CMS

Compact Muon Solenoid

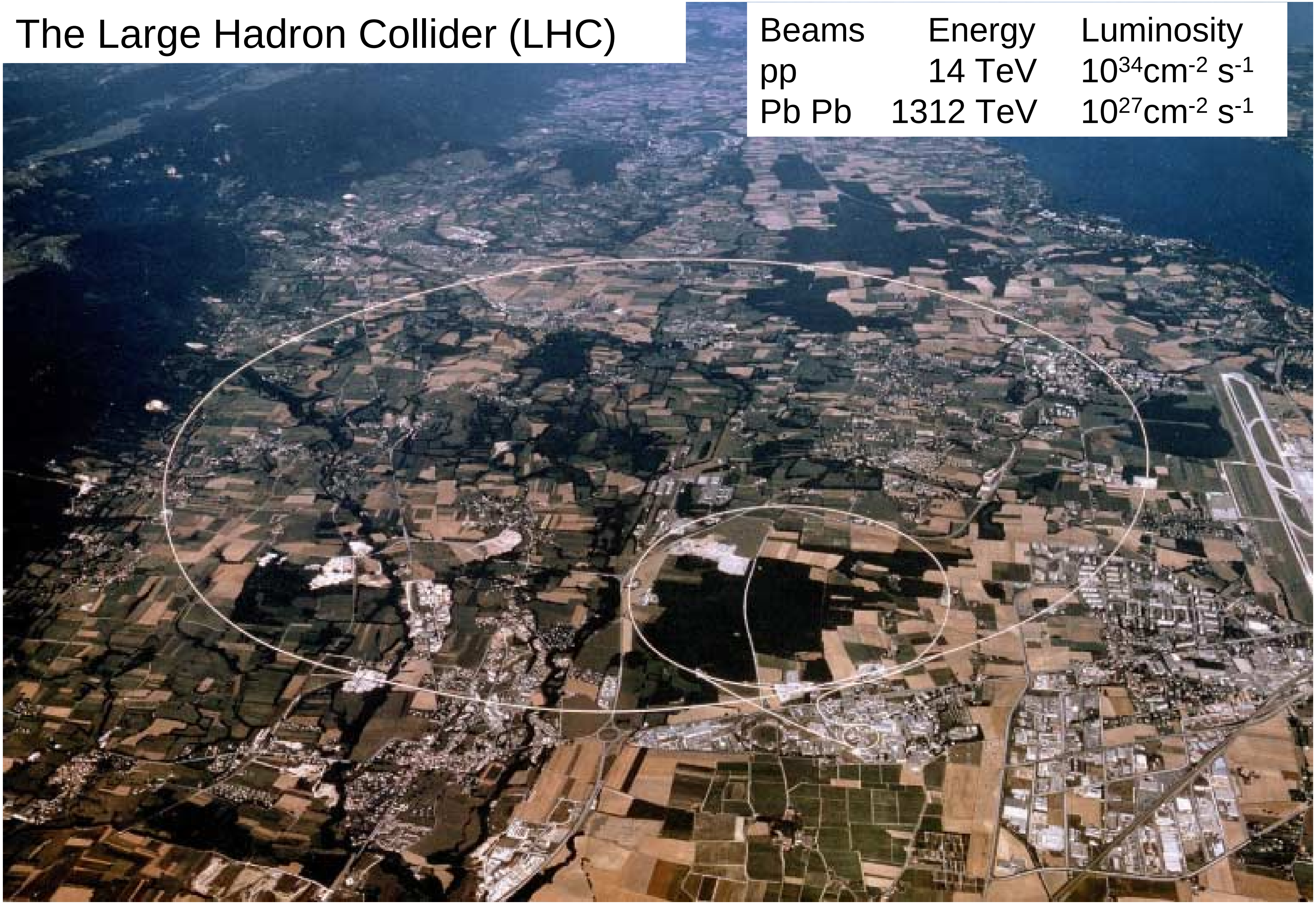
The Compact Muon Solenoidal Detector at LHC

M. Della Negra/CERN

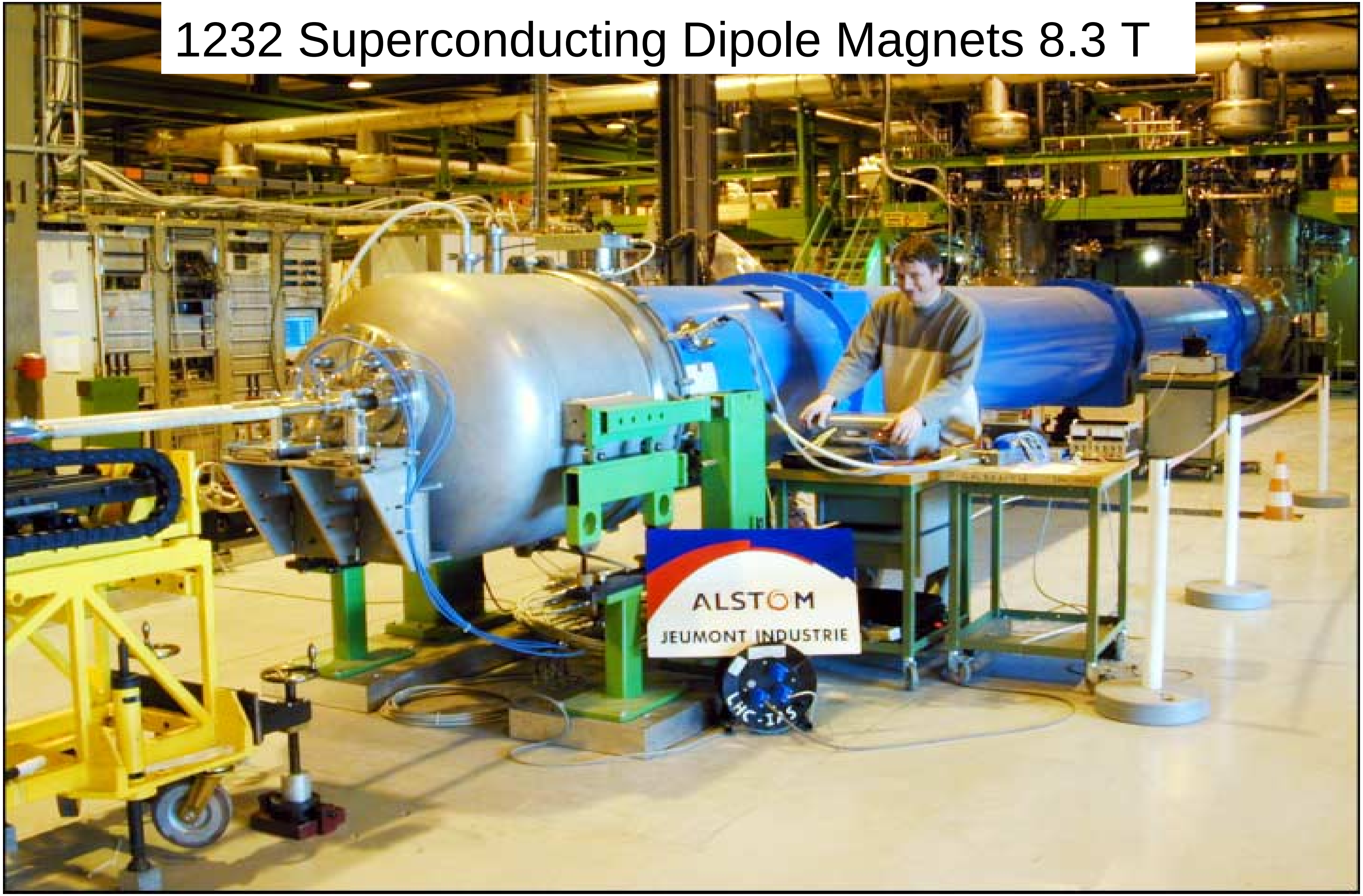
Desy, 10 June 2003

The Large Hadron Collider (LHC)

Beams	Energy	Luminosity
pp	14 TeV	10^{34}cm^{-2} s^{-1}
Pb Pb	1312 TeV	10^{27}cm^{-2} s^{-1}



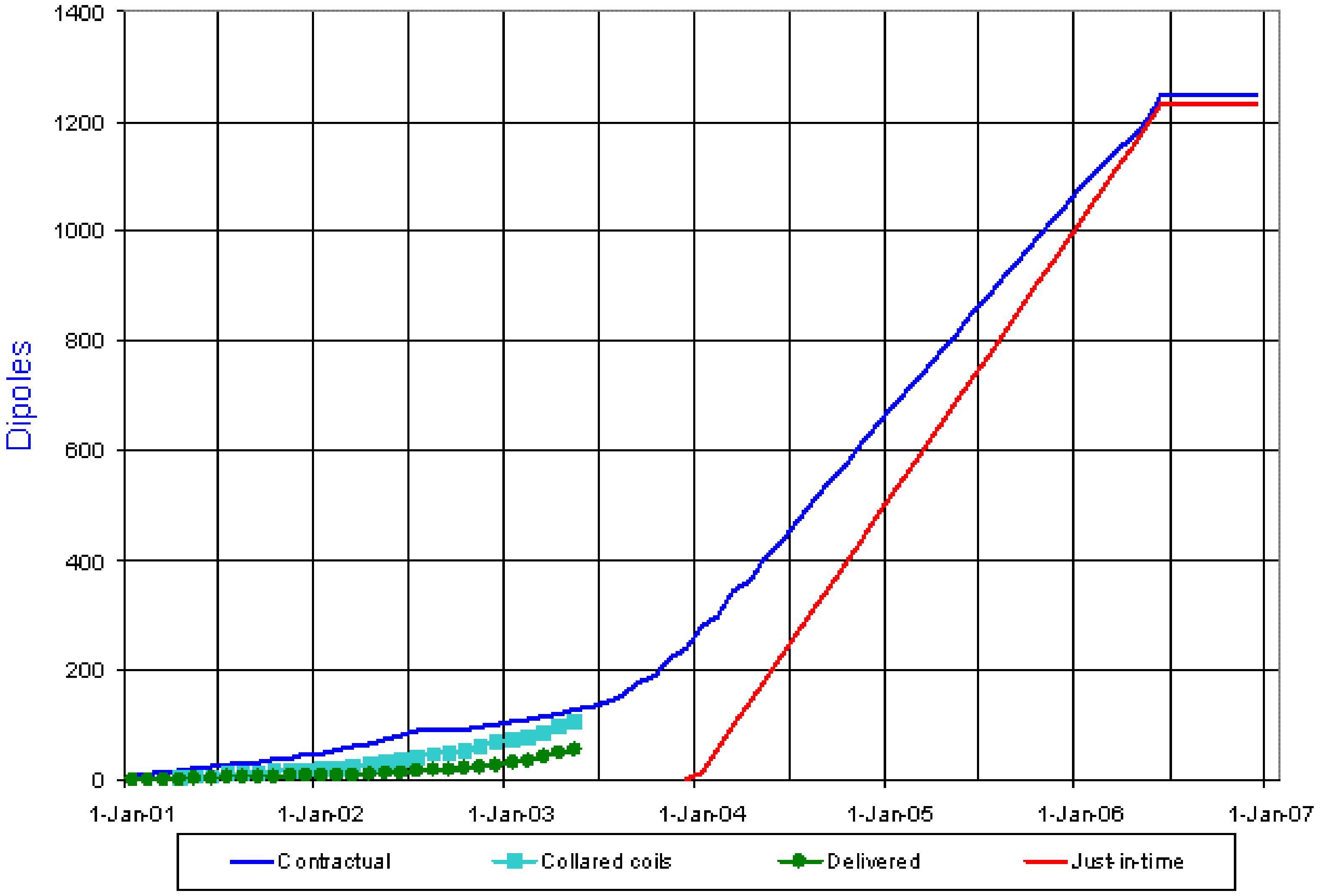
1232 Superconducting Dipole Magnets 8.3 T



LHC Progress Dashboard

Accelerator
Technology
Division

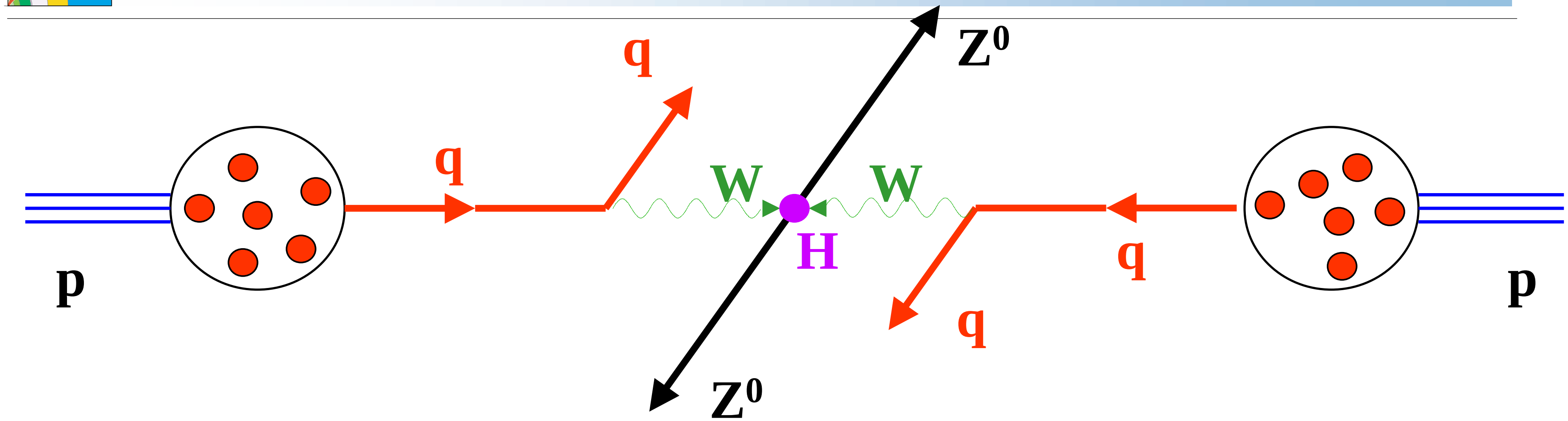
Dipole cold masses



Updated 31 May 2003

Data provided by P. Lienard AT-MAS

Higgs Production in pp Collisions

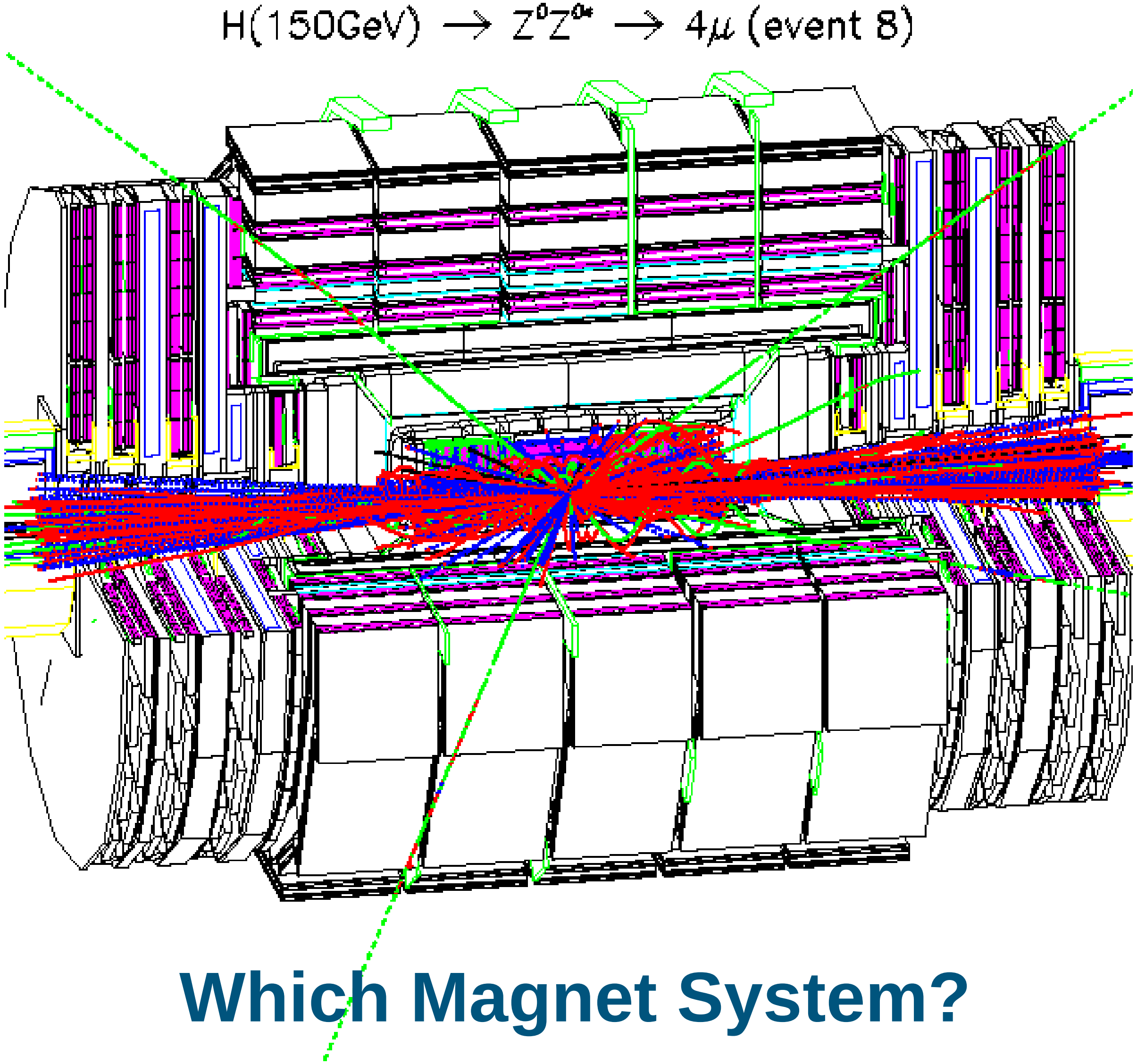


M_H ~ 1000 GeV

- ➥ E_W = 500 GeV
- ➥ E_q = 1000 GeV (1 TeV)
- ➥ E_p = 6000 GeV (6 TeV)

⇨ **Proton Proton Collider E_p = 7 TeV @ 10^{34}cm^{-2}s^{-1} Luminosity**

The Higgs into four Muons Problem

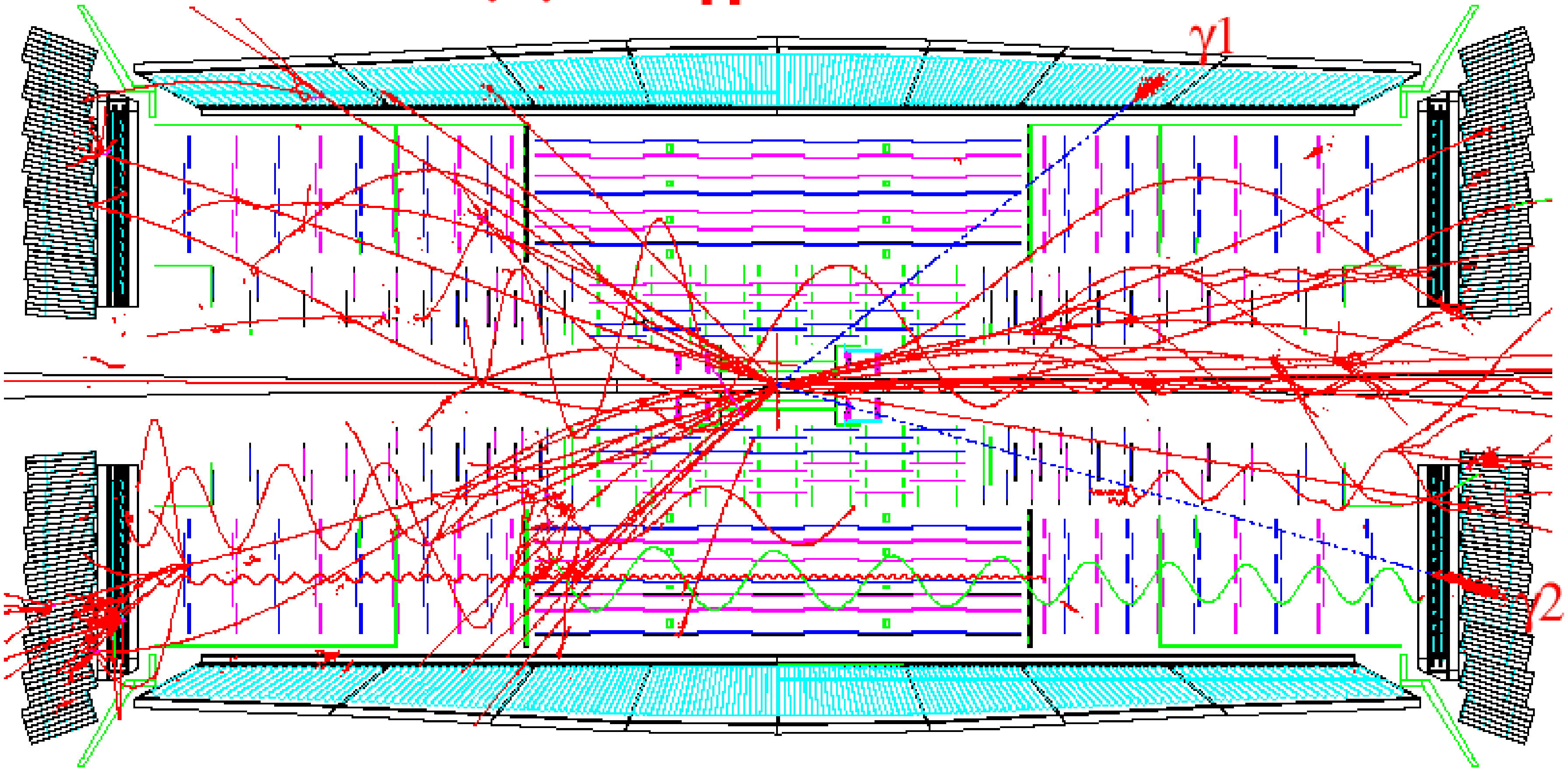


$H(150GeV) \rightarrow Z^0 Z^{0*} \rightarrow 4\mu$ (event 8)

Which Magnet System?

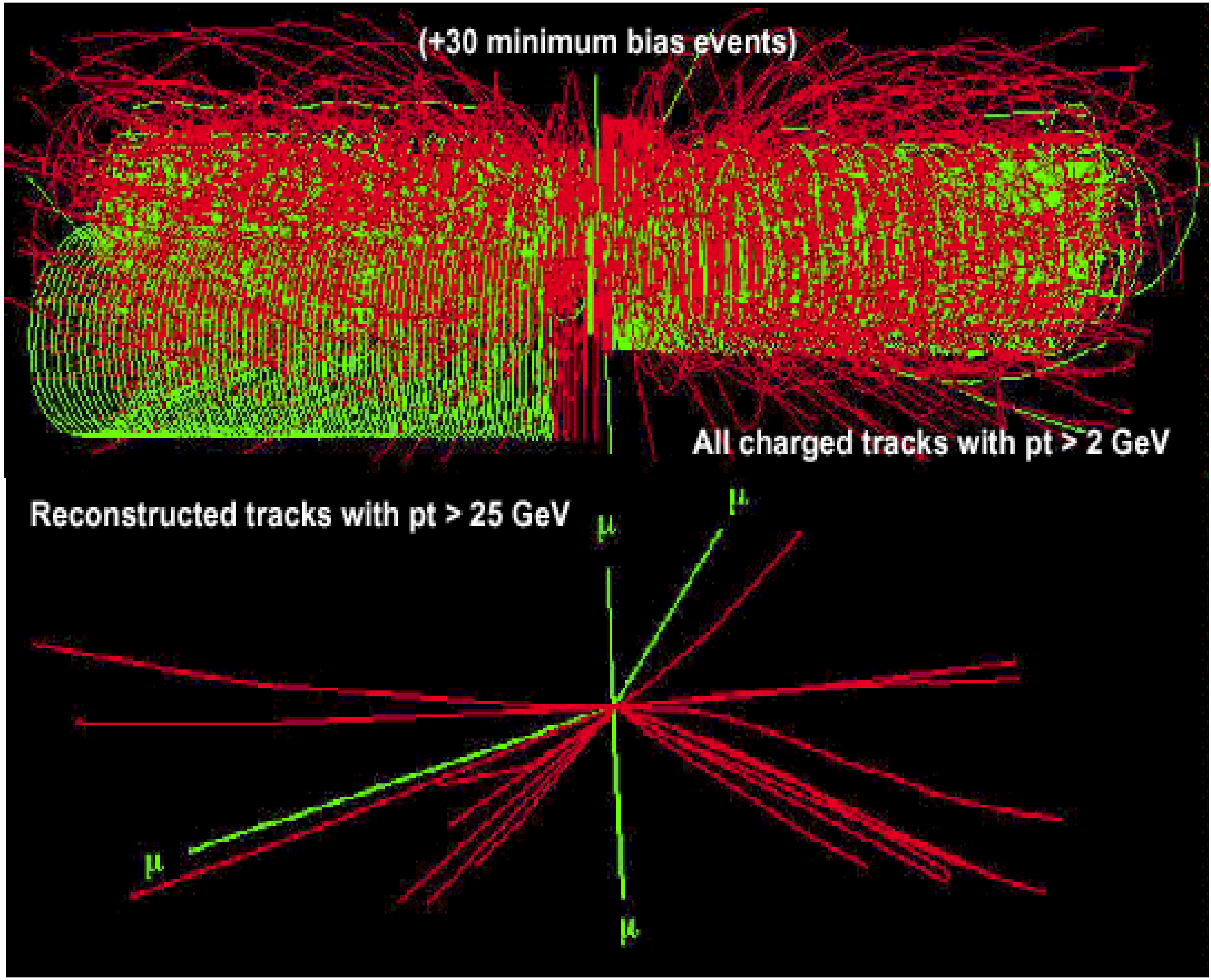
The Higgs into two Photons Problem

$H \rightarrow \gamma\gamma$, M_H = 115 GeV



A precise e/γ Calorimeter @ 10^{34} ?

The Tracking Problem



At 10^{34} one crossing every 25 ns.

30 Min Bias events superimposed per crossing

Is Tracking possible at high luminosity?

Detector Design Priorities

1. A robust and redundant Muon system

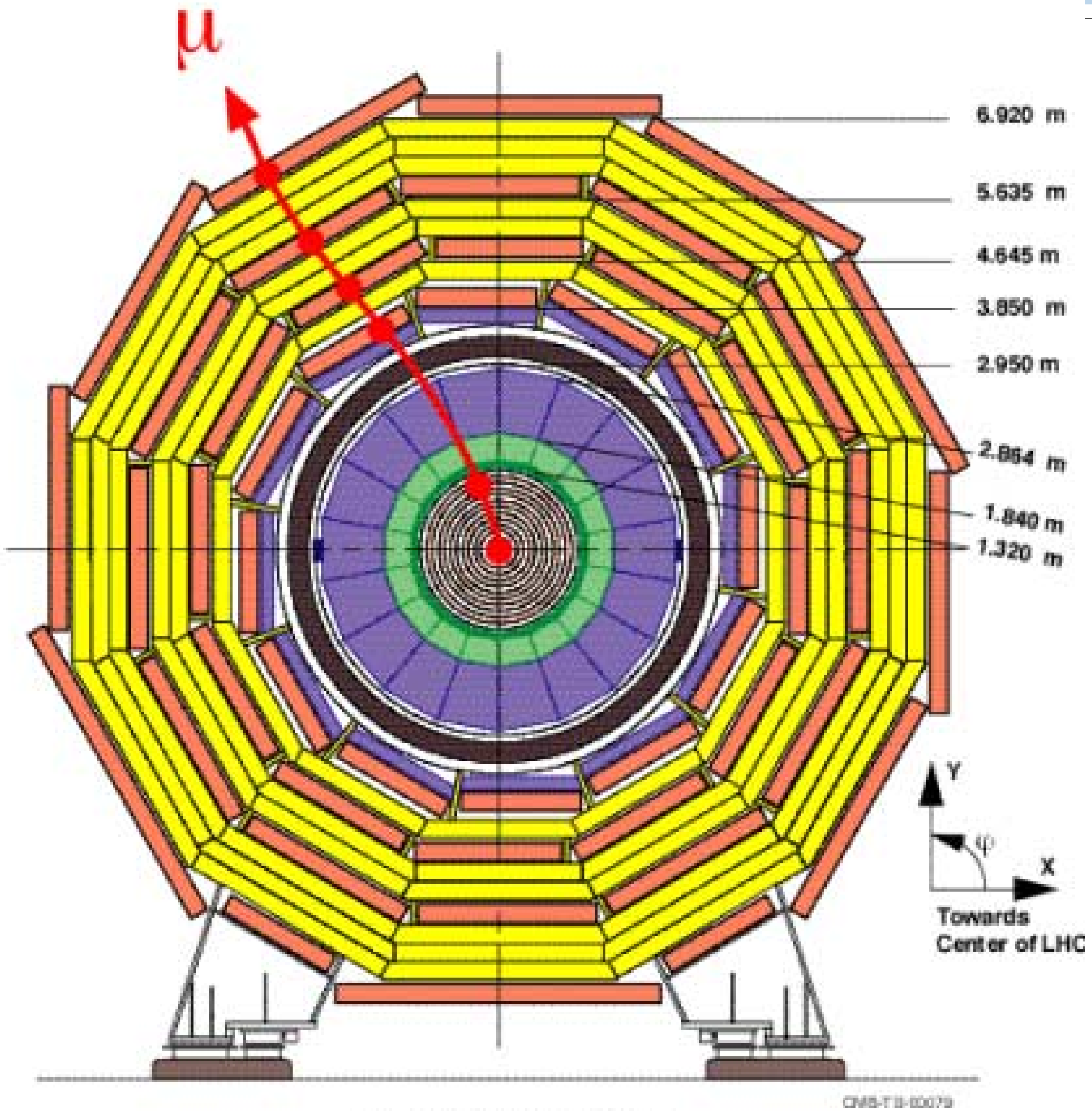
2. The best possible e/γ calorimeter consistent with 1.

3. A highly efficient Tracking system consistent with 1. and 2.

4. A hermetic calorimeter system.

5. A financially affordable detector.

noid (CMS)



Transverse View

Strong Field 4T

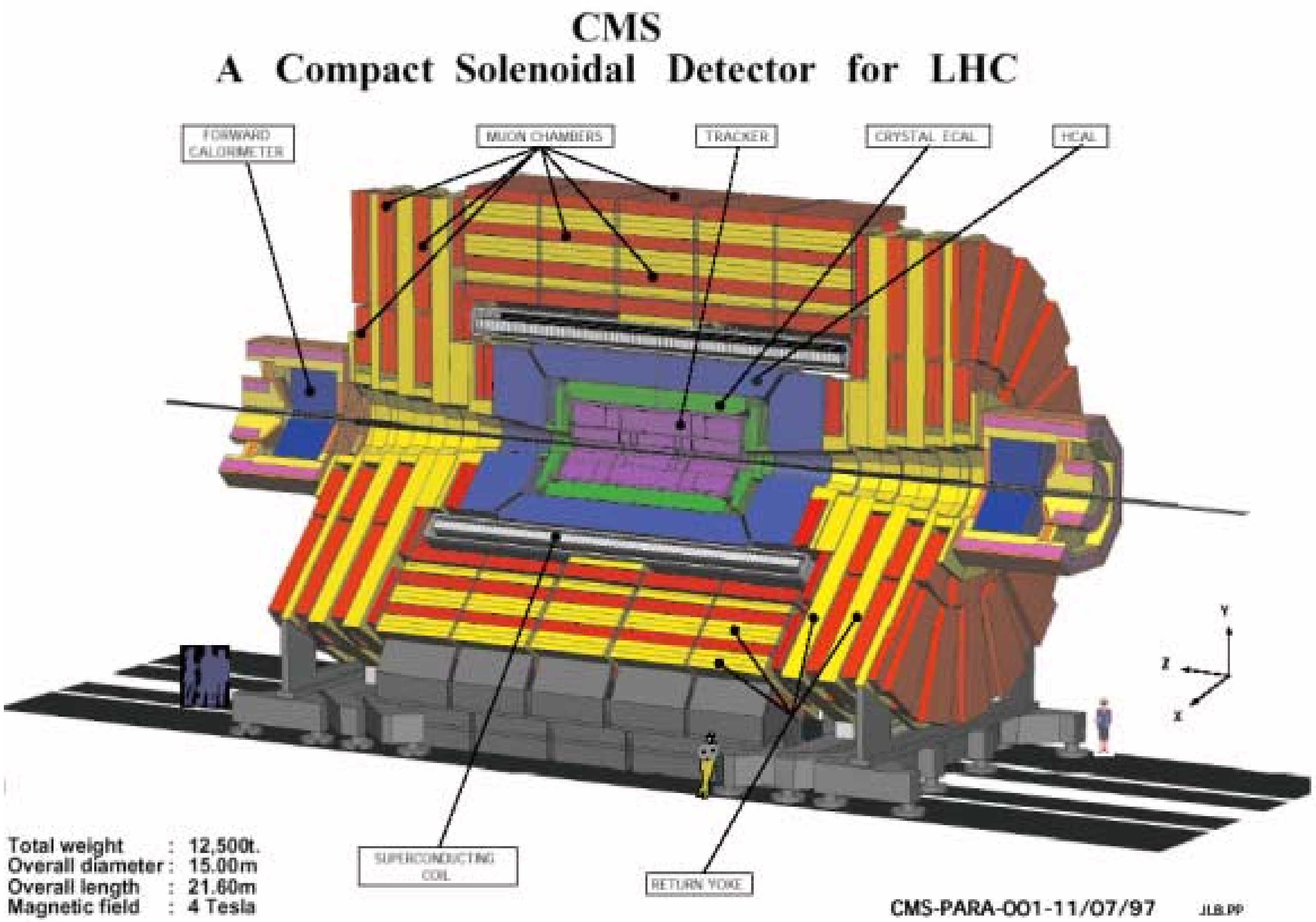
Compact design

Solenoid for Muon P_t trigger in transverse plane

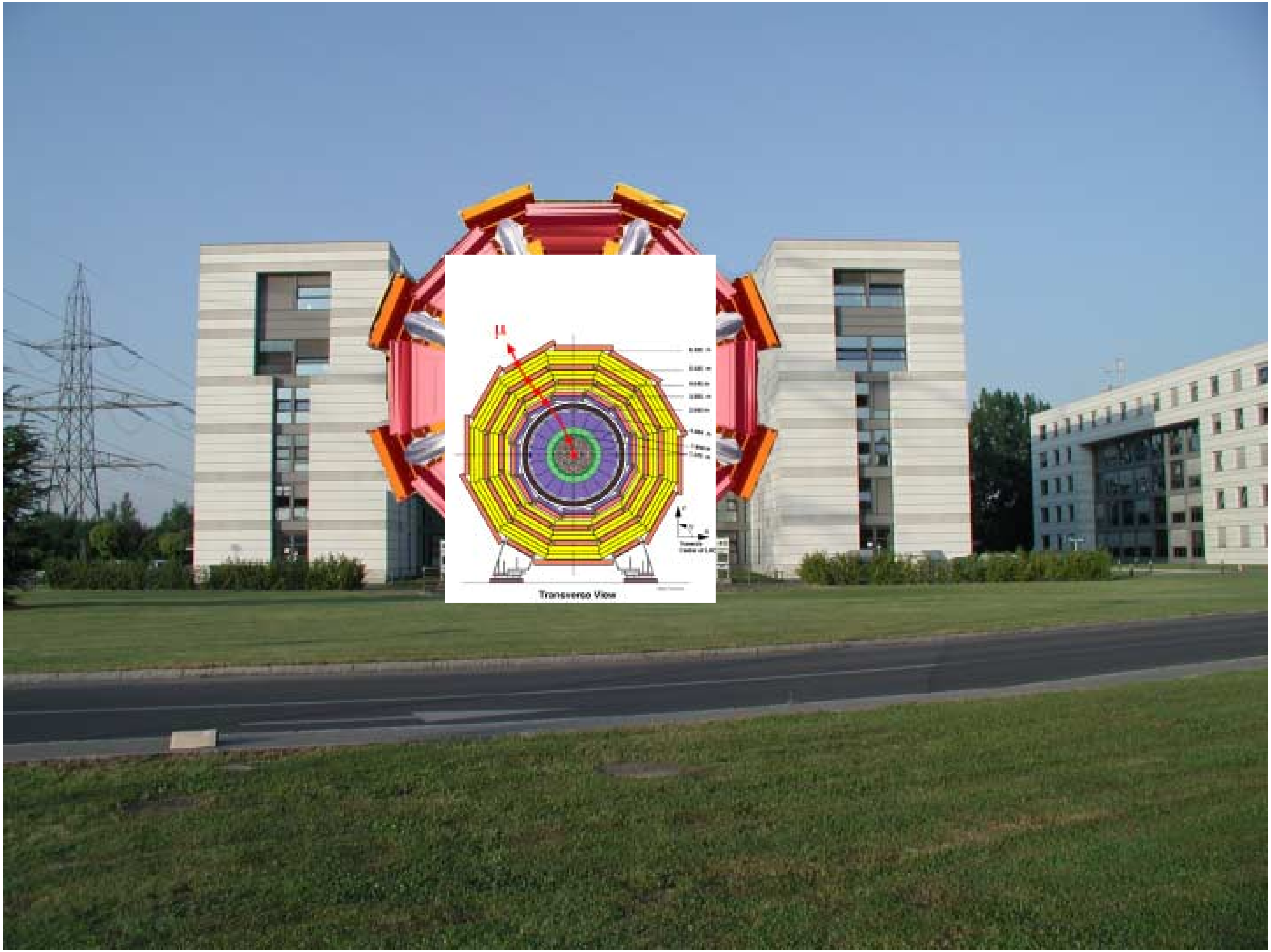
Redundancy: 4 muon stations with 32 r-phi measurements

$\Delta P_t/P_t \sim 5\%$ @1TeV for reasonable space resolution of muon chambers (200μm)

The CMS Detector



Total weight	: 12,500t.
Overall diameter	: 15.00m
Overall length	: 21.60m
Magnetic field	: 4 Tesla

