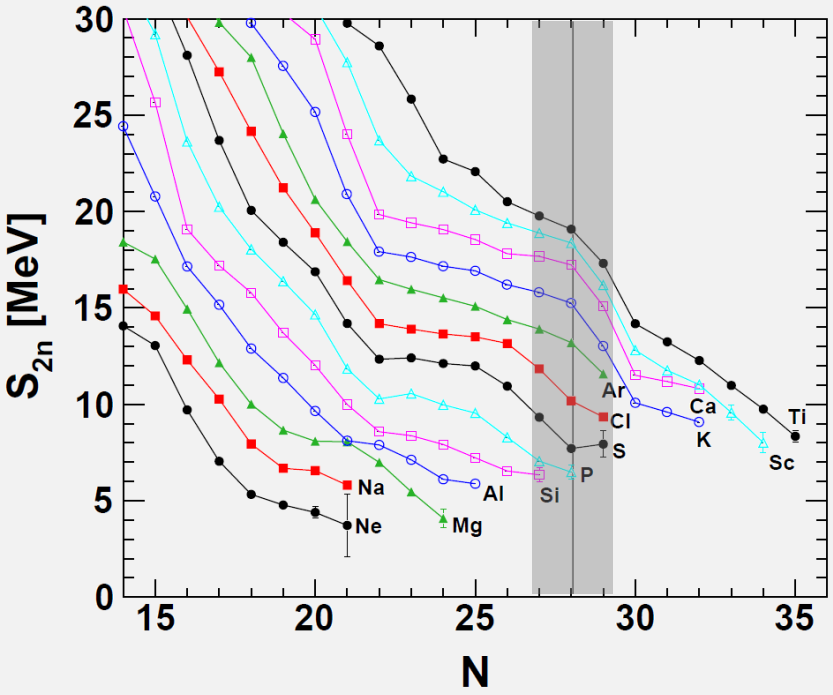
Recent Results in Time-of-Flight Mass Measurement

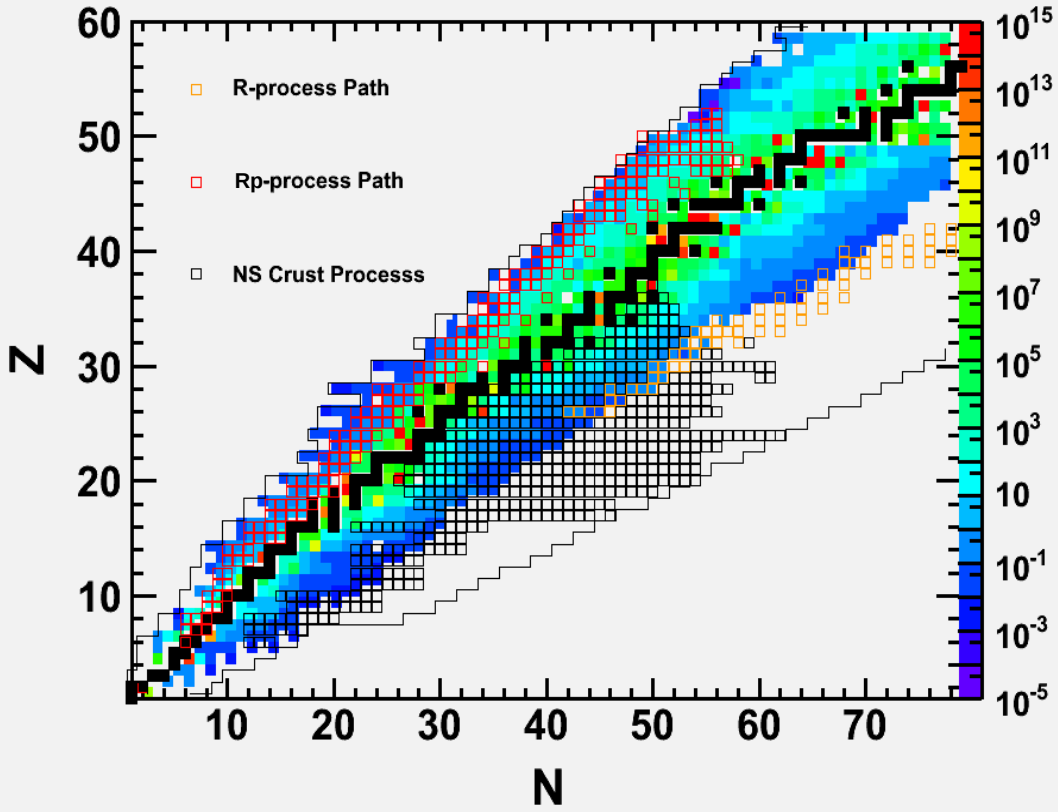
Zach Meisel
Physikzentrum Bad Honnef
25 April 2013

Motivation

Nuclear Structure



Astrophysics

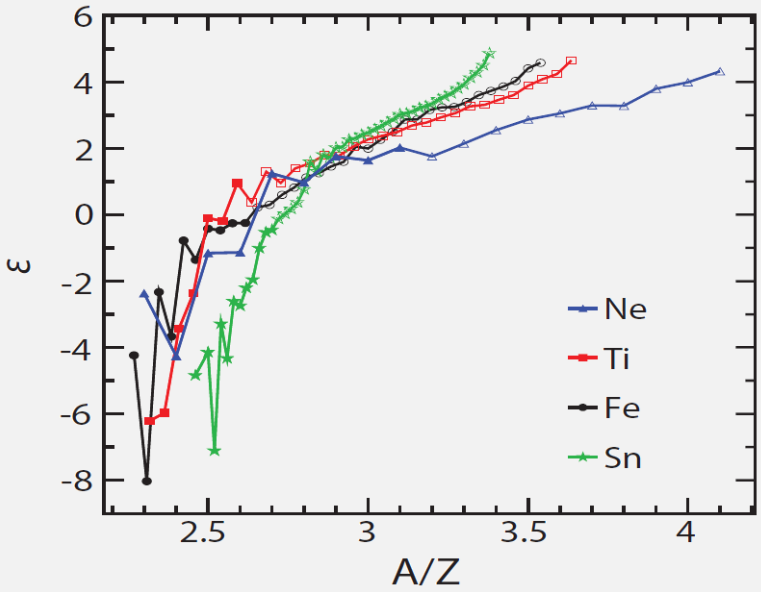


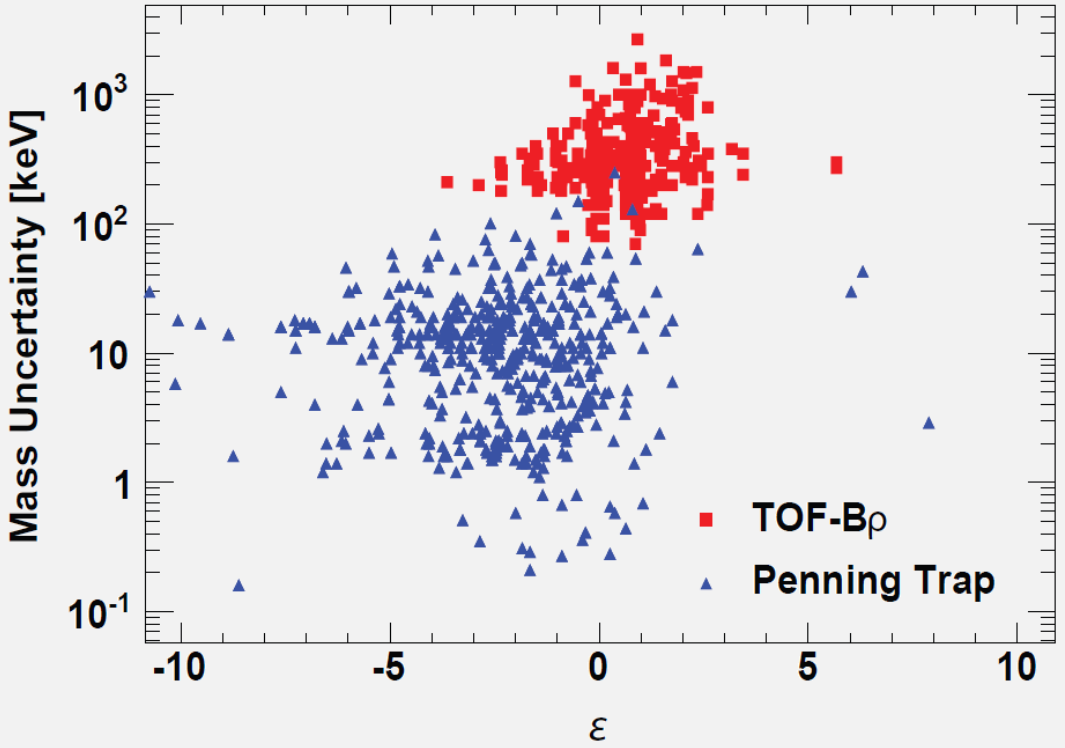
$\delta m \lesssim 500$keV for nuclei with $t_{1/2} \approx 10$ms

Relative Experimental Reach

Define *Exoticity*, ε,

$$\epsilon = log_{10}\left|\frac{dN_{stab}}{T_\beta * (dN_{drip}+1)}\right|$$





$T_\beta = t_{1/2}$ from Möller, Pfeiffer, & Kratz PRC 67, 055802 (2003) (… though in ADNDT 1997)

