UPPSALA UNIVERSITET

Diagnostic setup for 12 GHz stand-alone test-stand

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Breakdowns, what to measure?

Experience from the existing klystron based high-power RF test stand and CTF3/CLIC (CERN, KEK, SLAC)

Typically observed parameters (not always simultaneously):

- Incident RF power
- Reflected power from the breakdown site
- Transmitted power through the structure
- Emitted light
- X-rays
- Harmonics of the working frequency
- **Electron (ion) currents at exit from ACS**
- Pressure changes
- Acoustic signals

"Standard" equipment

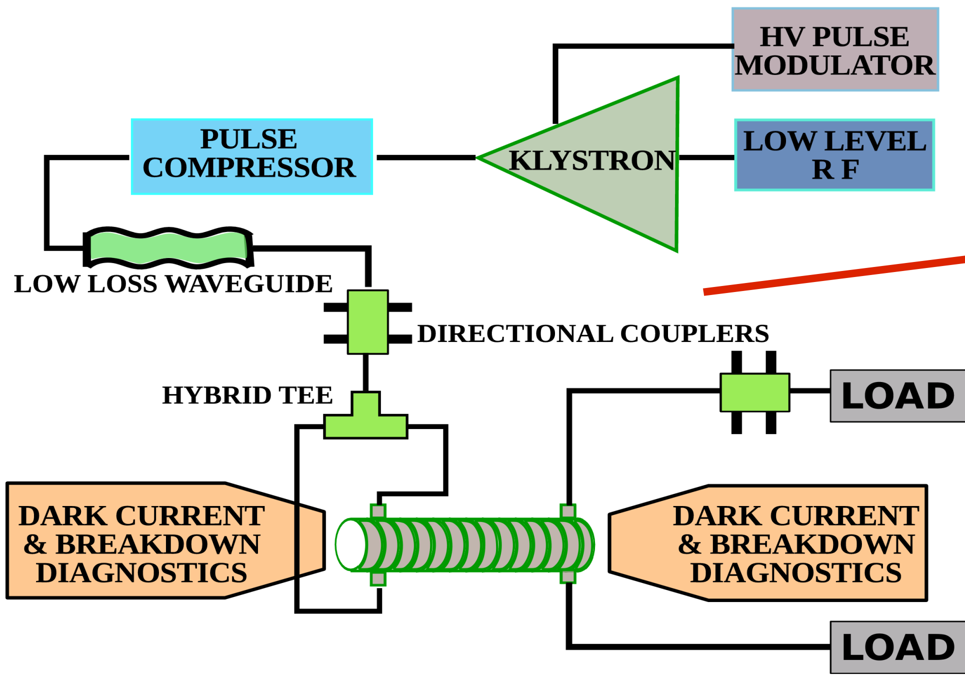
The Mission

Instrumentation for the test-stand must be versatile and allow for the conditioning of the accelerating structure with measurements of the breakdown rates at different power levels as well as detection of the emitted electric currents directly relevant to breakdown physics.

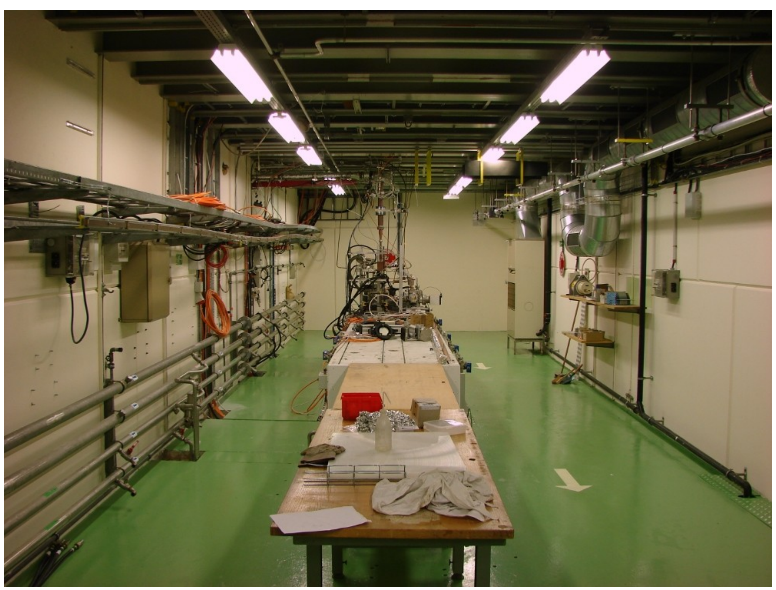
- **Dark current** (DC): current escaping from ACS under high-field operation due to the field emitted electrons
- **Breakdown current** (BRC): arcing in the region of high electric field leads to much higher current emission
- Study ...
  - What?
    - Phenomena involved in DC/BRC emissions and transport
  - Why?
    - Need to understand how field emission leads to the breakdown, identify important parameters for ACS conditioning (power level, field level, pulse length)
    - What is the effect of the DC/BRC electrons on bunches, can they affect orbit/emittance? Can be a problem to various diagnostic equipment along linac?

Where to measure?

12 GHz test stand in CTFII



The incident, reflected and transmitted power will be measured at the directional couplers



KLYSTRON	
Frequency	11.9942 GHz
Peak power	50 MW
Repetition rate	50 Hz
HV Pulse Modulator	
Type	solid state
Cathode current	335 A
Cathode voltage	450 kV
Pulse flat top	1.5μs
Repetition rate	50 Hz

Main idea

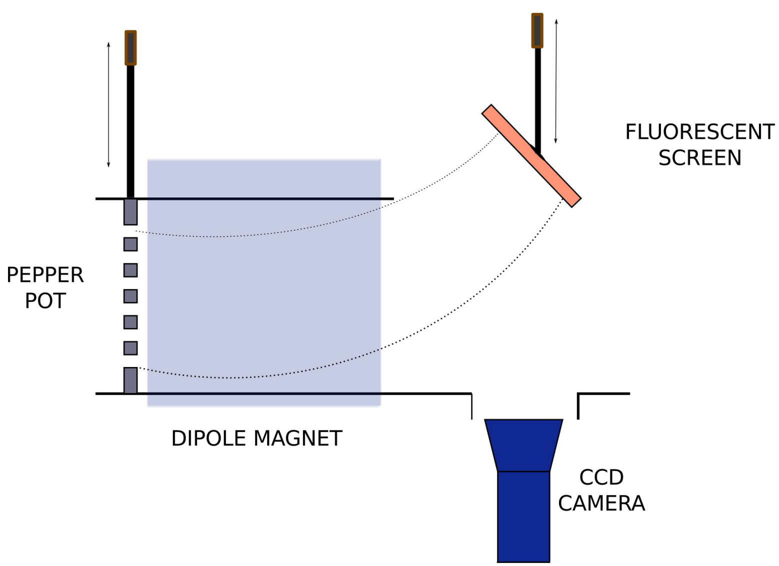
Can we measure spatial and spectral distributions of the outgoing current during one RF pulse?

