Report on **S181** experiment

Extending the quest toward the N=126 *r*-process waiting point

Peter Reiter[1], Giovanna Benzoni[2], Marta Polettini[3],
Anabel Morales[4], and **M. Kundu**[4]

On behalf of the

HISPEC–DESPEC collaboration

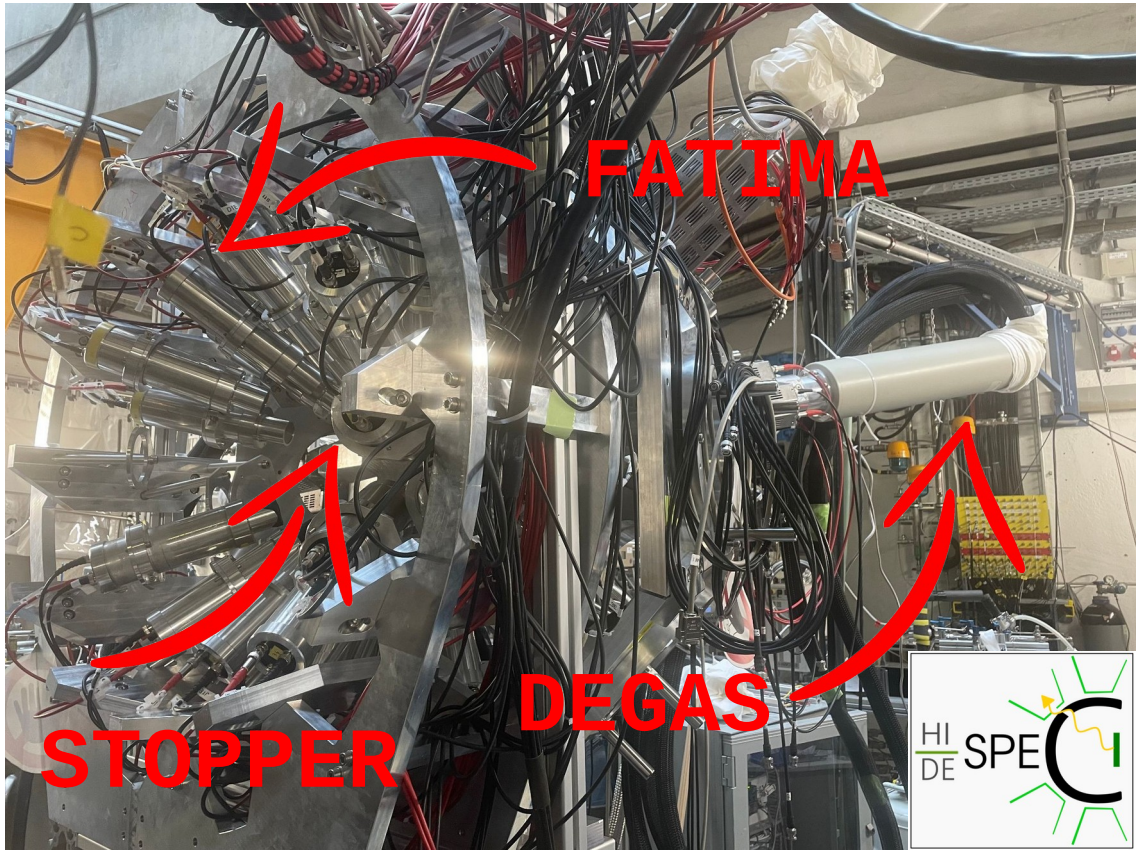
1) University of Cologne, 2) INFN Milano, 3) University and INFN Padova, 4) IFIC,CSIC–UV

S181 – Main Goals

Extending the quest towards the N=126 waiting point

Primary beam: ^{238}**U**
Energy: **1000 MeV/u**
Intensity: **10^9 ppb**
Pulse: **2(3) s**
Spokespersons: **P. Reiter, G. Benzoni, M. Polettini, A.I. Morales**

- Study of decay properties of nuclei leading to the formation of the “gold” peak in explosive stellar nucleosynthesis



Hybrid FATIMA + DEGAS spectrometer and wide implant-decay detector of the DESPEC experiment

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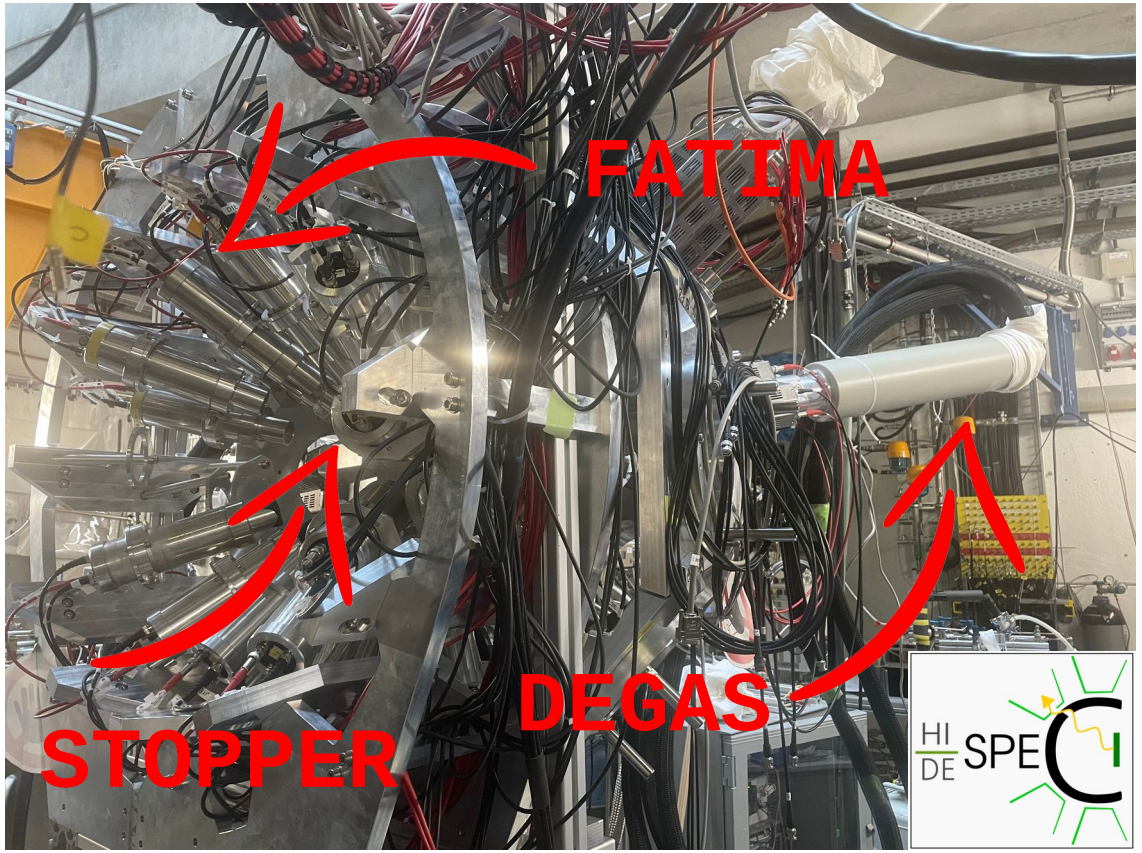
- Study of decay properties of nuclei leading to the formation of the “gold” peak in explosive stellar nucleosynthesis
- First decay spectroscopy of ^{222}At, ^{224}At isotopes



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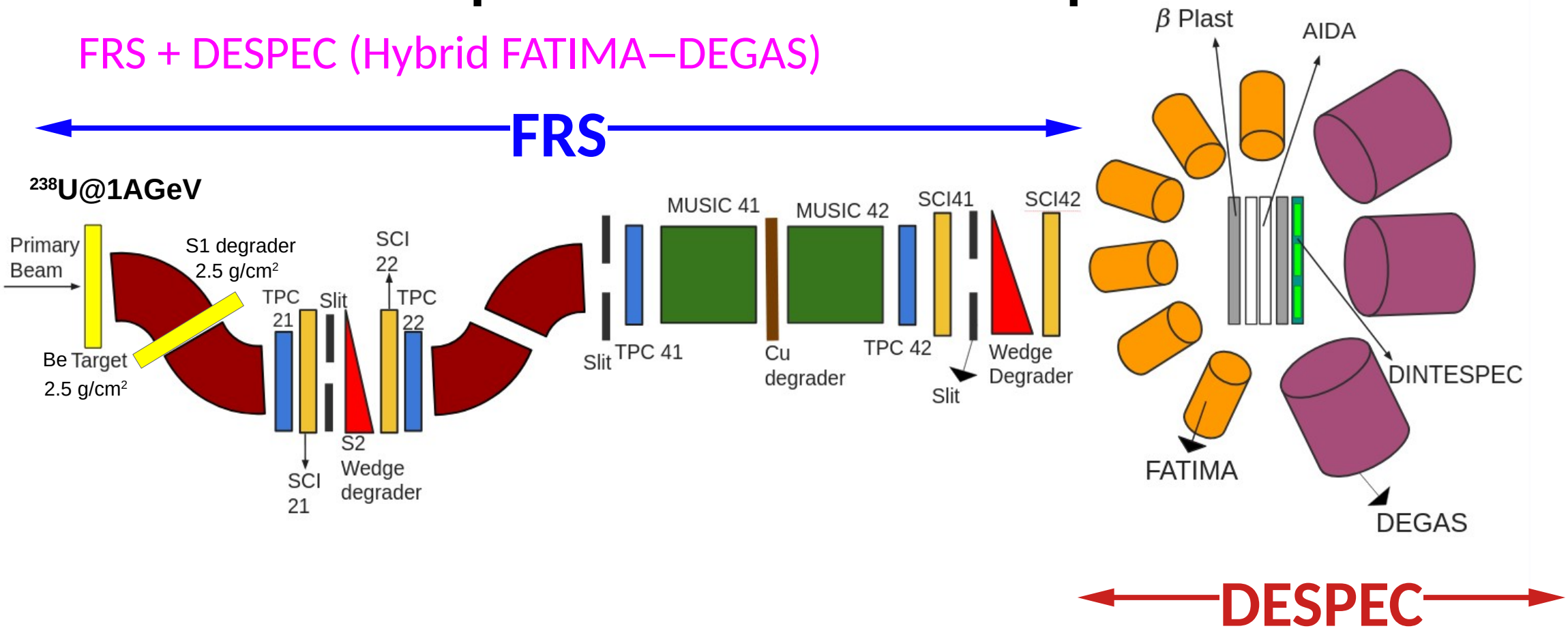
S181 – Experimental setup

FRS + DESPEC (Hybrid FATIMA–DEGAS)



[A. Mistry et al., NIMA 1033, 166662 (2022)]

S181 – Experimental setup

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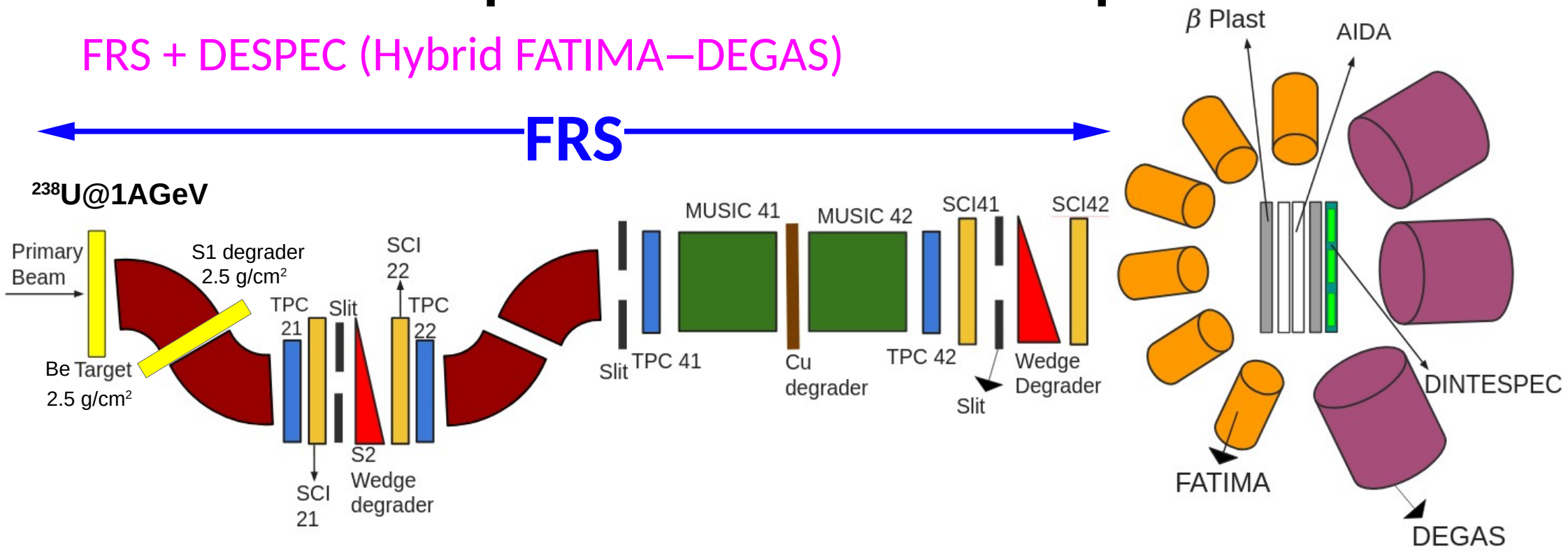
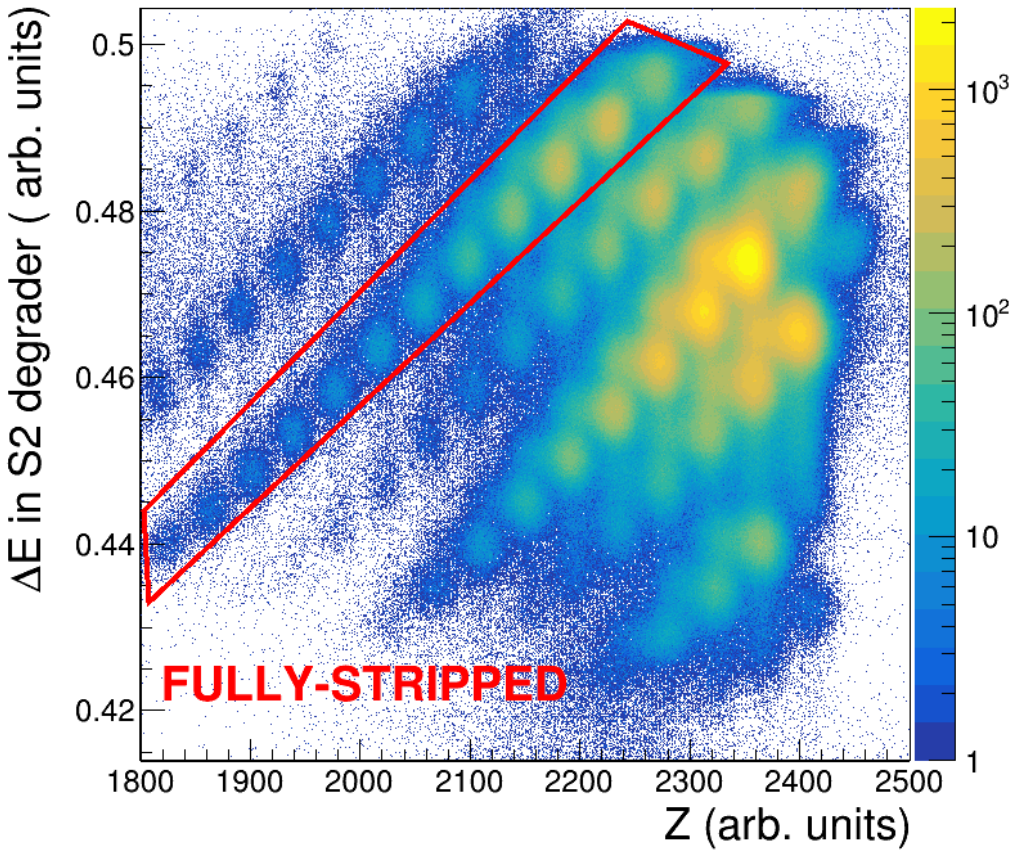


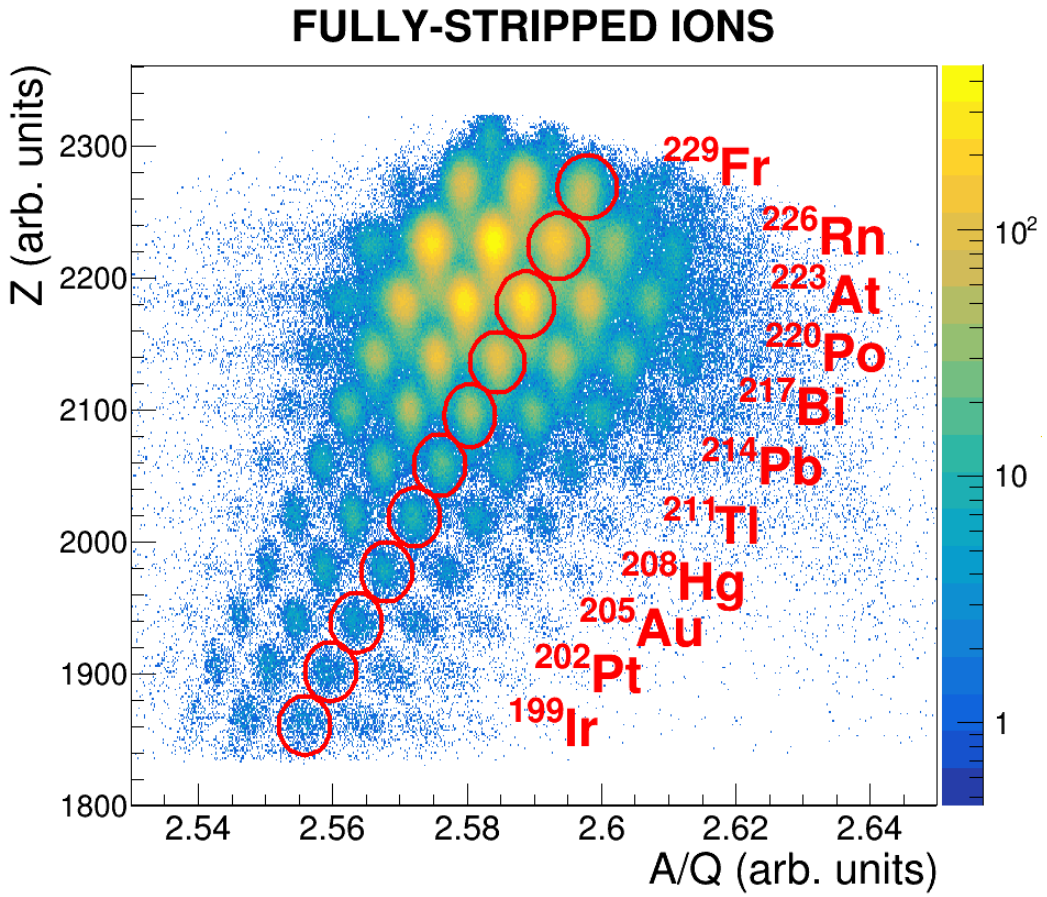
- **AIDA:** 2 DSSSD layers (24cm x 8cm, ~49000 pixels)
- **βPlast:** 2 fast plastic scintillation detectors
- **DEGAS:** 12 triple HPGe detectors
- **FATIMA:** 36 fast-timing $LaBr_3(Ce)$ detectors
- **DINTESPEC:** 1 DSSD layer with 2 wafers (6.5cm x 6.5cm, ~2000 pixels)

[A. Mistry et al., NIMA 1033, 166662 (2022)]

S181 – Preliminary PID

Multiple charge-state combinations

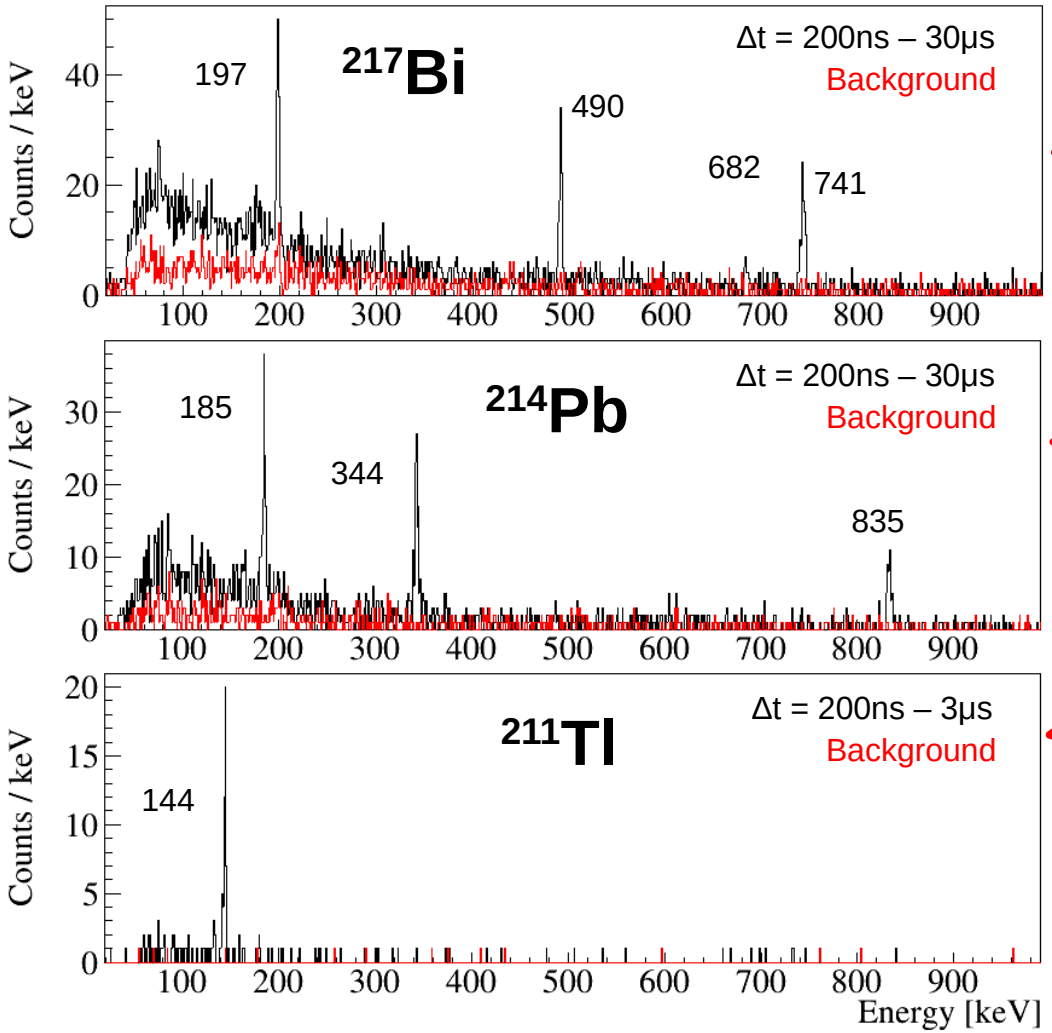


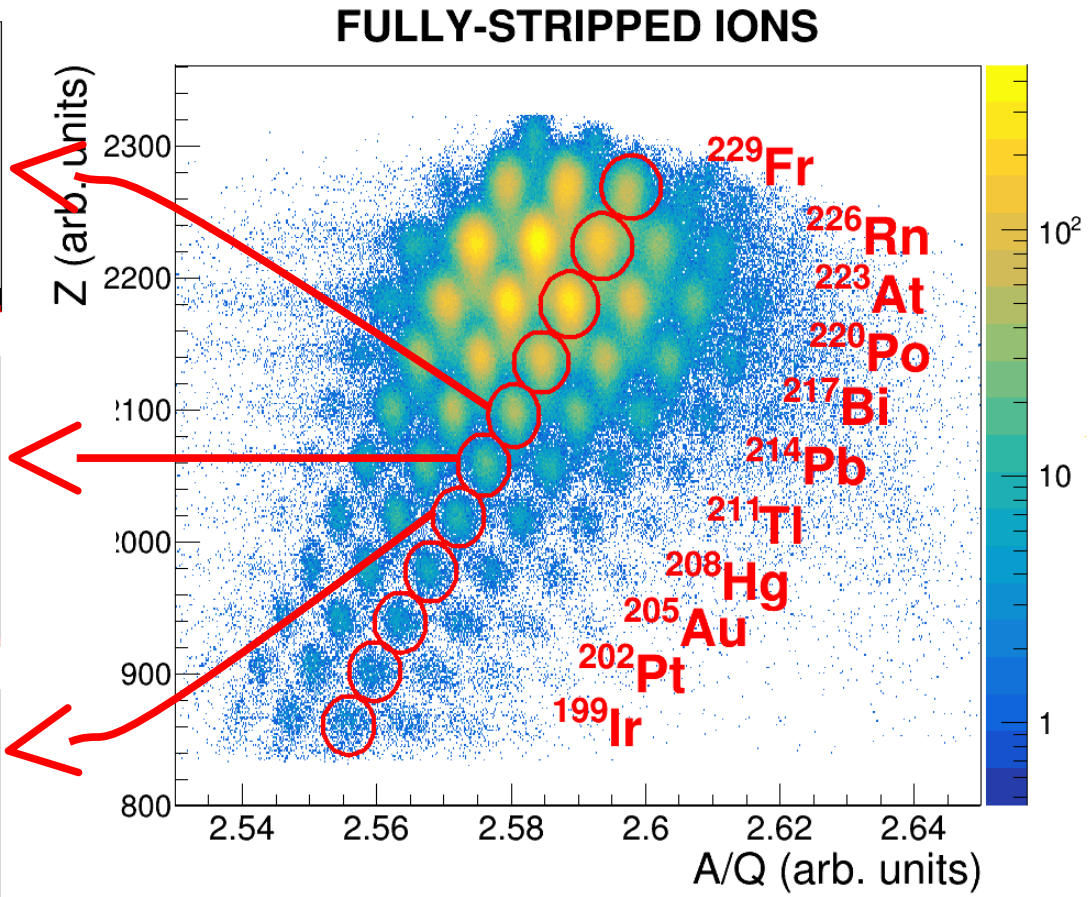


~22h data taking

S181 – Preliminary PID

Multiple charge-state combinations
Confirmed by isomer tagging





[A. Gottardo et al., PRL (2012), PRC (2013), PRC(2019)]

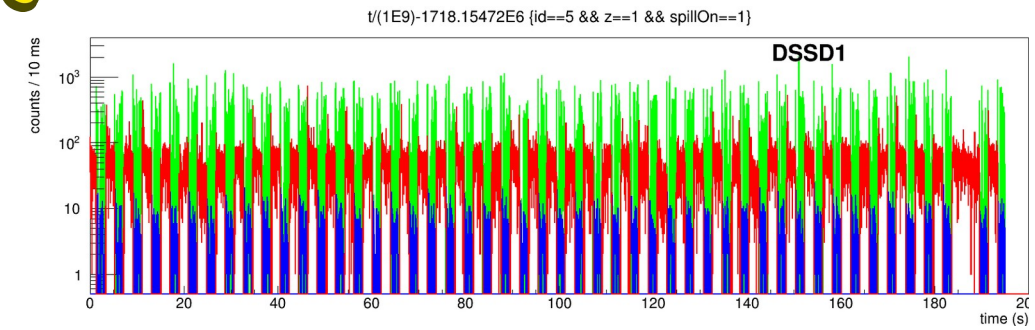
S181 – AIDA CHALLENGES

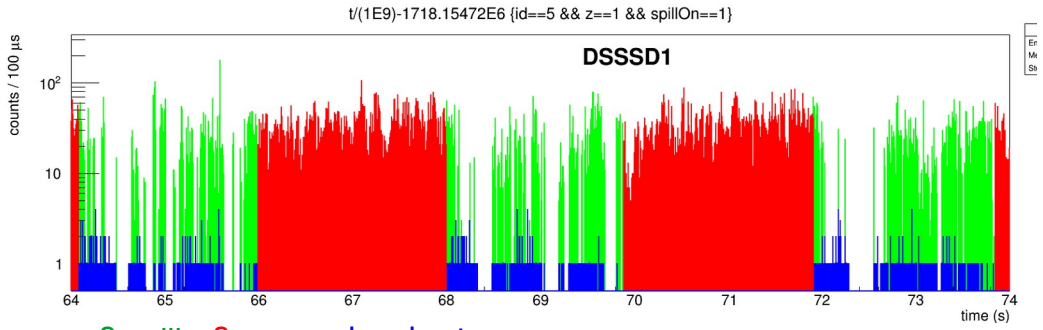
Extremely high levels of electronic noise

AIDA Scalers

	Implants	Decays
DSSD 1	1901	2288121
DSSD 2	1960	5047337

Dead time during spill in downstream DSSSD?





β spill β pause implant

Strange c4root time-stitched correlations

S181 – AIDA STRATEGY

Start from scratch:

- Undo clustering and study X & Y strips separately
- Check multiplicities of high- (implant) and low- (electron) energy signals
- Check multiplexer correction

Analysis approach:

- Make independent trees per sub-system (FRS, AIDA, DEGAS, FATIMA, βPlast)
- **AIDA**: Generate trees with program developed by O. Hall for BRIKEN
  - Undo clustering
  - Redefine implantations
  - Redo energy calibration with internal α activity (Mallicka's talks)
  - Check variation of thresholds with time & define thresholds/strip (Mallicka's talks)
- **Rest of subsystems**: Generate non-time-stitched c4root trees

S181 – AIDA APPROACH

Start from scratch:

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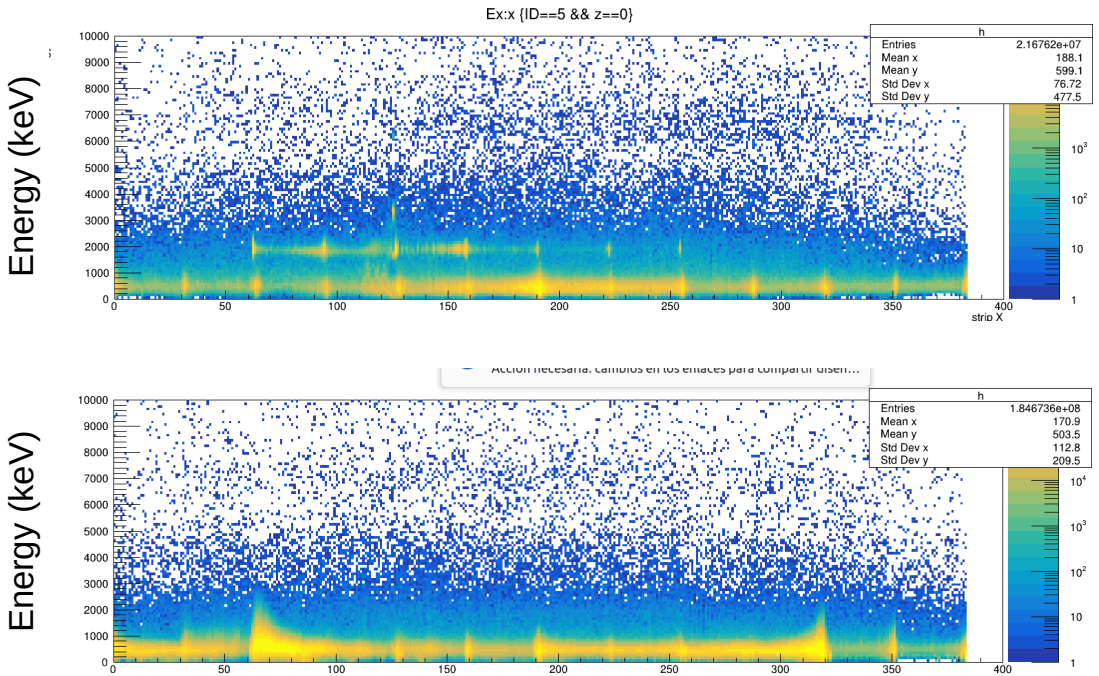
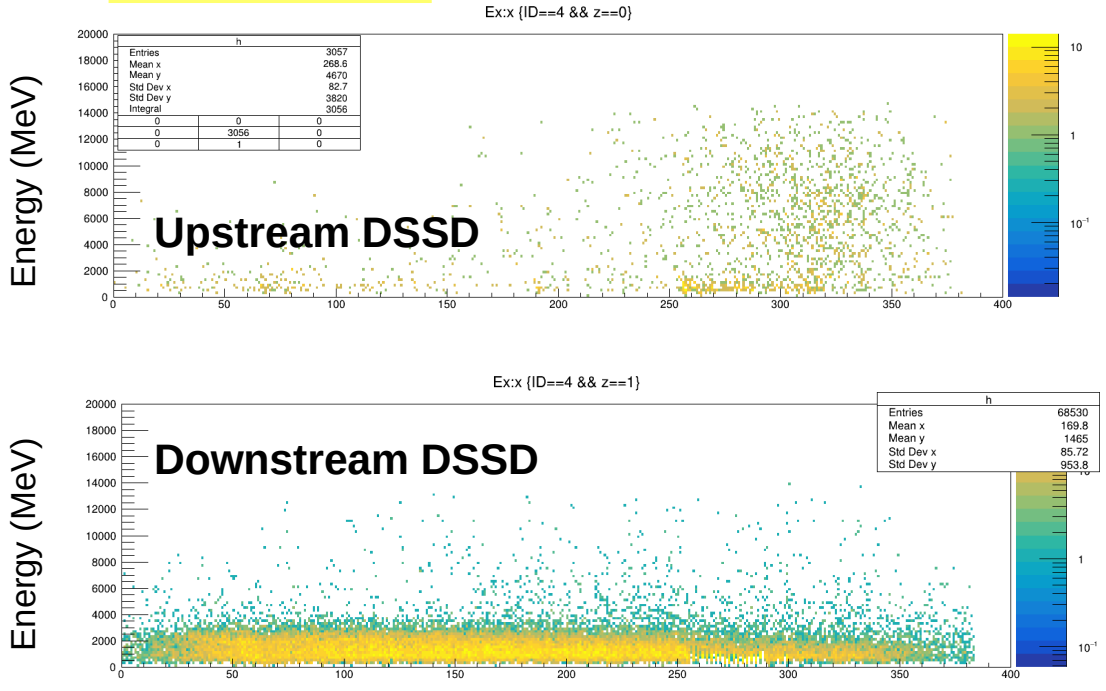
BETAS



