Search for double alpha decay

PHENIICS FEST 2024

Louis Heitz
Double alpha @CERN collaboration

17.05.2024

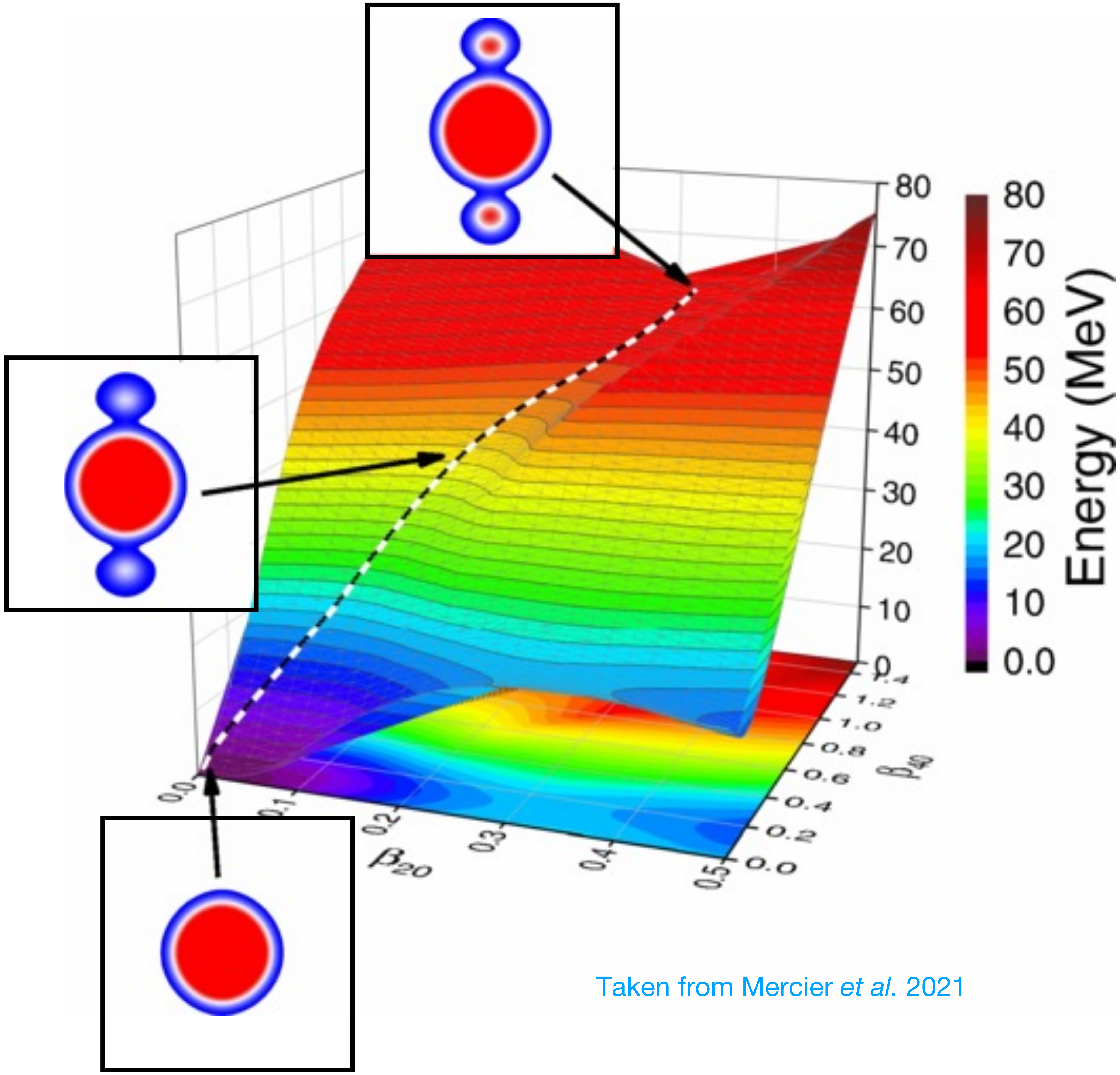
Me trying to be serious

PHENIICS FEST
Friday, 5pm

Enfant sage en cour de récréation
Paris, 1954
Robert DOISNEAU

Outline

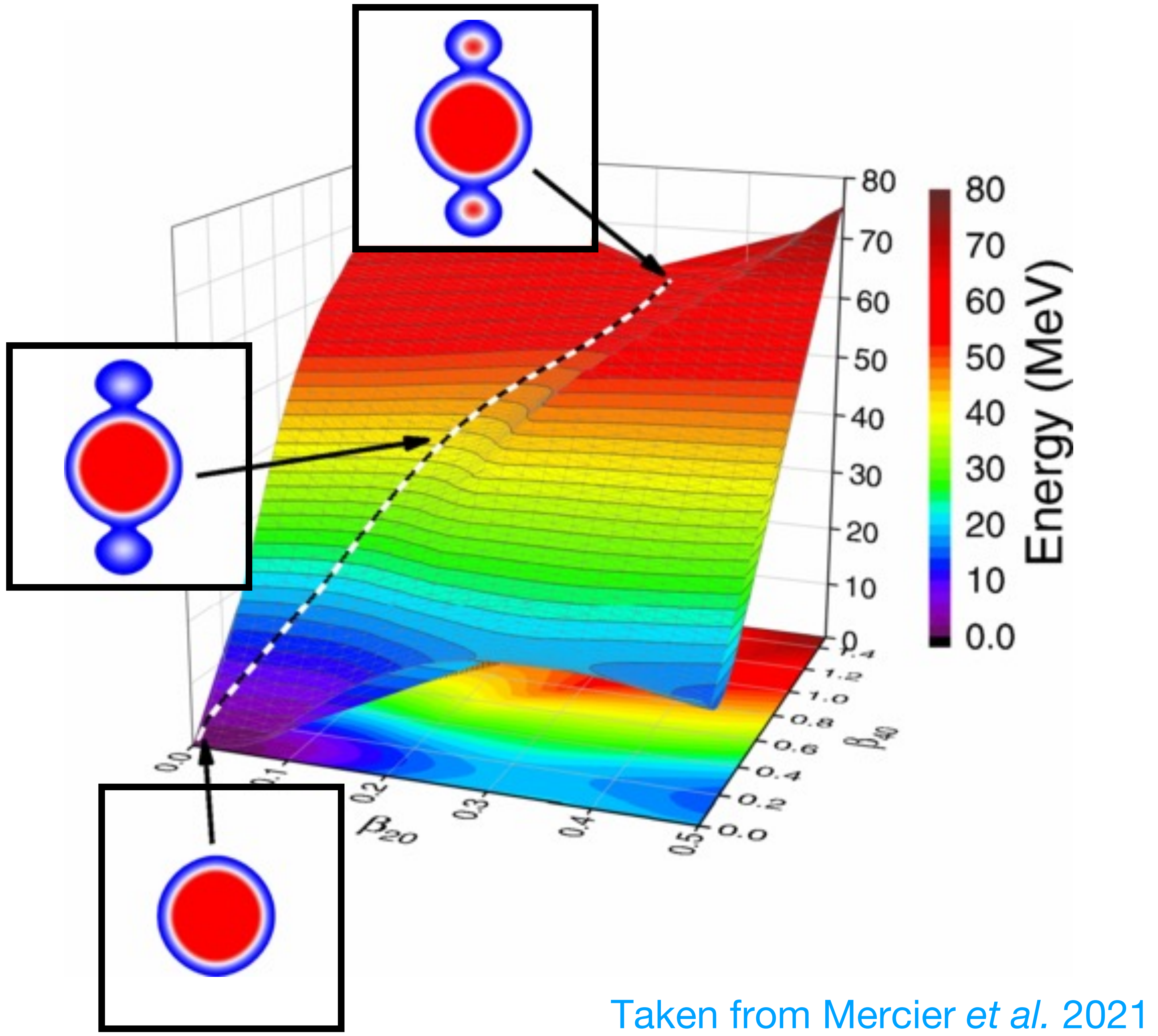
- Theoretical trigger
- Experimental search for 2α @Isolde



Taken from Mercier *et al.* 2021

Theoretical Trigger

Microscopic description of radioactivity



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2021

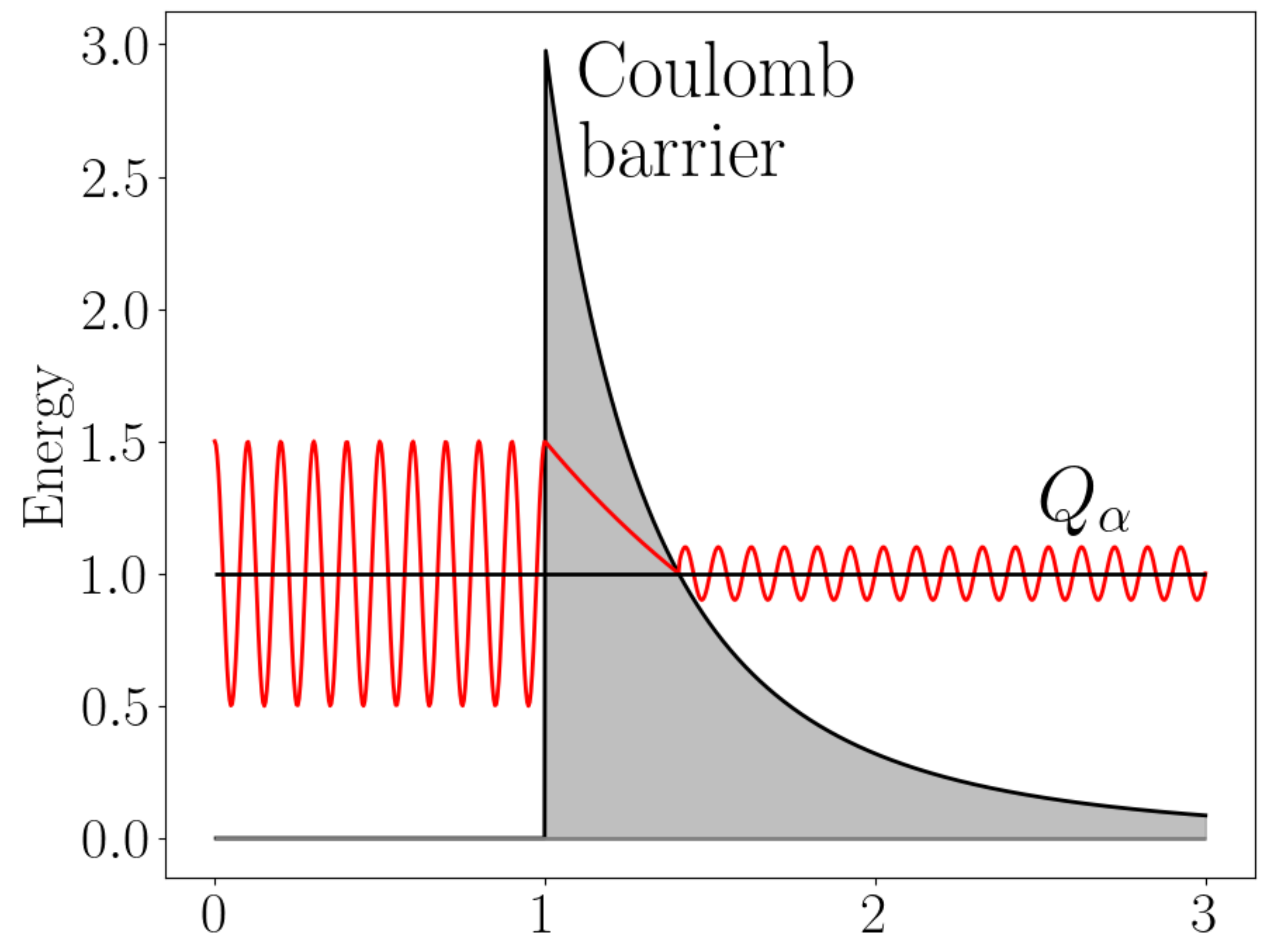
Theoretical trigger

Alpha & double alpha radioactivities

Theoretical trigger

Alpha & double alpha radioactivities

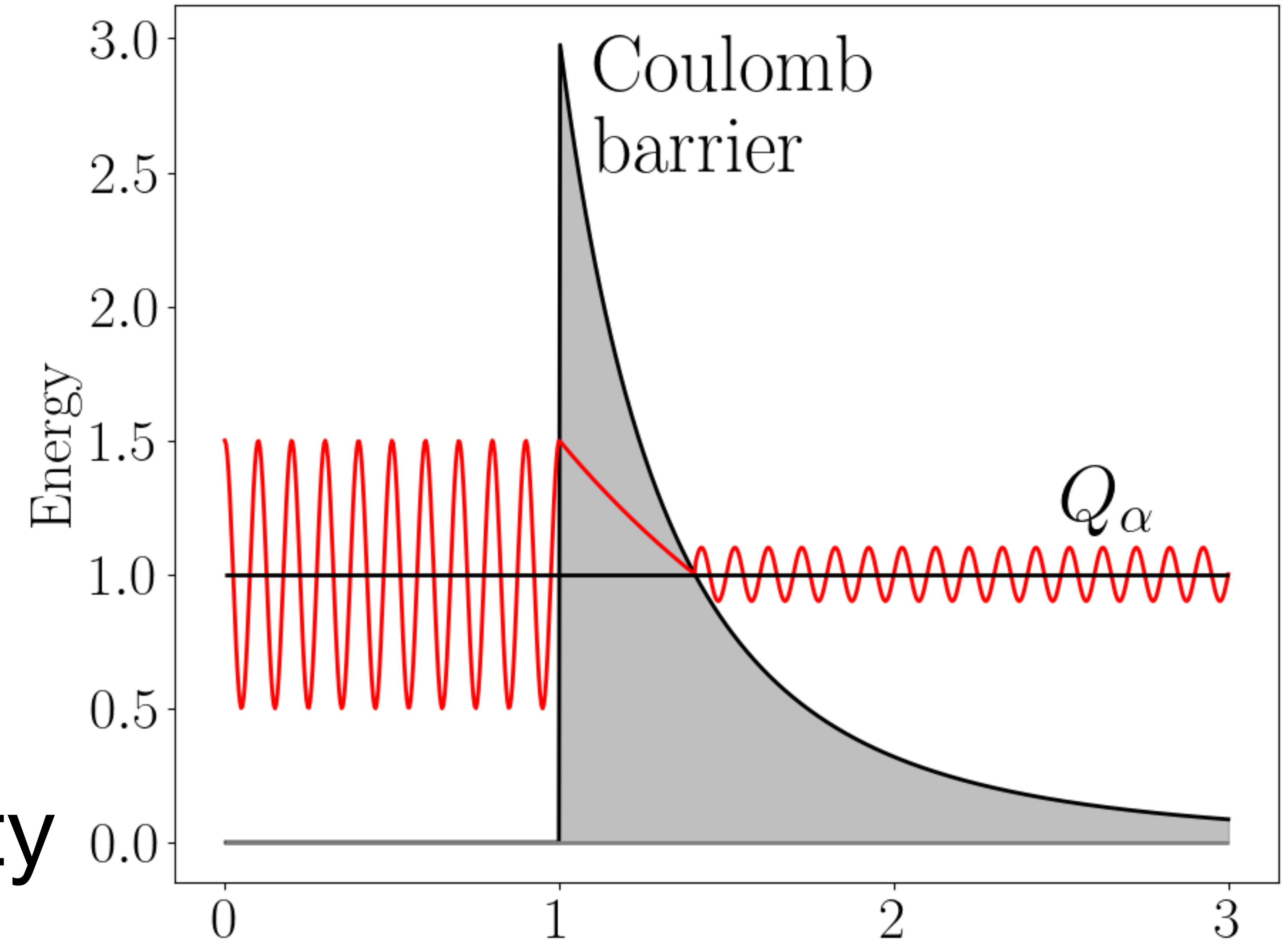
- **First model** for α decay : Gamow 1928 (tunneling)



Theoretical trigger

Alpha & double alpha radioactivities

- **First model** for α decay : Gamow 1928 (tunneling)
- **Phenomenological** models for alpha/cluster radioactivity



Theoretical trigger

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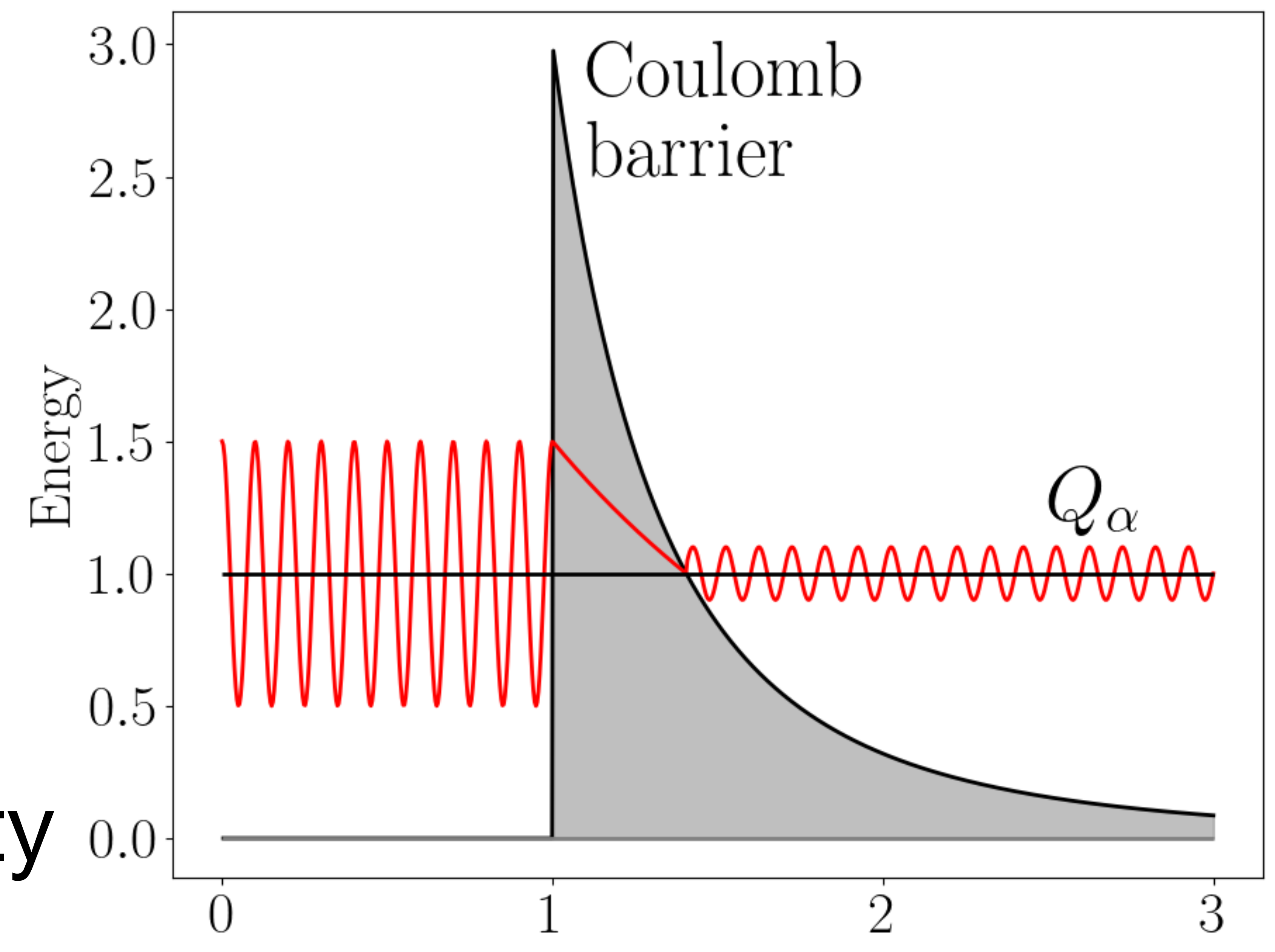

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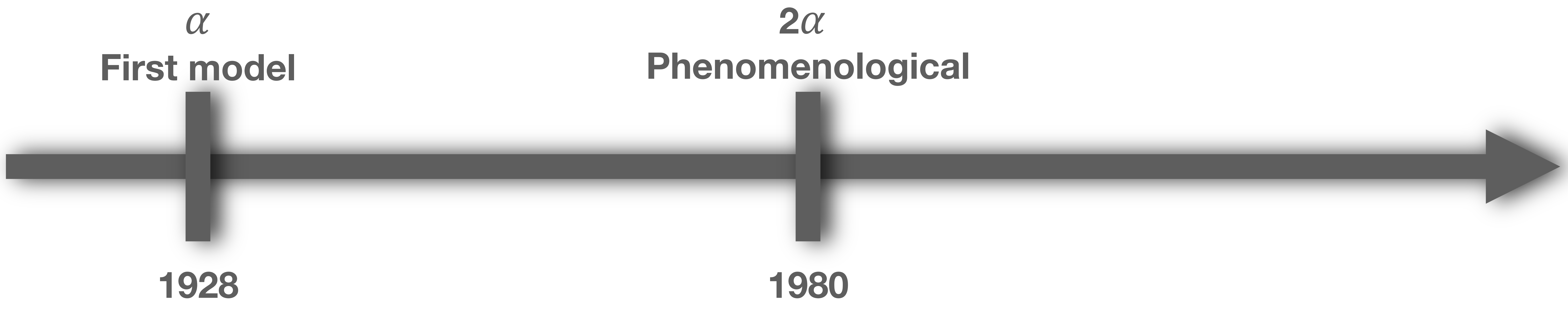

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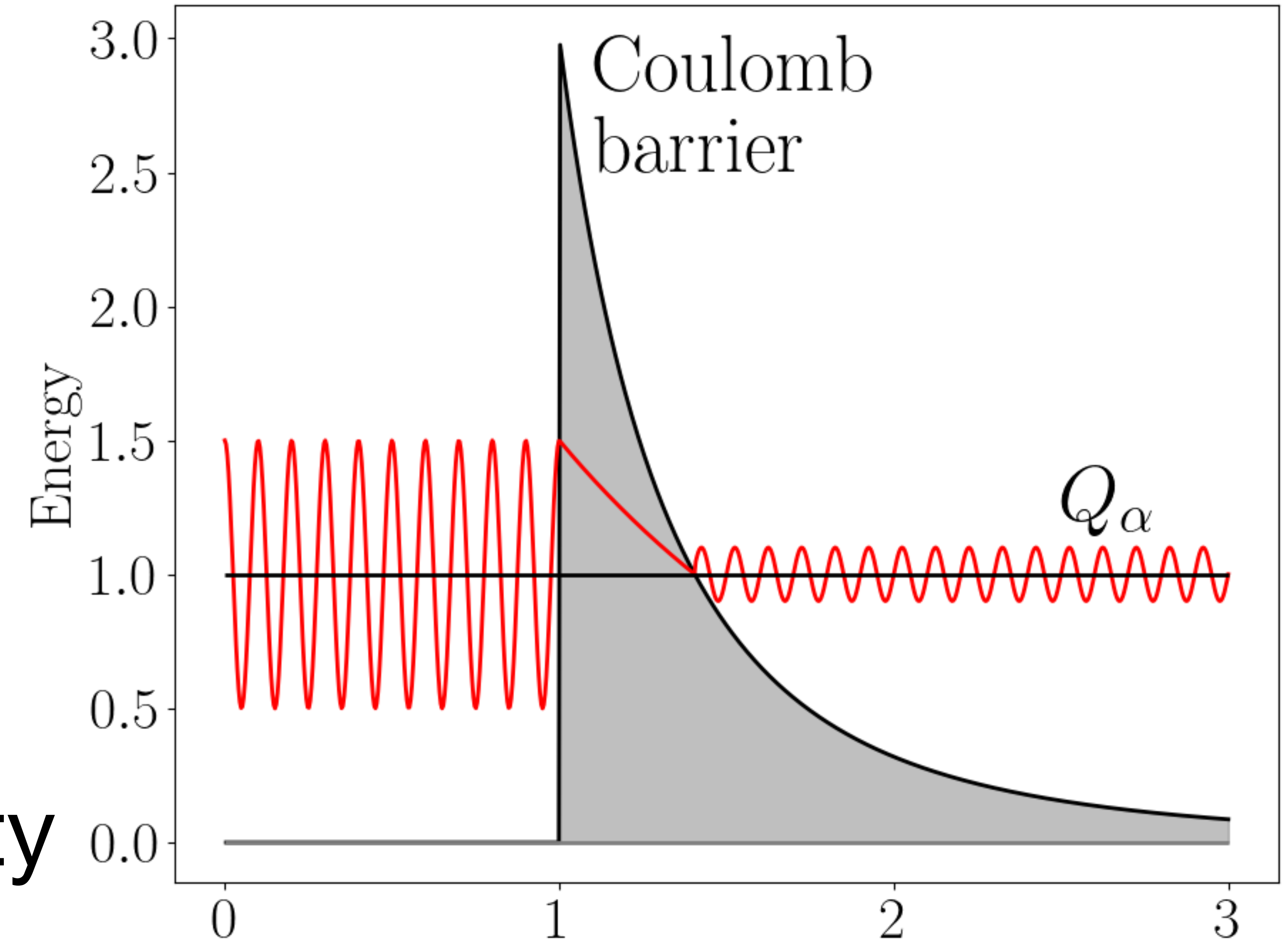

