CMS

Compact Muon Solenoid

Overview

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NCPP March 2002

Physics Motivation
LHC
Civil Engineering
Magnet
Tracker
Calorimetry
Muons
Trigger and DAQ
Physics Potential
Conclusion

Open Problems of SM

- **SM contains many apparently arbitrary features**

  e.g. why are there 6 quarks?

- **SM has a "missing element "**

  i.e. mechanism to generate the observed masses of the known particles

  (Higgs,Kibble,Brout,Englert ?)

- **SM gives "nonsense" at very high energies**

  $W_L W_L$ scattering probability becomes larger than 1 at energies above ~ 1 TeV

- **SM is logically incomplete**

  Gravity is not incorporated

$\Rightarrow$

Need to:

Find the Higgs

Find clues for physics beyond the SM

Open Problems of SM

- **What is the origin of mass?**

  Why is the Z boson massive whereas the related photon massless?
- **Is there a new symmetry ; SUSY?**

  Grand Unification of all fundamental forces?

  Is a fundamental particle responsible for the dark matter in the universe?
- **Origin of matter-antimatter asymmetry?**

  Does the answer lie in CP violation?
- **Does a new form of matter exist?**

  Quark-Gluon Plasma?
- **Do elementary particles of today have substrucure?**
- **Are there only 3 families of quarks and leptons?**

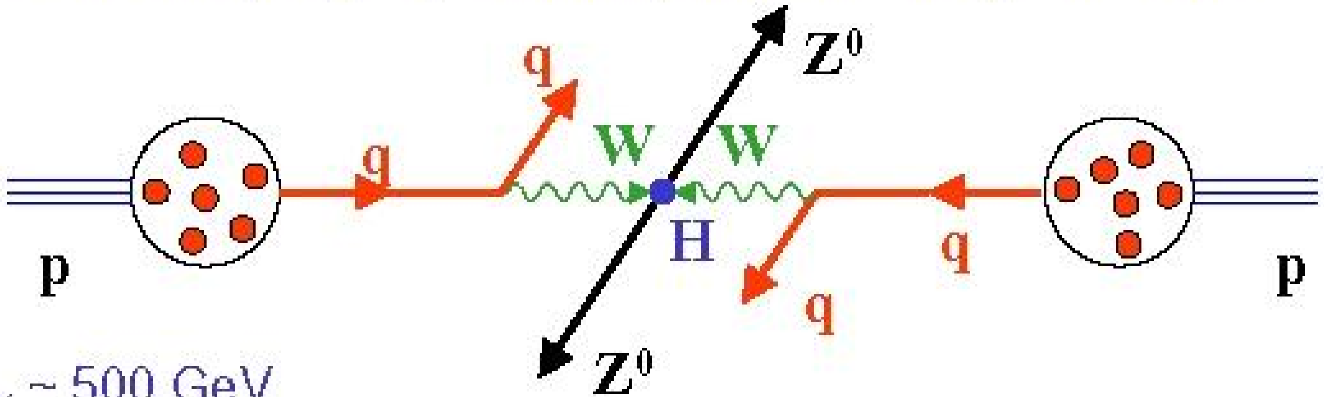
??? + ???

The LHC program will address all these issues

Hadron Colliders

Hadron colliders are broad-band exploratory machines

May need to study W_L-W_L scattering at a cm energy of ~ 1 TeV



- ⇨ E_W ~ 500 GeV
- ⇨ E_{quark} ~ 1 TeV
- ⇨ E_{proton} ~ 6 TeV

⇨ **pp collisions at 7 + 7 TeV**

Event Rate = L.σ.BR

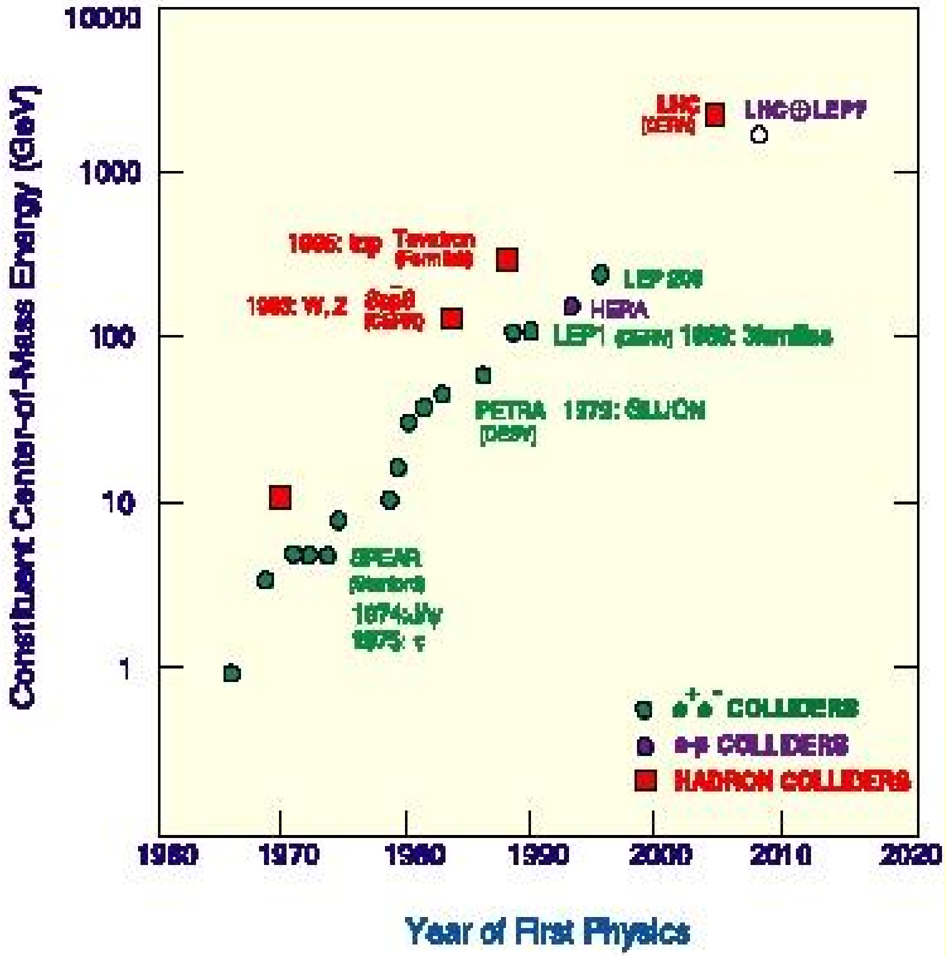
e.g. H(1 TeV) → ZZ → 2e+2μ or 4e or 4μ

For L ~10^{34} , Evts/yr = **10^{34}** $10^{-37}.10^{-3}.10^{7}$ ~ 10 /yr !!

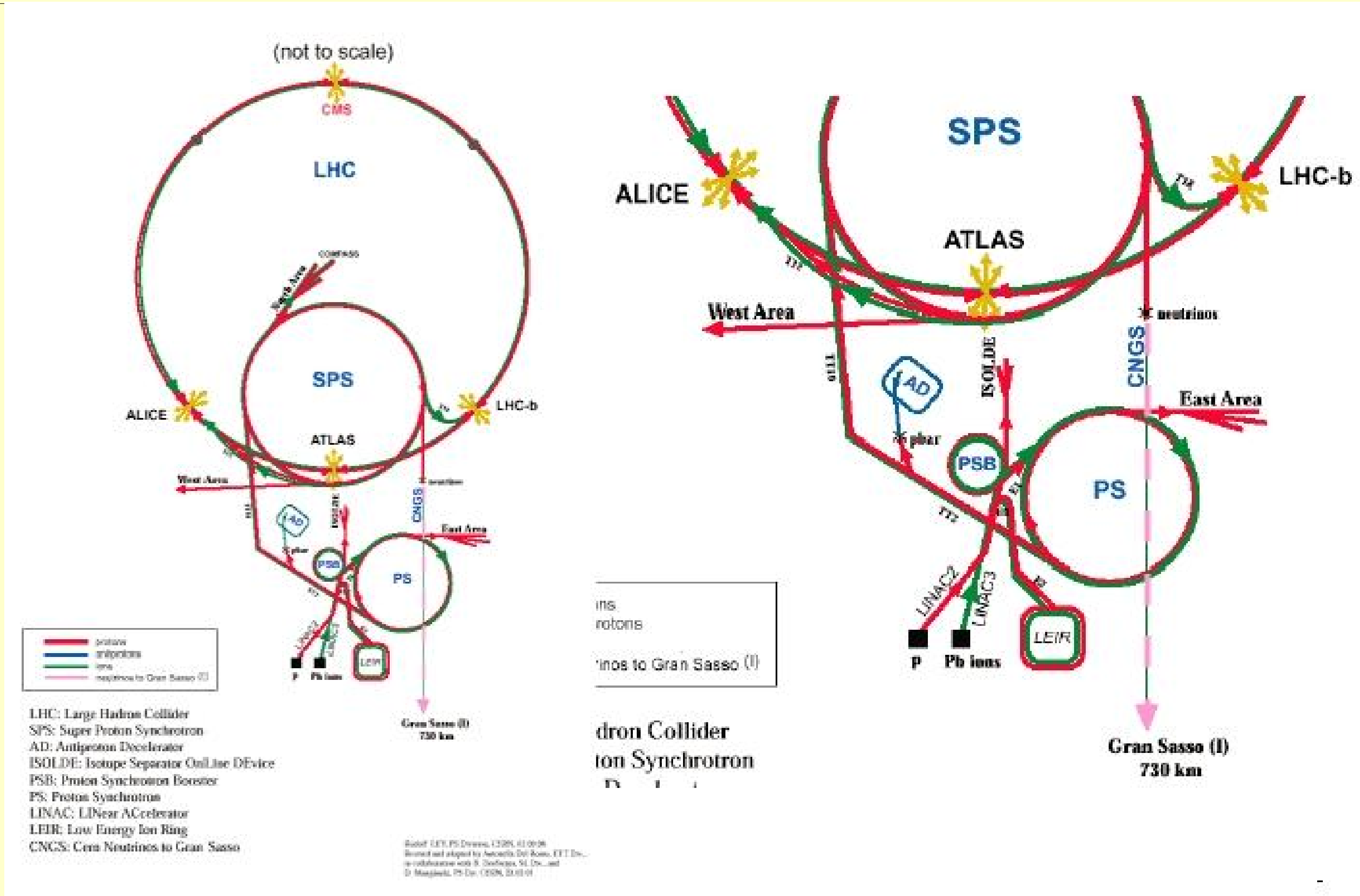
SM + New Physics

New Energy Domain
Search for the unexpected
Cover domain ~ 1 TeV in which SM without the Higgs (or equivalent) gives nonsense

Exploratory machine required
⇨ hadron-hadron collider with:
Largest possible primary energy
Largest possible luminosity



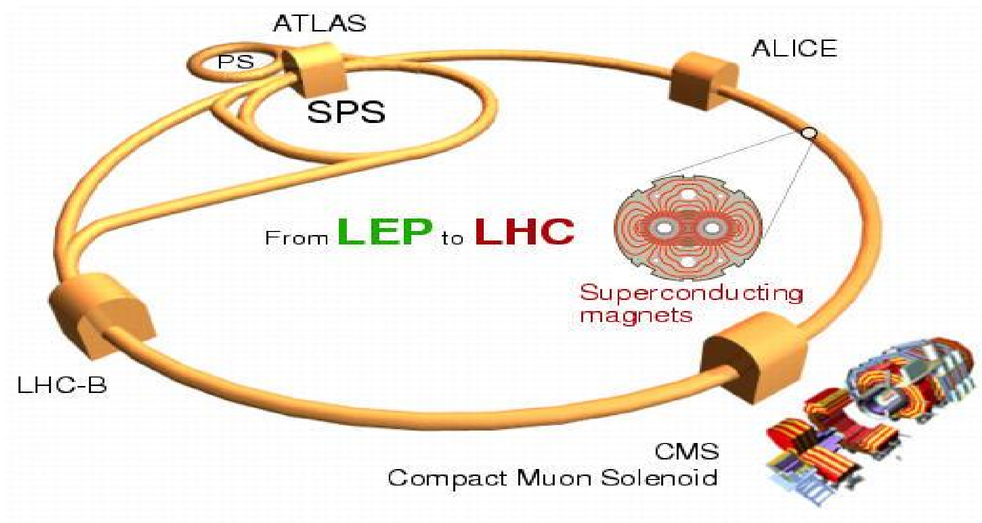
CERN Accelerators



CERN

LHC

The Large Hadron Collider (LHC)



	Beams	Energy		Luminosity
LEP	e+ e-	200	GeV	10^{32} cm^{-2}s^{-1}
LHC	p p	14	TeV	10^{34}
	Pb Pb	1312	TeV	10^{27}

CERN & LHC

LHC parameters

$$L = \frac{\gamma f k_b N_p^2}{4\pi \varepsilon_n \beta^*} F$$

f	revolution frequency
k_b	no. of bunches
N_p	no. of protons/bunch
ε_n	norm transverse emittance
β^*	betatron function
F	reduction factor xing angle

Magnetic Field

p (TeV) = 0.3 B(T) R(km)

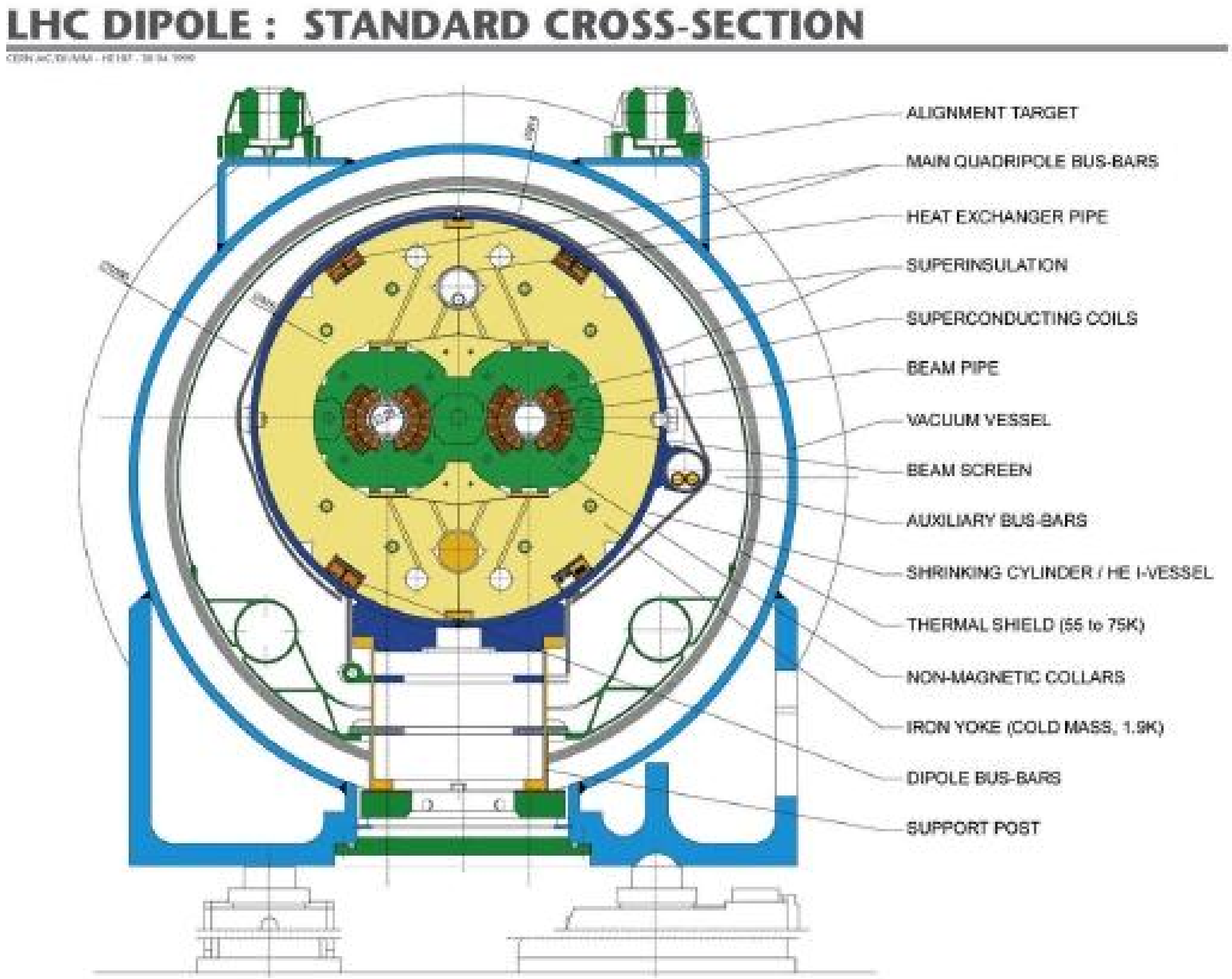
For p= 7 TeV, R= 4.3 km

⇨ **B = 8.4 T**

Beam-beam tune shift $\xi = \frac{N r_p}{4\pi \varepsilon_n}$

Energy at collision	E	7	TeV
Dipole field at 7 TeV	B	8.33	T
Luminosity	L	10^{34}	$cm^{-2}s^{-1}$
Beam beam parameter	ξ	3.6	10^{-3}
DC beam current	I_{beam}	0.56	A
Bunch separation		24.95	ns
No. of bunches	k_b	2835	
No. particles per bunch	N_p	1.1	10^{11}
Normalized transverse emittance (r.m.s.)	ε_n	3.75	μm
Collisions			
β-value at IP	β^*	0.5	m
r.m.s. beam radius at IP	σ^*	16	μm
Total crossing angle	ϕ	300	μrad
Luminosity lifetime	τ_L	10	h
Number of evts/crossing	n_c	17	
Energy loss per turn		7	keV
Total radiated power/beam		3.8	kW
Stored energy per beam		350	MJ

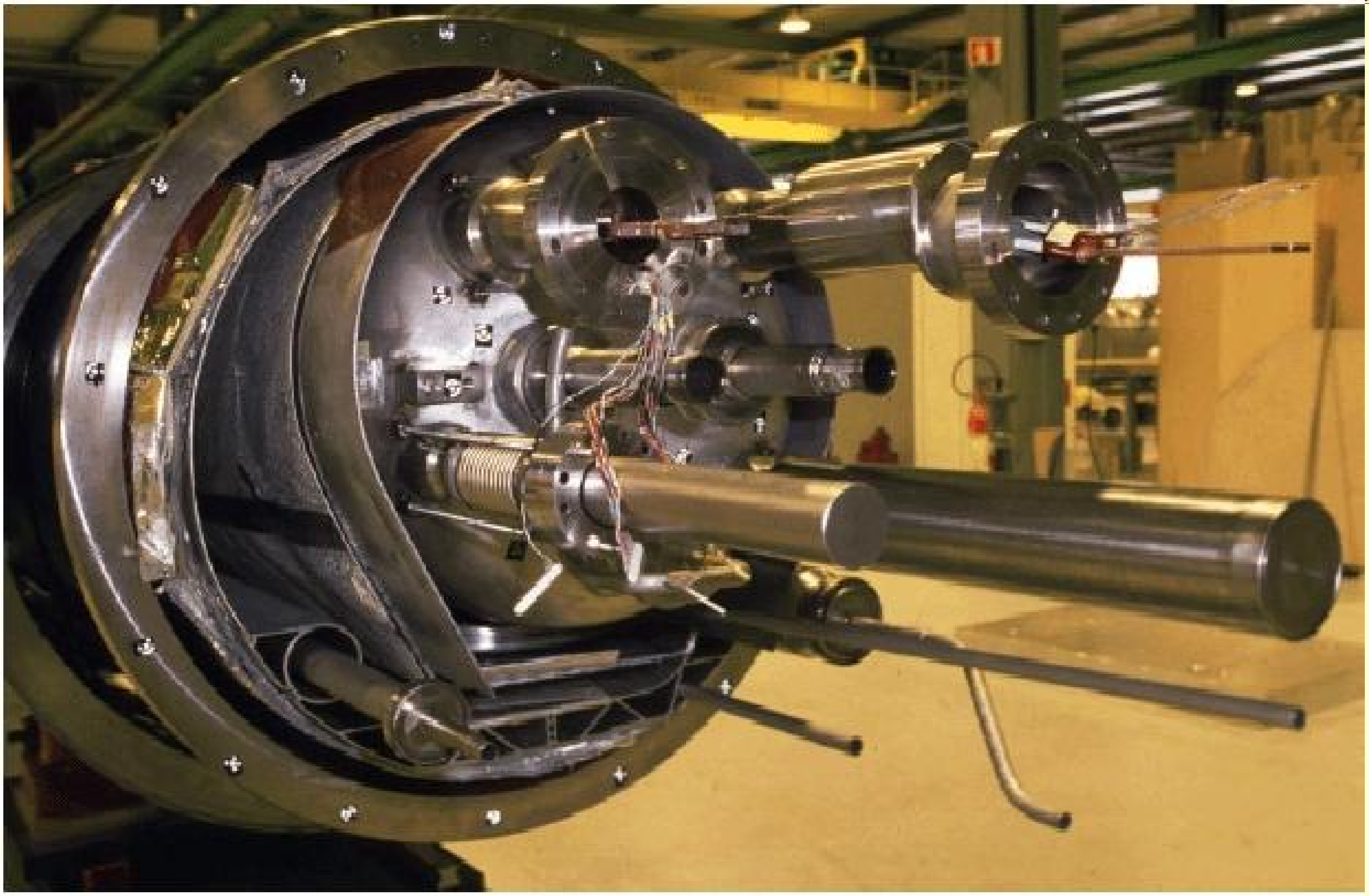
LHC DIPOLE



LHC DIPOLE : STANDARD CROSS-SECTION
ALIGNMENT TARGET
MAIN QUADRIPOLE BUS-BARS
HEAT EXCHANGER PIPE
SUPERINSULATION
SUPERCONDUCTING COILS
BEAM PIPE
VACUUM VESSEL
BEAM SCREEN
AUXILIARY BUS-BARS
SHRINKING CYLINDER / HE I-VESSEL
THERMAL SHIELD (55 to 75K)
NON-MAGNETIC COLLARS
IRON YOKE (COLD MASS, 1.9K)
DIPOLE BUS-BARS
SUPPORT POST

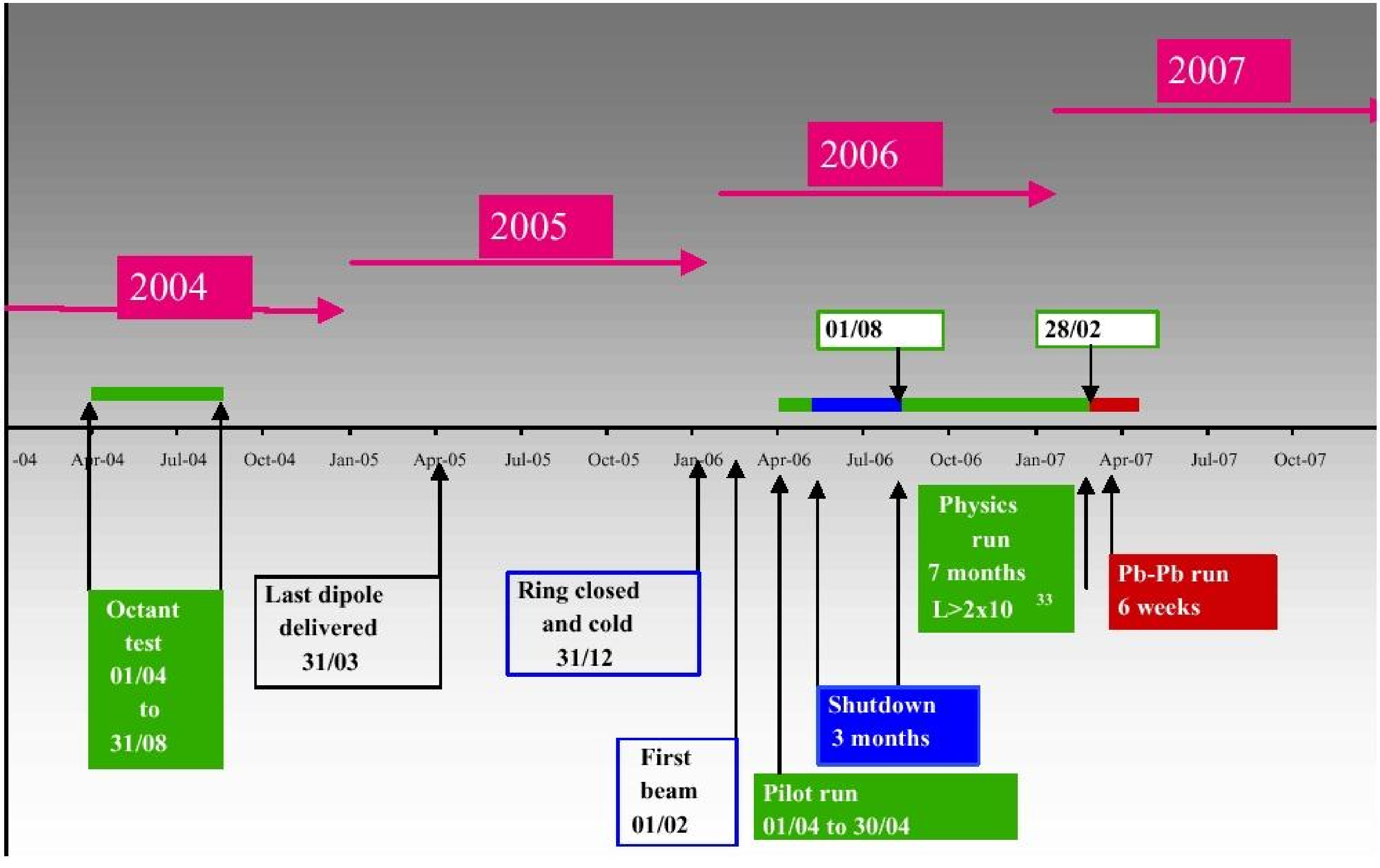
LHC Dipoles

LHC superconducting dipole

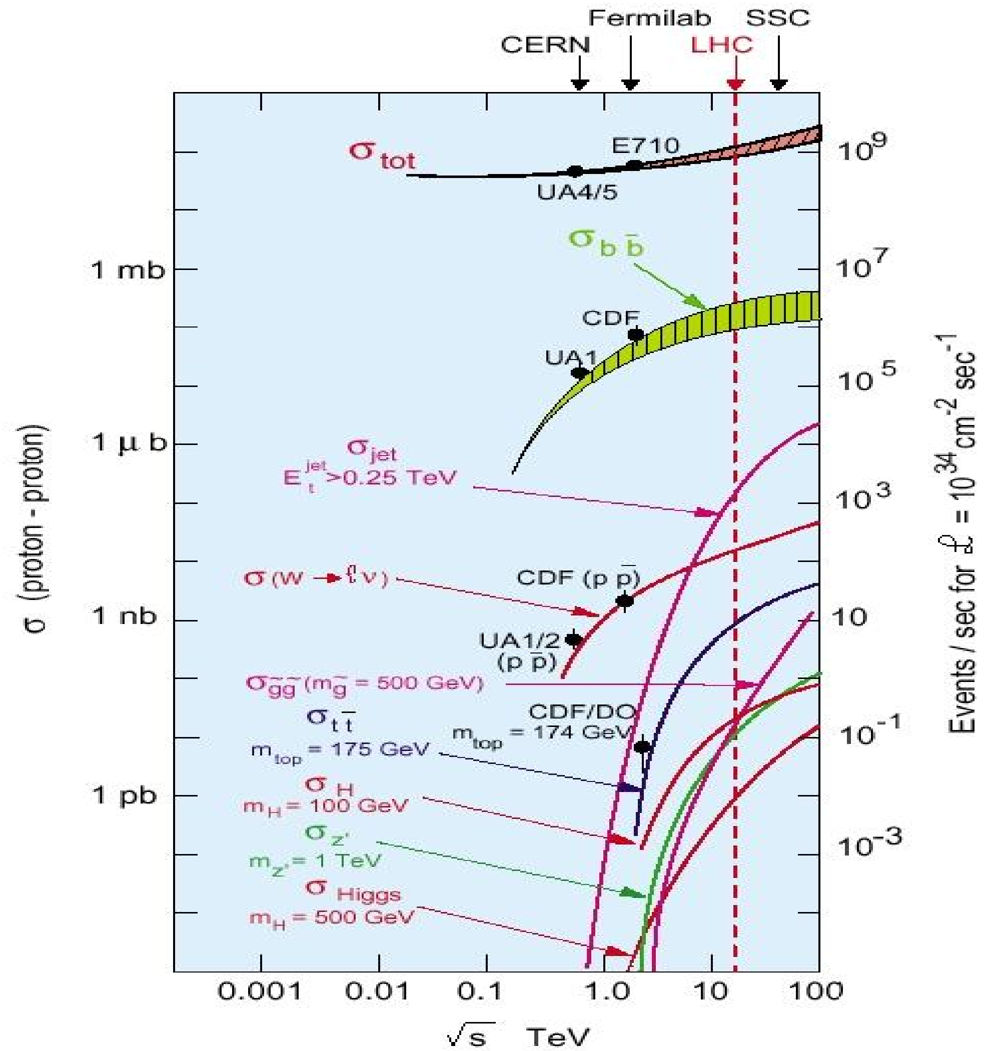


LHC magnet string

LHC schedule



pp cross-sections



Detector requirements

High Interaction Rate

pp interaction rate 10^9 interactions/s
data for only ~100 out of the 40 million crossings can be recorded per sec
Level-1 trigger decision will take ~2-3 ms
⇨ electronics need to store data locally (pipelining)

