Calorimeter beyong Phase 1 upgrade

Workshop : La Biodola

The LHCb calorimeter upgrade group
and many others
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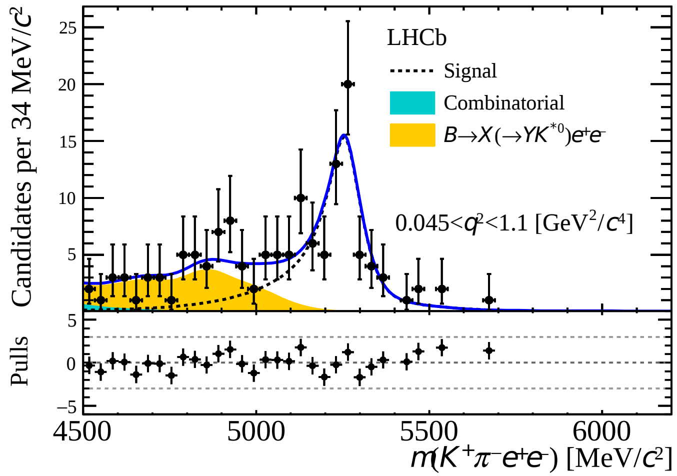
Tuesday 30th May 2017

- We already produced very nice results with electrons, photons, π^0
  - The present detector is working well

$$\frac{\delta E}{E} = \frac{S}{\sqrt{E}} \oplus C \oplus \frac{N}{E}$$

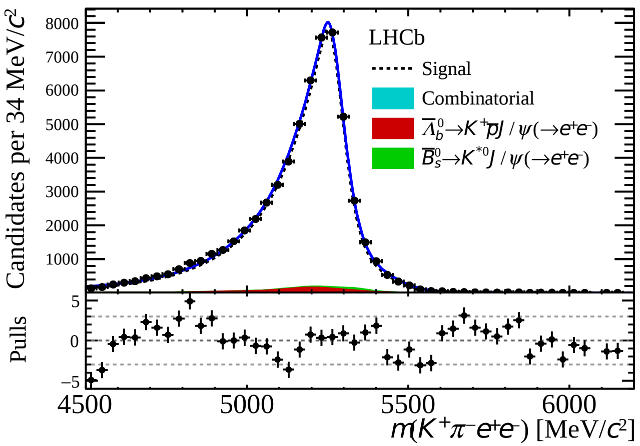
	S [GeV$^{1/2}$]	C	N [MeV]	Material
LHCb	~10%	~0.8%	~10-20	~1X_0
ATLAS	10-12%	~0.2%	~250	~0.5-1.5 X_0
CMS	3-6%	~0.5%	200-600	~0.5-2.0 X_0

RK*, low q² region



- Some of the new high profile channels rely on the calorimeter reconstruction
  - Lepton universality tests
  - π^0, η final states
  - Rares decays with photons, electrons
  - Exotics
  - Charm physics, etc...

Ctrl channel



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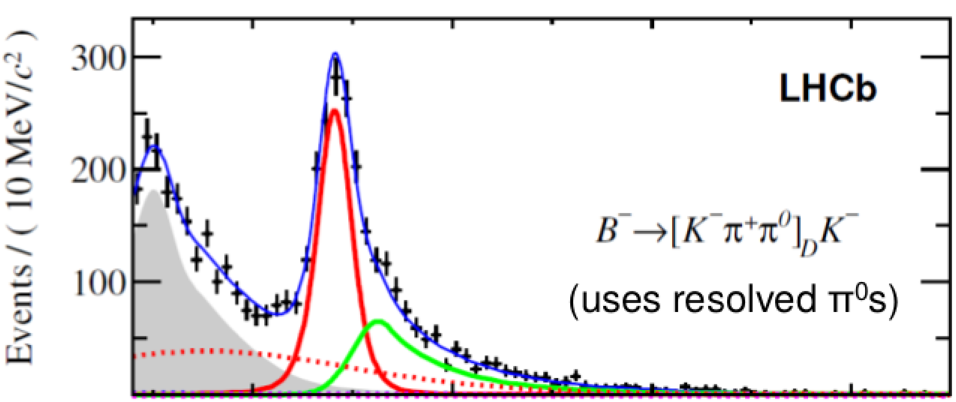


$B \to \eta' X$
$B^+ \to K^+\pi^0$, $B^+ \to \rho^+\rho^0$
$\Lambda_b \to pK\eta^{(\prime)}$, $B^0 \to K^*\eta^{(\prime)}$
$B^0, B_s \to h^+h^-\pi^0$

$D^0 \to e\mu$
$D^+ \to \pi^+\pi^0(\to \gamma e^+e^-)$
$D^0 \to \Phi\gamma$, $K^*\gamma$, $\rho/\omega\gamma$

$B^+ \to D(hh\pi^0)K$
$B_s \to D_s^*K$
$B^+ \to D^*K$

$B_s \to \Phi\gamma$
$B \to K^*\gamma$
$B_s \to \gamma\gamma$
$B \to K^*e+e-$

$B^0 \to J/\psi\pi^0$
$B^0 \to J/\psi\omega$
$B^+ \to J/\psi\rho^+$

$Z \to e^+e^-$
$W \to e\nu$
WW,ZZ,WZ
Top (l^+l^-b)
γ + jet

$B_{s,1} \to B_s\gamma$
$\Lambda_b^{**} \to \Lambda_b\gamma$
$B_c^* \to B_c\gamma/\pi^0$
χ_c, χ_b polarisation
Pentaquarks $\to \chi_{c,b}X$

$B \to D^{**}(\to D^0\pi^0X)\mu\nu$
$B \to De\nu$ vs. $B \to D\mu\nu$

Why would we like to improve the calorimeter after LS3 ?

