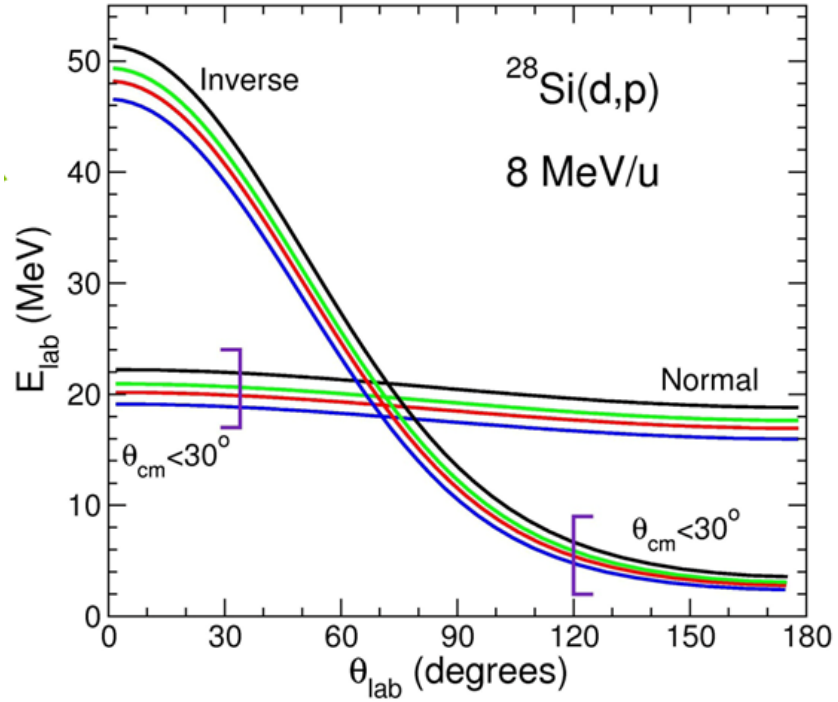
# Helical Orbit Spectrometer for SPES and its possible applications

Nuclear structure studies with low intensity beams → direct reactions

- Elastic Scattering (density distribution of p,n)
- Inelastic Scattering (excited states, collectivity, B(E2),B(E3))
- One nucleon transfer (single particle states, astrophysical processes)
- Two nucleon transfer (pair correlations)

Two-body reactions in inverse kinematics: easier to detect the light reaction partner

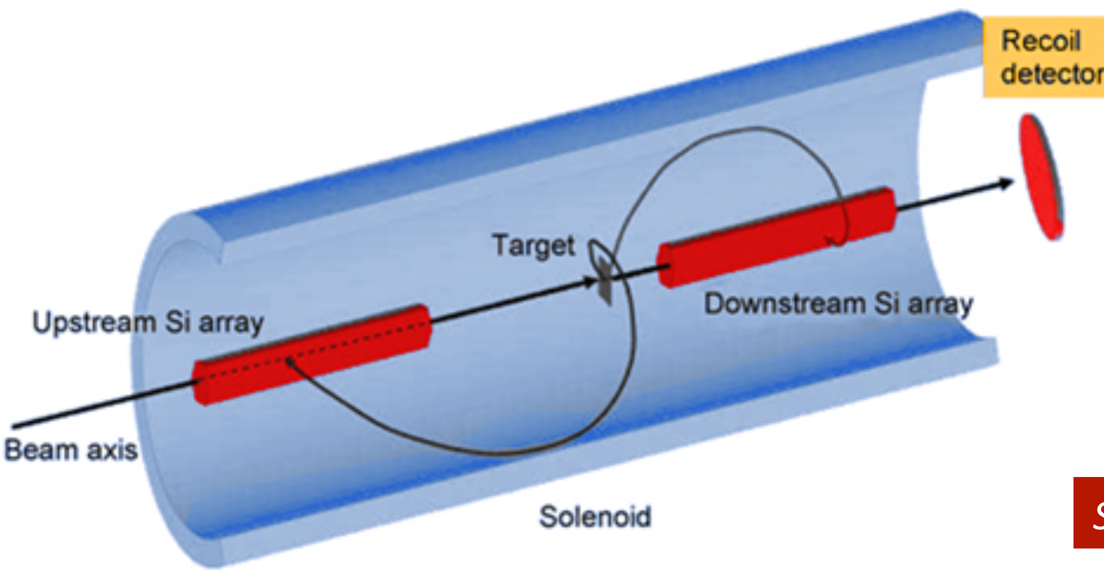
Problems:
- Low energy particles - identification
- Strong angular dependence
- Kinematical compression at large lab. angle
- Low intensity beam (detection efficiency)



# Helical Orbit Spectrometer

MAIN IDEA:

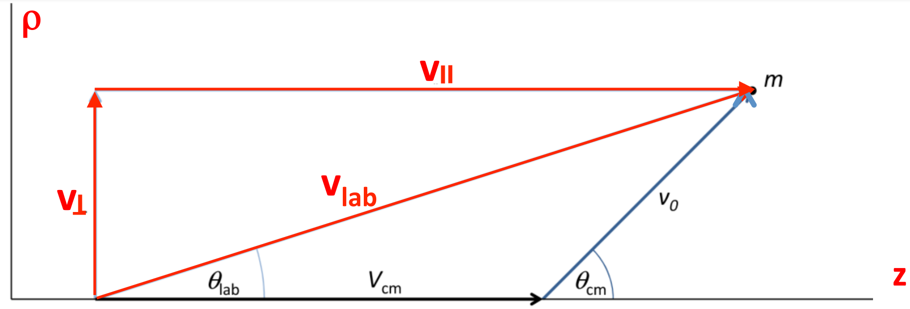
- Large-bore solenoid with a magnetic field (2-5 Tesla), uniform in the volume
- Beam intercepts a target inside the solenoid along its magnetic axis
- Light charged particles ejected from the target follow an helical orbit and are focused on the solenoid main axis.
- Detection: position sensitive Si array placed around the beam axis allowing for beam transport and recoil measurement




*Scheme HELIOS*

# Solenoid Kinematics

Particles trajectories can be defined by the orientation of the $\vec{V}_{lab}$ relative to solenoid axis




$v_\perp$ defines the radius of cyclotron motion for a particle of mass *A* and charge *q* in *B* field

$$r = v_\perp \, m/qB$$

$$T_{cycl} = 2\pi r/v = 2\pi m/Bq = 65.6\, m/Bq \text{ (ns)}$$

The position at which particles return to solenoid axis varies according to:

$$z = v_{par} T_{cyc}$$

What we need to measure:

- Particles **ToF**
- Impact point **z**
- $\mathbf{E_{lab}}$

Derived quantities:

- m/q
- $\mathbf{E_{cm}}$
- $\Theta_{cm}$

$$\Theta_{cm} = \arccos(qeBz - 2\pi m V_{cm}/(2\pi\sqrt{2mE_{lab} + m^2V_{cm}^2} - mV_{cm}qeBz/\pi)$$

$$E_{cm} = E_{lab} + 1/2 m V_{cm}^2 - V_{cm} eqBz/2\pi$$

# Helical Orbit Spectrometer: from ($E_{lab}$, $\Theta_{lab}$) to ($E_{lab}$,z)

Advantages:

- Particle identification through ToF = $T_{cycl}$
- Enhanced Q-value resolution
- No kinematical compression effects ($\Delta E_{lab} = \Delta E_{cm}$)

| Ion | $T_{cycl}$ = ToF (ns) | |
|---|---|---|
| | B = 2 Tesla | B = 3 Tesla |
| p | 32.8 | 21.9 |
| d, Alfa$^{2+}$ | 65.6 | 43.7 |
| t | 98.4 | 65.6 |
| $^{3}$He | 49.1 | 32.7 |

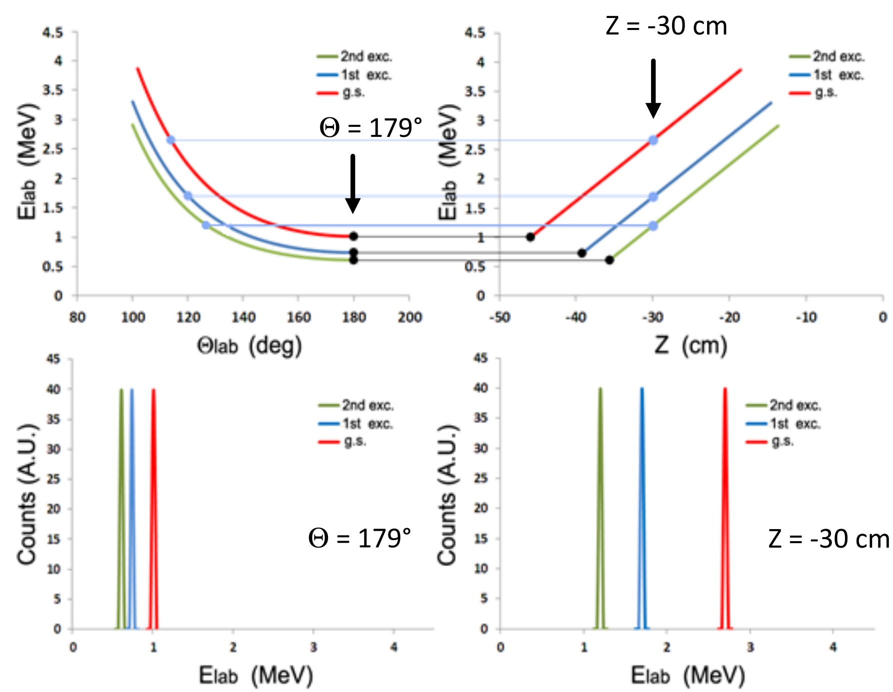
What it can be studied depends on :

- Two-body Kinematics
- Solenoid Size
- Solenoid B intensity
- Array

The quality of the results:

- B field degree of homogeneity
- type/shape of the detection array
- beam energy resolution
- beam spot size

