The FRIENDS^3 project

Fast Radioactive Ion Extraction and Neutralization Device for S^3

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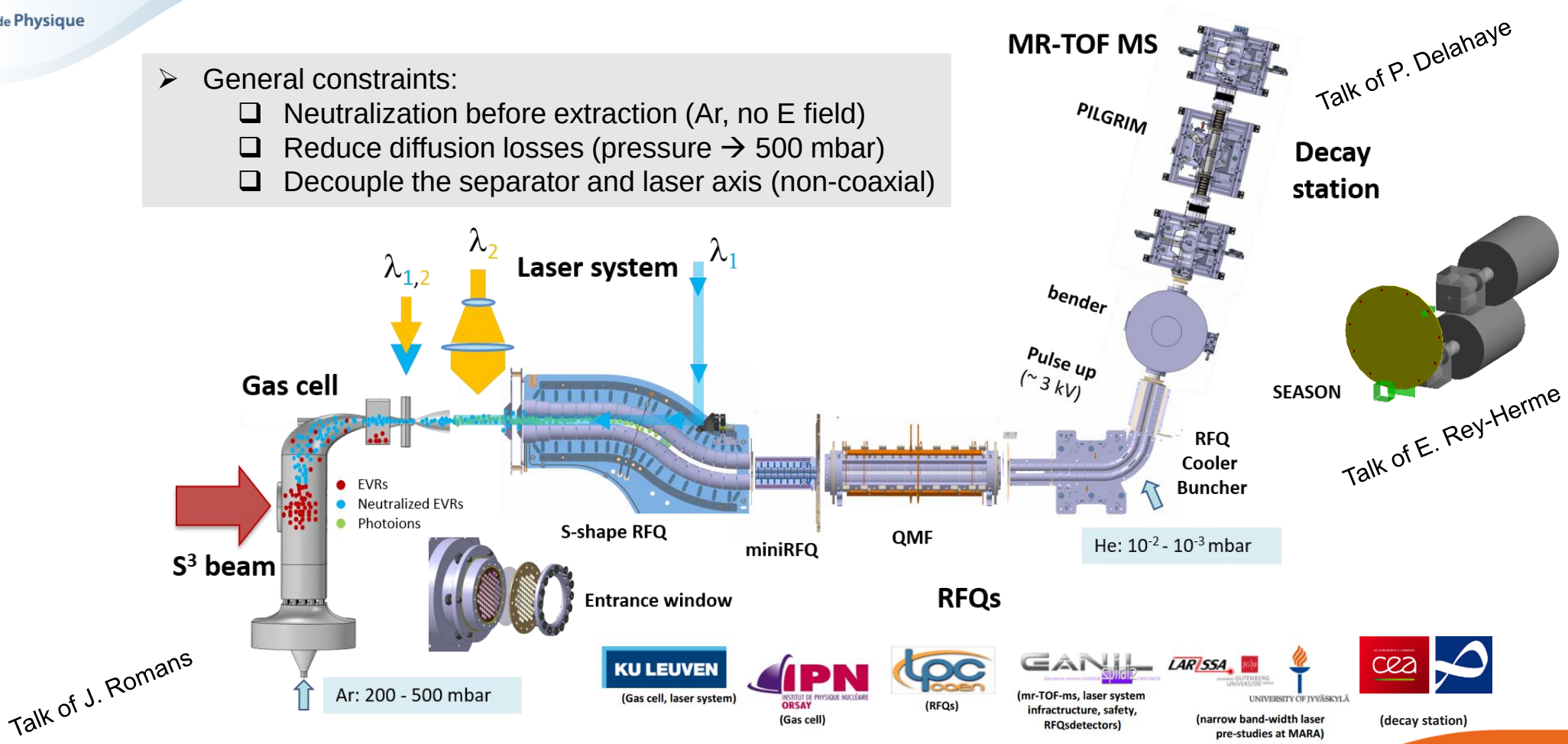
Outline

- Past work
- Current gas-cell design
- Physics for faster spectroscopy S^3-LEB gas cell
- FRIENDS^3 project

S³-LEB schematic

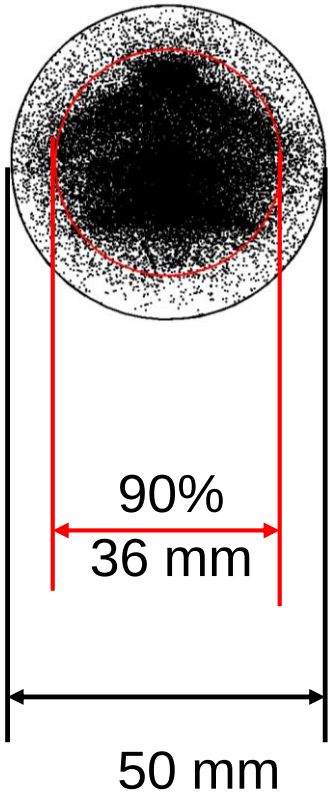
- General constraints:
  - Neutralization before extraction (Ar, no E field)
  - Reduce diffusion losses (pressure → 500 mbar)
  - Decouple the separator and laser axis (non-coaxial)



Past work

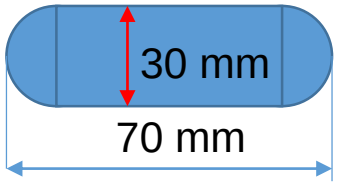
- The current gas cell design is the result of a dedicated study and optimization performed a few years ago (work of Evgeny Mogilevskiy et al.)

