Simulation study of proton scattering on Carbon target and GEM-based polarimeter detector

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Outline

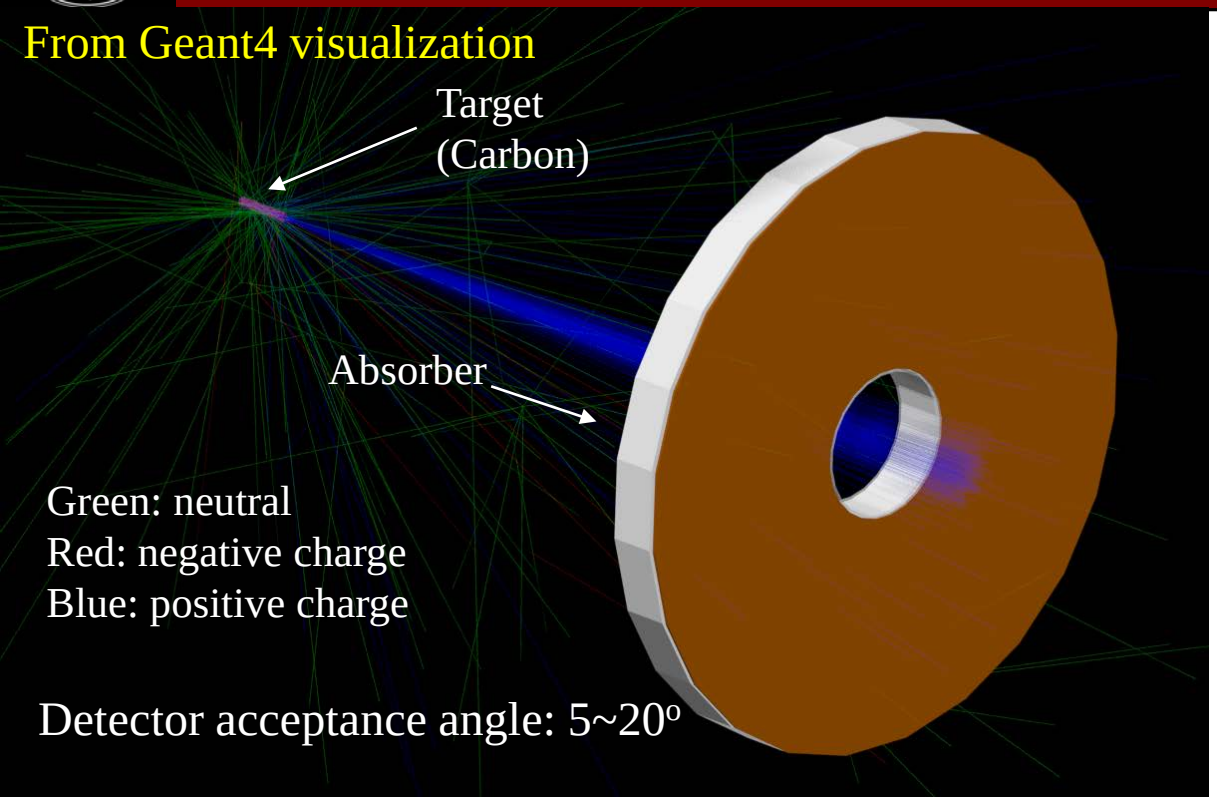
1. Simulation setup and detector geometry
2. Proton interaction in carbon target
3. Particle hit information on the detector plane
4. Rate capability and equal rate anode pad design for GEM detector
5. About GEM detector and cost estimate
6. DAQ system for GEM detector
7. Summary

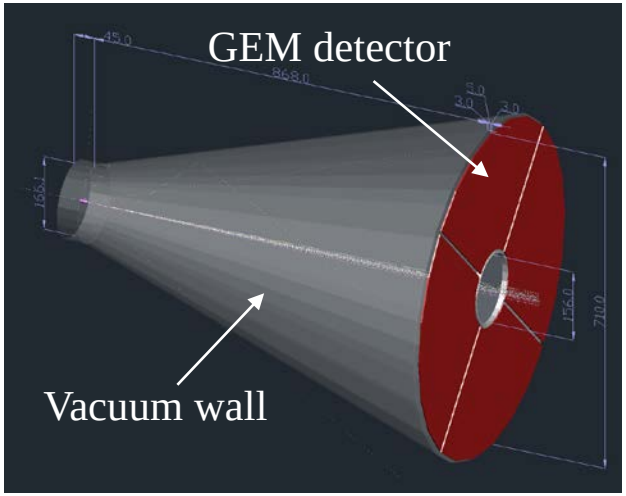
MC Simulation (Geant4)

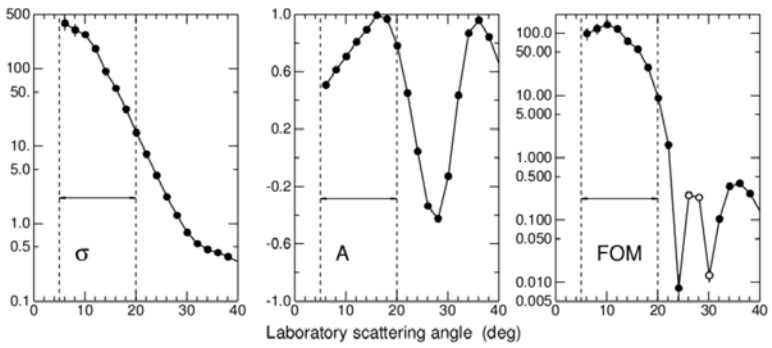
- Simulation tool: Geant4 v4.10.p02
- Physics list used for simulation: QGSP_BERT
- Input particle: protons, 1,000,000 POTs
  - ✓ P=701 MeV/c, $\Delta p/p=4.6\times10^{-4}$, $\beta=0.6$, K=233 MeV
- Target length: 60mm
- Target dia.: 10 mm
- Target material: Graphite(C:N:O=99:0.7:0.3, 1.7 g/cm^3)
- Distance between target and detector: 900 mm
- Absorber: Iron, Teflon, to be tested more…
- Absorber thickness: varied(0~60 mm)
- GEM detector: Ar:CO_2=80:20 mixture, 3 mm drift gap
- Other detector materials: Silicon, Plastic scintillator

