First full β-strength measurement with DTAS across N=126 at FAIR phase-0

David Rodríguez García

On behalf of DESPEC collaboration

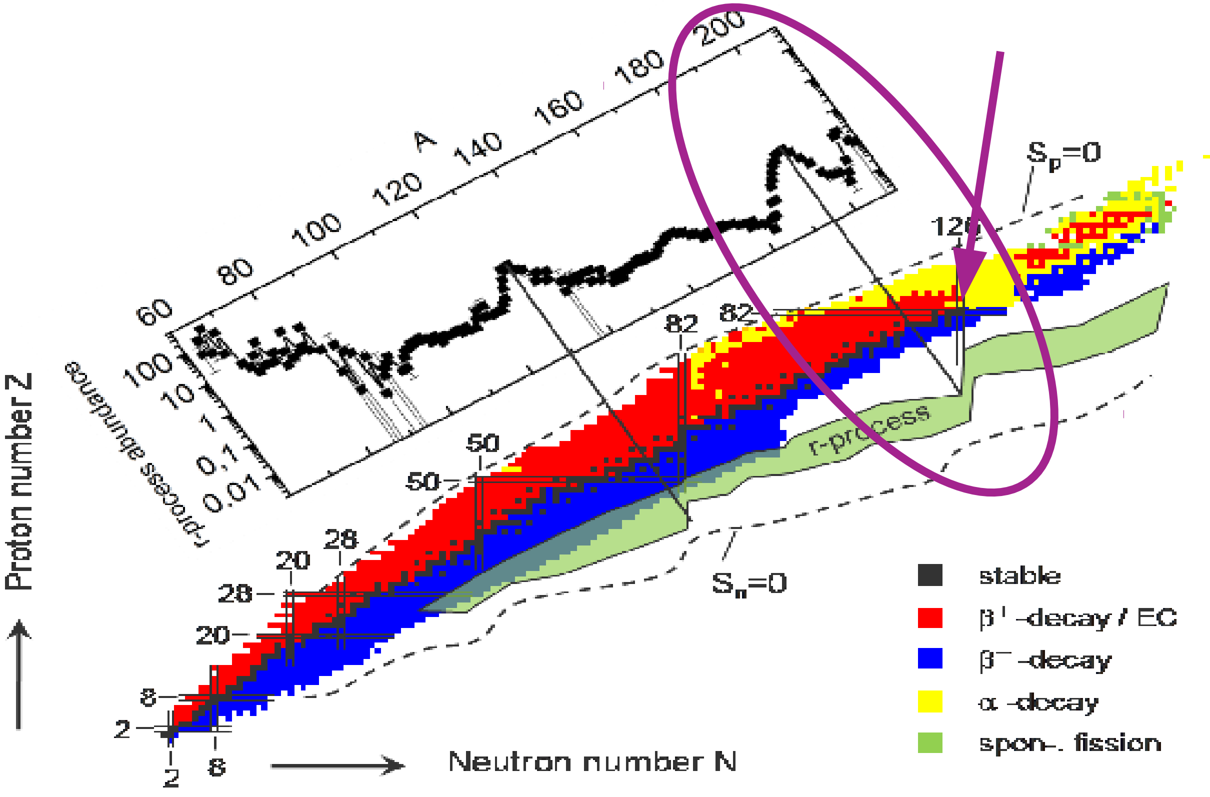
IFIC INSTITUT DE FÍSICA CORPUSCULAR

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

VNIVERSITAT DE VALÈNCIA

XV CPAN DAYS, 2-4 October 2023, Santander

Aim of the experiment



- Site for the astrophysical r-process is still uncertain
- Nuclear input data is also uncertain: lack of experiments
- In particular data for the 3rd r-process peak (~N=126)
- Benchmarking β-strength theoretical models used for $T_{1/2}$ and P_n prediction on r-process calculations
- Using Total Absorption Gamma-ray Spectroscopy (TAGS) to benchmark directly the β-strength (and not the $T_{1/2}$ and P_n)

! $T_{1/2}$ and P_n derived from S_β (β-strength) calculations:

$$\frac{1}{T_{1/2}} = \int_0^{Q_\beta} S_\beta(E_x) \cdot f(Q_\beta - E_x)\, dE_x$$

$$S_\beta^{th}(E_x) = \frac{1}{D}\frac{g_A^2}{g_V^2}\frac{1}{2J_i+1}\left|\langle f \| M_{\lambda\pi}^{\beta} \| i \rangle\right|^2$$

$$P_n = T_{1/2}\int_{S_n}^{Q_\beta} \frac{\Gamma^n(E_x)}{\Gamma^{tot}(E_x)} S_\beta(E_x) \cdot f(Q_\beta - E_x) \cdot dE_x$$

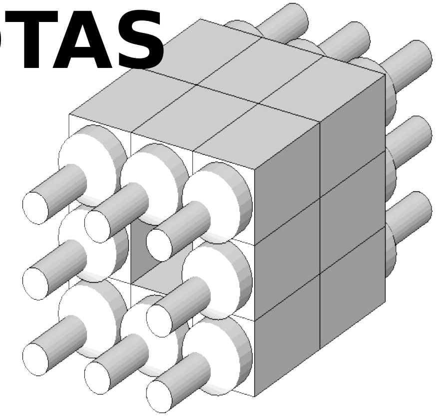
$$S_\beta^{exp}(E_x) = \frac{I_\beta(E_x)}{T_{1/2}\, f(Q_\beta - E_x)}$$

TAGS

S505 – Experimental Set-up at S4

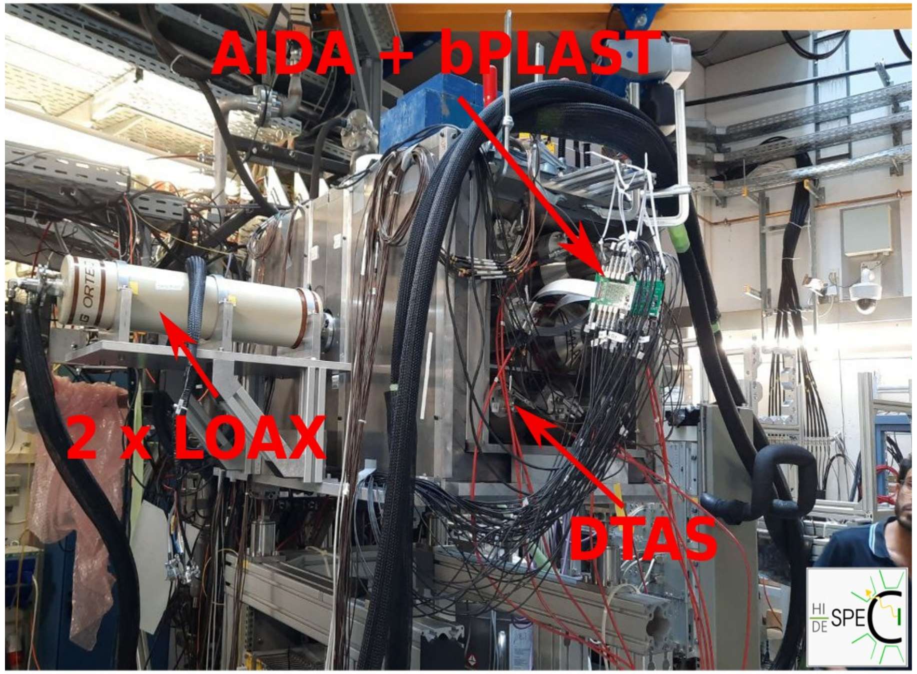
Spokepersons: Jose Luis Tain, Ana Isabel Morales, Enrique Nacher

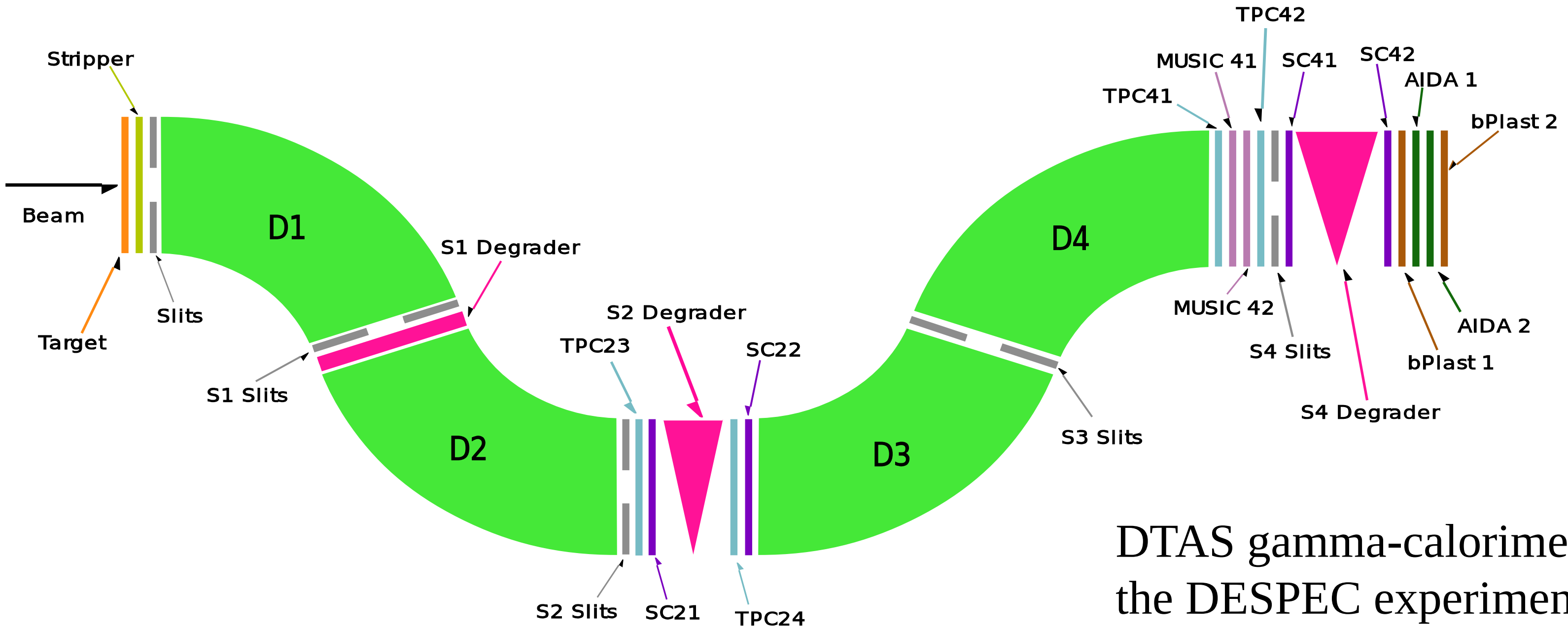
DTAS



Primary beam: **^{208}Pb**
Energy: **1000 MeV/u**
Goal: **^{207}Hg, $^{204-206}$Au, ^{203,204}Pt ^{203}Pt, ^{205}Au isomer**
Intensity: ~**10^9 ppb**
Spill on/off: **1.6/2.2 s**

		207Hg 2.9m 4.6MeV (9/2+)
204Au 39.8s 4.0MeV (2-)	205,205mAu 32.5/6s 3.5/4.4MeV (3/2+,11/2-)	206Au 45s 6.7MeV (?)
203,203mPt 22s/12s 3.5MeV (1/2-,?)	204Pt 16s 2.7MeV 0+	

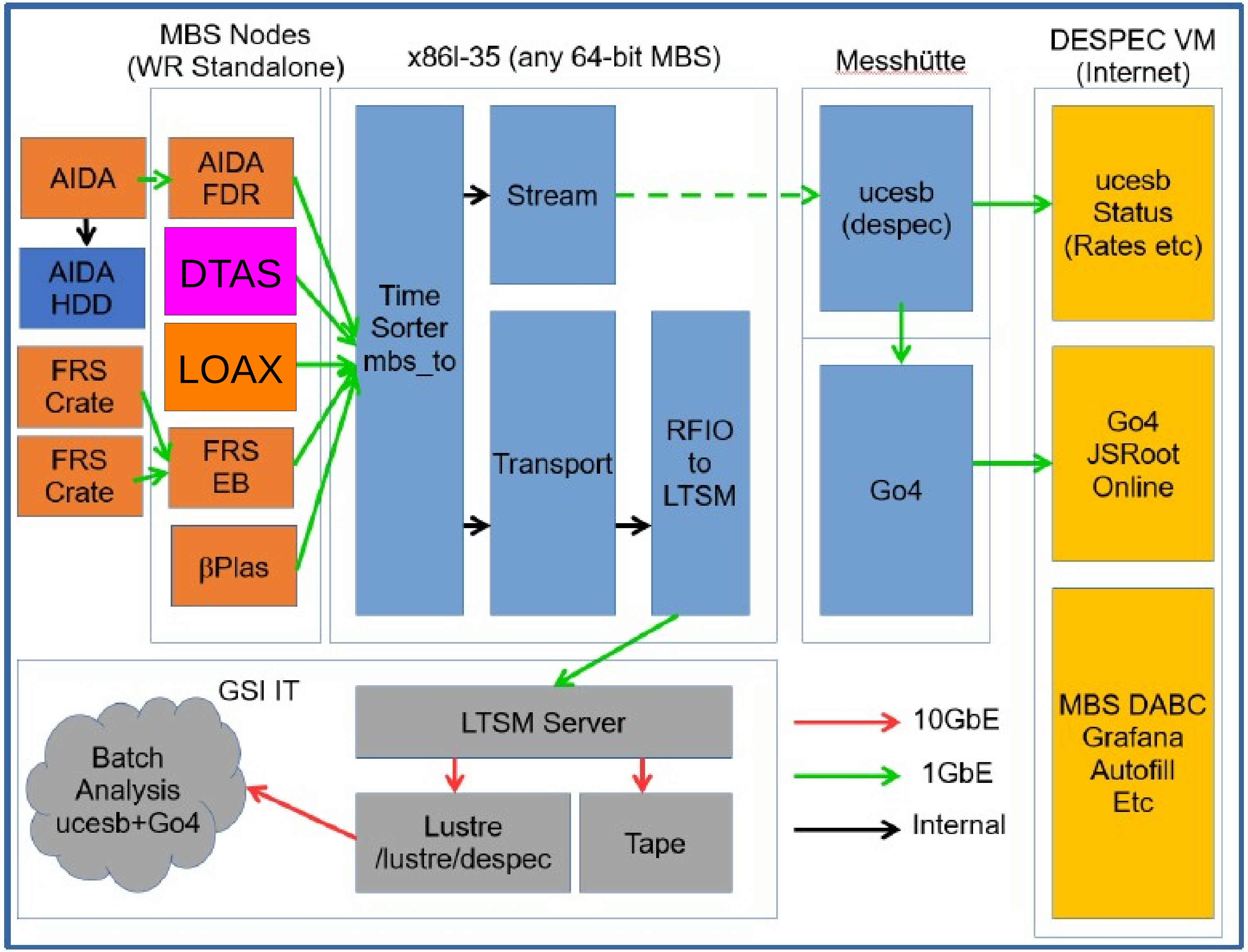




DTAS gamma-calorimeter, narrow AIDA implant-decay detector of the DESPEC experiment, 2 bPlast and 2 LOAX-HPGe detectors

S505 DACQ Scheme

- Five ***independent*** DACQs: **FRS, AIDA, DTAS, LOAX & βPLAS**
- Common **White Rabbit Time Stamping**
- **DTAS** DACQ WR implementation*



*Thanks to developments made at Chalmers Unv. Tech./GSI

FRS

PID at FRS: Bρ-ToF-ΔE method

- Ion identification combining information for each ion, on magnetic rigidity Bρ in the dipoles, the time-of-flight between detectors in the spectrometer flight path, and the energy loss in suitable “thin” detectors

A/Q calculation

$$\beta = \frac{L}{c \cdot ToF}$$

$$B\rho = B\rho_0 \cdot \left(1 + \frac{x_4}{D_x^{24}} + \frac{x_2}{D_x^{02}}\right)$$

$$\frac{A}{Q} = \frac{e}{u \cdot c}\frac{B\rho}{\beta\gamma}$$

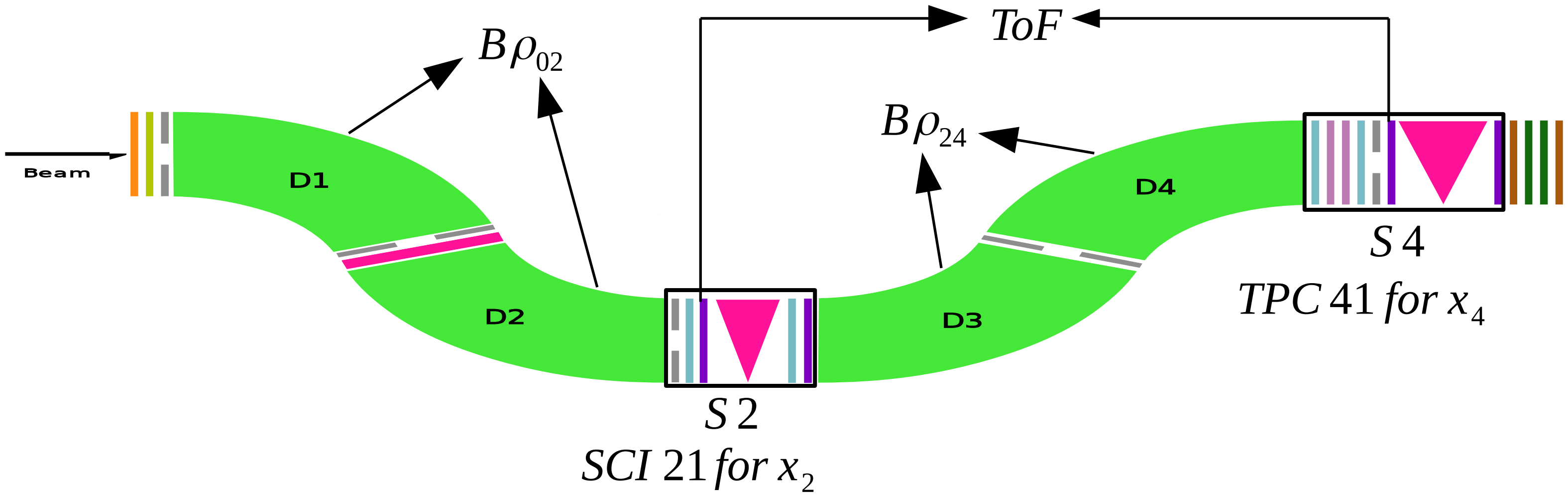
Z identification

Using the MUSIC

$$\Delta E_{MUSIC} \propto Z^2$$

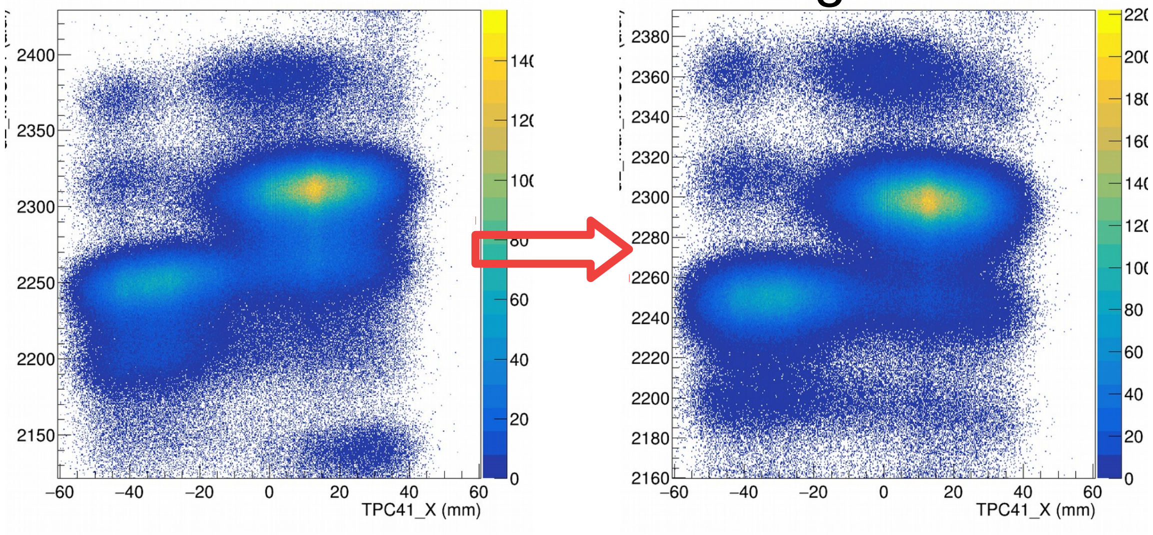
Loss energy in the degrader

$$\Delta E_{deg} = c \cdot e \cdot Q \cdot \left(\frac{B\rho_{02}}{\beta_{02}} - \frac{B\rho_{24}}{\beta_{24}}\right)$$

