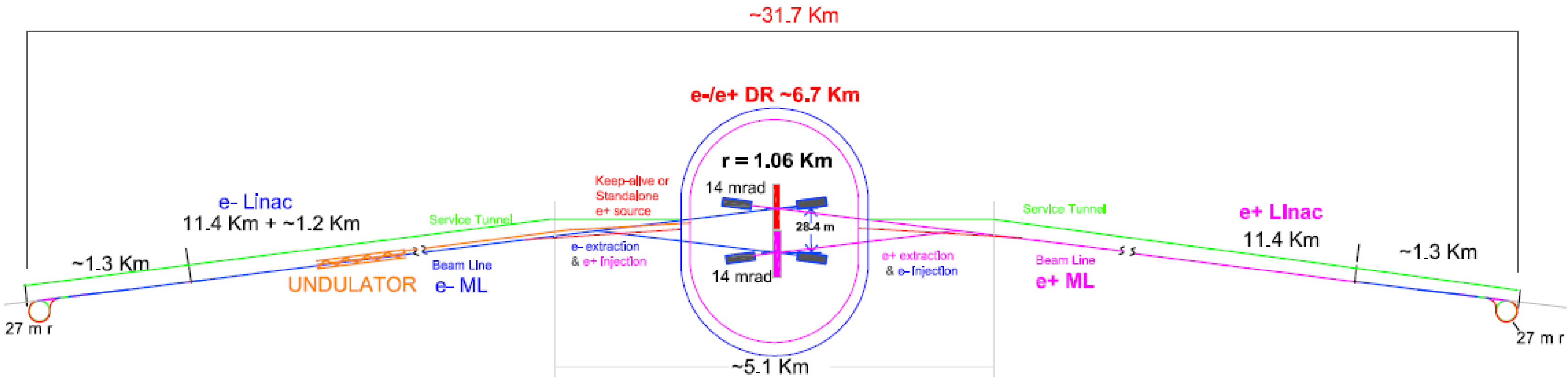
Electrons
To produce electrons scientists will fire high-intensity, two-nanosecond light pulses from a laser at a target and knock out billions of electrons per pulse. They will gather the electrons using electric and magnetic fields to create bunches of particles and launch them into a 250-meter linear accelerator that boosts their energy to 5 GeV.

Drawing not to scale
February 2007



= International Linear Collider

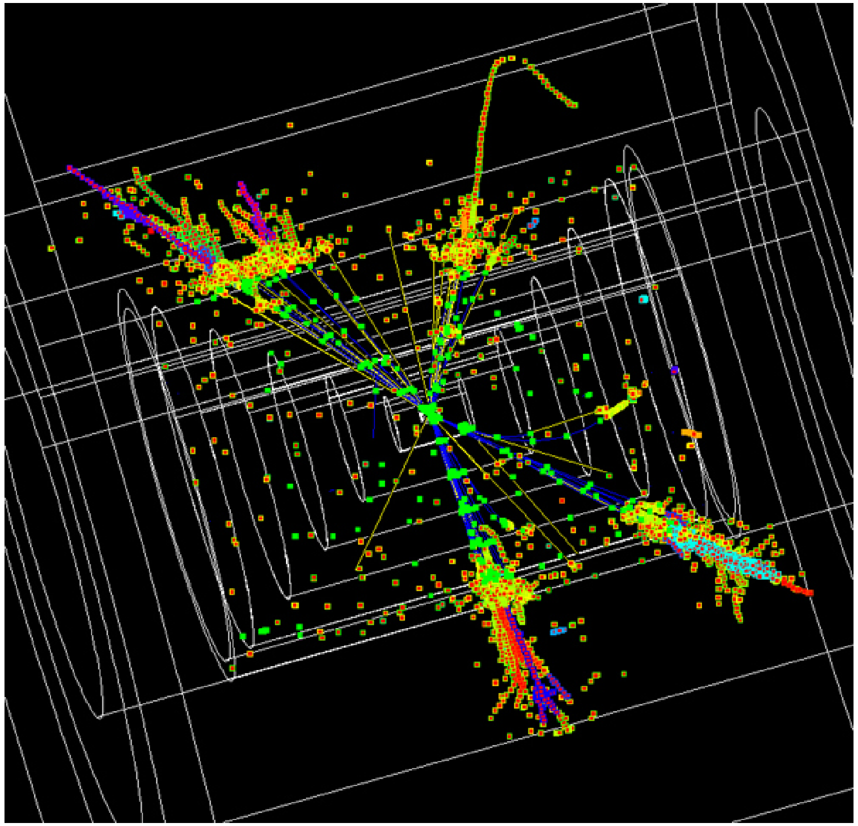
- e^+e^- urychlovač s dvěma trubicemi, každá na energii 250 GeV supravodivé radiofrekvenční kavity (rf cavities)
- nižší energie než LHC, ale mnohem čistší interakce → fyzikální výsledky s menší chybou
- LHC = urychlovač učiní ‚objev', ILC ho změří
- S vývojem urychlovače se rozvíjejí detektory – a to je náš hlavní zájem



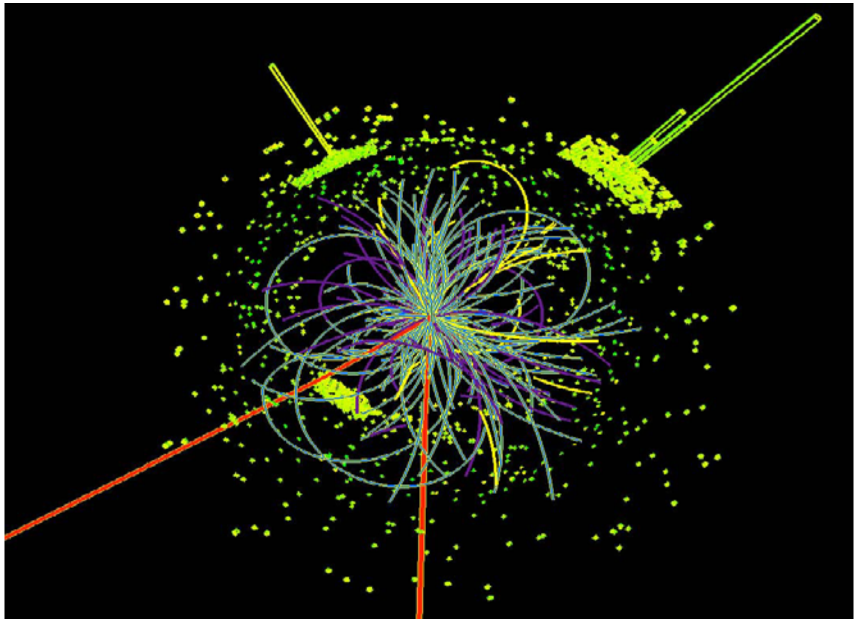
Schematic Layout of the 500 GeV Machine

Higgs production

e+e- → Z + Higgs na ILC



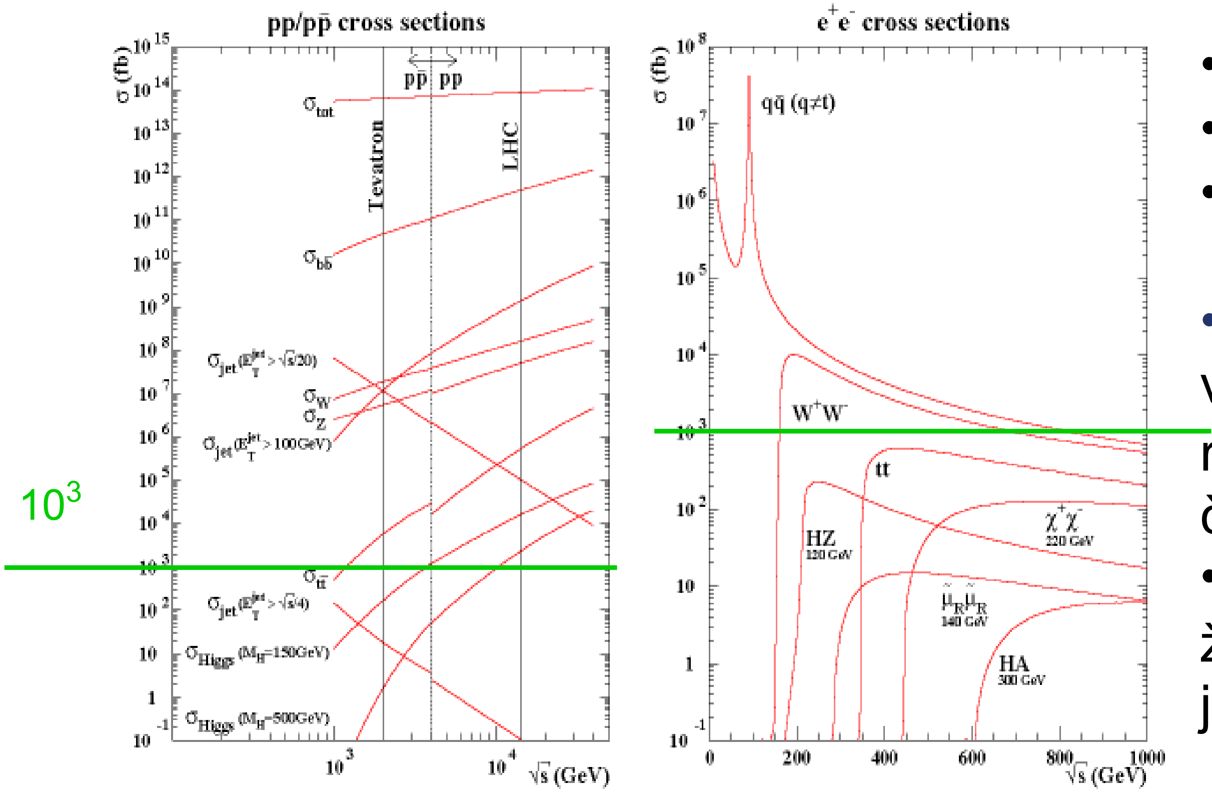
pp → Higgs v CMS, LHC



- Složitější topologie případu především kvůli fragmentům obou protonů
- Pouze část těžišťové energie vstupuje do ‚tvrdé' srážky

Četnosti případů na LHC a ILC

- Na LHC 10^9 interakcí každou sek., lze zapsat jen 100 na disk
- Vzácné případy ukryty ve velmi četných případech s jety
- Velké úsilí na straně detektorů i softwaru



- Na ILC pouze 10^3 inter./s
- $\bar{t}\,t$: 10^2/hod.
- Higgs: 10/hod

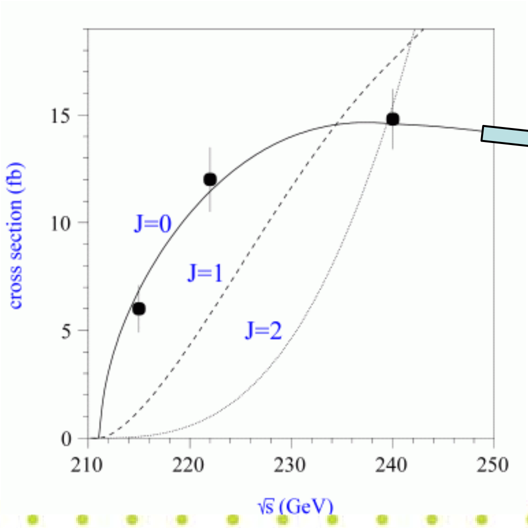
- *ILC nepotřebuje triger*, všechny případy lze rekonstruovat v reálném čase
- Vycházíme z předpokladu, že luminosita na LHC a ILC je 10^{34} $cm^{-2}s^{-1}$

Proč ILC?

- Přesná fyzikální měření
  - **polarizace e^- (e^+)**
  - **e^-e^-**
  - **$e\gamma/\gamma\gamma$ interakce**
  - **GigaZ**
- Prahová produkce SM Higgse

$\sigma[e^+e^- \rightarrow ZH] \sim \sqrt{[s - (m_H + m_Z)^2]}$

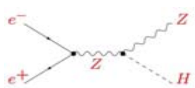
Možnost stanovit spin H (20 fb^{-1})



Vylučuje:

$J^P=0^-,1^-,2^-,3^{\pm},\ldots$

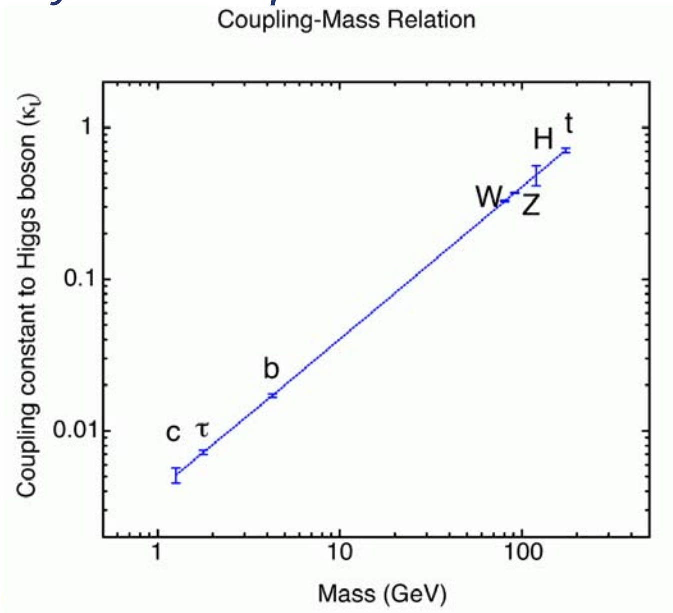
$J^P=\quad 1^+,2^+$



- Vazbová konstanta - SM částice p

$$\kappa(\mathrm{Hpp}) = \sqrt{2\sqrt{2}G_F}\, m_p$$

- Higgs strahlung: $e^+e^- \rightarrow ZH$
- WW fusion: $e^+e^- \rightarrow \nu\nu H$
- ❖ Účinné průřezy pro produkci
- ❖ Rozpadové větvící poměry
- ❖ Vyzáření t z Higgse
- ▪ *Výrazné zlepšení vzhledem k LHC*



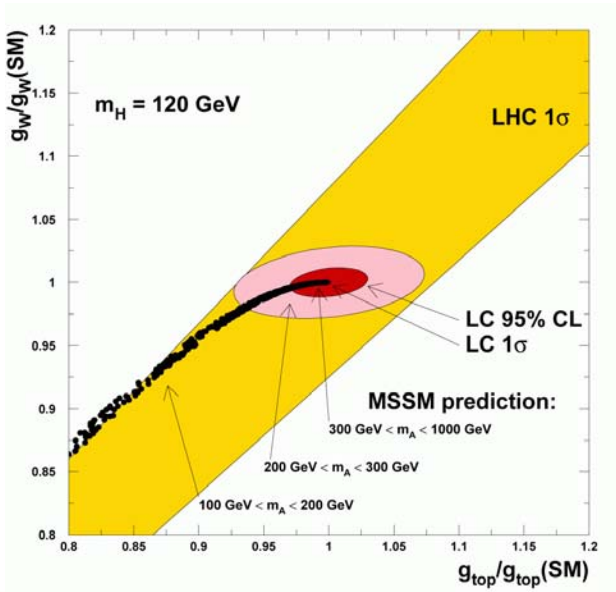
SM – MSSM vazbové konstanty

Přesnost LHC a ILC pro hmotu, šířku a trojné vazby k Higgsovu bosonu.

	M_H (GeV)	$\delta(X)/X$ LHC $2 \times 300\,\mathrm{fb}^{-1}$	$\delta(X)/X$ LC $500\,\mathrm{fb}^{-1}$
M_H	120	9×10^{-4}	3×10^{-4}
M_H	160	10×10^{-4}	4×10^{-4}
Γ_{tot}	120-140	-	0.04 - 0.06
$g_{Hu\bar{u}}$	120-140	-	0.02 - 0.04
$g_{Hd\bar{d}}$	120-140	-	0.01 - 0.02
g_{HWW}	120-140	-	0.01 - 0.03
$\frac{g_{Hu\bar{u}}}{g_{Hd\bar{d}}}$	120-140	-	0.023-0.052
$\frac{g_{Hb\bar{b}}}{g_{HWW}}$	120-140	-	0.012-0.022
$\frac{g_{Ht\bar{t}}}{g_{HWW}}$	120	0.070	0.023
$\frac{g_{HZZ}}{g_{HWW}}$	160	0.050	0.022
$\mathcal{CP}$ test	120	-	0.03
λ_{HHH}	120	-	0.22

MSSM Higgsovy bosony

- Higgsův sektor rozšířen na 2 doublety → 5 částic
  - **Lehký h^0**
  - **H^0,A^0,$H^{\pm}$ s hmotou < 1 TeV**
- Srovnání přesností trojných vazeb na LHC a ILC a předpověď MSSM pro různé M_A

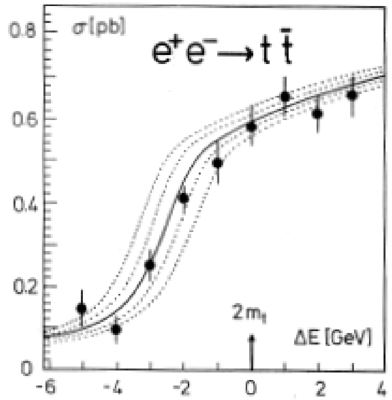


Threshold Measurements

Threshold Scan: $\sqrt{s} \simeq 350$ GeV (Phase I)

- ▷ count number of $t\bar{t}$ events
- ▷ color singlet state
- ▷ background is non-resonant
- ▷ physics well understood

  (renormalons, summations)



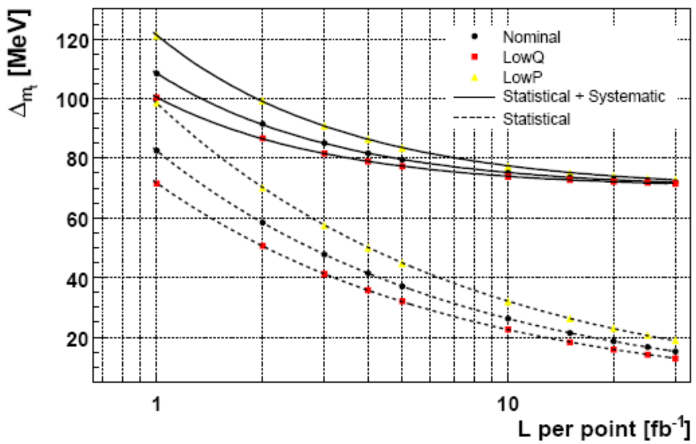
$\rightarrow \delta m_t^{\text{exp}} \simeq 50$ MeV

$\rightarrow \delta m_t^{\text{th}} \simeq 100$ MeV

What mass?

$\sqrt{s}_{\text{rise}} \sim 2m_t^{\text{thr}}$ + pert.series

(short distance mass: 1S $\leftrightarrow \overline{\text{MS}}$)



Boogert, Gounaris 2007
9+1 scan points

Physics driving calorimeter design

Missing mass peak or $b\bar{b}$ jets

- **Higgs production** $e^+ e^- \to Z\,H$ at E_{cms} = 500-1000 GeV
  - separate from WW, ZZ (in all jet modes)
- **Higgs couplings** e.g.
  - g_{ttH} from $e^+ e^- \to t\bar{t}H \to W^+W^- b\bar{b}\ b\bar{b} \to q\bar{q}\ q\bar{q}\ b\bar{b}\ b\bar{b}$!
  - g_{HHH} from $e^+ e^- \to ZHH$
- **Higgs branching ratios** $H \to b\bar{b}$, WW^*, $c\bar{c}$, gg, $\tau^+\tau^-$
- **Strong WW scattering**: separation of
  - $e^+e^- \to \nu\bar{\nu}W^+W^- \to \nu\bar{\nu}\ q\bar{q}\ q\bar{q}$
  - $e^+e^- \to \nu\bar{\nu}ZZ \to \nu\bar{\nu}\ q\bar{q}\ q\bar{q}$
  - $e^+e^- \to \nu\bar{\nu}\ t\bar{t}$

Z →	BR
$\ell^+ \ell^-$	10%
$q\bar{q}$(jets)	70%

- Heavy boson production → multifermion + boson final states = many jets
- Z,W$^\pm$ identification improves if $\sigma_{dijet\ mass} < \Gamma_{tot}$ (Z,W)
  - → jet energy resolution $\sigma(E_j)/E_j < 30\%/\sqrt{E_j}$ (GeV) at the Z mass

Technology

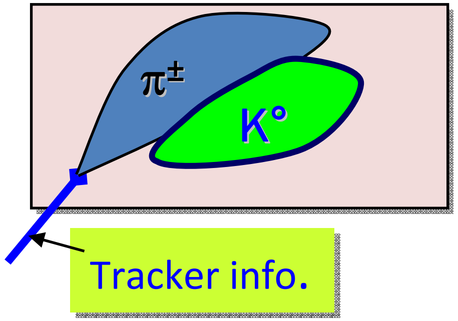
Integrated detector design

- The tracker placed in strong magnetic field provides excellent momentum resolution (good enough for replacing cluster energies in the calorimeter with track momenta), but *also* must:
  - efficiently find all the charged tracks:
- Any missed charged tracks will result in the corresponding energy clusters in the calorimeter being measured with lower energy resolution *and* a potentially larger confusion term
- ➔ highly granular calorimeter
- ➔ integrated detector design

Particle flow

▪ The corresponding software providing the best jet energy resolution is called Particle flow. It is well suited to give :

- o Shower separation based ONLY on topology

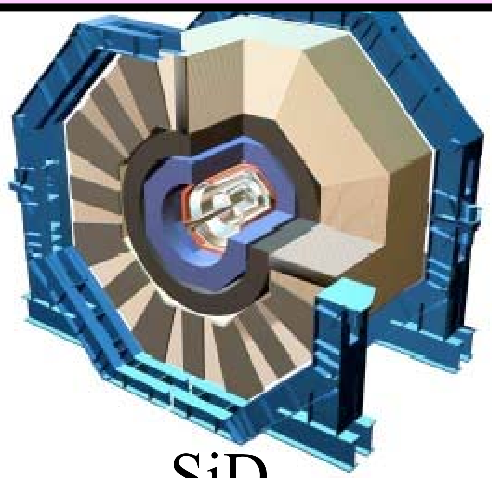


▪ This is NOT Energy flow, where balance of energy with tracker momentum is made to extract neutral from shower with charged hadrons

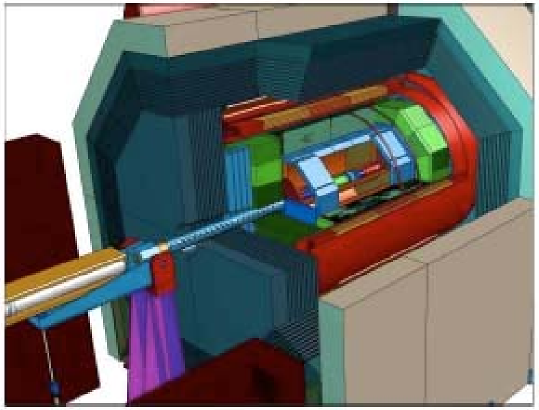
▪ Based on track momentum – cluster energy matching in an iterative process

3. Detektory pro ILC

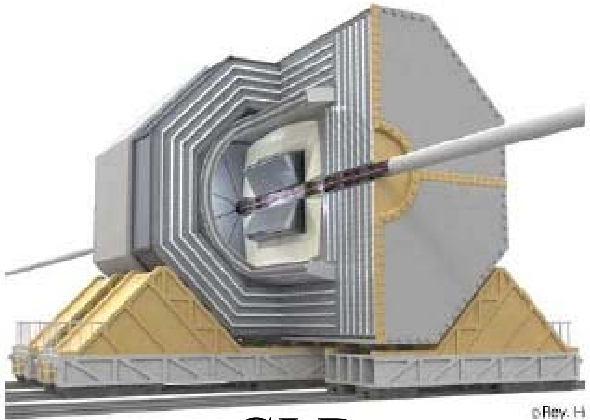
- Particle Flow Algorithm (PFA)



SiD

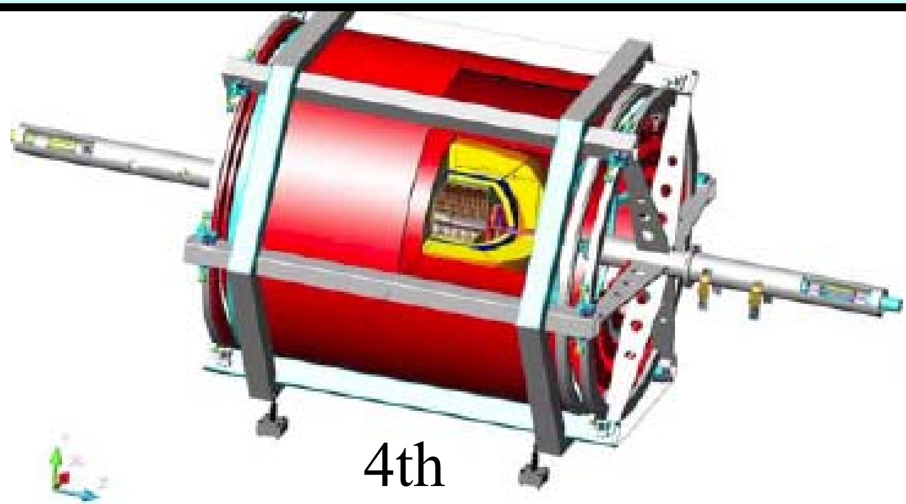


LDC



GLD

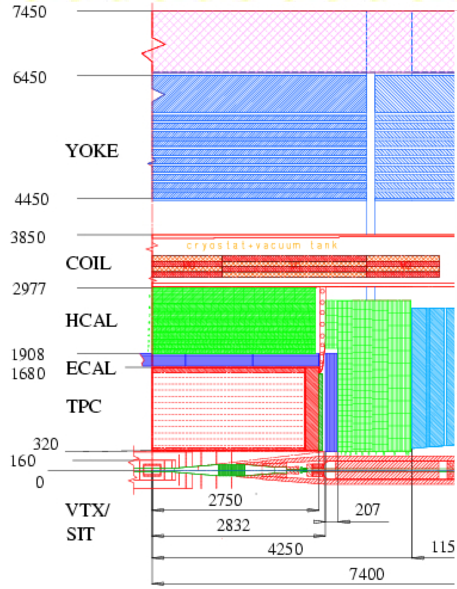
- Compensation (Dual-Readout Calorimeter)