Large Particle Multiplicity

~ <20> superposed events in each crossing
~ 1000 tracks stream into the detector every 25 ns
need highly granular detectors with good time resolution for low occupancy
⇨ large number of channels

High Radiation Levels

⇨ radiation hard (tolerant) detectors and electronics

Detector requirements

Very good muon identification and momentum measurement

trigger efficiently and measure sign of a few TeV muons

High energy resolution electromagnetic calorimertry

~ 0.5% @ E_T~50 GeV

Powerful inner tracking systems

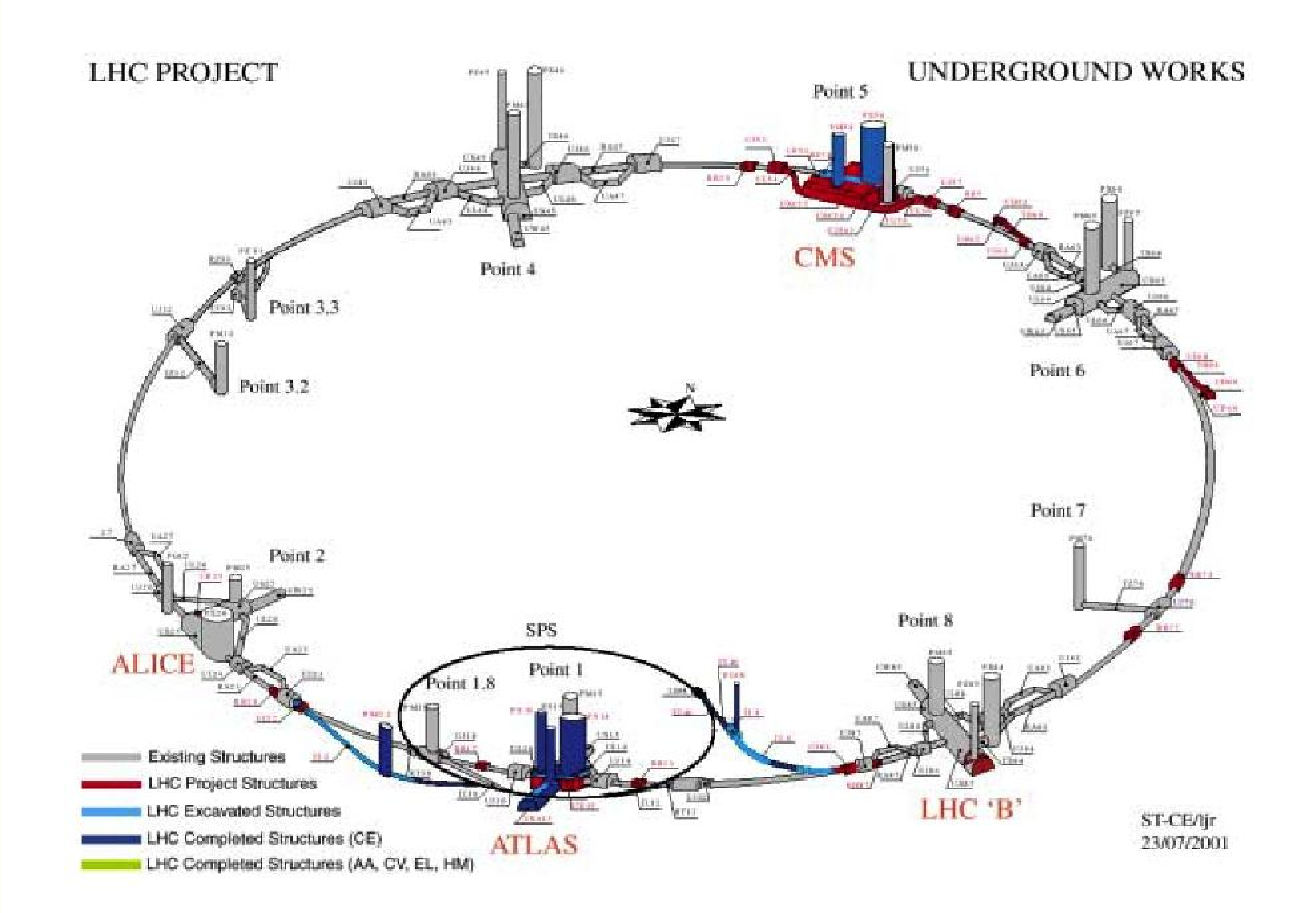
factor 10 better momentum resolution than at LEP

Hermetic calorimetry

good missing E_T resolution

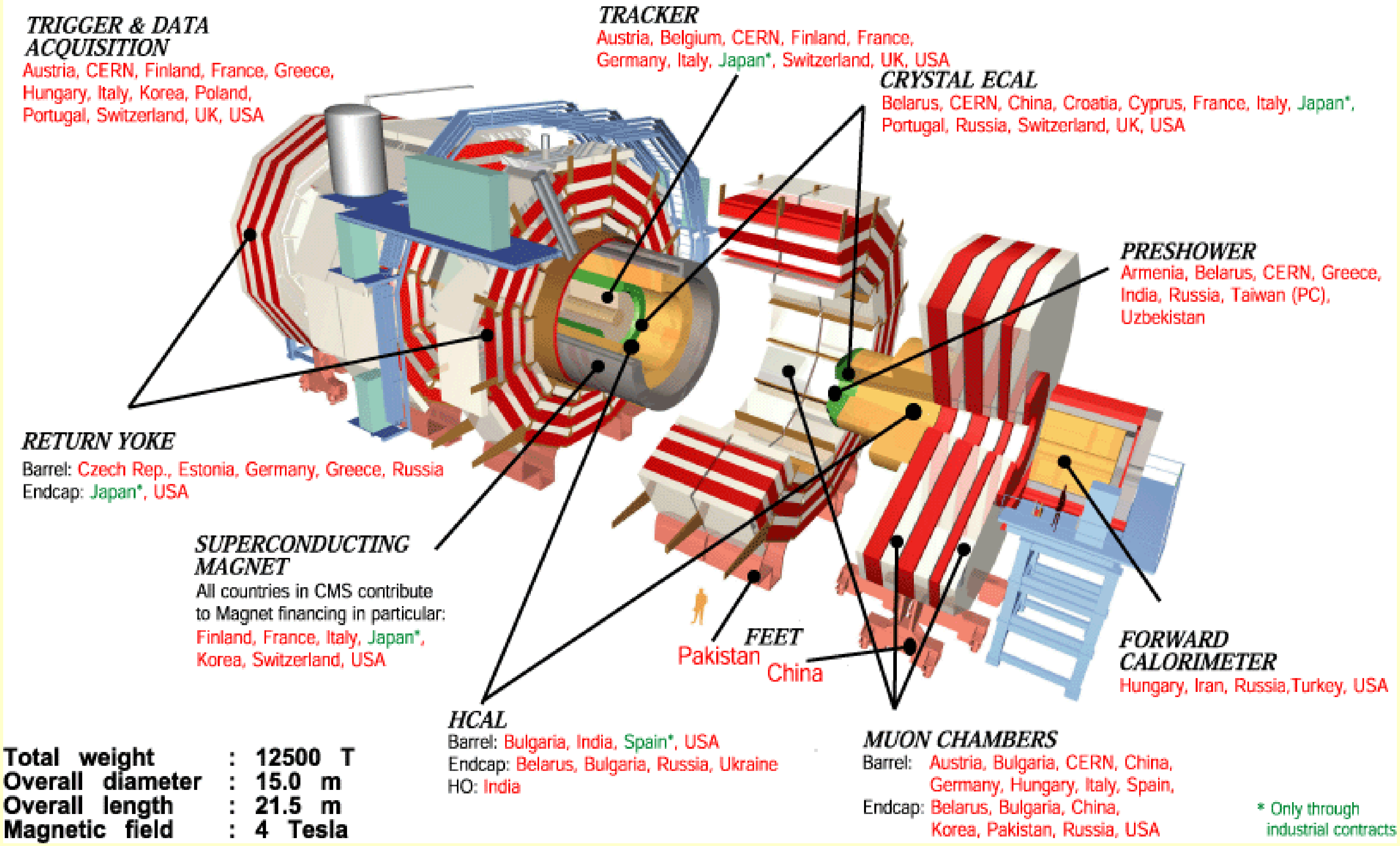
(Affordable detector)

LHC


LHC PROJECT
UNDERGROUND WORKS
Point 5
CMS
Point 4
Point 3.3
Point 3.2
Point 6
Point 7
Point 2
ALICE
SPS
Point 1
Point 1.8
Point 8
LHC 'B'
ATLAS
Existing Structures
LHC Project Structures
LHC Excavated Structures
LHC Completed Structures (CE)
LHC Completed Structures (AA, CV, EL, HM)
ST-CE/ljr
23/07/2001

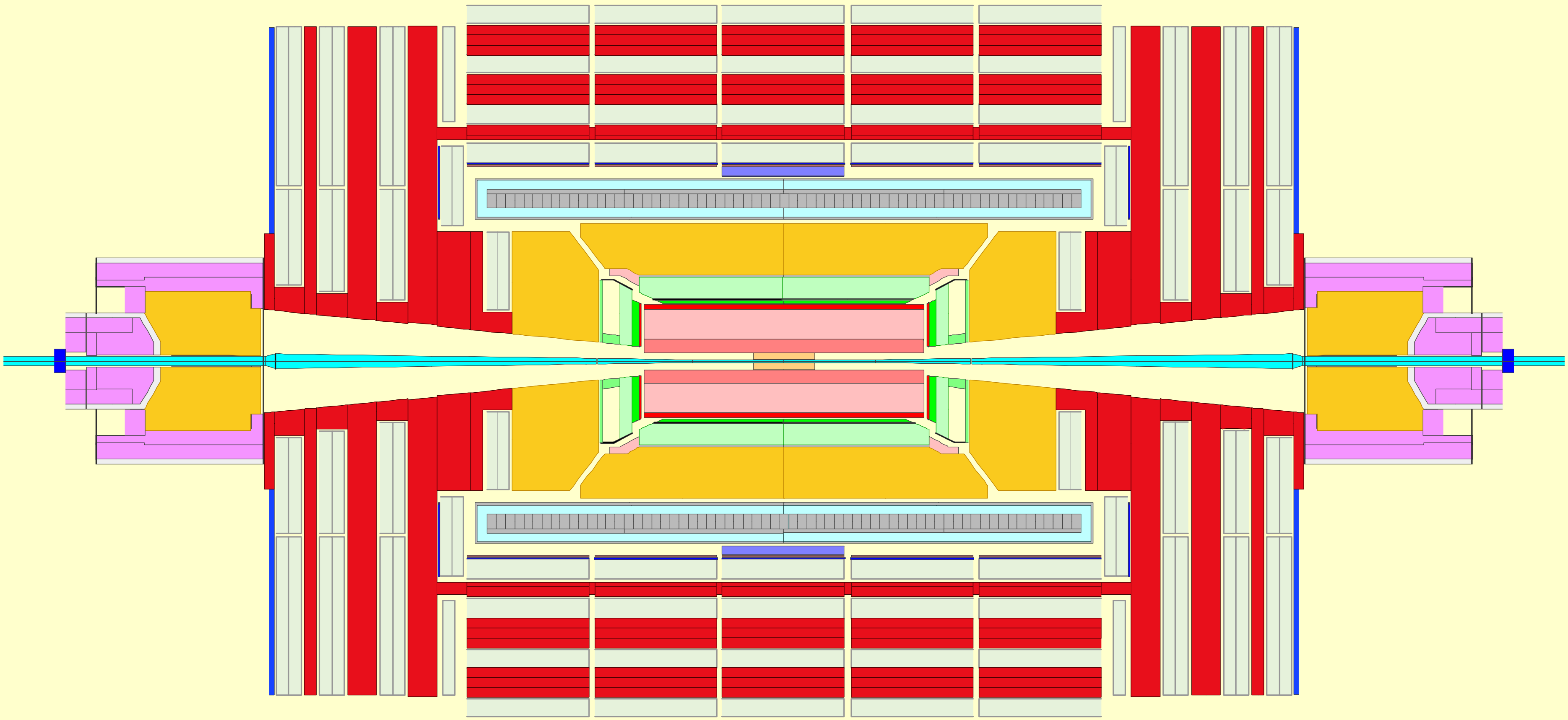
CMS Detector

31 Nations, 150 Institutions, 1870 Scientists

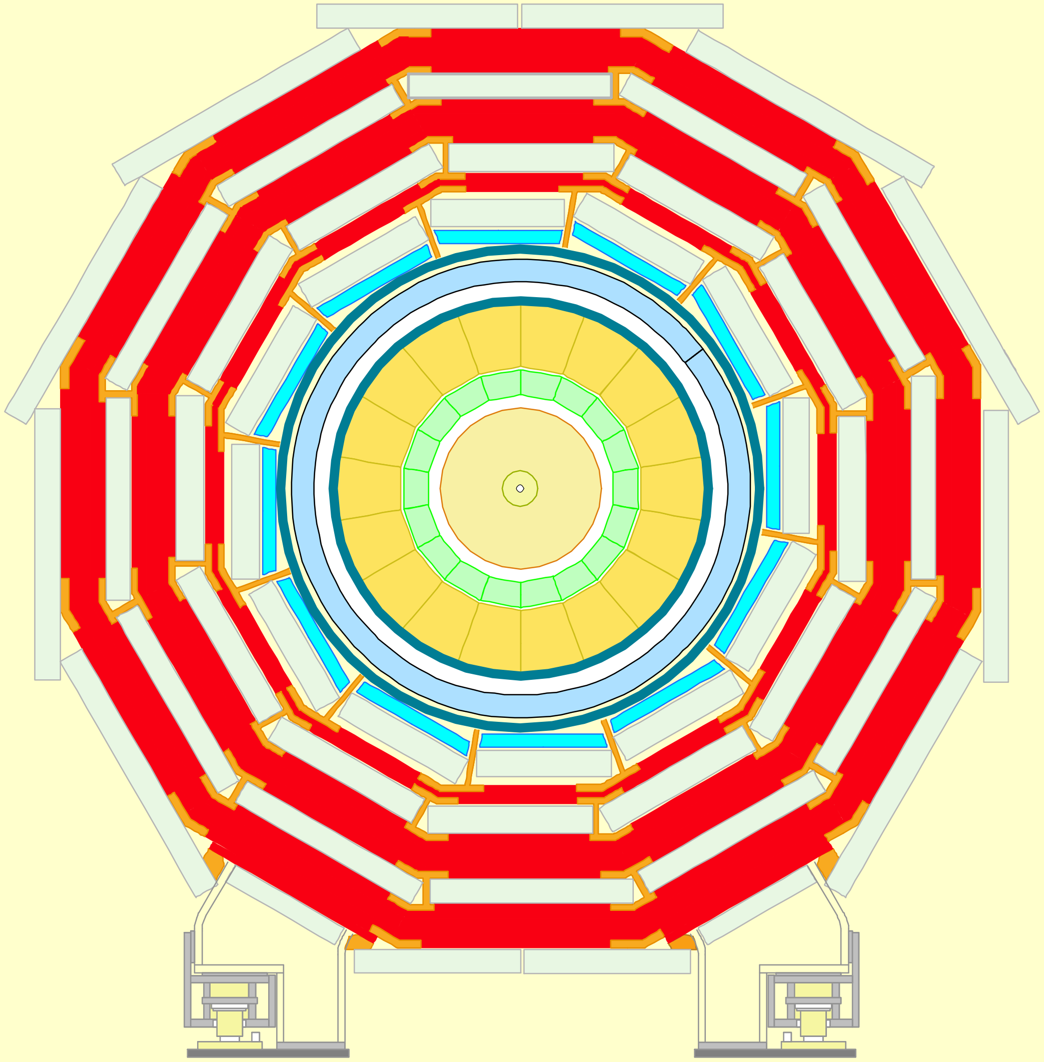


Total weight	:	**12500 T**
Overall diameter	:	**15.0 m**
Overall length	:	**21.5 m**
Magnetic field	:	**4 Tesla**

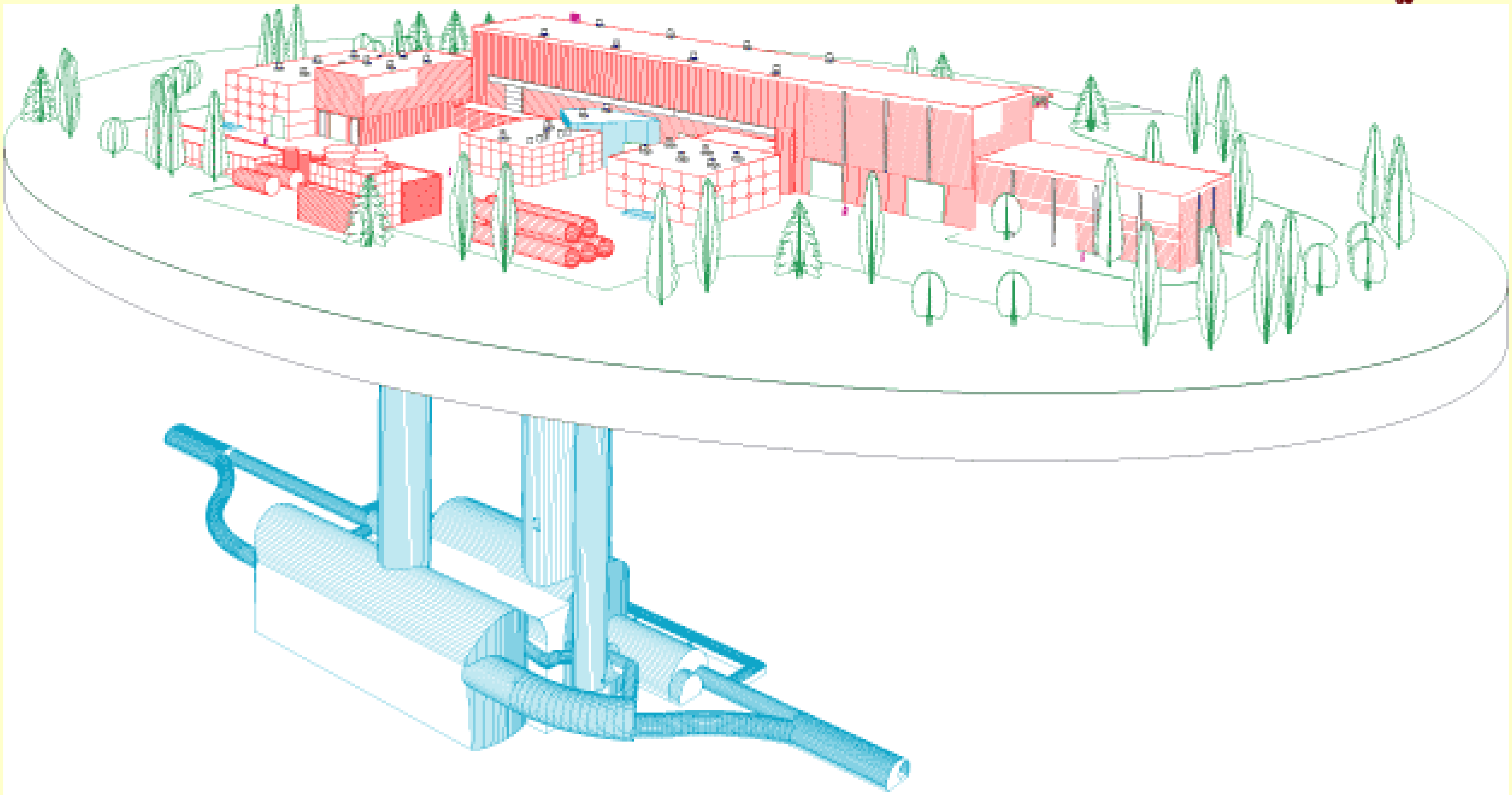
CMS Longitudinal view



CMS Transversal view



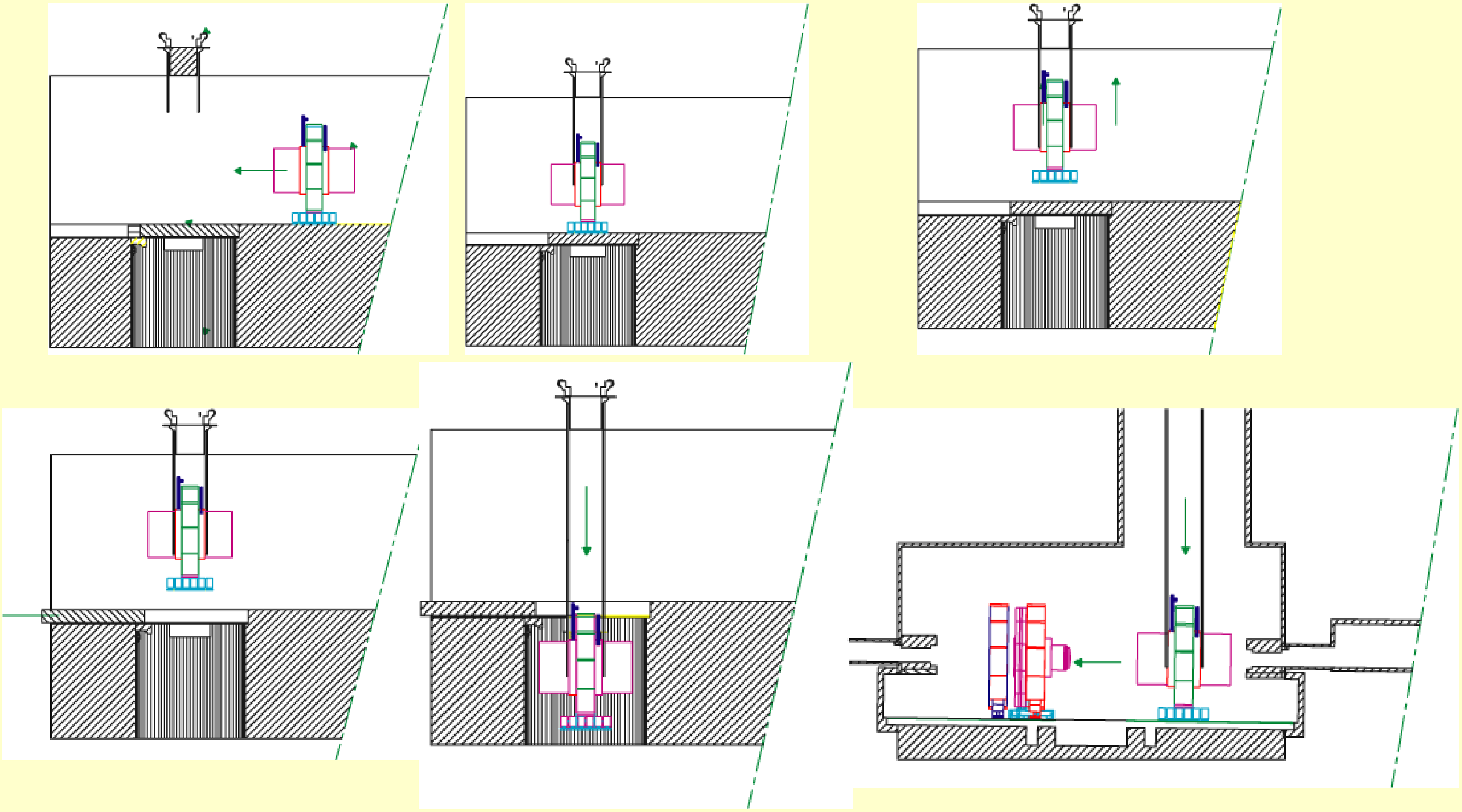
CMS experimental Area



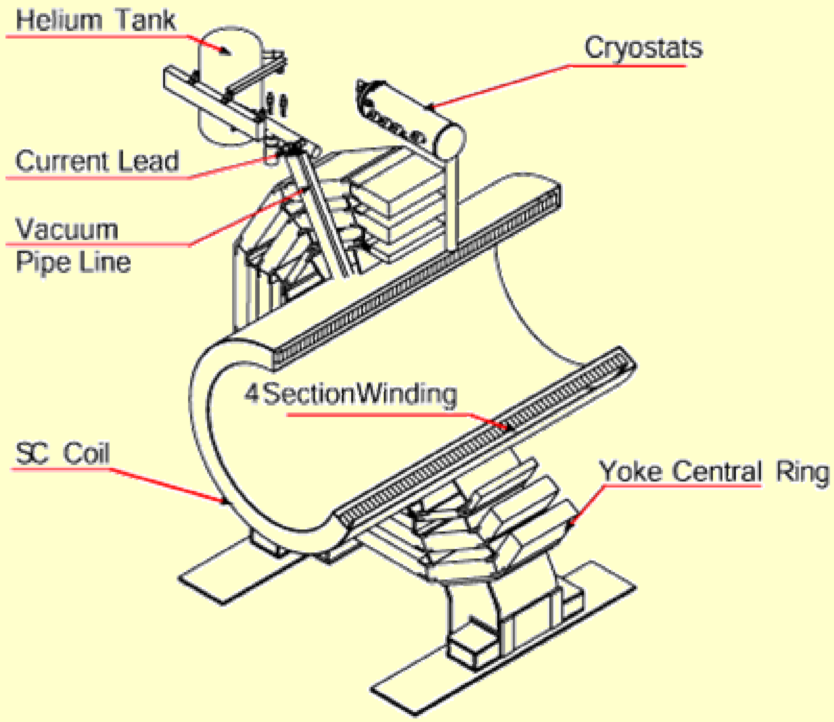
CMS experimental area overview

LHC Point 5

CMS Installation



CMS Magnet



Helium Tank
Cryostats
Current Lead
Vacuum
Pipe Line
4 Section Winding
SC Coil
Yoke Central Ring