IMPLANTS



X strip number

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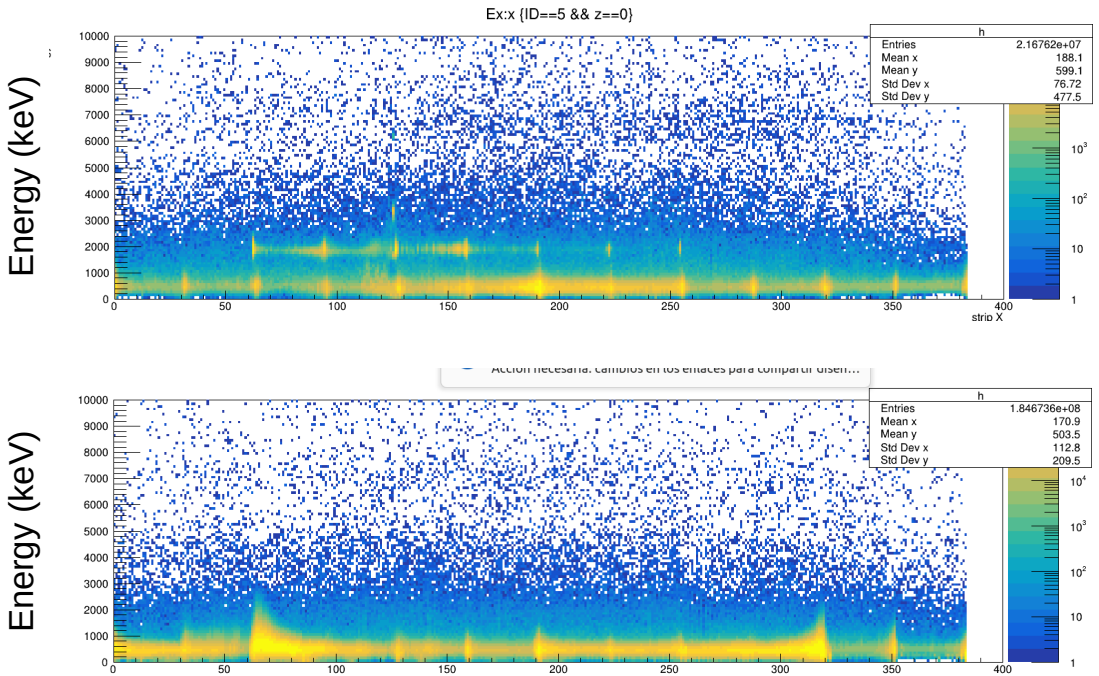

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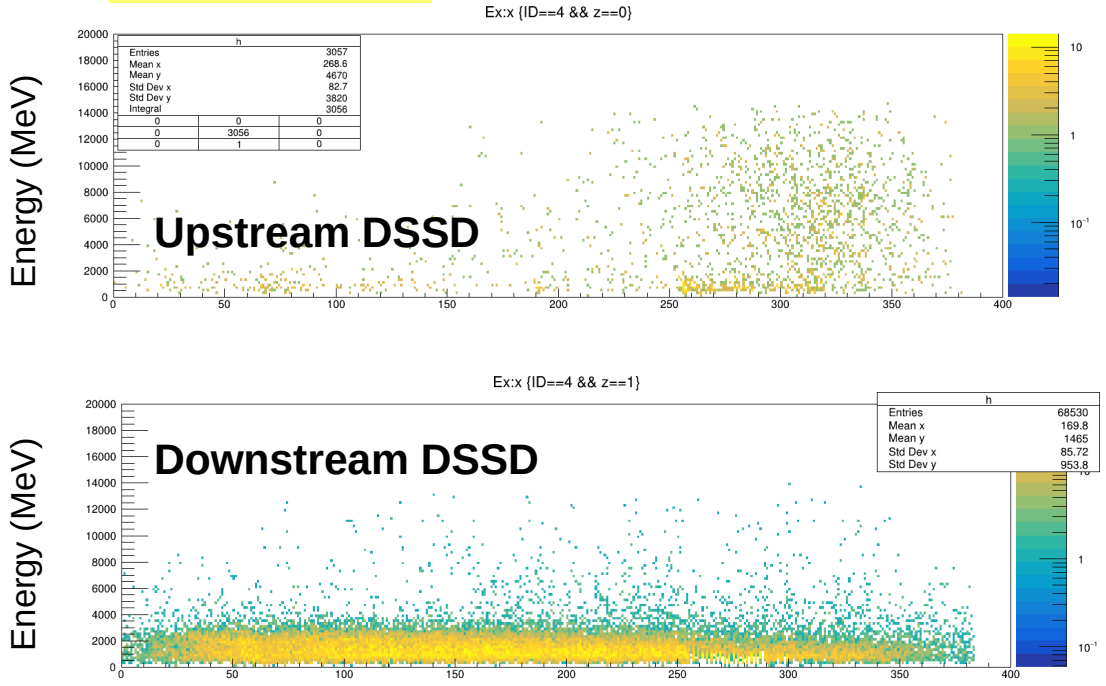

X strip number

Pattern every 32 strips

S181 – AIDA APPROACH

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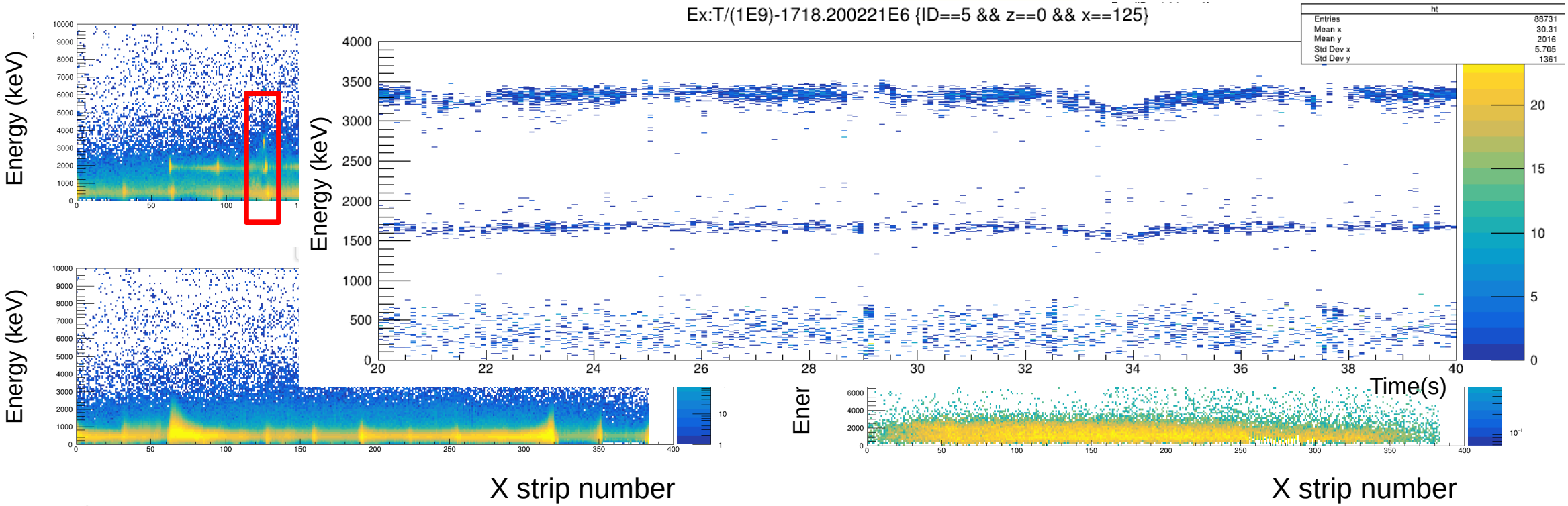
BETAS

IMPLANTS



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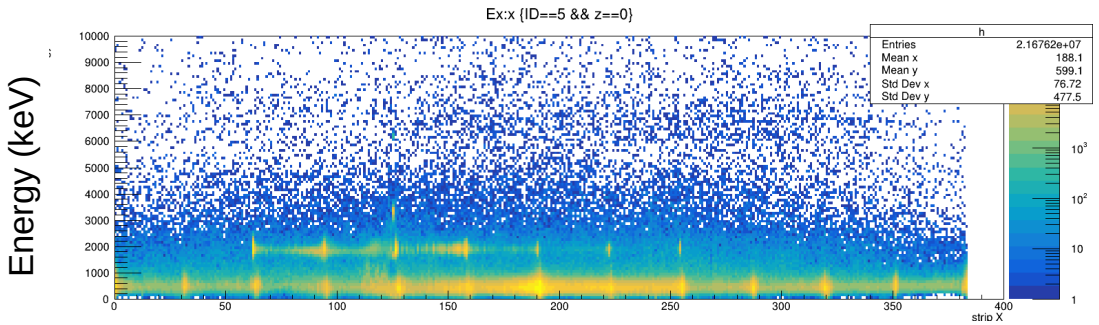

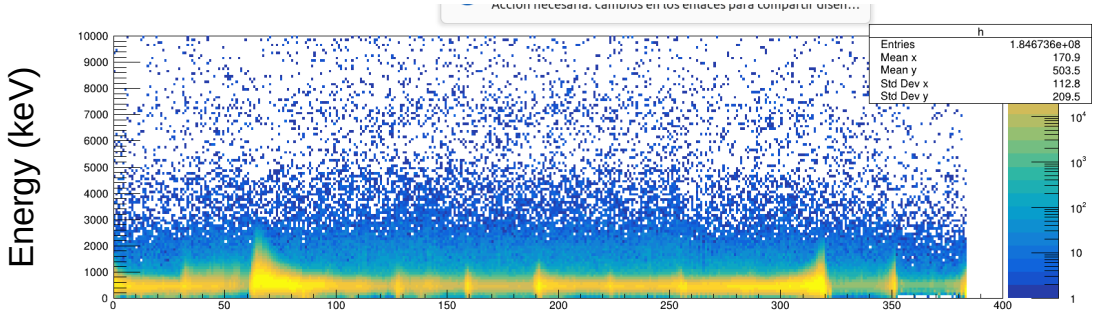

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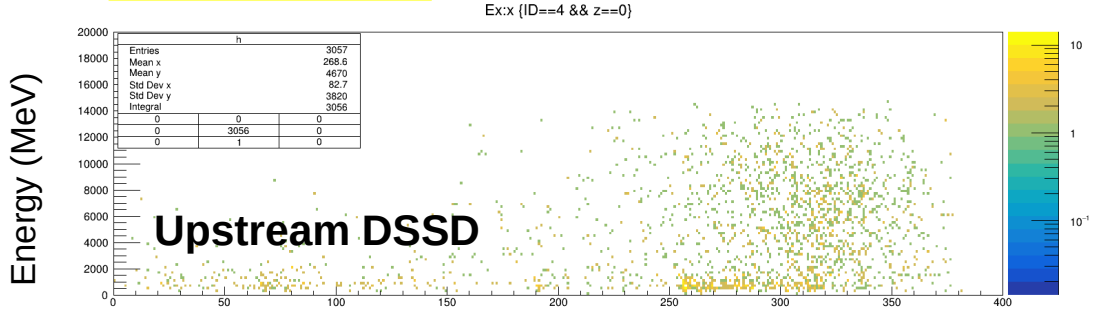

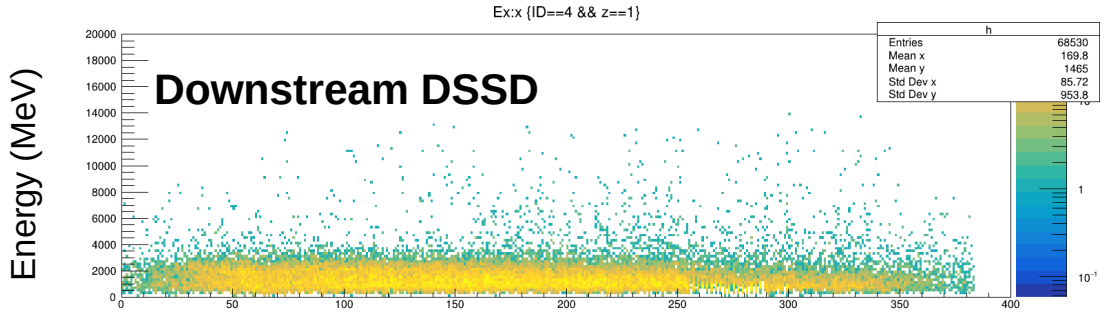

X strip number

👉 Very noisy downst. DSSSD

S181 – AIDA APPROACH

Solution:

- Remove **noisy X & Y strips** before clustering for β-like events
- Analyze **only upstream DSSSD**, where implants show good pattern

QUESTION

Remove only noisy strips?

(henceforth “**loose background suppression**”)

or the whole AIDA event defined by the ASIC’s clock?

(henceforth “**strong background suppression**”)

S181 – AIDA

XY cluster analysis. **Clustering**

- Beta-like **cluster:** add adjacent X / Y strips detected within 4 μs. XY cluster within 2.2 μs
- Implant-like **pixel:** if adjacent strips fire, select X & Y strips with maximum energy in AIDA (X & Y signal detected in the same AIDA event)

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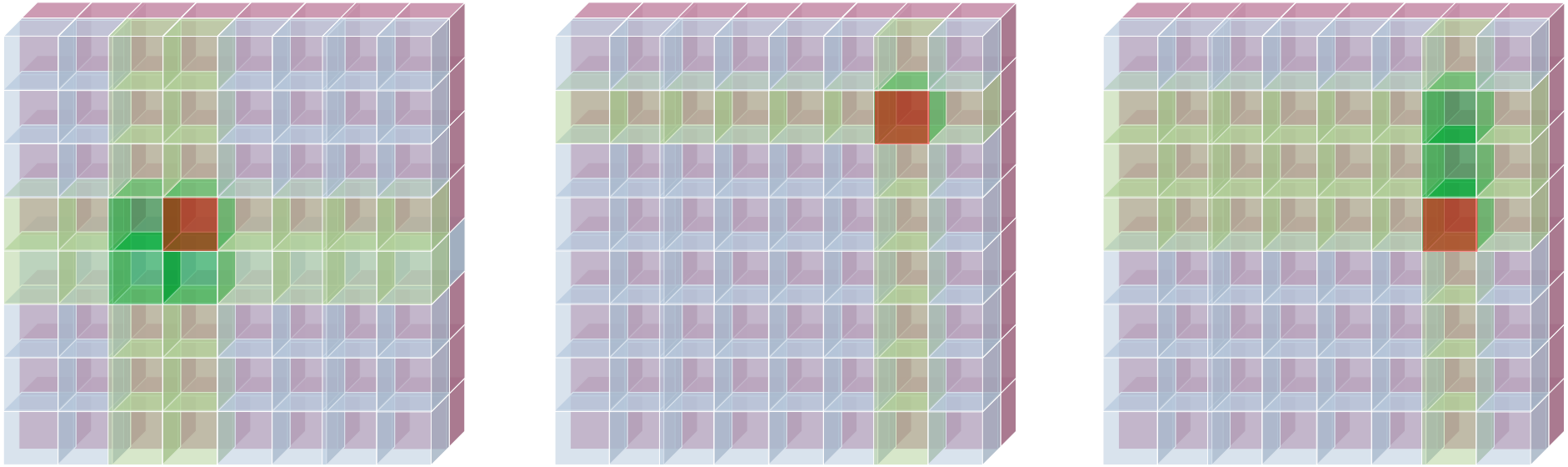
POSITION CORRELATION $\Delta XY = 0$



S181 – AIDA

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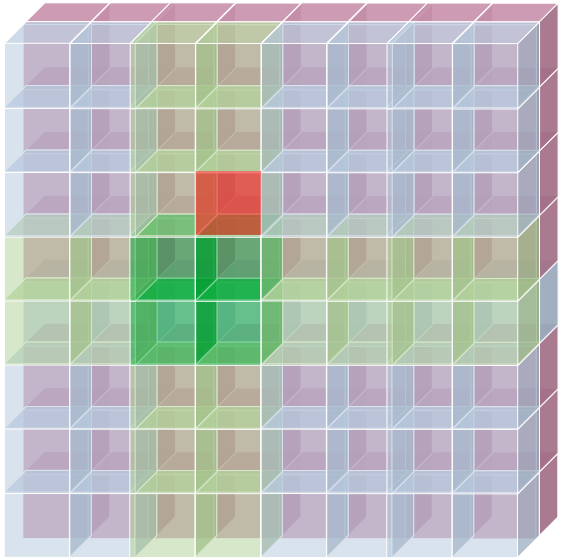

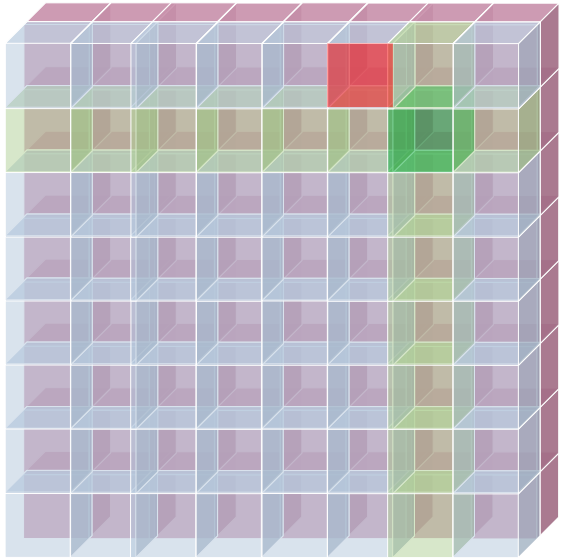

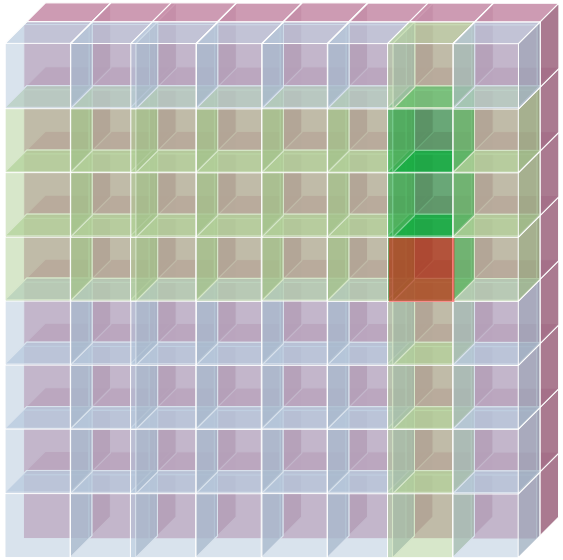

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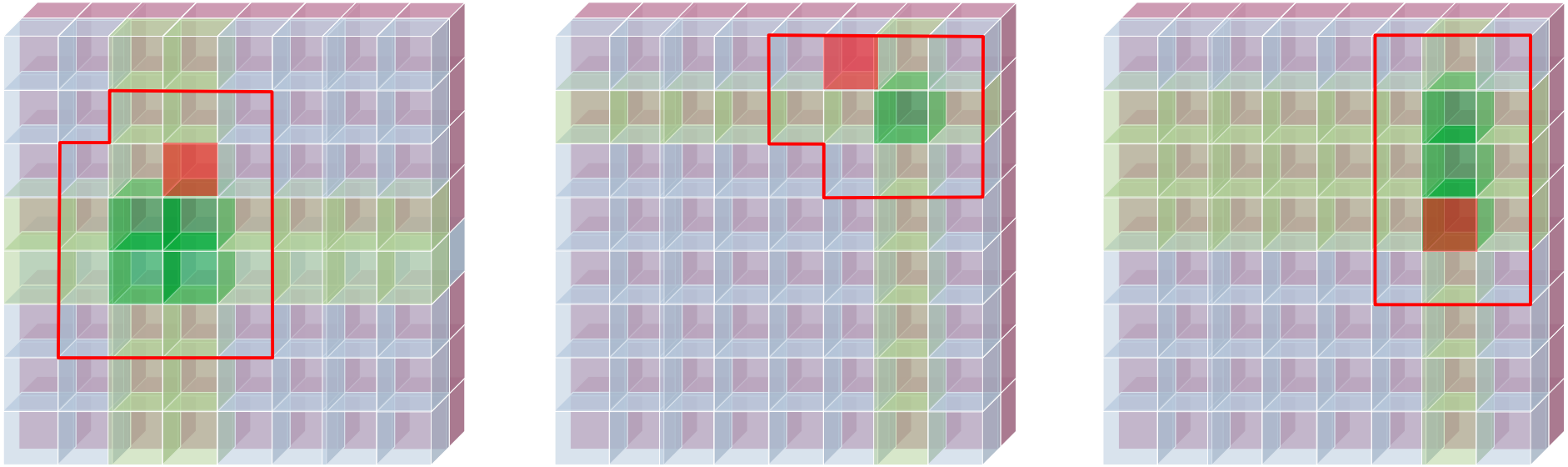
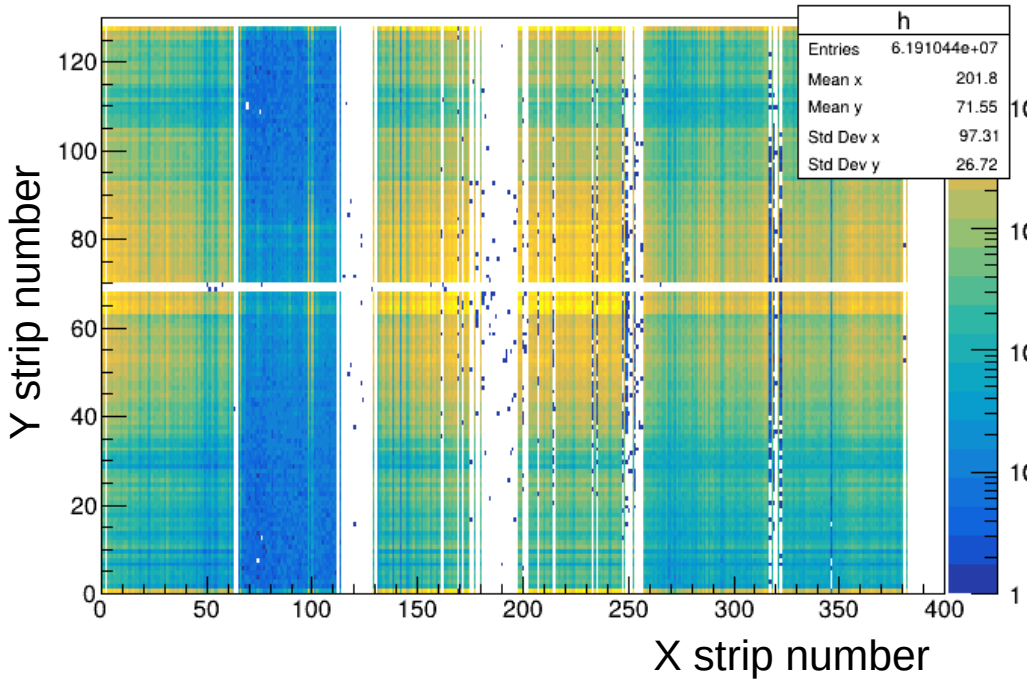


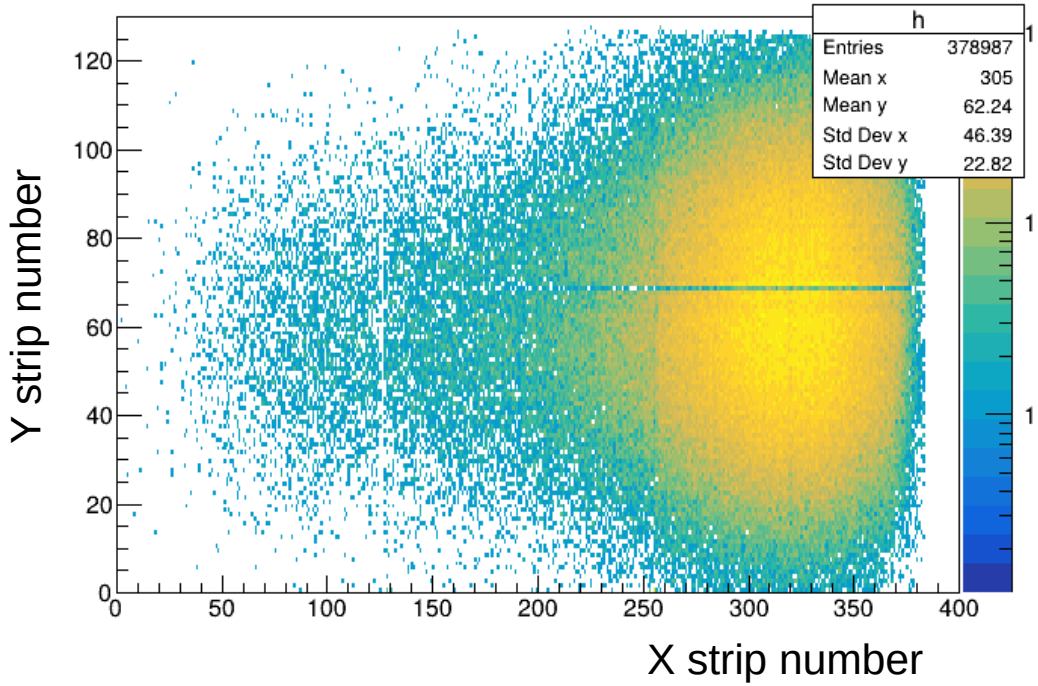
S181 – AIDA

XY cluster analysis. **Loose* background suppression**

BETAS



IMPLANTS

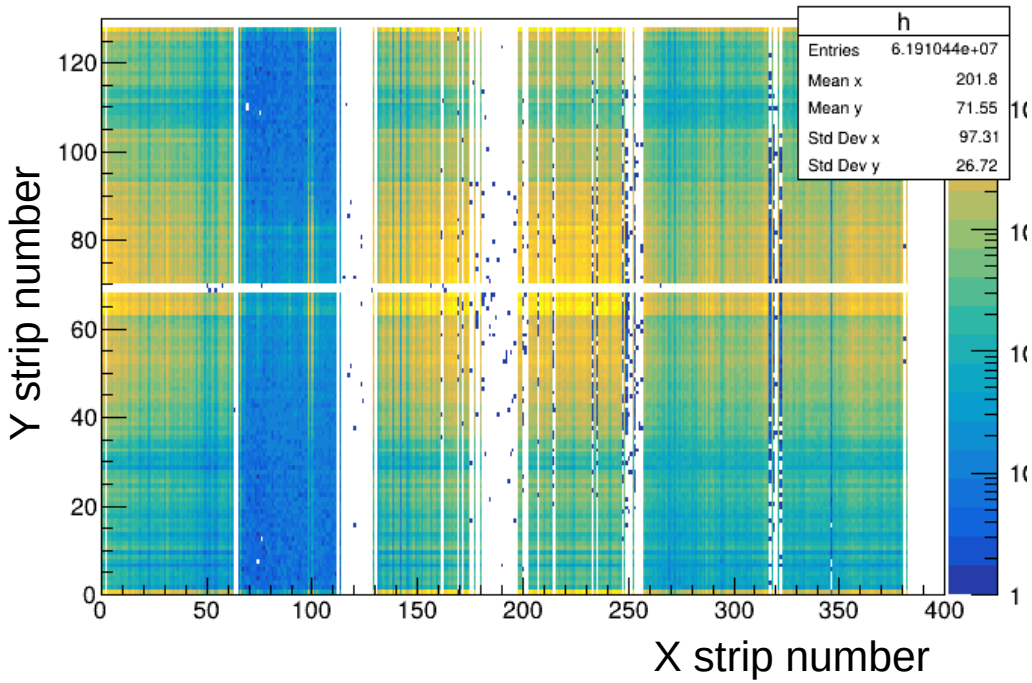


***Loose:** only bad strips are removed. For Y strips, only 68-69 are removed

S181 – AIDA

XY cluster analysis. **Loose* background suppression**

BETAS



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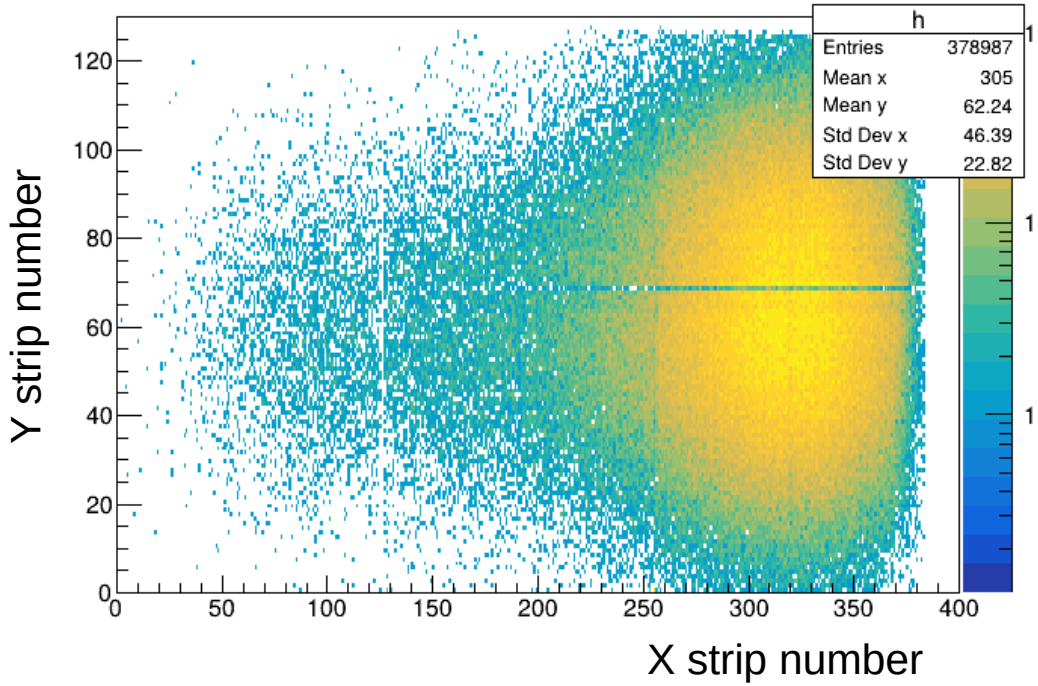


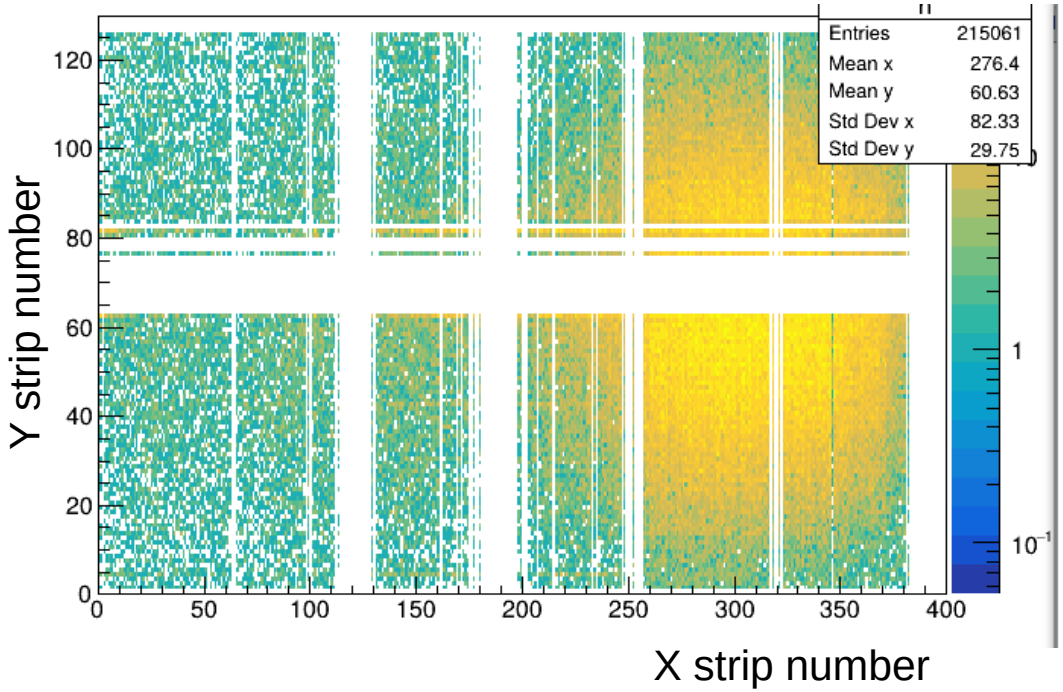
***Loose:** only bad strips are removed. For Y strips, only 68-69 are removed

