REGLIS^3-LEB

Radio Frequency Quadrupole simulations

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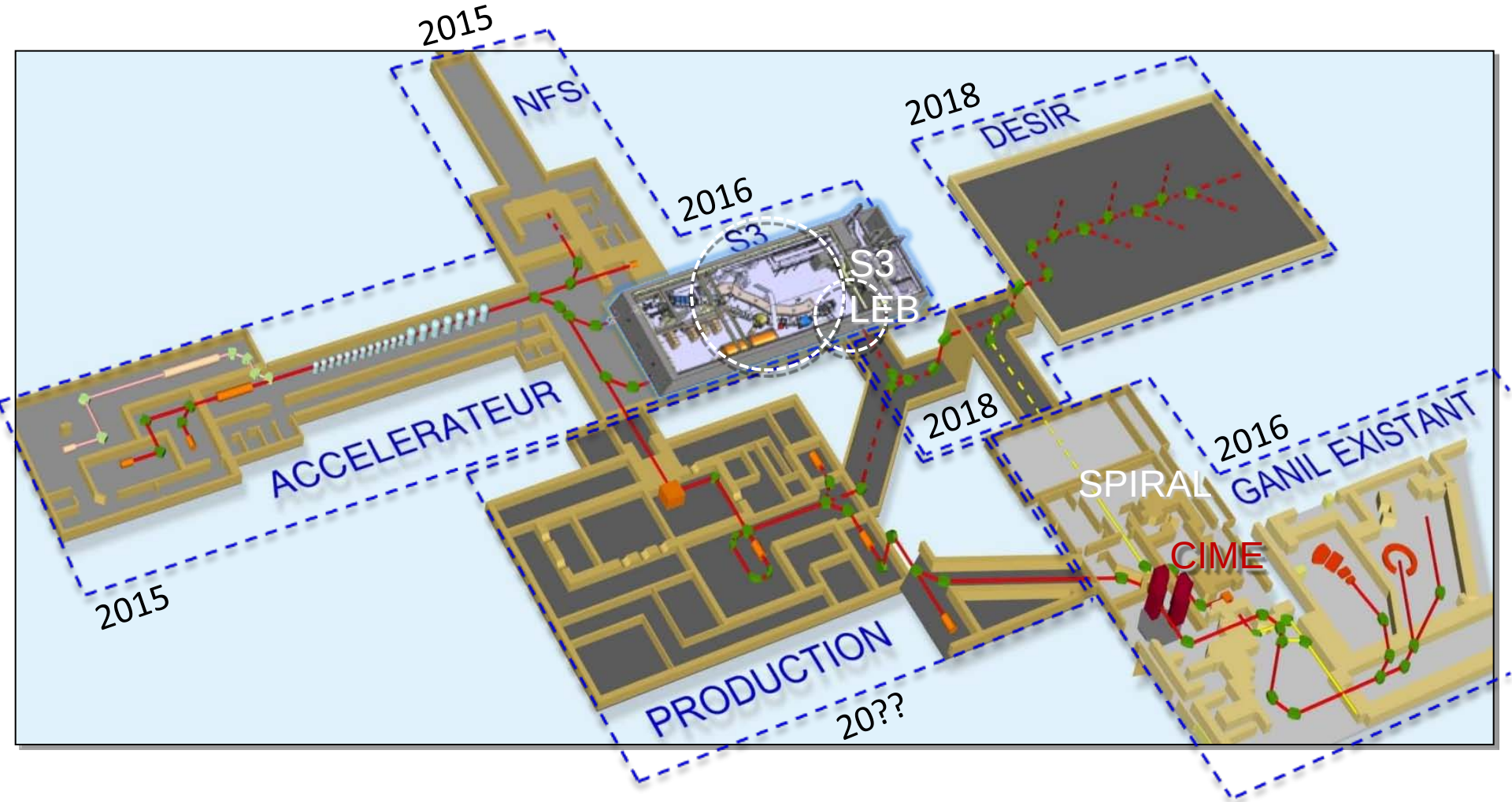
LA^{3}NET workshop

Outline

- Radioactive isotope/beam production with S^3 spectrometer
- Nuclear spectroscopy (delayed and IGLIS)
- S^3 Low Energy Beam (S^3-LEB) line concept
- Simulations for REGLIS^3 and S^3-LEB
    - Gas jet interaction with ions
    - S-shaped Radio Frequency Quadrupole (SRFQ) cooler
    - miniRFQ stage for differential pumping
    - Quadrupole Mass Filter (QMF)
    - 76° bent RFQ buncher (RFQb)
    - Multi-reflection Time-of-Flight mass spectrometer
    - Connections to identification station and DESIR
- Status and outlook

RIB lines of SPIRAL2 and S³ spectrometer



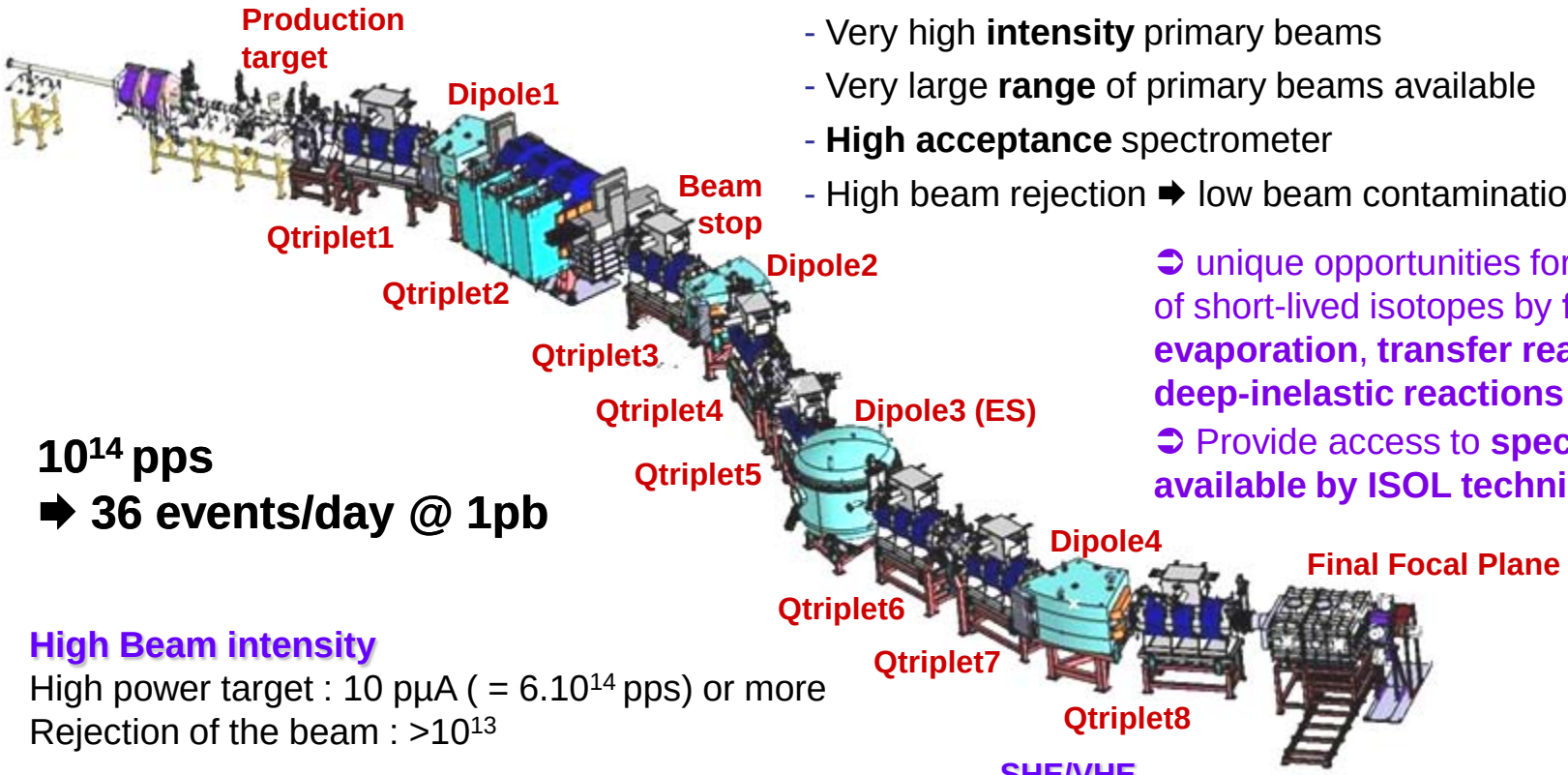
Radioactive isotope (beam) production from S³ spectrometer