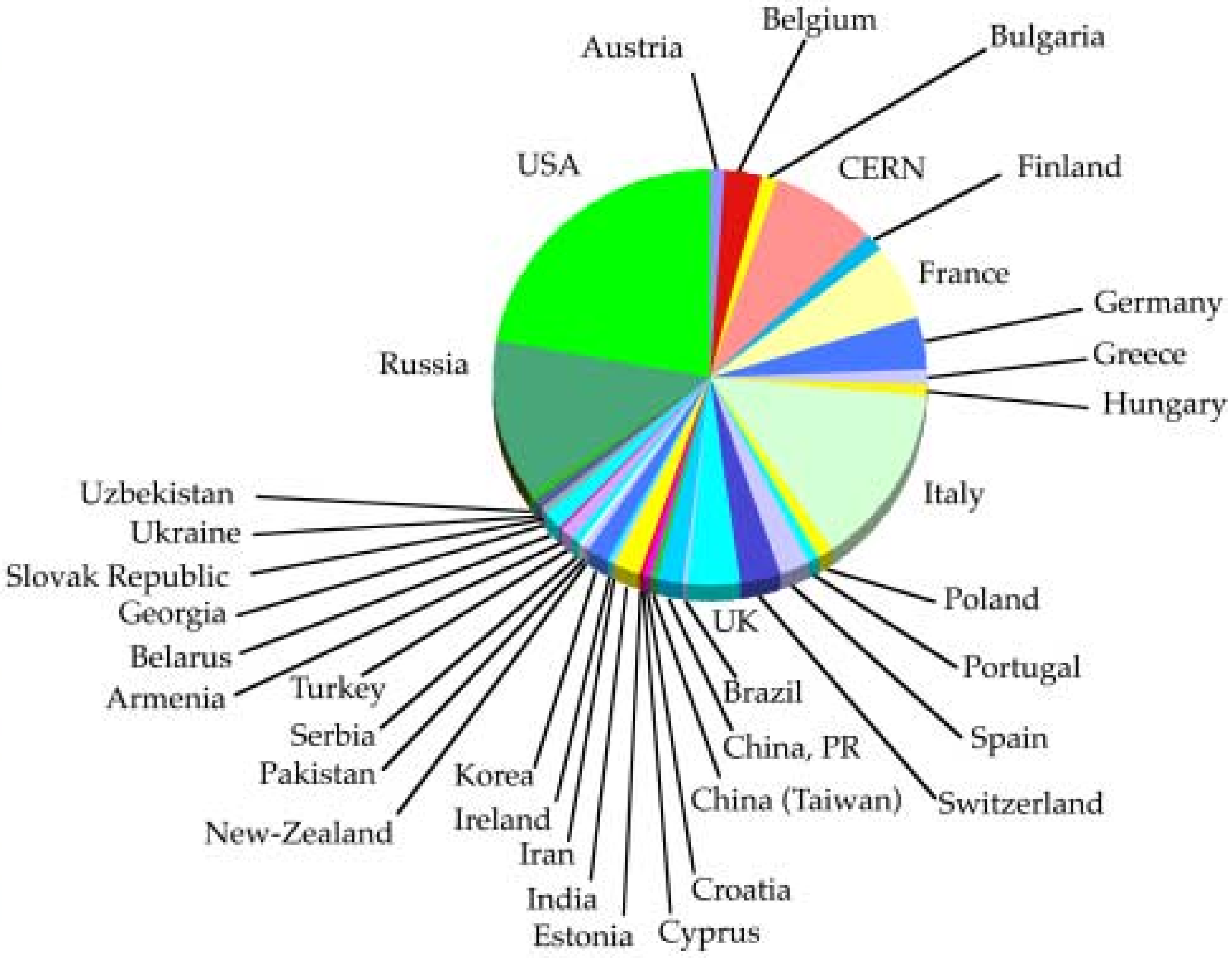

μ
Transverse View

The CMS Collaboration

	Number of Laboratories
Member States	58
Non-Member States	56
USA	38
Total	152

	Number of Scientists
Member States	983
Non-Member States	481
USA	426
Total	1890

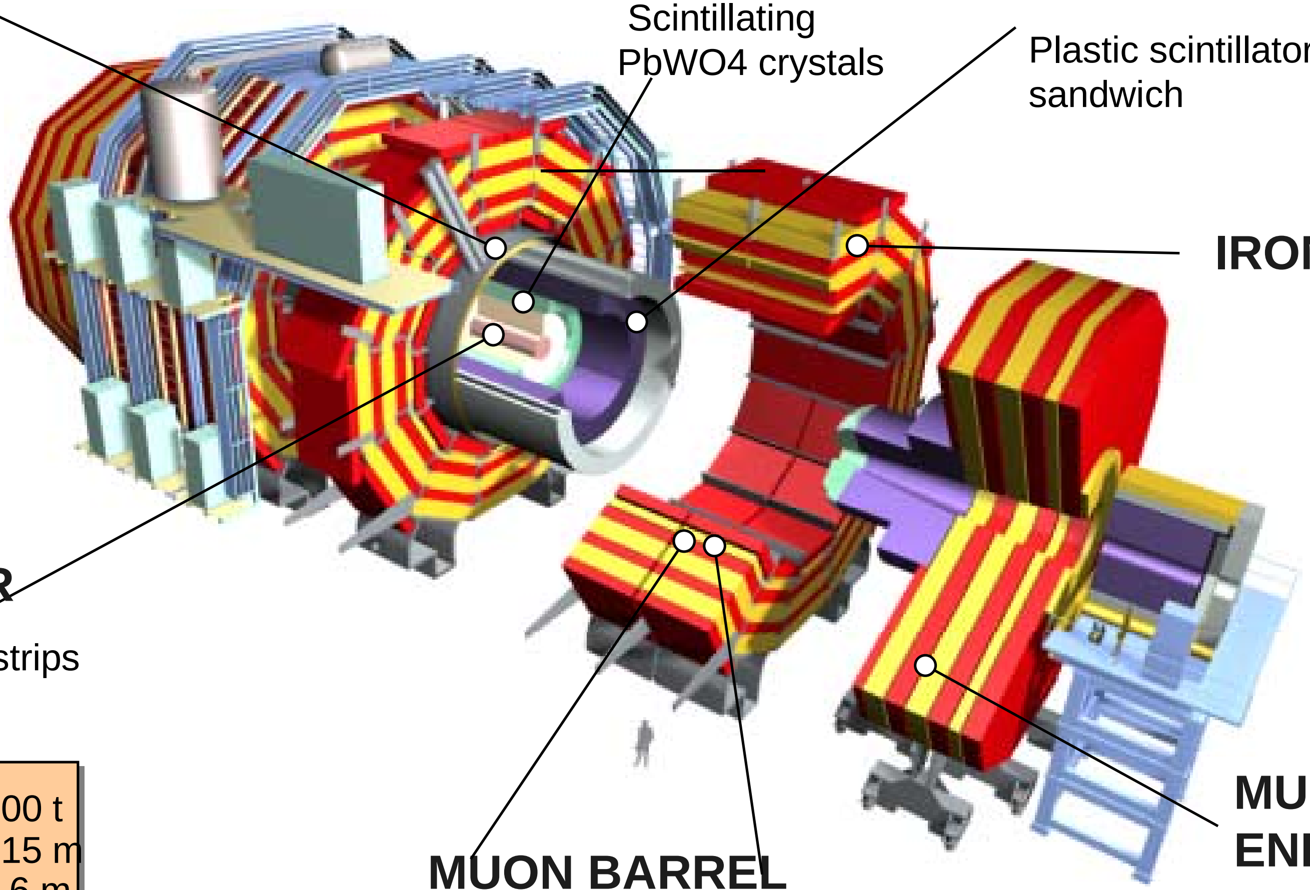
Associated Institutes	
Number of Scientists	67
Number of Laboratories	9



1890 Physicists and Engineers
36 Countries
152 Institutions

March 17, 2003/gm
http://cmsdoc.cern.ch/pictures/cmsorg/overview.html

The Modular Design of CMS



SUPERCONDUCTING COIL

CALORIMETERS

ECAL

Scintillating PbWO4 crystals

HCAL

Plastic scintillator/brass sandwich

IRON YOKE

TRACKER

Silicon Microstrips
Pixels

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

MUON BARREL

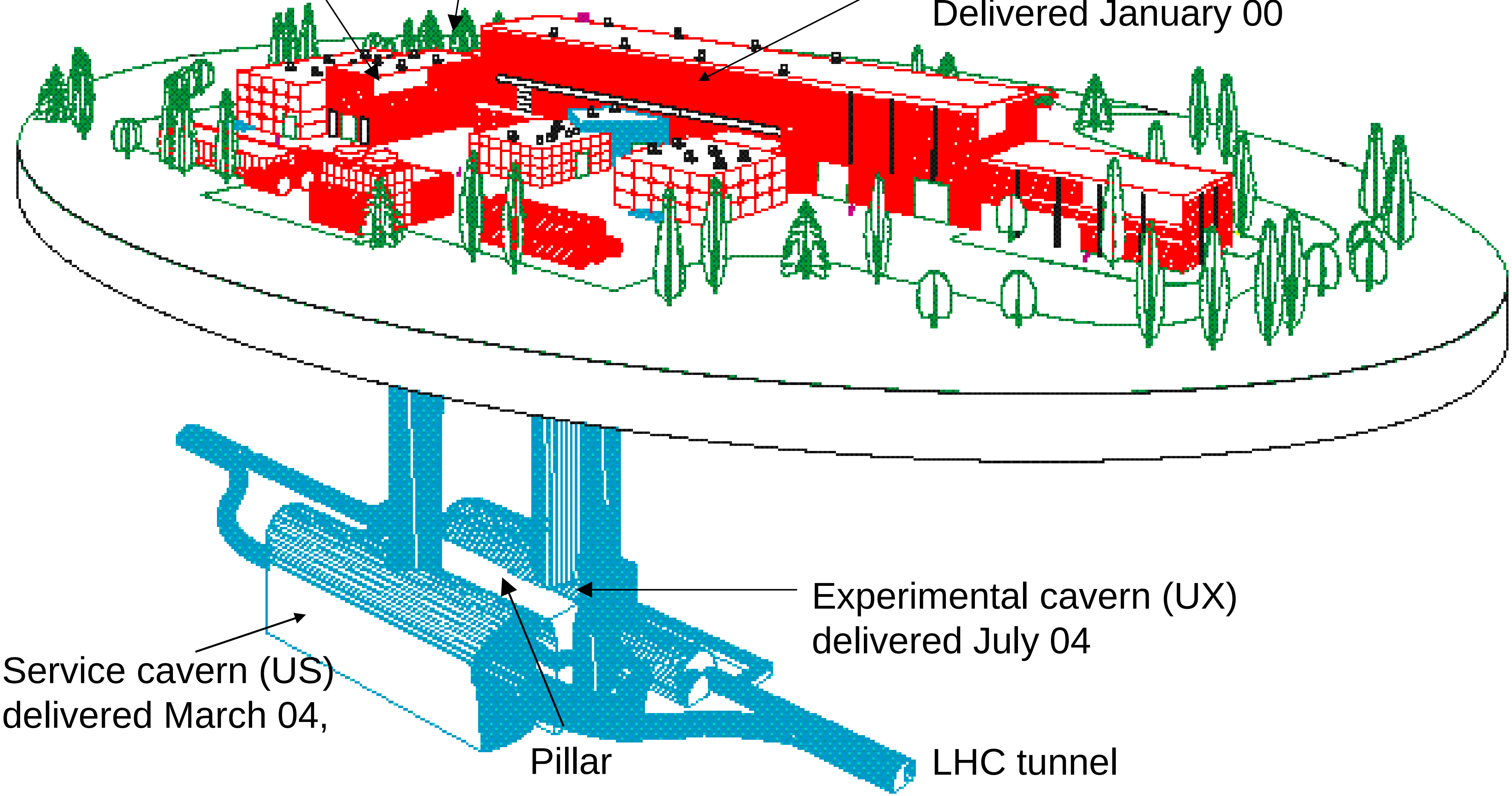
Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

MUON ENDCAPS

Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Surface and Underground Installations



SDX with 80t crane
delivered August 04

SCX DAQ Control Room
delivered January 05,

Surface building (SX)
Delivered January 00

Experimental cavern (UX)
delivered July 04

Service cavern (US)
delivered March 04,

Pillar

LHC tunnel

Experimental Caverns

V33: Service US delivered Mar 04;

Experiment UX delivered July 04

LHC Point 5 - USC 55 Cavern - Crown waterproofing - 17-03-2003 - CERN ST-CE

LHC Point 5 - UXC 55 Cavern - Point 4 Headwall - 17-03-2003 - CERN ST-CE

1st Barrel Yoke Wheel YB+2 Extracted (26 Oct 2000)

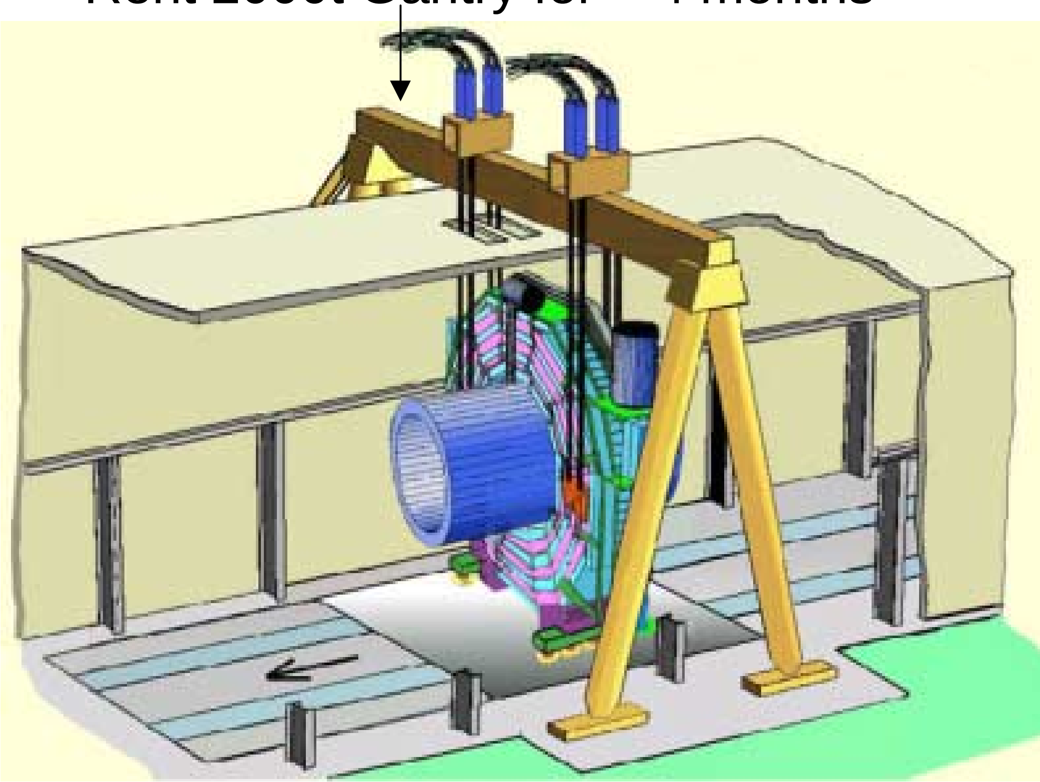
YB0 support Vacuum Tank

1st Disk Assembly : YE-3 (May 01)

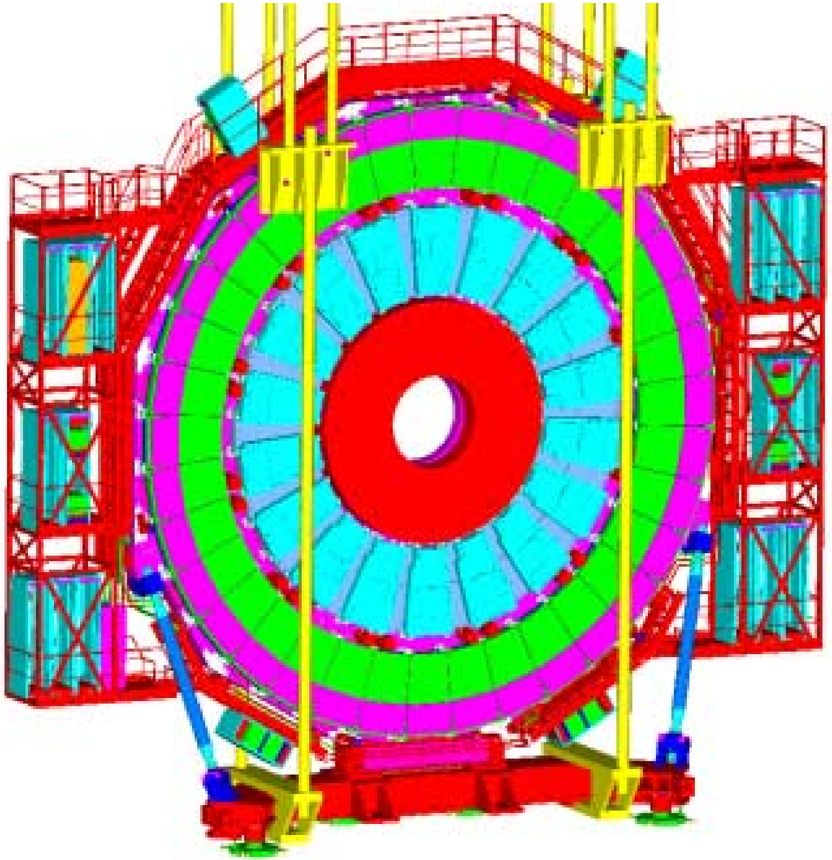
Transfer CMS Underground mid-05

The design of CMS has been made modular to allow the transfer of big commissioned pieces underground. After the Magnet test on the surface mid-05 , CMS can be transferred in the cavern in about 4 months.

Rent 2000t Gantry for ~ 4 months

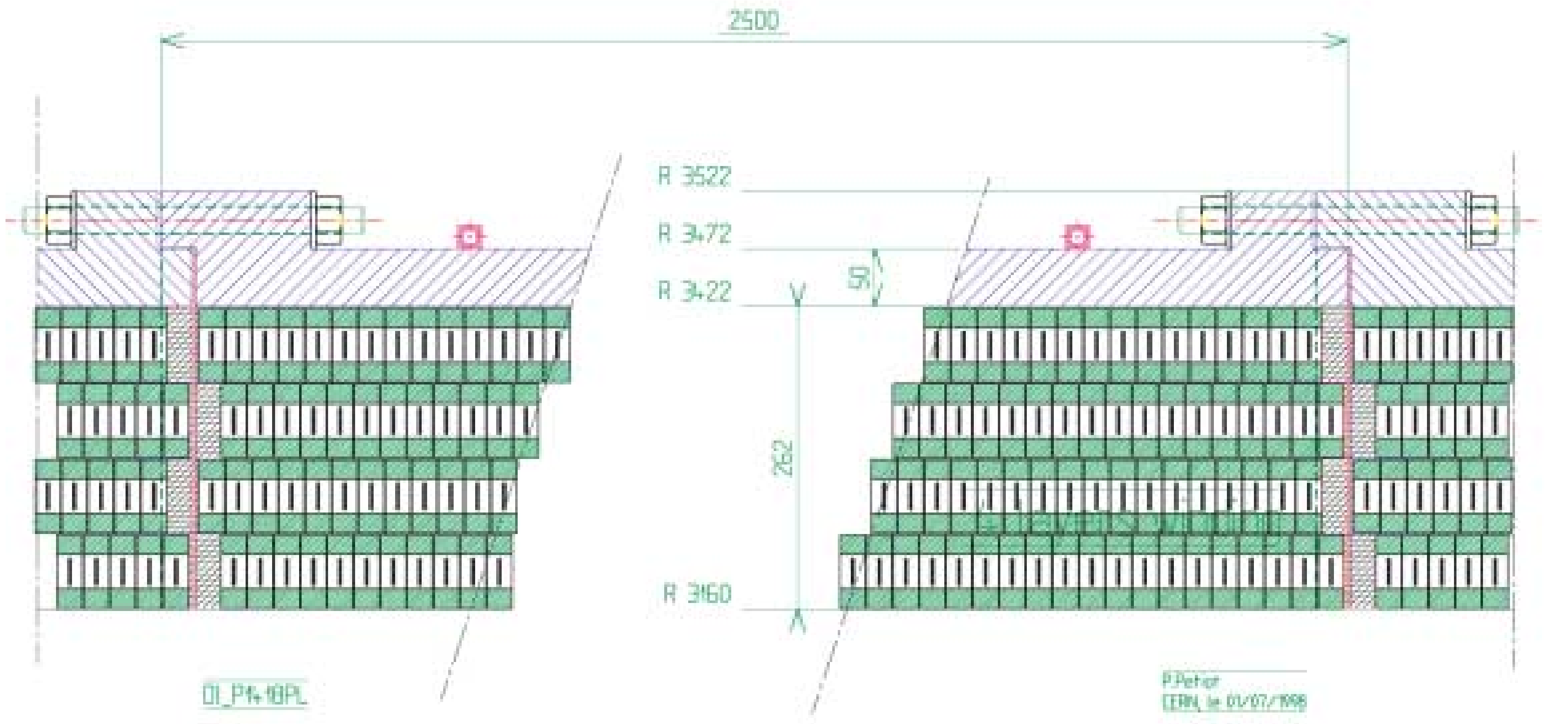


Transfer YB0 (2000t)



Transfer YE2 (800t each)

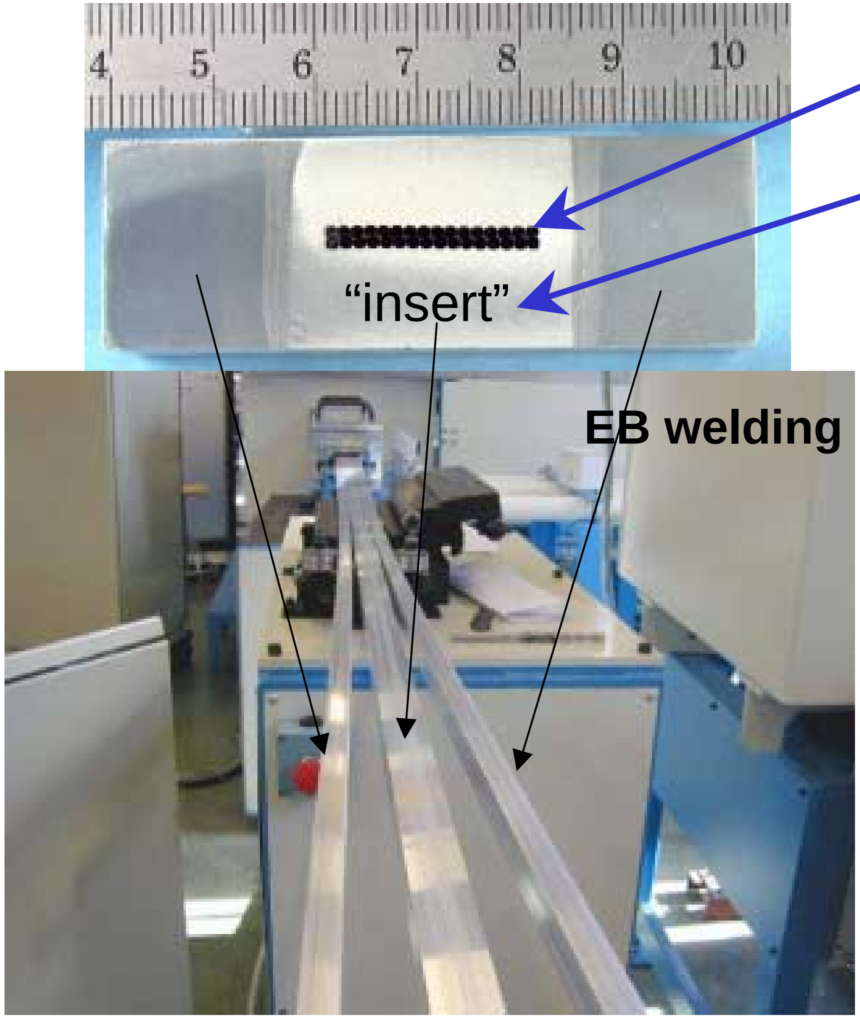
4 Tesla Coil Design: 4 Layer Winding



Magnetic length	12.5 m
Free bore diameter	6 m
Central magnetic induction	4 T
Nominal current	20 kA
Stored energy	2.7 GJ
Magnetic Radial Pressure	64 Atmospheres!

Status of Conductor

We need 21 lengths (2.65 km each) of reinforced conductor.
4 lengths/coil_module x 5 coil_modules + 1 spare = 21 lengths



- ☑ All 21 superconducting cables have been produced (November 2002)
- ☑ All 21 inserts have been produced (January 2003)
- ☐ 17 (out of 21) Electron Beam (EB) welded conductors have been produced so far.

4 lengths
left to be
reinforced.
Finish by
June 03.

Coil Winding (Ansaldo, Genova)

Coil is made of 5 coil modules: CB-2, CB-1, CB0, CB+1, CB+2
CB-2 completed, CB-1 winding well advanced, last coil (CB+2) at CERN beg 04.
4 mo delay in mandrel production (critical path), aim to recover 2 mo

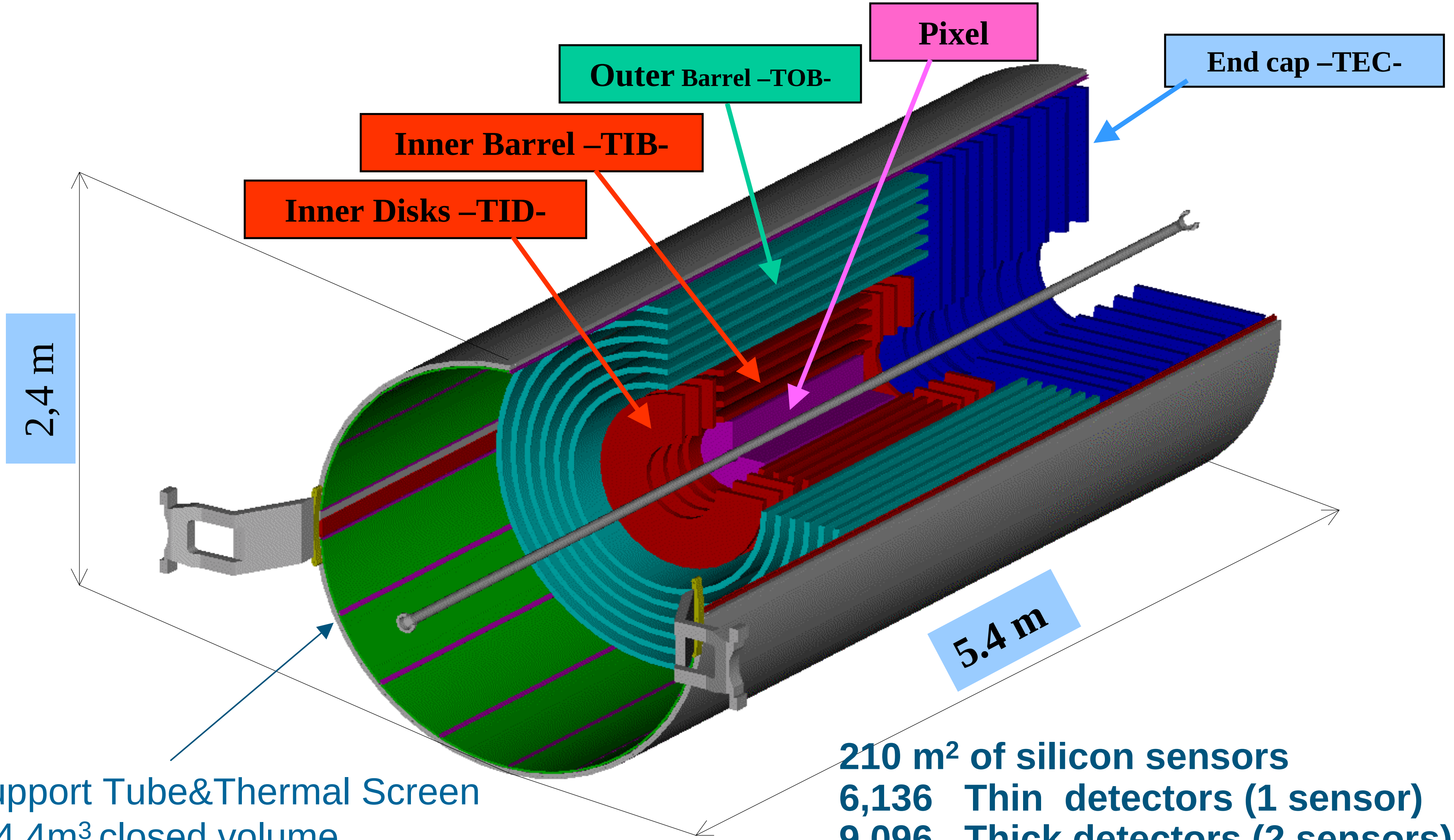
Winding last layer of CB-2

Mandrel Production Critical

Magnet test on the surface ends mid-05

(2 mo delay wrt V33 planning, use master contingency in underground phase)

Inner Tracker

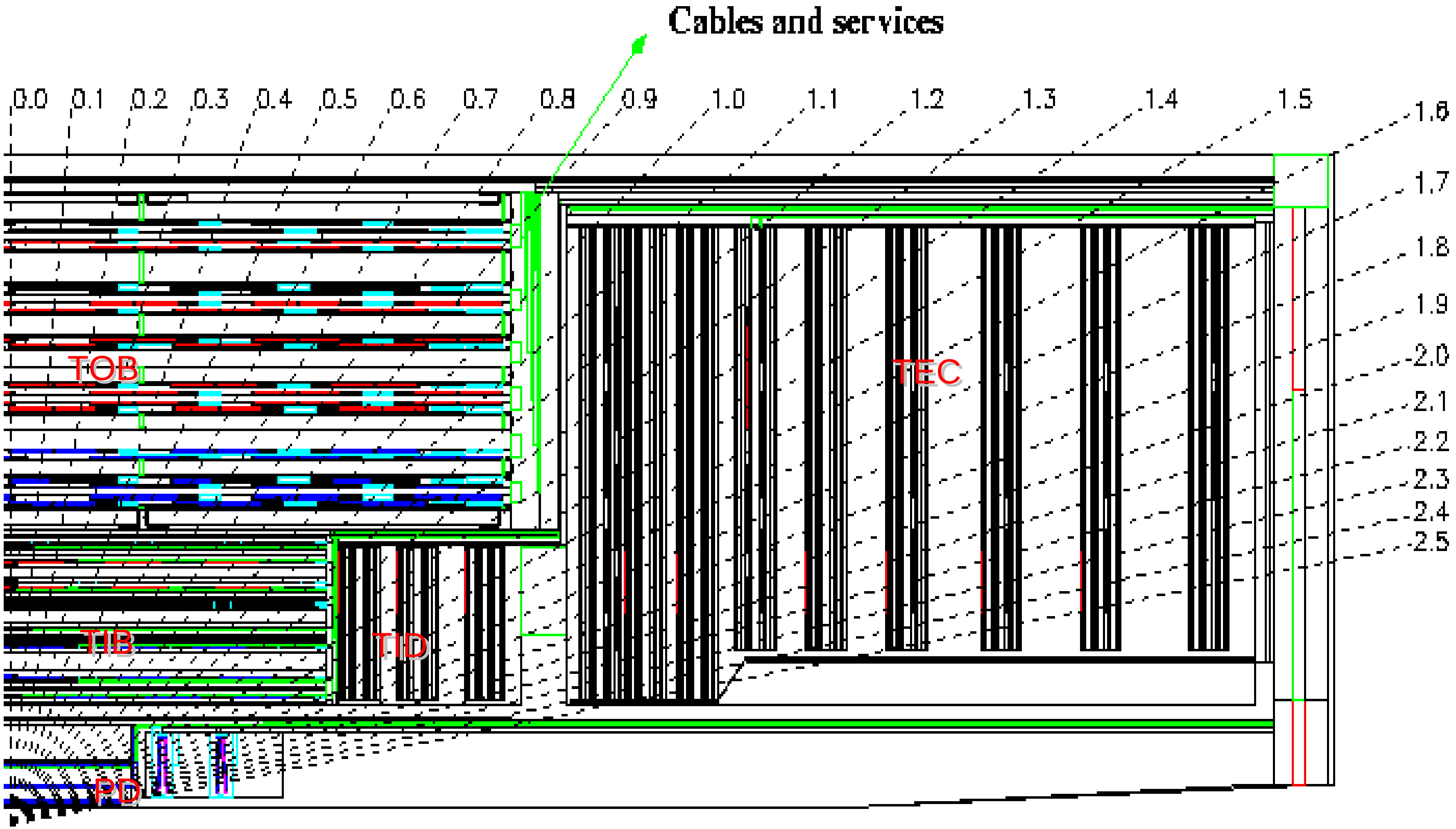


Support Tube&Thermal Screen

- 24.4m^3 closed volume
- operating temperature –10^{o}C

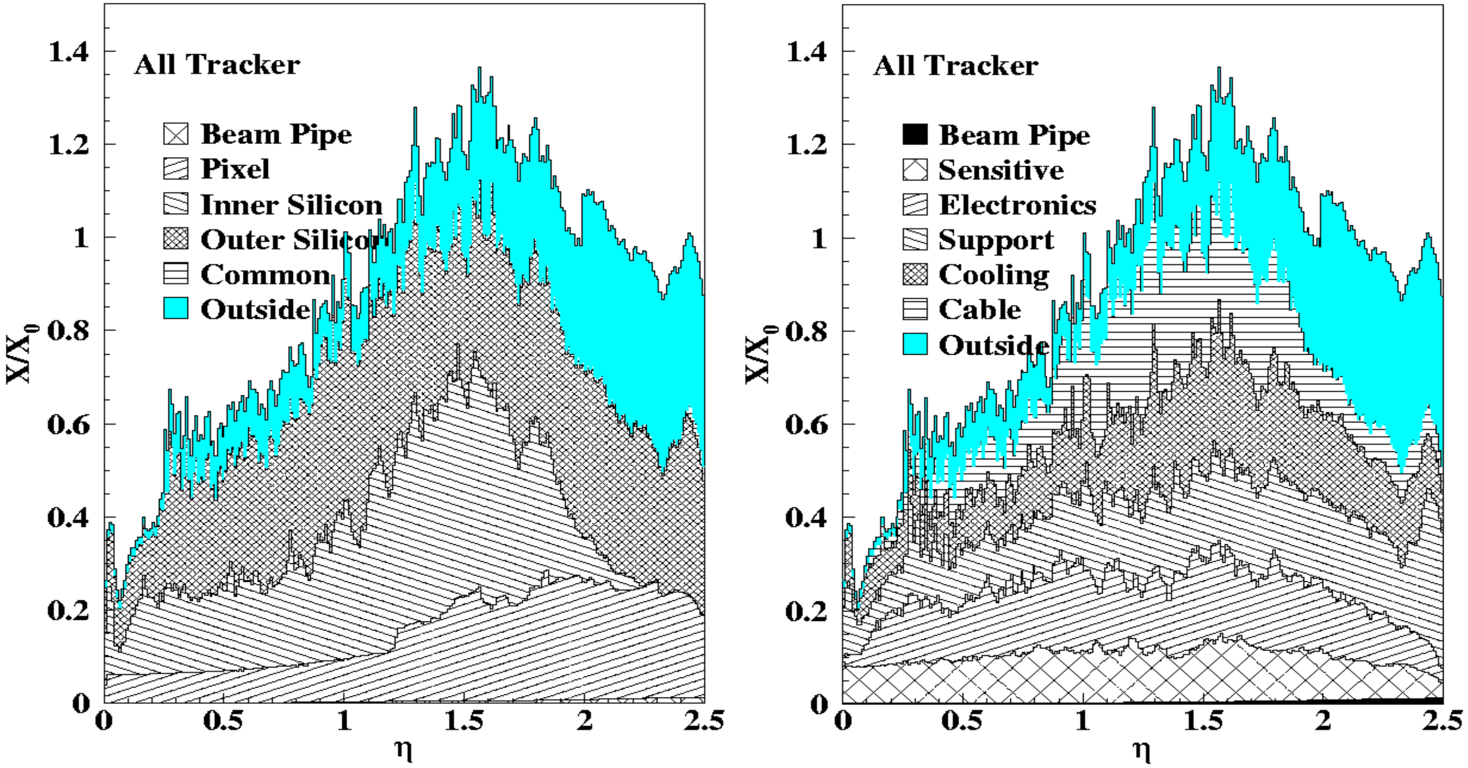
210 m^2 of silicon sensors
6,136 Thin detectors (1 sensor)
9,096 Thick detectors (2 sensors)
9,648,128 electronics channels

Tracker General Structure



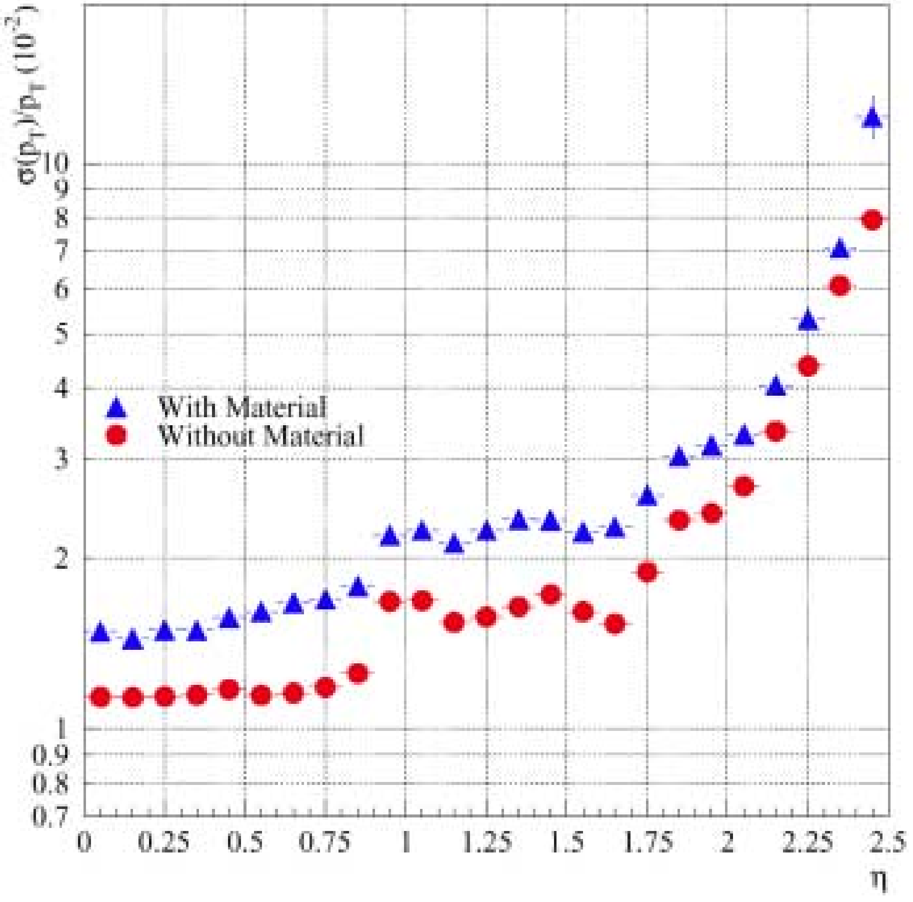
2-3 pixels + 10-14 strip hits

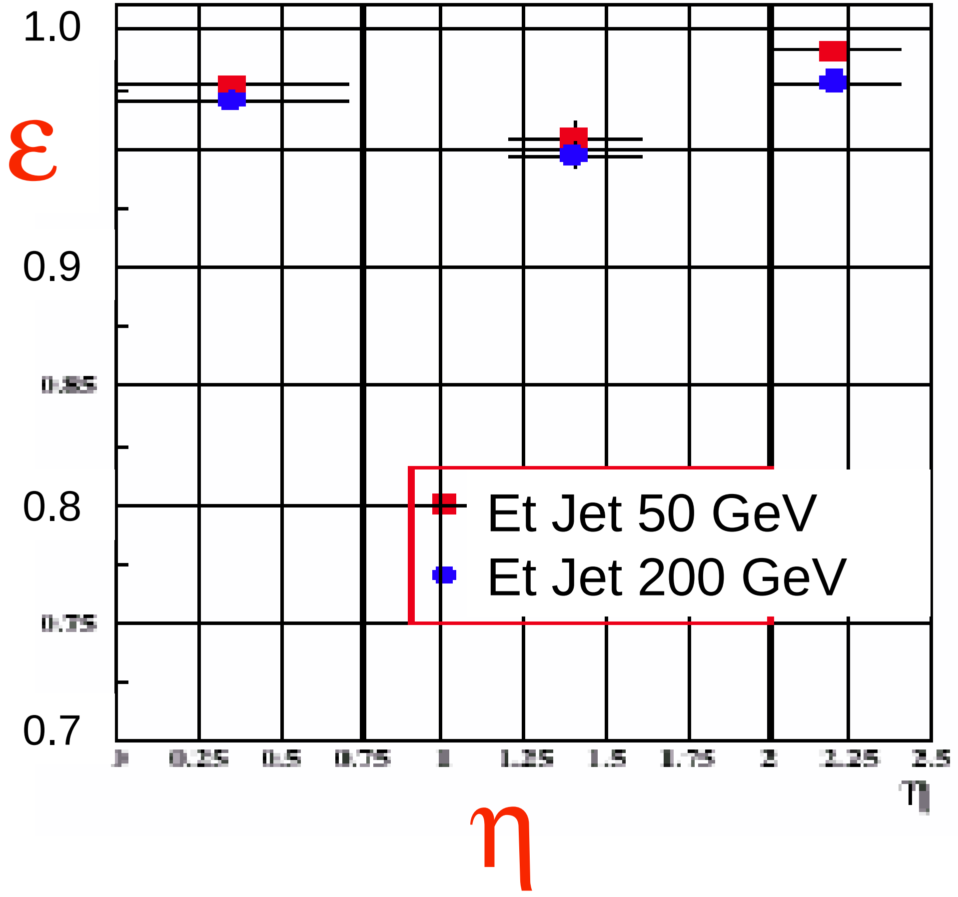
Radiation Length in the Tracker



As a result of the attention paid to controlling the material budget in the design of the CMS Tracker, nothing sticks out particularly. It does, however, add up…

