Development of Compact Isobar Separator for Study of Exotic Decays using Multi-pass Time-of-Flight Principle: MTOF

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Motivation

Many decay studies not limited by production rate, but by background from isobaric contamination →

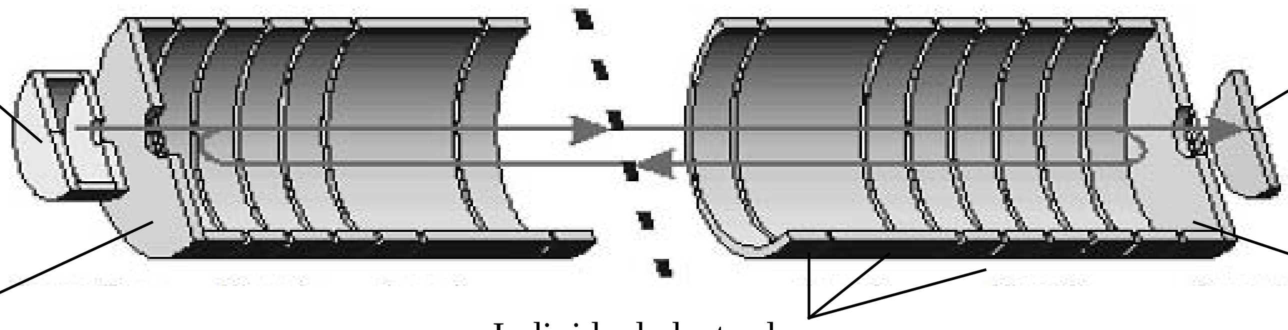
Add high resolution separator to an existing mass separator (in our case UNISOR at HRIBF) to achieve isobar suppression !

Wish list:

- High mass resolving power, $M/\Delta M$ = 15,000 or better
- Suppression of neighboring isobar by a factor of 100 or better
- High transmission 50% or better
- Chemistry independent
- Portable
- Cost effective

Can be achieved using multi-pass Time of Flight concept!

Multi-pass Time-of-Flight concept (I)



Time of Flight measurement for ion pulses between source and detector

Same flight path is used multiple times, up to 300 laps = 780 m

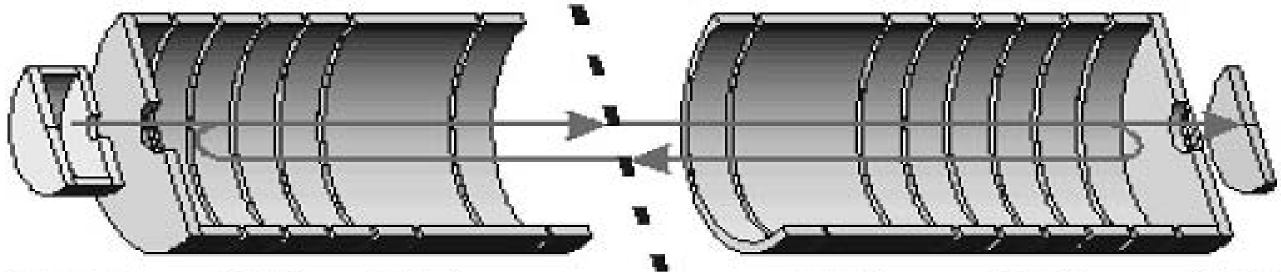
Grid-free electrostatic mirrors

Longitudinal mass dispersion: lightest isobar arrives first

***Spectrum* taken with MCP or physical isobar *Separation* using fast gate**

MTOF is *Spectrometer* or *Separator*

Multi-pass Time-of-Flight concept (II)



Dispersion:

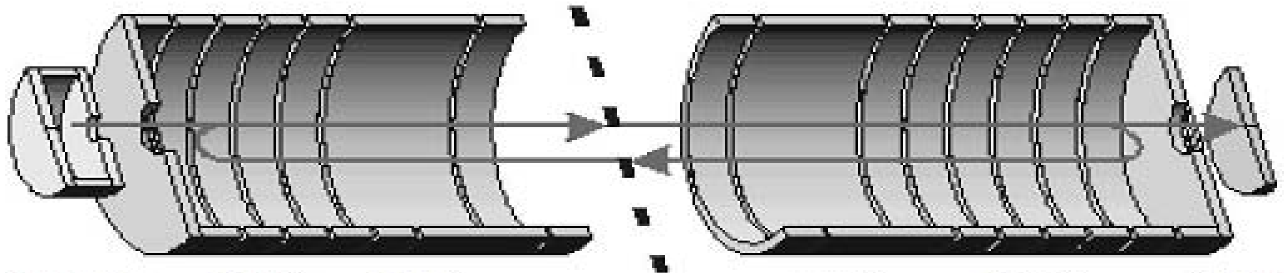
$\Delta T = 1/2 \times \Delta M/M \times ToF$

Examples:

A=28, ΔM = 3 MeV, ToF = 3.9 ms, 120 laps, ΔT = 200 ns

A=100, ΔM = 10 MeV, ToF = 7.4 ms, 120 laps, ΔT = 380 ns

Multi-pass Time-of-Flight concept (III)



MTOF is isochronous: ToF independent of ion energy starting position or starting angle (within limits)

Transversal focusing needed to minimize beam losses

Small longitudinal and transversal emittance of ion source needed for good mass resolving power

MTOF uses electric fields only. Therefore "portable" unlike a large sector field magnet

A pre-separation (according to mass number) is generally needed

- MTOF concept in nuclear physics pursued at

  RIKEN: mass measurements of exotic nuclei extracted from a gas cell

  GSI: may be used in conjunction with SHE program

- ToF flight devices similar, but not identical to MTOF, are widely used in analytical chemistry

Ion optical calculations

Complex ion optical problem of electrode design and voltage settings →
Need to develop "Voltage optimizing program" based on differential algebra
All ToF aberrations up to 5th order are minimized

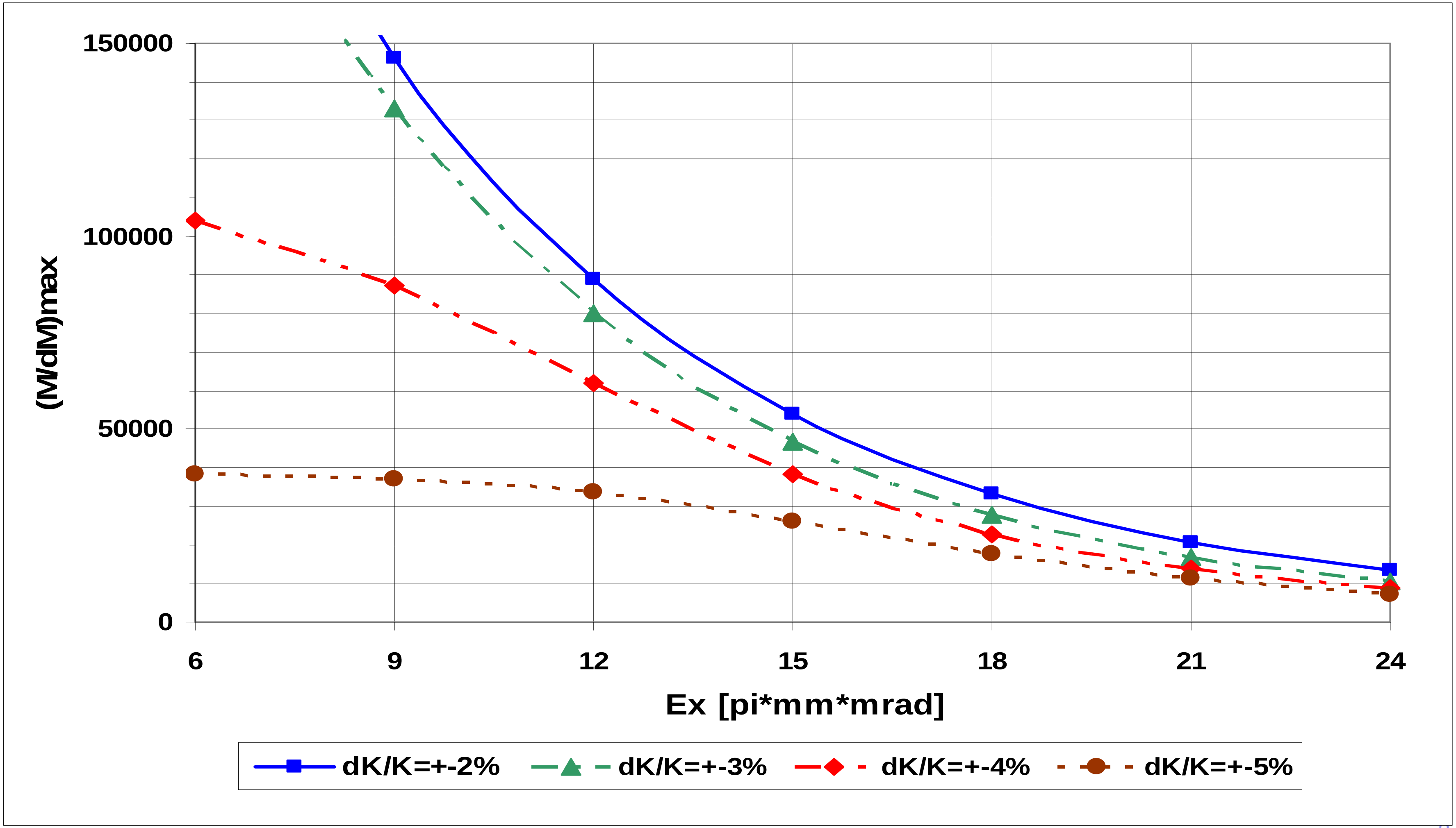
Input:
MTOF electrodes and ion source geometry
Initial ion cloud parameters in ion source:mass, charge, positions, initial velocities
Set of electrode voltages and extraction field strength in ion source

