High-precision mass measurements at ISOLTRAP for nucleosynthesis studies

r process

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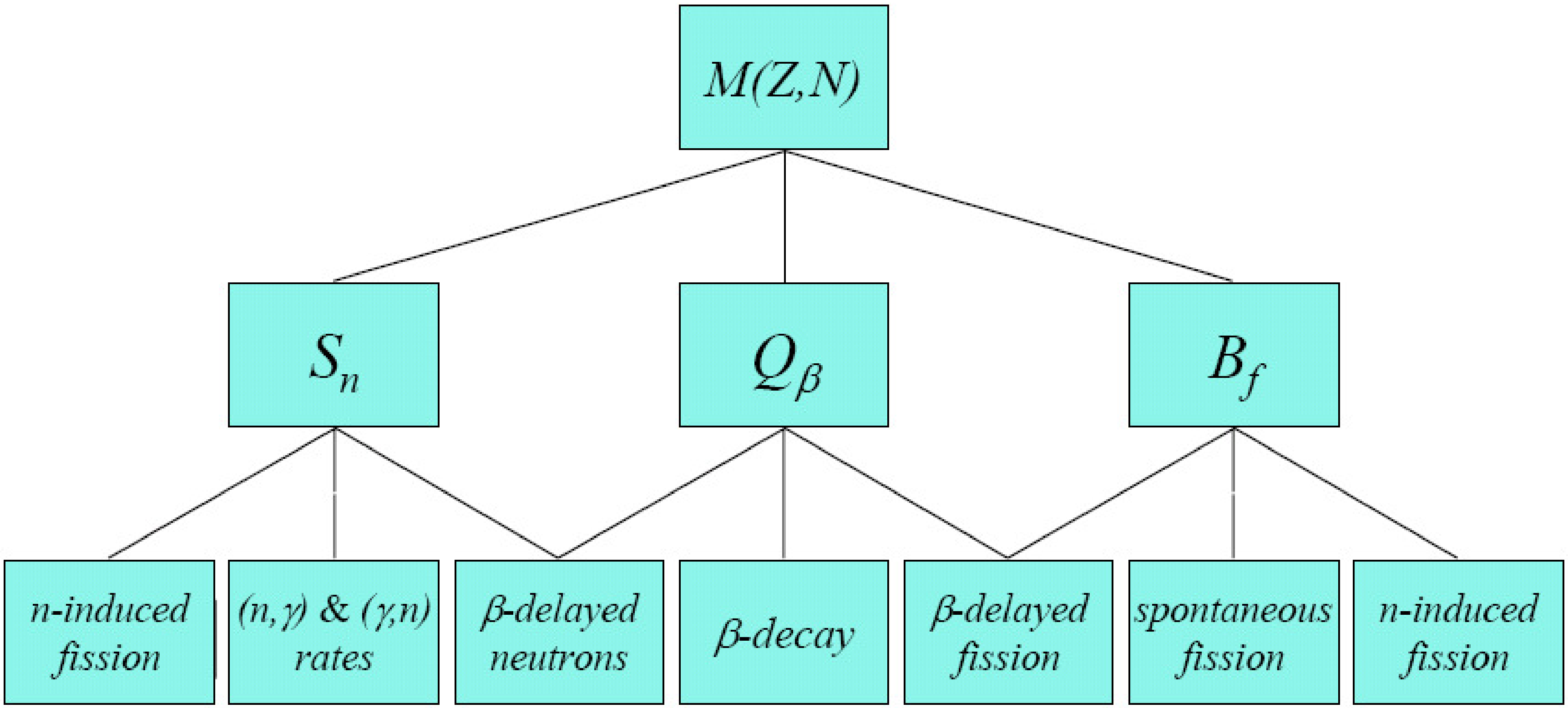
Masses and r process
ISOLDE and Isoltrap
Recent results
Summary and outlook

