

Superaligned ^{10}C β -decay branching ratio measurement with high-count rate: a revised edition of Exp. 22.72.

Report on the AGATA experiment number 24. 44



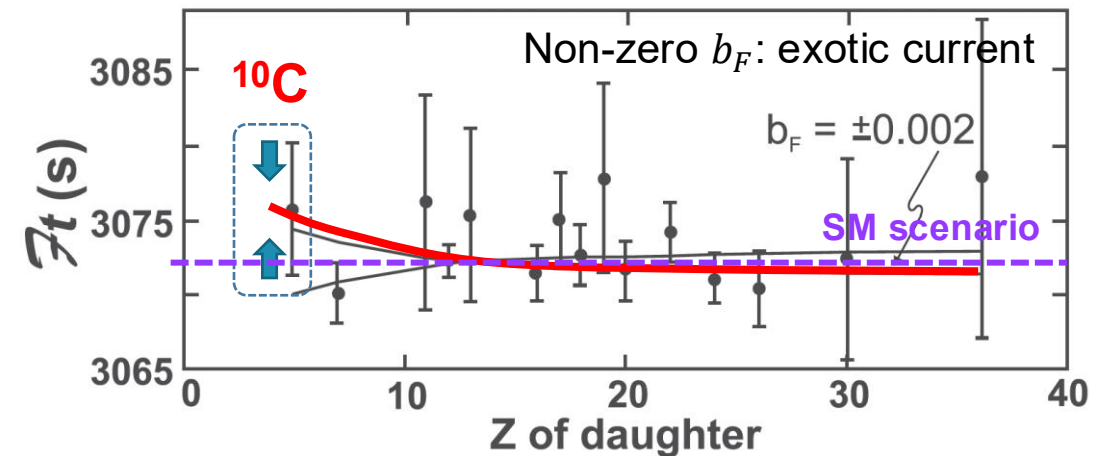
Spokespersons: Jeongsu Ha, Pablo Aguilera and Yonghyun Son

Physics Motivation

- ❑ Superalowed beta decay has been utilized to obtain $|V_{ud}|$ of the CKM matrix with high precision
- ❑ In particular, ^{10}C is the most sensitive case for the Fierz interference term search
- ❑ **High-precision measurement of ^{10}C superallowed beta-decay branching ratio**
- ❑ Exp. 22. 72 performed in 2023

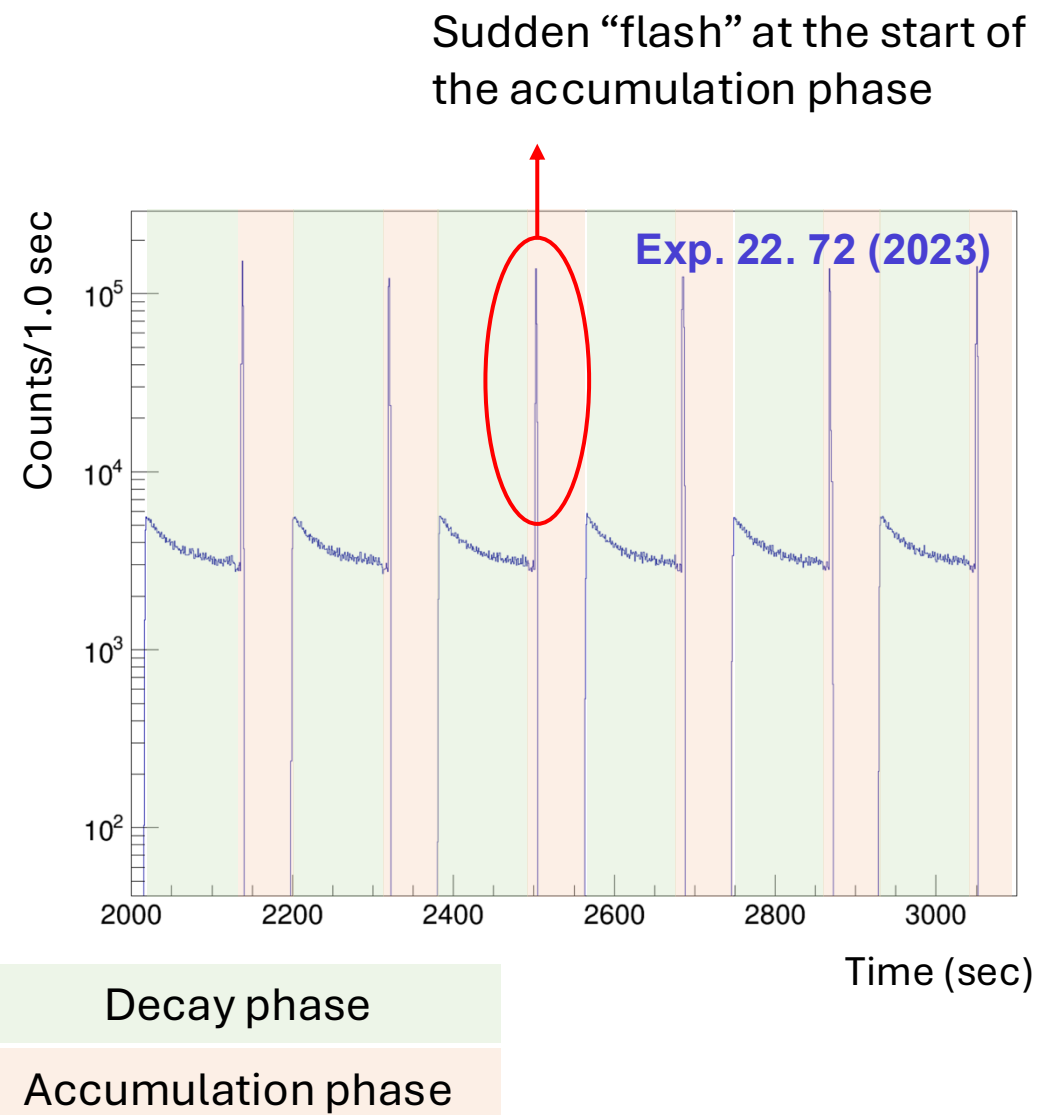
$$\begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$