- ⇨ In-flight production experiments at S³ experimental hall - dedicated detection setups
- ⇨ Low energy beams using In-Gas Laser Ionization and Spectroscopy
  - ⇨ MR-TOF-MS isobaric selection and decay station downstream S³ LEB line
  - ⇨ DESIR experimental hall DESIR LEB line (in addition to SPIRAL1 beam line)

S³ The Super Separator Spectrometer

Unique combination of characteristics:

- Very high **intensity** primary beams
- Very large **range** of primary beams available
- **High acceptance** spectrometer
- High beam rejection ➡ low beam contamination



➲ unique opportunities for the production of short-lived isotopes by **fusion-evaporation**, **transfer reactions** and **deep-inelastic reactions**

➲ Provide access to **species not available by ISOL techniques**

10^{14} pps
➡ 36 events/day @ 1pb

High Beam intensity
High power target : 10 pμA (= 6.10^{14} pps) or more
Rejection of the beam : $>10^{13}$

Low Energy (fusion-evaporation residues)
Large angular acceptance: +/- 80 mrad (X and Y)
Large Charge state acceptance: Bρ acceptance: +/- 10%

Many reaction channels (evaporation channels)
M/q selection : 1/350 resolution
Identification when possible

SHE/VHE
- ➡ **SHE/Heavy synthesis + spectroscopy**
- ➡ **SHE/Heavy chemistry**
- ➡ **SHE/Heavy (gas cell/masses/laser)**

N = Z (Proton-rich nuclei)
- ➡ **^{100}Sn region (gas cell/masses/decays/laser)**
- ➡ **Secondary Coulex with inverse kinematics**

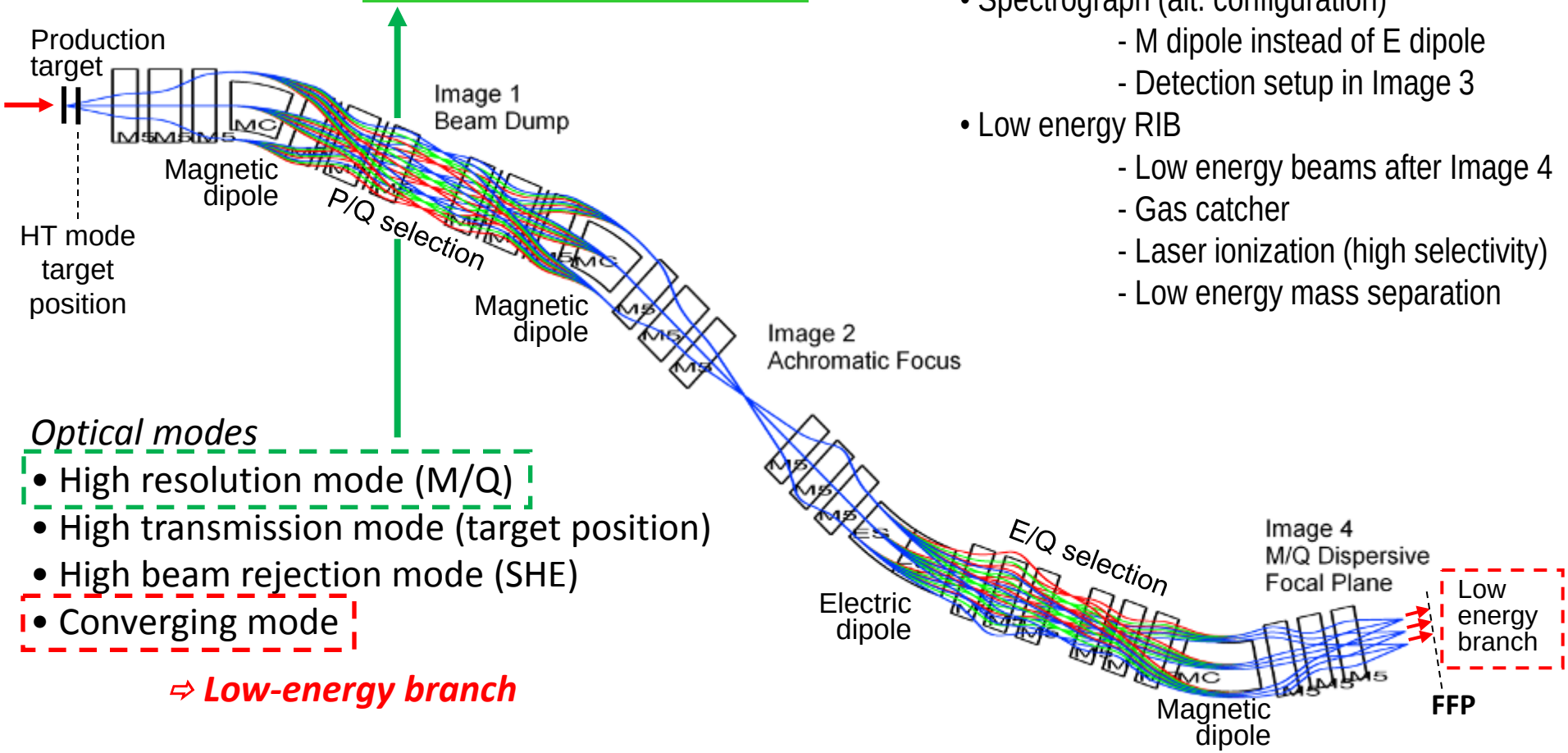
Light nuclei (transfer reactions)

Operation and optical modes of S^3 spectrometer

Operation modes

- Momentum achromat (P/Q)
  - up to Image 2
- Mass separator (M/Q)
  - from Image 2 to Image 4
- Spectrograph (alt. configuration)
  - M dipole instead of E dipole
  - Detection setup in Image 3
- Low energy RIB
  - Low energy beams after Image 4
  - Gas catcher
  - Laser ionization (high selectivity)
  - Low energy mass separation

Standard operation



Optical modes

- High resolution mode (M/Q)
- High transmission mode (target position)
- High beam rejection mode (SHE)
- Converging mode

