WESTFÄLISCHE
WILHELMS-UNIVERSTÄT
MÜNSTER

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ββ-decay matrix elements
&
charge-exchange reactions
(some surprises in nuclear physics ??)

KVI: (d,^{2}He) reactions → GT$^+$
RCNP: (^{3}He,t) reactions → GT$^-$
(TRIUMF: EC rates with ion-traps)

OUTLINE

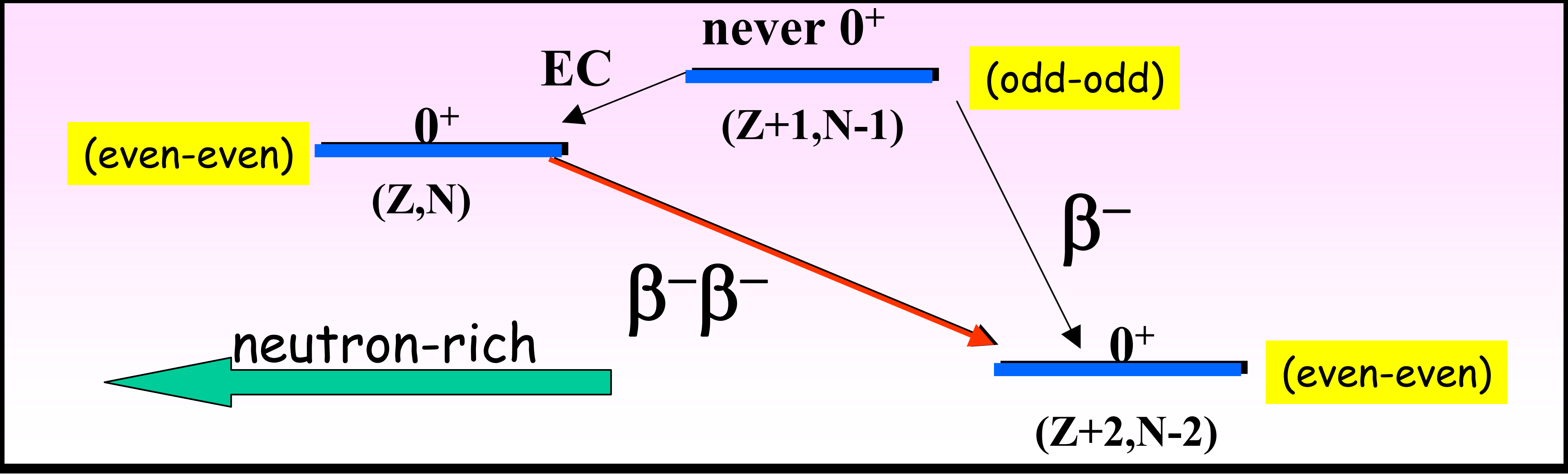
1) ~~some basics about ν's and nuclear $\beta\beta$ matrix elements~~

2) understanding the nuclear physics of $2\nu\beta\beta$ -decay
   - charge-exchange reactions (d,^{2}He) and (^{3}He,t)

	^{48}Ca	**CANDLES**
	^{64}Zn	**COBRA**
→	^{76}Ge	**GERDA**
	^{82}Se	**NEMO**
→	^{96}Zr	**NEMO**
→	^{100}Mo	**MOON/NEMO**
	^{116}Cd	**COBRA**
→	$^{128/130}$Te	**CUORE**
→	^{136}Xe	**EXO, KamLAND-ZEN**
	^{150}Nd	**SNO+**

3) possibilities towards the nuclear physics of $0\nu\beta\beta$-decay.
4) wish list and issues for theorists to deal with

$\beta^-\beta^-$ decay



$2\nu\beta^-\beta^-$ **decay:** $$\Gamma = \underbrace{(\text{ph-spc})}_{\text{5-body}} \times \left| \underbrace{NME}_{\text{allowed}} \right|^2$$

$0\nu\beta^-\beta^-$ **decay:** $$\Gamma = \underbrace{(\text{ph-spc})}_{\text{3-body}} \times \left| \underbrace{NME}_{\text{any degree}} \right|^2 \times \left| \sum_{i=1}^{3} U_{ei}^2 m_i \right|^2$$

Quick reminder of neutrino mass problem

$$\Gamma \propto \left| \quad NME \quad \right|^2 \cdot \left| \sum_{i=1}^{3} U_{ei}^2 m_i \right|^2$$

$$\boldsymbol{U = V \cdot \mathrm{diag}(e^{-i\Phi_1}, e^{-i\Phi_2}, 1)}$$ ⟵ **2 extra Majorana phases**

$$V_{\alpha i} = \begin{pmatrix} V_{e1} & V_{e2} & V_{e3} \\ V_{\mu 1} & V_{\mu 2} & V_{\mu 3} \\ V_{\tau 1} & V_{\tau 2} & V_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12}c_{13} & c_{13}s_{12} & s_{13}e^{-i\delta} \\ -c_{23}s_{12} - c_{12}s_{13}s_{23}e^{-i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{-i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{13}c_{23}s_{13}e^{-i\delta} & -c_{12}s_{23} - c_{23}s_{12}s_{13}e^{-i\delta} & c_{13}c_{23} \end{pmatrix}$$

known quantities:

$$\Theta_{12} = 0.6 \pm 0.1 \quad \rightarrow \approx \pi/6$$

$$\Theta_{23} = 0.7 \pm 0.2 \quad \rightarrow \approx \pi/4$$

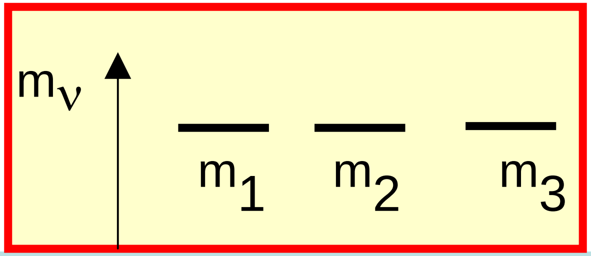
$$\Theta_{13} < 0.14$$

$$\Delta m_{atm}^2 = \left| m_3^2 - m_2^2 \right| \approx 2.6 \times 10^{-3}\,\mathrm{eV}^2 \approx \underline{(0.05\,\mathrm{eV})^2}$$

$$\Delta m_{sol}^2 = \left| m_2^2 - m_1^2 \right| \approx 7.9 \times 10^{-5}\,\mathrm{eV}^2 \approx \underline{(0.009\,\mathrm{eV})^2}$$

Neutrino mass scenarios:

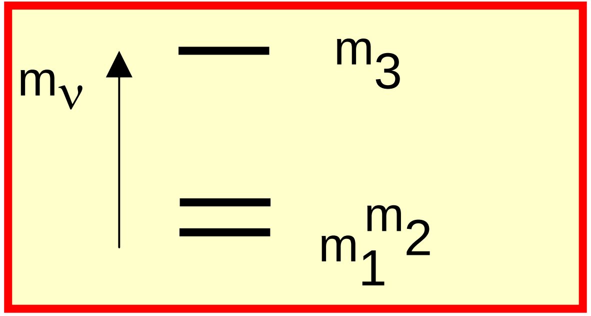
1) degenerate:



$$\left|m_{\nu_e}\right| \approx 0.2eV$$

best of all cases

2) normal hierarchy:

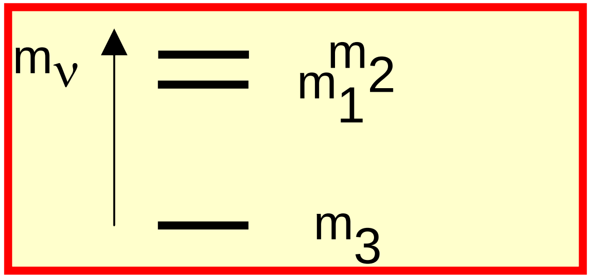


$$\left|m_{\nu_e}\right|^2 \propto \Delta m_{sol}^2 \times \left|\frac{3m_1}{\Delta m_{sol}} + e^{-2i(\Phi_2-\Phi_1)} + (<0.5)e^{-2i(\delta-\Phi_1)}\right|^2$$

= zero!! for:

$$\Theta_{13} = 0 \quad (\Phi_2 - \Phi_1) = \frac{\pi}{2} \quad \frac{3m_1}{\Delta m_{sol}} = 1$$

3) inverted hierarchy:



$$\left|m_{\nu_e}\right|^2 \propto \Delta m_{atm}^2 \times \left|3 + e^{-2i(\Phi_2-\Phi_1)}\right|^2$$

if inverted hierarchy were determined
(by LHC or spectral distortion of SN-neutrinos)
THEN: $\left|m_{\nu_e}\right| \approx \Delta m_{atm}$

or the neutrino is a Dirac particle

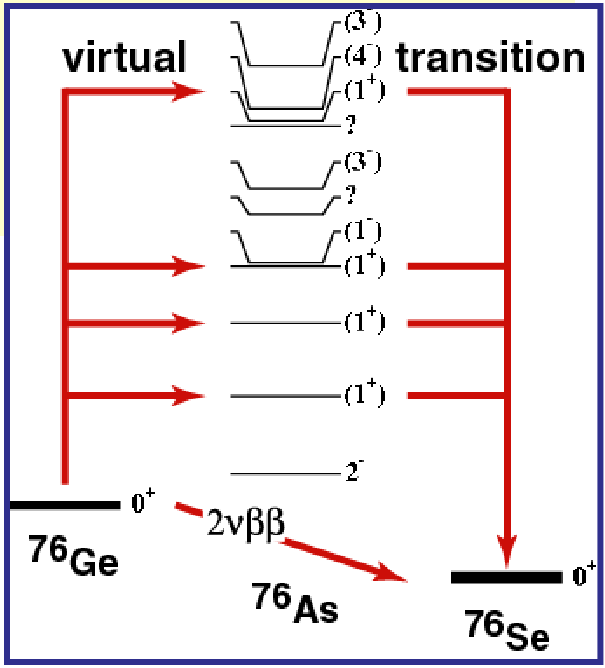
NME important

NME
$2\nu\beta^-\beta^-$ decay

q-transfer like ordinary β-decay
($q \sim 0.01\ \mathrm{fm}^{-1} \sim 2\ \mathrm{MeV/c}$)
only allowed decays possible

$$\Gamma^{2\nu}_{(\beta^-\beta^-)} = \frac{C}{8\pi^7}\left(\frac{G_F\;\overset{!!}{g_A}}{\sqrt{2}}\cos(\Theta_C)\right)^4 \left|M^{(2\nu)}_{\mathrm{DGT}}\right|^2 \mathcal{F}^2_{(-)}\, f(Q)$$

$$= \underbrace{G^{2\nu}(Q,Z)}_{\propto\, Q^{11}\cdot Z^2}\;\underbrace{\left|M^{(2\nu)}_{\mathrm{DGT}}\right|^2}_{\overset{\exp}{\approx}\, 10^{-3}\ \mathrm{MeV}^{-2}\ \propto\, \frac{1}{N-Z}}$$

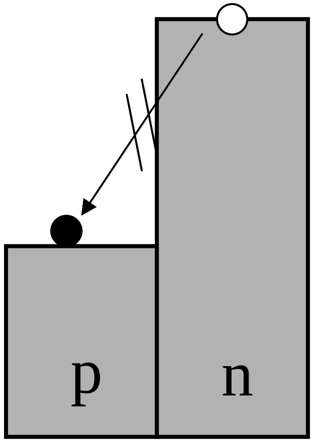


favorable:

1. High Q-value
2. High Z

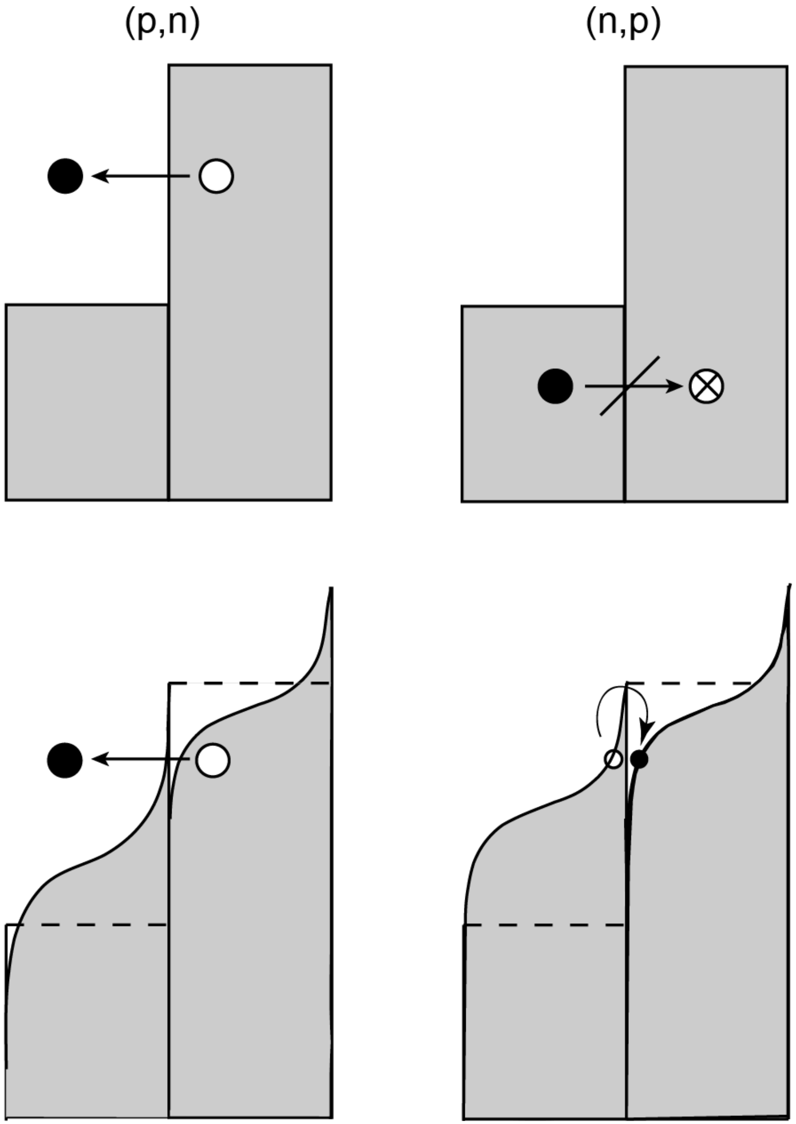
Unfavorable:

1. high neutron excess
   (because of Pauli-Blocking)



A layman‘s sketch of thePauli-blocking

remember: GT requires $\Delta\hbar\omega=0$!!



