Preliminary Design Considerations for a Faraday Cup for a 5 MeV RF Photo Gun

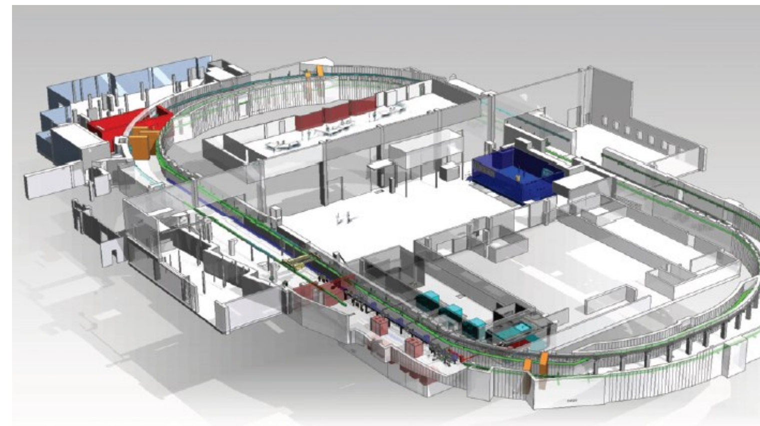
Gero Kube[(1)] and Sergey Strokov [(2)]
(1) DESY (Hamburg) (2) Tomsk Polytechnic University (Russia)

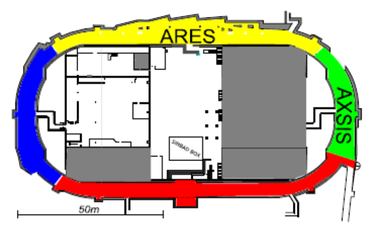
- Introduction: SINBAD / ARES @ DESY
- Faraday Cup Design: general Considerations
- Geant4 Simulation Results

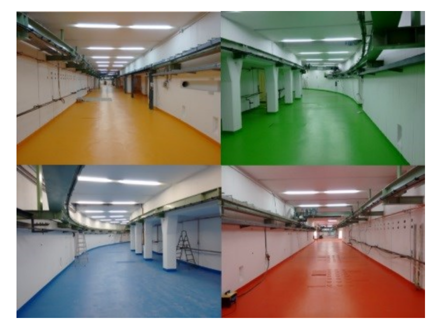
Accelerator R&D Facility „SINBAD"

- Short Innovative Bunches and Accelerators at DESY
  - currently under construction
    - → re-use of former DORIS tunnel
  - multiple experiments on acceleration of ultra-short electron bunches and advanced acceleration schemes
  - will initially host 2 experiments:
- AXSIS
  - Attosecond X-ray Science: Imaging and Spectroscopy
    - → ERC-synergy grant funded project
  - THz acceleration in dielectric loaded waveguides
    - → develop compact ~ 15 MeV accelerator
  - X-ray generation via Inverse Compton Scattering (ICS)
- ARES
  - Accelerator Research Experiment at Sinbad
    - → 1st step: build 100MeV electron linac for ultra-short bunches
    - → 2nd step: optimize performance, compare various compression techniques
    - → 3rd step: use of beam (ACHIP, THz experiments, Trans-National Access…)

SINBAD



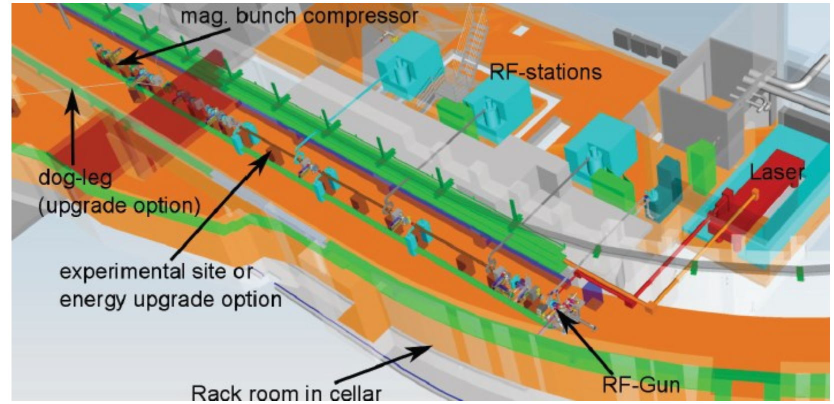




U. Dorda et al., Proc. IPAC 2017, Copenhagen (Denmark), MOPVA012

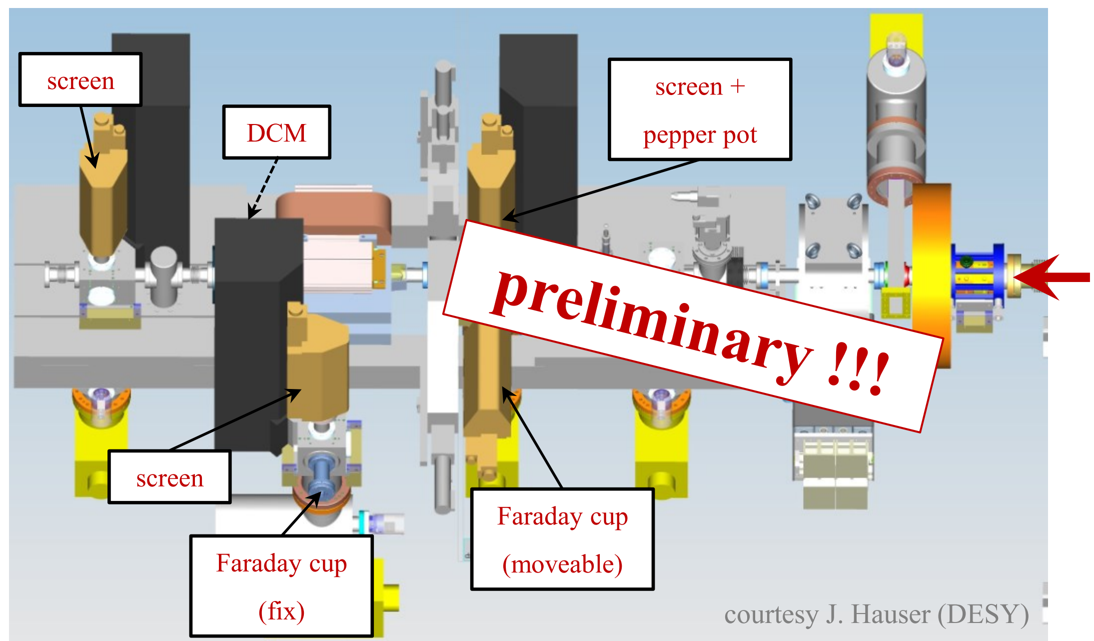
ARES Linac

- linac parameters
  - normal conducting linac
    - → E ~ 100 MeV, ΔE/E ~ 0.2%
    - → Q_b = 0.5 – 30 pCb, (sub-) fsec duration
  - 2 about 4.5 m long S-band structures (upgrade: 3)
  - magnetic bunch compression / velocity bunching
  - upgrade option for 2nd experimental site



