CMS

Compact Muon Solenoid

Test Beam Programme

E. Tsesmelis
LHCC Open Session
CERN, 21 May 2003

INTRODUCTION

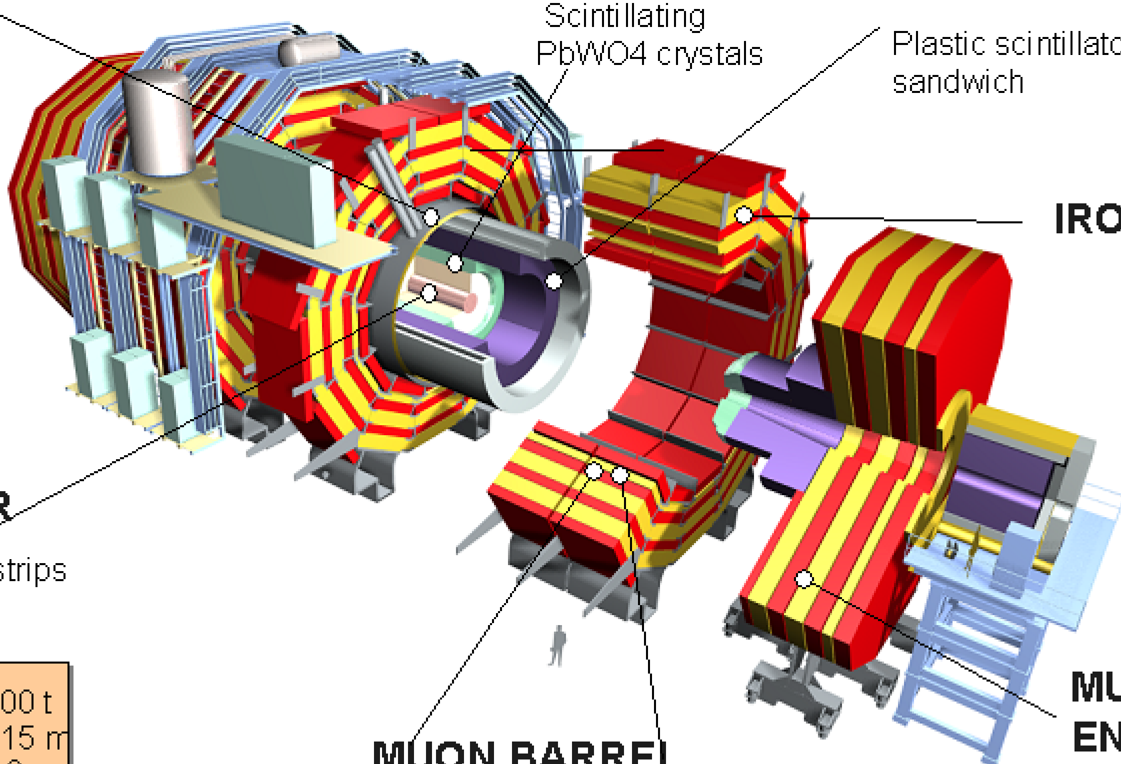
Test beams, have and continue to be used extensively by CMS:
(with standard SPS FT beam & with LHC-type beam structure)

- Detector conceptual design phase.
- Prototyping and large systems tests.
- Performance checks, calibration and quality control of detector components from the series production.

In order to study the detector stability and to evaluate improvements, limited test beam activity will be required after start of physics.

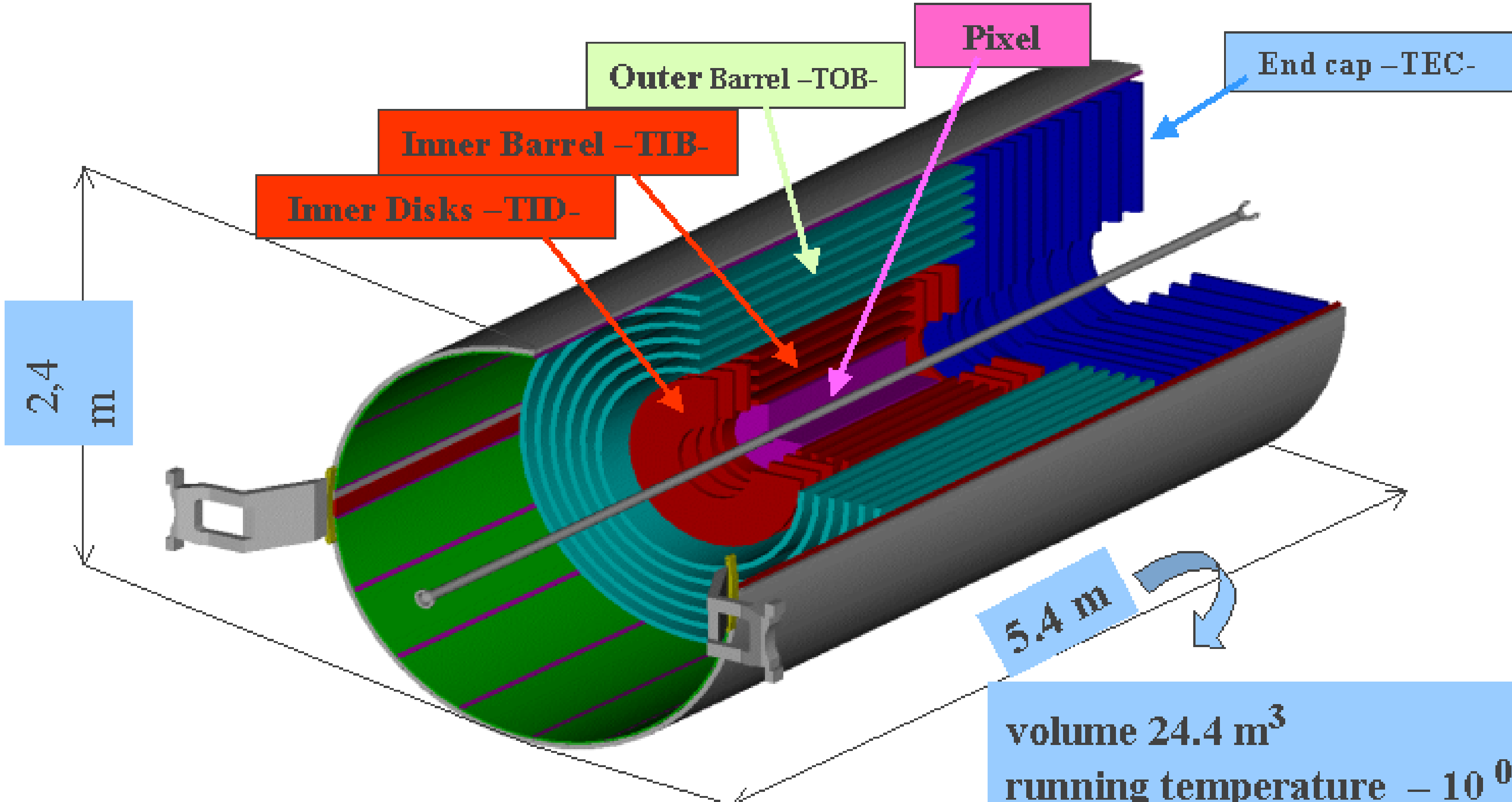
Although not the primary reason for test beams, they nonetheless provide invaluable experience, especially to the younger physicists, in designing, setting-up, commissioning and analysing data from numerous complex test beam activities.

THE CMS DETECTOR



Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

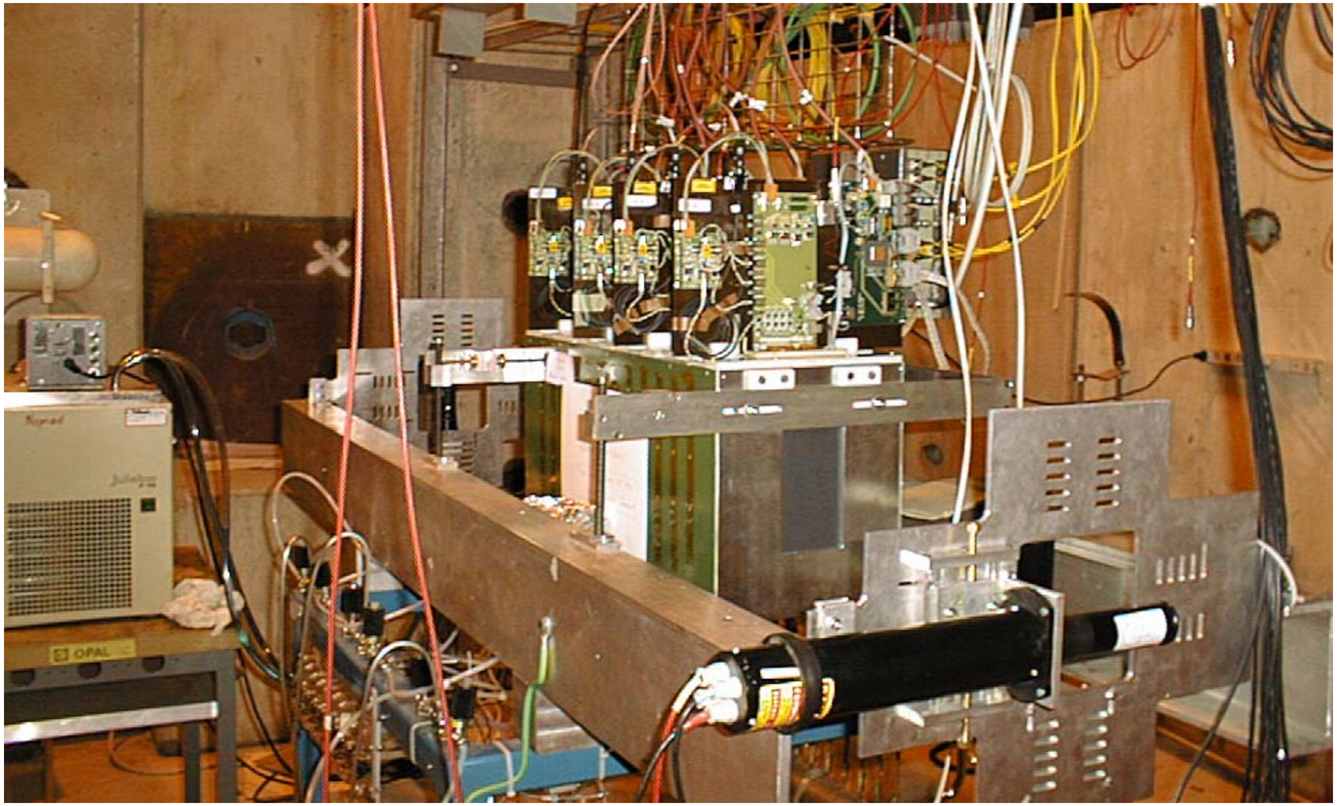
TRACKER



volume 24.4 m^3
running temperature – 10 ^{0}C
dry atmosphere for YEARS!

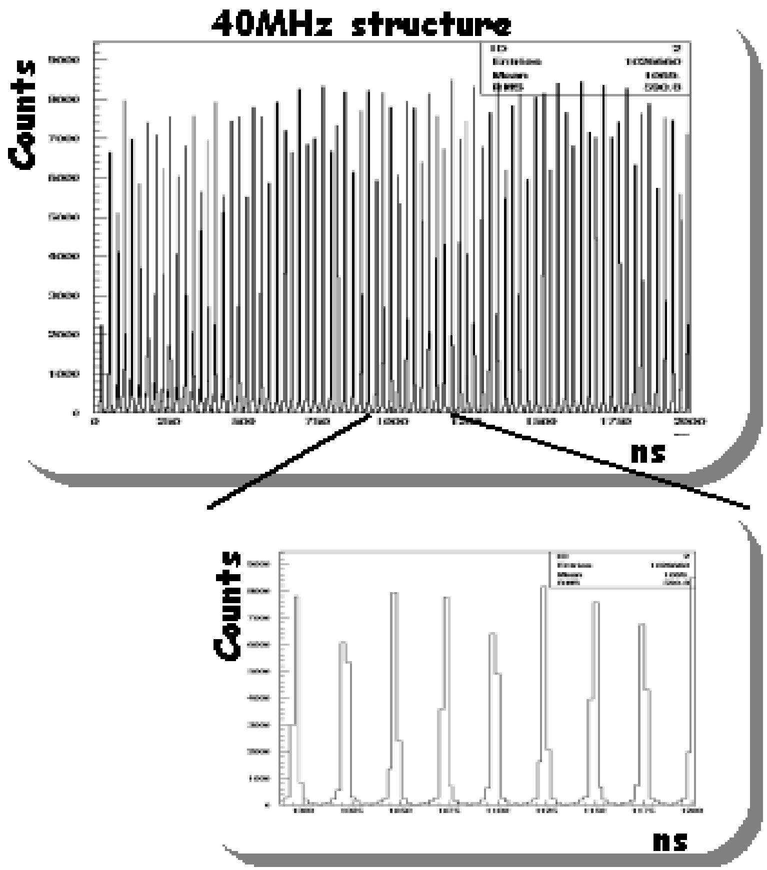
TRACKER TESTS WITH LHC-TYPE BEAMS - AIMS

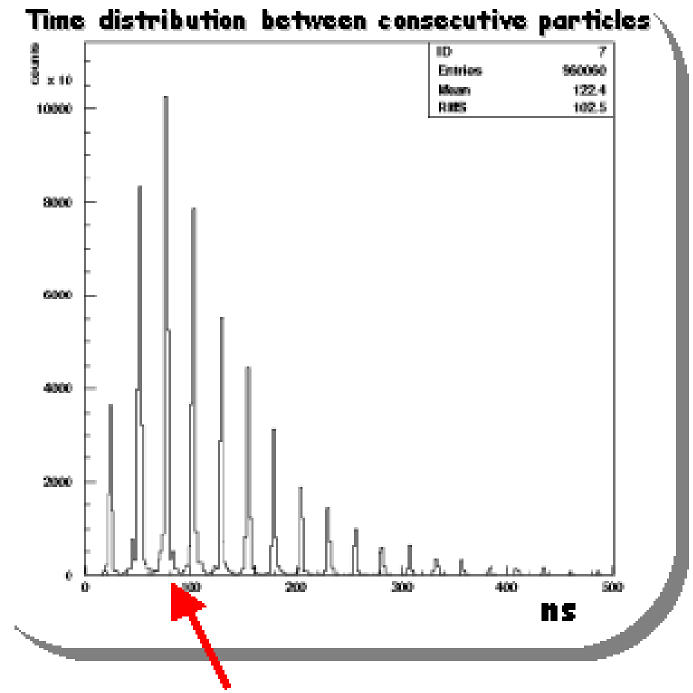
- An LHCC Milestone for the CMS Tracker requested a test of the complete R/O electronics chain in an LHC-like environment with the 25 ns structured beam.



