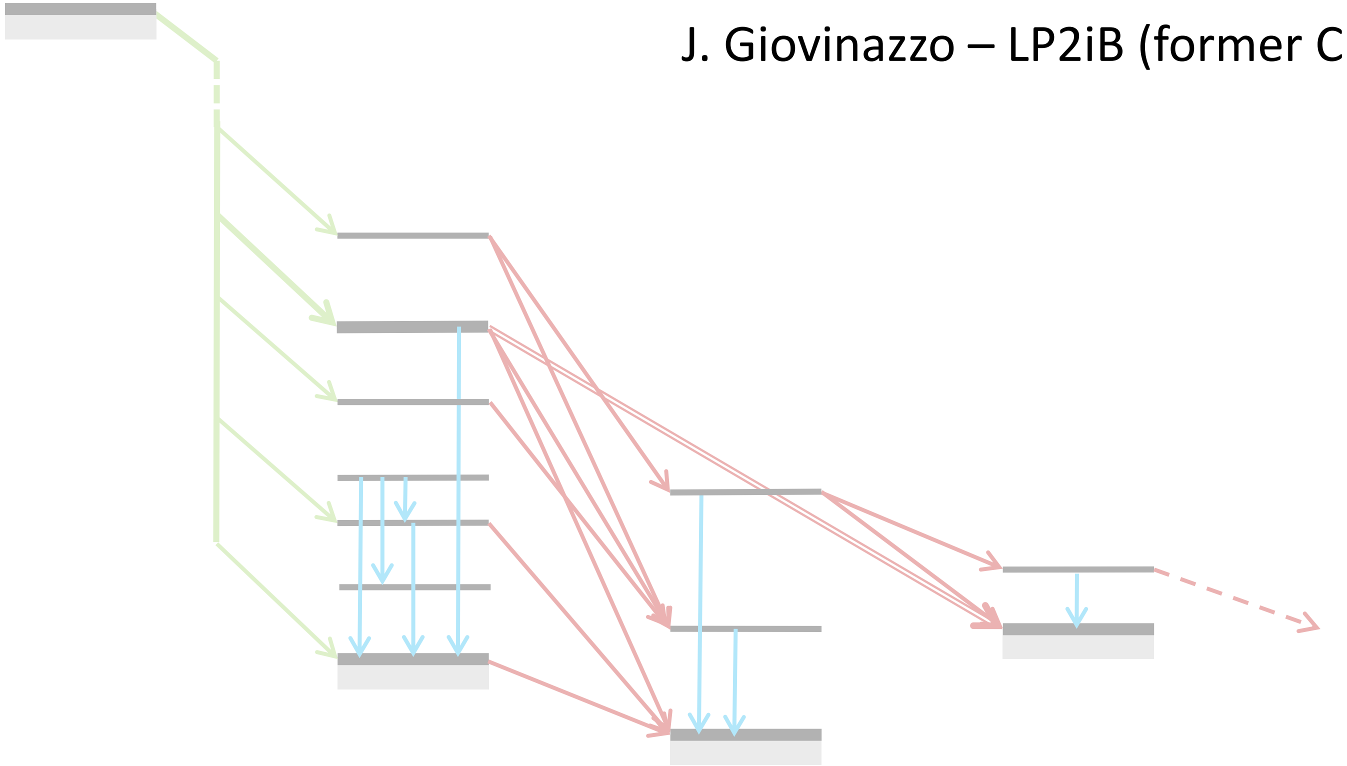
beta delayed (multi-)proton emission at DESIR

J. Giovinazzo – LP2iB (former CENBG) – Bordeaux

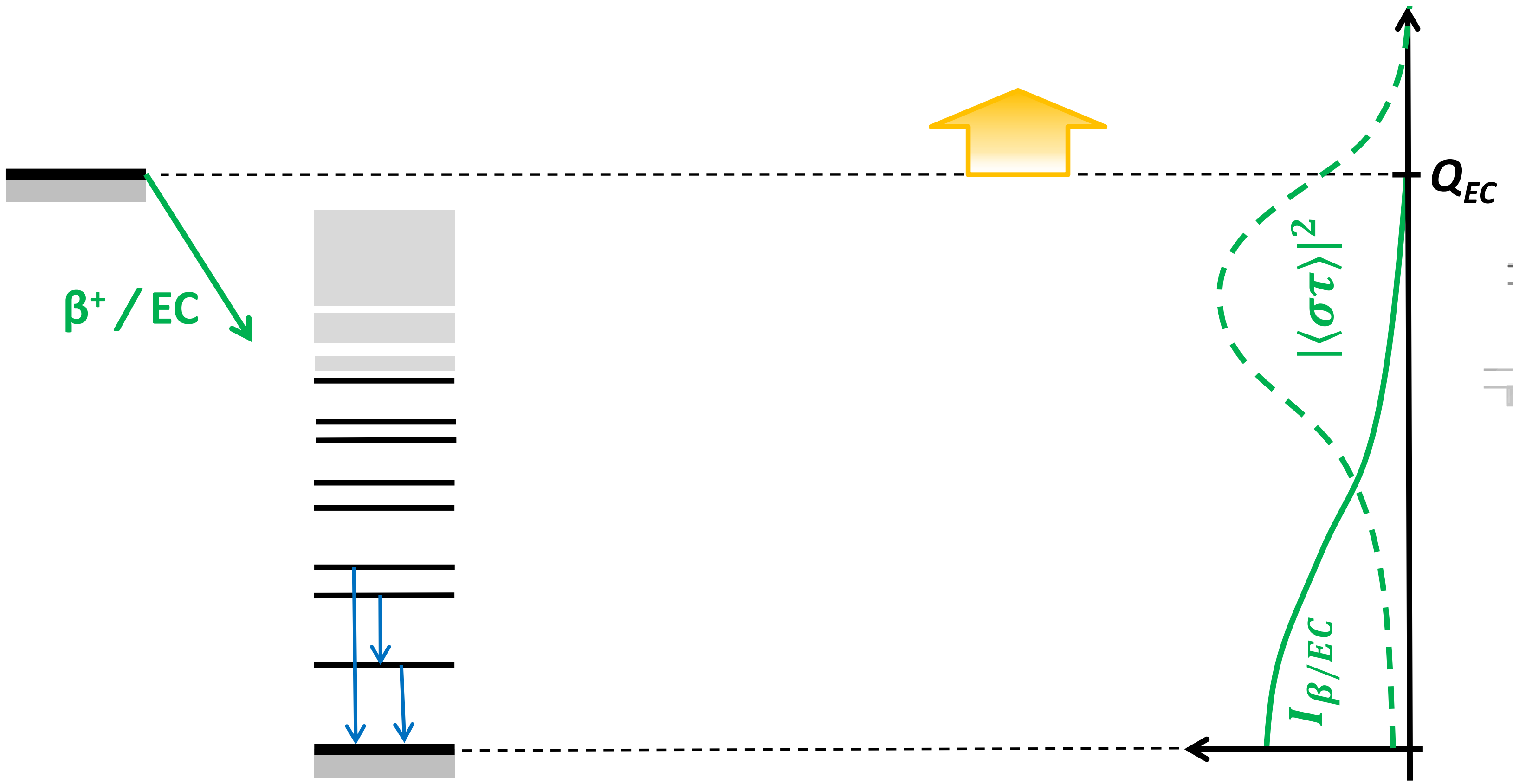


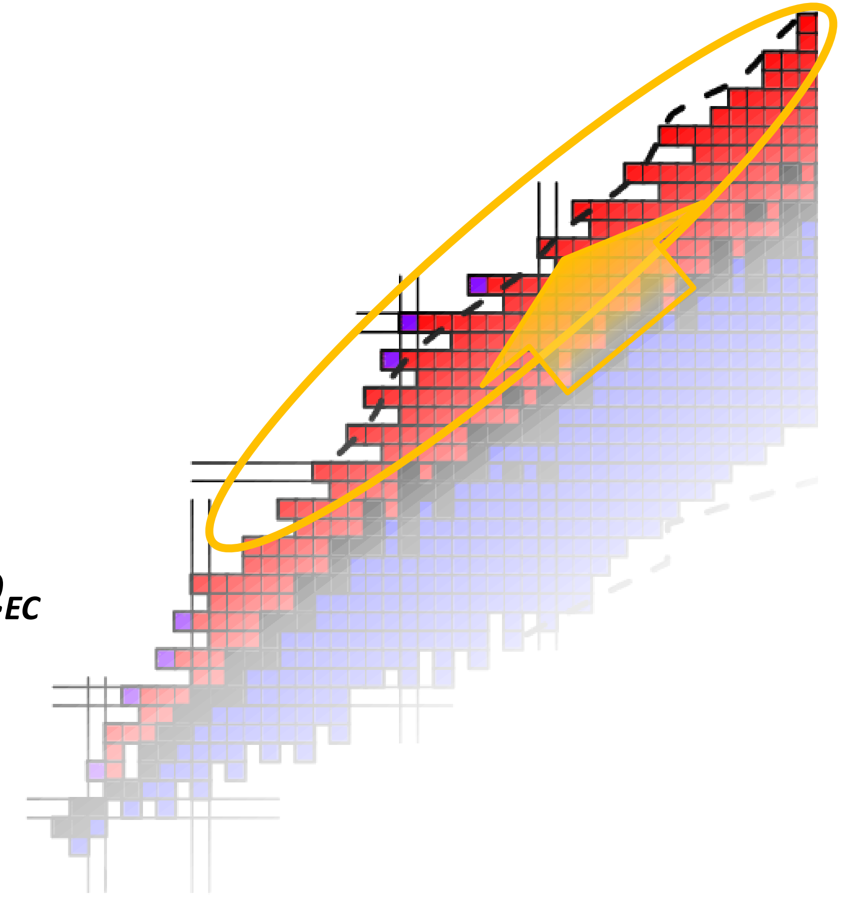
- why ?
- how ?
- when ?

DESIR workshop – 27/02-01/03/2024

towards the proton drip-line

→ Q_{EC} increases



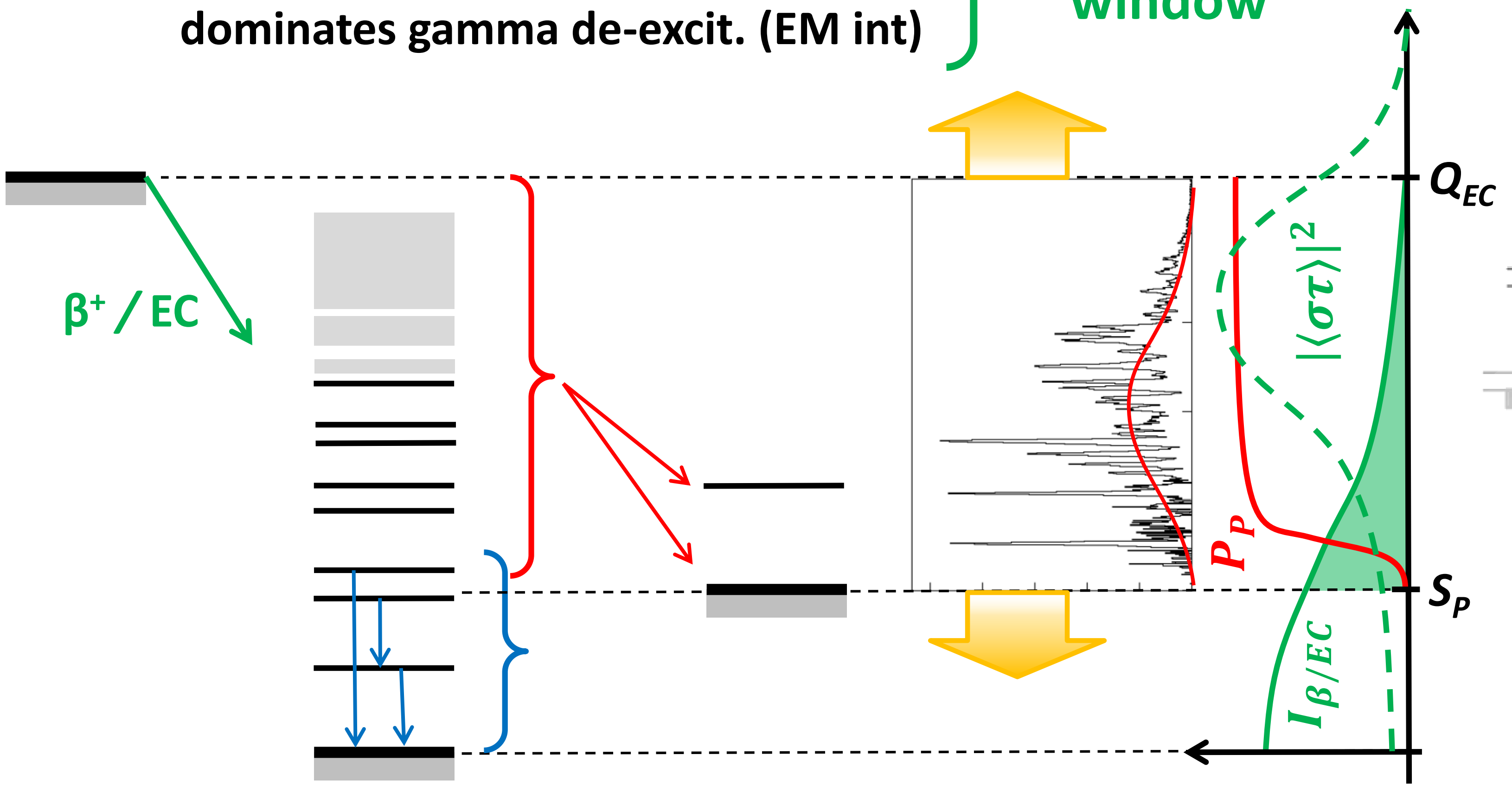


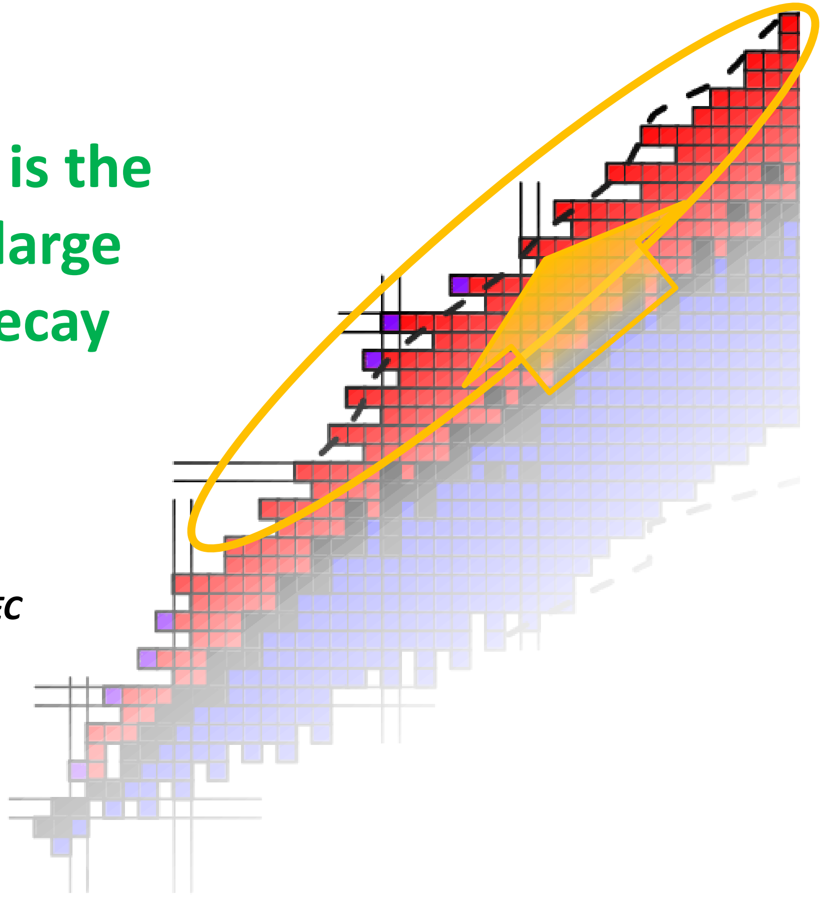
towards the proton drip-line

→ Q_{EC} increases
S_P decreases

→ proton emission (strong int.)
dominates gamma de-excit. (EM int)

