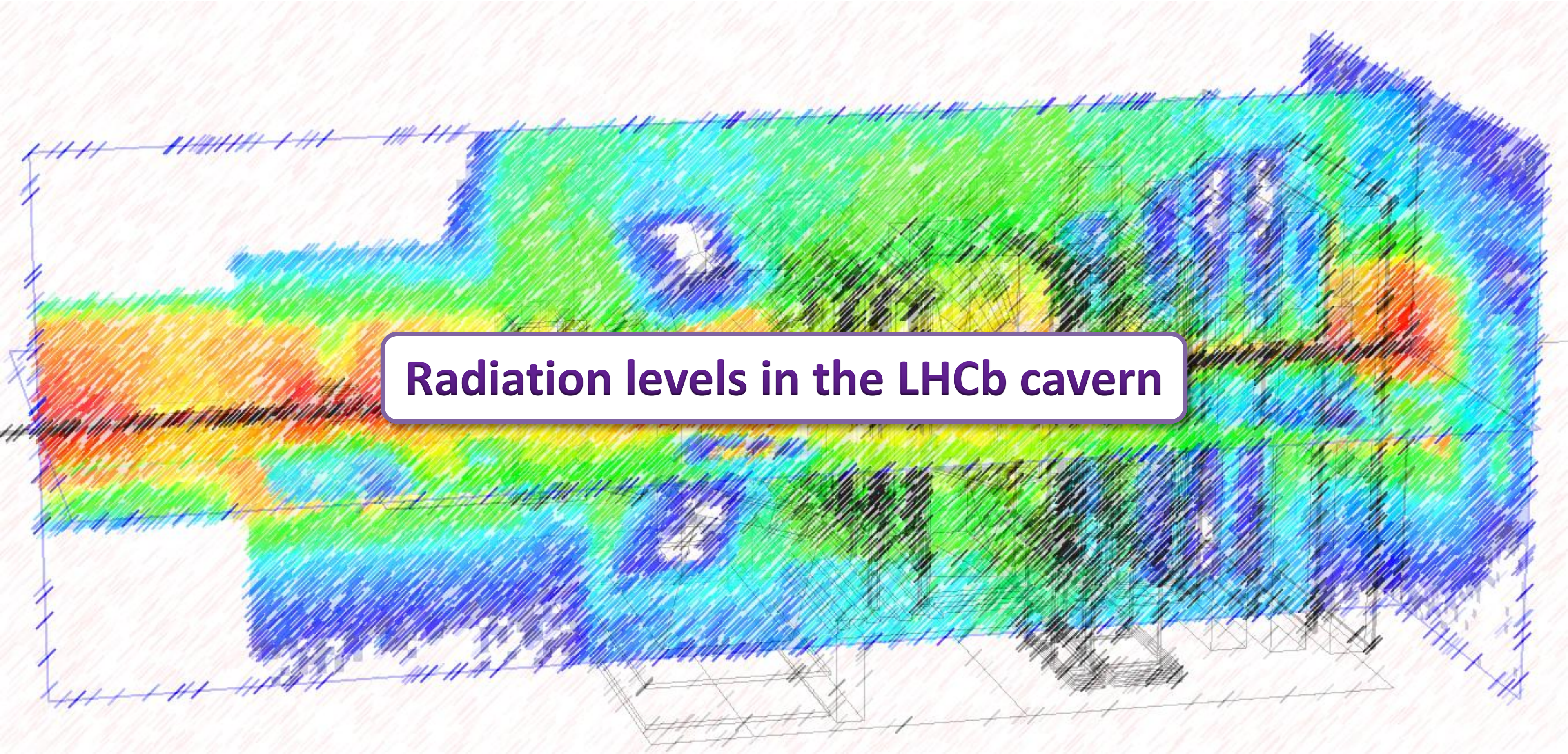
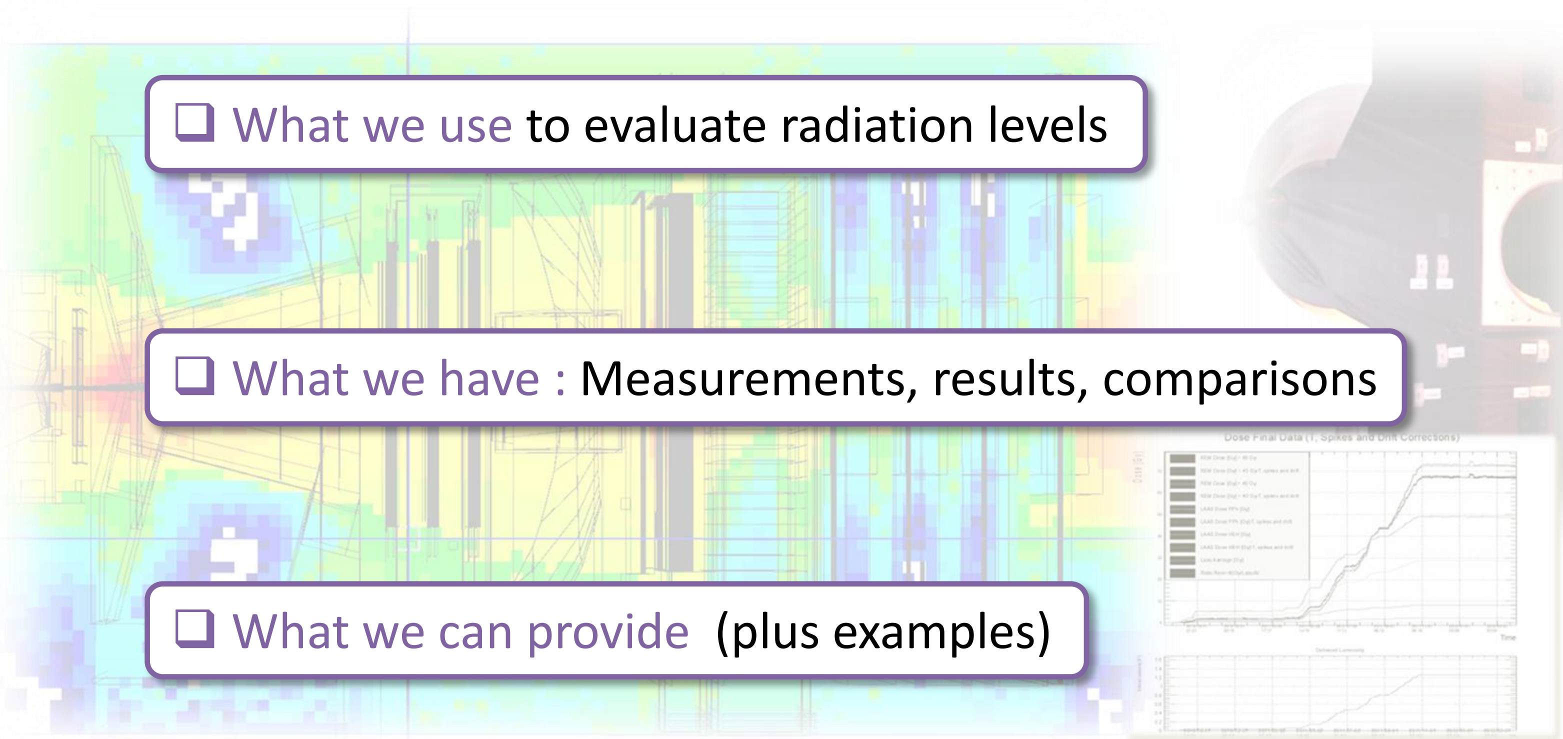


Radiation levels in the LHCb cavern

LHCb Upgrade Electronics, 14th February

Matthias Karacson

Short overview



- ❑ What we use to evaluate radiation levels
- ❑ What we have : Measurements, results, comparisons
- ❑ What we can provide (plus examples)

What we use to evaluate radiation levels

Active (ARMS) monitor rea[illegible]

online r[illegible]ine evaluation

Not used yet for simulation cross-checks

Passive radiation monitor readouts

Replaced during Christmas break

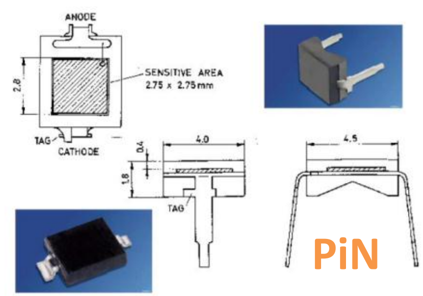
FLUKA radiation environment simulations

Available for some energies

Passive Radiation Monitor Types

Each box usually contains 4 different types of sensors:

- Thermo-Luminescent Dosimeters (**TLD**): 10 µGy to 100(0) Gy
  (Collaboration with IFJ Krakow; B.Obryk)
- Polymer-Alanine-Dosimeters (**PAD / "Alanine"**): 10 Gy to 120 kGy
- Radio-Photo-Luminescent (**RPL**) Dosimeters: 100 mGy to 1 MGy
  (both CERN Radiation Protection Group)
- **PiN** Diodes : 10^{11} to $5*10^{14}$ 1MeV equ. neutrons/cm^2
  (CERN PH DT Federico Ravotti, Maurice Glaser)



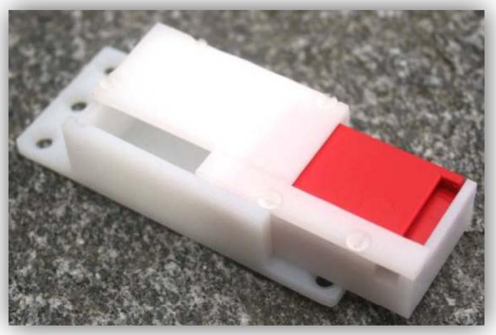
RPL and Alanine are calibrated with Co60, not for mixed fields

Passive Radiation Monitor locations

In the cavern, passive sensor boxes are placed next to /in the vicinity of active sensors, plus some additional positions, mostly on edges of experiment

From Calorimeters, 17 passive sensor boxes on 4 planes each were recovered during last Christmas break, containing:

- Alanine (Dose)
- TLDs (Dose)
- PIN-Diodes (1MeV n-equ)



Additionally, 5 boxes recovered from ECAL test modules in the upstream tunnel

The boxes recovered from the Calorimeters did not contain RPLs

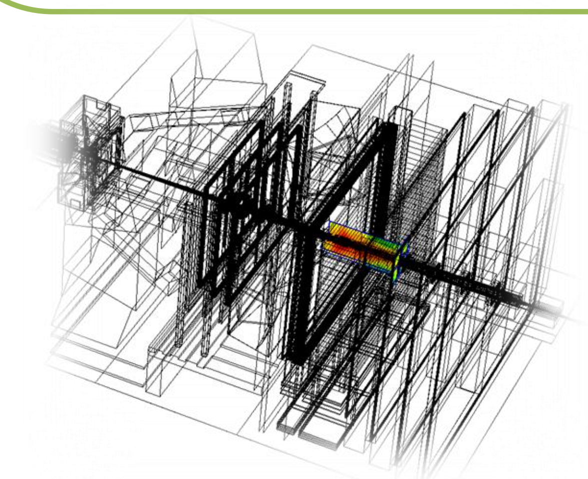
FLUKA simulation

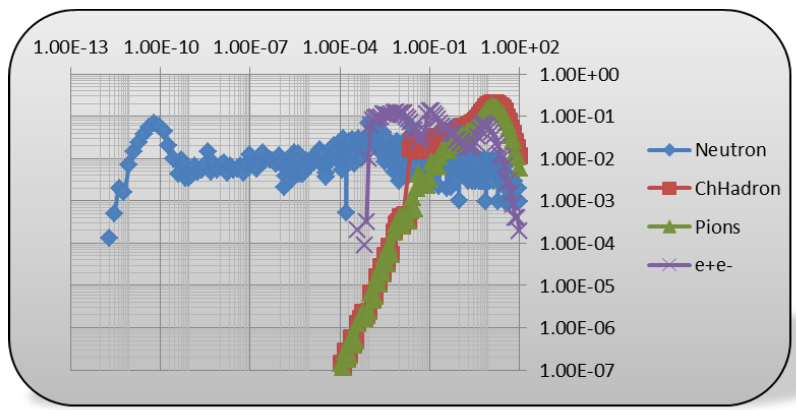
Simulation results available with reasonable statistics for most points around the experiment (cavern geometry will be improved before attempting to score further outside on Accessible and Cryo sides):

- ❑ 7 TeV CM ready
- ❑ 14 TeV CM ready for the current geometry
- ❑ 8 TeV CM finishes very soon, will not differ much from 7 TeV CM