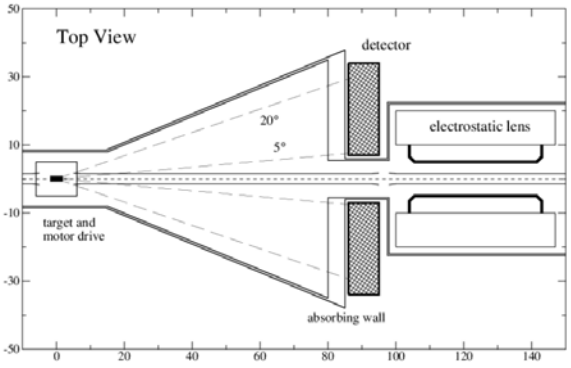
Detector geometry

From Geant4 visualization



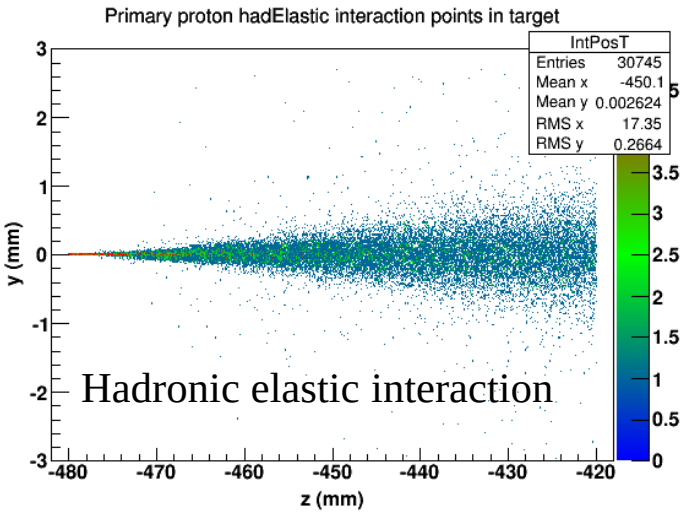


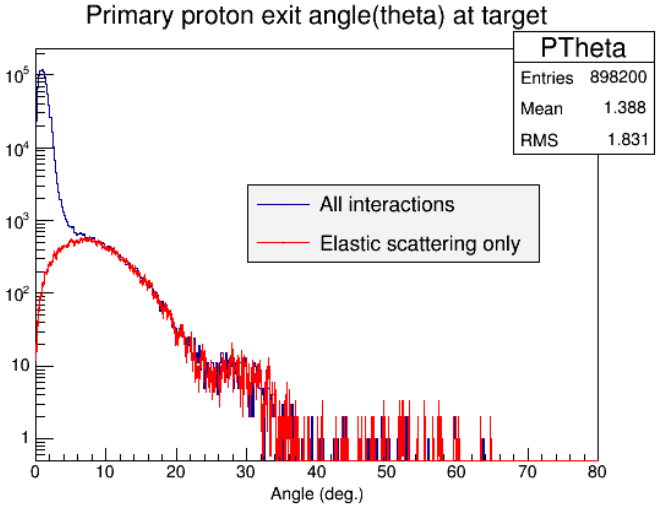


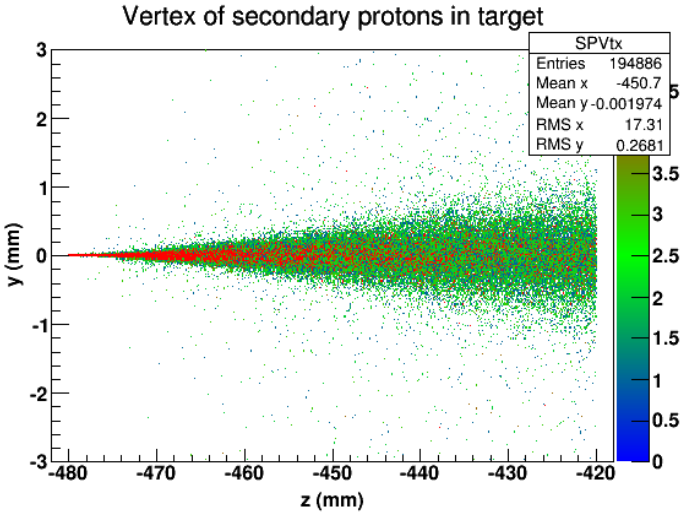


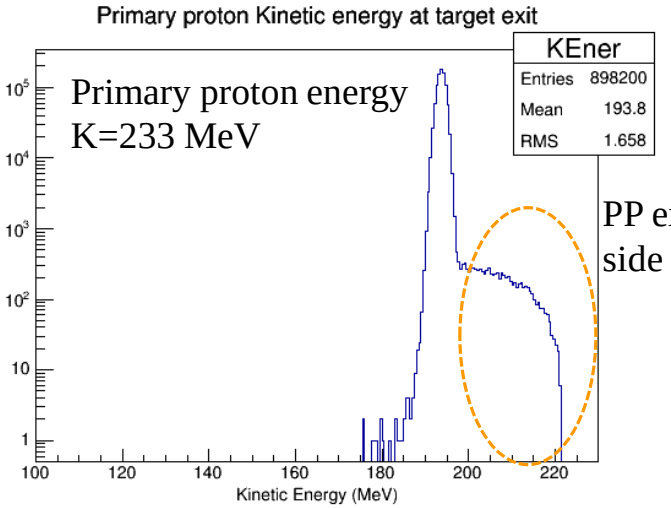
Design from the SR pEDM proposal

Proton interaction in Carbon target





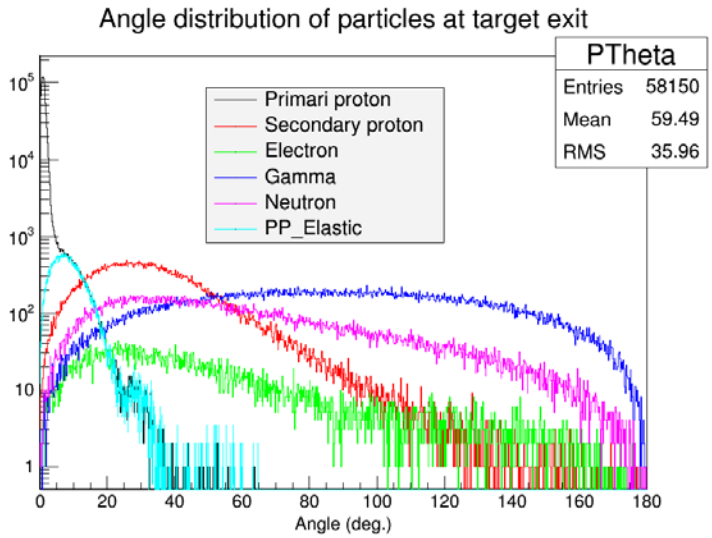


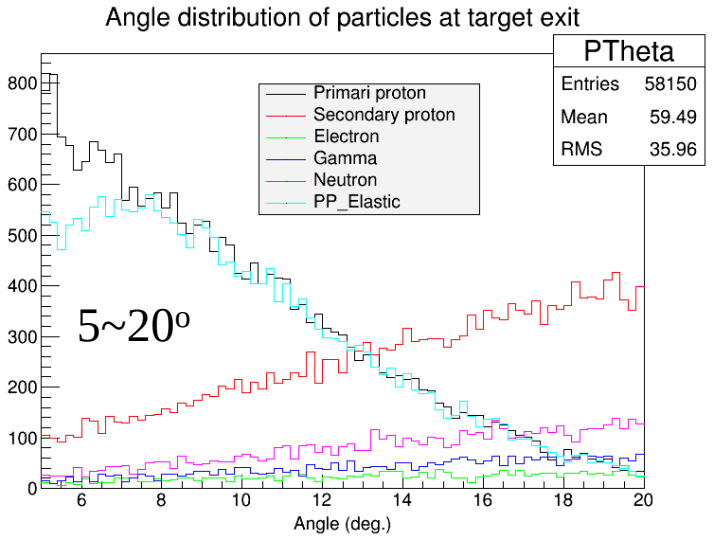


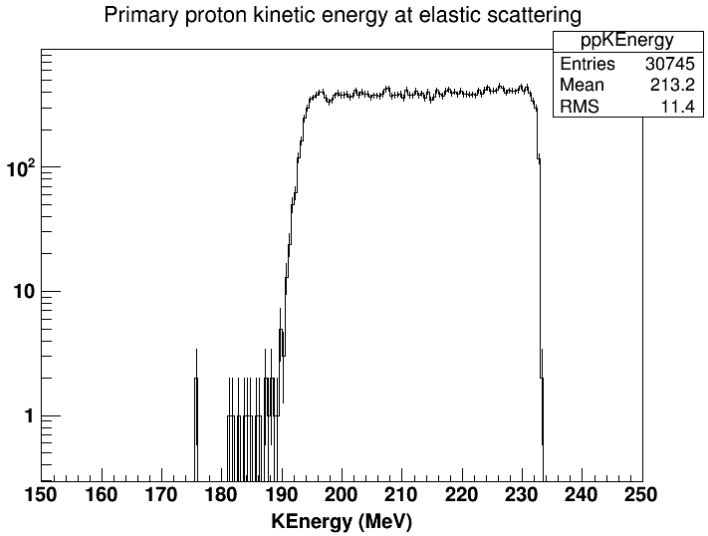
PP exiting on the side of the target

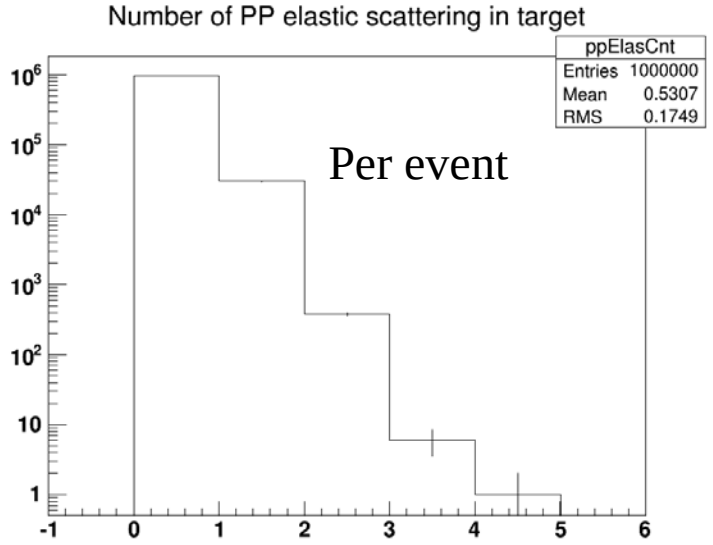
101800 protons out of 1000000 are absorbed in the target.(10.18%)
Target length=60 mm