Improved energy resolution

X

$B^{+}\to\rho^{+}\rho^{0}$

$\Lambda_b\to pK$ … $K^{*}\eta^{(\prime)}$

$B^{0},B_s\to h^{+}h^{-}\pi^{0}$

Improved position resolution and granularity

$\pi^{+}\pi^{0}(\to\gamma e^{+}e^{-})$

$D^{0}\to\Phi\gamma$, $K^{*}\gamma$, $\rho/\omega\gamma$

B^{+} … $\pi^{0})K$

$B_s\to D_s^{*}K$

$B^{+}\to D^{*}K$

$B^{0}\to J/\psi\pi^{0}$

$B^{0}\to J/\psi\omega$

$B^{+}\to J/\psi\rho^{+}$

$B_s\to\Phi\gamma$

$B\to K^{*}\gamma$

Timing information to reduce combinatorics

Improved sensitivity at low E_T

$\to e\nu$

WW,ZZ,WZ

$B_{s,1}\to B_s\gamma$

$\Lambda_b^{**}\to\Lambda_b\gamma$

$B_c^{*}\to B_c\gamma/\pi^{0}$

polarisation

quarks $\to\chi_{c,b}X$

$B\to D$ … $(\to D^{0}\pi^{0}X)\mu\nu$

$B\to De\nu$ vs. $B\to D\mu\nu$

Wider dynamic range

γ + …

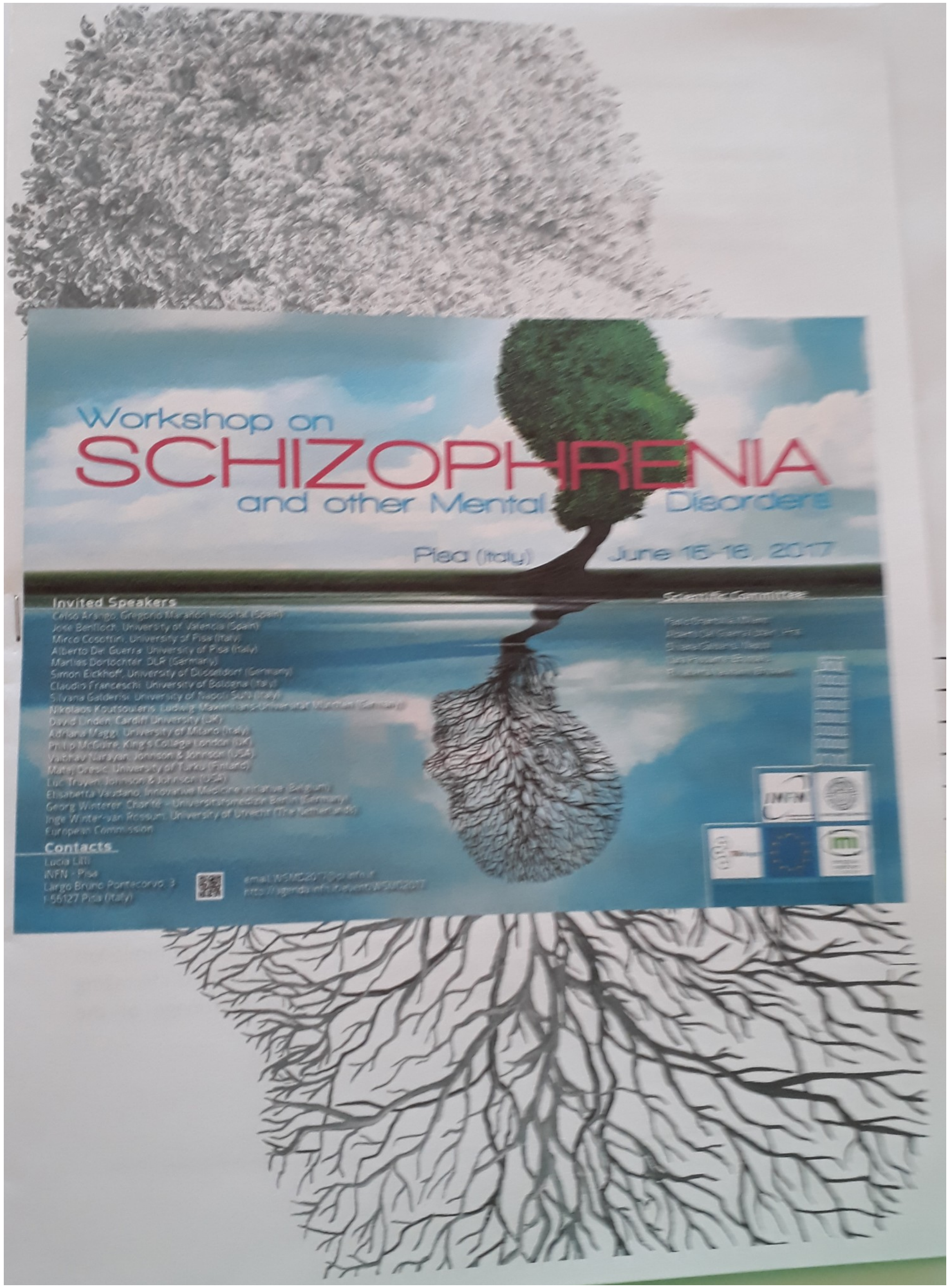
- The constraints from the physics groups are often different and sometimes contradictory...

Working on two upgrades in parallel can be dangerous...

