Possible consequences of LHC beam losses for CMS

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Our worries

Loss of full beam into one spot

Major physical destruction of all components hit

Too catastrophic to really worry about

Local loss of full beam but spread in time or space

Limited/no physical damage

Cumulative damage to detectors ?

Damage due to huge dose rate ?

Partial loss of beam or injection failure

Probably no physical damage

Cumulative damage to detectors ?

Damage due to huge dose rate ?

Loss of full intensity beam in CMS

Assume the loss is spread in time/space such that no material is melted/vaporised

Normally 10^9 pp-interactions per second

Beam loss deposits 3×10^{14} energy of protons

$$\text{Ratio} = \frac{3 \times 10^{14}}{10^9} = 3 \times 10^5$$

Even a full loss corresponds to cumulative radiation equivalent to only $\sim$10 days operation

Partial beam loss close to CMS

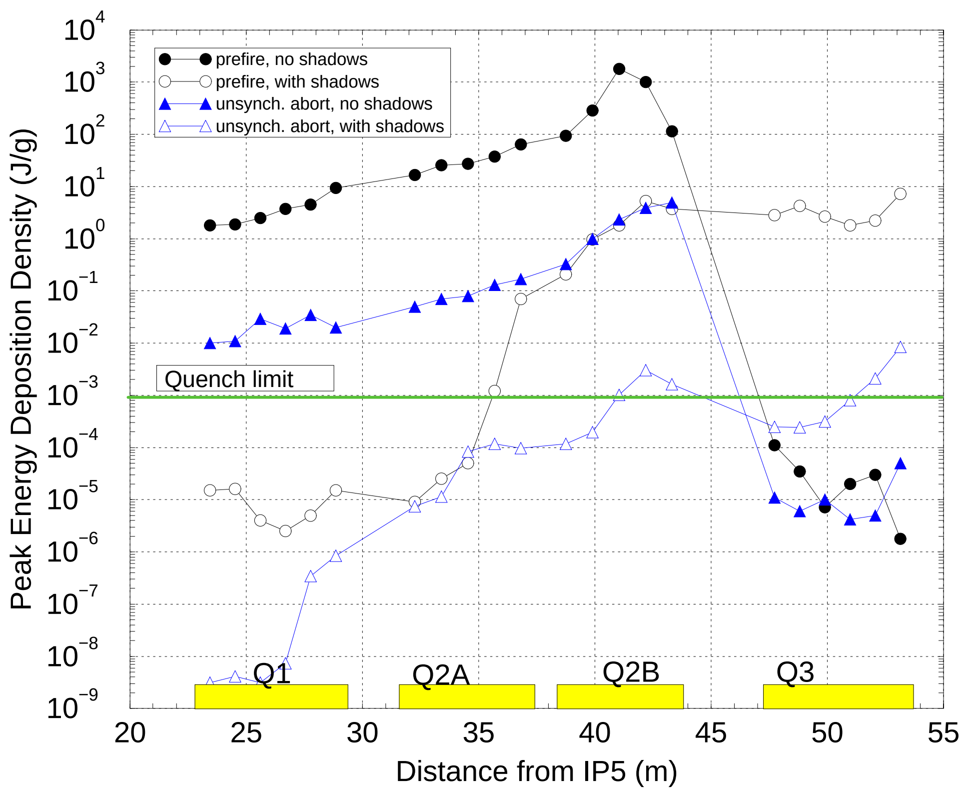
How could it arise ?