Angle distribution of particles at target exit

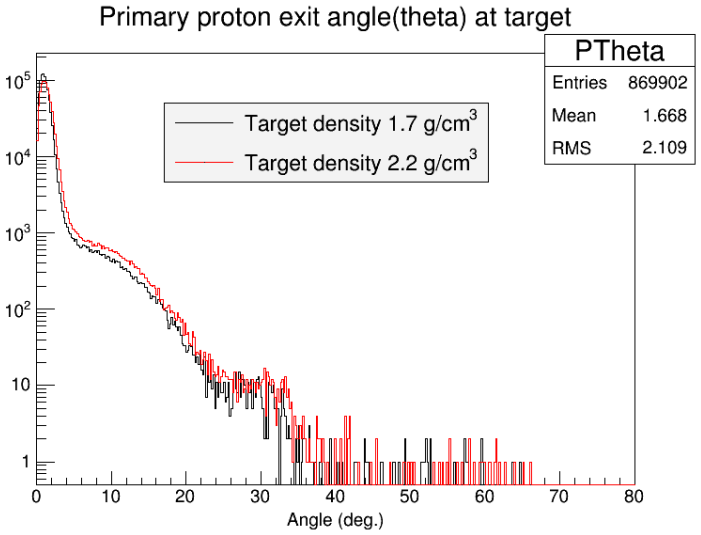








Effect of target density

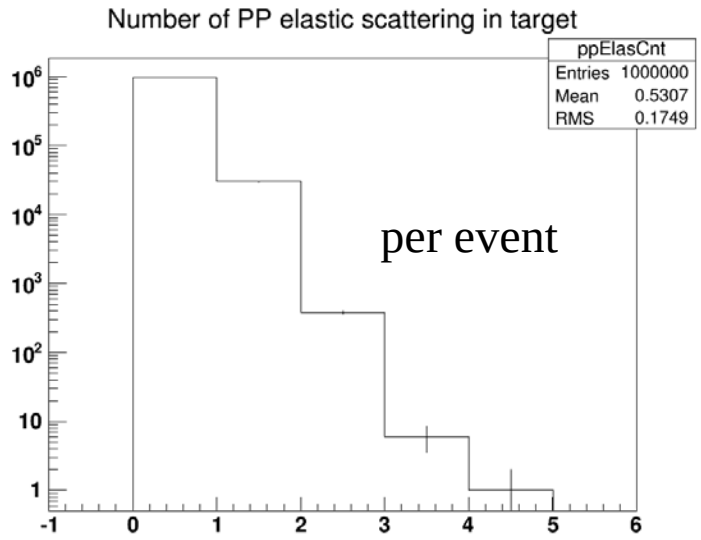


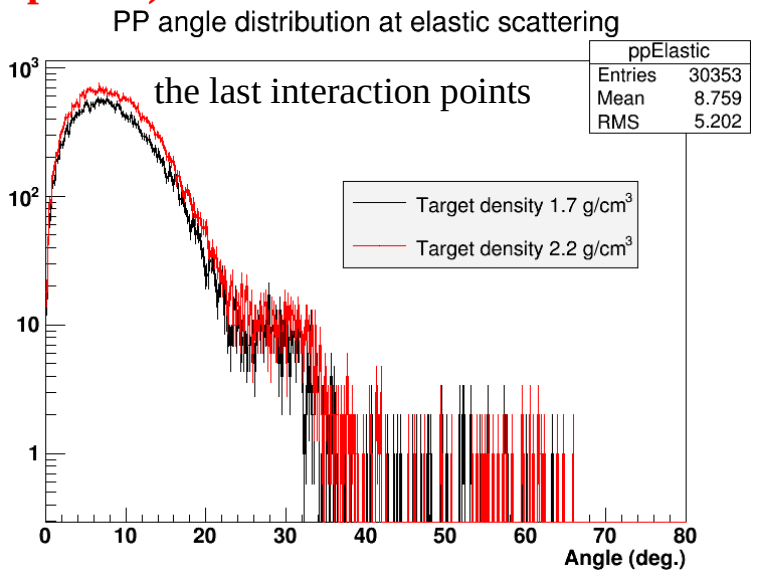
Target density: 1.7 g/cm^3

- ✓ 10.2% of primary protons are absorbed in the target.
- ✓ Primary proton hits on the detector plane: 2.5 %
- ✓ All hits on the detector plane: 6.6 %
- ✓ **Elastic PP in angle 5-20^o: 2.3 %(detector acceptance)**

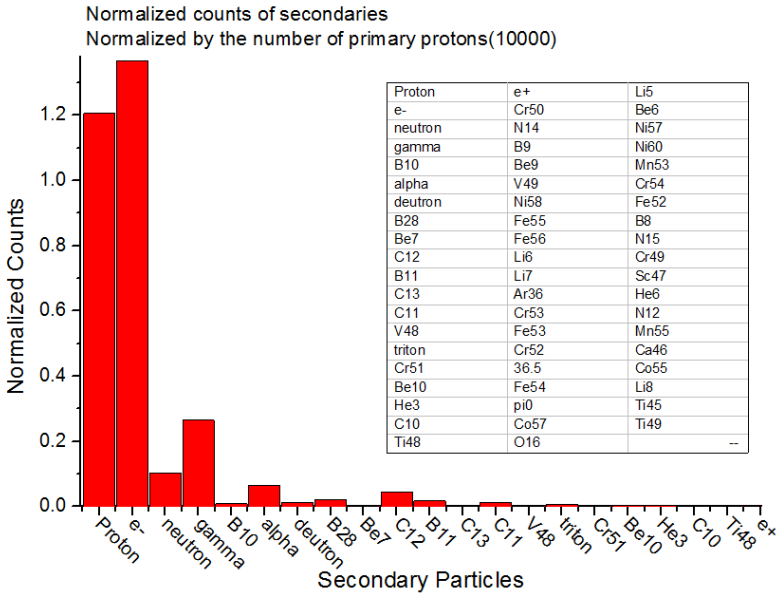
Target density: 2.2 g/cm^3

- ✓ 13.0% of primary protons are absorbed in the target.
- ✓ Primary proton hits on the detector plane: 3.2 %
- ✓ All hits on the detector plane: 7.9 %
- ✓ **Elastic PP in angle 5-20^o: 2.9 %(detector acceptance)**

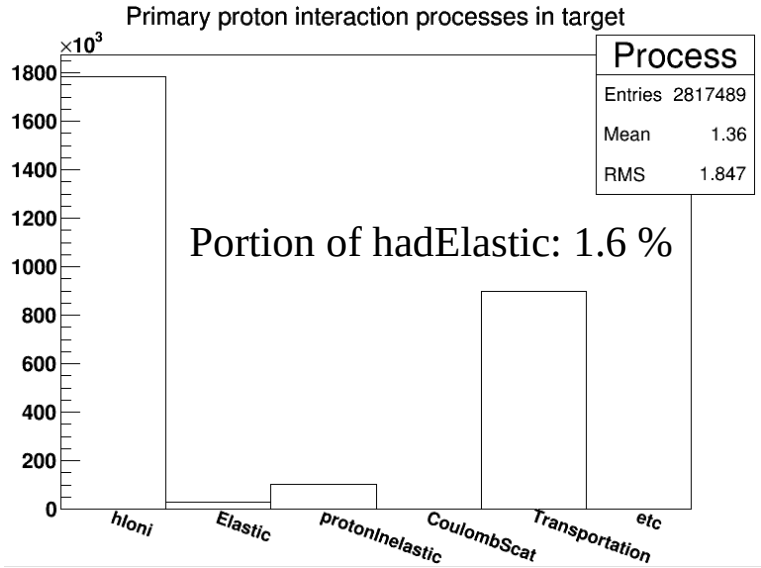


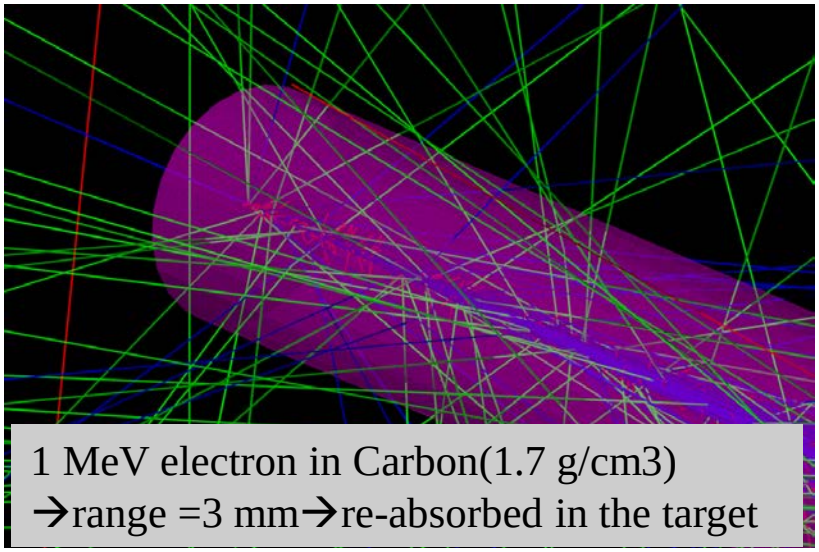


Secondary particles produced in the target

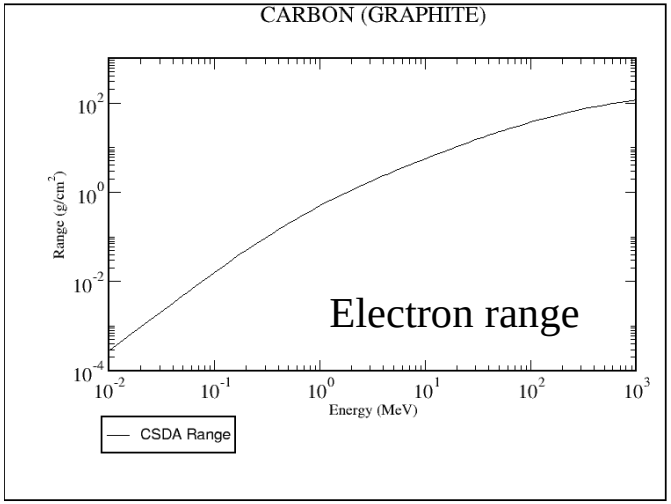


Proton	e+	Li5
e-	Cr50	Be6
neutron	N14	Ni57
gamma	B9	Ni60
B10	Be9	Mn53
alpha	V49	Cr54
deutron	Ni58	Fe52
B28	Fe55	B8
Be7	Fe56	N15
C12	Li6	Cr49
B11	Li7	Sc47
C13	Ar36	He6
C11	Cr53	N12
V48	Fe53	Mn55
triton	Cr52	Ca46
Cr51	36.5	Co55
Be10	Fe54	Li8
He3	pi0	Ti45
C10	Co57	Ti49
Ti48	O16	--