Such beams used in 2000, 2001 & this year

TRACKER TESTS WITH LHC-TYPE BEAMS





Measurements with Beam Telescope

Emmanuel Tsesmelis
EST-LEA

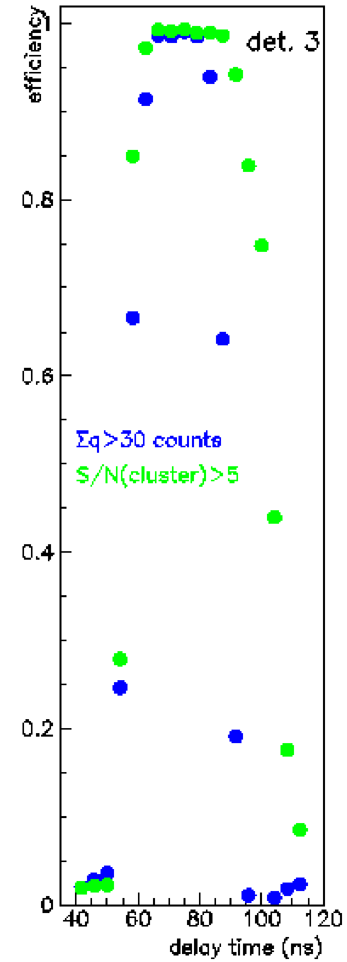
TRACKER TESTS WITH LHC-TYPE BEAMS - RESULTS

- The overall integration of components (hardware and software & including TTC) was successful
- Synchronization of the system (together with machine) was achieved.

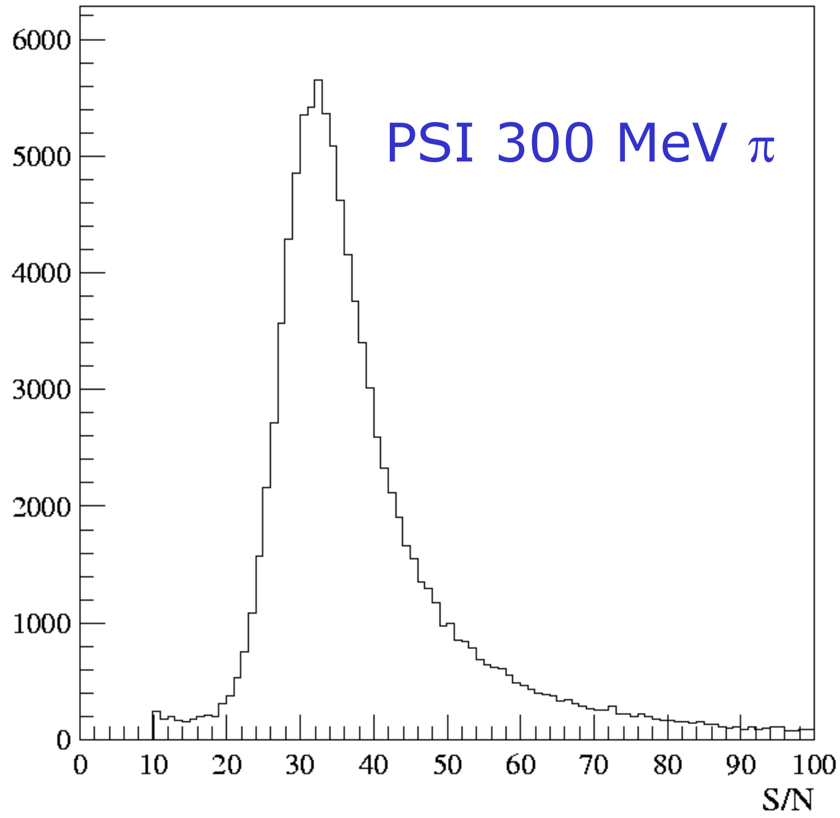
Cluster Reconstruction Efficiency vs. Latency

X5 120 GeV π

Tracker design figure of `1001' bunch scheme met



TRACKER PERFORMANCE - TOB

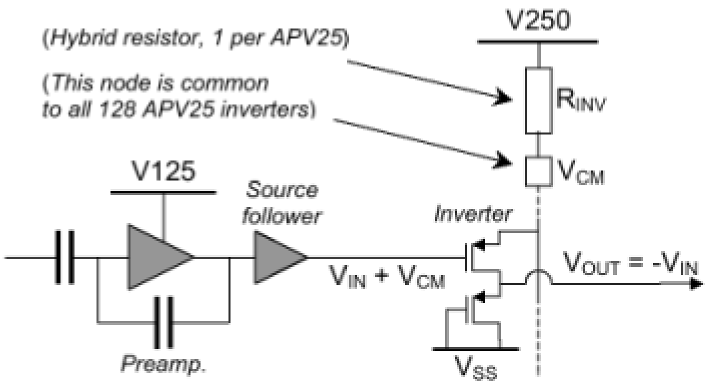


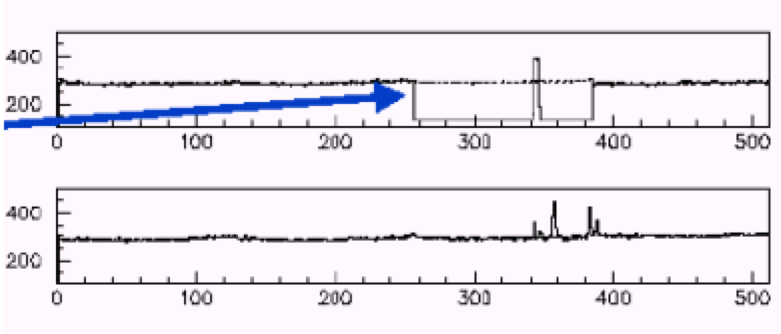
Signal-to-Noise

TRACKER HIP EFFECT - EXAMPLE OF UNFORESEEN EVENTS

HIP event produced by nuclear interactions of a particle crossing the Si

- APV inverter stage is powered via resistor R_{INV}, which by design is 100 Ω
- Large signal on one channel drives down output on the other 127 and could saturate them
- Originally observed at X5 in 2001 (CMS Note 2002/038)

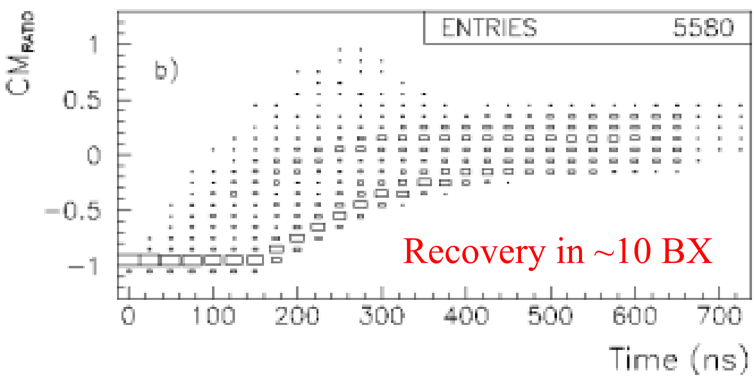




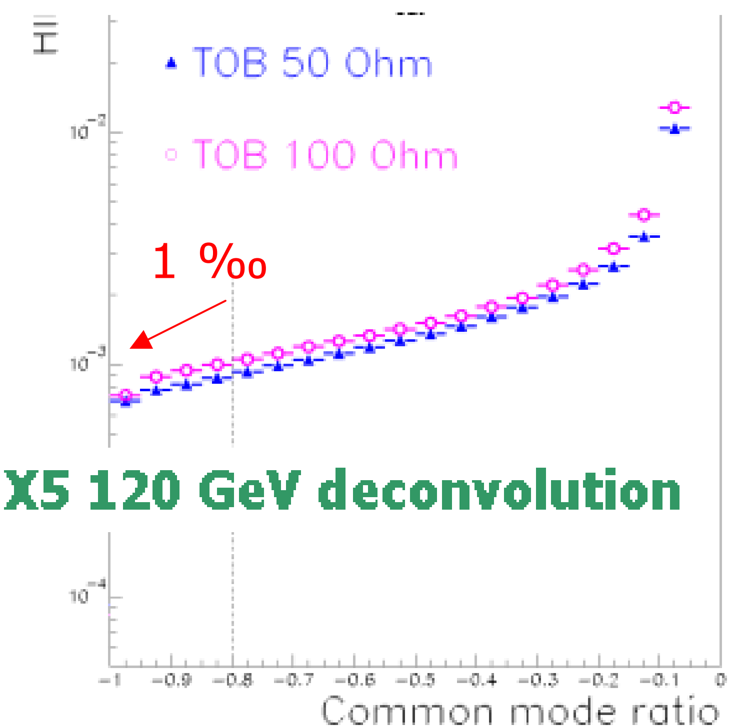
TRACKER HIP EFFECT

Effects studied at SPS X5 (25 ns beam) and PSI π beam (300 MeV).

Baseline recovery for HIP



Hit inefficiency due to saturation of chip from HIP in same BX and while recovering from previous BXs.



Tracker design found to be robust against loss of a hit from HIP effect

CMS TRACKER FUTURE PLANS: 2003 & 2004

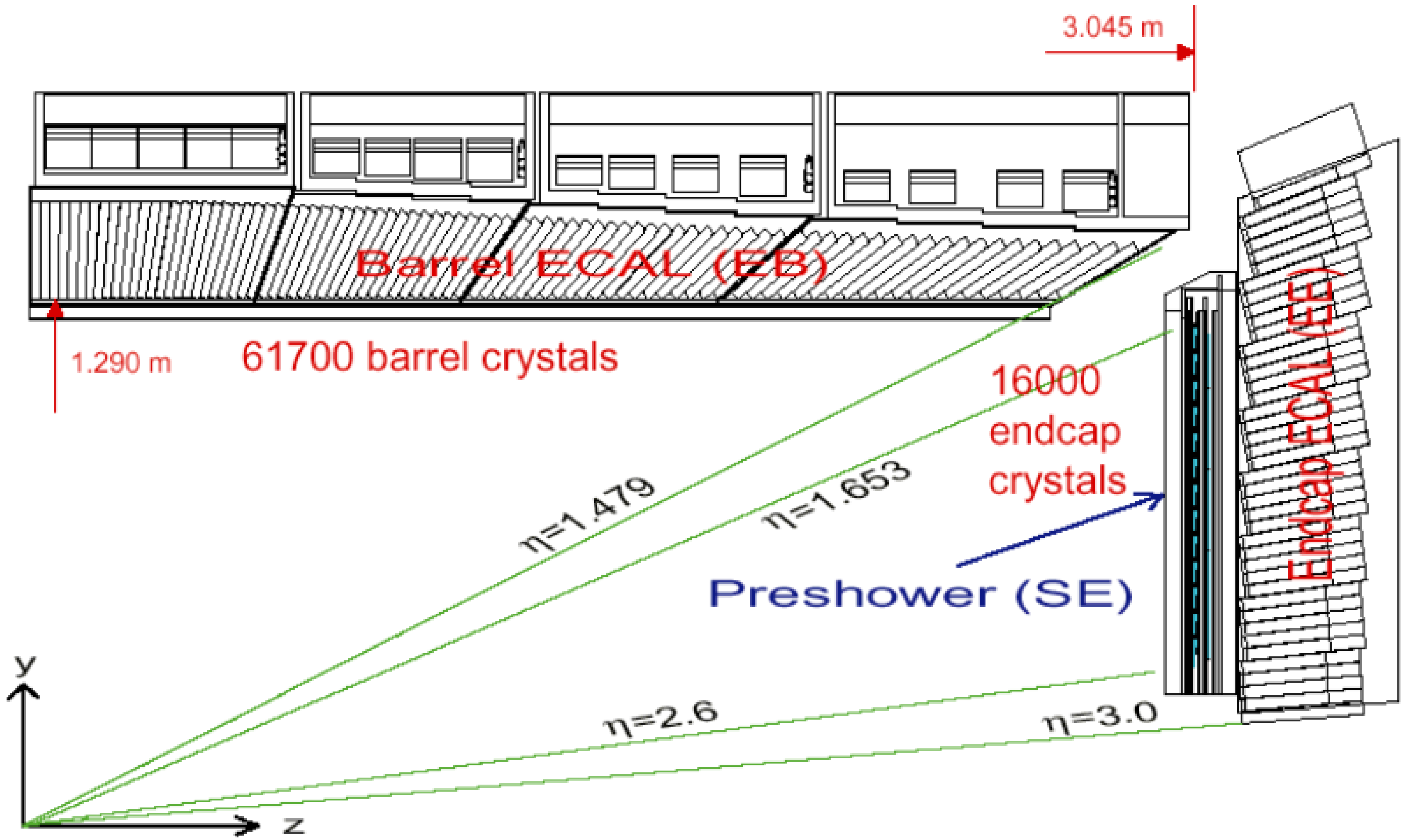
- Modules (+ system aspects) are being produced at a rate which makes them available for testing in beam.

- Tracker modules (TIB, TOB, TEC) to be chosen on a sampling basis from the series production with final components

  - APV25, hybrids, analog optical links for data, digital optical links for controls, FECs, CCU 25, PLL and corresponding control software

- LHC-type beams with 25 ns may also be used.

ELECTROMAGNETIC CALORIMETER (ECAL)



ECAL ELECTRONICS

In 2002 two major concerns:

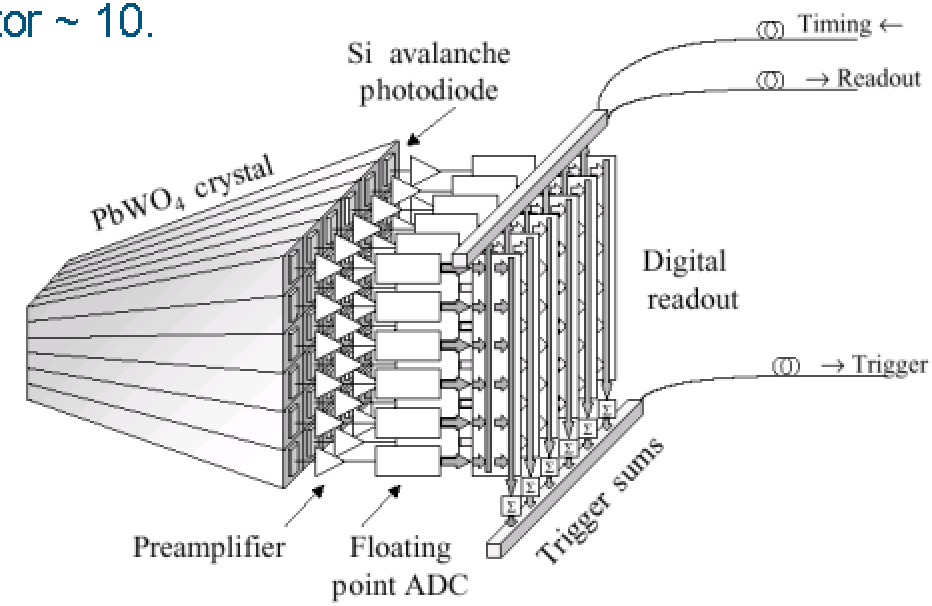
1) Very Front End (VFE) analogue electronics: FPPA too noisy

2) Cost overrun: hope for cheap digital links (one per crystal) never materialised

Decision:

1) Organise full review of FPPA design with outside experts and resubmit. Develop back up solution in 0.25 µm (DSM).

2)Alter electronics architecture: generate L1 trigger primitive (Σ25 xtals) on-detector rather than off-detector- reduce links and off detector electronics by factor ~ 10.