proton emission is the only access to a large fraction of the decay window





precise probe !!
- easily detected
- precise energy

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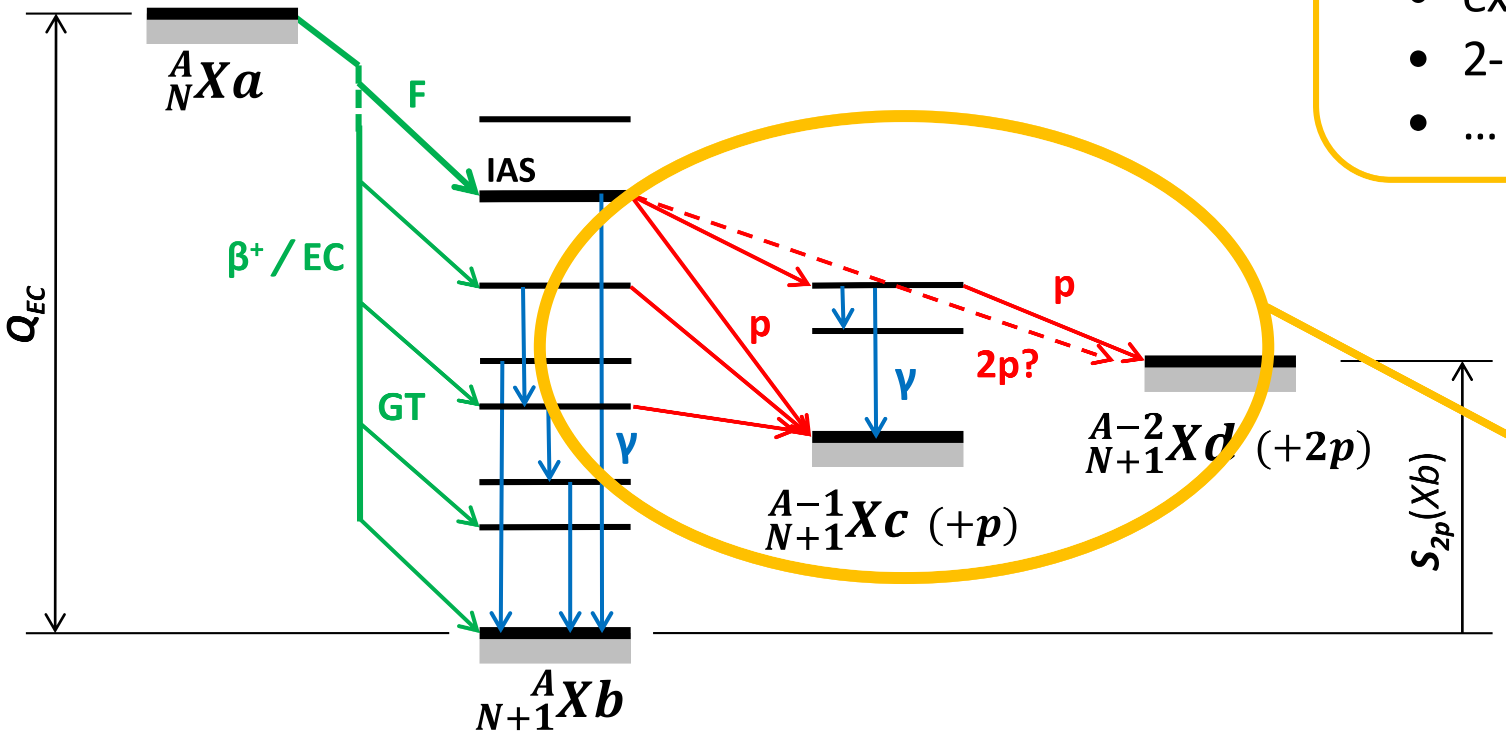
physics cases: decay spectroscopy

beta decay
Fermi / Gamow Teller

daughter nucleus de-excitation
- gamma transitions
- (multi-)proton emission



many physics cases
- masses
- isospin symmetry
- weak interaction
- nuclear structure
- deformation
- nuclear astrophysics
- level densities
- excited states lifetimes
- 2-proton decay
- …

detailed decay spectroscopy
→ address several topics simultaneously

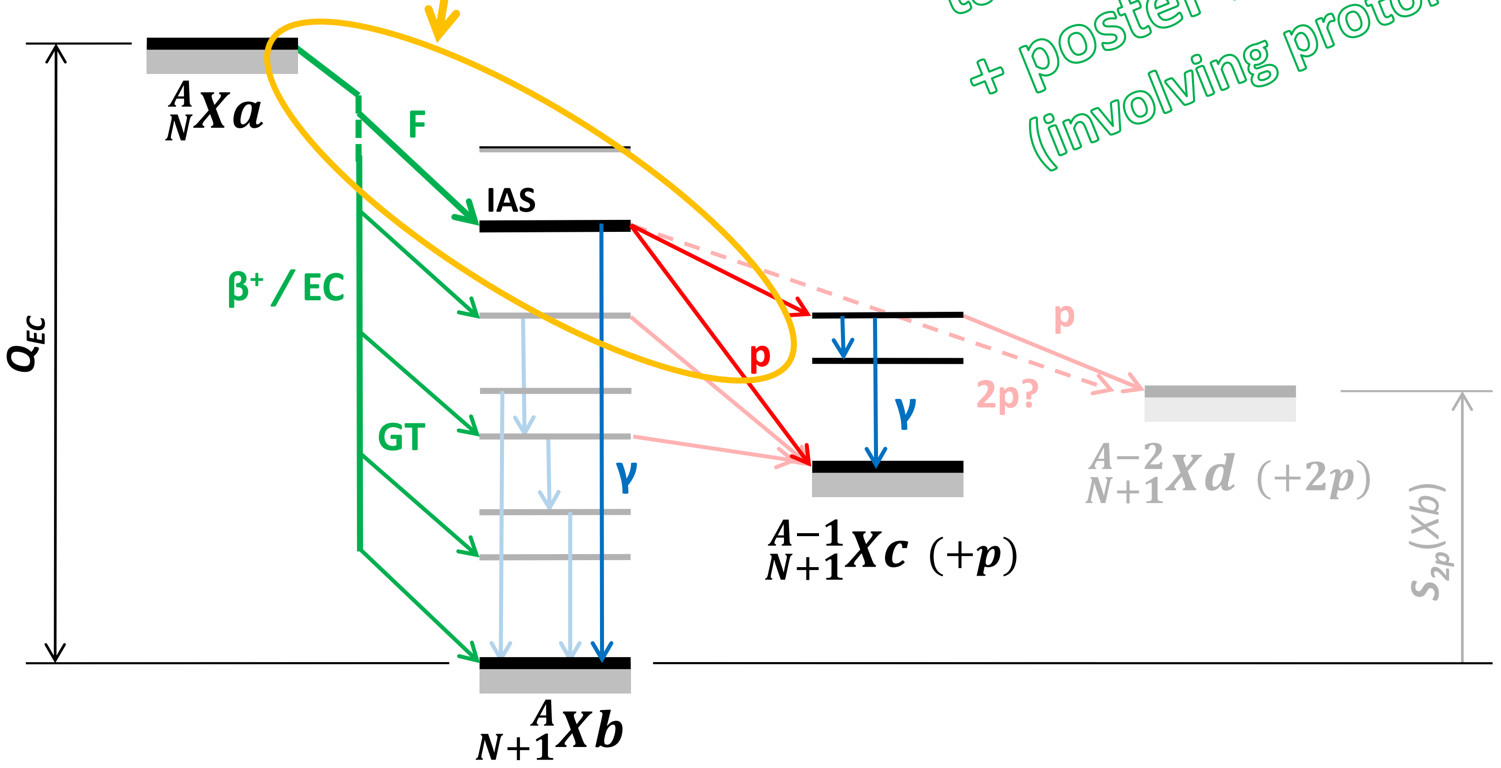
very exotic stuff…
→ exploration: fragmentation
→ details/precision: ISOL

physics cases: Fermi decay

+ weak interaction studies

β(F)-p: IMME (masses)
isospin mixing

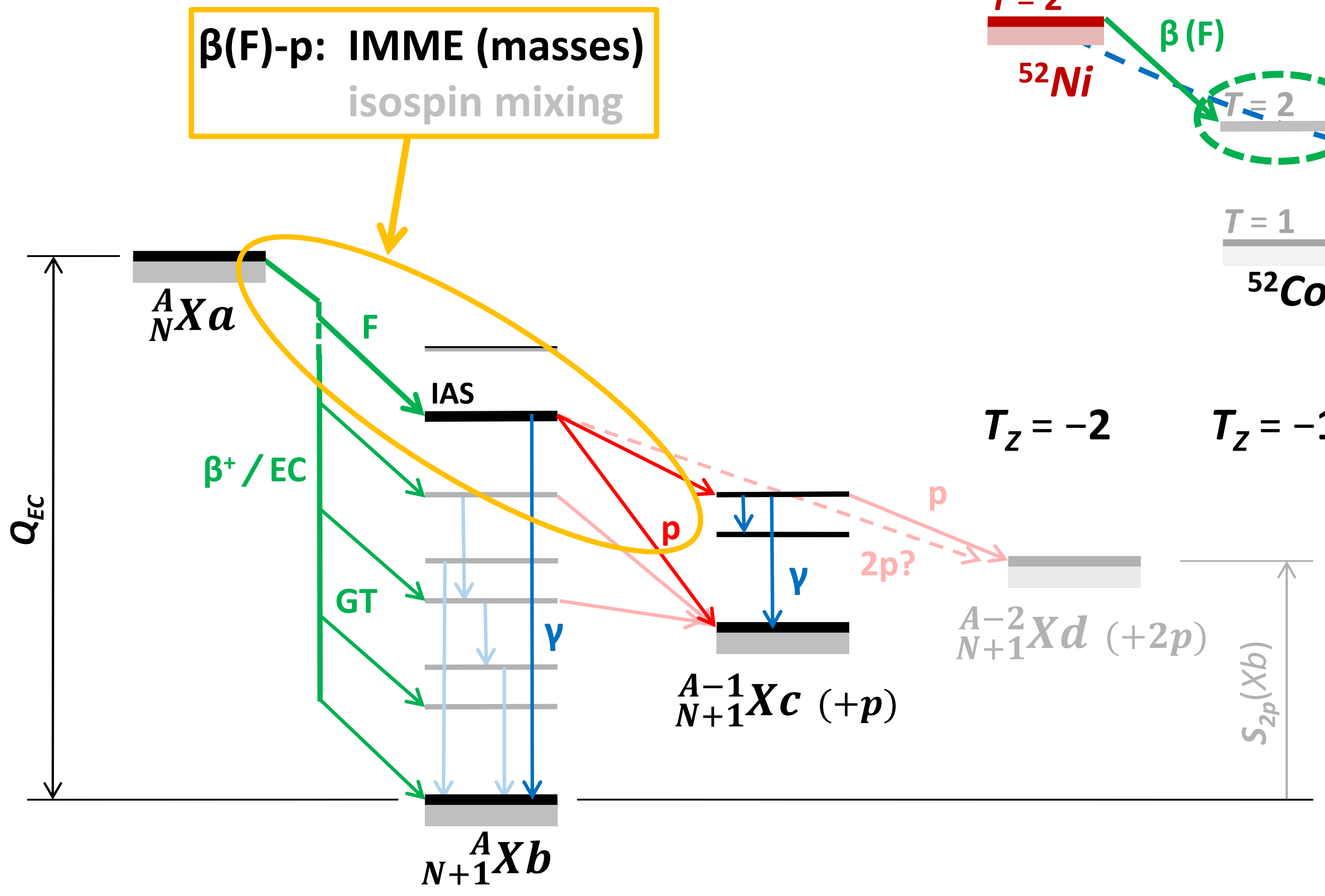
talks from M. Versteegen
+ poster from S. Lecanuet
(involving proton emission)

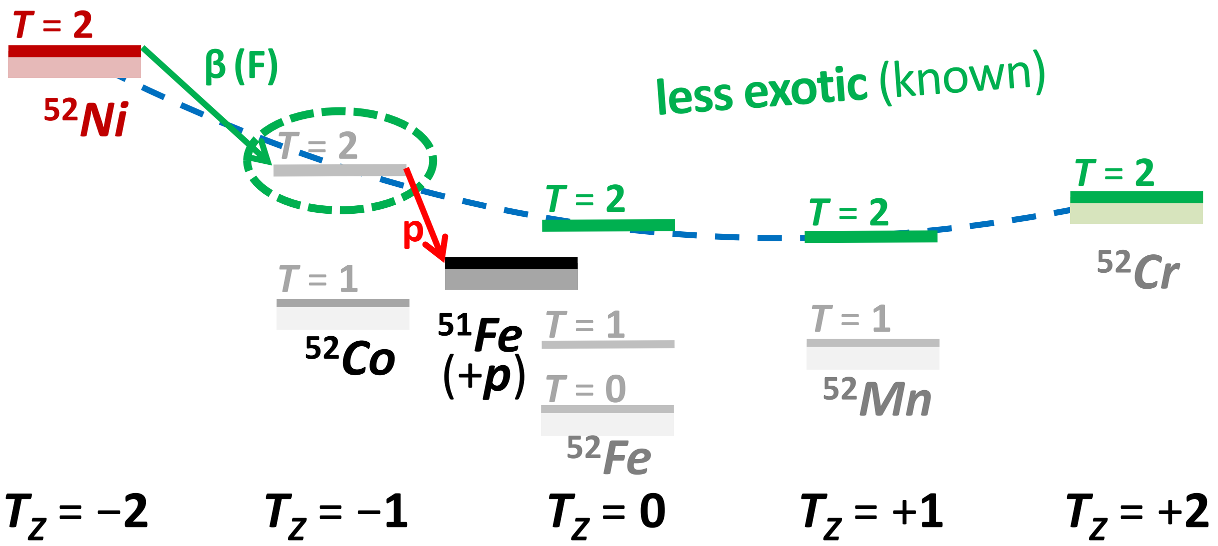


physics cases: Fermi decay

Isobaric Multiplet Mass Equation (IMME, Wigner, 1957)
charge independent strong nuclear interaction + Coulomb

$$M(T_Z) = a + b \times T_Z + c \times T_Z^2$$



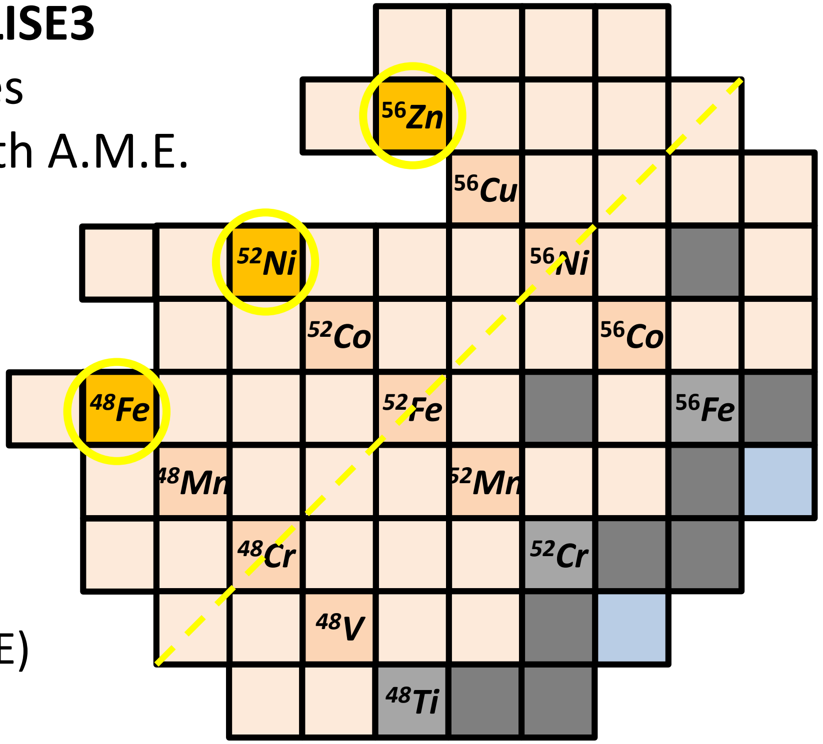


worst mass precision !!!
does not compete with precision (trap) measurements

but the first access to mass for the most exotic nuclei
(→ when produced in fragmentation)