***Spoiler:** no ion–β or ion–α correlations seen ➡ move to “strong” bg suppression

S181 – AIDA

XY cluster analysis. **Strong* background suppression**

BETAS



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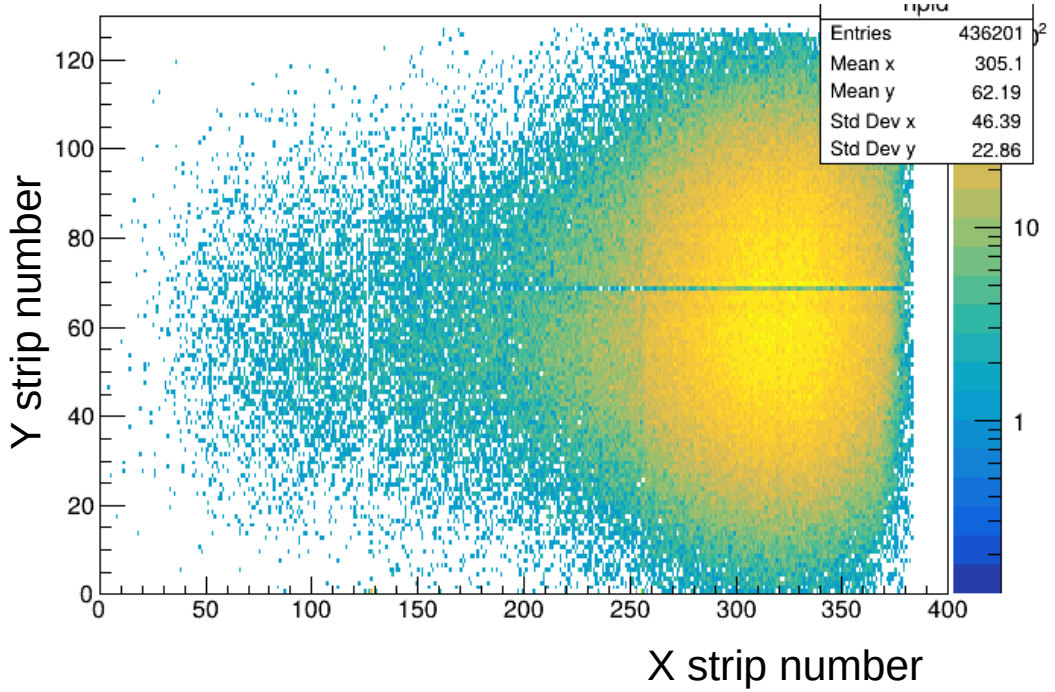
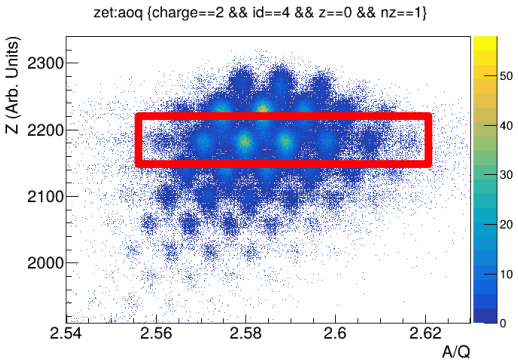


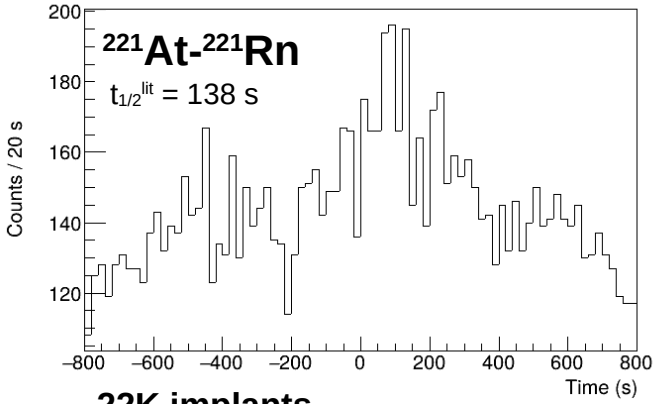
***Strong:** all β-like signals in the same AIDA event than a bad strip are removed

S181 – AIDA

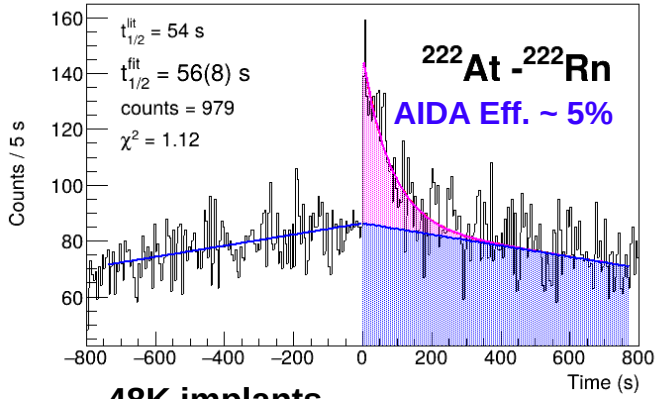
XY cluster analysis. **Strong* background suppression**



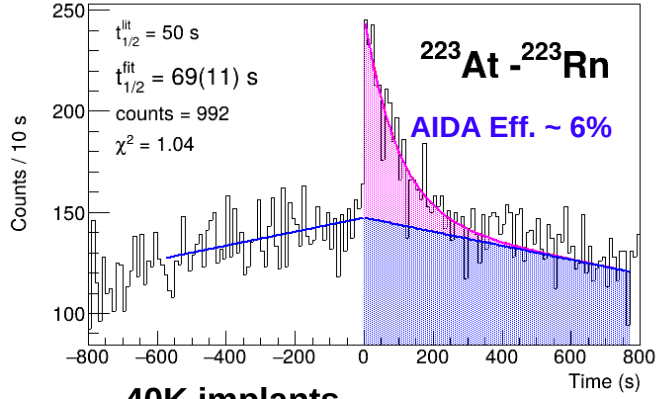
Ion-β time spectra



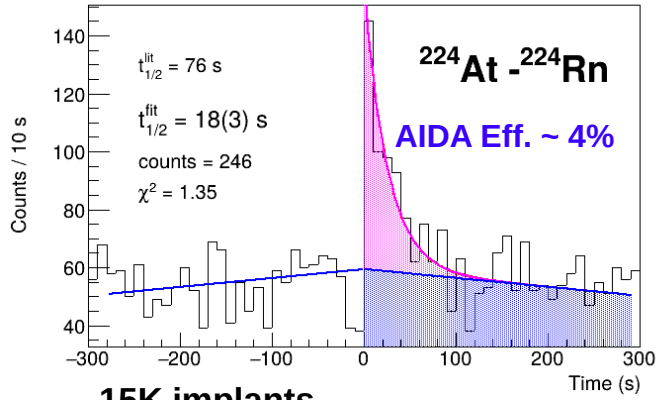
22K implants



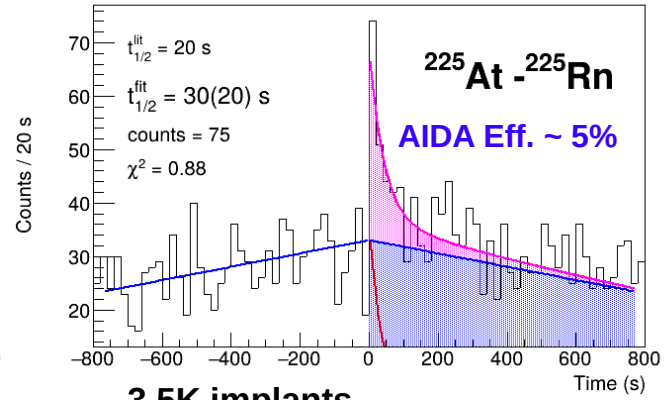
48K implants



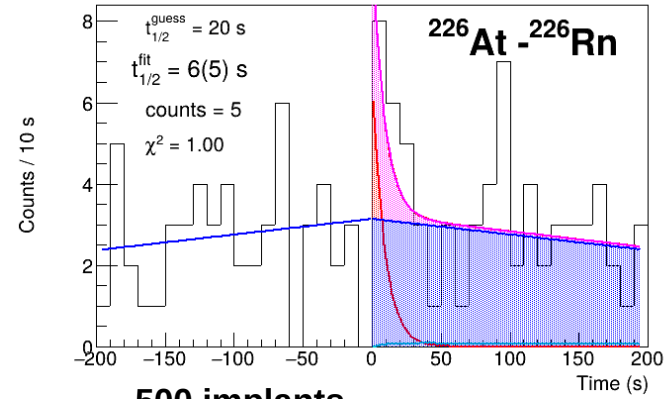
40K implants



15K implants



3.5K implants

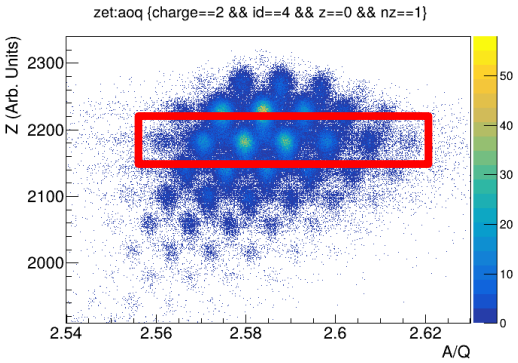


500 implants

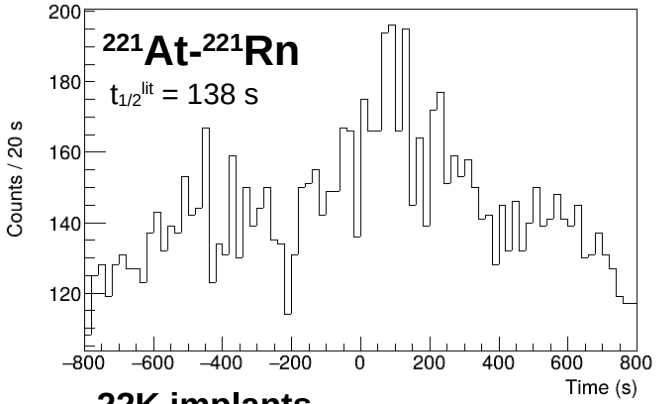
AIDA Eff. ~ 3%

S181 – AIDA

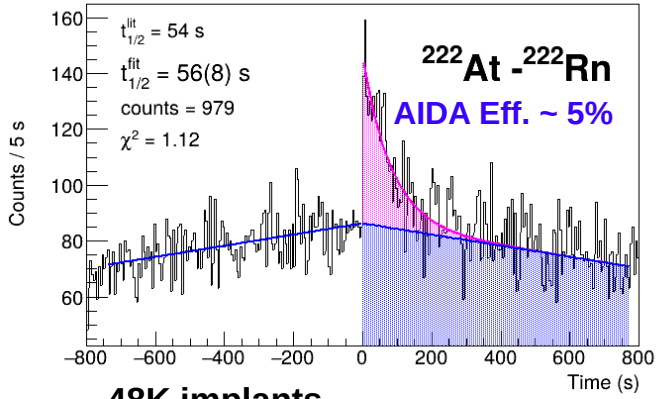
XY cluster analysis. **Strong* background suppression**



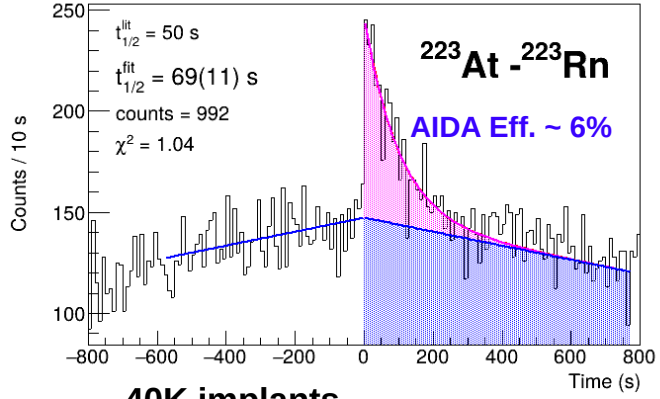
Ion-β time spectra



22K implants

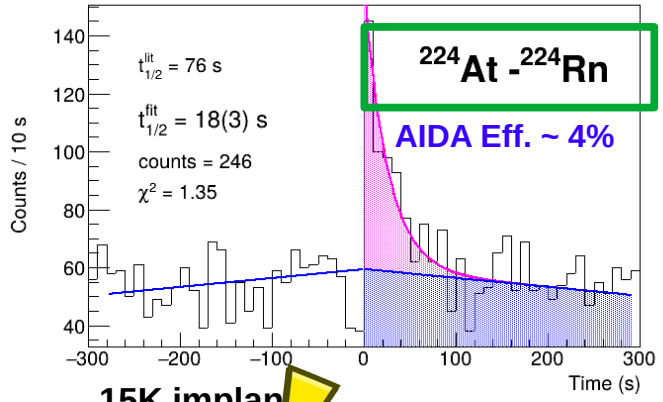


48K implants



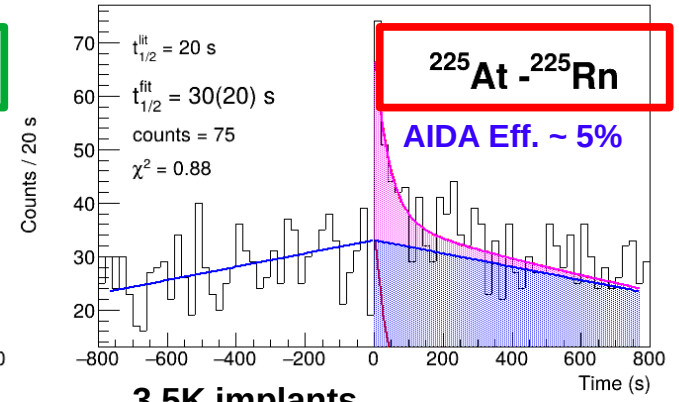
40K implants

[L. Chen et al., PLB 691, 234 (2010)]

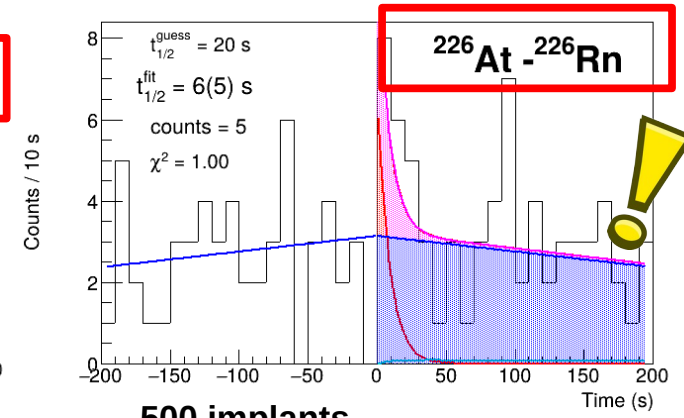


15K implan

IMPROVED



3.5K implants

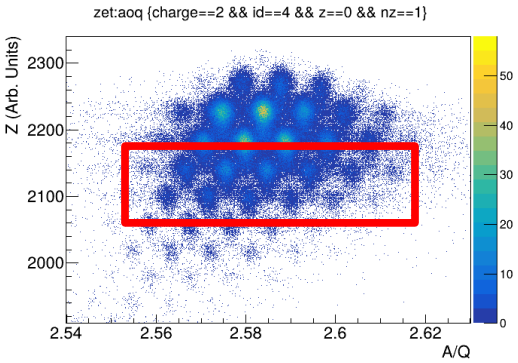


NEW

500 implants

AIDA Eff. ~ 3%

S181 – AIDA



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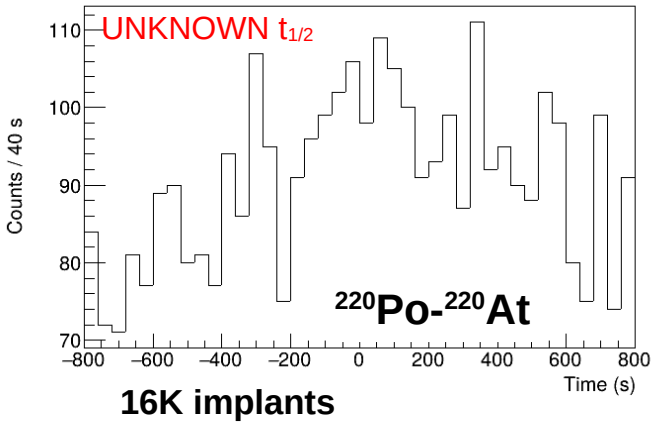
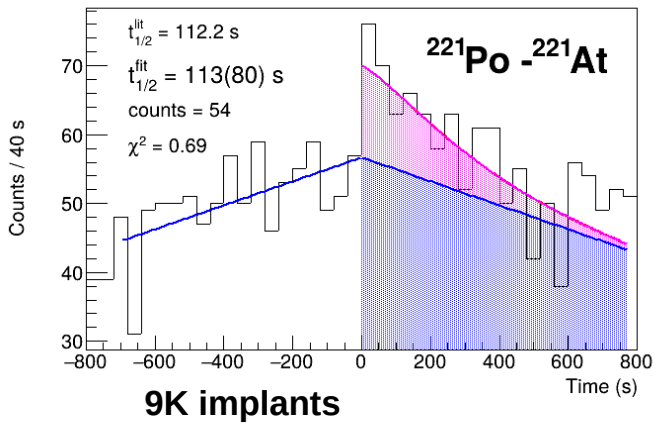
Ion-β time spectra

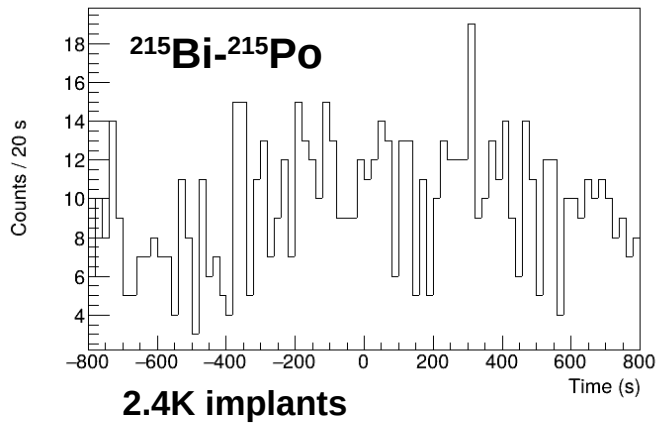


16K implants

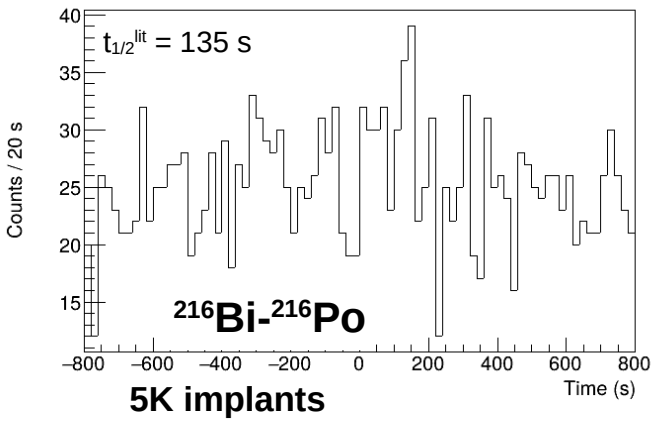
AIDA Eff. ~ 1.5%



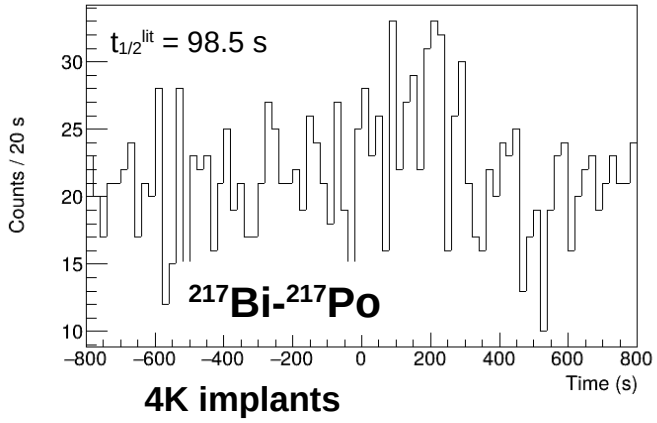
9K implants



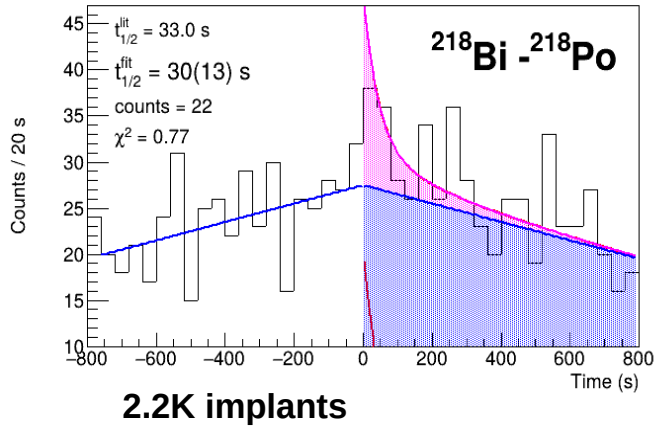
2.4K implants



5K implants



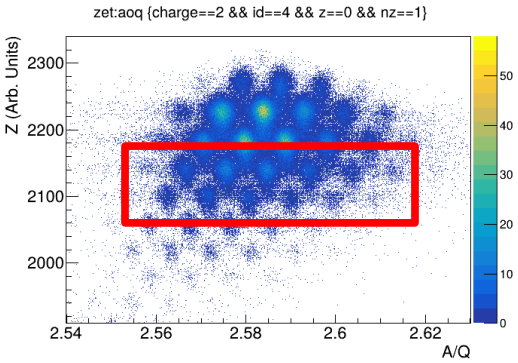
4K implants



2.2K implants

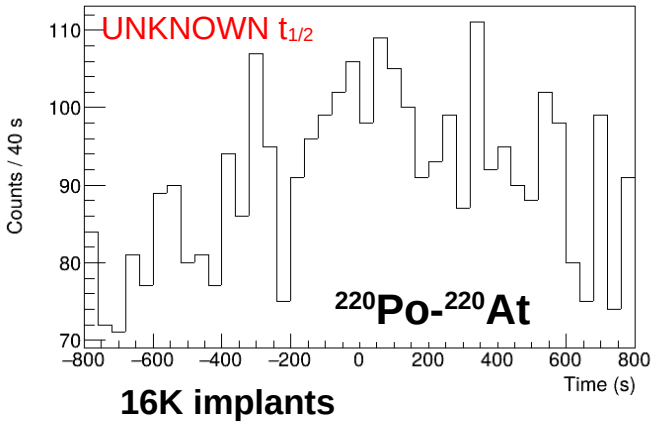
AIDA Eff. ~ 1.8%

S181 – AIDA



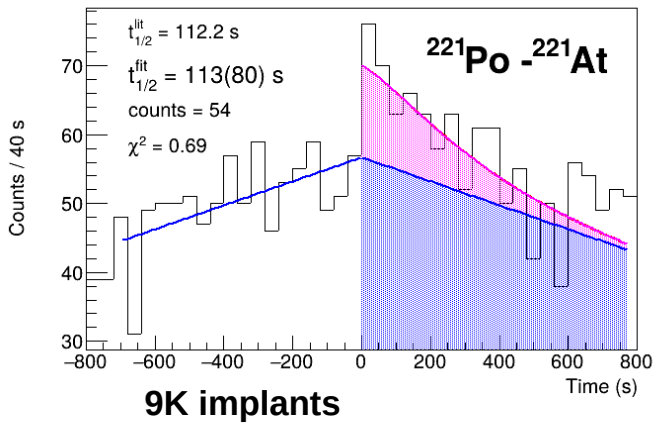
XY cluster analysis. **Strong* background suppression**