$$\mathcal{F}t(0^+ \rightarrow 0^+) = \frac{K}{2G_F^2 |V_{ud}|^2 (1 + \Delta_R^V)}$$



Physics Motivation

- ❑ Following the experiment EXP. 22. 72, an improvement of the experimental setup has been discussed
- ❑ Main problem: synchronization between ‘Beam off’ and ‘AGATA start’
- ❑ High-count γ rays “flashed”
→ Global Trigger and Synchronized System (GTS) alignment breaking
- ❑ Solution confirmed in the test beamtime EXP. 24. 12



Exp 24. 44 – experimental setup

Spokespersons: Y. Son, JH and P. Aguilera, performed at INFN-LNL in July-August 2025

* Experimental configuration

❑ AGATA stand-alone mode

AGATA's advantage:

Small pile-up probability (segmented crystals)

If we look at the 511 keV pileup rate compared to the real 1022 keV gamma-ray rate, we have the simple expression

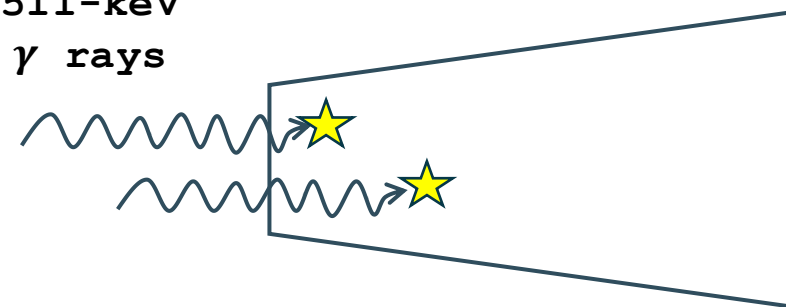
$$\frac{Y(\text{pileup})}{Y(1022)} \approx \frac{R^2(511)\epsilon^2(511)\Delta\tau}{R(1022)\epsilon(1022)}, \quad (4)$$

with $\Delta\tau$ being the resolving time of the amplifier pileup rejection system. If the same total detector efficiency is now split in N independent detectors, this ratio is decreased by a factor of N :

$$\begin{aligned} \left(\frac{Y(\text{pileup})}{Y(1022)} \right)_N &\approx \frac{NR^2(511)[\epsilon(511)/N]^2\Delta\tau}{NR(1022)\epsilon(1022)/N} \\ &\approx \boxed{\frac{1}{N} \frac{Y(\text{pileup})}{Y(1022)}}. \end{aligned} \quad (5)$$