U. Dorda et al., Proc. IPAC 2017, Copenhagen (Denmark), MOPVA012

- gun
  - modified version of REGAE gun
    - → S-band RF photo gun (5 MeV)
  - followed by ~ 2.5 m long beam line
    - → beam diagnostics section
  - operation shall start end of 2017

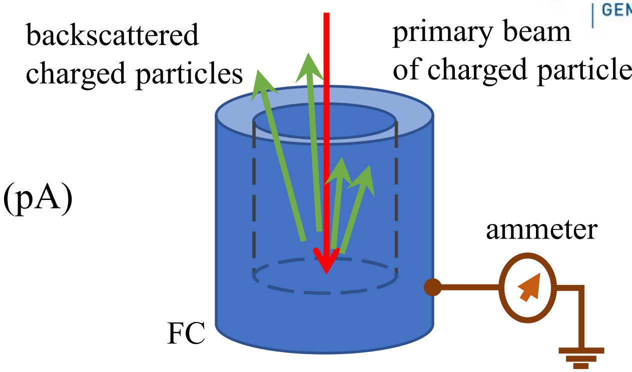


courtesy J. Hauser (DESY)

- moveable Faraday Cup (FC)
  - compact design (< 30 mm)
  - particle free vacuum condition
  - accuracy better than 1%

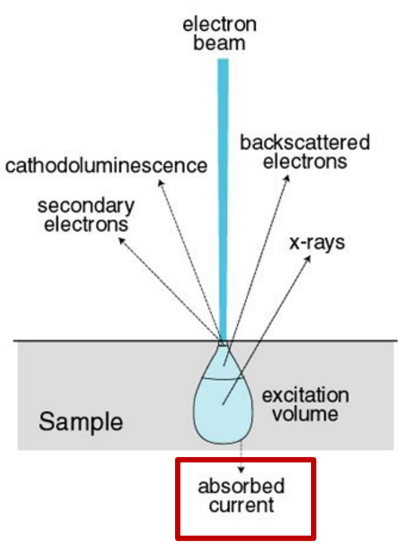
Faraday Cup

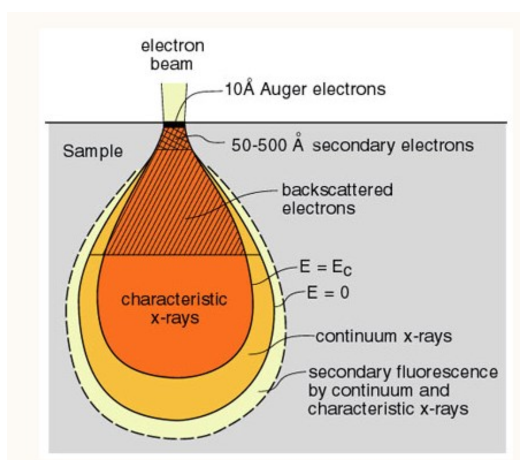
- FC operational principle
  - beam stopper, isolated from beam pipe ground potential
  - connected to current meter → sensitive to low currents (pA)

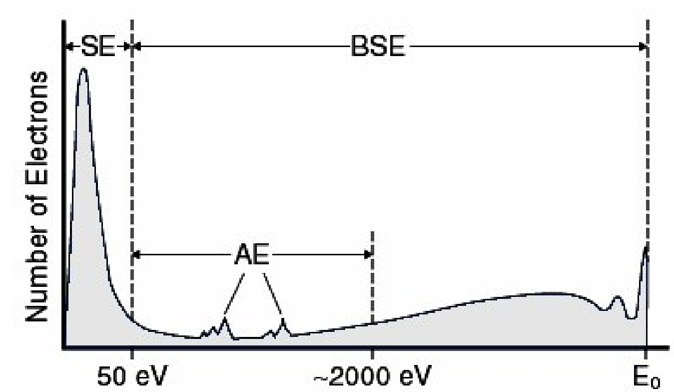


- signal leakage
  - goal: minimize number of escaping electrons
    → (i) choice of material & geometry, (ii) external repelling mechanisms
  - consider experience of electron microscopy
    → use of "leakage signals" for material analysis

- backscattered electrons (BSE)
  → elastic scattering
- secondary electrons (SE)
- Auger electrons (AE)
  → inelastic scattering
- X-rays (Bremsstrahlung)
  → particle shower





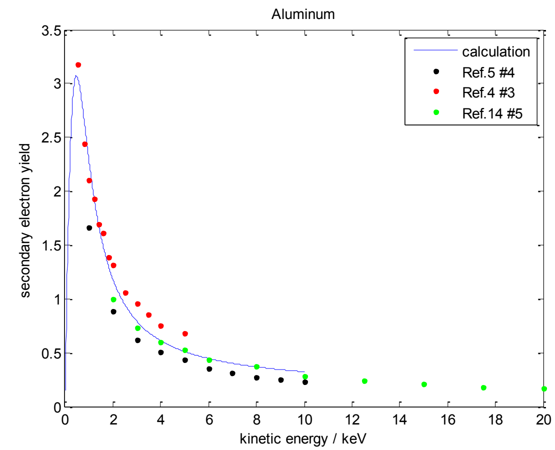


http://nau.edu/cefns/labs/electron-microprobe/glg-510-class-notes/signals/

Secondary- / Auger Electrons

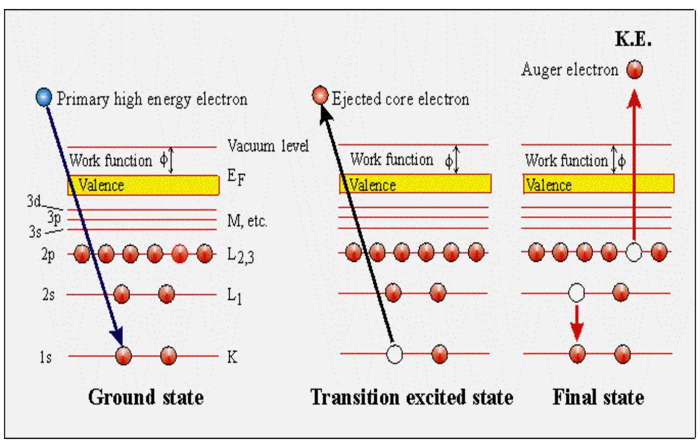
- secondary electrons
  - takes place between incident electrons and outer (weak bound) electrons of the atom
  - outer electrons can be ejected from atom with energies lower than 50 eV
  - if SEs are produced near the surface with energy higher than surface energy (~ 6eV) → escape to vacuum