On behalf of the Isoltrap collaboration

ISOLDE
CERN

Atomic masses and r process

courtesy: D. Lunney



Atomic masses and r process

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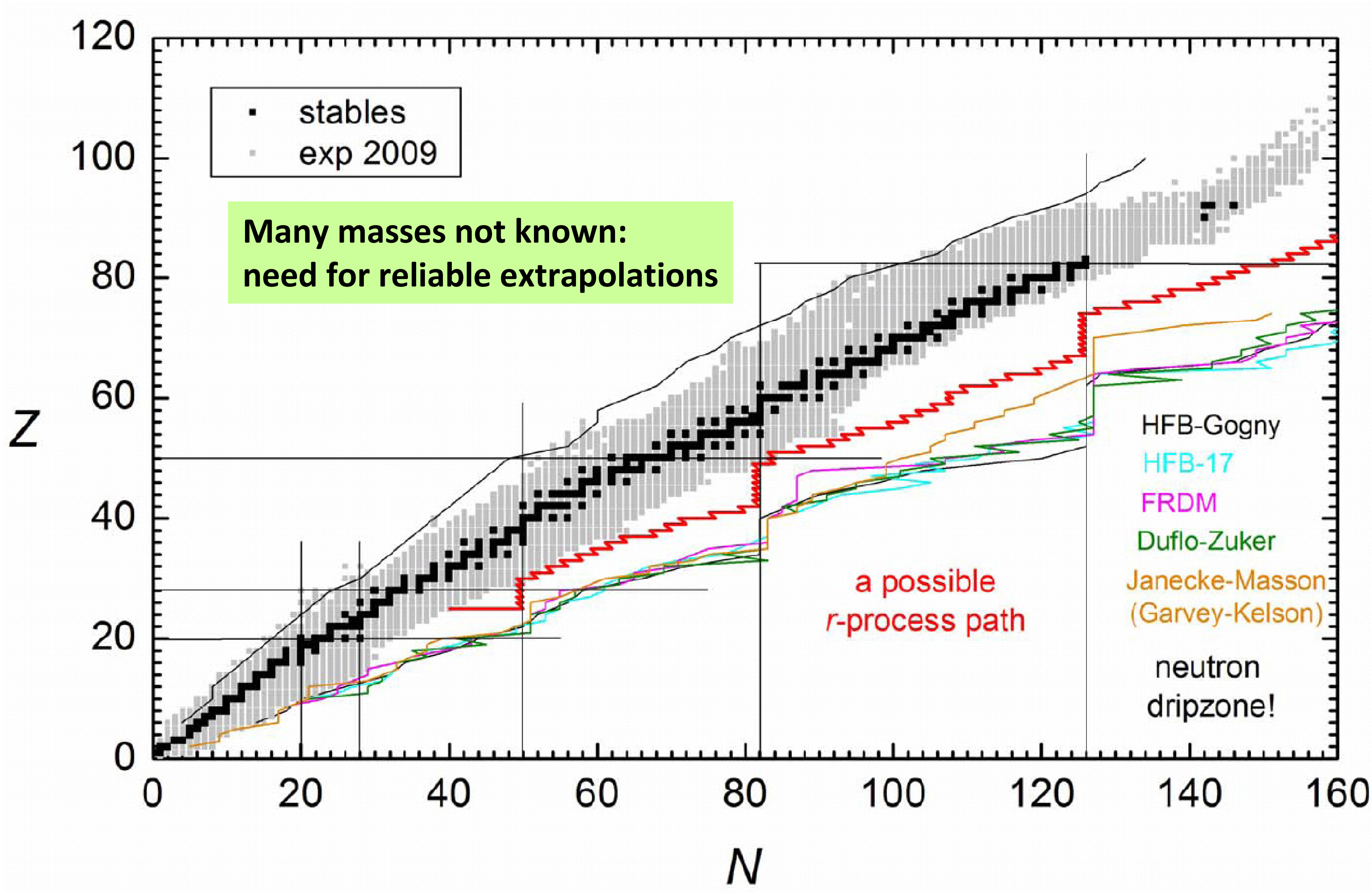
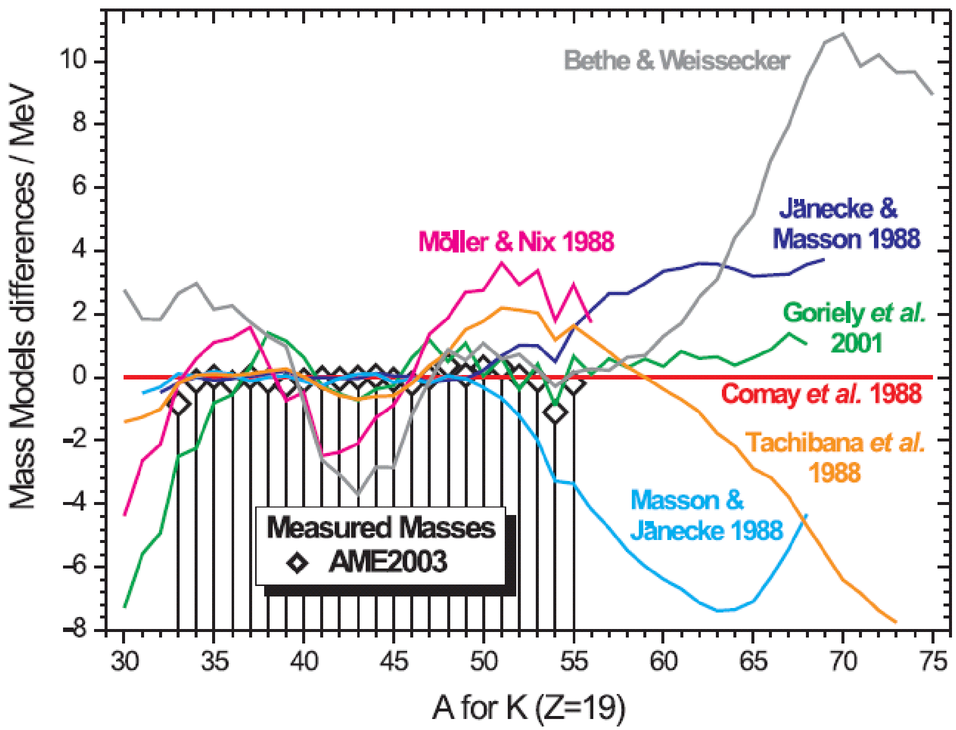


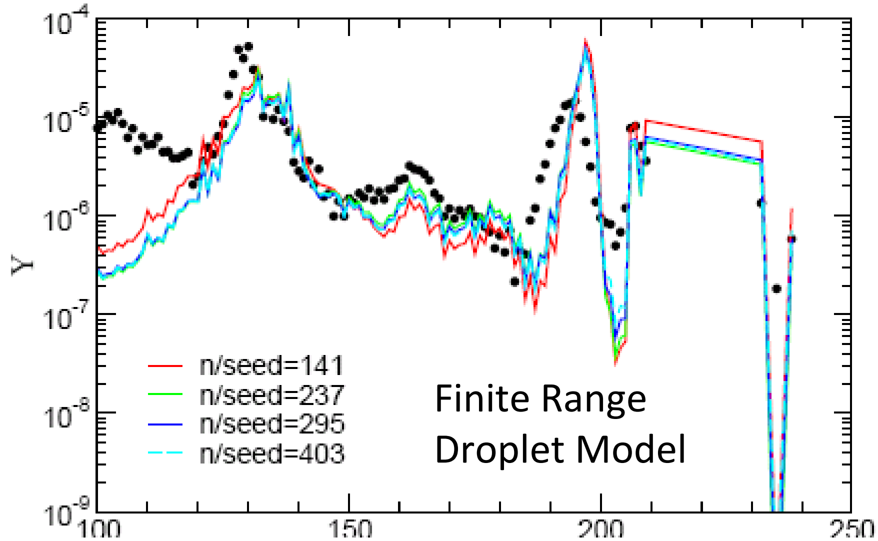
Mass extrapolations

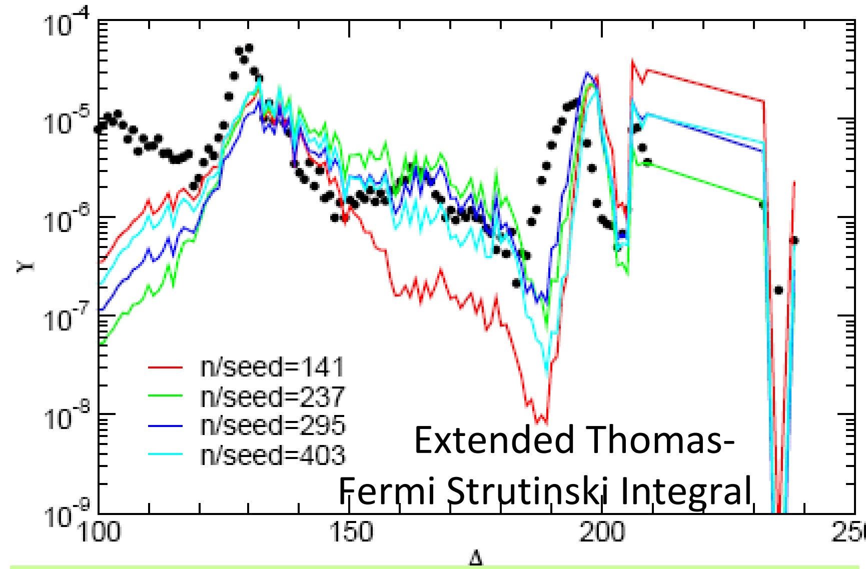
R-process abundances with FRDM and ETFSI mass models for different initial neutron-to-seed ratios
I. Petermann et al, J. Phys: Conf. Series 202, 012008 (2010)

