AWAKE: D2E for Alexey beam properties

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DGS/RP

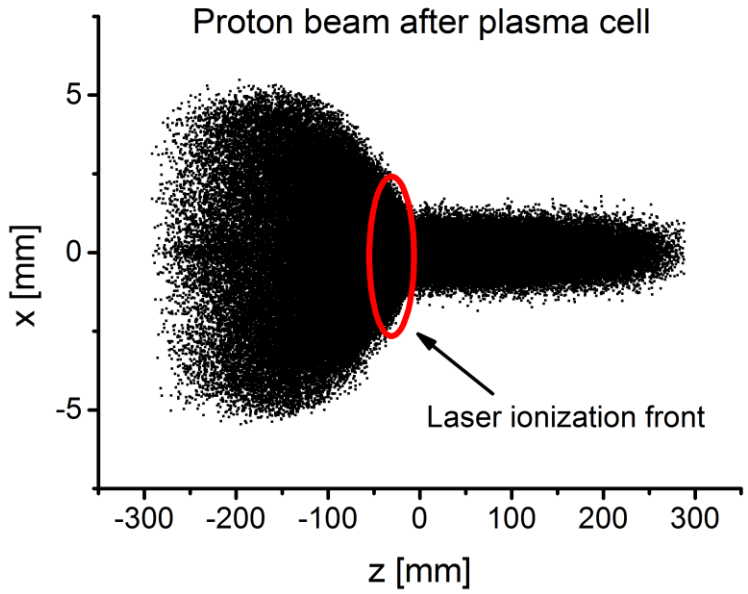
Outline:

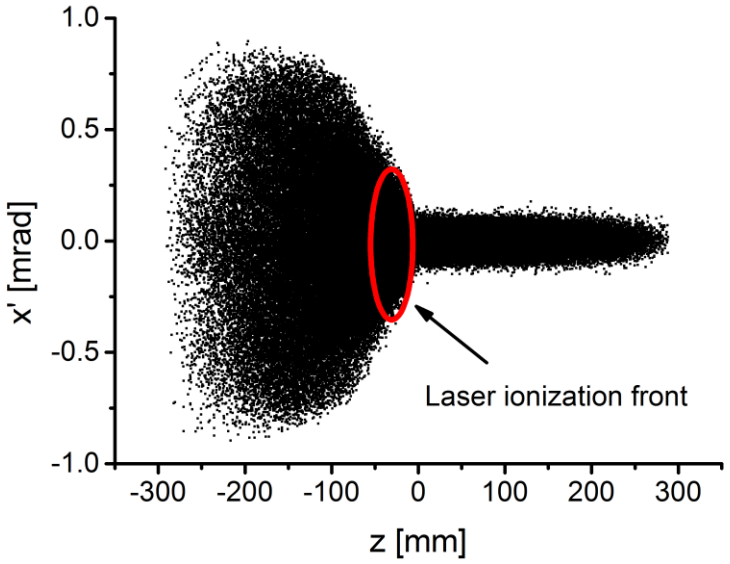
- Alexey's simulations output
- Preliminary D2E results for different scenarios:
  - 3 mm radius 6 m long steel cylinder
  - 10 mm radius 6 m long steel cylinder
  - 10 mm radius 9 m long steel cylinder
  - 15 mm radius 9 m long steel cylinder
  - 4 cm diameter new plasma cell
    - 3 mm radius 6 m long steel cylinder
    - 10 mm radius 6 m long steel cylinder
    - 15 mm radius 6 m long steel cylinder
- Alexey's simulations output for compressed beam

Alexey's simulations output

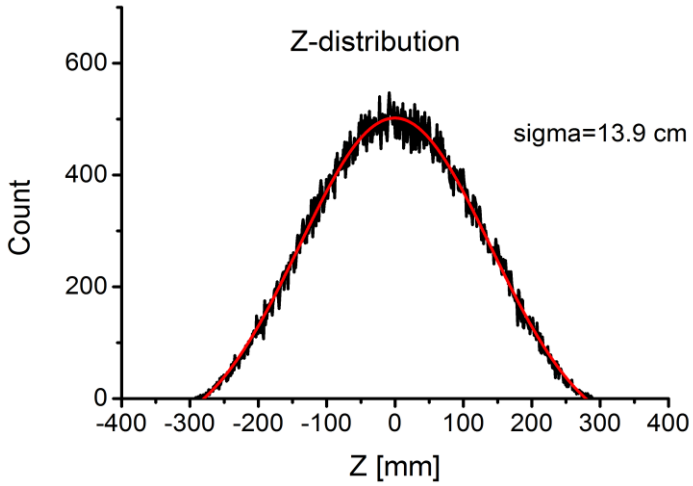
- Proton beam in plasma undergoes SMI->increasing in beam divergence