→ typically to neglect for MeV beams

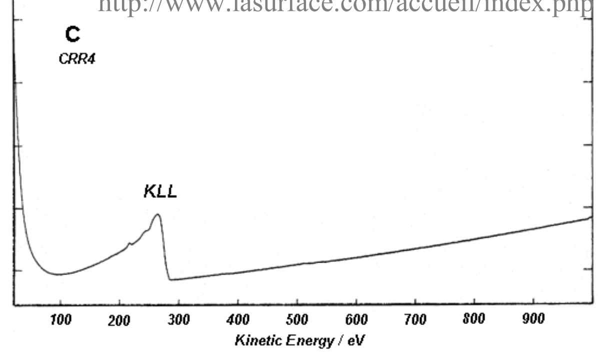


- Auger electrons
  - occurence of electron vacancy in core level (K, L)
  - vacancy filled by secondary electron from upper energy level
  - energy of emitted electron can serve for

    (i) emission of X-ray (Z > 30) (ii) ejection of Auger electron (non-radiative process)



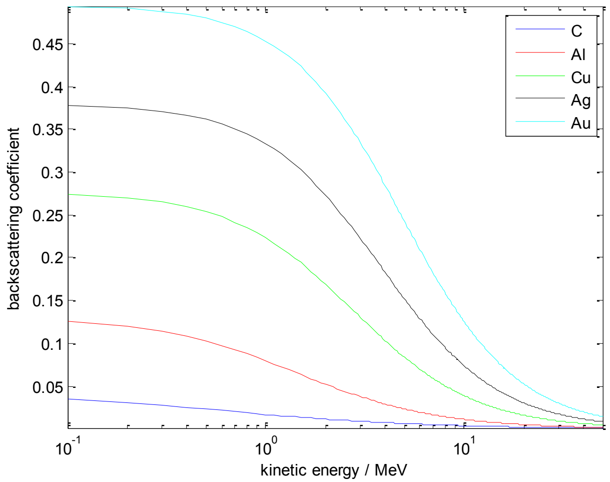
http://www.lasurface.com/accueil/index.php

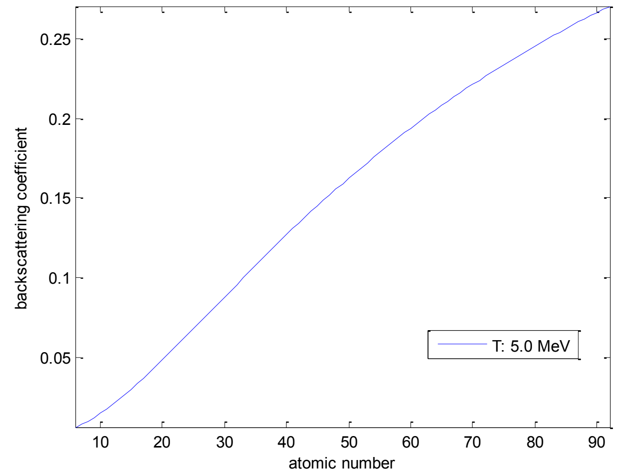


→ to neglect

Backscattering and Bremsstrahlung

- backscattering
  - parametrization for few MeV energies: T. Tabata, R. Ito and S. Okabe, Nucl. Instruments and Methods **94** (1971) 509





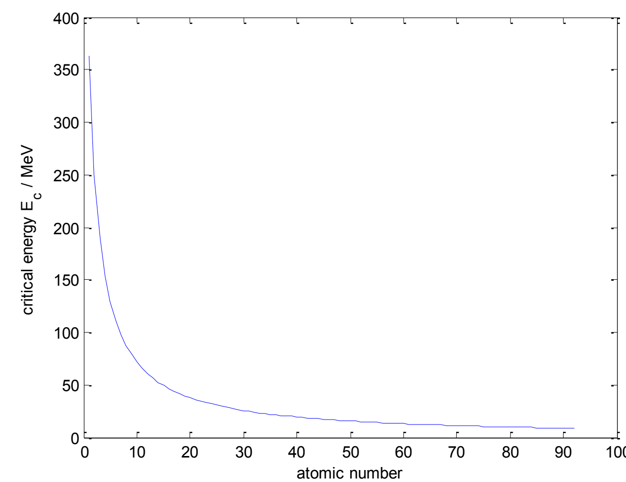
	Z	η
C	6	0.0063
Al	13	0.0234
Cu	29	0.0838
Ag	47	0.1522
Au	79	0.2431

- Bremsstrahlung
  - above 2 x 0.511 MeV: pair production

    → reduce Bremsstrahlung generation
  - characterized by critical energy E_c

    → Bremsstrahlung losses = collisional losses (i.e. ionization)

reduce signal losses ➡ use of low Z materials



Material Choice

- periodic table
  - suitable low-Z material → reduce signal losses

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	~~6 C~~	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr