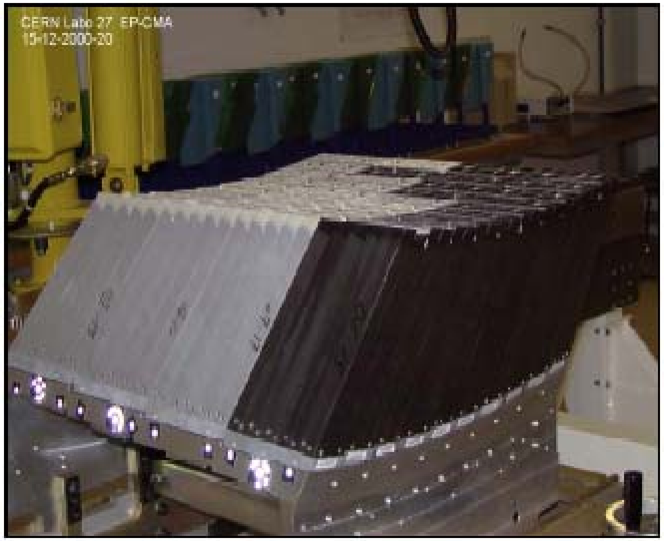


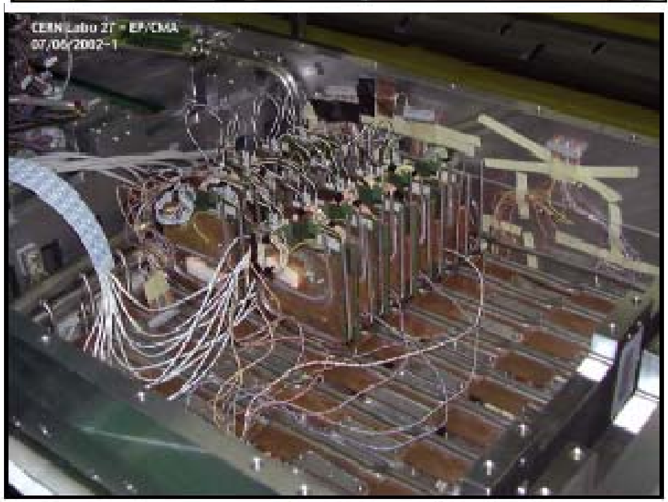
One new radhard 0.25µm chip to be developed: FENIX (trigger sums, digital pipeline). Build on experience with APV.

3) Use tracker technology for Optical links and Control system

4) Reorganise ECAL electronics team

ECAL 2002 TEST BEAM M0′





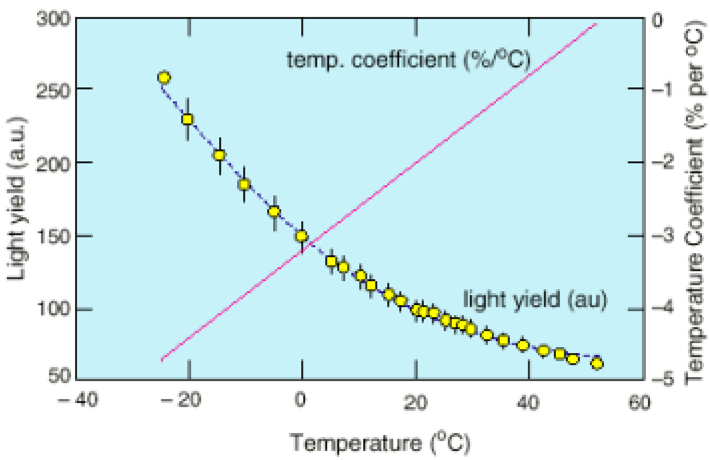
- M0'
  - First complete barrel system test
  - Uniform construction procedure
  - 100 channels of a module type 2
    - "Old" electronics,
    - Final Laser monitoring
    - Services (Cooling, HV, LV, DCS)
- H4 test beam area
  - Scanning table with automatic positioning of crystals in front of beam (electrons, pions)
  - Online monitoring (laser, beam data)

ECAL 2002 TEST BEAM OBJECTIVES

- Large scale system test
  - VFE, HV, LV, DAQ, DCS
  - Cooling for a large number of channels
- Step towards ECAL calibration
  - System readiness for testbeam in 2003 and calibration in 2004
    - DAQ and online software
    - Moving table
    - Understand laser monitoring system
    - Stability checks (laser, temperature)
    - Preparation for offline analysis
- Crystal behaviour under irradiation
  - Compare laser with beam response, many crystals
  - Universality
- Calibration
  - Compare lab measurements with beam data

ECAL 2002 TEST BEAM COOLING SYSTEM

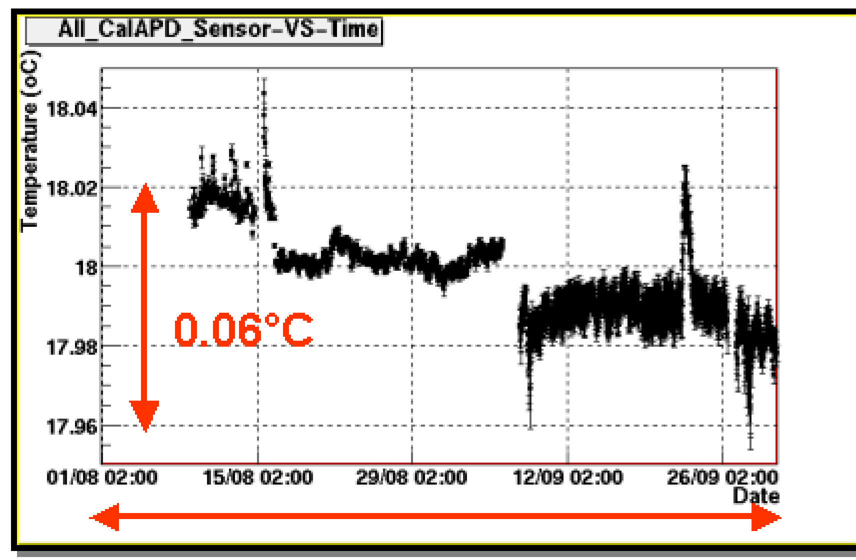
Why is temperature stability so important?



- Strong dependence of crystal light yield with T, -2%/^{0}C at 18^{0}C
- Strong temperature dependence of APD gain, dM/dT = -2.4%/^{0}C

Thus the requirements are:

- Long term stability of xtals and APDs < 0.1 ^{0}C

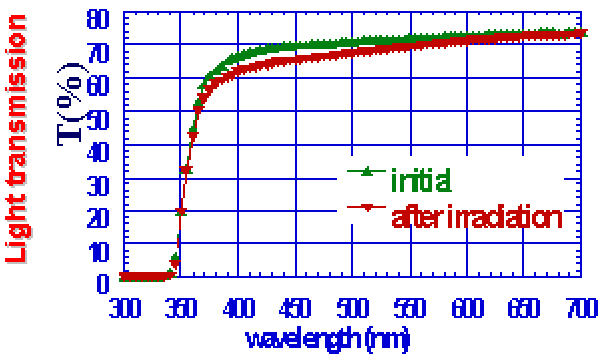


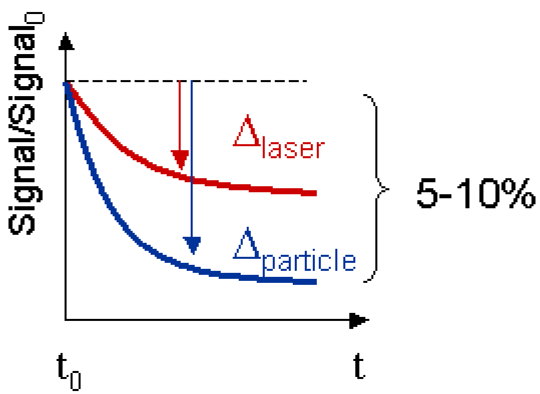
2 months

temperature measured on APDs

ECAL 2002 TEST BEAM
LASER MONITORING

Why is the laser monitoring so important?

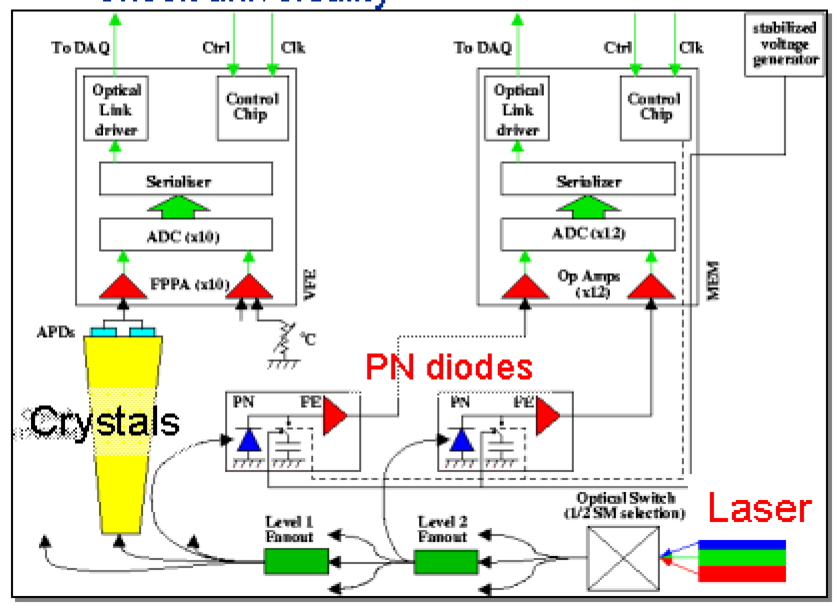




$\Delta_{particle}$ vs Δ_{laser} ?

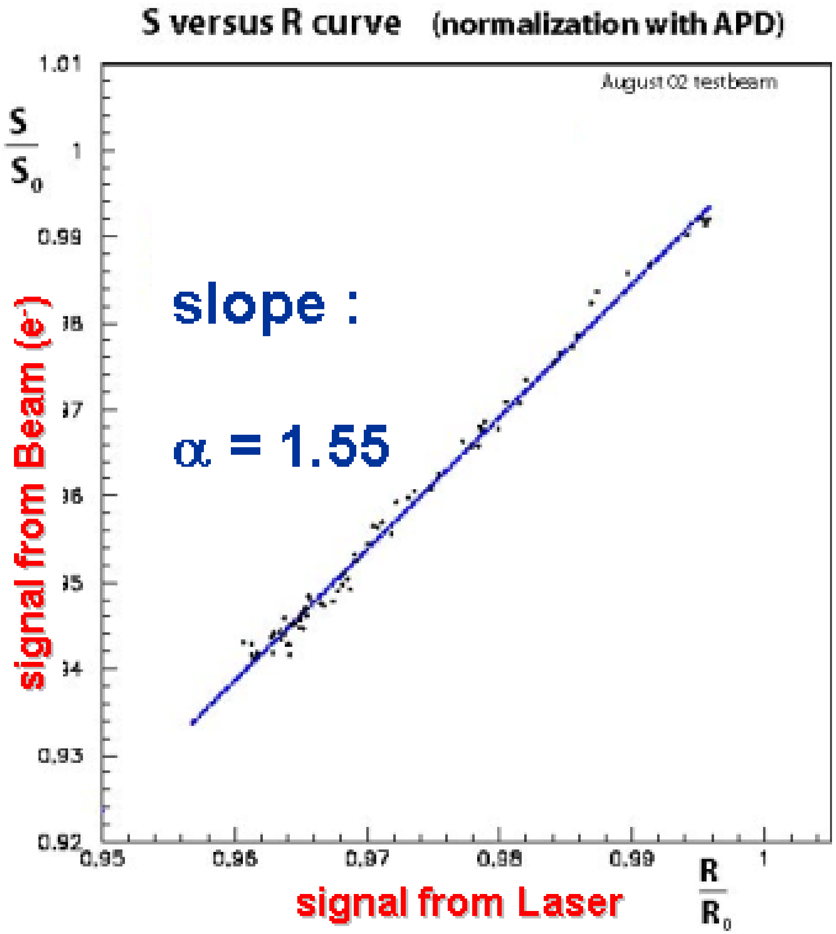
Thus the idea is:

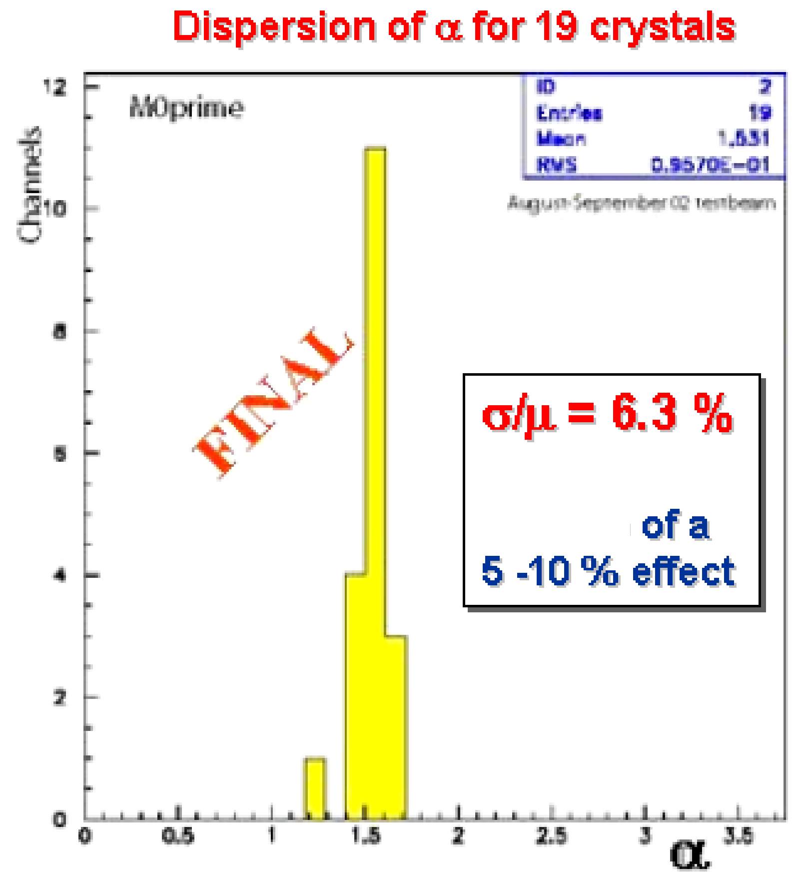
- Inject laser light to monitor crystal transparency
- Follow signals from beam and laser
- Determine slope laser vs. beam
- Check universality



excellent stability of the laser system achieved, stable at the 0.1% level !

