Physics Commissioning of CMS

- Physics Commissioning during Pilot Physics Run in 2007 (main focus)
- Early Physics with CMS (short)

Note: Pre-Physics Commissioning of CMS is presented in the talk from M. Huhtinen

Oliver Buchmueller CERN/PH

On Behalf of the CMS Collaboration

TEV4LHC workshop at CERN

28/04/05

Time Frame

Pilot Physics Run | **Shut Down** | **75/25ns Physics Run**

Jul 2007
CMS closed

Nov 2007
End Pilot Run

Apr 2008
Start Physics Run

End 2008
End Physics Run

Alternating periods of single beam and collision setting

E_{beam}: 6 - 7 TeV
N_{bunch}: 43 - 156
β^*: 10 - 2 m
Lumi: ~3×10^{28} - ~2×10^{31}

Install PIXEL detector (3x2) and ECAL Endcaps

collision setting

E_{beam}: 6 - 7 TeV
N_{bunch}: 936 - 2808
β^*: 10 - 0.55 m
Lumi: ~1×10^{32} - ~2×10^{33} (10^{34})
Bunch Spacing: 25ns - 75ns

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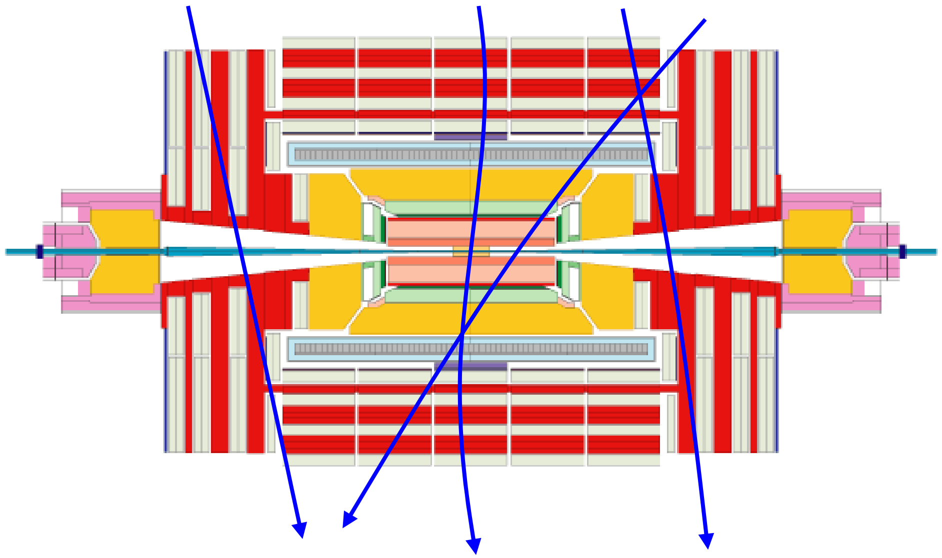
“Pre-Collision Physics Structures”

Cosmic Muons

High energetic muons that traverse the detector vertically

→particular useful for alignment
and calibration - *barrel region.*



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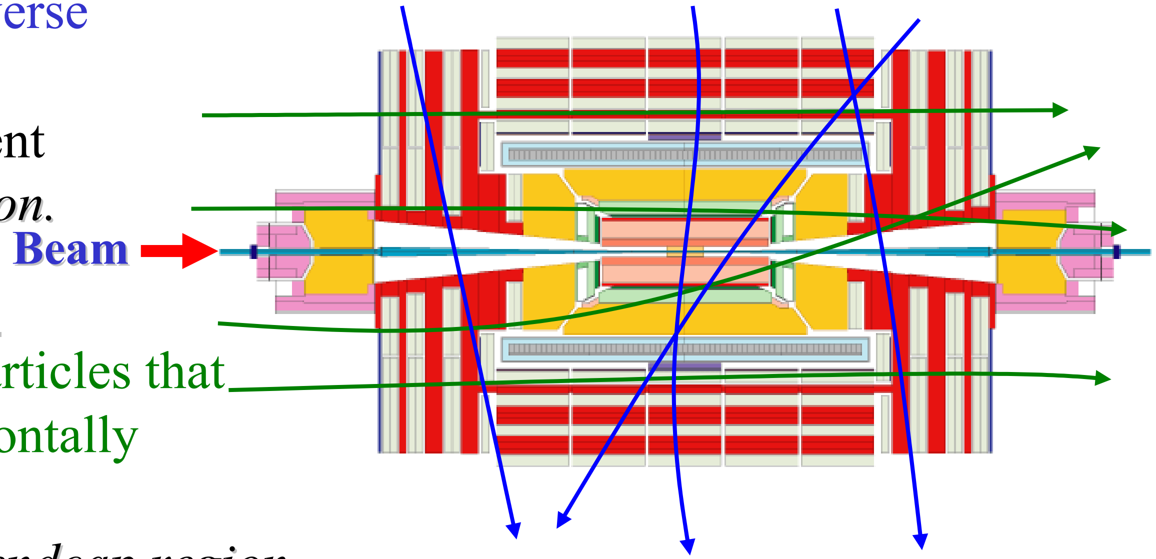

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Machine induced secondary particles that cross the detector almost horizontally
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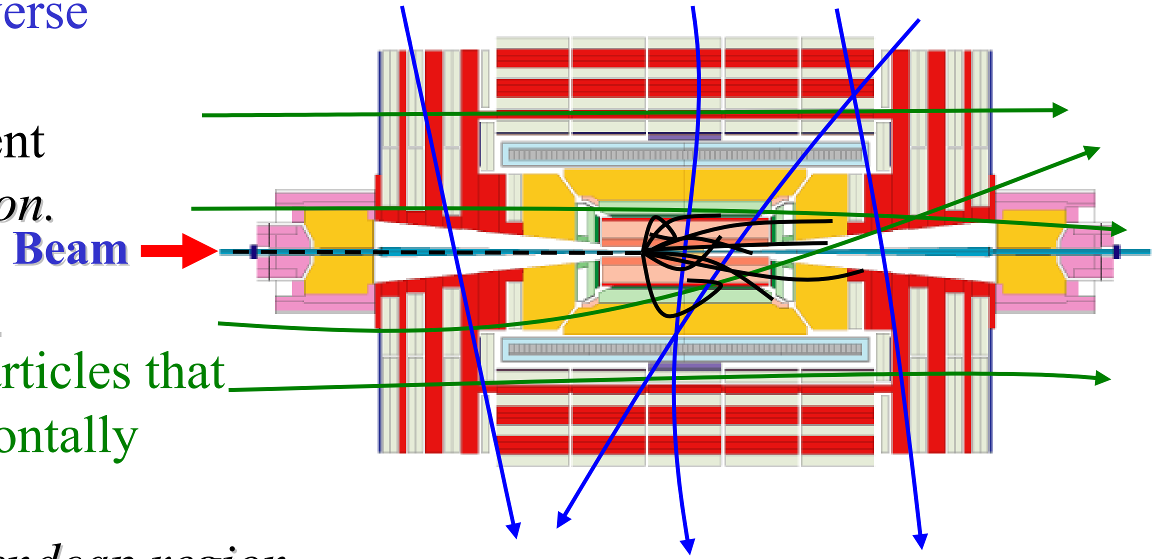

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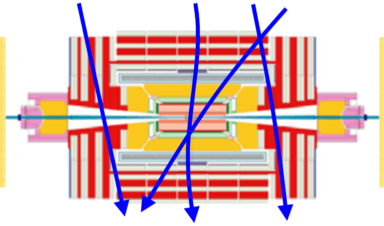
Beam Gas Interactions

Proton-nucleon interaction in the active detector volume (7TeV→E_{cm}=115 GeV)

→resemble collision events but with a rather soft p_T spectrum (p_T<2 GeV)

All three physics structures are interesting for alignment, calibration, gain operational experience, dead channels, debug readout, etc …

Cosmic Muons



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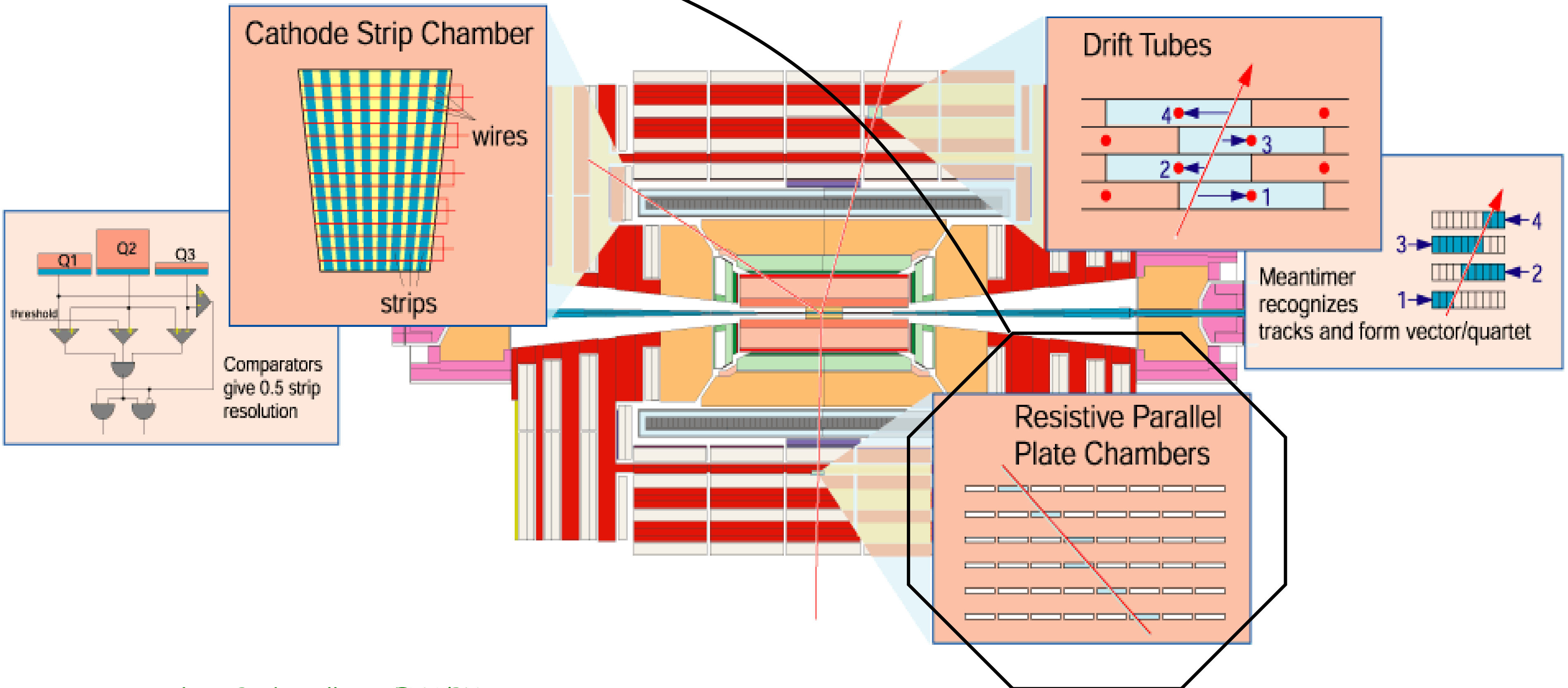

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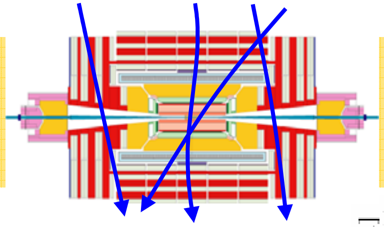

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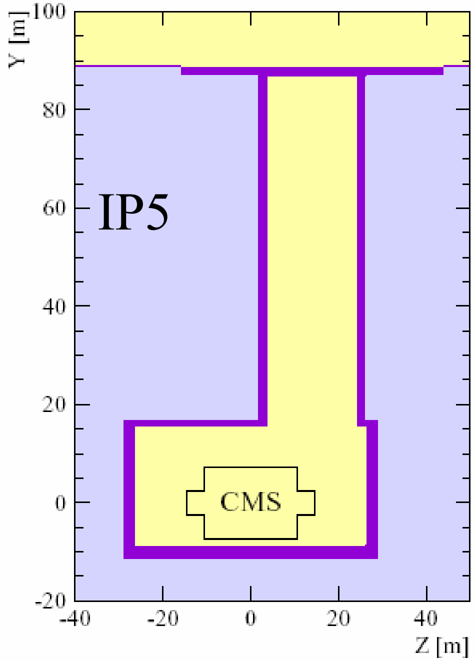

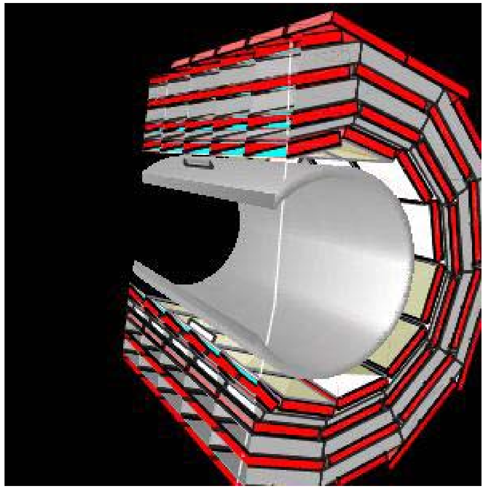

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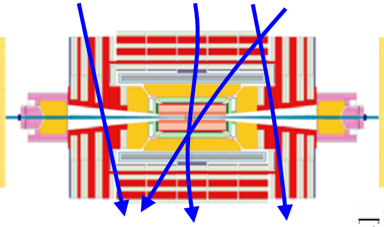

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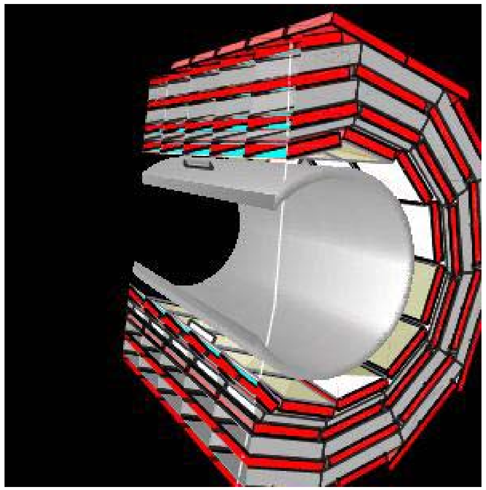

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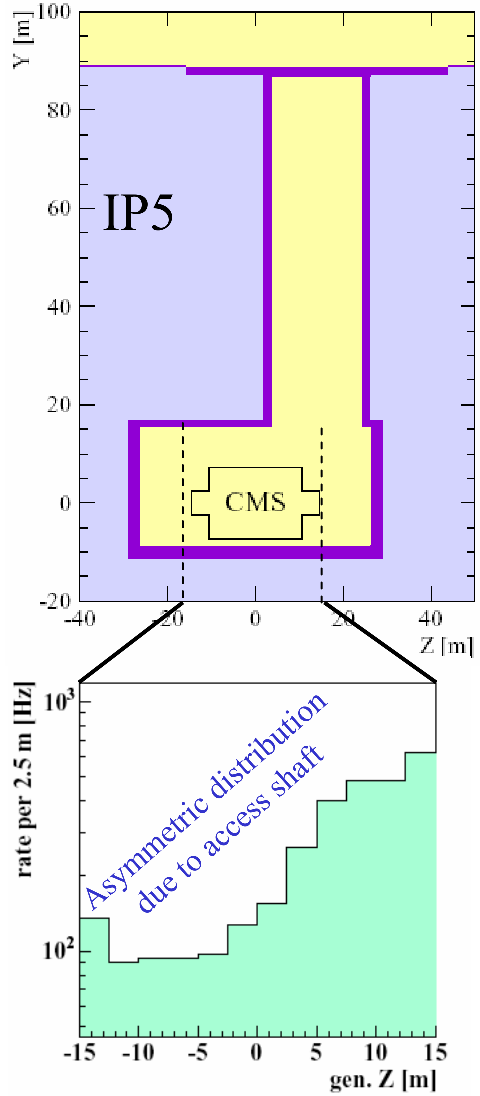
Substantial Expected Rates for $E_{\mu}>10$ GeV

$N_{HIT}\geq1$	Rate[Hz]
CMS tot	~1800
Muon only	~1800
calorimeter	~ 700
tracker	~ 60



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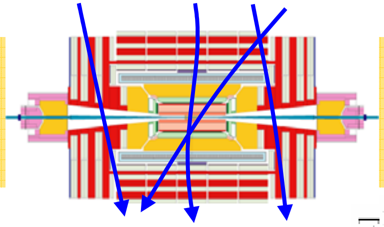