Magnet Return Yoke

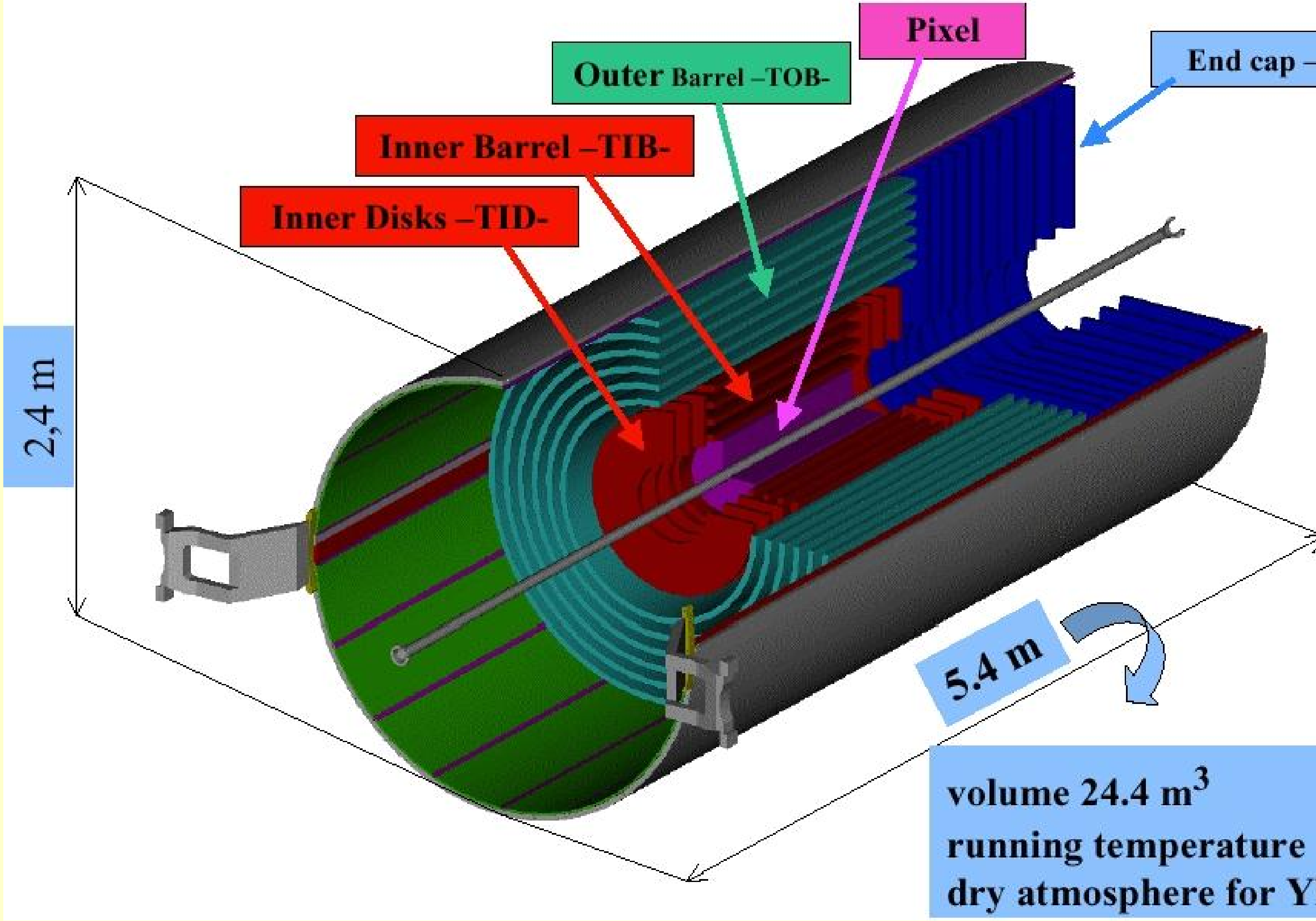
Magnet Endcap

CMS Coil

Magnet Coil

Magnet

Central Track Detector



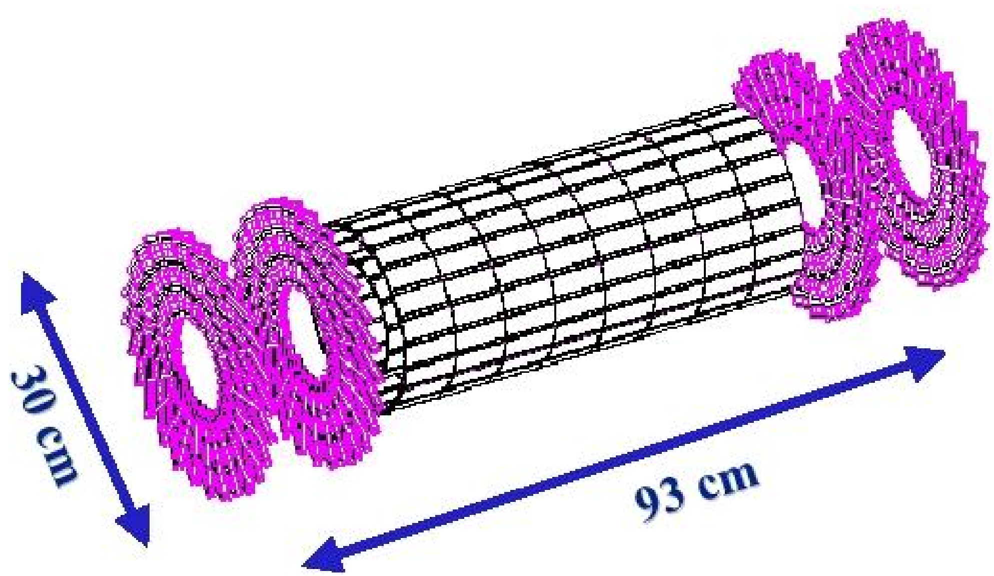
volume 24.4 m^3
running temperature – 10 ^{0}C
dry atmosphere for YEARS!

Central Pixel Detector

Still in R&D phase. Construction starts at end of 2003

Challenge: low mass, rad-hard, fast and efficient readout, large production yield, bump bonding

Today: integration with beam pipe and SST, installation scheme, services

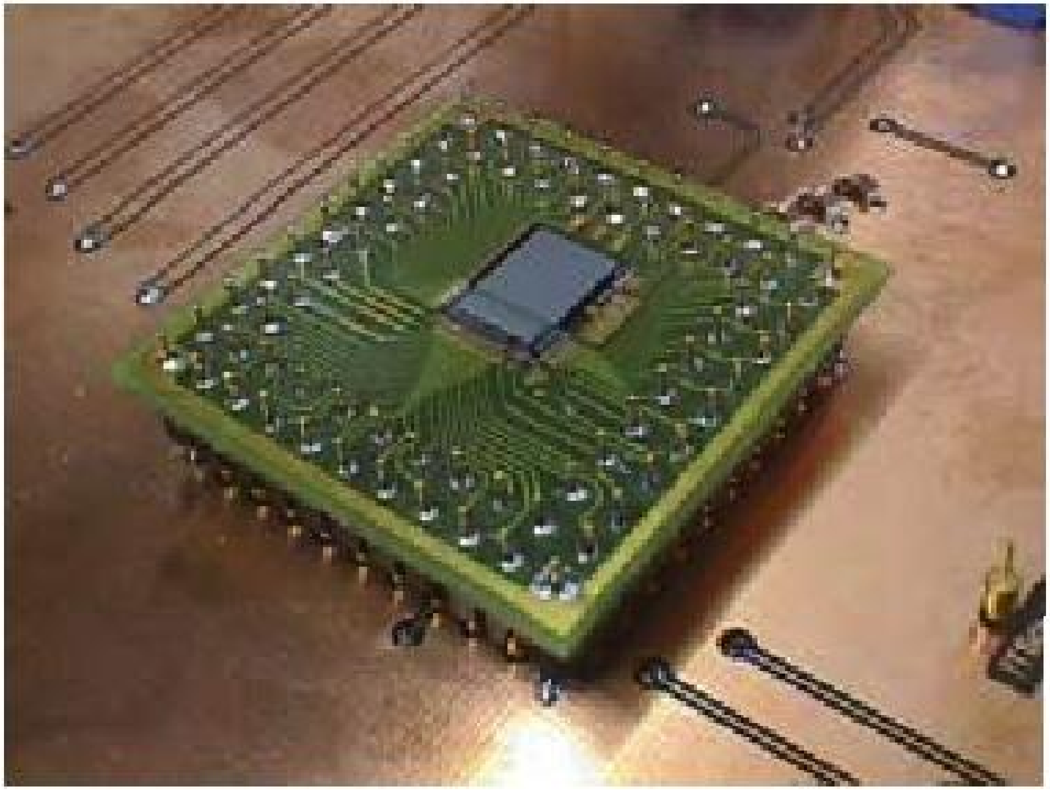


39 10^6 pixels

14.192 chips

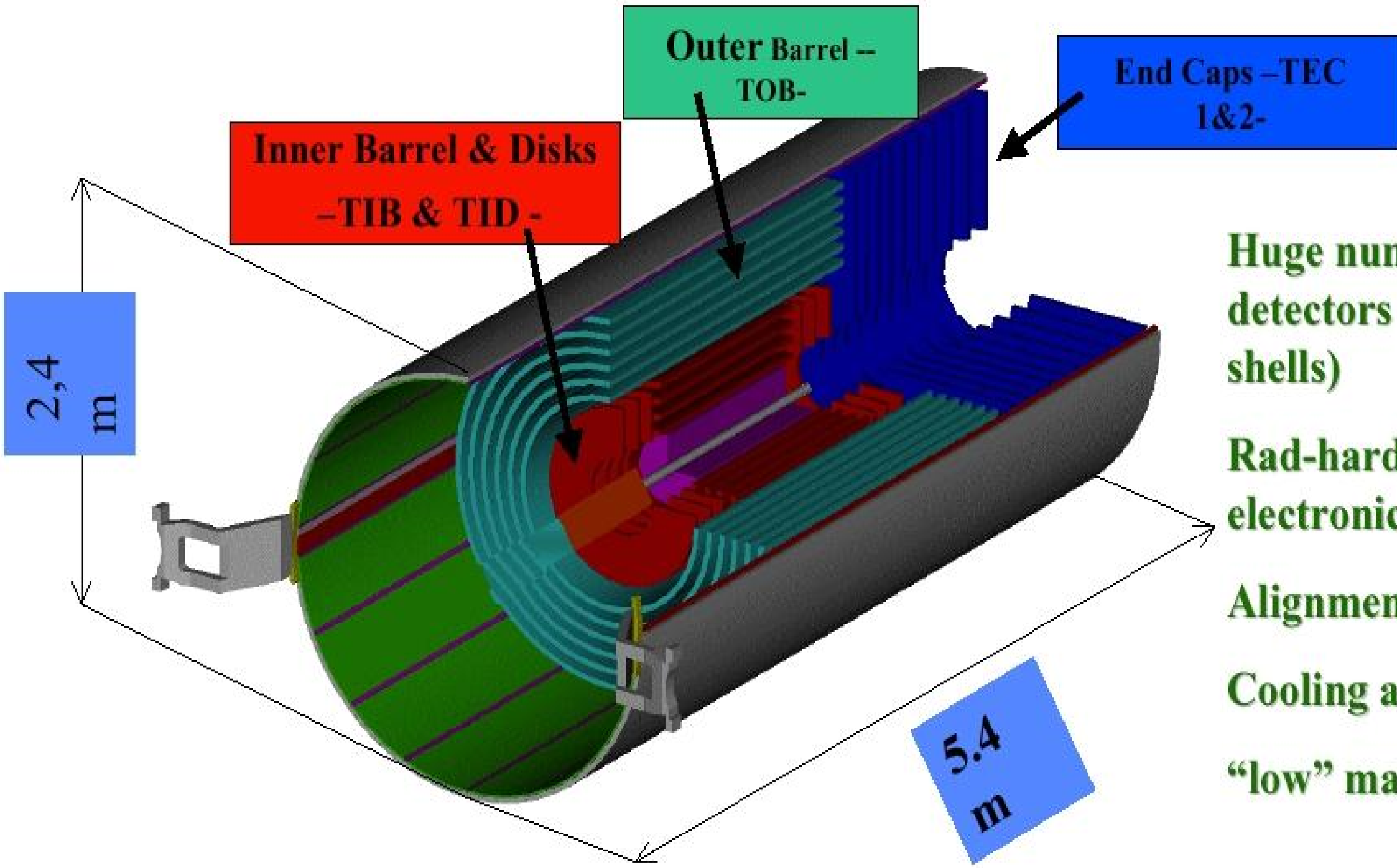
Occupancy 10^{-4}

Pixel Chip



- 36x40 pixel chip
- chip size 8.4mm x 6.3mm
- pixel size 150μ x 150μ

Central Microstrip Detector



Huge number of silicon detectors (rods, petals, shells)

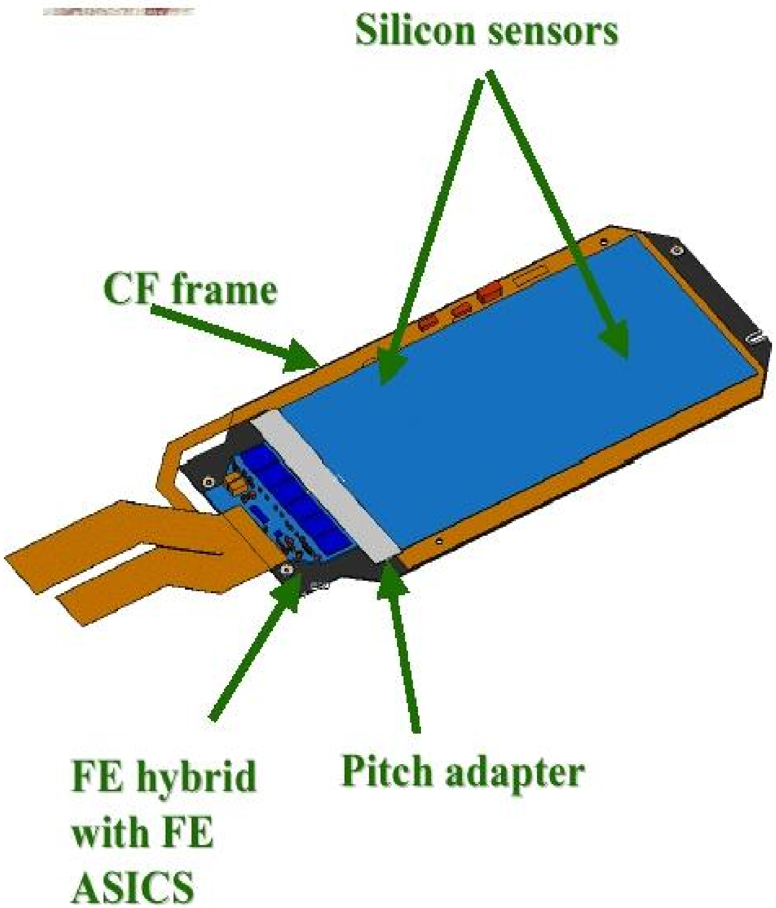
Rad-hard modules and electronics

Alignment

Cooling and –10 ^oC

"low" mass

Silicon Microstrip Module



6,136 Thin sensors
18,192 Thick sensors

6,136 Thin detectors (1 sensor)
9,096 Thick detectors (2 sensors)

3112 + 1512 Thin modules (ss +ds)
5496 + 1800 Thick modules (ss +ds)

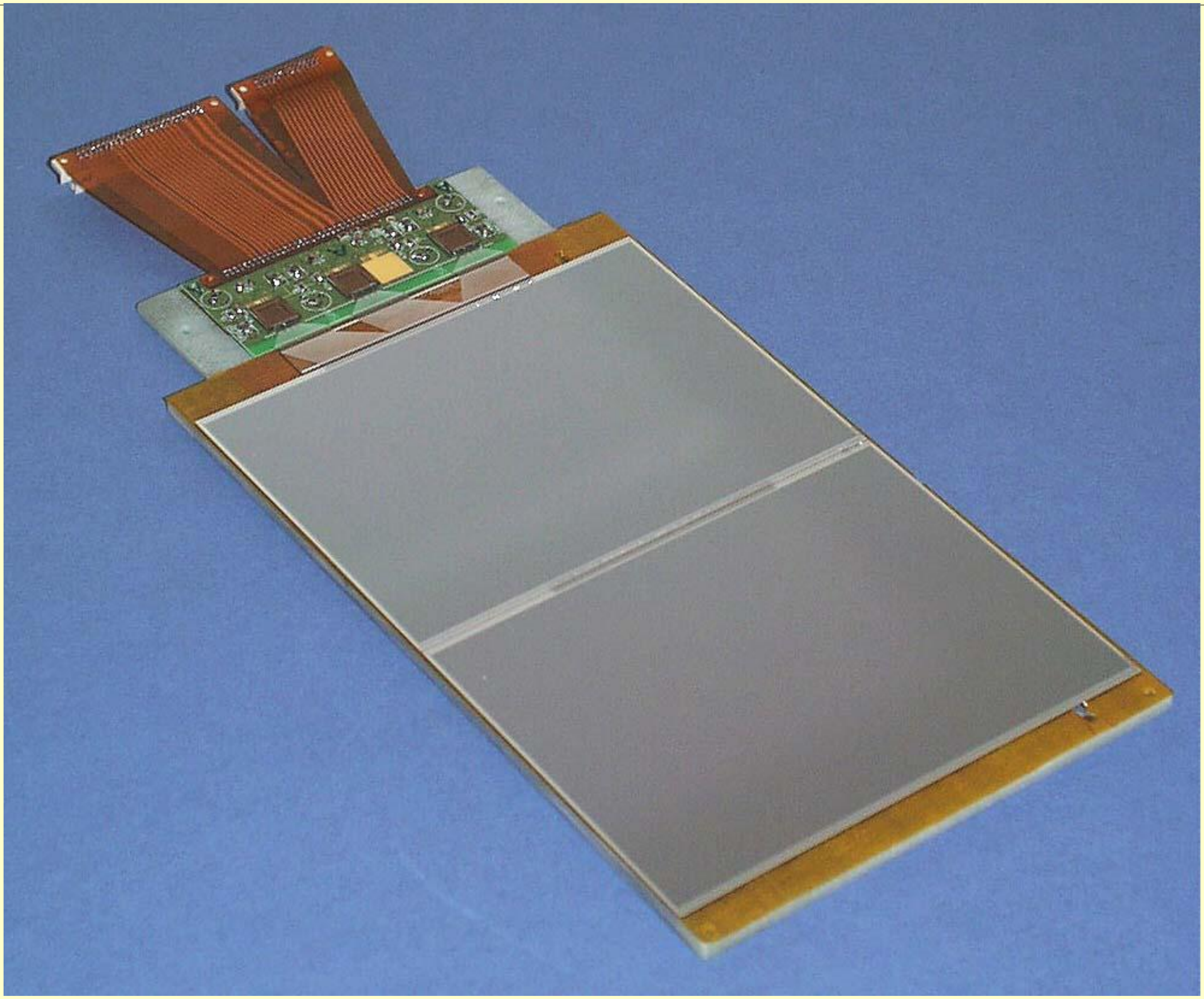
9,648,128 strips ≡ electronics channels

75,376 APV chips

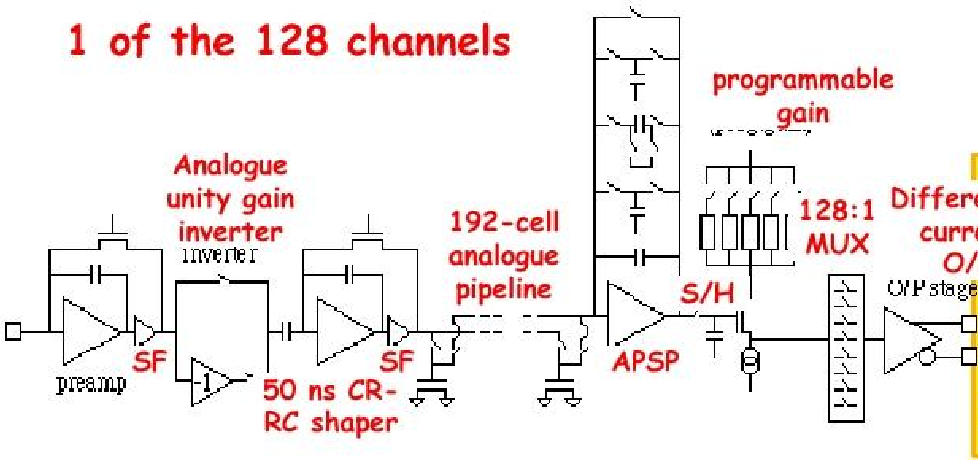
25,000,000 Bonds

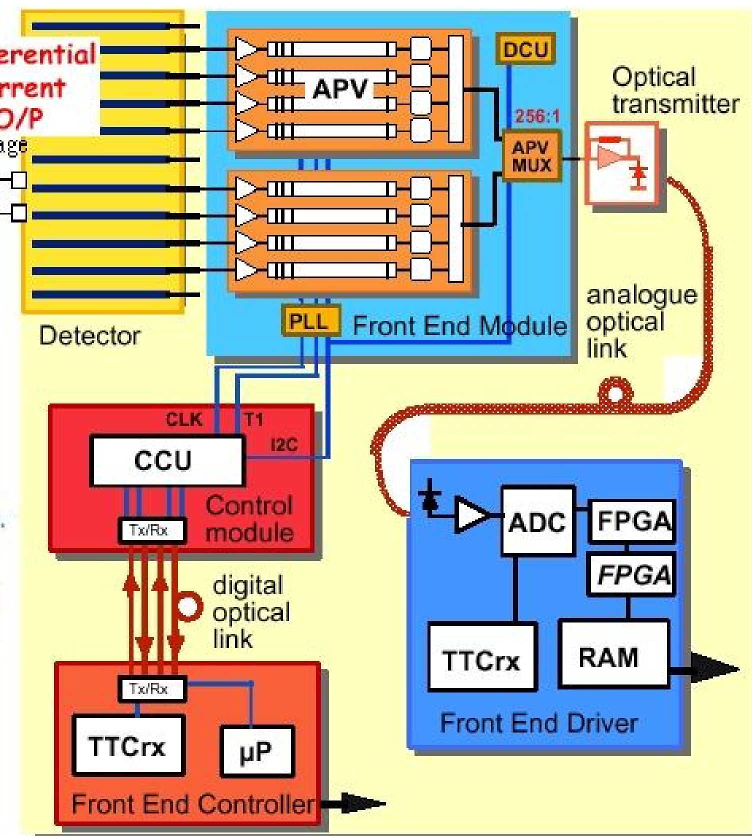
440 m^2 of silicon wafers
210 m^2 of silicon sensors ($162m^2 + 48m^2$)