TOF-Bρ Method

Obtain mass via equation of motion of massive charged particle through a magnetic system:

$$F_{Lorentz} = F_{centrifugal}$$

$$\rightarrow qvBsin(\theta) = \frac{mv^2}{\rho}$$

$$m = \gamma m_0$$

$$v = \frac{L_{path}}{TOF}$$

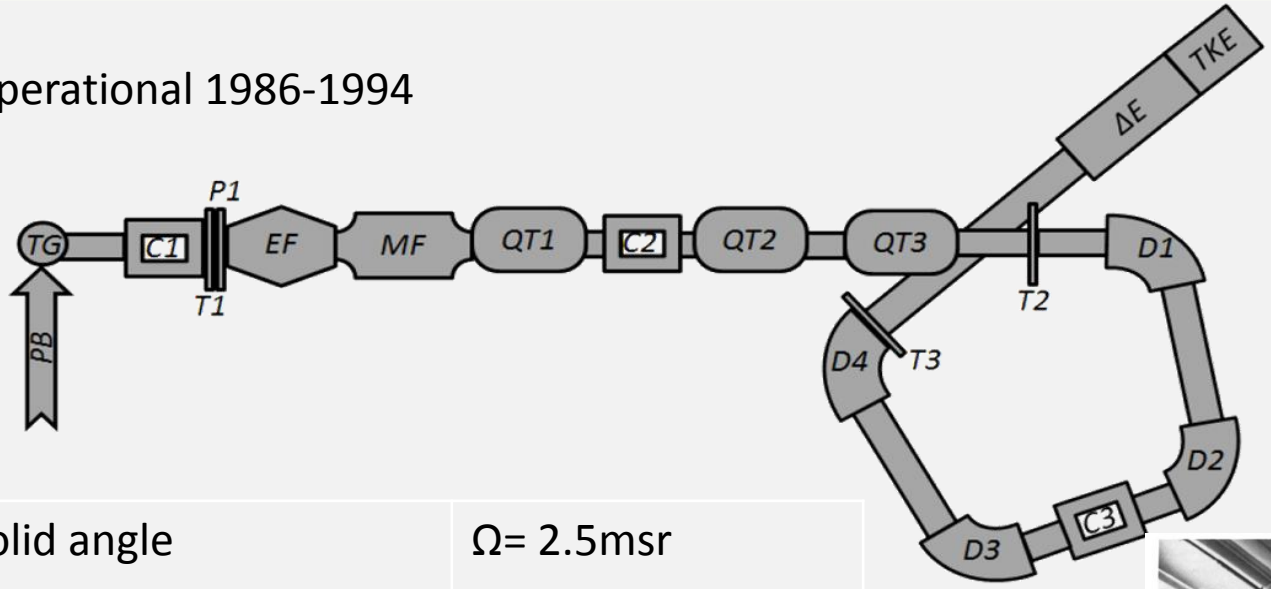
$$\Rightarrow m_0 = \frac{TOF}{L_{path}} \frac{q(B\rho)}{\gamma}$$

High precision **measurement of rigidity (Bρ) and time-of-flight (TOF) directly corresponds to a high precision mass measurement**.

…in practice measure mass of known nuclei in order to calibrate **relationship between mass and time of flight**.

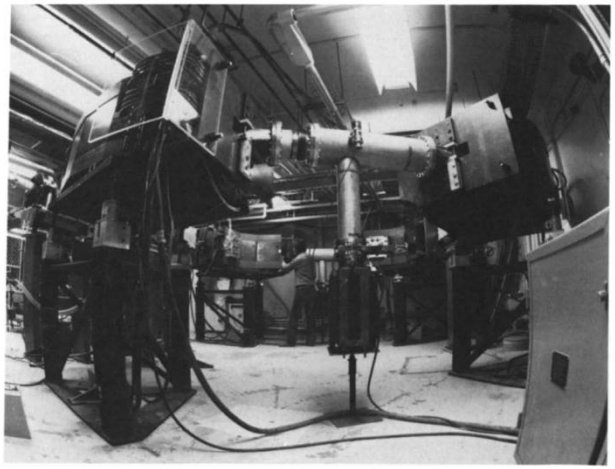
TOF Mass Measurement: *TOFI at LANL*

Operational 1986-1994



~90 new or improved masses

Solid angle	Ω= 2.5msr
Momentum-acceptance	$\delta p/p \approx 4\%$
Max Rigidity	$B\rho \approx 0.9Tm$
Central flight Path	$L_0 = 14.0m$
Achieved Mass Resolution	$M/\Delta M \approx 2600$



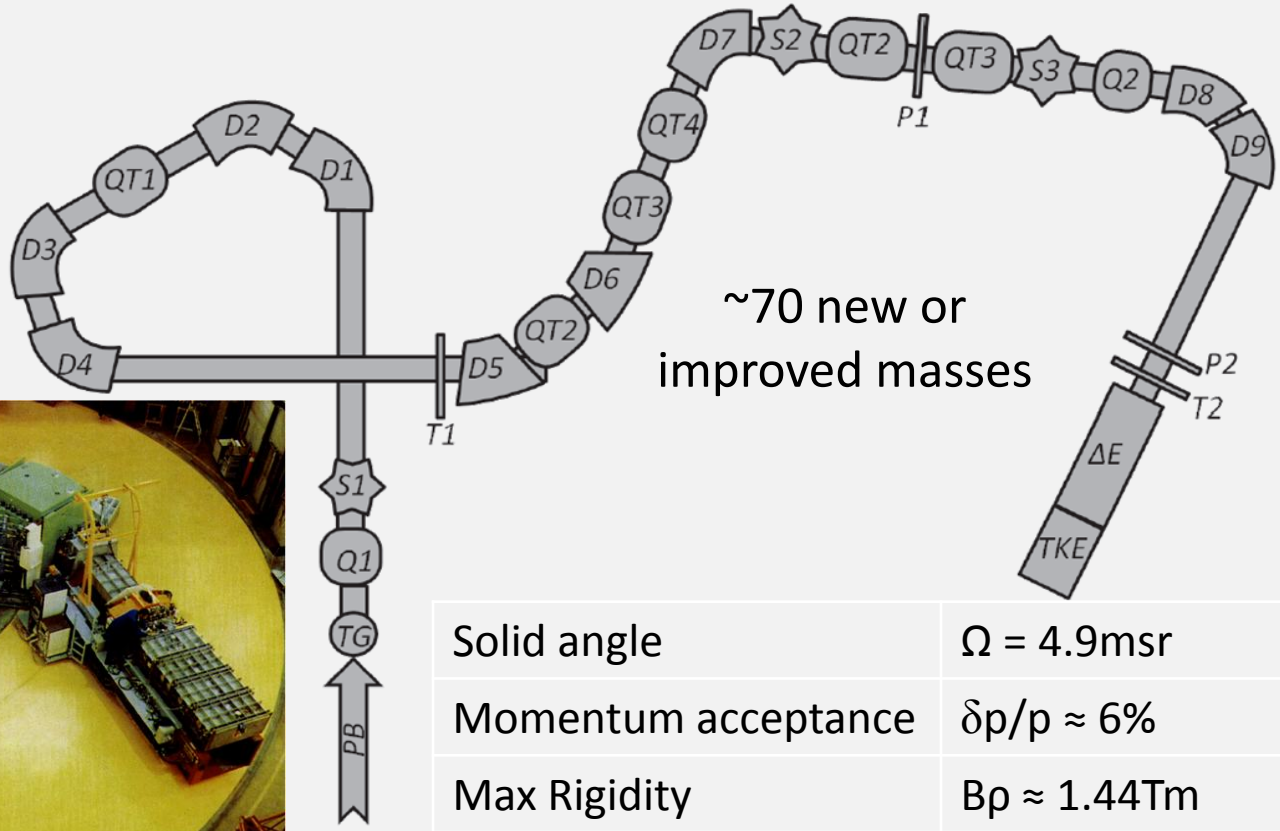
J. Wouters et al. NIMA 240, 77 (1986)

