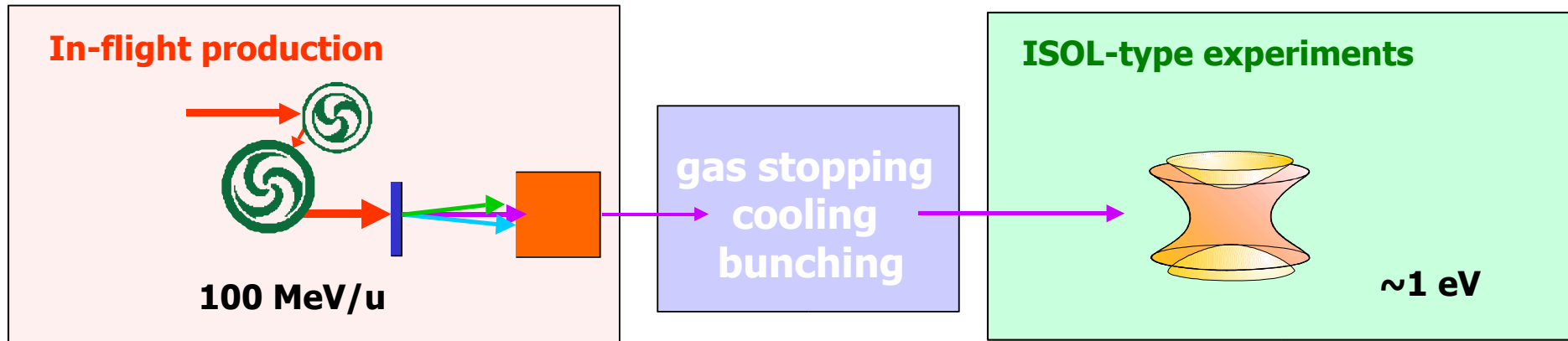


Simulations & more from LEBIT



Low-Energy Beam and Ion Trap Project



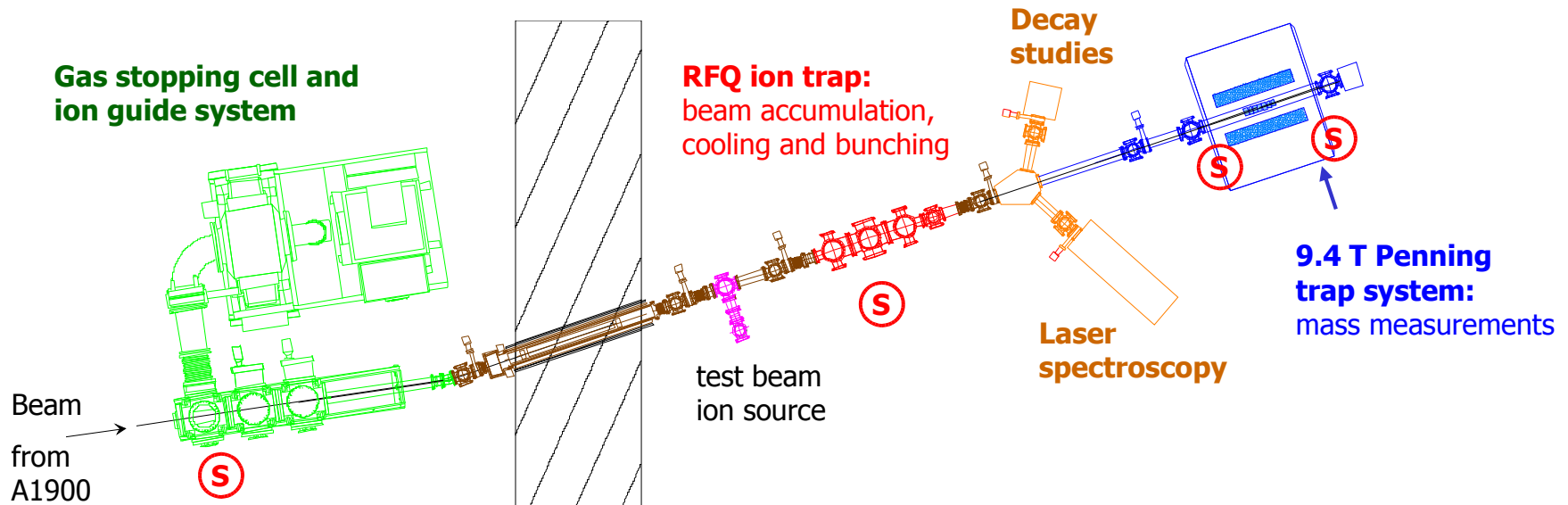
Coupled Cyclotron Facility
National Superconducting
Cyclotron Laboratory
Michigan State University

The LEBIT team:

G. Bollen, D. Davies, D.J. Morrissey,
R. Ringle, P. Schury, J. Savory,
S. Schwarz, T. Sun, L. Weissman

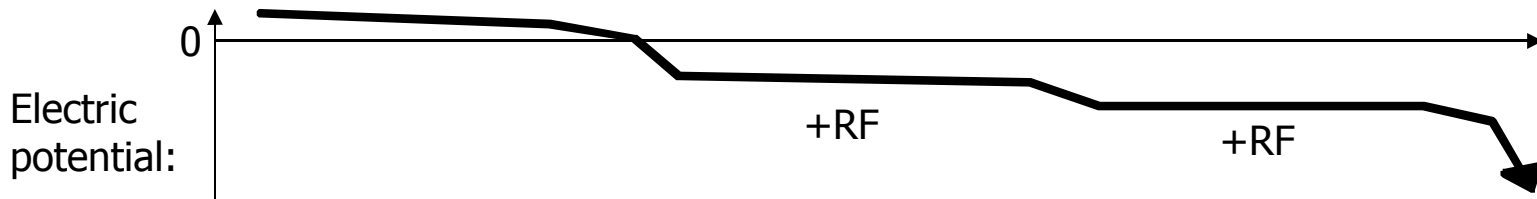
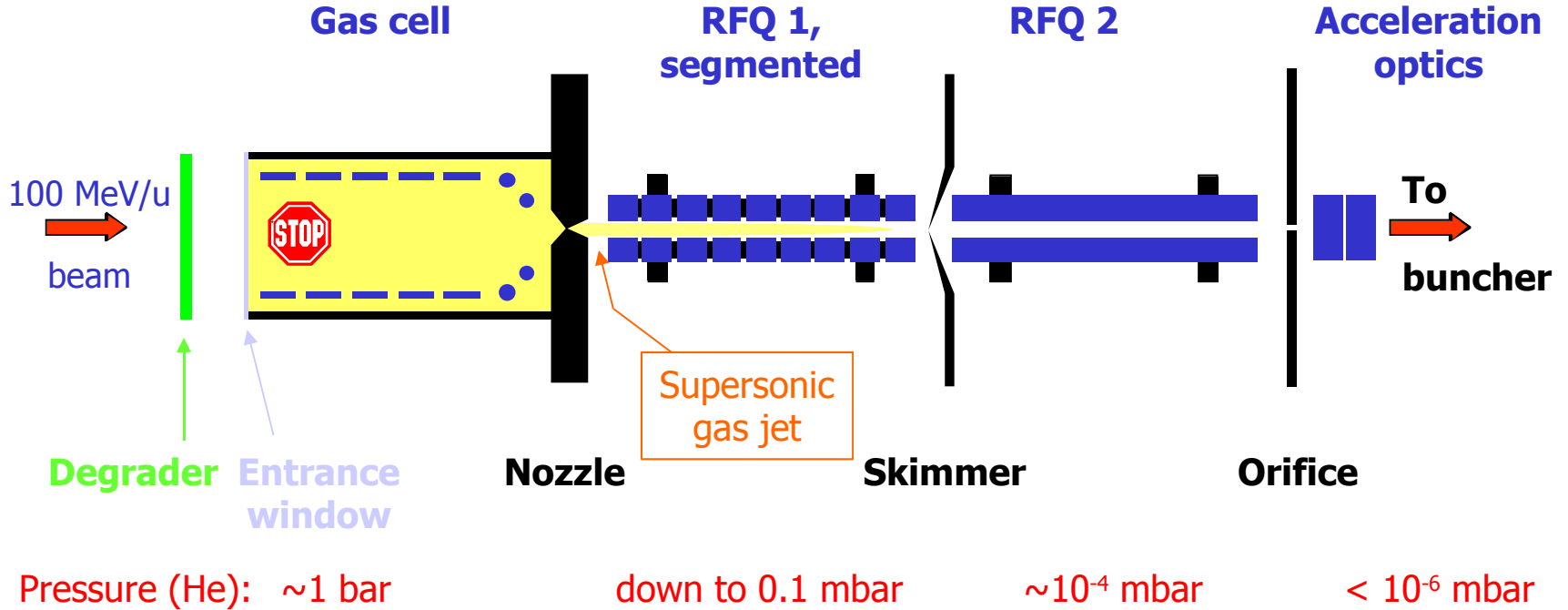


LEBIT - a facility for Low-Energy Beam and Ion Trap experiments

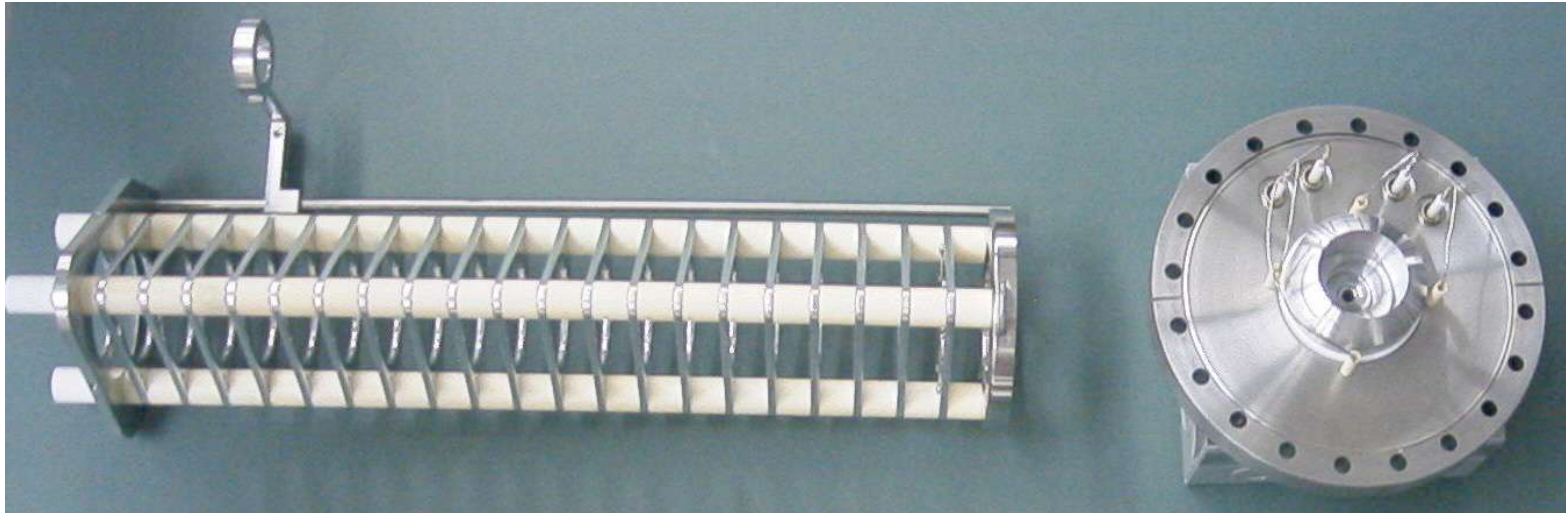


- Gas cell - stops fragment beams: $E \sim 100 \text{ MeV/u} \Rightarrow 5\text{keV}$, DC
- Beam cooling and Bunching
- Experiments - Penning trap mass spectrometry, laser spectroscopy, decay studies