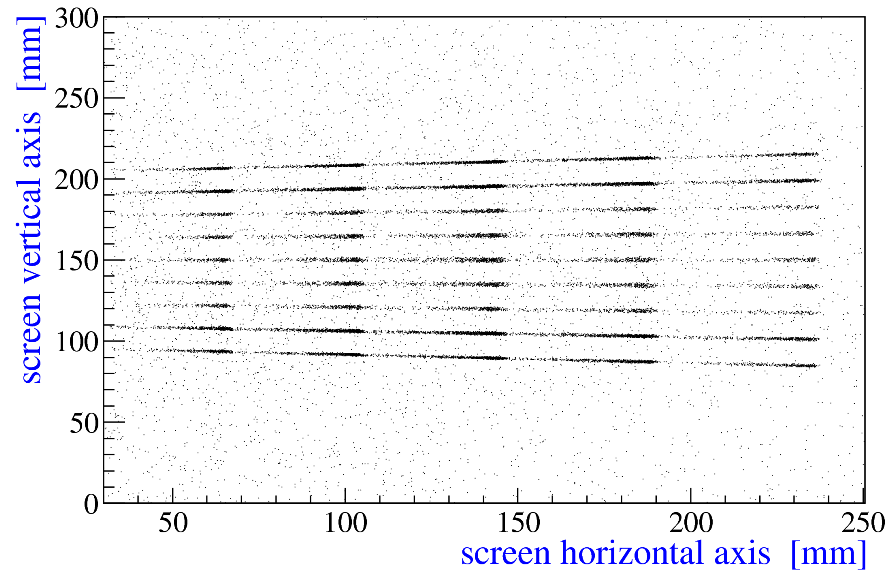
Let's use pepper-pot grid and spectrometer with fluorescent screen

Electrons hit a plate with a number of small holes arranged in a matrix

Passing particles defined by this pattern form beamlets

A deflecting field placed directly after the pepper-pot grid gives an energy-dependent pattern on the screen behind





Important questions:

How will dark current “beam” look like? What can we expect?

- Relevant info from previous studies:
  - **Flux:**

    The typical dark current is of the order of few μA (averaged over an rf pulse) in a disk-loaded ACS with field ~ 20 MV/m but current grows exponentially with the field.

    Breakdown current can be 2 orders of magnitude higher.
  - **Energy:**

    Field emitted electrons are captured and accelerated along the structure
    ⇨ assuming 100 MV/m maximal gradient and 20 cm of active structure length we should see electrons with 0-20 MeV energies
  - **Emission angle:**

    emitted electrons follow complicated trajectories according to simulations and there is no established model. But what we can expect is that particles generated near the end of the ACS have larger angles and smaller energies, the ones generated at the beginning smaller angles and higher energies

Pepper-pot size

Estimate of electron flux

From µA measured current at 20 MV/m we expect 10^{12} electrons leaving ACS per RF pulse

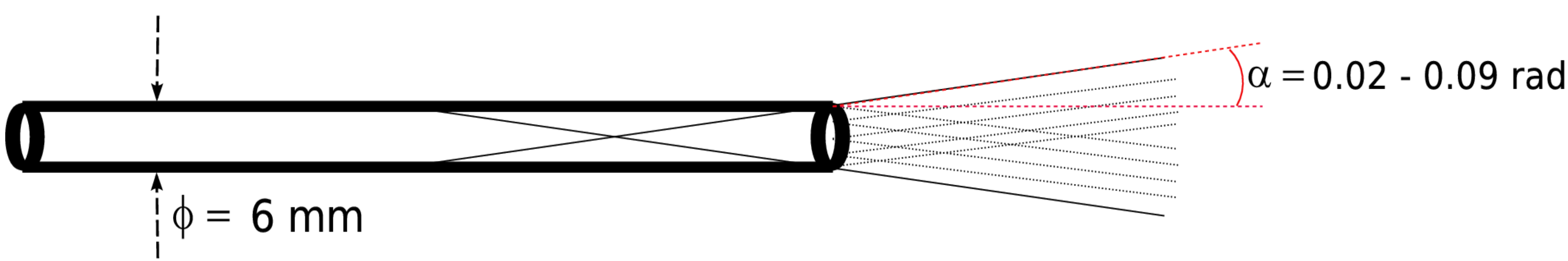
Assuming 1% collimator acceptance we expect 10^{10} e- passing pepper-pot slit or with e.g. 25-hole pattern ⇨ 4×10^{8} electrons in each beamlet

Maximal emission angle

From ~ 0.02 rad (from dimensions of the ACS: L = 250mm, ϕ_{iris} = 6 mm)

To ~ 0.09 rad (limited by the flange size 4 mm)

This corresponds to image size at the collimator between 18 to 50 mm



Deflector

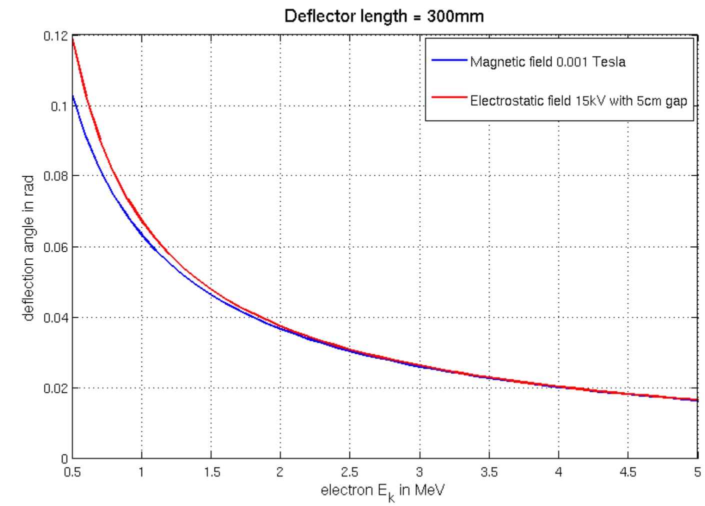
To catch all beamlets on small screen behind we need

small deflection angle. We can choose:

Magnetic field (circular path)

Electrostatic field (parabola)

giving practically the same results.