Leaflet of a workshop that

will take place

mid-june at la Biodola



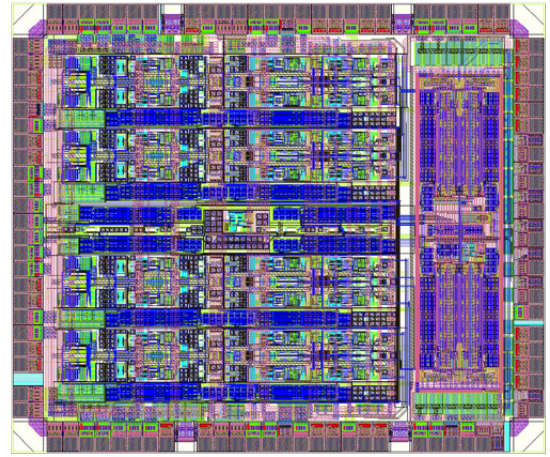
Schizophrenia

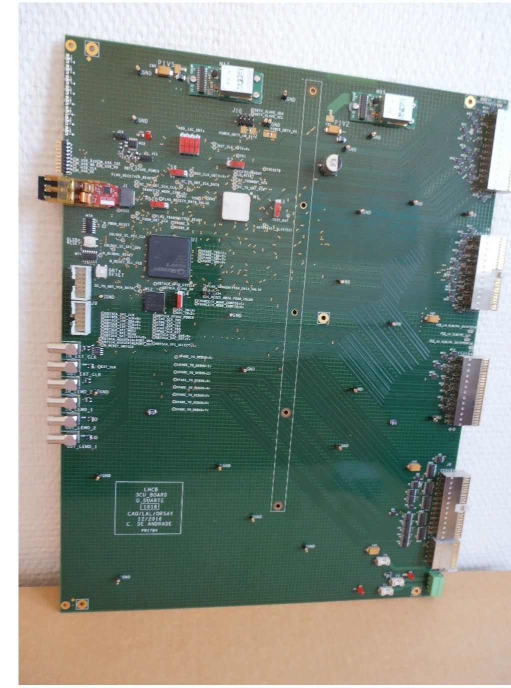
And other

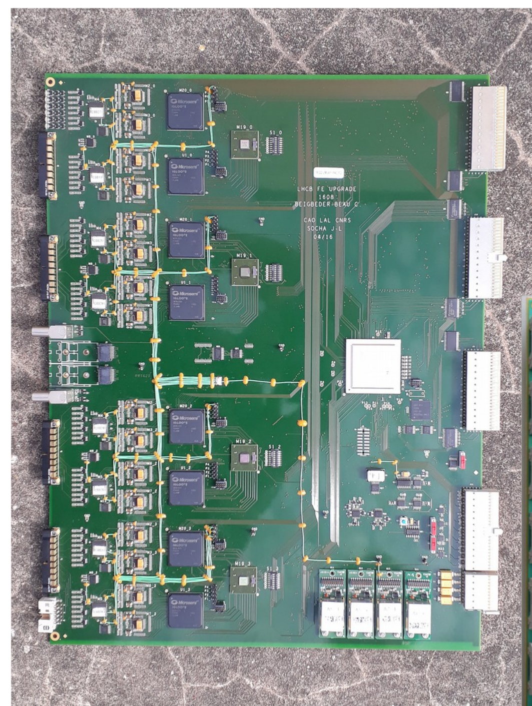
Mental disorders

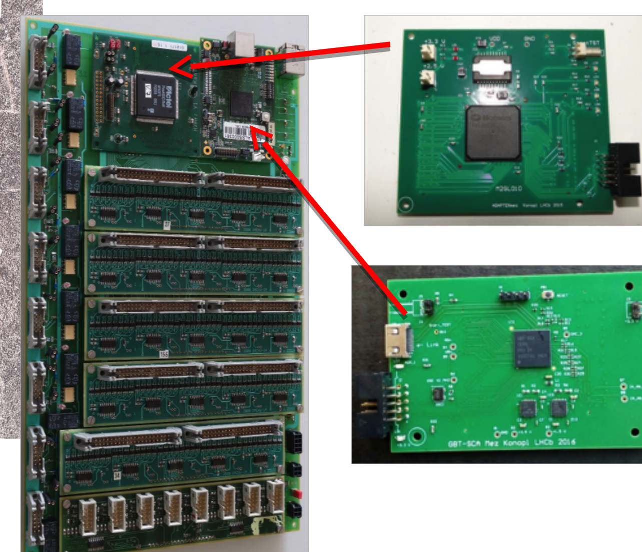
LS2 activities

- The plan for the LS2 is
  - Keep the PMT after a x5 gain reduction and perform a 40MHz readout
  - Requires a new electronics
    - New Analog chip (ICECAL)
    - New FEB (300 boards)
    - New Control boards
    - Re-design of part of the HV, calibration, monitoring elect.
  - New reconstruction adapted to the larger occupancy
  - Dismantling of the SPD, PS and lead converter
    - Major, time-limited task
    - Done in parallel with installation/commissioning



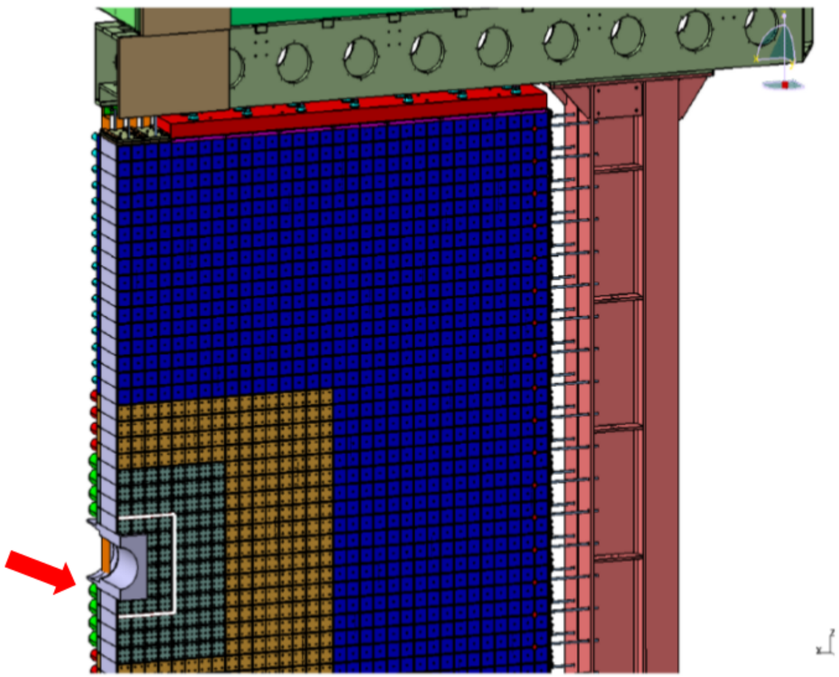






LS3 baseline activities

- The other big activity planned for the future is the replacement of the modules in the innermost region of the ECAL (LS3)

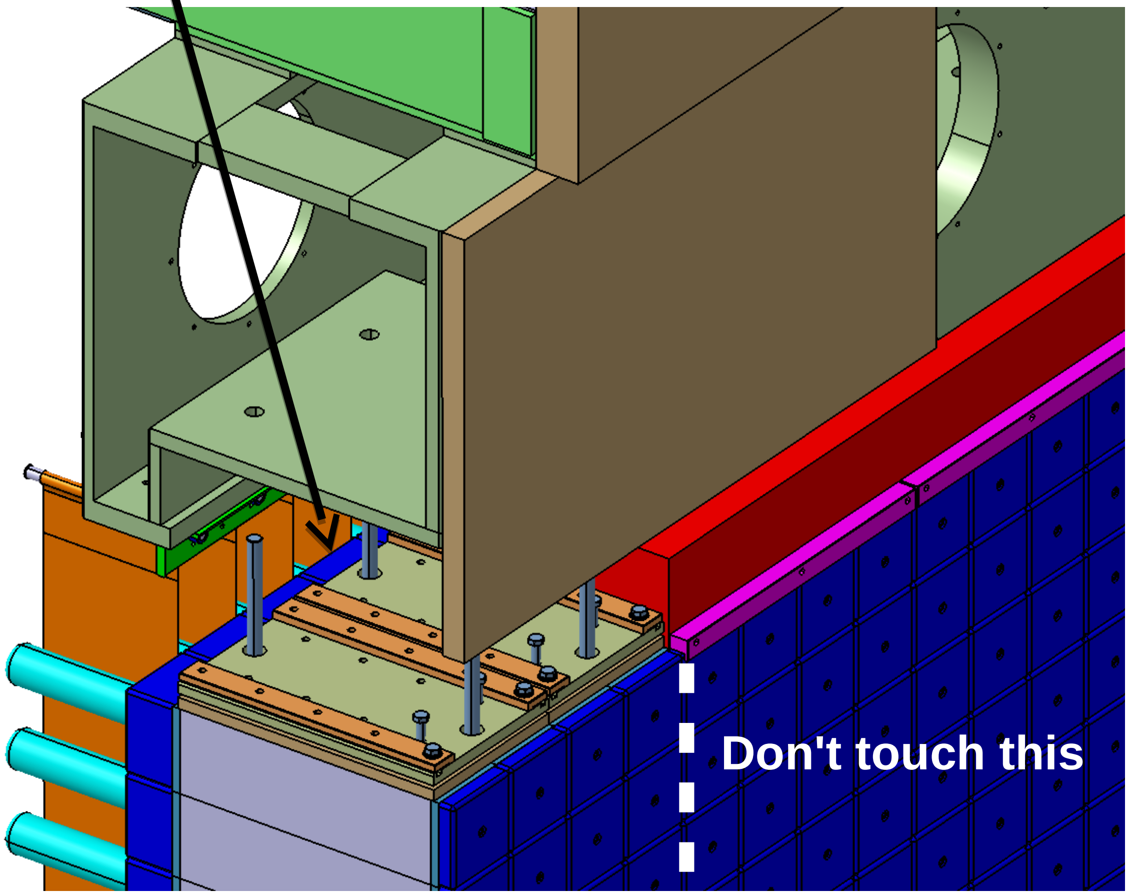


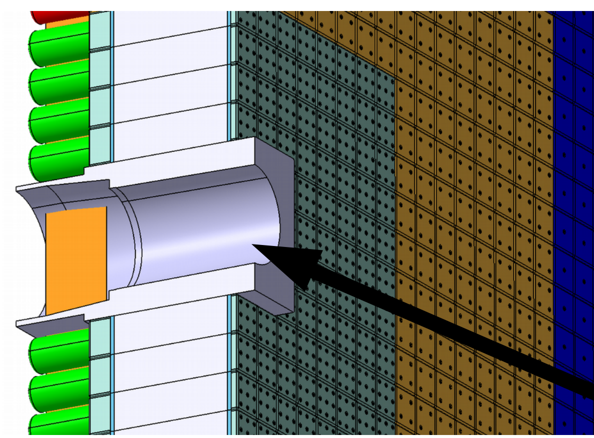
- At present the “baseline” plan is to replace the innermost region of the inner part of the calorimeter
  - “The performances should remain satisfactory up to 2.5Mrad” (~ cte term ~<3%)
    - → 20fb^{-1} or ~2023 according to the TDR
- We have the 32 spare modules
- 3 months should be enough to perform the operation

