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Oslo Workshop
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@Oslo, Norway

Oslo Studies Near ^{92}Nb and the Implications for Stellar Production of the Cosmochrornometer ^{92}Nb

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U.S. DEPARTMENT of ENERGY

Outline

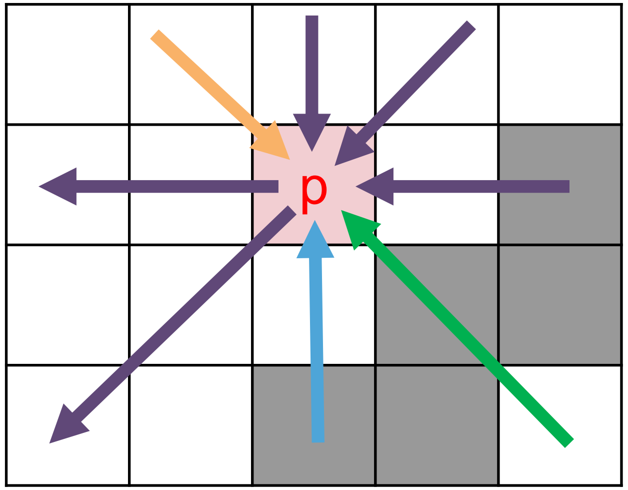
- Supernovae Study of ^{92}Nb
- Neutrino Study of ^{92}Nb
- Charge-Exchange Oslo Method

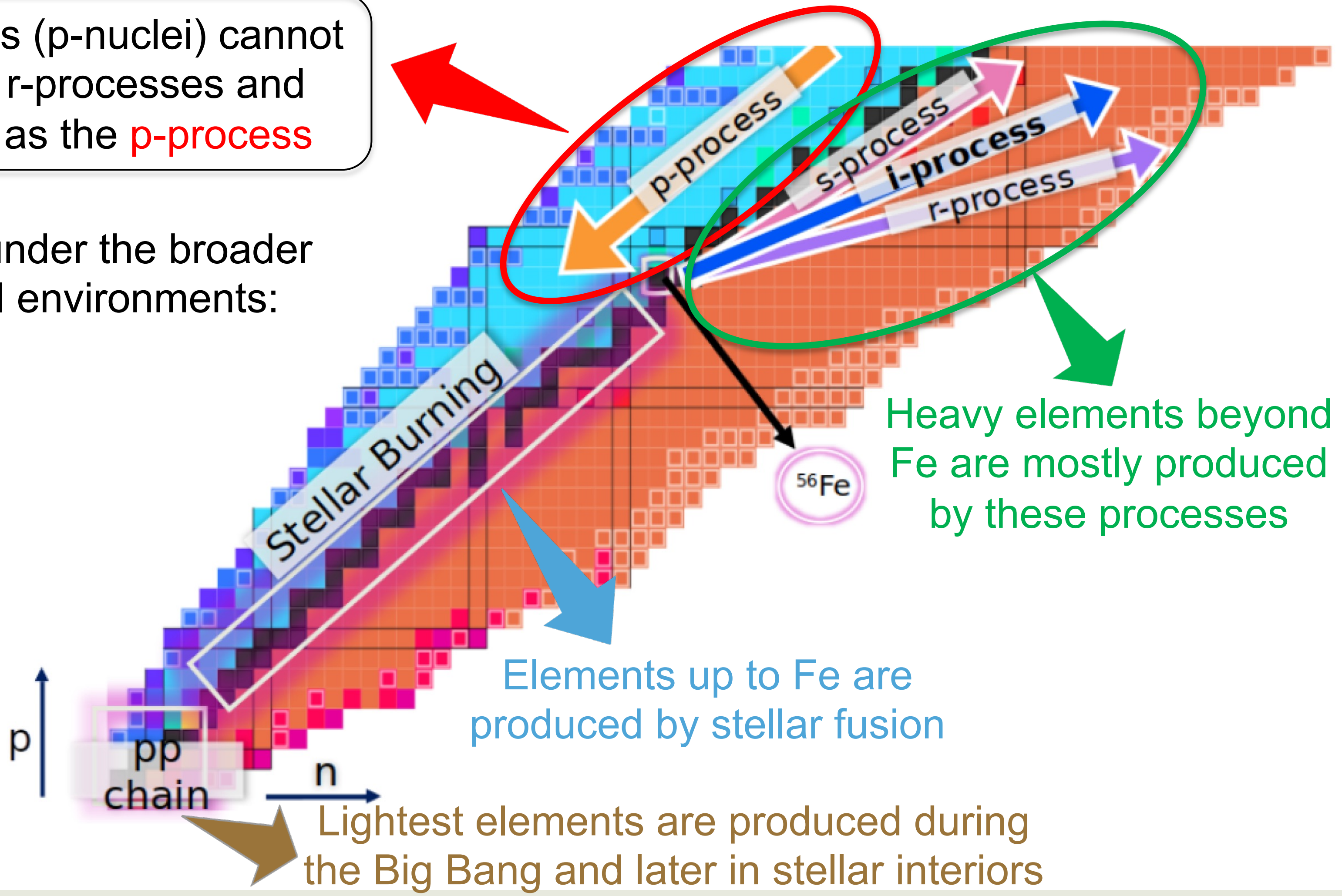
How the Elements are Made in the Universe: p-process Nucleosynthesis

Bandyopadhyay et al., *Universe* 11, 229 (2025)

A smaller group of rare, proton-rich isotopes (p-nuclei) cannot be produced efficiently by the s-, i- and r-processes and require distinct mechanisms referred to as the p-process

- Several mechanisms have been proposed under the broader p-process umbrella in different astrophysical environments:
  - γ-, rp-, νp-, $\nu/\nu r$-processes





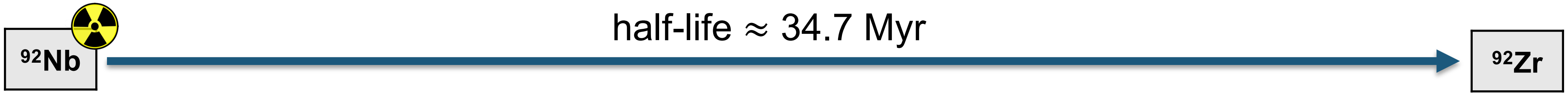
Heavy elements beyond Fe are mostly produced by these processes

Elements up to Fe are produced by stellar fusion

Lightest elements are produced during the Big Bang and later in stellar interiors

Today's Topic is Another p-Nucleus: ^{92}Nb

- Short-lived radionuclides (SLRs), with half-lives of 0.1–100 Myr, are powerful chronometers of Solar System formation
- Among the 19 known SLRs, ^{92}Nb is one of the few confirmed proton-rich SLRs
- It's synthesized in supernovae environments and became extinct shortly after the formation of the Solar System
- Its former presence is inferred from excesses in its EC-decay daughter, ^{92}Zr , measured in meteorites from both the inner and outer Solar System[i,ii]

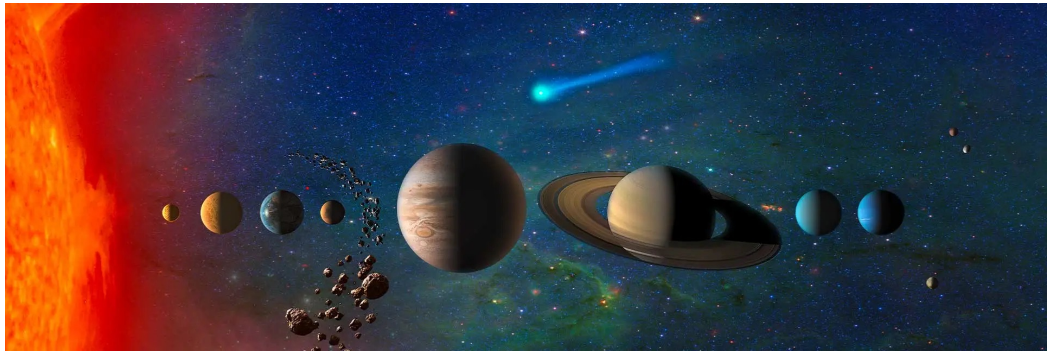


$$^{92}\mathrm{Nb} \xrightarrow{\text{half-life} \approx 34.7\ \text{Myr}} {}^{92}\mathrm{Zr}$$

Supernovae

Cassiopeia A Supernovae (JWST-NASA)

Solar System formation



(NASA)

Meteoric Analysis

NWA 6074 (Hibiya et al., (2019))

i. Harper, C. L., Jr. 1996, ApJ, 466, 437
ii. Haba et.al, (2021) Proc. Natl. Acad. Sci. U.S.A. 118 (8)

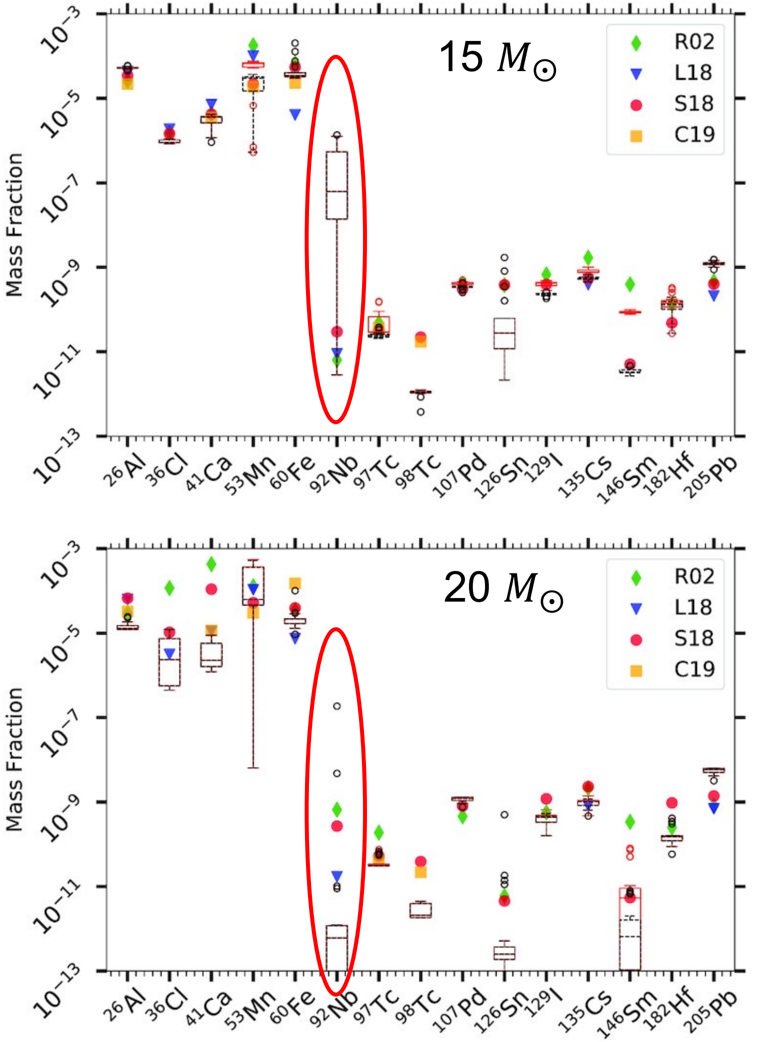
Why is ^{92}Nb Important?

- The abundance of ^{92}Nb is usually discussed relative to ^{92}Mo because both are p nuclei

- The initial Solar System ^{92}Nb/^{92}Mo ratio is important for:
  - Probing early Solar System timescales in Galactic Chemical Evolution (GCE), and
  - Probing proton-rich nucleosynthesis

- The most recent inferred meteoric ^{92}Nb/^{92}Mo ratio for the inner Solar System is [i]$3.3 \pm 0.2\times10^{-5}$

- Interpreting this meteoritic ratio is currently limited by both astrophysical and nuclear-physics uncertainties in ^{92}Nb production. For example:
  - If ^{92}Nb were produced only in Type Ia supernovae, the inferred meteoric ^{92}Nb/^{92}Mo ratio would be ~50% lower to match time scales from other SLRs: Lugaro (2016)
  - Among the 15 SLRs, the production of ^{92}Nb is one the most uncertain in CCSNe stellar models: Lawson (2022)



Lawson et. al, MNRAS 511, 886–902 (2022)

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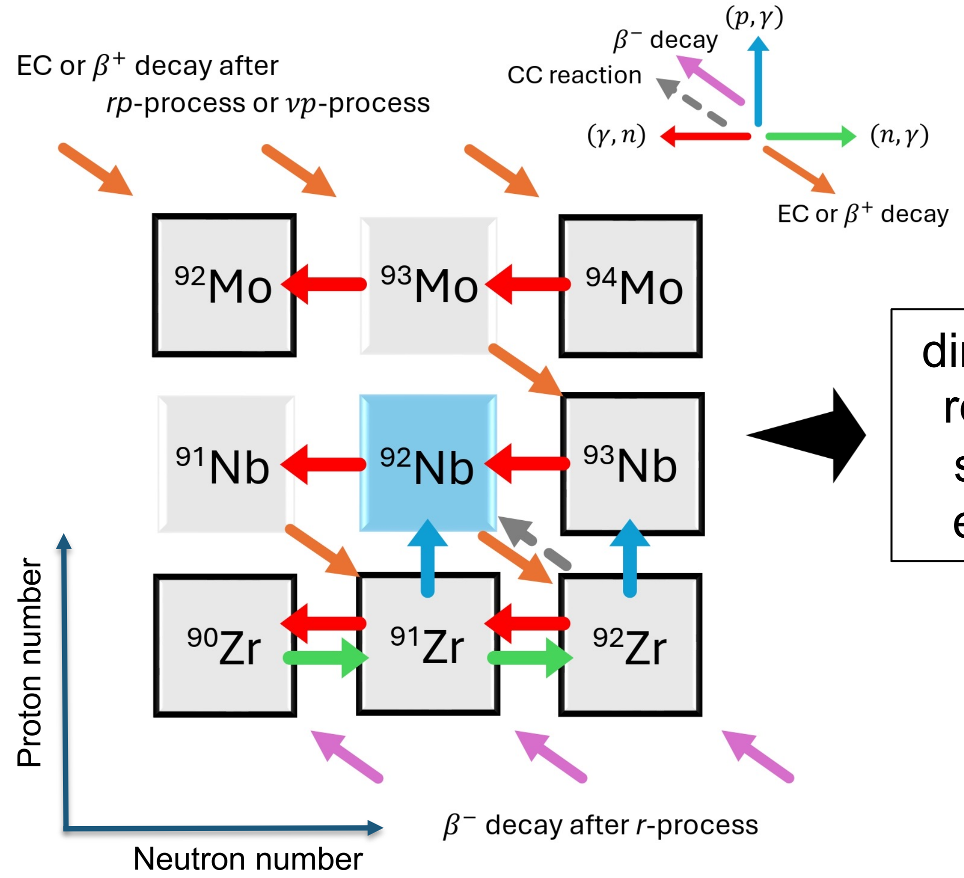
i. Haba et.al, (2021) Proc. Natl. Acad. Sci. U.S.A. 118 (8)

Possible Production Sites of ^{92}Nb

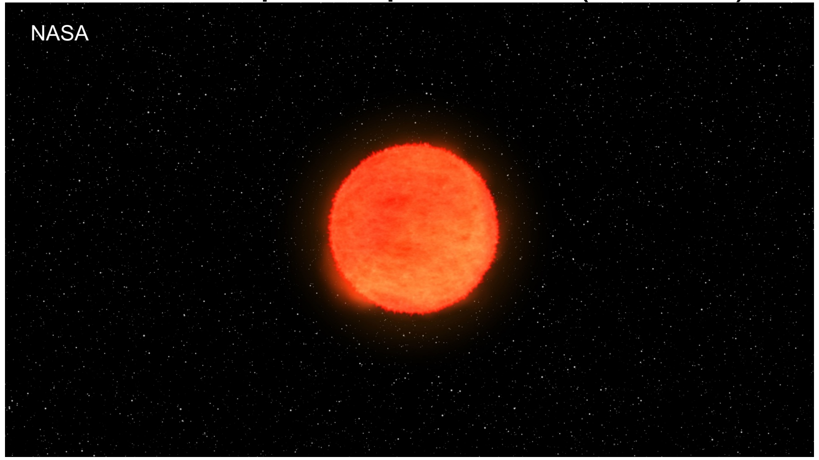
- The origin of ^{92}Nb remains uncertain because it is shielded by the stable isobars ^{92}Zr and ^{92}Mo



direct nuclear reactions in supernova explosions

1. γ-process[i]
2. ν/νr-process[ii]
3. α-process[i]