All with with magnetic fields DOWN & UP

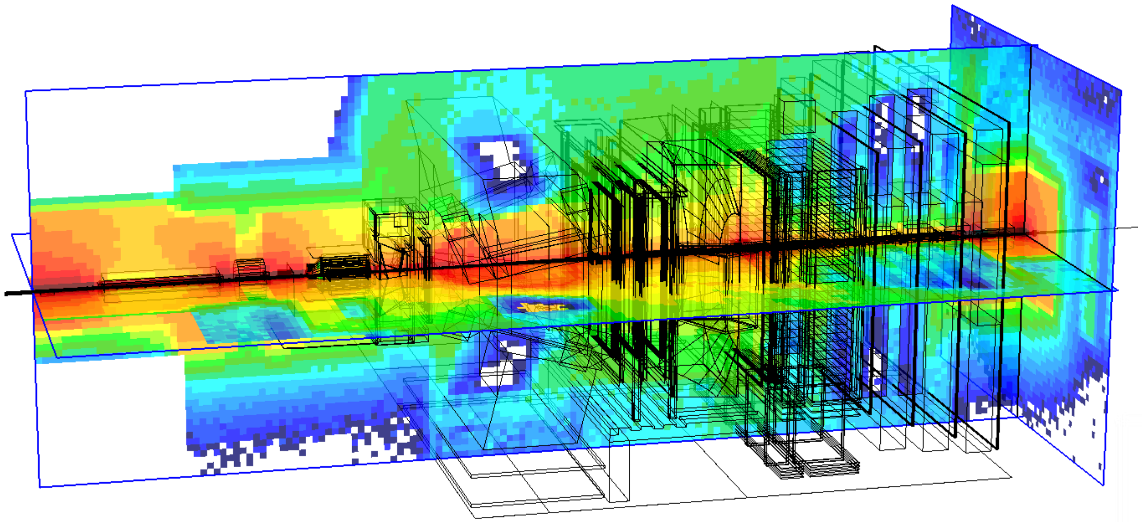
300.000 primary collisions at each energy (150.000 per MF direction)





FLUKA simulation

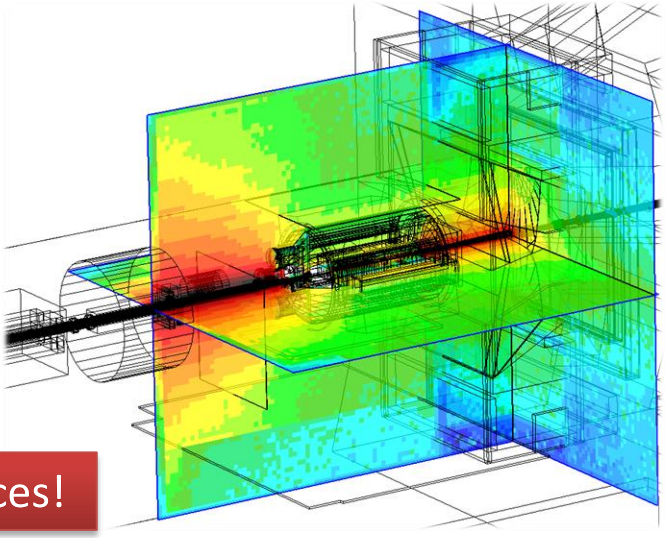
General 3D scoring in 20x20x20 cm3 bins over the whole experiment



Quantities scored:

- Particle Fluences (ALL-PART, charged hadrons, **hadrons>20MeV**, proton, neutron, photon, e+e-)
- **1MeV neutron equ. fluence**
- **Dose [Gy]**

3D Scoring in 5x5x5 cm3 bins over the VELO alcove

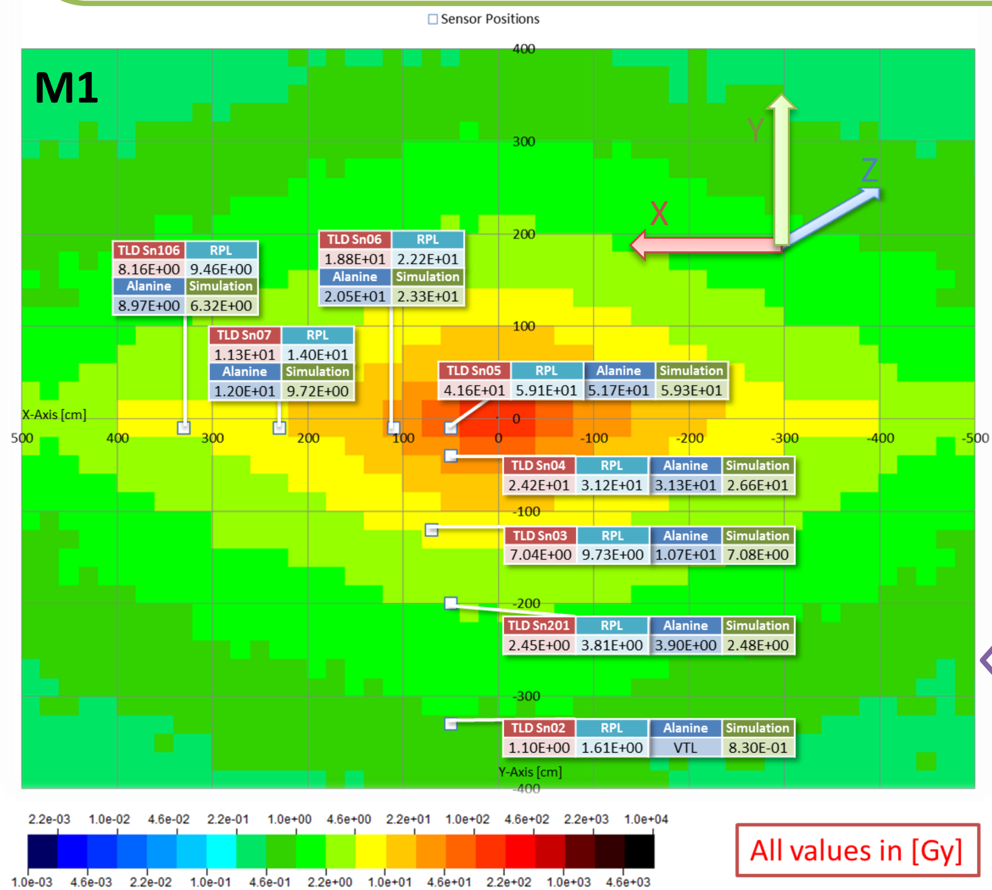


Averaging over larger volumes necessary in most places!

Comparison of Passive measurements versus Simulation results

Comparisons show simulation results are supported by measurements from 2011, however:

- At the center of the experiment simulation results fit measurements nicely
- Close to edge of the experiment, areas where lower dose is deposited:
  Support structures are manifold and complicated, and still have influence
  this far from the interaction point, but are difficult to add into the simulation.



All values in [Gy]

Exact position of some sensors needs to be re-examined during long shutdown

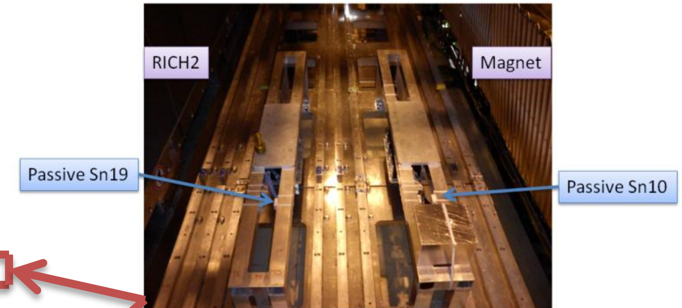
10 cm can already make a difference for estimation of dose

Boxes show TLD values with Serial numbers of the box, RPL, Alanine and Simulation results at the positions of the sensors

VTL stands for "VALUE TOO LOW"

Comparison of Passive measurements versus Simulation results

Year 2011	1.22 fb^{-1}	Dose (av) [Gy]			TLD Nonlinearity correction (With IRF) [Gy]			
Passive Box Sn	Description	RPL	Alanine	Sim	MCP-7	MCP-7	MTS-7	MTS-N
4IRCERPW000005	M1 Xcenter	5.91E+01	5.17E+01	5.93E+01	4.36E+01	3.87E+01	3.96E+01	4.56E+01
4IRCERPW000006	M1 Xcenter+1	2.22E+01	2.05E+01	2.33E+01	1.90E+01	1.86E+01	1.98E+01	2.27E+01
4IRCERPW000007	M1 Xcenter+2	1.40E+01	1.20E+01	9.72E+00	1.11E+01	1.16E+01	1.04E+01	1.35E+01
4IRCERPW000106	M1 Xouter	9.46E+00	8.97E+00	6.32E+00	8.54E+00	7.79E+00	6.87E+00	8.61E+00
4IRCERPW000002	M1 Youter	1.61E+00	Value Too low	8.30E-01	1.13E+00	1.08E+00	1.05E+00	2.32E+00
4IRCERPW000201	M1 Ycenter+2	3.81E+00	3.90E+00	2.48E+00	2.44E+00	2.47E+00	2.45E+00	4.76E+00
4IRCERPW000003	M1 Ycenter+1	9.73E+00	1.07E+01	7.08E+00	6.96E+00	7.14E+00	6.43E+00	9.14E+00
4IRCERPW000004	M1 Ycenter	3.12E+01	3.13E+01	2.66E+01	2.34E+01	2.51E+01	2.43E+01	2.58E+01
4IRCERPW000009	RICH1 exit	2.32E+01	2.11E+01	2.30E+01	1.84E+01	1.96E+01	1.97E+01	1.90E+01
4IRCERPW000010	IT U-support Magnet-side	Value Too low	Value Too low	8.70E-01	4.64E-01	4.75E-01	4.63E-01	1.58E+00
4IRCERPW000077	ECAL top easy view	Value Too low	Value Too low	2.60E-01	4.81E-02	4.89E-02	4.96E-02	2.80E-01
4IRCERPW000013	Bunker extension	Value Too low	Value Too low	1.50E-01	5.26E-02	5.54E-02	5.59E-02	1.90E-01
4IRCERPW000014	Bunker middle	Value Too low	Value Too low	6.80E-02	5.80E-02	5.13E-02	5.50E-02	2.22E-01
4IRCERPW000015	Balcony	Value Too low	Value Too low	no scoring	4.50E-02	4.77E-02	4.67E-02	1.83E-01
4IRCERPW000016	VELO repeater	1.34E+01	1.27E+01	1.21E+01	1.14E+01	9.18E+00	9.84E+00	1.19E+01
4IRCERPW000018	RICH2 HPD bottom A-side	7.94E+00	5.57E+00	5.00E+00	5.99E+00	5.20E+00	4.72E+00	4.96E+00
4IRCERPW000019	IT U-support CALO-side	1.11E+00	Value Too low	1.15E+00	7.26E-01	7.63E-01	6.74E-01	1.88E+00
4IRCERPW000020	IT ST1 on detector panel	2.03E+00	Value Too low	1.10E+00	7.30E-01	7.31E-01	7.10E-01	2.19E+00
4IRCERPW000021	TT service boxes Magnet Aside	3.20E+00	Value Too low	4.00E-01	7.53E-01	7.56E-01	7.61E-01	1.36E+00
4IRCERPW000022	ECAL LV powersupplies Q2A01	1.18E+00	Value Too low	3.00E-02	2.38E-01	2.12E-01	2.31E-01	2.78E+00
4IRCERPW000023	ECAL/HCAL racks L3B04	Value Too low	Value Too low	6.00E-01	1.09E-01	1.08E-01	1.07E-01	3.54E-01
4IRCERPW000024	Muon intermediate board M2A02	Value Too low	Value Too low	2.40E-01	2.09E-01	2.09E-01	2.04E-01	3.55E-01
4IRCERPW000025	Muon service board M1A12	Value Too low	Value Too low	2.40E-01	1.35E-01	1.23E-01	1.25E-01	2.00E-01
4IRCERPW000026	Close to beam exit at RB86	Value Too low	Value Too low	2.50E-02	3.83E-02	3.33E-02	3.44E-02	5.25E-01
4IRCERPW000027	above beampipe powersupply	1.46E+01	1.10E+01	6.30E+00	9.70E+00	1.03E+01	9.55E+00	1.14E+01
4IRCERPW000035	wall/pillar next to VELO	7.67E+00	5.79E+00	5.50E+00	5.00E+00	5.14E+00	4.93E+00	6.84E+00
4IRCERPW000036	RICH1 HPD bottom Aside	5.90E+00	3.28E+00	4.60E+00	4.11E+00	3.48E+00	3.39E+00	4.42E+00
4IRCERPW000037	BLS beam entrance	2.25E+03	3.09E+03	2.68E+03	2.77E+03	3.06E+03	N/A	1.76E+03
4IRCERPW000039	black PATROL box	7.81E+00	4.52E+00	4.60E+00	4.42E+00	4.07E+00	3.67E+00	5.54E+00



Results normalized assuming 1.22 fb-1 delivered luminosity until the end of 2011

Comparison between simulation results and passive measurements taken during 2011 showed a reliability of the simulation well within a factor of 2 for most places. In areas with higher radiation this factor even drops well below 1.5. The exception are very remote locations like the ECAL LV power supplies, where massive amounts of shielding and several details that are not accounted for in the simulation increase the difference to a factor of up to 6, but with measurements being in the region of some 100 mGy only.