Model predictions for K masses



Courtesy of D. Lunney



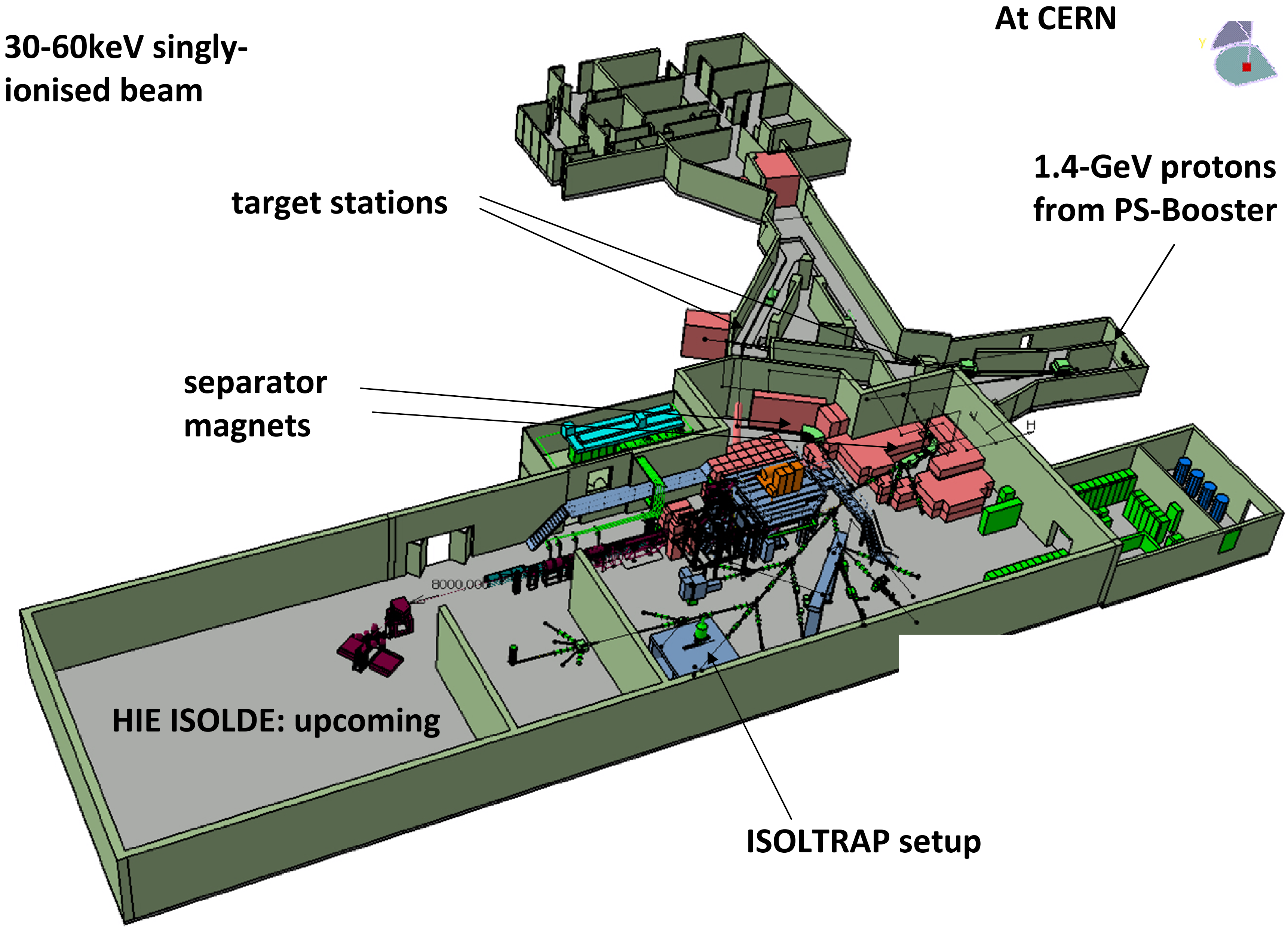


Large discrepancies for unmeasured masses

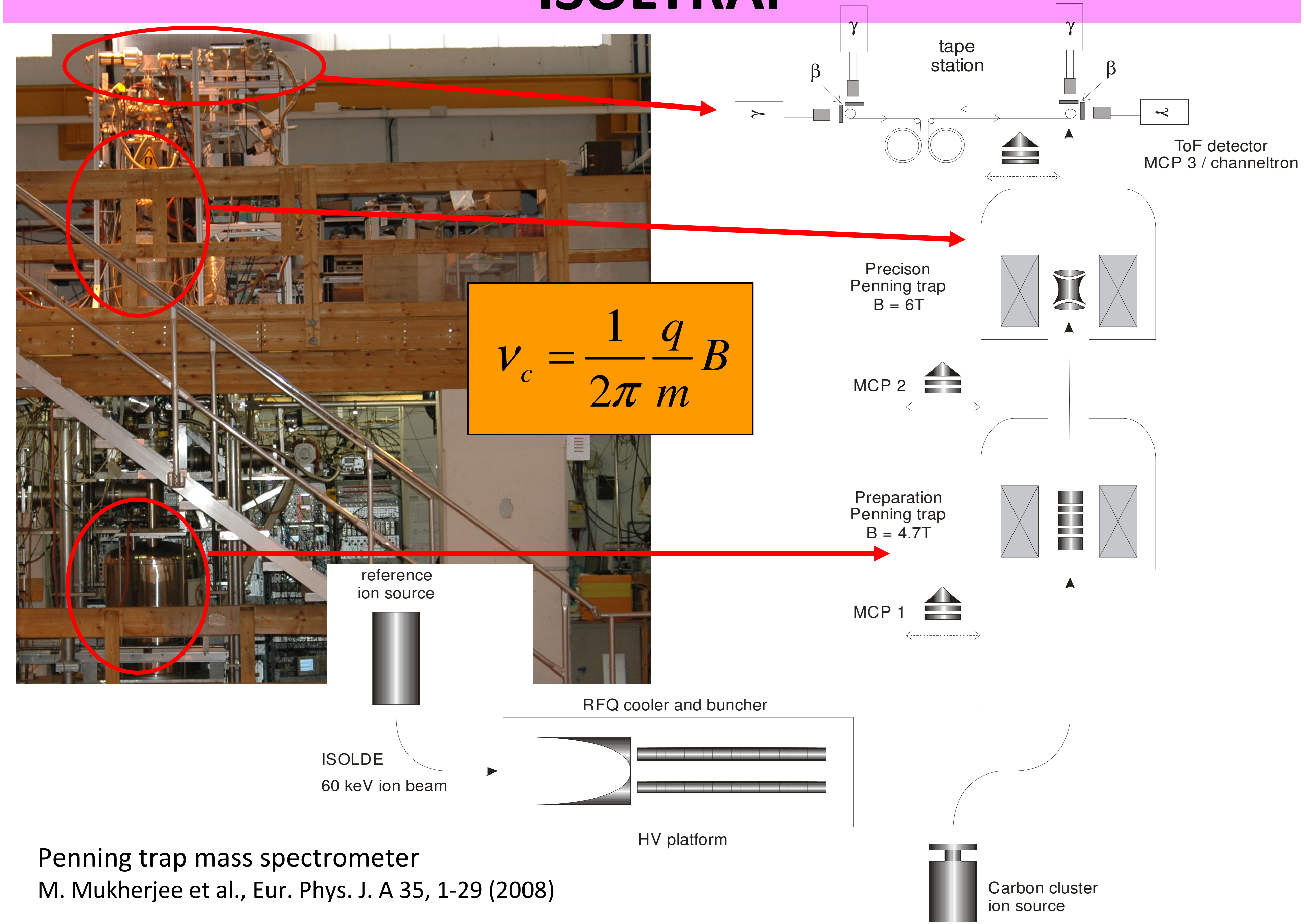
Different predictions for different models