Core-Collapse supernovae (CCSNe)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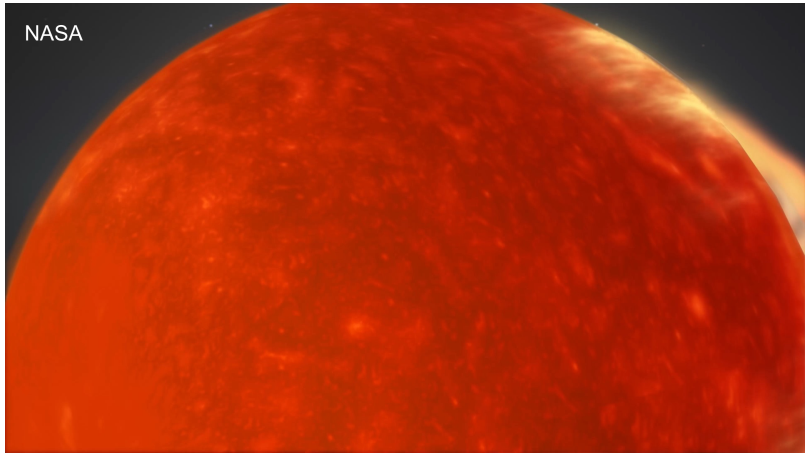
1. γ-process[iii]

Type Ia Supernovae (SNe Ia)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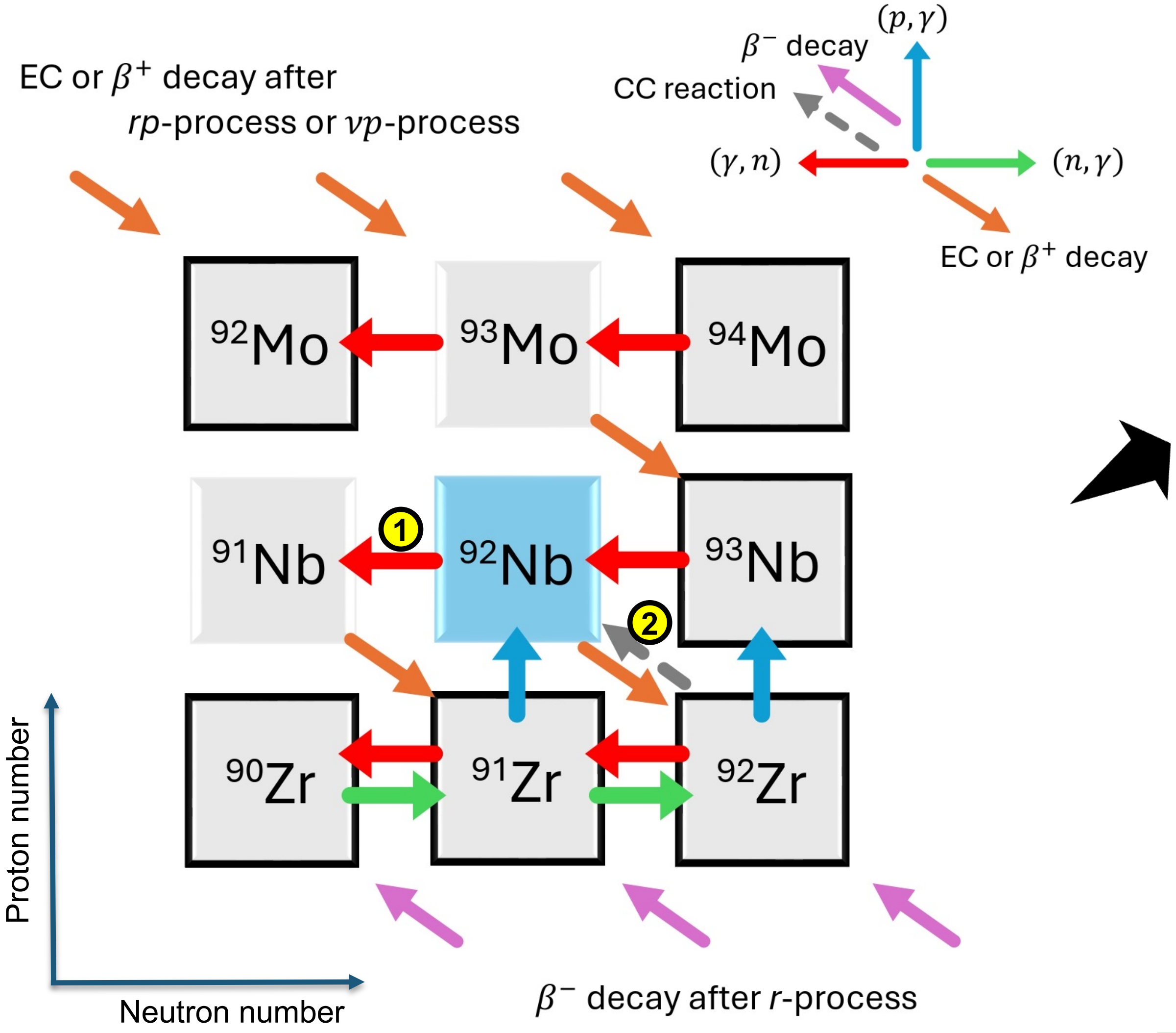
i. Lugaro, Proc. Natl. Acad. Sci. U.S.A. 113 (4) 907-912 (2016)
ii. T. Hayakawa et al., Ap.J.Lett. 779, L9 (2013)
iii. C. Travaglio et al., Ap.J. 795: 141 (2014)

What Matters Most for ^{92}Nb Production?



- The main destruction channel is **^{92}Nb(γ,n)^{91}Nb** ① in the γ-process in CCSNe and SNe Ia
- Neutrino-driven reaction **^{92}Zr(ν_e,e^-)^{92}Nb** ② in CCSNe has been proposed as an additional production pathway
- Neither reaction has direct experimental constraints yet, whereas most other relevant reactions are better constrained and have smaller impact

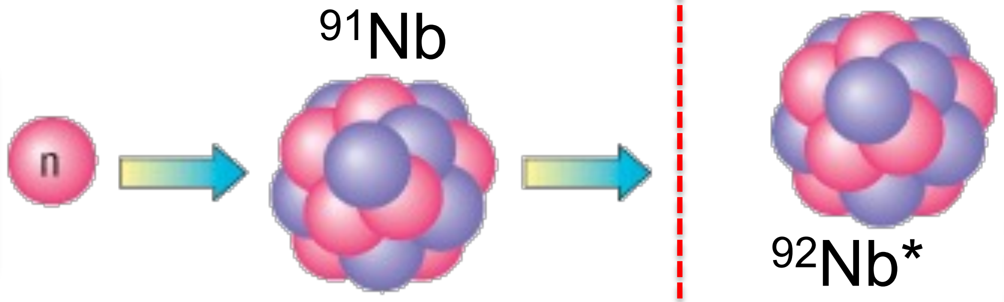
The goal is to constraint these two reactions experimentally and evaluate their impact in GCE

i. Lugaro, Proc. Natl. Acad. Sci. U.S.A. 113 (4) 907-912 (2016)
ii. C. Travaglio et al., Ap.J. 795: 141 (2014)
iii. T. Hayakawa et al., Ap.J.Lett. 779, L9 (2013)

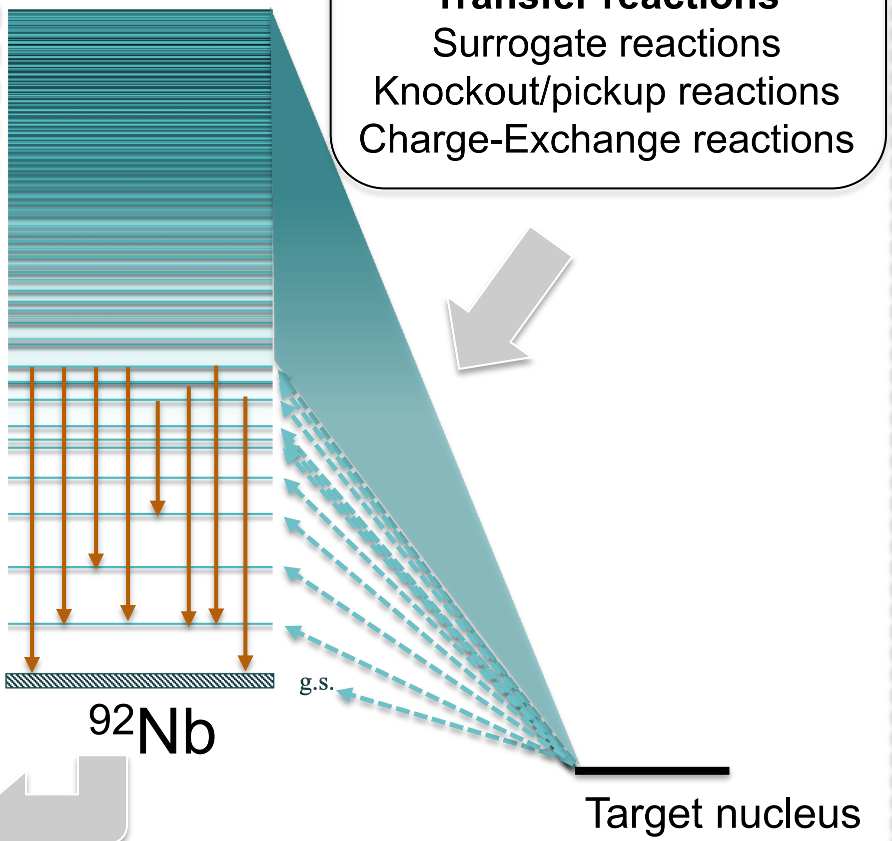
How Can We Constrain the ^{91}Nb(n,γ)^{92}Nb Reaction?

Direct measurements

Not feasible because ^{91}Nb is unstable and there is no practical neutron target for inverse kinematic measurements



Nuclear Experiments
Beta decays
Transfer reactions
Surrogate reactions
Knockout/pickup reactions
Charge-Exchange reactions



Indirect measurements

Hauser-Feshbach Calculations

Can access the same compound nucleus and can be applied for short-lived nuclei

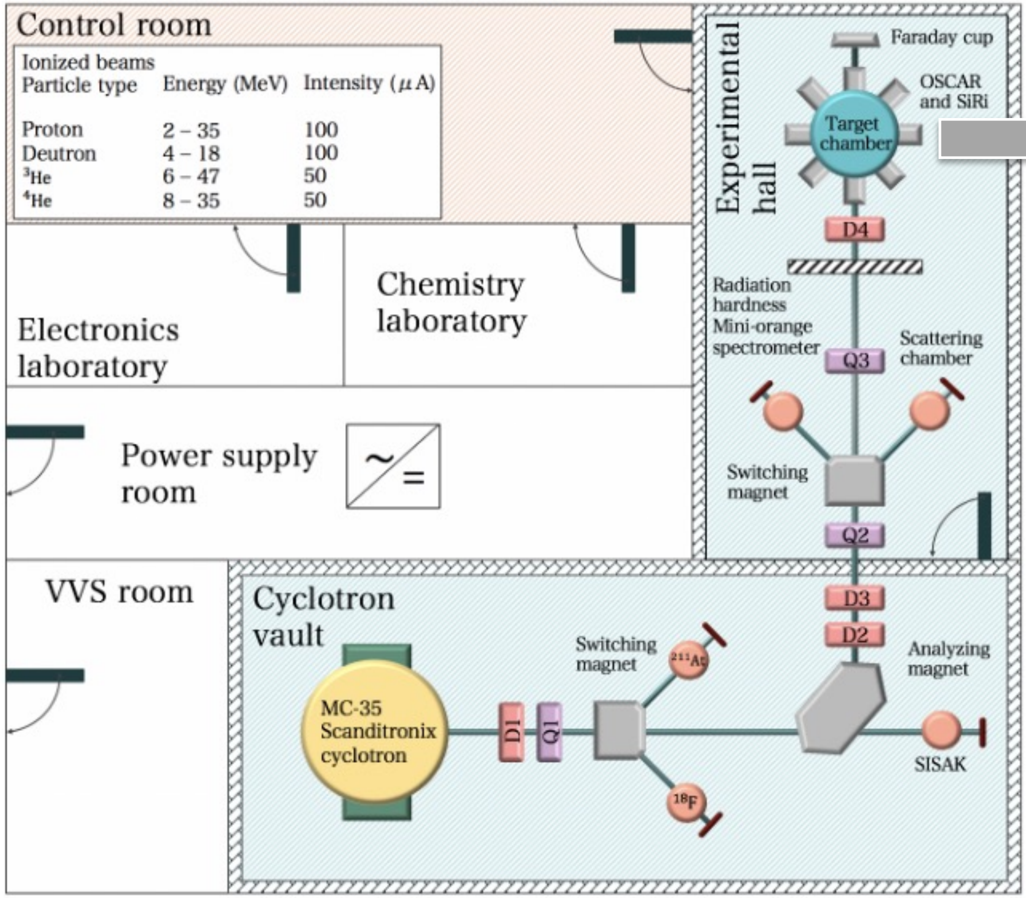
Optical Model Potential (OMP)

Odd-odd nucleus near N=50

Nuclear Level Density (NLD) of ^{92}Nb
γ-ray Strength Function (γSF) of ^{92}Nb

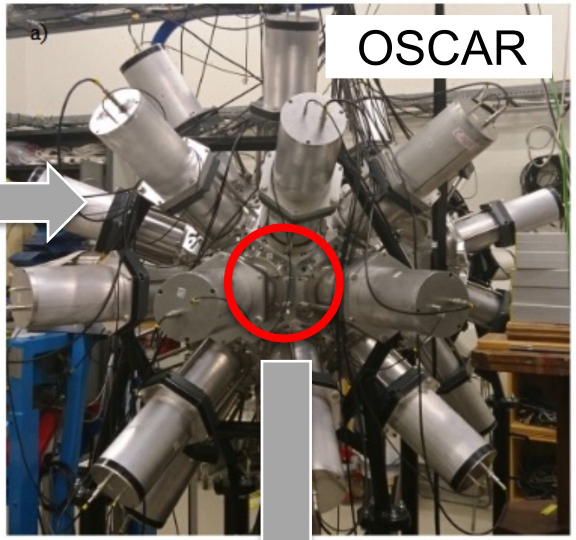
Oslo Method
β-Oslo Method
CE-Oslo Method
Surrogate Method
Inverse Oslo Method
γ-ray Strength Method
Particle Evaporation Method

$^{90}\mathrm{Zr}(\alpha,d+\gamma)^{92}\mathrm{Nb}$ Experiment at Oslo Cyclotron Laboratory

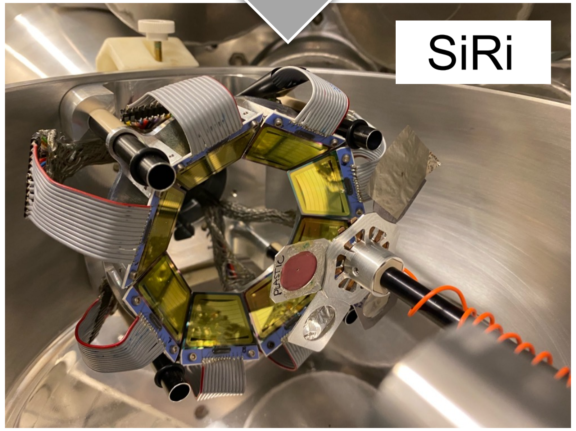


Ionized beams Particle type	Energy (MeV)	Intensity (μA)
Proton	2 – 35	100
Deutron	4 – 18	100
^{3}He	6 – 47	50
^{4}He	8 – 35	50