Kicker prefire → unsynchronised abort

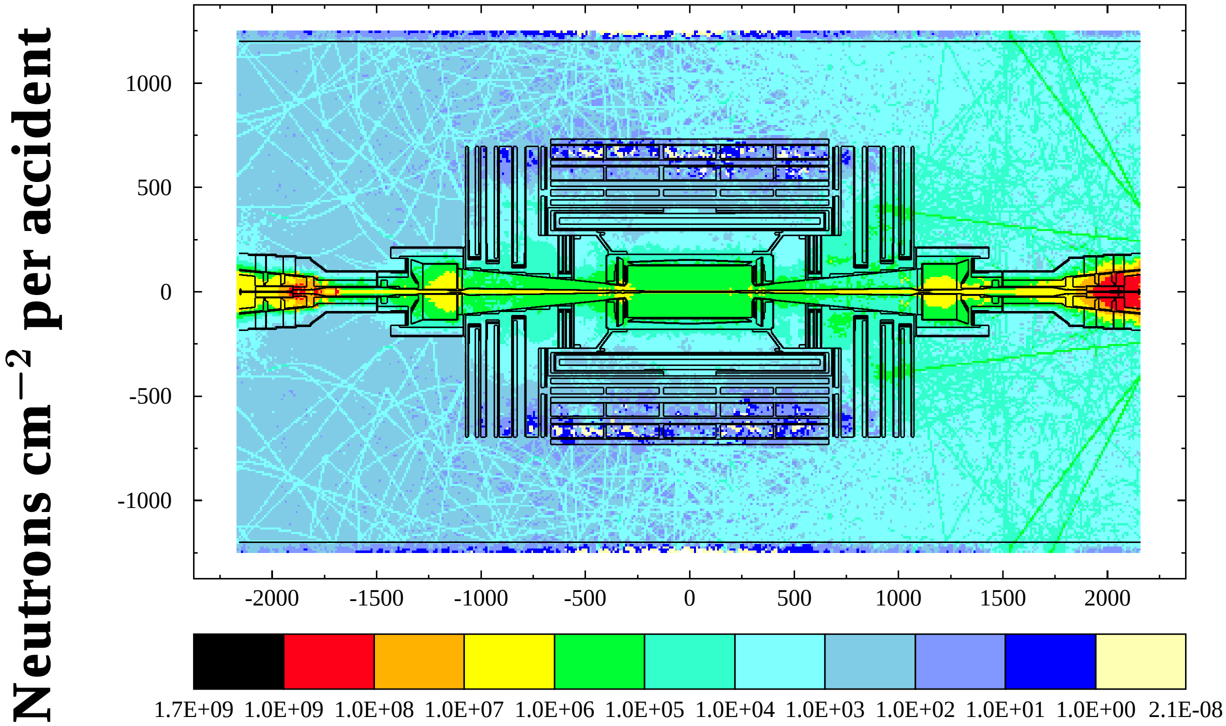
Suggested as accident scenario in 1999 by N. Mokhov