Ion-β time spectra



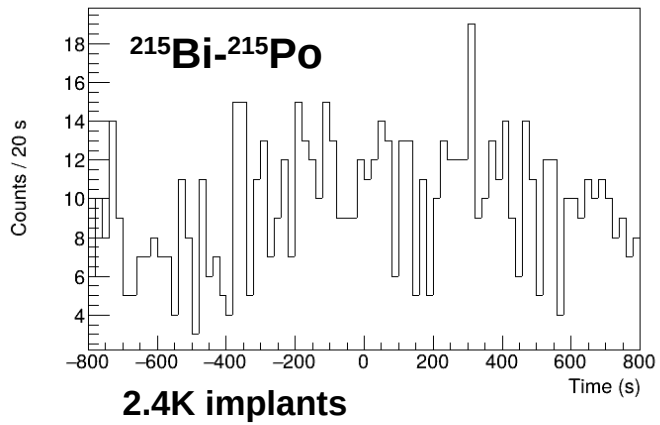
16K implants

AIDA Eff. ~ 1.5%

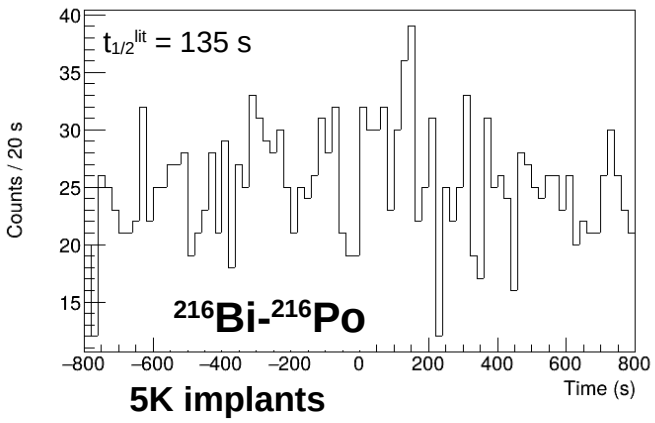


9K implants

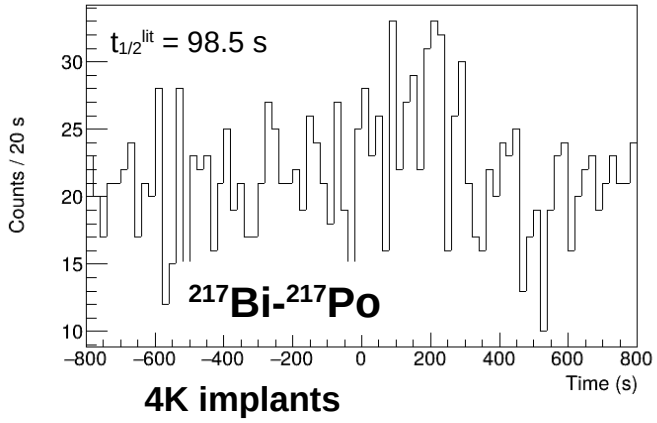
$t_{1/2}^{lit}$ = 456 s



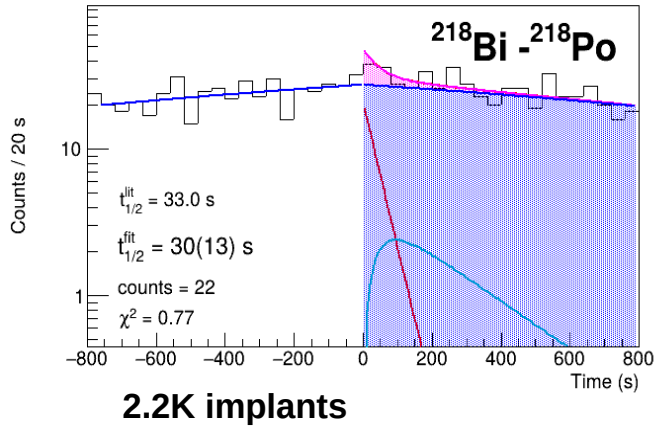
2.4K implants



5K implants



4K implants

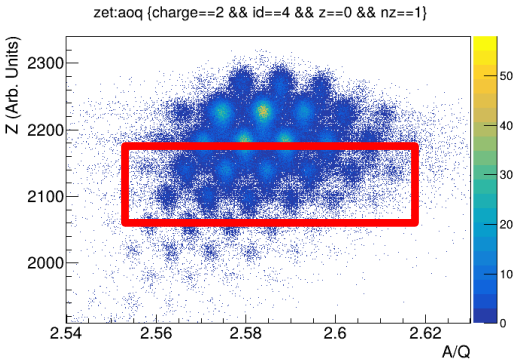


2.2K implants

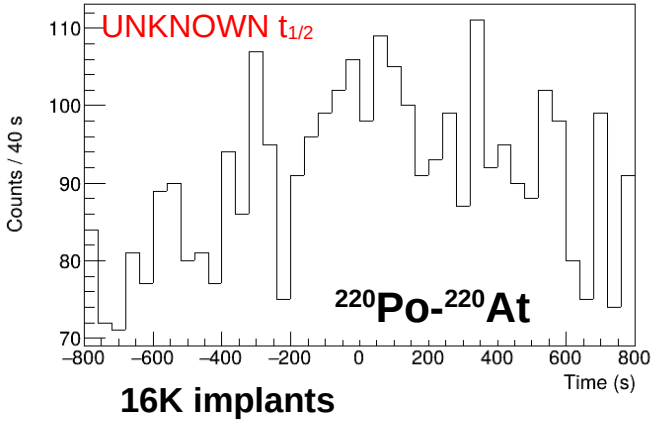
AIDA Eff. ~ 2.5%

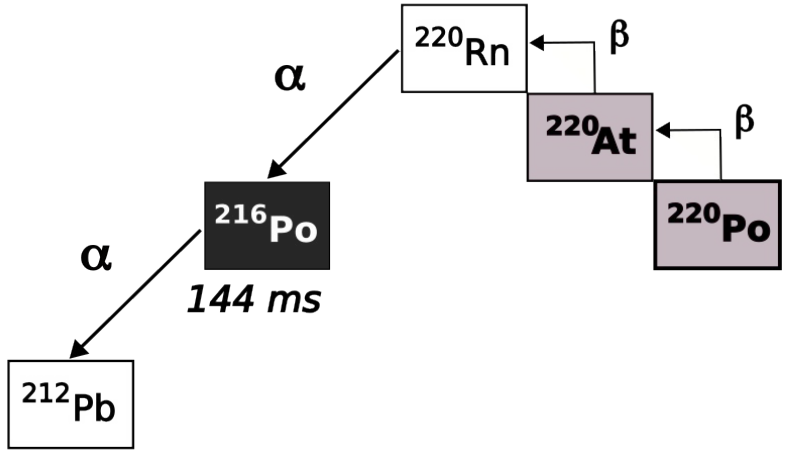
S181 – AIDA

XY cluster analysis. **Strong* background suppression**



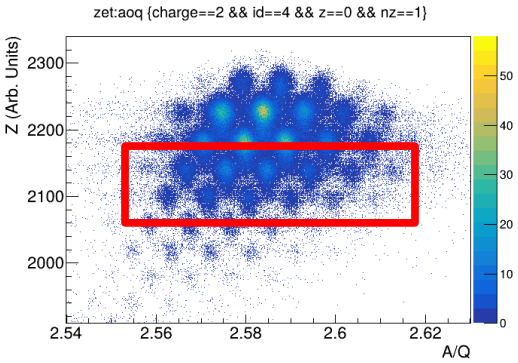
Ion-β time spectra





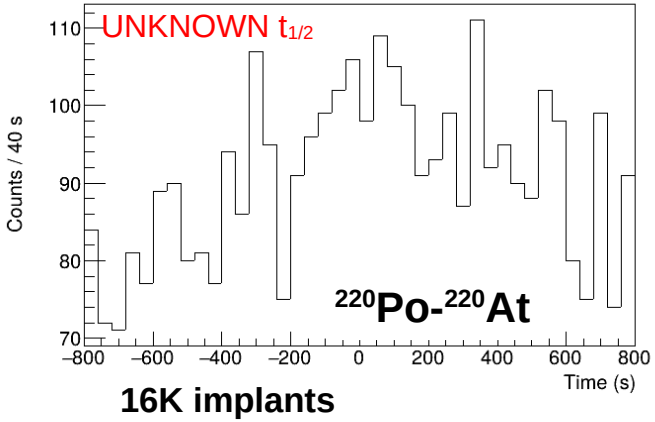
Ion-α time spectra

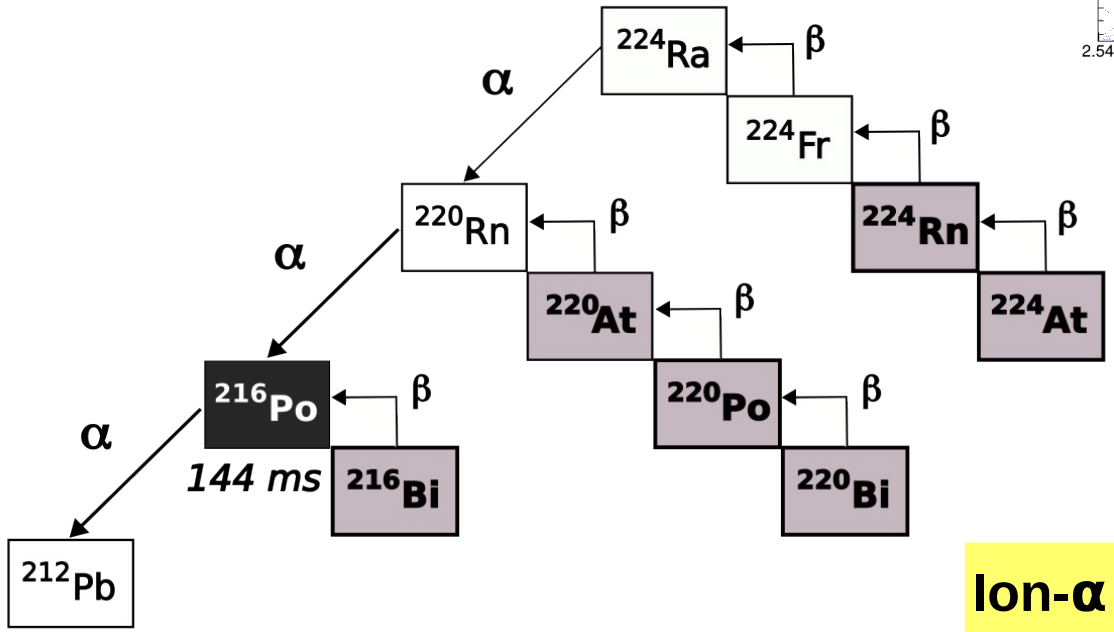
S181 – AIDA



XY cluster analysis. **Strong* background suppression**

Ion-β time spectra

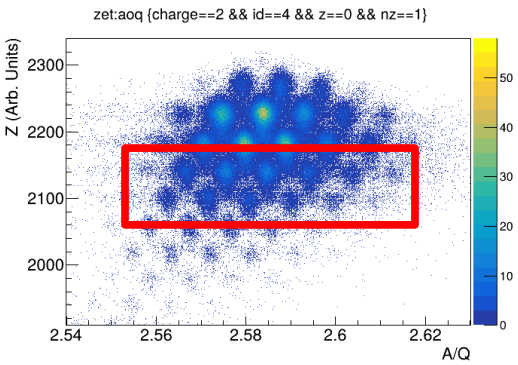




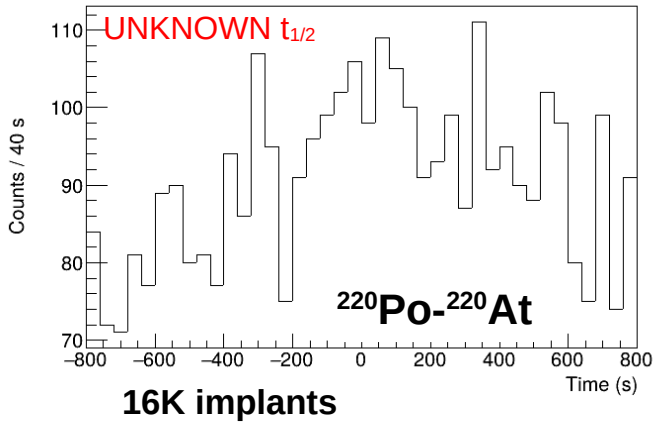
Ion-α time spectra

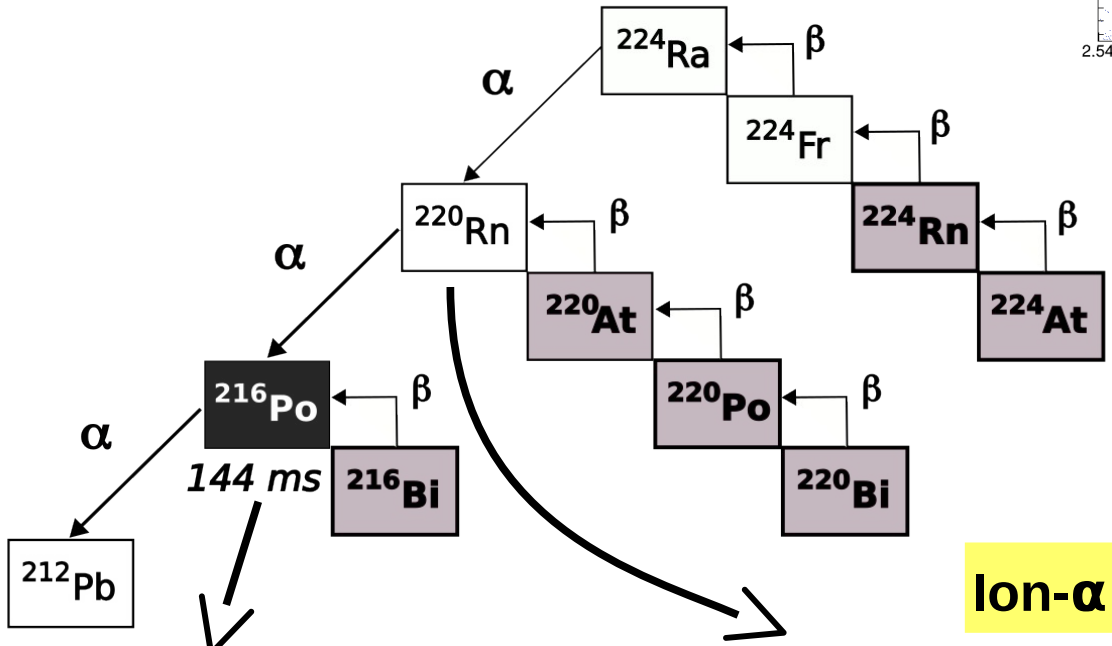
S181 – AIDA

XY cluster analysis. **Strong* background suppression**

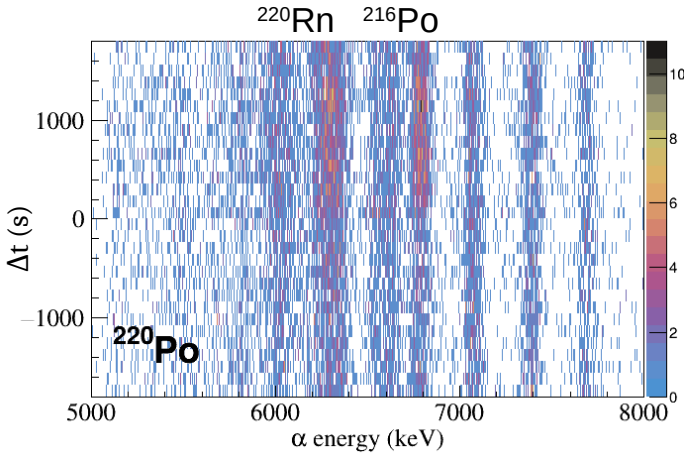


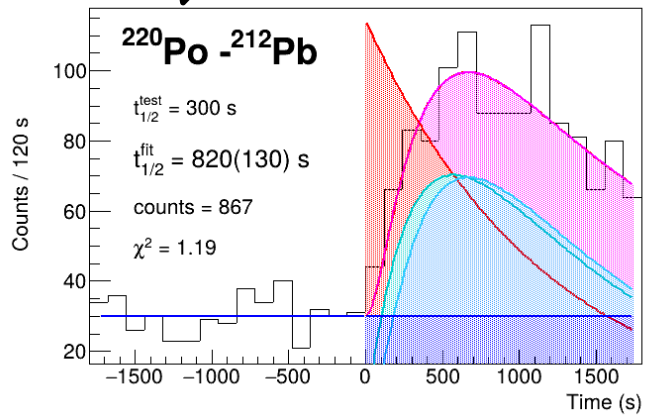
Ion-β time spectra

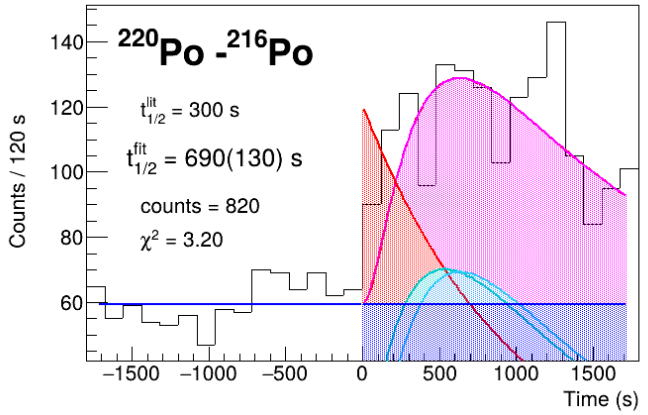




Ion-α time spectra

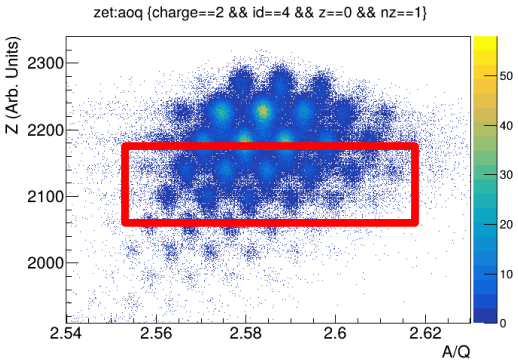




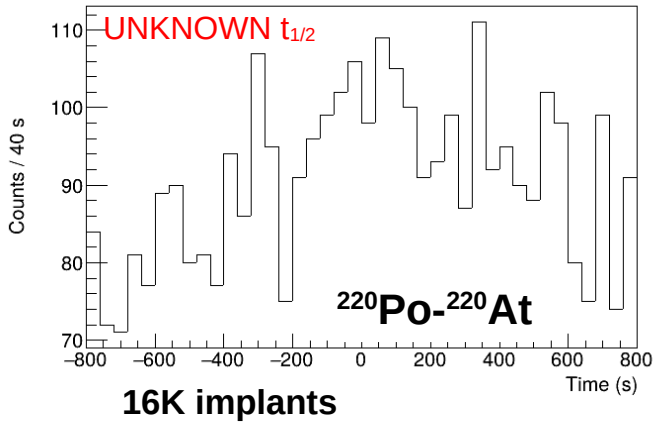


S181 – AIDA

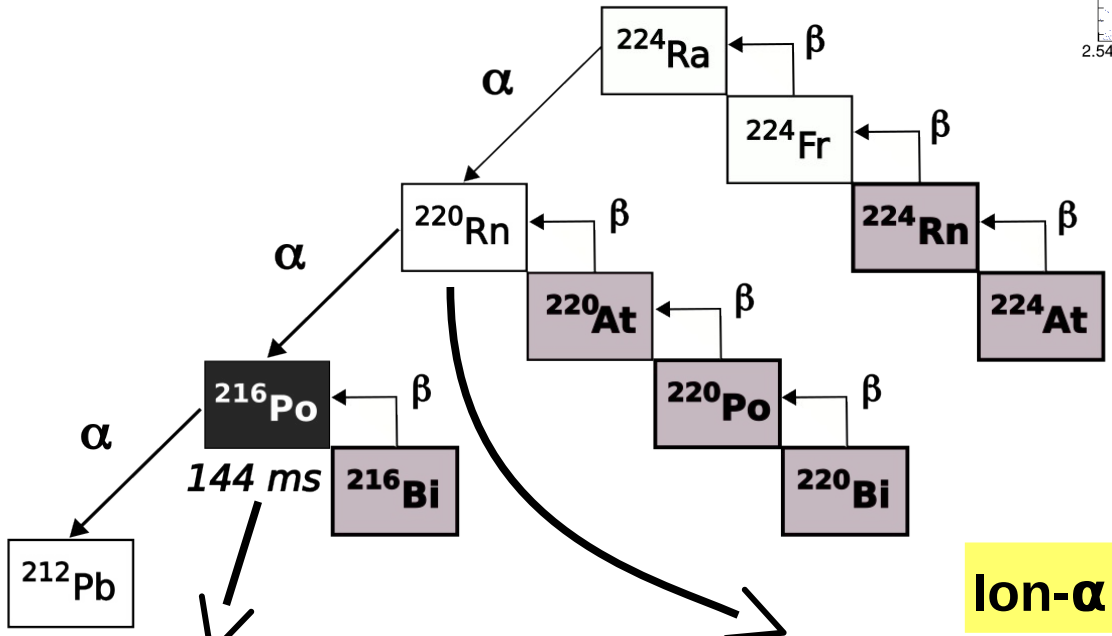
XY cluster analysis. **Strong* background suppression**



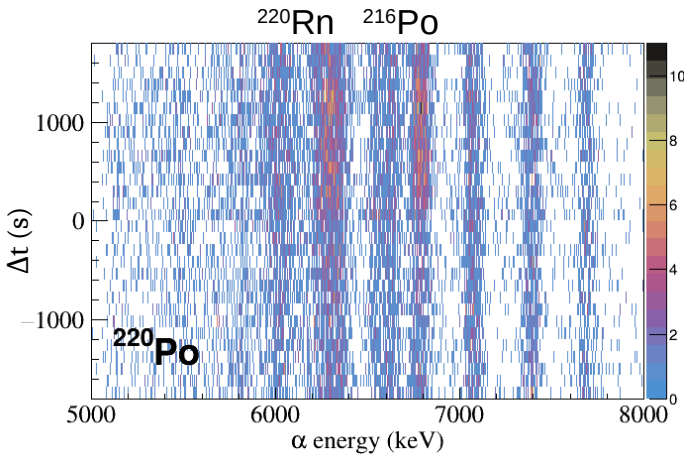
Ion-β time spectra

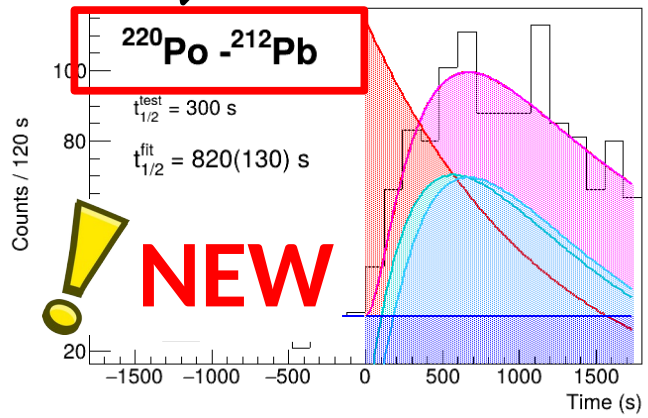


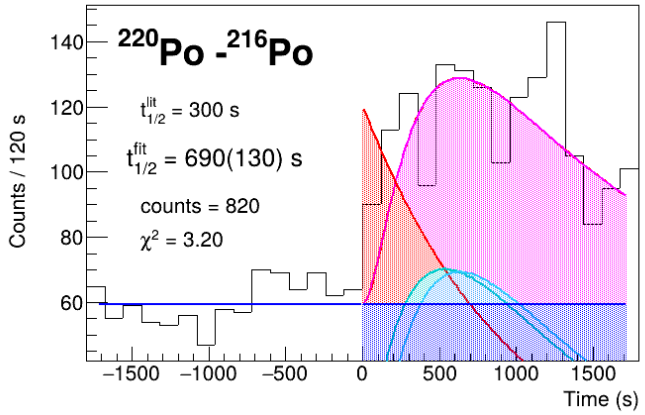
16K implants



Ion-α time spectra

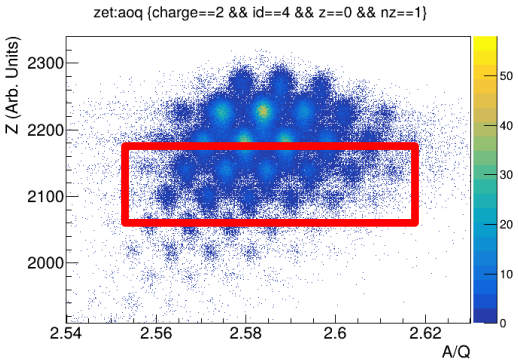




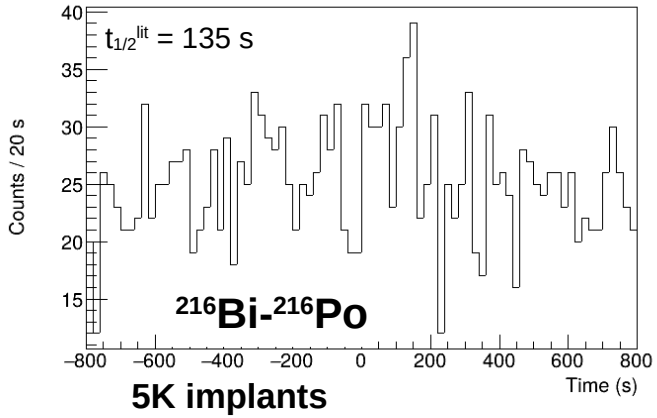


S181 – AIDA

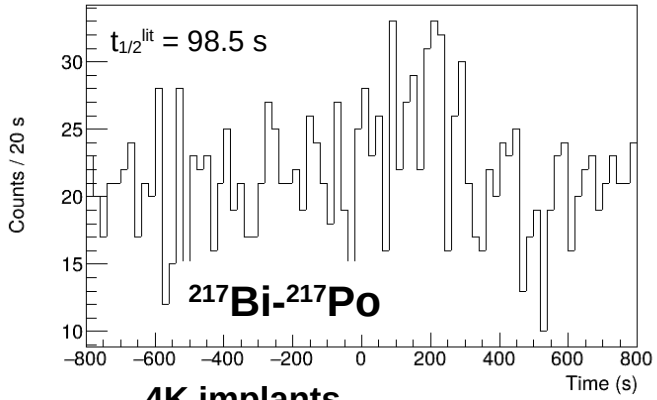
XY cluster analysis. **Strong* background suppression**



Ion-β time spectra

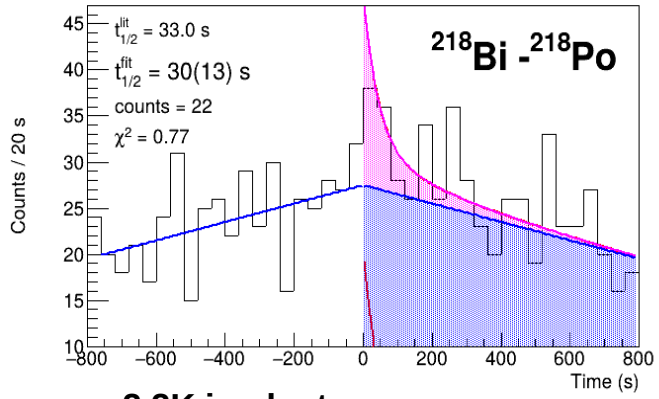


5K implants



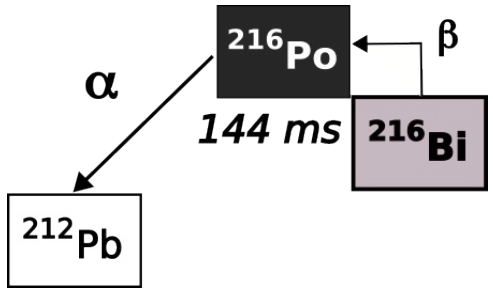
4K implants

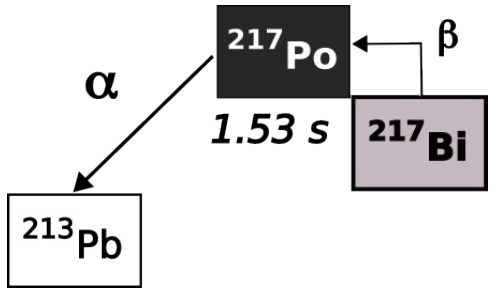
AIDA Eff. ~ 2.5%

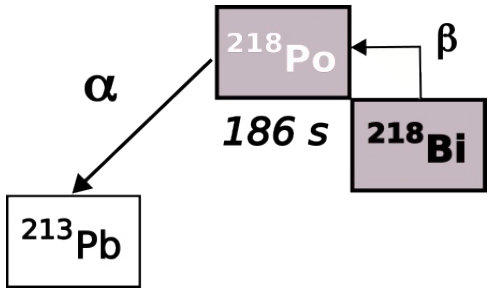


2.2K implants

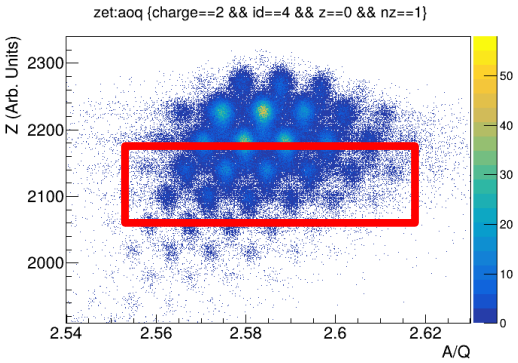
Ion-α time spectra





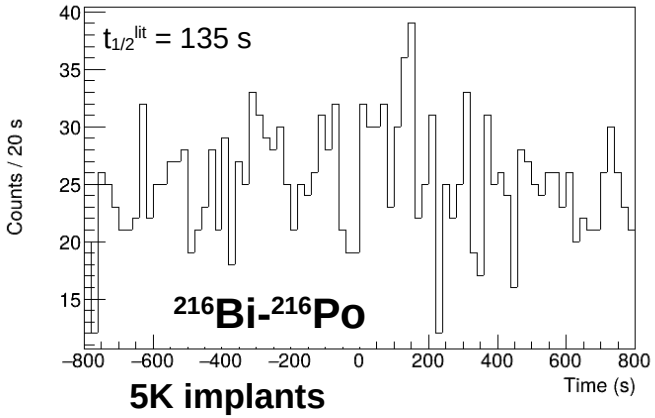


S181 – AIDA

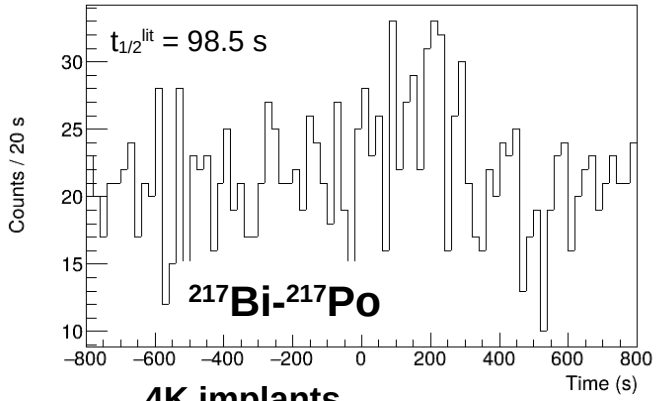


XY cluster analysis. **Strong* background suppression**

Ion-β time spectra

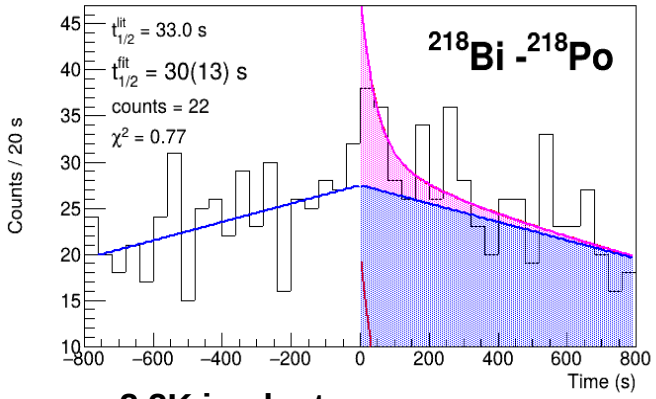


5K implants



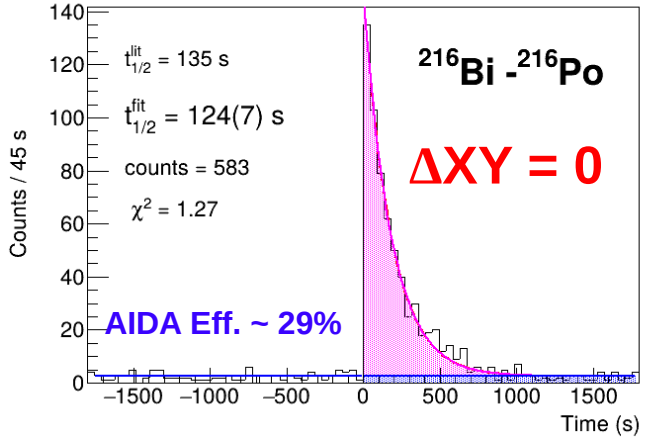
4K implants

AIDA Eff. ~ 1.8%

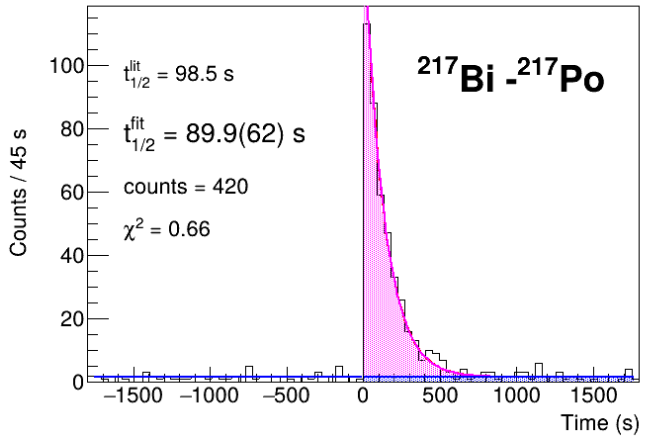


2.2K implants

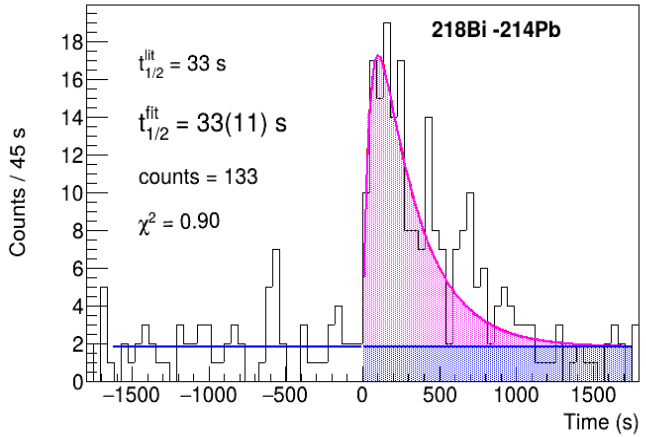
Ion-α time spectra



AIDA Eff. ~ 26%

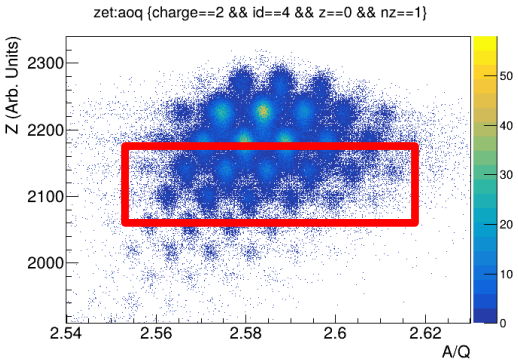


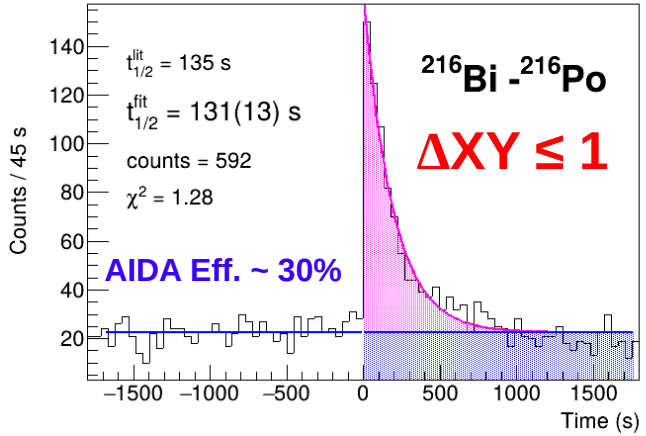
AIDA Eff. ~ 15%

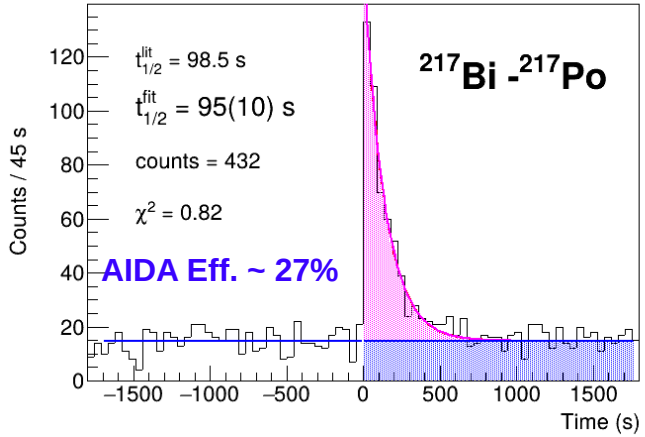


S181 – AIDA

XY cluster analysis. **Strong* background suppression**





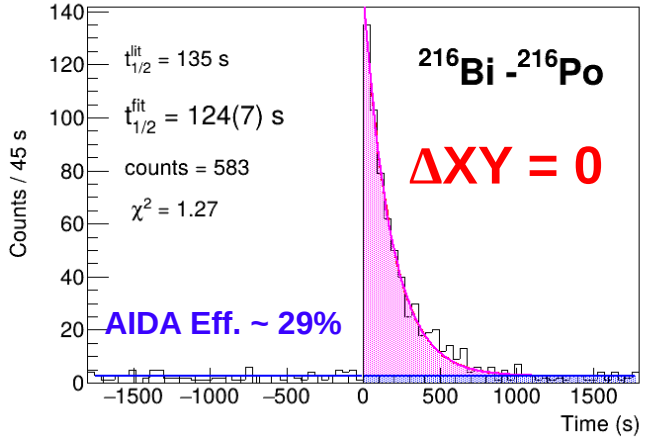


5K implants

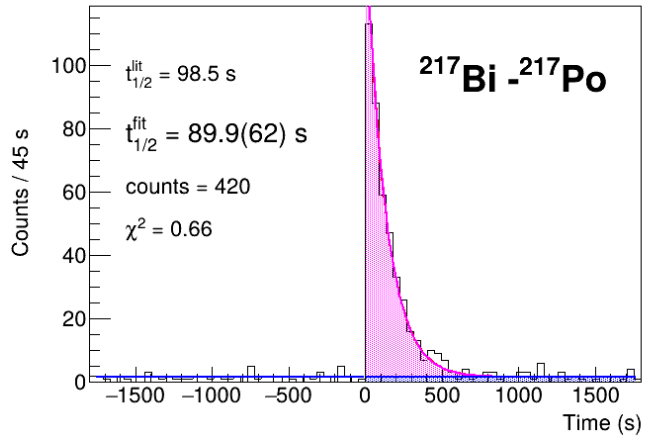
4K implants

2.2K implants

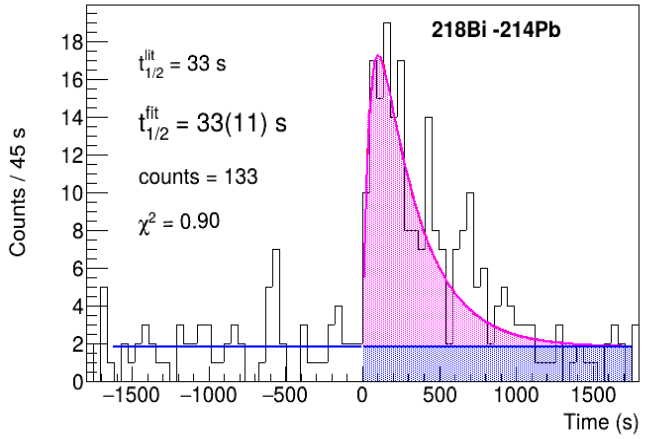
Ion-α time spectra



AIDA Eff. ~ 26%

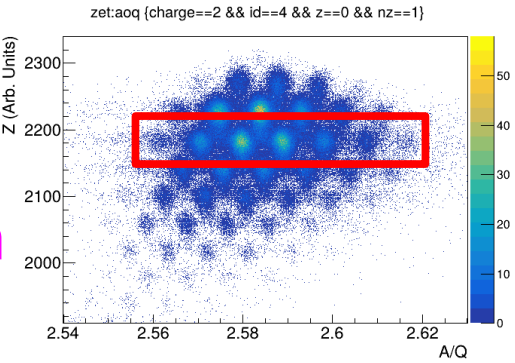


AIDA Eff. ~ 15%

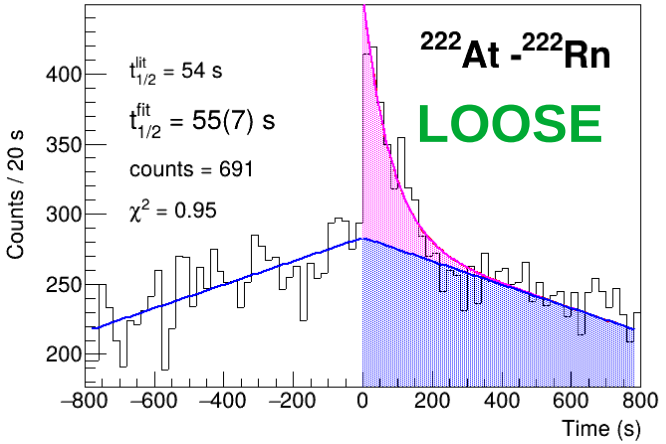


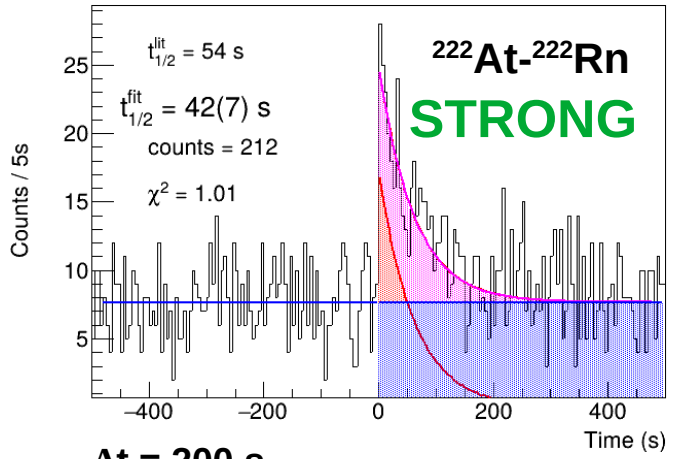
S181 – AIDA

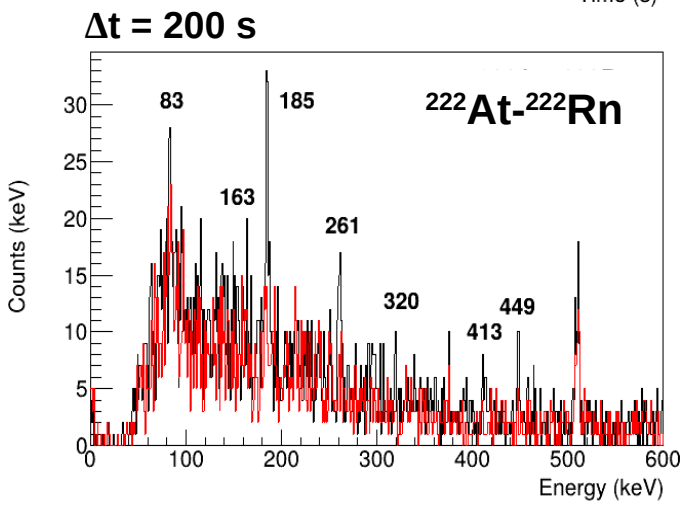
XY cluster analysis. **Strong vs loose background suppression**