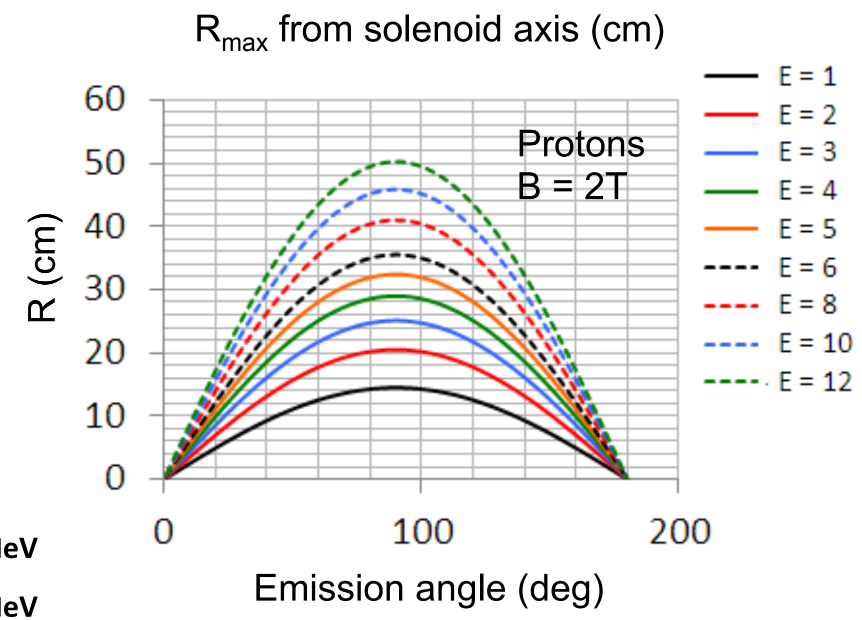
D($^{134}$Sn,p)$^{135}$Sn @ 6*A* MeV



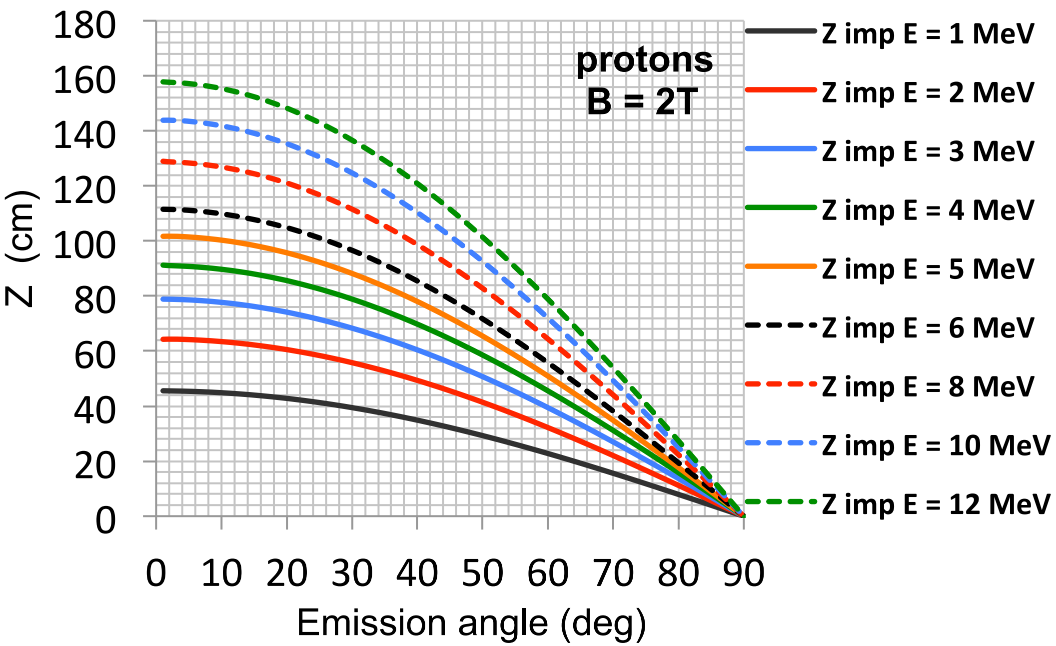
# Solenoid

Main parameter governing spectrometer acceptar

- B intensity
- Radius(R)
- Lenght (L)
- The extent of the magnetic field and array geometry imposes  limits on the acceptance region




Impact point along the solenoid axis




Requirements:

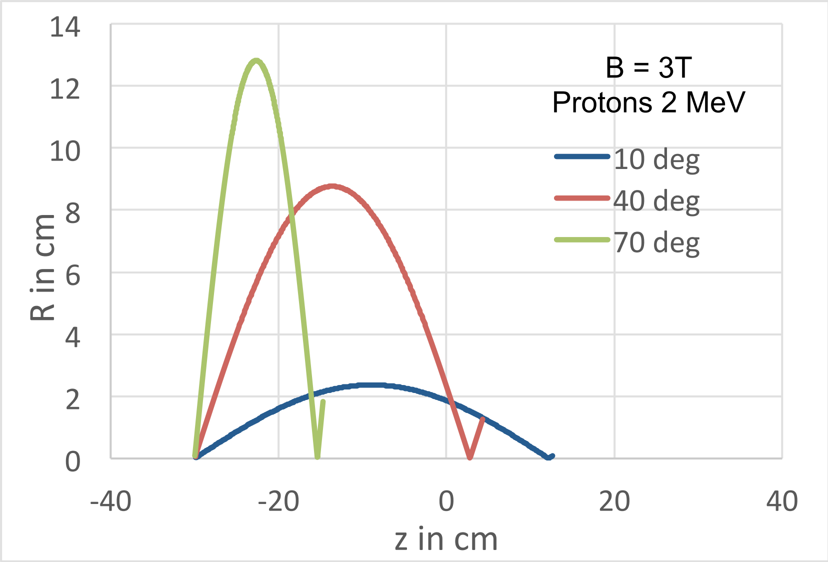
- Variable field to optimize the focalization of particles  (p,d,t,a) on the detector array
- Homogenous field size:
  Radius 40 cm
  Length ~100-120 cm

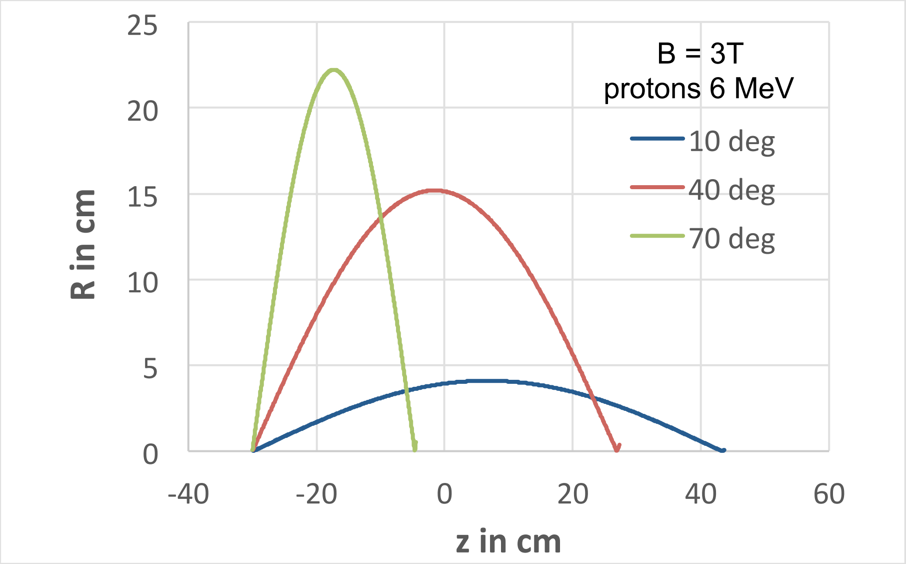
# Solenoid magnetic field homogeneity

Helios uses a solenoid built for NRM with a B field homogeneity of the order $10^{-4}$

Region of homogeneity Lenght ≈ 2 Radius

Simulations: Solenoid with a degree of homogeneity of the order of $10^{-3}$ and $10^{-4}$



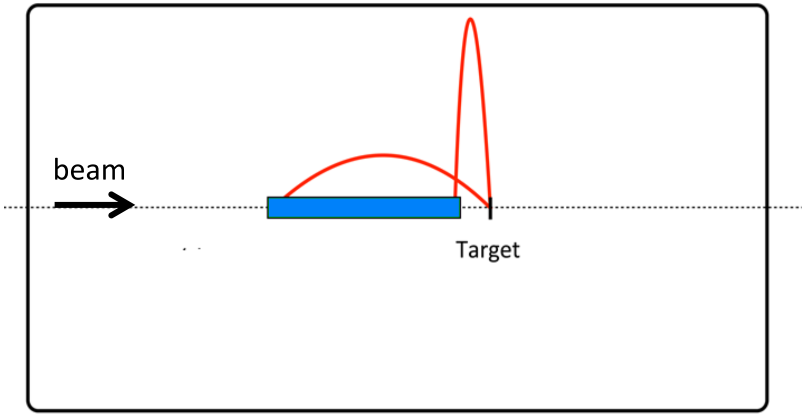




$\Delta x$ (Sole_ideal – Sole_$10^{-3}$) = f(E,Theta_lab) Es: proton 6 MeV, $\Theta_{lab}=10°$ $\Delta x$= 1.2 mm

