# How to characterize an electrostatic analyzer

## by simulations and experiments

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# OUTLINE

## Introduction

- Principle of particle measurement
- Geometric factor

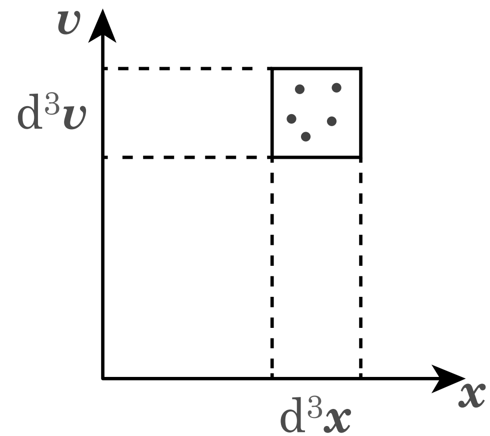
## How to get G factor

- Simulations
  - The simple way
  - Optimization of parameter space coverage
- Experiments
  - Aspects not considered in simulations

# PRINCIPLE OF PARTICLE MEASUREMENT (1)

We want to know

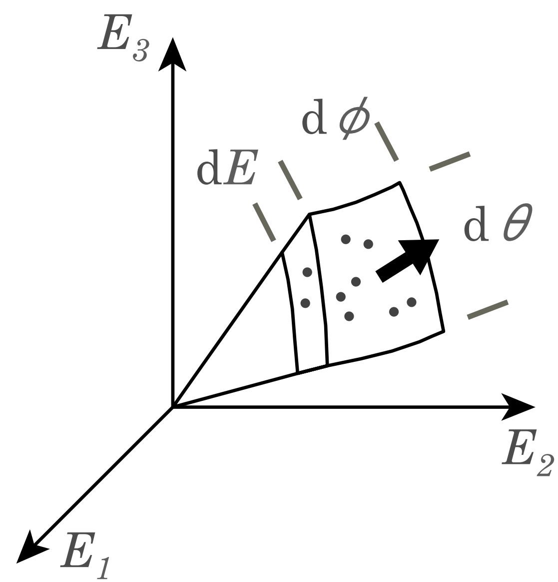
- $f(\boldsymbol{x}, v; t)$: particle distribution function [# m$^{-6}$ s$^{3}$]
- not directly measurable




We can measure

- $j(x_1, x_2, x_3; E, \theta, \phi; t)$: differential flux [# cm$^{-2}$ s$^{-1}$ sr$^{-1}$ eV$^{-1}$]

- $f = m^2/(2*E) * j$



# PRINCIPLE OF PARTICLE MEASUREMENT (2)

$j$ is measured by counting numbers

- $C(t)$: count rate of particles [$s^{-1}$] selected by analyzer and detected by detector

Therefore

$$j(x, y, z; E, \theta, \phi; t) = C(x, y, z; t) / \varepsilon / G(E_A, \theta_A, \phi_A)$$

- $\varepsilon$: total detection efficiency [-]
- $G(E_A, \theta_A, \phi_A) \equiv dA * d\Omega * dE$
  - Geometric factor [$m^2$ sr eV]
  - Coverage of the particle selection region in coordinate, angular and energy spaces, at $x, y, z, E_A, \theta_A, \phi_A$

Calibration to establish $\varepsilon * G(E_A, \theta_A, \phi_A)$

(subscript A is for the energy and direction selected by the analyzer, a “setting”)

# CALIBRATION BY SIMULATIONS

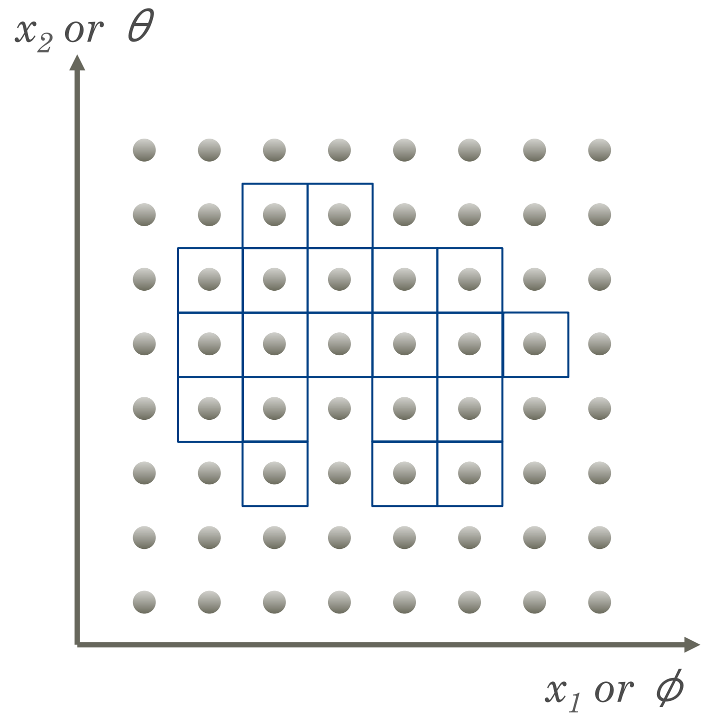
# THE SIMPLE WAY

Use a beam that is

- a pencil beam (δ function in area)
- parallel (δ function in direction)
- mono-energetic  (δ function in energy)

Continuous scans:

- over accepted area
- over acceptance solid angle
- over accepted energy range




Hit: in the G factor

Miss: not

- This is how simulations could be done in principle

# THE SIMPLE WAY: INEFFICIENT IN PARAMETER SPACE

Unobvious instrument coverage in most dimensions

- Scans have to cover very large area, wide angular range
- Resolution needs be sufficient