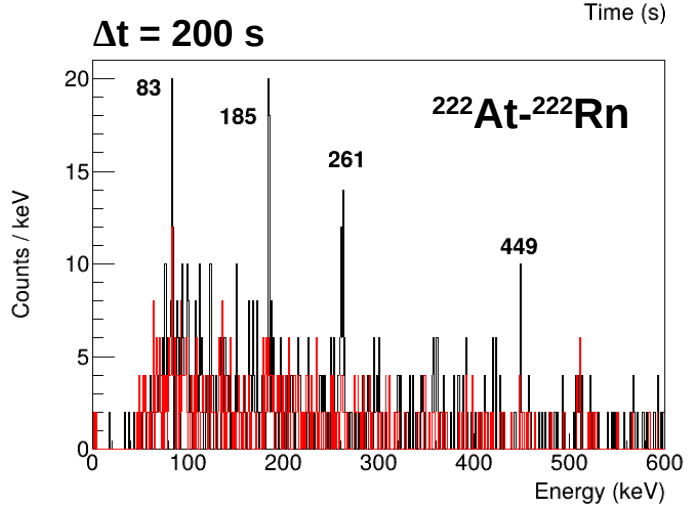


Ion-β(γ) time spectra



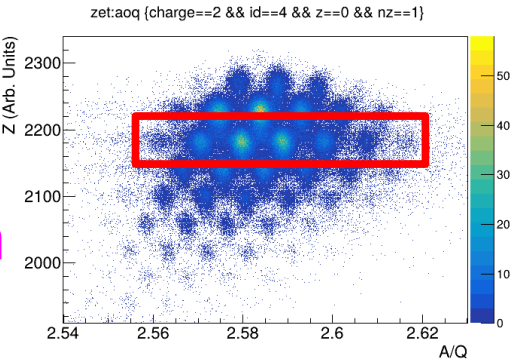




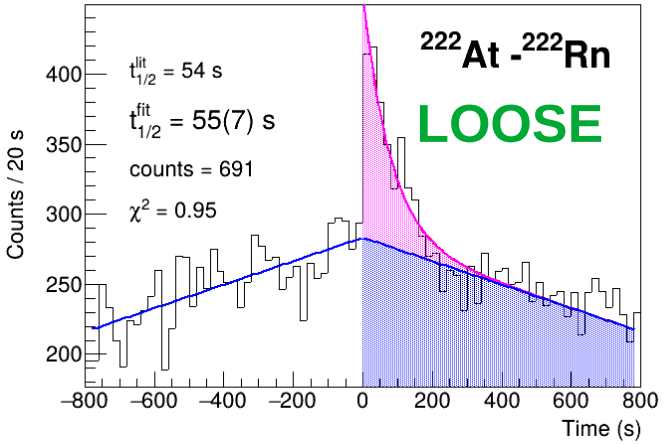


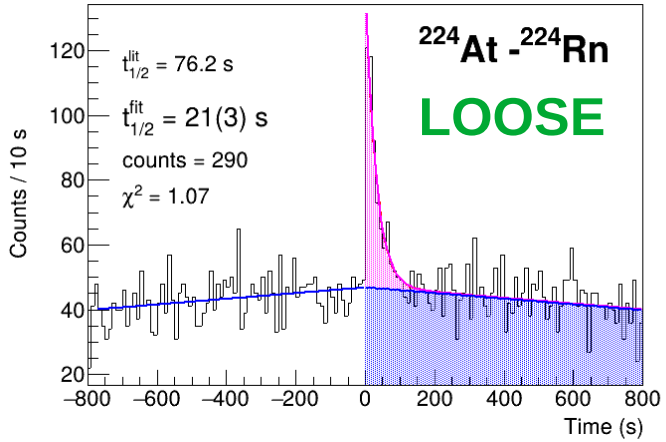
S181 – AIDA

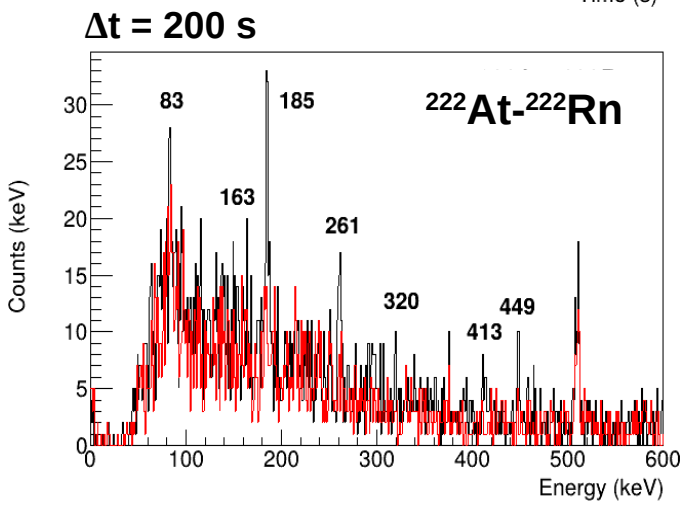
XY cluster analysis. **Strong vs loose background suppression**

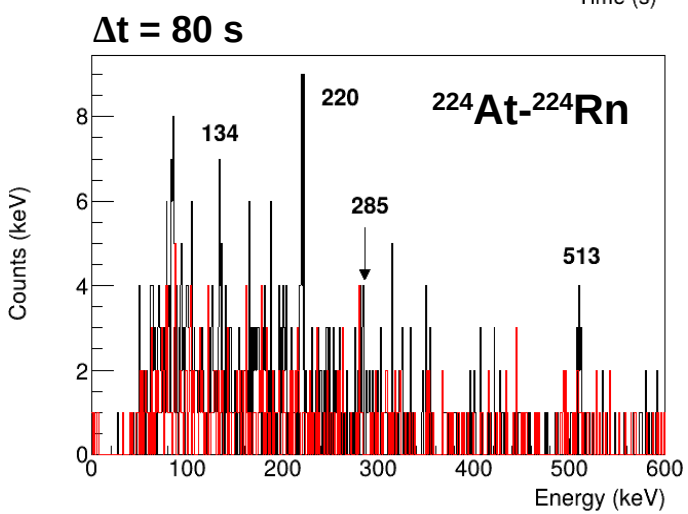


Ion-β(γ) time spectra



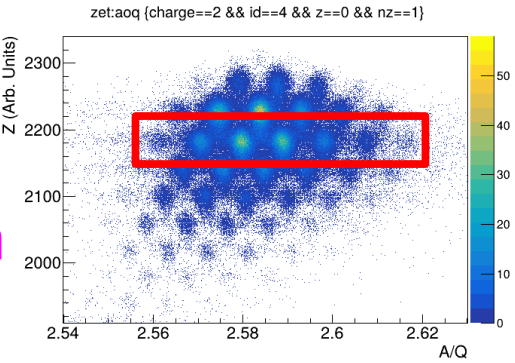




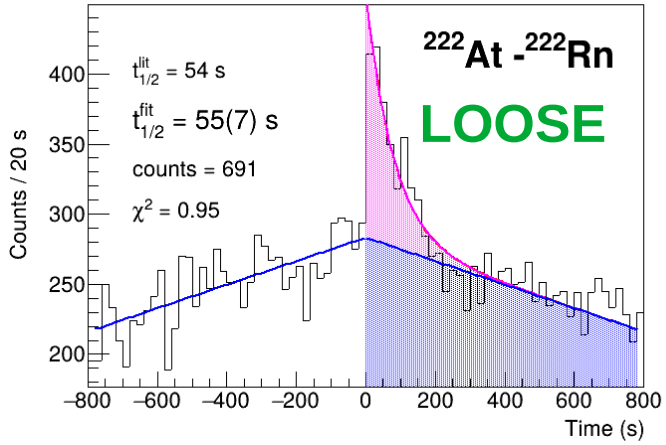


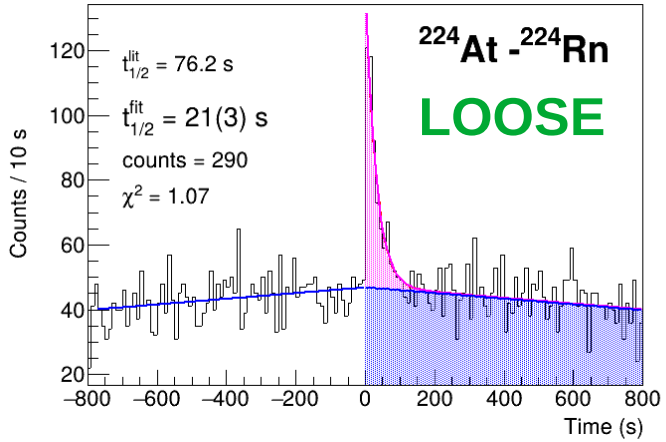
S181 – AIDA

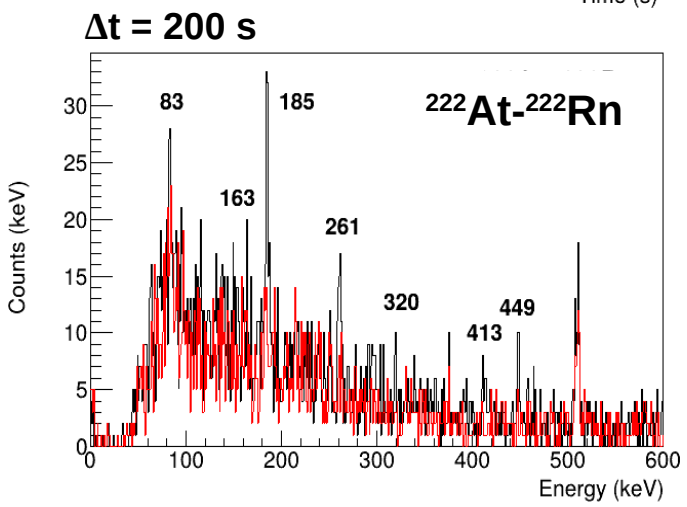
XY cluster analysis. **Strong vs loose background suppression**

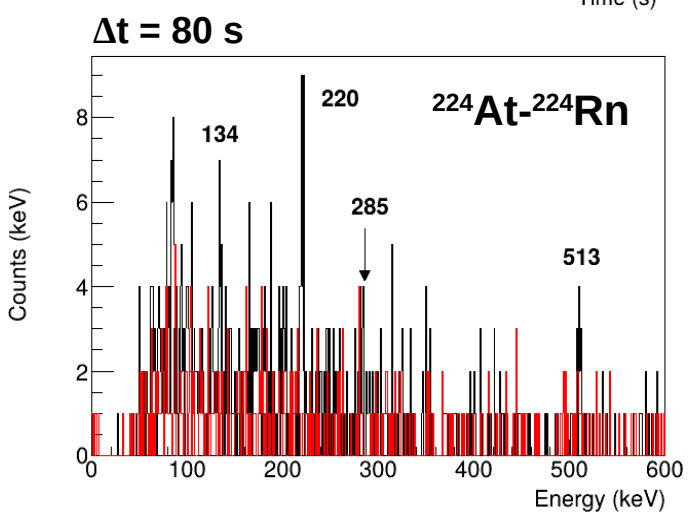


Ion-β(γ) time spectra

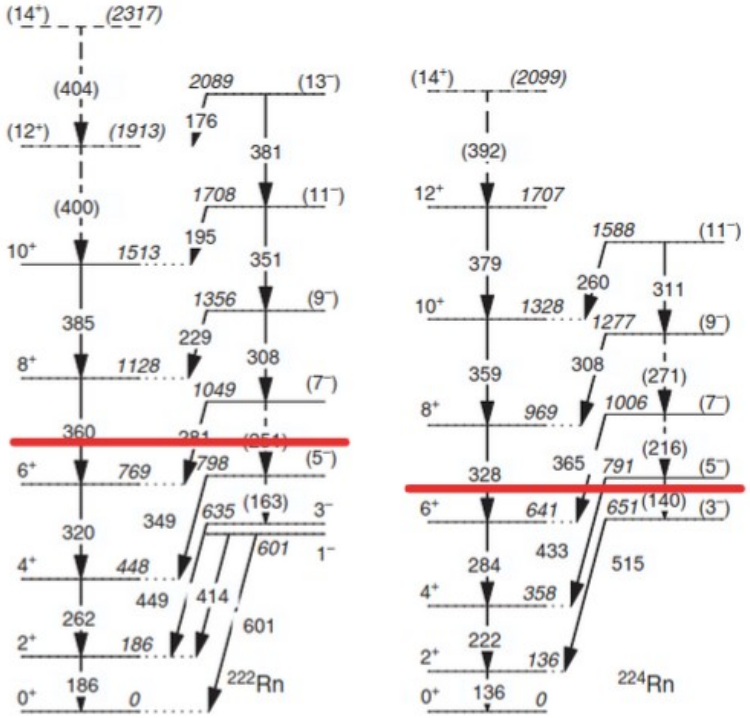






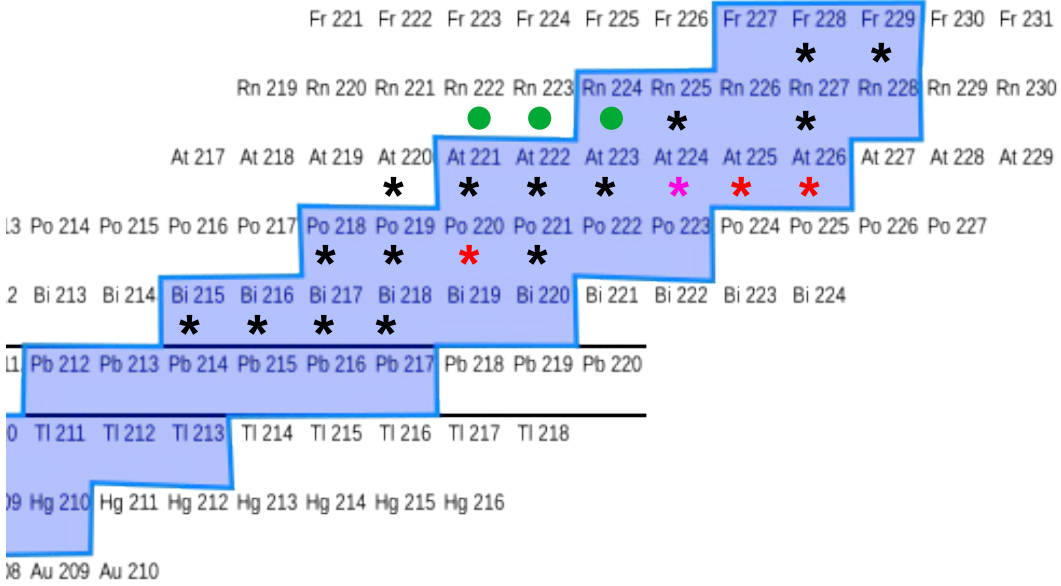


COULEX



[P.A. Butler et al., Nature Communications 11, 3560 (2020)]

Summary

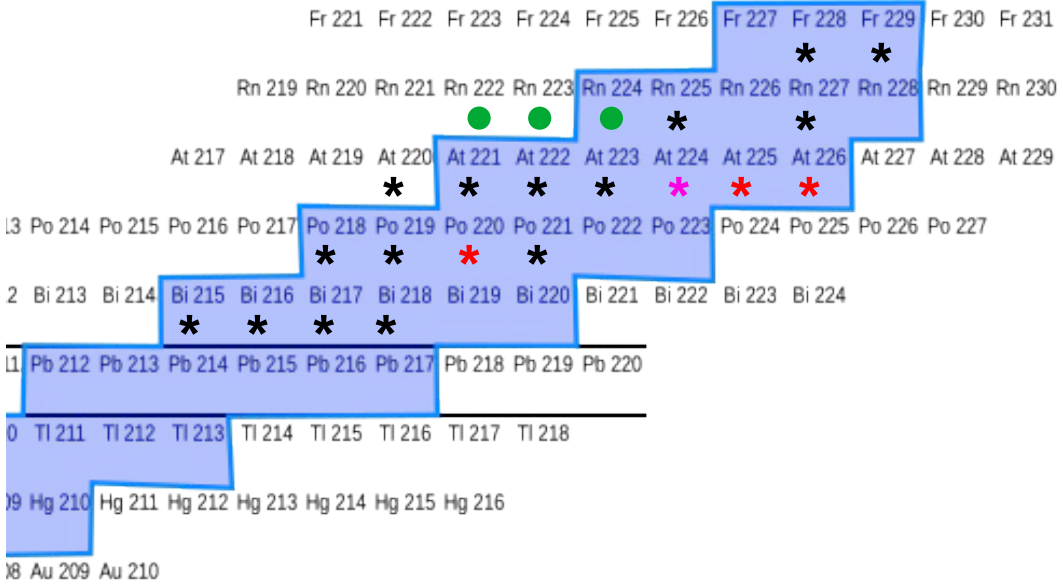


- 👉 **~20 β half-lives** measured applying ion–α, ion–β, and ion–β(γ) correlations
  - ✅ ~3 unknown: **^{225}At, ^{226}At, ^{220}Po**
  - ✅ 1 improved: **^{224}At**
- 👉 β-delayed γ spectroscopy achievable with *loose* background suppression
  - ✅ First ever observed γ spectra of **^{222}At → ^{222}Rn** and **^{224}At → ^{224}Rn** decays

Future plans

- 👉 PID for all the experiment (Ongoing Mallicka's work)
- 👉 (Try to) improve AIDA efficiency for low-energy signals by applying AI methods (under discussion with Giorgio)
- 👉 Analyze βPlast data (charge-states of heavy At-Fr)

S181 Collaboration



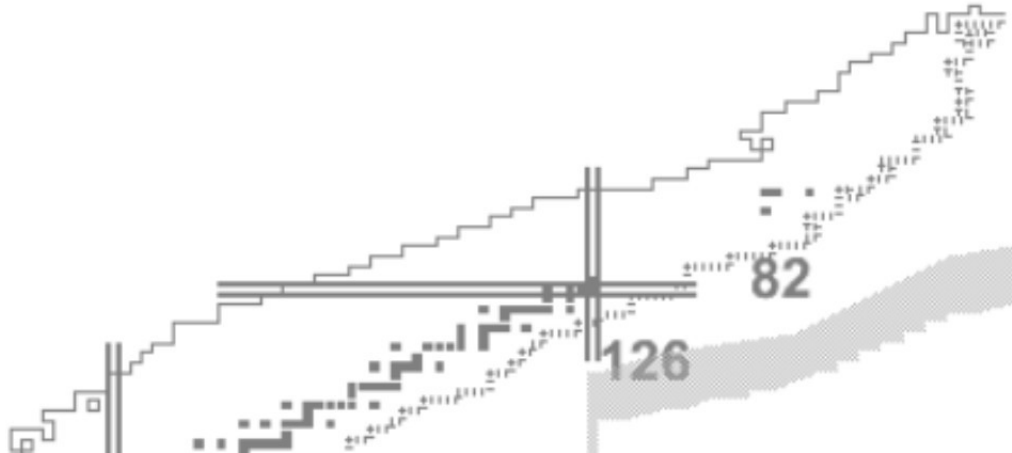
[1]IFIC (CSIC-UV), [2]INFN-Padova, [3]GSI, [4]INFN-Milano, [5]U. Köln, [6]U. Edinburgh, [7]T.U. Darmstadt, [8]RIKEN, [9]ICJLab, [10]U. Complutense, [11]TIFR, [12]U. Surrey, [13]INFN-Firenze, [14]U. Delhi, [15]JSI, [16]IMPCAS, [17]U. Liverpool, [18]STFC Daresbury Lab, [19]KU Leuven, [20]U. Qassim, [21]IMSIU, [22]KTH Stocholm, [23]U. Korea

M. Kundu[1], M. Polettini[2,3], A.I. Morales[1], G. Benzoni[4], P. Reiter[5], M. Górka-Ott[3], J. Gerl[3], H. Albers[3],N. Hubbard[3], B. Das[3], H. Schaffner[3], I. Kojouharov[3], G. Aggez[3], N. Kurz[3], T. Dickel[3], E. Haettner[3], C. Scheidenberger[3], C. Hornung[3], T. Davinson[6], K. Wimmer[3], , C. Chatel[3,7], S. Alhomaidhi[7,3], P. Herrmann[3], C. Jones[3], M. Mikolajczuk[3], H.J. Wollersheim[3], A. Yaneva[5,3], J. Bormans[3], J.E. Larsson[3], E. Gandolfo[3], B. Bles[3], M. Reece[3], W. Poklepa[3], H. Hao[3], F. Drent[3], T.T. Yeung[8], D. Das[3,7], R. Lozeva[9], A. Illana[10], R. Palit[11], Zs. Podolyak[12], P. Regan[12], J.J. Valiente-Dobón[2], J. Pellumaj[2], S. Pietri[3], P. Aguilera[2], F. Angelini[2], G. Andreetta[2], S. Laskar[4], M. Rocchini[13], G. Kumar[3], P. Priyanka[3], J. Bardak[3], S. Mandal[14], J. Vesić[15], G. Kosir[15], K. Zagar[15], M. Vencelj[15], Z. Liu[16], G. Bartram[12], V. Piau[9], N. Marchini[13], N. Alwadie[17], P. Papadakis[18], R. Page[17], D. Judson[17], M. Satrazani[19], B. Alayed[20], M. Alaqeel[21], D. Bittner[5], A. Algora[1], J.A. Briz[10], D. Rodríguez-García[1], T. Milanovic[22], M. Labiche[18], Z. Chen[3], S. Orrigo[1], J. Kim[23], A. Gottardo[2], D. Genna[4], M. von Tresckow[7], R. Prajapat[3], S. Kumar[3]

Due to the Covid outbreak by the end of S181 experiment, there's no photo of the collaborators.

Whoever interested, please send us a photo. We'll make a collage that we can show in conferences, etc.

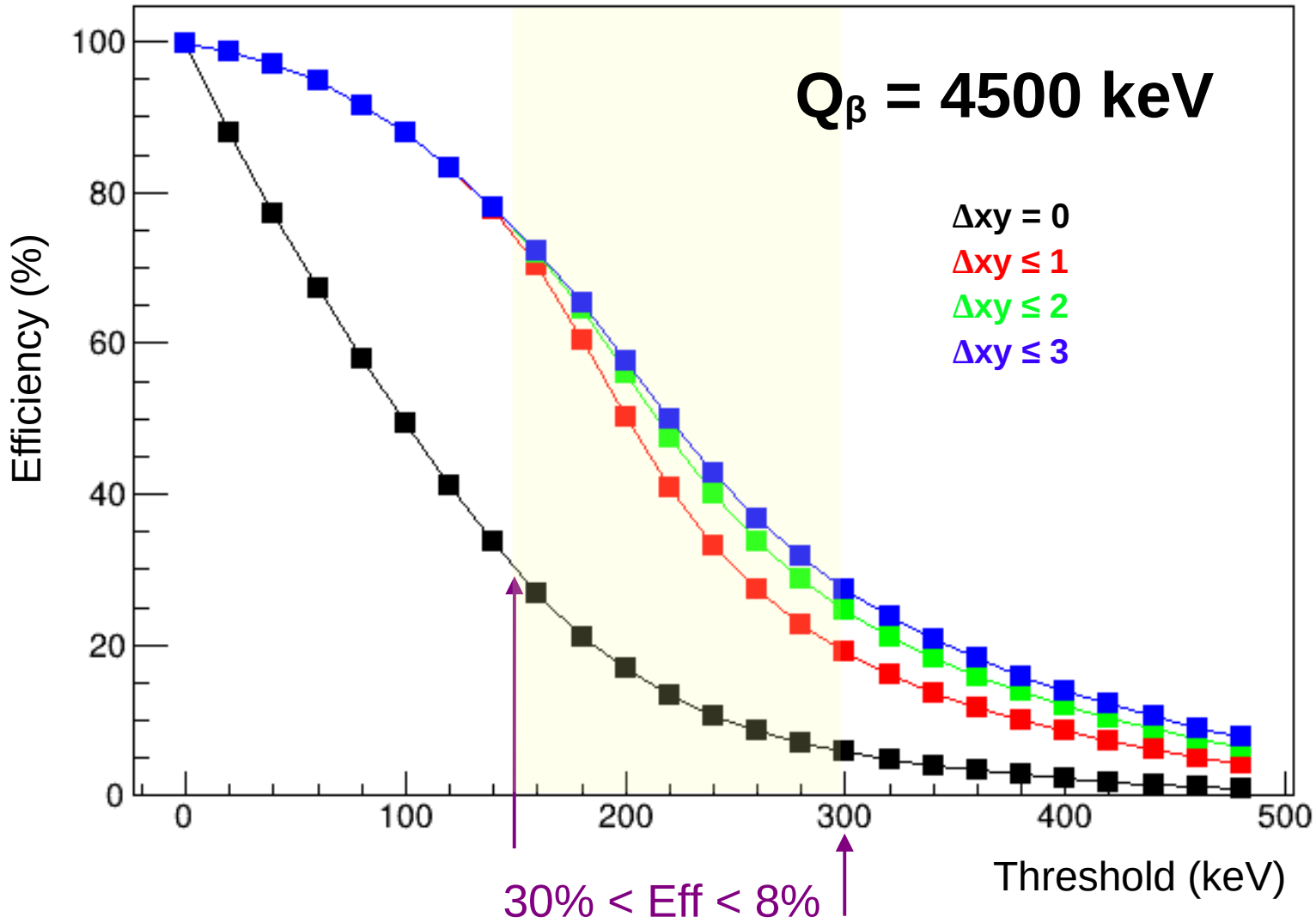
Thank you very much for your attention



Backup slides

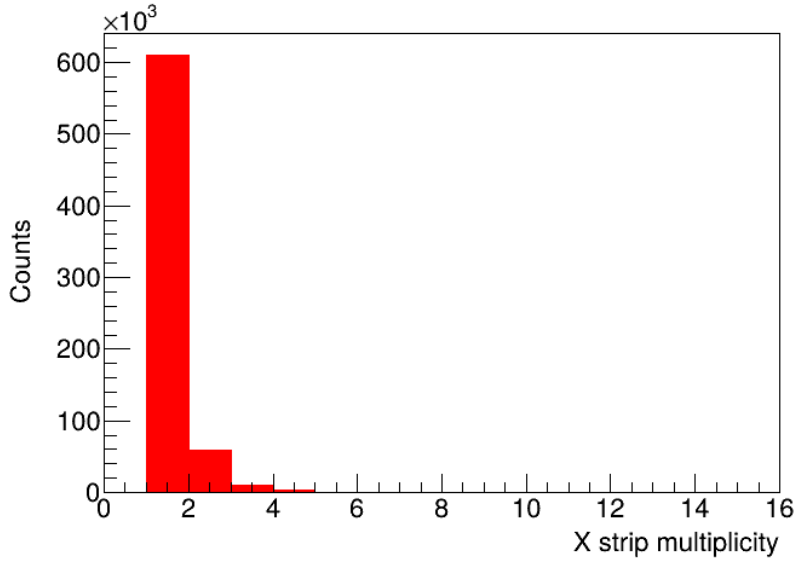
S181 – AIDA

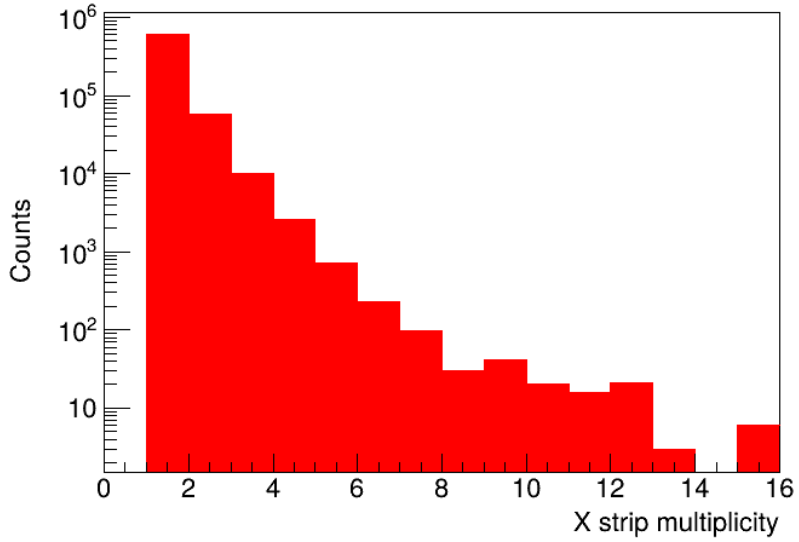
Simulated efficiency before experiment S505