physics cases: Fermi decay

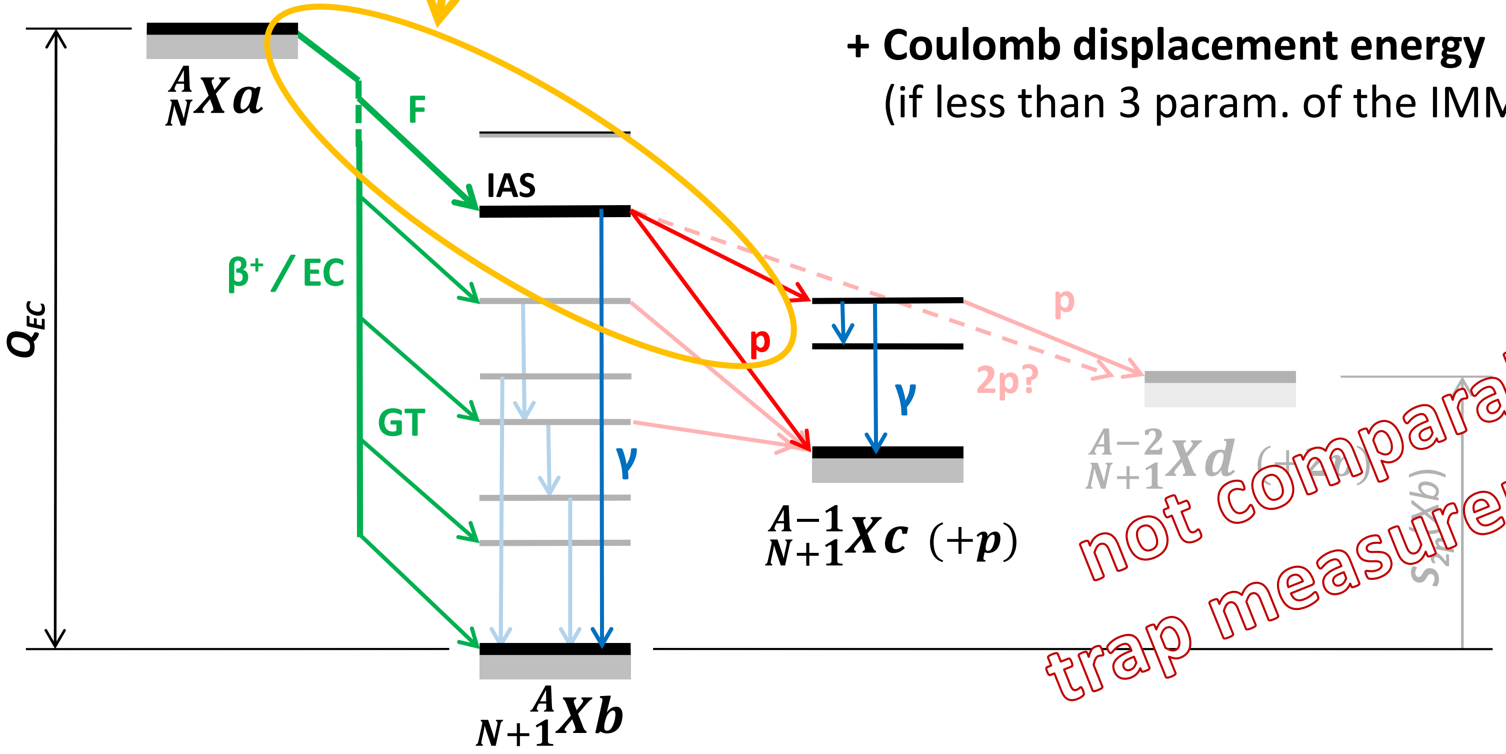
experiment @ GANIL / LISE3
comparison of masses
from IMME (exp.) with A.M.E.



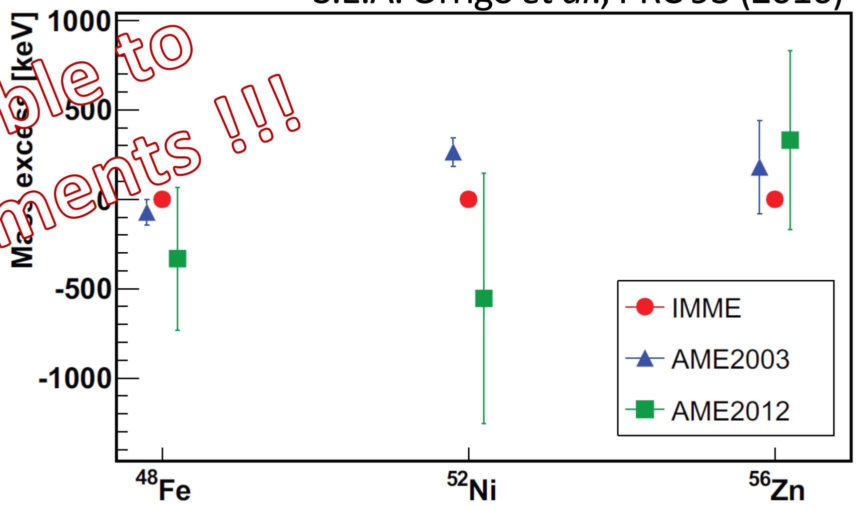
β(F)-p: IMME (masses)
isospin mixing

several cases in A ~ 50 mass region
in C. Dossat *et al.*,
Nucl. Phys. A 792 (2007)

+ Coulomb displacement energy
(if less than 3 param. of the IMME)



S.E.A. Orrigo *et al.*, PRC 93 (2016)



not comparable to trap measurements !!!

physics cases: Fermi decay

proton emission from IAS is forbidden (isospin)

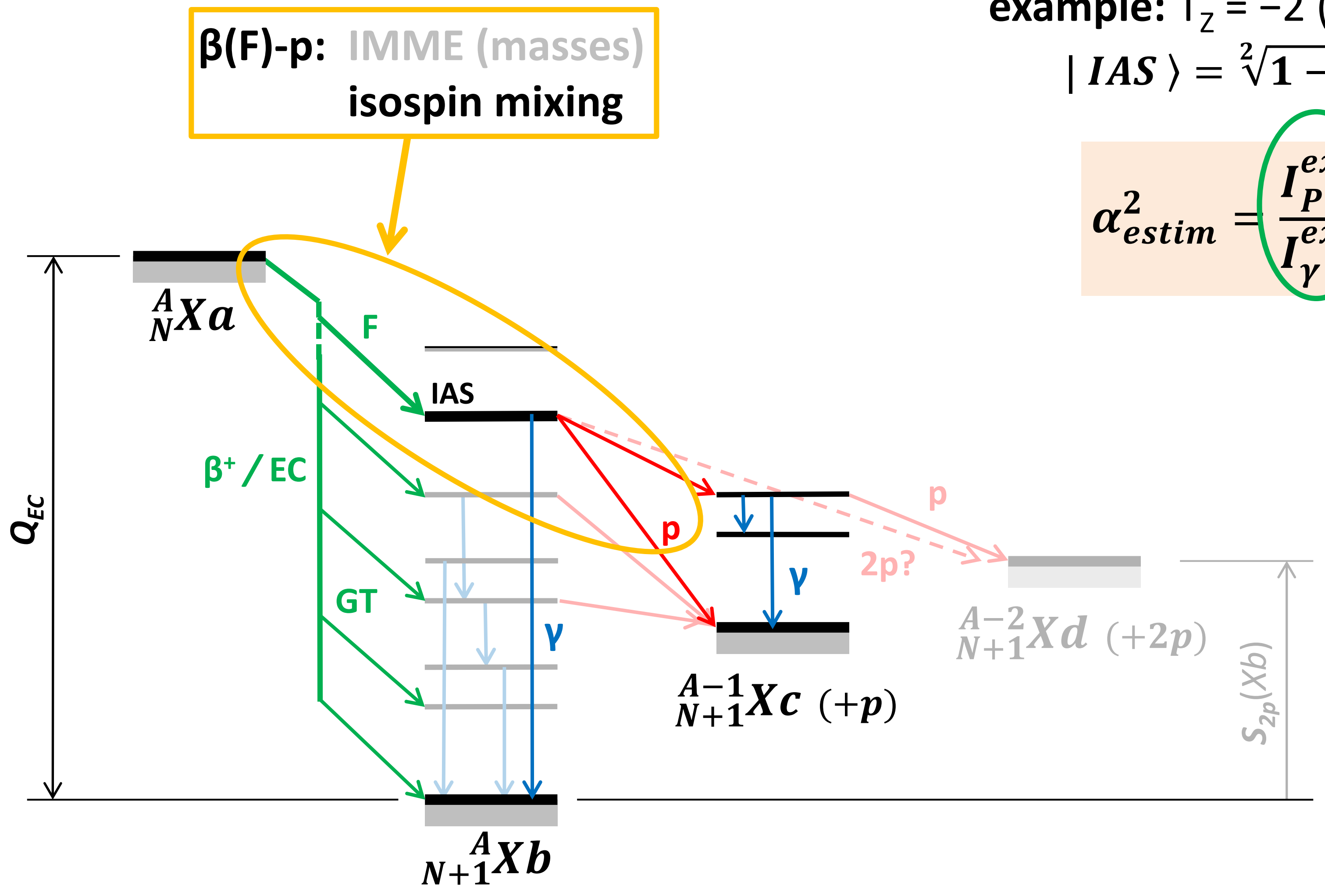
→ isospin mixing

→ test of INC terms in nucl. interaction (collab. N. Smirnova)

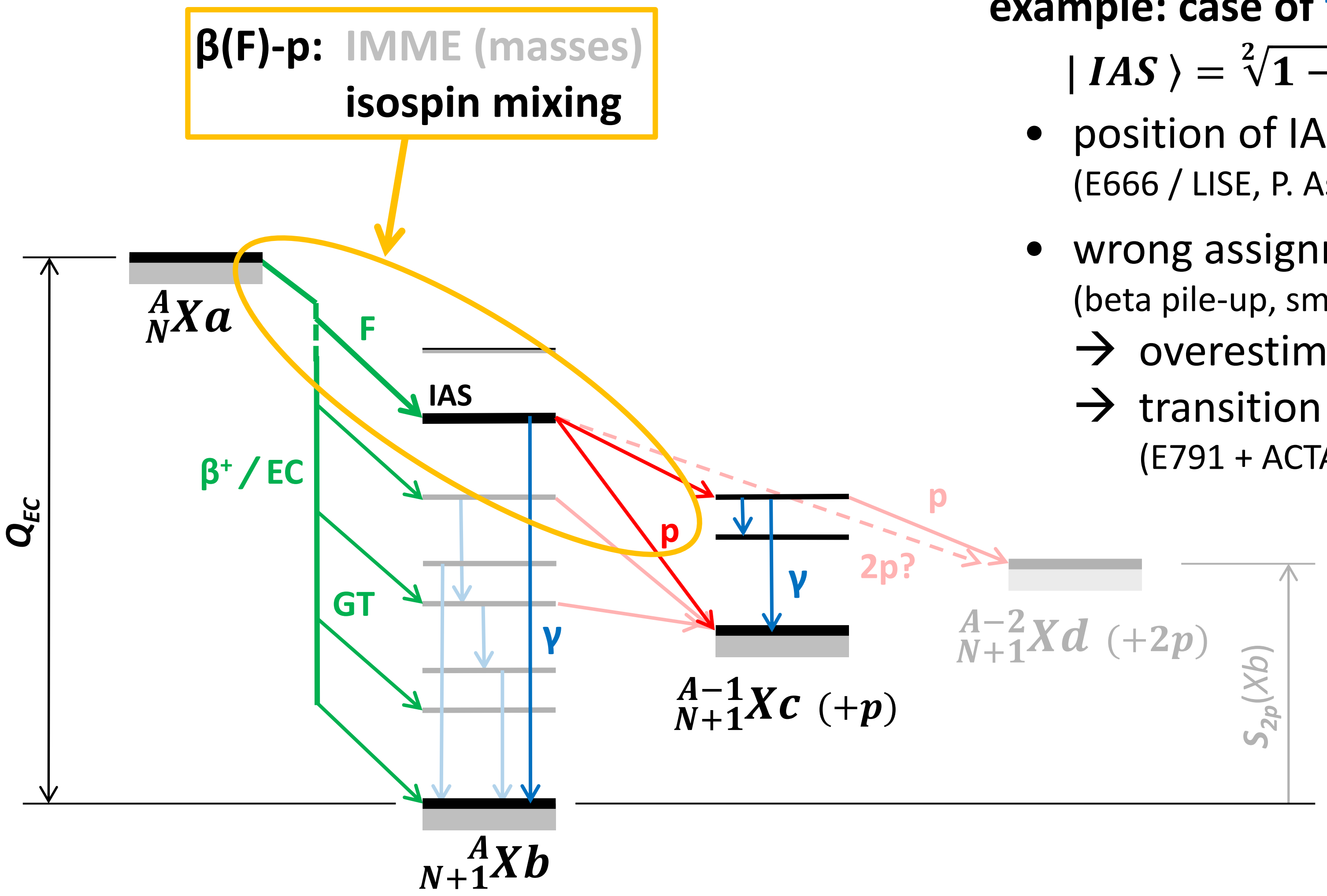
example: $T_Z = -2$ (simple 2-states mixing)

$$|\, IAS \,\rangle = \sqrt[2]{1-\alpha^2} \cdot |\, T=2 \,\rangle + \alpha \cdot |\, T=1 \,\rangle$$

$$\alpha^2_{estim} = \frac{I_P^{exp}}{I_\gamma^{exp}} \times \frac{\Gamma_\gamma}{\Gamma_{s.p.}^{T=1} \cdot S_{T=1}}$$



physics cases: Fermi decay



proton emission from IAS is forbidden (isospin)

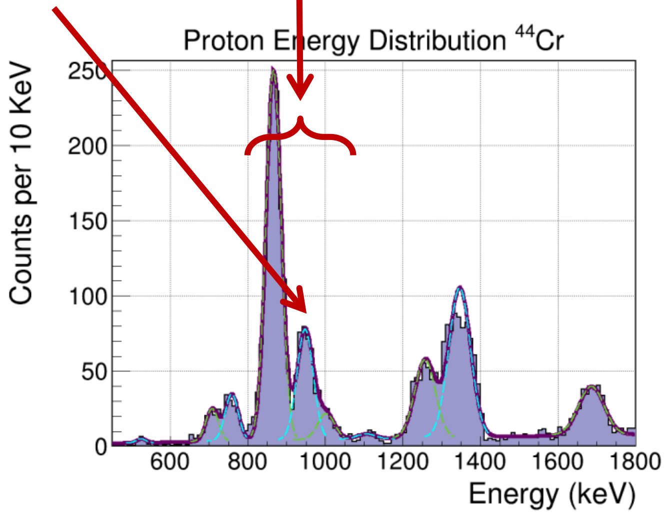
→ **isospin mixing**

→ **test of INC terms in nucl. interaction** (collab. N. Smirnova)

example: case of ^{44}Cr ($T_Z = -2$)

$$|\, IAS \,\rangle = \sqrt[2]{1-\alpha^2} \cdot |\, T = 2 \,\rangle + \alpha \cdot |\, T = 1 \,\rangle$$