Many steps in each dimension

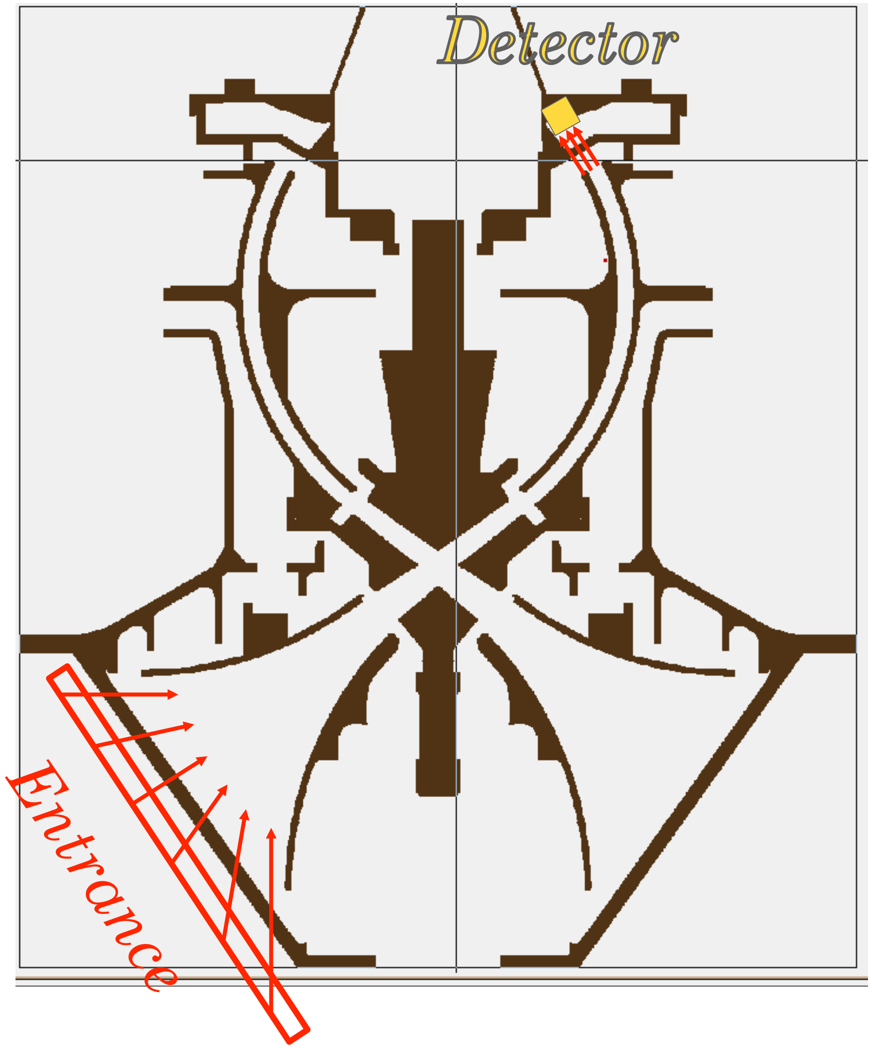
5 dimensions

```
for x in range(0, 10, 0.1):  # 100
    for y in range(0, 10, 0.1):  # 100
        for elevation in range(0, 90, 1):  # 90
            for azimuth in range(-90, 90, 1):  # 180
                for E in range(4000, 5000, 10): # 100
                    launch_particle(x, y, elevation, azimuth, E)  # 1.62e10 particles in total
```

This is just for ONE setting of the instrument.

Smart optimization needed

# OPTIMIZATION OF SCAN RANGES: REVERSE SIMULATION




The detector

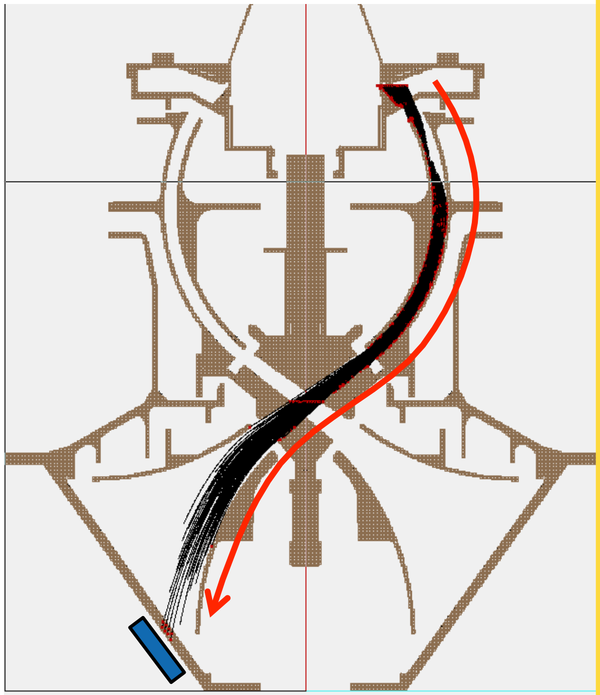
- where spatial, angular and energy are constrained well
- Much smaller parameter space to start from

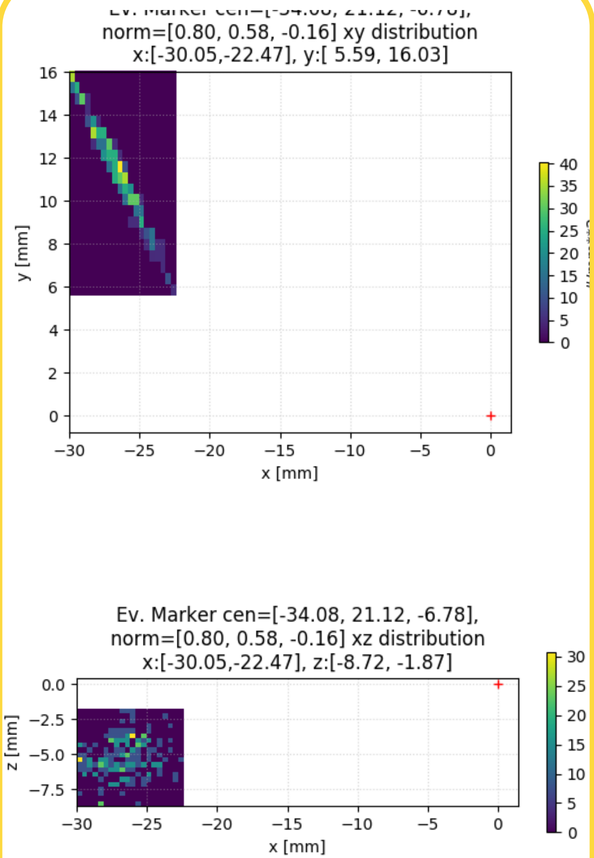
Reverse simulations with very high resolutions

