Dose in ZDC and consideration for performance and cost

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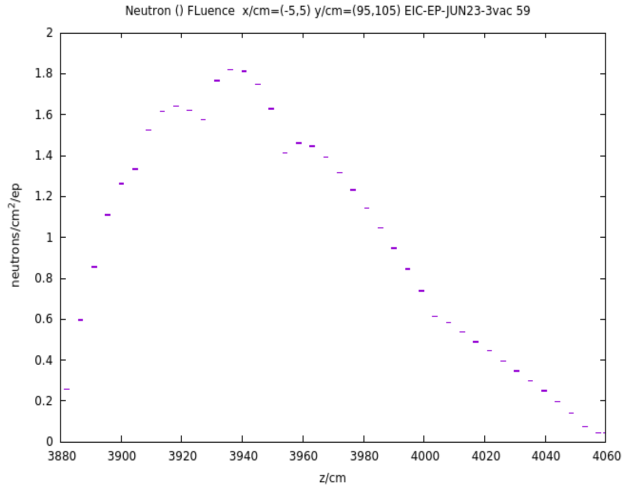
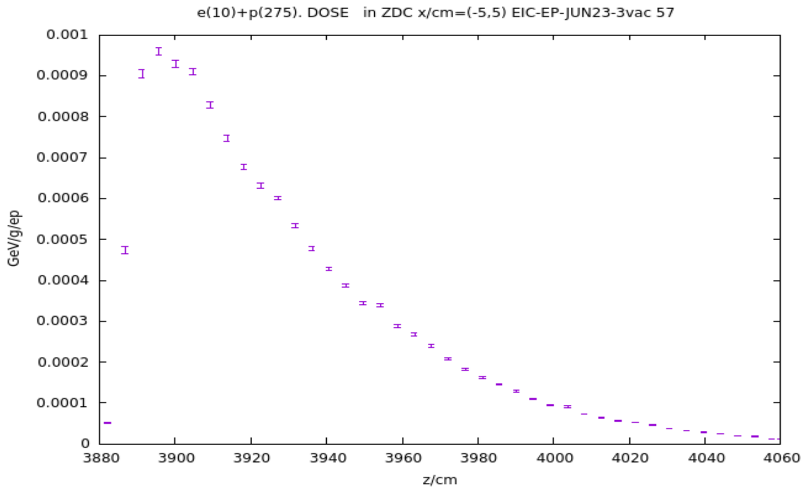
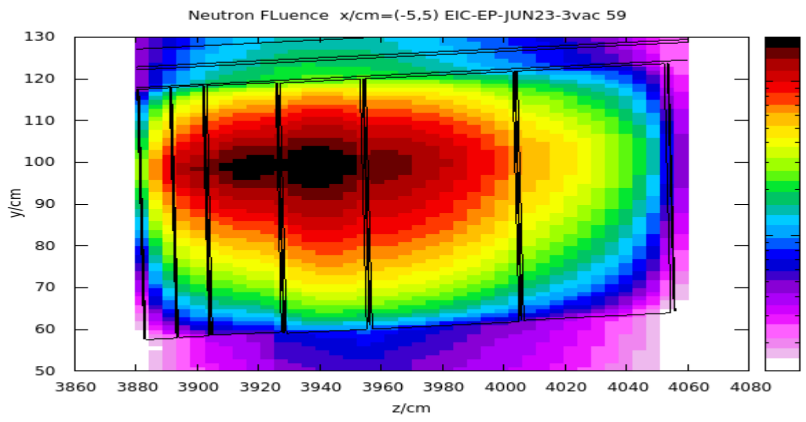
Dose estimation by Vitali

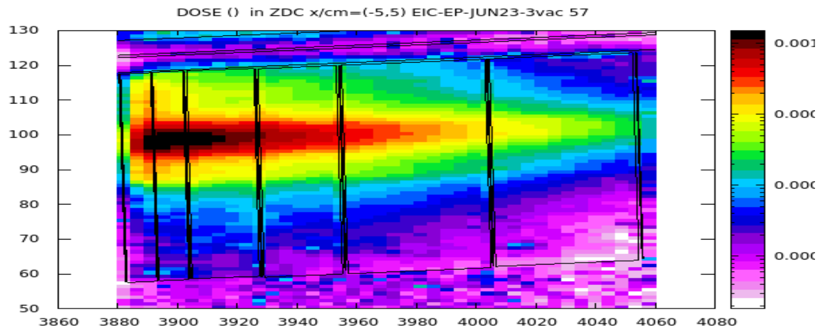
- Thank you so much for sharing the results!!