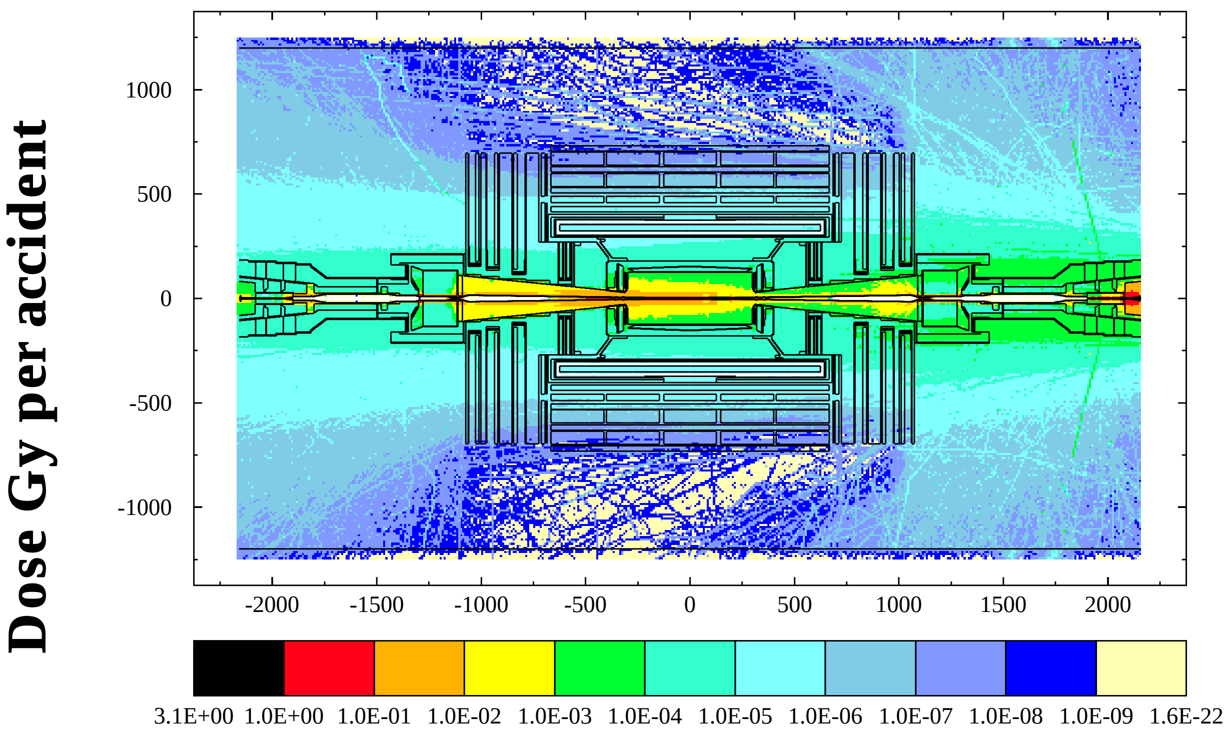
Unsynchronised abort deflects ∼10 integral bunches

Unless these are captured in IP6 the counterclockwise bunches are lost in the low-β of CMS



Neutron flux & dose from Unsync-abort





Rates in CMS Tracker after Unsync-abort

Duration of unsynchronised abort loss:
260 ns (estimate of 1999)

Cumulative dose during 10 years normal operation and one unsynchronised abort

R (cm)	Normal Dose (Gy)	Acc. Dose (Gy)	Time Eq.
4.5	$(8.28 \pm 0.07) \times 10^5$	1.6±0.3	100 s
22	$(6.66 \pm 0.06) \times 10^4$	$(9.4 \pm 1.8) \times 10^{-3}$	7 s
74.5	7000±100	$(1.3 \pm 0.4) \times 10^{-3}$	10 s

