Search for double alpha decay

Louis Heitz
Supervisors : E. Khan, Ch. Theisen†, M. Vandebrouck
- Double alpha @CERN collaboration -

European nuclear physics conference 2025
CAEN
22 September 2025

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Cuts to identify
double alpha events

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Results

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Microscopic Description of 2α Decay in ^{212}Po and ^{224}Ra Isotopes

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First microscopic (EDF)
model of α **decay**

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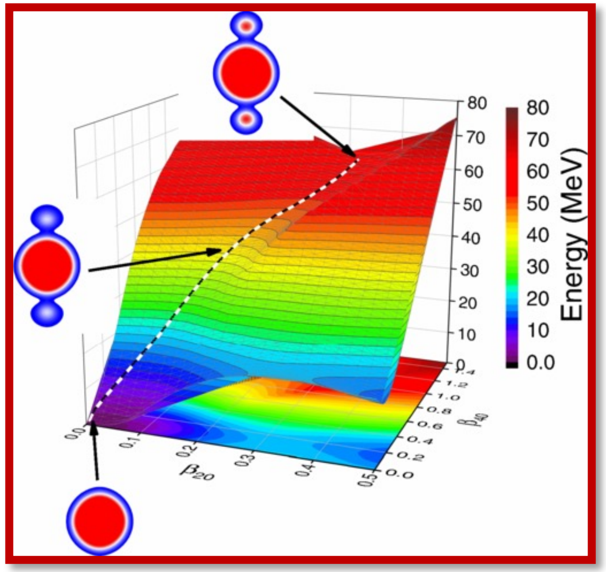

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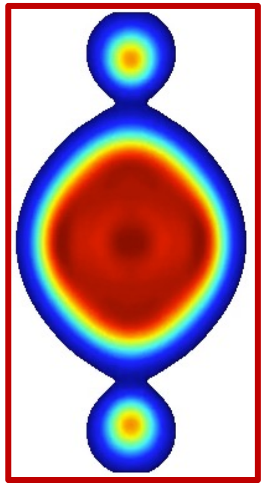

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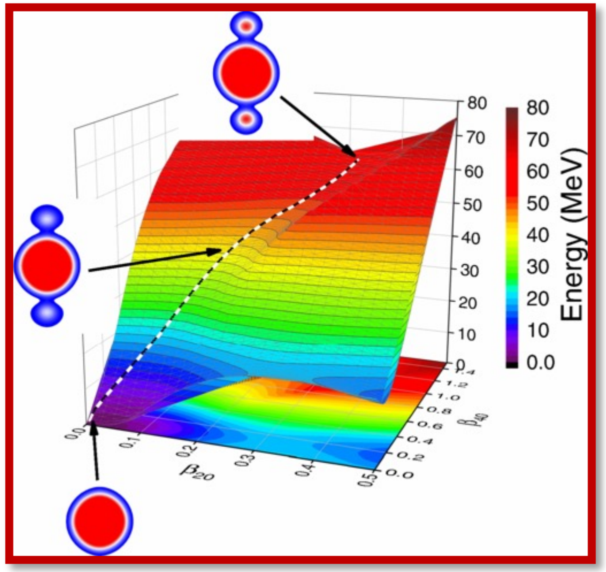

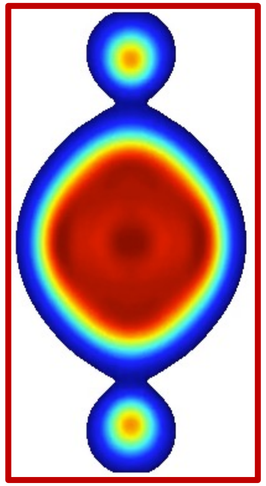

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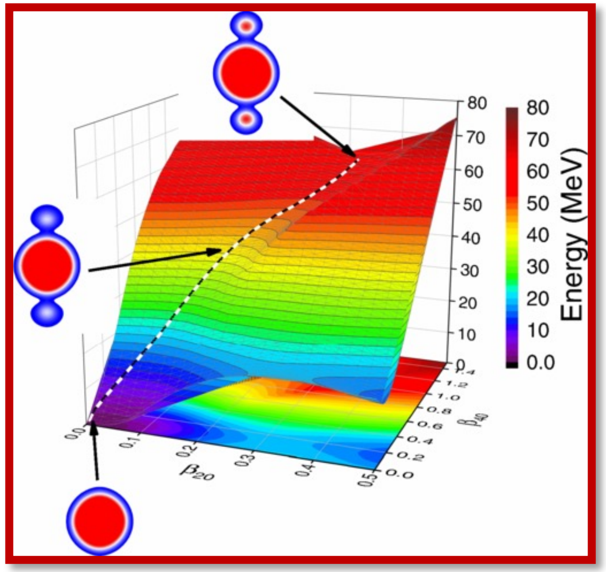

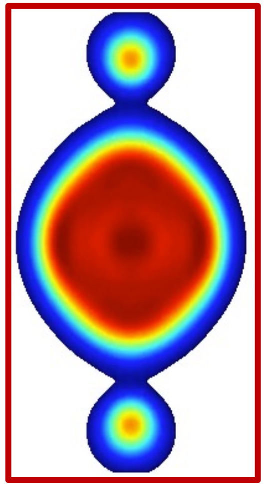

Other predictions
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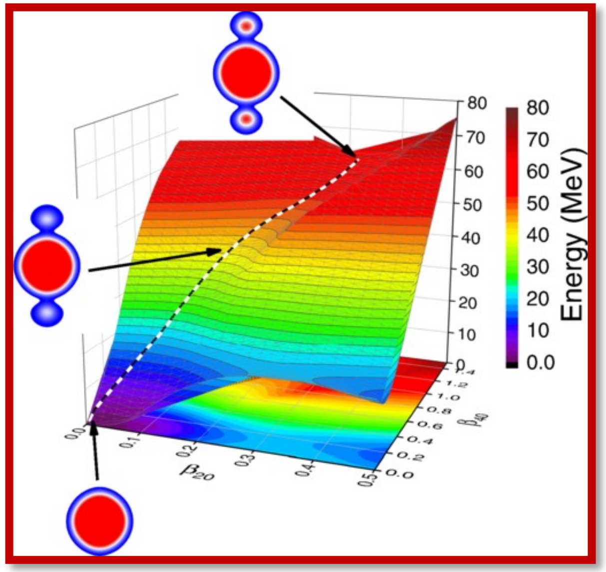

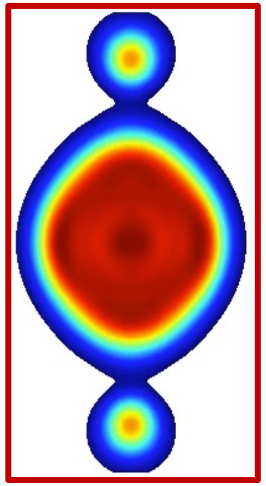

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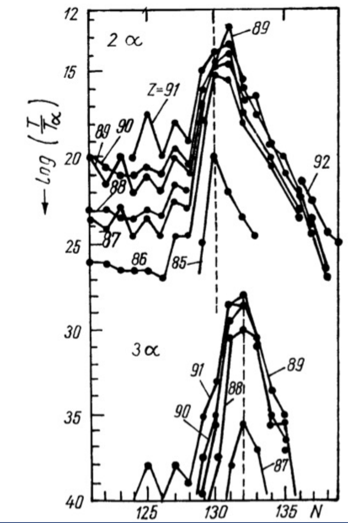
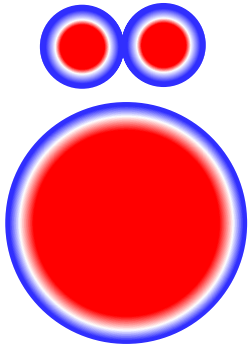


Poenaru (1979)
BR < 10^{-12}
« ^{8}Be-like »

$\alpha + \alpha = {}^8\mathrm{Be}$



Schematic view

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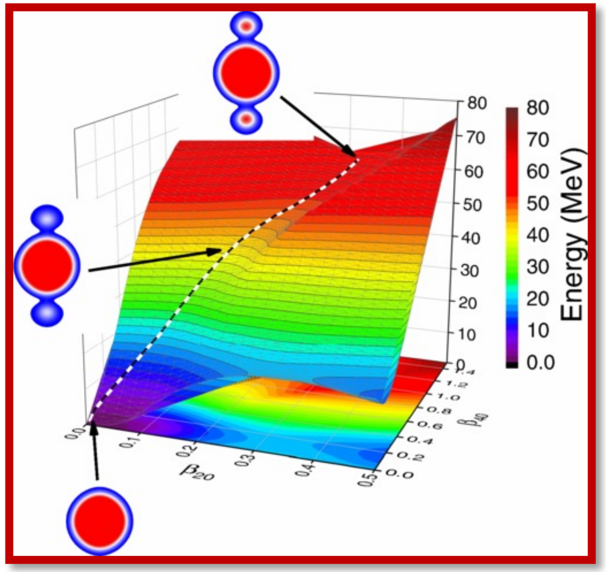

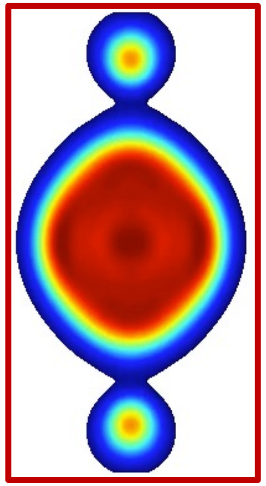

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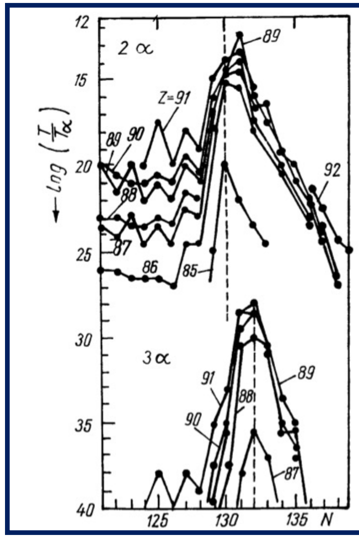

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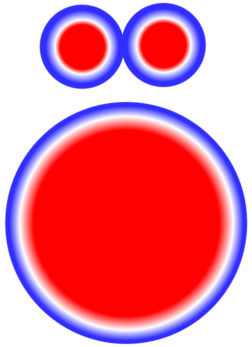

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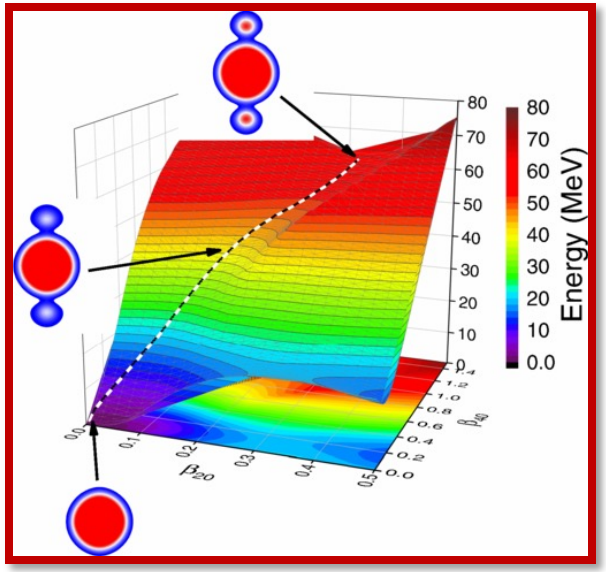

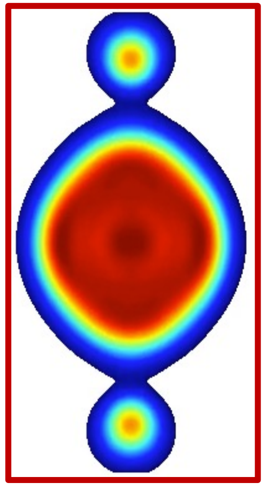

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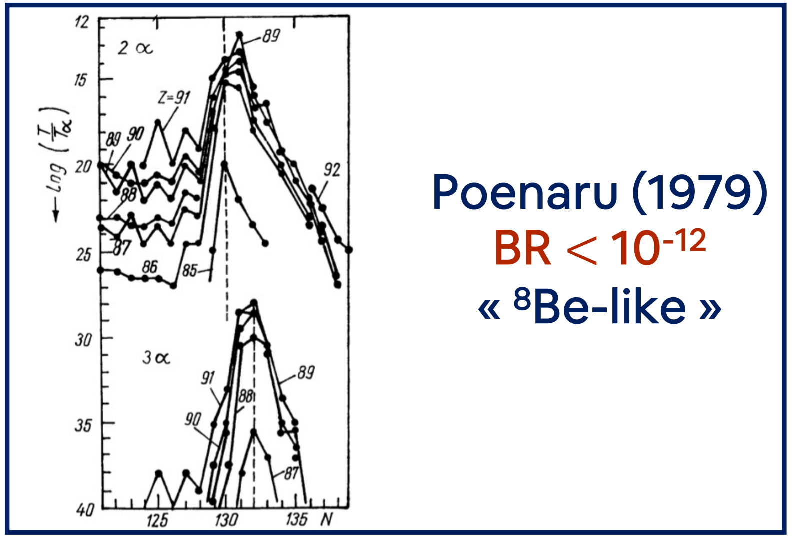

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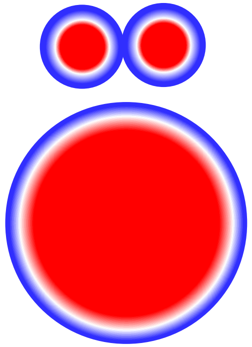

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BR ~ 10^{-2} (!)
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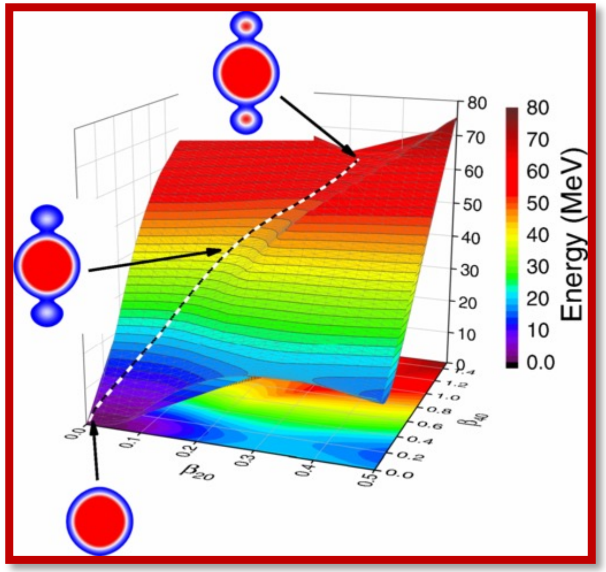

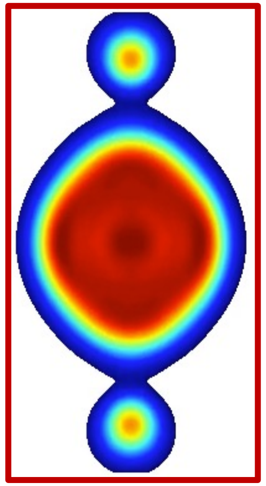

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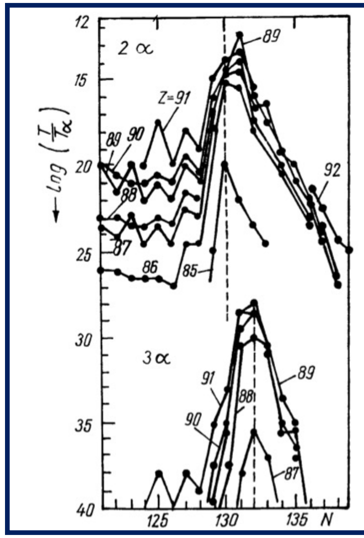

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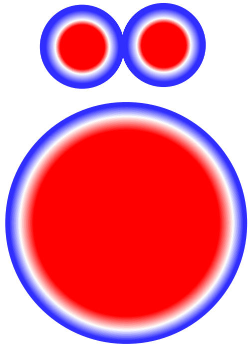

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Several decay configurations possible
Predictions span several orders of magnitude !

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Best candidates for 2α decay ?

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Expected

$$Q_{2\alpha} \nearrow \Longleftrightarrow T_{2\alpha} \searrow$$

~Geiger-Nutall
more energy available = more probable

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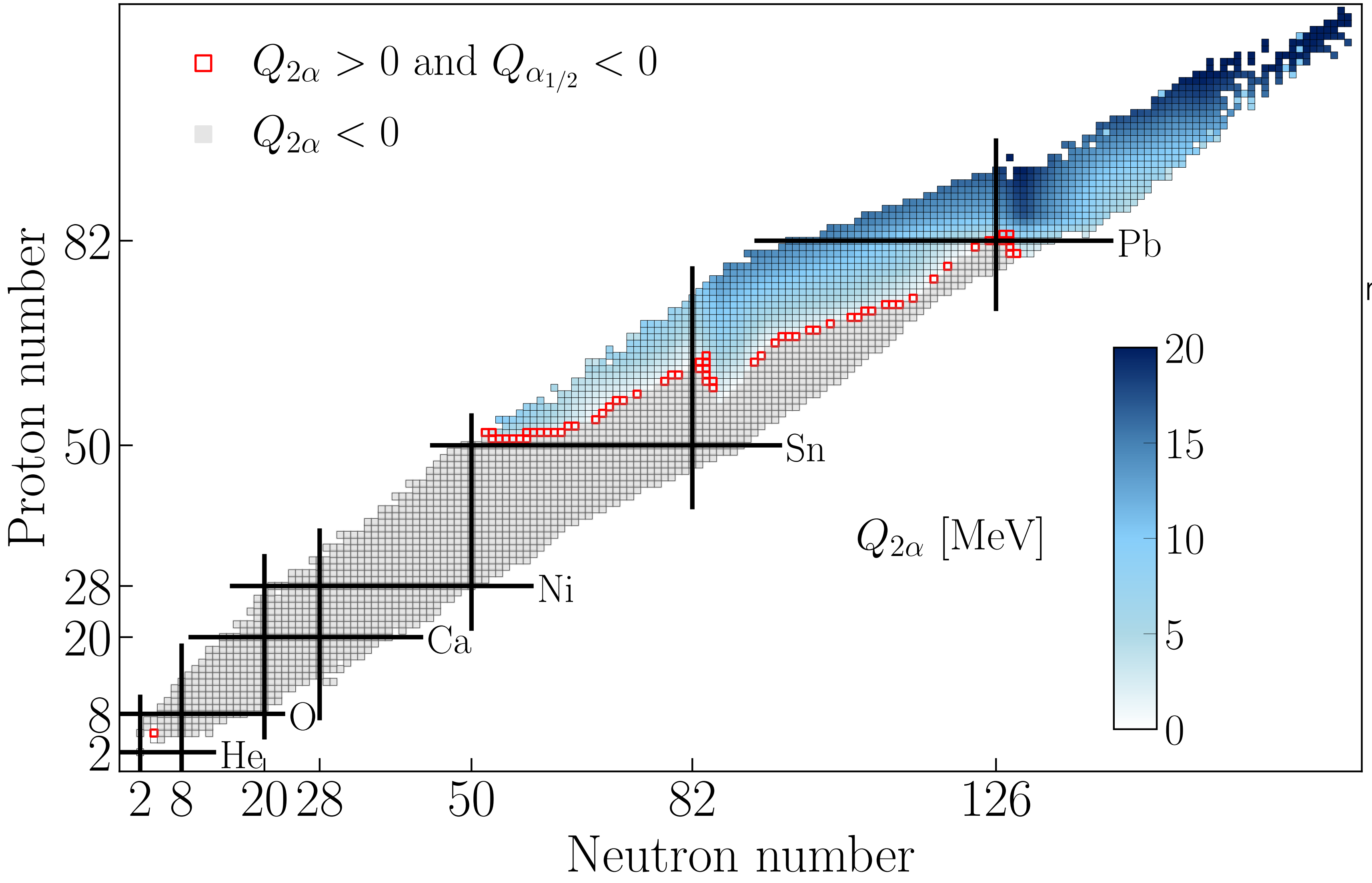

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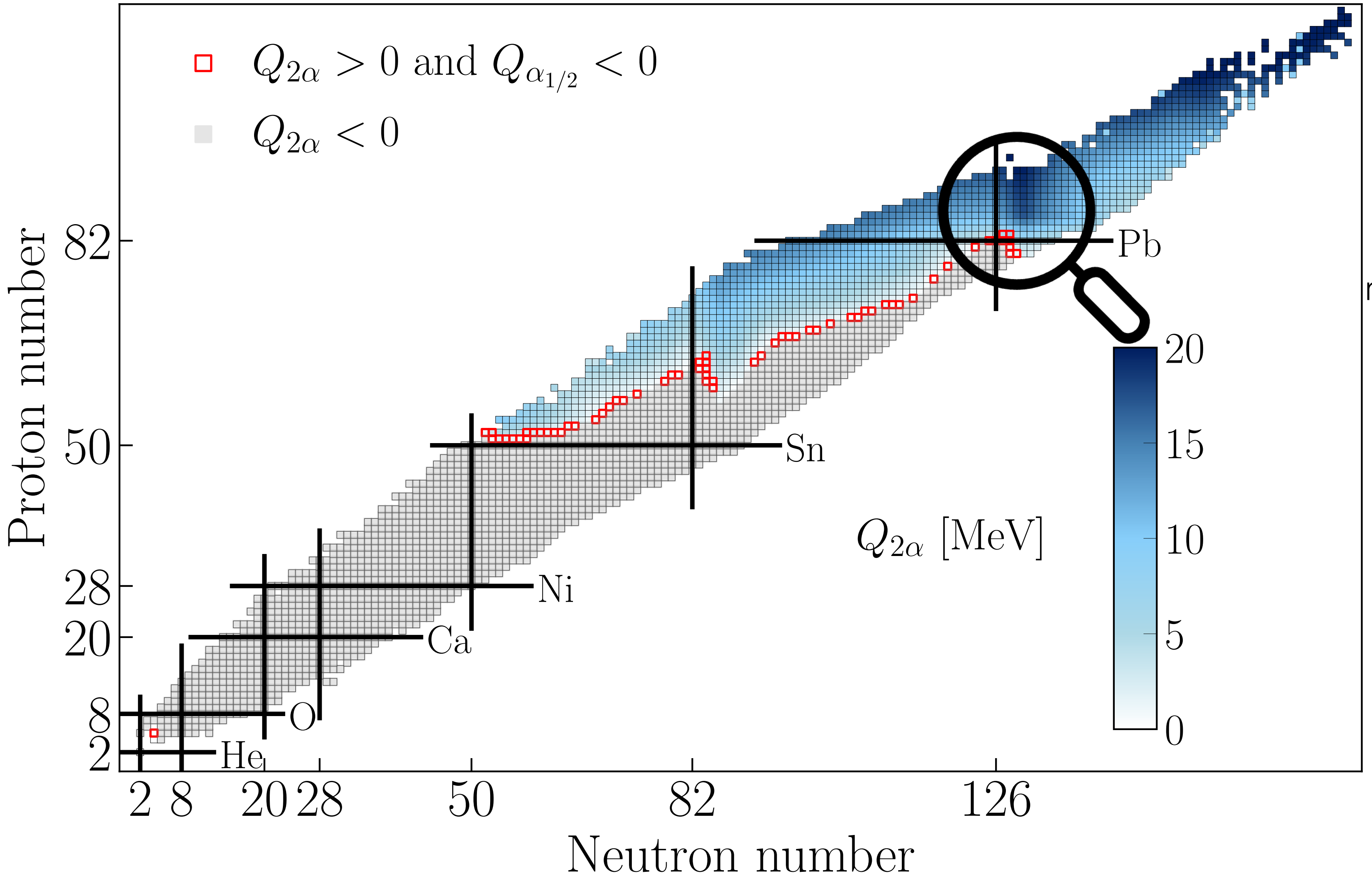