quite spread all over





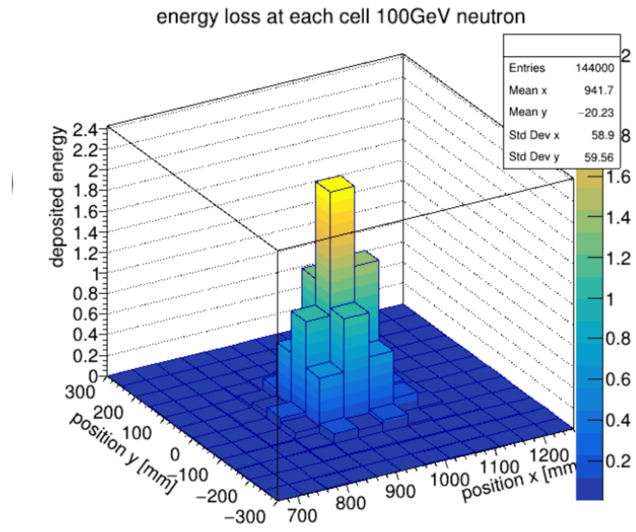
concentrated at zero degree

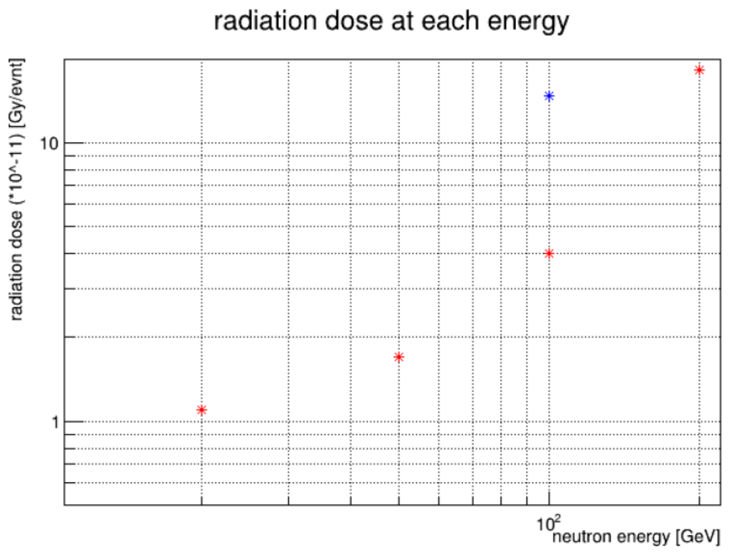
dn/dt =2.E+0[neut/cm^2/ep]*1.E+6[ep/s]=**2. E+6 [neut/cm^2/s]**

dE/dt =1.E-3[GeV/g/ep]*1.E+6[ep/s]=**1. E+3 [GeV/g/s]**

Total ionization dose: comparison with Yuya's study

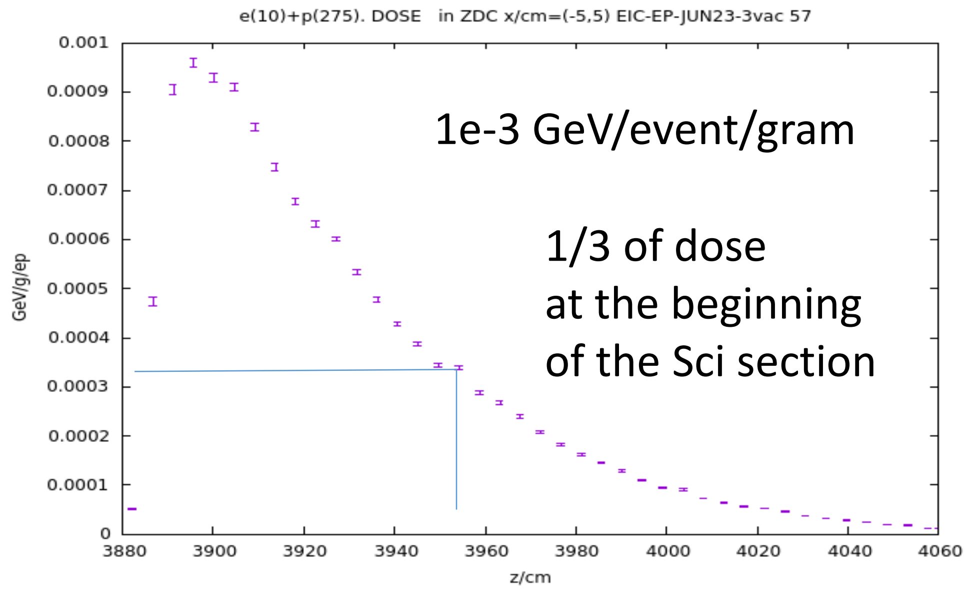
- Yuya's numbers were:
  - He used single neutron,
    not the cocktail of π^0, n, stray charged particles
  - **Maximum dose** with a 200 GeV neutron: 1.5×10^{-10} Gy / event
  - Assuming 10^7 beam gas rate (very pessimistic, like 10^{-7} mbar)
    it corresponds to 15kGy / year
  - If it is scaled to 10^6 ep rate, 1.5 kGy/year
    - assuming that the primary neutron spectrum is similar
    - no consideration for beam gas about the vacuum profile:
      assuming things coming from near the interaction point