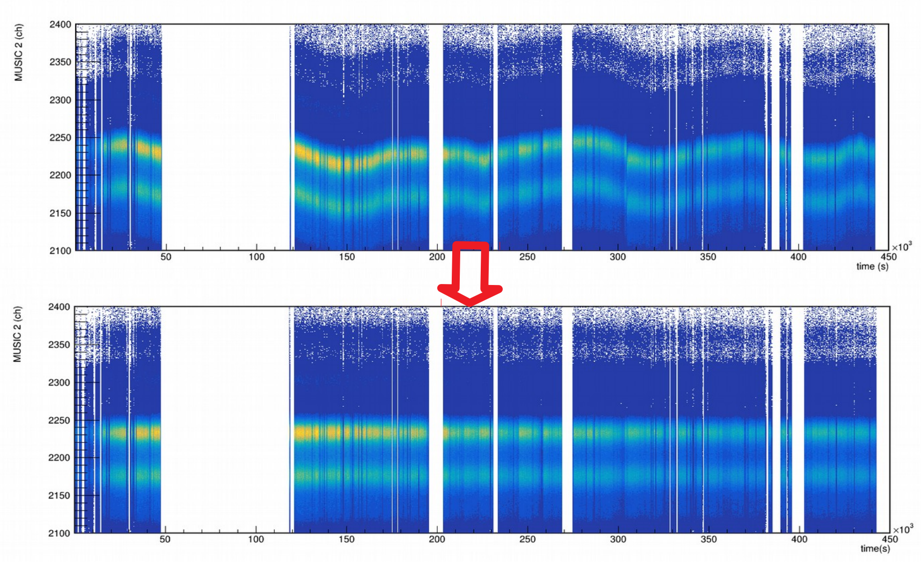


FRS Calibrations – MUSIC41-Eloss vs MUSIC42-Eloss

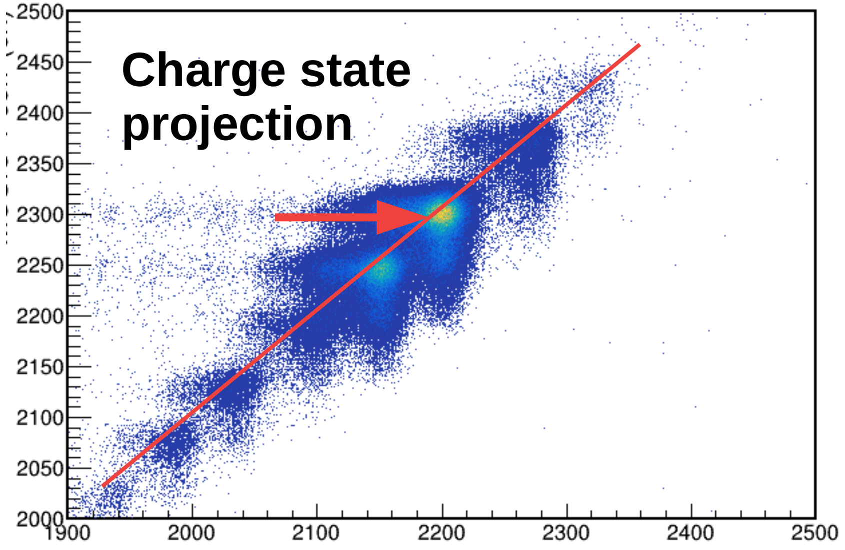
Position Correction using TPC41



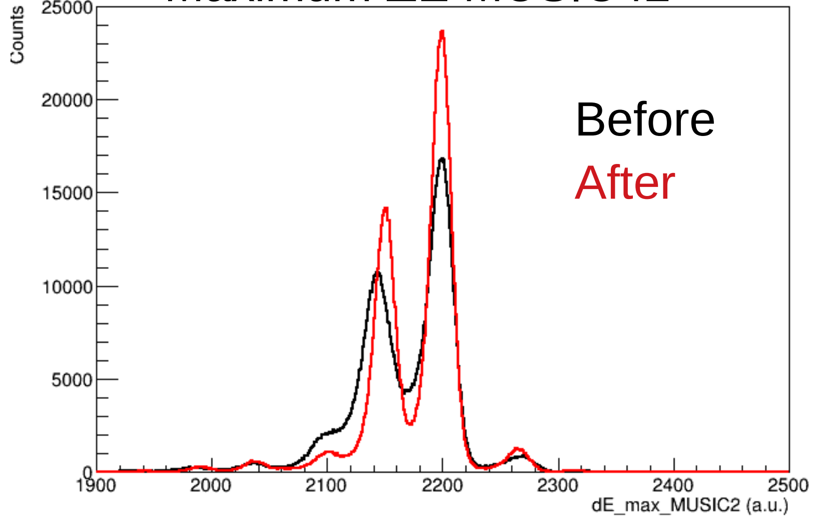
Drift correction over the time



MUSIC41 vs MUSIC42 Eloss

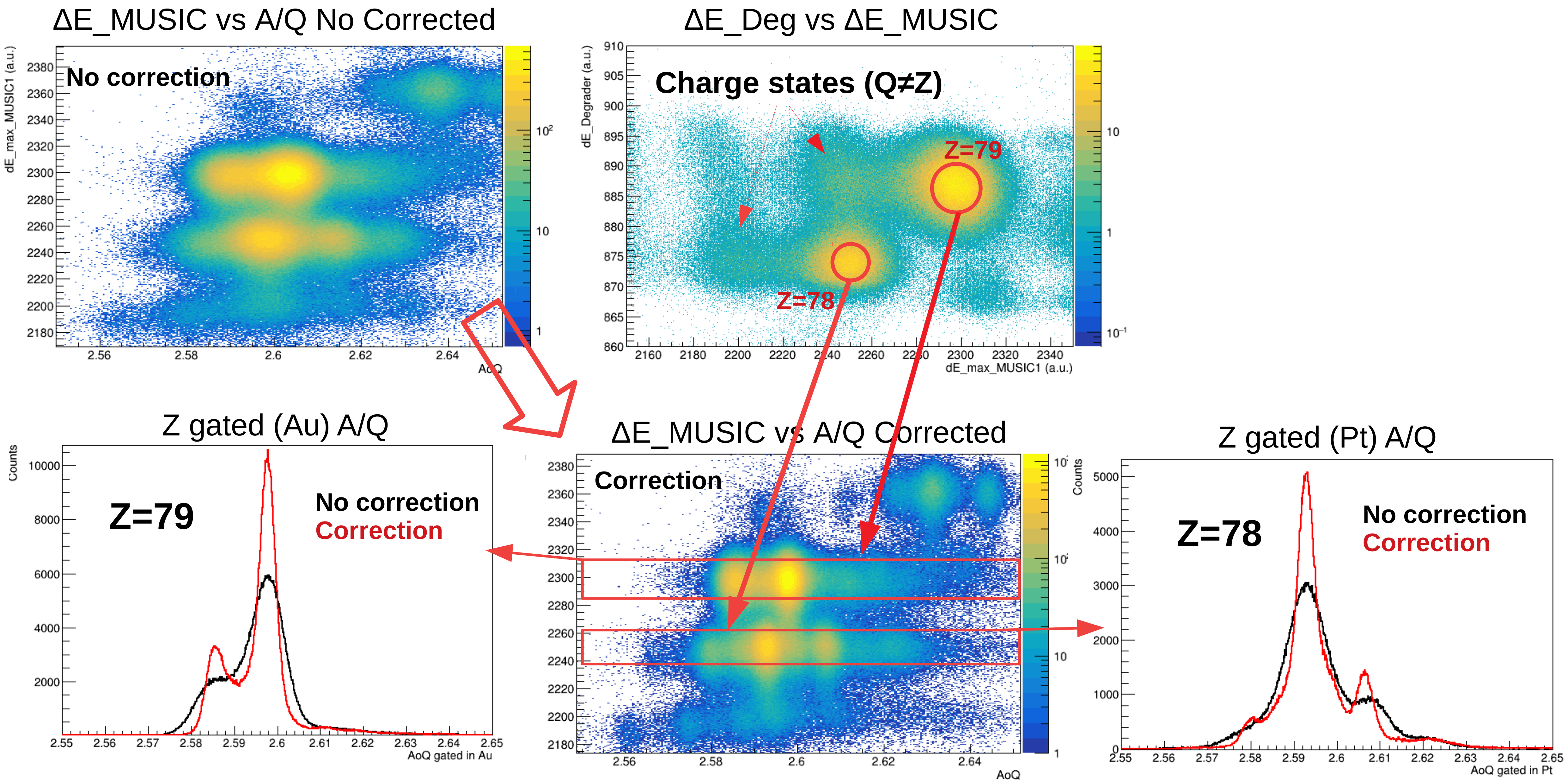


Maximum ΔE MUSIC42



Temporal & position dependence correction

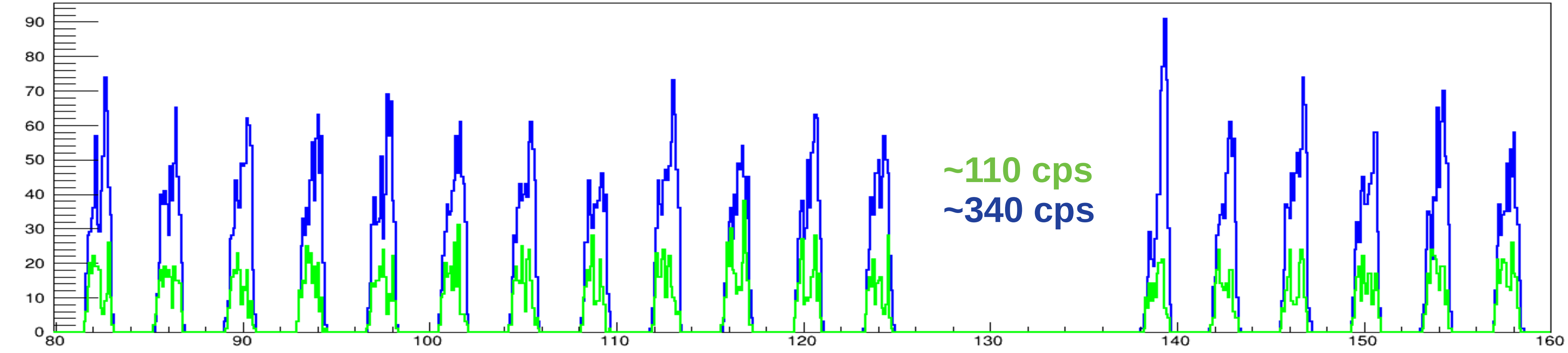
FRS Calibrations – A/Q and ΔE_Deg



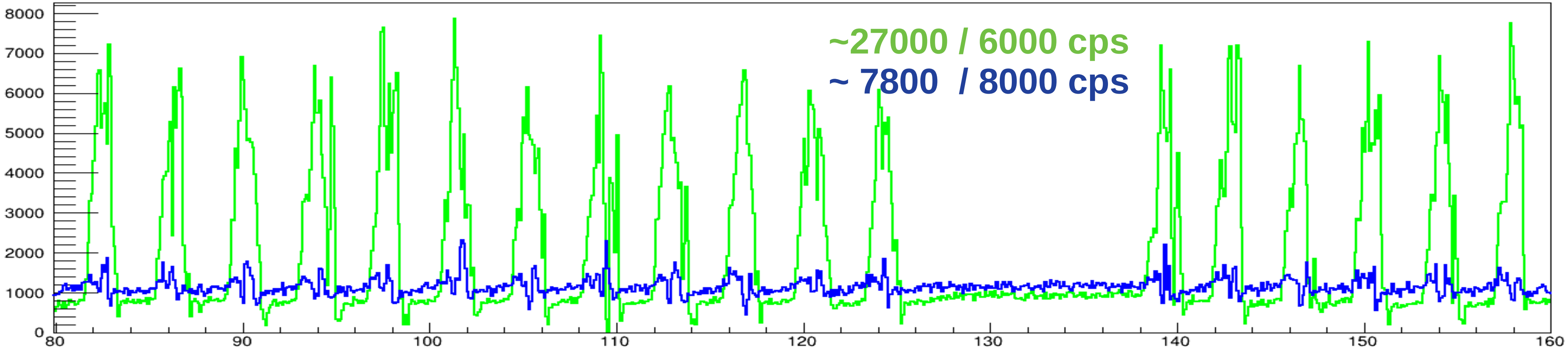
AIDA

Rates

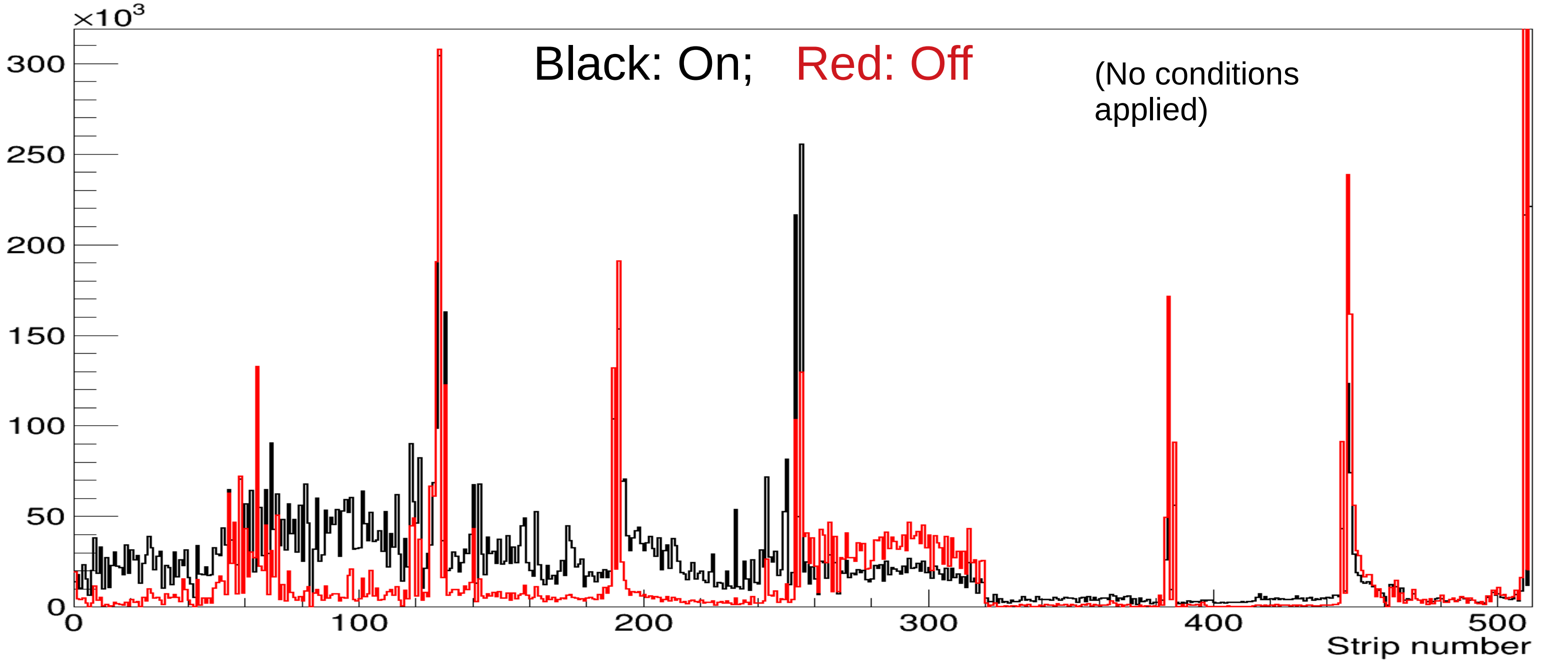
Up: implants, Down: decays. Green: DSSD0, Blue: DSSD1



Bin=100ms



Very high rate in the decays. Due to noise?



What did we try to improve the signal to noise ratio??:

1) Increase threshold

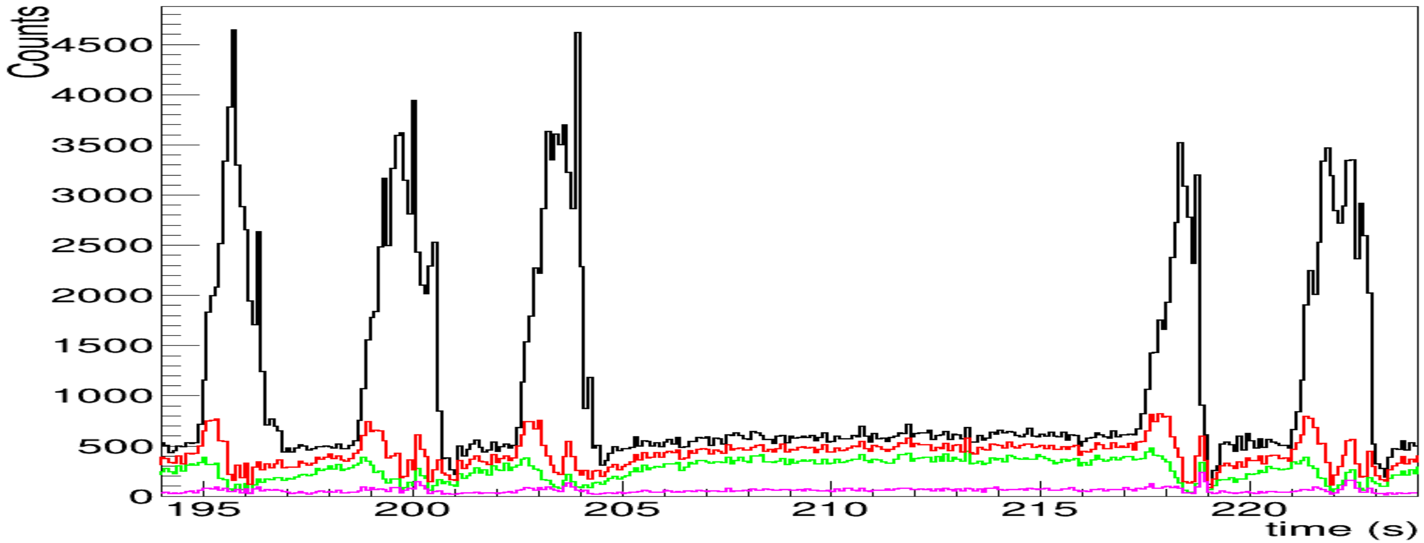
2) Condition in the multipicity of the strips in the event (nx, ny)
   i. nx, ny < 11
   ii. nx, ny < 6

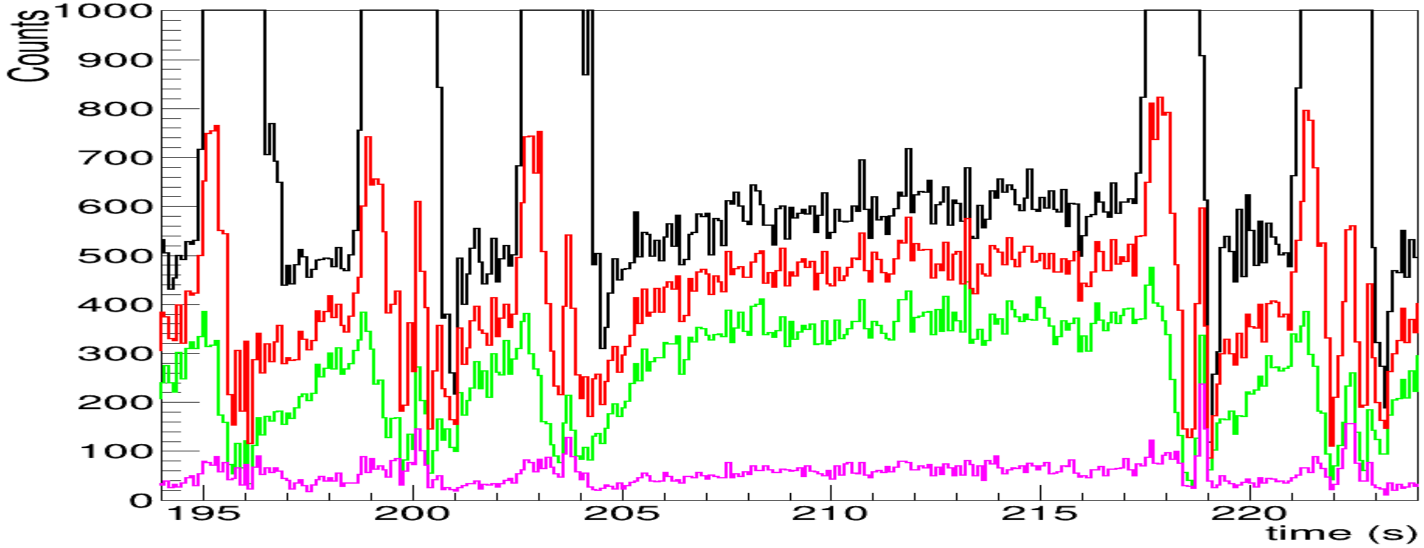
3) Avoid the most noisy strips in each detector

Hardware strip threshold
Ex,Ey>250keV
|Ex-Ey|<450keV

Beta Rates in DSSD0:

Black: No condition, Red: nx,ny<11, Green: nx,ny<6, Pink: nx,ny<6 & no noisy strips





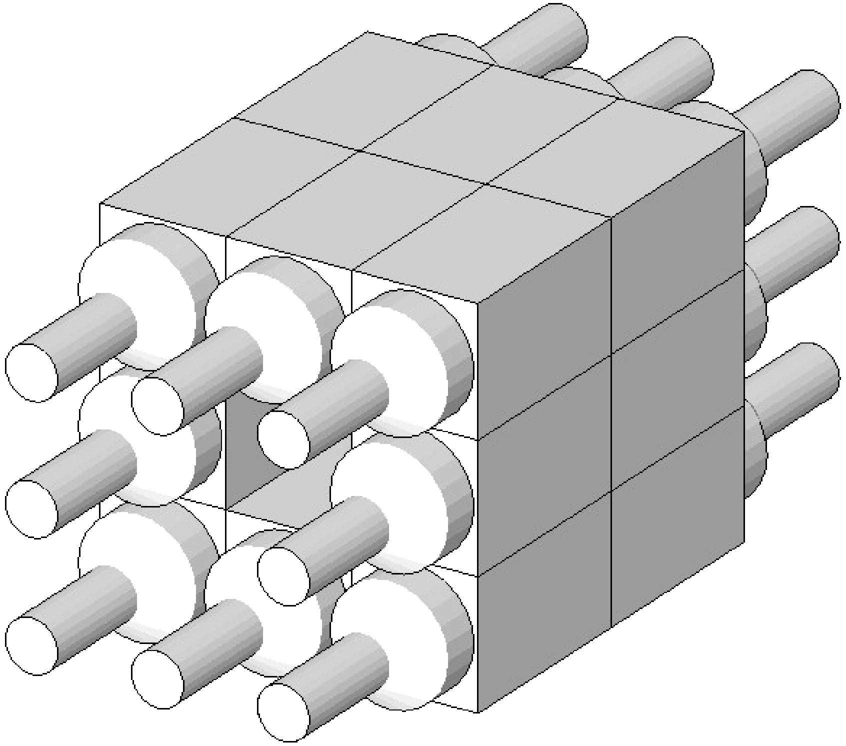
No condition:
Spill-On: ~27000 cps
Spill-Off: ~5800 cps