Example:

Aiming at 0.1 rad deflection angle and 30 cm deflector field we need:

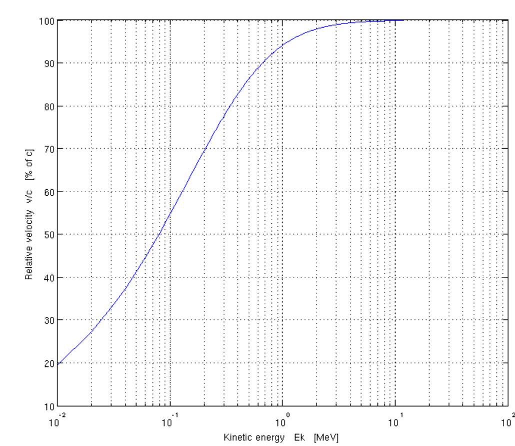
either 1mTesla magnetic field or

15kV/5cm gap electrostatic field

<u>Problem:</u>

Energy range 0.1 – 20 MeV corresponds to transition range between non-relativistic and relativistic velocities

For small deflection angles we can resolve well only <u>lower</u> energies

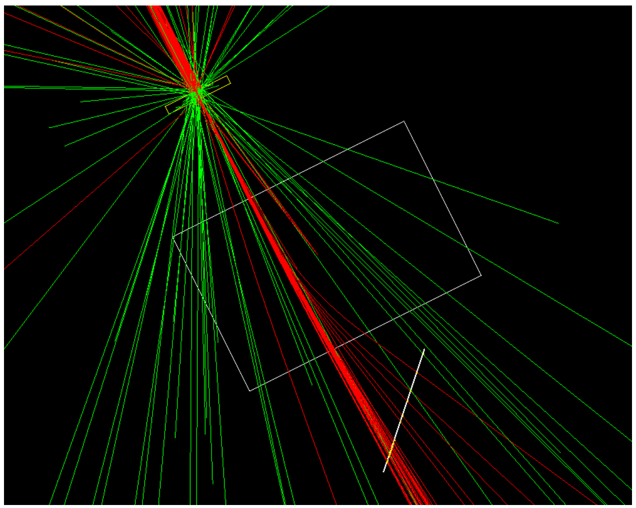


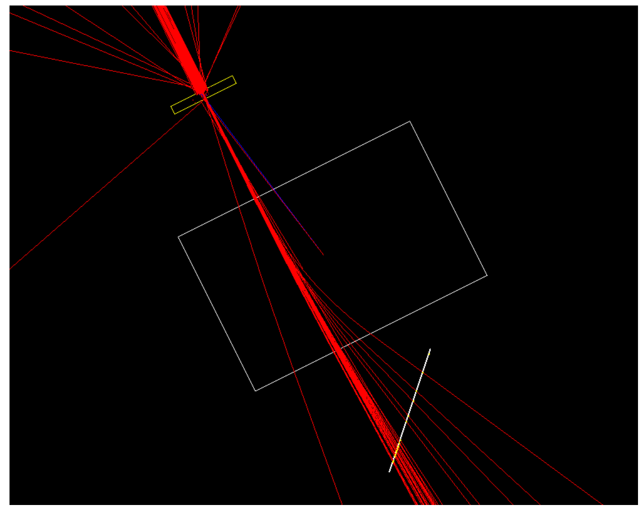
Simulations with GEANT4

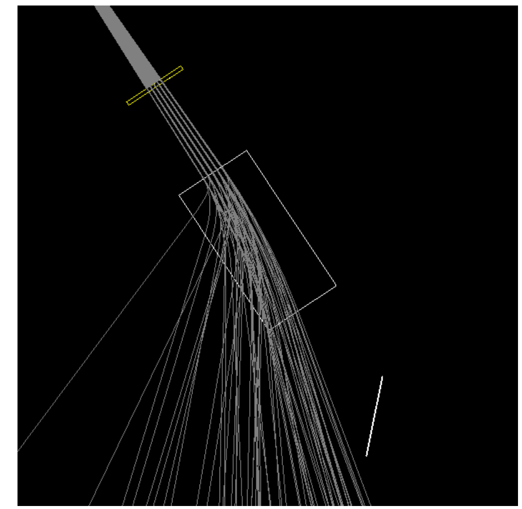
Different geometries, material, thickness etc

Full physics simulation e.g. gives estimate of background from secondary particles

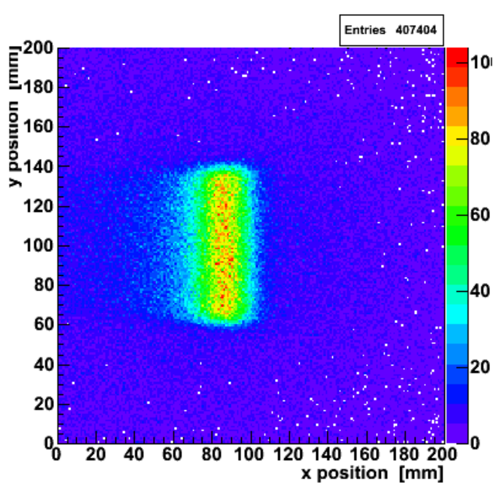
Uniform fields, no fringe field effects (unless provided directly by user)