^{254}No distribution

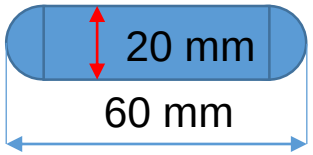


- Optimization constraints (examples):
  - S^3 beam size in convergent mode
  - Laminar gas flow (gas injection geometry)
  - Reduced extraction time (transversal section)

Gas cell section

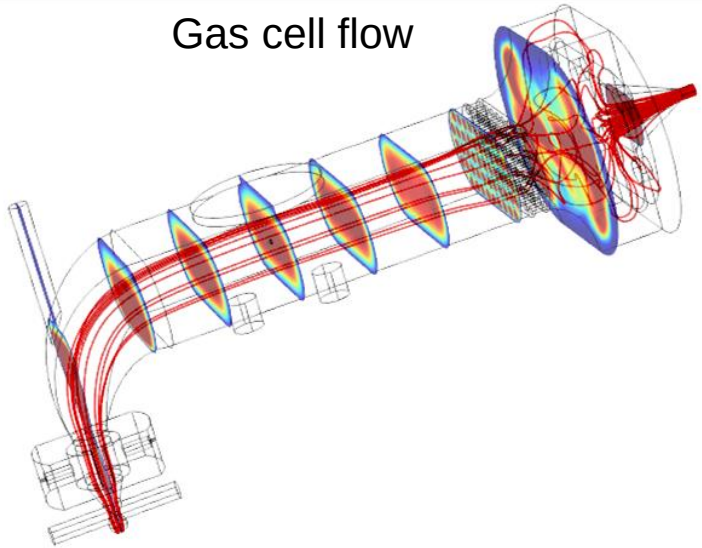


"wide cell"



"narrow cell"

Gas cell flow



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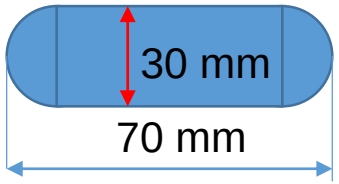

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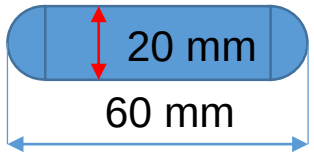

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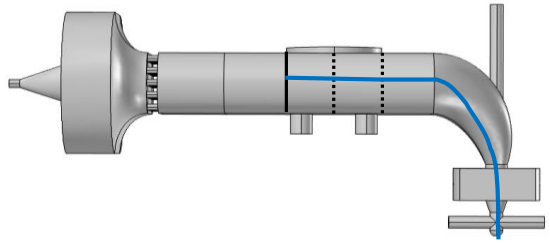

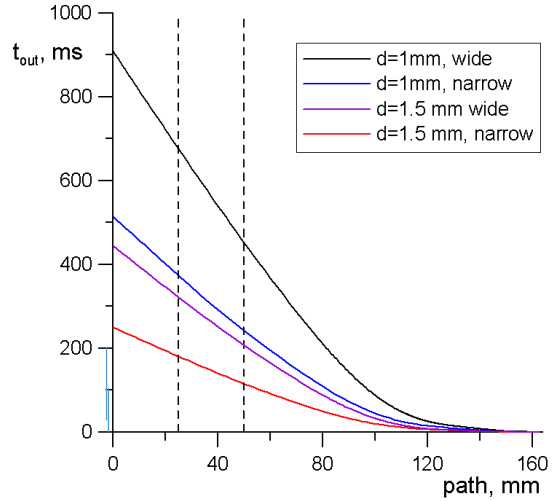

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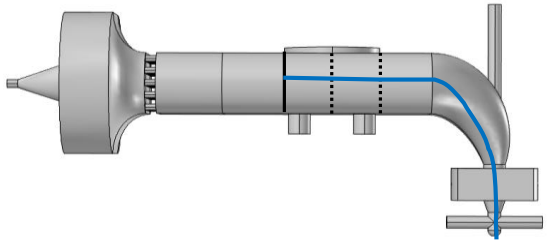