- from detector to instrument entrance
- Get parameter space coverage at the entrance

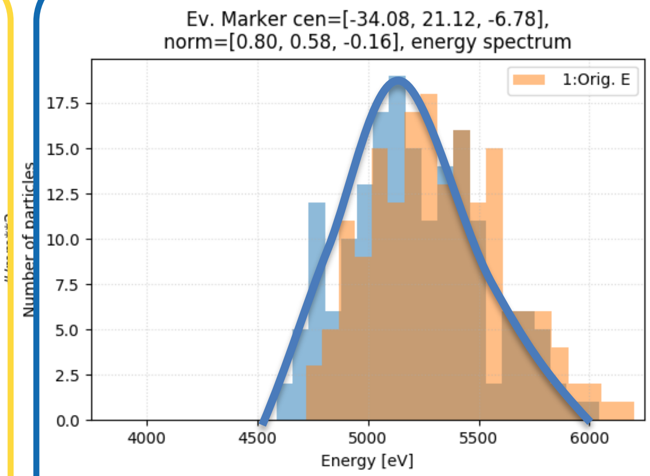
Expand a little, as the parameter ranges for forward simulation from the entrance

# REVERSED SIMULATION: FOR THE COVERAGE AT ENTRANCE

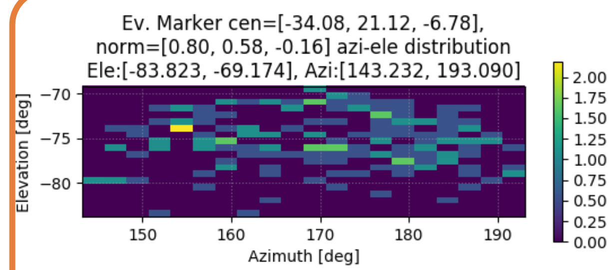





*position coverage*




*energy coverage*



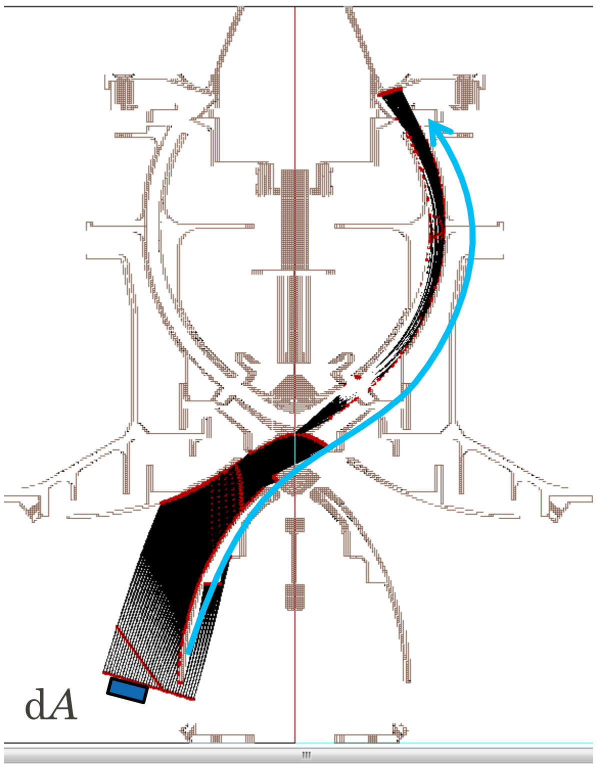

*angular coverage*

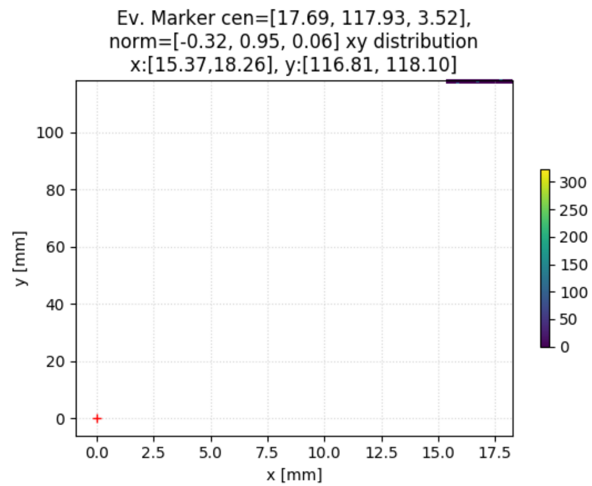
# FORWARD SIMULATION: PARALLEL WIDE BEAM