Extreme case:

(p,n) completely open

(n,p) completely blocked

Soft surface case:

(p,n) still largely open

(n,p) still largely blocked

yet probabilities could be finite

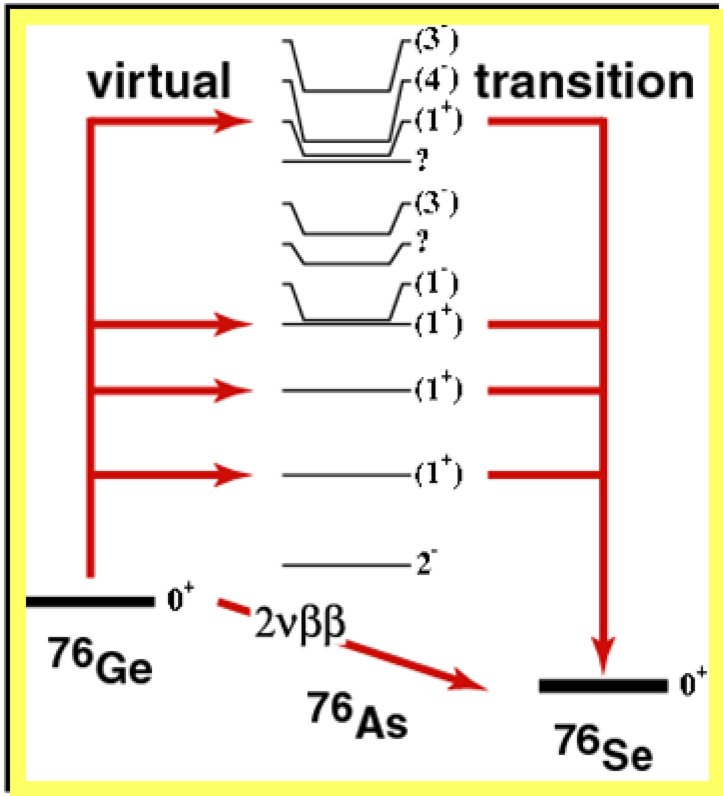
but tiny

$$
\begin{aligned}
M_{\mathrm{DGT}}^{(2\nu)} &= \sum_m \frac{\left\langle 0_{g.s.}^{(f)} \left| \sum_k \sigma_k \tau_k^- \right| 1_m^+ \right\rangle \left\langle 1_m^+ \left| \sum_k \sigma_k \tau_k^- \right| 0_{g.s.}^{(i)} \right\rangle}{\tfrac{1}{2} Q_{\beta\beta}(0_{g.s.}^{(f)}) + E(1_m^+) - E_0} \\
&= \sum_m \frac{M_m\left(GT^+\right) M_m\left(GT^-\right)}{E_m}
\end{aligned}
$$

To note:

1. two sequential & „allowed“ β^--decays of „Gamov-Teller“ type
2. „first-“ oder „higher order forbidden“ decays negligible
3. Fermi–transitions don't contribute (because different isospin-multiplet)

accessible thru charge-exchange reactions in (n,p) and (p,n) direction (e.g. (d,^{2}He) or (^{3}He,t))



NME
$0\nu\beta^-\beta^-$ decay

neutrino enters as virtual particle,
$q \sim 0.5\,\mathrm{fm}^{-1}$ ($\sim$ 100 MeV/c)
degree of forbiddeness weakened

$$\Gamma^{0\nu}_{(\beta^-\beta^-)} = \underbrace{G^{0\nu}(Q,Z)}_{\propto Q^5\cdot Z^4}\, \overset{!!}{g_A^4} \underbrace{\left| M^{(0\nu)}_{\mathrm{DGT}} - \left(\frac{g_V}{g_A}\right)^2 M^{(0\nu)}_{\mathrm{DF}} \right|^2}_{\overset{\text{theory}}{\approx} 10\ !!} \left|m_{\nu_e}\right|^2$$

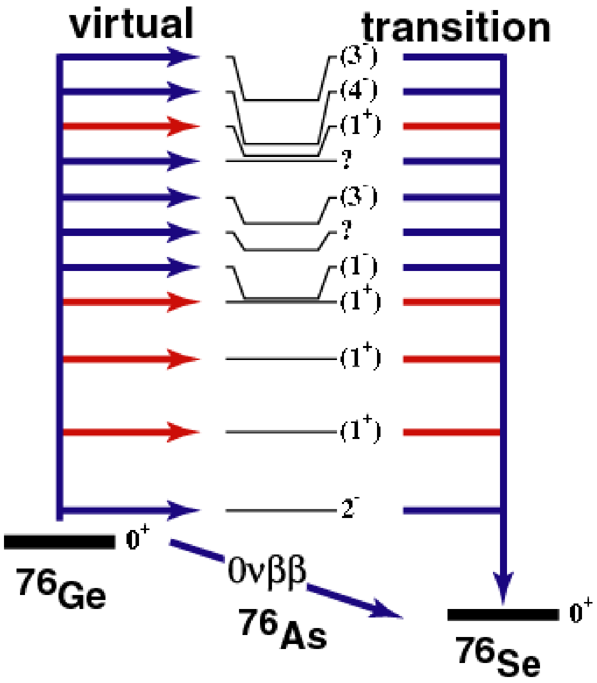
indepnt. of (A,Z)
(except for magic nuclei)

Mass of Majorana-ν !

To note:

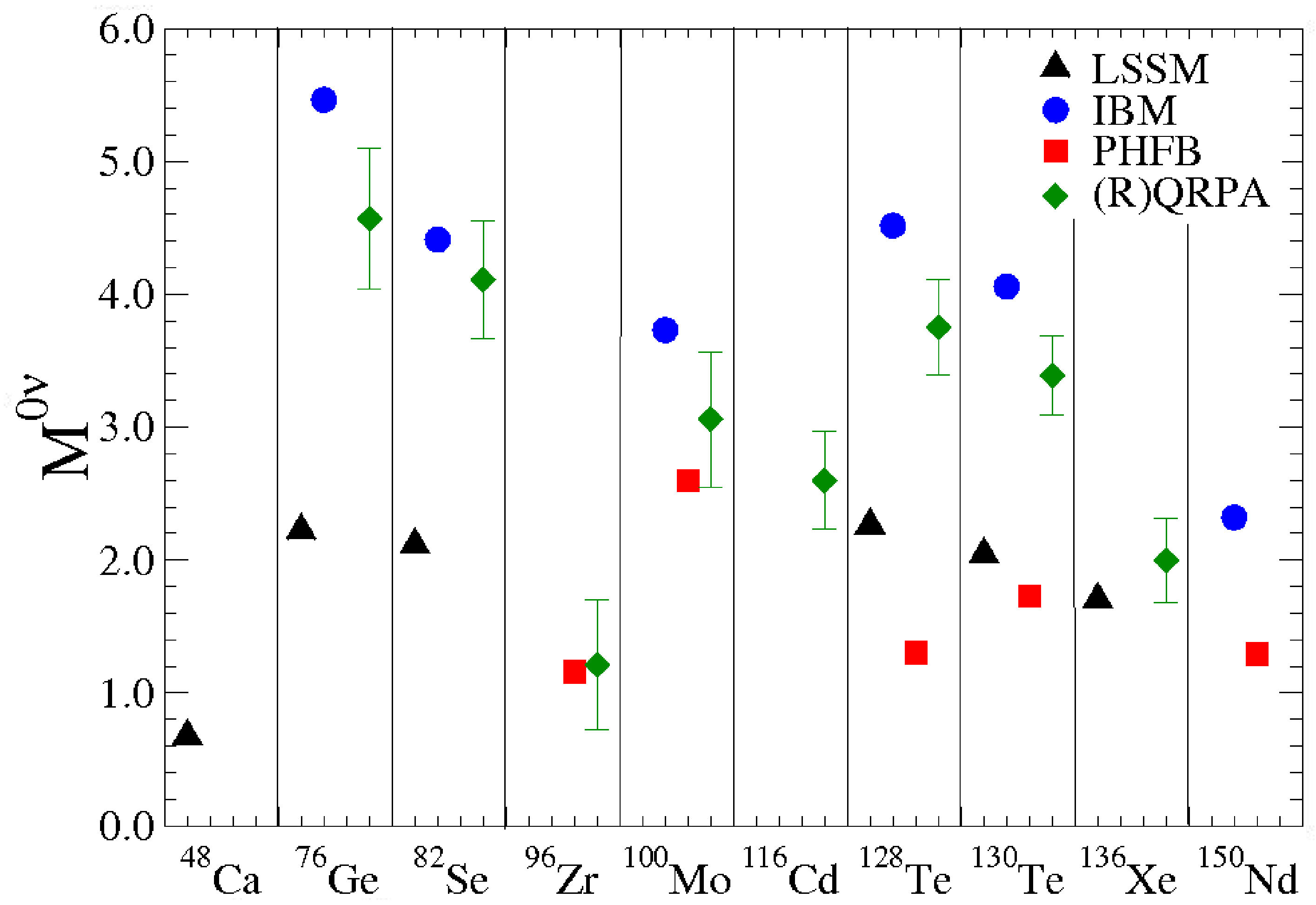
1. „first-“ or „higher order forbidden“ transitions important
2. Fermi –transitions important
3. Pauli-blocking largely lifted
4. high Q-value, high Z important

NOT accessible thru charge-exchange reactions

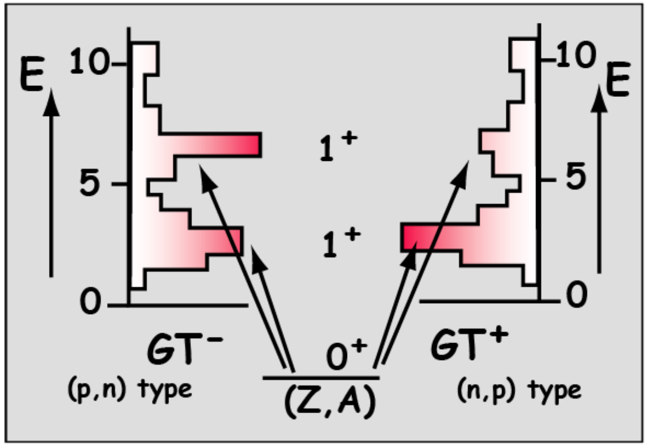


Neutrinoless Double Beta Decay Nuclear Matrix Elements

V.Rodin, A. Faessler, F. Šimkovic, P. Vogel, PRC 68 (2003) 044303;



Back to $2\nu\beta\beta$ decay and charge-exchange reactions



Q: How to connect the weak $\vec{\sigma}\tau$ GT operator with hadronic reactions?

A: at intermediate energies exploit the dominance of $V_{\sigma\tau}$ interaction.

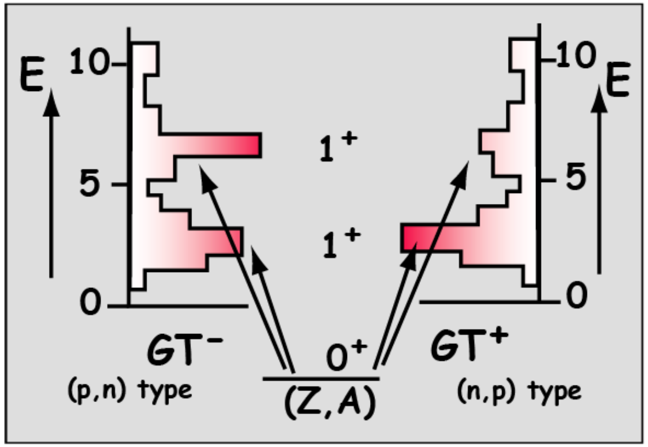
$$M(GT) = \langle 1^+ \| \sigma\tau^{\pm} \| 0^i_{g.s.} \rangle$$

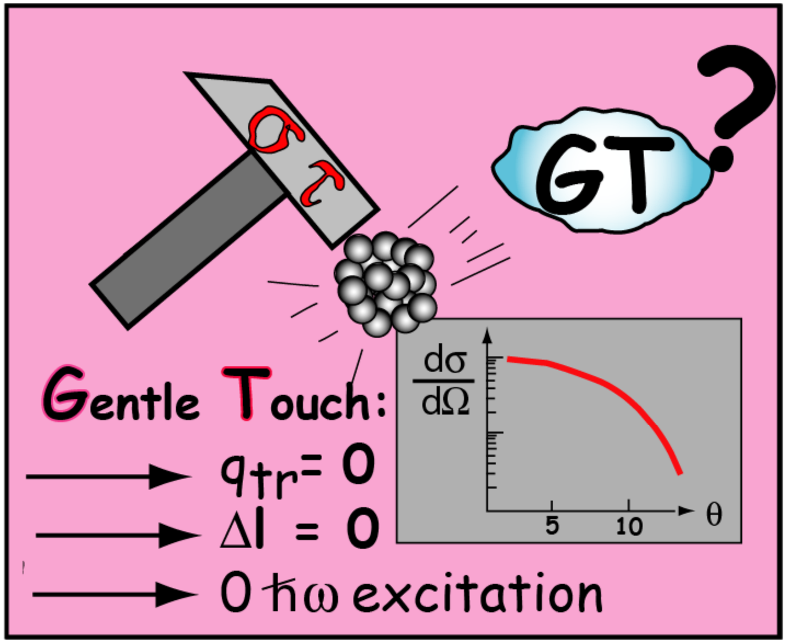
$$B(GT) = \frac{1}{2J_i+1} \, | M(GT) |^2$$

hadronic probes: (n,p), (d,^{2}He), (t,^{3}He)

or (p,n), (^{3}He,t)

$$\left[\frac{d\sigma}{d\Omega}\right] = \left[\frac{\mu}{\pi\hbar}\right]^2 \underbrace{\frac{k_f}{k_i} N_d \, |V_{\sigma\tau}|^2 \, |\langle f \,|\, \sigma\tau \,|\, i \rangle|^2}_{\text{largest at 100 - 300 MeV/A}}$$





Gentle Touch:

- → $q_{tr} = 0$
- → $\Delta l = 0$
- → $0\,\hbar\omega$ excitation

$$M(GT) = \langle 1^{+} \| \sigma\tau^{\pm} \| 0^{i}_{g.s.} \rangle$$

$$B(GT) = \frac{1}{2J_i+1}\,|\,M(GT)\,|^{2}$$

hadronic probes: (n,p), (d,^{2}He), (t,^{3}He)

or (p,n), (^{3}He,t)

$$\left[\frac{d\sigma}{d\Omega}\right] = \left[\frac{\mu}{\pi\hbar}\right]^{2} \frac{k_f}{k_i}\, N_d \underbrace{\left|V_{\sigma\tau}\right|^{2}}_{\text{largest at 100 - 200 MeV/A}} \left|\langle f \,|\, \sigma\tau \,|\, i \rangle\right|^{2}$$

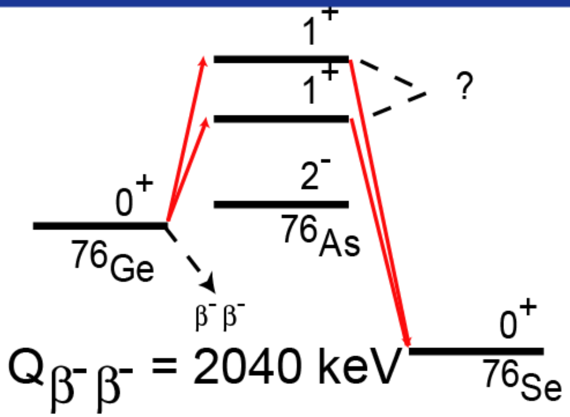
The message after many years of expmlt studies of $2\nu\beta\beta$!! -NME

1. In all cases the low-energy part of the GT-excitation makes up most of the NME.
2. The GT giant resonance has little to no effect on the NME (Pauli-blocked from the 2nd leg).
3. A large difference of the nuclear shape between mother and grand-daughter leads to a suppression of the NME (case: ^{76}Ge).
4. There are some very special and simple cases (^{96}Zr, ^{100}Mo)
5. What is the effect of a 2n-pair in ^{128,130}Te ?
6. What is wrong with ^{136}Xe – why is it so stable ?