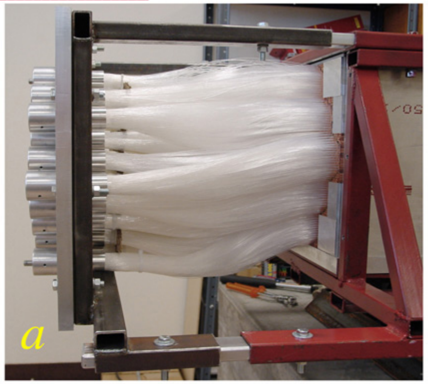


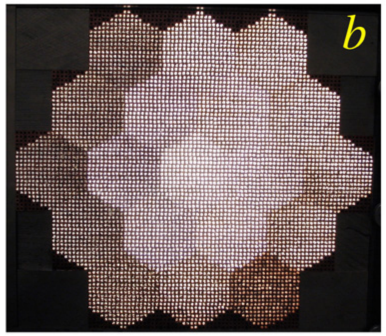
4th

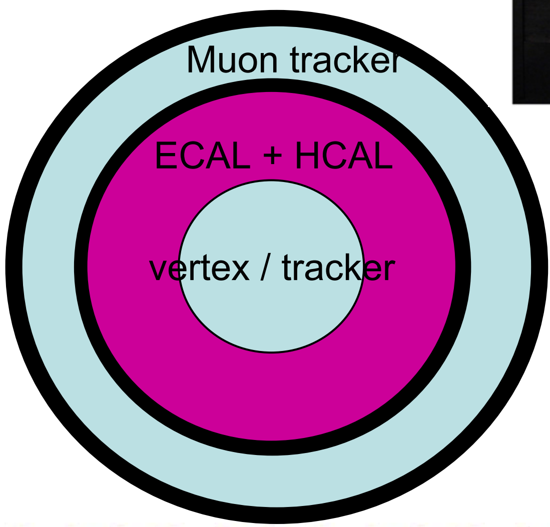
Four detector concepts

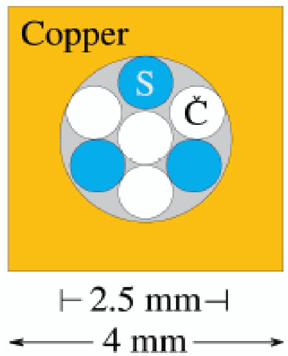
- Detectors significantly smaller than at LHC
- Three classical detectors SiD, LDC, GLD in advance stage
- DREAM detector relies on
  - Separate measurement of electromagnetic shower component f_{em} using Čerenkov light
  - Scintillation fibres measure total hadron energy, clear fibers Č light from electromagnetic energy ($\pi^0 \rightarrow \gamma\gamma$) → f_{em}
  - complementary information about both showers suppresses fluctuations in energy measurement
  - See e.g., N. Akchurin etal., NIM A537 (2005) 537
- R&D programs ongoing, do not follow necessarily the detectors but rather different technologies











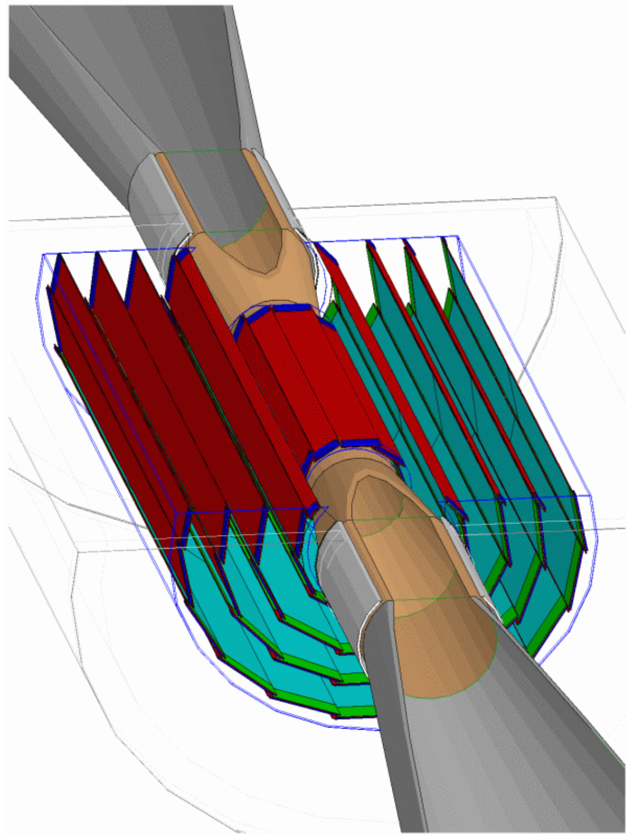
Vertex detector LDC+GLD=ILD

Pixel sensors :

- *pixel technologies developed : CCD, CMOS sensors, DEPFETS, 3D-PS (SoI)*
- *read-out architectures :*
  - ***continuous r.o. (during train) vs delayed r.o. (inbetween trains)***
  - ***various degrees of signal processing inside pixels (time stamping, discri., ...)***
- *CCD: UK (LCFI), Japan – DEPFET: Germany – CMOS: France, Italy, US ? – 3DPS: US, France, Italy*

Global detector design 2 approaches

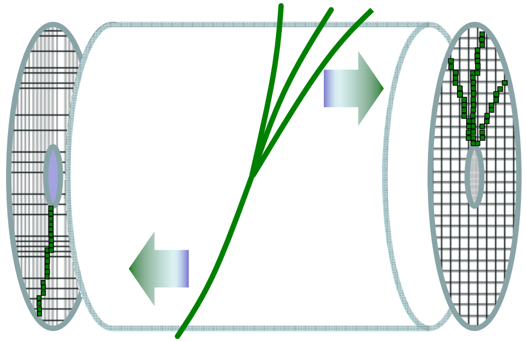
- *extrapolated from SLD vertex*
- *detector FNAL based studies*

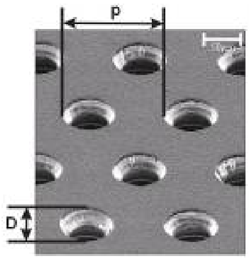


Layer radii: *15, 26, 37, 48, 60 mm*
Ladder lengths : *125 mm(in), 250 mm(out)*
Ladder support structure:
carbon fiber (100 μm thick)

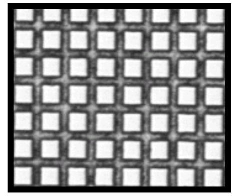
Gaseous Tracker

- Gaseous tracker : TPC
  - **Robust tracking by many 3D points**
  - **Minimum material in tracking volume**
  - **Particle ID possible**
  - **To meet the goal of $\Delta p_t/p_t$, GEM or MicroMegas are used.**





GEM



MicroMegas

- Challenges
  - **Minimize positive ion feedback**
  - **Gas selection: low diffusion, less H atom, …**
  - **Operation in non-uniform magnetic field cause by Anti-DID**
  - **Endplate design and readout electronics:**
  - **Demonstrate performance with a large scale proto-type**

- Silicon tracker (between vertex detector and TPC) is used as
  - **Main tracker of SiD**
  - **Intermediate, Forward, Endcap Trackers of other concepts**

Superconducting Magnet

- One of the major part of a detector cost
- Design
  - **GLD, LDC, SiD: Large bore**
  - **4th: Dual coil, no iron return yoke**

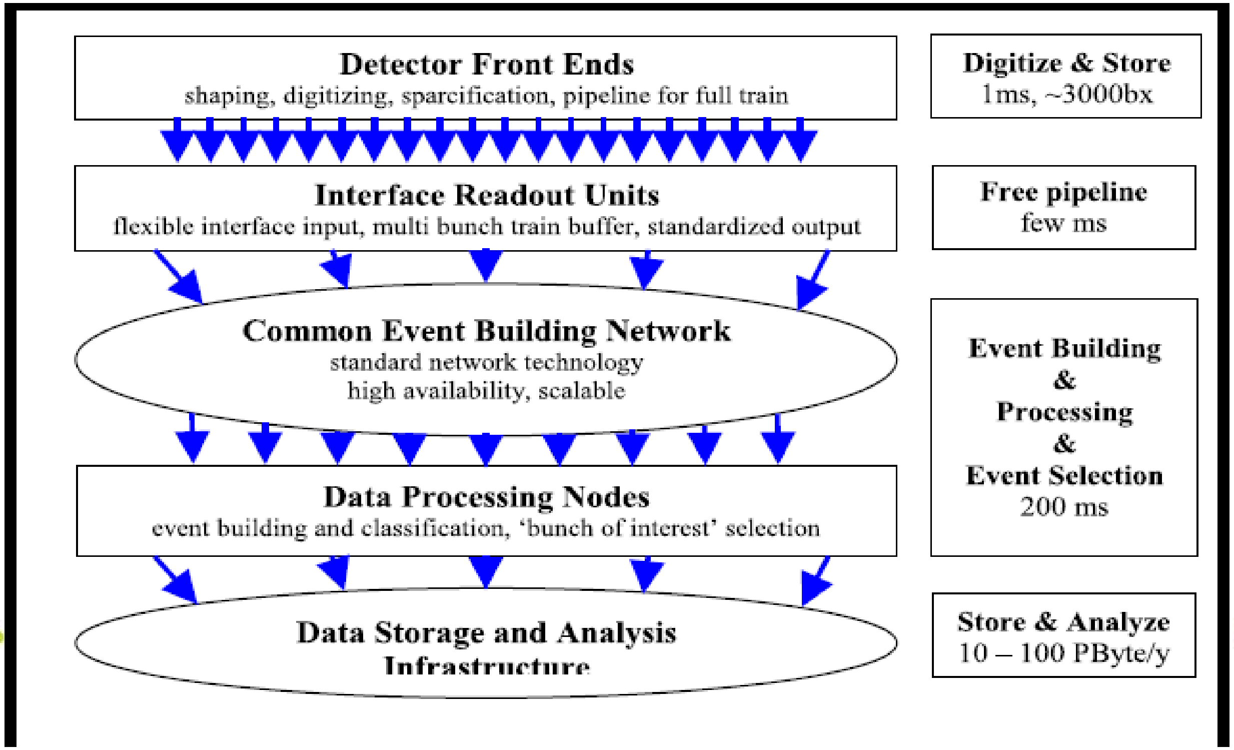
	unit	CMS	GLD	LDC	SiD	4th(In/Out)
Magnetic Field	Tesla	4	3	4	5	3.5/1.5
Coil Radius	m	3.25	4	3.16	2.65	3/4.5
Coil half length	m	6.25	4.43	3.3	2.5	4/5.5
E(stored energy)	GJ	2.6	1.6	1.7	1.4	5.7
M(cold mass)	ton	220	78	130		
E/M	kJ/kg	12.3	20	13	12	

- Experience of LHC magnets is useful. Especially, technology for CMS magnet can be applied and extended.
- More cold mass for GLD and special effort for 4th magnets will be required.

Data Acquisition

- ILC operation feature
  - **Burst collision rate ~3 MHz in 1ms → pipeline**
  - **~200 msec quiet time**
    → Average event rate is ~15 kHz, moderate compare to LHC
  - **No hardware trigger → event selection by software**
  - **High granularity detectors**
    - Need front end zero suppression and data compression

Conceptual DAQ system
details depend on the final design of sub-detector electronic components



4. Calorimeters

CALORIMETRY	
ECALs	Silicon - Tungsten
	MAPS - Tungsten
	Scintillator - Tungsten
HCALs	Scintillator - Steel
	RPCs - Steel
	GEMs - Steel
	MicroMegas - Steel
TCMT	Scintillator - Steel
Dual-Readout	Scintillator - Steel

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

ILD (LDC, GLD)

All calorimeters with very fine segmentation of the readout

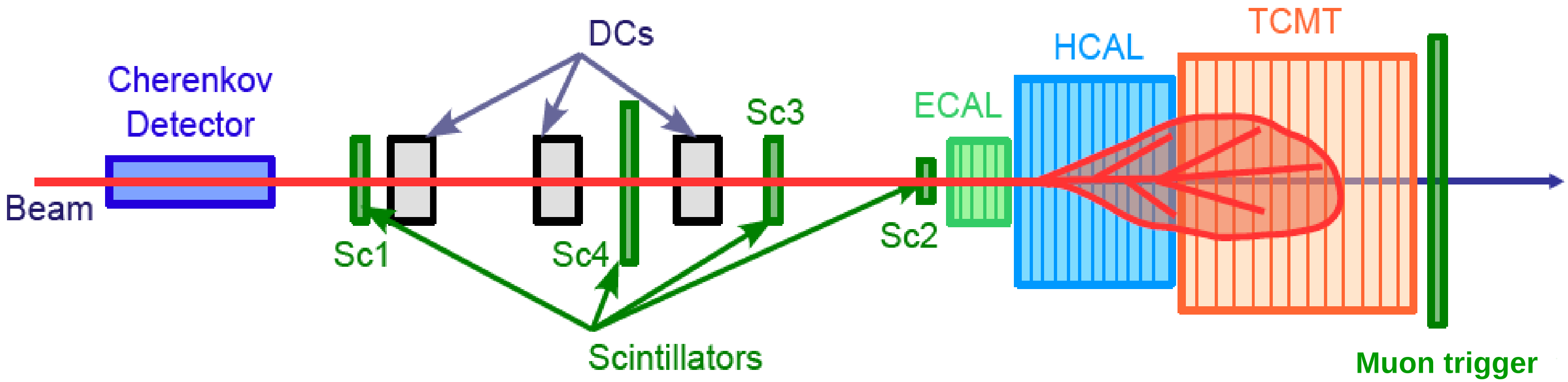
Calorimeter Prototypes

- CALICE Collaboration –
  worldwide calorimeter R&D effort

- EUDET – European grant under 6th FP, I3 (2006-10)

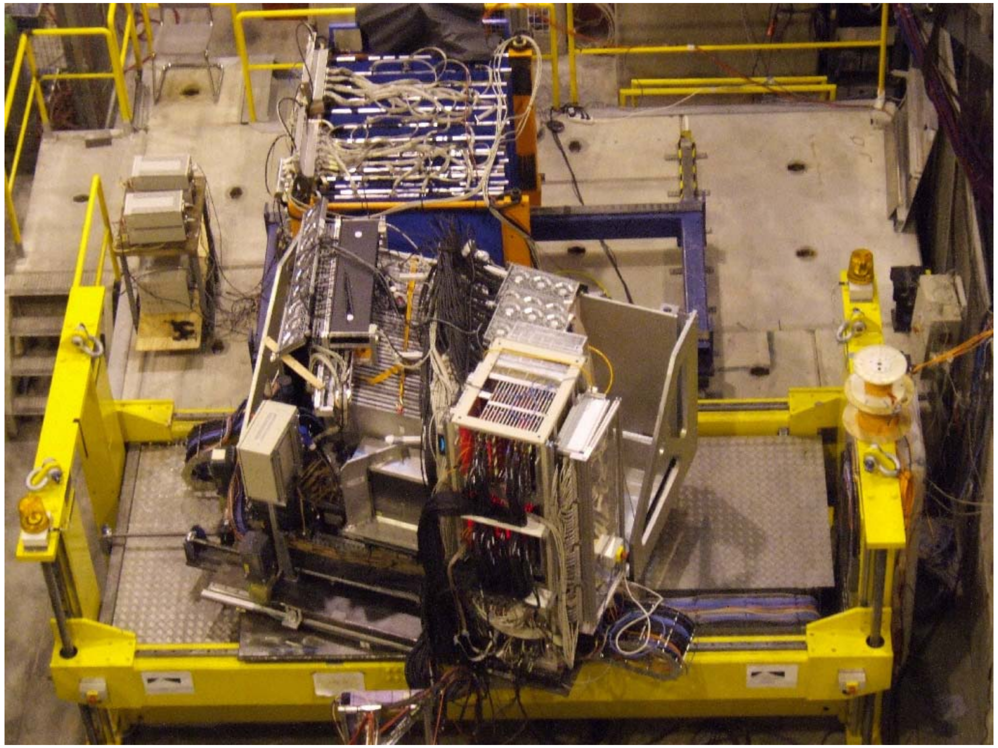
- Electromagnetic Calorimeter with W absorber
  - **Silicon pads 1 cm² / MAPS Option**
  - **Scintillator strips 1 x 4 x 0.35 cm³ with MPPC readout**
- Hadronic Calorimeter with steel absorber
  - **Scintillator with Analogue Readout**
  - **RPC / Micromegas / GEM – with Digital Readout**
- Tail Catcher – steel absorber and scintillator - analog
- Coordinated test beam programme to combine different technologies at the same time, extract meaningful physics and prove Particle flow paradigm

5. CALICE Test Beam Program

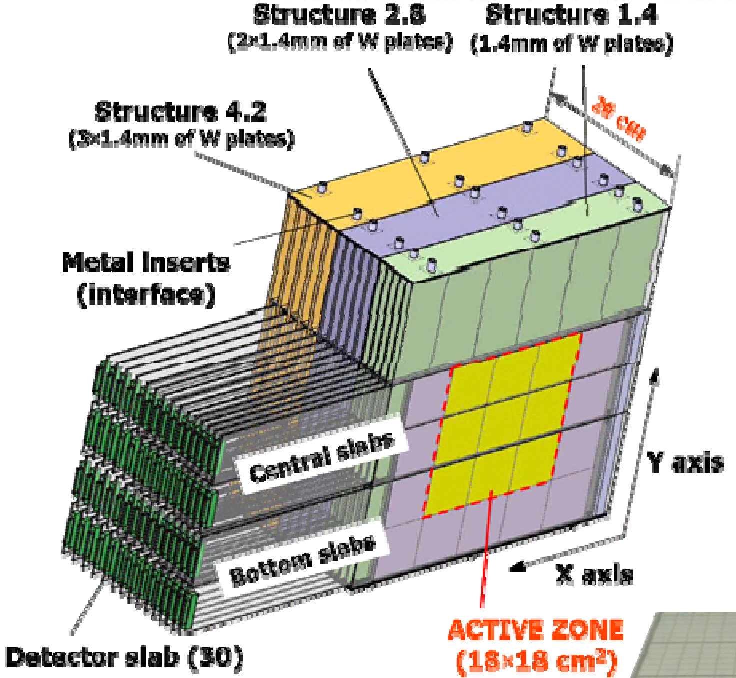


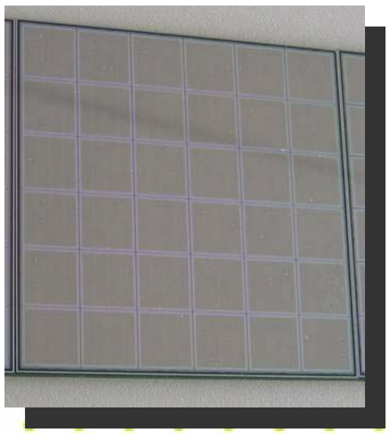
Data recorded:

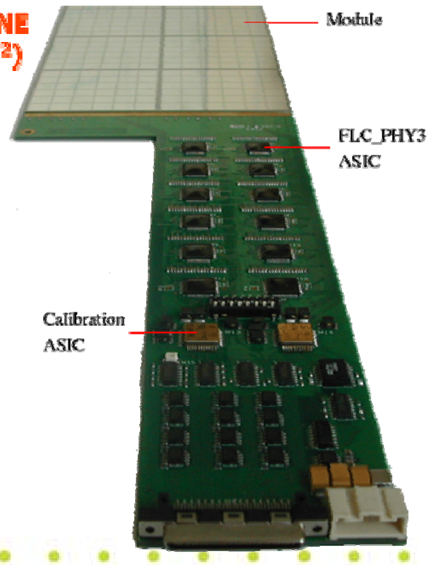
- 2006 – DESY/CERN
- 2007 - CERN
- 2008 – Fermilab
- Si-W ECAL, HCAL, TCMT
- $e^{\pm}$ 1-50 GeV
- $\mu^{\pm}$ (mainly for calibration)
- $\pi^{\pm}$ 2-180 GeV
- Various impact points
- Angles of incidence 0°, 20°, 30°, 45°
- Typically ~200K events per configuration.



Silicon-Tungsten ECAL

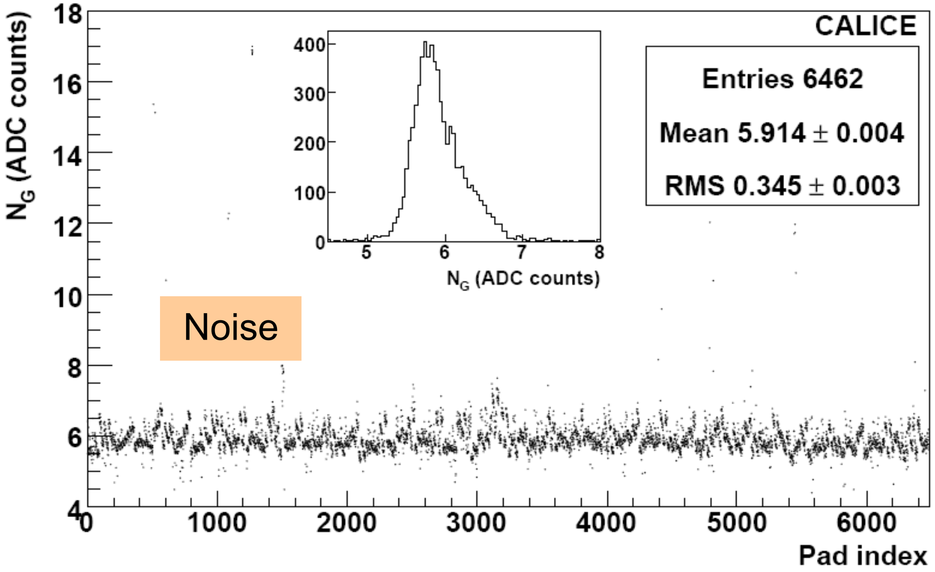


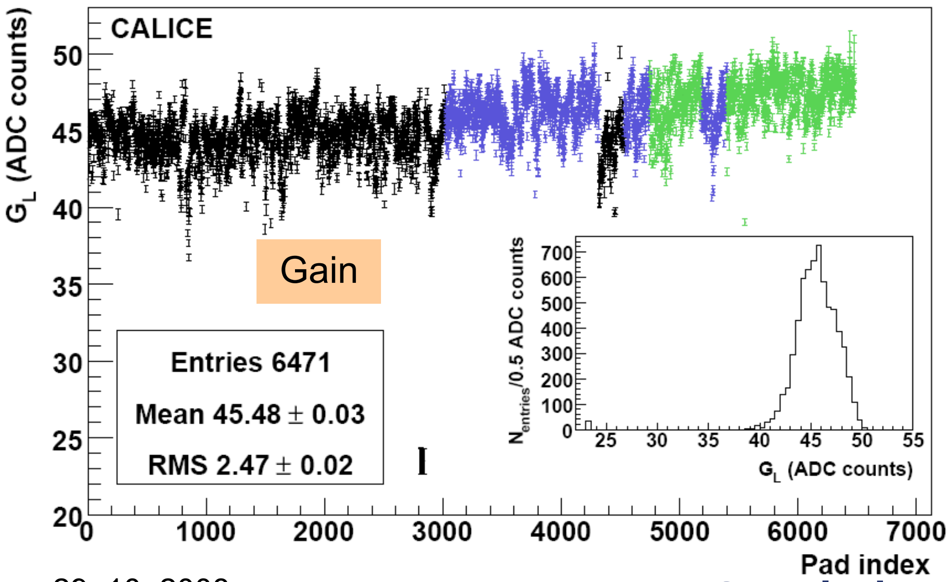




- Absorber
  - **30 layers of W: 1.4, (0.4 X_0), 2.8 and 4.2 mm thick**
  - **24 X_0 in total**
- Active Element
  - **30 layers of Si diode pads**
    - 1 cm^2, 525 μm thickness
    - 6480 channels
  - **~ ½ sensors from Czech rep.**
- Read-out by ASIC
  - **Large dynamic range**
  - **Auto-trigger on ½ MIP**
  - **On chip zero suppress**
  - **Ultra-low power « 25 μW/ch**
- In beam since 2006

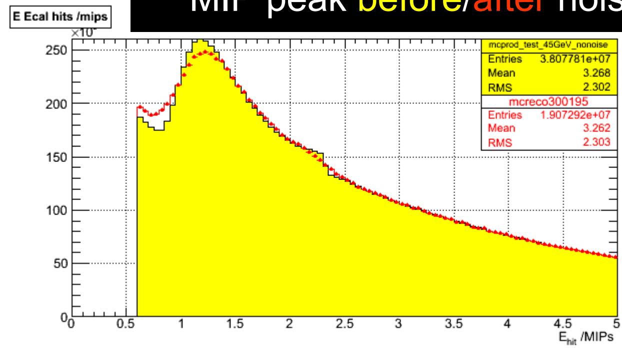
ECAL – noise and gain

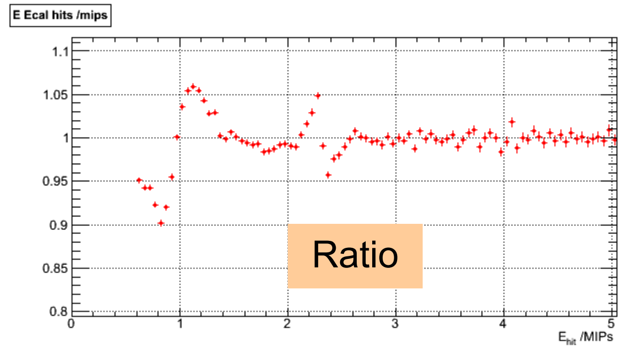




- Gain calibrated with muons. Rather uniform channel to channel.
- Average noise ~6 ADC counts. Signal/Noise ~8.
- With a typical threshold cut for analysis of ~0.6 MIP, the effect of noise on the MIP peak is small. We include in simulation, but the effect is minimal for most purposes.

MIP peak before/after noise sim.