Transverse stability condition
Limit on magnification between ion source and MCP

Output:
Set of optimized electrode voltages
ToF aberrations
Mass resolving power etc.

V. Shchepunov and H. Wollnik, in: Proc. of the Particle Accel. Conf., May 16-20, 2005, Knoxville TN

Calculated optical limit M/ΔM versus transverse beam emittance and ion energy spread



Calculated alignment tolerances

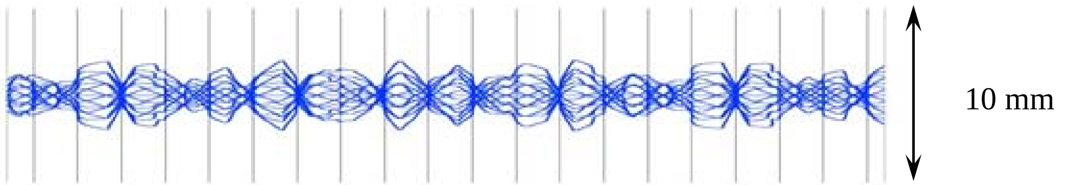
Electrode misalignments result in

- **Increased beam envelope**
- **Worse mass resolving power**

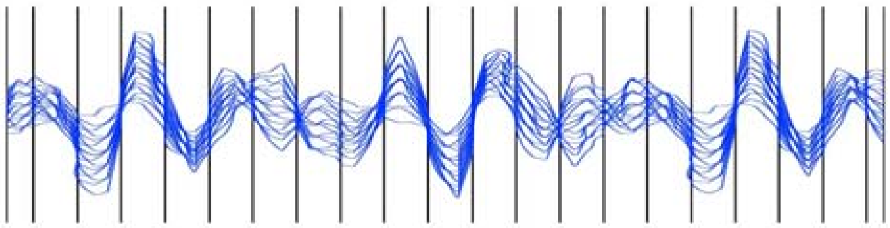
Motion remains stable

Transverse shifts < 0.25 mm,

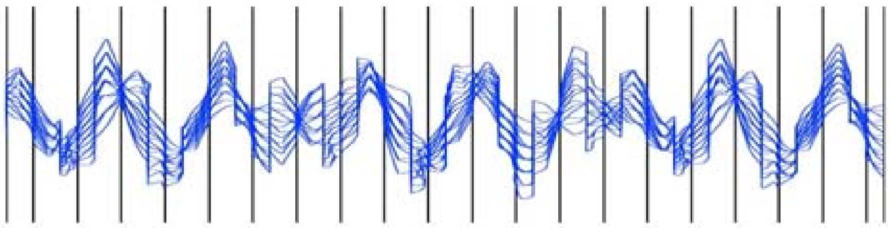
Tilts < 0.50 mrad,



No misalignments



The 2nd mirror is 2.0 mrad tilted



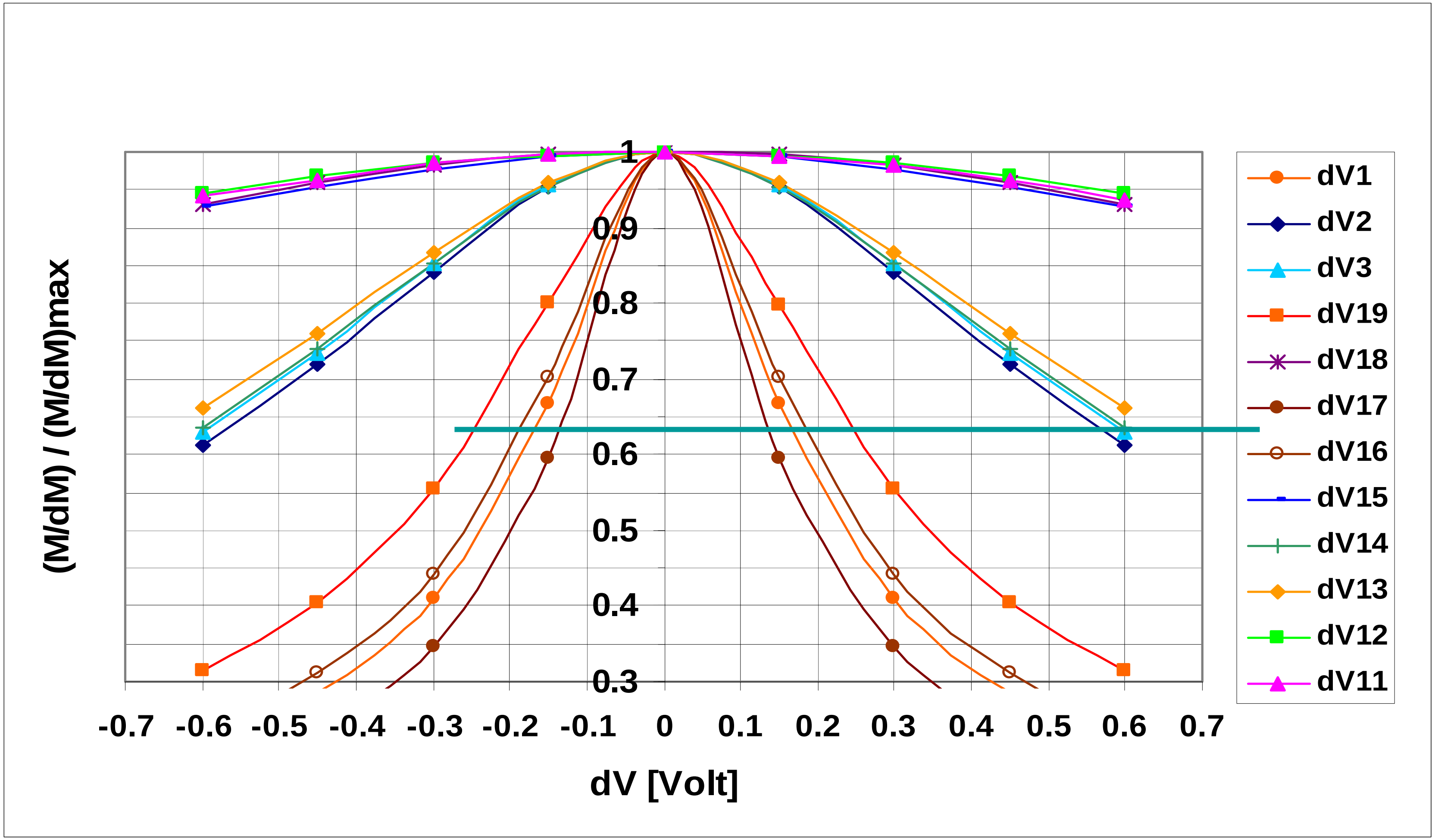
The 2nd mirror is 1.0 mm shifted

Calculated requirements on stability of power supplies

At K_0 = 1500 Volt and (M/dM) ≈ 100,000 :

