R&D pour le LHC Haute Luminosité

- Rappel SLHC
- R&D des détecteurs de CMS pour le SLHC
  - Trajectographe
  - Calorimètre Electromagnétique
  - LVL1 Trigger
- Electronique des détecteurs pour le SLHC
- Conclusions …

References

Large Hadron Collider Project

LHC Project Report ??

LHC Luminosity and Energy Upgrade: A Feasibility Study

O. Brüning[§], R. Cappi[‡], R. Garoby[‡], O. Gröbner[†], W. Herr[§], T. Linnecar[§], R. Ostojic[†], K. Potter[*], L. Rossi[†], F. Ruggiero[§] (editor), K. Schindl[‡], G. Stevenson[¶], L. Tavian[†], T. Taylor[†], E. Tsesmelis[*], E. Weisse[§], and F. Zimmermann[§]

CERN-TH/2002-078
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April 1, 2002

PHYSICS POTENTIAL AND EXPERIMENTAL CHALLENGES OF THE LHC LUMINOSITY UPGRADE

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CMS Workshop on Detectors and Electronics for SLHC

PROPOSED AGENDA

[last update: Friday 05 March 2004]

Thursday 26 February 2004 09:00->19:00	no title	(40-S2-A01)
Friday 27 February 2004 09:00->18:00	no title	(40-S2-A01)

Date/Time: from Thursday 26 February 2004 (09:00) to Friday 27 February 2004 (18:00)
Location: CERN - VRVS SUN
Room: 40-S2-A01
Chairperson: T. Virdee / P. Sharp

Thursday 26 February 2004

(09:00->19:00) **Location:** CERN **Room:** 40-S2-A01

09:00	**Introduction and Welcome** (document more information)	T. Virdee
09:15	Overview of SLHC **The Physics case and Timescales for SLHC** (transparencies)	**D. Denegri** *(Saclay)*
09:45	**Accelerator Upgrades** (transparencies)	Oliver Bruening *(CERN)*
10:15	**Radiation Considerations** (transparencies)	Mika Huhtinen *(CERN)*
10:45	Coffee Break	
11:15	Review of CMS Detectors	Roland Horisberger

The Machine Upgrade

What is a Super LHC ?

Upgrade luminosity – target $L = 10^{35}$ cm^{-2}s^{-1}

Upgrade energy – up to 28 TeV !

This talk deals with the option that has

moderate extra cost (10-15%) relative to initial LHC investment

would be implemented ~ 5-6 years after LHC physics startup

Upgrade in 3 main Phases:

- Phase 0 – maximum performance without hardware changes
- Phase 1 – maximum performance while keeping LHC arcs unchanged
- Phase 2 – maximum performance with major hardware changes to the LHC

Reminder: LHC Nominal baseline parameters: $L = 10^{34}$ cm^{-2}s^{-1} @ 7 TeV @ $1.1.10^{11}$ p/bunch

Phase 0

Phase 0 – maximum performance without hardware changes

1) Collide beams only in IP1 and IP5 (no collisions in IP2 and IP8)

2) Increase protons/bunch up to ultimate intensity ($1.7.10^{11}$ p/bunch)

$\Rightarrow$ ***L* = 2.3 10^{34} $cm^{-2}s^{-1}$**

3) Optionally increase main dipole field to 9T (ultimate field) **E → 7.5 TeV**

Phase 1

Phase 1 – maximum performance while keeping LHC arcs unchanged

Change LHC insertions and/or injector complex

1) Reduce β^* (from nominal 0.5 m to 0.25 m, say)

2) Increase crossing angle (from nominal 300 μrad by a factor of about $\sqrt{2}$)

3) Increase protons/bunch up to ultimate intensity ($1.7.10^{11}$ p/bunch)

$\Rightarrow L = 3.3\ 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

4) Halve bunch length (new RF system) $\Rightarrow$ $\boldsymbol{L = 4.7\ 10^{34}\ \mathrm{cm^{-2}s^{-1}}}$

Phase 2

Phase 2 – maximum performance with major hardware changes to the LHC

1) Reduce β^* (from nominal 0.5 m to 0.25 m, say)
2) Increase crossing angle (by a factor of about $\sqrt{2}$)
3) Increase protons/bunch up to ultimate intensity

   $\Rightarrow L = 3.3\ 10^{34}\ cm^{-2}s^{-1}$ (not beam-beam limited)
4) Halve bunch length $\Rightarrow L = 4.7\ 10^{34}\ cm^{-2}s^{-1}$
5) Double number of bunches $\Rightarrow$ **$L = 9.4\ 10^{34}\ cm^{-2}s^{-1}$**

- (5) is thought to be v. difficult due to the electron cloud effect.
- Reach ~ 10^{35} by employing a superbunch (300m long) but probably excluded from point of view of experiments (higher no. of superbunches ?).
- Another way is to equip SPS with s.c. magnets and inject into LHC at 1 TeV ⇨ increase LHC luminosity by factor ~ 2.

Scenario de base pour le workshop

- 1 année pleine lumi au LHC = 100 fb^{-1}
- 1 année pleine lumi au SLHC = 1000 fb^{-1}
- 2008-2010 montée en lumi du LHC
- 2011-2013 régime pleine lumi LHC
- … à partir de 2013 passage à SLHC
- … il est (déjà) temps de penser à l'upgrade de CMS !

R&D des détecteurs de CMS pour le SLHC

Detectors: General Considerations

	LHC	SLHC
$\sqrt{s}$	14 TeV	14 TeV
L	10^{34}	10^{35}
Bunch spacing Δt	25 ns	12.5 ns *
σ_{pp} (inelastic)	~ 80 mb	~ 80 mb
N. interactions/x-ing	~ 20	~ 100
(N=L σ_{pp} Δt)		
$dN_{ch}/d\eta$ per x-ing	~ 150	~ 750
$\langle E_T \rangle$ charg. particles	~ 450 MeV	~ 450 MeV
Tracker occupancy	1	10
Pile-up noise in calo	1	~3
Dose central region	1	10

Normalised to LHC values.