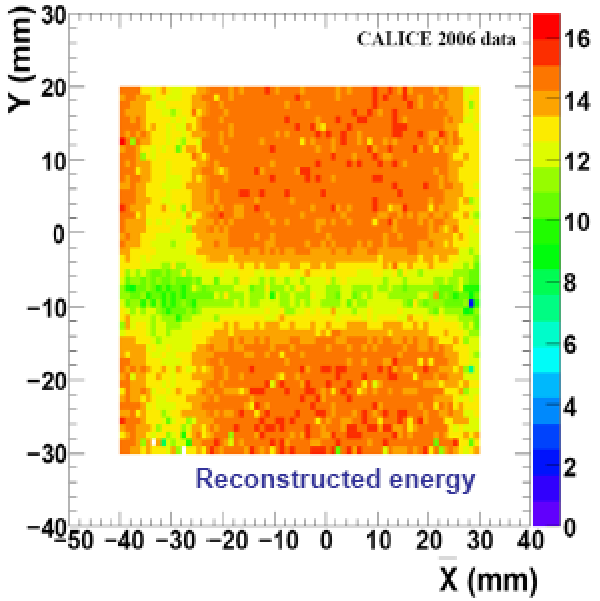


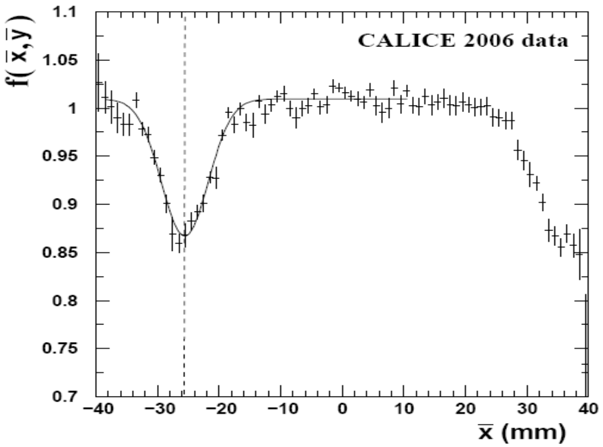


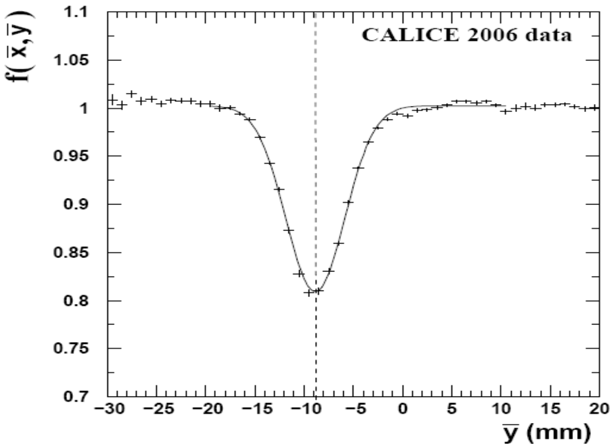
Effect of guard rings

15 GeV
e⁻ beam

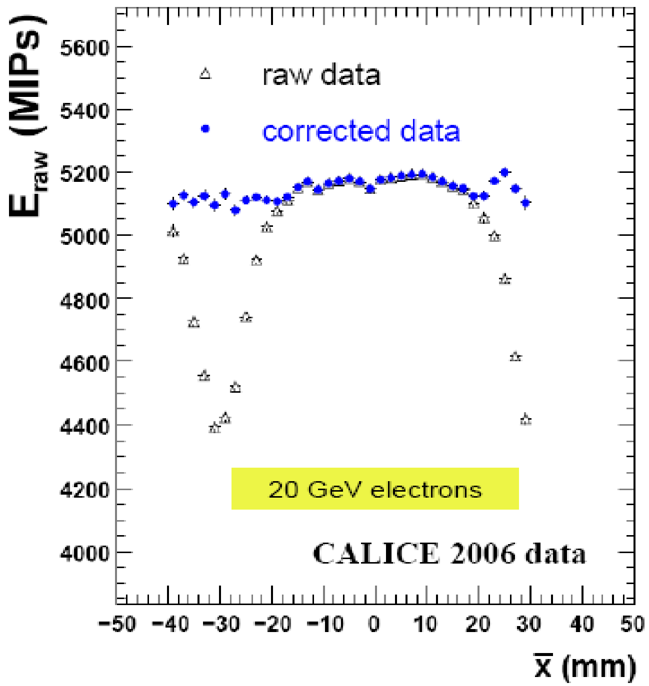
•1mm guard rings around wafers ! 2 mm dead zone between wafers (7% of area).
•See as a drop in response as scan across the calorimeter.
•Deeper in y than x because wafers aligned in y, staggered in x.
•n.b. larger gaps at alveolar boundaries.

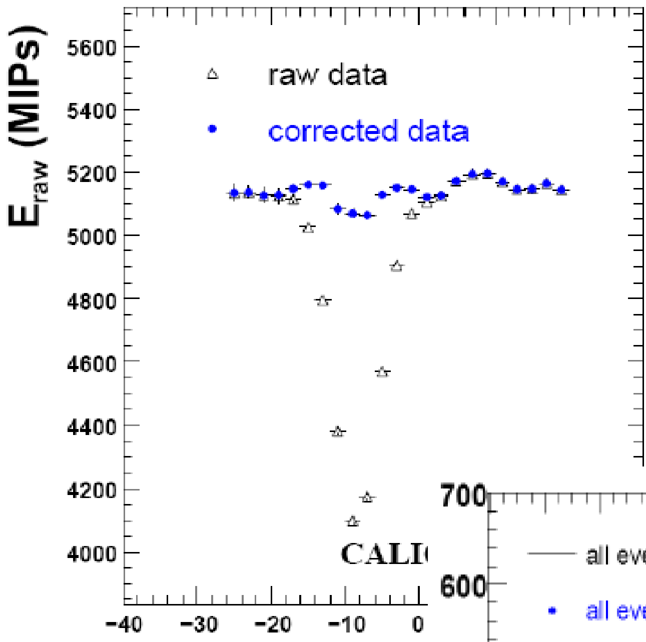


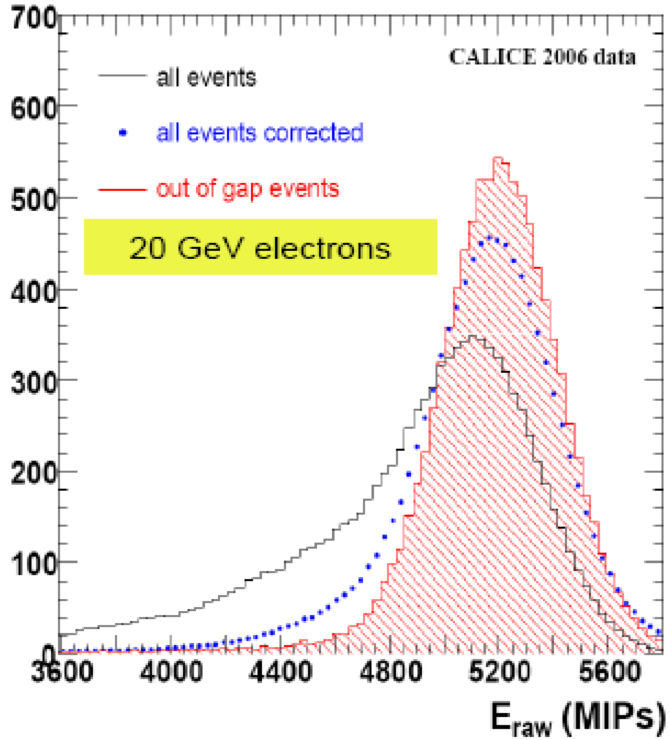




Guard ring correction

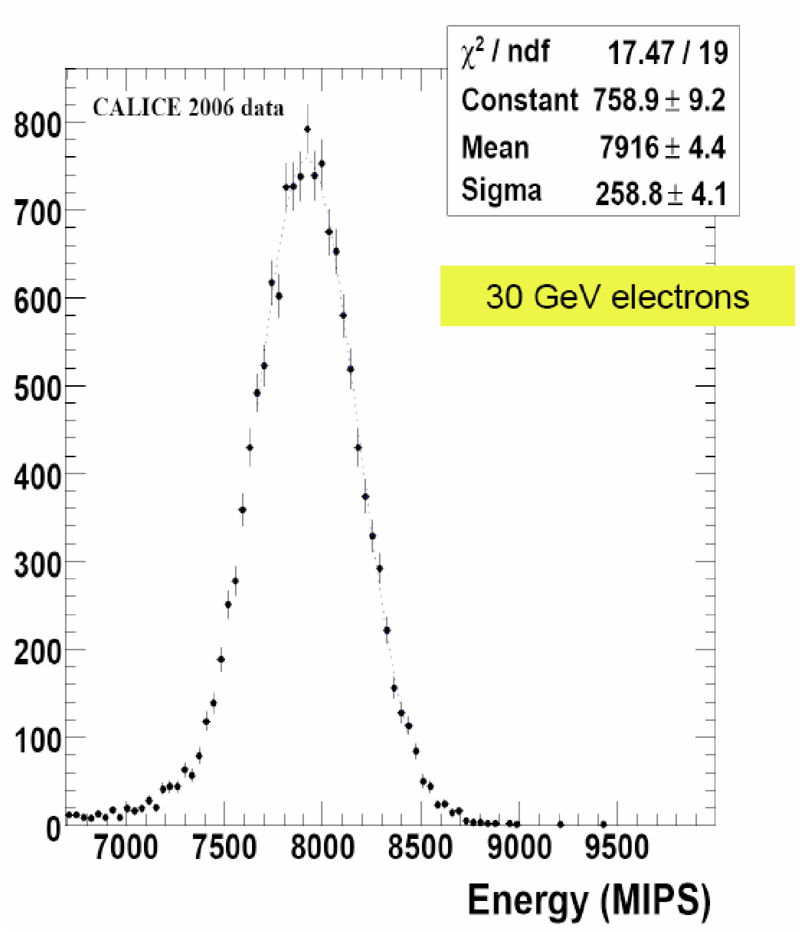


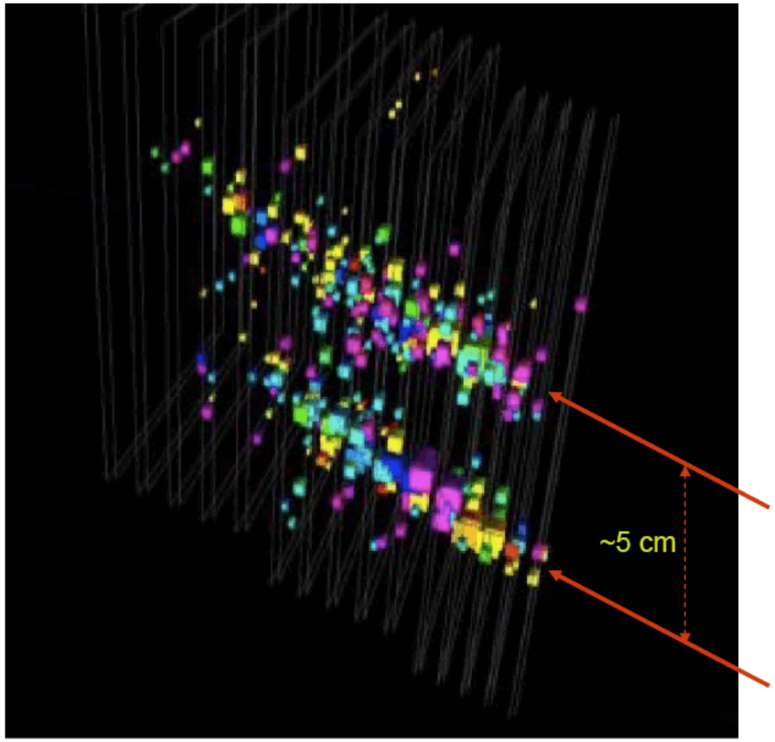




- Gaussian parametrisation of energy loss
- Permits a reasonable uniformity vs (x,y)
- Reduces low tail in measured energy
- But inevitable penalty in resolution.

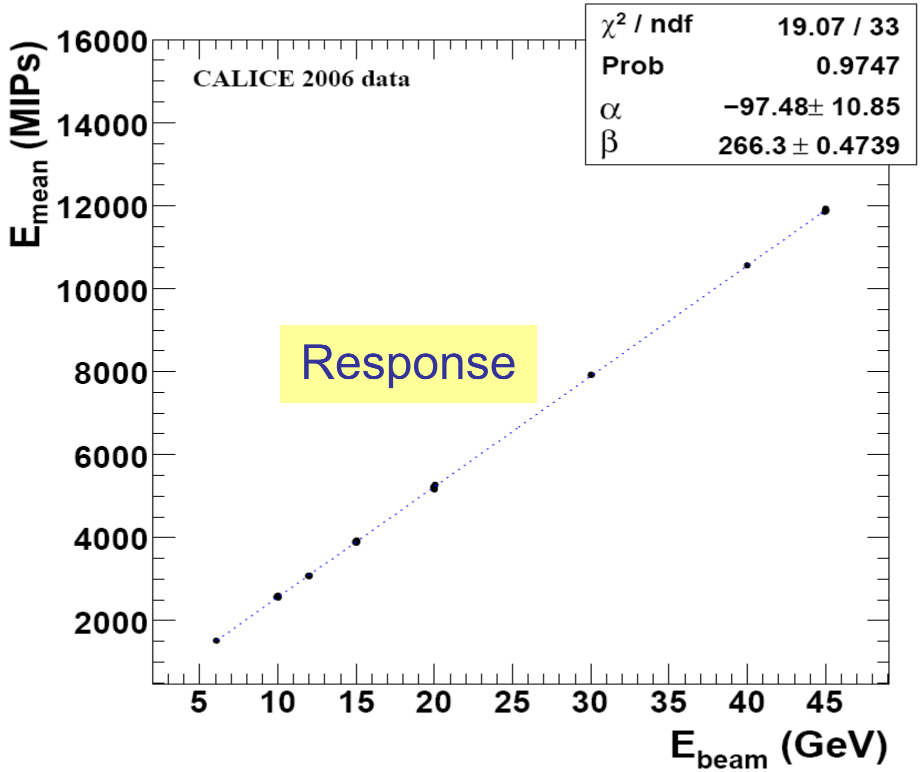
Si-W ECAL Perfomance

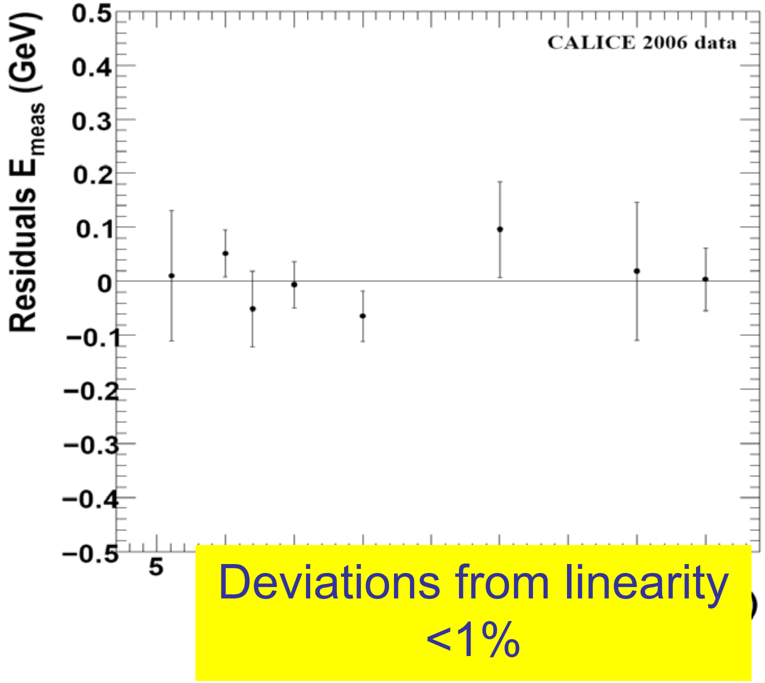




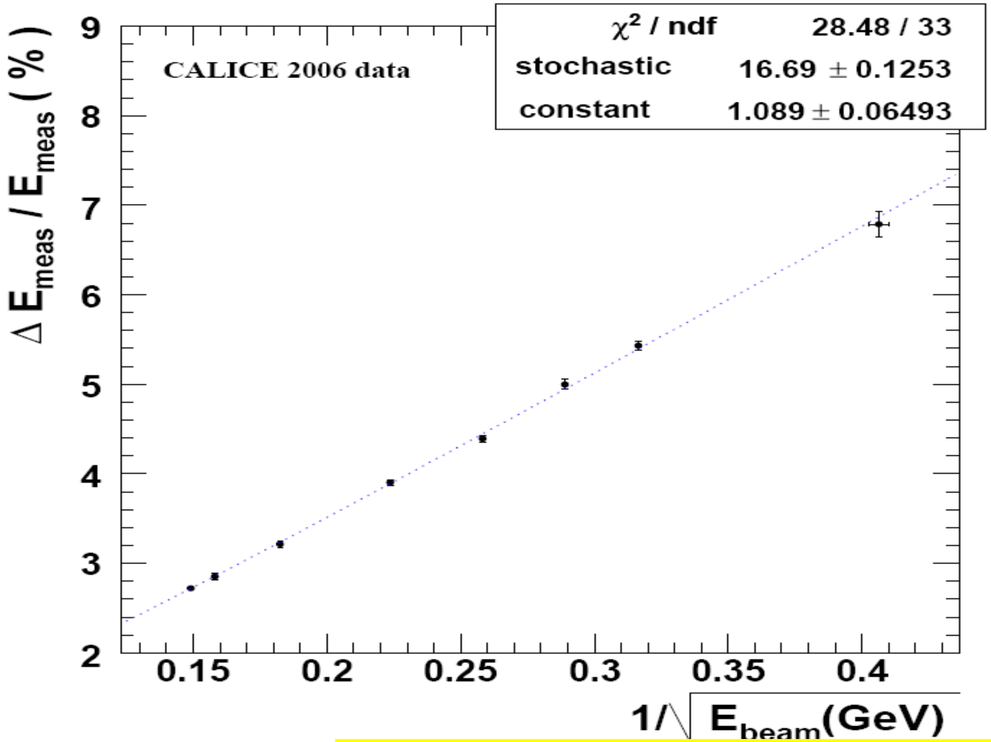
Gausian energy distribution, good spatial distribution of nearby showers

ECAL energy response for e⁻





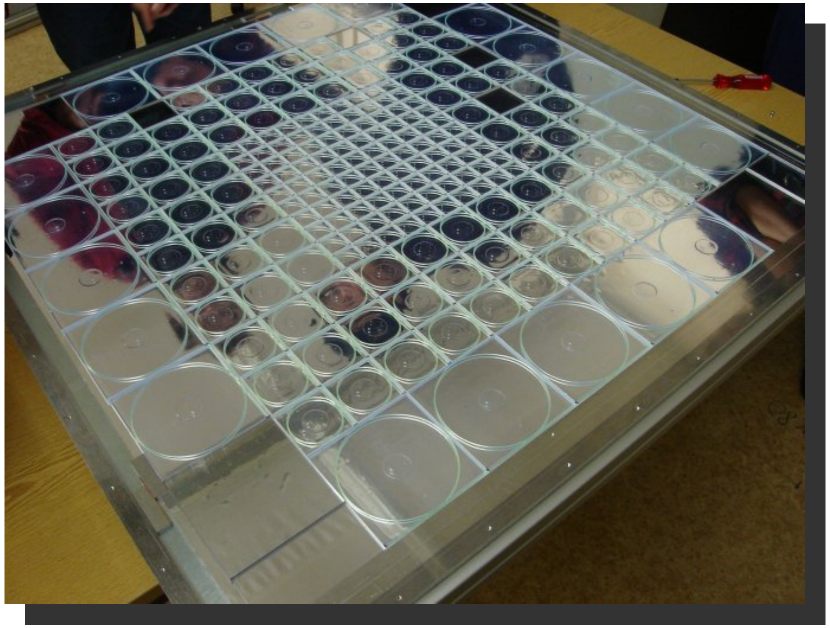
ECAL energy resolution for e⁻

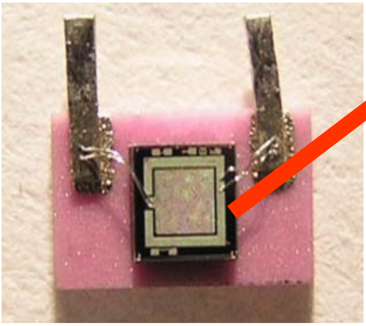


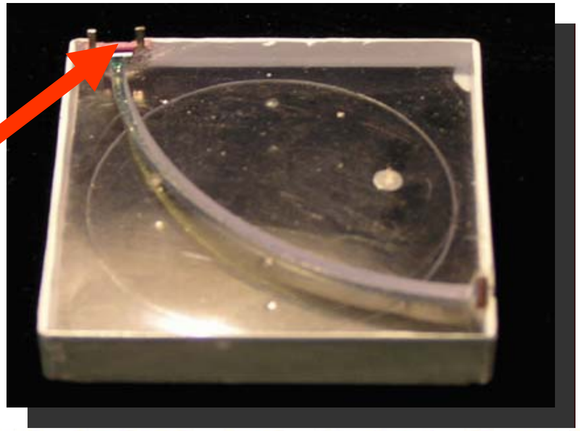
Δ E/E=16.69%/√E©1.09%

Analogue HCAL

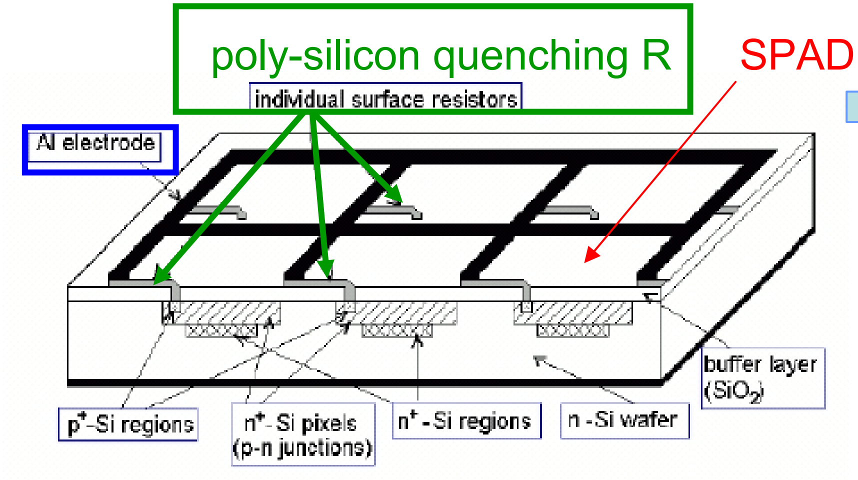
- Absorber
  - **38 layers of steel, 2 cm thick**
  - **4.5 λ_{int} in total**
- Active element
- **Scintillator tiles 3x3 – 12x12 cm^2 with embedded WLS fibres**
- **Multi-pixel Geiger mode photo-diodes (SiPMs), B-field proof, small, affordable, integrated**
- Read-out by ASIC
- **2 gains (normal, calibration)**
- **HV settings for SiPMs**
- **Shaping and multiplexing**
- **Power consumption 200 mW/5 V**
- Calibration and monitoring by LED flashes, Temp recorded
- In beam since 2006







Array of Single Photon Avalanche Diodes



I will refer to one SPAD as pixel in the following

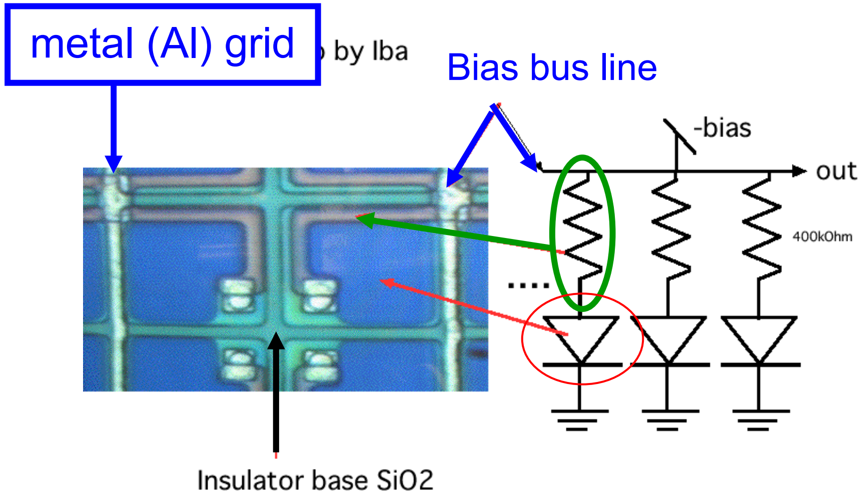
➔ typically 100-1000 pixels / mm²

Some typical pixel parameter:

-pixel size ~20-30 mm

-pixel capacitance C_{pixel} ~ 50 fmF

-quenching resistor R_{pixel} ~ 1-10 MΩ



all pixels connected in parallel

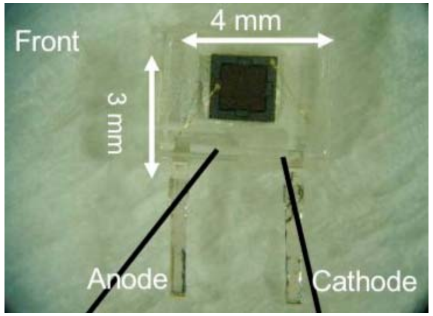
only one signal line

➔ output = Σ pixel signals

typical Bias voltage ~ 2 V above breakdown

Many different names / and different products

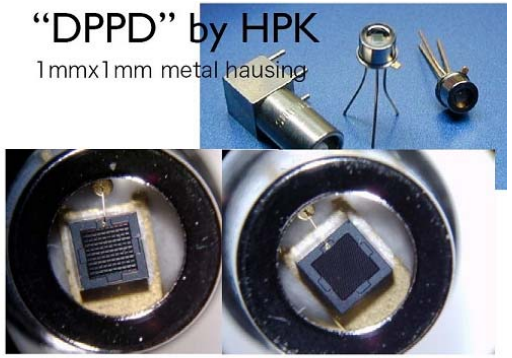
MPPC from Hamamatsu, Japan



Available on Hamamatsu catalogue

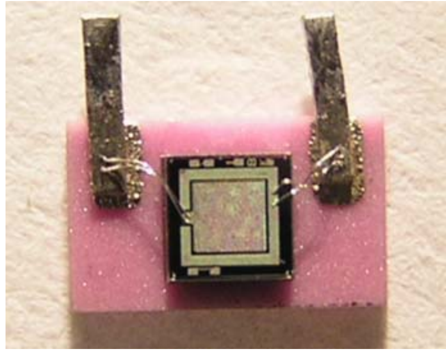
“DPPD” by HPK

1mmx1mm metal hausing



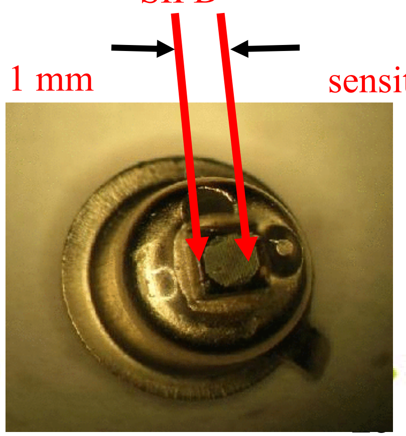
10x10=100pixels 20x20=400pixels

SiPM from MEPHI / PULSAR, Moscow



Short disclaim:
using the name SiPM I will refer to multi-pixel avalanche photo-diodes operated in Geiger mode

