The ELI-IGISOL radioactive ion beam facility at ELI-NP

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EUROPEAN UNION

Structural Instruments 2014-2020

Competitiveness Operational Programme (COP)

nuclear physics

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) - Phase II

Project Co-financed by the European Regional Development Fund

IFIN-HH

OUTLINE

- **The ELI-NP Gamma Beam System**
- **The ELI-IGISOL Radioactive Ion Beam**
- **Design of its Gas Stopping Cell**

The ELI–NP Gamma Beam System

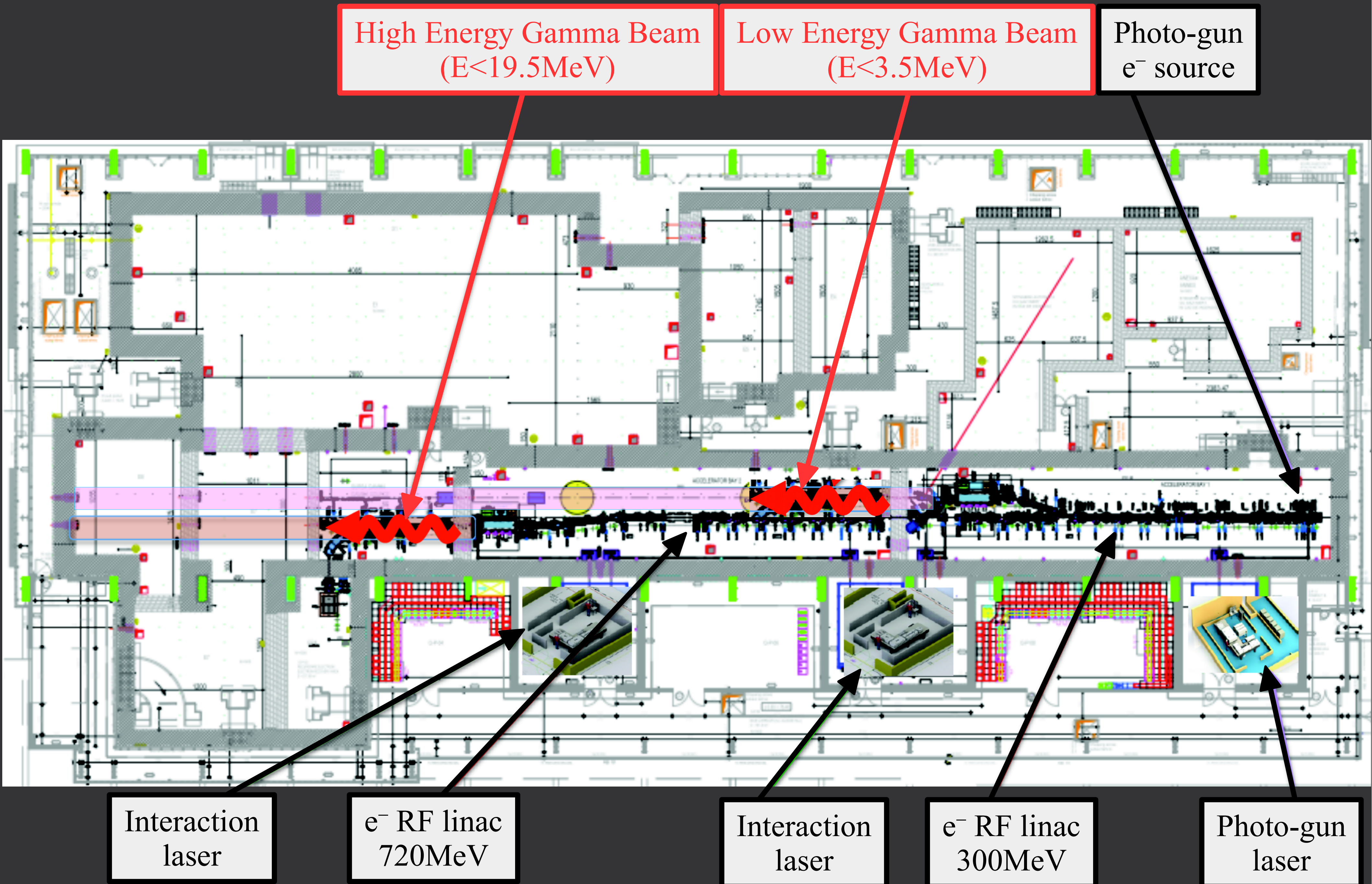
Extreme Light Infrastructure – Nuclear Physics

High Power Laser: maximum 2x10PW at 0.1Hz
world record! Experiments start next year

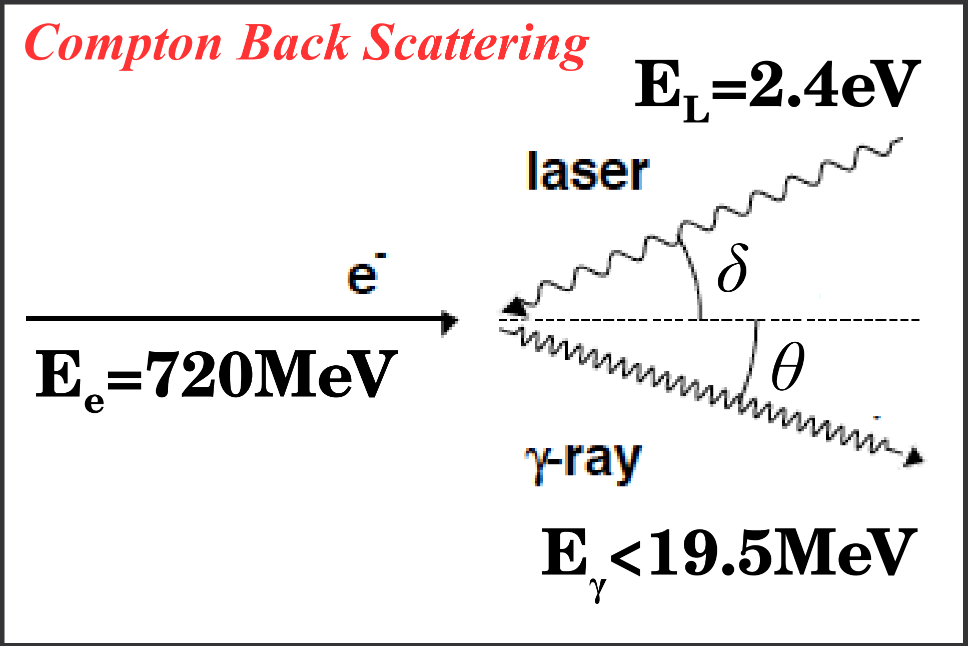
Gamma Beam: 0.2-20MeV, $\Delta E/E > 0.3\%$, spectral density $4 \cdot 10^4\ \gamma/(s \cdot eV)$, pol. 99%
contract cancelled! New contract this year:
3 years delay

- **Laser driven experiments**:
  fission-fusion, nuclear reactions in plasma
- **Gamma driven experiments**:
  NRF, photofission, (γ,n), charged particles, **exotic nuclei**
- **Combined experiments**: high field QED