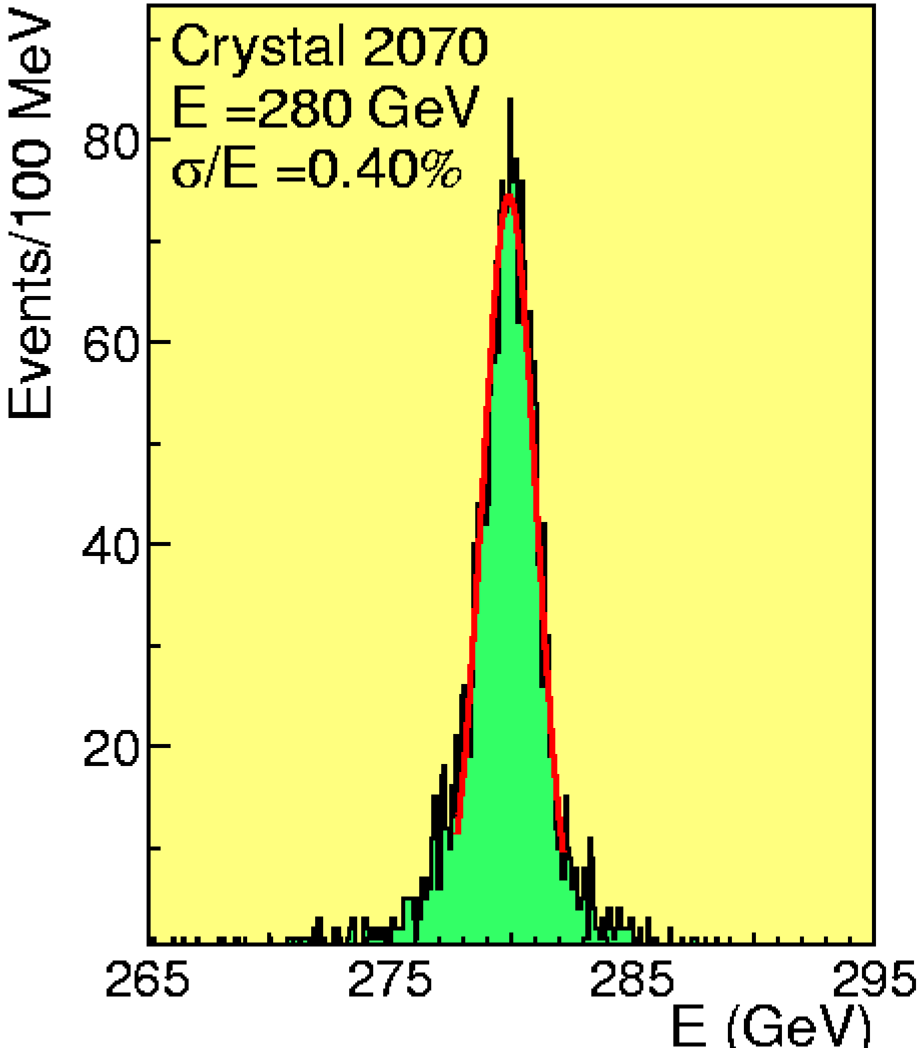
ECAL 2002 TEST BEAM
LASER MONITORING





⇒ Use of same coefficient for all crystals possible !

ECAL TEST BEAM
ENERGY RESOLUTION

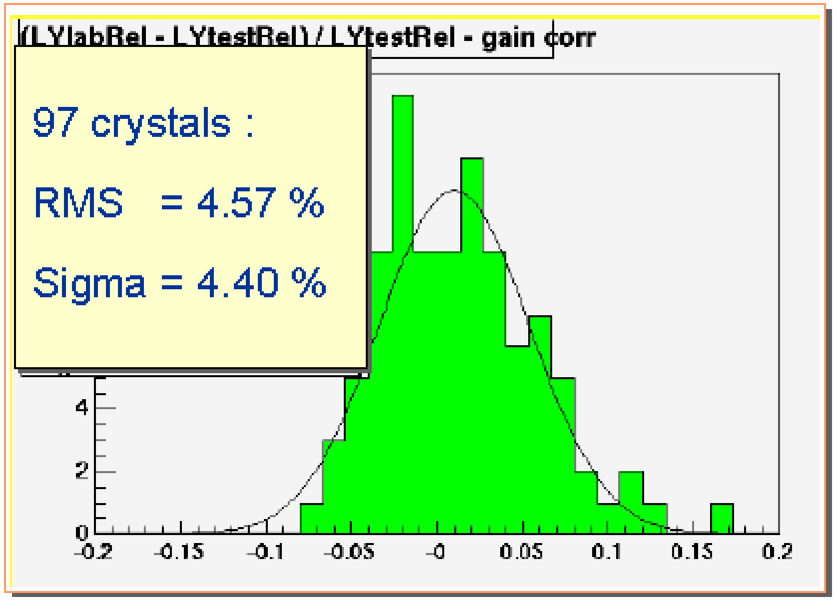


SPS H4 Electrons

ECAL PRECALIBRATION SOURCE VS. BEAM

- Idea:
  - Obtain preliminary crystal intercalibration from light yield measurements (and comparison to reference crystal) in the **LAB**
  - Previously expected: 6% achievable, as starting point for calibration
  - Put crystals in test beam and check intercalibration
  - Then compare **LAB - BEAM**

Comparison of Light Yield LY



(LAB - BEAM)/BEAM

- **Result:**
  - Possible to infer intercalibration coefficient from LAB measurements at a precision of **4.5 % !** … good starting point…

ECAL CALIBRATION PROCEDURE

- **Precalibration:**
  - Lab measurements, **< 5%**
  - Test beam, **< 2%**

  but only a fraction of ECAL will be calibrated

$$\frac{\sigma}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

intercalibration goes directly into constant term (most of the energy in a single crystal)

- **In-situ calibration:** — at low Lumi
  - A) Fast intercalibration using Φ - **symmetry**, **≈2%** — **few hours**
  - B) Use **Z** $\rightarrow$ **e$^+$e$^-$** for intercalib in η and absolute E scale — **few days**
  - C) When tracker fully operational : E/p from **W** $\rightarrow$ **eν** — **few months**
  - Final goal : **0.5 %**

- **Laser monitoring:**
  - Correct for variations in crystal transparency due to irradiation

ECAL SCHEDULE

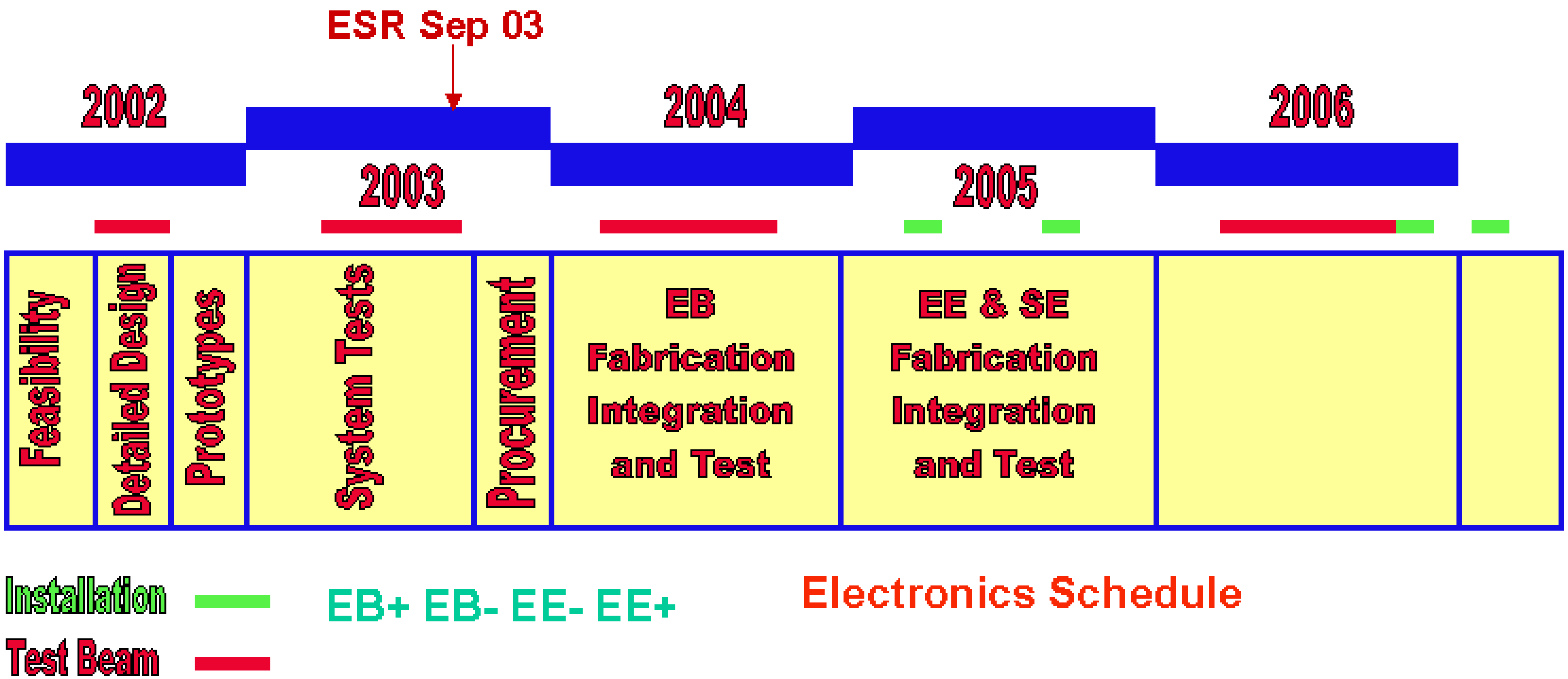
Goal: Apr 07 - ECAL complete and commissioned

System test of both solutions mid-2003, followed by decision.

ESR in Sep 03.

EB electronics mounted in 2004/2005 – calibrate at least 9 SMs in 2004

EE and SE mounted in 2006/2007, calibrate 1 Dee in 2006



ECAL TEST BEAM CONCLUSIONS

- Learned a lot, still a lot to learn

- Important achievements:
  - Stability of cooling system and laser monitoring system
  - Behaviour of APDs, HV, LV, VFE electronics
  - Universality of irradiation behaviour
  - Intercalibration from LAB measurements

- To be improved/changed/foreseen for 2003, 2004:
  - Final electronics (noise level, auto-gain switching)
  - Test larger system (up to 400 channels in 2003)
  - Quick online/offline analysis of incoming data

ECAL Precalibration in testbeam $\leq$ 2006

HADRON CALORIMETRY – HCAL BARREL & END-CAP

HB & HE Sampling Calorimeters Brass (passive) & scintillator (active)

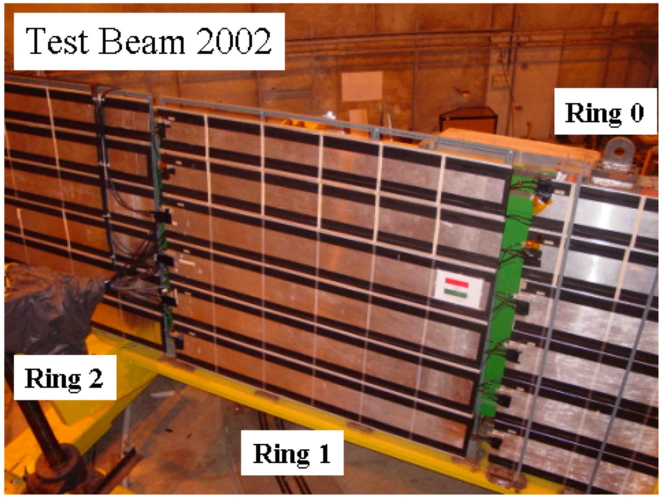
HB complete,

HE-1 assembled & installed

HADRON CALORIMETRY – HCAL OUTER & HADRONIC FORWARD

Total number of λ_{int} till the last sampling layer of HB is ~8.

HO: 2 scint. tiles around first μ layer (extend to~11.8 λ_{int})



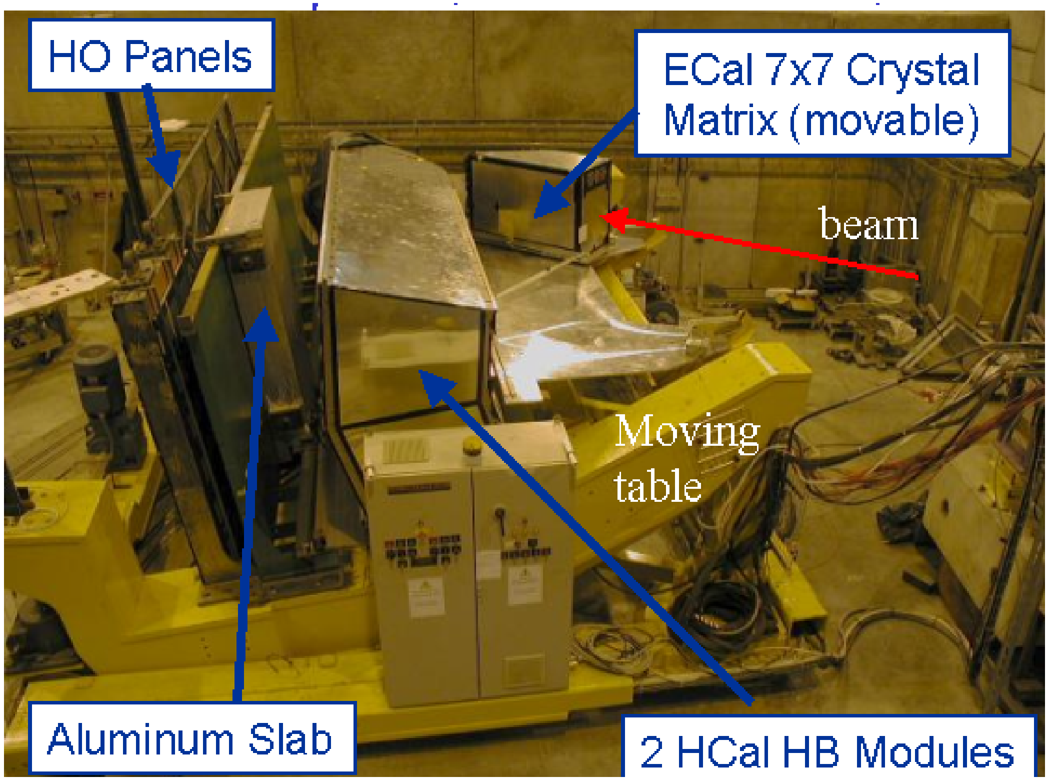
~ 5% of a 300 GeV π energy is leaked outside the HB

HO improves π resolution by ~25% at 300 GeV & linearity

HF: Quartz fibers embedded in steel

HADRON CALORIMETRY – 2002 TEST BEAM

Small scale experiment to demonstrate that HCAL works: 49 ECAL crystals, 144 HB channels, 16 HO channels.



Over

100 Million

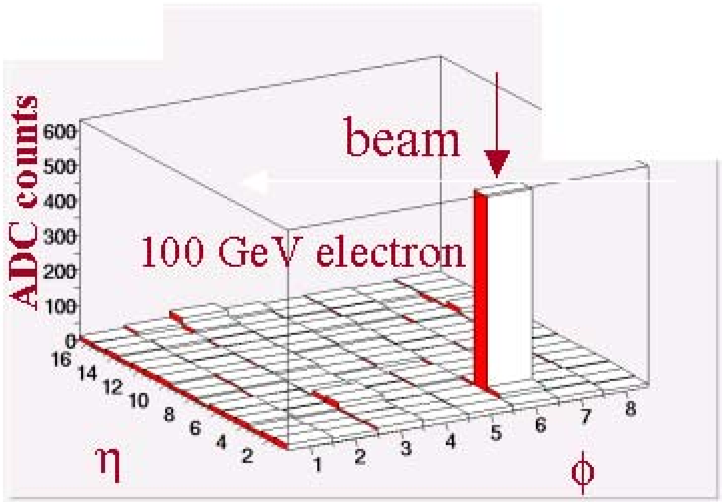
Events!

