SLHC – Physics motivation

Summary of reach and comparison of various machines ...

Only a few examples .... in many cases numbers are just indications ....

Units are TeV (except $W_L W_L$ reach)
$\int L dt$ correspond to 1 year of running at nominal luminosity for 1 experiment

PROCESS	LHC 14 TeV 100 fb^{-1}	SLHC 14 TeV 1000 fb^{-1}	28 TeV 100 fb^{-1}	LC 0.8 TeV 500 fb^{-1}	CLIC 5 TeV 1000 fb^{-1}
Squarks	2.5	3	4	0.4	2.5
$W_L W_L$	2σ	4σ	4.5σ	6σ	90σ
Z'	5	6	8	8†	30†
Extra-dim (δ=2)	9	12	15	5-8.5†	30-55†
q*	6.5	7.5	9.5	0.8	5
Λ compositeness	30	40	40	100	400
TGC λ_γ (95%)	0.0014	0.0006	0.0008	0.0004	0.00008

† indirect reach (from precision measurements)

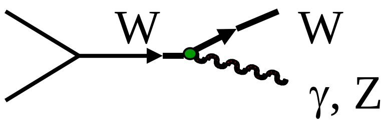
Approximate direct mass reach :
$\sqrt{s}$ = 14 TeV, L=10^{34} (LHC) : up to ≈ 6.5 TeV
$\sqrt{s}$ = 14 TeV, L=10^{35} (SLHC) : up to ≈ 8 TeV
$\sqrt{s}$ = 28 TeV, L=10^{34} : up to ≈ 10 TeV
$\sqrt{s}$ = 28 TeV, L=10^{35} : up to ≈ 11 TeV

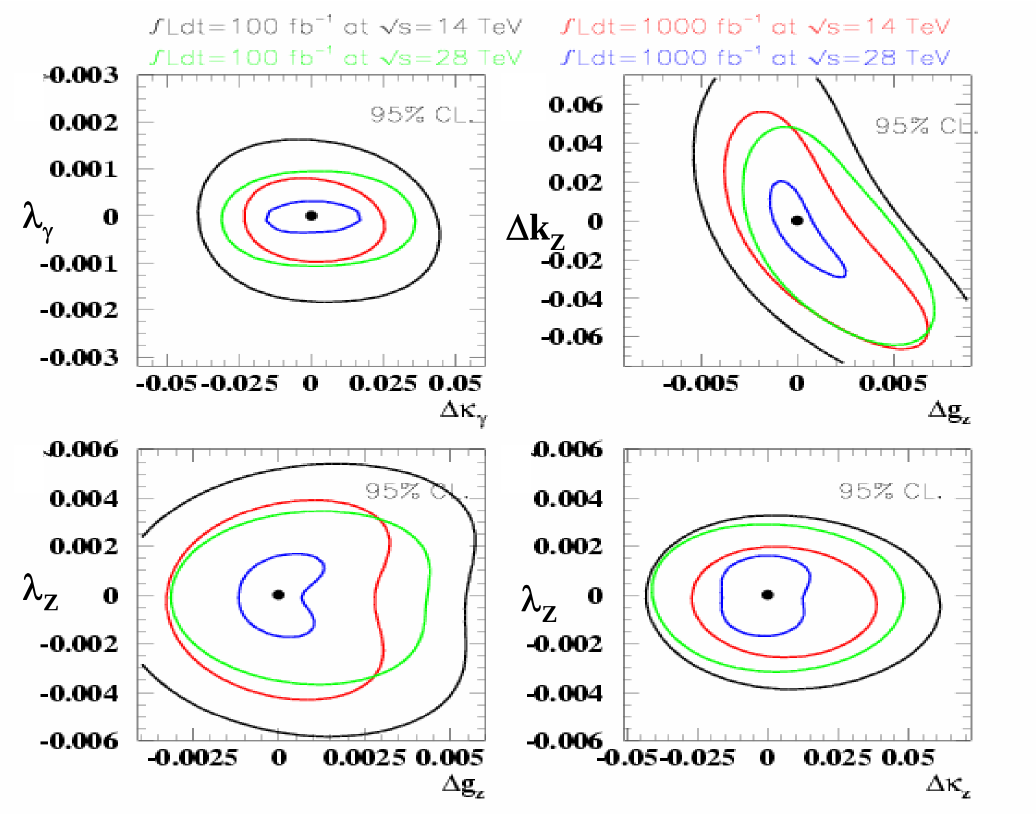
F. Gianotti, High Luminosity WG, 31/8/2004