ELI-NP Gamma Beam Facility



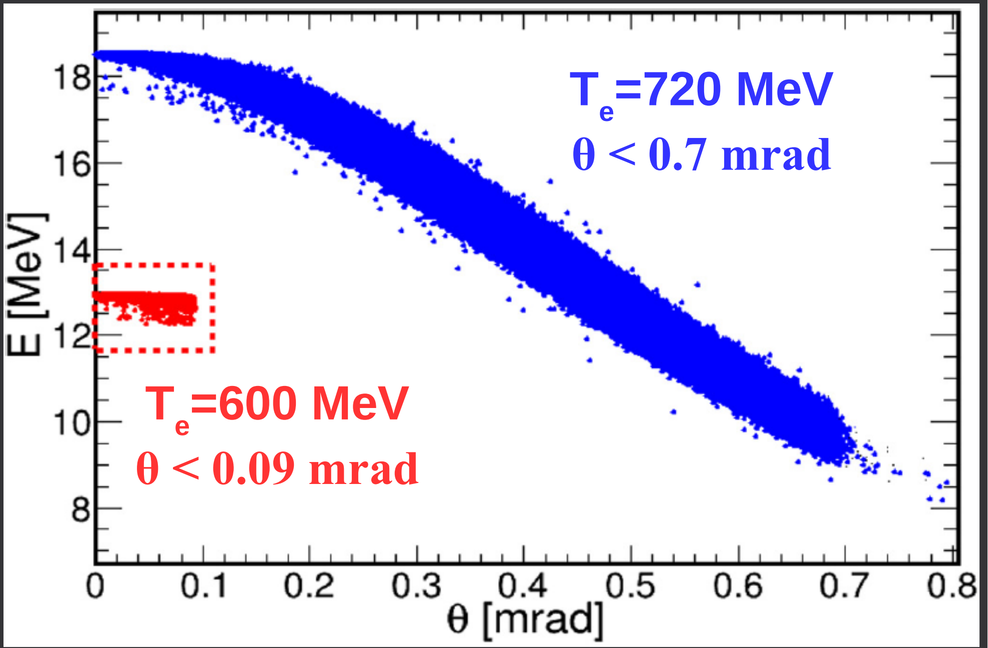
The ELI-NP Gamma Beam

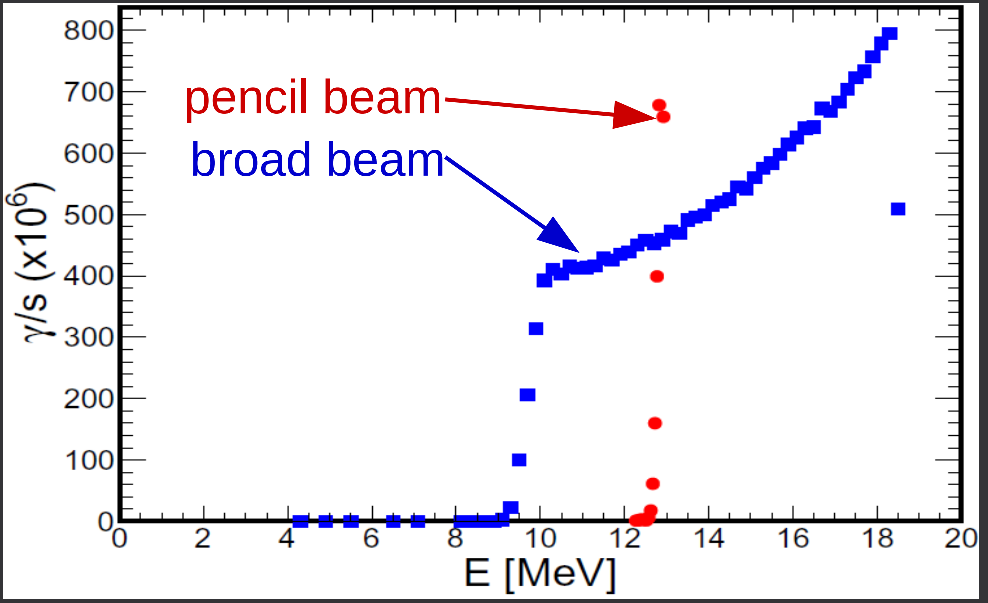


$$E_\gamma(\theta, T_e) = \frac{4\gamma_e^2 E_L}{(1+\delta^2/4 + a_{0p}^2/2) + \gamma_e^2\theta^2}$$

$$\gamma_e = 1 + T_e/m_e c^2$$

$$E_\gamma^{max} = 9.55\, eV \cdot \gamma_e^2$$

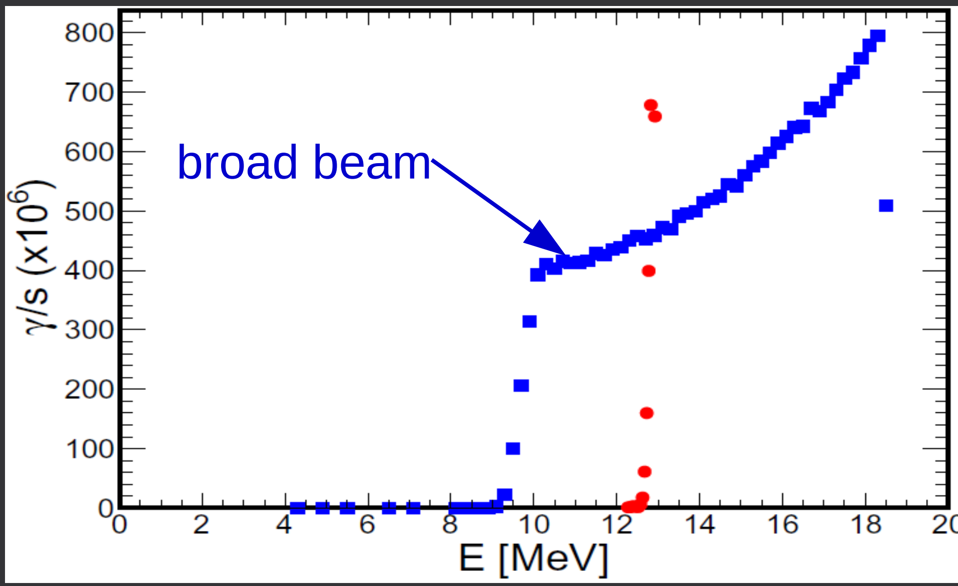


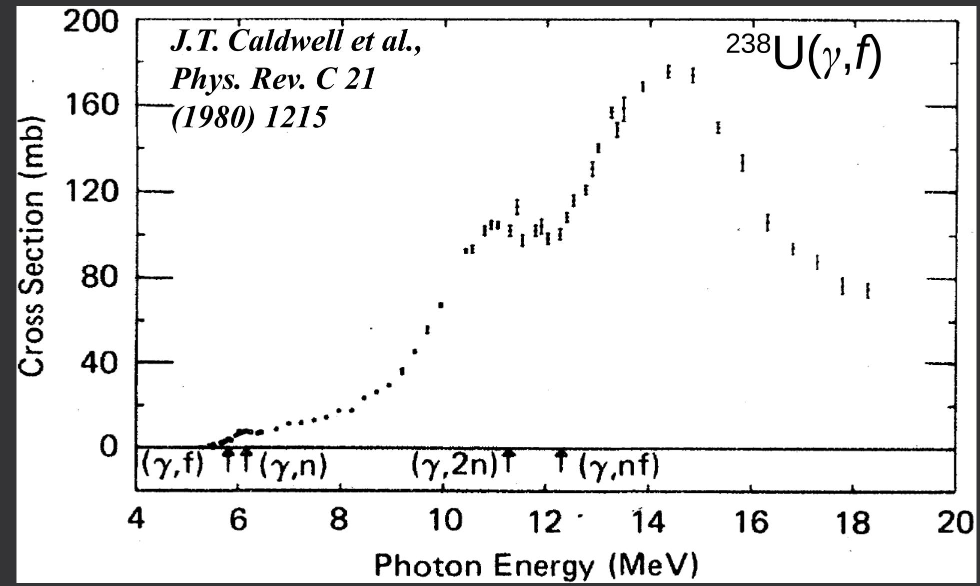


The ELI-IGISOL
Radioactive Ion Beam

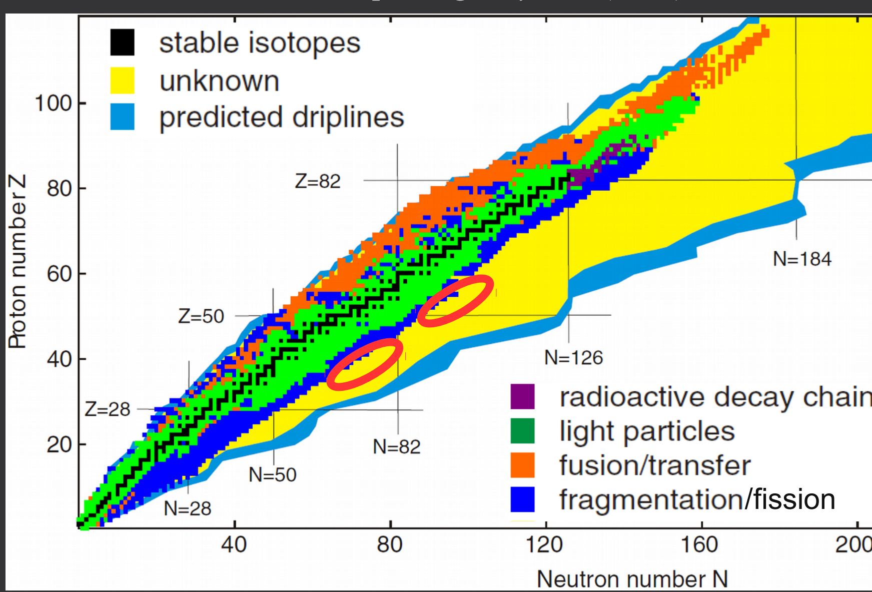
Radioactive Ion Beams with the Gamma Beam

Beam energy range up to ~19 MeV covers the GDR: RIB via photofission in an actinide thick target