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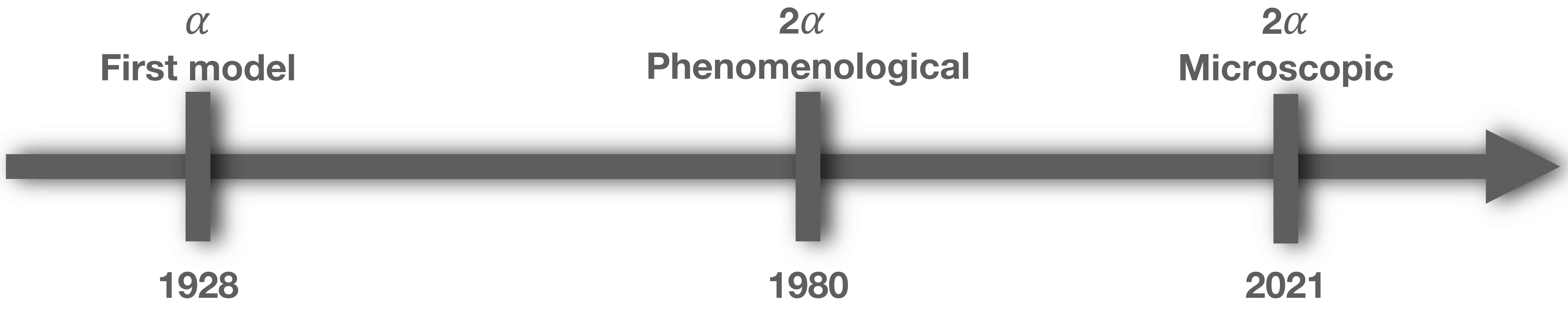

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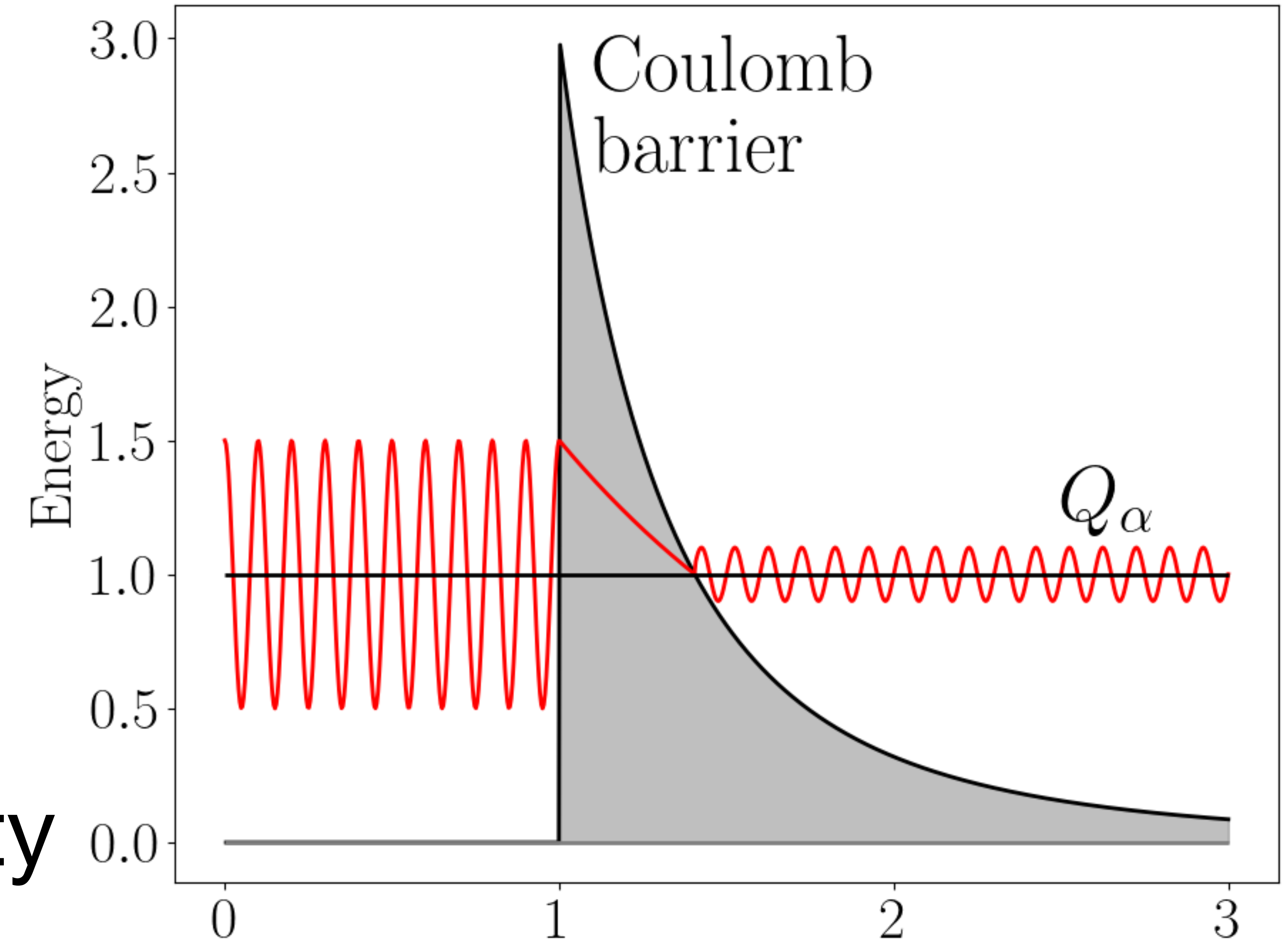

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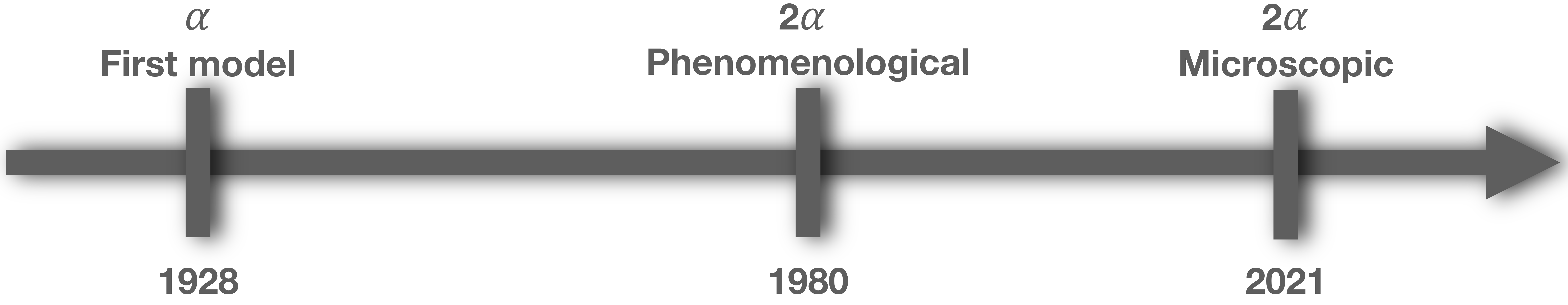

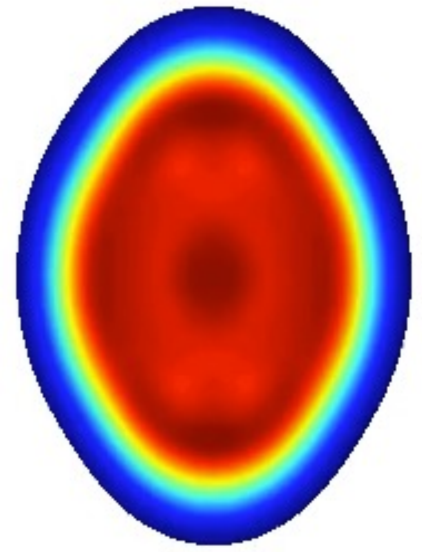

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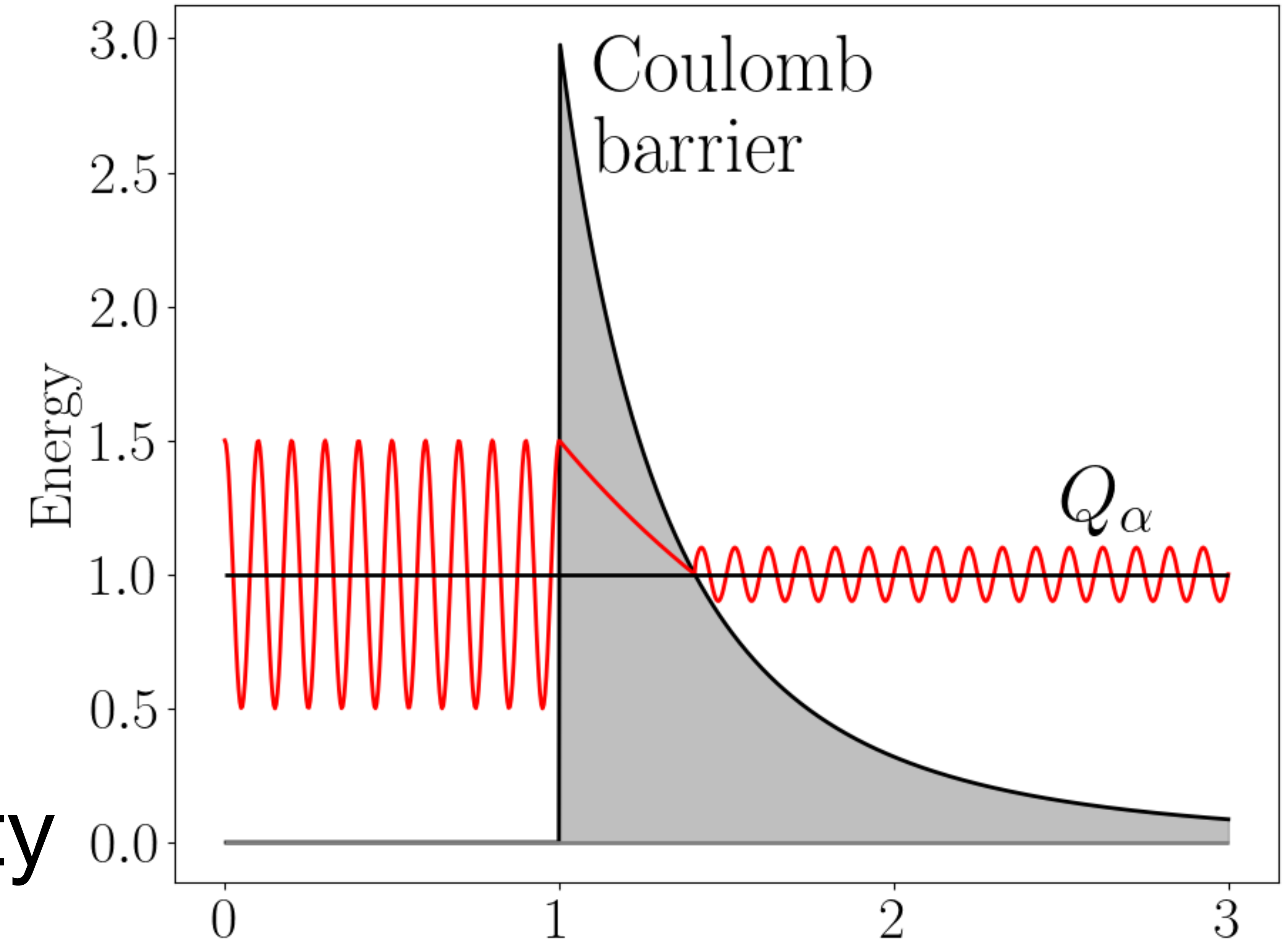

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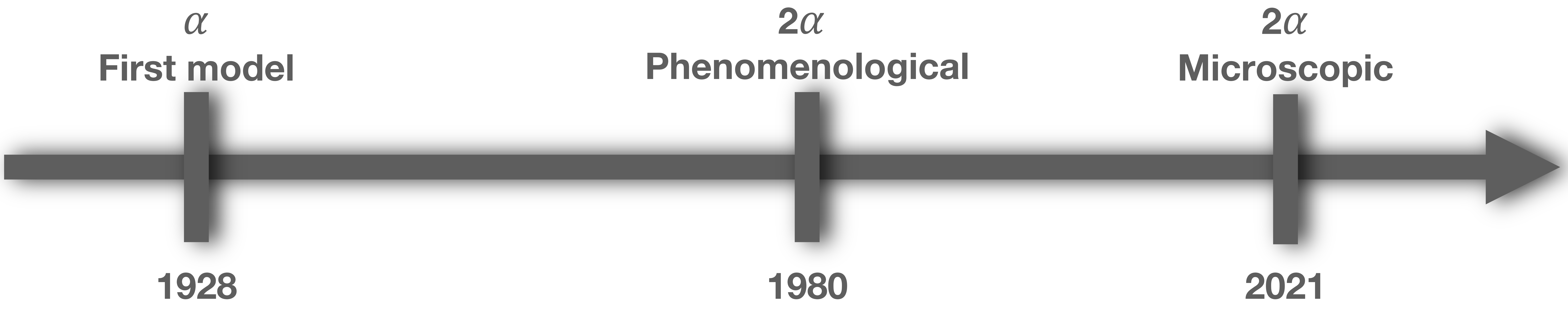

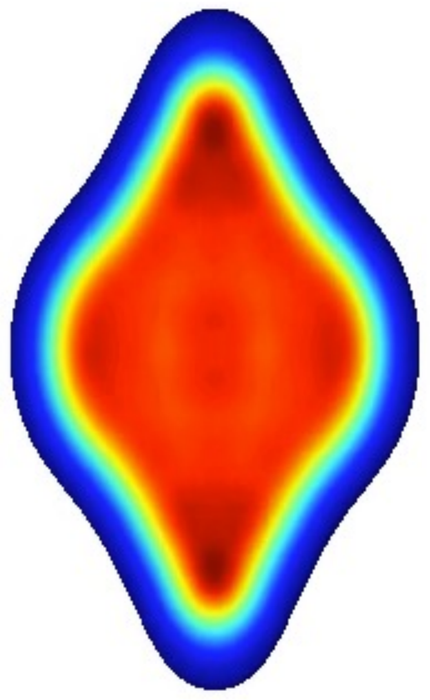

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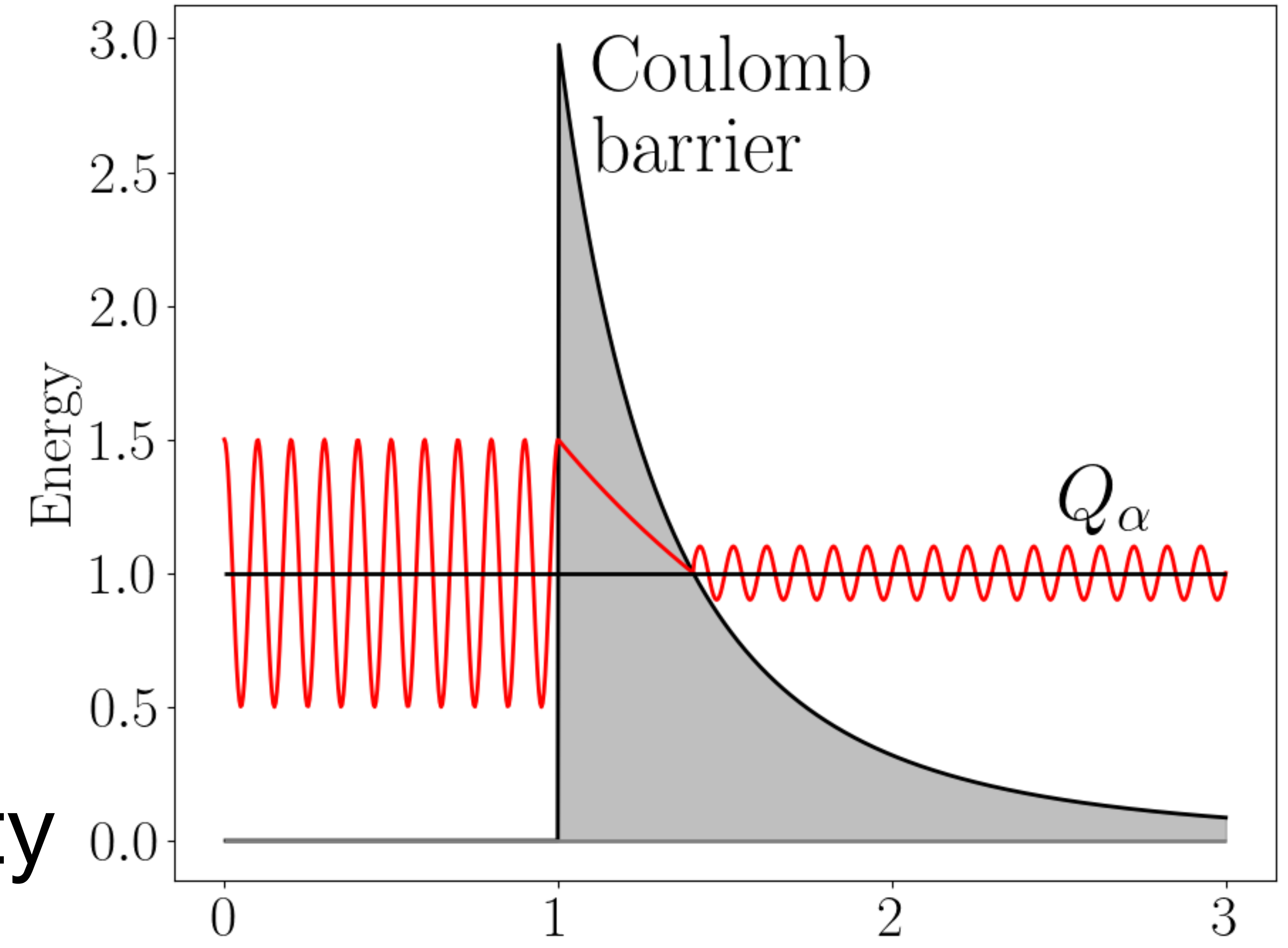

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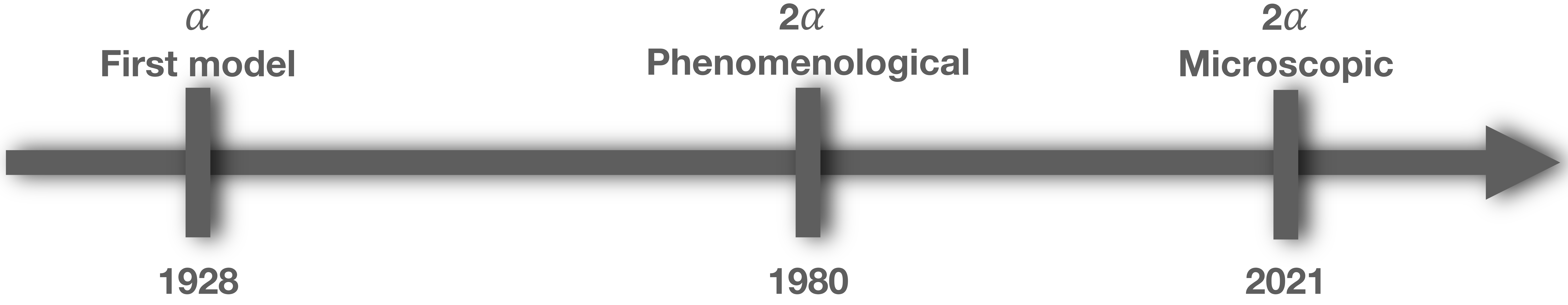
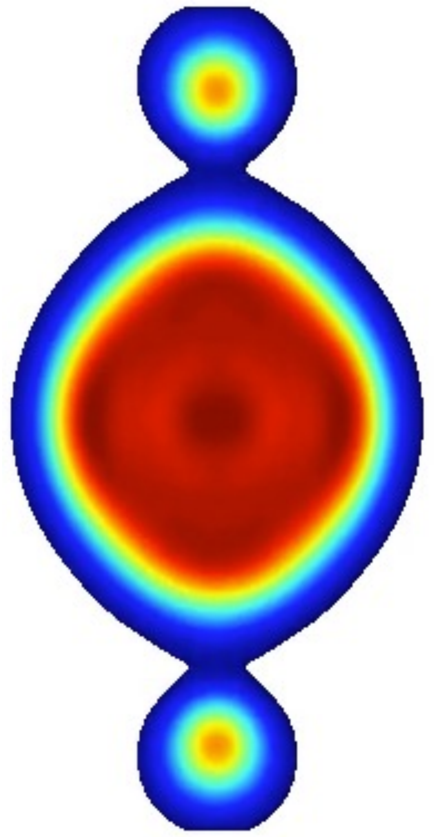
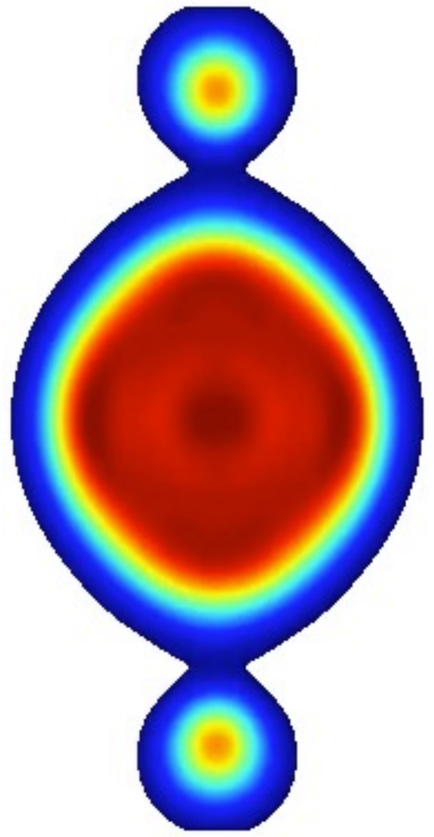




Theoretical trigger

$$\mathrm{BR} \sim \frac{\tau_{2\alpha}}{\tau_\alpha} \sim \frac{N_{2\alpha}}{N_\alpha} \sim 10^{-7}$$

Double alpha candidates



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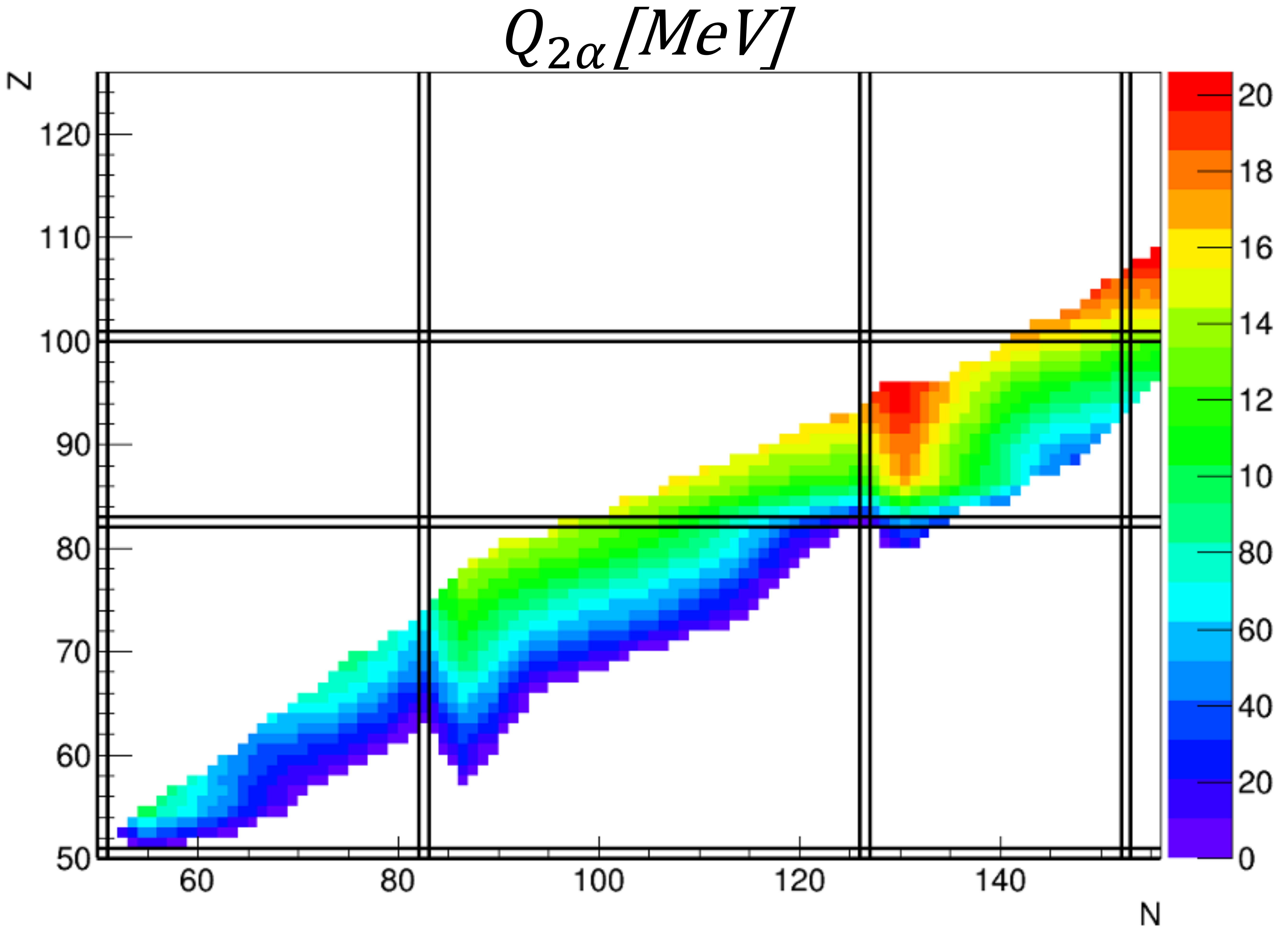