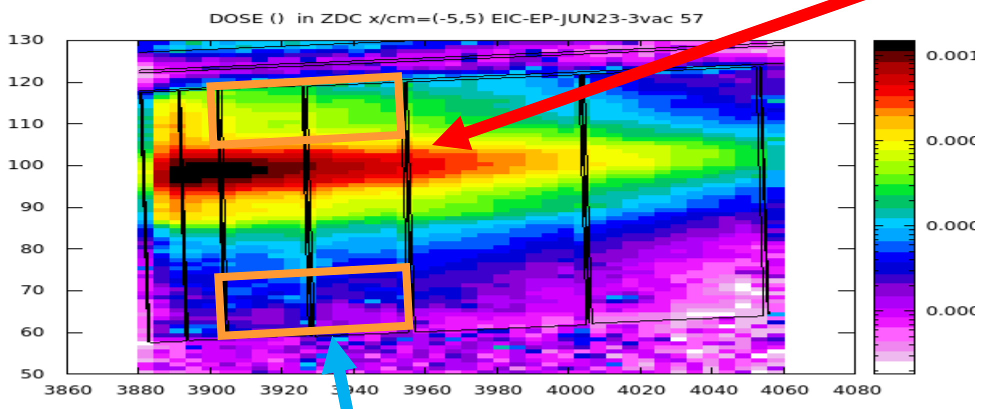




Vitali's number for ep(10×275)

- 1.0×10^{6} eV/g/event $= 1.6 \times 10^{-10}$ Gy/event
  - Yuya's number was 1.5×10^{-10} Gy/event
    They agree, what a coincidence!
- beam gas is negligible, at least for stable operation at 10^{-9} mbar
- **At the beginning of the Pb/Sci section:**
  The dose would be about 1.5 kGy/year,
  OR it is **0.5kGy/year**
  - OR 0.18 Gy / hour
- You see the dose is quite concentrated in the center
  - Perhaps we could use scintillators
    for area behind the aperture obstacles
    - e.g. outer 10cm of the W/Si or Pb/Si section