10^4 Gy/year R=25 cm

In a cone of radius = 0.5 there is E_T ~ 80GeV.

This will make low E_t jet triggering and reconstruction difficult.

Trajectographe

Conclusions du rapport du groupe de travail

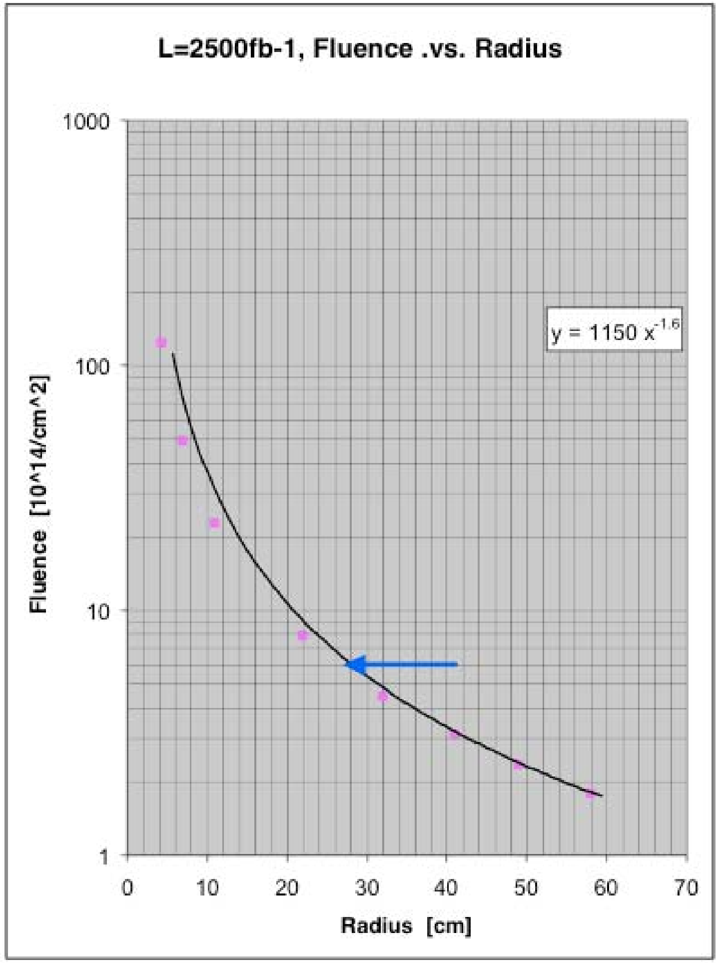
- « We conclude that the only viable solution is to completely rebuild the Inner Detectors system of ATLAS & CMS »
  - R > 60 cm « push the existing technology of microstrips »
  - 60 > R > 20 cm « further developped hybrid pixels »
  - R < 20 cm « new approaches »

Situation au SLHC

SLHC situation

- use 5x TDR fluencies
- old fluence limit of $6x10^{14}/cm^2$
  → r_{min} ~ 26cm !! Problem!
- What can we do?
  - Change detector more often
  - Improve fluence limit off sensor
- Need to study sensors more !

  → RD50



Proposition de R. Horisberger au workshop

- R&D pour pousser la technologie des 'double sided' pixels de 1 X 10^{15} à 3 X 10^{15}
- 3 systemes de Pixels:
  - Pixels # 1 = 3 layers 8, 11, 14 cm 'double sided n^+ on n-silicon', coût cible 400CHF/cm^2
  - Pixels # 2 = 2 layers 18, 22 cm 'single sided n^+ on p-silicon', coût cible 100CHF/cm^2
  - Pixels # 3 = 3 layers 30, 40, 50 cm 'DC coupled macropixels(ie 200 um X 500 um) p^+ on n-silicon', coût cible 40CHF/cm^2

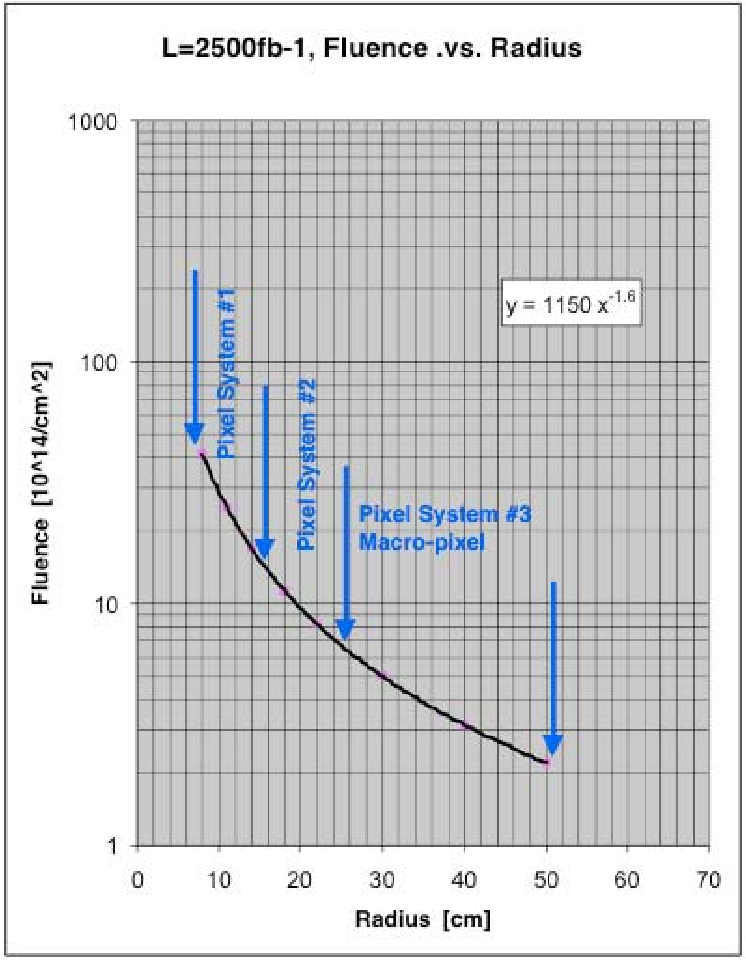
Résumé de R. Horisberger

Summary

- Propose 3 Pixel Systems 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

- 8 Layer pixel system can eventually deal with 1200 tracks per unit pseudo – rapidity
- Use cost control and cheap design considerations from very beginning.
- Can this be done for 2012/13 ????