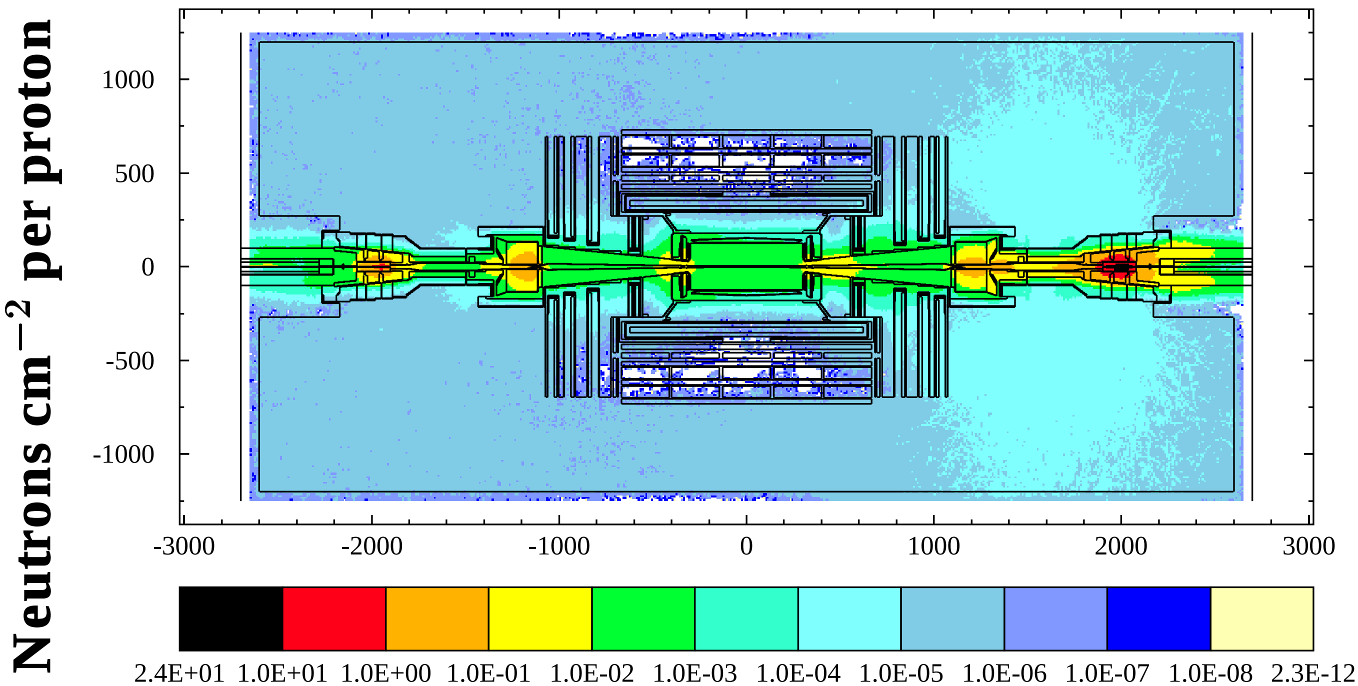
Contribution to integral dose (damage) is negligible

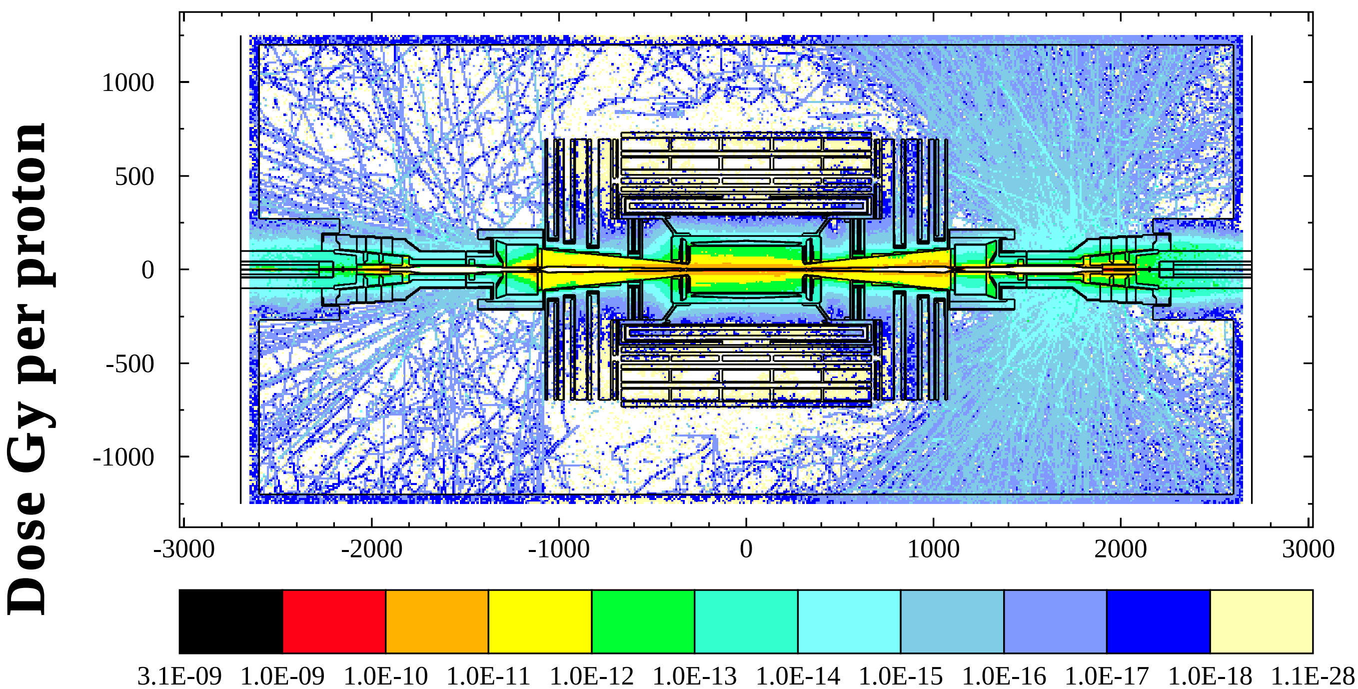
Dose during normal operation and during an unsynchronised abort