Silicon Microstrip Sensor



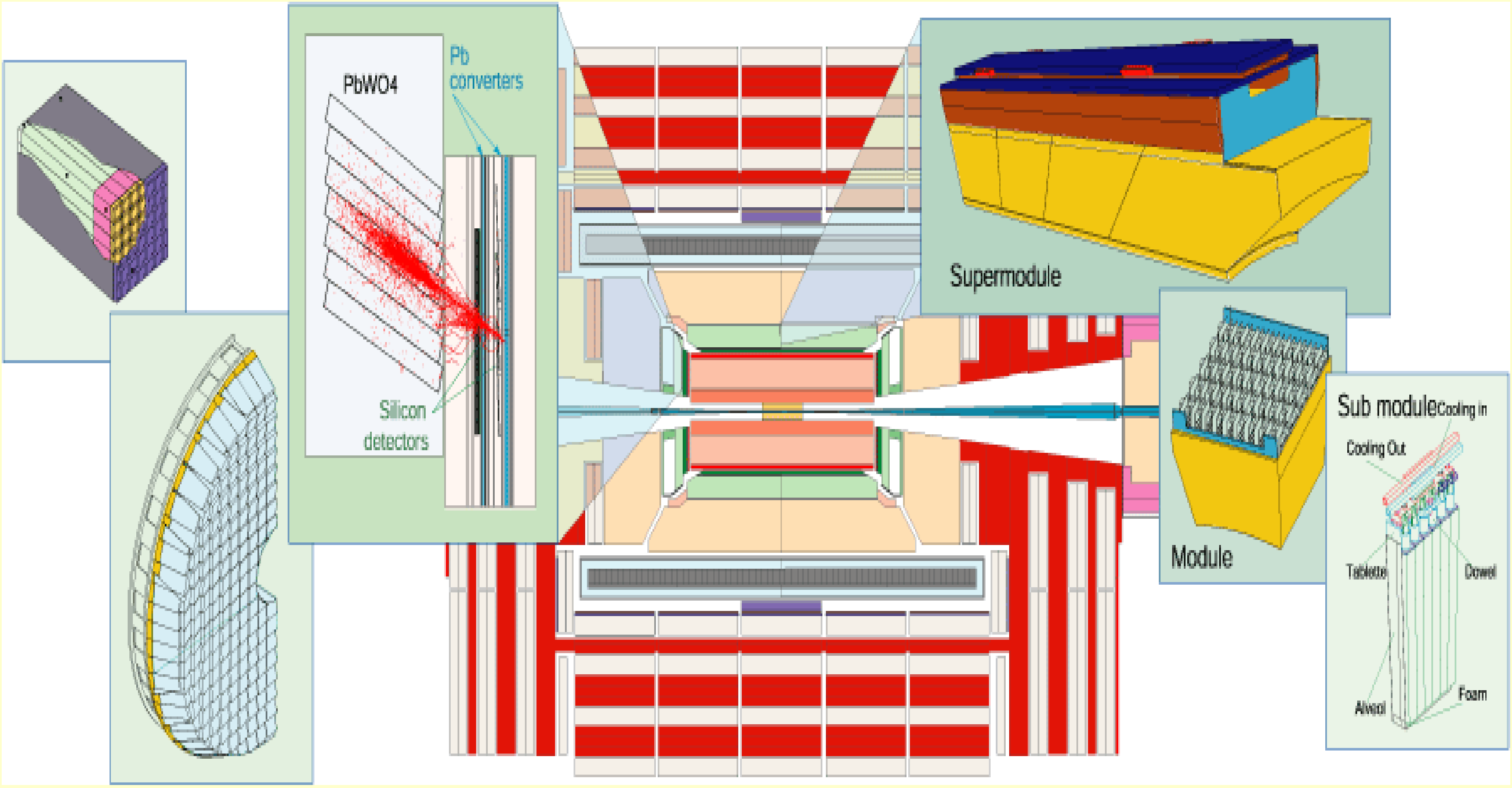
Tracker readout





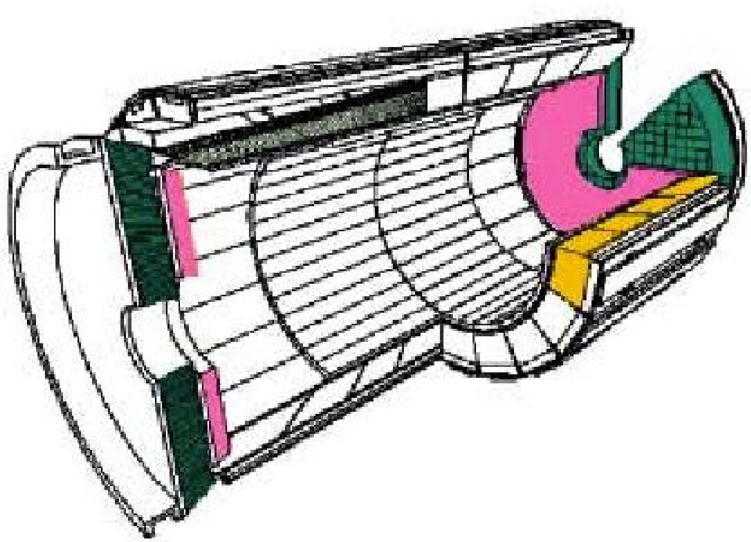
Each microstrip is read out by a charge sensitive amplifier with τ= 50 ns.
The o/p voltage is sampled at the beam crossing rate of 40 MHz.
Samples are stored in analog pipeline for up to Level-1 latency (3.2 µs)
Following a trigger form a weighted sum of 3 samples in analog circuit
This confines signal to single bx and gives pulse height
Buffered pulse height data multiplexed out on optical fibres
Output of laser modulated by the pulse height for each strip

ECAL Overview



ECAL

ECAL: $PbWO_4$ crystals



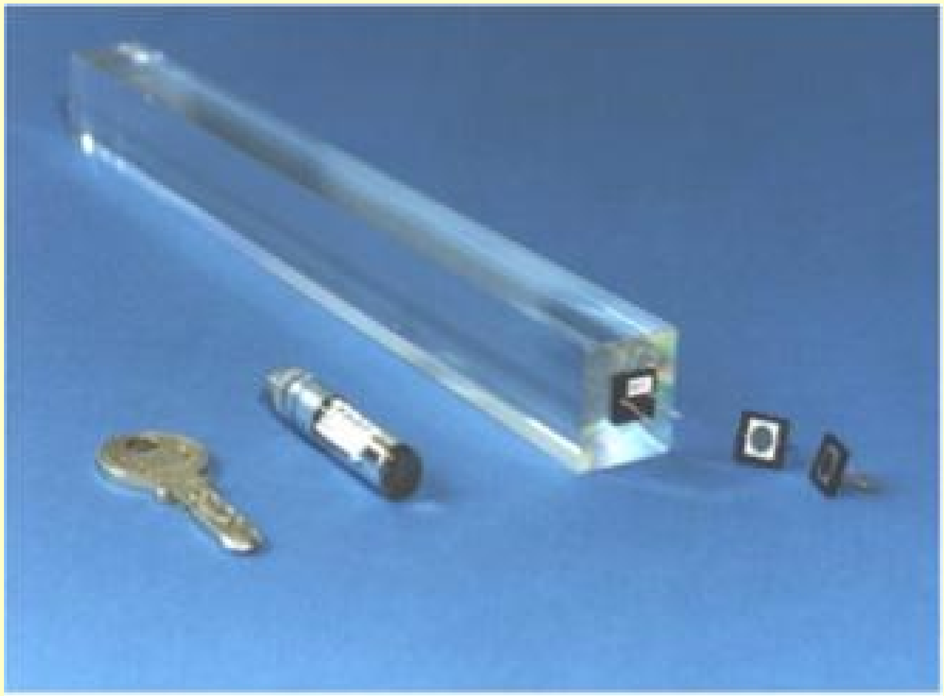
Parameter	Barrel	Endcap
η coverage	|η| < 1.48	1.48 < |η| < 3.0
Granularity (Δη×Δφ)	0.0175×0.0175	varies in η
Crystal Dims. (cm^3)	2.18×2.18×23	2.85×2.85×22
Depth in X_0	25.8	24.7 (+3X_0)
No. of crystals	61,200	14,950
Crystal Volume (m^3)	8.14	3.04
Photodetector	APDs	VPTs
Modularity	36 supermodules	4 Dees

HCAL

Central Region (|η|<3) : Brass/Scintillator with WLS fibre readout, projective geometry, granularity $\Delta\eta x \Delta\phi$ = 0.0875x0.0875

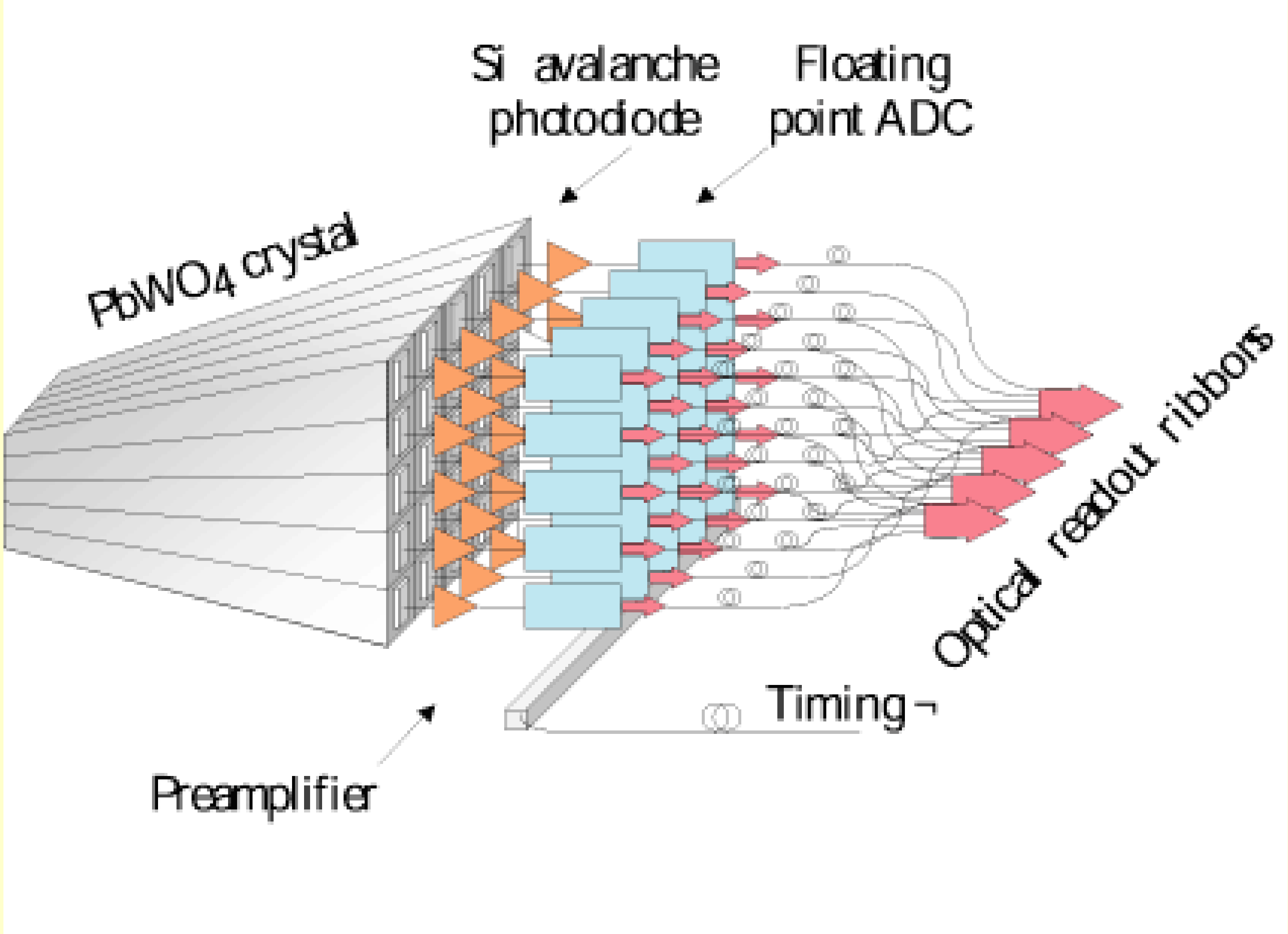
Forward Region (3<|η|<5): Fe/Quatz Fibre, Cerenkov light

$PbWO_4$ crystals



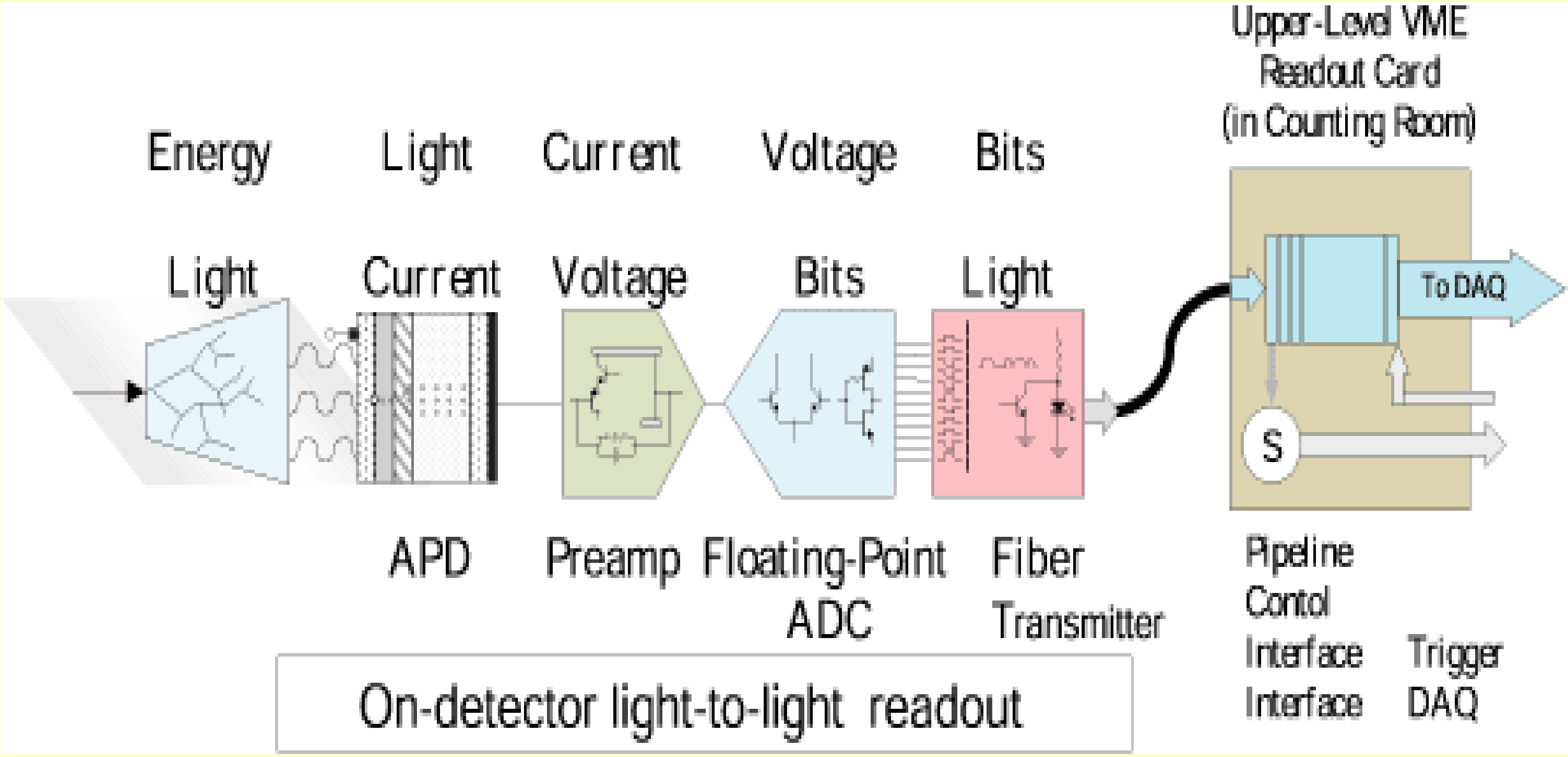
ECAL module

ECAL

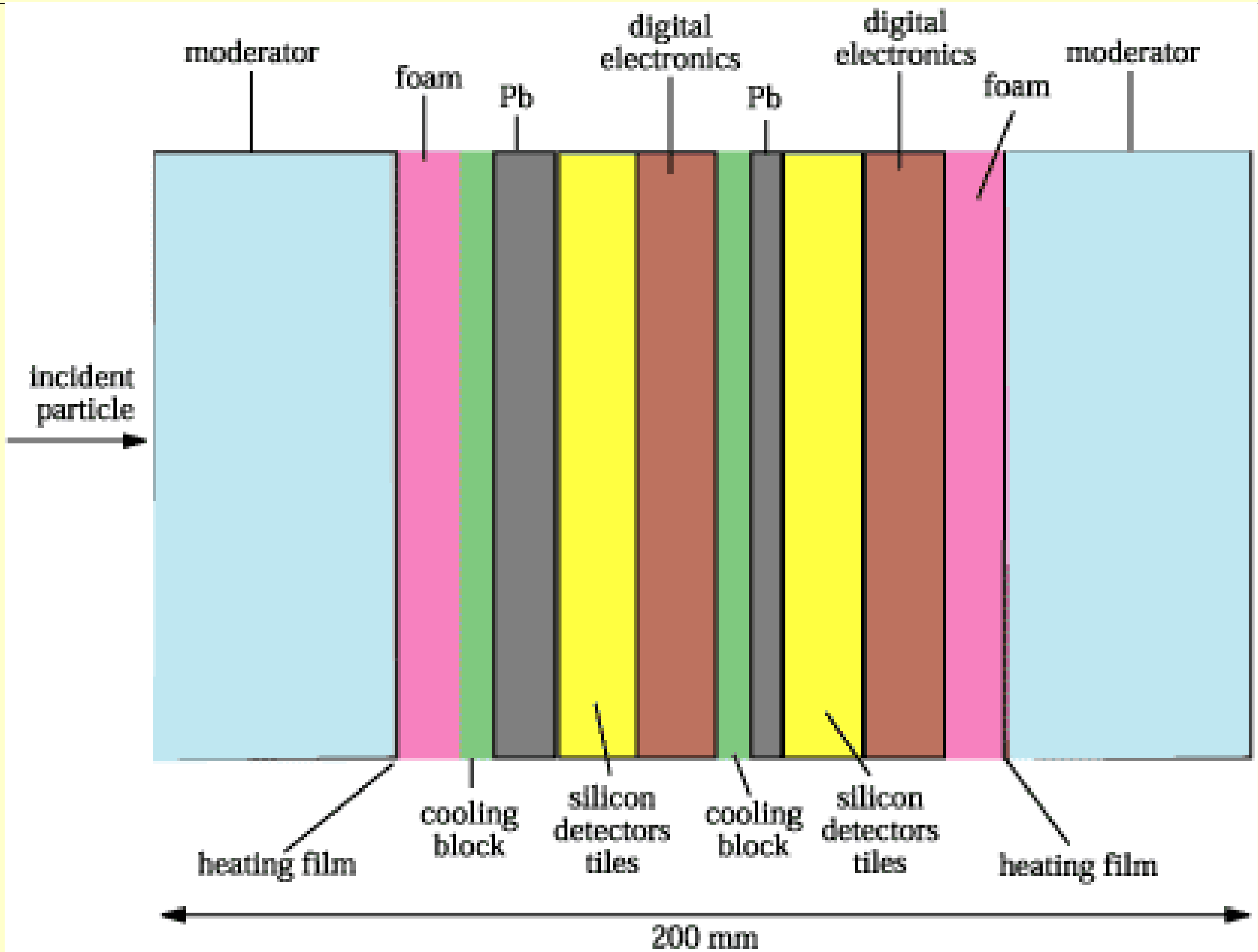


Si avalanche photodiode
Floating point ADC
PbWO4 crystal
Optical readout ribbons
Timing
Preamplifier

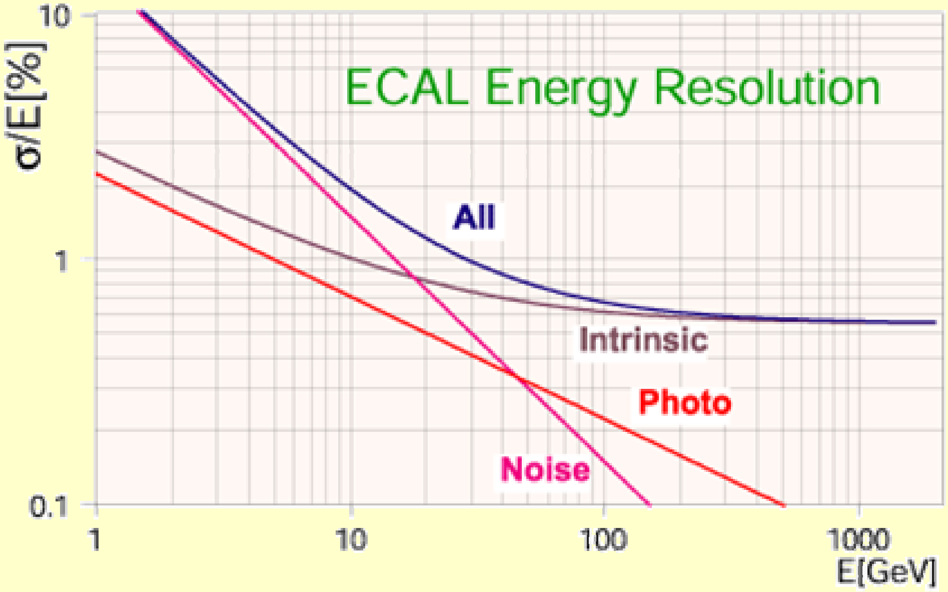
ECAL readout



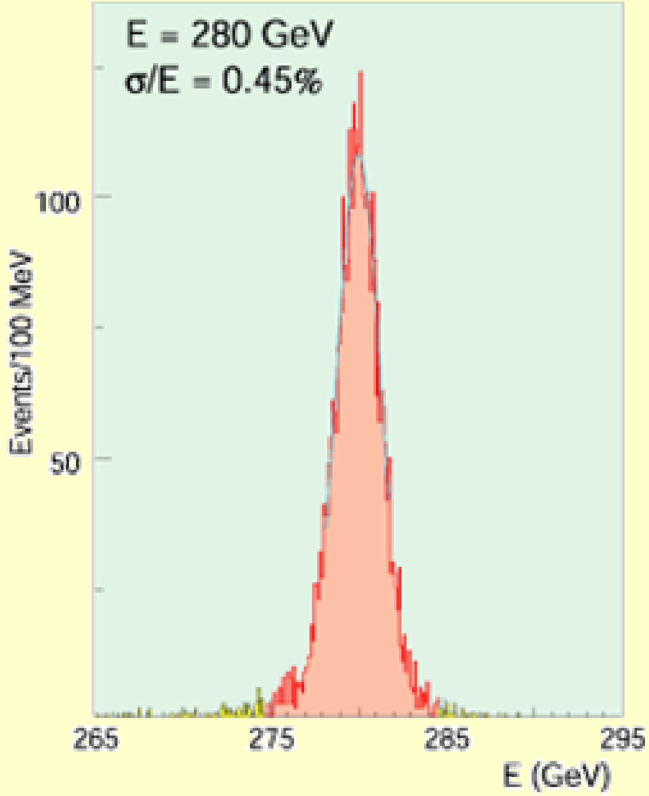
Preshower


moderator
foam
Pb
digital
electronics
Pb
digital
electronics
foam
moderator
incident
particle
heating film
cooling
block
silicon
detectors
tiles
cooling
block
silicon
detectors
tiles
heating film
200 mm

ECAL

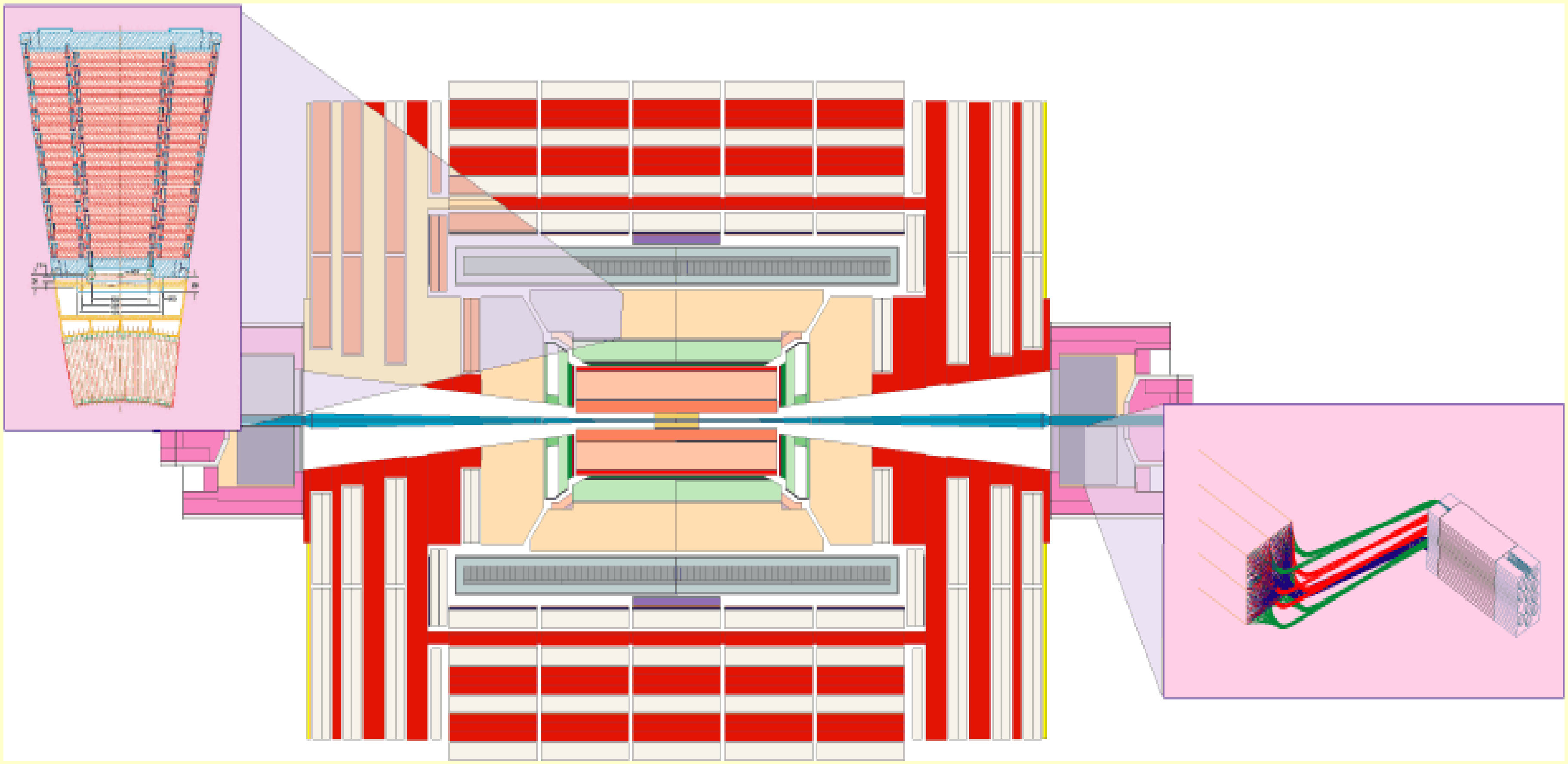


ECAL Energy Resolution
σ/E[%]
10
1
0.1
1
10
100
1000
E[GeV]
All
Intrinsic
Photo
Noise