TOF Mass Measurement: *SPEG at GANIL*

Operational 1986-2012

Pioneered rigidity correction
*→TOF-**Bρ***

L. Bianchi et al. NIMA 276, 509 (1989)

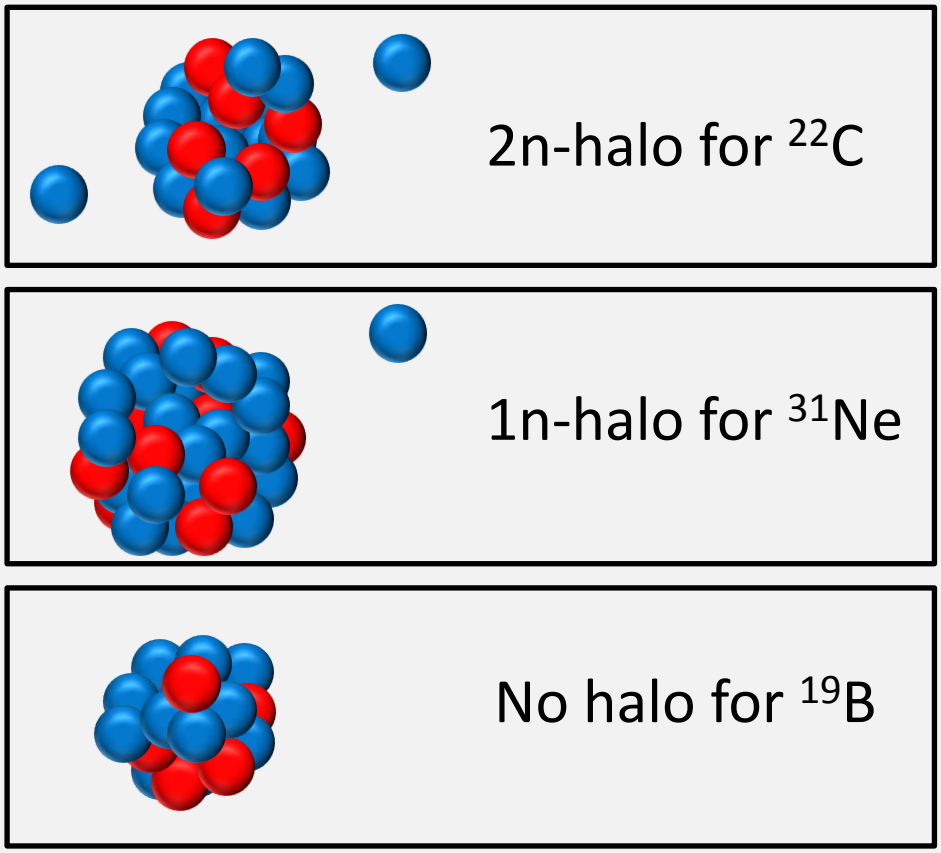


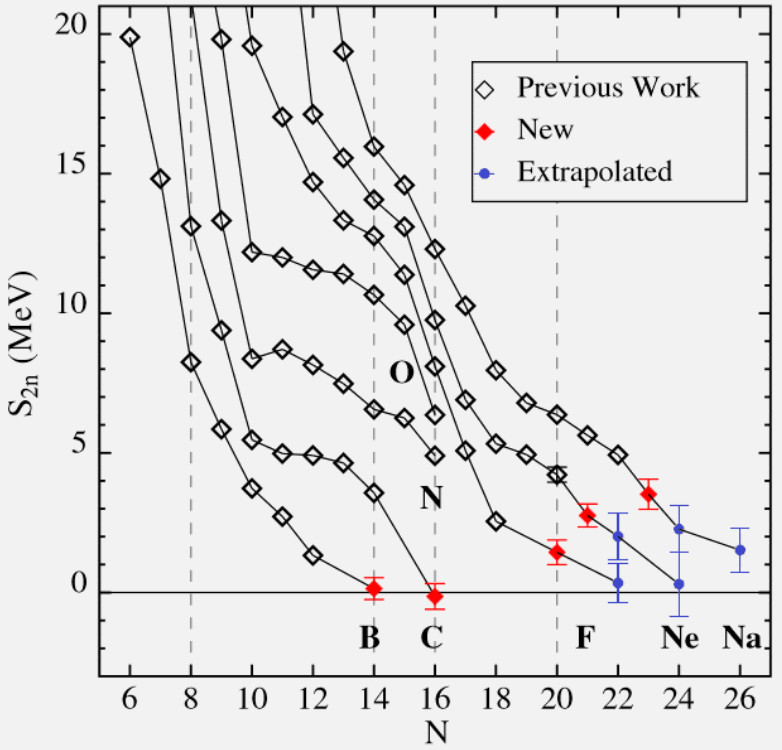
~70 new or improved masses

Solid angle	Ω = 4.9msr
Momentum acceptance	δp/p ≈ 6%
Max Rigidity	Bρ ≈ 1.44Tm
Central flight Path	L_0 = 116m
Achieved Mass Resolution	M/ΔM ≈ 4000

Recent Results: *SPEG*

First mass measurement for : ^{34}Na & Borromean Nuclei ^{19}B, ^{22}C, ^{29}F

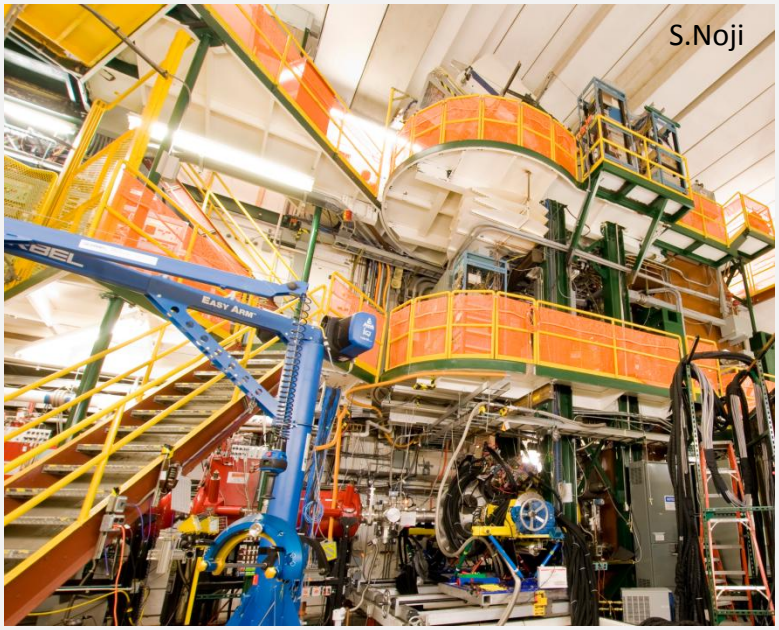




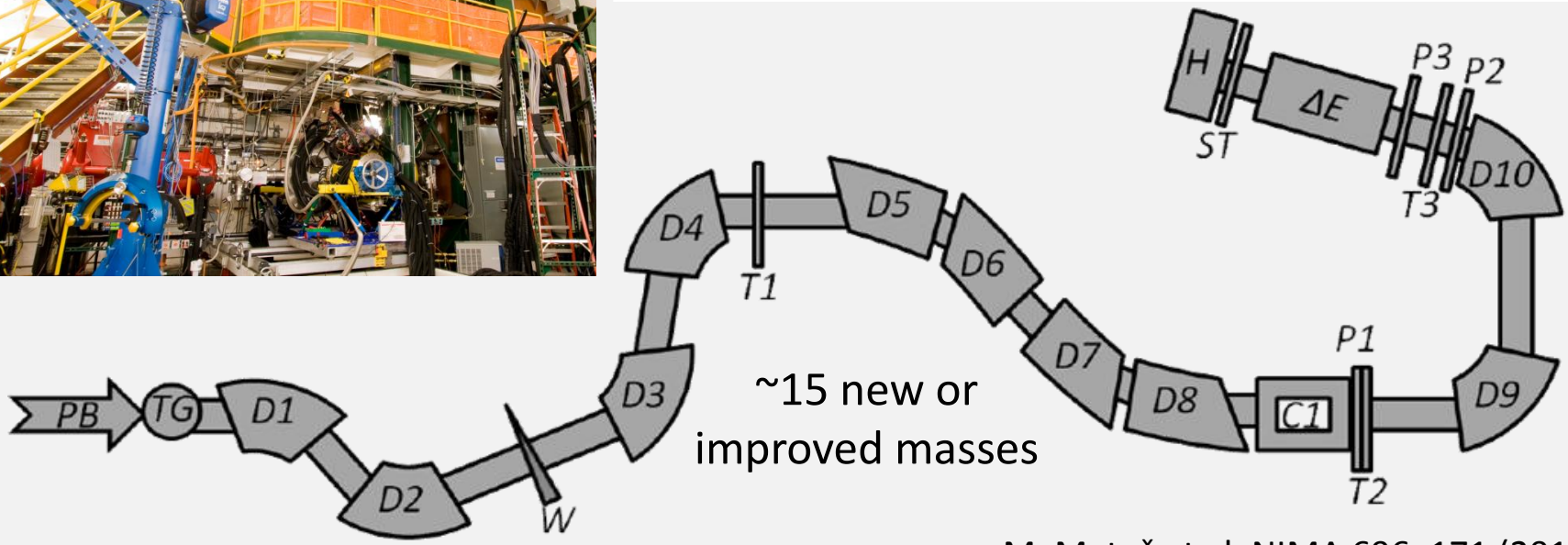
L. Gaudefroy et al. PRL 109, 202503 (2012)

TOF Mass Measurement: *S800 at NSCL*

Operational 2006-Present



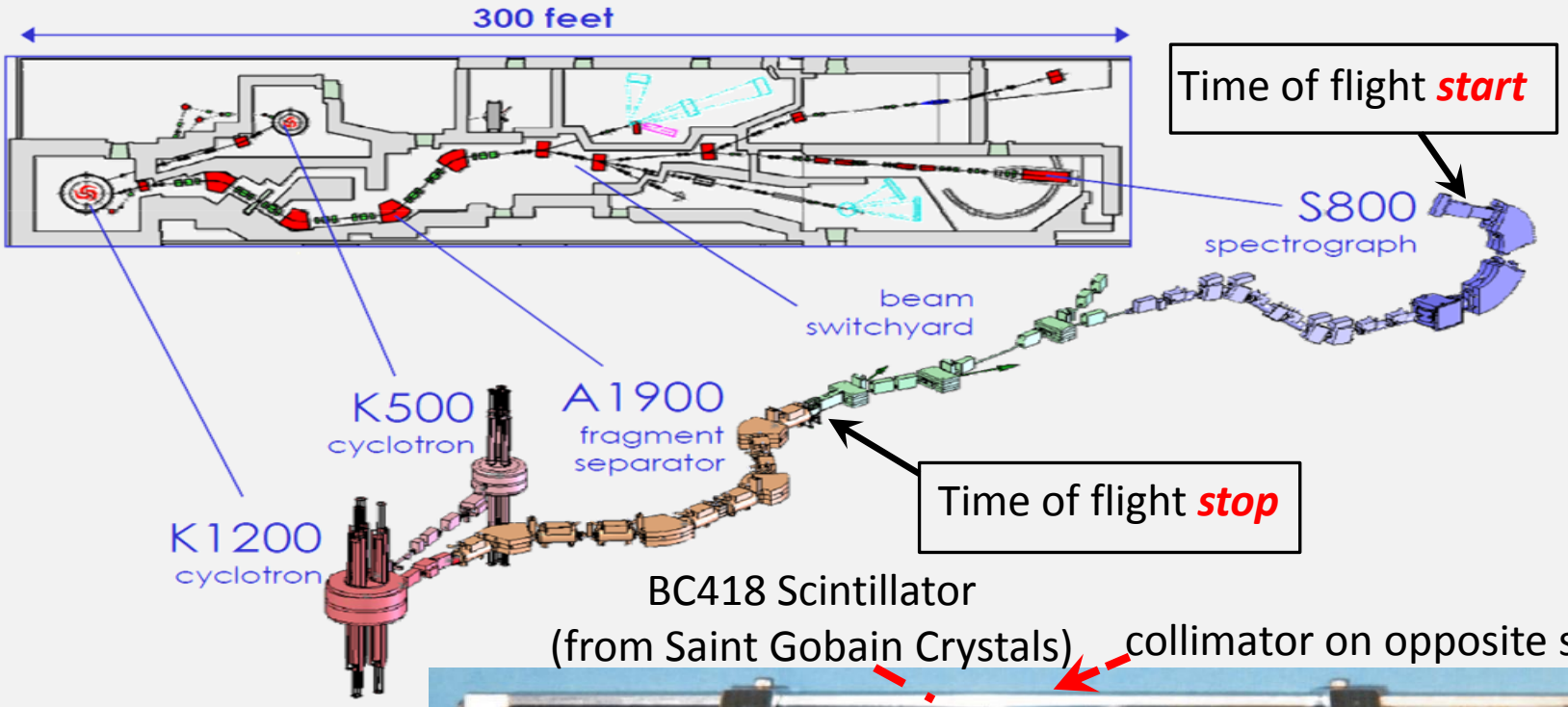
Solid angle	Ω = 20msr
Momentum acceptance	δp/p ≈ 1 % (due to MCP)
Max Rigidity	Bρ ≈ 4Tm
Central flight Path	L_0 = 59m
Achieved Mass Resolution	M/ΔM ≈ 5500