dV < 60 mV, if there is only one unstable power supply

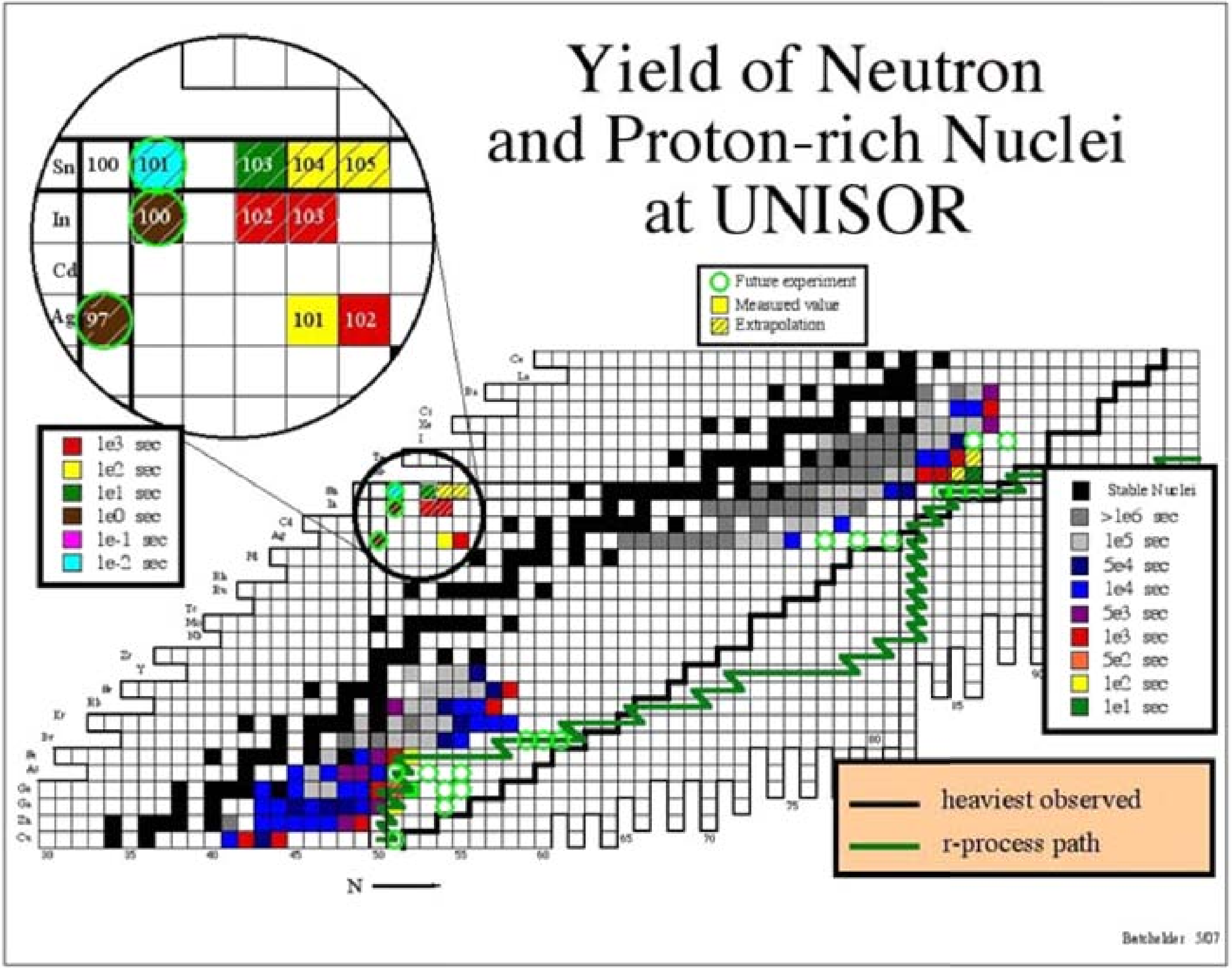
dV < 30 mV, if all the power supplies are unstable ⟹ **Loss of (M/dM) is less than 10%**



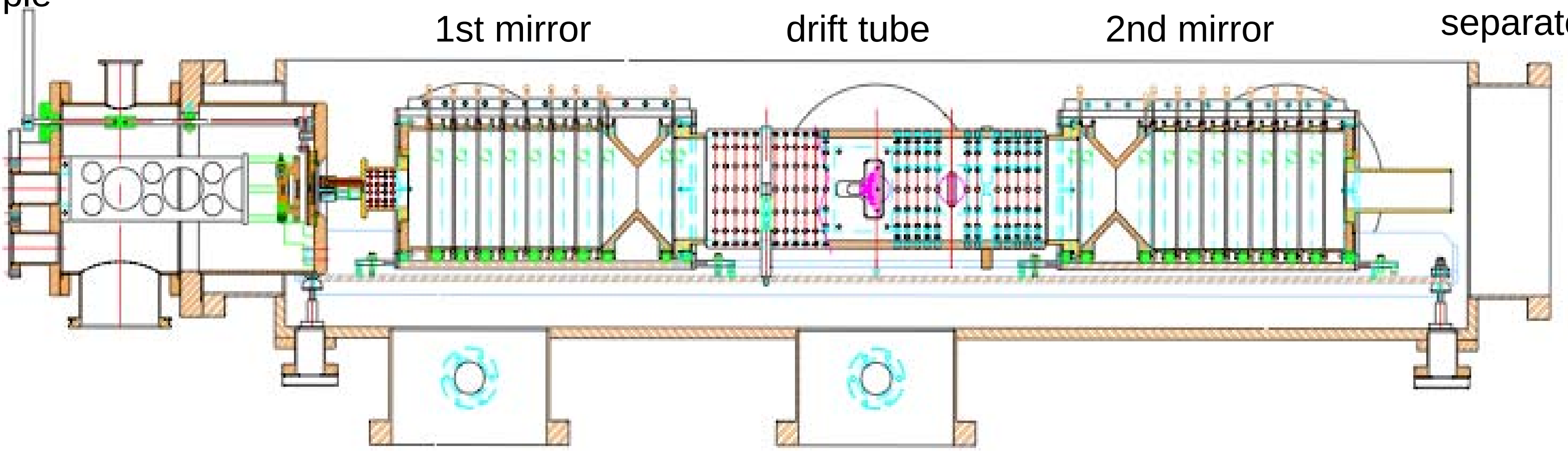
Decay Studies Near ^{100}Sn at UNISOR facility using fusion-evaporation reactions

- **Beta Decay Near ^{100}Sn**
  - **The Physics:**
    - **Separation between the $pg_{9/2}$ and $pp_{1/2}$ single particle/hole states**
    - **Low-energy structure for comparison to the shell model**
    - **N>50, Z<50 particle-hole configurations**
  - **Experiments:**
    - **Isomers in the Light Ag Isotopes: Search for M4 isomer in ^{97}Ag**
    - **Isomers in ^{101}In: Search for M4 isomer**
    - **Beta Decay of ^{101}Sn: Decay scheme**
    - **Later: Beta Decay of ^{100}Sn**