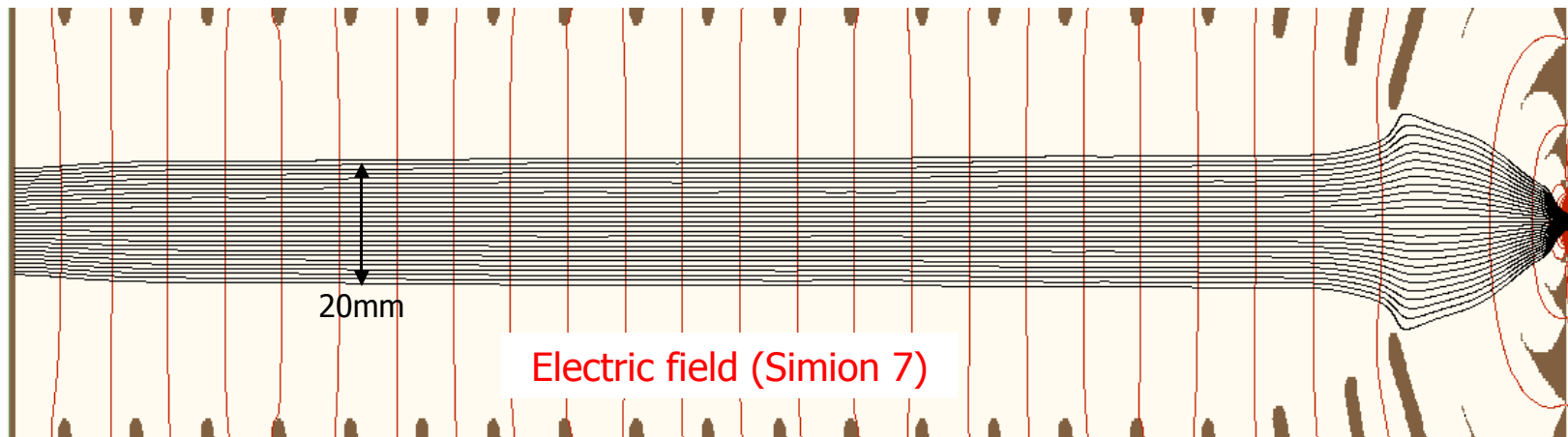
Gas stopping cell and ion guide system: **overview**



Ion extraction from the gas cell, **flower power**

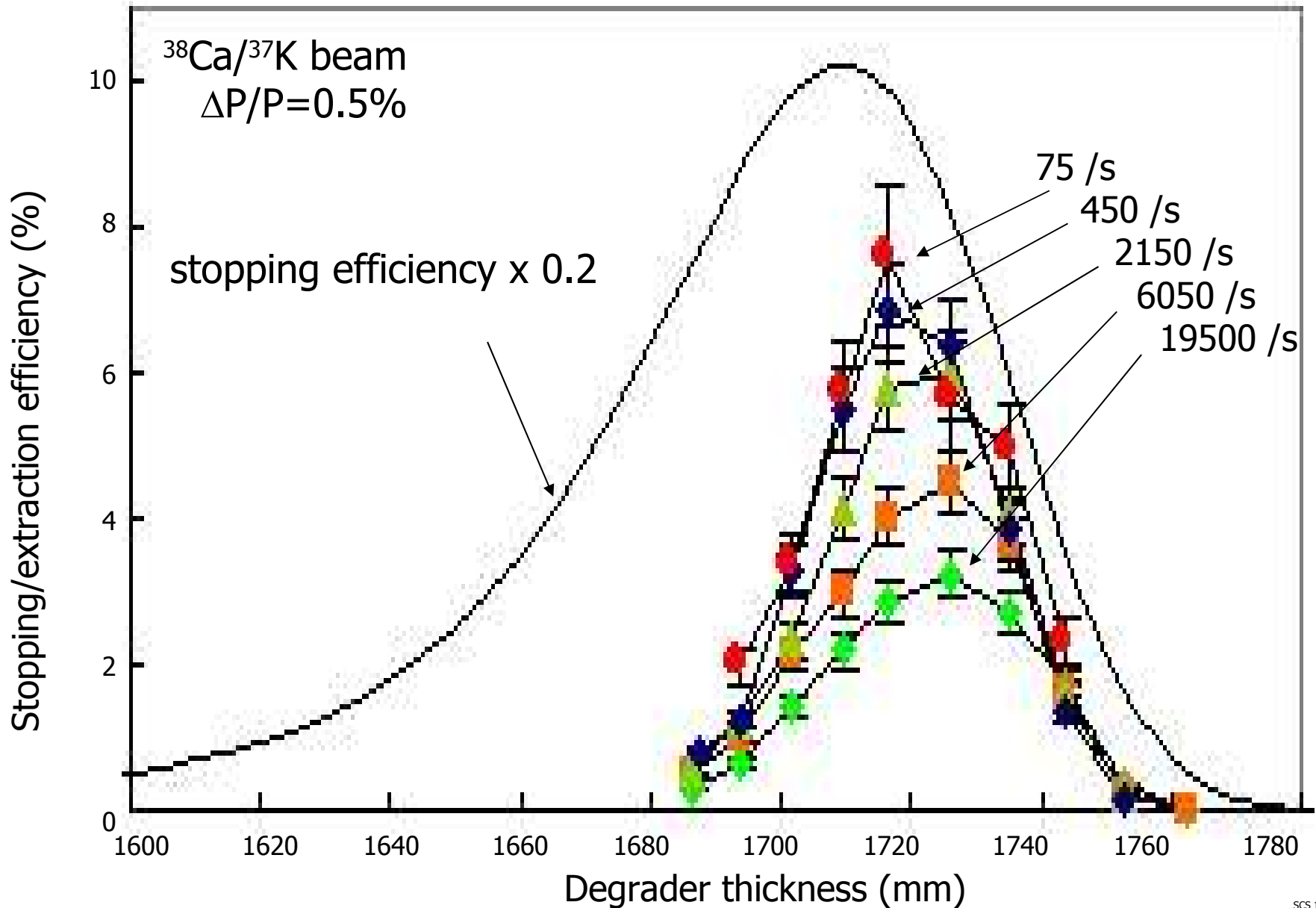


Simulation: Electric field + gas flow (VarJet) -> $\epsilon=1$

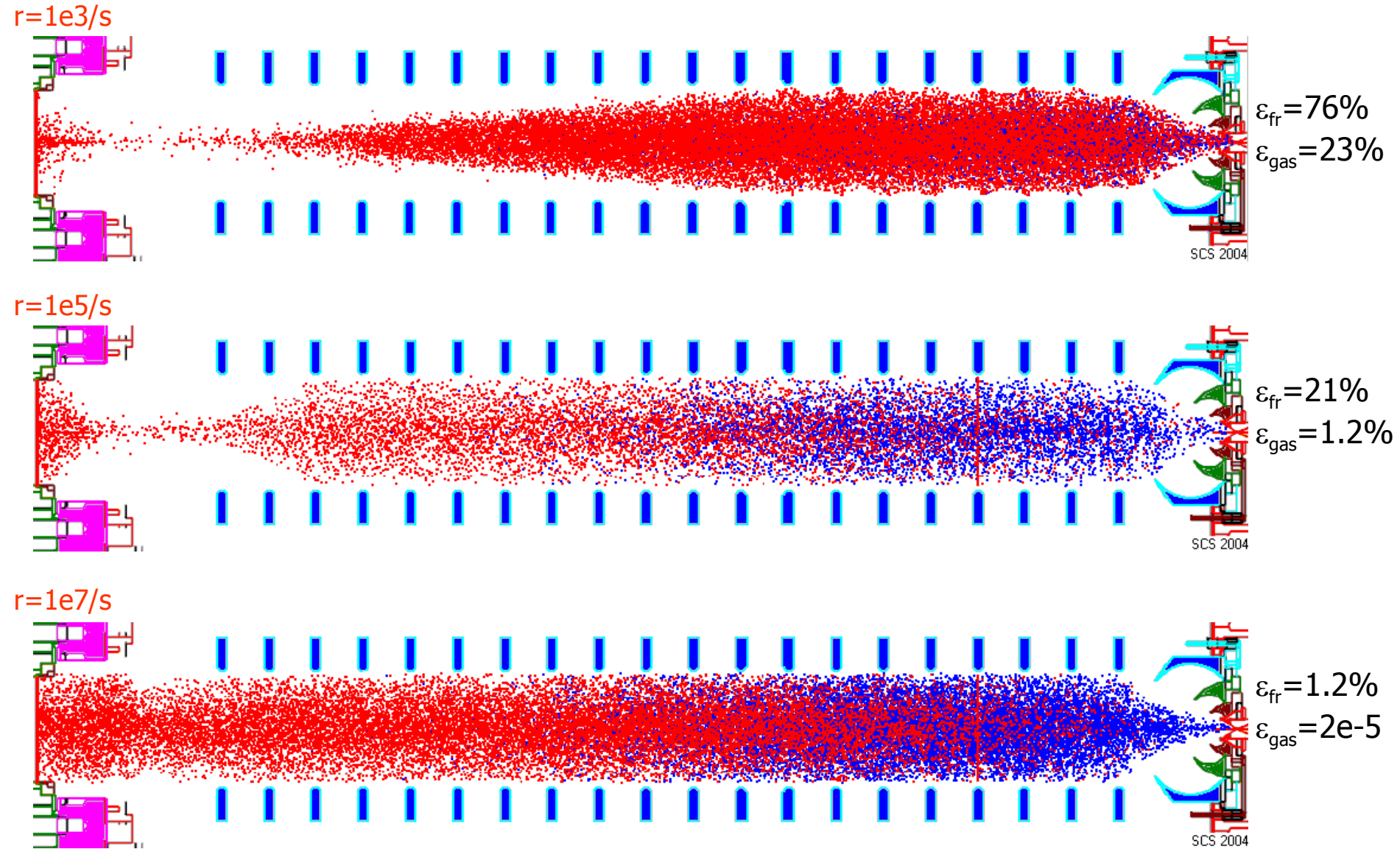


But there is space charge ... and lots of it !!!