⇨ ***Low-energy branch***

Optical modes of S^3 spectrometer

1. High Resolution mode

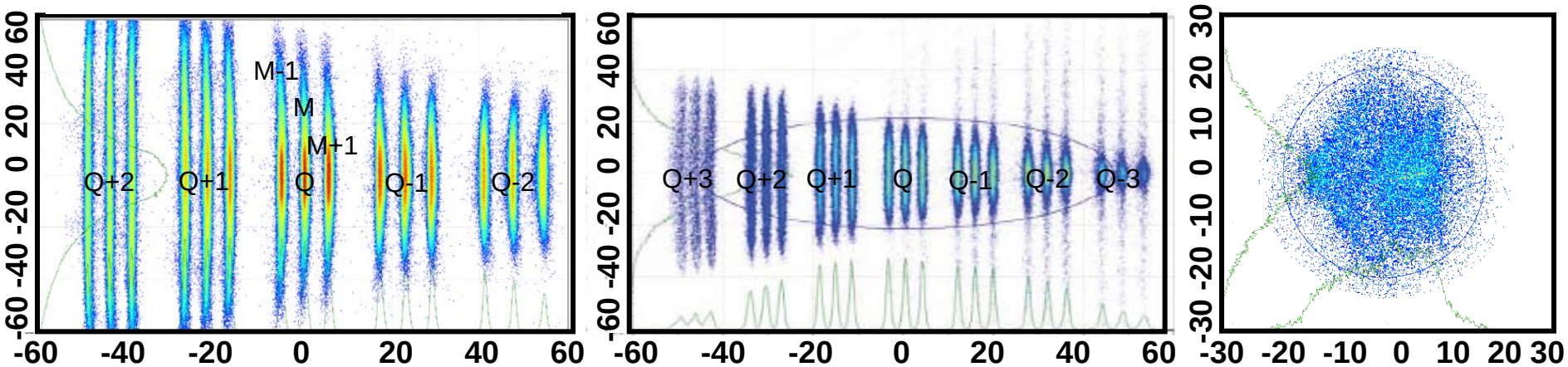
- Designed for maximum selection
- Weighted mass resolution: **M/ΔM = 460**
- Folded transmission: 50% for $^{58}Ni + ^{46}Ti \Rightarrow ^{100}Sn^{24+} + 4n$

2. High Transmission mode

- Designed for very asymmetric reactions (large emittances)
- Weighted mass resolution: **M/ΔM = 260**
- Folded transmission: 15-20% for $^{22}Ne + ^{238}U \Rightarrow ^{255}No + 5n$

3. Converging mode

- Designed for gas cell – Laser spectroscopy
- Folded transmission: 68% for $^{58}Ni + ^{40}Ca \Rightarrow ^{94}Ag + p3n$
- Folded transmission: 56% for $^{48}Ca + ^{208}Pb \Rightarrow ^{254}No + 2n$



x-y distributions at the Final Focal Plane [mm] for different operating modes

Low energy beam line of S³ spectrometer

REGLIS³: In-gas cell laser ionization and spectroscopy

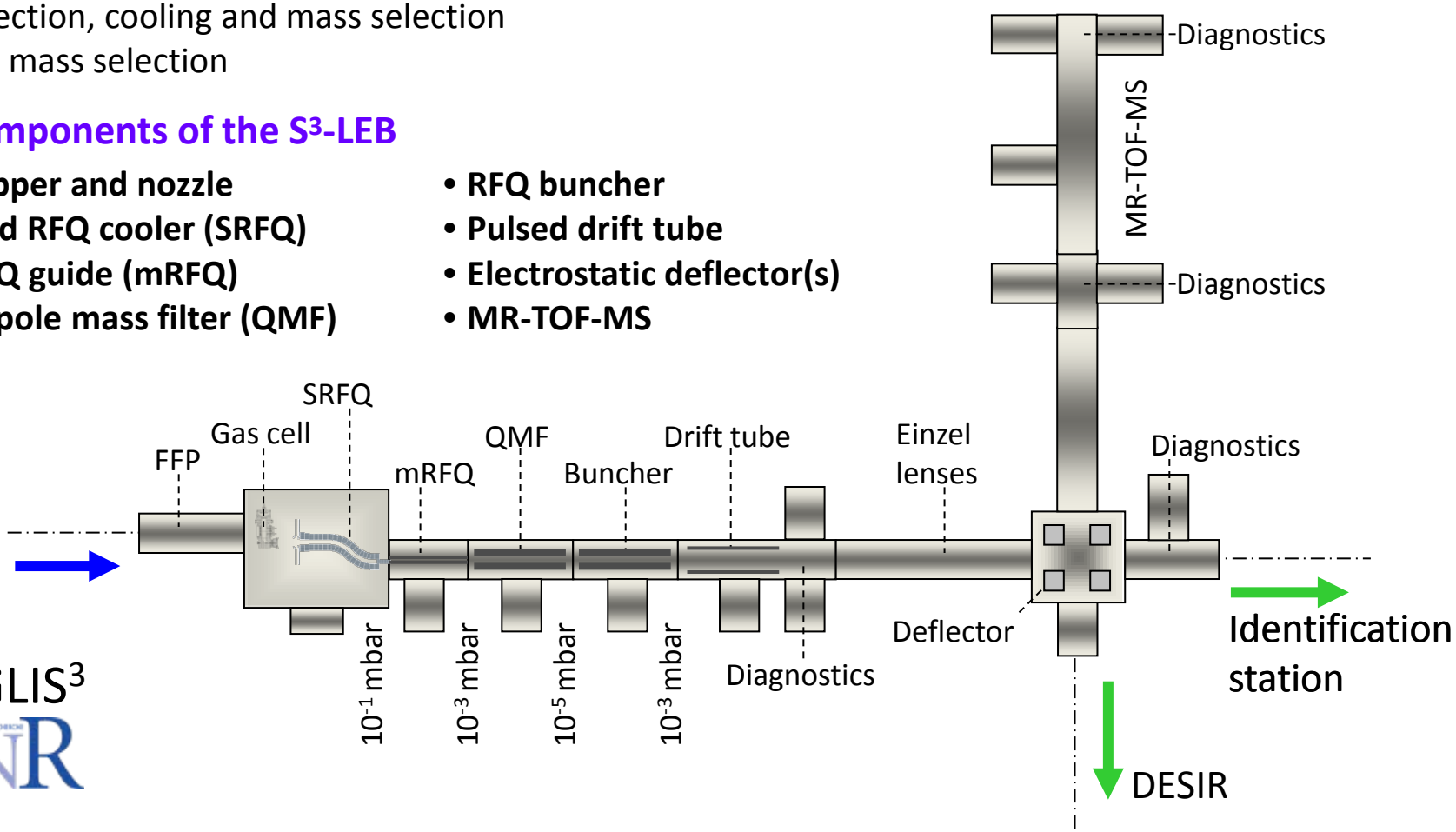
- Thermalization/neutralization in gas (Ar, He)
- Selective laser ionization of reaction products
- HR laser spectroscopy in gas jet ($^{94-96}$Ag, $^{101-105}$Sn, trans-actinides)
- Decay spectroscopy and mass measurements
- RIB collection, cooling and mass selection
- Isobaric mass selection

Ion transport simulations

- Dimensions and distances
- DC and RF electronics
- Vacuum and gas systems

Main components of the S³-LEB

- **Gas stopper and nozzle**
- **S-shaped RFQ cooler (SRFQ)**
- **Mini RFQ guide (mRFQ)**
- **Quadrupole mass filter (QMF)**
- **RFQ buncher**
- **Pulsed drift tube**
- **Electrostatic deflector(s)**
- **MR-TOF-MS**