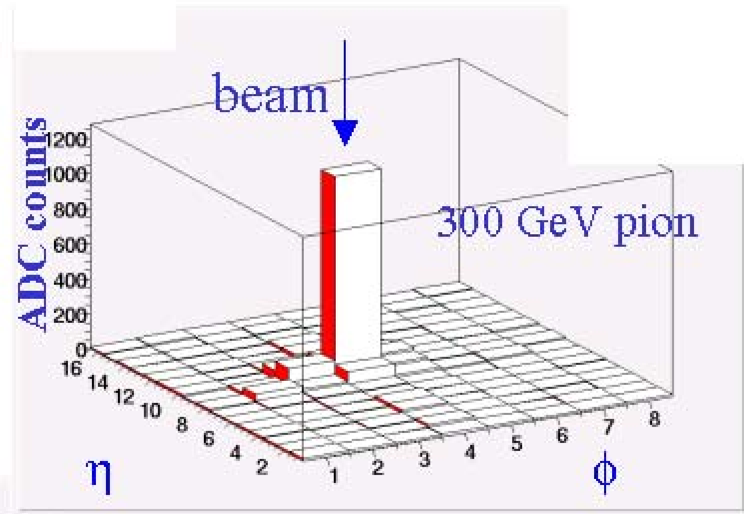
μ^-: 225 GeV

e^-: 20,30,50,100 GeV

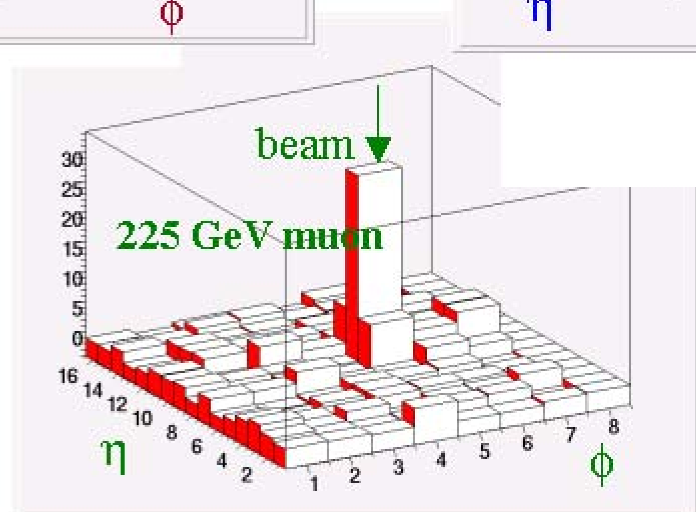
π^-: 20,30,50,100, 300 GeV

HADRON CALORIMETRY – 2002 TEST BEAM



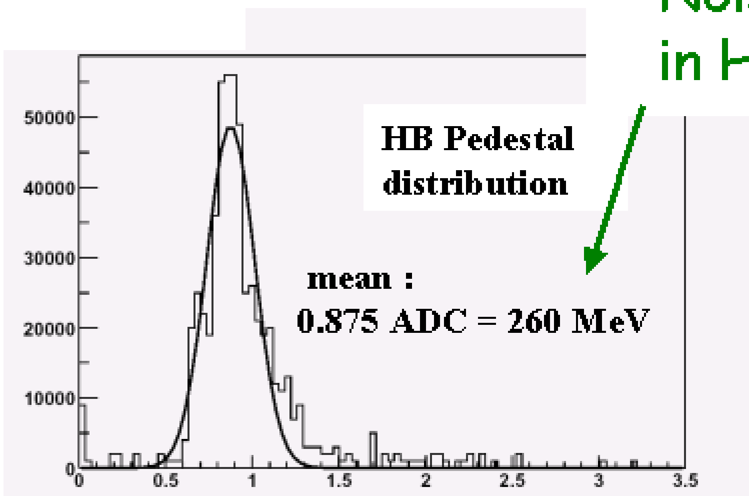


97% of electron contained in a 3x3 crystal matrix

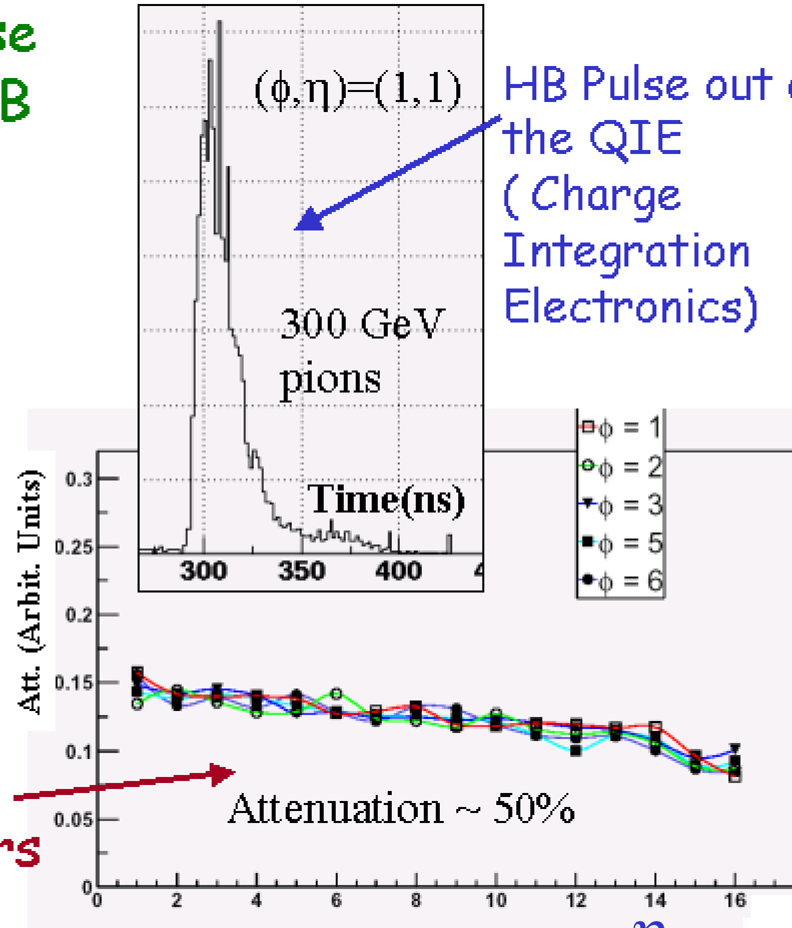


99% of energy contained in a 5x5 HB tower matrix

HADRON CALORIMETRY – 2002 TEST BEAM



Noise in HB

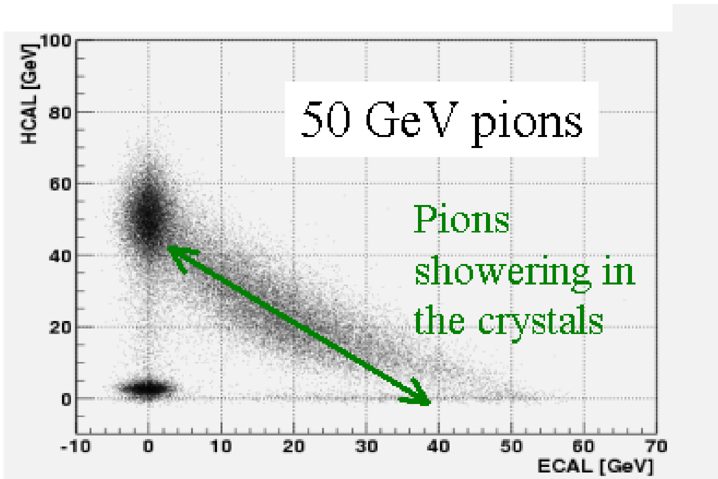


HB Pulse out of the QIE (Charge Integration Electronics)

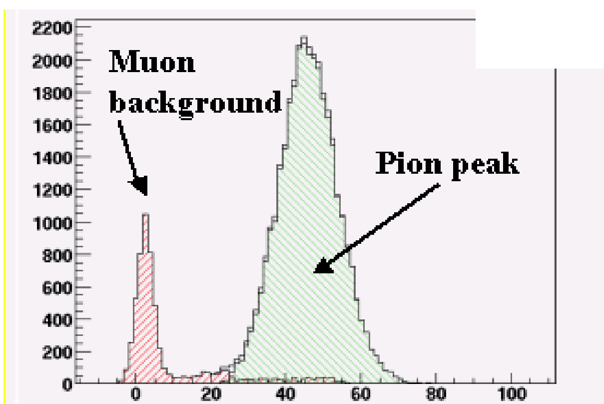
Response attenuation as the signal travel longer distances to the QIE from low η towers