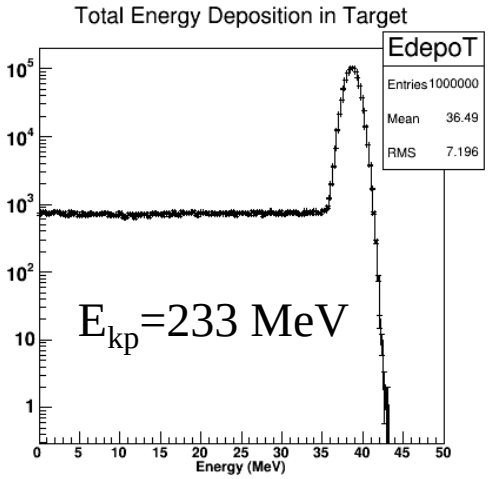


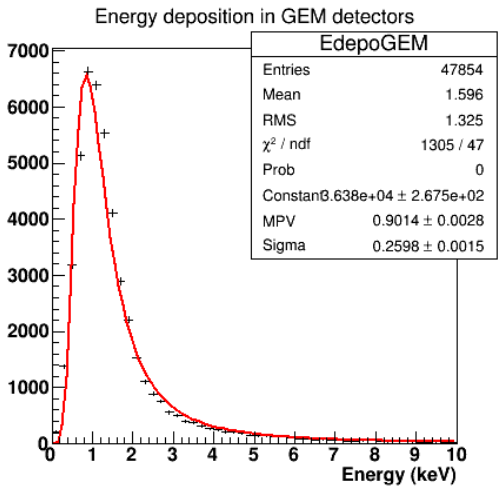


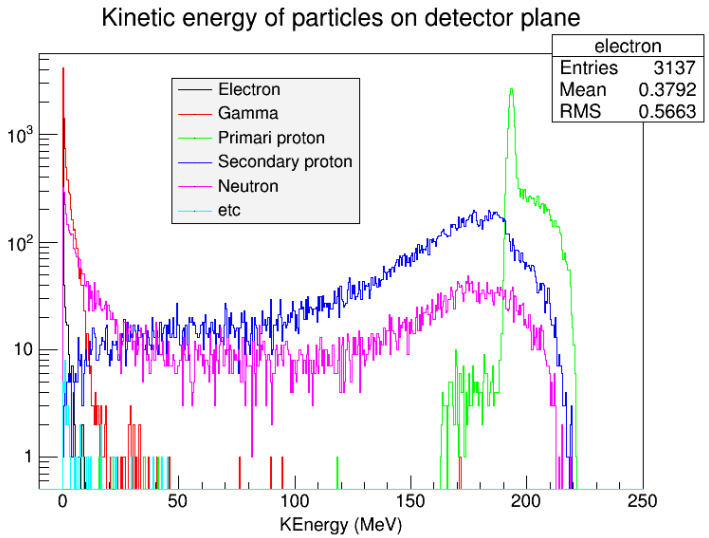
1 MeV electron in Carbon(1.7 g/cm3)
→range =3 mm→re-absorbed in the target

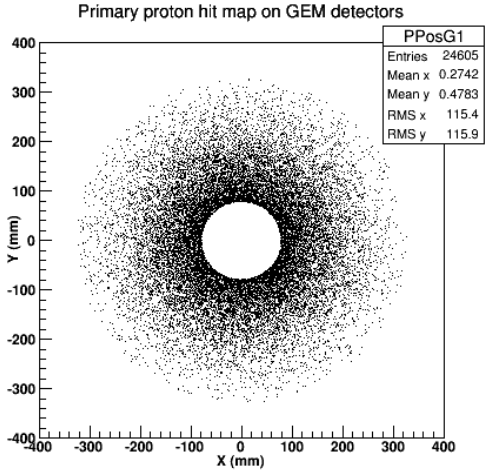


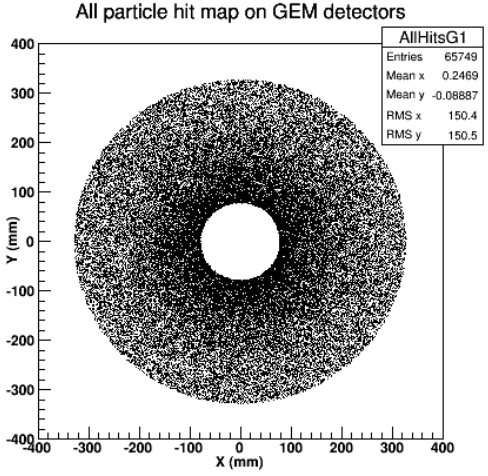
Particles on the detector plane/Detector acceptance