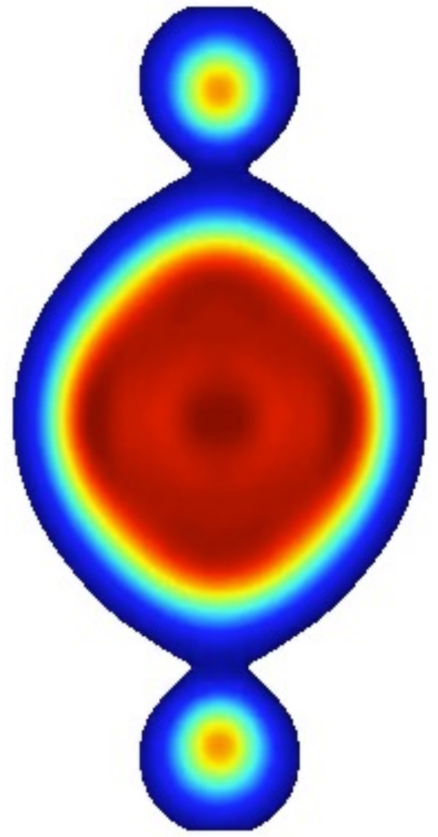

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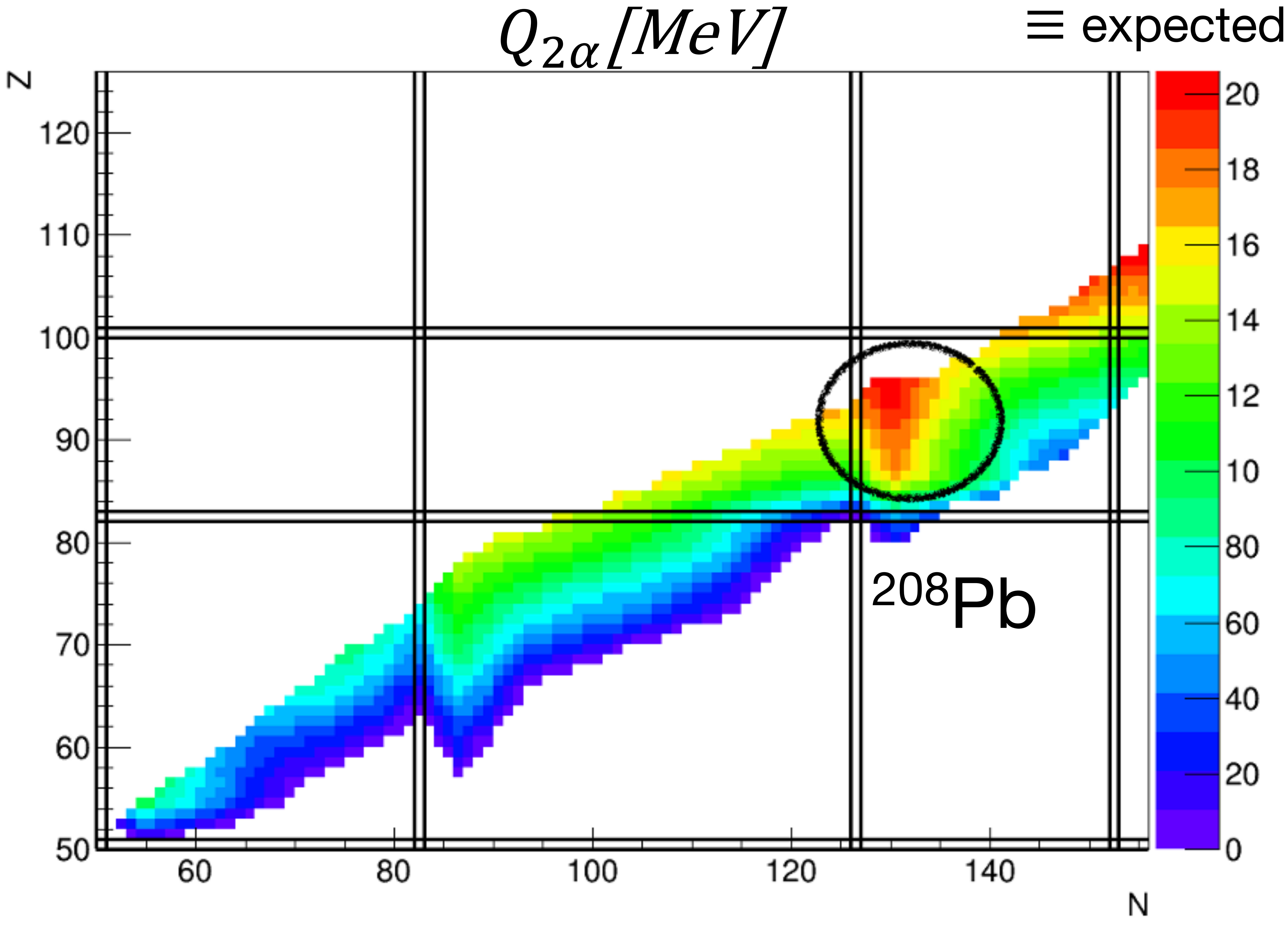
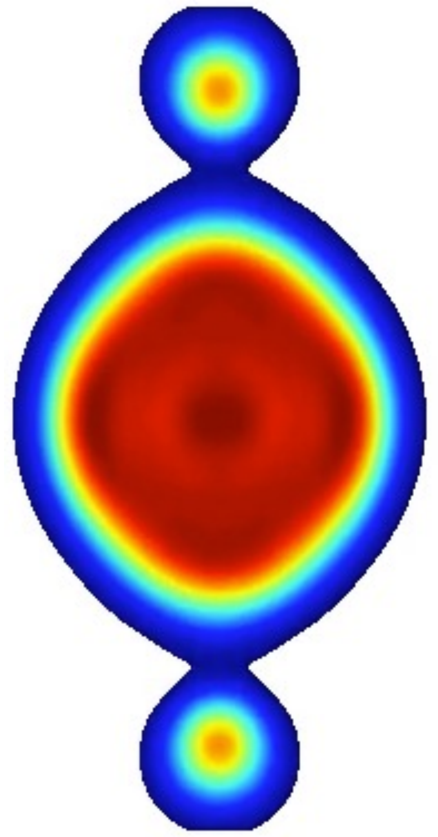
Double alpha candidates

Region of interest : large $Q_{2\alpha}$ value

≡ expected smaller τ (~Geiger-Nuttall)





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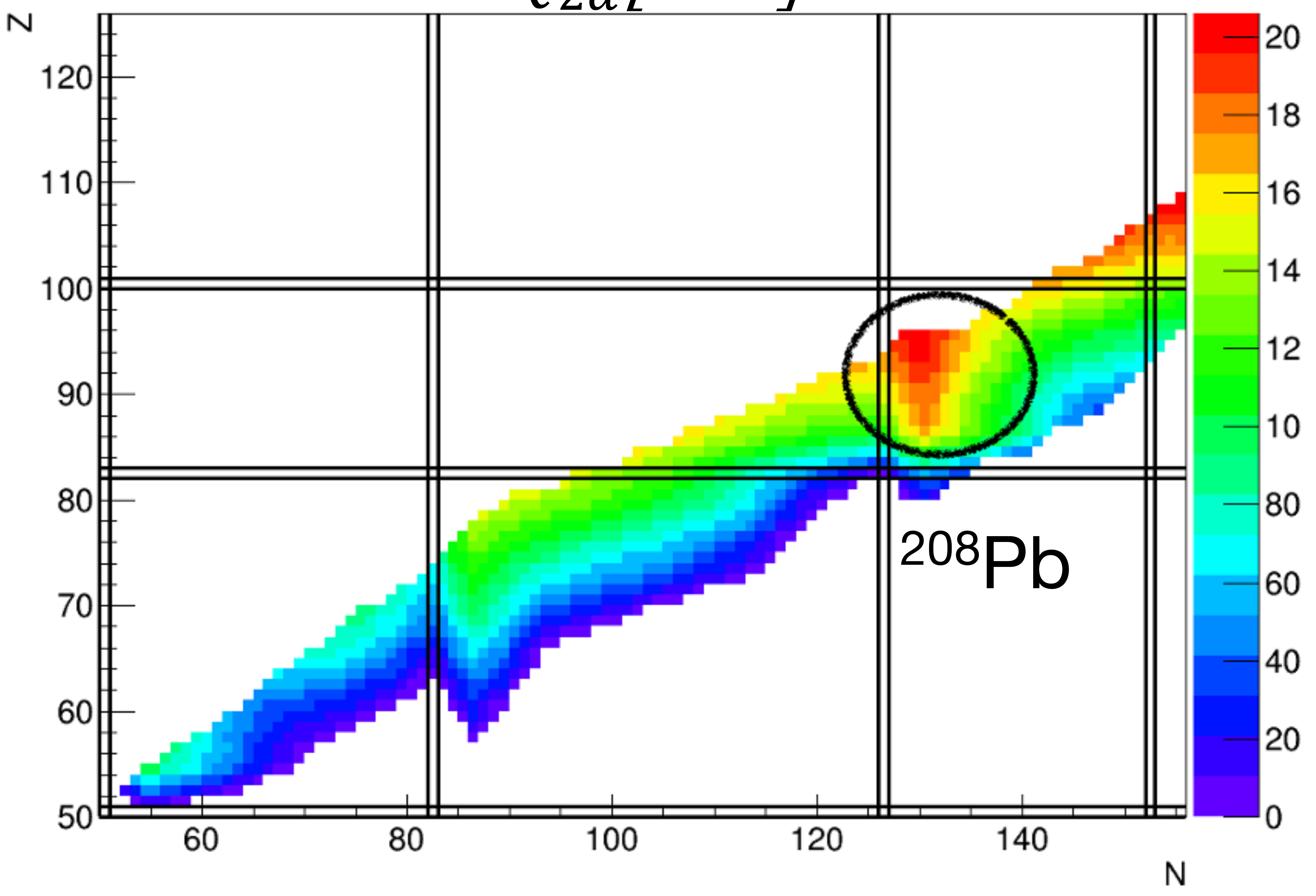
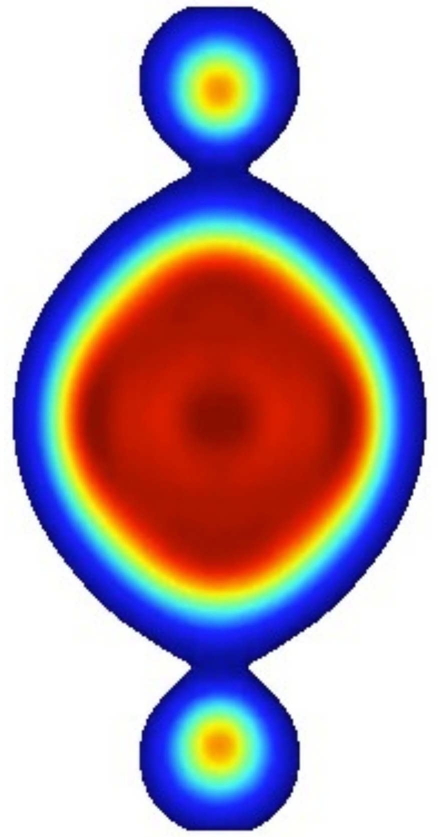
$Q_{2\alpha}$[MeV]



^{208}Pb+2α $\equiv$ ^{216}**Rn**



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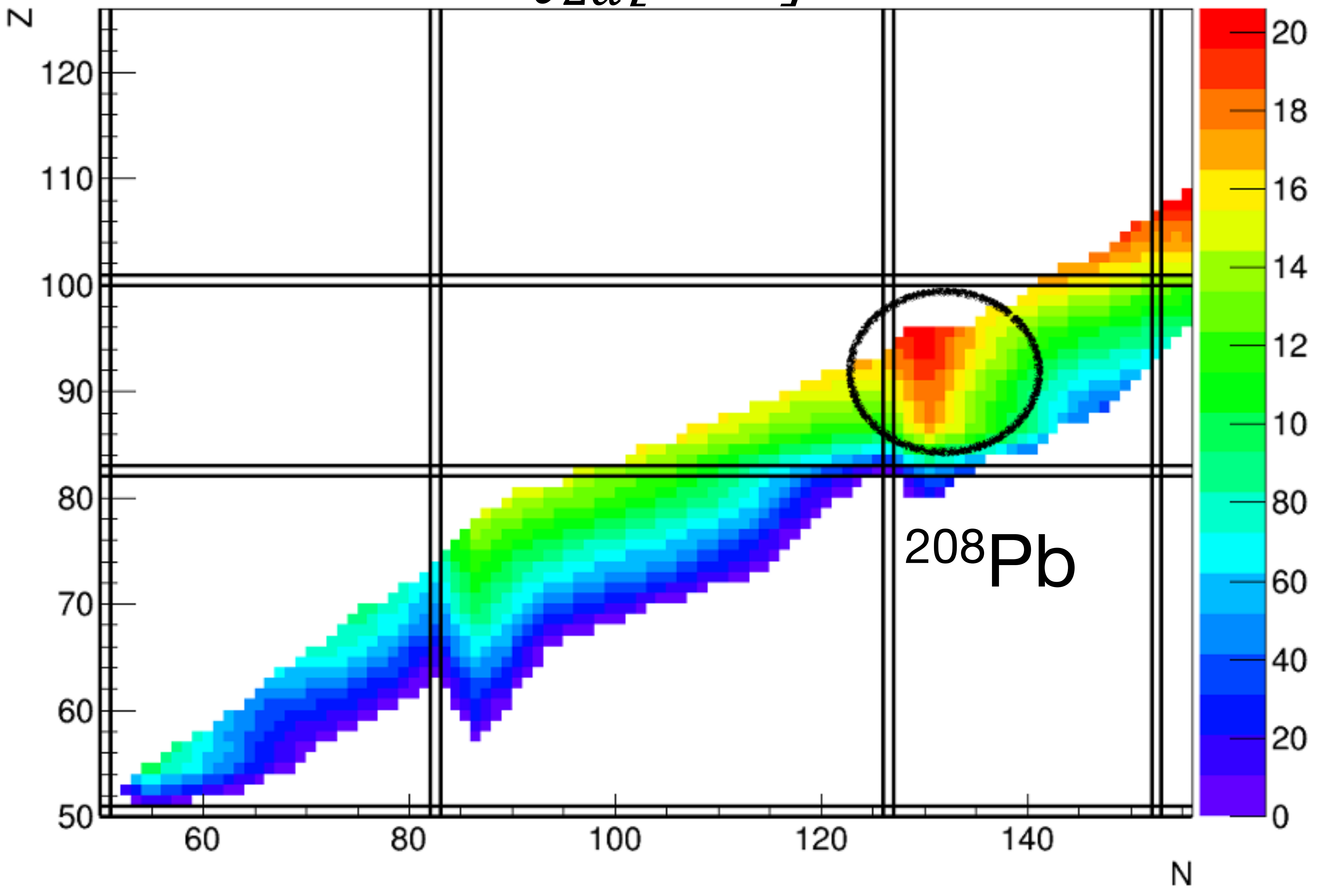

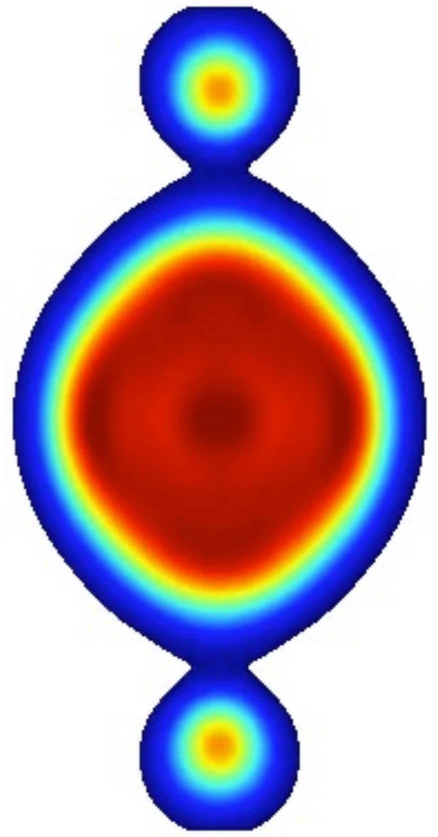

^{208}Pb+2α $\equiv$ **^{216}Rn**

^{216}Rn

« Double alpha Roll's Royce »

Theoretical trigger

Double alpha candidates

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Region of interest : large $Q_{2\alpha}$ value

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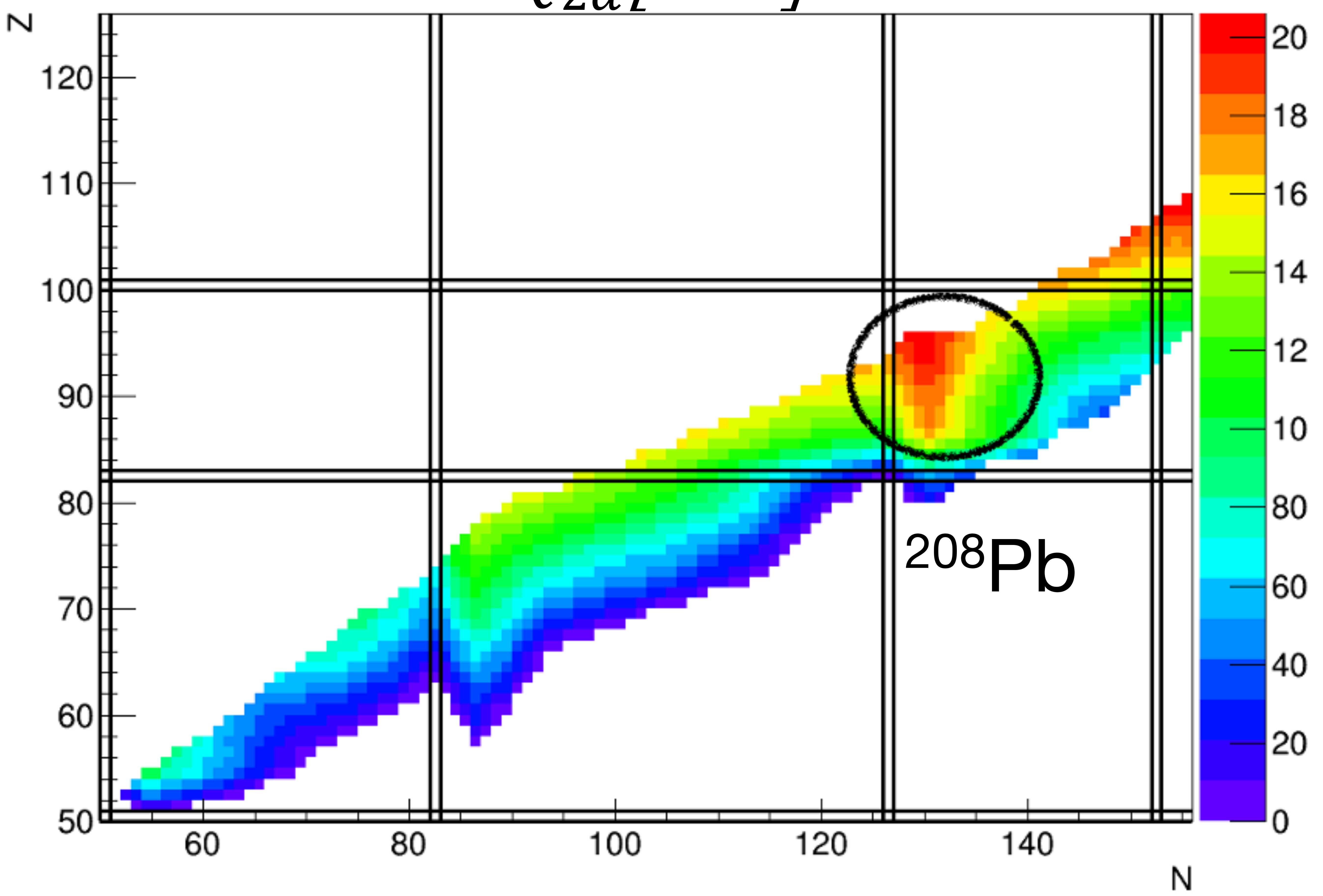
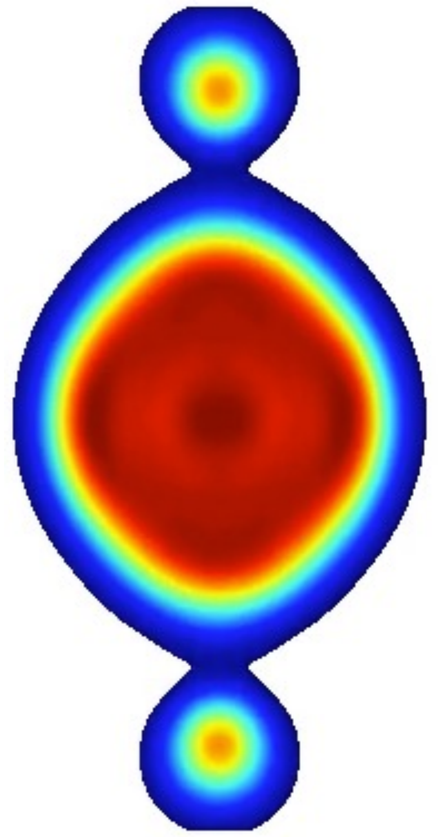
$Q_{2\alpha}$[MeV]





$^{208}Pb + 2\alpha \equiv$ **^{216}Rn**

Other candidates :

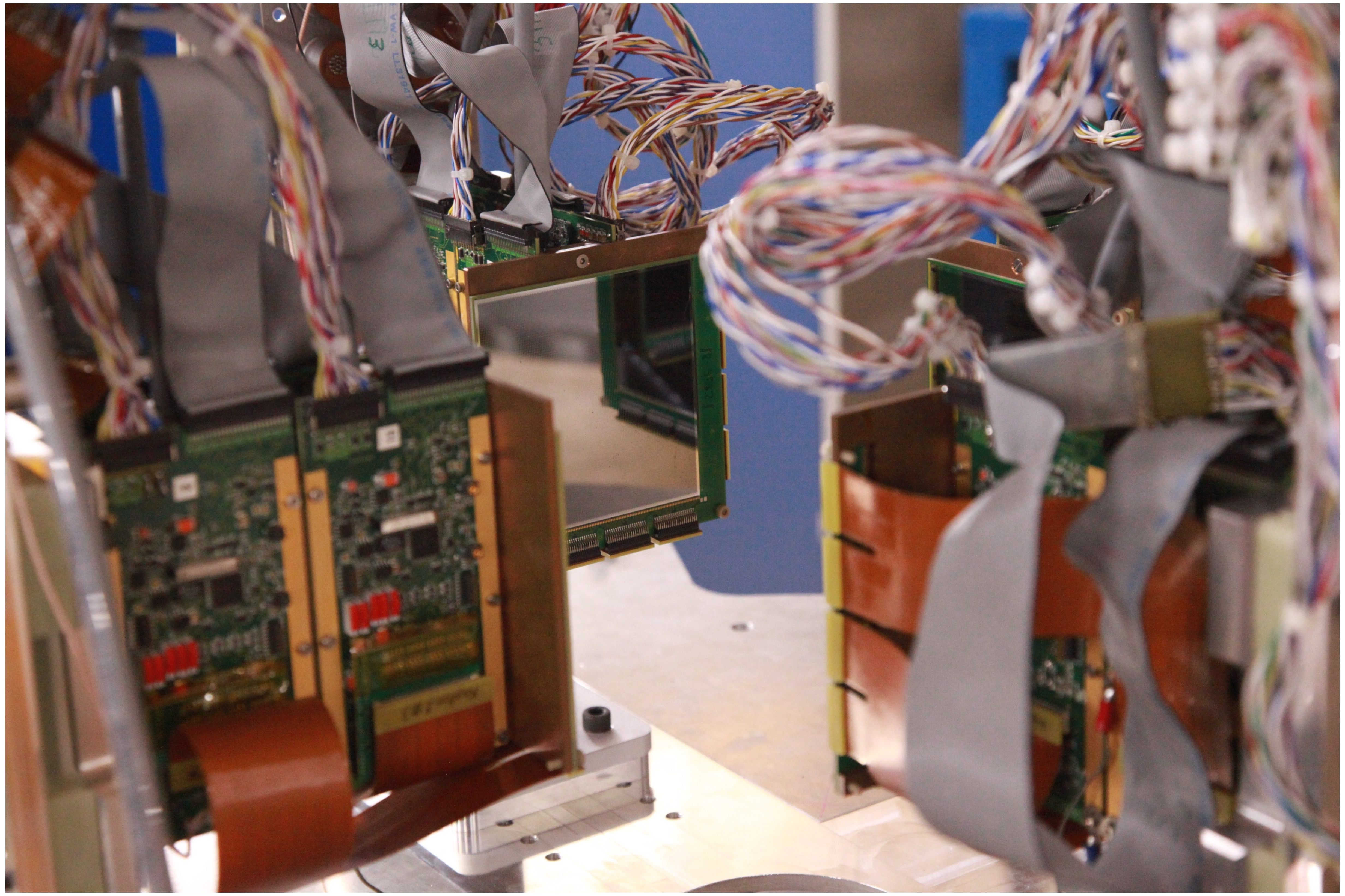
^{218,220}Rn **$^{220-224}$Ra**

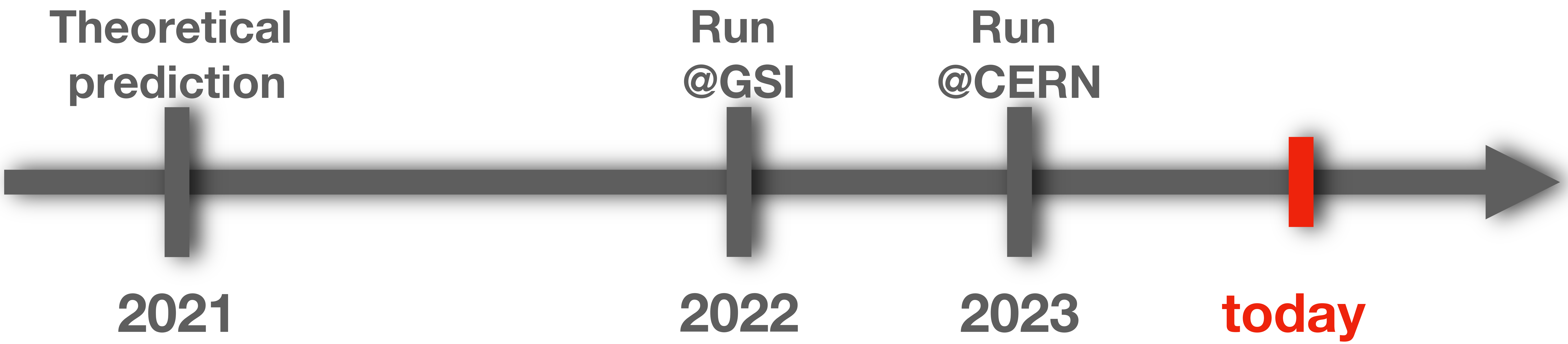
^{216}Rn

« Double alpha Roll's Royce »