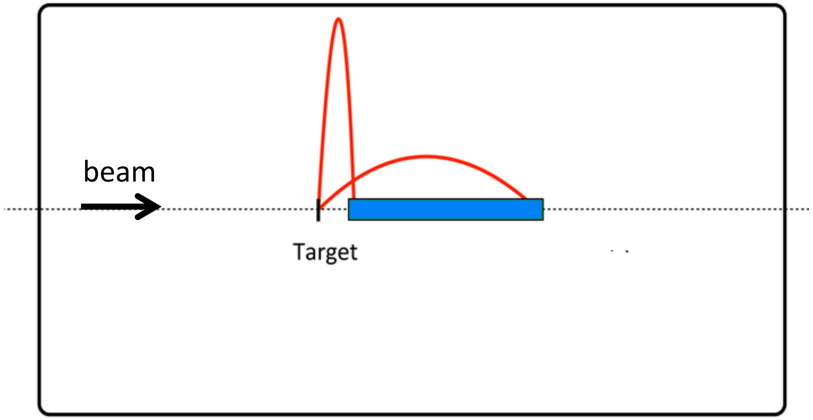
$\Delta x$ (Sole_ideal – Sole_$10^{-4}$) = f(E,Theta_lab) Es: proton 6 MeV, $\Theta_{lab}=10°$ $\Delta x$= 0.5 mm

# Detection system: Si array

Array geometry depends on the kinematics

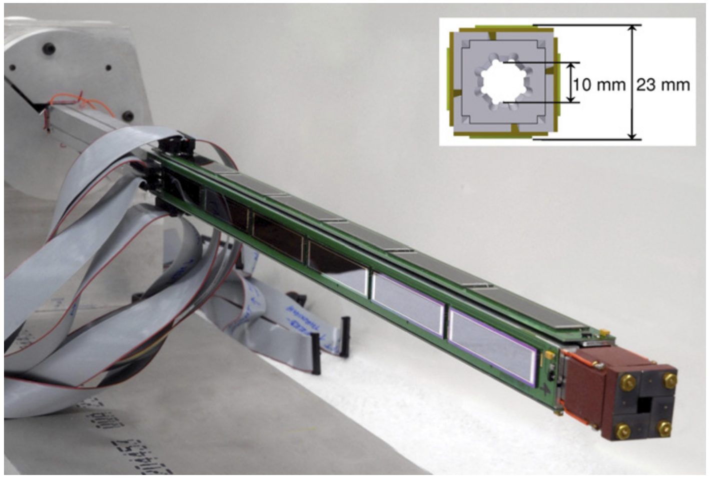



Es:(d,p) (t,p) ($^3$He,d) ($^3$He,$\alpha$)




Es: (p,p') (p,d) ($^3$He,t)

Setup Si di HELIOS




**Detectors:**

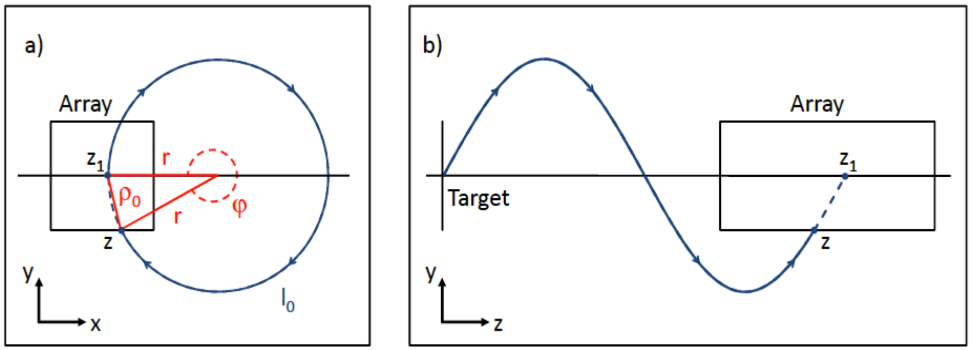
- Position sensitive Si, thickness: 1000-1500 $\mu$m

**Geometry:**

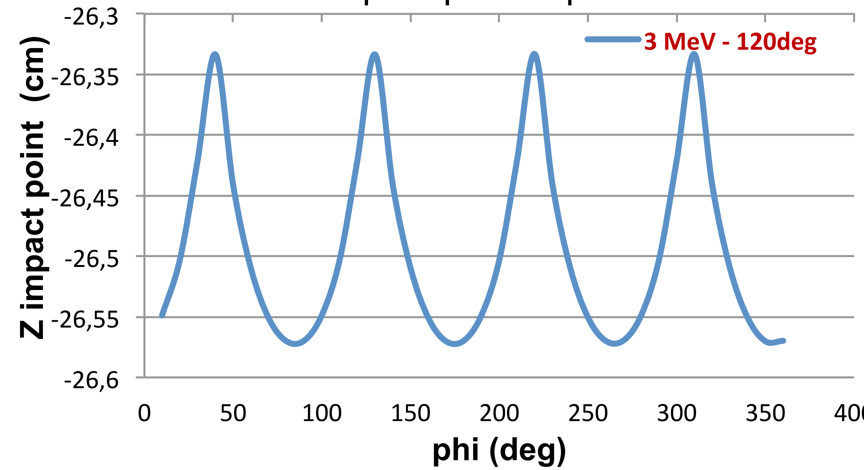
- Array with a regular polygonal cross-section
- Array lenght: 500 – 800 mm
- Two opposite requirements (beam trasport – particle detection