Some results of extraction measurements

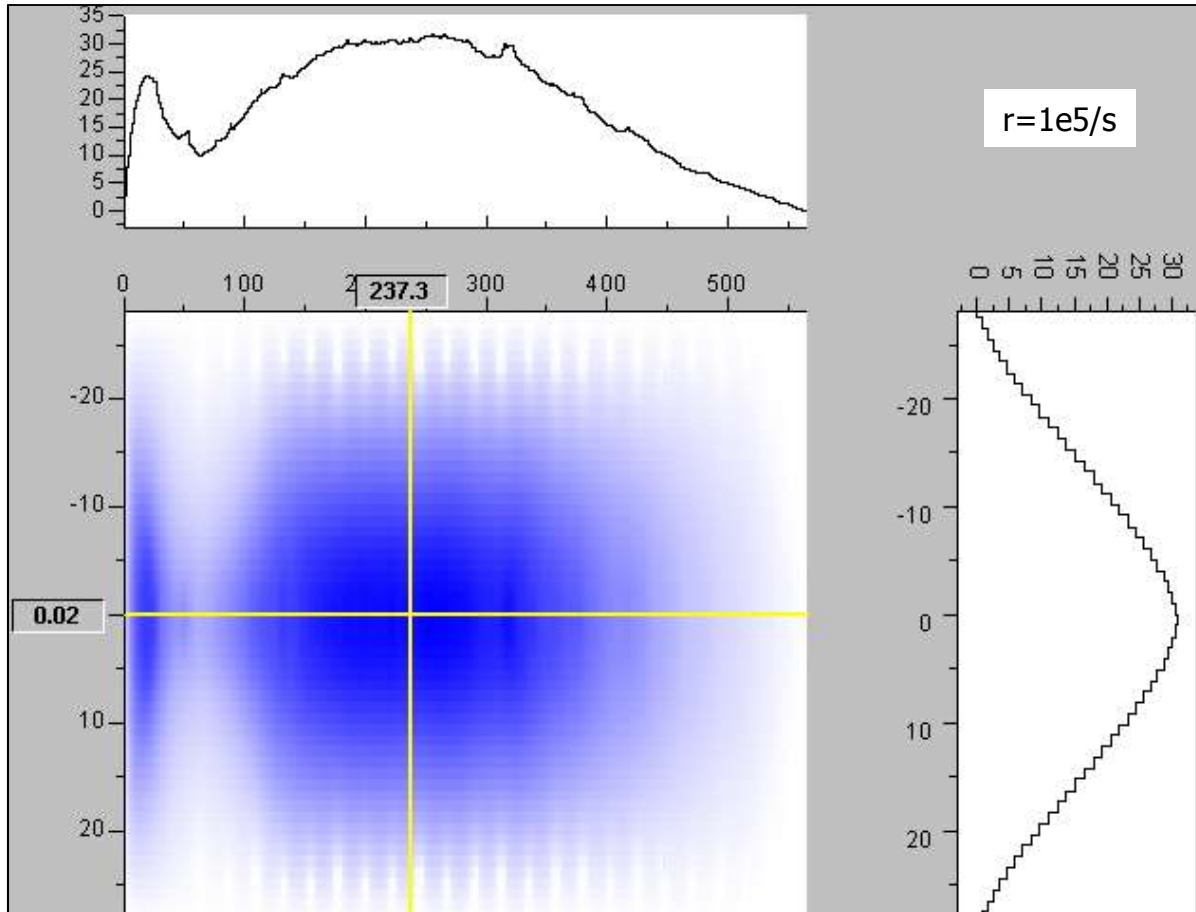


Ion extraction from the gas cell, space charge at work



$U_{Ring1} = 1300V, U_{Ring2} = 1600V, U_{Ring21} : 1025V - {}^{40}Ca$

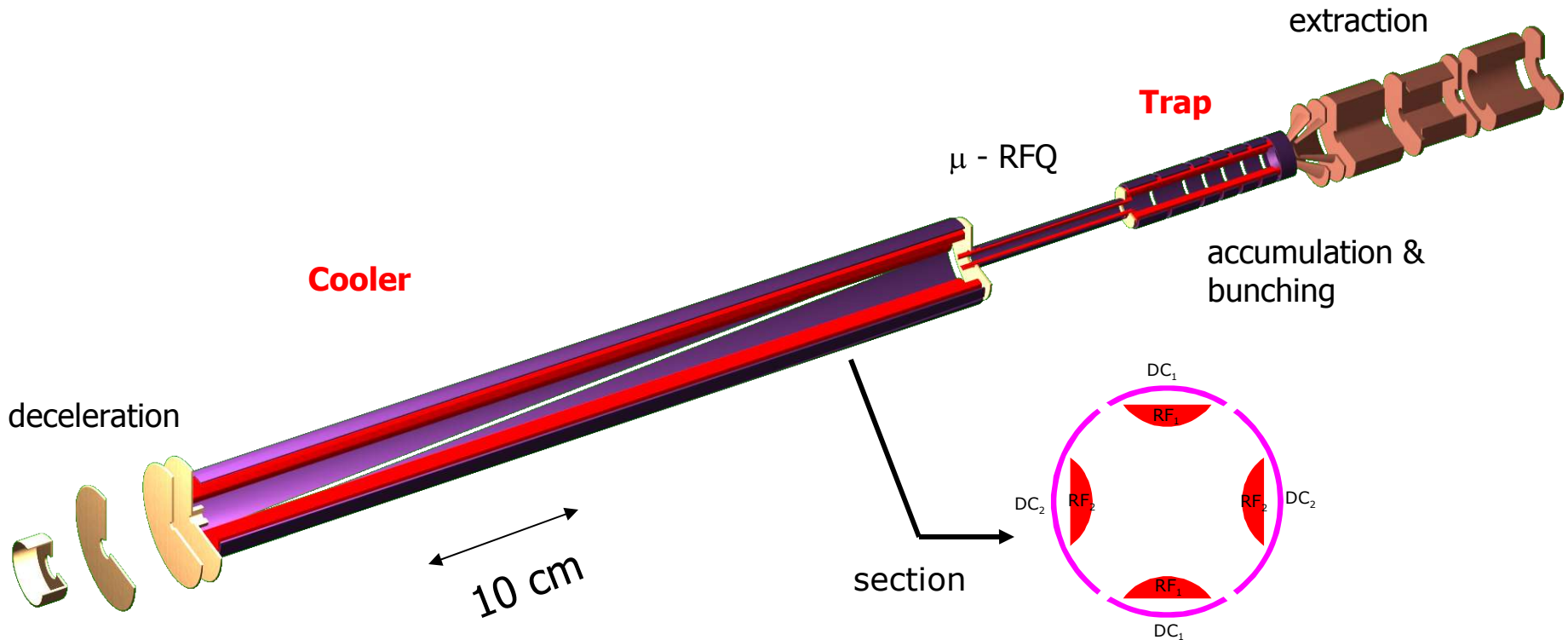
Ion extraction from the gas cell, **space charge & potential**



- PIC code:
FAST! ~10min – 10kions
- Handles He^+ , Ca^+
and even e^-
- \Rightarrow Efficiency
- \Rightarrow Where ions get lost
- \Rightarrow Extraction time
- **Work in progress !**

$$U_{\text{Ring1}}=1300\text{V}, U_{\text{Ring2}}=1600\text{V}, U_{\text{Ring21}}:1025\text{V} - {}^{40}\text{Ca}$$

The LEBIT cooler & buncher



Features:

Two-stage system

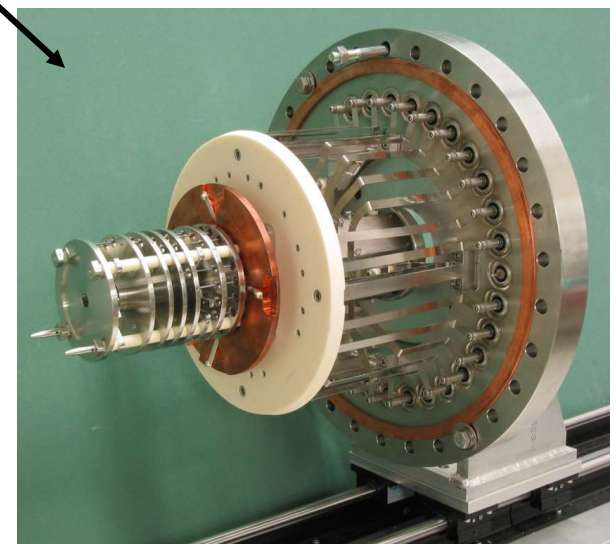
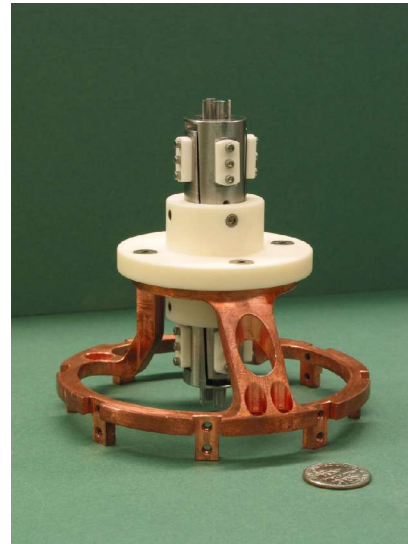
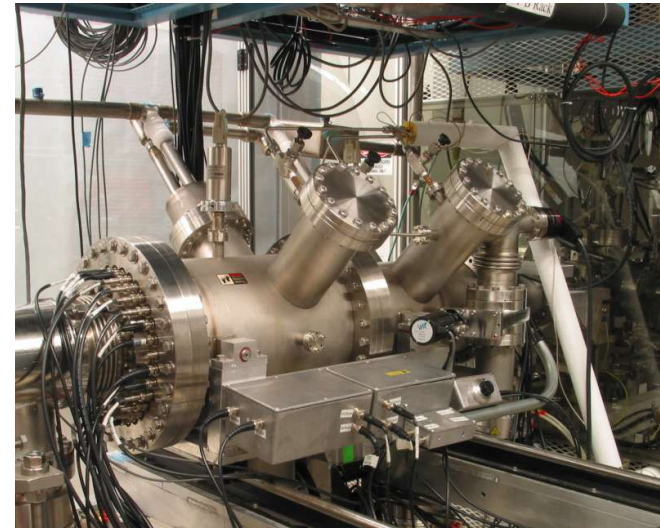
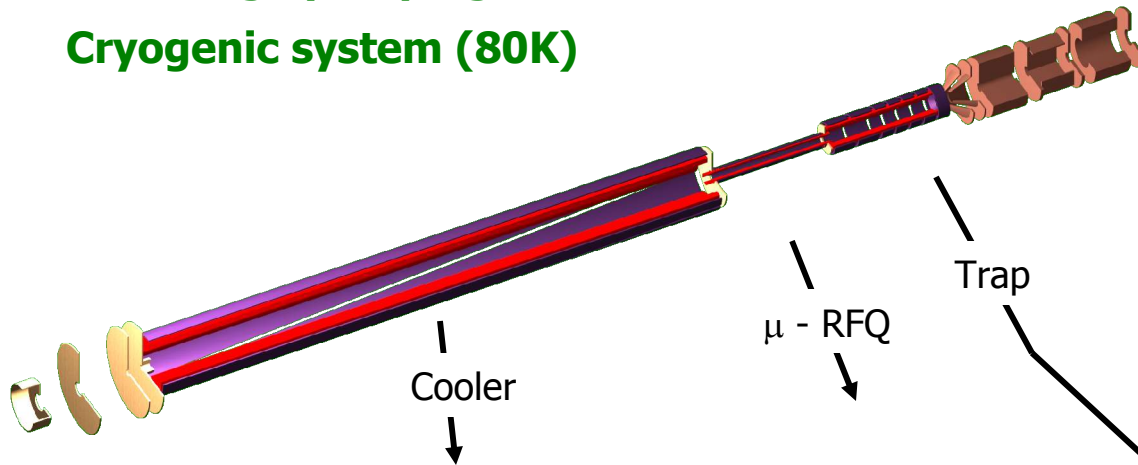
Wedge-type electrodes

Cryogenic system

- high-pressure cooling (~ 0.1 mbar)
- low-pressure trapping & bunching ($< 10^{-3}$ mbar)
- no segmentation (except for DC in trap section)
- N₂-cooled, clean, no charge-exchange
- very low emittance, high efficiency