Experimental search for 2α

CERN/Isolde - Saclay





Experimental search for 2 α

2α candidate

Alpha emitter

Beta emitter

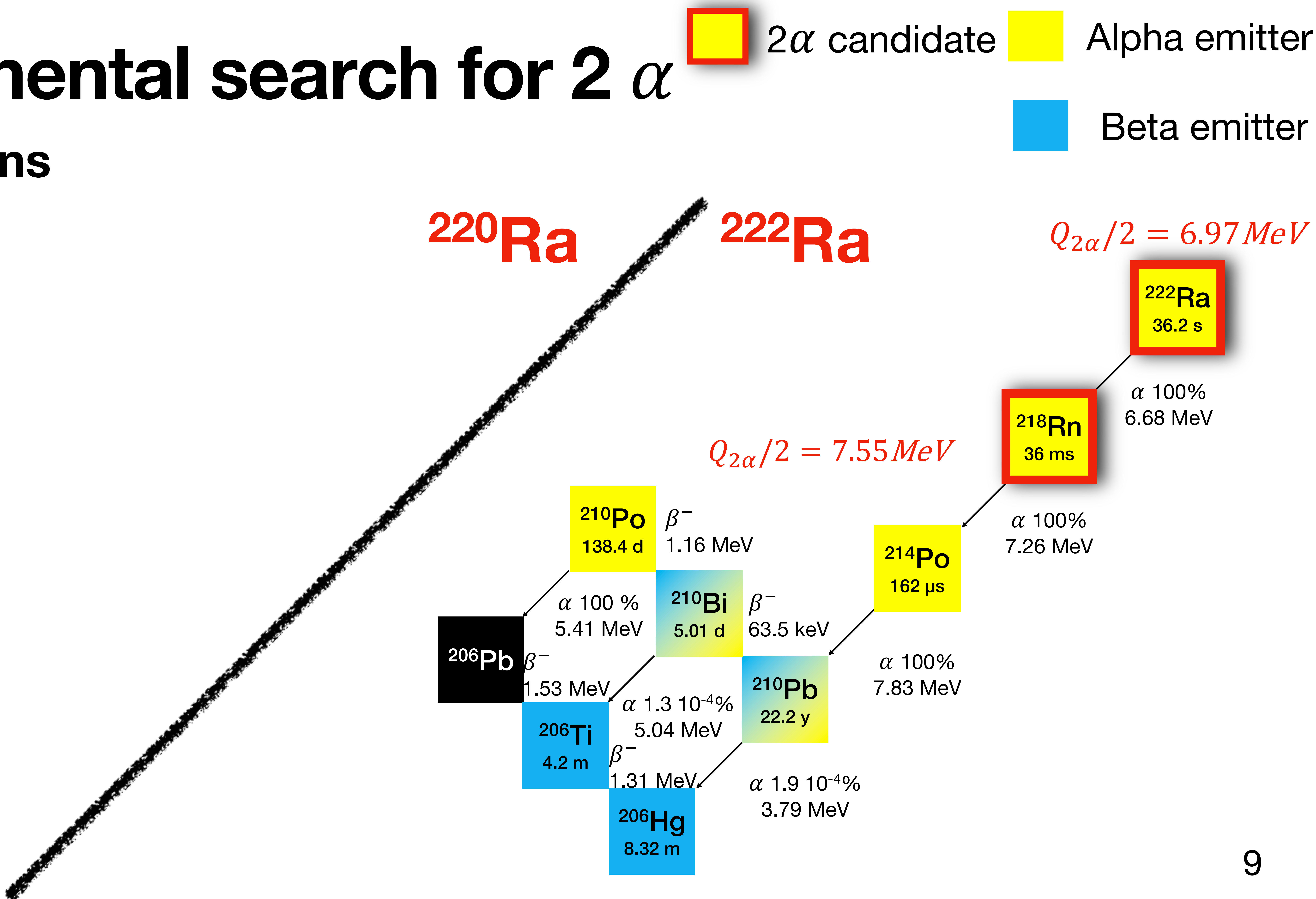
Decay chains

^{220}Ra

^{222}Ra

Experimental search for 2 α

Decay chains



Experimental search for 2 α

Decay chains

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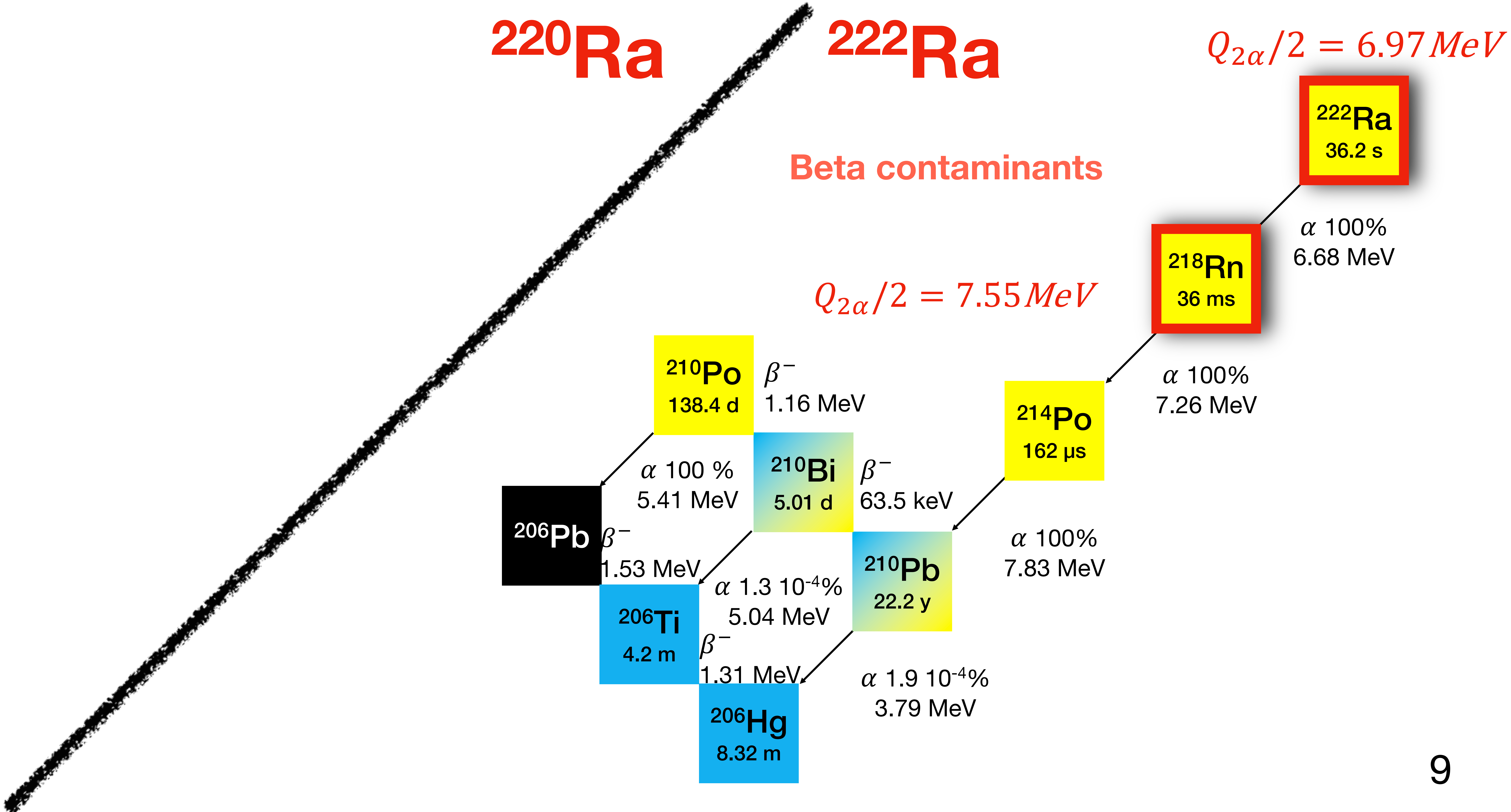

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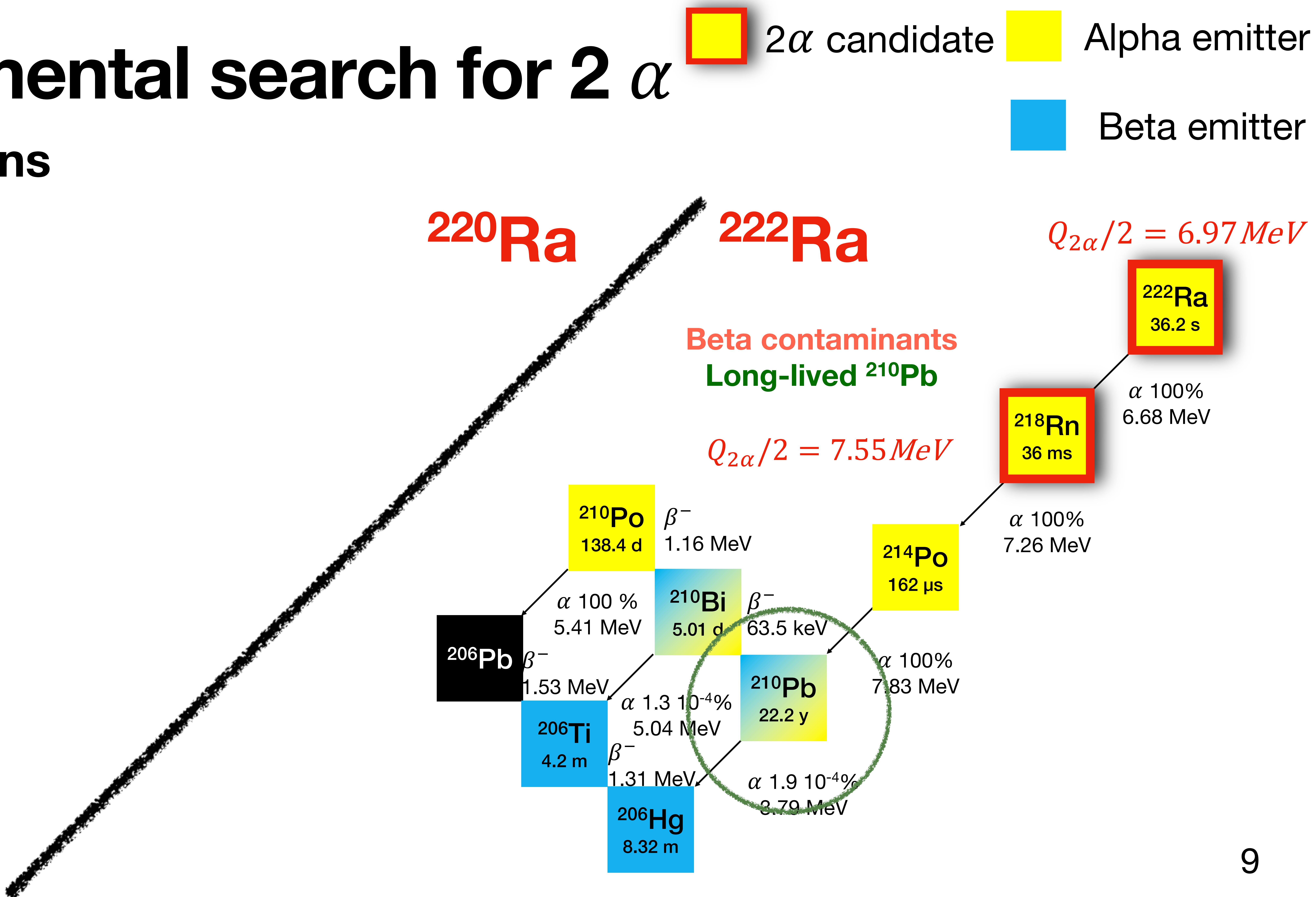

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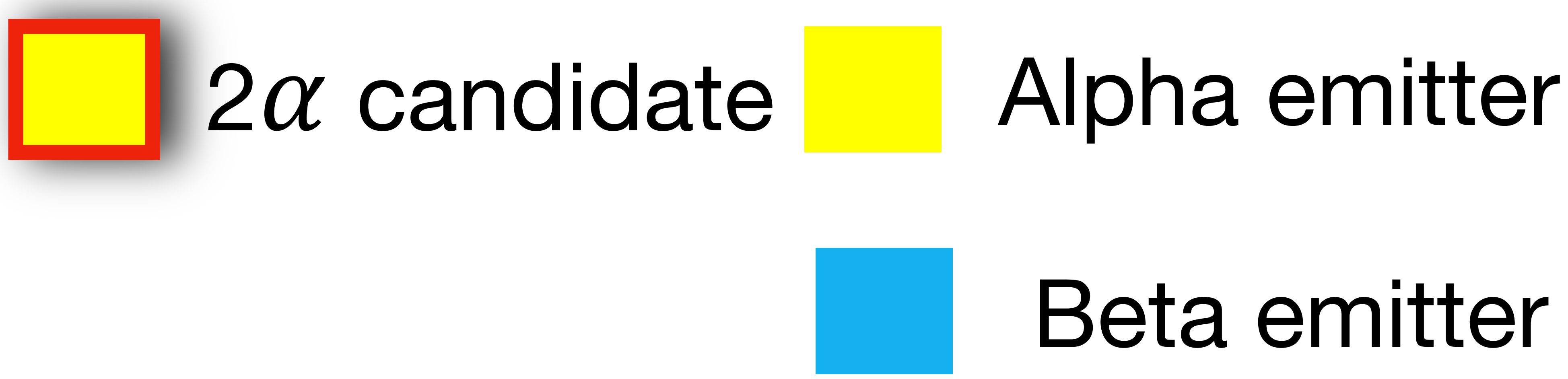

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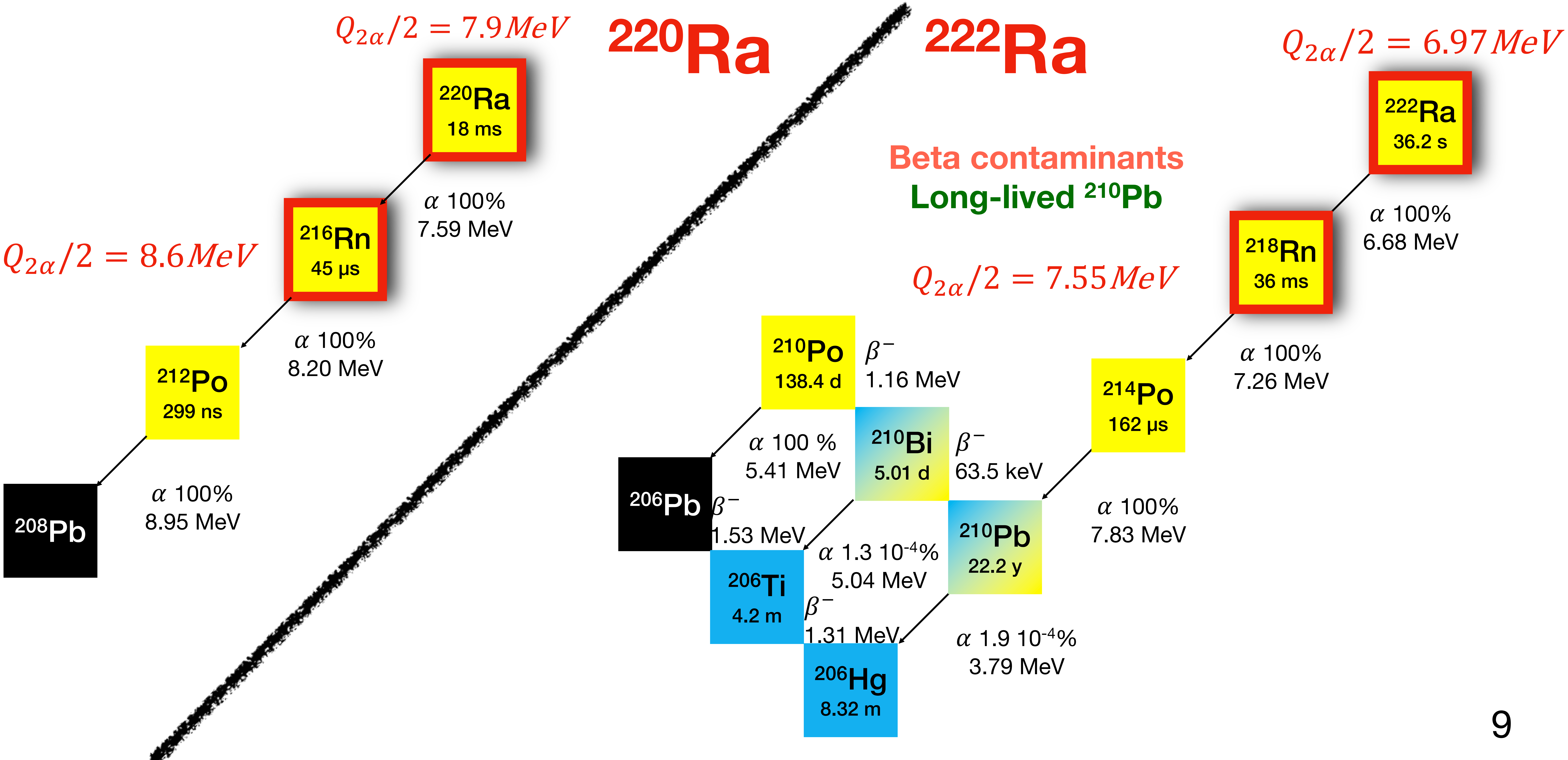
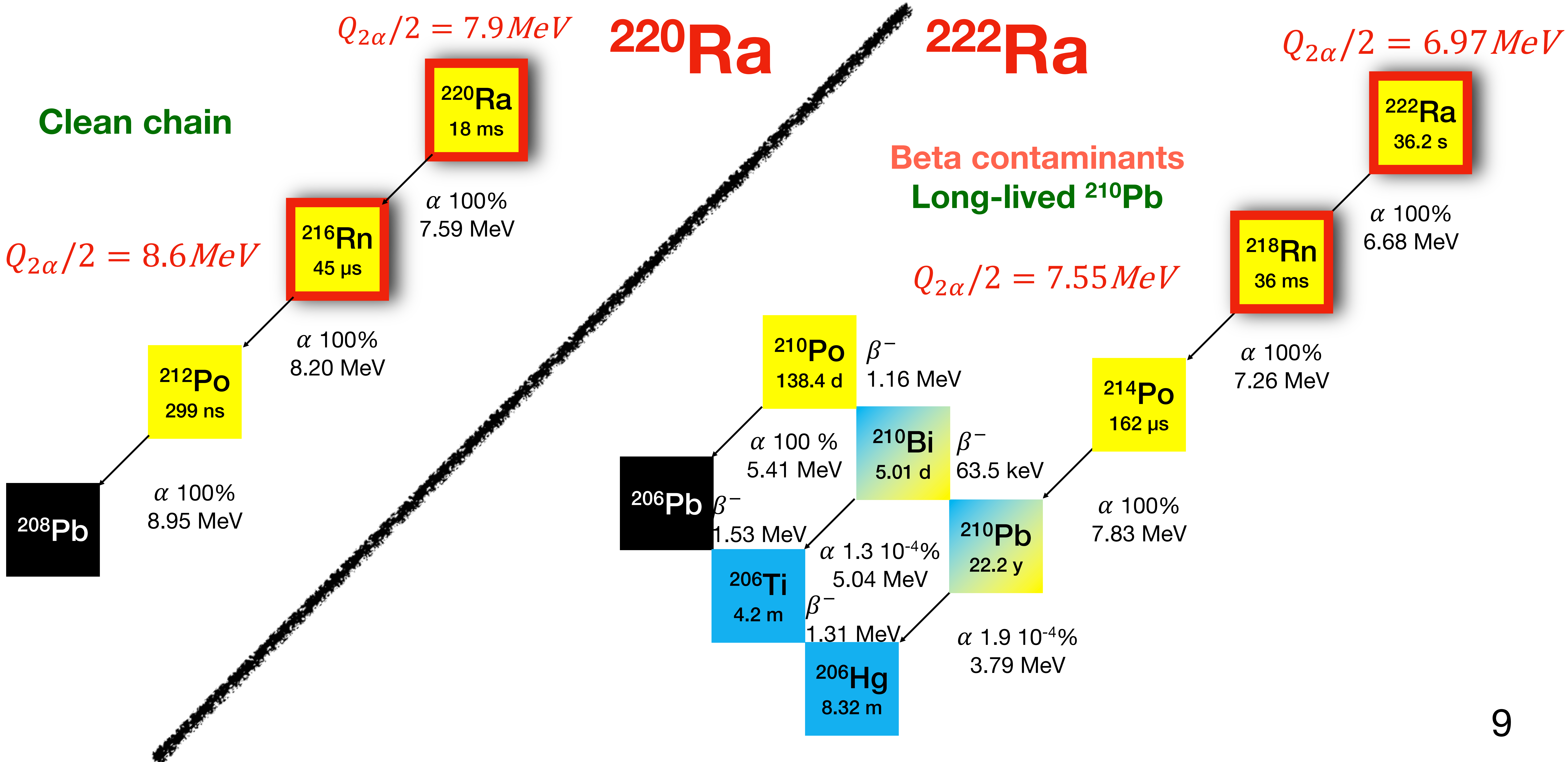


Experimental search for 2 α

2α candidate | Alpha emitter | Beta emitter

Decay chains



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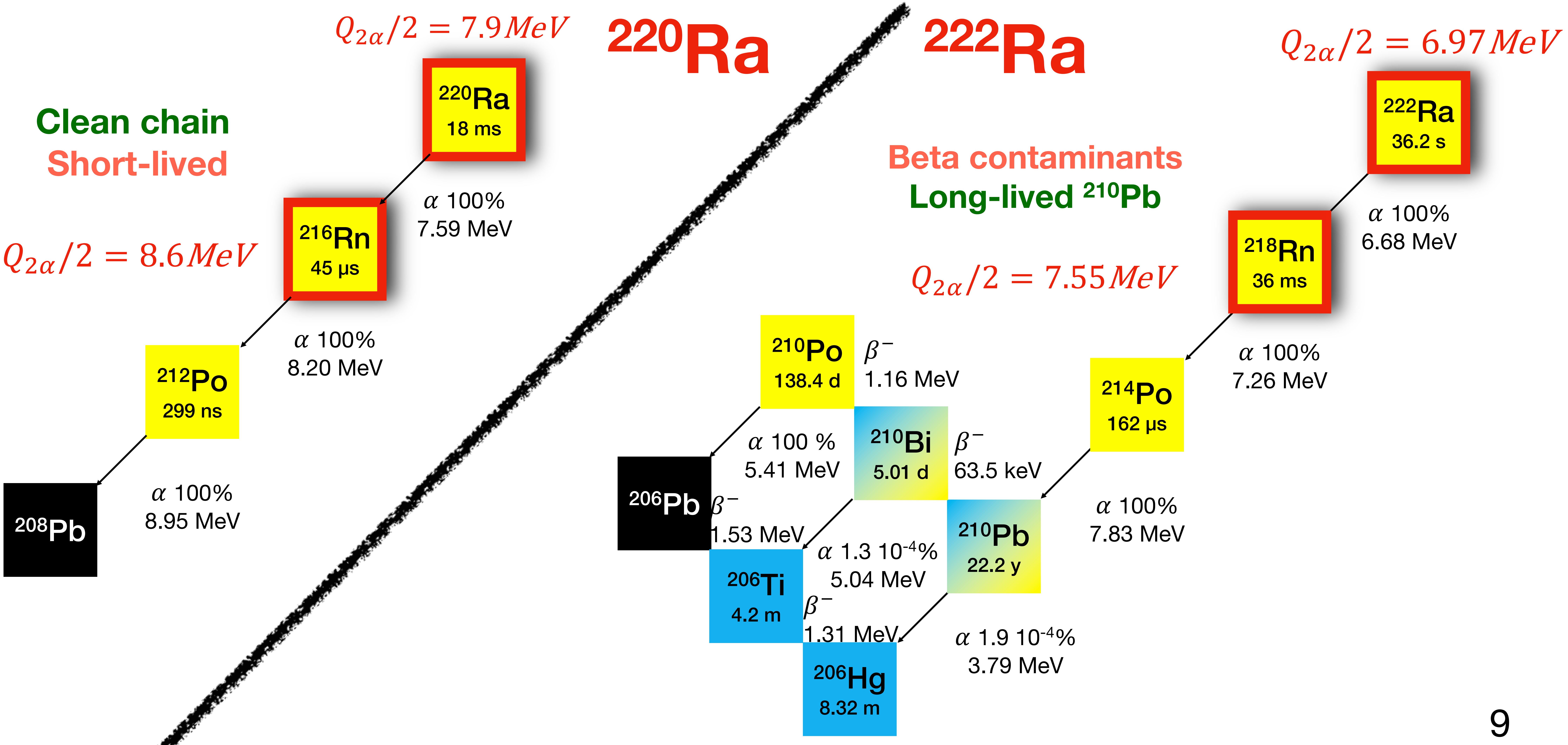



HOW
TO...