What we can provide

Simulation results with general 20x20x20 cm and some specialized binning <u>available right now</u>

Specialized scoring with current geometry can be arranged but needs some weeks, up to months, of computing time

Results are normalized to 1 collision –> can be scaled with Luminosity

For now: Personal consultation

Contact me directly with request at exact locations and a short description of the associated problem, so I can try to help efficiently

What we can provide

Future: Replacement of summary tables from 2003

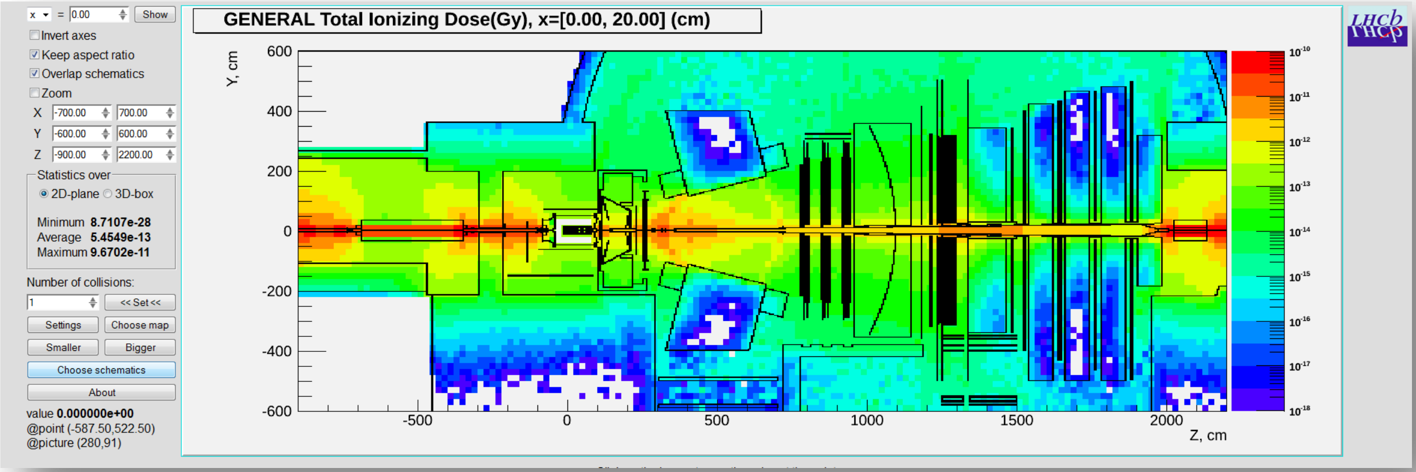
Needs Input from you:

Define **locations** and **type of estimator** (e.g. fluences, dose, etc.) that are of use to you

Further along the line, but for **<u>Experts only</u>:**

Web page for value extraction

In development, but has to be adapted and fed with results, which needs time



How results are provided

All values usually given **per collision**. In order to obtain the values for upgrade conditions of **1 year** (10^7 s, assuming 180 days at 50% efficiency) at a Luminosity of **$2x10^{33}$** per second, one has to multiply the numbers by the number of collisions, which, for a cross section of 72 mb, equal 14.4E+14 collisions per year. In addition, you also have to multiply by the **number of years** you are planning for.

Up to now, I have used a **cross section of 72 mb** (inelastic + diffractive) as I did for 7 TeV CM calculations. The actual cross section for 14 TeV CM is expected to be 20% higher.

Provided numbers **do NOT contain any safety factor**. Please consider:

- Close to beam pipe: Type of binning makes a difference!
- Certain distance from BP (>60cm): A safety factor of 2 is appropriate for the AVERAGE value of a bin. Maximum values differ at the edges of a bin.
- Close to the edge of the acceptance: Besides statistical errors coming from MC methods, also systematic errors/details inherent to the current status of the simulation can make a difference in the end. Larger safety factors are advised!

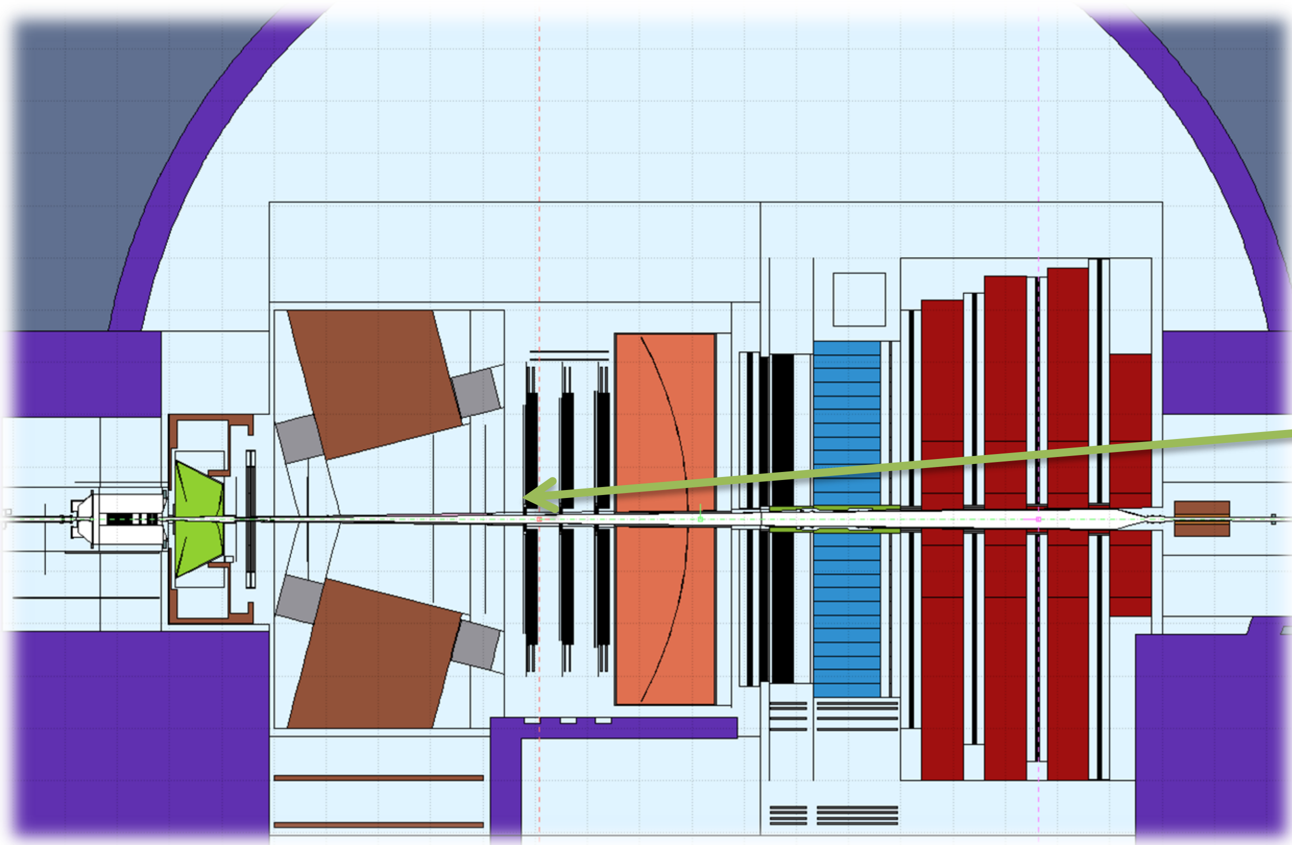
Additional safety factor for reliability of electronics is your responsibility!

Examples

(Or: Why it is not always as simple as getting a value from a point in a map)

Example: Fiber Tracker Upgrade

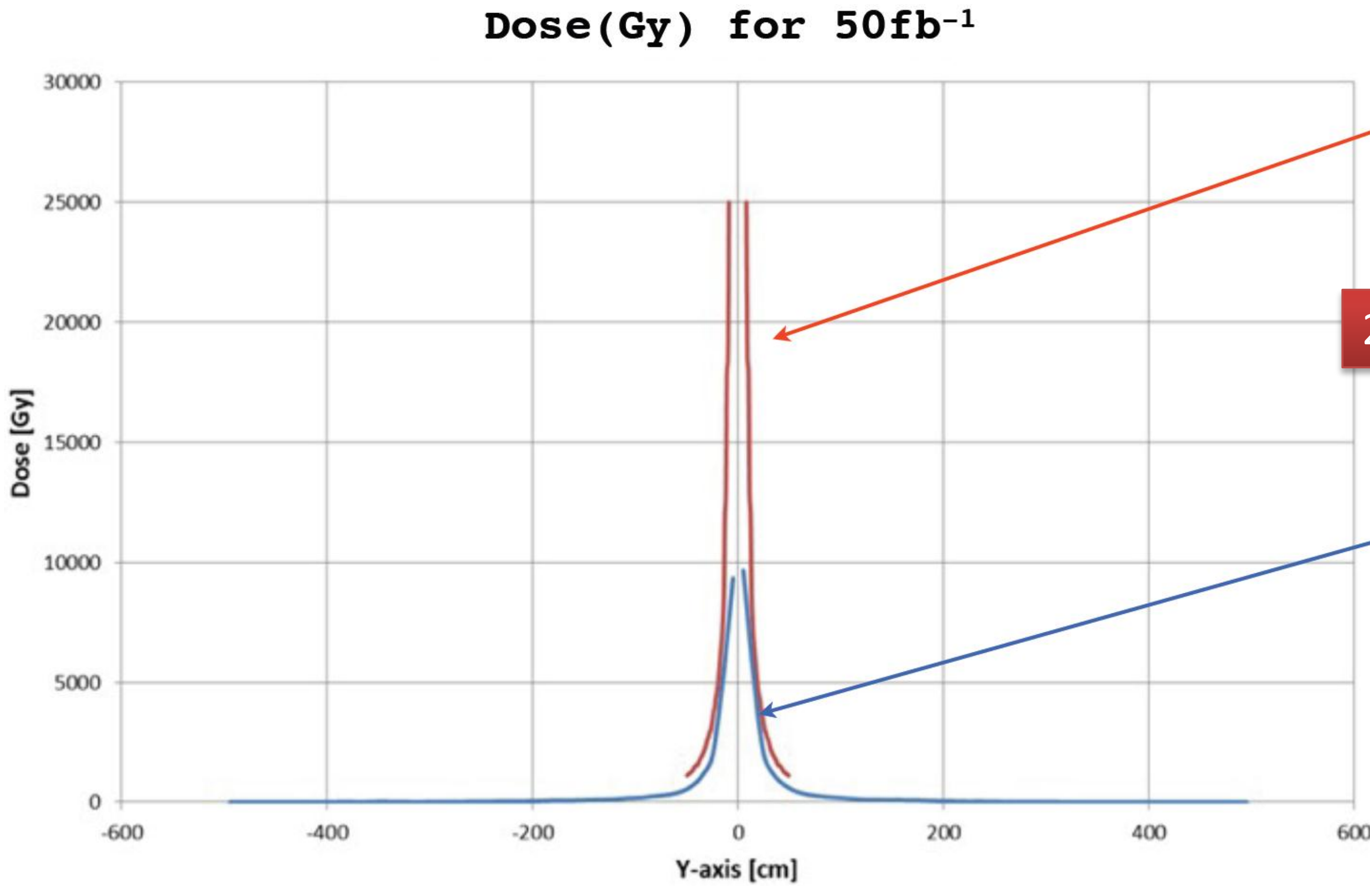
Problem: Estimation of Maximum Dose at Center around beam pipe

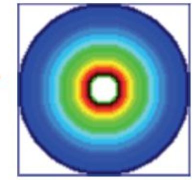


- Simulation of 14 TeV CM with current geometry
- Scored Dose and 1MeV neutron equivalent fluence at Z=783 cm (IT1)
- Corresponding to 50 fb-1, at a Cross Section of 72 mb

Exposition to high doses results in rise of photon absorption rate of scintillation fibers

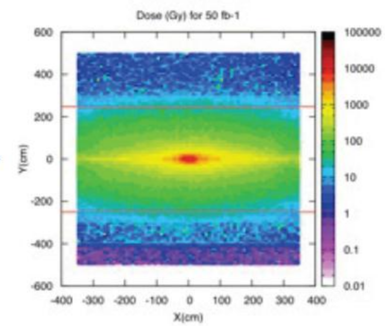
Example: Fiber Tracker Upgrade





1cm width ring

2 different binnings



10x10cm^2 bin
(made by Neus Lopez March)

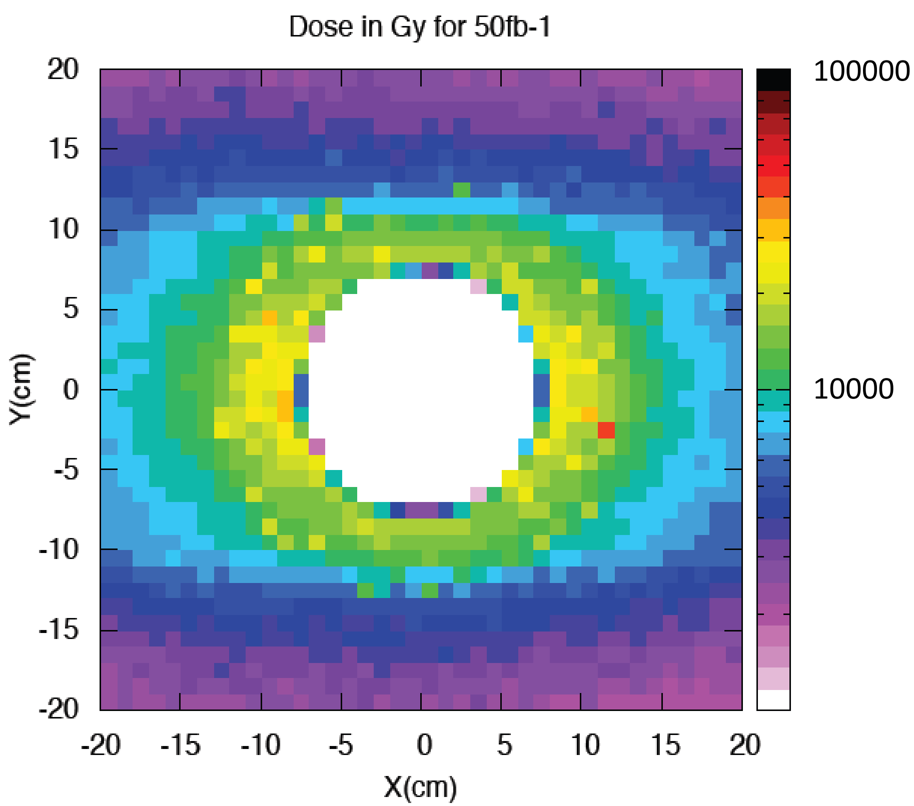
Large bin sizes around beam pipe raise two issues:

- **Bin volume** includes **vacuum** region of beam pipe, which drags the average down.
- **High gradient** within bin means the average is far below its maximum (=crucial) value.