Nx,ny<11: Spill-On: ~4600 cps
Spill-Off: ~4600 cps

Nx,ny<6: Spill-On: ~2000 cps
Spill-Off: ~3400 cps

Nxn,ny<6 & no noisy strips:
Spill-On: ~700 cps
Spill-Off: ~600 cps

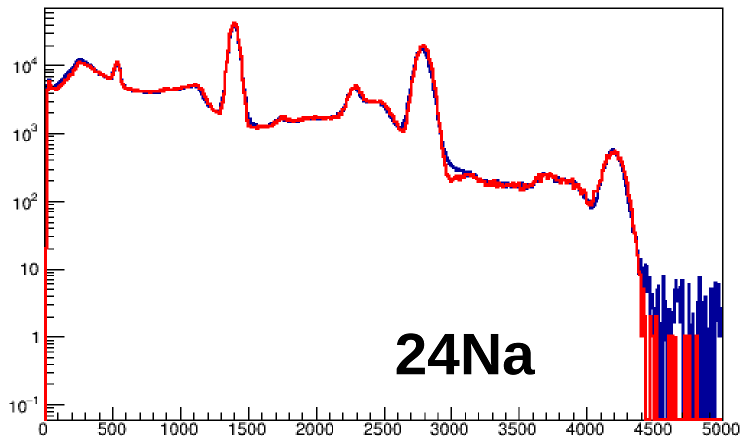
DTAS



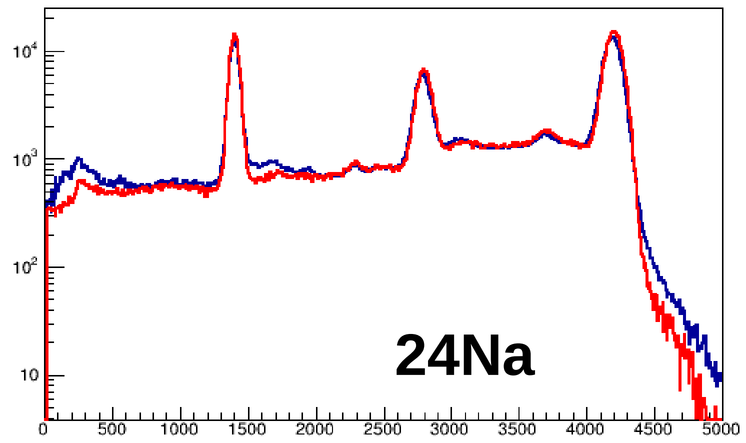
DTAS MC Response Benchmarking

DTAS alone

Crystal energy

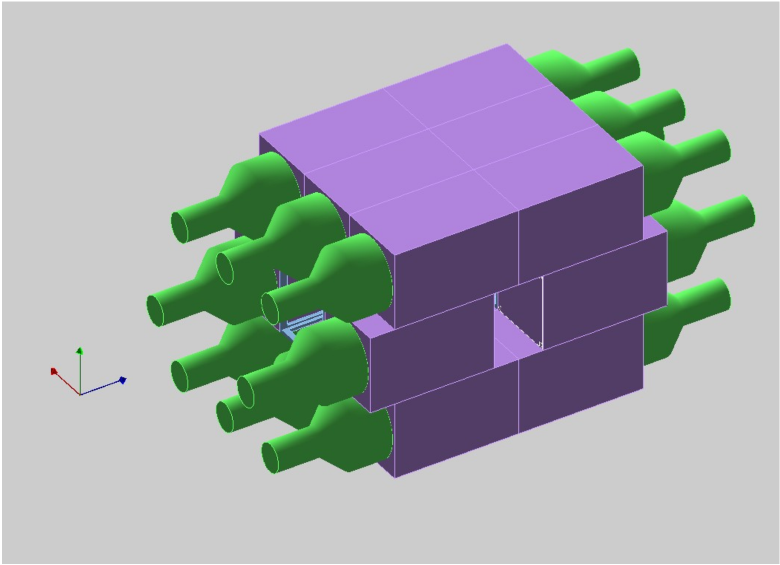


Sum energy



: Experiment :Geant4

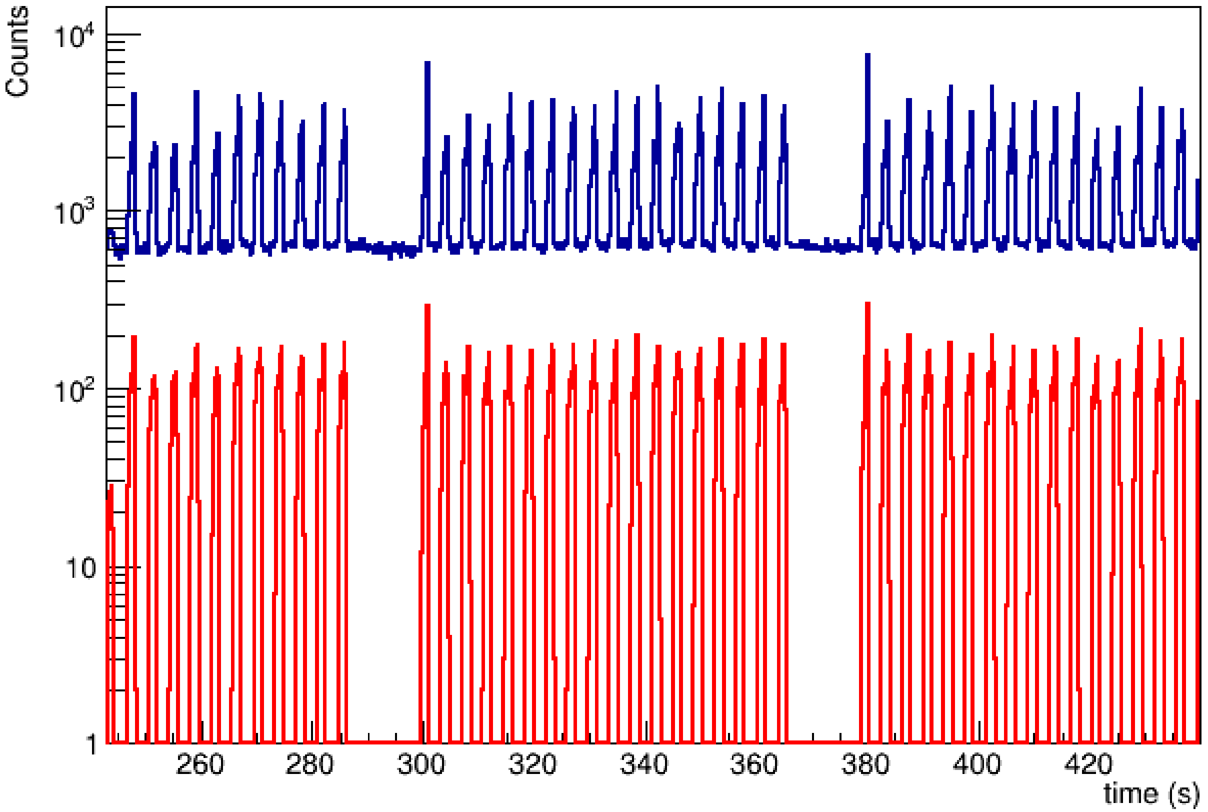
Geant4 geometry



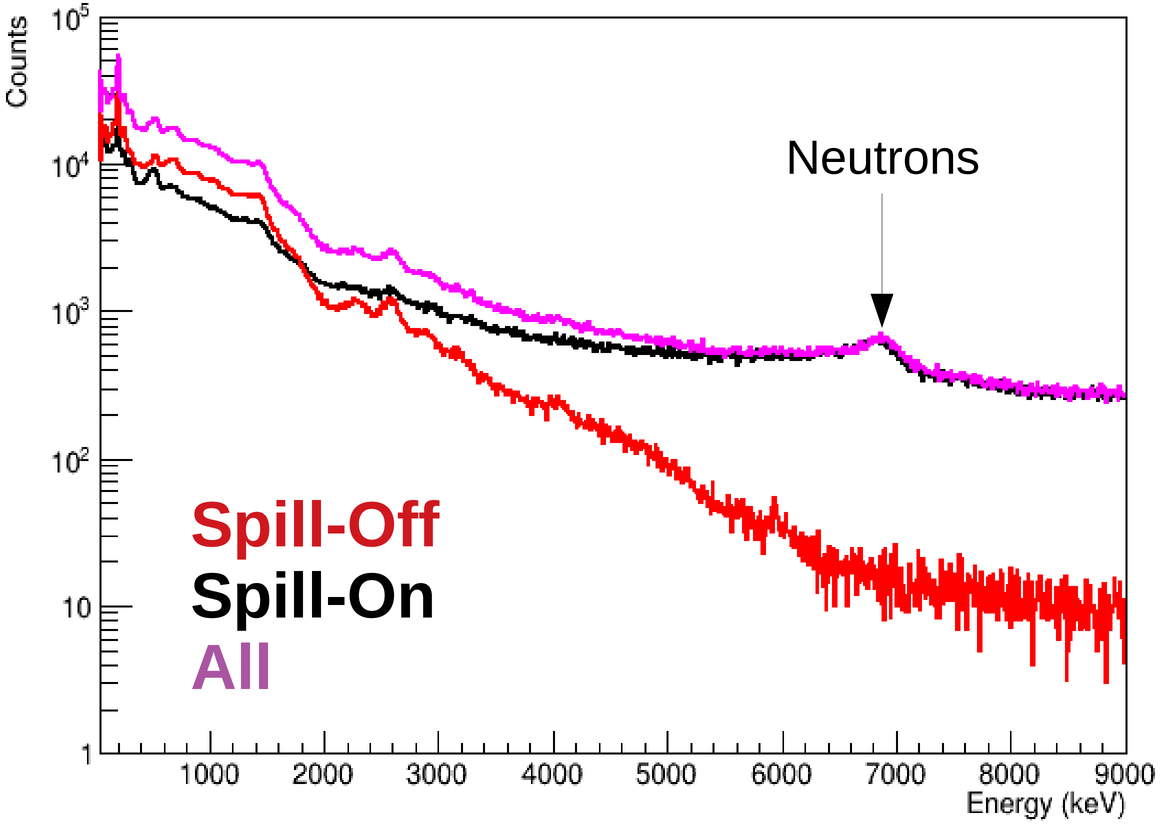
- Point sources placed at the center
- Differences likely due to the missing summing-pileup contribution (in progress)

Rates and comparison: Spill-Off, Spill-On

Rates: DTAS, Beam



Sum energy in DTAS



Beam (spill) → ~1000 pps
DTAS spill-off → ~8000 cps
DTAS spill-on → ~42000 cps

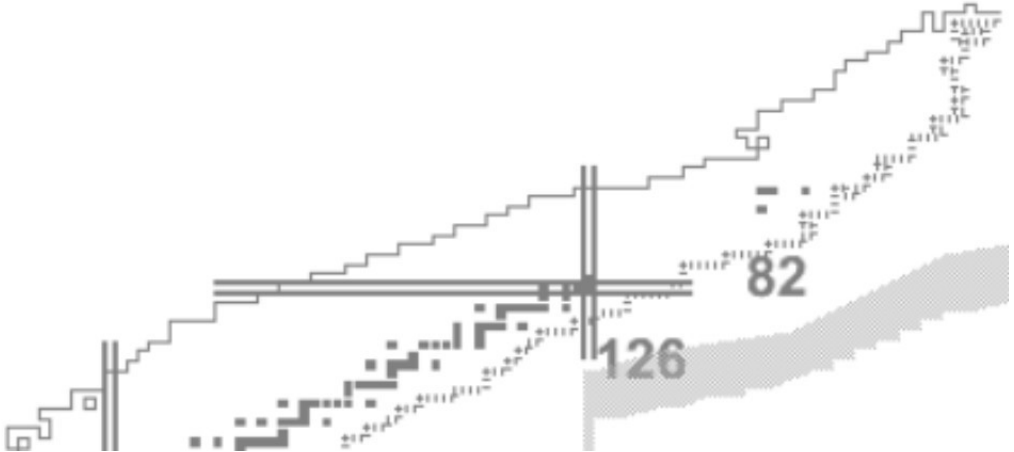
- Huge rate on spill, too high rate off spill
- Particles (neutrons, …) and EM radiation coming with the beam disturbing the spectra
- Possibly only spill-off data is useful

Next Steps:

- Finish the data (FRS, AIDA, DTAS) selection study (sorting conditions)
- Study of implant-beta-gamma correlations with PID: development of data merging software
- Full data reduction: decay gamma spectra for TAGS analysis
- Finish benchmarking AIDA and DTAS response: full detector geometry

HI DE SPEC
FAIR
GSI

Thank you very much for your attention



IFIC
INSTITUT DE FÍSICA CORPUSCULAR
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
VNIVERSITAT DE VALÈNCIA

Backup slides

S505 analysis plan

- Calibrations, dependencies corrections, gain matchings, time aligments, definition of events, etc.

FRS DACQ Tree
(A/Q, Z, β, ΔE_{deg}, Bρ, WRT…)

DTAS DACQ Tree
(E_{crys}, E_{sum}, TS, CFT, E_{LOAX}, WRT…)

AIDA DACQ Tree
([X, Y, Z, $E_{implantation}$], [x, y, z, E_{β}], WRT…)

βPlas DACQ Tree
(Slow ToT, Fast ToT, WRT…)

MERGED Tree
Vectors of correlations among the different sub-systems, built on the common WRT. Position correlation algorithms between β-like particles & implantations in AIDA

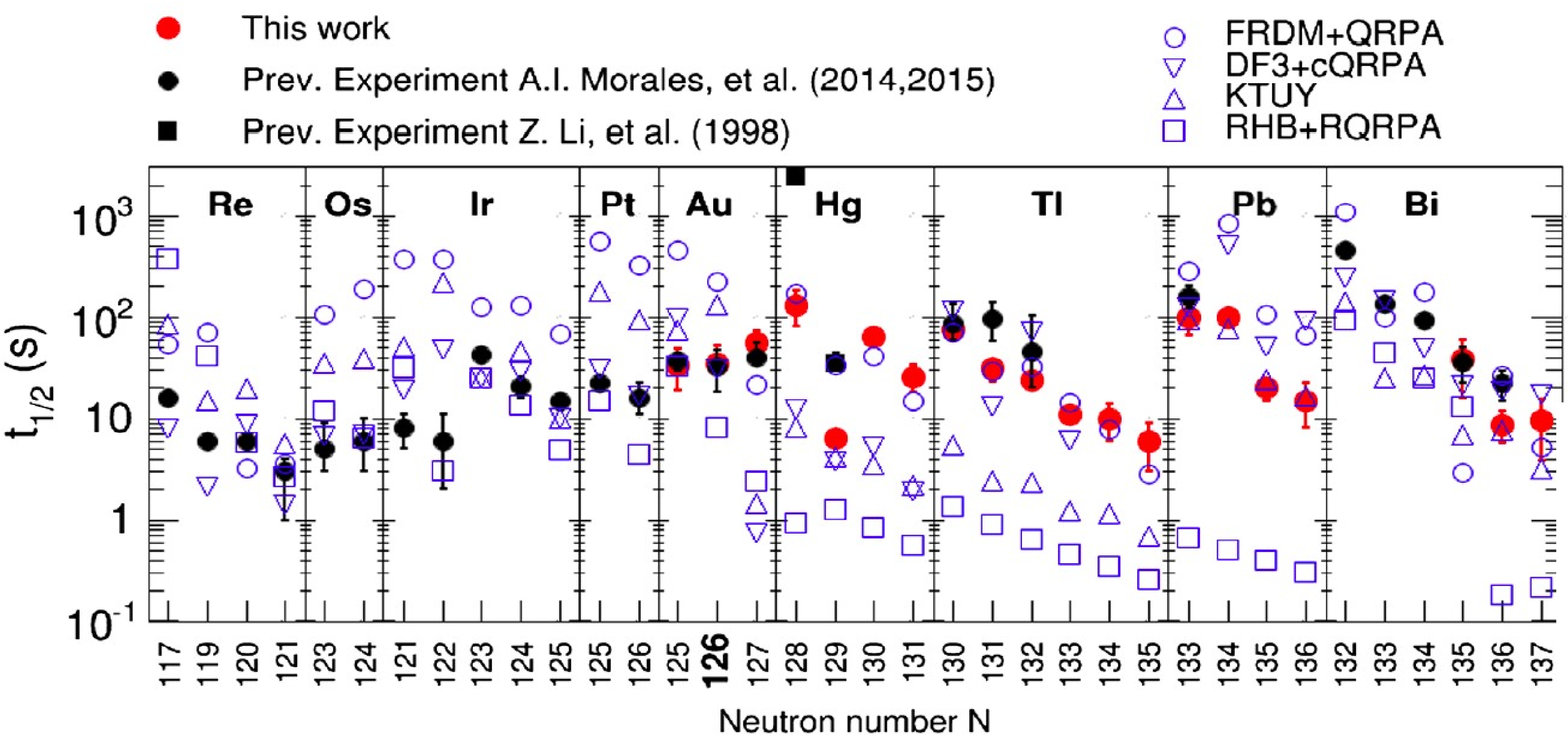
ANALYSIS programs
Specific programs to obtain correlation plots, fitting scripts to measure the observables of interest, Monte-Carlo simulations, error evaluation, etc.

[A. Tolosa+, NIMA, 925, 133 (2019)]

Why?

Because benchmaking with direct $T_{1/2}$ (or P_n) measurements seems not enough

Large discrepancies between measured data and theories, and between theories themselves. Change in trend across N=126



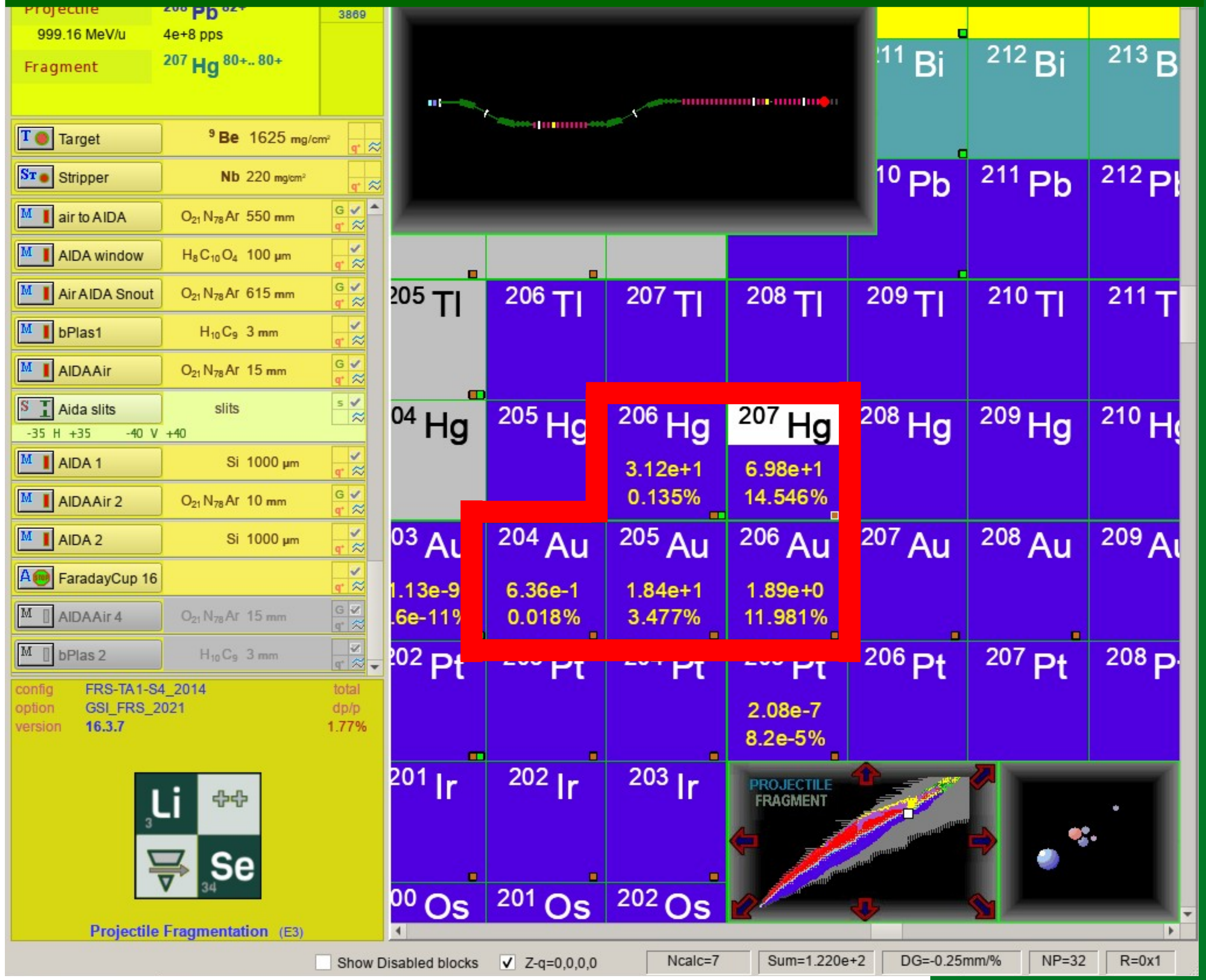
[T. Kurtukián et al., NIMA(2008),
Z. Podolyák et al., PLB(2012),
G. Benzoni et al., PLB(2012),
N.Al-Dahan et al., PRC(2012),
T. Kurtukián et al., EPJA(2014)
A.I. Morales et al., PRL(2014),
A.I. Morales et al, EPL(2015)
R. Caballero et al, PRL (2016)]

S505 FRS Settings

		207Hg 2.9m 4.6MeV (9/2+)
204Au 39.8s 4.0MeV (2-)	205,205mAu 32.5/6s 3.5/4.4MeV (3/2+,11/2-)	206Au 45s 6.7MeV (?)
203,203mPt 22s/12s 3.5MeV (1/2-,?)	204Pt 16s 2.7MeV 0+	

