Accidental Beam Losses at LHC
and
Impact on CMS Tracker

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Some LHC Parameters

Proton Energy	7 TeV
Particle per bunch	1.05×10^{11}
Number of bunches	2835
Number of protons per beam	3×10^{14}
Revolution time	88.924 μs
Abort gap	3.17 μs
Kicker rise time	3 μs
Closed orbit deviation	max 4 mm (x and y)
Stored beam energy	336 MJ

0^{th} order approximation:

Lost beam energy in IP $\propto$ Dose $\propto$ Hadron fluence

At 10^{34} we expect 8×10^{8} collisions per second.

$\Downarrow$

Integrated dose/flux from a full beam loss would amount to roughly 10 days of normal running.

$\Downarrow$

We do not expect integral effects from beam losses

Studied Accident Scenarios

1. **Single module prefire**
   Very unlikely worst case scenario

   Assume that only one out of the 14 abort kickers fires.

   $\Rightarrow$ the whole beam suffers a 12 σ kick which allows it to continue in the machine

   Most of the deviated beam is lost at the next limiting aperture (for counterclockwise beam CMS low-β)

   Accident duration: 86 μs, 4×10^{13} protons lost in IP5

2. **Unsynchronized abort**
   Very likely accident with many possible causes

   Assume that the dump kicker does not hit the abort gap

   $\Rightarrow$ bunches are swept out for $\sim$3 μs until the kicker reaches full strength.

   Some of the deviated bunches continue in the machine and are lost at the next limiting aperture

   Accident duration: $\sim$0.26 μs, 1×10^{12} protons lost in IP5

Beam abort malfunctions affect mainly CMS since it is the only experiment neighbour to the dump insertion (IP6).

Protection Possibilities

Without protection:

- **the prefire case would lead to physical damage of the CMS quadrupoles.**
- **the unsynchronized abort would result in a quench.**

Two possibilities to protect (at least the magnets):

1. **Fixed aperture shadow collimators close to the IP5 insertion (studied in this work)**

   Advantage: technically simple and reliable

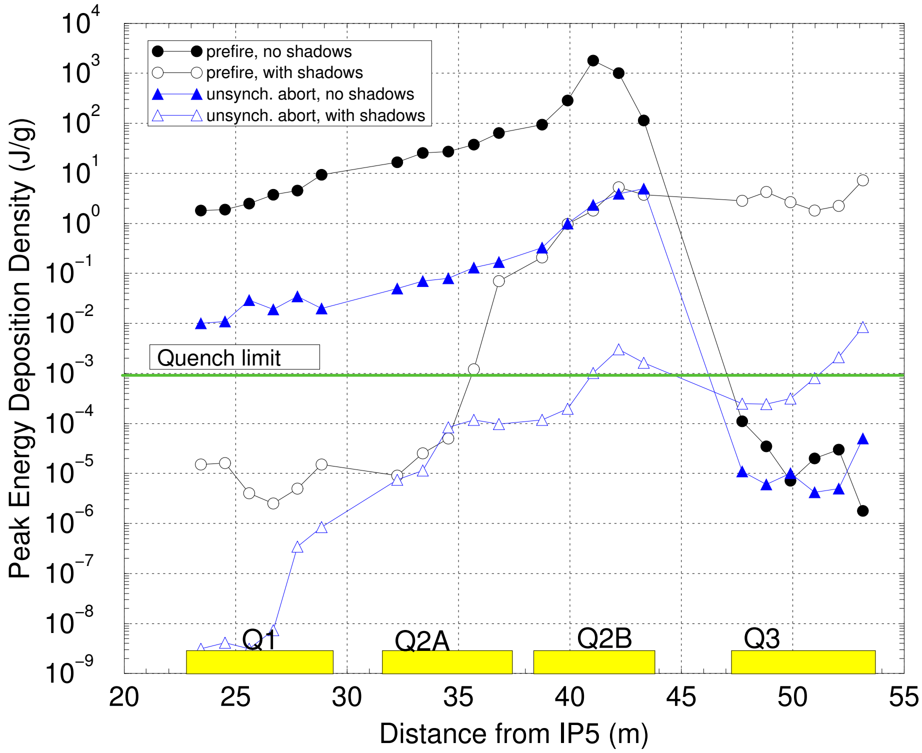
   Disadvantage: Still losses close to CMS

