Hadron damage in $PbWO_4$ extrapolated to SLHC

ETH Institute for Particle Physics

Francesca Nessi-Tedaldi
ETH - Zürich

Reminder: Approximate radiation levels and fluences, rescaled from the ECAL TDR for 3500 fb^{-1} at $10^{35} cm^{-2} s^{-1}$:

in front of crystals:

η=2.0: 5×10^{13} fast hadrons/cm^2

η=2.9: 4×10^{14} fast hadrons/cm^2

at shower max →crystals :

η=2.6: 570 kGy, 50 Gy/h

η=2.9: 1400 kGy, 140 Gy/h

Expected changes in $PbWO_4$ at LHC and SLHC

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- Radiation and particle fluxes change the crystals Light Output and Light Output Uniformity (L.O. dependence on shower position in the crystal)
- Reduced Light Output → effect on E-resolution stochastic term, increased importance of noise
- Change in Uniformity → effect on E-resolution constant term, especially in the front part of crystals (Front-Non-UniFormity, FNUF)
- Activation → maintenance problems
- Higher L and Int L at SLHC will make the issue more severe.

Changes due to ionizing radiation

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➢Radiation and particle fluxes change the crystals Light Output and Light Output Uniformity

➢ Measurements indicate that at LHC and SLHC, the scintillation mechanism is not affected. Instead, Light Transmission (LT) is reduced. This is quantified as an induced absorption coefficient μ_{IND}:

$$\frac{LT(\lambda)}{LT_0(\lambda)} = e^{-\mu_{IND}(\lambda)L}$$

➢ Ionizing radiation causes a damage by forming color centers: this damage reaches an equilibrium at a level proportional to the dose rate.
At SLHC, the dose rate is expected to reach ~140 Gy/h at η = 2.9.

Throughout the EE, the damage from ionizing radiation is expected to saturate with Light Output losses reaching 40%-60% (from ^{60}Co irradiations at the Geneva Hospital, ~200 Gy/h).

Changes due to hadron fluxes

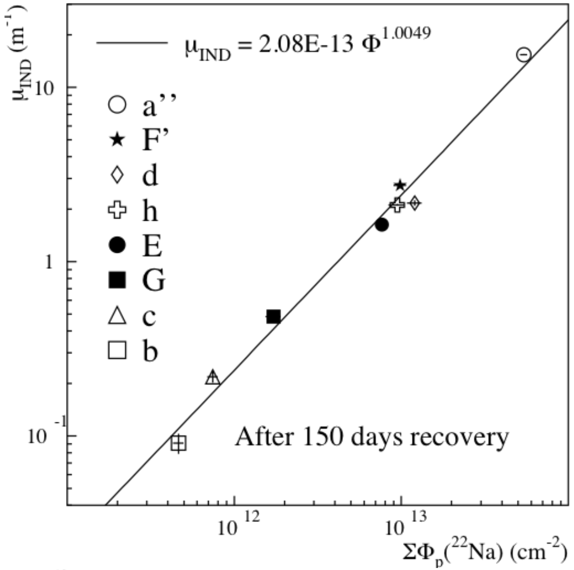
Hadrons induce as well a reduction of Light Transmission.

⟶ There is a specific hadron damage. It can probably be mostly ascribed to the high dE/dx of heavy fragments.

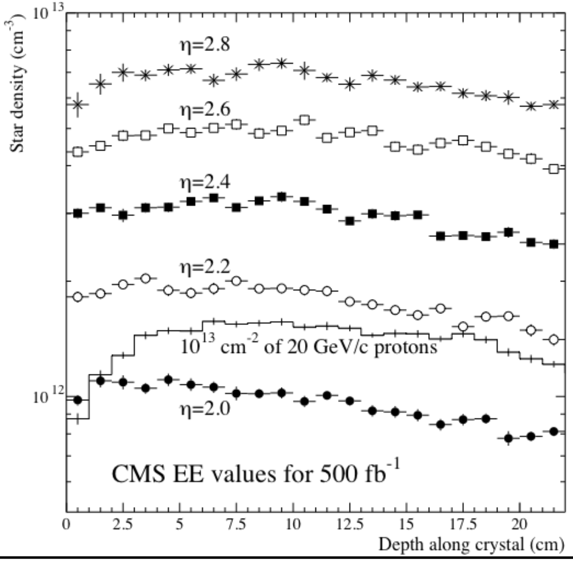
⟶ It is cumulative, thus a function of delivered Int L

⟶ It is nearly permanent on an LHC and SLHC time scale.