^{76}Ge

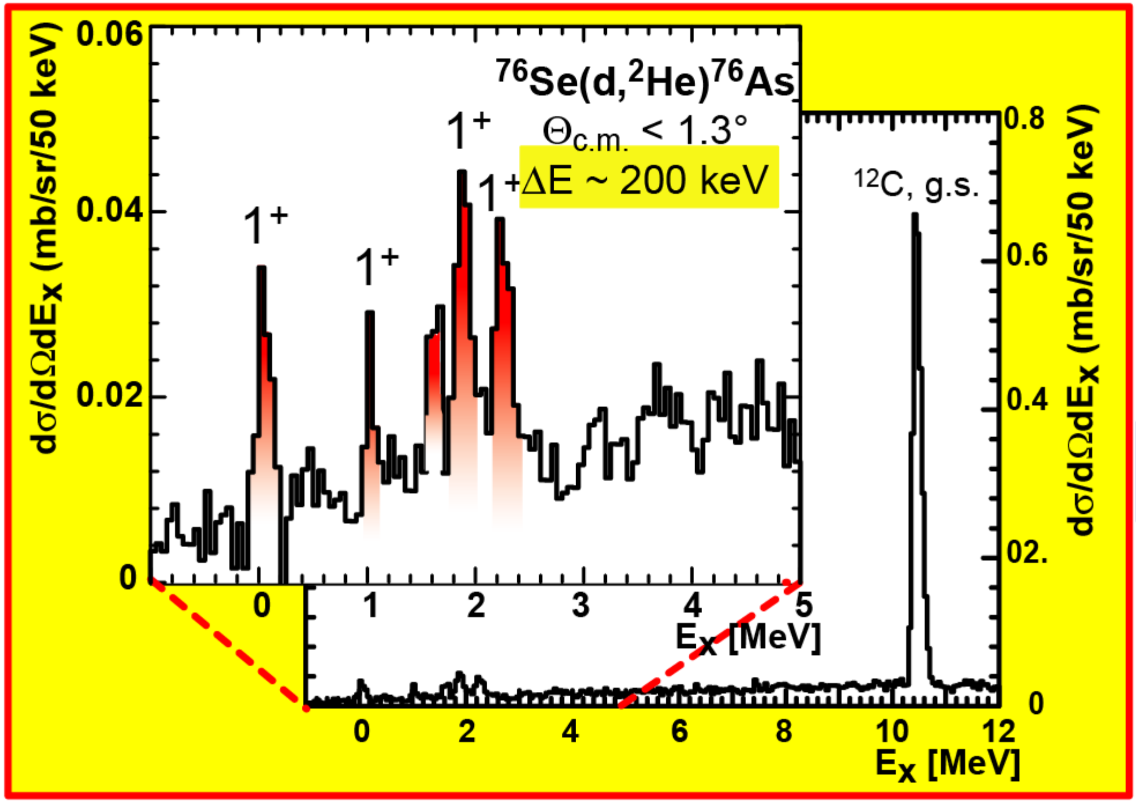
the most important ββ-decaying nucleus

^{76}Ge ββ ^{76}Se

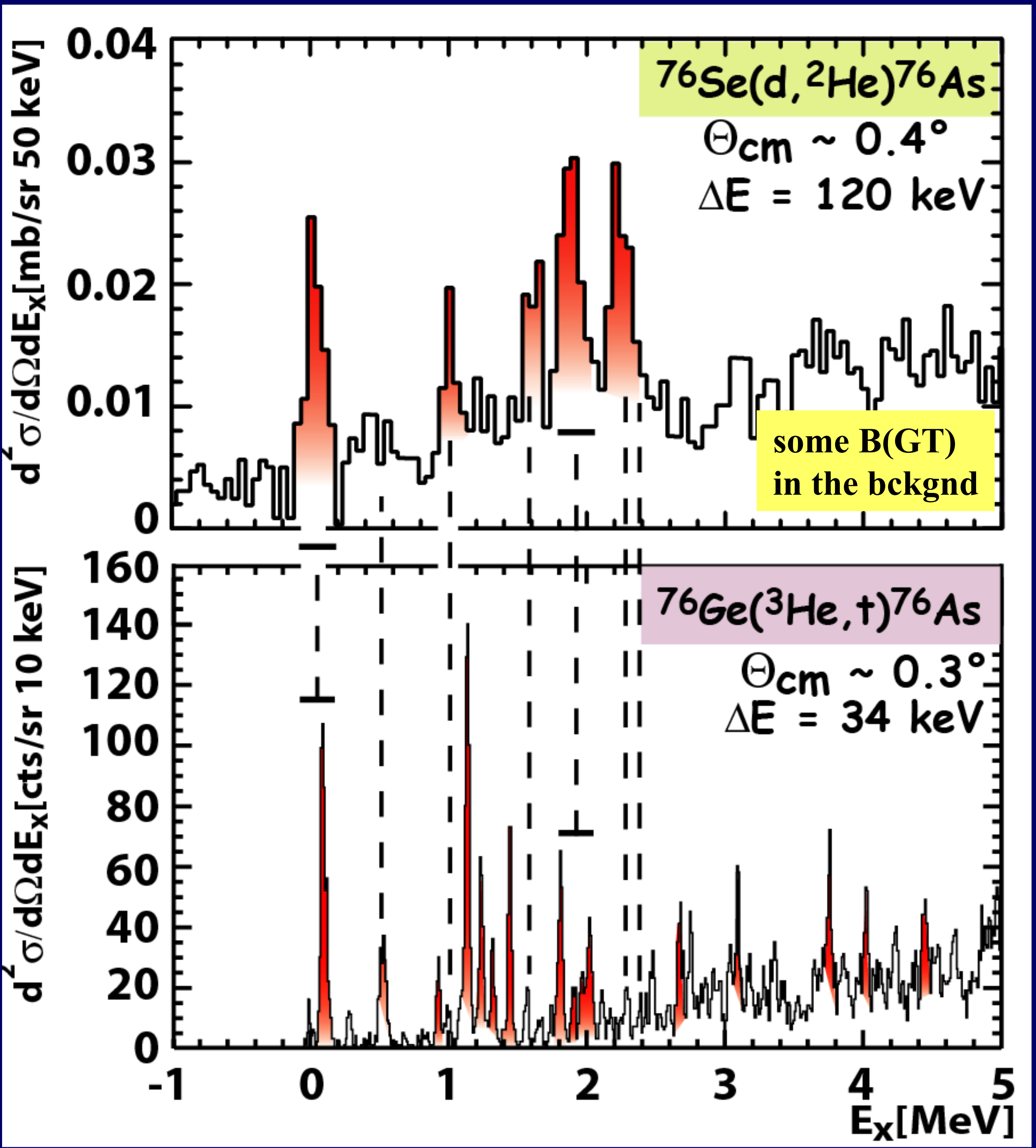


$Q_{\beta^- \beta^-}$ = 2040 keV

^{76}Se(d,^{2}He)^{76}As



Σ B(GT$^+$) ~ 0.54



some B(GT) in the bckgnd

an anticorrelation of strength (very similar to ^{48}Ca)

! ! ! ! ! ! !

An effect of the difference of deformation ??

^{76}Se:

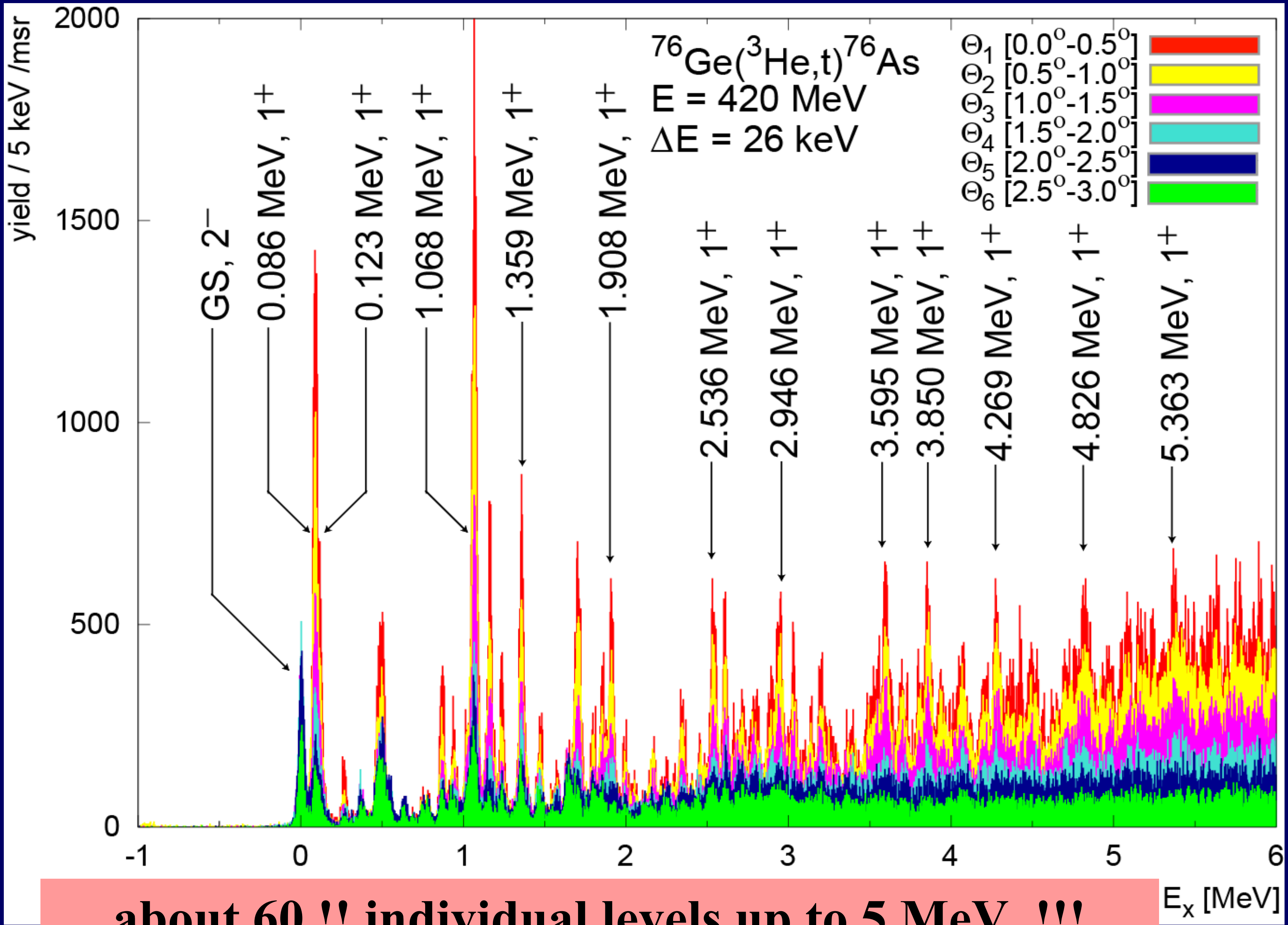
oblate

(β_2 ~ –0.2)

^{76}Ge:

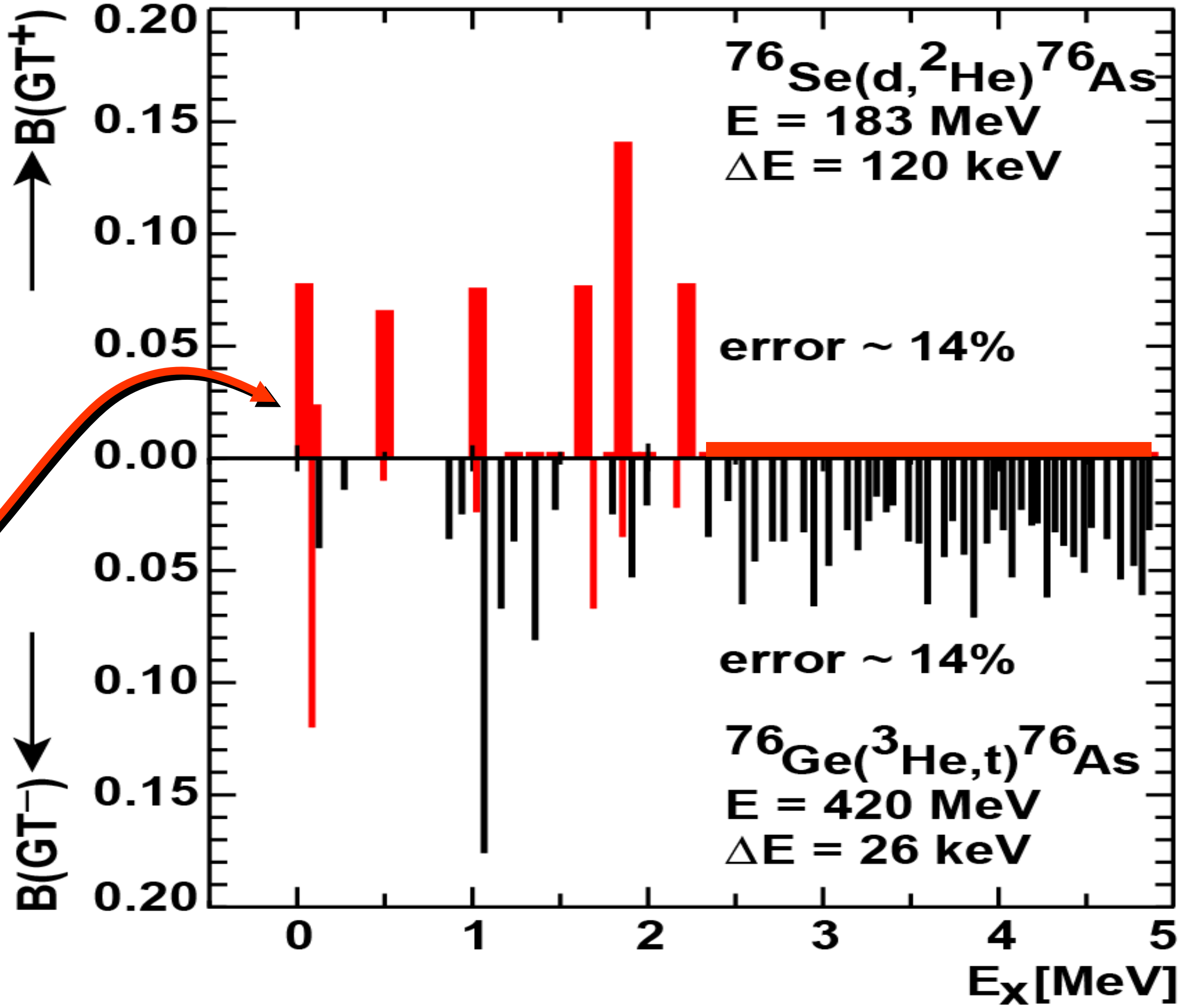
moderately oblate/ prolate

(β_2 ~ 0.1)