It is important to measure masses

ISOLDE facility



ISOLTRAP



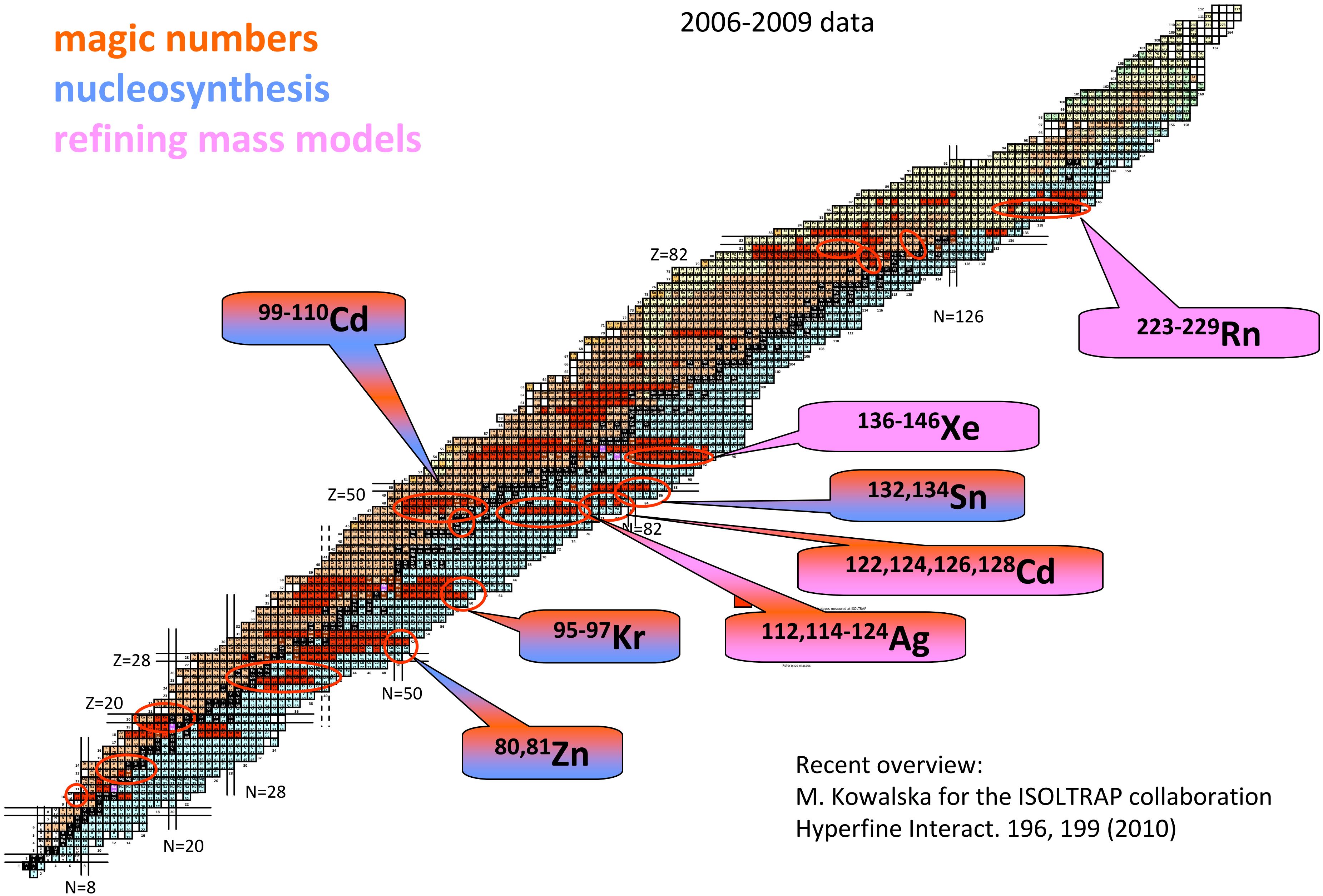
$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

Penning trap mass spectrometer

M. Mukherjee et al., Eur. Phys. J. A 35, 1-29 (2008)

ISOLTRAP and nucleosynthesis

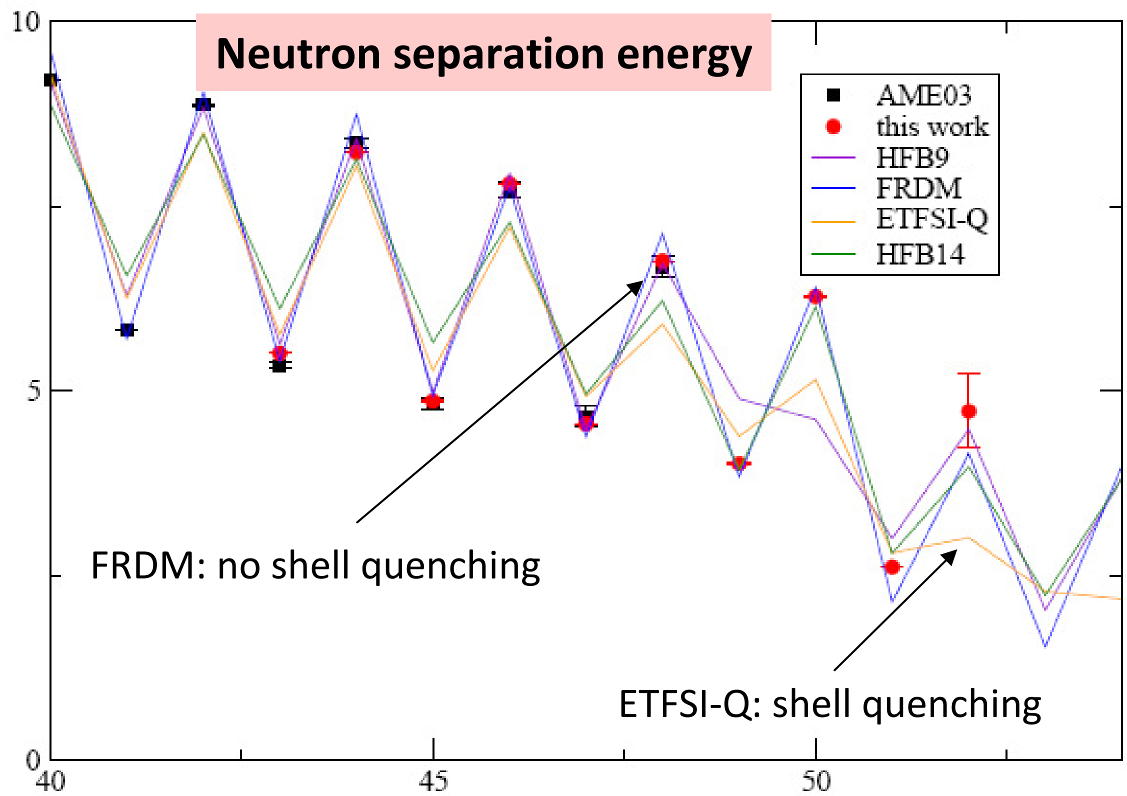
magic numbers
nucleosynthesis
refining mass models