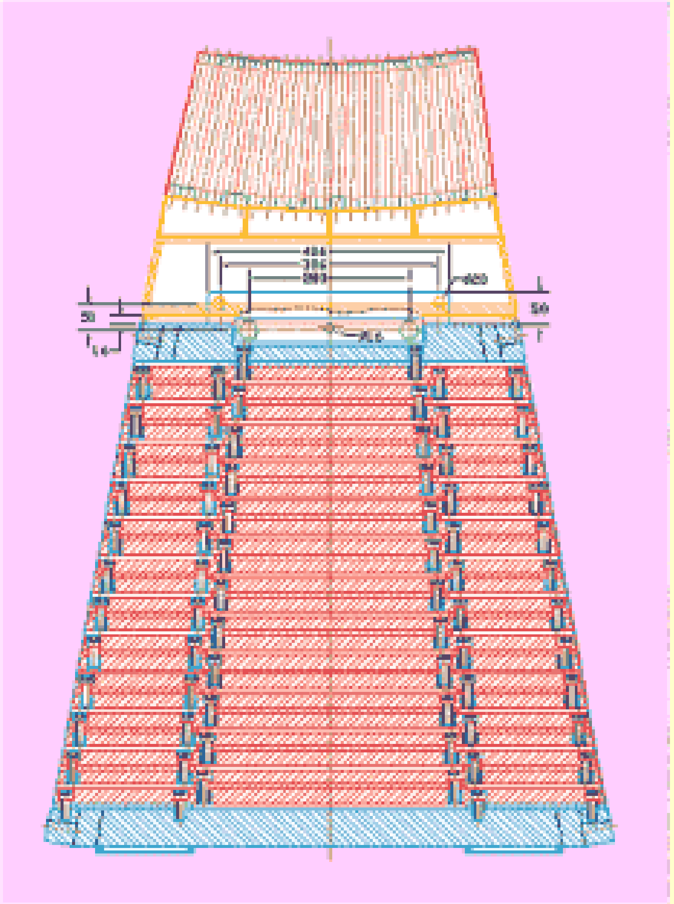


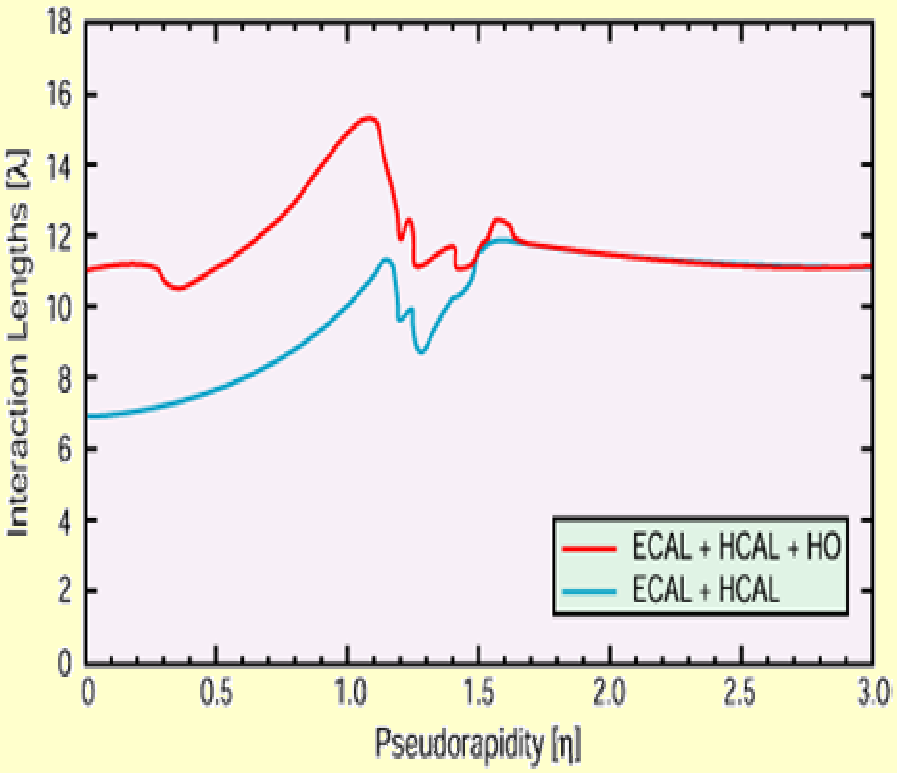
E = 280 GeV
σ/E = 0.45%
Events/100 MeV
100
50
265
275
285
295
E (GeV)

HCAL overview



HCAL wedge

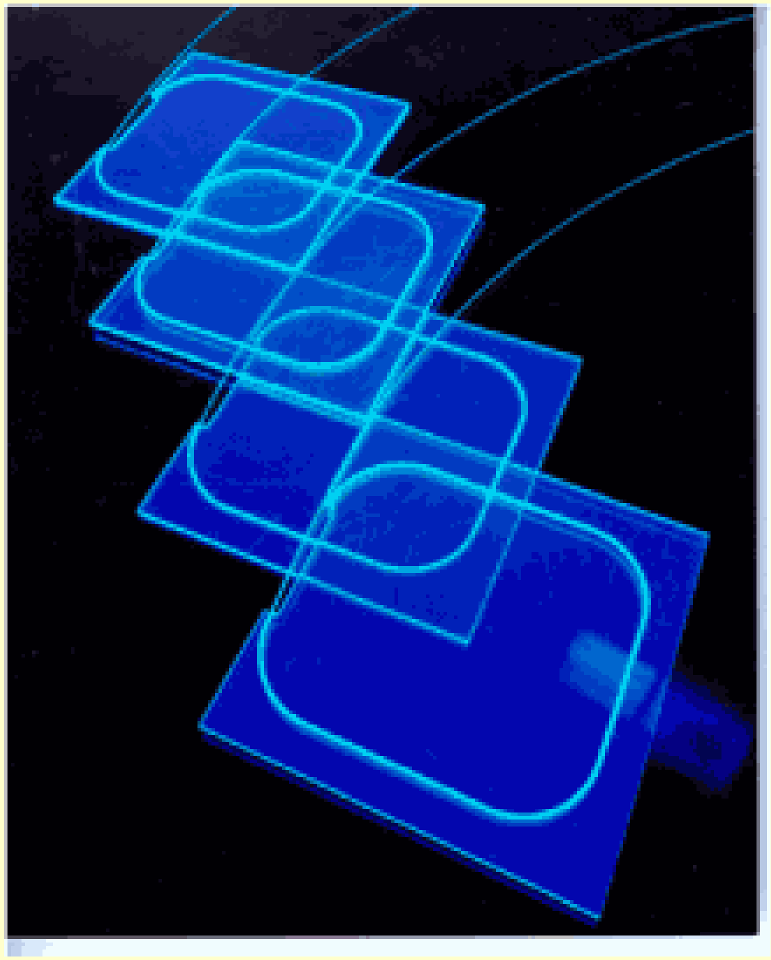


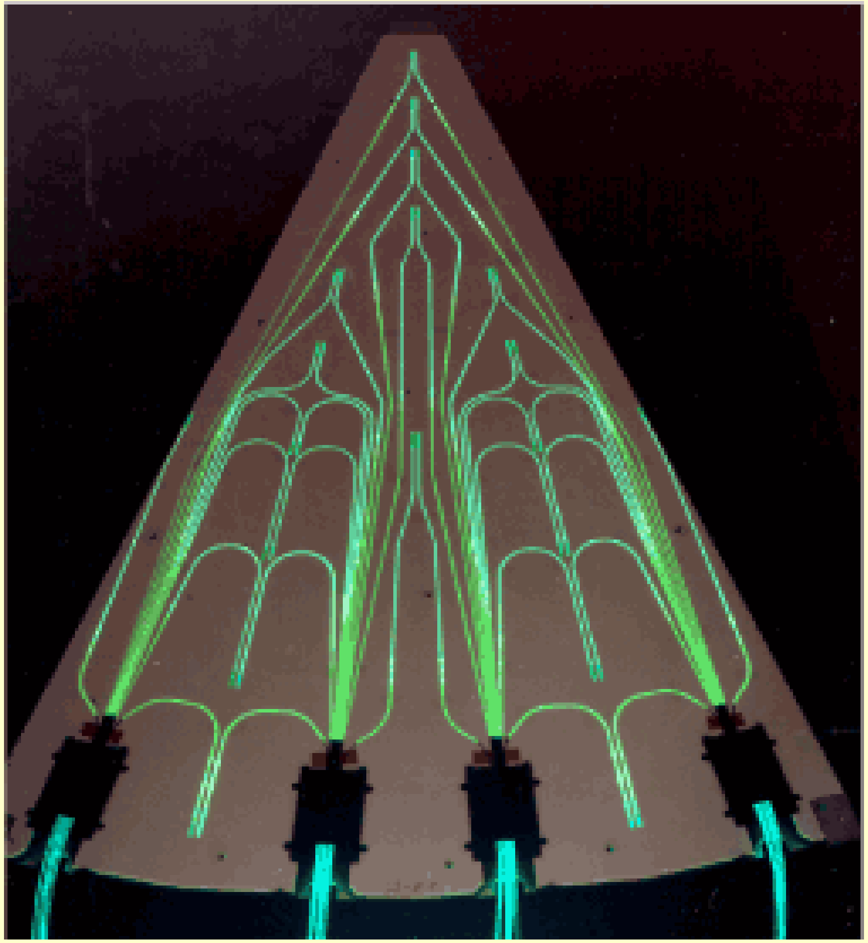


Interaction Lengths [λ]
0
2
4
6
8
10
12
14
16
18
0
0.5
1.0
1.5
2.0
2.5
3.0
Pseudorapidity [η]
ECAL + HCAL + HO
ECAL + HCAL

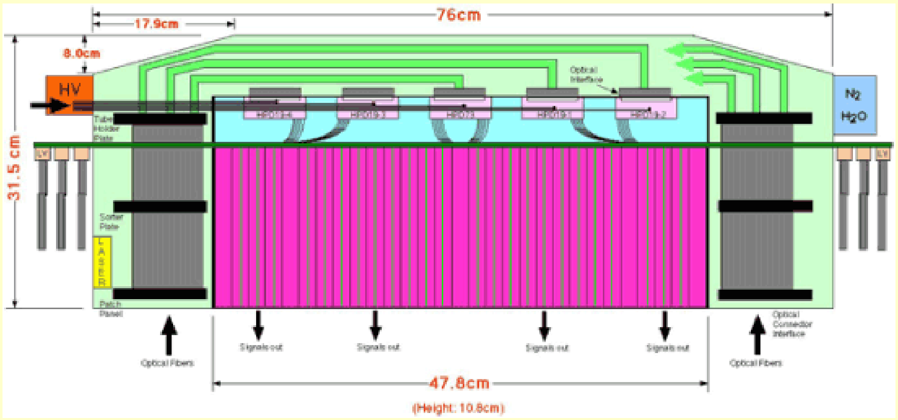
HCAL barrel wedge

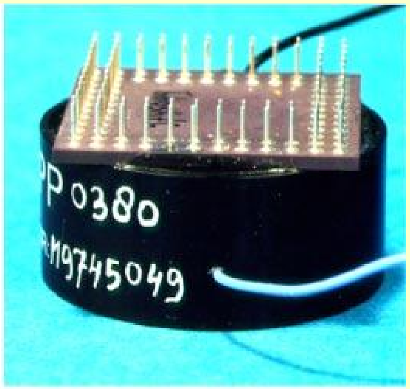
HCAL Scintillators



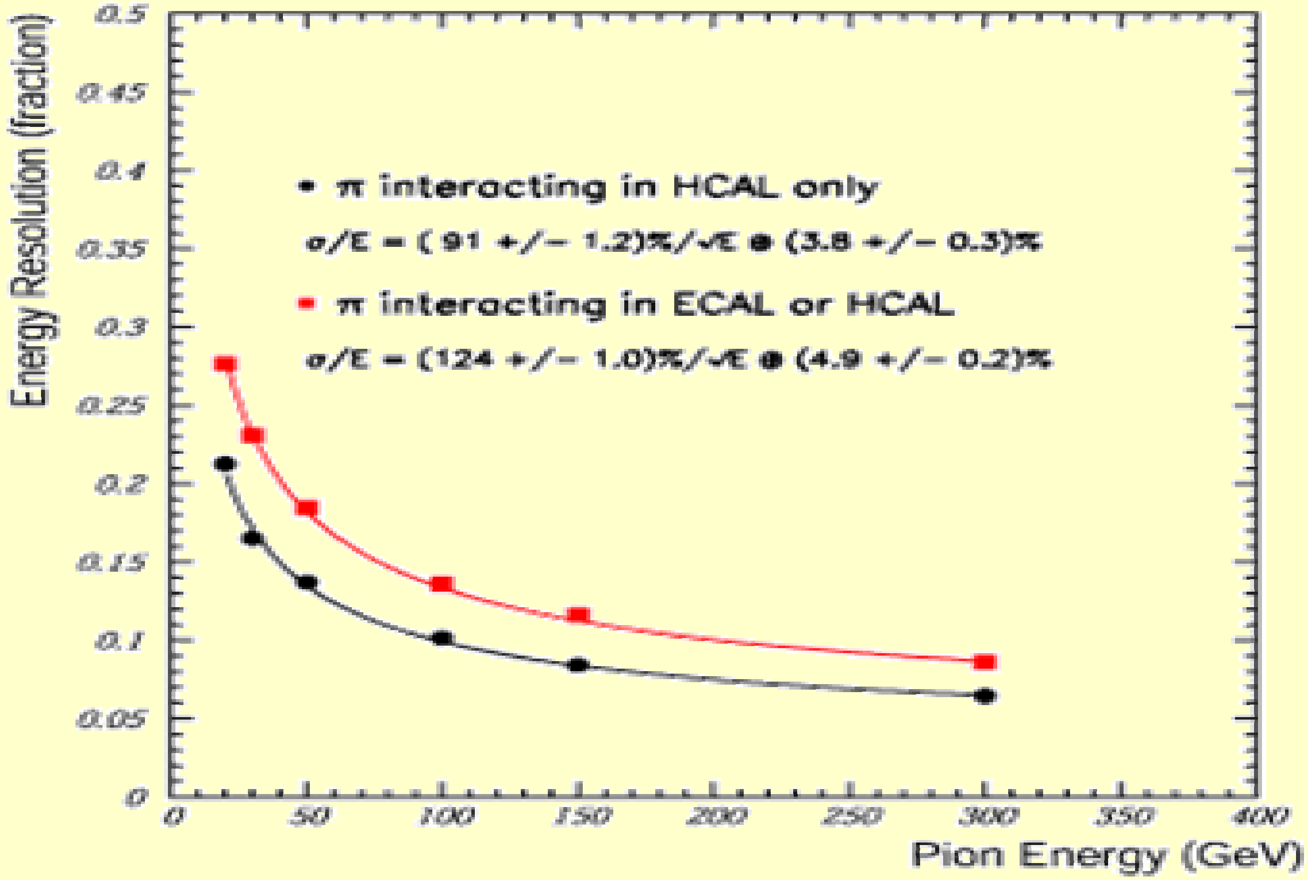


HCAL readout





HCAL energy resolution



HCAL assembly

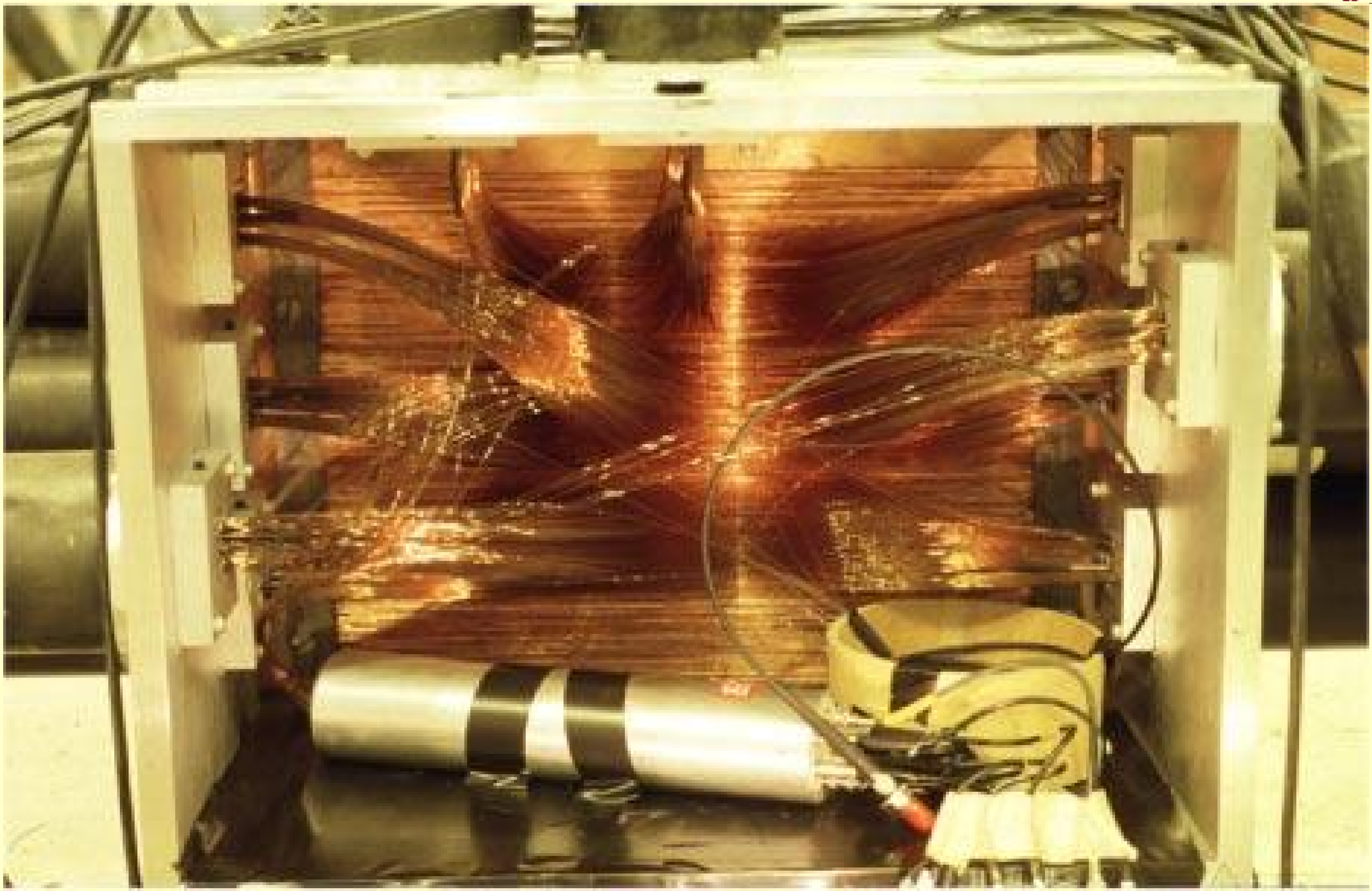
HCAL Barrel

HCAL assembly

HCAL assembly

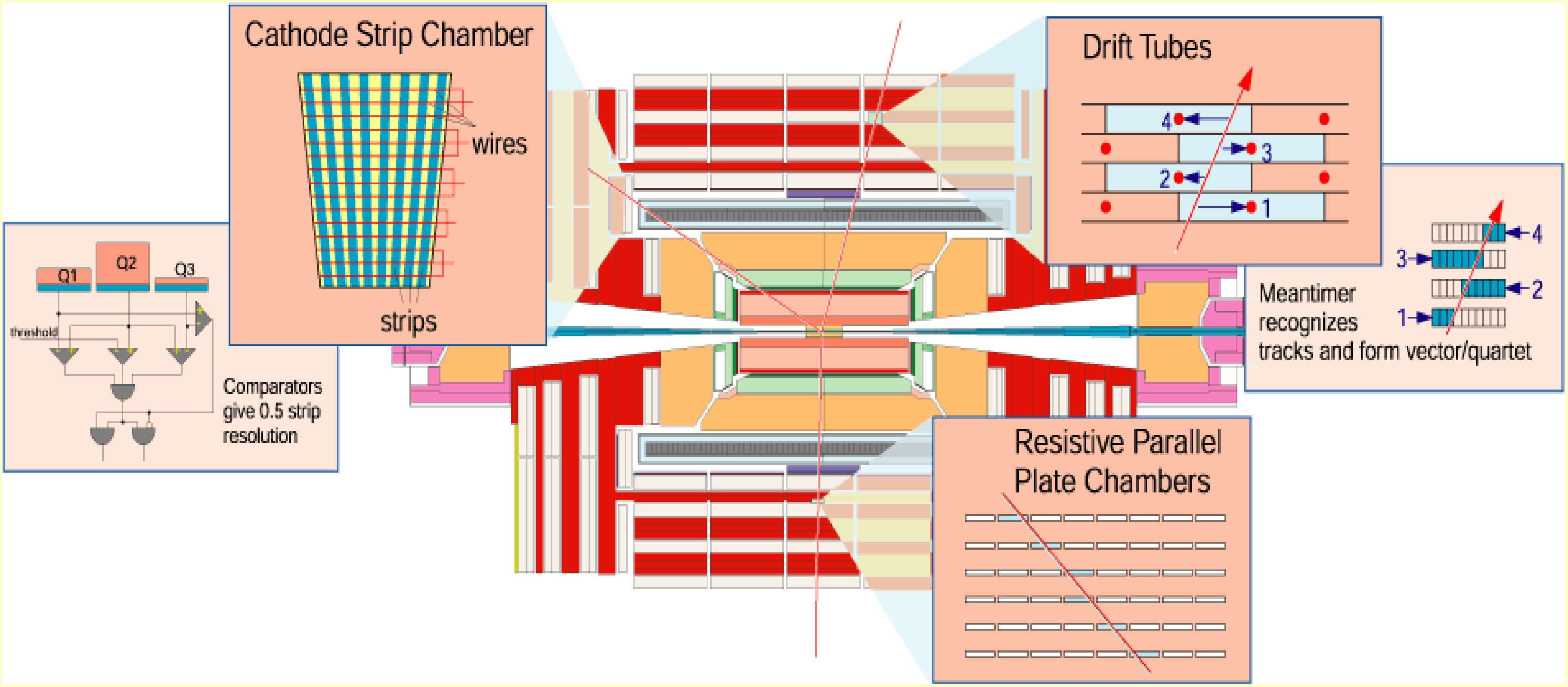
HCAL Endcap

VFHCAL



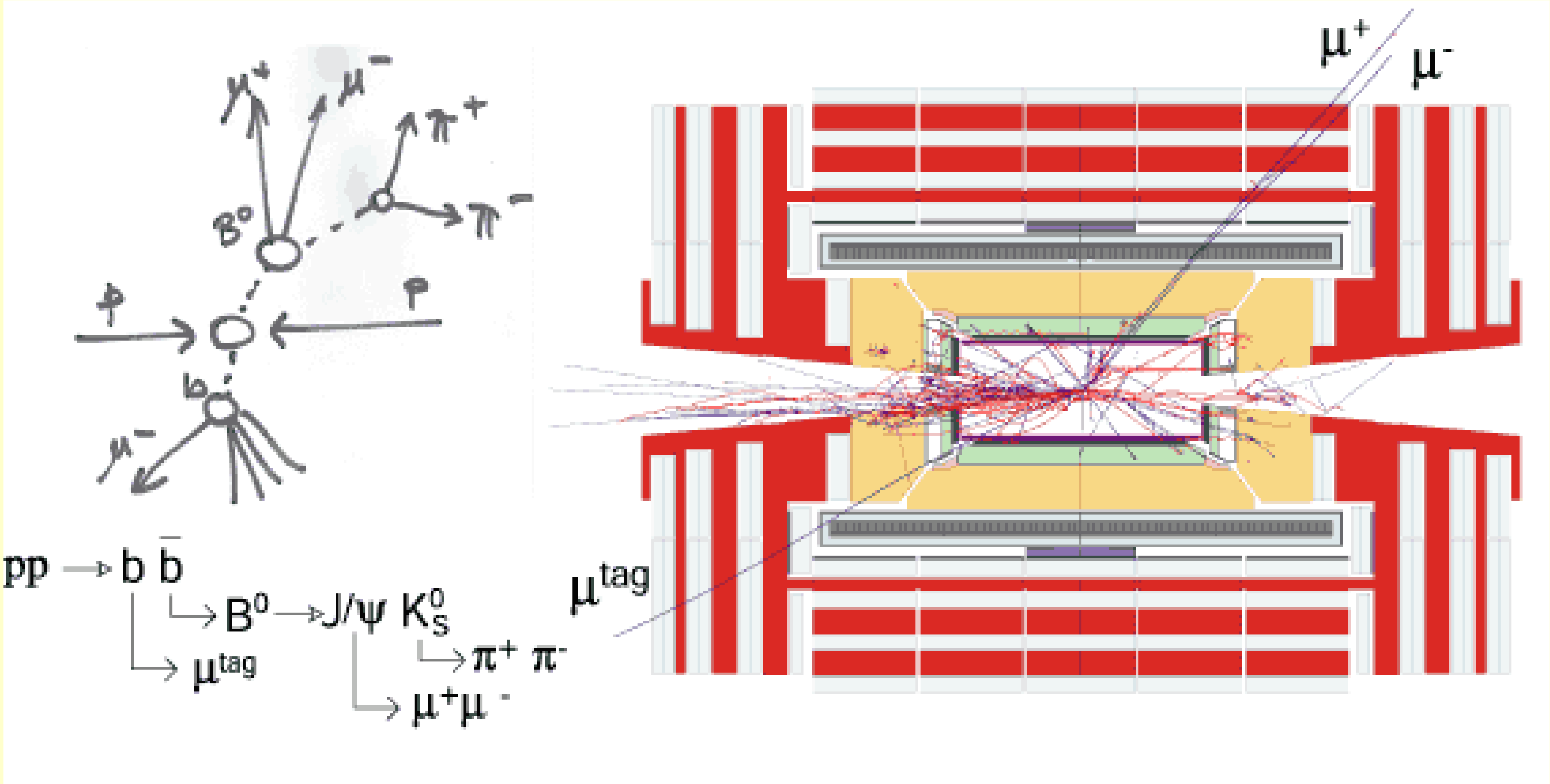
VFHCAL module

Muon system

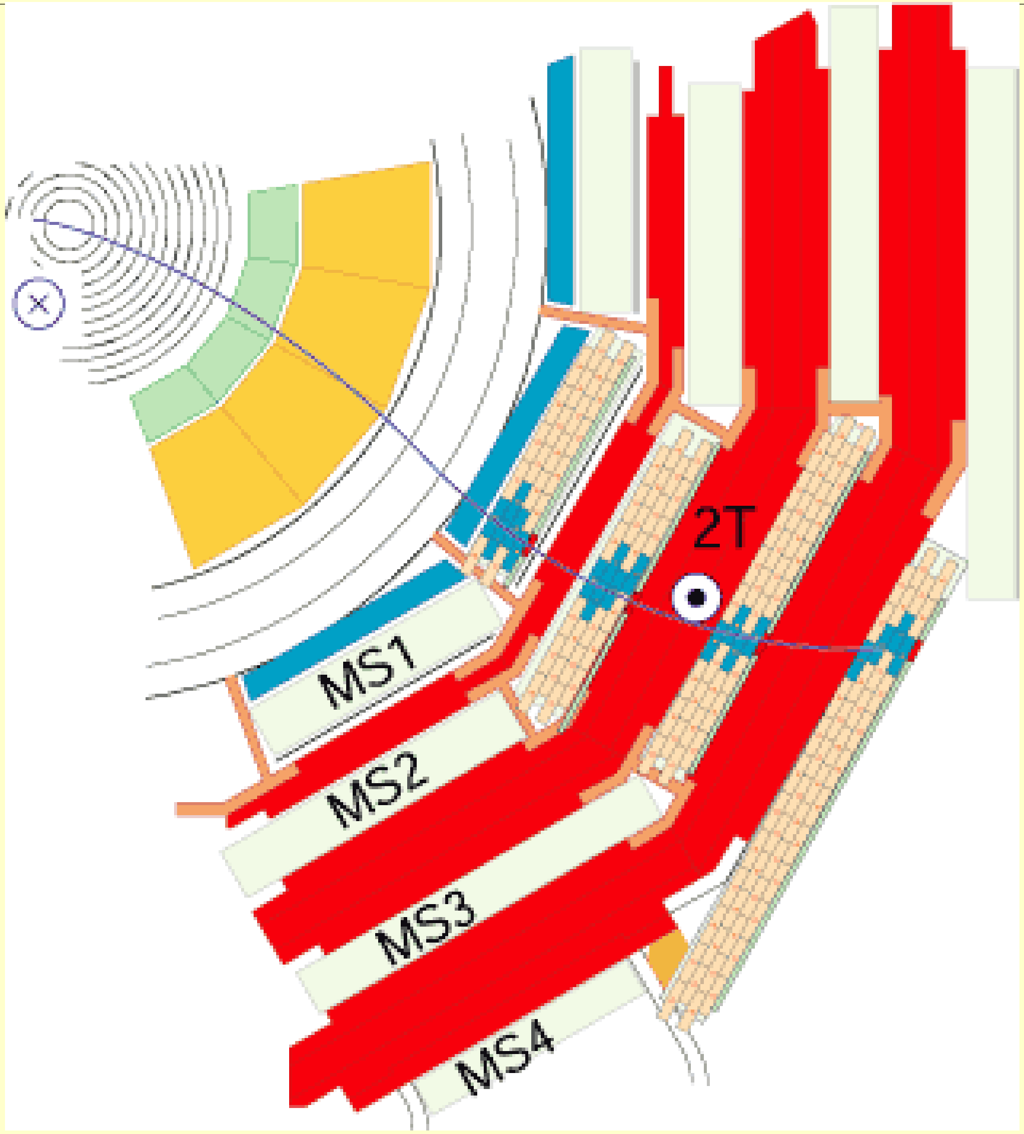


Cathode Strip Chamber
wires
strips
Q1
Q2
Q3
threshold
Comparators give 0.5 strip resolution
Drift Tubes
4
3
2
1
Meantimer recognizes tracks and form vector/quartet
Resistive Parallel Plate Chambers