~15 new or improved masses

M. Matoš et al. NIMA 696, 171 (2012)

TOF-detection @ NSCL



BC418 Scintillator
(from Saint Gobain Crystals)

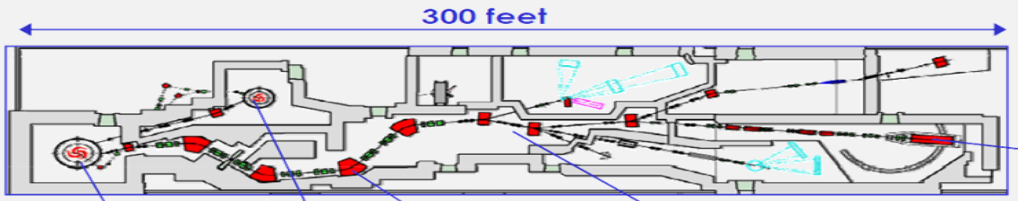
collimator on opposite side

R4998 Photomultiplier tubes (PMTs) (from Hamamatsu)

$\sigma_{timing} \approx 30ps$

*developed by Alfredo Estrade & Milan Matos

Bρ-detection @ NSCL



*S.George, Z.Meisel, D.Shapira

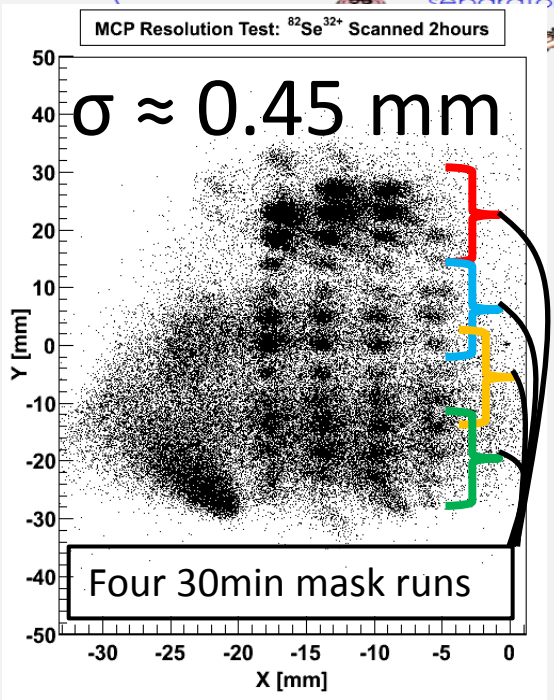
S800 spectrograph

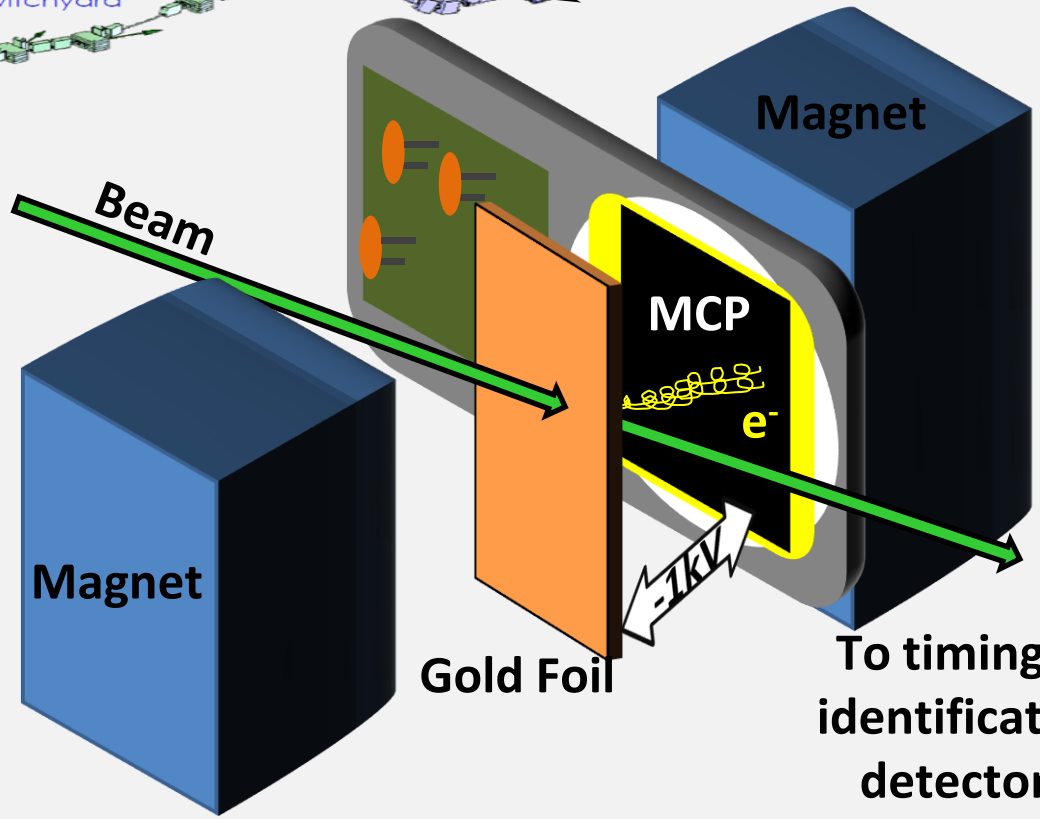
Bρ-measurement

beam switchyard

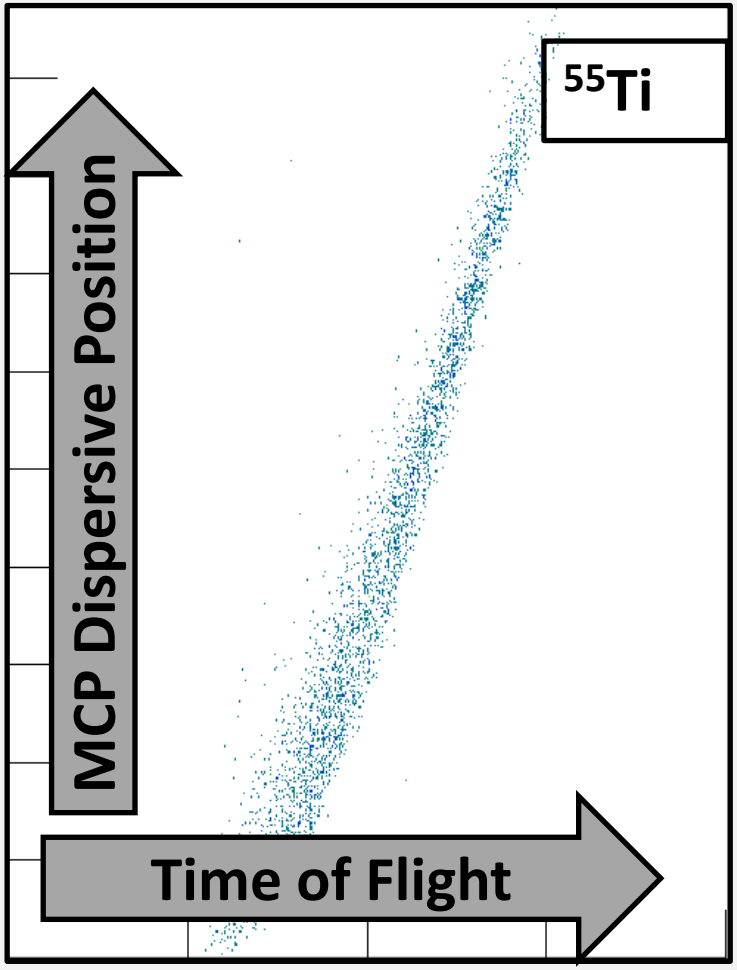
K500 cyclotron

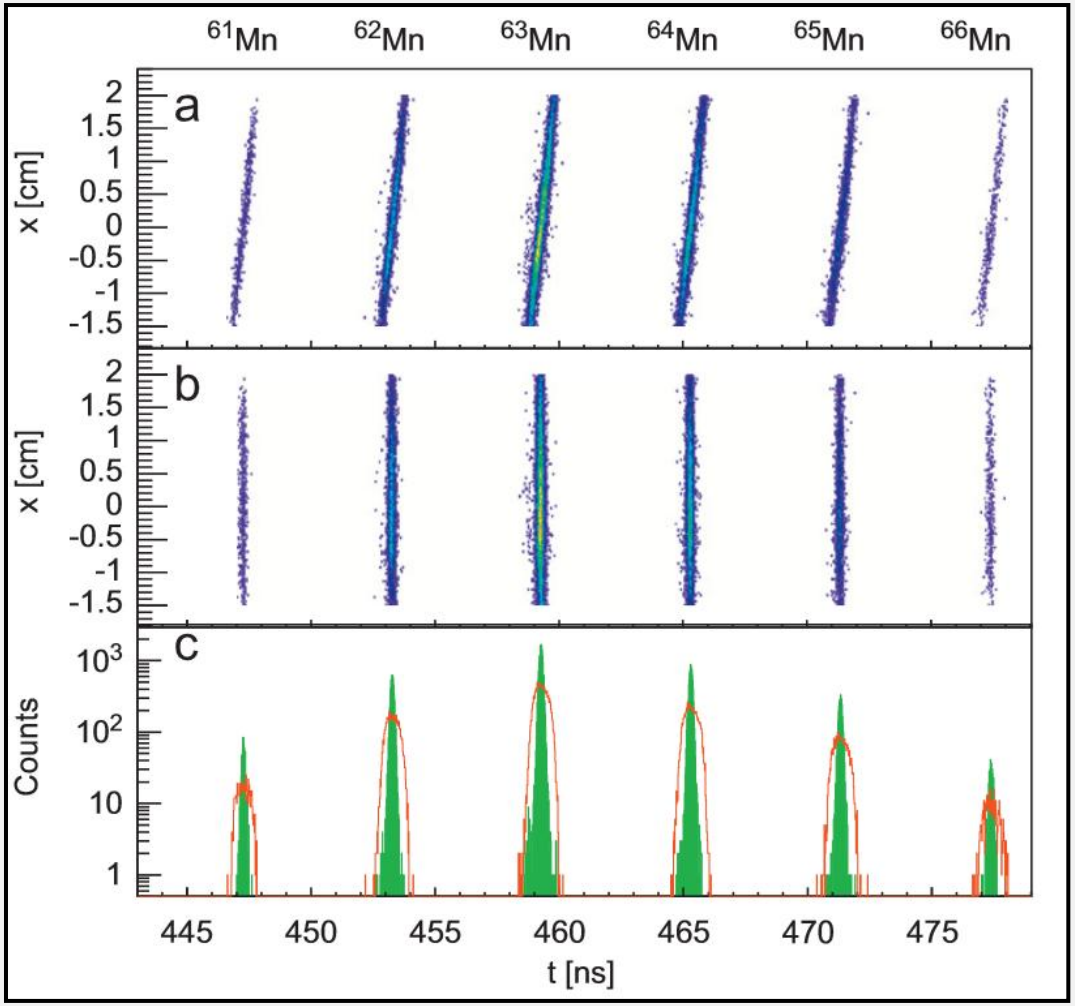
A1900 fragment separator