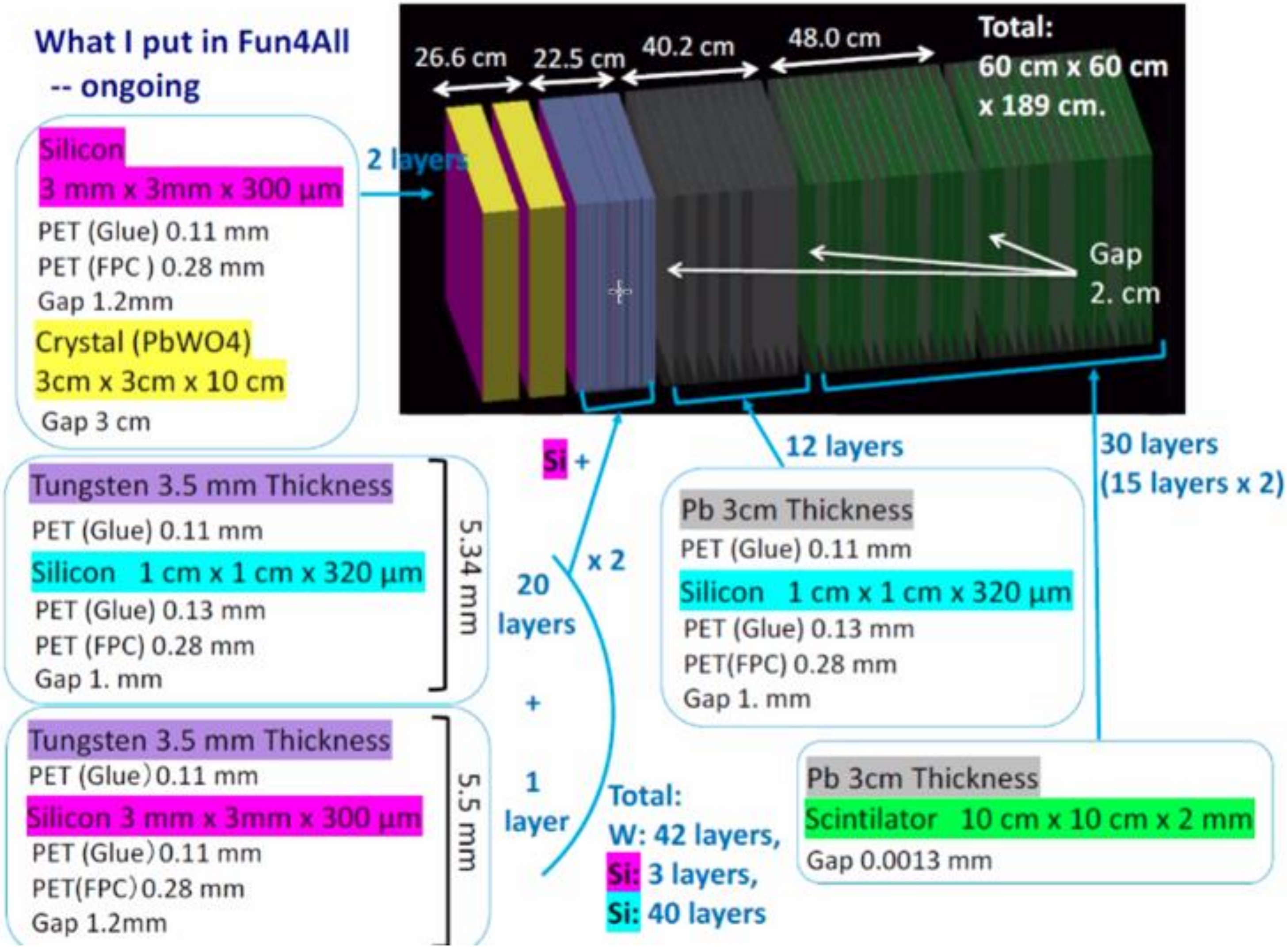
Highest spot in Pb/Sci section 0.5 kGy per year

not much EM deposit: Sci enough?

$$dE/dt = 1.E\text{-}3[\mathrm{GeV/g/ep}]*1.E{+}6[\mathrm{ep/s}] = \mathbf{1.\ E{+}3\ [GeV/g/s]}$$

The structure in FUN4ALL

- Shima's first implementation
- Shima's first study shows that one layer of crystal is perhaps enough



Scintillator dose rate and maximum dose

from CMS HGCAL TDR

- Dose constant: the dose with 1/e light yield
  - strongly depending on dose rate per unit time
  - slow dose gives more damage
- EIC ZDC:
  - 0.18 Gy / hr = 0.018 krad / hr
  - 5 kGy for 10 years
- The radiation rate is quite optimum
  - we should accept 1/e light yield after 10 years