R (cm)	Norm. Dose rate (Gy/s)	Acc. Dose rate (Gy/s)	×norm.
4.5	$(1.66 \pm 0.01) \times 10^{-2}$	$(6.2 \pm 1.2) \times 10^6$	4×10^8
22	$(1.33 \pm 0.01) \times 10^{-3}$	$(3.6 \pm 0.7) \times 10^4$	3×10^7
74.5	$(1.40 \pm 0.02) \times 10^{-4}$	5000±1500	4×10^7

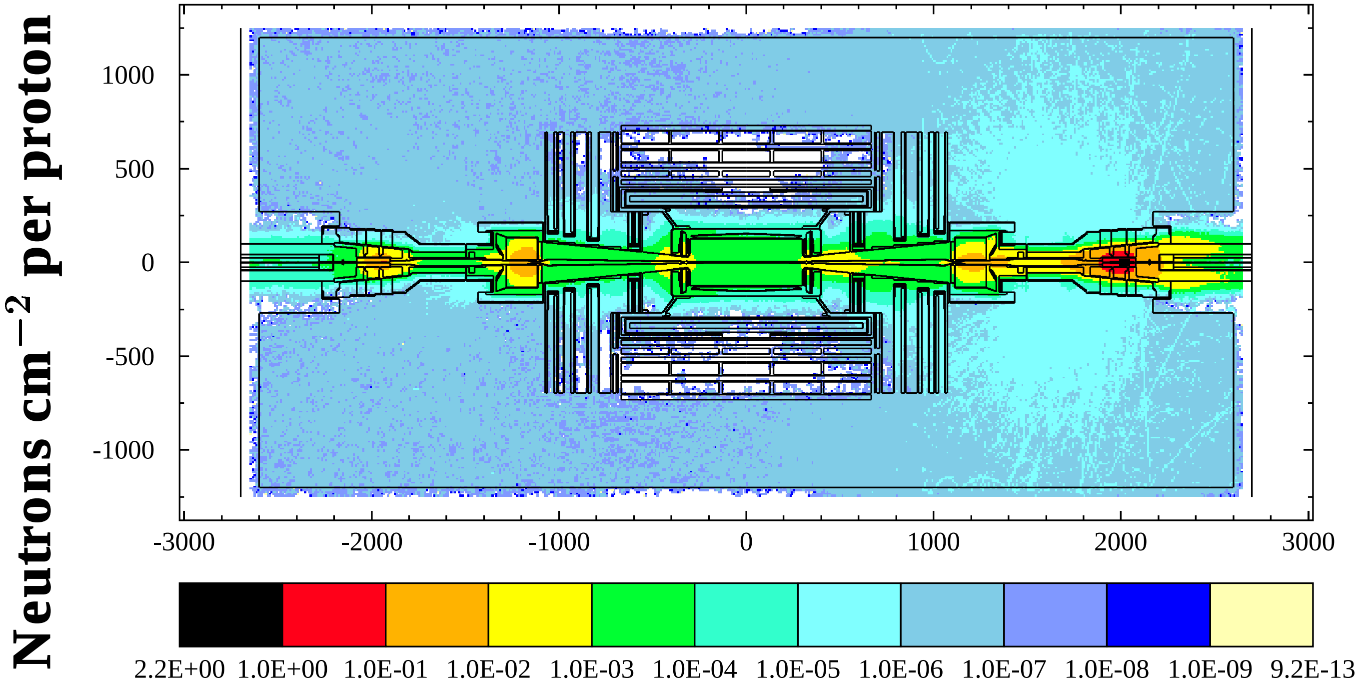
Tracker has to survive instantaneous rates many orders of magnitude above normal conditions