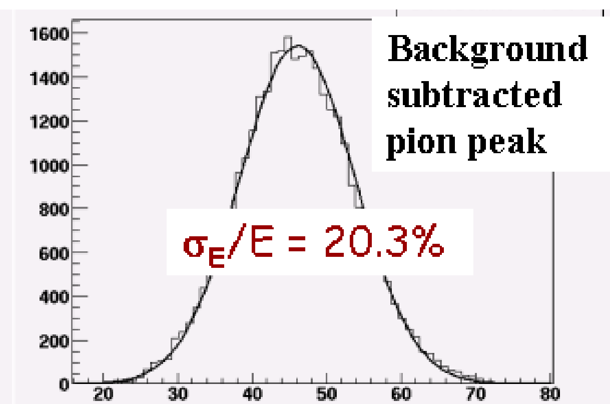
η

HADRON CALORIMETRY – 2002 TEST BEAM

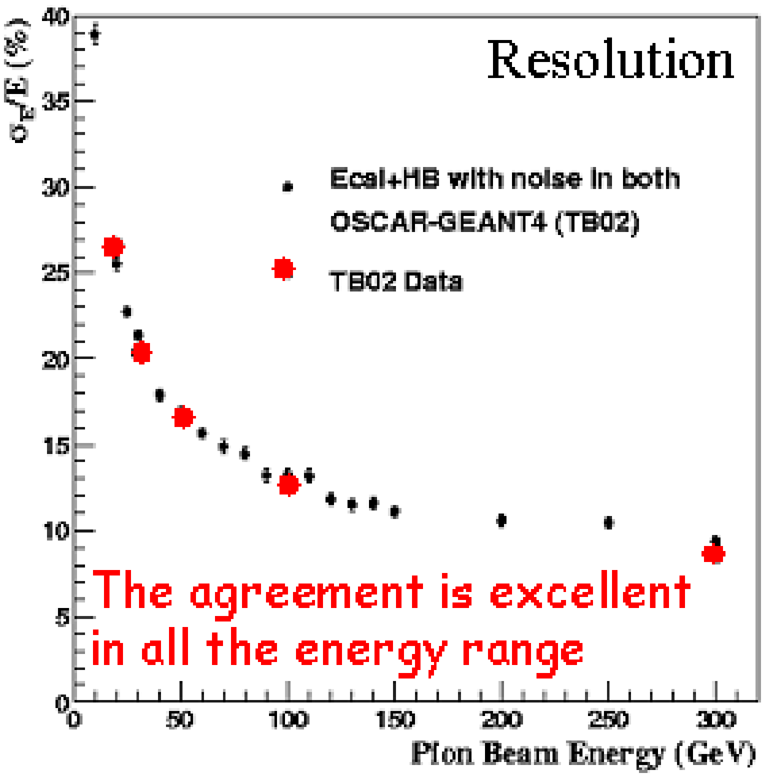


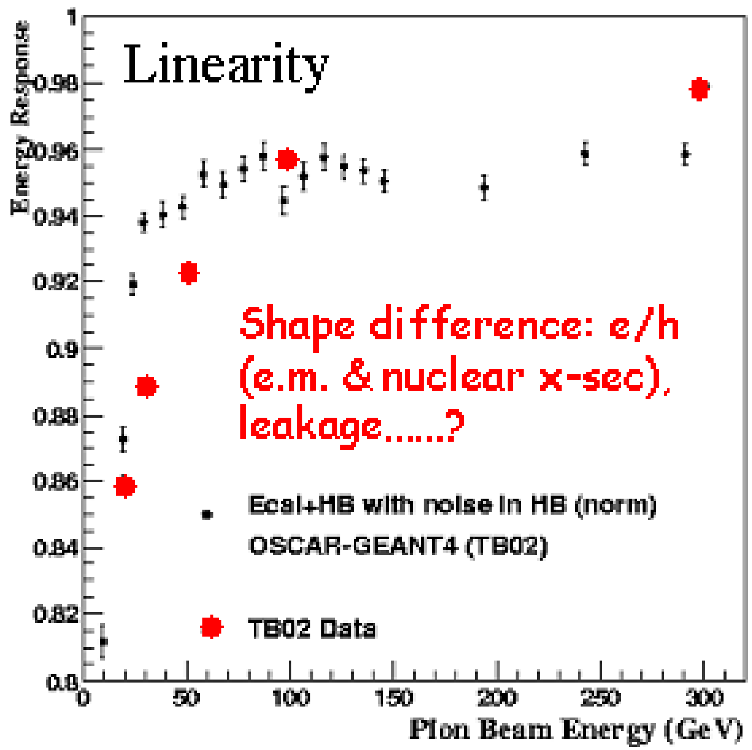
Data energy resolution for 50 GeV pions





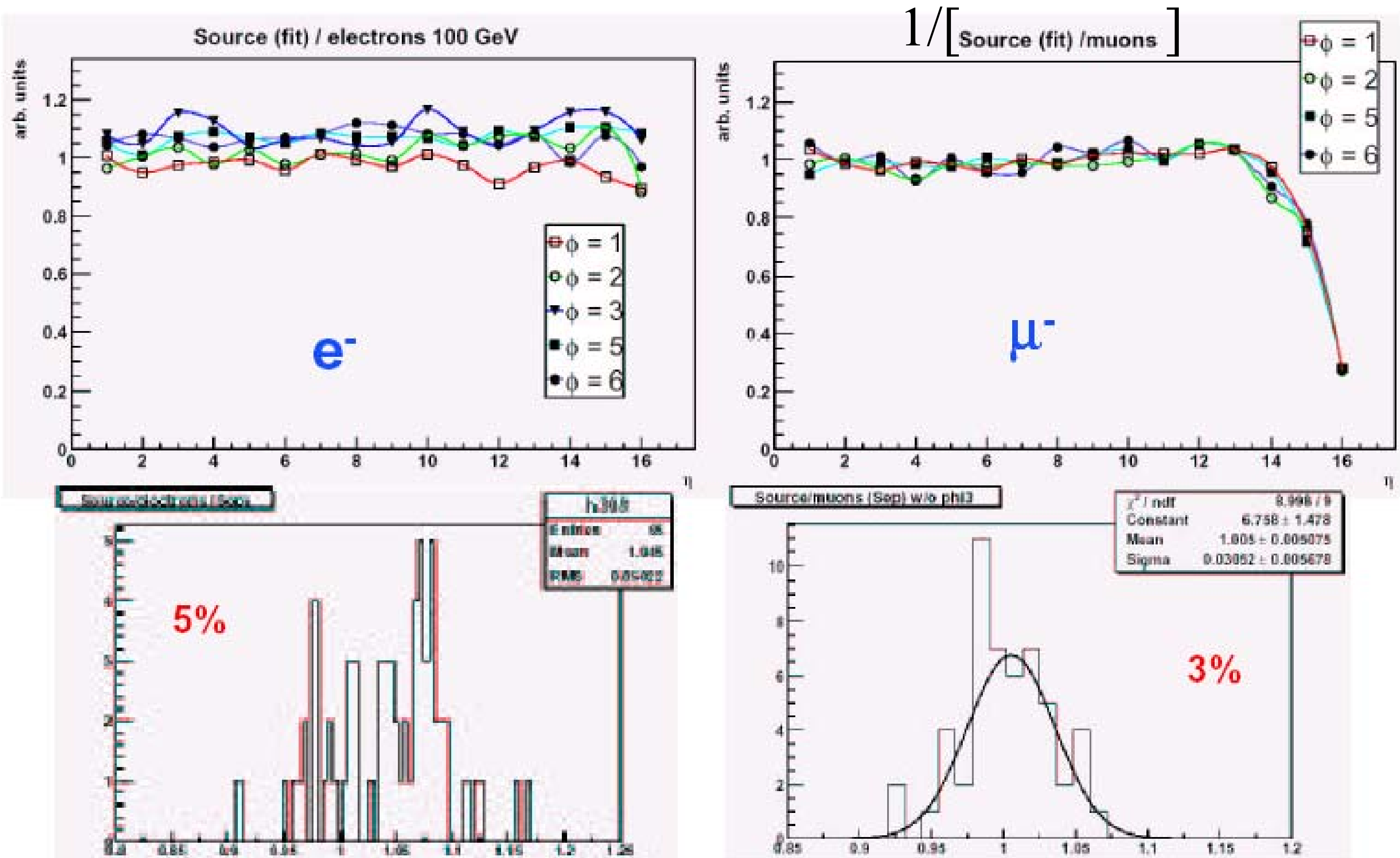
HADRON CALORIMETRY – 2002 TEST BEAM





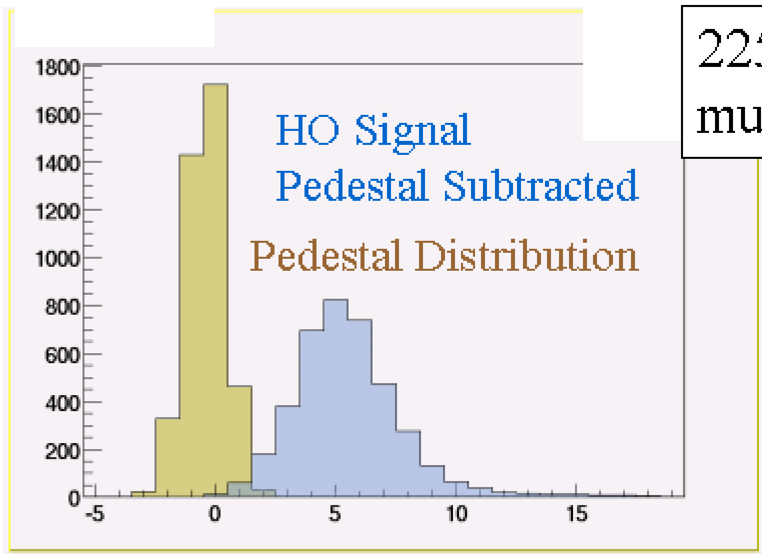
Data systematic error analysis in progress → Validate GEANT4 physics models

HADRON CALORIMETRY – 2002 TEST BEAM SOURCE VS. BEAM

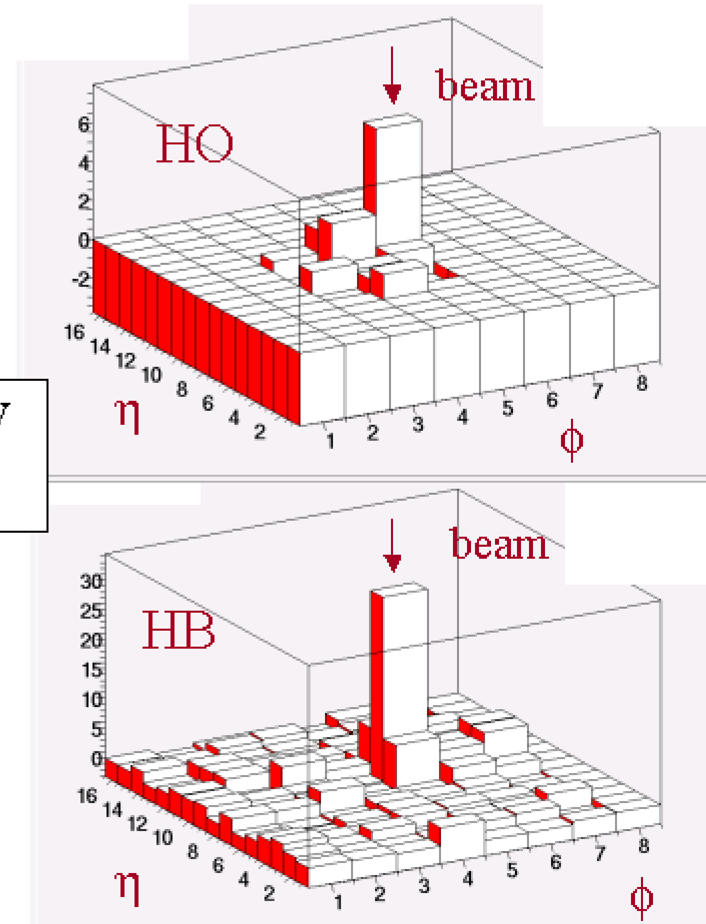


HADRON CALORIMETRY – 2002 TEST BEAM

Measurement of HO muon signal for RPC trigger (Goal: use the HO as part of muon trigger)

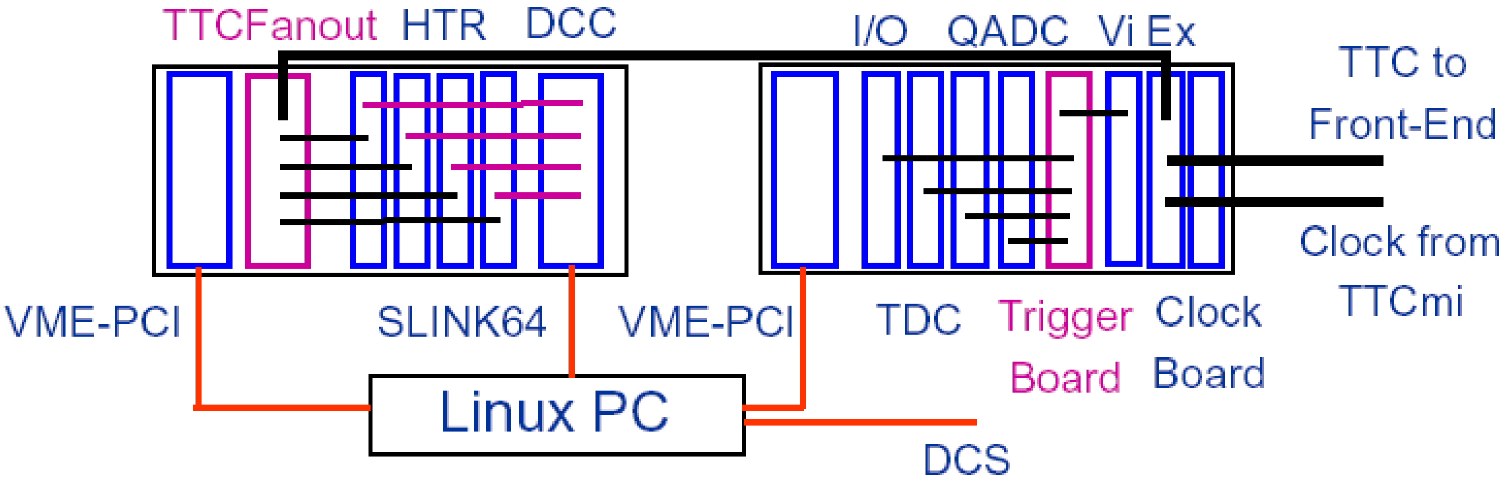


225 GeV muon



HADRON CALORIMETRY – CMS-TYPE X-DAQ

Sketch of 2003 Test Beam Readout (2×Copies: HB and HF):



Trigger Board and 6U Readout Crate (Complete and Tested)

TTCFanout and TTCrx Mezzanines (Complete and Tested)

DCC – SLINK64 – PC Readout will be tested soon

- **With hardware data formatting**

HTR Status – New Revision under development

Goals for the 2002 test beam -

- Operation of 144 channels at 33.79 MHz
- Absolute calibration using beam/source
- Determination of pulse shape
- Measurement of hadron attenuation
- Determination of Layer-0 weighting
- Measurement of muon signal (HO) for RPC trigger
- Control of HV, front end, and moving source

have been met!

Aims for 2003 HCAL Beam Tests

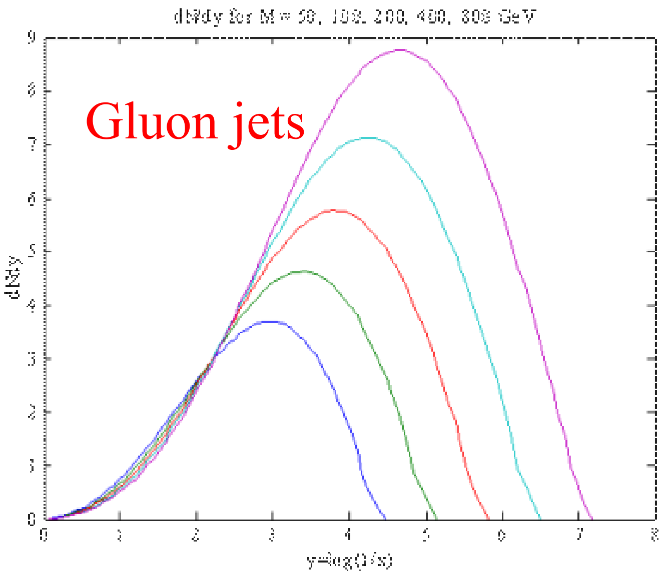
- Repeat TB02 tests with final components
- Local synchronisation in all channels (25 ns beam)
- HB-HE boundary (53^{o} gap)
- Calibration of several HF production modules
- Remote monitoring & analysis
- Test of CMS-type X-DAQ

LOW ENERGY BEAMS

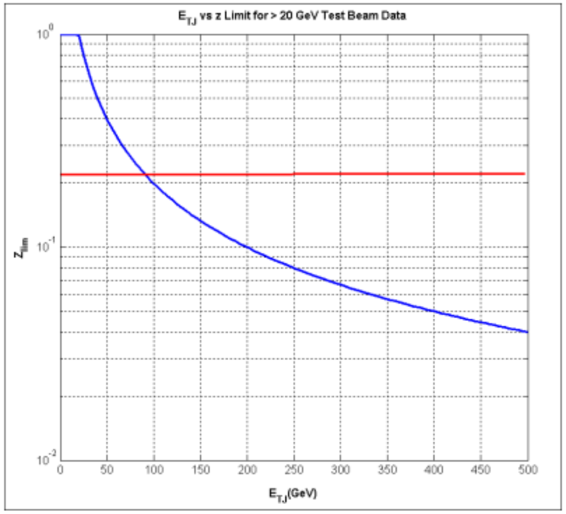
Data collected so far for HCAL & ECAL go down to 20 GeV

- *Request extension to 2-3 GeV in 2004 & 2006 to expose existing HCAL & ECAL modules to complete calibration of CMS calorimeters (π, e & μ)*

Physics motivation



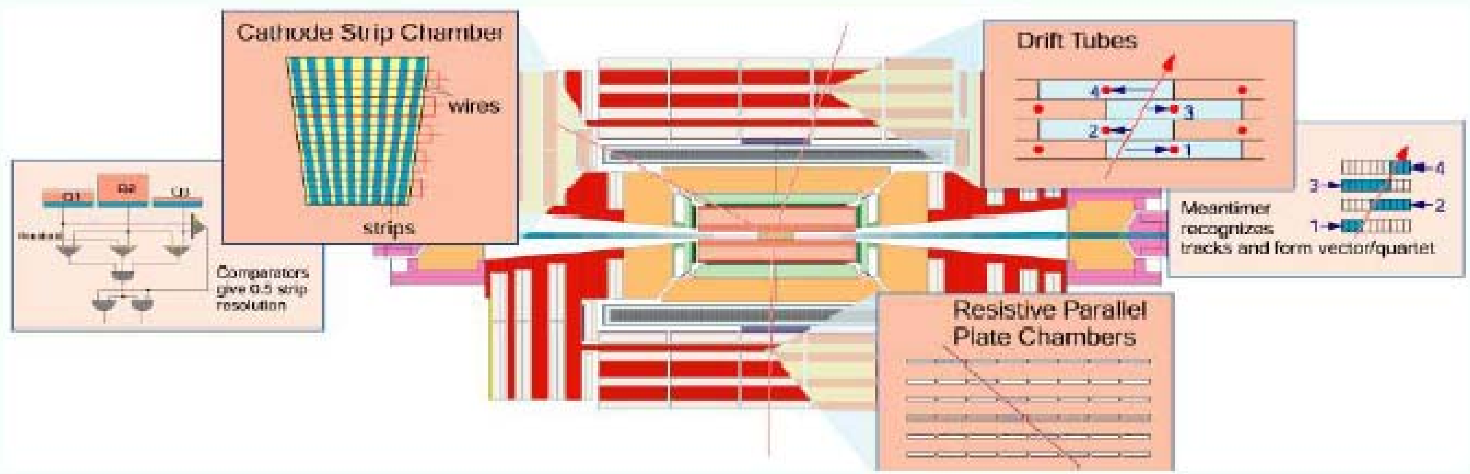
Distribution of y ≡ log(1/z)



Limit (blue) of jet fragment's z imposed by 20 GeV beam energy vs. E_T(jet)

+ Unreliability of MCs of hadronic jets at low energy

MUON SYSTEM



Three type of gaseous detectors:

- Drift Tubes in barrel region,
- Cathod Strips Chambers in endcap regions,
  - ◇ DT's and CSC's provide precise position measurements, ($\longrightarrow\ p_t^{\mu}$),
- Resistive Plate Chambers in both barrel and endcaps.
  - ◇ RPC provide precise bunch crossing (bx) id.
  - ◇ all the 3 sub-sistem contribute to the L1-trigger.