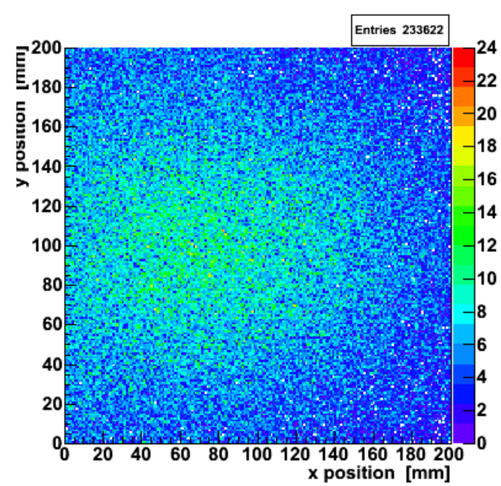




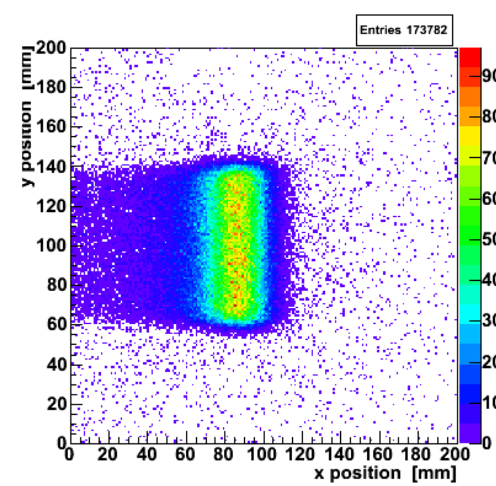
Example with 1.5 mm slit configuration



All particles



Only photons



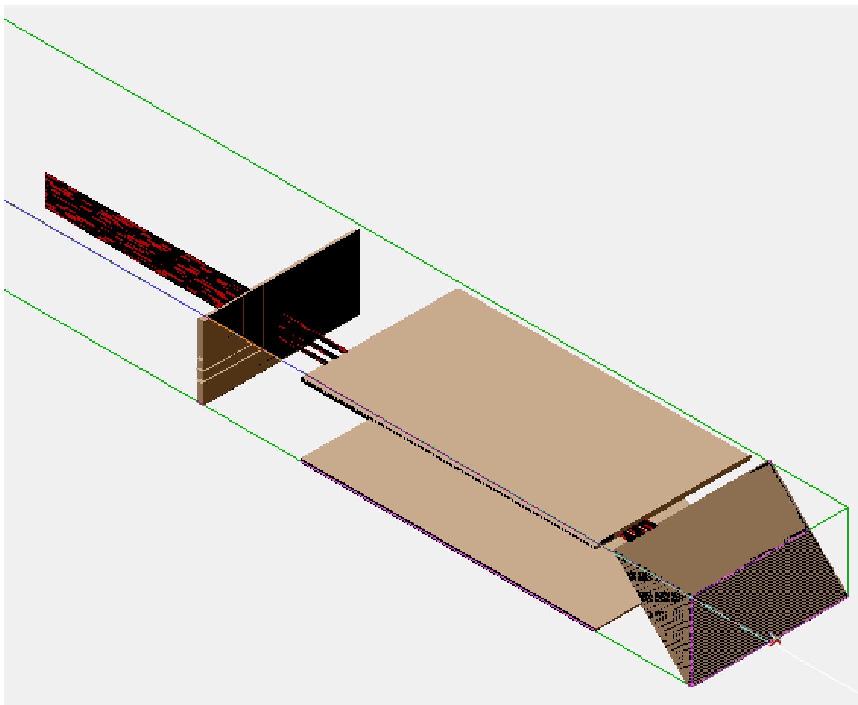
Only electrons

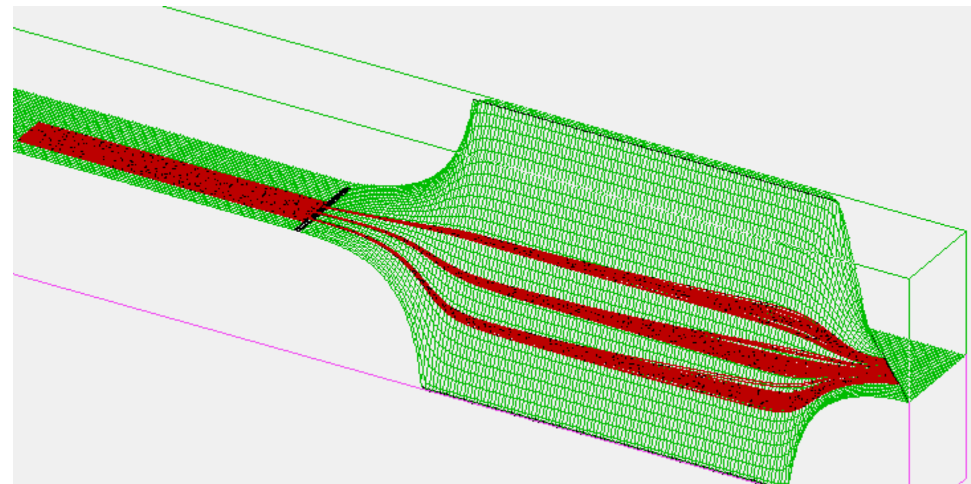
Simulations with SIMION

Can model complex potential arrays

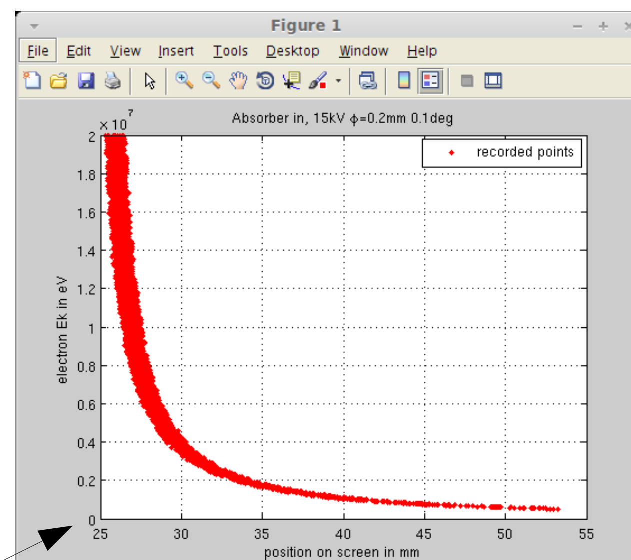
Good for final setup optimization

Limited physics simulation e.g. no secondary interactions





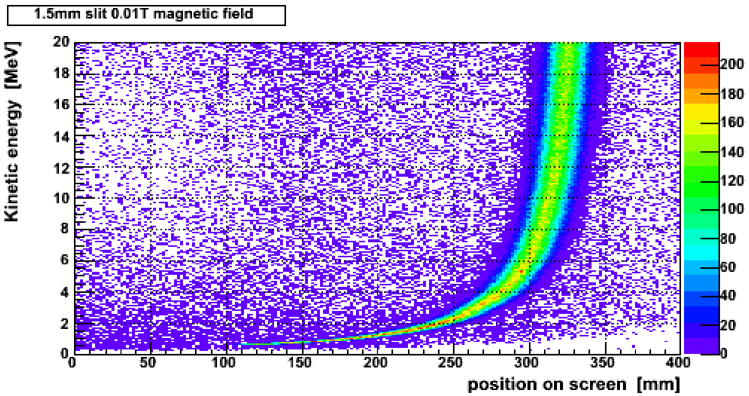
Field profile

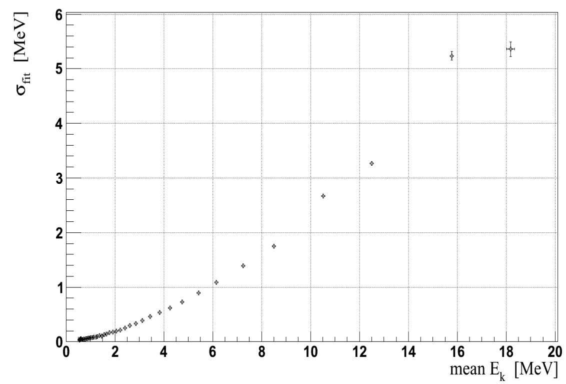


Saved data from SIMION

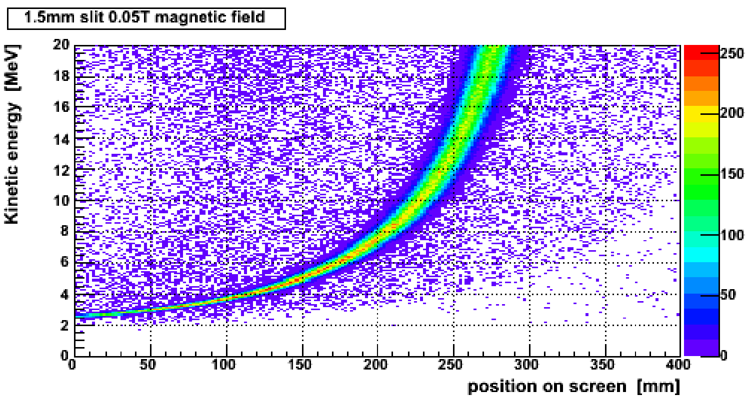
Energy resolution vs magnetic field