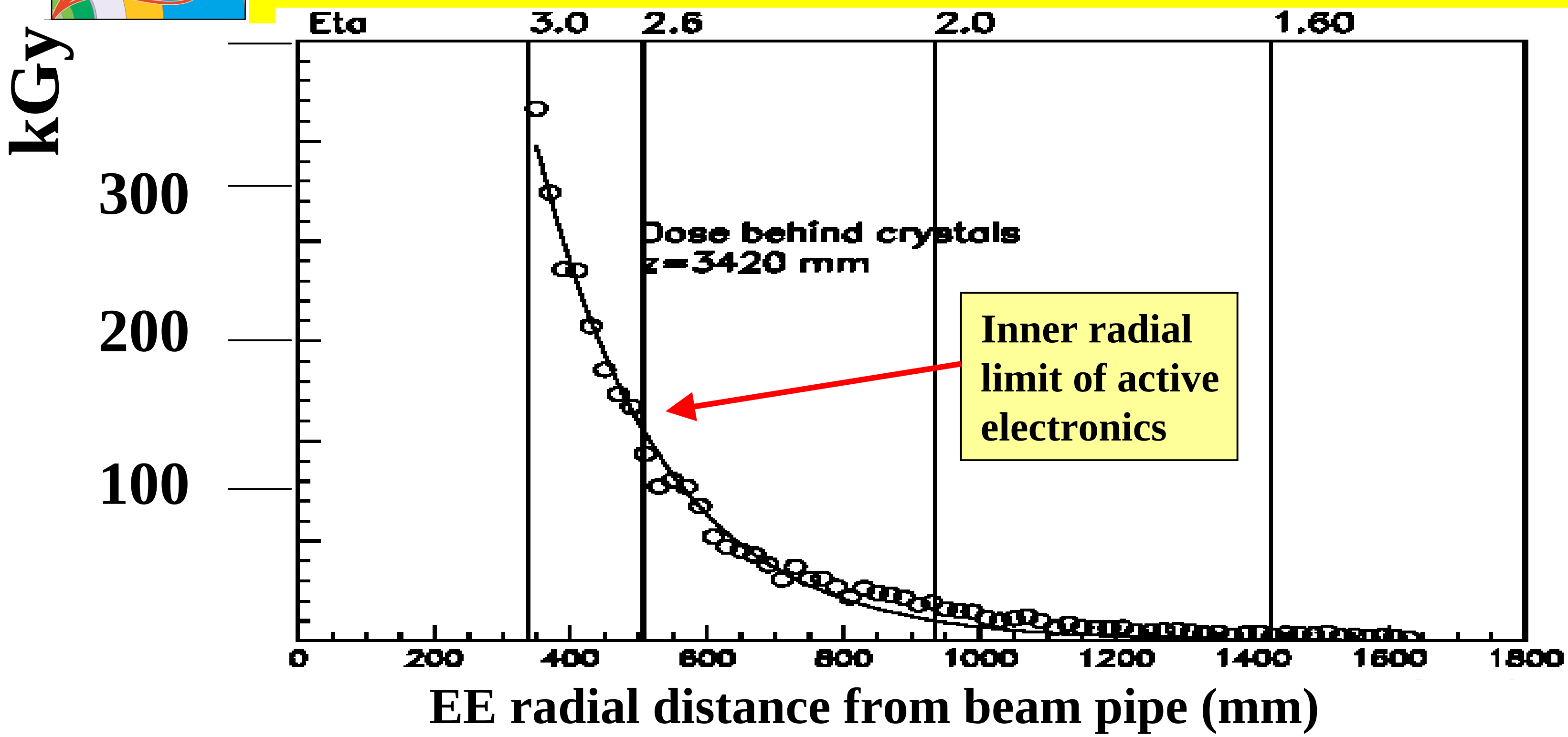


Calorimètre Electromagnétique

Scenario de base pour ECAL

- On garde en «l' état » … et on voit les effets

EE Integrated Dose for 3300 fb^{-1}



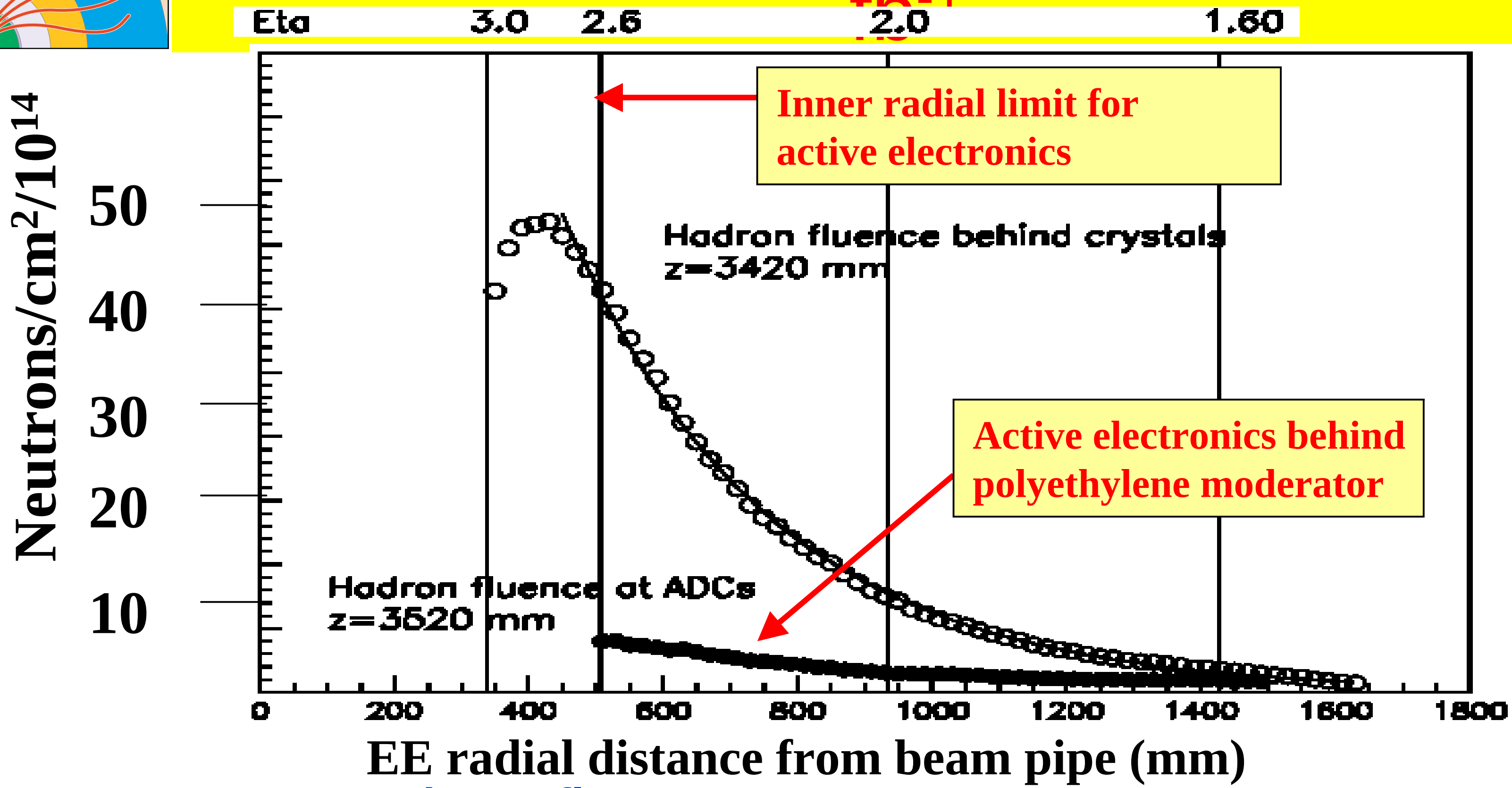
Maximum Dose at η = 3 **350kGy (35MRad)**

SCs, VPTs, HV pcbs (capacitors, resistors), HV/LV cables, monitoring fibres

Maximum Dose at η = 2.6 **150kGy (15MRad)**

Active ECAL readout electronics

EE Integrated Neutron Fluence for 3300 fb^{-1}



Maximum fluence at η = 3
$5.10^{15}/cm^2$

SCs, VPTs, HV pcbs (capacitors, resistors), HV/LV cables, monitoring fibres

Maximum fluence at η = 2.6 **$5.10^{14}/cm^2$**
Active ECAL readout electronics

Supercrystal items, Co^{60} Irradiation tests

Eta (SLHC equivalent)	2			2.6			3			
Dose (kGy)	20-50	100		200		300	350	400		500
VPT faceplates										
VPTs										
DC 3145 VPT-xtal glue										
HT cable, 2KV, LO-GE No461										
RG 179PE signal cable	(not final choice)									
