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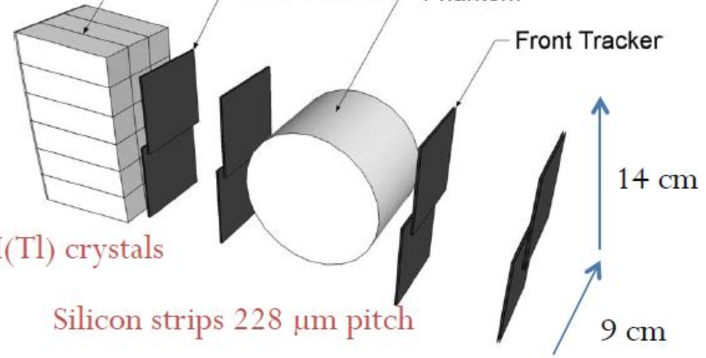
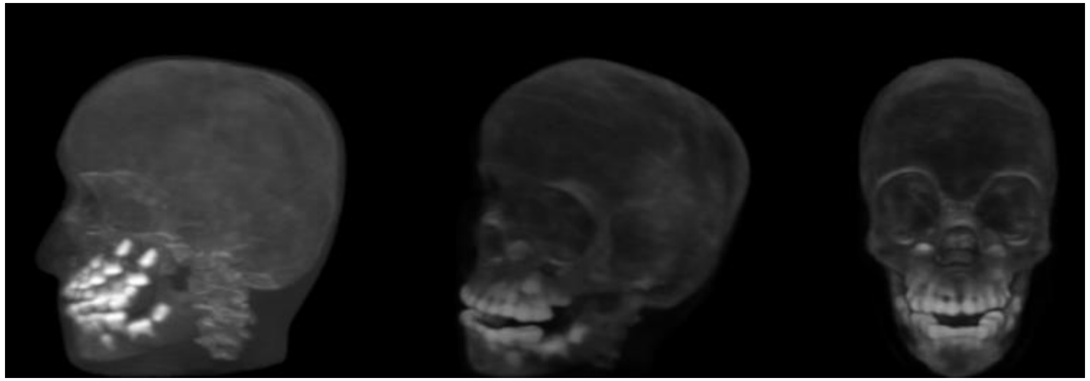
# pCT using LGAD (feasibility study)

G. KRAMBERGER

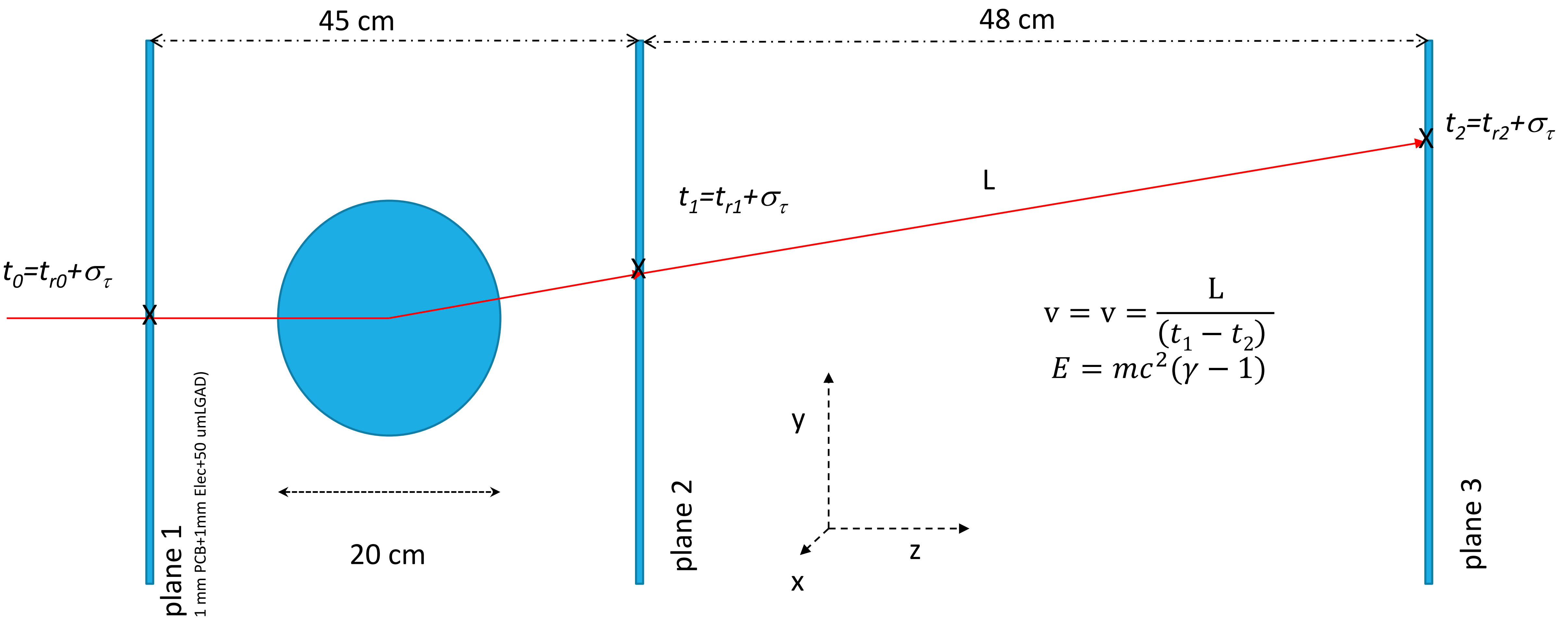
# pCT design: summary

| Category | Parameter | Value |
|---|---|---|
| Proton source | Energy | ~200 MeV (head) |
| | | ~250 MeV (trunk) |
| | Energy spread | ~ 0.1% |
| | Beam intensity | $10^3 - 10^7$ protons/sec |
| Accuracy | Spatial resolution | < 1 mm |
| | Electron density resolution | < 1% |
| Time Efficiency | Installation time | < 10 min |
| | Data acquisition time | < 5 min |
| | Reconstruction time | < 15 min (treatment planning)<br>< 5 min (dose verification) |
| Reliability | Detector radiation hardness | > 1000 Gy |
| | Measurement stability | < 1% |
| Safety | Maximum dose per scan | < 5 cGy |
| | Minimum distance to patient surface | 10 cm |