[Single crystal]

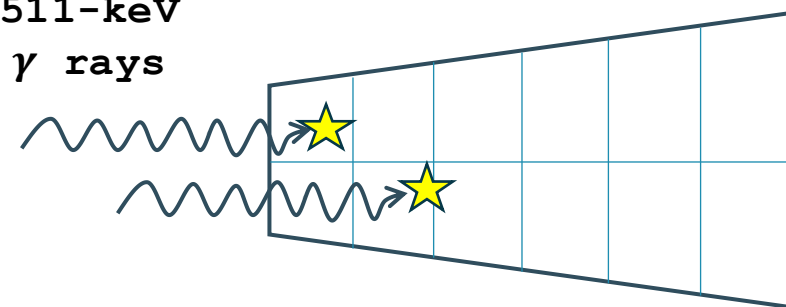
511-keV
 γ rays



511 + 511 keV
= 1022 keV

[Segmented crystal]

511-keV
 γ rays



two γ rays are
distinguished

Exp 24. 44 – experimental setup

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☐ AGATA stand-alone mode

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Small pile-up probability (segmented crystals)

☐ Proper shielding for the scattered protons



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☐ AGATA stand-alone mode

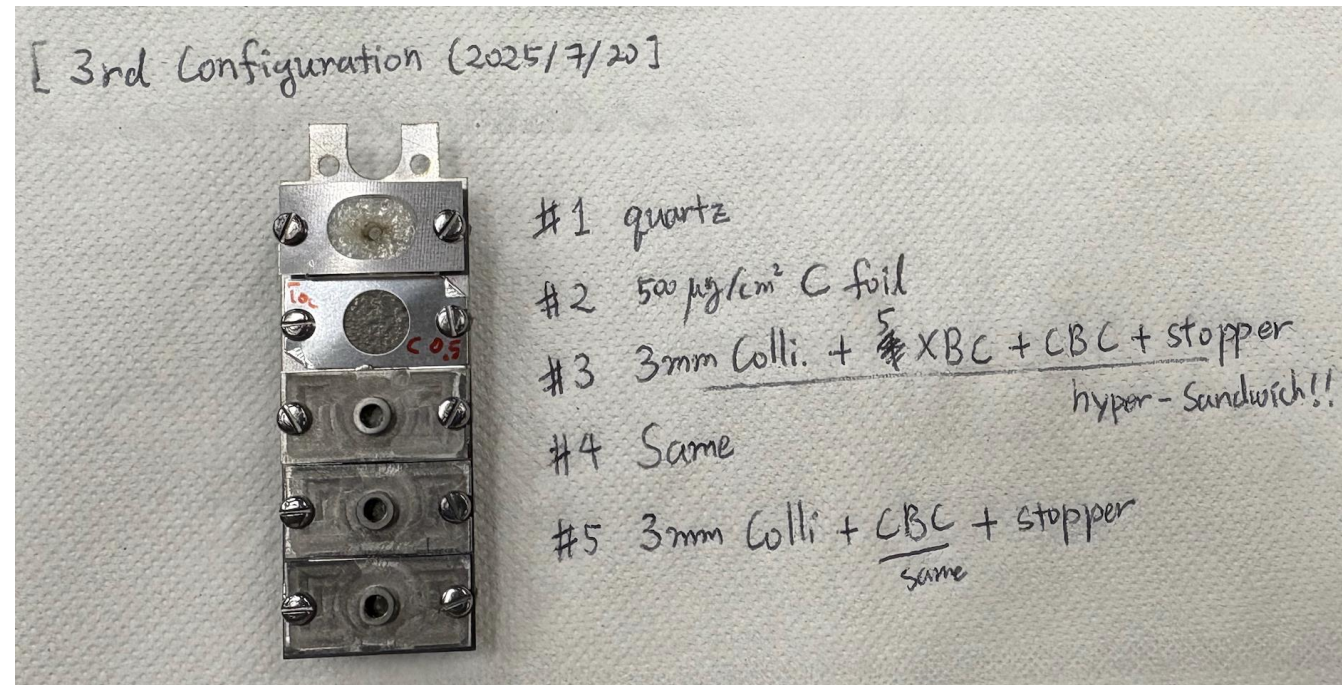
AGATA's advantage:

Small pile-up probability

☐ Proper shielding for the scattered protons

☐ Stack of 1-mg/cm²-thick ¹⁰B target sandwiched by C layers

☐ 8 MeV, 30 pA (beam on/off) / 2 pA (continuous) proton beam



Exp 24. 44 – experimental setup

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☐ AGATA stand-alone mode

AGATA's advantage:

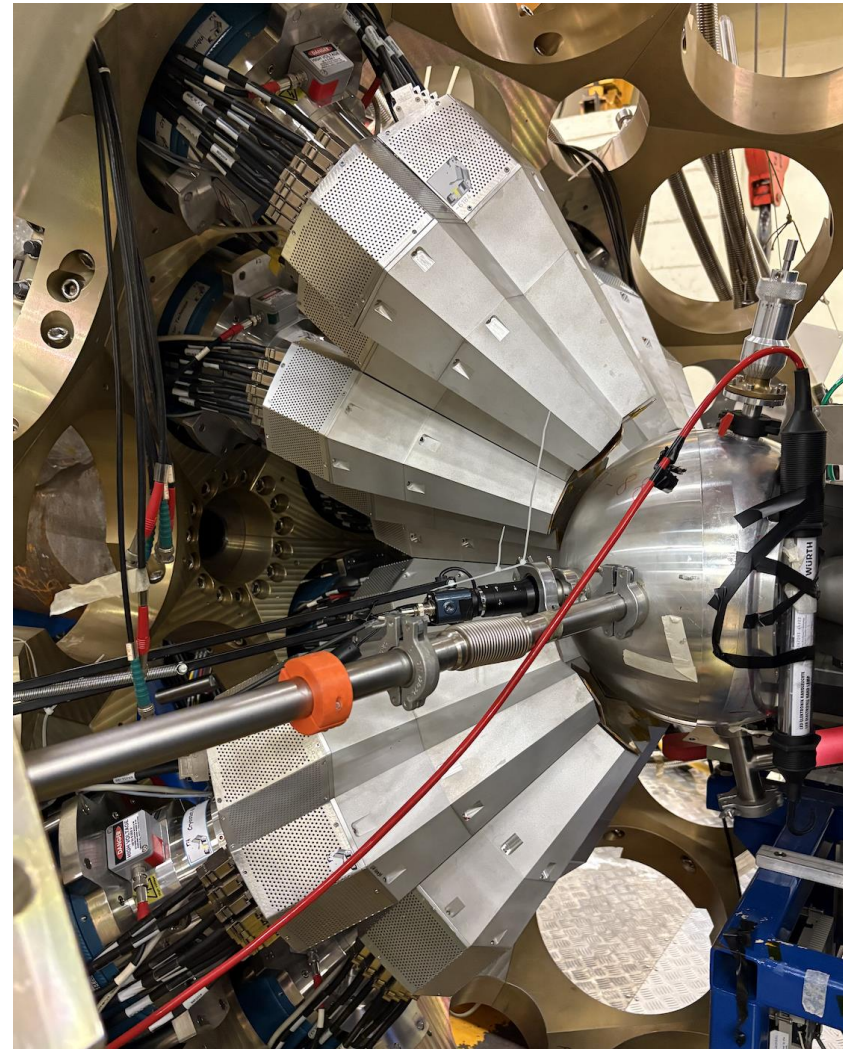
Small pile-up probability

☐ Proper shielding for the scattered protons

☐ Stack of 1-mg/cm²-thick ¹⁰B target sandwiched by C layers

☐ 8 MeV, 30 pA (beam on/off) / 2 pA (continuous) proton beam

☐ LaBr detectors were dismantled to minimize an artificial 414 + 1022 keV coincidence