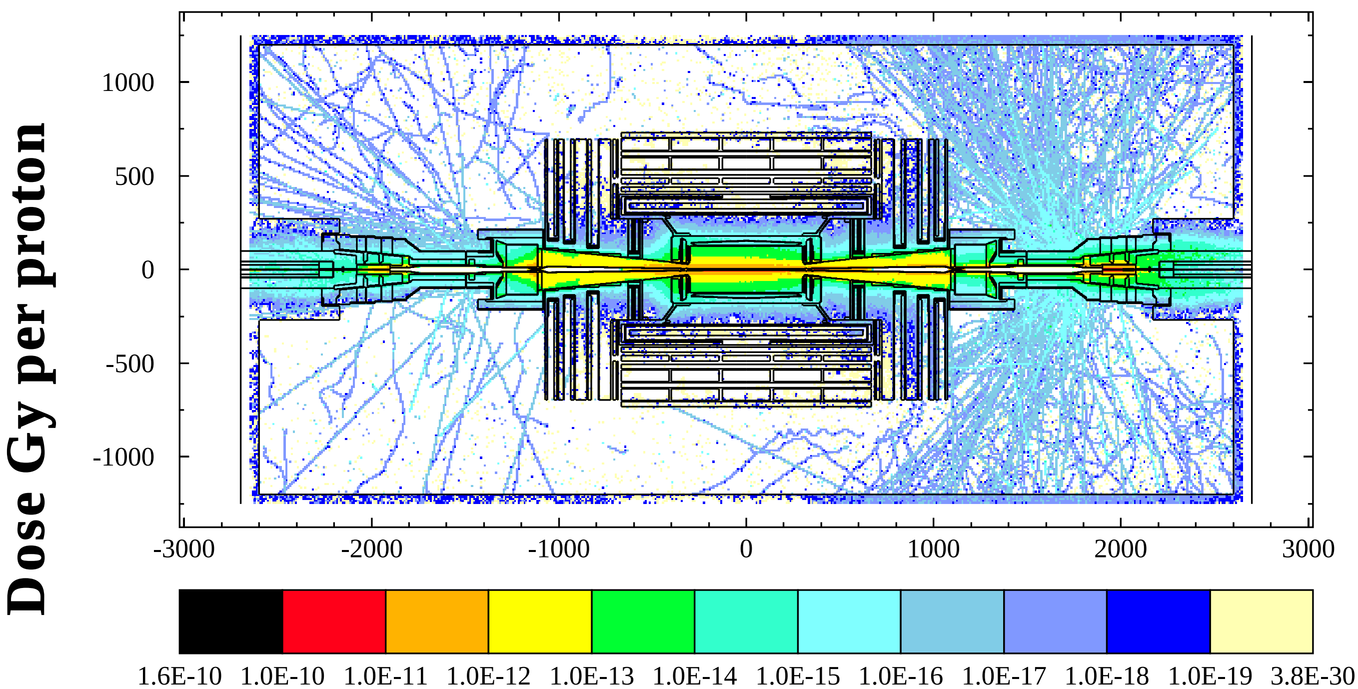
Neutron flux & dose from 7 TeV on TAS





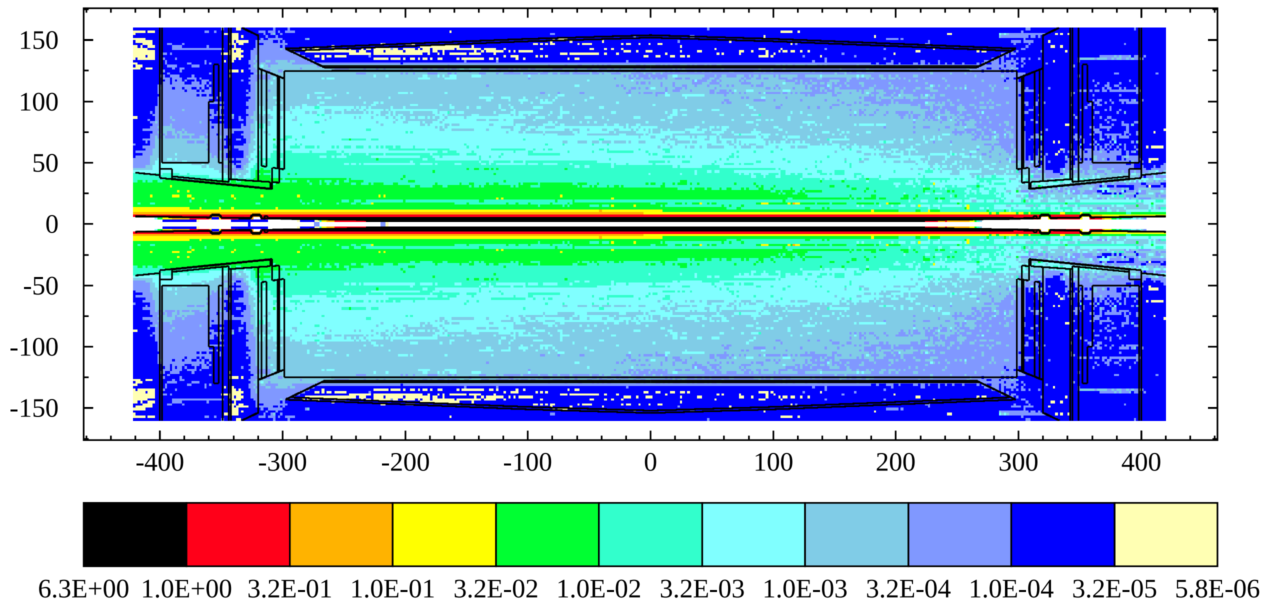
Neutron flux & dose from 450 GeV on TAS



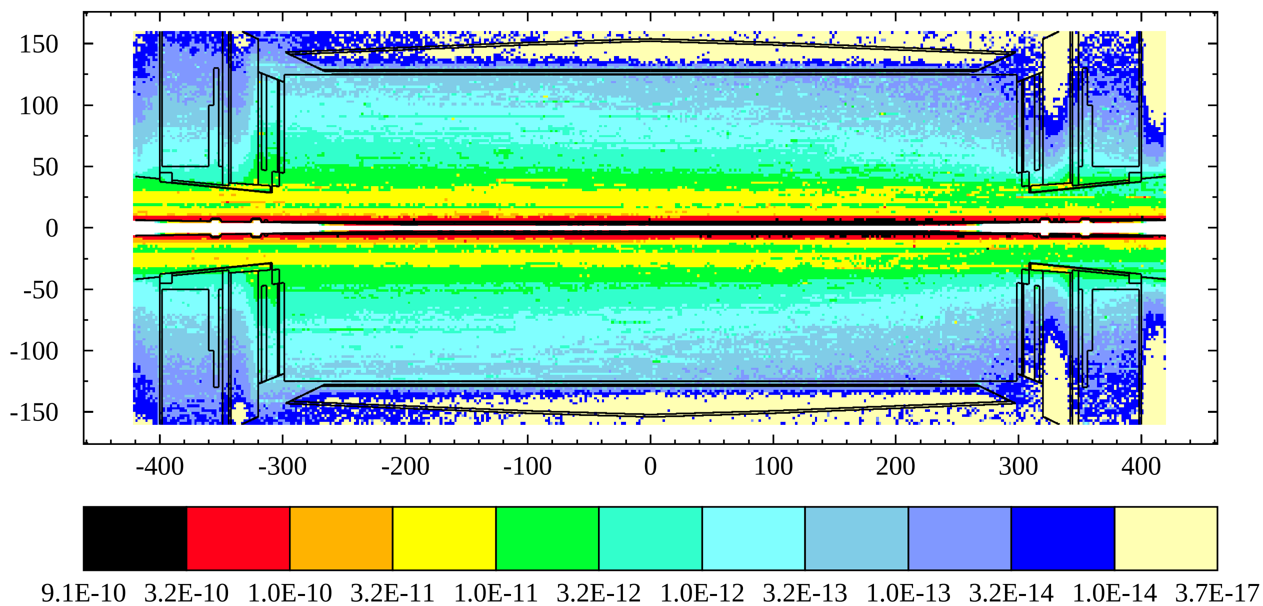


Dose (Gy) in Tracker for 2 loss scenarios

Unsynchronised abort



One 7 TeV proton on TAS



”Generic” Accident

Dose in innermost Si-strip layer of CMS Tracker (R=22 cm)

Loss type	Dose per event	Ratio
Unsynchronised abort	**10 mGy**	
7 TeV proton on TAS	**15 pGy**	7×10^8
450 GeV proton on TAS	**1 pGy**	1×10^{10}

Losses directly on the TAS
worse than
unsynchronised abort

Dose rates up to 1000 times higher if complete consecutive bunches lost on TAS

An unsynchronised abort we (CMS) just have to survive

Losses directly on the TAS we might be able to detect early and take protective/preventive action

CMS Beam Condition Monitor (BCM)

Proposal to install small sensors (diamond) very close to central (Be) beam pipe at about z=200 cm, r=4 cm.

Purpose