M.Markova's M.Sc. thesis



M.Markova's M.Sc. thesis



Captured by A.C. Larsen

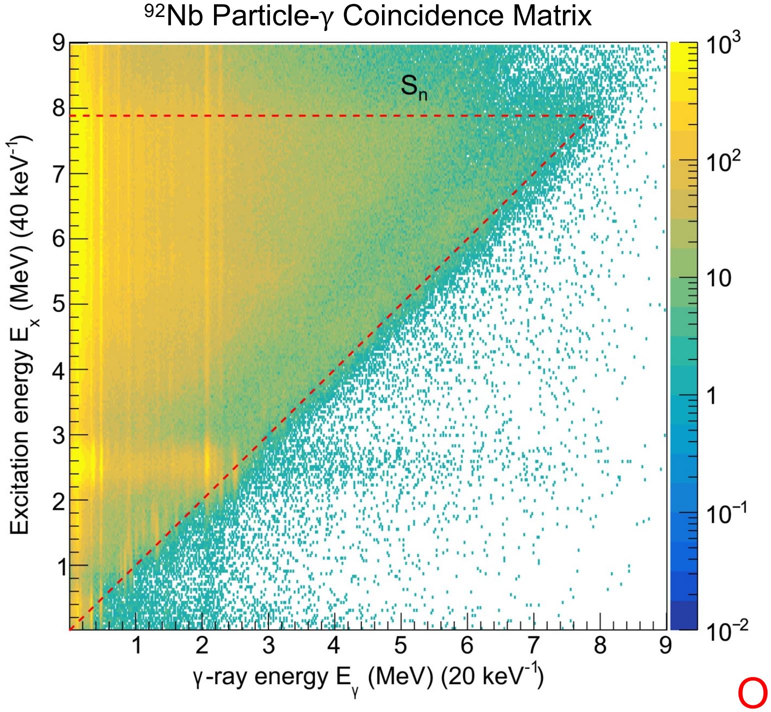
The experiment was run in forward kinematics using the SiRi[i] particle telescope in coincidence with the Oslo SCintillator ARray (OSCAR[ii])

- ^{4}He-beam energy: ~ 30 MeV
- ^{90}Zr Target thickness: ~ 1.9 mg/cm^{2}
- γ-rays were detected with OSCAR array, which consists of 30 large-volume $\mathrm{LaBr_3(Ce)}$ detectors
  - resolution: ~ 32 keV (FWHM) at Eγ ~ 0.5 MeV
- Deuterons were detected and identified with SiRi
  - resolution: ~ 175 keV (FWHM)

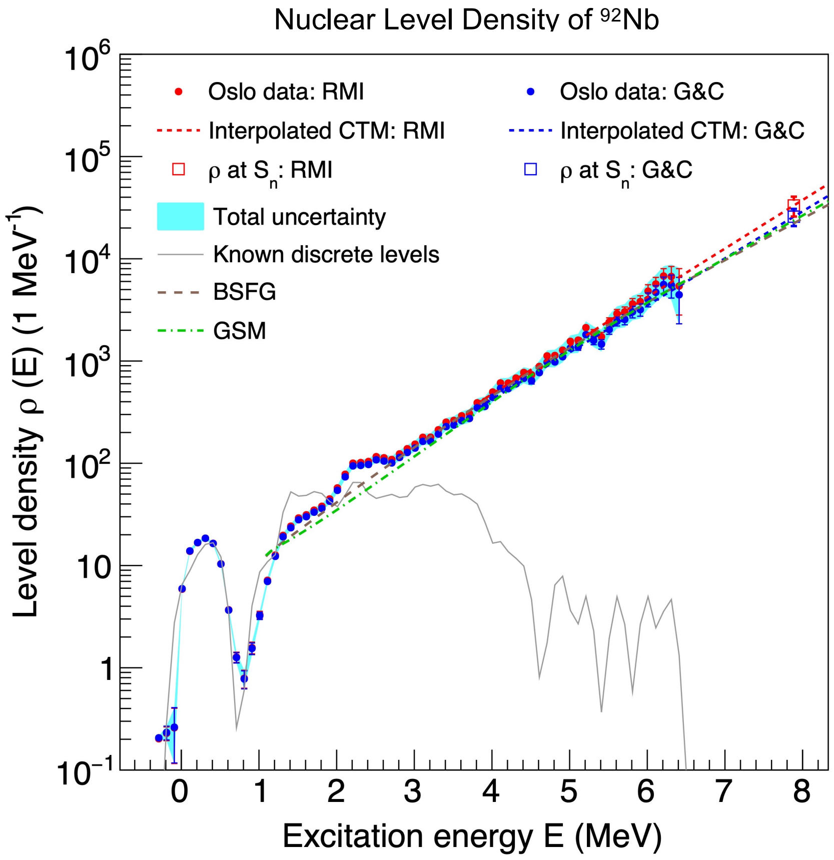
i. M. Guttormsen *et al*., *Nucl. Instrum. Methods Phys. Res., Sect. A* **648**, 168 (2011)
ii. F. Zeiser *et al*., *Nucl. Instrum. Methods Phys. Res., Sect. A* **985**, 164678 (2021)

Experimentally Extracted NLD and γSF of ^{92}Nb

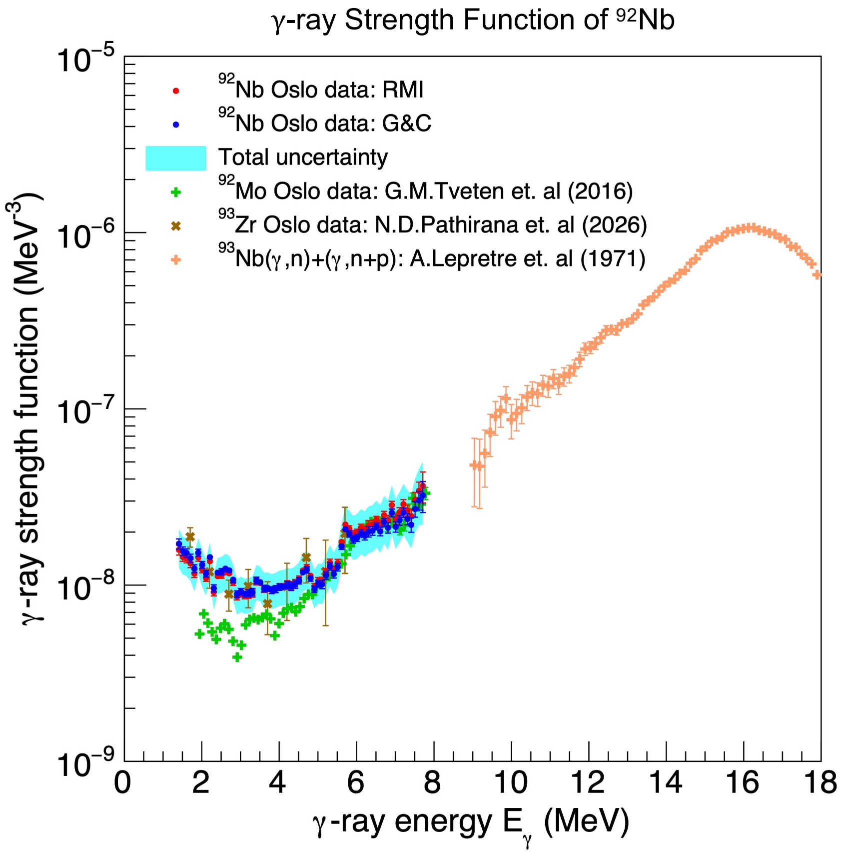
Measured excitation energies in ^{92}Nb, combined with coincident γ-rays detected at each excitation energy



Oslo Method



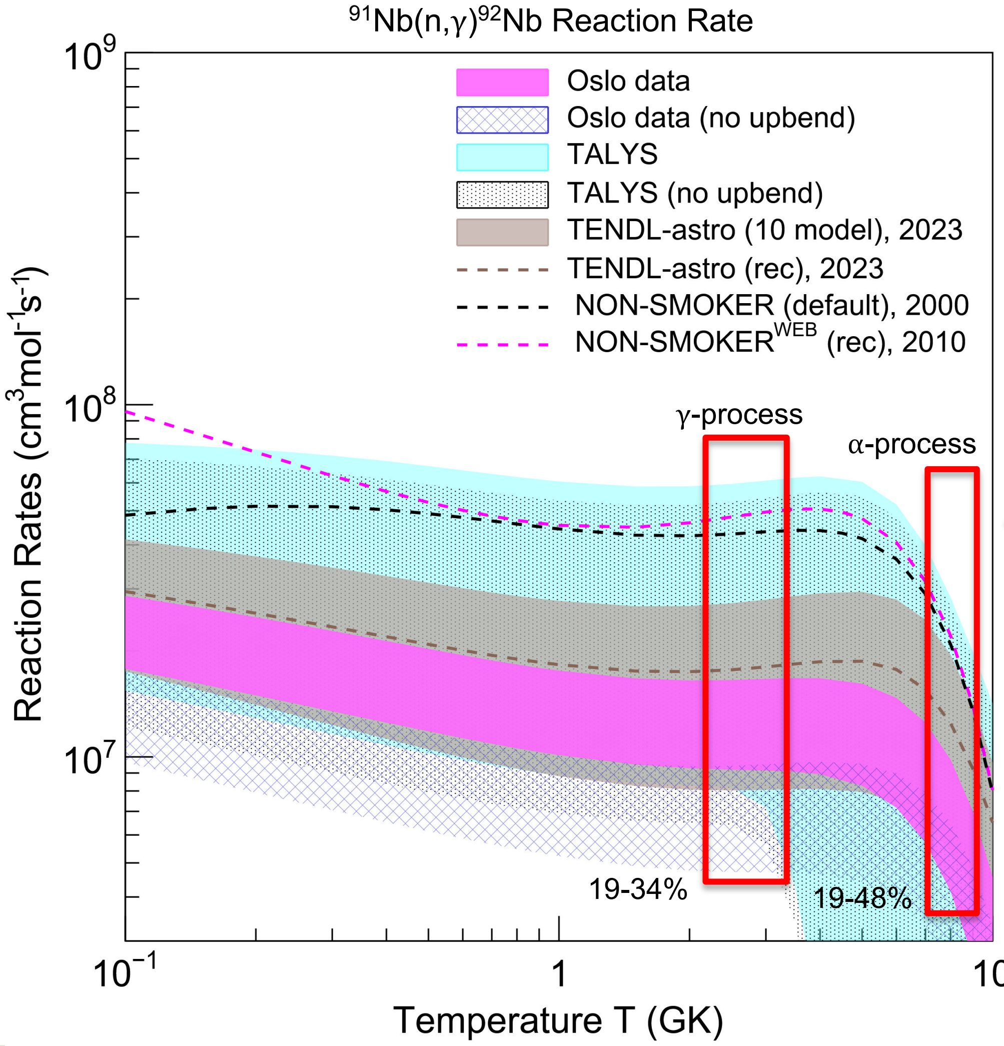
NLD: Number of levels per MeV as a function of E_x

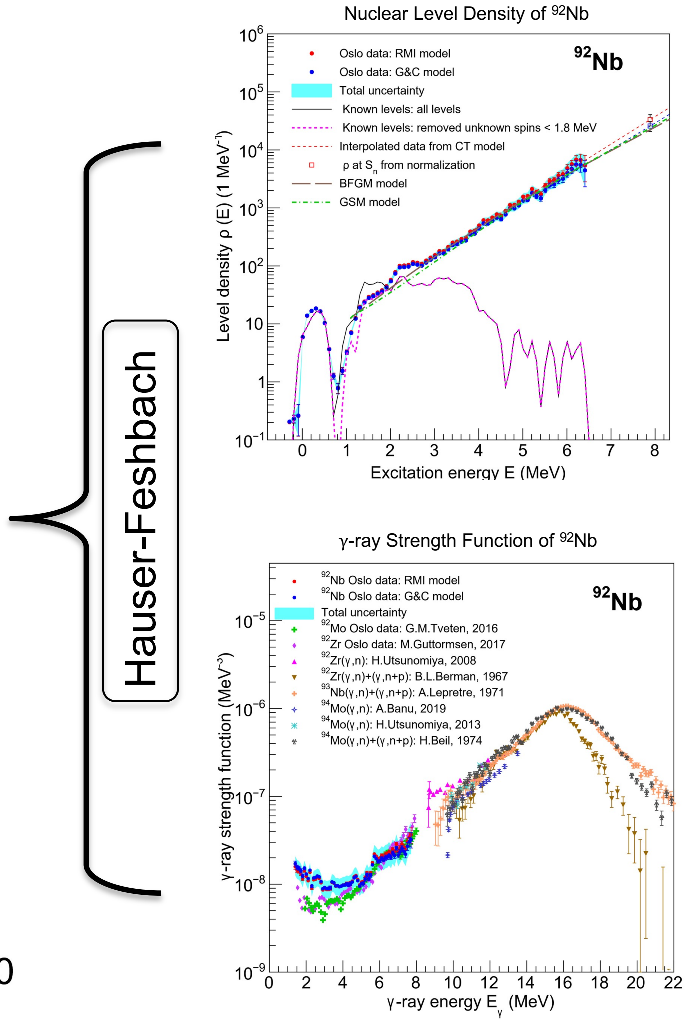


γSF: Probability to emit any γ-ray with different multipolarity

Constrained ^{91}Nb(n,γ)^{92}Nb Reaction Rate

- The reaction rate was constrained by propagating the extracted NLD and γSF of ^{92}Nb through Hauser-Feshbach calculations using TALYS (v1.96)[i]
- The experimentally constrained rate is significantly lower than the recommended NON-SMOKER[ii] rate
- This NON-SMOKER rate is widely used in supernovae simulations





[i] A. Koning et al., Eur. Phys. J. A (2023) 59:131

[ii] R.H. Cyburt et al., (2010), ApJS, 189, 240

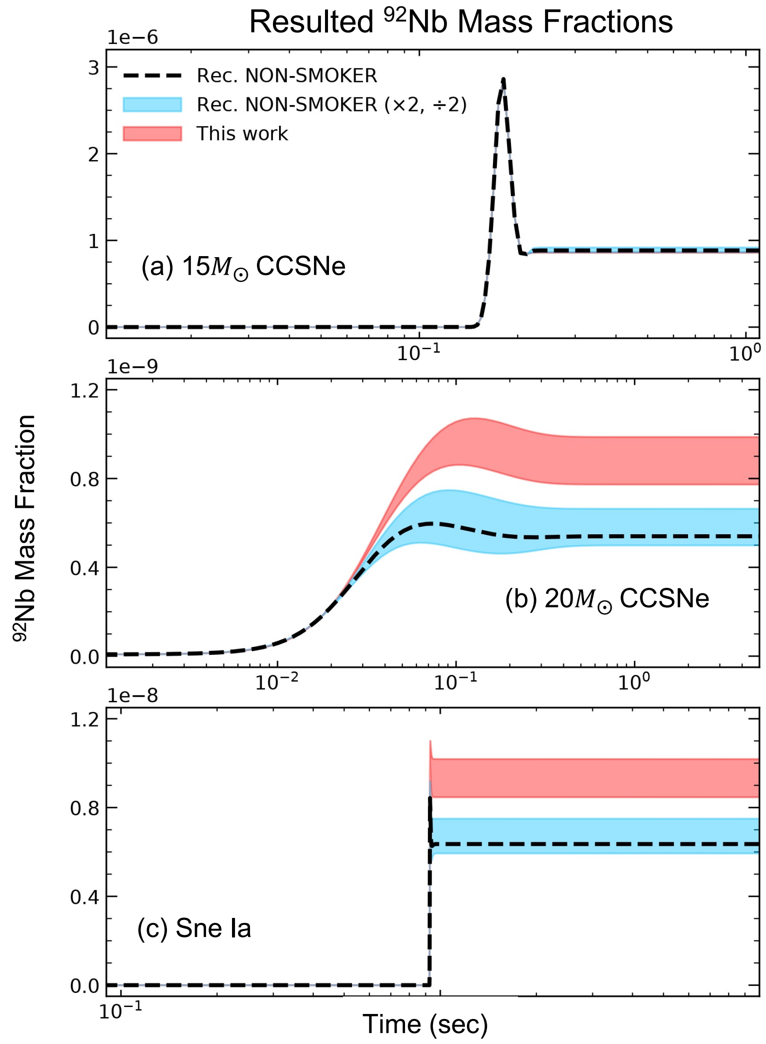
CCSNe and SNe Ia Simulations and Impact on GCE