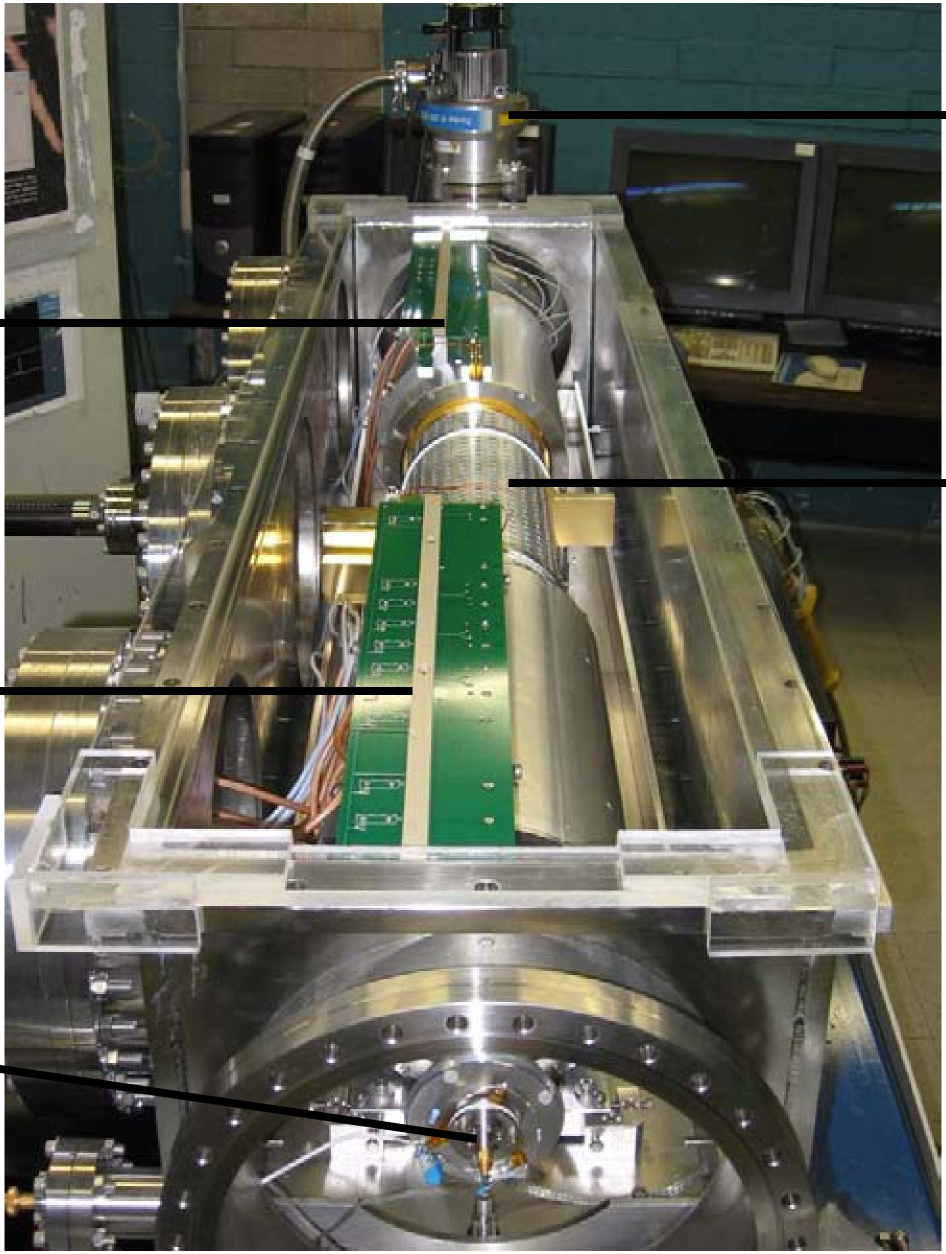
Decay Studies of neutron rich nuclei at UNISOR facility using p-induced fission of Uranium

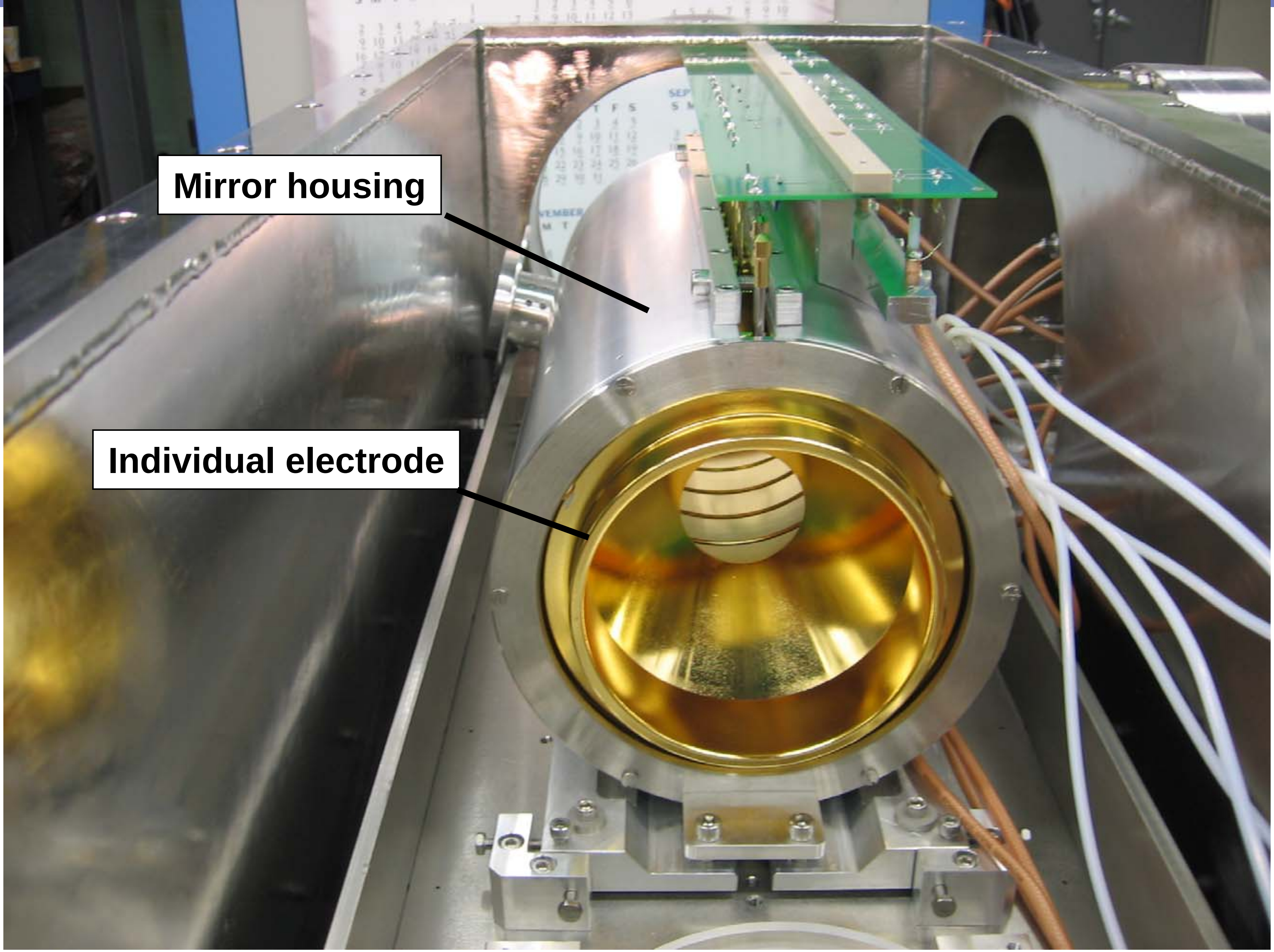


MTOF - Design and operation



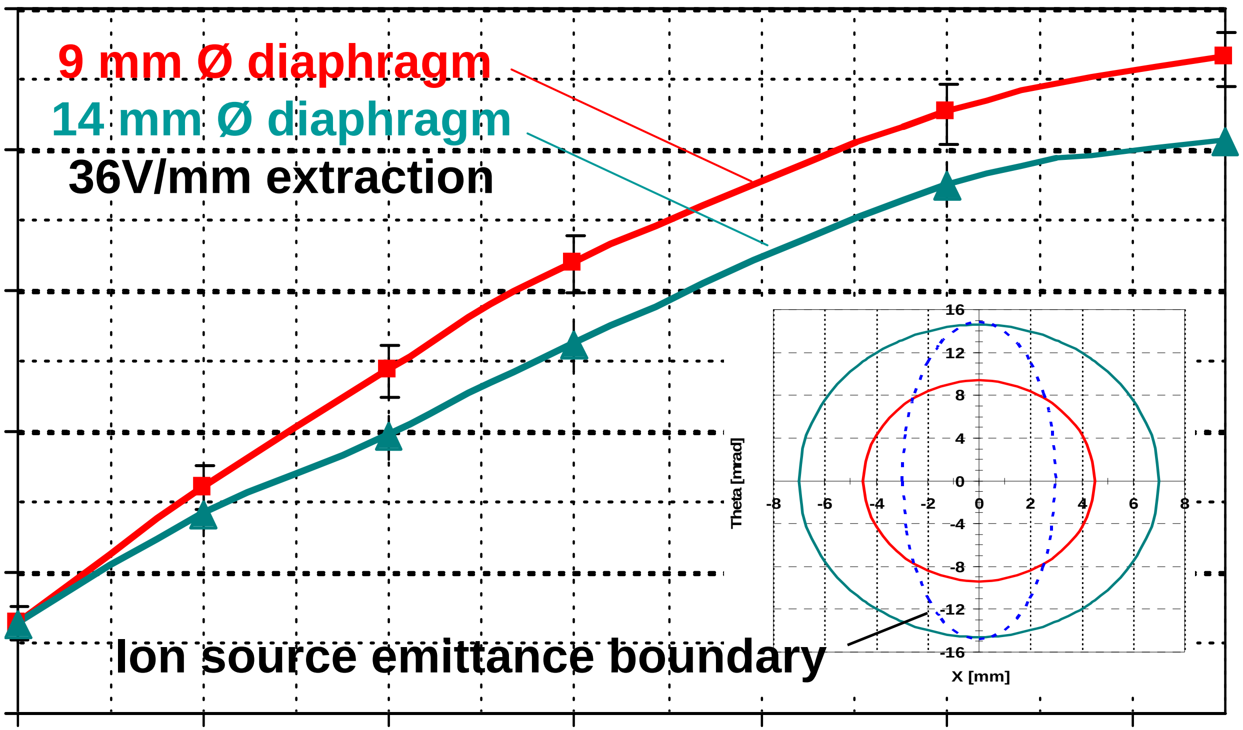
Electron impact ion source for stable gaseous elements presently being used
Number of ions per pulse: ~ 1
11 electrostatic electrodes, independently controlled by stacked-15 bit DACs
DEI-4150 solid state pulsers to open and close mirror electrodes
Electrode voltages 0 - 2 kV, ISEG DPR series power supplies
"Long" and "short" mirror
Repetition rates 100 - 1000 Hz, depending on mass and desired resolution
ToF: 1 - 10 ms, depending on mass and desired resolution
ToF peak width (after 120 laps): 30 ns (FWHM)
Peak broadening: 0.5 ns/lap
Pressure in MTOF chamber: 1*10^{-7} Torr
Best resolution is achieved by adjusting the calculated voltage settings of 1-2 electrodes by < 0.5 V