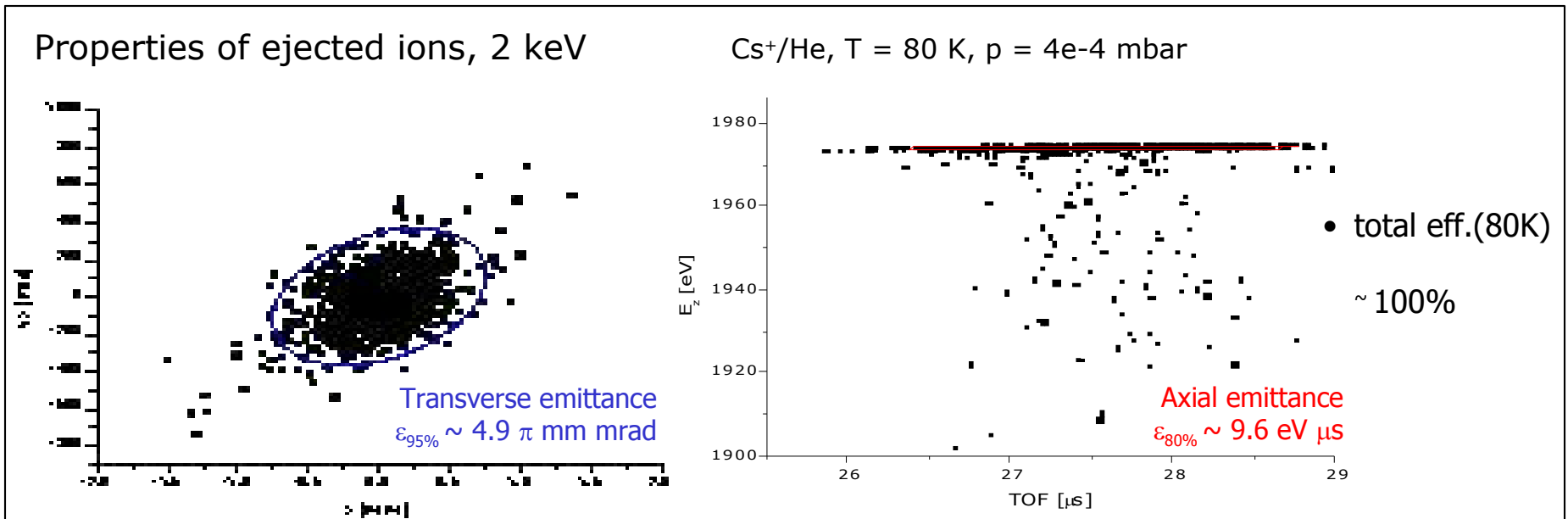
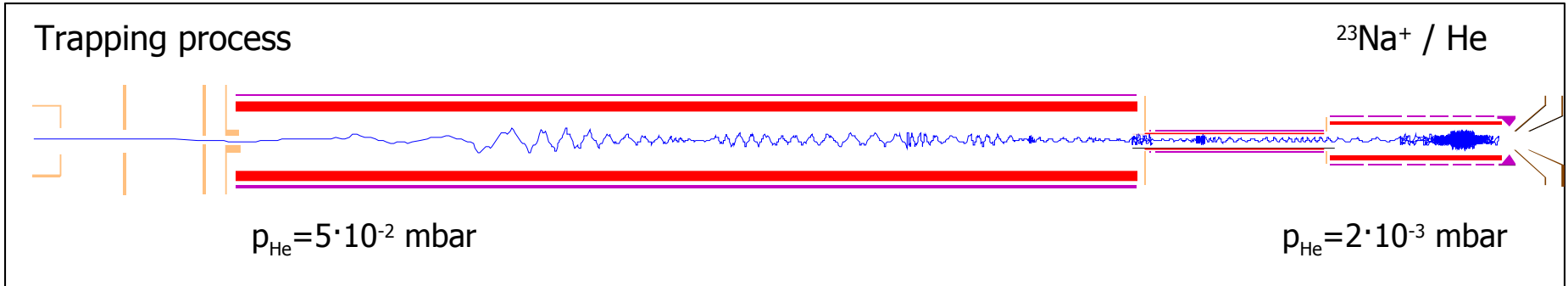
The LEBIT cooler & buncher - setup

2-stage electrode concept
Multistage pumping
Cryogenic system (80K)



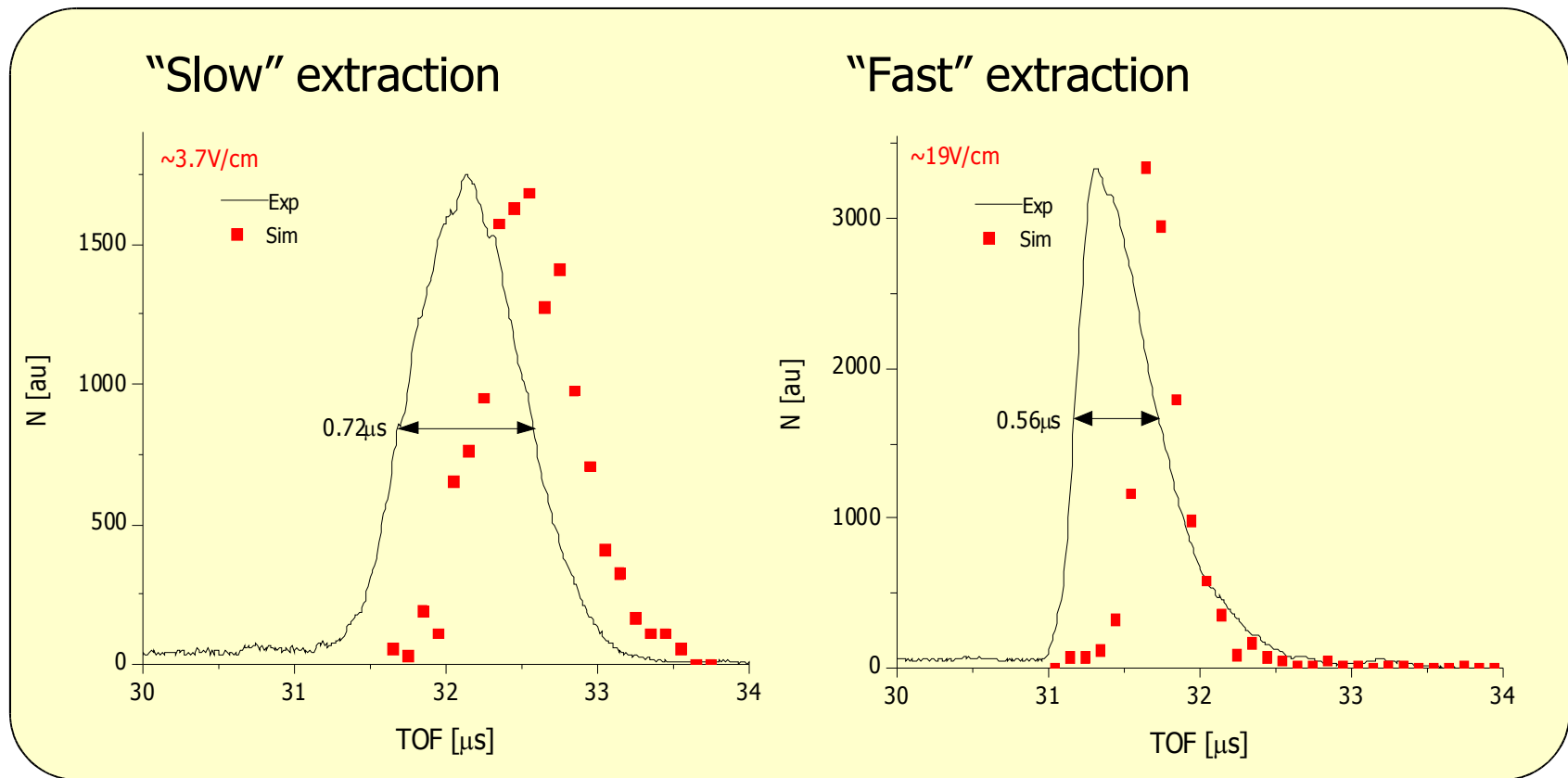
The LEBIT ion accumulator & buncher for LEBIT, **simulations**

- Simulation of complete transfer process
- ^{23}Na , ^{133}Cs (realistic potential scattering), ^{200}XX
- $T = 80\text{ K}$, 300 K



Pulsed mode operation

Time-of-flight distributions, measured with an MCP detector.



... with cooling times $\sim 20\text{ms}$

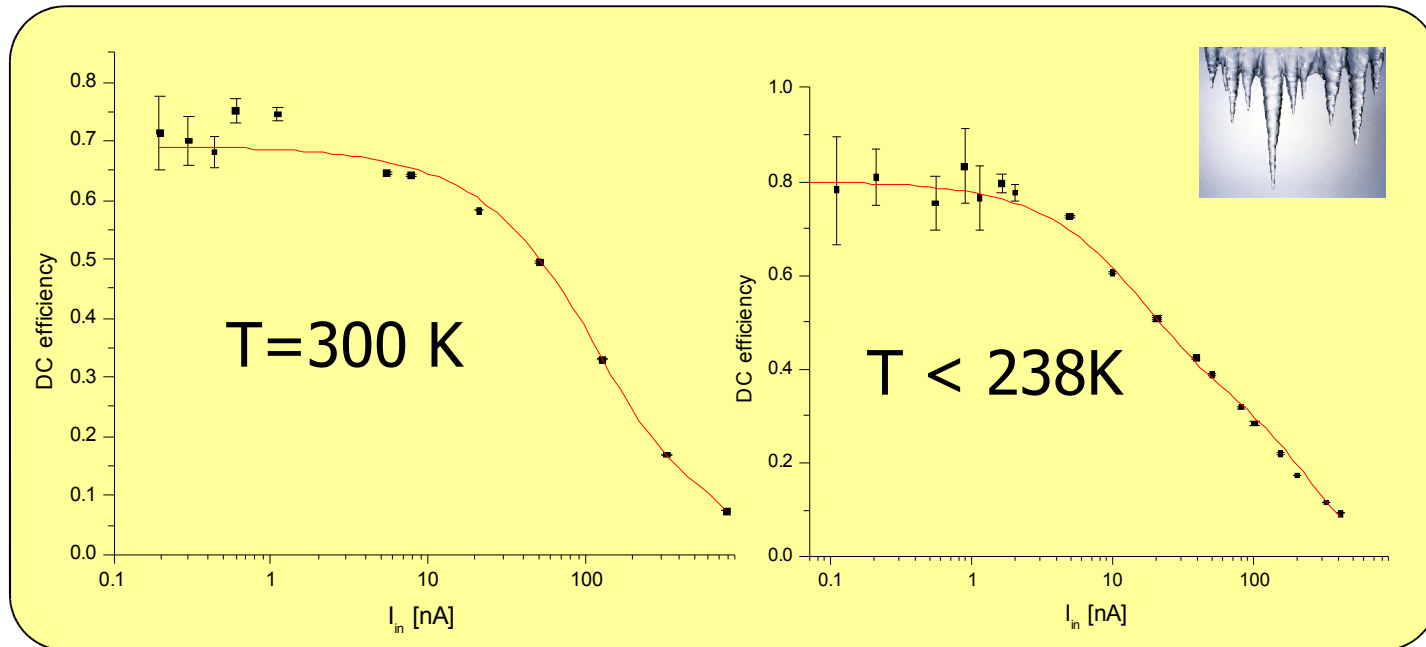
The LEBIT cooler & buncher: efficiency

Pulsed mode:

Total efficiency (with Penning trap):

$\varepsilon > 10\text{-}15\%$ (not corrected for MCP detector efficiency)

DC mode: Transmission efficiency vs. beam current:



RIA R&D proposal submitted to DOE:
High intensity beam cooling for better isobar separation

Experiment

Simulations

T. Kim, R.B Moore, McGill, Montreal

Beam size as a function of beam current \Rightarrow
beam temperature assuming no space charge