- position of IAS known from gamma
  (E666 / LISE, P. Ascher *et al.*)
- wrong assignment of the proton transition
  (beta pile-up, small transition **not resolved**)
  → overestimated isospin mixing
  → transition resolved
  (E791 + ACTAR TPC, A. Ortega Moral *et al.*)



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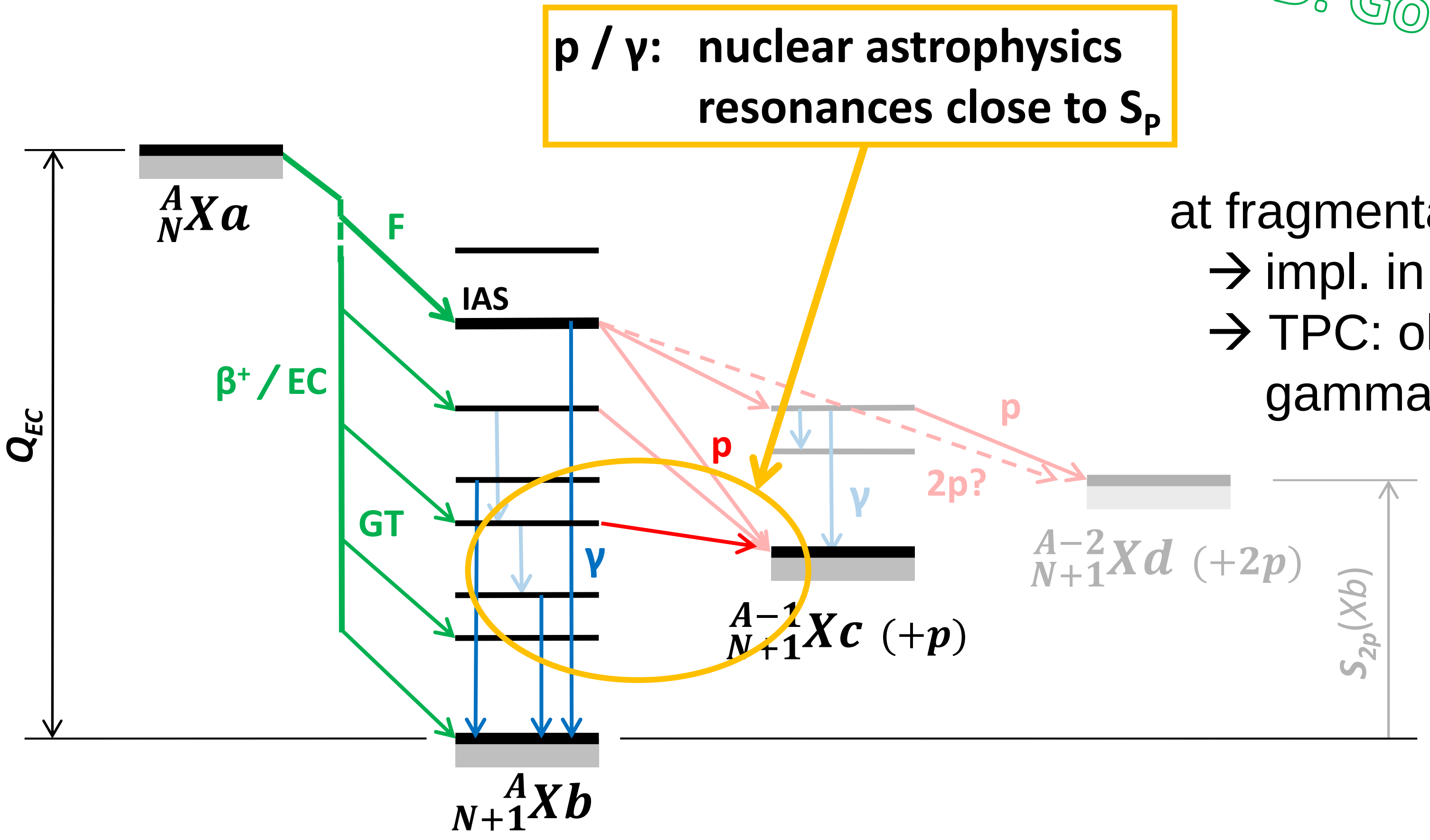
physics cases: astrophysics

states close to the proton emission threshold

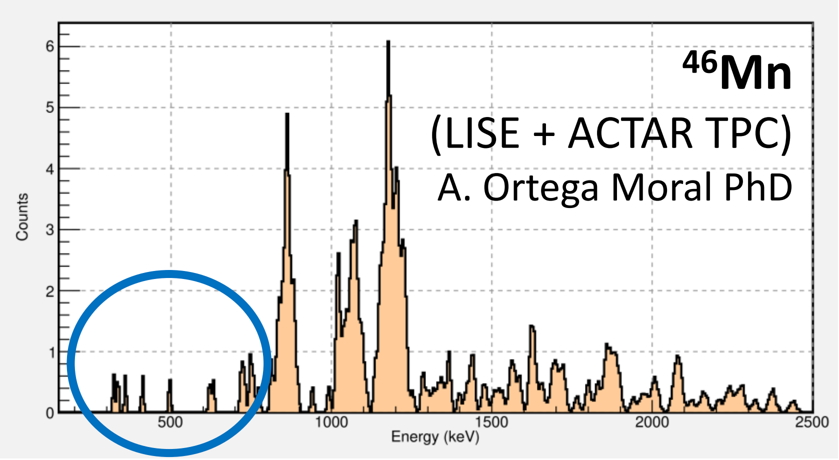
decay of ^{35}Ca → **proton capture ^{34}Cl(p,γ)^{35}Ar**
gamma / proton **widths** in **^{34}Ar**

decay of ^{46}Mn → **proton capture ^{45}V(p,γ)^{46}Cr**
→ type II supernovae

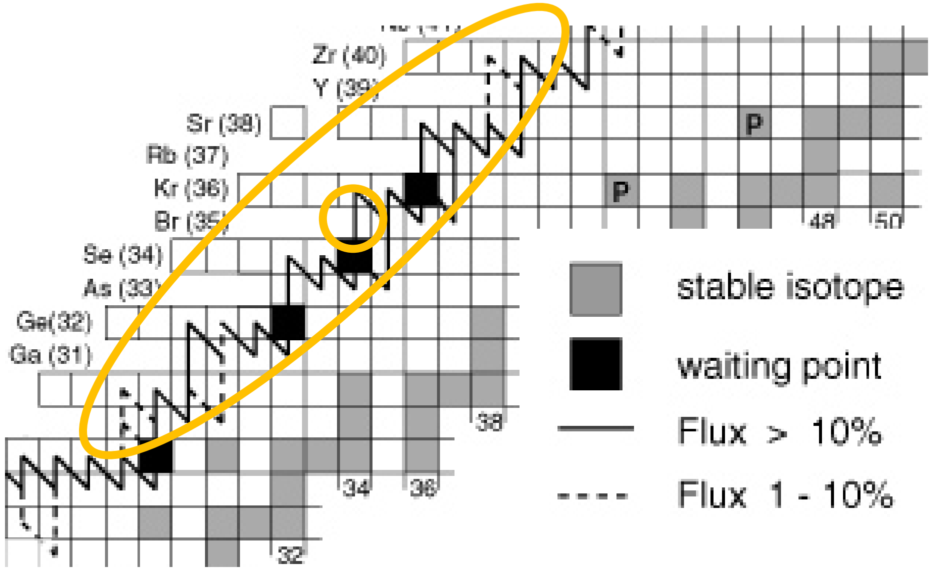
poster from
D. Godos / A.M. Sanchez

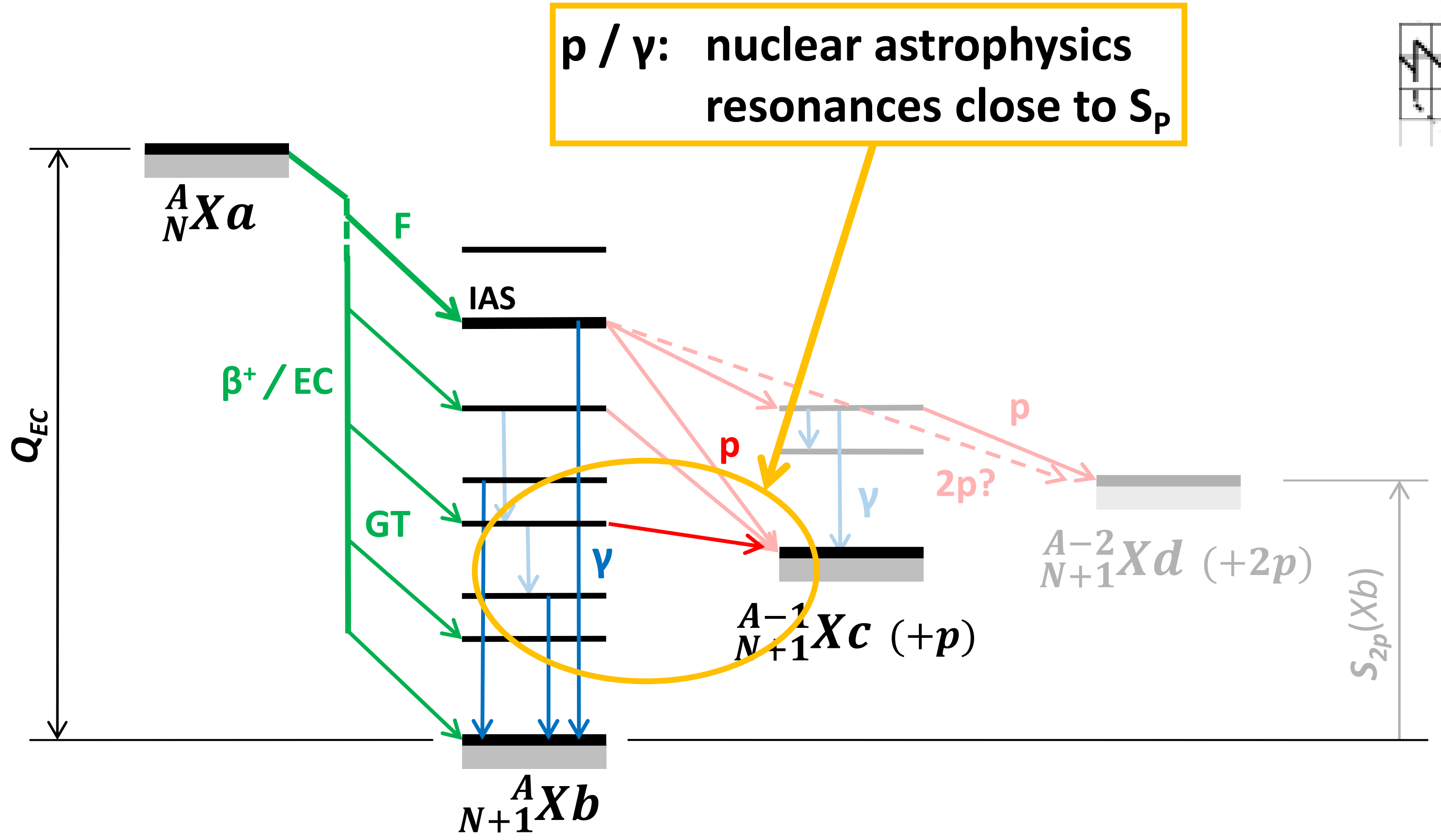


at fragmentation facilities
→ impl. in silicon: killed by beta background
→ TPC: ok, but need for complementary gamma detection



physics cases: astrophysics





region Z < 50

→ *rp*-process
(waiting points, e.g. ^{69}Br)