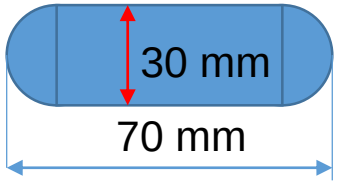

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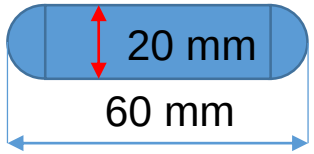
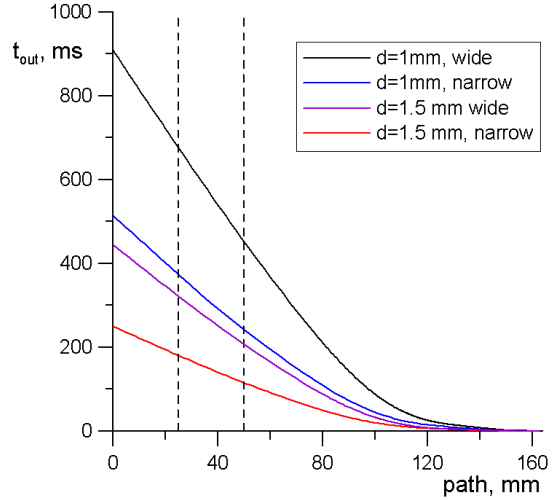


"narrow cell"

Average evacuation time

	Wide	Narrow
d=1 mm	630 ms	400 ms
d=1.5 mm	280 ms	190 ms



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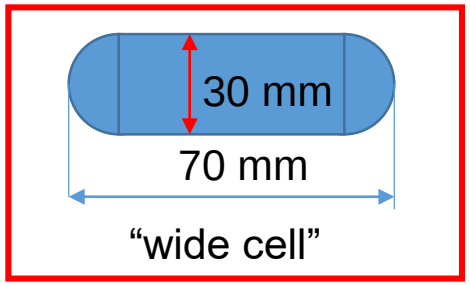

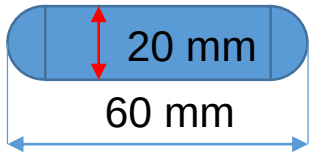

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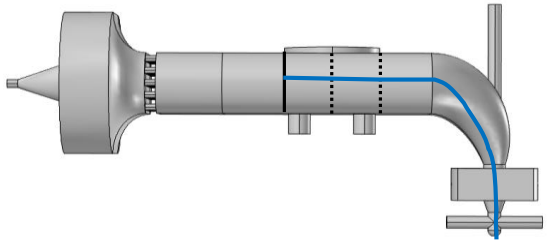
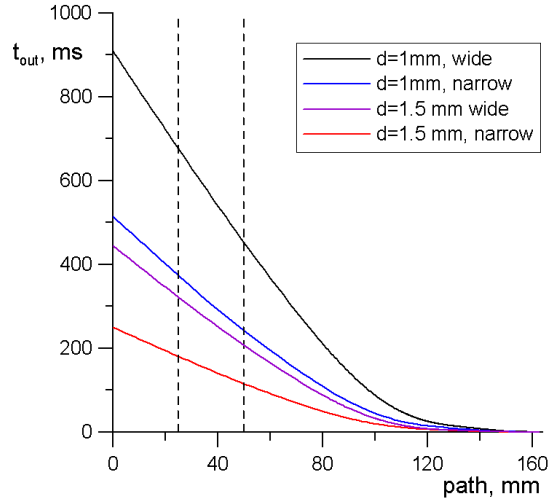
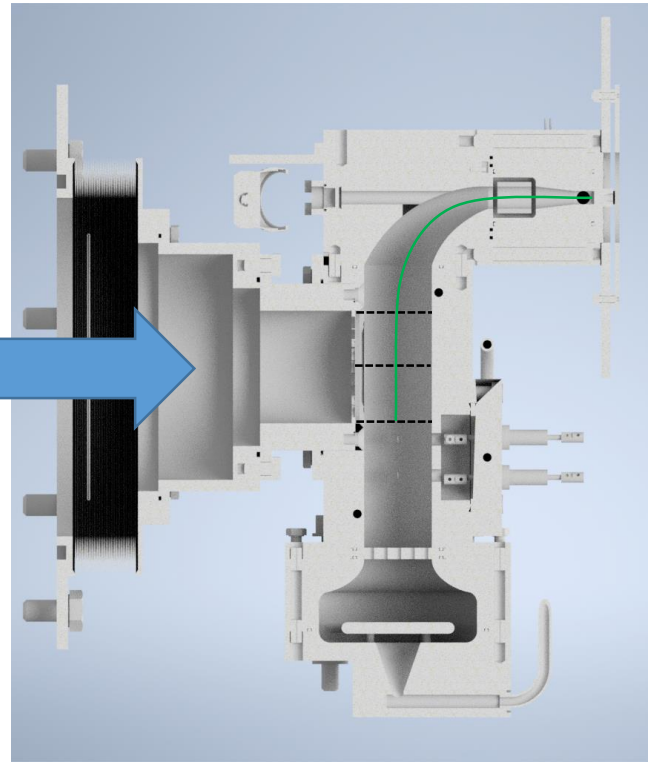