- This requires “only” the dismantling of the columns of modules above the central region
  - Other intervention would require the dismantling of a large fraction of the calorimeter → long task

Replacement of the central cells

Working area to remove modules or beam plug





500 kg beam plug to removed (crane to be used)

Energy and position resolution

- We should reduce the transversal extension of the showers and reduce the size of the cells accordingly
  - It does not seem necessary to replace the full detector
    - The area the most affected by
      - Radiation, pile-up

      and that
      - mostly contributes to the physics

      should be considered
    - Inner, extended outwards, and to the horizontal band ?
    - The addition of new frontiers should be avoided
- The new geometry should benefit from the modular present design
  - New modules of the size of a module (12cm x 12cm)
  - Easier integration with the modules kept
  - The modularity of the detector and the aimed Moliere radius pushes towards a “natural” 2x2 cm^2 cell size (36 cells per module)
- Can we implement some longitudinal stack readout ?
  - Different fibre lengths ?
  - Looks difficult…

Energy and position resolution

- The thickness of this new ECAL should be ~25X_0 to contain the Electromagnetic shower
  - A denser absorber means a thinner detector in the newly instrumented region
- Full projectivity is not feasible → would require many different modules
  - Can we integrate some projectivity in the horizontal plane ?
    - Requires a full replacement of the band
- What technology to use ?
  - Absorber has probably to be based on Tungsten
    - Different types of tungsten alloy absorbers
  - Signal collection:
    - Scintillator and fibres(?) readout by PMT/SiPM
    - Silicon detector
      - Very expensive
      - Could be used in a "hybrid" detector (few layers only) for
        - ultra-precise position measurement
        - time measurement (see later)

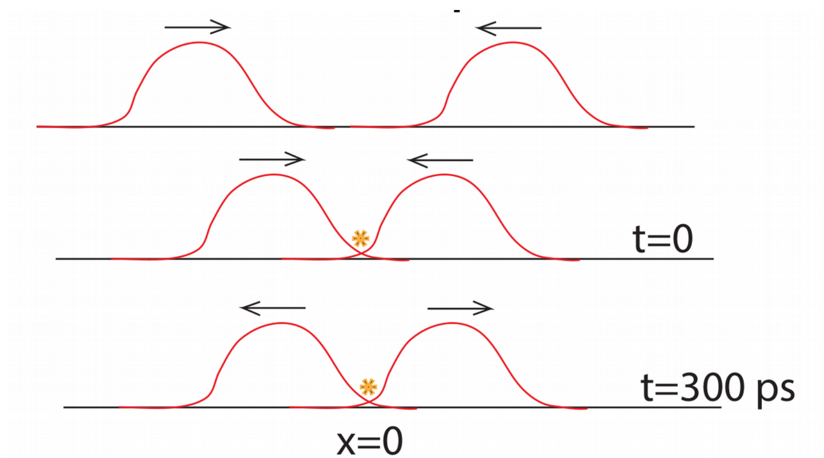
- The effect of the position resolution is often underestimated
  - Neutral pion case
    - The energy resolution is assumed to be $\frac{\sigma(E)}{E} = \frac{\sigma_S}{\sqrt{E[GeV]}} \oplus \sigma_C$
    - The extra (electronic noise) $\oplus 1\% / (E[GeV] \times \sin\theta)$ contribution is supposed to be negligible
    - Two situations:
      1. The position comes from the energy of the cells (cluster)
      2. The position is given from an external device (Si layers ?)
         - Perfect spatial knowledge

	Spatial information from clusters σ_C		Perfect spatial knowledge σ_C	
σ_S	1%	2%	1%	2%
7%	7.5	8.2	4.2	5.2
10%	8.5	9.3	5.5	6.5
15%	10.5	11.3	8.0	8.9

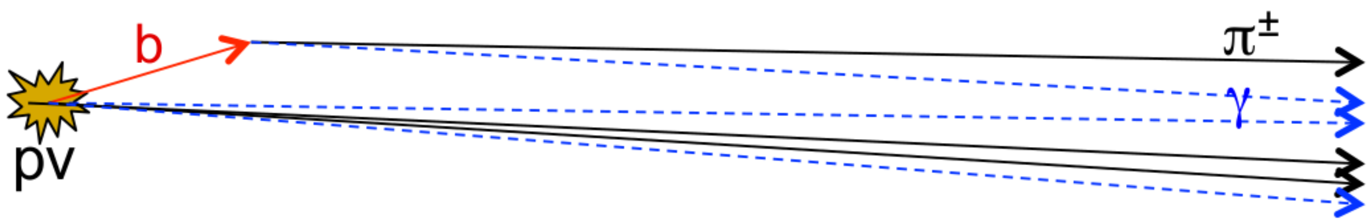
- Neutral pion resolution in MeV: would go down from 9 to 6 MeV