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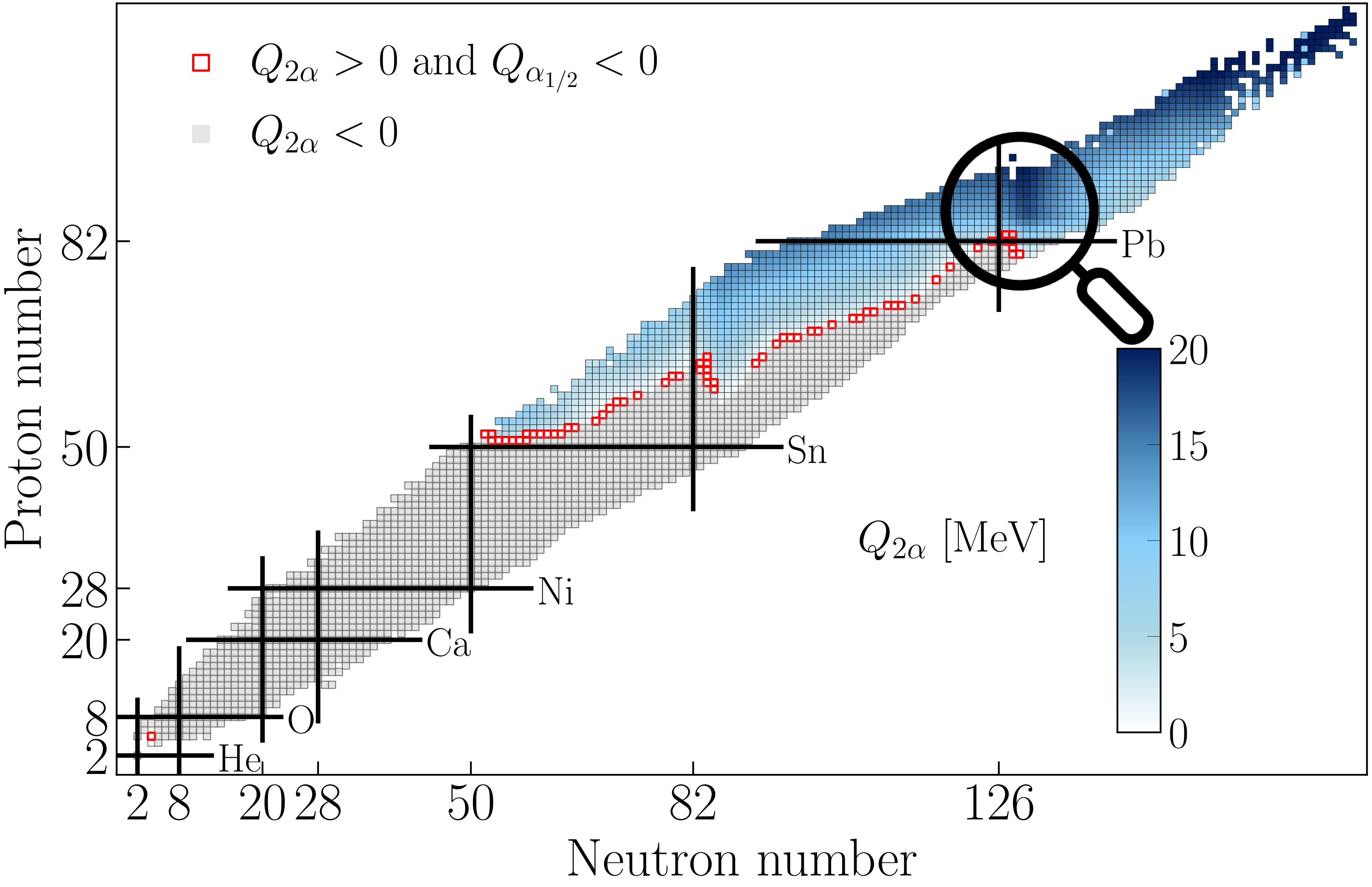

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« Natural » candidate

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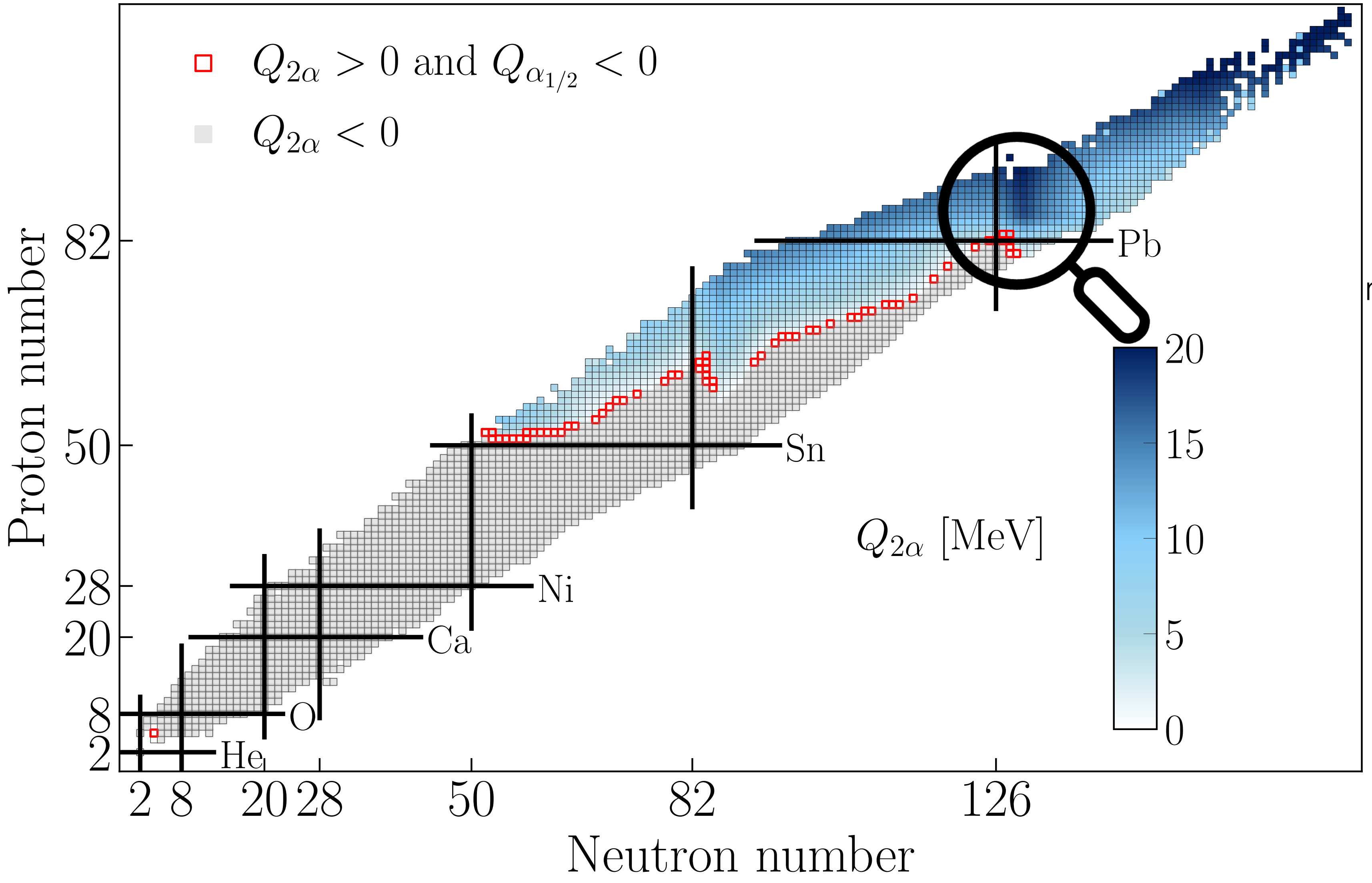

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Other candidates

$^{218\text{-}220}\mathrm{Rn}, {}^{220\text{-}224}\mathrm{Ra}$

Experimental campaigns

2021

Theoretical trigger

Experimental campaigns

2021

Theoretical trigger

2022

GSI – FRS Ion Catcher

^{224}Ra – ^{220}Rn

DSSD

Source

~3 months

Experimental campaigns

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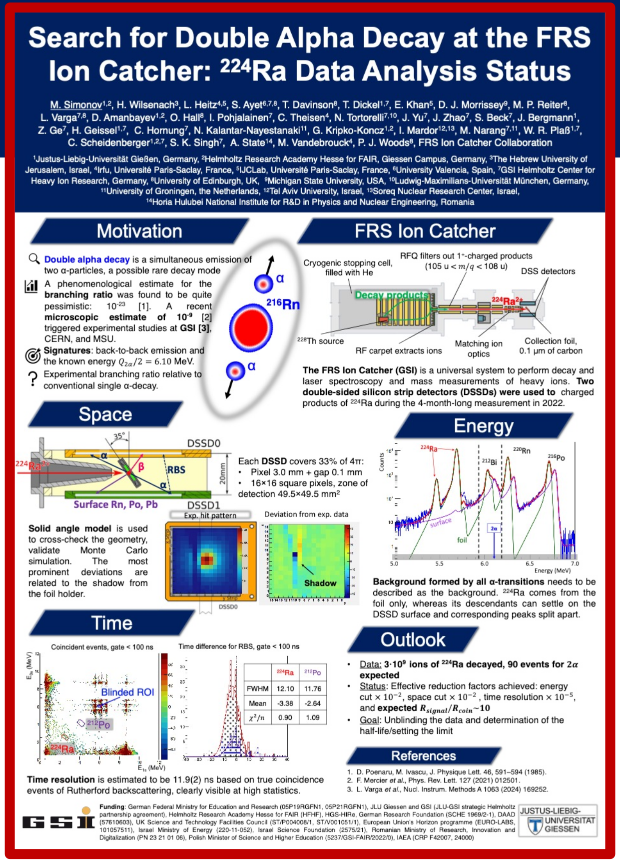
See M. Simonov's poster !



Experimental campaigns

2021 | **Theoretical trigger**

2022 | **GSI – FRS Ion Catcher**
$^{224}Ra - {}^{220}Rn$
DSSD
Source
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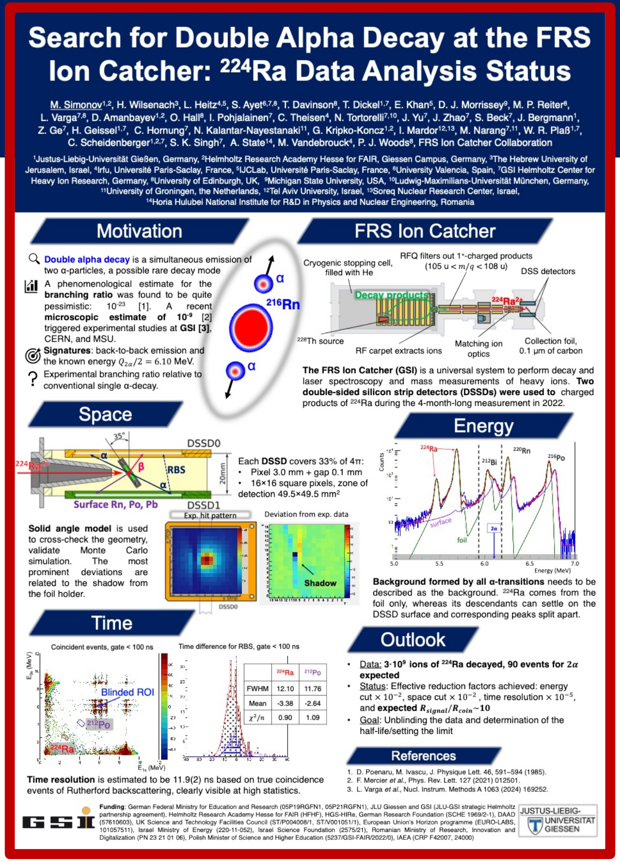

2023 | **CERN - ISOLDE**
$^{220,222}Ra - {}^{216,218}Rn$
DSSD
Beam
~1 week

Experimental campaigns

2021

Theoretical trigger

2022

GSI – FRS Ion Catcher

^{224}Ra – ^{220}Rn

DSSD

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~3 months

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CERN - ISOLDE

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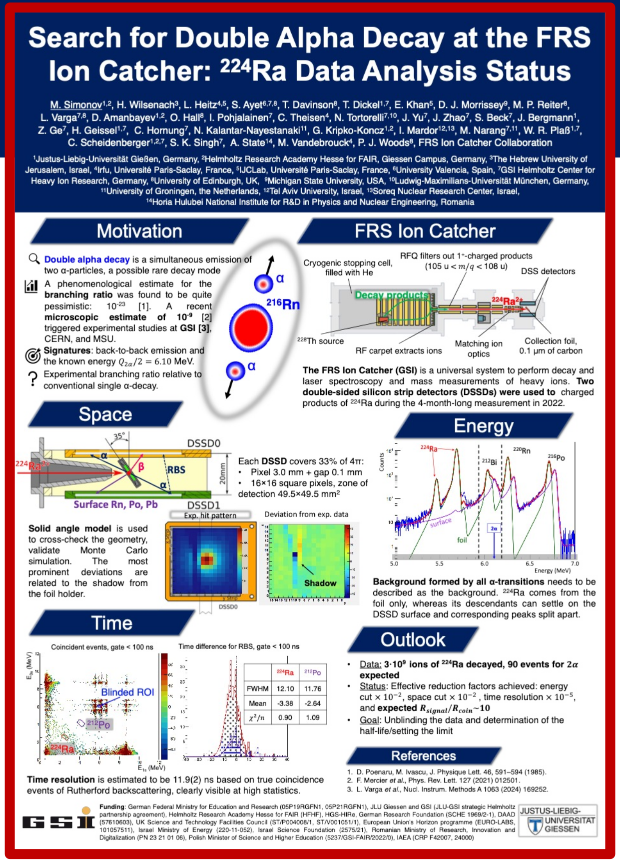

2024

GADGET II - MSU

^{220}Rn

TPC

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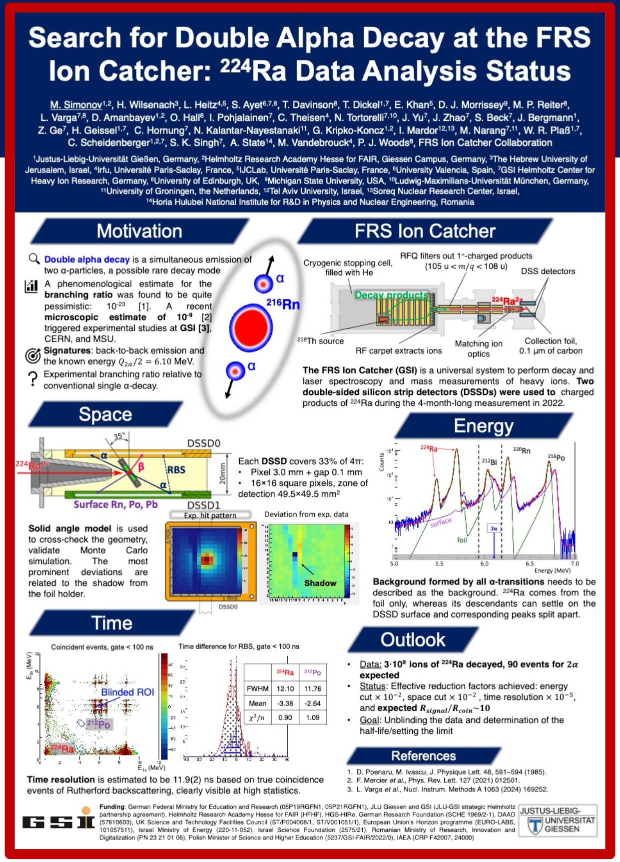

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^{220}Rn

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Right now !

Experimental setup

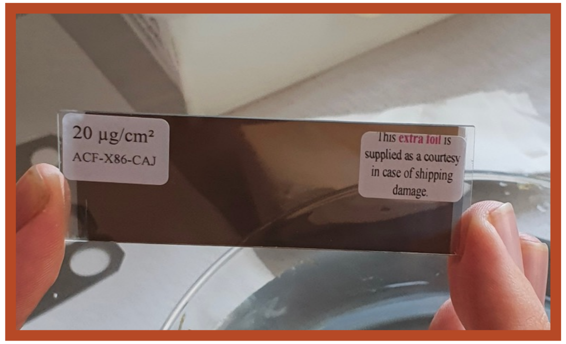
Incoming beam
^{220}Ra / ^{222}Ra
30 keV

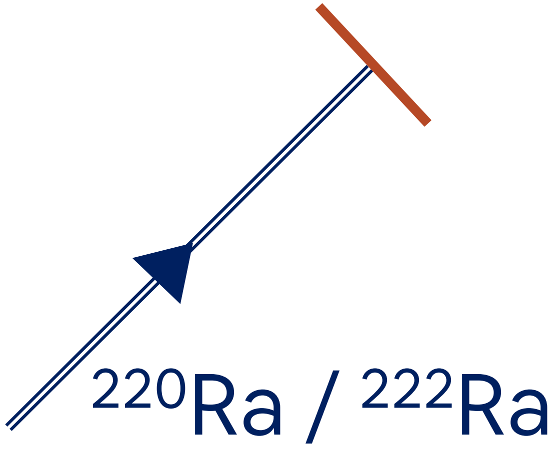
^{220}Ra / ^{222}Ra

Experimental setup

Incoming beam
^{220}Ra / ^{222}Ra
30 keV

Implantation in carbon foil
20μg/cm²





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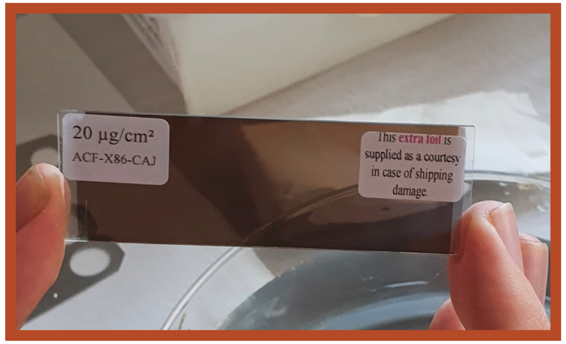
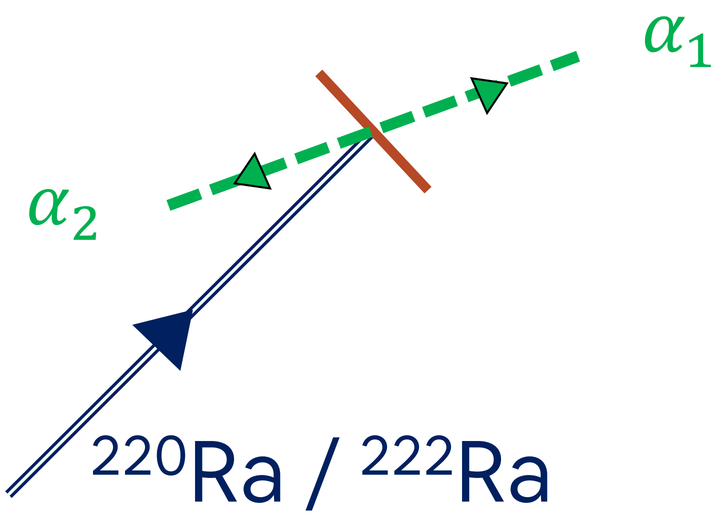
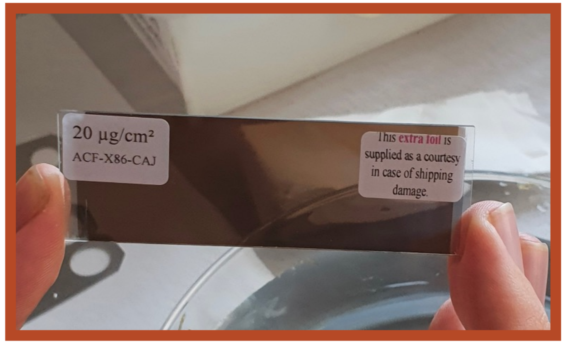




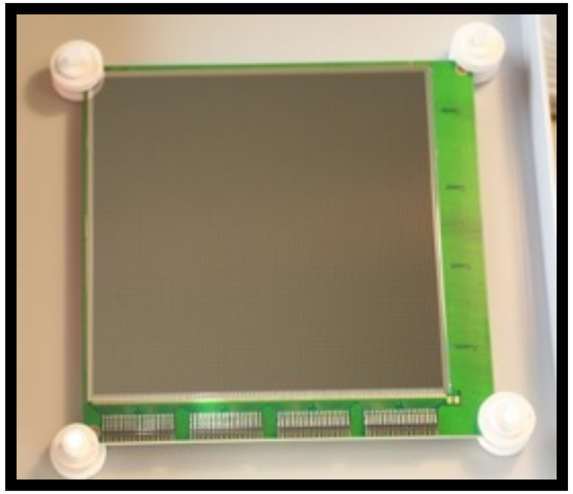
Experimental setup

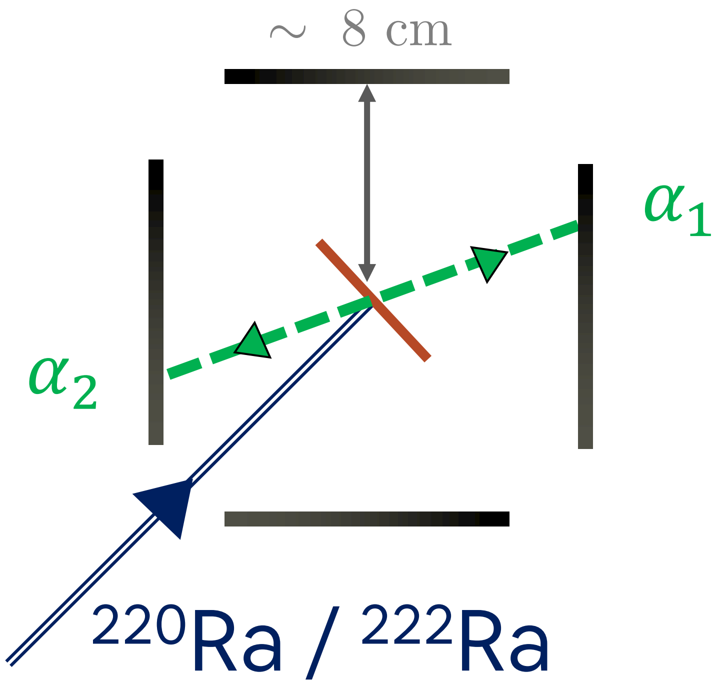
Incoming beam
^{220}Ra / ^{222}Ra
30 keV