→ Carbon

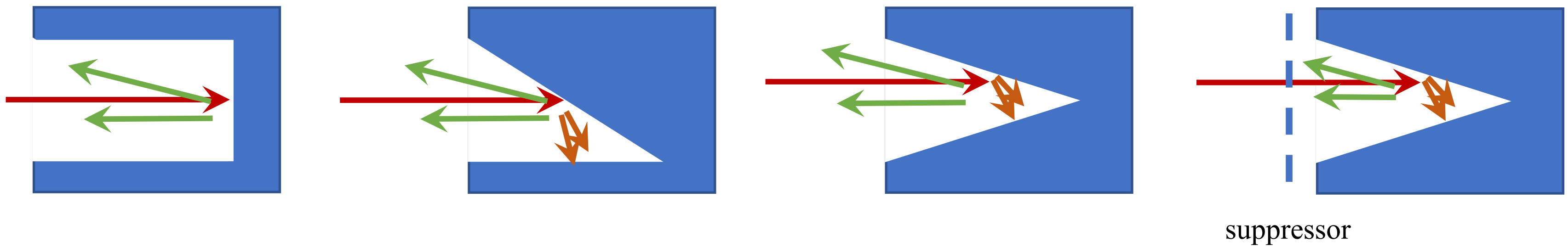
- occurence of carbon
  - graphite
    → DIAMOND, based on SLS design
    A. Morgan, Proc. DIPAC 2005, Lyon (France), POM011
    particle free vacuum
  - diamond
    → semiconductor, band gap ~ 5.5 eV → doping with boron ???
    time
  - glassy carbon (trading name: SIGRADUR)
    → test of vacuum compatibility:
    outgasing
    (acts as sponge…)

http://www.htw-germany.com/index.php5?lang=en&nav0=0

- final choice → **Aluminum**

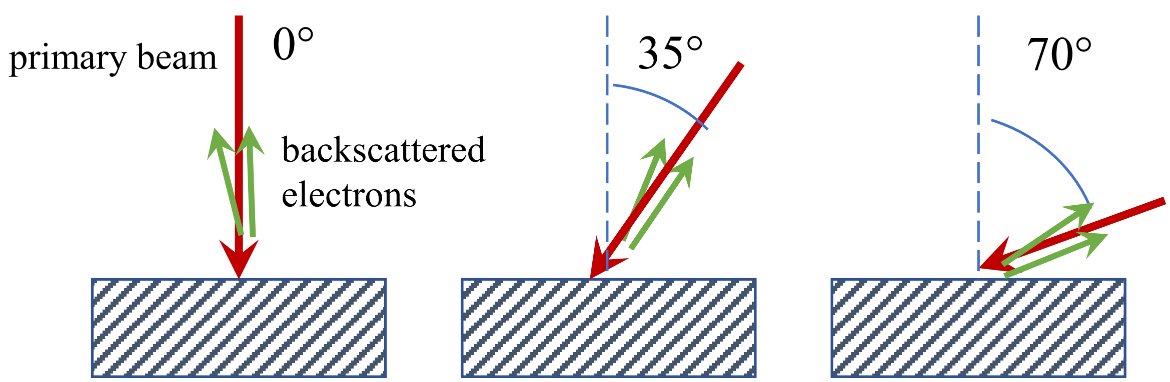
Geometry

- investigation of various geometries → suppression of backscattering



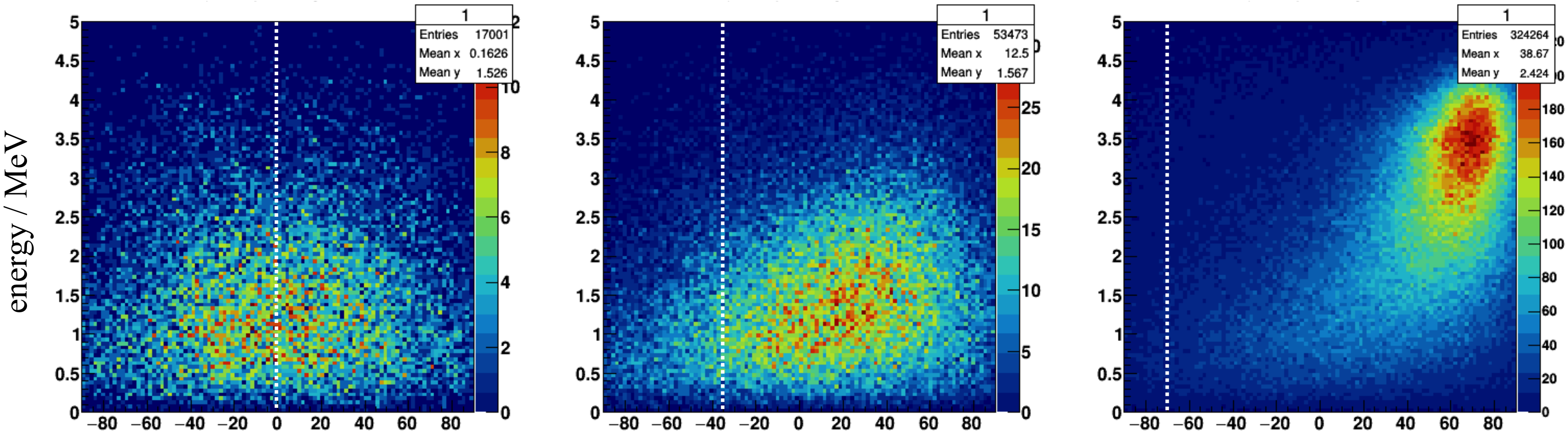
  - task: find geometry which produces smallest quantity of backscattered particles

- Geant4 simulation
  - beam: pencil-like, 5 MeV electrons, 10^6 particles
  - geometry: beam hits Al-target under three different angles wrt. target surface:

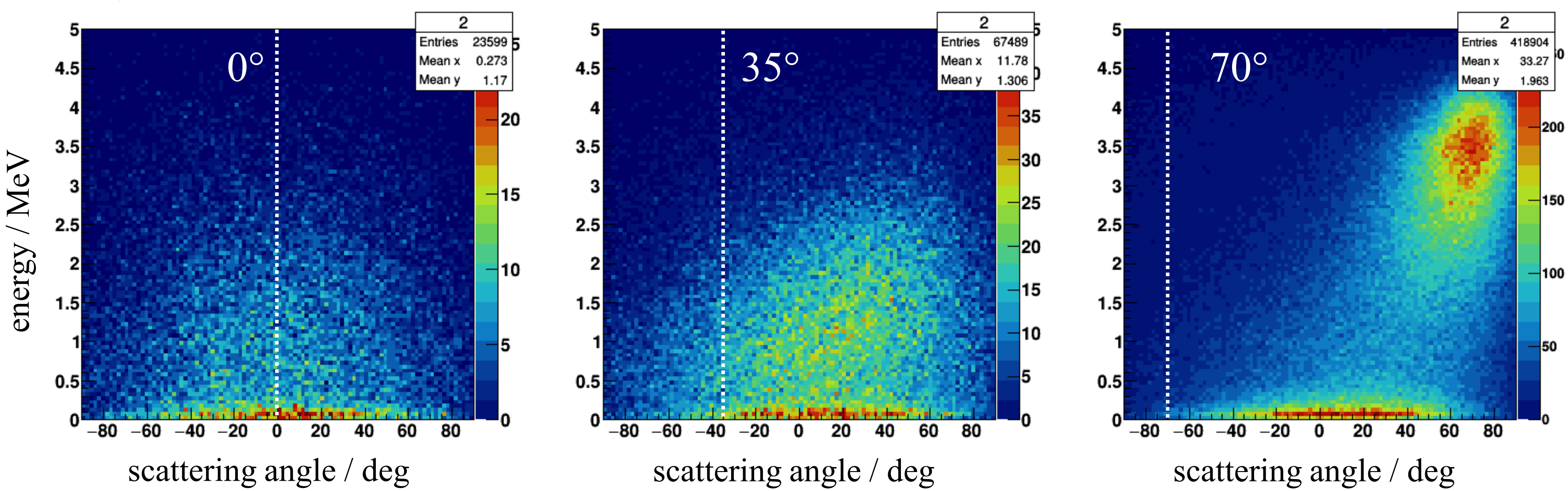


Simulation Results (1)

- primary electrons, scattered from Al substrate

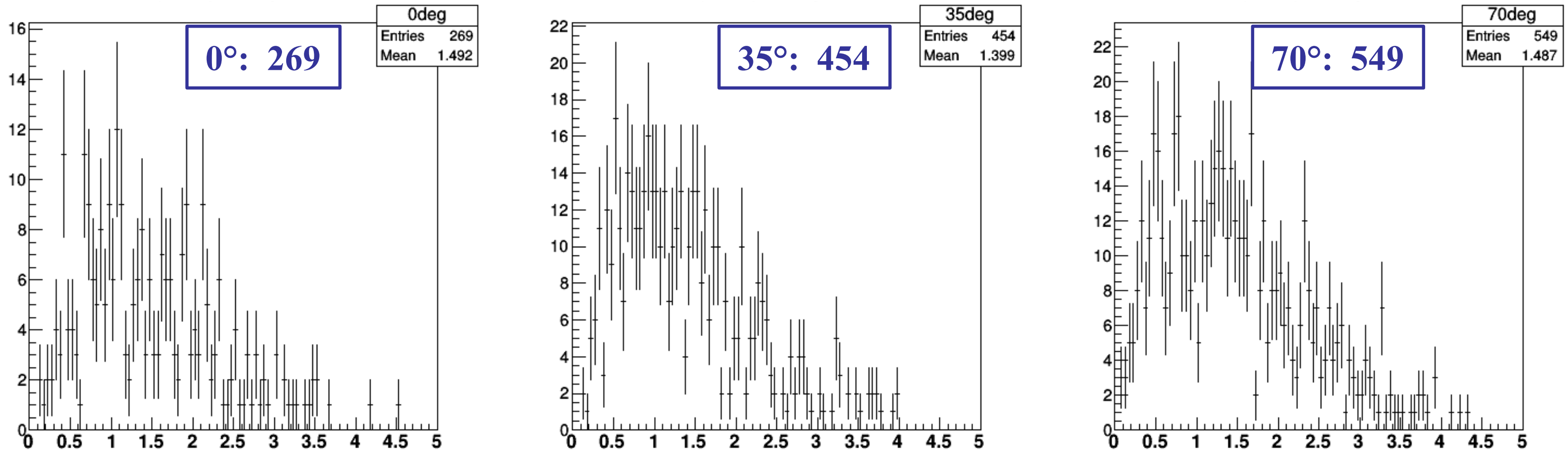


- primary and secondary electrons, scattered from Al substrate

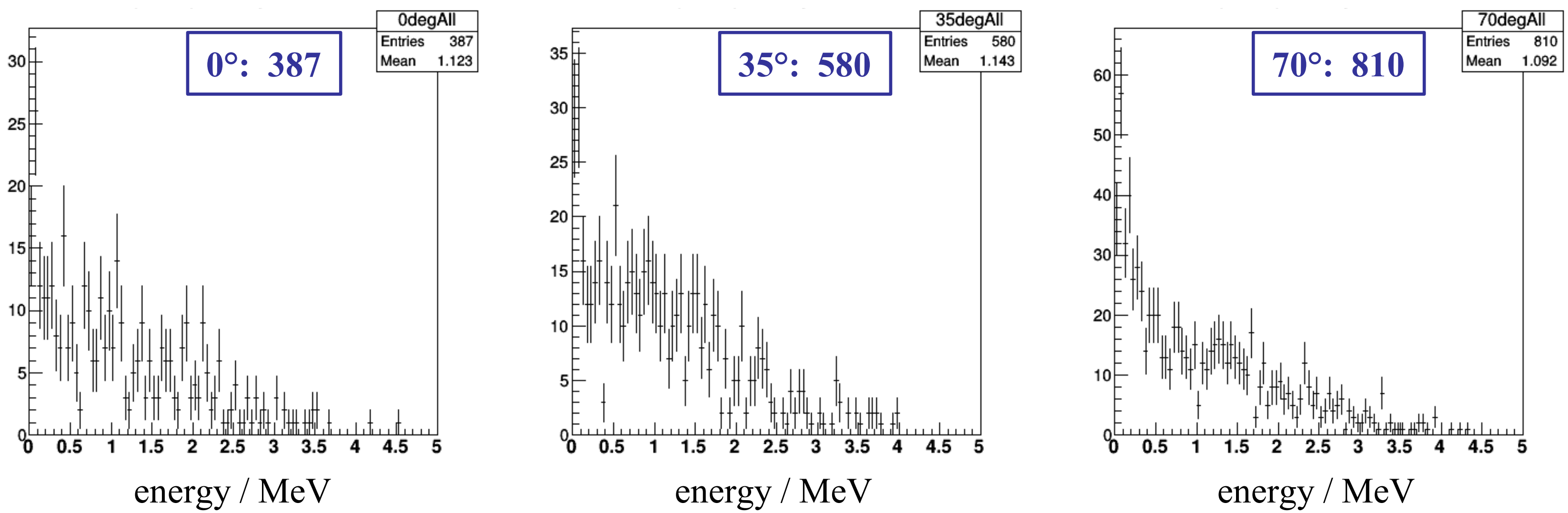


Simulation Results (2)

- primary electrons, scattered from Al substrate



- primary and secondary electrons, scattered from Al substrate



Design Considerations

- recapitulation
  - material: Al → vacuum requirements & backscattering
  - geometry: normal incidence → backscattering
  - suppressor electrode: no need → backscatter energies to high