SLHC – Physics motivation

- Extensive study done in 2002
  - hep-ph-0204087//Eur. Phys. J, C 39, 293-333 (2005)
  - L= 10^{35} bunch spacing 12.5 ns
- Larger pileup (x5)
  - dNch/dη per x-ing 150→750 (approaching HI run at LHC)
- Worse detector performance
  - Jet resolution ~ factor 2 worse
  - B-tagging ~ factor 8→2 worse improving with energy
  - e/jet separation at 40 GeV (W/Z) 40% worse

Example – Triple boson vertex





14 TeV 100 fb^{-1} 28 TeV 100 fb^{-1}

14 TeV 1000 fb^{-1} 28 TeV 1000 fb^{-1}

SLHC sensitivity at the level of SM radiative corrections

Example – Higgs couplings

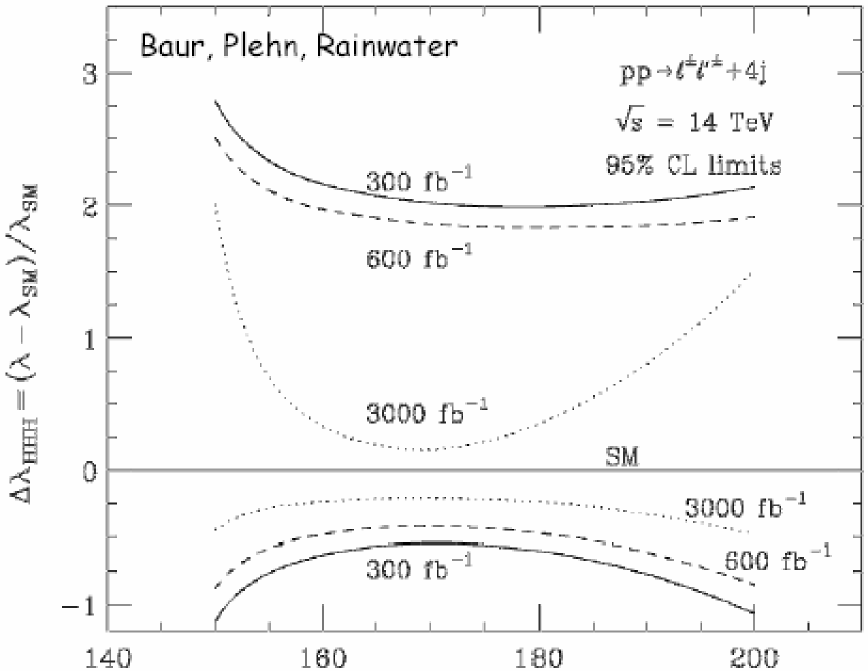
Rare Higgs decays at SLHC

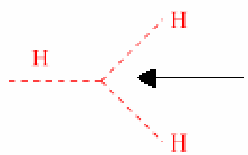
BR ~ 10^{-4} both channels

Channel	m_H	S/√B LHC (600 fb^{-1})	S/√B SLHC (6000 fb^{-1})
$H \to Z\gamma \to ll\,\gamma$	~ 140 GeV	~ 3.5	~ 11
$H \to \mu\mu$	130 GeV	~ 3.5 (gg+VBF)	~ 7 (gg)

→ additional coupling measurements : e.g. Γ_μ / Γ_W to ~ 20%

Higgs self-couplings at SLHC ?





~ λv
$m_H^2 = 2\lambda v^2$

$HH \to W^+ W^- W^+ W^- \to l^\pm \nu\ jj\ l^\pm \nu\ jj$

LHC: λ = 0 may be excluded at 95% CL.