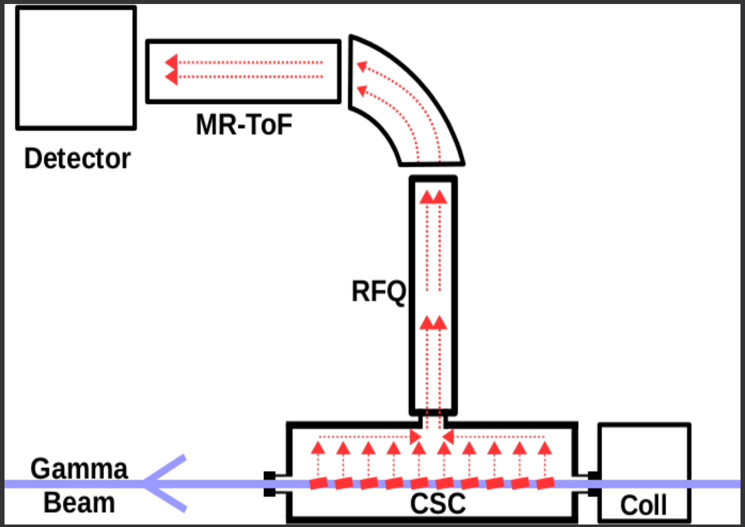
M. Thoennessen, Rep. Prog. Phys. 76 (2013) 056301



- **nuclear EOS** ***e=e(ρ,δ)***:
  – RIBs opened the relative neutron excess δ>0 region
- **stellar r-process nucleosynthesis**
- **tests of nuclear structure models**:
  – special regions: sudden deformation onset A~100, doubly-magic ^{132}Sn

ELI-IGISOL beamline:
Exotic Neutron-Rich Isotopes

Production of exotic neutron-rich fission fragments
Refractory elements: light region Zr-Mo-Rh and heavy rare-earths region around Ce



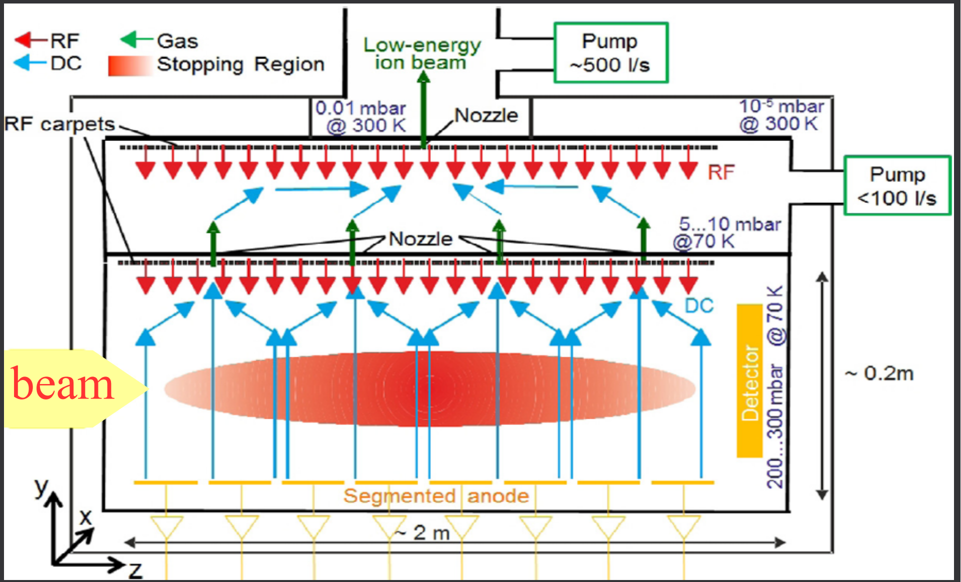
T. Dickel et al., NIM B 376 (2016) 216

^{238}U target:
- thick because σ(γ,f)~1b
- sliced in many thin foils: refractory, fast extraction
- tilted foils:
  (1) avoid hitting neighboring foils
  (2) increase γ pathlength w/ increasing thickness

IGISOL beam line:
ELI-NP, IFIN-HH, GSI, Giessen, IPN Orsay, IoP VAST

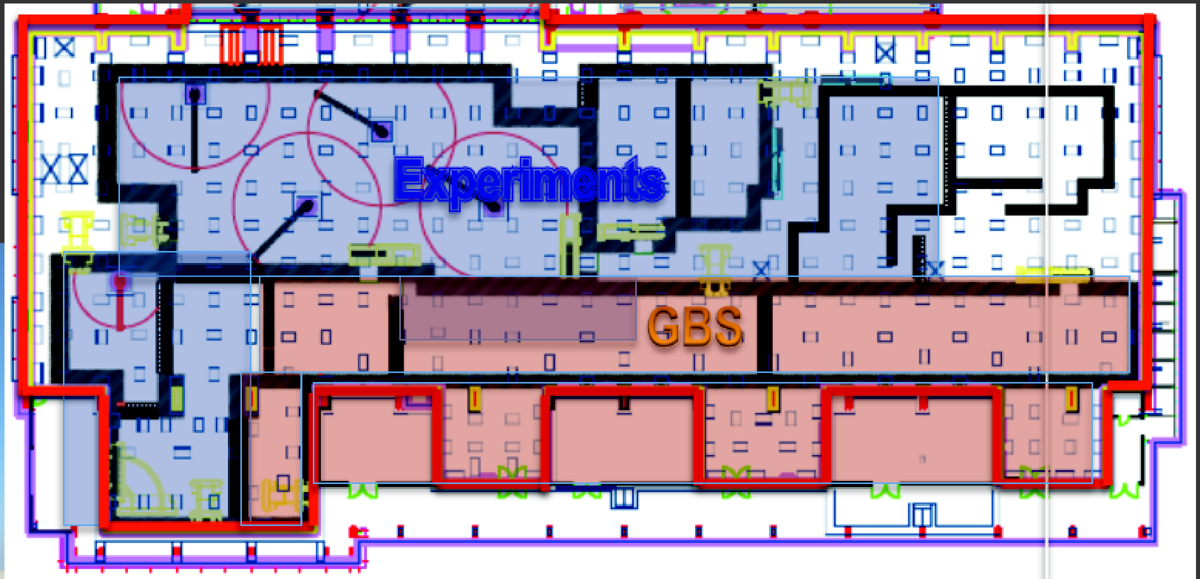
Phase I
1) Cryogenic Stopping Cell (orthogonal extraction)
2) RFQ (Radio Frequency Quadrupole)
3) MR ToF (Multiple Reflection Time of Flight)

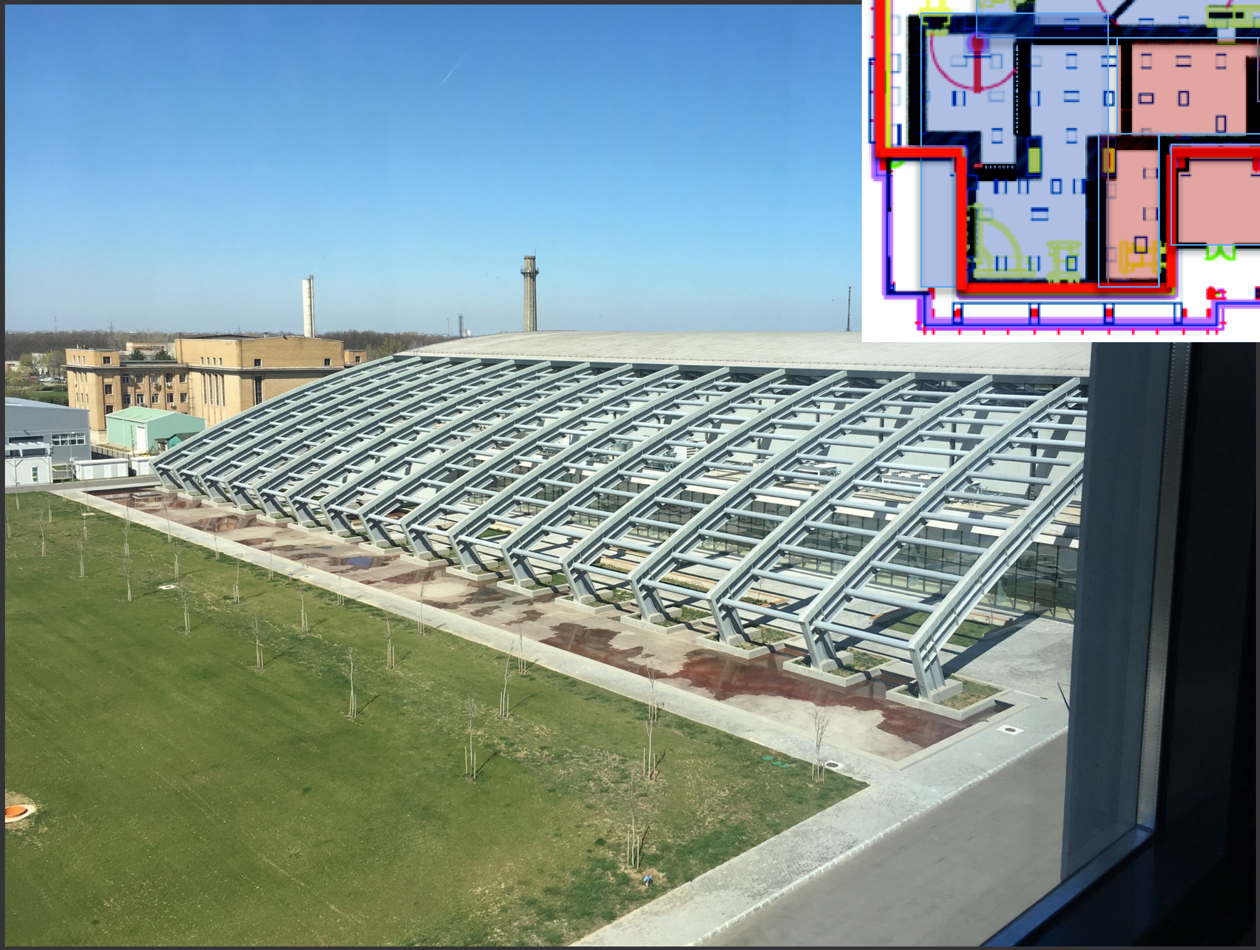
Phase II
1) β-decay station: HPGe detectors, tape station
2) collinear laser spectroscopy station