Track Reconstruction and Pt Resolution

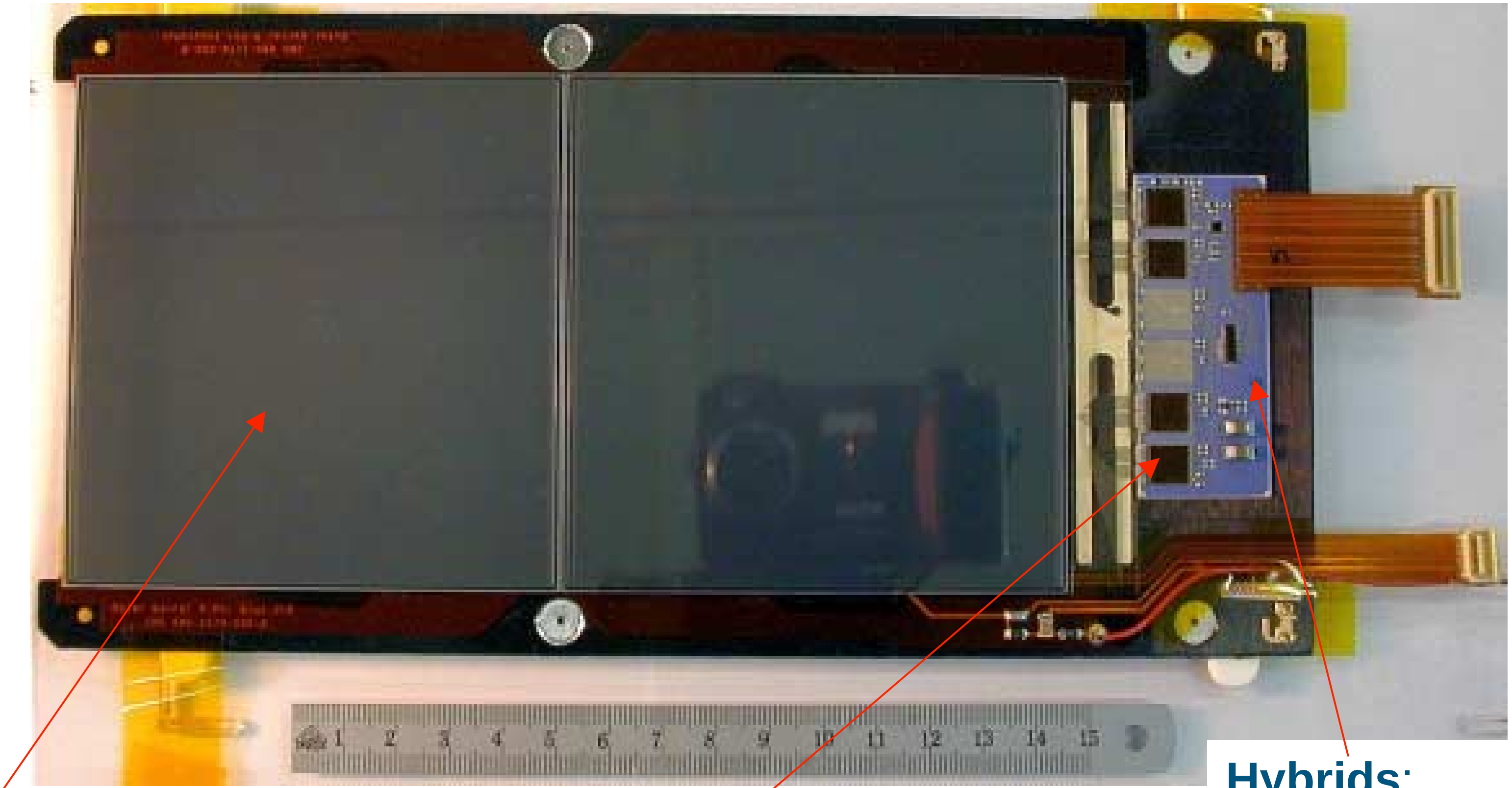




ΔPt/Pt ~ 2 % for 100 GeV muons in central region |η| < 2

Algorithm efficiency for track reconstruction in Jets > 95%

Final TOB Module

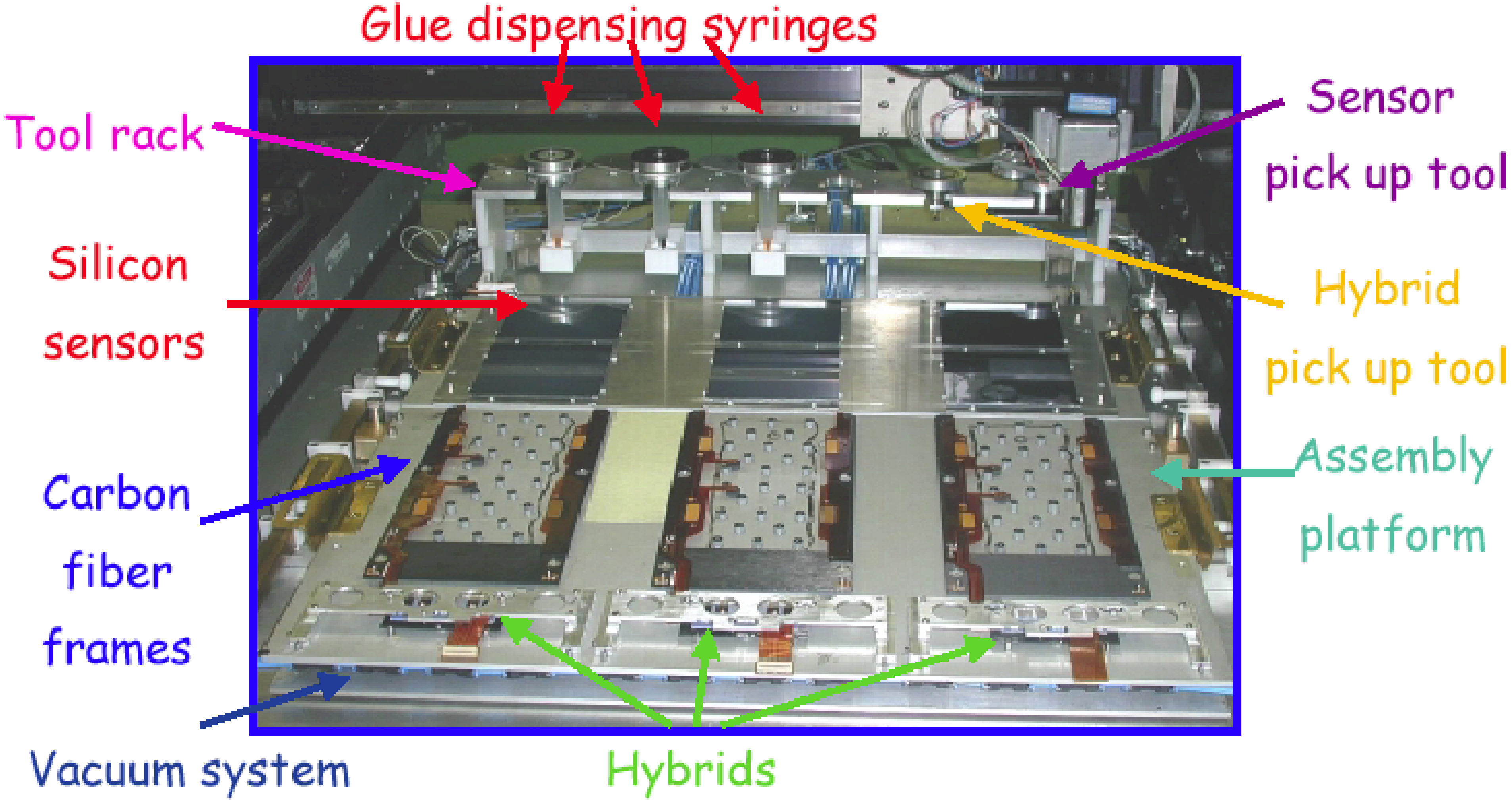


Sensors: 2 producers
- ST thick 500µm (6” wafers)
- Hamamatsu thin 320µm

4 ASICs: APV25 0.25µm (DSM) rad hard technology: Analog pipeline, analog read-out. 128 channels/ASIC, one fiber per module

Hybrids:
Major challenge:
Critical path for module assembly.
4 layer Kapton flex circuit, laminated onto a ceramic substrate

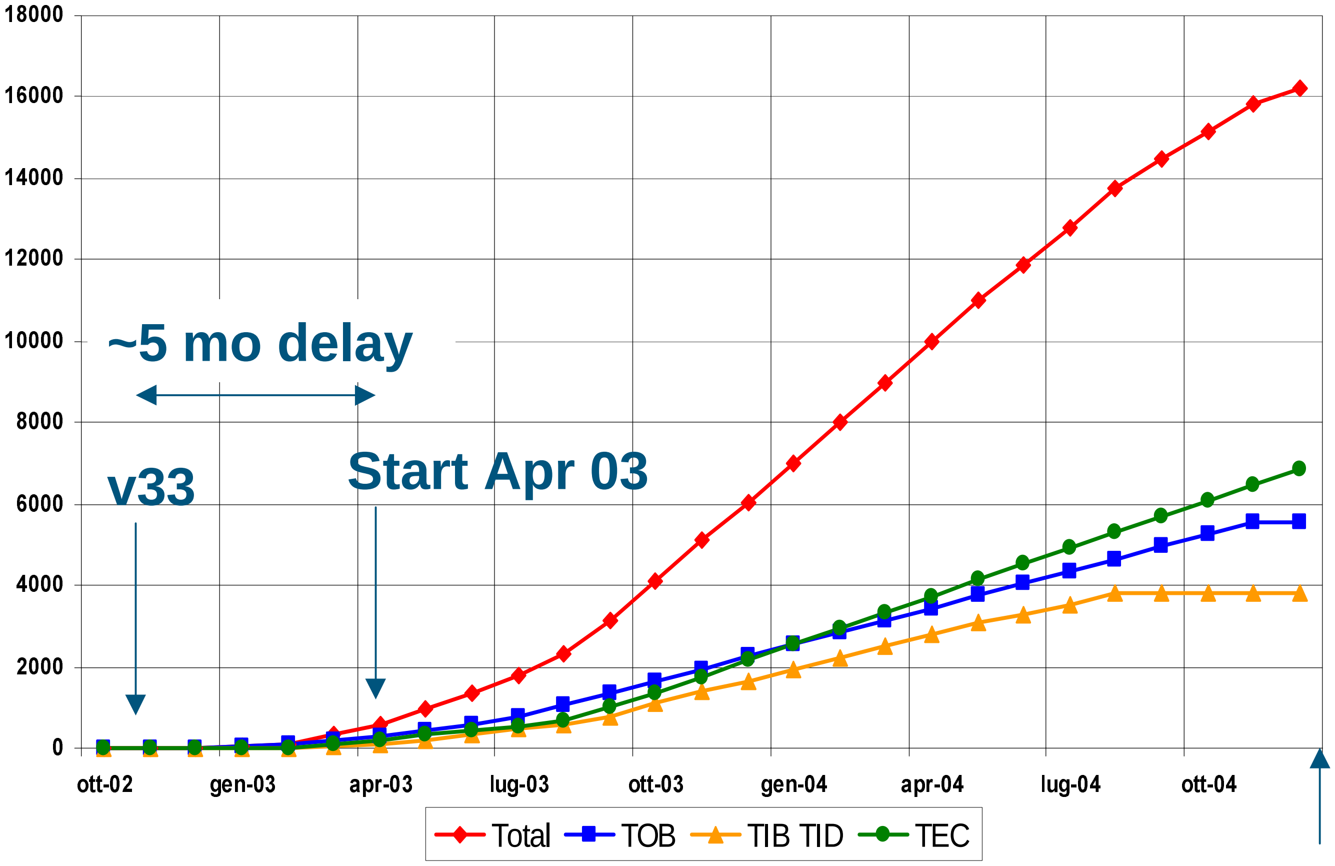
Gantry in action: Assembly of 3 TOB modules



Need 16,000 modules ⇒ Automated module assembly

Tracker Module Production

TOB 300 mod/mon. - 18 mod/day - 17 work days/month - ends Nov. 04
TIB 300 mod/mon. - 16 mod/day - 19 work days/month - ends Aug. 04
TEC 390 mod/mon. - 18 mod/day - 21 work days/month - ends Dec. 04



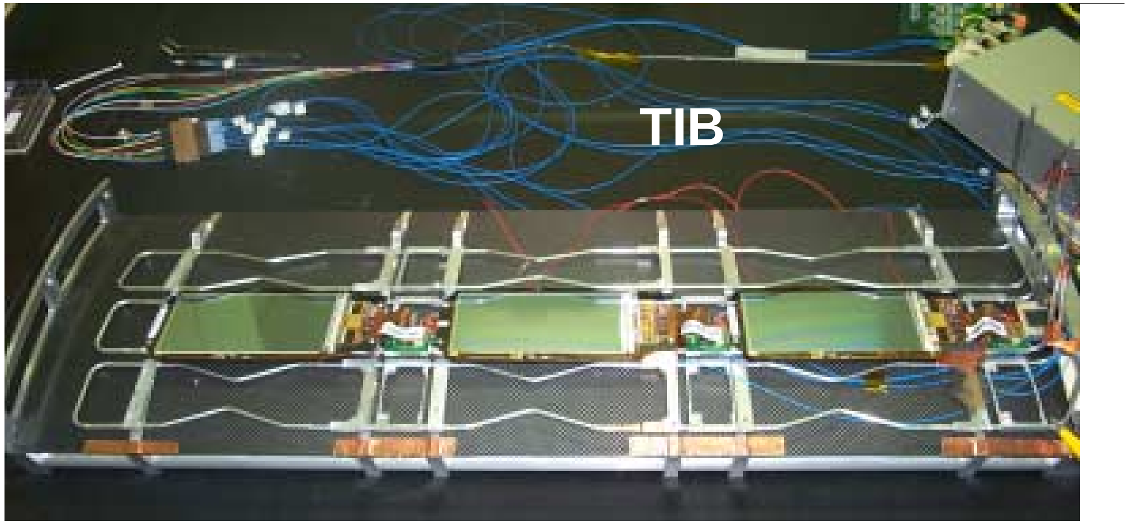
Dec 04

Start of module manufacture delayed ~5 months because of hybrids

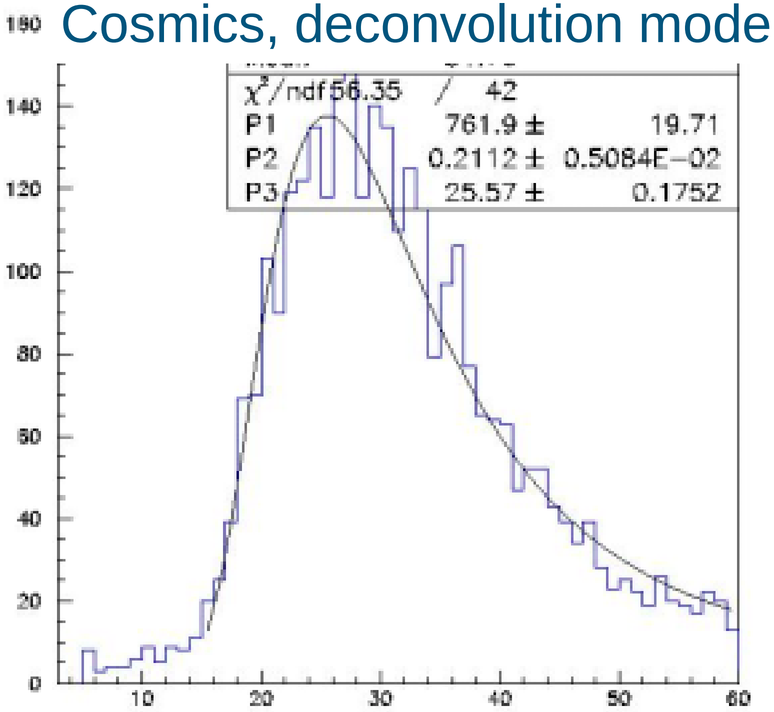
50 Modules made last month.
Expect 800 modules by July 03 (5% milestone)

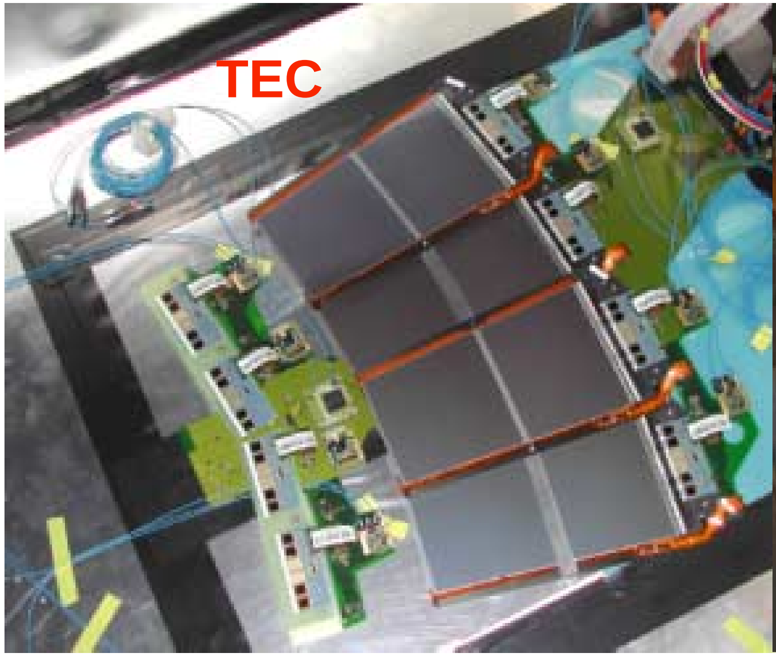
Tracker ready for installation : Nov 05 (V33 milestone, includes 3 month float)

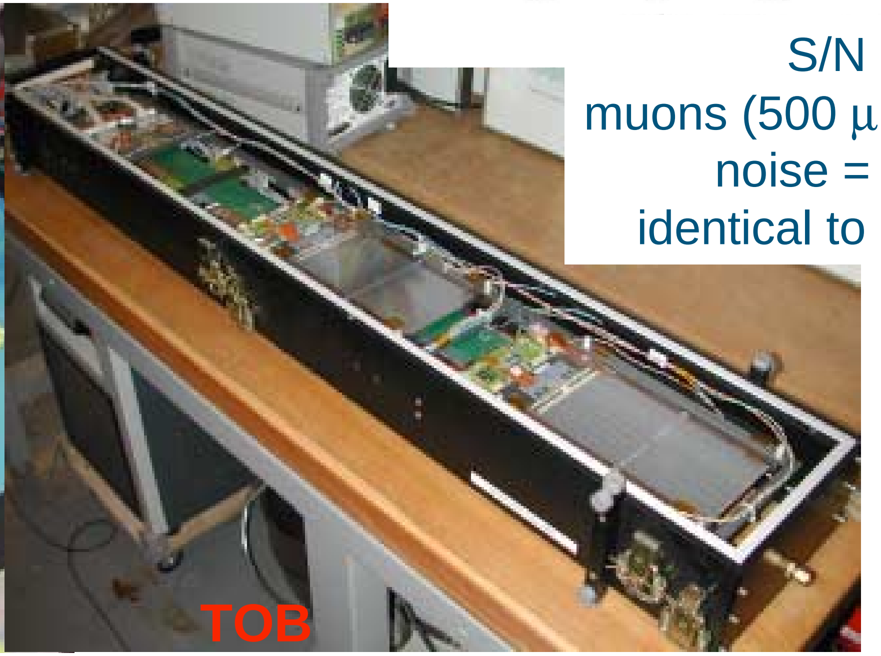
System Tests



Cosmics, deconvolution mode







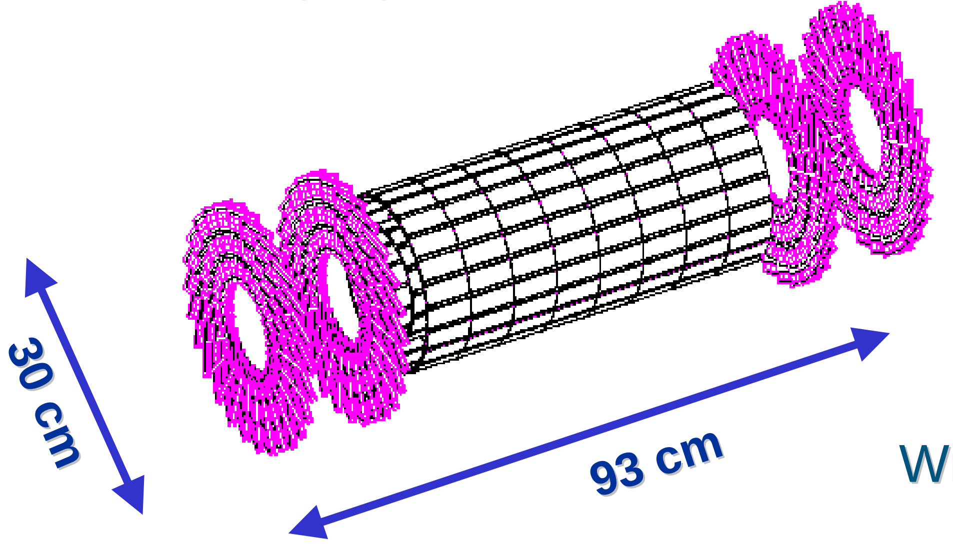
S/N ~ 25
muons (500 µm) = 40000 e-
noise = 1600 e-
identical to predictions.

The CMS Pixel Detector

The region below 20cm is instrumented with Silicon Pixel Vertex systems

4 10^7 pixels

Shaping time ~ 25ns



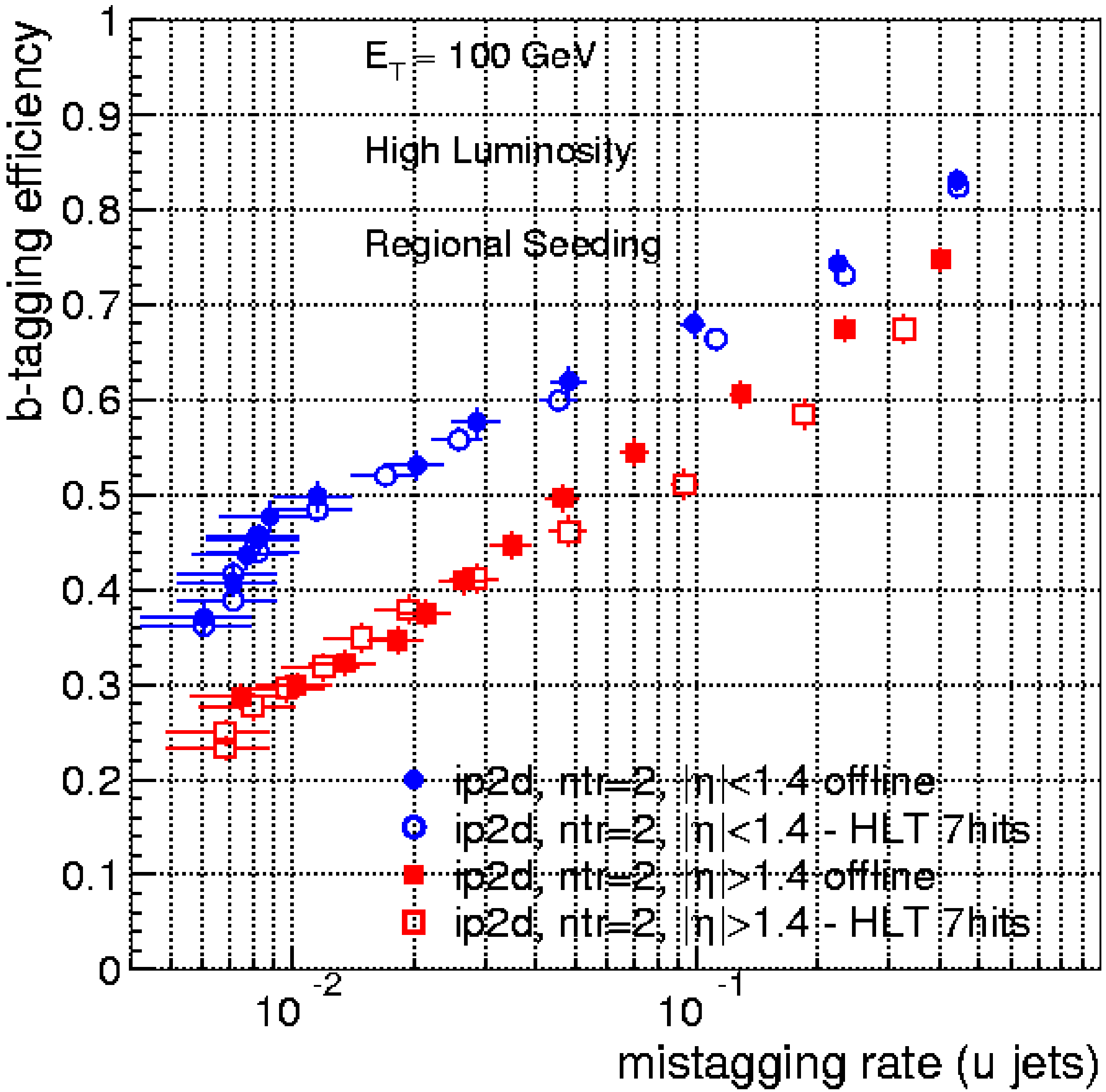
CMS pixel ~ 150 * 150 μm^2
With this cell size, and exploiting
the large Lorentz angle

We obtain $IP_{trans.}$ resolution ~ 20 μm
for tracks with P_t ~ 10GeV

With this cell size occupancy is ~ 10^{-4}

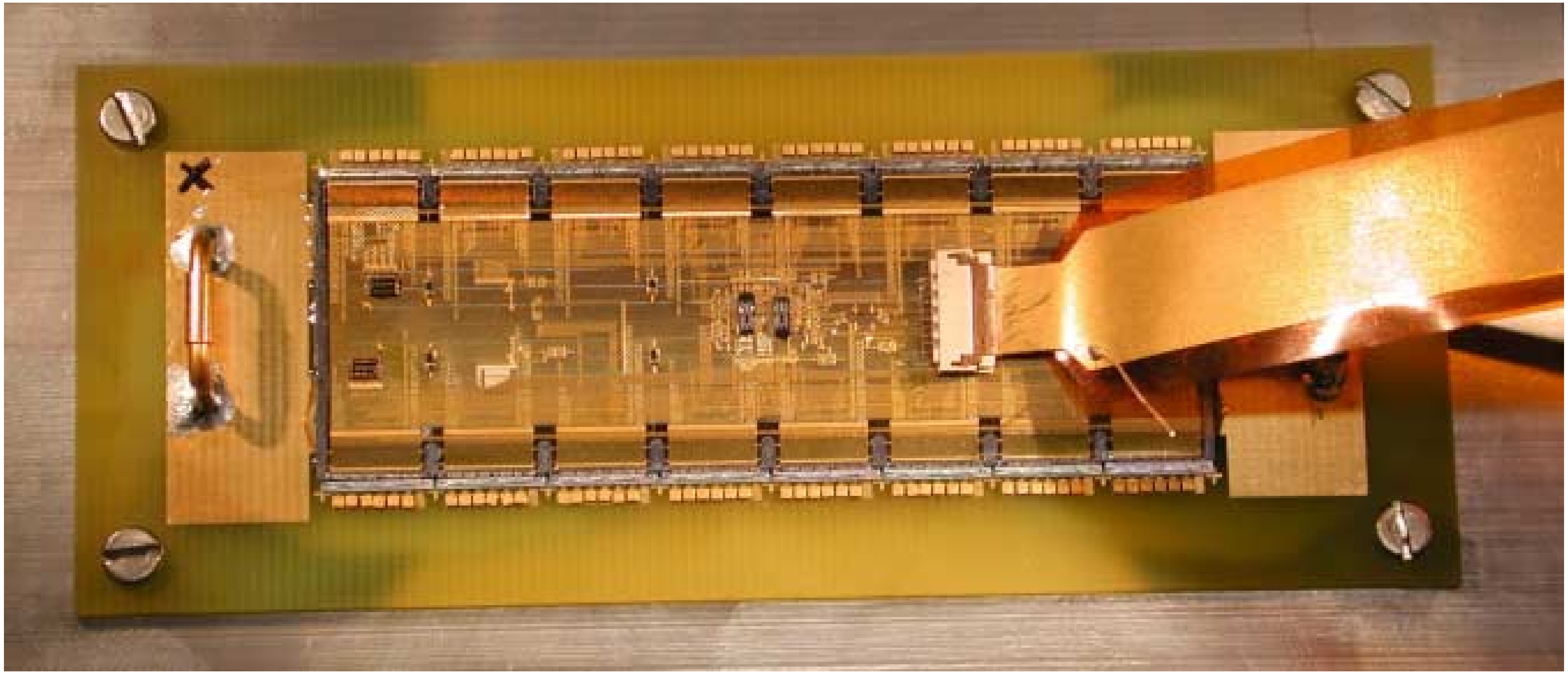
This makes Pixel seeding the fastest
Starting point for track reconstruction
Despite the extremely high track density

Inclusive b tagging in High Level Trigger (HLT)



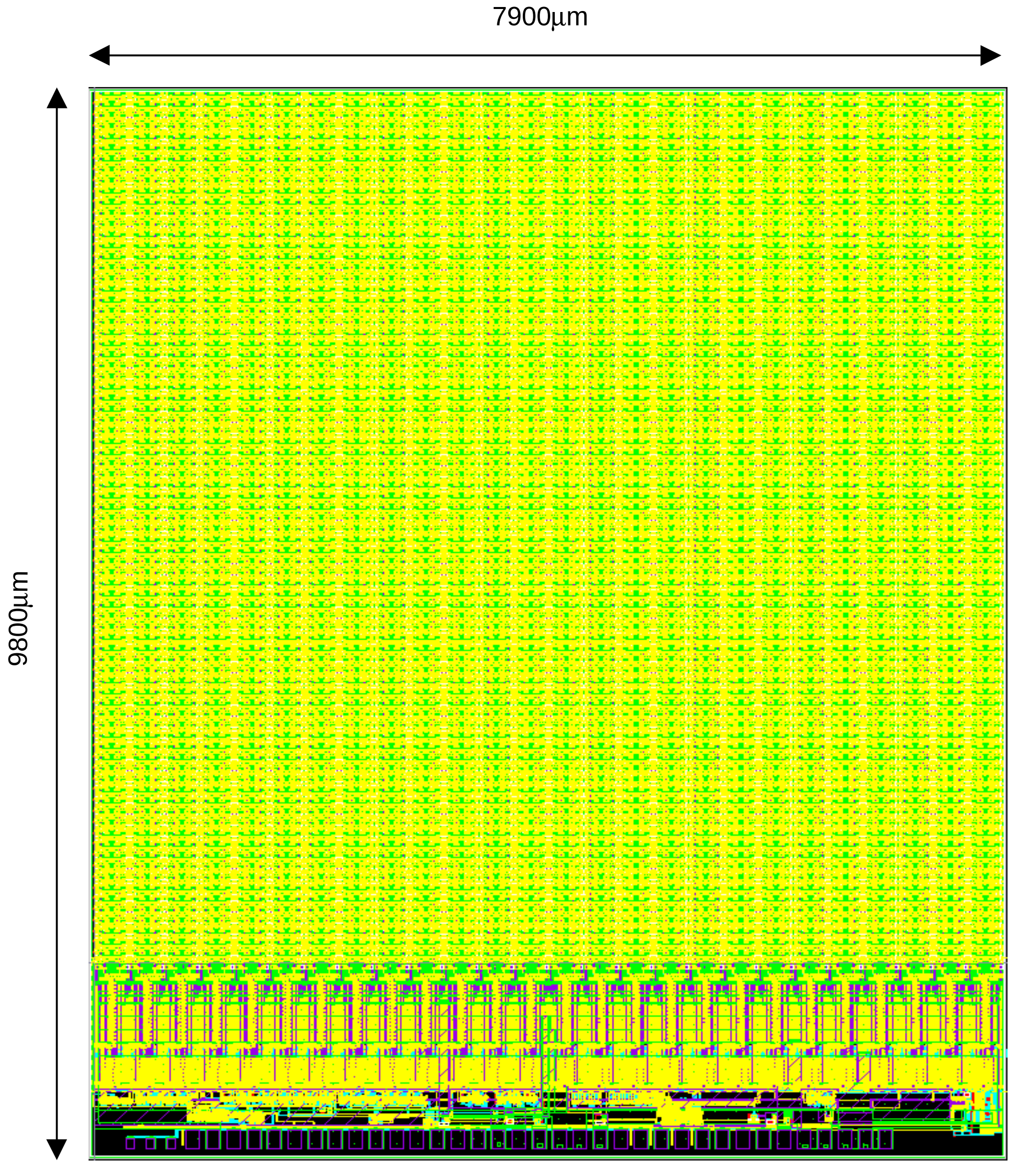
Measurements on Module 00 (Feb 03)

- Module 00: 2x8 DMILL readout chips
- Works well at 40 MHz



Final 0.25μm ROC Design (IBM_PSI146)

- Chip considerably modified and improved compared to DMILL version.
- 52X80 pixels (100μ x 150μ)
- Tape out to IBM in 2nd week June.
- Expect ~12 weeks production.
- Yield ?

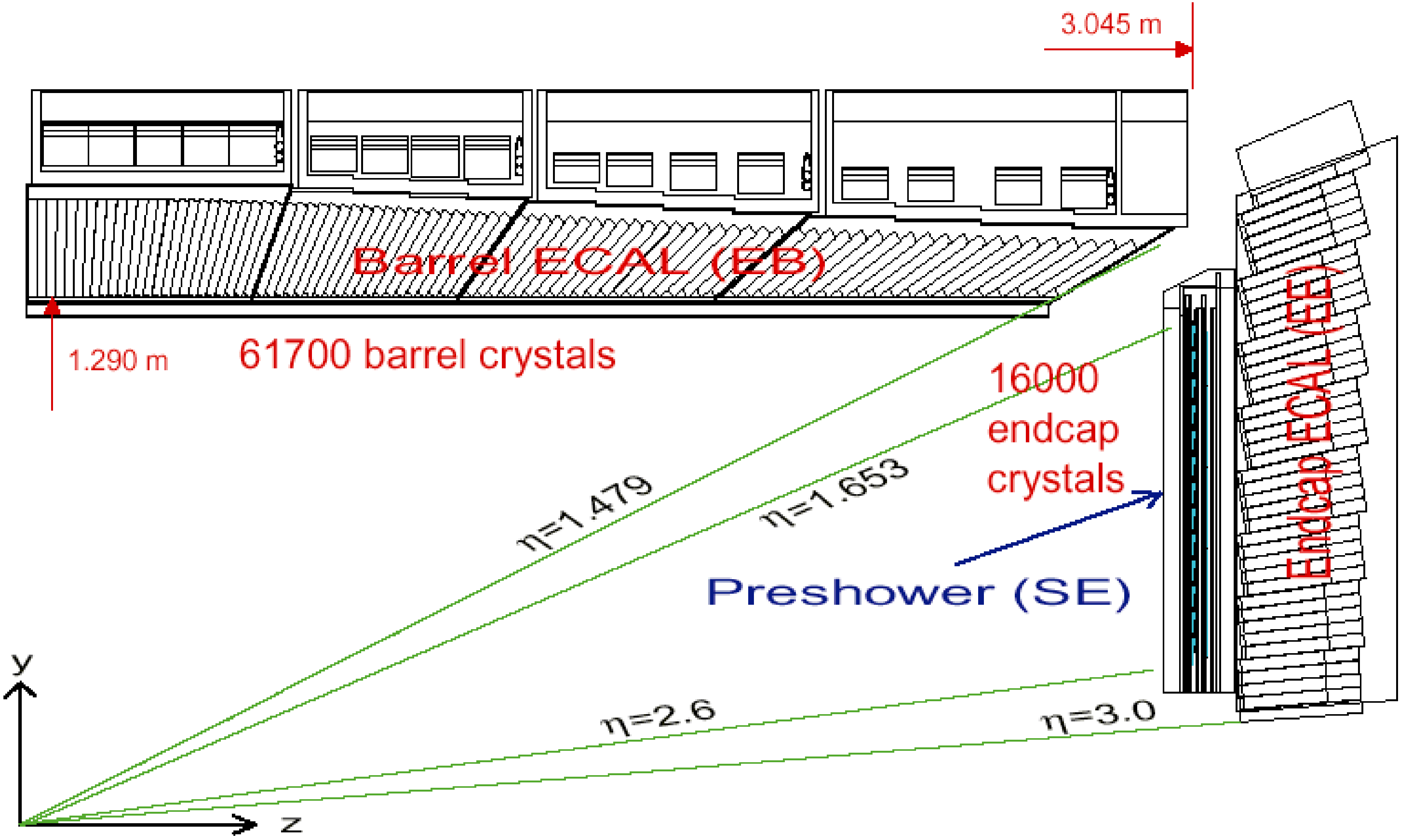


Beam Pipe EDR and Pixel installation

The Pixel detector can be installed with the beam pipe in place.