*Schulte TNS 51 (2004)*

Measure of x, p, E with $\sigma_x < 1mm$ $\sigma_E < 1\%$

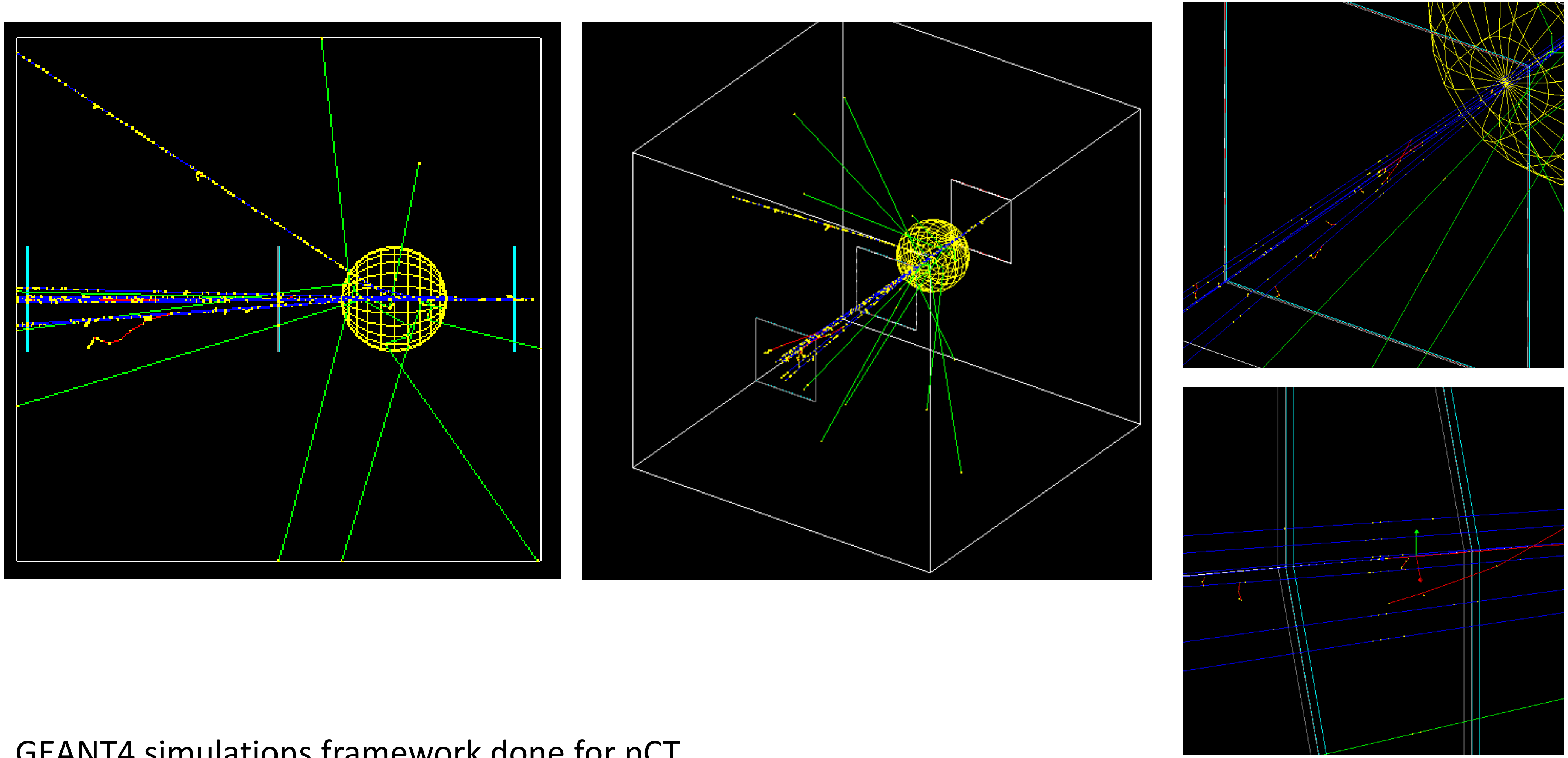
MHz DAQ :
A head with 100 p, 1 mm voxel
$7\ 10^8$ p: 10 kHz = 20 hrs
2 MHz = 6 min
GPU recontruction