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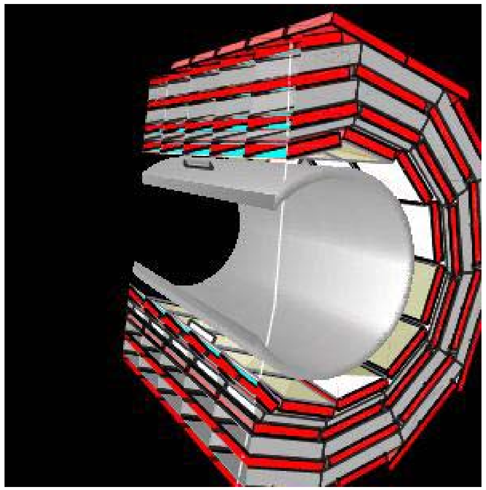

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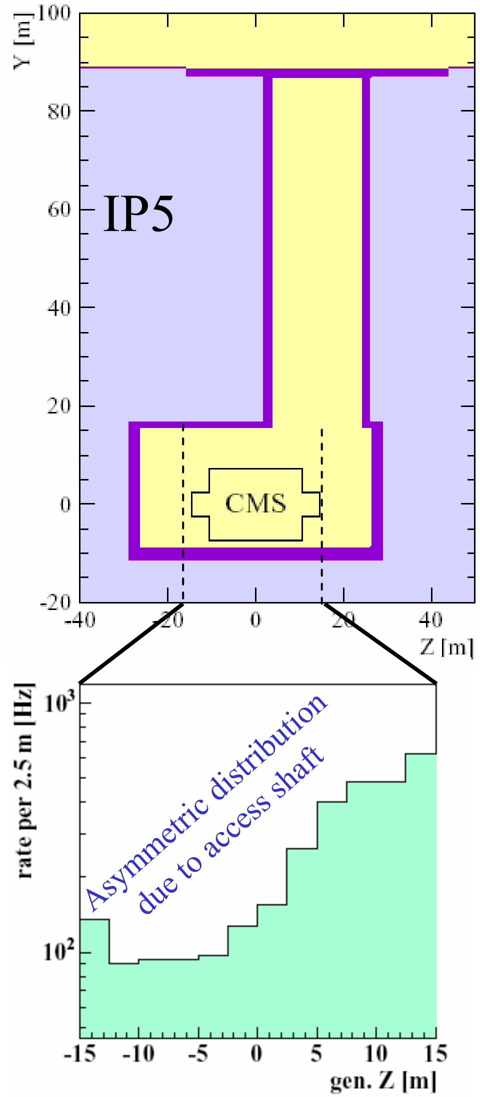


Cosmic Muons:
Special Topology (traverse whole detector) makes them very attractive for various commissioning activities (e.g. alignment, operational experience with high energetic muons, etc …

$\Rightarrow$Setup the tools necessary for dedicated cosmic runs (e.g. during Physics Pilot Run when there is no beam in the machine)

Beam Gas Events

Proton-Beam Gas collisions inside the active detector volume, so-called "Beam Gas Events", take place at a center-of-mass Energy around 115 GeV (7 TeV proton and nucleon at rest) and resemble p-p interactions.

Advantages:

- Relative large rate already during single beam running (track statistic equivalent to a few days of real data taking) .
- Event Topology is very similar to real collision data.

Disadvantages:

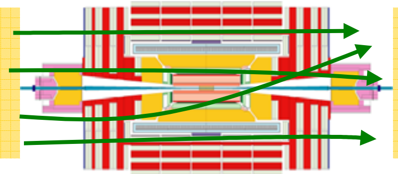
- Soft p_T spectrum makes it very hard to trigger these events and limits its use to inner detector issues (e.g. tracker alignment).

Important Issues:

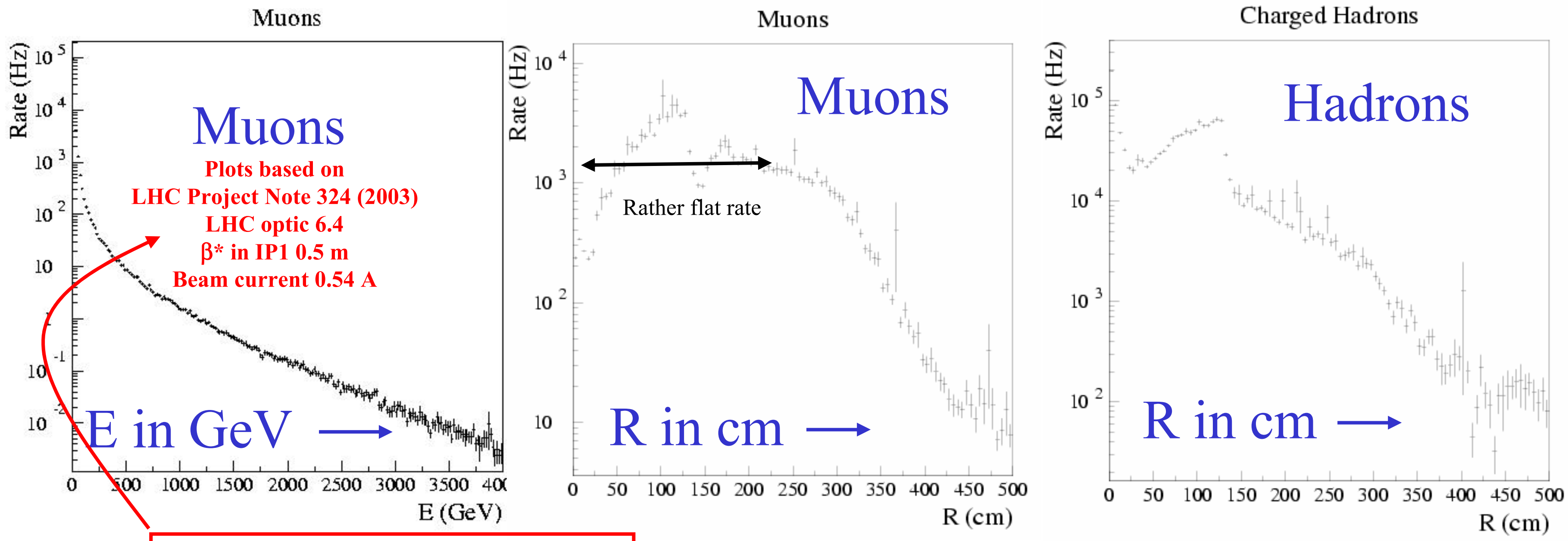
- How to trigger these events
- Need to establish a full simulation for beam gas events in CMS

Simulation of 114.6 GeV ($E_{cm}^2 = 2\ m_p\ 7$ TeV) center-of-mass fixed target proton-proton collision.
Assuming 47.5mb for the proton-nucleon inelastic cross section and $\sigma_{Gas\text{-}Atom} = \sigma_{p\text{-}n} \times A^{0.7}$ (A = mass number)
Typical Beam Gas: H_2, CH_4, CO and CO_2

Beam Halo Muons



⇒Beam halo muons are machine induced secondary particles and cross the detector almost horizontally. Thus leaving essentially signals in the endcaps.



Note: Results are strongly dependent on machine parameter settings. These settings are not anymore more fully up-to-date. **Improved machine simulations are in preparation**!

⇒Very interesting for several commissioning efforts of the endcap regions

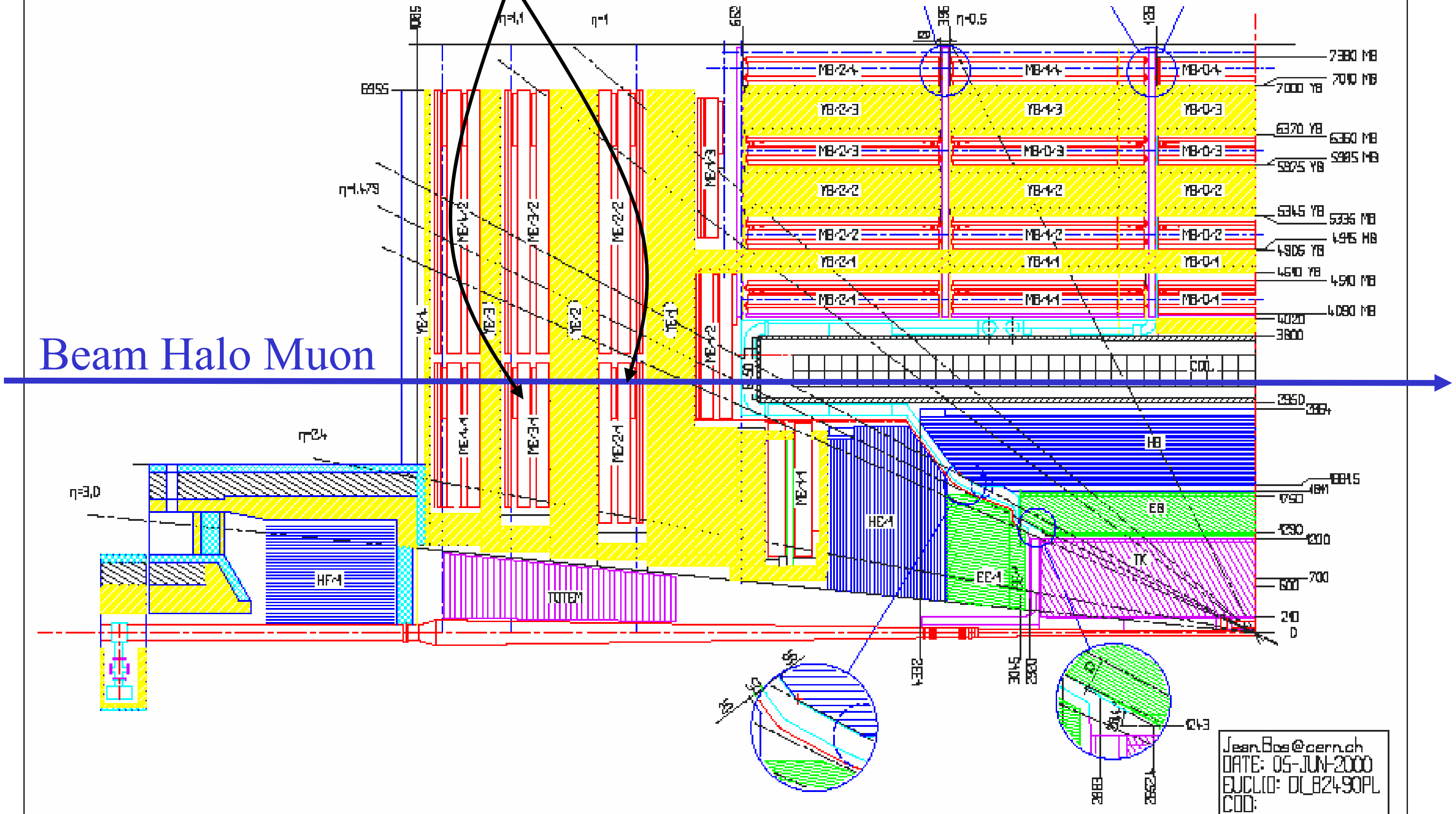
Substantial Expected Rates for E_μ>100 GeV

However, still significant uncertainties in simulations but probably good enough for a first impression

$N_{HIT}\geq 1$	[Hz]
CMS tot	~1000
Muon	~ 800
Calo.	~ 800
tracker	~ 200

Trigger for Beam Halo Muons(Beam Gas)

There will be a Halo Muon trigger based on the Muon CSCs but the trigger covers only R>~140cm (Tracker R<110cm) (lowest chambers are ME3/1 and ME2/1)



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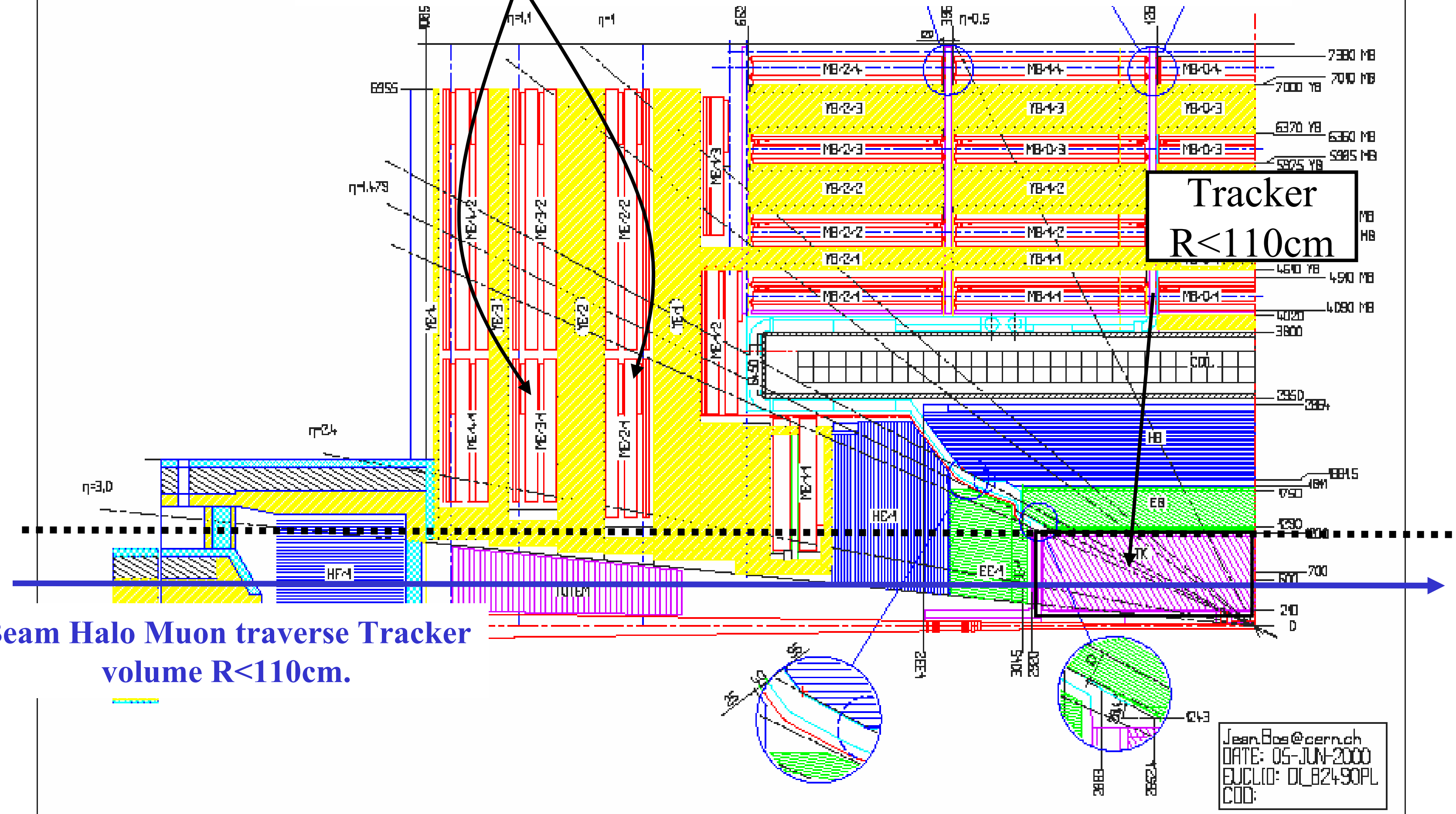

Beam Halo Muon traverse Tracker volume R<110cm.