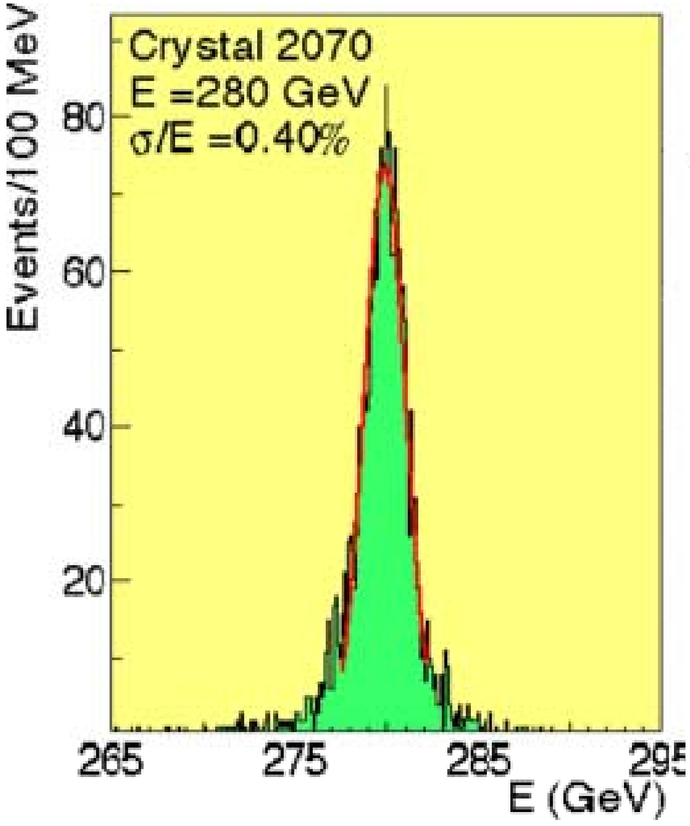
Install only after pilot run and stable beams (~ Oct 07?)

ECAL: PbWO4 Crystals

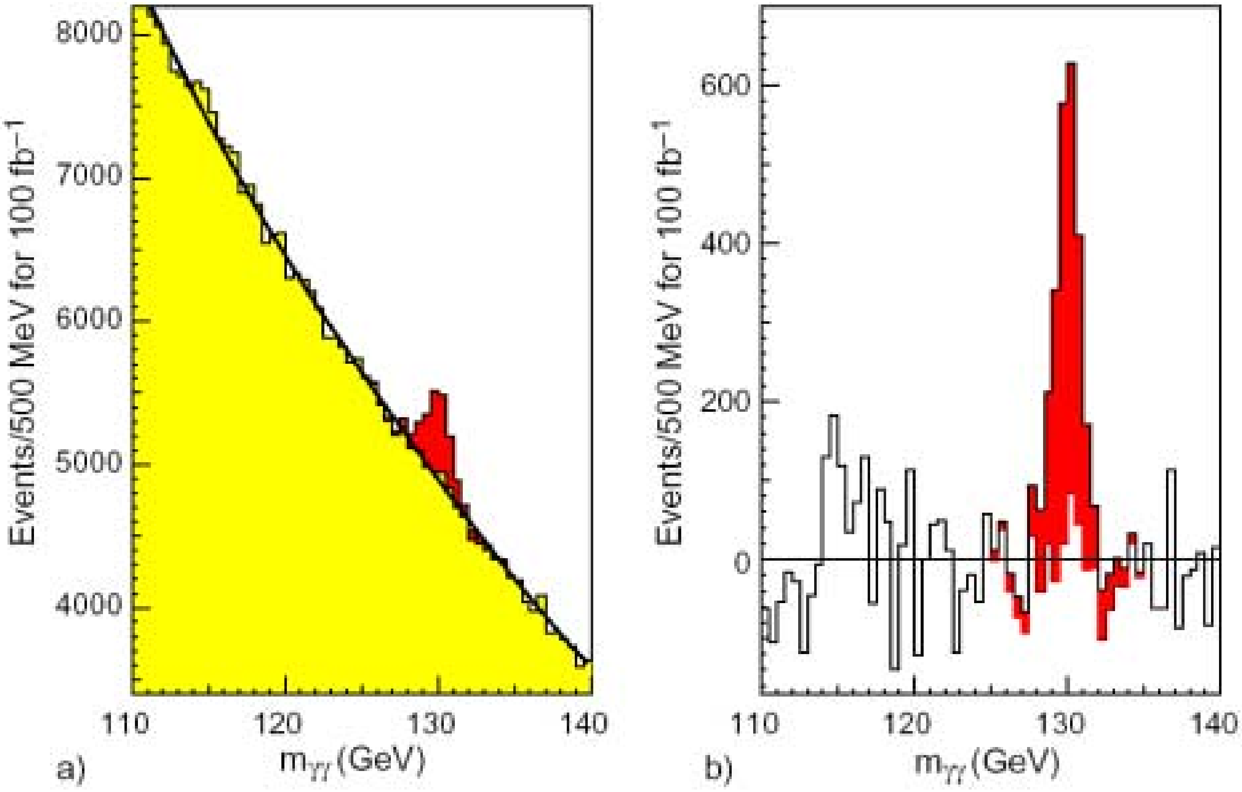


PbWO4 crystal: Energy Resolution

99 test beam



$H \rightarrow \gamma\gamma$ Simulation (100 fb^{-1})

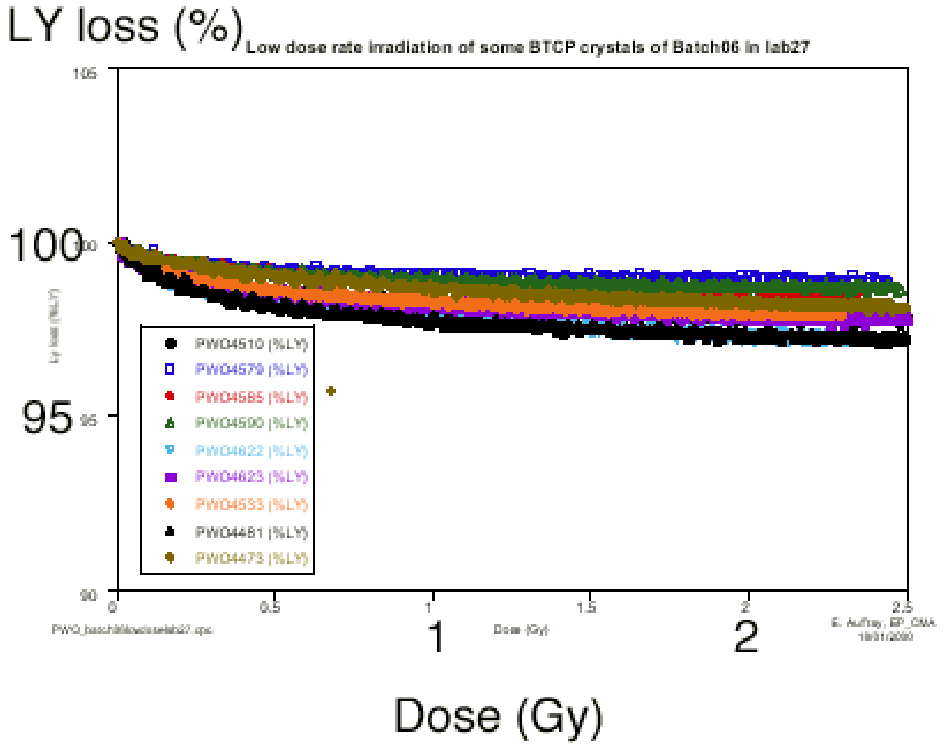


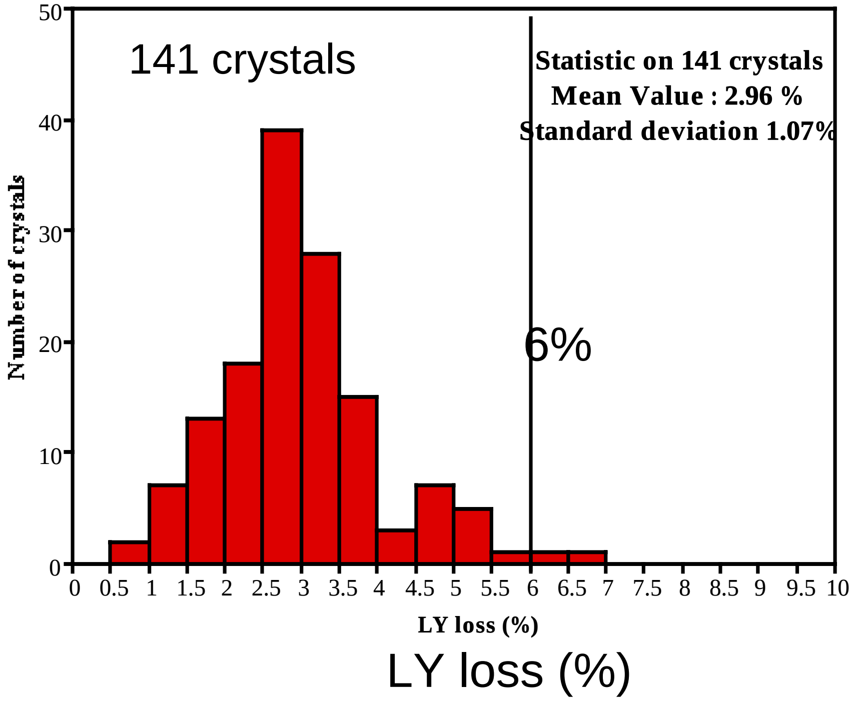
$$\frac{\sigma}{E} = \frac{2.7\%}{E} \oplus 0.5\% \oplus \frac{200\,MeV}{E}$$

$$\sigma_m/m = 0.5\,[\sigma_{E1}/E_1 \oplus \sigma_{E2}/E_2 \oplus \cot(\theta/2)\Delta\theta]$$

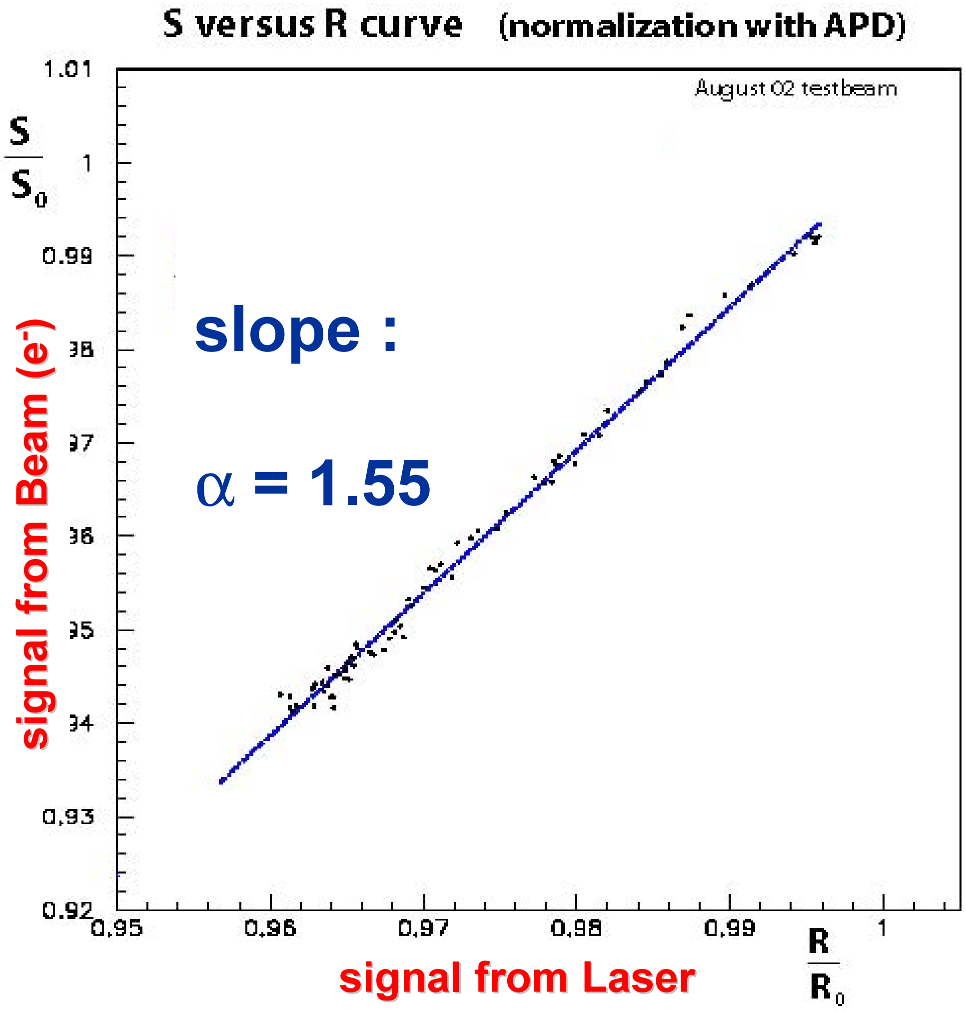
PbWO4 Crystals: Radiation Tolerance

Low dose rate irradiation at TIS : Front Irradiation: 1.5 Gy, 0.15 Gy/hr





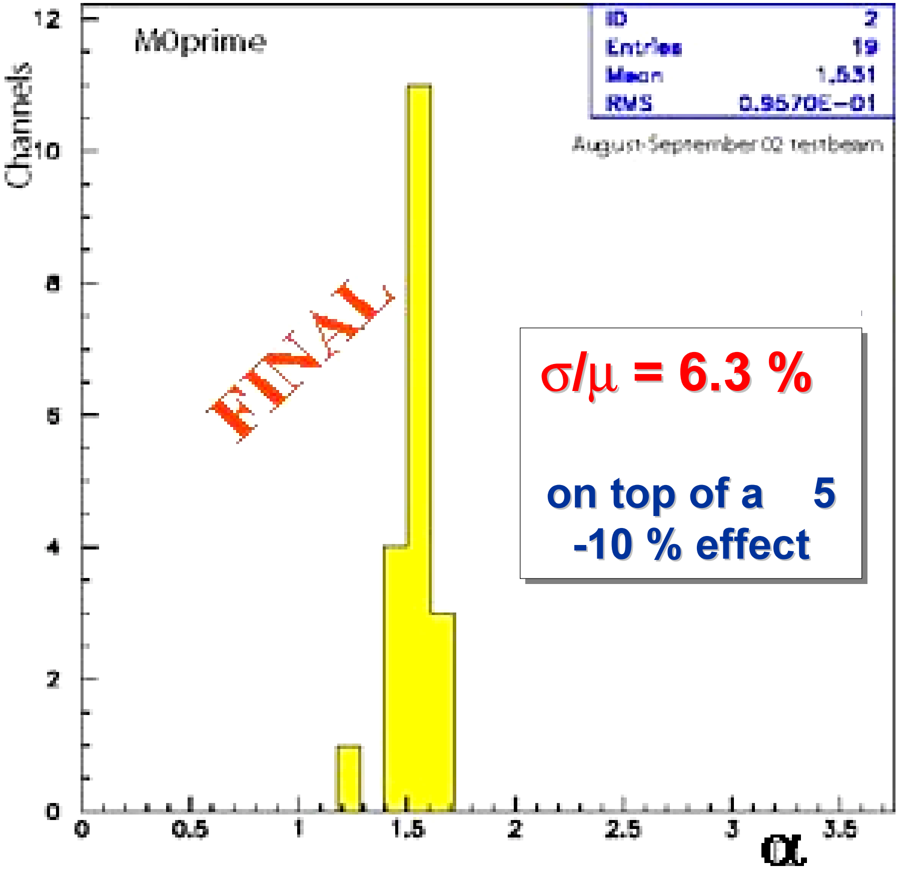
Laser monitoring



slope :

α = 1.55

Dispersion of α for 19 crystals

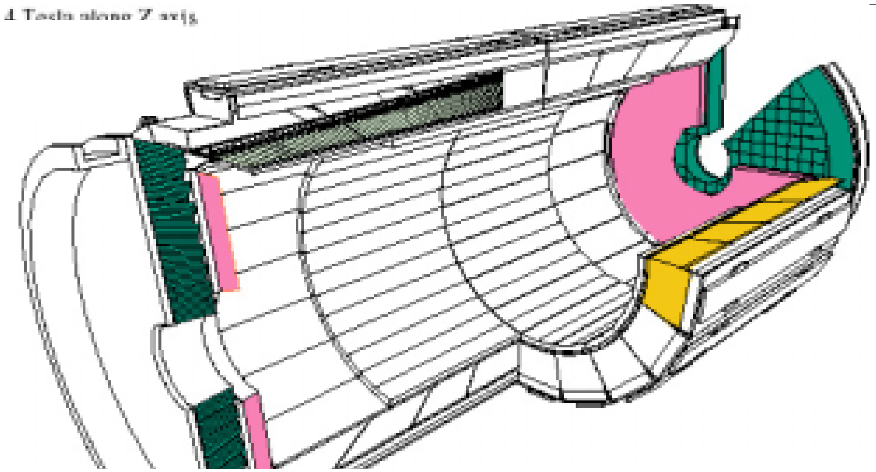


σ/μ = 6.3 %

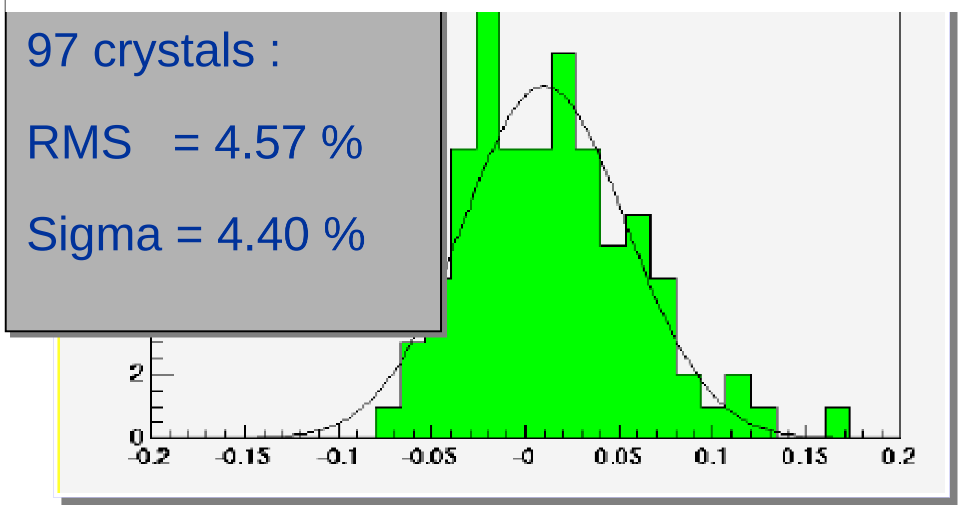
on top of a 5 -10 % effect

$\Rightarrow$ Use of same coefficient for all crystals possible !

CMS ECAL Calibration (~80,000 channels)



4.5 % intercalibration from Lab Measurements

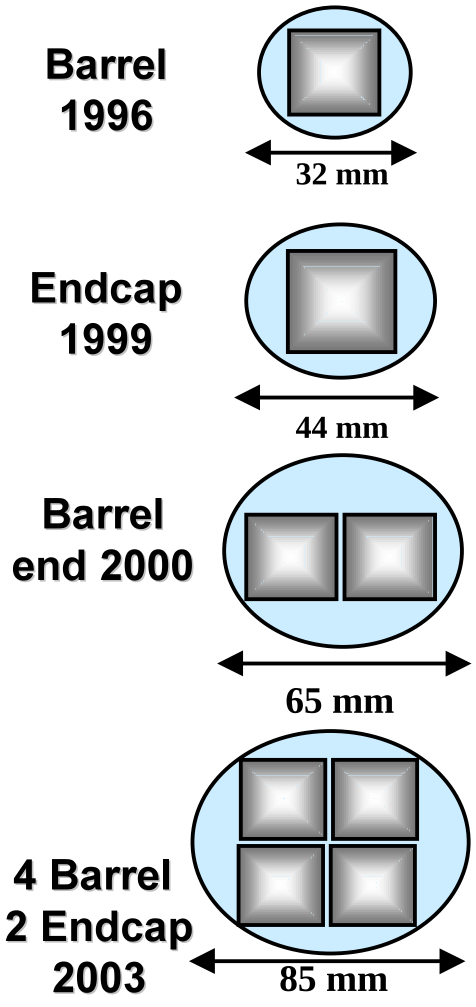


(LAB - BEAM)/BEAM

- **Lab measurements** of all modules; light yield, APD gain etc. → 4.5 %
- **Testbeam** precalibration transported to CMS (for 25% of detector) → 2.0 %
    - Distributed within detector, as “standard candle”
- **Min-bias** phi symmetry → 2 %
    - Fast calibration to reduce number of calibration constants
- **Isolated e from W/Z** → 0.5 %
    - Needs tracking in Si-tracker
    - Within ~2 months
- Laser **monitoring system** over time to monitor crystal transparency

PbWO4 Crystals and Photodetectors

Technological steps in Bogoroditsk

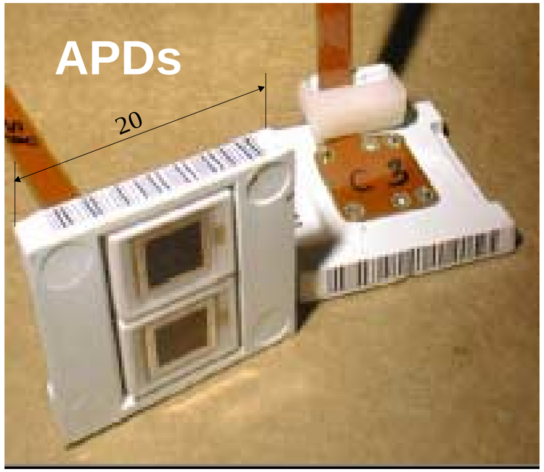

Barrel 1996
32 mm

Endcap 1999
44 mm

Barrel end 2000
65 mm

4 Barrel 2 Endcap 2003
85 mm

- 16k barrel crystals (out of 62k) delivered.
- Growth of large ingots is now very successful and reproducible
- Technical problems for cutting large ingots being solved.
- Crystal production critical: last barrel crystal mid 05



85k out of 130k APDs delivered

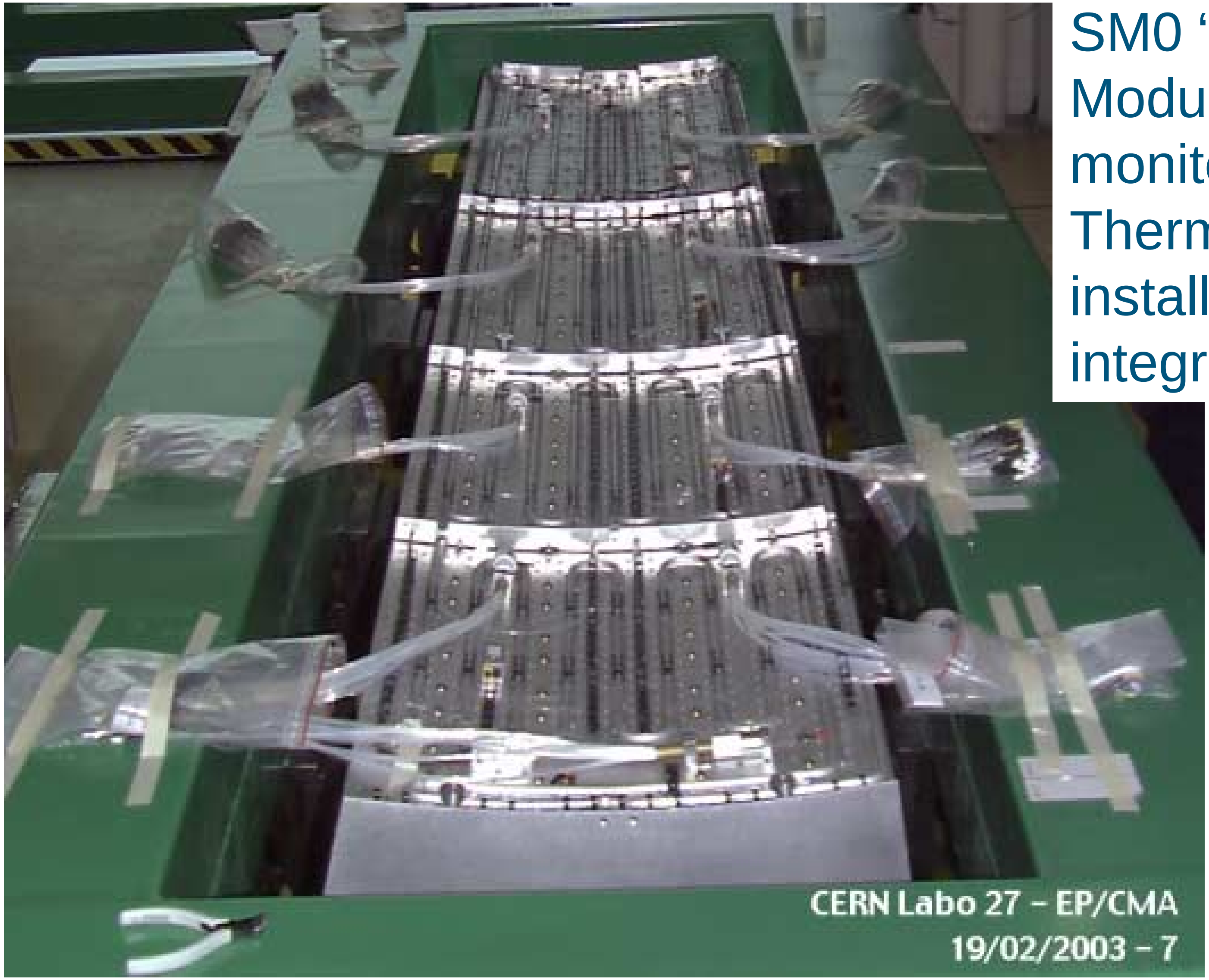
4100 production VPTs delivered

Supermodule Assembly

Need 2x18 supermodules (SMs) of ~ 1700 crystals each

Finish 12 bare (no electronics) SMs by end-03 (out of 36 total)

EB mechanical construction



SM0 “bare” Super Module completed with monitoring and Front Thermal screen installation. Ready to integrate electronics

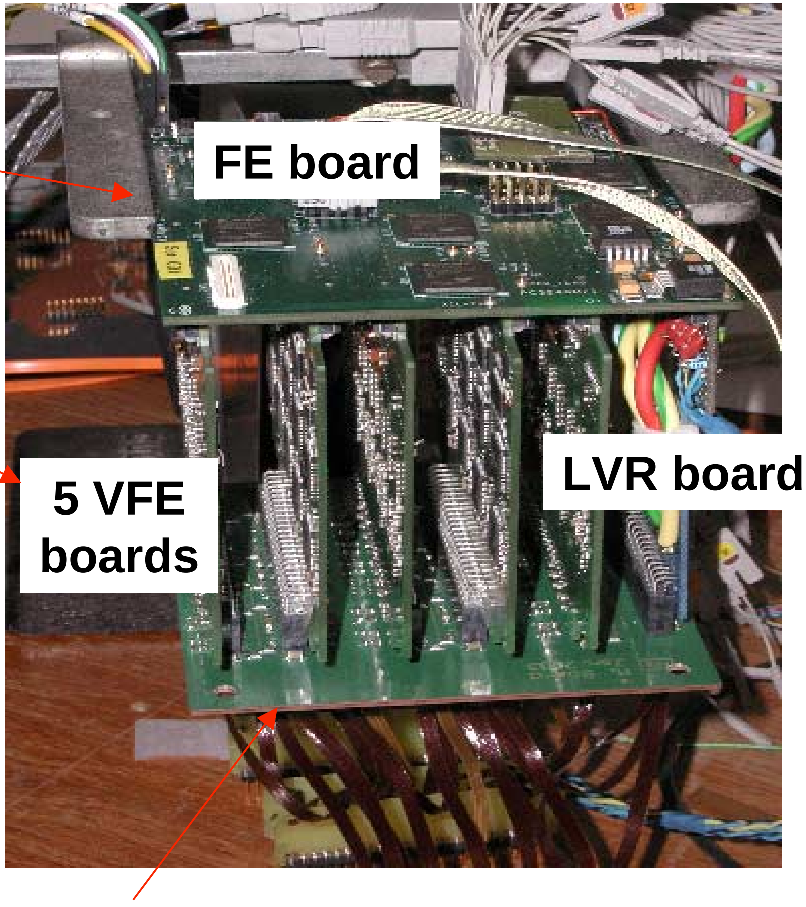
ECAL Electronics

Front-end Electronics redesigned recently: One fiber per trigger tower 5x5 crystals.

1)FE Board: 5x5 crystals
FENIX : New chip DSM for trigger sums and digital pipeline.
2)**VFE Board: 5 crystals**
Two versions for multigain preamp and ADC.

•DSM front-end expected to be substantially cheaper, consume less power and have slightly better performance

- **DECISION in July-2003 after comparative tests of alternative systems**



Motherboard with kaptons

ECAL Planning

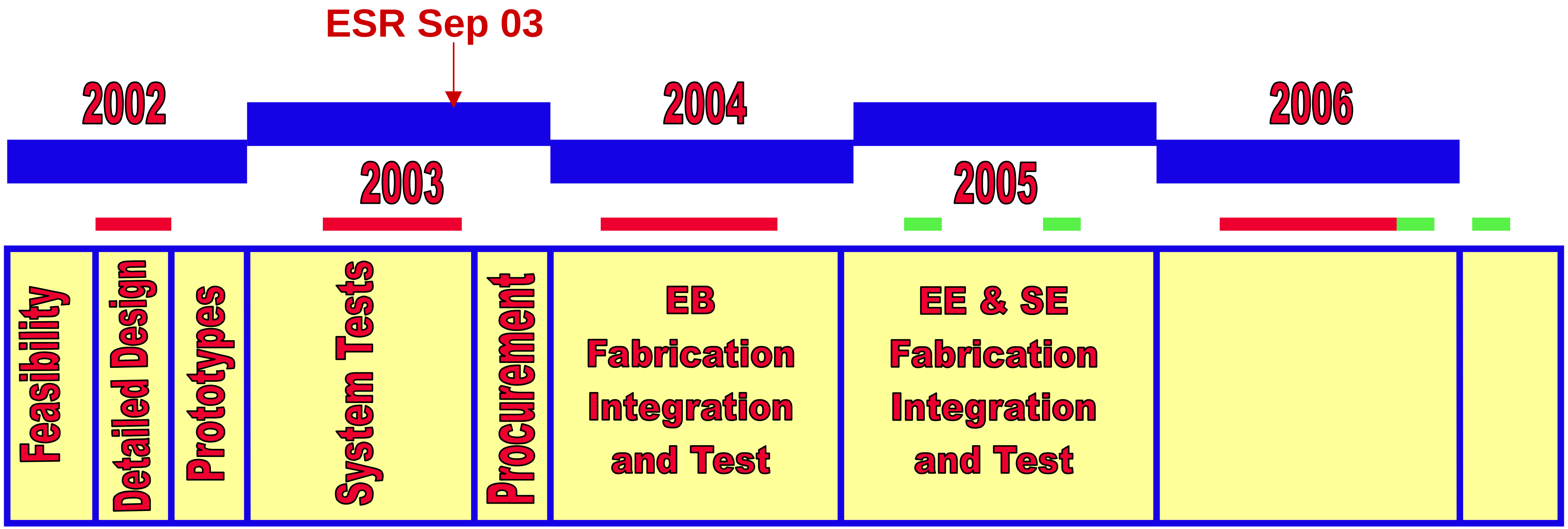
Goal: Apr 07 - ECAL complete and commissioned

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



ESR Sep 03

2002

2003

2004

2005

2006

Feasibility

Detailed Design

Prototypes

System Tests

Procurement

EB Fabrication Integration and Test

EE & SE Fabrication Integration and Test

Installation 🟩

Test Beam 🟥

EB+ EB- EE- EE+

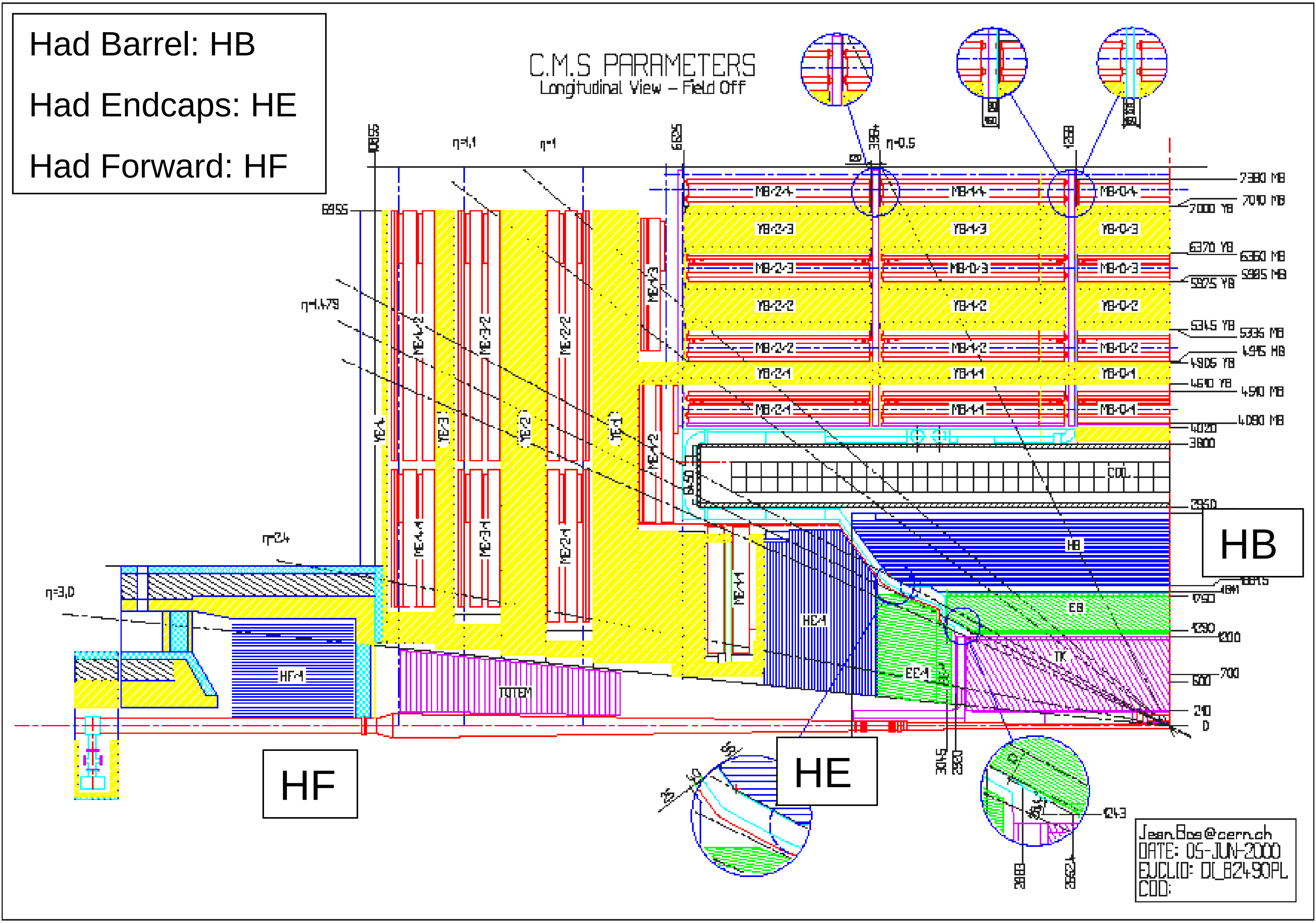
Electronics Schedule

Hadronic Calorimeter: HCAL

Had Barrel: HB

Had Endcaps: HE

Had Forward: HF



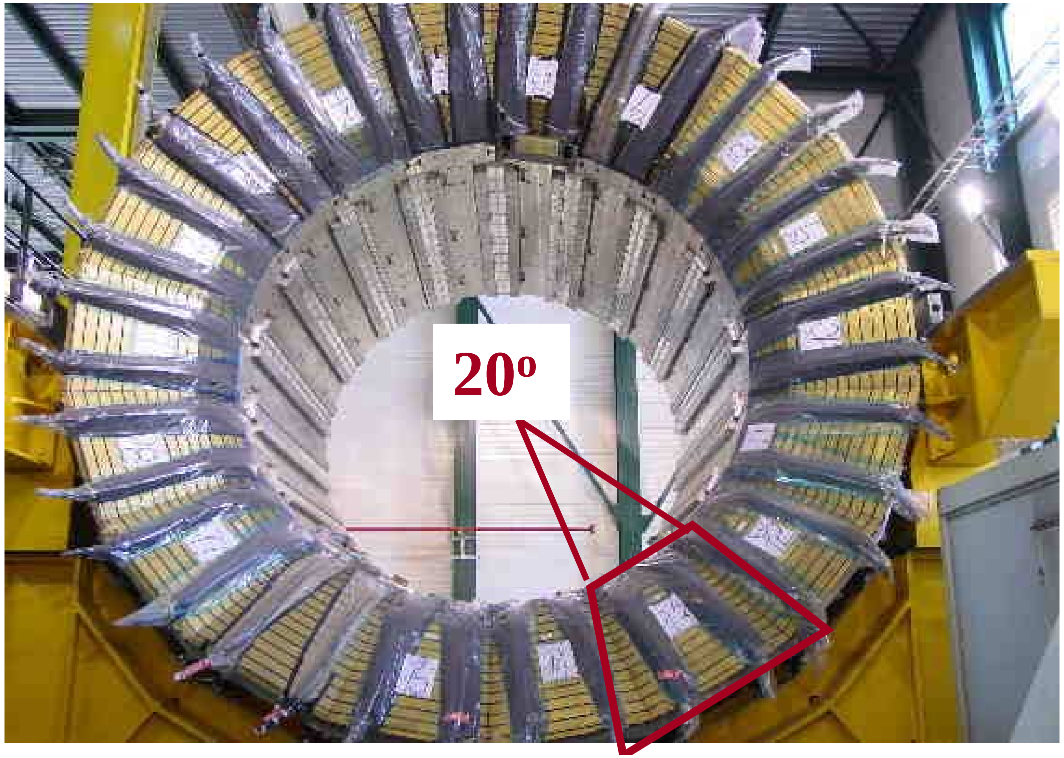
Hadronic Barrel (HB)

Sampling calorimeter: brass (passive) & scintillator (active)

Coverage: $|\eta|<1.3$

Depth: $5.8\ \lambda_{int}$ (at $\eta=0$) $\Delta\phi \times \Delta\eta = 0.087 \times 0.087$

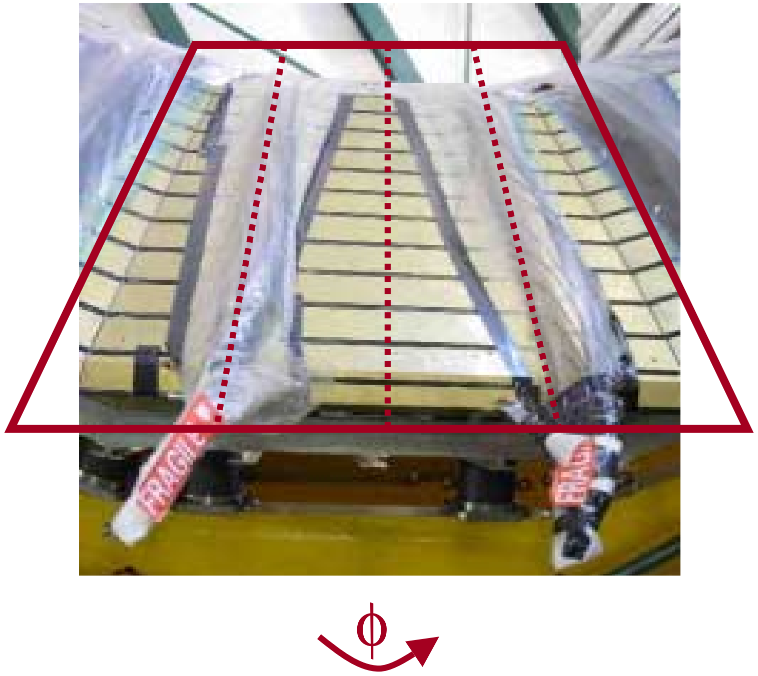
E resolution: $\sim (120/\sqrt{E} + 4)\%$



Completed & assembled

17 layers longitudinally,

$\phi \times \eta = 4 \times 16$ towers



Hadronic Endcap (HE)

Sampling calorimeter: brass (passive) & scintillator (active)

Coverage: $1.3<|\eta|<3$

Depth: $10\ \lambda_{int}$ $\Delta\phi \times \Delta\eta = 0.087 \times 0.087$

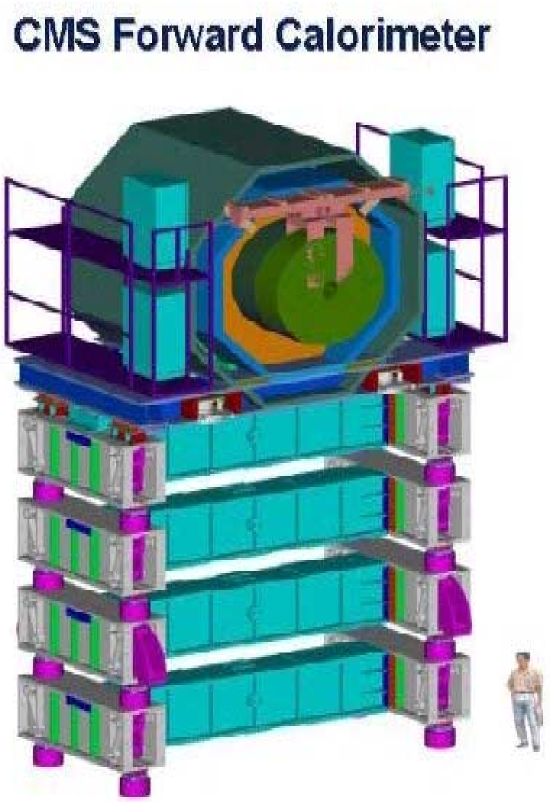
E resolution: $\sim (120/\sqrt{E} + 4)\%$

19 layers longitudinally

Hadronic Forward (HF) calorimeter

Steel absorbers, embedded quartz fibers // to the beam.
Fast (~10 ns) collection of Cherenkov radiation.