Muon Detector

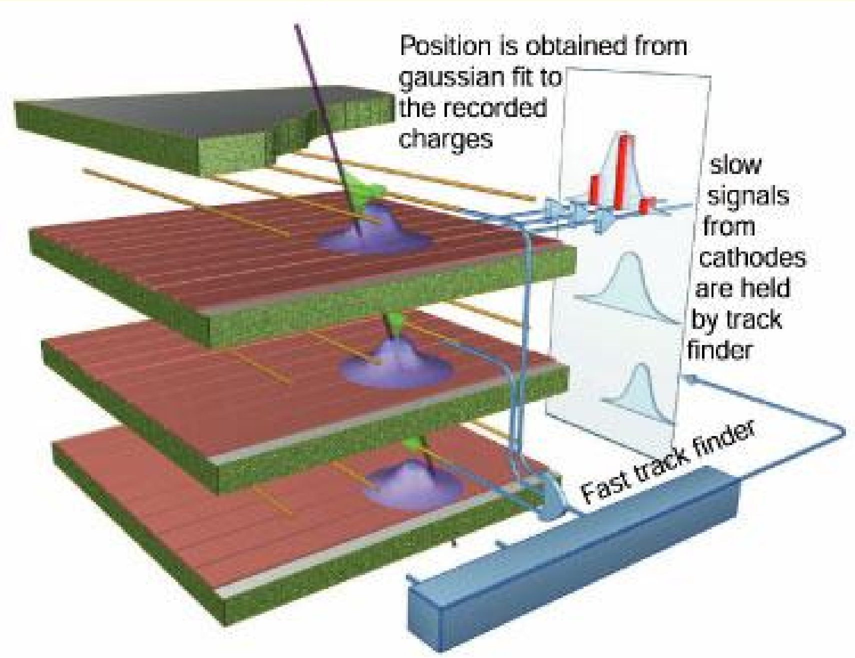


Muon Stations

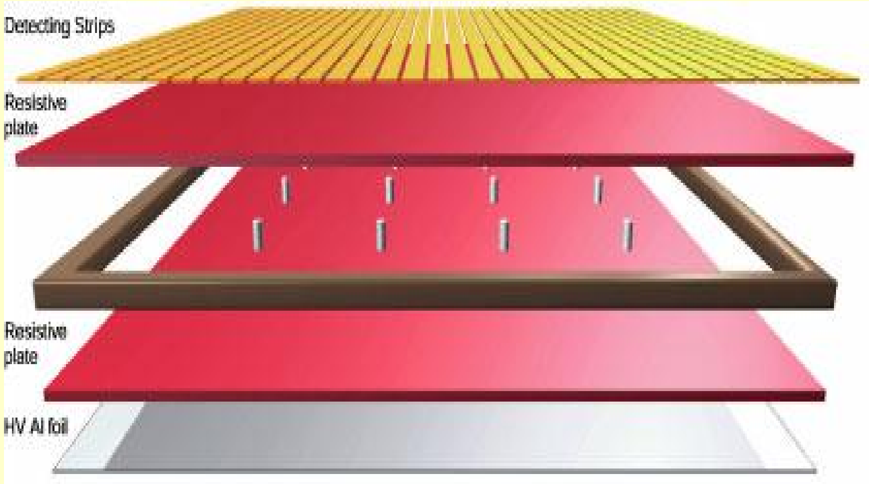


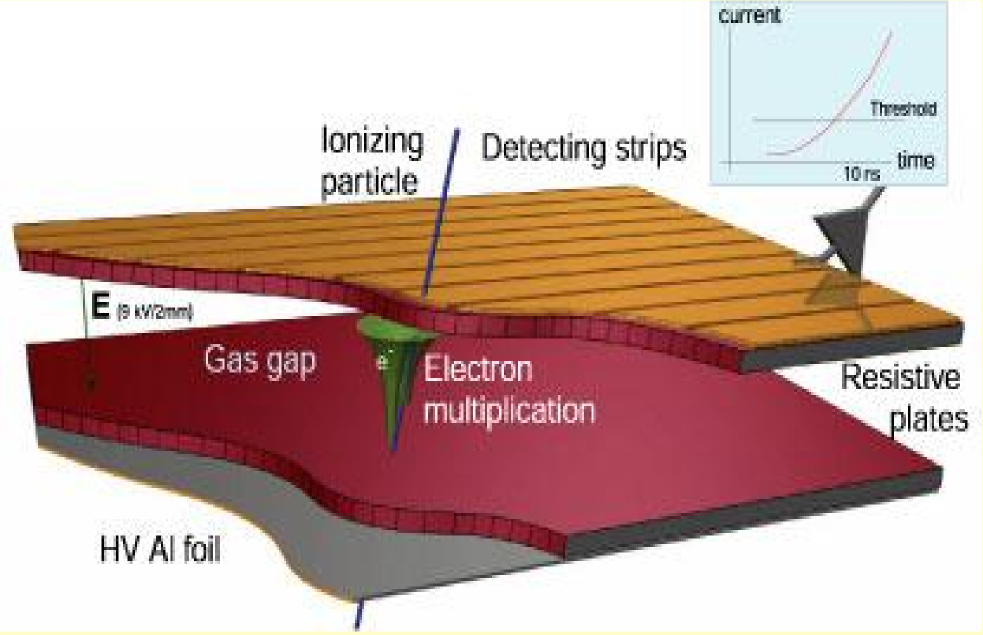
Drift Tubes

Cathode Strip Chambers

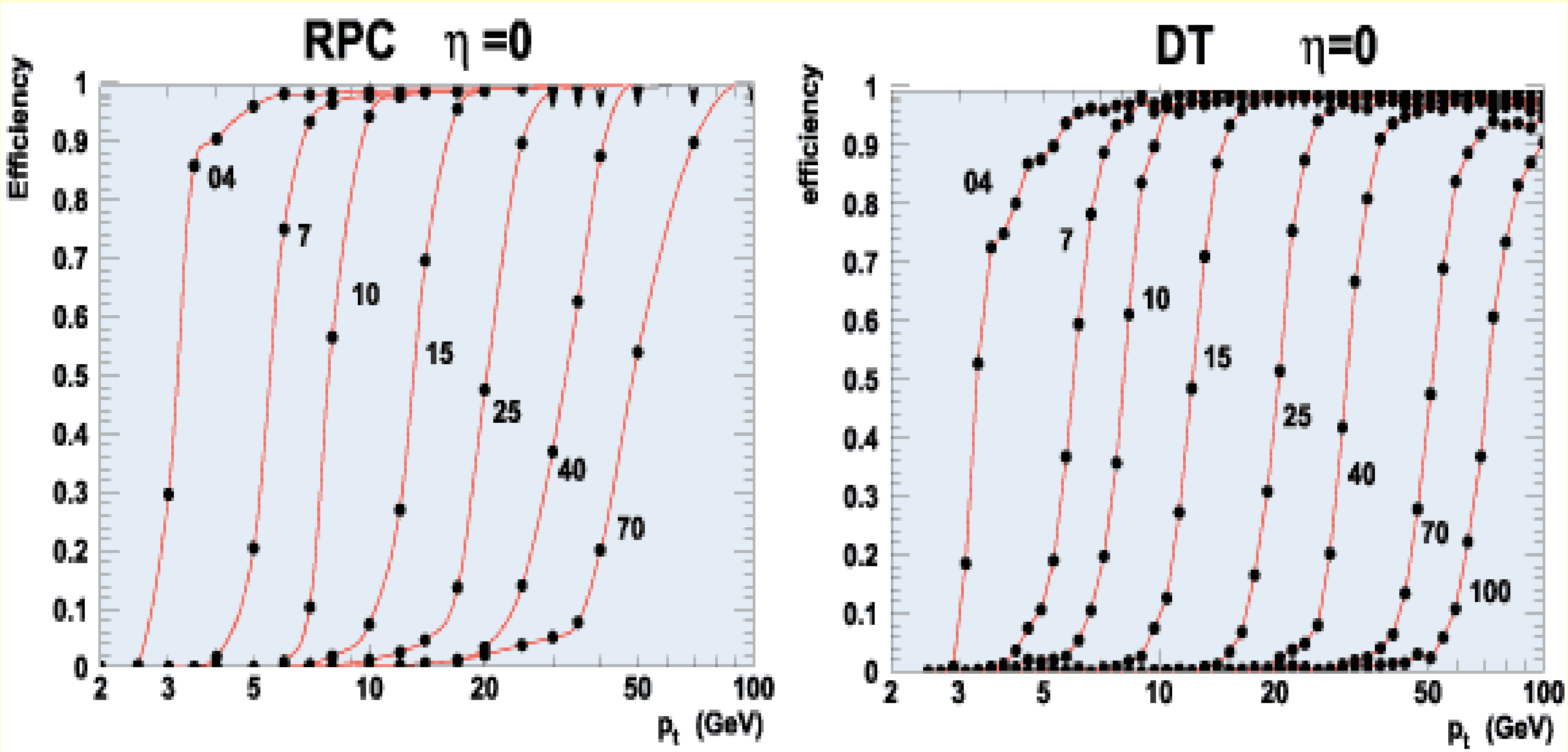


Resistive Plate Chambers

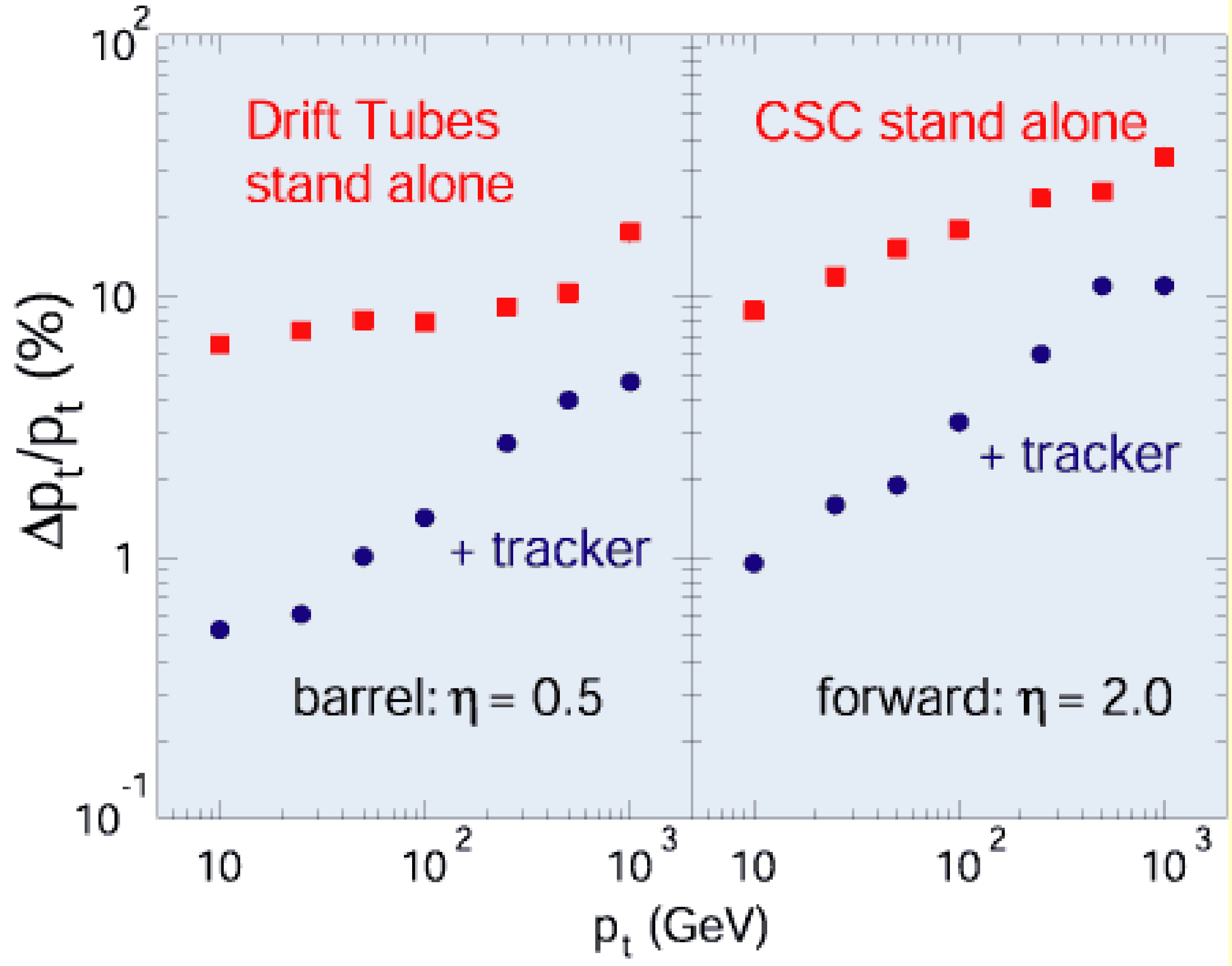




Chambers Efficiency



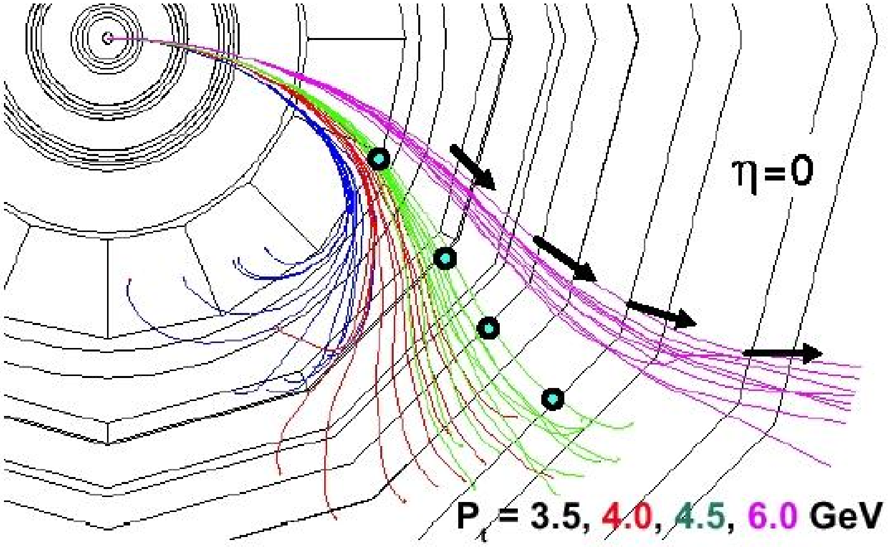
Momentum Resolution



Muon Trigger

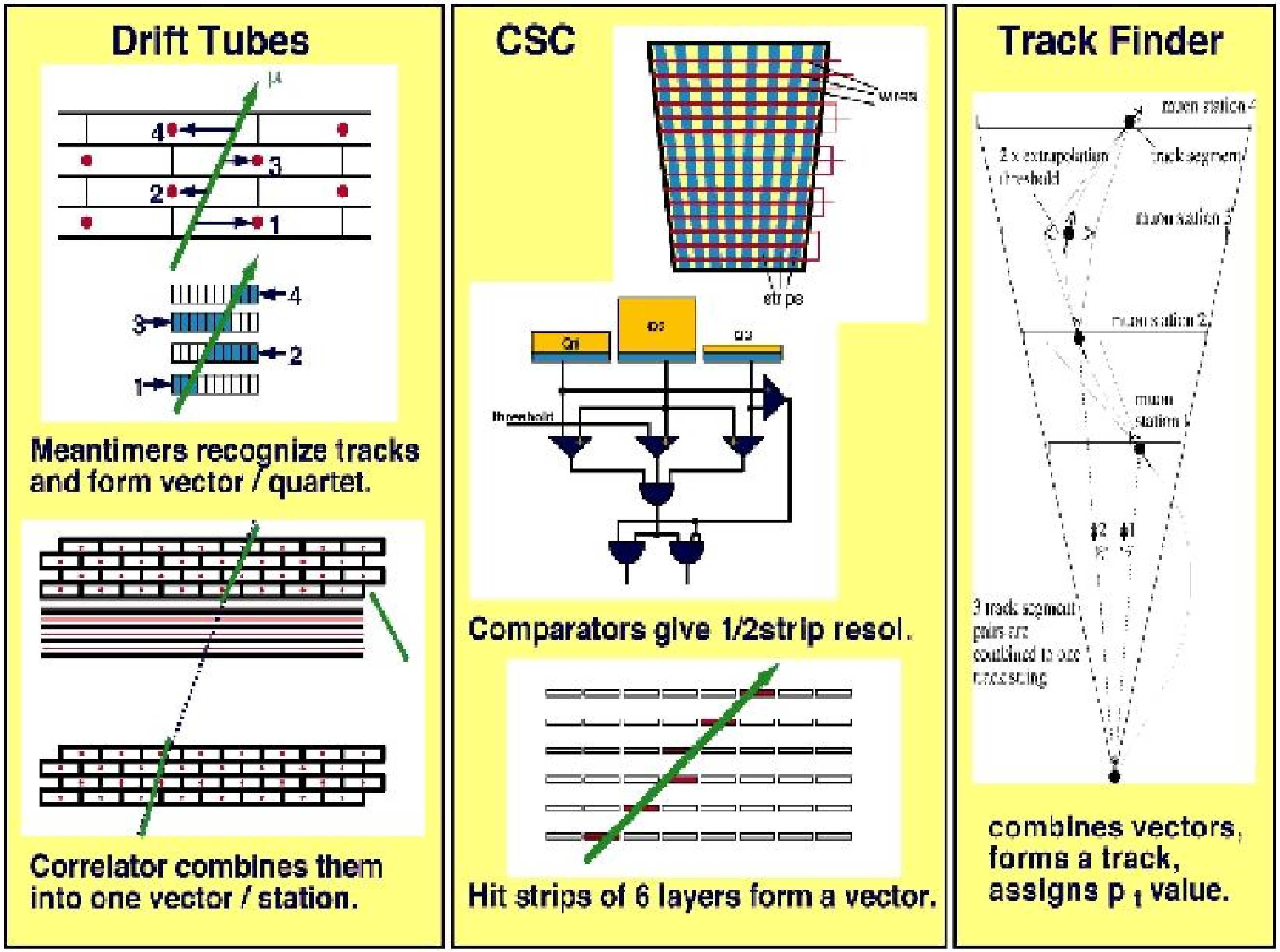
Trigger based on tracks in external muon detectors that point to interaction region

- Low-p_T muon tracks don't point to vertex
  - Multiple scattering
  - Magnetic deflection
- Two detector layers
  - Coincidence in "road"



Detectors:
RPC (pattern recognition)
DT(track segment)

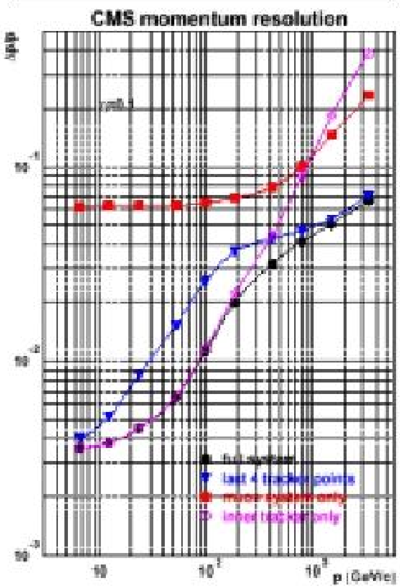
Muon trigger



Trigger

Muon Momentum Resolution

Spatial resolution
Š 100 μm/station



$\delta p_t/p_t$ - 10%
at p_t=500 GeV at η=2

SOLENOID B = 4 Tesla, R=3m

Radius of tracking cavity = 1.3 m

High Granularity Tracker

Track Finding Efficiency

p_t > 2 GeV, |η| < 2.5

isolated μ tracks	98%
isolated h± tracks	92%
trks in 300 GeV b-jets	90%

b - tagging

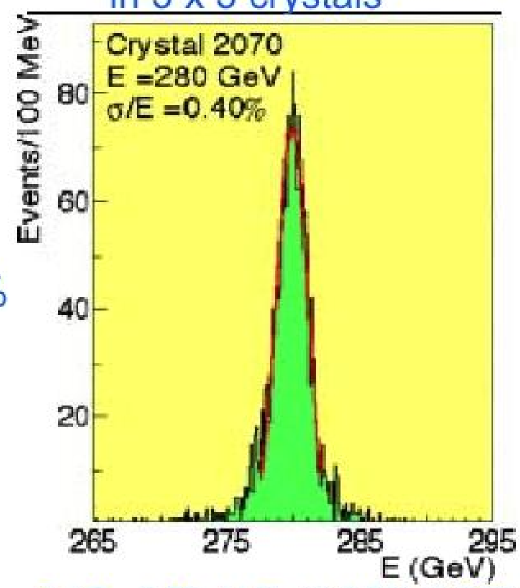
50% efficiency for a
rejection factor of 100
against u, d and s jets

Momentum Resolution

$\Delta p_t/p_t$ - 0.15p_t ⊕ 0.5% (p_t in TeV)

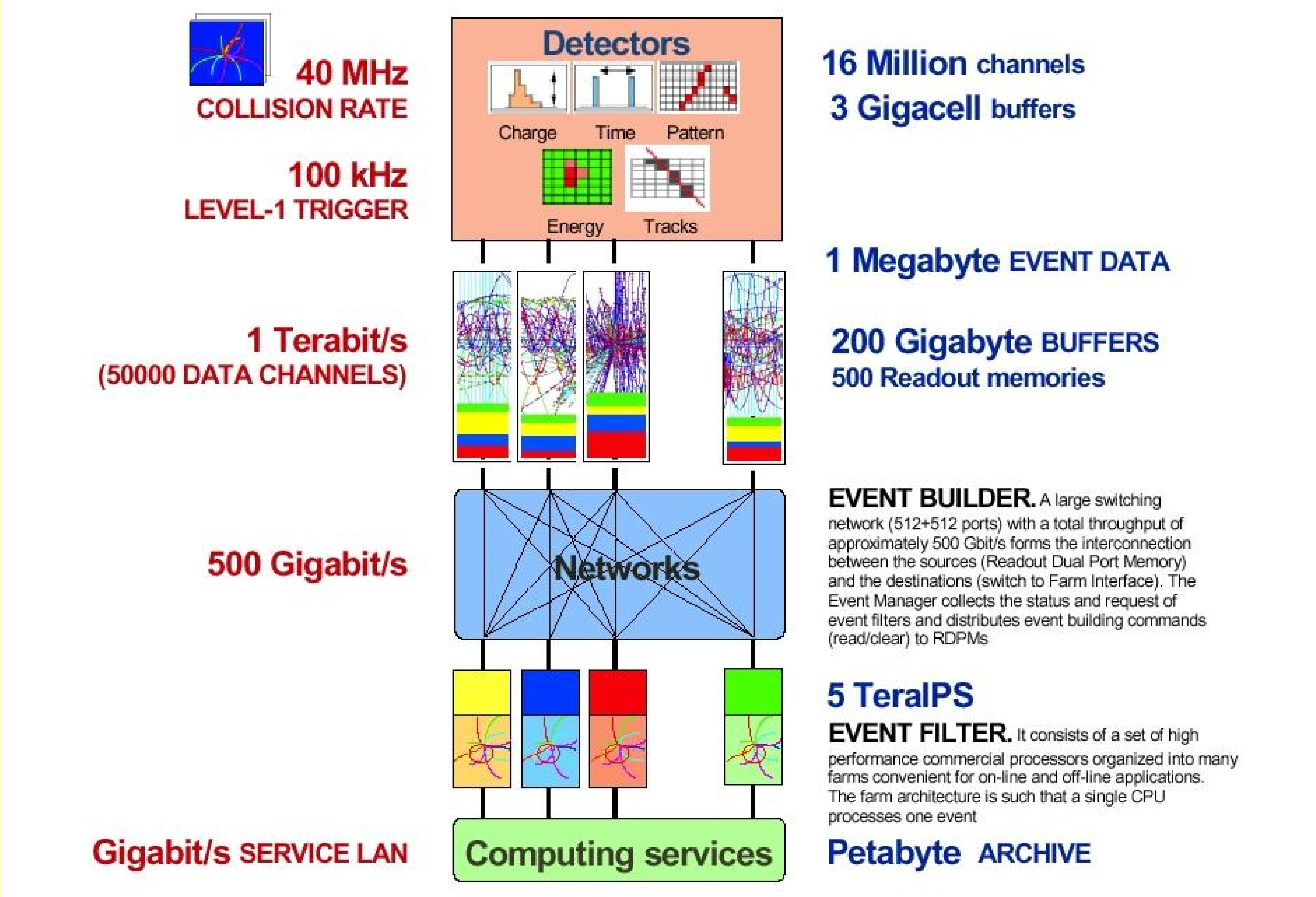
$PbWO_4$ CRYSTAL ELECTROMAGNETIC CALORIMETER

Energy reconstructed
in 3 x 3 crystals



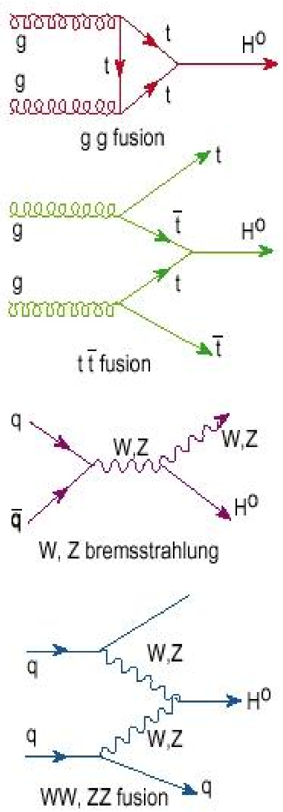
σ / E - 2.7% / ¦ E ⊕ 0.5% ⊕ 20%/E
(E in GeV)