Alexey's data

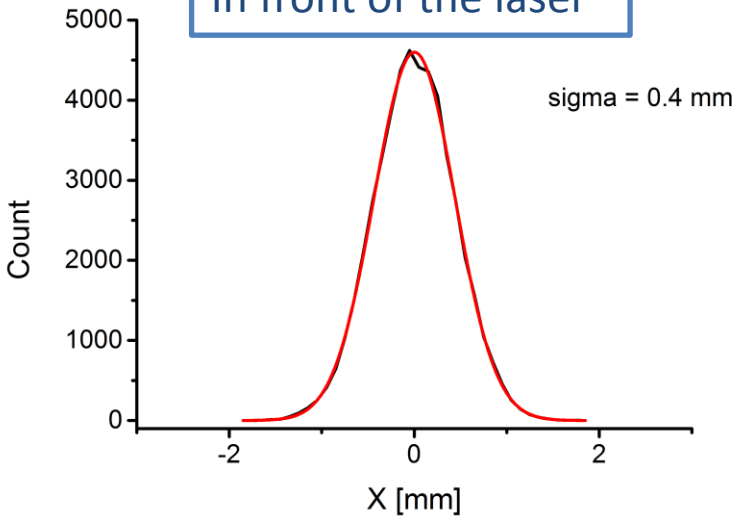




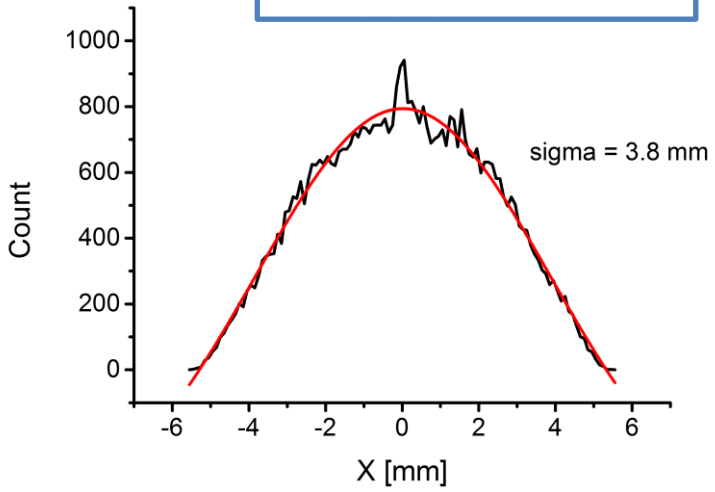
Alexey's simulations output



In front of the laser

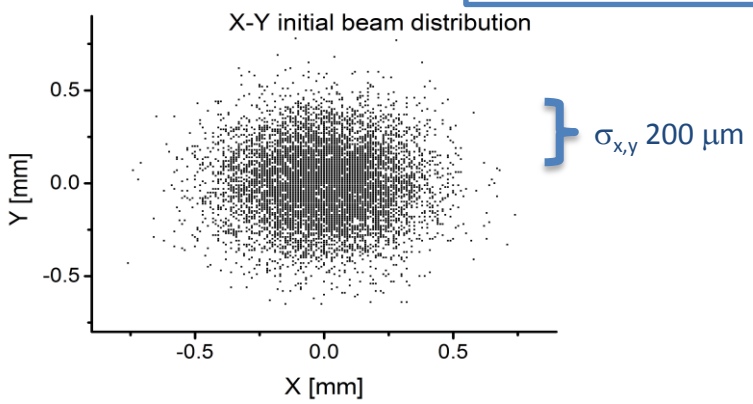


Behind the laser

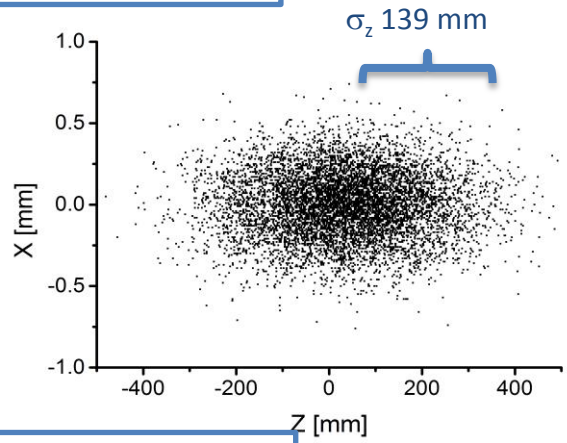


FLUKA implementation

Initial spatial distribution

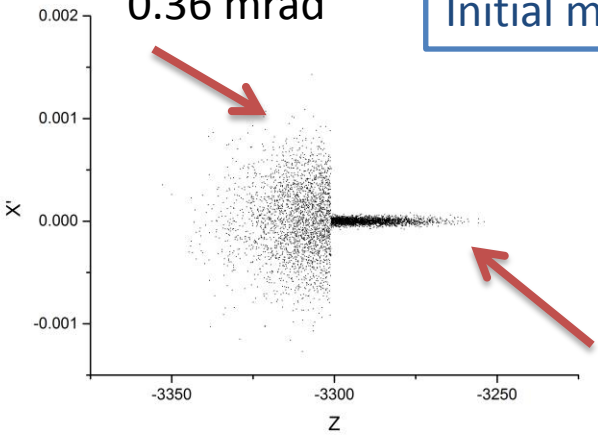


$\sigma_{x,y}$ 200 μm



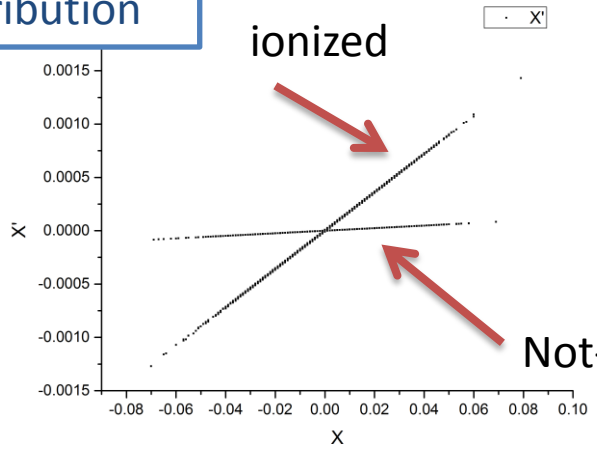
σ_z 139 mm

Initial momentum distribution



0.36 mrad

0.024 mrad

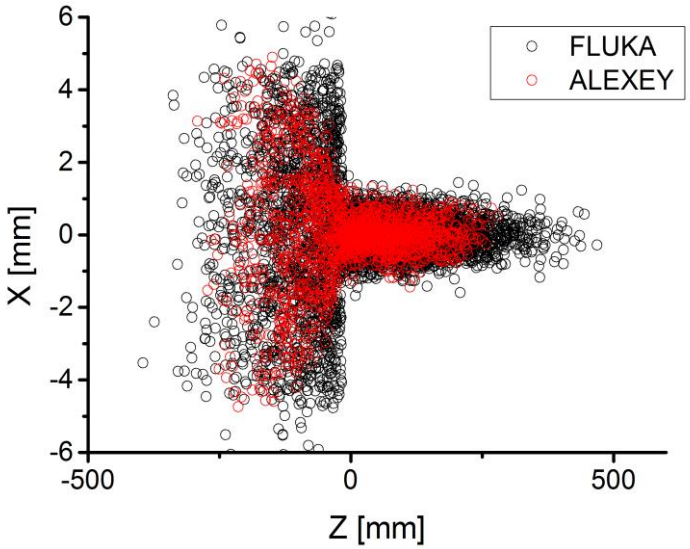


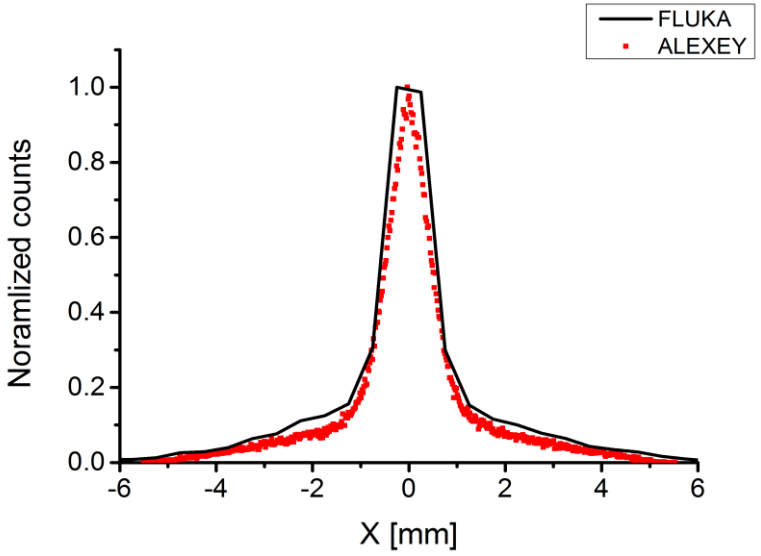
ionized

Not-ionized

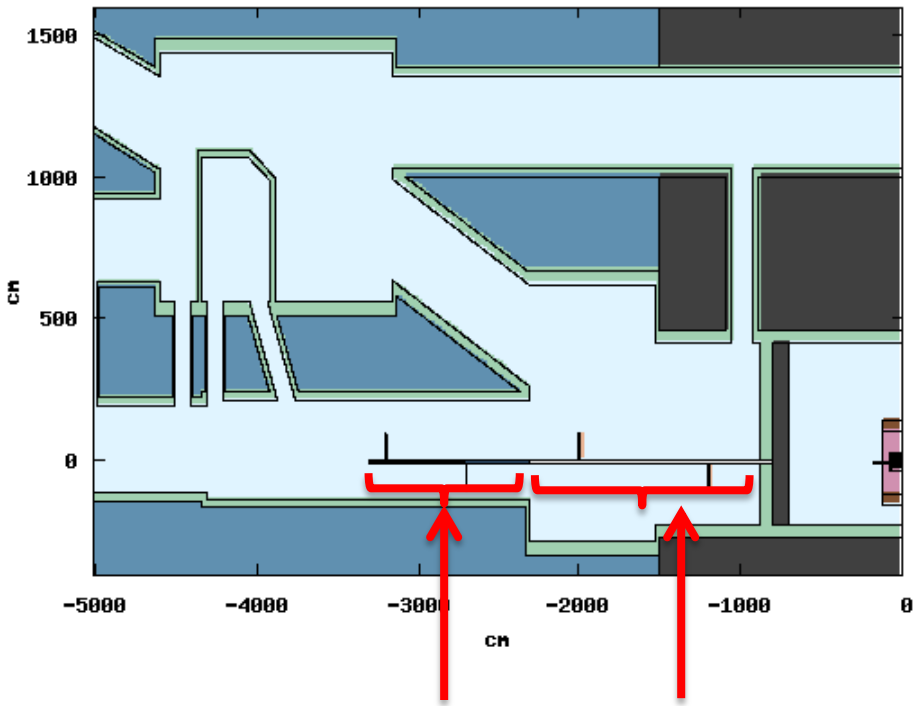
Alexey-FLUKA Comparison

- Proton distribution after plasma cell





FLUKA simulations

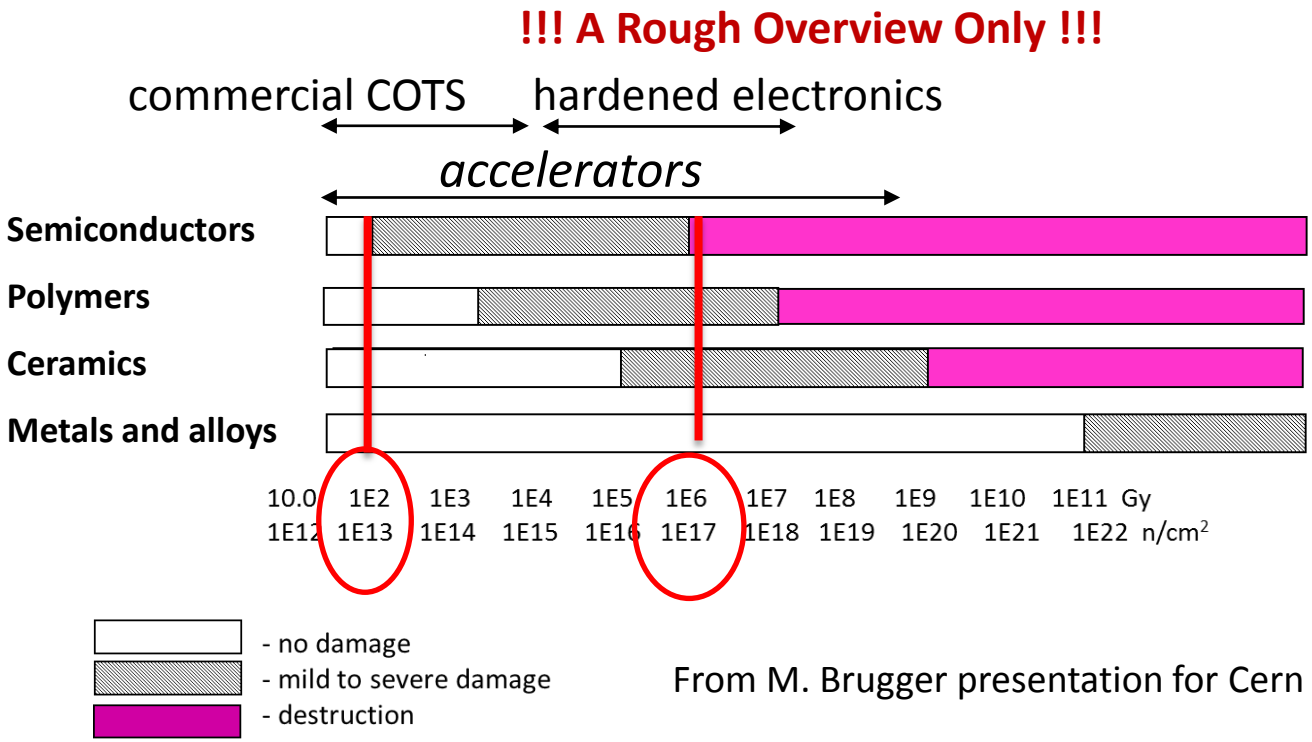


- Protons : 400 GeV, 0.3 % E-spread
- Valve ‘opened’
- Plasma cell
  - 10 m long
  - 10 cm Ø
  - Rb vapor (10^{15} cm^{-3} ->$1.4x10^{-7}$ g/cm^3)