# Detection system: Si array geometry

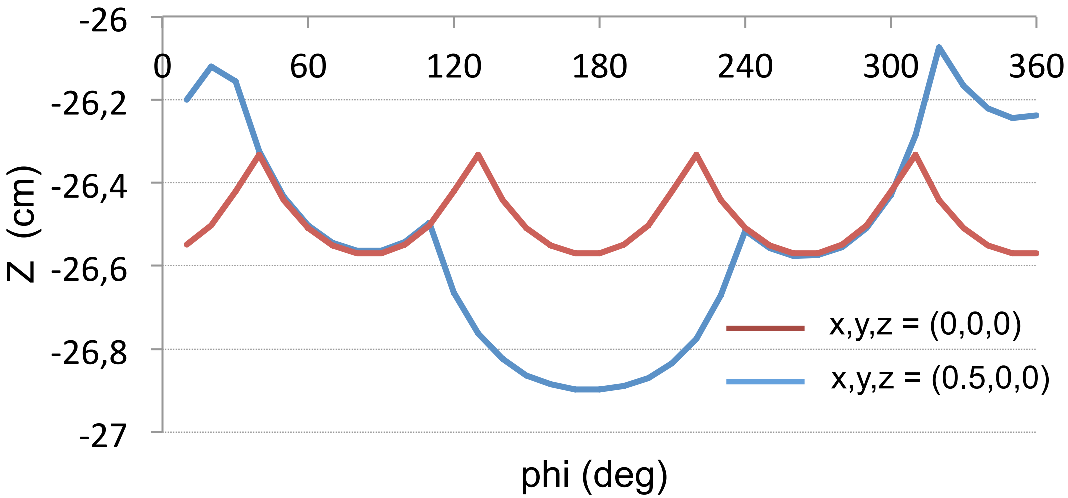
Particle trajectories in the solenoid




Z impact point – protons




Beam size effects




Strip or Bidim Si detectors: improvement in the determination of the emission angle ($\theta_{lab}$)

Array with hexagonal or octagonal cross section reduce finite size detector effects

# Detection system

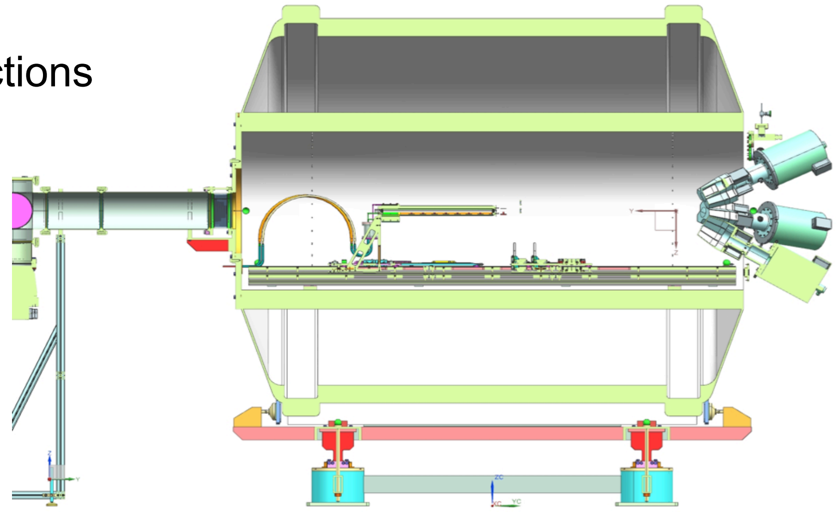
## Recoil detector:

- Dependent on the reaction investigated and on the beam purity
- Implication in the Si array geometry in forward direction

## HPGe detectors array for gamma detection:

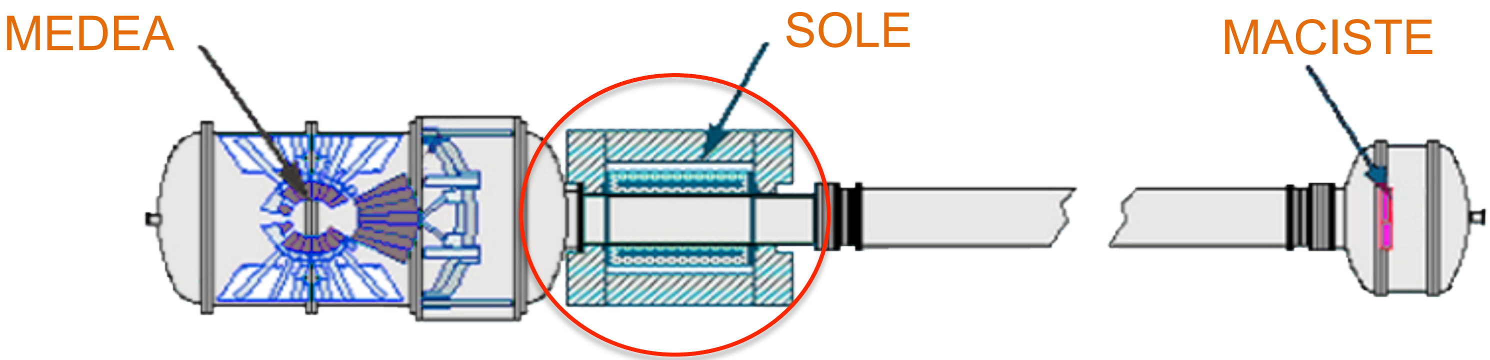
- Coincidence measurement particle-gamma
- Resolution Improvement
- Gamma detection in inelastic scattering reactions
- $J^p$ determination of unknown states
- Level scheme determination
- Geometry
- Working condition in B field
- Detector Efficiency
- Detector Resolution

Setup Geometry



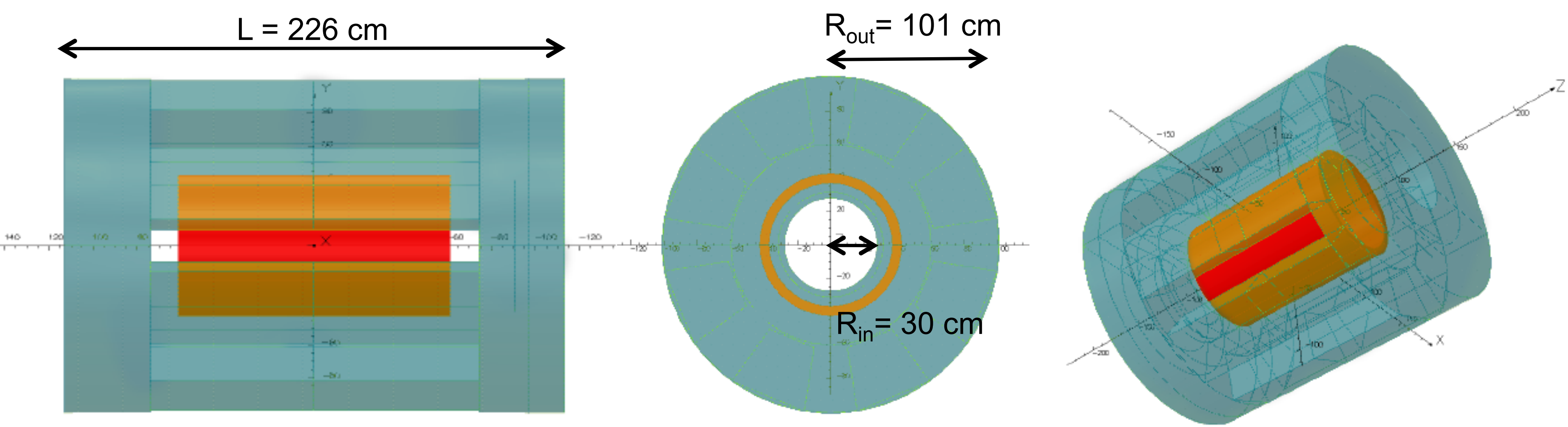
Study to use HPGe in magnetic field
(F. Recchia (Pd))