Recent overview:
M. Kowalska for the ISOLTRAP collaboration
Hyperfine Interact. 196, 199 (2010)

^{80,81}Zn

^{80}Zn as r process 'waiting-point', strength of N=50



mass of ^{82}Zn: derived from systematic trends

Shifted by 400 keV compared to previous estimate

Mass of ^{79,80}Zn in agreement with Jyfltrap value (Hakala et al. '08)

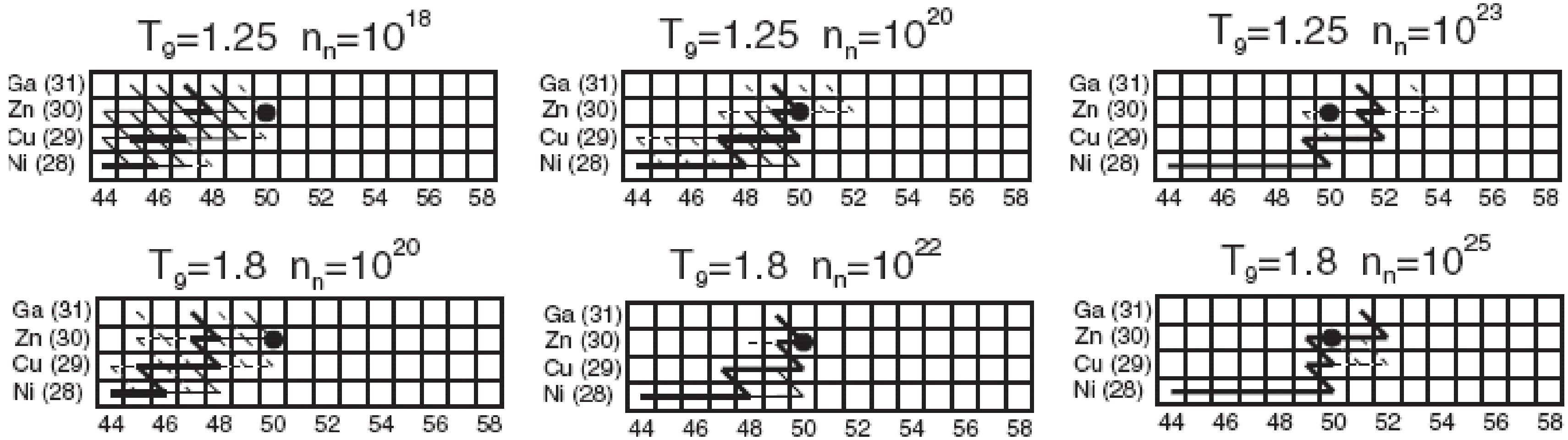
No evidence for shell quenching: N=50 is a good magic number

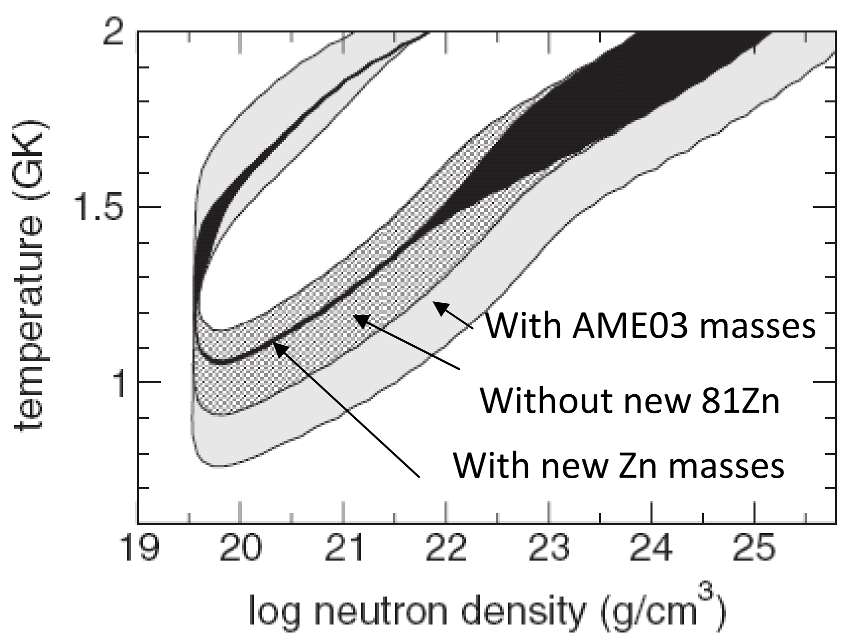
S. Baruah *et al.* , PRL 101, 262501 (2008)

^{80,81}Zn

Reaction flows for different conditions based on new data

>5x1e-3





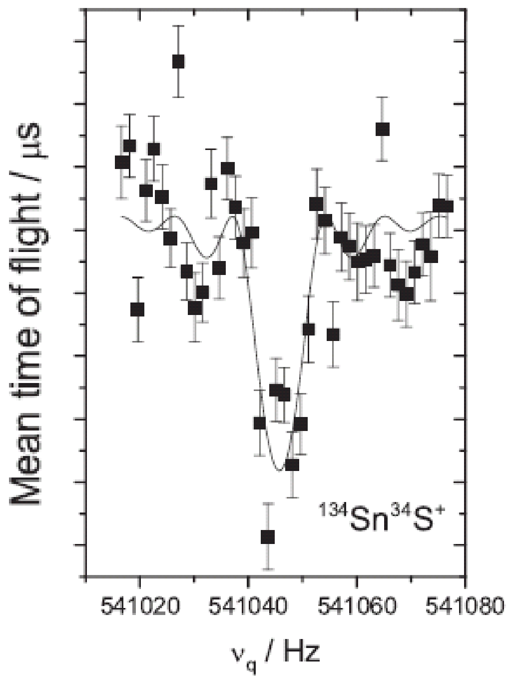
Below 1.5 GK, where $(n,\gamma) \rightleftharpoons (\gamma,n)$ equilibrium begins to break down, previously dominating mass uncertainties to the reaction flow are now negligible