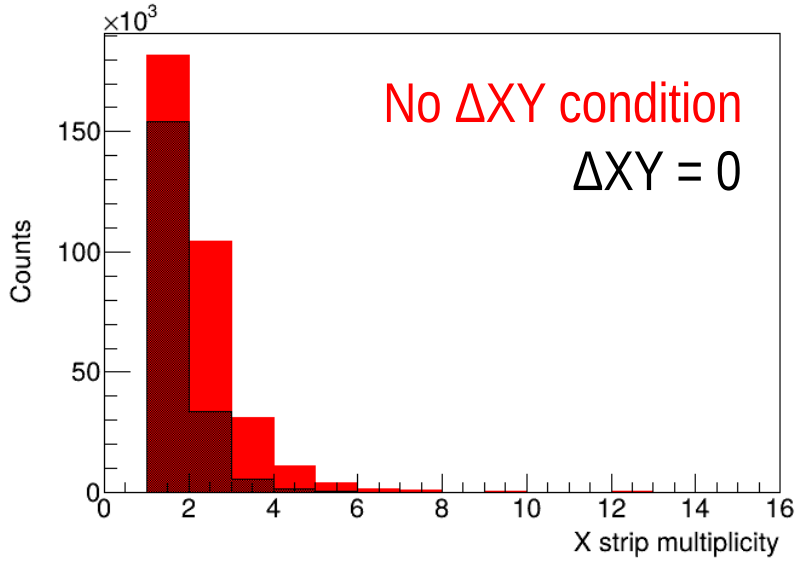
S181 – AIDA X strip multiplicity

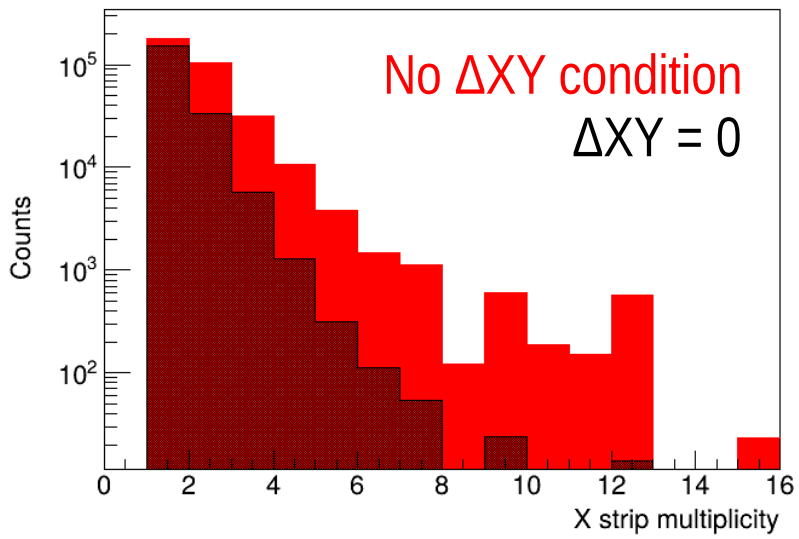
All β's out of spill





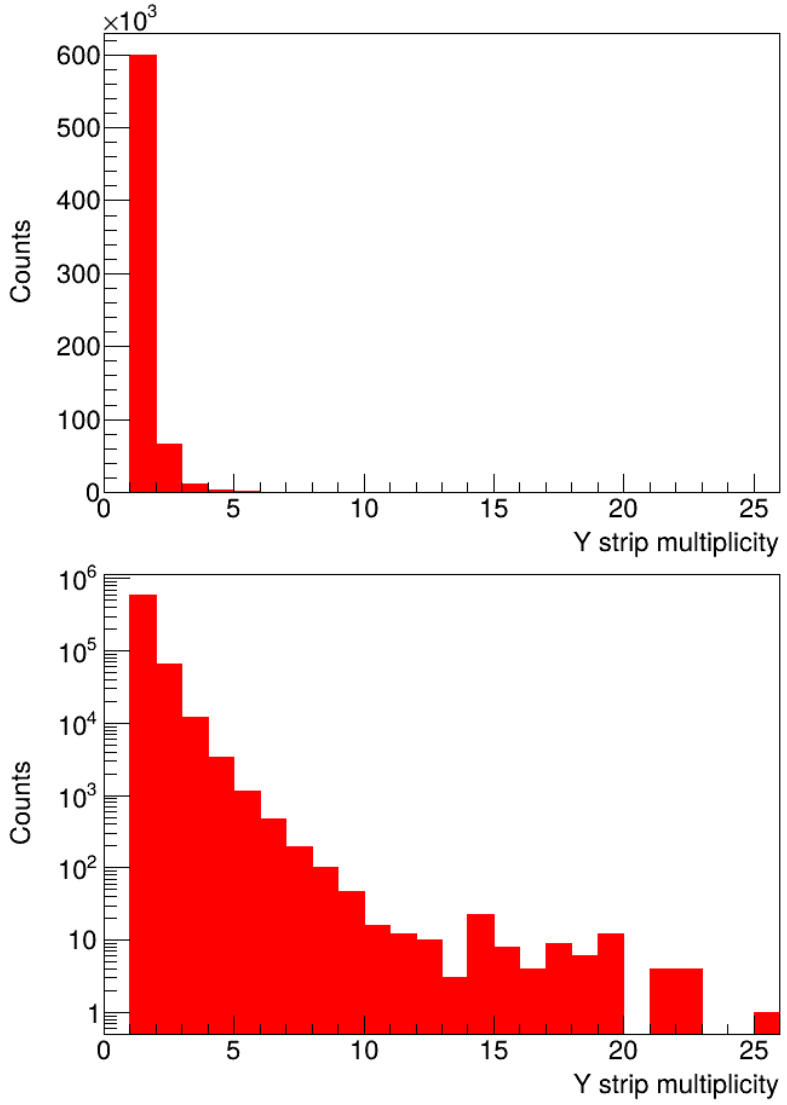
Correlated β's out of spill



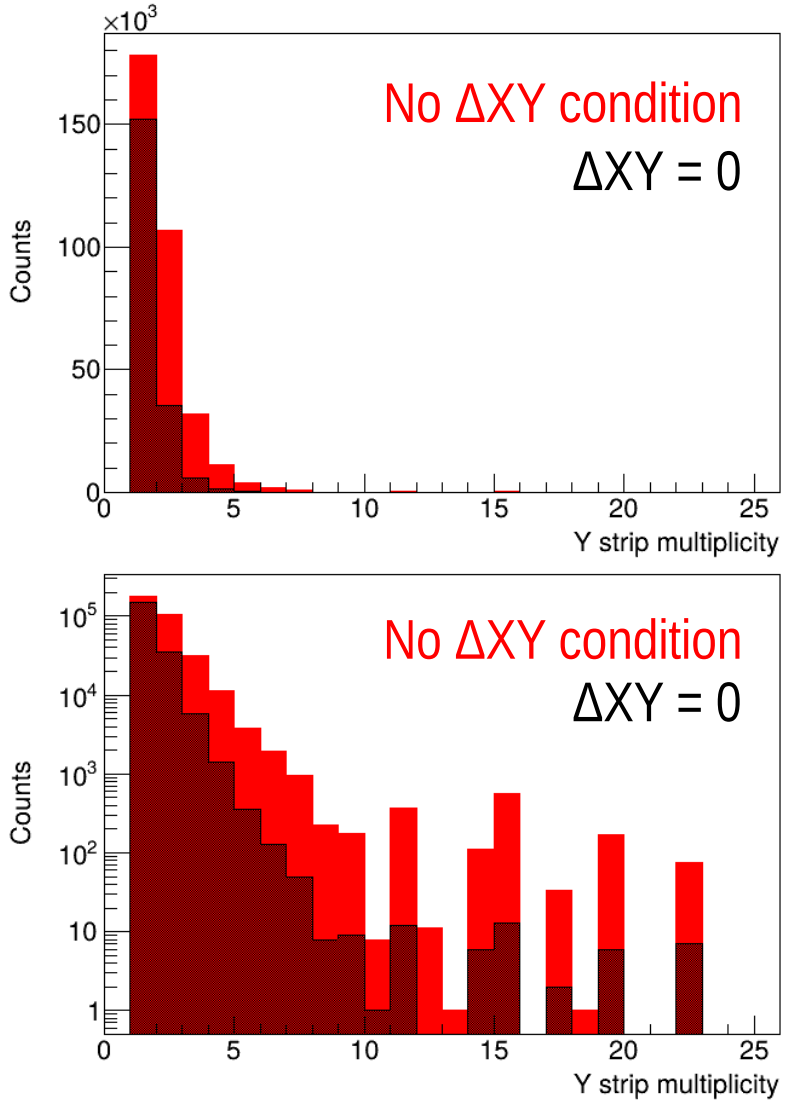


S181 – AIDA Y strip multiplicity

All β's out of spill



Correlated β's out of spill

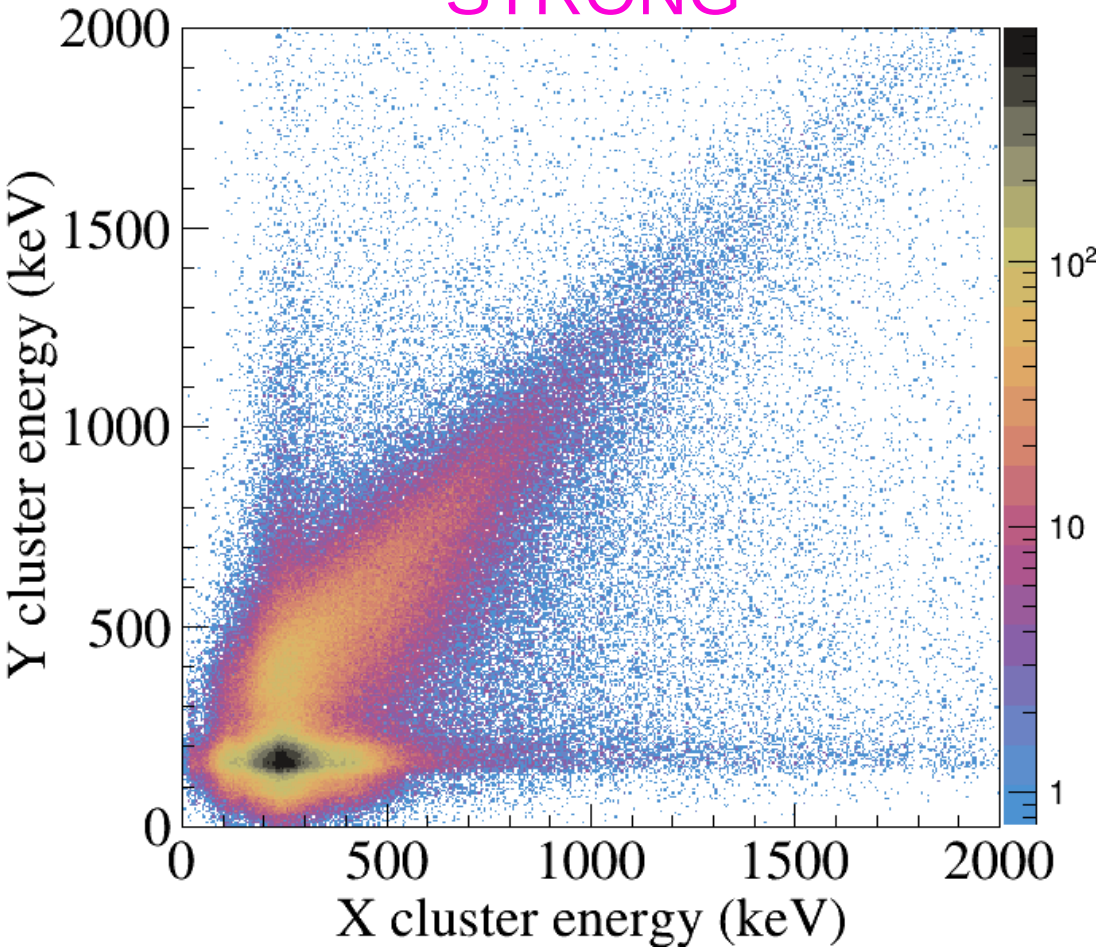


S181 – AIDA

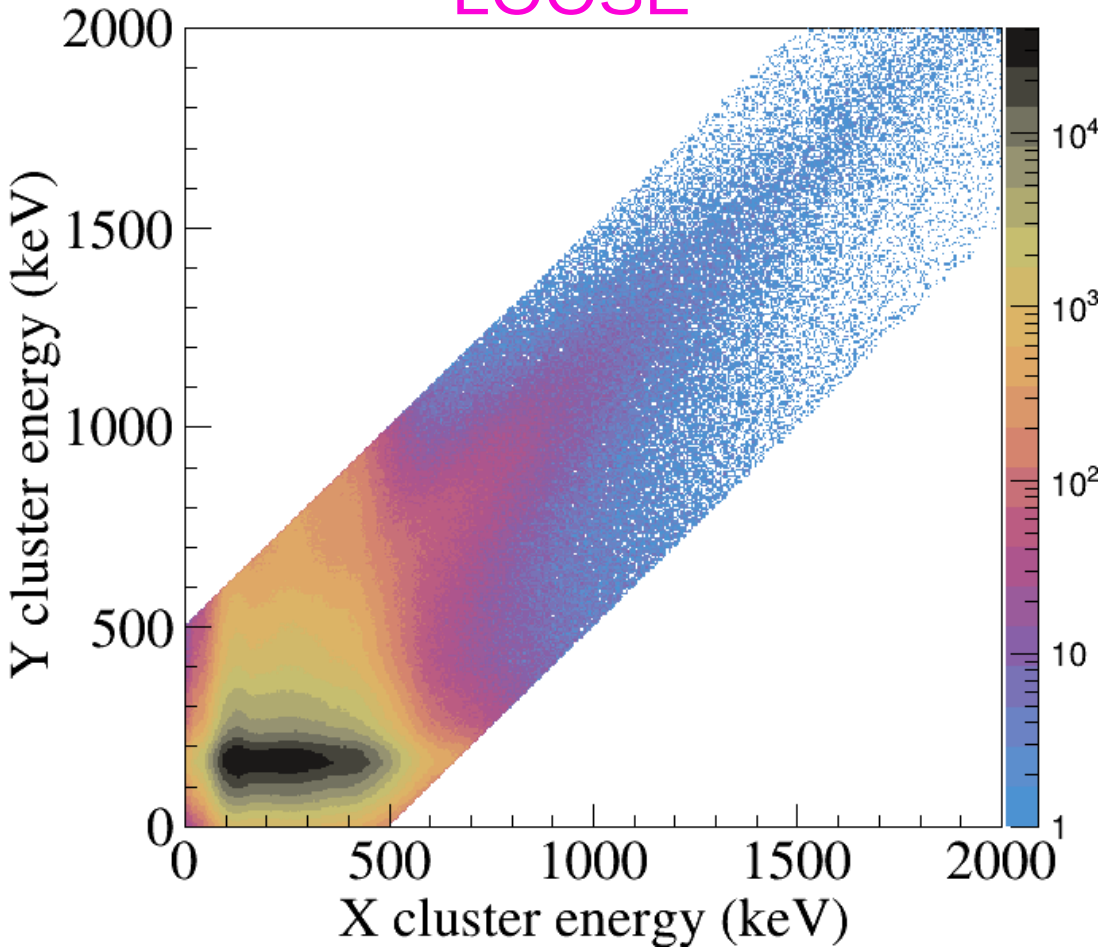
Strong vs **Loose** background suppression