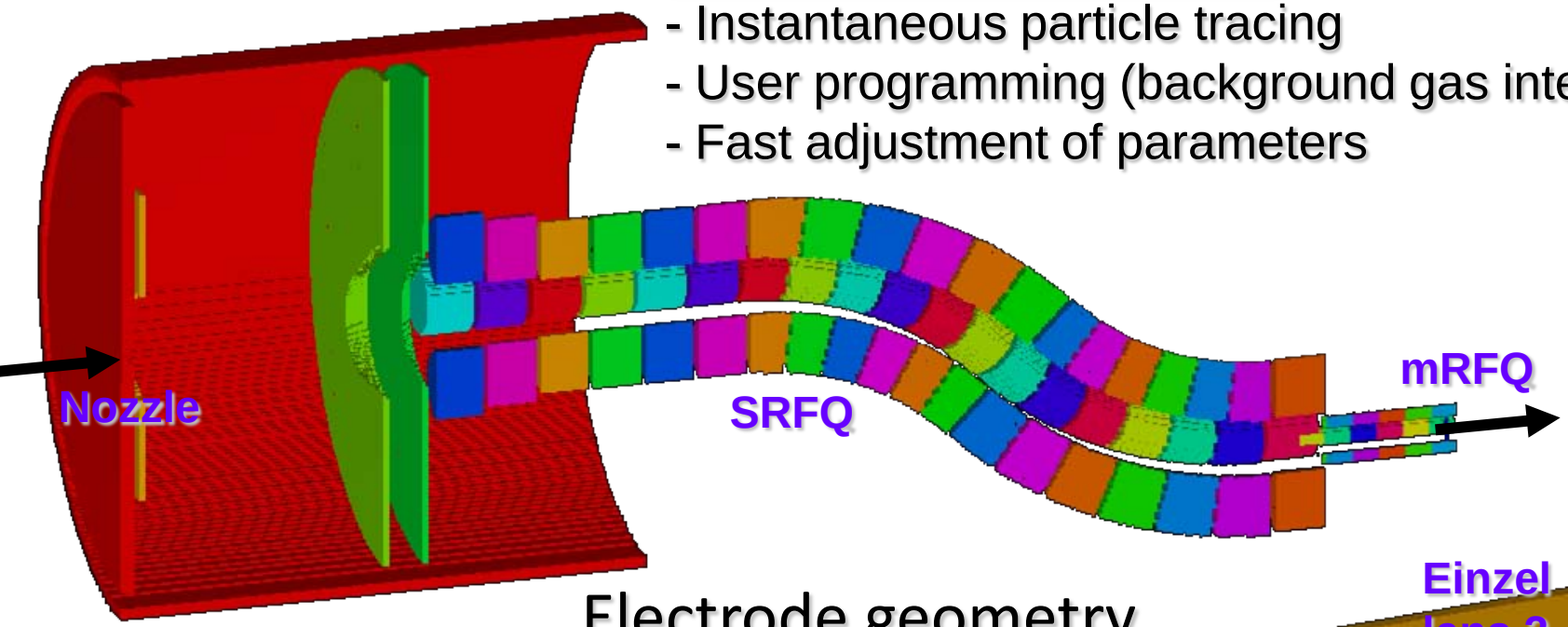


REGLIS³

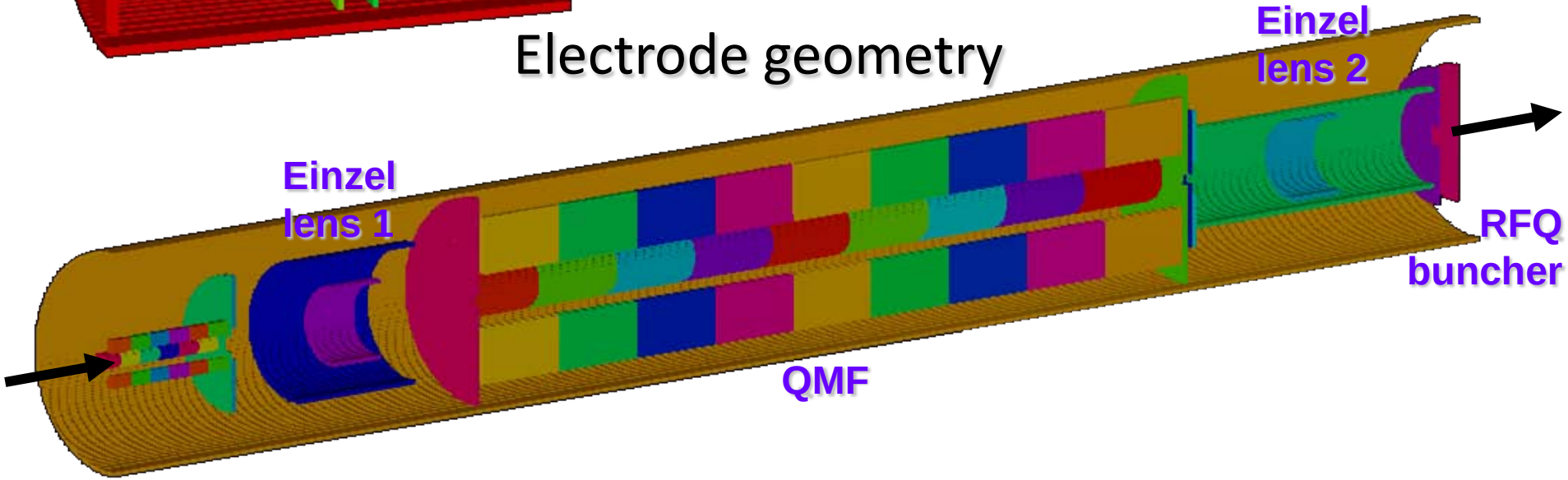
EM simulations with SIMION + gas-ion interactions

SIMION – main advantages

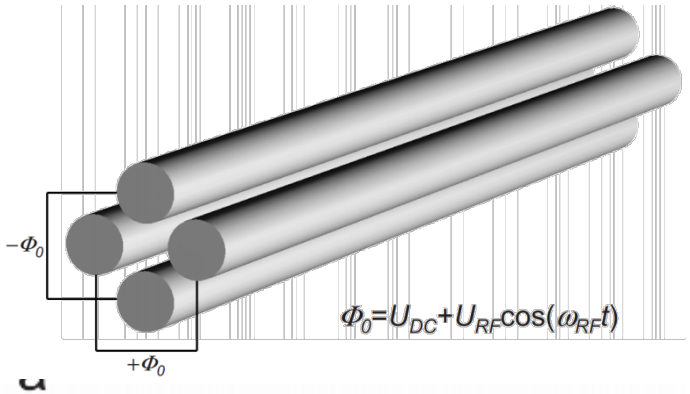
- Instantaneous particle tracing
- User programming (background gas interaction)
- Fast adjustment of parameters