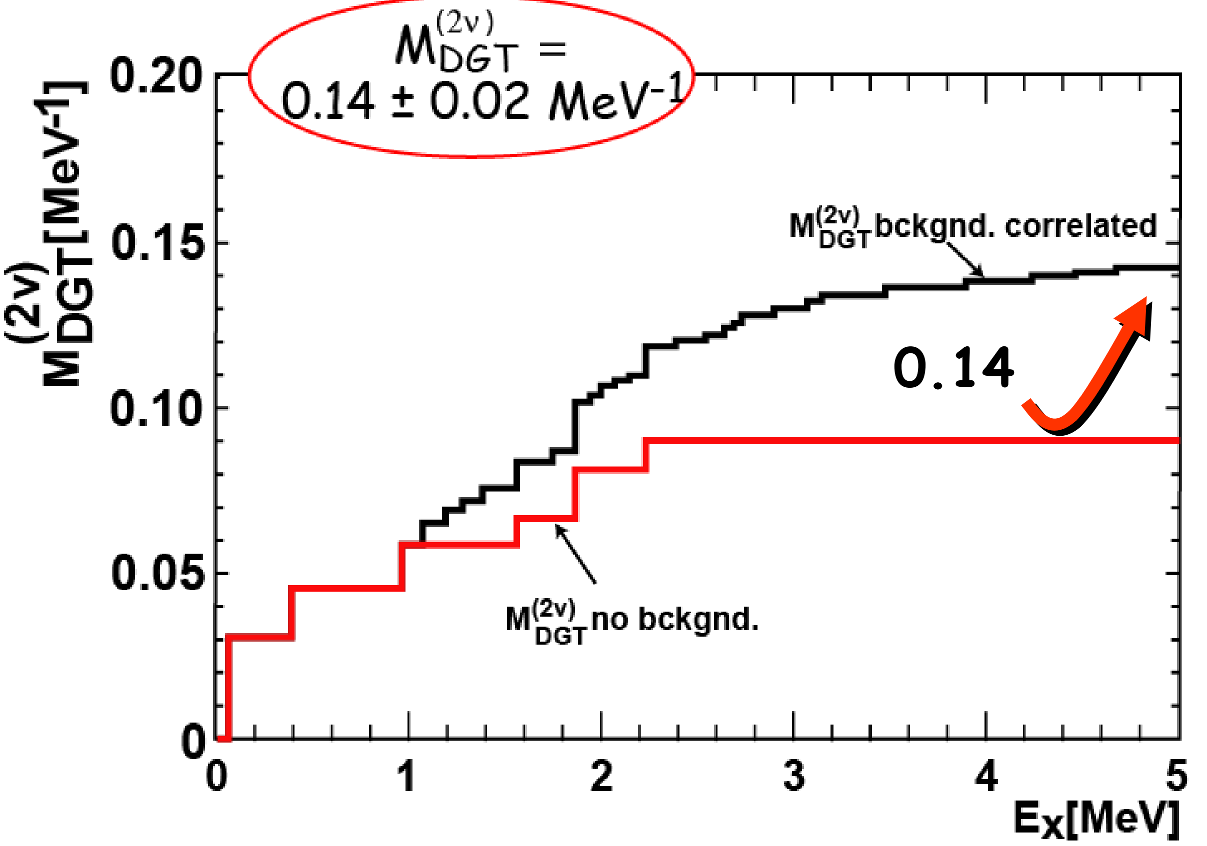


about 60 !! individual levels up to 5 MeV !!!

triplet of states: 0.044, 0.082, 0.12 MeV



Correlate states within the expmtl resolution



$M^{(2\nu)}_{DGT}$ = 0.14 ± 0.02 MeV-1

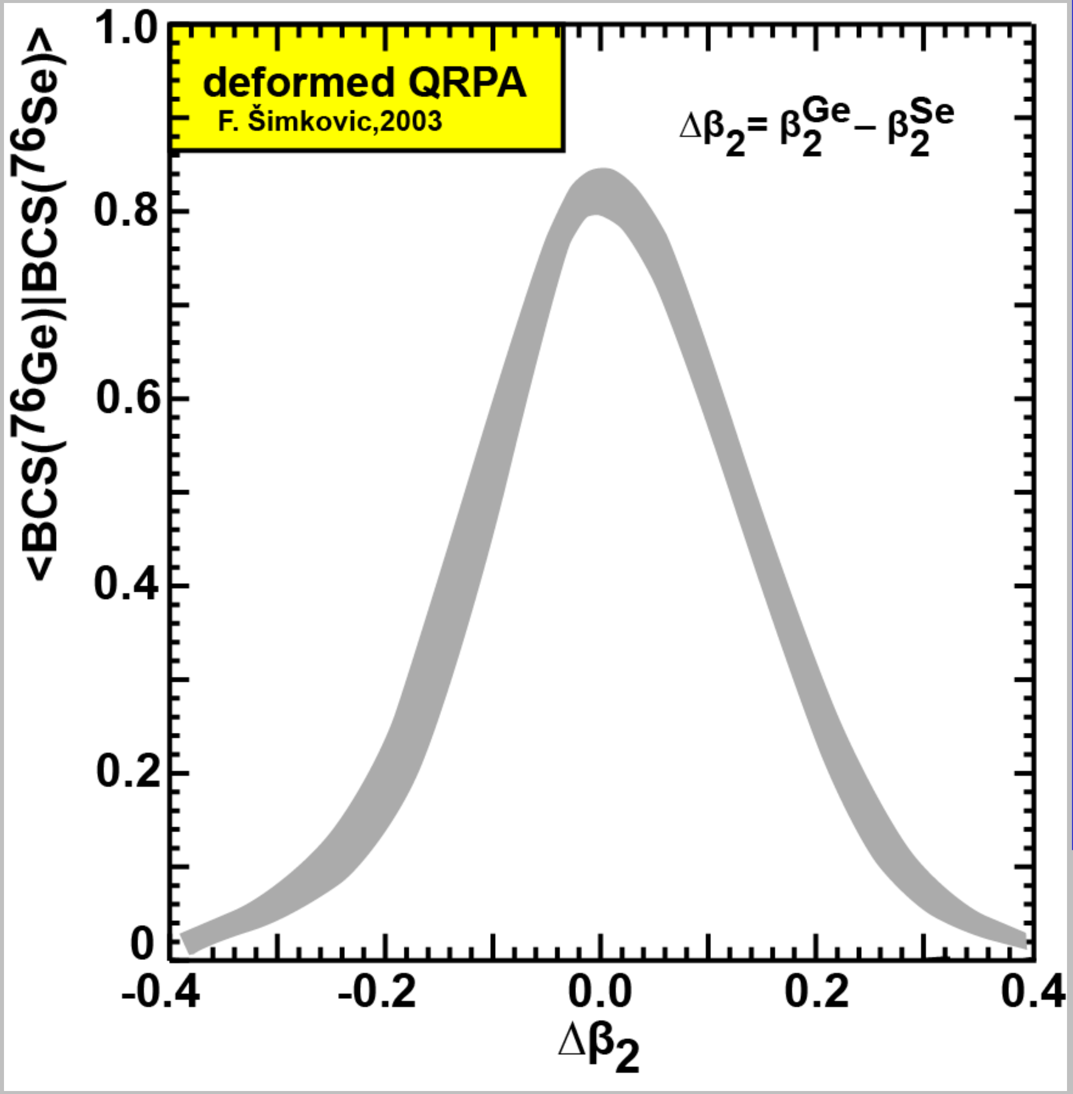
Correlated states make up 55% of 2νββ-ME

$M_{DGT} = 0.09\ \mathrm{MeV}^{-1}$

Adding correlation with undifferentiated bckgnd makes up ~100% of 2νββ-ME

$M_{DGT} = 0.14 \pm 0.02\ \mathrm{MeV}^{-1}$

$T_{1/2} = (1.5 \pm 0.4) \times 10^{21}$ yr



taken from F. Simkovic et al.
(cf also P. Sarriguren et al.,
PRC67,44313 (2003))

Intrinsic deformation seems to affect the 2νββ-ME, however, it is the difference of deformation between mother and daughter and not their absolute values which counts.

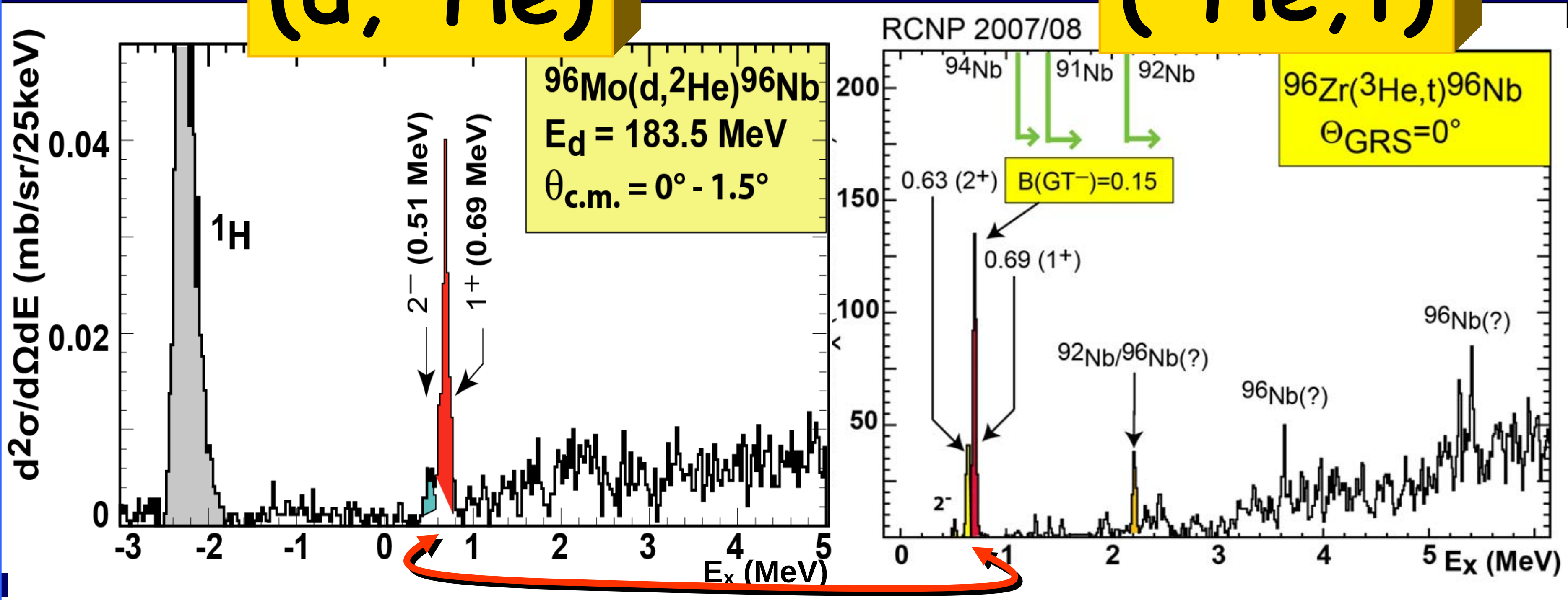
Exp'lly the deformation seems to manifest itself in a state-by-state mismatch, rather than an overall reduction of B(GT)'s.

^{96}Zr

the most neutron-rich Zr-isotope N-Z=16

(d,^{2}He)

(^{3}He,t)



B(GT$^+$) = 0.3

B(GT$^-$) = 0.15

Fascination: With this 1 level only:

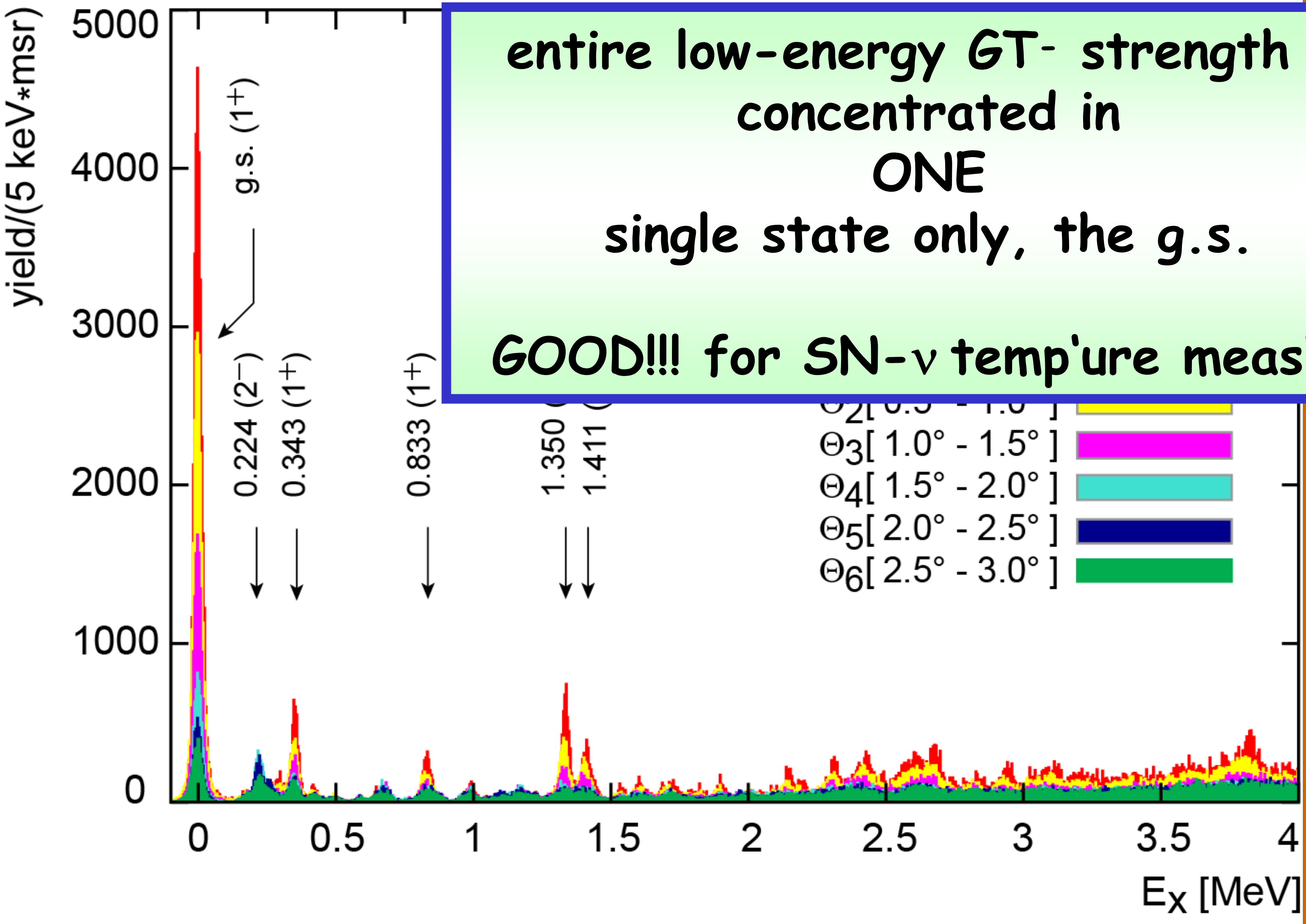
$$T_{1/2}^{calc.}(2\nu\beta\beta) = (2.4 \pm 0.3) \cdot 10^{19}\,\text{years}$$

$$T_{1/2}^{exp.}(2\nu\beta\beta = (2.2 \pm 0.4) \cdot 10^{19}\,\text{years}\quad\text{(NEMO3-result)}$$

^{100}Mo

Important for
ββ-decay
solar neutrino detector
(Q=-168 keV)