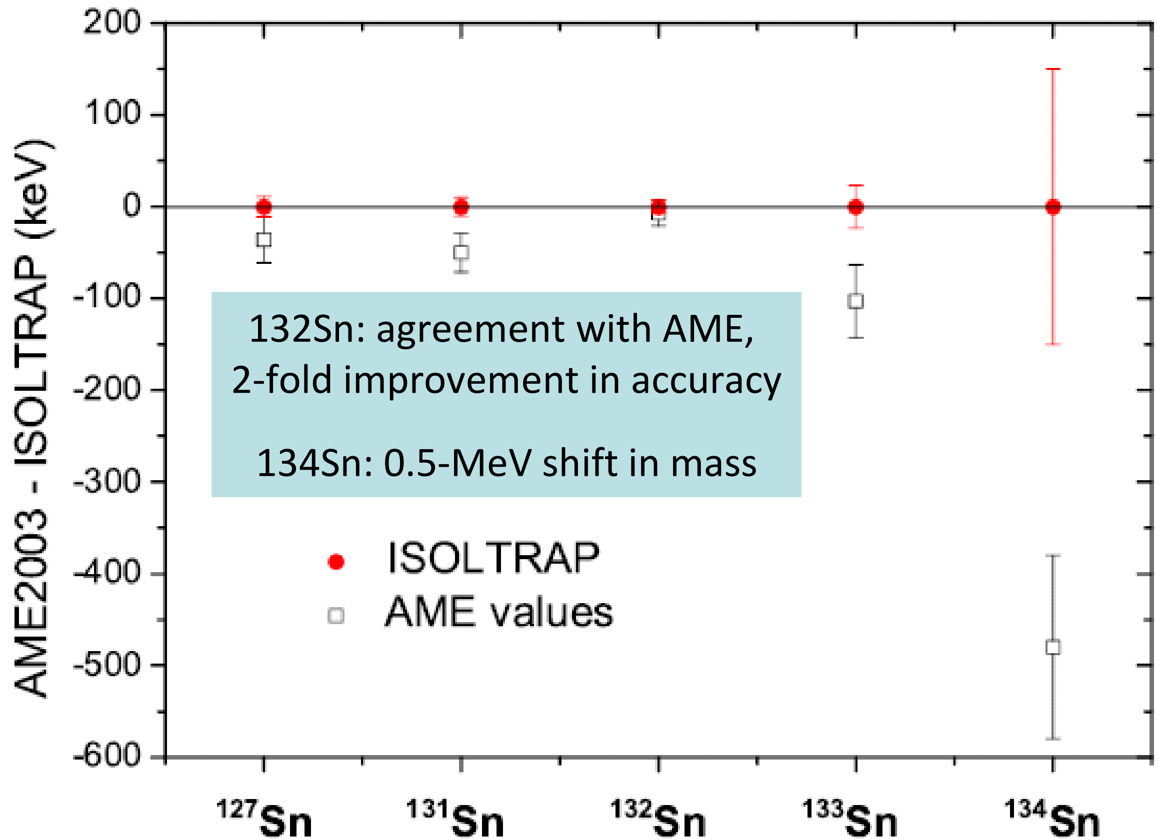
^{80}Zn: - 1st major r-process waiting point with masses (S_n and n-capture Q-value) and half-life determined experimentally

S. Baruah *et al.* , PRL 101, 262501 (2008)

^{132,134}Sn

^{132}Sn as r process 'waiting-point',
previous experimental evidence for N=82 shell quenching





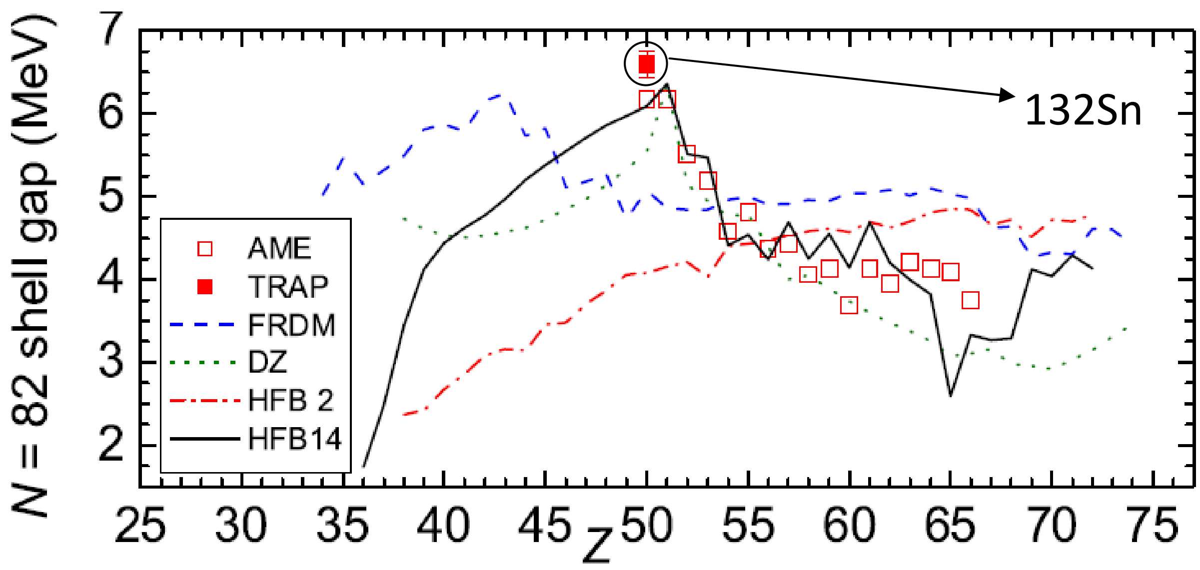
132Sn: agreement with AME,
2-fold improvement in accuracy

134Sn: 0.5-MeV shift in mass

M. Dworschak et al., PRL 100, 072501 (2008)

^{132,134}Sn

neutron shell gap $\Delta_n(N_0, Z) = S_{2n}(N_0, Z) - S_{2n}(N_0 + 2, Z)$



Restoration of N=82 gap

In agreement with recent determination of high purity of wave-functions for ^{133}Sn low-lying states,