- The astrophysical impact of the improved ^{91}Nb(n,γ)^{92}Nb reaction rate was evaluated using NuGrid one-zone PPN[i] simulations for both CCSNe (Ritter 2018[ii]) and SNe Ia (Travaglio 2014[iii]) scenarios:
  - 15$M_\odot$ CCSNe : α-process – no-change in ^{92}Nb abundance
  - 20$M_\odot$ CCSNe : γ-process
  - SNe Ia : γ-process

  } 50-90% enhancement in ^{92}Nb abundance

- This shifts γ-process predictions in the direction needed to ease the long-standing ESS ^{92}Nb/^{92}Mo discrepancy and aligning with timescales from other SLRs

- By removing the dominant nuclear uncertainty in the ^{92}Nb production network, this work implies that resolving the remaining discrepancy will require improved astrophysical models and revised GCE calculations



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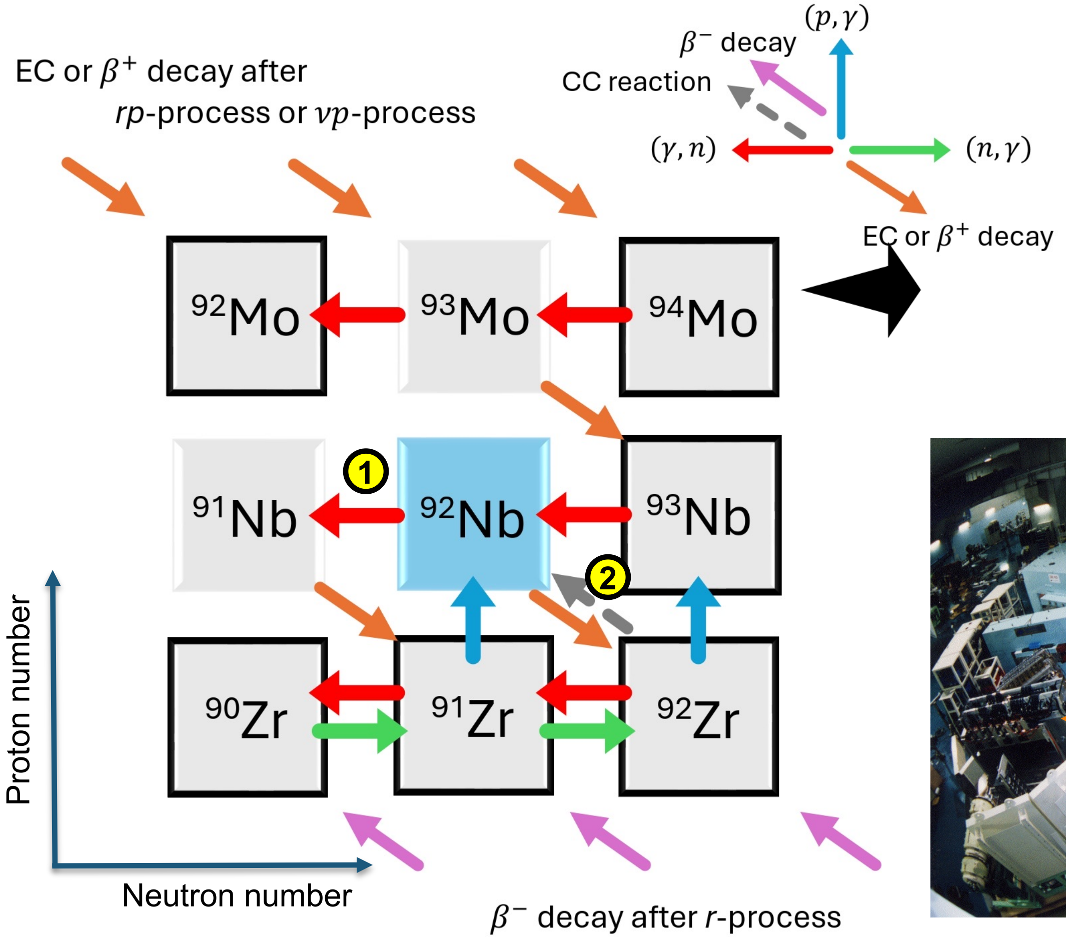
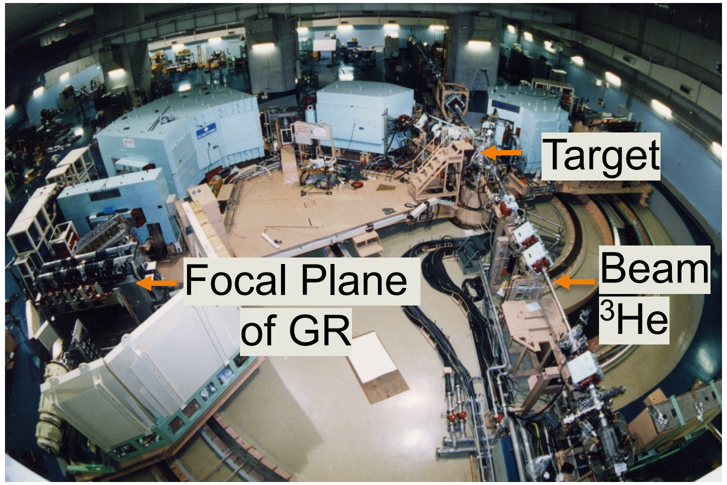
i. F. Herwig et al., PoS NIC X 053 (2009) 023.
ii. Ritter et al., MNRAS 480 (2018) 538–571
iii. C. Travaglio et al., Ap.J. 795: 141 (2014)

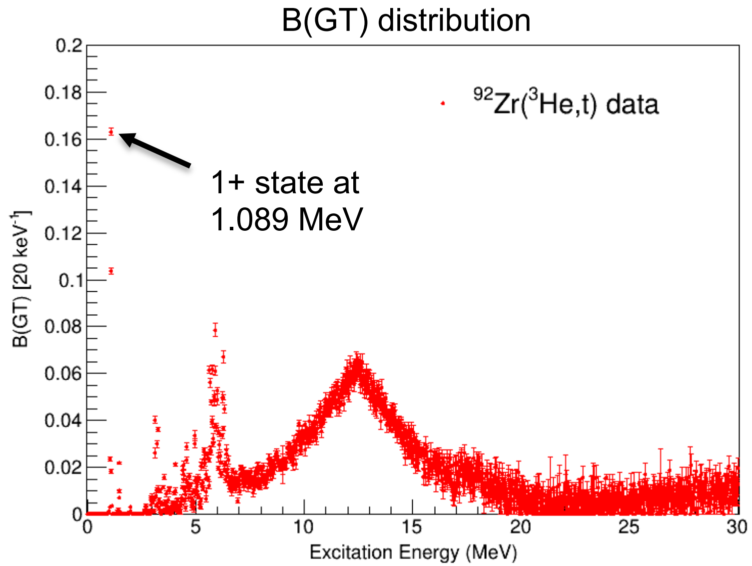
Experimental Study of ^{92}Nb Production via Charged-Current Neutrino Reaction



- The first experimental extraction of CC **^{92}Zr(ν_e,e^-)^{92}Nb**[i,ii] ② cross sections is currently in progress
- The main nuclear input at supernovae energies is the Gamow-Teller strength distribution, which is extracted using Multipole Decomposition Analysis applied to the experimental data obtained from ^{92}Zr(^{3}He,t) experiment performed at RCNP



https://www.rcnp.osaka-u.ac.jp/



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[i] T. Hayakawa et al., Ap.J.Lett. 779, L9 (2013)
[ii] Z. Xiong et al., Phys. Rev. Lett. 132, 152701 (2024)

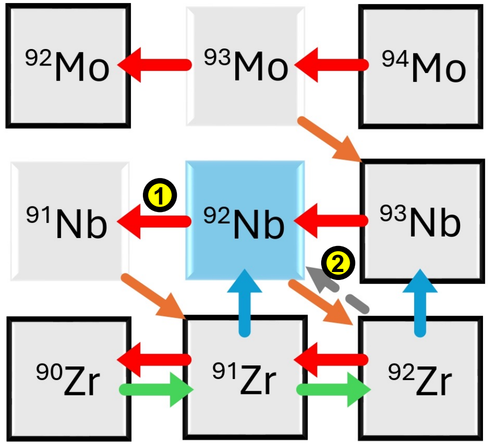
It is Planned to Run a ^{92}Zr(^{3}He,t+γ) Experiment at RCNP

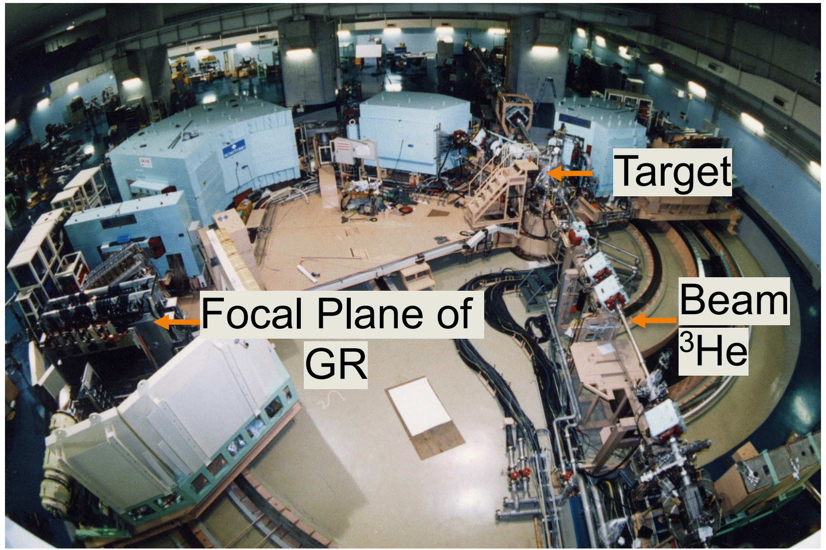
The goal is to constrain both the ^{92}Nb(γ,n)^{91}Nb ① and ^{92}Zr(ν_e,e^-)^{92}Nb ② reactions in a single experiment

methods

Charge-Exchange Oslo Method

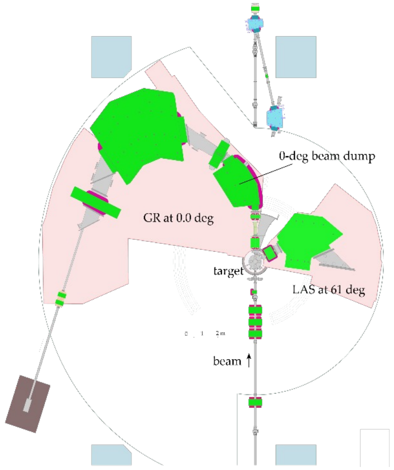
Multipole Decomposition Analysis



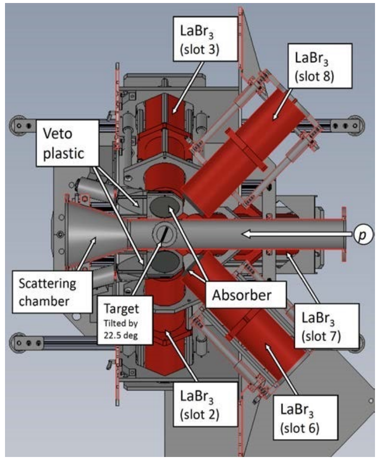


https://www.rcnp.osaka-u.ac.jp/

- The experiment will be run in forward kinematics using the Grand Raiden Spectrometer (GR) in coincidence with the Scintillation Gamma-Ray Detector (SGD) array
  - ^{3}He beam energy: 420 MeV
  - ^{92}Zr Target thickness: ~ 4 mg/cm^{2}
  - Tritons will be detected and identified in the focal plane of the GR in the 0^{o} setting
  - The SGD array will consist of 8 large-volume LaBr$_3$ detectors (3.5” in diameter and 8” deep)



A. Tamii, N. Kobayashi c

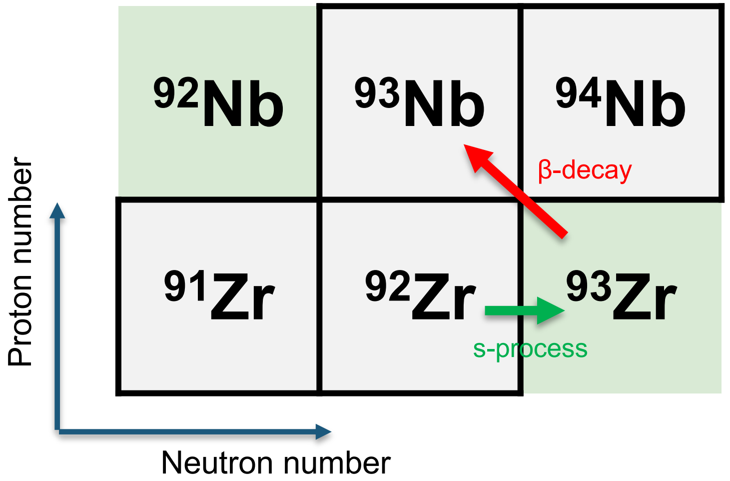


A. Tamii, N. Kobayashi c

First Application of the Charge-Exchange Oslo Method: Experiment Details

The ^{93}Nb(t,^{3}He+γ)^{93}Zr experiment was conducted at 115 MeV/u at NSCL/FRIB using the S800 spectrometer in coincidence with GRETINA[i]

- The primary purpose was to measure Gamow-Teller Transitions from ^{93}Nb to ^{93}Zr
- The CE-Oslo method was later tested using the resulting particle-γ coincidence data
- Hence, the ^{92}Zr(n,γ)^{93}Zr cross section was benchmarked indirectly