SN-neutrino detector
SN-neutrino temperature



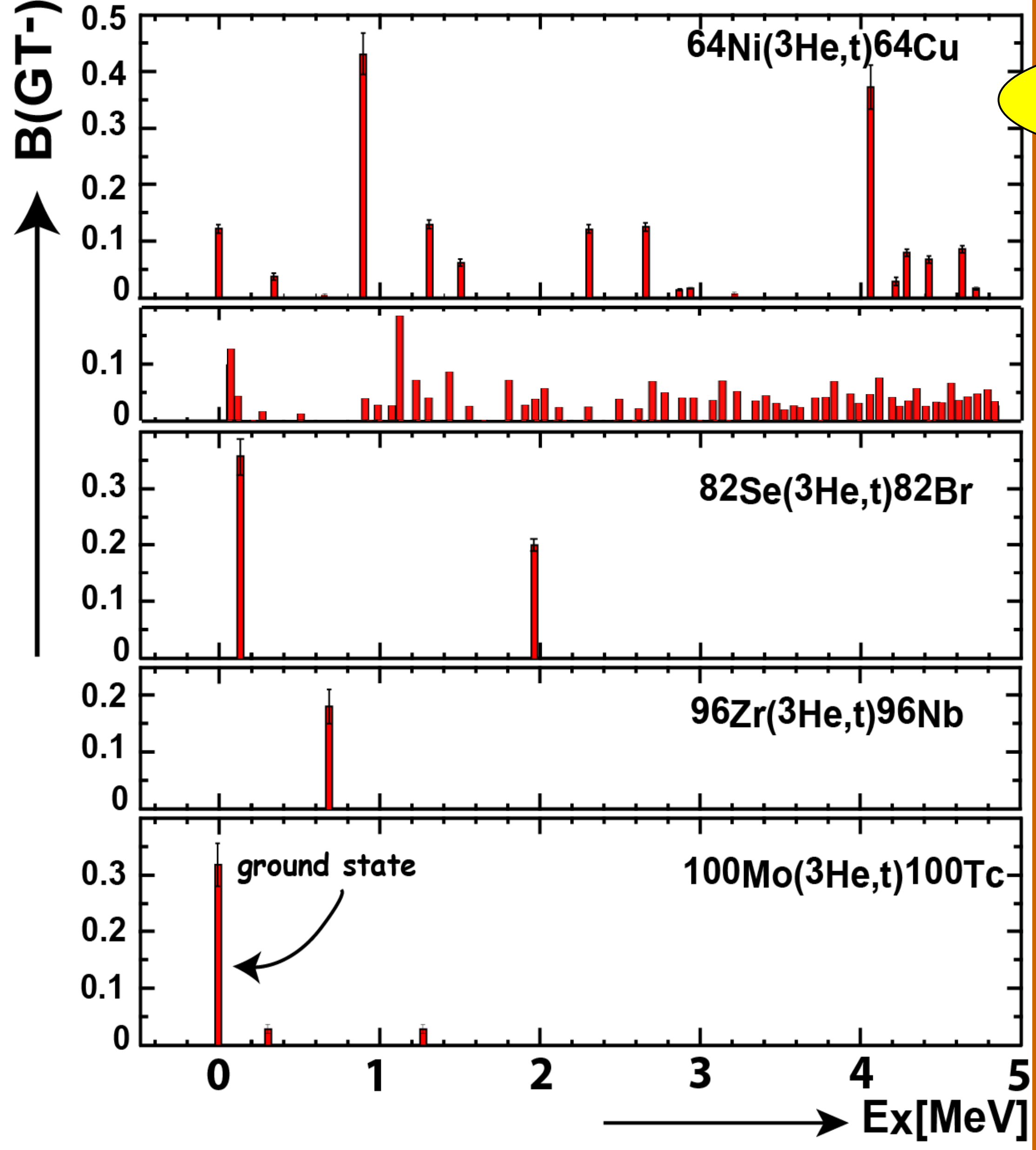
entire low-energy GT- strength is concentrated in
ONE
single state only, the g.s.

GOOD!!! for SN-ν temp'ure meas'nt

B(GT) =0.32 → logft (EC) = 4.54

In perfect agreement with Ejiri et al. (1998):

B(GT) = 0.33



^{64}Zn($\varepsilon\varepsilon$, $\varepsilon\beta^+$)

^{76}Ge($\beta^-\beta^-$)

^{82}Se($\beta^-\beta^-$)

^{96}Zr($\beta^-\beta^-$)

^{100}Mo($\beta^-\beta^-$)

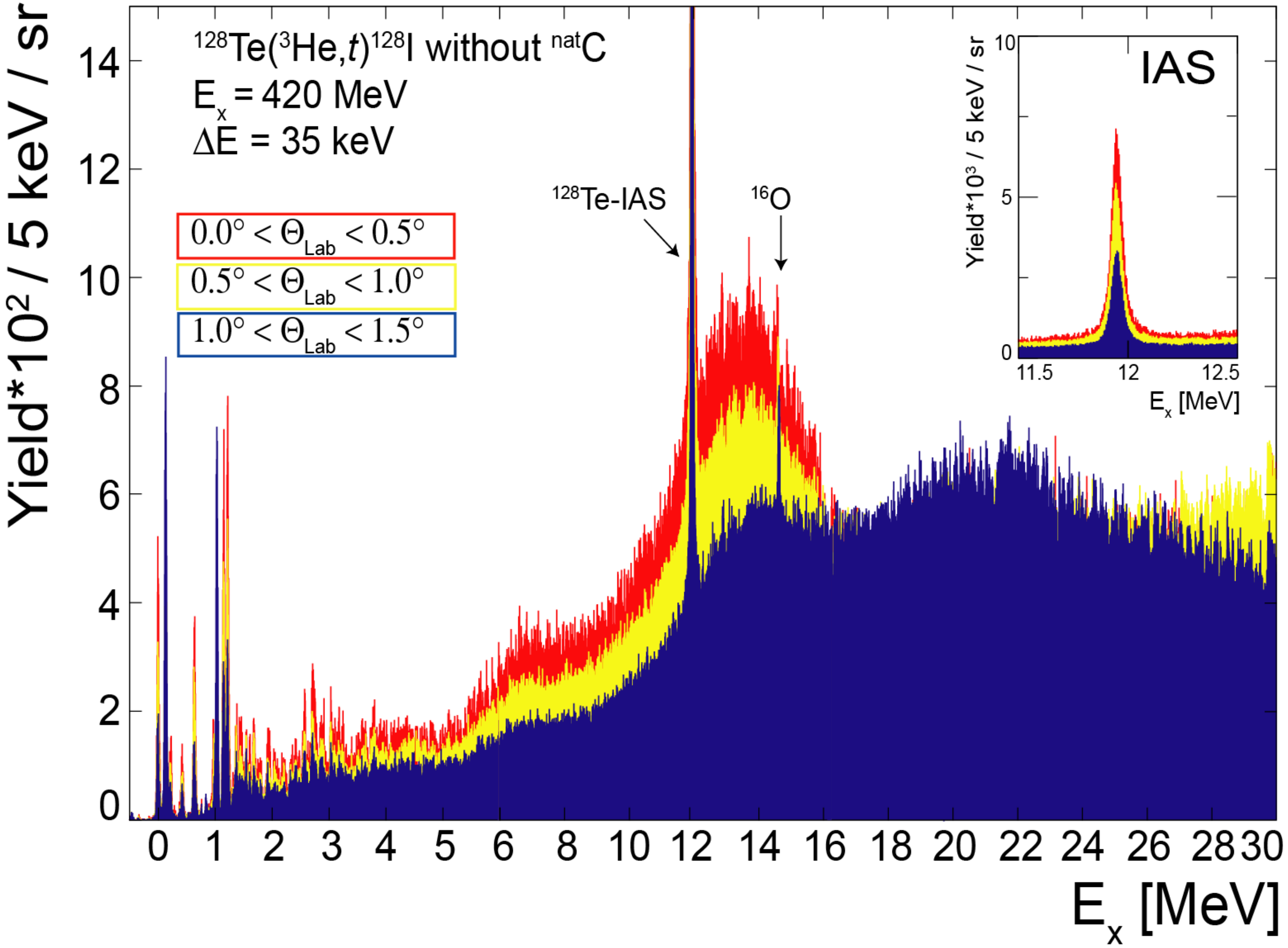
reduced spreading of GT strength

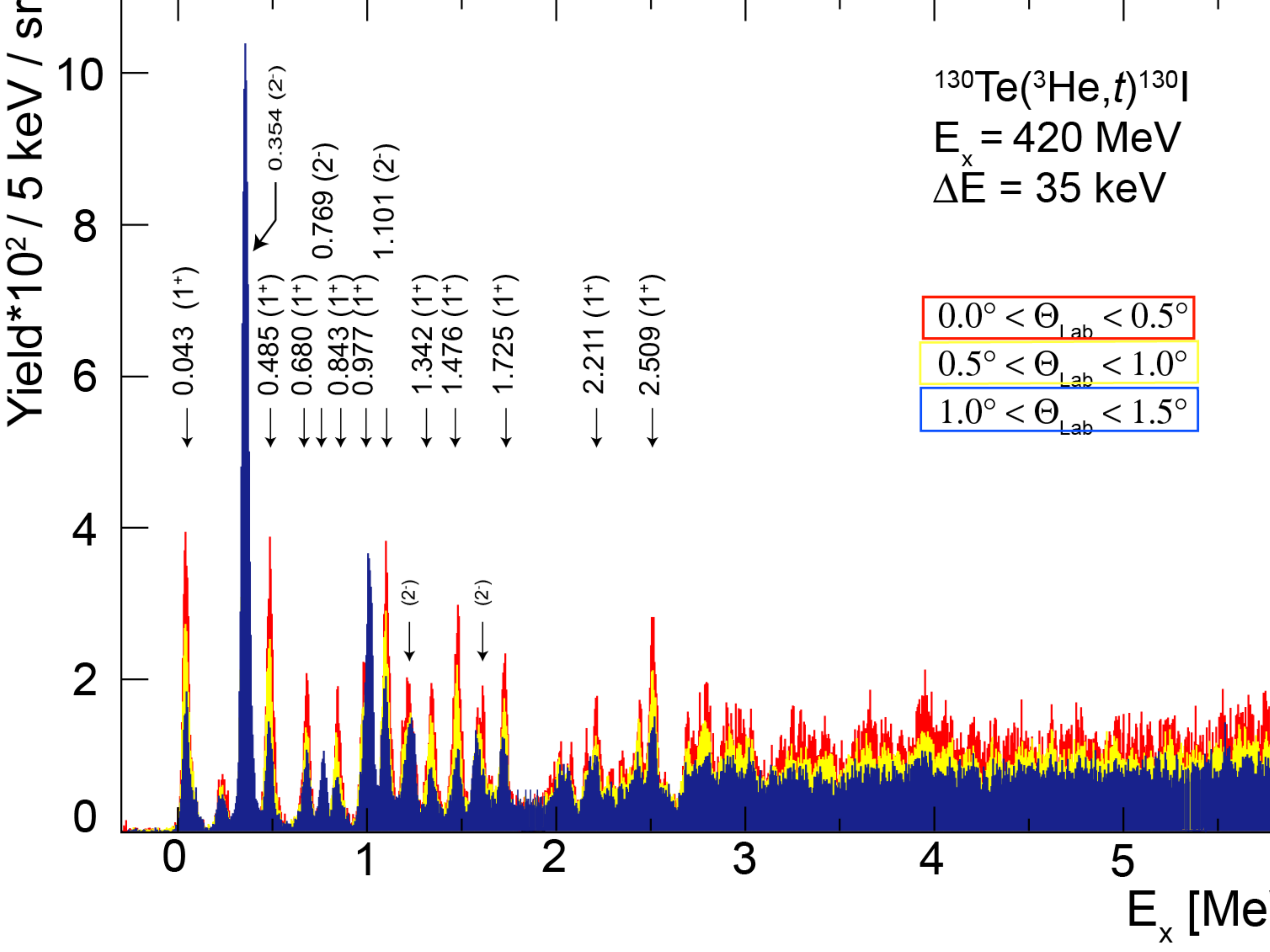
What about

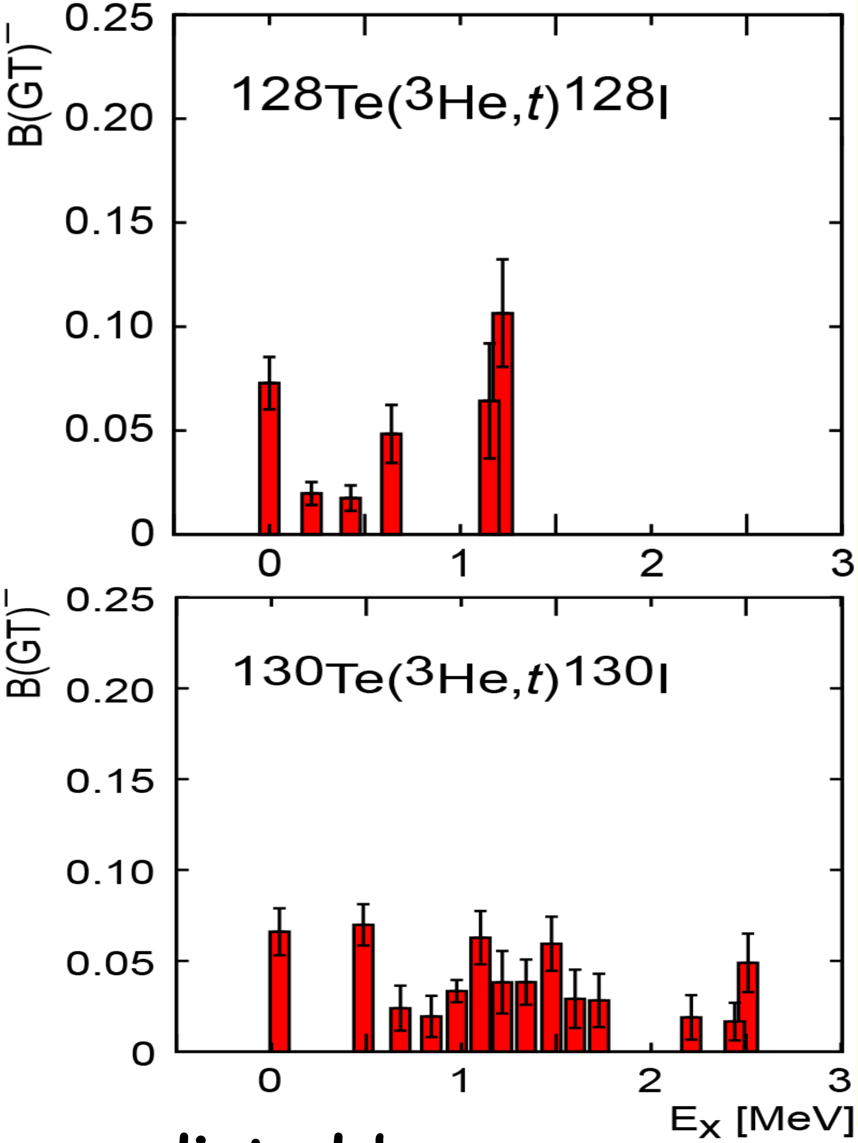
$^{128}\mathrm{Te}$

$^{130}\mathrm{Te}$

$^{136}\mathrm{Xe}$


^{128}Te(^{3}He,t)^{128}I without ^{nat}C
E_x = 420 MeV
ΔE = 35 keV
0.0° < Θ_{Lab} < 0.5°
0.5° < Θ_{Lab} < 1.0°
1.0° < Θ_{Lab} < 1.5°
^{128}Te-IAS
^{16}O
IAS
Yield*10^2 / 5 keV / sr
0
2
4
6
8
10
12
14
E_x [MeV]
0
1
2
3
4
5
6
8
10
12
14
16
18
20
22
24
26
28
30
Yield*10^3 / 5 keV / sr
0
5
10
11.5
12
12.5
E_x [MeV]