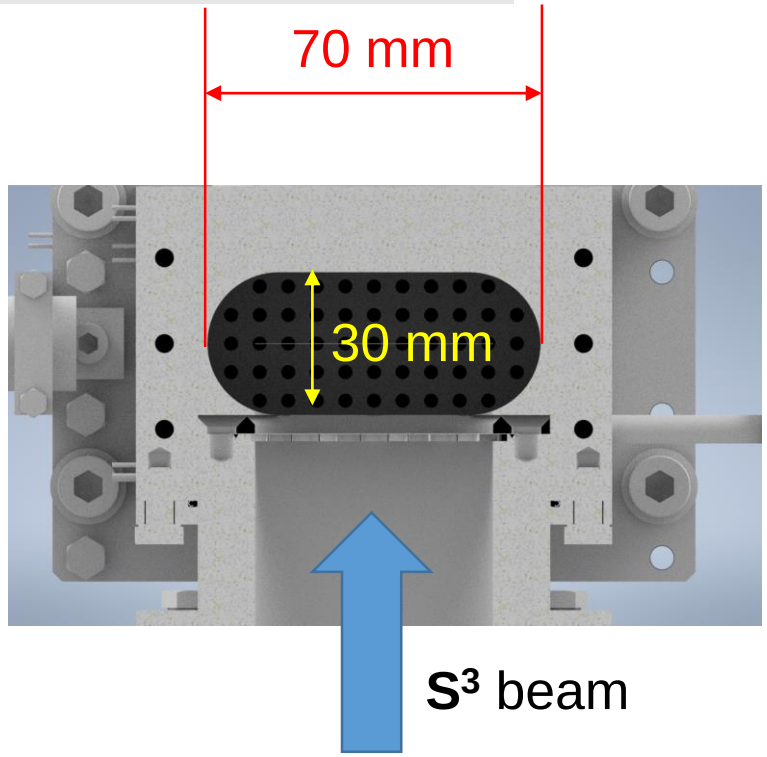


Current gas-cell design

- Current gas cell design is the “wide” version
- Extraction time can only be reduced by increasing the throat diameter