- Metal shielding 2 mm think:
  - 3 mm radius steel 6 m long
  - 10 mm radius steel 6 m long
  - 10 mm radius steel 9 m long
  - 15 mm radius steel 9 m long

R2E recommendation

- Cumulative damage



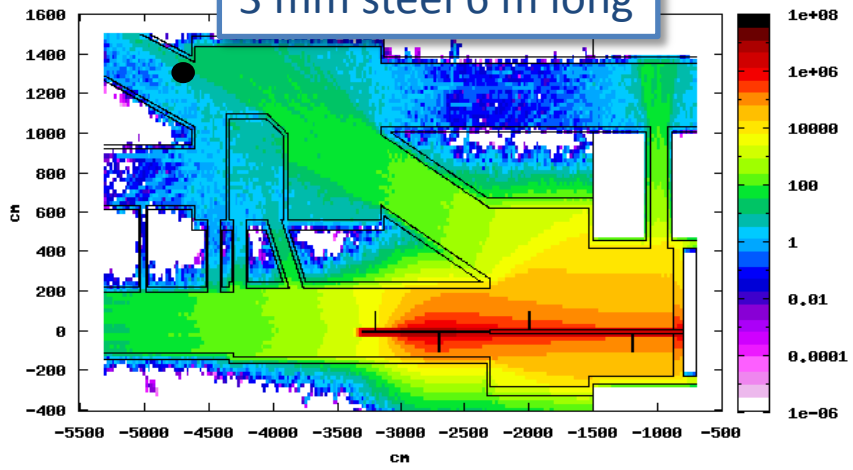
From M. Brugger presentation for Cern Fluka user meeting 2008

- Stochastic damage
  - From M. Brugger 'Radiation Damage to electronics at the LHC', IPAC2012:
    - Commercial equipment: ~10^7 HEH/cm^2/year

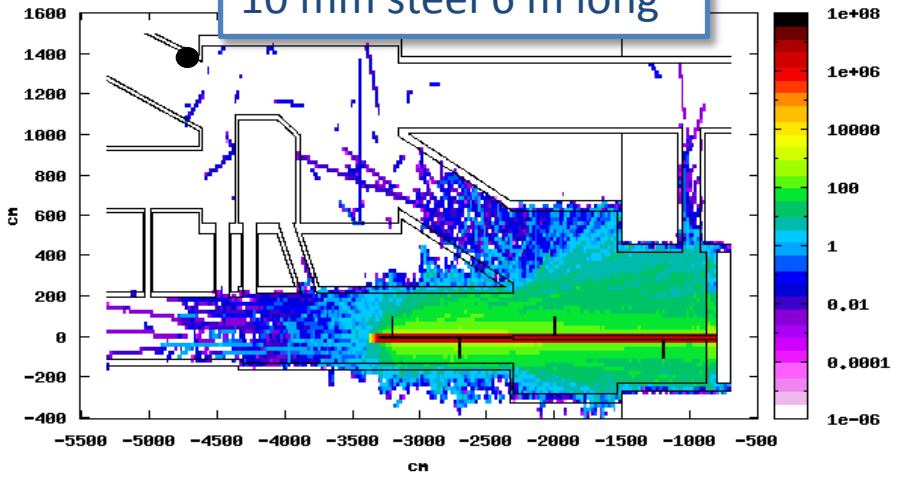
Dose equivalent

μSv/ bunch

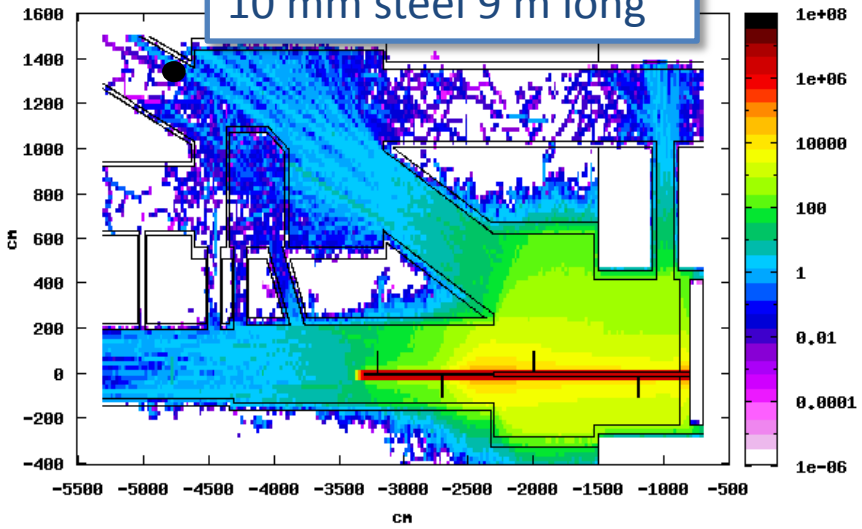
3 mm steel 6 m long



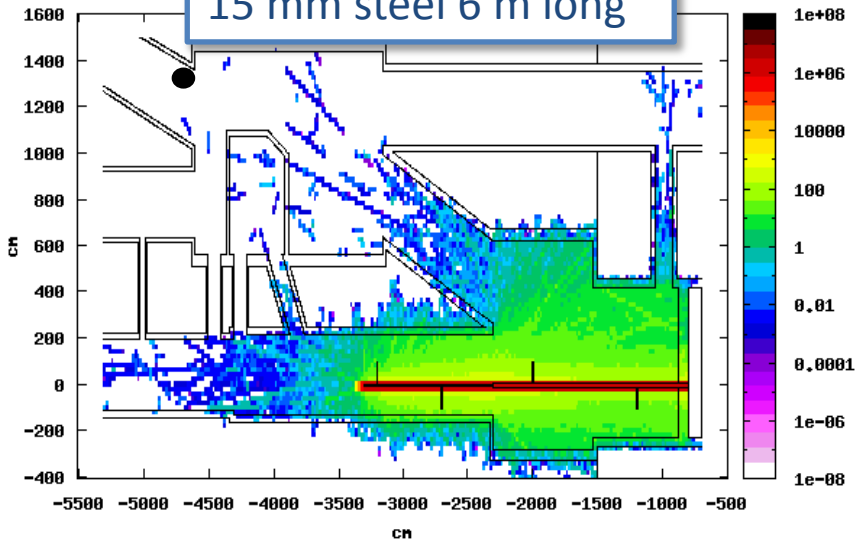
10 mm steel 6 m long



10 mm steel 9 m long



15 mm steel 6 m long



Dose equivalent

shielding	pSv/p+	error	μSv/h
3 mm-6m	3.2e-5	29%	1.15e+03
10 mm-6m	-.-	-.-	-.-
10 mm-9m	3.6e-6	58%	1.3e+02
15 mm-9m	-.-	-.-	-.-