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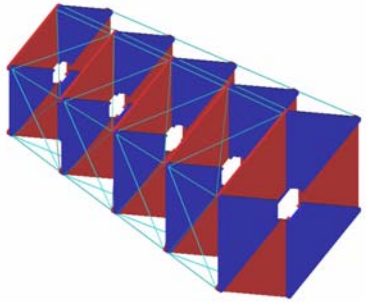
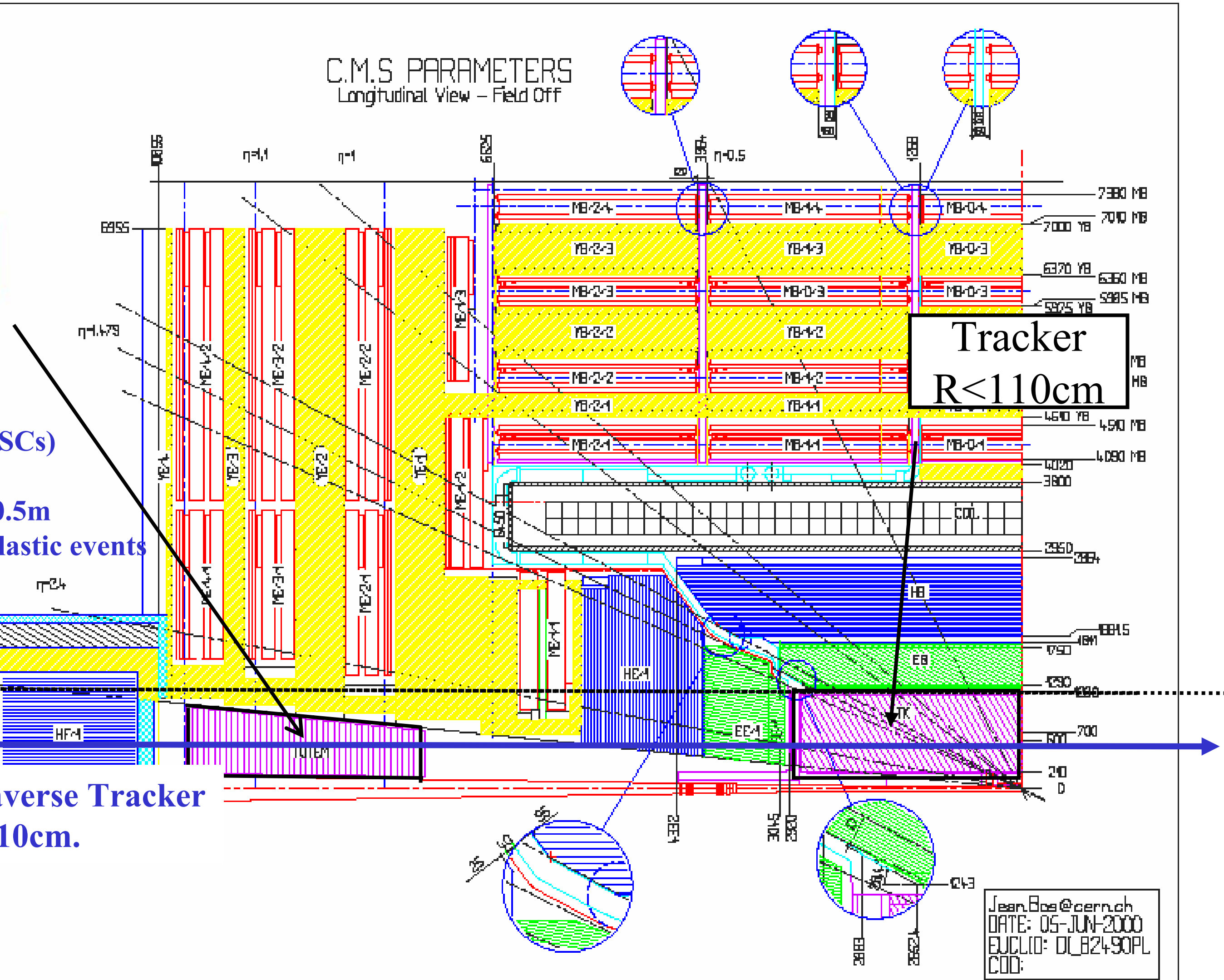


TOTEM T1-Telescope
- 5 CSC planes (like muon CSCs)
- $3.1 < |\eta| < 4.7$
- $|z|$ ranging from 7.5m to 10.5m
- trigger and reconstruct inelastic events



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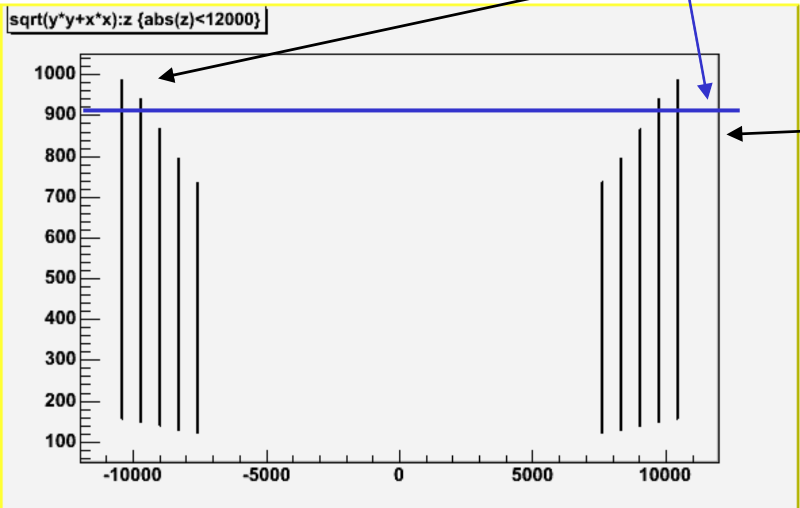
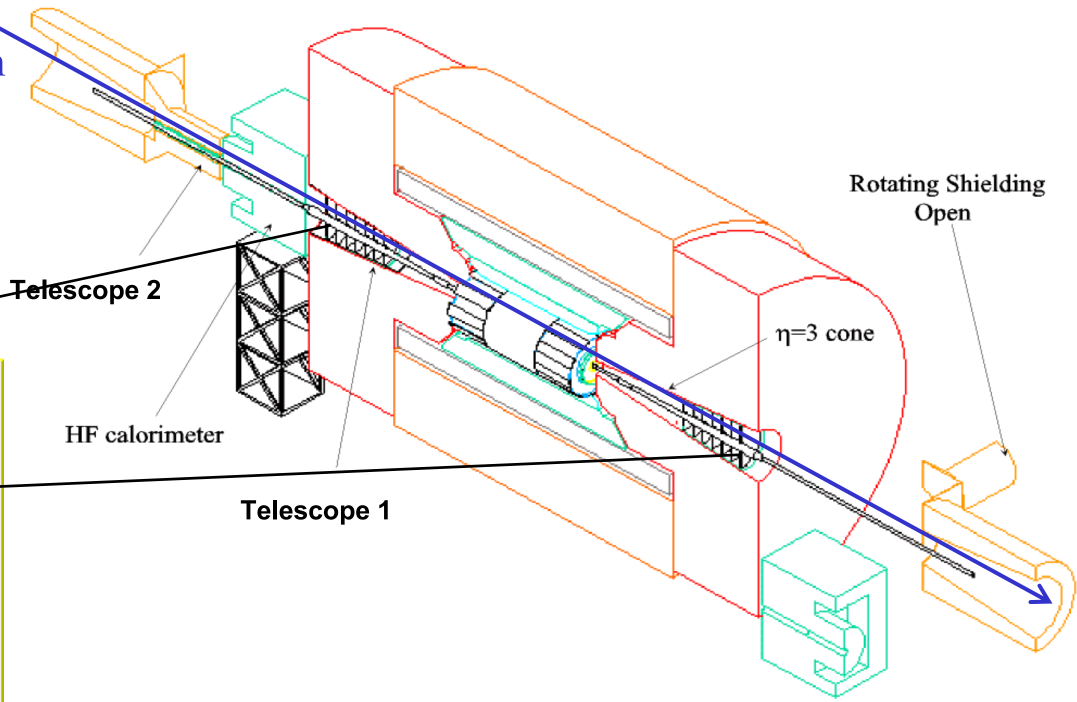
T1 to trigger Beam Halo Muons

Beam halo muon

Coincidence trigger between the two T1 can be used to trigger on beam halo muons.
ΔZ=20m → ~60ns



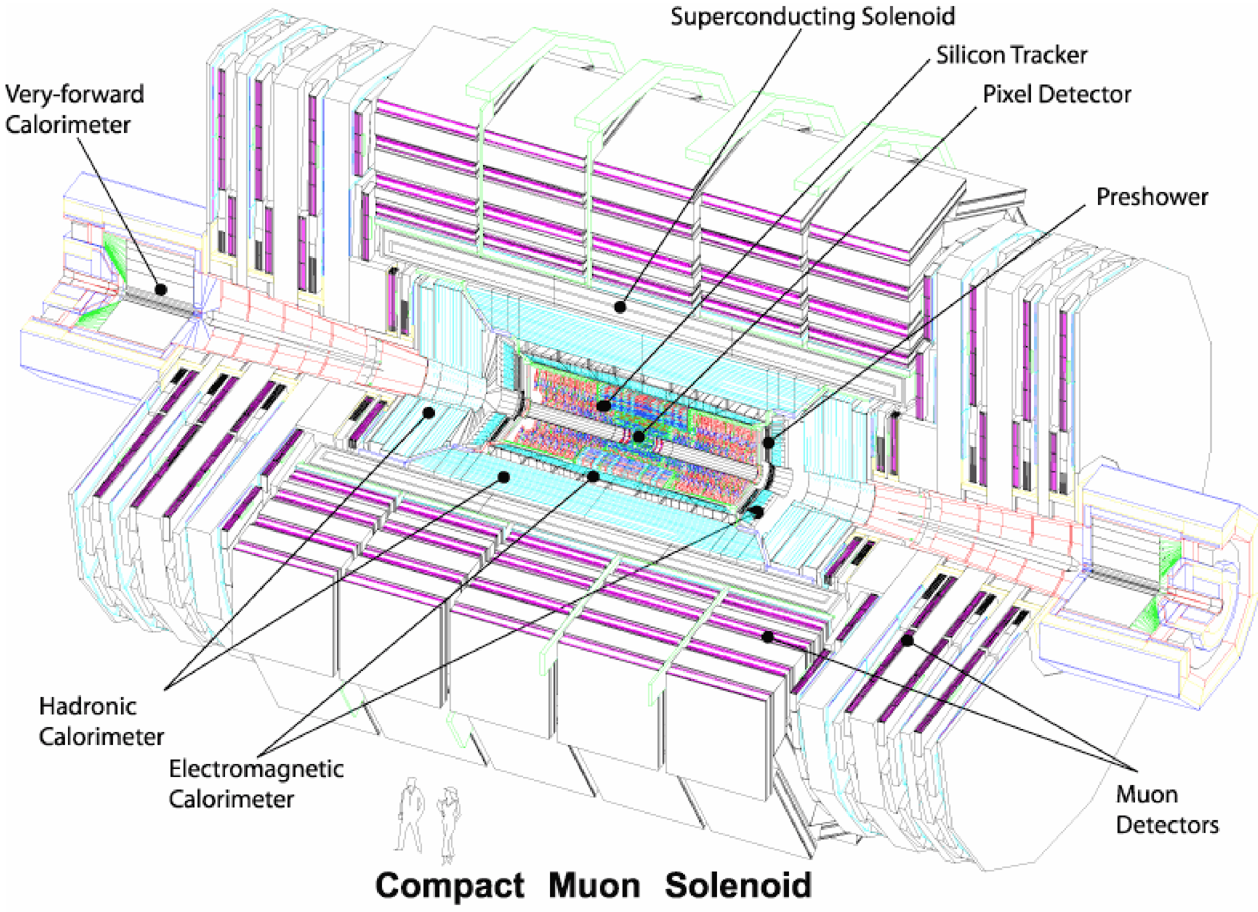


T1 provides a very good coverage of the Tracker volume. For a "two plane" coincidence the radial coverage goes up to ~90cm. that gives almost 80% coverage of the tracker but without the pixel.

Agreement with TOTEM that they will provide a beam halo trigger.

Alternatively we also pursue the possibility to use dedicated scintillators (e.g as ATLAS) …

CMS @ Pilot Physics Run

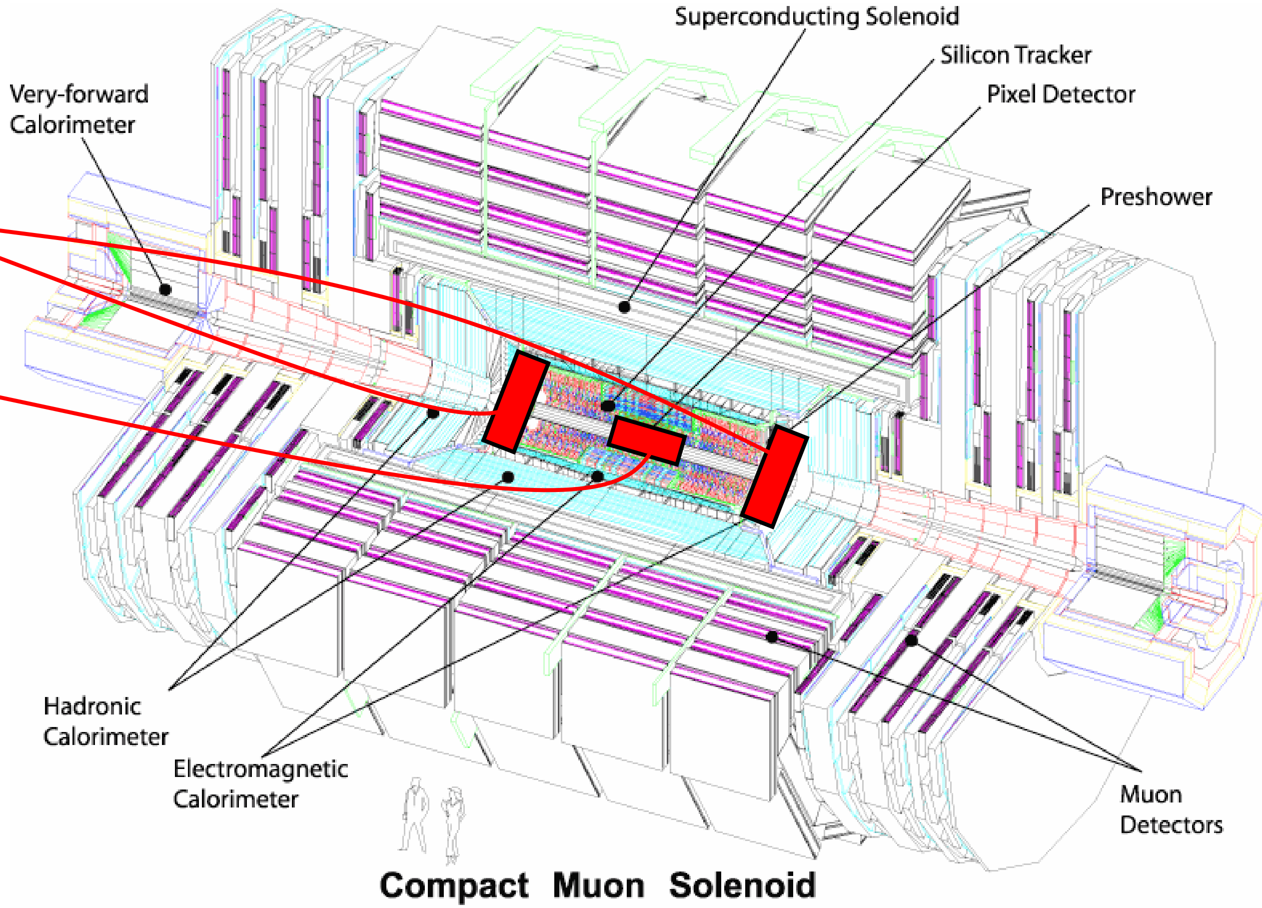


CMS @ Pilot Physics Run

At the Pilot Physics Run
CMS will operate without:

Endcaps of the ECAL

Pixel detector



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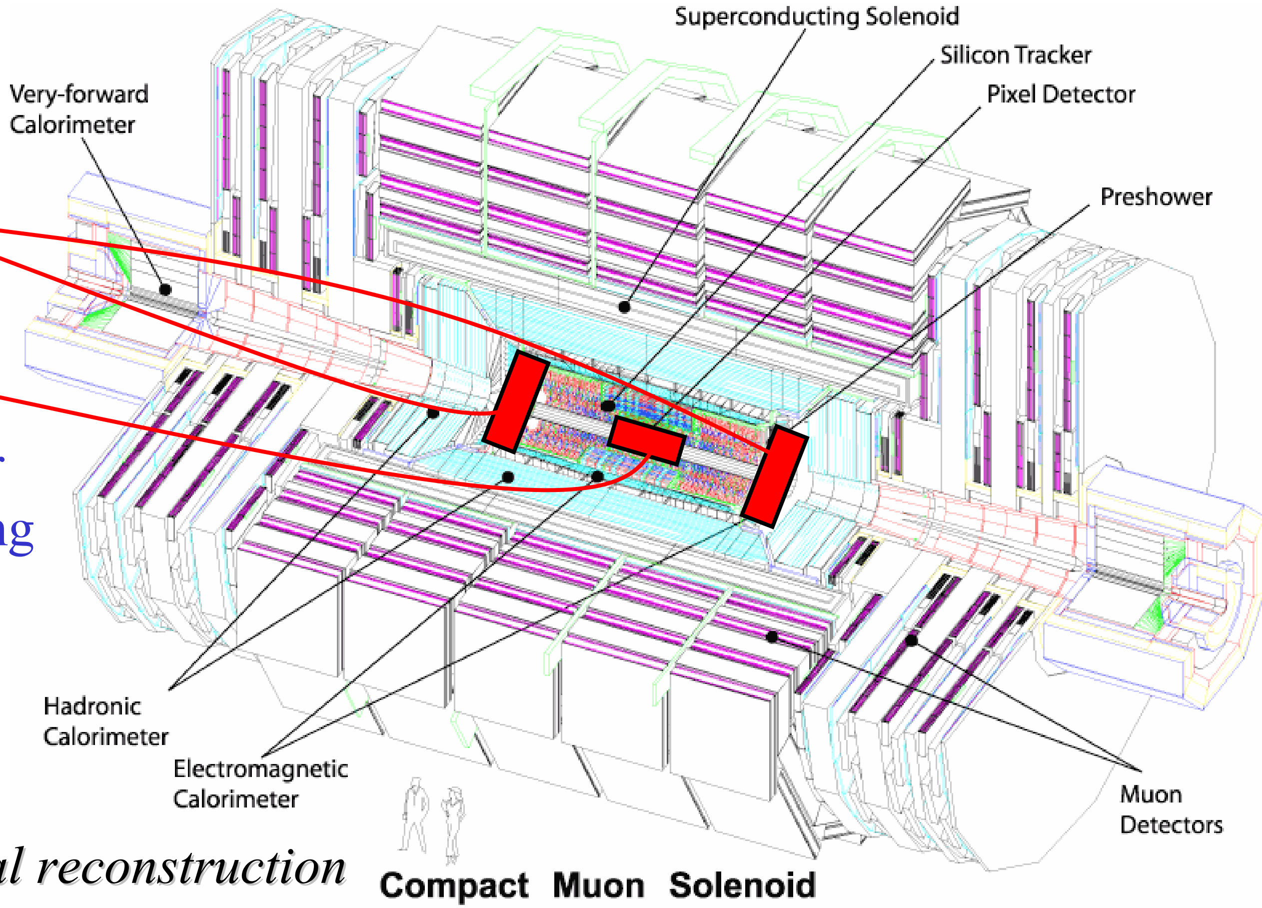
Additional Challenge for the Physics commissioning of CMS



- *Can't commission ECAL Endcaps and PIXEL at the Pilot Run - obvious!*
- *Need to develop additional reconstruction tools $\rightarrow$ e.g. tracking without PIXEL (new seeding, etc)*

$\Rightarrow$adaptation has already started for the Pilot Physics Run

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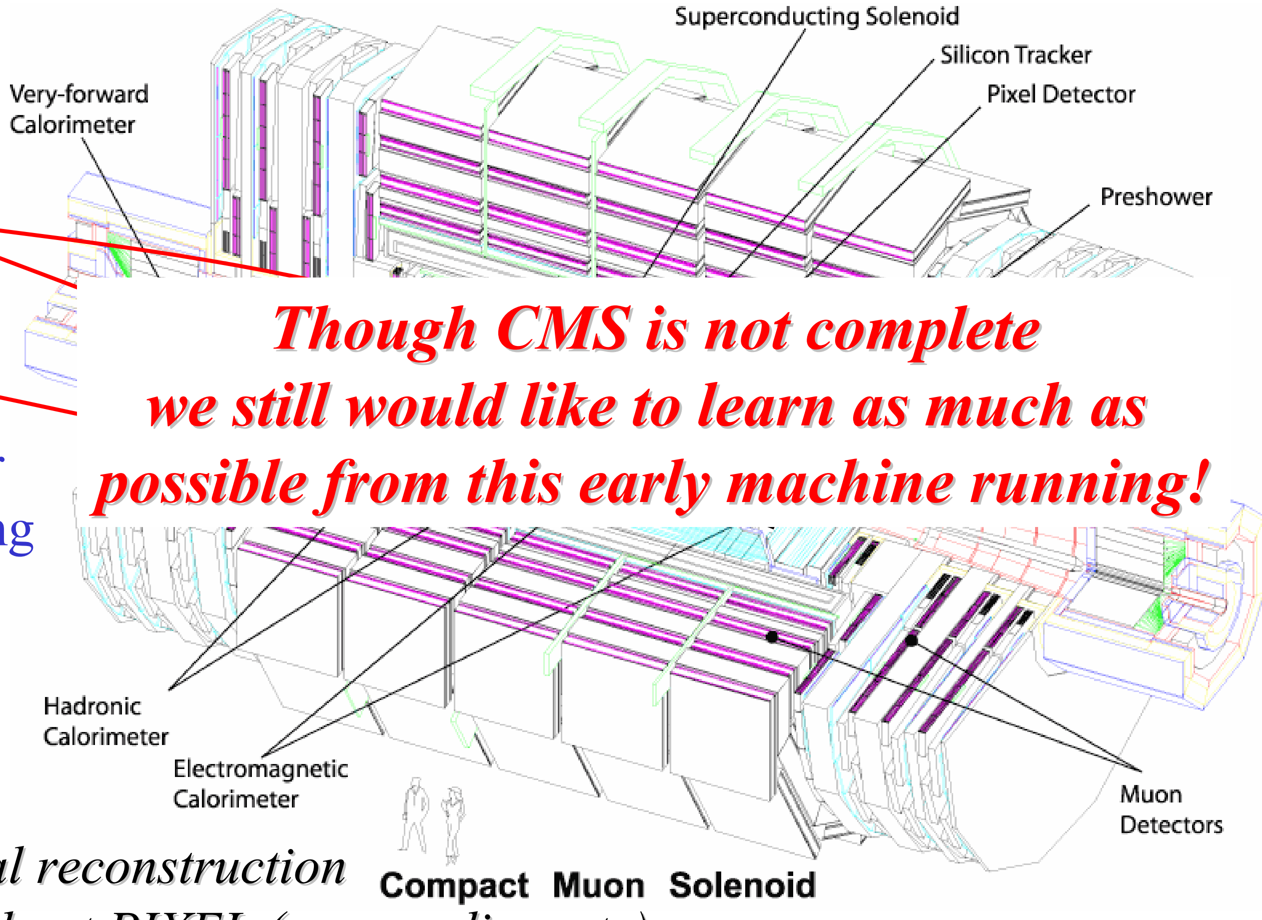

Though CMS is not complete
we still would like to learn as much as
possible from this early machine running!

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CMS @ Pilot Physics Run

Assume that we get a reasonable amount of collision data which are completed by significant Cosmic Muon and Beam Gas/Beam Halo Muon datasets.

What can be done …

LVL1/HLT/DAQ

Timing-in, data coherence, sub-system synchronization, calibration, debug algorithms, …

ECAL and HCAL calibration

Utilize dedicated calibration stream (1kHz) for min.bias events to:

- Intercalibrate barrel crystals - “Phi Symmetry Method” → ~2%
- Cross check and complete source calibration for HCAL channels → ~2%

Tracker and Muon alignment

Utilize tracks from Cosmic and Beam Halo Muons as well as collision tracks to:

- To align the tracker strip detector significantly below the 100 μm level
- To align the muon chambers at the 100 μm level

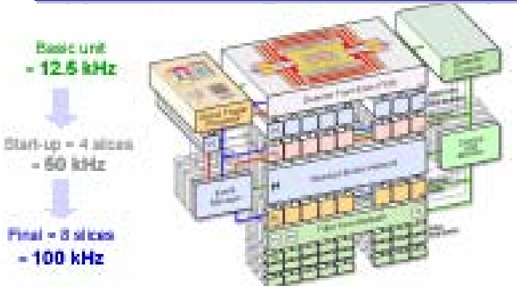
What can’t be done … (left over for 2008 Physics Run)

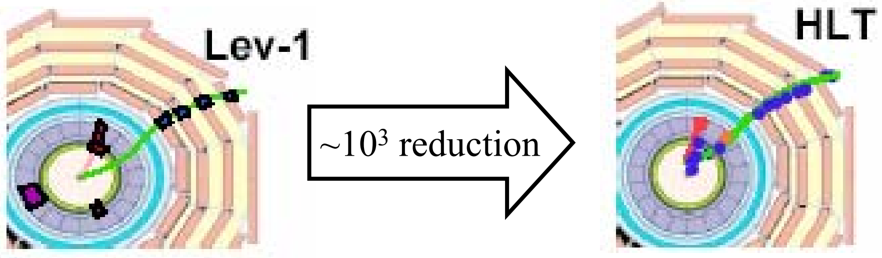
- final HCAL and ECAL barrel calibration (need large $W \to e\nu$ and $Z \to ee$ samples)
- final alignment (not enough statistic and no PIXEL)
- no full E_T^{miss} calibration (not enough statistic)
- no b-tag calibration (no PIXEL detector)

…

Major Commissioning Challenges

Efficient operation of Trigger (Level1/HLT) and DAQ System





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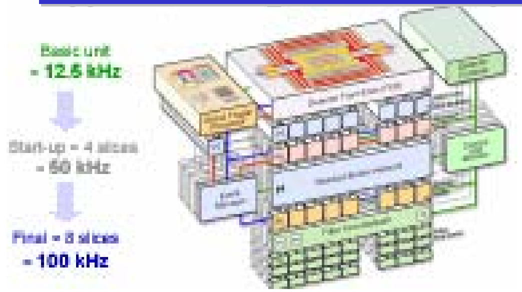
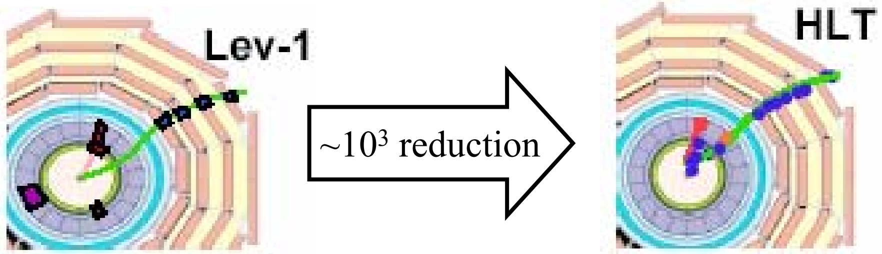
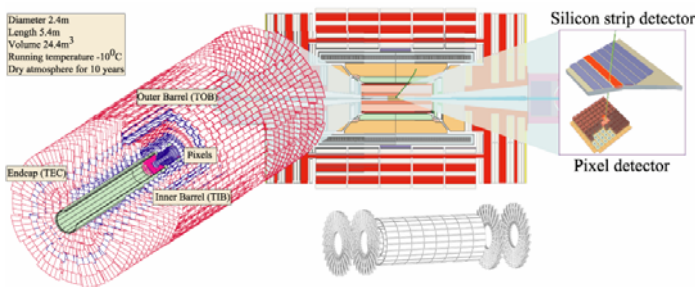
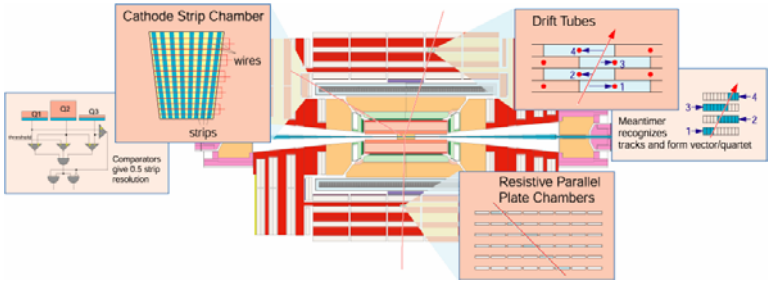




Alignment of the tracking devices Tracker(PIXEL,Strip) and Muon System





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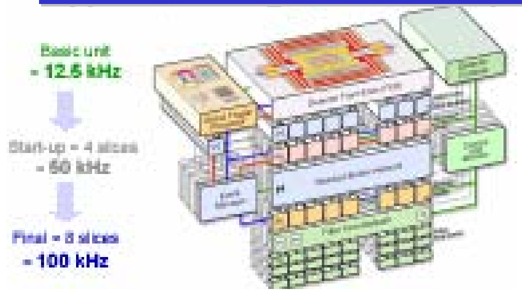

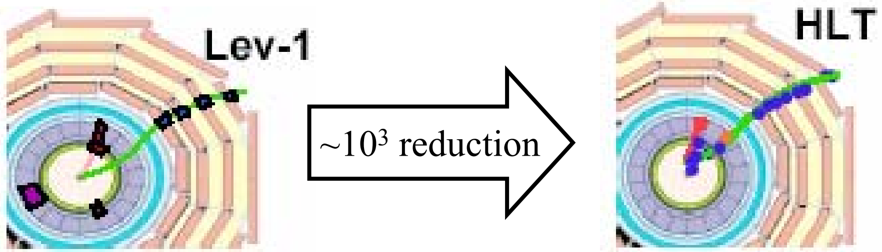

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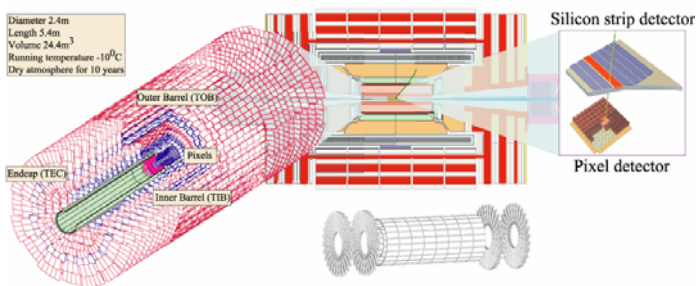
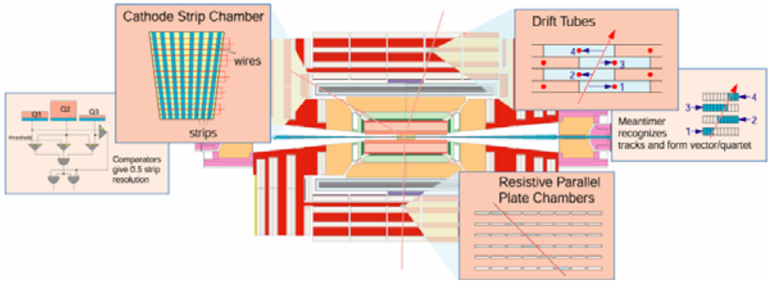
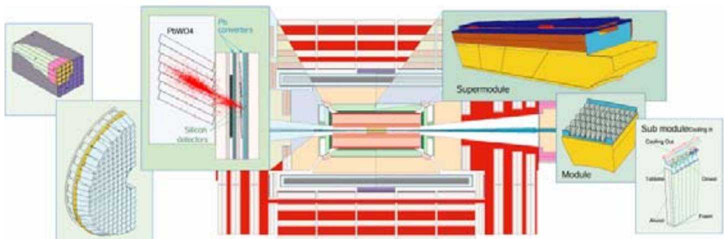
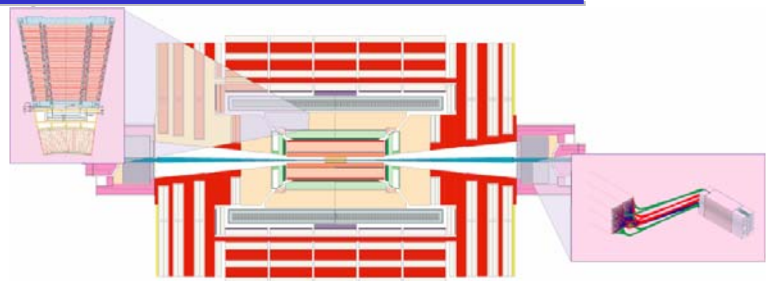




Calibration of the Calorimeter Systems ECAL and HCAL





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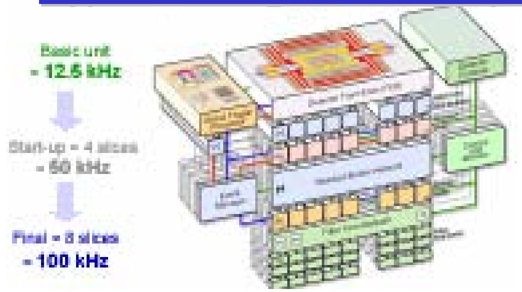
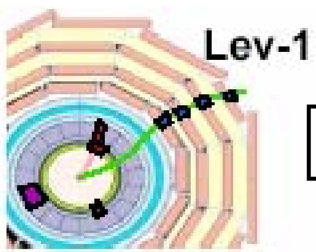
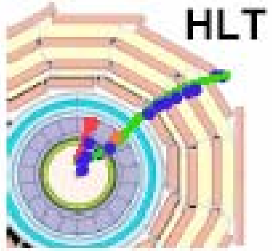