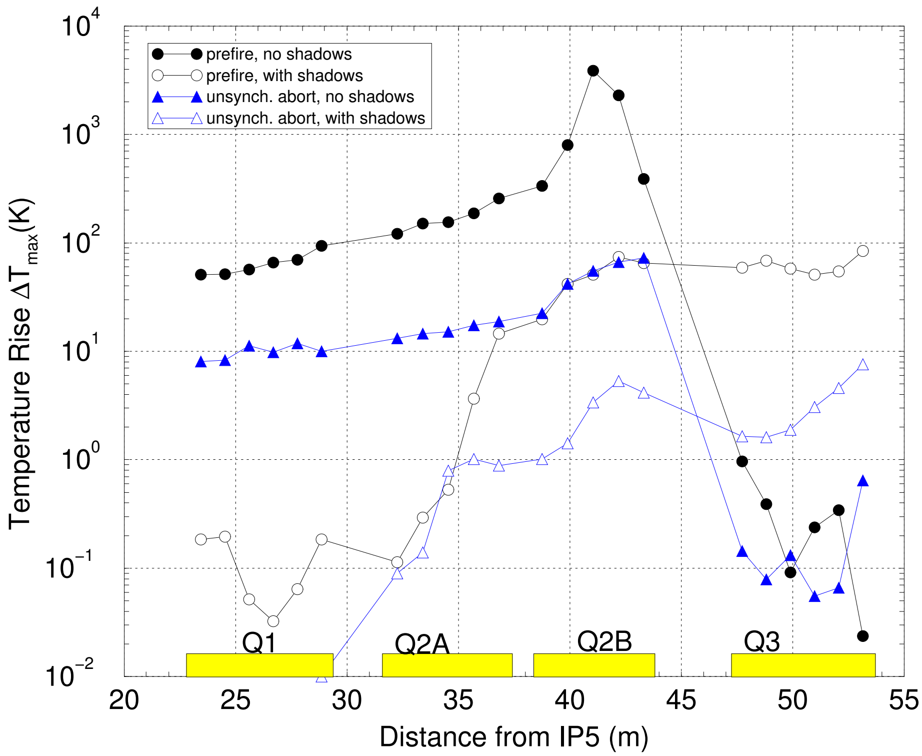
2. **Adjustable aperture jaws in IP6 (to be investigated)**

   Advantage: should provide better protection for rest of machine

   Disadvantage: complicated mechanical system

Energy deposition in Inner Triplet





Simulation Methods

Three phase simulation:

1. **Simulate abort kicker malfunction and particle tracking in LHC with the STRUCT code (Drozhdin)**
2. **Simulate 7 TeV proton interactions in machine elements and subsequent tracking of secondaries with the MARS code (Mokhov)**
3. **Simulate radiation environment created within CMS with the FLUKA code (Huhtinen)**

The FLUKA/MARS interface was defined at z=21.6 m.

Three types of <u>incident</u> particle files were created with MARS:

1. **Muons**
2. **Others**
3. **Hadrons with energy $>$3.5 TeV (mostly diffractive protons)**

Both FLUKA and MARS runs were extremely time-consuming

(and still statistics is poor)

FLUKA Simulations

The three different file types were treated separately for reasons of efficiency (and to understand their relative importance).

Especially the MARS simulations were heavily biased $\Rightarrow$ need several samples (independent MARS runs) to get statistical error estimate.

The CMS geometry was the same as for the Tracker TDR, only biasing was adjusted to this very different case