Example: Fiber Tracker Upgrade

Rings are still underestimating dose in horizontal direction, because of magnetic field

Complications trying to estimate horizontal dose in detail:



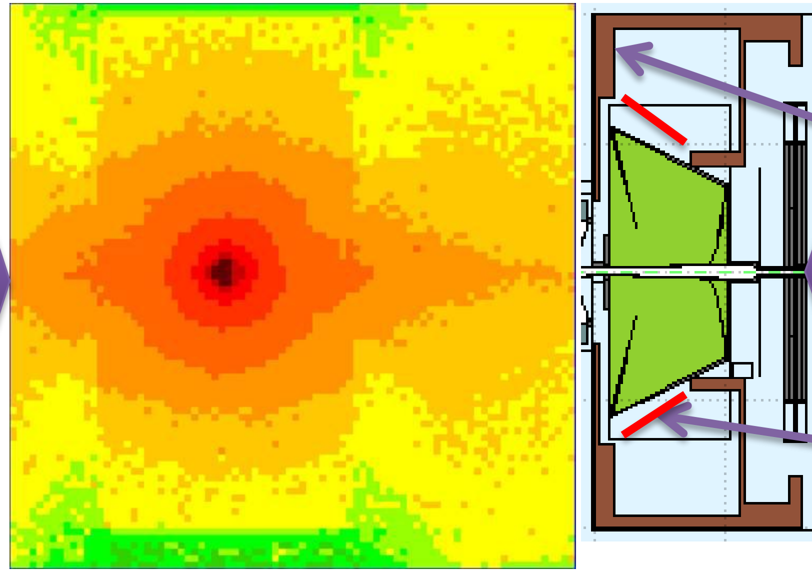
1cm binning in X and Y proves too small

Bad statistics even with 1 Million primaries (compared to the usual 300.000 which already take some weeks to calculate)

Detail has its limits!

Example: RICH1 Upgrades

Region of interest: HPDs at current location and eventual horizontal flip



- **HPDs not yet implemented** in simulation. Scoring in empty space would yield lower dose.
- **Shielding** has a **large influence on dose deposition** due to the initialization of secondary particle showers (visible within dose binning shown above).
- **Horizontal plane has additional dose component** due to LHCb **dipole.** This would even be increased by introducing shielding. Impossible to estimate without modeling in simulation.

Example: RICH1 Upgrades

Region of interest: HPDs

Approach for estimation:

Extracting values at different positions at entrance of HPD enclosure to make sure not to underestimate the dose inside (highest values closest to beam pipe), while averaging over volumes of 10x10x10 cm to reduce error

Horizontal values were given, but with **big caution sign** and **no guarantee!**

RICH1 HPD Entrance Bottom

X [cm]	Y [cm]	Z [cm]	DOSE per collision [Gy]	1 MeV neutron equ per collision [cm-2]	Hadrons g.t. 20 MeV per collision [cm-2]
[-5 , 5]	[-125 , -115]	[145 , 155]	6.64E-14	2.77E-04	9.31E-05
[-30 , 30]	[-125 , -115]	[145 , 155]	6.75E-14	2.77E-04	9.15E-05
[-70 , 70]	[-125 , -115]	[145 , 155]	6.43E-14	2.65E-04	8.57E-05
[-5 , 5]	[-105 , -95]	[165 , 175]	9.98E-14	3.52E-04	1.31E-04
[-30 , 30]	[-105 , -95]	[165 , 175]	9.75E-14	3.43E-04	1.28E-04
[-70 , 70]	[-105 , -95]	[165 , 175]	9.42E-14	3.29E-04	1.21E-04
[-5 , 5]	[-145 , -135]	[125 , 135]	3.63E-14	2.23E-04	6.39E-05
[-30 , 30]	[-145 , -135]	[125 , 135]	3.88E-14	2.26E-04	6.31E-05
[-70 , 70]	[-145 , -135]	[125 , 135]	3.63E-14	2.18E-04	5.99E-05

RICH1 Horizontal HPD Aside — CAREFUL! Results from current empty air filled region.

X [cm]	Y [cm]	Z [cm]	DOSE per collision [Gy]	1 MeV neutron equ per collision [cm-2]	Hadrons g.t. 20 MeV per collision [cm-2]
[115 , 125]	[-5 , 5]	[145 , 155]	1.96E-13	3.22E-04	1.23E-04
[115 , 125]	[-30 , 30]	[145 , 155]	1.58E-13	3.05E-04	1.17E-04
[115 , 125]	[-70 , 70]	[145 , 155]	1.19E-13	2.82E-04	1.03E-04
[95 , 105]	[-5 , 5]	[165 , 175]	2.36E-13	3.55E-04	1.39E-04
[95 , 105]	[-30 , 30]	[165 , 175]	2.03E-13	3.43E-04	1.37E-04
[95 , 105]	[-70 , 70]	[165 , 175]	1.36E-13	3.04E-04	1.12E-04
[135 , 145]	[-5 , 5]	[125 , 135]	1.54E-13	2.85E-04	9.86E-05
[135 , 145]	[-30 , 30]	[125 , 135]	1.26E-13	2.68E-04	9.10E-05
[135 , 145]	[-70 , 70]	[125 , 135]	9.90E-14	2.55E-04	8.47E-05

Safety Factor should be chosen generously!

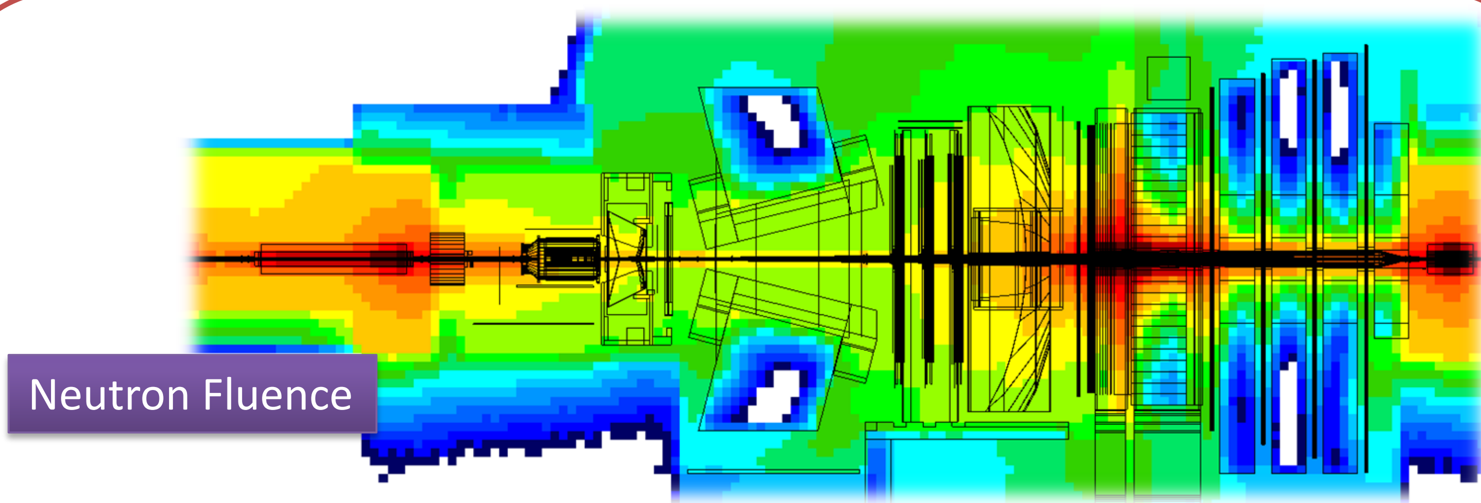
Even with result tables and web page available:

If in doubt, **contact us!**

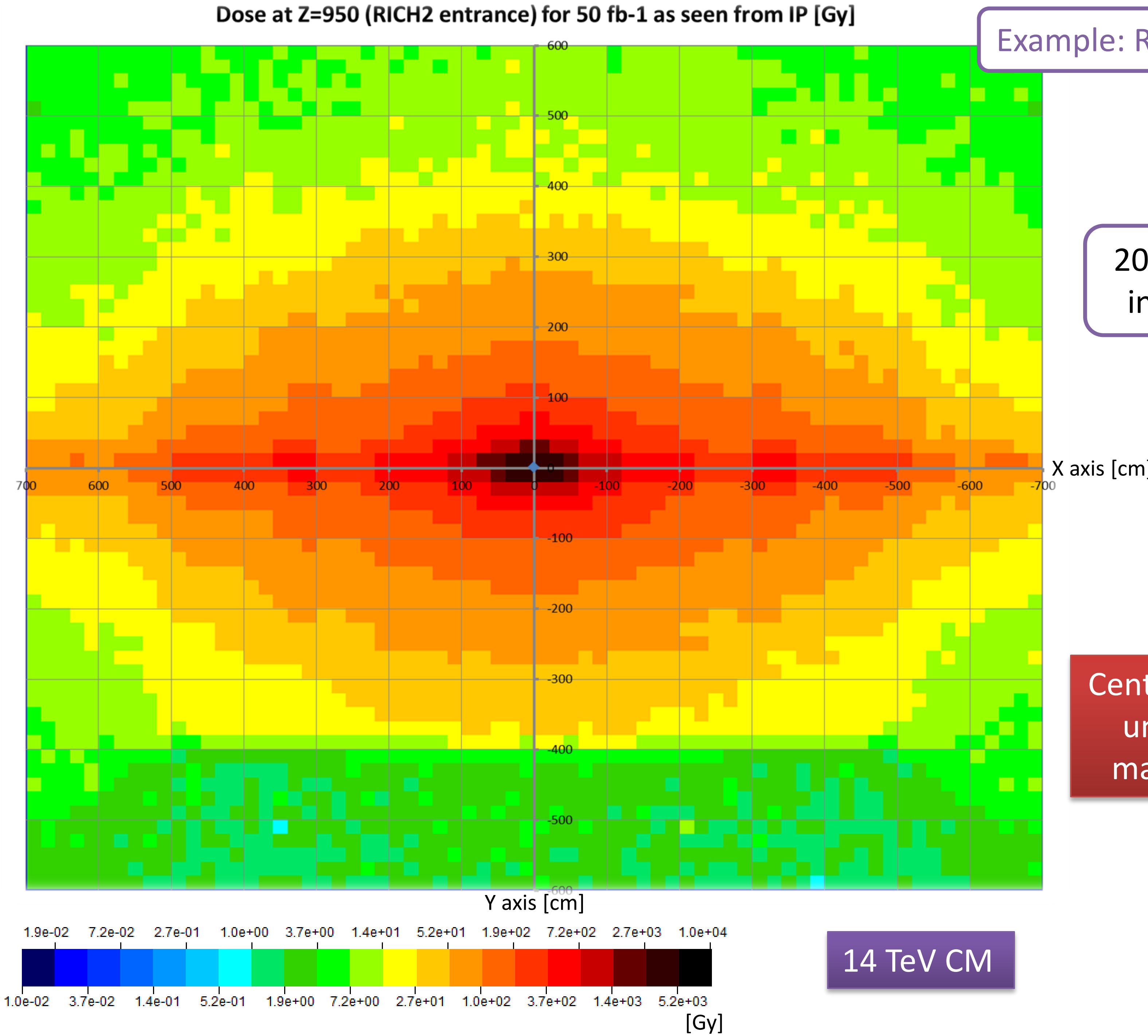
Example: RICH2 Upgrades

RoI: RICH2 Quartz windows covering acceptance up to Y = 3.5m

Center around beam pipe:
Same issues as with Fiber tracker request:
20 cm binning will heavily underestimate maximum values!