Coverage: $3<|\eta|<5$ $\Delta\phi \times \Delta\eta = 10^{o} \times 13$ η towers
Depth: $10\ \lambda_{int}$



Permanent H2 Testbeam Facility

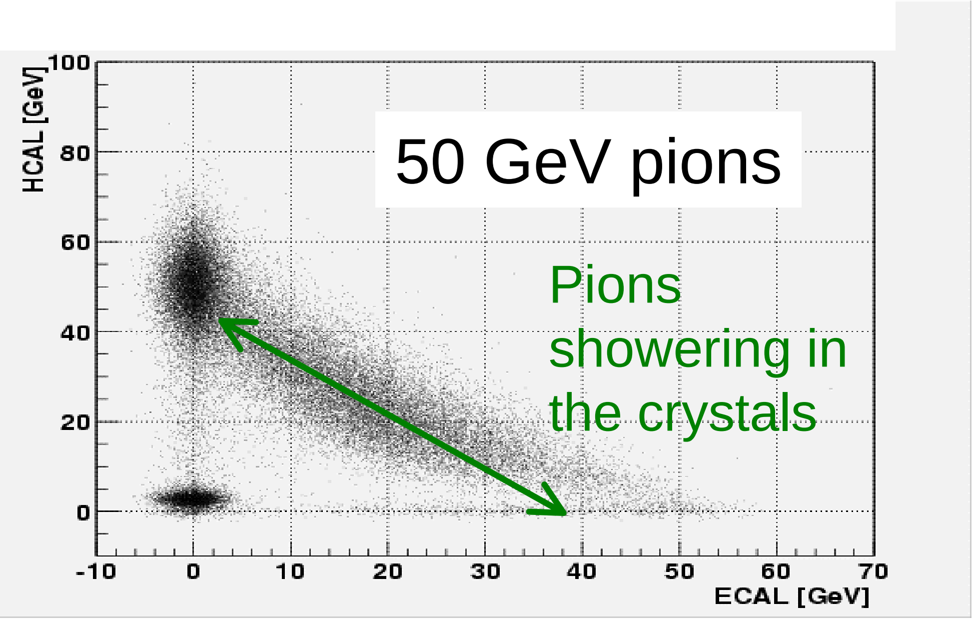
HO Outer Calorimeter

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})

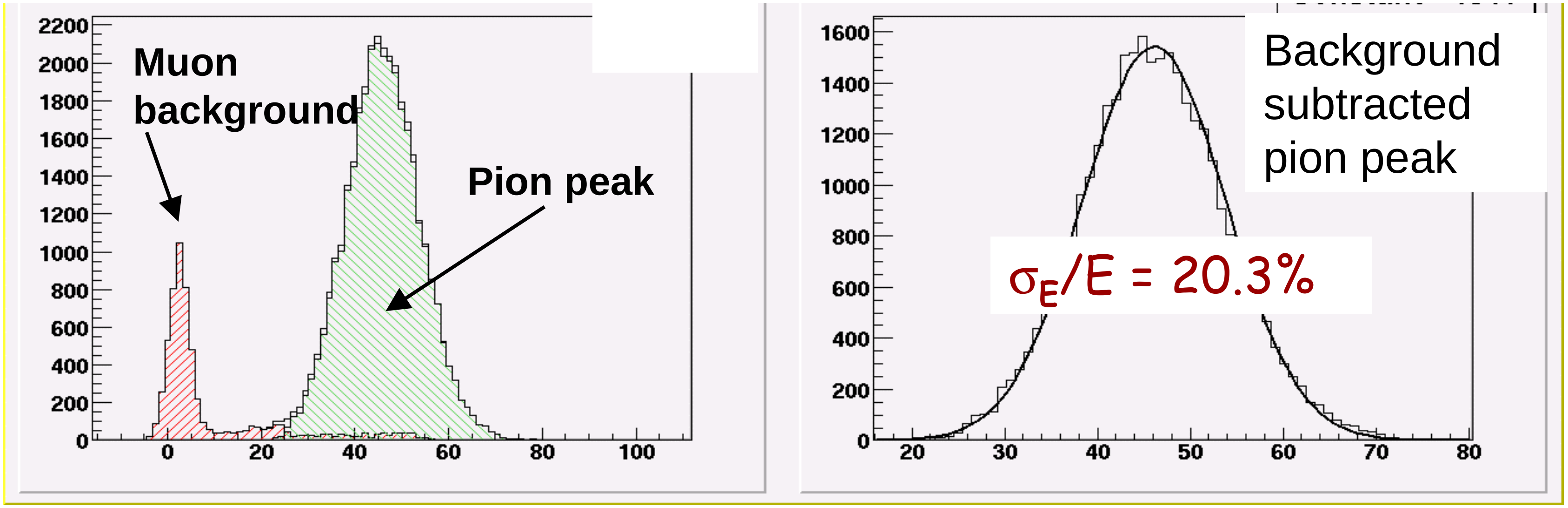
~ 5% of a 300 GeV π energy is leaked outside the HB

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

Test Beam 2002: Mixed Calorimetry Resolution

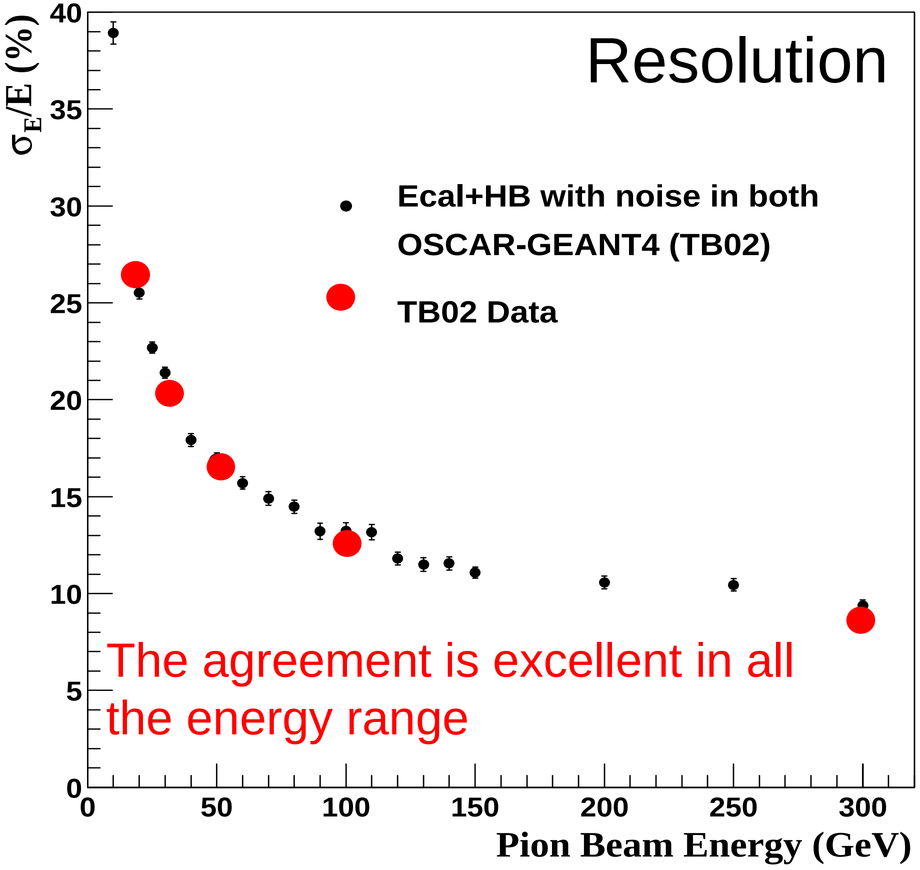


Data energy resolution for 50 GeV pions

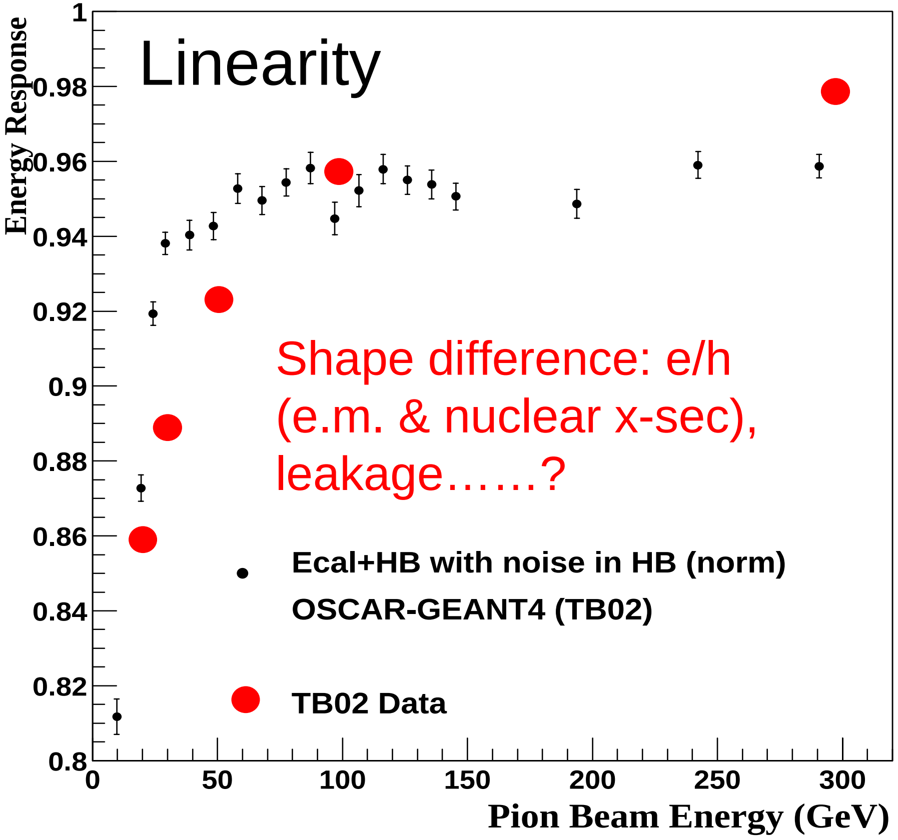


$\sigma_E/E = 20.3\%$

Test Beam 2002: Resolution and Linearity



The agreement is excellent in all the energy range



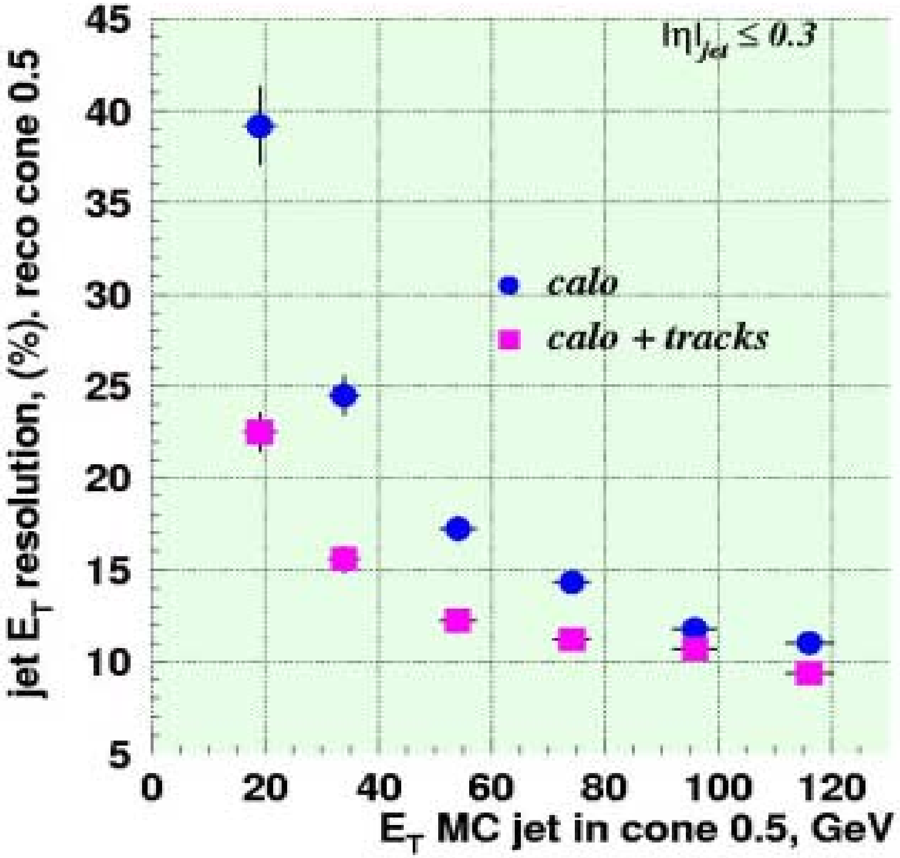
Shape difference: e/h (e.m. & nuclear x-sec), leakage……?

Data systematic error analysis in progress → Validate GEANT4 physics models

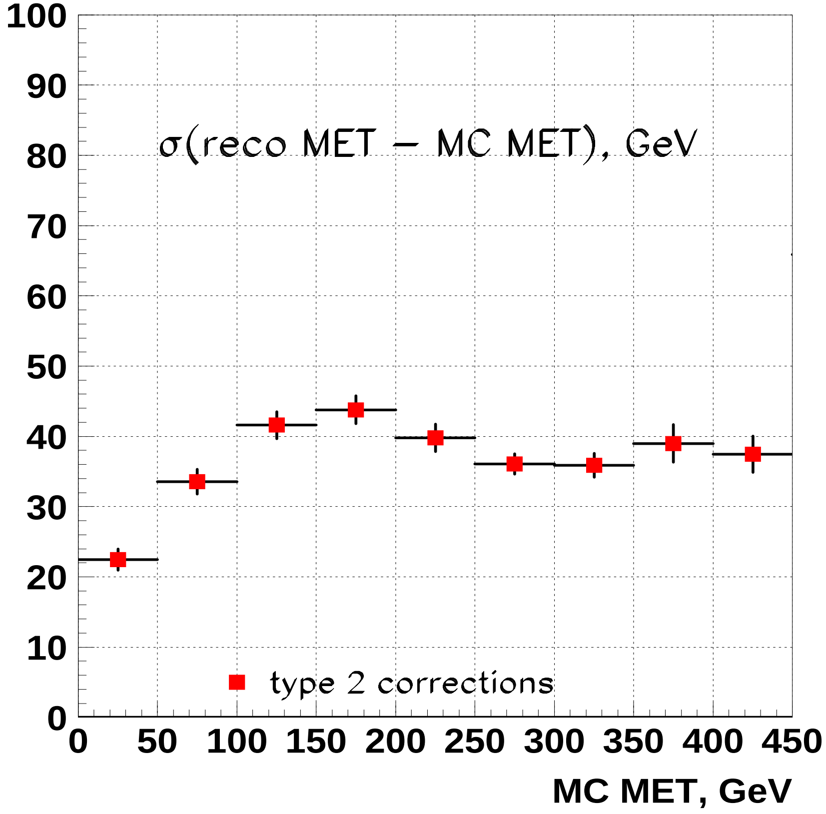
Jet and $\not{E}_T$ Resolution

PYTHIA + CMSIM + ORCA

single jets (R=0.5 cone algorithm)

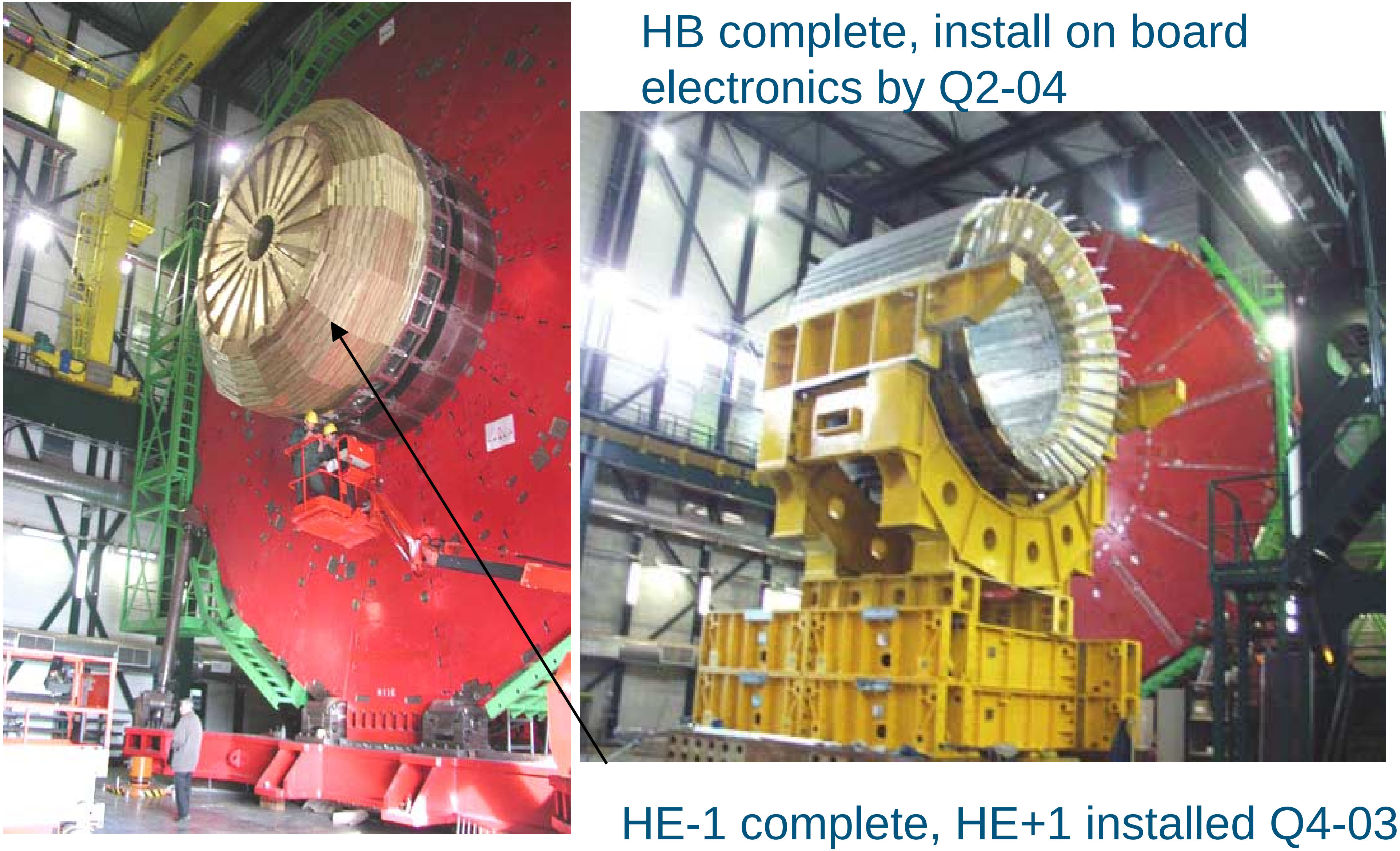


Squarks/gluinos of M~500 GeV decaying to jets + $\not{E}_T$



HCAL : HB and HE

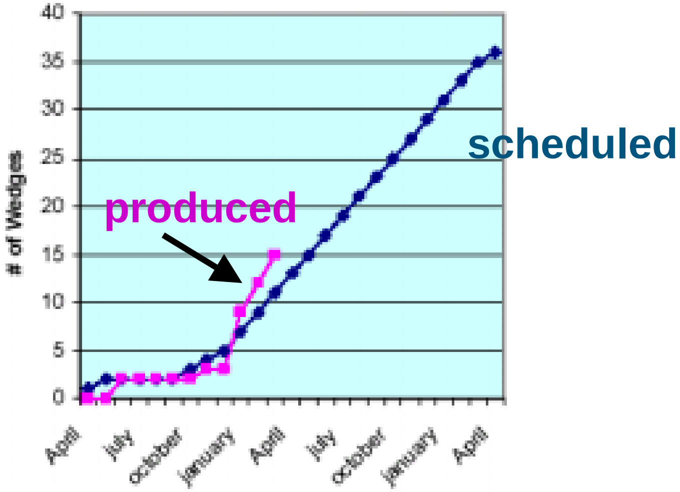
HB complete, install on board electronics by Q2-04



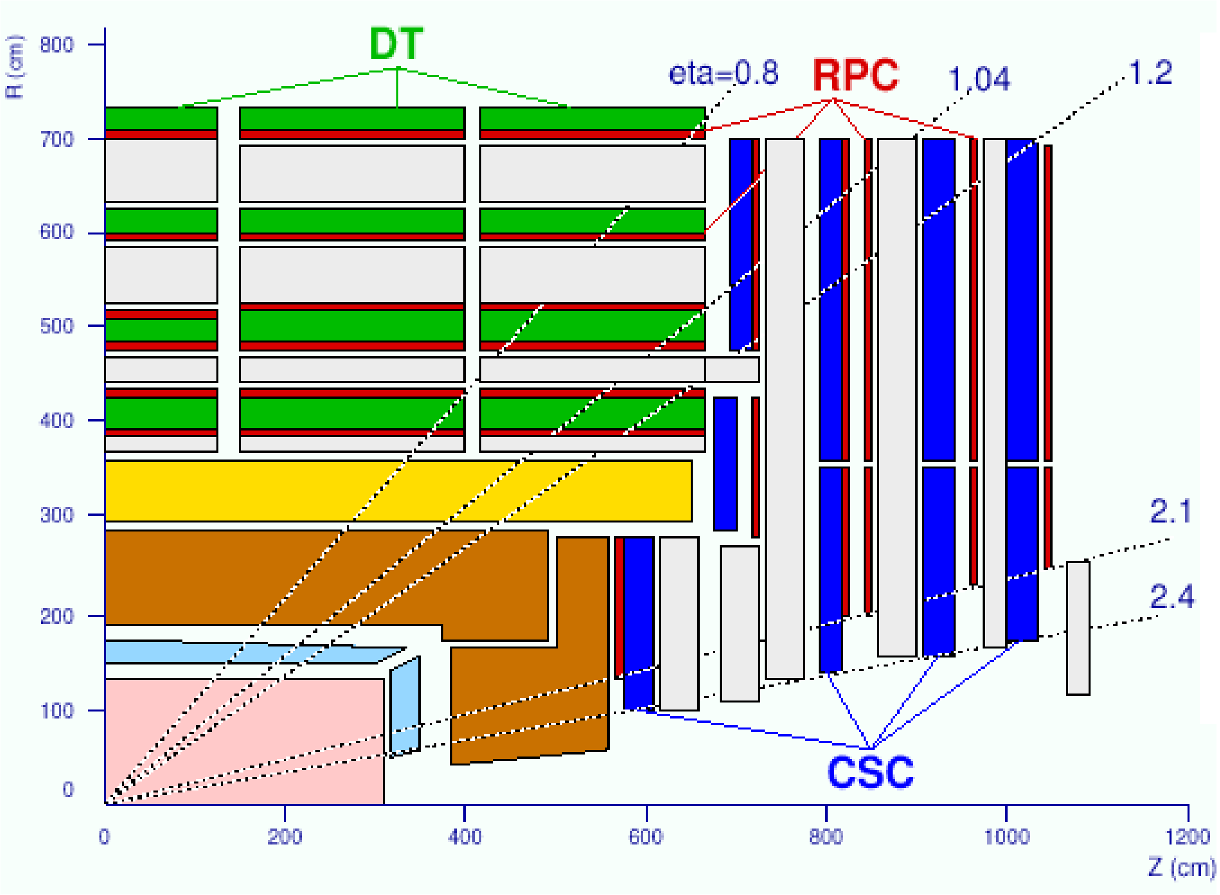
HE-1 complete, HE+1 installed Q4-03

HCAL: HF Fibre Insertion

If present rate maintained fibre insertion will be finished in November 2003
(instead of April 04)



Muon Detectors



Three types of gaseous detectors:

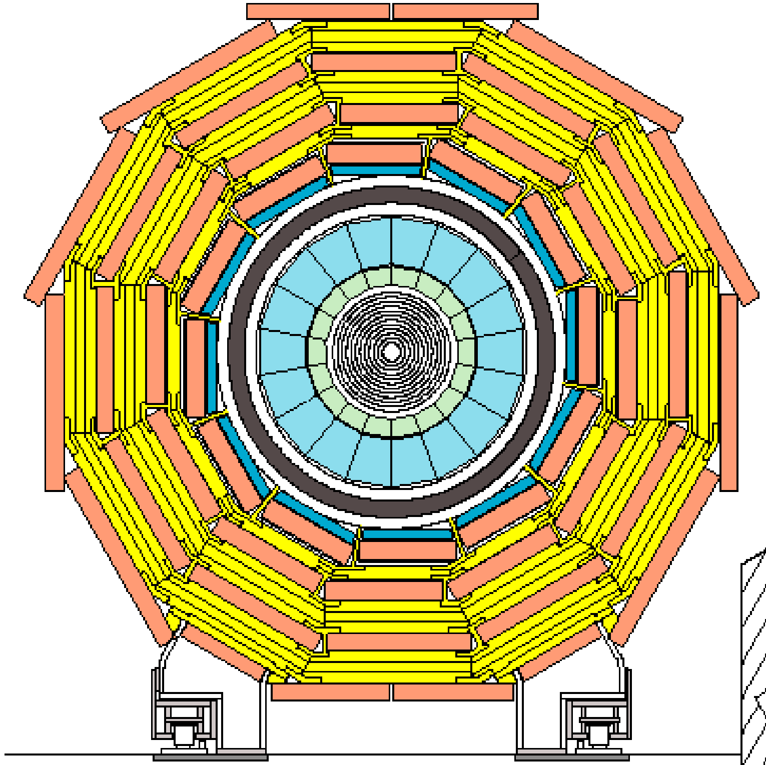
•Drift Tubes in Barrel (DTs)

•Cathode Strip Chambers in Endcaps (CSCs)

•Resistive Plate Chambers (RPCs) in both barrel and endcaps

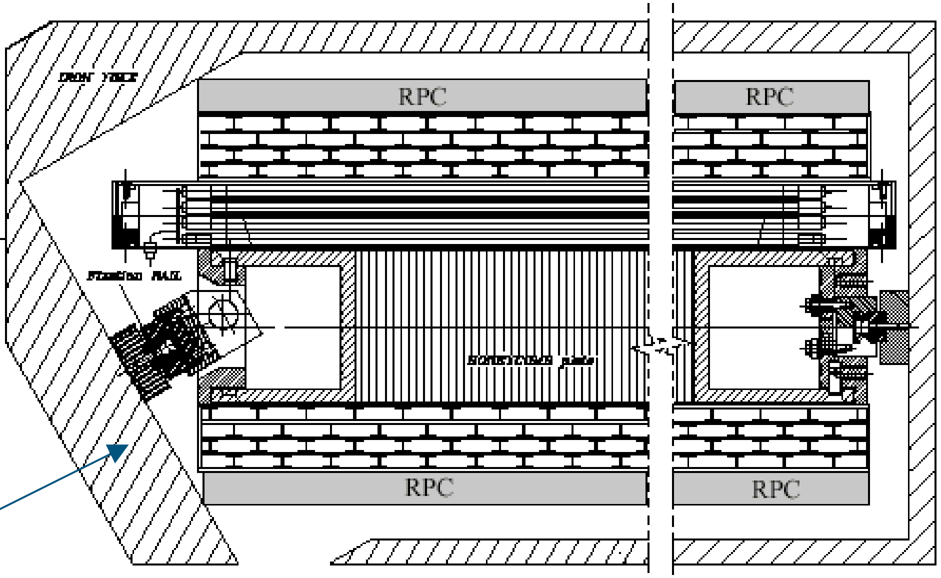
DTs and CSCs provide precise position measurements (~100-200μm)
RPCs provide precision bunch crossing identification (~1 ns)
All 3 systems contribute to the L1-trigger.

Drift Tubes in Barrel



- MB1,2,3= 8 ϕ-layers
  + 4 θ-layers
- MB4= 8 ϕ-layers

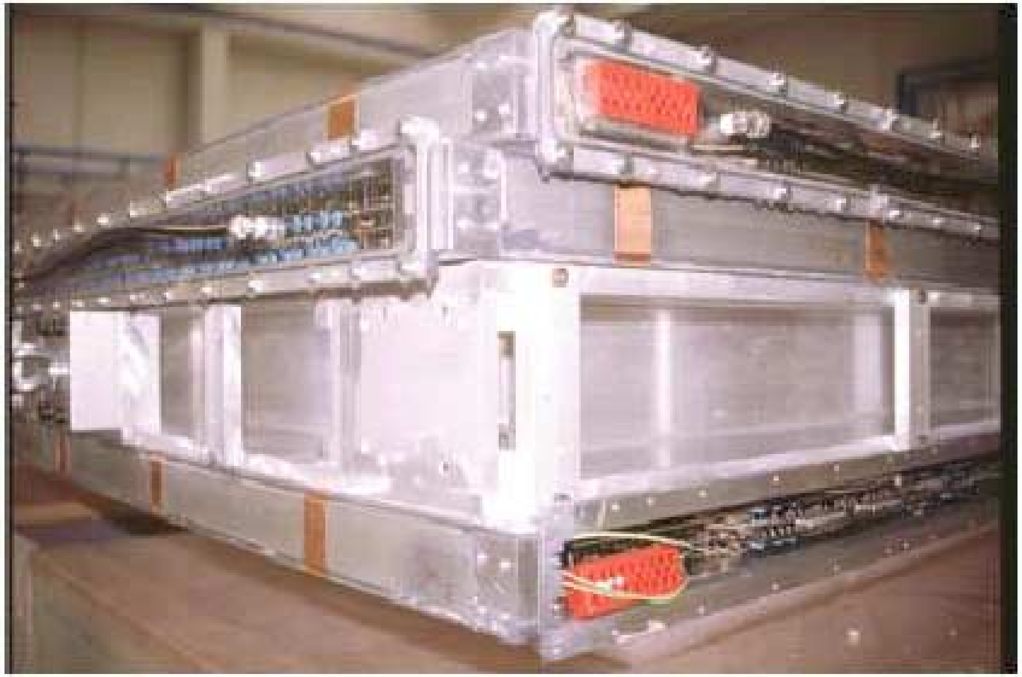
- 250 chambers
- 192 000 channels



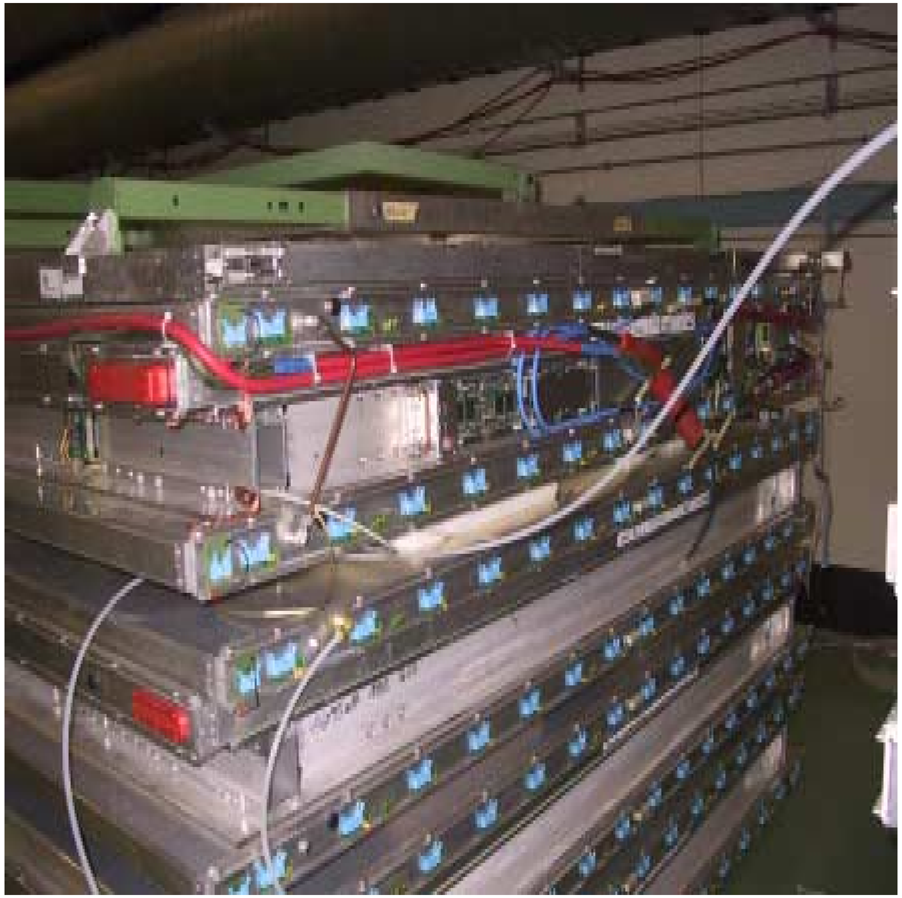
- wire pitch = 4.2 cm
- max. drift time = 380 ns

Chamber Resolution:
Pos ~ 100µm, Dir ~ 1 mrad

Muon Barrel DT Chambers



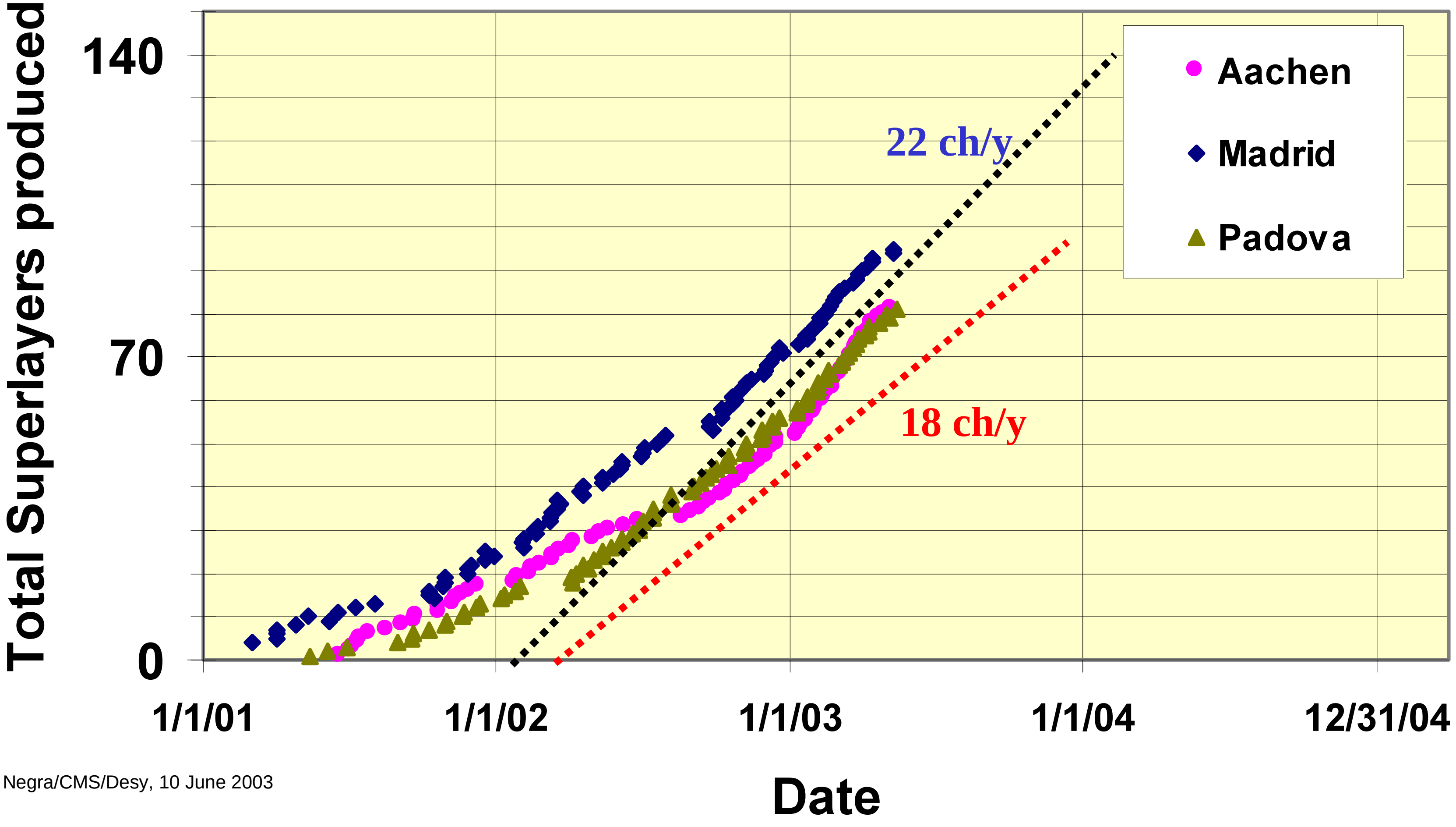
3 superlayers (SLs) :
2 phi and 1 theta SL
Each SL has 4 layers of DTs.
12 precise measurements per station.