Time information

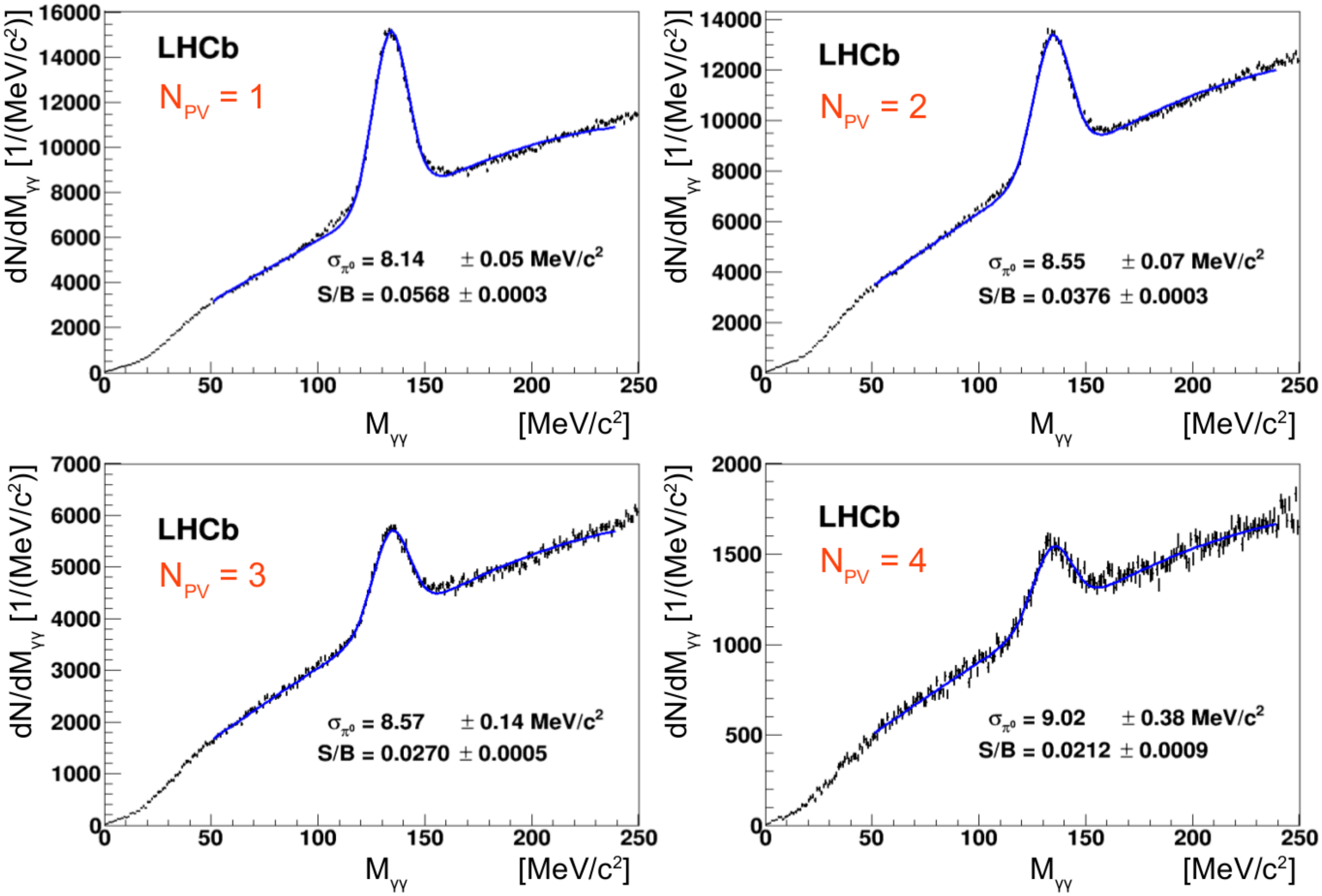
- To reduce shower overlap, one possibility consists in increasing the granularity (should also reduce the Moliere radius…)
- Background and combinatorics reductions can be achieved by using a new dimension → time
  - Ex:
    - 300 ps for beams to cross each other
    - Assuming 10 int/xing → 20 ps between collision (gauss. Distr.)



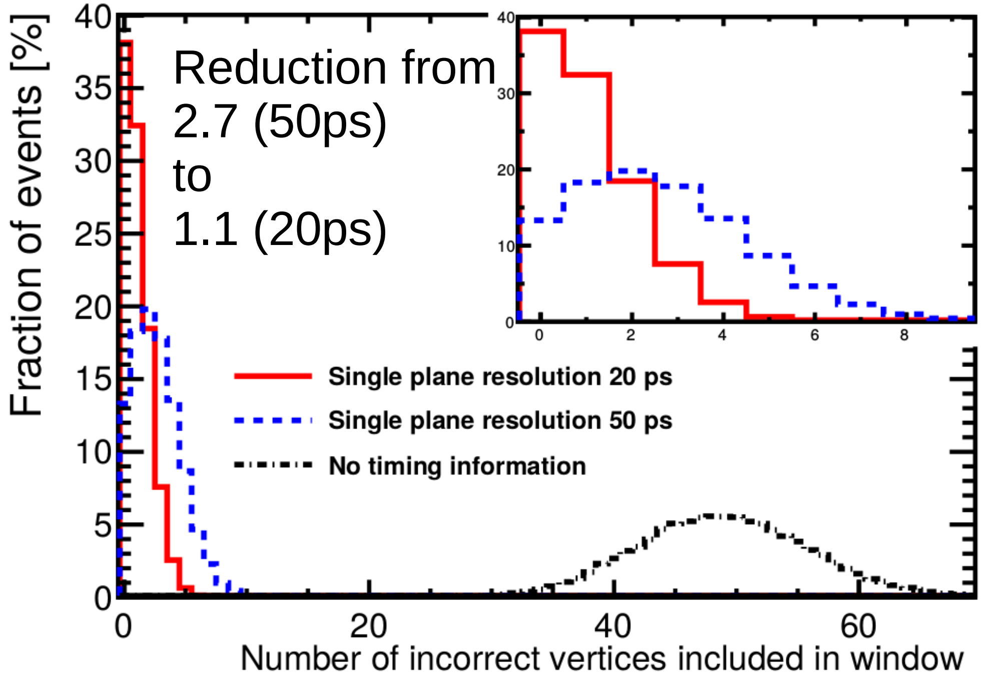
- Strategy :
  1) Sort the charged particles to the PV (timing info)
  2) Associate the photons to the charged tracks (highly relativistic)

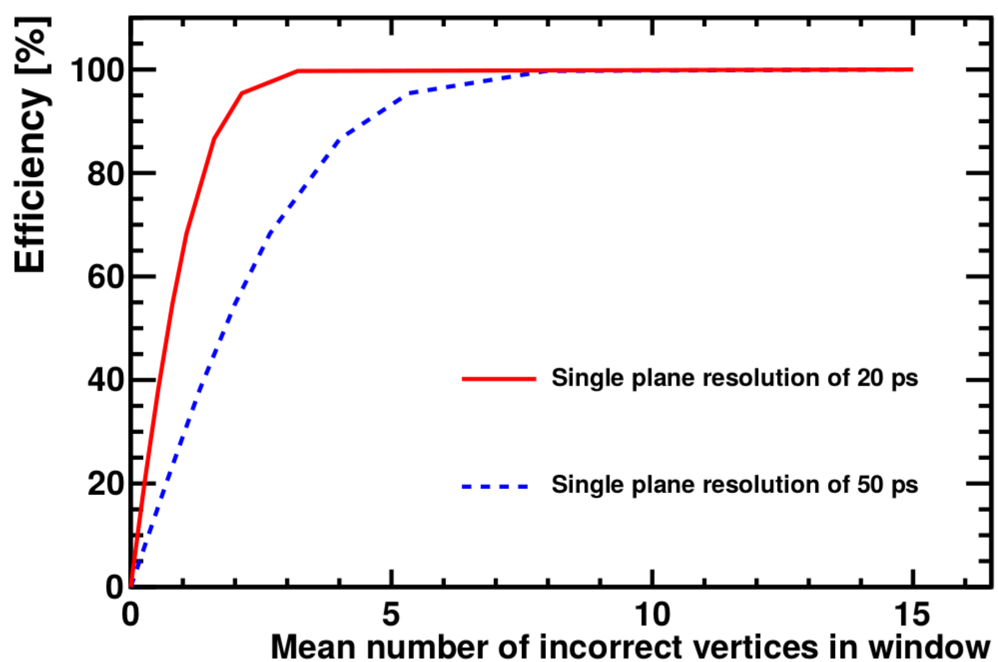


- The effect of the number of primary vertices is already obvious in the present reconstruction
  - Run 2 minimum bias data split wrt the number of PV
  - The selection applied is $p_T(\gamma)$>300MeV/c and $p_T(\pi^0)$>550MeV/c