Implantation in carbon foil
20µg/cm²



4 DSSD
MUSETT
10x10 cm, 128x128 strips
Energy + Position + Time





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30 keV

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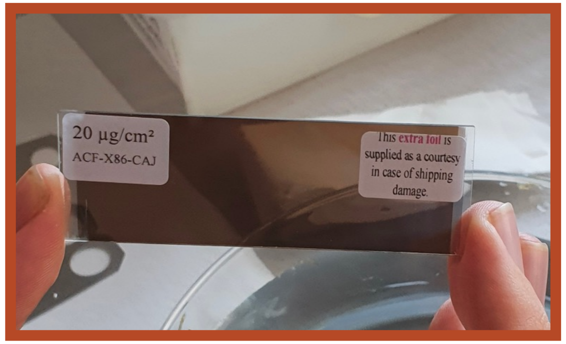
20µg/cm²



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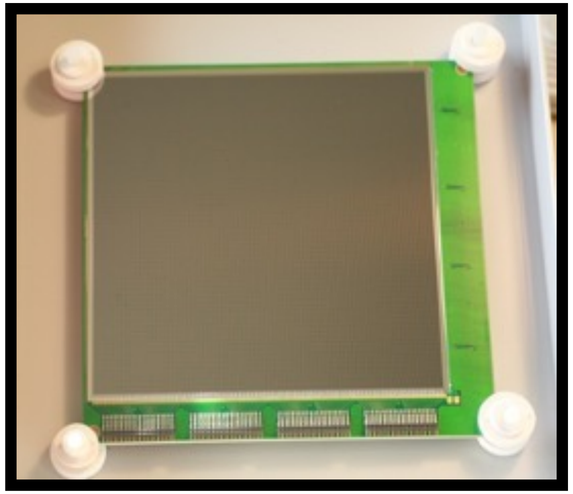
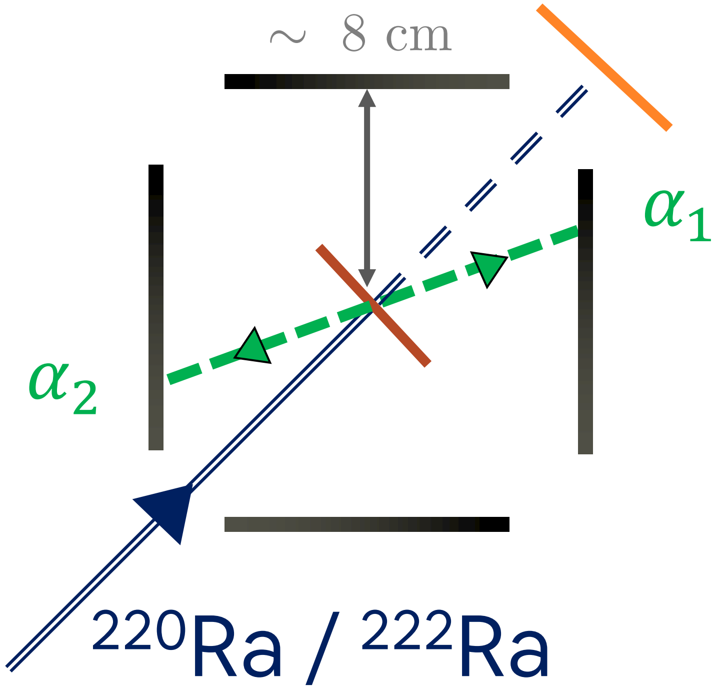
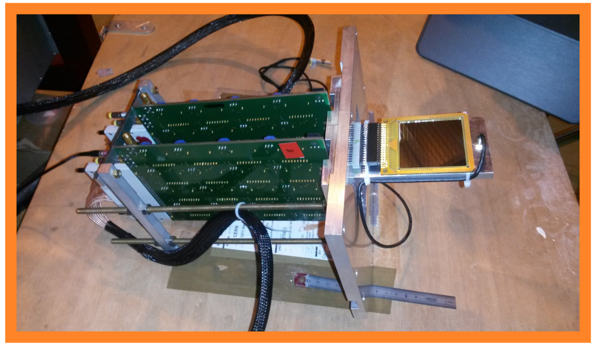
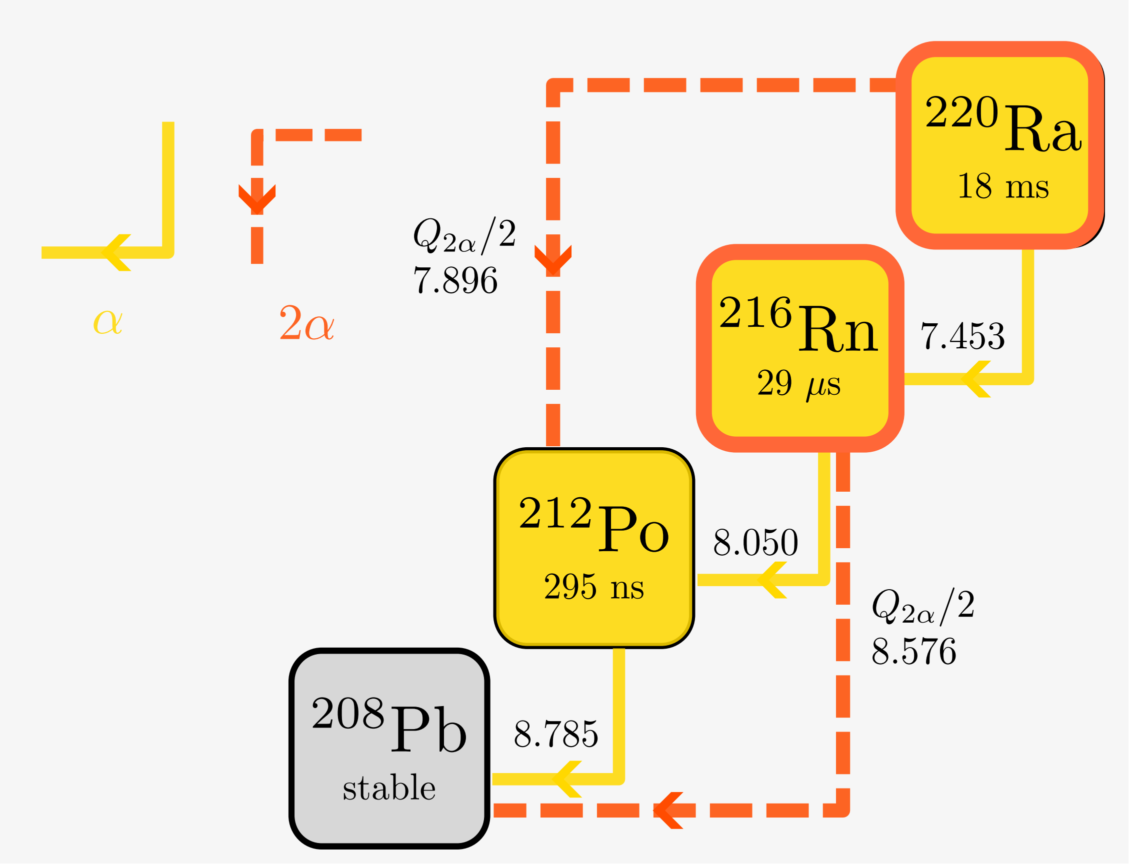


Beam Inspection DSSD



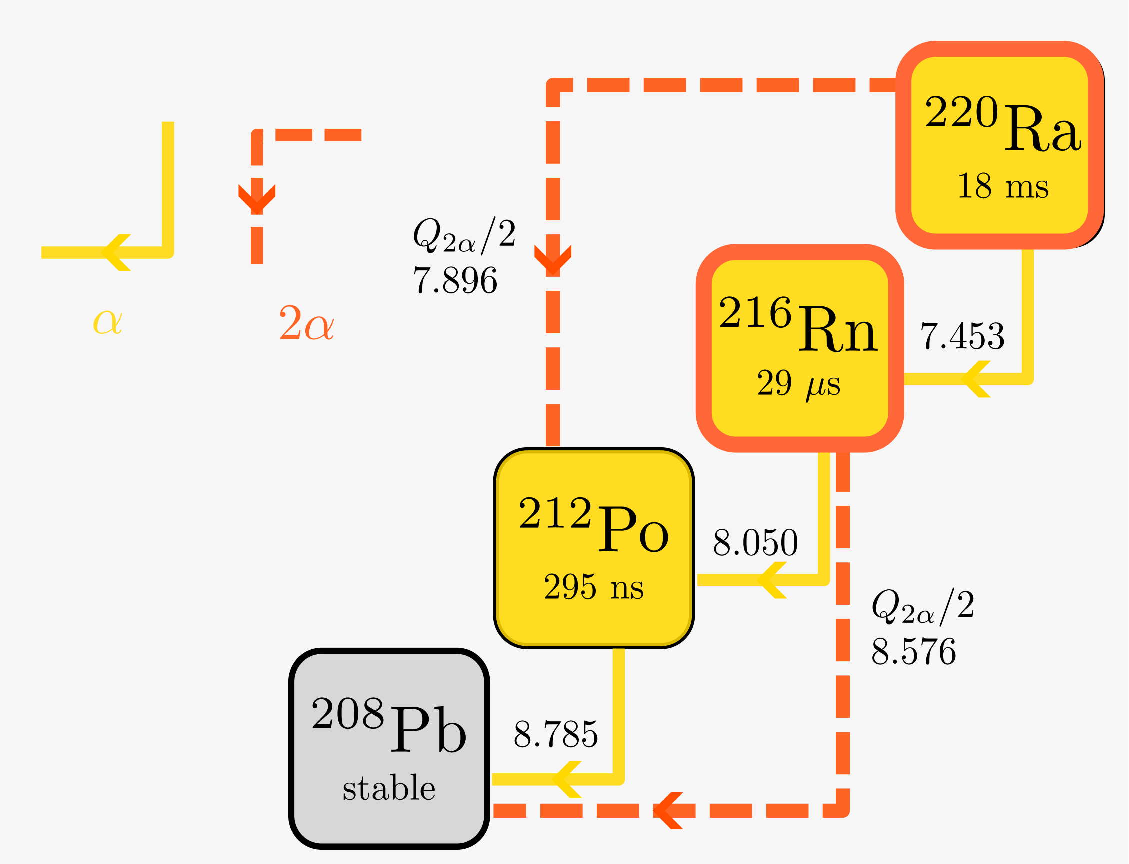


A few numbers



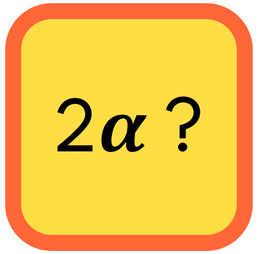
2α ?

A few numbers



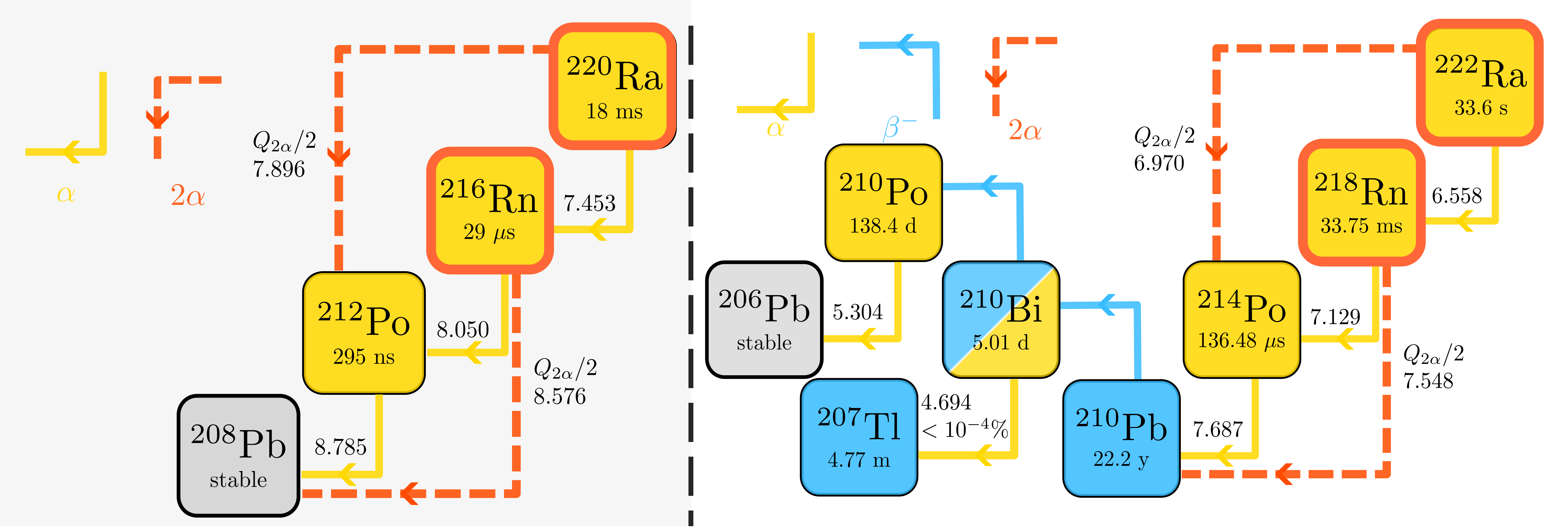
~10^8 implantations

<u>~10^1 events expected*</u>



*Microscopic prediction

A few numbers



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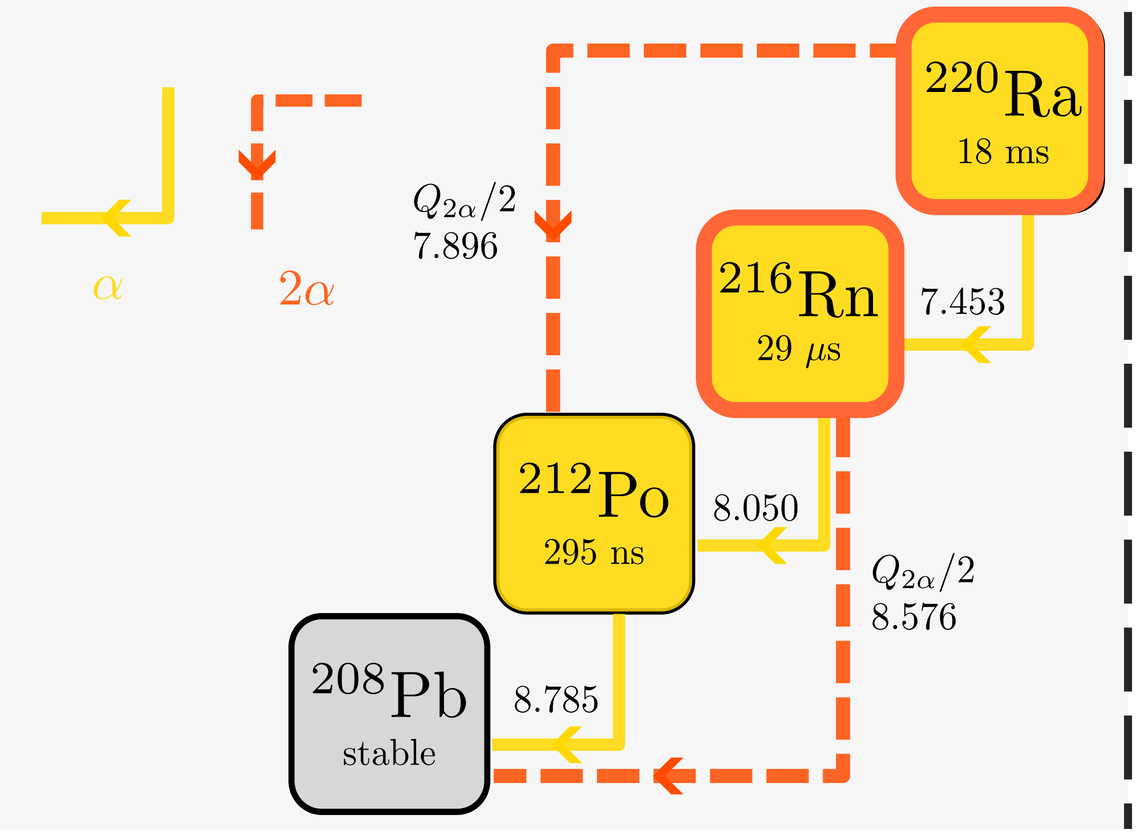

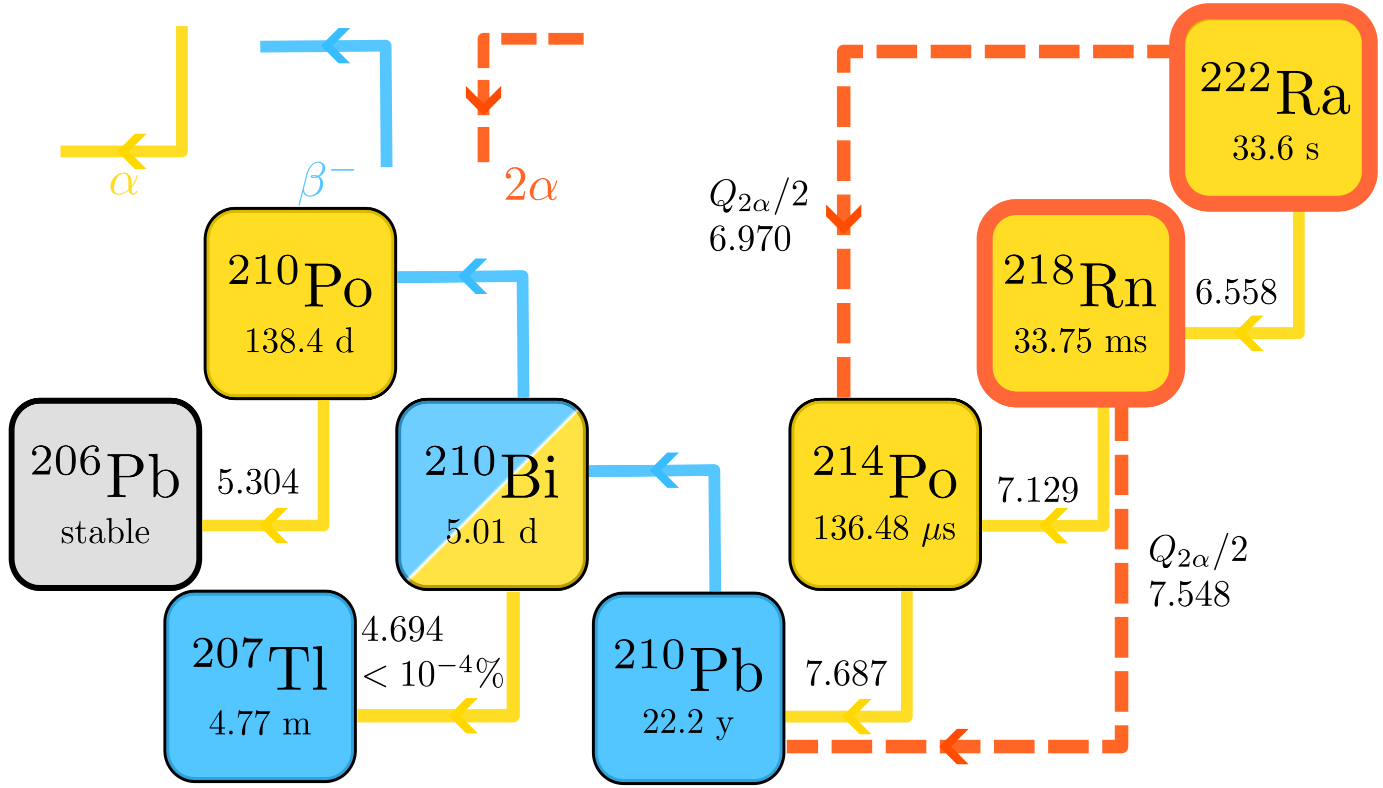

~10^8 implantations

~10^1 events expected*

2α ?

~10^{10} implantations

~10^2 events expected*

*Microscopic prediction

Outline

Introduction
Motivations, setup

Cuts to identify
double alpha events

How to identify double α decay ?

2 α particles +...

Kinematics

$$\boxed{E_1 + E_2 \simeq S_{2\alpha}(E_1, E_2, \theta)}$$

Detector resolution
FWHM ~ 30 keV

How to identify double α decay ?

2 α particles +...