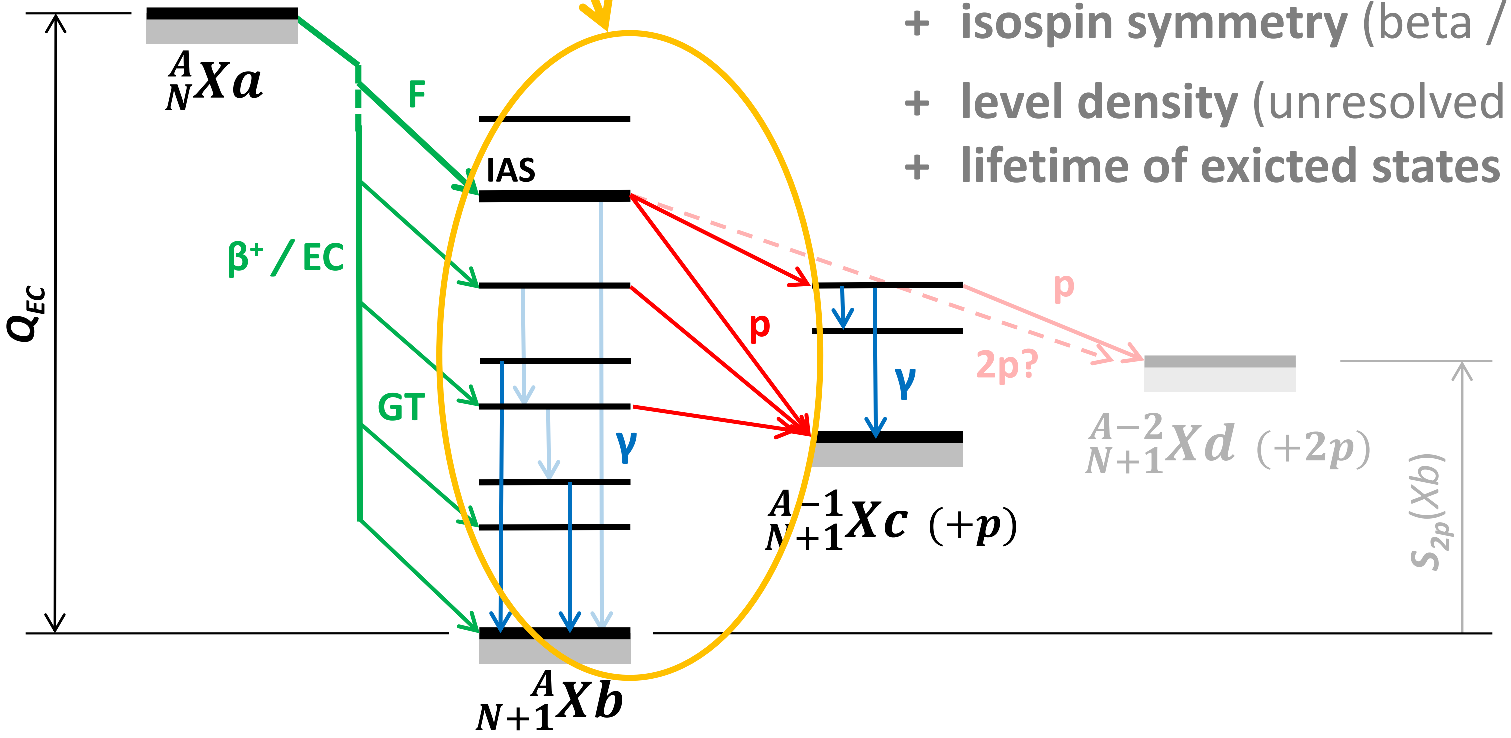
→ short half-lives

physics cases: Gamow-Teller decay

β(GT)-p: nuclear structure deformation

+ weak interaction studies

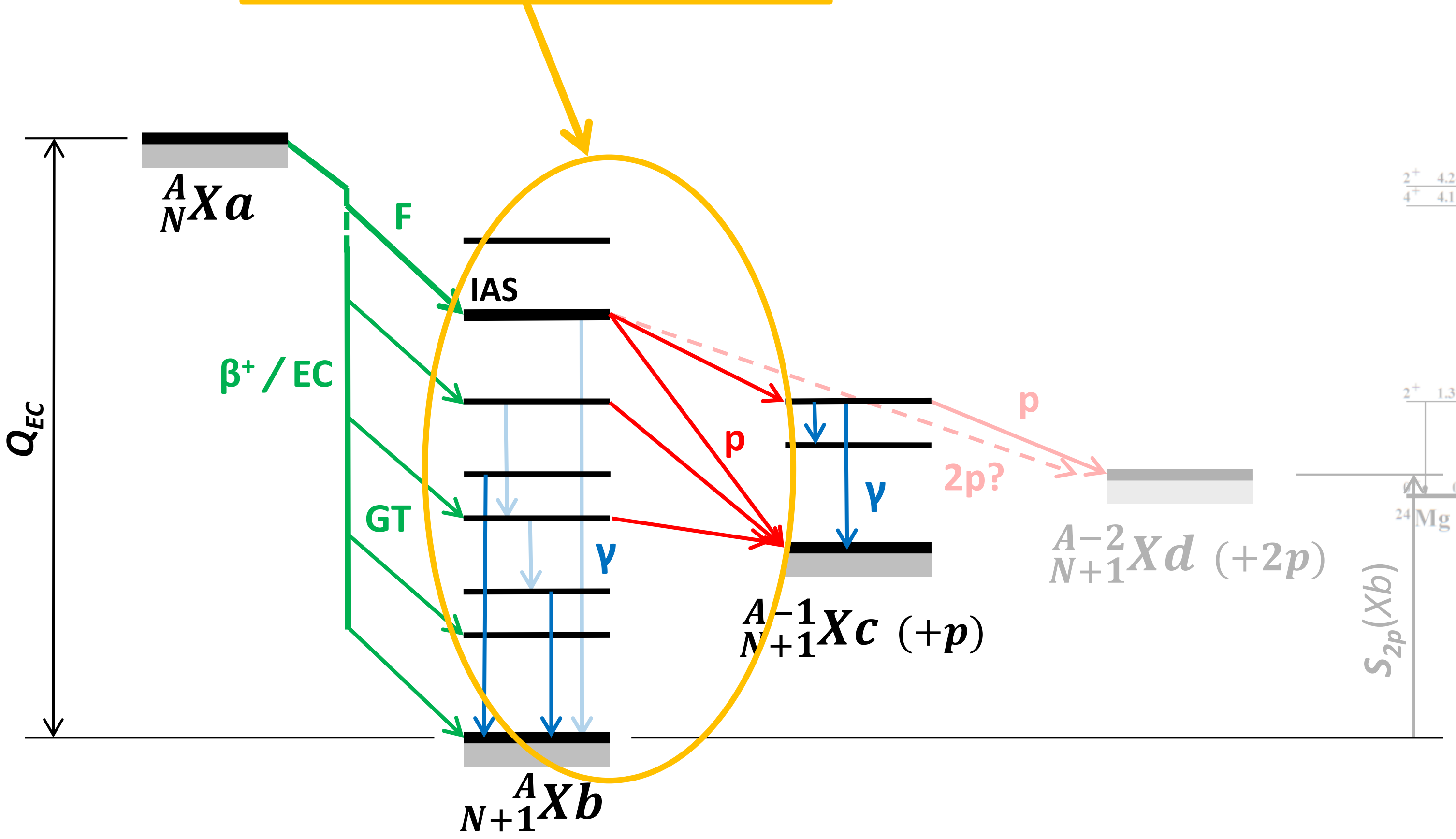
+ **isospin symmetry** (beta / charge exch.)
+ **level density** (unresolved transitions)
+ **lifetime of exicted states** (PXCT)

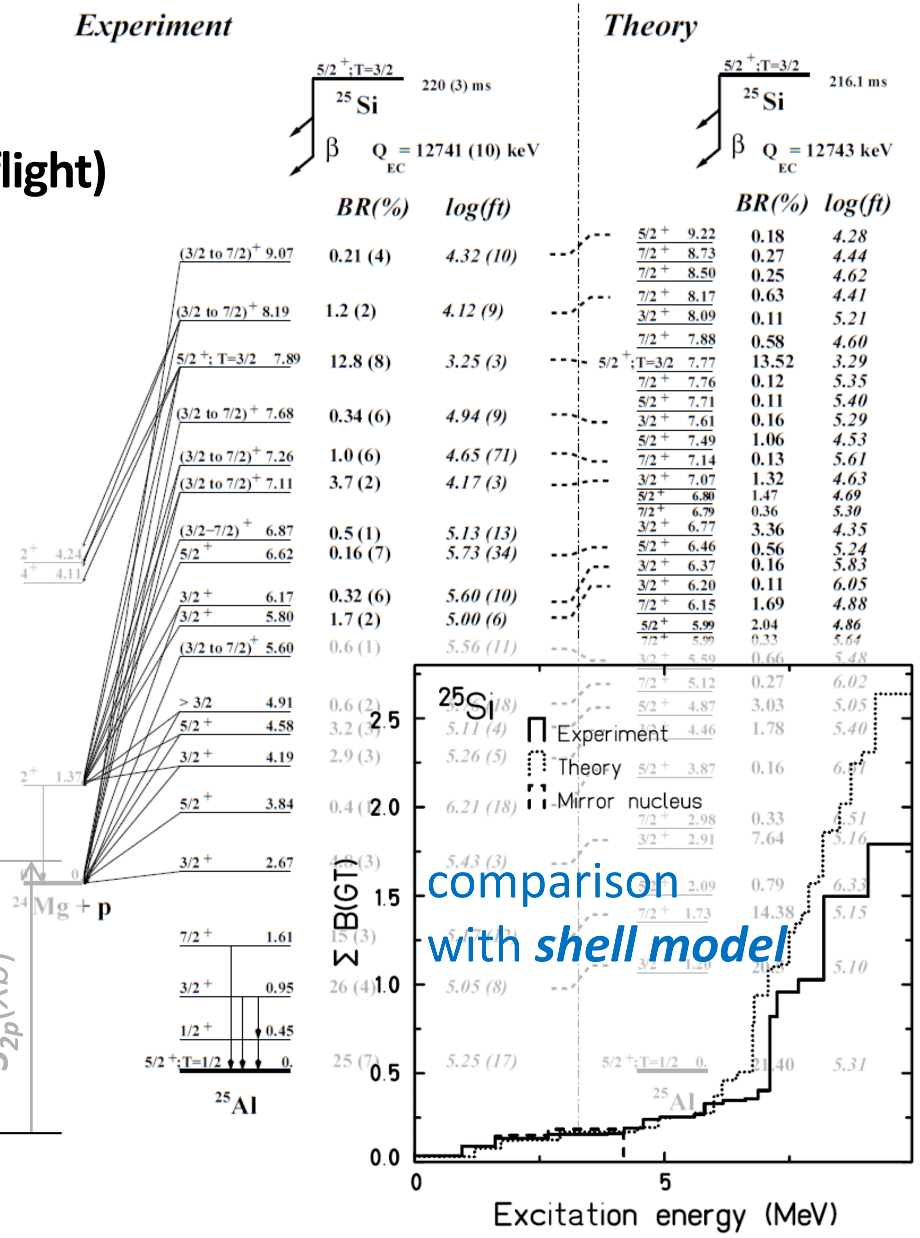


physics cases: Gamow-Teller strength distribution

B(GT) in light nuclei
decay of ^{25}Si @ GANIL (in-flight)

β(GT)-p: nuclear structure
deformation





comparison with ***shell model***

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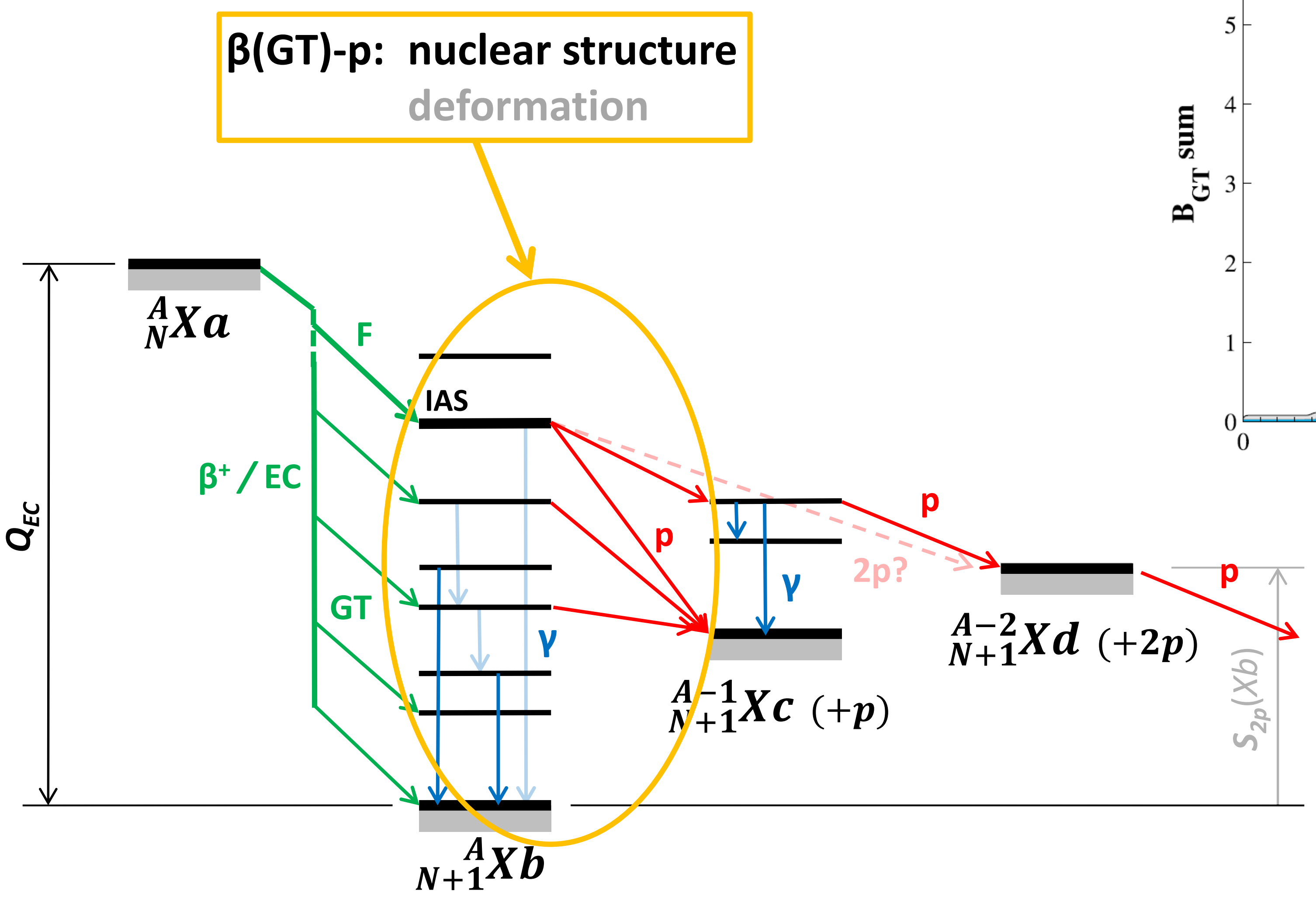
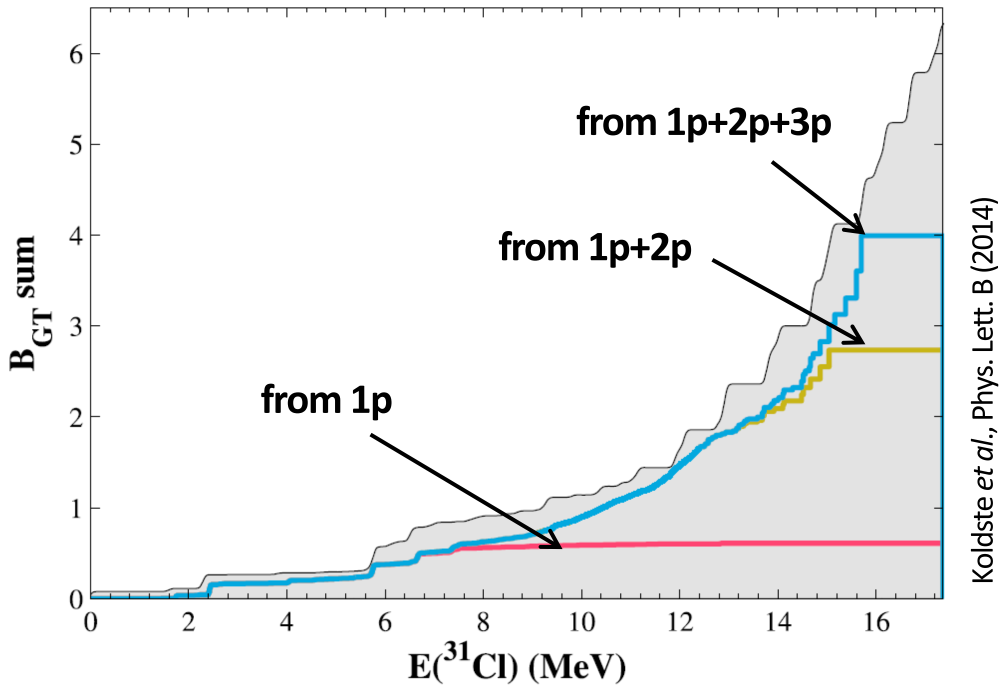
physics cases: Gamow-Teller strength distribution