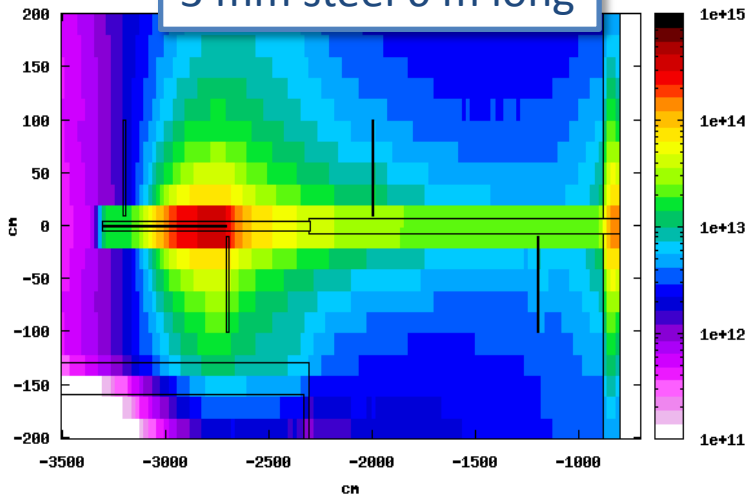
>> 15 μSv/h

High error, proper evaluation needs biasing:
just order of magnitude

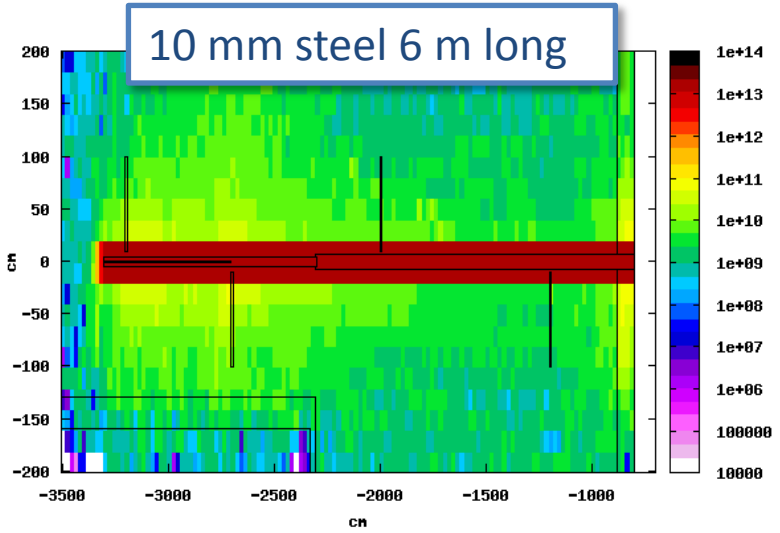
1 MeV neutron equivalent per year

"SAFE" limit: 10^{13} n/cm^2

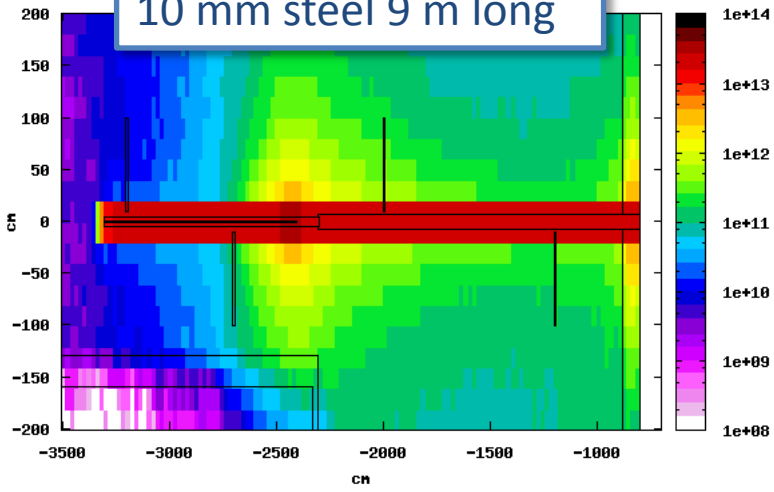
3 mm steel 6 m long



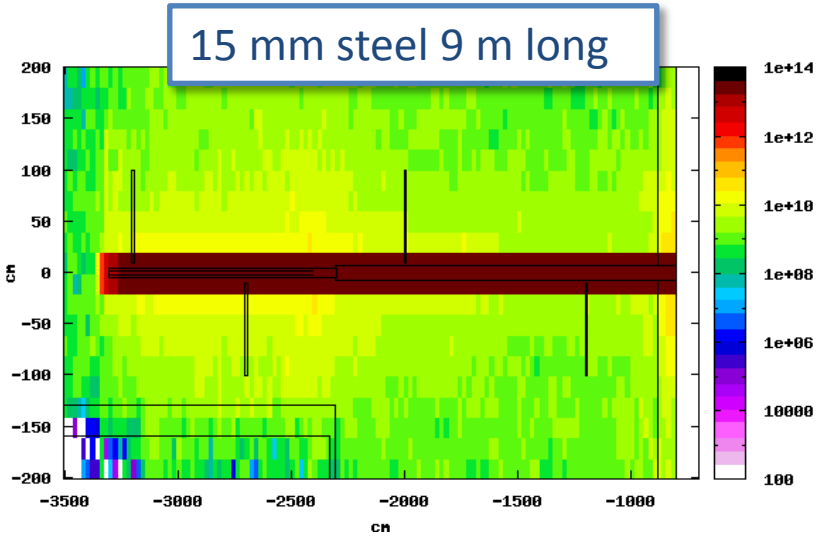
10 mm steel 6 m long



10 mm steel 9 m long

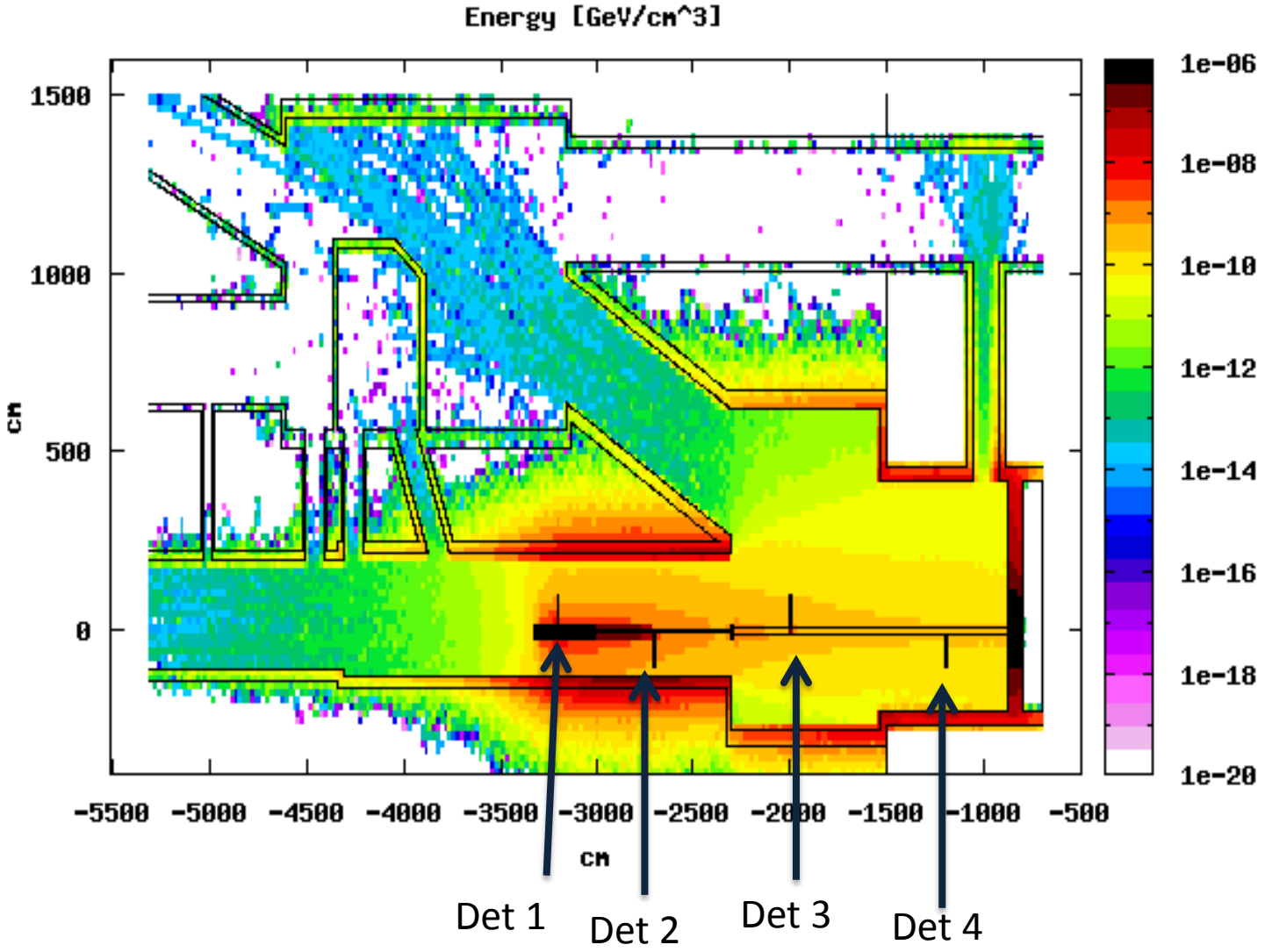


15 mm steel 9 m long



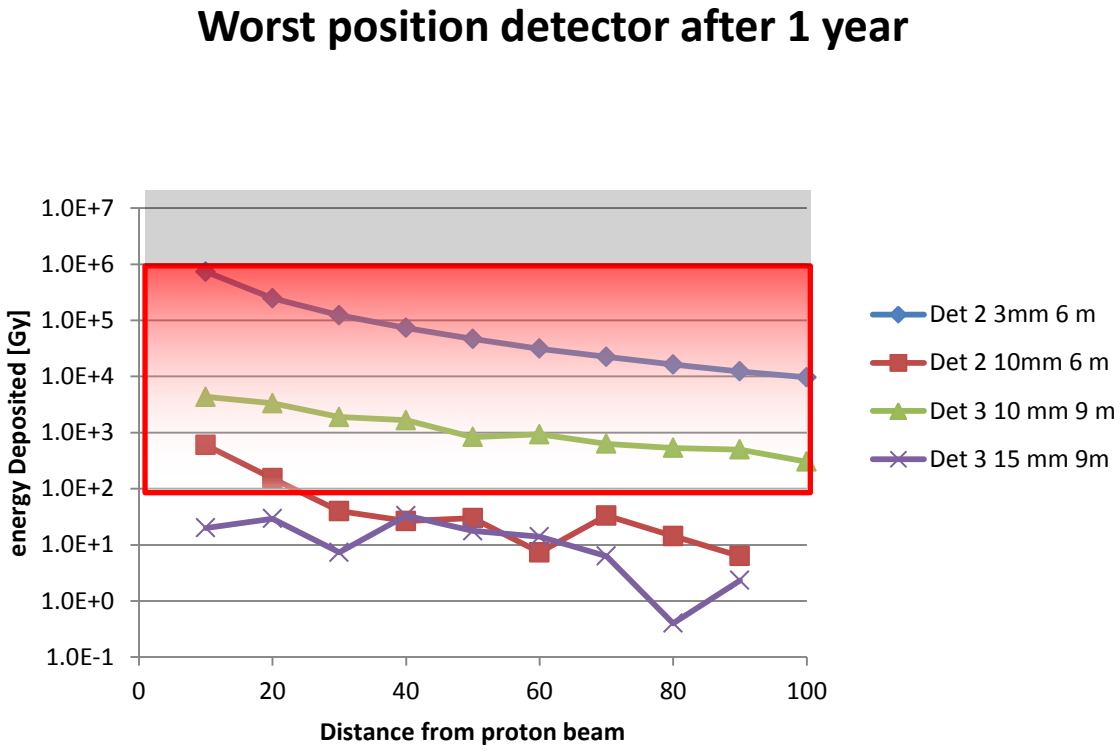
Energy deposition

10^2 -10^6 GeV: from mild to severe damage (semiconductor)