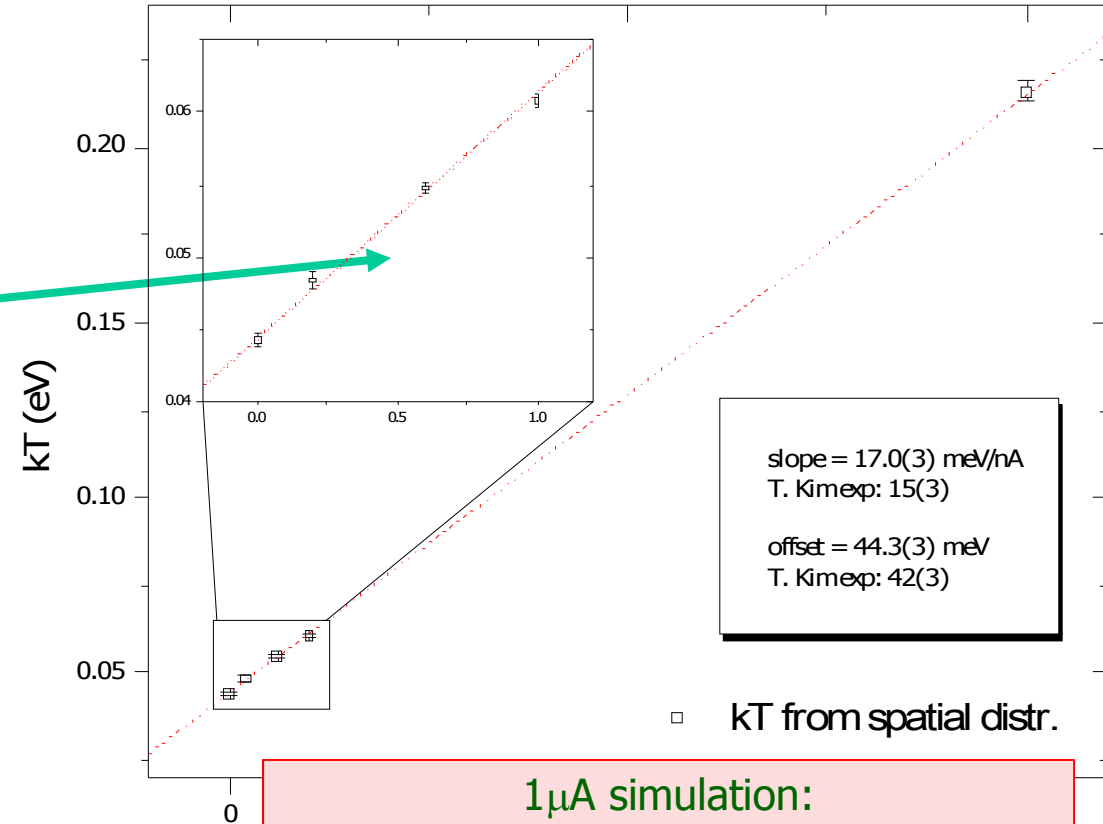
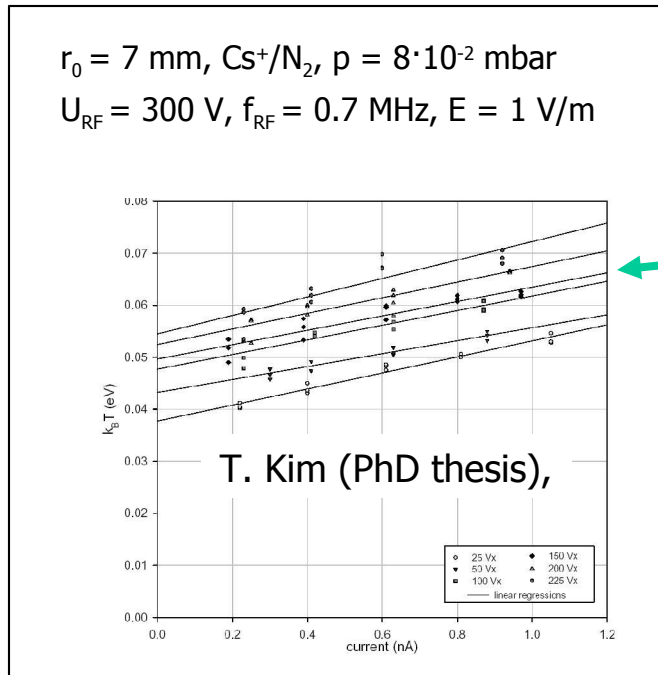
"Mean field"-code: (FH & SCS)

RF + Buffer gas collisions + Coulomb interaction

0.8

$\epsilon_{95\%}$ [π mm mrad @ 60 keV]

2.3



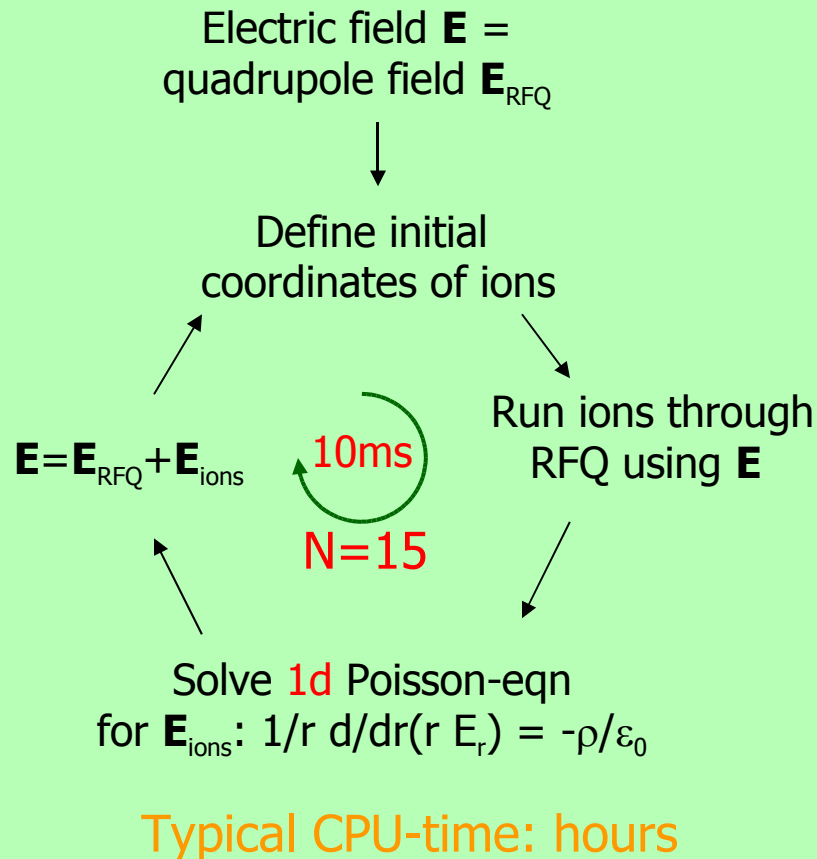
Agreement for spatial distribution
(0 - 1.2 nA)
& slow rise of beam temperature

1 μ A simulation:
 $U_{\text{RF}} = 15$ kV, $f_{\text{RF}} = 5$ MHz, $E = 10$ V/m
 $\epsilon_{95\%} \approx 3 \pi$ mm mrad @ 60 keV

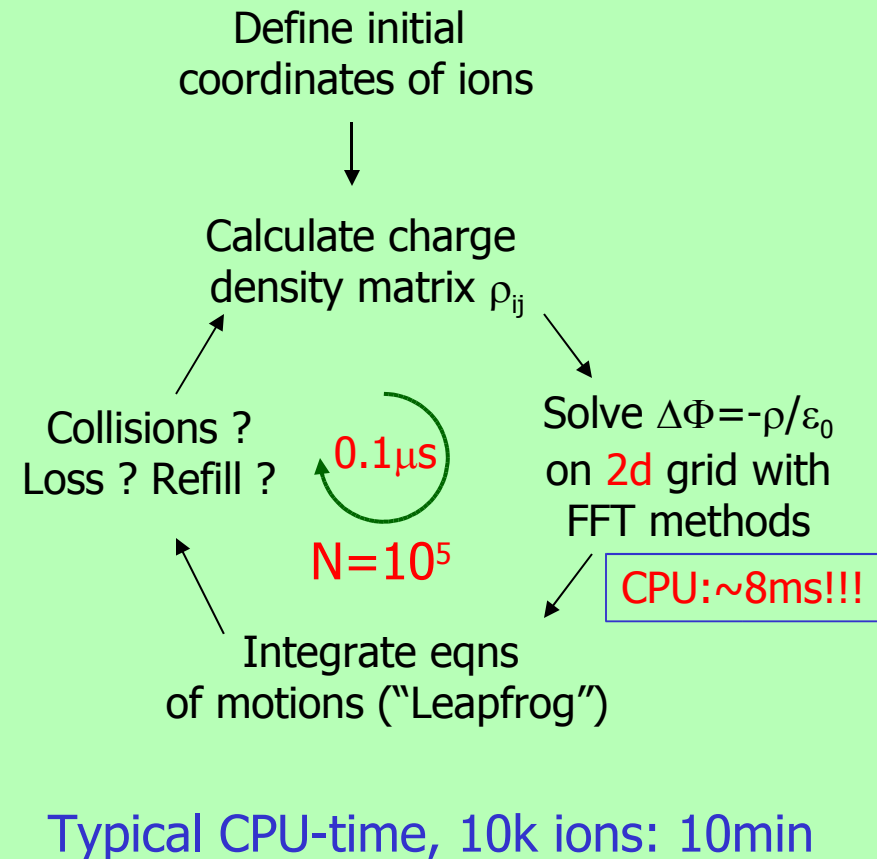
"Mean field" vs. PIC code

MD simulations not very efficient for space charge calculations

Mean field:



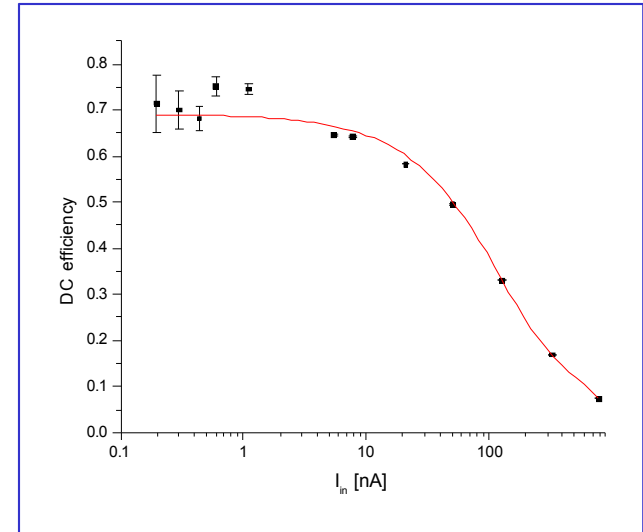
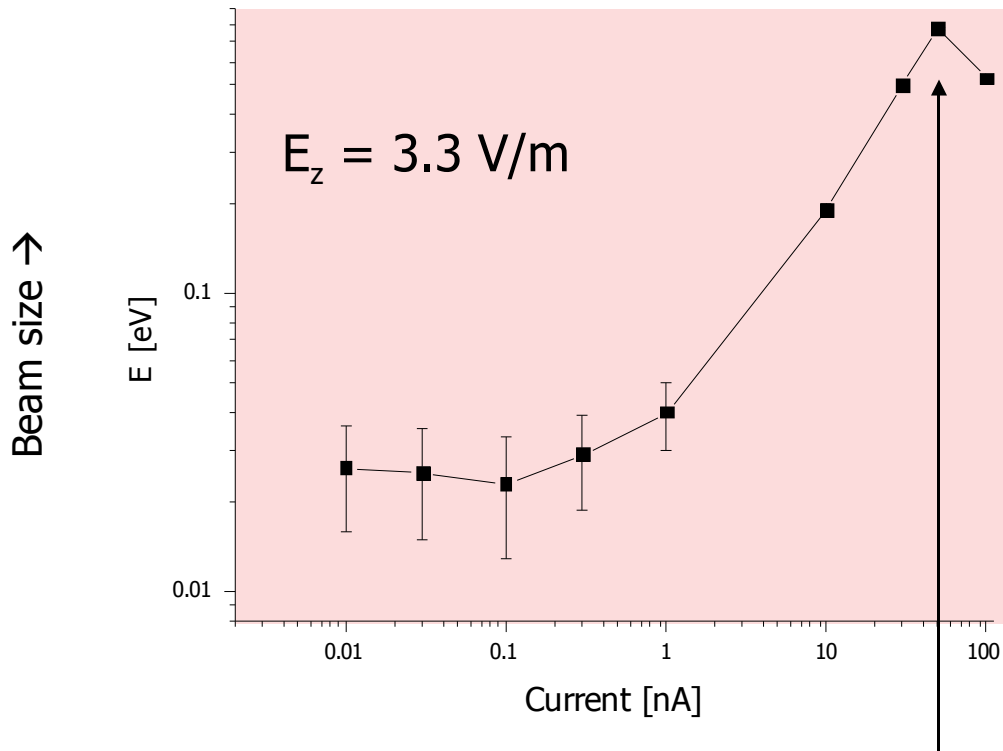
Particle in cell:



Method: D.W.Mitchell, R.D.Smith: IJMS Ion Proc 165 (1997) 271

The LEBIT miniature RFQ: space charge "heating"

Beam size as a function of beam current
⇒ beam temperature

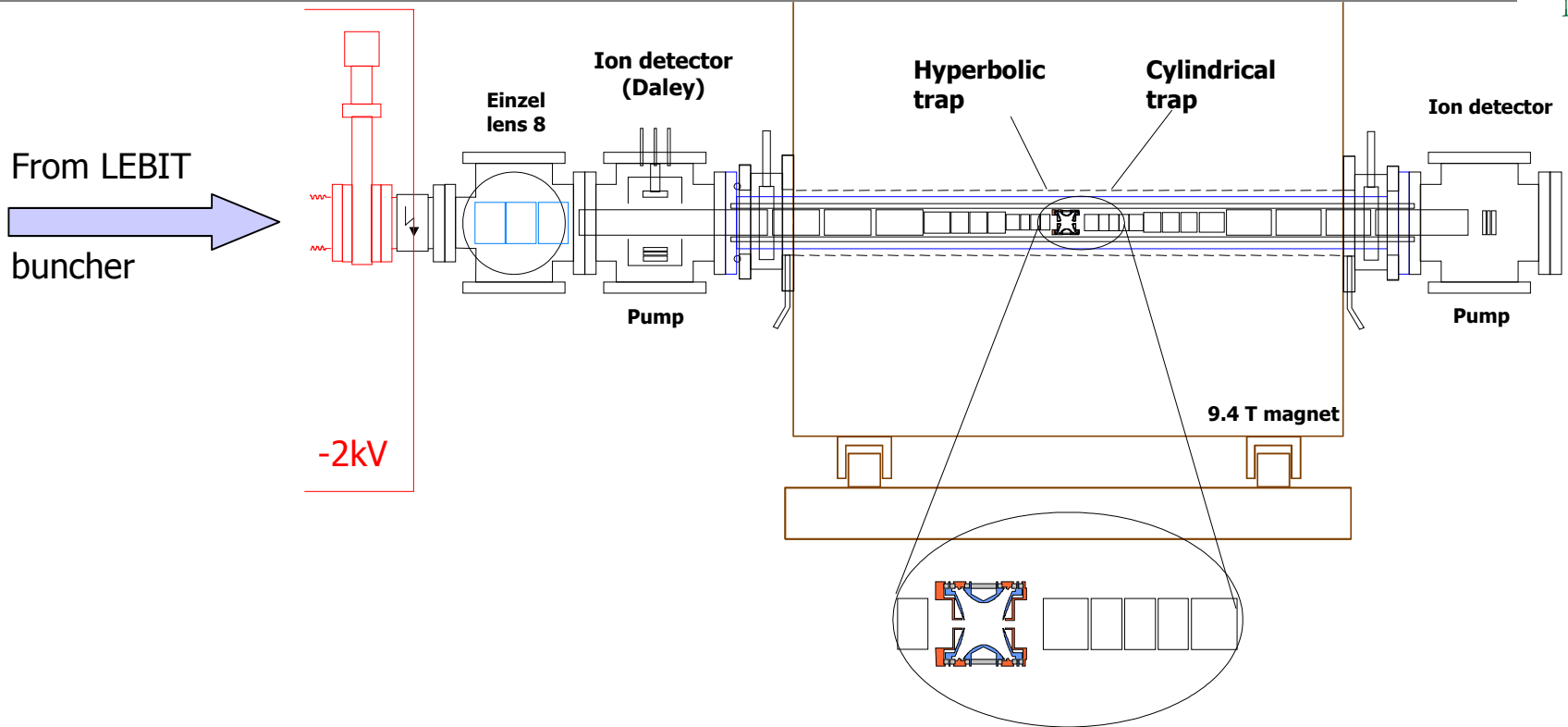


- Code will yield:
 - emittance
 - efficiency ...

Losses start here
- agrees with experiment!

- **Fast & promising !**
- **Work in progress !!**

The 9.4 T Penning trap mass spectrometer



Features:

9.4 T magnet

Hyperbolic trap

Cylindrical trap

Cold traps at 80K

Backwards TOF detection

- shielded and compensated (ambient fields!)
- mass measurements via determination of cyclotron frequency $\omega_c = (q/m) \cdot B$
- ion parking, decay studies
- improved vacuum
- free access to traps

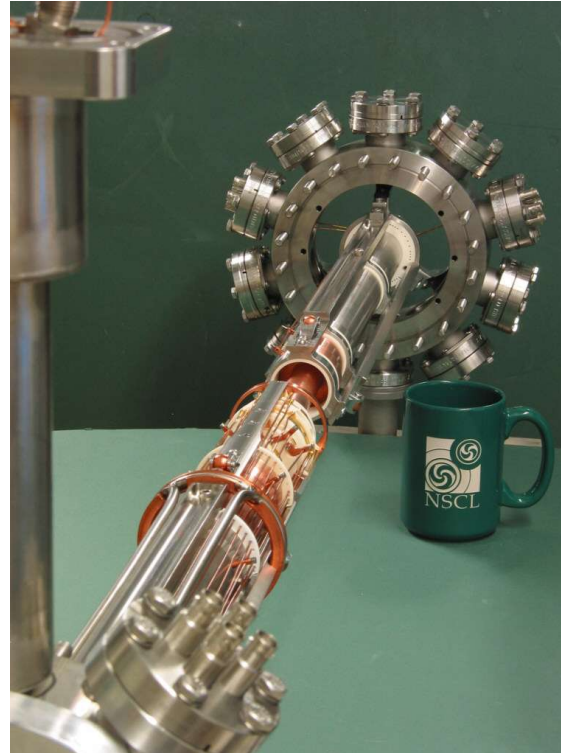
Why 9.4T ?

$$\delta m/m \approx c \cdot R^{-1} \cdot N^{-1/2}$$

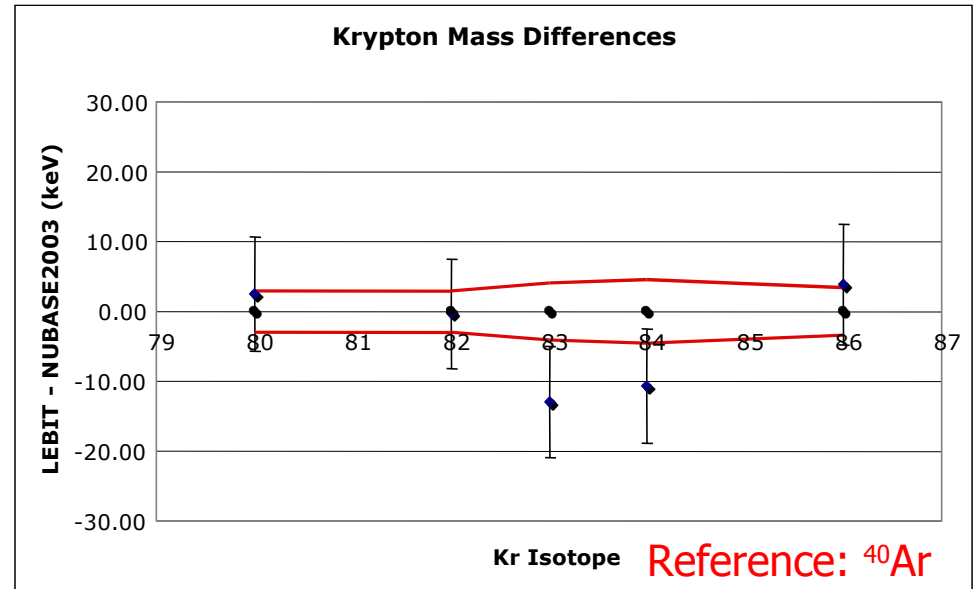
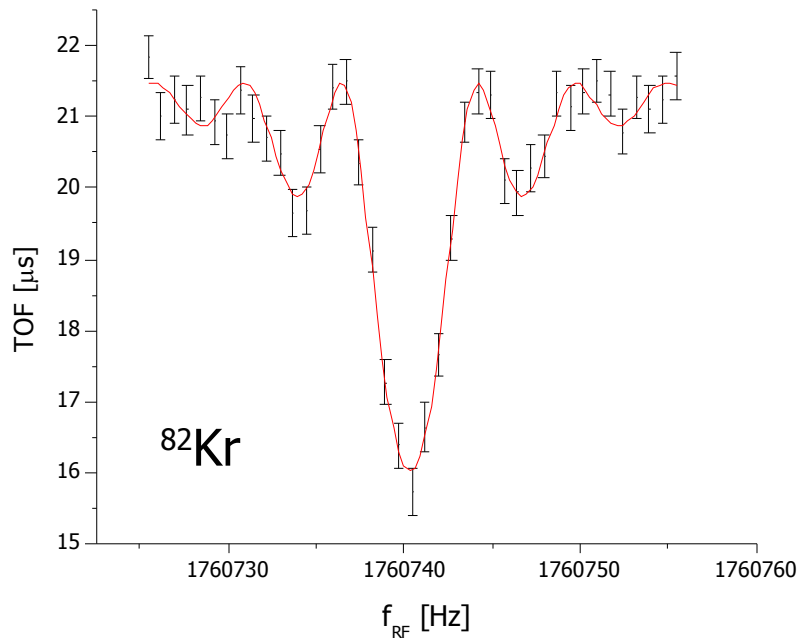
⇒ Same $\delta m/m$ in half the time compared to

6T systems

The LEBIT 9.4 T Penning trap system



Test Measurement with Stable Krypton Isotopes



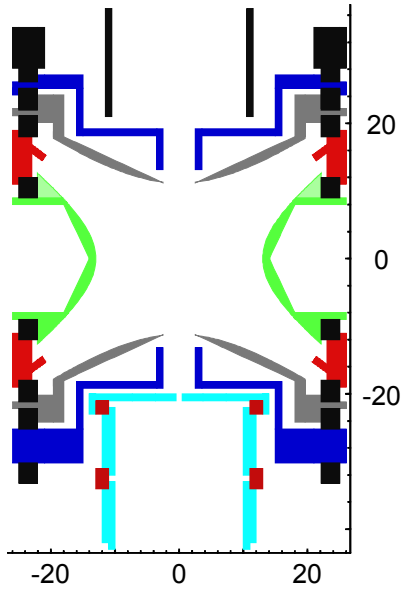
- $R = v/\Delta v \sim v \cdot T_{\text{exc}} \sim 4 \cdot 10^5$
 $R_{\text{max}} \sim 2.5 \cdot 10^6$
- $\delta m/m_{\text{stat}} \sim 4 \cdot 10^{-8}$