- requirement
  - compact design: stopping power

    → charcterization via CSDA range

    (Continuous Slowing Down Approximation)

  - estar (NIST) calculation → 5 MeV

	Z	R_{csda}/mm
C	6	17.09
Al	13	11.46
Cu	29	3.80
Ag	47	3.33
Au	79	1.90

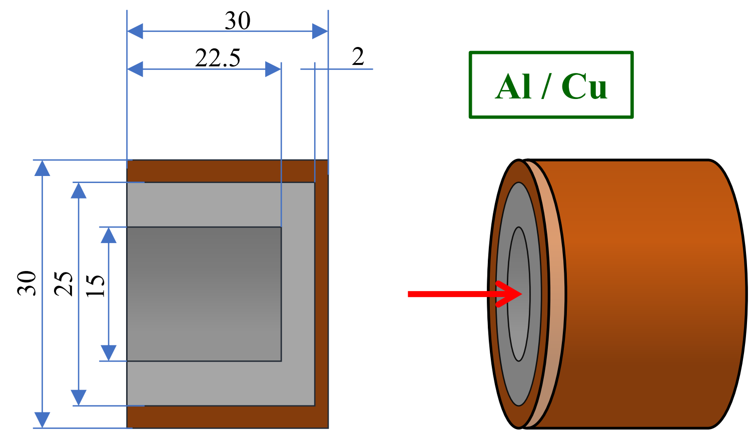
http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html

⇒ Al not best choice…

⇒ material combination:

→ low Z: low backscattering

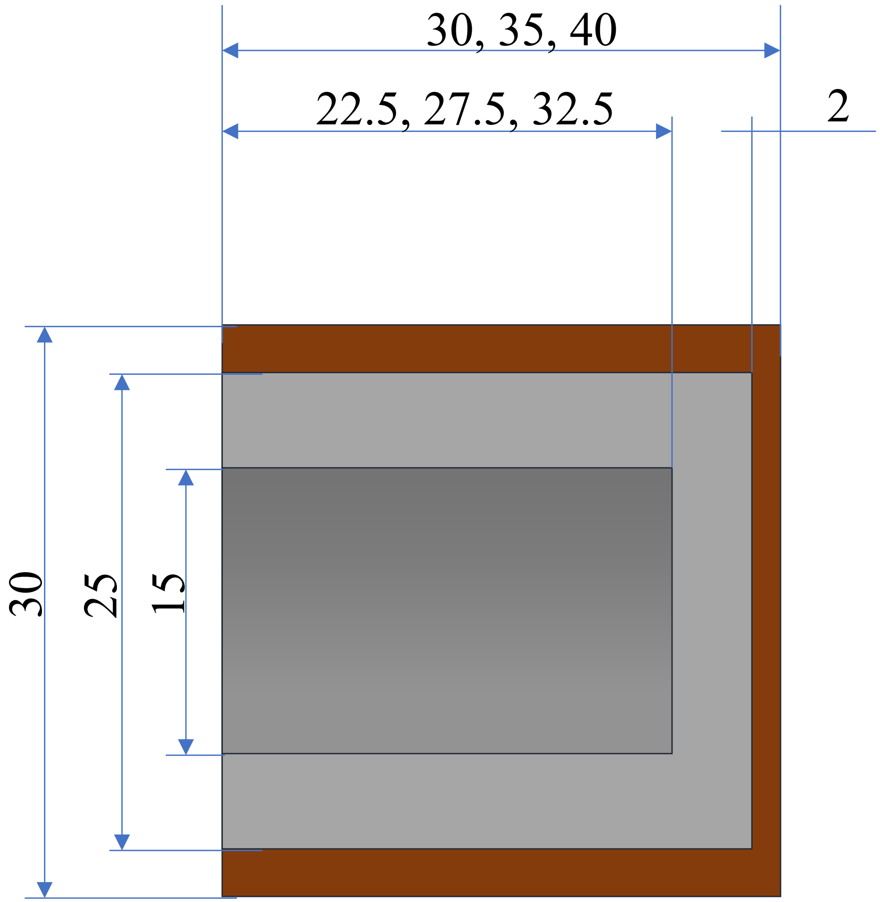
→ high Z: high stopping power



- further optimization option
  - solid angle for particle escape

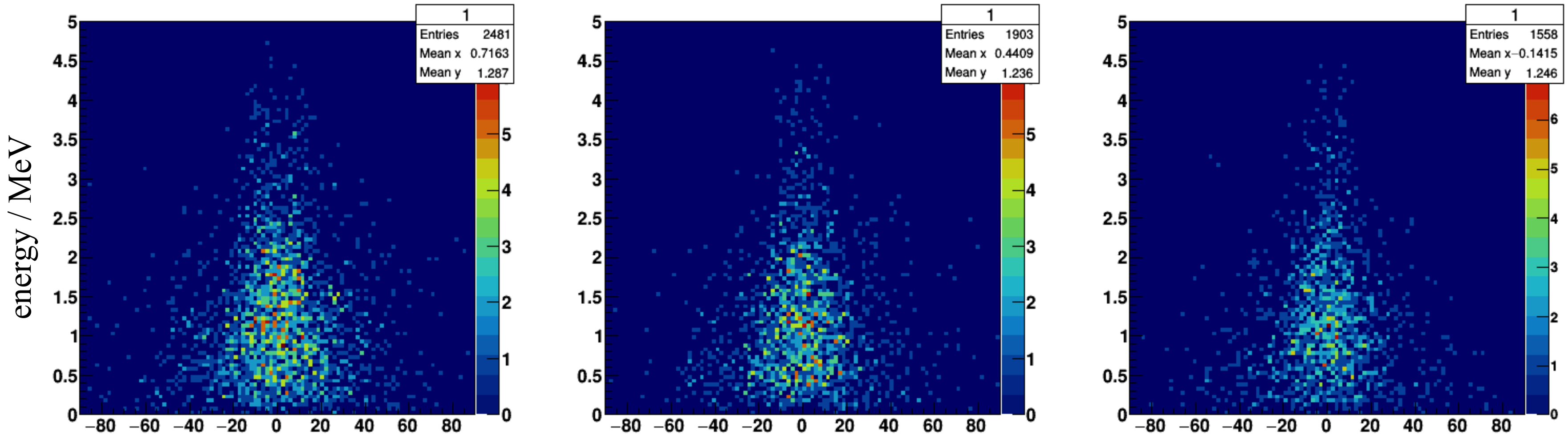
Influence of Solid Angle

- FC length variation
  - 3 different FC lengths: 30mm, 35mm, 40mm
  - keep bottom thickness of FC constant: 7.5mm Al + 2mm Cu