^{204}Pt in central trajectory

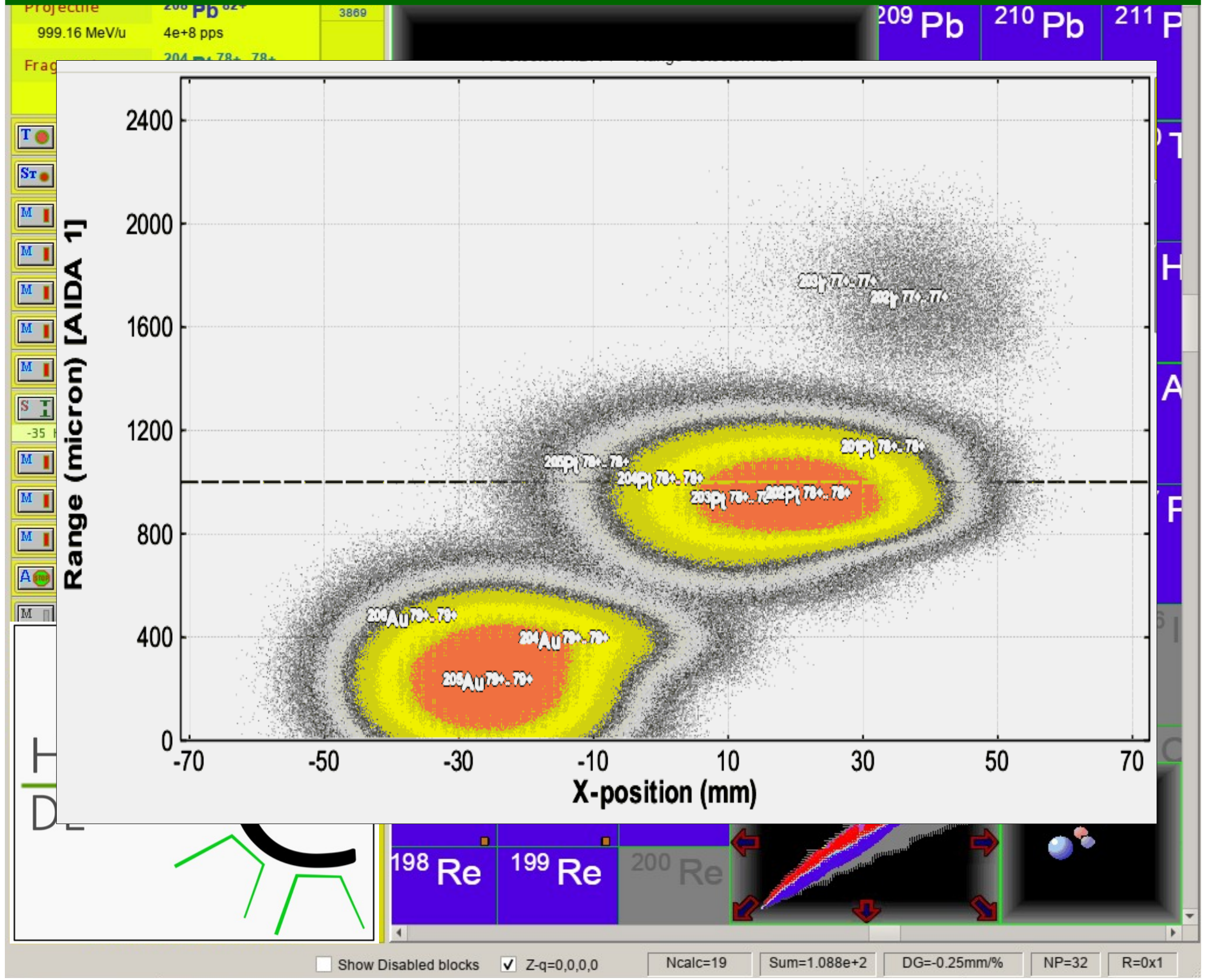
^{207}Hg in central trajectory



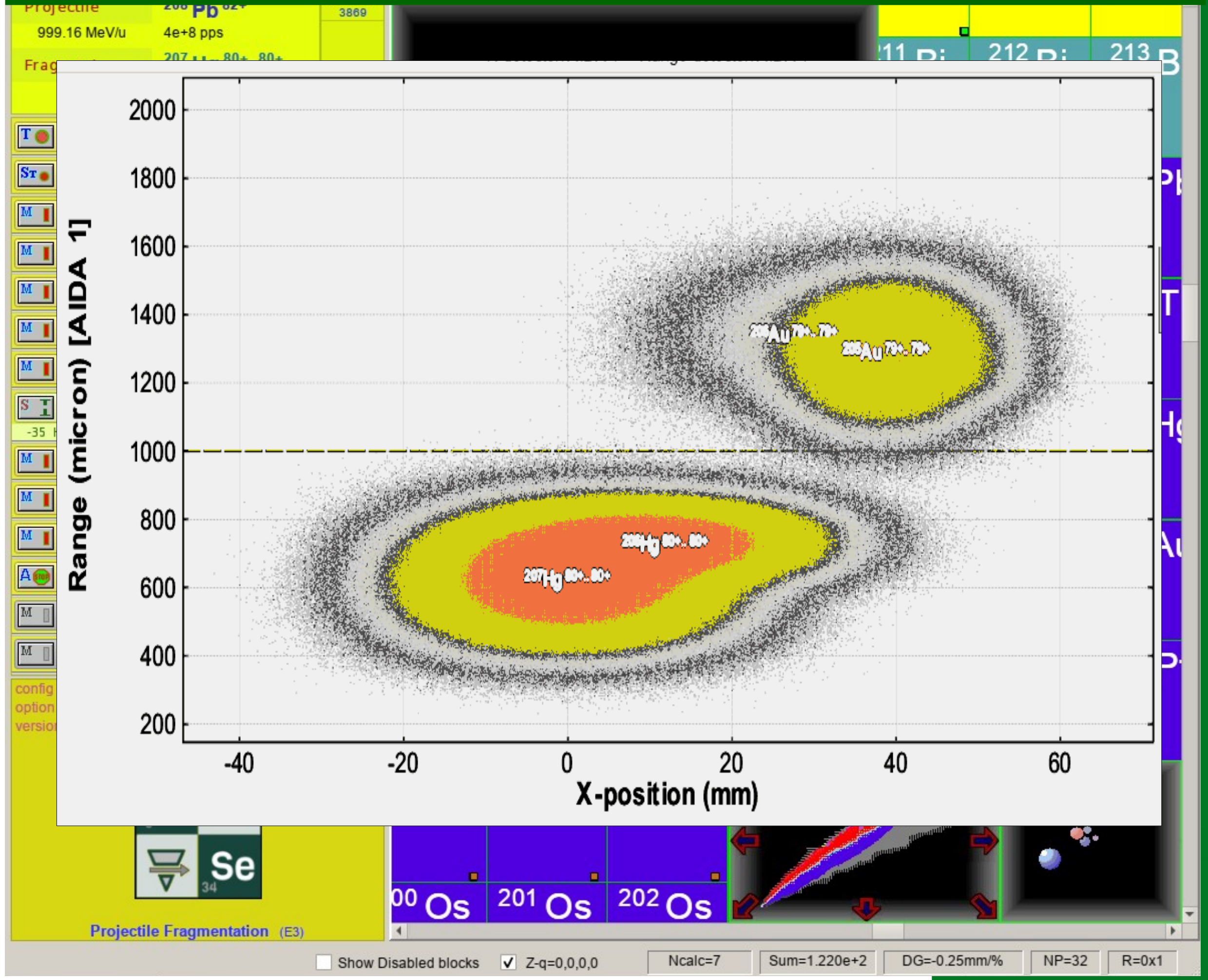
S505 FRS Settings

		207Hg 2.9m 4.6MeV (9/2+)
204Au 39.8s 4.0MeV (2-)	205,205mAu 32.5/6s 3.5/4.4MeV (3/2+,11/2-)	206Au 45s 6.7MeV (?)
203,203mPt 22s/12s 3.5MeV (1/2-,?)	204Pt 16s 2.7MeV 0+	

^{204}Pt in central trajectory



^{207}Hg in central trajectory



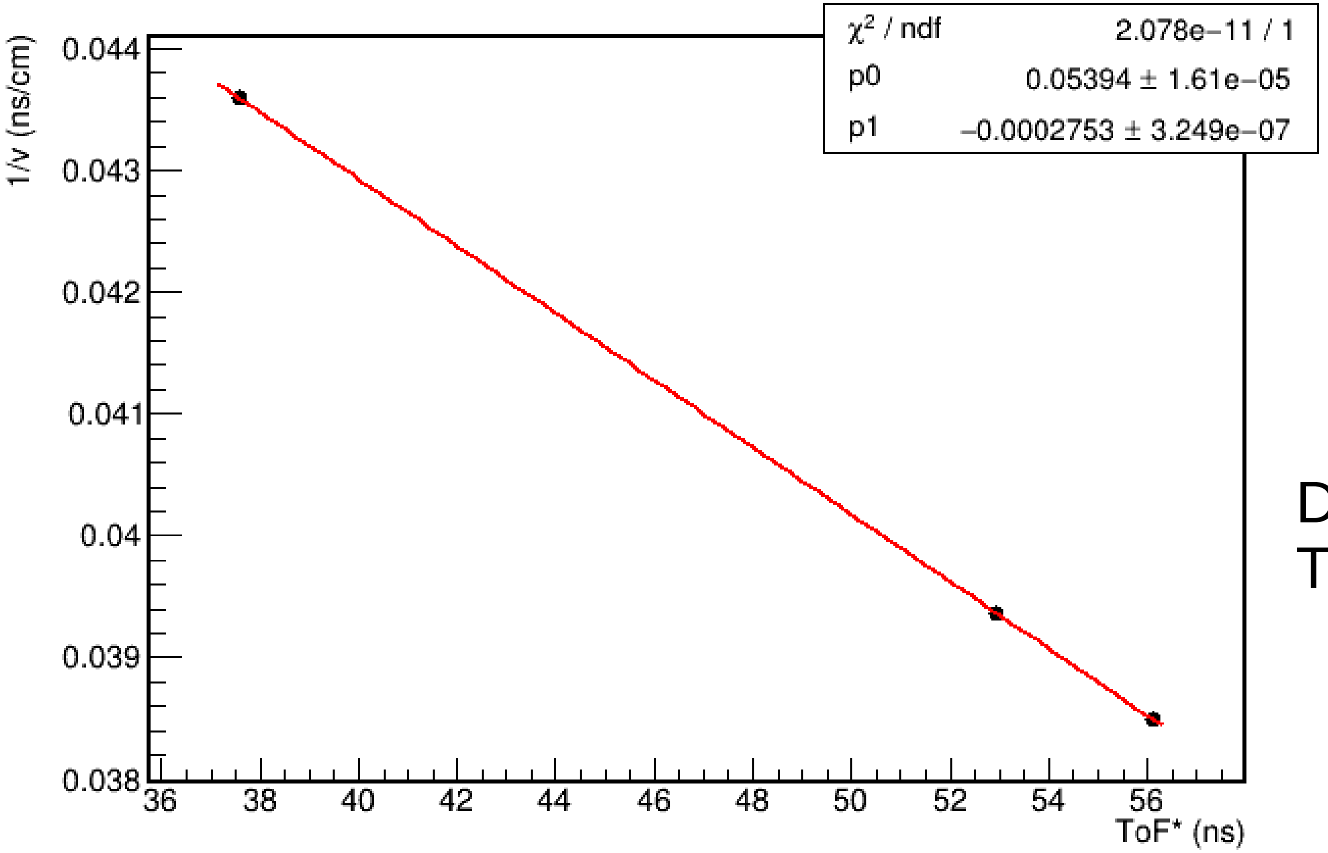
FRS Calibrations - ToF

$$ToF^{\cdot*\cdot} = \frac{ToF_L^{\cdot*\cdot} \cdot \alpha_L + ToF_R^{\cdot*\cdot} \cdot \alpha_R}{2}$$

$$\alpha_{LR} = TAC\ calibration$$

$$\frac{1}{v} = \frac{T_0}{d} - \frac{ToF^{\cdot*\cdot}}{d}$$

	1/v (ns/cm)	ToF* (ns)
Primary beam	0.0384947	56.113
Prim. beam + Target	0.0393516	52.955
Prim. beam + Target + Degrader	0.0435952	37.579

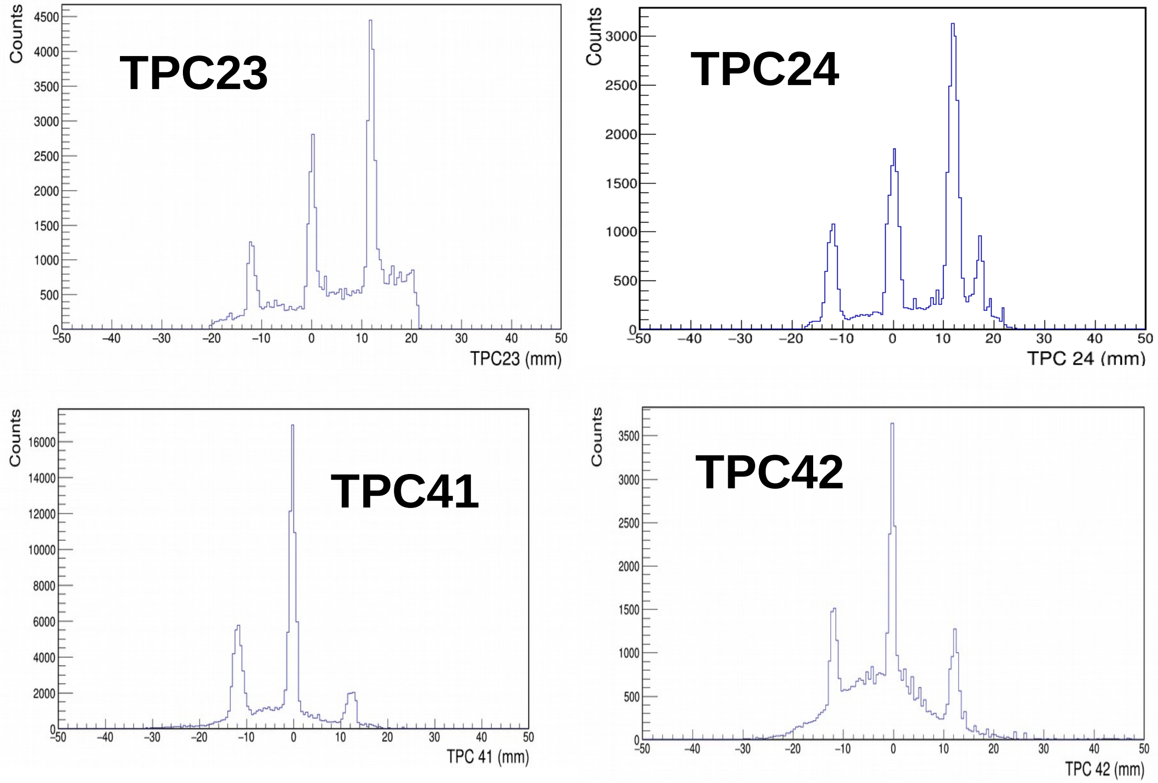


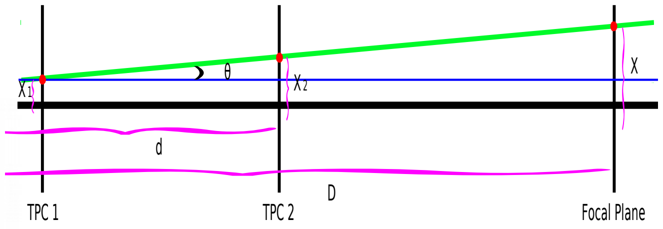
Distance SCI21-SCI41 = 36.30 m

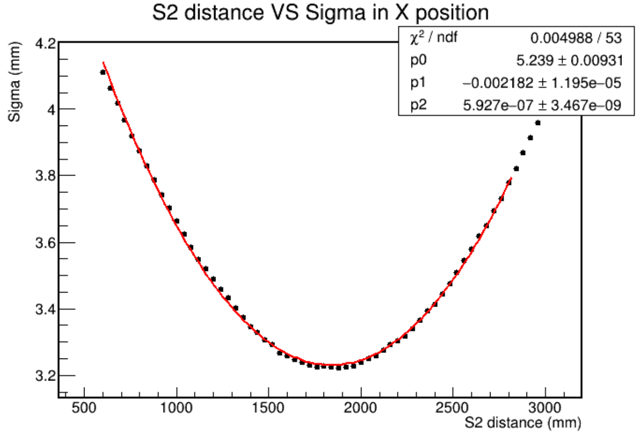
T_0= 195.85 ns

FRS Calibrations – TPC x-position and Focal Plane position

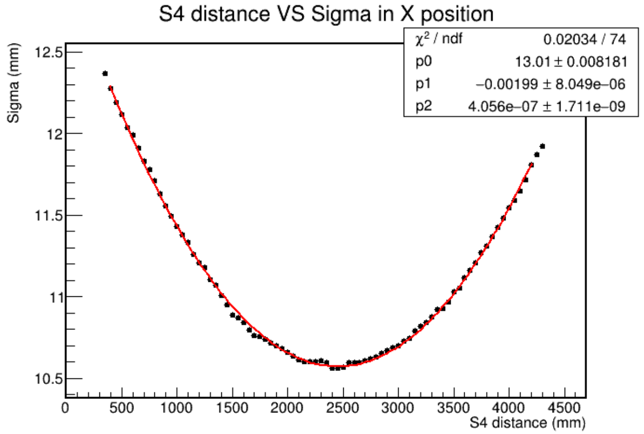
Using scintillator mask







$$tg\,\theta = \frac{x_2 - x_1}{d}$$

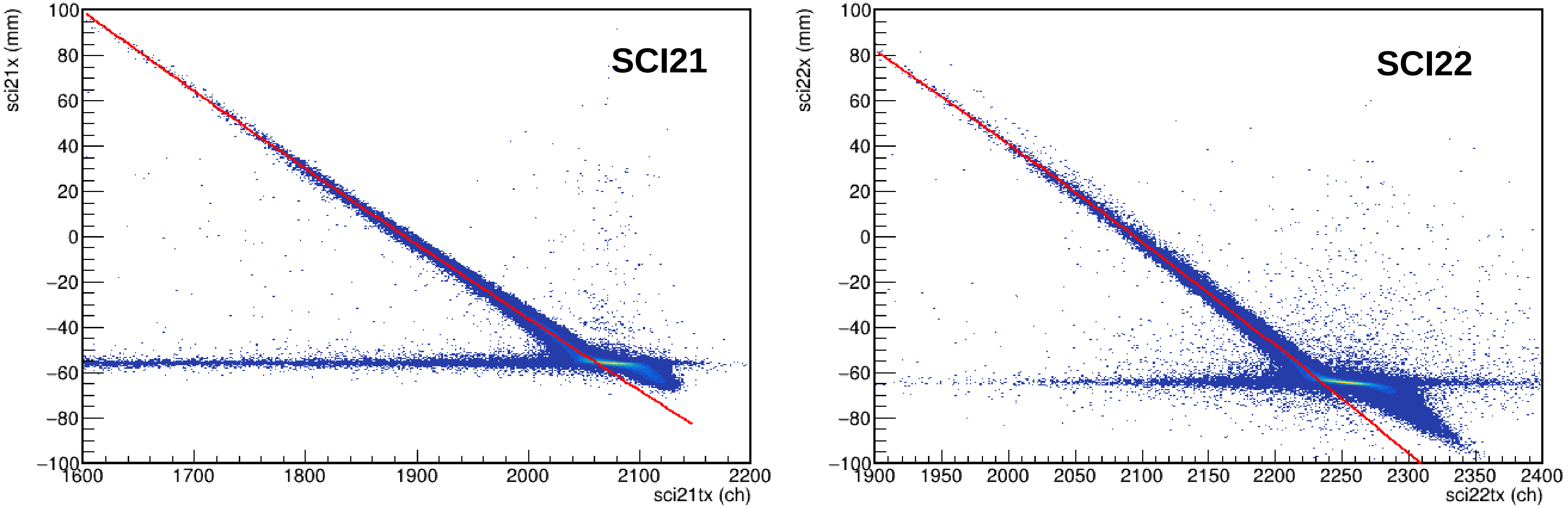


$$tg\,\theta = \frac{x - x_1}{D} \rightarrow x = tg\,\theta \cdot D + x_1$$

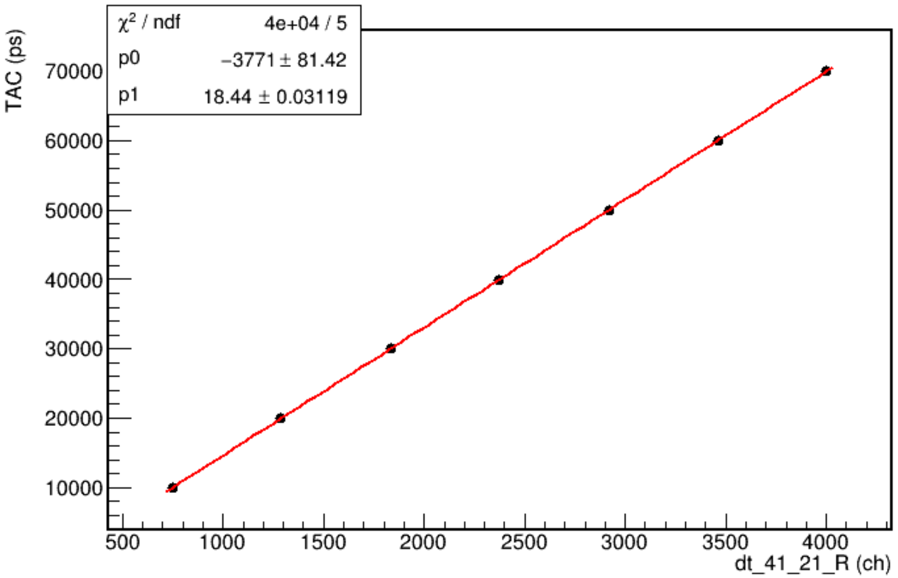
FRS Calibrations – SCI calibrations using TPC