Energy deposition per year

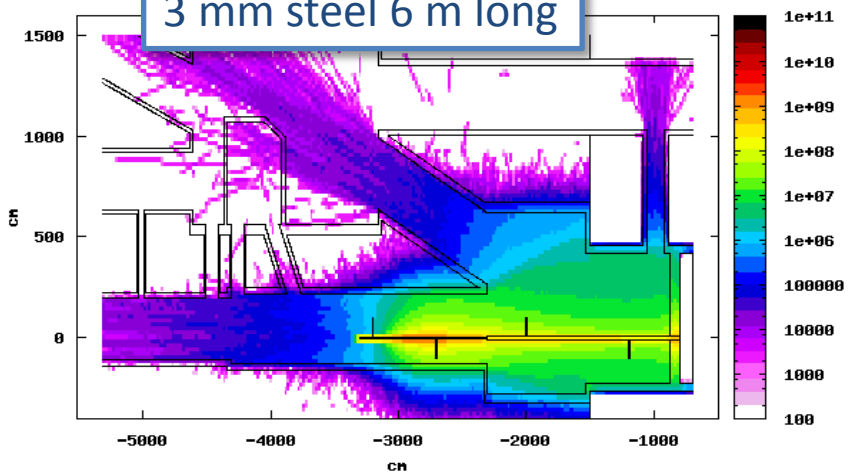
10^2 -10^6 GeV: from mild to severe damage (semiconductor)



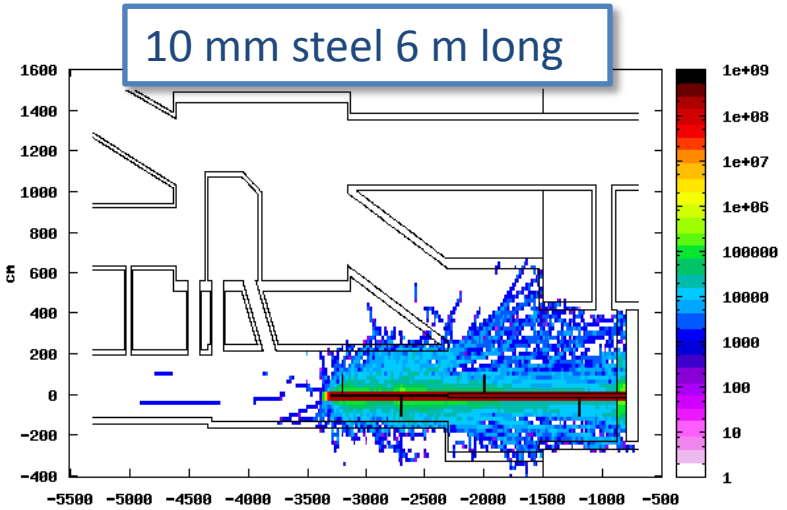
HEH Fluence per bunch

"SAFE" limit: 10^7 HEH/cm^2 /year

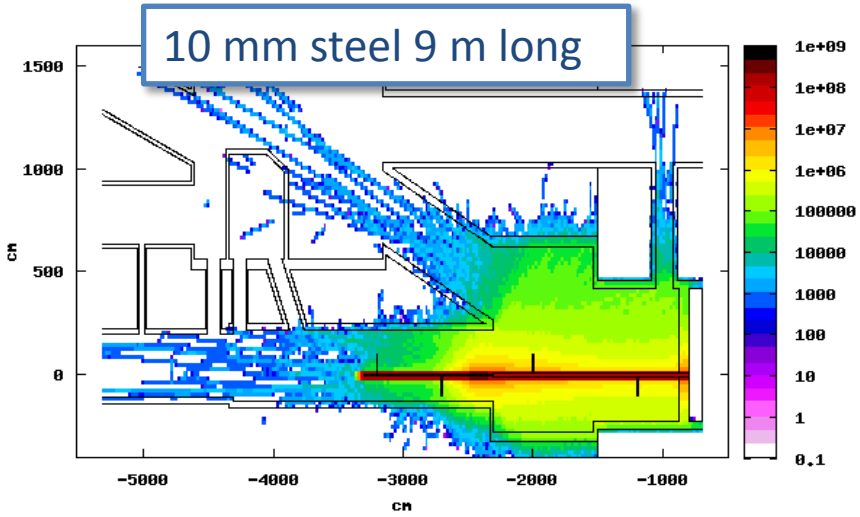
3 mm steel 6 m long



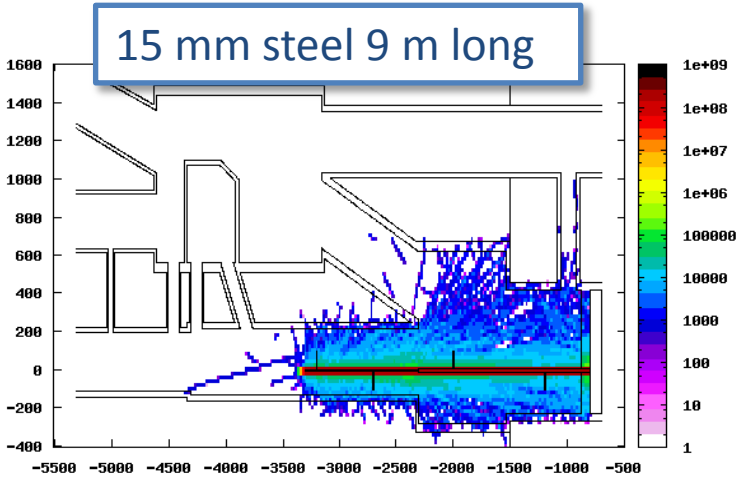
10 mm steel 6 m long



10 mm steel 9 m long



15 mm steel 9 m long



HEH Fluence per year

"SAFE" limit: 10^7 HEH/cm^2 /year

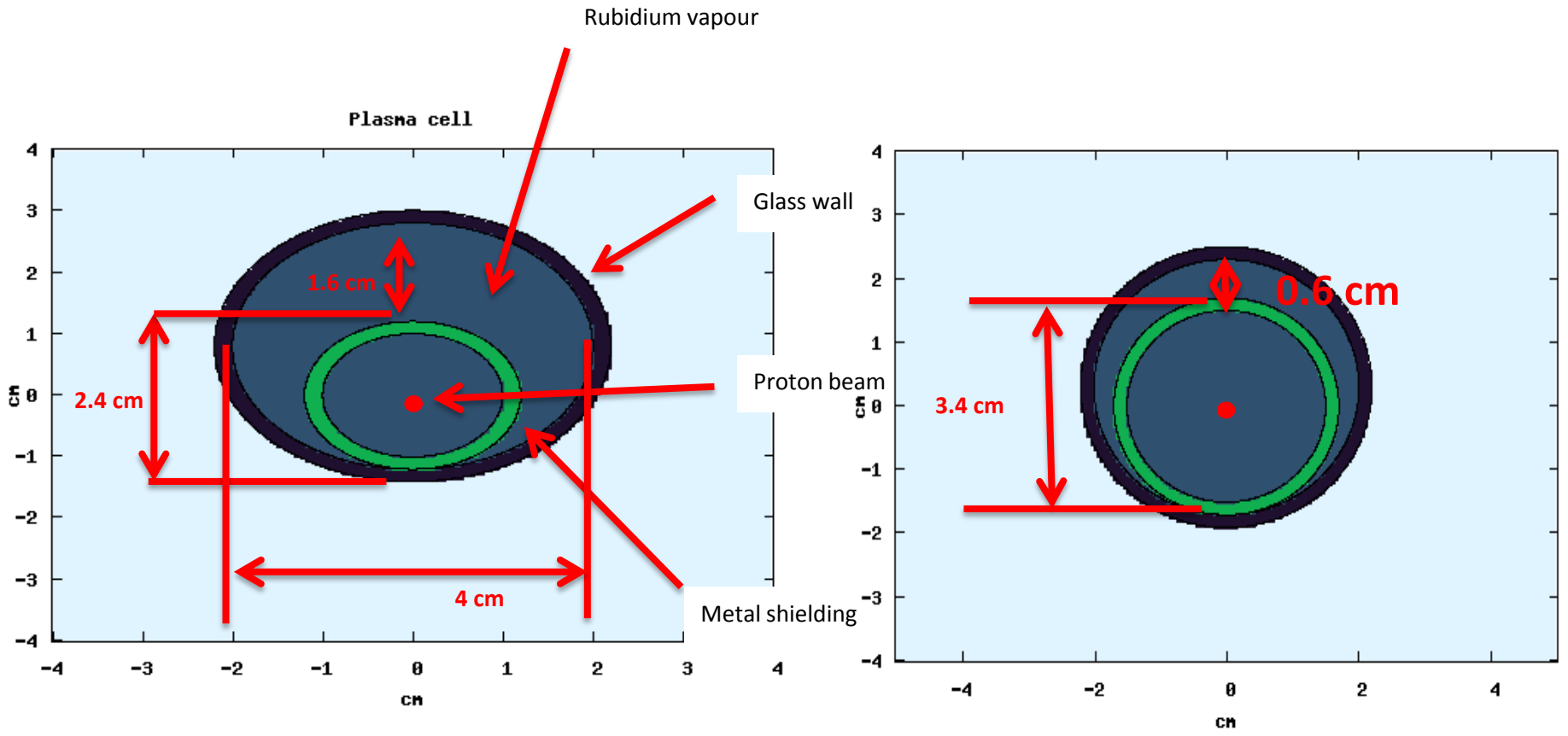
Values at the end of metal shielding 20 cm from proton axis

shielding	cm^{-2}/p+	cm^{-2}/year
3 mm – 6m	9.40E-04	4.55E+13
10 mm – 6m	5.00E-07	2.42E+10
10 mm – 9m	2.90E-05	1.40E+12
15 mm – 9m	2.80E-07	1.35E+10