SiPM-CPTA from Photonique, Switzerland



AMPD from Z. Sadygov, Moscow

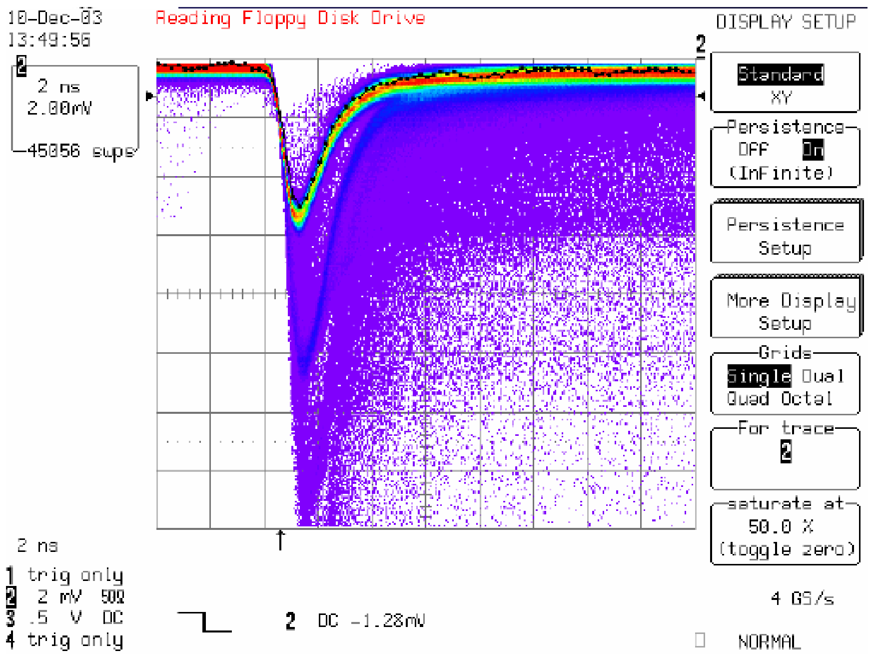
GMPD from INR/JINR, Moscow

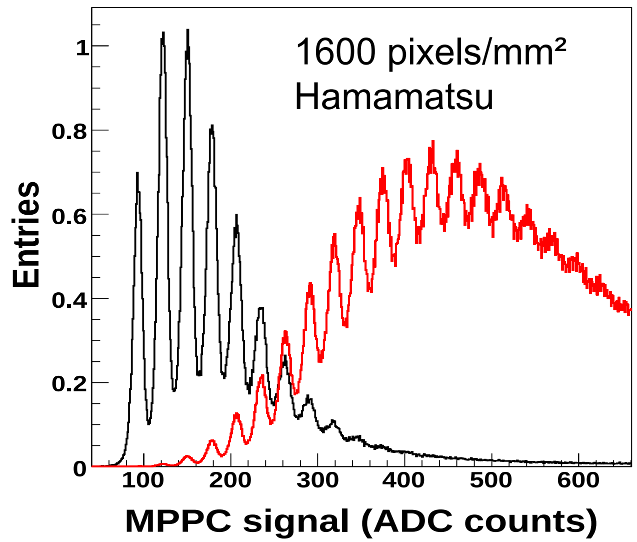
“SiPM” from SENSL, Irland is coming…

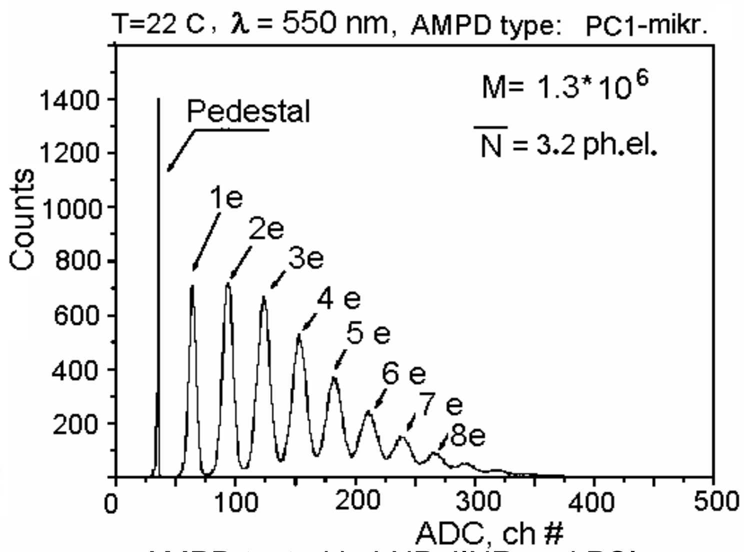
… and many others

SiPM properties: single pixel resolution

SiPM output is the analog sum of all pixel signals







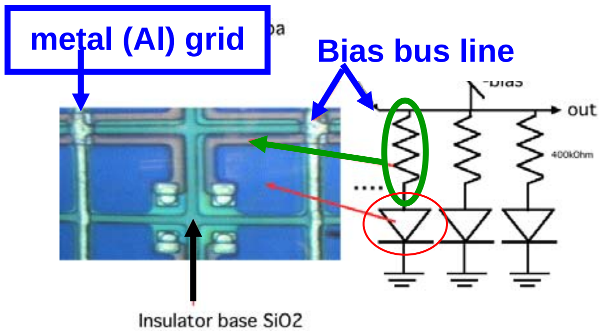
AMPD tested in LNP JINR and PSI

high gain ➔ pixel signal visible on scope
- signal rise time < 1 ns
- fast fall ~ 5-10 ns

recovery time tunable by choice of quenching R

$\tau \sim R_{pixel} C_{pixel} \sim 20 – 500$ ns

Dynamic range



➔ output = Σ pixel signals

output ≤ total N pixel

Dynamic range naturally limited by number of pixels

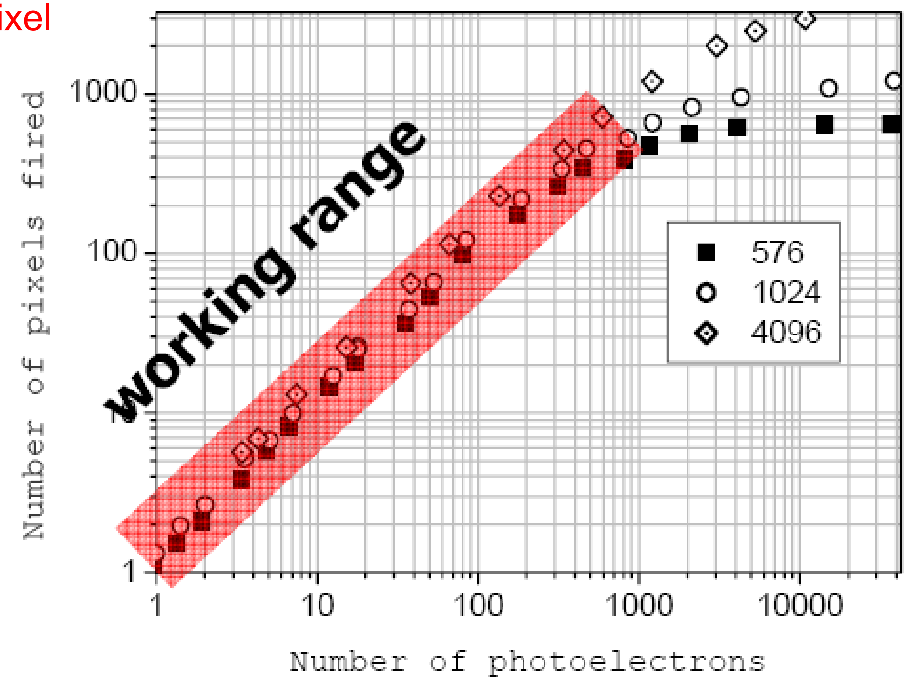
Optimal working condition:
number of photo-electrons < N pixels

from probability considerations:

$$N_{pixels} = N_{available} \cdot \left[1 - e^{\frac{N_{photo\text{-}electrons}}{N_{available}}} \right]$$

$N_{available}$ = total number of pixels in a SiPM

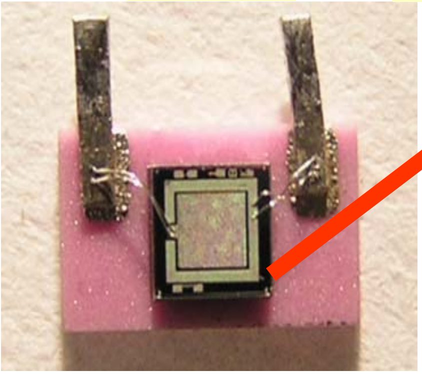
Measured on SiPM MEPHI/Pulsar, from B. Dolgoshein



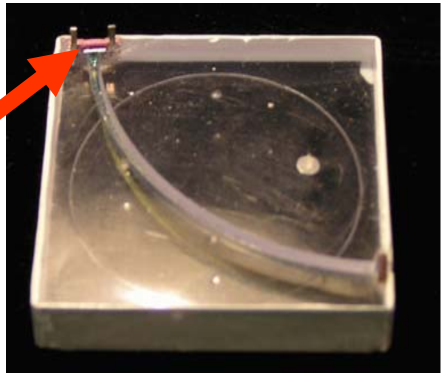
~20% deviation from linearity if 50% of pixels are fired

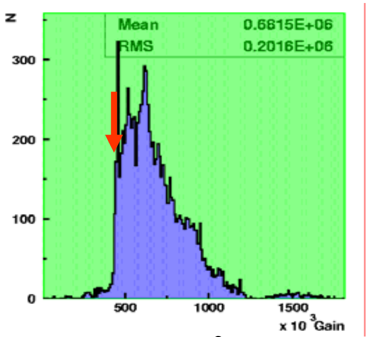
Silicon "photomultiplier" in AHCAL

SiPM

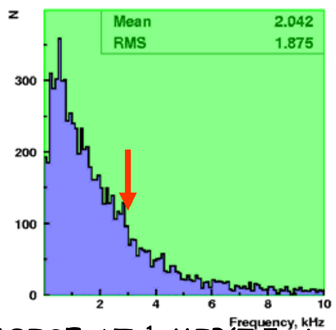


Tile 3x3 cm^2,WLS fiber,SiPM

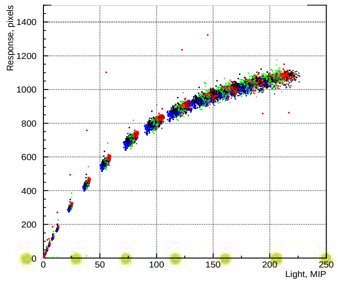




GAIN /10^3



NOISE AT ½ MIP(7.5 pixels)



SATURATION CURVE

Limited dynamic range due to limited number of pixels ⇒ saturation at $N\gamma \sim N_{pixels}$

SiPM properties

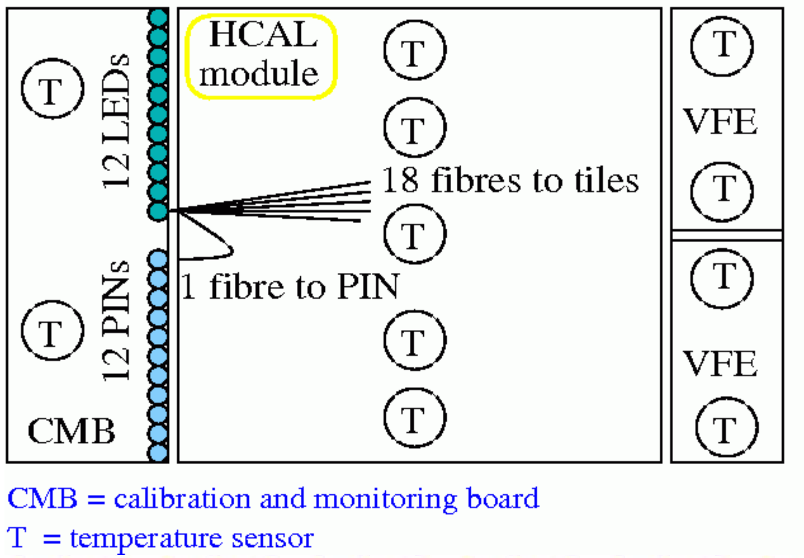
- Sensitive area - 1x1 mm^2, Matrix of 1156 (34x34) pixels operating in Geiger mode
- A fired pixel gives $\Delta Q = \Delta U \bullet C$
- Net signal ~ number of detected photons
- Light registration efficiency = QE(~80%) x ε_{Geiger}(~60%) x ε_{geom}(~35%) ~ 17%, max for green light
- First massive use of SiPMs
- Producer PULSAR, Moscow in coll. with MEPhI, DESY
- Gain ~10^6 (ΔU~3 V, C~50 fF)
- Noise ~2 MHz, exp falls with threshold
- Optical inter pixel crosstalk <~ 0.3 restricted operation voltage
- Operational voltage 45-70 V
- Insensitive to magnetic field up to 4 T

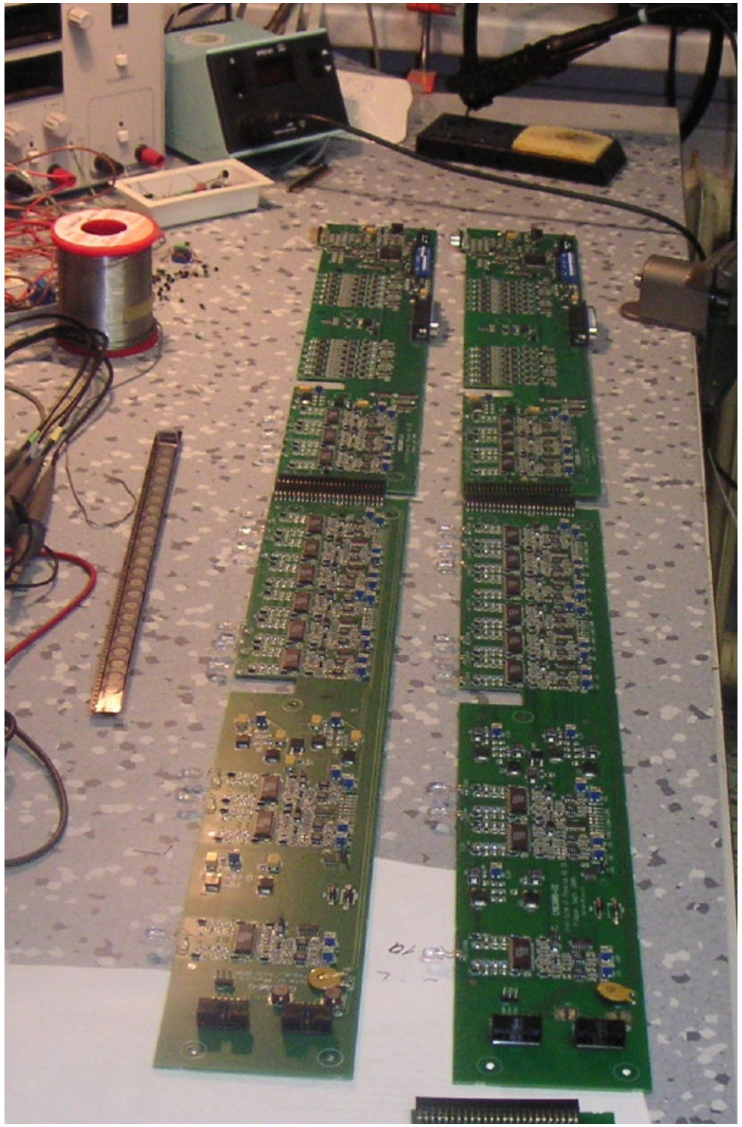
Calibration and monitoring system

Functionalities of the LED system:

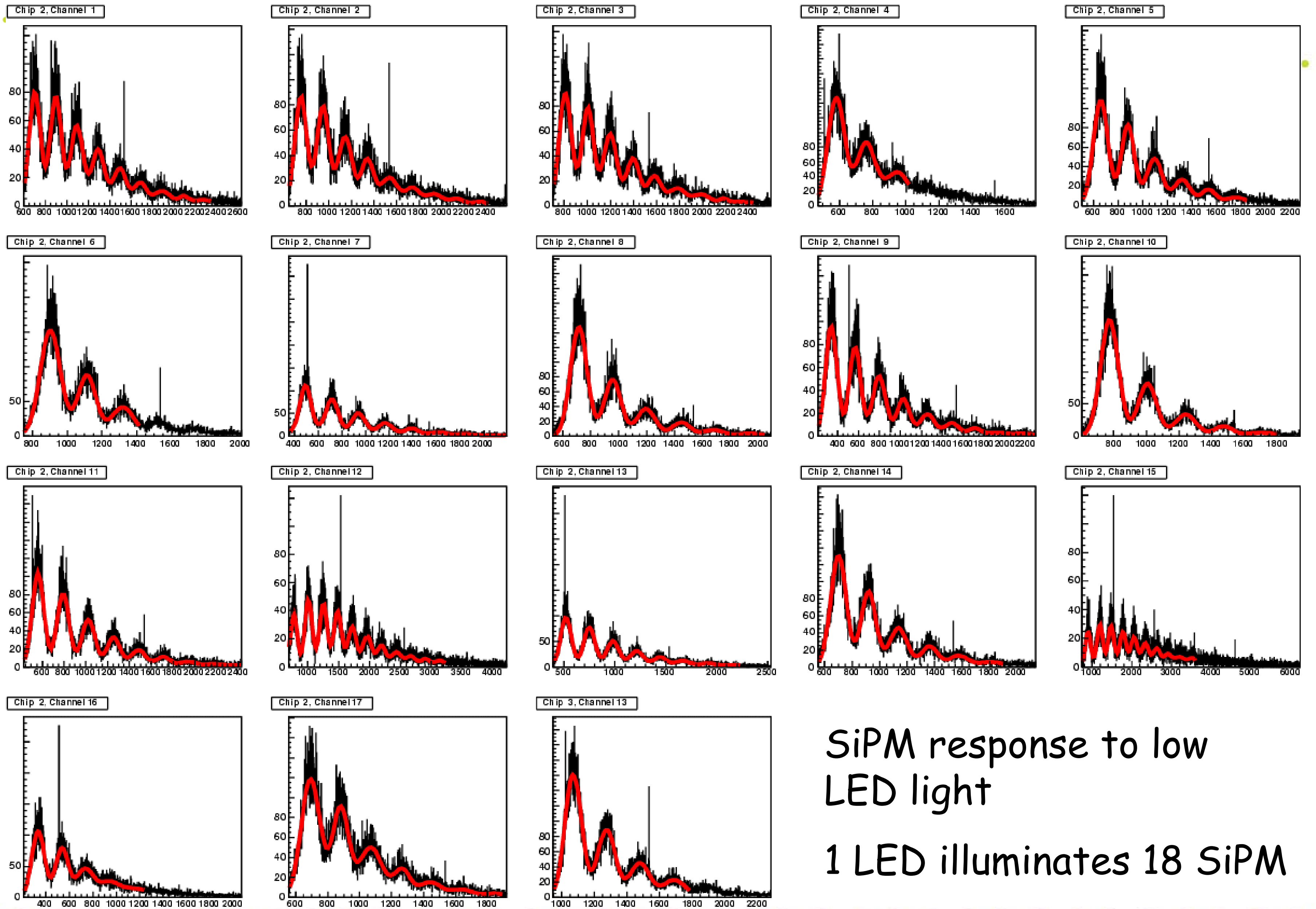
1) gain calibration at low intensity light
2) provide reference pulses monitored by PIN diodes
3) provide full dynamic range for checking the SiPM response function

Temperature monitored by temperature sensors





Run 201353 - LED 2 - SER013, Slot 12, FE3 - Entries vs. ADC channels

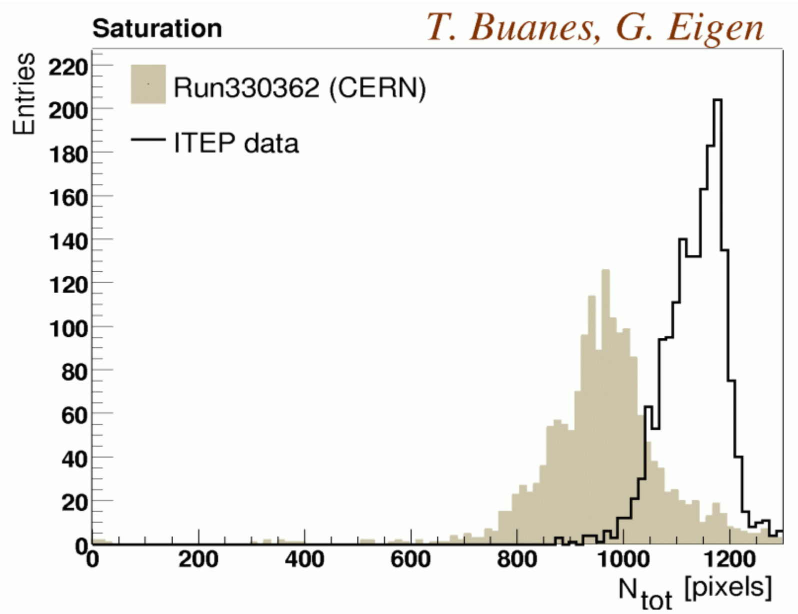


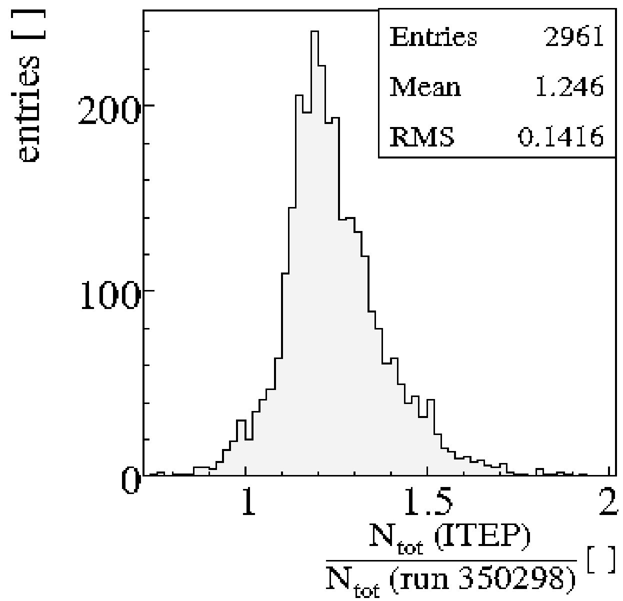
SiPM response to low LED light

1 LED illuminates 18 SiPM

Saturation correction

- Use simple model to describe SiPM response function: $N_{pixels} = N_{tot} \cdot \left[1 - e^{\frac{N_{p.e.}}{N_{tot}}}\right]$
- Compare ITEP and CERN measurements

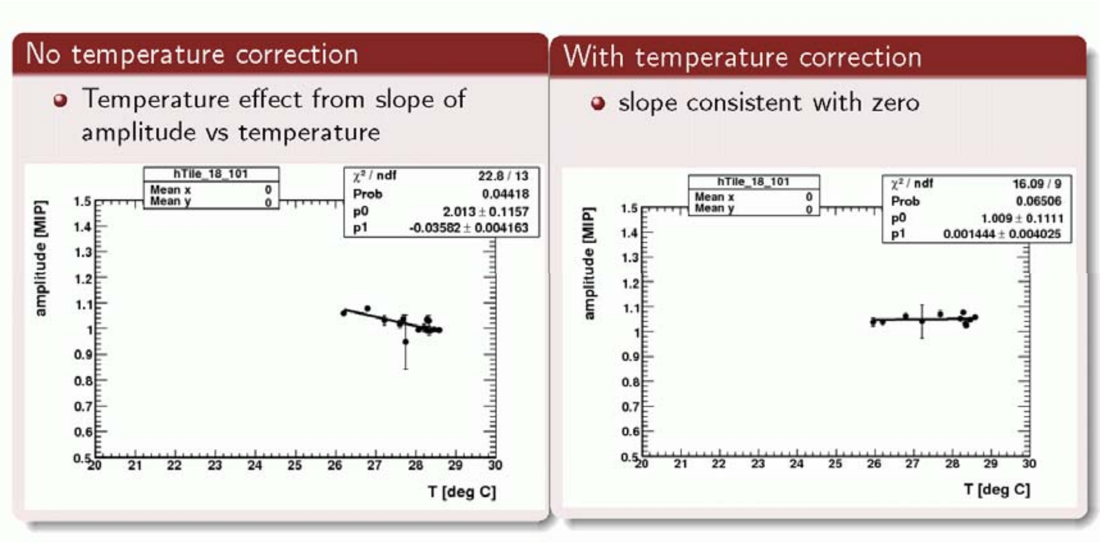




- Clear shift between N_{tot} from ITEP and CERN measurements (about 20%)
- Reason:
  - ✓ fibre does not illuminate whole SiPM
  - ✓ less effective pixels contributing to light detection