Eventual implementation of boron glass was discussed, which would **increase dose received from neutrons** coming from Calorimeters



Example: RICH2 Upgrades

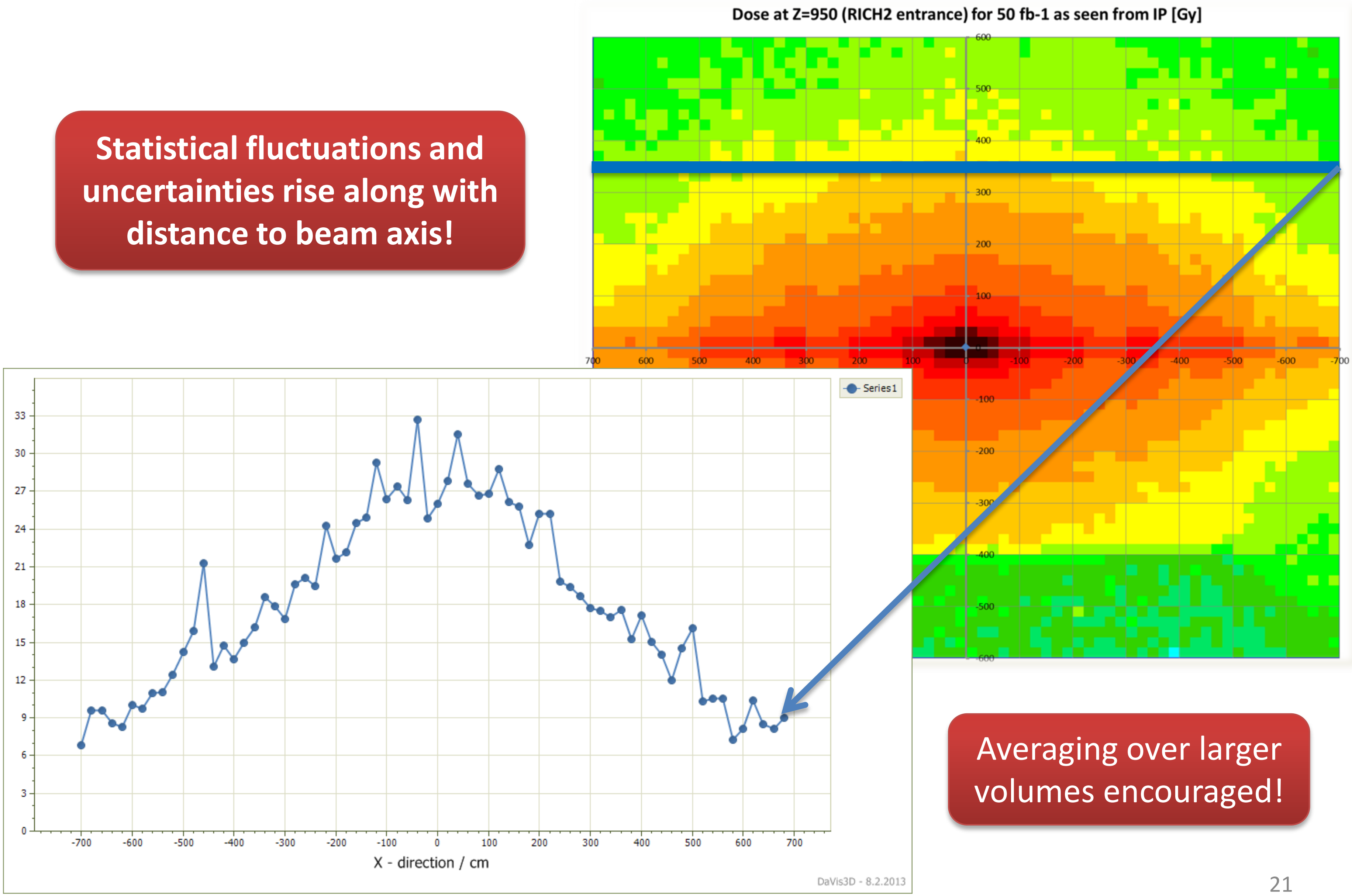
20 cm binning
in X, Y and Z

Central bins heavily
underestimate
maximum dose!

14 TeV CM

Example: RICH2 Upgrades

Statistical fluctuations and uncertainties rise along with distance to beam axis!



Averaging over larger volumes encouraged!

Example: Outer Tracker FEBs

Region of interest: FEB locations for OT1, OT2 and OT3

Low dose Levels, weak statistics

Given assumption:
For **1 year** (10^7 s) at a Luminosity of **$1x10^{33}$** per second, which equals 7.2E+14 collisions for 72mb XS

Average Values

OT Front End	Z [cm]	X [cm]	Y [cm]	Dose [Gy]	Si1MeVne [cm^{-2}]	Hgt20MeV [cm^{-2}]
T1	800	betw. -290 and 290	240	5.8	1.29E+11	1.55E+10
T2	870	betw. -290 and 290	240	8.1	1.47E+11	1.96E+10
T3	940	betw. -290 and 290	240	12	1.59E+11	2.45E+10

Maximum Values

OT Front End	Z [cm]	X [cm]	Y [cm]	Dose [Gy]	Si1MeVne [cm^{-2}]	Hgt20MeV [cm^{-2}]
T1	800	betw. -20 and 20	240	6.7	1.45E+11	1.70E+10
T2	870	betw. -20 and 20	240	9.5	1.75E+11	2.30E+10
T3	940	betw. -20 and 20	240	14	1.91E+11	2.81E+10

Y = 220 to 240

Uncertainties of a few Gy might make a difference within 10 years!

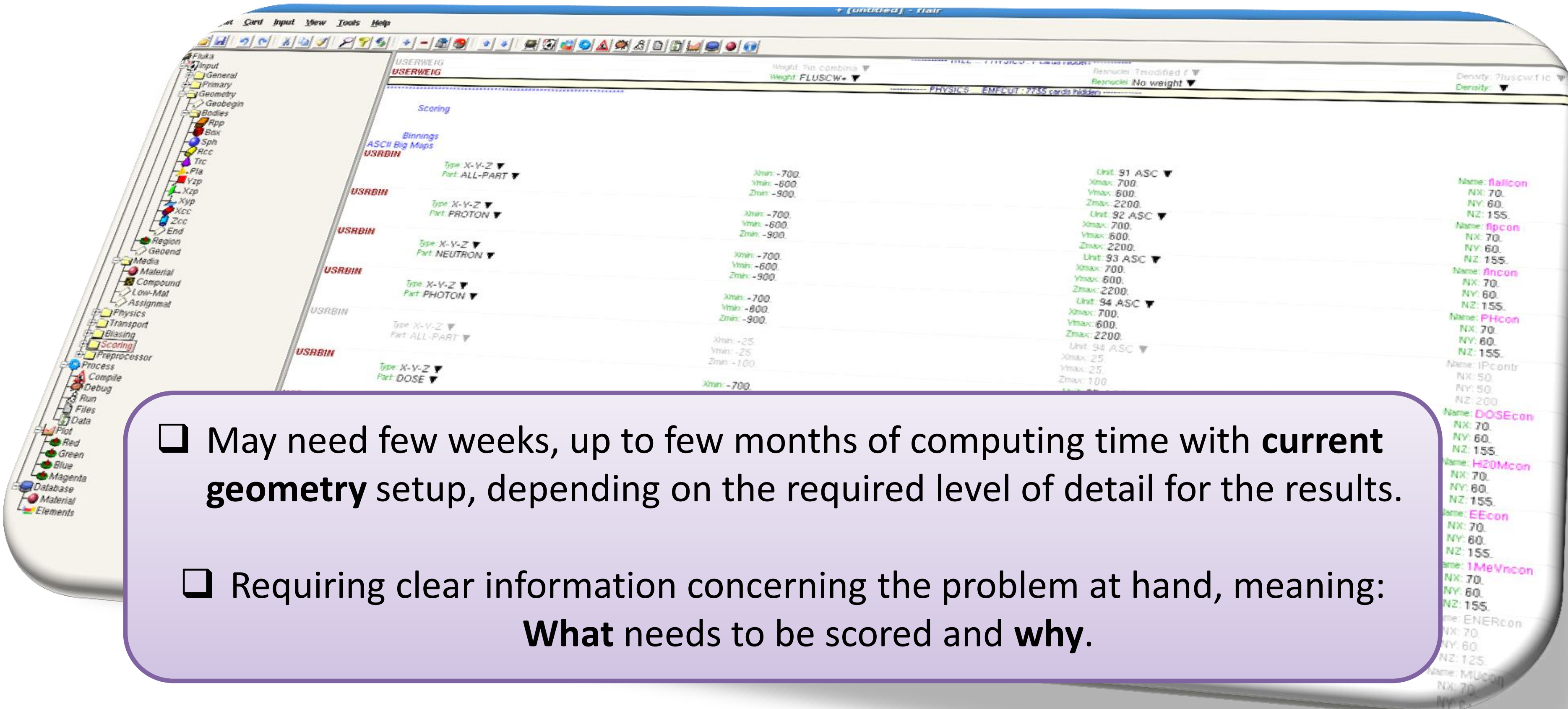
Changes of geometry (especially taking into account heavy materials, or special components (Boron, Silver, etc.)) will have HUGE influence on outcome of simulation!

Estimations with current simulation are not to be trusted in these cases! Re-runs with changed geometry obligatory!

Regions far from the beam pipe suffer from weak statistical MC data and systematic errors of the simulation due to the lack of detail concerning support structures and are therefore to be taken with extra care!

Use larger safety factors!

Possibility of dedicated runs



- May need few weeks, up to few months of computing time with **current geometry** setup, depending on the required level of detail for the results.

- Requiring clear information concerning the problem at hand, meaning: **What** needs to be scored and **why**.

So we can help you in the most efficient way!

Summary and Outlook

- 14 TeV simulation results available for **current geometry.** Will be given out **per collision**. **Caveats** for regions around the beam pipe and remote locations far away from the beam pipe with low dose.

- Please direct estimation requests to Gloria Corti and Matthias Karacson (<-me) for now, especially for sophisticated problems.

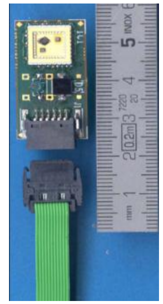
- Long Shutdown will yield measurements for 2012 at 8 TeV CM with more sensors reaching their thresholds, leading to better opportunities to cross check simulation results by summer 2013.

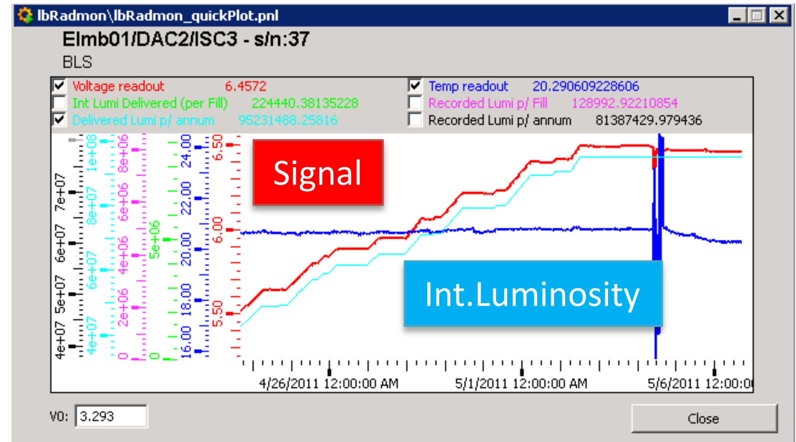

THANK YOU!