Exp 24. 44 – experimental setup

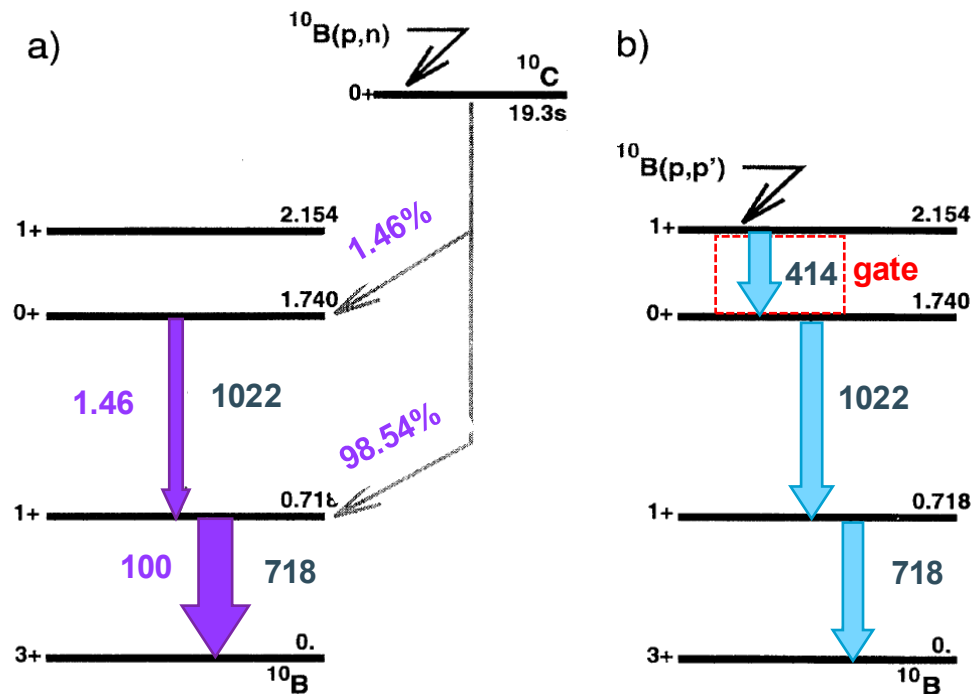
* Two measurements

$$BR(0^+ \rightarrow 0^+) = \frac{N_{1022}}{N_{718}} \cdot \frac{\epsilon_{718}}{\epsilon_{1022}}$$

a) $^{10}\text{B}(p,n)^{10}\text{C}$: superallowed β -decay count ratio (beam on/off) - decay

b) $^{10}\text{B}(p,p')^{10}\text{B}^*$: efficiency ratio $\epsilon(718\text{keV})/\epsilon(1022\text{keV})$ (continuous) – 414-keV gated

*G. Savard et al., Phys. Rev. Lett 74,
1521 (1995)*

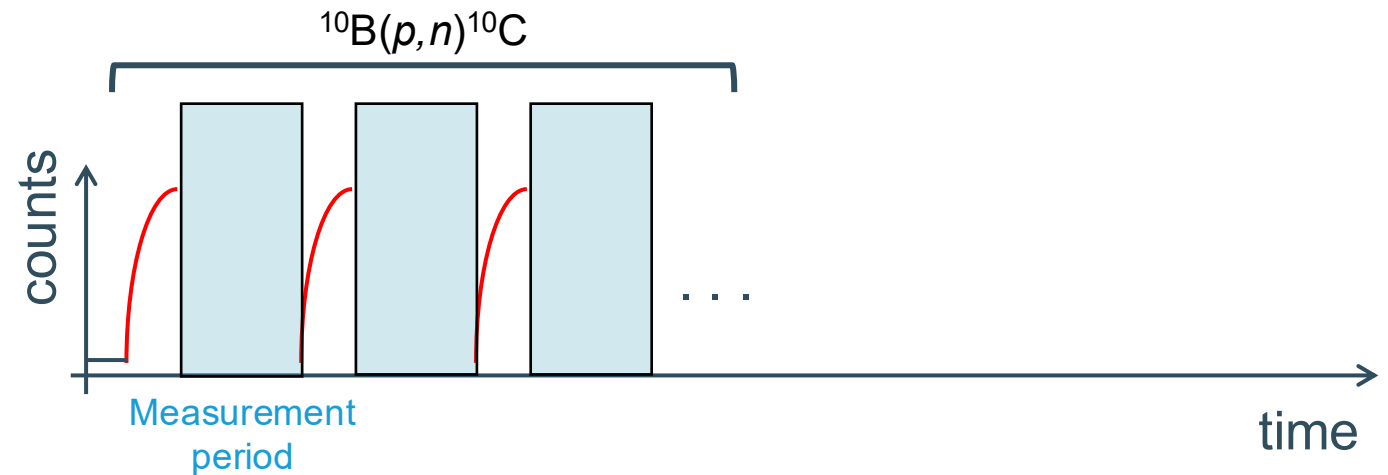
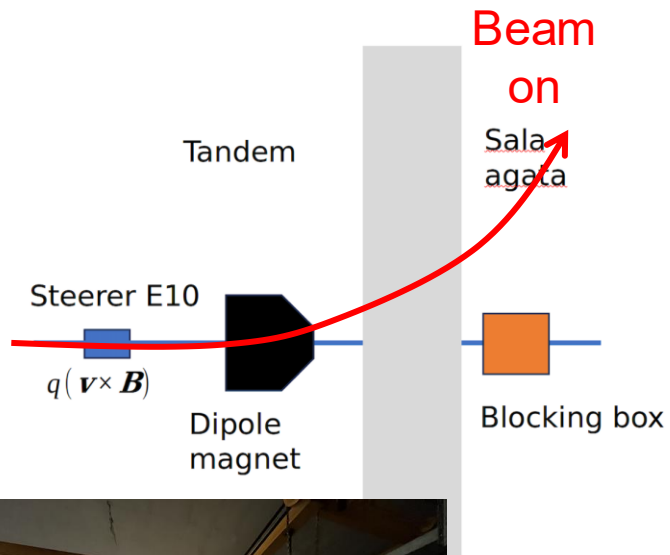