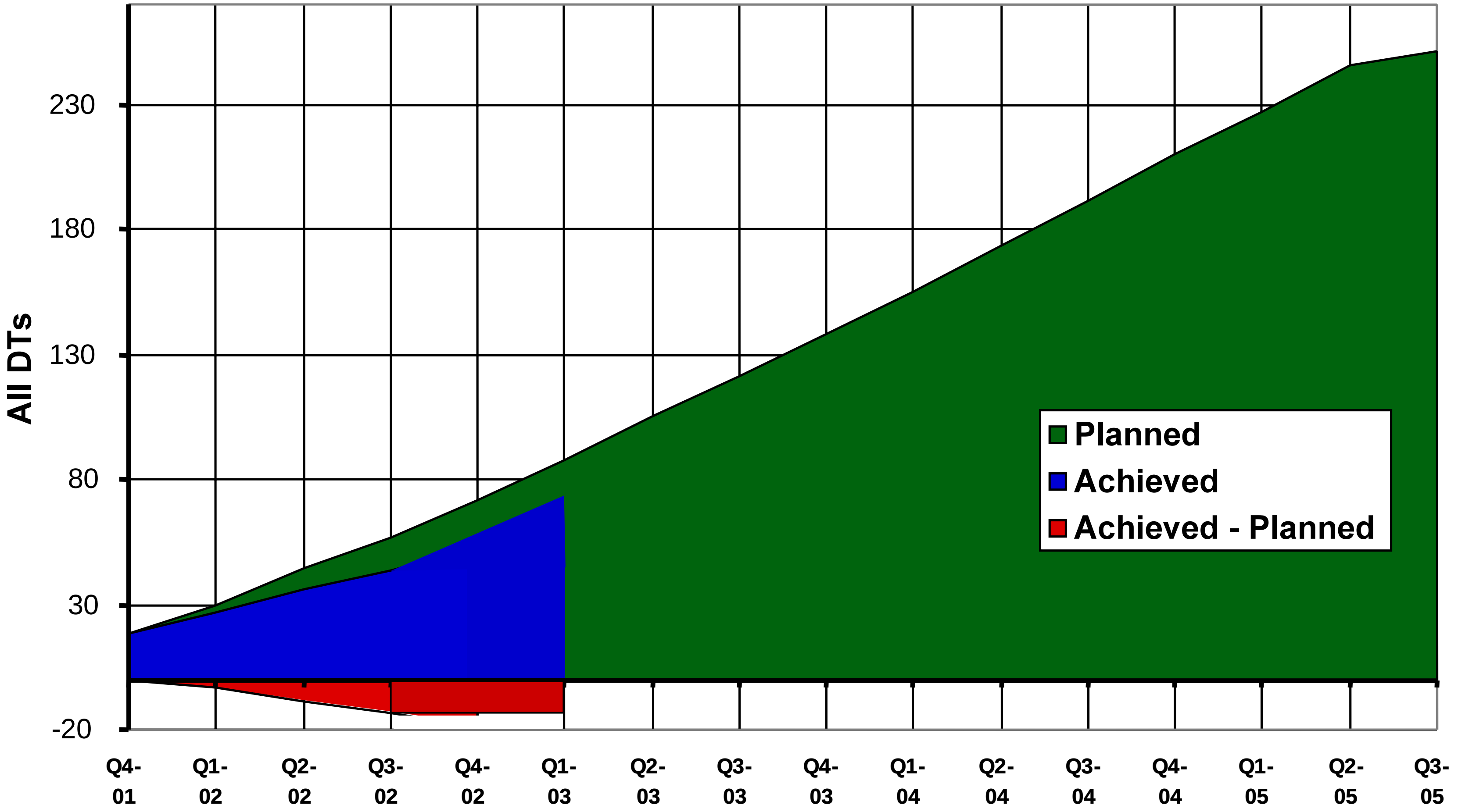
DT Chamber ready for installation with minicrates: trigger and readout electronics

Muons: DT Production

- All 3 sites (Aachen, Ciemat, Legnaro) assembling chambers at necessary rate (18 ch/year).
- 4th site inTorino: start assembly in autumn 03 (MB4).



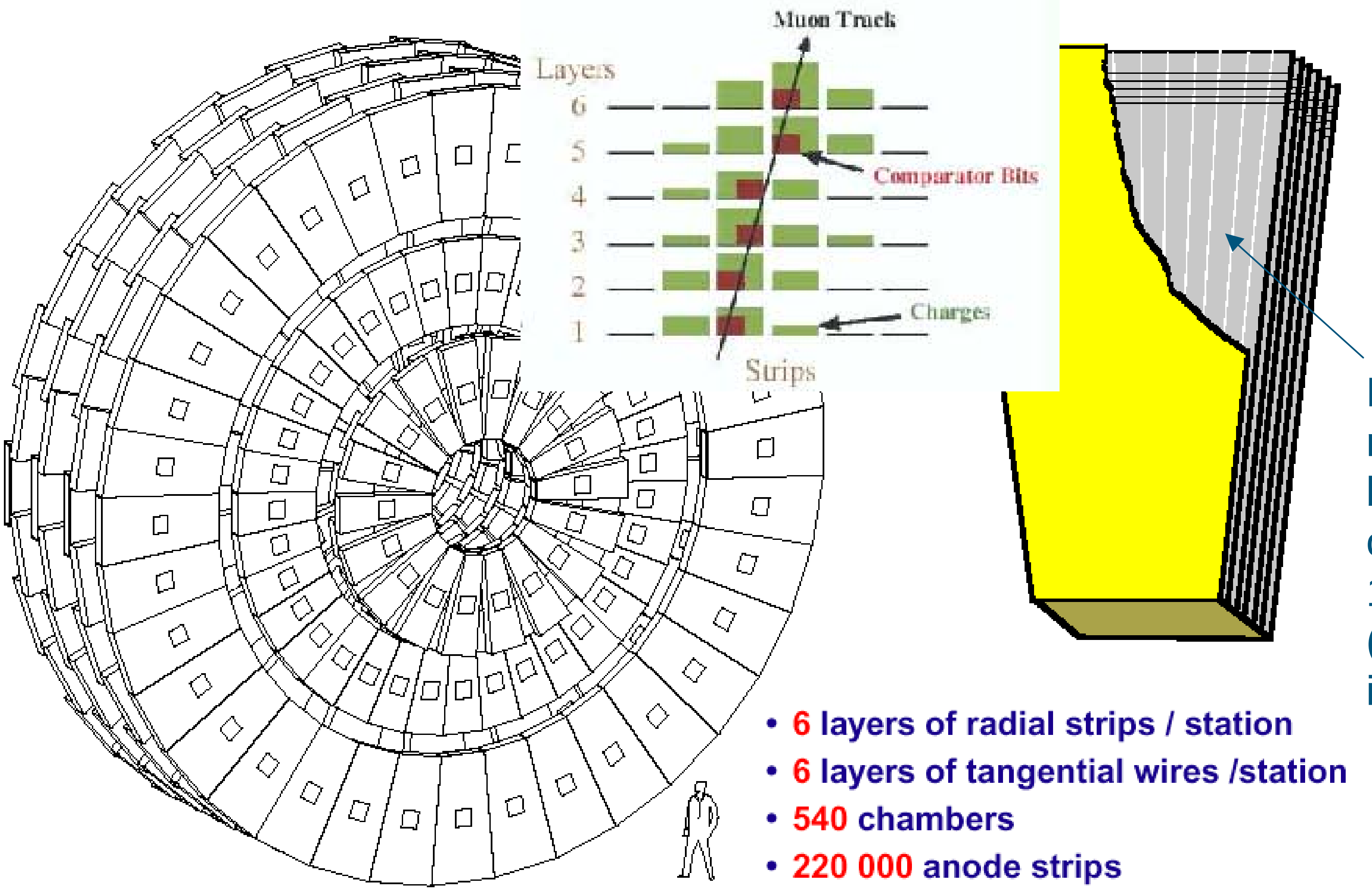
Muon DT Production



Integral of produced chambers /quarter.

Installation of first MB1 chamber

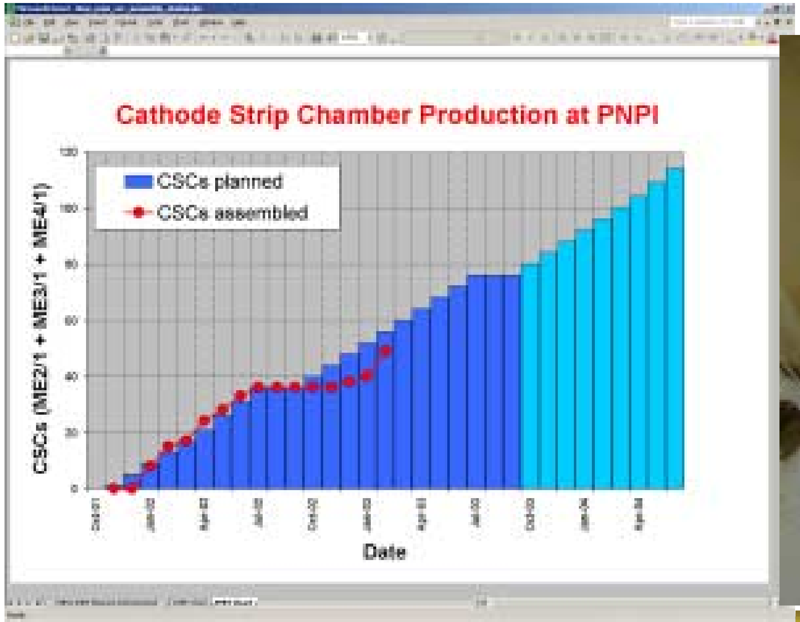
Cathode Strip Chambers in Endcaps

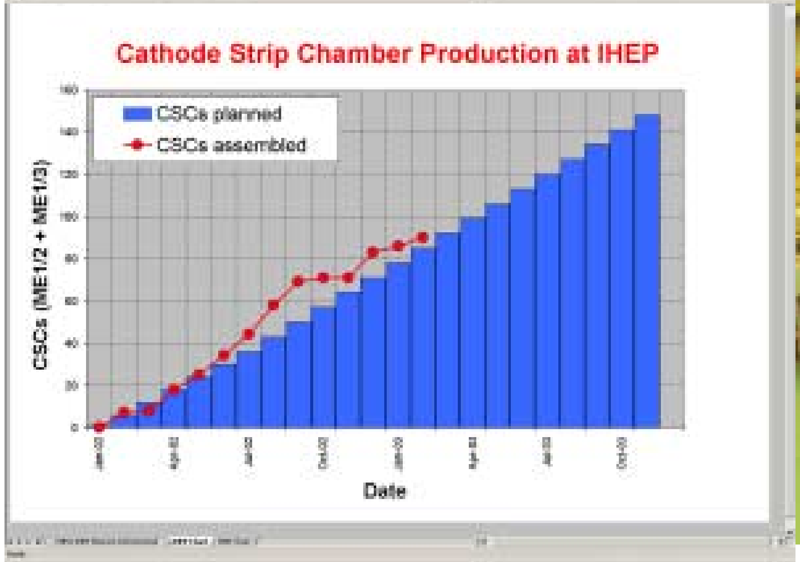


Radial strips measure bending coordinate to 100-240μm (charge interpolation)

- **6 layers of radial strips / station**
- **6 layers of tangential wires /station**
- **540 chambers**
- **220 000 anode strips**
- **320 000 cathode wire groups**

Muons: CSC Assembly



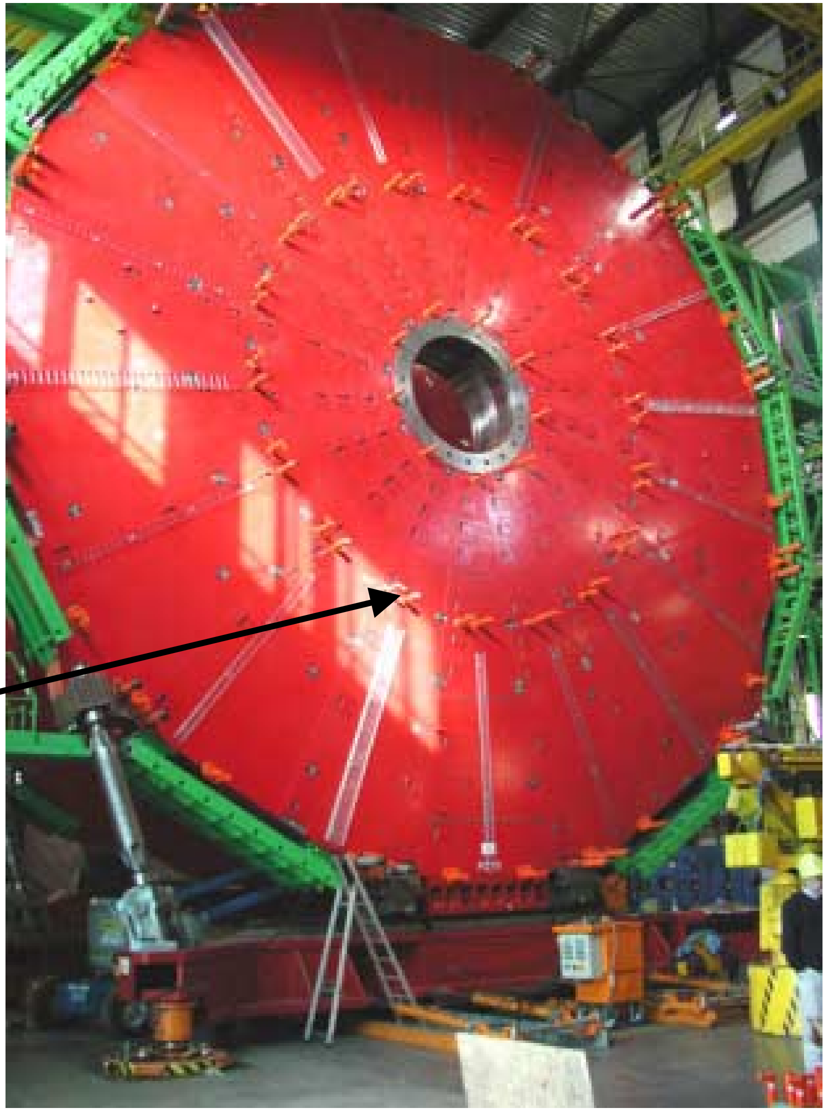


45 US_CSCs at CERN

US: production of 148 chambers finished.

Dubna
ME1/1
50 out of 72
assembled

Installing CSCs

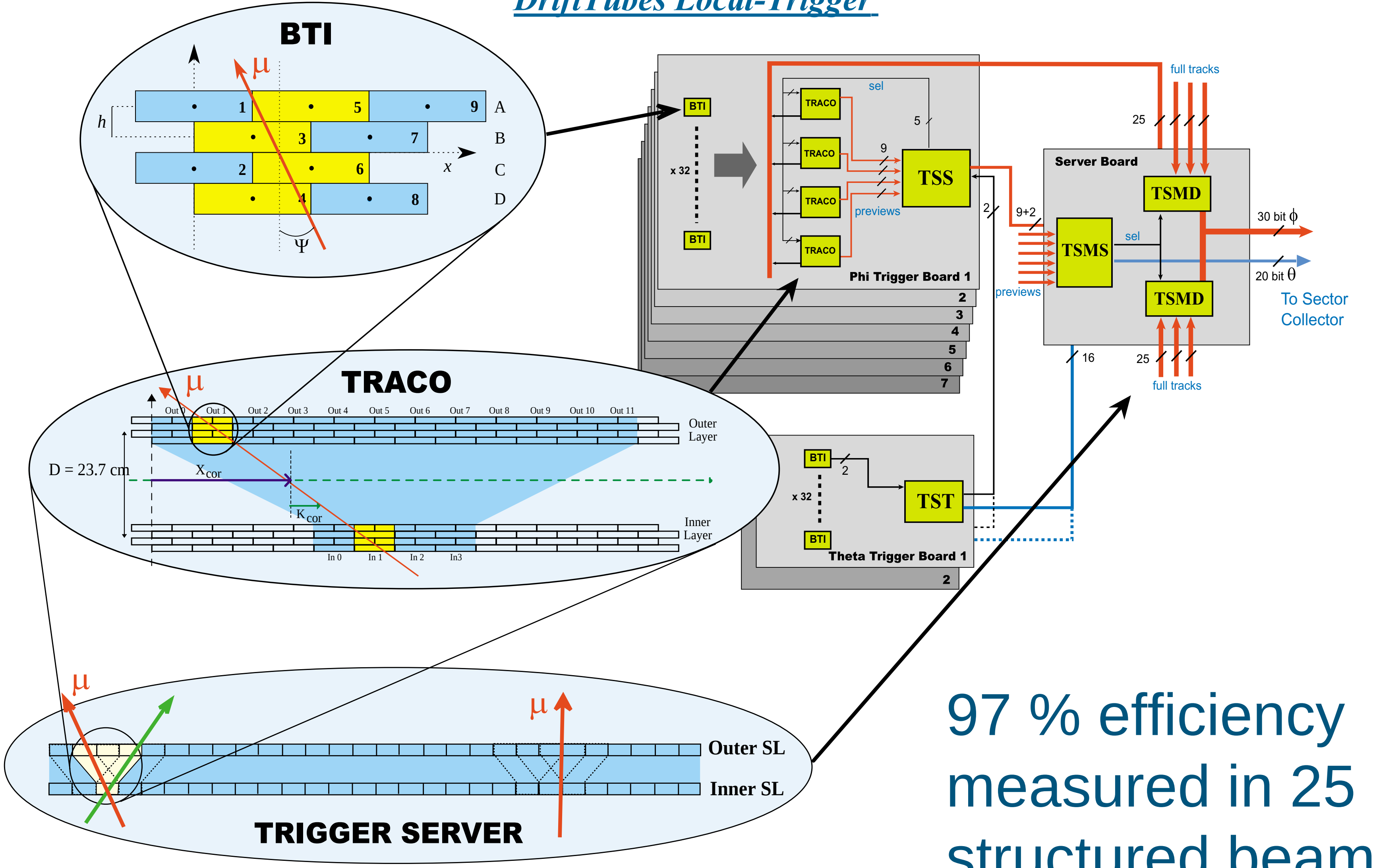


The support posts have been installed on YE+2, ready for CSCs to be mounted as soon as gas distribution pipes have been laid down.

Start installation in Jun 03

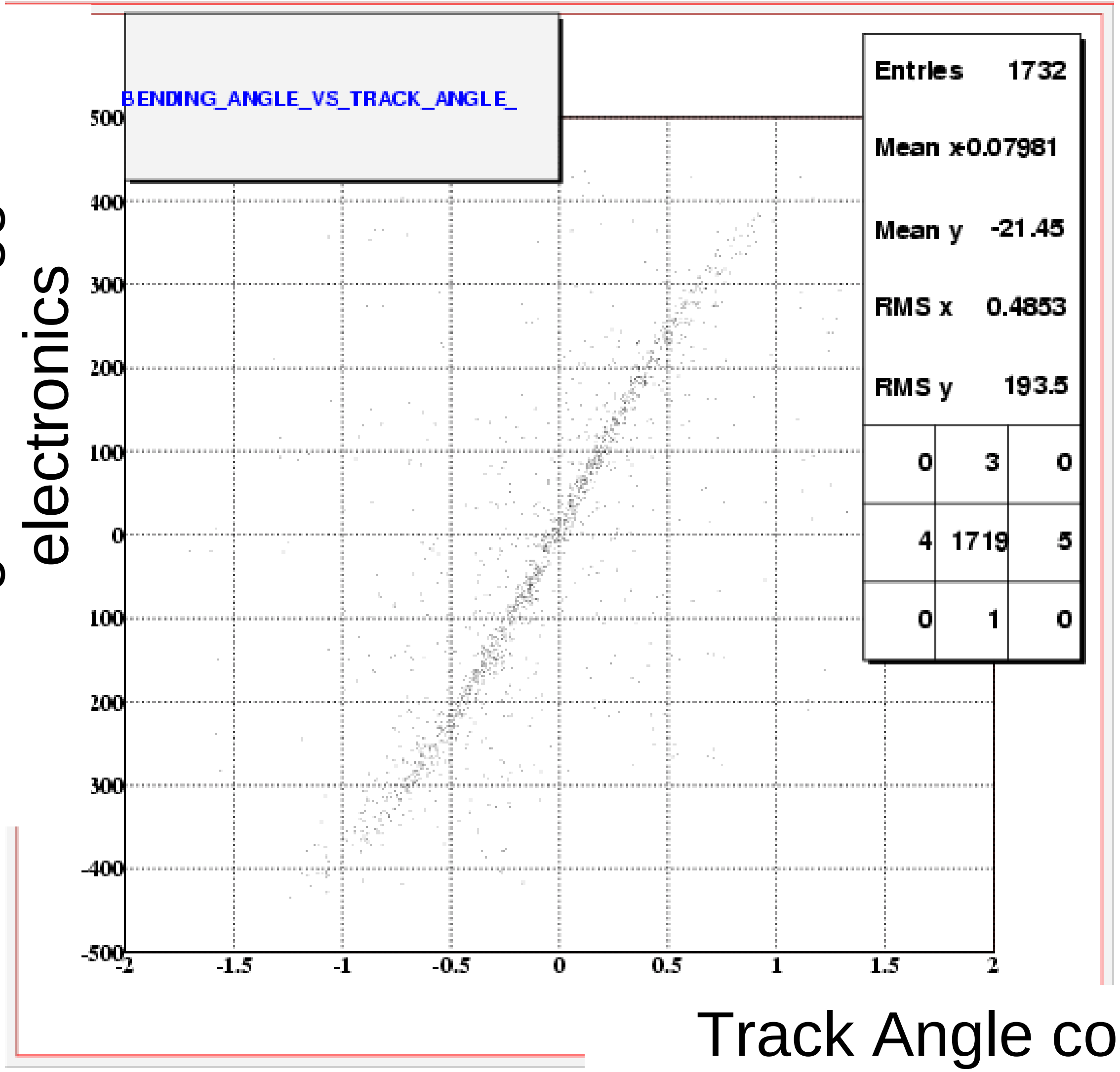
DT Trigger Electronics

DriftTubes Local-Trigger



97 % efficiency measured in 25 ns structured beam

Bending Angle from DT Trigger

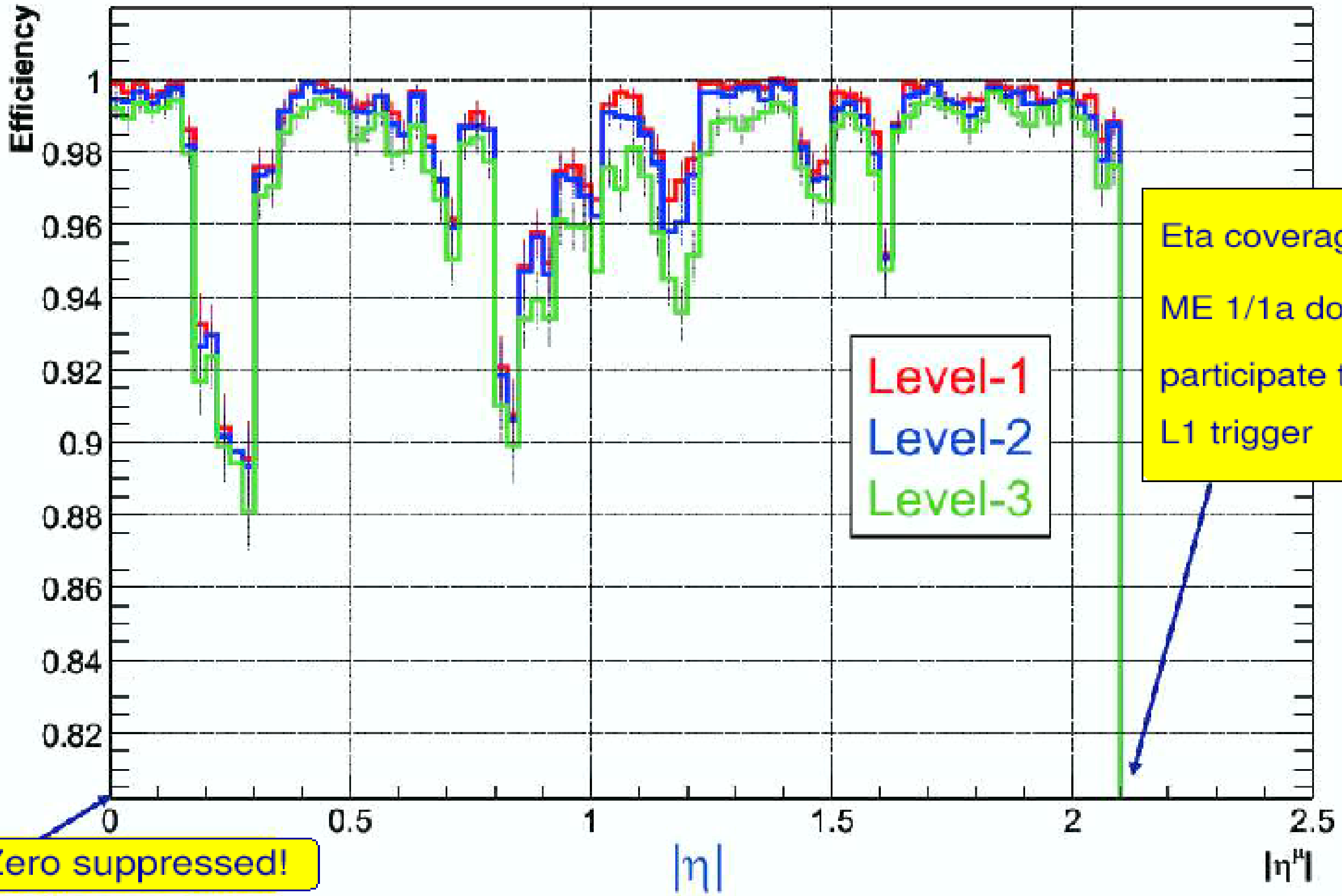


Angle from Trigger electronics

Track Angle cosmics telescope

Muon Trigger Efficiency

L1, L2, L3 efficiency vs $|\eta|$



Eta coverage limit 2.1

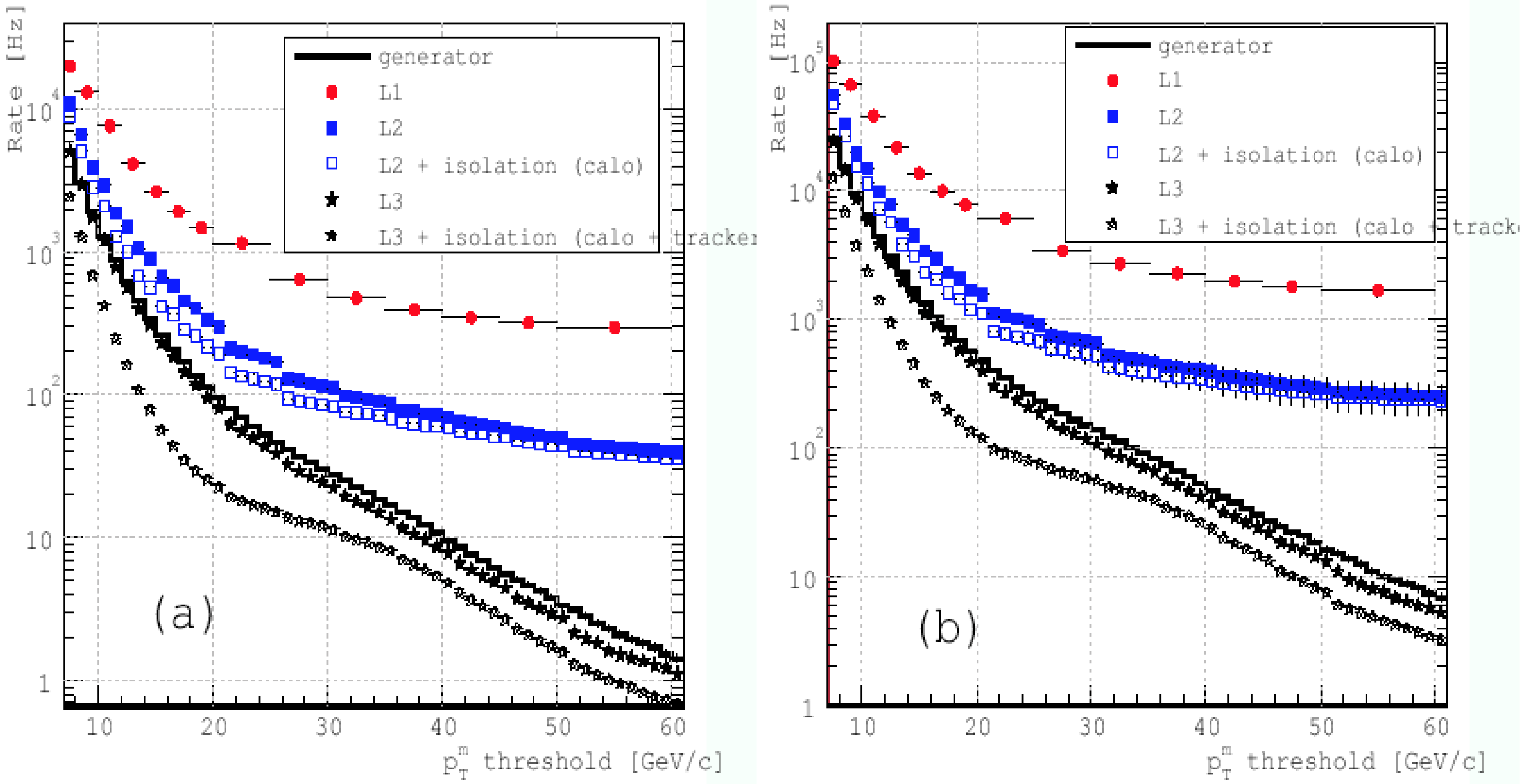
ME 1/1a does not participate to L1 trigger

Zero suppressed!

$|\eta|$

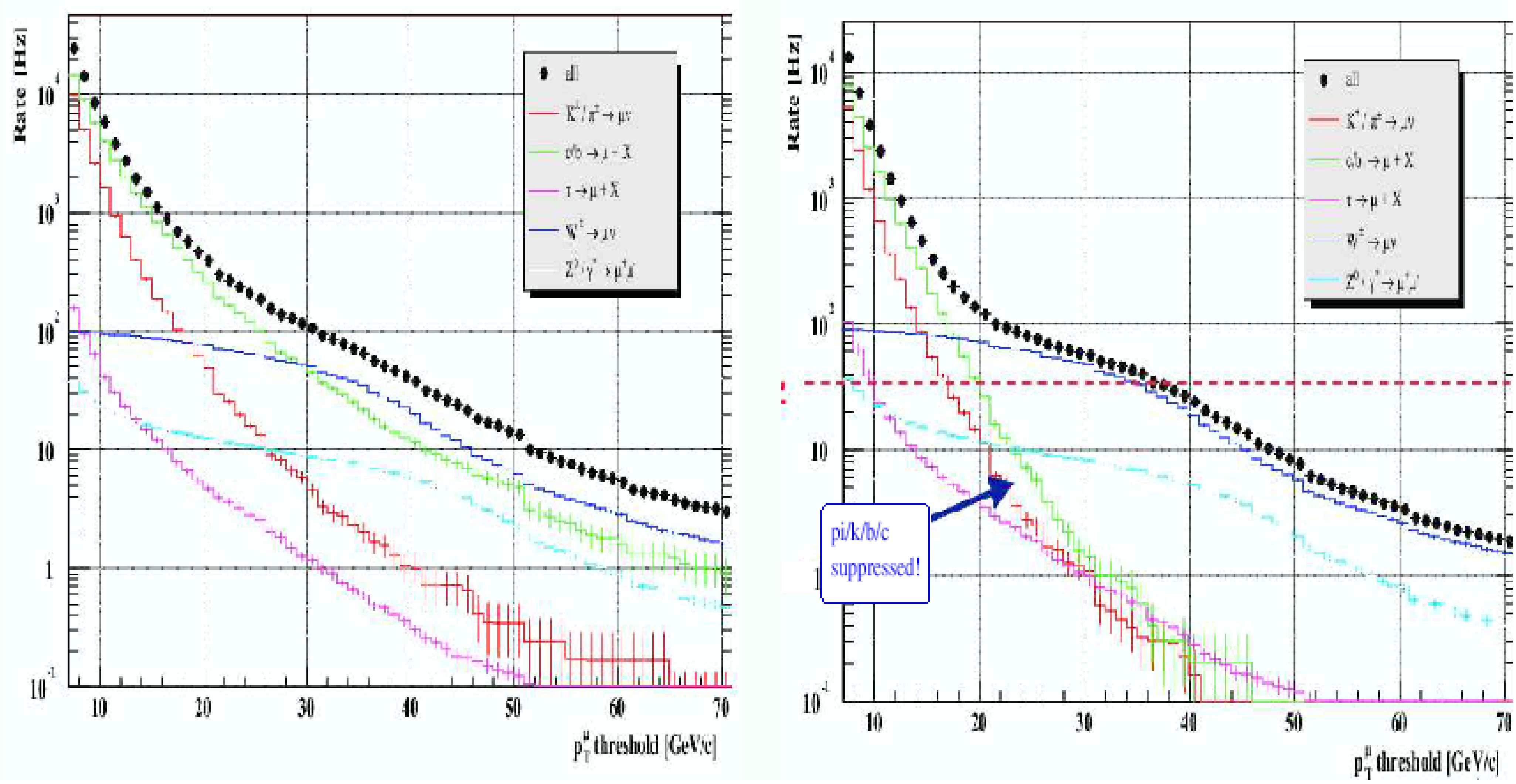
Physics Performance

Single muon rate Low (a) and High (b) lumi:



Physics Performance

Contribution to single μ rate High Lumi before and after isolation:



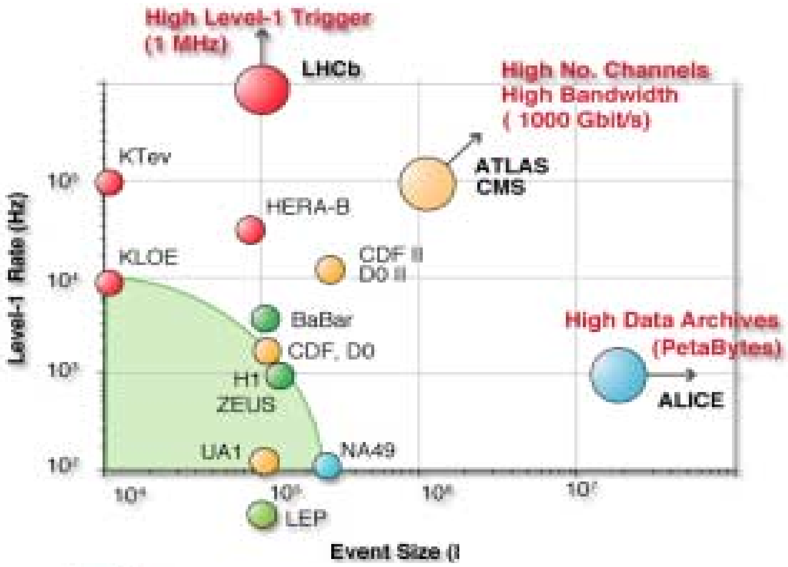
pi/k/b/c suppressed!