$$\Downarrow$$

Results directly comparable to Tracker TDR

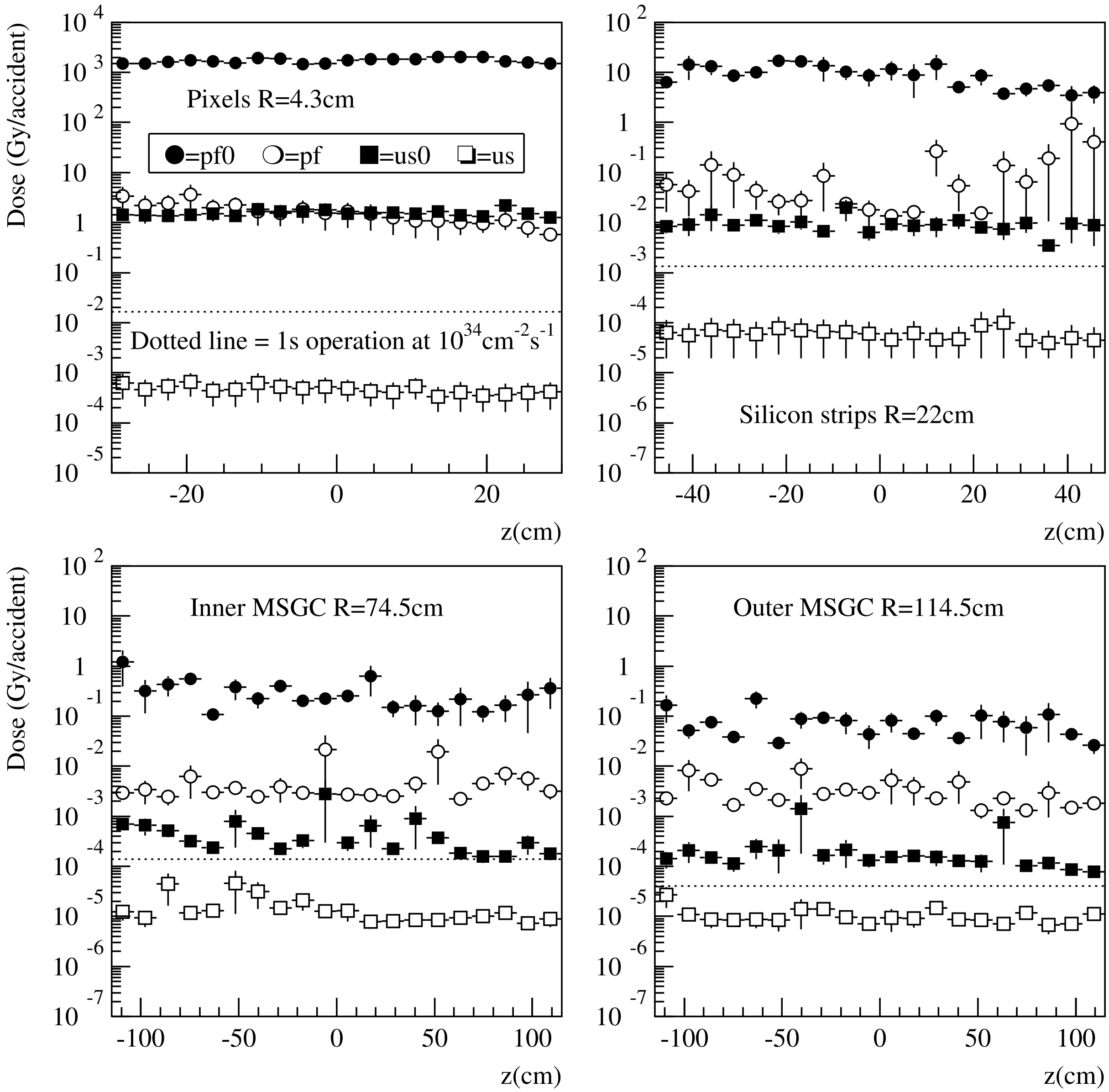
Concentrated on the Tracker (but some results available also for endcap muon system)

Main emphasis on Radiation dose because (for mips):

$$\textbf{Dose} \propto \textbf{Deposited energy} \propto \textbf{Ionization}$$

Results: Dose along z

<u>**Accident durations:**</u>
prefire (pf0), prefire with shadows (pf): 86 μs
unsynchronized (us0), unsynch. with shad. (us): 260 ns



Results: Integral dose

Inner pixels (R=4.3cm):

	Δt	Dose (Gy)	Time Equivalent
Nominal	5×10^7 s	$8.28\pm0.07\times10^5$	1800 days
Prefire0	86 μs	1720$\pm$20	2.4 days
Unsyn0	260 ns	1.6$\pm$0.3	100 s
Prefire	86 μs	1.7$\pm$0.7	100 s
Unsyn	260 ns	$4.7\pm2.4\times10^{-4}$	30 ms

Inner Silicon (R=22cm):

	Δt	Dose (Gy)	Time Equivalent
Nominal	5×10^7 s	$6.66\pm0.06\times10^4$	1800 days
Prefire0	86 μs	9.4$\pm$1.2	2 hours
Unsyn0	260 ns	$9.4\pm1.8\times10^{-3}$	7 s
Prefire	86 μs	0.133$\pm$ 0.112	100 s
Unsyn	260 ns	$6.1\pm4.7\times10^{-5}$	50 ms

Inner MSGC (R=74.5cm):

	Δt	Dose (Gy)	Time Equivalent
Nominal	5×10^7 s	7000$\pm$100	1800 days
Prefire0	86 μs	0.50$\pm$0.15	1 hour
Unsyn0	260 ns	$1.3\pm0.4\times10^{-3}$	10 s
Prefire	86 μs	$9.4\pm2.7\times10^{-3}$	60 s
Unsyn	260 ns	$3.8\pm1.1\times10^{-5}$	0.3 s

In all cases negligible Integral dose

Results: Dose rates

Inner pixels (R=4.3cm):