Exp 24. 44 – experimental setup

Measurement cycle

The cycle consist of the following repetitions

*** Repetition of 1-min. accumulation + 2-min. decay measurement for 6 hours**

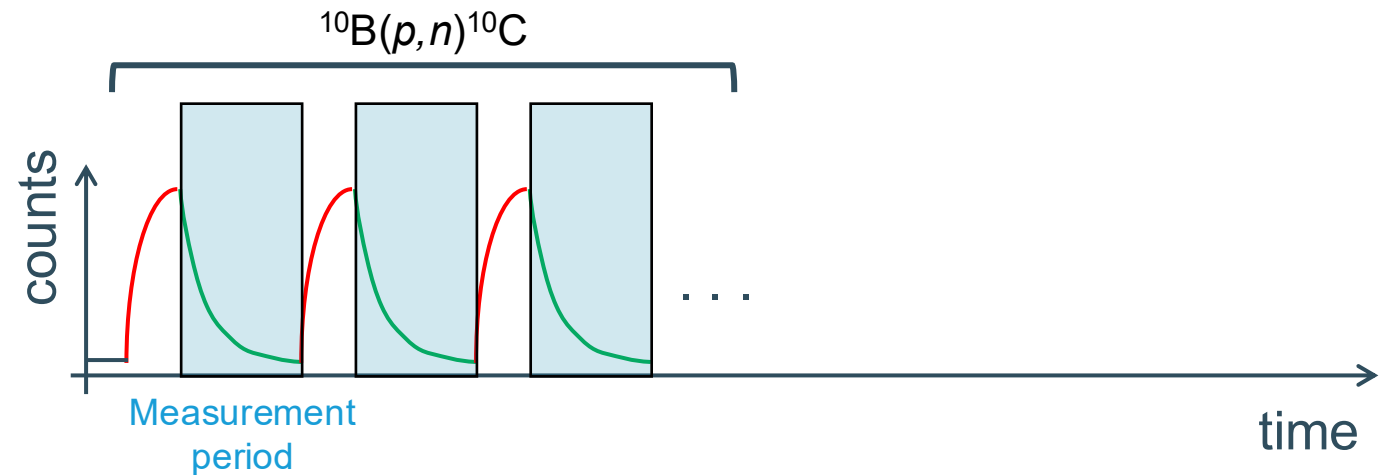
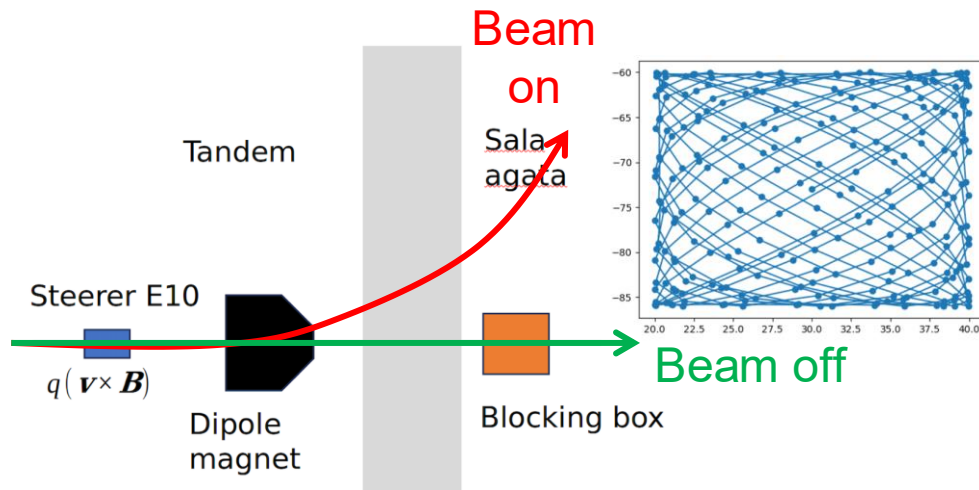