S³ beam

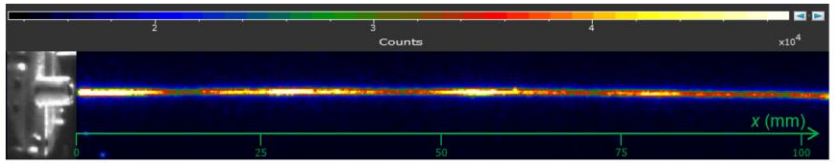


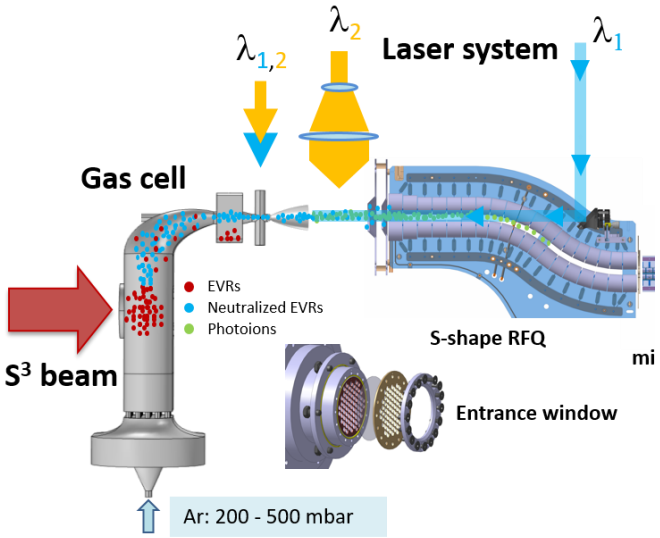


Patricia Duchesne, Olivier Pochon, IPNO

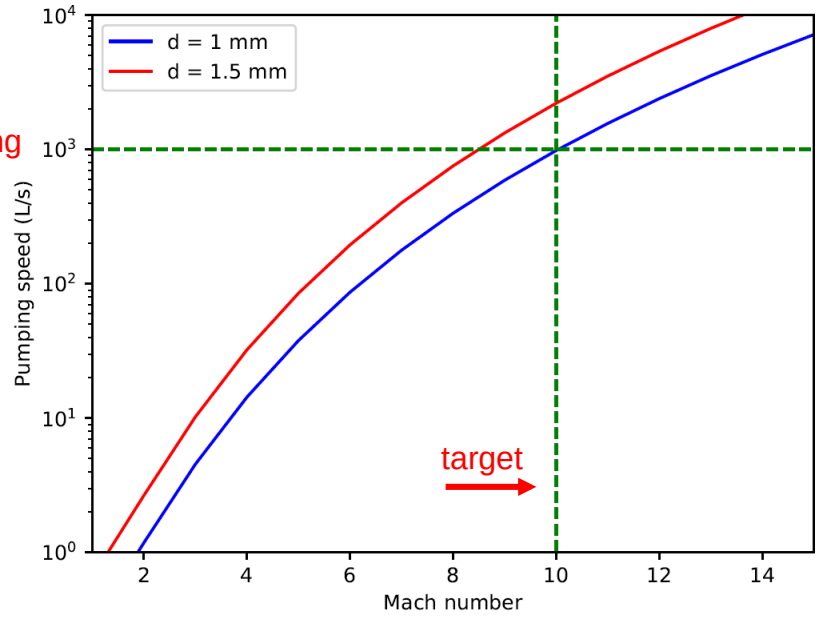
Limitation on nozzle throat diameter

- High Mach number (low jet temperature) and uniform jet required for high resolution
- Uniform jet requires pressure matching
- High Mach number requires high pumping speed



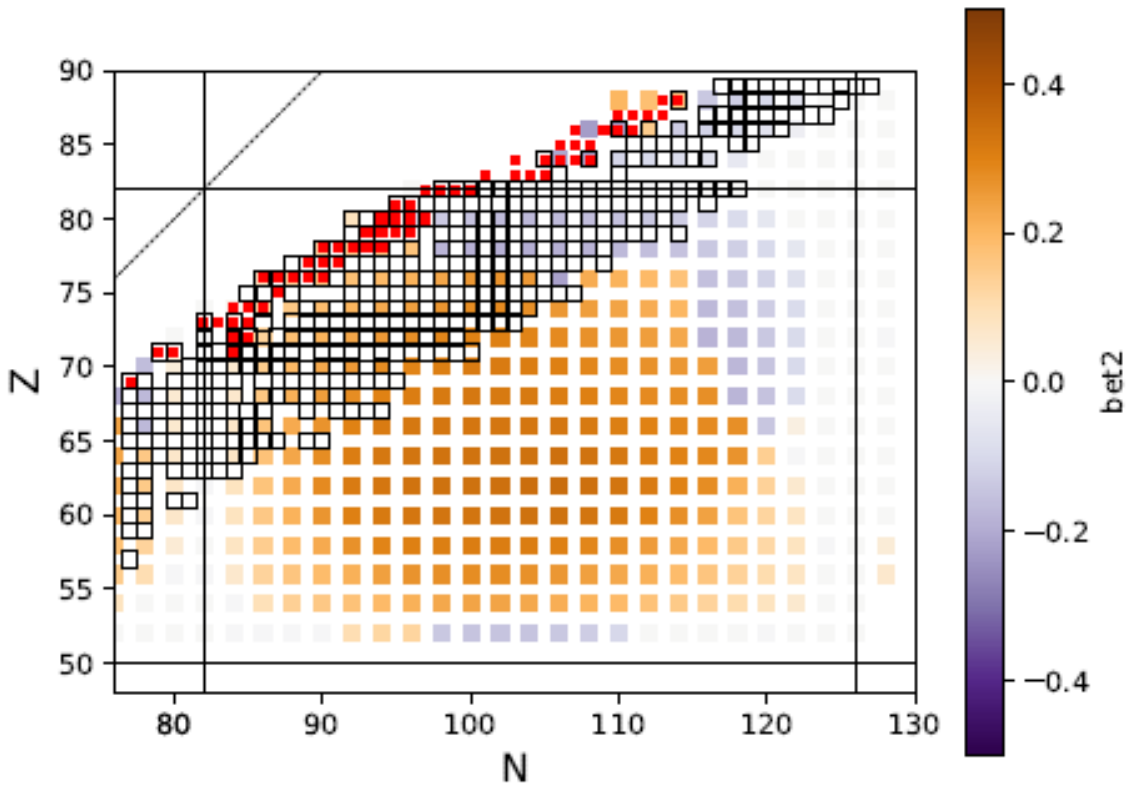


current pumping speed



Yu. Kudryavtsev et al., NIMB **297** 7–22 (2013)