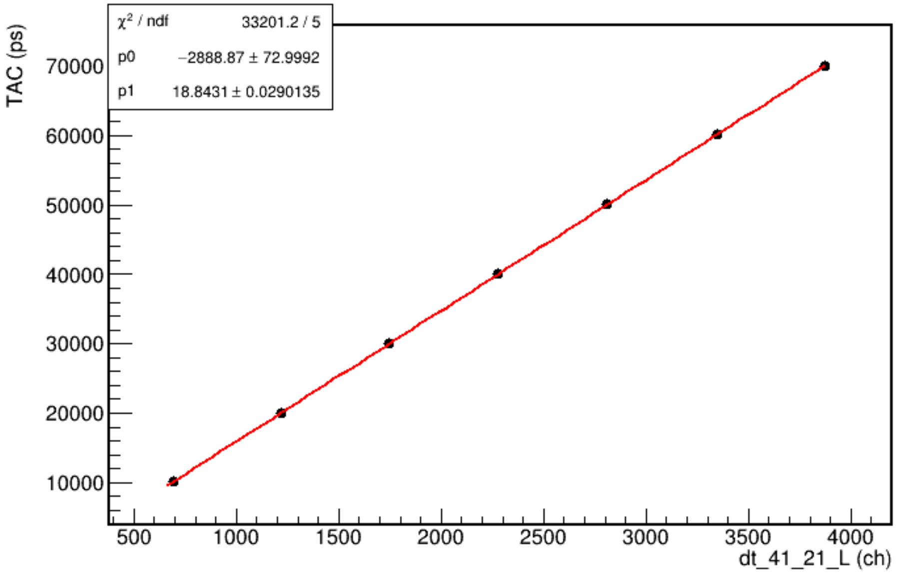
- No TPC in S2 during the experiment, except the first 4h❗
- Need to use SCI in S2 but no file of defocused beam to calibrate them
- Use TPCs to calibrate SCIs using the first 4h of experiment

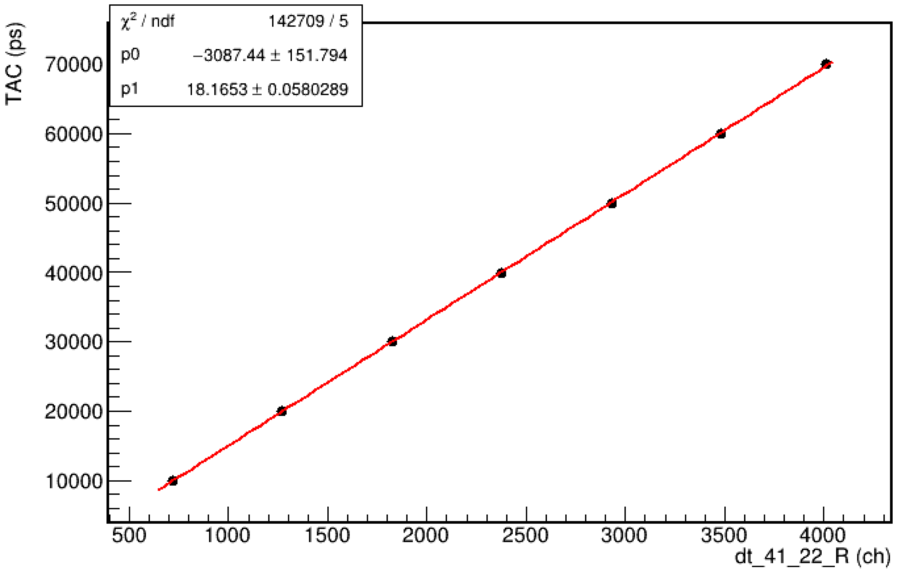
SCI reconstructed position vs raw position



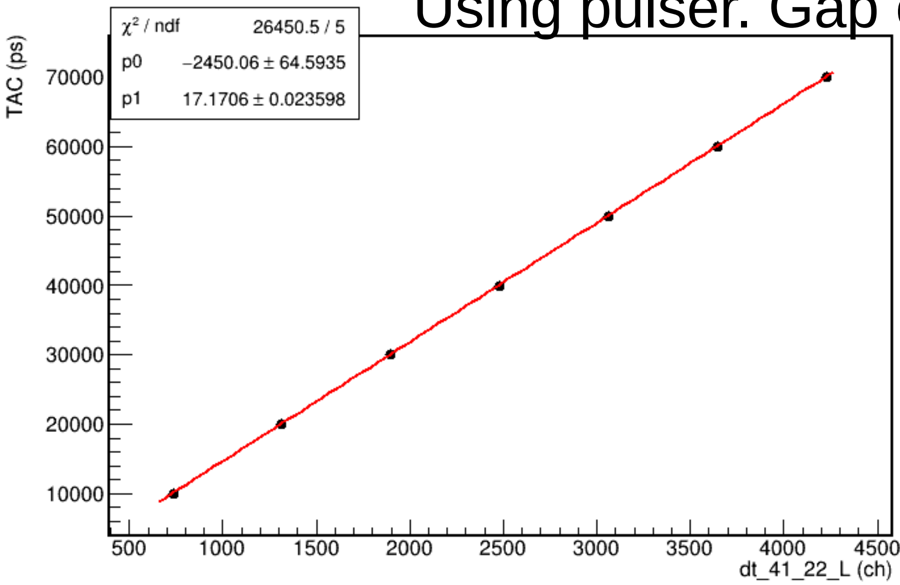
FRS Calibrations – Time to Amplitud Converter (TAC)





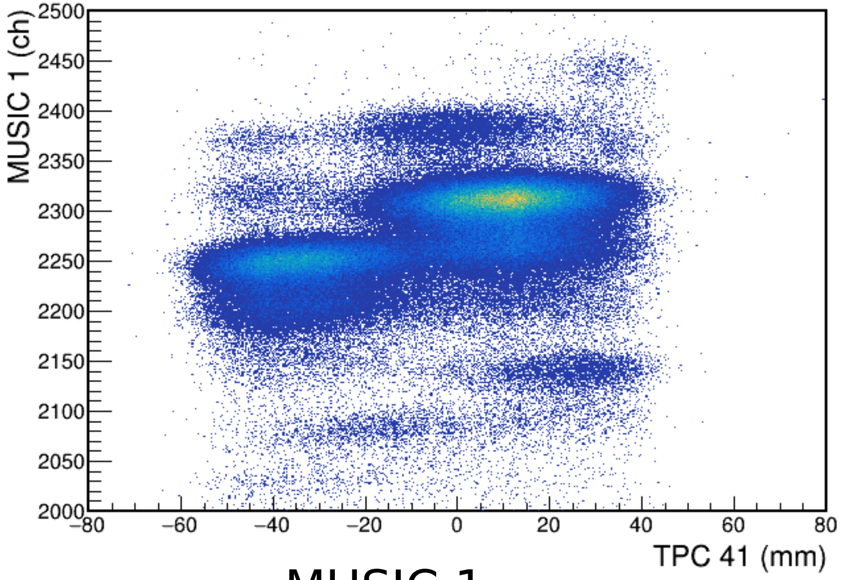


Using pulser. Gap of 10 ns

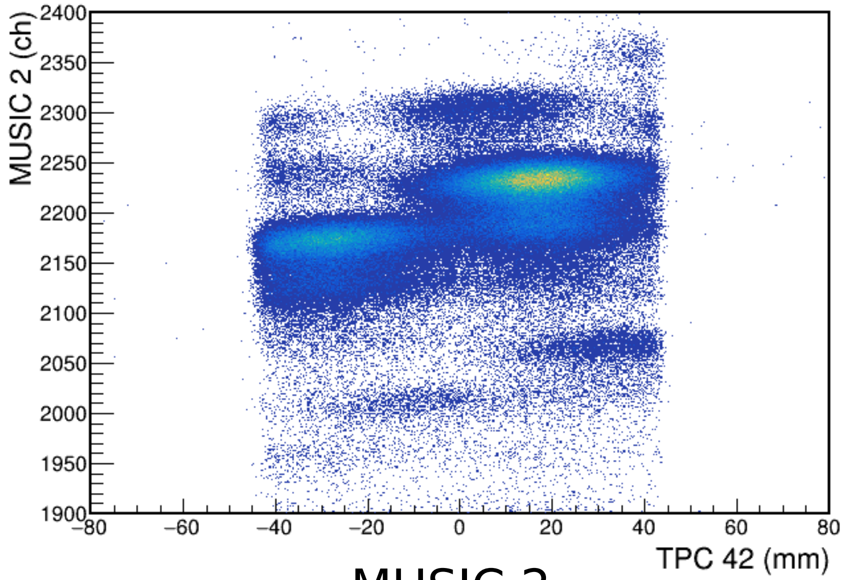


FRS Calibrations – MUSICs spatial correction

MUSIC energy loss vs TPC position

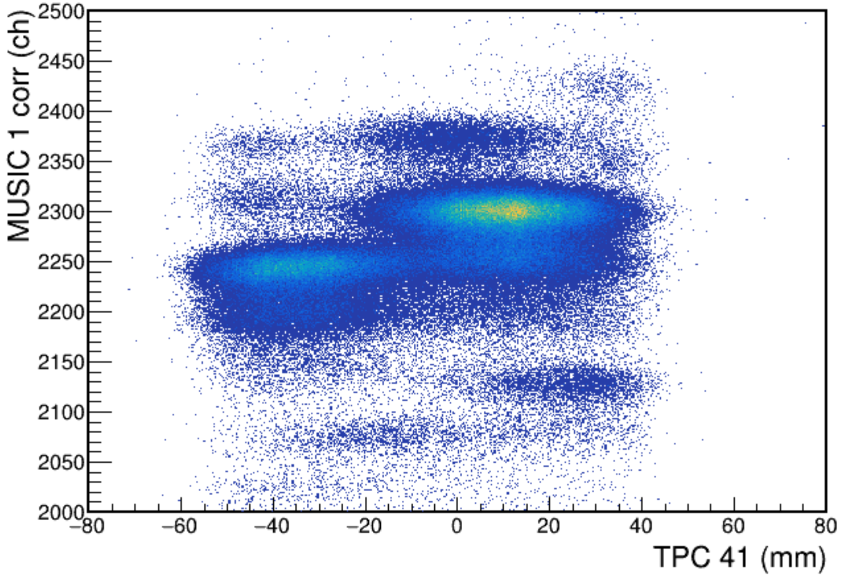


Before

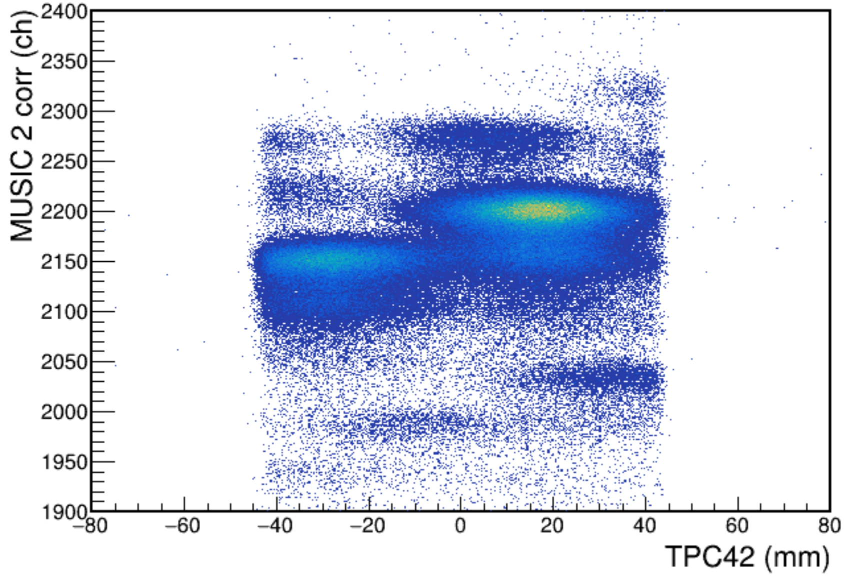


MUSIC 1

MUSIC 2

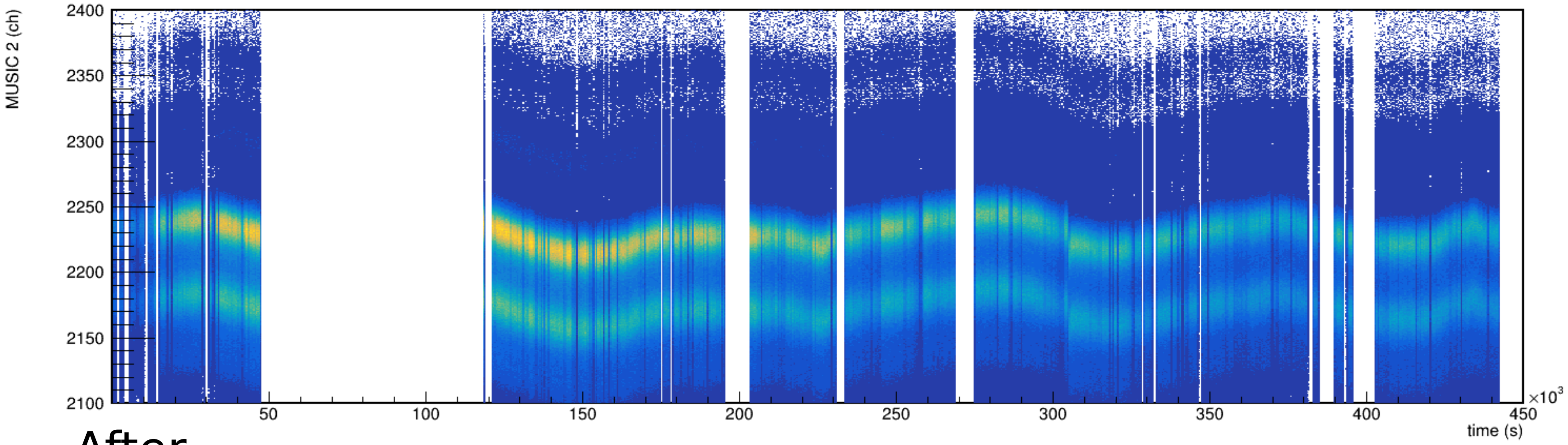


After

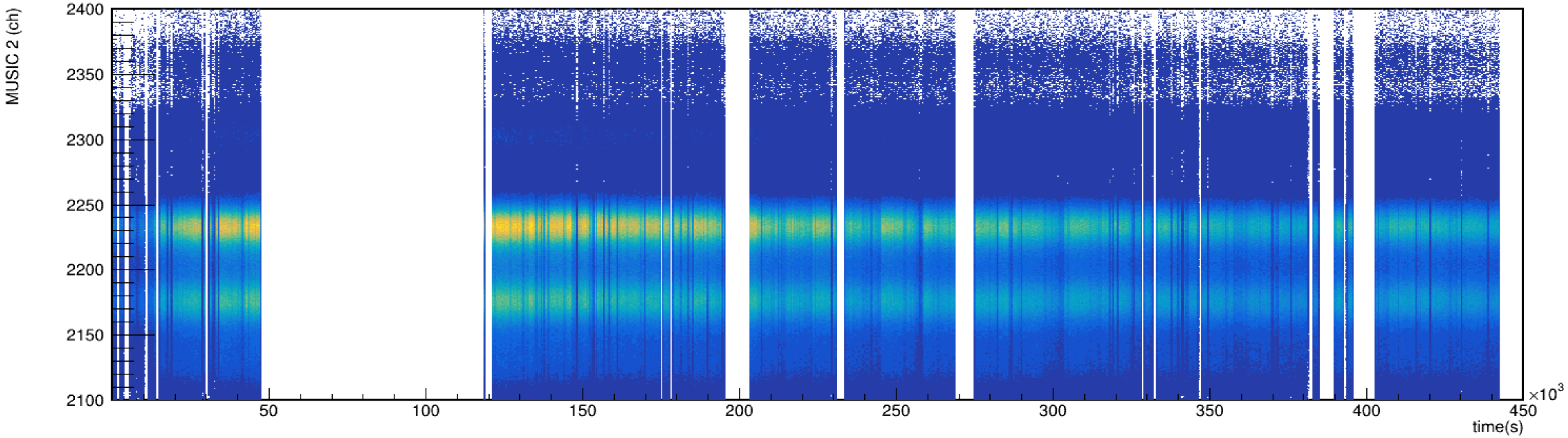


FRS Calibrations – MUSIC 2 temporal evolution correction

Before



After



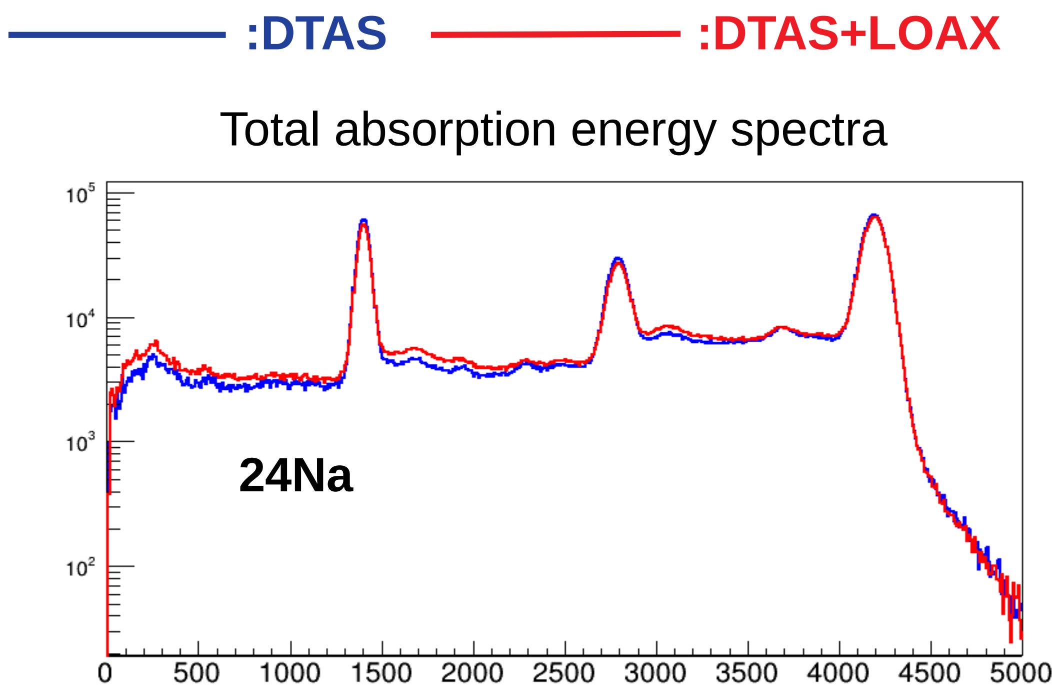
DTAS

We need to verify the accuracy of Geant4 simulations using laboratory sources:
- Gain matching of data and energy and width calibrations
- Quantification of background contributions: ambient background and summing-pileup
- Implementation of setup geometry in Geant4

Complex geometry → scaled complexity measurements:
- DTAS alone
- DTAS + LOAX-HPGe
- DTAS + AIDA(+bPlast)
- DTAS + AIDA(+bPlast) + LOAX

Sources (with a range of activities):
- 241Am
- 57Co
- 133Ba
- 137Cs
- 22Na
- 60Co
- 152Eu
- 24Na, thanks to the collaboration of Uni.. Mainz (D. Renisch)

Comparison of DTAS and DTAS+LOAX measurements



- Measurements span two days
- All (off-line) re-calibrated to a single 2 min reference measurement

AIDA Simulations

- Ingredient of TAS response ***R*** to decay: needed in the analysis

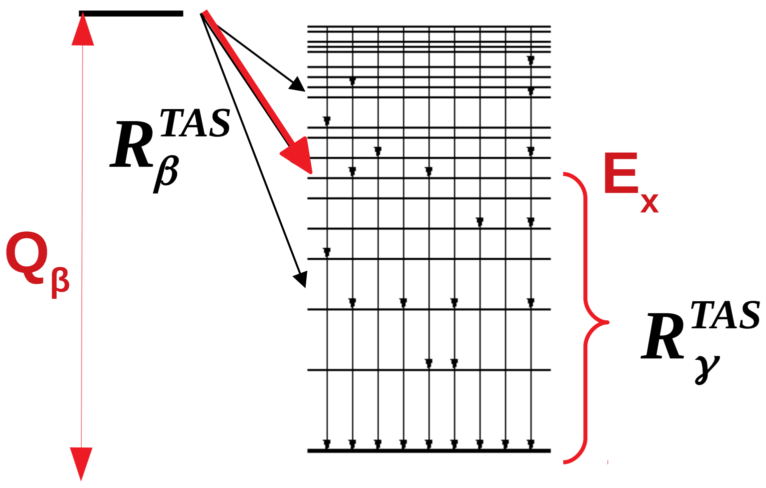
$$d = R \cdot f$$

$$I_\beta = \frac{f}{\sum f}$$

d: TAS spectrum in coincidence with AIDA
f: β-feeding

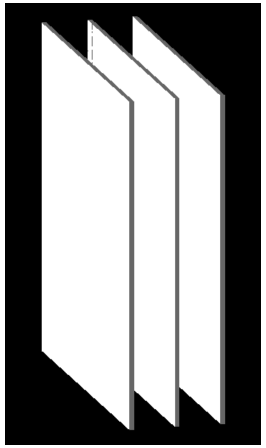
$$R(E_x) = \varepsilon_\beta^{AIDA} R_\beta^{TAS} * R_\gamma^{TAS}$$

relative β− efficiency

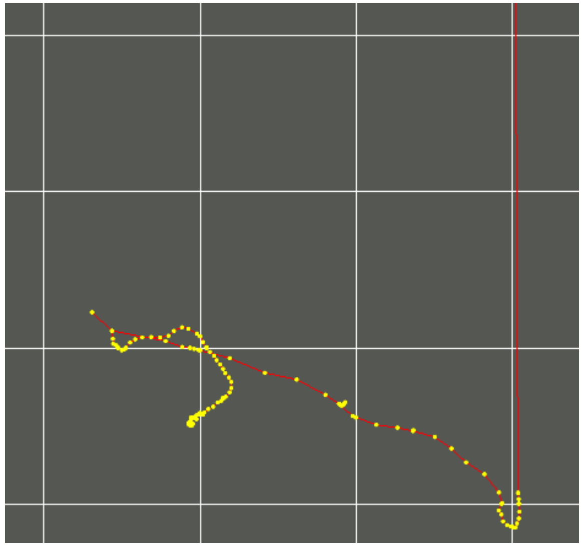


Because of energy threshold: strong energy dependence on Q_β-E_x

- Use Geant4 to obtain $\varepsilon_\beta(Q_\beta - E_x)$ and study systematics
- Validate with measurements