	Δt	Dose rate (Gy/s)	$\times$ nominal
Nominal	1 s	$1.66 \pm 0.01 \times 10^{-2}$	1
Prefire0	86 μs	$2 \pm 0.02 \times 10^{7}$	10^{9}
Unsyn0	260 ns	$6.2 \pm 1.2 \times 10^{6}$	4×10^{8}
Prefire	86 μs	$2 \pm 0.8 \times 10^{4}$	10^{6}
Unsyn	260 ns	1800$\pm$900	10^{5}

Inner Silicon (R=22cm):

	Δt	Dose rate (Gy/s)	$\times$ nominal
Nominal	5×10^{7} s	$1.33 \pm 0.01 \times 10^{-3}$	1
Prefire0	86 μs	$1.1 \pm 0.1 \times 10^{5}$	8×10^{7}
Unsyn0	260 ns	$3.6 \pm 0.7 \times 10^{4}$	3×10^{7}
Prefire	86 μs	1500$\pm$ 1300	10^{6}
Unsyn	260 ns	230$\pm$180	2×10^{5}

Inner MSGC (R=74.5cm):

	Δt	Dose rate (Gy/s)	$\times$ nominal
Nominal	5×10^{7} s	$1.40 \pm 0.02 \times 10^{-4}$	1
Prefire0	86 μs	6000$\pm$2000	4×10^{7}
Unsyn0	260 ns	5000$\pm$1500	4×10^{7}
Prefire	86 μs	110$\pm$30	8×10^{5}
Unsyn	260 ns	150$\pm$40	10^{6}

Very high dose rates in all cases

Results: Particle fluxes

Very bad statistics

Unsynchronized with shadows (duration ∼260 ns):

R	Ch. Hadr.	Muons	e^+e^-	n (E>100 keV)	Total mip
4.3	$8\pm4\times10^4$	$2.2\pm1.6\times10^4$	$1.7\pm0.9\times10^6$	$1.2\pm0.7\times10^4$	$1.8\pm0.9\times10^6$
22	$4\pm3\times10^4$	$1.9\pm0.6\times10^4$	$1.8\pm1.4\times10^5$	$1.0\pm0.8\times10^3$	$2.3\pm1.4\times10^5$
74.5	$2\pm1\times10^3$	$2.9\pm1.3\times10^4$	$2.1\pm0.5\times10^4$	$3.3\pm1.9\times10^3$	$5.2\pm1.4\times10^4$

mip rate in MSGC: $\sim 10^{11}$ cm^{-2}s^{-1} (during the 260 ns)

Some observations can be made:

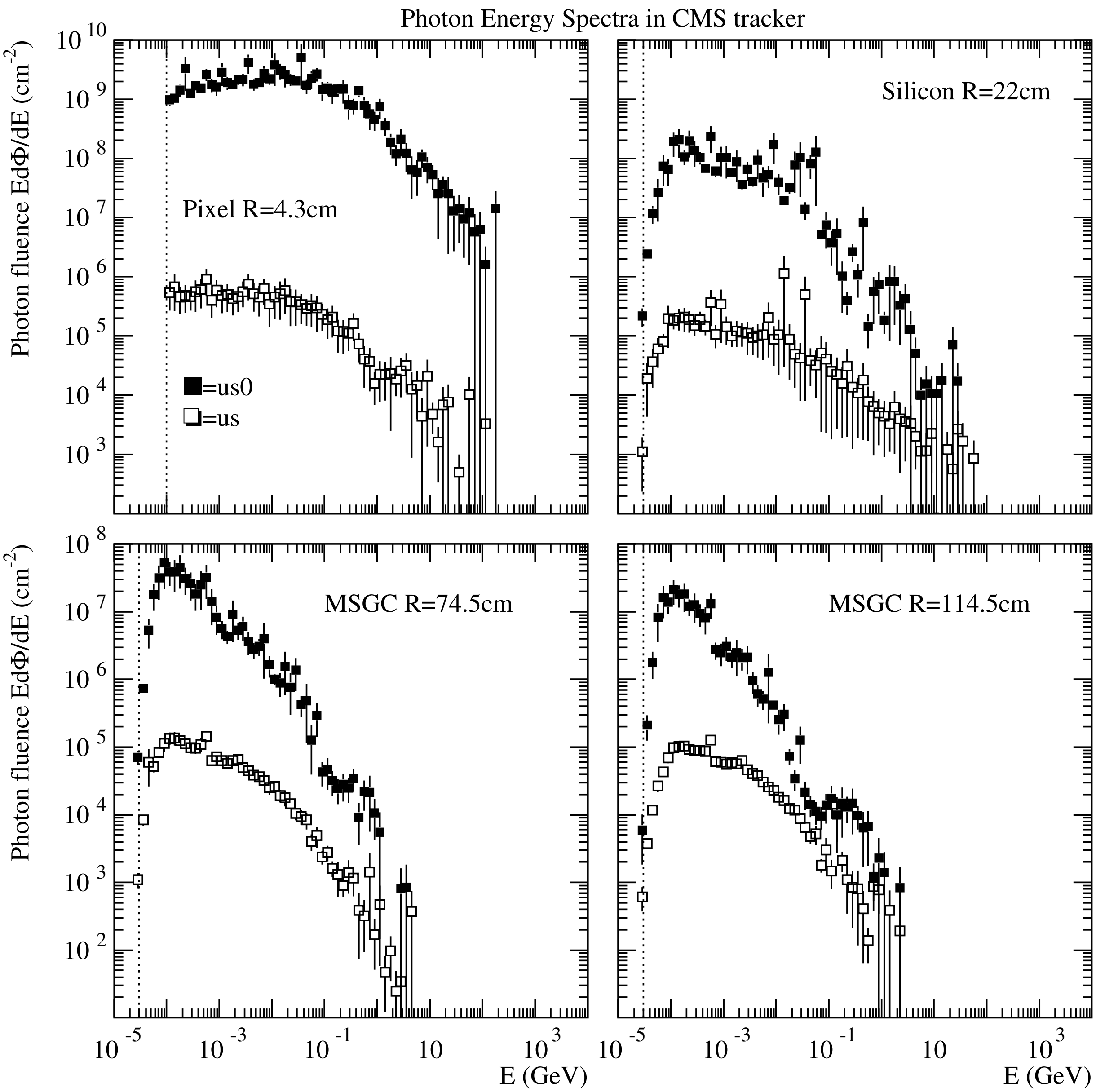
- **At larger radii the muon source (not muons themselves) become dominant**
- **These muons are not significantly affected by the shadow collimators in IP5**
- **The e$^{\pm}$/Hadron ratio of particle flux are much larger in the accident case than in nominal conditions:**

EM/HADR ratio	Nominal (TDR)	Unsyn-case
R=4.3 cm	0.3	20
R=22 cm	0.5	5
R=74.5 cm	0.9	10

Results: Particle spectra

Too bad statistics to show hadrons

Photon spectra in different layers:



Is this realistic...

Realism of our assumptions:

- **The prefire case is unlikely, because the kicker will be build to immediately fire all others modules.**
- **The unsynchronized case is very realistic. Any timing or control loss could cause this. Observed several times a year at Tevatron.**

First response from LHC (E. Weisse, B. Jeanneret)

- **Agree on the non-zero probability of unsynchronized aborts.**
- **No possibility to prevent them from ever happening**
- **Proposed an absorber in IP6 instead of IP5.**
  - **Would protect rest of machine (including CMS)**
  - **Mechanical and alignment problems to be studied**
  - **Efficiency to be studied (will most probably not be 100%)**

...or optimistic?

Could it come worse?

The prefire assumption (10% of beam lost in IP5) is very close to the worst case. Only a full point-like beam loss on the TAS would be worse (physical destruction and even higher dose rates).

But how could this happen?

- **Double failure: e.g. D1 quenches and abort system not available (still cleaning would probably take most of the beam).**
- **TAS mechanical support system breaks and TAS falls into the beam...**

Such alternative seem very unlikely

In normal conditions (lattice at IP5 OK) the inner triplet is the smallest aperture in IP5. So even the most severe beam losses should resemble our prefire case (= no losses on TAS).

Summary

We have studied a worst case (1-kicker prefire) and a commonly agreed realistic beam accident (unsynchronized abort).

In both cases the dose rates in CMS are about the same (but durations 86 and 0.26 μs, respectively)

	Unprotected	**Protected in IP5**
Pixel	$\sim 10^9\times$**nominal**	$\sim 10^6\times$**nominal**
Silicon	$\sim 10^8\times$**nominal**	$\sim 10^6\times$**nominal**
MSGC	$\sim 10^7\times$**nominal**	$\sim 10^6\times$**nominal**

A protective collimator in IP6 might improve the situation.

In any case our results should give a good indication of dose rates in beam accidents (which will happen...)

Conclusions

- **Beam losses are very unlikely to add to the integral damage of detectors/electronics**
- **ALL COMPONENTS FOR THE CMS TRACKER SHOULD SURVIVE PULSES OF ABOUT 1 μs DURATION WITH 10^7 TIMES THE NOMINAL RATES (OF MIPS OR DOSE)**