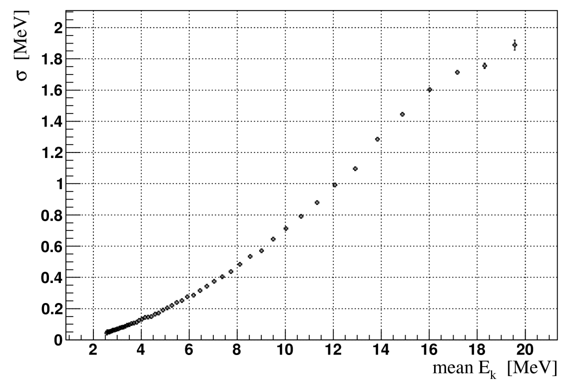
Example with single slit 1.5 mm



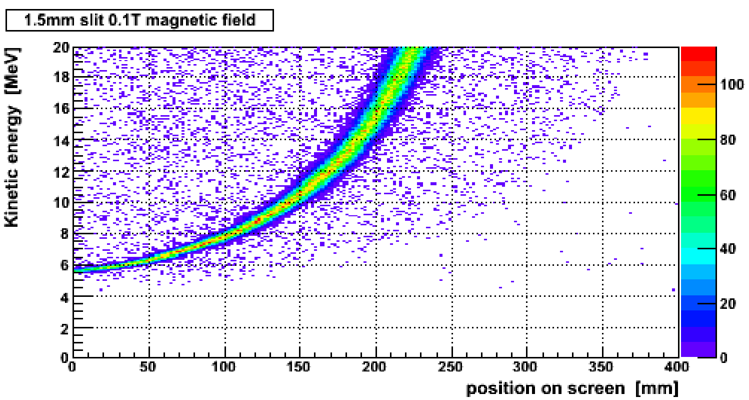


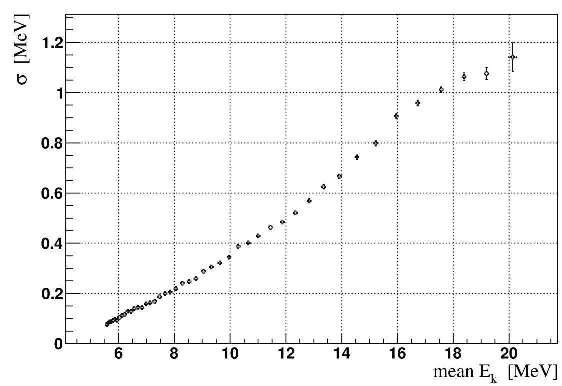
0.01 Tesla
On-screen size ~250mm
Energy range: 0.5 – 10 MeV





0.05 Tesla
On-screen size ~300mm
Energy range: 2.5 – 20 MeV



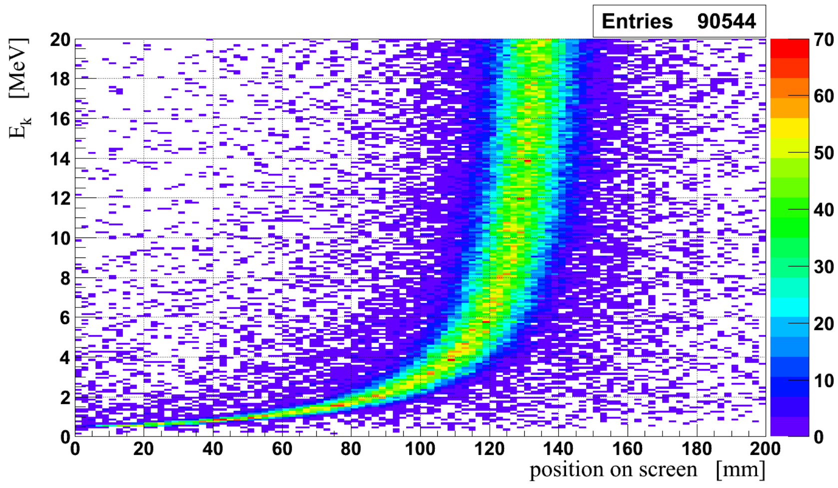


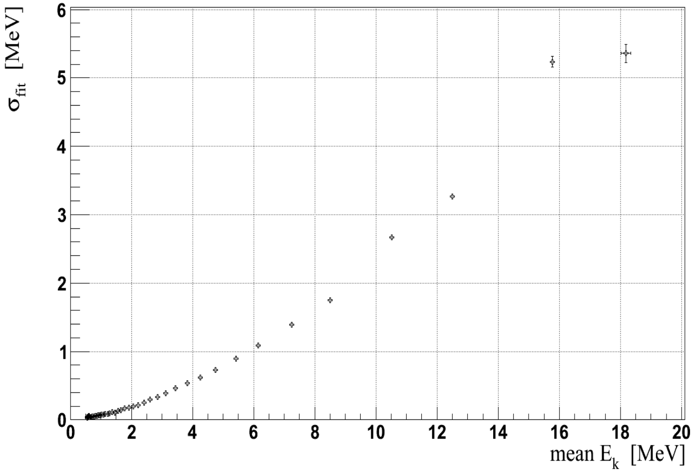
0.1 Tesla
On-screen size ~250mm
Energy range: 5.5 – 20 MeV

Energy resolution vs slit size

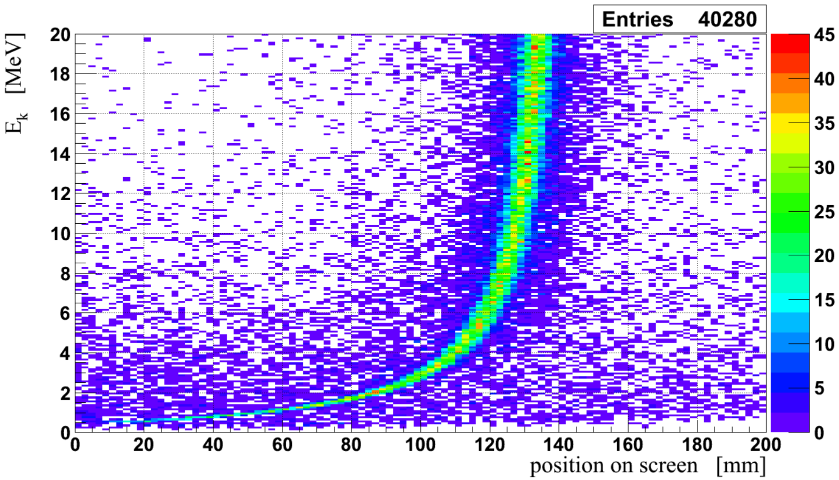
Example with single slit

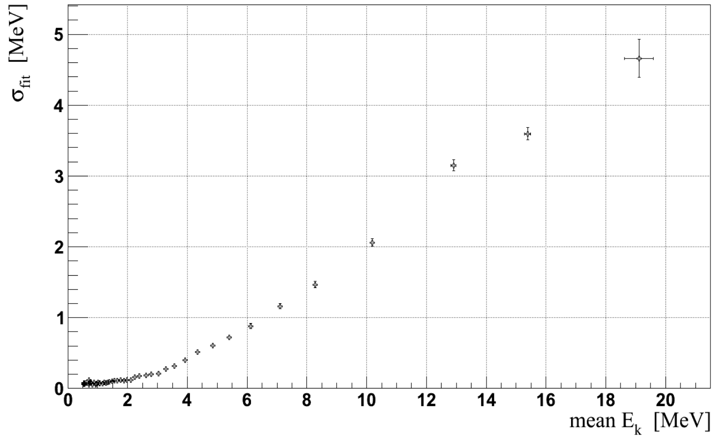
5mTesla field, 0.5 mm slit, 15mm collimator: size on screen ~120mm