Turbo pump of
Ion source chamber
Entrance mirror with
filter board
Drift tube
Exit mirror with
filter board
MCP


Mirror housing
Individual electrode

Electron impact ion source

Experimental mass resolving power (FWHM)



M/dM (FWHM) of 113,000 was achieved

Tune value Q = 0.75

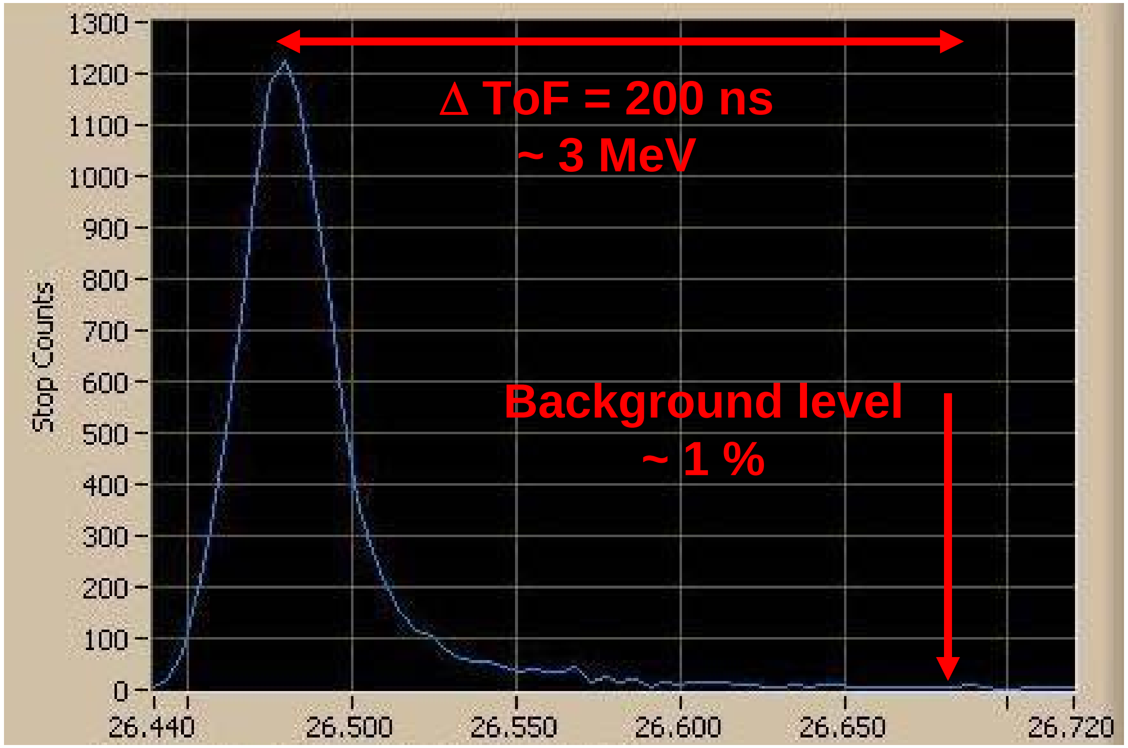
Beam diameter in center of MTOF $\leq$ 9 mm

$\rightarrow$ Isochronous acceptance = 42 π mm mrad for M/dM ~ 100,000

Transmission of N_2 ~ 50% for 300 laps

Losses caused by collision with residual gas atoms @ 1×10^{-7} Torr

ToF peak for N_2 molecules after 3.901 ms, M/dM = 64,000



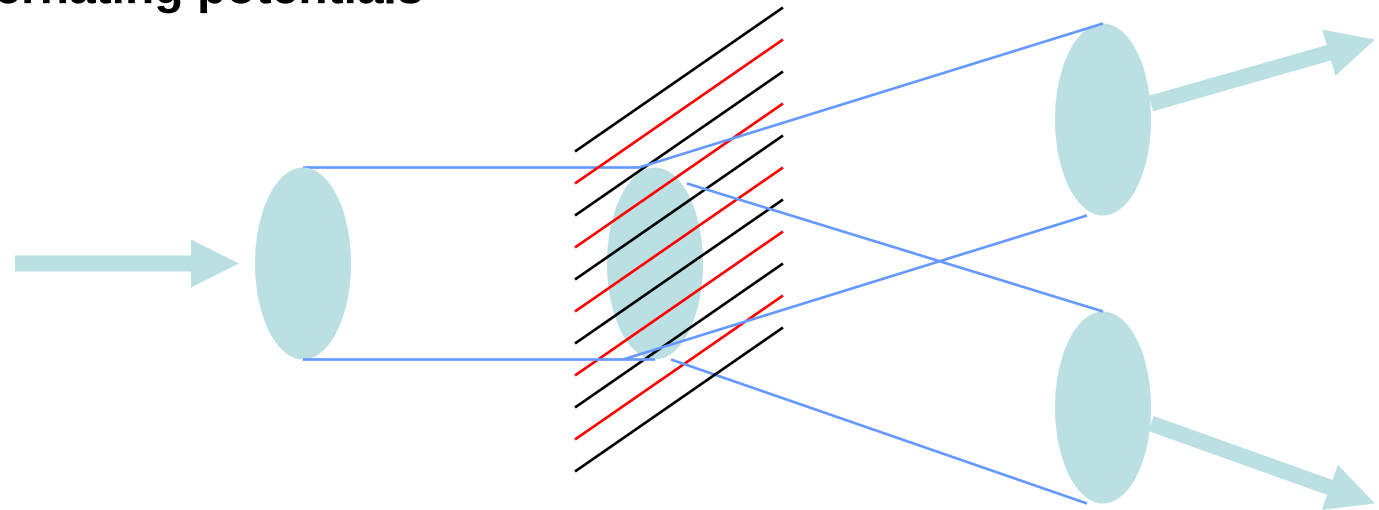
Expected isobar suppression > 100

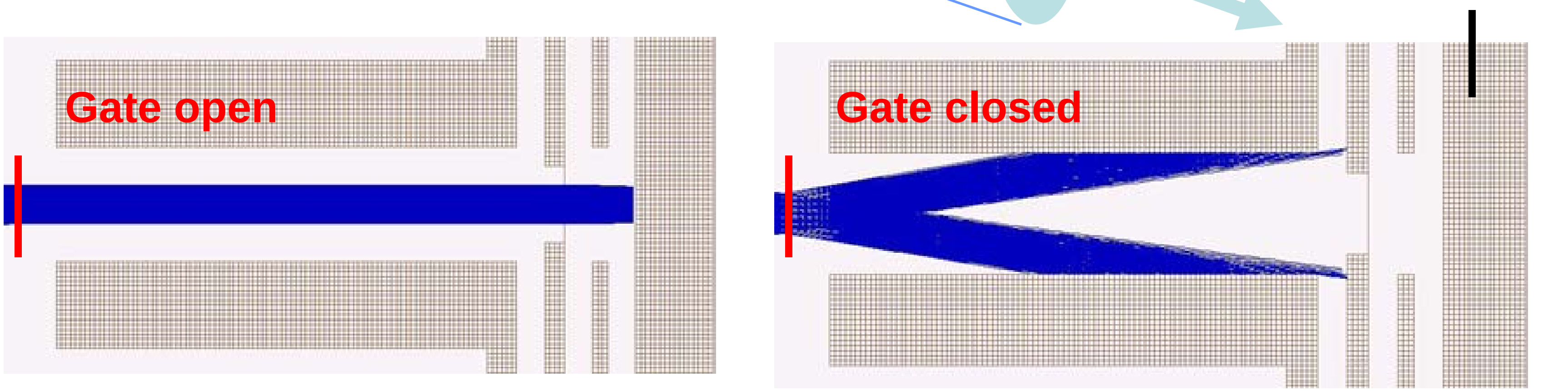
Background likely caused by properties of test ion source

Background will be further reduced when cooler and buncher For RIB injection are used!