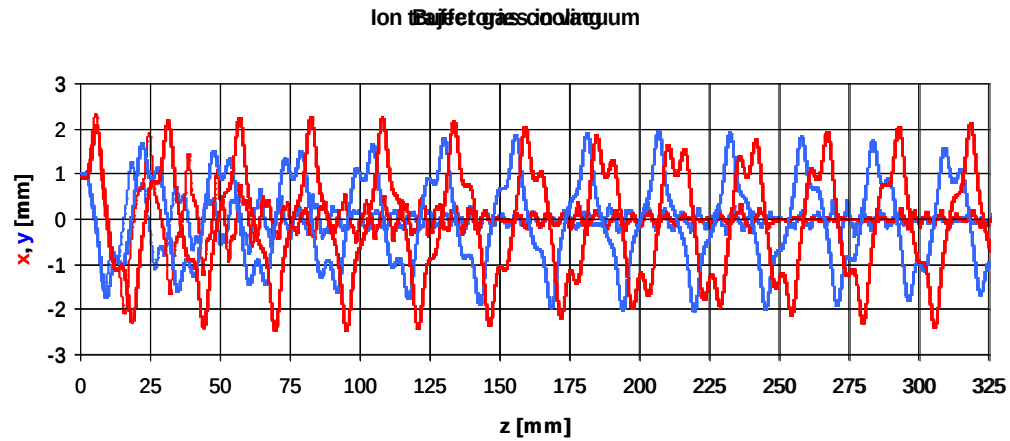


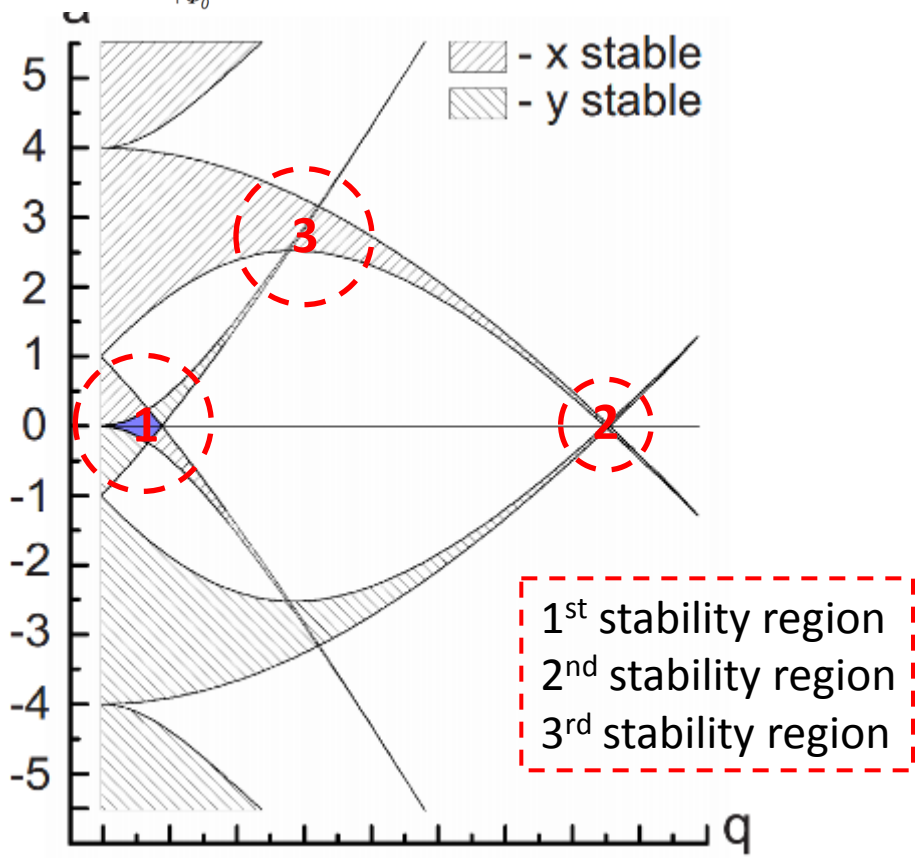
Electrode geometry



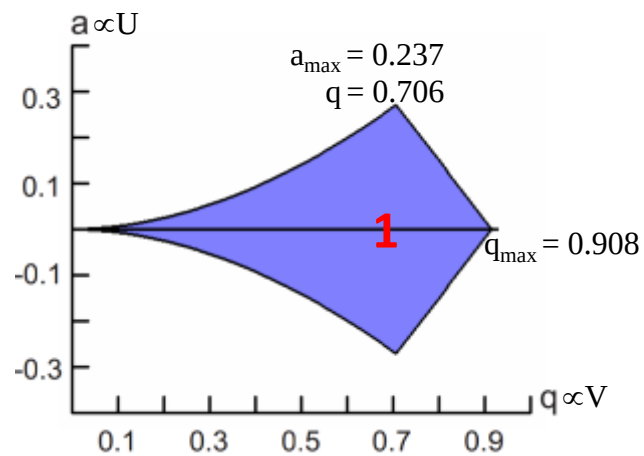
Linear RFQ: ion stable motion – operating modes







1st stability region
2nd stability region
3rd stability region

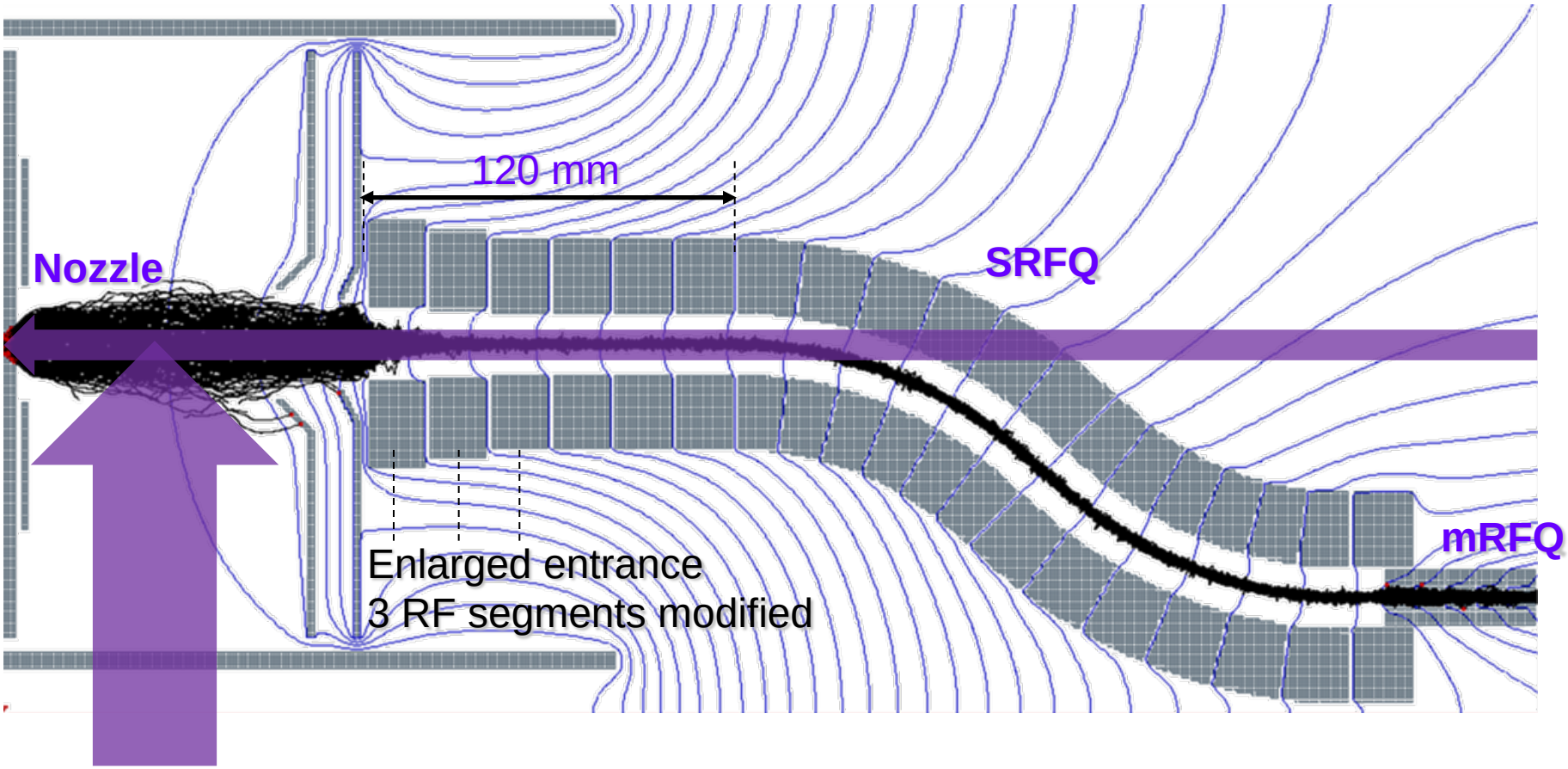


Mathieu equation:

$$\frac{d^2u}{d\xi^2}+\left(a_u-2q_u\cos(2\xi)\right)u=0 \qquad \xi\equiv\frac{\Omega t}{2}$$