K. Jones et al, Nature 465, 454 (2010)

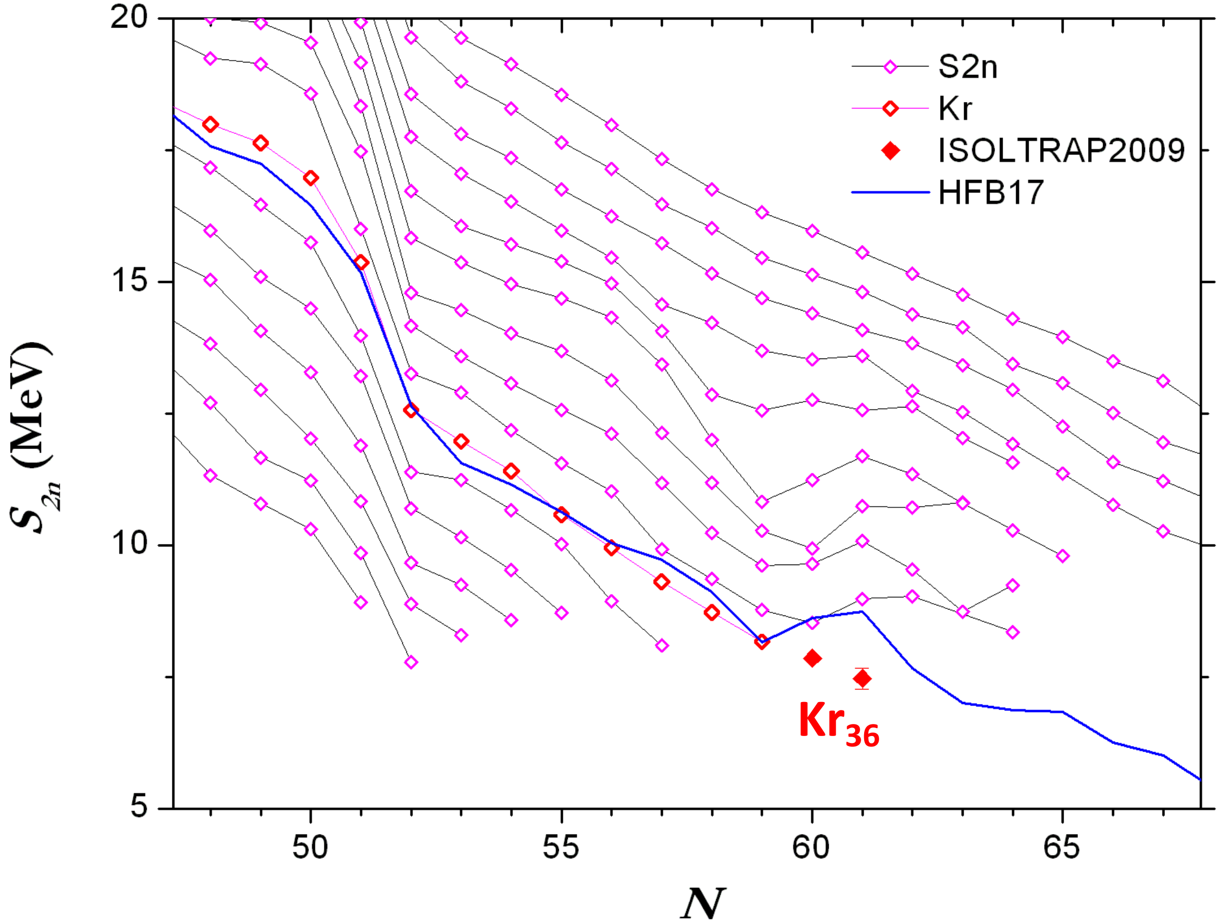
G. Martinez-Pinedo et al., Proc. Sci. NIC-IX (2006) 064: "mass models with strong shell gaps yield final abundances that are practically independent of the conditions once the neutron-to-seed ratio is large enough"

- New N = 82 shell gap in ^{132}Sn is larger than N = 28 shell gap of ^{48}Ca
- N= 82 shell gap might influence r process fission cycling: in presence of shell gap, r process slows down and more neutrons are created by photodisintegration inducing more fission

M. Dworschak et al., PRL 100, 072501 (2008)

$^{96-97}$Kr

- structure beyond *N* = 58 sub-shell
- location of *r*-process path



S. Naimi et al,
PRL accepted

$^{84,86-95}$Kr:
ISOLTRAP results,
Delahaye et al,
PRC74, 034331 (06)

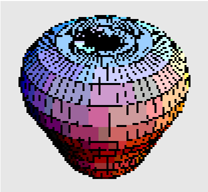
- Smooth continuation of S_{2n} trend, no evidence for large structural changes, unlike neighbours
- Deviation from mass models => influence on r-process models

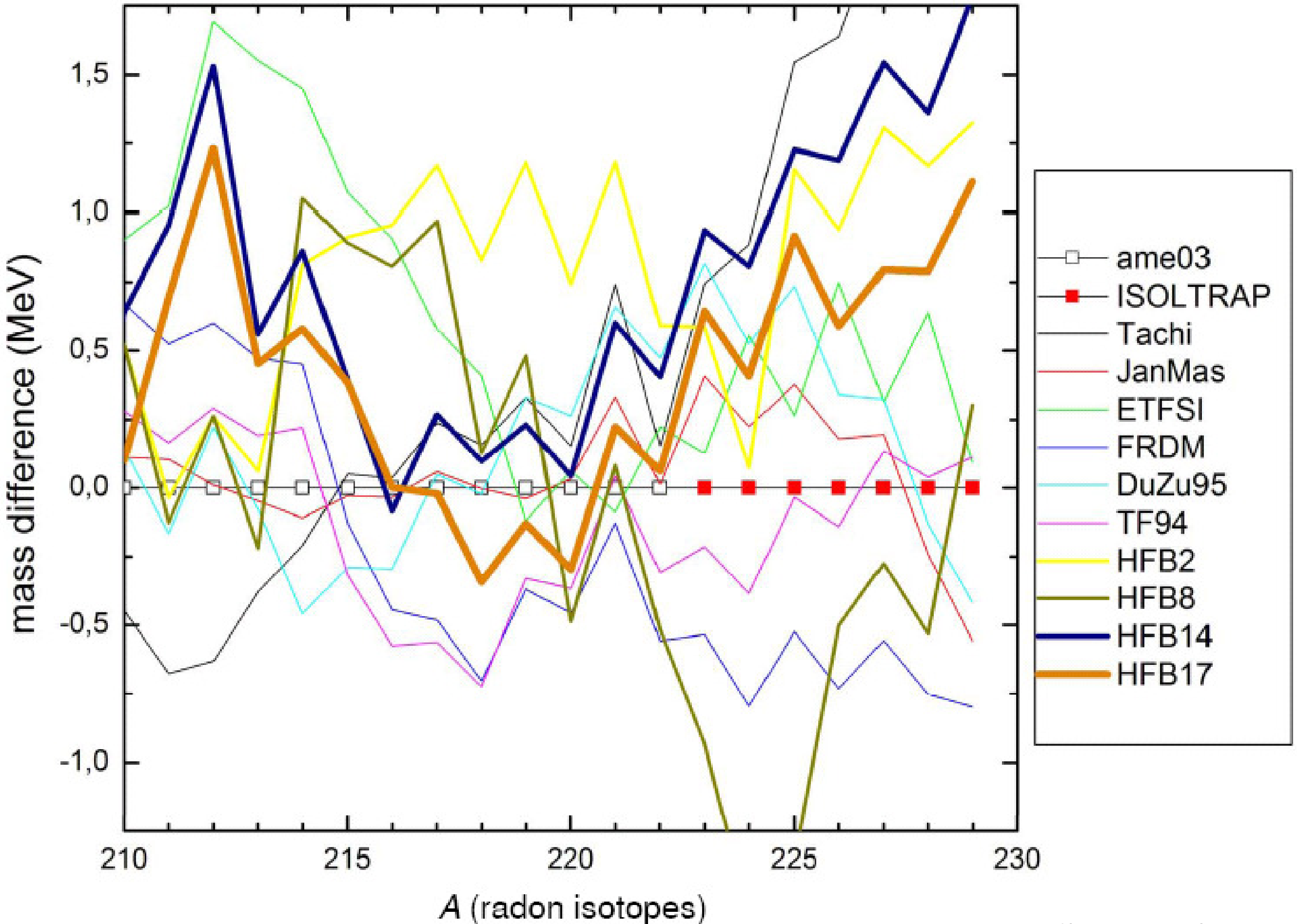
$^{223-229}$Rn

- proton - neutron interaction
- possible link to octupole deformation
- improvement of mass models

