Simulation Studies for a Neutron Shield for the new SciFi Tracker in LHCb

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on behalf of the LHCb Collaboration
The LHCb Experiment

The LHCb detector is a single-arm forward spectrometer

Designed for collisions at 14 TeV CM
Run1 operation at 7 and 8 TeV CM
Run2 now at 13 TeV CM

Large dipole warm magnet
(4 Tm over 10m)

Several Tracking stations:
Vertex locator (VELO)
Trigger Tracker (TT)
Inner and Outer Tracker (T1-T3)

Particle ID:
Ring Imaging Cherenkov (RICH) x2
Calorimeters (SPD/PS, ECAL, HCAL)

Muon:
5 Stations, 1 before calorimeters
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NSS 2016 Talk by Sebastian Bachmann on SciFi: N42-2

Replaced by SciFi Tracker
Aim to improve physics performance after upgrade by increasing luminosity $(4\times10^{32} \rightarrow 2\times10^{33} \text{ cm}^{-2} \text{ s}^{-1})$.

The LHCb Upgrade—The SciFi Tracker

SiPM locations

Sci(ntillating)Fi(bre) mats will replace inner & outer tracking stations, covering the full outside acceptance and attempting to close in to the beam pipe as much as possible.

SiPM based multichannel array photodetectors connected above and below the fiber mats measure scintillation photons.

Dark count rate of the SiPMs increases proportionally with 1 MeV neutron fluence.

The difference in the radiation field due to the similar density of the material is expected to be minimal.
Aim to improve physics performance after upgrade by increasing luminosity (3E+32 → 2E+33 cm⁻² s⁻¹)

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SiPM locations

~6m

~5m

Leads to new issues including (but not limited to) increased damage and noise by radiation.

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At the borderline of feasibility: central fibers struggle with dose values, SiPMS require fluence reduction!
Removal of 3 subdetectors just upstream of the ECAL:

- First muon detector M1, made of mostly gas-filled chambers mounted on an aluminum support wall
- Preshower (PS) and the Scintillating Pad detector (SPD), partially made of polystyrene and aluminum, including a 1.4 cm thick lead plate between PS and SPD.

Radiation field will change when lead, plastic and metals are removed!

FLUKA simulation required to assess new situation
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FLUKA simulation required to assess new situation
FLUKA simulation studies for LHCb

Using a very detailed model of current LHCb detector + some support structures and close-by cavern walls

Since 2010:
Studies performed for current LHCb geometry and evaluated via measurements (Alanine, TLD, + many more) in yearly campaigns during Run1.

Simulation considered to be precise within a factor <2 inside acceptance and around the detector edge.

First studies at 14 TeV CM: SiPMs already require a fluence reduction by factor ~2, despite cooling to -40 °C.
Upgrade studies based on current parameters at 14 TeV CM with M1, SPD/PS and lead removed and replaced with air.

Simulation shows that most neutrons at the location of SiPMs come from calorimeter central region (interaction with lead of ECAL modules).

1MeV n. equ. Fluence for “UPGRADE (10y)”

**NO M1/PS/SPD** (new reference)
XS: 84mb

- **T1**: $8.1 \times 10^{11}$ cm$^{-2}$
- **T3**: $1.4 \times 10^{12}$ cm$^{-2}$
The complete removal of M1/PS/SPD increases the 1MeV neutron fluence by a factor of 1.6 at T3 and higher around RICH2!

Before: Smaller local shielding might have been sufficient. (little available space)

Higher Fluence

Yellow: No Change

Lower Fluence

Now: Fluence requires a larger neutron shielding for SiPMs at the location of M1.
SciFi neutron shielding first drafts

Best candidate: Polyethyylene ($C_2H_4$) blocks with 5% Boron content

(Boron is useful for reducing the otherwise increased thermal neutron fluence around the experiment)

Shielding against 1 MeV neutrons is primarily achieved by moderation using the hydrogen content of materials, (neutron thermalization by recoil protons)

Choice of material based on:
- Hydrogen content
- Rigidity
- Material density (in regard to downstream detectors)
- Activation
- Fire safety

Will be strongly reduced by adding 5% Boron
SciFi neutron shielding first drafts

After optimization involving several steps & calculations

**Concept**

10 cm thickness along beam with 5x5 m perpendicular to the beam line (similar in size to 1 Tracking Station)

+ 10 cm conic plug at center (circular opening close to the beam pipe)

20 cm thickness at critical central region

1 MeV n. equ. Fluence with 10 + 10 cm pure PE Shielding (10y)

- 2x5 cm + 10 cm shielding
  X5: 84mb
  T1: $3.5 \times 10^{11}$ cm$^{-2}$
  T3: $4.7 \times 10^{11}$ cm$^{-2}$

New polyethylene shield + plug
SciFi neutron shielding first drafts

After optimization involving several steps & calculations

1 MeV n. equ. fl.: RATIO between 20 cm pure PE Shielding VS No Shielding

Using PURE (No Boron) PE leads to a reduction of fluence by a factor of 2.2 (T1) to 3 (T3)

Less than 0.25

Concept works: numbers are below critical point!
Asymmetric conic plug from simulation study unfeasible: structure needs to be symmetric for balance.

Current support wall of M1 is able to hold the full weight (3.5t) of the shielding and will be reused.

While 20 cm thickness of inner region should be sufficient, 30 cm are envisaged (providing a safety margin).

Increase of thickness only has small additional shielding effect, because high energy neutrons are slowed down to 1 MeV and new ones are created. 30 cm vs. 20 cm yields around 15% more shielding effect at T1-T3.

Fire safety achieved by covering PE volume in thin aluminum plating and adding fire resistant paint. No sources of incineration nearby.
SciFi neutron shielding final design

Final geometry design (30 cm thickness of inner part) was put into simulation for verification of its effect
Effect of final shielding design

Physics simulations are being conducted by calorimeter group to evaluate the effect of different shielding thickness on the performance of the calorimeters.

Absolute prediction values are expected to be precise within a factor of 2:
- densities and materials of new detector are similar to old tracking stations
- no other changes for upgrade detector are expected to have an impact on the radiation field in this area

1 MeV n. equ. fl.: RATIO between final 30 cm Shielding VS No Shielding

15-18% improvement over 20 cm design, leaving some safety margin.

Fluence reduction by a factor of 2.5 (T1) to 3.4 (T3)
Summary

- FLUKA simulation of LHCb Upgrade conditions highlighted need for reducing 1 MeV neutron equivalent fluence around SiPMs of new SciFi Tracker to decrease their dark count rate.

- Simulation showed that the most relevant amount of fluence arrives as backsplash from calorimeters.

- Previously evaluated FLUKA geometry was modified and used to find an optimized shielding solution, using available space (and support) of expiring subdetectors in front of calorimeters.

- Material chosen (polyethylene plus 5% Boron) because of high hydrogen content and favorable mechanical properties. Fire resistance will be achieved by additional plating.

- Final Design validated by new FLUKA simulation. Achieved fluence reduction by a factor of ~3.
Thank you!
References

LHCb Tracker Upgrade Technical Design Report
The LHCb Collaboration
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3D Geometry & Plot Visualizer: SimpleGeo (+DaVis3D)
BACKUP
Backup
A 58% reduction of 1MeVne fluence can be observed around OT1 compared to a setup that completely omits M1/PS/SPD.

1MeV neutron equivalent fluence ratio:
2x5cm + 10 cm conic PE VS NO M1/PS/SPD at z=780cm

The red box indicates the location of T1 electronics around y = -2.5 m