5mTesla field, 0.1 mm slit, 15mm collimator: size on screen ~120mm



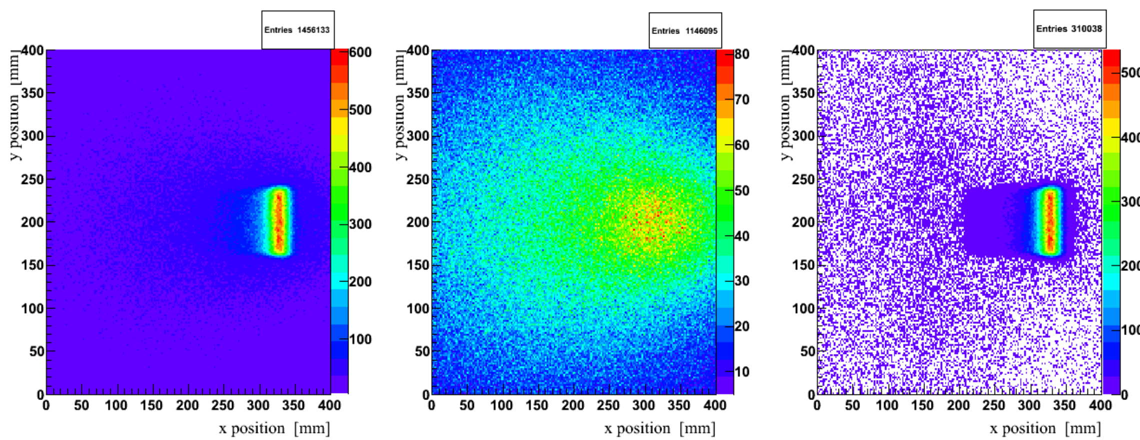


We can resolve higher energies with smaller slit size, but there is price to pay ...

Background situation

THICKNESS

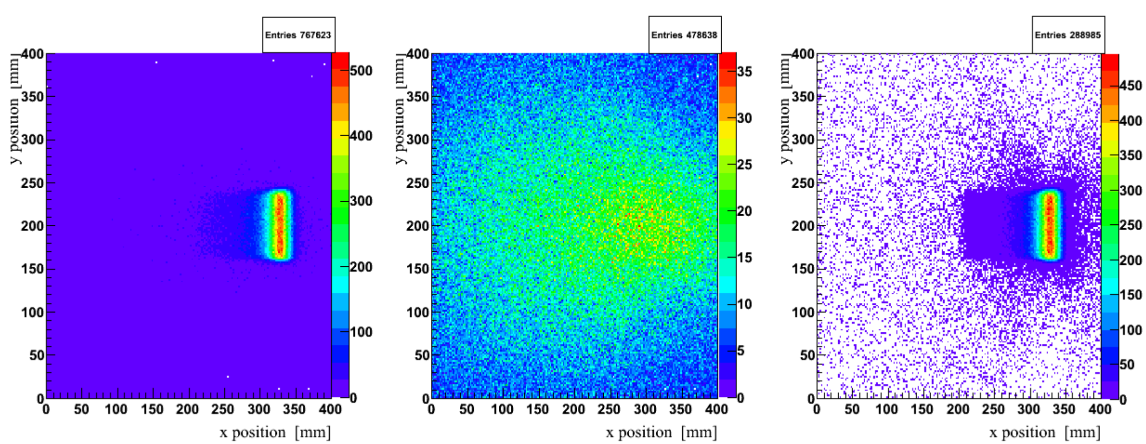
1.5 mm slit, 5mTesla field, 5 M events simulated, Absorber (tungsten) thickness 5 mm



Signal: 310038
(acceptance 6.2%)

S/B ratio (full screen surface)
0.27

1.5 mm slit, 5mTesla field, 5 M events simulated, Absorber (tungsten) thickness 15 mm



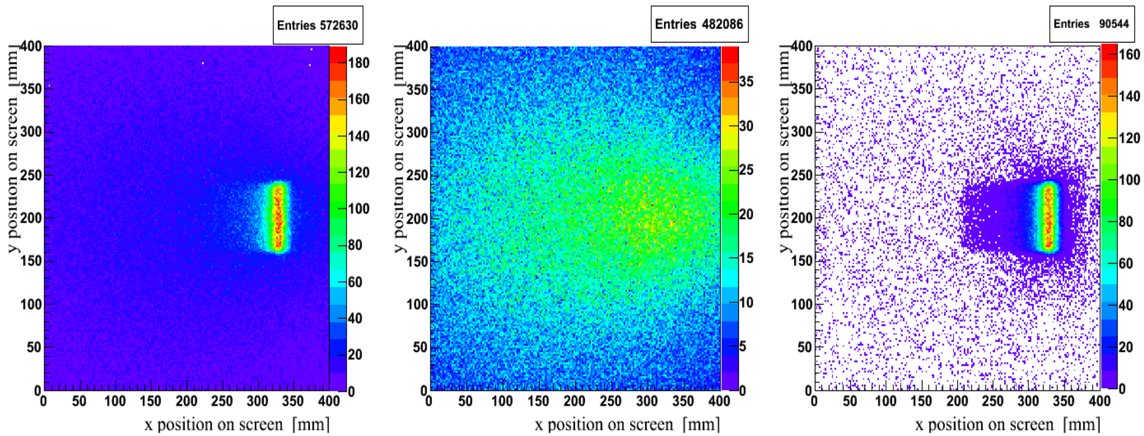
Signal: 288985
(acceptance 5.8%)

S/B ratio (full screen surface)
0.60

Background situation

MATERIAL

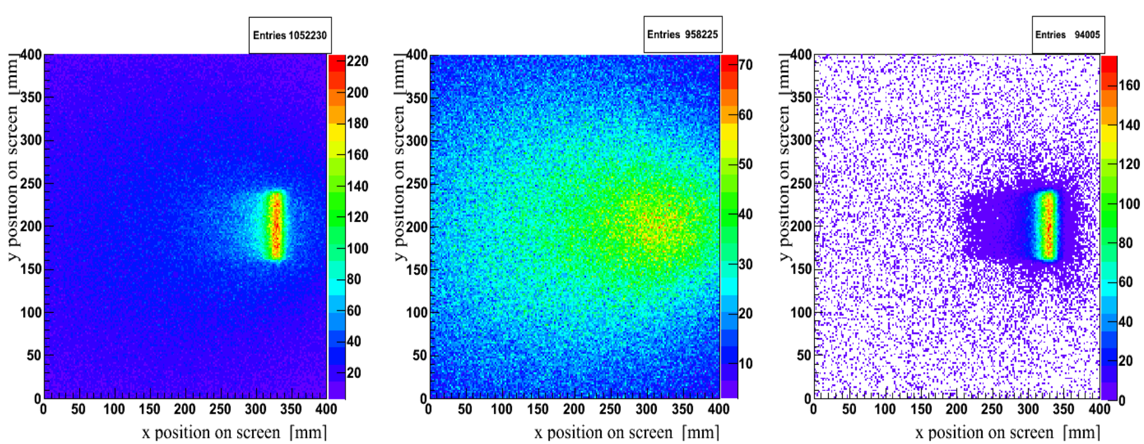
0.5 mm slit, 5mTesla field, 5 M events simulated, Absorber (**tungsten**) thickness 15 mm