~10^3 reduction



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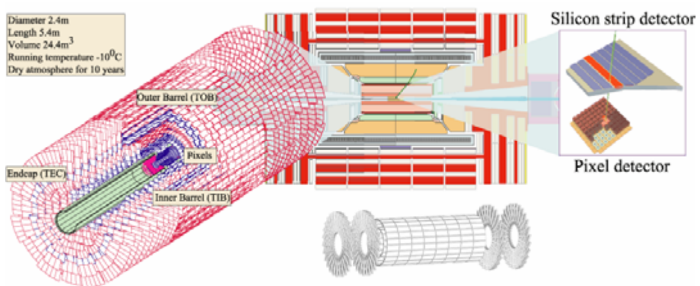

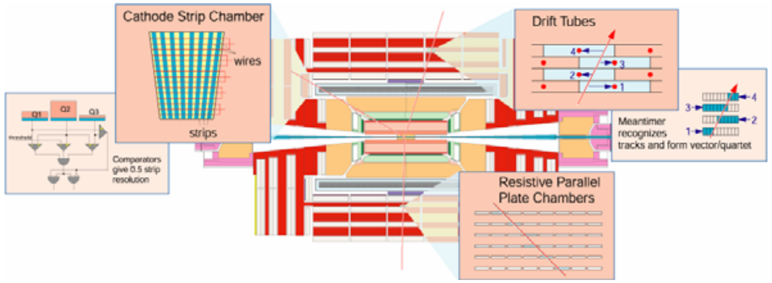

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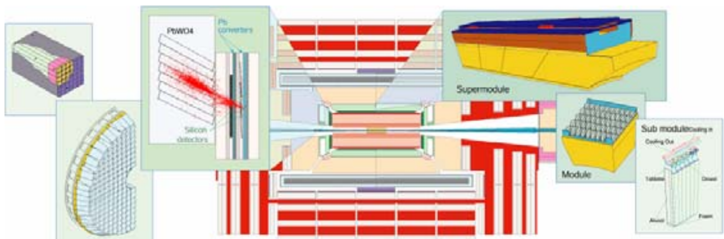
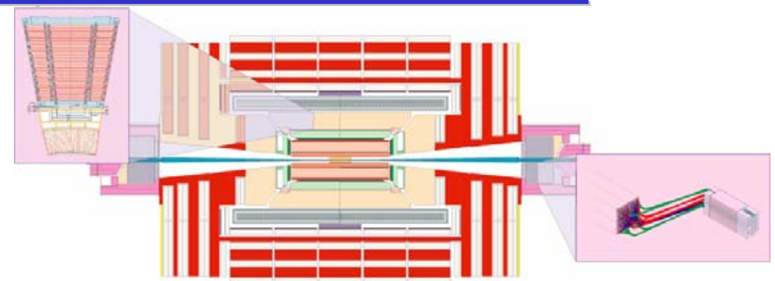
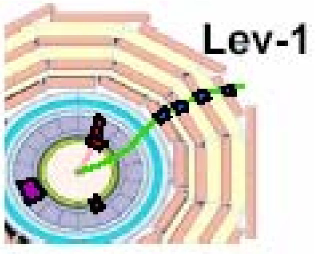




→form the base for the "commissioning of physics tools" like b and τ tagging, jets, missing E_T …

Level-1&HLT @ low Lumi

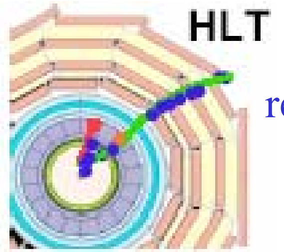
Tot Rate x Safety = Rate
50 kHz x 1/3 ~ 16kHz
~1/4 per class
(e/γ, muon, tau, jet)
+ 1kHz calibration



Channel	Threshold [GeV] ε = 95%	Individual Rate [kHz]
Inclusive isolated e/γ	29	3.3
Di-electrons/di-photons	17	1.3
Inclusive isolated muon	14	2.7
Di-muons	3	0.9
Single tau-jet trigger	86	2.2
Two tau-jets	59	1.0
1-jet, 3-jets, 4-jets	177 , 86 , 70	3.0
Jet * E_T^{miss}	88 * 46	2.3
Electron * jet	21 * 45	0.8
Min-bias (Calibration)		0.9

Sum ~16kHz

Event Selection: ~10^3 reduction from Level-1 to HLT



Utilize dedicated offline reconstruction tools at HLT.
No intermediate level (i.e. Level-2) required.

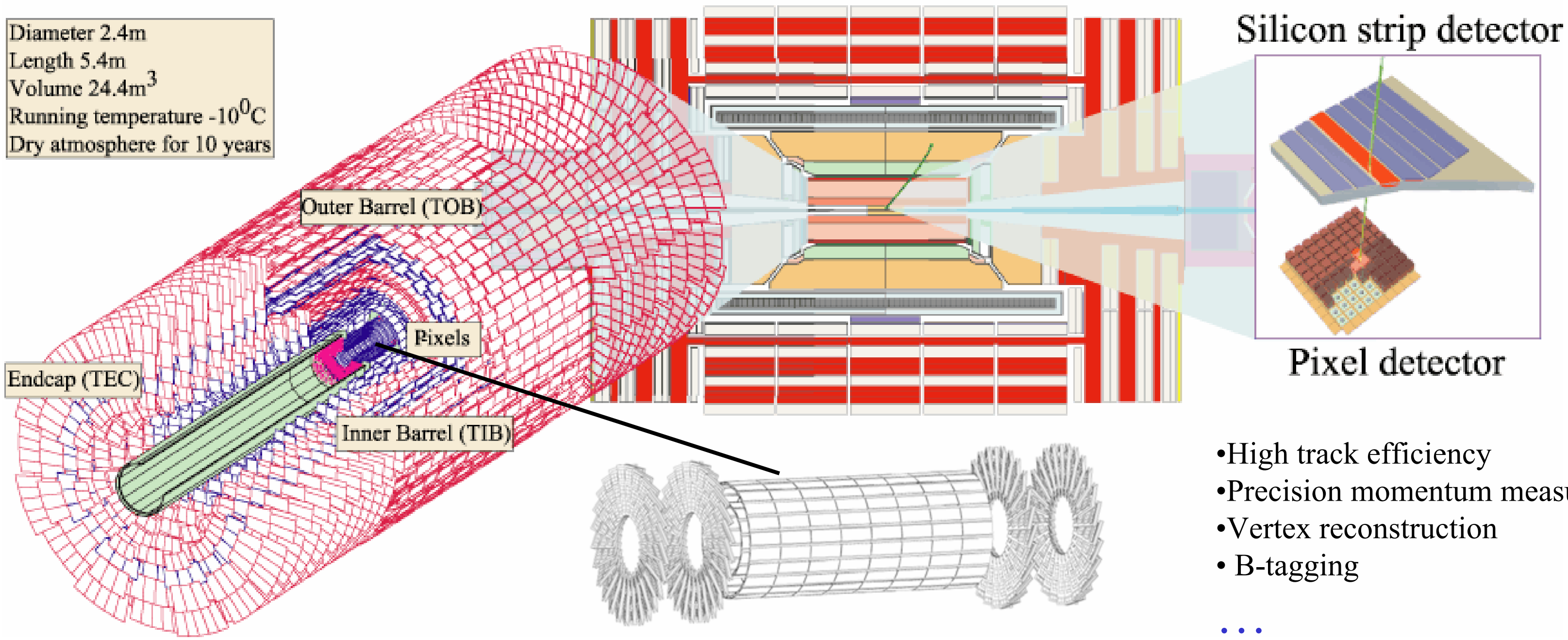
Channel	Threshold [GeV] ε = 90...95%	Rate [Hz]
1 e, 2 e	29 , 17 + 17	34
1 γ, 2 γ	80 , 40 + 25	9
1 μ, 2 μ	19 , 7 + 7	29
1 τ, 2 τ	86, 59 + 59	4
1-jet OR 3–jet OR 4	657 , 247, 113	9
e * jet	19 + 45	2
Jet * E_T^{miss}	180 + 123	5
Inclusive b-jets	237	5
Calibration,Other		~10
Sum		~105 Hz

Efficient Level1/HLT operation is insured when:

ECAL and HCAL calibrated to ~2%; Muon System aligned ~500 μm,
Silicon Strip Detector aligned ~20 μm; PIXEL detector aligned to ~10 μm.

⇒Most of these requirements can already be met during the Pilot Physics Run

Alignment of Silicon Tracking Devices



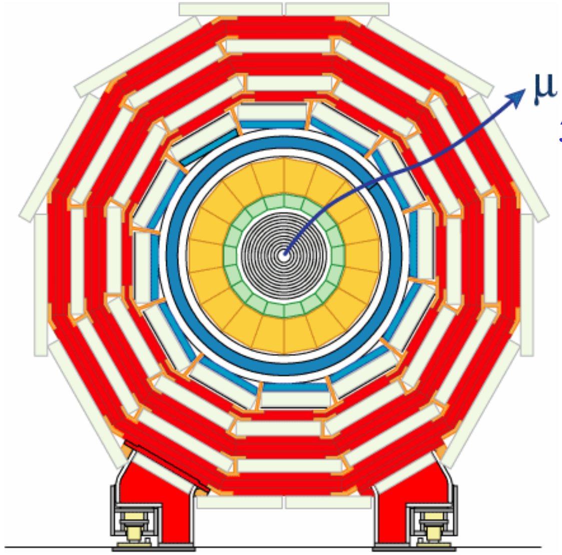
- High track efficiency
- Precision momentum measurements
- Vertex reconstruction
- B-tagging

…

The Silicon Strip and PIXEL detectors are the core of the CMS tracking. With roughly 20000 sensors exhibiting individual resolutions at the level of ~20µm (PIXEL even below 10µm) the alignment of these tracking devices is real challenge!

⇒Need to align ~200m² of silicon at the 10µm level

Alignment of Muon Chambers

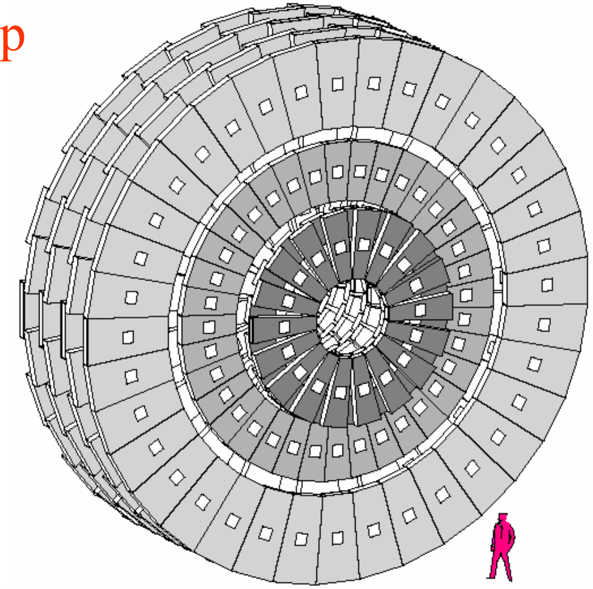


Muon Barrel

5 wheels/4 layer each
250 chambers

Muon Endcap

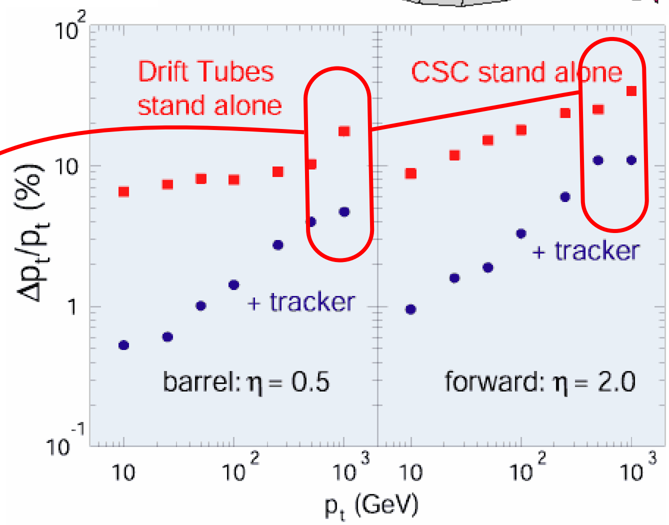
6000m^2 of
sensitive area
540 chambers



Intrinsic resolution of DT and RPC (Barrel)
is ~100μm and CSC and RPC (Endcap) ~100-75μm

⇒Need to align large structures to less than 100μm

A precision alignment is especially important for high p_T muon tracks (TeV region) and to insure efficient muon triggering



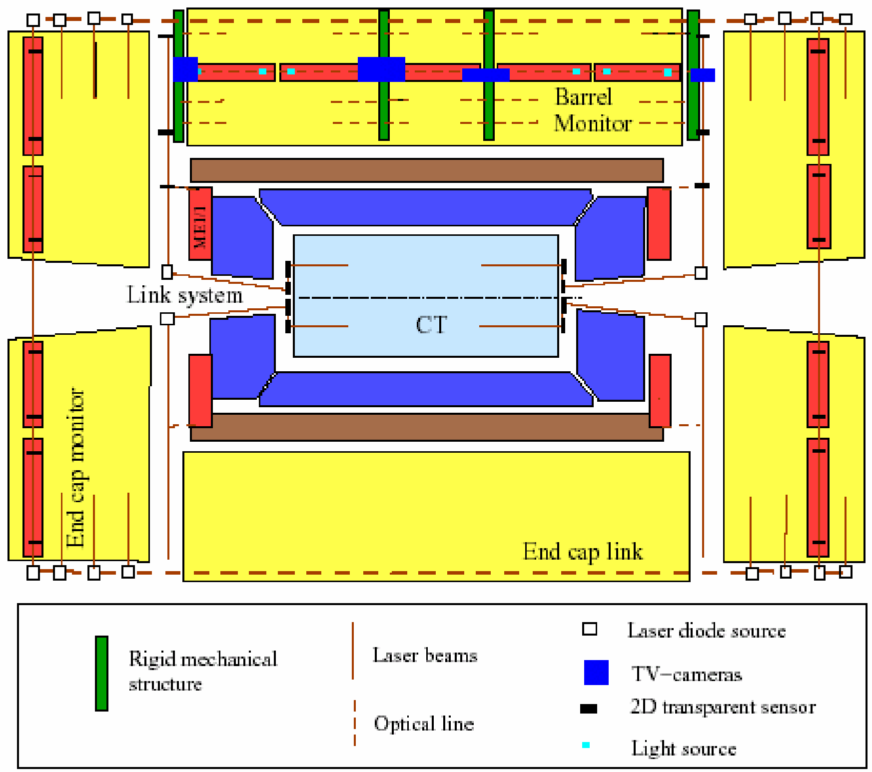
"Hardware Alignment System"

Four important ingredients:

- Internal Muon Alignment Barrel
- Internal Muon Alignment Endcap
- Internal Tracker Alignment
- Alignment of Muon w.r.t Tracker (Link System)

Specifications:

- Monitor tracker support structures at ~10µm
- Monitor Muon support structures at ~100µm
- Monitor Muon w.r.t Tracker at ~100µm



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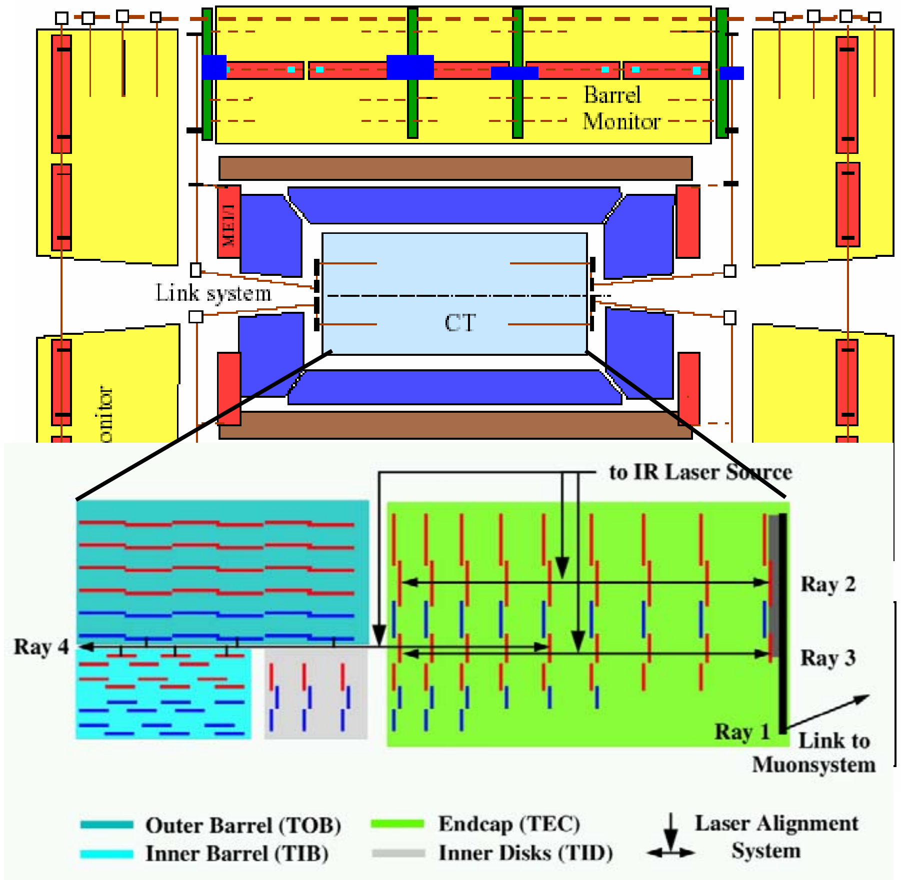

Note: Only Strip Tracker and Muon System are included in the Hardware Alignment System.
The PIXEL detector will be aligned and monitored with tracks only.