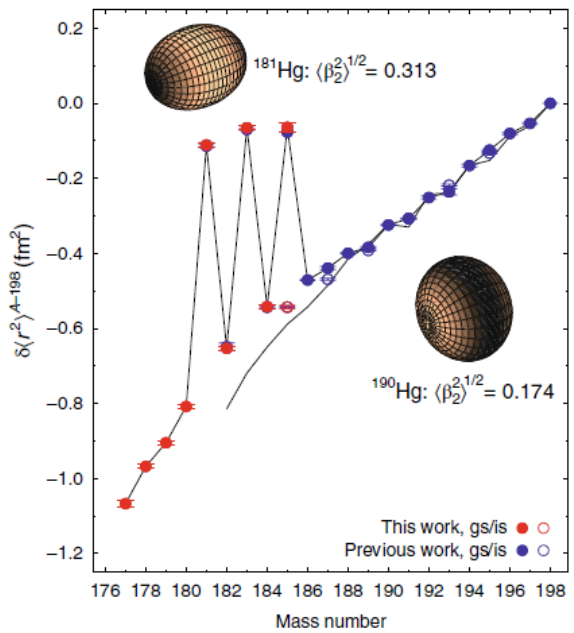
Physics for new S^3-LEB gas cell



Empty squares: S^3 production
Red squares: $T_{1/2}$ < 250 ms
Color map: quadrupole deformation based on UNEDF0

https://u.ganil-spiral2.eu/chartbeams/
M. Kortelainen *et al.*, Phys. Rev. C **82**, 024313 (2010)

B. A. Marsh et al., Nature Physics **14**, 1163–1167 (2018)



FRIENDS^3 project

- ANR Jeunes Chercheuses et Jeunes Chercheurs

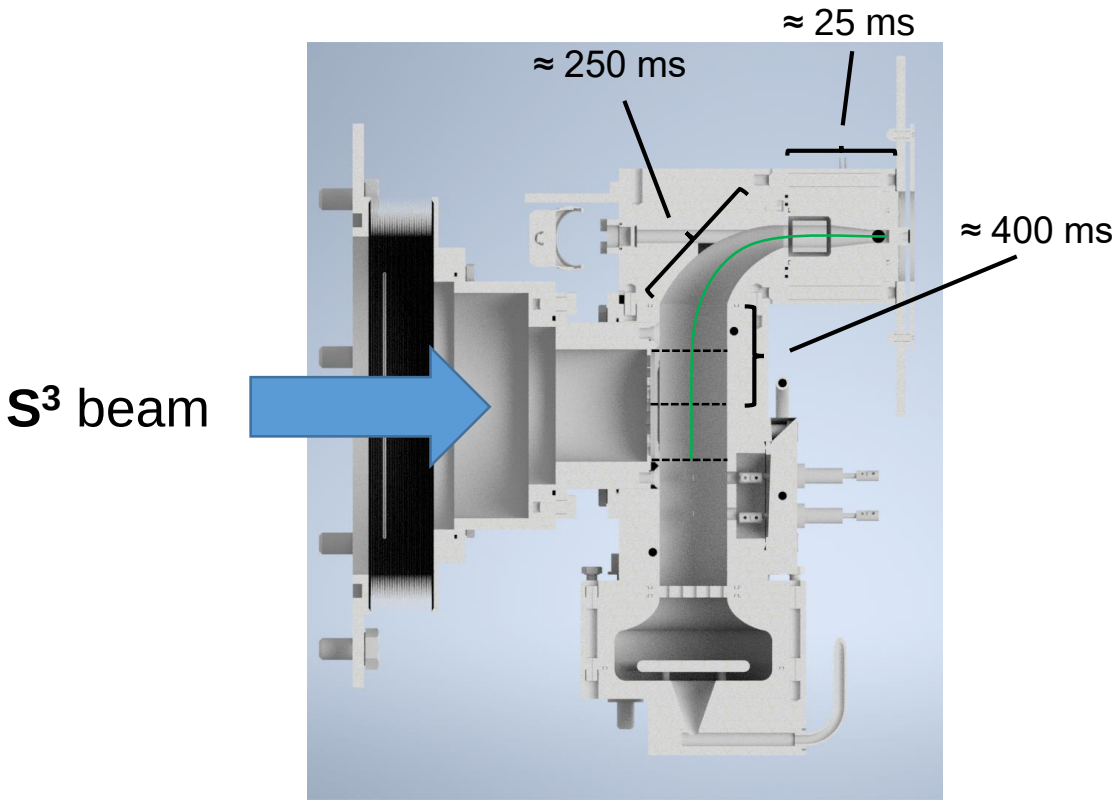
- Expand the range of the S^3-LEB gas cell by
  - Reducing extraction time
  - Improving neutralization efficiency
  - Exploring lower-pressure regime