^{93}Nb(t,^{3}He+γ)^{93}Zr experiment setup at FRIB

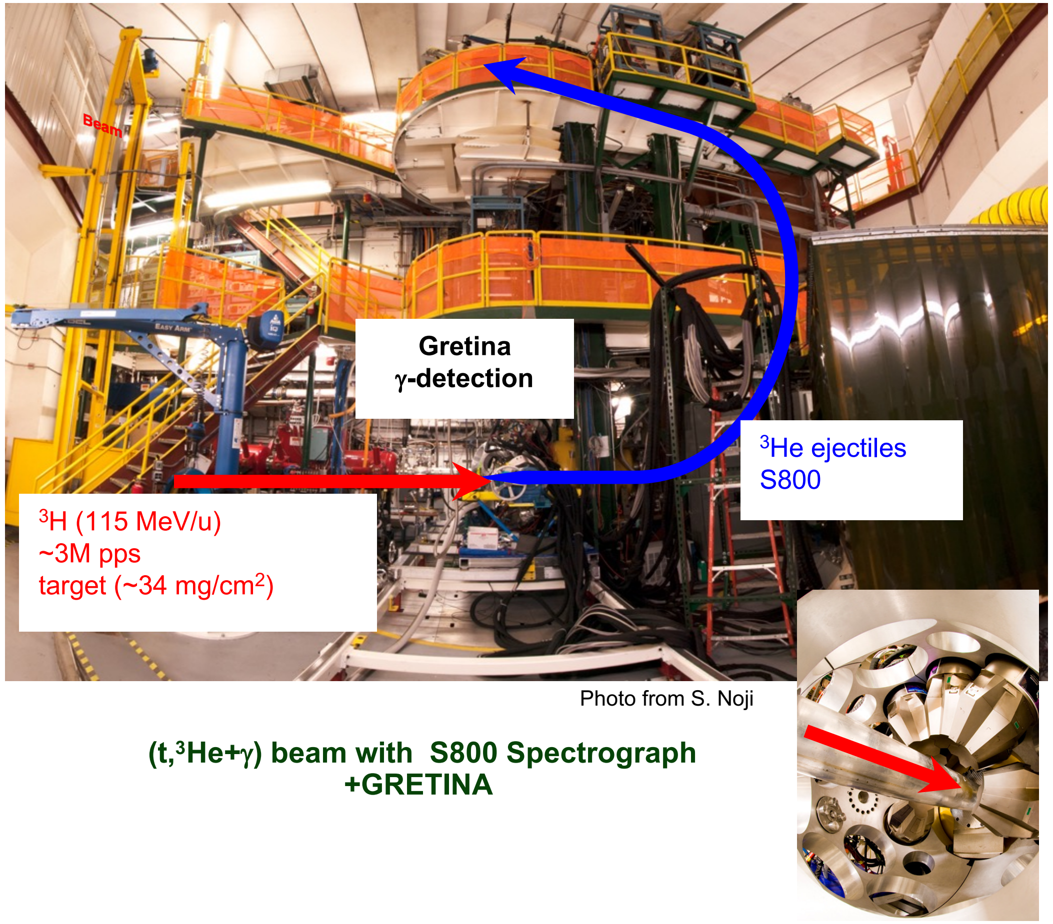


Photo from S. Noji

(t,^{3}He+γ) beam with S800 Spectrograph +GRETINA

Gamma-Ray Energy Tracking In-beam Nuclear Array

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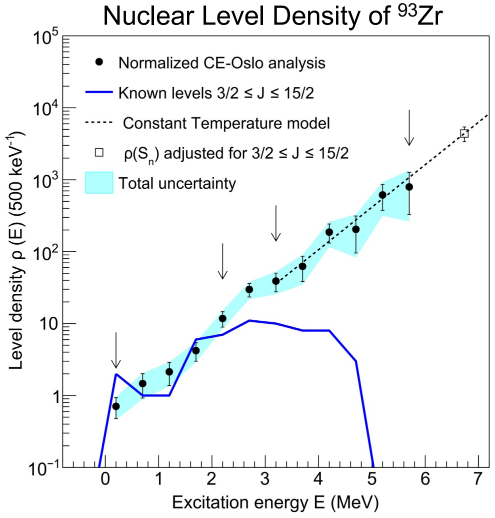
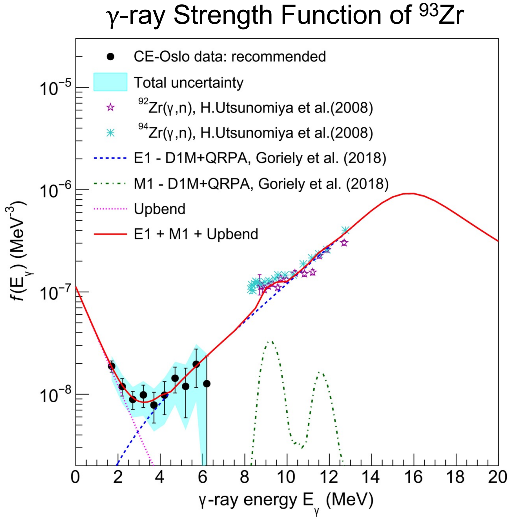
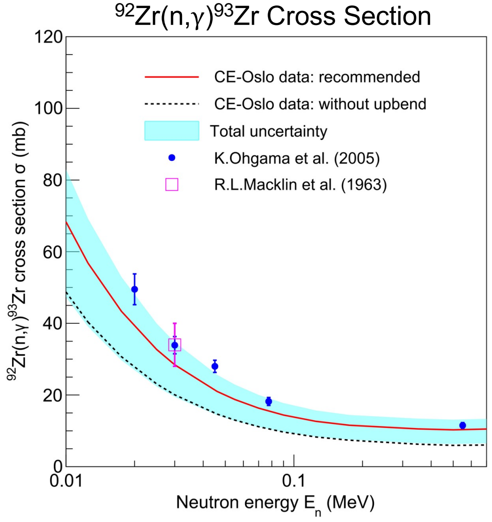
[i] B.Gao et al., PhysRevC.101.014308, 2020

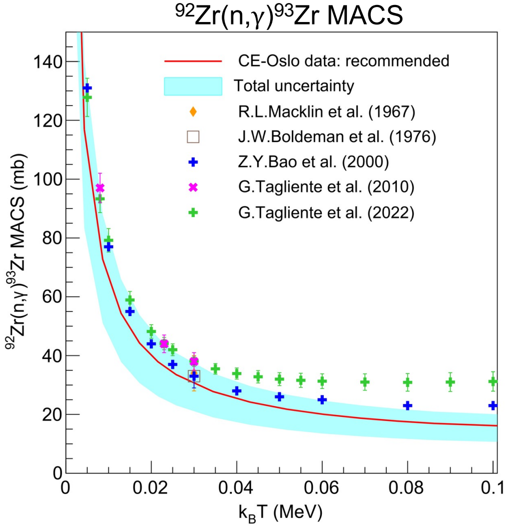
First Application of the Charge-Exchange Oslo Method: Results

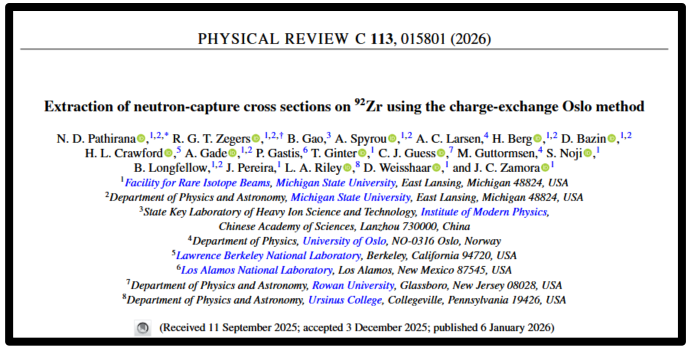
- The ^{92}Zr(n,γ)^{93}Zr cross section was constrained using the experimentally extracted NLD and γSF of ^{93}Zr
- This was the 1st time that:
  - The NLD and γSF of ^{93}Zr were experimentally constrained
  - The CE-Oslo method was applied to constrain an (n,γ) cross sections
  - The Oslo method was applied to particle-γ coincidence data taken with S800 and GRETINA to constrain an (n,γ) cross section
- The results were published in Physical Review C 113, 015801 as the first application of the CE-Oslo Method










PHYSICAL REVIEW C **113**, 015801 (2026)

Extraction of neutron-capture cross sections on ^{92}Zr using the charge-exchange Oslo method

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Summary

- We obtained the first experimental constraints on the NLD and γSF of ^{92}Nb and used them to derive a semi-experimental ^{91}Nb(n,γ)^{92}Nb reaction rate
- The revised rate shifts predictions in the direction needed to ease the long-standing ESS ^{92}Nb/^{92}Mo discrepancy, but the remaining tension points to the need for improved astrophysical models and updated GCE calculations
- The first experimental constraints on neutrino-driven ^{92}Nb production are in the late stage
- As an independent verification, a ^{92}Zr(^{3}He, t+γ)^{92}Nb experiment is planned at RCNP
- The CE-Oslo Method has now been demonstrated and provides a powerful new tool for constraining indirect neutron-capture reactions

Thank You!

FRIB

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J. Zamora
R.G.T. Zegers
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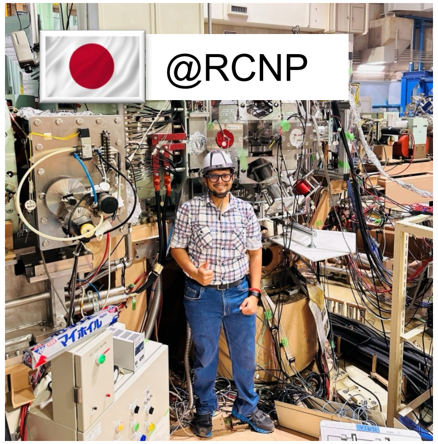
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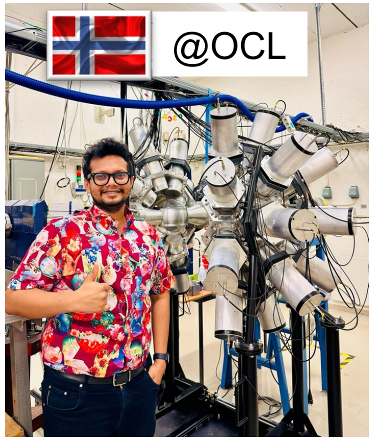
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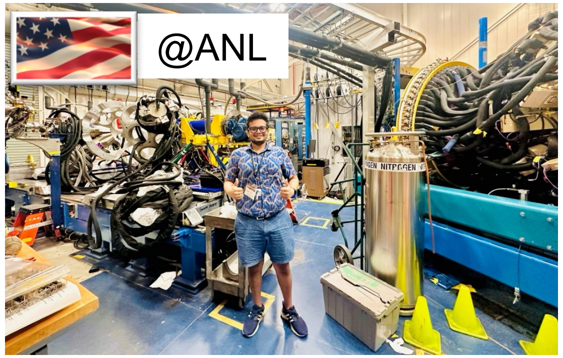
P. von Neumann-Cosel


@ANL


@Felsenkeller

NSF

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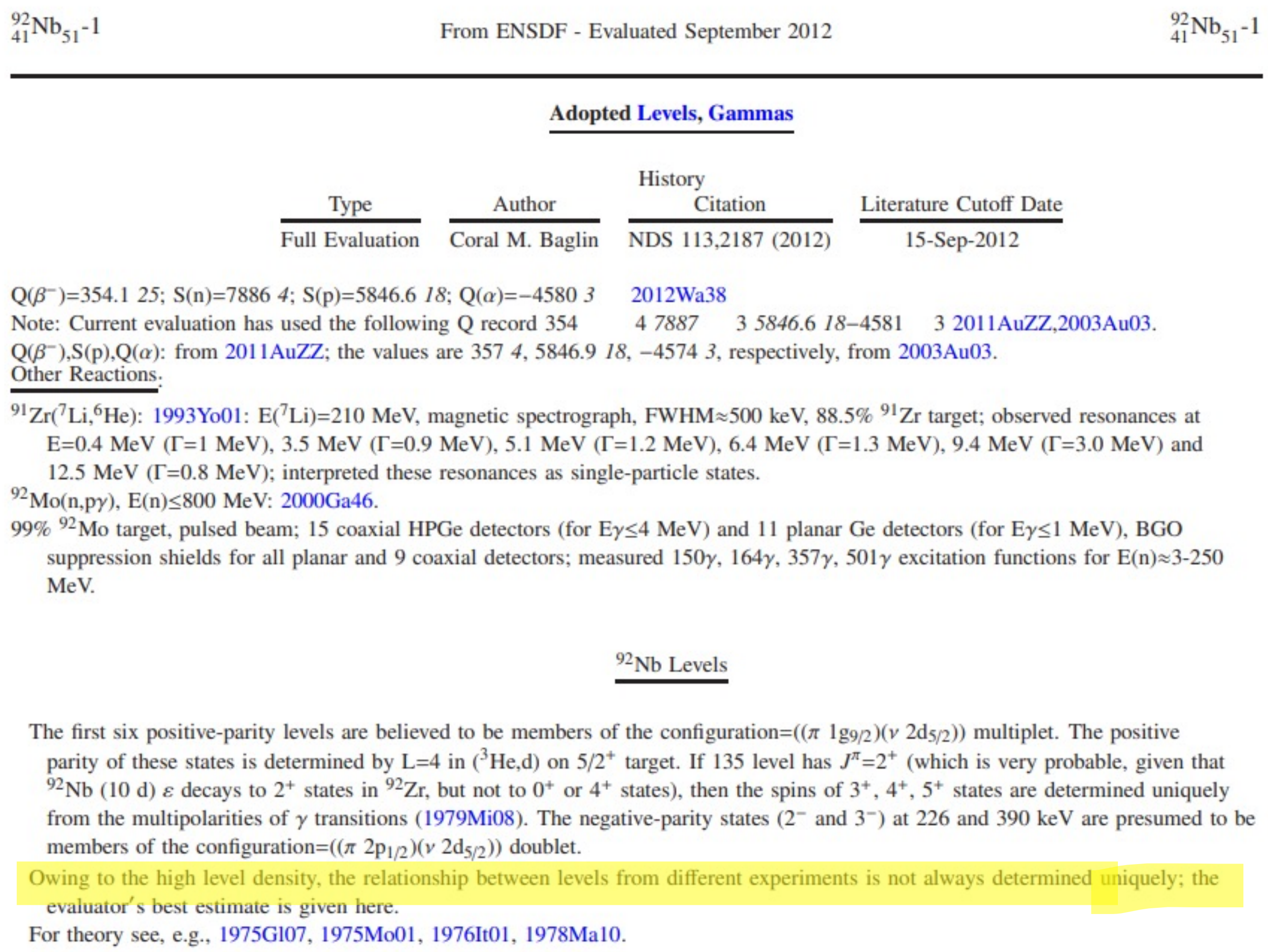
Travel support

^{92}Nb Levels @ENSDF



$^{92}_{41}$Nb$_{51}$-1 From ENSDF - Evaluated September 2012 $^{92}_{41}$Nb$_{51}$-1

Adopted Levels, Gammas

Type	Author	History Citation	Literature Cutoff Date
Full Evaluation	Coral M. Baglin	NDS 113,2187 (2012)	15-Sep-2012

Q(β^-)=354.1 *25*; S(n)=7886 *4*; S(p)=5846.6 *18*; Q(α)=−4580 *3* 2012Wa38
Note: Current evaluation has used the following Q record 354 4 *7887* 3 *5846.6 18*−4581 3 2011AuZZ,2003Au03.
Q(β^-),S(p),Q(α): from 2011AuZZ; the values are 357 *4*, 5846.9 *18*, −4574 *3*, respectively, from 2003Au03.

Other Reactions.

^{91}Zr(^{7}Li,^{6}He): 1993Yo01: E(^{7}Li)=210 MeV, magnetic spectrograph, FWHM≈500 keV, 88.5% ^{91}Zr target; observed resonances at E=0.4 MeV (Γ=1 MeV), 3.5 MeV (Γ=0.9 MeV), 5.1 MeV (Γ=1.2 MeV), 6.4 MeV (Γ=1.3 MeV), 9.4 MeV (Γ=3.0 MeV) and 12.5 MeV (Γ=0.8 MeV); interpreted these resonances as single-particle states.

^{92}Mo(n,pγ), E(n)≤800 MeV: 2000Ga46.

99% ^{92}Mo target, pulsed beam; 15 coaxial HPGe detectors (for Eγ≤4 MeV) and 11 planar Ge detectors (for Eγ≤1 MeV), BGO suppression shields for all planar and 9 coaxial detectors; measured 150γ, 164γ, 357γ, 501γ excitation functions for E(n)≈3-250 MeV.

