Endcap Response Evolution: Model, Validation and Projections

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ECAL General Meeting, CMS Week
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overview

- description of the model for evolution of ECAL signals with radiation damage

- validation of the model with various experimental measurements

- predictions for ECAL performance using the model

1 Model for light output

CRYSTAL TRANSPARENCY

Described by index of absorption $\mu(\vec{x})$, inverse of absorption length

Model needs prediction of μ for certain LHC conditions

LIGHT COLLECTION EFFICIENCY

$\mathcal{E}_{LC}(\vec{x}, \mu)$ is probability for photons emitted isotropically from location $\vec{x}$ to produce photo-electron in VPT. Use LITRANI to calculate it

ENERGY DEPOSITIONS IN ECAL CRYSTAL (ECAL HIT)

$E(\vec{x})$, simulated by Geant4

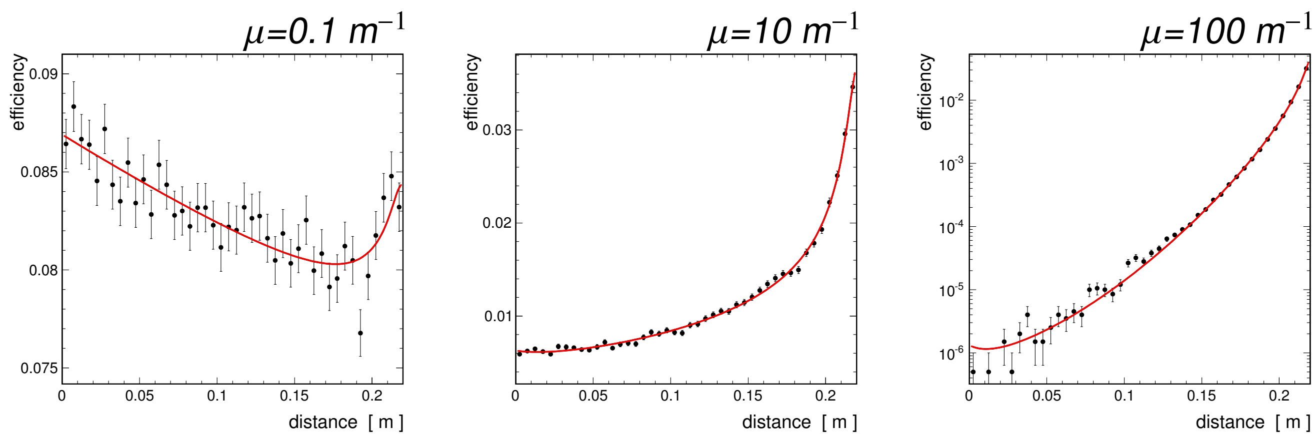
AMPLITUDE OF ECAL HIT

Simple integral with calibration C_0

$$E_{meas}(\mu) = C_0 \cdot \int \mathcal{E}_{LC}(\vec{x}, \mu) \cdot E(\vec{x})\, d\vec{x}$$

MODEL: analytic function for light collection efficiency $\mathcal{E}_{LC}(z,\mu)$

- LITRANI generated longitudinal profiles (black dots) for ***uniform*** μ
- Fit with analytically function (red lines)
- Introduce μ into the function to cover range from 0.1 m^{-1} to 200 m^{-1}



Expected induced absorption from hadronic damages:

L [fb^{-1}]	η=2.9	η=2.8	η=2.7	η=2.6	η=2.4	η=2.2	η=2.0	η=1 .8	η=1.5
10	0.373	0.297	0.233	0.179	0.100	0.051	0.024	0.011	0.003
50	1.859	1.487	1.166	0.896	0.498	0.256	0.121	0.053	0.013
100	3.718	2.974	2.332	1.792	0.996	0.511	0.242	0.106	0.026
500	18.59	14.87	11.66	8.959	4.981	2.556	1.210	0.529	0.131
1000	37.18	29.74	23.32	17.92	9.963	5.112	2.420	1.058	0.262
2000	74.36	59.48	46.64	35.84	19.93	10.22	4.841	2.116	0.526
3000	111.5	89.22	69.95	53.75	29.89	15.34	7.262	3.173	0.788

Additionally, **EM damages** contribute $\mu = 0 \ldots 2$, depends on instantaneous luminosity

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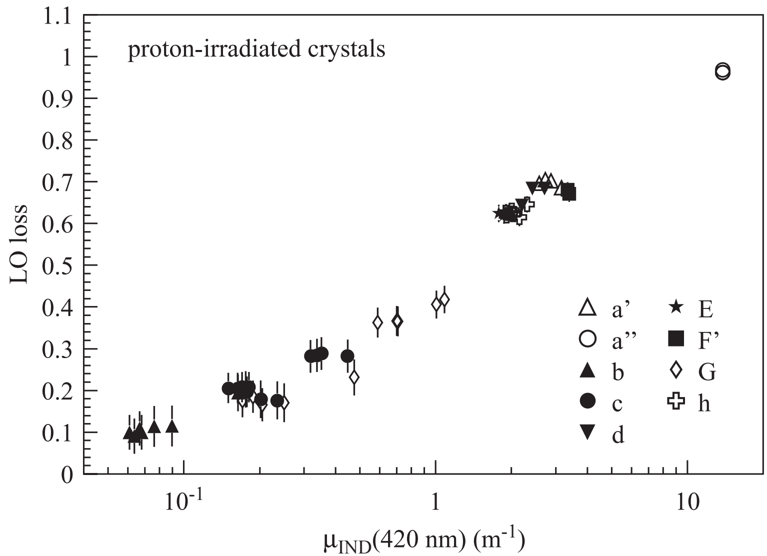
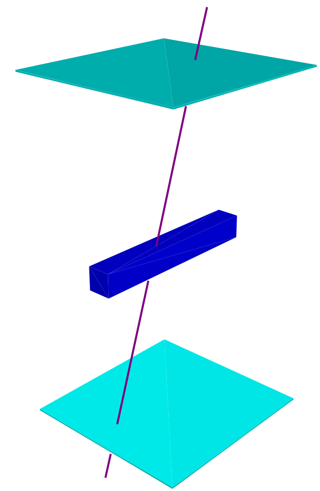
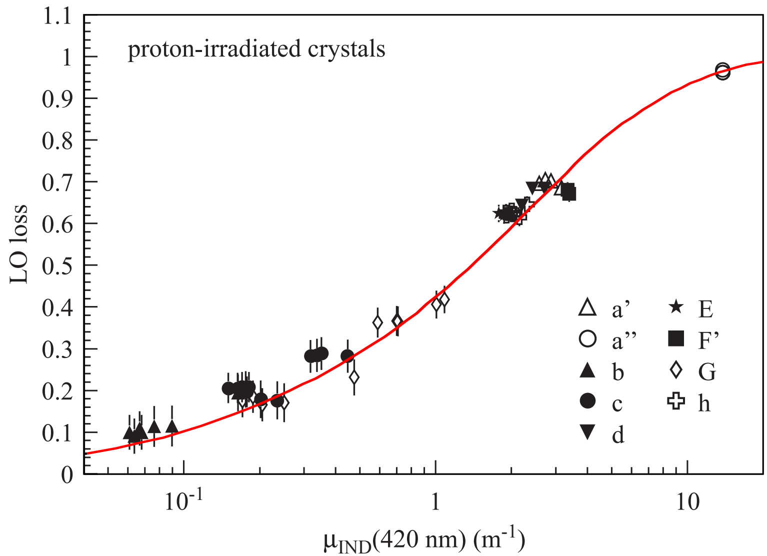
Model vs Lab Tests

P. Lecomte et al., NIM A 564 (2006) 164-168

Average light output from a crystal is measured with cosmic muons before and after irradiation. Light loss vs μ_{IND} is plotted.