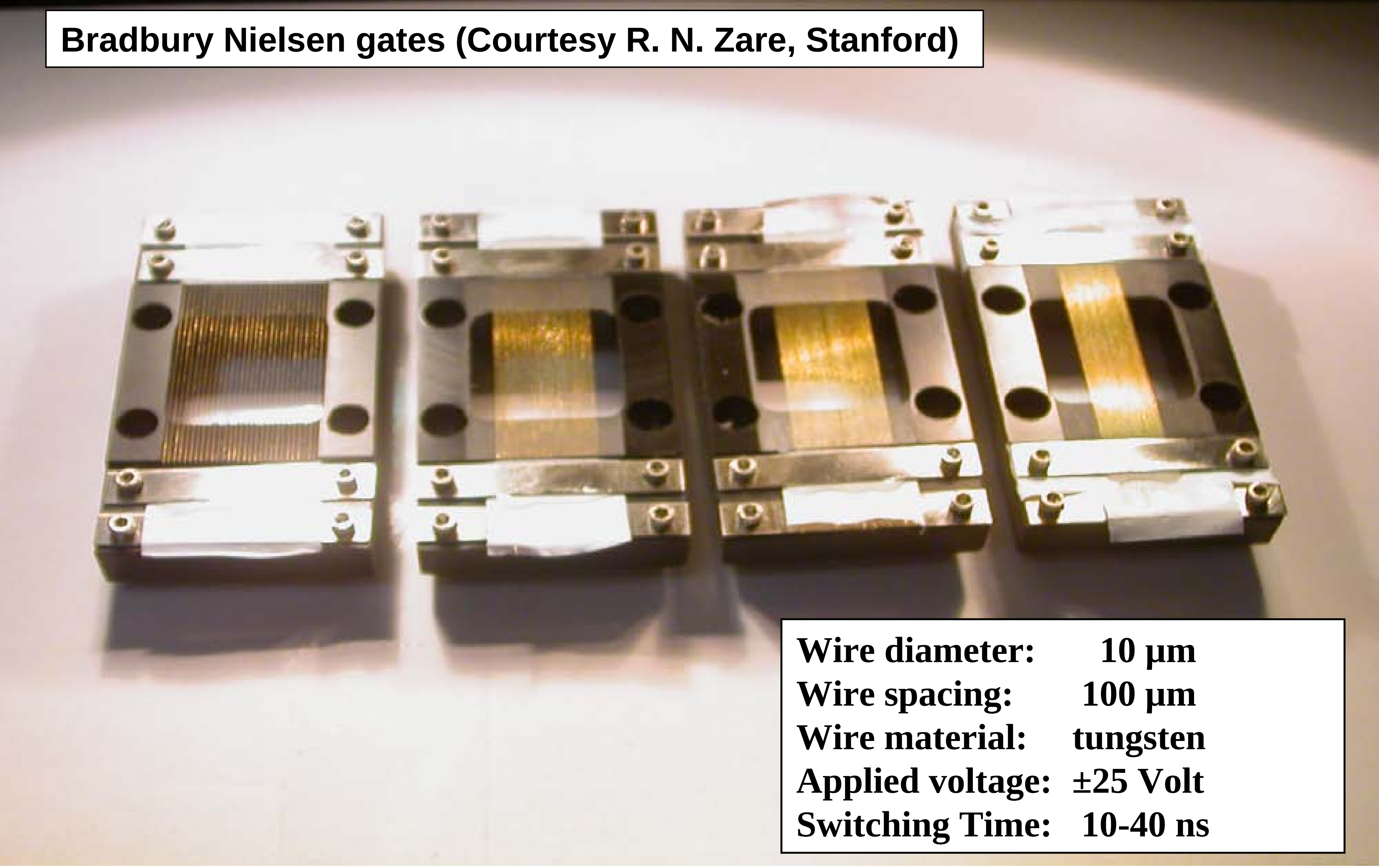
Separator: Bradbury-Nielson gate

Widely used in analytical chemistry with ToF devices
Set of parallel wires perpendicular to beam on identical or alternating potentials





Bradbury Nielsen gates (Courtesy R. N. Zare, Stanford)



Wire diameter: 10 μm
Wire spacing: 100 μm
Wire material: tungsten
Applied voltage: ±25 Volt
Switching Time: 10-40 ns

RIB Injection into MTOF at UNISOR: concept

40kV Platform

Ion Source (exists)

Pre-separating Magnetic Sector with M/ΔM≈800-1000 (exists)

M/ΔM > N_{laps}

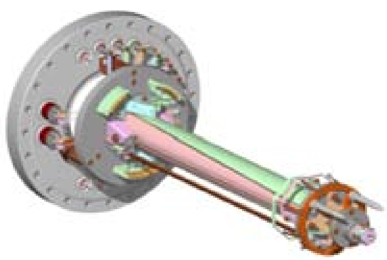
40 kV Platform, to be built

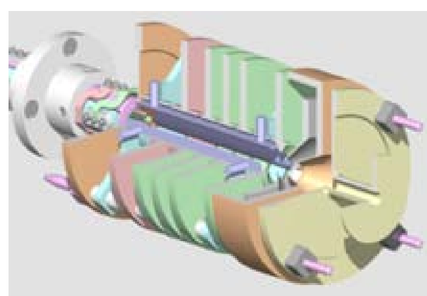
Cooling RFQ (to be built)

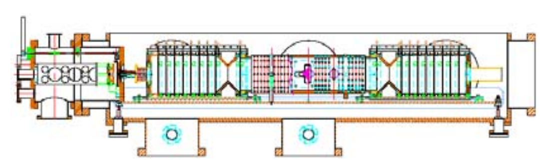
Bunching RFQ (to be built)

MTOF and Separator (BNG)