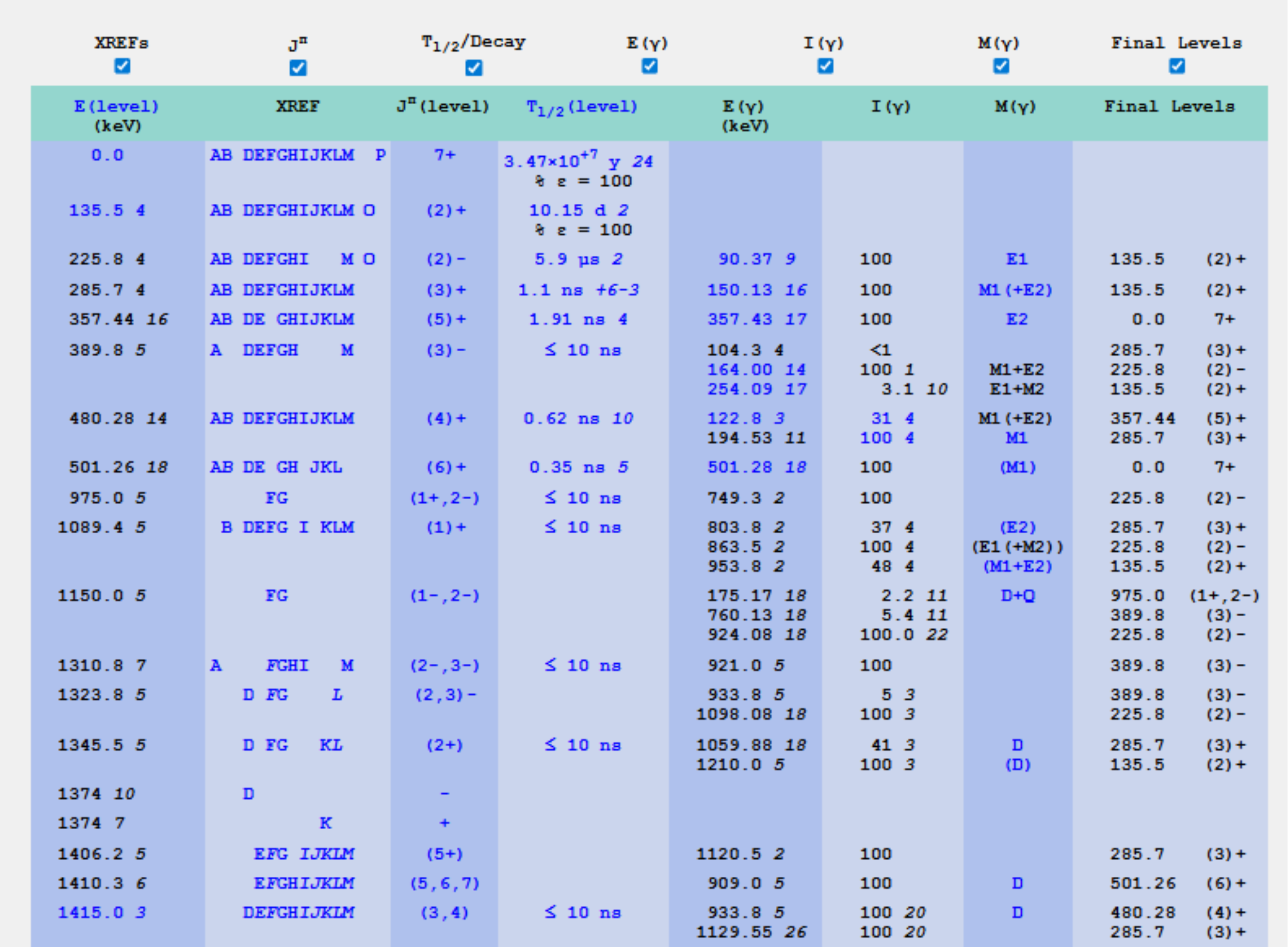
^{92}Nb Levels

The first six positive-parity levels are believed to be members of the configuration=((π 1g$_{9/2}$)(ν 2d$_{5/2}$)) multiplet. The positive parity of these states is determined by L=4 in (^{3}He,d) on 5/2$^+$ target. If 135 level has J^π=2$^+$ (which is very probable, given that ^{92}Nb (10 d) ε decays to 2$^+$ states in ^{92}Zr, but not to 0$^+$ or 4$^+$ states), then the spins of 3$^+$, 4$^+$, 5$^+$ states are determined uniquely from the multipolarities of γ transitions (1979Mi08). The negative-parity states (2$^-$ and 3$^-$) at 226 and 390 keV are presumed to be members of the configuration=((π 2p$_{1/2}$)(ν 2d$_{5/2}$)) doublet.

Owing to the high level density, the relationship between levels from different experiments is not always determined uniquely; the evaluator's best estimate is given here.

For theory see, e.g., 1975Gl07, 1975Mo01, 1976It01, 1978Ma10.

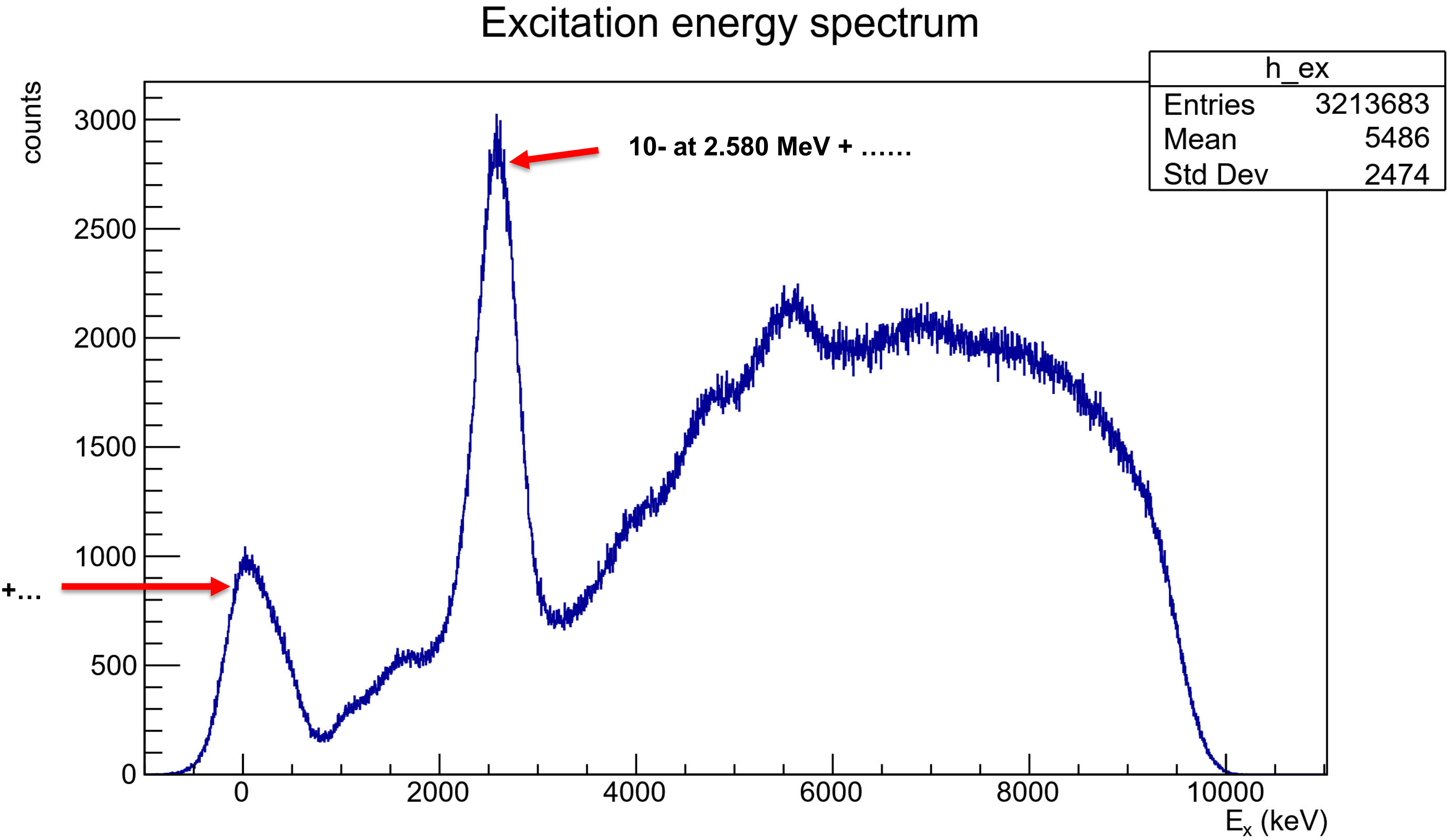
^{92}Nb Levels @ENSDF



XREFs	J^π	$T_{1/2}$/Decay	E(γ)	I(γ)	M(γ)	Final Levels
☑	☑	☑	☑	☑	☑	☑

E(level) (keV)	XREF	J^π(level)	$T_{1/2}$(level)	E(γ) (keV)	I(γ)	M(γ)	Final Levels	
0.0	AB DEFGHIJKLM P	7+	$3.47\times10^{+7}$ y 24 % ε = 100					
135.5 4	AB DEFGHIJKLM O	(2)+	10.15 d 2 % ε = 100					
225.8 4	AB DEFGHI M O	(2)-	5.9 μs 2	90.37 9	100	E1	135.5	(2)+
285.7 4	AB DEFGHIJKLM	(3)+	1.1 ns +6-3	150.13 16	100	M1(+E2)	135.5	(2)+
357.44 16	AB DE GHIJKLM	(5)+	1.91 ns 4	357.43 17	100	E2	0.0	7+
389.8 5	A DEFGH M	(3)-	≤ 10 ns	104.3 4 164.00 14 254.09 17	<1 100 1 3.1 10	 M1+E2 E1+M2	285.7 225.8 135.5	(3)+ (2)- (2)+
480.28 14	AB DEFGHIJKLM	(4)+	0.62 ns 10	122.8 3 194.53 11	31 4 100 4	M1(+E2) M1	357.44 285.7	(5)+ (3)+
501.26 18	AB DE GH JKL	(6)+	0.35 ns 5	501.28 18	100	(M1)	0.0	7+
975.0 5	FG	(1+,2-)	≤ 10 ns	749.3 2	100		225.8	(2)-
1089.4 5	B DEFG I KLM	(1)+	≤ 10 ns	803.8 2 863.5 2 953.8 2	37 4 100 4 48 4	(E2) (E1(+M2)) (M1+E2)	285.7 225.8 135.5	(3)+ (2)- (2)+
1150.0 5	FG	(1-,2-)		175.17 18 760.13 18 924.08 18	2.2 11 5.4 11 100.0 22	D+Q	975.0 389.8 225.8	(1+,2-) (3)- (2)-
1310.8 7	A FGHI M	(2-,3-)	≤ 10 ns	921.0 5	100		389.8	(3)-
1323.8 5	D FG L	(2,3)-		933.8 5 1098.08 18	5 3 100 3		389.8 225.8	(3)- (2)-
1345.5 5	D FG KL	(2+)	≤ 10 ns	1059.88 18 1210.0 5	41 3 100 3	D (D)	285.7 135.5	(3)+ (2)+
1374 10	D	-						
1374 7	K	+						
1406.2 5	EFG IJKLM	(5+)		1120.5 2	100		285.7	(3)+
1410.3 6	EFGHIJKLM	(5,6,7)		909.0 5	100	D	501.26	(6)+
1415.0 3	DEFGHIJKLM	(3,4)	≤ 10 ns	933.8 5 1129.55 26	100 20 100 20	D	480.28 285.7	(4)+ (3)+

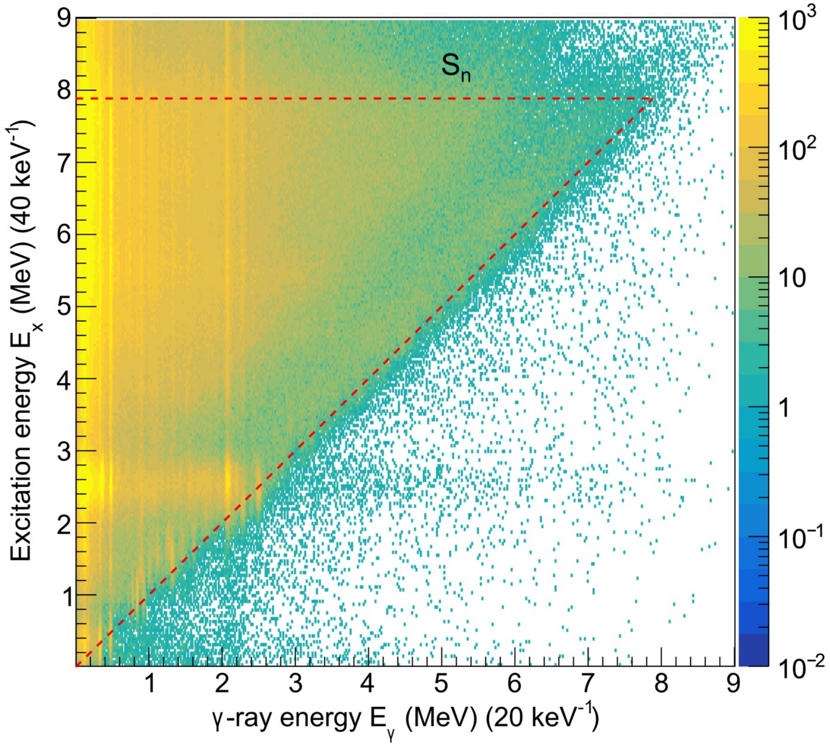
Recalibrated 92Nb Excitation Energy Spectrum

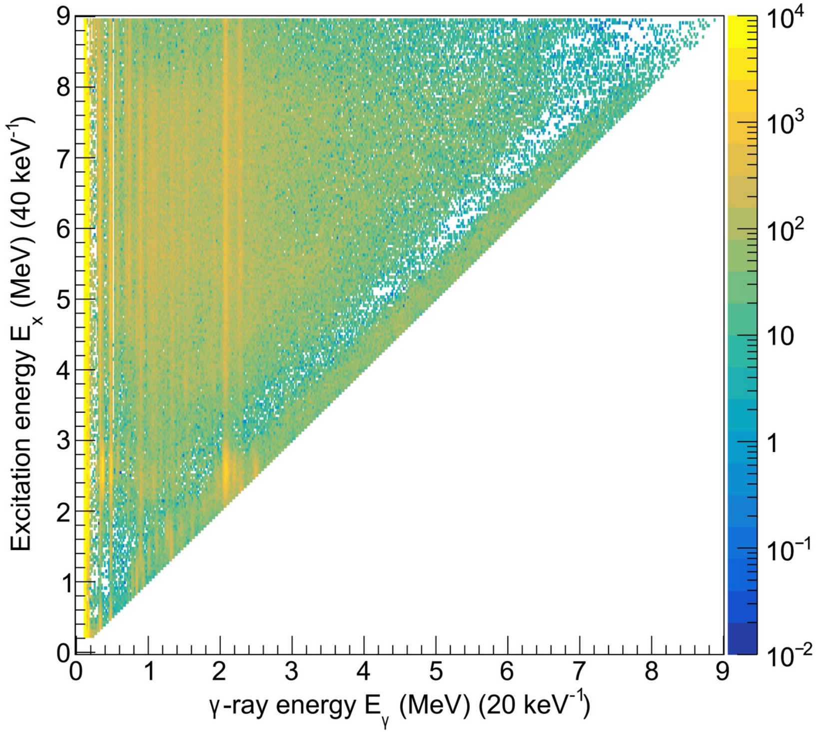


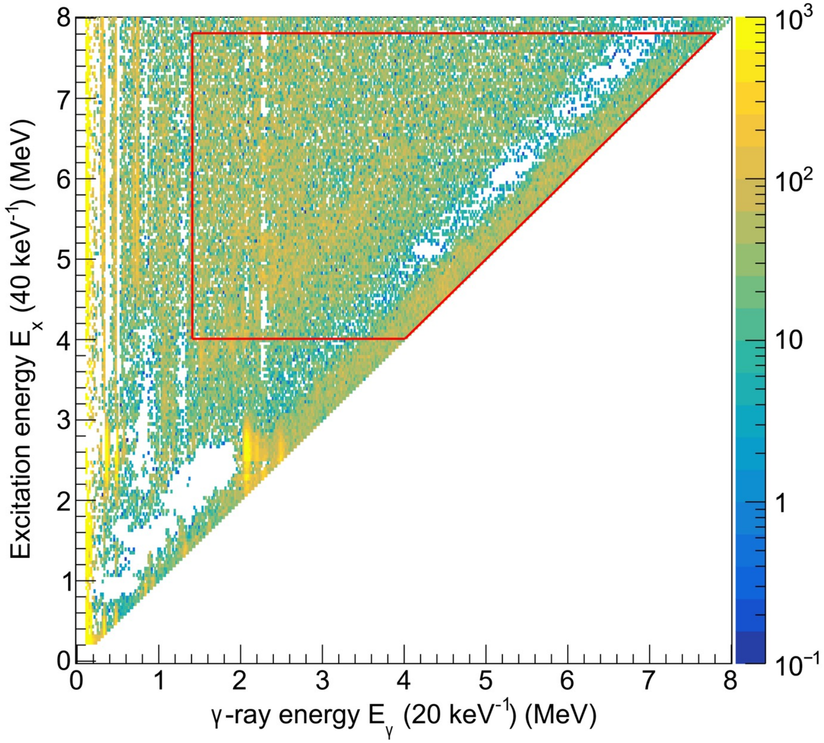
10- at 2.580 MeV + ……

GS+…

92Nb Primary Matrix (New-Final!!!)