⟶ Tested over 2 orders of magnitude in fluence, up to 5×10^{13}cm^2 , i.e. $\eta \approx 2.0$ at SLHC
and for fluxes between 5×10^{11} /cm^2/h and 10^{13} /cm^2/h.
M. Huhtinen et al., Nucl. Instr. Meth. A545 (2005) 63-87



Scintillation does not appear to be affected measurably. Thus, the damage can be monitored.
P.Lecomte et al., Nucl. Instr. Meth. A564 (2006) 164-168



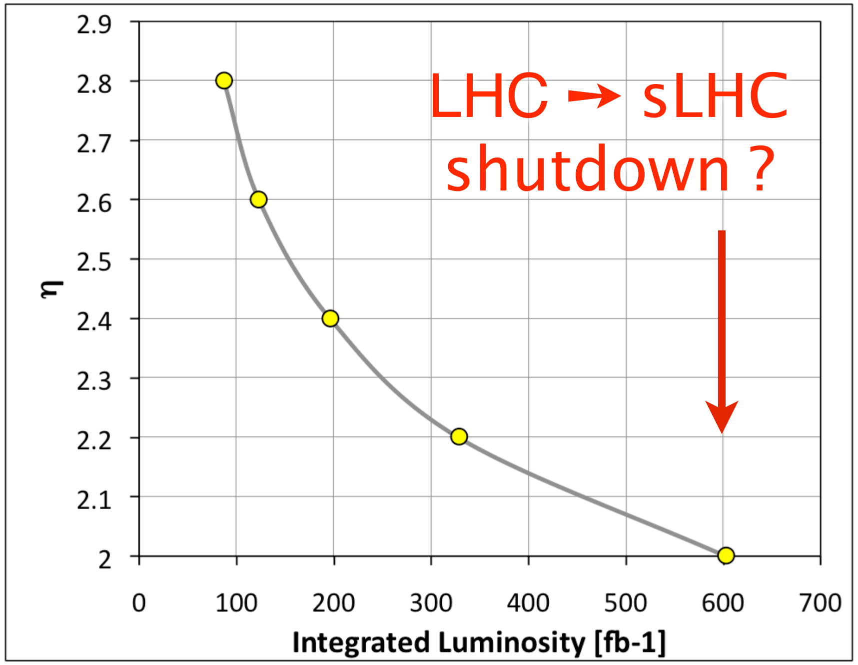
We know how to can scale from our 24 GeV/c proton results: we cross-checked with a 290 MeV/c π^+ irradiation (typical for EE energy spectrum). Damage ratio was measured to be consistent with star density ratios from FLUKA.
P.Lecomte et al., Nucl. Instr. Meth. A587 (2008) 266-271)

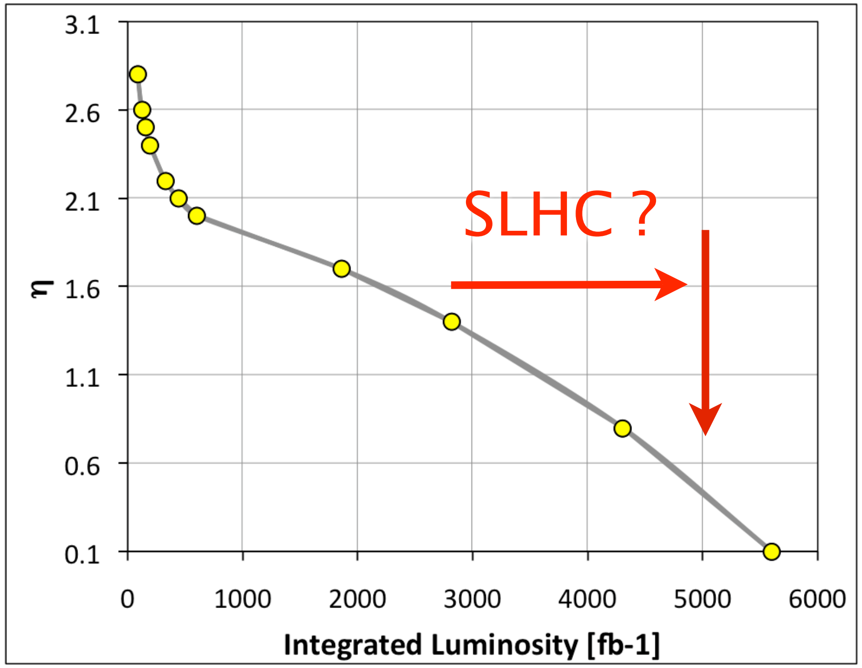
Evolution of ECAL performance due to hadrons

F. N., ECAL XPG meeting, 27-FEB-08

η value vs. $\int \mathcal{L}dt$, at which μ_{IND}(420 nm) = 2 m^{-1} (~60% of Light Output loss) is expected to be reached in the ECAL

(LHC and SLHC scenario presented yesterday by J. Nash)