The CMS Trigger

Formidable task:

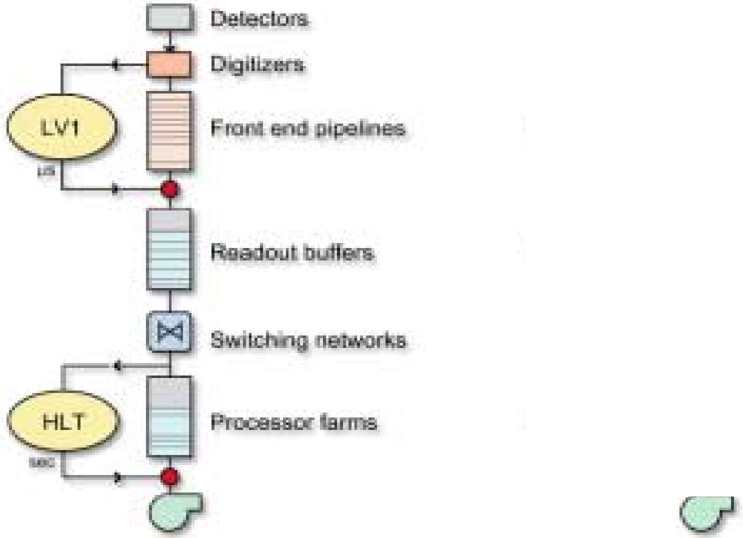
Bunch crossing rate → permanent storage rate for events with size ~1MB

$40\text{MHz} \rightarrow O(10^2)\text{Hz}$



CMS design:

Beyond **Level-1** there is a **High Level Trigger** running on a single processor farm



CMS DAQ and Trigger System

Event size: 1MB from
~700 front-end electronics modules

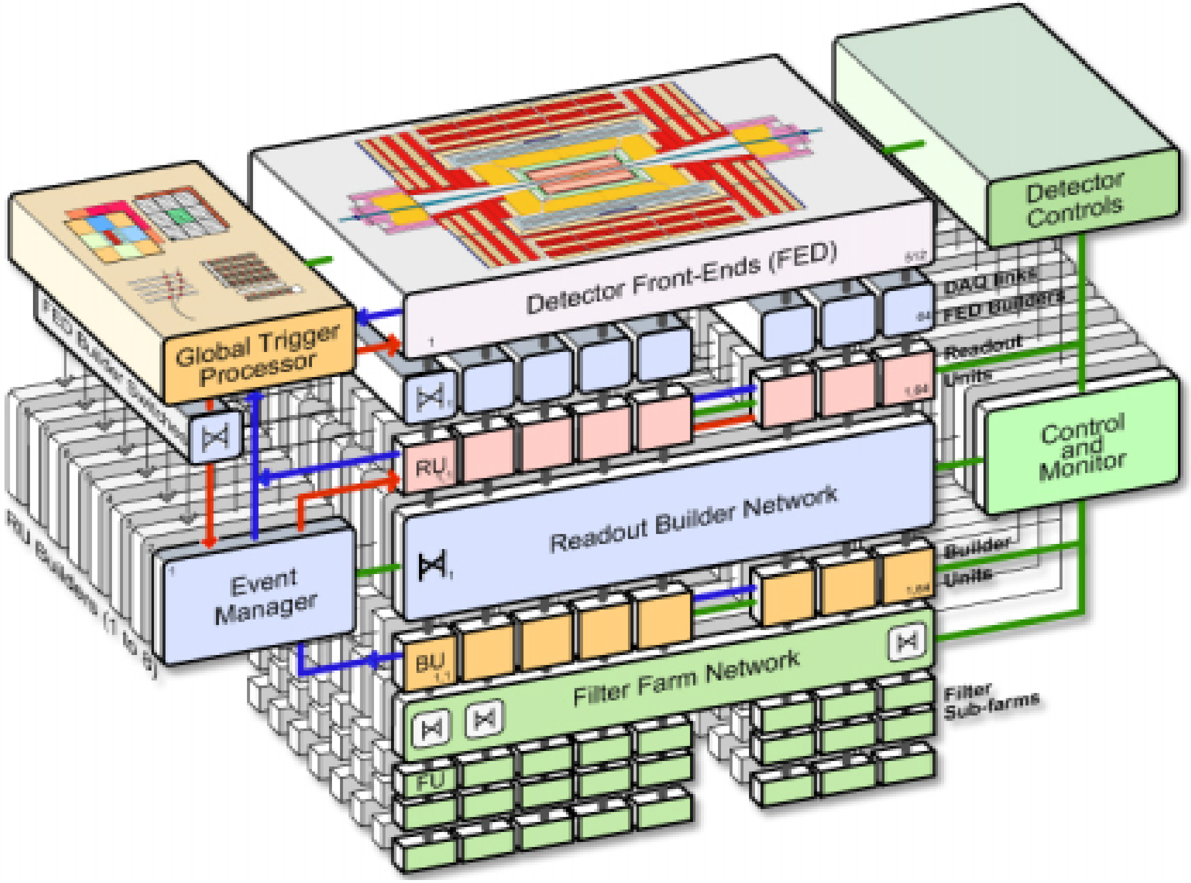
Level-1 decision time: ~3µs
~1µs actual processing
(the rest in transmission delays)

DAQ bandwidth:
designed to accept
Level-1 rate of 100kHz

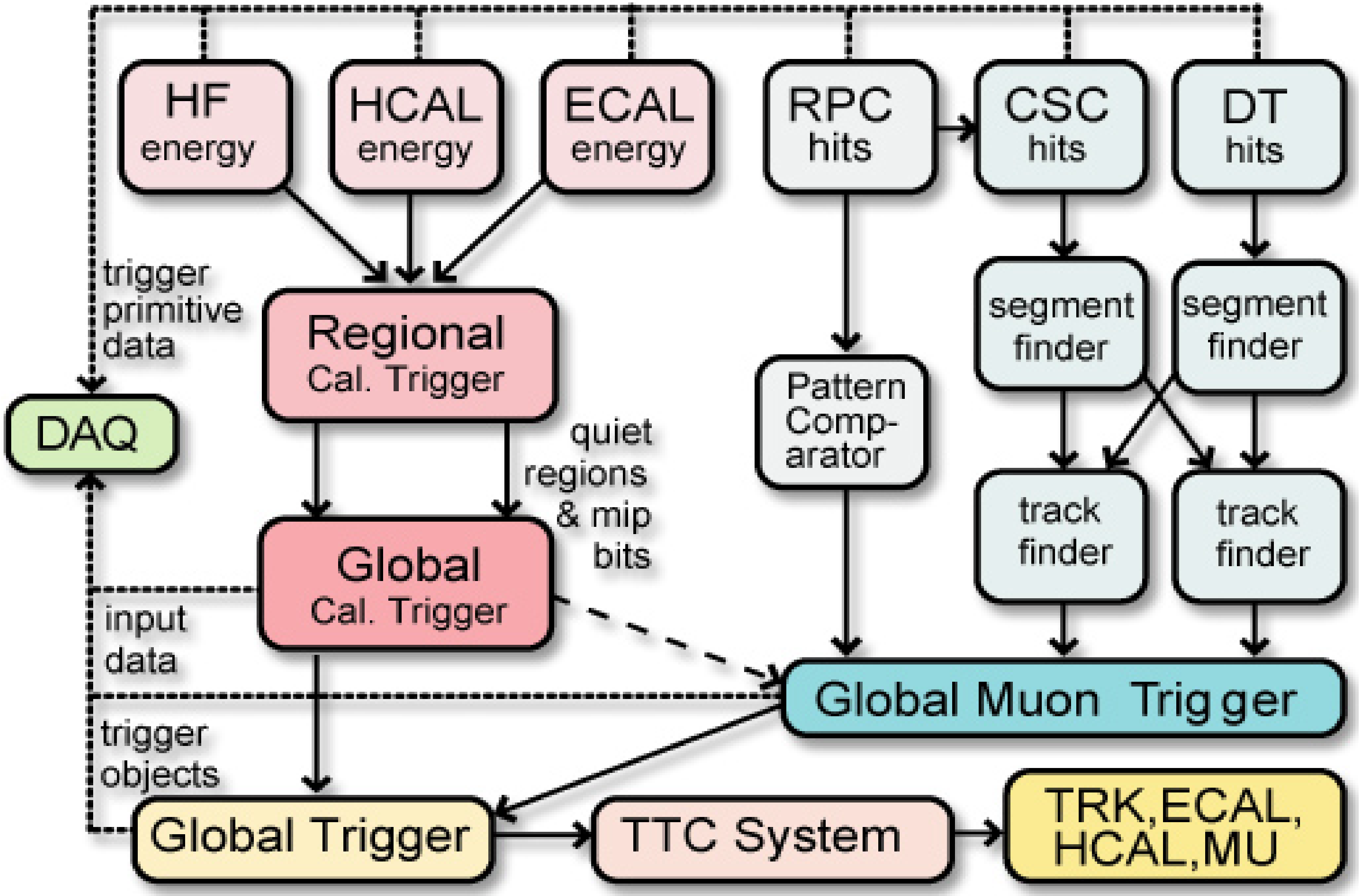
HLT: designed to output
O(10^2)Hz.. Rejection of 1000

Modular DAQ:
8 x 12.5kHz units.

DAQ staging: start with 4
slices (50kHZ) for first physics
run at $2x10^{33}$



Level-1 Trigger



Level-1 Trigger table (2x10^{33})

Trigger	*Threshold (GeV or GeV/c)*	*Rate (kHz)*	*Cumulative Rate (kHz)*
Isolated e/γ	29	3.3	3.3
Di-e/γ	17	1.3	4.3
Isolated muon	14	2.7	7.0
Di-muon	3	0.9	7.9
Single tau-jet	86	2.2	10.1
Di-tau-jet	59	1.0	10.9
1-jet, 3-jet, 4-jet	177, 86, 70	3.0	12.5
Jet*E_T^{miss}	88*46	2.3	14.3
Electron*jet	21*45	0.8	15.1
Min-bias		0.9	16.0
TOTAL			**16.0**

L1 rate at 2x10^{33}:16 kHz

(Factor 3 safety: 50kHz max bandwidth at the start)

HLT Summary: 2x10^{33} cm^{-2}s^{-1}

Trigger	Threshold (GeV or GeV/c)	Rate (Hz)	Cuml. rate (Hz)
Inclusive electron	29	33	33
Di-electron	17	1	34
Inclusive photon	80	4	38
Di-photon	40, 25	5	43
Inclusive muon	19	25	68
Di-muon	7	4	72
Inclusive tau-jet	86	3	75
Di-tau-jet	59	1	76
1-jet * E_T^{miss}	180 * 123	5	81
1-jet OR 3-jet OR 4-jet	657, 247, 113	9	89
Electron * jet	19 * 45	2	90
Inclusive b-jet	237	5	95
Calibration etc		10	105
TOTAL			**105**

Adjust to O(100 Hz) to mass storage

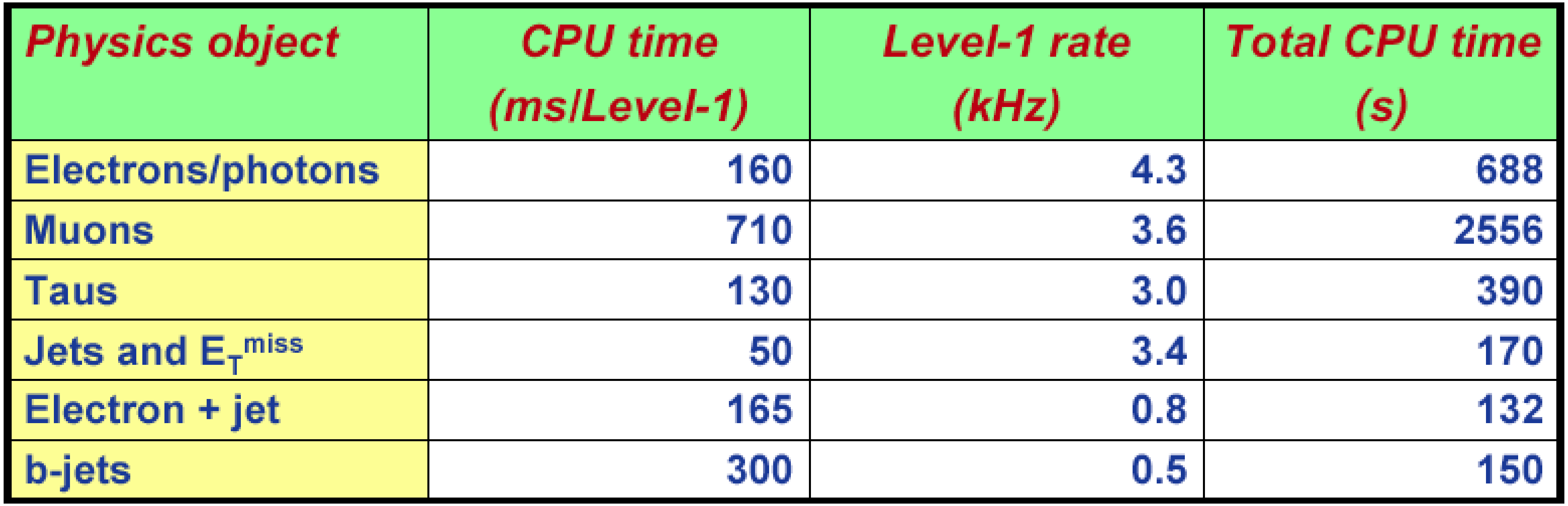
HLT performance — signal efficiency

With previous selection cuts

Channel	*Efficiency* *(for fiducial objects)*
H(115 GeV)→$\gamma\gamma$	77%
H(160 GeV)→WW* →2μ	92%
H(150 GeV)→ZZ→4μ	98%
A/H(200 GeV)→2τ	45%
SUSY (~0.5 TeV sparticles)	~60%
With R_P-violation	~20%
W→eν	67% (fid: 60%)
W→$\mu\nu$	69% (fid: 50%)
Top→μ X	72%

CPU time usage

All numbers for a 1 GHz, Intel Pentium-III CPU



Physics object	*CPU time (ms/Level-1)*	*Level-1 rate (kHz)*	*Total CPU time (s)*
Electrons/photons	160	4.3	688
Muons	710	3.6	2556
Taus	130	3.0	390
Jets and E_T^{miss}	50	3.4	170
Electron + jet	165	0.8	132
b-jets	300	0.5	150

Total: 4092 s for 15.1 kHz → 271 ms/event

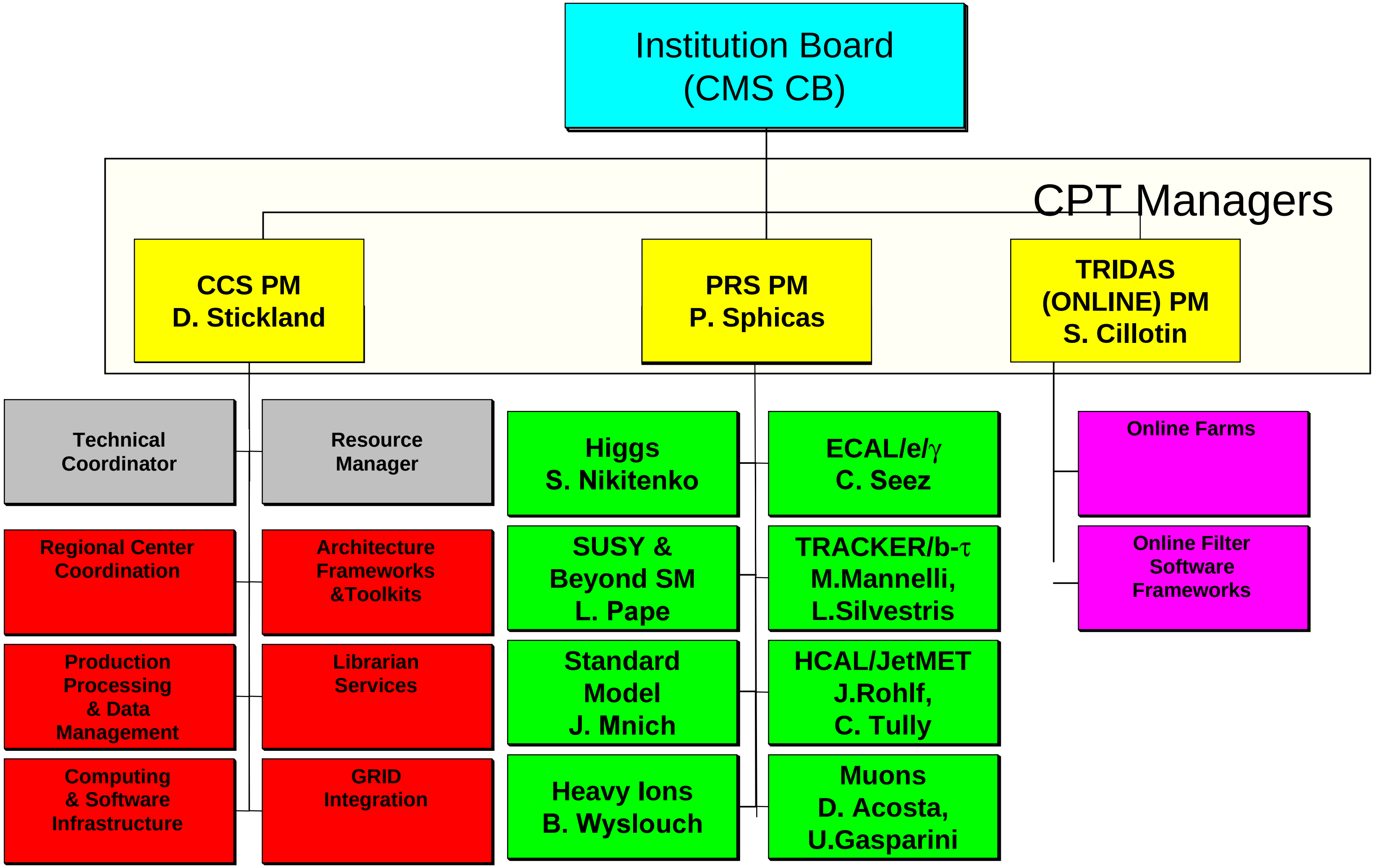
HLT summary

Today: need ~300 ms on a 1GHz Pentium-III CPU

- **For 50 kHz, need 15,000 CPUs**
- **Moore's Law: 2x2x2 times less time (fewer CPUs) in 2007**
  - Central estimate: 40 ms in 2007, i.e. 2,000 CPUs
  - Thus, basic estimate of 1,000 dual-CPU boxes in TDR
- **Start-up system of 50kHz (Level-1) and 105 Hz (HLT) can satisfy basic "discovery menu"**
  - Some Standard Model physics left out; intend to do it, at lower luminosity and pre-scales as luminosity drops through fill.
    - Examples: inclusion of B physics (can be done with high efficiency and low CPU cost; limitation is Level-1 bandwidth)

Single-farm design works

Software/Computing: CPT



Institution Board
(CMS CB)

CPT Managers

CCS PM
D. Stickland

PRS PM
P. Sphicas

TRIDAS
(ONLINE) PM
S. Cillotin

Technical Coordinator

Resource Manager

Regional Center Coordination

Architecture Frameworks &Toolkits

Production Processing & Data Management

Librarian Services

Computing & Software Infrastructure

GRID Integration

Higgs
S. Nikitenko

SUSY & Beyond SM
L. Pape

Standard Model
J. Mnich

Heavy Ions
B. Wyslouch

ECAL/e/γ
C. Seez

TRACKER/b-τ
M.Mannelli, L.Silvestris

HCAL/JetMET
J.Rohlf, C. Tully

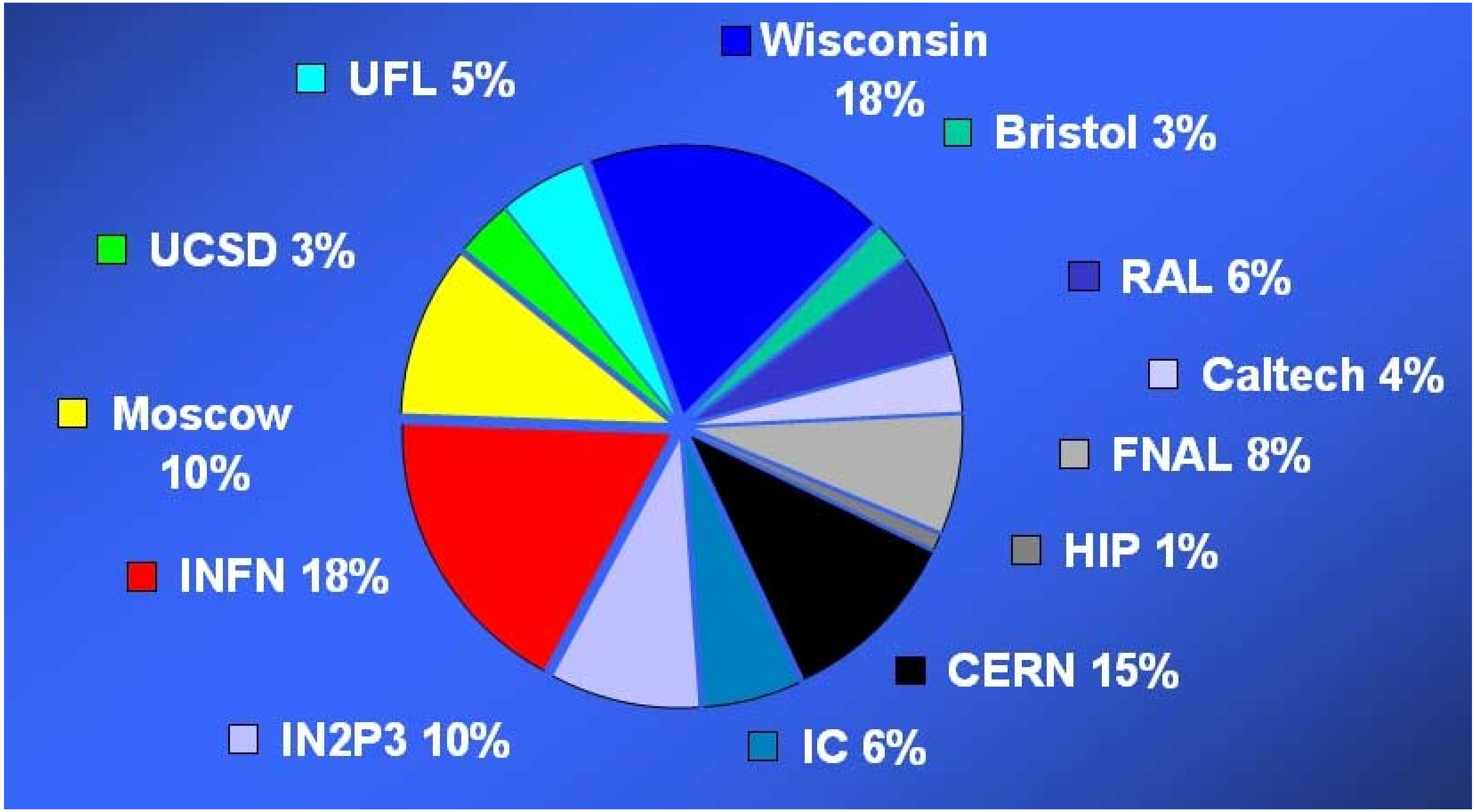
Muons
D. Acosta, U.Gasparini

Online Farms

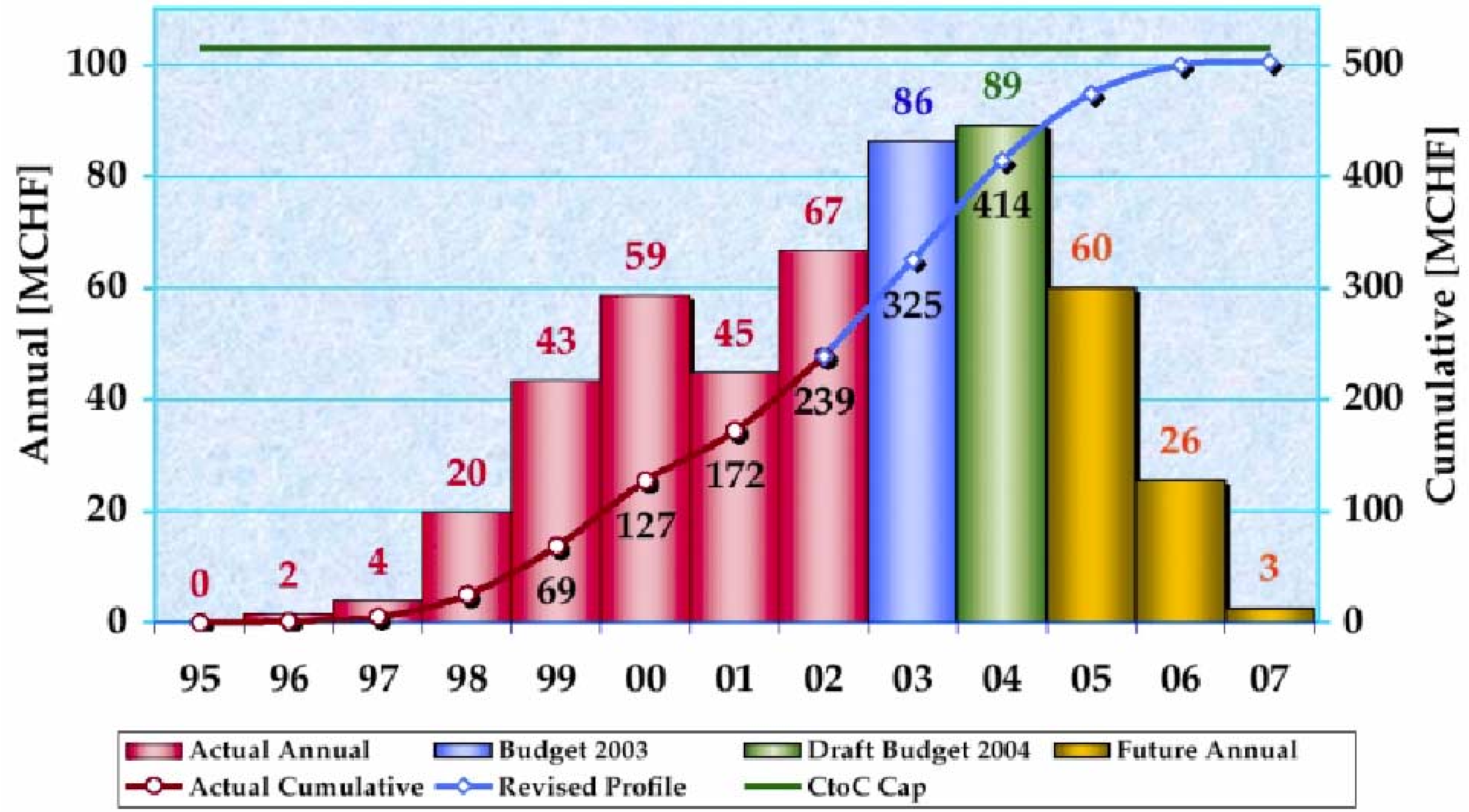
Online Filter Software Frameworks

Data Challenge DC02

Spring 2002 production for HLT: 6 million events fully simulated (Geant 3) and reconstructed in ORCA.



Cost, Funding, Payment Profile



Initial Low Luminosity Detector

LHC start up scenario?

First Beam in April 2007. Beam commissioning for 4 mo.

Goal: attain > 5.10^{32}@25ns bunch spacing.

Shutdown 2-3 months?

Physics Run starts ~Oct-07: Run until 5-10 fb^{-1} @ 1-2 10^{33}

Initial CMS detector: Complete CMS (as described in TDRs) except:

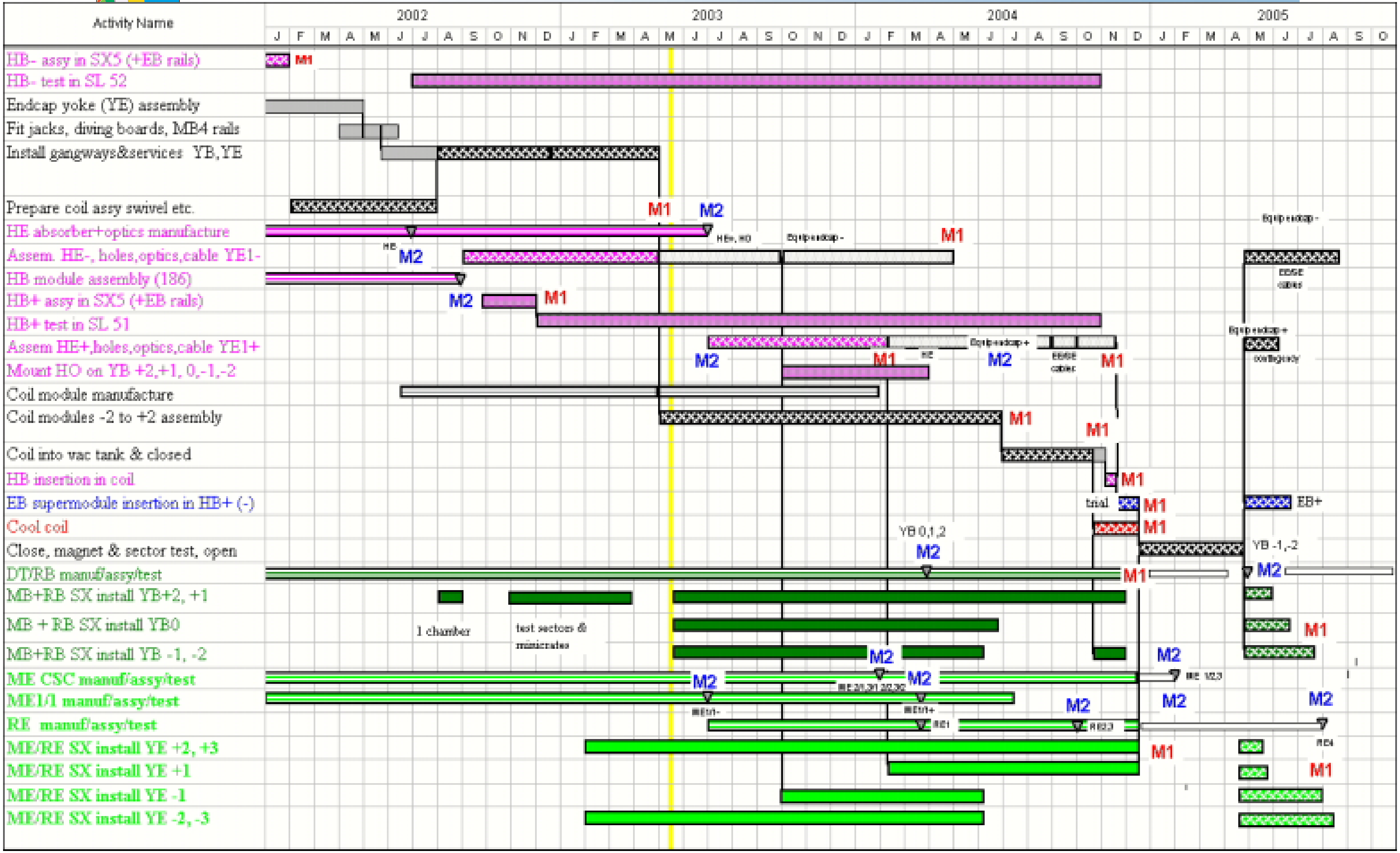
1. ME4 staged
2. 3rd forward pixel disks missing
3. Start with 50% DAQ (limit L1 rate at 50kHz instead of 100 kHz)
4. Reduced End-Cap RPC system: RE1,2,3 ($|\eta| < 1.6$).

Staging scenario consistent with Financial Plan approved by RRB

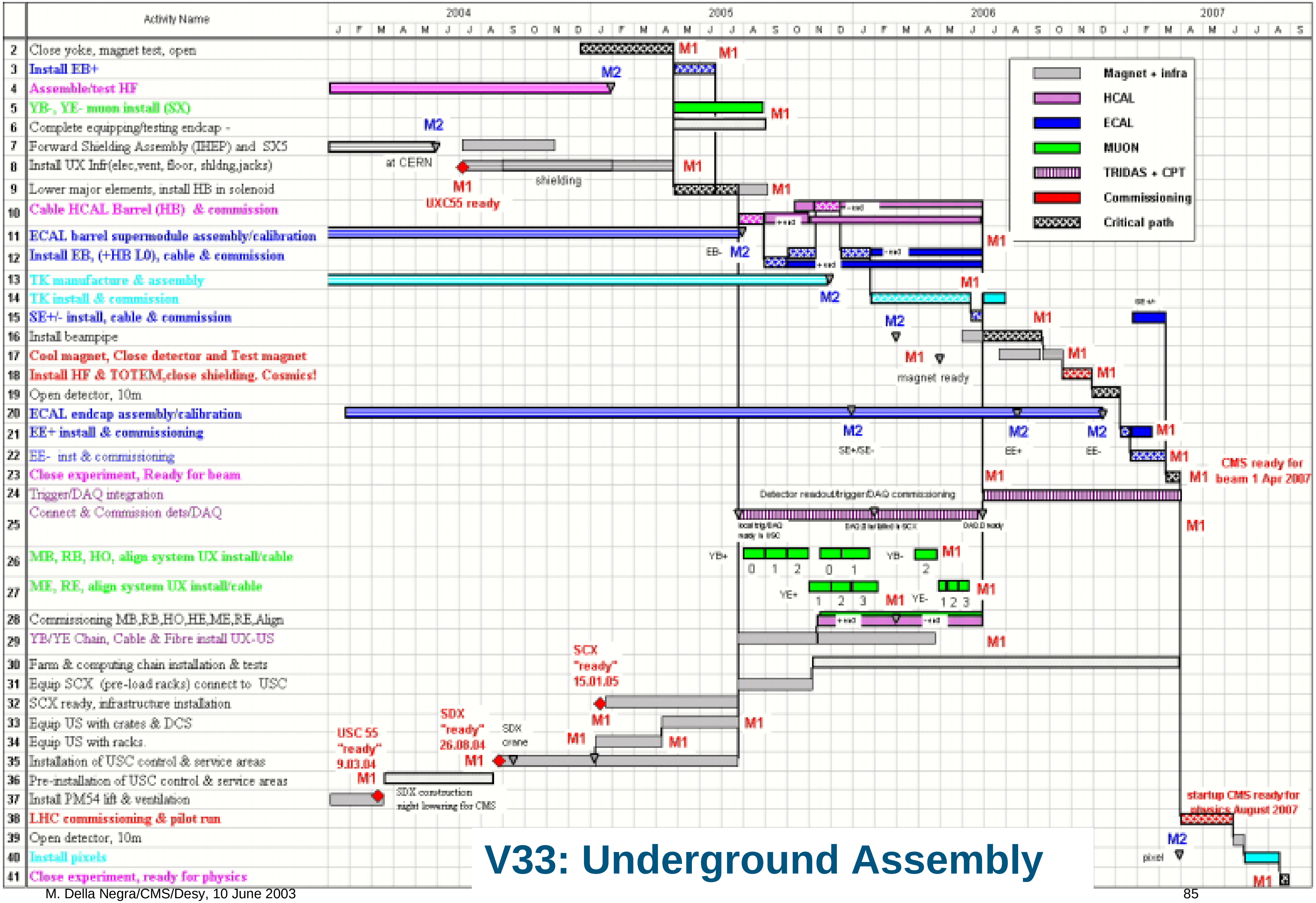
The Financial Plan is based on **50 MCHF of additional funds** promised by Funding Agencies on top of their global MoU commitment of 450 MCHF.

The cost of the initial CMS detector is ~ 500 MCHF

CMS planning v33: Surface Assembly



V33: Underground Assembly

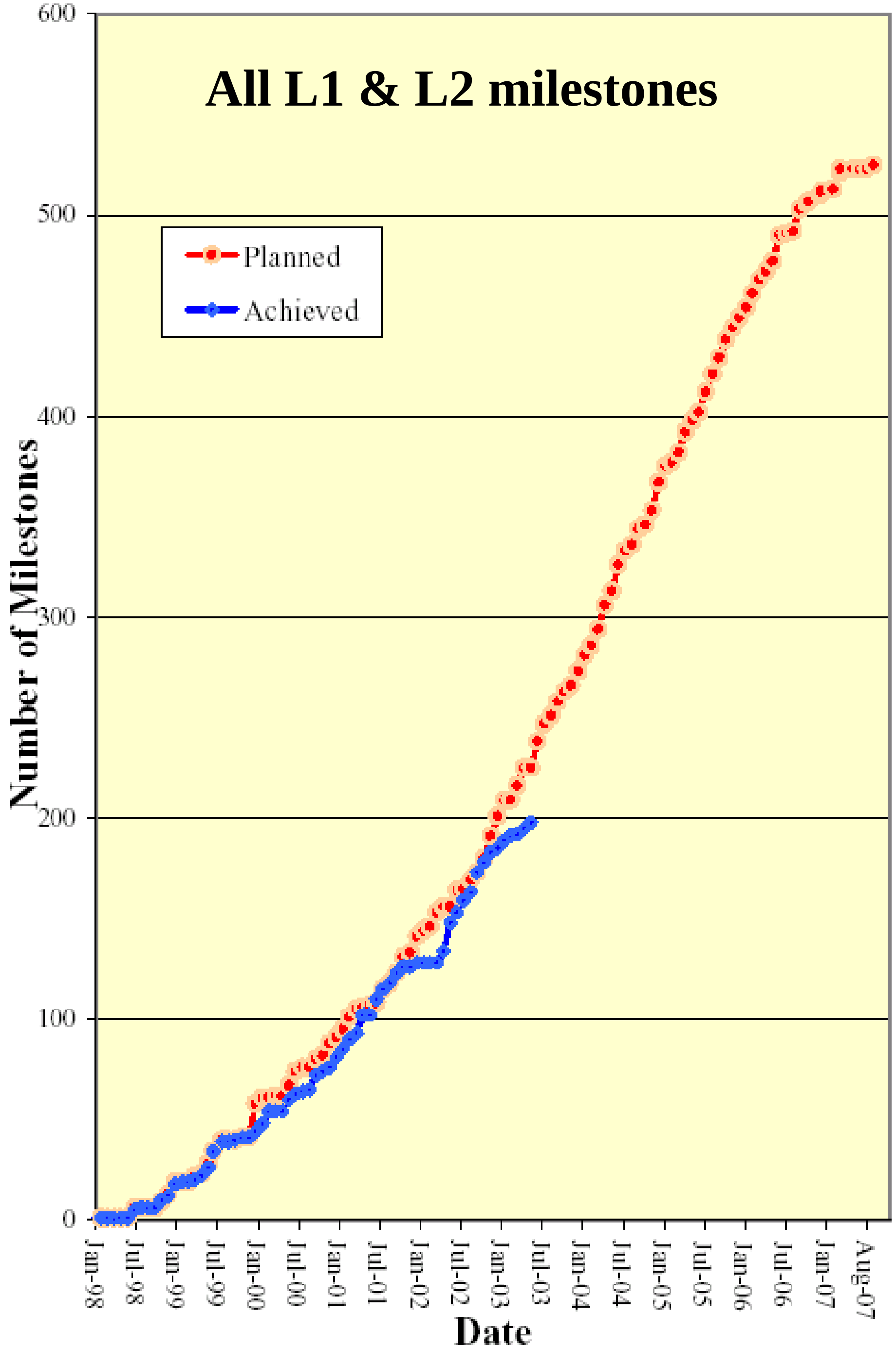


v33 Schedule

Objective: Complete CMS (except ME4, RE system $|\eta|>1.6$, 50% DAQ) for April 2007

• US and UX area delivered to CMS	Mar 04, Jul 04	
• Install floor plates and shielding in UX area	Nov 04- Apr 05	
• Magnet test on surface	Jan 05- Apr 05	**+ 2 mo**
• Lowering CMS	May 05-Sep 05	**+ 2 mo**
• ECAL barrel EB+ installation	May 05-Jun 05	
• ECAL: EB- installation + EB cabling	Oct 05-Nov 05	
• Tracker installation + cabling	Feb 06-Jun 06	
• Beampipe Installation	Jul 06-Sep 06	
• Underground Magnet Test	Sep 06-Dec 06	**- 2 mo**
• EE installation	Jan 07-Mar 07	
• Det/Trig/DAQ Integration and Commissioning	Apr 06-Apr 07	**- 2 mo**
• CMS closed ready for beam	Apr 07	

‘ready for installation’ milestones are set 3 mo ahead of projected installation start date



Milestone Plot

> 500 milestones monitored by LHCC.

best estimate of actual delay is ~2- 3 months in parallel over several sub-systems

Physics at Startup

Example SM Higgs Discovery Reach (5σ): ATLAS +CMS

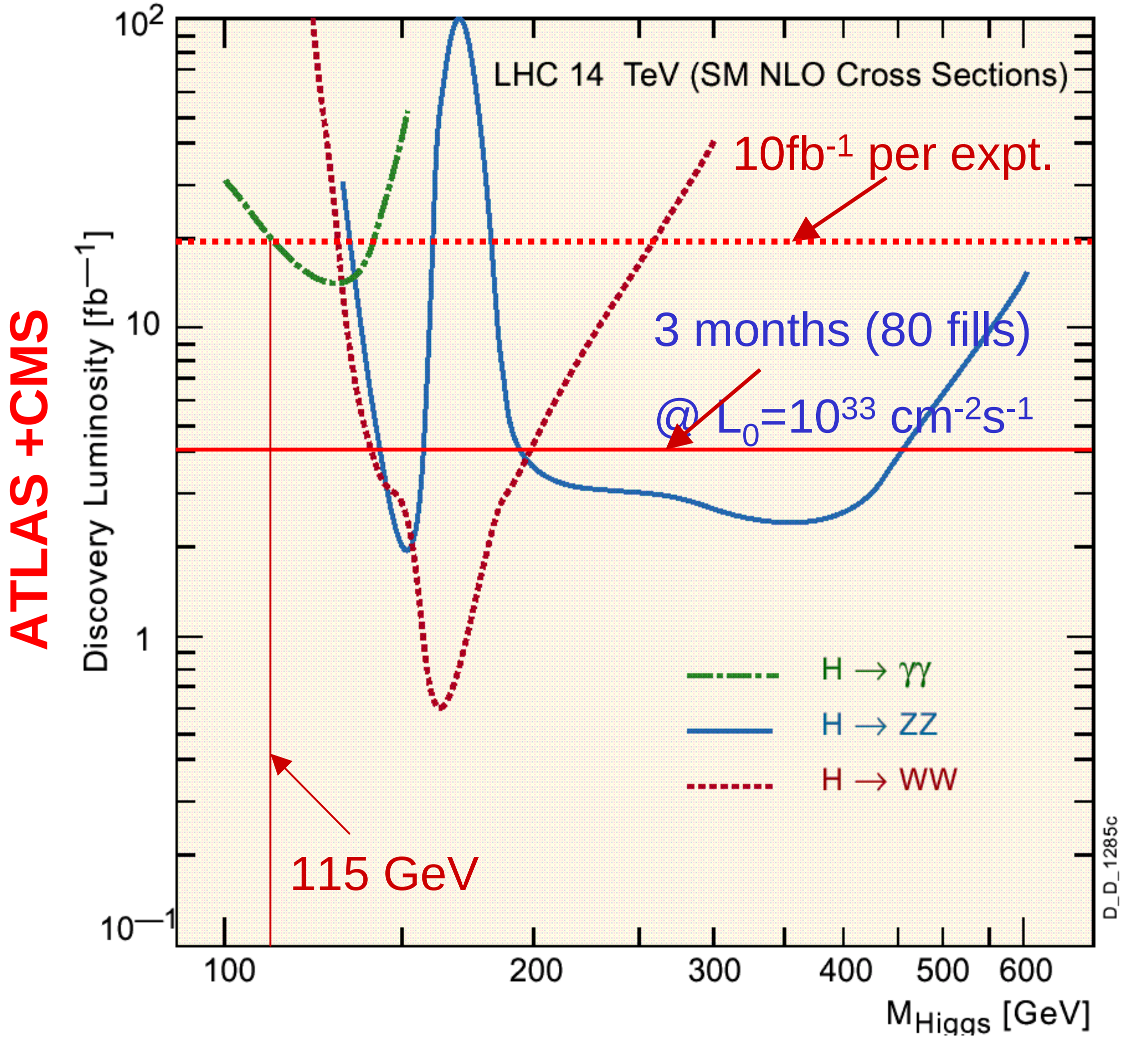
At $L_0=10^{33}\ \mathrm{cm^{-2}s^{-1}}$

1 month ~ 0.7 $\mathrm{fb^{-1}}$

At $L_0= 3.10^{33}\ \mathrm{cm^{-2}s^{-1}}$

1 month ~ 2 $\mathrm{fb^{-1}}$

Assumptions: 14hr run
and 10hr to refill
i.e. 1 fill/day
t_L ~ 20 hr, Efficiency of 2/3



10$\mathrm{fb^{-1}}$ per expt.