# Study of an Helical Orbit Spectrometer @ LNS




**SOLE:**

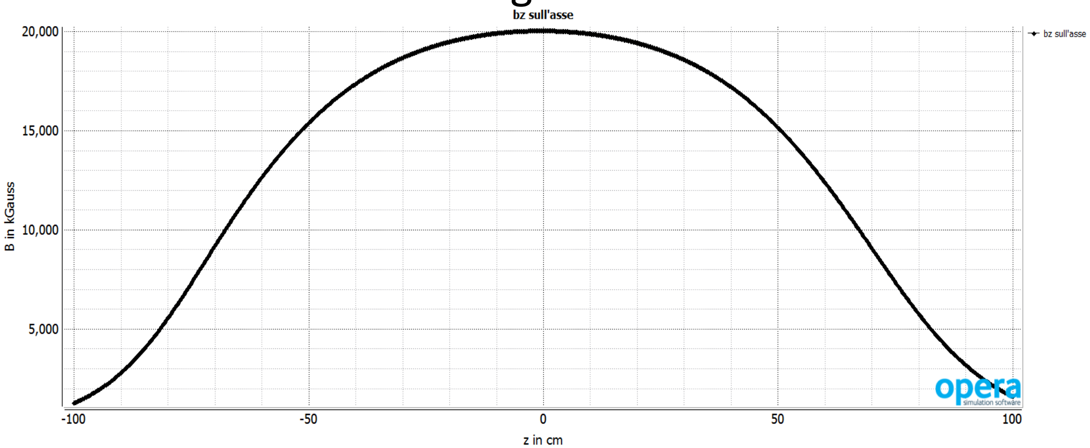
Superconductive solenoid with $B_{max}$ = 5 Tesla

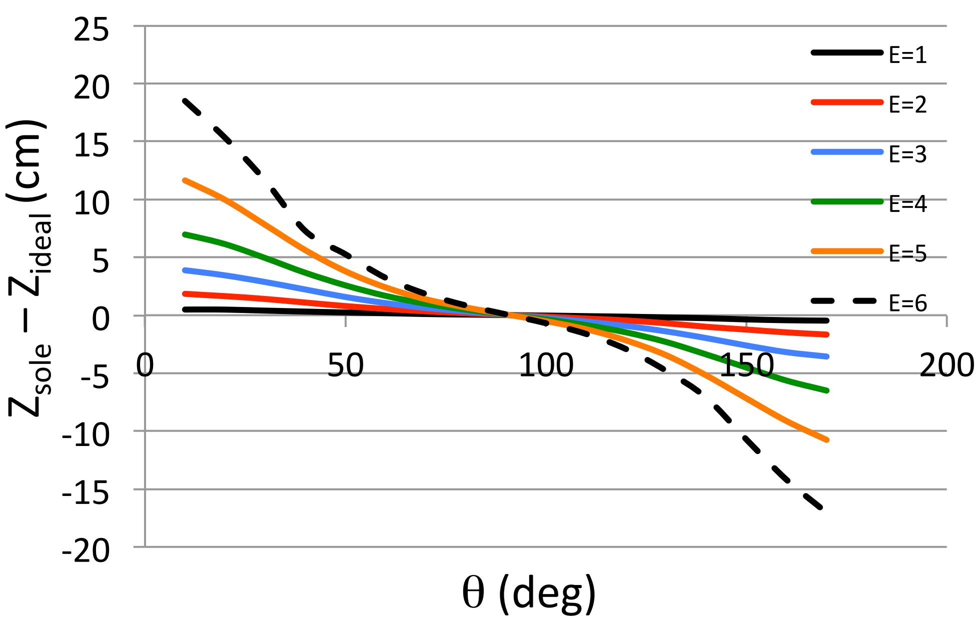



SOLE model using OPERA

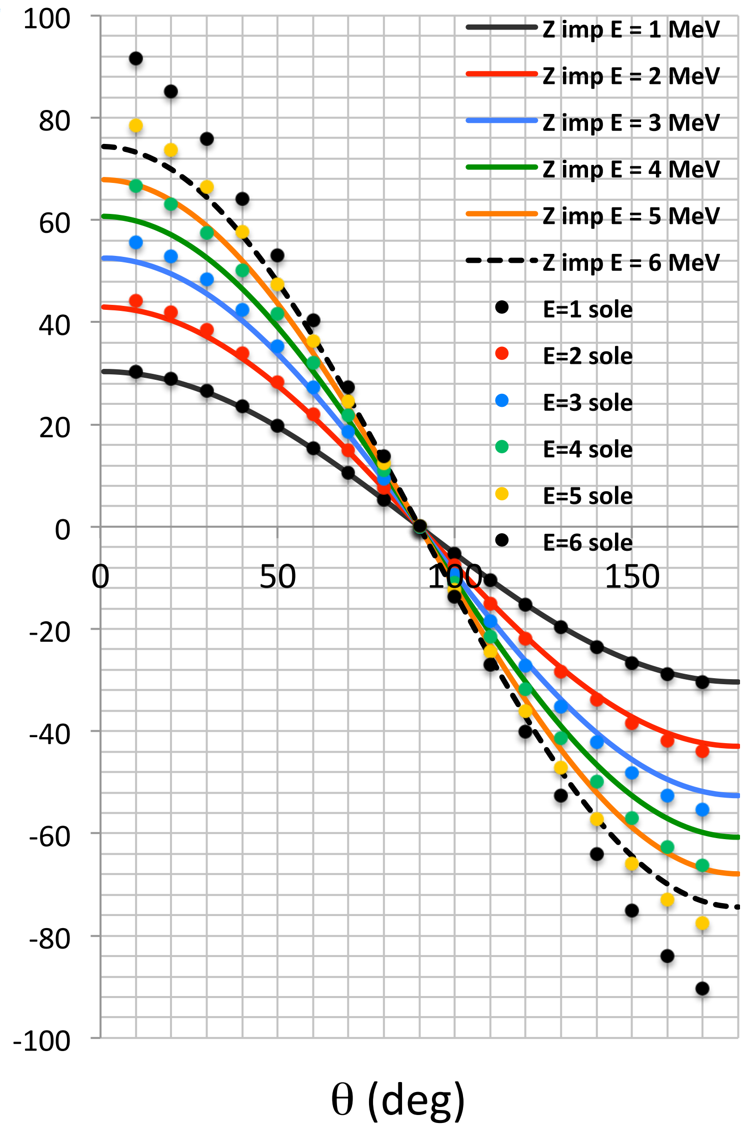
# Study of an Helical Orbit Spectrometer @ LNS