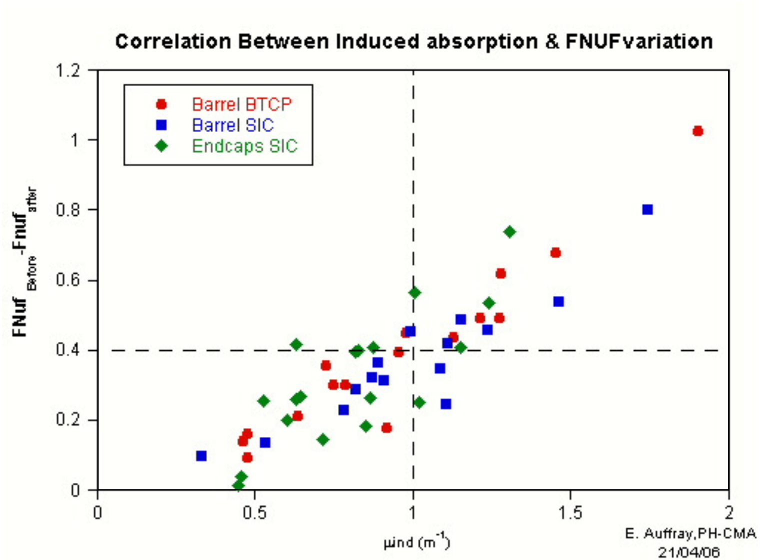
Red line:
Model prediction

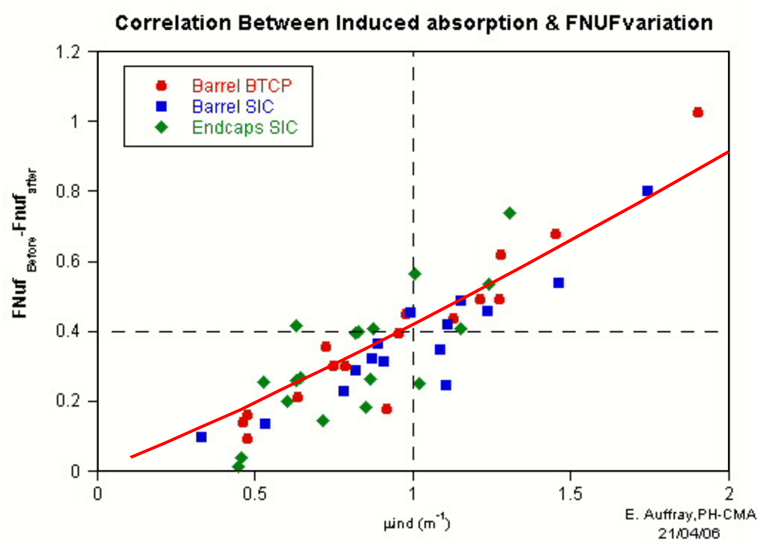
First, simulate longitudinal profile of energy depositions from cosmic muons

Then, apply $\mathcal{E}_{LC}(z,\mu)$

E. Auffray, ECAL XPG, April 26, 2006

Radiation damages change longitudinal non-uniformity of light collection around EM shower maximum (FNUF). Measured ΔFNUF vs μ_{IND} is plotted





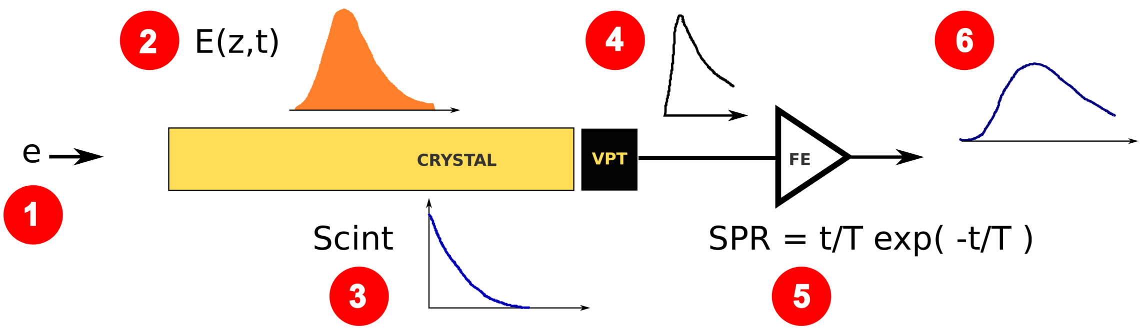
Red line:
Model prediction

Repeat the same procedure used for FNUF measurements on $\mathcal{E}_{LC}(z,\mu)$

3 Model vs ECAL Timing

INGREDIENTS FOR ECAL TIMING:

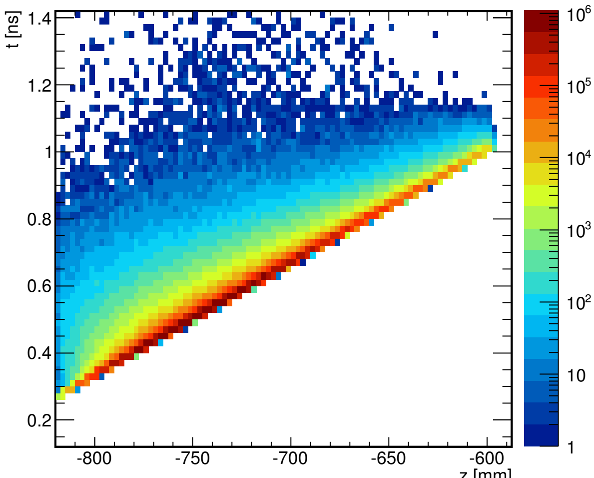
1. Incoming electron at time T_0
2. Time evolution of energy depositions in EM shower
3. Scintillating photons emitted with delays according $PbWO_4$ properties
4. Travel distance inside the crystal before hitting photo-cathode
5. VPT pulse is shaped by FrontEnd according to SPR
6. FrontEnd pulse is ready for digitizing and recording