Capacitors (HV, unbiase	5									
Capacitors (HV, biased)	5									
Resistors (HV,LV)	20					2 to 362kGy				
Thermal compound										
Carbon fibre alveolar composite strength tests								to 5MGy!!		

All tests so far OK – no show stoppers, capacitors (unbiased) 9% change

To do in 2004:

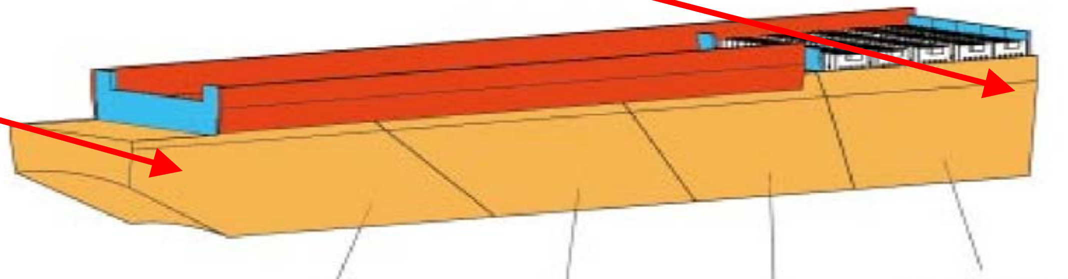
VPTs, faceplates, capacitors and resistors to 500 kGy

Brunel University source, 1kGy/h, ~ 21 days

EB at SLHC for 3300 fb^{-1}

Dose 2kGy
Neutrons 7.10^{13} cm^{-2}

η= 1.48 at APDs
Dose 5kGy
Neutrons $1.3.10^{14}$ cm^{-2}



APD certification
All screened to 5kGy (some have received 10kGy) – most OK
(some have significant change in breakdown voltage - rejected most change by only ~1V, vs. 40V breakdown margin)

Other tests
2001, Karlsruhe, 48 APDs, 20kGy, 2.10^{13} n/cm^2 – all OK
Minnesota, >1000 APDs, 1-2. 10^{13} n/cm^2 – all OK

Need a programme of APD neutron tests to ~2.10^{14} n/cm^2 and annealing tests at 18°C