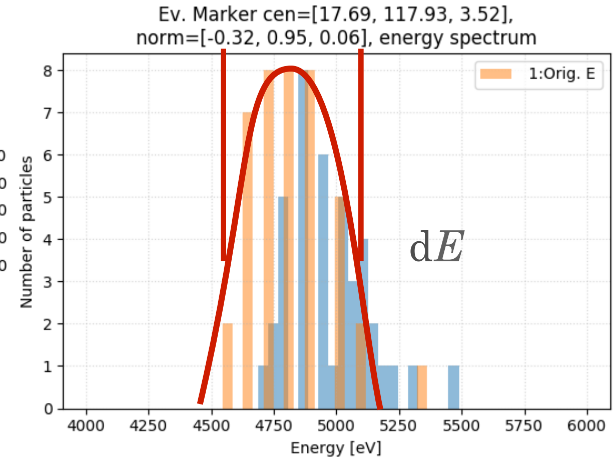
$E = 5\ keV$

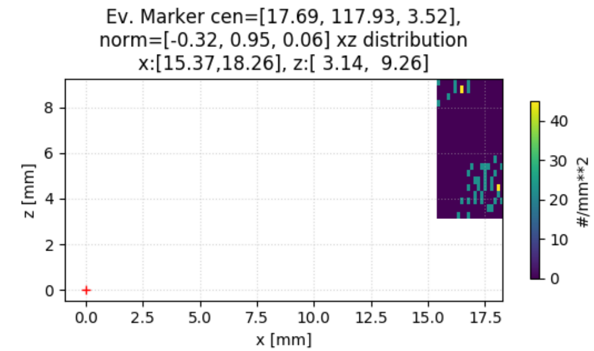
$\theta = 72.9°$

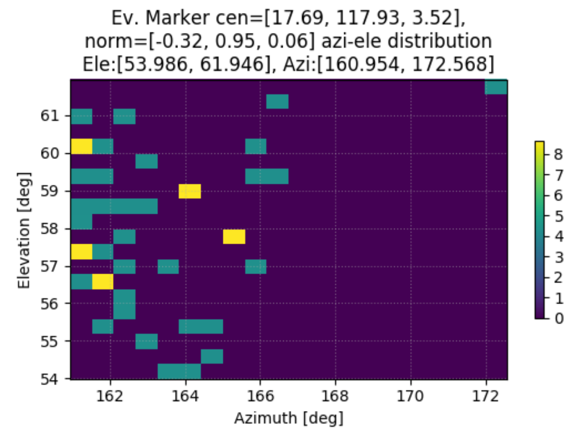
$\phi = -10°$



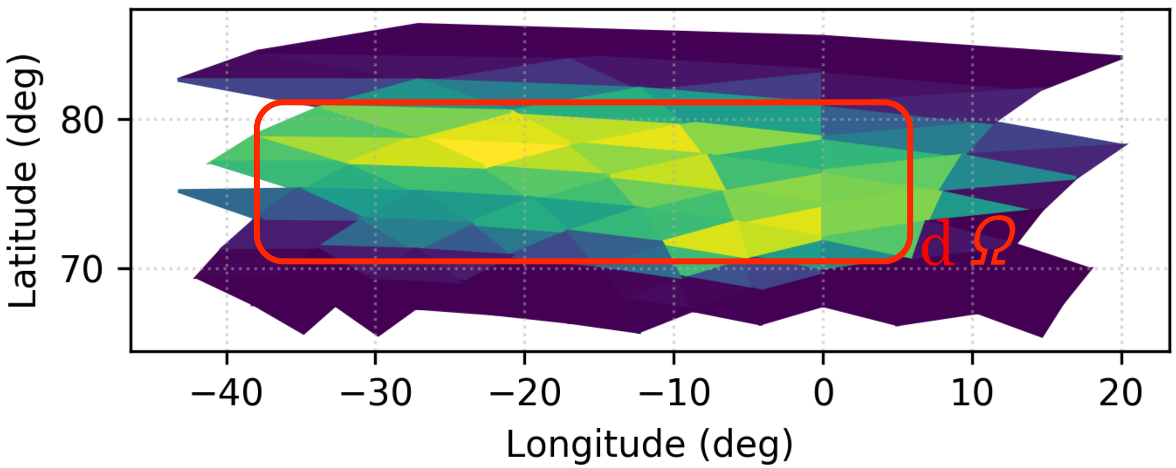




*position & energy scan*

# GEOMETRIC FACTOR DERIVATION

- Rotation scan: repeat parallel wide beam from different directions within entrance coverage for directions for one
- $d\,\Omega$ can be obtained
- $G = dA * d\,\Omega * dE$



# CALIBRATION BY EXPERIMENTS

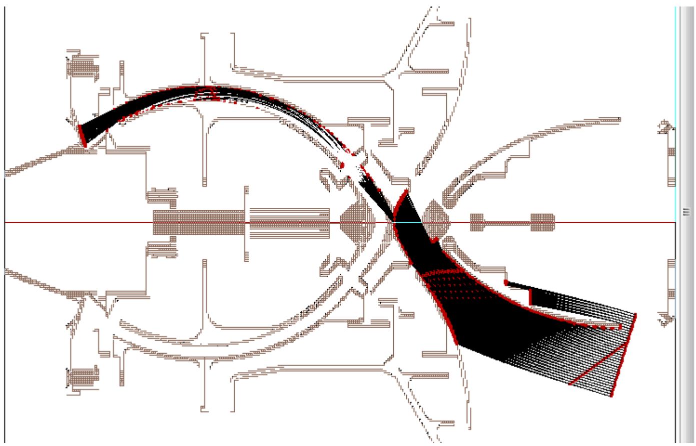
# MODEL ≠ REALITY

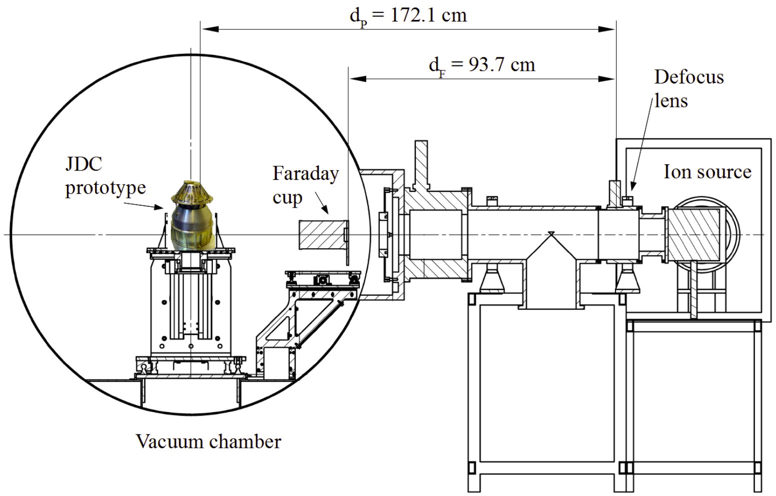
Simulations

- Fixed analyzer voltage, varying particle energy
- Known beam properties
- Perfect detectors (counts = hits)