PROBE DOUBLE ALPHA DECAY ?

PROBE DOUBLE ALPHA DECAY ?

Step 1 : Get a radioactive Beam

Isolde experiment

Principle of the setup

Incoming beam

$^{220-222}Ra$

~10^4 pps
30 keV
1 week

~tens of events
expected

PROBE DOUBLE ALPHA DECAY ?

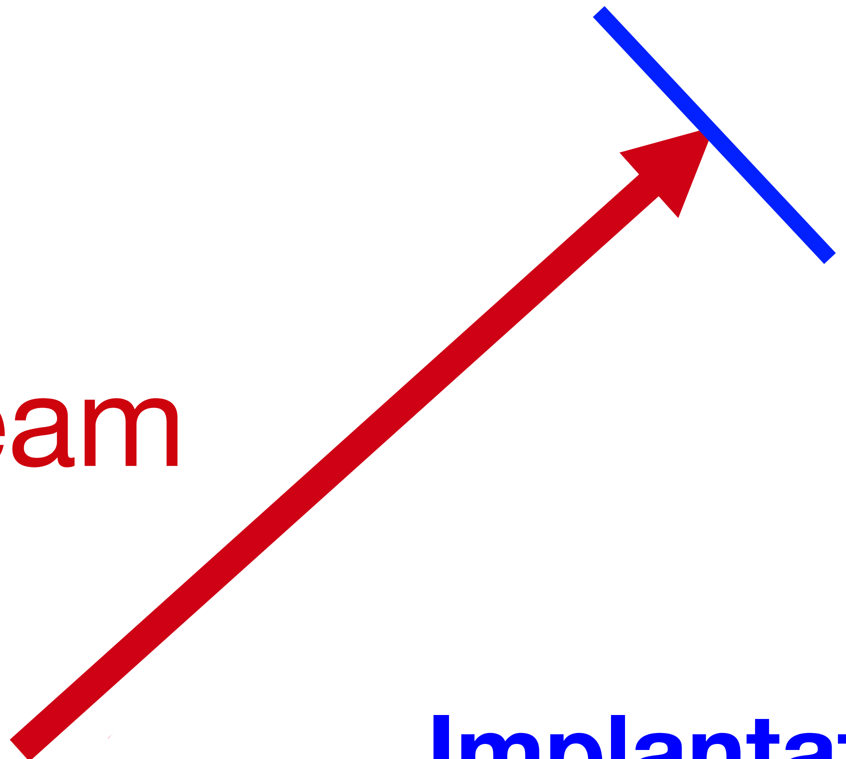
Step 1 : Get a radioactive Beam

Step 2 : Stop the radioactive Beam

Isolde experiment

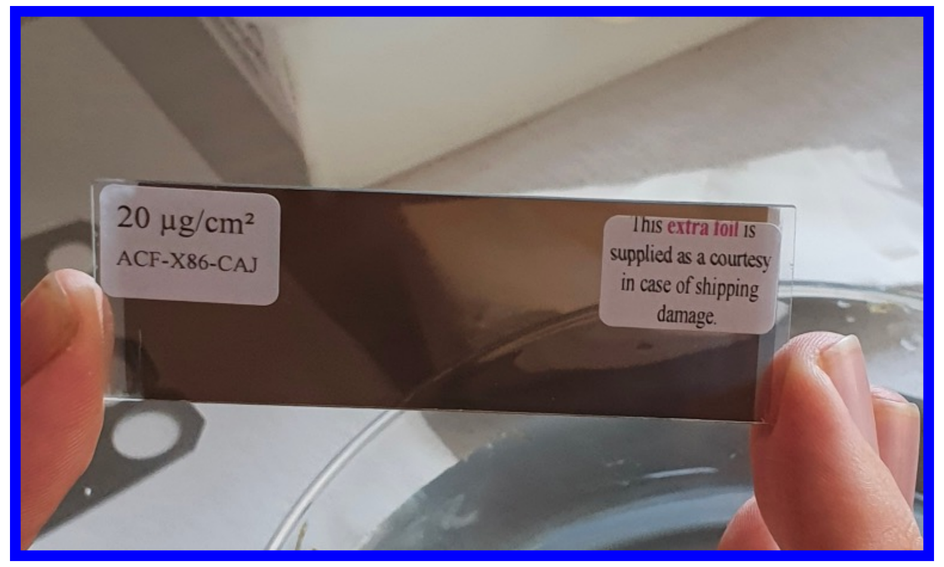
Principle of the setup

Incoming beam



$^{220-222}$Ra

Implantation foil

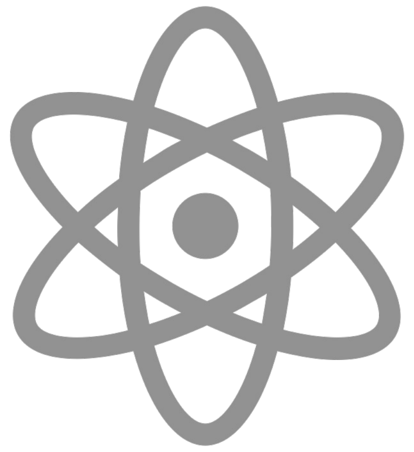


20 µg/cm² Carbon foil

~10^4 pps
30 keV
1 week

~tens of events expected

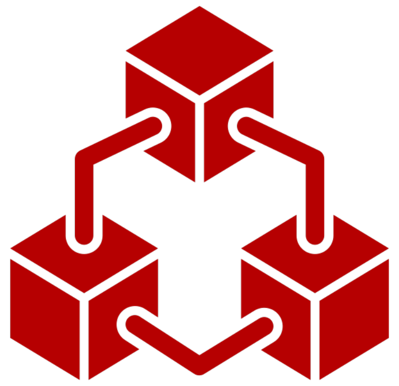
PROBE DOUBLE ALPHA DECAY ?



Step 1 : Get a radioactive Beam

Step 2 : Stop the radioactive Beam

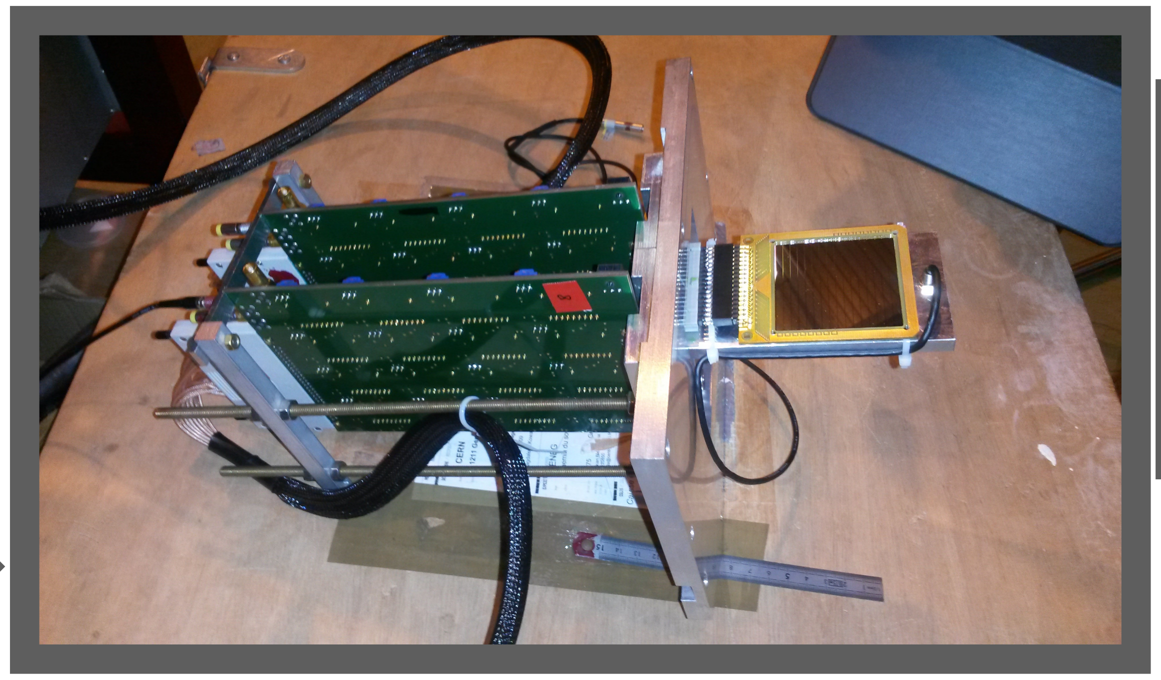
Step 3 : Place detectors

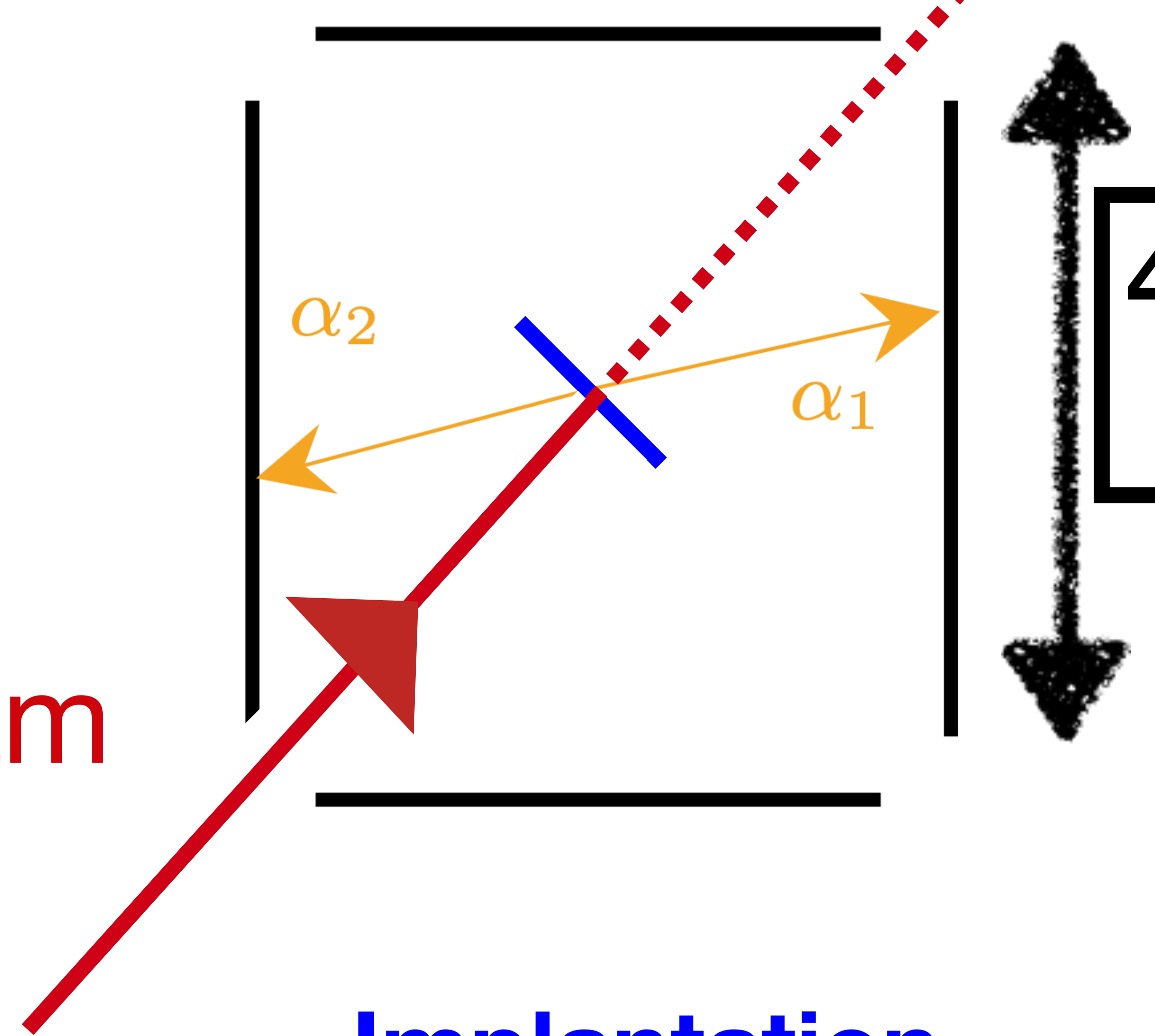


Isolde experiment

Principle of the setup

Beam inspection DSSD

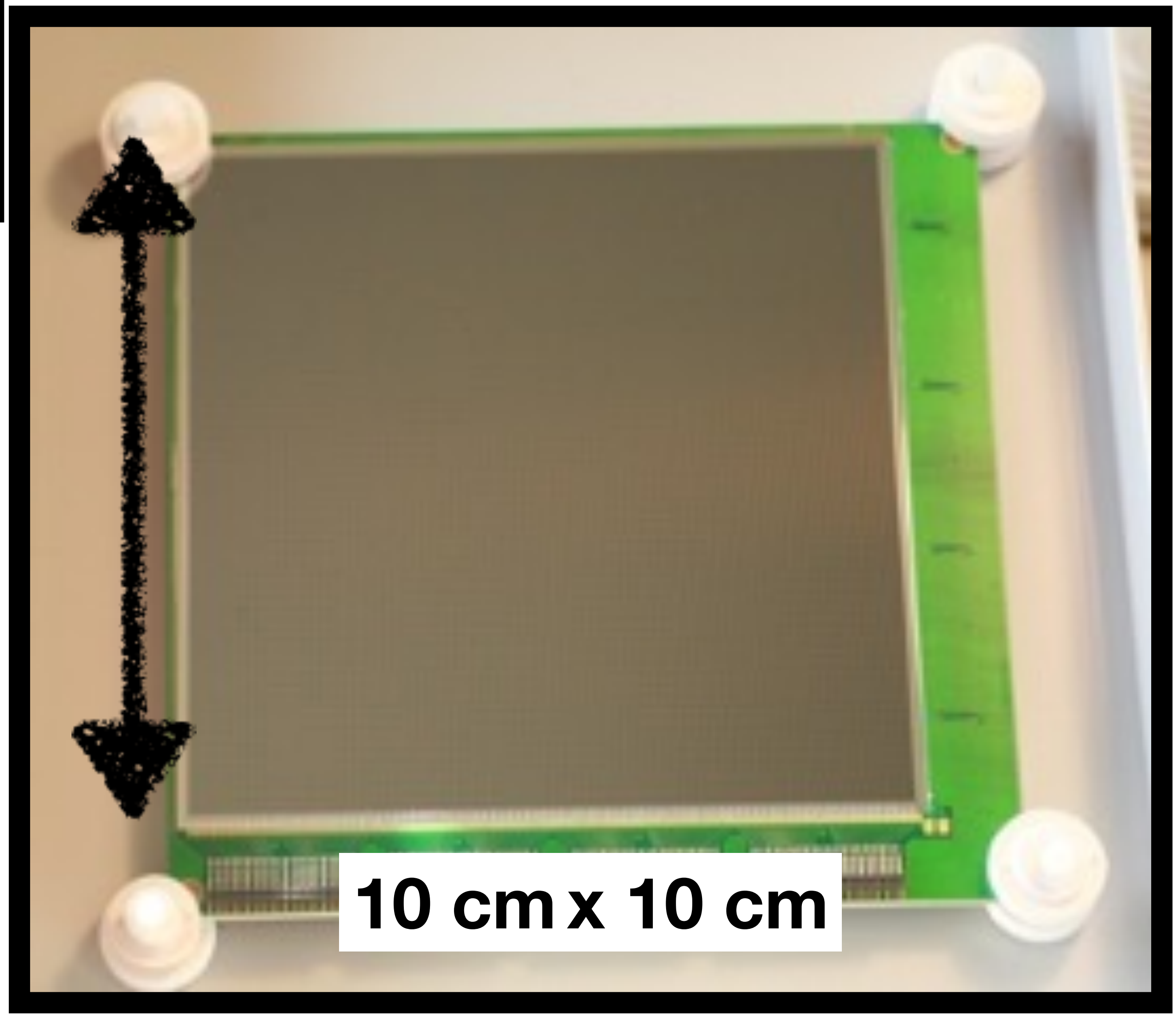




4 detection DSSD

10 cm

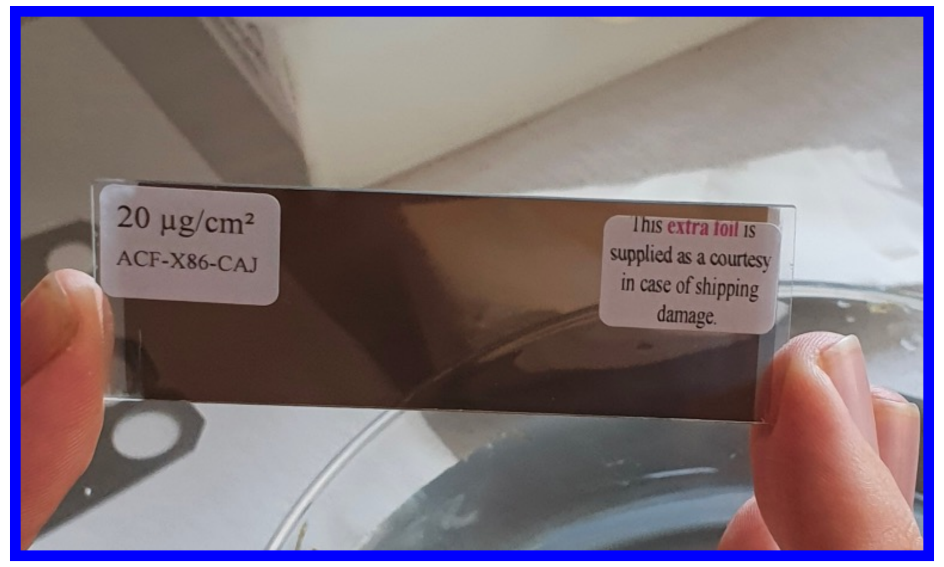
MUSETT setup



Incoming beam

$^{220-222}$Ra

Implantation foil



20 µg/cm^2 Carbon foil

128 + 128 strips

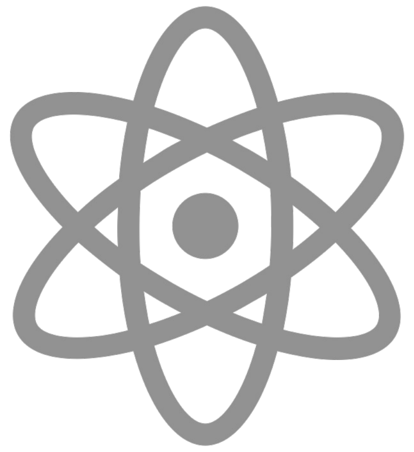
Electronics & DAQ by GANIL & IJCLab

~10^4 pps
30 keV
1 week

~tens of events expected

Good spatial resolution (~1mm)

PROBE DOUBLE ALPHA DECAY ?



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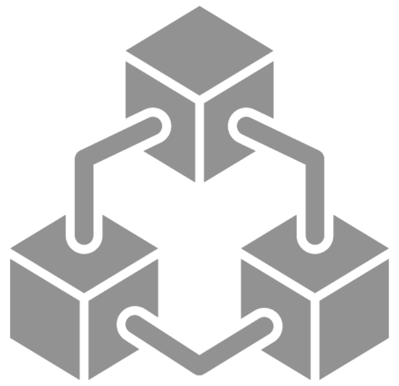

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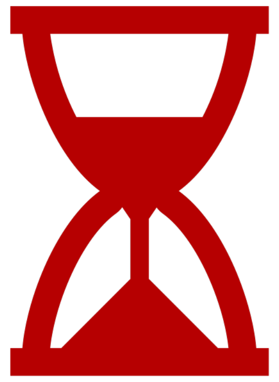
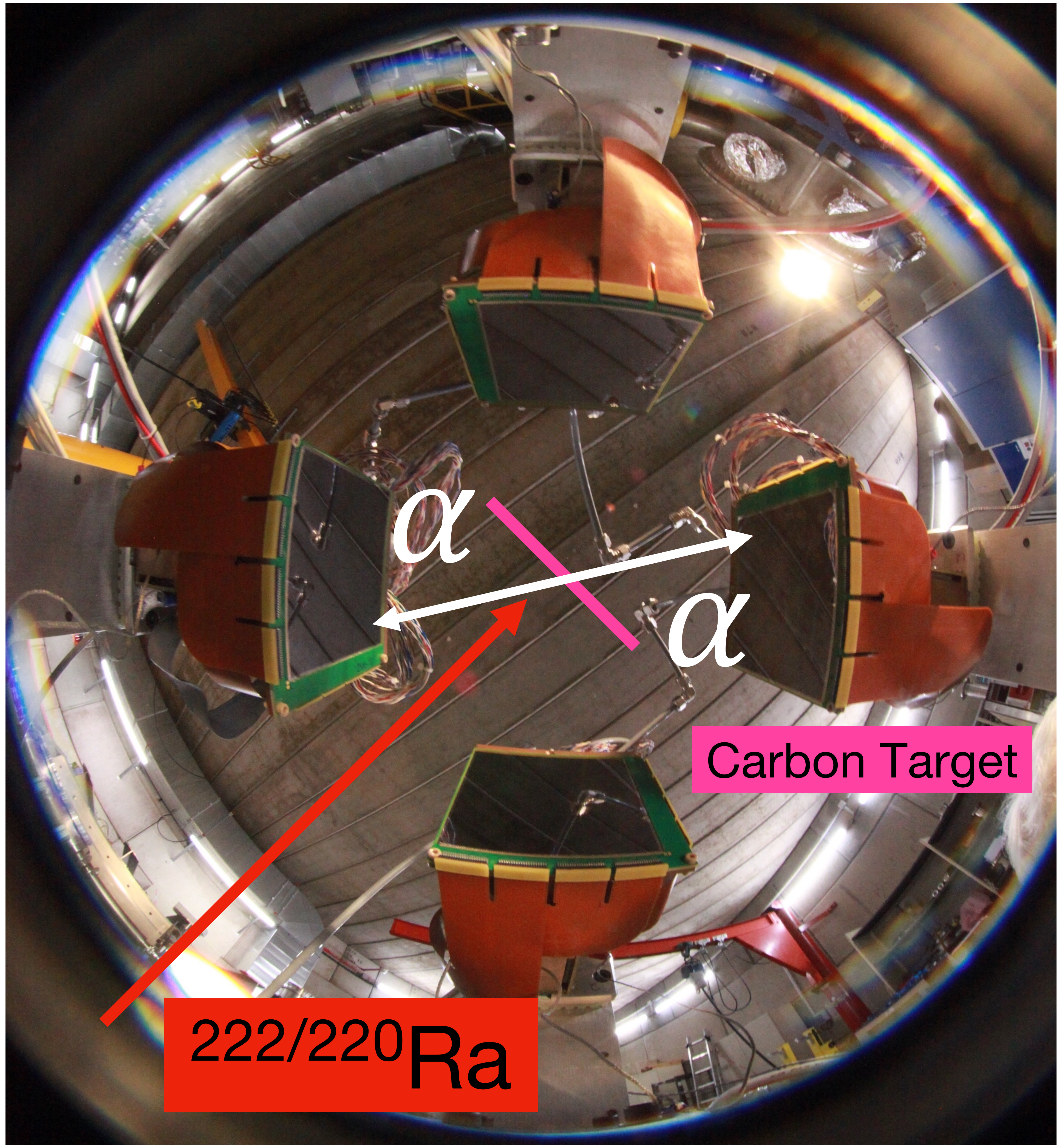
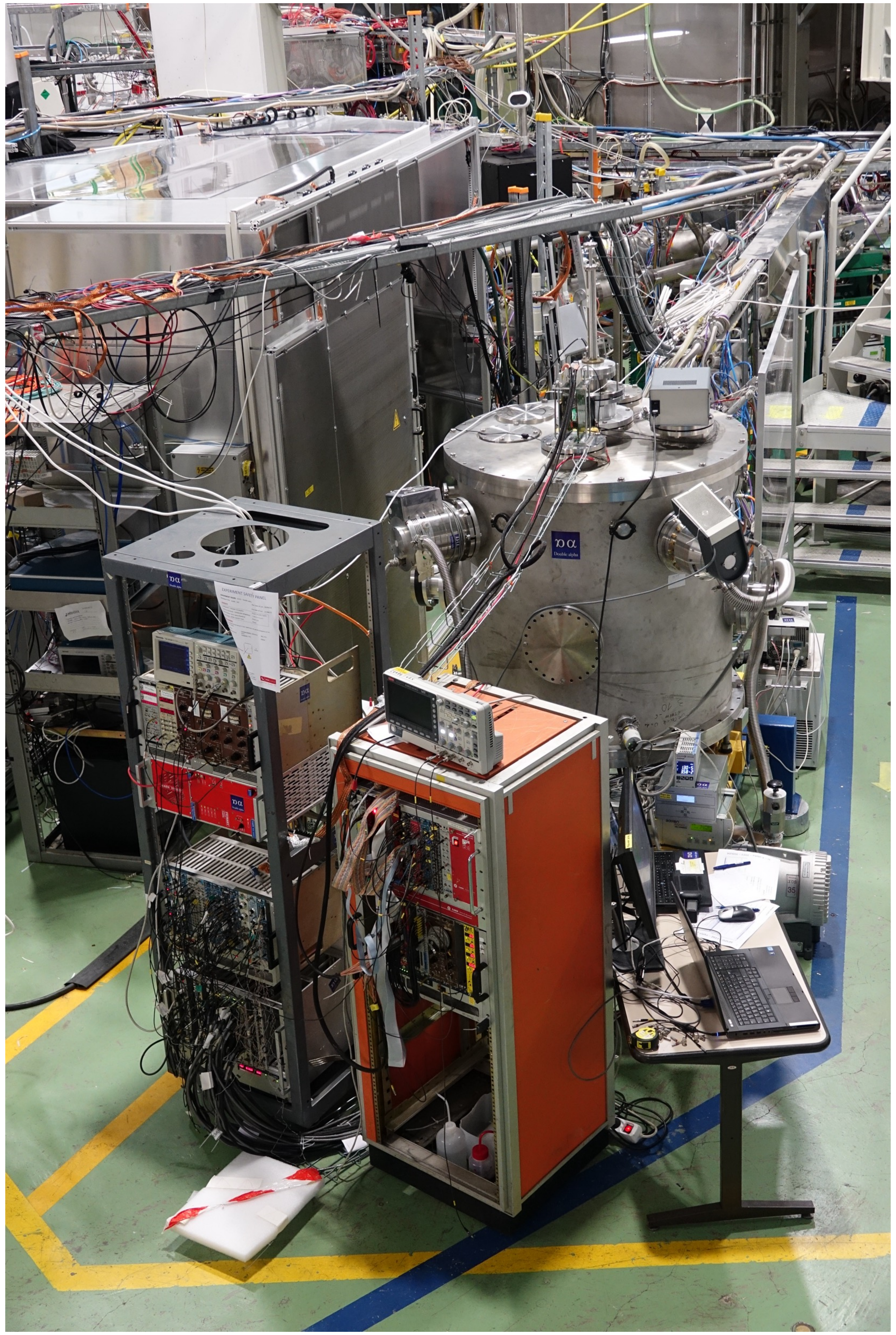