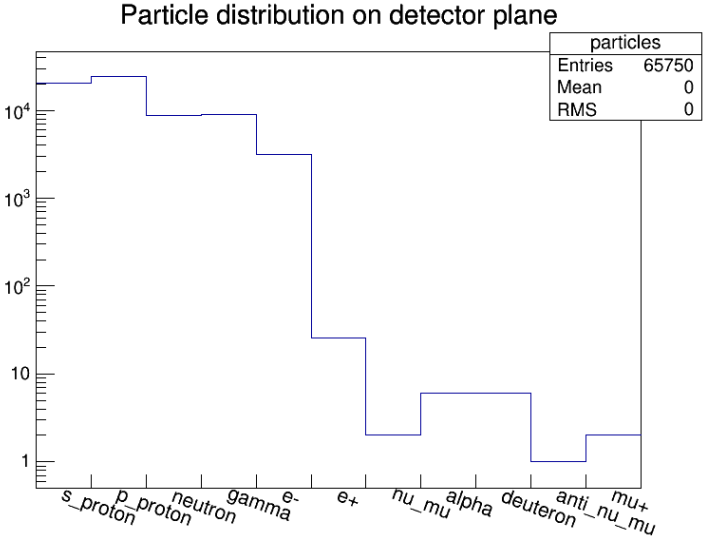












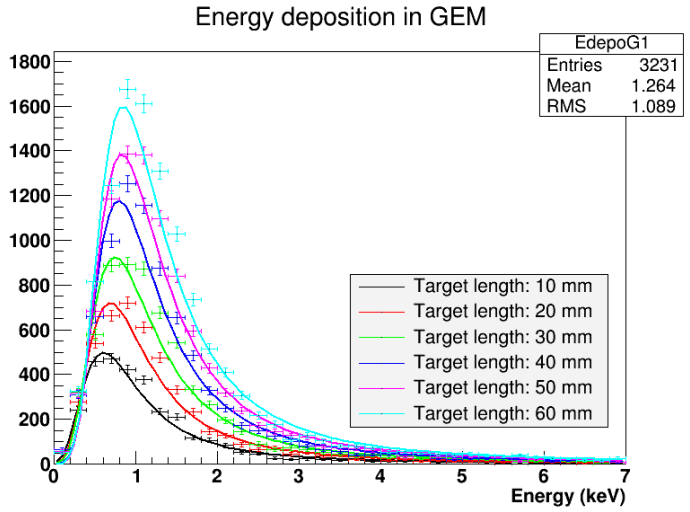
Hits by primary protons only

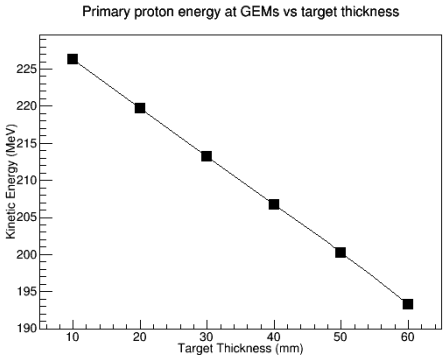
Detector acceptance : 2.4 %

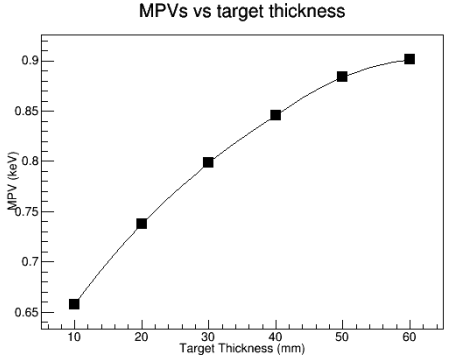
All hits including secondaries

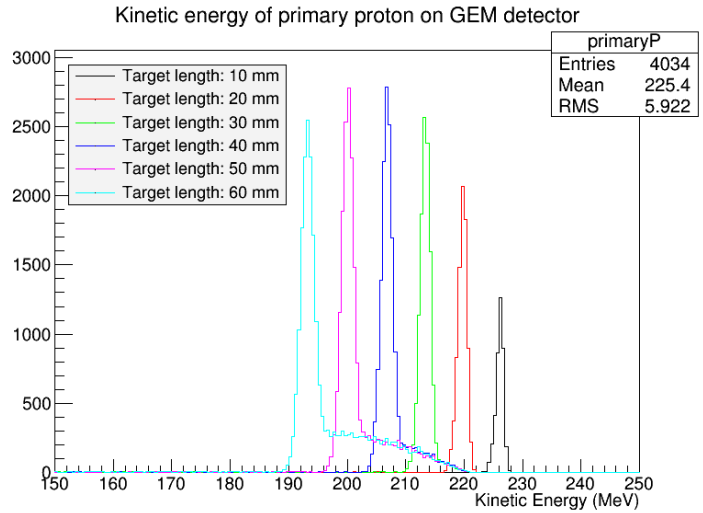
Detector acceptance: 6.5 %

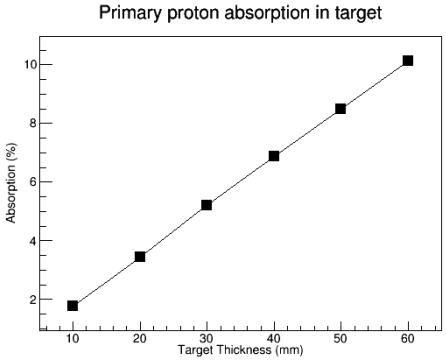
Target length dependency

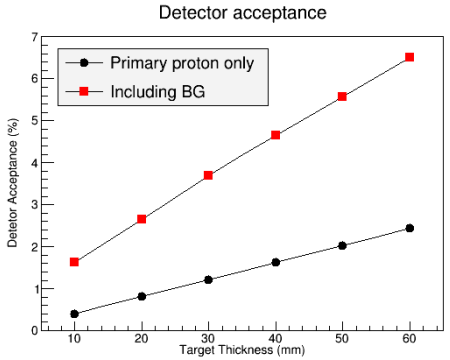








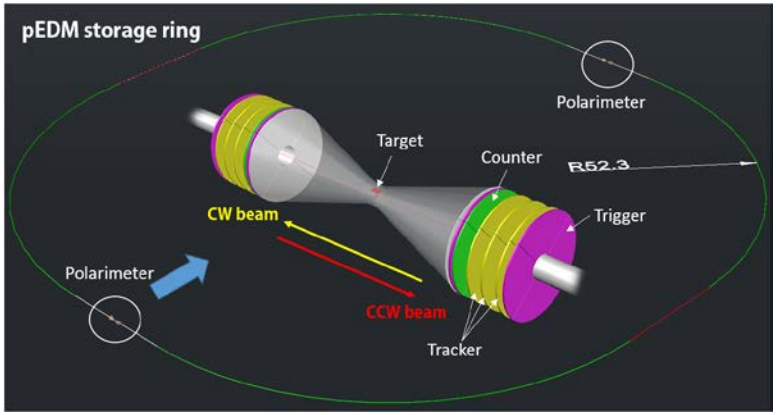




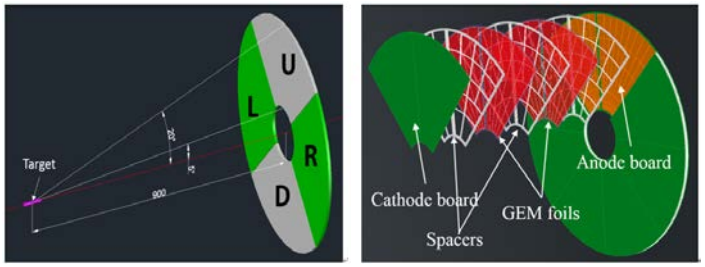
About detector counting rate

Beam parameters:

1. 701 MeV/c protons (E_k=233 MeV, β=0.6→v=1.8x10^8 m/s)
2. Ring circumference 500 m.
3. Revolution frequency is about 0.36 MHz.
4. About 100 bunches
   - ✓ 5 m between bunches
   - ✓ 28 ns bunch spacing
   - ✓ 0.36MHz x 100=3.6x10^7 bunches/s
5. **5x10^{10} particles/storage**
   - ✓ 5x10^8 particles/bunch
6. 4 polarimeters on the ring for CW/CCW beams

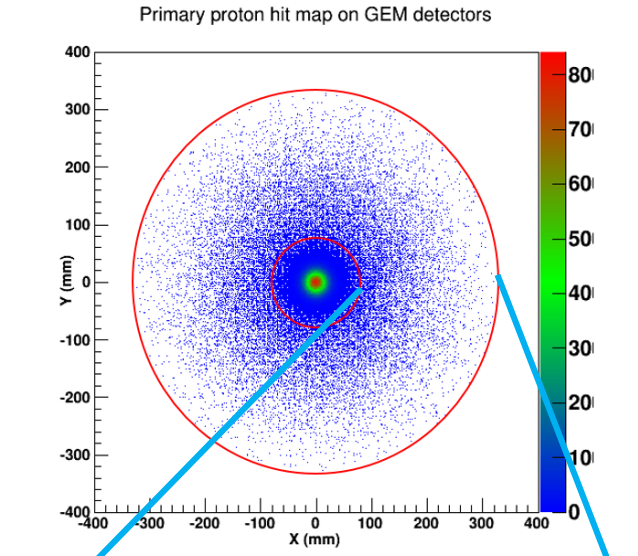


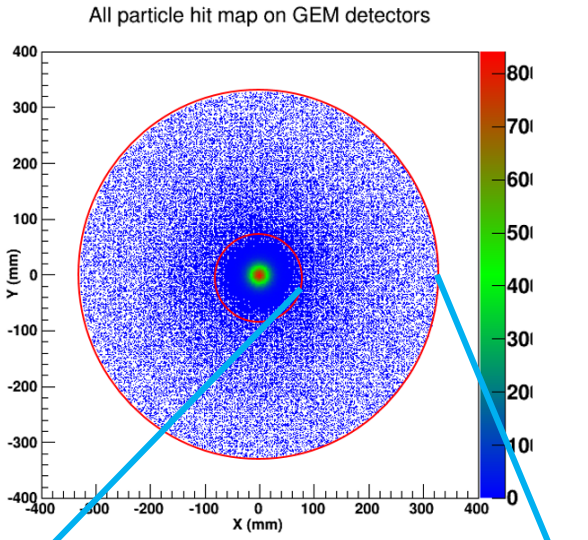
- ✓ Beam extraction for 1000s
- ✓ Assuming full extraction at the constant extraction rate for the entire extraction
  - **5x10^7 interactions/s**
- ✓ 5x10^7/3.6x10^7=1.4 interactions/bunch
- ✓ Assume 6.5 % of detector acceptance(including BG, from simulation)
  - **3.25x10^6 hits on detector/s**
  - 4 detectors(1024x4=4096 channels)
  - →**800 hits/ch/s (including BG)**
- ✓ For signal(2.4 % acceptance)
  - **1.2x10^6 hits on detector/s**
  - →**300 hits/ch/s (signal)**