Kinematics

$$E_1 + E_2 \simeq S_{2\alpha}(E_1, E_2, \theta)$$

Detector resolution
FWHM ~ 30 keV

Spatial condition

angle θ

Beam spot reconstructed
with **simulations**

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Detector resolution
FWHM ~ 30 keV

Spatial condition

angle θ

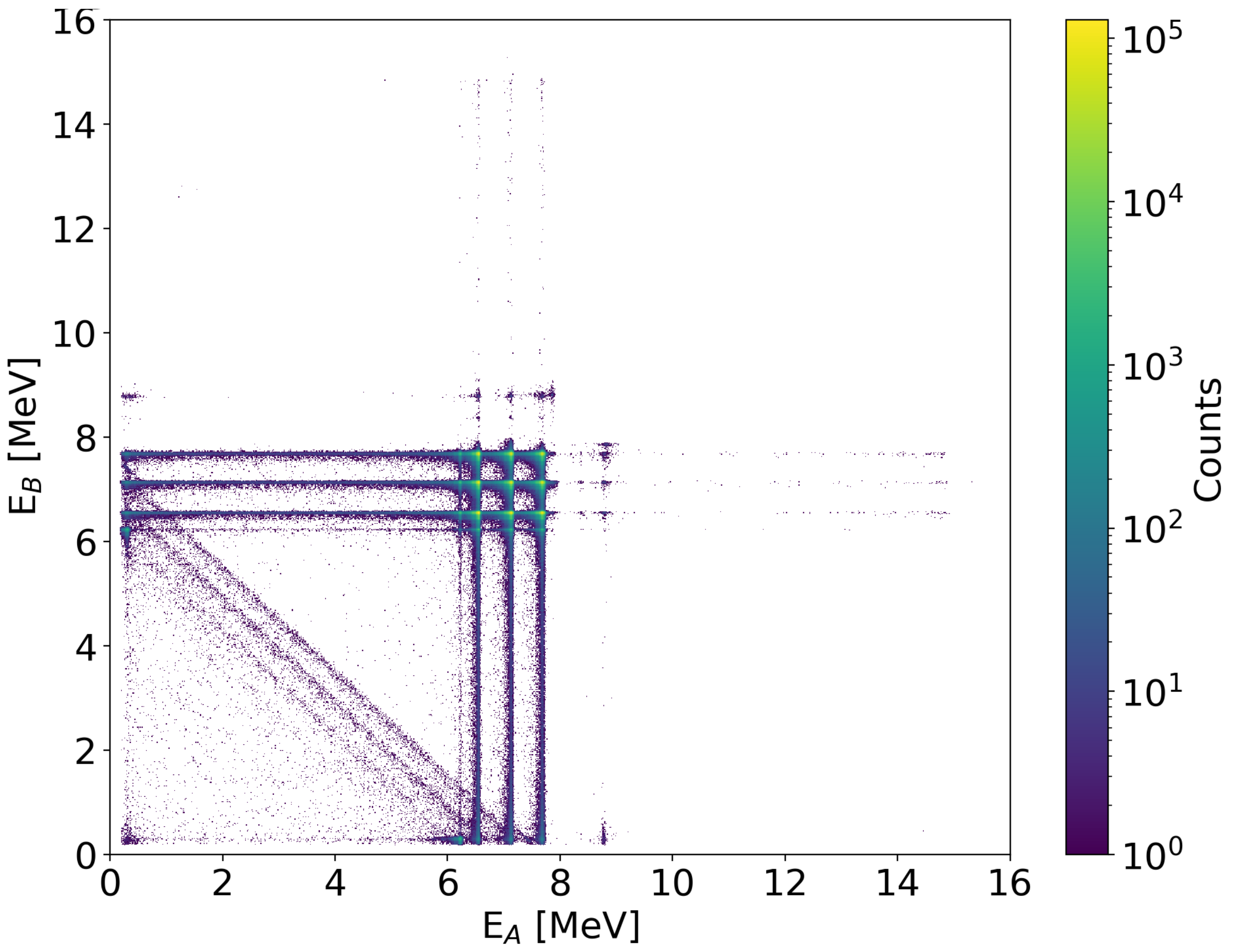
Beam spot reconstructed
with **simulations**

Time condition

« $T_1 \simeq T_2$ »

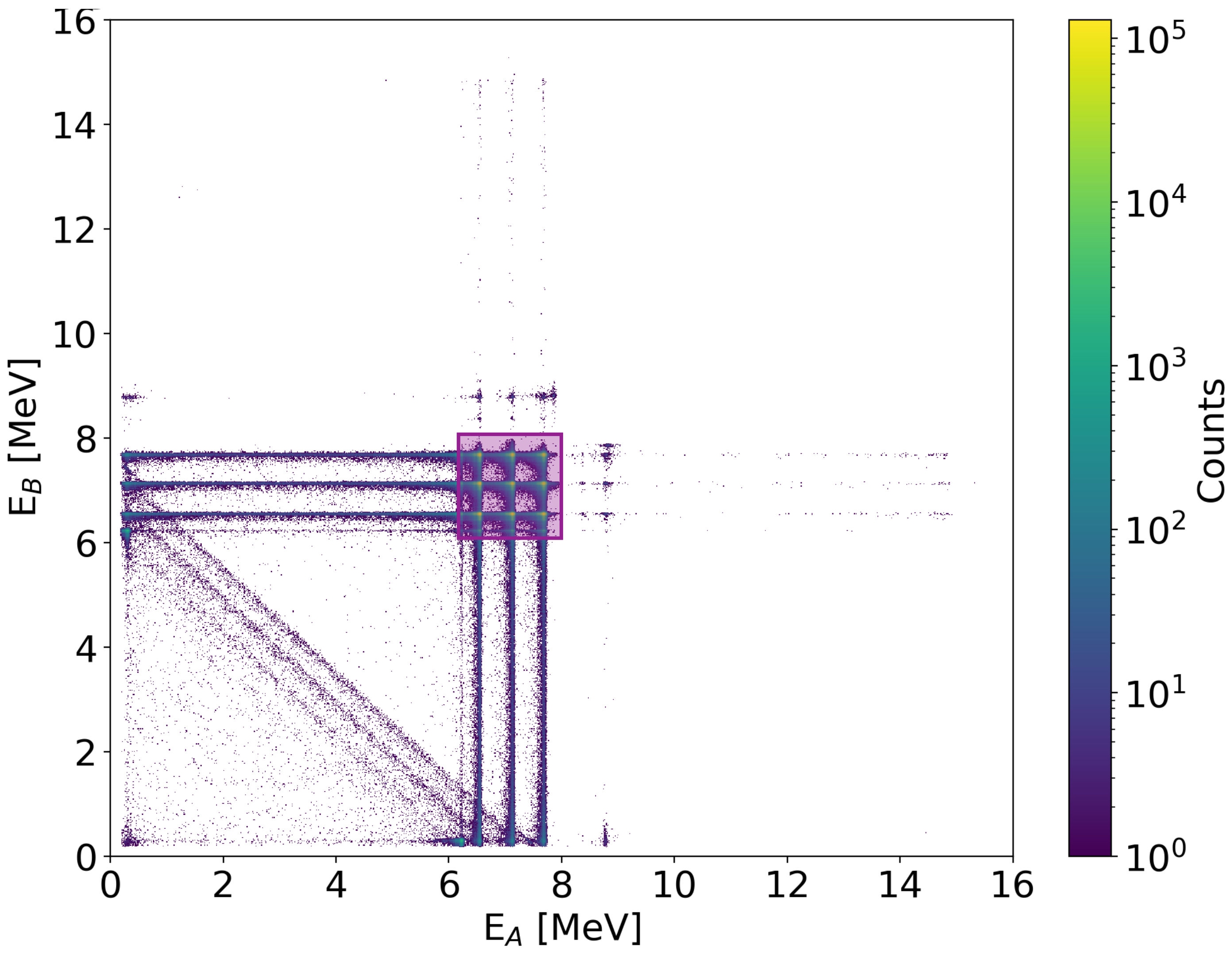
Detector resolution
FWHM ~ 5 ns

Main spectra features: ^{222}Ra



Main spectra features: ^{222}Ra

$\alpha - \alpha$ coincidence
3 peaks = Po, Rn, Ra



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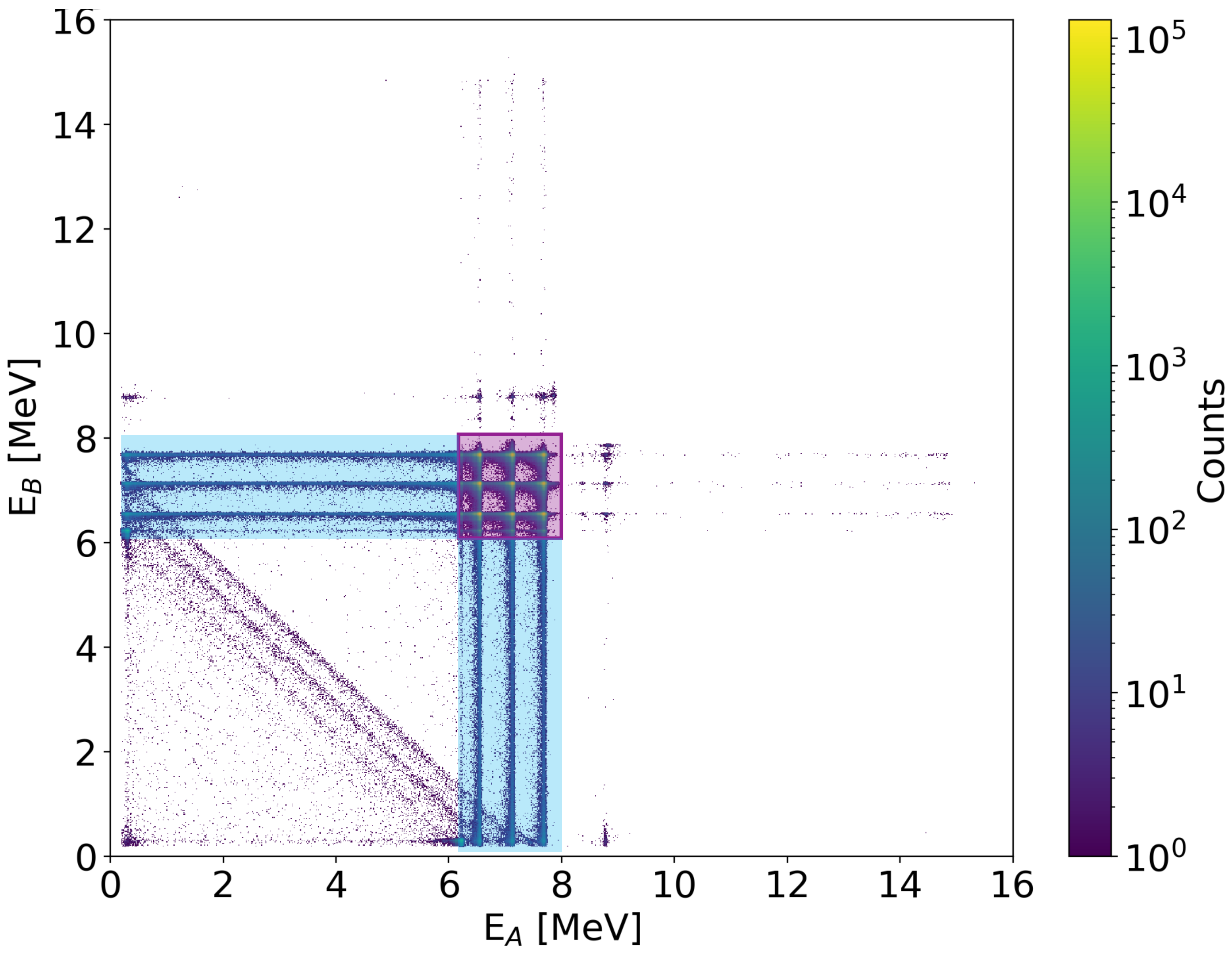

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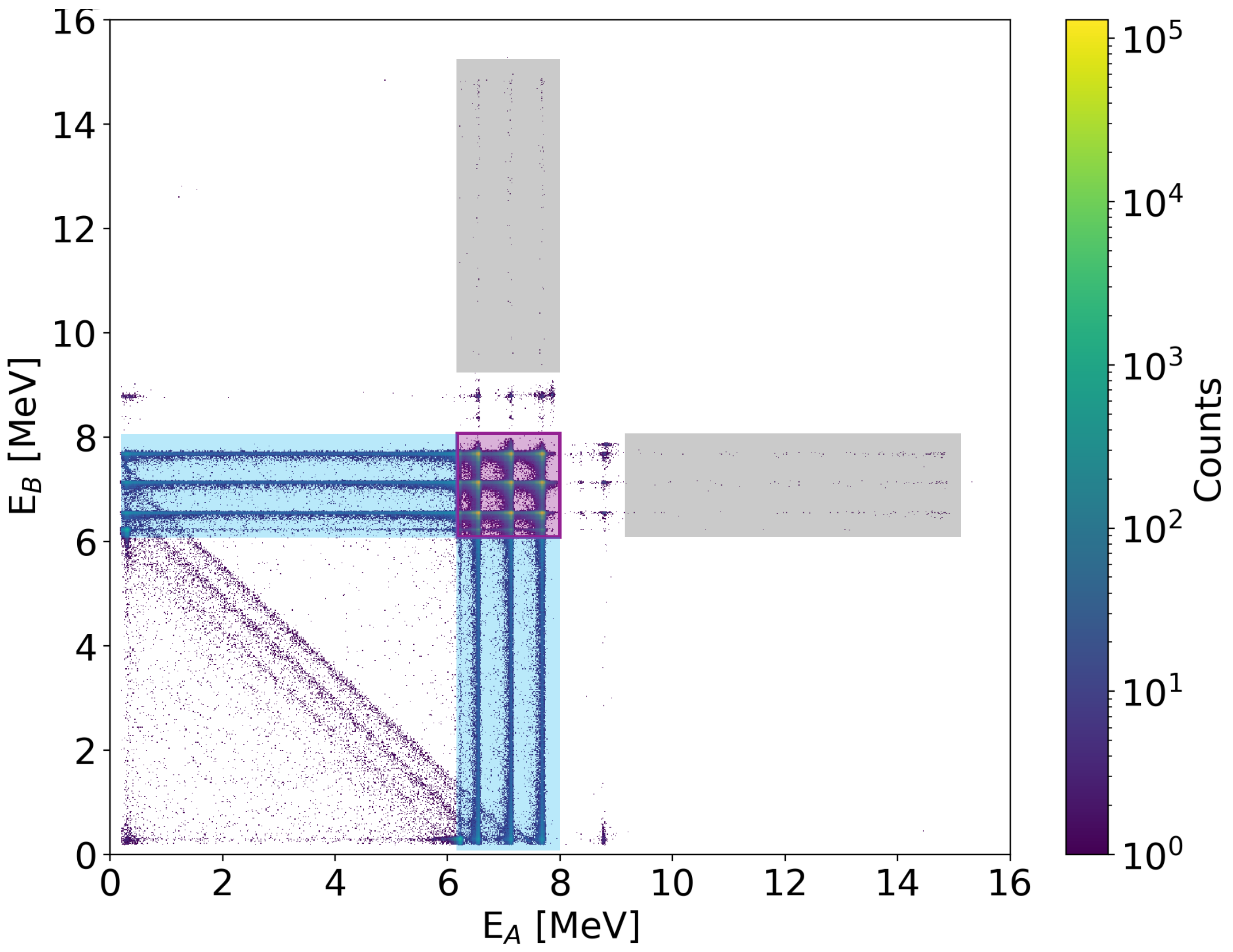

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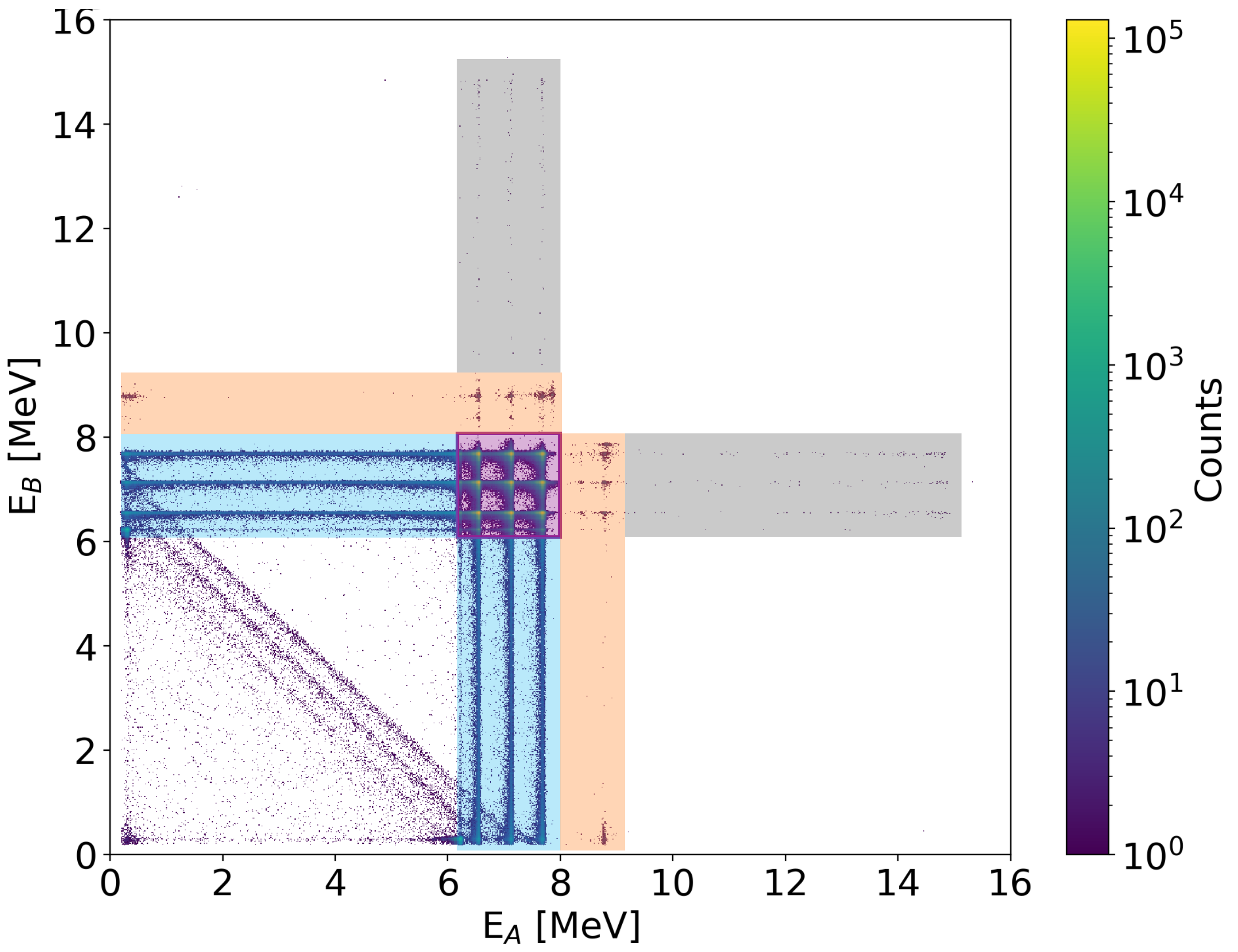

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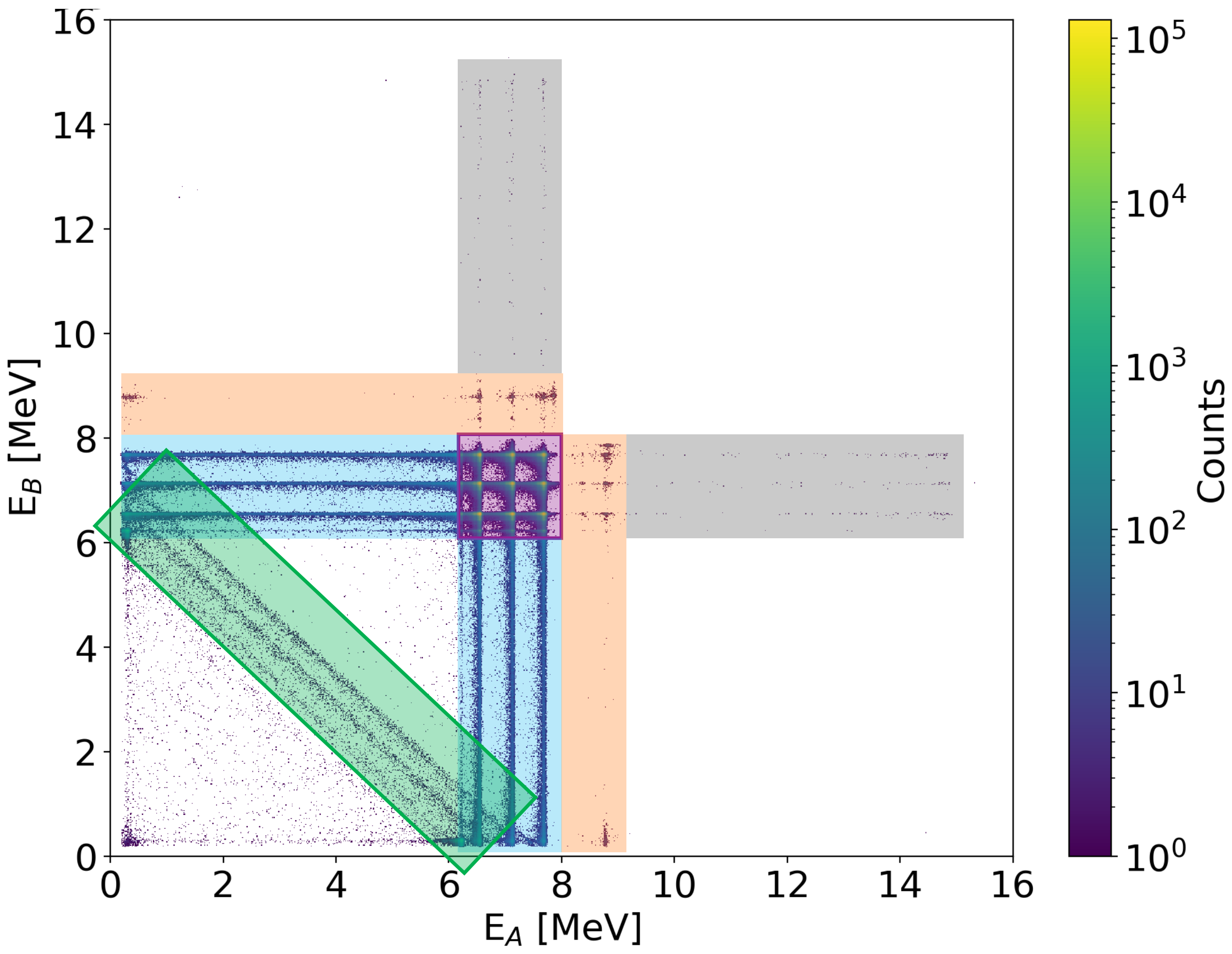

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Rutherford **B**ack**S**cattering
(see later)

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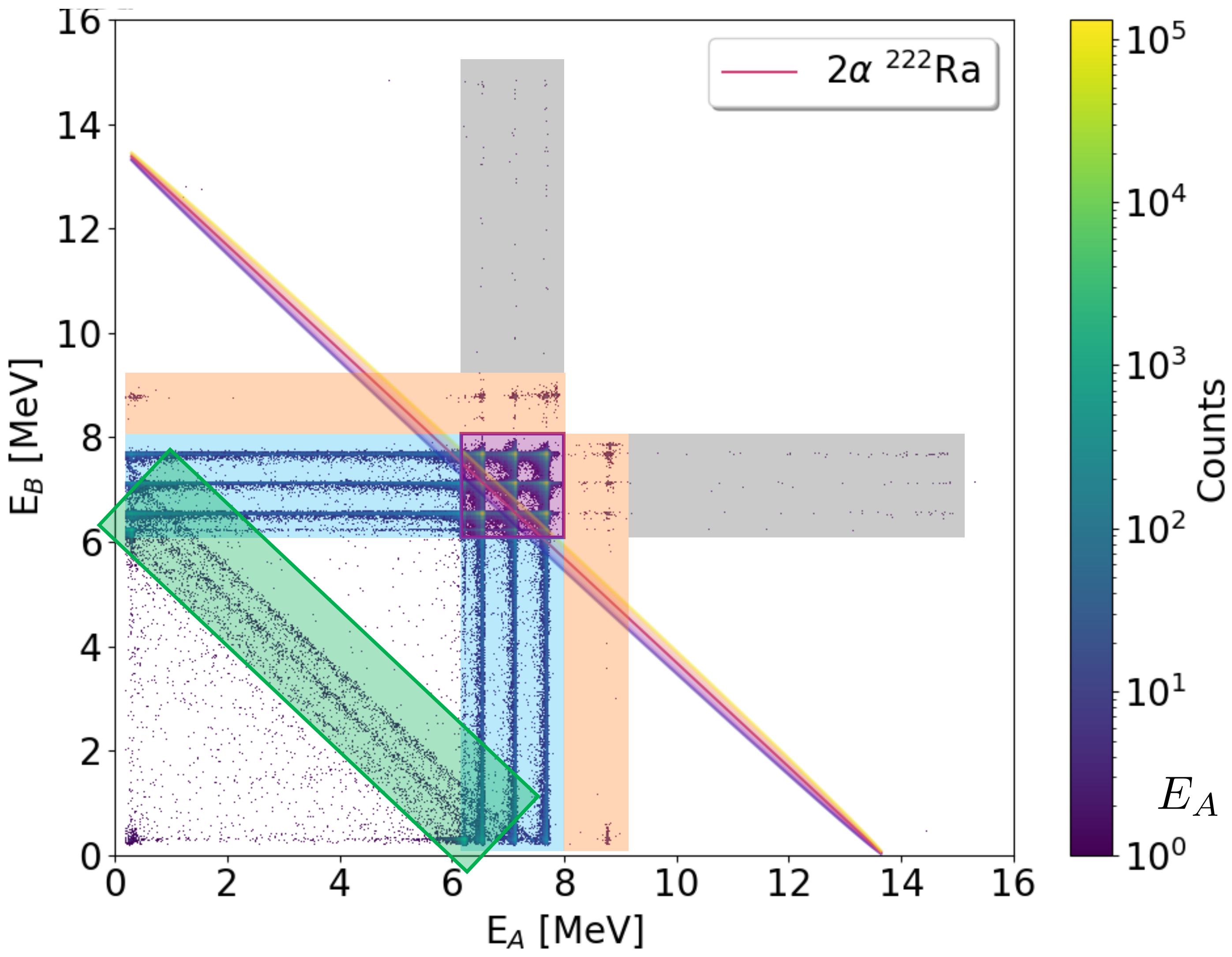