ELI-IGISOL beamline project

Part of ELI-NP extension to the former nuclear reactor: approved by the Romanian Government

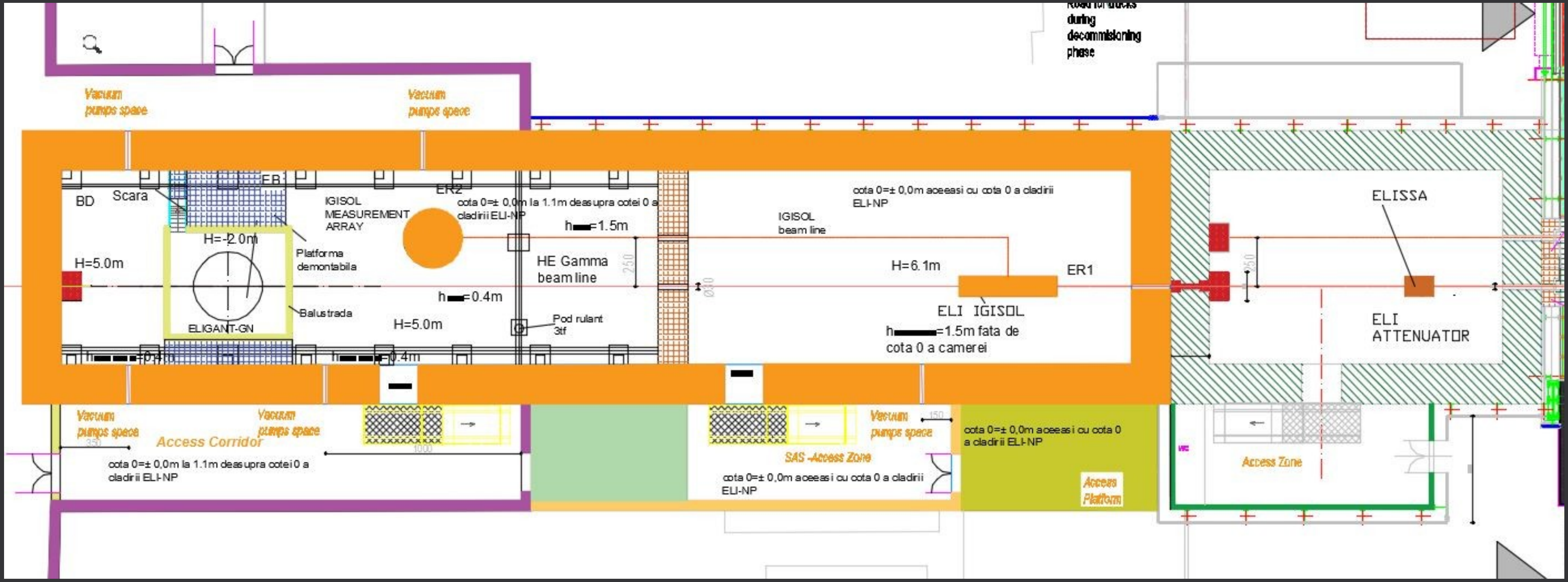




ELI-IGISOL beamline project

- tunnel construction and reactor building upgrade starts in 2020
- experimental setups implementation starts in 2021

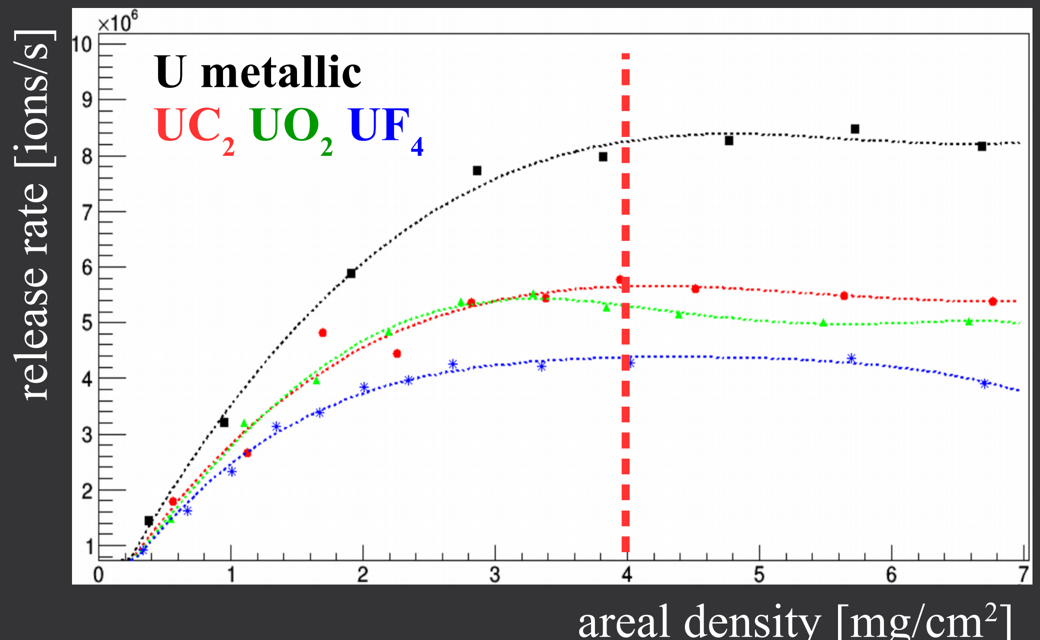
Tunnel to reactor building



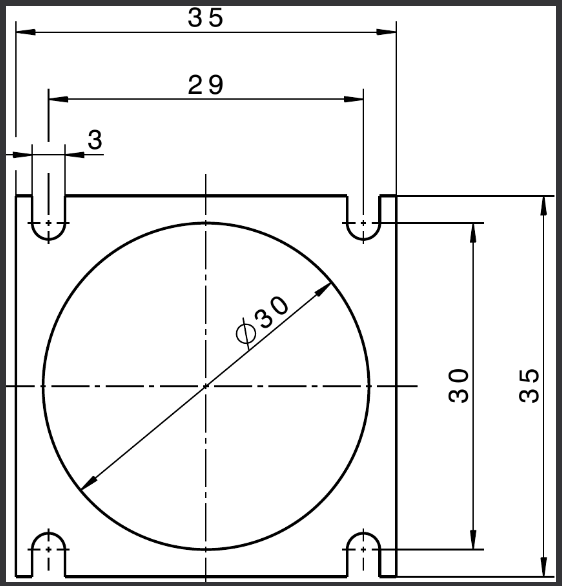
Design of the Gas Stopping Cell

Fission fragment release rates

GEANT4 program: fission process + energy loss until release



GSI Target Laboratory:
6 UO_2 targets 2µm (2.2mg/cm^2)
0.5µm graphite backing
$AlMg_3$ frame



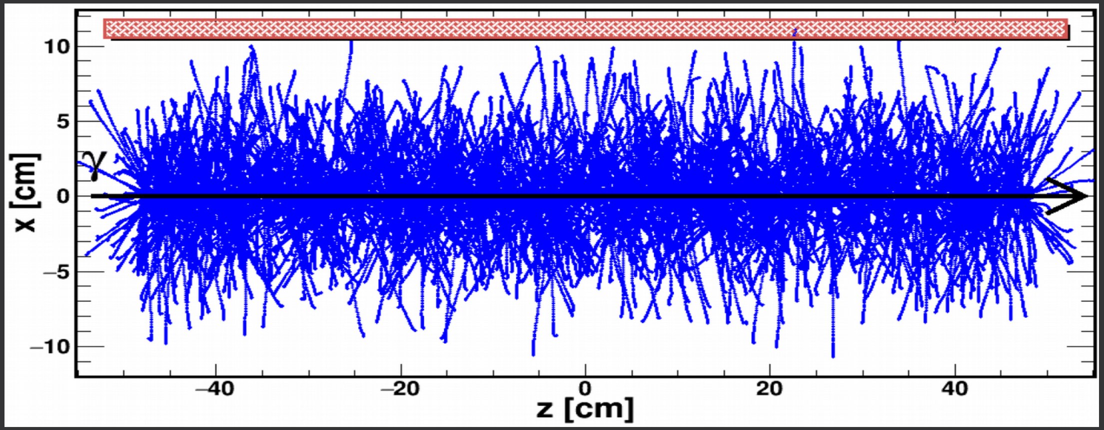
Target foils: 4mg/cm^2 (2µm metallic U) with 0.5µm graphite backing