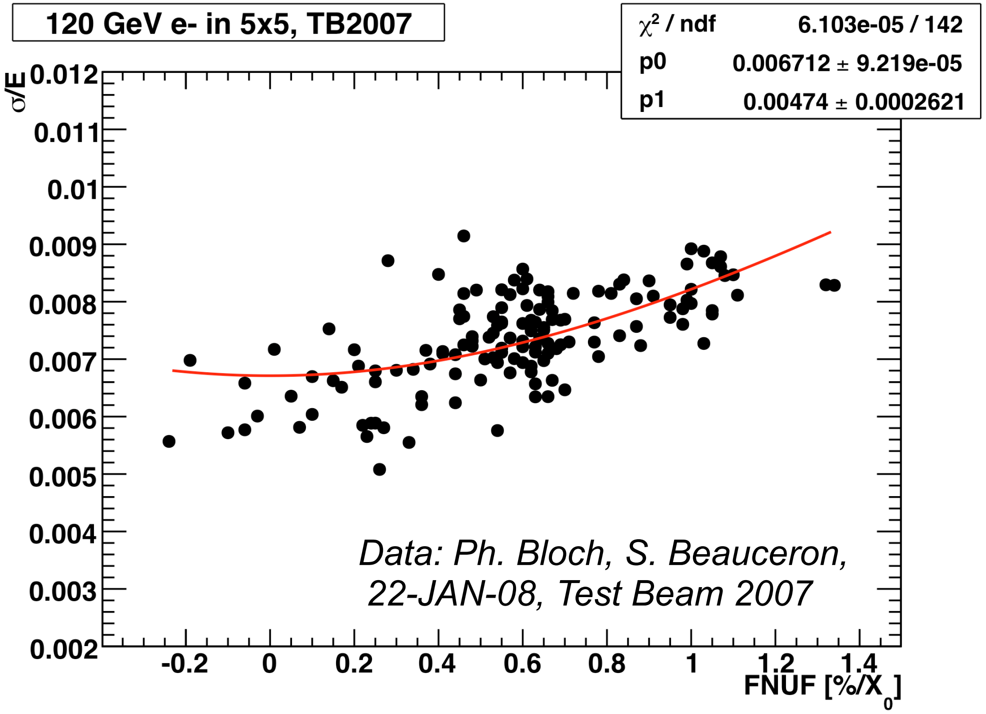
(using EB star densities from draft Radiation Hardness ECAL detector paper, Ed. I. Dafinei)

Let’s attempt a very crude extrapolation to estimate the evolution of ECAL performance as a function of integrated Luminosity

Constant term in σ/E depends on FNUF

Notice: crystals are non-uniform to some extent from production, but their non-uniformity changes due to radiation damage

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{S}{\sqrt{E}}\right)^2 + \left(\frac{N}{E}\right)^2 + C^2$$

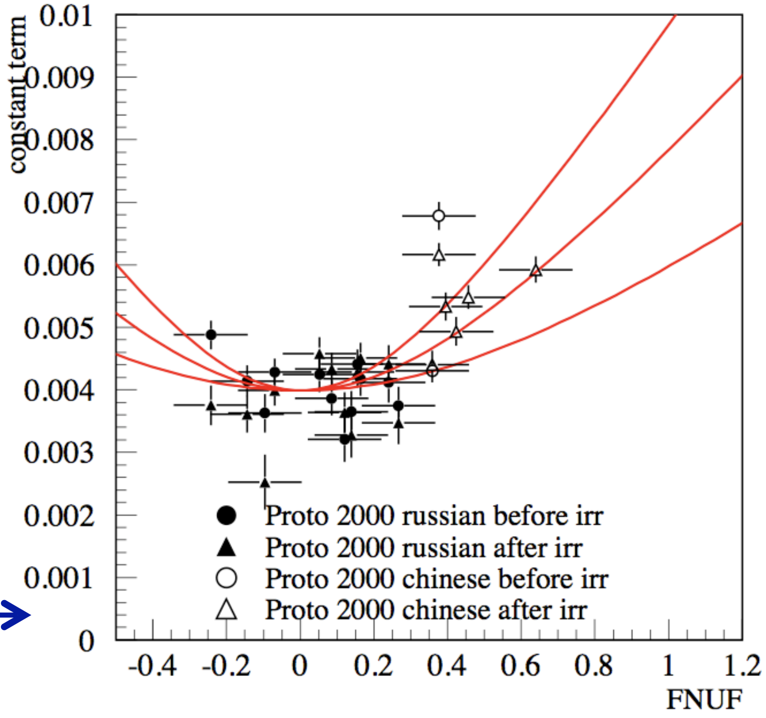


Data: Ph. Bloch, S. Beauceron, 22-JAN-08, Test Beam 2007

Fit $$\mathrm{c} = \sqrt{(\mathrm{c1})^2 + (\mathrm{c2} \cdot \mathrm{FNUF})^2}$$