The value of the HEH flux is still 3 order of magnitude higher that recommended around plasma cell

New Plasma cell implementation

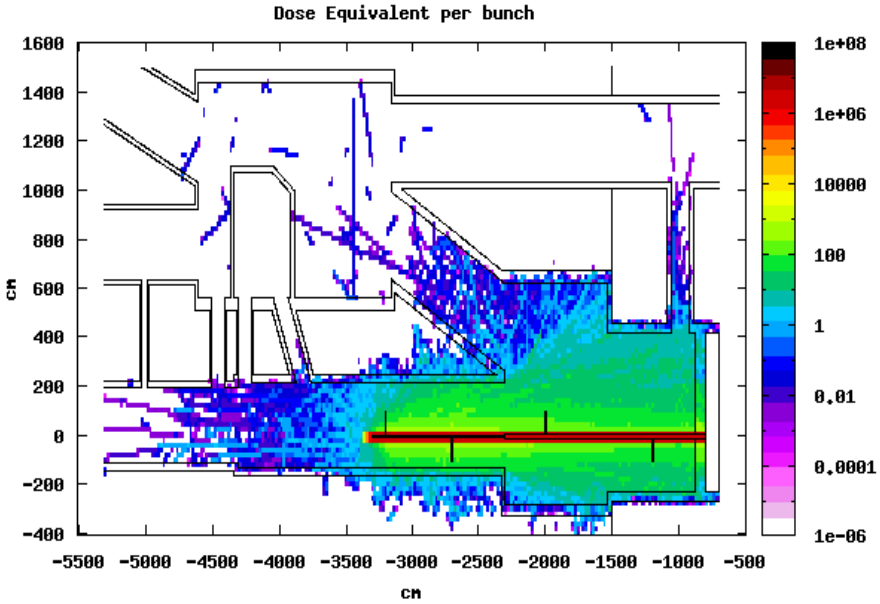
- New plasma cell 4 cm diameter
- Metal shielding 6 m long different radii
- 2 m vacuum pipe before the plasma cell (in previous simulations air)
- Electron beam big at the entrance of the plasma cell (still optimizing)



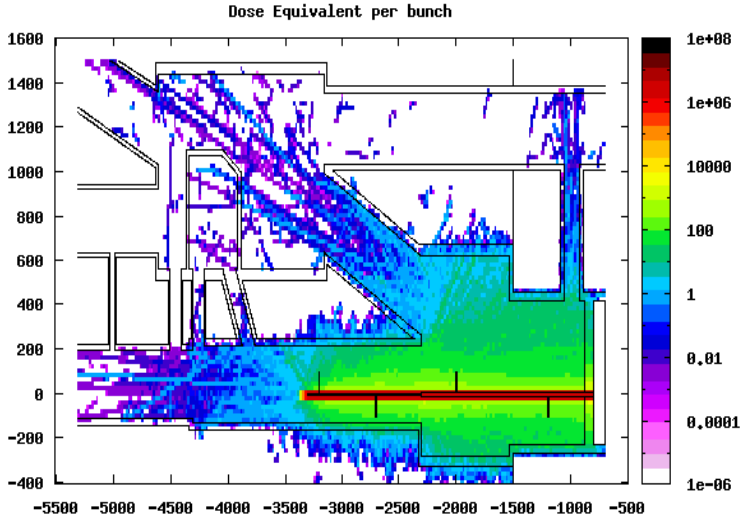
New Plasma cell implementation

10 mm shielding radius

10 cm diameter

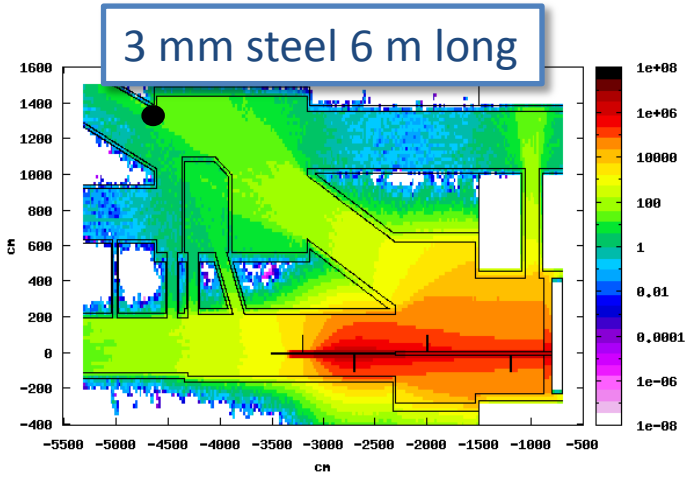


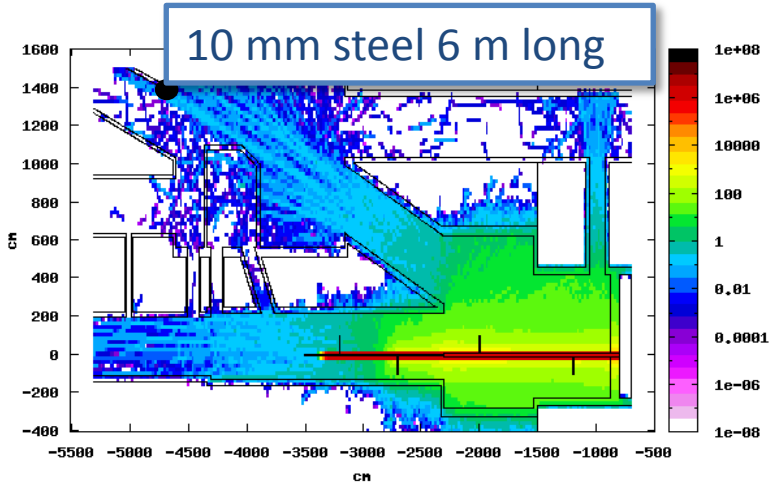
4 cm diameter 2 mm glass wall

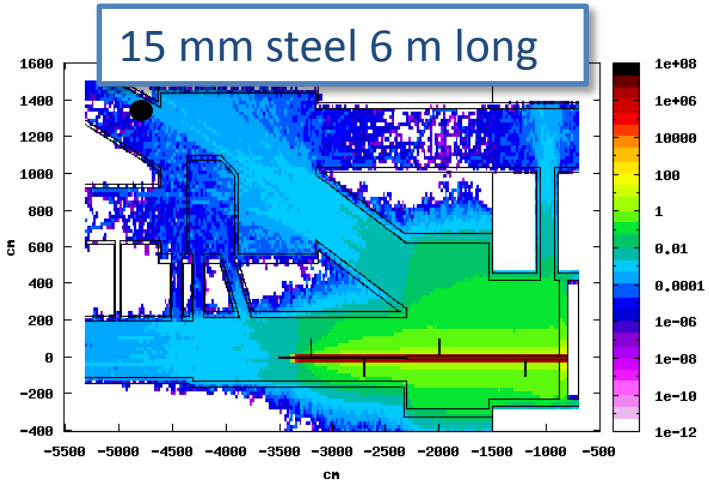


The smaller size of the plasma cell and the presence of the plasma cell wall change the dose deposition profile downstream

New Plasma cell: dose equivalent





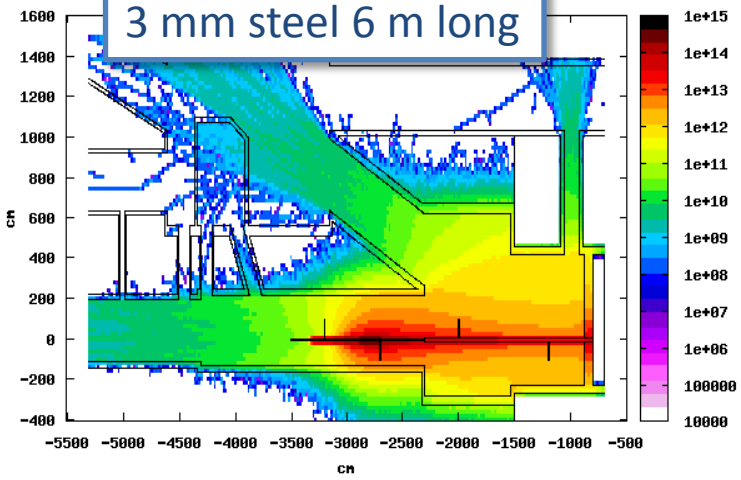


Shielding radius [mm]	Shielding length [m]	Dose equivalent [pSv/p+]	Dose equivalent [µSv/h]	error
3	6	4.1e-5	1.5e3	18%
10	6	2.1e-7	7.56	70%
15	6	6.9e-10	2.45e-2	39%