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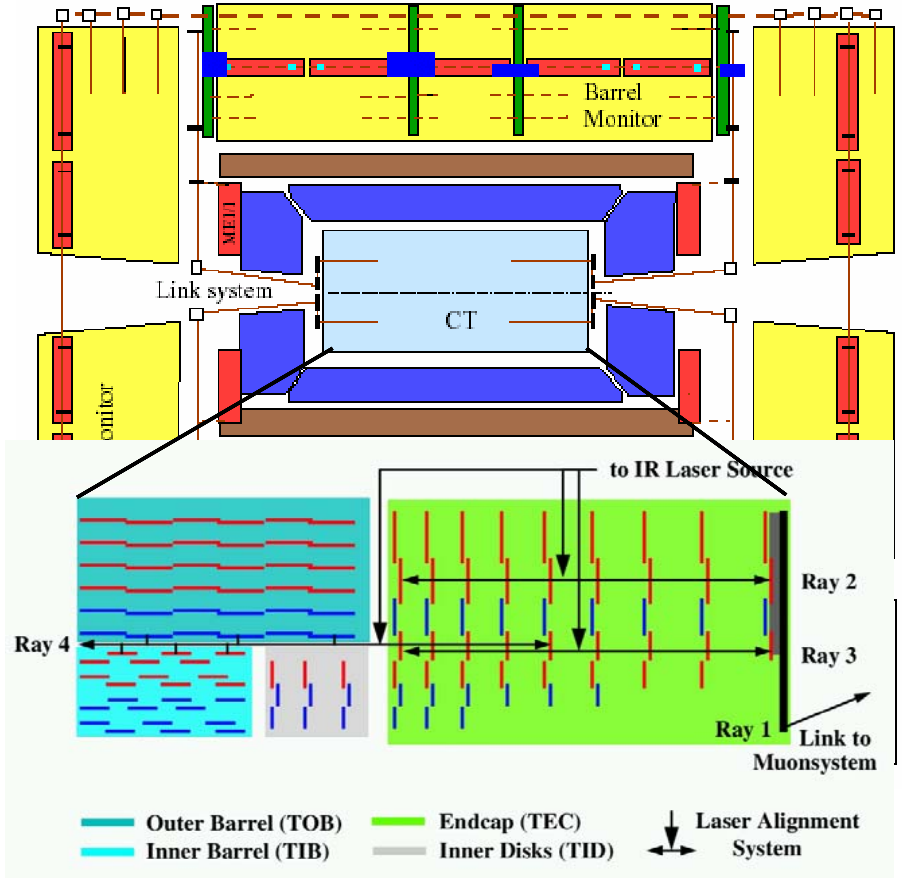


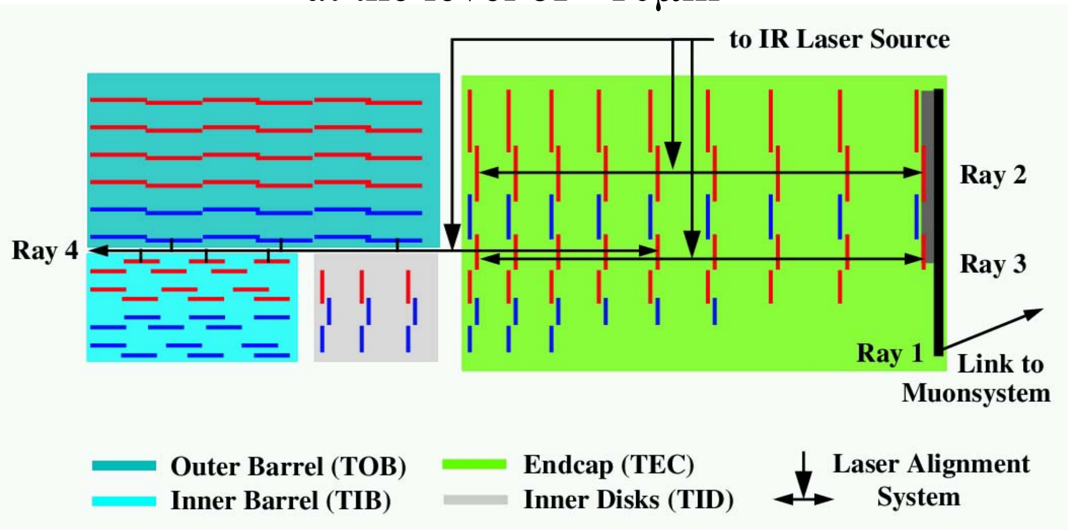
Hardware Alignment System monitors only global structures of the CMS tracking devices. The final alignment of the individual measurement units (e.g. silicon sensors) will be carried out with tracks!

Note: Only Strip Tracker and Muon System are included in the Hardware Alignment System. The PIXEL detector will be aligned and monitored with tracks only.

Tracker Alignment Concept in a Nutshell

Challenge: Alignment uncertainties must not degrade intrinsic tracker resolution: ≈20μm

LAS: Aligns global support structures and will monitor relative movements at the level of ≈10μm



Mechanical Constraints:
Sensors on Modules: ≈10μm
Composted Structures: 0.1-0.5 mm

First Data Taking:

Laser Alignment
$\otimes$
Mechanical Constraints
⇒≈100μm alignment uncertainties

Sufficient for a first efficient pattern recognition.

Final Alignment: Use Tracks in order to achieve the desired level of alignment uncertainties of ≈10μm. A combination of track based alignment and laser alignment will insure an accurate monitoring of time dependent alignment effects.

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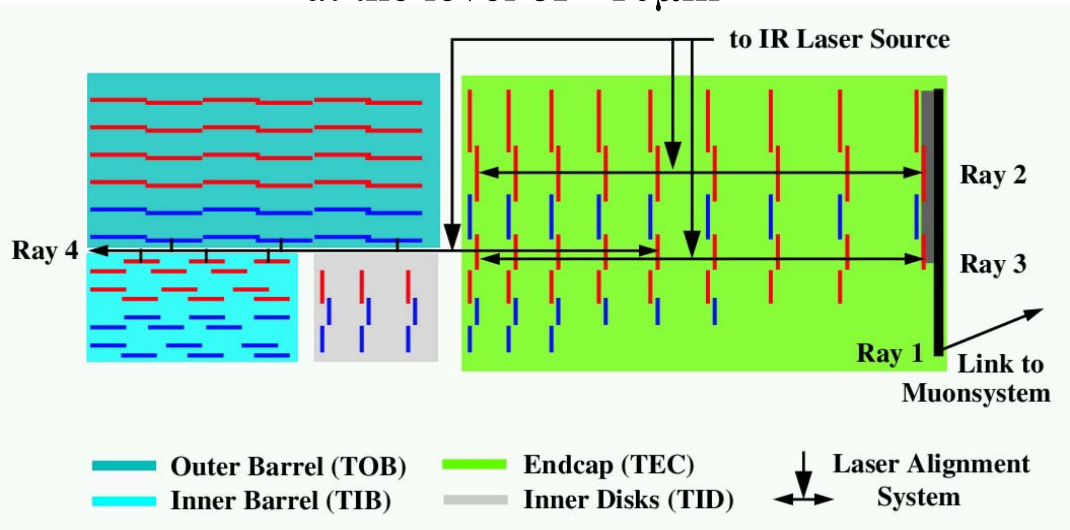

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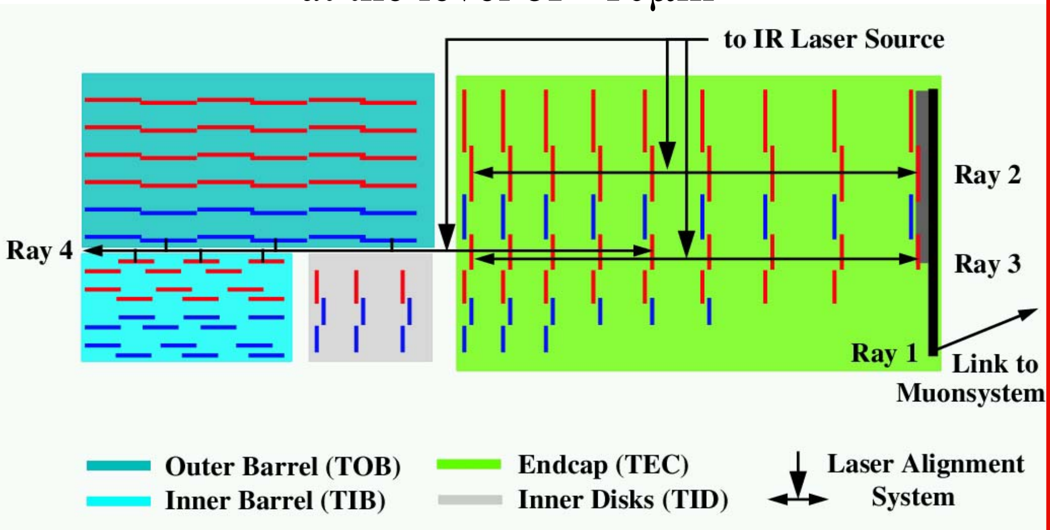

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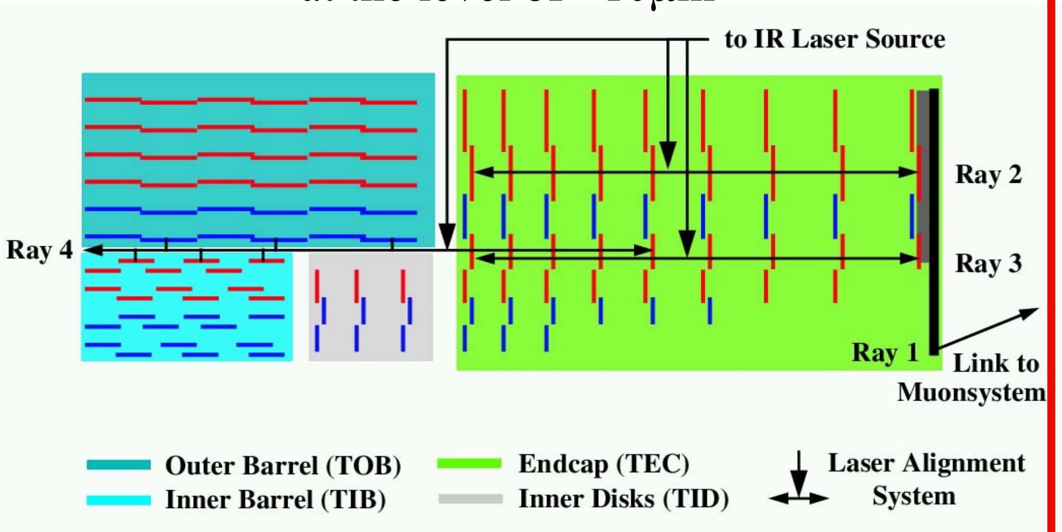

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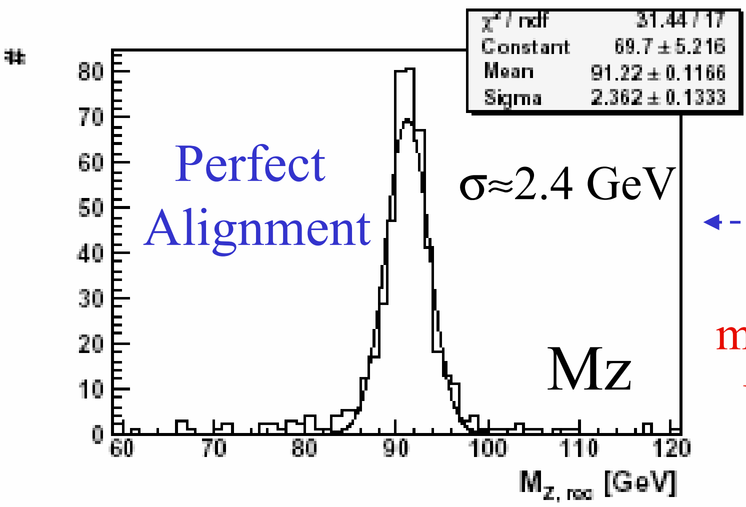
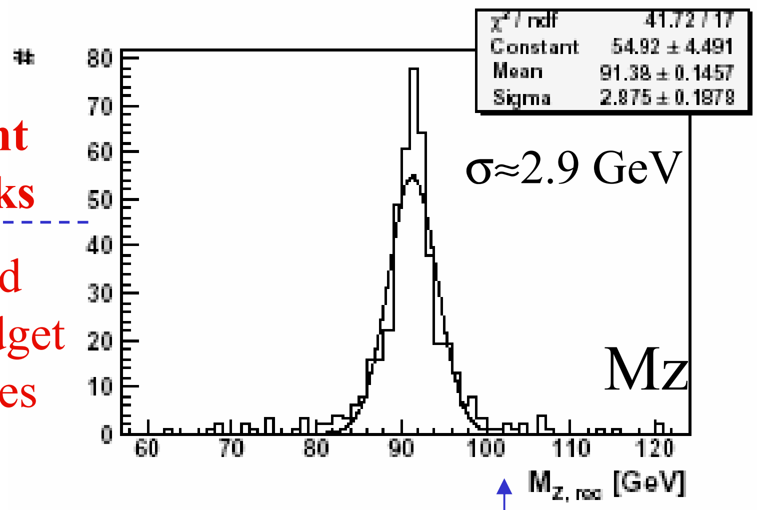
Mis-Alignment: Impact on Physics

⇒ Use $Z \rightarrow \mu\mu$ to illustrate the impact of mis-alignment on physics