All β's out of spill

STRONG

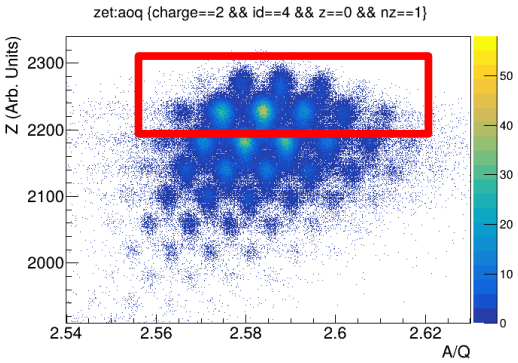


LOOSE

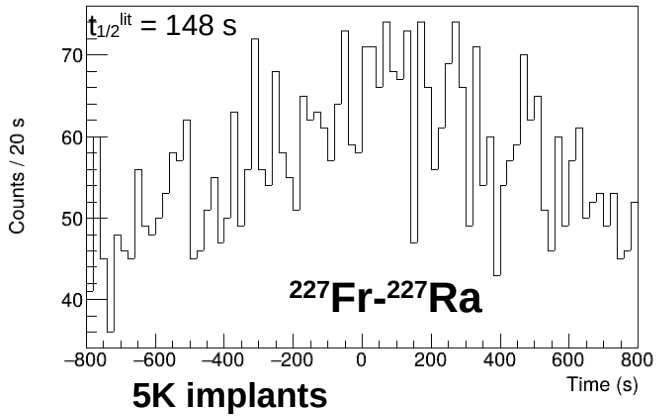


S181 – AIDA

XY cluster analysis. **Strong* background suppression**

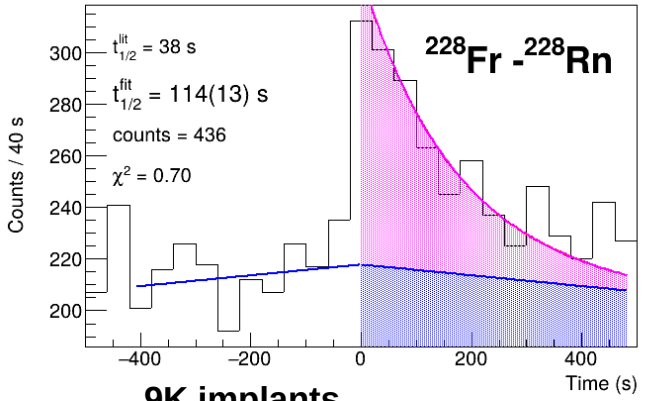


Ion-β time spectra



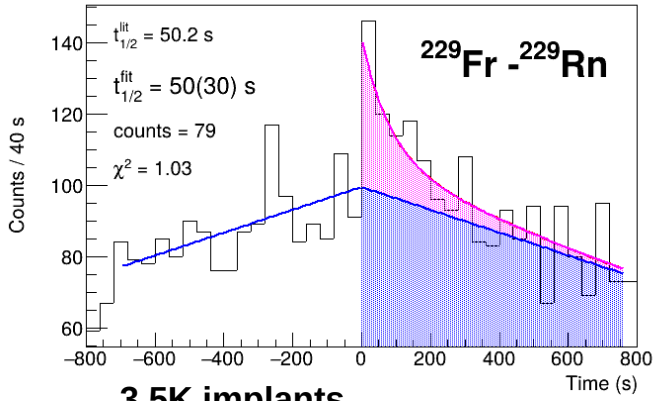
5K implants

AIDA Eff. ~ 12%

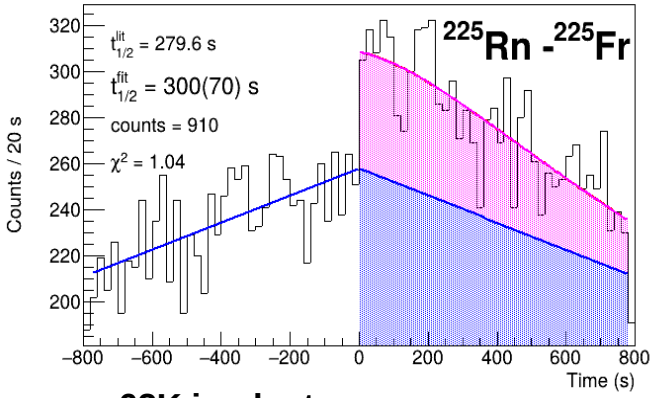


9K implants

AIDA Eff. ~ 4%

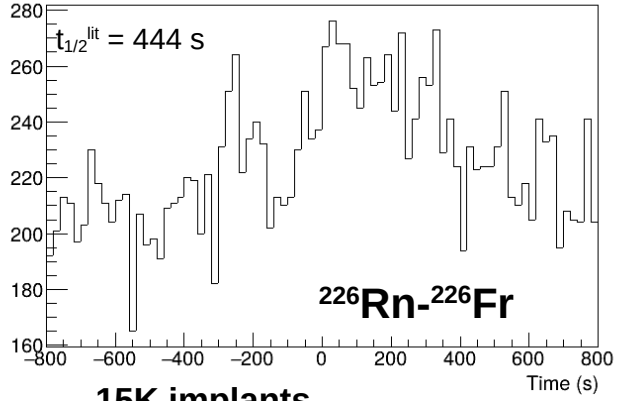


3.5K implants

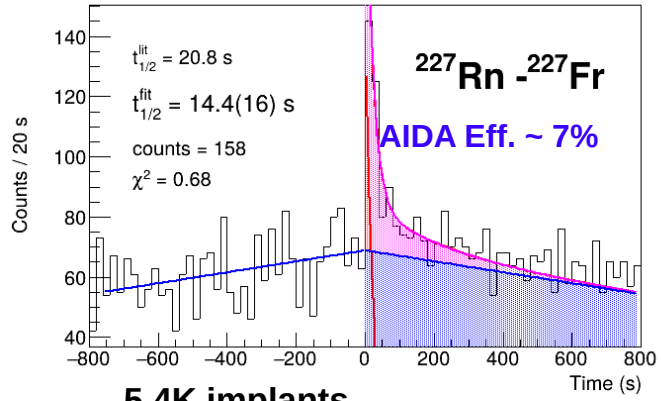


62K implants

AIDA Eff. ~ 4%



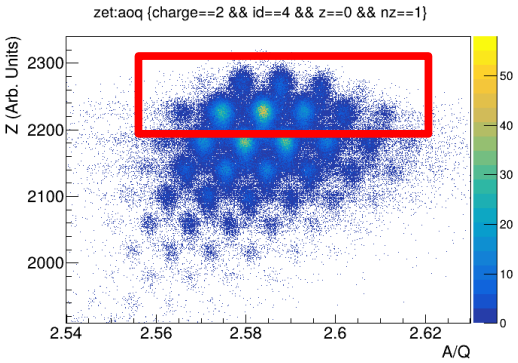
15K implants



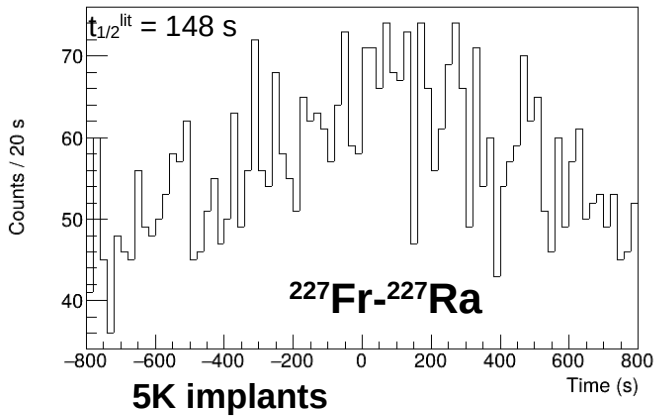
5.4K implants

S181 – AIDA

XY cluster analysis. **Strong* background suppression**

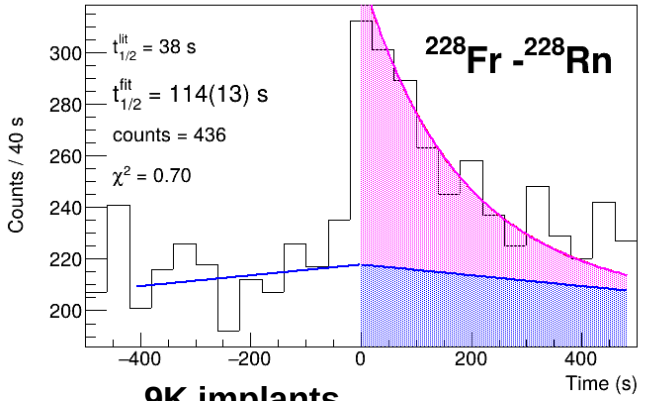


Ion-β time spectra



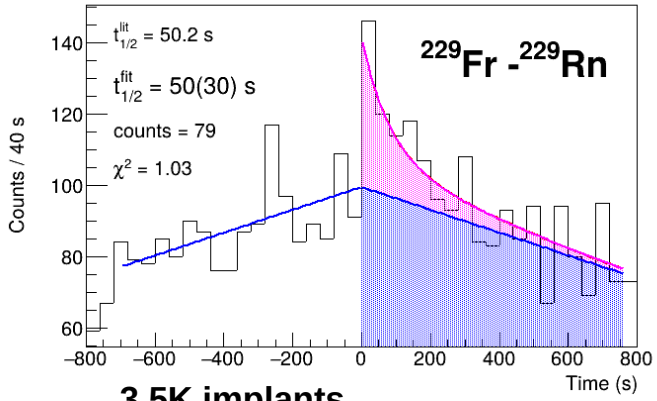
5K implants

AIDA Eff. ~ 12%

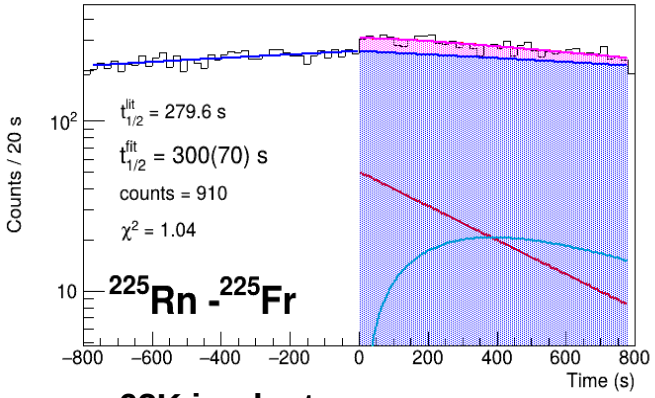


9K implants

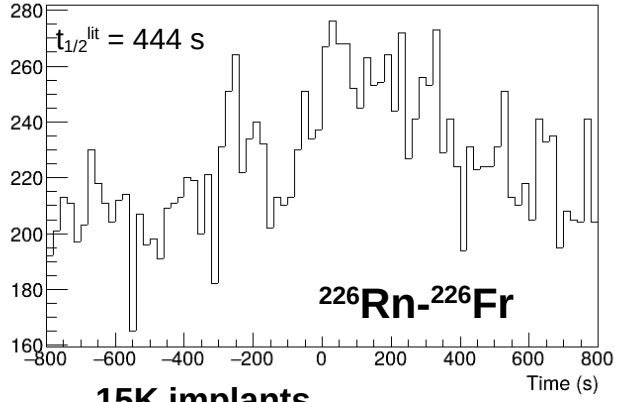
AIDA Eff. ~ 4%



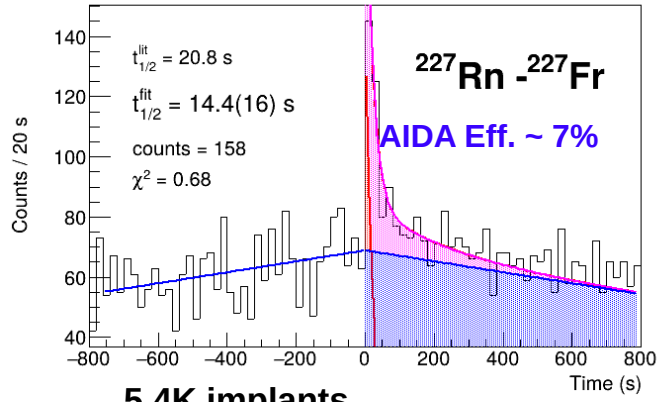
3.5K implants



62K implants



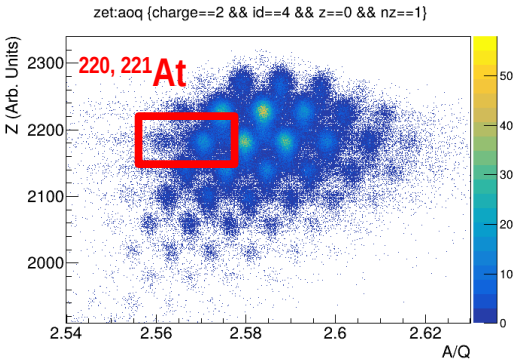
15K implants



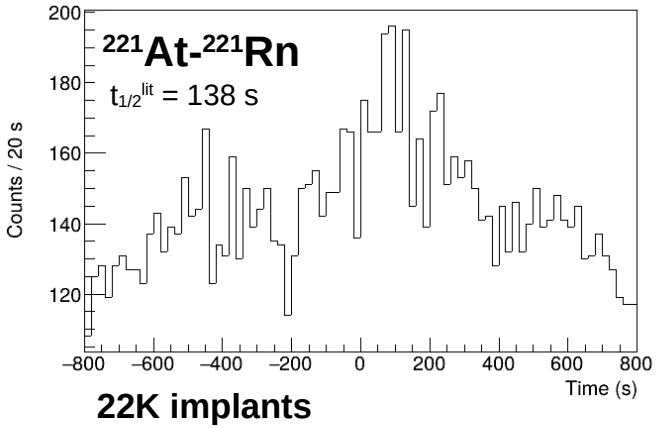
5.4K implants

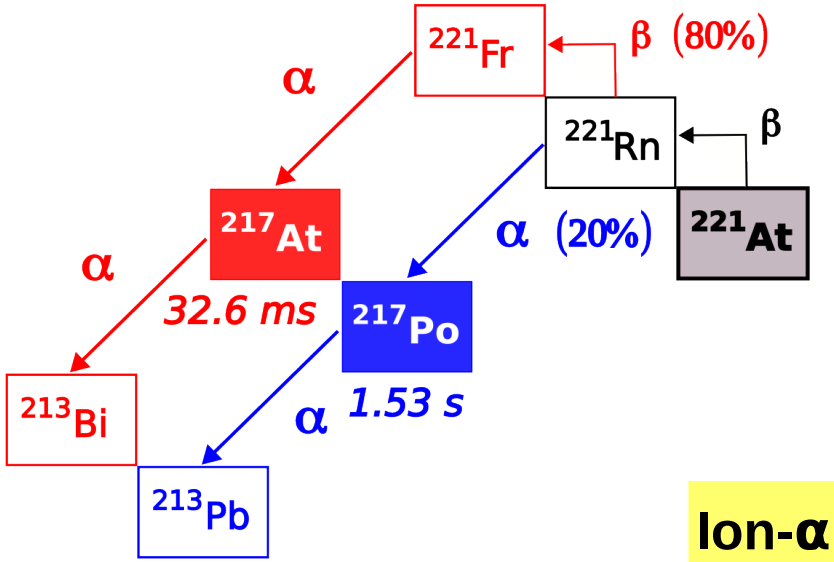
S181 – AIDA

XY cluster analysis. **Strong* background suppression**



Ion-β time spectra

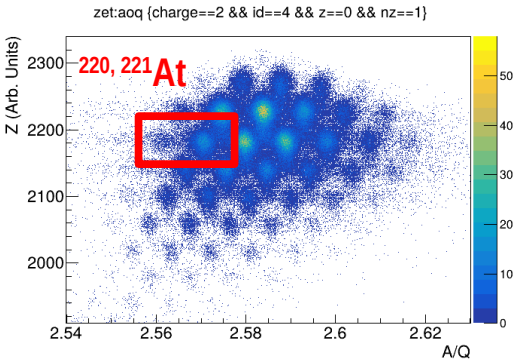




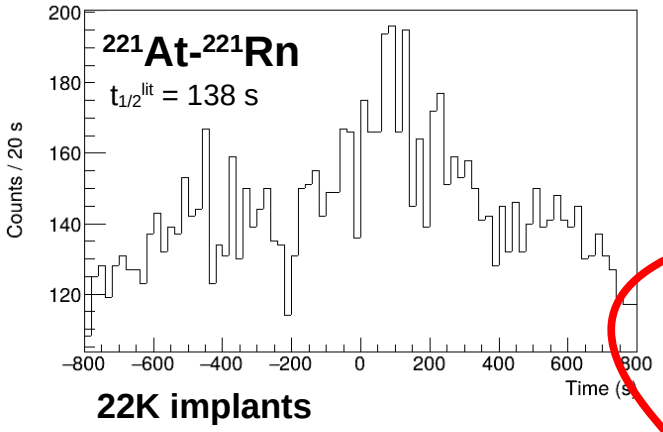
Ion-α time spectra

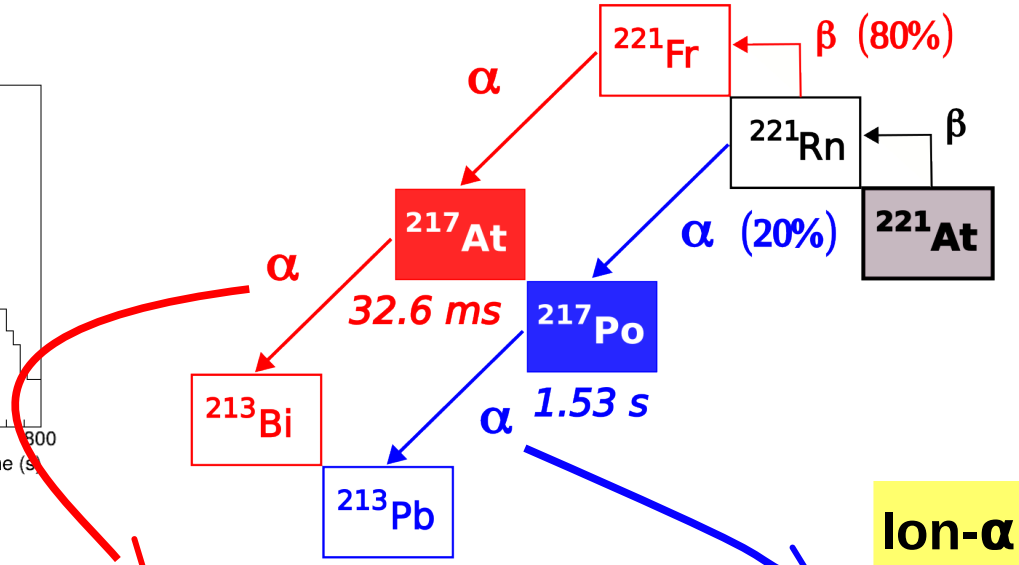
S181 – AIDA

XY cluster analysis. **Strong* background suppression**

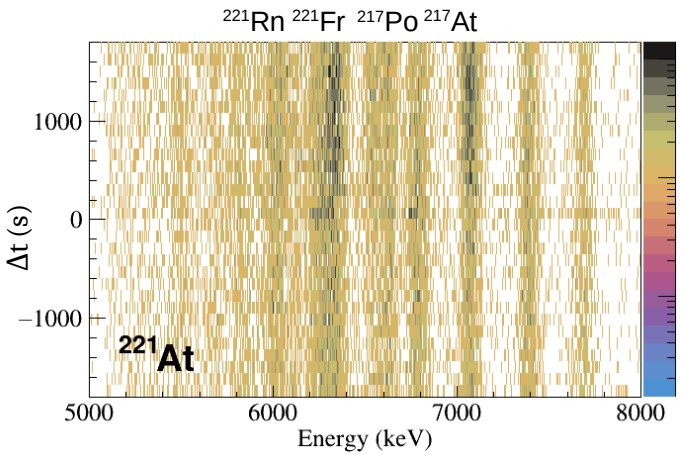


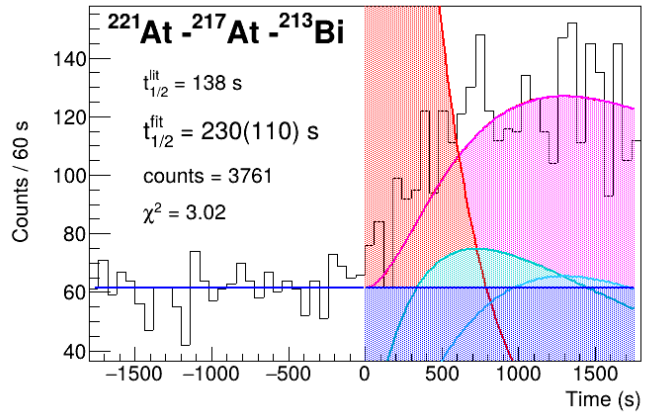
Ion-β time spectra

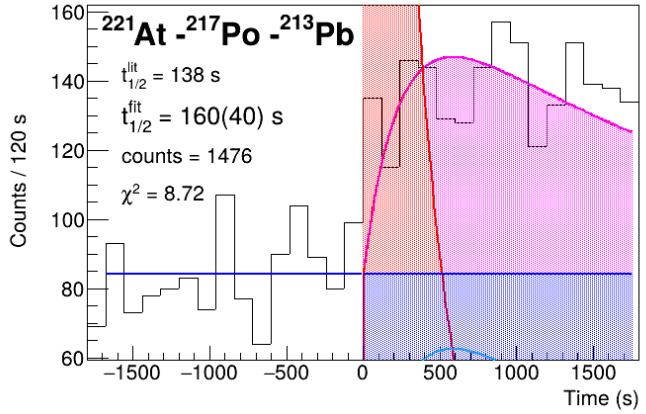




Ion-α time spectra

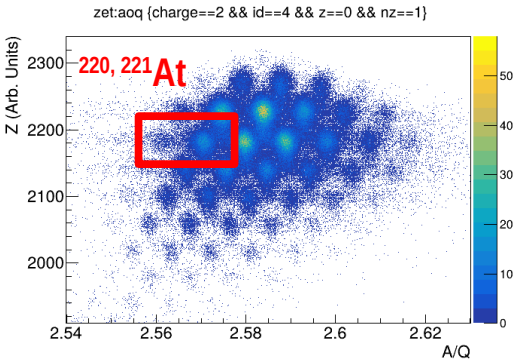




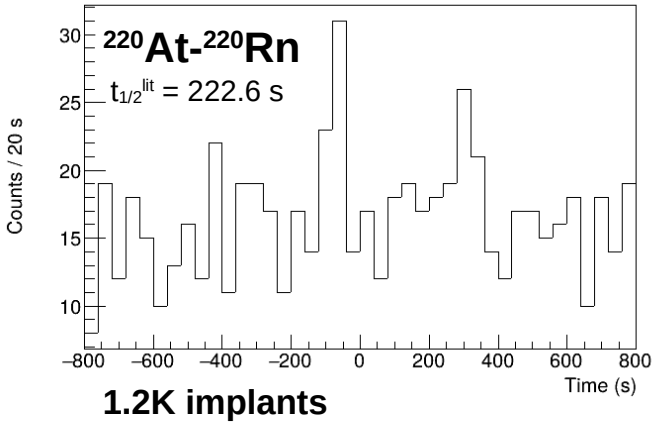


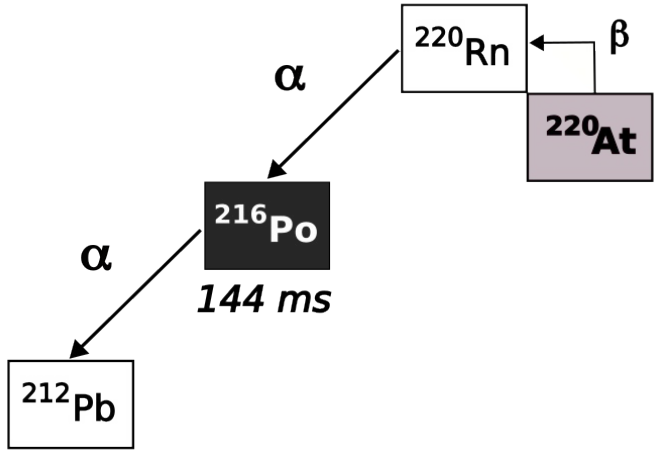
S181 – AIDA

XY cluster analysis. **Strong* background suppression**



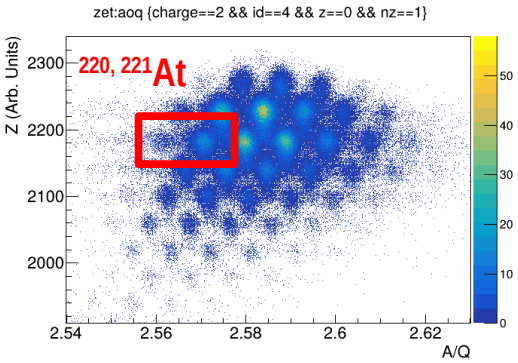
Ion-β time spectra





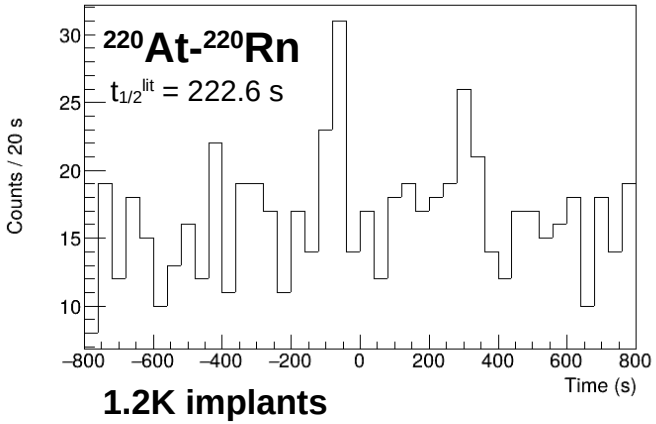
Ion-α time spectra

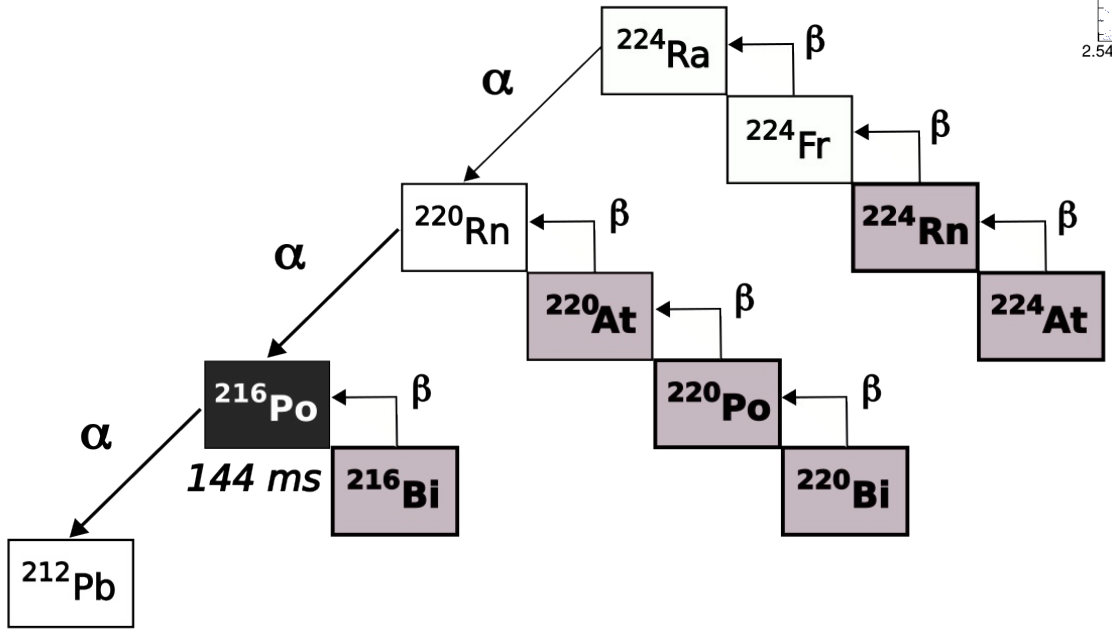
S181 – AIDA



XY cluster analysis. **Strong* background suppression**

Ion-β time spectra

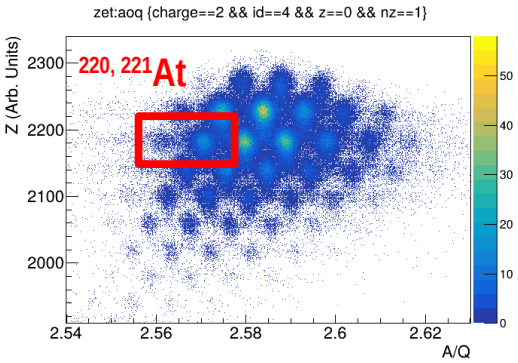




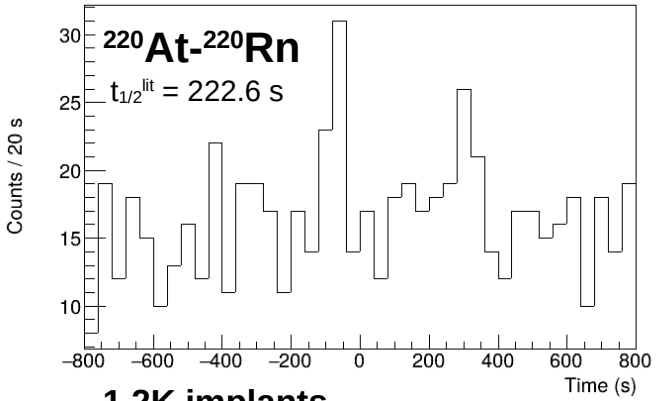
Ion-α time spectra

S181 – AIDA

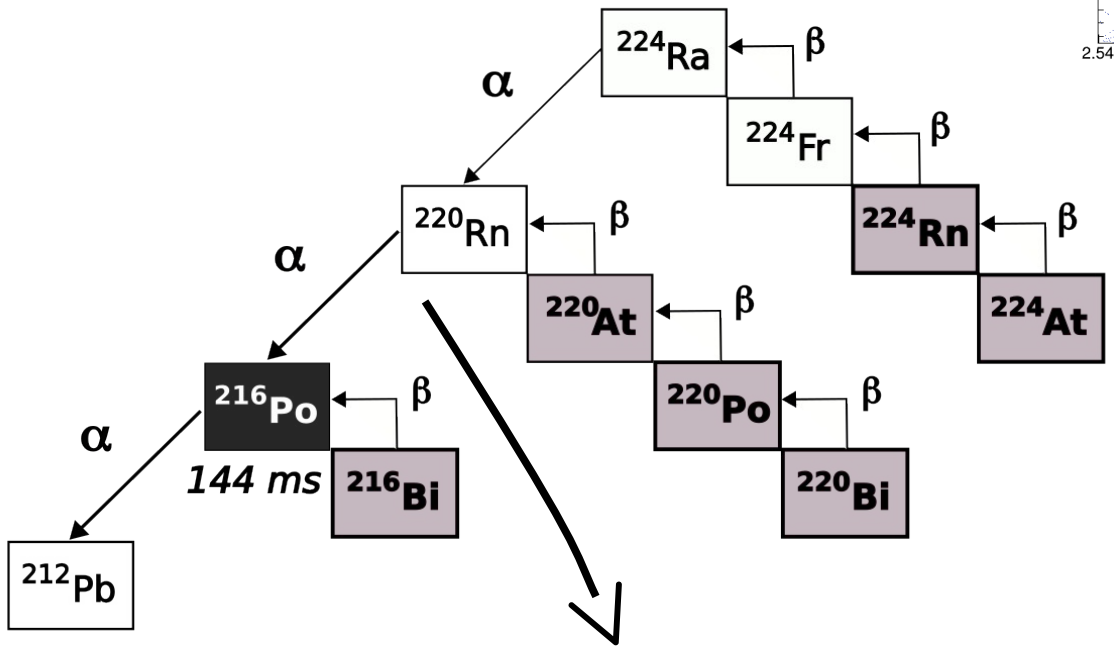
XY cluster analysis. **Strong* background suppression**

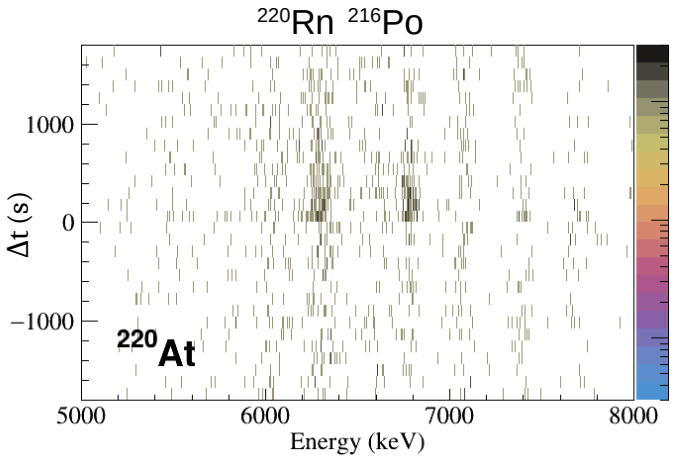


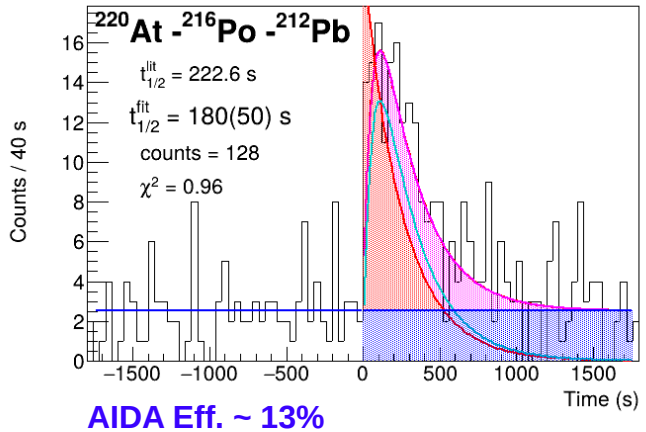
Ion-β time spectra



1.2K implants





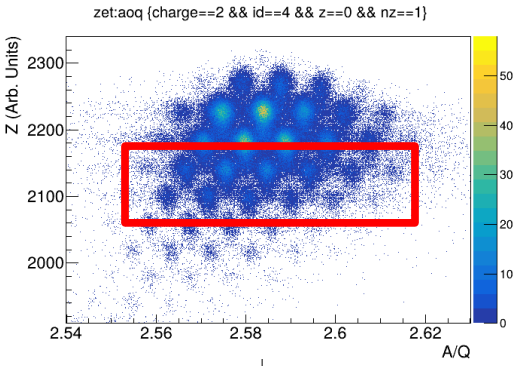


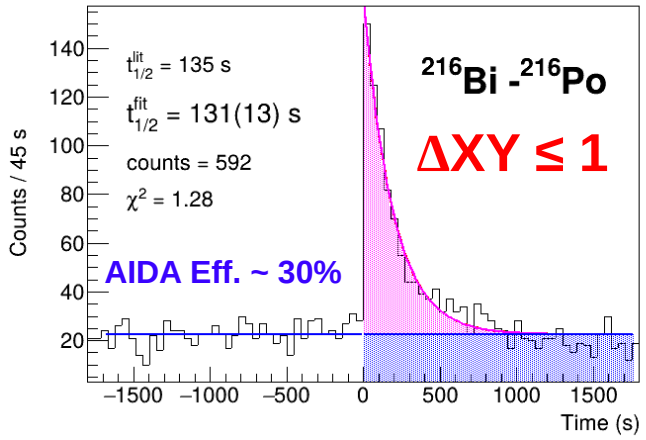
AIDA Eff. ~ 13%

Ion-α time spectra

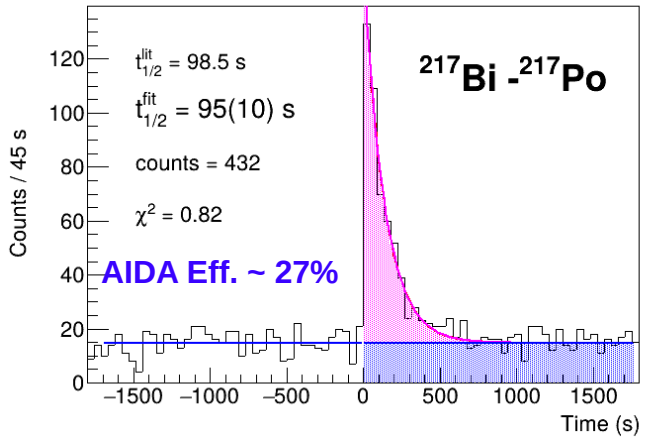
S181 – AIDA

XY cluster analysis. **Strong* background suppression**

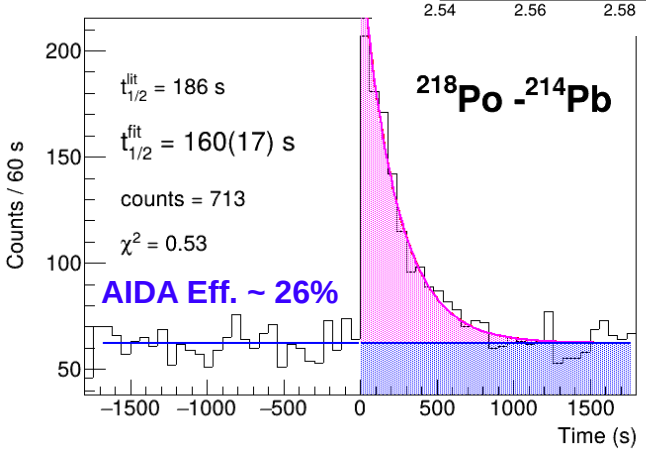




5K implants

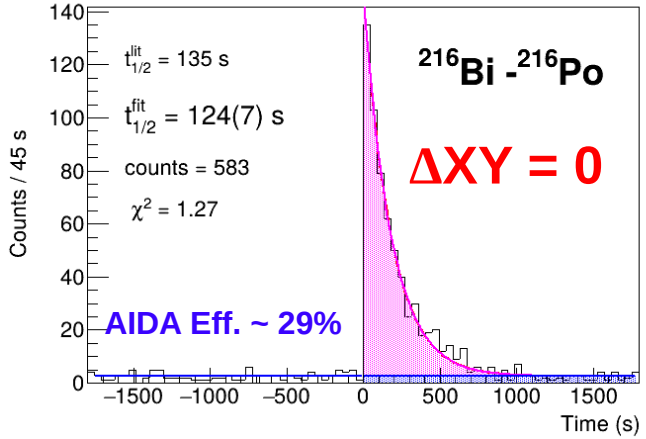


4K implants

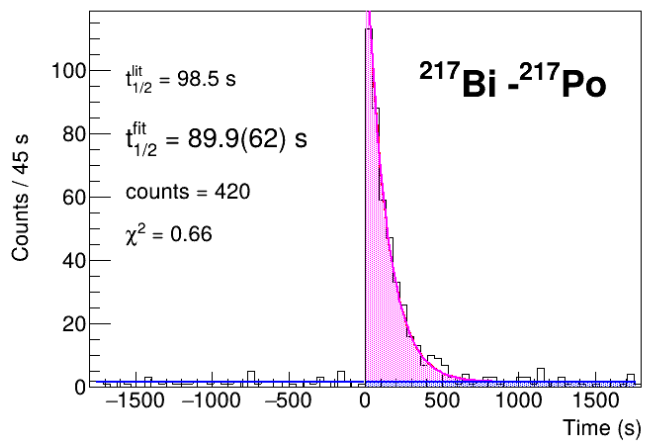


6.8K implants

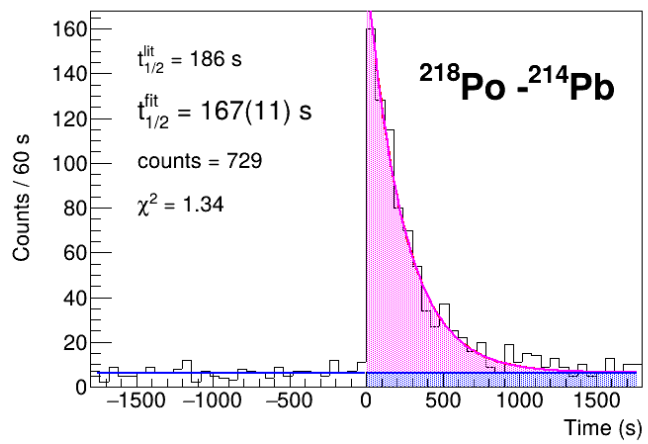
Ion-α time spectra



AIDA Eff. ~ 26%



AIDA Eff. ~ 27%



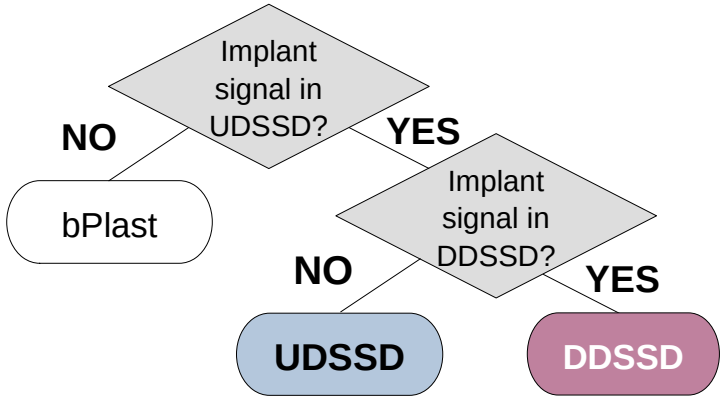
S181 – AIDA APPROACH

Solution:

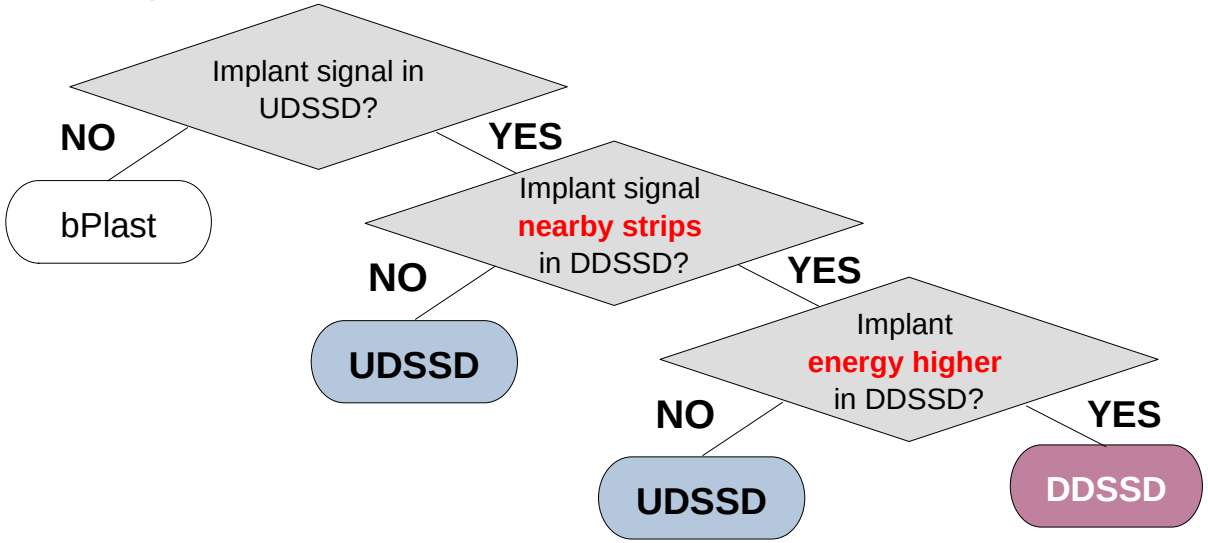
- Remove **noisy X & Y strips** before clustering
- Analyze **only upstream DSSSD**, where implants show good pattern

DEFINITION OF IMPLANTATION LAYER

Before



After



S181 – AIDA APPROACH

Solution:

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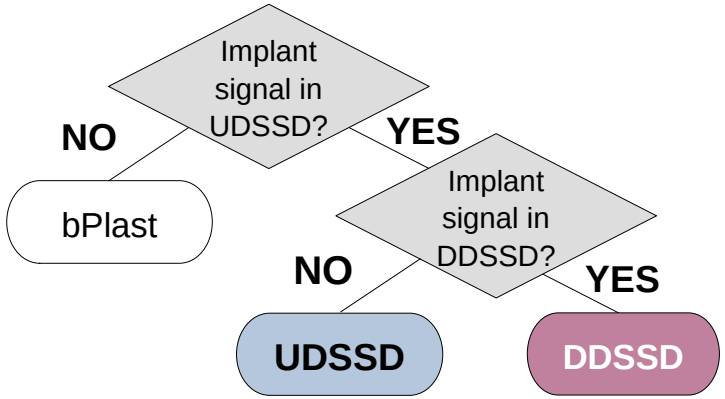
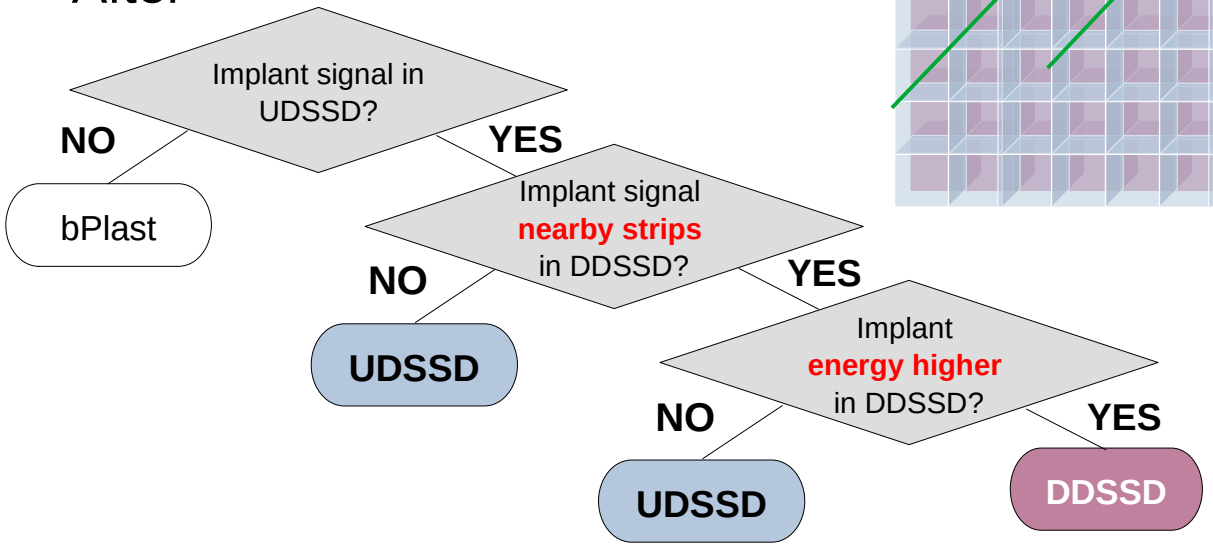
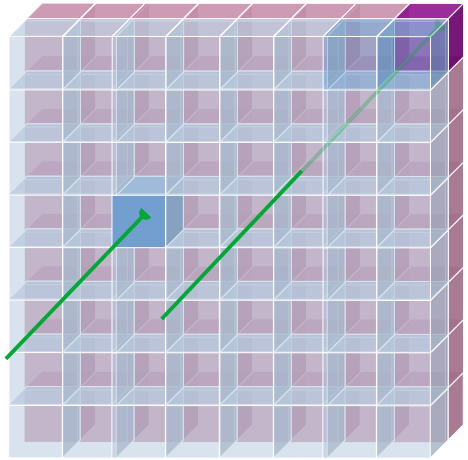
DEFINITION OF IMPLANTATION LAYER

Before



After





S181 – AIDA APPROACH

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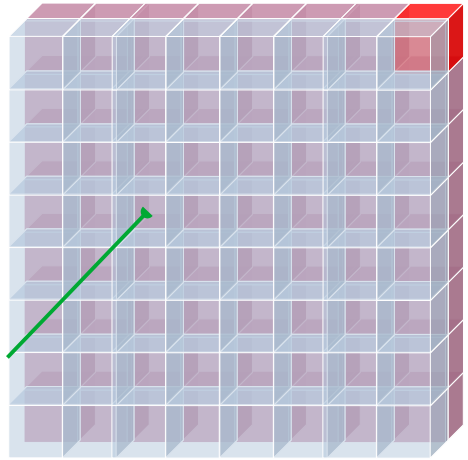
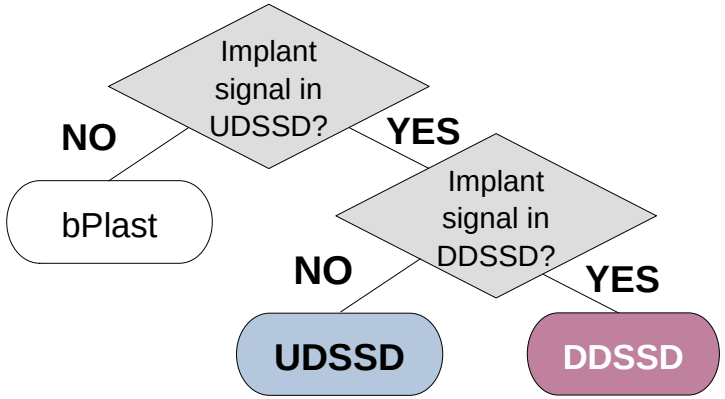
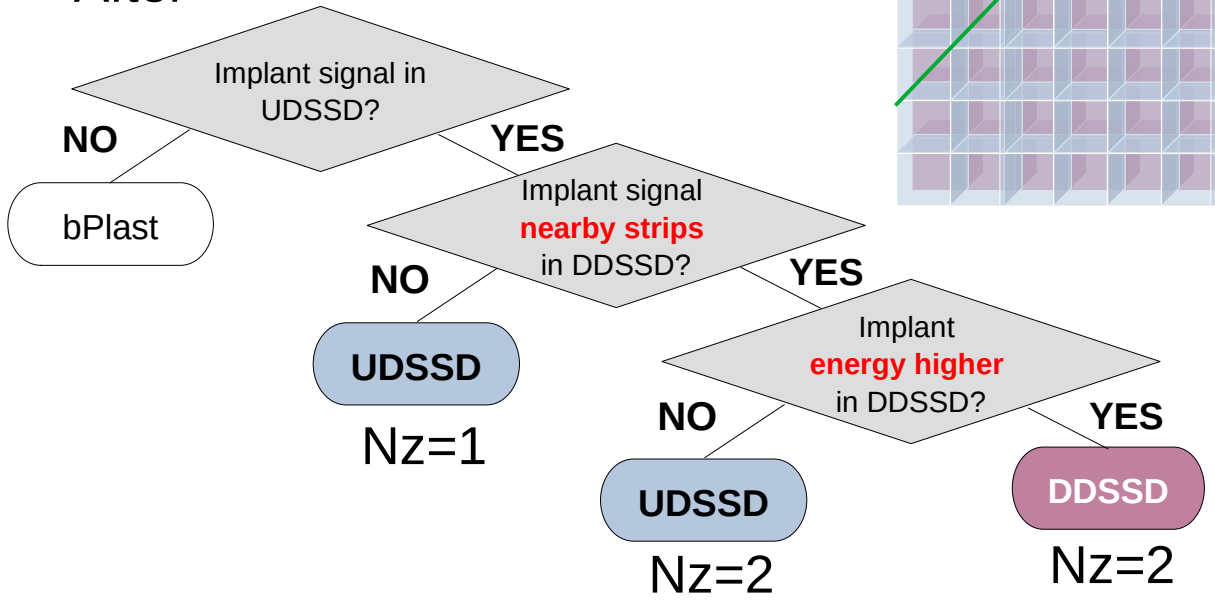
DEFINITION OF IMPLANTATION LAYER



Before



After



S181 – AIDA APPROACH

Solution:

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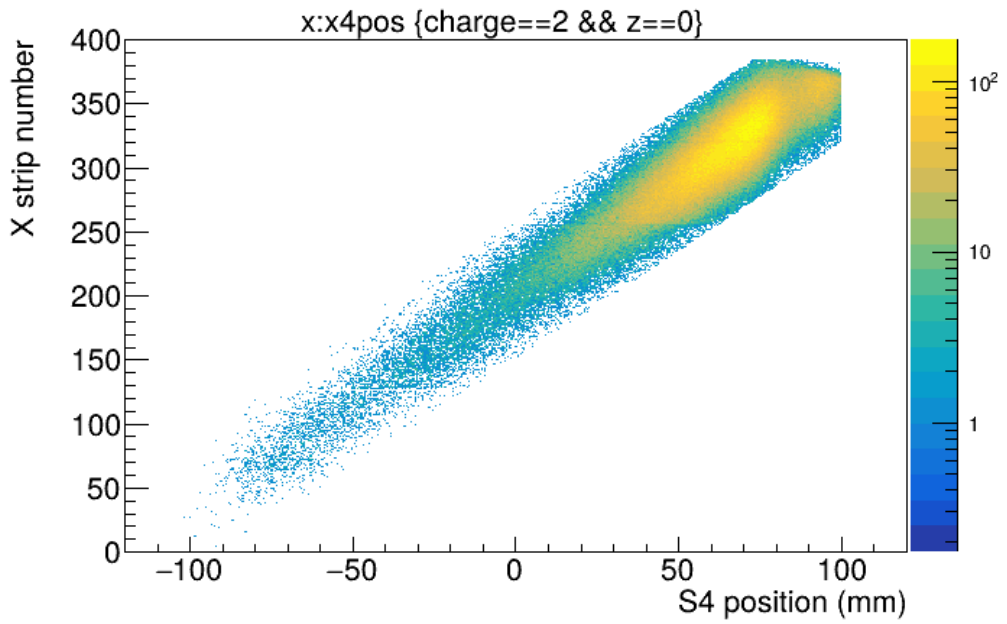
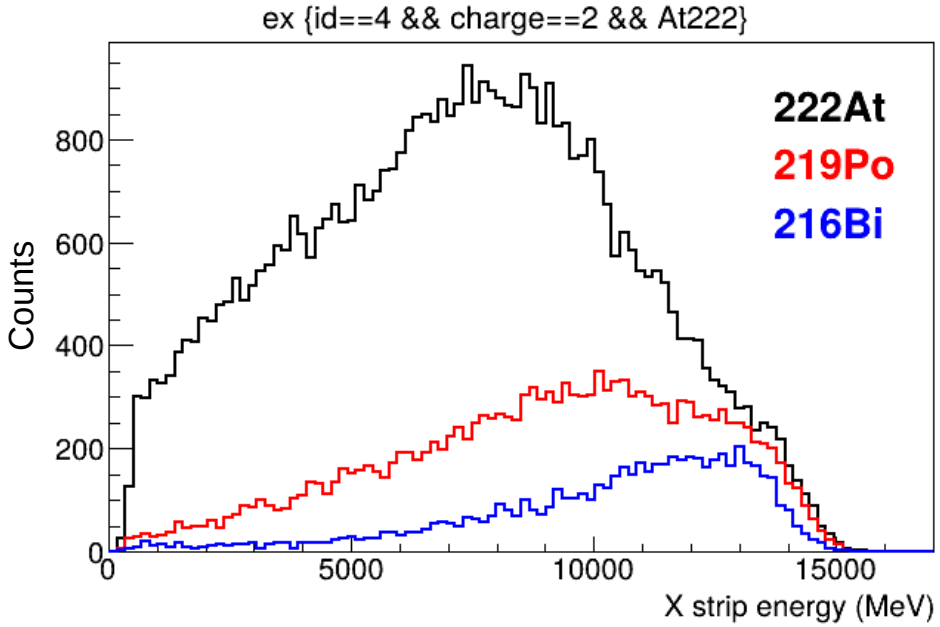
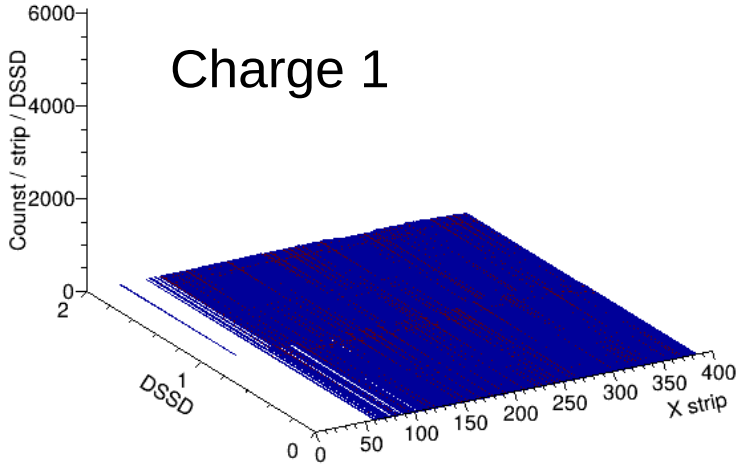
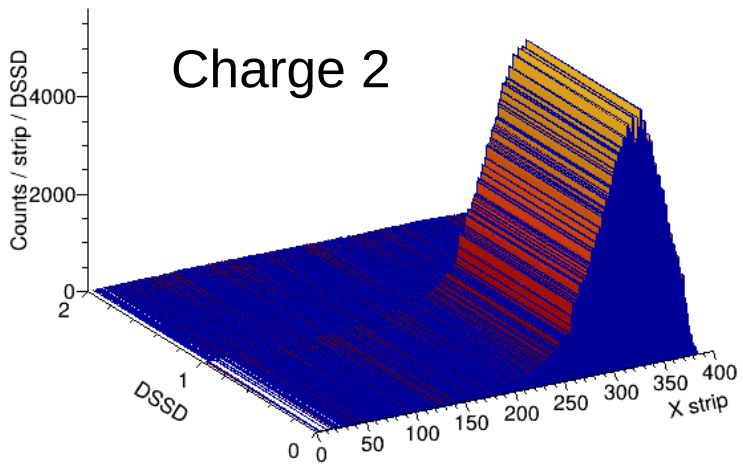