- Simplified geometry: 3 AIDA (BB18) DSSD, 10 mm apart
- 128x0.56 mm strips X/Y
- 1 mm thick
- Implant in middle DSSD



AIDA

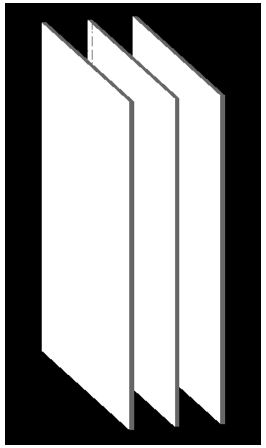
In progress:

- First MC study of AIDA beta-efficiency

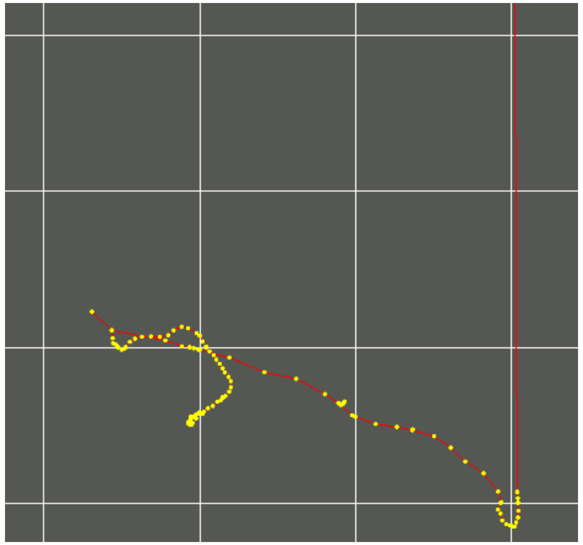
AIDA Simulations

Knowledge of AIDA beta-efficiency (only shape!) as function of endpoint energy is necessary for TAGS analysis

- Use Geant4 to obtain $\varepsilon_\beta(Q_\beta - E_x)$ and study systematics
- Validate with measurements

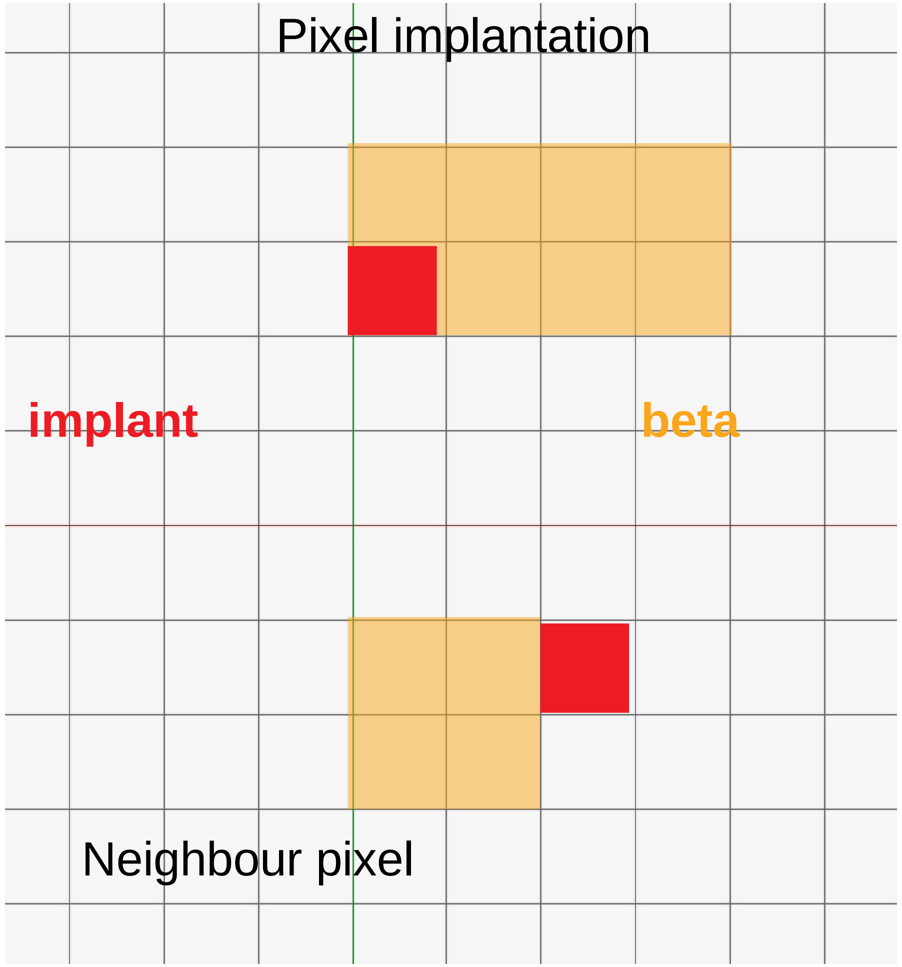


- Simplified geometry: 3 AIDA (BB18) DSSD, 10 mm apart
- 128x0.56 mm strips X/Y
- 1 mm thick
- Implant in middle DSSD



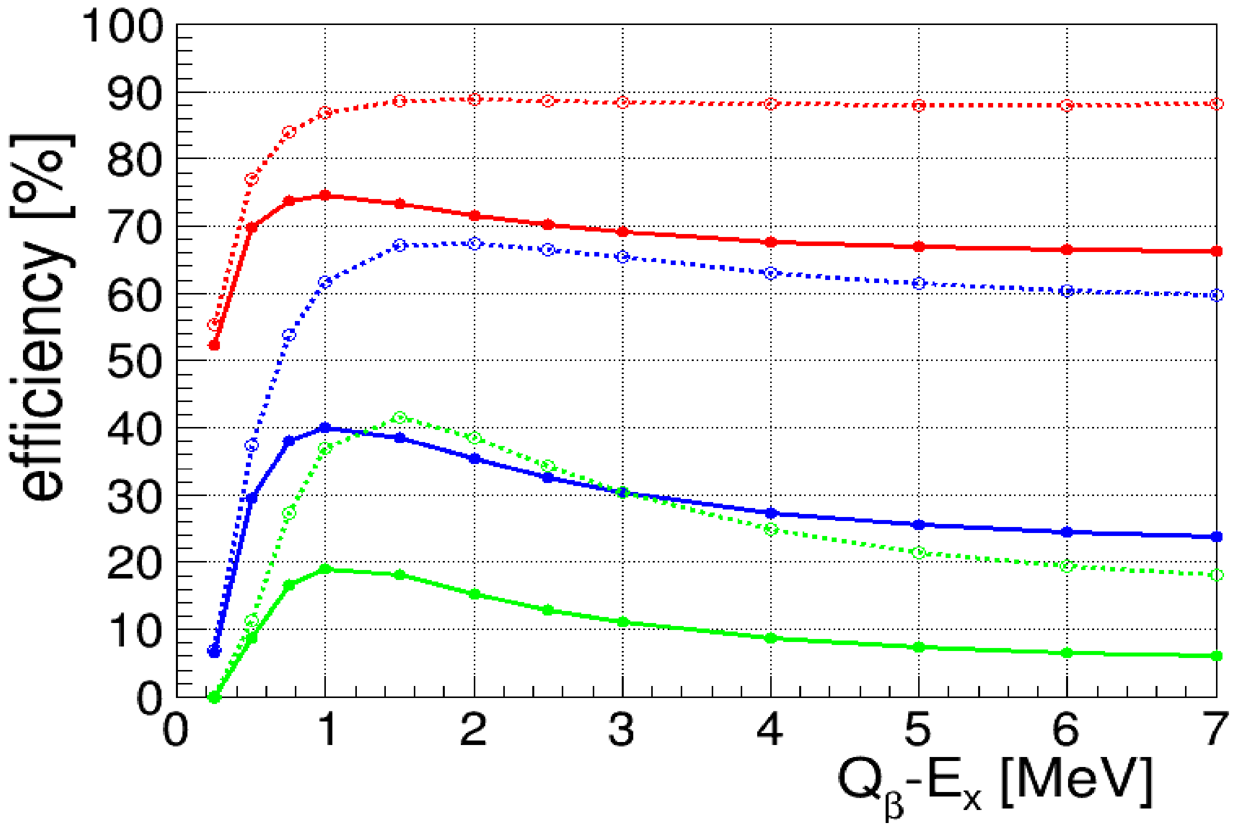
Realistic simulation:

- Implant-β spatial correlation as in AIDASort (O. Hall): overlap of implant and β cluster areas
- Beta event:
  - Condition on strip energy: $\mathbf{E_{strip}>E_{th}}$ before clustering
  - Condition on X-Y cluster energy difference: $\mathbf{|E_{CX}-E_{CY}|<E_{cut}}$



Effect of strip energy threshold

—— : pixel implantation   - - - - - - - : pixel implantation+neighbor pixel



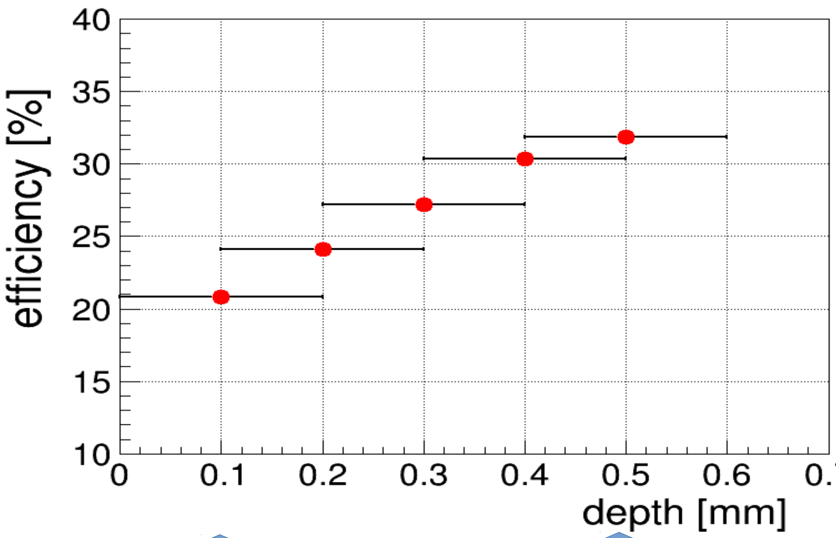
- **Strong effect at low Q_{β}-E_x**
- **Good AIDA energy calibration**

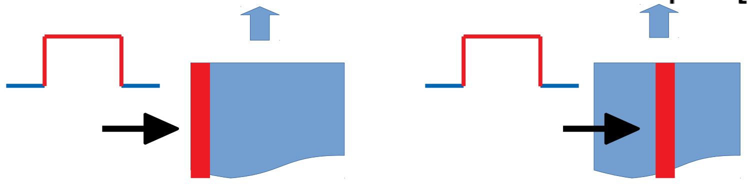
E_{th}=50keV **E_{th}=150keV** **E_{th}=250keV**

(E_{cut} = E_{thr})

AIDA Simulations of beta-detection efficiency as a function of depth of implantation

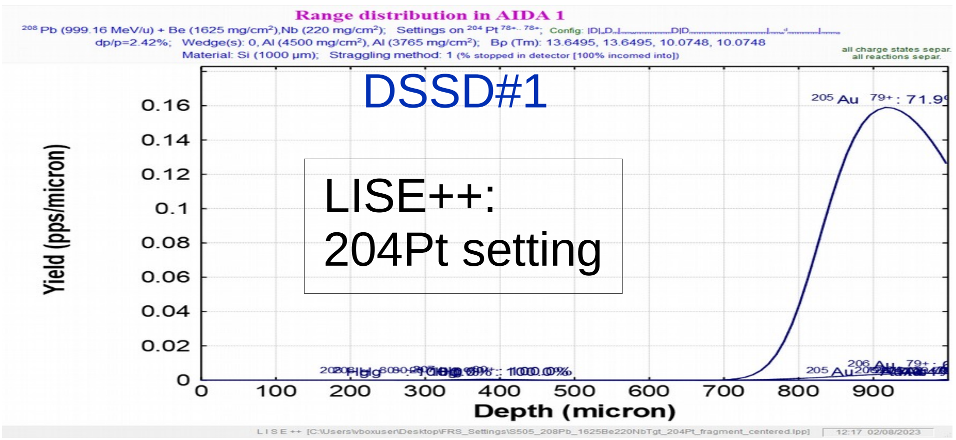
Effect of Z (depth) implant position:

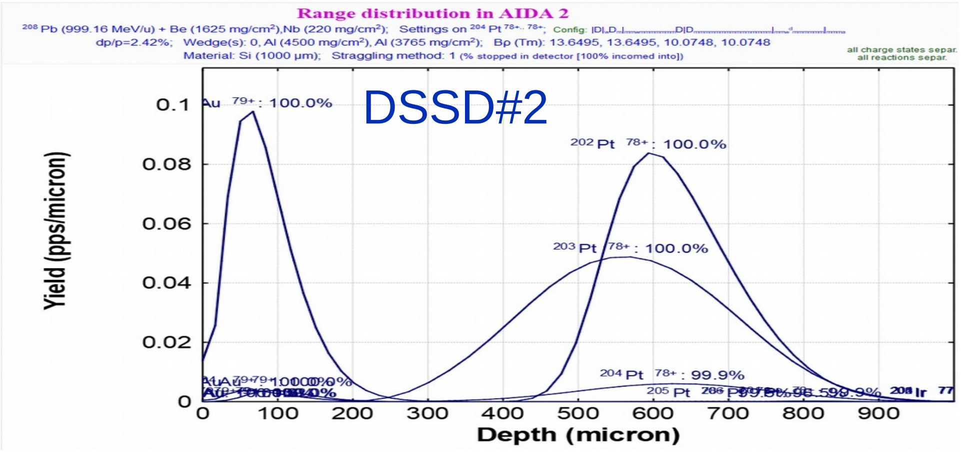




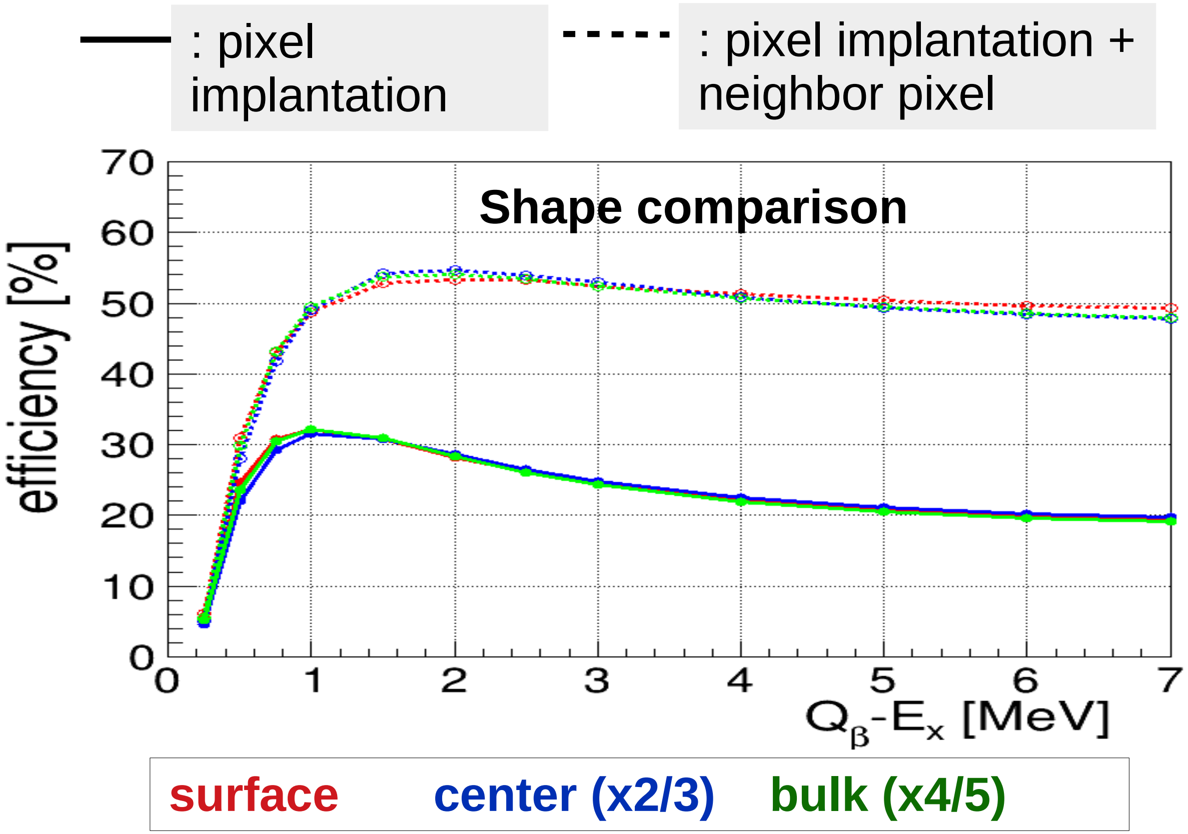
- **Strong effect**

Can be obtained from LISE++ (!?)





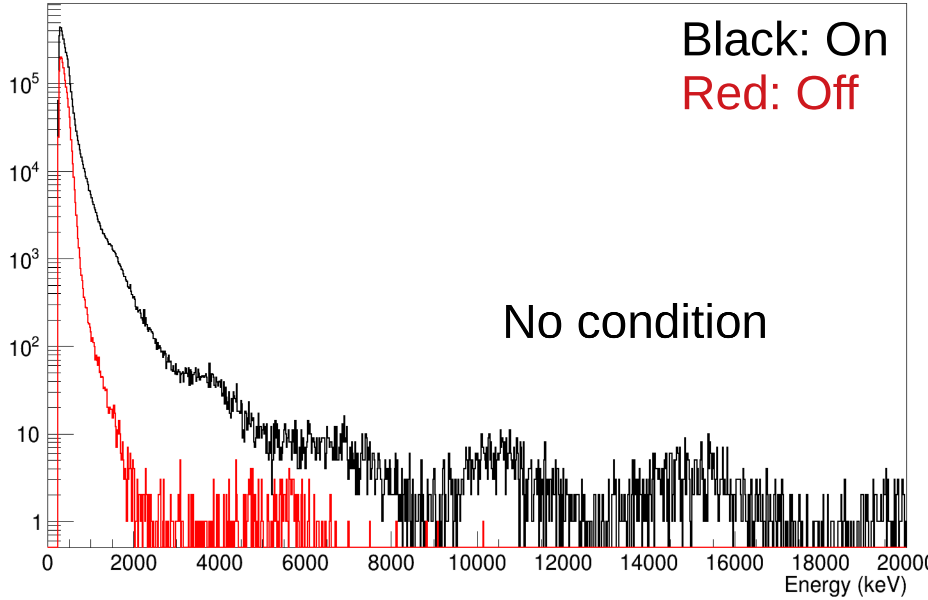
AIDA Simulations of beta-detection efficiency as a function of endpoint energy

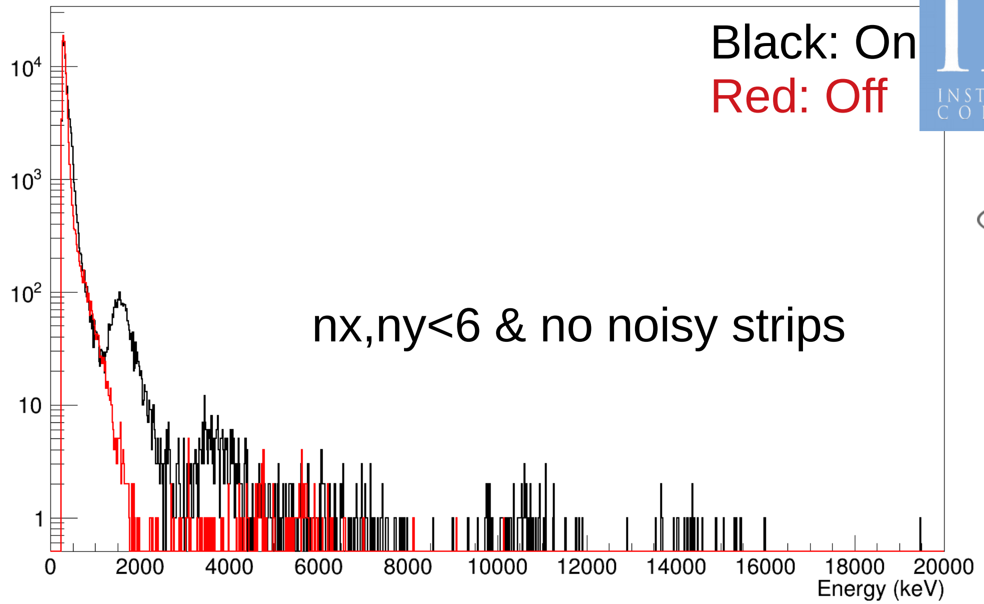


- **Small effect: maximum deviation ±2% for Q_β-E_x≥ 0.75MeV**
- **Not an issue**

Final goal: determine the effective β-efficiency curve **shape** and assign an uncertainty band combining simulations and data

Beta Energy DSSD0:

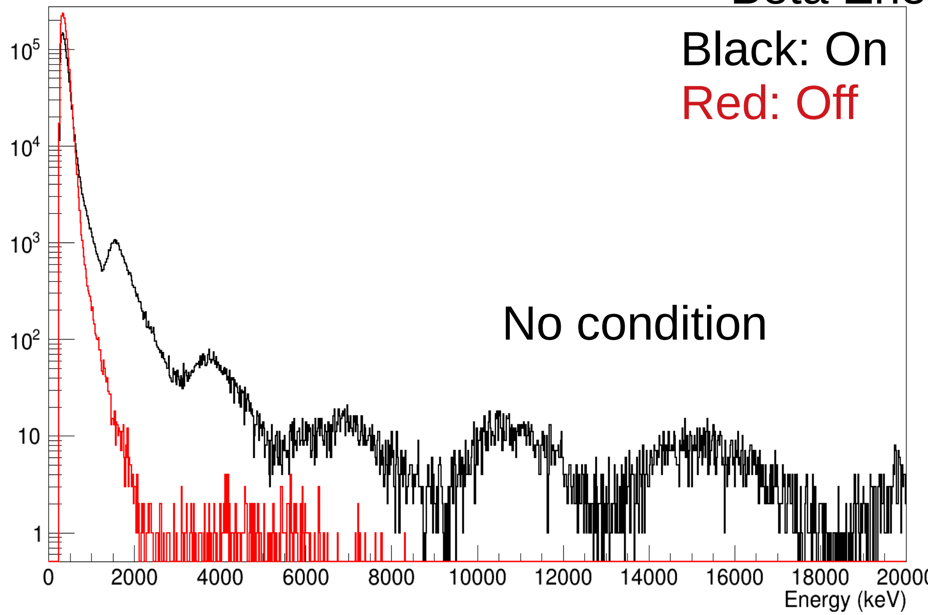


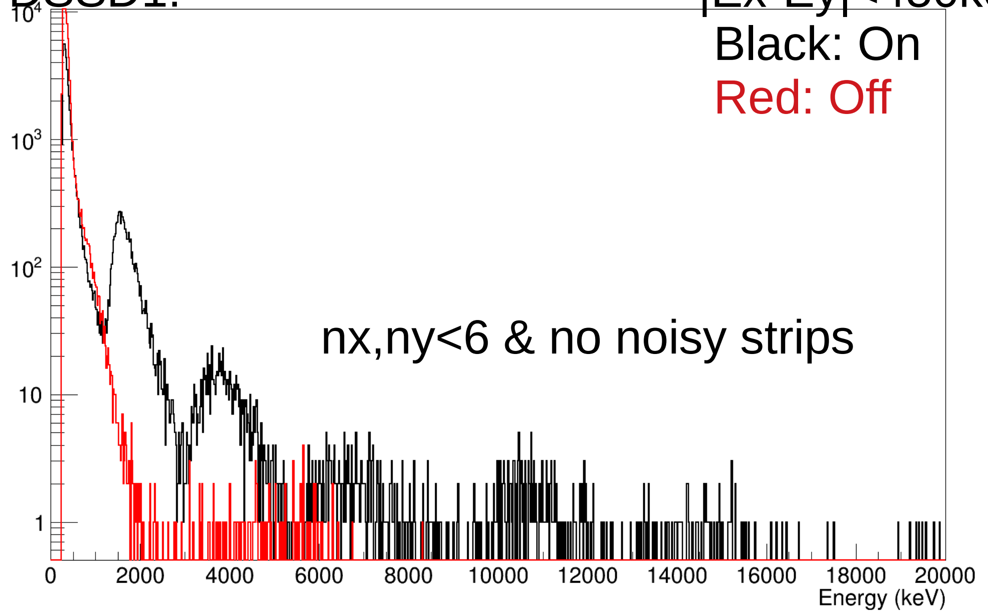


Hardware strip threshold

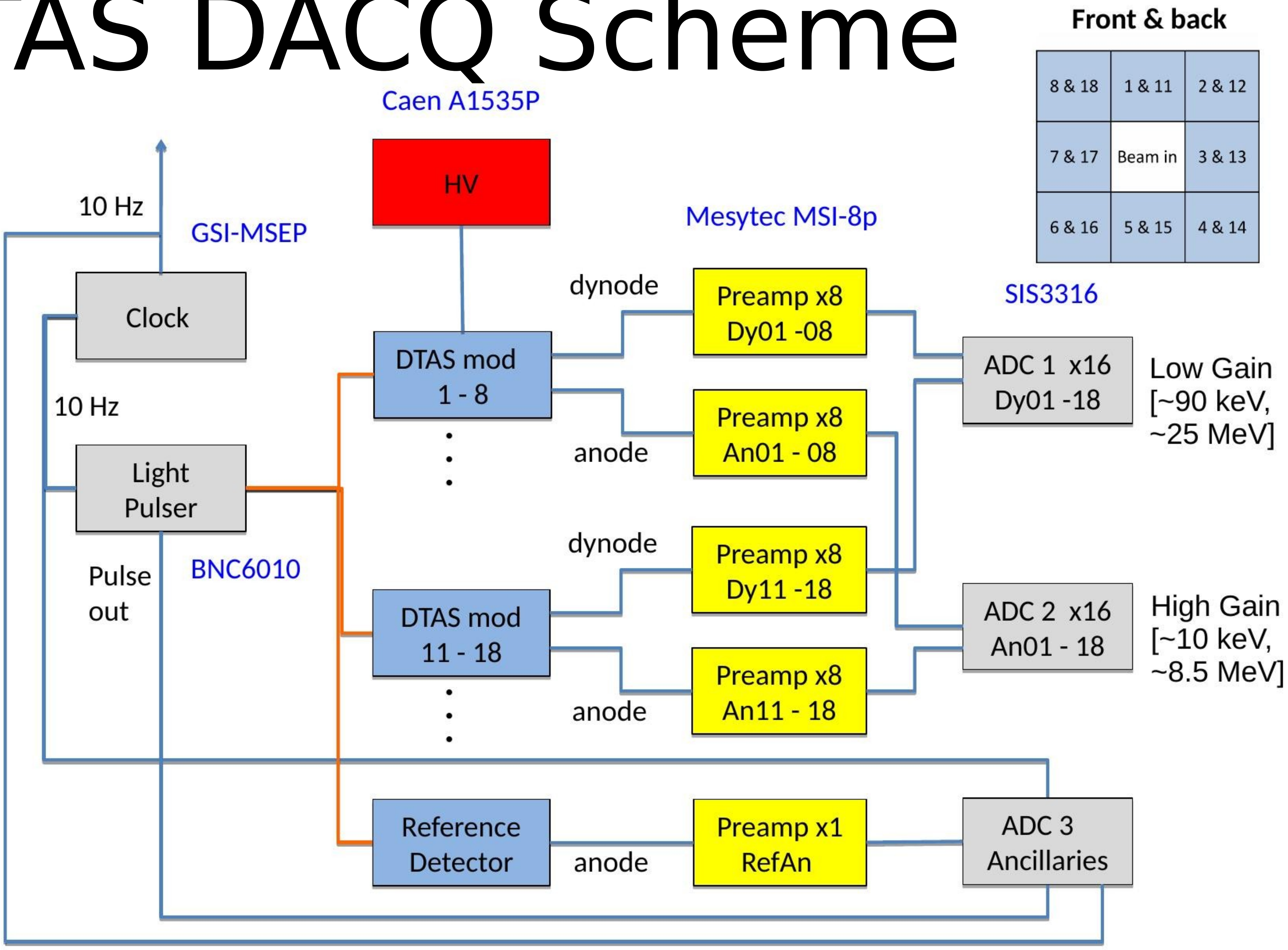
Ex,Ey>250keV
|Ex-Ey|<450keV

Beta Energy DSSD1:



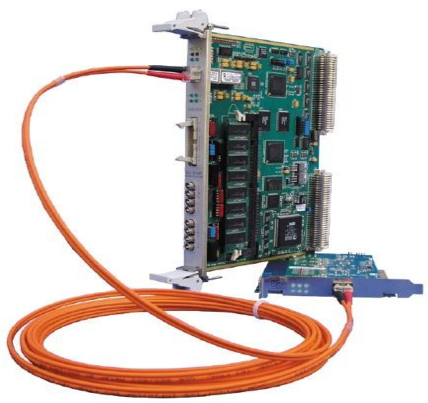


DTAS DACQ Scheme



DTAS DACQ

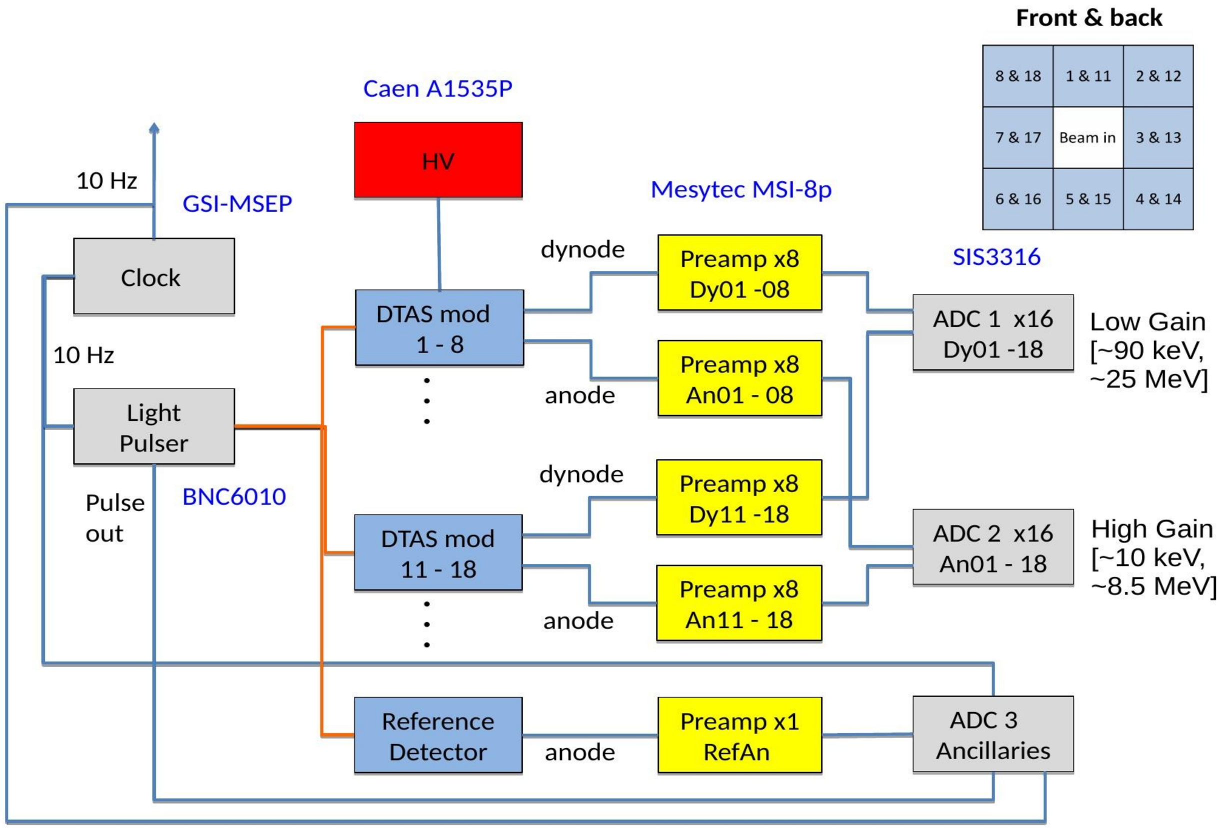
DACQ:
· 1x SIS 3100/SIS1100 (VME-PCIe)
· 3x SIS3316 Digitizer
· VETAR-2
· EXPLODER-2 (standalone)
· Optic fiber to Messhütte
· PC CentOS 7




WR implementation

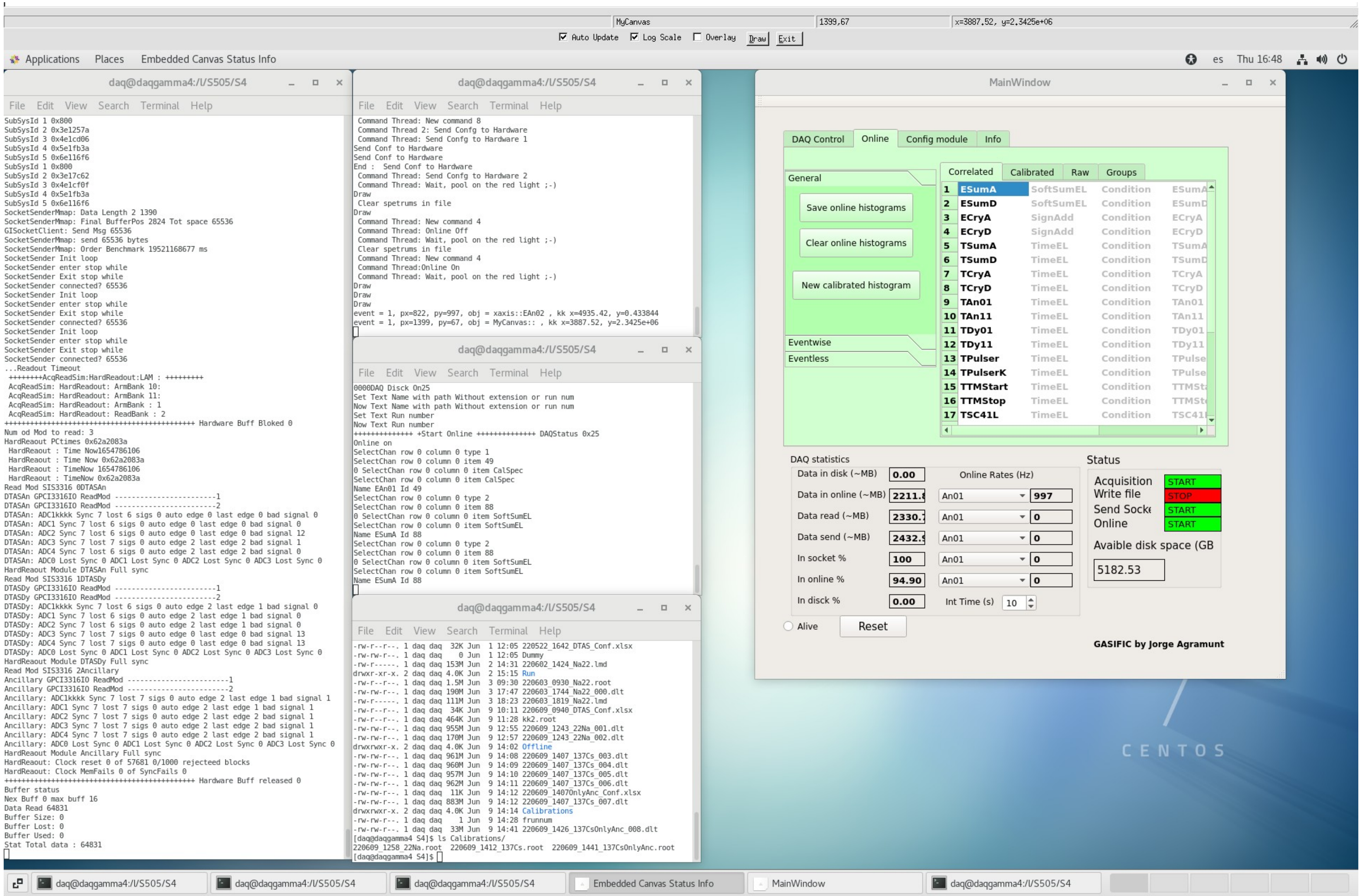
H. Johansson and S.Löeher, priv communication

http://fy.chalmers.se/~f96hajo/rataser/



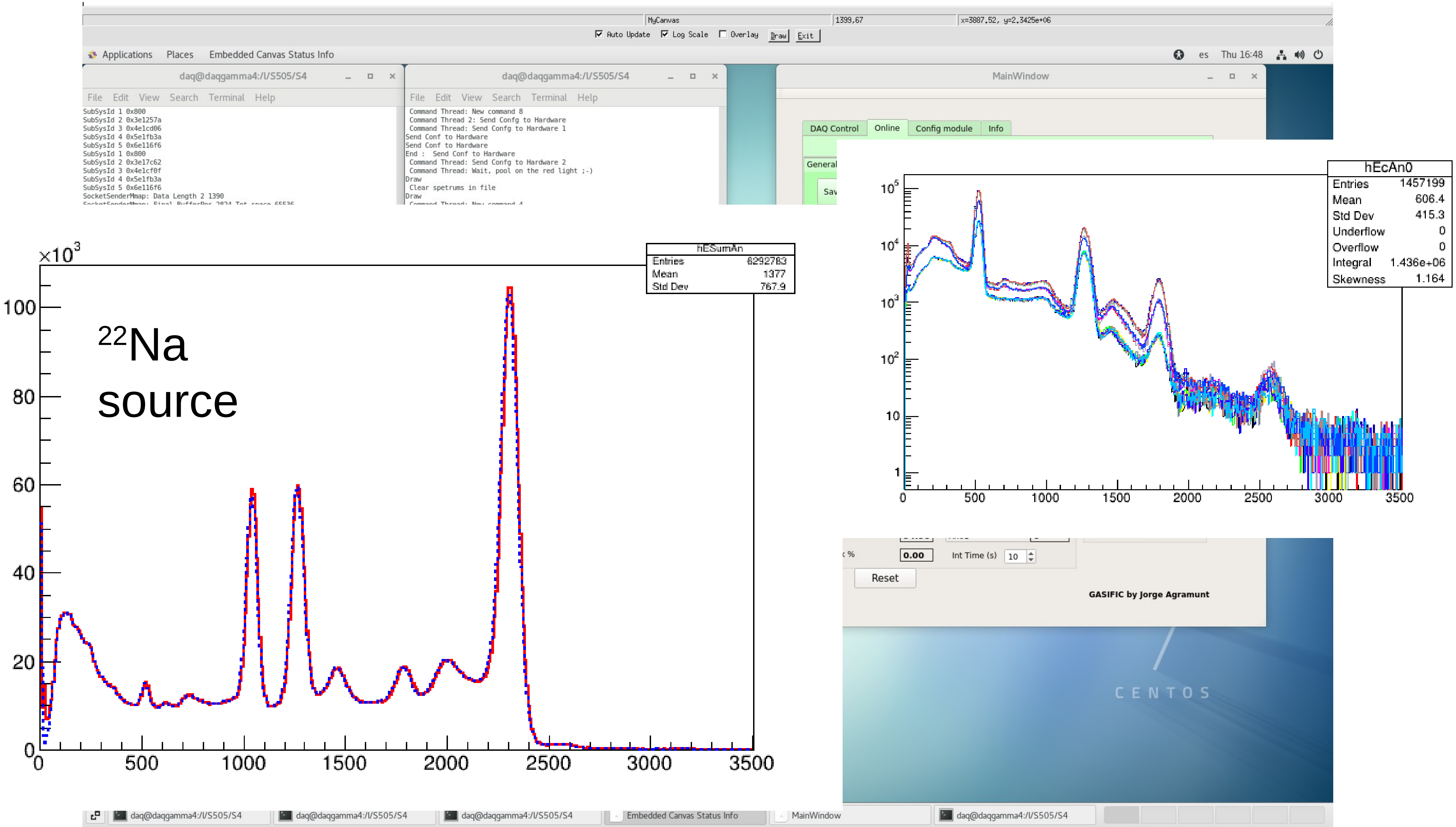
DTAS DACQ GASIFIC

[J. Agramunt et al., NIMA (2016)]



DTAS DACQ GASIFIC

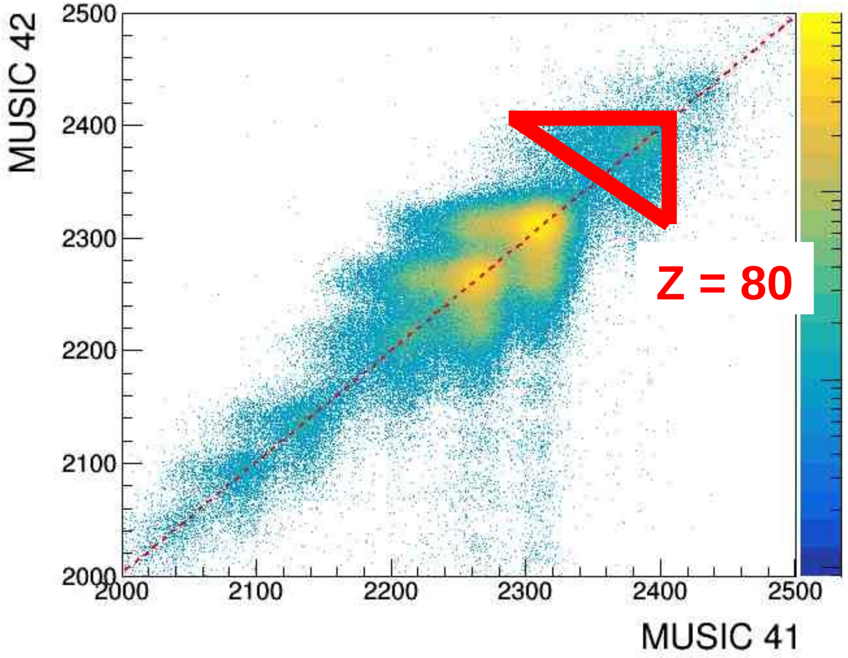
[J. Agramunt et al., NIMA (2016)]