7 masses never measured before

A new nuclide discovered: ^{229}Rn



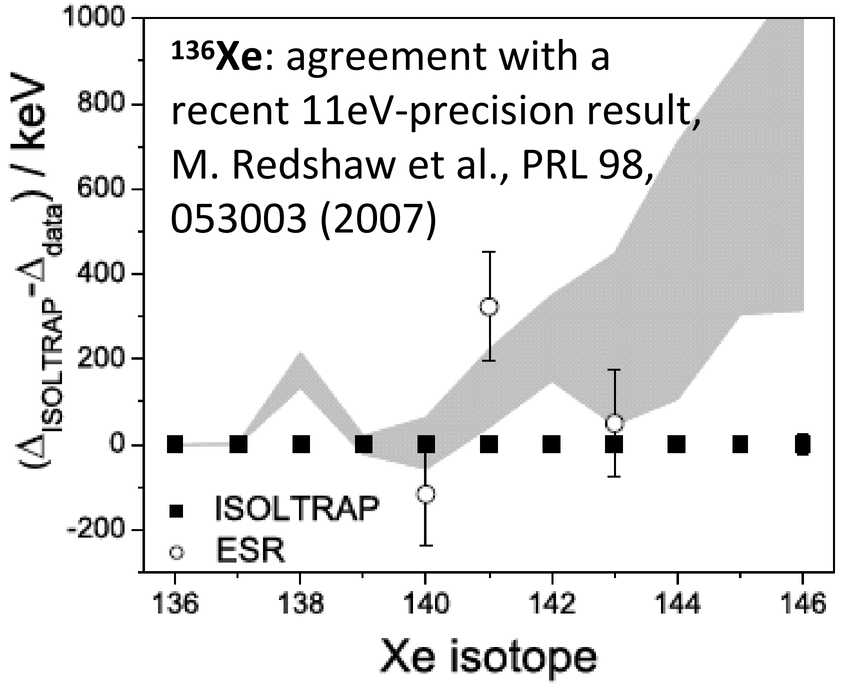


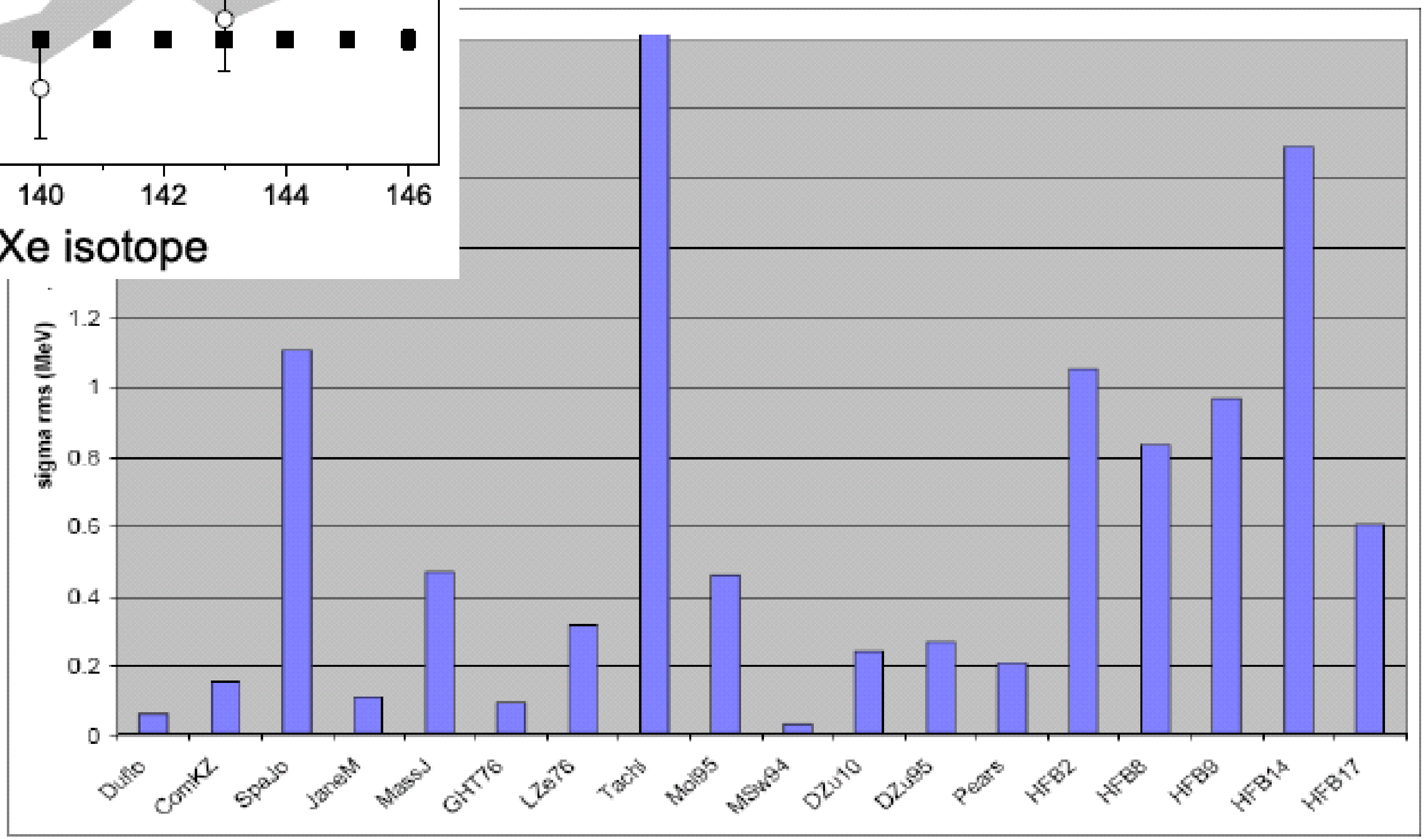
D. Neidherr *et al.*, PRL 102, 112501 (2009)

$^{143-146}$Xe

Nuclear structure:

- proton - neutron interaction
- link to octupole deformation ?
- input for mass models





D. Neidherr et al.,
PRC 80, 044323 (2009)

Summary and outlook

Atomic masses provide crucial input for r-process calculations

Many masses are inaccessible experimentally => reliable extrapolations

ISOLTRAP spectrometer at ISOLDE-CERN provided recently masses of:
- waiting-point nuclei ^{82}Zn and ^{132}Sn and confirmed their magicity
- very n-rich nuclei for mass model extrapolations

More input is needed to refine better the models

Plans to measure ^{82}Zn and ^{130}Cd

Overview of 2006-2009 results: M. Kowalska, Hyperfine Interact. 196, 199 (2010)
Mass database: www.cern.ch/isoltrap/database/isodb.asp