Exp 24. 44 – experimental setup

Measurement cycle

The cycle consist of the following repetitions

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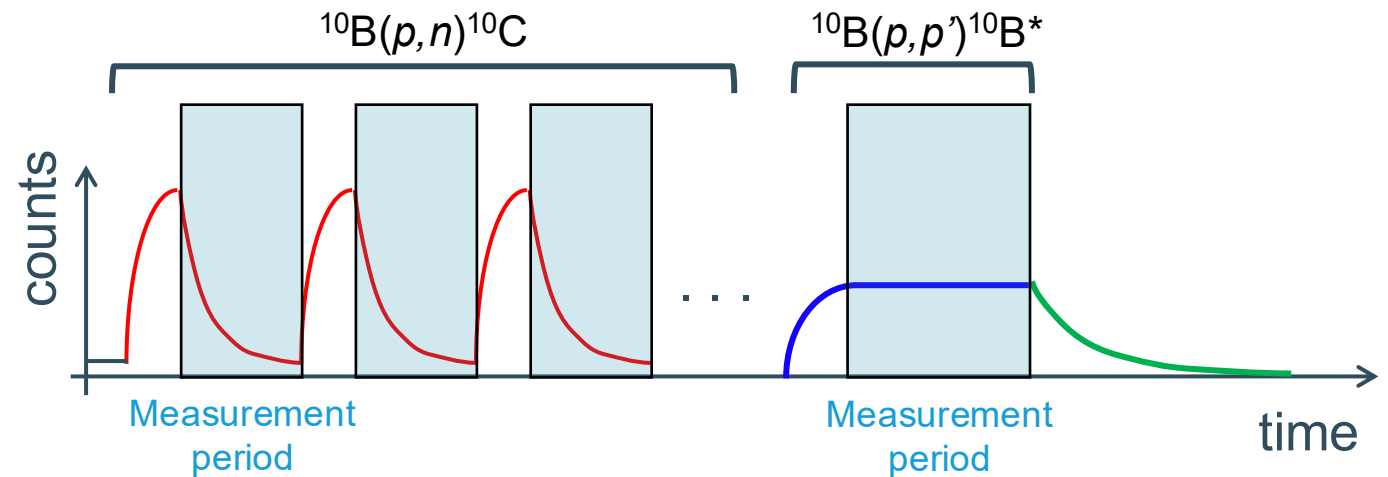
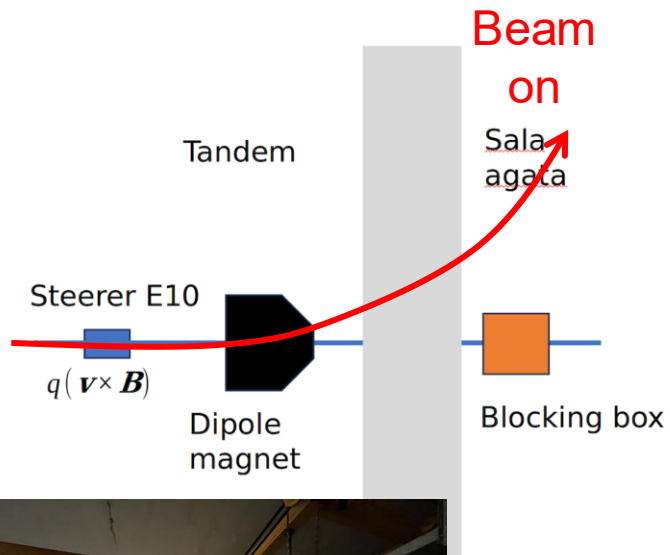