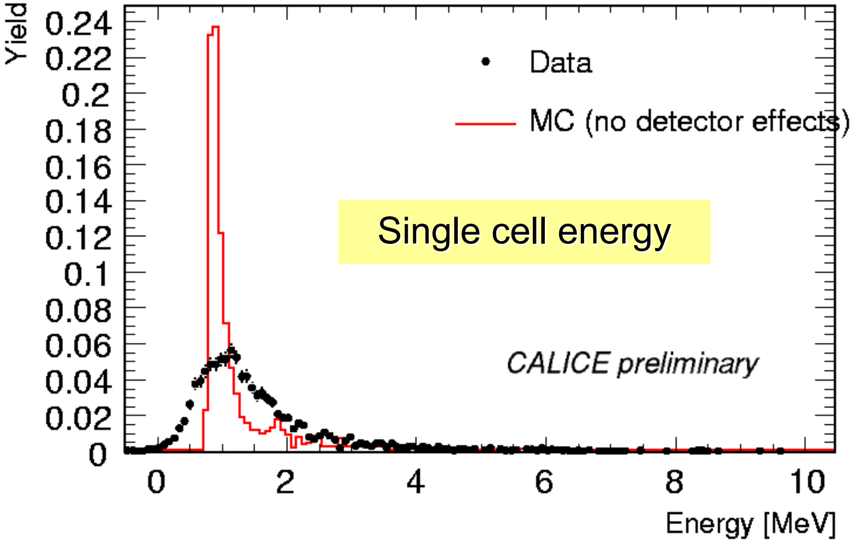
Temperature correction

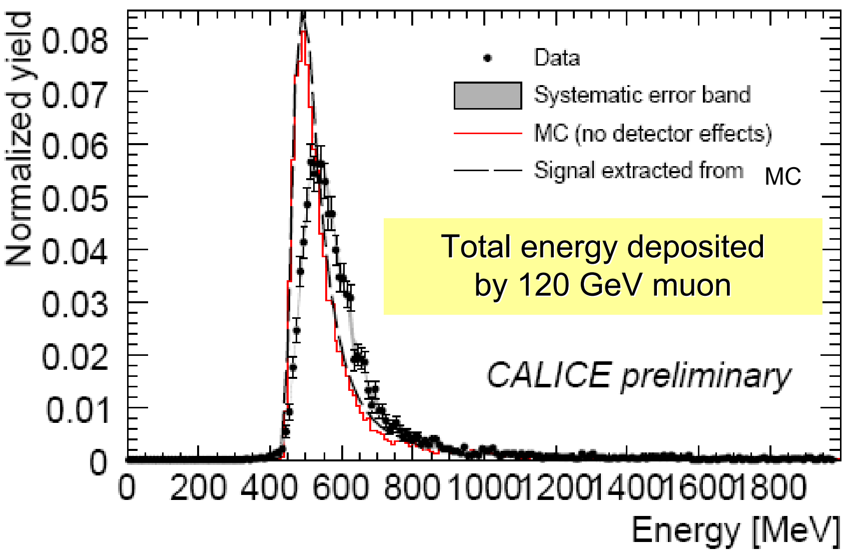
- Aim: correct the effects of temperature changes of the SiPM gain



The calibration and monitoring system proved its justification during 2006-8 data taking campaign – DESY, CERN, FERMILAB

Muon response of AHCAL





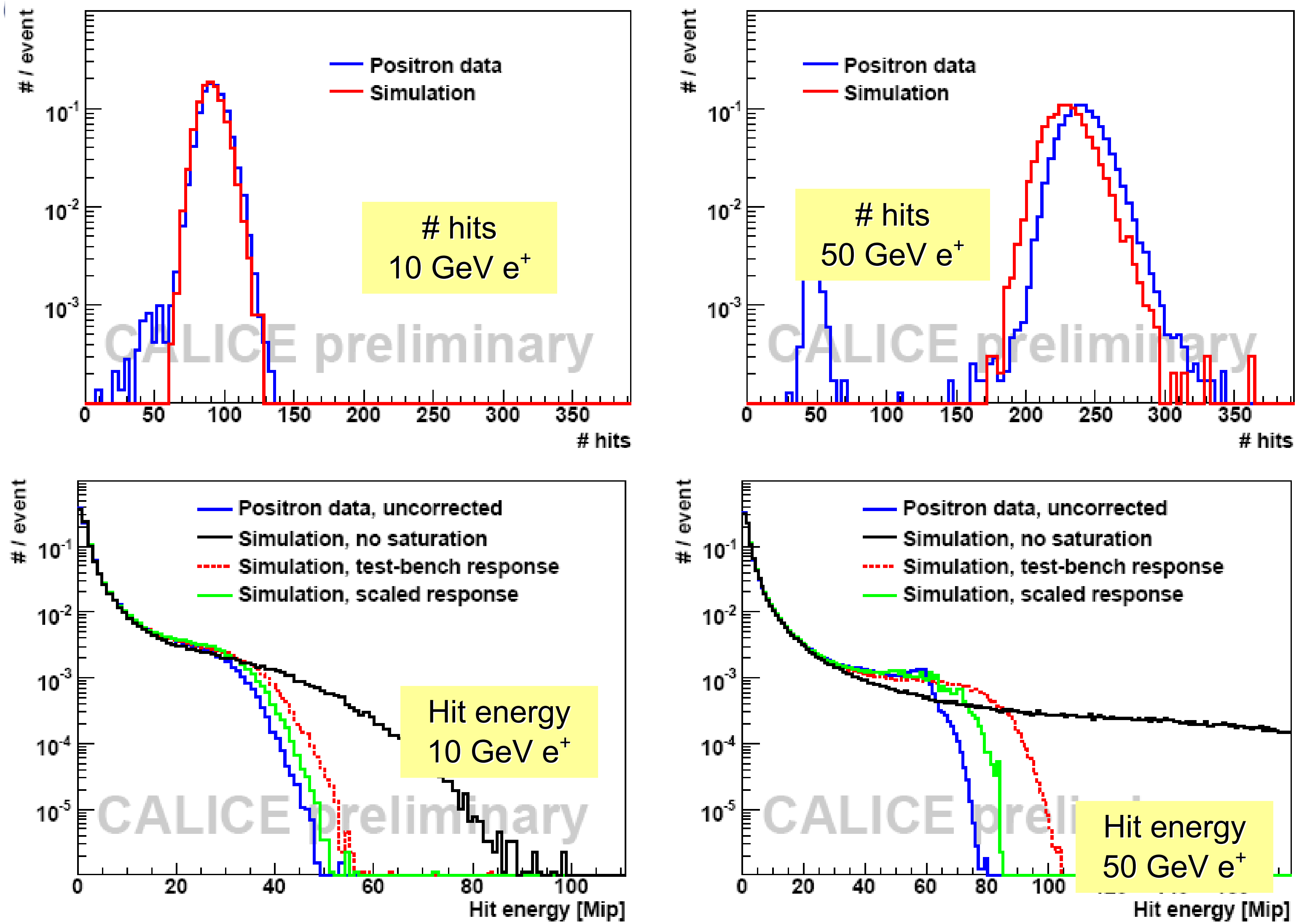
Considered in MC digitisation:

- Signal leakage to neighbours (global factor only)
  - Non-linear response (response curves and calibration constants)
  - Pixel statistics
  - Energy scale (calibration constants)
  - Dead/uncalibrated channels

Not (yet) considered, but likely to be significant:

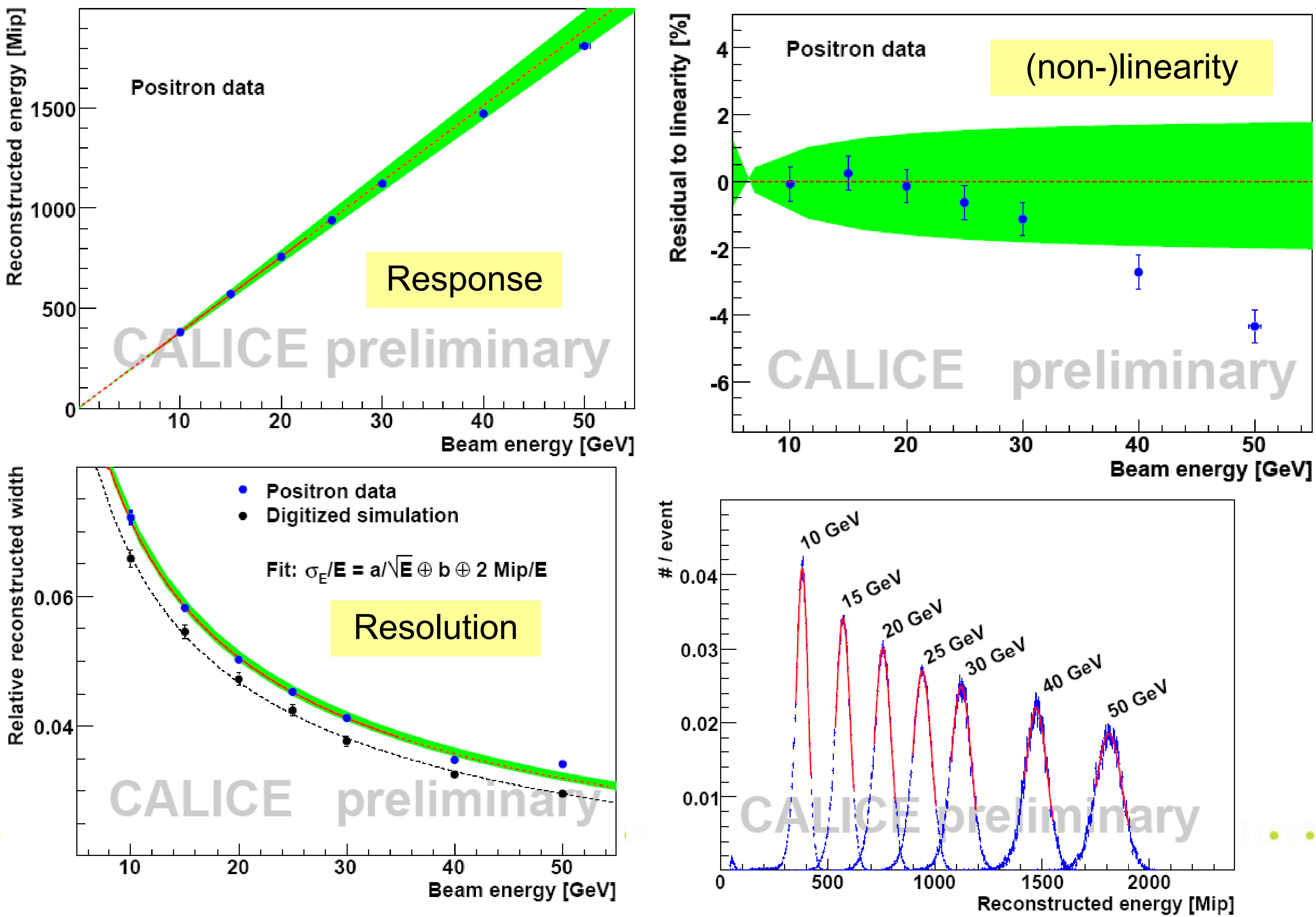
- Birks' law in simulation
- Tile non-uniformity (edge effects)

Positron response of AHCAL

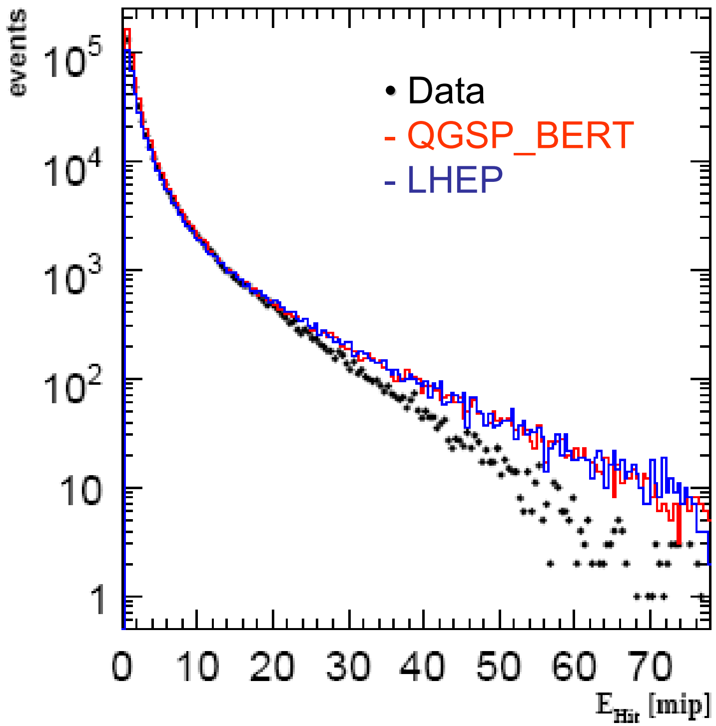


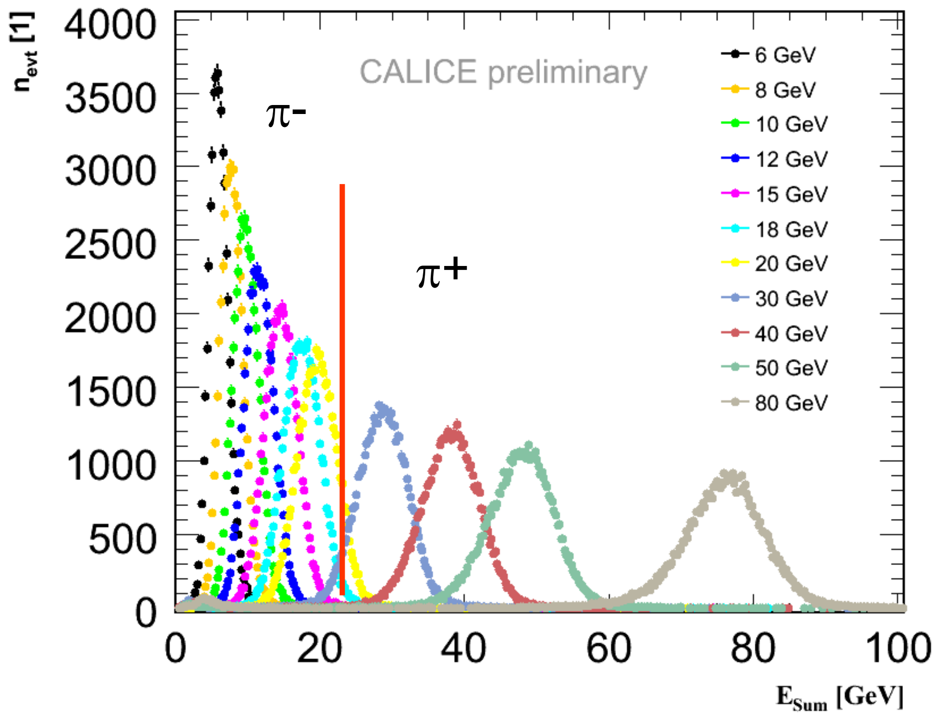
Still some discrepancies between data and MC, especially at higher energies.

Positron response of AHCAL



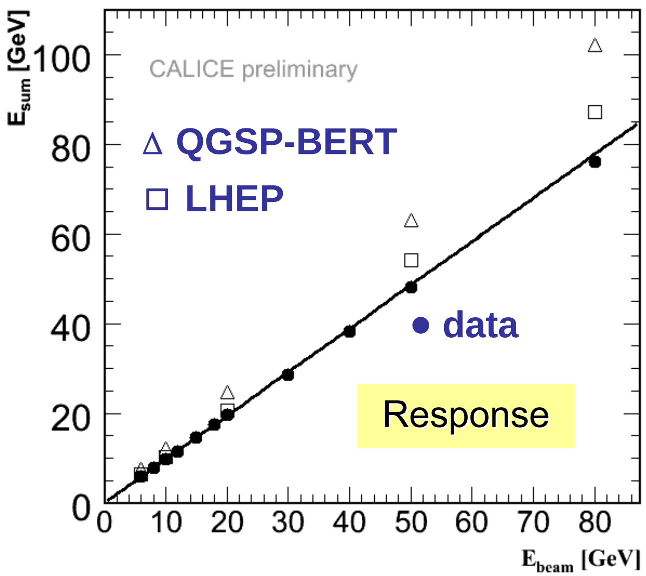
Pion response of AHCAL

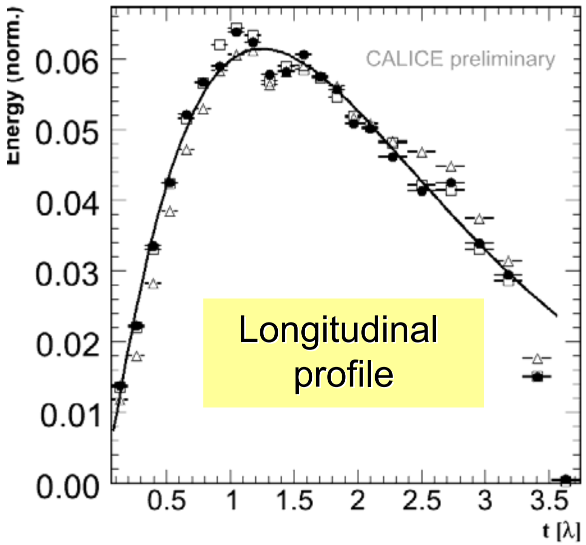


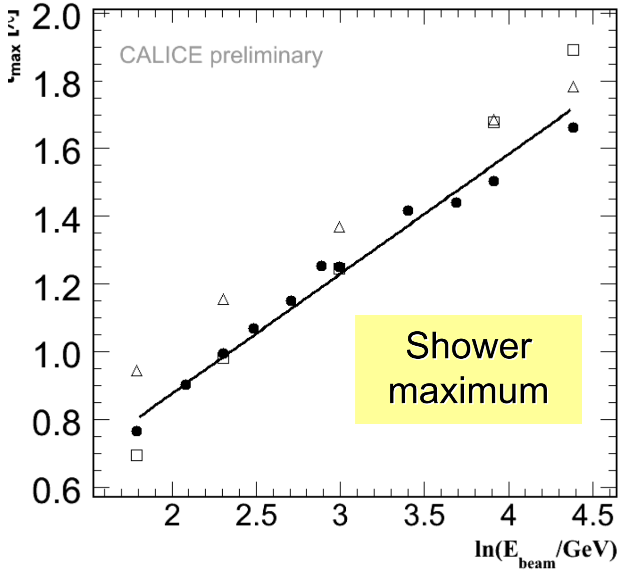


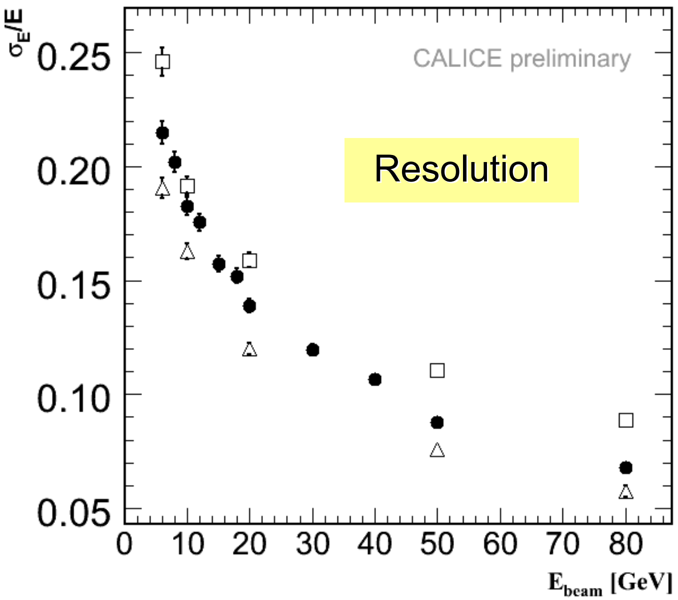
- Hit energies typically much lower than in e^+ showers
- Hence saturation corrections less critical, but simulation of data still imperfect.
- Comparisons with MC models should be regarded as provisional.

AHCAL – pion response, c.f. MC





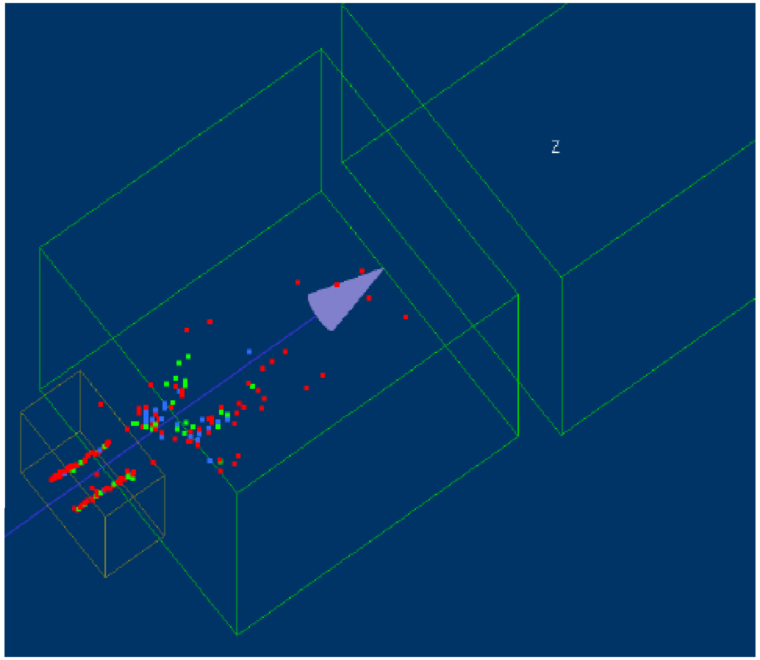


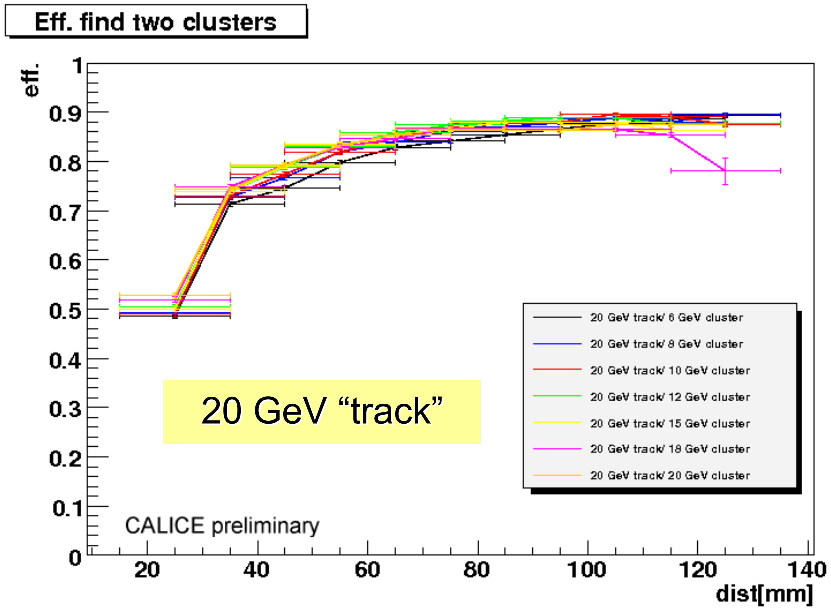


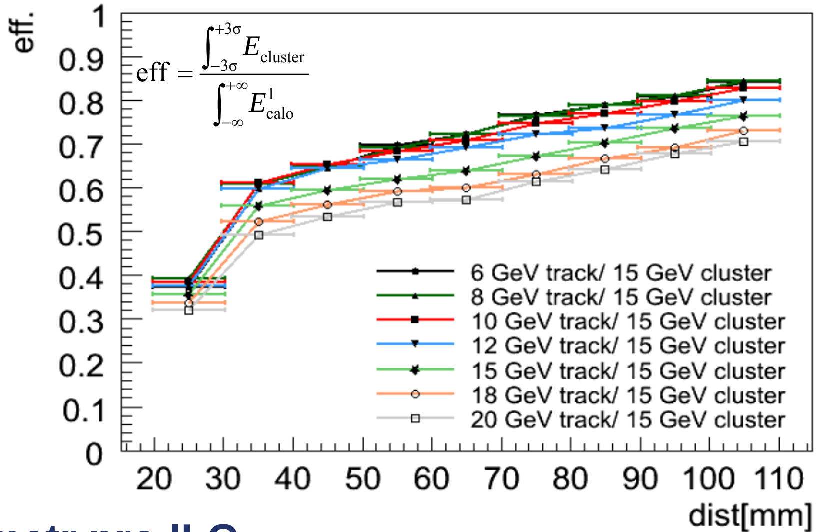
Compare two (extreme?) models with data

- Both models give reasonable trends.
- On this basis, probably LHEP seems slightly favoured over QGSP_BERT (¼ LCPhys)
- But both (or the data) have deficiencies.
- Too early to draw firm conclusions

Two shower separation





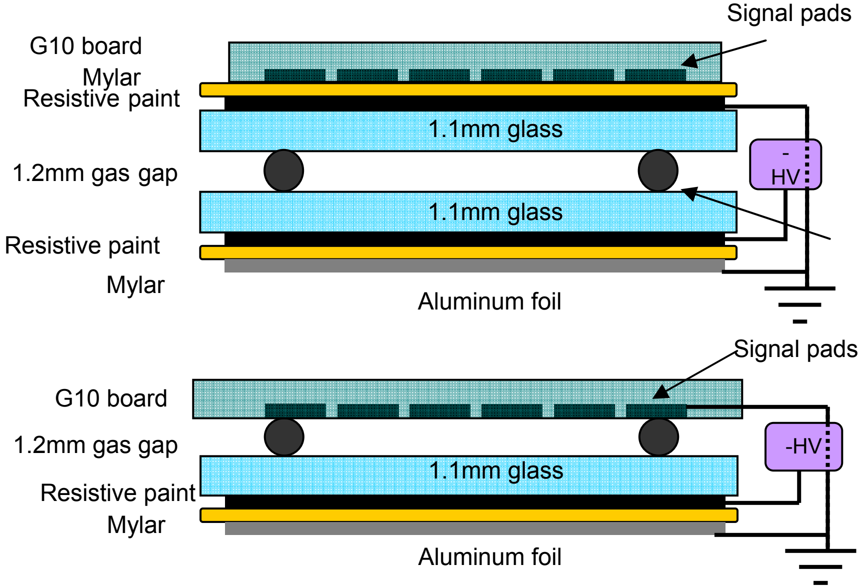


- Superimpose pairs of data pion events taken at two different energies up to 10 cm separation.
- Pretend one is charged, one neutral.
- Apply track-like particle flow.
- Look at separation between particles' energy.
- More will be done along these lines…