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$$E_A + E_B \simeq Q_{2\alpha}\left(1 - \boxed{\epsilon}\left[1 + \boxed{f\left(\frac{E_A}{E_B}\right)}\cos\theta\right]\right)$$

$\boxed{\frac{M_\alpha}{M_{\text{daughter}}} \simeq 2.10^{-2}}$ $\boxed{\lesssim 1}$

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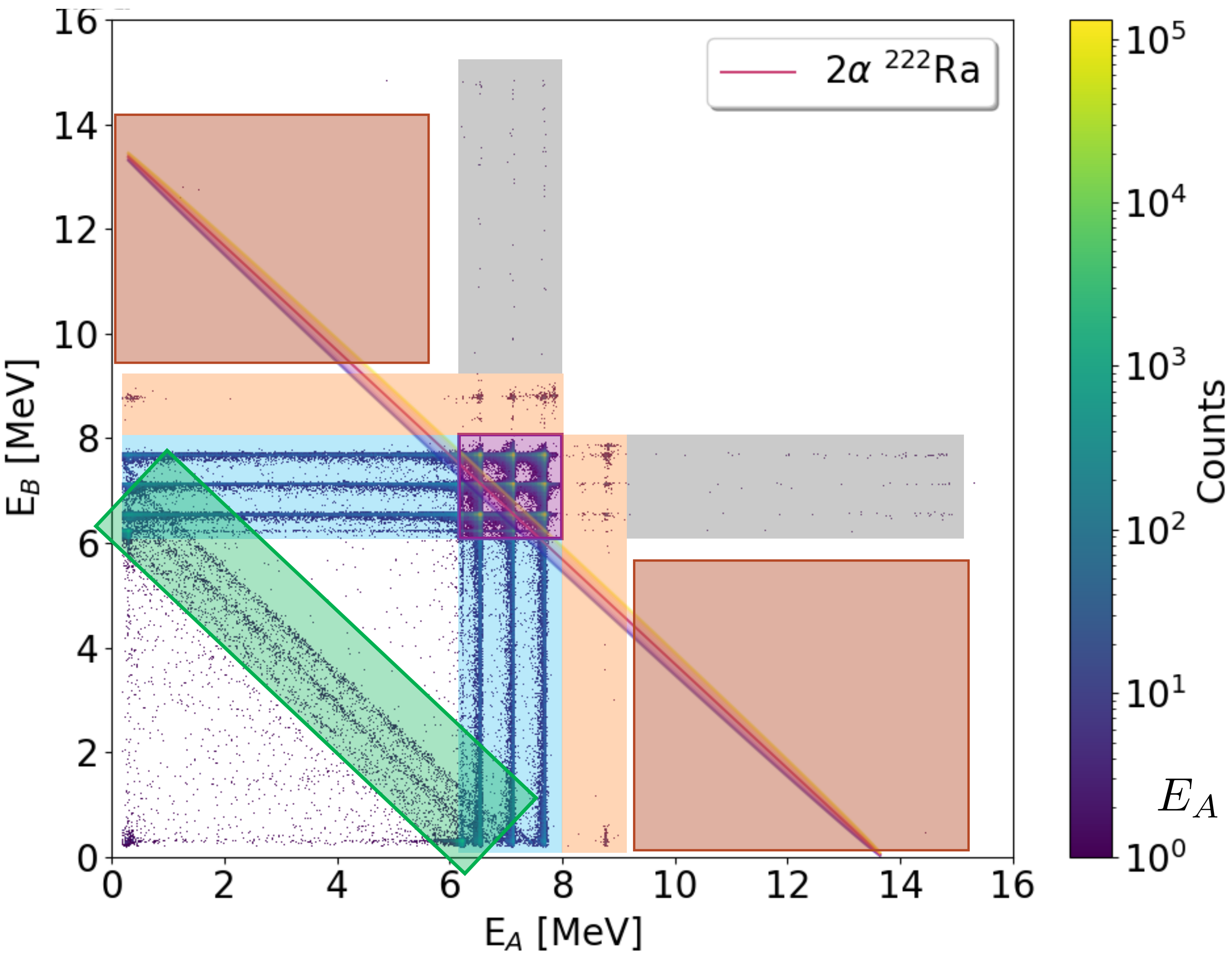

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Rutherford BackScattering
(see later)

« Out of Random » region

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Candidates summary

4 double α candidates

^{220}Ra, ^{216}Rn*, ^{222}Ra, ^{218}Rn*

* Can escape from implantation foil

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2 ROI / candidate

A) $\theta = 180°,\ E_A = E_B$: « <u>symmetric »</u>

B) E_A & E_B« out of random » : « <u>asymmetric »</u>

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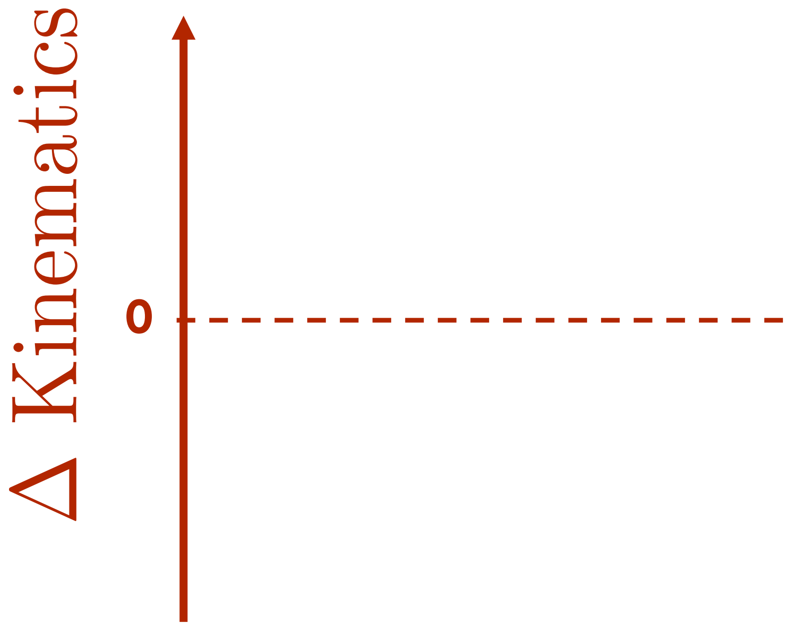
2 informations / cut

1) Kinematics: $E_A + E_B = S_{2\alpha}(E_A, E_B, \theta)$



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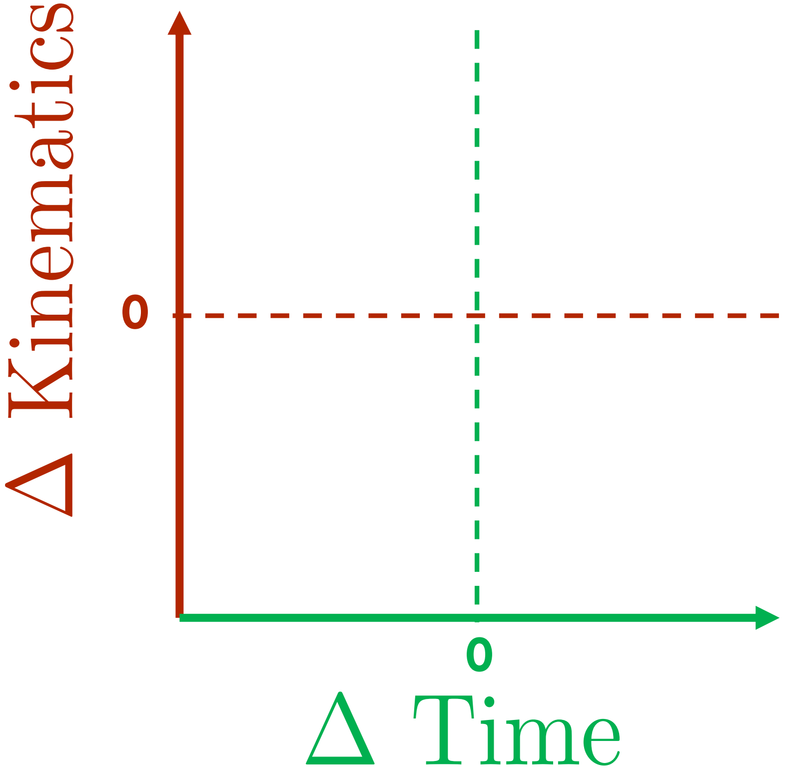

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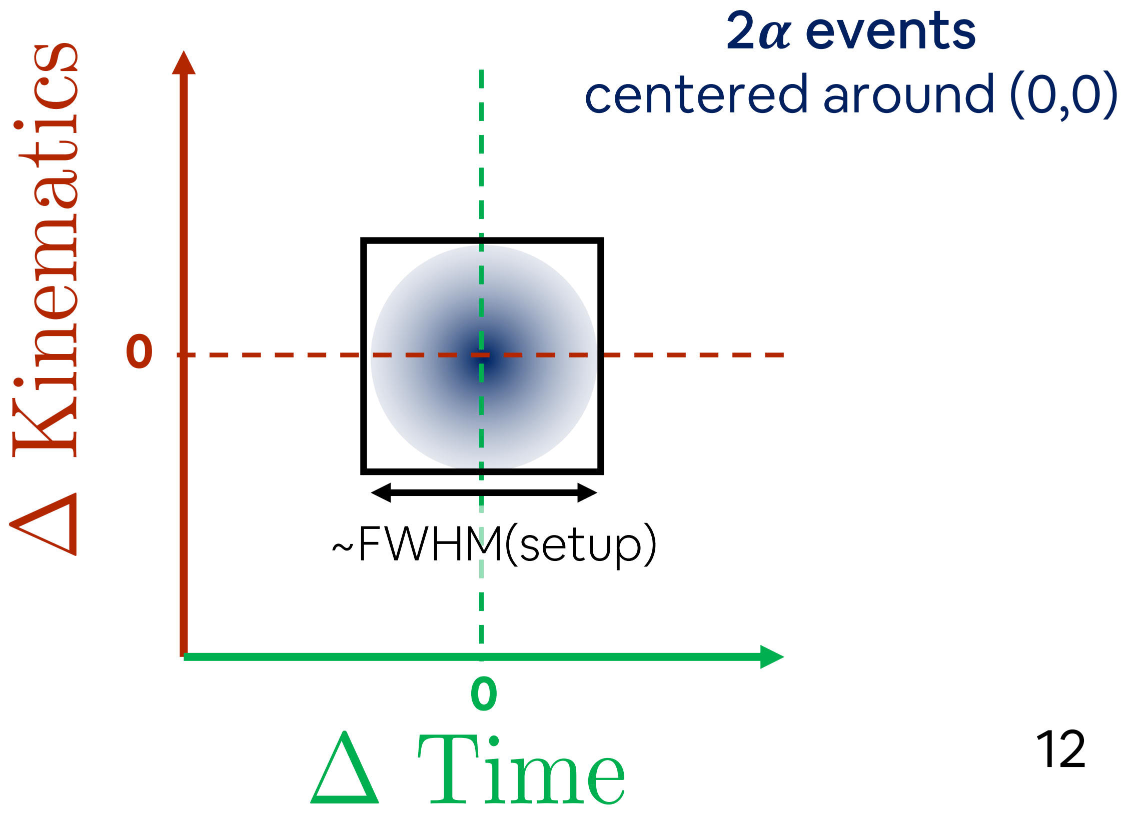

Outline

Introduction
Motivations, setup

Calibrations + cuts
Methodology

Preliminary results

Symmetric 2α : ^{222}Ra

Same E & $\theta = 180°$

Expected : few 10^2 (microscopic)

Symmetric 2α : ^{222}Ra

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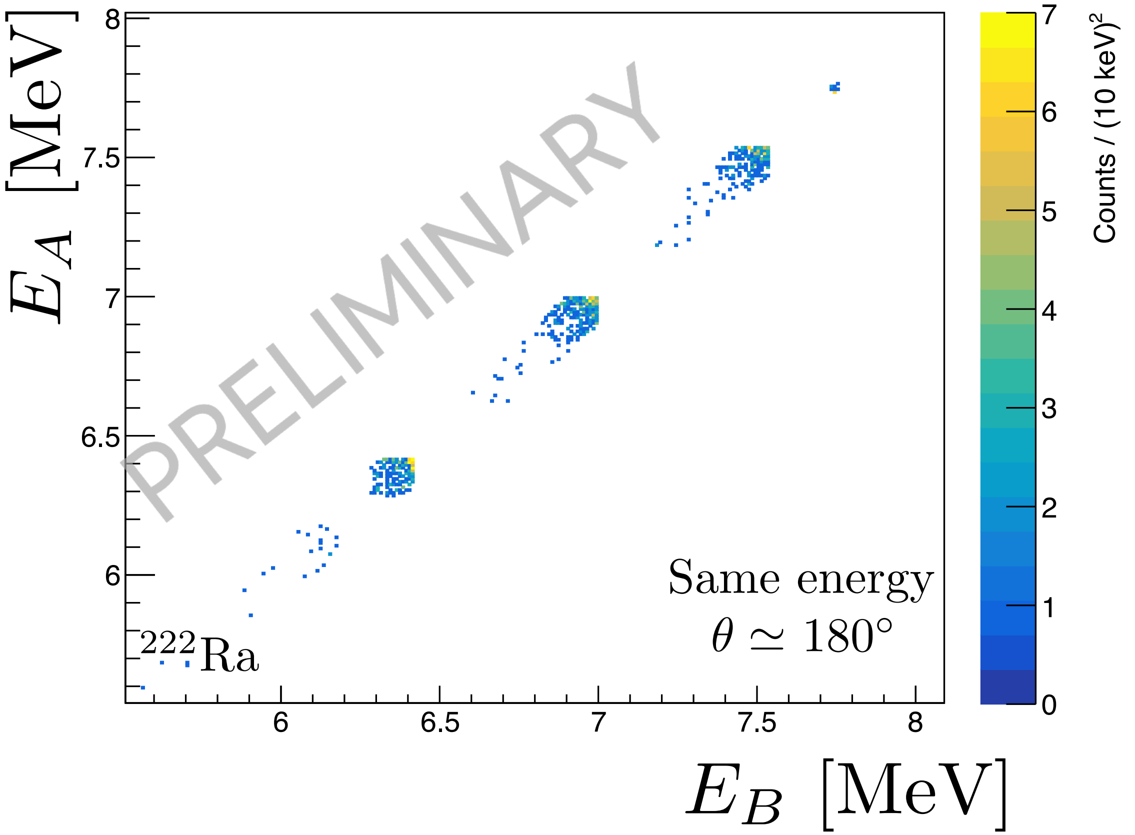

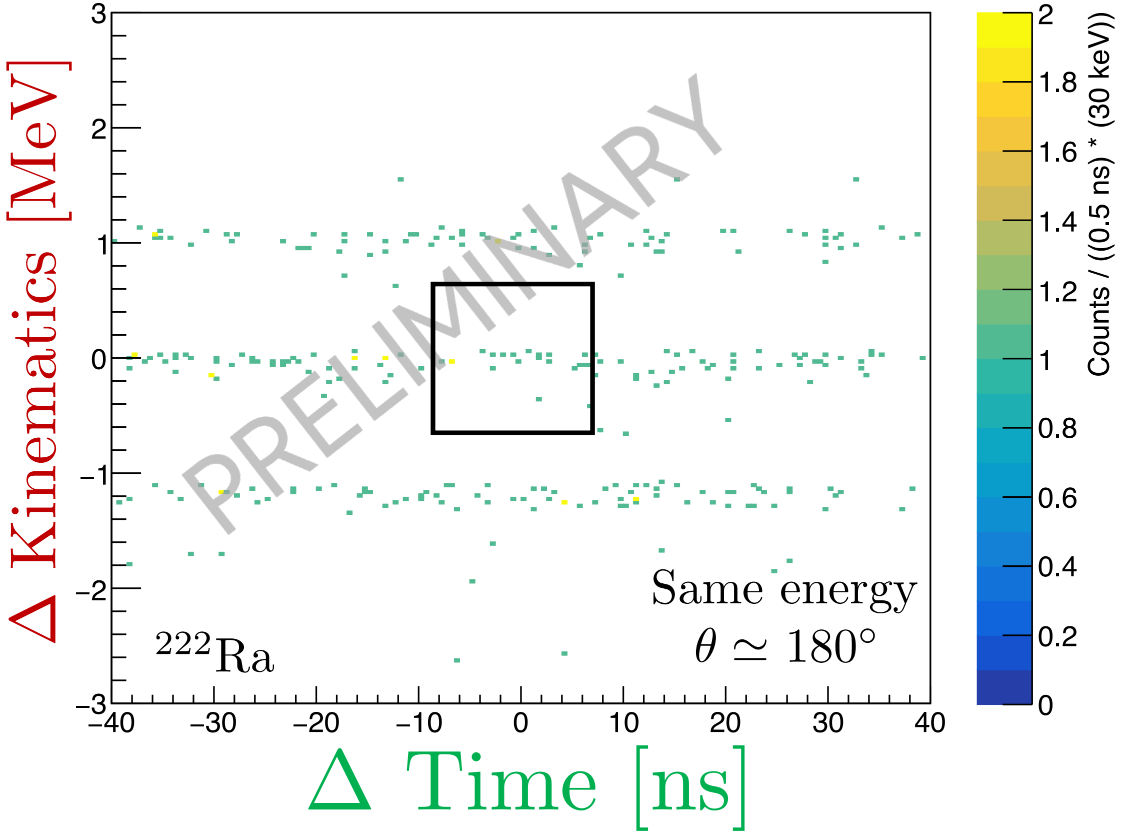

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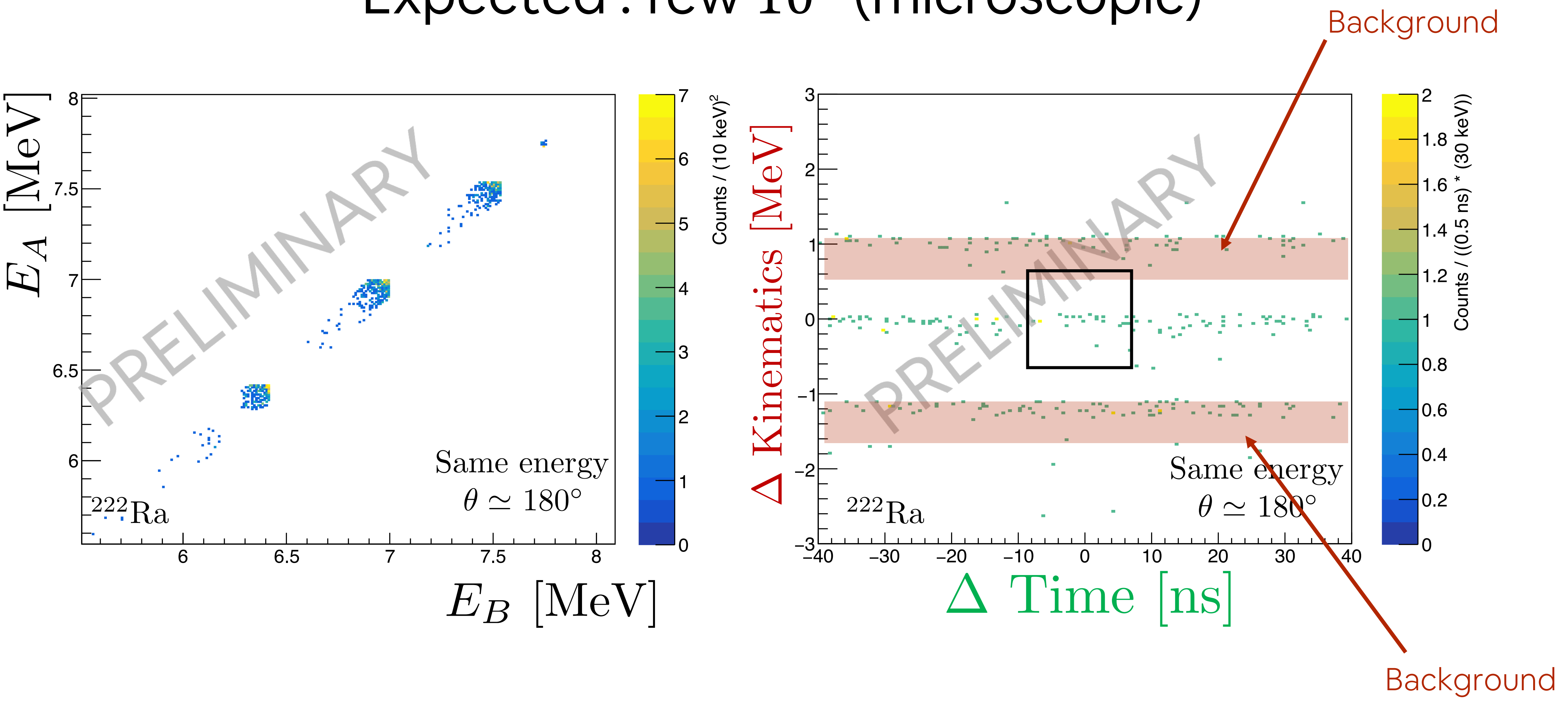