Rigidity Correction





M. Matoš et al. NIMA 696, 171 (2012)

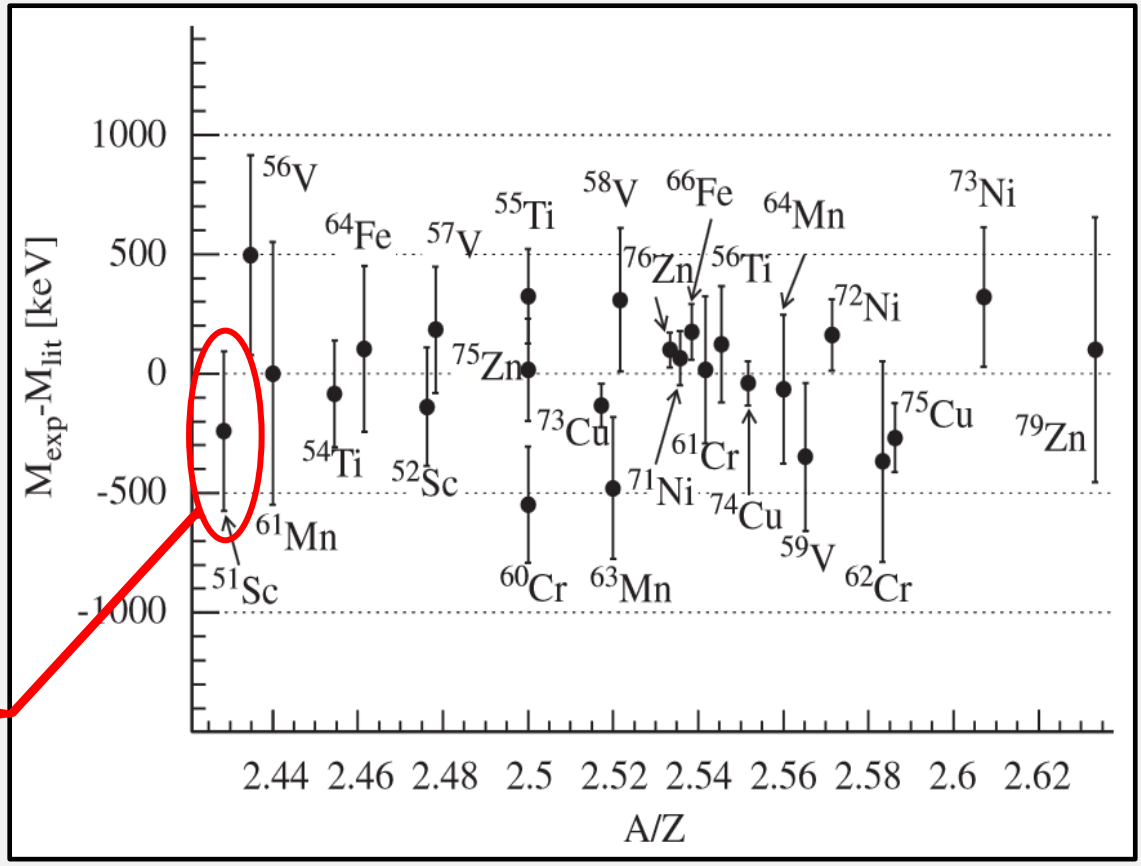
Fit to Calibration Masses

$$m/q = f(\tau,z) = a_0 + a_1 \cdot \tau + a_2 \cdot \tau^2 + a_3 \cdot z + a_4 \cdot z^2 + a_5 \cdot z^3$$

$$\chi^2 = \sum_{\text{calibrants}} \frac{((m/q)_{\text{lit}} - f(\tau,z))^2}{(\sigma_{\text{lit}})_i^2 + (\sigma_{\text{stat}})_i^2 + \sigma_{\text{sys}}^2}$$

$$(\sigma_{\text{stat}})_i^2 = \left(\frac{\partial f(\tau,z)}{\partial \tau}\right)^2 \times \sigma_i^2(\tau)$$

Include additional error until χ_{red}^2=1 to account for systematic errors



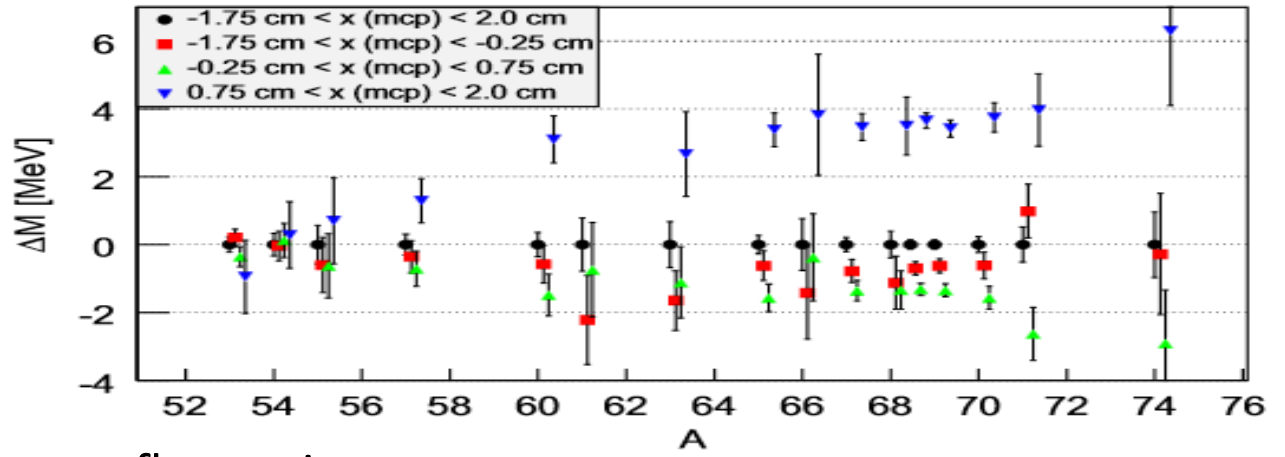
M. Matoš et al. NIMA 696, 171 (2012)