- Average relative mass difference:
 $5 \cdot 10^{-8}$
- Mass dependent systematic effects:
 $< 2 \cdot 10^{-9}/\text{amu}$

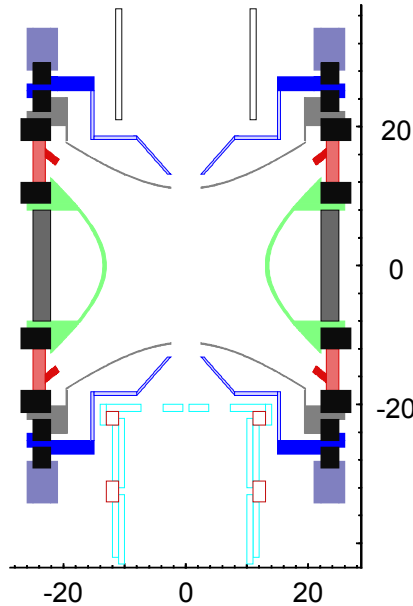
Rare isotope measurements soon

The LEBIT Penning trap – B-Field

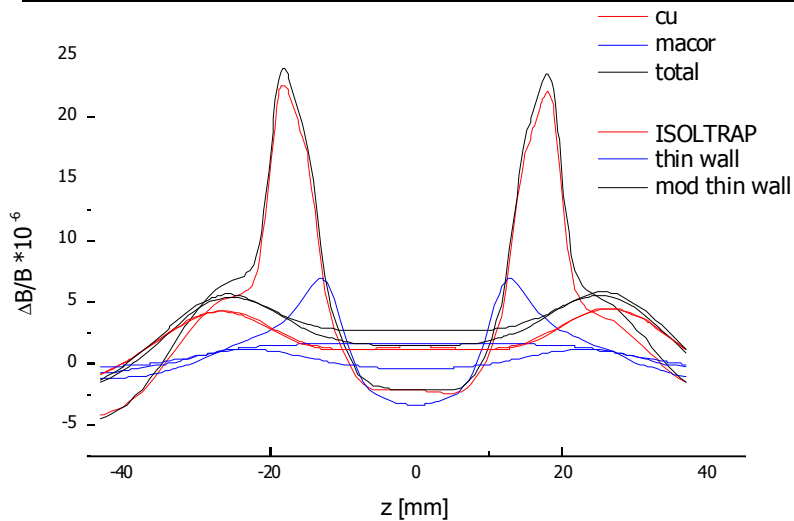
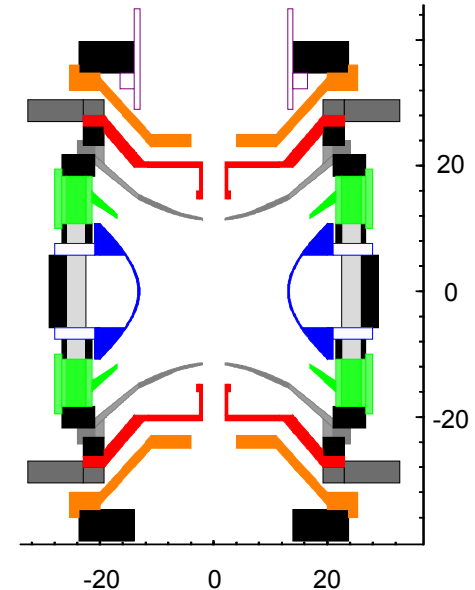
ISOLTRAP



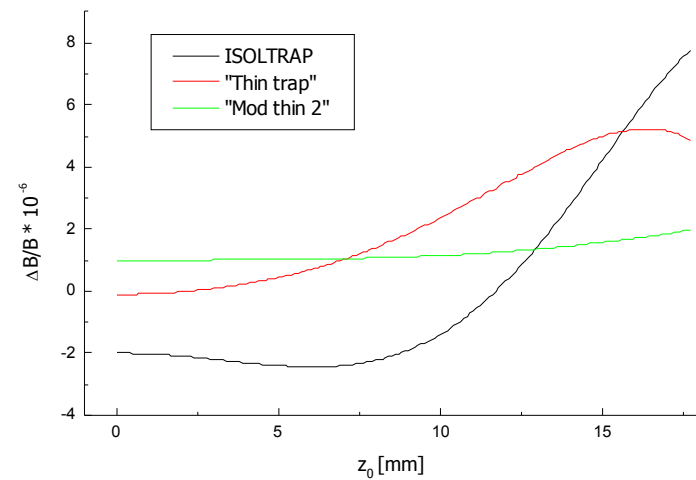
"Thin" wall #1



"Mod. thin wall #2"



Deviation of B-field on z-axis introduced by material

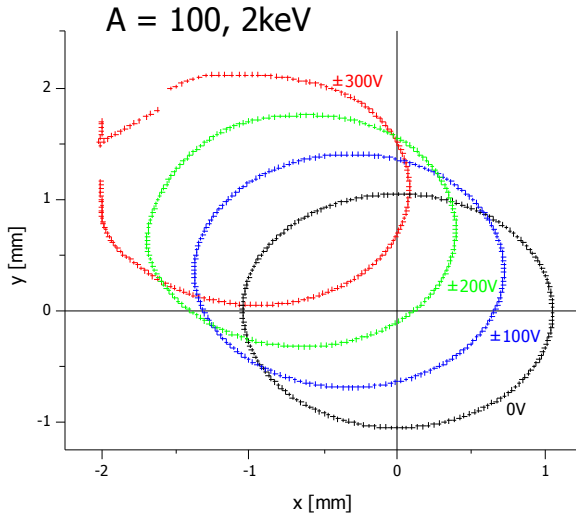
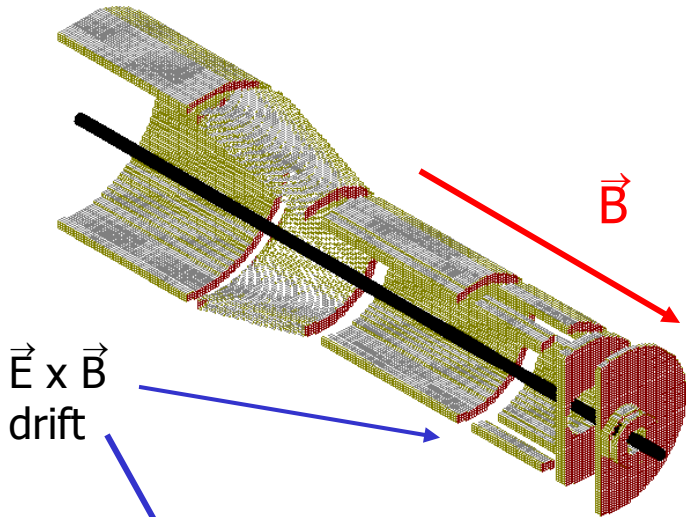


Avg B-field felt by a particle with amplitude z_0

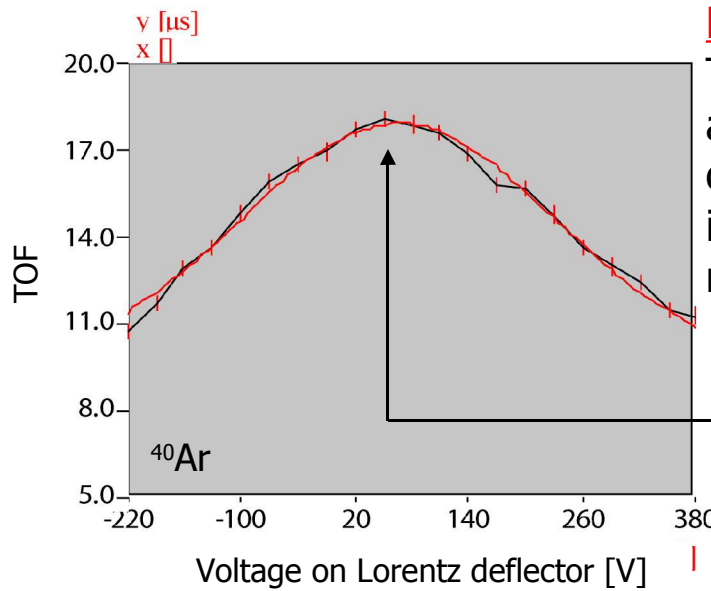
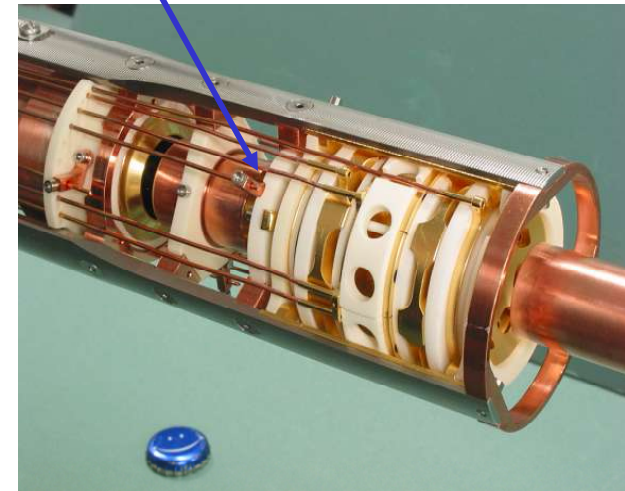
The LEBIT Penning trap – Lorentz steerer for magnetron preparation

True cyclotron frequency detection needs magnetron motion

“Lorentz”-deflector:
 Avoids time-consuming magnetron excitation !
 No phase-locking required



Simulation:
 Trapped ions having passed the Lorentz steerer. Deflection of beam increases until at ± 300 V ions begin to hit the endcaps



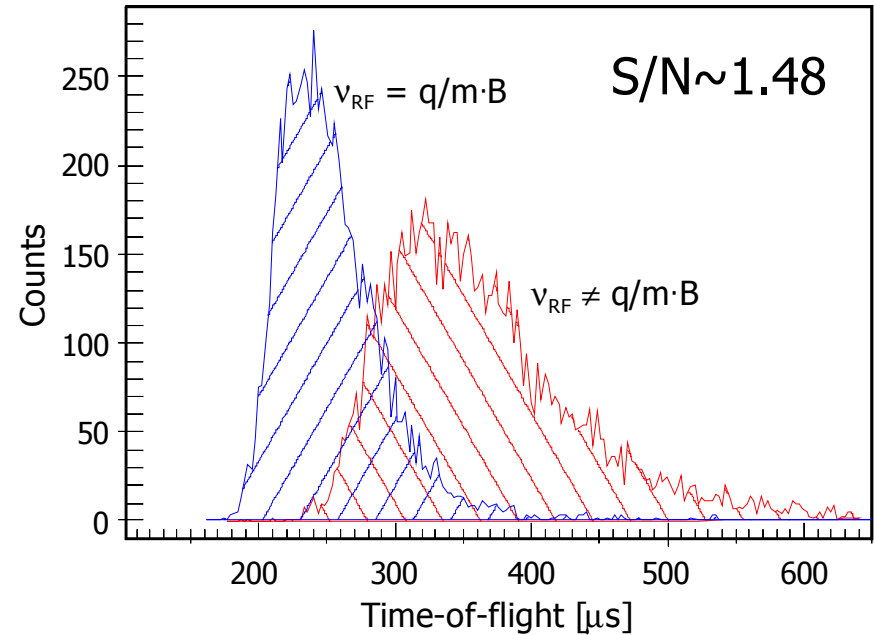
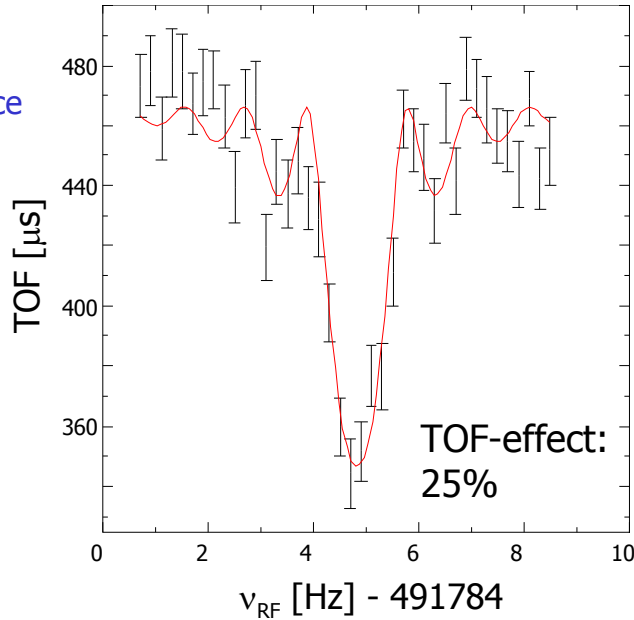
Experiment:
 TOF recorded after conversion of magnetron into cyclotron motion:
 Injection of ions with smallest $\langle \rho \rangle$