Monitor fluctuations of background and react on any significant excess

Minor excess in background	⟶	**ramp down detector voltages**
Major excess background	⟶	**trigger beam abort**
Anomalies during injection or ramping	⟶	**trigger injection inhibit or abort**

Provide a log-file with time structure of background close to IP to aid in any post-mortem analysis after beam incidents

Needed time resolution for BCM

Have to discriminate beam instabilities against background from 8×10^8 events per second

Losses likely to happen on inner triplet or TAS

1 proton on TAS gives 0.65 nGy at BCM

1s running at 10^{34} gives 31 mGy/s

5 protons on TAS $\equiv$ 100 ns normal running

Design BCM for $\sim$100 ns sampling time to have maximum sensitivity for proton losses

Beam loss on central Be-pipe

Seems quite unlikely

However, some "theoretical" possibilities

breaking of beam pipe support wire

mis-steering of 450 GeV beam during injection

Not yet studied, but probably less severe for CMS than losses on TAS

however

An intense beam with small cross section could melt or vaporise the beryllium

Assume 200 μm spot size, no cascade formation:

Melting: 44 bunches
Vaporisation: 470 bunches

Cascading might decrease these more than factor 10

Conclusions

We do not consider catastrophic point-like beam losses which would physically destroy any material

Any beam loss is negligible for cumulative radiation

In the (likely) case of an unsynchronised abort the CMS Tracker must survive instantaneous dose rates $\sim 10^8$ times above normal conditions
"Single shot" beam test done in 2002 show that CMS Si-Strip Tracker modules survive such conditions

We have done simulations for "generic" worst case accidents: beam particles lost on the TAS

CMS will design a dedicated Beam Condition Monitor close to the IP to detect early any losses in IR5

This BCM will be connected to the CMS slow control and LHC interlock system to trigger shut-down of CMS or beam abort of the LHC