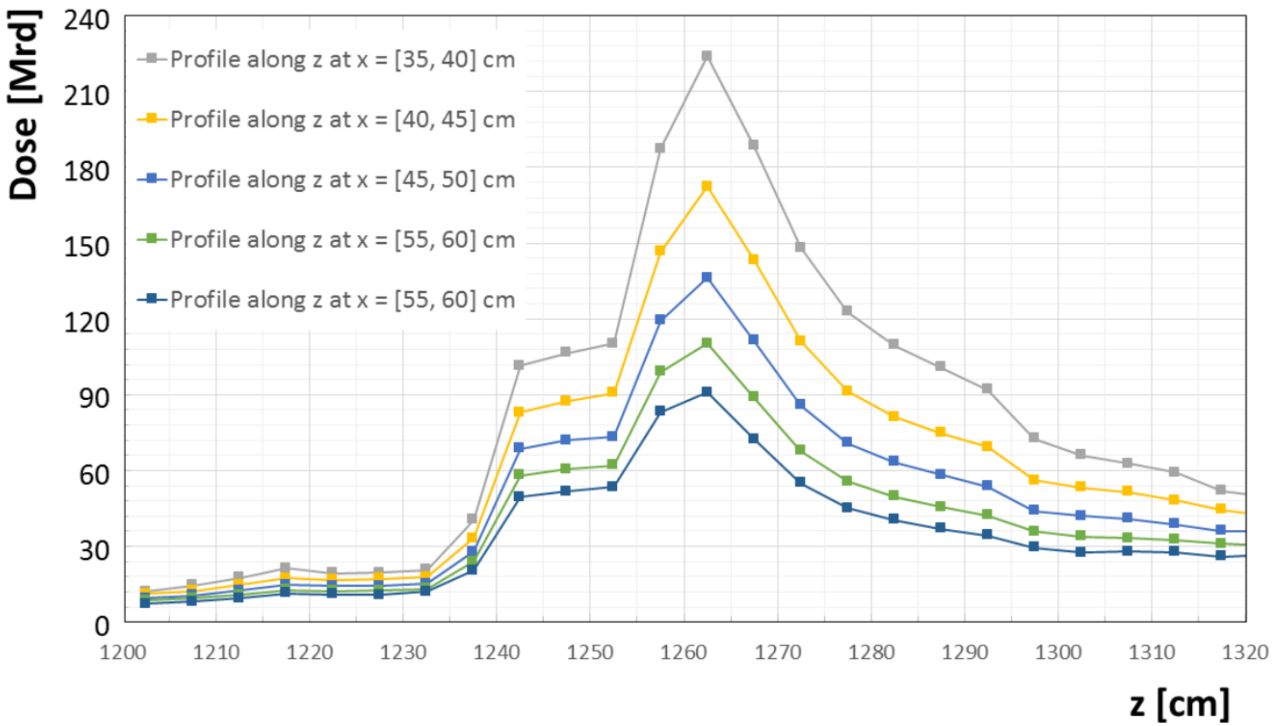


- Assuming
  - 50 interactions per crossing and simulating temporal/spatial distribution of the interactions
  - The introduction of 3 layers of Si planes with precision of
    - 50ps or 20ps each
  - Take a one-sigma window around arrival times corresponding to the interaction of interest
- Estimates the wrong vertices included in the time window





- Could the fast-time be done from the measurement of the start of the shower of the incoming photons
  - The PRS lead converter could be used for this purpose...



Dose in the innermost region after 300fb^{-1}

Here, a safety factor x4 is added in the calculation

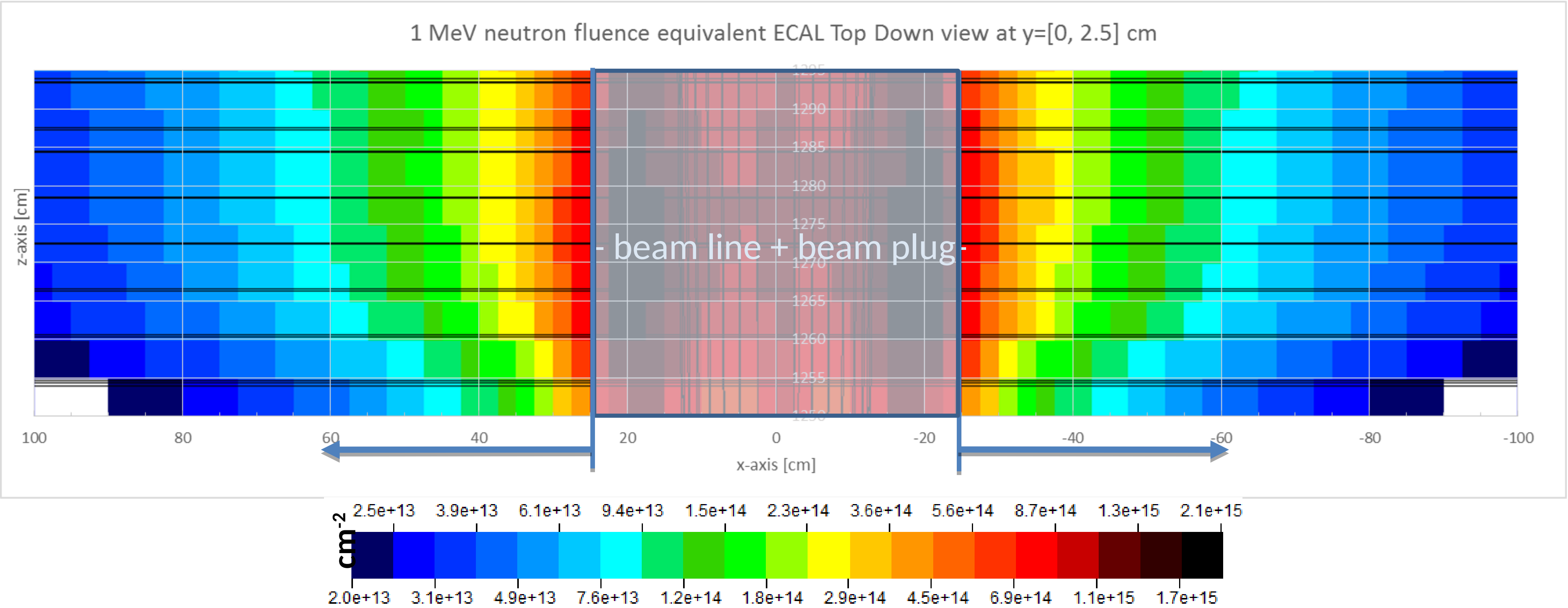
x2 simulation

x2 SPD/PS

Maybe a bit pessimistic ?