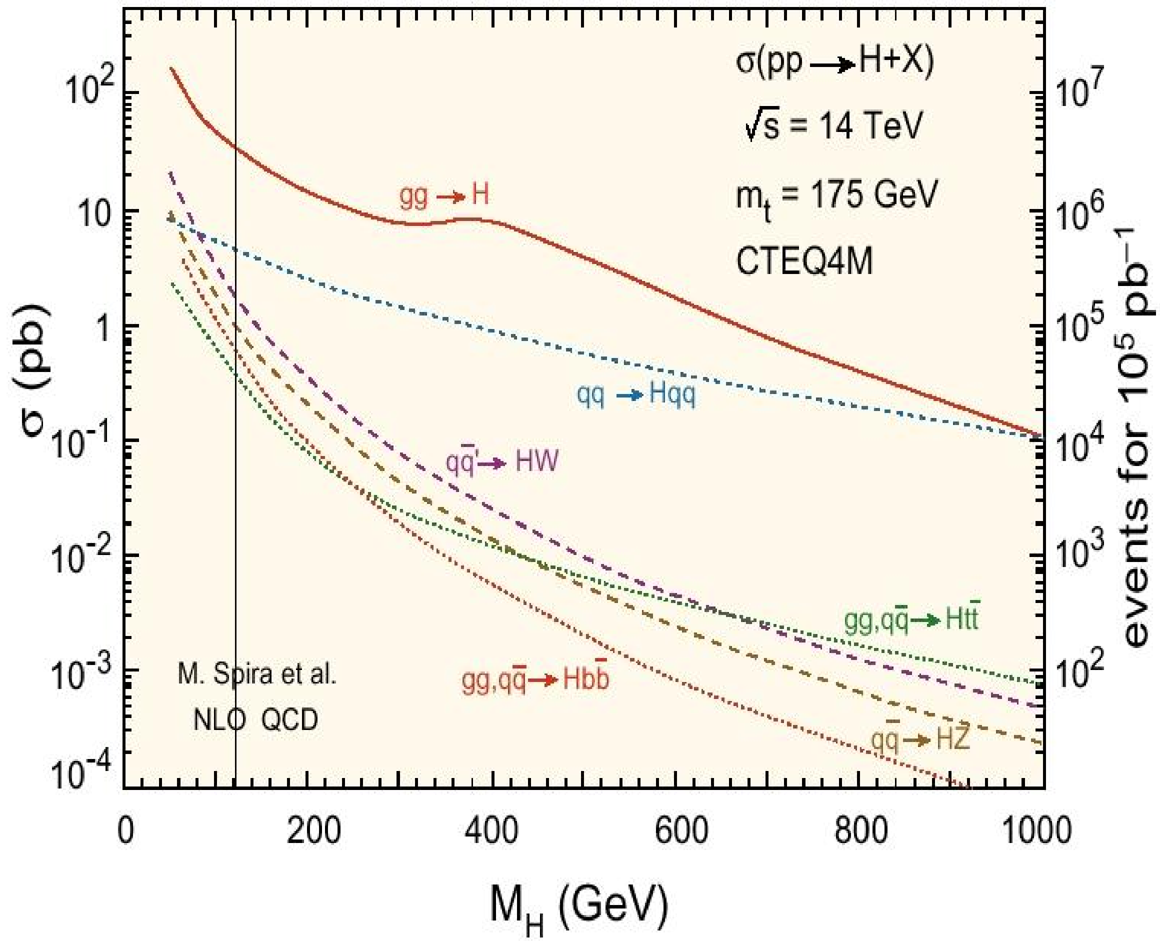
DAQ



40 MHz
COLLISION RATE
100 kHz
LEVEL-1 TRIGGER
1 Terabit/s
(50000 DATA CHANNELS)
500 Gigabit/s
Gigabit/s SERVICE LAN
Detectors
Charge
Time
Pattern
Energy
Tracks
Networks
Computing services
16 Million channels
3 Gigacell buffers
1 Megabyte EVENT DATA
200 Gigabyte BUFFERS
500 Readout memories
EVENT BUILDER. A large switching network (512+512 ports) with a total throughput of approximately 500 Gbit/s forms the interconnection between the sources (Readout Dual Port Memory) and the destinations (switch to Farm Interface). The Event Manager collects the status and request of event filters and distributes event building commands (read/clear) to RDPMs
5 TeraIPS
EVENT FILTER. It consists of a set of high performance commercial processors organized into many farms convenient for on-line and off-line applications. The farm architecture is such that a single CPU processes one event
Petabyte ARCHIVE

SM Higgs Boson Search





- $gg \to H$: K=1.6– 1.9
- residual uncertainties on NLO cross-sections (PDF, NNLO, etc.) $\leq 20\%$ (except ttH)

SM Higgs Boson Search

- Decays & discovery channels
  - Higgs couples to m_f^2

Heaviest fermion (b quark) always dominates

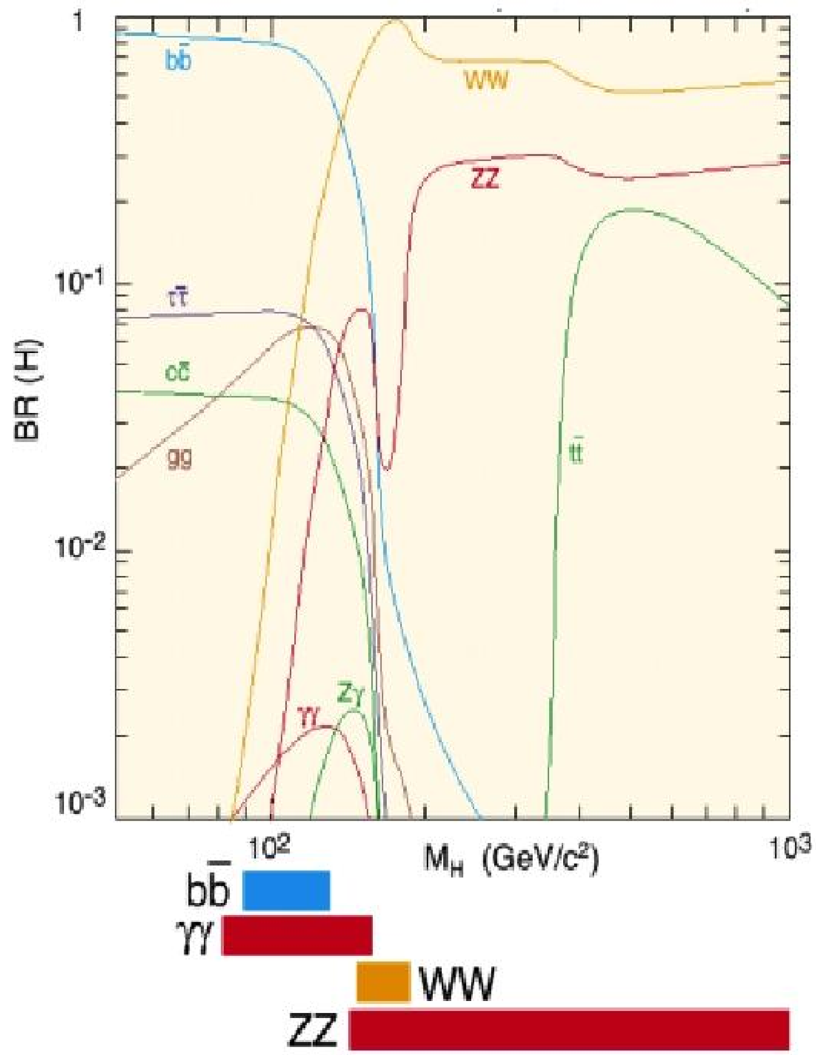
Until WW, ZZ thresholds open

- Low mass: b quarks→ jets; poor resolution ~ 15%

Only chance is to use ECAL (use γγ decay mode)

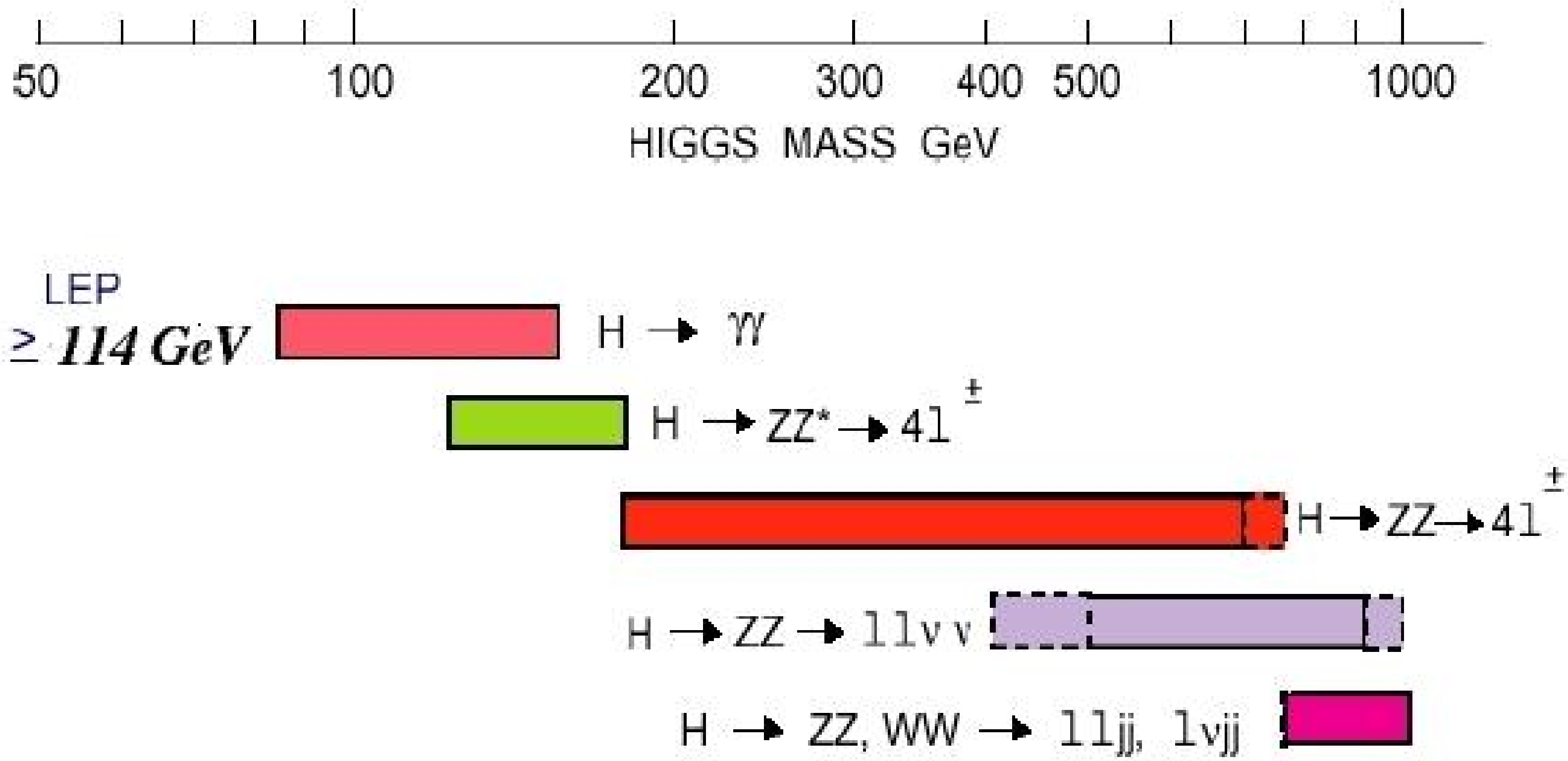
- Once $M_H>2M_Z$, use ZZ mode

W decays to jets or lepton+neutrino (missing E_T)



SM Higgs Boson Search

Explorable mass range at $\sqrt{s}$ =14 TeV with 10^5 pb^{-1} taken at 10^{34} $cm^{-2}s^{-1}$



SM Higgs Boson Search

Fully hadronic final states dominate but cannot be used due to large QCD bkg.
⇨**look for final states with isolated leptons and photons despite smaller BR**

Region 1: Intermediate mass region (LEP limit < m_H < 2 m_Z)

m_H < 120 GeV: pp → WH → $\ell\nu$ bb or tt H → $\ell\nu$X bb

m_H < 150 GeV: H → $\gamma\gamma$, Zγ

130? < m_H < 2 m_Z : H → WW* → $\ell\nu$ $\ell\nu$

130? < m_H < 2 m_Z : H → ZZ* → $\ell\ell$ $\ell\ell$

Region 2: High mass region (2 m_Z < m_H < 700)

H → ZZ → $\ell\ell$ $\ell\ell$

Region 3: Very high mass region (700 < m_H < 1 TeV)

H → ZZ → $\ell\ell$ $\nu\nu$, H → ZZ* → $\ell\ell$ jet-jet

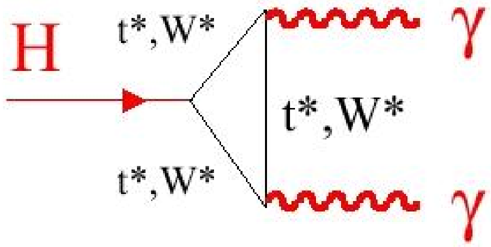
H → WW → $\ell\nu$ jet-jet

forward jet tagging

Recently: qq → qqH with H → $\tau\tau$ (mH~130 GeV), H → WW etc.

$H \rightarrow \gamma\gamma$

Most promising channel in the range $m_H < 150$ GeV



($\sigma.B \sim 50.10^{-3}$ pb @ $m_H \sim 150$ GeV)

σ.B can be modified by heavy undiscovered fundamental fermions or bosons

Backgrounds are large (2pb/GeV), H natural width is small (~MeV)

⇨ **excellent mass resolution** required

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

⇨ energy resolution and precise vertex localisation

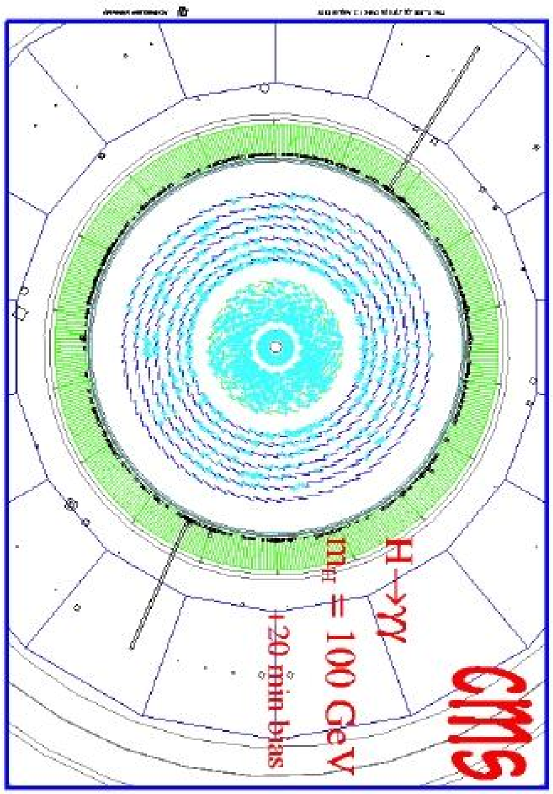
Typical Cuts

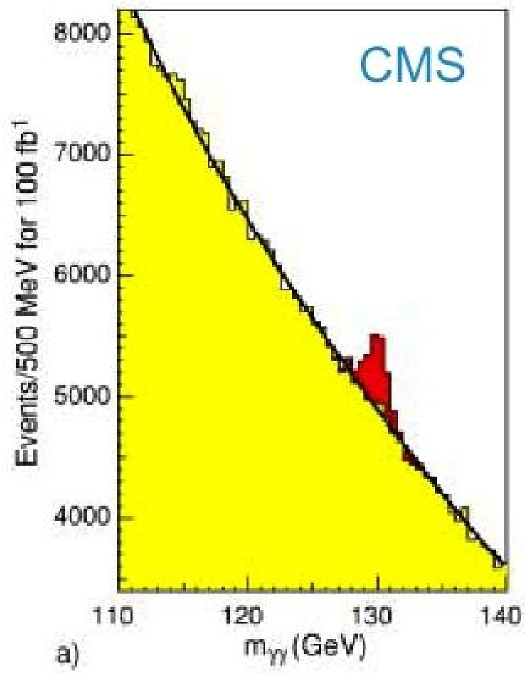
2 isolated photons – $p_T > 25$, 40 GeV with $|\eta| < 2.5$

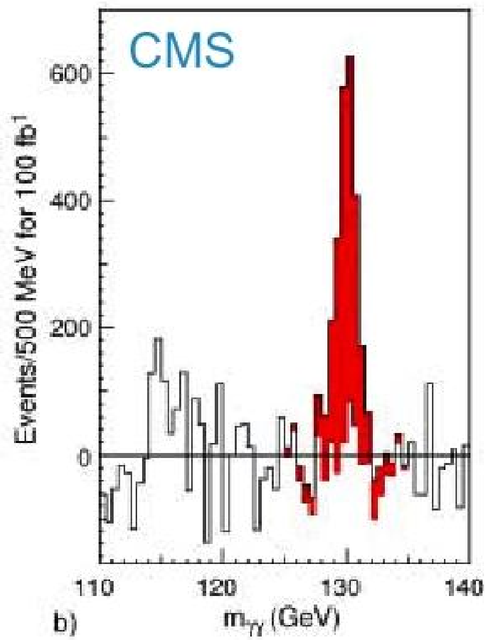
No track or em cluster with $p_T > 2.5$ GeV in a cone size $\Delta R = 0.3$ around γs

Signal: ~ 1000's of events

H → γγ signal in CMS







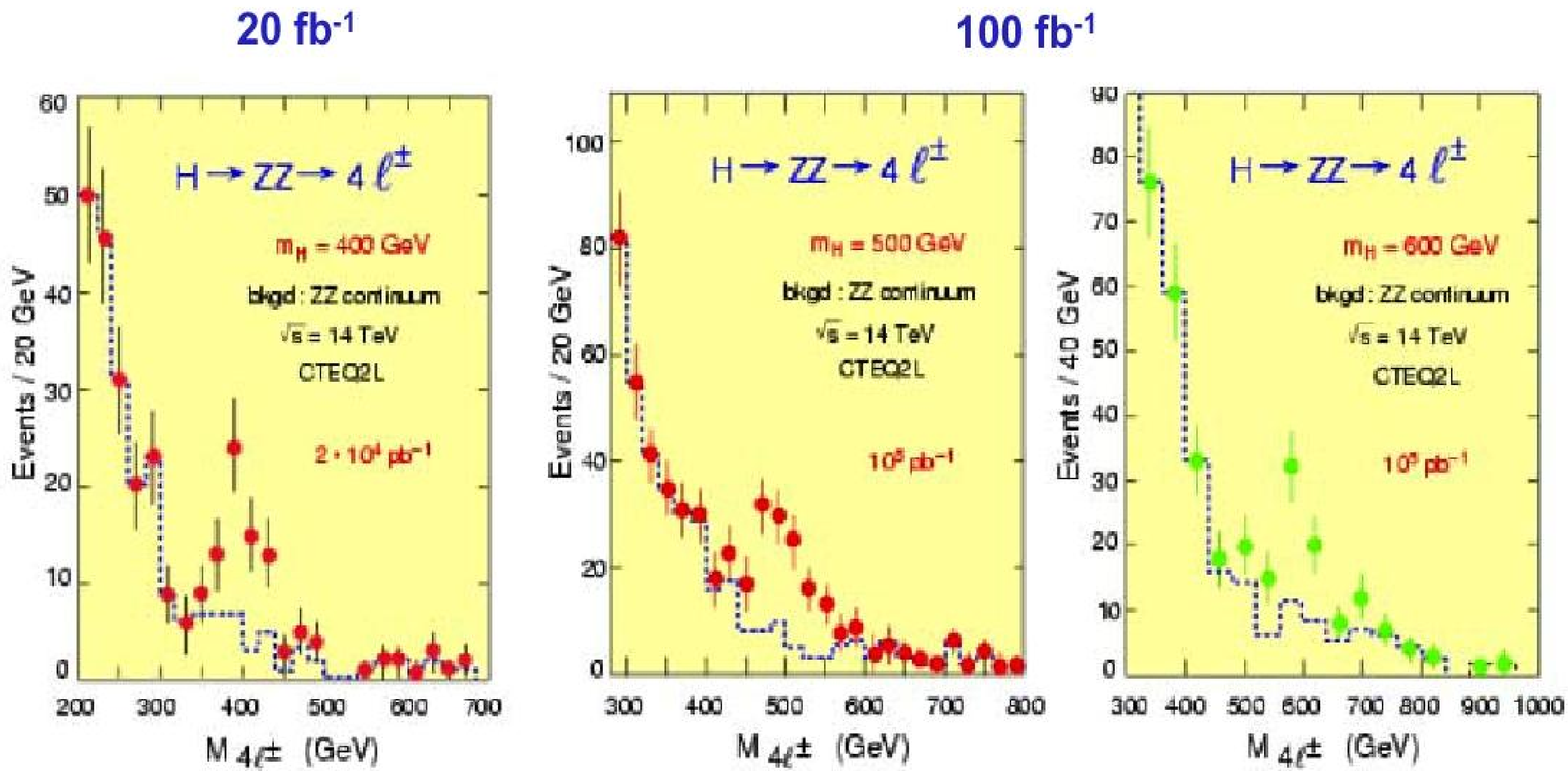
ATLAS, 100 fb^{-1}

m_H (GeV)	120	130	150
S (evts)	1280	1200	650
S/B	0.03	0.035	0.03
S/√B	6.5	6.5	4.3

ATLAS + CMS

S/√B 30 fb^{-1}	5.8	5.9	3.9

SM Higgs Boson Search



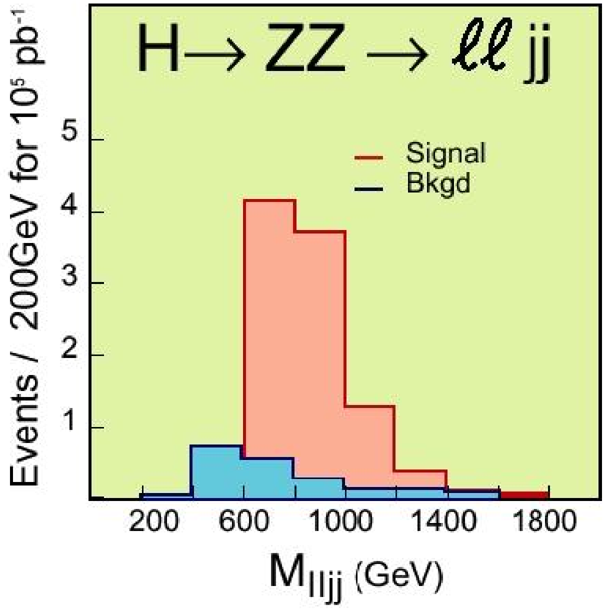
Typical Cuts

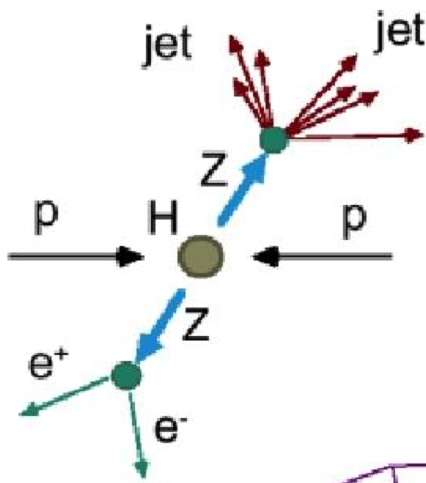
2 isol ℓ : p_T^{ℓ} >50 GeV, $p_T(Z)$>150 GeV

$M_{\ell\ell} = m_Z$ -10 GeV

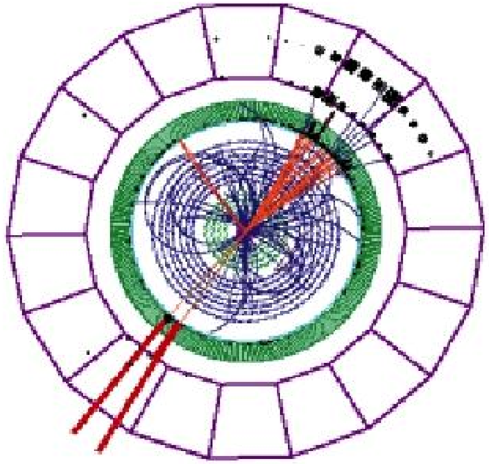
I.e. 2 central jets E_T^j > 40 GeV in $|\eta|$<3

2 tagging jets E^j > 400 GeV, E_T^j>20 GeV





CMS

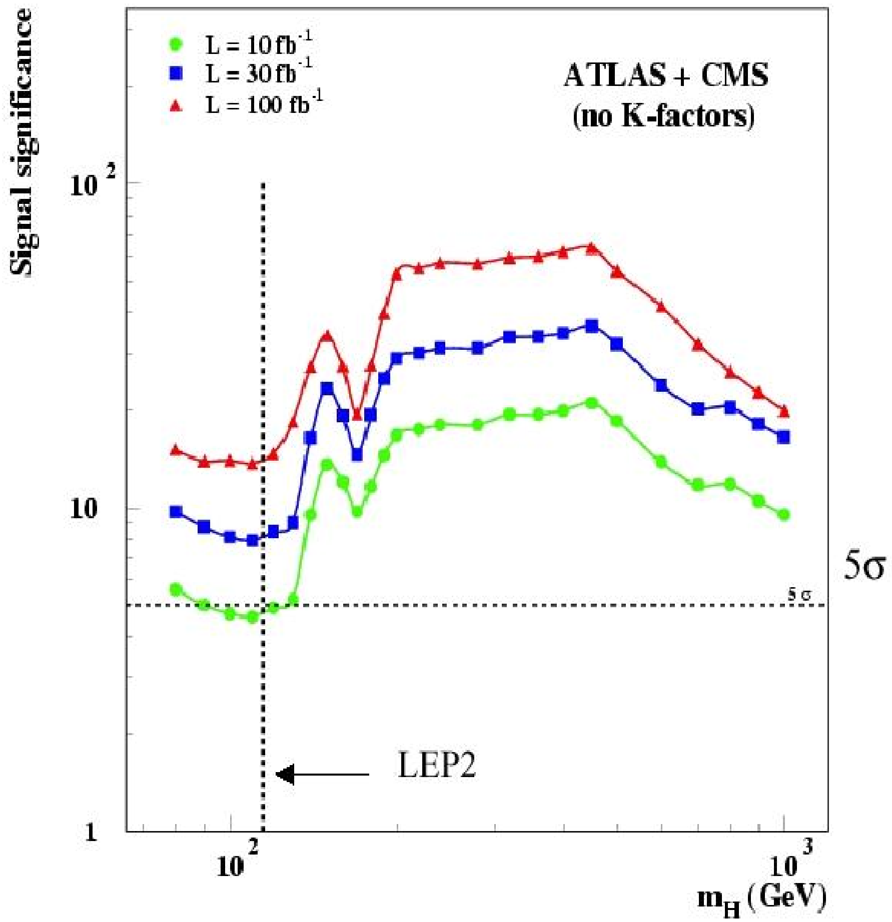


SM Higgs Boson Search - summary

SM Higgs boson can be **discovered** at ≈ 5 σ after 1 year of operation (10 fb^{-1}/ experiment)
excluded at 95% CL after 1 month of running at 10^{33} cm^{-2} s^{-1}.