ECAL Crystal Performance

Crystal LY loss from Co^{60} dose rate studies

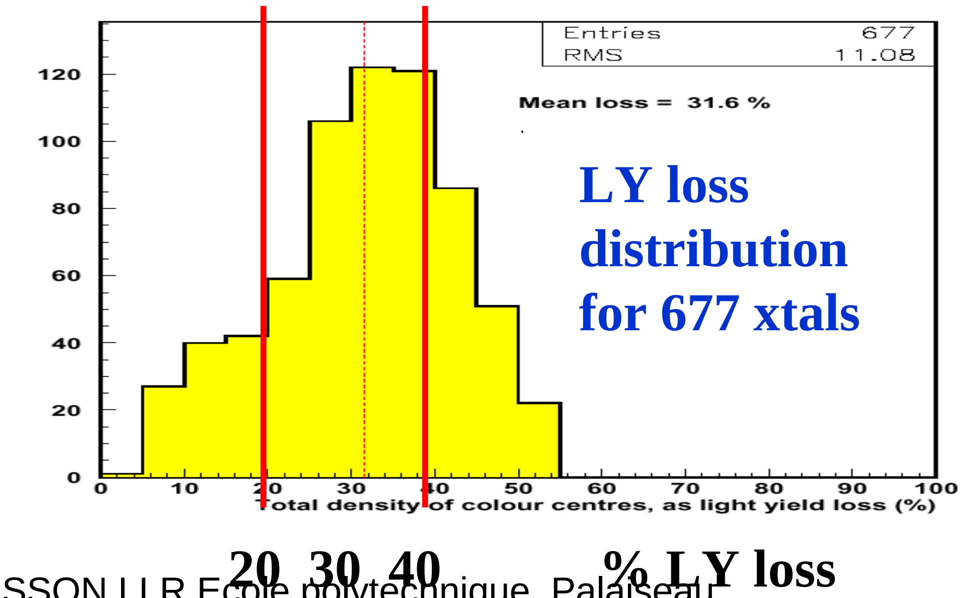
At SLHC, η=3, at shower max
Dose rate = 10 x 15 = **150Gy/h**

Data rate, Cantonal Irradiation **240 Gy/h**, 2h
Representative of SLHC worst case

Densely ionising hadron shower effects not included

LY loss calculated from measured induced absorption

Assume all colour centres activated – gives worst case



EE performance at SLHC

Initial performance 50 MeV E_T, preamp noise 3500e$^-$		
Activation noise, SLHC	**η = 2.5, 10000e$^-$ $\equiv$ 140 MeV E_T per channel**	
	Losses	
Xtal LY loss	**0.7 $\pm$ 0.2**	**Induced abs data**
VPT faceplate	**0.8 $\pm$?**	**Guess, 10% to 20kGy**
VPT Q.E. (burn-in study)	**0.4 $\pm$?**	**60% loss, 6 days at I_k = 1μA $\equiv$ 18y at 10^{34} at η = 2.5**
VPT gain	**1.0**	**No change observed**
Reduced HV	**0.9**	**Working margin**
Resultant factor	**0.2**	**(Hadron damage to xtals, another factor 0.5?)**

Resultant noise 250 (700 with activation) MeV E_T per channel

- excluding pileup contributions & other electronics issues

Charged hadron effects on xtal LY need to be taken into account

EB Performance at SLHC

	Leakage Current/xtal	Noise equiv	Comment
APD current (TDR)	20μA	**60MeV**	With annealing, single sampling?
APD current (SLHC)	130 μA	**150MeV**	As √(leakage current) Annealing not included
Add EB preamp noise		**140MeV**	50MeV in quadrature
	Losses		
Crystal factor	0.75	**190MeV**	LY loss in crystals
APD - Xtal glue	?		Measured to 5kGy?
APD Q.E., Gain	?		Reduce gain, leakage?

EB noise likely to be ~190 MeV per channel
- excluding pileup contributions & other electronics issues
Charged hadron effects on xtal LY need to be taken into account

ECAL at SLHC - Conclusions

EE

Repairs very difficult if not impossible, activation

Qualify all components to SLHC levels before EE build

VPT and component irradiation tests in 2004 to 350kGy

Induced activity noise could be important limitation

Charged hadron effects on Xtal LY, tests to be completed

Detector Noise/channel E_T 250 MeV or greater (excl. pileup)

EB

APD studies to ~2.10^{14} n/cm^2 needed

Detector Noise/channel 190 MeV or greater (excl. pileup)

Preshower

Replacement of inner silicon likely to be needed – very difficult

LVL1 Trigger

Scenario de base pour le LVL1

- On … refait tout !

Level-1 Objects at SLHC

- Electrons, Photons, τ-jets, Jets, Missing E_T, Muons
  - Build Level-1 decision using basic L1 Objects
- Bottom line
  - Must hold the thresholds low to study electro-weak symmetry breaking physics
  - Only option is to further reduce the QCD background
  - Improved algorithms necessary
- Strategy for QCD background reduction
  - Fake reduction: $e^{\pm}$, γ, τ
  - Improved resolution and isolation: μ
  - Exploit event topology: Jets
  - Association with other objects: Missing E_T

Level-1 Calorimeter Objects

- Electrons/photons/τ-jets
  - Dominated by tails of jet fragmentation
  - Use of tracking in level-1
    - Pixel only or pixel + outer tracker layers?
  - Mandates higher granularity calorimeter trigger output
- Jets and missing E_T
  - These are real
    - Resolution improvement not likely without fancy calibration, e.g., track matching to calorimeter clusters
    - Small cleanup using smaller jet cones + better ϕ binning for E_x,E_y
  - Event topology and Global trigger improvements
    - Multi-jets, jet+lepton and jet+missing E_T combinations
    - Require jets in specific $\eta-\phi$ bins
      - Improved binning
    - Use missing E_T direction
  - Vertex finding to reject pileup contamination of trigger event
    - Pixel tracker provides vertex?

e/γ Improvements for SLHC

- Learn from current High Level Trigger Algorithms
  - Improved isolation
    - Gains realized when pileup is small
  - Veto π^0 using careful analysis of shower profile
    - Improved Fine-Grain analysis
  - Use track match
    - Pixel only track match
    - Pixel + Outer layer track match
    - This provides most improvement in $S^2/S+B$ for electrons
    - Must report calorimeter e/γ objects in finer $\eta-\phi$ bins

Electronique des détecteurs pour le SLHC

R. Horisberger , PSI
27/02/04

Electronics issues for Pixel System at SLHC

- Pixel front-end electronics (ROC, control chips e.g. TBM etc.) affected by SLHC in two ways:

  particle fluence → radiation damage to chips
  instant Lumi → data rates, data losses

- SHLC operation supposedly 2500 fb^{-1} and L= 10x 10^{34} $cm^{-2} sec^{-1}$

- Does it make a difference for ROC if L= 3x or 5x or 10x 10^{34} $cm^{-2} sec^{-1}$?