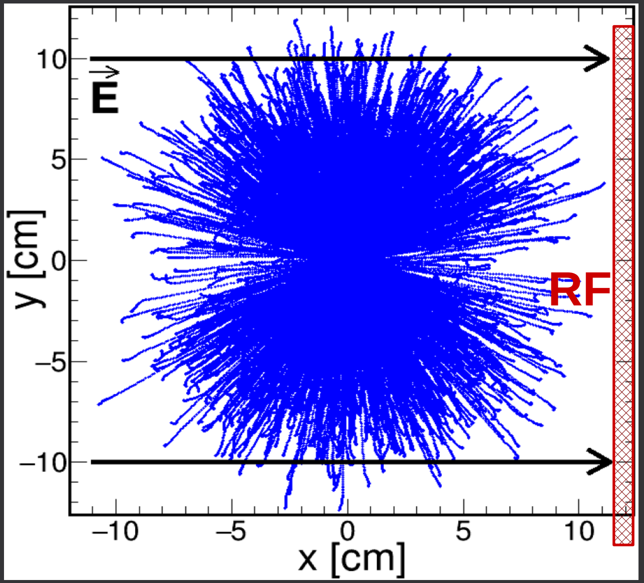
Gamma beam rate $10^{12}\gamma$/s → Radioative Ion Beam rate ~**10^7 frag/s**

P. Constantin et al., NIM B 397 (2017) 1-10

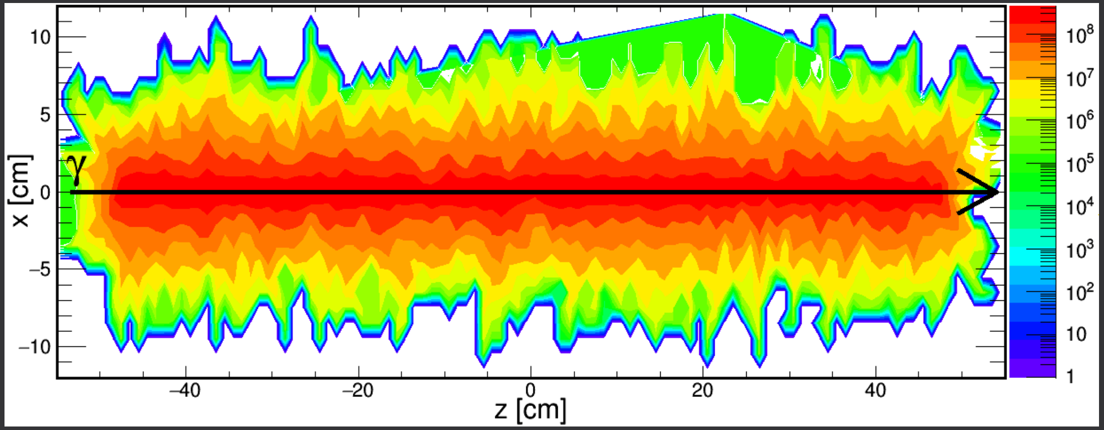
Fragment Slowing Down in Gas

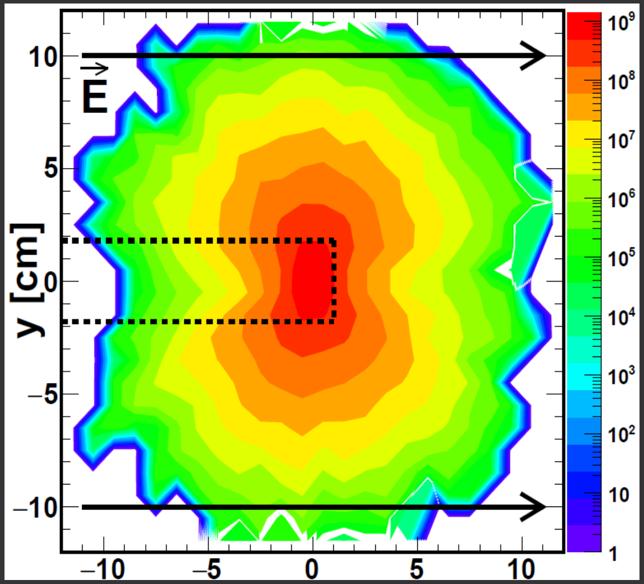
Geant4: He, T=70K, p=300mbar (ρ=0.206mg/cm^3)
>95% of fragments stop in 11.3cm → **width~24cm**





Space charge = He$^+$ cloud created by fragment (>90%)
Above a certain **charge density rate Q**: field saturation, strong e-ion recombination, weak plasma.

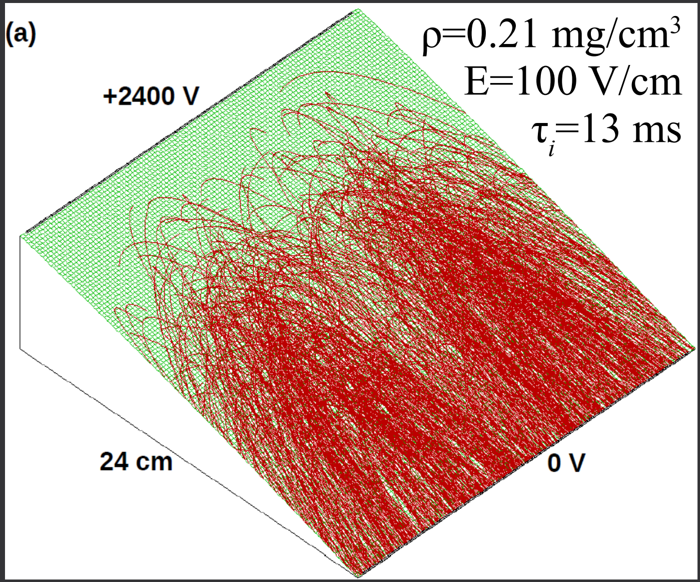




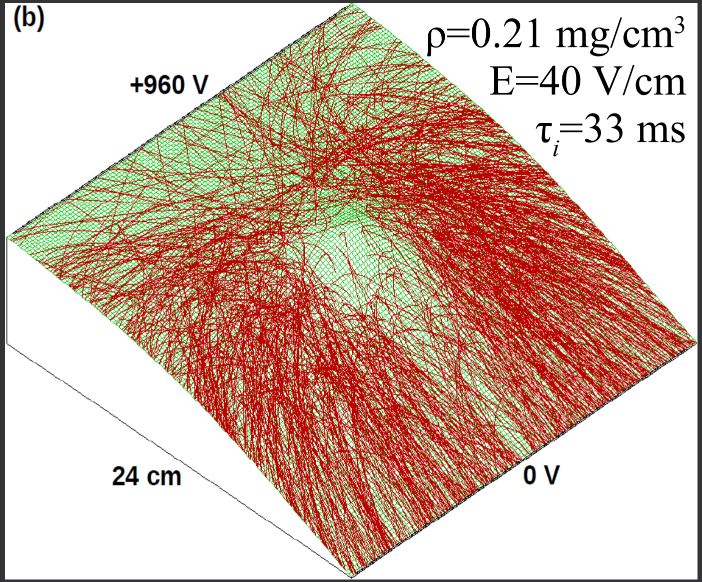
Space Charge Effects

SIMION 8.1 program:
solves Poisson eq. dynamically (PIC simulation) → extraction efficiency ε and time τ

$$\epsilon \nabla^2 \Phi(x, y) = -e\tau_i Q(x, y)$$



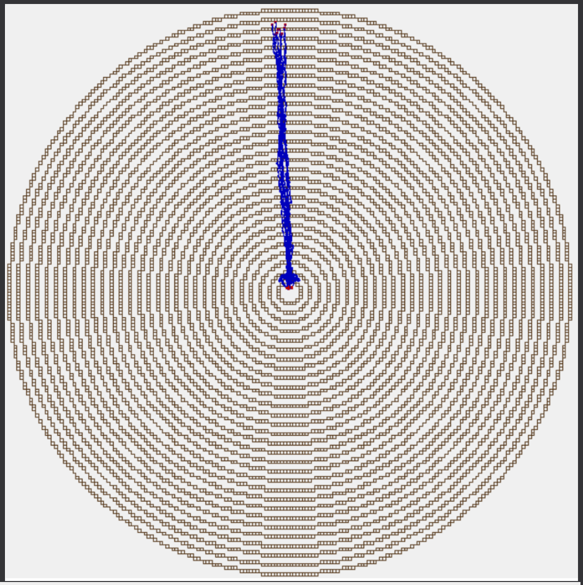
$\varepsilon = 89\%$ $\langle\tau\rangle = 6.8$ms