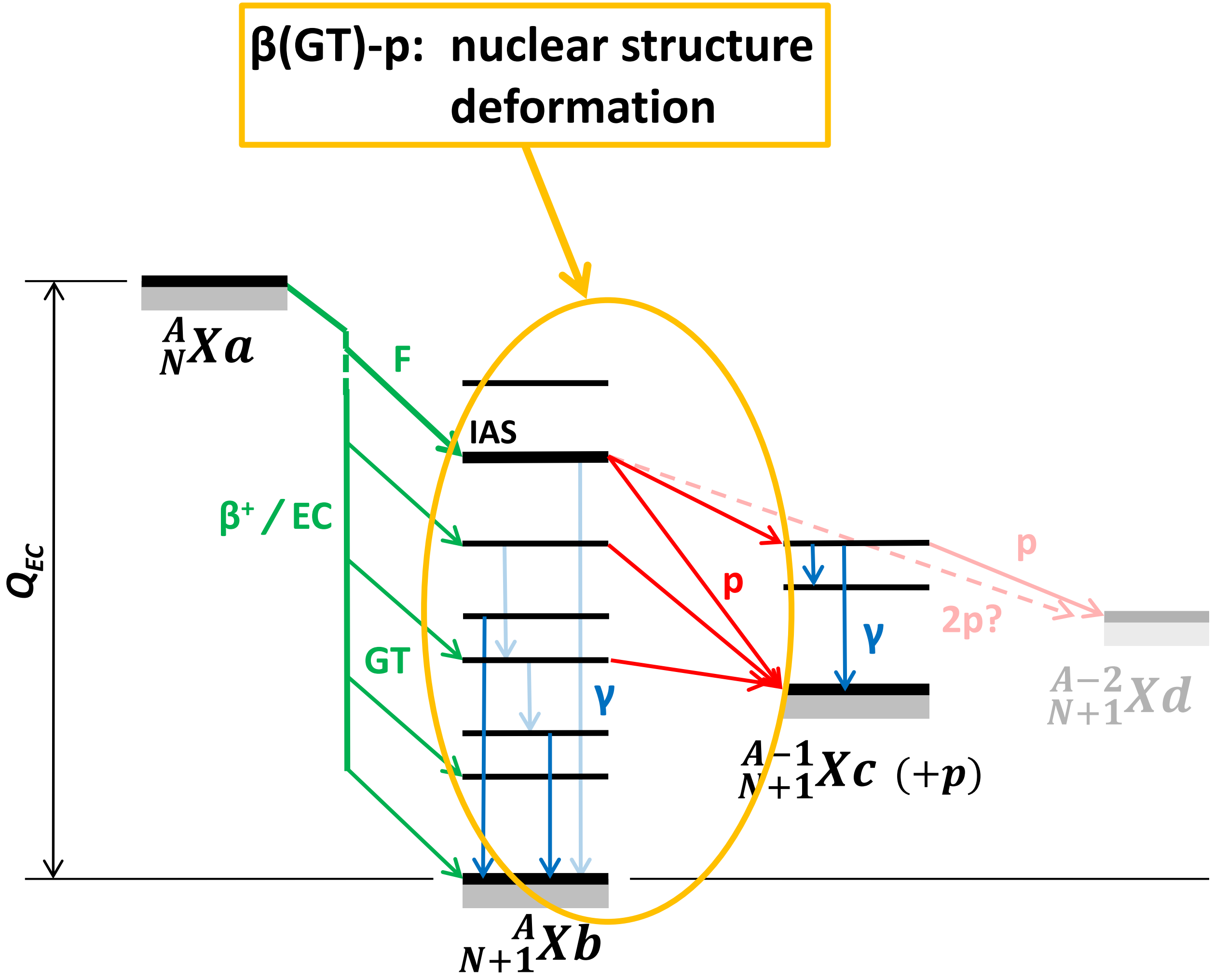


B(GT) ← β-p,2p,3p

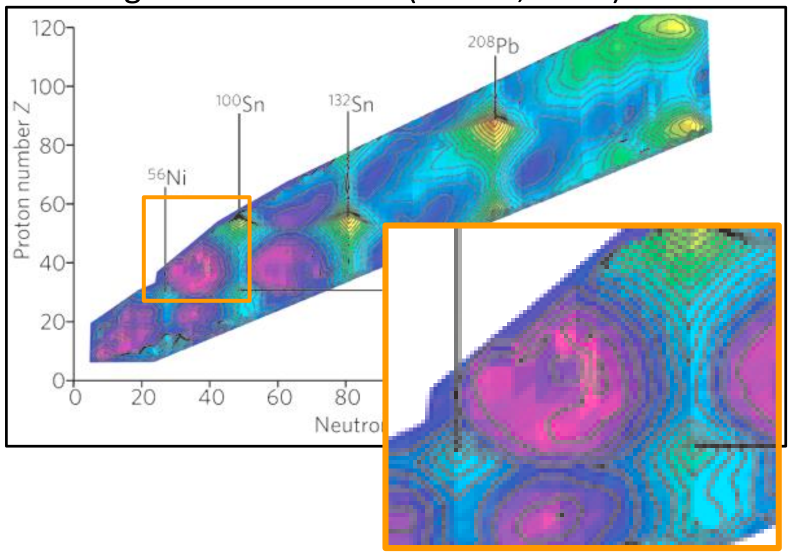
ISOLDE & Si-Cube

in ^{31}*Ar* (Koldste *et al.*, PRC **2014**)

physics cases: Gamow-Teller decay

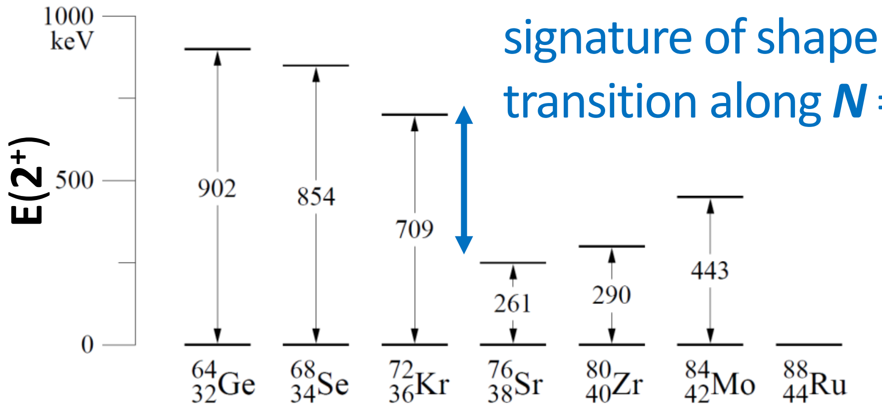


R. Bengtsson & P. Möller (nature, 2007)



28 < Z < 50

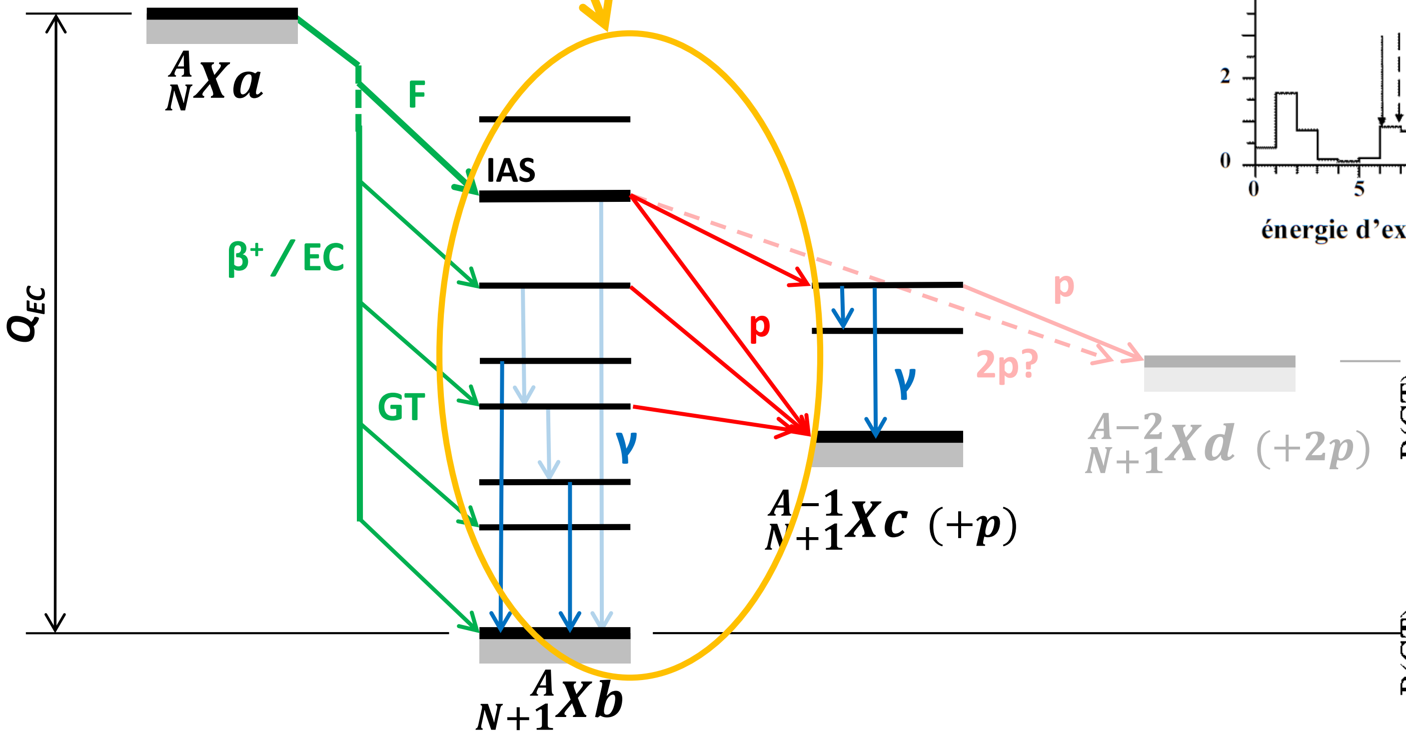
W.Gelletly *et al.*, Phys. Lett. B253 (1991)

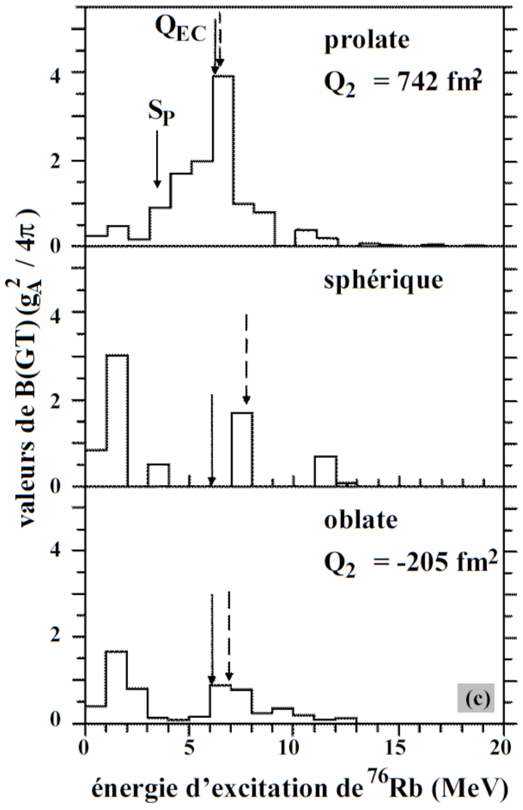


signature of shape transition along ***N*** = ***Z***

physics cases: Gamow-Teller decay

β(GT)-p: nuclear structure deformation

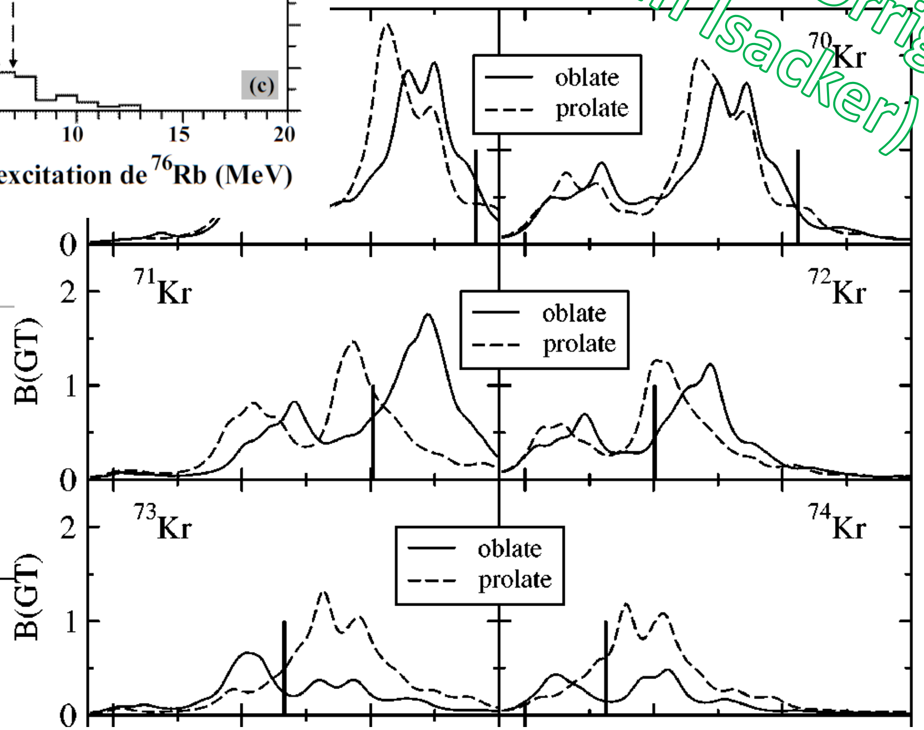




I. Hamamoto *et al.*, Z. Phys. A353 (1995)c

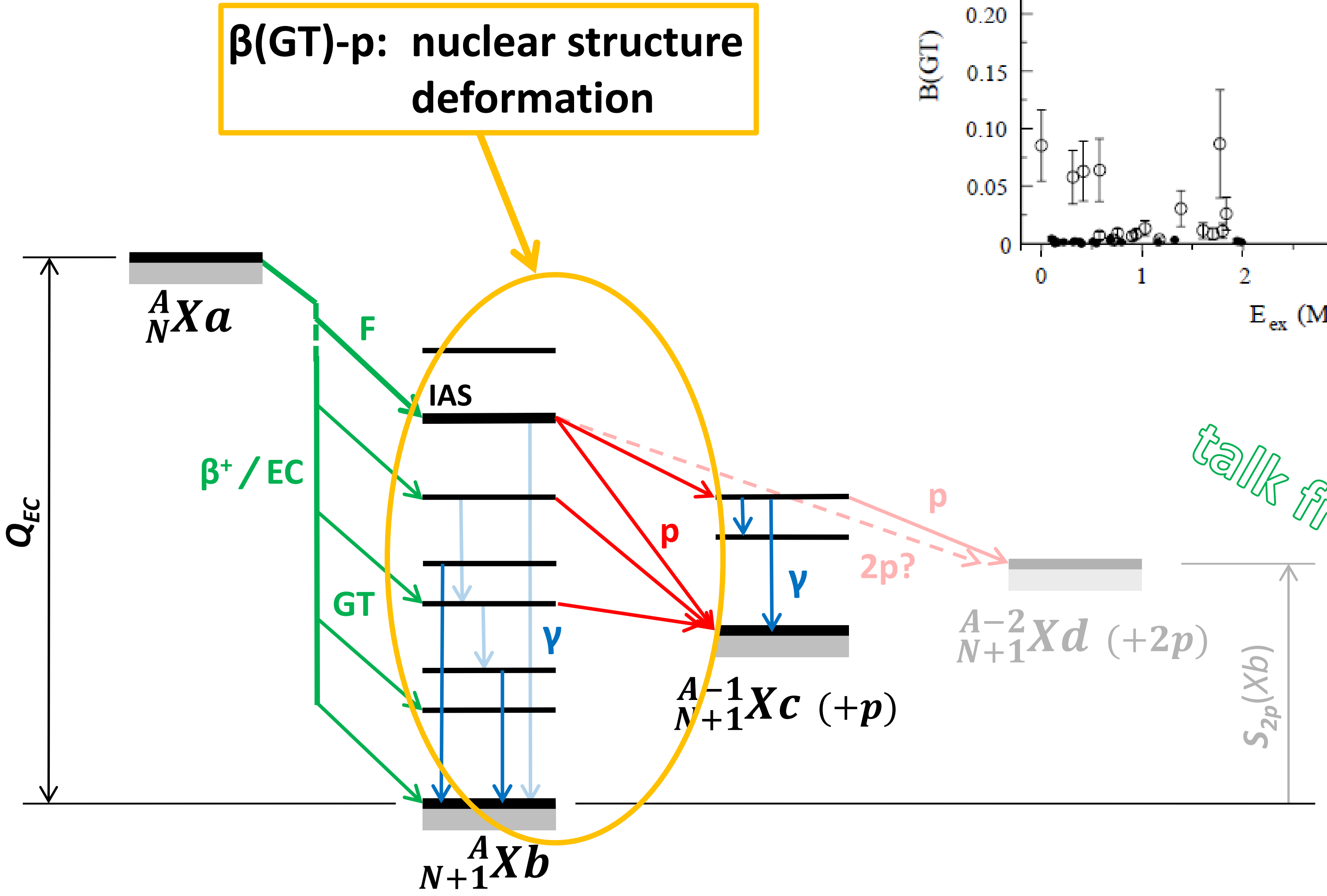
influence of deformation on ***B***(**GT**) distribution

talk from S. Orrigo (+ P. van Isacker)