Systematic Error Sources

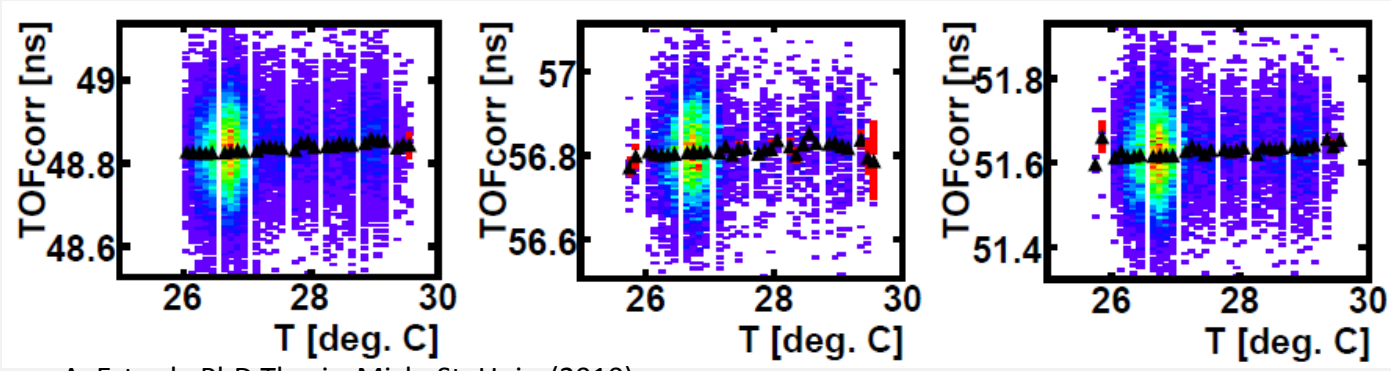
*Sensitive to TOF effects of **~1ps***

e.g. Details of Bρ-correction:

M. Matoš et al. NIMA 696, 171 (2012)



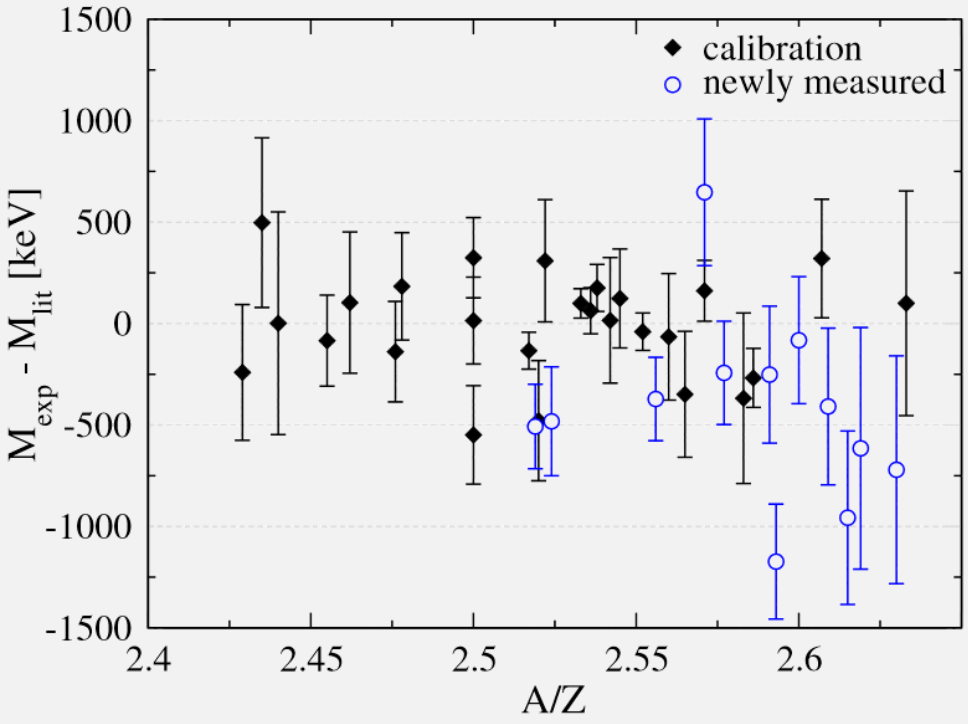
e.g. Temperature fluctuations:



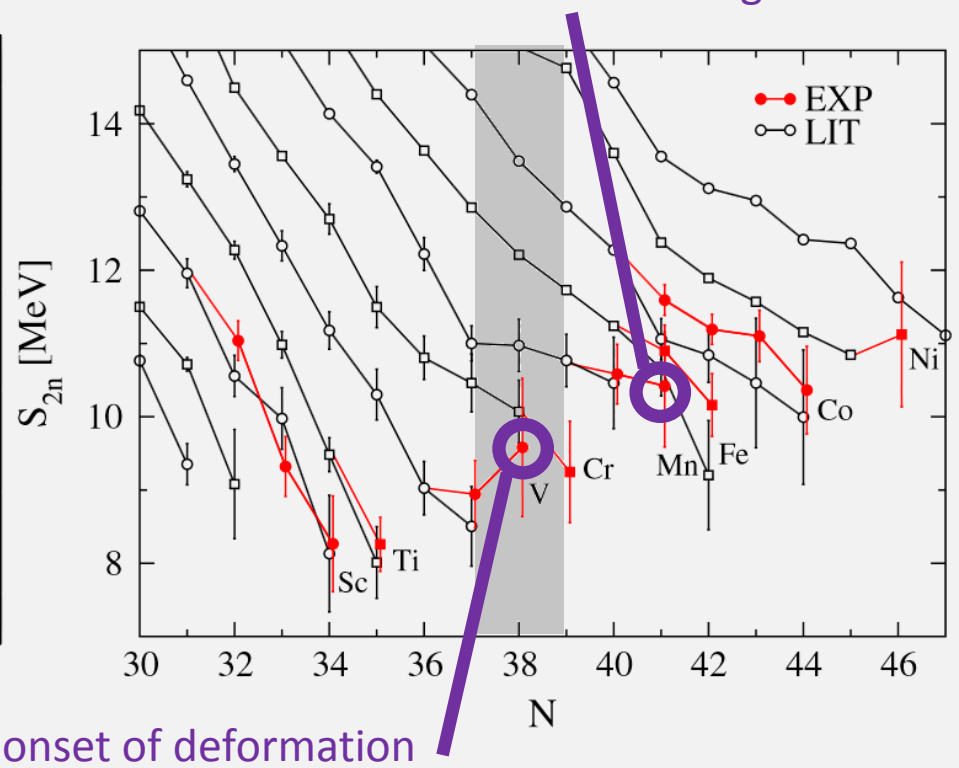
A. Estrade PhD Thesis, Mich. St. Univ. (2010)

Recent Results: *NSCL*

First mass measurement for : ^{61}V, ^{63}Cr, ^{66}Mn, ^{74}Ni



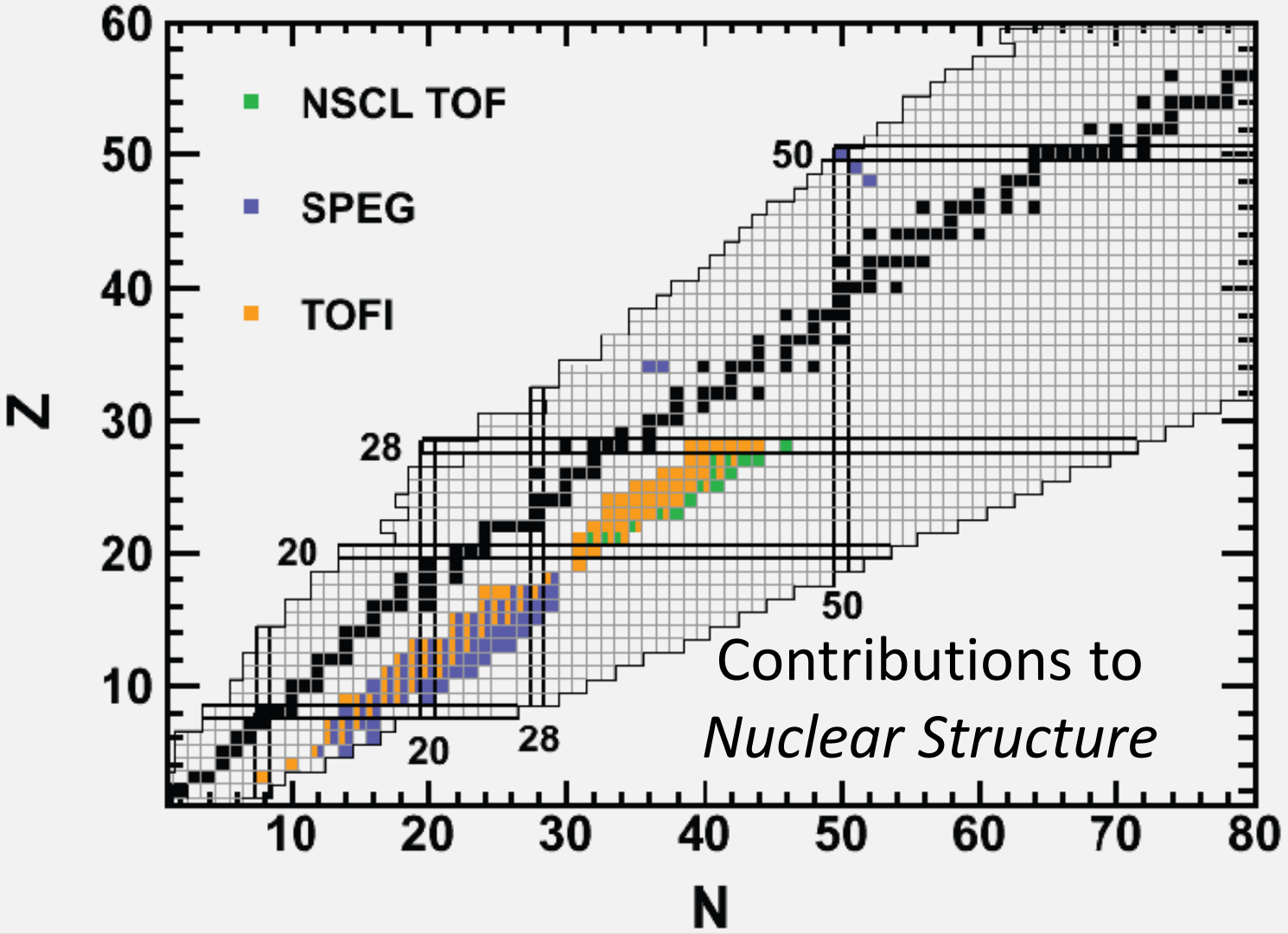
Sets depth of major Neutron Star crustal heating