SLHC: λ may be determined to 20-30% (95% CL)

Comparable to √s = 0.5 TeV LC , not competitive with CLIC (precision up to 7%)

SLHC – Physics motivations

- Physics reach of SLHC larger than LHC in many relevant channels
- Difficult to say today – before LHC – if this is a fundamental step for discovery of new physics or if this is a consolidation of the physics program of LHC
- In both scenario SLHC is very attractive and is a natural upgrade of the LHC program

SLHC reach and experimentation

- Experimentation at LHC will be more difficult due to the large increase in pile-up
- The physics reach is the result of a compromise between LARGE increase in integrated luminosity and worse detector performance
- What is relevant is not running at 10^{35} (bad for the detectors) but integrating 1000 fb^{-1} per year (good for physics)

SLHC : ATLAS and CMS

- Both experiments have started in 2005 a SLHC project with a number of workshops aimed to
  - discuss technical aspects and
  - define a "supported" R&D program

- Main technical challenges :
  - Radiation – especially in the forward region
  - Tracking
  - Integration
    - of machine elements
    - of services in the existing space

Thanks: S. Tapprogge, J. Nash, F. Palla

General Strategy for the upgrade

- **Most detector systems will survive and continue to operate without changes to (inaccessible) electronic systems (After many years of LHC operation they will be quite stable)**

- Major exceptions
  - **Trackers -** which are expected to be replaced for SLHC
  - **Integration of Machine elements** (Forward regions)
  - **Electronics** – depending on bunch crossing frequency
  - Shielding

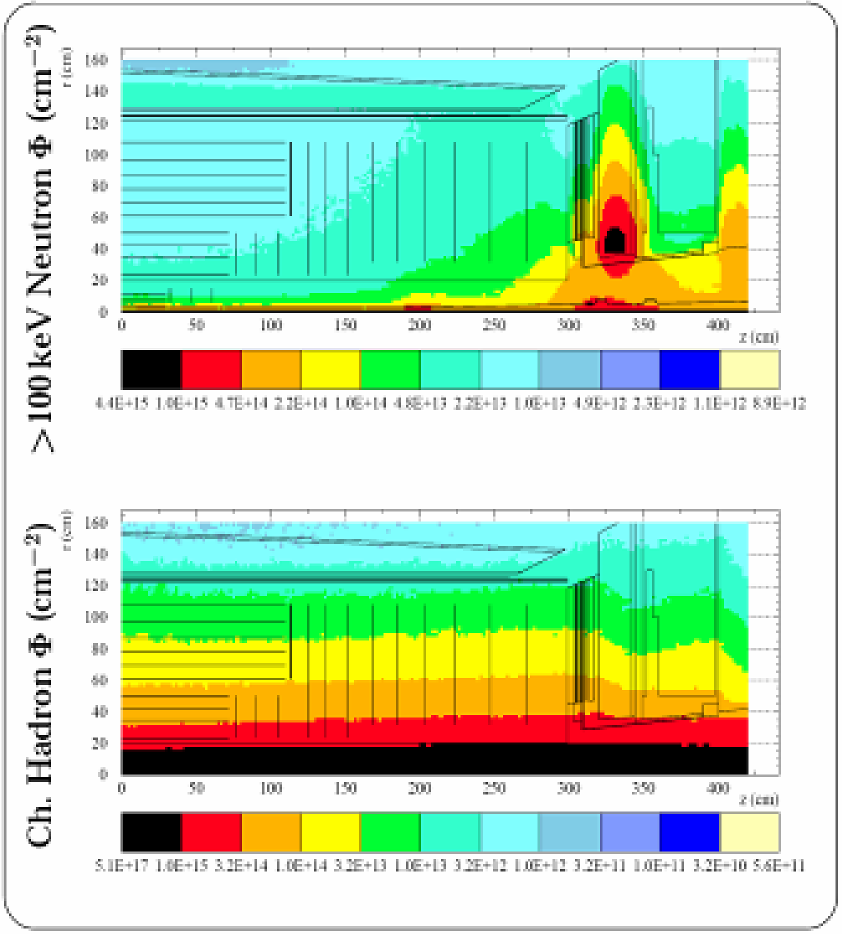
Radiation Issues in CMS (similar in ATLAS)

Values for integrated Lumi = 2500 fb^{-1}

Pixel:	4 cm layer:	Fast hadrons:	1.6×10^{16} cm^{-2}
		Dose :	4.2 MGy
	11 cm layer:	Fast hadrons:	2.3×10^{15} cm^{-2}
		Dose :	940 kGy

Tracker:	22 cm :	Fast Hadrons:	8×10^{14} cm^{-2}
		Dose :	350 kGy
	75 cm :	Fast Hadrons:	1.5×10^{14} cm^{-2}
		Dose :	35 kGy
	115 cm :	Fast Hadrons:	1×10^{14} cm^{-2}
		Dose :	9.3 kGy