yields

c1 = 0.67 % and c2 = 0.47%

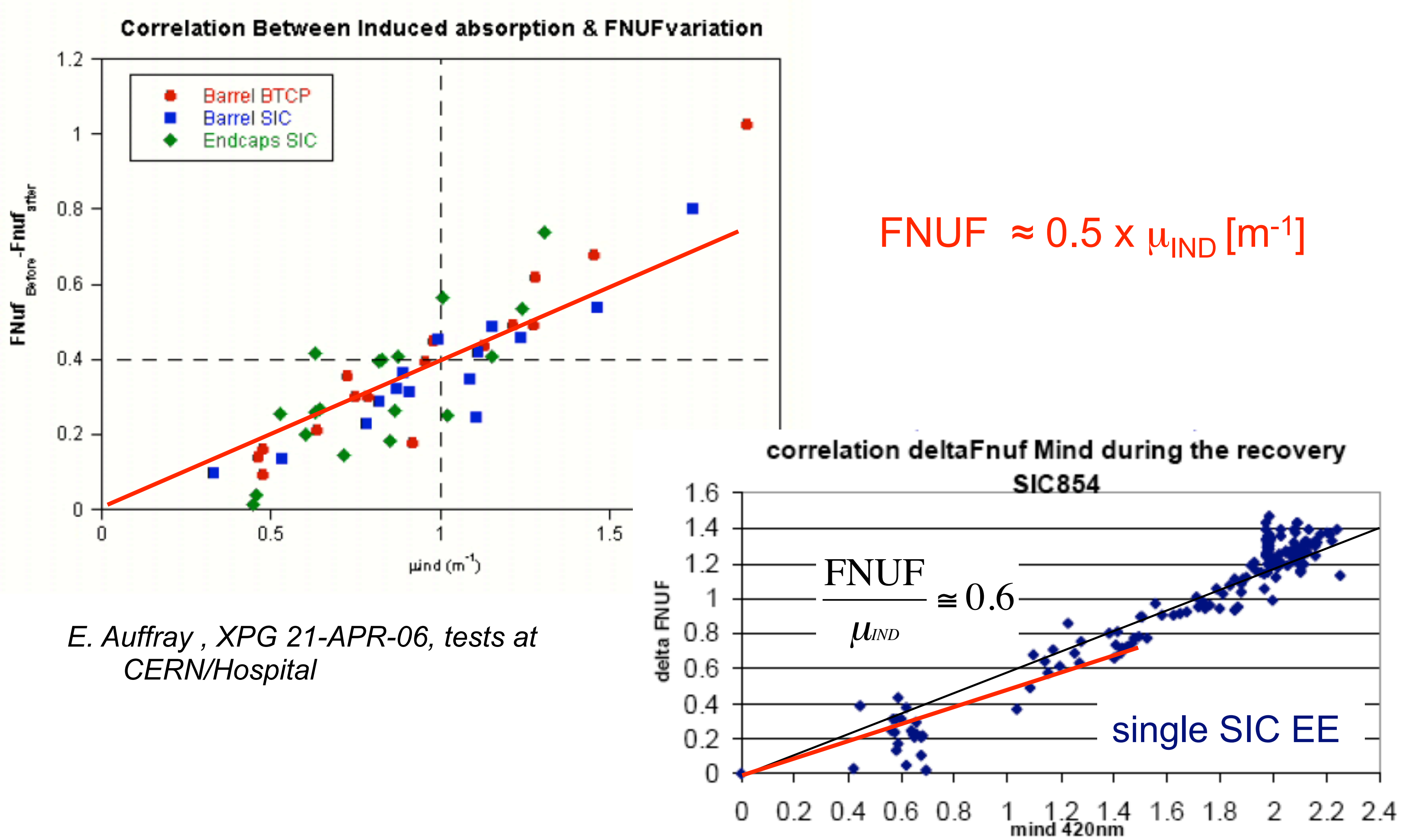


C2 consistent with σ_{FNUF}/E for all previous MC and data. See in particular F. Cavallari et al, CMS IN 2001/033:

c1 = (0.40 ± 0.01)% and

c2 = (0.68 ± 0.23)% for [FNUF] = %/X_0

Correlation FNUF vs μ_{IND}

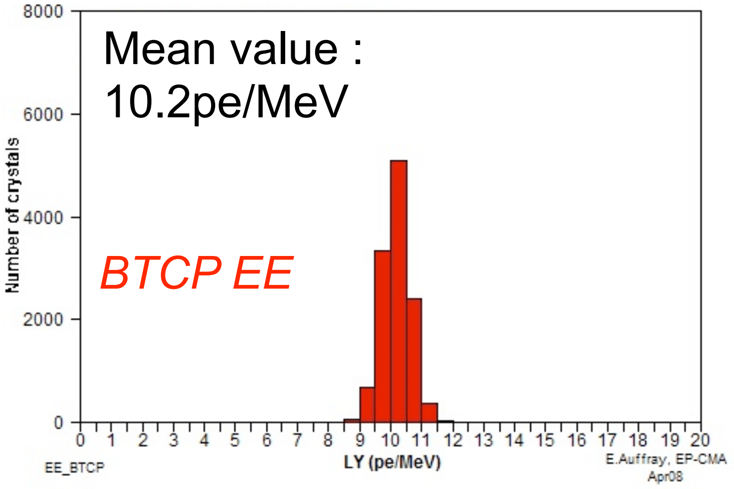


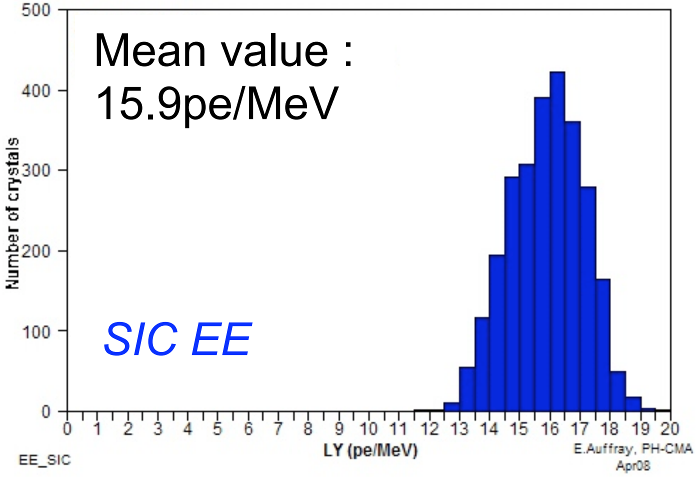
FNUF ≈ 0.5 x μ_{IND} [m^{-1}]

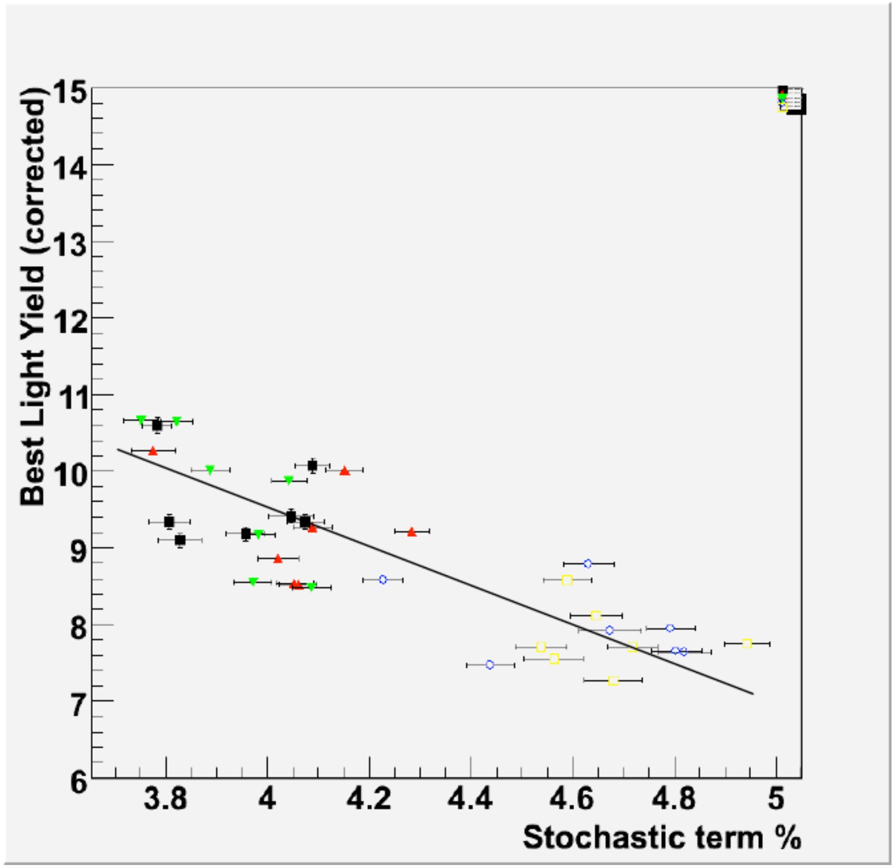
E. Auffray , XPG 21-APR-06, tests at CERN/Hospital

Stochastic term depends on Light Output

Notice: crystals Light Output varies at production from crystal to crystal, but it changes also due to radiation damage





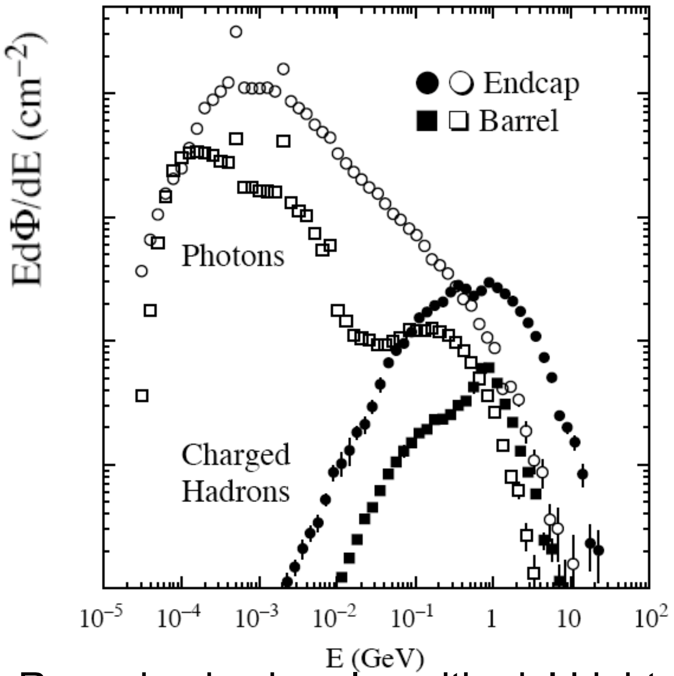


P. Jarry, 15-JAN-07, Results from EB Test Beam campaign 2006

E. Auffray, XPG 15-APR-08, Status of endcap production

Light Output loss vs μ_{IND}

Caveat: ^{60}Co used for most γ tests, but ECAL spectrum goes to high energies.