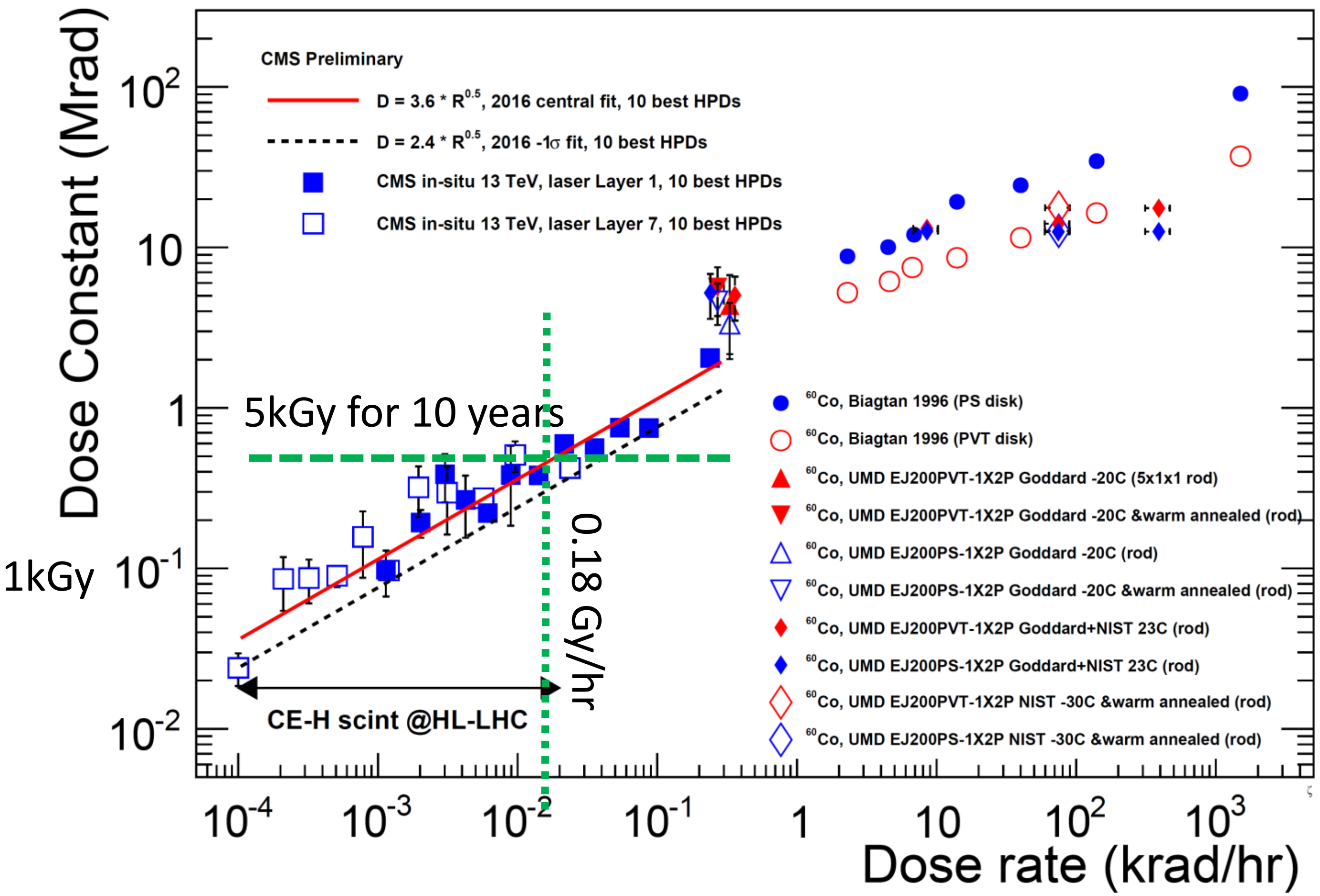


Figure 2.10: Dose constant, D_c, versus dose rate, R, for both in situ measurements from CMS (boxes) and dedicated studies. Lines corresponding to $D_c = 3.6 \times R^{0.5}$, and $D_c = 2.4 \times R^{0.5}$ are shown. The in situ measurements refer to SCSN81, a PS based scintillator used in the endcaps of the present detector.

Reading light from plastic scintillator tiles + signal routing

- Shashlik or side readout by WLS fibers/plates would be difficult
  - WLS material is usually less rad-hard
  - Shashlik may still be an option since we can read light with small PMTs from behind
- Ideally we may like to use SiPM + scintillator tiles like for CALICE or HGCAL
  - easy cable routing (two low-voltage lines only)
  - need to see if it works for e.g. 5x5 cm tiles
    - 2mm thick may be difficult, may need 5mm or even more
    - Pb:Sci ~= 5:1 would give good e/h value
  - SiPM may work for $10^{14}\ n_{eq}$: https://arxiv.org/pdf/2106.12344.pdf

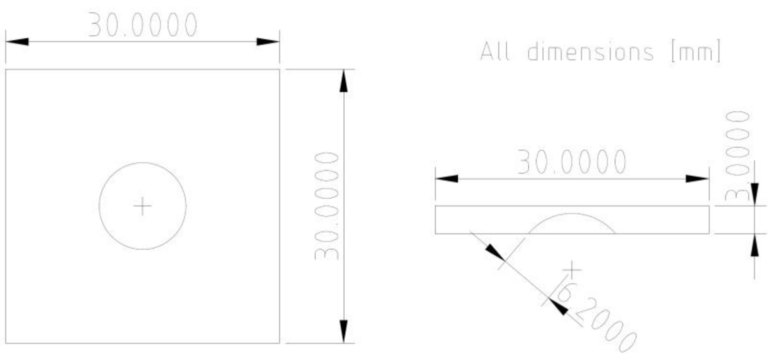


Figure 2.11: Parameter drawing of typical square tiles developed by the CALICE Collaboration. Tiles for the CMS endcap calorimeter will be ring-sections rather than squares due to the geometry of the endcap.