Raw Matrix Compressed

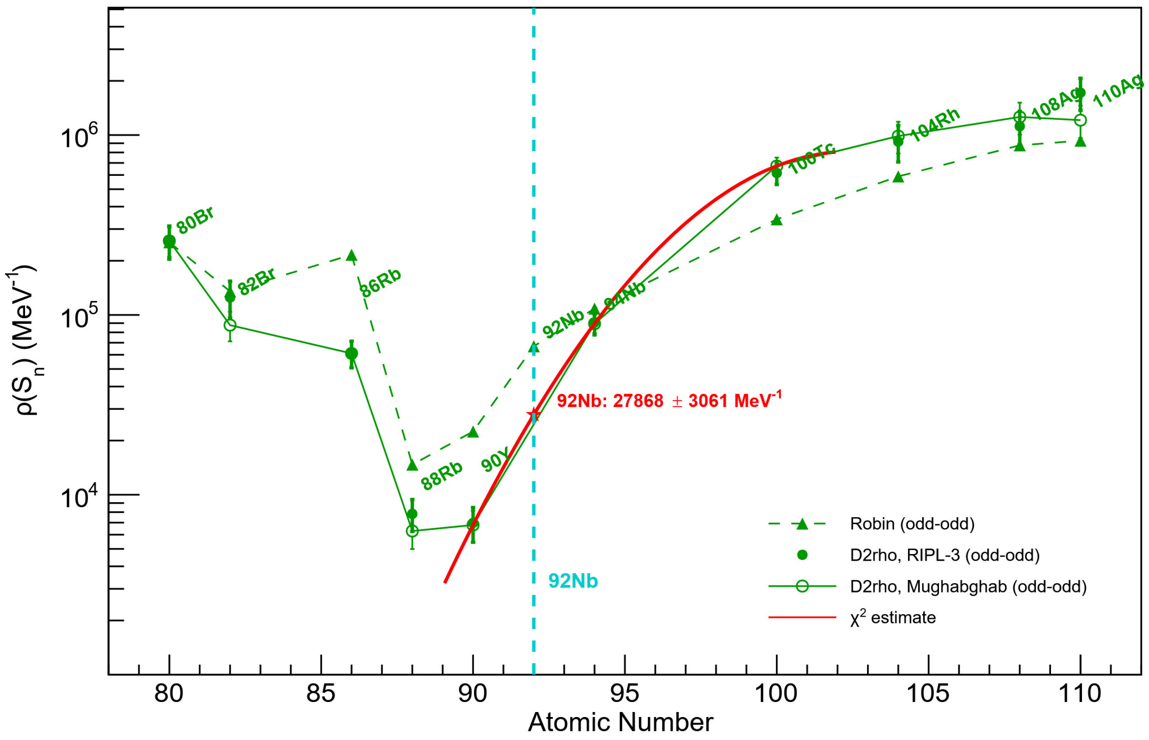

Unfold Matrix Compressed


Primary Matrix

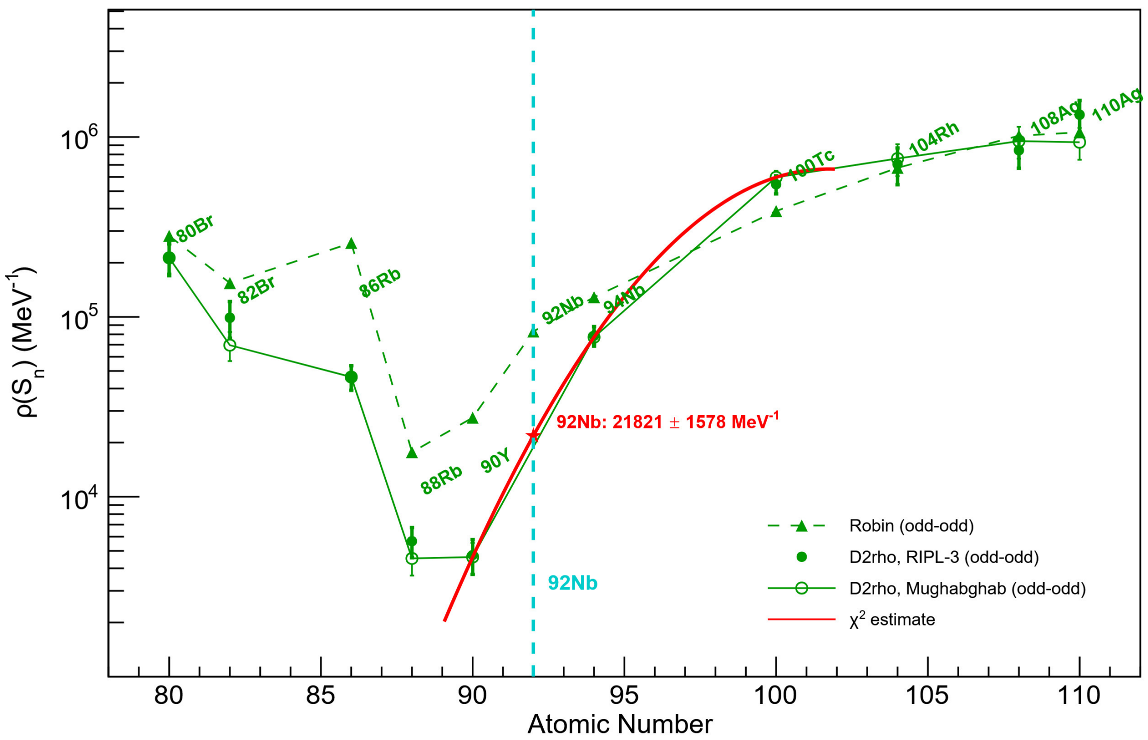
Estimation of ^{92}Nb Systematic Level Density at S_n

- The Robin (theoretical) and D2rho-RIPL3 and Mughabghab (semi-experimental) calculated systematic level densities at Sn for the Br–Ag range were plotted separately for odd-odd nuclei with respect to atomic number
- The results from D2rho-Mughabghab were fitted with a quadratic function ($y=\exp(ax^2+bx+c)$)
- The error σ at A=92 was calculated using the fitting parameters $p_{i,j} = a, b, c$

Rigid Moment of Inertia Model (RMI)(E&B2006)

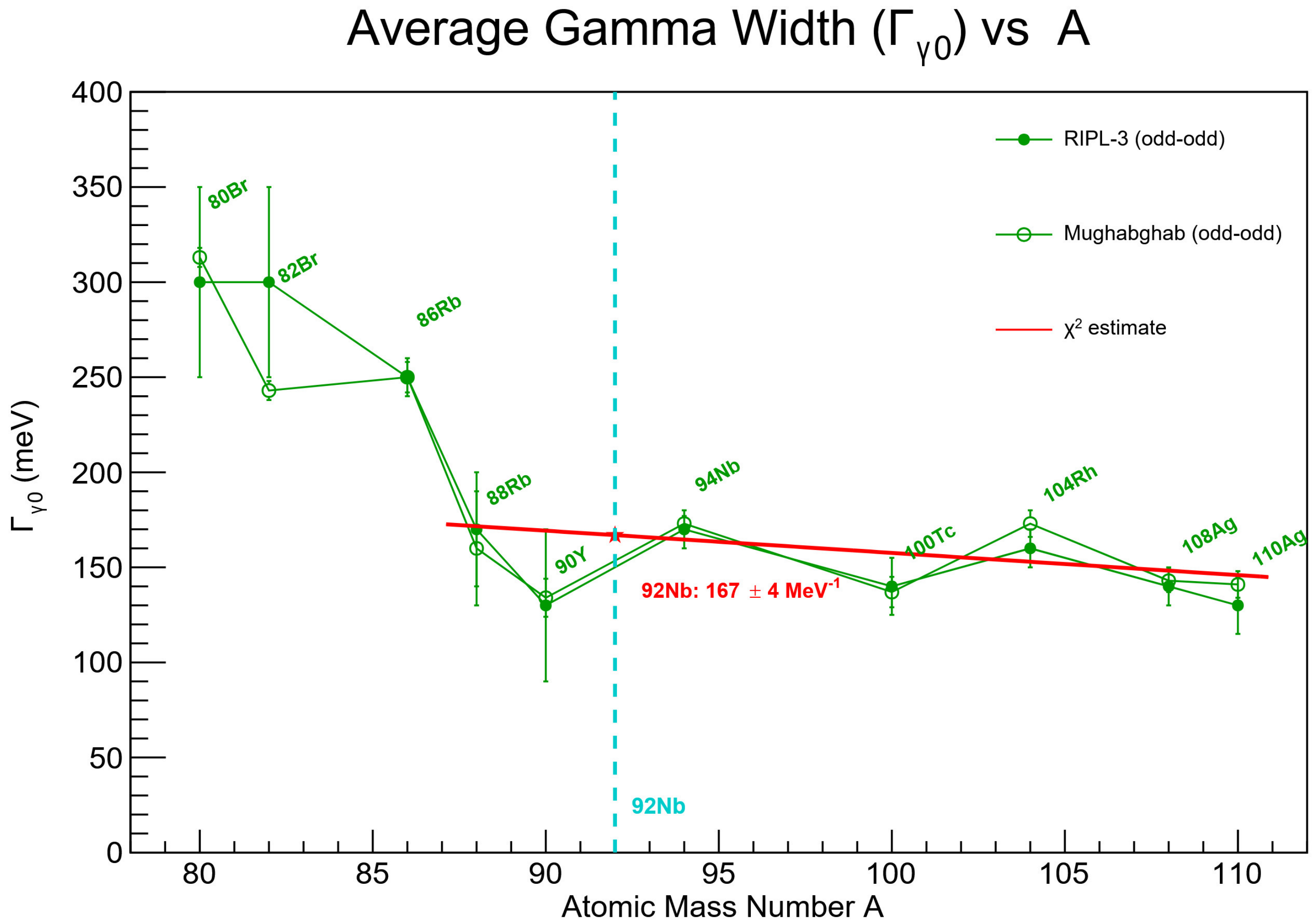


Gilbert-Cameron 1965 Model (G&C)



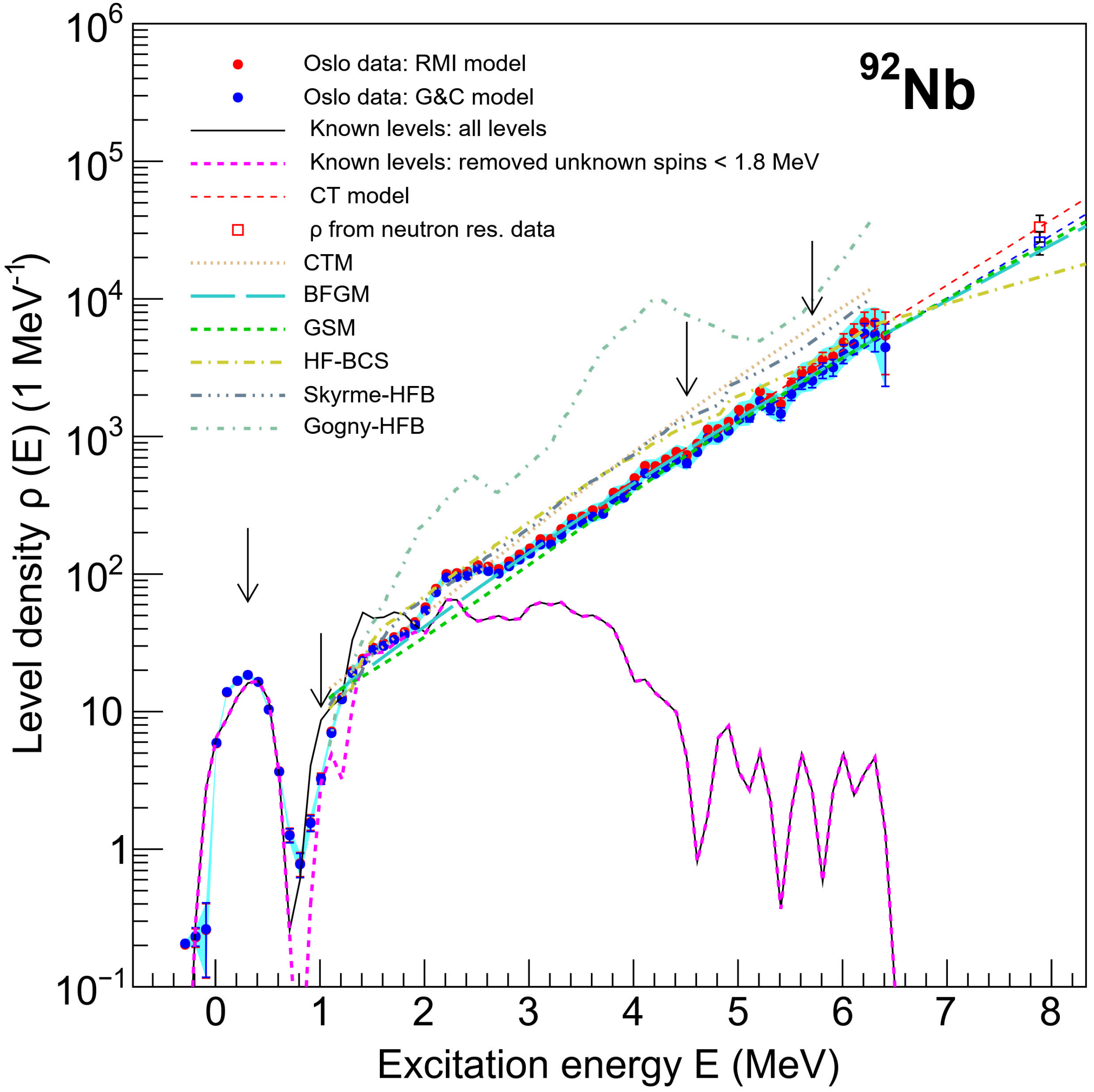
Estimation of ^{92}Nb Average Radiative Width $\Gamma_{\gamma 0}$

- The neutron resonance $\mathbf{\Gamma_{\gamma 0}}$ from both RIPL3 and Mughabghab were plotted separately for odd-odd nuclie in Br–Ag range with respect to A
- The results from Mughabghab were fitted with a linear function (y=ax+b)
- The error σ at A=92 was calculated using the fitting parameters $p_{i,j} = a, b$:



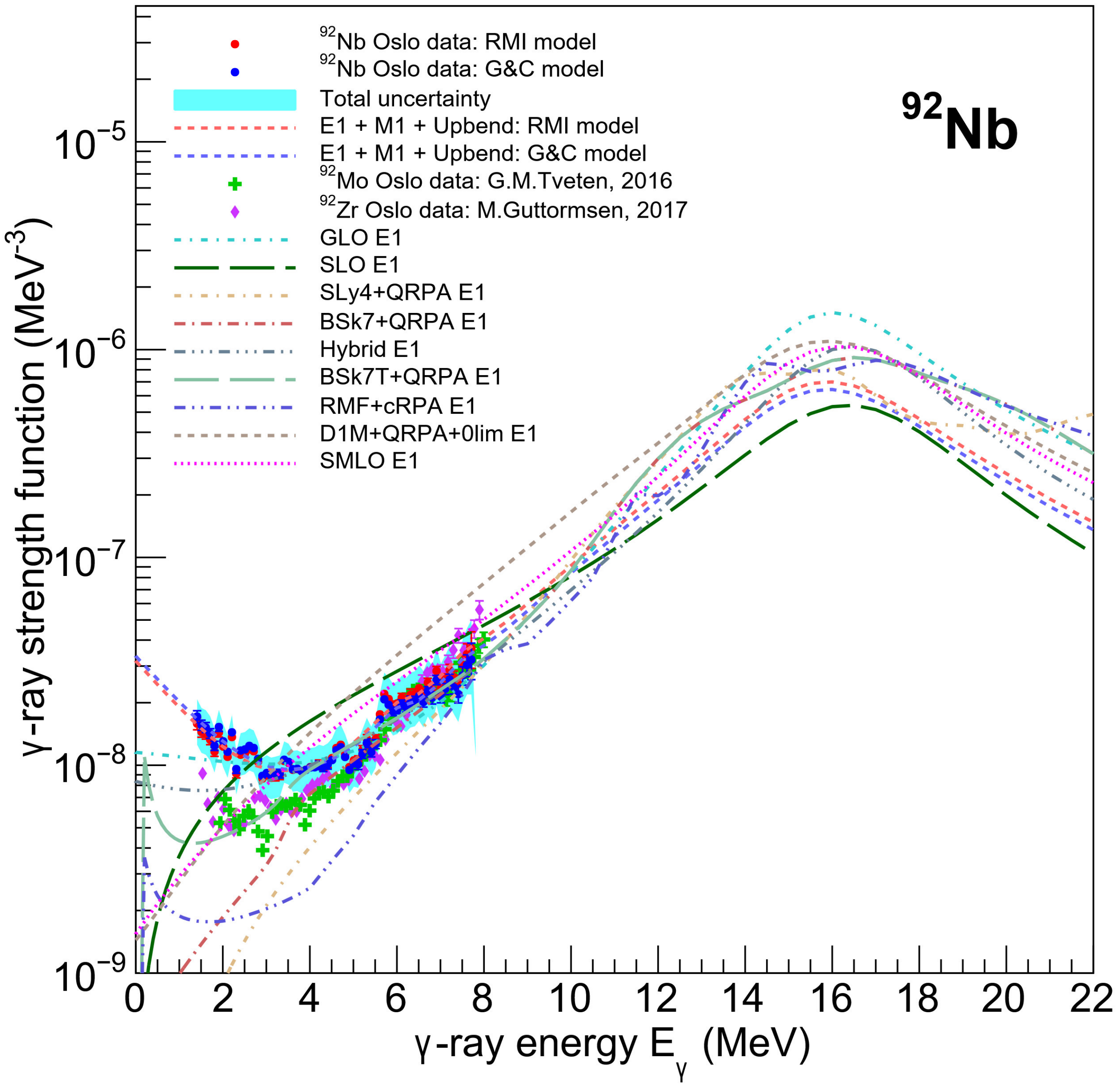
^{92}Nb NLD Comparison with Theoretical NLDs