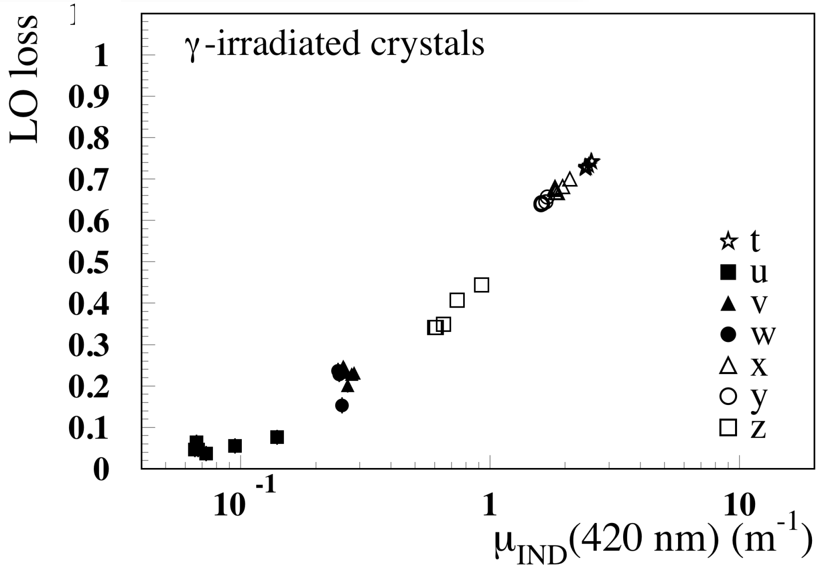


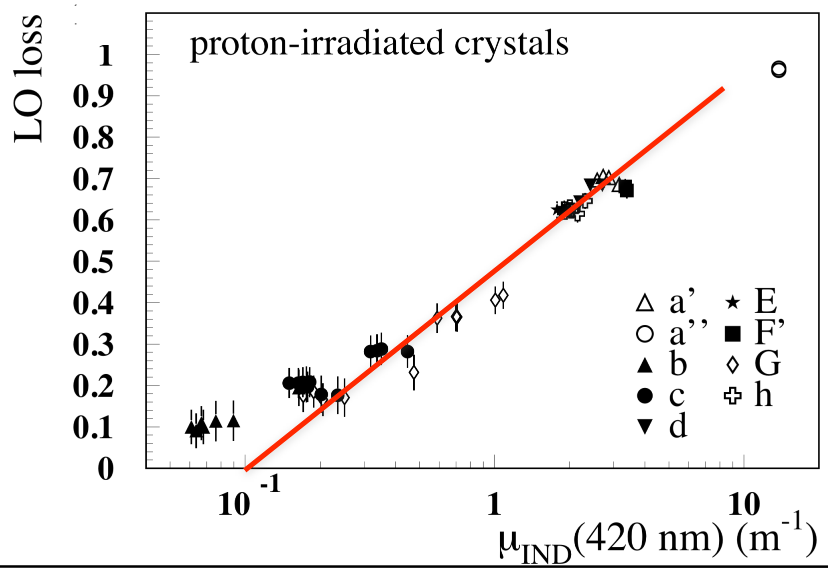
ECAL TDR, CERN/LHCC 97-33

Remark: abscissa logarithmic! Light Output loss flattens for high μ_{IND} values

Very approximative parametrization VALID ONLY for 0.1 m^{-1} μ_{IND} <10 m^{-1}:

$$\text{LOloss} \approx 0.5 \times \log_{10}(\mu_{IND}) + 0.5$$





P. Lecomte et al., NIM A 564 (2006) 164

Extrapolated evolution of σ/E due to hadron damage

Typically,

- FNUF [%/X_0] ≈ 0.5 x μ_{IND} [m^{-1}]
- The contribution [%] to the constant term from FNUF is ≈ 0.6 x FNUF [%/X_0] i.e., when FNUF is due to an induced absorption μ_{IND}, it is ≈ 0.3 x μ_{IND} [m^{-1}]
- The stochastic term contribution due to LO losses increases by a factor