Step 4 : Wait (and hope)

Isolde experiment

Experimental setup





Isolde experiment

Schedule

Tuesday **June 20th**	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday **June 30th**

Isolde experiment

Schedule

Tuesday **June 20th**	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday **June 30th**
Technical stop	**Technical stop**								

Isolde experiment

Schedule

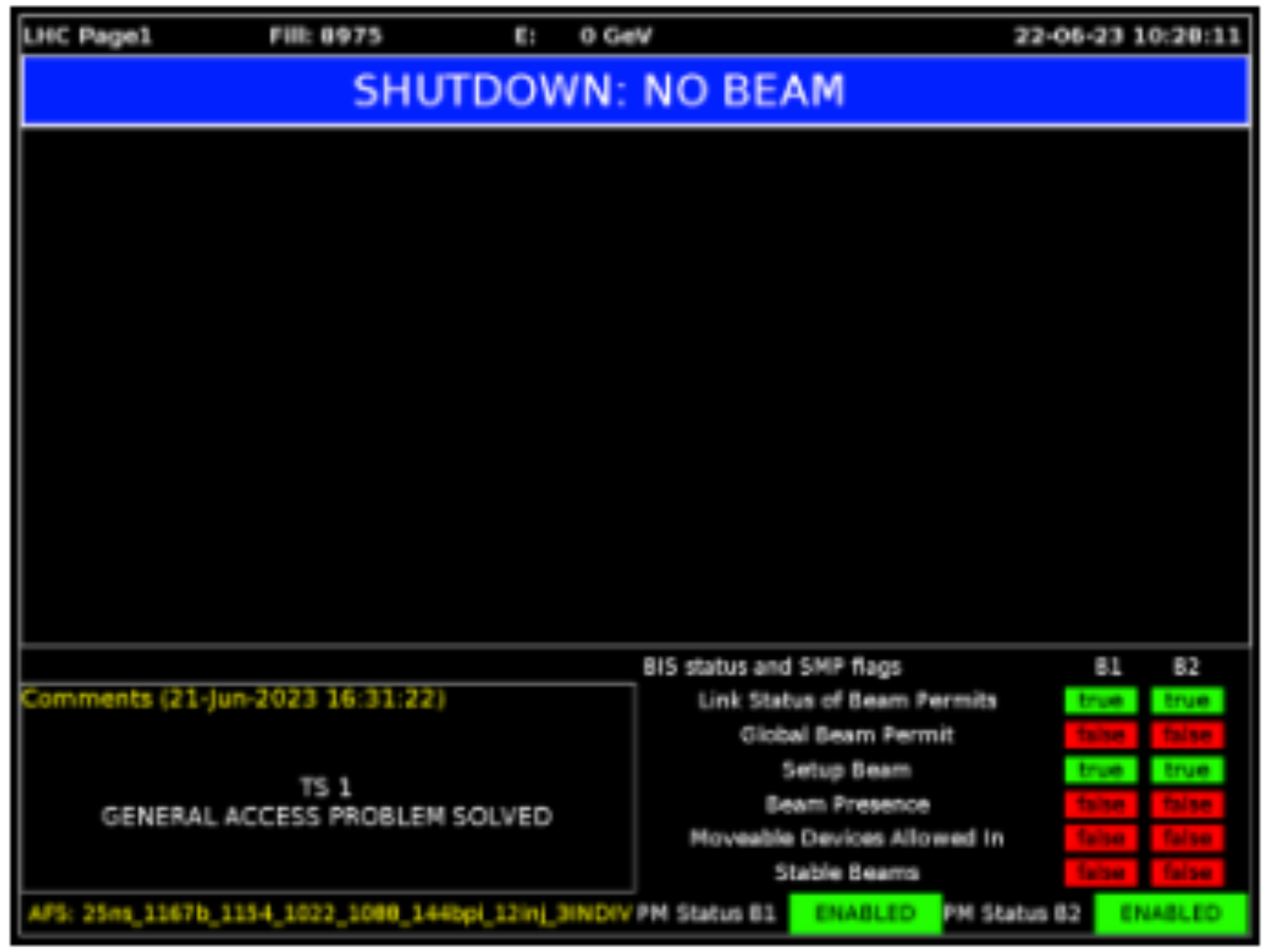
Tuesday **June 20th**	Wednesday	Thursda	sday **30th**
Technical stop	**Technical stop**		

Accelerator Report: LHC pausing production for maintenance to stay strong and highly performing

20 JUNE, 2023 | By Rende Steerenberg

Even the most cutting-edge machines require moments of respite. That's why, in the early morning of Monday, 19 June, LHC operation was paused for one week to allow the technical teams to carry out preventive and corrective maintenance on the machine and its subsystems.

One week earlier, in the afternoon of Tuesday, 13 June, the beams were dumped, marking a break in a successful period of luminosity production to switch to a busy and tightly scheduled machine development (MD)



Isolde experiment

Schedule

Tuesday **June 20th**	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday **June 30th**
Technical stop	**Technical stop**	^{222}Ra	^{222}Ra	^{222}Ra	^{222}Ra	^{222}Ra / ^{220}Ra			

Isolde experiment

Schedule

Tuesday **June 20th**	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday **June 30th**
Technical stop	**Technical stop**	^{222}Ra	^{222}Ra	^{222}Ra	^{222}Ra	^{222}Ra / ^{220}Ra	**CERN shutdown**		

Isolde experiment

Schedule

Network infrastructure affected by a major power cut

Type: Service Incident
Begin: Tue Jun 27, 2023 07:30
Impact: Down
Last Updated: Thu Jun 29, 2023 17:14
Locations: Not Specified

Resolution date: Tue Jun 27, 2023 14:30
SE Campus Network Service
FE Network Operations
Services Affected: Not Specified

Description:
The network infrastructure in the Meyrin site is affected by a major power cut.

The network engineers, together with the IT technicians, are working to recover the network infrastructure as soon as possible.

Monday	Tuesday	Wednesday	Thursday **June 30th**
^{222}Ra / ^{220}Ra	**CERN shutdown**		

Isolde experiment

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^{222}Ra / ^{220}Ra	**CERN shutdown**		

CERN IN THE DARK !

Double α team
Waiting for beam to be back

Boston Commons
1947
Henri Cartier-Bresson

Isolde experiment

Schedule

Tuesday **June 20th**	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday **June 30th**
Technical stop	**Technical stop**	^{222}Ra	^{222}Ra	^{222}Ra	^{222}Ra	^{222}Ra / ^{220}Ra	**CERN shutdown**	^{220}Ra	^{220}Ra

Isolde experiment

Schedule

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Rate ^{222}Ra ~ 10^5 pps → ~ 10^{10} implantations

Isolde experiment

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Rate ^{220}Ra ~ 10^3 pps → ~ 10^8 implantations

Isolde experiment

Schedule

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Rate ^{222}Ra ~ 10^5 pps → ~ 10^{10} implantations

Rate ^{220}Ra ~ 10^3 pps → ~ 10^8 implantations

Due to its short half-life : 18 ms (38 s for ^{222}Ra)

PROBE DOUBLE ALPHA DECAY ?

Step 1 : Get a radioactive Beam

Step 2 : Stop the radioactive Beam

Step 3 : Place detectors

Step 4 : Wait (and hope)

STEP 5 : Analyse the Data (and hope)

Cuts to identify double α

Cuts to identify double α

Energy

Cuts to identify double α

Energy **Time**

Cuts to identify double α

Energy **Time** **Space**

Cuts to identify double α

Energy

Cuts to identify double α

Energy

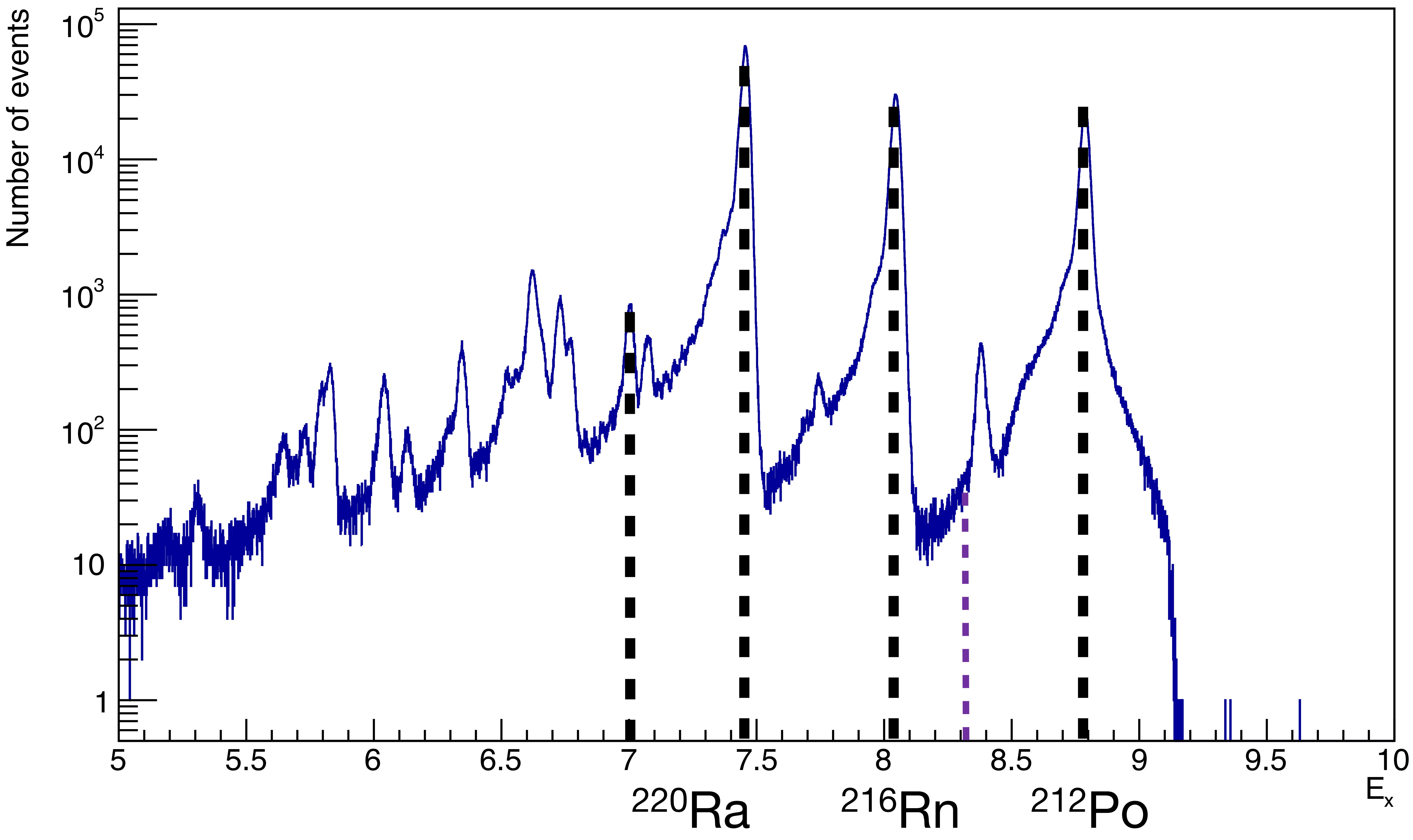
$$E_{\alpha 1} + E_{\alpha 2} \sim Q_{2\alpha}$$

Energy spectrum for ^{220}Ra

Expected :

$^{220}Ra \rightarrow {}^{216}Rn \rightarrow {}^{212}Po \rightarrow {}^{208}Pb$

Preliminary



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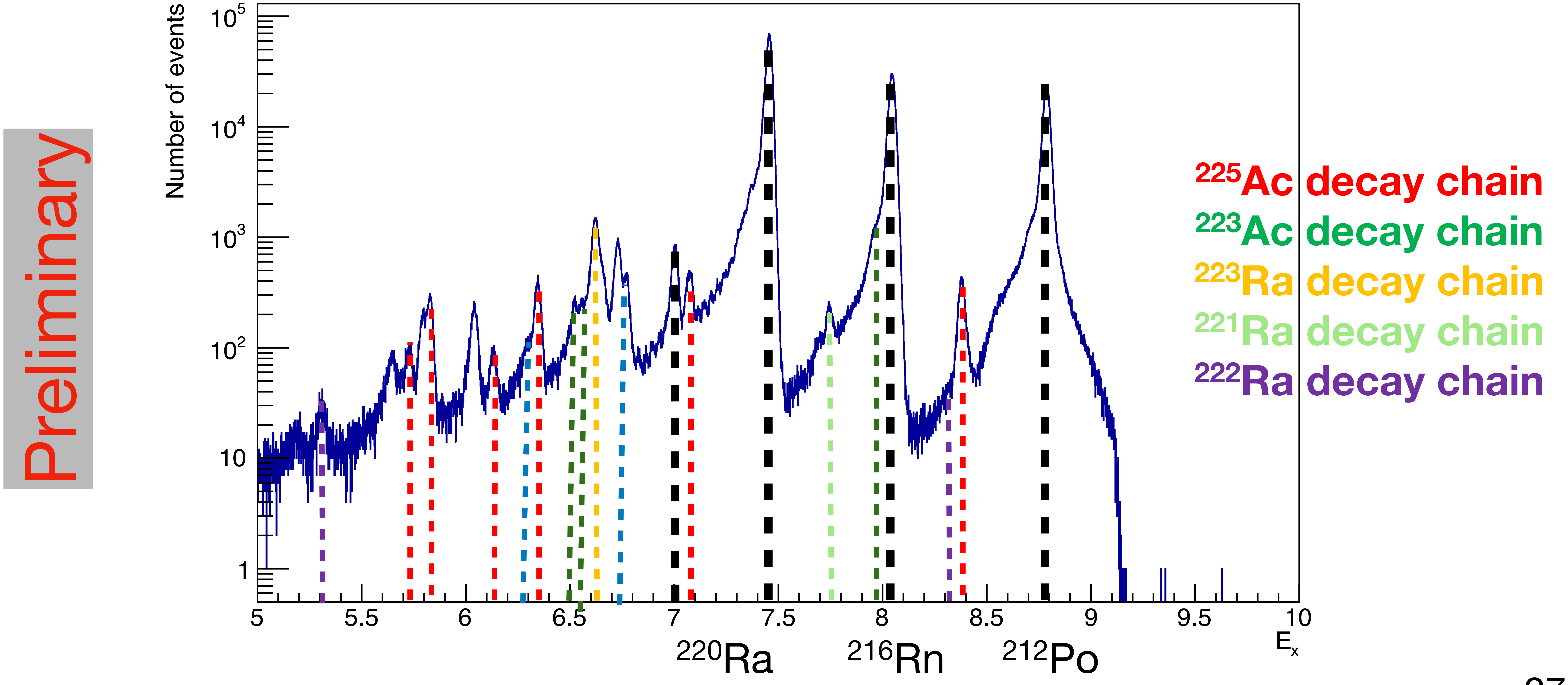

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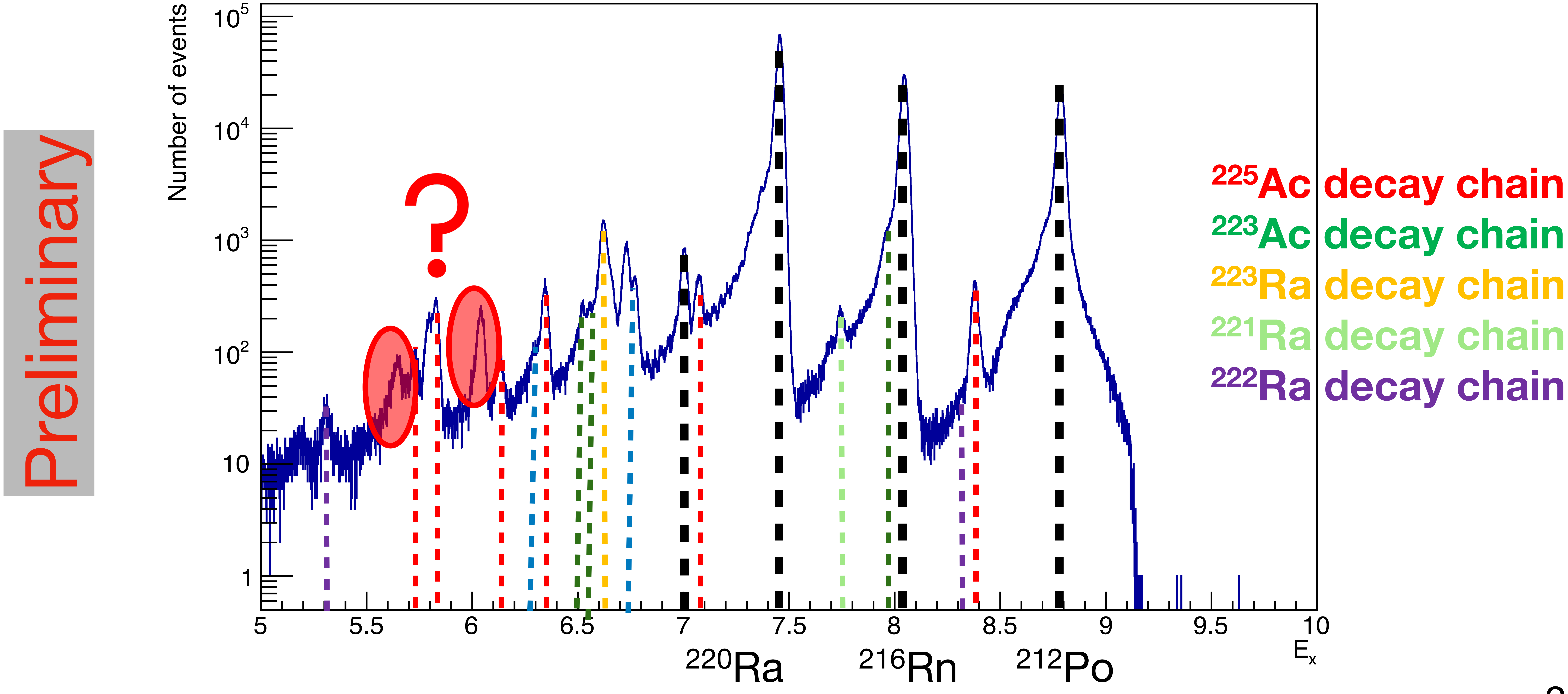
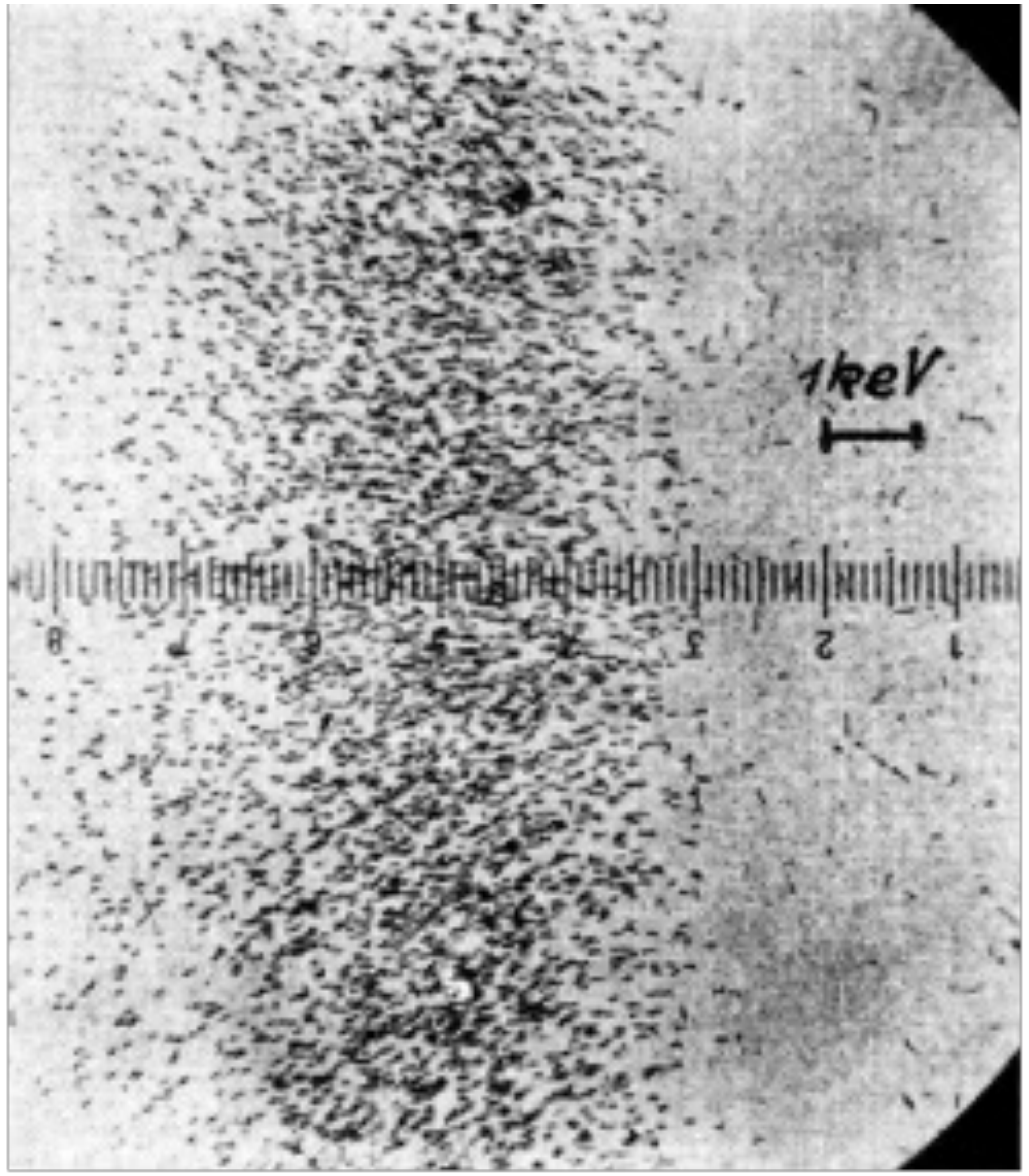


Energy spectra : literature



The example of ^{210}Po measured by Rytz using a photographic plate.