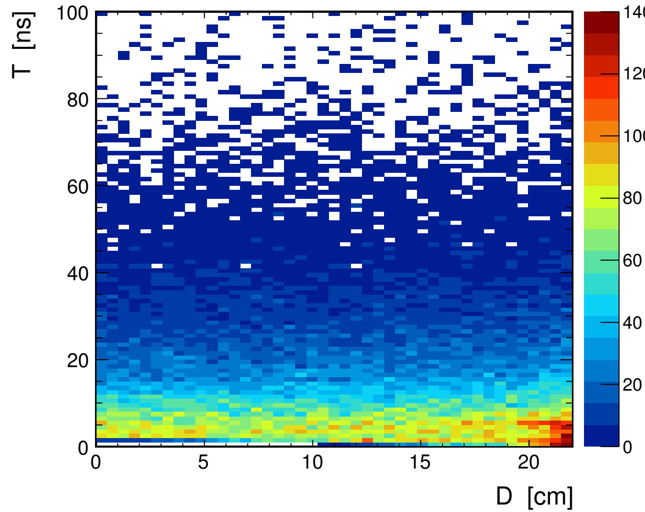
Map of energy depositions
E(z,t) in EM shower

Map of photo-electrons: T vs Z
T since energy deposition
Z of energy deposition

Geant4



LITRANI



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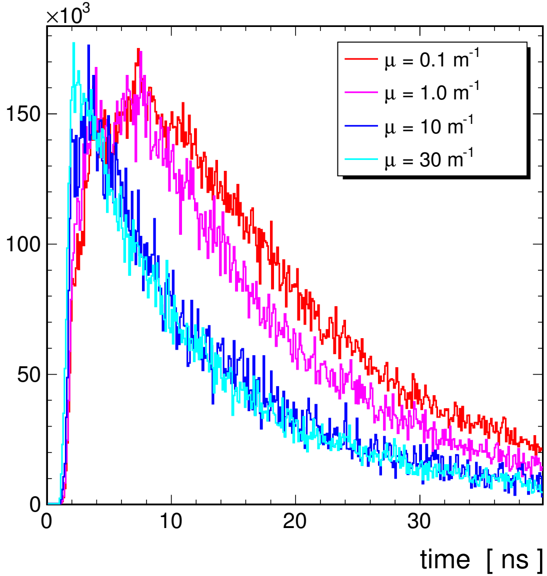
Time distribution of photo-electrons since electron trigger for several levels of crystal transparency. There is a strong dependence on index of absorption.

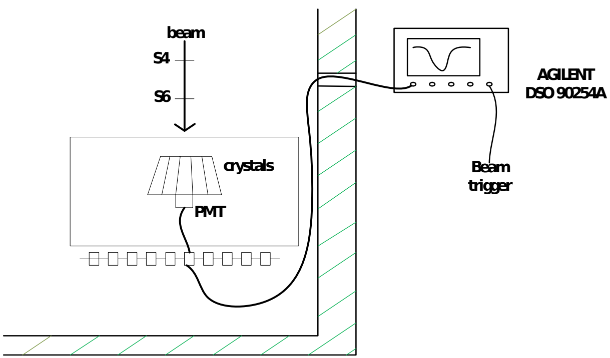


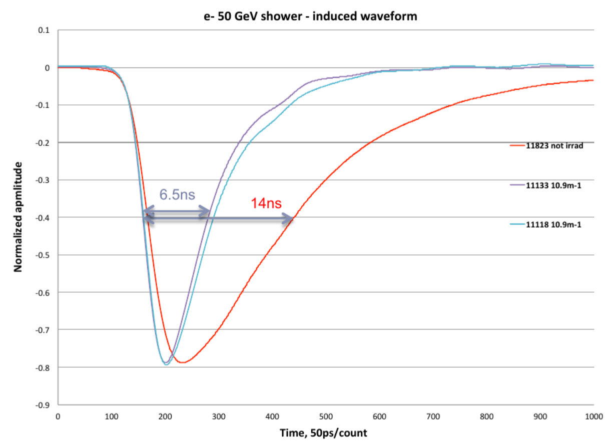
A. Singovski. Plenary Session. CMS Upgrade Week. May 25, 2012

Measurements of PMT pulse at H4 TestBeam

$\mu_{\mathrm{IND}} = \quad 0\ \mathrm{m}^{-1}$ FWHM = 14 ns

$\mu_{\mathrm{IND}} = 10.6\ \mathrm{m}^{-1}$ FWHM = 6.5 ns

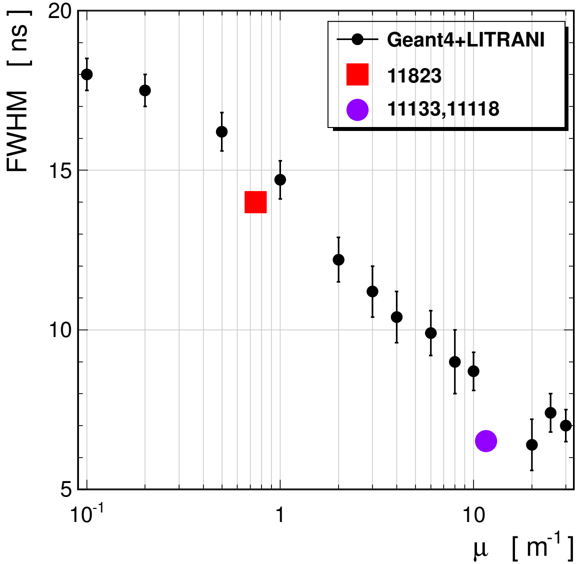




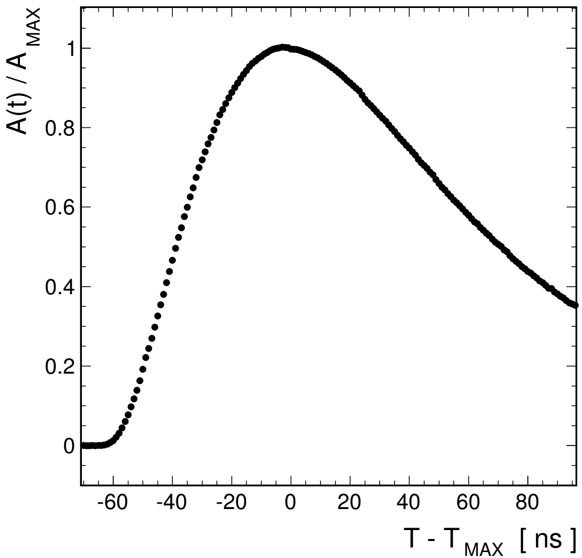
Comparison TB measurements vs Model for Pulse Width:

Simulation results for FWHM of the pulse vs μ (black dots) and two experimental measurements. There is a small offset.

Good agreement in overall change of pulse width.