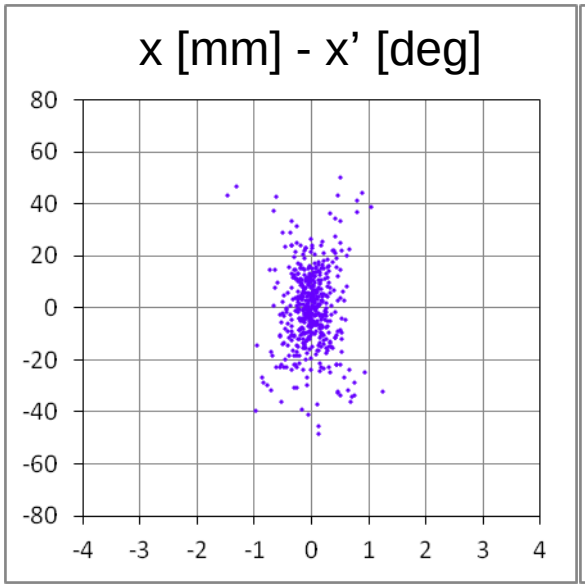
$$q_u=\frac{4zV}{mr_0^{\,2}\Omega^2} \qquad a_u=\frac{8zU}{mr_0^{\,2}\Omega^2}=0$$

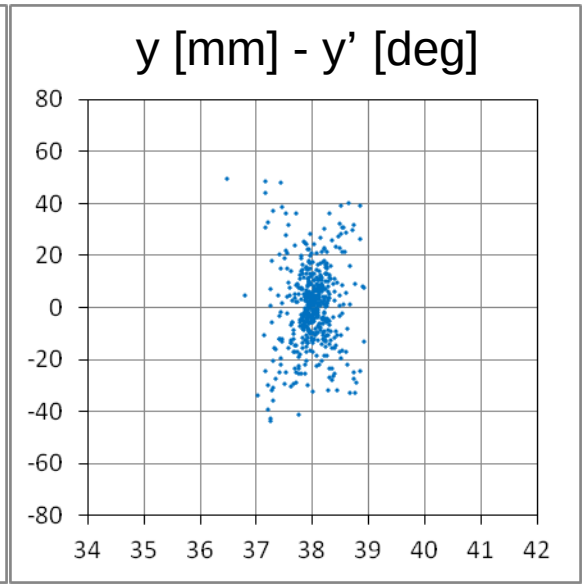
Optimized electrode design for injection into the SRFQ