Fluences in Inner Detectors (2500 fb^{-1})

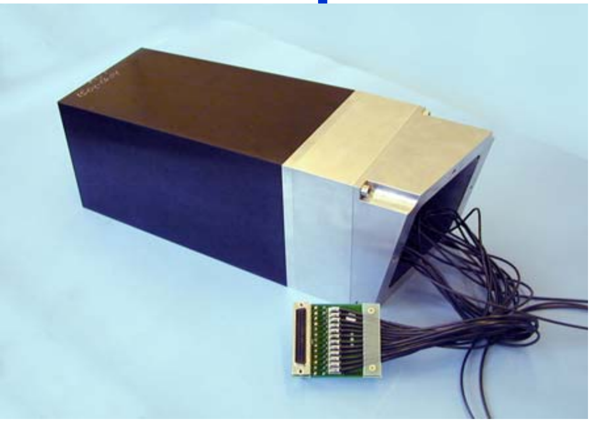


M. Huhtinen *SLHC Electronics Workshop 26 February 2004* 4

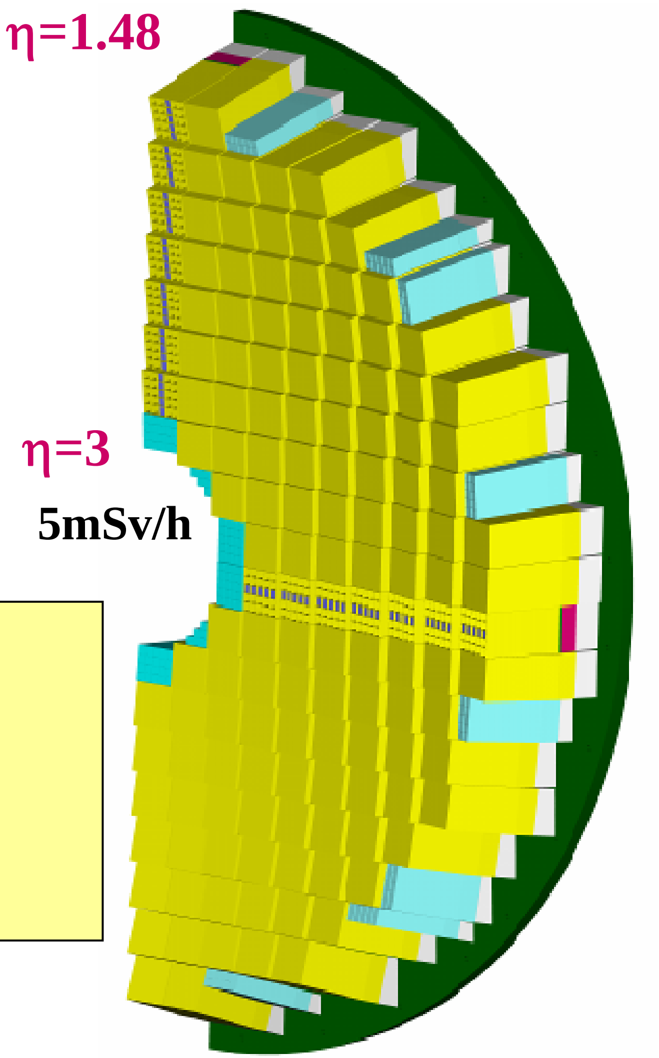
Radiation tolerance of current pixel system can be pushed to 3×10^{15} cm^{-2}

We will know more after first LHC runs when the radiation field will be measured

ECAL Endcaps



Unshielded dose rate*
0.2mSv/h



Supercrystals and their internal components are inaccessible and cannot be replaced.

Repair of Supercrystal array would require the dismounting of readout electronics on rear of backplate

High activation levels, access time limited

*3300 fb^{-1}

Tracker Upgrade

- Existing detectors designed to survive 10 years of LHC = 300 fb^{-1} (but radiation changes by ~ 20 between R=10 cm and R= 50 cm)
- Occupancy x5 is an important new parameter

CMS Tracker 10^{34}:

Pixel occupancy 10^{-4}

SST Occupancy at R=20 cm 1% (10 cm strips)

SST Occupancy at R=60 cm 0.3 % (20 cm strips)