Literature rather old :

^{220}Ra weighted average of 7449 (10) from Hessberger 2000, 7455 (10) from Valli **1970** and 7460 (20) from Andreev

^{214}Po : measurement with a magnetics spectrograph. Rytz. Helv.Phys.Acta 34, 240 (**1961**), again adjusted by Rytz in 1991.

In our background data, peaks not (yet) identified

Room to improve **alpha-decay data** in actinide region

Cuts to identify double α

Energy

$$E_{\alpha 1} + E_{\alpha 2} \sim Q_{2\alpha}$$

Seems OK but Contaminants to be checked

Cuts to identify double α

Energy

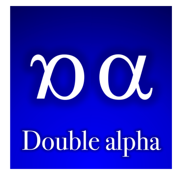
$$E_{\alpha 1} + E_{\alpha 2} \sim Q_{2\alpha}$$

Seems OK but Contaminants to be checked

Time

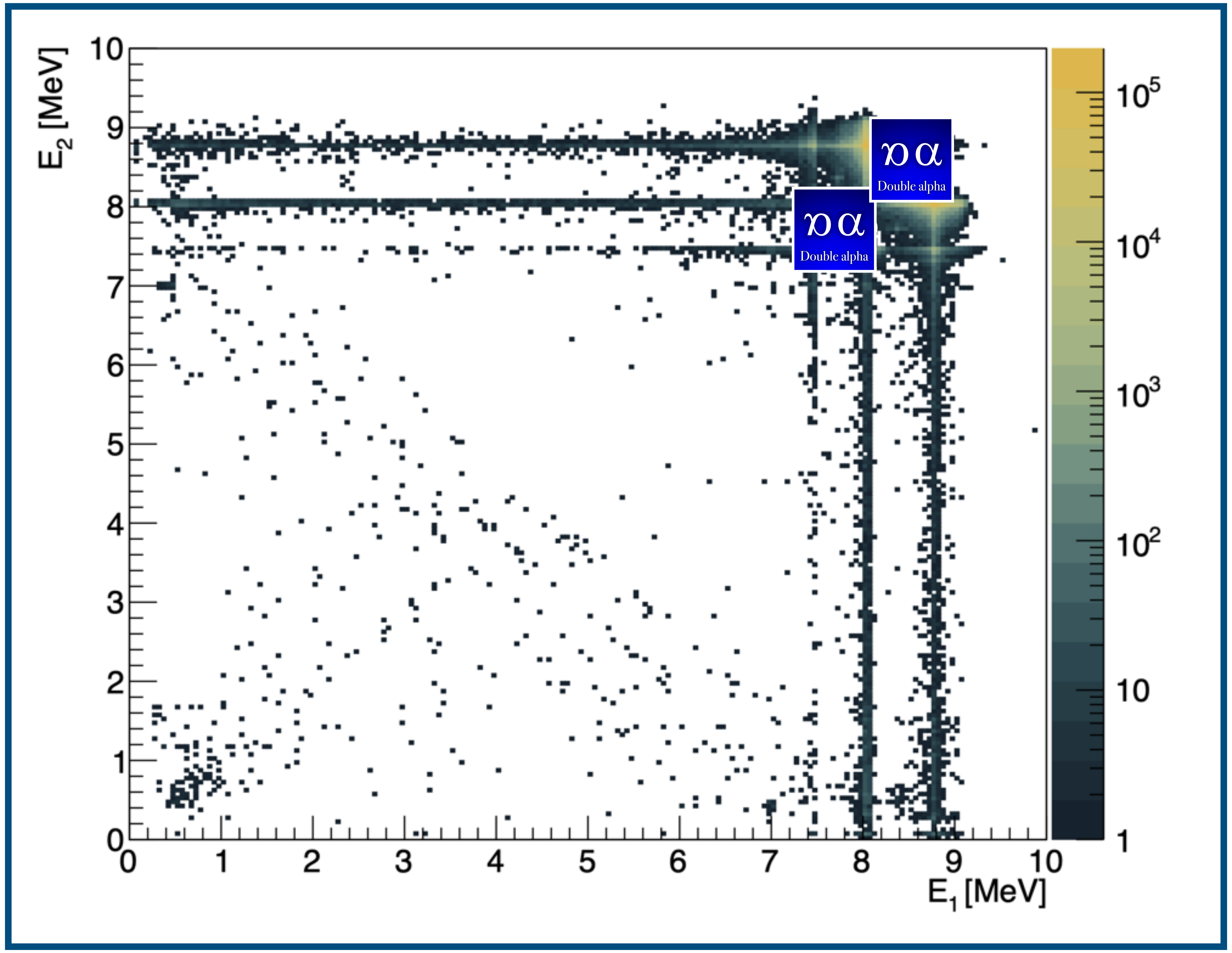
$$T_{\alpha 1} \sim T_{\alpha 2}$$

Effect of time cuts



: Region of interest

Preliminary

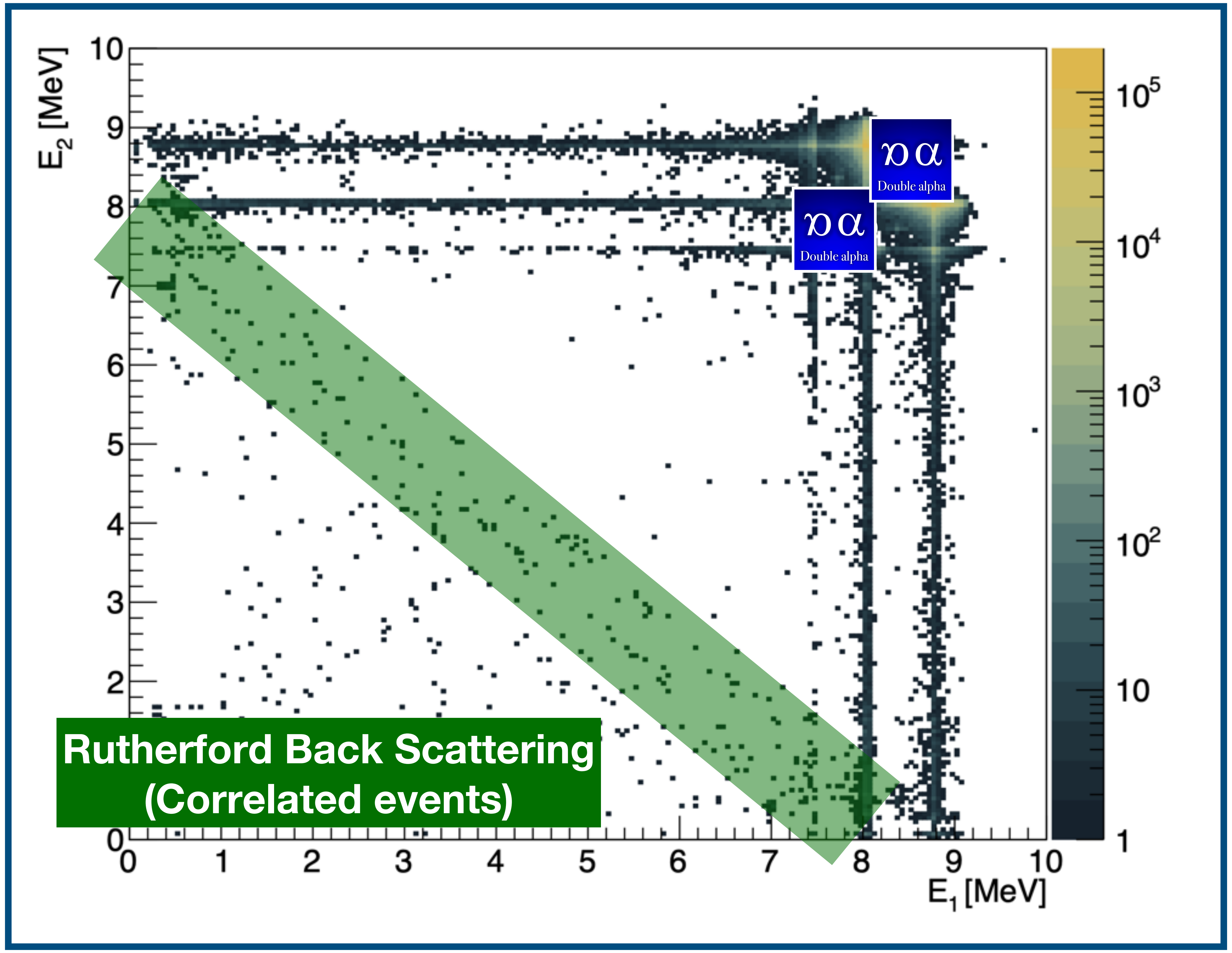


Without time cut

Effect of time cuts

: Region of interest

Preliminary

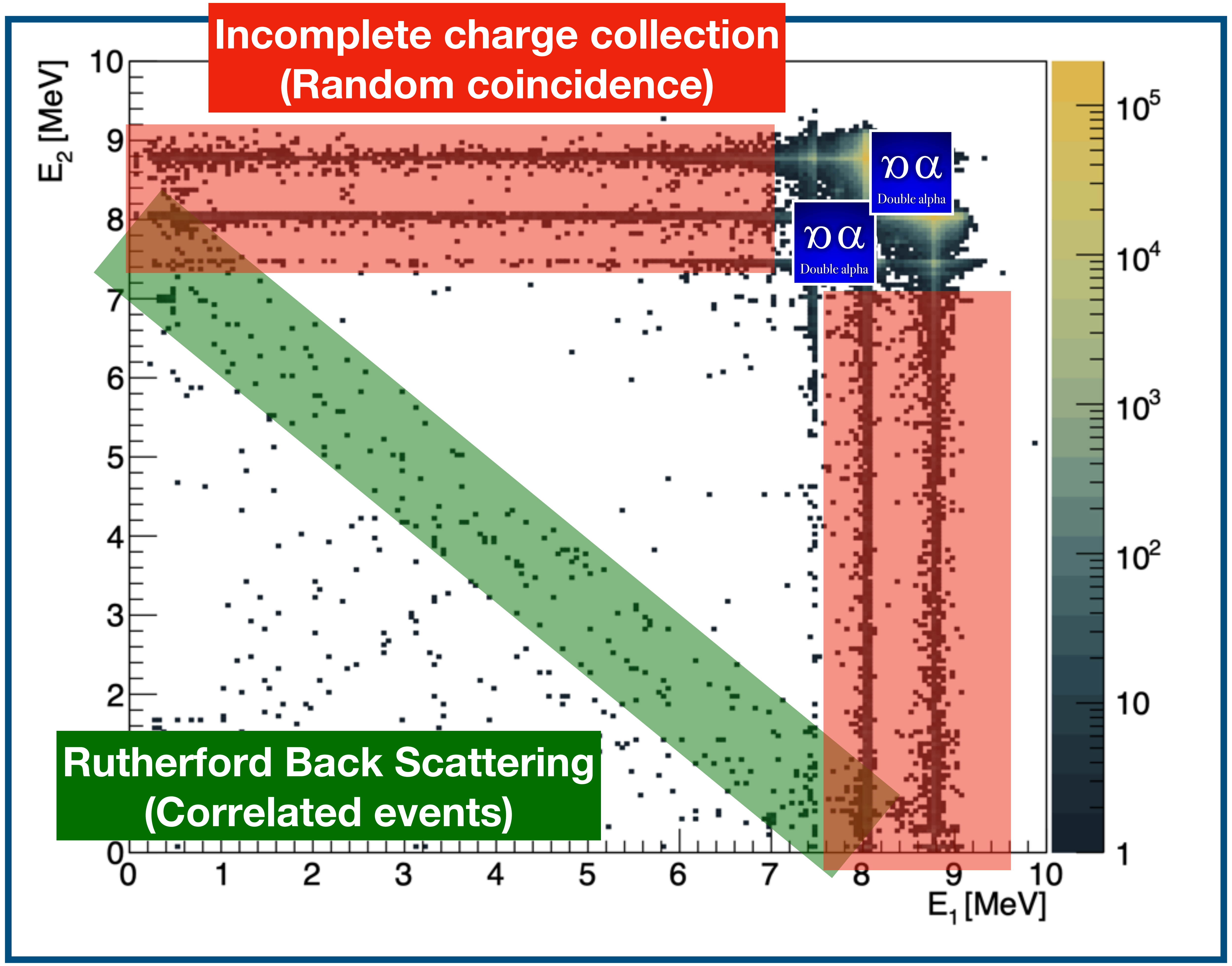


Without time cut

Effect of time cuts

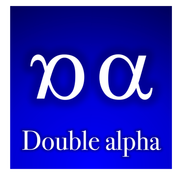
𝔇α Double alpha : Region of interest

Preliminary



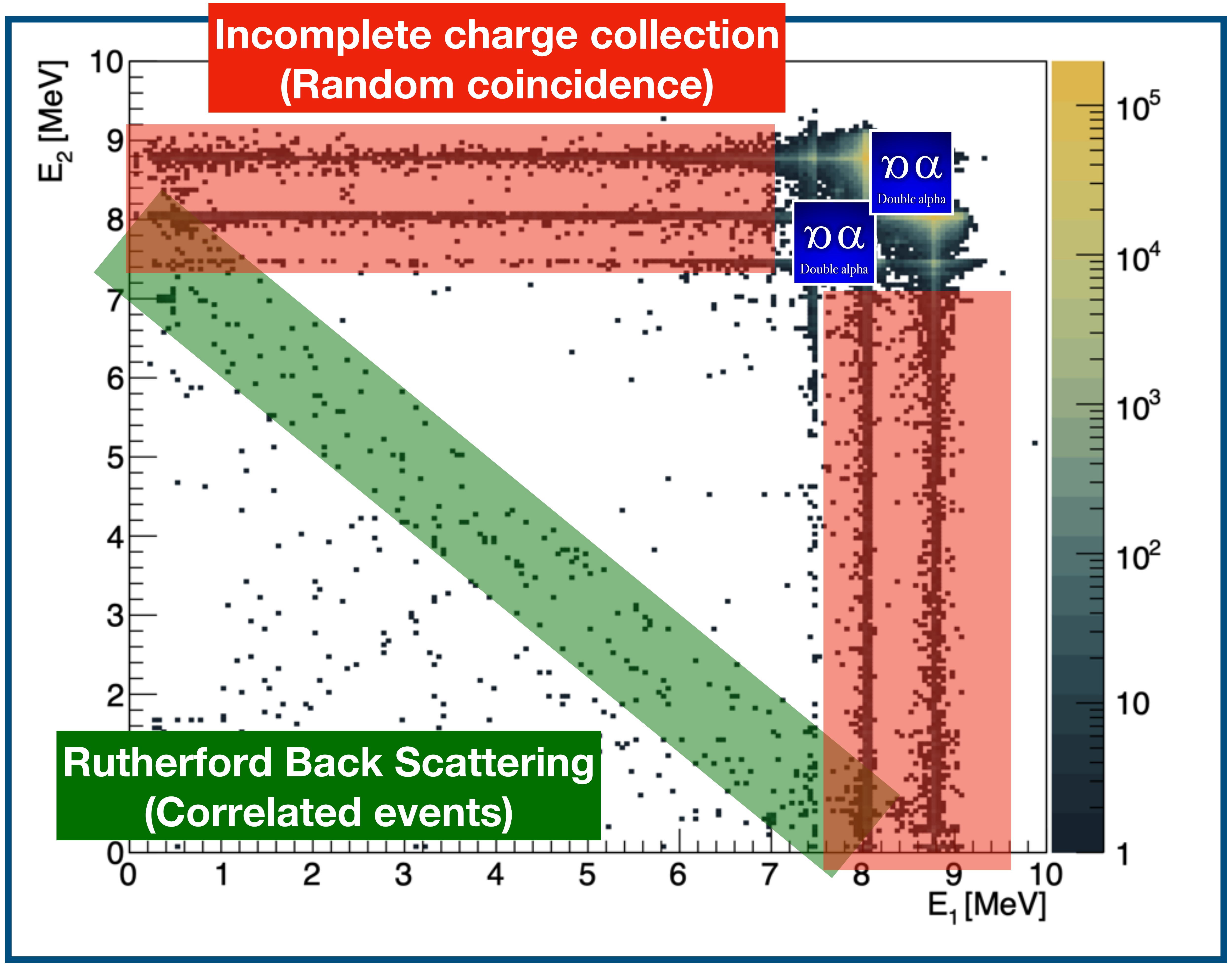
Without time cut

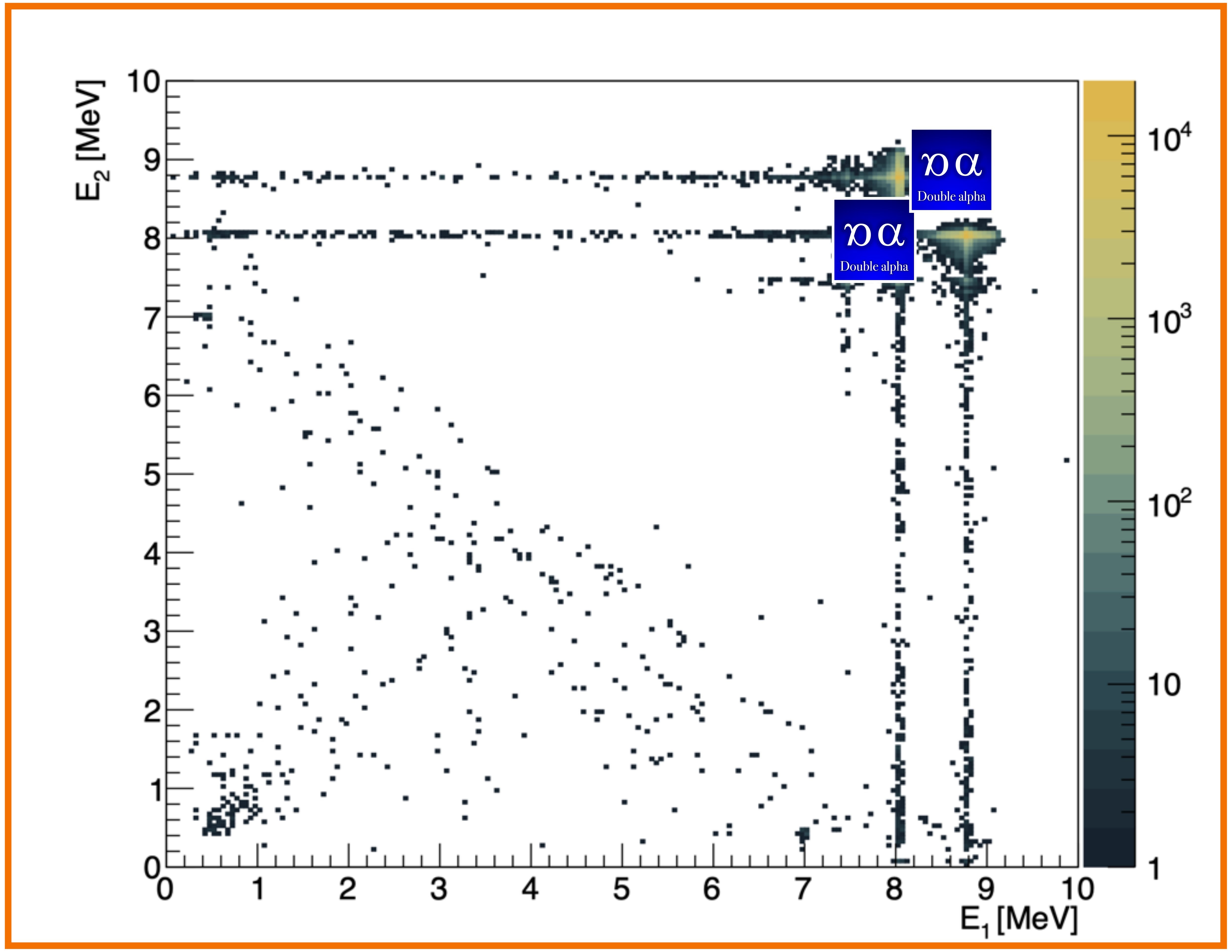
Effect of time cuts



: Region of interest

Preliminary





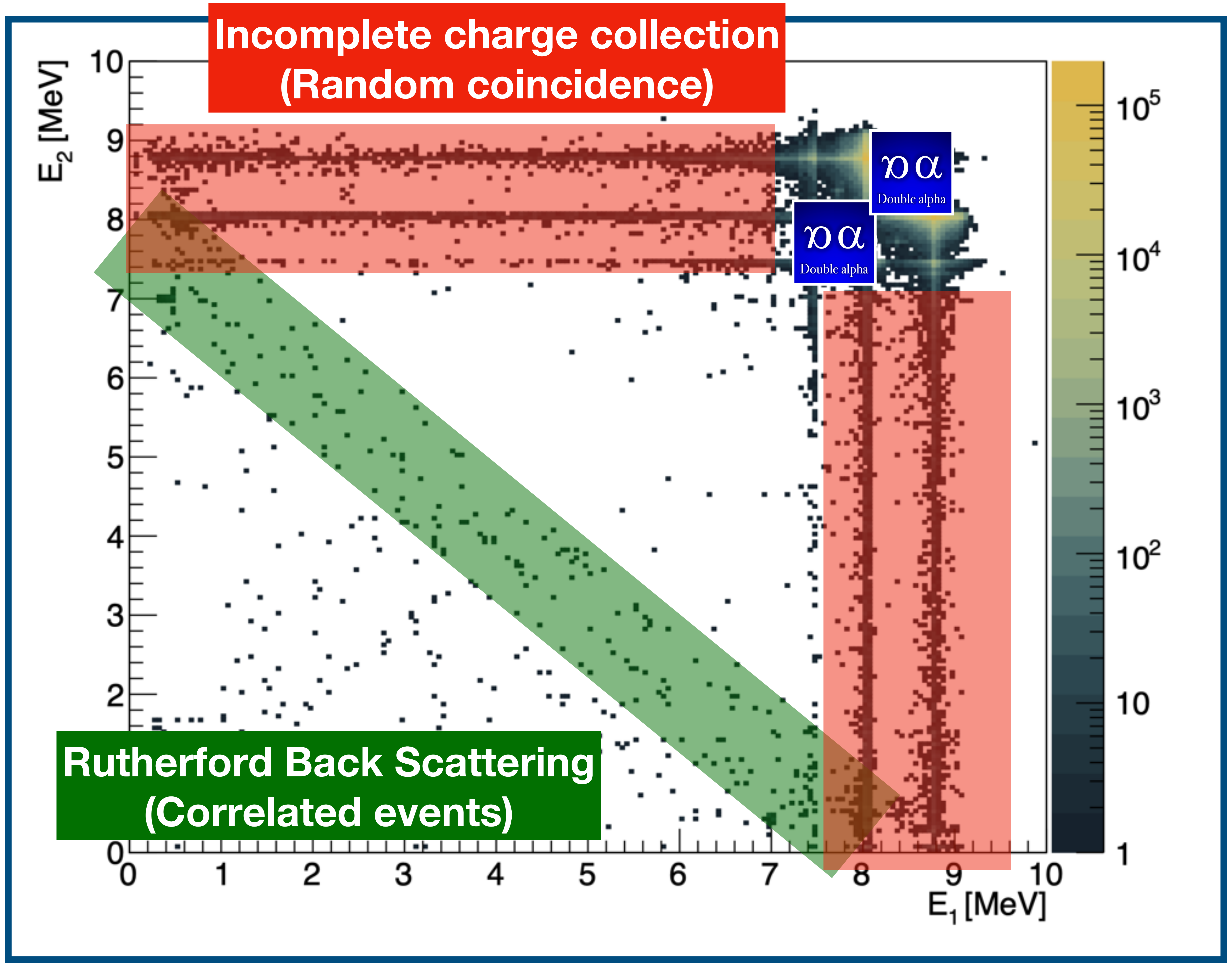
Without time cut

With time cut
ΔT < 20 ns

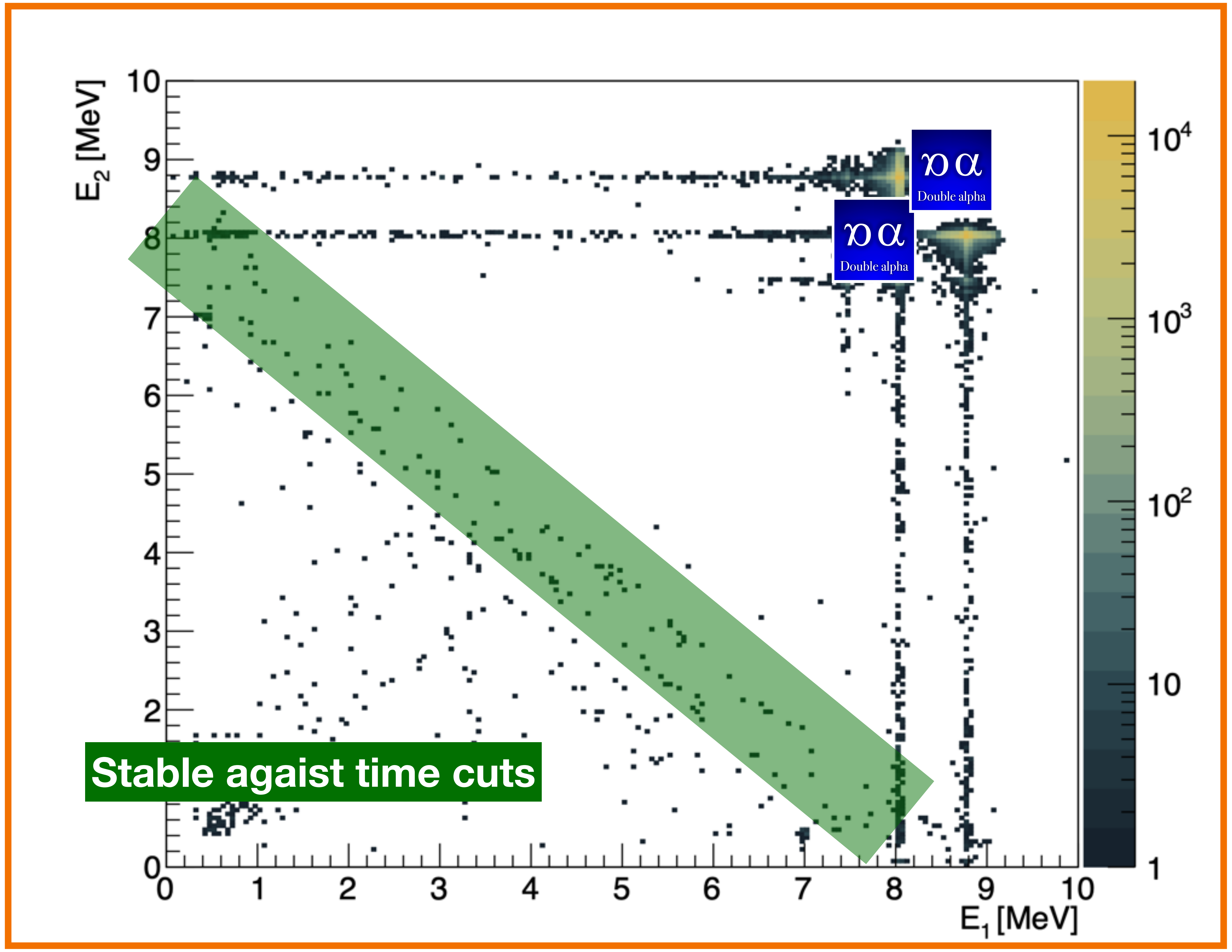
Effect of time cuts

ᴅα Double alpha : Region of interest

Preliminary



Without time cut



With time cut
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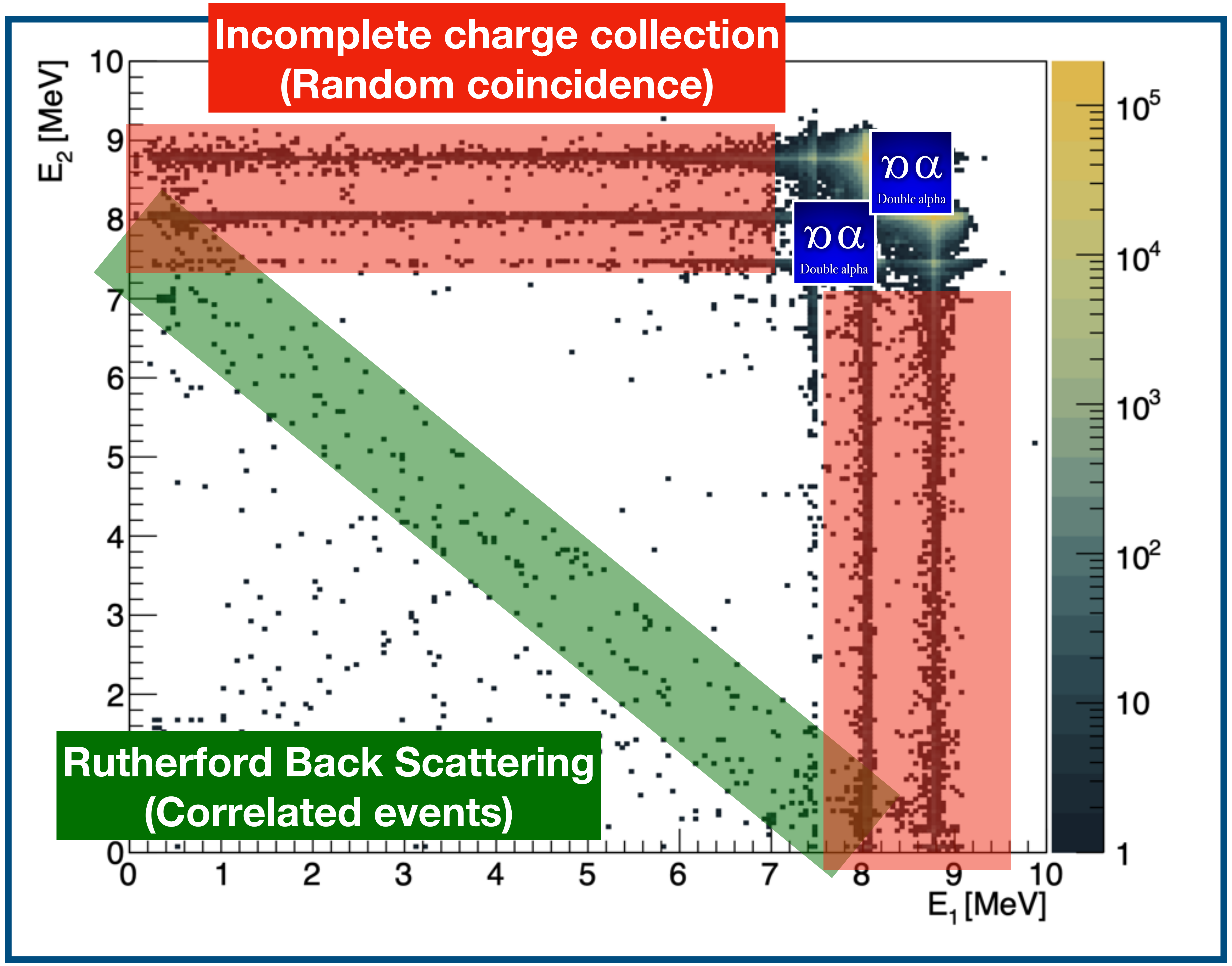
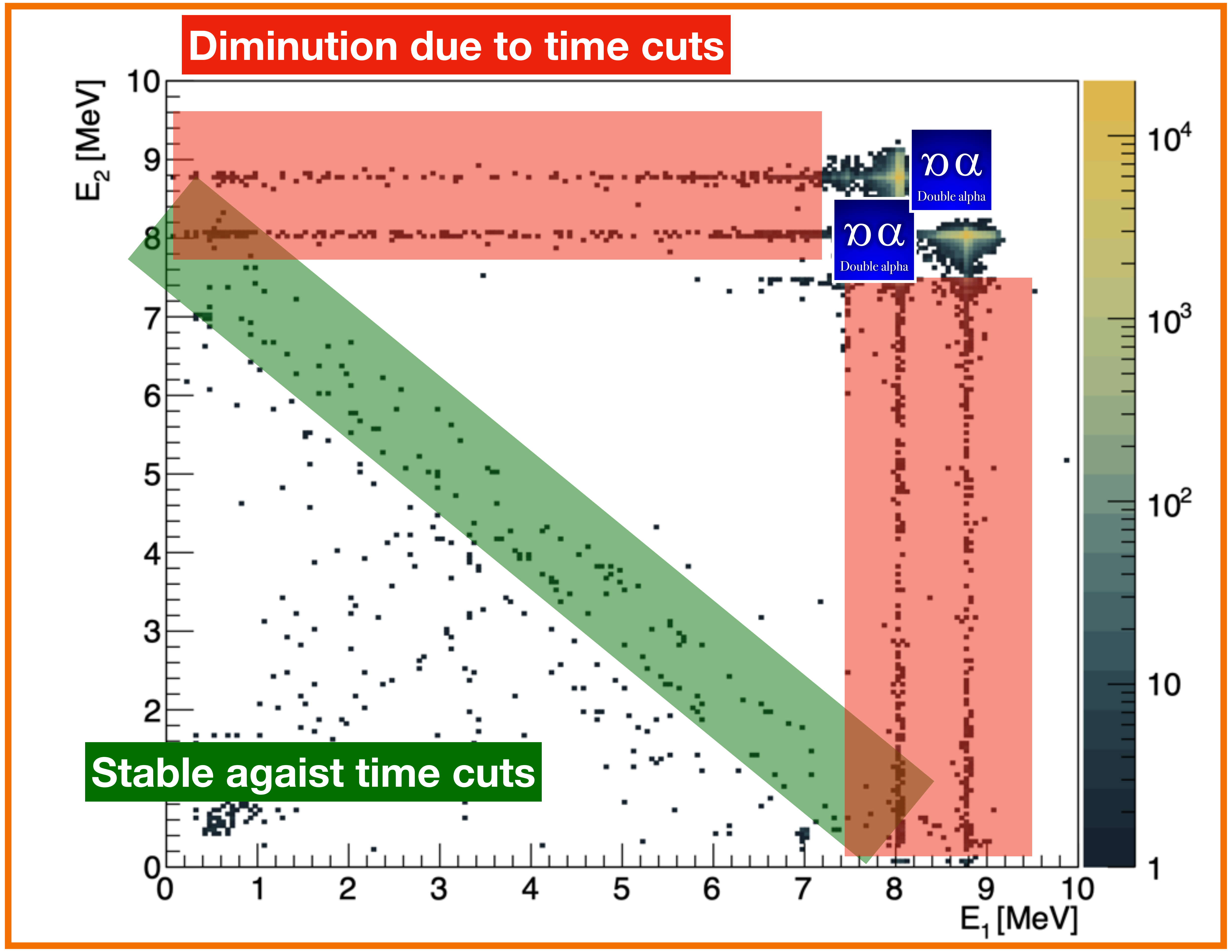


Without time cut



With time cut
$\Delta T < 20$ ns

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$$T_{\alpha 1} \sim T_{\alpha 2}$$

Time cuts seems to be consistent

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Energy

$$E_{\alpha 1} + E_{\alpha 2} \sim Q_{2\alpha}$$

Seems OK but Contaminants to be checked

Time

$$T_{\alpha 1} \sim T_{\alpha 2}$$

Time cuts seems to be consistent

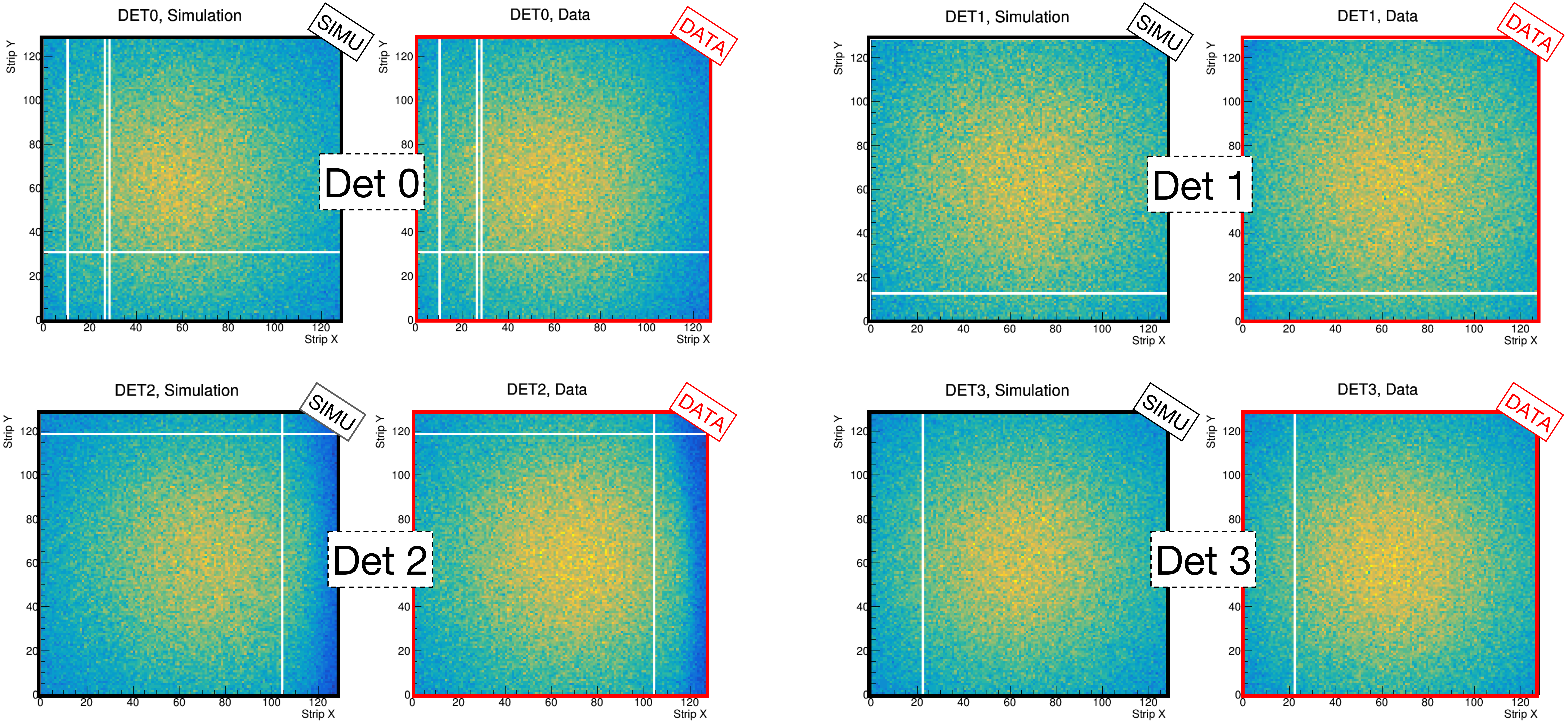
Space

$$\theta_{\mathrm{relative}} \sim 180°$$

Beam spot to be reconstructed using simulations

Hit Pattern Simulation

Preliminary



Conclusion

Data Energy Time Space

In good position to probe
Double alpha decay

Double α team
On its way to probe double α decay

The Melted Car
1944
Robert Doisneau

Thank you for your attention !

L. Heitz[1,2], E. Khan[2], Ch. Theisen[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], B. Sulignano[1], D. Thisse[1], L. Thulliez[1], G. Toccabens[1], M. Vandebrouck[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