$E_{phantom}$= $E_p$-$E_m$

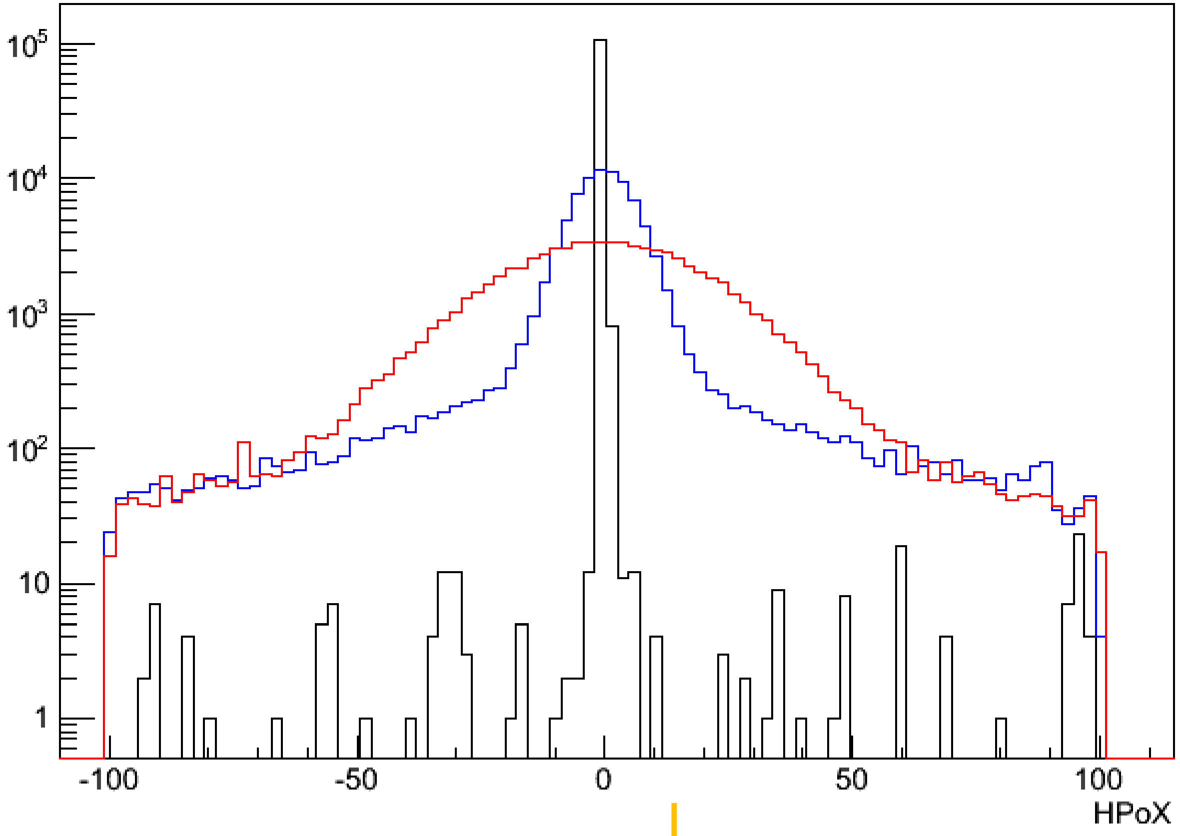
From $dt$=$t_0$-$t_1$ one can better assume ρ(r)

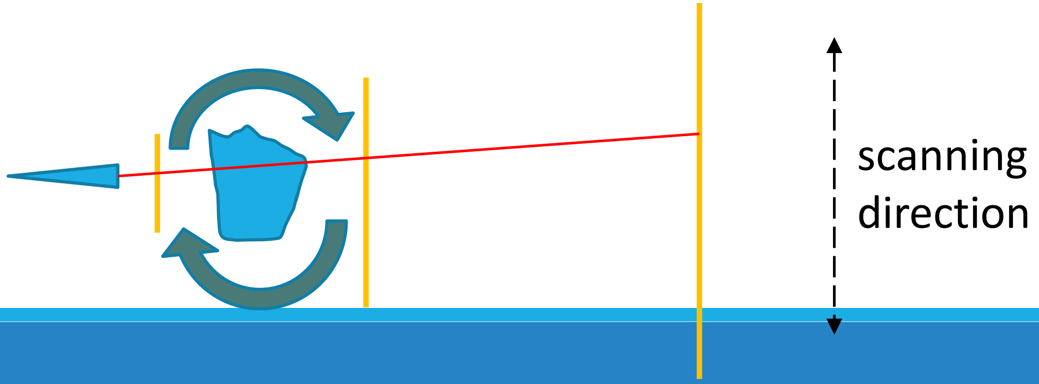
# GEANT4 simulations



GEANT4 simulations framework done for pCT
What we need is  someone who would run this and fully explore the possible benefits of using LGAD !

# SIZE OF THE SENSORS




Large distance between planes require large sensors -> ~10x~10 cm2 would be required in the third plane and ~4x4 cm2 in the second and first (maybe even smaller) if realized by scanning.

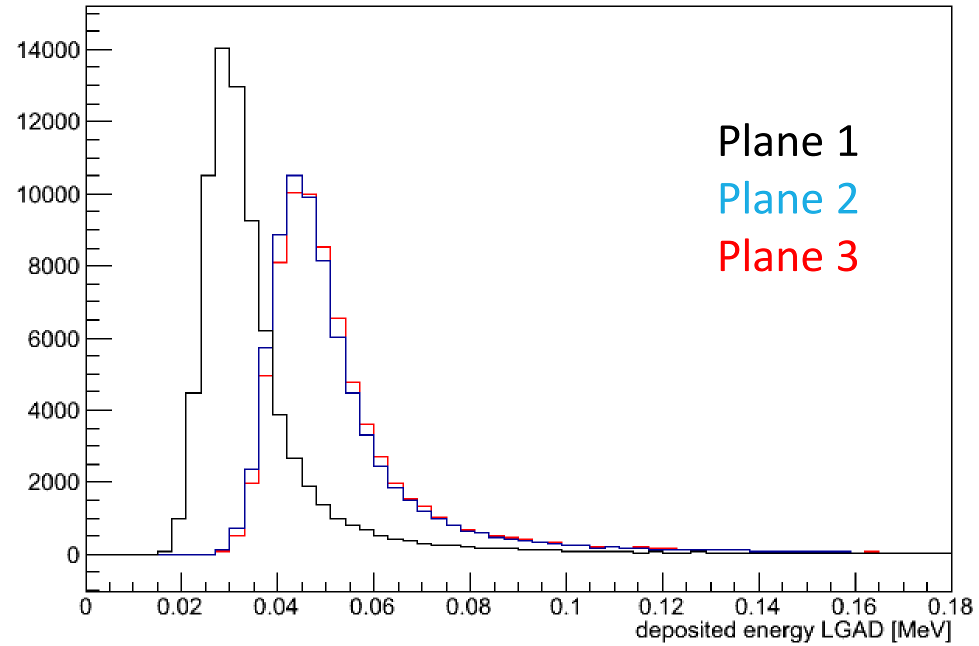
Different sizes would reduce potential cost.