Experiments

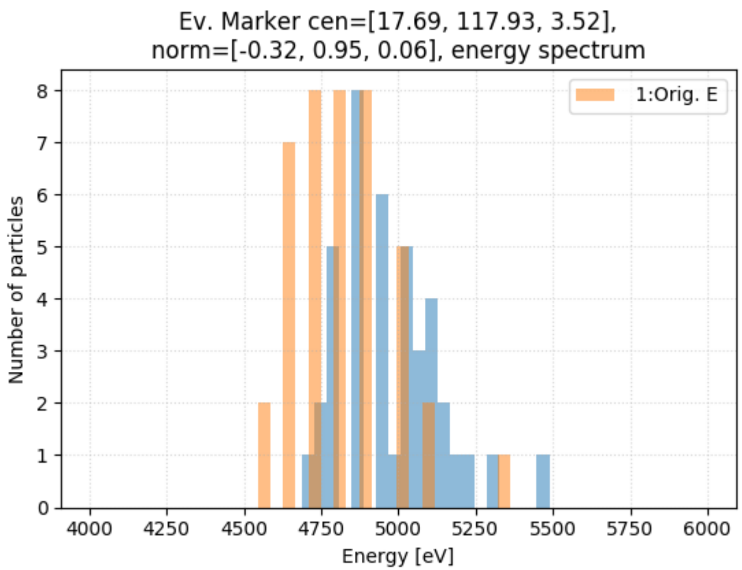
- Fixed particle energy, varying analyzer voltage
- Unknown beam properties
  - Position, spread, flux…
- Real detectors (counts < hits)

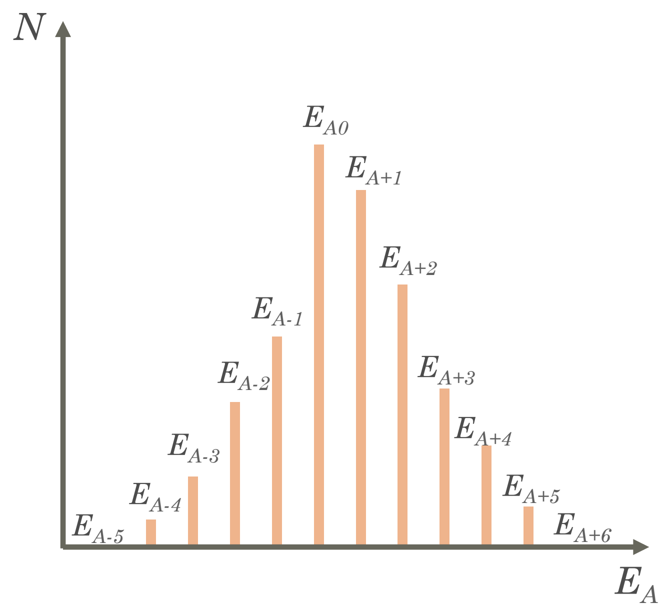





[Stude, 2016]