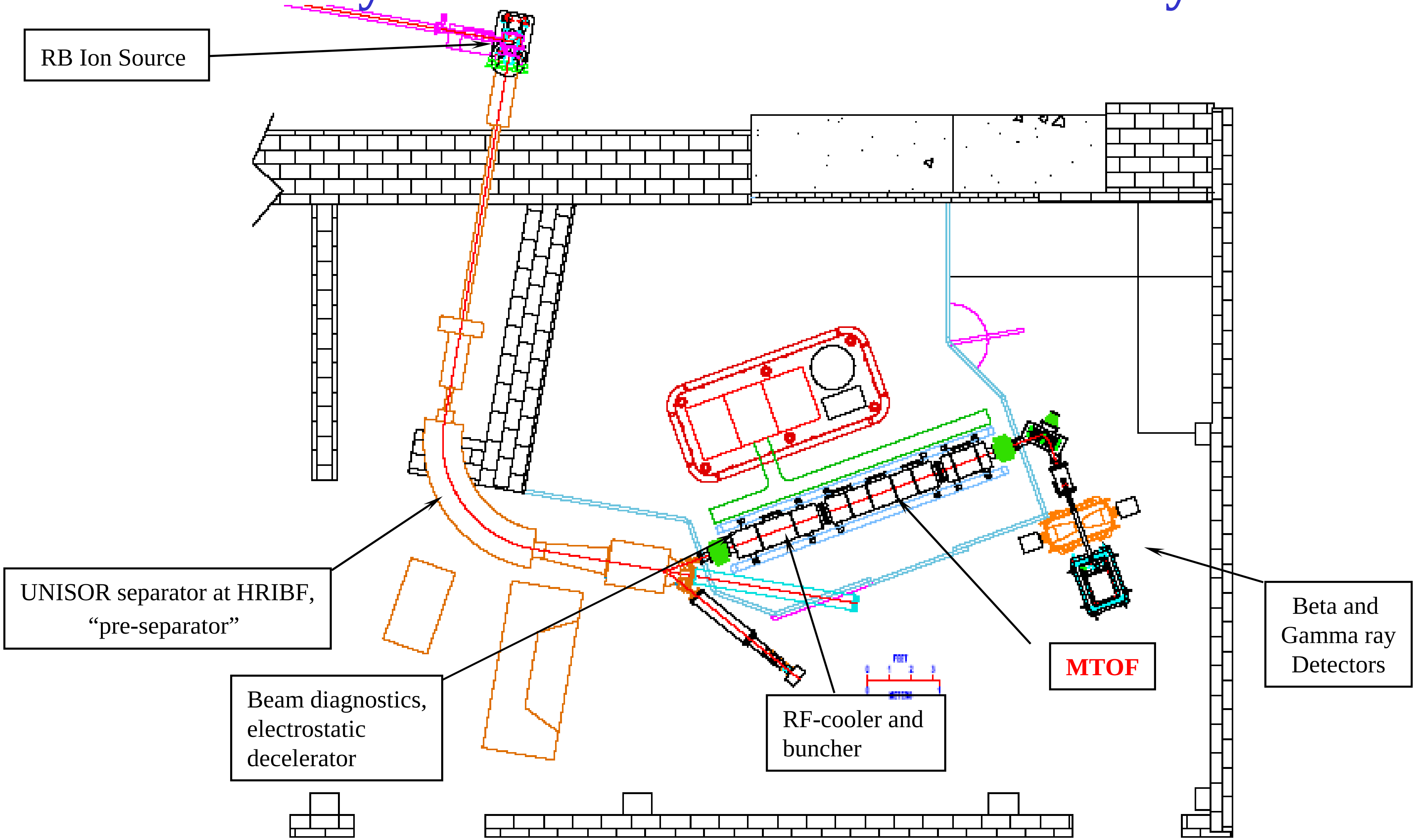
To Spectroscopy Station







Layout of MTOF at UNISOR facility



Next steps….

- Demonstrate Bradurry-Nielsen gate separator with m/Δm > 15,000
- Build RIB beam injection at UNISOR
- Do first spectroscopy experiments end of 2008

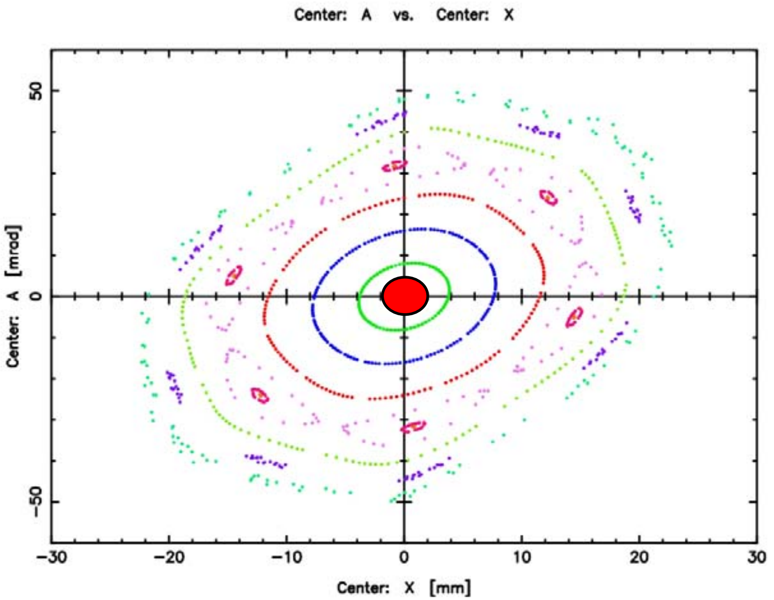
Outside Review of MTOF – Separator
July 2006

- Reviewers
  - Ernst Roeckl, GSI
  - Georg Bollen, NSCL / MSU
  - Ari Jokinen, Univ. of Jyvaskyla, Finland
- Conclusions-
  - "No doubt this will work… it is new project with risks but very impressed with approach"
  - "On the estimated through-put of 30 – 50%... There are plenty of examples of coolers and bunchers with >60% so should not be a problem"
  - "Impressed with work of [group] ..I don't see any way you can keep them from completing the job….you should try and go for it"

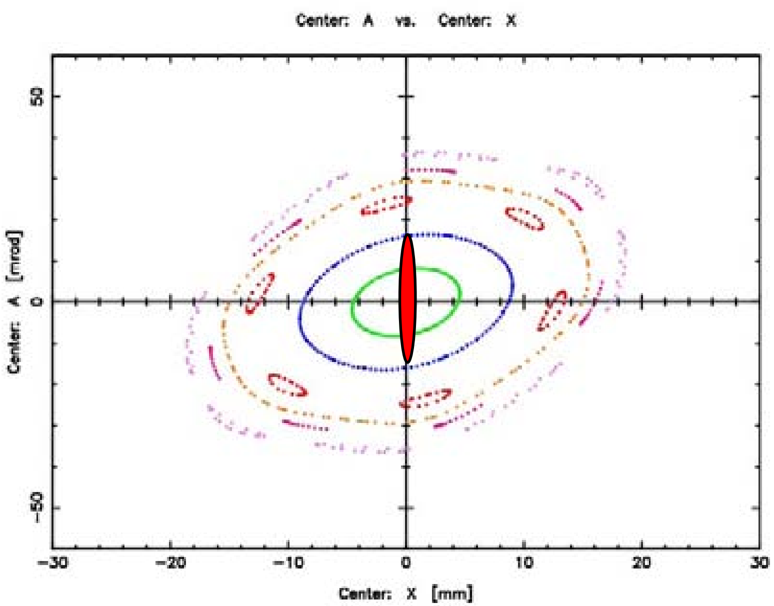
Motion in the transverse phase space X-A, Y=B=0, N=80, middle of the drift tube

1) Motion is unstable for |X|>24 mm (|A|>50 mrad)
2) Motion is strongly non-linear at 10 mm<|X|<24 mm
3) Motion is isochronous with high precision within |X|<5 mm and |A|<10 mrad (ε≈50π mm*mrad, green ellipse)
4) Motion is isochronous with very high precision at ε < 15 π mm*mrad

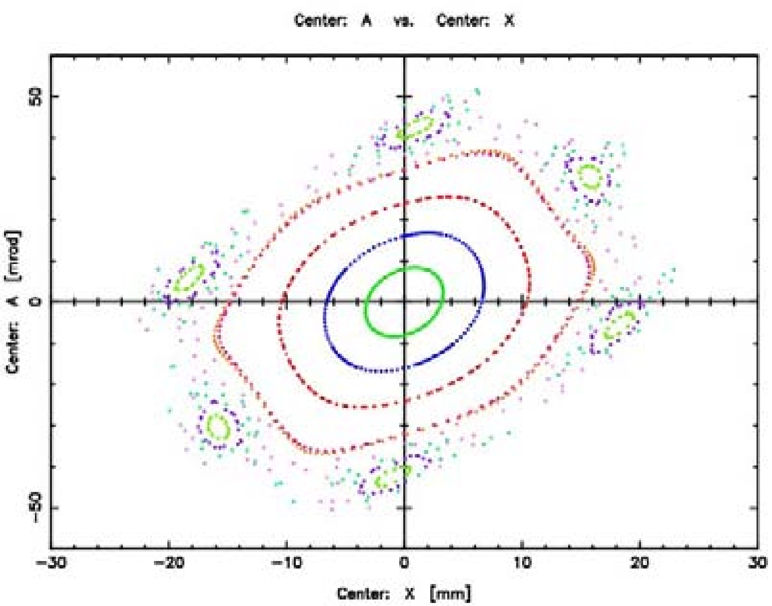
$K=K_0=1090$ V



K=1055V (-3.2%)