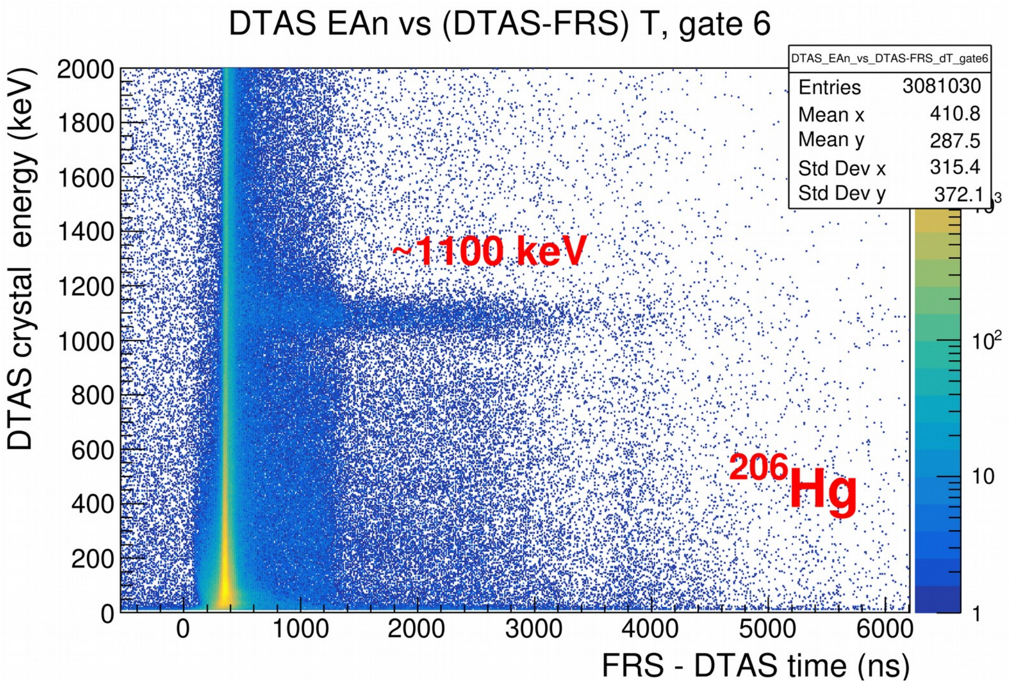


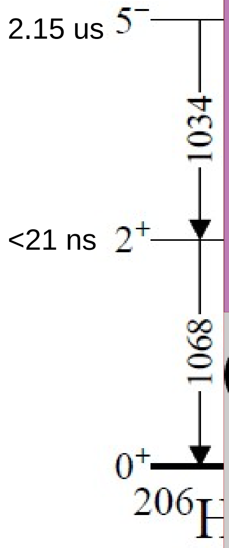
S505 Nearline

PRELIMINARY

Isomer tagging. The 5^- isomer in ^{206}Hg



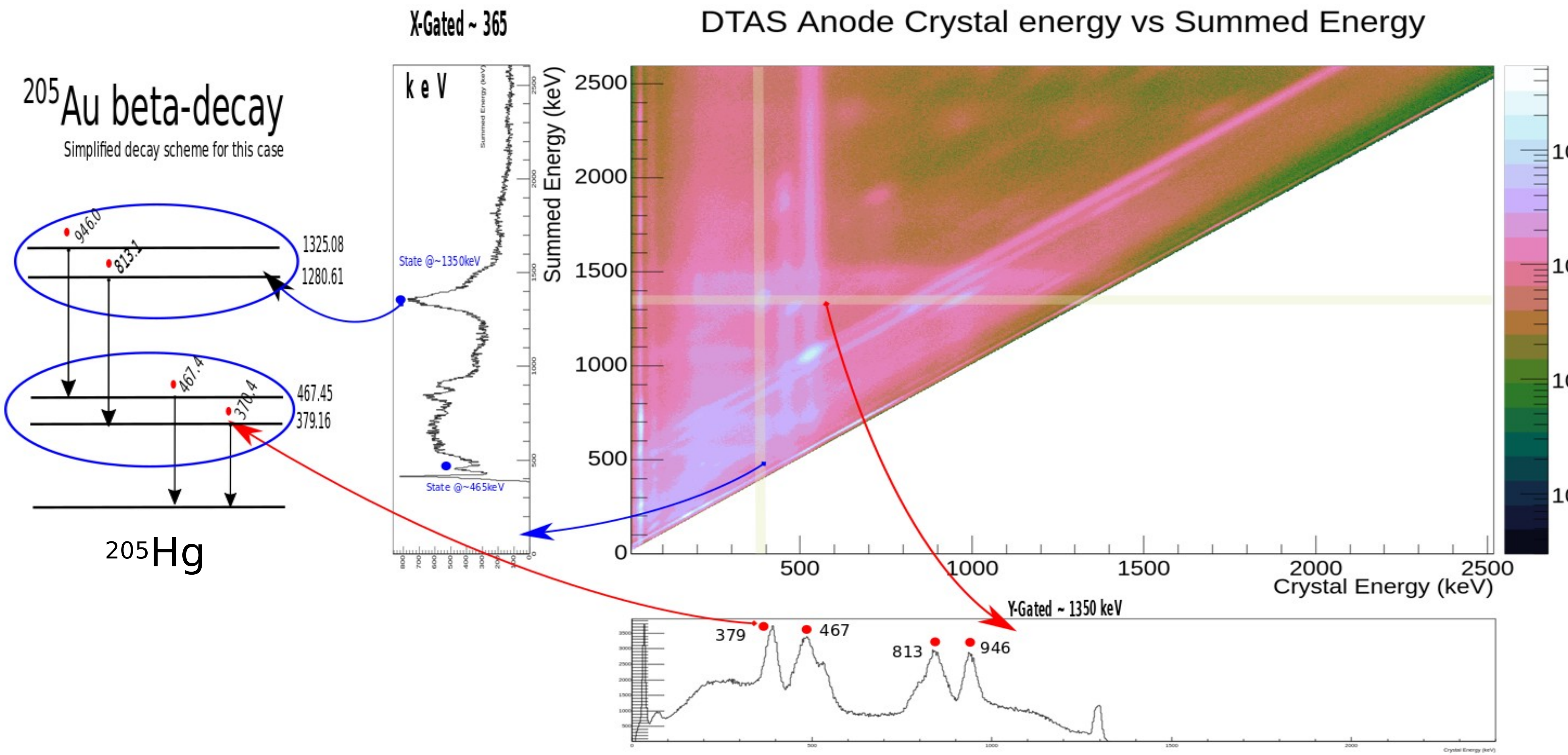




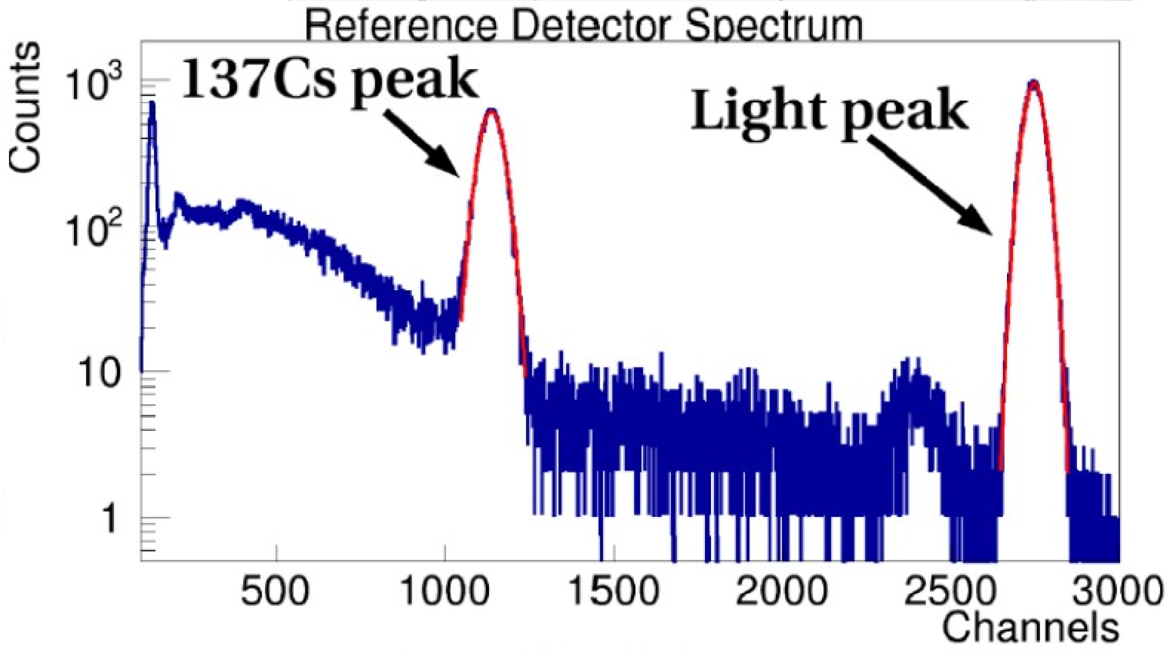
S505 Nearline

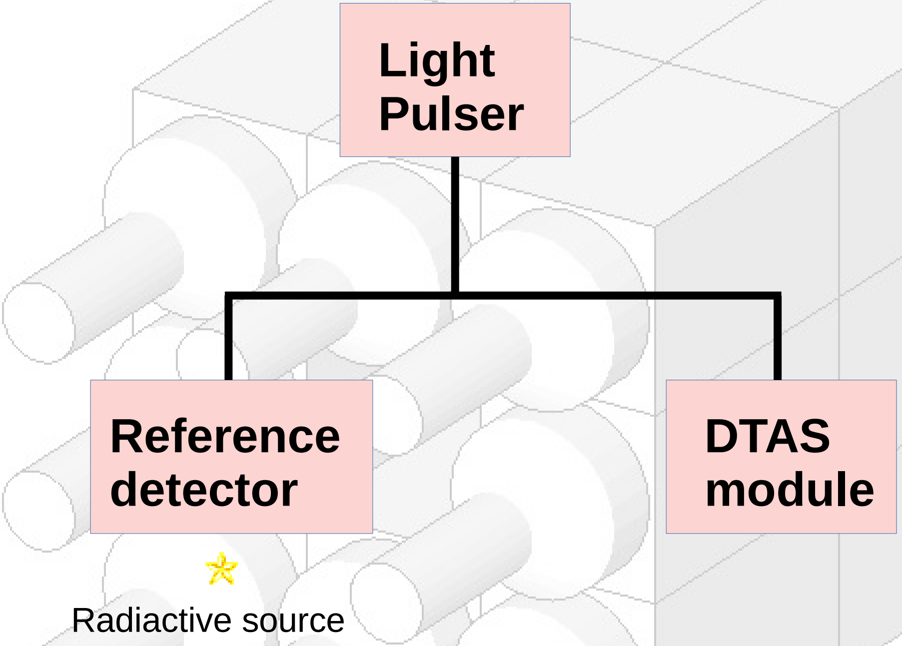
PRELIMINARY

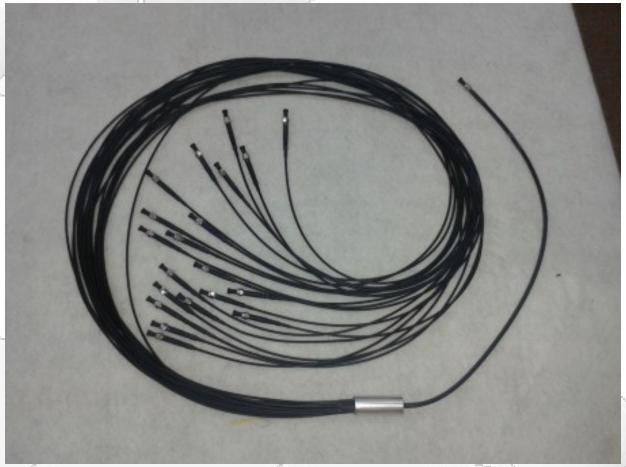
TAGS Spectra

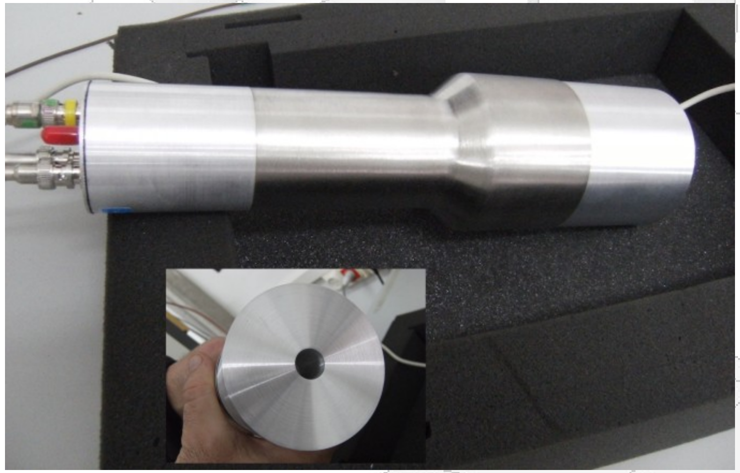


Gain Stabilization System









DTAS electronics

Electronics:

HV supply:
- CAEN SY2527
- 2 x A1535P

(SY crate)

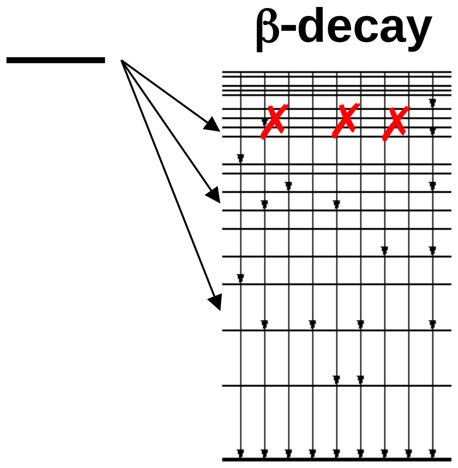
Preamplifiers:
- 2x Mesytec MSI-8p (Gain: x1)
- 2x Mesytec MSI-8p (Gain: x5)
- 1x Mesytec MSI-8p (Gain: x1)
- 2x Mesytec Low Voltage MNV-4

LP Clock:
- 1X GSI-MSEP clock

Additional:
- TTL-NIM conv.
- Shaping Amp
- ...

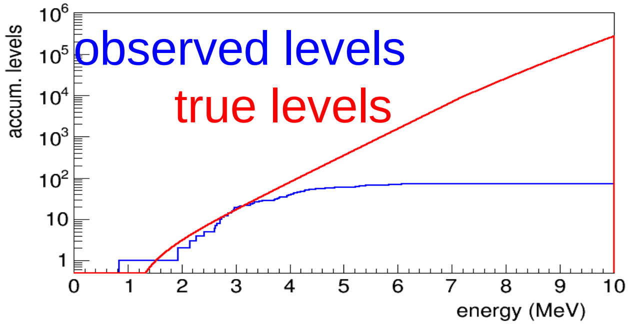
(NIM crate)

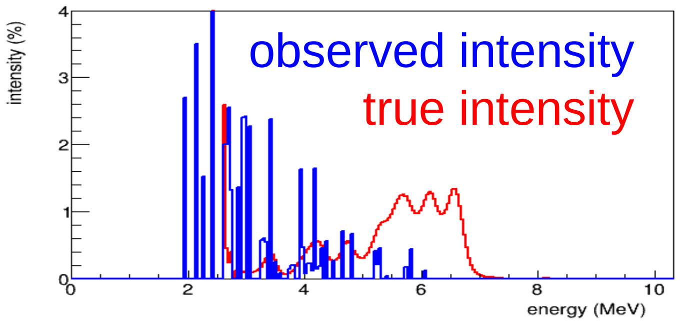
TAGS Technique



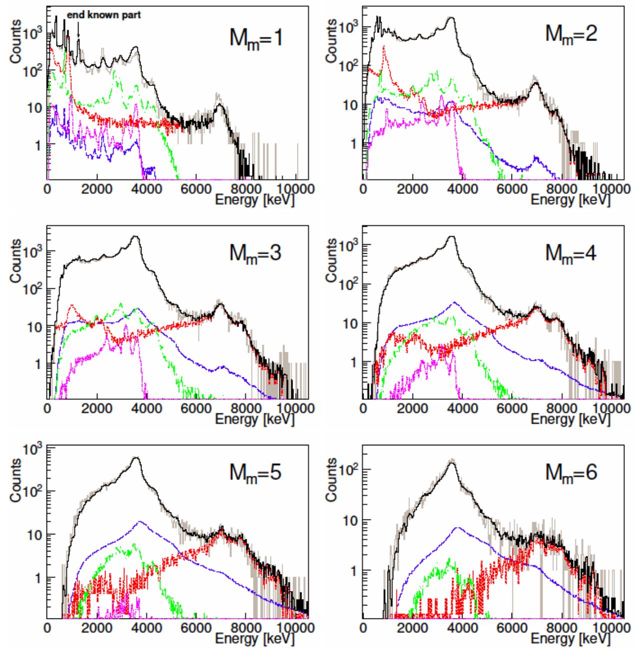
Goal of TAGS technique:

- Determine β-intensity distributions free of the Pandemonium effect (HPGe spectroscopy)





Multiplicity gated spectra



New generation of segmented spectrometers:

- Information on decay scheme
- Improved analysis

FAIR GSI

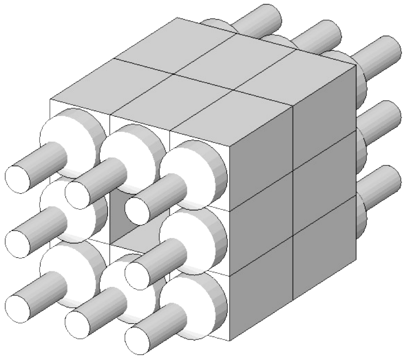
HI DE SPEC

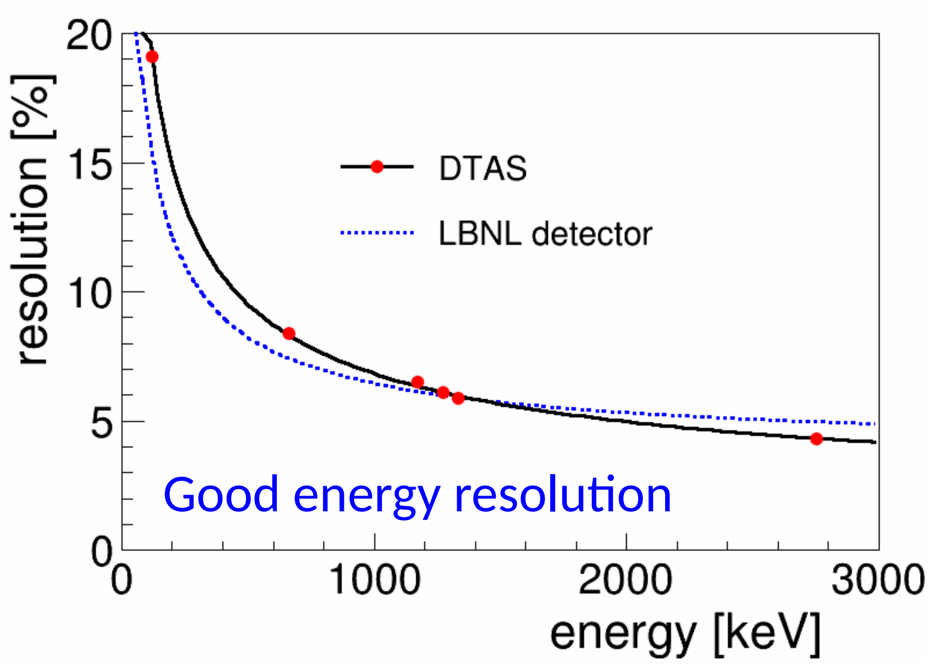
Gen—T

IFIC INSTITUT DE FÍSICA CORPUSCULAR

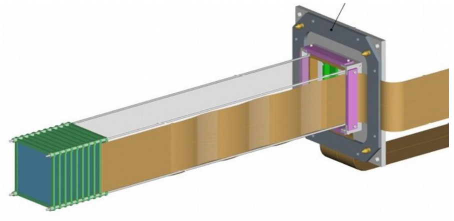
DTAS features

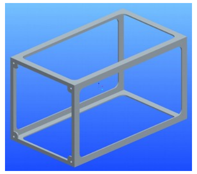
16 + 2 square shaped modules:
15×15×25 cm^3 **NaI(Tl)**
+ 5” PMT (50% light col.)
V= 95 L, M= 351 kg



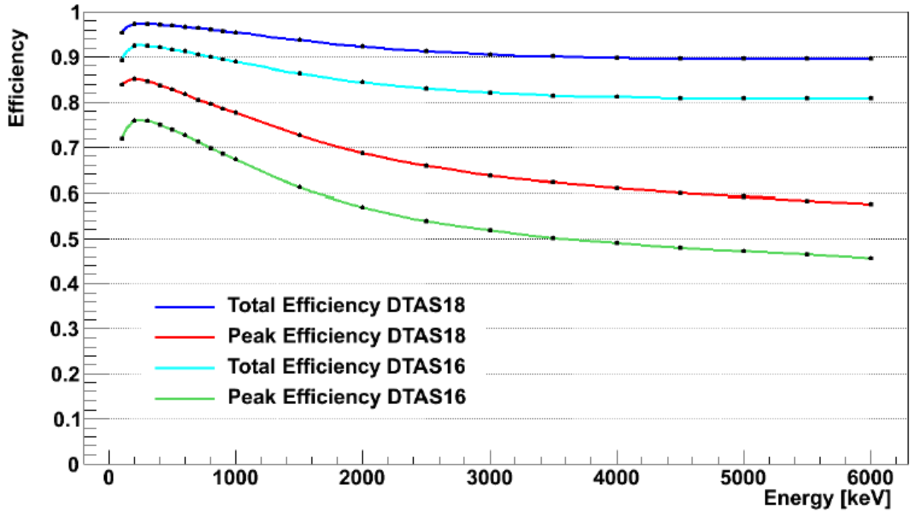


Designed to be coupled to AIDA





Good efficiency



TDR approved: Nov. 2012
Commissioned @ IFIC: Dec. 2013
Commissioned @ IGISOL: Feb. 2014
Commissioned @ BigRIPS@RIBF: June 2019
Comissioned @ DESPEC@GSI: June 2022

Tain+, NIMA803(2015)36
Guadilla+, NIMA910(2018)79

The TAGS analysis in a nutshell

1) Reduce the analysis to a **linear inverse problem** taking the b.r. as parameters:

$$d_i = \sum_j R_{ij}(\mathbf{b}) \cdot f_j$$

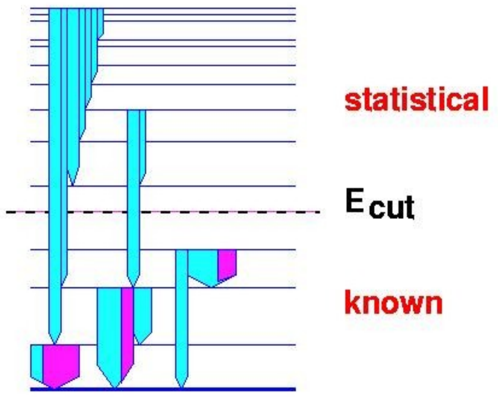
2) Make a reasonable choice of b.r. matrix: we use the **nuclear statistical model** plus **known level-scheme**

3) Construct the spectrometer response using **MC simulations carefully bench-marked to calibrations**

$$\mathbf{r_j} = \sum_{k=0}^{j-1} b_{jk} \gamma_{\mathbf{jk}} \otimes \mathbf{r_k}$$

$$\mathbf{R_j} = \beta_j \otimes \mathbf{r_j}$$

4) Apply any suitable (**deconvolution**) algorithm: we use the EM method



5) Study the effect of different b.r assumptions, MC simulations and other **systematic errors**

NIM: A430(1999)p333, A571(2007)p728, A571(2007)p719