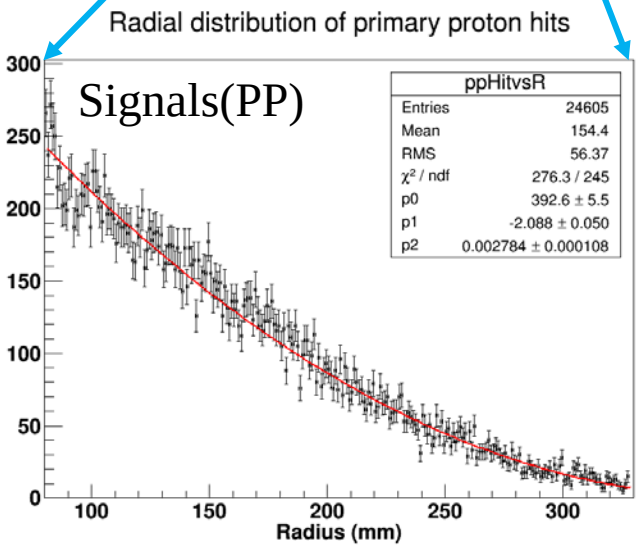


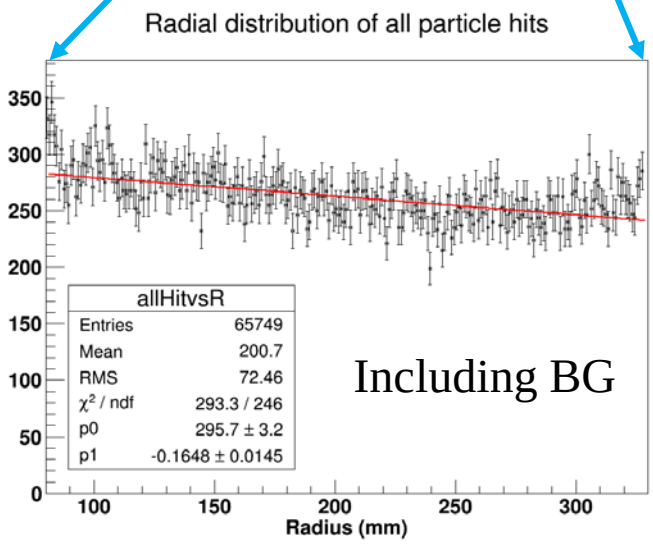
GEM-based polarimeter concept

Radial distribution of particle hits on the detector plane



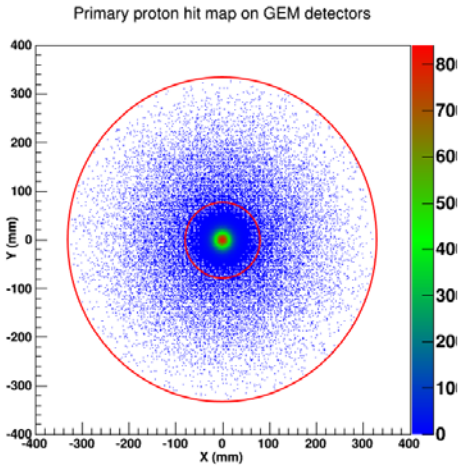






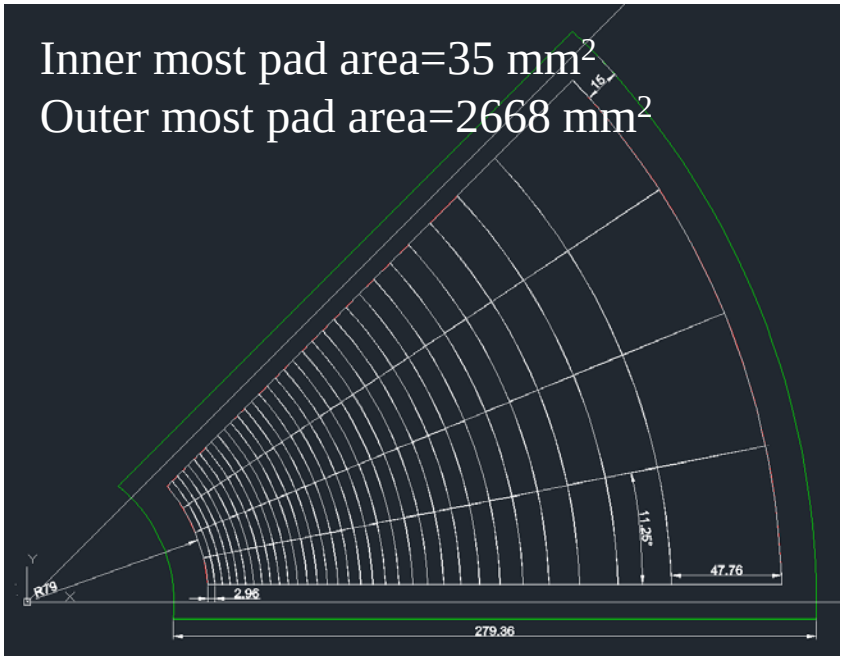
R=79~328 mm(5~20°)

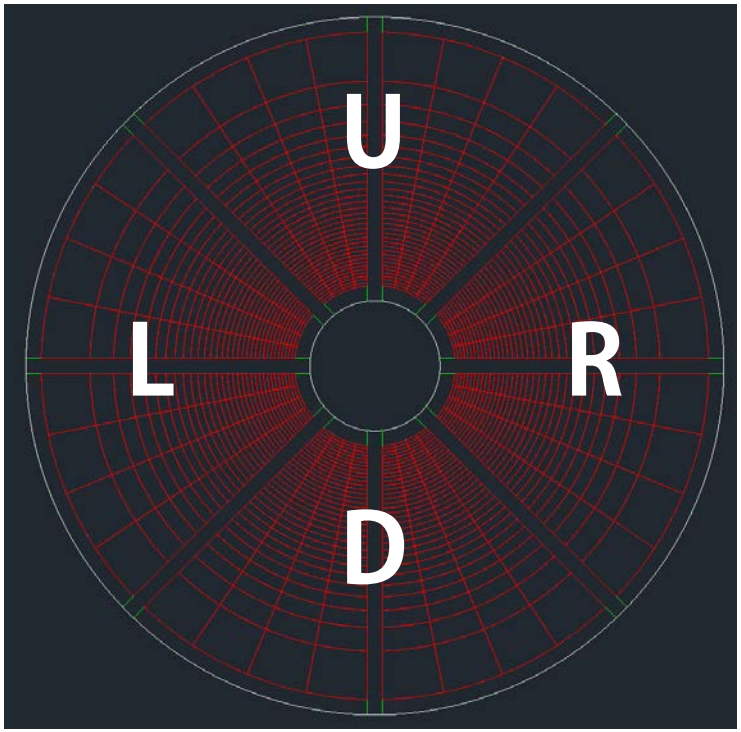
Equal rate anode pads/Primary proton only



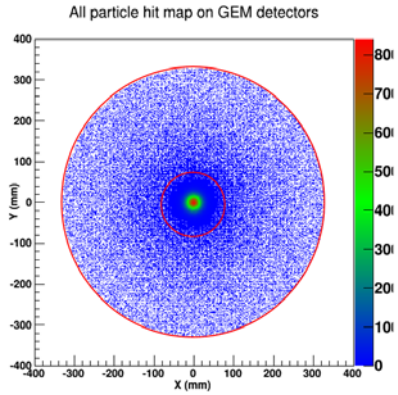
- 128 ch/octant
- 8 octants/polarimeter(counter)
- 1024 ch/polarimeter
- **300 Hz/ch(for signal)**

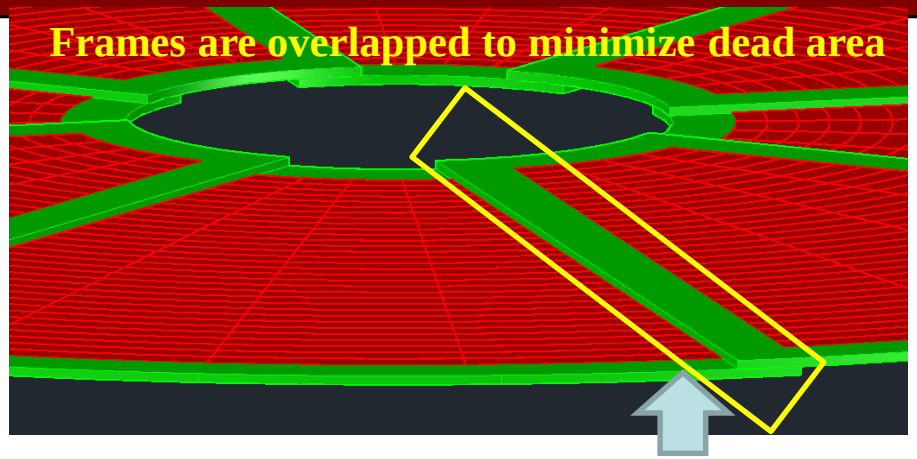
Counting rate on the inner most pad=857 Hz/cm^2
Counting rate on the outer most pad=11 Hz/cm^2