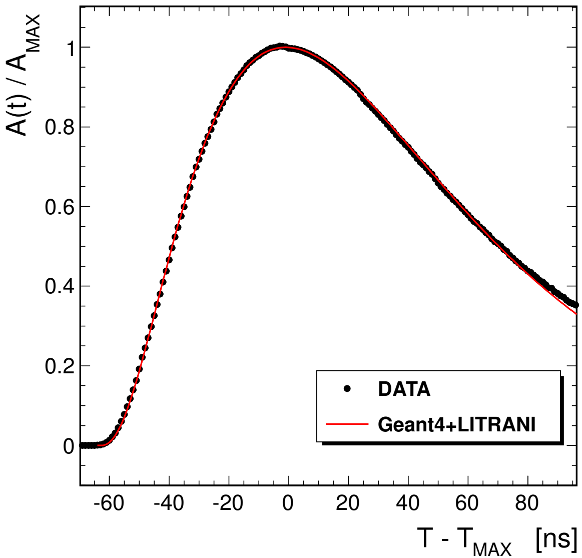


FRONT-END PULSE



Average EE pulse

Measurements in CMS with collisions during r/o phase scan in 2010



Red line:
Model prediction

Convolution of

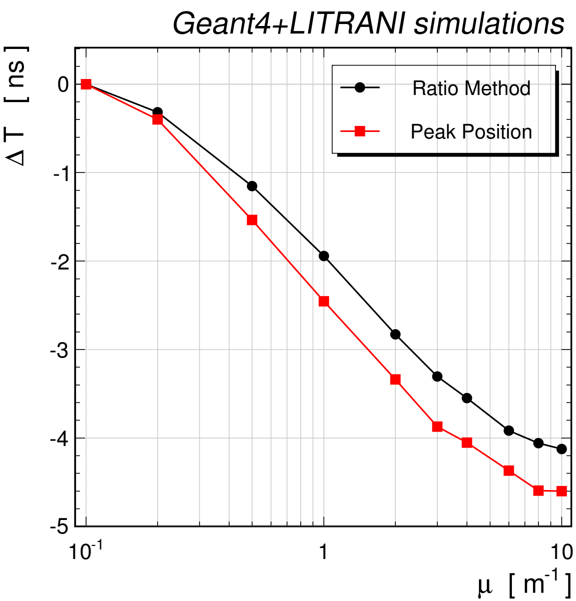
- time of photo-electrons from Geant4+LITRANI
- $t/\tau \cdot exp(-t/\tau)$

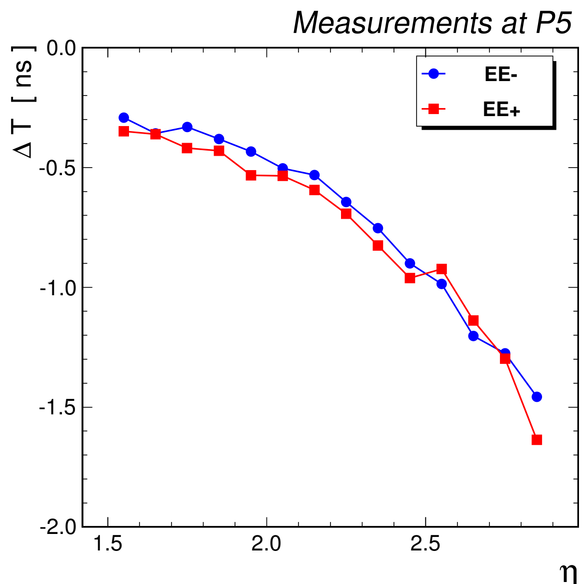
Best value for τ=41.5±0.5 ns.
Previously measured τ=(40-43) ns

ECAL TIMING DRIFT WITH RADIATION DAMAGE

Left: Model predictions

Right: Measured time drift Apr-Aug 2011





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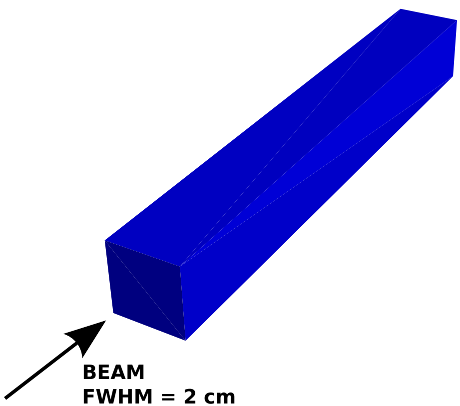
4 Model vs TestBeam 2011

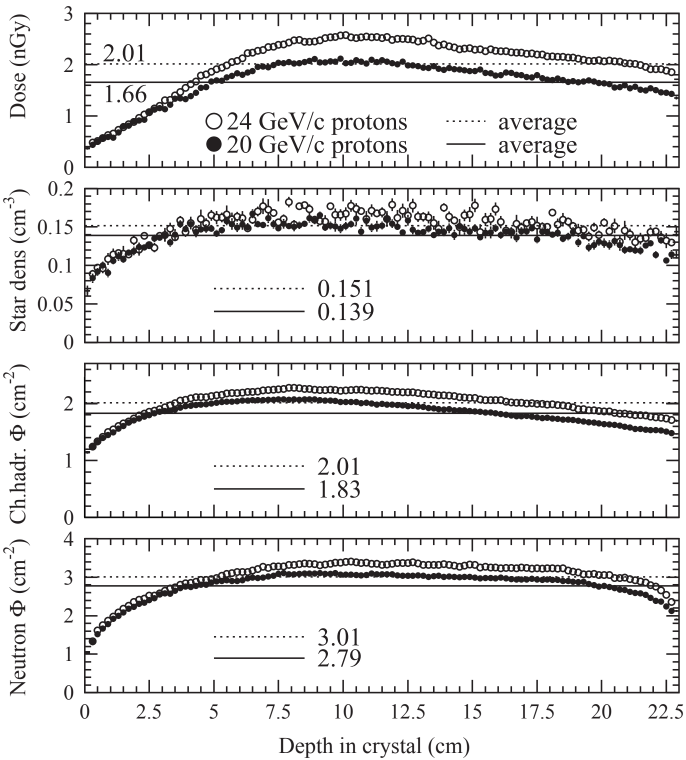
IRRADIATION OF CRYSTALS FOR TESTBEAM IS NOT UNIFORM

Transverse profile of proton beam had FWHM about 2 cm
How model with uniform μ can be applied to TestBeam results?



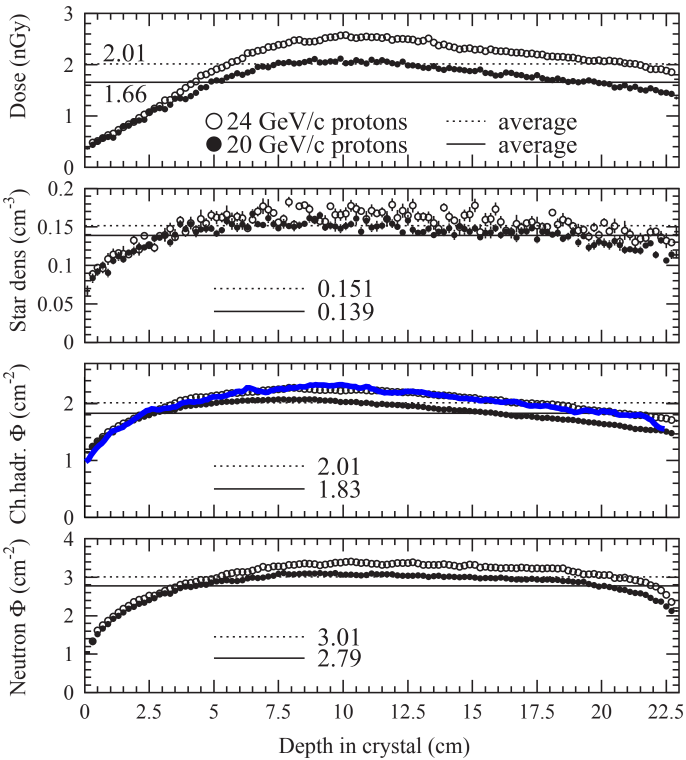
Estimate profile of hadron radiation damage with Geant4:

- protons 24 GeV, FWHM=2 cm
- EE crystal
- fluence of hadrons (charged+neutral) E>20 MeV
- total deposited energy by hadrons (charged+neutral)



M. Huhtinen et al.,
NIM A 545 (2005) 63-87

FLUKA simulations of longitudinal profile of dose, star density, fluence of charged and neutral hadrons



Blue line:

Geant4 predictions for fluence of hadrons E>20 MeV

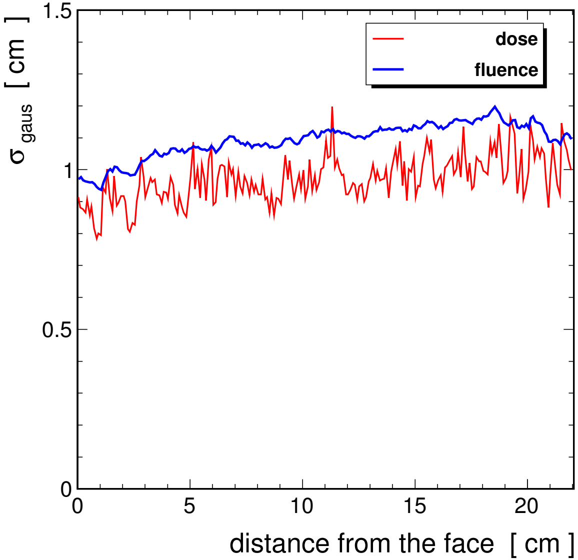
Good agreement with results in *M. Huhtinen et al., NIM A 545 (2005) 63-87*

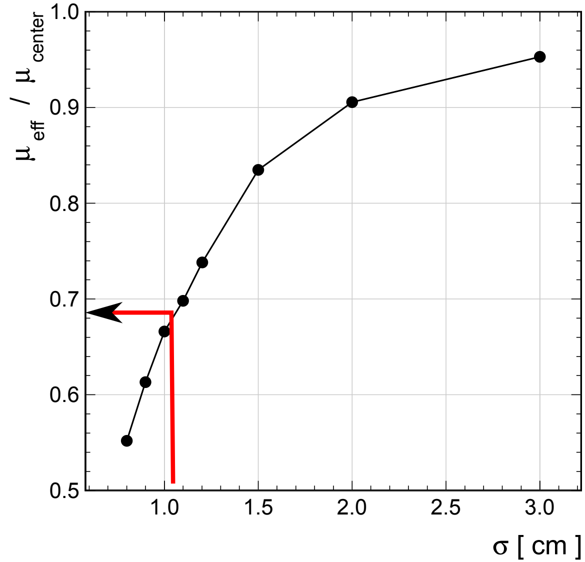
UNIFORM vs NON-UNIFORM TRANSVERSE PROFILE

Left: Geant4 results for width of transverse profile

Right: Same amplitude from EM shower of 50 GeV is given by

a:uniform μ_{eff} and b:Gaussian ($\mu_{\mathrm{center}}, \sigma$)





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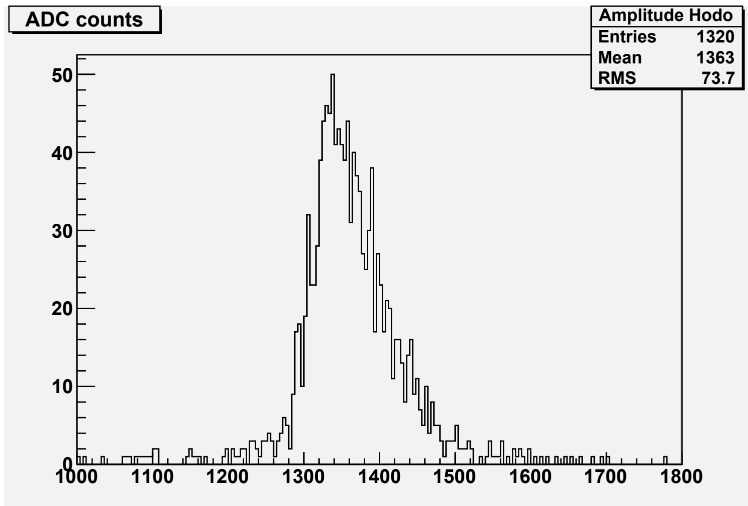
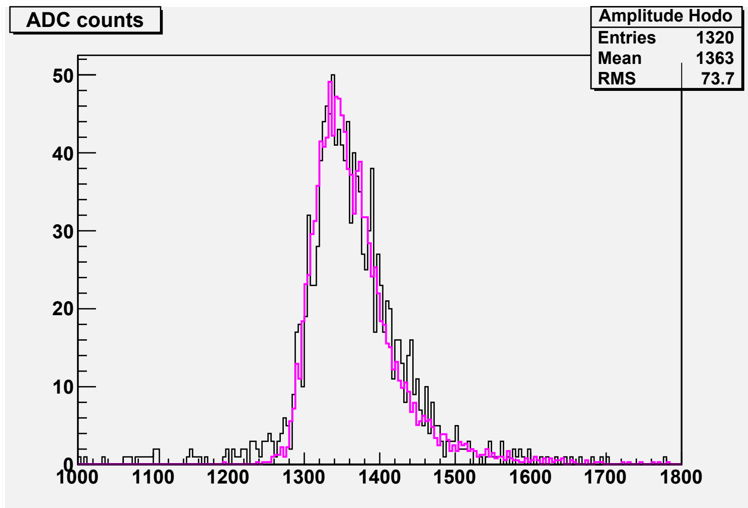
Electron beam of 50 GeV is centered on 3x3 array

Central crystal has μ_{IND}=10.6 m^{-1}

Measured amplitude in a central crystal is plotted





Magenta line:
Model prediction

Model uses measured μ scaled by factor $\times 0.7$

Model does ***NOT*** include:

- photo-statistics
- noise

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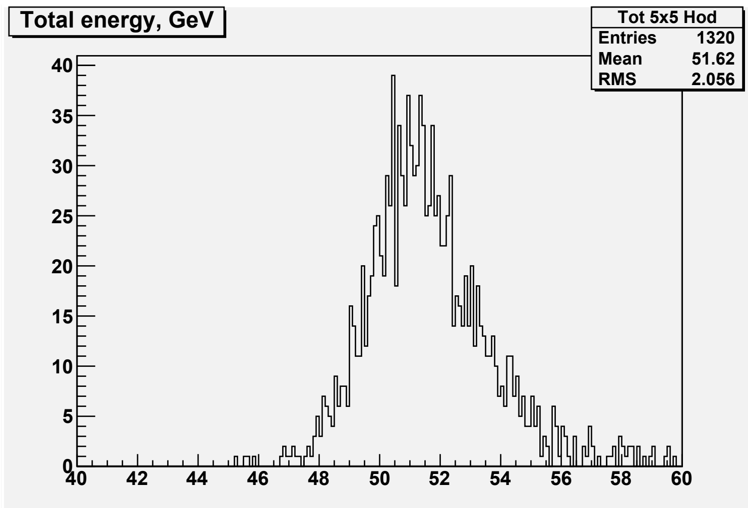
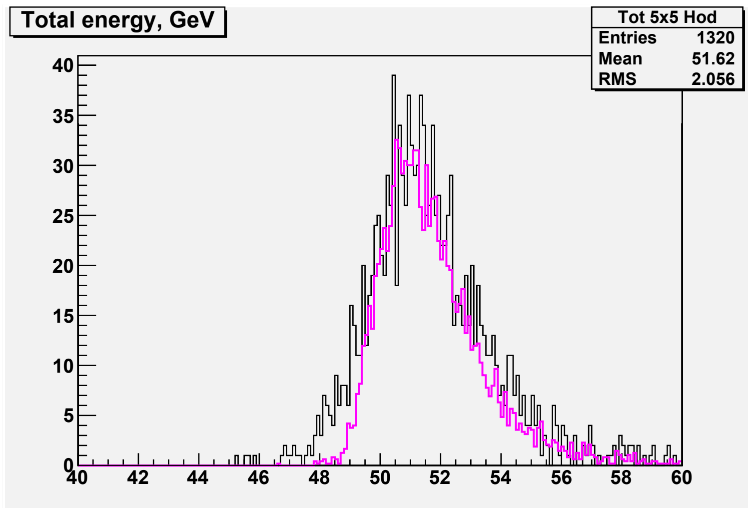
Electron beam of 50 GeV is centered on 3x3 array

Measured amplitude in 3x3 array after calibration is plotted





Magenta line:
Model prediction

Model uses measured μ scaled by factor $\times 0.7$ for each crystal

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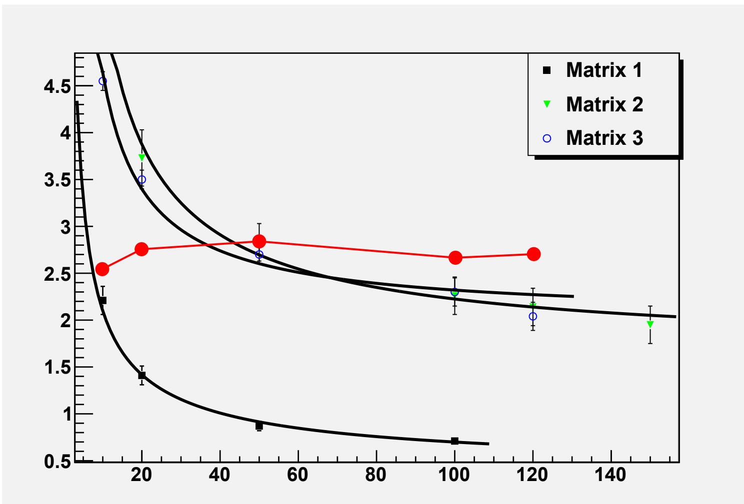
Measured energy resolution in 3x3 (%) vs beam energy



Red Dots+line:

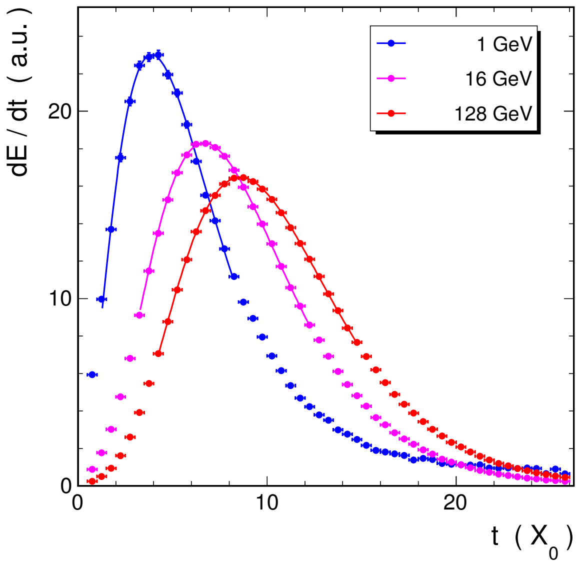
Model prediction for Matrix 3

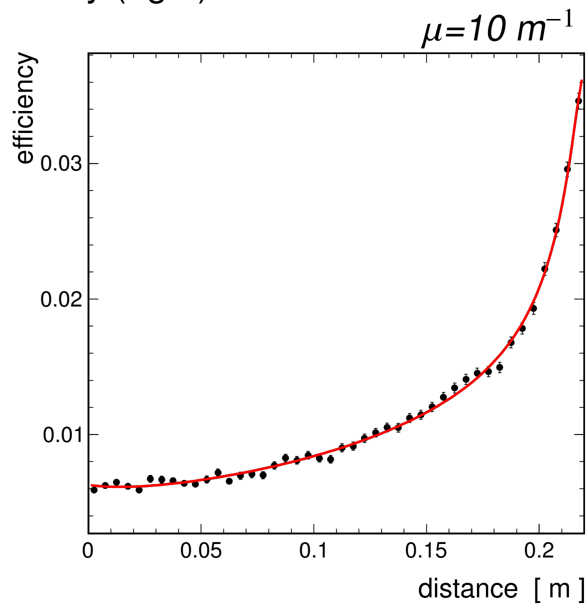
Model uses measured μ scaled by factor $\times 0.7$ for each crystal

NON-LINEARITY OF ENERGY MEASUREMENTS

results from combination of two effects:

- average shape of EM shower depends on energy (left)
- non-uniformity of light collection efficiency (right)