Tracker Upgrade

- Higher granularity and more pixels are required
- **Power requires major effort & new ideas**
  - Chip voltages reduce with technology evolution, currents may (??), but number of channels will not
  - Need to bring increased total currents through volumes which can't expand
- Material budget should not increase
- Large systems are hard to build
  - Qualification must be taken seriously
  - True industrial production is likely to be required
- Sensors are one of many issues
  - Any new material technology must be large-scale commercial within ~5 years

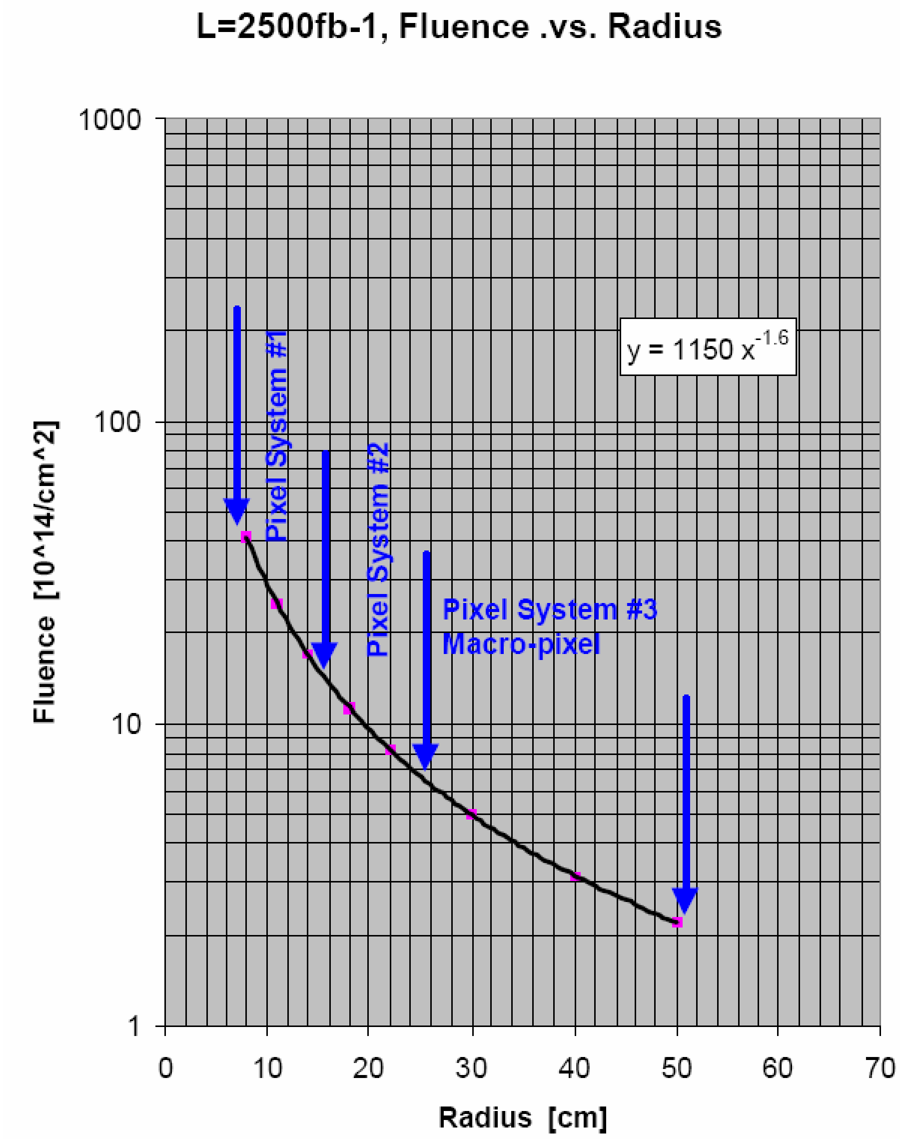
RD50 sensor R&D

- Electronic technology evolution will bring benefits
  - and also more complexity and much difficult work