$$\boxed{\frac{1}{0.7 \times \sqrt{1 - \log_{10} \mu_{IND}}}}$$

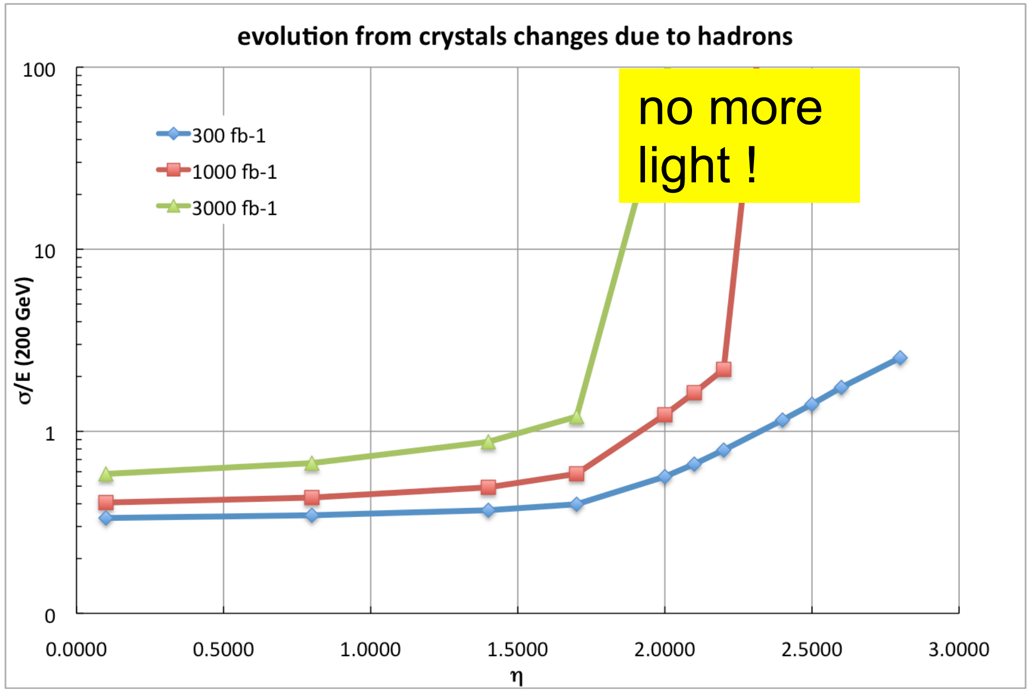
for $0.1\ m^{-1} < \mu_{IND} < 10\ m^{-1}$

- The noise term contribution due to LO losses increases in the same range by a factor

$$\boxed{\frac{1}{0.5 \times (1 - \log_{10} \mu_{IND})}}$$

Example for 200 GeV:
Assume stochastic term 4.5%
Neglect further contributions from

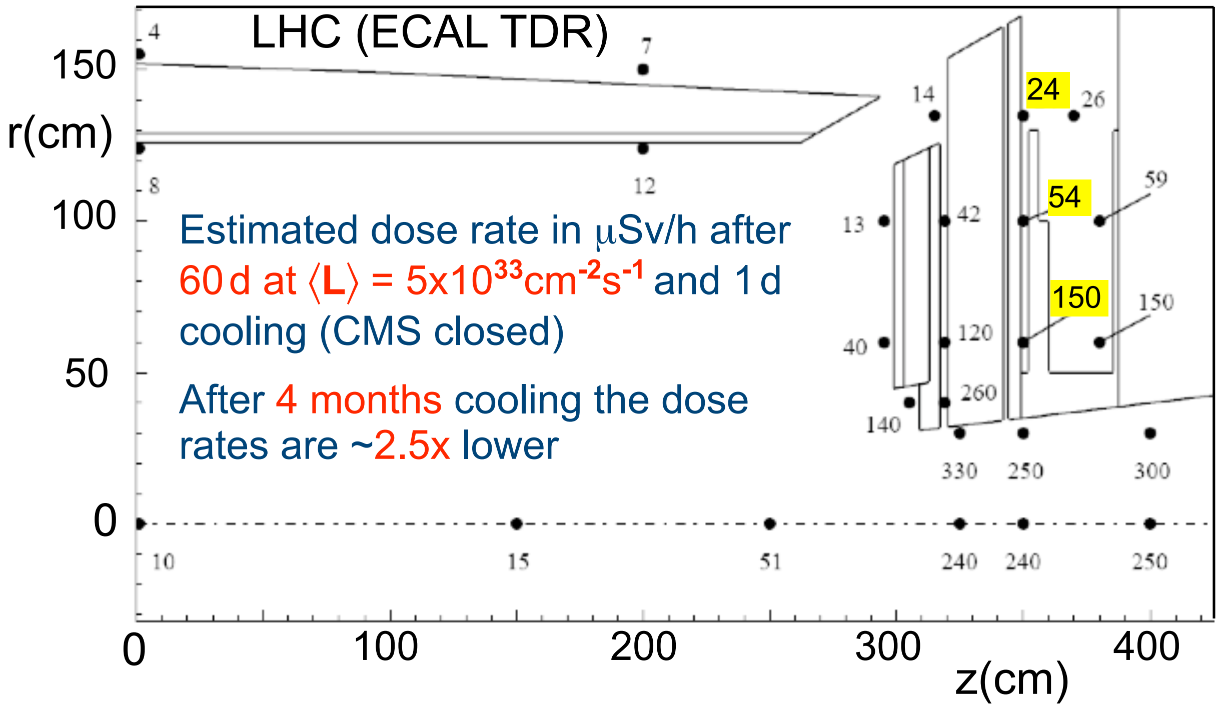
- losses from γ-damage
- damage to VPT glass
- noise from VPT current induced by activated crystals
- Preshower (*E. Auffray et al., NIM A412 (1998) 223)*
- Constant term from other sources



no more light !