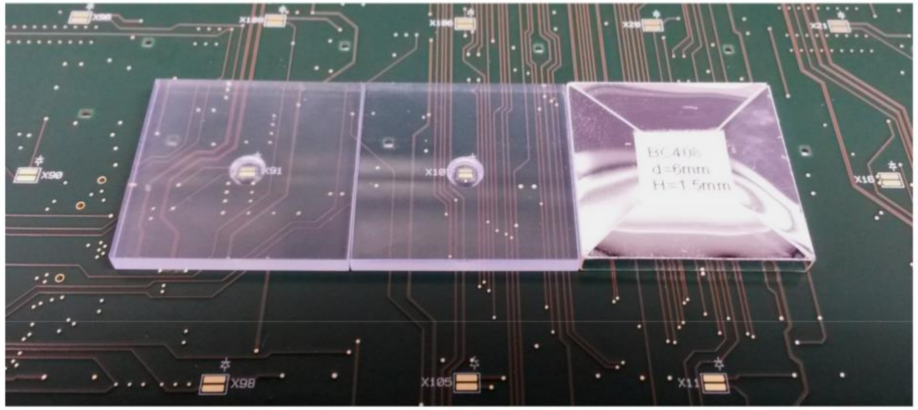


Figure 2.12: Example of three CALICE $3 \times 3\,\mathrm{cm}^2$ scintillator tiles mounted on a PCB that holds one SiPM per tile. The left two scintillators are unwrapped to show the SiPM within the small dome at the centre of the tile, while right-most tile is wrapped with reflective foil.

ハドロンカロリメーター (Pb+Sci) 部の中性子試験

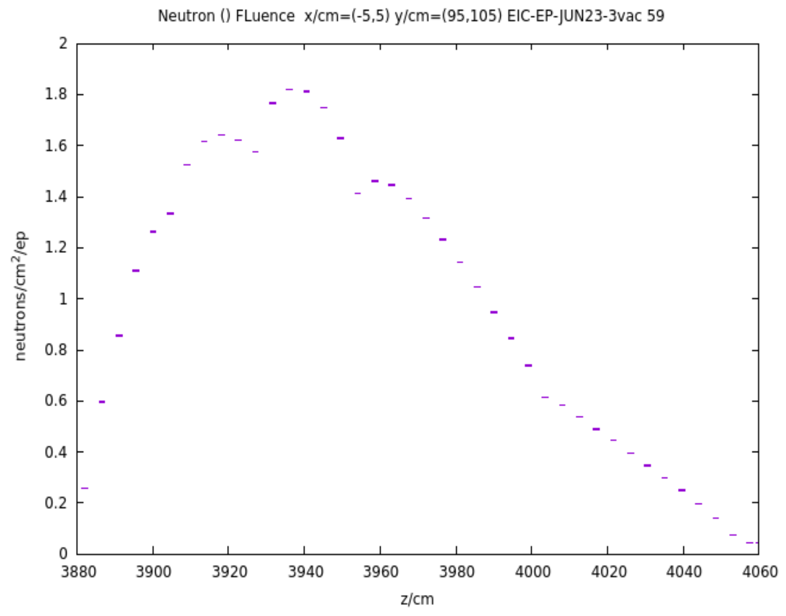
- プラスチック自体 (TID) は大丈夫そう (p6)
- WLS を使うとすれば，その耐性 (TID) は若干気になる
  - 横から WLS 板で読み出し – ビーム付近からの何者かでやられるかも
  - Shashlik は少し安全か (後方から小型 PMT で読み出し)
- SiPM はなかなか厳しい
  - STAR のテスト: 10^{10} 1MeV n_{eq} で dark current が 10^4 倍, 10uA に (HPK 12572-015P)
    - 13360, 14160 シリーズははるかにノイズ少ない
      テストする価値はあるかも
  - ハンブルク大のテスト: KETEK
    https://doi.org/10.1016/j.nima.2017.11.003
    - 5e14 neq で 10nA くらい (???)，テストする価値あるかも