Yield*10^2 / 5 keV / sr
^{130}Te(^{3}He,t)^{130}I
E_x = 420 MeV
ΔE = 35 keV
0.0° < Θ_{Lab} < 0.5°
0.5° < Θ_{Lab} < 1.0°
1.0° < Θ_{Lab} < 1.5°
0.043 (1$^+$)
0.354 (2$^-$)
0.485 (1$^+$)
0.680 (1$^+$)
0.769 (2$^-$)
0.843 (1$^+$)
0.977 (1$^+$)
1.101 (2$^-$)
1.342 (1$^+$)
1.476 (1$^+$)
1.725 (1$^+$)
2.211 (1$^+$)
2.509 (1$^+$)
(2$^-$)
(2$^-$)
0
2
4
6
8
10
0
1
2
3
4
5
E_x [Me

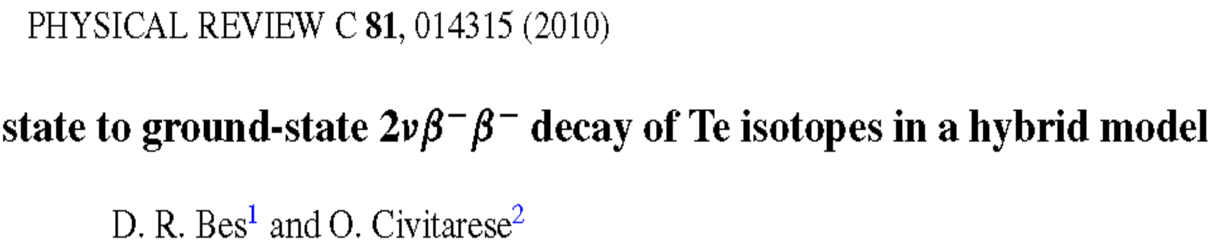


^{128}Te

^{130}Te

(slightly more fragmented)

also predicted by

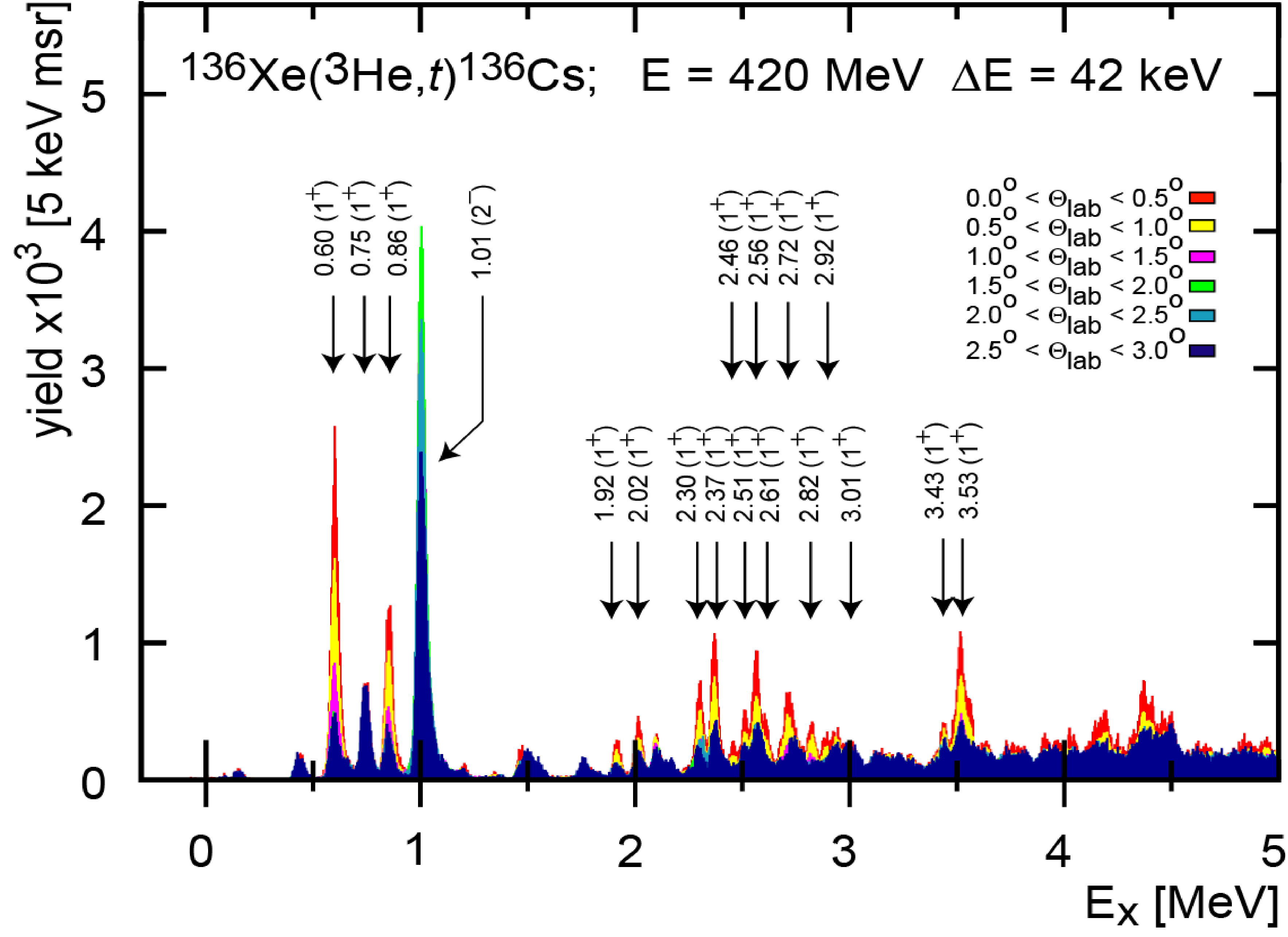


PHYSICAL REVIEW C **81**, 014315 (2010)

Matrix elements for the ground-state to ground-state $2\nu\beta^-\beta^-$ decay of Te isotopes in a hybrid model

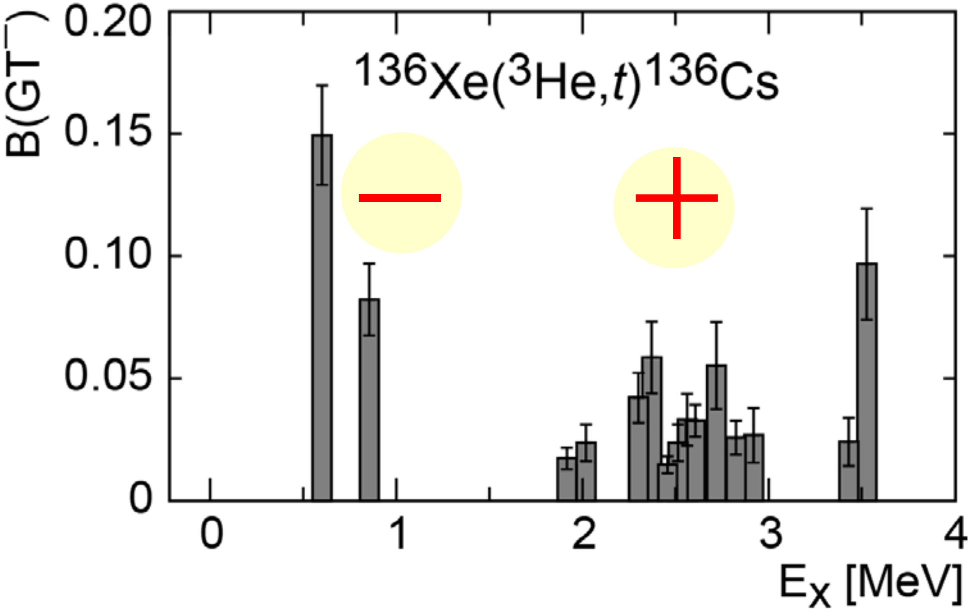
D. R. Bes[1] and O. Civitarese[2]

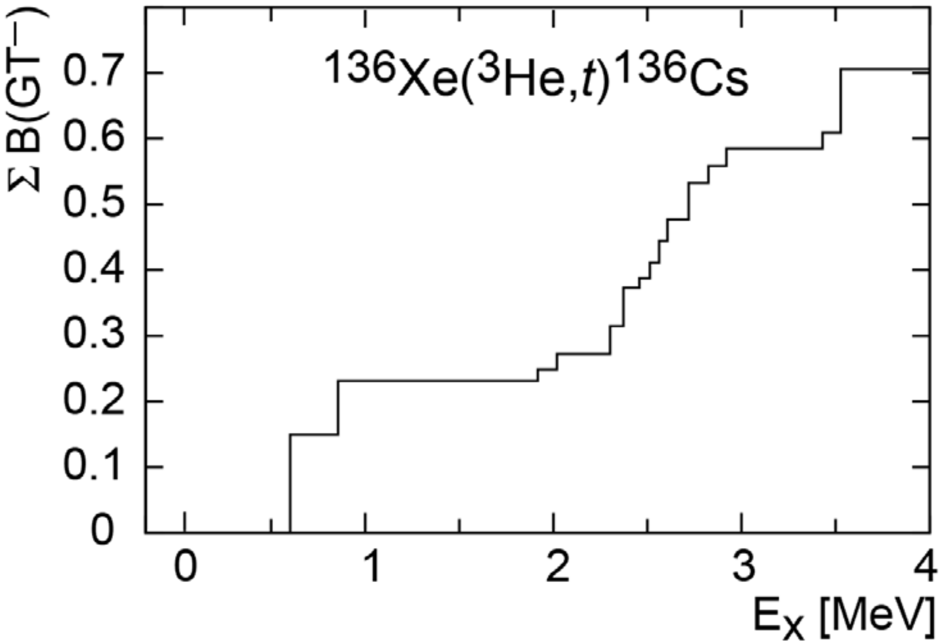
^{136}Xe



^{136}Xe(^{3}He,t)^{136}Cs; E = 420 MeV ΔE = 42 keV
yield x10^3 [5 keV msr]
E$_X$ [MeV]
0
1
2
3
4
5
0
1
2
3
4
5
0.60 (1^+)
0.75 (1^+)
0.86 (1^+)
1.01 (2^-)
2.46 (1^+)
2.56 (1^+)
2.72 (1^+)
2.92 (1^+)
1.92 (1^+)
2.02 (1^+)
2.30 (1^+)
2.37 (1^+)
2.51 (1^+)
2.61 (1^+)
2.82 (1^+)
3.01 (1^+)
3.43 (1^+)
3.53 (1^+)
$0.0^o < \Theta_{lab} < 0.5^o$ 🟥
$0.5^o < \Theta_{lab} < 1.0^o$ 🟨
$1.0^o < \Theta_{lab} < 1.5^o$ 🟪
$1.5^o < \Theta_{lab} < 2.0^o$ 🟩
$2.0^o < \Theta_{lab} < 2.5^o$ 🟦
$2.5^o < \Theta_{lab} < 3.0^o$ 🟦

How big is the matrix element?





$$T_{1/2}^{2\nu} \geq 8.5 \cdot 10^{21}\,\mathrm{yr}$$

$$M_{DGT}^{(2\nu)} \leq 5 \cdot 10^{-3}$$

scenario-1

all positive sign —>

$$\mathbf{B_m}\left(GT^+\right) \approx \mathbf{10^{-3}} \cdot \mathbf{B_m}\left(GT^-\right)$$

unlikely

scenario-2

sign(clst-1) = - sign (clst-2)

likely

Early Conclusion

1 Chargex reactions are a powerful tool to determine the $2\nu\beta\beta$ NME
(d,^{2}He) (t,^{3}He) → „GT$^+$ leg" & (^{3}He,t) → „GT$^-$ leg"
high resolution is essential.

2 The difference between the intrinsic deformation of mother and daughter nucleus seems to cause „state-by-state mismatch" of B(GT)'s ---------→ How big is the effect on the $0\nu\beta\beta$ NME ??

3 In all cases the low energy part of the GT distribution seems to be most relevant for the 2ν decay
even „Single-State-Dominance" for ^{96}Zr und ^{100}Mo

Would this be true for the $0\nu\beta\beta$ decay as well ?

4 Radioactive beam facilites and ion traps can provide nice tools for getting access to 0ν-$\beta\beta$ decay matrix elements

5 What is the importance of Nordheim states ??
they are strongly excited in CEX and μ-X

My personal wish list and unresolved issues:

1. Need a more modern reaction theory and appropriate reaction code
2. Need updated NN t-matrix fits (we use Love and Franey 81) and have them implemented into a reaction theory code
3. Need theories, which can predict 0νββ matrix elements and which can be tied to experimental data/observables along the way (presently, g.s. β-decay and EC-decay rates are utterly wrong!!)
4. Need to understand more quantitavely the physics, which cause certain matrix element to have a different sign
5. Need to address more agressively the GT-quenching issue (g_A^{eff}) (experimentally and theoretically)

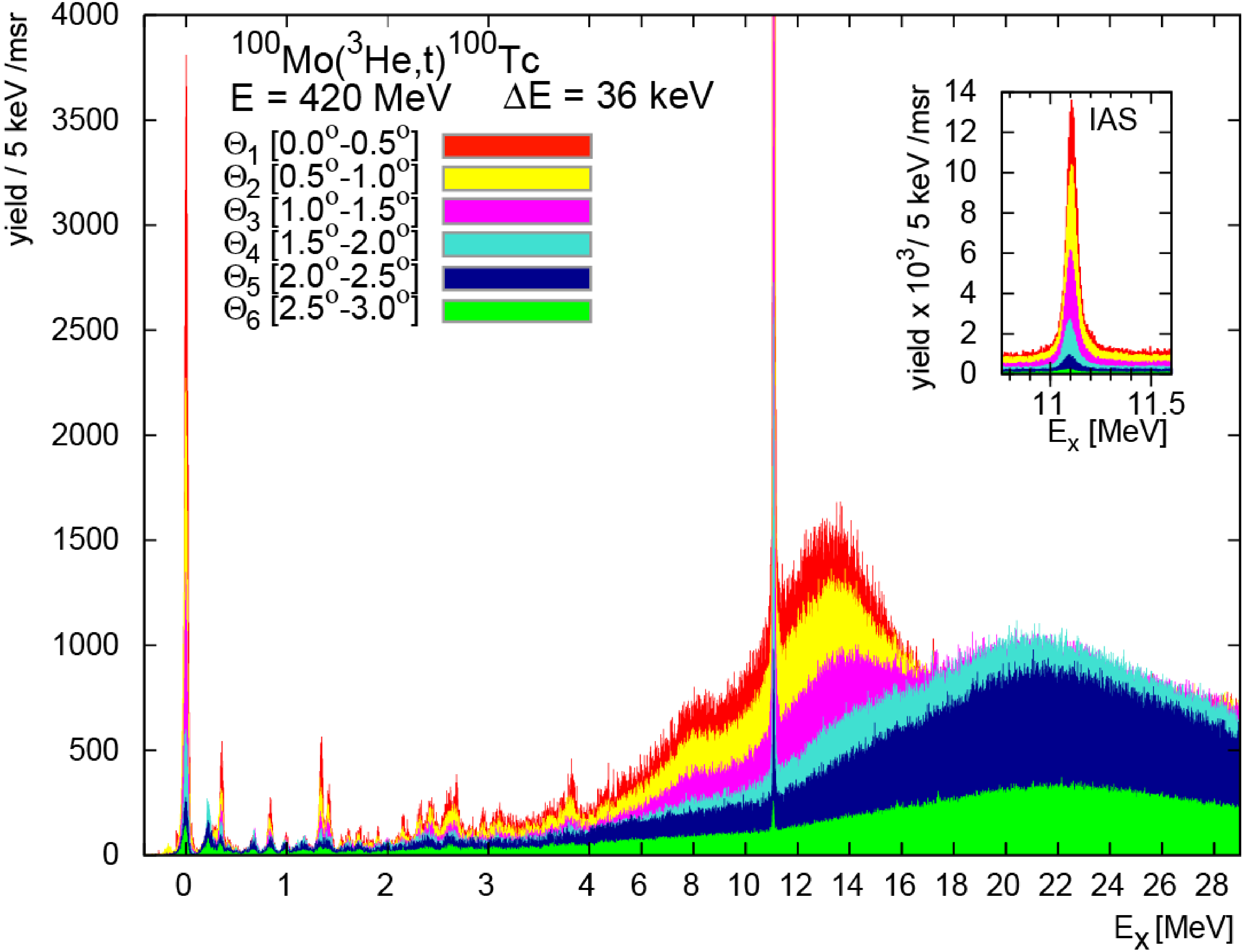
The g_A^{eff} -problem or the quenching of the Ikeda sum-rule $S(\beta^-) - S(\beta^+) = 3(N-Z)$