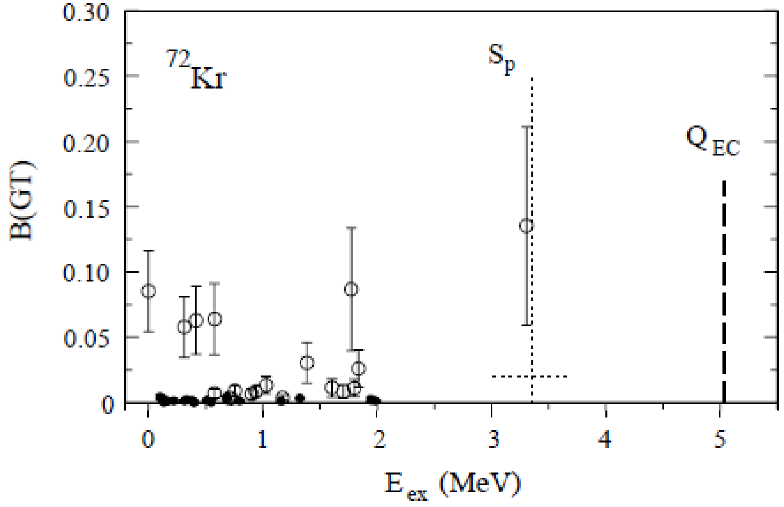


P. Sarriguren *et al.*, Phys. Rev. C64 (2001)

physics cases: Gamow-Teller decay

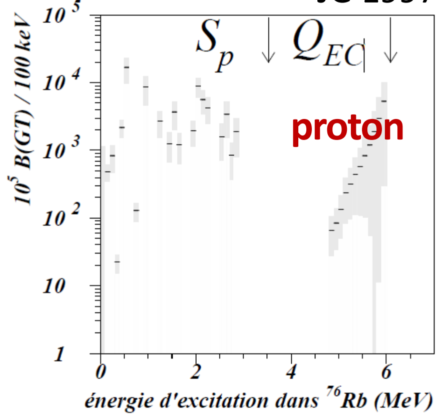


I. Piqueras et al., EPJA 2003



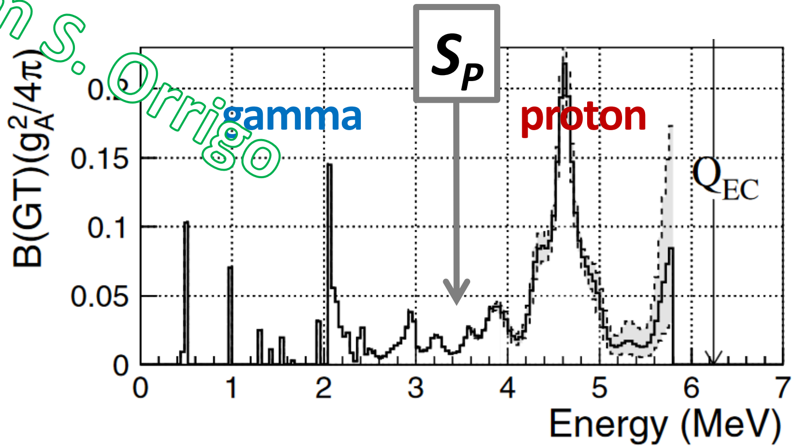
limited contribution of protons in that case
→ more important for more exotic (e.g. ^{70,71}Kr, A. Algora)

JG 1997



talk from S. Orrigo

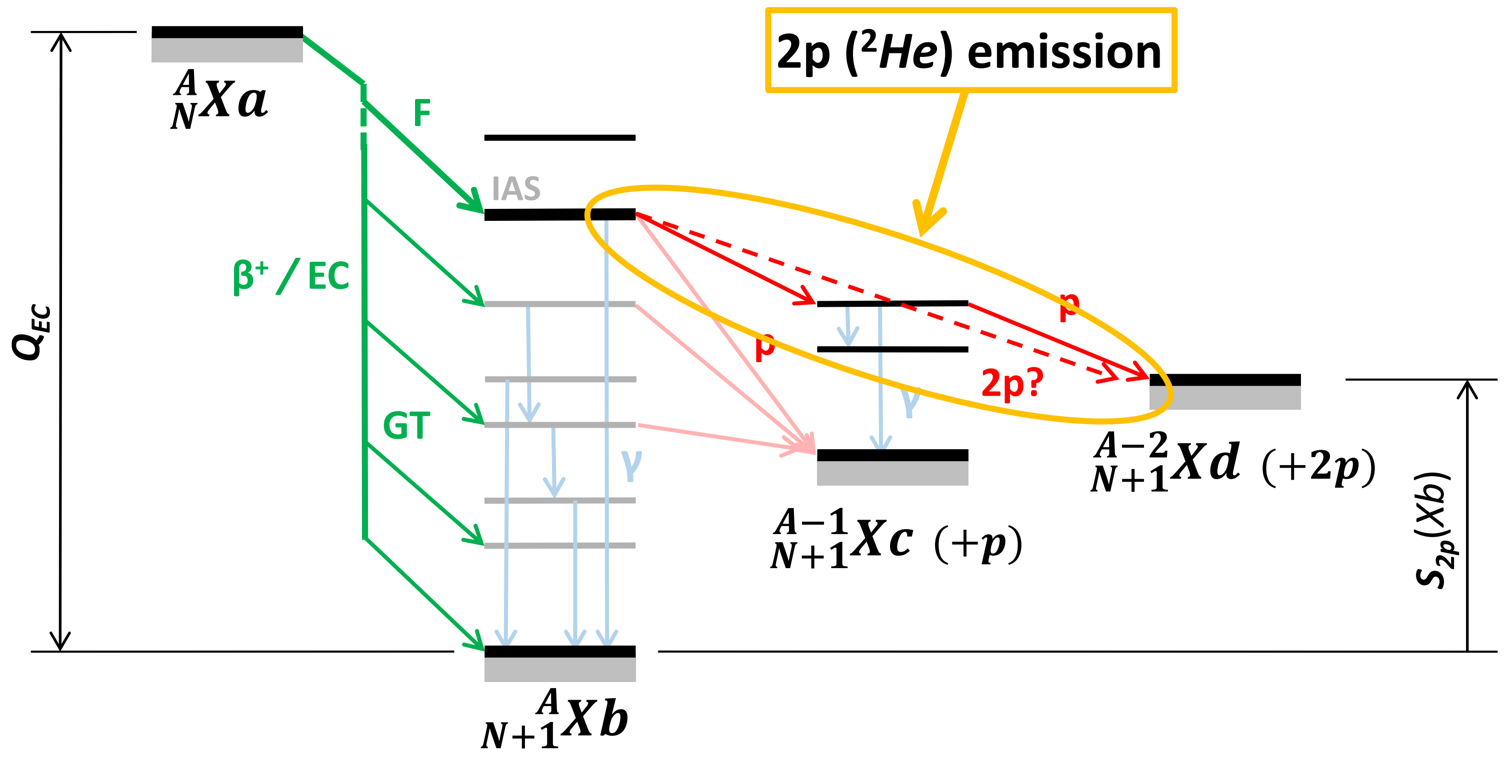
E. Nacher *et al.*, PRL 92 (2004)

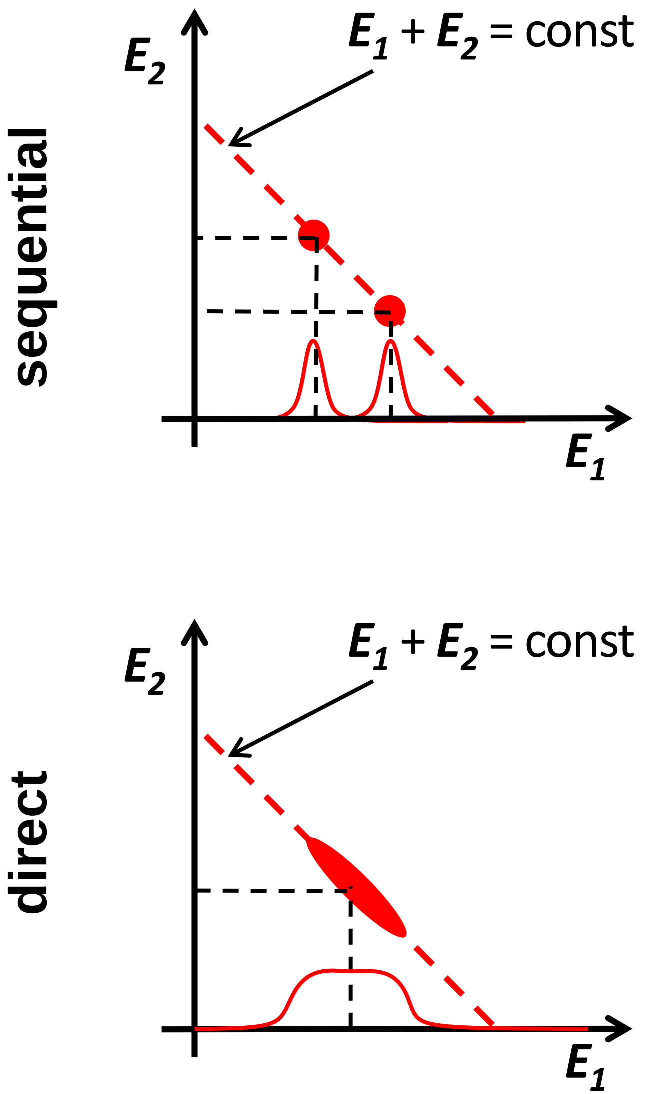


physics cases: β–2proton emission

sequential emission — complete decay scheme (levels of intermediate nucleus, B(GT),…)

direct emission — search for correlation pattern; comparison with ground-state 2P

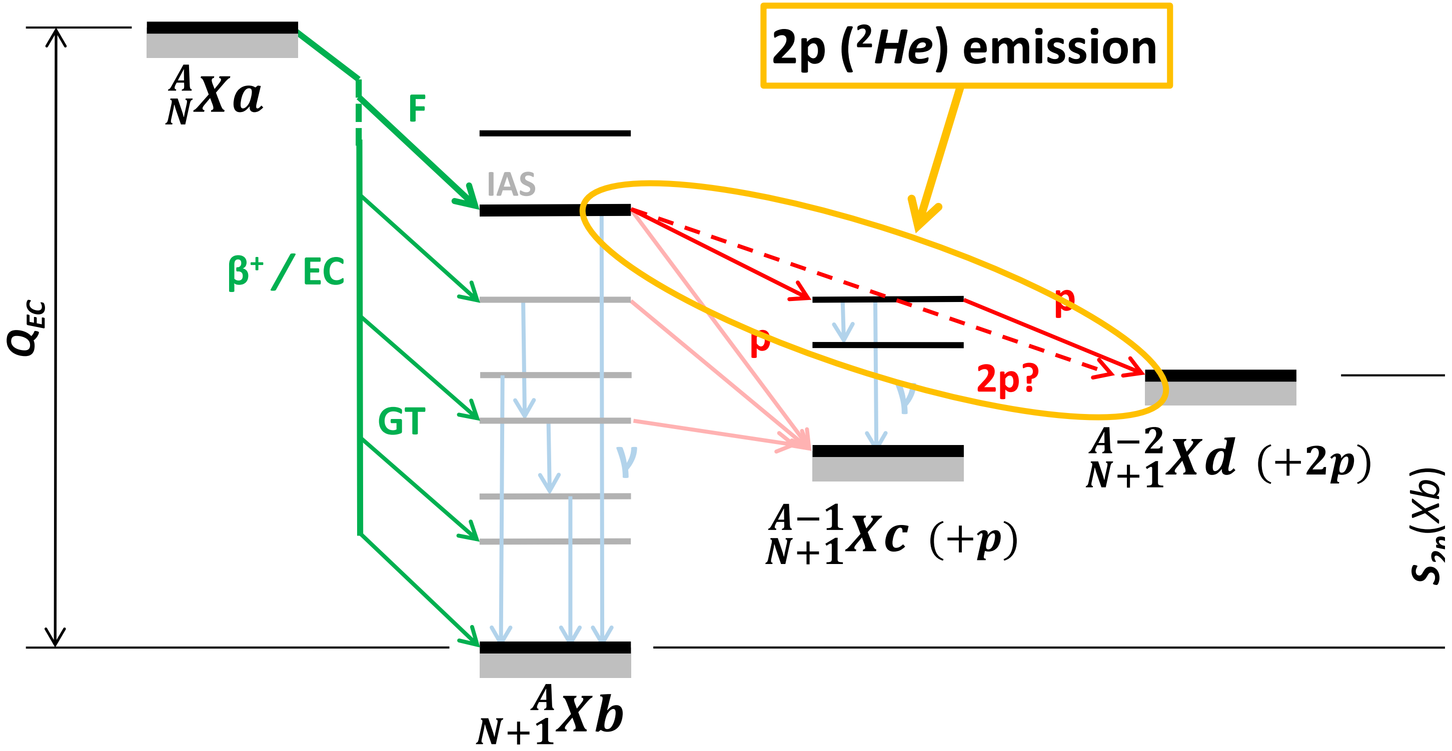


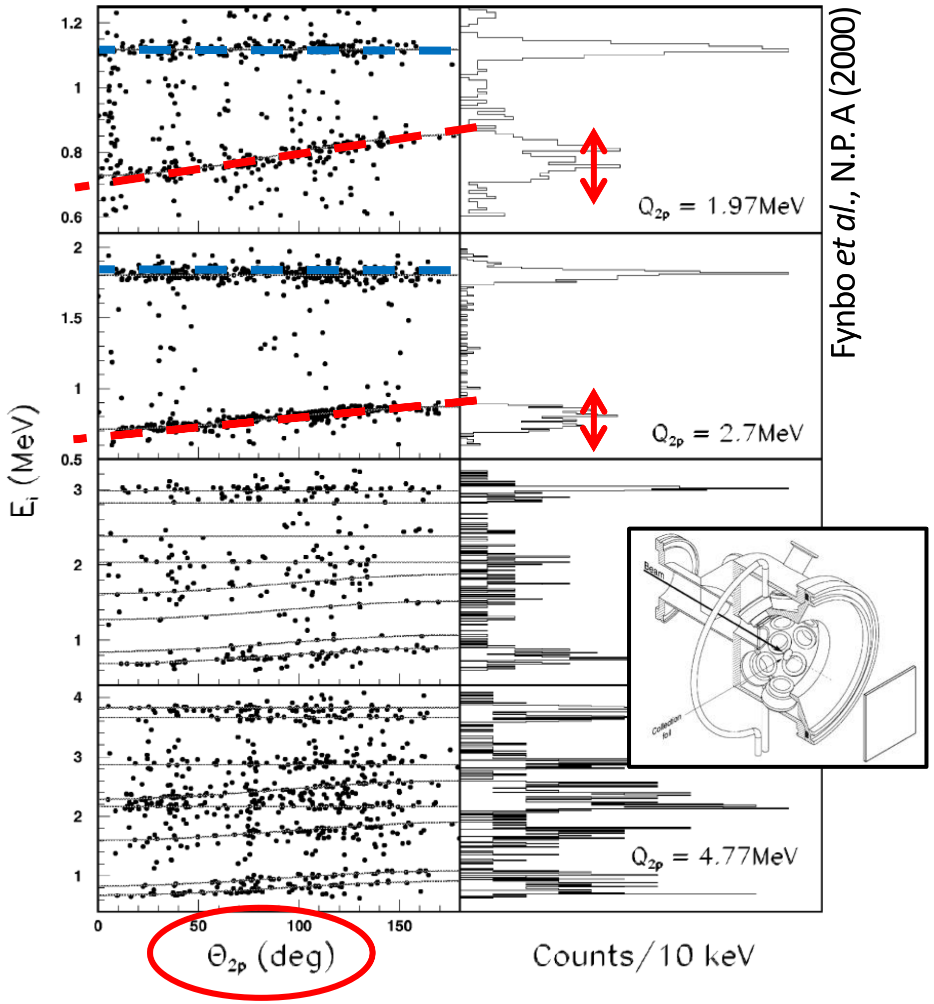


physics cases: β–2proton emission

β-2P direct emission never observed
(only sequential decay) → 2 energy peaks; → kinematic shift of the 2nd proton

few % direct 2P expected
(B.A. Brown, PRL 1990, calc. from IAS decay, ^{22}Al)





^{31}***Ar*** **beta-2p decay** (ISOLDE)

physics cases: β–2proton emission

best candidates for β-2P direct emission ?