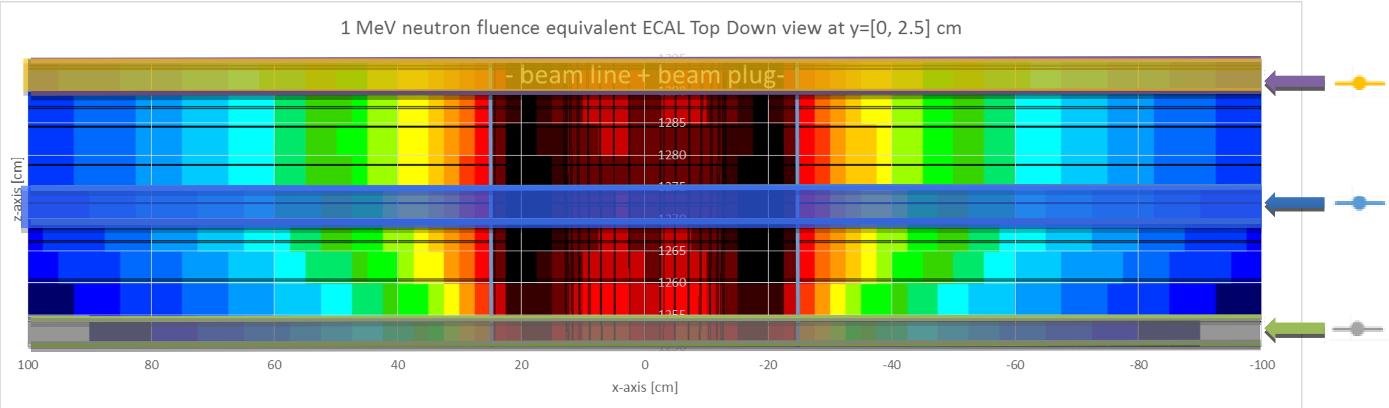
- The dose is particularly important in the inner region but decreases rapidly with the distance to the beam
  - Essentially the innermost cells will suffer
  - This region is also the most occupied one
  - Can we regularly replace this zone if a sufficiently radtol solution is not found ? will probably be the case…
  - Notice that the present coverage of the ECAL in the inner region is smaller than the tracking coverage. We sometime lose efficiency in the ECAL (bremstrahlung reconstruction in the inner region, …)

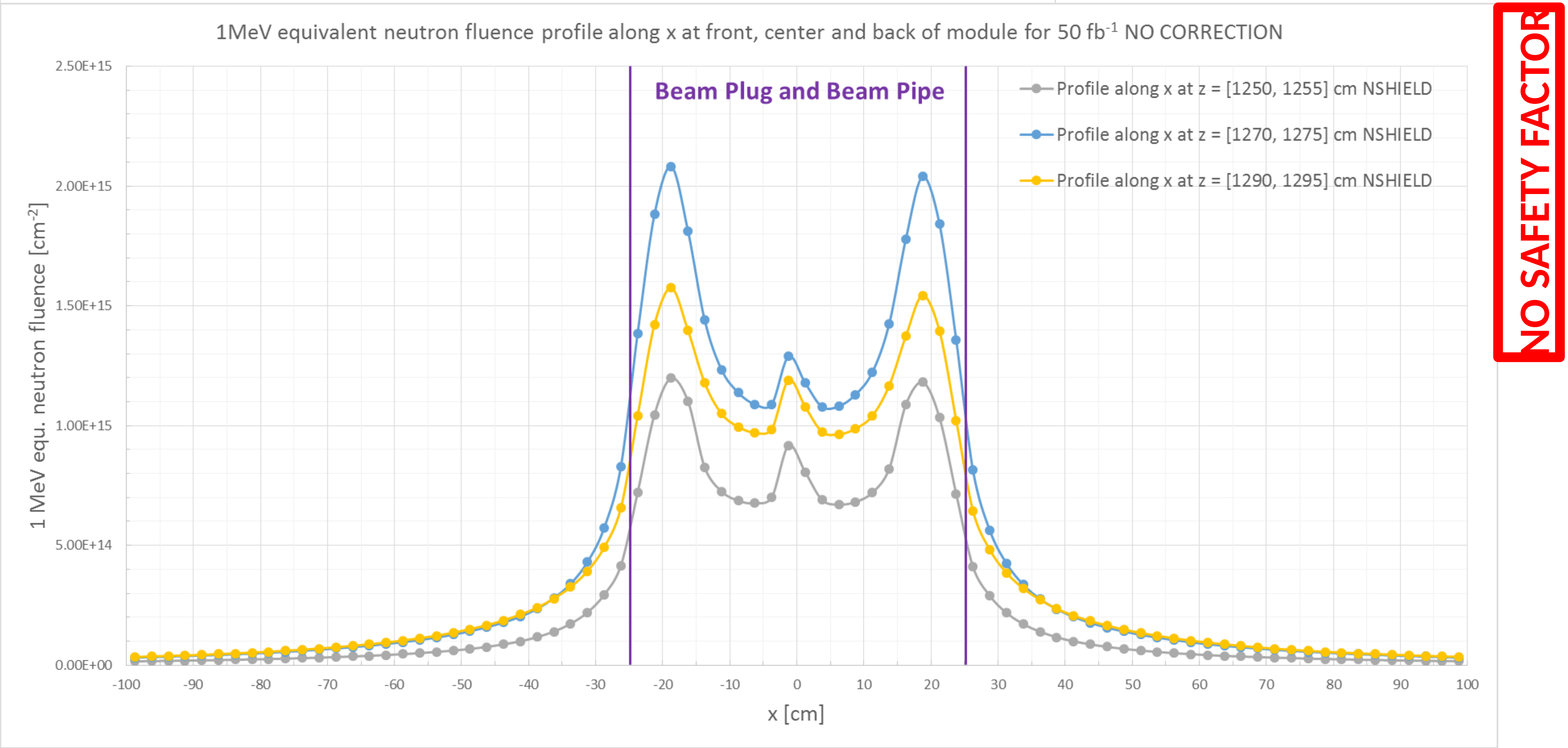
1 MeV neutron equivalent fluence – 50fb^{-1} @14 TeV