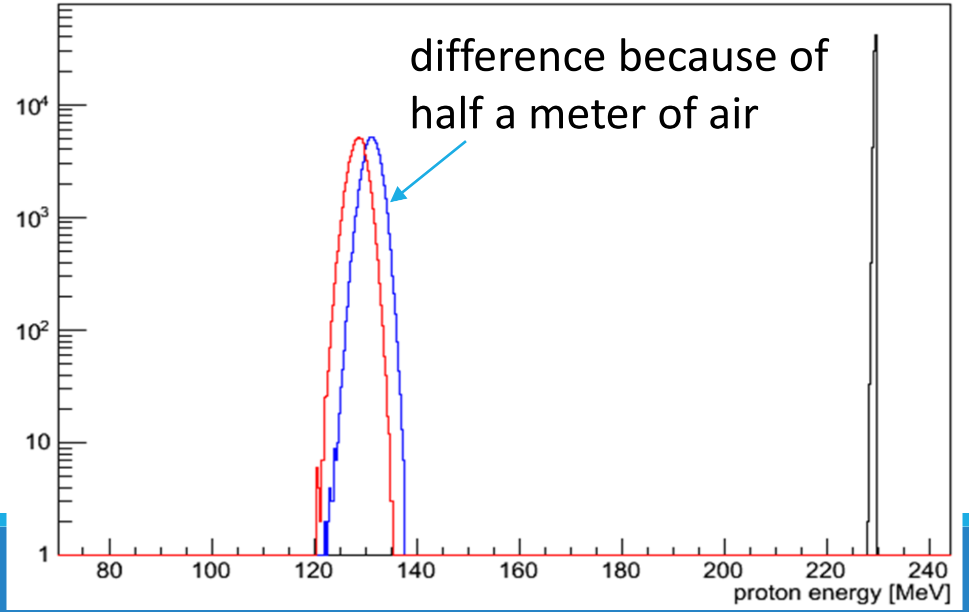
Head scan required 1e9 reconstructed p.
Presently most use strip sensors -> hours
Requirement: 10-15 min scan with full reconstruction in an hour

Required DAQ rate >1 MHz:

- <1000 $\mu$m position resolution is required – lower than 200 $\mu$m doesn't help much
- This gives enough floor plan for fast electronics (~1x1 $mm^2$ pixels – something like ALTIROC)

# PROTON ENERGY and DEPOSITED ENERGY




In planes 2 and 3 MPV is around 50 keV (5x larger than for mip)

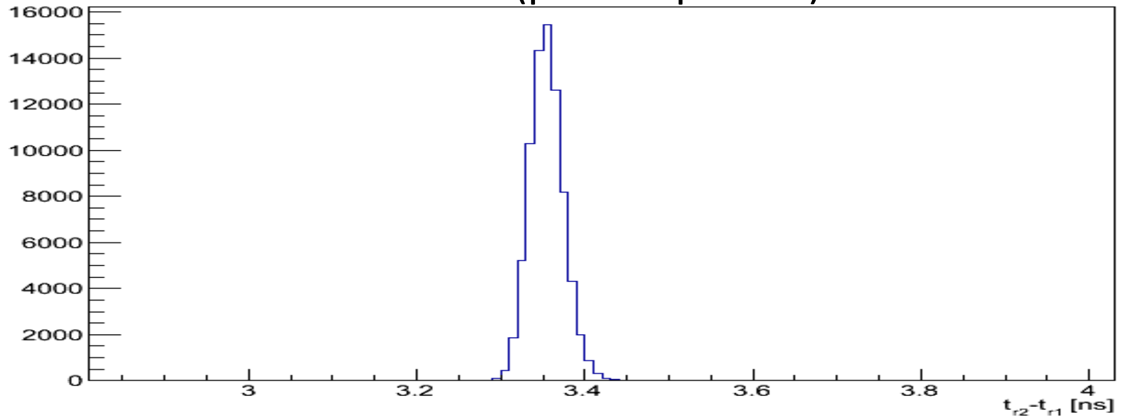
At a given gain this will improve the time resolution, and allow for 35 um thick LGADs which have been shown to have time resolution of around 20 ps (less Landau fluctuations) with non optimized electronics.