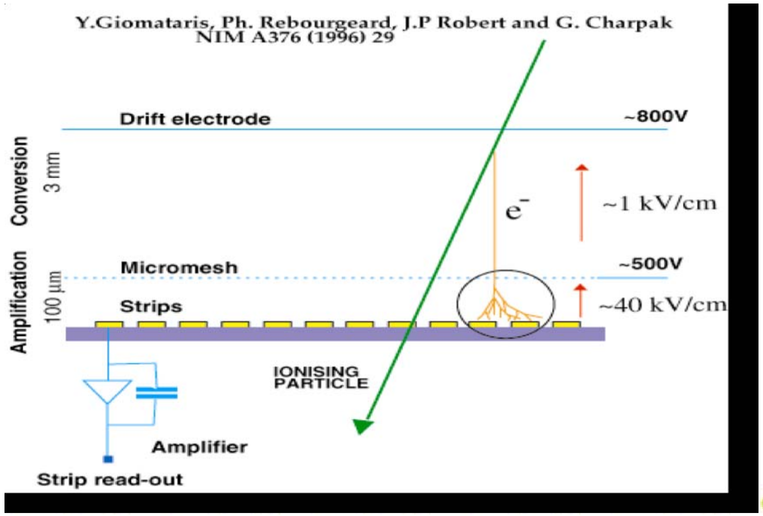
Digital HCAL concepts

- Digital or semi-digital HCAL – 1 cm^2 pads
- Gas detector readout – different technologies investigated:

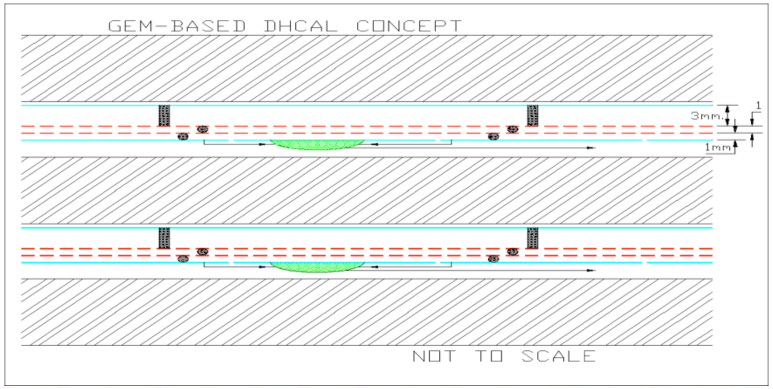
RPCs



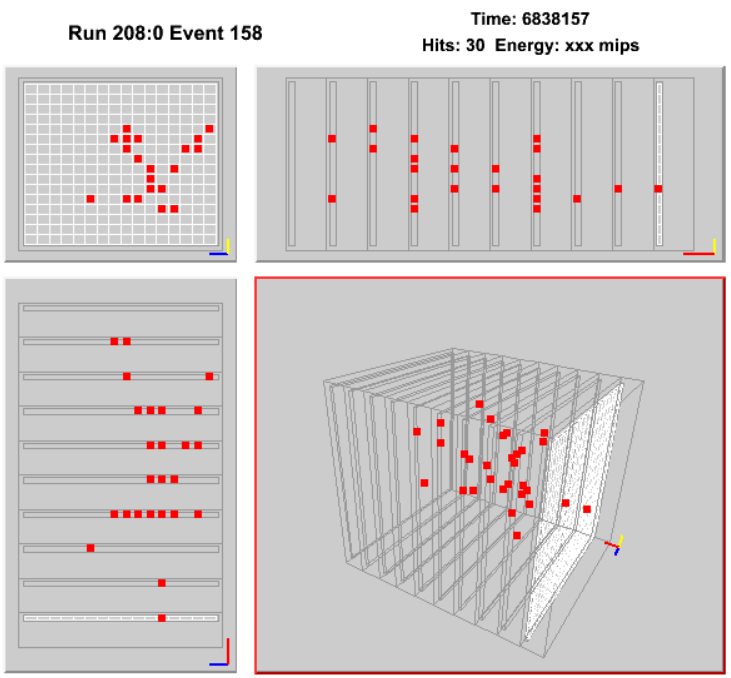
MicroMegas

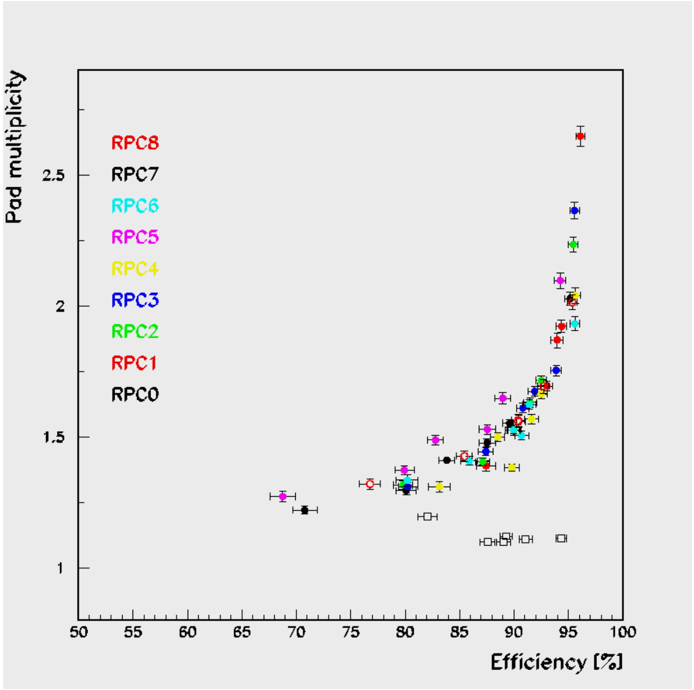


GEMs



RPC - DHCAL results





A pion shower

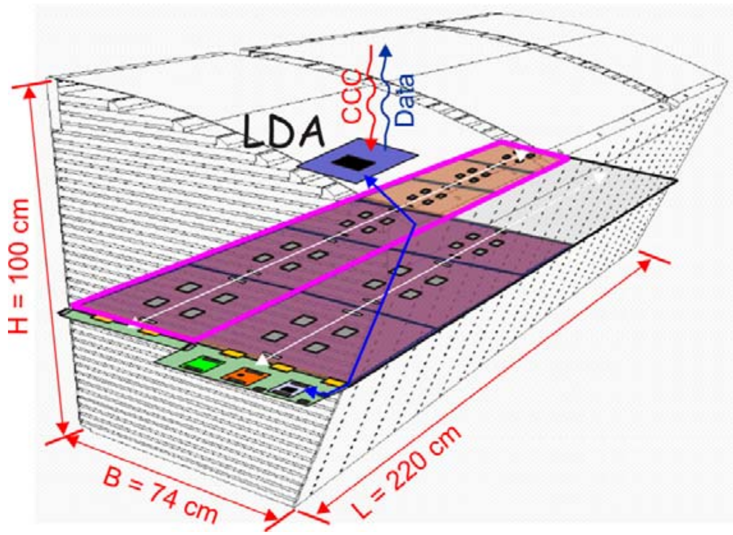
Muon beam – pad multiplicity vs efficiency

Noise measurements – observed especially around the fishing line spacers. At the default setting the rate measured ~ 0.1 Hz/cm^2

Near future

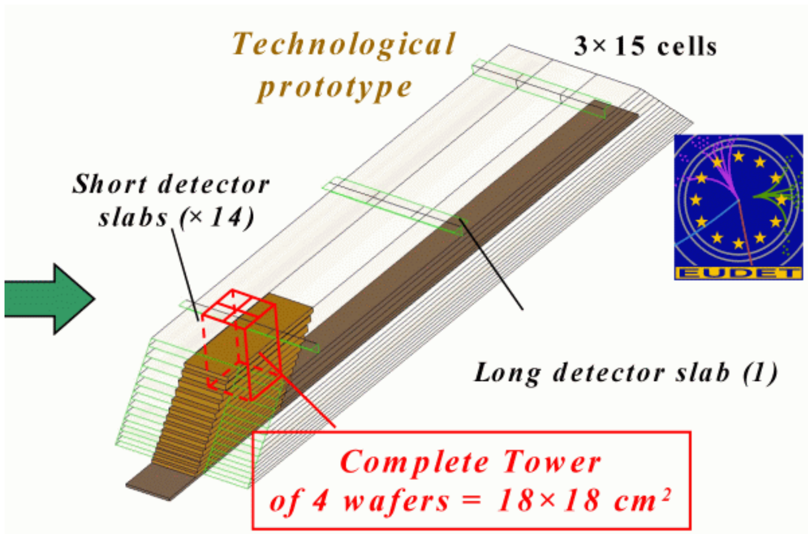
AHCAL (scint + stainless steel)

- A compact design with integrated sensors and electronics (1/16 barel)
  - **embedded electronics and calibration system for minimal dead zones**
  - **thin readout gap (9 mm)**
  - **ASIC with integrated ADCs**



ECAL (SiW)

- study and validation of most of technological solutions which could be used for the final detector (moulding process, cooling system, wide size structures,…) and taking into account industrialization aspect of process
- First cost estimation of one module

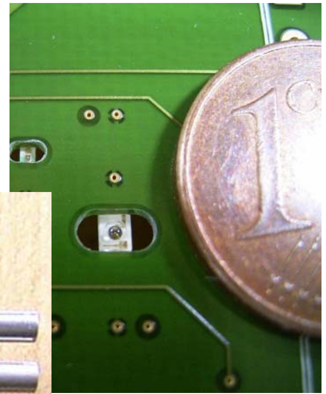


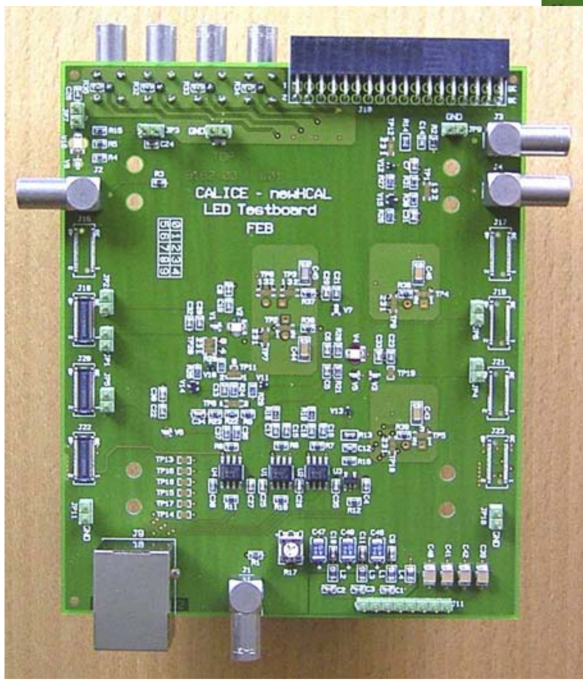
Other concepts will use existing absorber frame to test prototypes

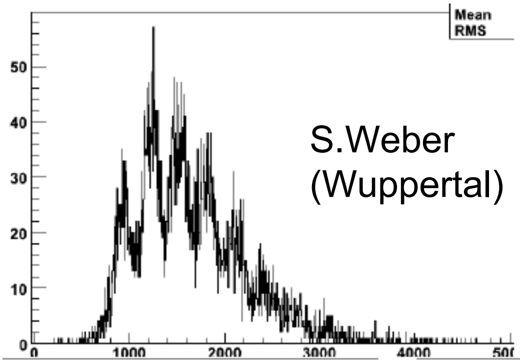
Calibration 1: embedded LEDs

- electronic signal distribution
- tested, no cross-talk to sensors seen
- To be optimized: dynamic range, LED uniformity
- Followed up by Wuppertal group (non-EUDET)

M.Reinecke (DESY)

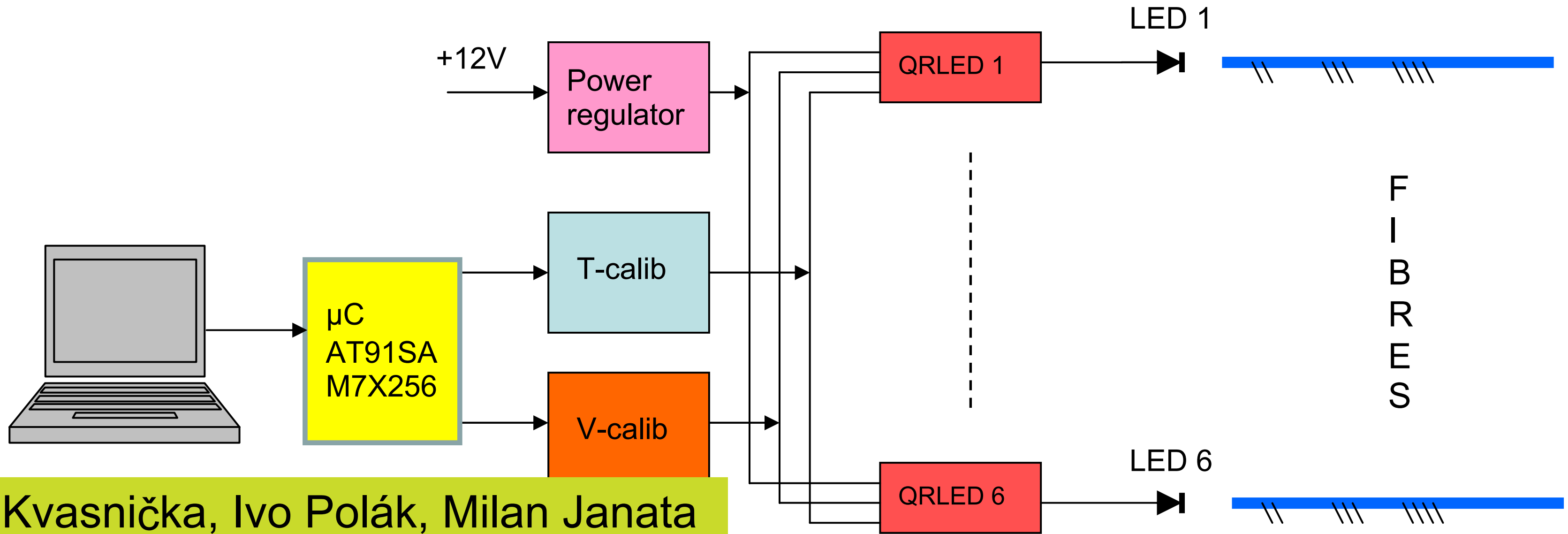






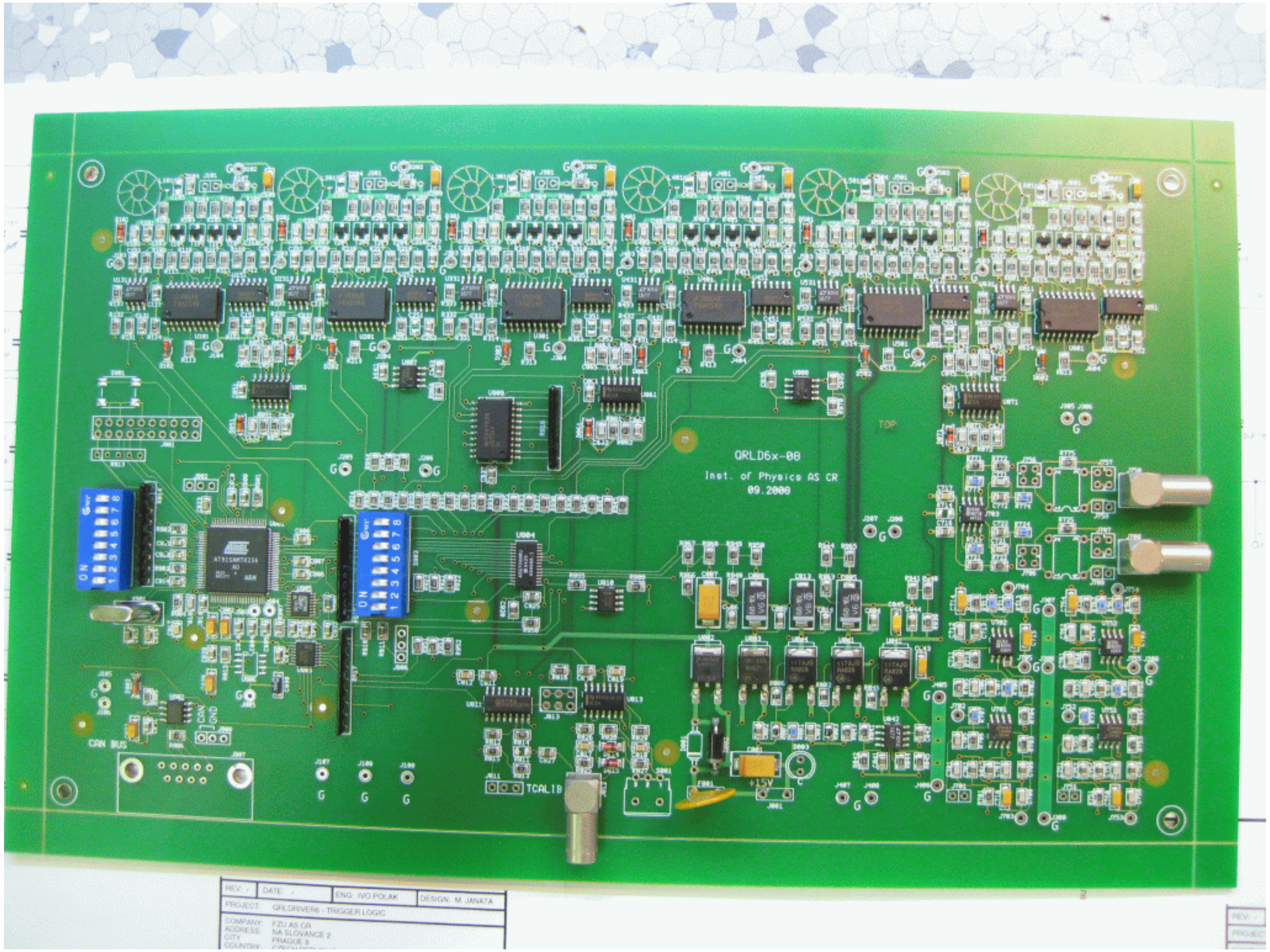
Calibration 2: Multichannel LED driver

- 1 PCB with the communication module μC, power regulator, 6 channels of QRLed driver
- The communication module communicate with the PC via CAN bus or I2C
- The communication module controls the amplitude, LED Enables, and it monitors temperature and voltages
- LED pulse width is ~ 5 ns fixed, the tunable amplitude in range up to 50-100 MIPs is controlled by the V-calib signal
- 2 LEDs can be monitored by a PIN photodiode



Jiří Kvasnička, Ivo Polák, Milan Janata

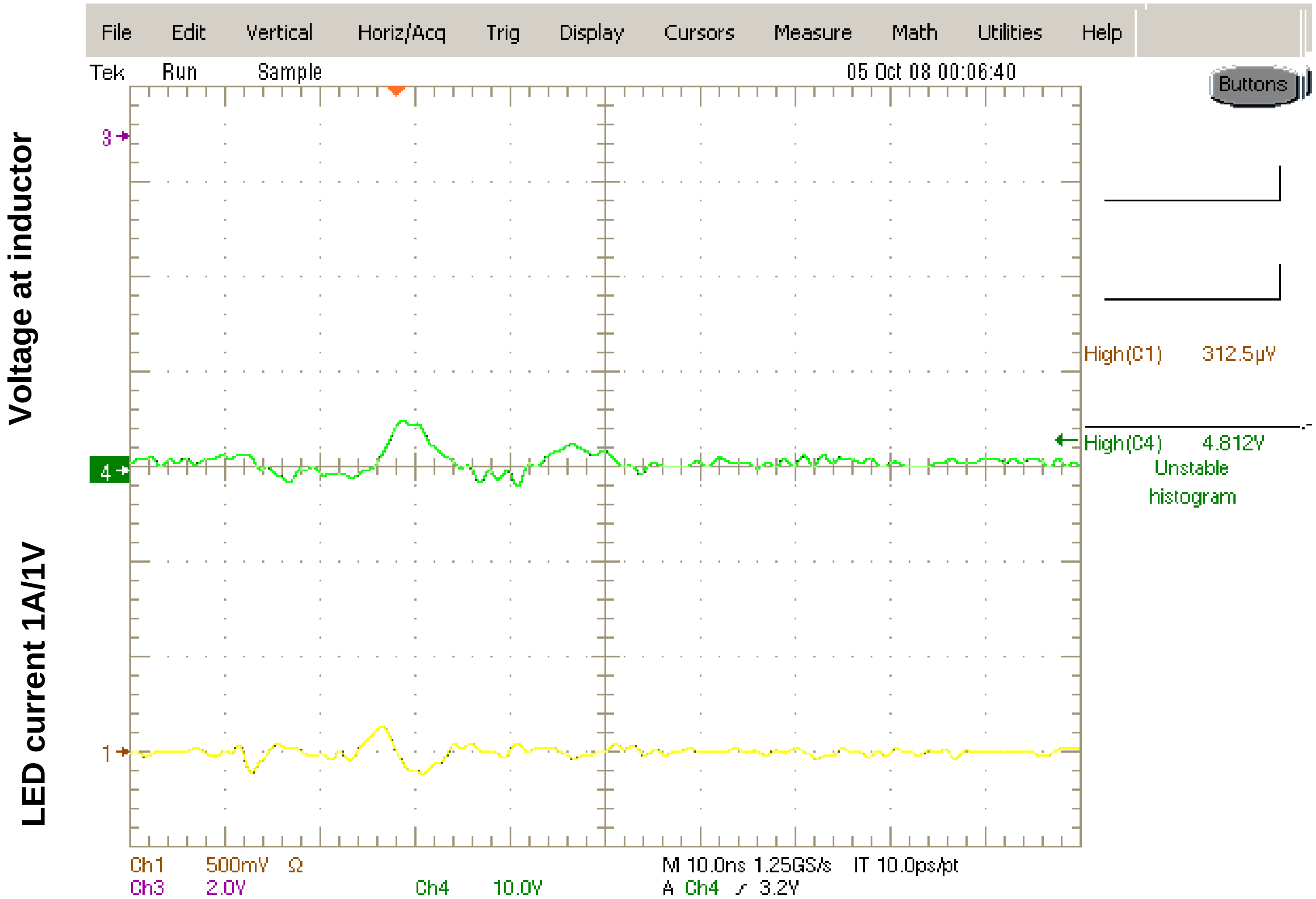
6-LED QR driver board



Consists:

- 6 QR LED drivers
- 2 PIN PD preamps
- CPU + comm module CANbus
- Voltage regulators
- temperature and voltage monitoring

Oscillograms of LED current



Development of the optical system

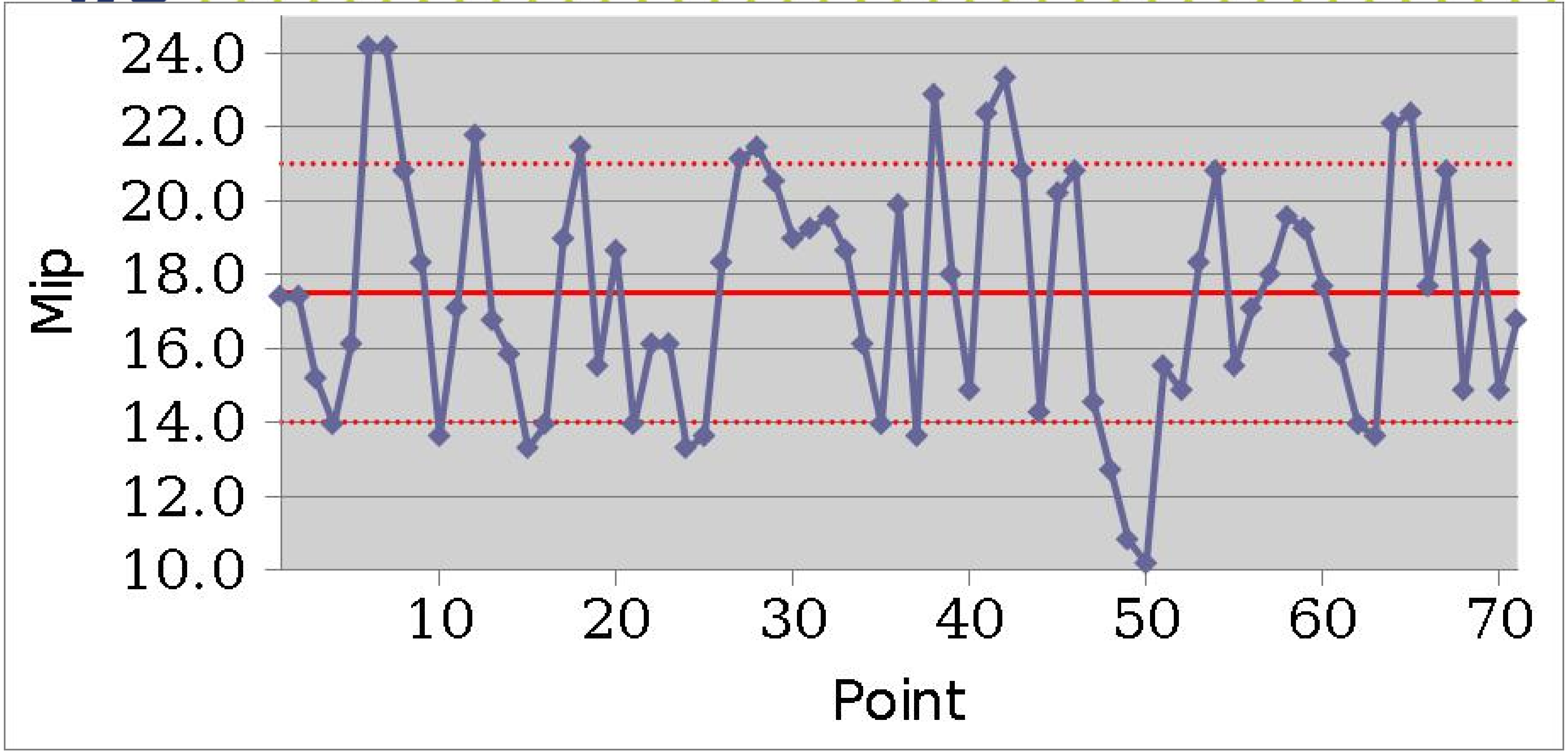
Idea: use one fibre for one row of tiles

Problems:
- uniformity of distributed light
- enough intensity of distributed light
- concentration of LED light into one fibre

Two fibres:
- Side-emitting (FiberTech SLS600 series)
  - exponential fall of intensity
  - possibilities to buy at market
- Notched fibre (manually produced by Safibra comp.)
  - better uniformity of distributed light
  - need to mechanize production - R&D