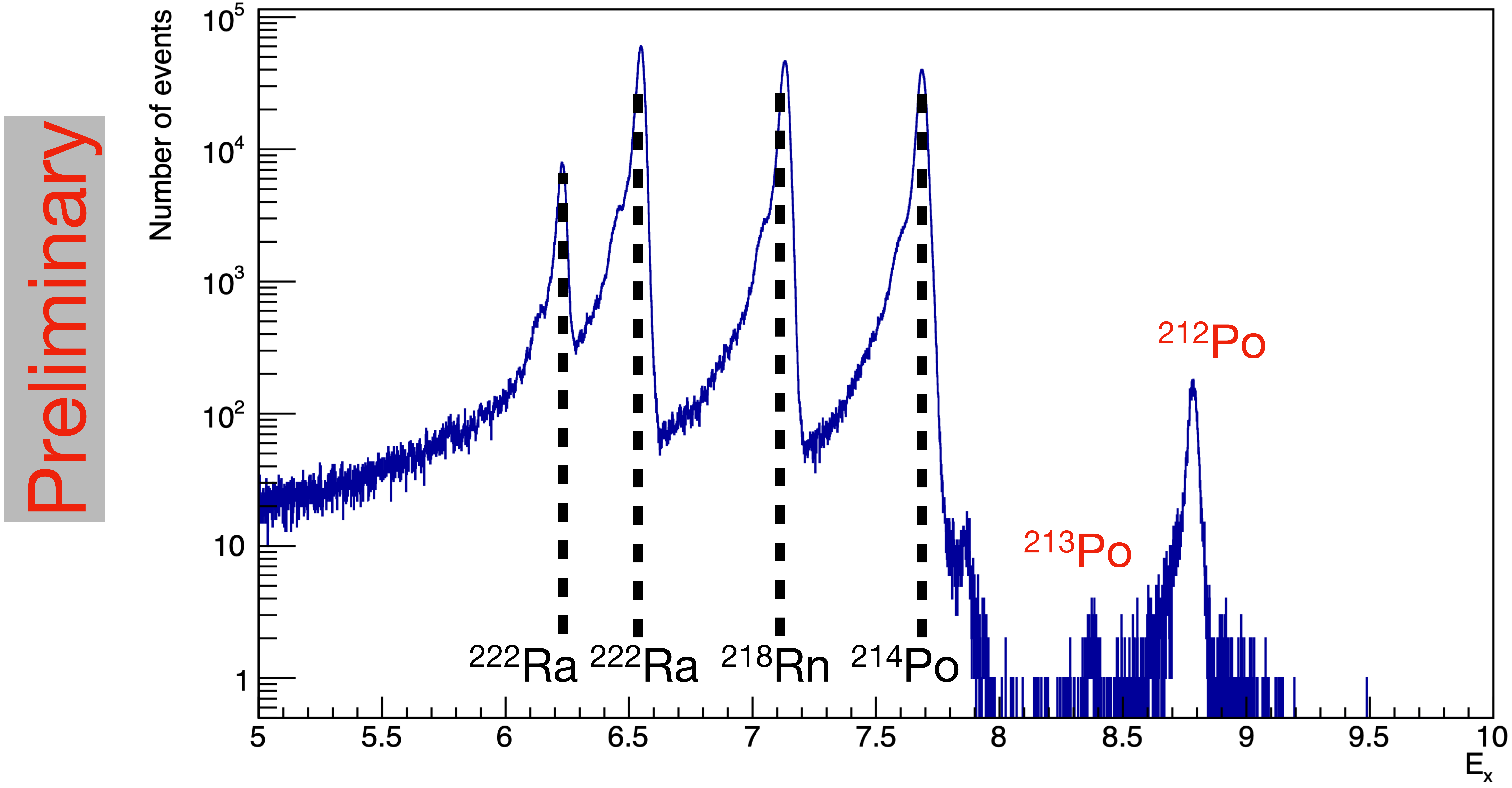
Double alpha

Back-up

Energy spectrum for ^{222}Ra

Expected :

$^{222}Ra \rightarrow$ $^{218}Rn \rightarrow ^{214}Po \rightarrow ^{210}Pb \rightarrow ^{210}Po \rightarrow ^{208}Pb$



2 alpha predictions

	Approach	Comments	Best B.R.
Poenaru - 1985	Super Asymetric Fission	Large BR. Close to ^{8}Be	~10^{-13}
Tretyak - 2021	^{8}Be cluster	Very Large BR ($T_{2alpha}>10^{33}$ yr)	…
Santhosh - 2021	Modified Liquid Drop Model	Large BR. Close to ^{8}Be, weird ^{209}Bi	Close to Poenaru
Mercier Zhao - 2021,2023	Time Dependant evolution, EDF	uncertainties hard to estimate	~$10^{-6.5}$
Denisov - 2022	Modification of Unified Model for Alpha Decay	Very small B.R.	~10^{-2}

Half-life computation

- **Generic (phenomenological) formula for radioactive decays**

$$\tau^{-1} = \nu \times S \times P_s$$

Half-life

Assault frequency ($\sim 10^{20}\ s^{-1}$)

Preformation factor
Hard to estimate

Barrier Penetration Probability
WKB-like expressions

$$\log P_s \propto -2\int dr \sqrt{2B(r)(E(r) - E_0)}$$

B ~ reduced mass
E ~energy of the system

- **Different models : different** S, P_s $(E\, and\, B)$

Half-life computation

$$\tau^{-1} = \nu \frac{1}{1 + \exp 2S}$$

Half-life computation

$$\tau^{-1} = \nu \frac{1}{1 + \exp 2S}$$

Assault frequency

Half-life computation

$$\tau^{-1} = \nu \frac{1}{1 + \exp 2S}$$

Assault frequency

Minimised integral action

$$\delta S = 0$$

$$S = \int_{s_{in}}^{s_{out}} ds \sqrt{\mathcal{M}_{eff}(s)(V_{eff}(s) - E_0)}$$

Half-life computation

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PES

Information about energy cost of a path

(Computed w/ RHB)

Half-life computation

$$\tau^{-1} = \nu \frac{1}{1+\exp 2S}$$

Assault frequency

Minimised integral action

$$\delta S = 0$$

$$S = \int_{s_{in}}^{s_{out}} ds \sqrt{\mathcal{M}_{eff}(s)(V_{eff}(s) - E_0)}$$

$$\mathcal{M}_{\text{eff}}(s) = \sum_{ij} \mathcal{M}_{ij} \frac{\mathrm{d}q_i}{\mathrm{d}s} \frac{\mathrm{d}q_j}{\mathrm{d}s}$$

$$\mathcal{M} = M_{(1)}^{-1} M_{(3)} M_{(1)}^{-1}$$

$$\left[M_{(k)}\right]_{ij} = \sum_{\mu\nu} \frac{\langle 0|\hat{q}_i|\mu\nu\rangle \langle \mu\nu|\hat{q}_j|0\rangle}{(E_\mu + E_\nu)^k}$$

Inertial effective mass

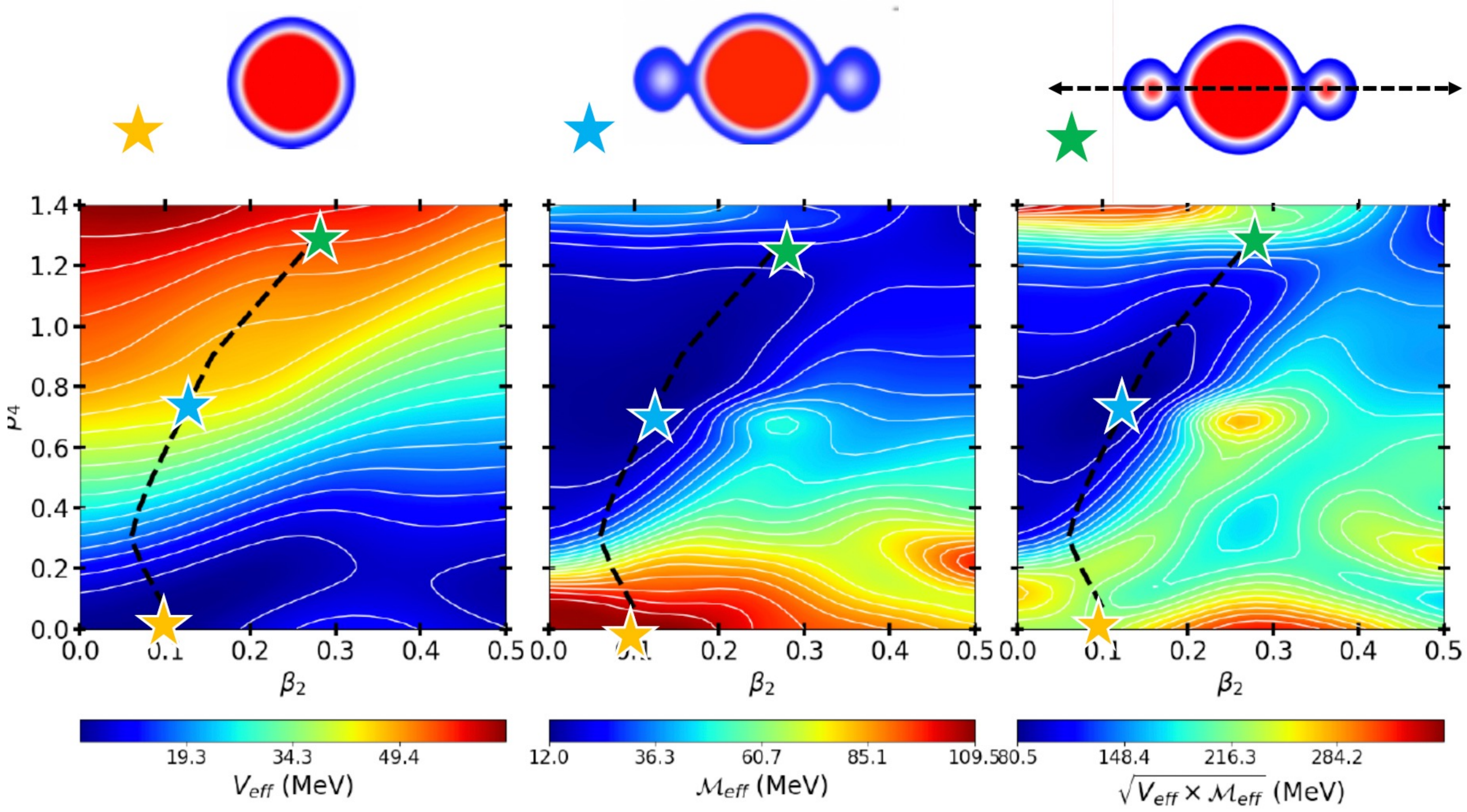
Information about energy needed to deform nucleus

(Computed w/ ATDHB & perturbed cranked approx)

PES

Information about energy cost of a path

(Computed w/ RHB)



H. Wilsenach courtesy

$$S(L) = \int_{s_{\rm in}}^{s_{\rm out}} \frac{1}{\hbar} \sqrt{2\mathcal{M}_{\rm eff}(s)[V_{\rm eff}(s) - E_0]} ds \qquad P = \frac{1}{1 + \exp[2S(L)]} \qquad T_{1/2} = \frac{\ln(2)}{nP}$$