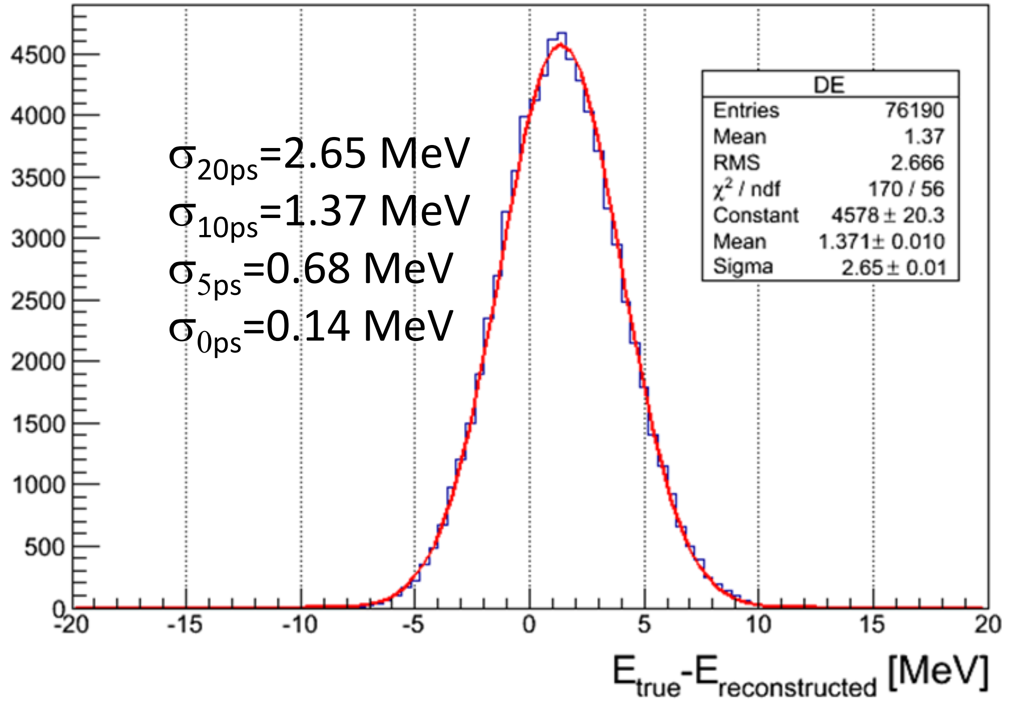
For thin iLGADs for proton detection it is reasonably to assume time resolution of <20 ps

Energy of the protons is reduced by the phantom.
This improves the energy resolution as they slow down.