The LEBIT Penning trap – TOF detection / Signal-to-noise #1

Can we improve on the signal-to-noise ratio ?

$$S/N = (\overline{TOF_2} - \overline{TOF_1}) / \sqrt{(\sigma_1^2 + \sigma_2^2)}$$

Measured
ISOLTRAP
TOF-resonance
and spectra



Yes! Optimize layout & voltages... LEBIT ejection optics:



Trap

Drift section #1

Change voltage here !!!

Drift section #2

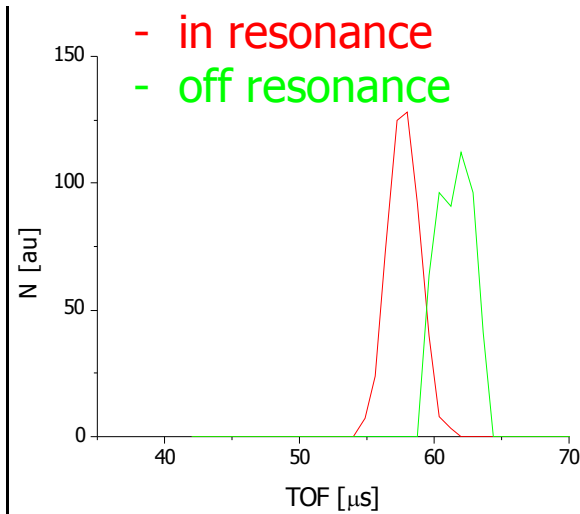
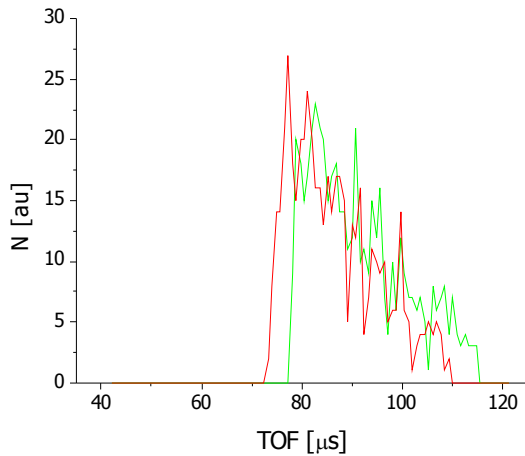
Drift section #3

#4

#5

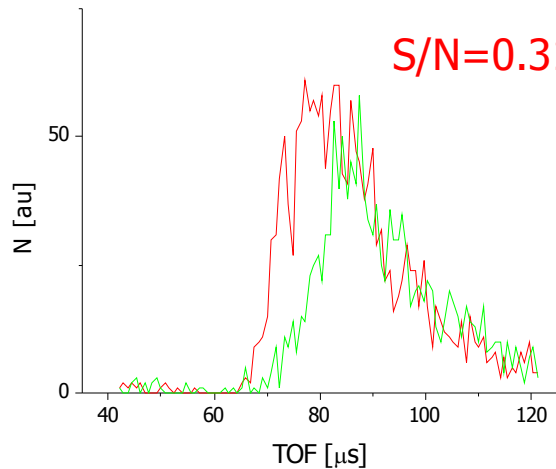
MCP
detector

Simulations

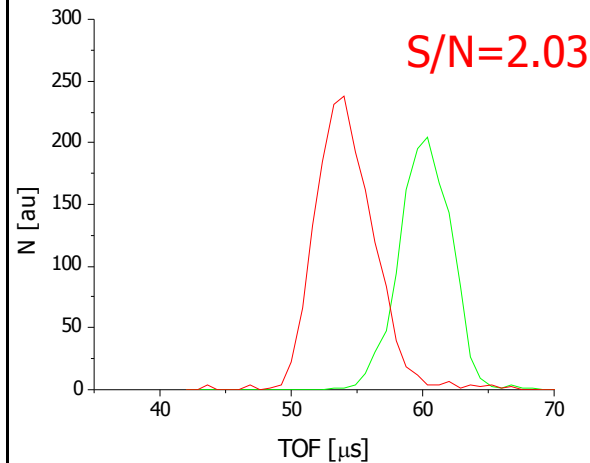


- ^{84}Kr
- Initial radial distribution:
 $\rho_r = 0.75 \text{ mm}, \sigma = 0.3 \text{ mm}$
- Initial axial distribution:
 $\pm 6 \text{ mm}$ (rectangular)
- 500 ions simulated
- **Work in progress !**

Experiment:



Drift #1: -10V



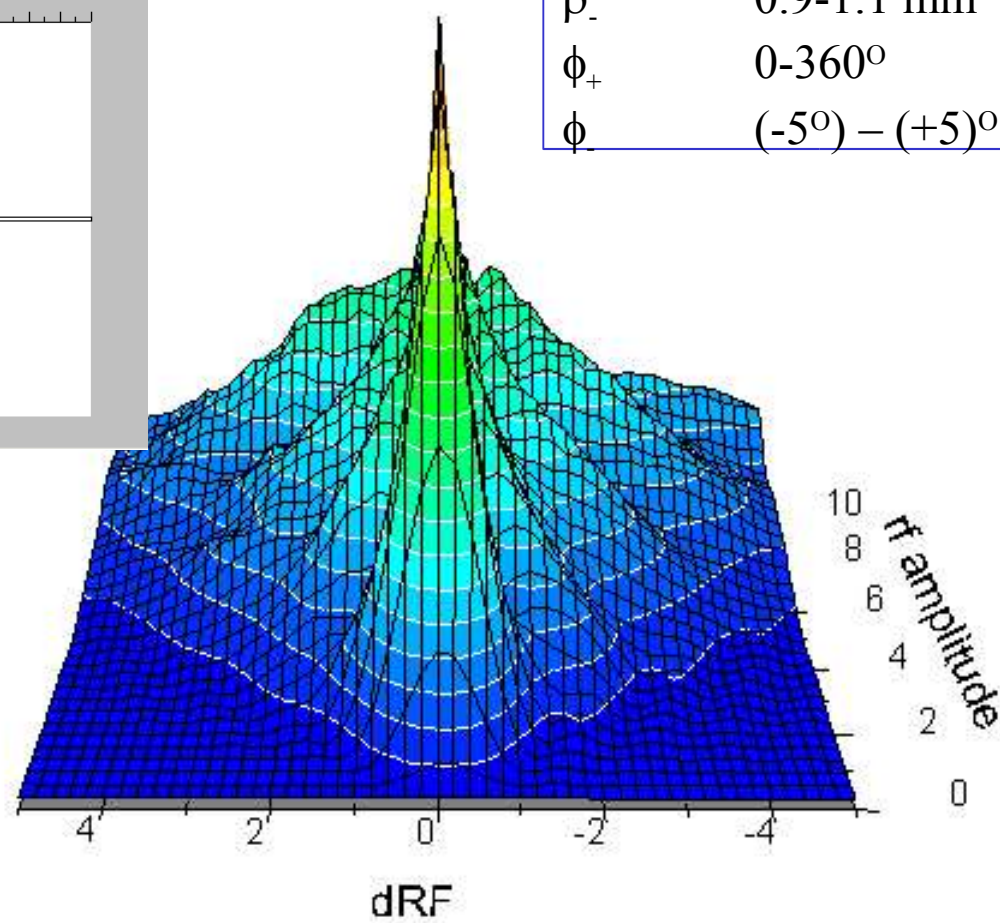
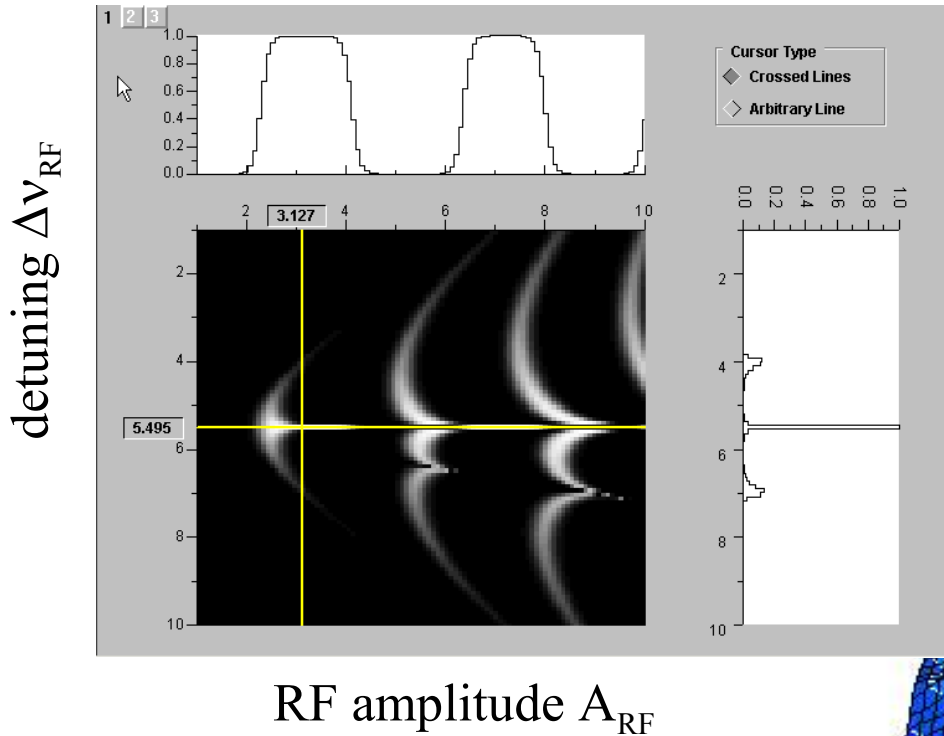
Drift #1: -70V

Octupole excitation at $2\omega_c$

Ideal conditions $\rho_+ = 0, \rho_- = 1, \phi_- = 0, \phi_+ = 17^\circ, T_{rf} = \text{const}$,

Realistic resonance profile

ρ_+	0-0.2 mm
ρ_-	0.9-1.1 mm
ϕ_+	0-360°
ϕ_-	(-5°) - (+5°)



Experimental studies needed

LEBIT – is in commissioning phase – rare isotope mass measurements soon

Simulations have played a very important role in LEBIT design and still do:

- Latest development: PIC code
 - gas cell optimization
 - high intensity beam cooling
 - other possible applications : space charge effects in RFQ and Penning traps
- Octupole excitations - analytical description desirable – experiments needed