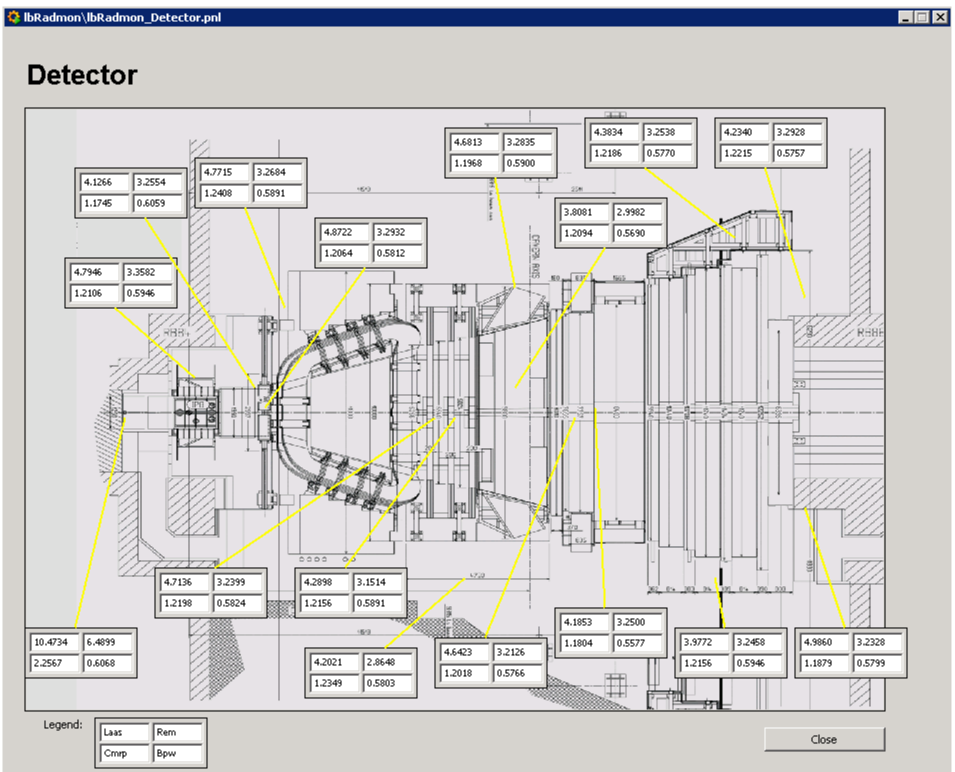
Backup Slides

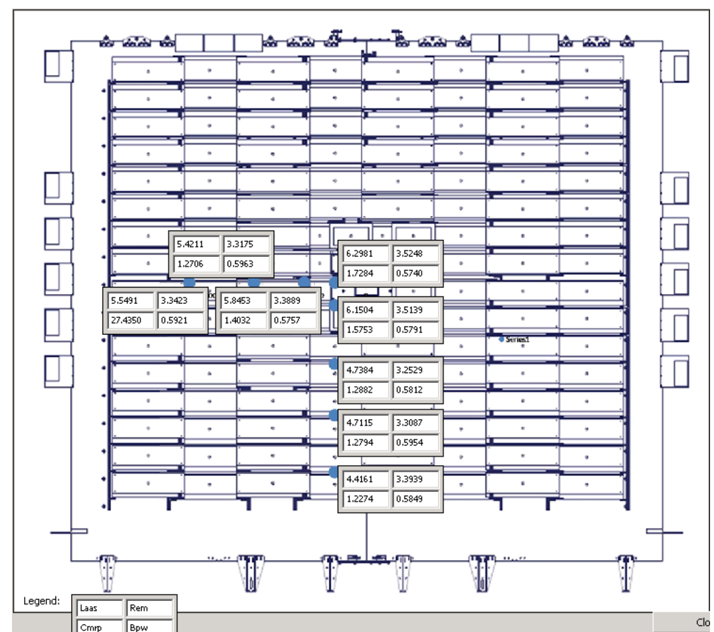
Active Radiation Monitors

28 boxes distributed underground
4 Sensors in each box:
- 2 for Dose measurements
(< 10Gy and 1Gy < X < 10kGy)
- 2 for 1 MeV n equ.
(10^8 to 10^{12} and 10^{11} to 10^{14} 1MeV n/cm^2)



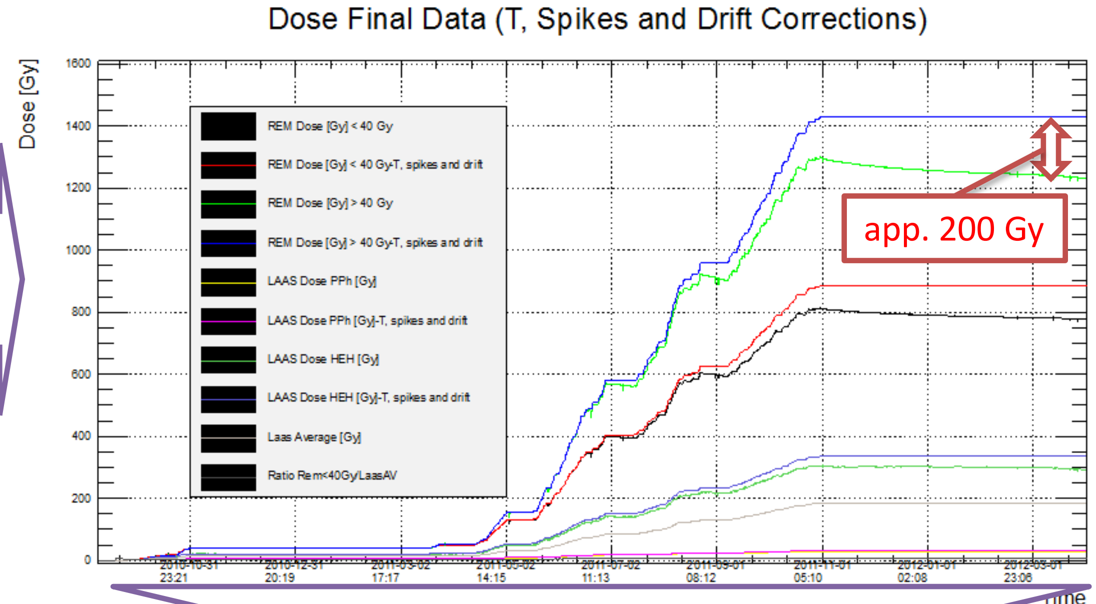




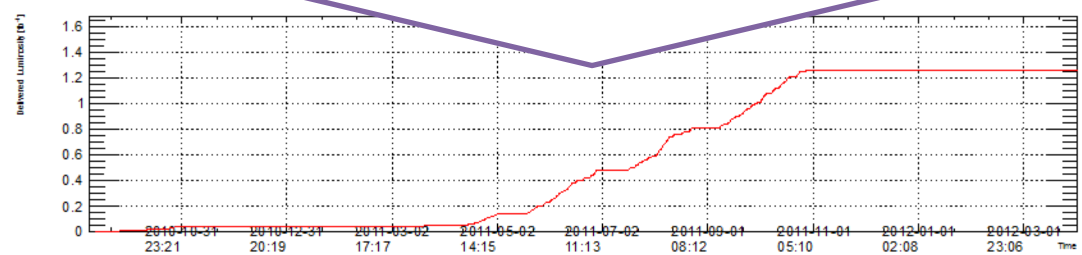


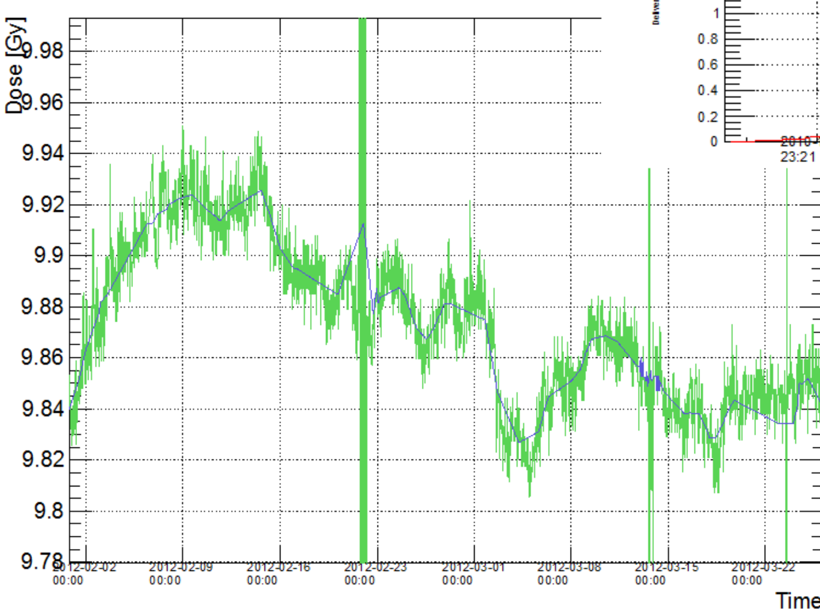
Corrected Dose curves for ECAL Tunnel module Sn 39, with and without drift correction

(blue/green) for Dose > 40 Gy
(red/black) for Dose < 40 Gy



Corresponding Int. Del. Luminosity





Noise and spike correction for a region of LAAS readout

Thanks to Vincenzo Battista!

We do have active sensor readouts, however:

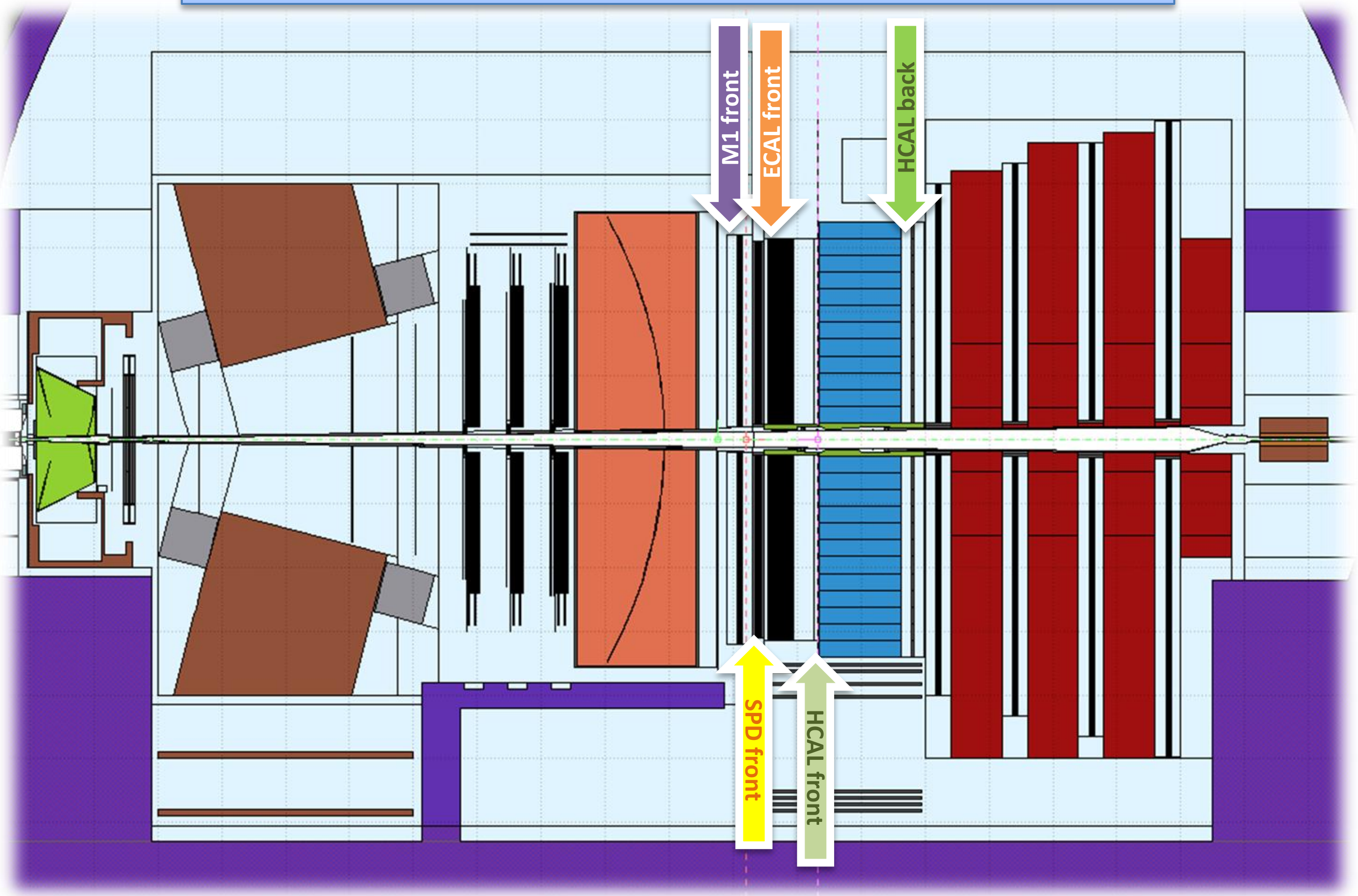
- We have not yet implemented corrections into online readout, offline readout is a very complicated and time consuming act.
- High dose REM sensors already give a somewhat reasonable estimate after applying all corrections. More passive measurements are required to further refine corrections.
- Low dose LAAS sensors (covering the dose range of most sensor locations) need calibration depending on dominant incident particle type. They do not really give useful info otherwise.
- 1 MeV neutron equivalent sensors are being evaluated versus simulation results, with only a few measurements above threshold to compare.

In short, active readouts at the moment are hard to get at and are of limited use. Passive measurements are more accurate and are used to calibrate simulation as well as active sensors.