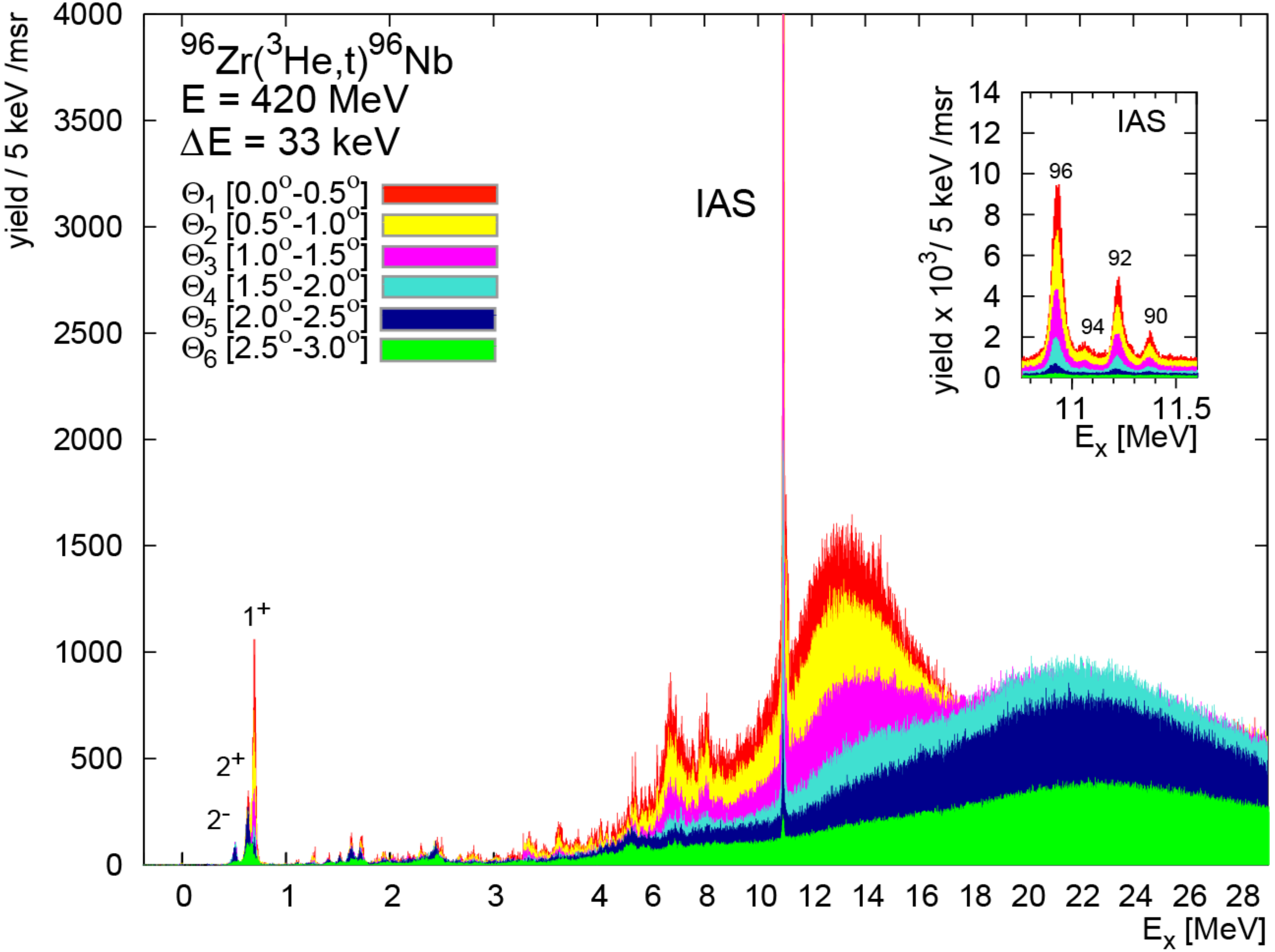
can this be attacked??

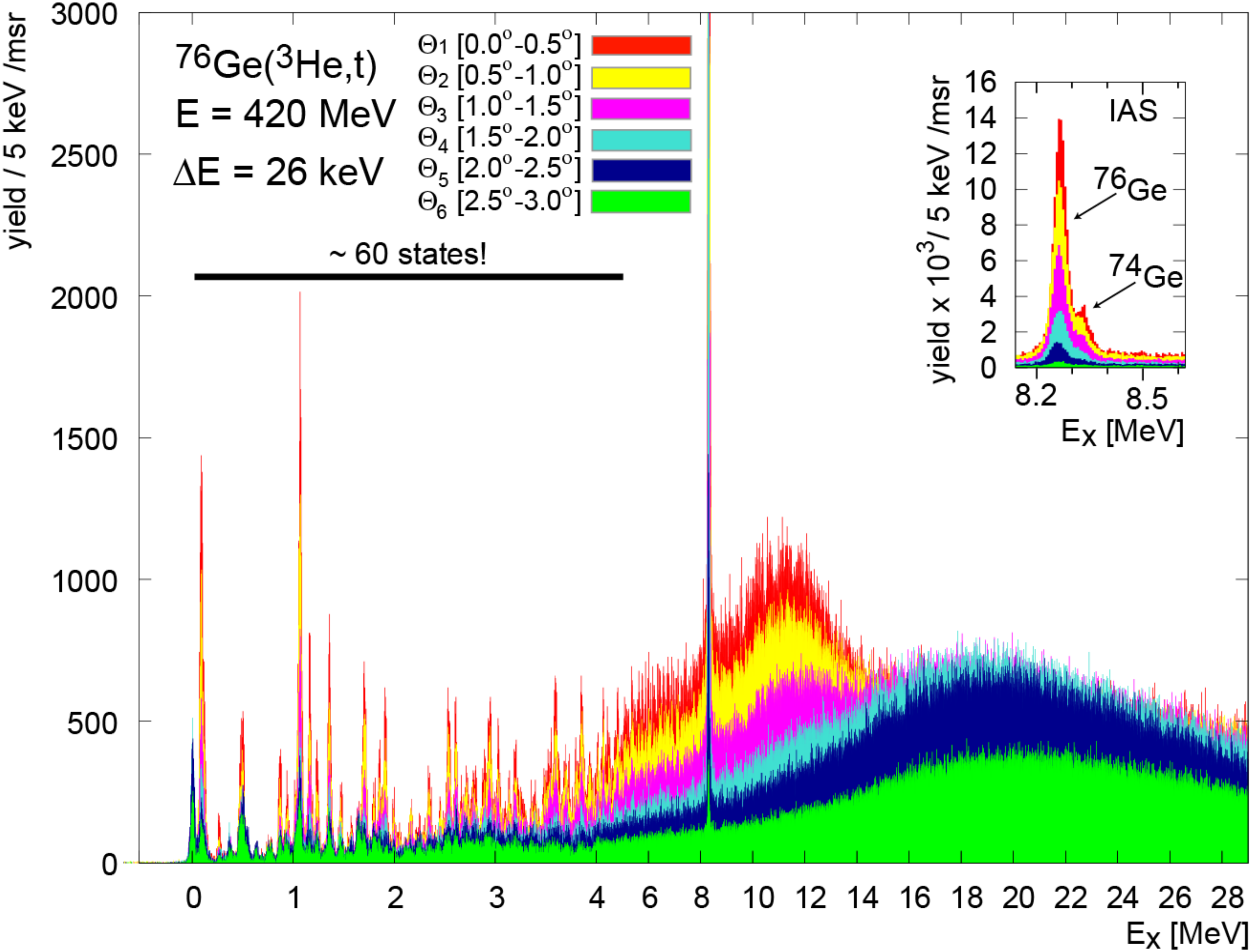
Recall: $(T_{1/2})^{-1} \sim (g_A^{eff})^4 \qquad g_A^{eff} \approx 0.7 g_A$

Reasons for GT quenching

- **nuclear structure**
  - – but then quenching should depend on the underlying nuclear structure
- **non-nucleonic degrees of freedom**
  - – quenching should not strongly depend on the underlying nuclear structure (but rather on nucl. density)

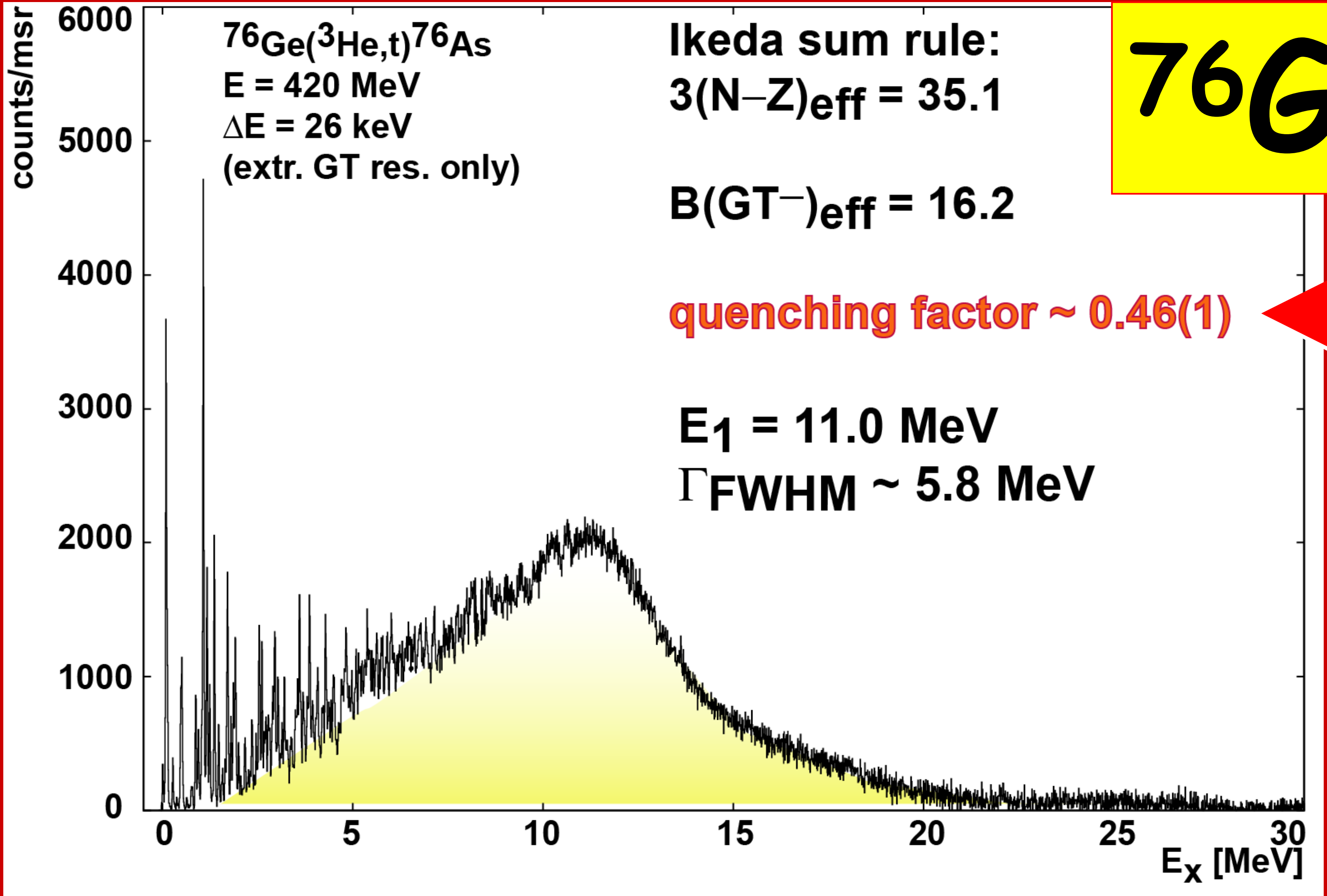

^{100}Mo(^{3}He,t)^{100}Tc
E = 420 MeV ΔE = 36 keV
Θ$_1$ [0.0°-0.5°]
Θ$_2$ [0.5°-1.0°]
Θ$_3$ [1.0°-1.5°]
Θ$_4$ [1.5°-2.0°]
Θ$_5$ [2.0°-2.5°]
Θ$_6$ [2.5°-3.0°]
yield / 5 keV /msr
4000
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
6
8
10
12
14
16
18
20
22
24
26
28
E$_x$ [MeV]
IAS
yield x 10^3/ 5 keV /msr
14
12
10
8
6
4
2
0
11
11.5
E$_x$ [MeV]


^{96}Zr(^{3}He,t)^{96}Nb
E = 420 MeV
ΔE = 33 keV
Θ_1 [0.0°-0.5°] 🟥
Θ_2 [0.5°-1.0°] 🟨
Θ_3 [1.0°-1.5°] 🟪
Θ_4 [1.5°-2.0°] 🟦
Θ_5 [2.0°-2.5°] 🟦
Θ_6 [2.5°-3.0°] 🟩
IAS
1+
2+
2-
yield / 5 keV /msr
0
500
1000
1500
2000
2500
3000
3500
4000
0
1
2
3
4
6
8
10
12
14
16
18
20
22
24
26
28
E_x [MeV]
IAS
96
94
92
90
yield x 10^3/ 5 keV /msr
0
2
4
6
8
10
12
14
11
11.5
E_x [MeV]