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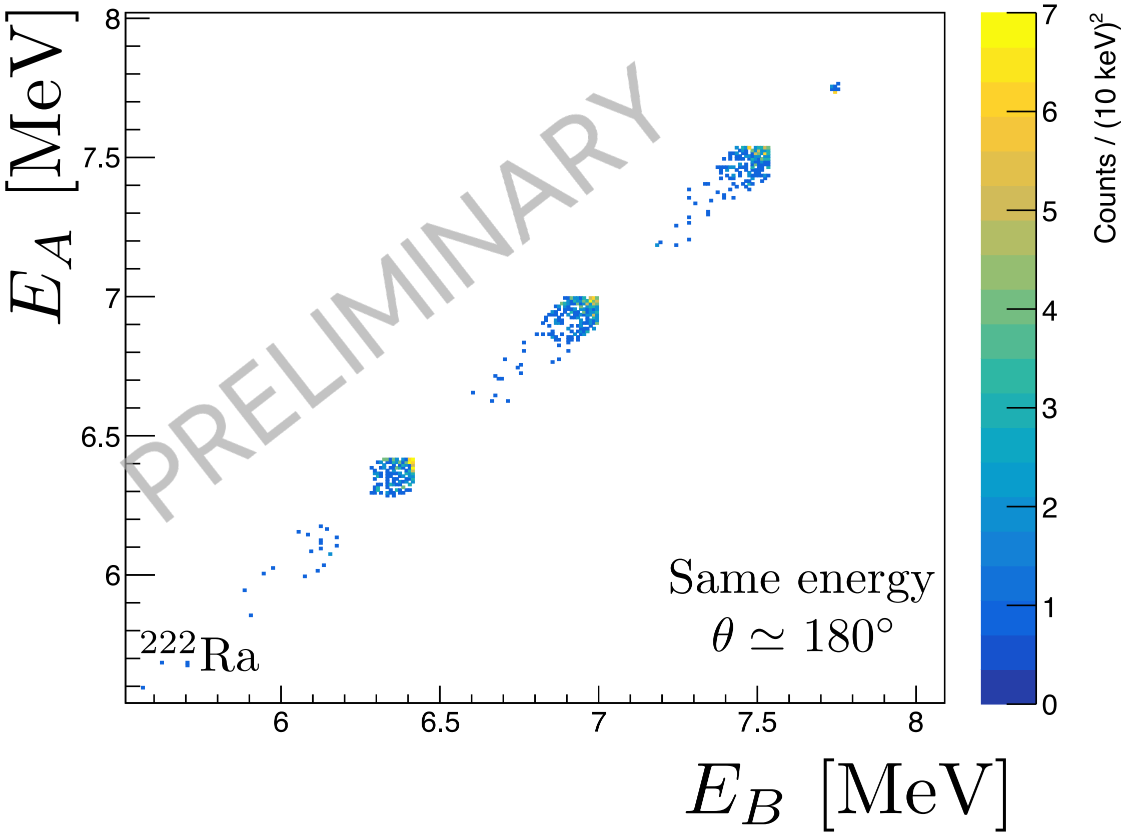

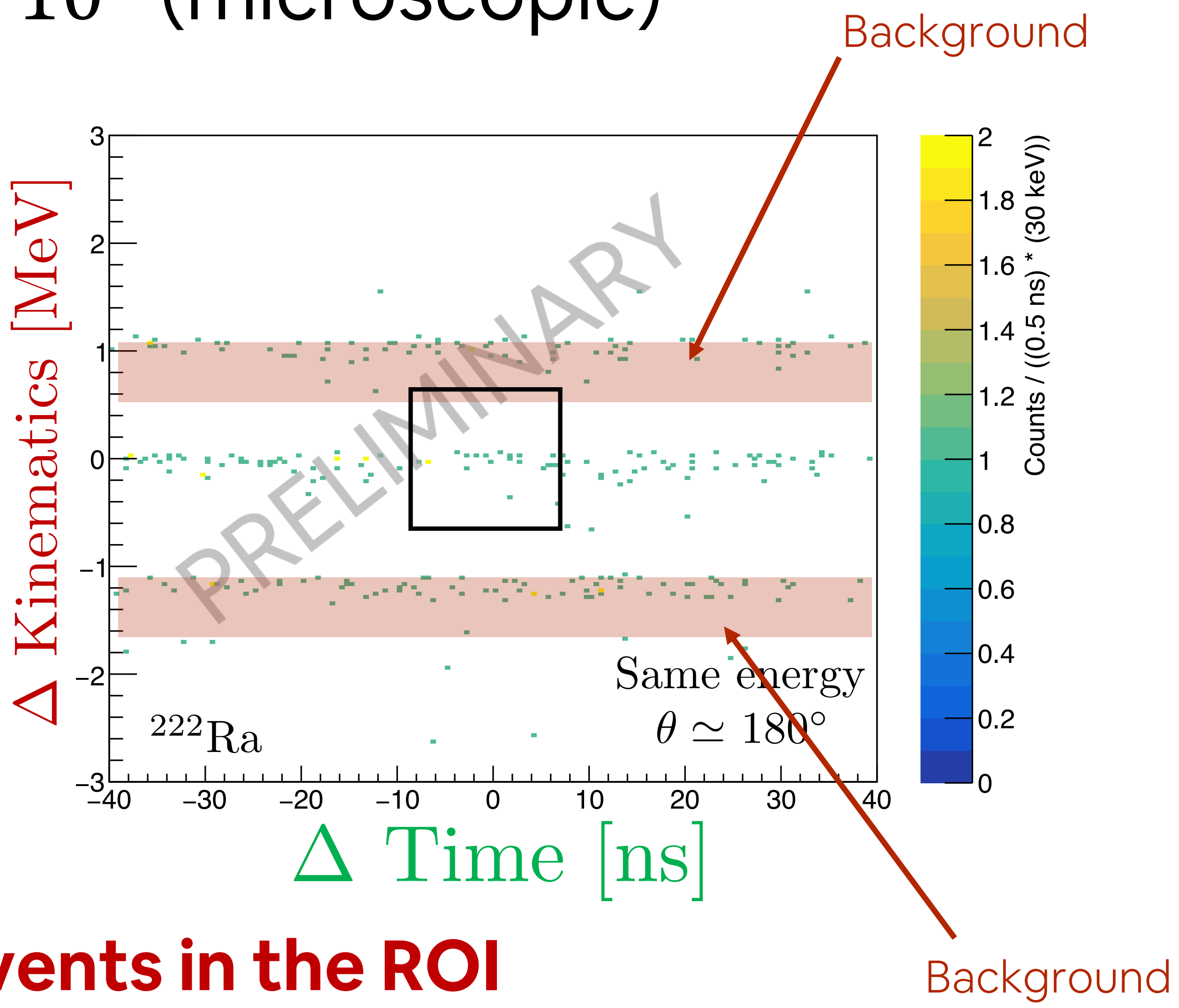

No excess of events in the ROI

Microscopic branching ratio overestimated

Summary : symmetric 2α (same E, $\theta = 180°$)

Upper limits on 2α branching ratio :

^{222}Ra : 4.47 10^{-11} ^{218}Rn : 9.88 10^{-11}	^{220}Ra : 1.60 10^{-8} ^{216}Rn : 4.14 10^{-8}

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PRELIMINARY

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PRELIMINARY

Microscopic prediction overestimated

BR(th) / BR(upper limit, exp)

^{222}Ra : 1750
^{218}Rn : 6400

^{220}Ra : 3
^{216}Rn : 19

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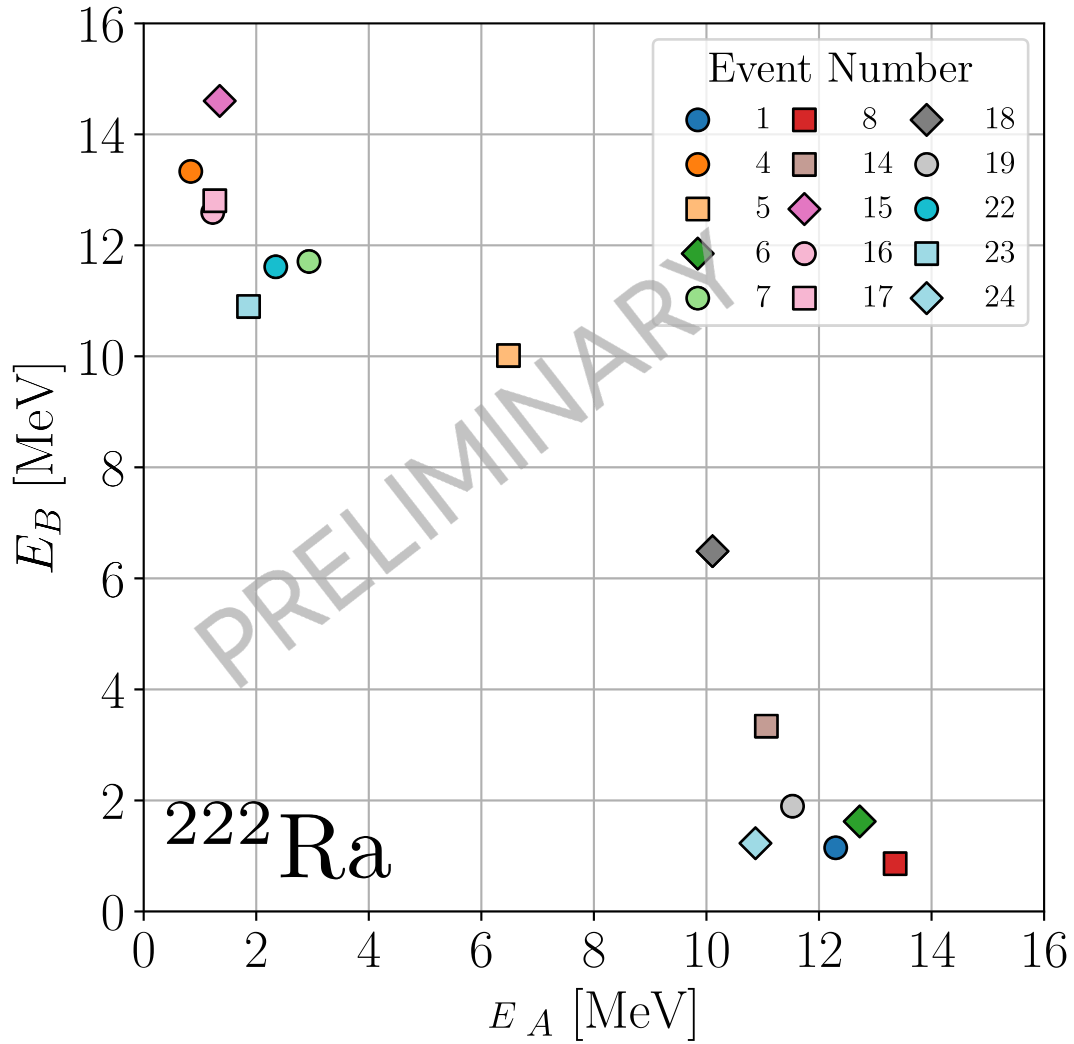
BR(th) / BR(upper limit, exp)

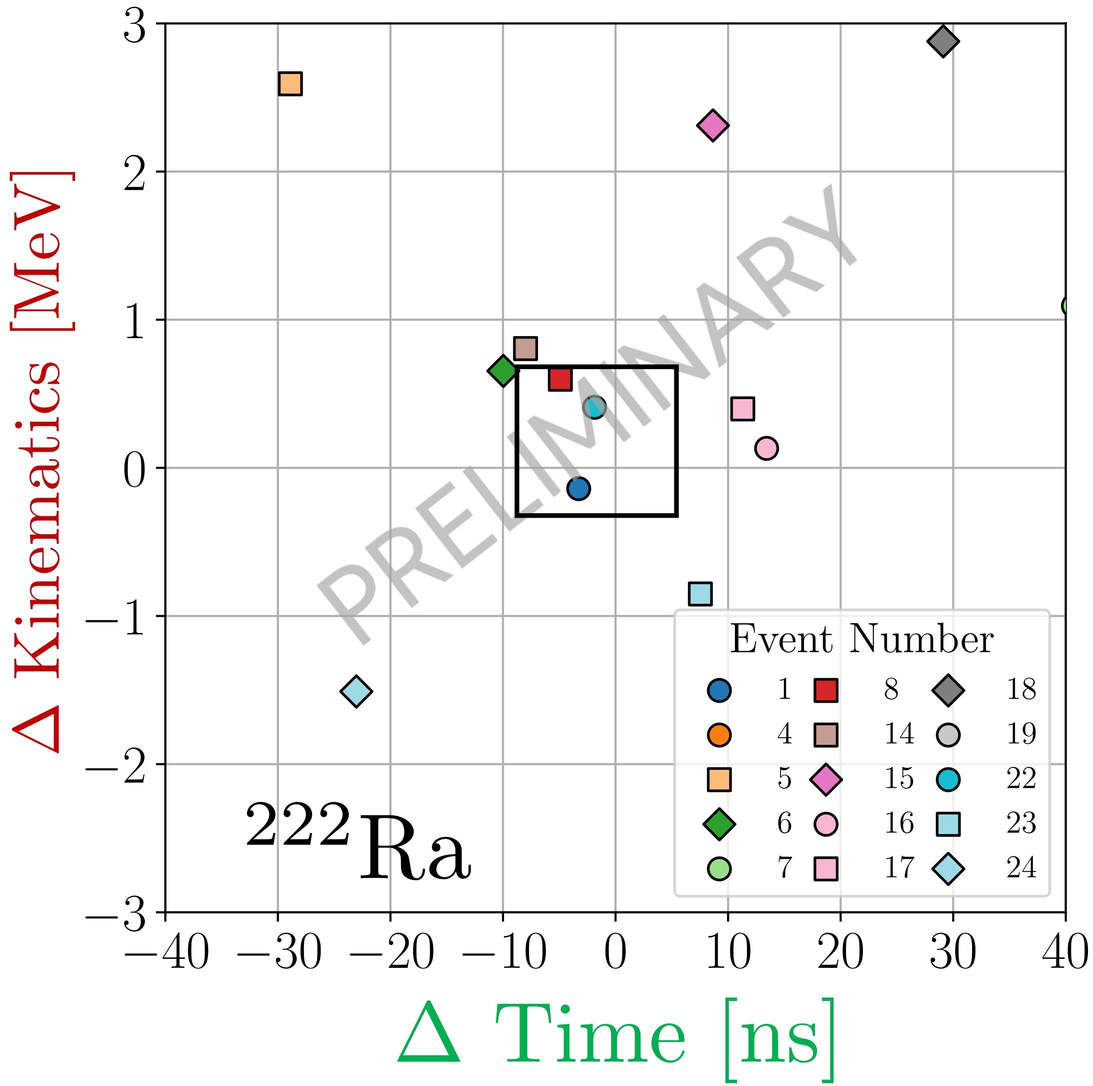
^{222}Ra : 1750 ^{218}Rn : 6400	^{220}Ra : 3 ^{216}Rn : 19
~3 orders of magnitude too large	~1 order of magnitude too large

Need to refine the microscopic theoretical model

Out of random : ^{222}Ra

E_A, E_B « out of random »
Any θ





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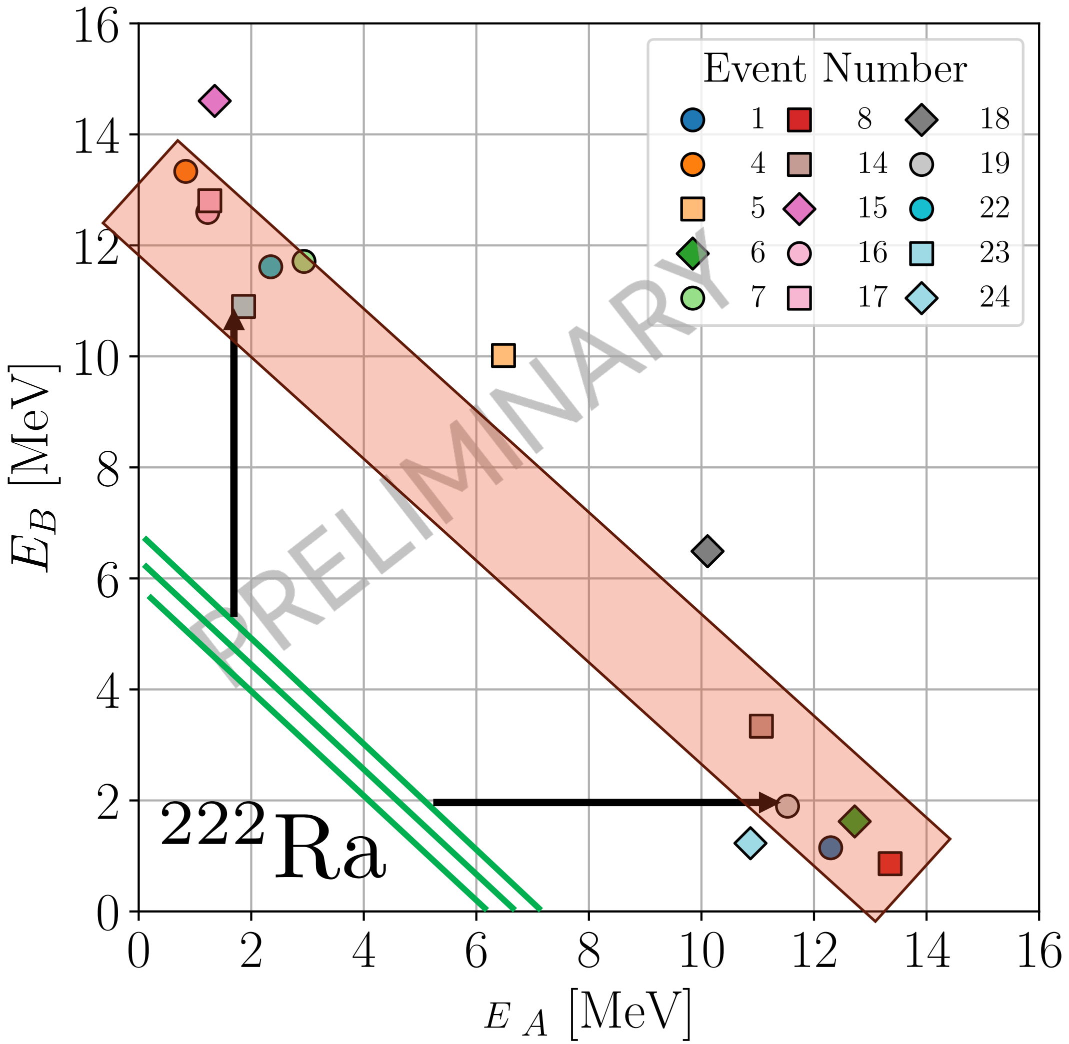
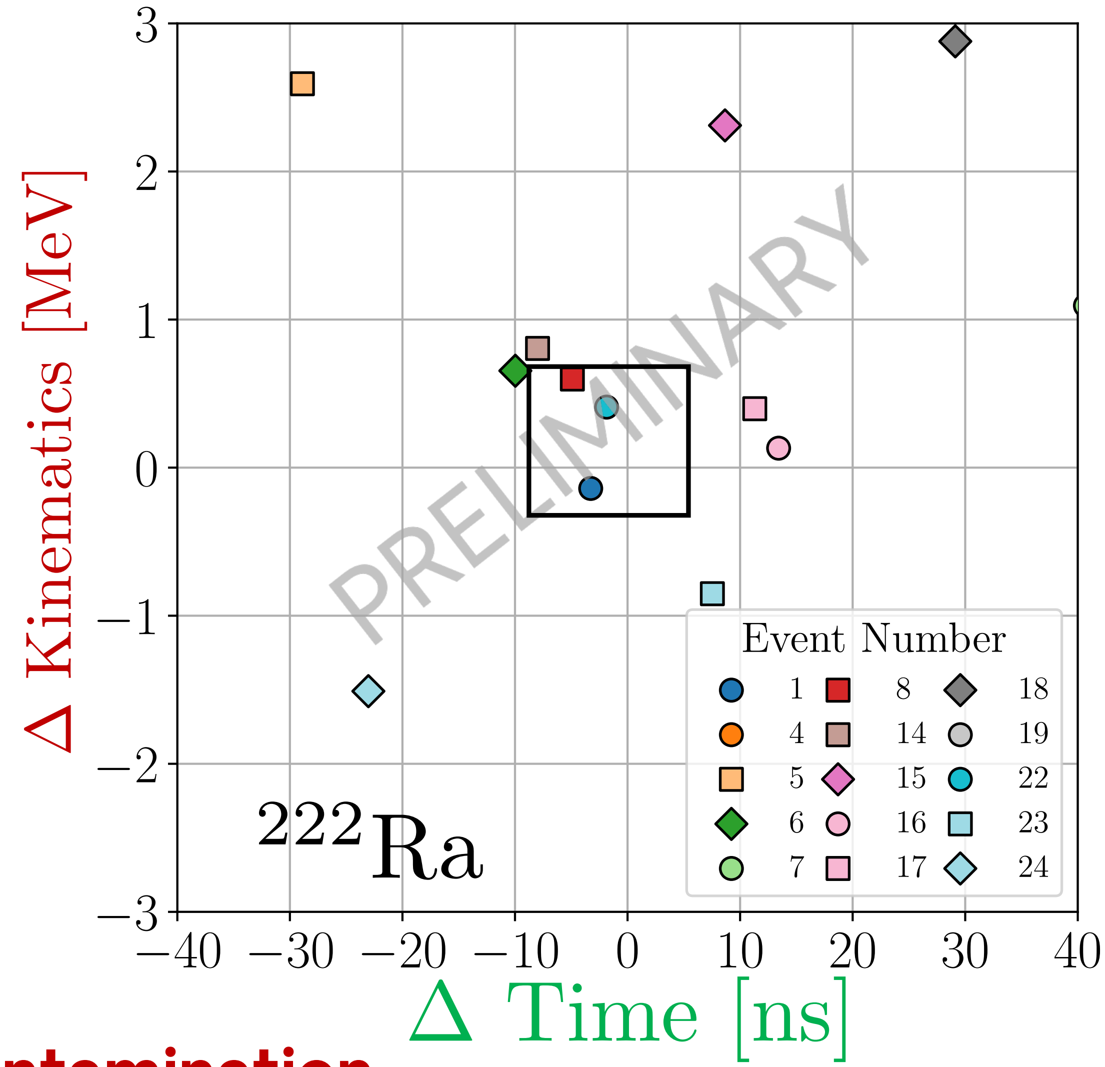




Background contamination

Rutherford BackScattering + single alpha

→ to be studied with even more refined simulation

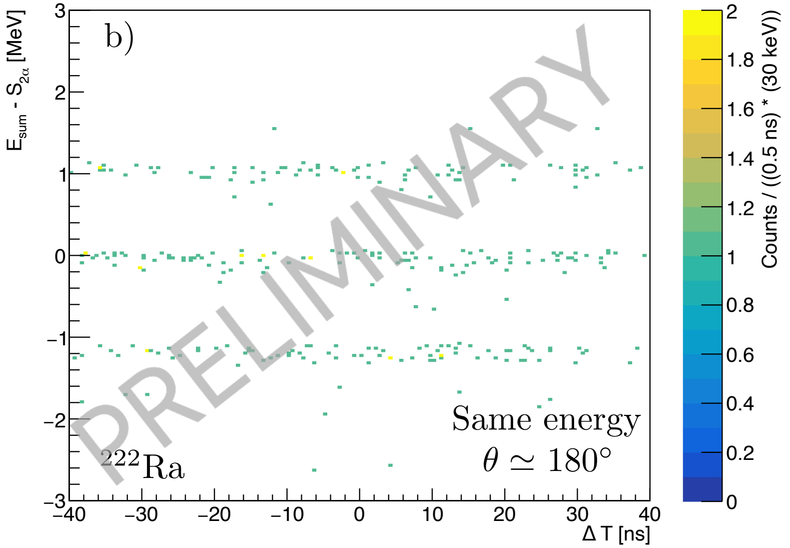
Outlook & conclusion

Successful campaign

Able to (at least) set upper limits on branching ratios

Outlook & conclusion

<u>Symmetric 2α decay</u>
Upper limit :
<u>1-3 orders of magnitude</u>
w.r.t.
microscopic prediction