SOLE axial magnetic field in OPERA




Z impact point vs theta



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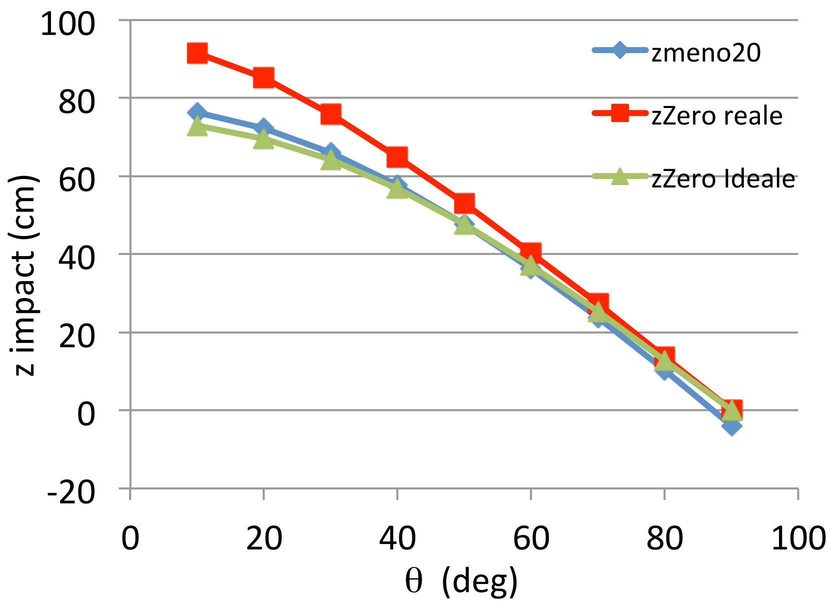
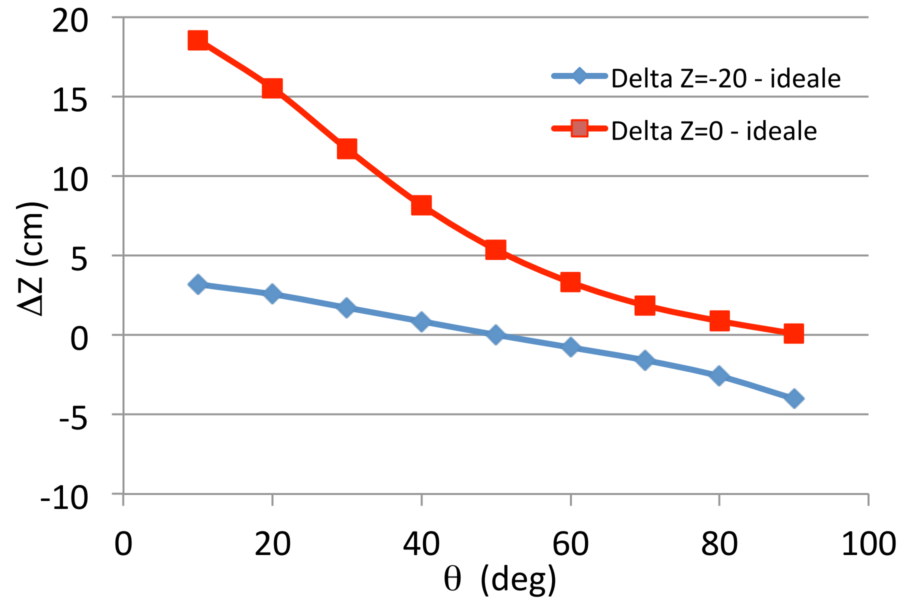
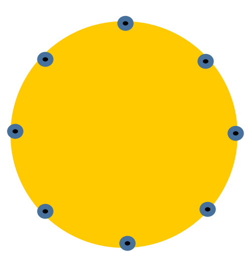
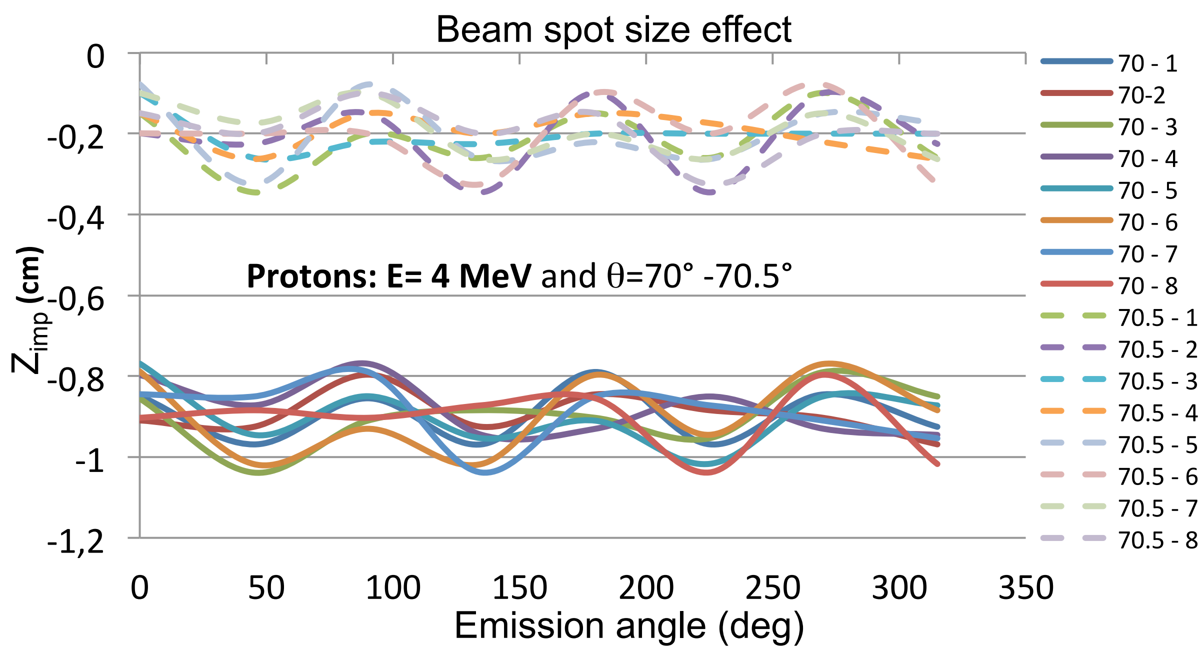