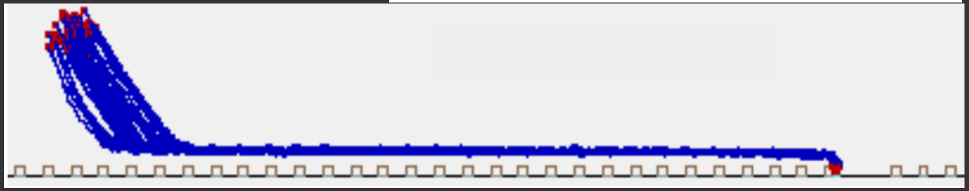


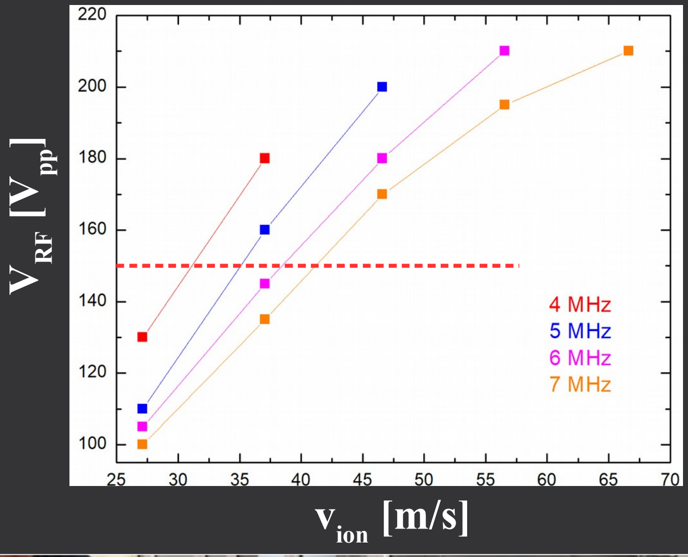
$\varepsilon = 67\%$ $\langle\tau\rangle = 17$ms

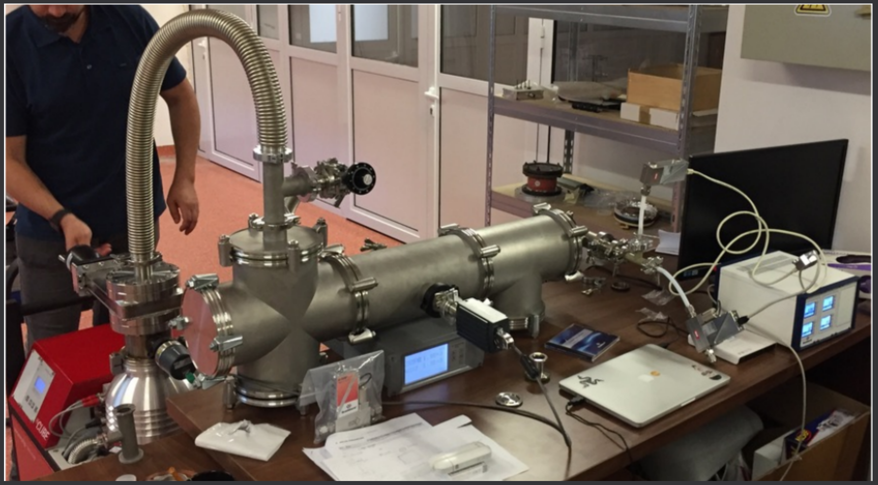
Fragment extraction – RF carpet transport

SIMION 8.1:
ion catching
at upper wall
with RF+DC fields









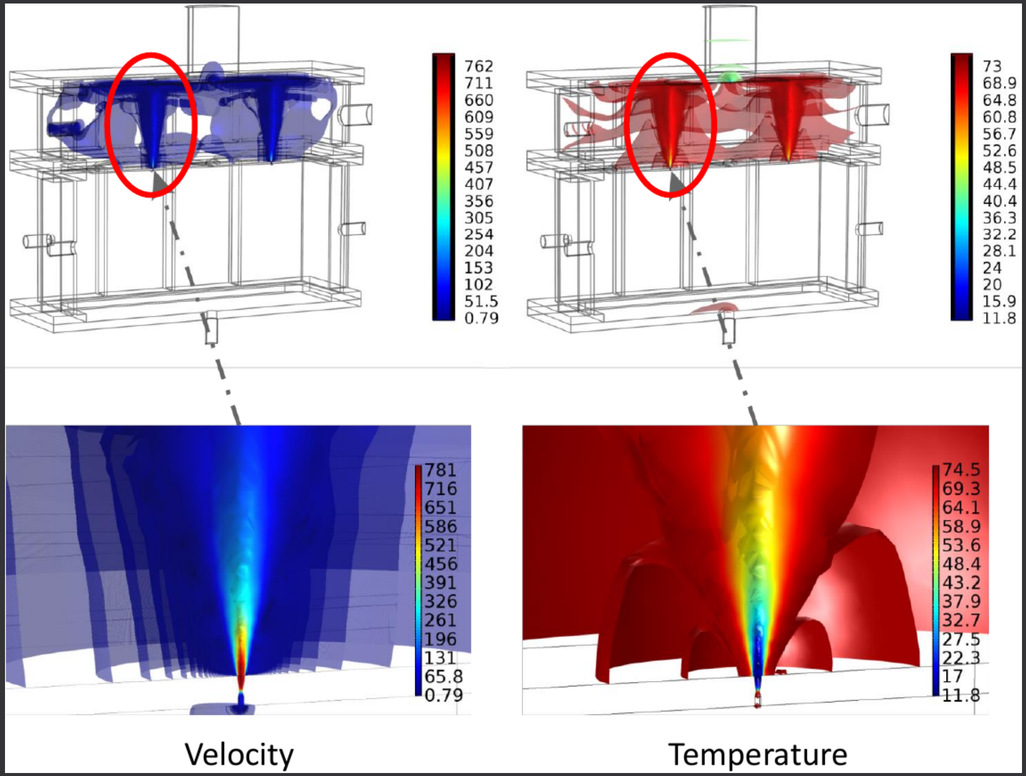
$$V(t)=V_{DC}+V_{RF}\sin(2\pi\nu_{RF}t)$$

V_{DC}=180V , V_{RF}=150V_{pp} , ν_{RF}=6MHz
r_0=125μm , p=200mbar, T=80K

Optimal density ρ: large for fragment stopping, small for carpet repulsion
Optimal U_{DC}, U_{RF}, ν_{RF}, r_0 for best ε and τ → ε>90% and τ≈10ms are obtained
A traveling wave carpet will be used in the upper extraction cell.

Fragment extraction – Hypersonic Gas Jets

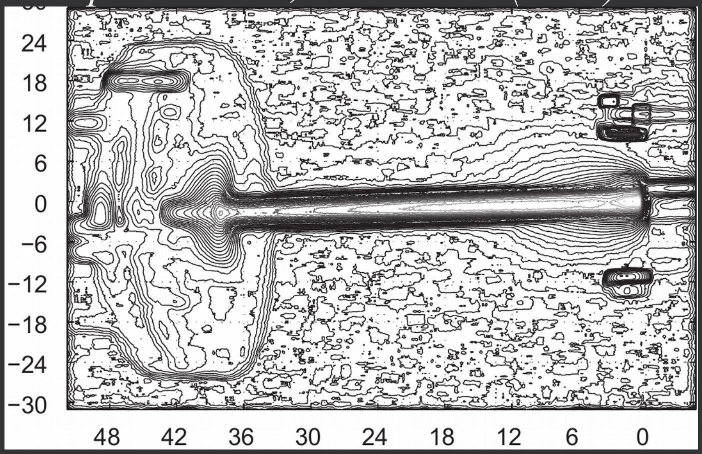
COMSOL: ion drag by supersonic gas jets



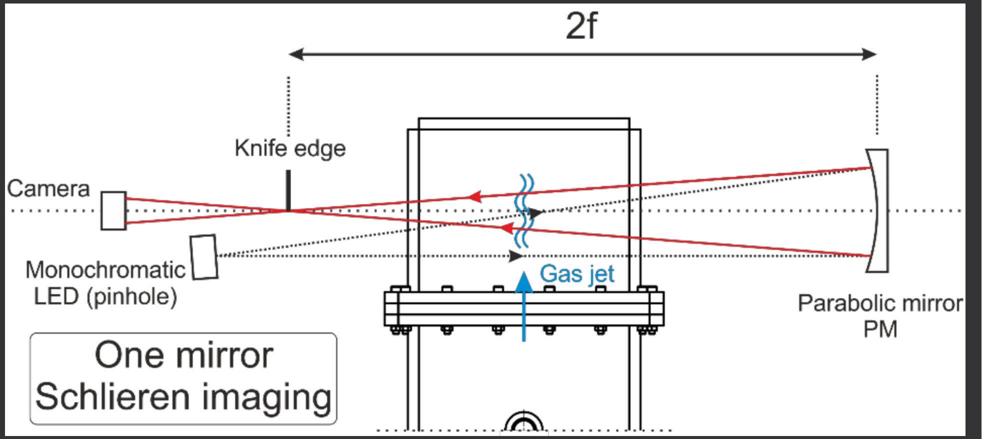
At nozzles: v_{max}=800m/s, T_{min}=12K → M_{max}~$v/\sqrt{T}$=4
At upper wall: v_{max}=30m/s, T_{min}=50K, time~2ms