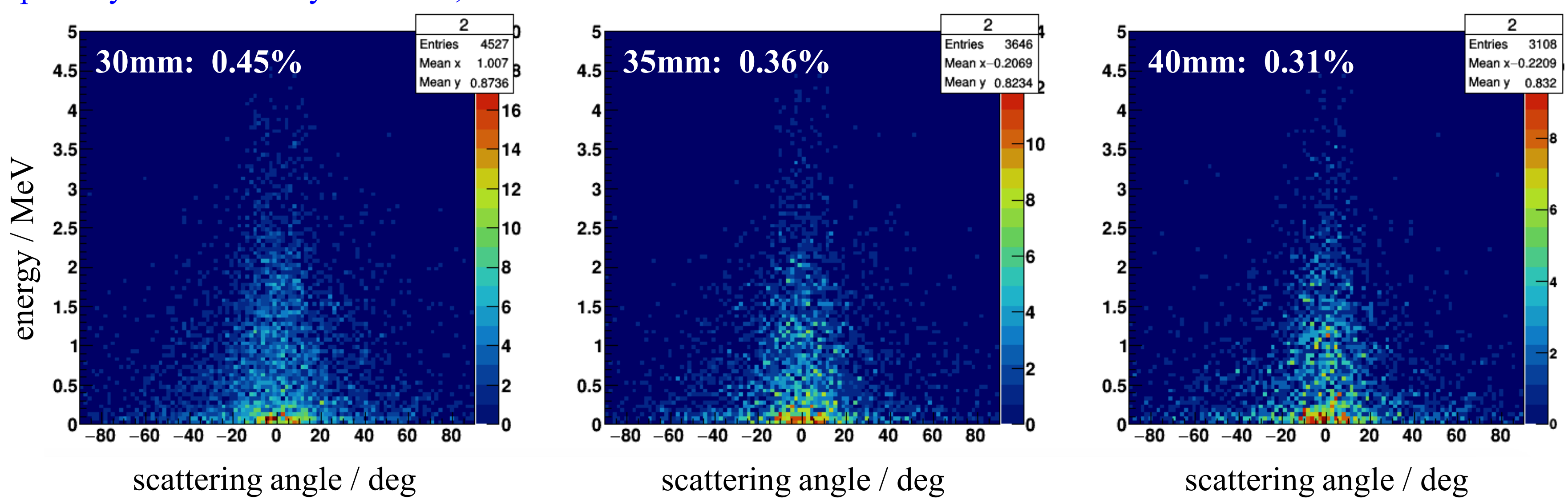


Simulation Results (1)