Protons:
E = 4 MeV, θ= 70°
E = 4 MeV, θ= 70.5°





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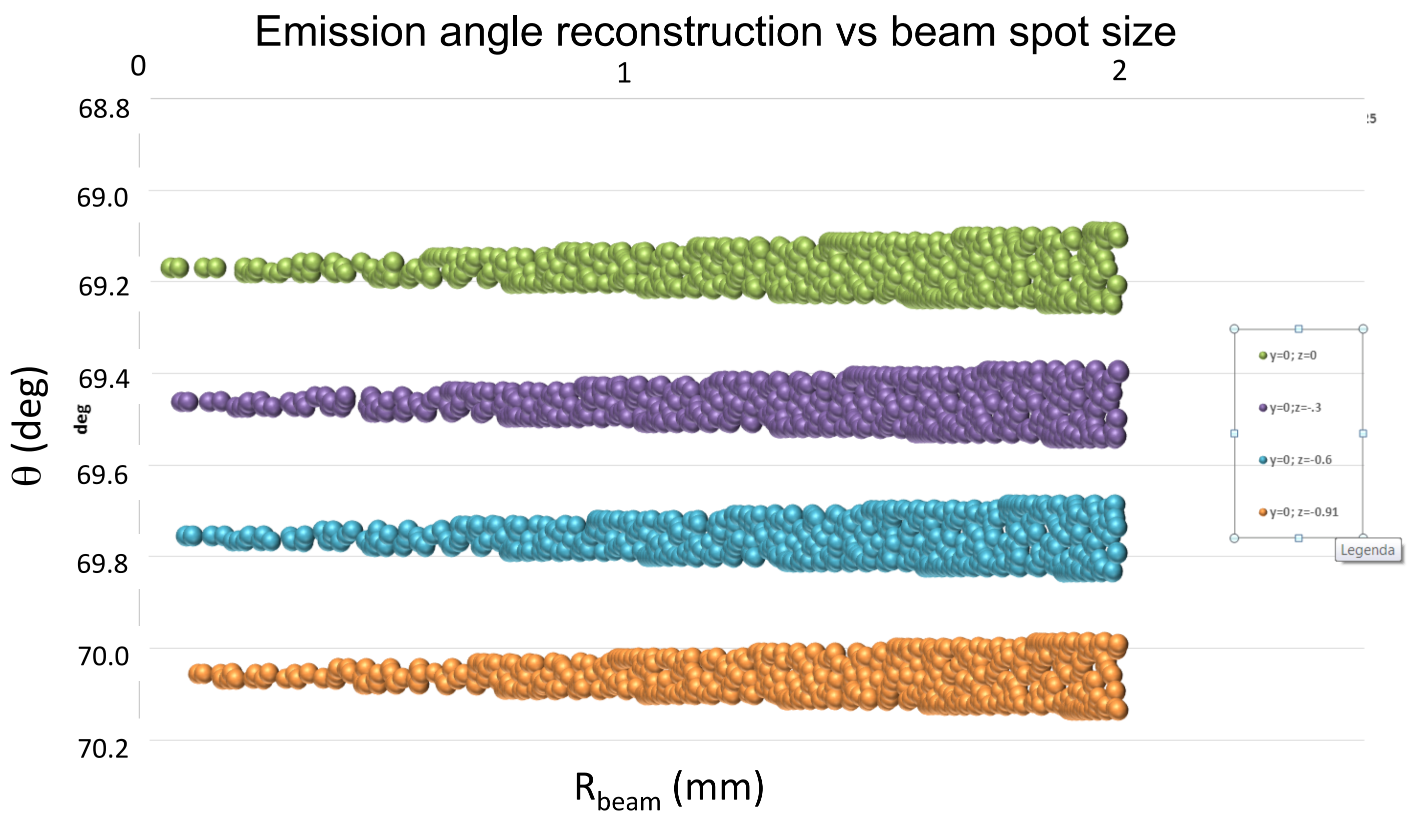


Activities:

- Detailed map of the magnetic field
- Charged particles transport simulations with measured field
- Test of the performances with a tandem beam

# Possible measurements with Helical Orbit Spectrometer @ LNL

Octupole deformations corresponding to reflection asymmetry or “pear shaped” nuclei:

$Z \approx 34, 56, 88$ and $N \approx 34, 56, 88, 134$

Evidences in :

$^{220}$Rn (Z=86,N=134), $^{224}$Ra(Z=88,N=136) at ISOLDE-CERN through Coulomb excitation experiments

Octupole moments in nuclei & permanent EDM moments.

Observation of non zero EDM would indicate time-reversal (T) or charge-parity (CP) violation ⟶ physics beyond standard model

A measurable electric dipole moment could be induced by the so called Schiff moment, a quantity sensitive to details of charge distribution

Importance of nuclear structure and comparison with model predictions

See Talk P. Butler

# Possible measurements with Helical Orbit Spectrometer @ LNL

What would be interesting to measure ?

- B(E3) strenght

Which nuclei at SPES ?

Region: Z ≈ 56 and N ≈ 88 (Barium isotopes for example)

How ?

- Inelastic scattering (p,p')
- Detection using an helical orbit spectrometer
- High detection efficiency
- Possible with low intensity beams (≈ $10^4$ – $10^5$ pps)

# Conclusions

- Properties of Helical Orbit Spectrometer for SPES
- Main advantages of ($E_{lab}$,z) detection
- Detection Array main features
- Study of an Helical Orbit Spectrometer @ LNS
- Possible application to pear-shaped nuclei

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