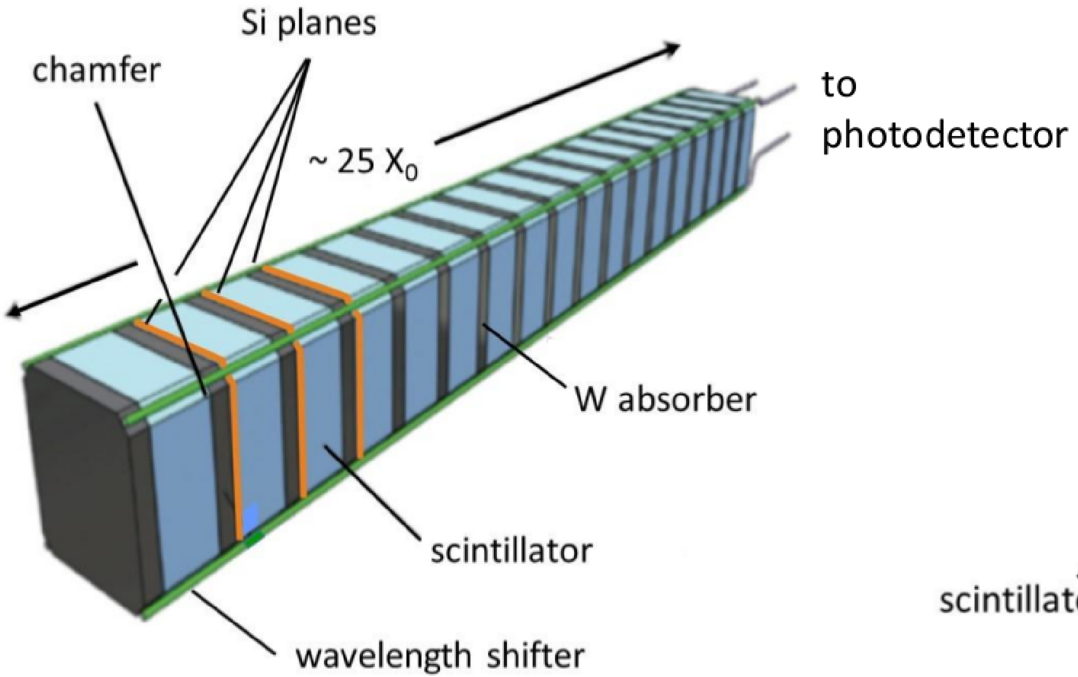


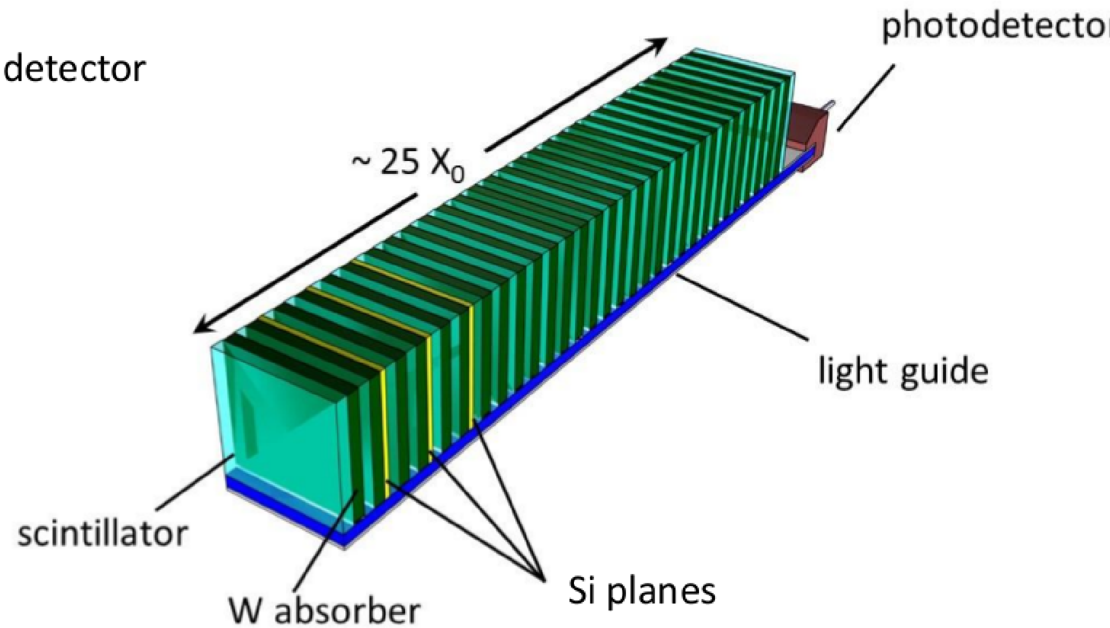
- In term of 1 MeV neutron equivalent fluence, the maximum value which is reached is 1.1×10^{15} cm^{-2}
- But the calculation does not include any safety factor
  - The usual recipe consists in having a x2 factor safety

1 MeV neutron equivalent fluence – 50fb^{-1} @14 TeV









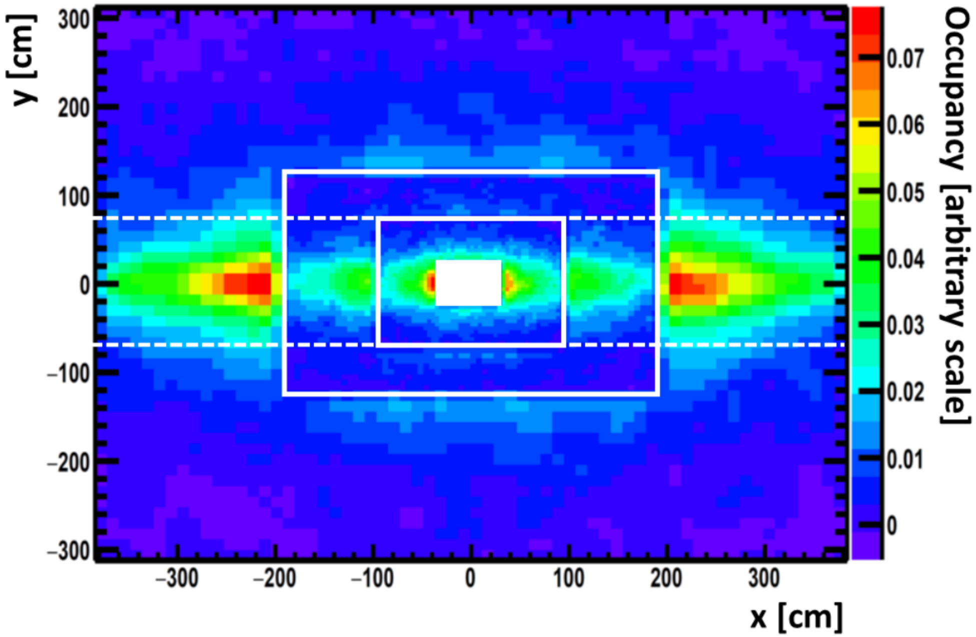
Inspired from CMS R&D

Fibre are replaced by light guides

For mechanical constraints and because of the present module geometry, it would probably be advantageous to have absorber plates of 12x12 cm^2

To be studied further

Overall geometry



- It is difficult to replace the full detector surface, but we could imagine some intermediate solution
  - Replace the inner region with fast-timing and good spatial resolution (Si layers) for the LS3 ?
  - 176 modules would be needed
  - The removed innermost cells which are still in specifications could be re-deployed in the middle region
  - In turn, the middle region modules would replace some outer ones
  - This could be done in higher priority in the horizontal band which is also affected by the magnetic field
    - 50% of the photons from a neutral pion produced by a b-hadron (single π^0 final state) fall into this horizontal band
- Those last steps would require a full dismantling of the calorimeter. Difficult to do during the LS3 ?

Some comments

- The main usage of the HCAL is to give an input to the hardware trigger and the LLT for the upgrade to come
  - HCAL would not be so much needed after for an upgrade phase II
- Can we test a new technology already during LS3 ?
  - The baseline is to replace the innermost cells with spare modules
  - Could we think of using “improved” modules instead ?
- The technology used should be mature regarding
  - The timescale of the project
  - The human ressources that can contribute
- An estimation of the cost should be done early in order to determine the feasibility of the project