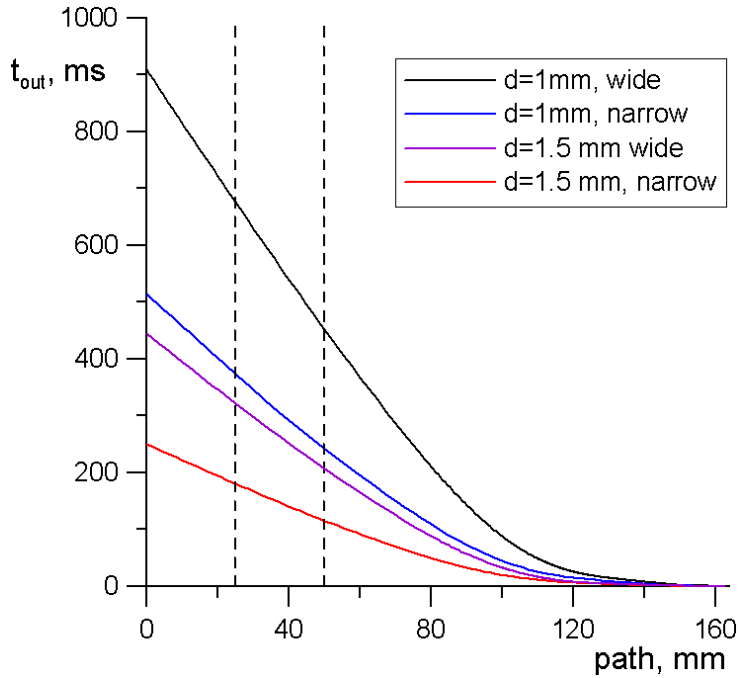
- Consolidate the involvement and know-how of IJCLab which was in charge (via IPNO) of building the current version of the gas-cell

- Contribute to the long-term gas-cell development program at S^3 and SPIRAL2

Reduce gas-cell extraction time

- Most time is “lost” in the stopping region

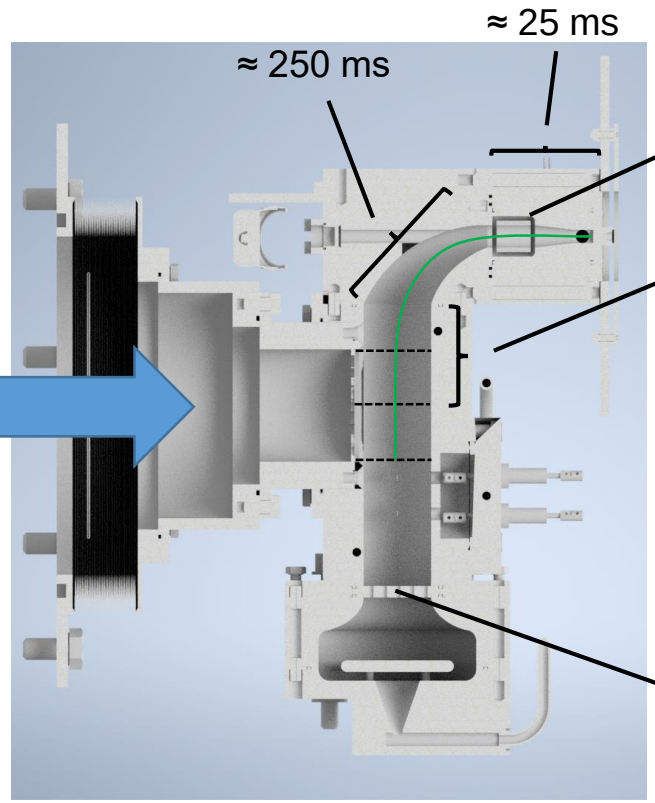




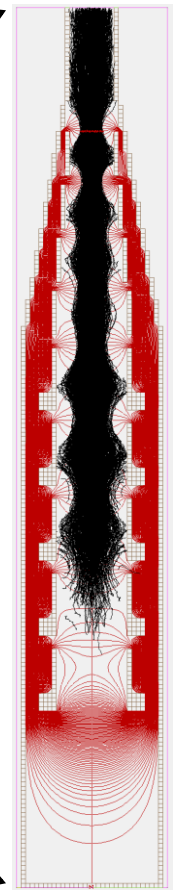
Reduce gas-cell extraction time

- Most time is “lost” in the stopping region
- Explore extraction by electrical field with neutralization at the end