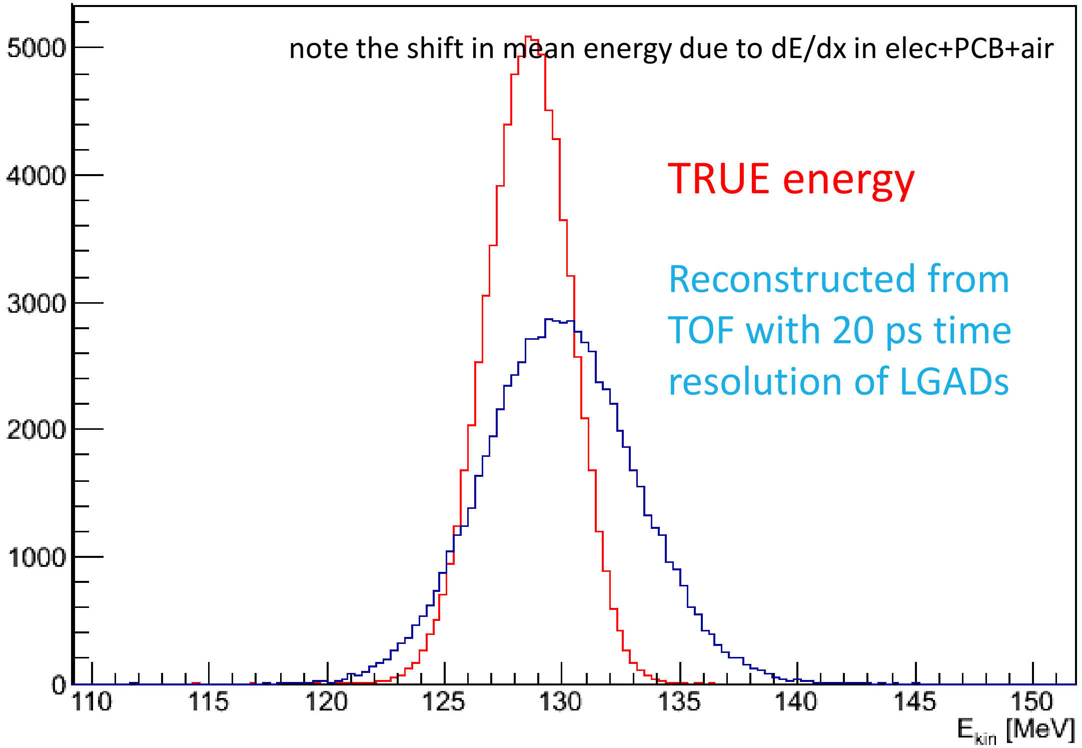
# RECONSTRUCTION

## simulated TOF (plane3-plane2)



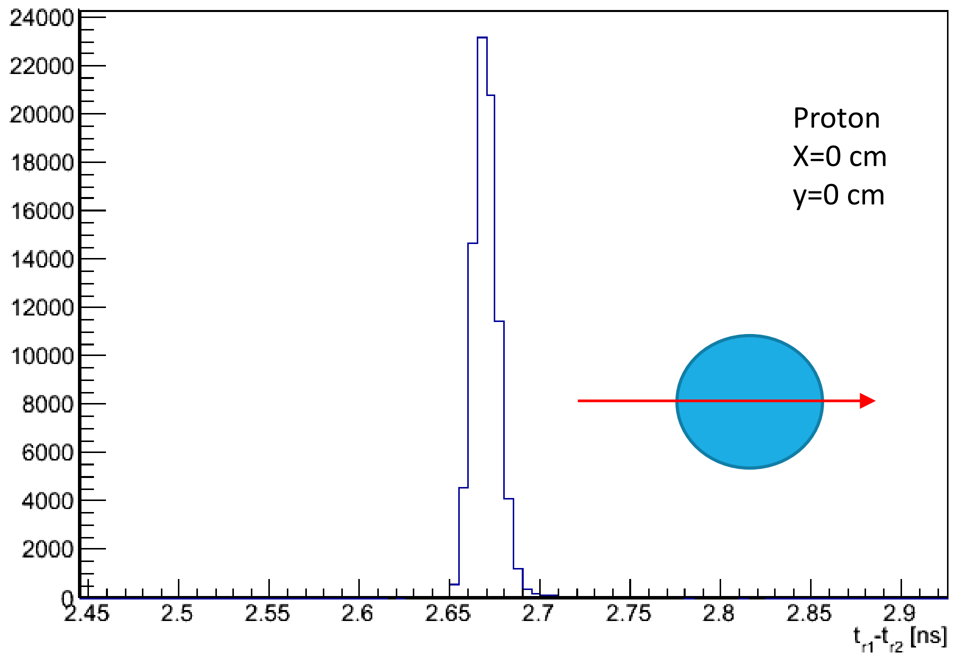

## Reconstructed energy

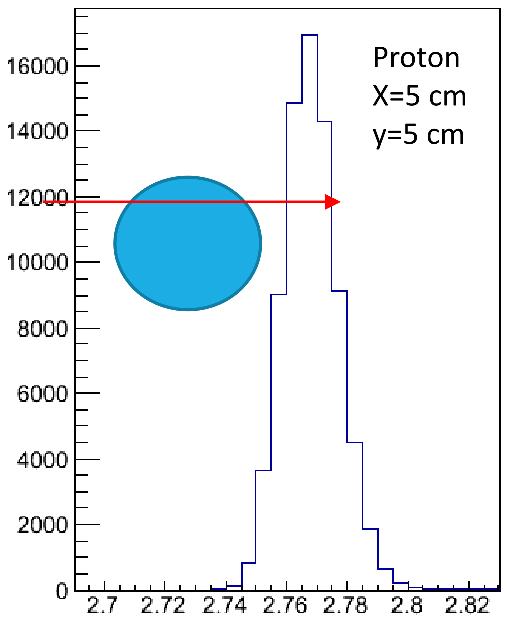



The energy resolution is 2.6 MeV which should be compared to energy resolution of typical CALs !
A drawback is that the energy resolution is a function of the material seen by the beam in the phantom -> a possible solution is using a constraint from the timing information from the first two layers

Better time resolution reduces it even further!