- Try to find out what changes are needed for these different scenarios

Conclusions on Data Loss of Pixel ROC at SLHC

- **If insist on L= 10^{35} cm^{-2} sec^{-1}**
  - Chip can operate at radius of > 10 cm with < 5% data losses
  - Pixel ROC needs **small** change

    # timestamp buffer 12 → 24
    # data buffers 32 → 64 → 650μ periphery increase

- **If insist on Radius = 7- 8cm**
  - either: Relax **L= 10^{35}** to **6×10^{34}**
  - or: Pixel ROC needs in addition **major** changes to remove

    DC drain 3 TS data loss
    DC Readout Reset data loss → increase L1 latency will worsen this

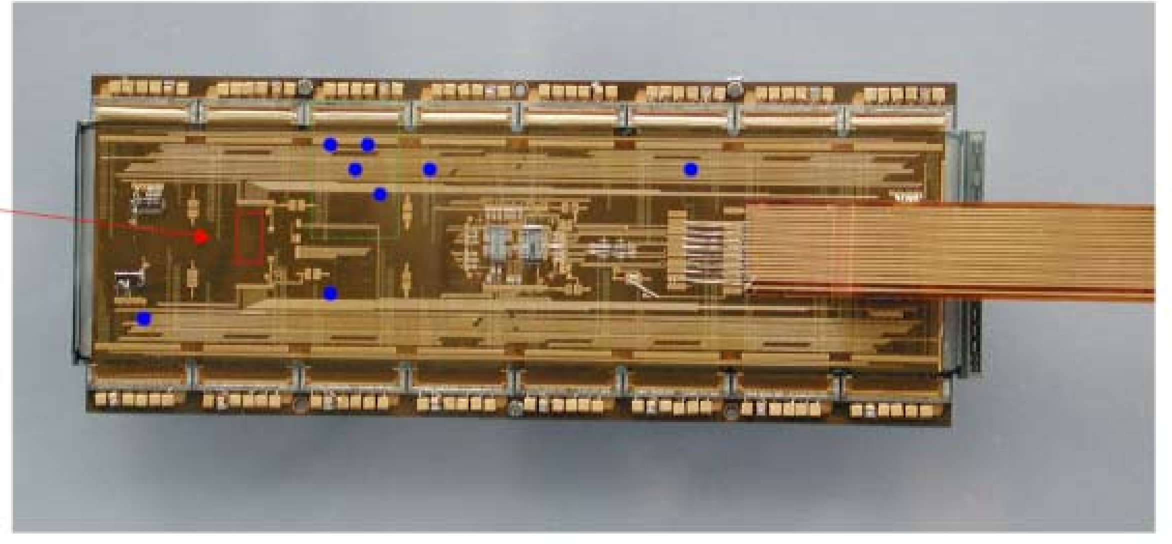
  - Optical links need doubling eventually quadrupling !
    → problematic due to tight space on present service cylinder
    → could try to use 80MHz readout speed of optical link

1st Level Trigger with Pixel Detector (IBM_PSI46)

- Local track clusters from jets used for 1st level trigger signal in ROC → jet trigger with σ_z = 6mm!
- Program in ROC track cluster multiplicity for trigger output signal (fuzzy logic signal)
- Combine in Module Trigger Chip (MTC) 16 trigger signals and decide on module trigger output
- HDI modifications, kapton cable traces, optical links (~100) are planned and designed

MTC

Version 0 done



Expected Dose rates

- The dose rate in EE for the electronics is roughly 10 times that of EB
  - Electronics out to η=2.6 where dose is 150KGy
  - EE electronics behind a moderator
- Current electronics is meant to be used in both EE and EB
  - Hence a priori we expect no problems for EB electronics at SLHC luminosities
- EE doses will enter a new realm at SLHC
  - Need to understand performance of components at this level
  - Activation of EE electronics is also an issue if we wanted to consider servicing electronics periodically

CMS ECAL : Integrated Luminosity of 2500 pb^{-1}

	η-range	$\int$Dose (kGy)	Dose rate (Gy/h)
Barrel	0–1.5	15	2.5
Endcap	2.0	100	14
Endcap	2.9	1000	140

At η=0 EB, fluence $7x10^{13}$ n/cm^2

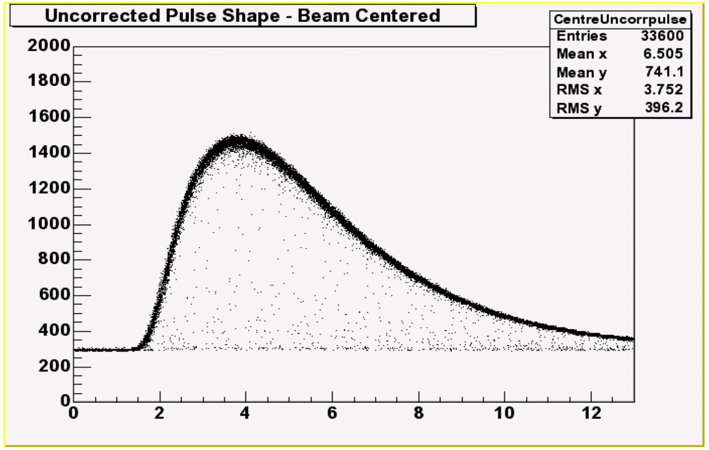
At η=1.5 EB, fluence $1.4x10^{14}$ n/cm^2