BARREL RPC AGEING TESTS IN GIF

GIF

4 Gap ($50x50\ cm^2$) under irradiation since June

3 Gap ($50x50\ cm^2$) with “new” bakelite under irradiation since September

2 RB1 under irradiation since January

We are continuously monitoring with and without Gamma SOURCE

Currents
Rates
Efficiency
Cluster size

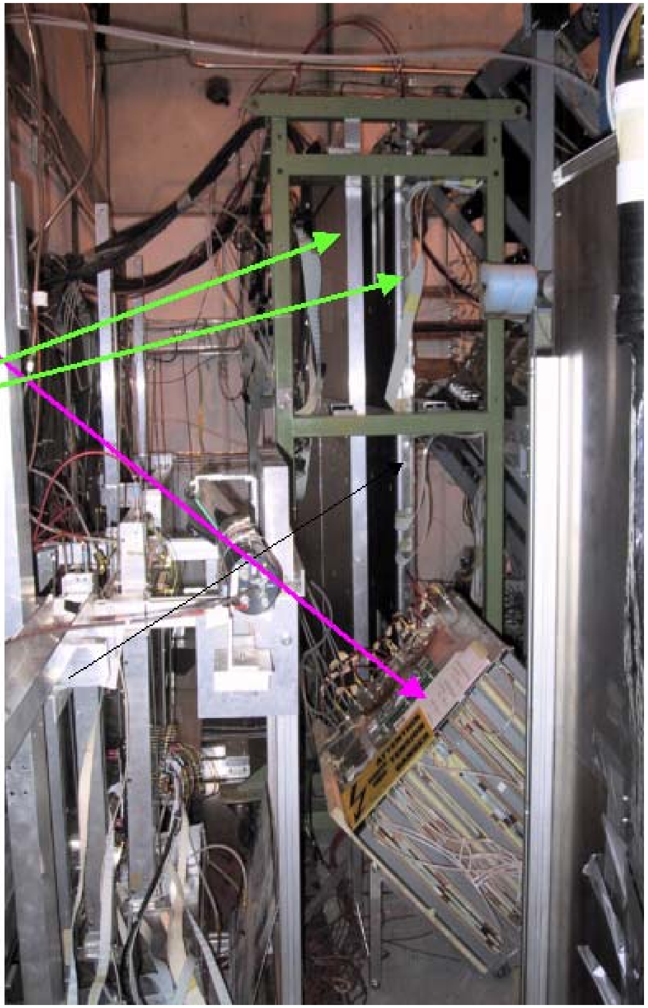
Rate: **$30\ Hz/cm^2$ (safety factor included)**

Average total charge: **30 pC**

Effective operation time: **$5x10^7$ s (10 LHC years)**

The total expected charge is be **$5\ 10^{-2}\ C/cm^2$**

c.f. RE need $0.1 – 1\ C/cm^2$

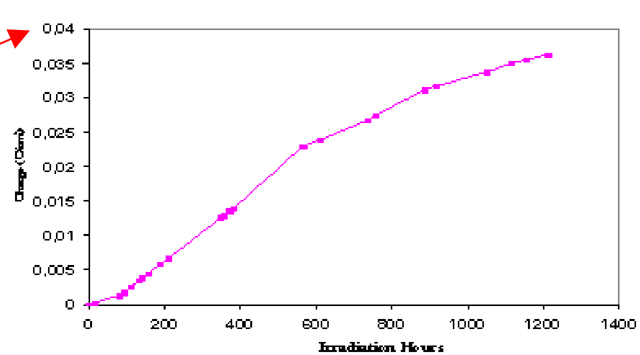


BARREL RPC AGEING TESTS IN GIF

Accumulated charge

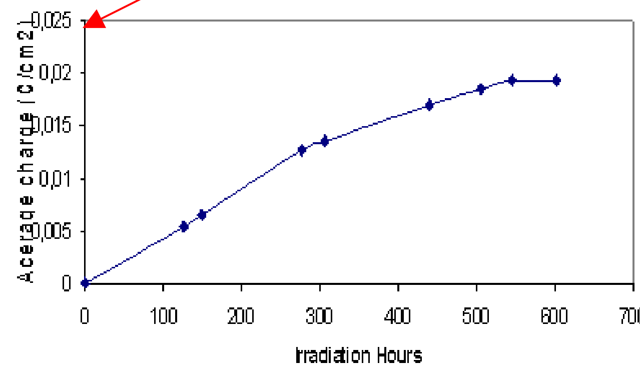
Small gaps "old bakelite", 7 CMS years

0.04

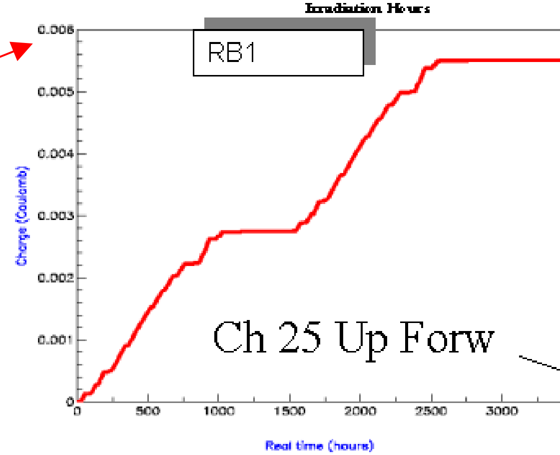


0.025

Small gaps "new bakelite", 4 CMS years



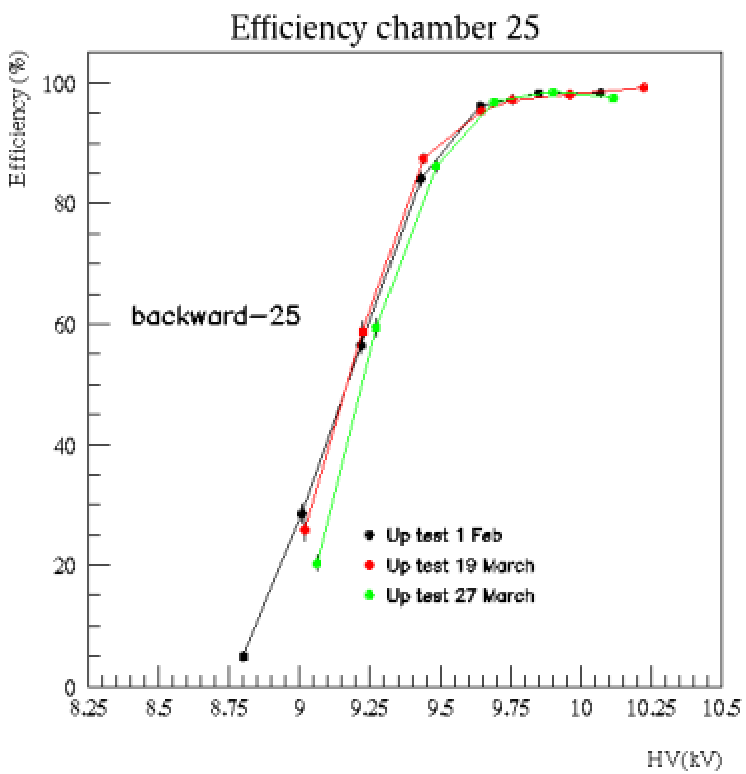
0.006

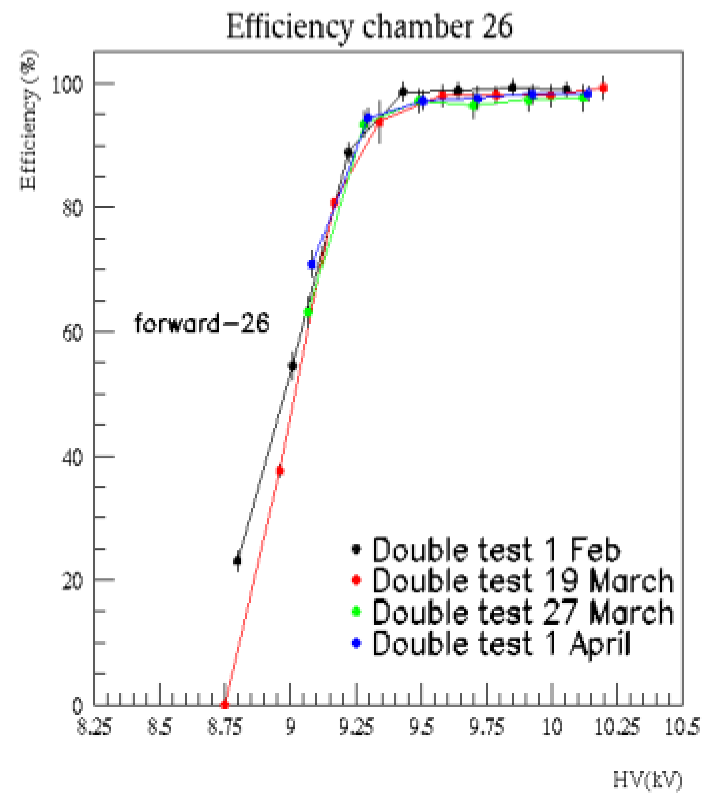


Less irradiated gap

We expect to reach the barrel limit end of summer for the small gaps and at the beginning of next year for RB1s

BARREL RPC AGEING TESTS IN GIF

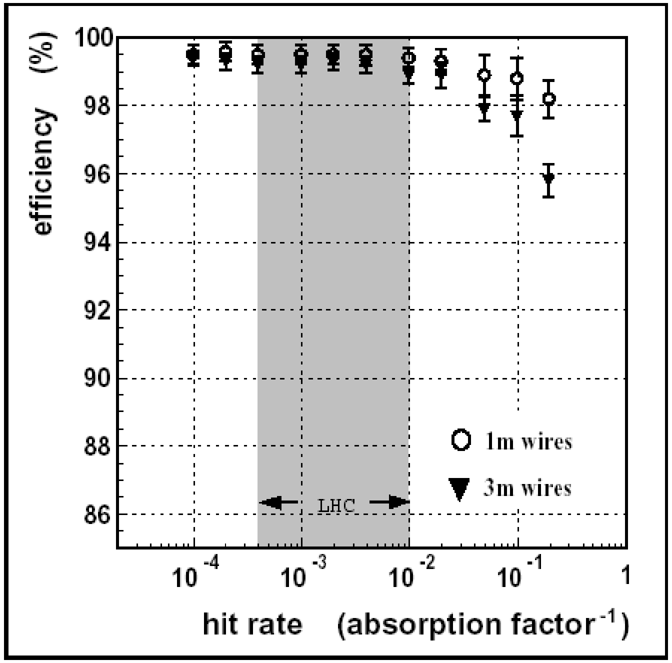




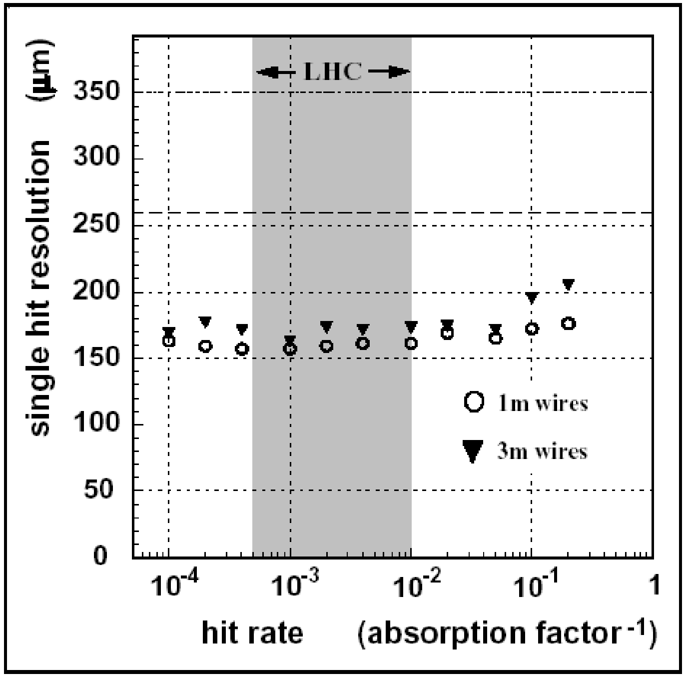
Cosmic trigger with source OFF
Test efficiency with X5 μ beam during 2003 SPS run

MUON SYSTEM QUALITY CONTROL @ GIF

During production QC with cosmic muons.
Subsample of chambers studied in testbeam.
→ Performance of individual chambers known at start-up.

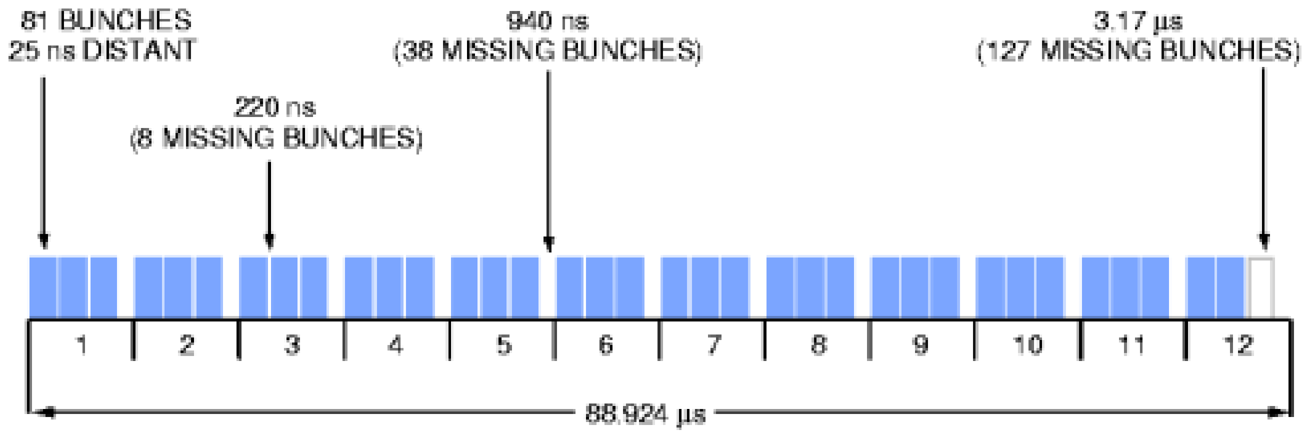


Efficiency of single drift cell



Single hit resolution

- **Track segments from different CSC modules that belong to the same event must be tagged with the same BXN.**
- **We do this by using anode timing and the known LHC bunch structure.**



LHC Bunch Structure

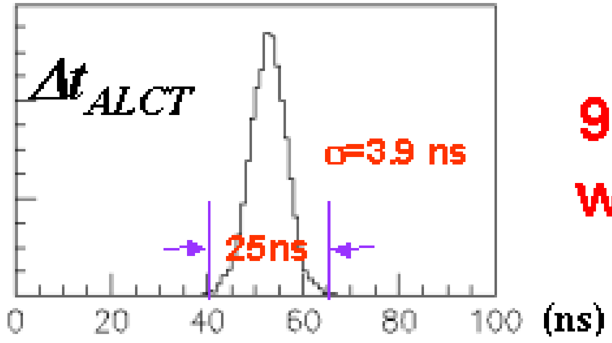
CSC ANODE TIME RESOLUTION

Time between collision and ALCT generated in a given CSC module:

$$t_{ALCT} = t_{TOF} + t_{CSC} + t_{Prop} + t_{Electronics}$$

- t_{TOF}: Time of flight from IR to chamber
- t_{CSC}: Response time of Chamber
- t_{Prop}: Propagation time to FE electronics
- $t_{Electronics}$: Processing time of FE electronics