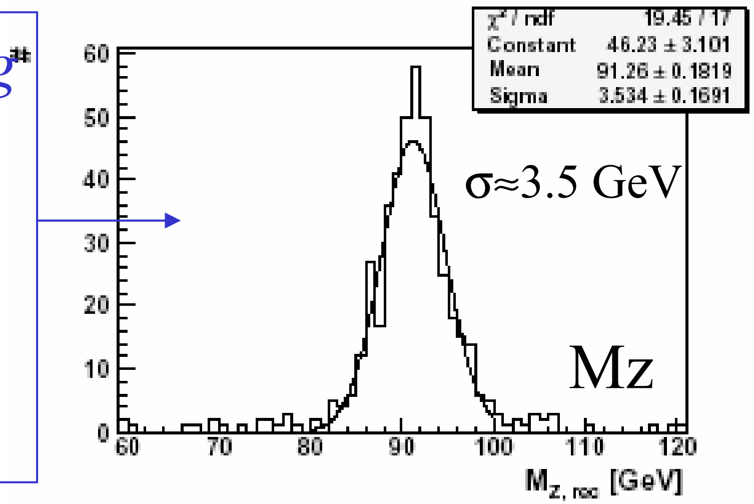
Alignment with tracks

B field and material budget uncertainties



First Data Taking
$<1fb^{-1}$

Laser Alignment
$\otimes$
Mechanical Constraints
⇒≈100µm alignment uncertainties

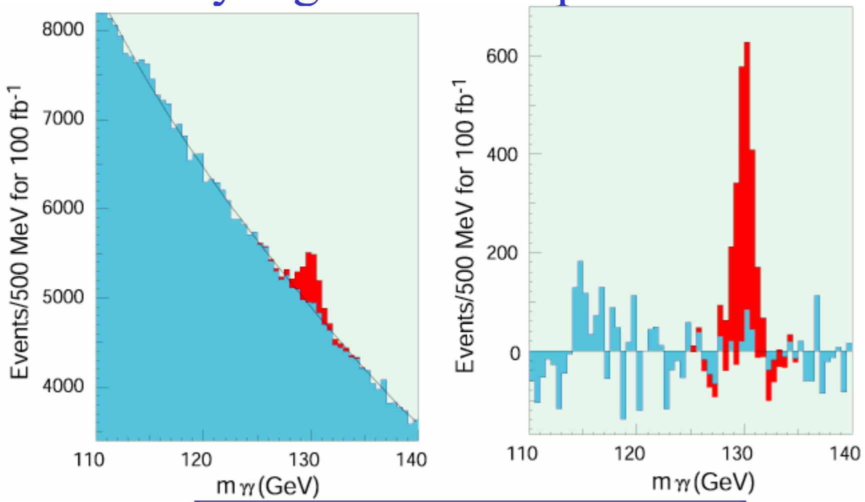


First Data Taking:
$\approx 1fb^{-1}$

First results of Alignment with tracks
⇒≈20µm alignment uncertainties

ECAL and HCAL

⇒ Key ingredient for precision measurements of γ, e, hadrons jets, E_t^{miss}…



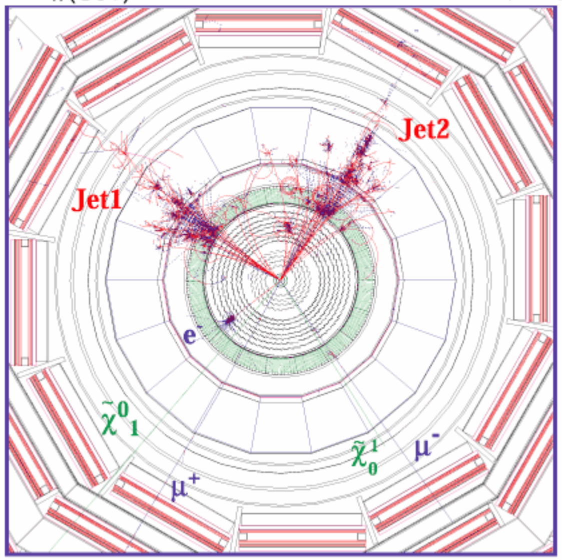
Physics processes (e.g. H→γγ) impose strictest performance requirements on the ECAL performance

Need precise energy calibration

E(GeV)=c x (ADC counts)

c = *conversion* x *laser_corr* x *intercalib*

Target 0.5% final precision for ECAL



Typical SUSY signatures involve leptons, jets and E_T^{miss}

“HCAL Primaries”:

- jet reconstruction (energy, direction)
- E_T^{miss} (|η|=5 coverage)

“HCAL Secondaries”

- particle ID in combination with other sub-systems

HCAL calibration target <2.0%

→ already achieved prior to physics collision

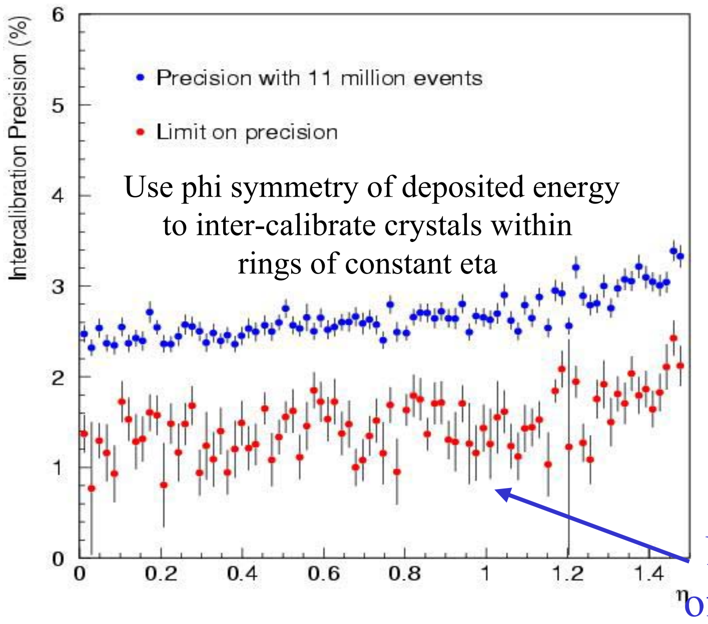
ECAL Calibration

E(GeV)=c x (ADC counts)

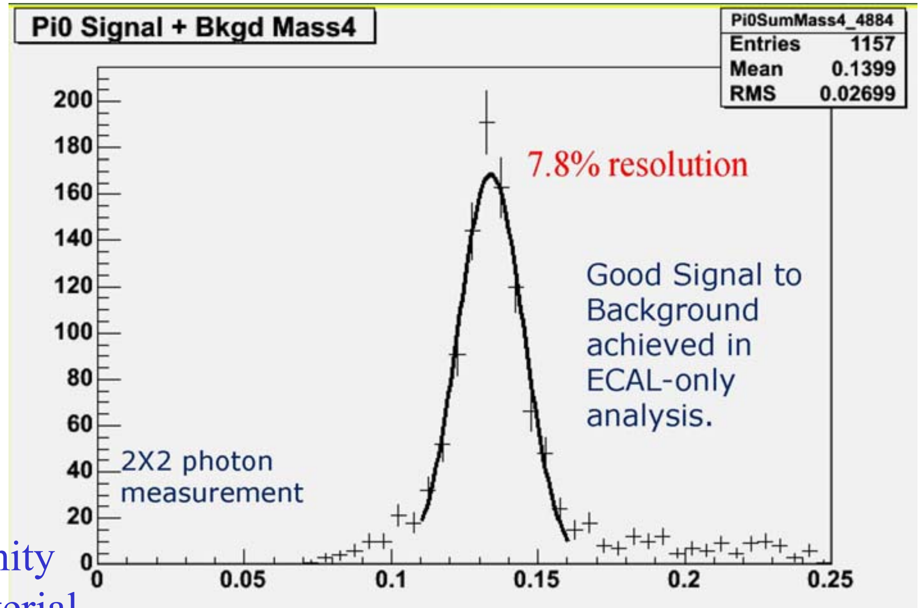
c = *conversion* x *laser_corr* x *intercalib*

Before data taking a pre-calibration based on test beam, light yield measurements and cosmic runs will give an inter- calibration accuracy at **4 %**
At start-up (Pilot Physics Run) few hours will be sufficient to reach a **1-2%** accuracy (utilize min.bias events from 1kHz calibration trigger):

Phi symmetry



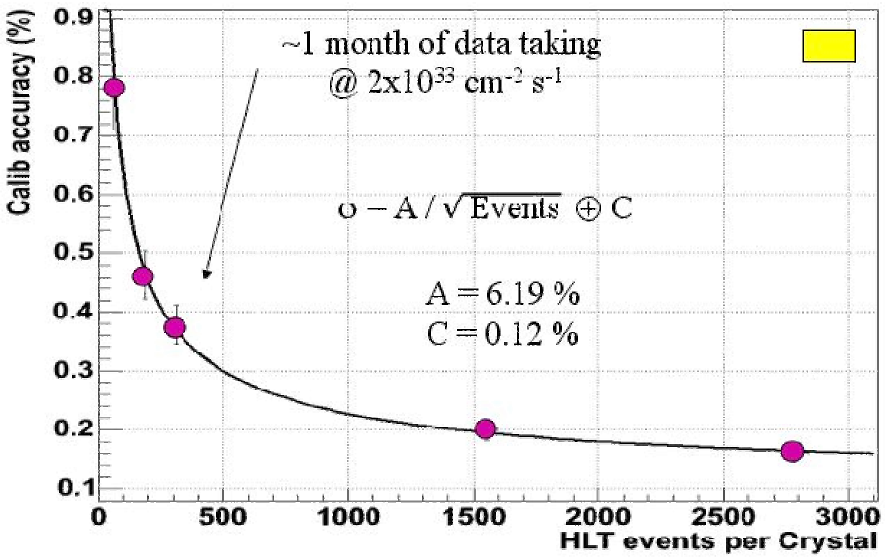
Two photon resonances

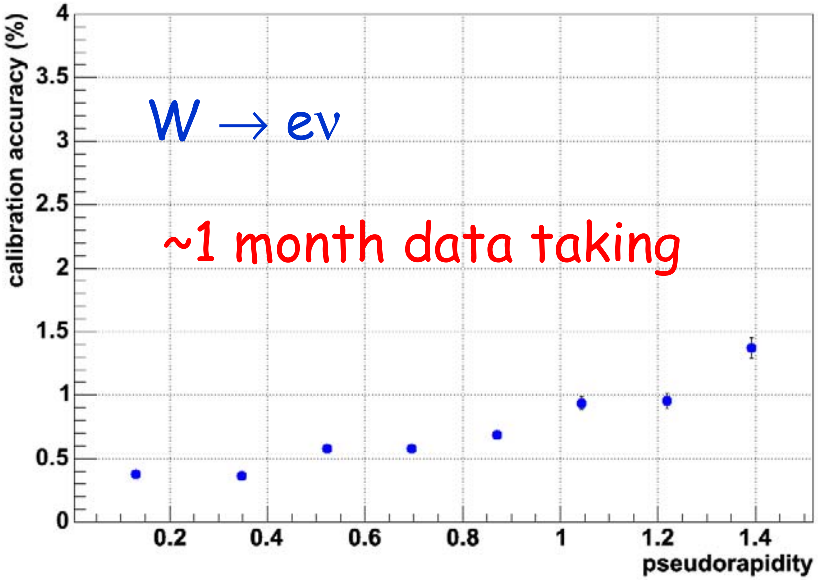


ECAL Calibration @ 0.5%

On a longer time scale (Physics Run 2008), events with isolated electrons (W ➔ eν, semileptonic b decays and Z ➔ ee) will give an accuracy up to **0.5%** using the tracker momentum as reference:

$$P(track) = \sum_{crystals} c^i E_i$$





Using the Z mass constraint, the Z → ee are less sensitive to tracker performance (B-field, material budget, alignment) and might give the absolute scale!

Early Physics @ CMS

We are currently in the process of preparing the CMS Physics TDR

- **Scope: 2 Volumes**
  - Volume 1 ("how to do")
    - Part 1: Detector performance and operations
    - Part 2: Physics reconstruction tools
    - Part 3: software and data issues
  - Volume 2 ("what can be done")
    - Part 1: "First-run" plans, $1fb^{-1}$ physics reach.
    - Part 2: full analyses, from raw data to physics.
    - Part 3: the physics of 10 and 30 fb^{-1}.
      include a chapter on 100 fb^{-1} and asymptotic (300 fb^{-1}) reach.
- **Schedule**
  - December 2005: Submit Vol 1
  - ~April 2006: Submit Vol 2

Very useful for testing the readiness of people, software, reconstruction tools, etc …
Will also result in refined expectations concerning the early physics reach of CMS.

(i.e analyses will include consistent and well defined systematic estimates, are based on full simulations, …)

Therefore, I will only touch briefly this subject (SM, SM Higgs).

SM Processes @ CMS

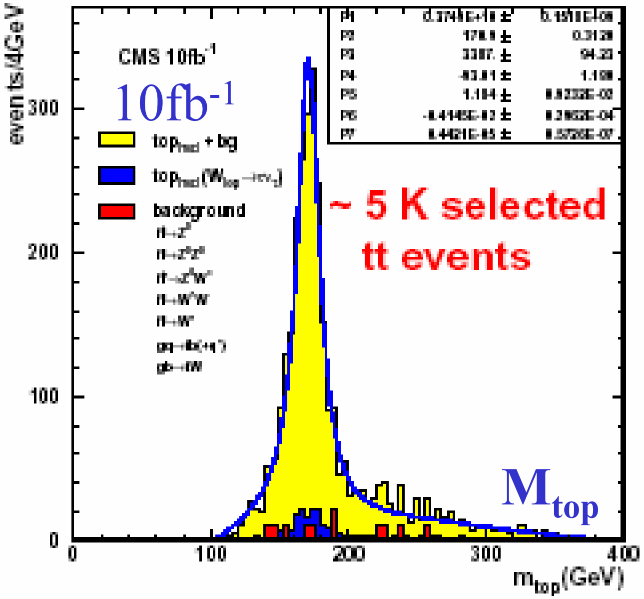
⇒ The first thing we need to understand/measure …

channel, NLO σ x Br	Level-1 + HLT efficiency	events for10 fb^{-1}
W->e ν, 20.3 nb	0.25	5.1×10^7
W->μν, 20.3 nb	0.35	7.1×10^7
Z->ee, 1.87 nb	0.53	1.0×10^7
Z->μμ, 1.87 nb	0.65	1.2×10^7
tt~->μ+X, 187 pb	0.62	1.2×10^6

Basic rates for W, Z, tt, …

Important for:

- calorimeter calibration, alignment, …
- the understanding of the major background sources for Higgs and SUSY searches such as Z+nj, W+nj, tt, …



Oliver Buchmueller CERN/PH
TEV4LHC workshop at CERN

Yet, there are also very exciting SM measurements!

Example: M_{top} from tt→WbWb→ bbqqlν

Ingredients:

- full kinematic reconstruction (utilize all constraints)
- b-tagging of jets
- isolated lepton + jet reconstruction + E_T^{miss}

⇒Target **ΔM_{top}~1GeV**
A clear challenge because this measurement is completely limited by systematic!
… looks like a perfect learn exercise …

Summary

⇒The "early physics performance" of CMS will strongly depend on a successful and speedy physics commissioning of the Experiment.

- A lot of the major commissioning tasks can already start during the ***Pilot Physics Run in 2007*** (i.e in parallel with the machine commissioning)
  - ECAL&HCAL calibration
  - Tracker&Muon alignment
  - efficient trigger operation
  - …
- In order to utilize the various data we need to put in place
  - trigger scenarios for Cosmic Muons, Beam Halo Muons, and Beam Gas Events
  - dedicated simulations for the individual process
- The physics commissioning will be finalized during the ***Physics Run in 2008***
  - final alignment (including PIXEL) and final calorimeter calibrations (including ECAL Endcaps) will be achieved by utilizing SM processes ($Z \rightarrow ll$, $W \rightarrow l\nu$, …)
  - "physics tools" like b and τ tagging, jets, E_t^{miss}, will be scrutinized/calibrated with various SM process
  - …

Conclusion

CMS has started to develop a comprehensive plan for physics commissioning.

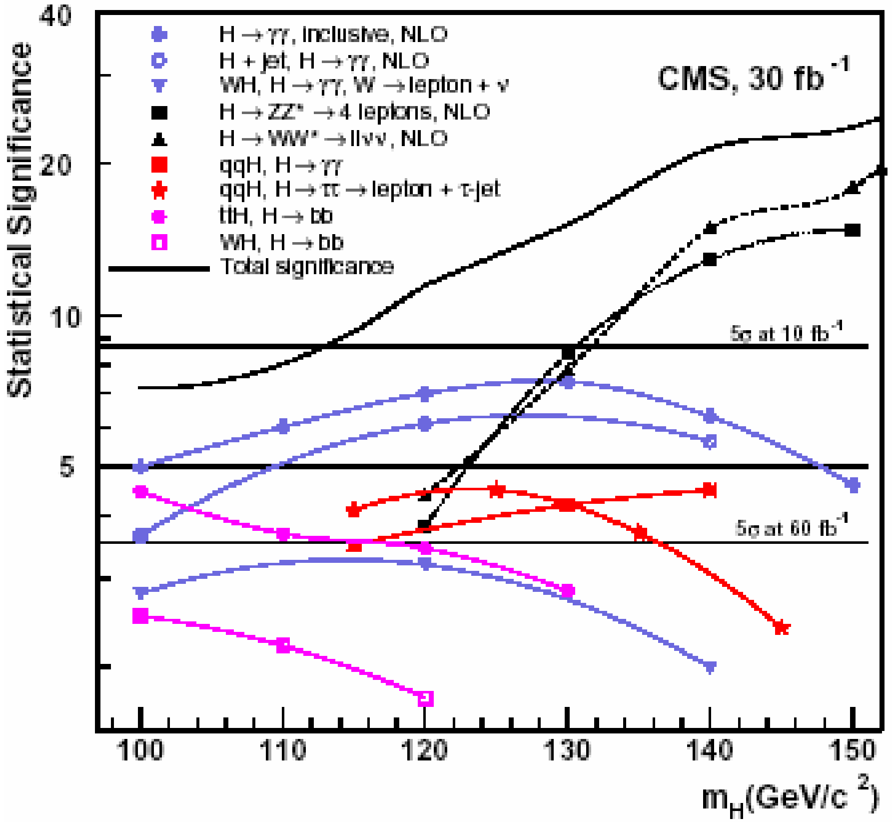
(Significant) Bits an pieces are sill under study but a much more refined commissioning concept will be made available in the forthcoming CMS Physics TDR!