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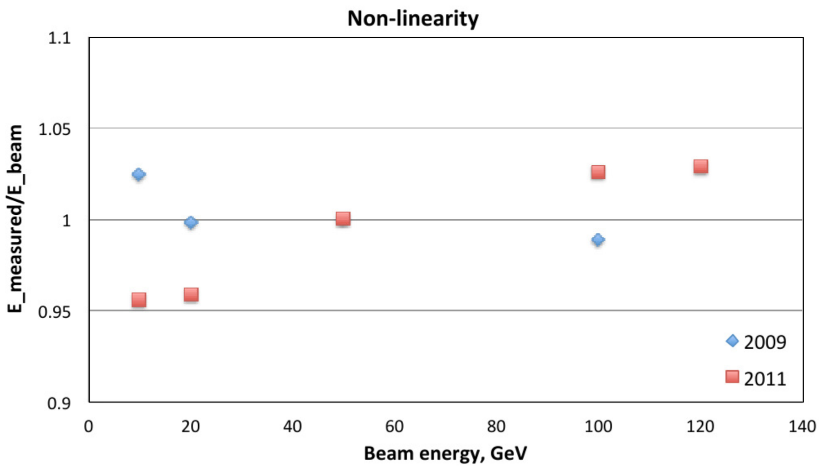
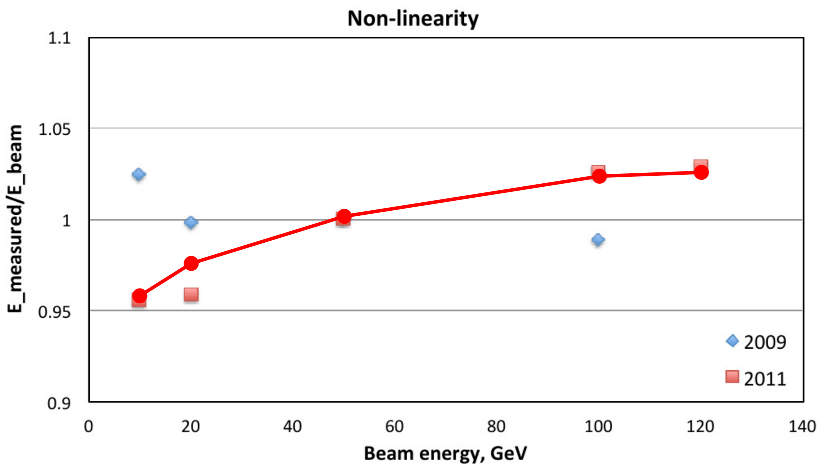
TestBeam results for non-linearity of energy measurements

Results from 2011 (red points) are relevant for this talk.





Red Dots+line:
Model prediction for 2011

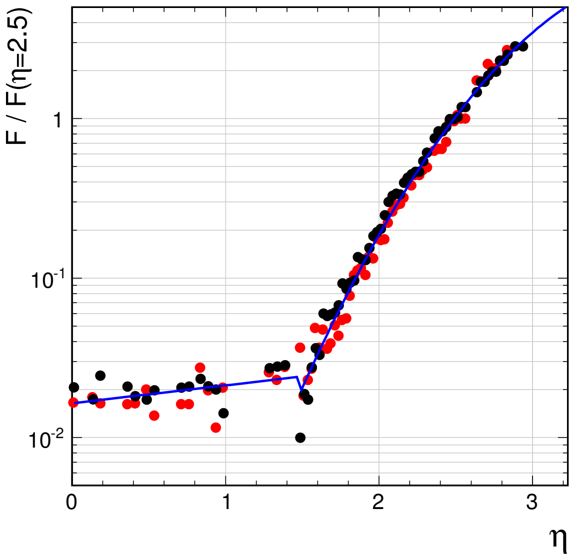
Model uses measured μ scaled by factor $\times 0.7$ for each crystal

5 Other inputs for Model Predictions

RADIATION DAMAGE PROFILE IN ETA

MARS simulations. EM dose (red) and hadron fluence (black)

http://cmstrk.fnal.gov/radsim/LHC_DoseFlux_Calculator.html

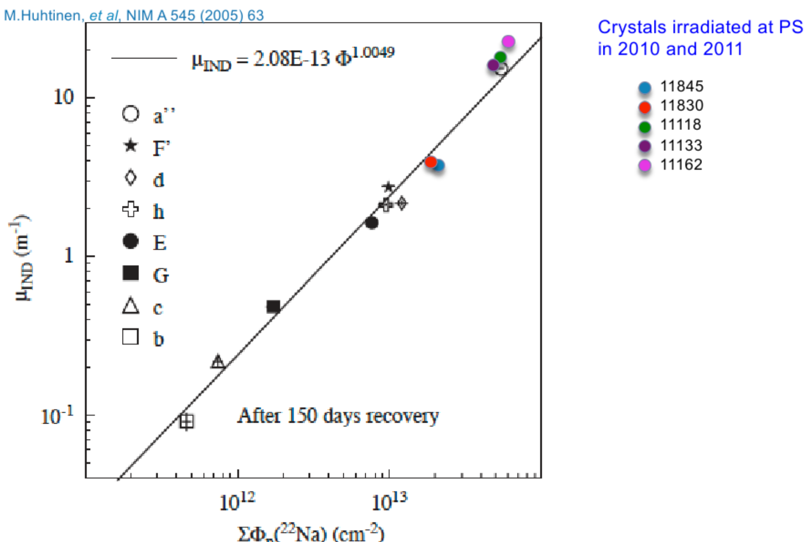


$$F = exp(a + b\eta + c\eta^2)$$

	EB	EE
a	-4.11065	-13.5112
b	0.258478	7.913860
c	0	-0.998649

HADRONIC DAMAGE VS HADRON FLUENCE

Plot from *M. Huhtinen et al., NIM A 545 (2005) 63-87*
with additional measurements from recent irradiation tests as reported by
E. Auffray, A. Singovski at Forward Calorimetry Taskforce Meeting,
CMS Upgrade Week 24-May-2012

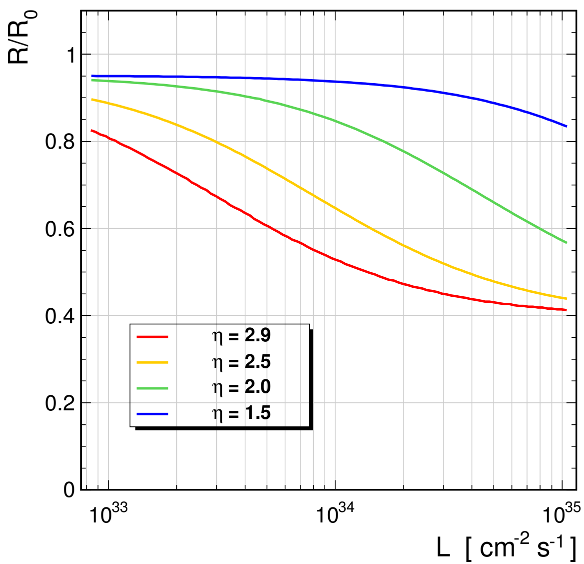


EM DAMAGE VS INST. LUMINOSITY

Assumes equilibrium during stable LHC operations

Equilibrium constant is tuned with CMS monitoring data

Assumes μ_{MAX}=2 m^{-1}

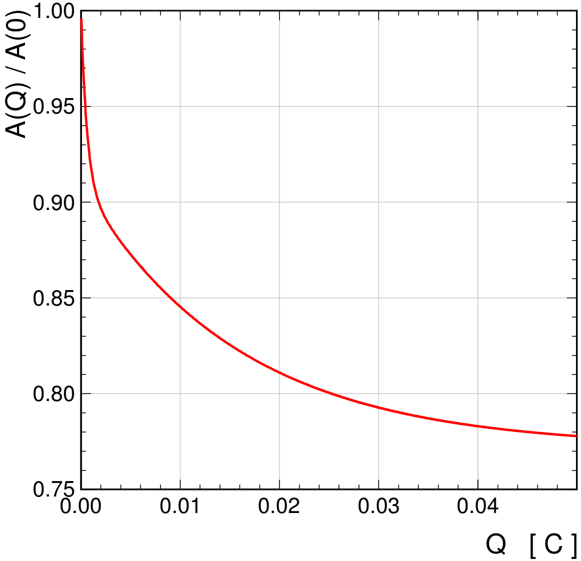


Model prediction for degradation of blue laser amplitude vs inst. luminosity during stable LHC operation (equilibrium)