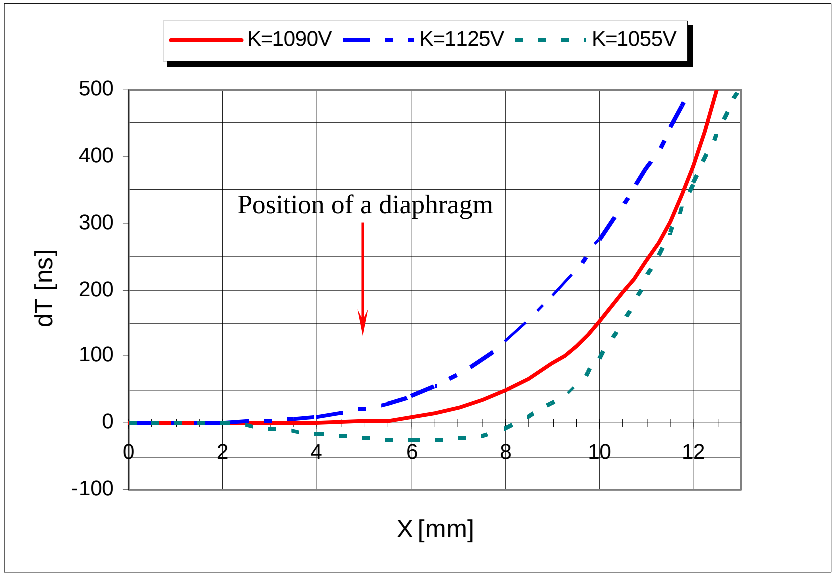


K=1125V (+3.2%)



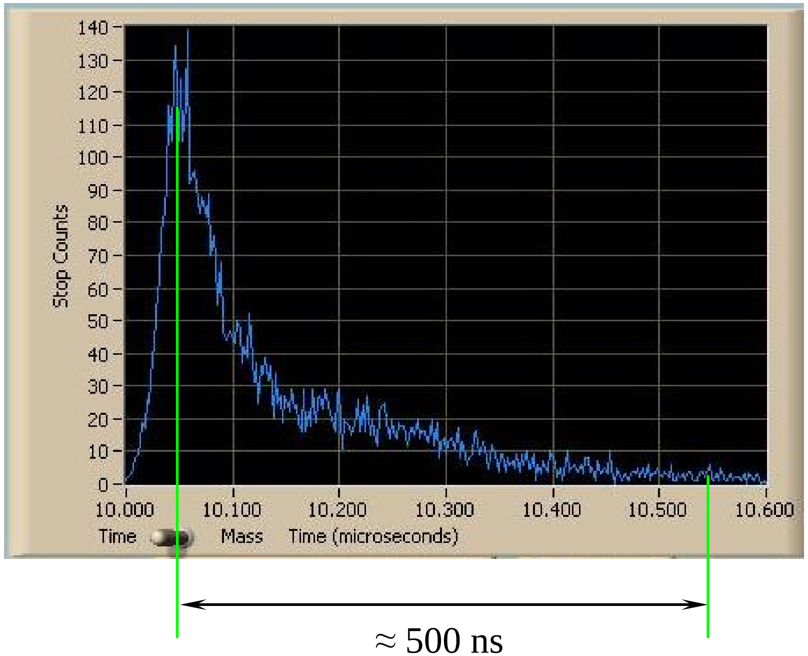
dT versus X, Tails in ToF spectra

Calculated dependence of dT versus X, (Y=B=0)



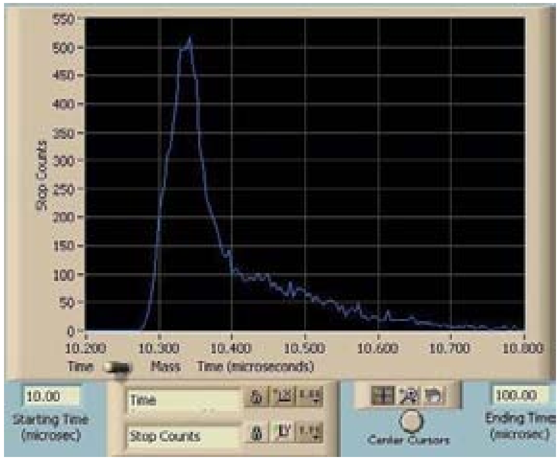
Placing a diaphragm of 8-12 mm in diameter in the middle of the drift tube may eliminate such tails.

Typical ToF spectrum, N=80

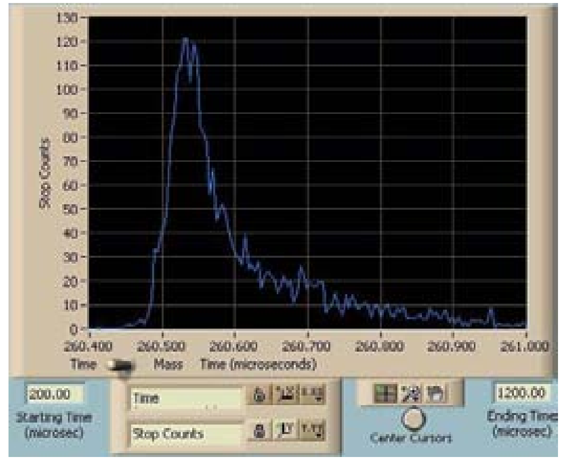


Tails are independent on the number of laps N (N<160) => caused by ToF optical aberrations.

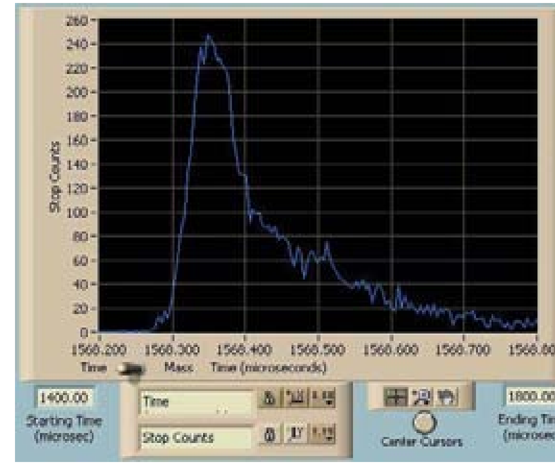
N_{laps}=40, E=36 V/mm



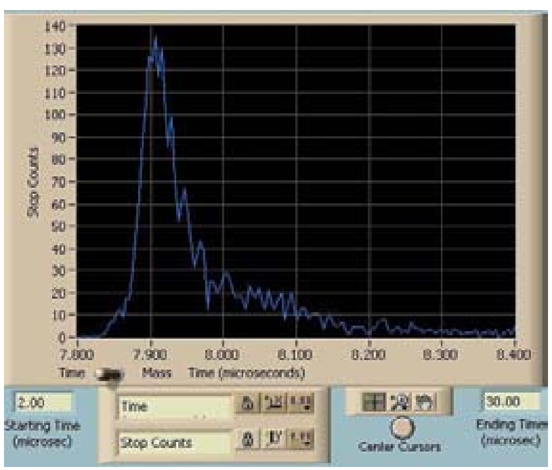
N_{laps}=80, E=36 V/mm



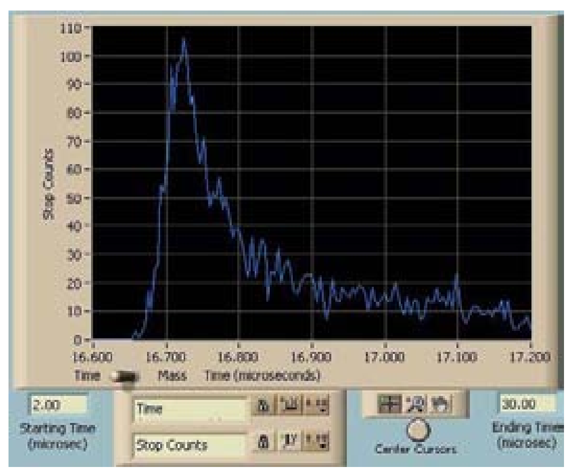
N_{laps}=120, E=36 V/mm



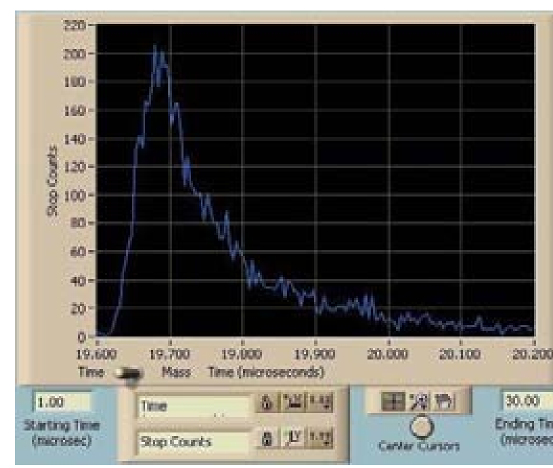
N_{laps}=40, E=60 V/mm



N_{laps}=80, E=60 V/mm



N_{laps}=160, E=24 V/mm



Energy-ToF Correlations

$dZ_{source} < (dK/E) = 1.8$ mm at E=36V/mm