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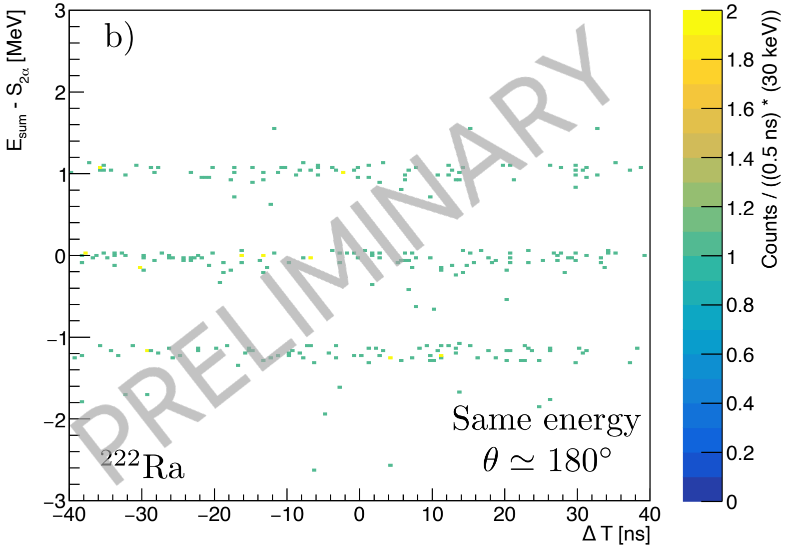
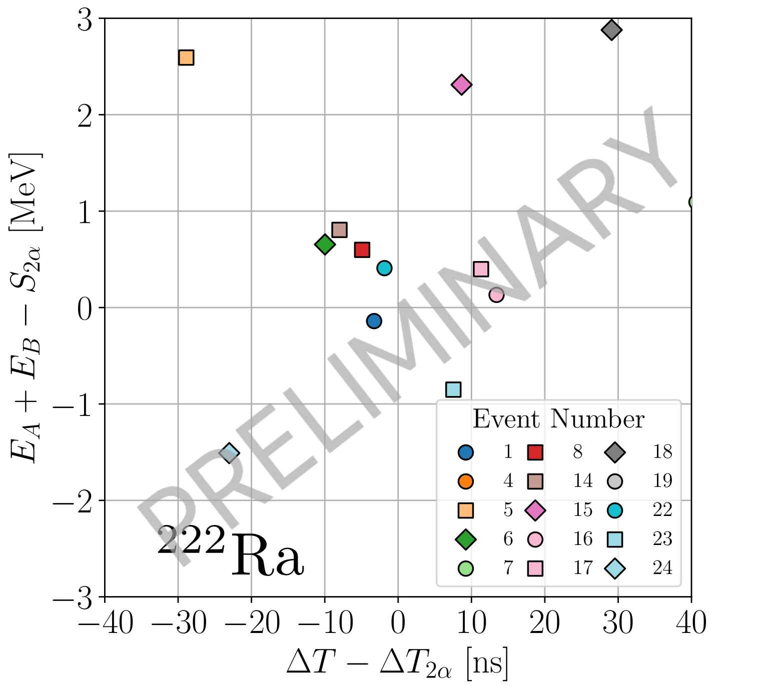


Successful campaign

Able to (at least) set upper limits on branching ratios

Asymmetric 2α decay
Background to be assessed



Outlook & conclusion

Symmetric 2α decay
Upper limit :
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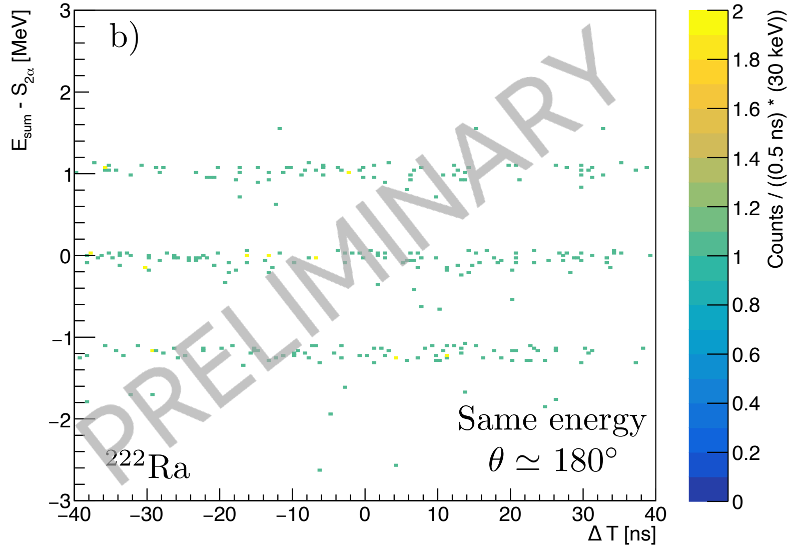

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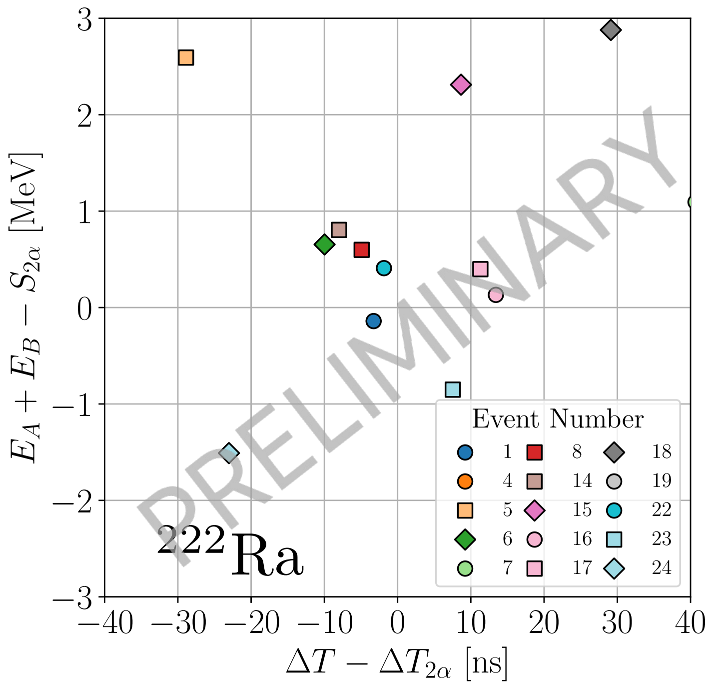


Next steps
Refine microscopic model
Detailed background simulation

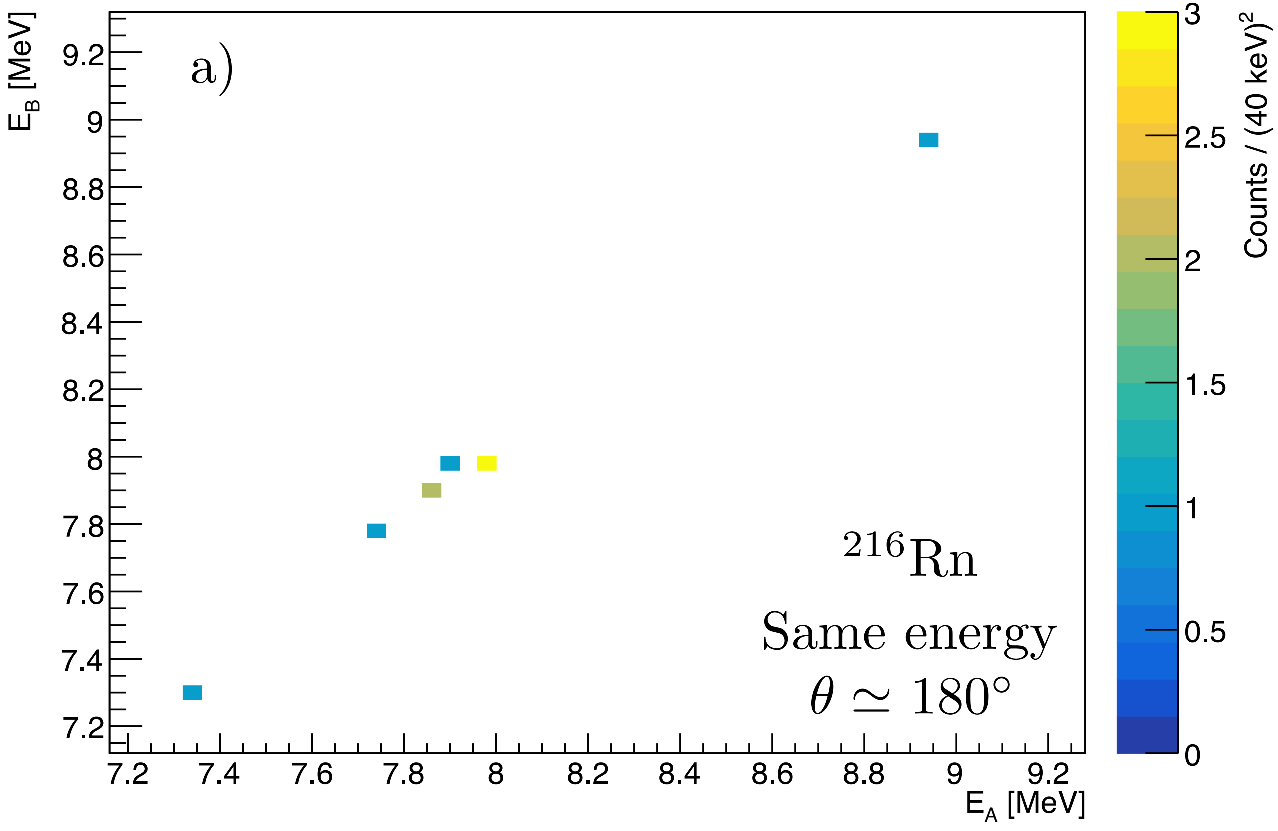
Thank you for your attention !

L. Heitz[1,2], Ch. Theisen[1,†], E. Khan[2], M. Vandebrouck[1], D. Thisse[1], B. Sulignano[1] ,T. Chaminade[1], V. Alcindor[2], M.Assié[2], B. Blank[3], D. Beaumel[2], J. Bequet[1], Y. Blumenfeld[2], D. Cotte[1,(4)], T.Davinson[5], D. Desforges[1], T. Dickel[6], J.-P. Ebran[7], J.Giovinazzo[3], C.Houarner[8], K. Johnston[4], M. Kowalska[4], U. Köster[9], I. Moore[10], V.Morel[8], L. Nies[6], A. Ortega-Moral[3], I. Pohjalainen[10],P.M. Reiter[5], T. Roger[8], F.Saillant[8], M. Simonov[6], L. Thulliez[1], G. Toccabens[1], H. Wilsenach[6]

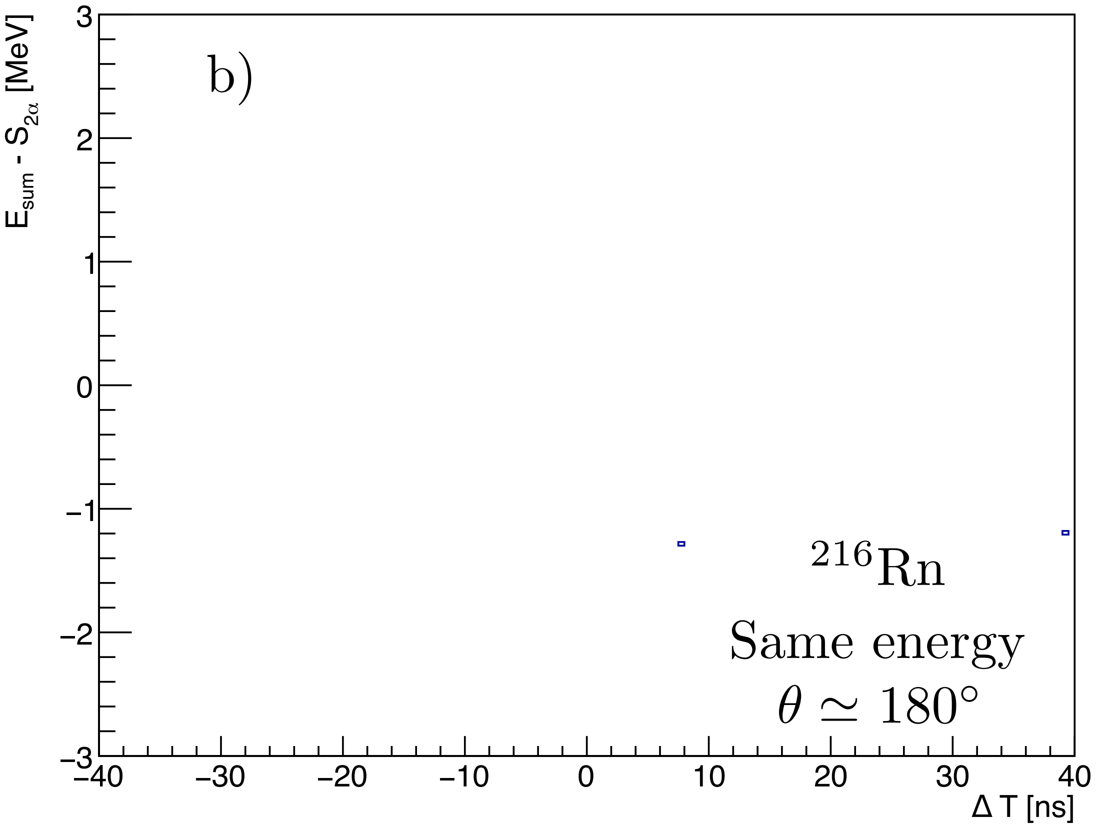
[1]Irfu, [2]IJCLAB, [3]Bordeaux, [4]CERN, [5]Edinburgh, [6]GSI, [7]CEA DAM, [8]Ganil, [9]ILL, [10]Jyväskylä,

This project has received funding from the European Union’s Horizon Europe Research and Innovation programme under Grant Agreement N°101057511

BACK-UP

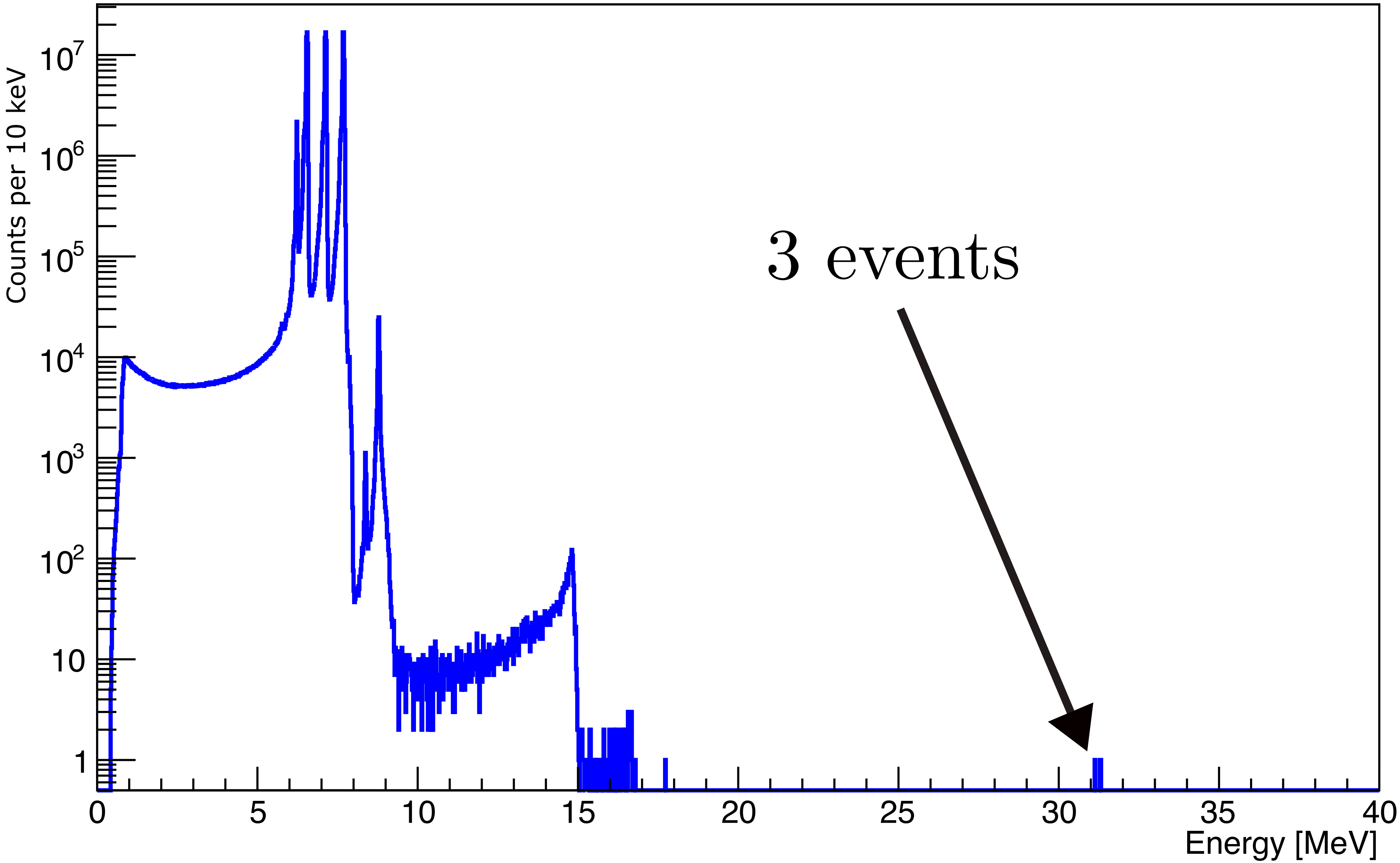


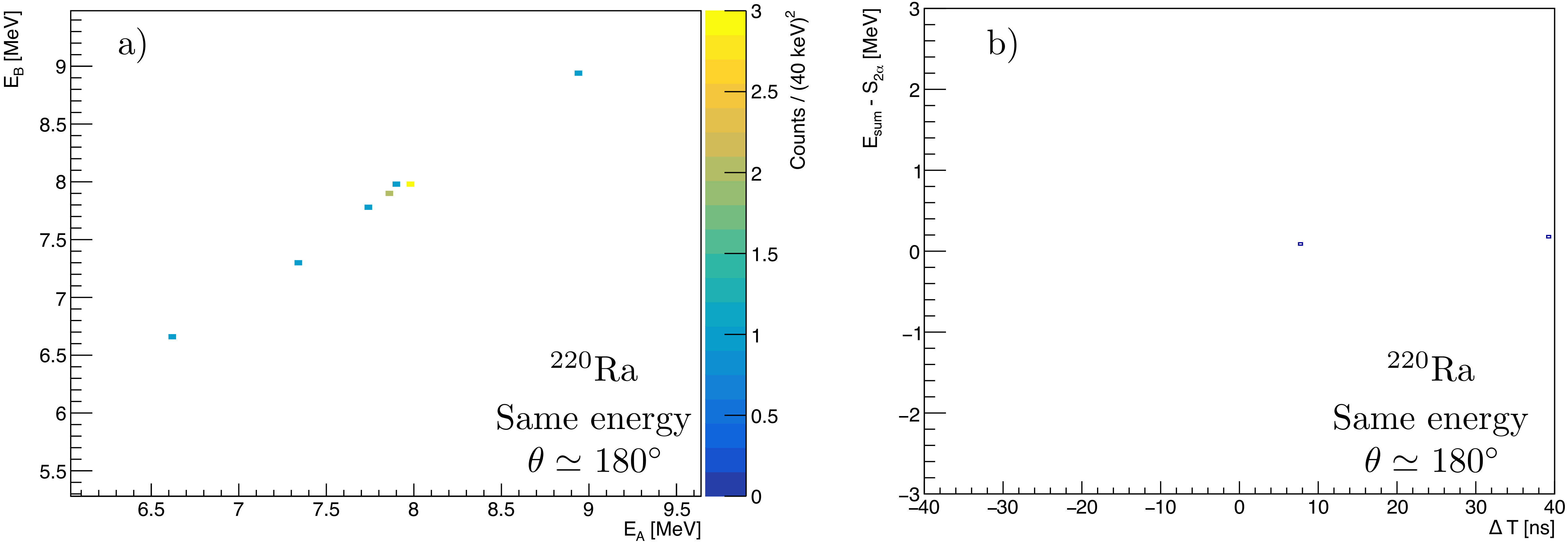
a)
E_B [MeV]
9.2
9
8.8
8.6
8.4
8.2
8
7.8
7.6
7.4
7.2
7.2 7.4 7.6 7.8 8 8.2 8.4 8.6 8.8 9 9.2
E_A [MeV]
^{216}Rn
Same energy
$\theta \simeq 180°$
Counts / (40 keV)^2
0 0.5 1 1.5 2 2.5 3



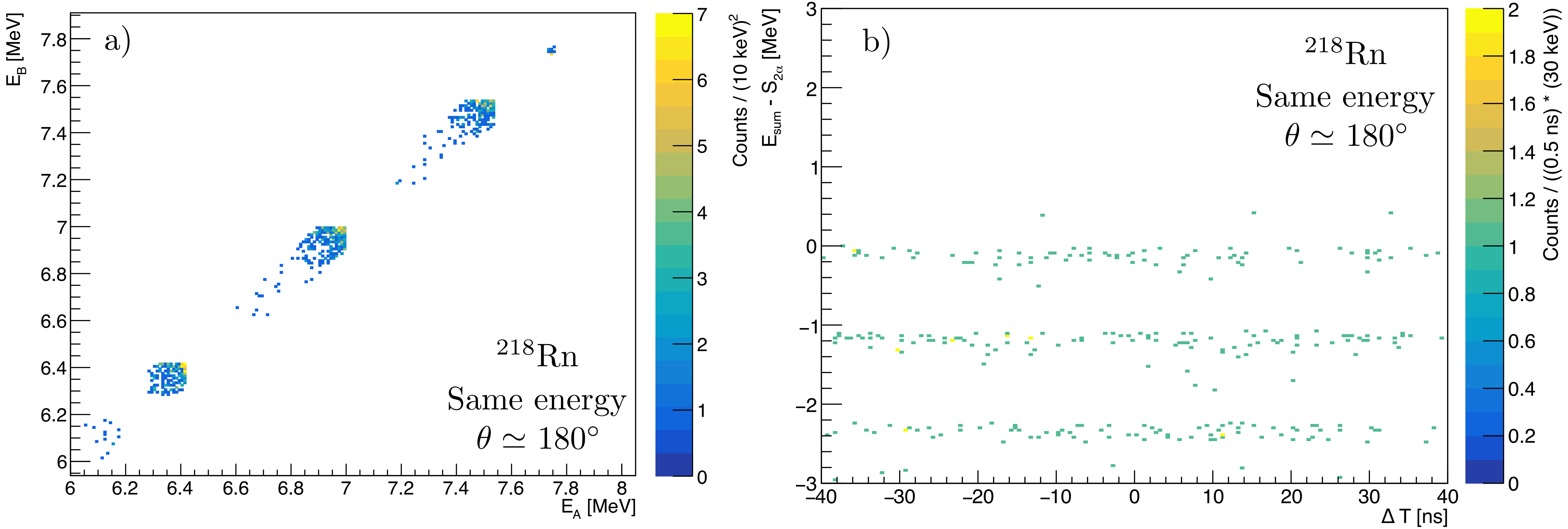
b)
E_{sum} - $S_{2\alpha}$ [MeV]
3 2 1 0 −1 −2 −3
−40 −30 −20 −10 0 10 20 30 40
Δ T [ns]
^{216}Rn
Same energy
$\theta \simeq 180°$