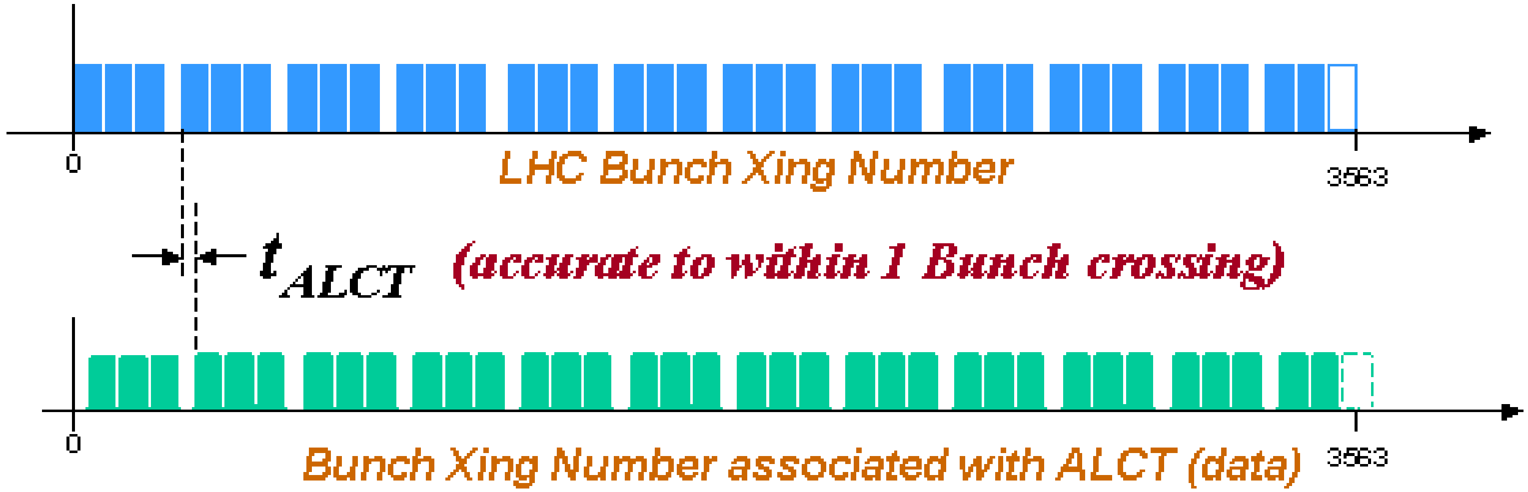
Test beam measurement of the spread in t_{ALCT}



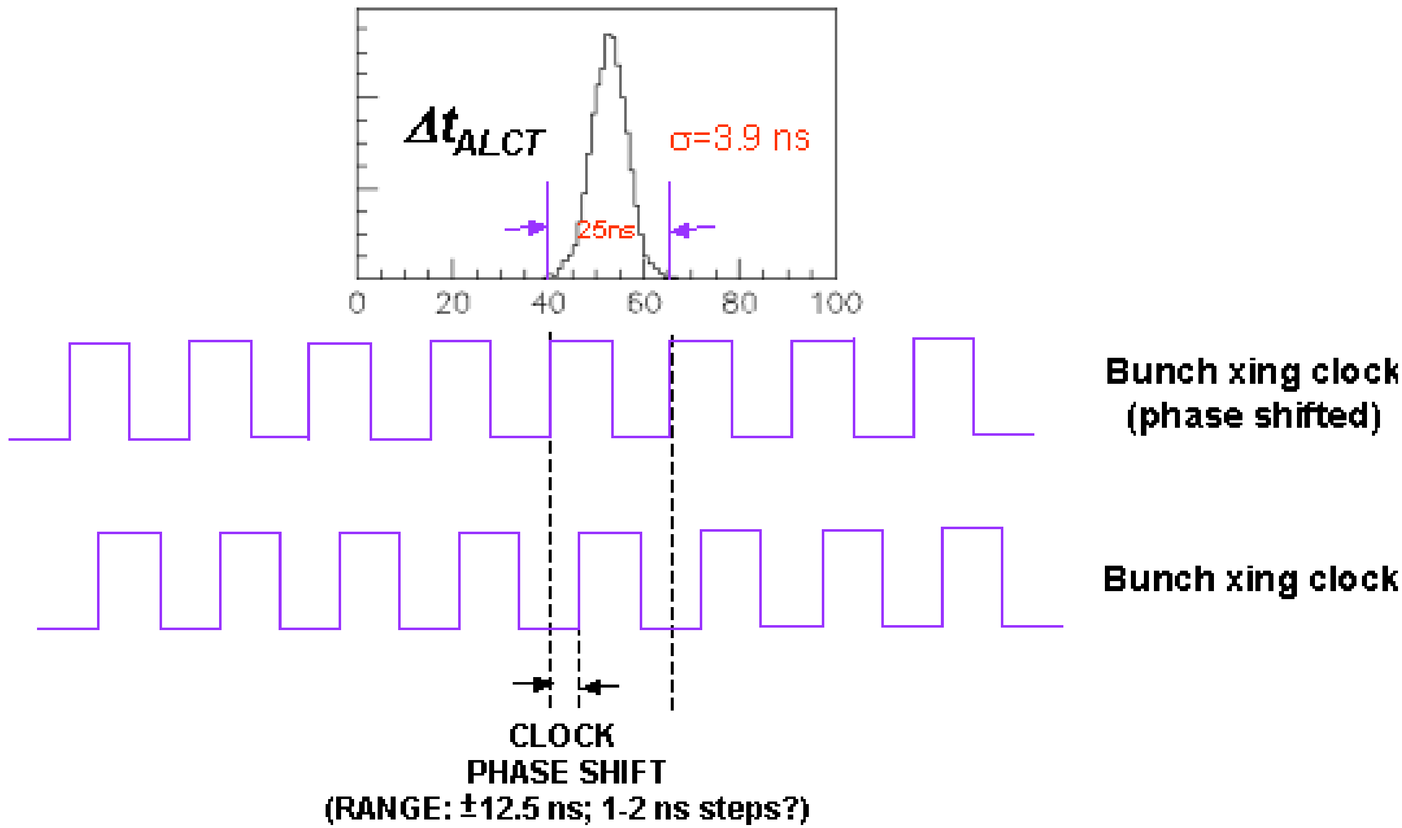
99% falls within window of 25 ns

BXN ID USING ALCT

- Take data with LHC like-beam
- Readout *anode LCT bunch crossing number* whenever muon trigger fires
- Plot *anode LCT bunch crossing number* and compare with master LHC bunch crossing structure



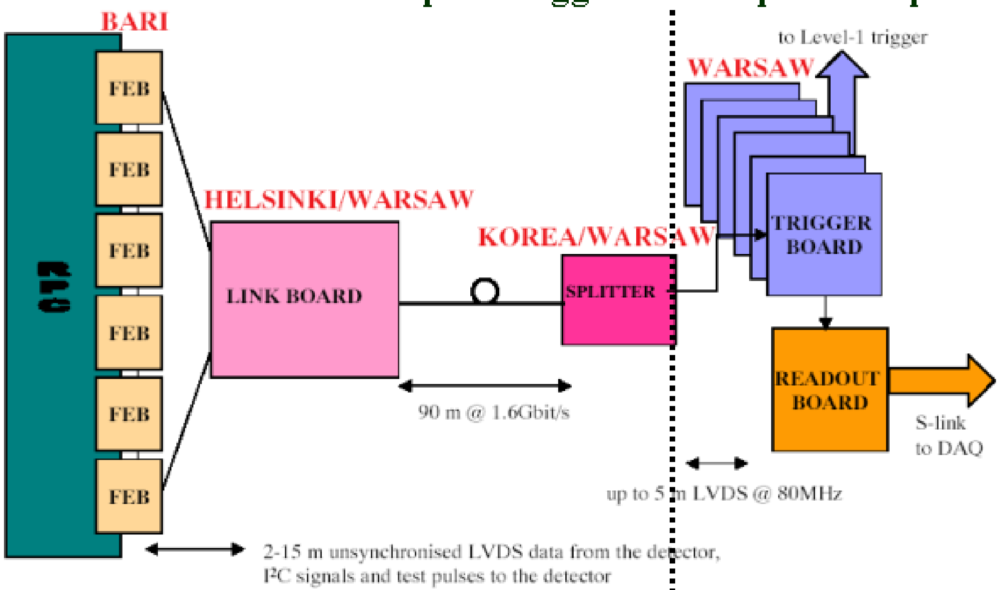
FINE ADJUSTMENT OF CSC CLOCK PHASE



Tune clock phase until BXN distribution is sharp

RPC TESTS WITH LHC-TYPE BEAM (MAY-JUNE 2003)

Aim of the test is to check the complete trigger chain up to the splitter board level



4 chambers from series production will be tested

We will test

-final interface FEB - LB (data, test pulses, I2C)

-almost final version of LB and Control Board

-test procedures

- data quality control (by the means of on line histogram at the level of LB).

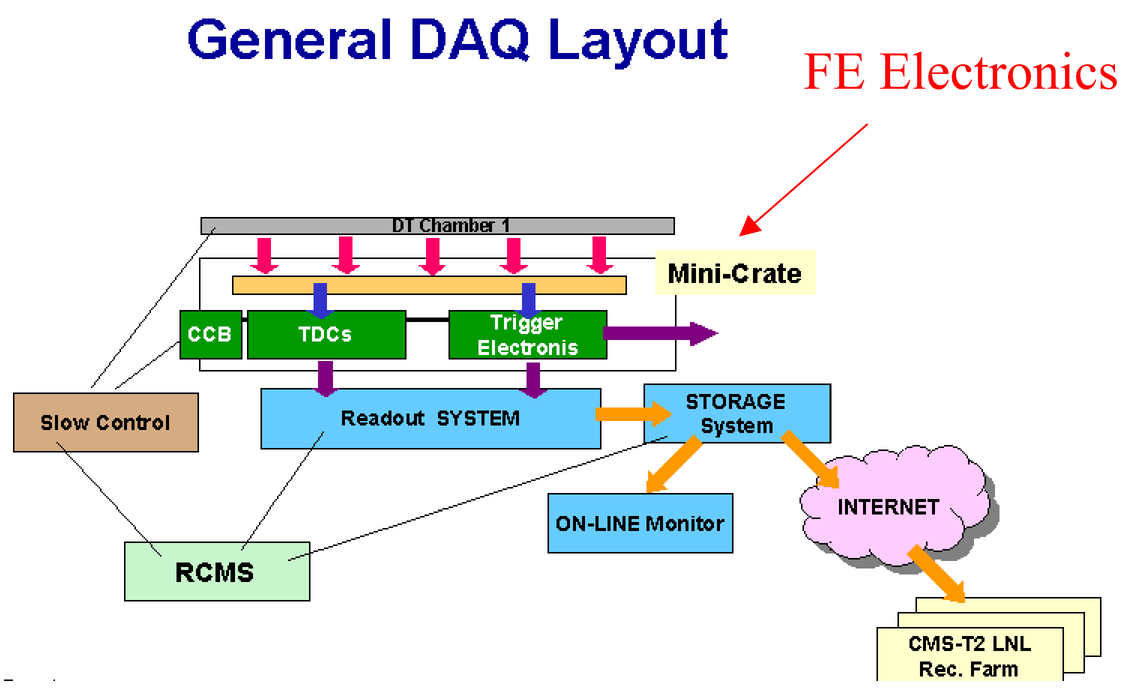
DT TESTS WITH LHC-TYPE BEAM (MAY-JUNE 2003)

First tests in beam of read-out & trigger electronics on fully-equipped DT chamber

Aims:

• Read-out chain – from TDCs to storage, monitor, online data analysis

• Trigger chain and response



Move to CMS-type x-DAQ

FUTURE USE OF THE GIF

CMS expects continued use of GIF (source & particle beams)

- Beyond the intended closure of the West Area secondary lines in 2004
- Experiment will be significantly inconvenienced if solution is not found for GIF's replacement

Aims:

- Certification on a sampling basis muon detectors from the series production.
- Continuation of muon detector ageing tests (in particular the RE chambers).
- ECAL crystal response to an electron beam (X5) before and after irradiation.
- Establish use of UV laser to excite ECAL crystal scintillation as means to follow any change in crystal production parameters (if not already understood by 2004)

2003 CMS SCHEDULE

CMS Main Users

Beam	Subdetector																	
			May			June				July				August		September		
		19	26	2	11	18	26	2	9	17	23	30	7	13	20	28	3	
	Tracker	■	■													■	■	
X5	RB	■	■															
	CSC	■	■															
GIF	RPC				■		■								■			
	ECAL					■				■		■						
	HCAL	■	■															
H2	HF/HCAL							■	■	■	■	■	■	■	■	■		
	Pixels				■	■	■											
	SiBT										P	P						
H4	ECAL										■	■	■	■	■	■	■	
	CASTOR						■											
H6	DT	■	■															

ECAL: 3 weeks of electron beam at H4 during heavy-ion run in Sept./Oct.

PS East Hall: one-shot tests on Si modules

CMS TEST BEAM PROJECTIONS

With respect to CMS Master Schedule V33

/	2004	2006
XS		
Tracker	2 (+1 Wk 25 ns)	-
Total XS	2 (+1 Wk 25 ns)	-
GIF		
DT	2 (+1 Wk 25 ns)	1
RPC	2 (+1 Wk 25 ns)	1
CSC	2 (+1 Wk 25 ns)	1
ECAL	2	-
TOTAL GIF	6 (+1 Wk 25 ns)	3
H2		
HCAL/ECAL	3 (Low E)	3 (Low E)
HF	4	-
Pixels	4	2
SiBT	2	2
TOTAL H2	13	7
H4		
ECAL	20	15
CASTOR	2	2
TOTAL H4	22	17
PS East Hall – T7 Irrad		
Radiation Monitoring	3	-
TOTAL T7 Irrad	3	-

[Weeks]

ECAL 2005
Commissioning of SMs without beam in H4

Technical services requested to remain on

RPC ageing tests in the GIF to continue up to LHC start-up (even in 2005)

CONCLUSIONS & OUTLOOK

•Test beams have been shown to be vital in all phases of the development of the CMS detector.

•Test beam activities prior to 2007 required to carry-out performance checks and QC of detector & DAQ components from the series production and to calibrate the calorimeters.

•Beyond 2006:Sub-detector modules available to check stability; CMS improvements and upgrades

•Availability of testbeam facilities also required to tackle unforeseen problems.

•Additional requests:
- Further SPS running with the 25 ns bunch structure
- Low energy beams at H2 for calorimeter calibration
- Continuation of GIF

ACKNOWLEDGEMENTS

CMS would like to express its deep appreciation to AB Division for the reliable and efficient operation of the accelerators and secondary beamlines over the years and to the SPS/PS Physics Coordinators for their continuous support.