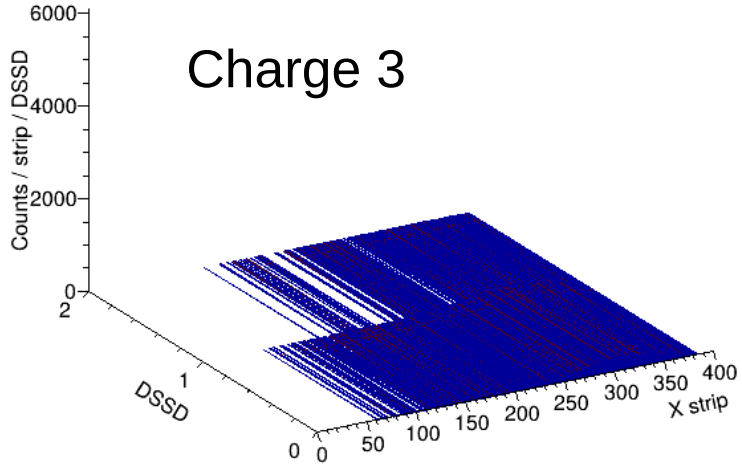


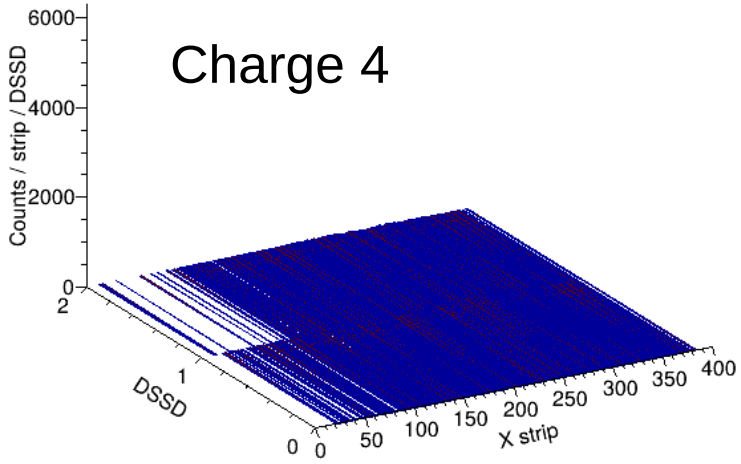
S181 – AIDA

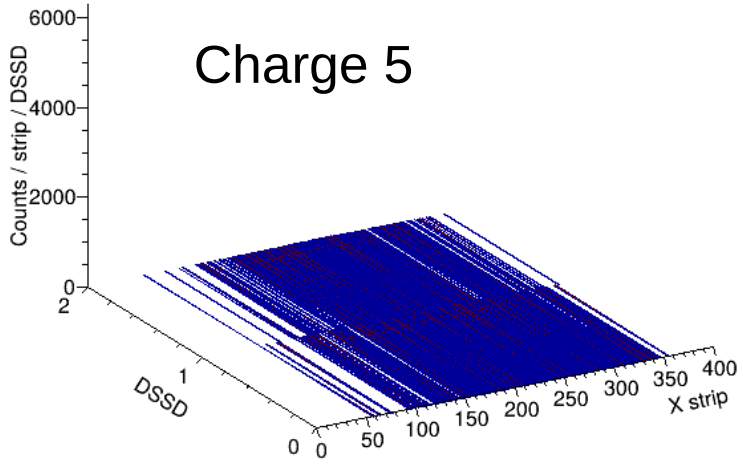
Implantation distributions & hit patterns

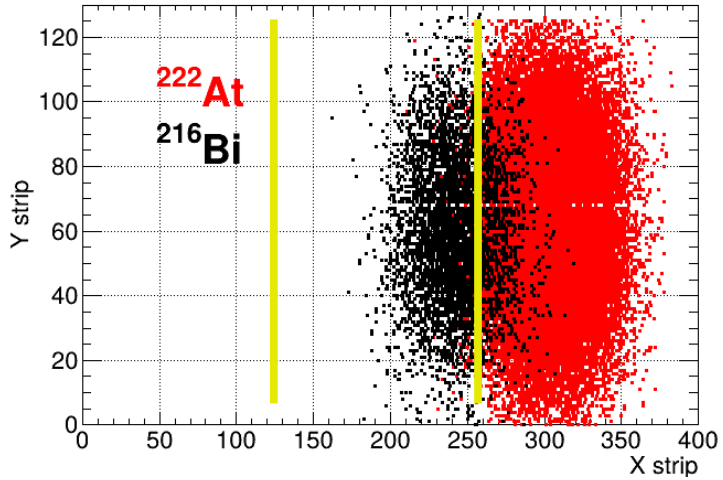






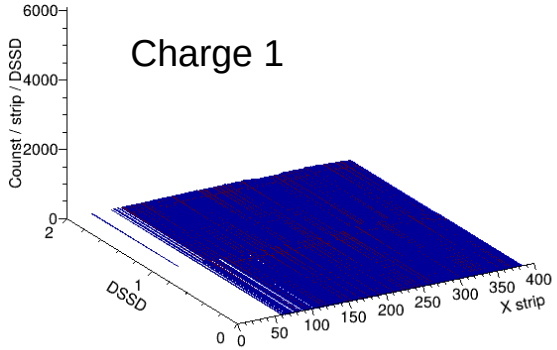


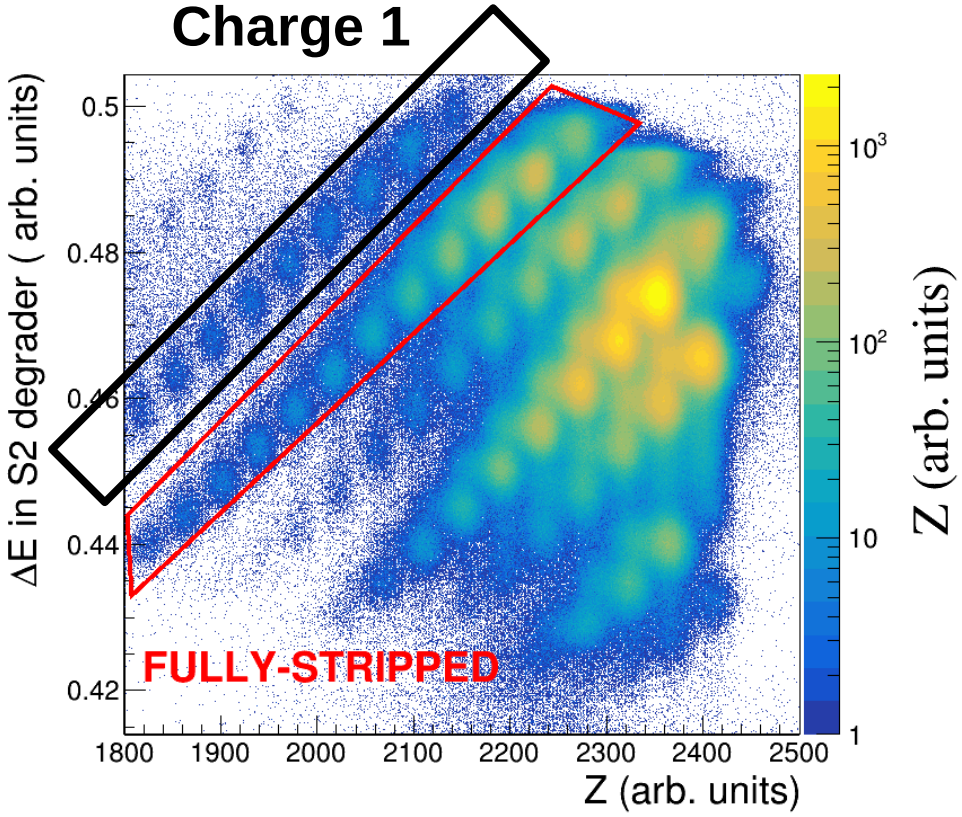


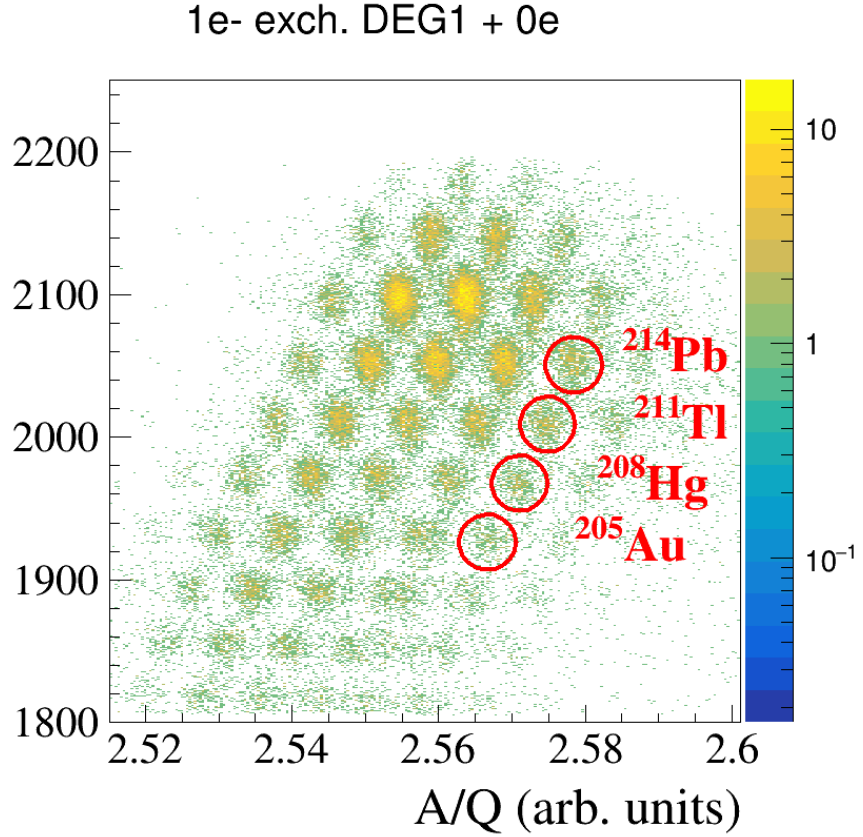


S181 – AIDA

Implantation distributions & hit patterns

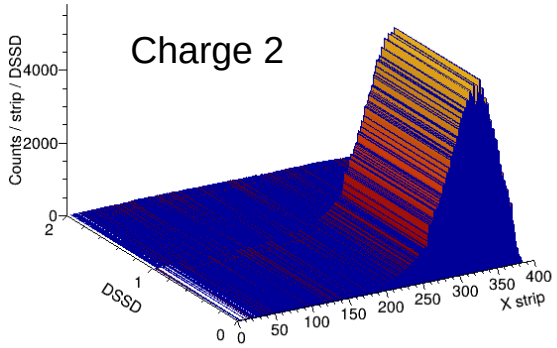


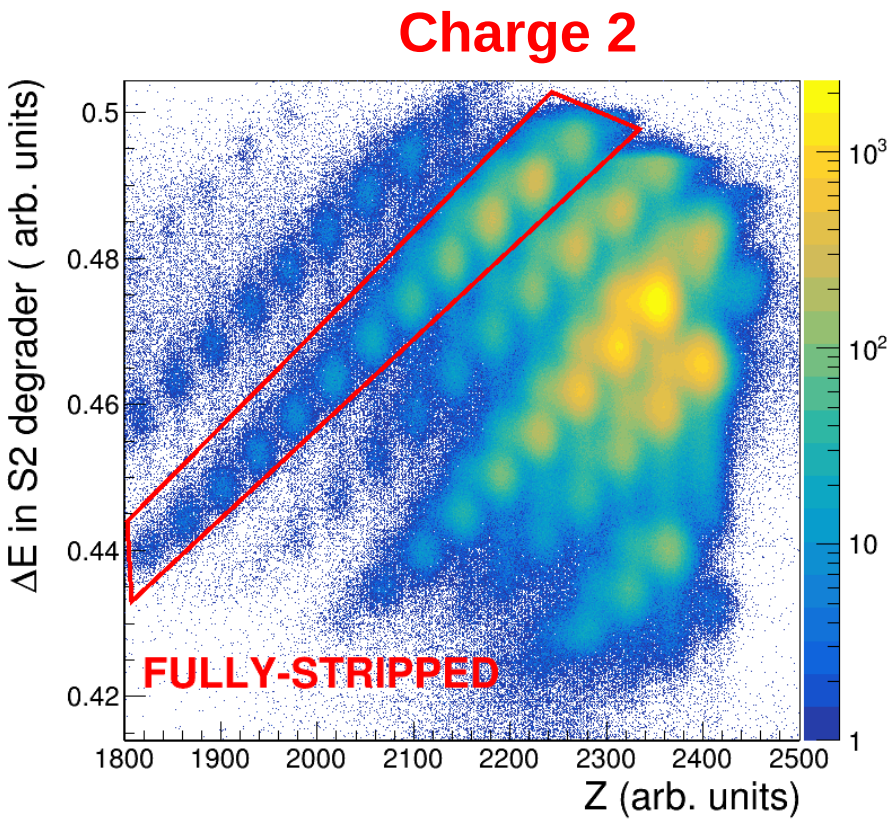


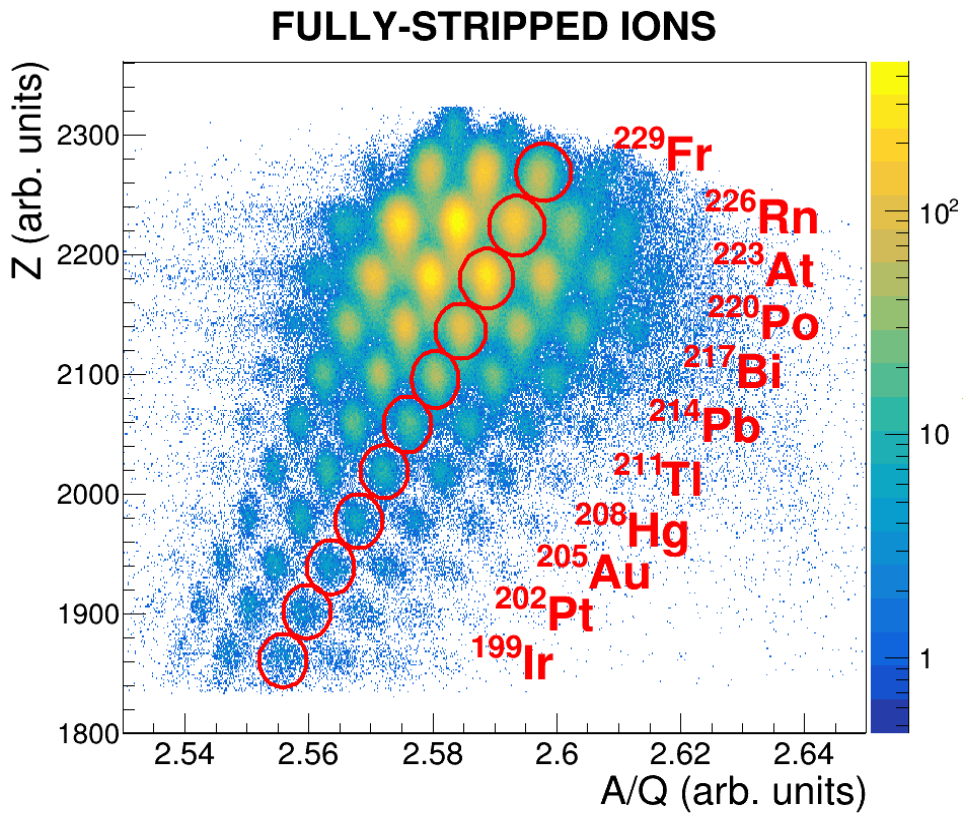


S181 – AIDA

Implantation distributions & hit patterns

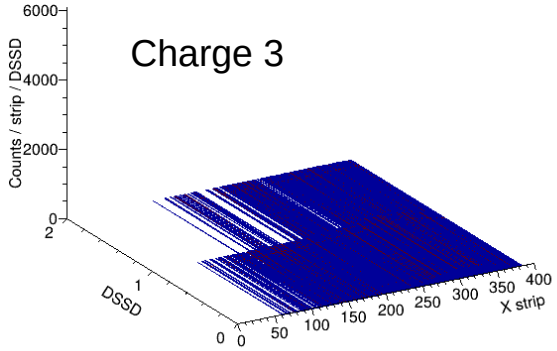


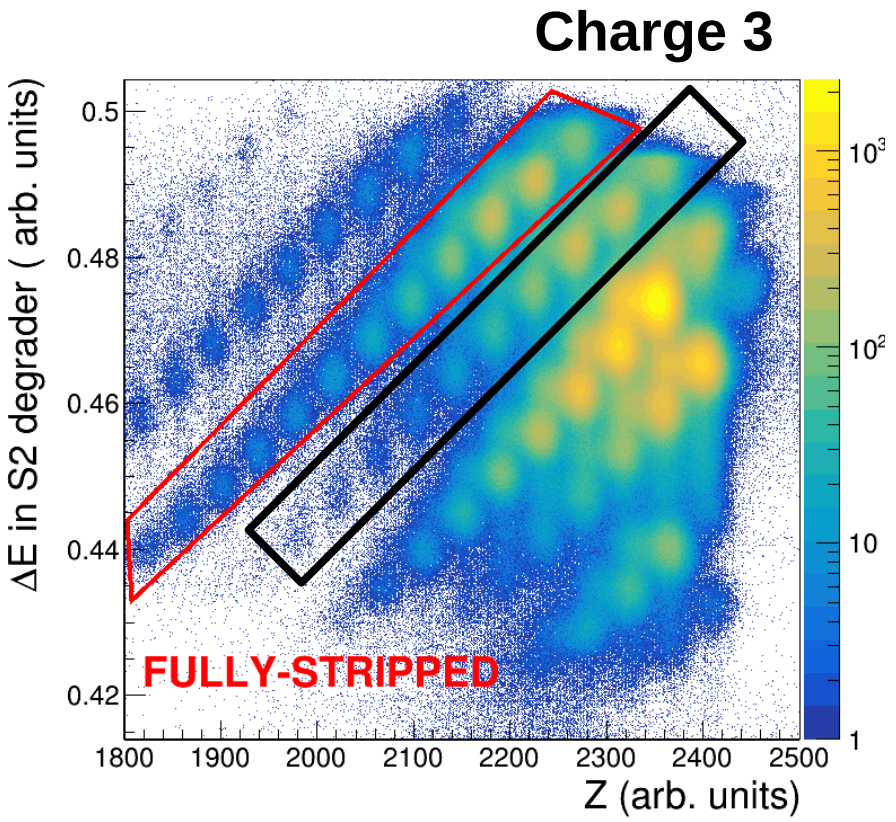


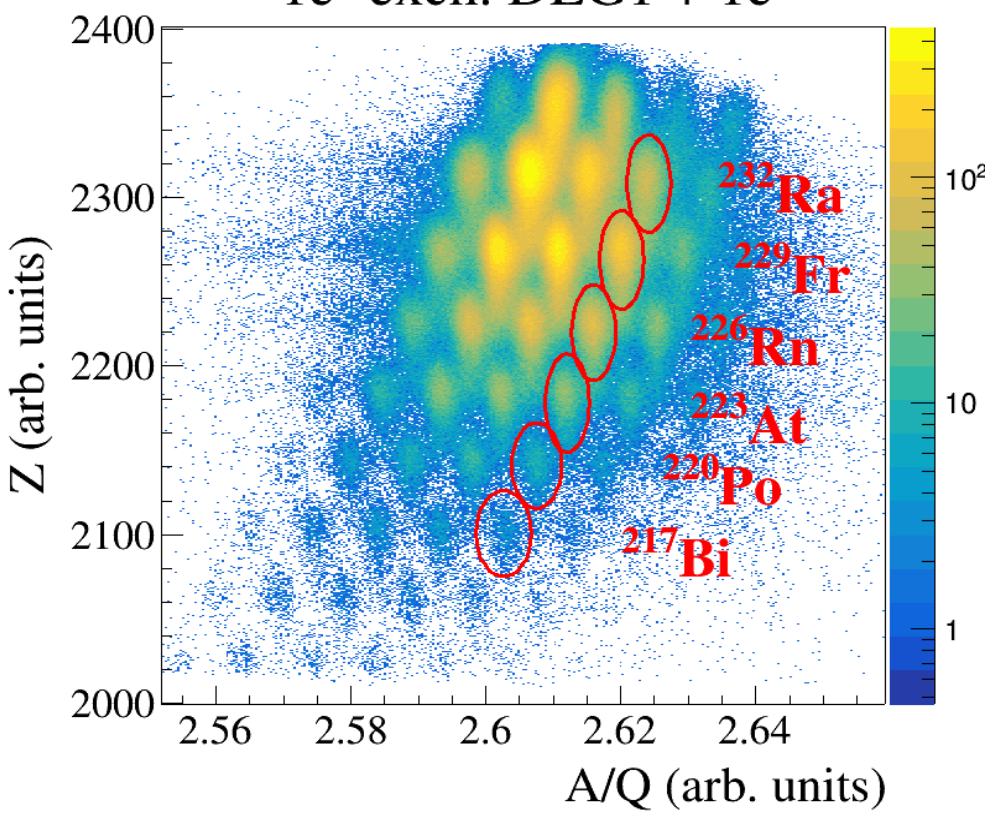


S181 – AIDA

Implantation distributions & hit patterns

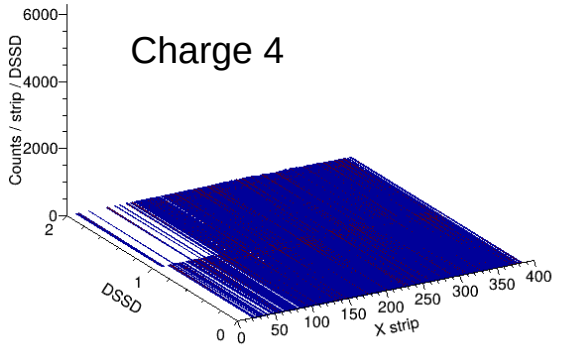


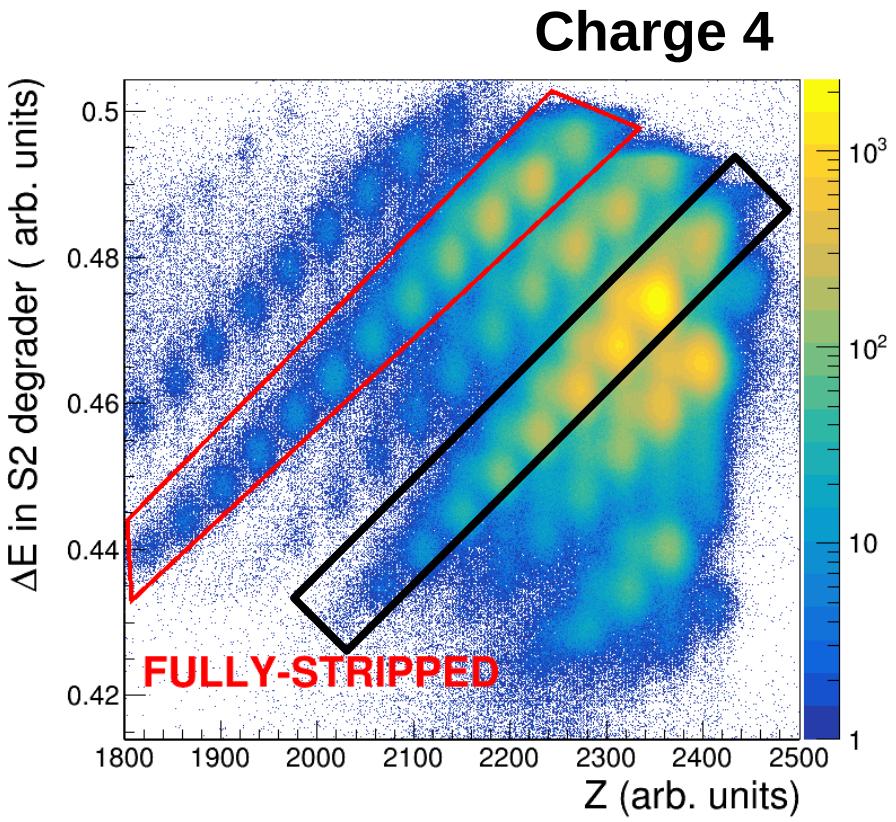


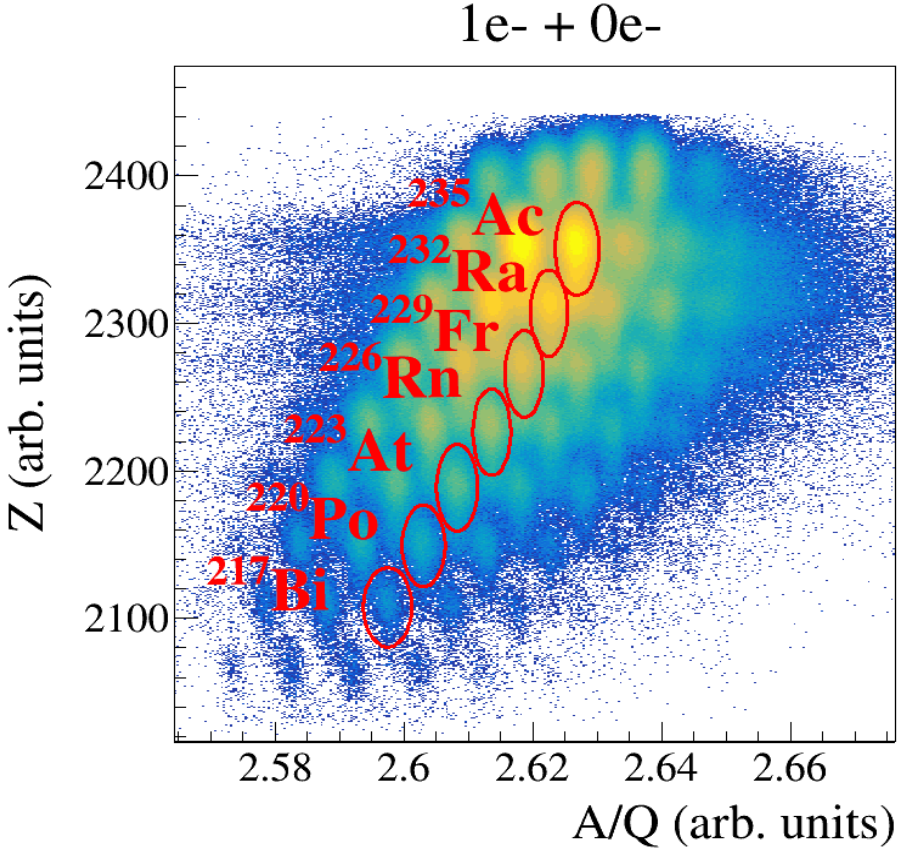


S181 – AIDA

Implantation distributions & hit patterns

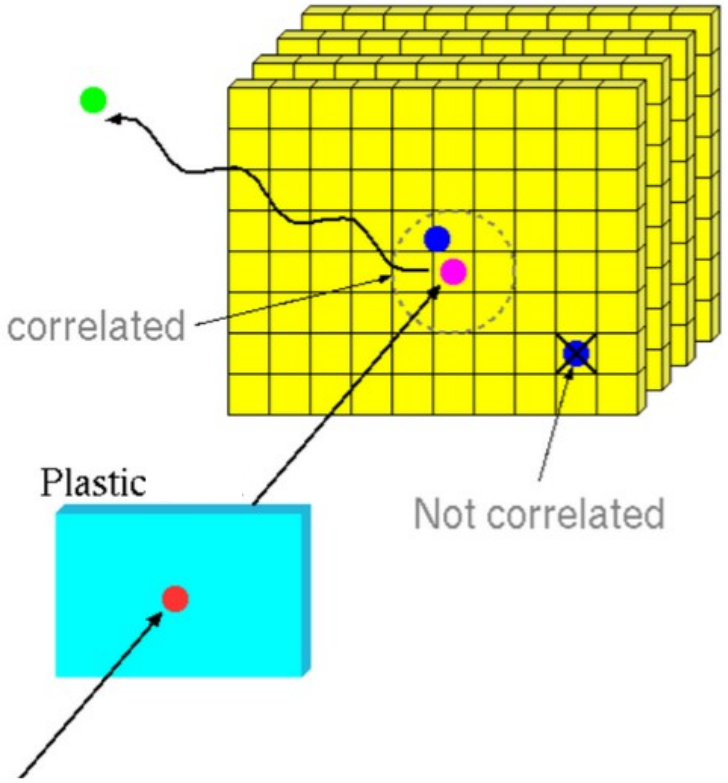


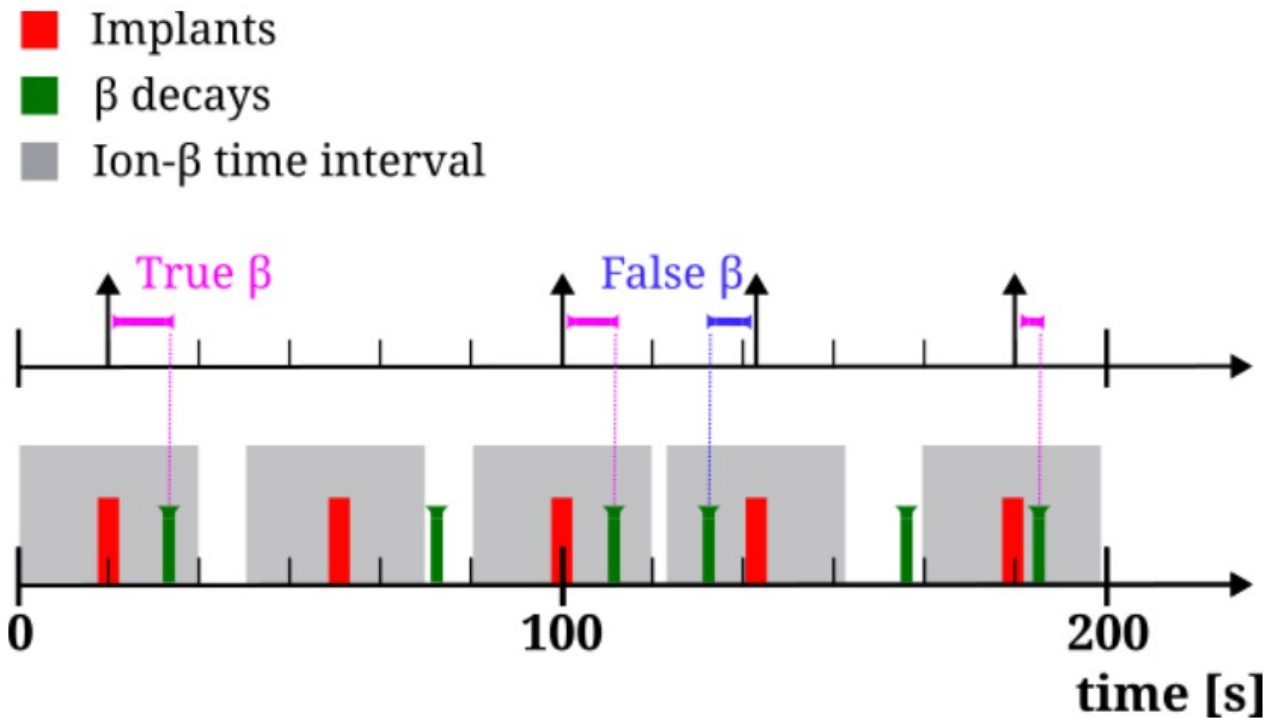




S181 – AIDA

Event-by-event position and time correlations

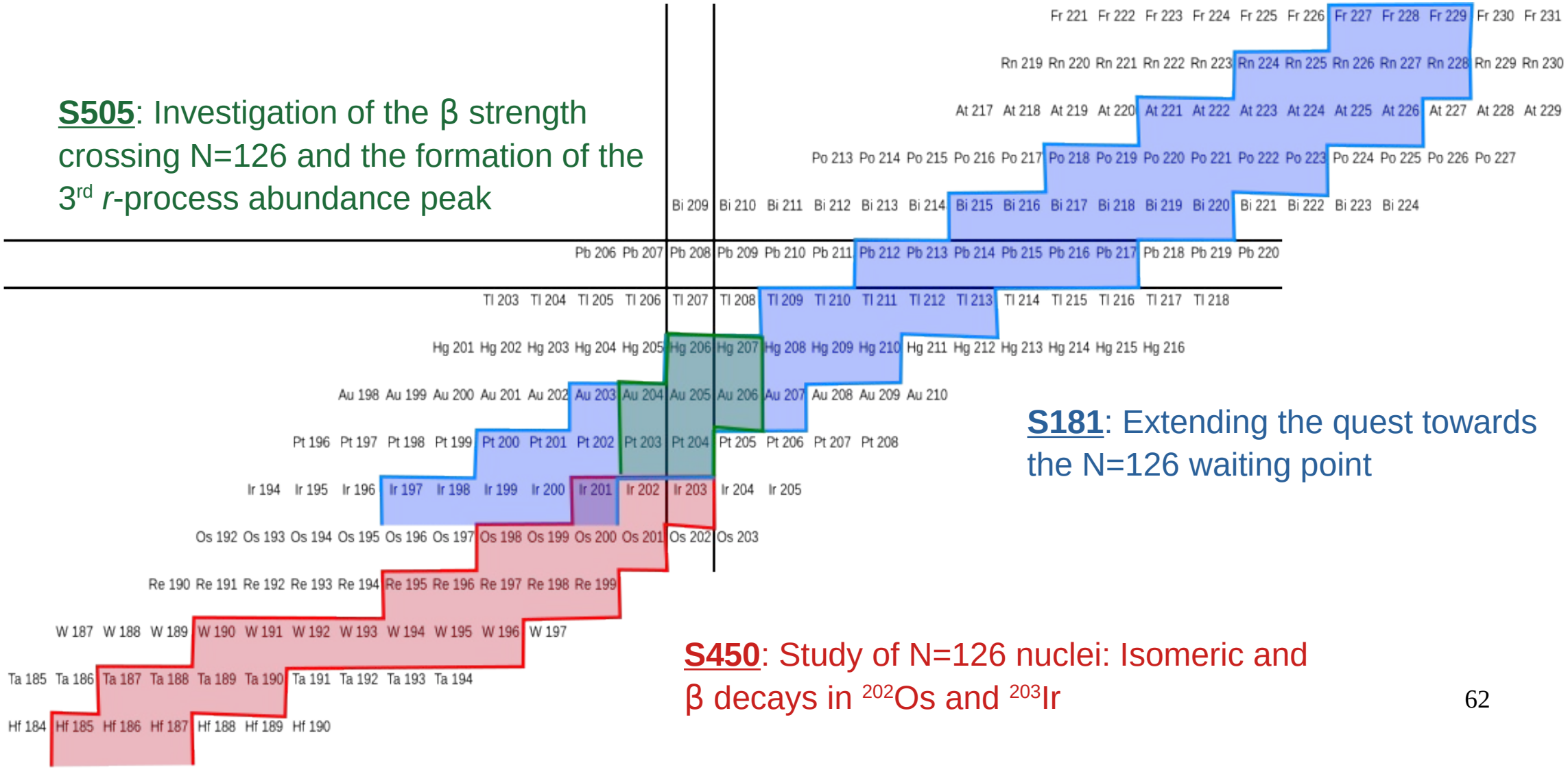




DESPEC Phase-0 Campaign

Overview of experiments around N=126

S505: Investigation of the β strength crossing N=126 and the formation of the 3rd *r*-process abundance peak



S181: Extending the quest towards the N=126 waiting point

S450: Study of N=126 nuclei: Isomeric and β decays in ^{202}Os and ^{203}Ir