Jaroslav Zálešák, Jan Smolík

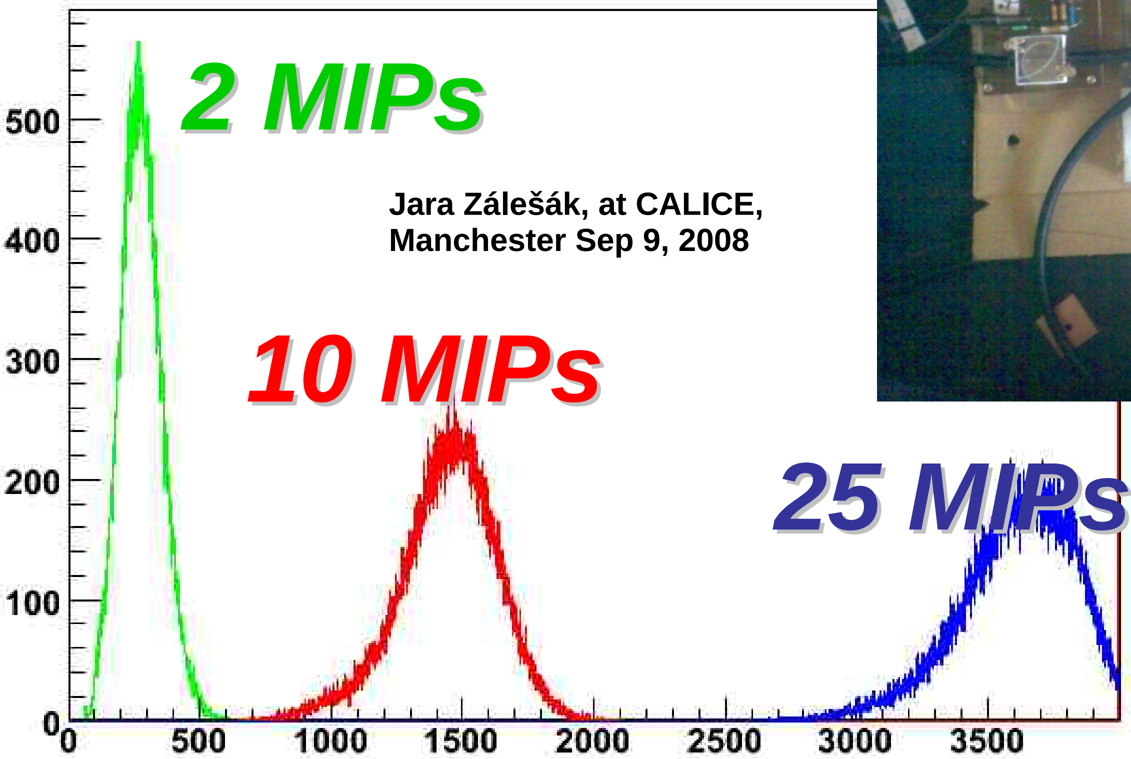
Notched fiber prototype #3

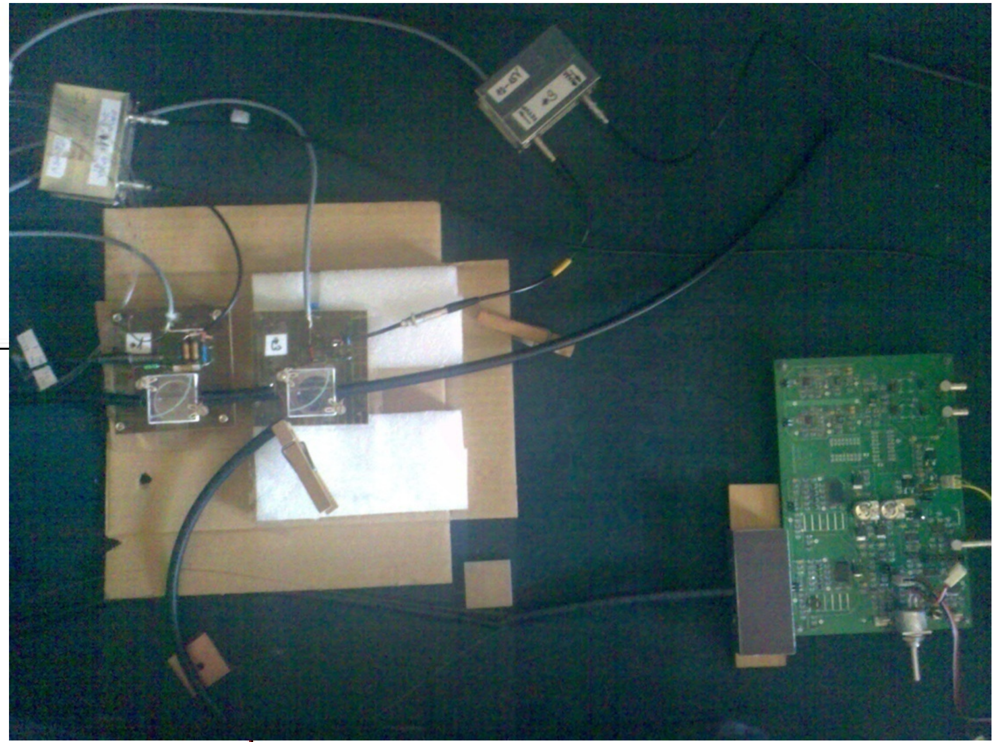


- Light output from fiber via notches uniform over all 70 points
- Approaching ±20% proposed limit of light variation
- New (better) notched fiber is expected soon

Optical X-talk on LED light

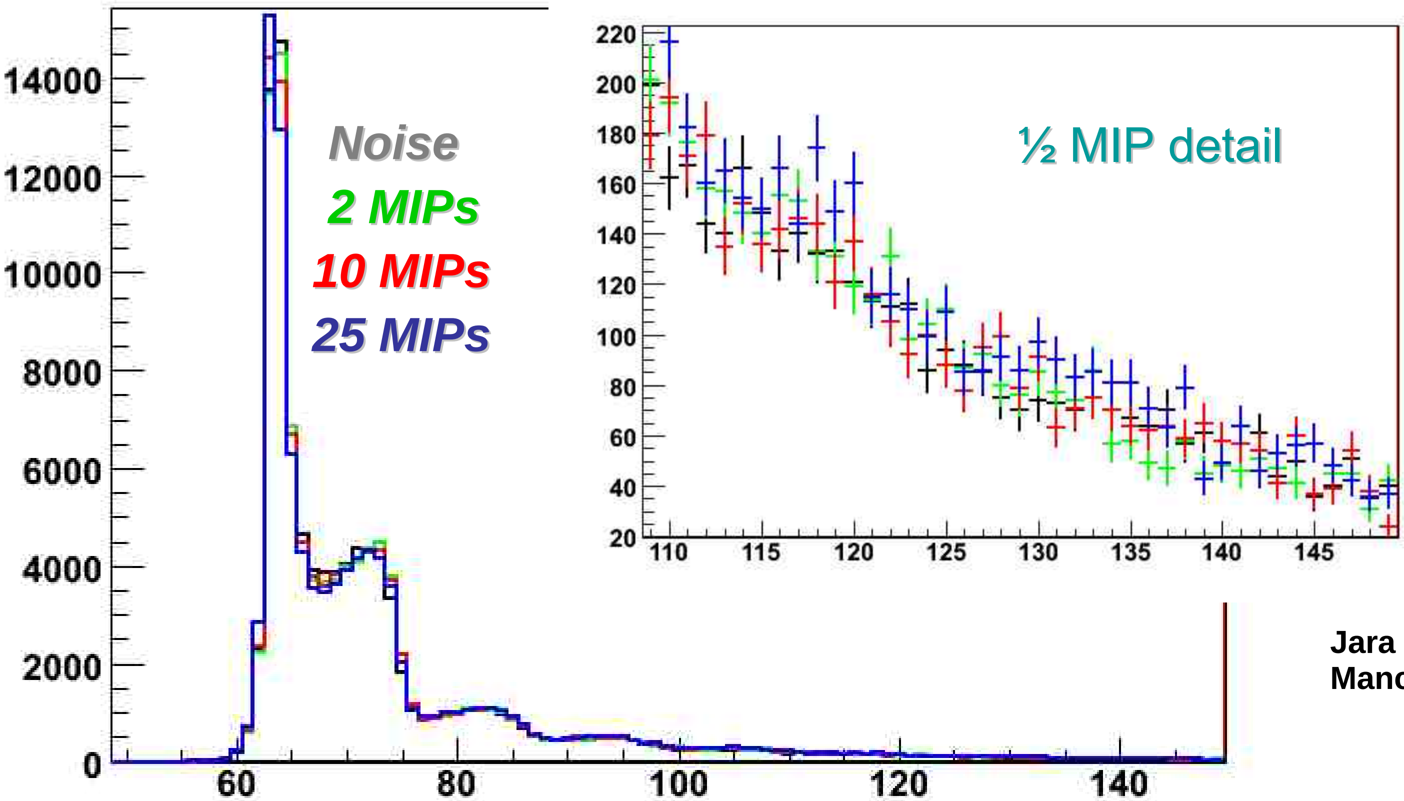
- more light to tile (up to 25 Mips)
- not particle but tunable amplitude
- better triggering





- LED light to SiPM1
- notched fiber SiPM 1→2
- at length of 9 cm
- ½ MIP on position 135

Optical X-talk on LED light - results



Jara Zalešák, at CALICE, Manchester Sep 9, 2008

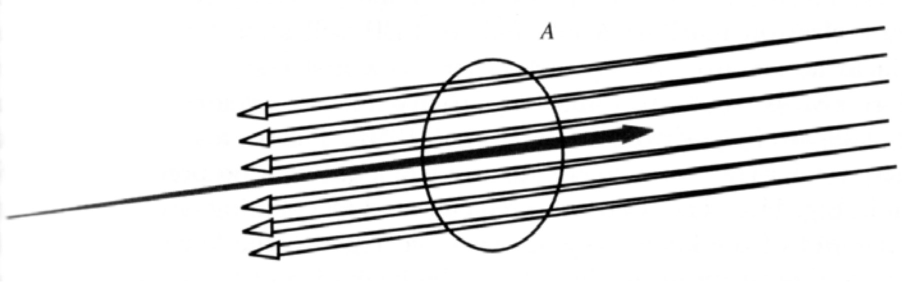
- No differences in response from various amplitudes
- No optical X-talk visible for large amount of light in tile
- No dependence on chosen pair of notches
  and light input direction

Na závěr

- Aktivity kolem ILC a detektorů jsou celosvětové a dobře koordinované
- Koncem března 2009 budou dokončeny ‚Letter of intent' ILC detektorů (očekávají se projekty 3 detektorů)
- R&D pro kalorimetry je nejvíce rozpracované a probíhá za aktivní účasti pražských pracovišť
  - **Prototyp ECAL dává očekávané výsledky**
  - **AHCAL používá nový fotodektor – SiPM (7500 ks)**
  - **Projekt a realizace tzv. technických prototypů v l. 2009-10**
  - **Podpora ze strany EU do r. 2010**
- V r. 2012 rozhodnutí o stavbě ILC v závislosti na výsledky LHC

BACK UP

Luminosita *L*



Luminosita je důležitou charakteristikou urychlovače

$$N = \varepsilon \sigma \int L \mathrm{d}t$$

N – počet zajímavých fyzikálních případů
ε – akceptance – schopnost detektoru zaznamenat
σ – účinný průřez fyzikálního procesu (cm^2)
L - luminosita urychlovače ($cm^{-2}\, s^{-1}$)

Jak dosáhnout velké luminosity urychlovače?

$$L = \frac{N_1 N_2 f}{W_x W_y} = \frac{N_1 N_2 f}{2\pi\left(\sigma_1^2 + \sigma_2^2\right)} = \frac{N_e^2 f}{4\pi\sigma_x\sigma_y}$$

N_i – počty částic ve shluku
f – počet shluků/sek
W – charakterizují profil svazků
σ_i – v případě gauss. profilu

Pro dosažení velké luminosity – potřeba dosáhnout minimálního průměru svazků – σ_1, σ_2 co nejmenší

Luminosita dnešních urychlovačů?

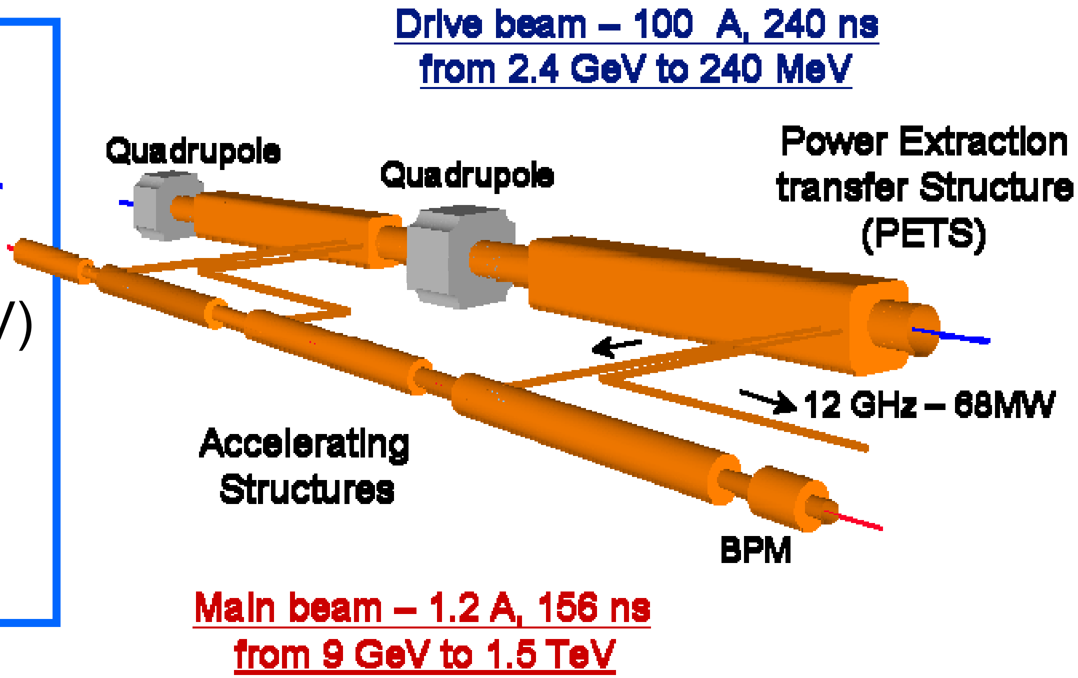
urychlovač	Energie(GeV)	Svazky	L ($cm^{-2}s^{-1}$)
SLC, SLAC, Kalifornie	50 + 50	$e^+ e^-$	8×10^{29}
LEP, CERN, Ženeva	90 + 90	$e^+ e^-$	3×10^{31}
HERA, DESY Hamburk	27 + 920	$e^\pm p$	2×10^{31}
Tevatron, FNAL, Illinois	1000 + 1000	$p \bar{p}$	$2{,}5 \times 10^{31}$
LHC, CERN, Ženeva	7000 + 7000	p p	3×10^{34}
ILC, ???	250 + 250	$e^+ e^-$	3×10^{34}

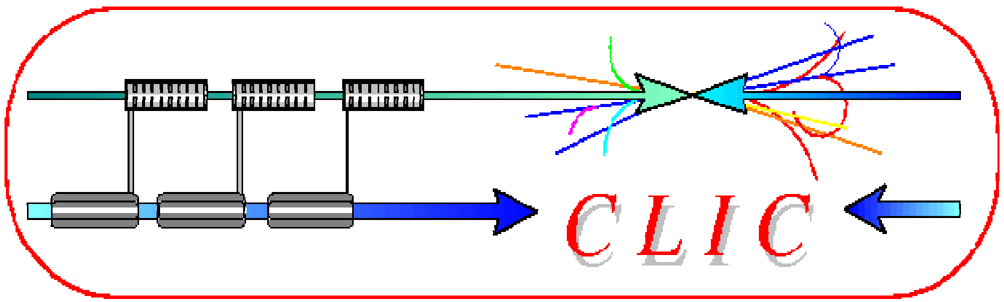
The CLIC Two Beam Scheme

Two Beam Scheme:

Drive Beam supplies RF power
- 12 GHz bunch structure
- low energy (2.4 GeV - 240 MeV)
- high current (100A)

Main beam for physics
- high energy (9 GeV – 1.5 TeV)
- current 1.2 A





No individual RF power sources

ILC vs CLIC parameters

Center-of-mass energy	0.5 TeV	3 TeV
Peak Luminosity	$2 \cdot 10^{34}$ cm^{-2} s^{-1}	$6 \cdot 10^{34}$ cm^{-2} s^{-1}
Peak luminosity (in 1% of energy)		$2 \cdot 10^{34}$ cm^{-2} s^{-1}
Repetition rate	5 Hz	50 Hz
Loaded accelerating gradient	31.5 MV/m	100 MV/m
Main linac RF frequency	1.3 GHz	12 GHz
Overall two-linac length	22 km	42 km
Bunch charge [nC]	1.6 - 3.2	3.72
Bunch separation	370 ns	0.5 ns
Beam pulse duration	950000 ns	156 ns
Beam power/beam	10.8 MWatts	14 MWatts
Hor./vert. normalized emittance	10000 / 400 nm rad	660 / 20 nm rad
Hor./vert. IP beam size bef. pinch	640 / 5.7 nm	40 / ~1 nm
Total site length	31 km	48 km
Total power consumption	230 MW	322 MW

Minimal Supergravity: SPS1a

LHC

- Prázdná místa ve spektru lehkých částic
- Přesnost %
- V rozdílech hmot ‰

ILC

- Zaplní prázdná místa ve spektru hmot
- Přesnost o 1-2 řády lepší

LHC + ILC

- Konzistentní a přesná představa o SUSY

	Mass, ideal	"LHC"	"ILC"	"LHC+ILC"
$\tilde{\chi}_1^\pm$	179.7		0.55	0.55
$\tilde{\chi}_2^\pm$	382.3	–	3.0	3.0
$\tilde{\chi}_1^0$	97.2	4.8	0.05	0.05
$\tilde{\chi}_2^0$	180.7	4.7	1.2	0.08
$\tilde{e}_R$	143.9	4.8	0.05	0.05
$\tilde{e}_L$	207.1	5.0	0.2	0.2
$\tilde{\nu}_e$	191.3	–	1.2	1.2
$\tilde{\mu}_R$	143.9	4.8	0.2	0.2
$\tilde{\tau}_1$	134.8	5-8	0.3	0.3
$\tilde{\tau}_2$	210.7	–	1.1	1.1
$\tilde{q}_L$	570.6	8.7	–	4.9
$\tilde{t}_1$	399.5		2.0	2.0
$\tilde{t}_2$	586.3		–	
$\tilde{g}$	604.0	8.0	–	6.5
h^0	110.8	0.25	0.05	0.05
A^0	399.4		1.5	1.5

Accuracies for representative mass measurements
hep-ph/0403133v1

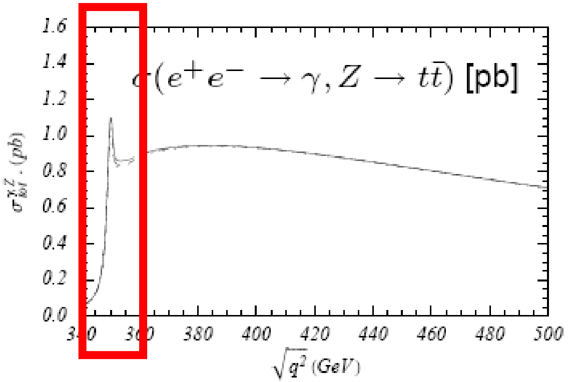
Top Physics and the ILC

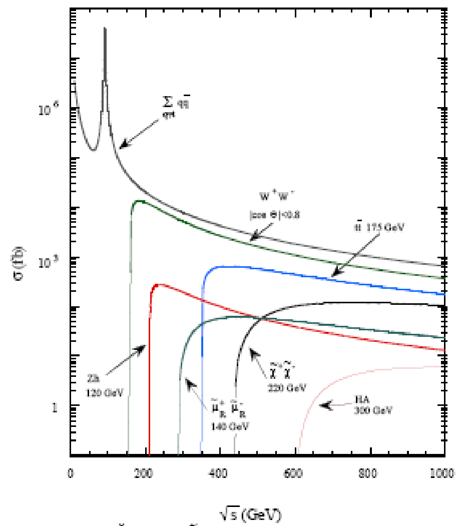
- e^+e^- collider: $E_{\rm cm} = 350$ GeV – 1 TeV
- Luminosity: 10^{34}–$10^{35}\,{\rm cm}^{-2}{\rm s}^{-1} \rightarrow 100$–$1000\,{\rm fb}^{-1}$/year

  LC $\sim 10^5\ t\bar{t}$ pairs $[\sigma_{\rm tot} < 1\,{\rm pb}]\ (e^+e^- \rightarrow t\bar{t})$

  LHC $\sim 10^8\ t\bar{t}$ pairs $[\sigma_{\rm tot} \approx 850\,{\rm pb}]\ (gg \rightarrow t\bar{t})$

- Initial state tunable and very well known $\rightarrow$ threshold & continuum
  - Centre of mass energy variable

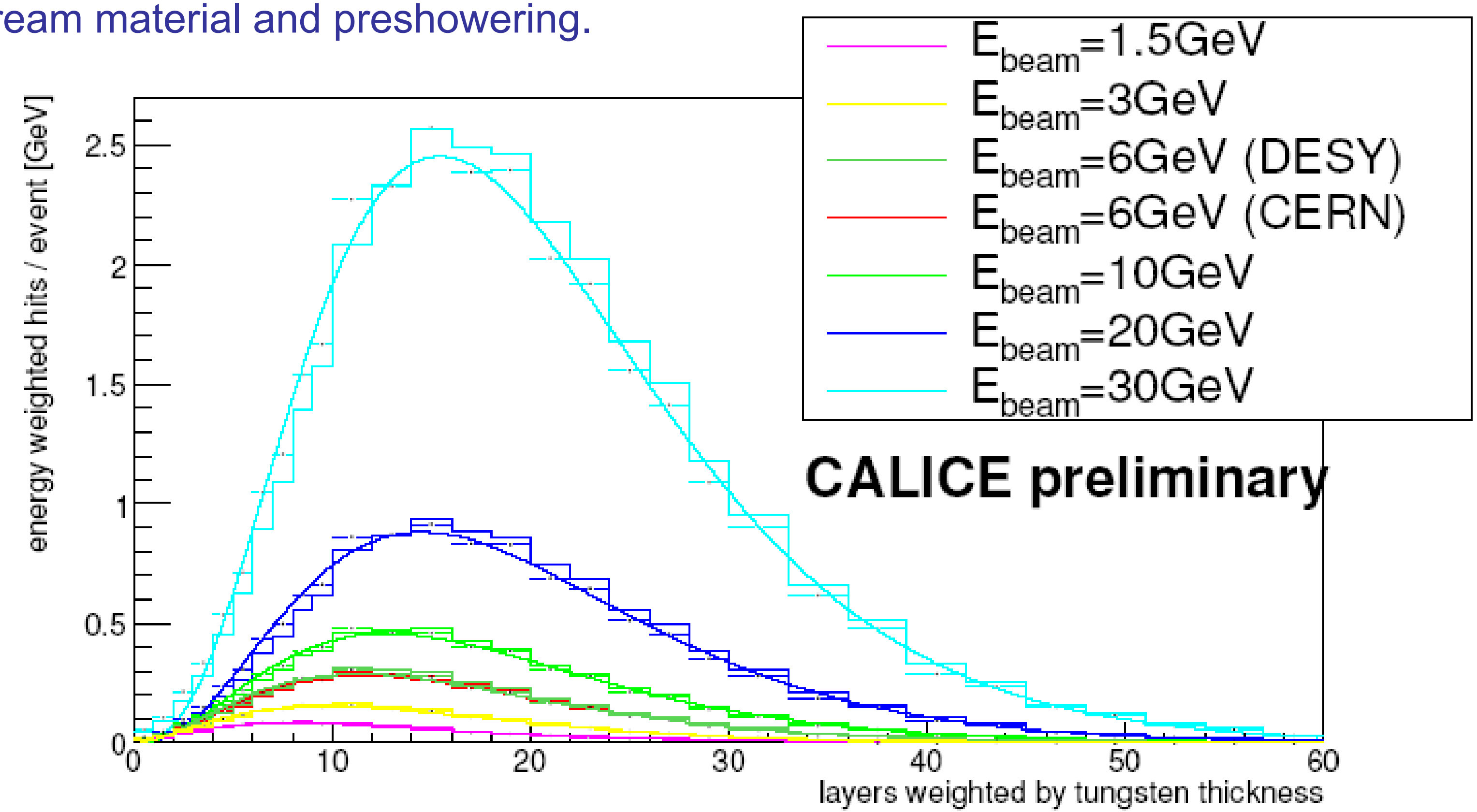




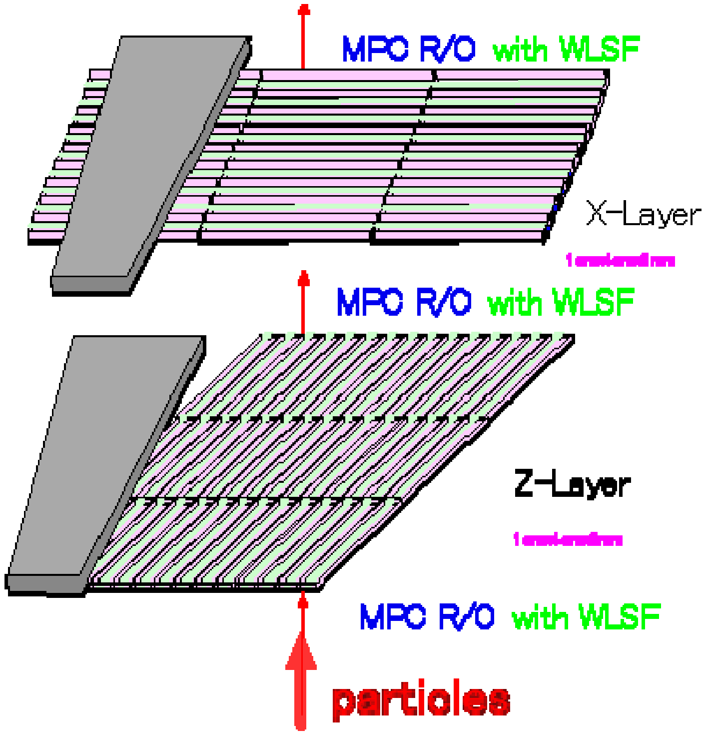
  - $e^{\pm}$ beam polarization: $P_{e^-} \sim 80\%,\ P_{e^+} \sim 60\%$
  - $\gamma\gamma$, γe options: $e^+e^- \rightarrow t\bar{t}\,(^3S_1)$, $\gamma\gamma \rightarrow t\bar{t}\,(^1S_0)$

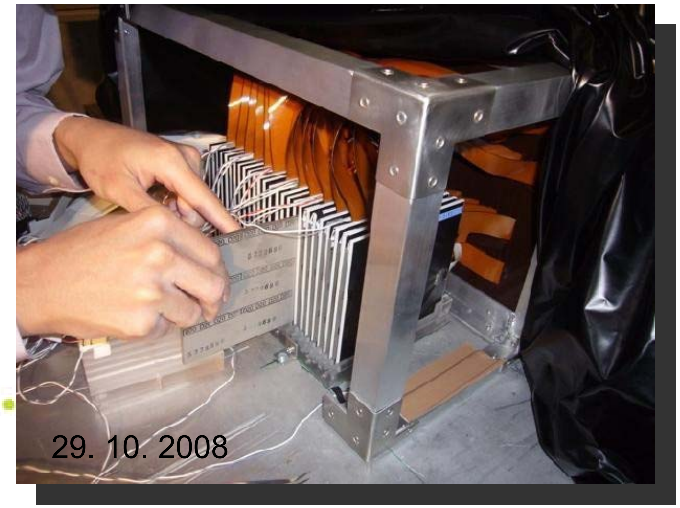
ECAL longitudinal shower profile for e⁻

- Data (dashed) agree quite well with Monte Carlo expectation (solid).
- Some shift – likely associated with upstream material and preshowering.