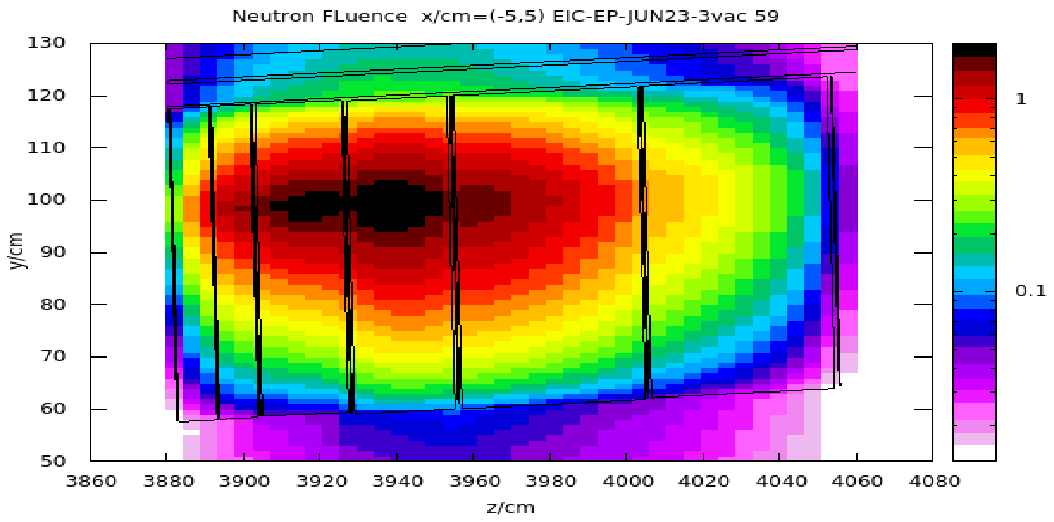
クリスタル部の材質

- EM section の一番多いところ: 2.5kGy/year
  - 10年で 25kGy or 2.5Mrad
- Glass scintillator is OK for 10kGy
  - 安いらしい
  - ひょっとしたらいけるかも
  - 速い検出器の併用は, いずれにせよ必要
全部を置き換えられるわけではない

Neutron yield and Si sensor tolerance

- 2.0×10^{6} neutron/cm²/s
  = $2.0 \times 10^{14}\ n/\mathrm{cm}^2$ for 10 years
  - Assuming that # of neutrons is not very different from # of 1MeV neutron equivalent
  - OK for conventional p-type sensors
  - we should be prepared to apply > 1000 V for bias



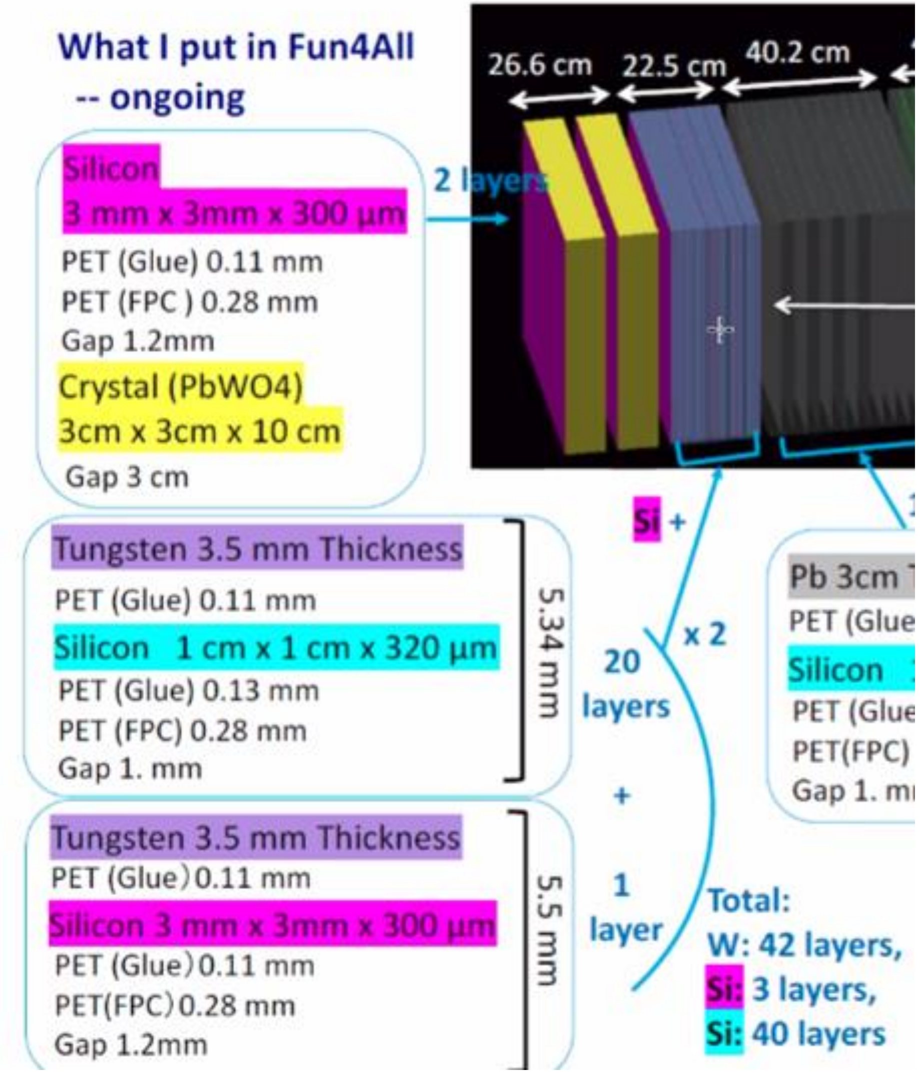


dn/dt =2.E+0[neut/cm²/ep]*1.E+6[ep/s]=**2. E+6 [neut/cm²/s]**

Fine-grid sensors: where do we need them?