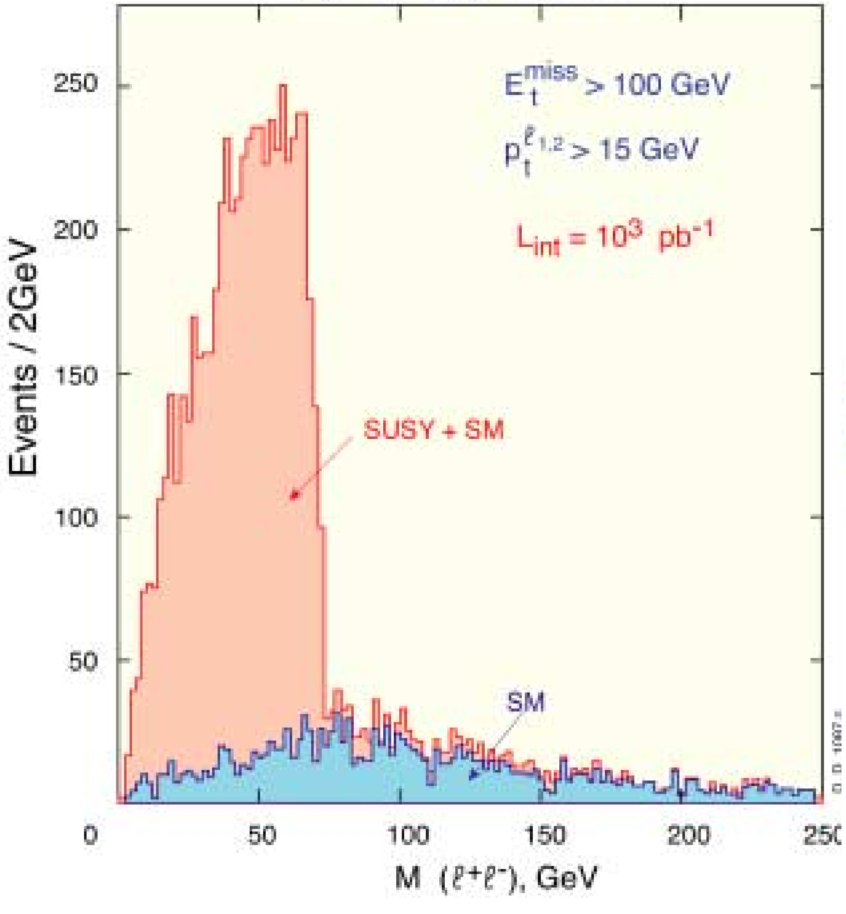
3 months (80 fills) @ $L_0=10^{33}\ \mathrm{cm^{-2}s^{-1}}$

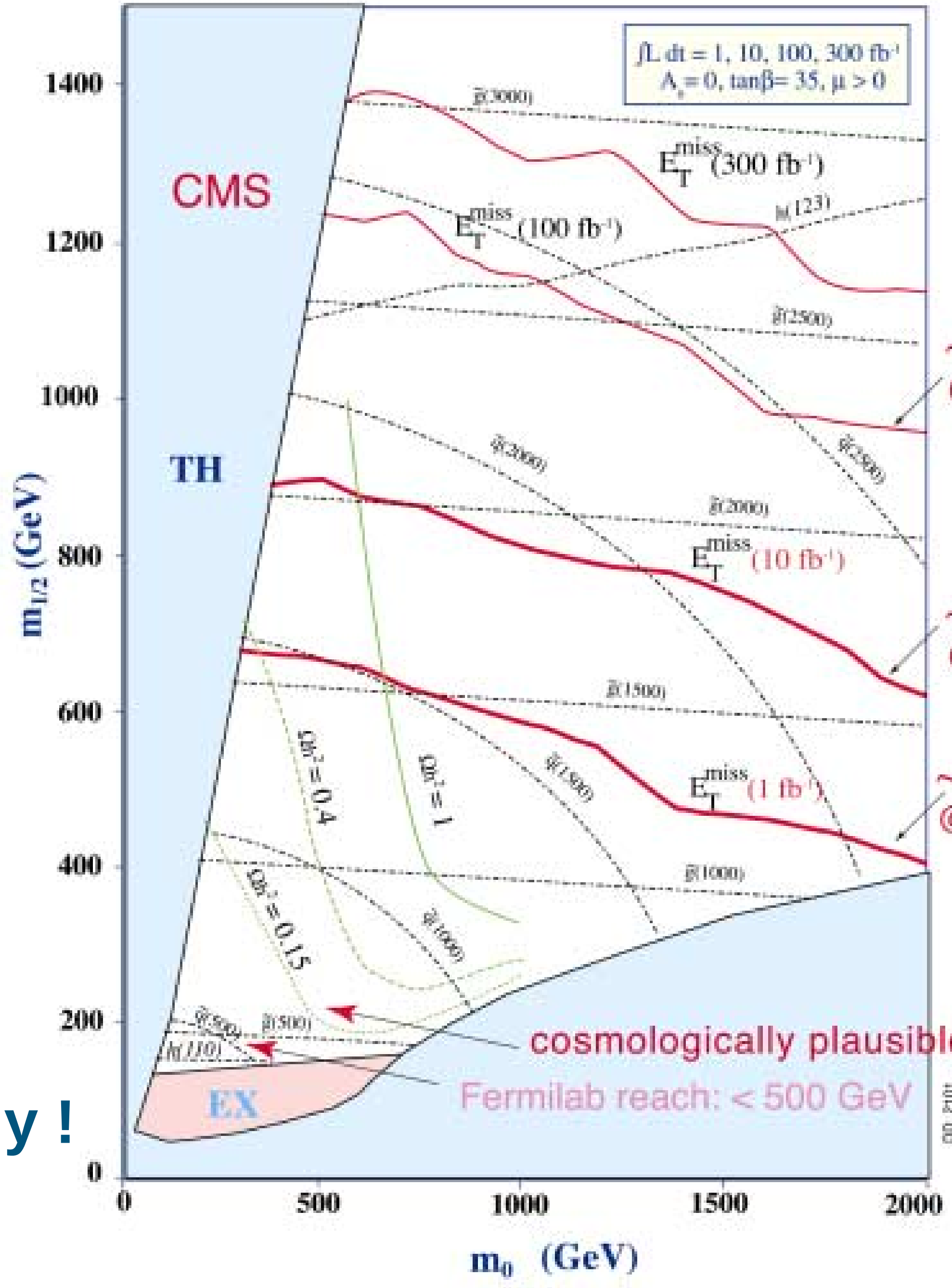
115 GeV

Inclusive $\ell^+\ell^- + E_t^{miss}$ final states

Squarks and Gluino mass reach

$m_0 = 200$ GeV, $m_{1/2} = 160$ GeV,
$tg\beta = 2$, $A_0 = 0$, $\mu<0$





~ one year
@10^{34}

~ one year
@10^{33}

~ one month
@10^{33}

cosmologically plausible region

Fermilab reach: < 500 GeV

SUSY will be found quickly !

Conclusions

Magnet: 4T Coil: proceeding well, but on critical path. Delay estimated to ~2 months. Can compensate the delay using master contingency.

Tracker : Tight schedule, delayed start requires full exploitation of production capacity to recover.

ECAL : Tight schedule. Revised electronics on track for decision in July 03 and start of production by Oct 03. Crystal delivery critical.

HCAL: on schedule, 80% complete.

Endcap Muons : on schedule, 80% complete.

Barrel Muons: 30% complete, back on schedule by May 04.

Trigger/DAQ: DAQ/HLT TDR recently approved by LHCC. CMS design validated. High Level Trigger (HLT) performance demonstrated with realistic algorithms using the OO offline reconstruction software. Same software running online and offline.

Computing TDR: Dec 04. Distributed computing and analysis based on common grid tools (LCG). OO data base using ROOT i/o (Pool project).

Physics TDR: Dec 05. Data Challenge 2004 50M events. Final Reconstruction software. Training Collaboration.

A low luminosity detector can be ready for physics in 2007. Exciting physics is likely to start 'tumbling out' soon after startup.

Backup slides

Radhard Silicon detectors

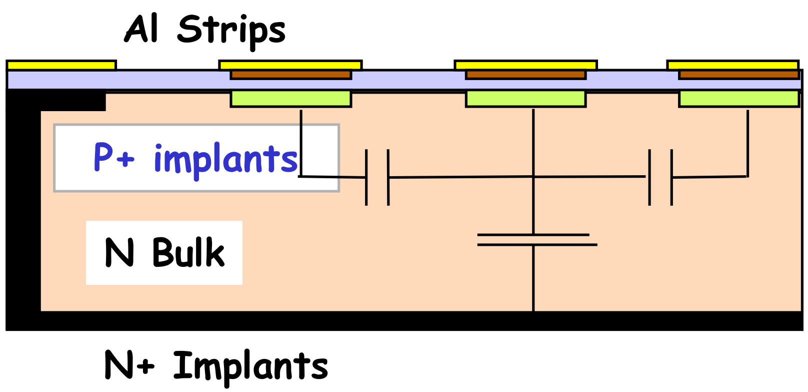
ECAL photodetectors

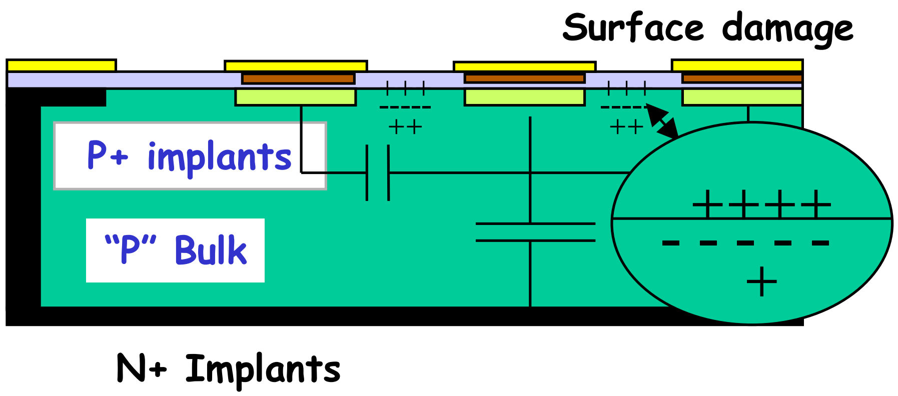
Endcap ECAL

Electron Reconstruction

The radiation hard P-on-N strip detector

Single-Sided Lithographic Processing
(AC, Poly-Si biasing)





Radiation hardness “recipe”

P-on-N sensors work after bulk type inversion, provided they are biased well above depletion.

Match sensor resistivity & thickness to fluence to optimize S/N over the full life-time.

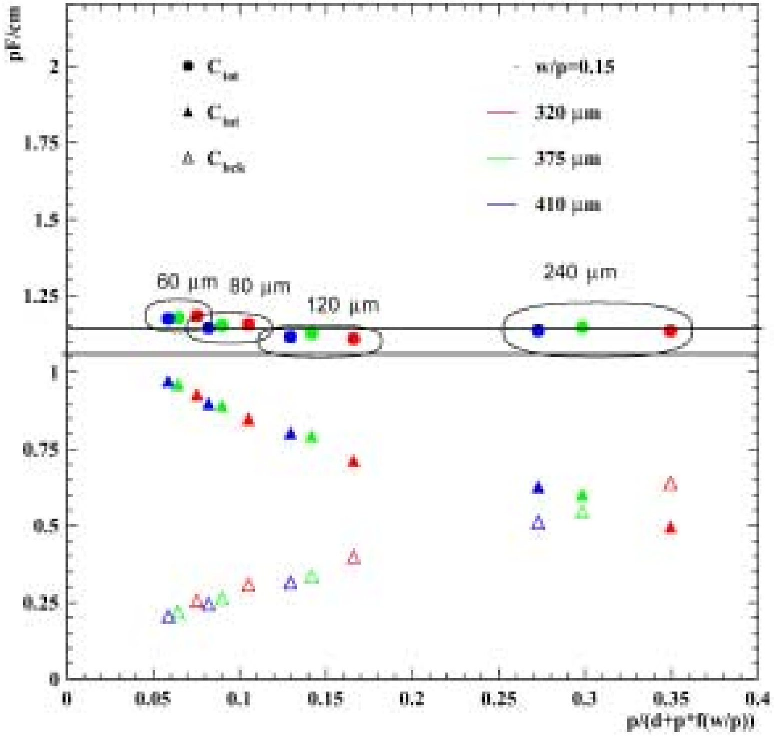
Strip width/pitch ~ 0.25: reduce C_{tot} maintain stable high bias voltage operation

Surface radiation damage can increase strip capacitance & noise

Use <100> crystal instead of <111>

Silicon Strip Sensor Properties

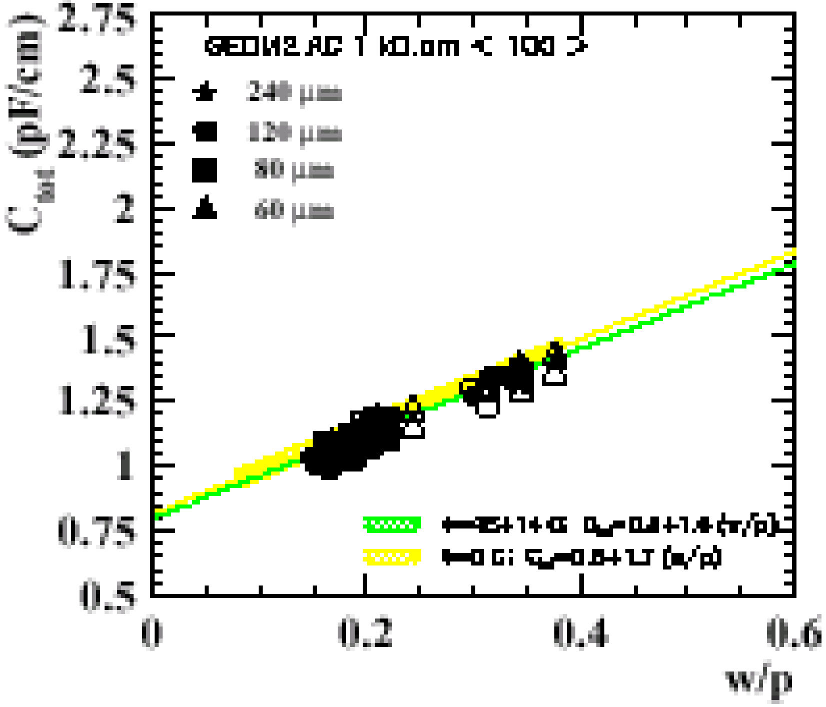
Strip capacitance ~ 1.2pF/cm for w/p = 0.25
Independent of pitch and thickness



Use 320µm thick Si for R < 60cm, Strip ~ 10cm

Use 500µm thick Si for R > 60cm, Strip ~ 20cm

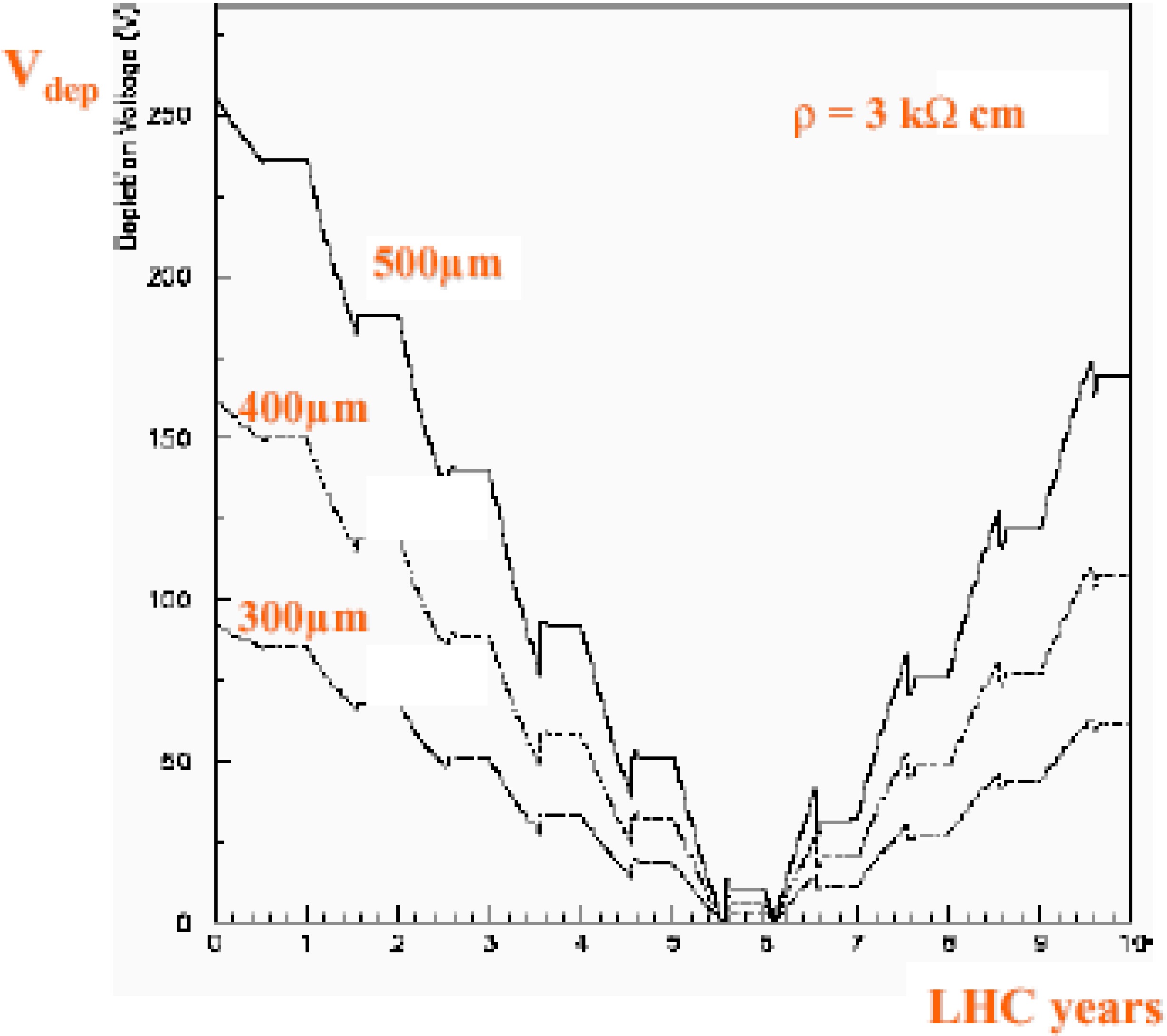
Insensitive to irradiation
for <100> crystal lattice



Expected S/N after irradiation

S/N ~ 13 for thin sensors, short strips
S/N ~ 15 for thick sensors, long strips

Depletion Voltage vs LHC Years



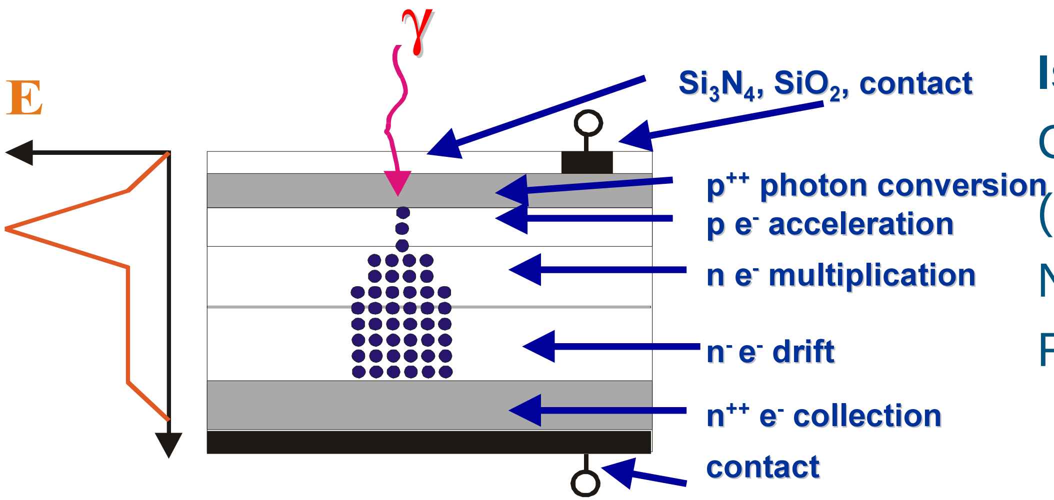
Running at -10°C

Standby at -15°C

21 days at 10°C per annum for maintenance

7 days at 20°C per annum for repairs

Avalanche Photo Diodes



Internal gain=50 for V=380 V

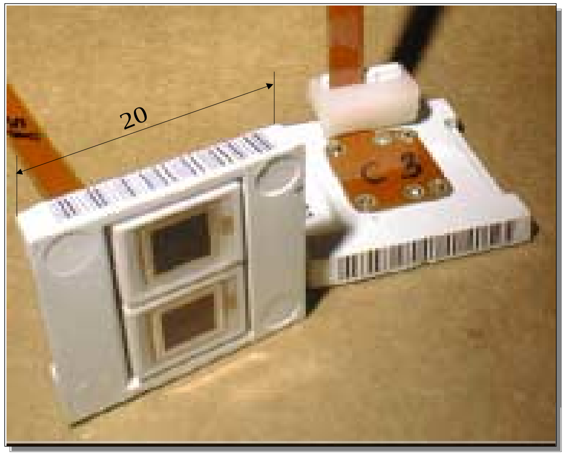
Issues:

Contributions to all resolution term

(C, I_{dark}, excess noise factor, gain stability)

Nuclear counter effect

Radiation hardness



Two APDs per capsule

Status:

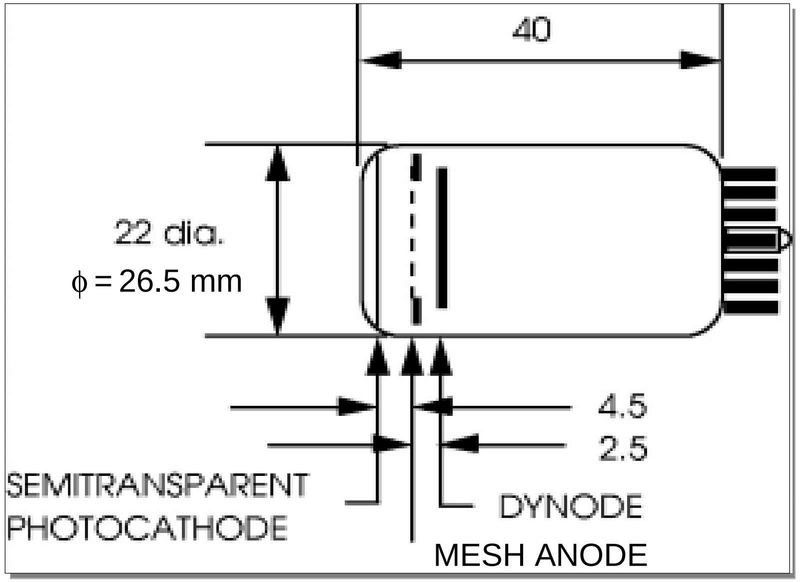
APDs optimized with extensive R&D programme

Strict Q&A applied, want 99.9% reliability

Production (Hamamatsu) well under way,

already > 50 % finished

Vacuum Photo Triodes (Endcaps)



Single stage photomultiplier tube

Gain 8-10 at B=4T, QE " 20% at 420 nm

Status:

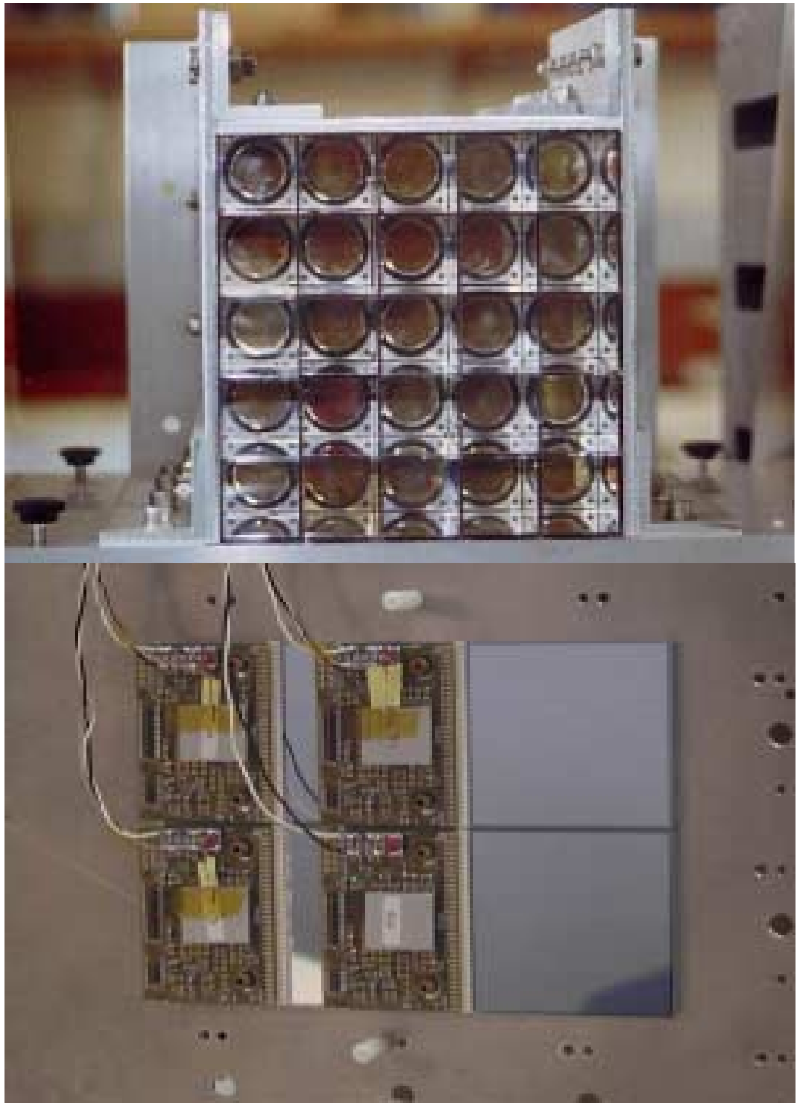
All VPTs are measured at $0 < B < 1.8$ T and $-30^0 < \theta < 30^0$ at RAL

Sample VPTs checked at B=4T and $\theta=15^0$ at Brunel, in addition faceplate irradiation.

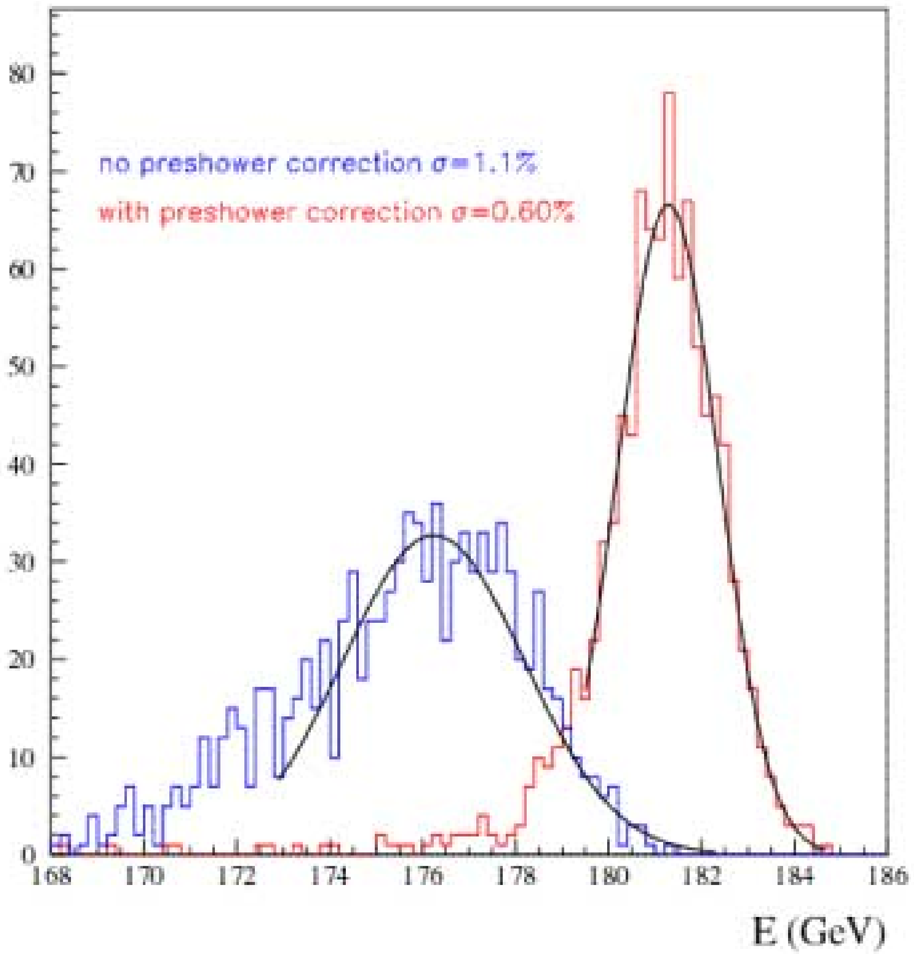
Measured performance matches EE design objectives, but ‘sorting’ might be needed to accommodate a spread in anode response

Production well under way >25% delivered

ECAL. Endcap 99 test beam results



180 GeV electrons at normal incidence



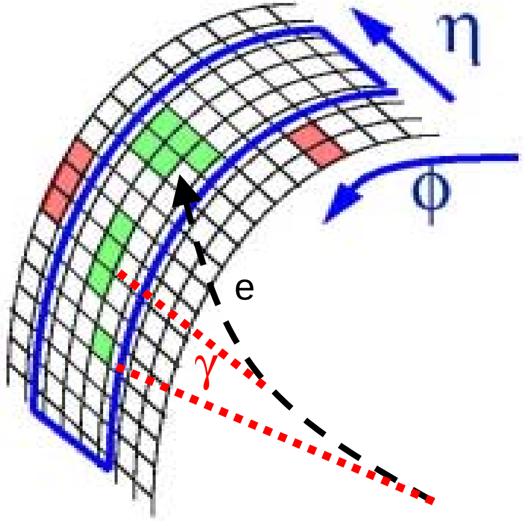
Electron reconstruction

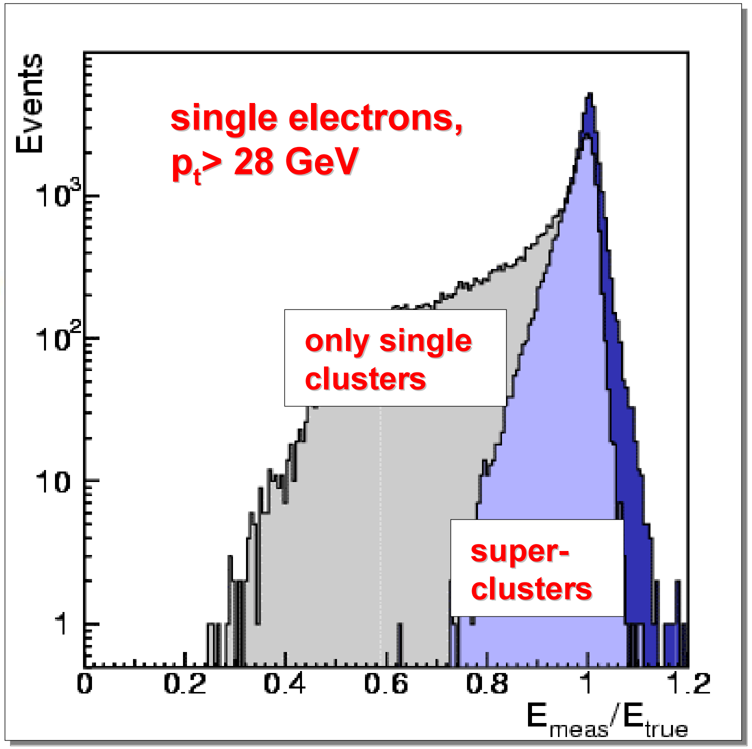
Main difficulty : tracker material ⇒ **bremsstrahlung**

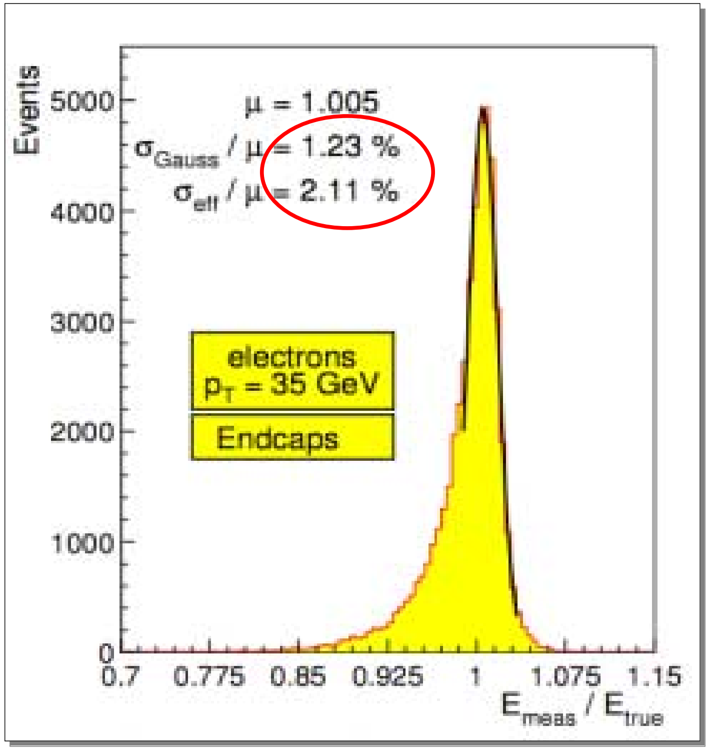
$\langle E_{breams}/E \rangle = 43.6\ \%,\ P_t = 35\ \mathrm{GeV},\ |\eta| < 1.5$

Recover by reconstructing clusters of clusters (**super-clusters**)

Essential for Z→ ee and W → eν reconstruction, find compromise between statistics and little bremsstrahlung-loss







HCAL Radiation Damage

Radiation Dose after 10 years of LHC:

30 krad (300 Gy)	at $\eta = 1.1$
0.4 Mrad (4 kGy)	at $\eta = 2.0$
2.4 Mrad (24 kGy)	at $\eta = 3.0$

Scintillator: Kuraray SCSN81 (polystyrene based plastic)
WLS fiber: Kuraray Y11-250 double clad doped with K27 dye

Tile/Fiber (10cm x 10 cm x 0.4 cm): SCSN81&Y11-250
Measured Light Yield Loss ~ exp(-Dose/6.5 Mrad) ~ 25 % loss for 2 Mrad

For $|\eta| > 2$ divide HE longitudinally into 3 segments (1, 4, 14 layers)
Correct drop of light yield by adjusting weights for each readout segment.