# IMPROVED RECONSTRUCTION

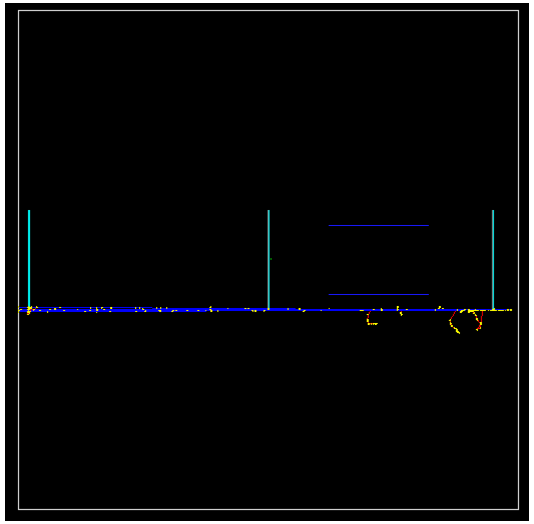


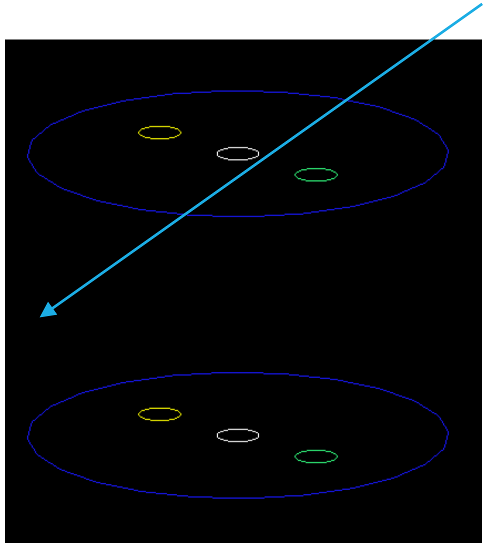



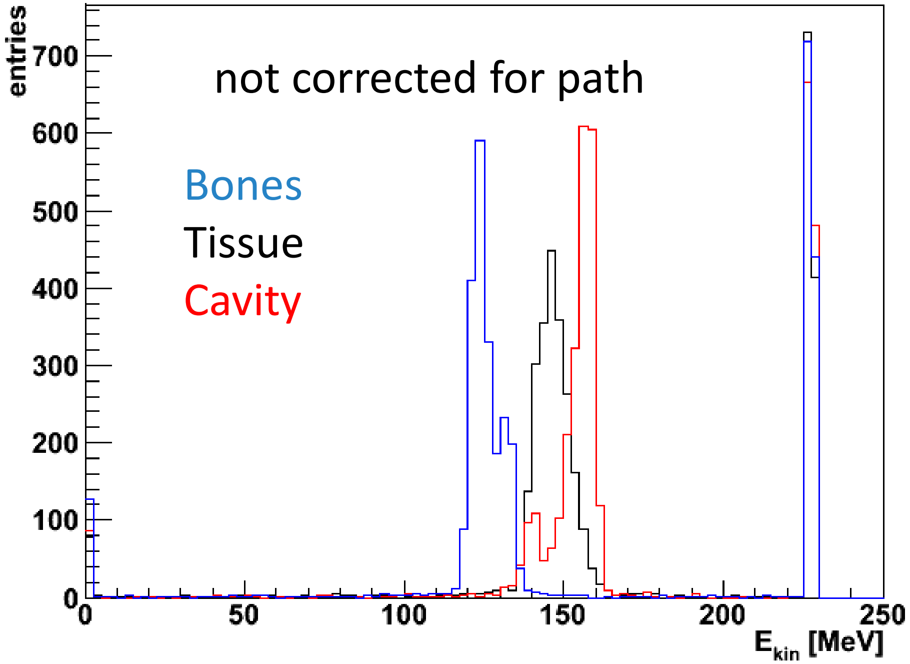

$$\int_L \eta_e(r)dx = \int_{E_{in}}^{E_{out}} \frac{dE}{S_{water}(E)}$$

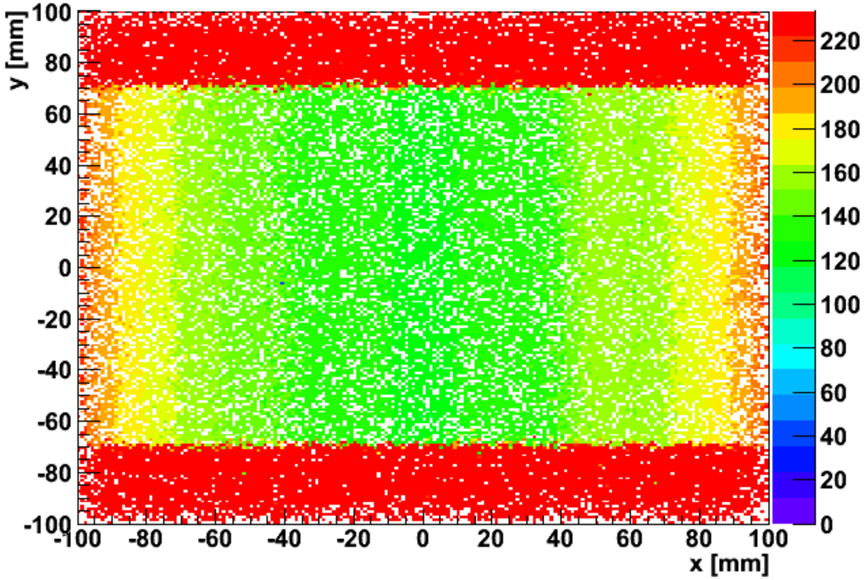
A difference in time t1-t0 can be used to improve MLP calculation -non of the algorithms used so far take this information into account.

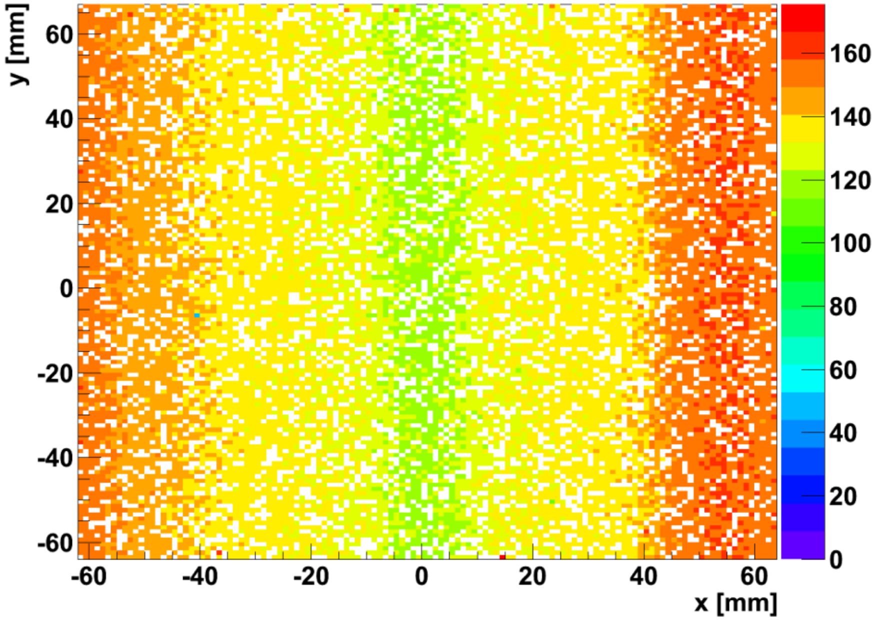

Same energy loss and hit position but different dt=t0-t1
A possible advantage over the conventional pCT and can significantly improve the reconstruction of MPL!