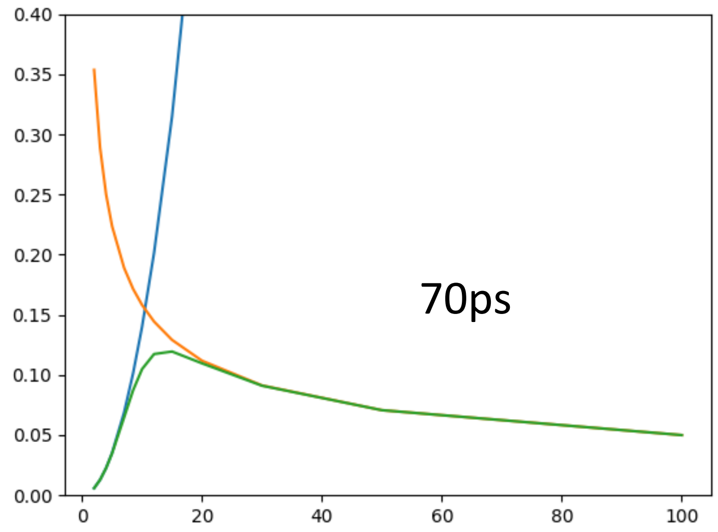
- 3mm x 3mm planned
- 3 layers in front, middle and end of the crystal layers
- We likely move to one crystal layer only
  - the third layer perhaps in the W+Si part
  - maybe at the end of the W+Si section, since this would give chance for neutron to give a signal

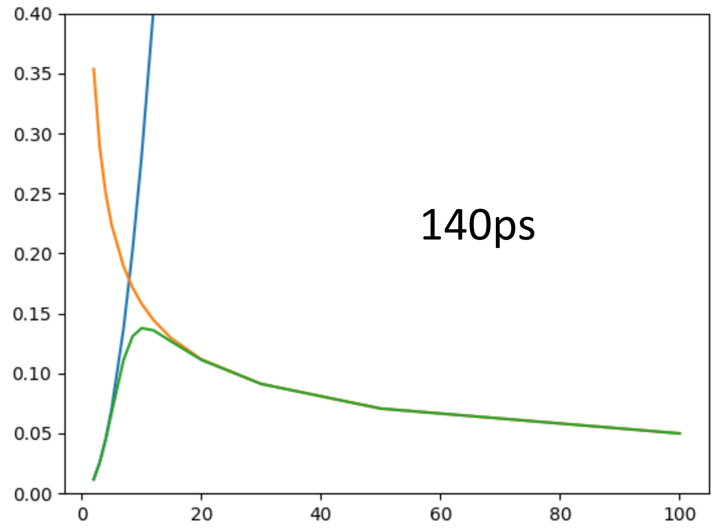
- Do we really need 3mm sensors for position?
  - Neutron needs ~0.5cm (0.15mrad) resolution only
  - Photon: we may like 1mm
    maybe even with the 1cm sensor + some weighting?



Neutron timing through silicon sensors

- 70ps measurement of timing would give big improvement for neutrons below 15 GeV thru ToF
- Dedicated Si sensor (e.g. LGAD)?
  - 35-70 ps according to ATLAS HGTD: 70ps is after irradiation
  - give signal to mip (avalanche gain: 20): good for neutrons
  - 1.3mm sensor: too fine for us
    - bigger sensors: worse timing due to capacitance
  - four layers for HGTD to measure mip at high efficiency
    - we perhaps do not high efficiency since anyhow not all the neutrons interact before the W+Si section
- Or, timing also via normal pad sensors with big signals?
  - 300um sensor with S/N > 30 (~ 10 mip) would give similarly good timing, in principle, according to CMS
  - Does it work for neutrons? Only a few MIPs, too small S/N in Si sensors?





Summary

- Plastic scintillators can be used for many part of the ZDC
  - light yield may be 1/e after 10 years, but would not completely degrade
  - light routing may be an issue: we may like to use SiPMs
  - need good SiPMs for NIEL if we go for CALICE-type readout

- Si sensors and readout chip also quite critical (> $10^{14} n_{eq}$) for radiation
- Could we reduce number of pads for cost?

- Neutron timing measurement would give ToF momentum measurement
  - good for resolution below 15 GeV, also good for calibrating calorimetry at low energy
  - may be useful also to remove stray particles when detecting 300 MeV photons