Scintillator-Tungsten ECAL (ScECAL)

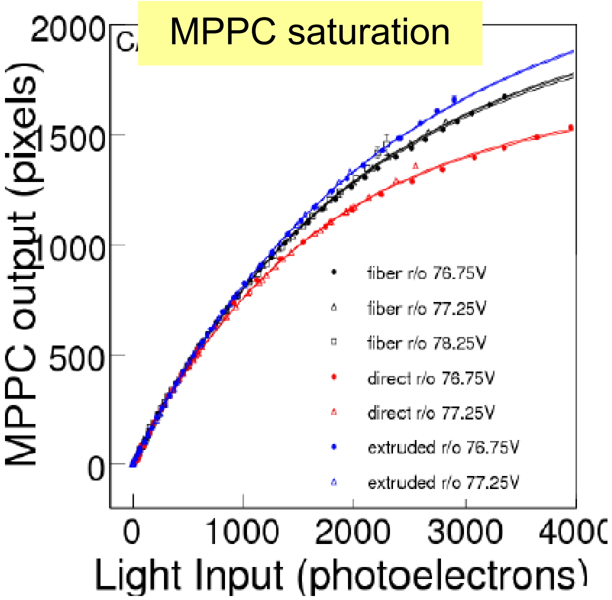


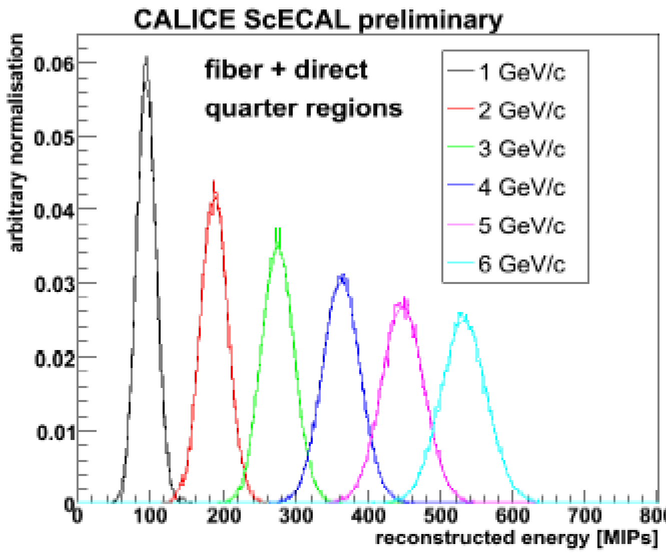


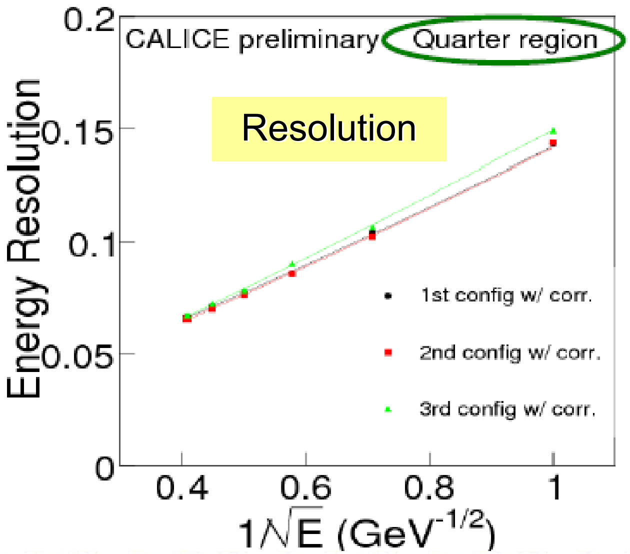
Sampling Calorimeter

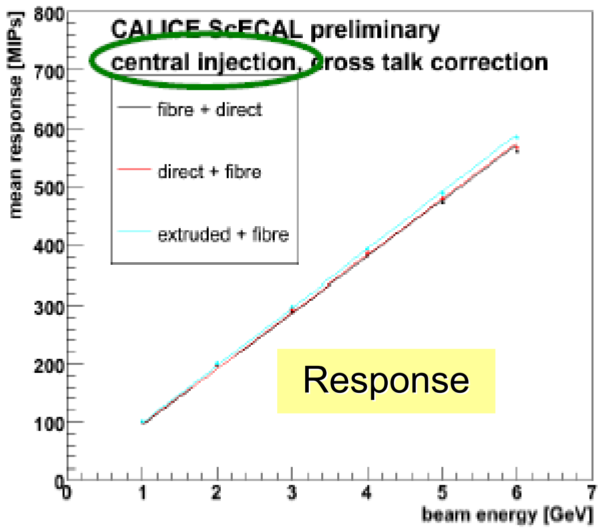
- Scintillator Active Material
  - **strips 1cm wide, 3.5mm thick**
    - 3 different configurations
    - WLS fibre readout
  - **each strip read out by M**ulti **P**ixel **P**hoton **C**ounter (1 mm^2, 1600 pixels)
- DESY Test-Beam in 2007, FNAL Test-Beam in 2008
  - **26 Layers alternatively rotated by 90°**
  - **468 MPPCs**

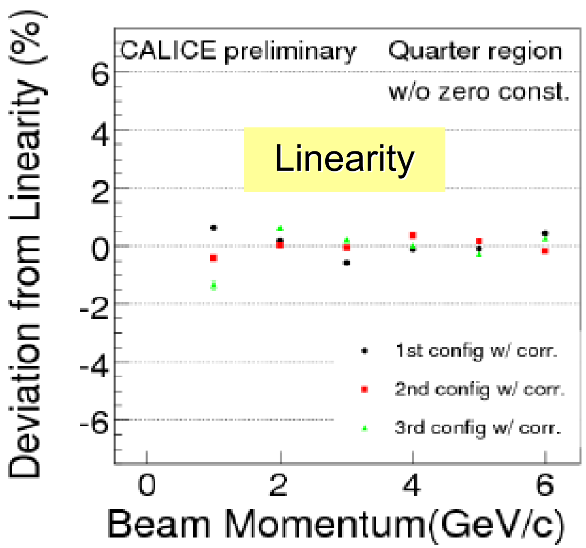
ScECAL – results from DESY test





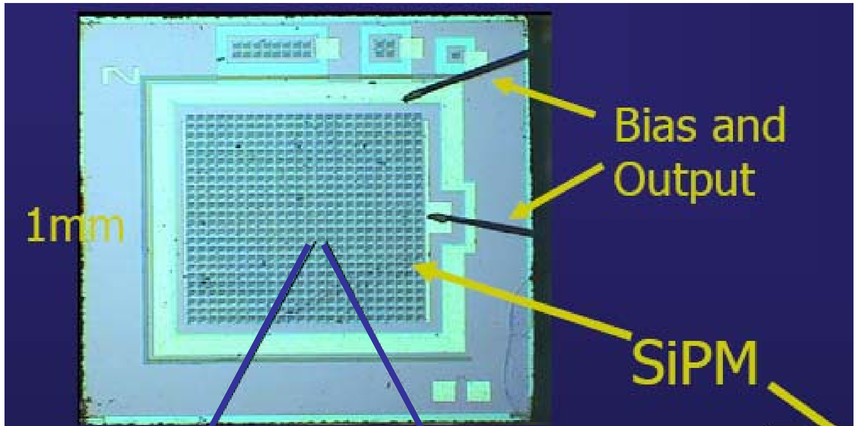




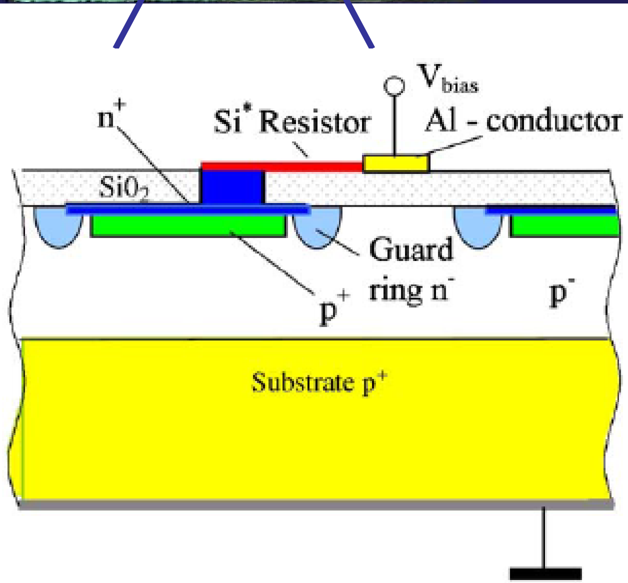


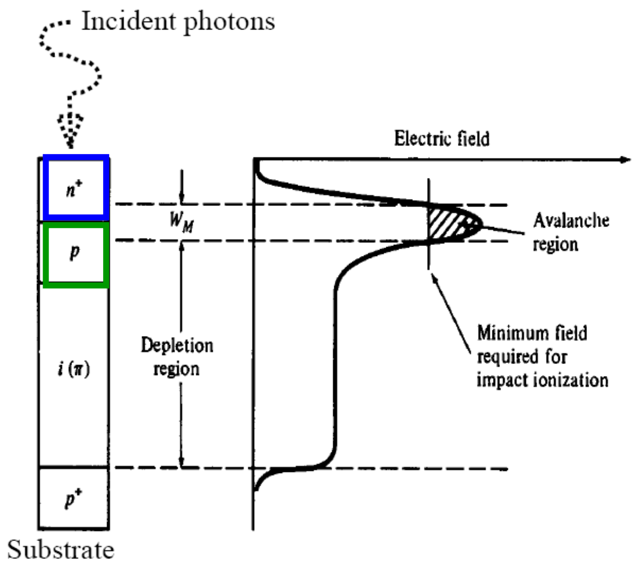
The Silicon Photo-Multiplier

Typical sensor area 1x1 mm² ➔ new developments 3x3, 5x5 mm²

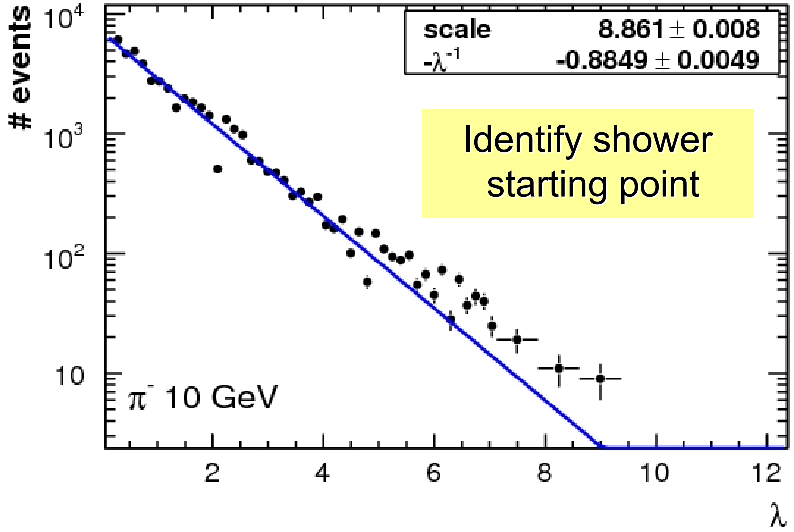


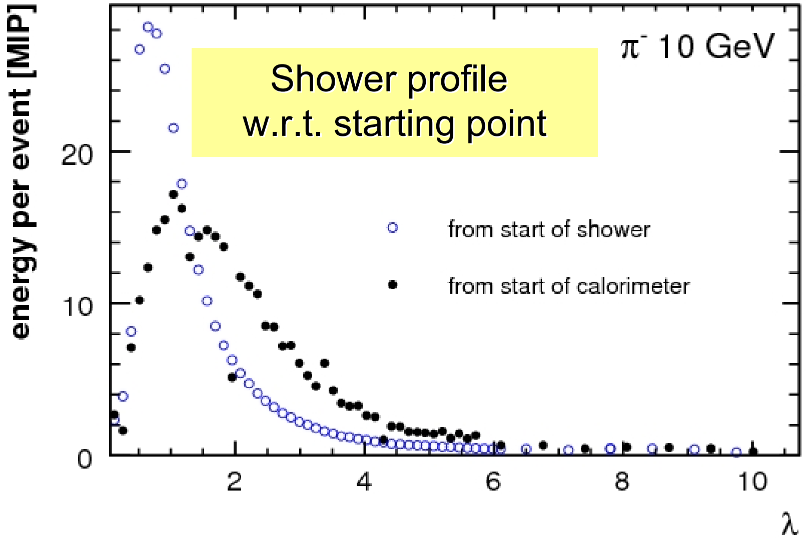
-small depletion region ~ 2μm
-strong electric field (2-3)x10^5 V/cm
-gain ~ 10^6
-carrier drift velocity ~ 10^7 cm/s
-very short Geiger discharge development < 500 ps

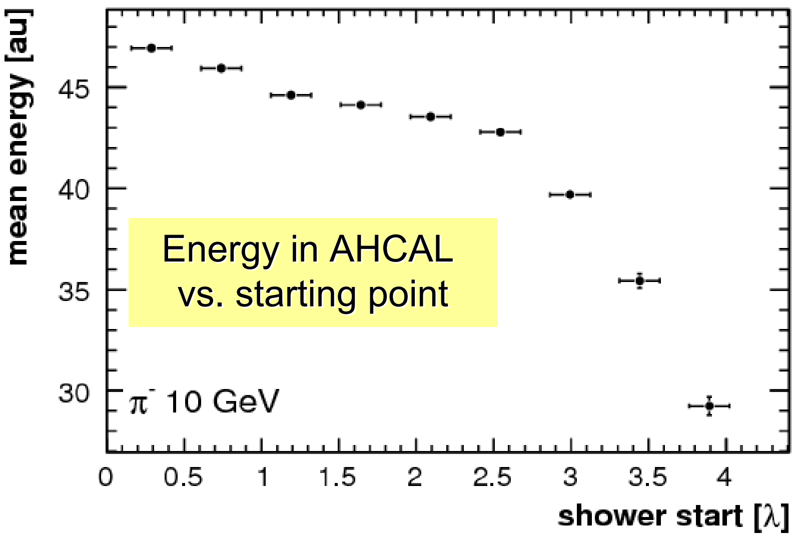


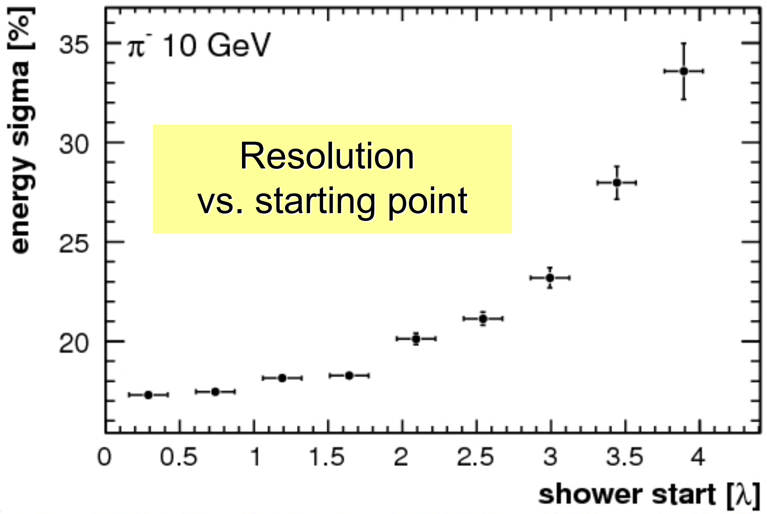


HCAL shower leakage study



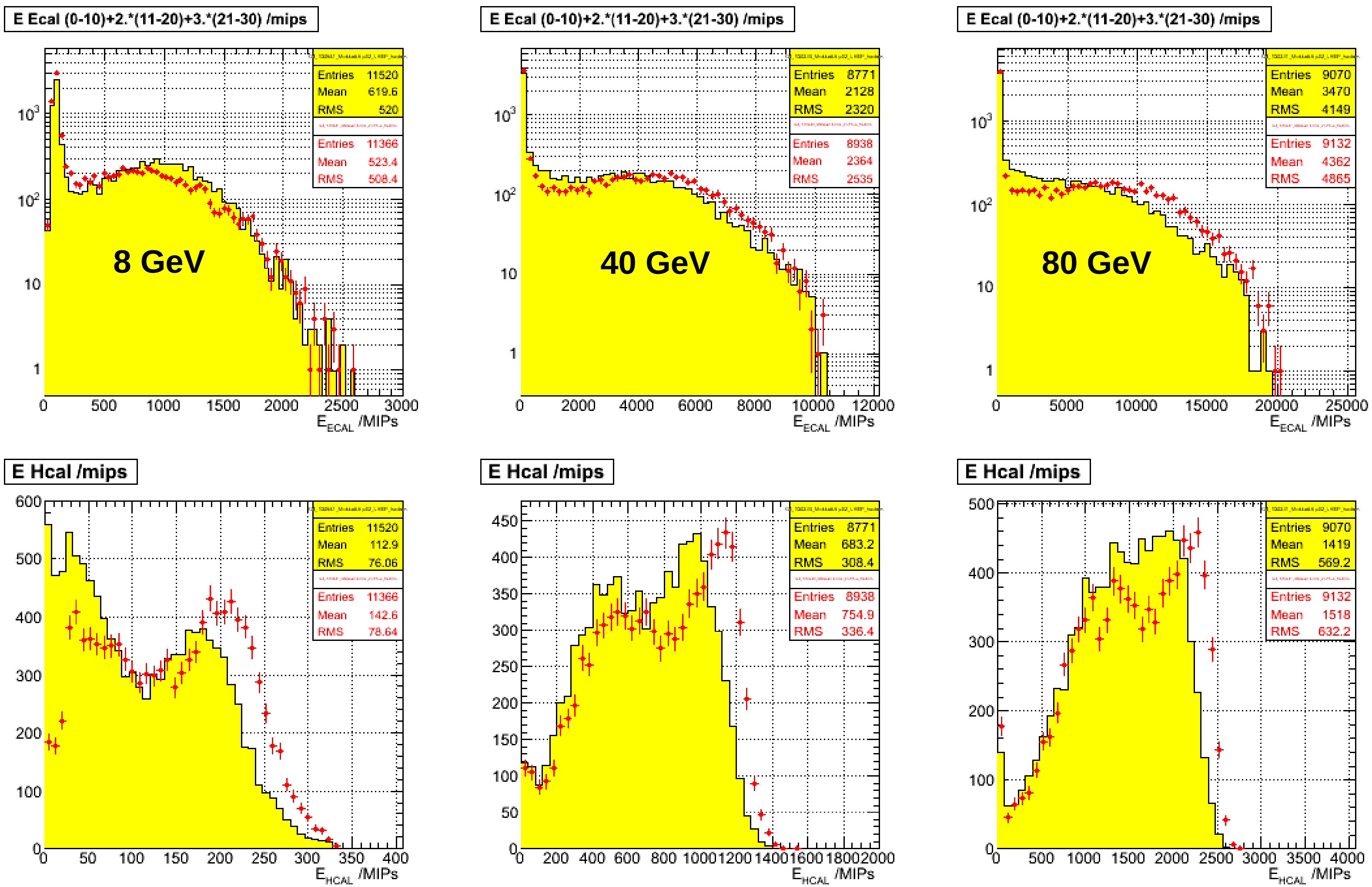






Pion showers in ECAL (MC only)

Compare LHEP with LCPhys



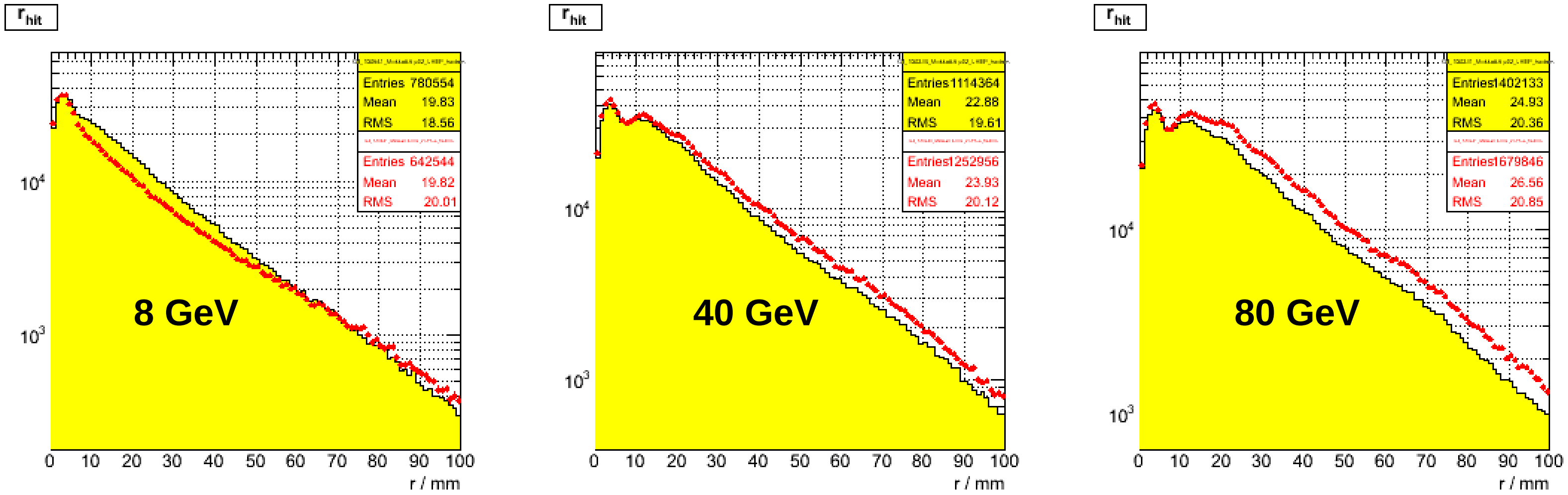
ECAL energy

HCAL energy

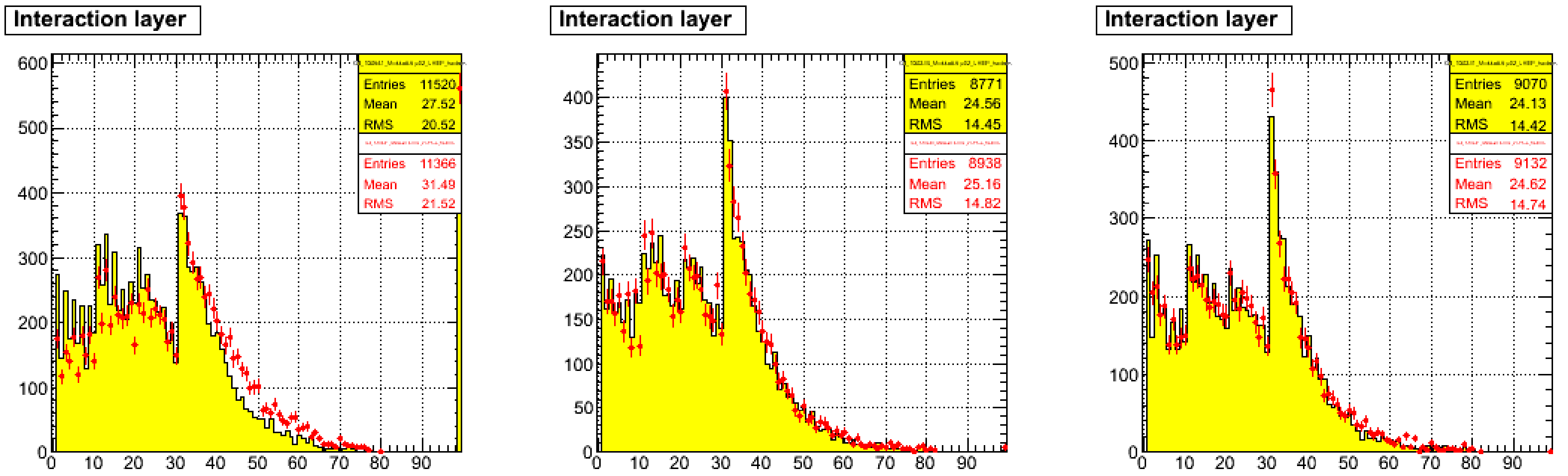
Pion showers in ECAL

Compare LHEP with LCPhys

Even ECAL alone has sensitivity to shower models
Also correlations between ECAL and HCAL are interesting



Radial distribution of hits



First interaction layer

DHCAL – electron showers

- Calorimeter ~9 X_0 : showers not confined.
- Can still compare with simulation.
- MC simulation:
  - Get (x,y,z) of each energy deposit in the active RPC gaps
  - Generate charge from *measured* charge distribution
  - Introduce cutoff to filter close-by energy deposity
  - Noise hits are ignored
  - Distribute charge according to exponential distribution
  - Tune parameters on muon data; tweak two-particle cutoff using positrons.
  - Apply threshold to pad energies → digital hits.

- Compare data with simulation at 8 GeV
- PRELIMINARY
- Longitudinal shower shape reasonably OK? Some indication of upstream material.
- r.m.s. shower radius – still some discrepancy at present.