First ideas for SHLC Tracker

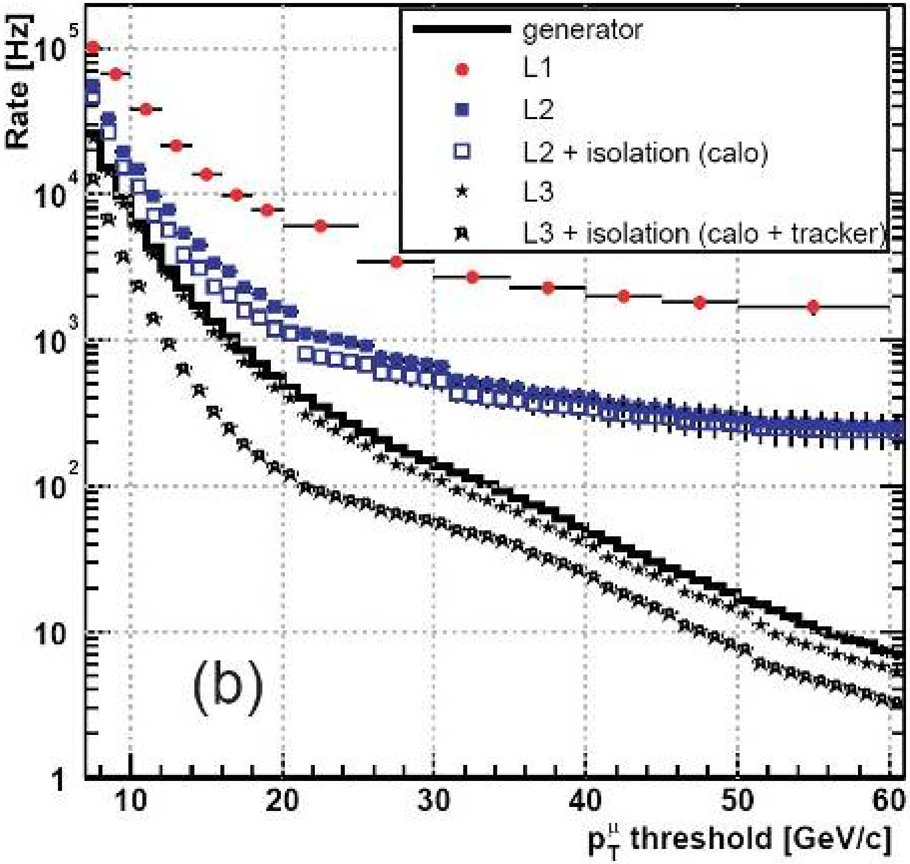
Pixels of different area that are adapted to fluence/rate and cost levels

- **Pixel #1 max. fluence system**
  - **~400 SFr/cm²**
- **Pixel #2 large pixel system**
  - **~100 SFr/cm²**
- **Pixel #3 large area system**
  - **Macro-pixel ~40 SFr/cm²**



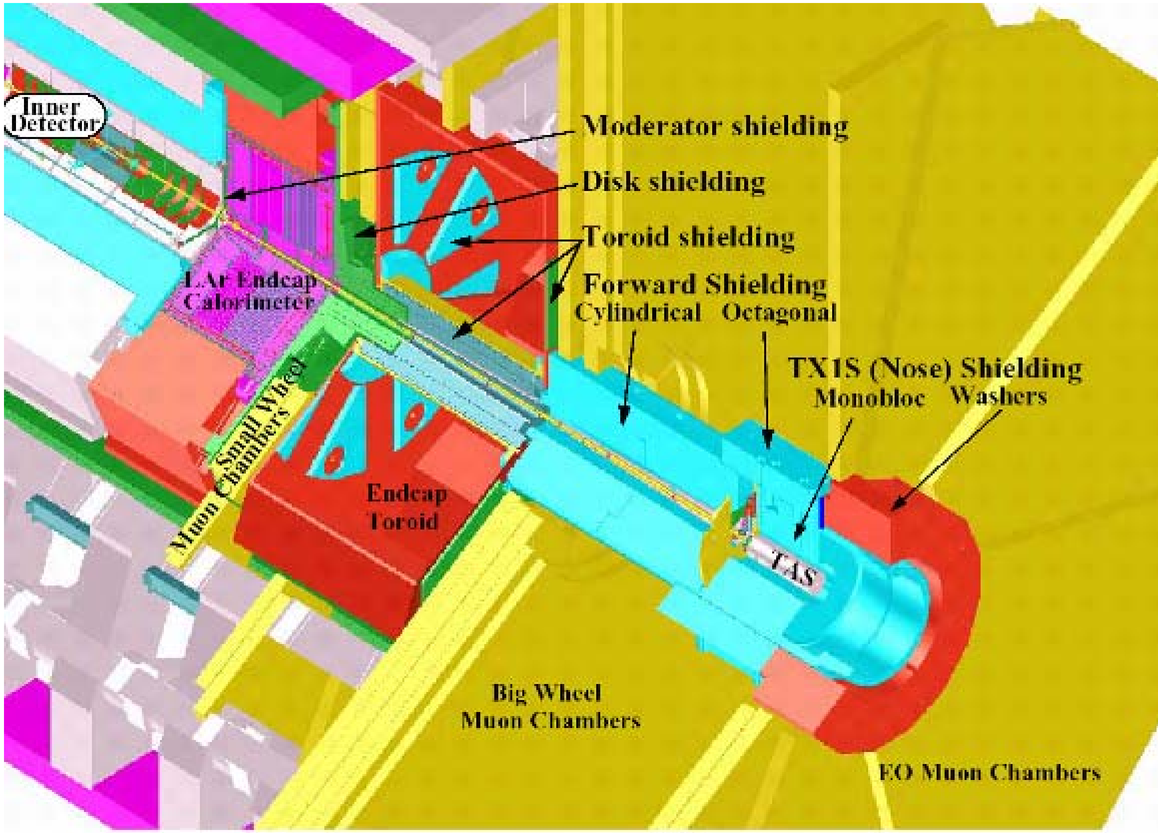
CMS : Tracker Trigger at L1 ?