Caveat: EE activation at LHC

R.M. Brown, EE at SLHC miniworkshop, 15-APR-08



Estimated dose rate in μSv/h after 60 d at $\langle \mathbf{L} \rangle = 5 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and 1 d cooling (CMS closed)

After 4 months cooling the dose rates are ~2.5x lower

Occupational dose limits:
- 1 mSv/wk
- 15 mSv/yr

Assume induced activity levels at SLHC ~10xLHC

The time for a worker to reach the annual exposure limit around the central part of the EE is ~10 h after CMS has run for 60 days with high L at SLHC

M. Huhtinen, SLHC electronics workshop, 26-FEB-04:

Dose at short cooling (maintenance) α rate

Dose at long cooling (waste) α integral

Activity saturates: after 10 y LHC, not much higher than above.

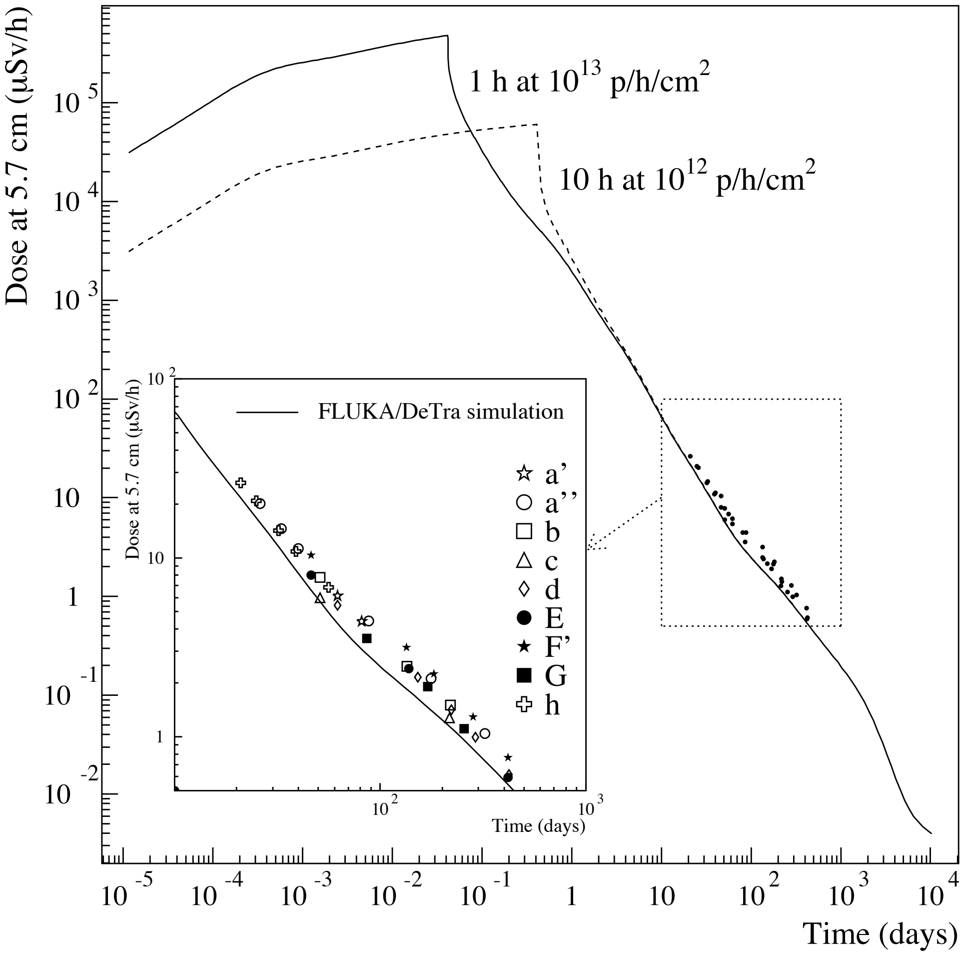
No linear scaling! Maintenance already prohibitive after early high-Luminosity running

Quality of radiation level simulations

Comparison between Lead Tungstate activation measured after p-irradiation as a function of cooling time, and the simulated values (lines).

M. Huhtinen et al., Nucl. Instr. Meth. A545 (2005) 63-87

Excellent agreement in magnitude and in cooling over time.



Conclusions

If we trust the hadron irradiation results:

- Crystals: hadron damage is likely to considerably affect all terms in the energy resolution, starting from large η values inwards, already during LHC running.

Less and less signal from EE over time

In the most extreme scenario, the replacement of $PbWO_4$ with something else might be necessary.

The anticipated evolution of ECAL performance has to be be folded into physics performance studies at SLHC.

Physics requirements studies are mandatory to define the work which is necessary for a sufficiently performing ECAL at SLHC

- Activation: Not to be forgotten, maintenance problems will be prohibitive. No work around high-η region unless robot.