Buffer gas cooling pressure (operational range): 0.01 mbar to 0.1 mbar

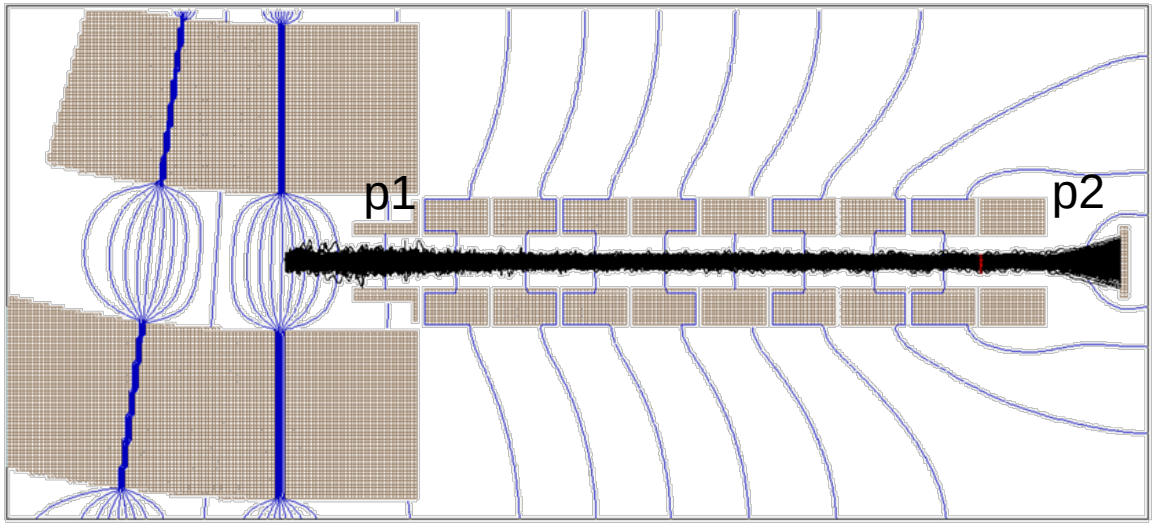
Simulations of mRFQ performance





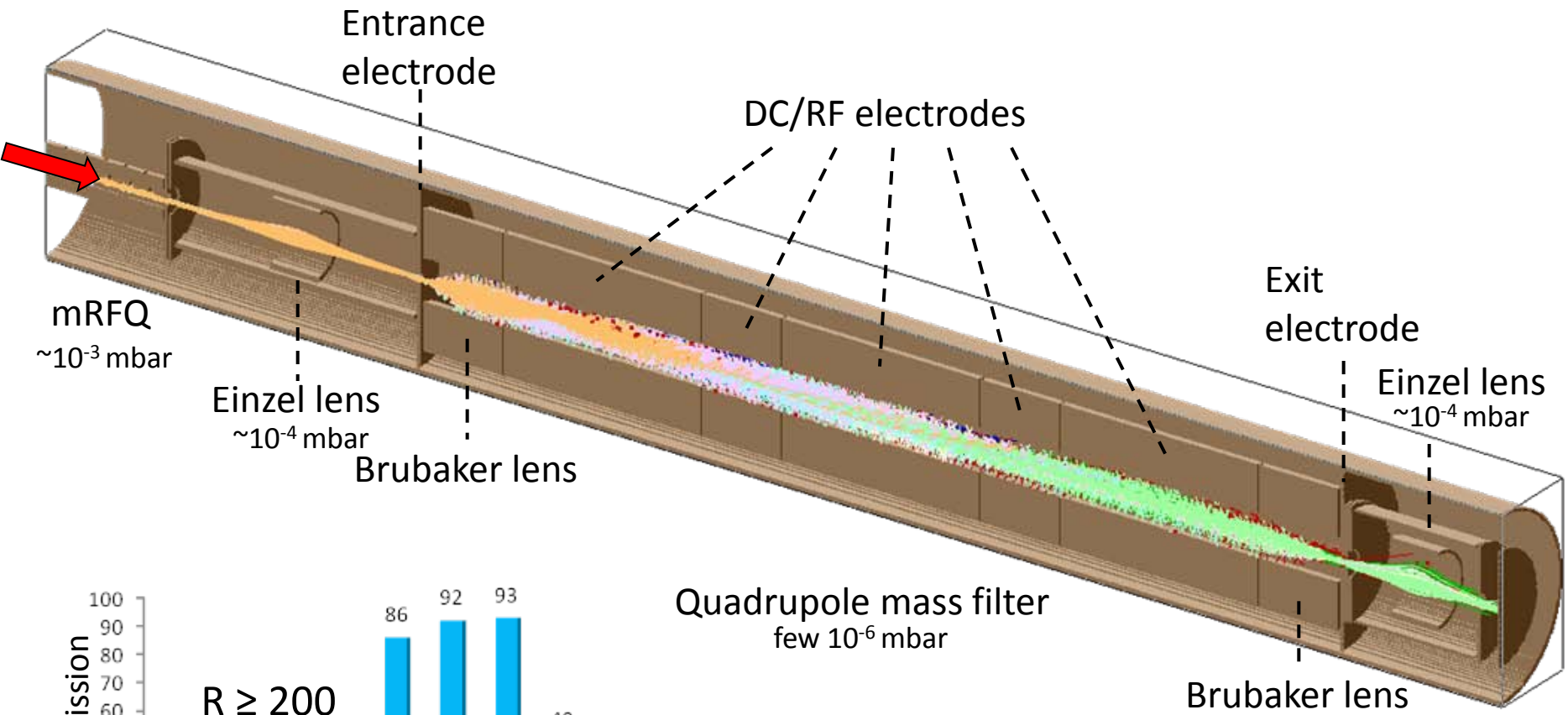
Beam properties downstream mRFQ

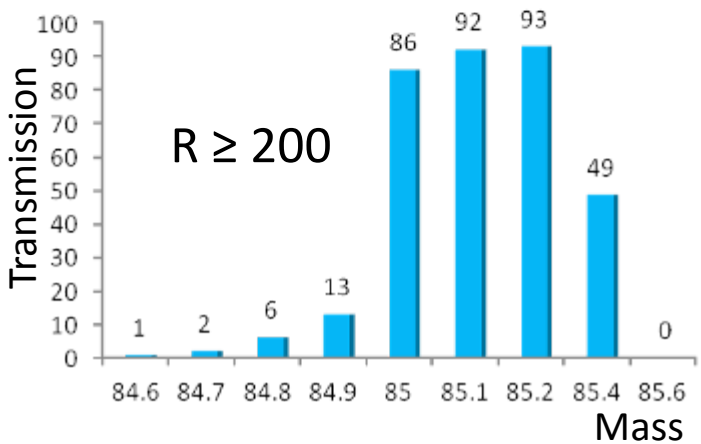
Sigma x	0.34 mm
Sigma y	0.32 mm
Mean KE	1.50 eV
Sigma KE	0.42 eV



- No losses in mRFQ
- Various SRFQ pressures
- Various RF amplitudes
- r_0 = 3 mm vs r_0 = 4 mm
- p1, p2 measured
- SRFQ-mRFQ RF phase correlation not critical
- SRFQ-mRFQ q parameter matching not critical

mRFQ and Quadrupole Mass Filter design

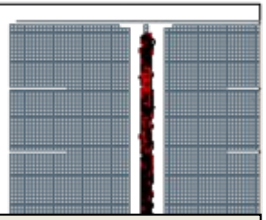


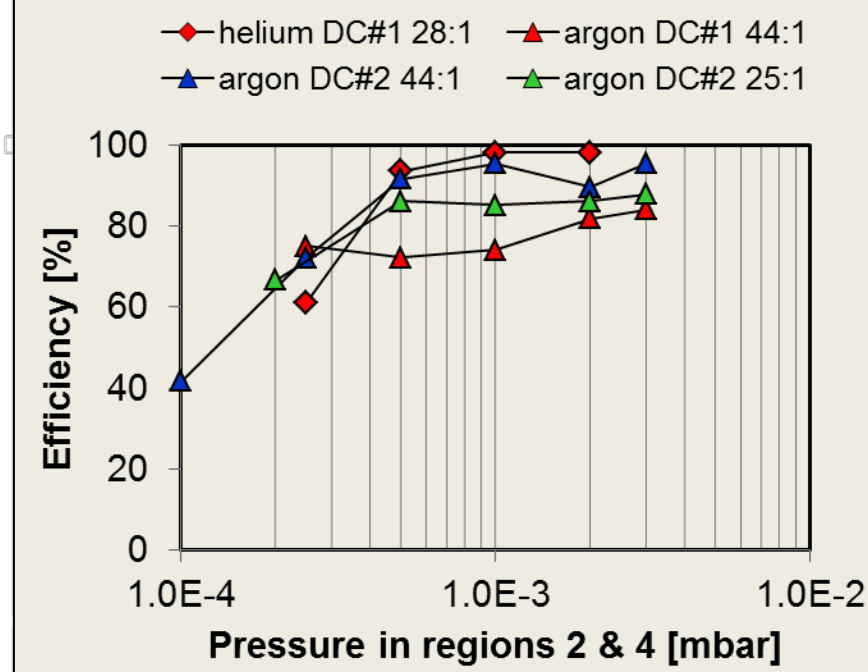


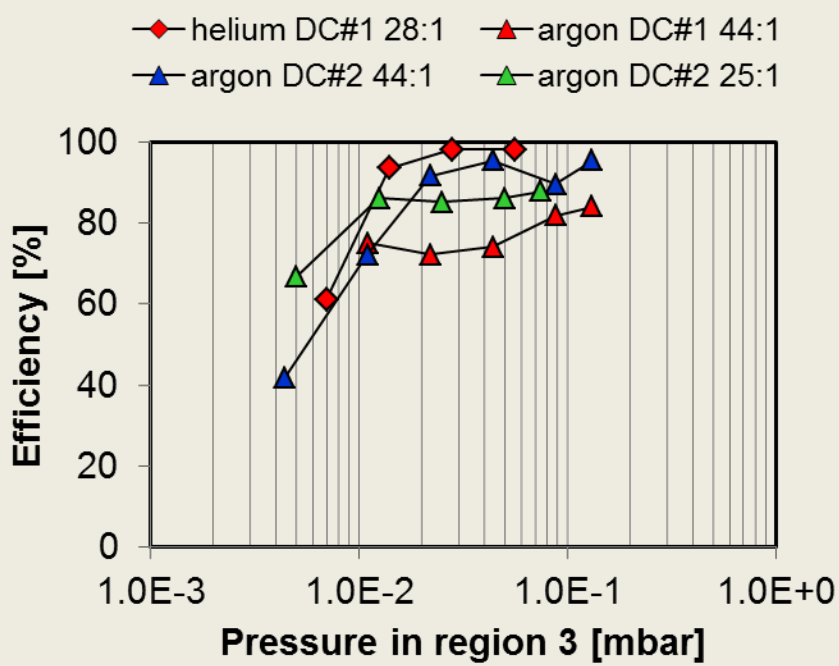
Standard QMF operation with DC = 0 V on the entrance and the exit Brubaker lenses