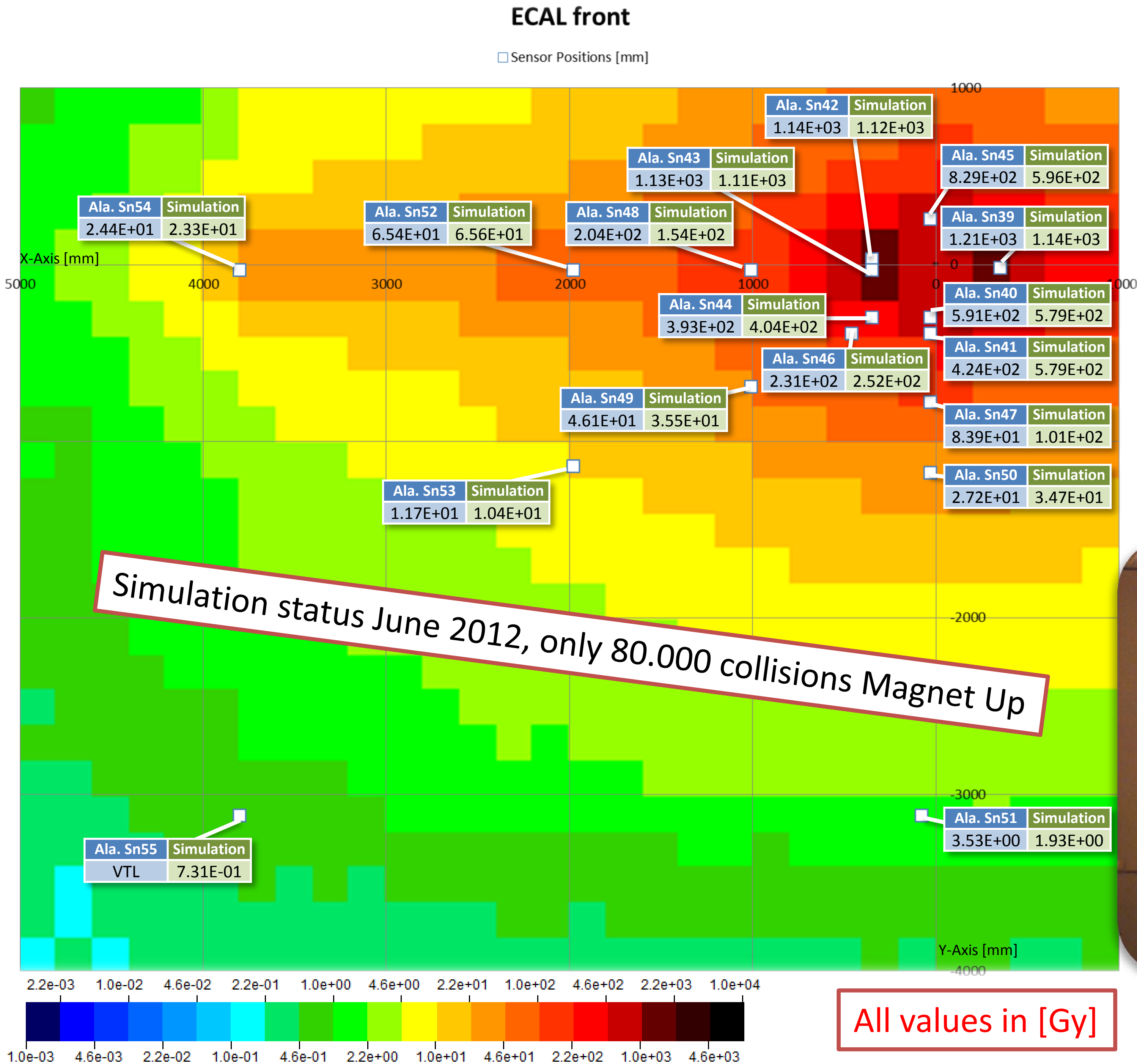
CALORIMETER sensor positions

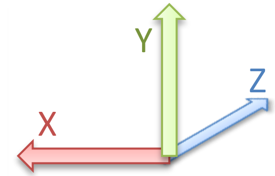
4 planes with sensors, which are always distributed around lower quarter A-side:

HCAL back, HCAL front, ECAL front and SPD front



All of the depicted dose values in the following figures are in [Gy]

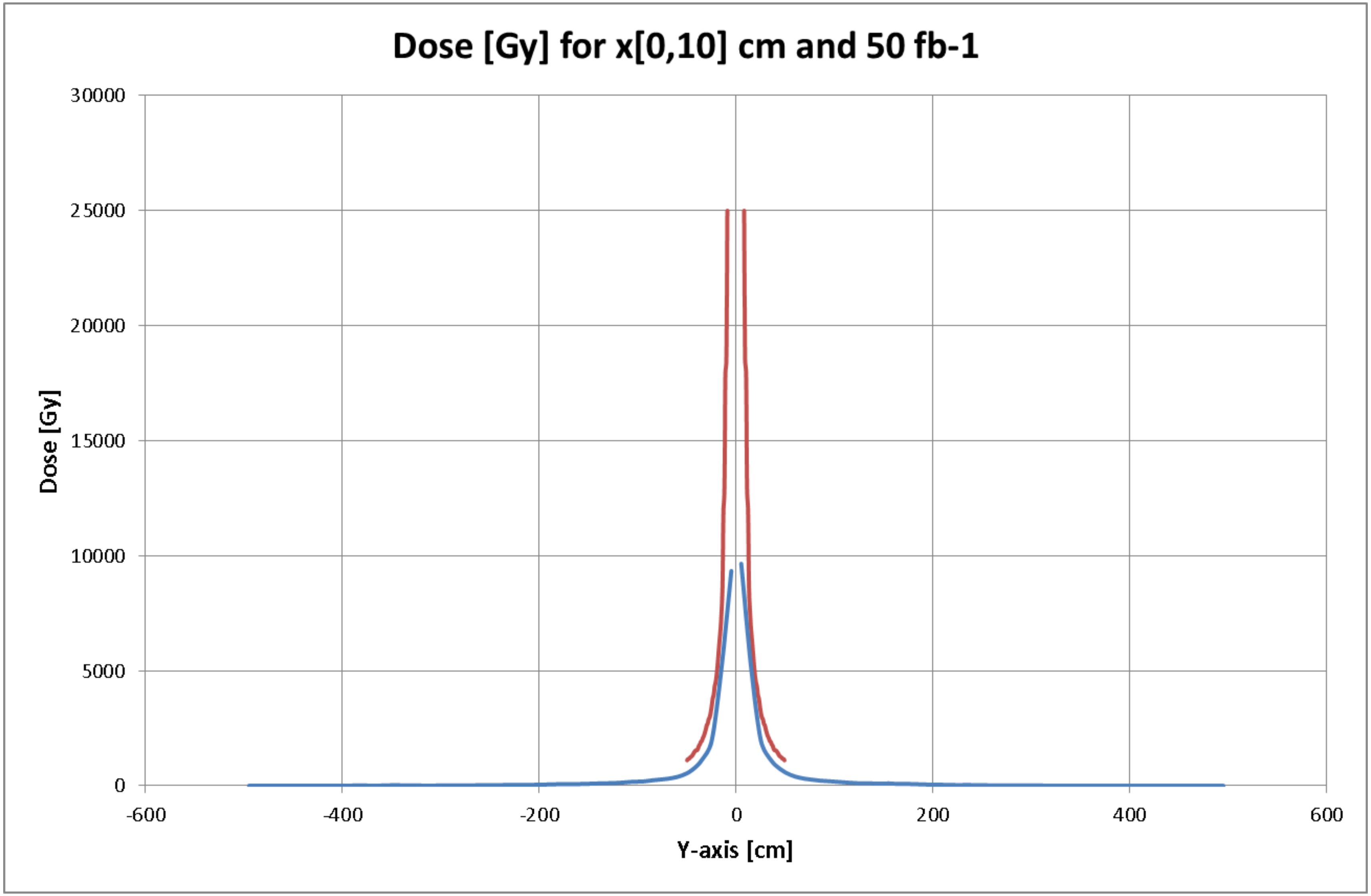




Boxes show Alanine (Ala.) values with Serial numbers of the box and Simulation results at the positions of the sensors

VTL stands for "VALUE TOO LOW"

All values in [Gy]



Dose [Gy] for x[0,10] cm and 50 fb-1
30000
25000
20000
15000
10000
5000
0
Dose [Gy]
-600
-400
-200
0
200
400
600
Y-axis [cm]

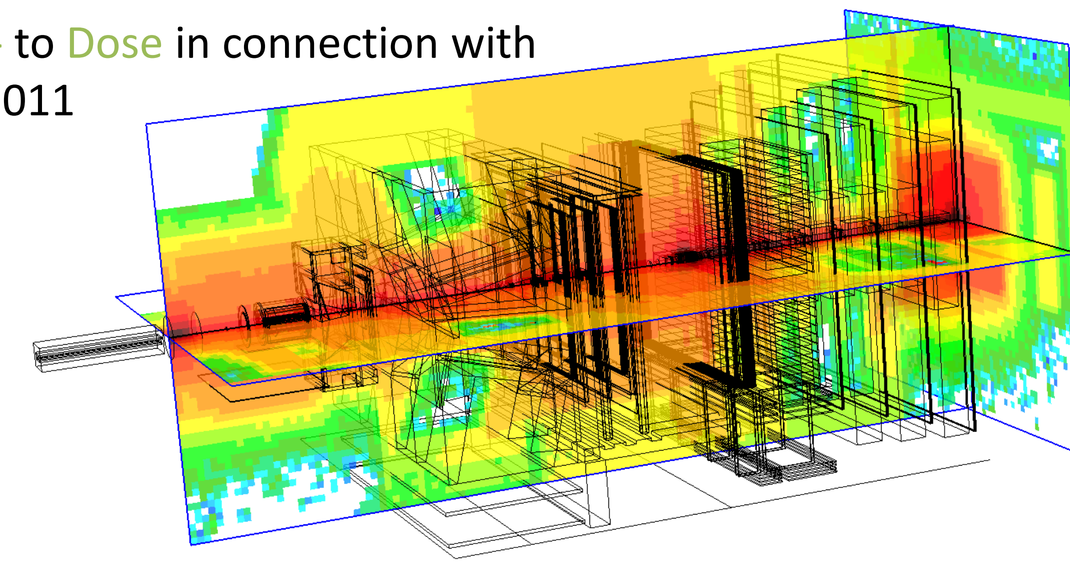
Status of Simulation of 14 TeV pp collisions

Performed only to compare it roughly to 2003 reference, to find and explain differences in order to be able to get trustable results from 7 TeV pp simulations!

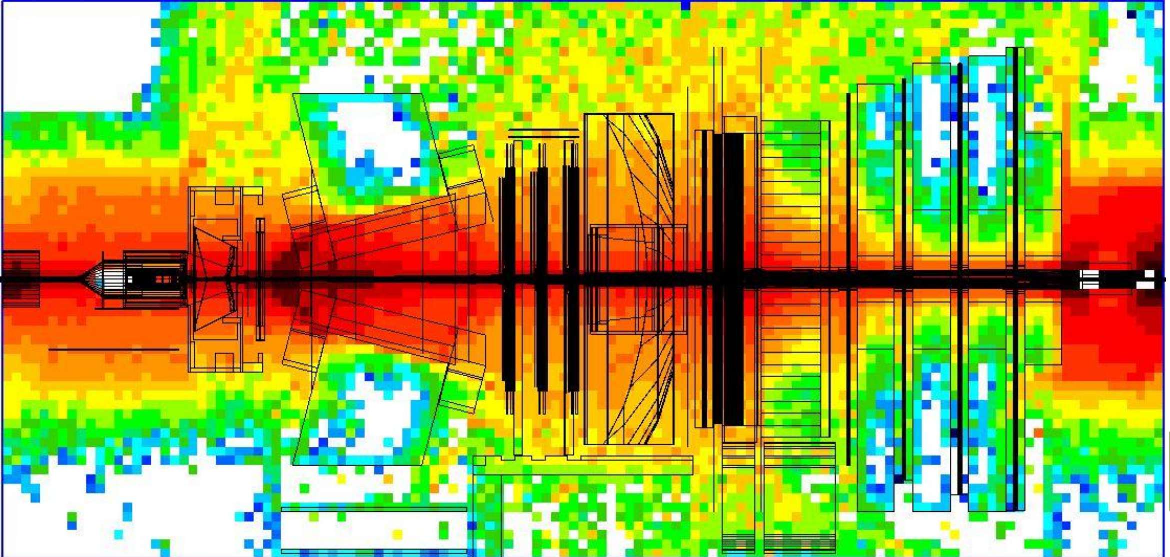
Simulation of 14 TeV pp collisions setup:
- magnetic field (recent maps) pointing downwards
- no beam crossing angle
- low statistics (enough for general comparisons via averaging over big bin sizes)

Focus on contribution from e+e- to Dose in connection with differences between 2003 and 2011

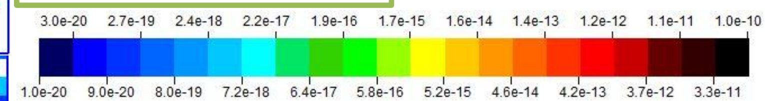
1 pp collision took around 1:15 min on average to calculate on a standard 3.2 GHz intel C2D desktop