^{76}Ge(^{3}He,t)
E = 420 MeV
ΔE = 26 keV
Θ_1 [0.0°-0.5°]
Θ_2 [0.5°-1.0°]
Θ_3 [1.0°-1.5°]
Θ_4 [1.5°-2.0°]
Θ_5 [2.0°-2.5°]
Θ_6 [2.5°-3.0°]
~ 60 states!
yield / 5 keV /msr
3000
2500
2000
1500
1000
500
0
0
1
2
3
4
6
8
10
12
14
16
18
20
22
24
26
28
E_X [MeV]
IAS
^{76}Ge
^{74}Ge
yield x 10^3/ 5 keV /msr
16
14
12
10
8
6
4
2
0
8.2
8.5
E_X [MeV]

^{76}Ge



^{76}Ge(^{3}He,t)^{76}As
E = 420 MeV
ΔE = 26 keV
(extr. GT res. only)

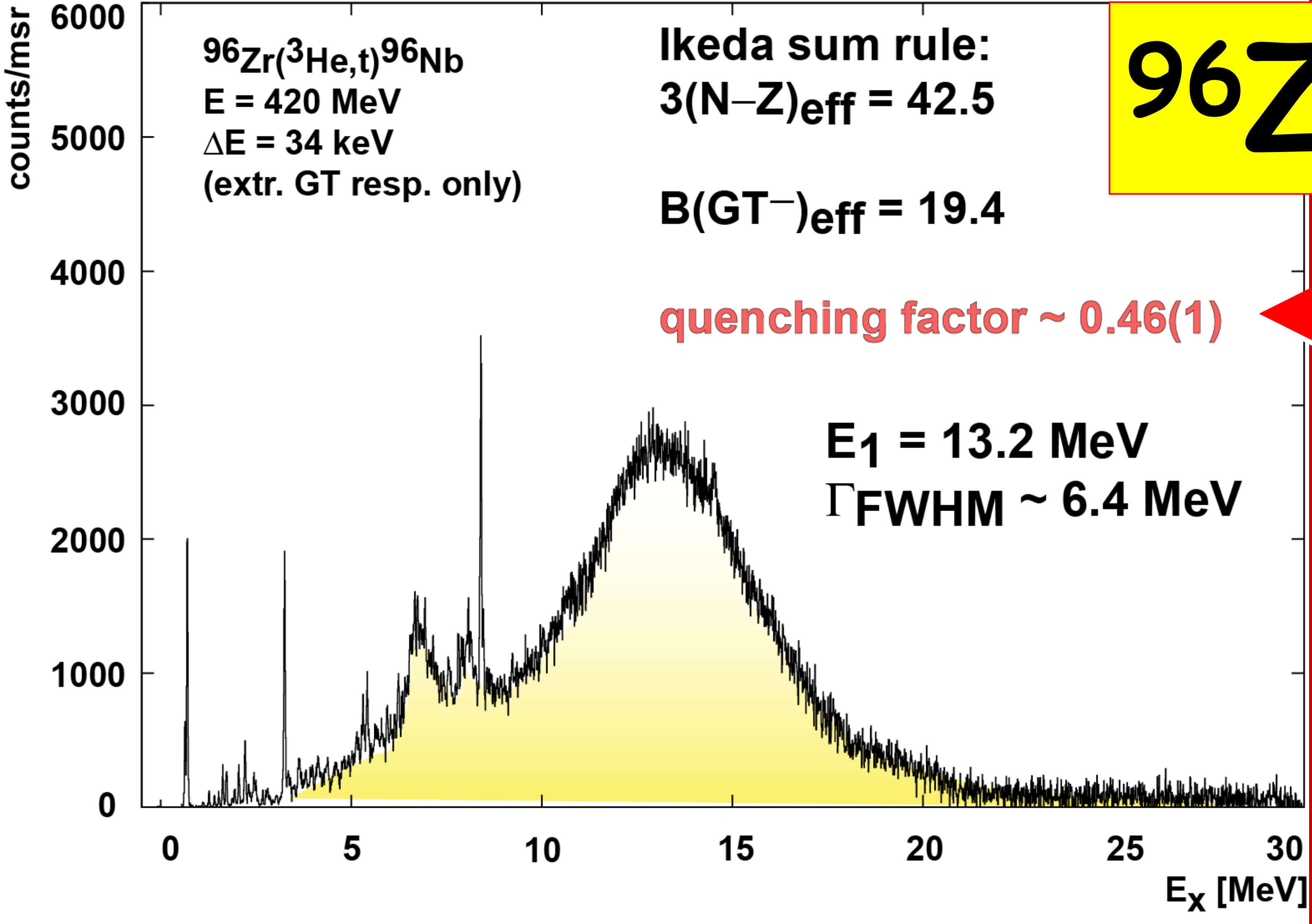
Ikeda sum rule:
$3(N-Z)_{eff} = 35.1$

$B(GT^-)_{eff} = 16.2$

quenching factor ~ 0.46(1)

$E_1 = 11.0$ MeV
$\Gamma_{FWHM} \sim 5.8$ MeV

^{96}Zr



^{96}Zr(^{3}He,t)^{96}Nb
E = 420 MeV
ΔE = 34 keV
(extr. GT resp. only)

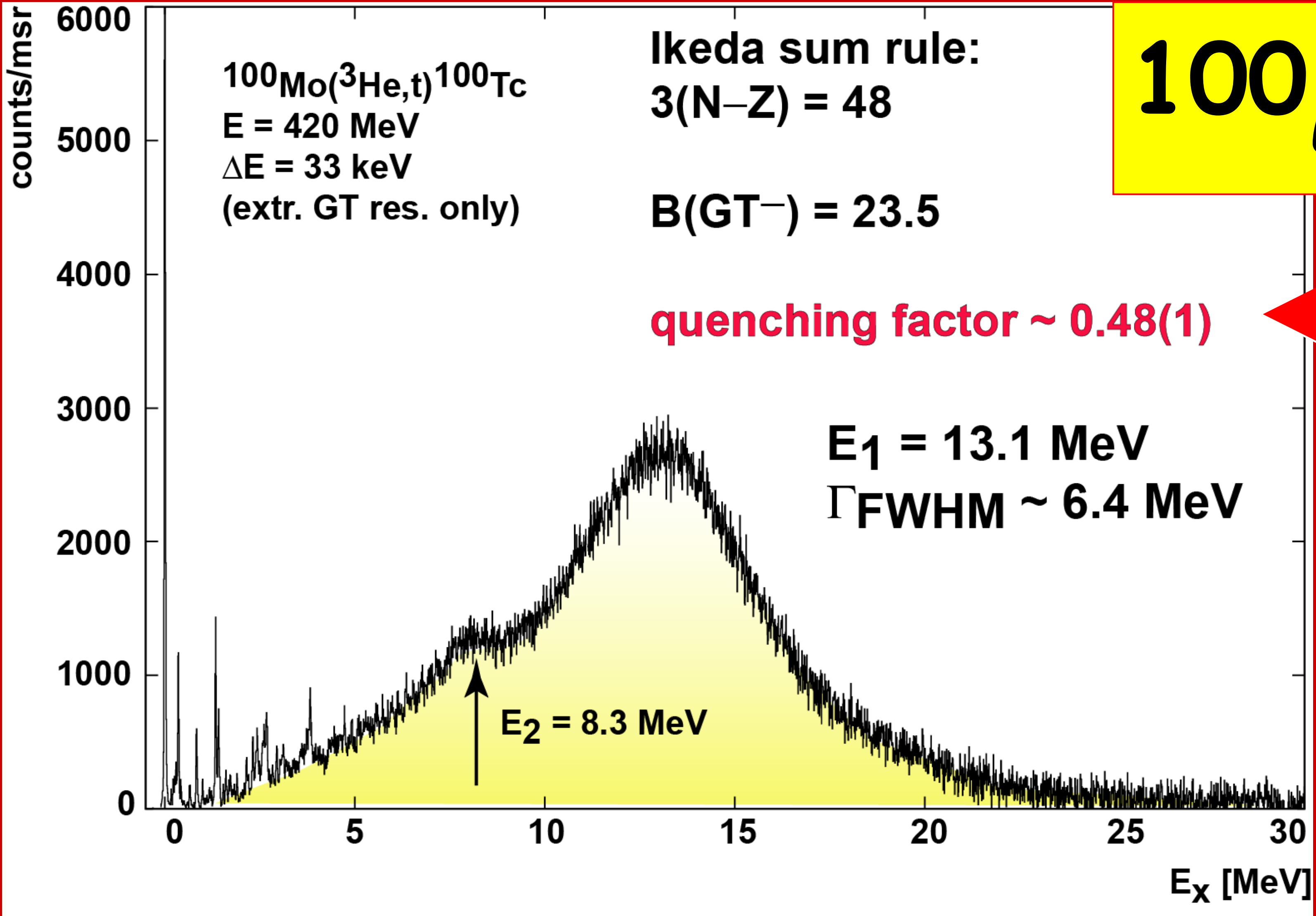
Ikeda sum rule:
$3(N-Z)_{eff} = 42.5$

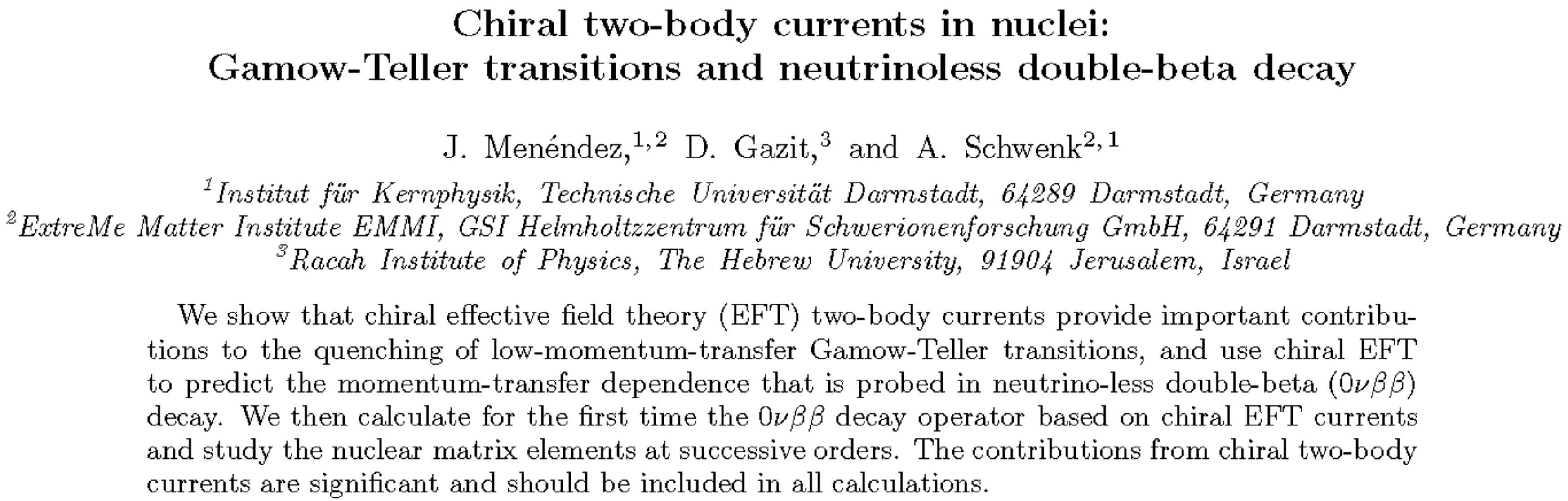
$B(GT^-)_{eff} = 19.4$

quenching factor ~ 0.46(1)

$E_1 = 13.2$ MeV
$\Gamma_{FWHM} \sim 6.4$ MeV

^{100}Mo


counts/msr
6000
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
E_x [MeV]
^{100}Mo(^{3}He,t)^{100}Tc
E = 420 MeV
ΔE = 33 keV
(extr. GT res. only)
Ikeda sum rule:
3(N–Z) = 48
B(GT$^-$) = 23.5
quenching factor ~ 0.48(1)
E_1 = 13.1 MeV
Γ_{FWHM} ~ 6.4 MeV
E_2 = 8.3 MeV



Chiral two-body currents in nuclei: Gamow-Teller transitions and neutrinoless double-beta decay

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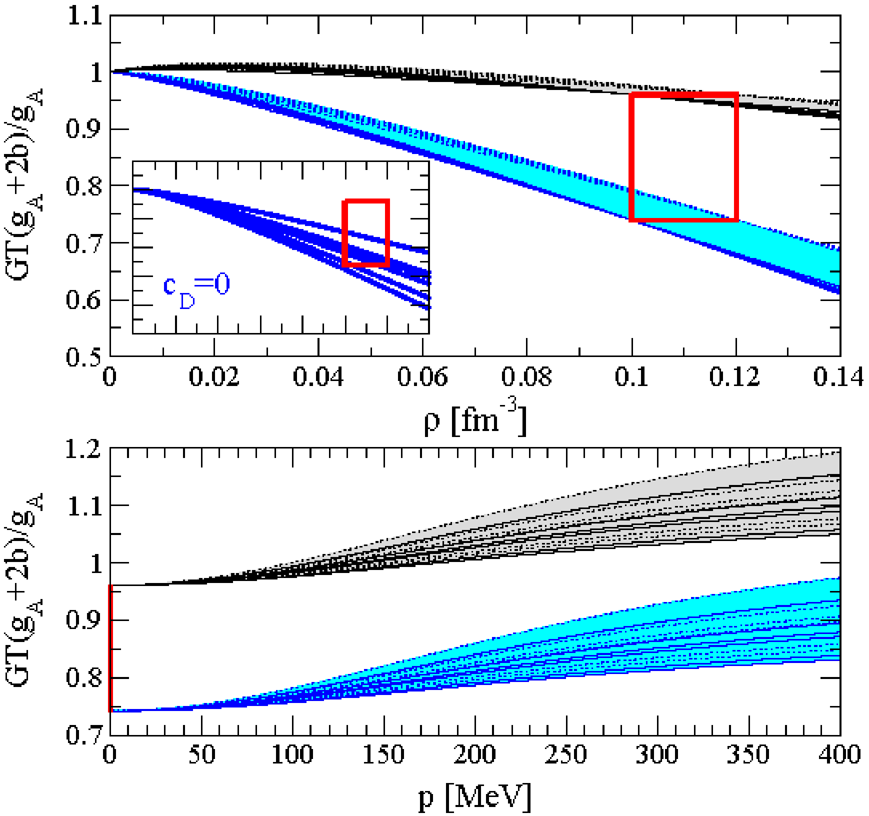
We show that chiral effective field theory (EFT) two-body currents provide important contributions to the quenching of low-momentum-transfer Gamow-Teller transitions, and use chiral EFT to predict the momentum-transfer dependence that is probed in neutrino-less double-beta ($0\nu\beta\beta$) decay. We then calculate for the first time the $0\nu\beta\beta$ decay operator based on chiral EFT currents and study the nuclear matrix elements at successive orders. The contributions from chiral two-body currents are significant and should be included in all calculations.



g_A- quenching

as a fctn. of nucl. density (long & short range effect due to 2B-currents)

un-quenching of g_A

as a function of momentum transfer

To prove the theory, need:

1) a heavy target consisting of neutrons only
2) a diluted nuclear density!!

may be possible with:

1) ^{132}Sn or even better $^{132+x}$Sn
2) check nuclear density by exciting pygmy resonances
3) perform (p,n) type reaction to excite GT giant resonance. 3(N-Z) = 96+3x. What is the quenching???

In the next round
get the $0\nu\beta\beta$ NME's
&
who knows?
may be Nature is indeed kind

Thank you