# ENERGY DISTRIBUTION: WHAT IS COUNTED



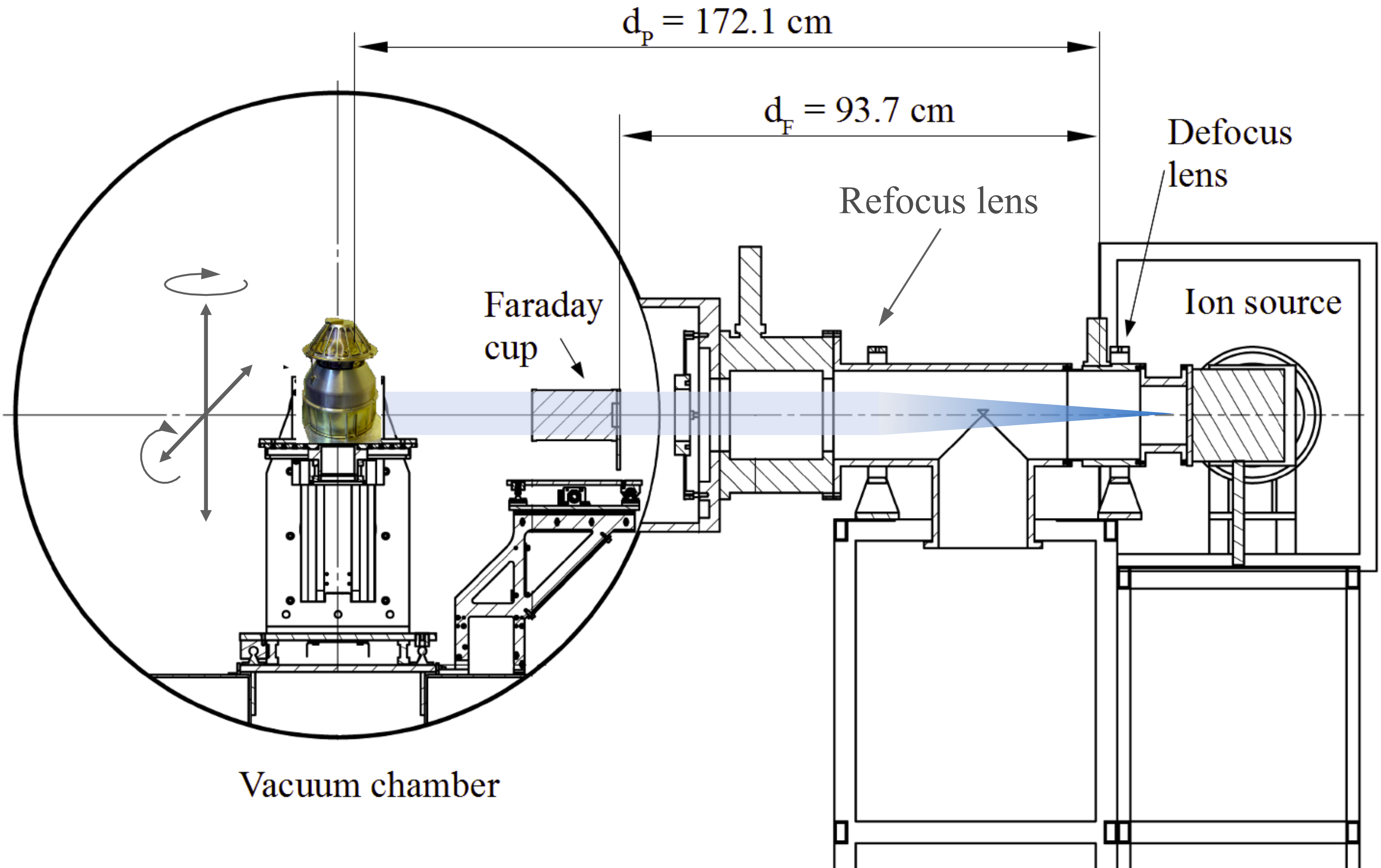

Simulation

- Fixed $E_A$, varying particle energy
- Number of particles that are
  - at energies $E_m$ $(m = 0, \pm 1, \pm 2\ldots)$ and
  - through analyzer energy $E_A$

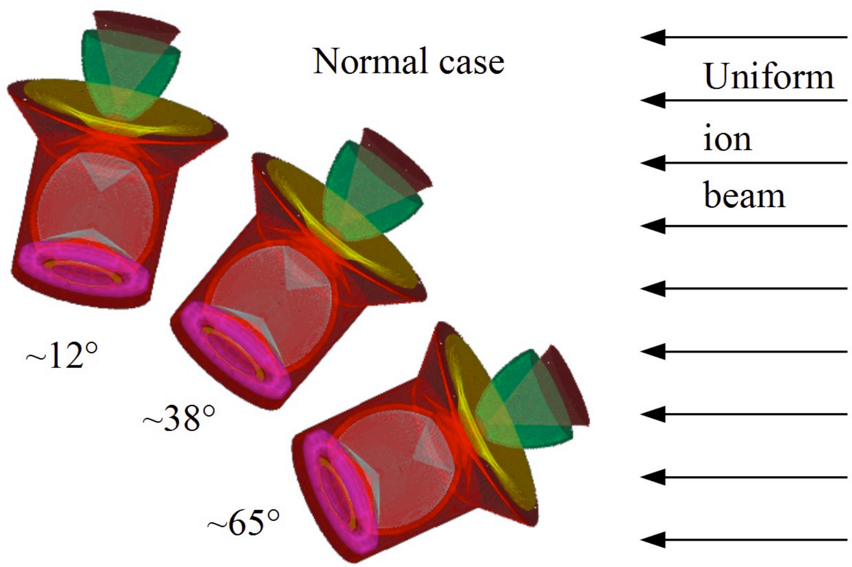
Experiment

- Fixed particle energy, varying $E_A$
- Number of particles that are
  - at energy $E_0$ and
  - through analyzer energies $E_{Am}$ $(m = 0, \pm 1, \pm 2\ldots)$
- Valid if $(E_m - E_{m-1}) << E_A$: calibration condition

# WHERE IS THE BEAM: INVISIBLE BEAM



# WHERE IS THE BEAM: OFF-CENTER APERTURE




*[Stude, 2016]*

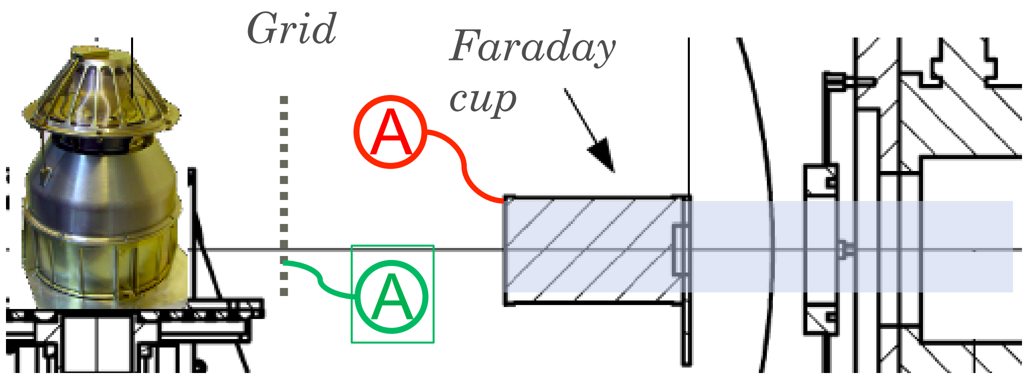
- Off-centered instrument effective area: may move during rotation scan
- Use wide beam
- Translation scan before rotation scan, stay in the beam center