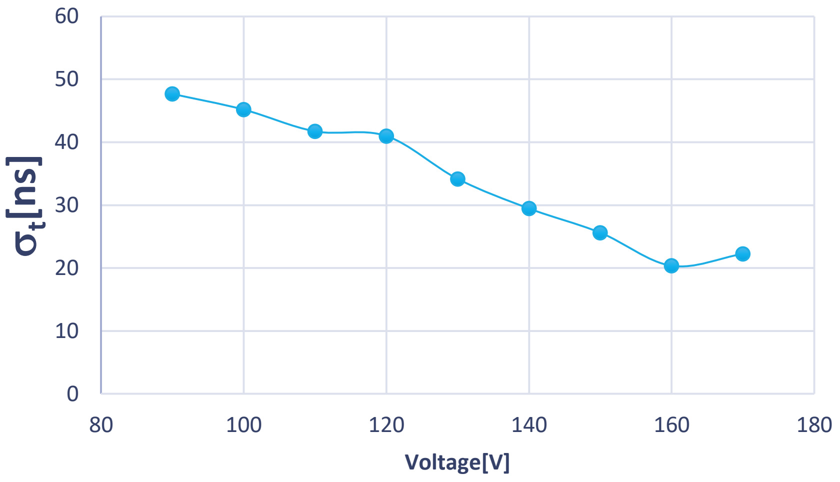


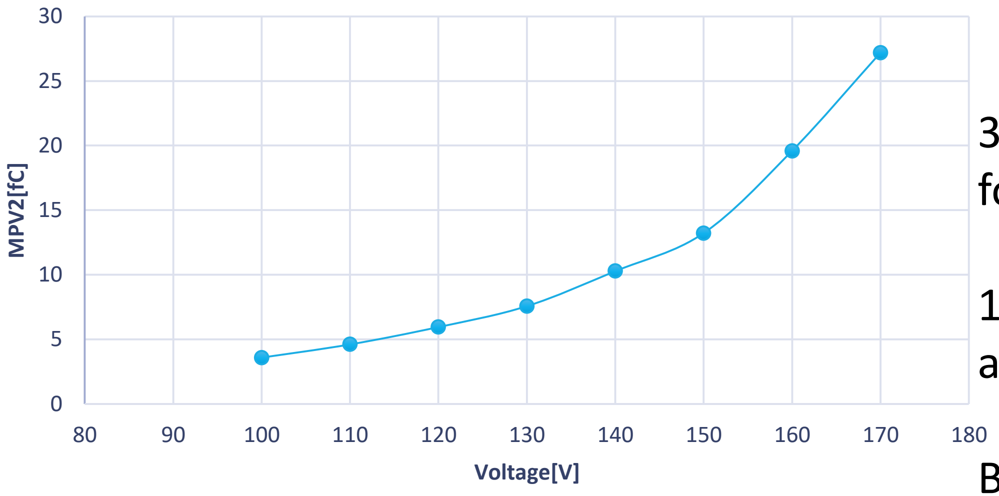

not corrected for path
Bones
Tissue
Cavity
entries
0
100
200
300
400
500
600
700
0
50
100
150
200
250
$E_{kin}$ [MeV]

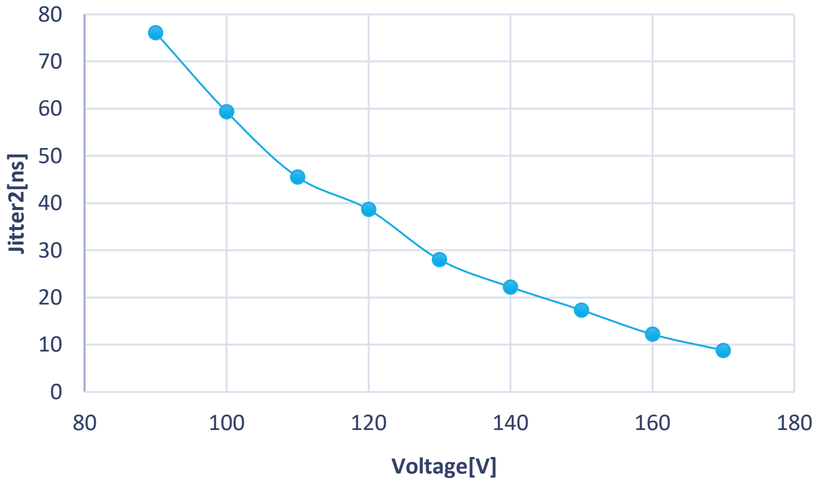

y [mm]
x [mm]
-100
-80
-60
-40
-20
0
20
40
60
80
100
0
20
40
60
80
100
120
140
160
180
200
220

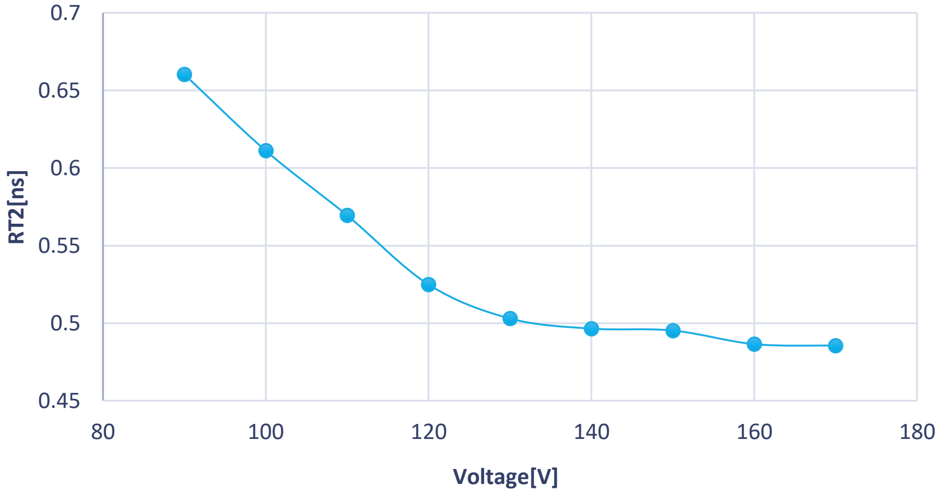

y [mm]
x [mm]
-60
-40
-20
0
20
40
60
0
20
40
60
80
100
120
140
160

Basically a detector that we have in the lab would do the job – room for improvement is certainly there




35 um thick LGAD for ATLAS – HGTD

15x15 arrays already done

Best achieved so far in out system was 18 ps

I think LGADs are ideal detectors for pCT:

- great simplification of the device – no complicated calorimeter needed.
- pixelated LGADs provide good position resolution even with what has been achieved today (ALTIROC)
- iLGAD would be ideal, but with larger pixels also conventional may be good enough (to be checked)
- with improvement of timing resolution to some ~15 ps (already achievable on the test bench in our lab) we can achieve energy resolution of 1.5 MeV which is around 1% of the Ep (to be converted to WEP)
- the fact that we have timing information from all three layers allows for better determination of MLP and in combination with other two improve proton energy resolution.
- LGADs are very fast and can easily achieve 1 MHz acquisition rate or even much higher
- the system can be lightweight and can more easily allow for scanning using even smaller modules – say 4x4 cm2 in all four planes.

If Slovenia is really going to take part in any form of proton therapy in the future this may be interested for us.