RF carpets: ion kinematics at upper wall
Gas system: mass flow ≈ 3 g/min, 2 inlets & 2 outlets

Jyvaskyla: He fluorescence gas jet visualization
Reponen et al., NIM A 635 (2011) 24



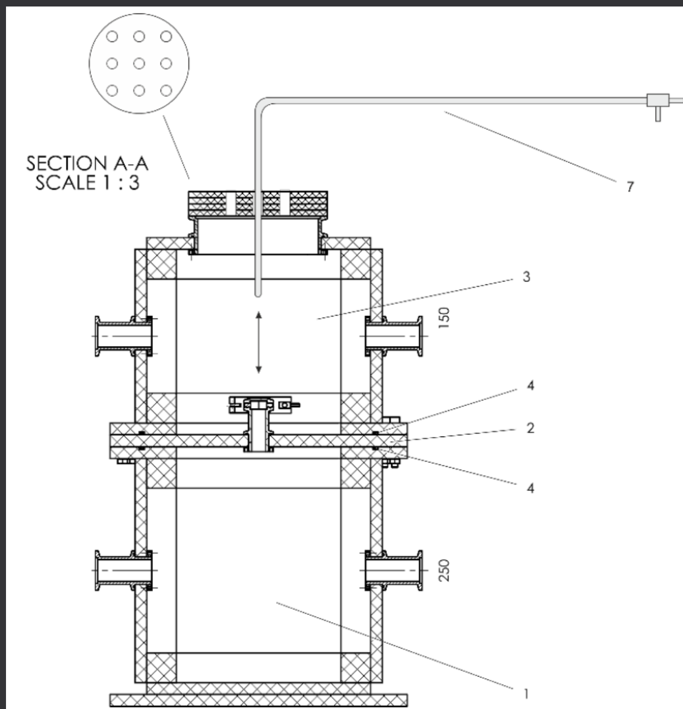
Schlieren setup for gas jet visualization

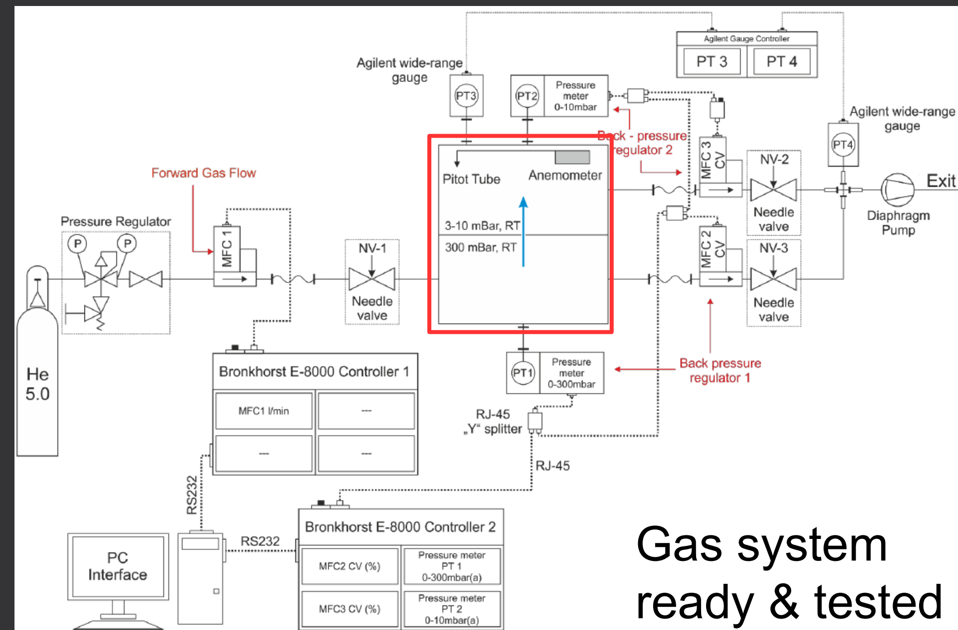


Alternative: converging-diverging lenses
Advantages: cryogenic operation; wide v range

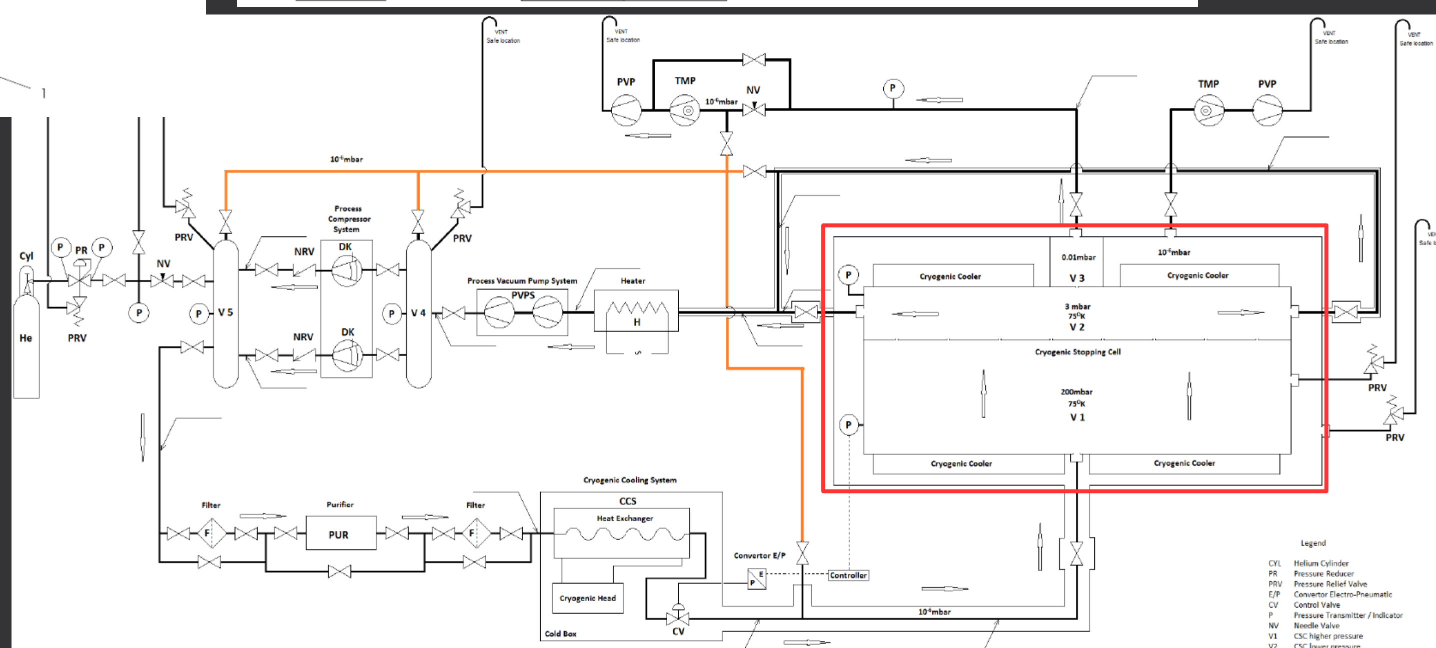
Hypersonic Gas Jets – Gas System

Design ready:





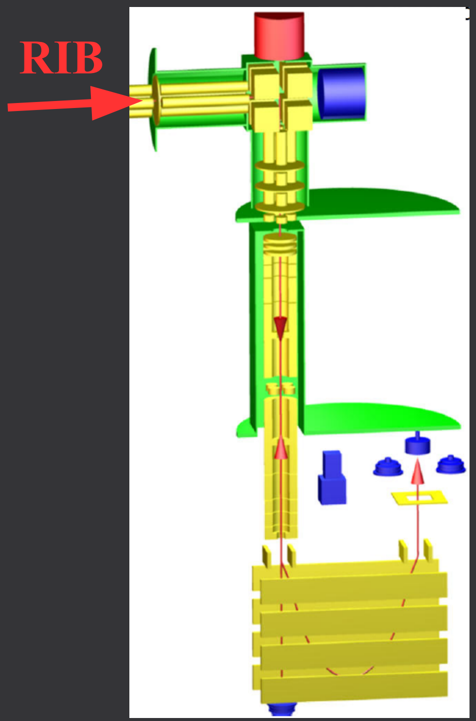
Gas system ready & tested



HADO-CSC Gas System Design

Exotic nuclei selection

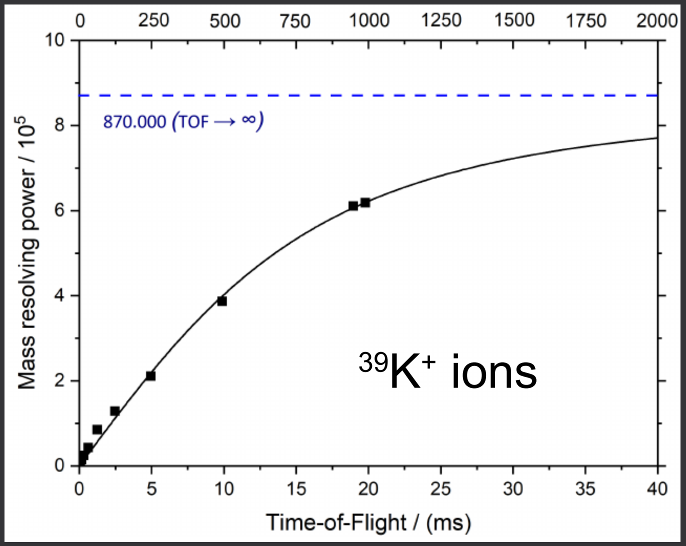
- ions extracted from the CSC are formed into a RIB by the RFQ: cooling, bunching, mass selection (m/Δm~200), CID
- high resolution mass selection and measurement by the MR-ToF



$$\frac{m}{q}=\frac{C\left(t-t_0\right)^2}{\left(1+bN\right)^2}$$

t = time of flight
N = number of turns
C, b, t_0=constants

m/Δm≈620000 for t≈20ms and N≈1000

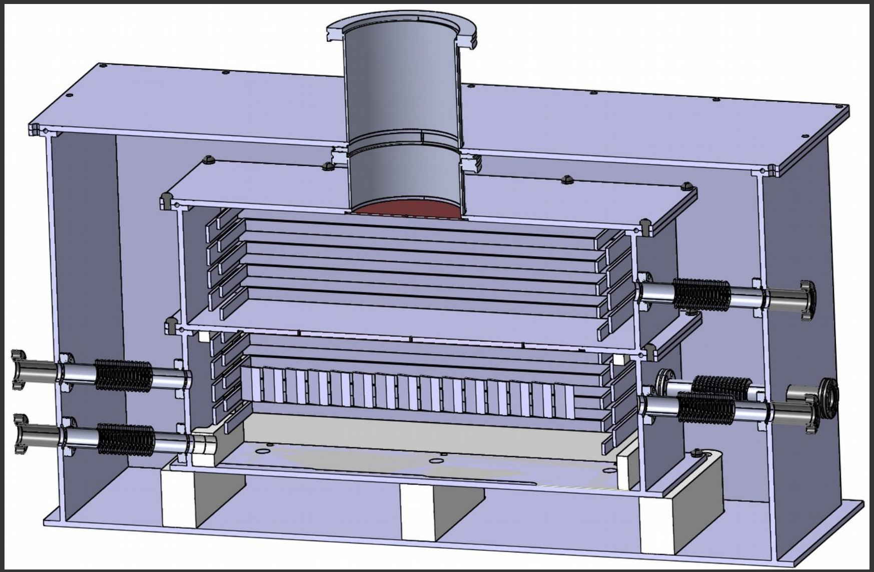


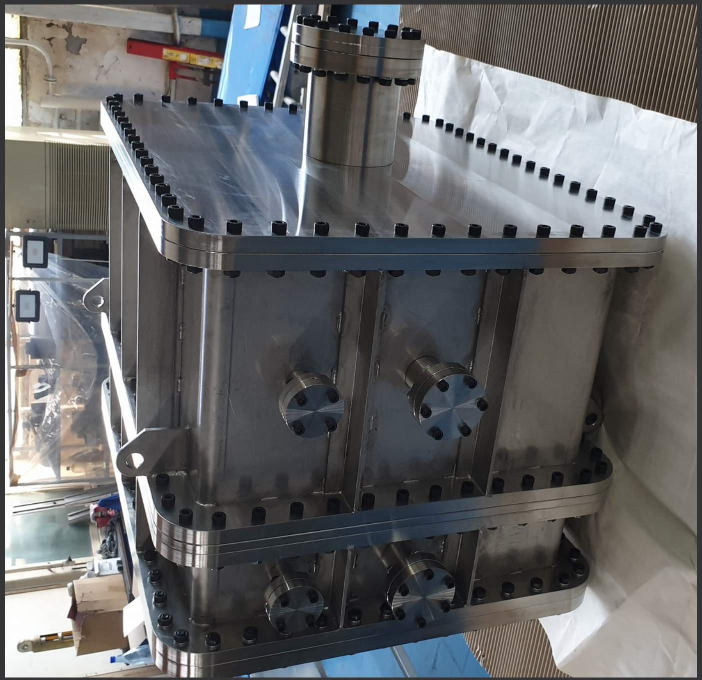
Ayet San Andres S. et al., Phys Rev C 99, 064313 (2019)

Summary & Outlook

- a two-phased IGISOL RIB facility will be built at ELI-NP
- its main characteristics are expected to be:
  - very low backgrounds (space charge)
  - high efficiency (70-90%) and low extraction time (12-20 ms)
  - very high mass selectivity ($\Delta m/m \sim 10^6$): isomeric beams
  - large range of measuring capabilities: mass, $\alpha/\beta/\gamma$ spectroscopy, nuclear moments and radii
  - emphasis on refractory isotopes

- **demonstrator gas cell**
- tests of components this year





Extreme Light Infrastructure - Nuclear Physics

(ELI-NP) - Phase I

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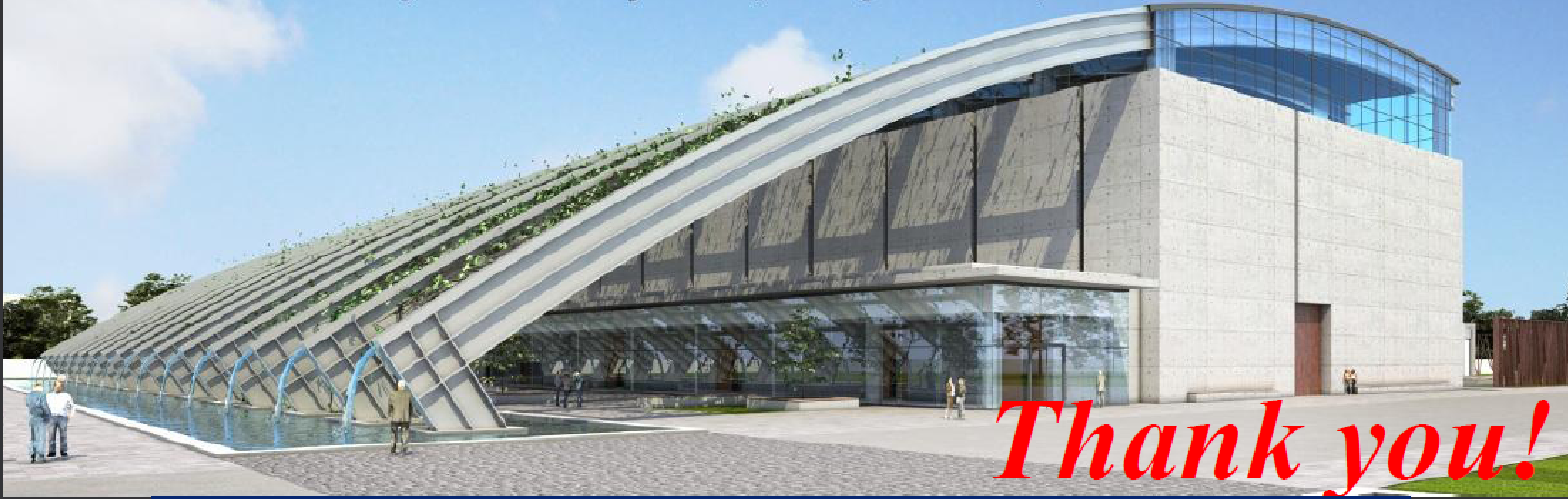

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