# WHAT IS THE PARTICLE FLUX? BY MEASURING CURRENTS

*Q: FC calibrated?*

1.1. Insert Faraday cup, measure current $I_{F0}$

1.2. Remove Faraday cup, measure grid current $I_{G0}$.

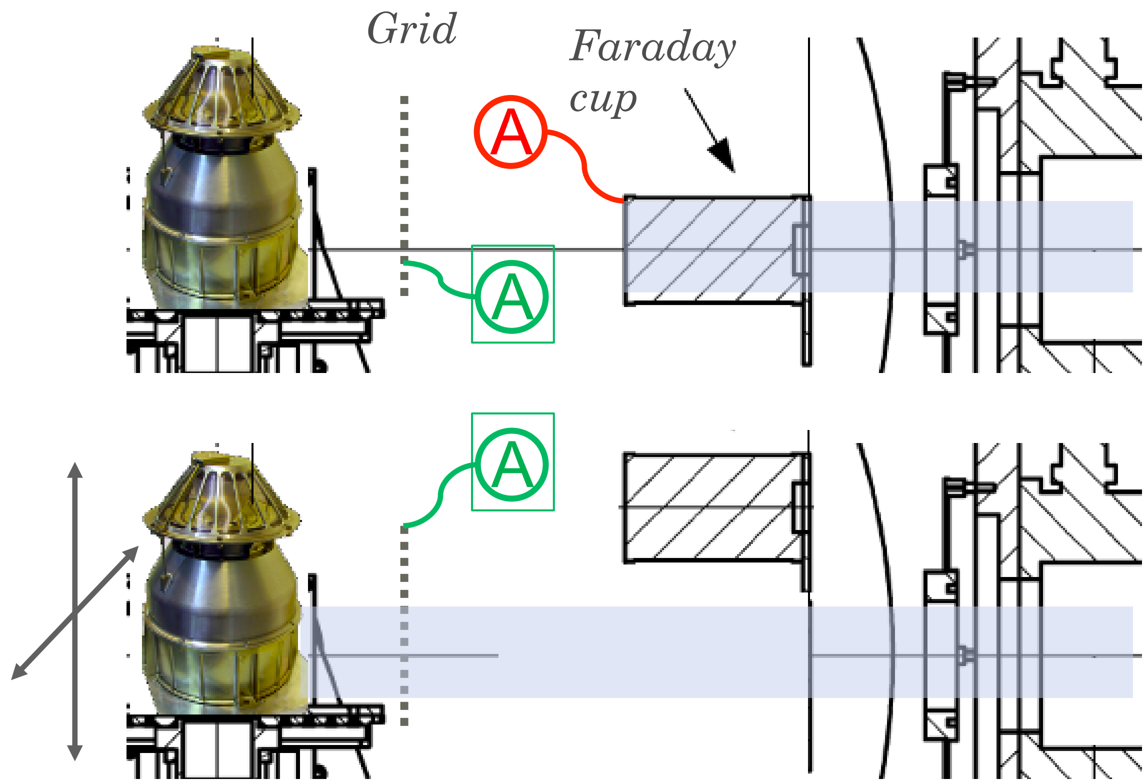


# WHAT IS THE PARTICLE FLUX?
# BY MEASURING CURRENTS

1.1. Insert Faraday cup, measure current $I_{F0}$

1.2. Remove Faraday cup, measure grid current $I_{G0}$.

2. Translation scan, find beam area $A_B$, monitor grid current $I_G(t)$



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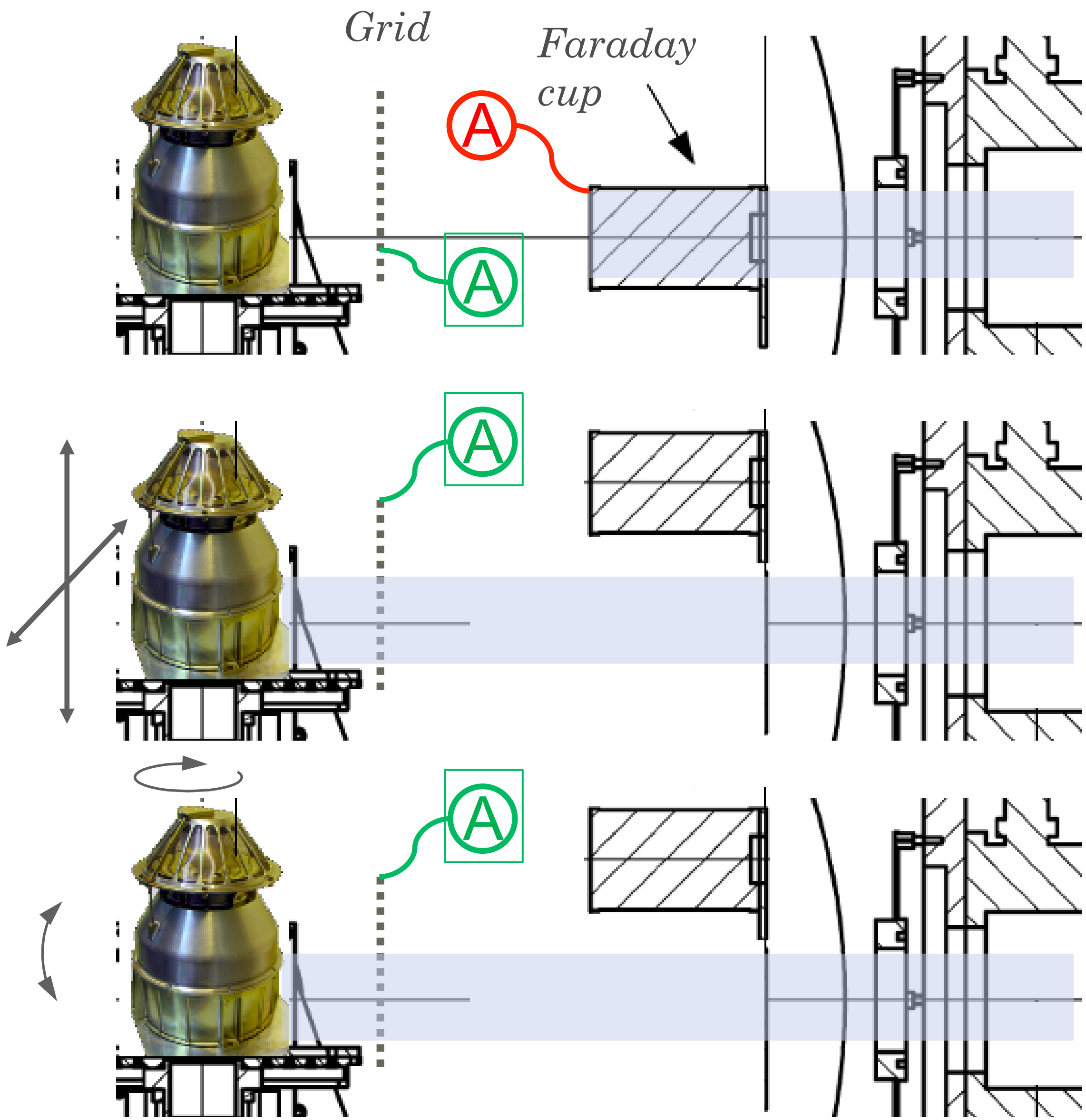
1.2. Remove Faraday cup, measure grid current $I_{G0}$.