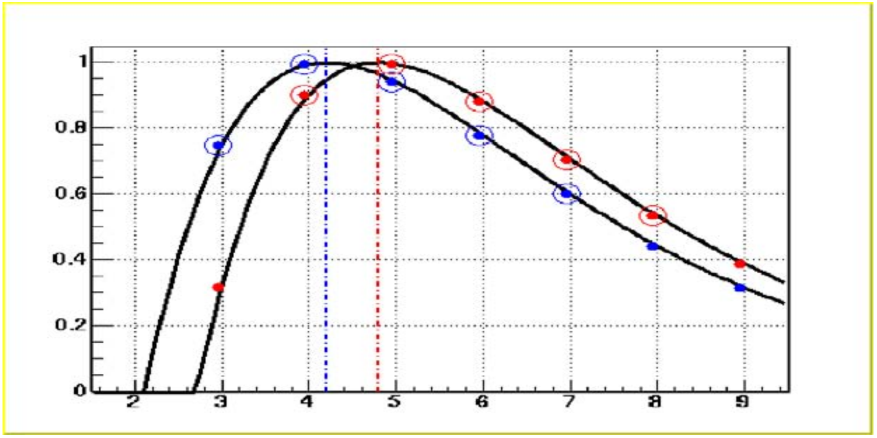
At η=2.6 EE fluence $5x10^{14}$ n/cm^2

Region	LHC	SLHC
Tracker	≈25 μSv/h	≈250 μSv/h
EE (high-η)	≈0.5 mSv/h	≈5 mSv/h
HF (high-η)	≈10 mSv/h	≈100 mSv/h
TAS-region	up to 30 mSv/h	up to 300 mSv/h
Expt. Cavern	<1 μSv/h	<10 μSv/h

Pulse shape in the ECAL: Data

- The Pulse shape from the MGPA is relatively wide compared with the bunch crossing time at both LHC/SLHC (40nsec)
- Sampling at 40MHz gives good energy and time resolution regardless of the phase of the beam with respect to sampling
- Extracting the energy from either odd/even pulse trains should not be a problem if we know which contains the event of interest
  - The samples are shipped off detector where this information is available
- Pileup can be a problem at high eta, but can be combated with appropriate choice of weights
  - Trade off timing resolution (pileup rejection) versus energy resolution

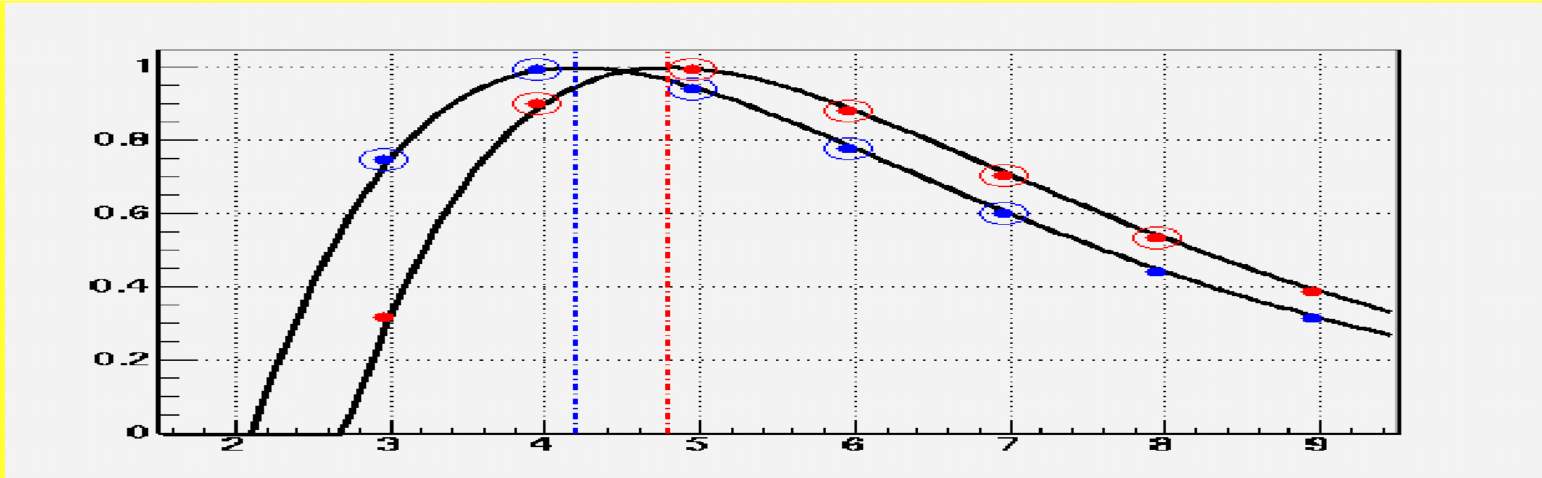




ECAL and the trigger

- The ECAL data forms one of the main inputs to the L1 calorimeter trigger
- Energy information is provided at 40 MhZ to the TCC which in turn provides input to the calorimeter L1 trigger
- Trigger primitives are generated in the FENIX chips located on the FE card
  - Strips of 5 crystals are summed
    - These are then summed into trigger towers
  - These chips are now in production
    - No way to change now
  - Some handles were placed in the chip to deal with SLHC running

Samples used vs clock phase



- The variation of the pulse shape between odd/even bunches is slow enough that there should be little degradation to the trigger by using the *wrong* weights on some of the strips.
- Detailed studies will need to be done to see how to optimize the filters and strategies for the best trigger performance at SLHC
  - There are options in the FENIX which allow different strategies

Conclusions

- The ECAL electronics in EB should in principle be able to cope with the SLHC without replacement as it is currently implemented
- The ECAL electronics in EE is more uncertain, the main risk being the low voltage regulators
  - R & D on voltage regulation schemes needed
- The trigger primitive generation has some flexibility built in to the current system to handle double the number of bunches
  - Will require study to determine optimal utilization