...when EM damage is the only effect in the model

VPT AGING VS ACCUMULATED CHARGE

Burn-in tests in UVa and Brunel are summarized by D. Cockerill at ECAL Monitoring and Calibration Meeting, June 14, 2012

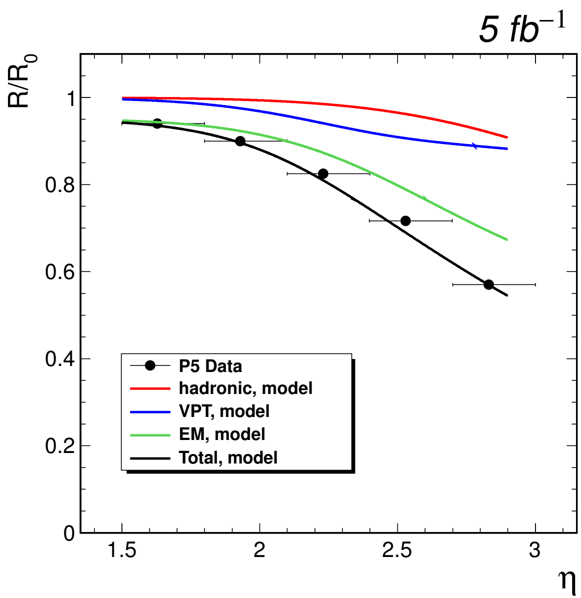


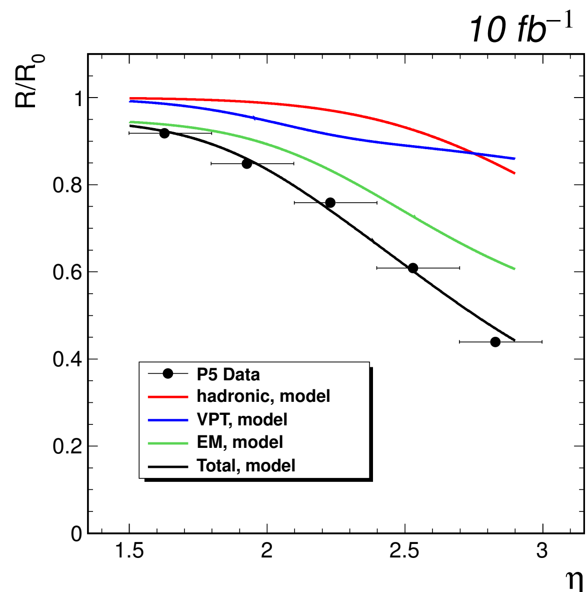
Reinterpretation of this summary
...based on 11 VPTs
...sum of two exponents
...plateau at 77%

DATA VS MODEL FOR LASER MONITORING

Data points from F. Ferri validation plots for Laser tags

Two stable periods in LHC running: 23-Oct-2011 and 18-Jun-2012





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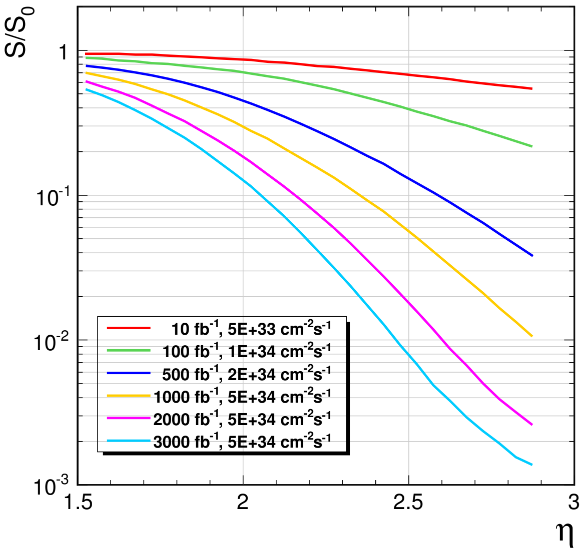
MODEL PREDICTIONS FOR SIGNAL LOSS

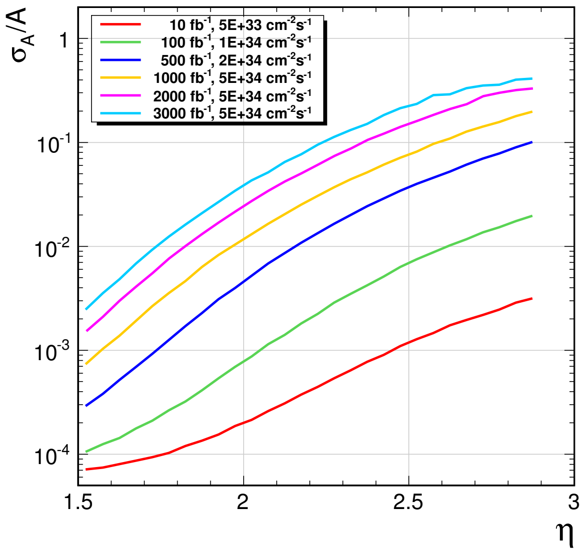
Electrons 50 GeV

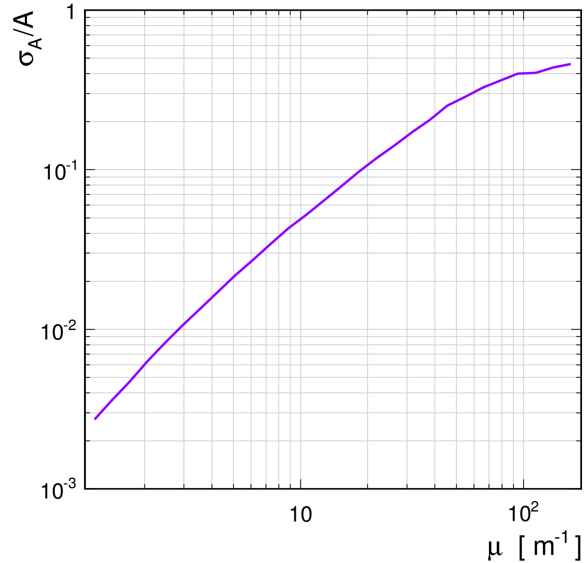


MODEL PREDICTIONS FOR CONSTANT TERM

due to increasing longitudinal non-uniformity of light collection

Electrons 50 GeV





summary

- Analytic $\mathcal{E}_{LC}(z,\mu)$ is prepared. Describes light output for EE crystals in μ range from 0.1 m^{-1} to 200 m^{-1}
- Model is compared with variety of experimental results. Good agreement!
- $\mathcal{E}_{LC}(z,\mu)$ can be used in FullSim directly. Additional parameterization needed for FastSim
- Few predictions for ECAL performance. Need CMSSW FullSim or FastSim to evaluate complete performance on physics cases.