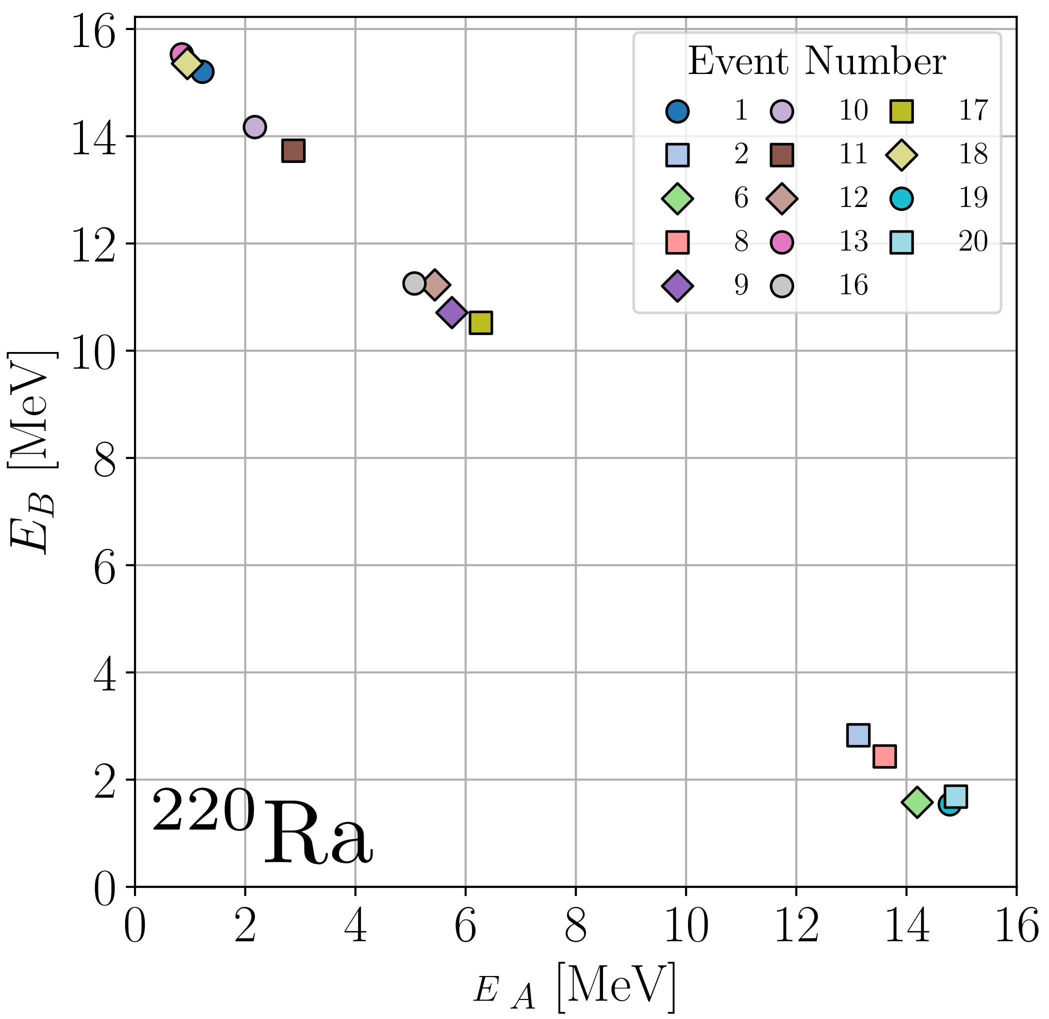
^{14}C decay of ^{222}Ra



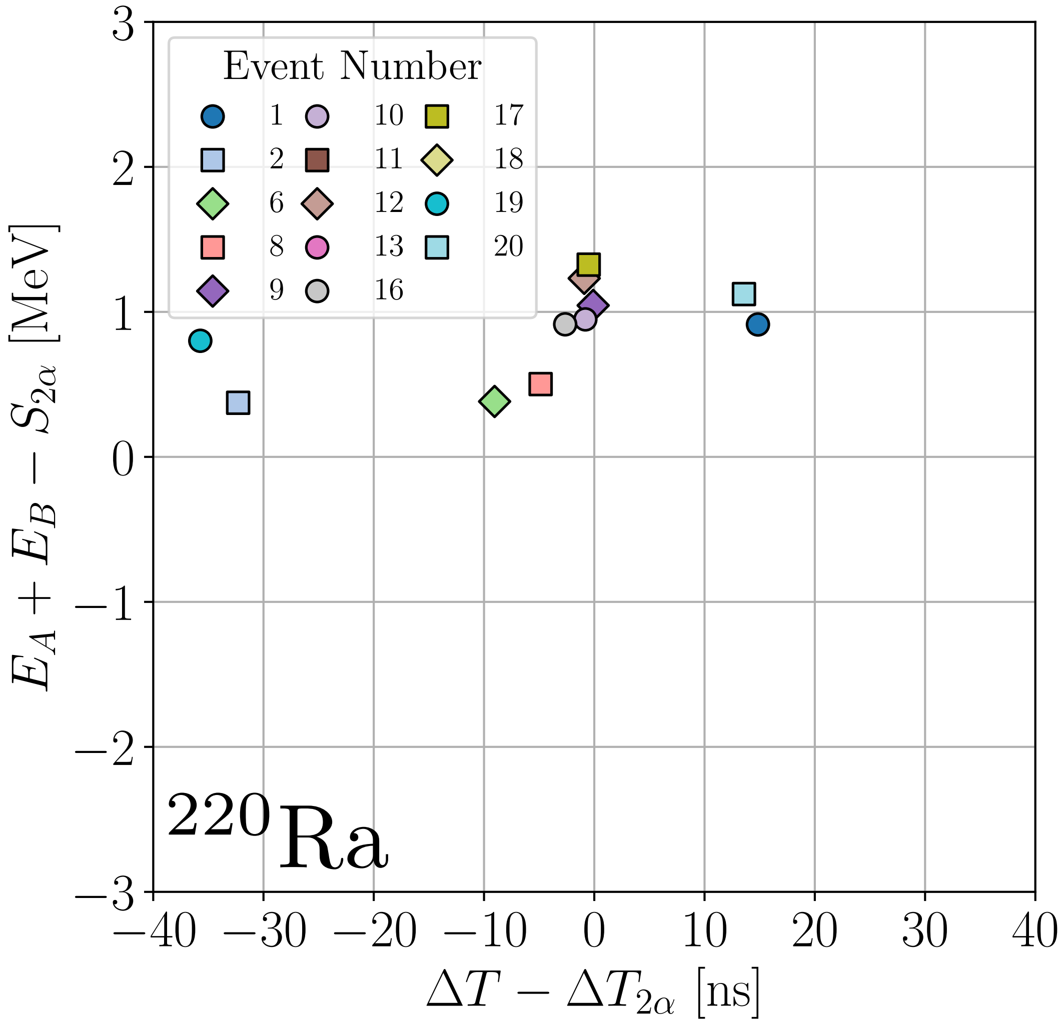


a)
b)
E_B [MeV]
E_A [MeV]
Counts / (40 keV)^2
E_{sum} - $S_{2\alpha}$ [MeV]
ΔT [ns]
^{220}Ra
Same energy
$\theta \simeq 180°$


a)
^{218}Rn
Same energy
$\theta \simeq 180°$
E_B [MeV]
E_A [MeV]
Counts / (10 keV)^2
b)
^{218}Rn
Same energy
$\theta \simeq 180°$
E_{sum} - $S_{2\alpha}$ [MeV]
Δ T [ns]
Counts / ((0.5 ns) * (30 keV))



Event Number
1
2
6
8
9
10
11
12
13
16
17
18
19
20
^{220}Ra
E_B [MeV]
E_A [MeV]



Event Number
1
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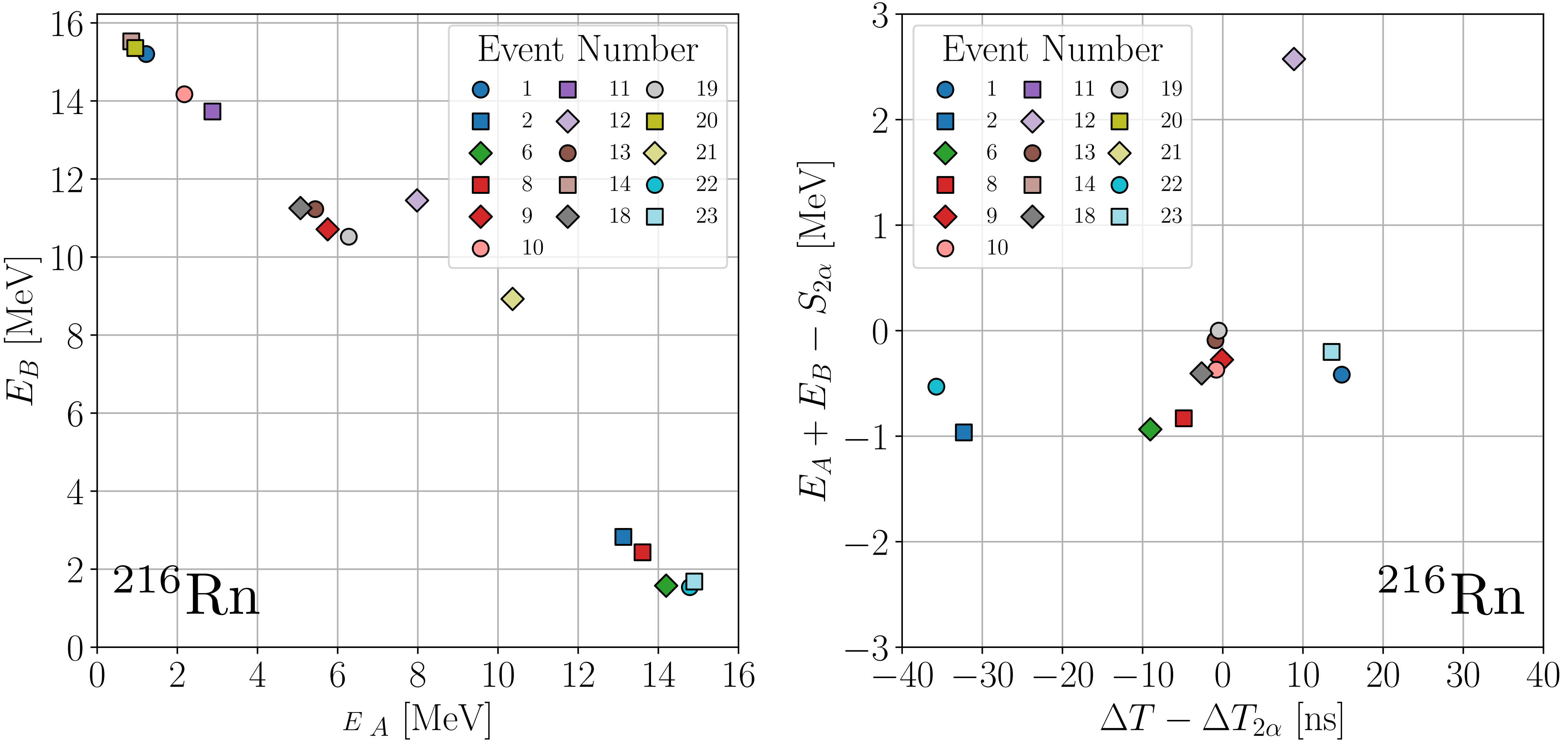
19
20
^{220}Ra
$E_A + E_B - S_{2\alpha}$ [MeV]
$\Delta T - \Delta T_{2\alpha}$ [ns]



Event Number
1
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6
8
9
10
11
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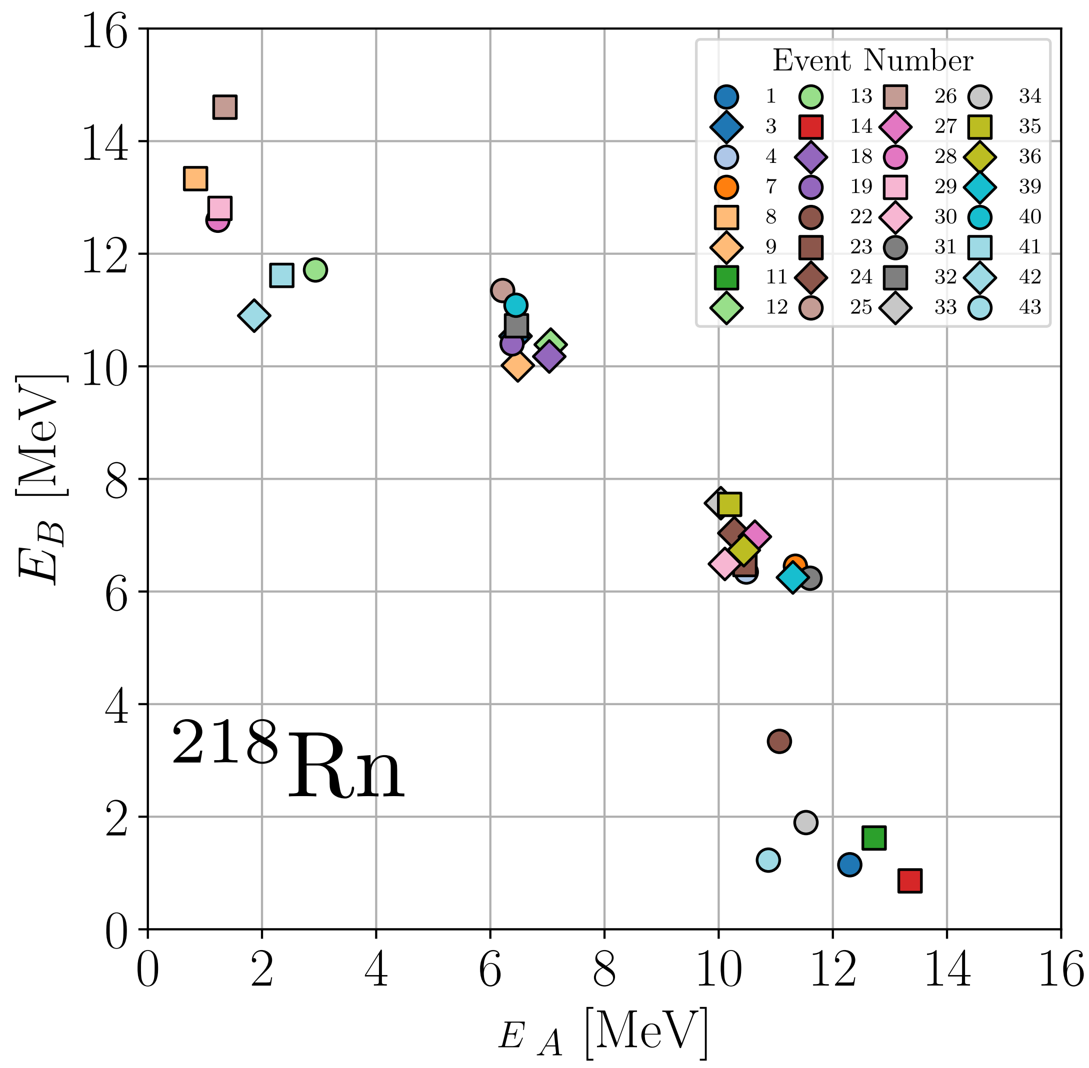
23
^{216}Rn
E_B [MeV]
E_A [MeV]
$E_A + E_B - S_{2\alpha}$ [MeV]
$\Delta T - \Delta T_{2\alpha}$ [ns]



Event Number
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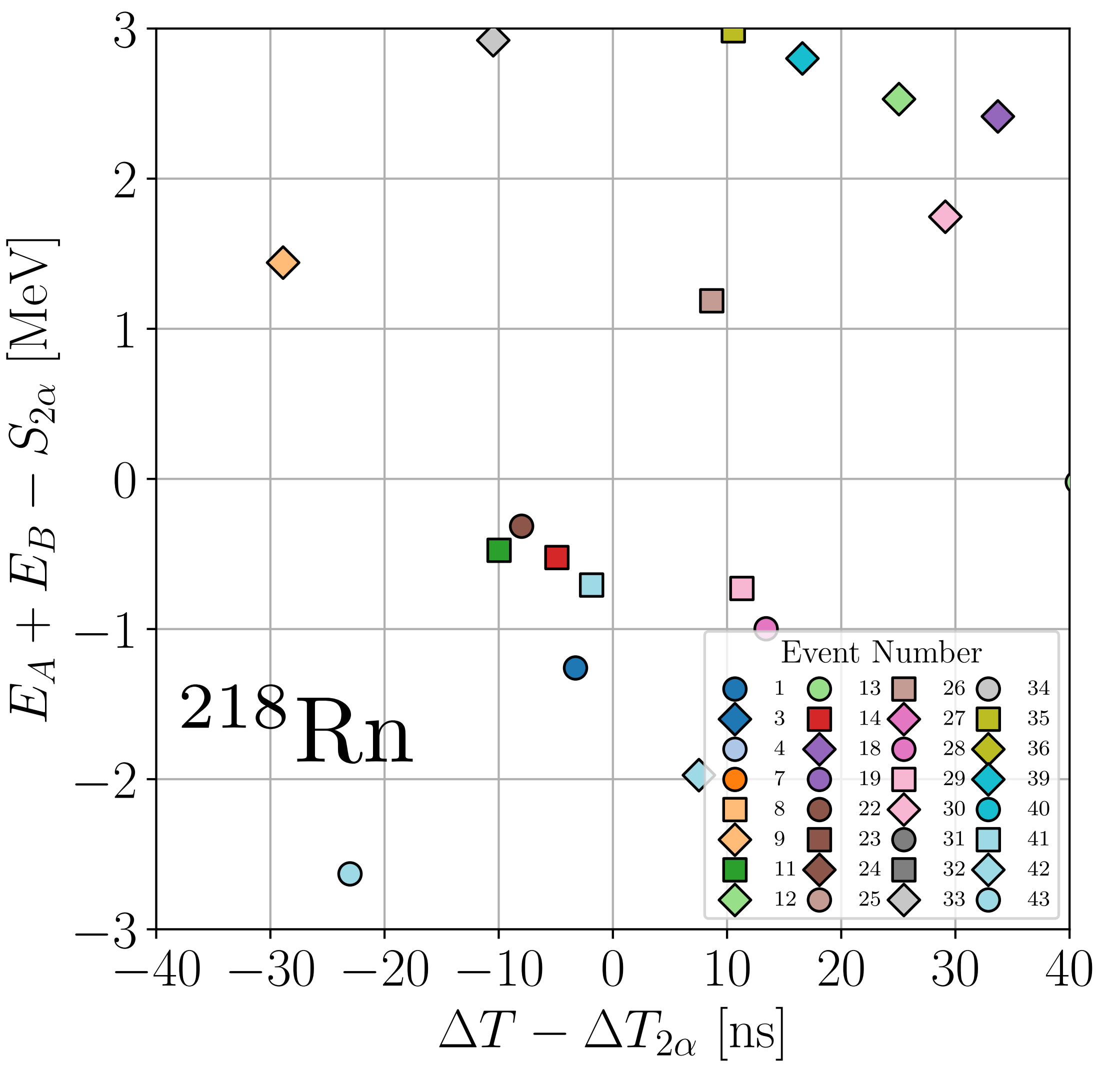
40
41
42
43
^{218}Rn
E_B [MeV]
E_A [MeV]



Event Number
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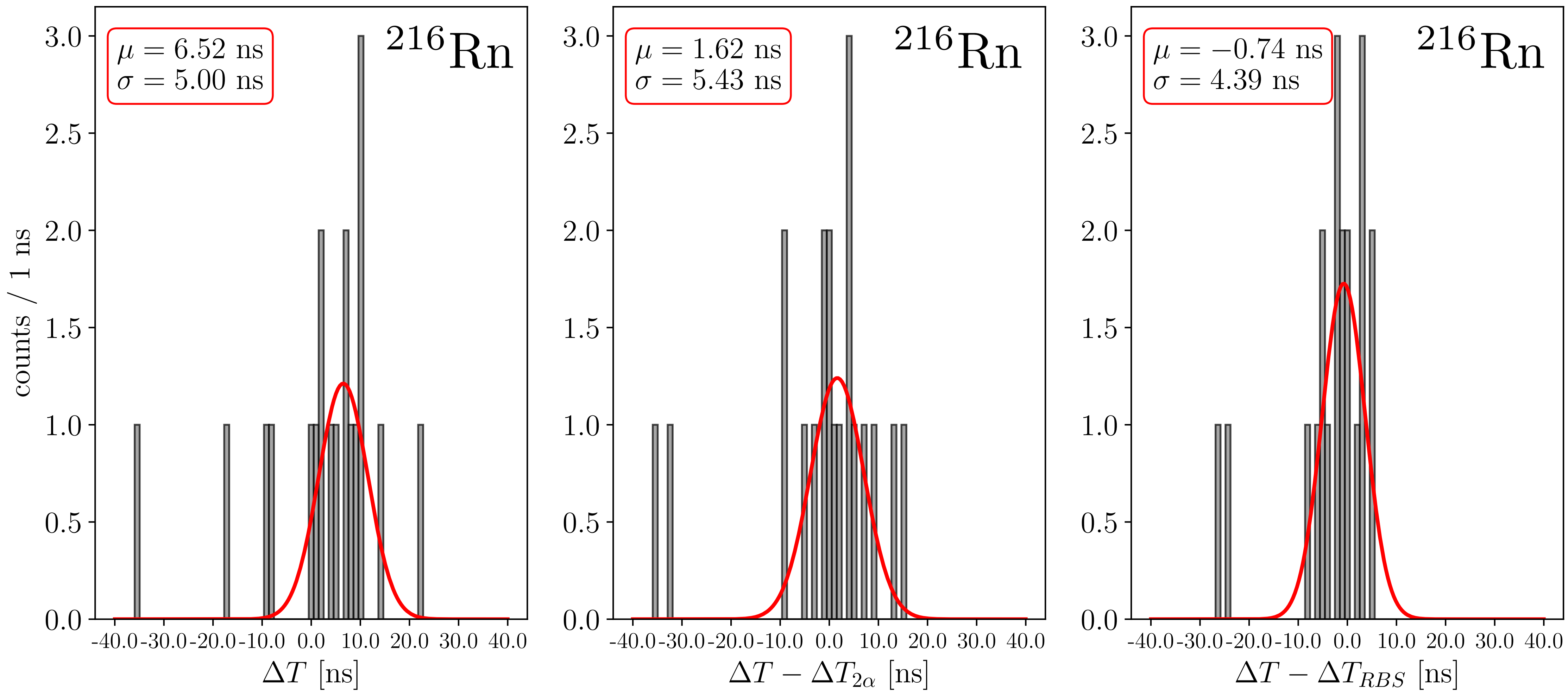
34
35
36
39
40
41
42
43
^{218}Rn
$E_A + E_B - S_{2\alpha}$ [MeV]
$\Delta T - \Delta T_{2\alpha}$ [ns]


$\mu = 6.52$ ns
$\sigma = 5.00$ ns
^{216}Rn
counts / 1 ns
ΔT [ns]
$\mu = 1.62$ ns
$\sigma = 5.43$ ns
^{216}Rn
$\Delta T - \Delta T_{2\alpha}$ [ns]
$\mu = -0.74$ ns
$\sigma = 4.39$ ns
^{216}Rn
$\Delta T - \Delta T_{RBS}$ [ns]