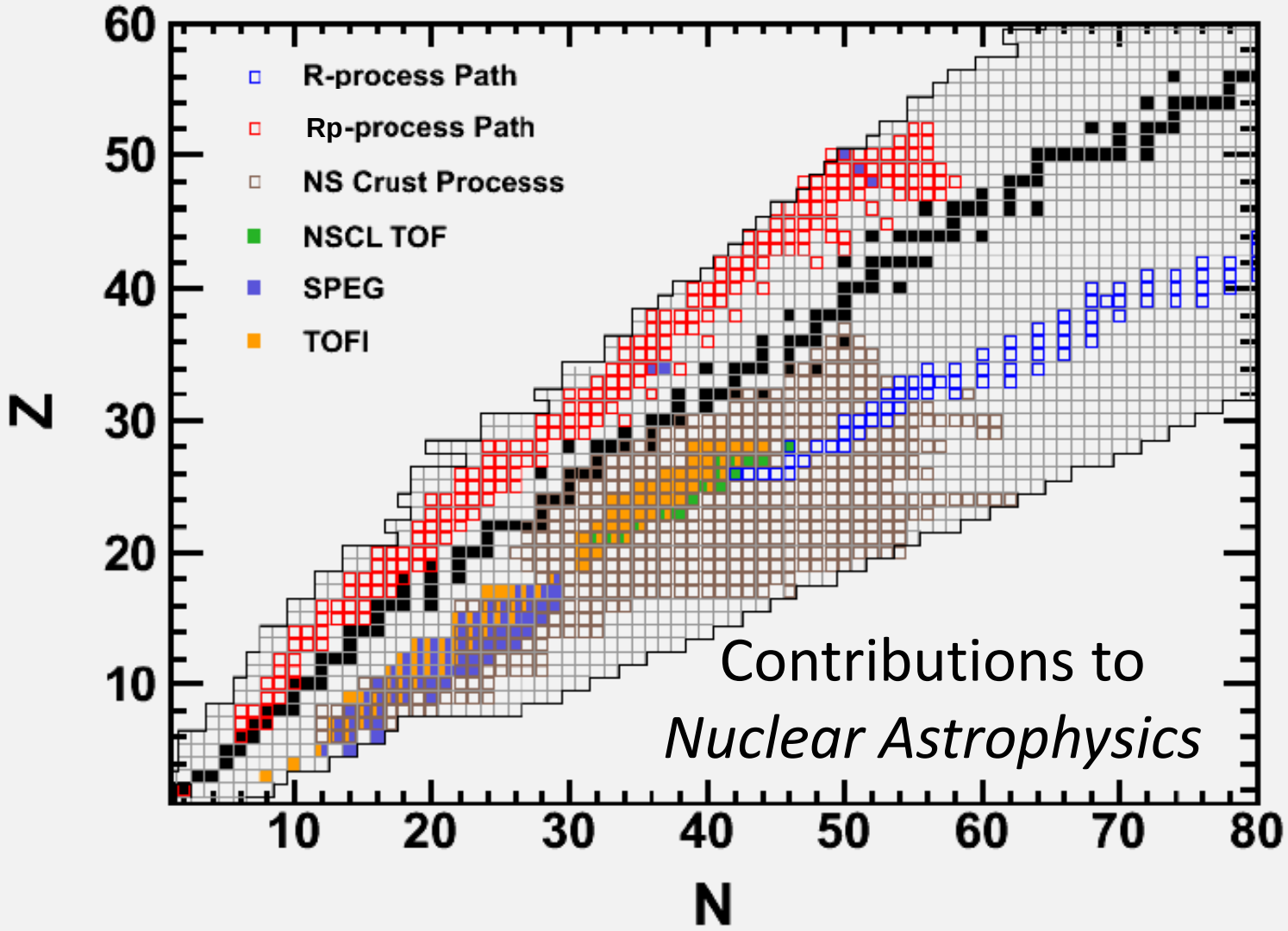
onset of deformation

A. Estrade et al. PRL 107, 172503 (2011)

TOF Results To-Date



TOF Results To-Date

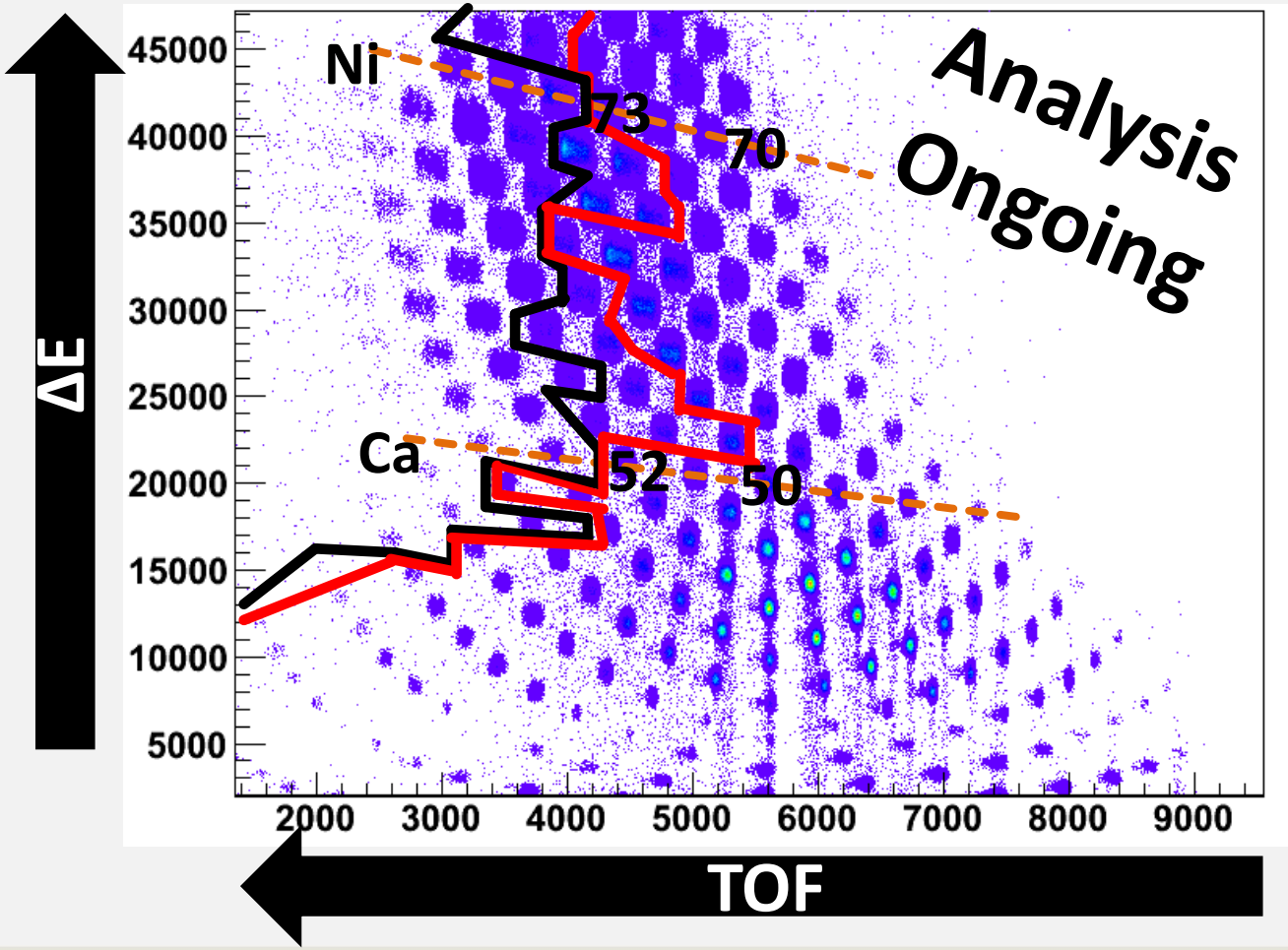


Coming Soon …

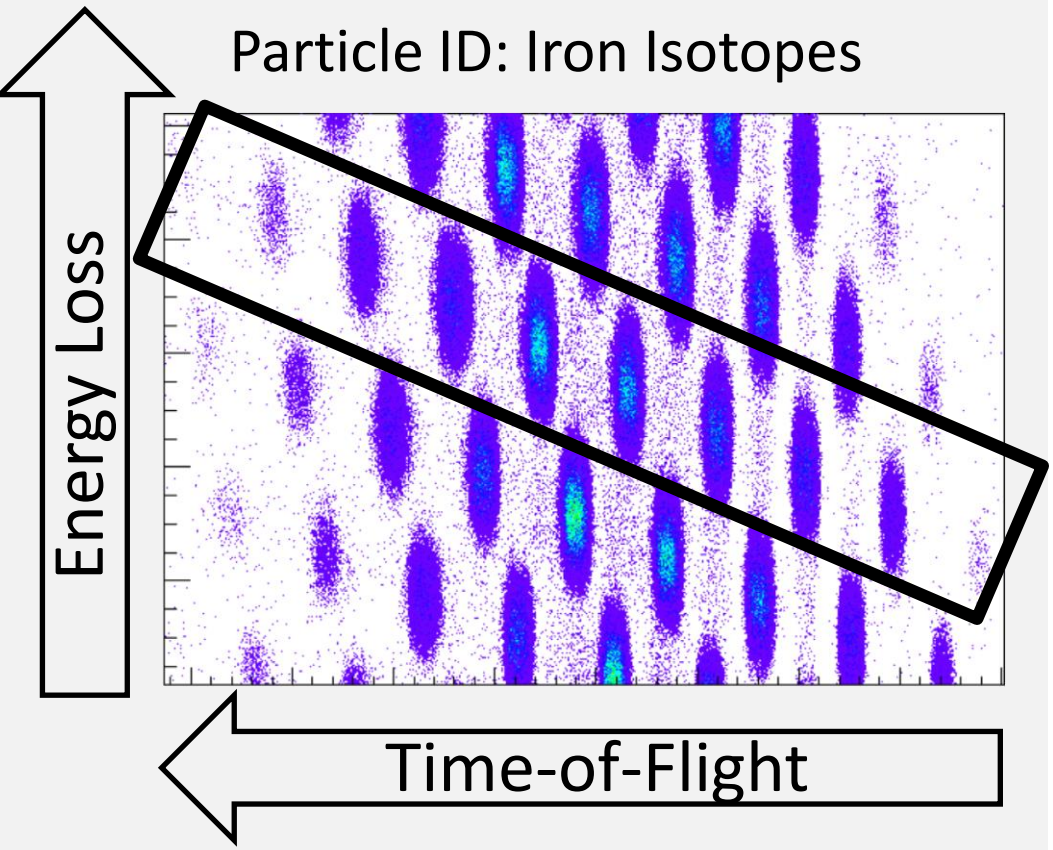
NSCL 2011 measurement:

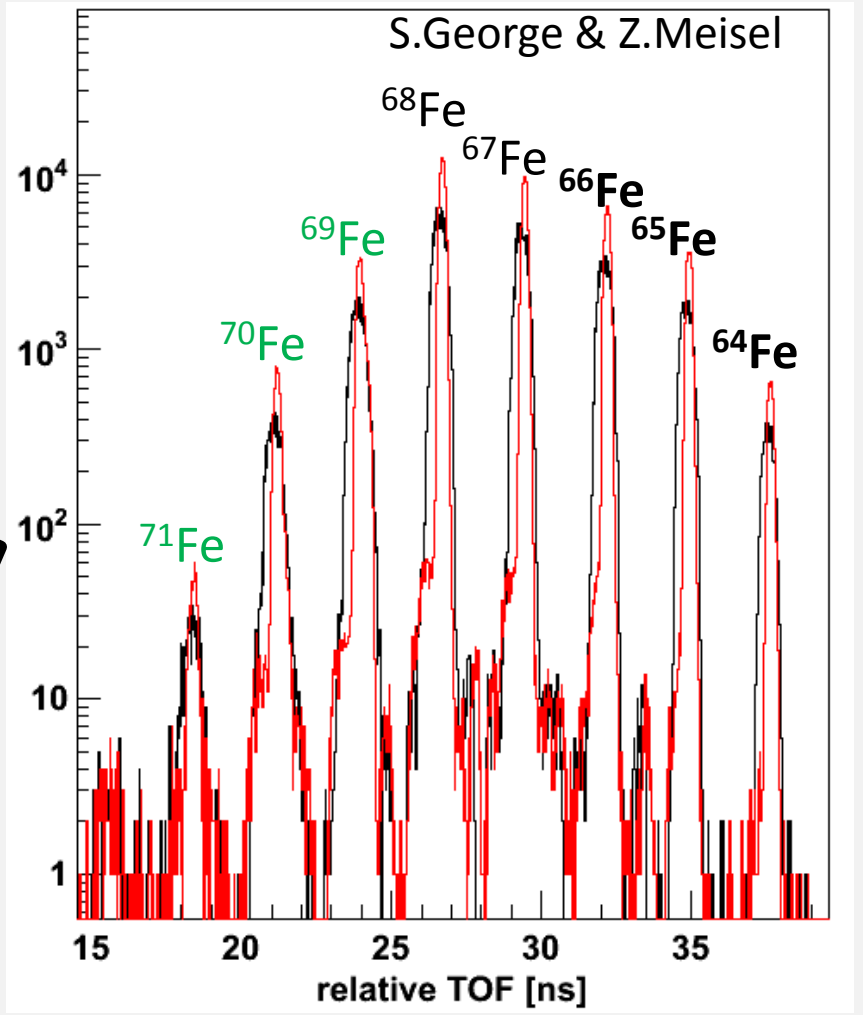
Left of **Black** = Unknown as of AME 2012
Right of **Red**: Δm<200keV as of AME 2012

S.George & Z.Meisel

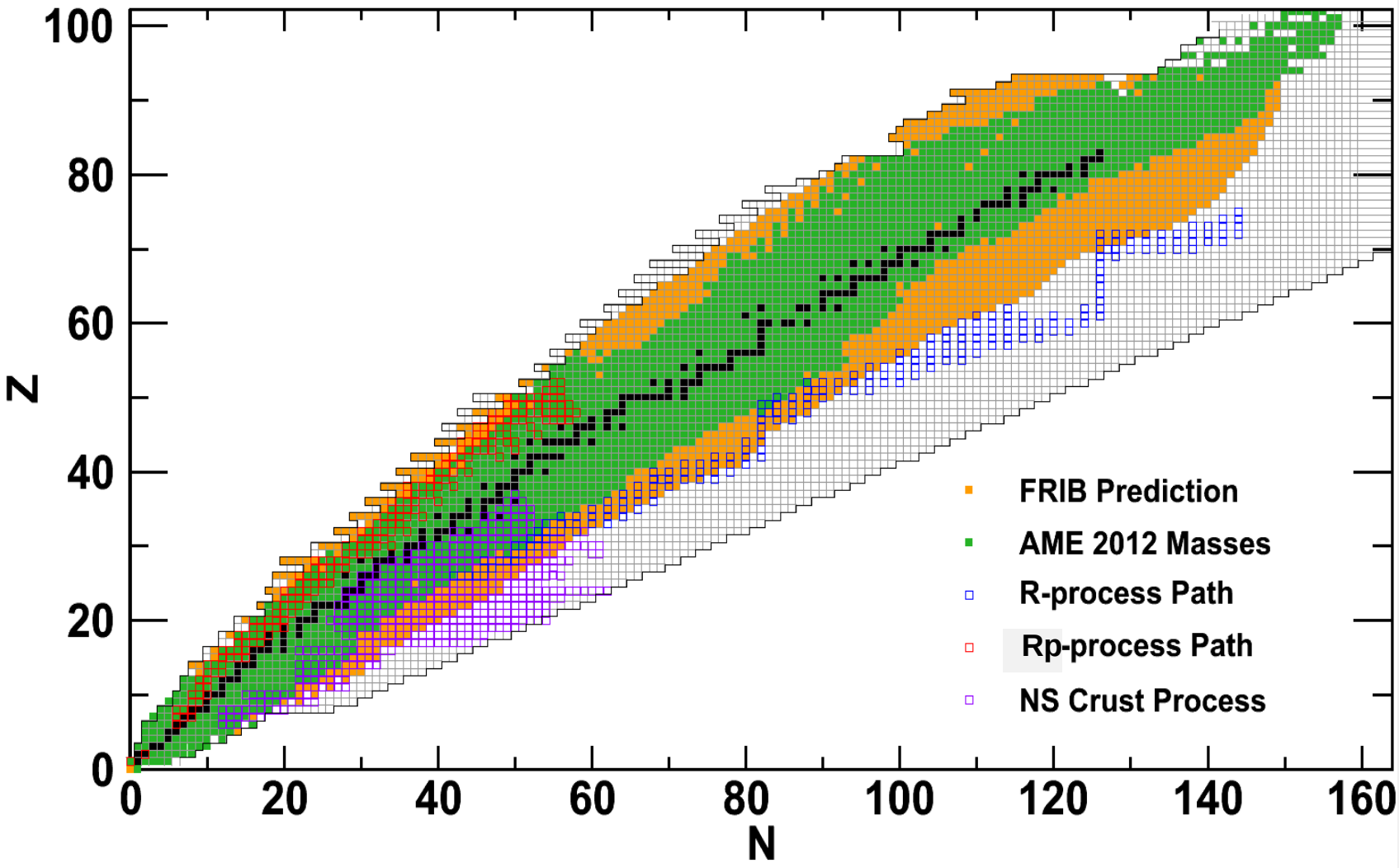


Coming Soon …


Particle ID: Iron Isotopes
Energy Loss
Time-of-Flight


S.George & Z.Meisel
68Fe
67Fe
66Fe
65Fe
64Fe
69Fe
70Fe
71Fe
10^4
10^3
10^2
10
1
15
20
25
30
35
relative TOF [ns]

TOF-Bρ at *FRIB*



Thanks to:

NSCL TOF Collaboration:

D. Bazin, B.A. Brown, J.Browne, F. Carpino, H. Chung, A. Estrade, M. Famiano, A. Gade, S. George, M. Matos, Z.Meisel, W. Mittig, F. Montes, D. Morrissey, J. Periera, H. Schatz, J. Schatz, M. Scott, D. Shapira, K. Smith, J. Stevens, W. Tan, O. Tarasov, S. Towers, K. Wimmer, J. Winkelbauer, J. Yurkon, R. Zegers

Conclusion

TOF mass measurements with spectrometers are able to reach the most exotic nuclei

- Measure 100s of nuclei simultaneously
- δm ~ few hundred keV possible

*depending on statistics

TOF mass measurement has been implemented successfully at NSCL …more results to come