2. Translation scan, find beam area $A_B$, monitor grid current $I_G(t)$

3. Rotation scan, monitor grid current $I_G(t)$



# WHAT IS THE PARTICLE FLUX? BY MEASURING CURRENTS

$$I_F(t) = I_G(t)/I_{G0} * I_{F0}$$

$$j(t) = I_F(t)/A_B$$

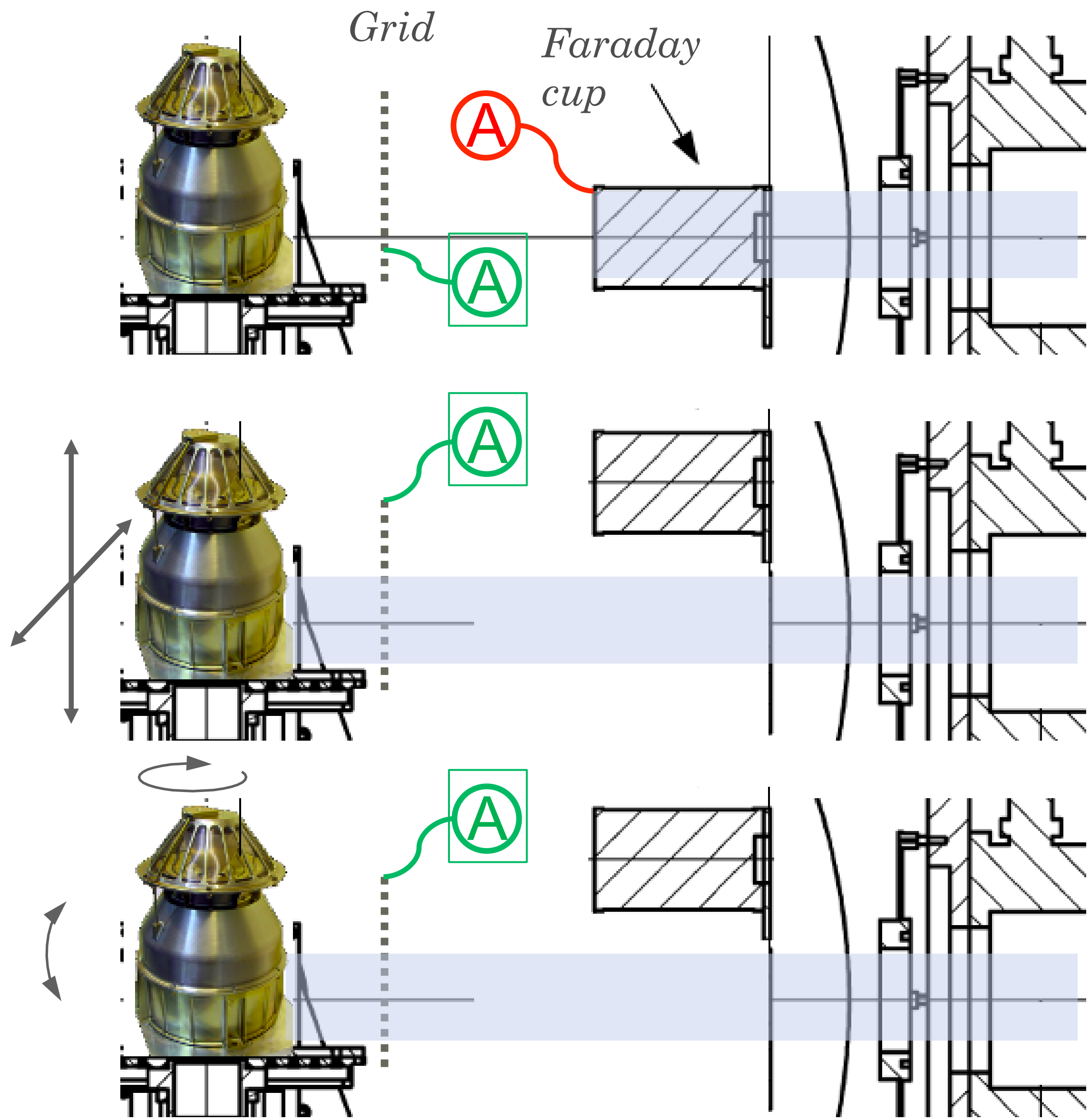
$$f_p(t) = j(t)(1-\xi)/e$$

$\xi$ : block ratio of the grid

$e$ : unit charge

$$max(C(t))/f_p(t) = dA * \varepsilon$$

Geometric factor INCLUDING efficiency



# SUMMARY

- Geometry factor is the coverage of the particle selection region in coordinate, angular and energy spaces, as function of analyzer settings, $E_A$, $\theta_A$, $\phi_A$

- Calibration for one setting means launching test particles filling the parameter space coverage, and observing what has gone through the analyzer

- Good simulations are hard, good experiments are harder.