- Our experimentally extracted NLDs were compared with all available theoretical NLD models from TALYS
- Beyond 3 MeV, the slope of our NLDs is comparable to the slope with the Back-Shifted Fermi Gas model (BFGM) and the Generalized Superfluid Model (GSM)



^{92}Nb γSFs Comparison with Theoretical E1 γSFs

- Our experimentally extracted γSFs were compared with all available theoretical E1 γSF models from TALYS



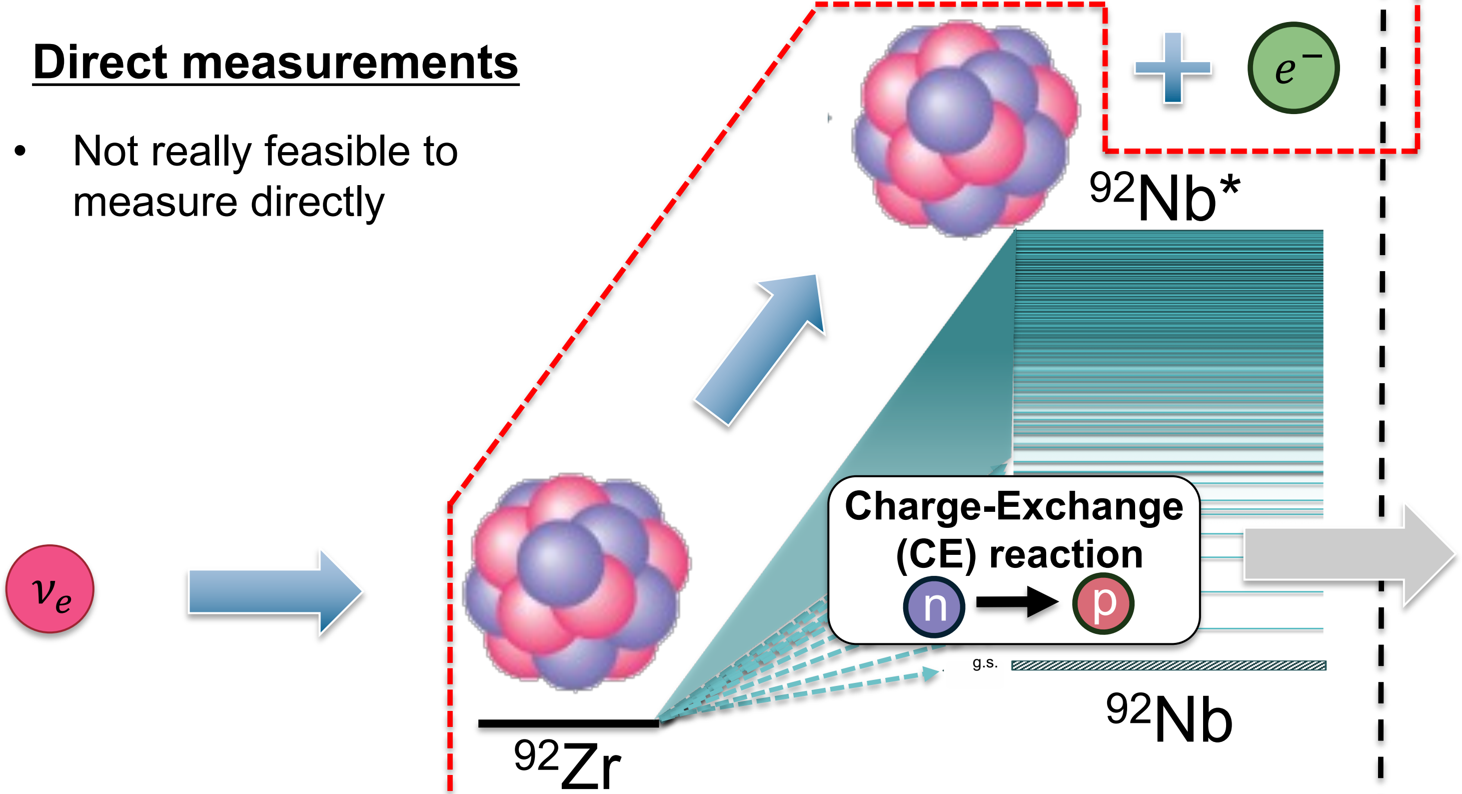
TENDL-astro 2023 and NON-SMOKER

Settings	TENDL-astro 2023 (rec)	NON-SMOKER (default)
Model	Hauser–Feshbach	Hauser–Feshbach
NLD	Skyrme force-from Hilaire's combinatorial tables	BSFG (corr. FRDM)
GSF	Gogny D1M HFB+QRPA	Lorentzian (GDR)
OMP	Koning-Delaroche	JLM
MASS	Goriely HFB-Skyrme table	FRDM
Width Fluctuation	Moldauer model	Hofmann-Richert-Tepel-Weidenmueller model

How Can We Constrain ^{92}Zr(ν_e,e^-)^{92}Nb Reaction Rate?

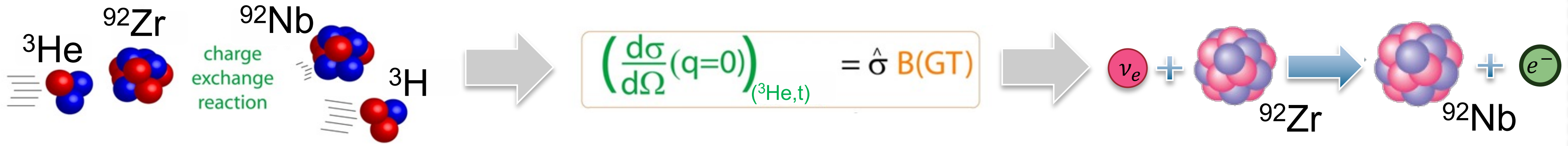
Direct measurements

- Not really feasible to measure directly



Indirect measurements

- The dominant contribution is the charged-current (CC) neutrino interactions
- At astrophysical energies, the CC cross section is dominated by Gamow-Teller B(GT) and Fermi B(F) transitions from the ground state of ^{92}Zr
- The CE experiments at ~ 100 MeV/u provide a way to extract these transition strengths through Multipole Decomposition Analysis (MDA)
- The CE differential cross section at zero momentum transfer (q~0) is proportional to B(GT) and B(F)

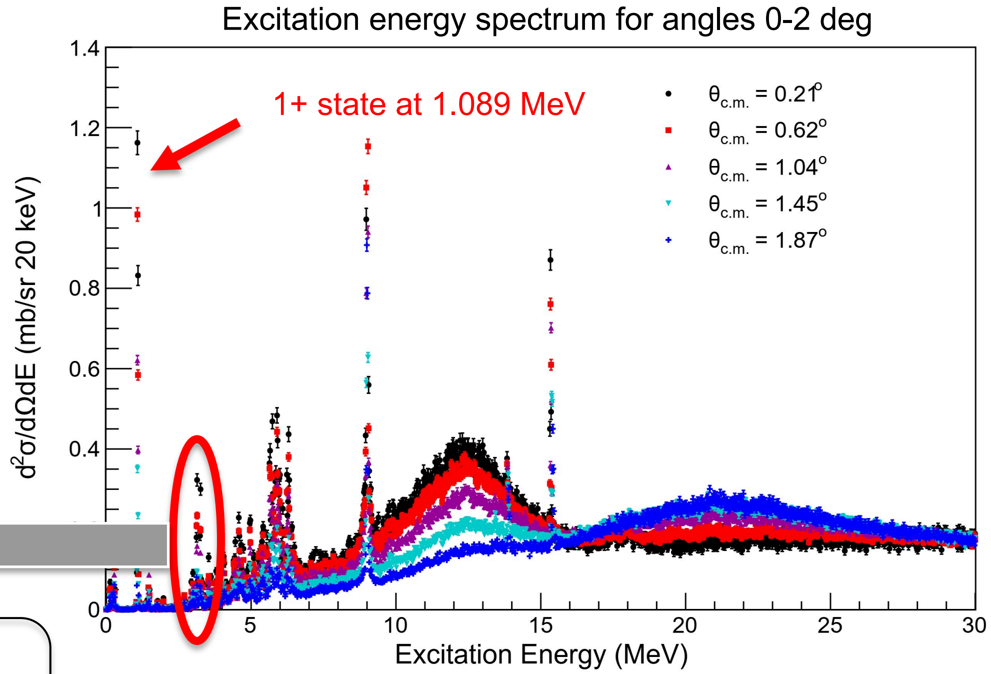


$$\left(\frac{d\sigma}{d\Omega}(q=0)\right)_{(^3He,t)} = \hat{\sigma}\, B(GT)$$

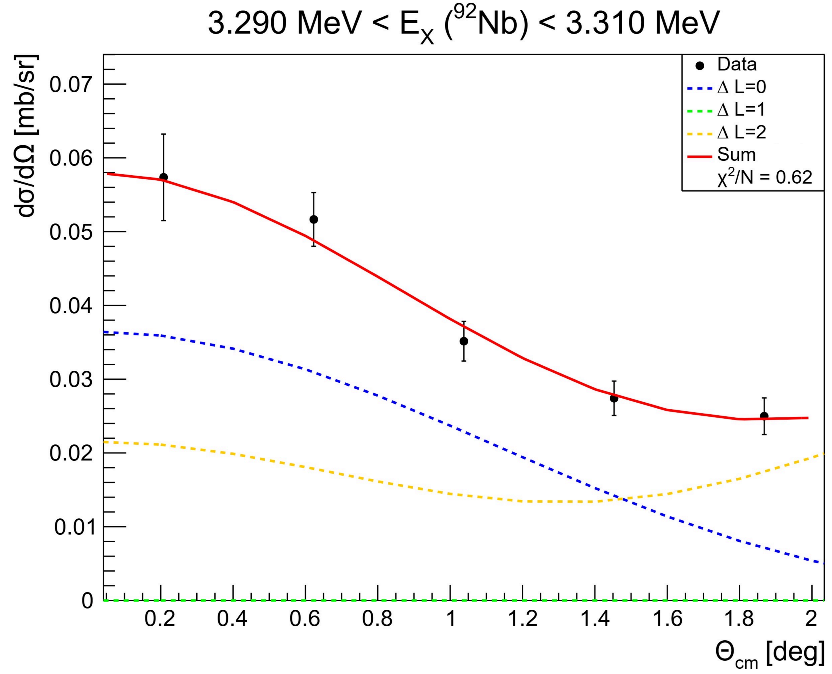
Experimental Differential Cross Sections and the Multipole Decomposition Analysis (MDA)

- At near 0^0 scattering angles, transitions with small angular-momentum transfers ($\Delta L \leq 2{,}3$) are preferred

- To decompose contributions from different ΔL, MDA[i] was performed by fitting the measured differential cross sections with theoretical angular distributions over the covered scattering angles



MDA



$$\left.\frac{d\sigma}{d\Omega}(\theta)\right|_{exp} = \sum_i c_i \left.\frac{d\sigma}{d\Omega}(\theta)\right|_{\Delta L_i}$$

- The theoretical angular distributions were calculated using the Distorted Wave Born Approximation (DWBA)

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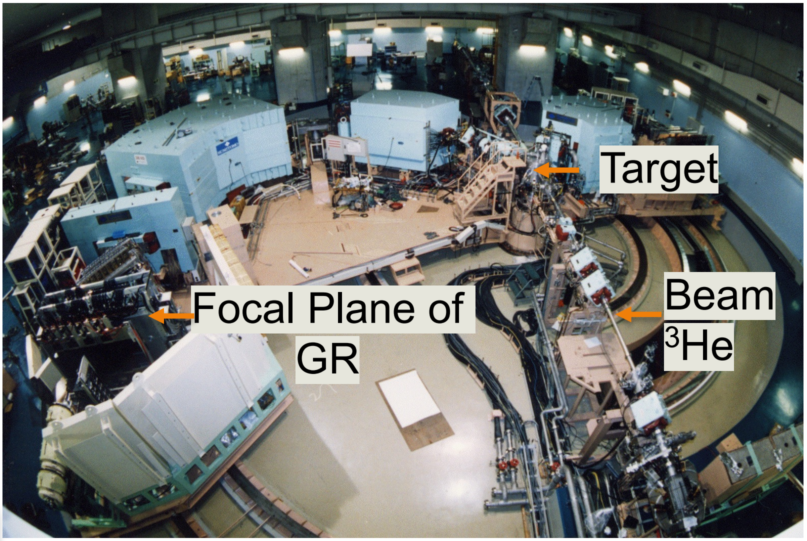
i. R.G.T Zegers, Handbook of Nuclear Physics, Springer, (2023)

Extracted B(GT) Distribution and Progress on CC ^{92}Zr(ν_e,e^-)^{92}Nb Cross Sections

- The experiment was run in forward kinematics using the Grand Raiden Spectrometer[i] (GR)
- Experimental B(GT) was extracted from the ΔL=0 component obtained from the MDA

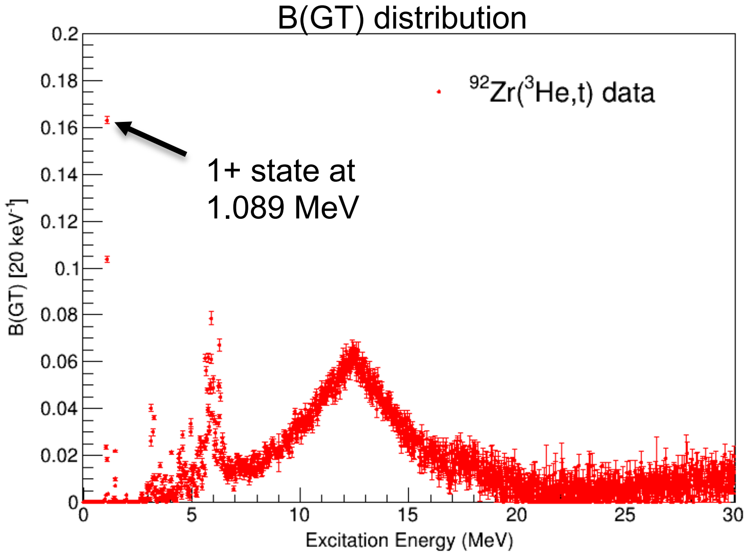


https://www.rcnp.osaka-u.ac.jp/

$$\frac{d\sigma}{d\Omega}(q=0)\Big|_{(^3He,t)} = \hat{\sigma}B(GT)$$

For zero momentum transfer

$$\sigma(E_\nu) = \frac{G_F^2}{\pi}F_{CC}\left[\frac{E_iE_f}{s}\right]E_l\,|p_l|\,\{B(F)+B(GT)\}$$



- The extraction of CC neutrino-^{92}Zr cross sections is currently in progress in collaboration with a theory group at the University of Zagreb
- These results will provide the first experimental constraints on this reaction
- The experimentally constrained ^{92}Zr(ν_e,e^-)^{92}Nb cross sections will provide a key test neutrino-driven ^{92}Nb production in CCSNe

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i. R.G.T Zegers, Handbook of Nuclear Physics, Springer, (2023)