Equal rate anode pads/BG included

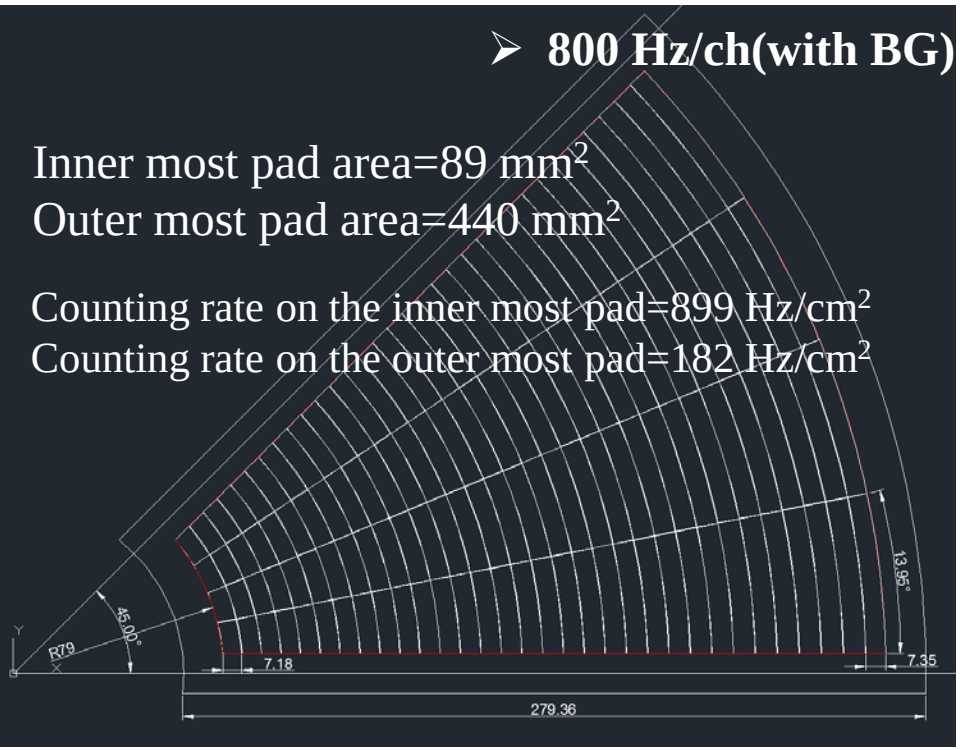


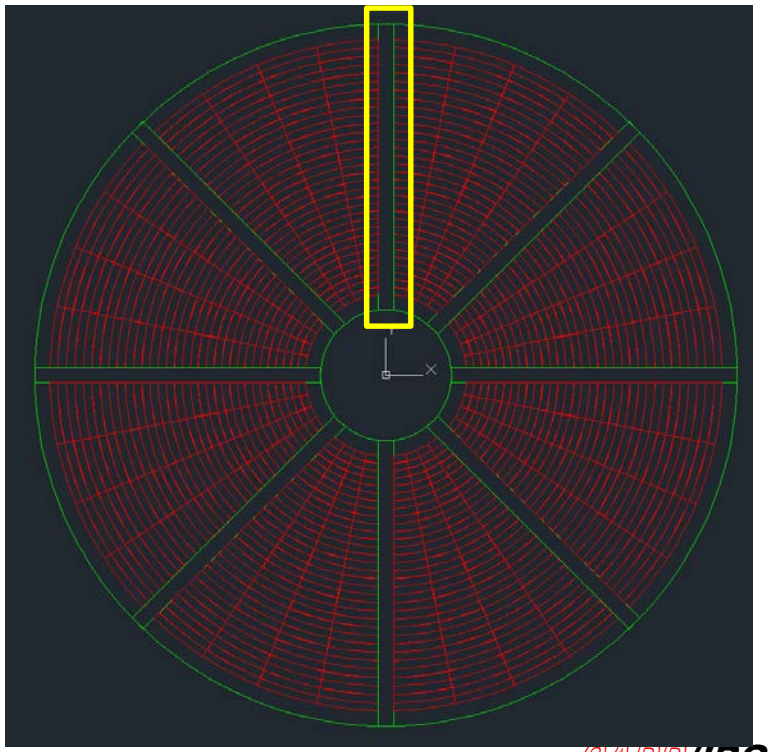


- **800 Hz/ch(with BG)**

Inner most pad area=89 mm^2
Outer most pad area=440 mm^2

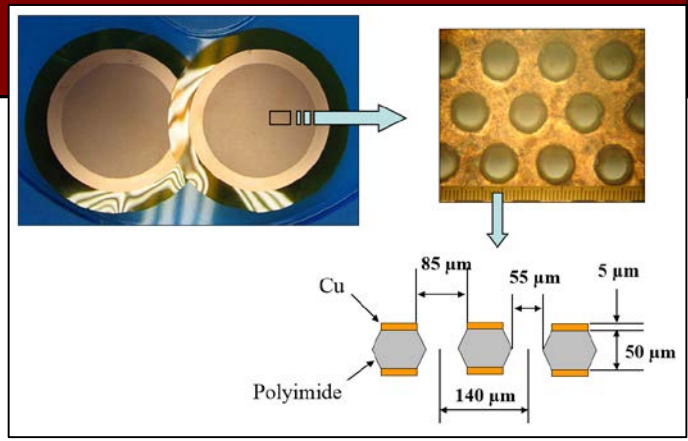
Counting rate on the inner most pad=899 Hz/cm^2
Counting rate on the outer most pad=182 Hz/cm^2



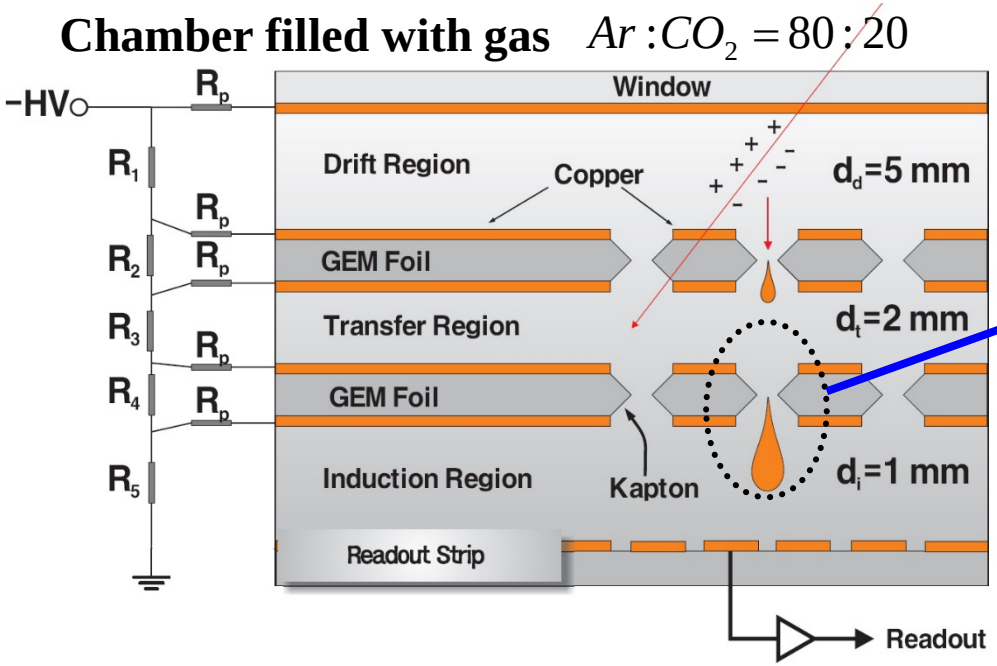


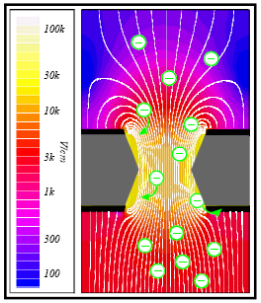
What is GEM detector?

- Cathode window is Cu coated Polyimide.
- HV is distributed through a resistive network
- Double/triple GEM layers (G ~100/layer)

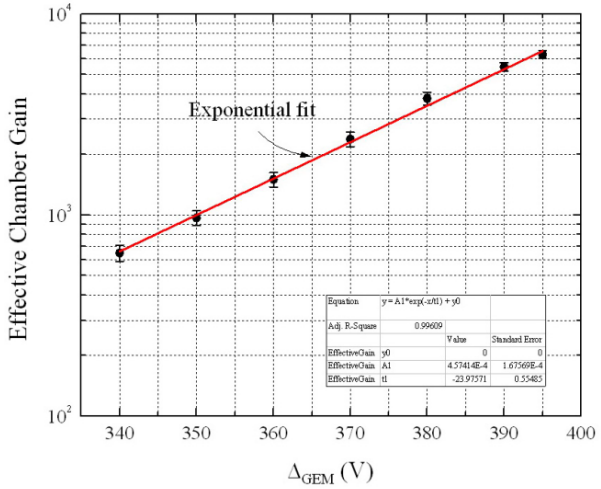


Chamber filled with gas $Ar:CO_2 = 80:20$





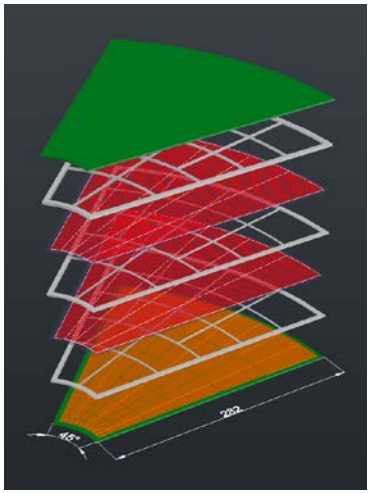
Electron Avalanche
→ Amplification



HV=-1900V: V_{GEM}=438V → E_{GEM}=8.76x10^4 V/cm

Characteristics of GEM detectors/Cost estimate

- Detector efficiency: ~100%(for MIP)
- Spatial resolution: 40μm(perpendicular track), 200μm(20^o track)
- Time resolution: 15 ns(Ar:CO_2=70:30), 5 ns(Ar:CO_2:CF_4:iso-C_4H_{10}=65/8/20/7)
- Energy resolution: ~20%(with X-ray)
- S/N ratio: 50(single GEM), 10^3(double GEM)
- Gains: $>10^4$
- Gain uniformity: ±10% over active area(10x10 cm^2)
- No significant gain shift for irradiation rates up to $5x10^5$ Hz/mm^2
  - ✓ No space charge or surface charging up
- Radiation hardness