Signal: 90544
(acceptance 1.8%)

S/B ratio (full screen surface)
0.2

0.5 mm slit, 5mTesla field, 5 M events simulated, Absorber (**copper**) thickness 15 mm



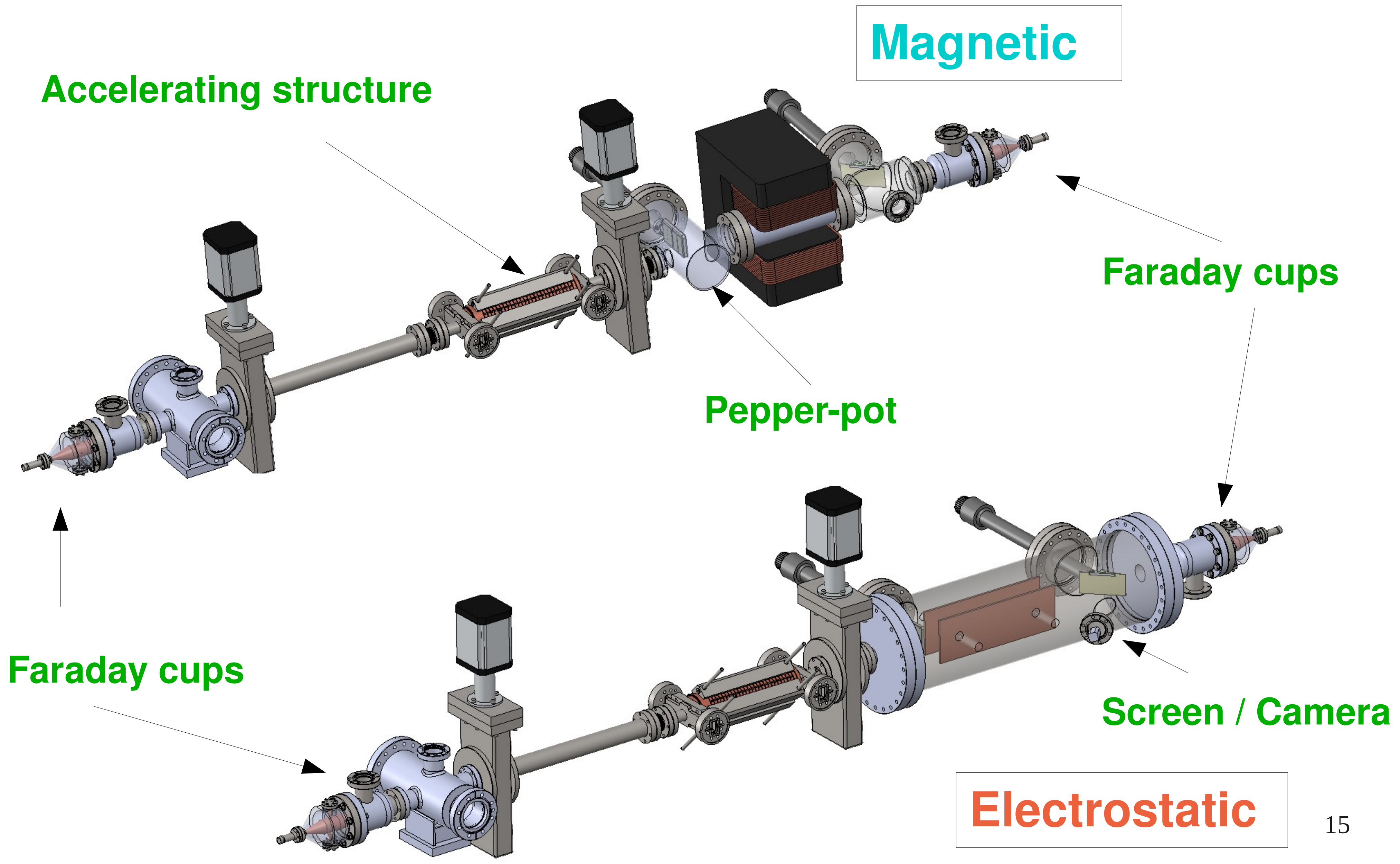
Signal: 94005
(acceptance 1.8%)

S/B ratio (full screen surface)
0.1

Similar value for stainless steel

Conceptual design

Two version:



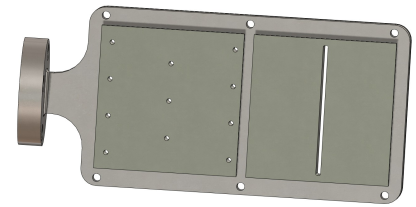
More details

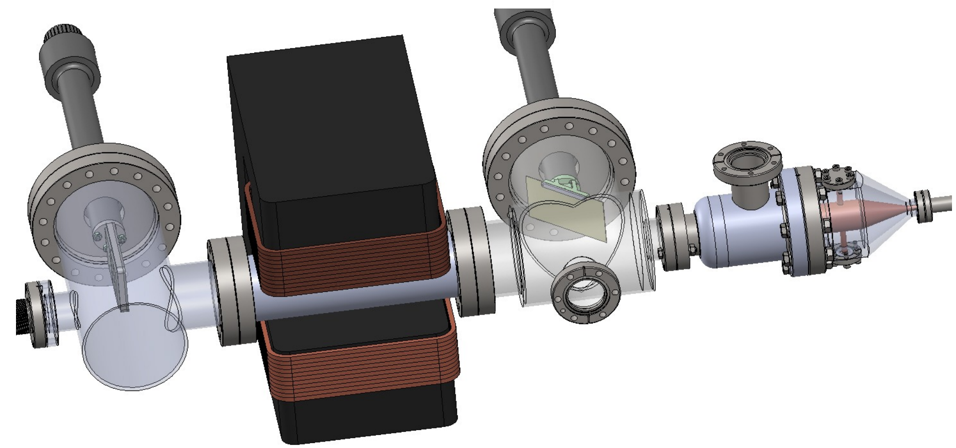
Two actuators for pepper-pot and screen

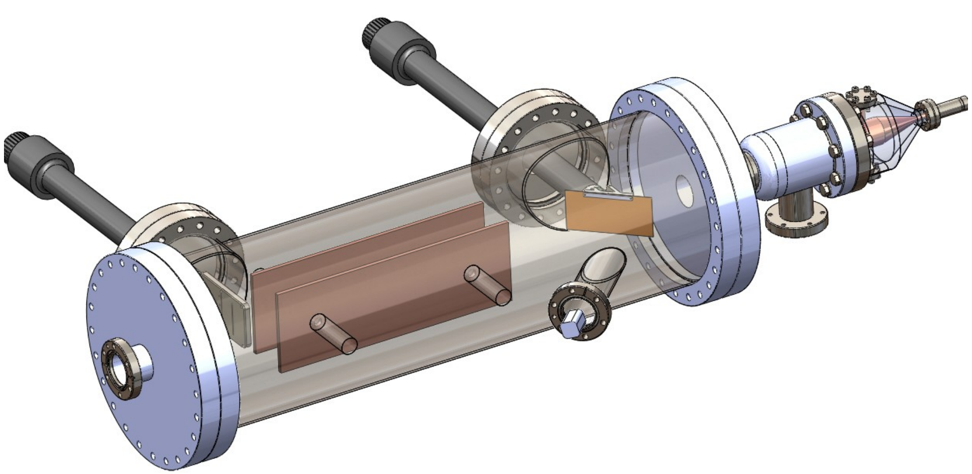
Holder for two or more pepper-pot collimators for more versatile setup

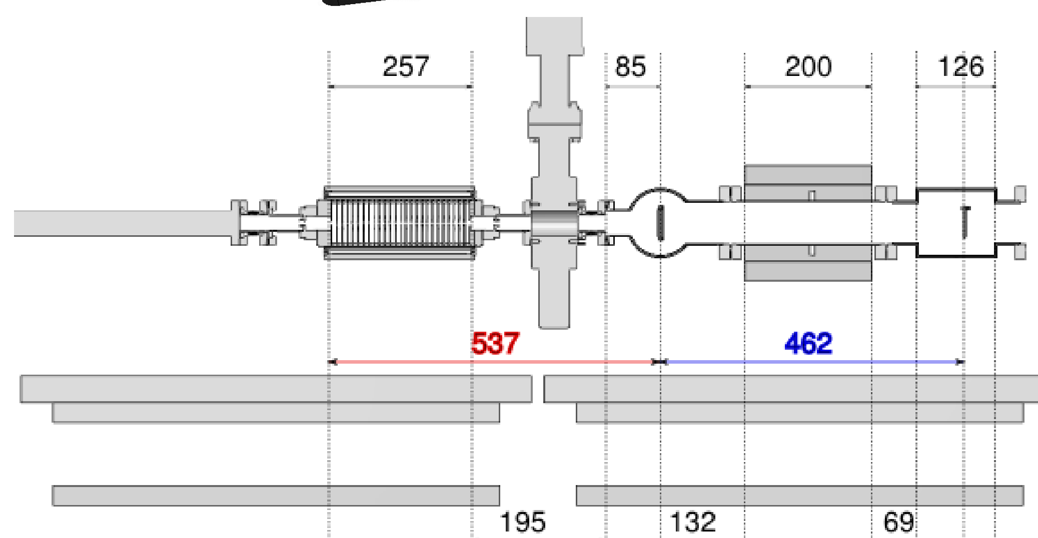
Faraday cups with mirror for light detection

Both collimator and screen can be removed from the beam allowing for current measurement on the Faraday cup









All dimensions in mm

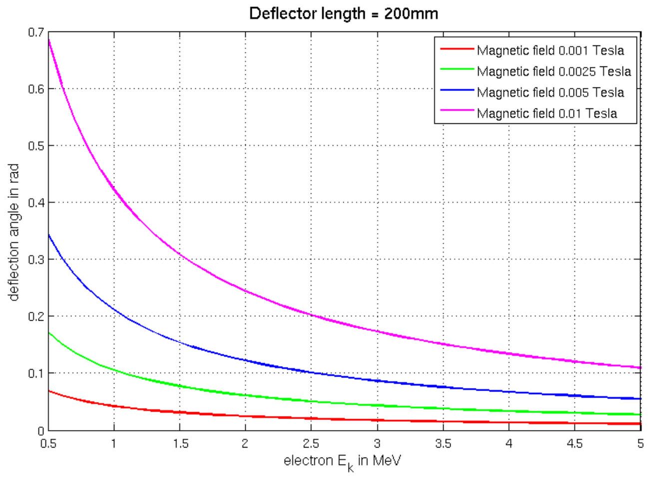
Deflector options

Magnetic deflector requirements:

Field range: 1 – 50 mTesla
Size ~20 cm
Gap size 7cm

Ions: not affected by these fields

Potential problems:
• Big gap for such a small field and the nonlinearities can be a problem.
• Interference from other sources i.e. pumps, might need shielding

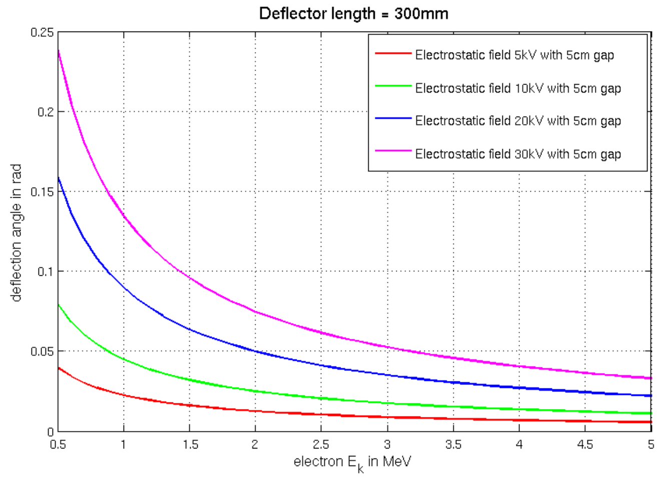


Electrostatic deflector requirements:

Field range: 100 – 1200 V/mm (± 5-30 kV)
Size ~30 cm
Gap size 5 cm

Ions: deflected earlier, but could also be studied with lower field values

Potential problems:
• High fields required for good energy resolution for 20 MeV electrons



Conclusions

- Magnet with such small and uniform field can be done but could be a challenge (discussion with A. Newborough)
- However with required small angle deflection we can choose in-vacuum parallel plate deflector over the dipole magnet with big gap

- Can resolve energies of electrons with E_k < 10MeV from many beamlets on one screen
- … but to get up till 20 MeV we need to:
  - spread the image on the screen and decrease number of holes in a row or use a slit
  - go to the smaller hole diameters, but suffer from decreased S/B ratio

Suggested setup

Pepper-pot tungsten absorbers	50mm×50mm×15mm 2 (or more) geometries, e.g. 1 slit, 0.5 mm width and 4x3 matrix with 0.5 mm diameter or 5x4 matrix with 0.25 mm diameter
Electrostatic parallel-plate deflector	300 mm length, 50 mm gap ±5kV to ±30 kV potential
Fluorescent screen	100mm×50mm, YAG:Ce 45 degrees angle 2M pixel fast CCD camera (e.g. Basler Aviator 1920x1080, 50fps)