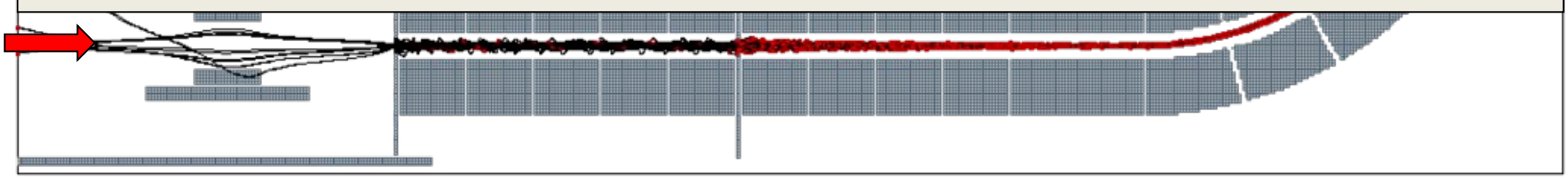
Bent RFQ buncher

76˚ bent
RFQ buncher

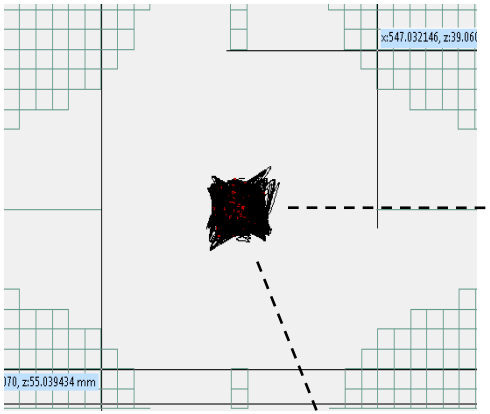


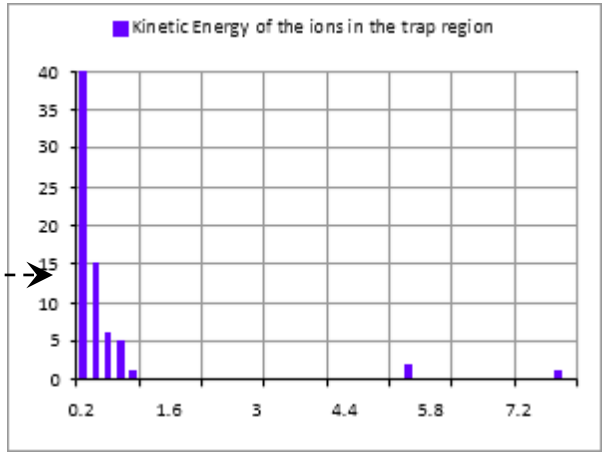






RFQ buncher extraction and acceleration to 3 kV





Kinetic energy
mean 0.173 eV
sigma 0.176 eV

Position distribution
y-sigma 0.85 mm
z-sigma 0.19 mm

RFQ buncher trap region

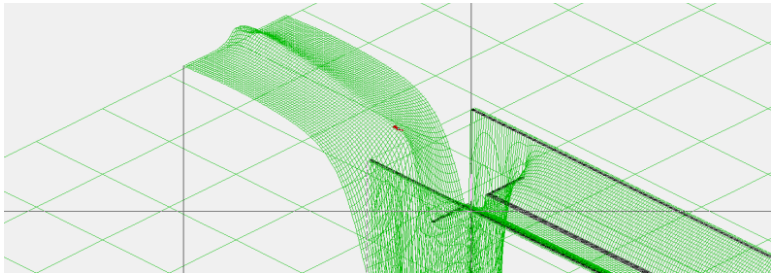
Lens
-5800V

Pulse up: -900V → 2200V

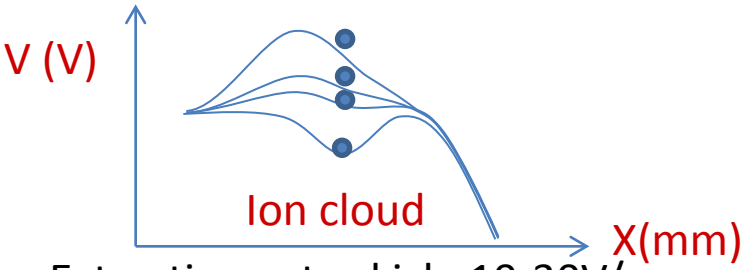
Extraction 0 V

Blade gradient

Plate: 0V

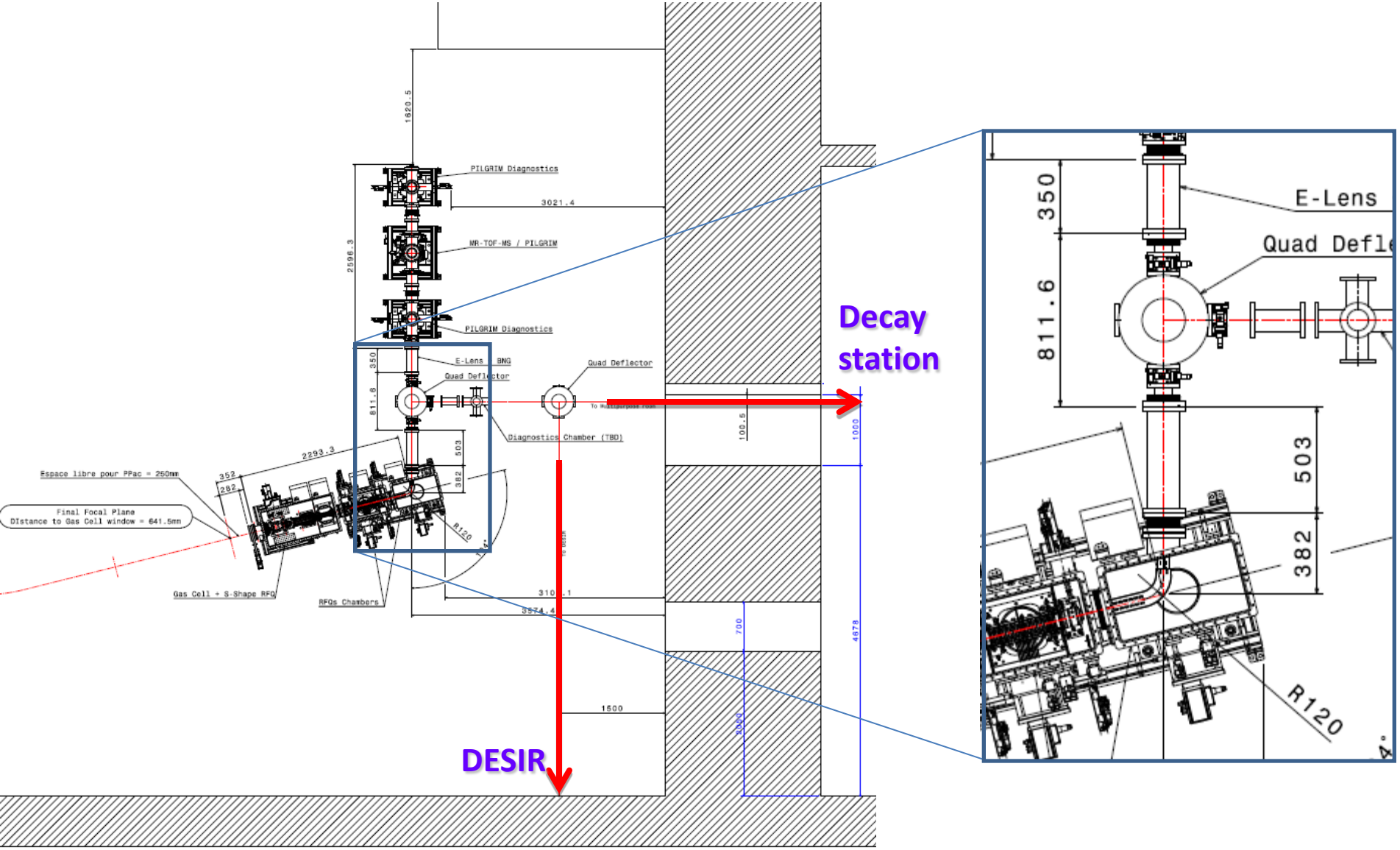


Extraction electrodes



Extraction extra-kick: 10-30V/mm
Switching time: 20 - 150ns

Connection to decay station DESIR beam line



Summary and future steps

Optical modes of S^3 – studied by simulations
- **Converging mode for low energy RIB**

REGLIS^3 – simulations and design of the S^3-LEB
- **Loading into SRFQ**
- **Transmission through a mRFQ**
- **Operation modes of QMF**
- **Ion bunch preparation in RFQb**

Next steps
- **Design of connection to DESIR beam line**
- **Commissioning tests**