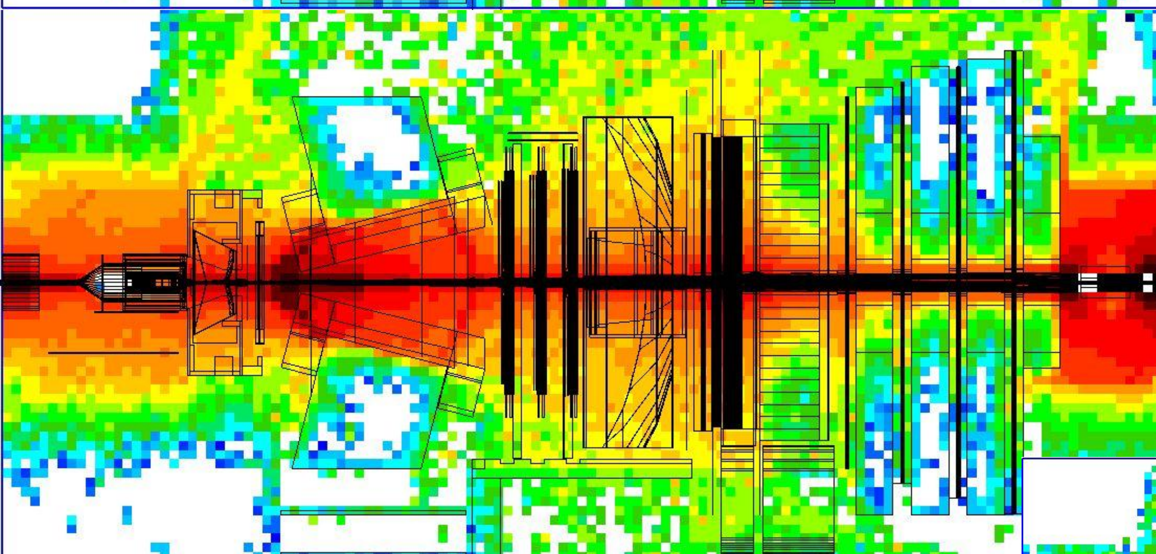
X=0 Prompt Dose / Fluence per pp collision 2011



<-Total Dose [Gy]



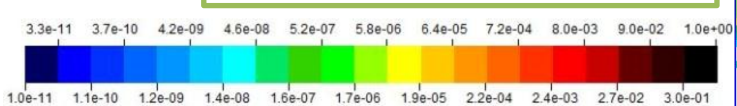
<-Dose from e+e- [Gy]

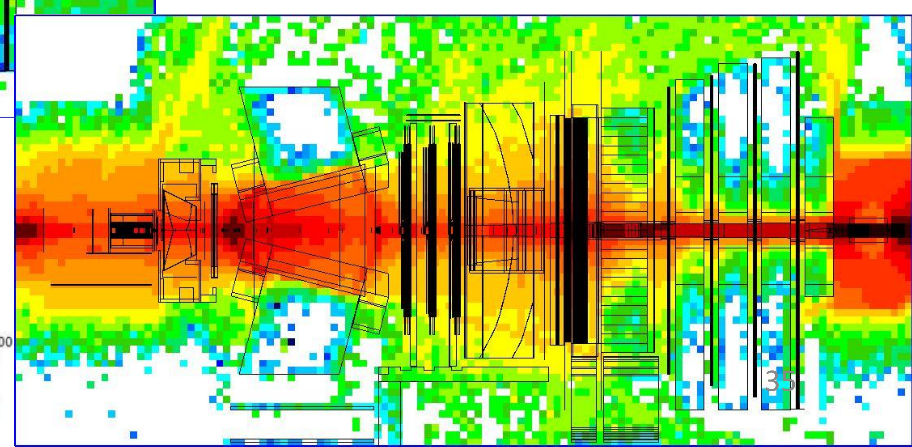


Inner Magnet: ~85% from e+e-
RICH2 edge: ~50% from e+e-

Inner Magnet <> RICH2 edge
10E+5 times as much Dose!

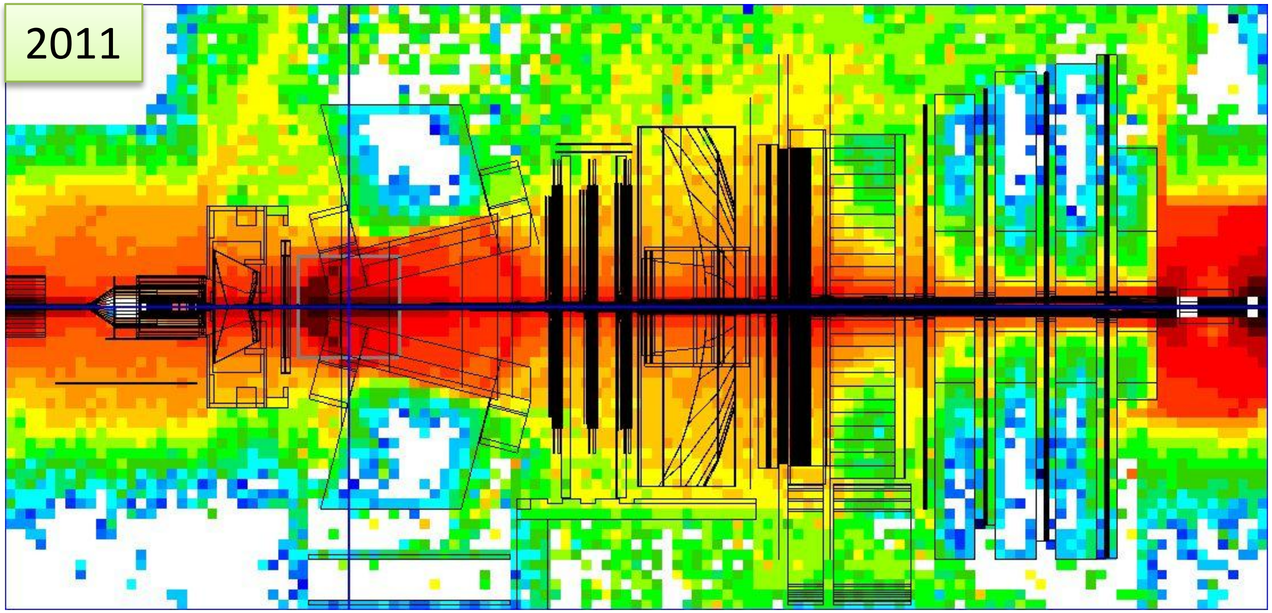
e+e- Fluence cm/cm3 ->





Comparisons of 2011 vs 2003 – low statistics run

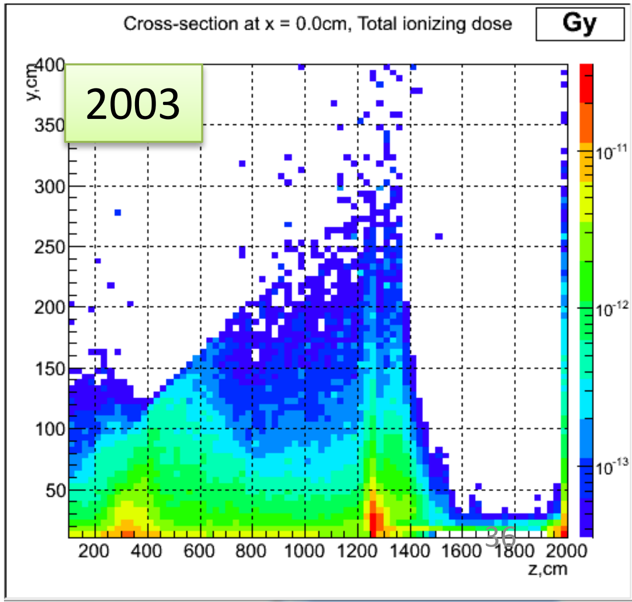
Averaging over 200x200x20 cm at several points in the X=0 plane



Av TD Gy	Av eeD Gy	Ratio eeD/TD	Av TD Gy 2003	Dose 2003/2011	ee Fluence 2011	ee Fluence 2003	Fluence 2003/2011
3.92E-12	3.34E-12	8.52E-01			9.85E-03		

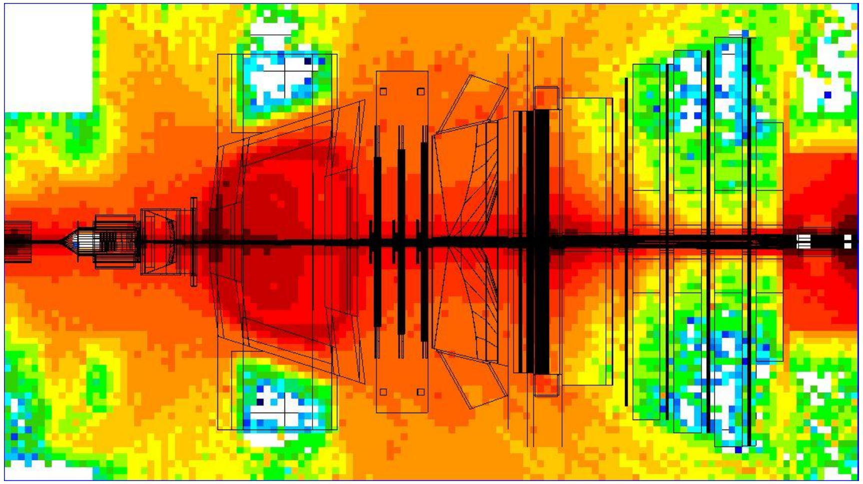
Lev Shektman did not score beneath Y=10 cm in 2003.
Also "Curling" of e+e- inside magnet is missing.

Summary:
Between 1.5 -2.5 times less Dose in 2011 around IT/OT.
About double as much Dose in 2011 at start of magnet.

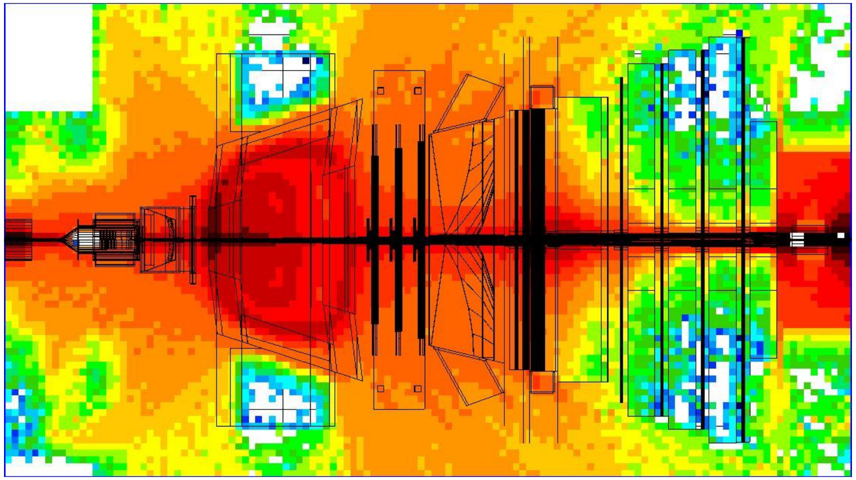


Y=0 Plane

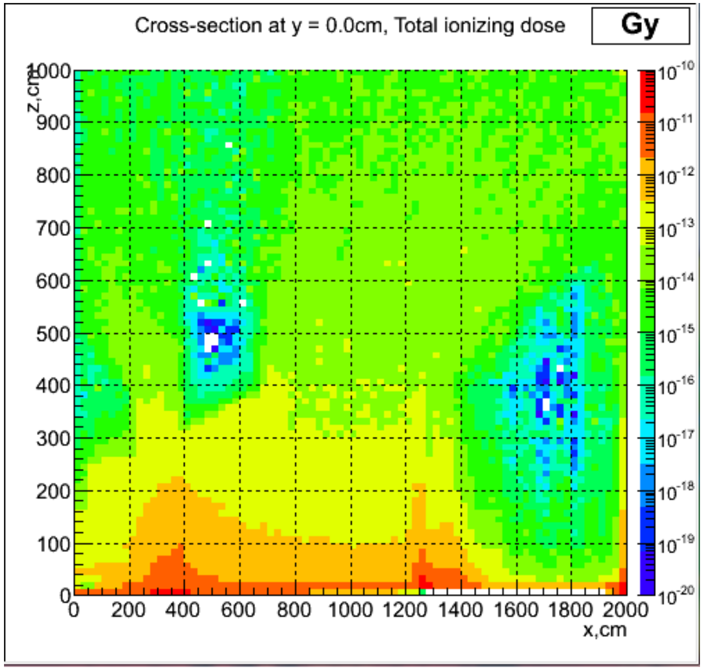
Total Dose 2011



Dose deposited by e+e- 2011



Total Dose 2003



Not as much difference in TD:

Magnet: 1.2x in 2011 vs. 2003
IT: 0.8x in 2011 vs. 2003
RICH2e: 1.5x in 2011 vs. 2003

Comparisons of 2011 vs 2003 – Summary

Mostly differences in X=0 plane, less in Y=0

Reasons for differences before reaching new HCAL geometry:
- Different distribution of e+e- which play major part in Dose distribution
- Different version of FLUKA
- Different geometry of magnet
- Different magnetic field (and curling electrons in 2011)
- Slightly Different binning (X: 0.07 cm 2003 vs 20 cm for 3D SG 2011)

(- No Leading Particle Biasing ?)

- To a certain degree also the error due to the low statistics

Considering all of the above, the simulation setup seems reasonably trustable to start simulating running conditions of 2011 and 2012

High statistics 14 TeV pp simulation can be performed rather easily in future with the existing geometry