- primary electrons, backscattered from FC

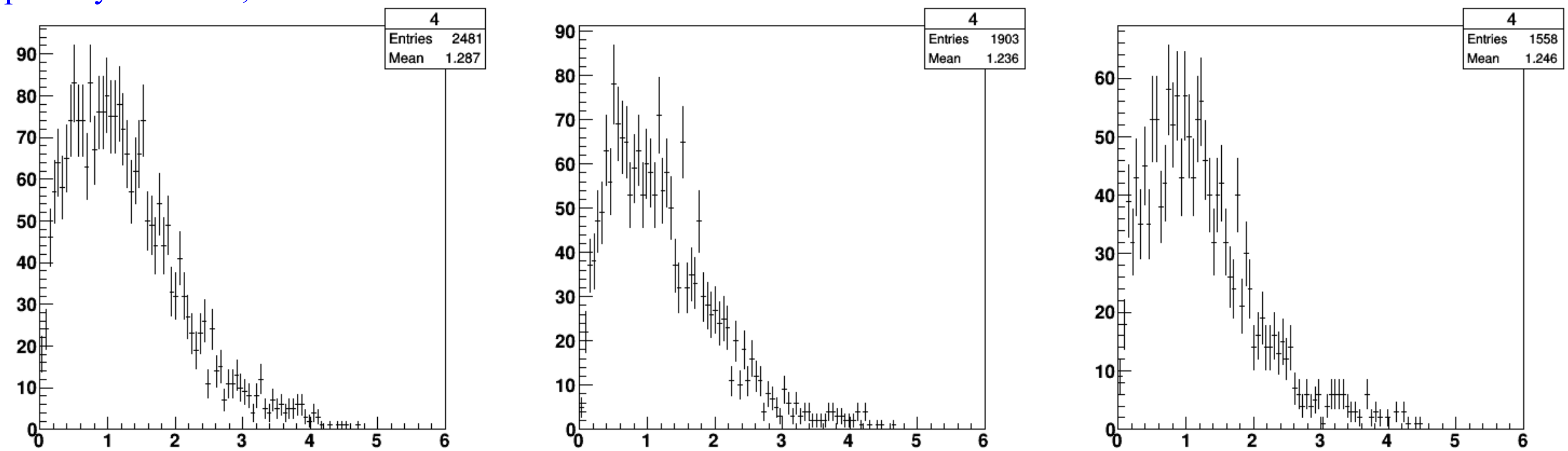


- primary and secondary electrons, backscattered from FC

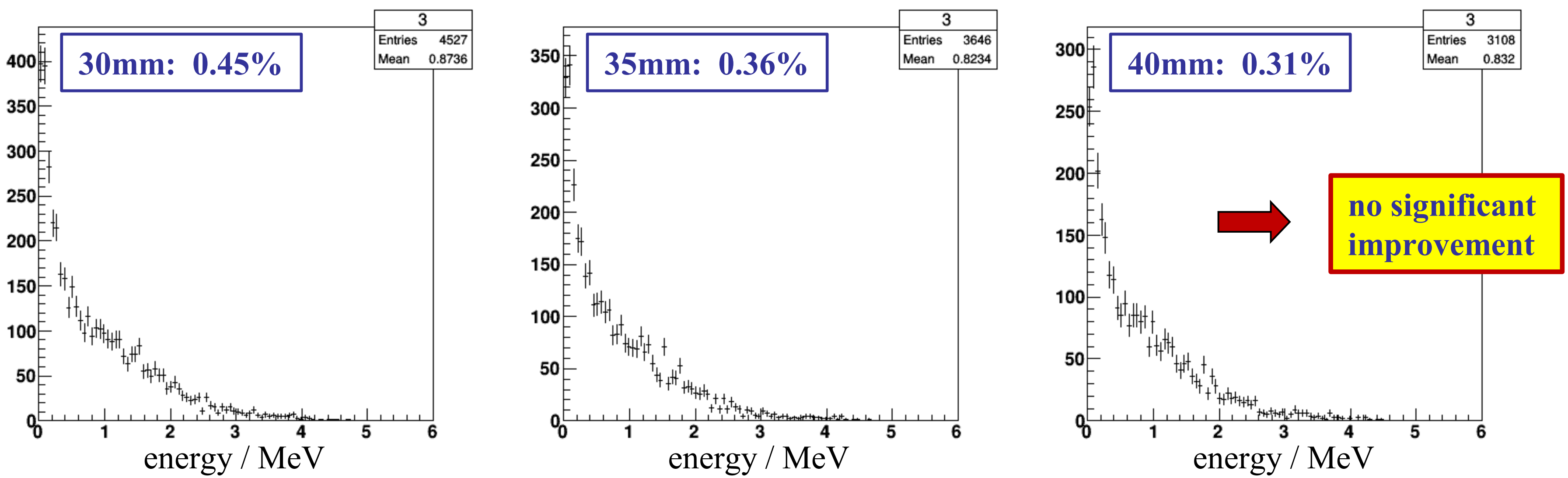


Simulation Results (2)

- primary electrons, backscattered from FC



- primary and secondary electrons, backscattered from FC

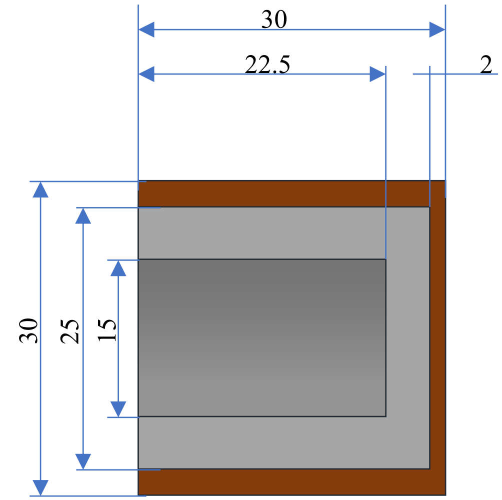


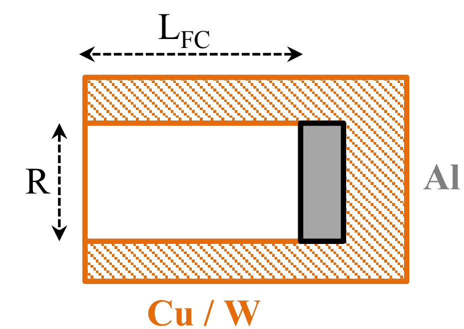
Summary and Outlook

- design study for compact Faraday cup
  - 5 MeV electrons
  - particle-free vacuum conditions
  - compact design
- investigation of particle leakage
  - backscattering is dominant loss process
    - → material choice: low Z
    - → tilt angle of stopping surface: normal incidence
    - → depth of cup L_{FC}: less important

      (P. Strehl, *Beam Diagnostics and Instrumentation*, Springer (2006): for $L_{FC} > R$)
- compact FC design
  - simulated particle losses ~ 0.45%
- change of specifications
  - outer dimensions to large… → new simulations under way…
- what happens, if a monitor is not designed by a beam diagnostician…
- heat load
  - not considered, but uncritical

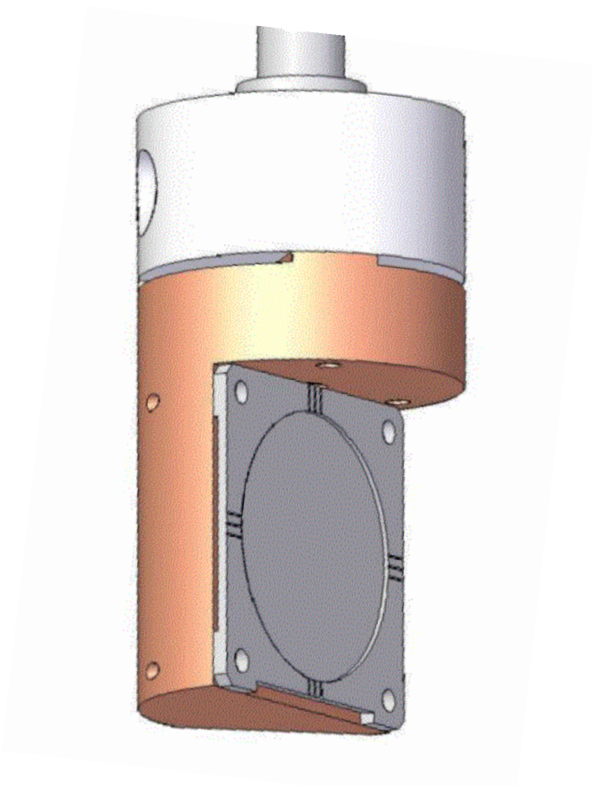
    → $Q_b = 0.5 – 30$ pCb



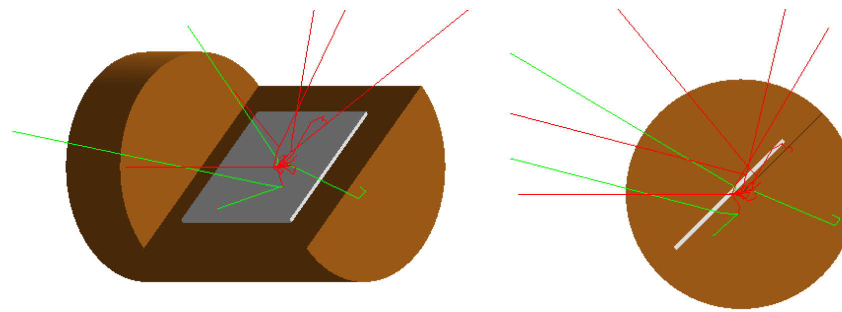


Simulation of present FC Design

- Cu based FC
  - 0.5mm thick Al plate placed 1mm above surface
    - → covered with YAG powder (screen)
  - surface tilted by 45°
    - → observation geometry for screen



- Geant4 simulation
  - 10^6 primary electrons



energy distribution of electrons escaping from FC