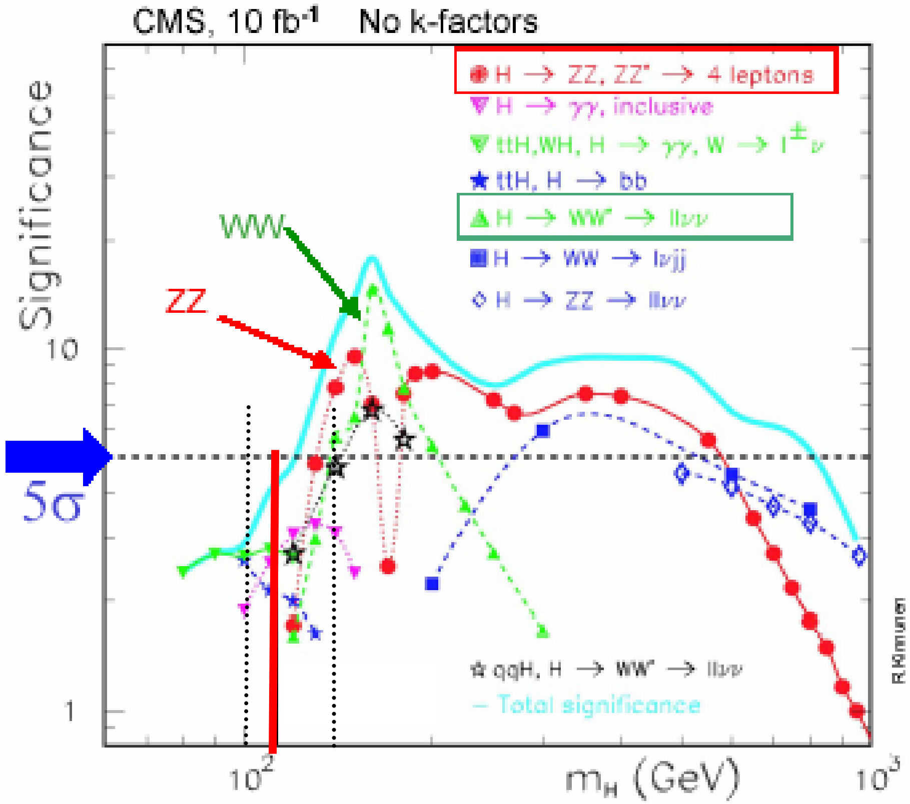
Backup Slides

LHC performance evolution

	Pilot Physics	75 ns	"1st Year"	Nominal	(Ultimate)
N_p^{Bunch} (x1E11)	0.1-0.4	0.4	0.3-0.5	1.15	1.67
N_{Bunch}	44/156	936	2808	2808	2808
β^* (m)	18/2	2/0.55	0.55	0.55	0.50
Luminosity	3E28-2E31	1-4E32	0.7-2E33	1E34	2.3E34
Events/BX	0.005-0.9	0.8-3	2-5	25	52
t_{BX} (ns)	2000/570	75	25	25	25
Θ_{cross} (μrad)	0	285	285	285	400
I_{beam} (mA)	0.8	6.7	150-250	580	850
$E_{stored/beam}$ (MJ)	0.5	4	90-155	360	530

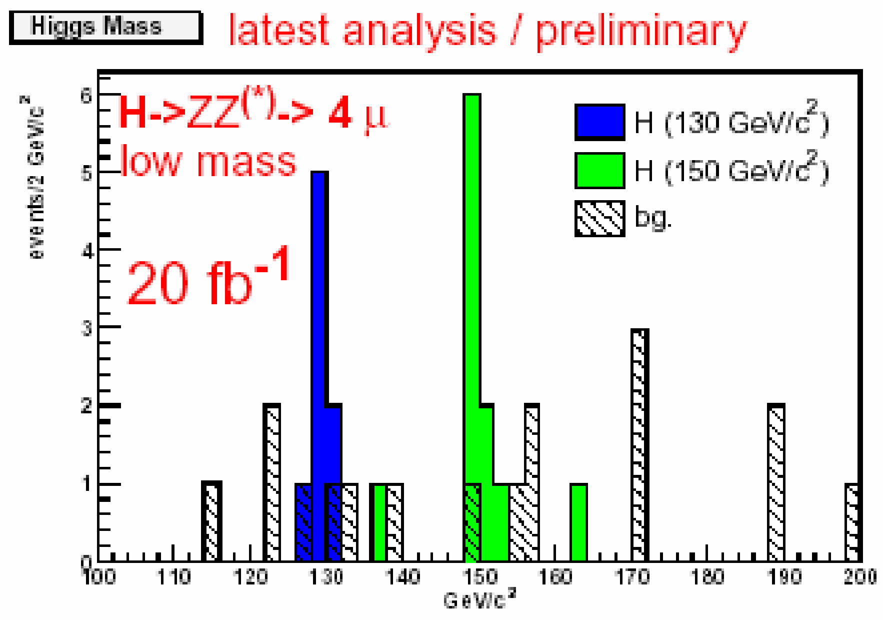
SM Higgs @ ~10 fb^{-1} - low Mass Region

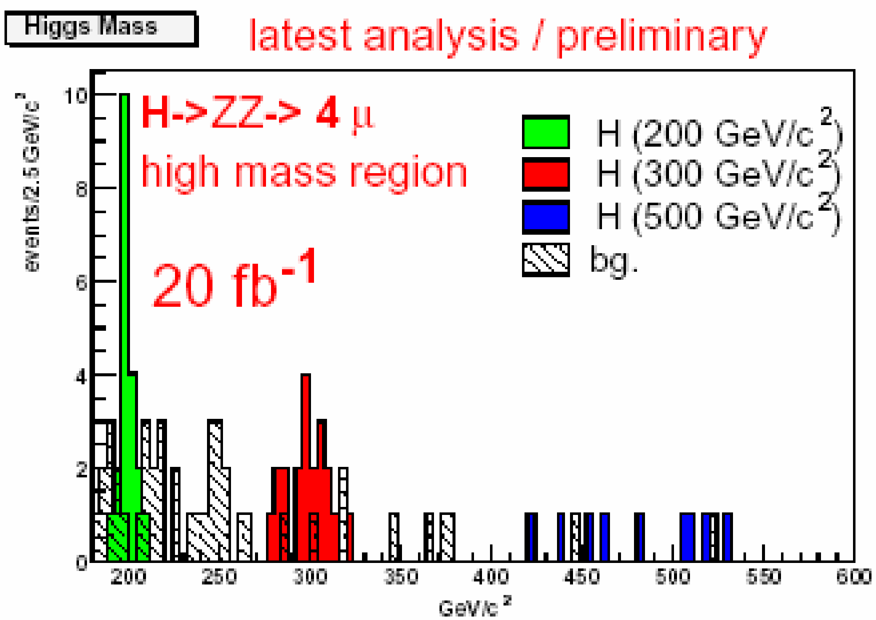




Discovery at low M_H (e.g <130 GeV) is tough!
For M_H > 130 GeV
$H \to ZZ^{(*)} \to 4l$ and $H \to WW^{(*)} \to 2l2\nu$
are the most promising discovery modes

H→ZZ$^{(*)}$ →4l





Statistics for 10 fb^{-1} . H->ZZ$^{(*)}$-> 4 l

H->ZZ$^{(*)}$->4 l	M_H=130 GeV/c^2	M_H=200 GeV/c^2
N Signal, 10 fb^{-1}	12.4	35.2
N Bkg., 10 fb^{-1}	3.1	12.5
Stat. significance	4.8 (Poisson)	10.0

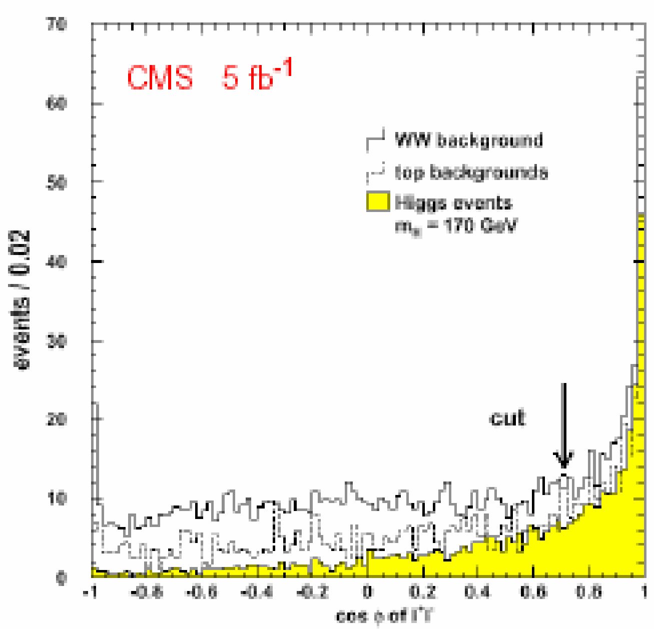
Very clear signature but analysis rests on well understood tracking and calorimeter isolation!
Need to study the impact of e.g. mis-alignment, material budget and B-field uncertainties.
Refined studies are underway for the CMS Physics TDR

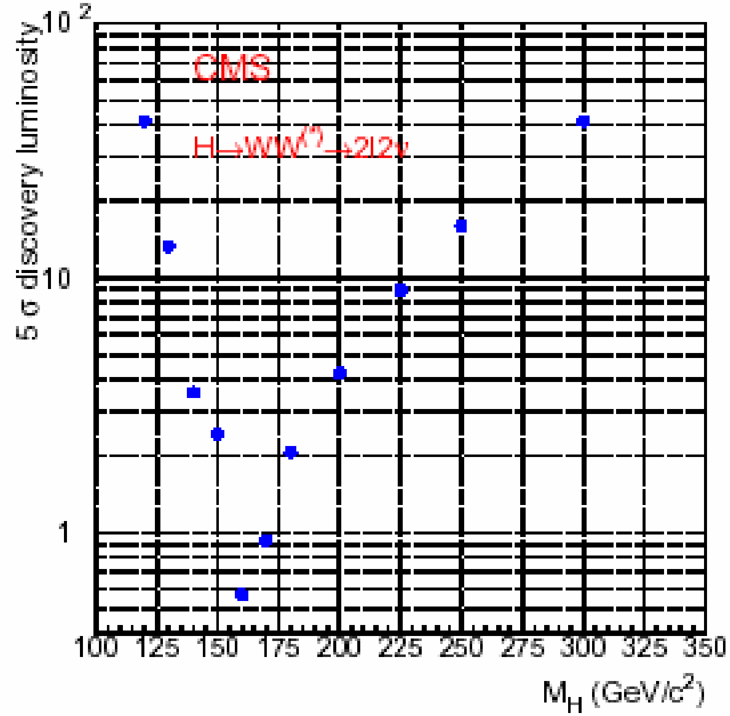
$H \rightarrow WW^{(*)} \rightarrow 2l2\nu$

Backgrounds: **tt, $WW^{(*)}$,Wtb**

Important ingredients:

- Tracking and calo. Isolation
- Jet veto (No jets E_T>20 GeV)
- WW spin correlation cut to reduce background



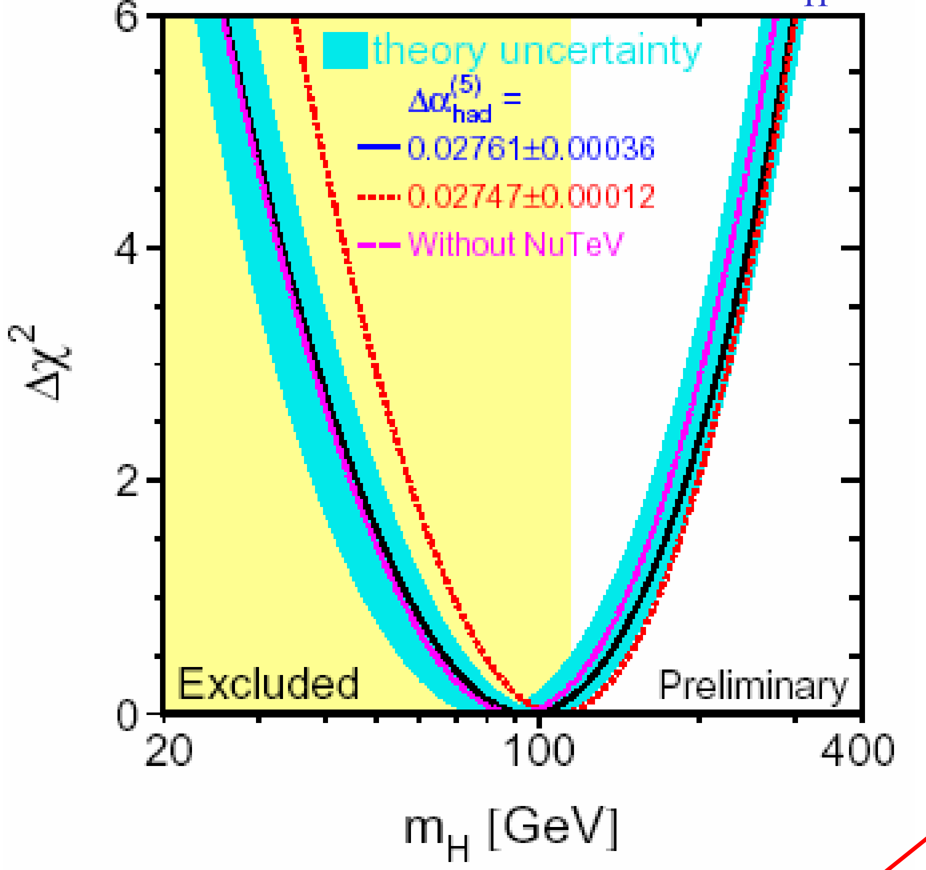


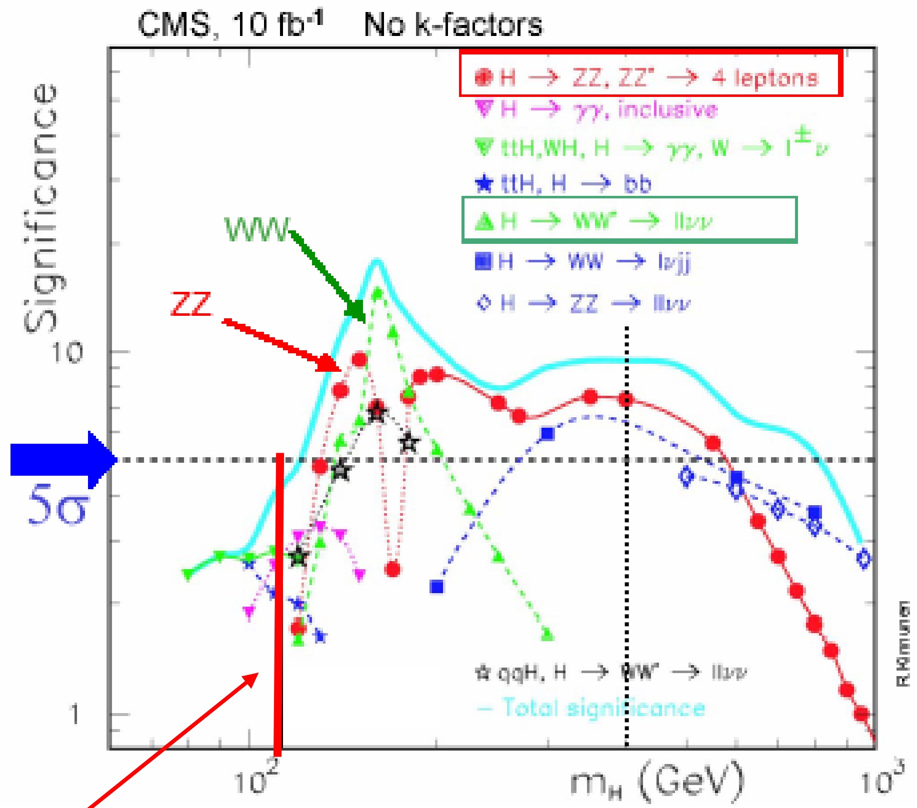
$H\text{->}WW^{(*)}\text{->}2l$	M_H=130 GeV/c^2	M_H=225 GeV/c^2
N Signal, 10 fb^{-1}	69	156
N Bkg., 10 fb^{-1}	254	686
Stat. significance	4.3	5.6

No systematic included!

SM Higgs @ ~10 fb^{-1}

LEP indirect/direct limits on M_H^{SM}





M_H^{SM}(LEP direct) >114 GeV

Bottom Line:
Substantial discovery potential
already with 10 fb^{-1}.
Though low mass region is a challenge!