- Muon L1 Trigger rate at L = 10^{34} $cm^{-2}\ s^{-1}$
- Note limited rejection power (slope) without tracker information
- Must develop Tracker Trigger at L1
  - Export some HLT algorithms to L1?
  - Lot of activities going on



Shorter β*: ATLAS layout

- ATLAS layout in forward region
  - Detectors (muon chambers) close to the cavern wall
  - Shielding around the beam pipe
    - Goal: reduce accidental background rates in muon system
  - Crowded area
    - Careful studies needed for additional objects
- Access scenario relies on space available to move detector components



Shorter β^*

- Questions to be addressed
  - Impact of moving machine elements closer to the IP
    - Backsplash of particles from absorber protecting the focusing quadrupoles and its impact on background rates in the experiment
    - Changes in the shielding
    - Activation of machine elements and restrictions arising in access scenarios
    - Removal of (well aligned) machine elements each time a longer access will be necessary and have to be possible
  - Very small focusing quads inside the experiment (a la HERA)
    - **Need a concrete example of a mechanical layout / envelopes of the elements as well as of the services necessary to study possible implications**

Bunch spacing

- One of the most crucial parameters determining issues in the upgrade of electronics
  - General preference for higher luminosities is to have shorter bunch spacing (dominantly for the tracking)
    - Reduce number of minimum bias events in same crossing
    - Ease pattern recognition in tracking detector
  - Tracking detector front-end electronics to be designed to the actual bunch spacing value
- Reduced bunch spacing
  - Bunch spacing of 12.5 ns
    - could allow to keep most of the front-end electronics (calorimeter and muon system) running at 40 MHz
  - Bunch spacing of 10 or 15 ns
    - Need to change Electronics on calorimeters and muons. Imply an important of work and costs
  - In both cases, no optimal use made of reduced bunch spacing
    - Expect still good performance
- Trigger/DAQ will need to be changed and in particular Lvl 1 parts need to be (partly) rebuilt (I assume this will in any case evolve with technology)

This issue should be quantified for each subdetector element

Upgrade schedule

- Installation of an upgraded tracking detectors will be a major operation
  - First estimates: about one year (at least)
  - But a number of other changes will be done adiabatically

- Questions to be addressed
  - Optimal point in time to make a detector upgrade
    - Relate to major upgrades in the machine, i.e. the interaction region upgrade?
  - Optimize integrated luminosity accumulated before and after upgrade
    - Take into account possible degradation of detector (ageing, radiation damage, performance limitation at larger instantaneous luminosities) and limitations from the machine

Summary

- SLHC Physics case very interesting
- Discussions on SLHC upgrade have started in ATLAS and CMS.
- (Inner) Trackers will be re-built
- Integration of machine elements in the detectors: need of a concrete proposal to be studied. Together with optimization of shielding and activation and access scenario.
- Bunch spacing: experiments should study the consequences of 10 and 15 ns for each of the existing subsystems. 75 ns reduce significantly the performance of the experiments