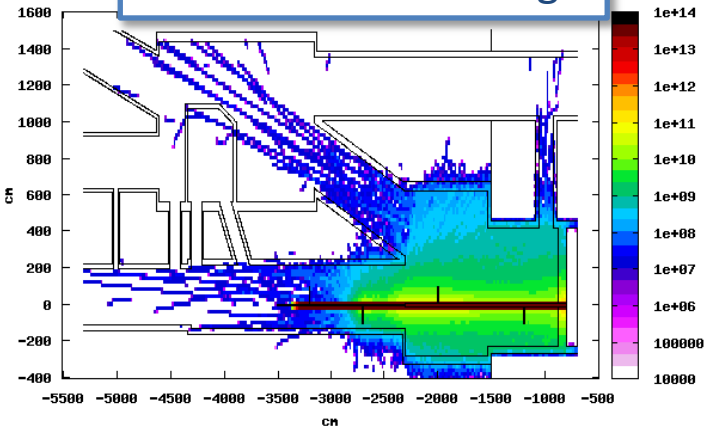
>> 15 µSv/h

New Plasma cell: HEH fluence per year

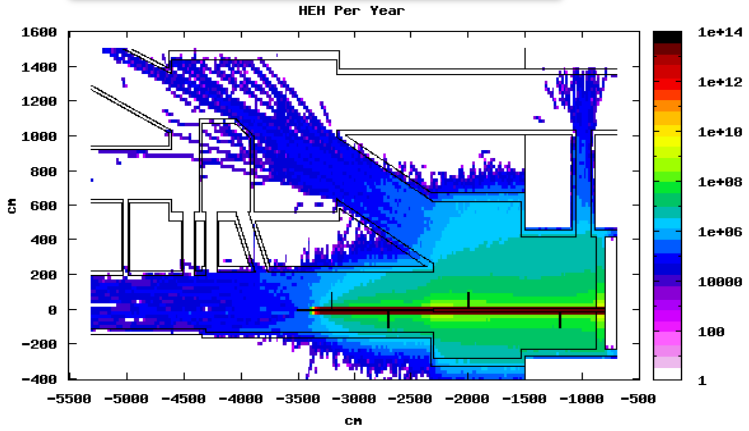
3 mm steel 6 m long



10 mm steel 6 m long

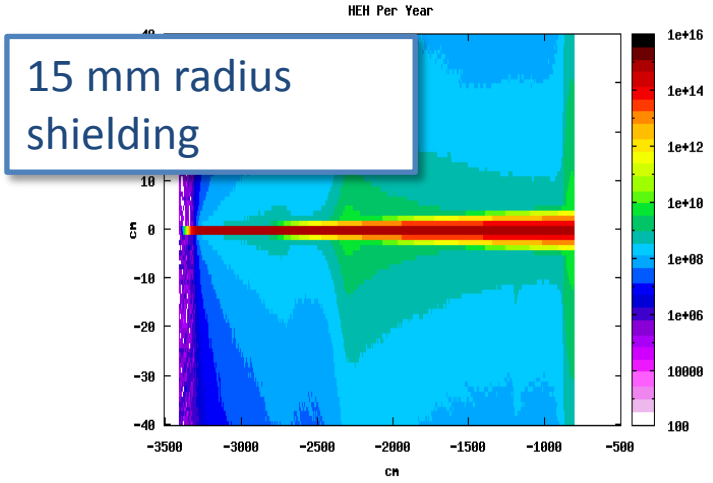


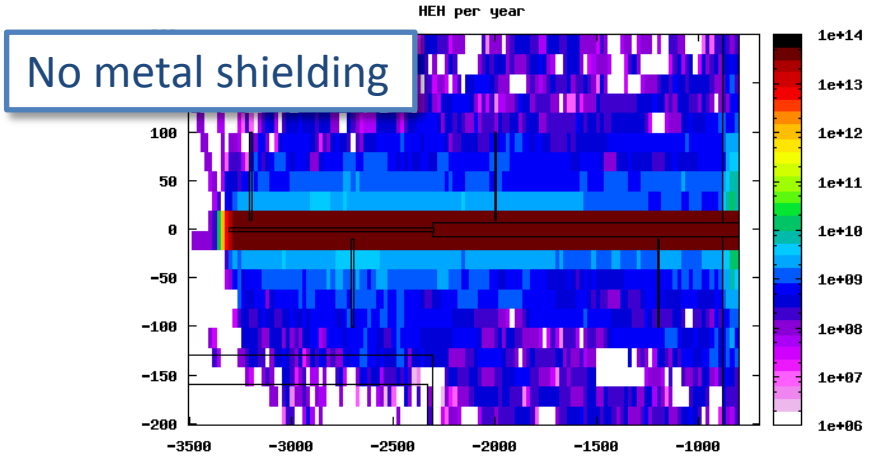
15 mm steel 6 m long

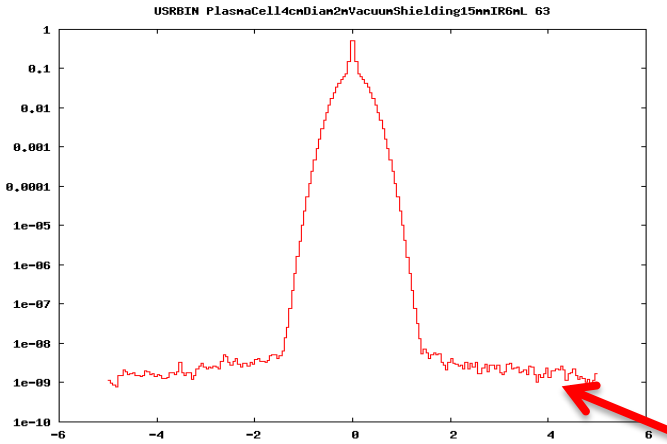


Also for 15 mm radius around plasma cell 1-2 orders of magnitude higher than recommended value

Metal shielding and gas effect







- Also without metal shielding around plasma cell HEH fluence higher than 10^7 HEH/year
- Looking at beam profile: halo due to the interaction of proton beam with gas:
- Gas interaction length for 400 GeV p+: 10^9 cm -> in 10 m $3x10^5$ p+ per beam interact with the gas and broaden the beam

Scattered particles

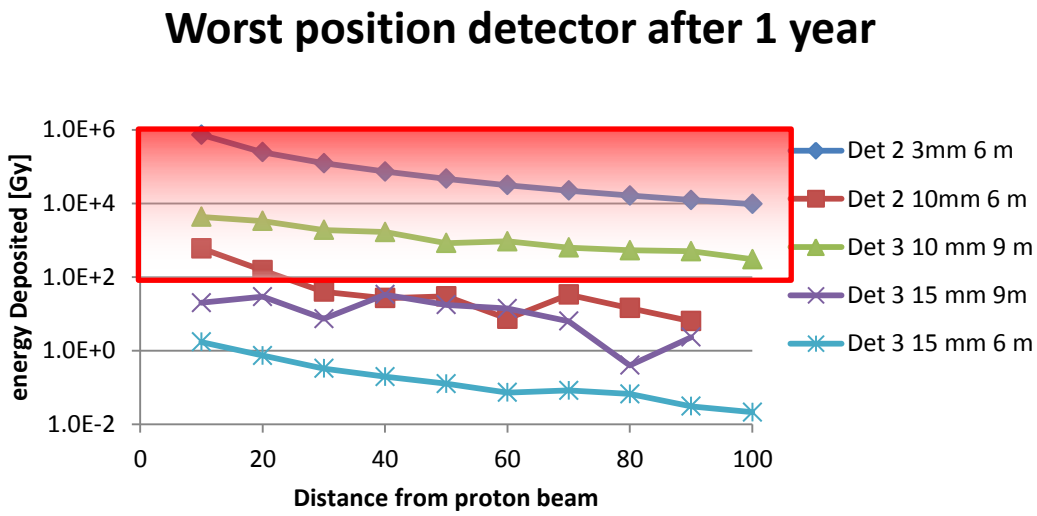
New Plasma cell implementation

HEH fluence summary:

shielding radius [mm]	plasma cell radius [cm]	Shielding length [m]	cm^{-2}/p+	cm^{-2}/year
3	2	6	1.80E-03	8.71E+13
10	2	6	5.20E-07	2.52E+10
15	2	6	2.11E-09	1.02E+08

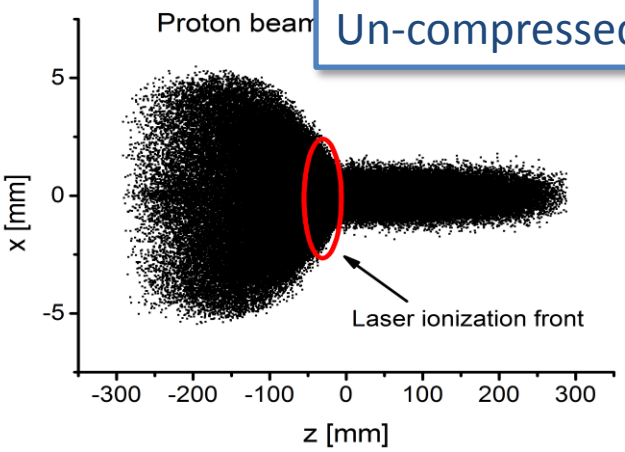
Still 1 order of magnitude too high

Energy deposition comparison:

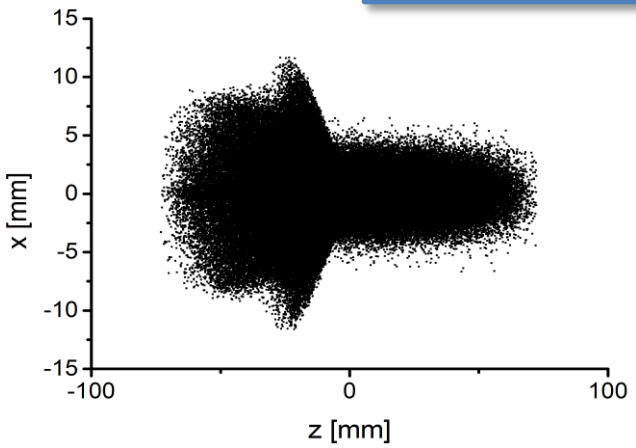


Compressed beam

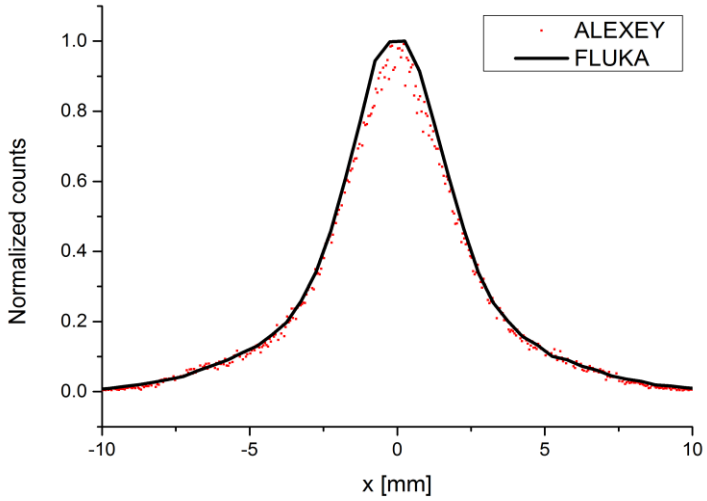
Un-compressed



Compressed

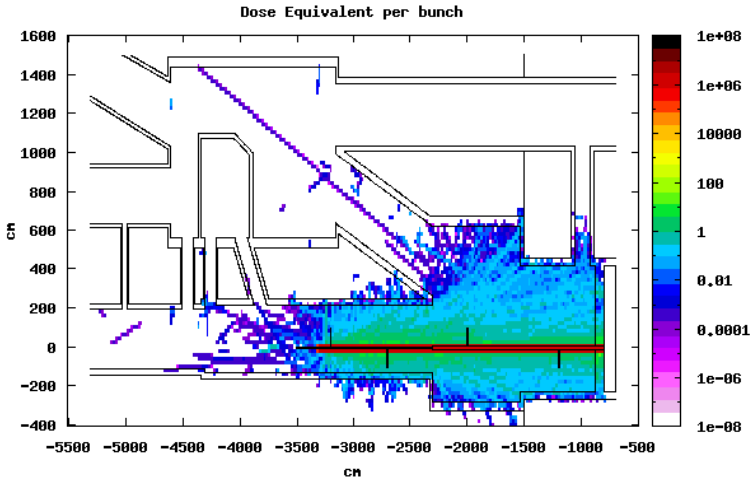


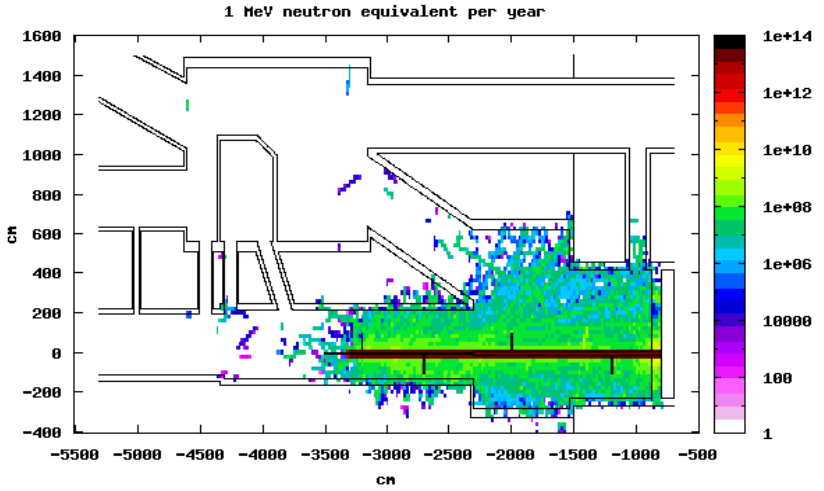
Simulated beam profile after plasma cell

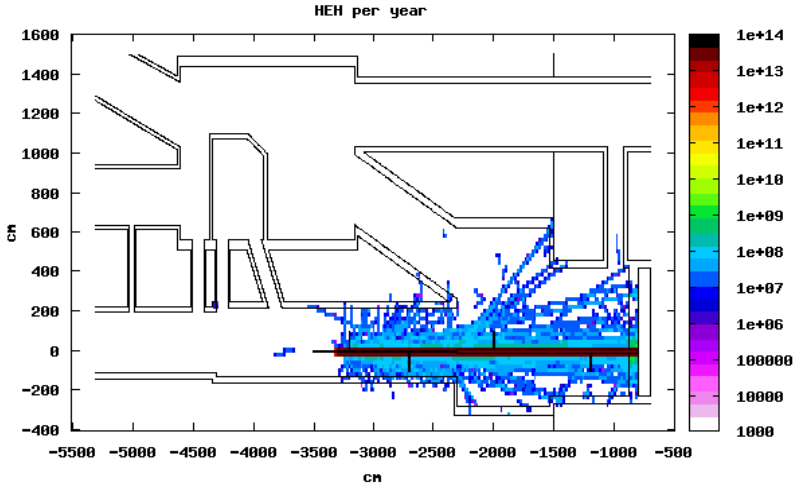


Not much difference expected:
max factor 2

Compressed beam



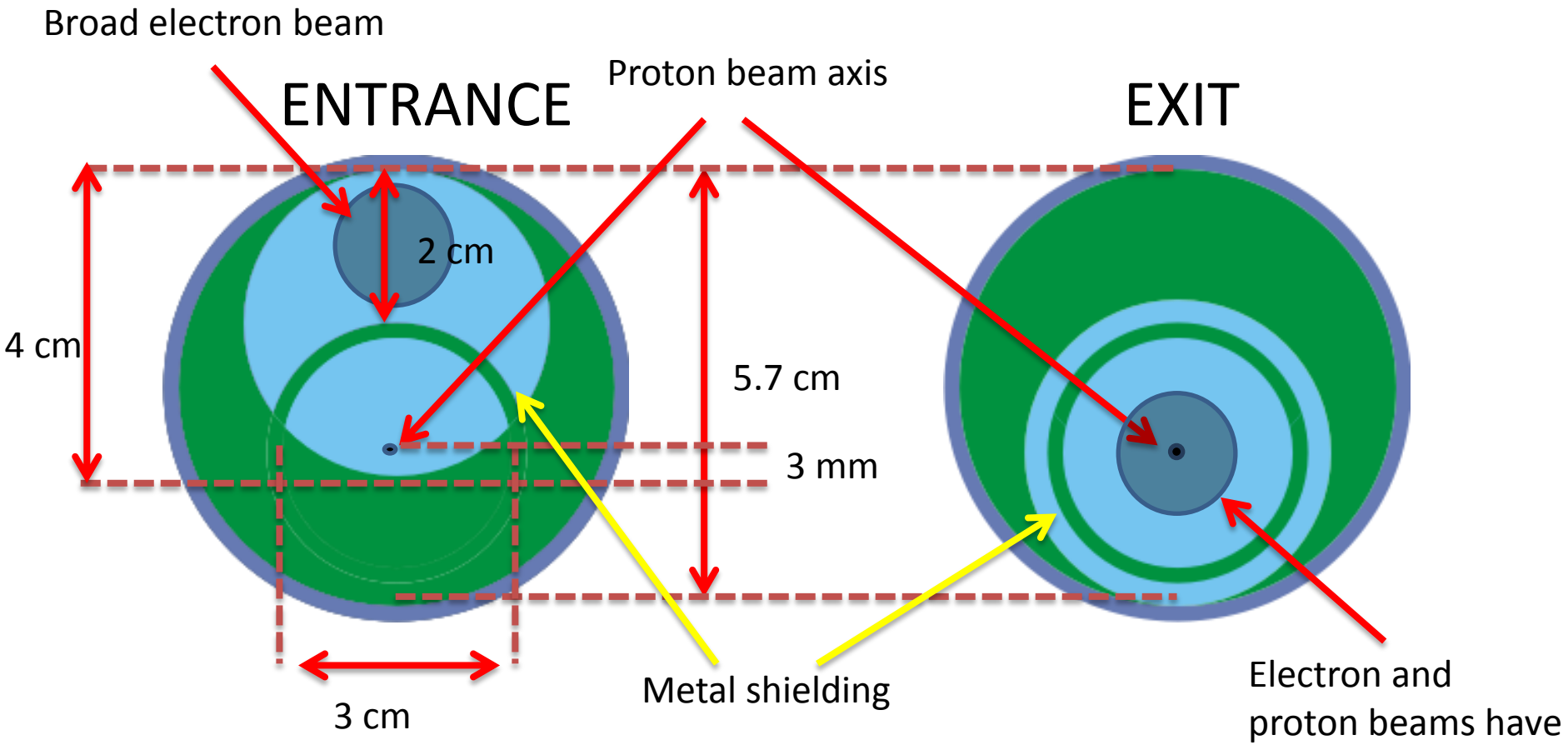




Same order of magnitude than for un-compressed bunch (fast simulations just to check order of magnitude)

Proposed solution

- Larger plasma cell with off set valve



- More room at the entrance for large electron beam
- Exit is not a problem: electrons and protons on the same axis

Conclusion

- The presence of the metal shielding for the electron beam creates hard environment for electronics
- The expected values for 1 MeV equivalent neutron, energy deposition and HEH fluence depend on the geometry of the shielding
- The minimum level of HEH fluence is set by the interaction of the proton beam with the gas: still 1-2 orders of magnitude higher than recommended -> shielding may be required for diagnostic around plasma cell
- Which material to use for the plasma cell wall? More details needed