SLHC Trigger @ 10^{35}

- Occupancy
  - Degraded performance of algorithms
    - Electrons: reduced rejection at fixed efficiency from isolation
    - Muons: increased background rates from accidental coincidences
  - Larger event size to be read out
    - Reduces the max level-1 rate for fixed bandwidth readout.
- Trigger Rates
  - Attempt to hold max level-1 at 100 kHz by increasing readout bandwidth
  - Implies raising E_T thresholds on electrons, photons, muons, jets and use of less inclusive triggers
    - Need to compensate for larger interaction rate & degradation in algorithm performance due to occupancy
- Radiation damage
  - Increases for part of level-1 trigger located on detector

SLHC Trigger @ 12.5 ns

- Choice of 80 MHz
  - Reduce pile-up
  - Be prepared for LHC Machine group electron-cloud solution
  - Retain ability to time-in experiment
    - Beam structure vital to time alignment
  - Higher frequencies ~ continuous beam
- Rebuild level-1 processors to work with data sampled at 80 MHz
  - Already CMS has internal processing up to 160 MHz and higher in a few cases
  - Use 40 MHz sampled front-end data to produce trigger primitives with 12.5 ns resolution
  - Save some latency by running all trigger systems at 80 MHz I/O

Trig. Primitives: Calorimeter

- HF: Possibly replaced
  - Very fast - gives good BX ID
  - Modify logic to provide finer-grain information
    - Improves forward jet-tagging
- HCAL: Barrel stays but endcap replaced
  - Has sufficient time resolution to provide energy in correct 12.5 ns BX with 40 MHz sampling. HTR cards may be able to produce 80 MHz already.
- ECAL: Stays
  - Also has sufficient time resolution to provide energy in correct 12.5 ns BX with 40 MHz sampling, may be able to produce 80 MHz output already.
  - Exclude on-detector electronics modifications for now -- difficult:
    - Regroup crystals to reduce $\Delta\eta$ tower size -- minor improvement
    - Additional fine-grain analysis of individual crystal data -- minor improvement
- Conclusions:
  - Front end logic same except where detector changes
  - Need new TPG logic to produce 80 MHz information
  - Need higher speed links for inputs to Cal Regional Trigger

SLHC L-1 Tracking Trigger

- Additional Component at Level-1
  - Actually, CMS already has a L-1 Tracking Trigger
    - Pixel z-vertex in $\Delta\eta \times \Delta\phi$ bins can reject jets from pile-up
  - Could use on-detector wire-/fiber-less interconnects?
    - Line of sight VCSELS? - reduce cable material
  - Provides outer stub and inner track
    - Combine with cal at L-1 to reject π^0 electron candidates
    - Reject jets from other crossings by z-vertex
    - Reduce accidentals and wrong crossings in muon system
    - Provide sharp P_T threshold in muon trigger at high P_T
  - Cal & Muon L-1 must produce output with suitable granularity to combine with L-1 tracking trigger
    - Also need to produce hardware to make combinations
- Move some HLT algorithms into Level-1

SLHC Trigger Architecture

- LHC:
  - Regional to Global Component to Global
- SLHC Proposal:
  - Combine Level-1 Trigger data between tracking, calorimeter and muon at Regional Level at finer granularity
  - Forward physics objects made from tracking, calorimeter and muon regional trigger data to the global trigger
  - Implication: performing some of tracking, isolation and other regional trigger functions in combination between regional triggers
    - New “Regional” cross-detector trigger crates

Technologies for SLHC Trig.

- Complicated Algorithms & Low Latency:
  - FPGA’s: faster, more logic
  - Faster and larger memories
- Moving more data at higher speed:
  - Link technology: speed & integration
  - Backplane technology: connectors & newer interconnect technology
- Higher Crossing Frequency:
  - High speed clocking: low jitter - design for links
- Overall Complexity:
  - Design for test, diagnostics, algorithm validation

Level-1 Latency

- Present Latency of 3.2 μsec becomes 256 crossings
  - Assuming rebuild of tracking & preshower electronics will store this many samples
- Do we need more?
  - Yield of crossings for processing only increases from ~70 to ~140
    - It's the cables!
  - Parts of trigger already using higher frequency
- How much more? Justification?
  - Combination with tracking logic
  - Increased algorithm complexity
  - Asynchronous links or FPGA-integrated deserialization require more latency
  - Finer result granularity may require more processing time
  - ECAL digital pipeline memory is 256 40 MHz samples = 6.4 μsec
    - Propose this as SLHC Level-1 Latency baseline

SLHC Trigger Roadmap

- CMS Workshop at CERN Feb 26, 27:
  - Provide summary of ideas and gather ideas from CMS
- Summer CMS Workshop (to be scheduled):
  - Propose initial plan of Trigger R&D for FY05
  - Develop overall CMS plan for Electronics R&D
    - Not detailed, just timescales for development & reporting
- Long Term:
  - R&D 2005-7
  - Prototype/Test 2008-10
  - Construct/Install 2010-13

Conclusions

Imperial College
London

CMS Workshop for SLHC - London, 12 & 13 July 2004

PLACE:	TIME:			
Lecture Theatre 3 **Level 1** Blackett Lab	14.00 - 18.00 Monday 12 July 9.00 - 18.00 Tuesday 13 July	**PROGRAMME**- Link to 1st SLHC	**Accommodation Directions**	**London Links**

This is the 2nd CMS Workshop on Detectors and Electronics for the SLHC, which will be an upgrade to the CERN Large Hadron Collider to eventually operate at 10^35 cm^-2.s^-1 luminosity with 28 TeV centre of mass energy.

Please register in order to confirm numbers - **List of Participants**

The Workshop will take place in the Lecture Theatre 3, Blackett Lab (**Physics Dept** - **No. 6** on the MAP, **SOUTH KENSINGTON Campus**).

Imperial College Conference Link provides a local Hotel service and cheaper but confortable rooms on Campus (**Beit Hall - No. 3 on Map**).Please note that at the moment, all Campus rooms are fully booked on 13 July, if you plan to stay longer. You can book directly or choose other alternatives:
The Regency Hotel The Brompton Hotel ASTON Apartments

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