Results are conservative:
- no K-factors
- simple cut-based analyses
- conservative assumptions on detector performance
- channels where background control is difficult are not included e.g. $WH \rightarrow \ell \nu b\bar{b}$ (large systematics)

L is per experiment



SUSY Higgs search

Plane fully covered (no holes) at low L (30 fb^{-1}). Main channels :

$$h \to \gamma\gamma, b\bar{b}, \quad A/H \to \mu\mu, \tau\tau, H^{\pm} \to \tau\nu$$

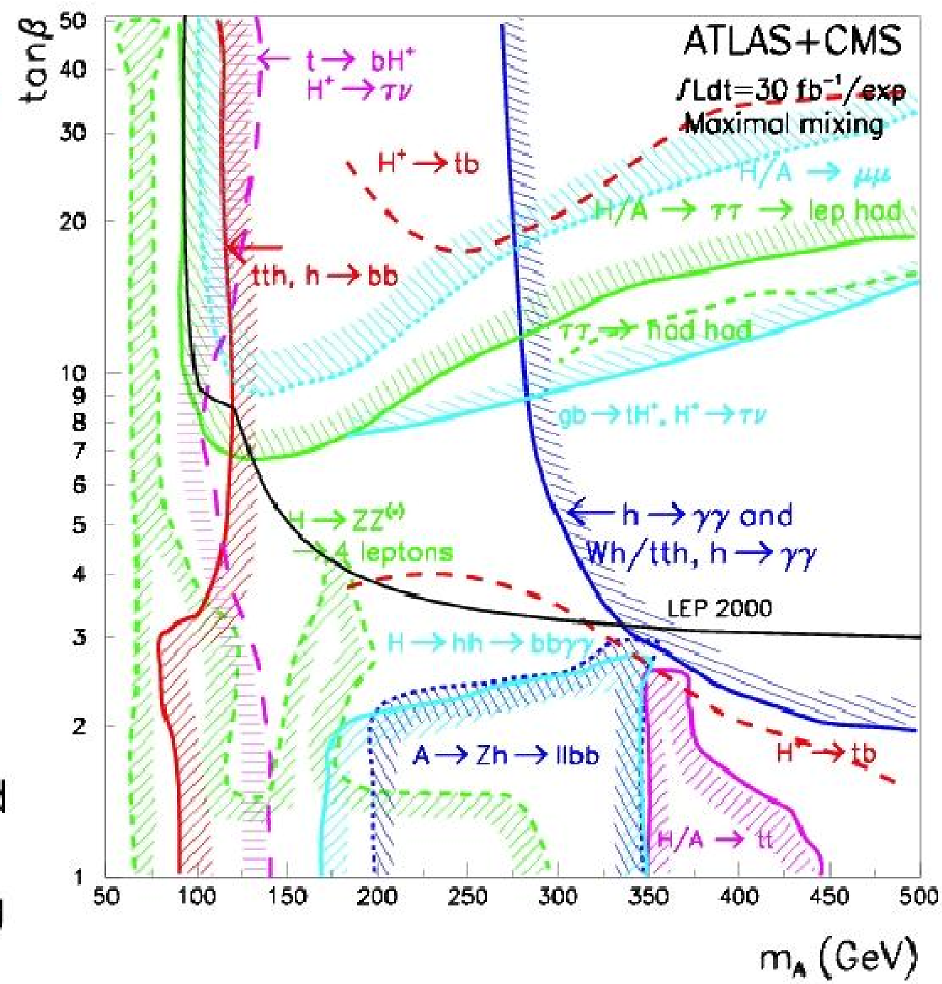
Two or more Higgs can be observed over most of parameter space ⇨ can disentangle SM / MSSM

LHC will observe h, A, H, $H^{\pm}$ for m_A < 400 GeV

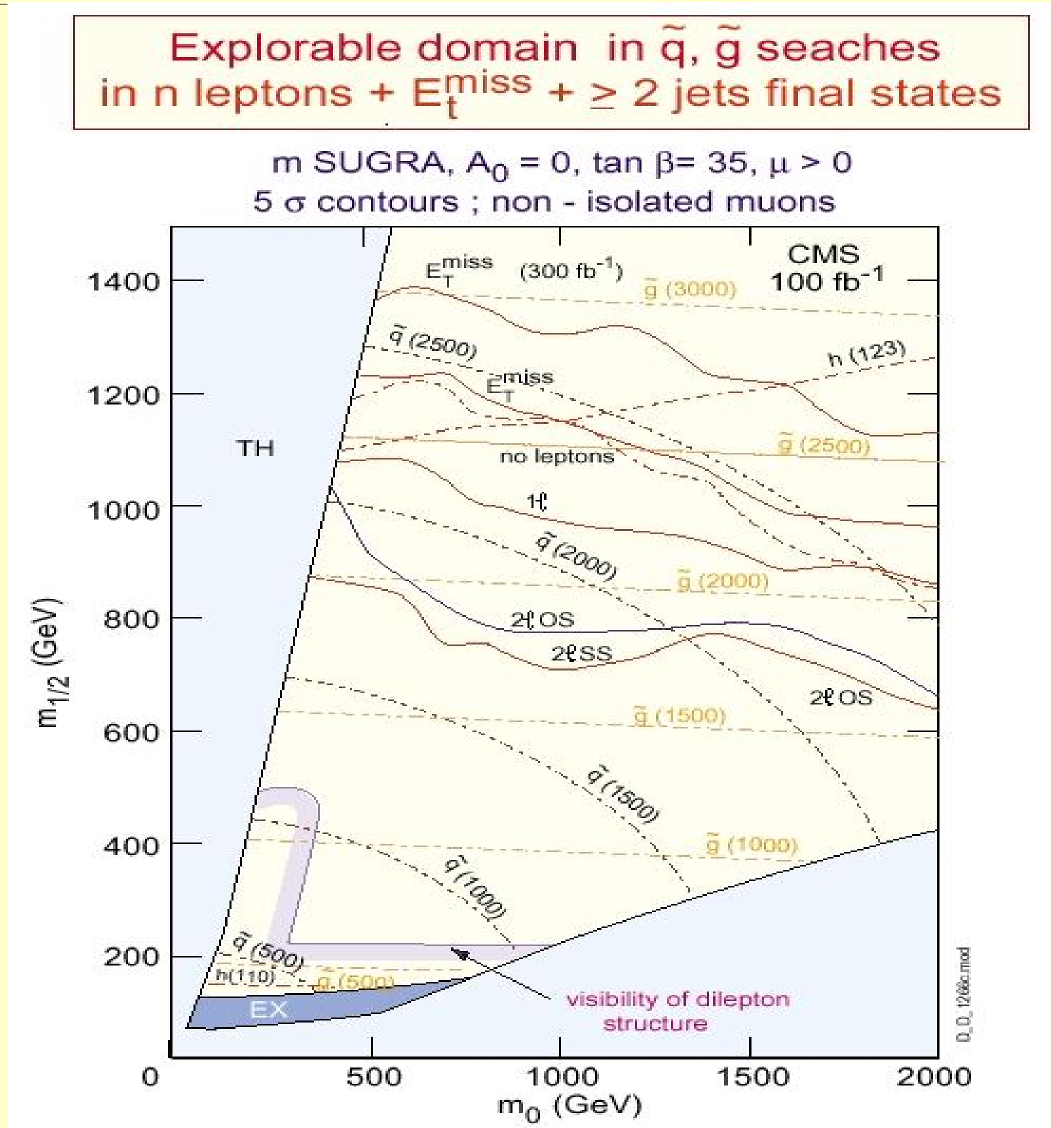
Uncertainties : $\Delta m_A \approx \pm 30$ GeV (e.g. from Δm_h ~3 GeV), $\Delta \tan\beta \approx \pm 0.7$

Impact of mixing on couplings studied for minimal mixing

but not for all possible mixing (evolving theory predictions)



SUSY Searches



SUSY Searches

- The ultimate SUSY reach in terms of squark/gluino masses is 2.5 - 3 TeV (mSUGRA) with 300 fb^{-1}; in the worst case of degenerate gaugino masses (and heavy squarks and sleptons) the gluino mass reach is still expected to be ~ 1.5 TeV.
- The cosmologically preferred region of mSUGRA parameter space ($0.1 < \Omega h^2 < 0.3$) is found to be within the LHC ultimate reach.
- Large domain of mSUGRA parameter space where $\tilde{\chi}_2^0$ decays into leptons (direct 3-body decay or cascade one via sleptons) is explorable in 2(3) leptons (+ $\not{E}_T$ + jets) channels with corresponding observation of dilepton mass edge used in various mass reconstruction methods.
- With integrated luminosity of 100 fb^{-1} the $\tilde{l}_L$ mass reach in 2 leptons + no jets + $\not{E}_T$ channel is ~ 340 GeV (up to 440 GeV if $m_{LSP} \sim (0.45 - 0.6) \cdot m_{\tilde{l}_L}$).

SUSY Searches

- For moderate values of $\tan\beta$ the range of $\tilde{\chi}_2^0$ mass explorable in 3 leptons + no jets + $\not{E}_T$ reaches 150-155 GeV with 100 fb^{-1}.
- Decay of the lightest SUSY Higgs into $b\bar{b}$ can be observed with S/B ratio of ~1 in a wide range of mSUGRA parameter space (where $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_2^0 h$).
- With integrated luminosity of 100 fb^{-1} stau mass in the minimal GMSB model (for high $\tan\beta$, $M/\Lambda = 200$, $\Lambda = 50$ -300 TeV) can be measured in the range from 90 to 700 GeV. The $\tilde{\chi}_1^0$ lifetime can be measured from 1cm to 1 km for $\sigma_{SUSY} > 100\ fb^{-1}$.
- In a R-parity violation scenario with $\lambda_{ijk} \neq 0$ (purely leptonic decay) the parameter region explorable with integrated luminosity of 10 fb^{-1} extends up to masses of squark/gluino of ~ 1.5-1.8 TeV.

Extra Dimensions

Two fundamental scales:

- **Electroweak — $M_{EW} \sim 10^2\text{-}10^3$ GeV**
- **Planck — $M_{Pl} \sim 10^{19}$ GeV**

Observation:

- **M_{EW} is established experimentaly**
  - EW interactions are tested down to distances $1/M_{EW} \sim 10^{-17}$ cm
- **M_{Pl} is just a number**
  - gravity tested only down to ~ 1 mm, far away from $1/M_{Pl} \sim 10^{-35}$ m

Solution: cut the Gordian Knot!

- **There is only one fundamental scale: M_{EW}**
- **M_{Pl} is just an effective constant**
- **Its high value is caused by additional spatial dimentions, compactified at radius R ~ 1 mm**

Extra Dimensions

Antoniadis, Benaklis, Quiros, PL B460, 176(1999)

Consider :

- p dimensions of R_1 ~ 0.1 mm
- n-p dimensions of R_2 ~ TeV $^{-1}$

$$M_{Pl}^2 = M_S^{n+2} R_1{}^p R_2{}^{n-p}$$

- gravity in all n extra-dimensions
- SM in n-p extra-dimensions $R_2 \Rightarrow$ ~TeV excitations of γ, W, Z, g

Build your favourite model:

- put each of $SU(3)_C$, $SU(2)_L$, $U(1)_Y$ in any subset of dimensions
- put higgses in standard dimensions, extra dimensions or both
- put fermions at "our wall", stack at other walls or let them propagate in more dimensions (in the bulk)
- study implications for LHC — will be very different !

Extra Dimensions

Consider the simplest case:

- **one TeV^{-1} dimension**
- **all SM in extra dimensions** (bulk)
- **all fermions at our wall**

LHC searches:

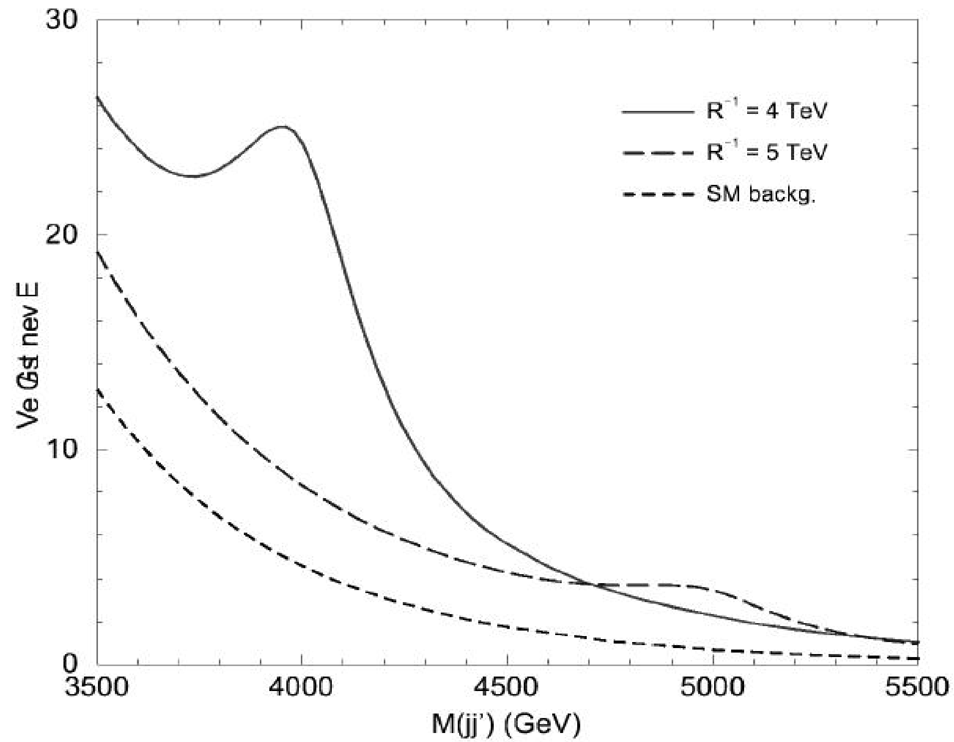
only the first resonance accessible

- $qq \to \gamma^{(1)} / Z^{(1)} \to \ell^+\ell^-$
- $qq \to W^{(1)} \to \ell^+\nu^-$
- $qq \to g^{(1)} \to gg$

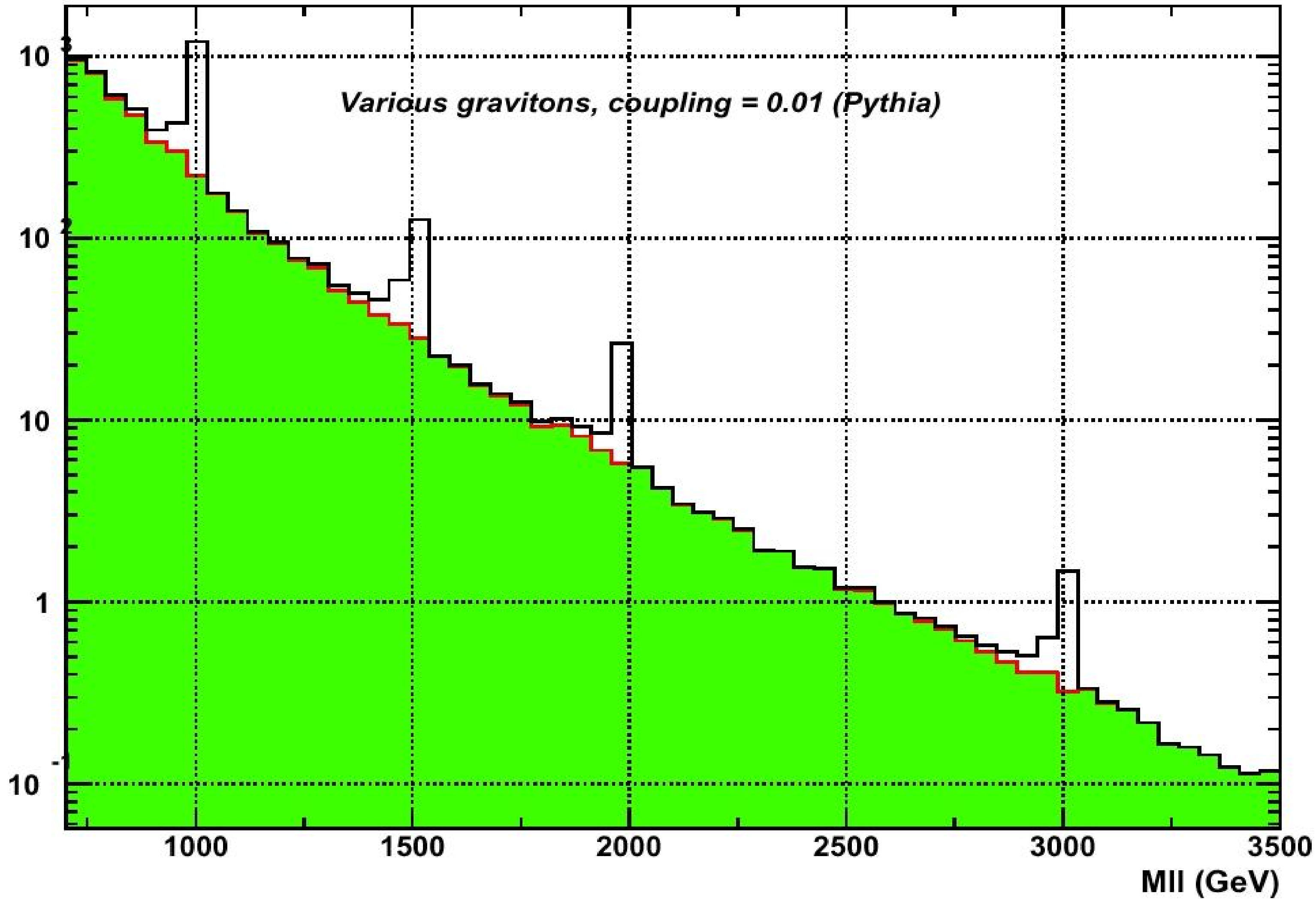
Current limit:

Tevatron:

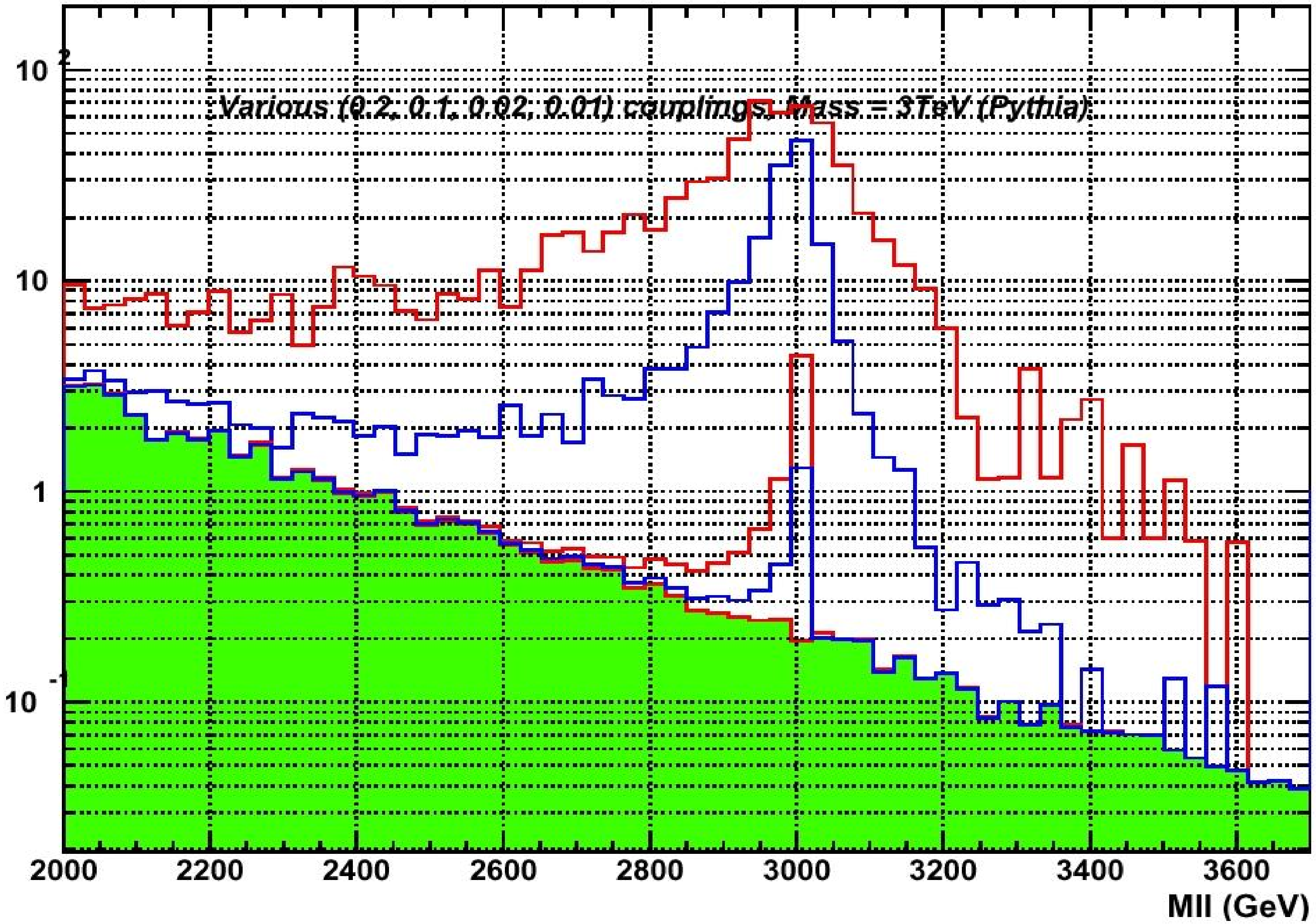
- $1/R_2 > 0.8$ TeV



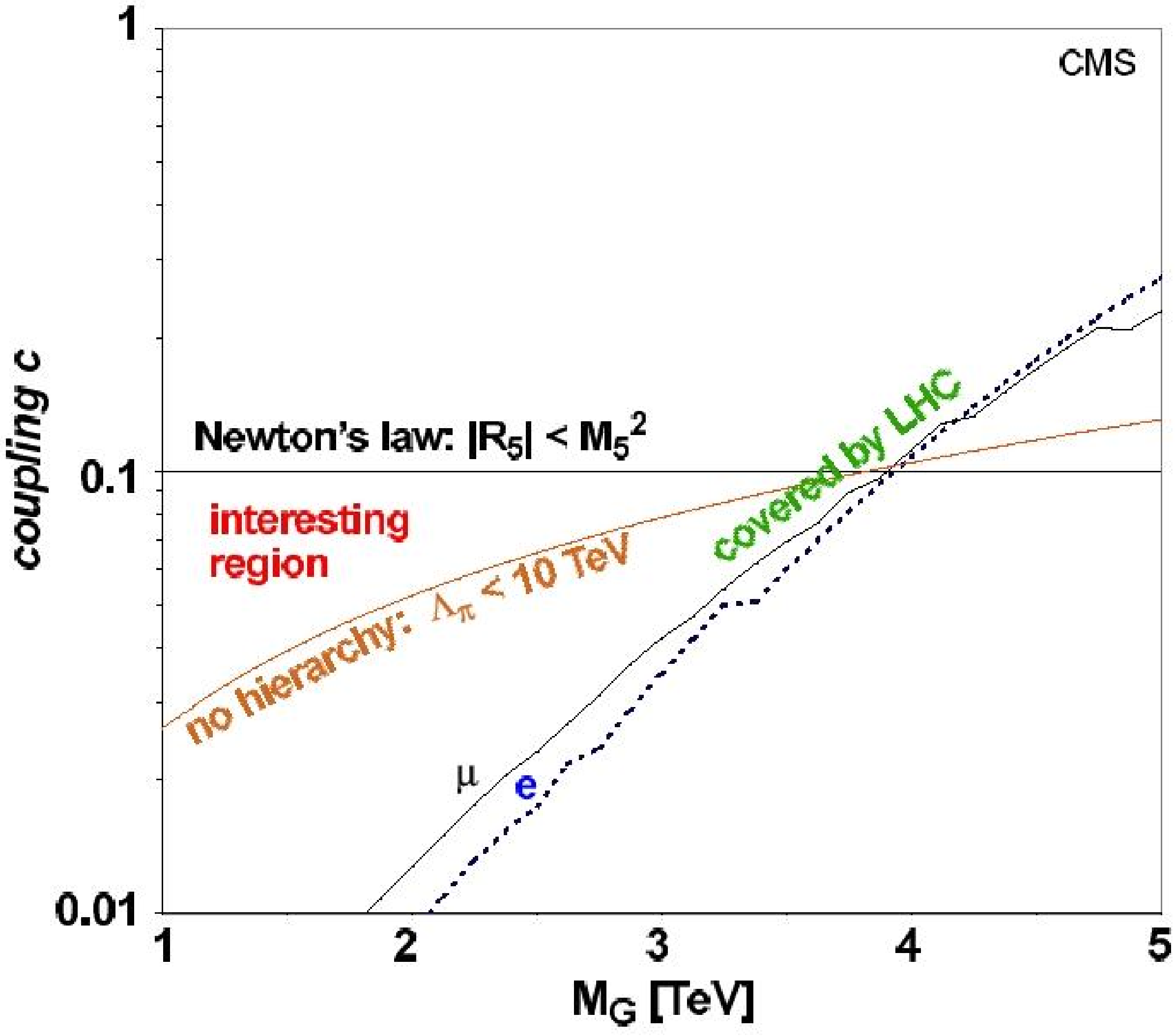
Extra Dimensions



Extra Dimensions



Extra Dimensions



Extra dimension perspectives

Models with extra dimensions can

- unify all interactions
- solve the hierarchy problem
- link String Theory to Standard Model
- make Quantum Gravity and String Theory accessible at LHC

  like Prometeus made the divine fire accessible for people

Perhaps it is only a dream...

But I wish you and me this dream to come true!

Conclusions

Higgs is still missing

- Symmetry Breaking in the SM (and beyond!) still not understood
- LHC and ATLAS/CMS designed to find it
- Numerous challenges, mostly "solved"

Physics at the LHC will be extremely rich

- SM Higgs (if there) in the pocket
  - Now turning to measurements of couplings, etc.
- Supersymmetry (if there) ditto
  - Can perform numerous accurate measurements
- Large com energy: new thresholds
  - Compositeness, new bosons, large extra dimensions within reach
- LHC++?

Just need to build machine/experiments.