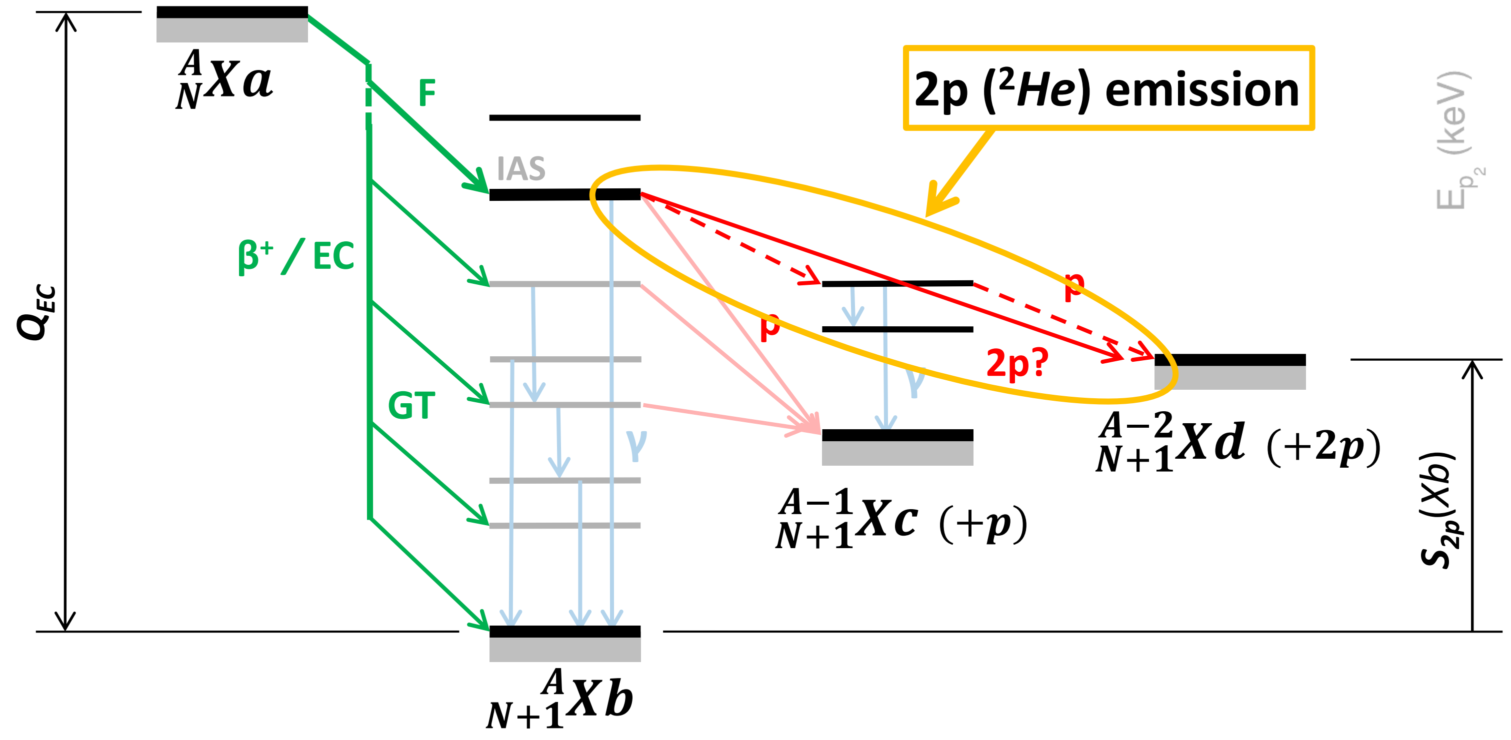
→ from IAS: 1p forbidden, 2p allowed: $T_Z < -3/2$

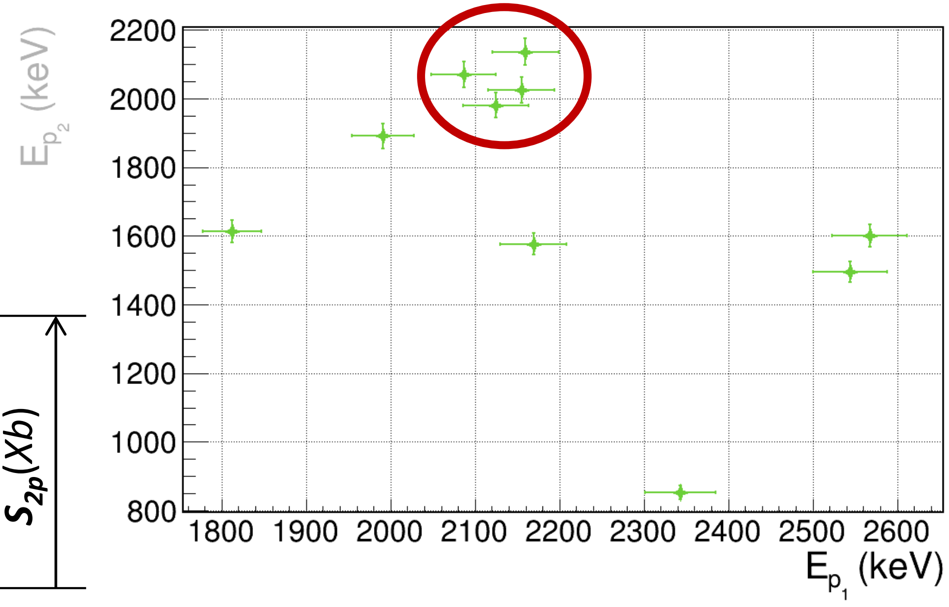
→ e.g.: ^{35}Ca, ^{39}Ti, ^{43}Cr, …

$I_{\beta\rightarrow IAS}$ ~ 5% ; $R_{2P/1P}$ ~ 2% → >10^4 counts for signature
>10^5 counts for correlations

E791 (LISE+ACTAR TPC)
(A. Ortega Moral *et al.*)

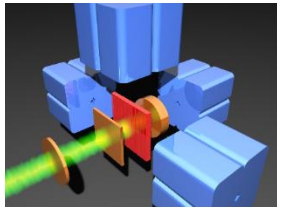
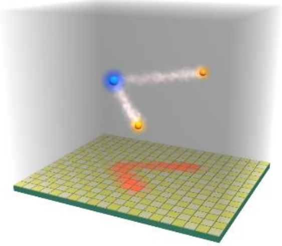
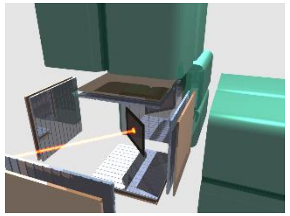
few events compatible with β-2P direct emission
→ ^{43}Cr (and ^{46}Fe?)

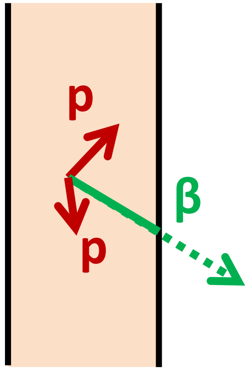


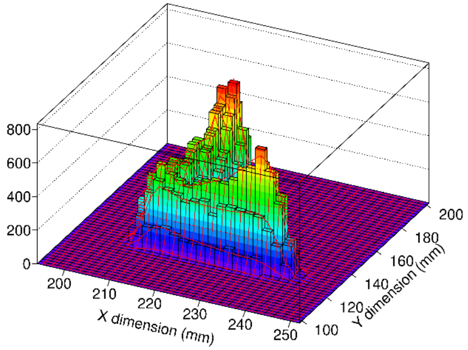


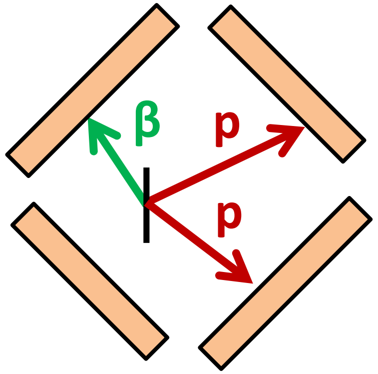
ISOL versus fragmentation: beta-proton detection capabilities

existing devices

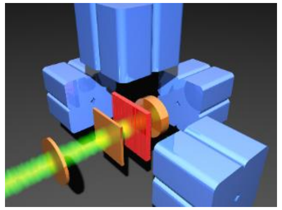
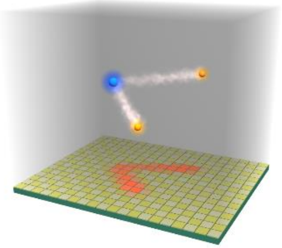
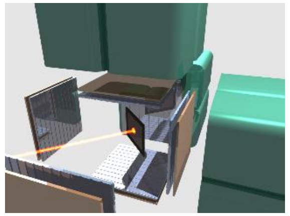
	existing devices		energy threshold	energy resolution	beta detection	multi proton
fragmentation	Si-tele + Ge		✗	~	⇦ beta pile-up	only sum energy
fragmentation	decay TPC		✓	~	transparent to beta	energy & angles (tracks)
ISOL	Si-cube + Ge		✓	✓	separated strips / pixels	ε_{1P}~70% ε_{2P}~50%



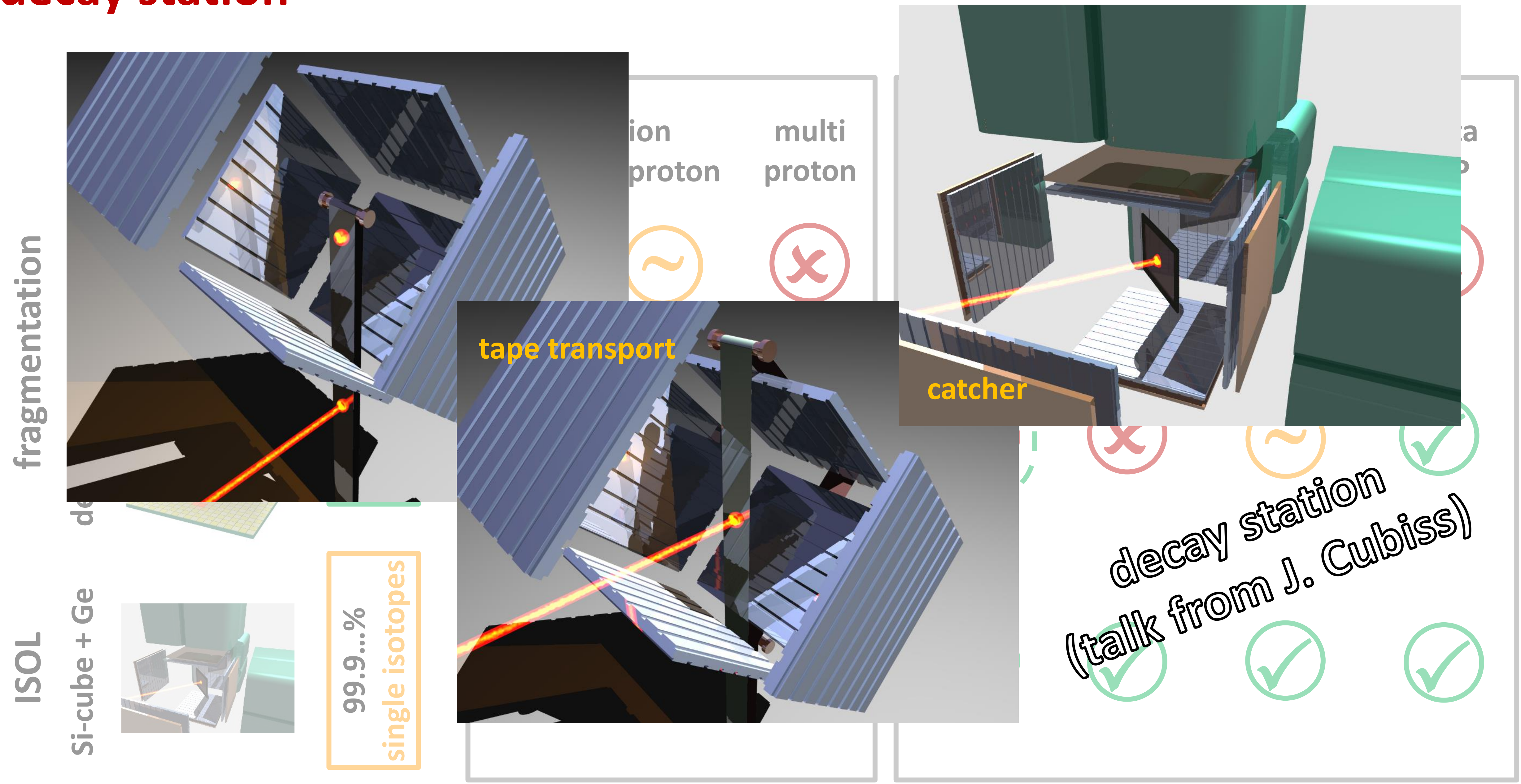




ISOL versus fragmentation

	existing devices		beam purity	detection gamma	detection proton	multi proton	IMME isospin	B(GT) distrib.	astro. (low E prot.)	beta -2P
fragmentation	Si-tele + Ge		cocktail beam / multiple isotopes	✓	~	✗	~	~	✗	✗
fragmentation	decay TPC		cocktail beam / multiple isotopes	✗	✓	✓	✗	✗	~	✓
ISOL	Si-cube + Ge		99.9...% / single isotopes	✓	✓	✓	✓	✓	✓	✓

decay station



production rates from website

Isotope	T1/2 (ms)	first A	rate	production
^{22}Al	91.1	**^{24}Al (+2)**	600 ?	SPIRAL1
^{23}Si	42.3	**^{24}Si (+1)**	420 18000	SPIRAL1 S3
^{26}P	43.7		0.3 **1300**	SPIRAL1 **S3**
^{27}S	**15.5**	**^{29}S (+2)**	160000	S3
^{31}Ar	**14.4**		**2 – 4 ?**	**SPIRAL1**
^{35}Ca	25.7		**8**	**S3**
^{39}Ti	31		**0.1 – 10**	**S3**
^{43}Cr	21.2	**^{46}Cr (+3)**	2000 60000	SPIRAL1 S3
^{46}Fe	**13.0**	**^{49}Fe (+3)**	300 – 2000	S3
^{69}Kr	28		**60 - 700**	**S3**

production reaction ???
(S3 or SPIRAL1)

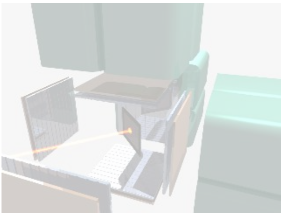
typical required rate
for these decay experiments
≥ ~1 / sec

short half-lives

production S3

- **extrapolation to lower masses ?**
- **at focal plane ?**
- **what about LEB → DESIR ?**
- **need for a fast gas cell ?**

thank you for your attention...

		setup	beam purity	detection gamma	detection proton	multi proton	IMME isospin	B(GT) distrib.	astro. (low E prot.)	beta -2P
fragmentation	Si-tele + Ge		cocktail beam multiple isotopes	✓	~	✗	~	~	✗	✗
fragmentation	decay TPC		cocktail beam multiple isotopes	✗	✓	✓	✗	✗	~	✓
ISOL	Si-cube + Ge		99.9...% single isotopes	✓	✓	✓	✓	✓	✓	✓