S³ beam



p_{Ar} = 500 mbar



non-electrical region

gas velocity at interface is critical

electrical region

TOF_{avg} = 77 ms

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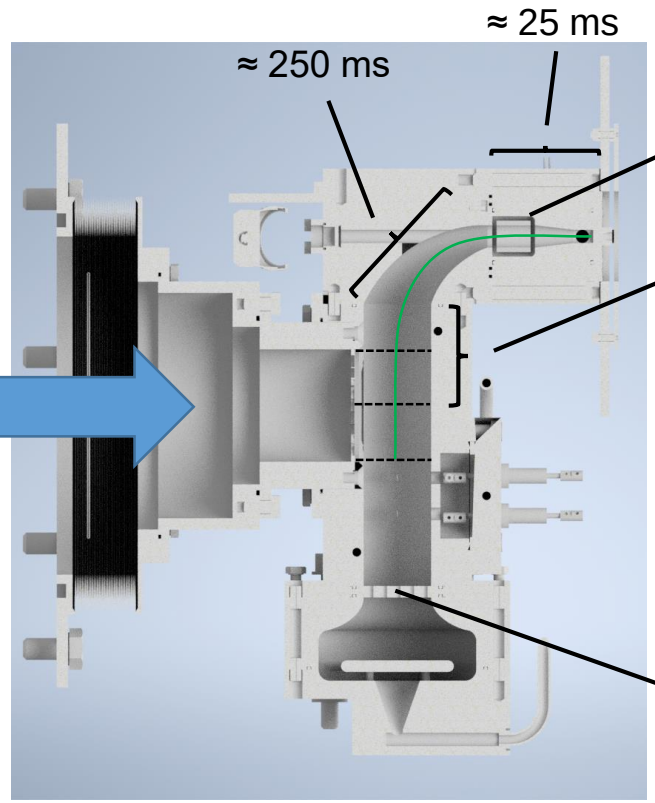
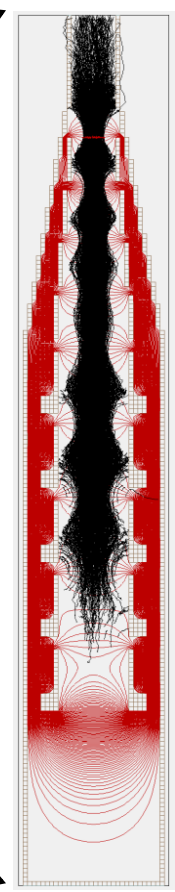


S³ beam

p_{Ar} = 100 mbar



non-electrical region

gas velocity at interface is critical

electrical region

TOF_{avg} = 17 ms

Improve neutralization efficiency

- Ultrapure Ar gas
  - direct charge exchange not favored for thermalized beam
  - processes depending on free electron density
- Current design → primary source of electrons is Ar ionization by stopped beam
- Neutralization efficiency can be a problem for:
  - Fast extraction (not enough time to recombine)
  - Electrical field (electrons do not follow the ion path)
  - Low-yield beams (e.g. superheavy elements)

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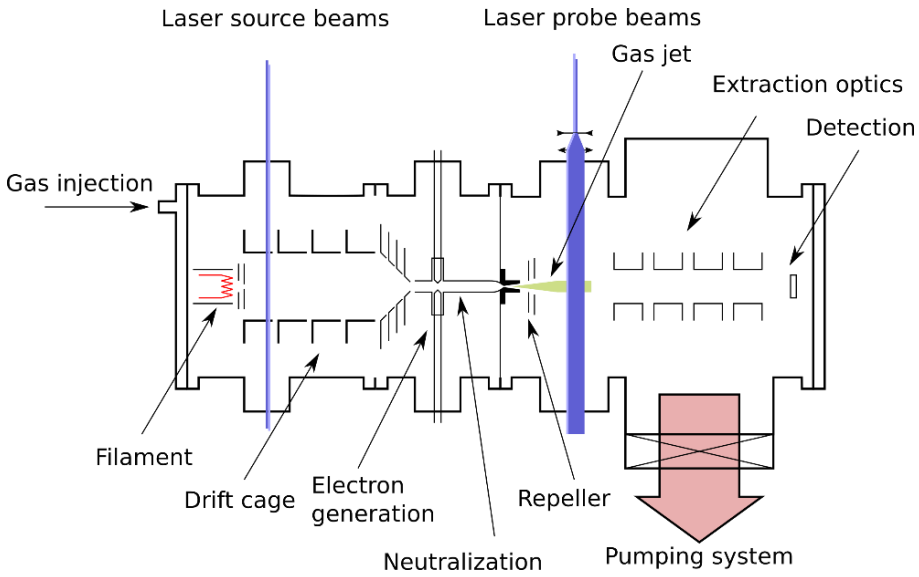
- Artificial free-electron generation needed:
  - Decay-induced ionization of Ar
    (proposed by R. Ferrer *et al.*, NIM B **317**, 570-581, 2013)
  - Ionization of “donor” atoms by laser
    (observed by Yu. Kudryavtsev *et al.*, NIMB **179**, 412-435, 2001)
  - Induced electrical discharge

Improve neutralization efficiency

- Test bench for fast extraction, injection into no-field area and neutralization methods.
- Version 0 inspired by DC cage + funnel design
  (see e.g. recent version of RADRIS collaboration at GSI)
- Neutralization area allowing different methods to be tested



- In-depth simulations of the different processes
- Experienced postdoc to help with the work

S. Raeder *et al.*, Nucl. Instrum. Meth. B **463**, 272–276 (2020)

Conclusions

- Gas cell development is a continuous improvement and learning process
- Gas-cell can be thought of as a taylor-made front-end in ISOL sense
- Improvement ideas for gas cell extraction time and neutralization efficiencies: FRIENDS^3 project
- Building a French community of gas-cell experts