Cost estimate (GEM chamber only)

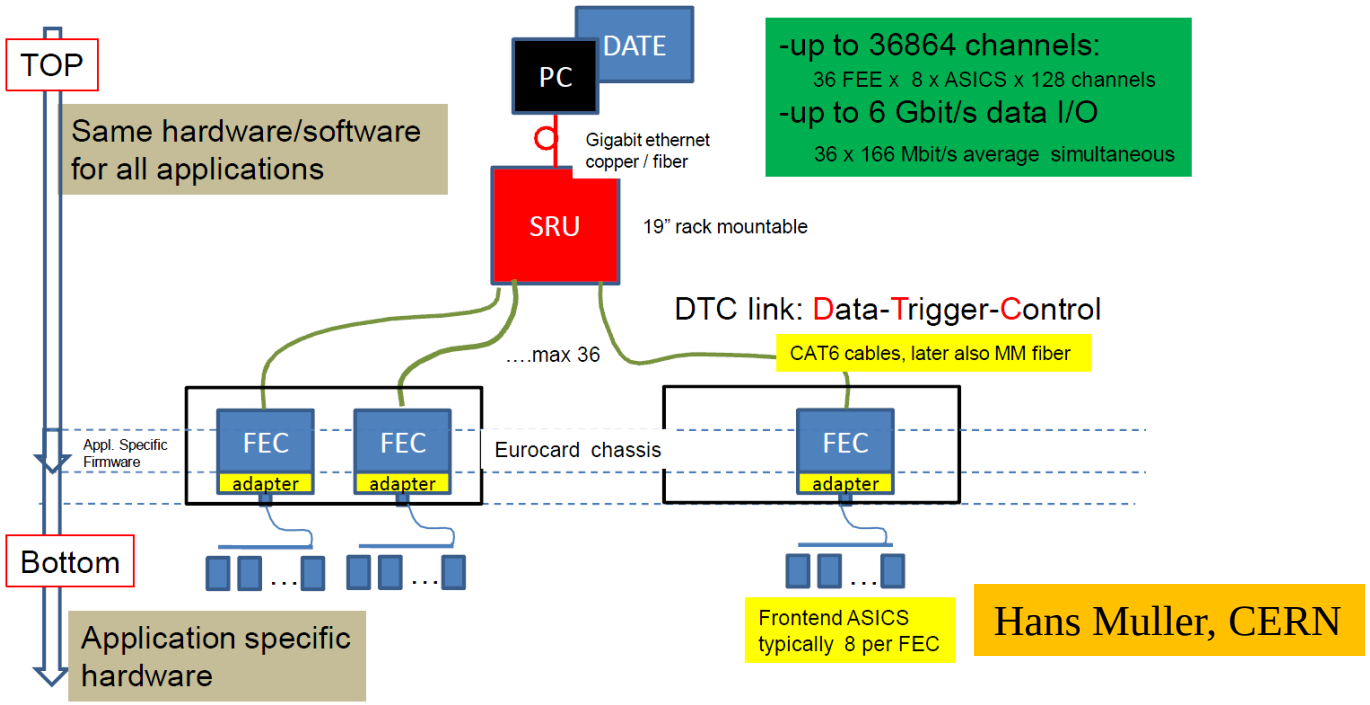
- ✓ ~$5000/octant GEM chamber with triple GEM
- ✓ 8 unit GEM counters per polarimeter layer
- ✓ 4 polarimeter systems for CW/CCW beams

→ Total 4x8x5000=$160,000

Other materials have to be considered:

- ✓ Gas system, DAQ system, Other assembly system like supporting structures etc..

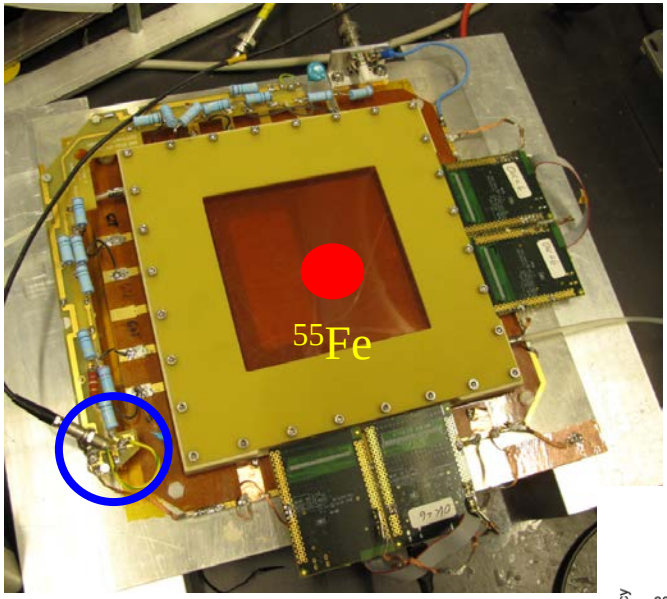
DAQ system/ GEM test



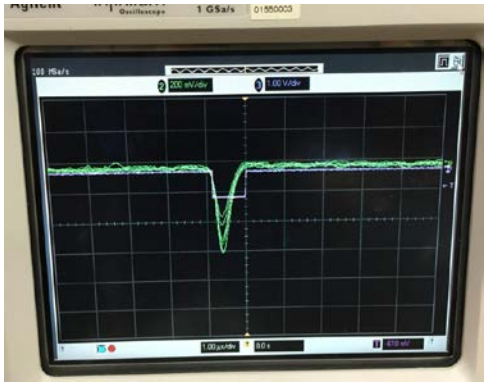
- ❖ SRS: Scalable Readout System
- ✓ Developed and distributed by the RD51 collaboration
- ✓ FE Hybrid+ adapter card+FEC+DAQ PC
  - Hybrid: **APV25**, **VMM**, GEMROC, Beetle, etc
  - APV: analog chip
  - VMM: digital chip with peak detection and time information

Test results/Source run(Fe55)

Test at CERN GDD lab.

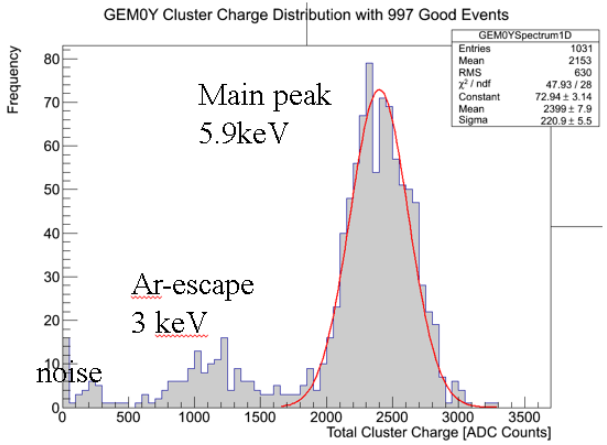


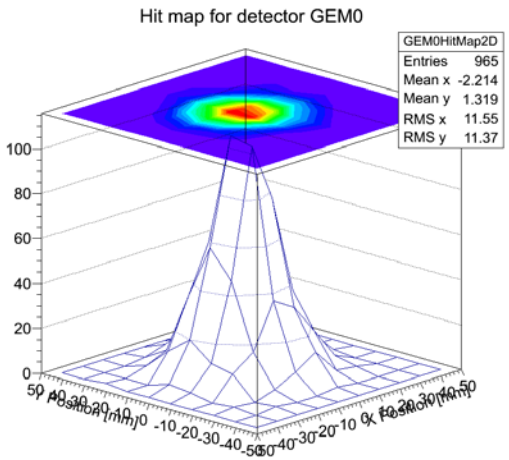
Trigger signal from the bottom electrode of the third GEM.
Rate=~280



- 10x10 cm^2 GEM chamber
- Triple GEMs
- Ar:CO_2=70:30
- HV=3900,3800V
- P=400μm strip→R~115μm

Fe55 energy spectrum





Summary and plans

1. MC simulation for detector design, FOM, systematic error study and so on.
   - ✓ **Adding spin-orbit interaction in the Geant4 code(Hoyong Jeong)**
2. Establishing lab. for detector construction and test
   - ✓ Clean room and other infra-structures
3. Working on DAQ system for GEM detectors
   - ✓ Visited CERN GDD lab. to learn the DAQ system and analysis program
   - ✓ Ordered one mini SRS system
4. Will start the detector design soon base on the results of the simulation
   - ✓ Need information on the space at the polarimeter sections for the detector installation
   - ✓ Diameter of beam pipe, longitudinal space available for detector stack etc..
5. Small GEM detector (10x10 cm2) will be ready soon and tested with SRS DAQ
   - ✓ Radiation source: Fe-55, Cs-137, Ru-106, Sr-90 etc
   - ✓ Cosmic rays

Center for Axion and Precision Physics (CAPP/IBS, KAIST)

We are working on:

- **Axion search**
- **Proton/Deutron EDM**
- **Muon g-2 experiment**
- **Etc.**

Thank you!

http://capp.ibs.re.kr/html/capp_en/

Located at KAIST campus in Daejeon, South Korea