Exp 24. 44 – experimental setup

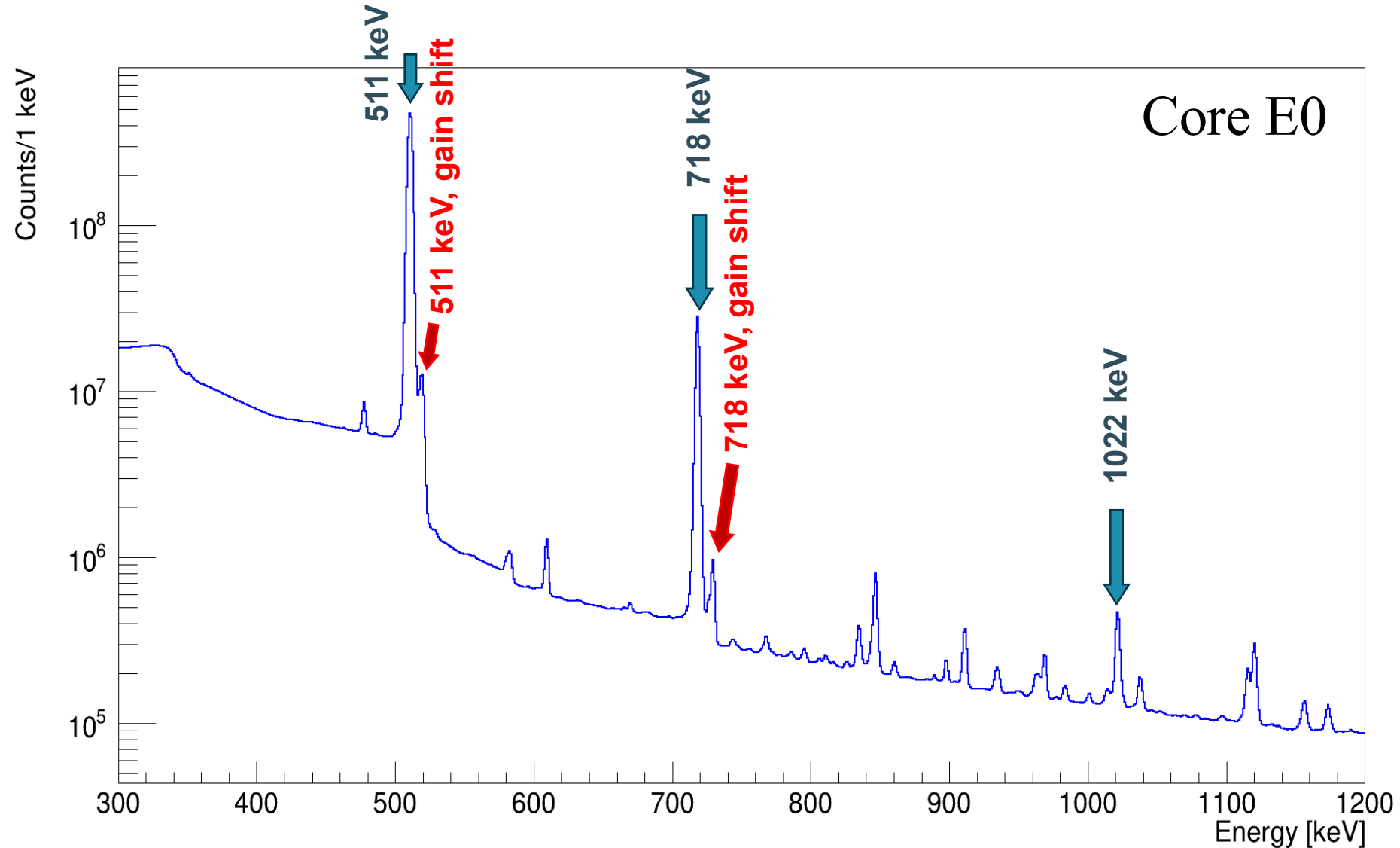
Measurement cycle

The cycle consist of the following repetitions

- * Repetition of 1-min. accumulation + 2-min. decay measurement for 6 hours
- * Continuous beam measurement for 2 hours



On-line results - beam on/off run



□ Number of counts of the 1022 keV peak: $\sim 1.5 \times 10^6$

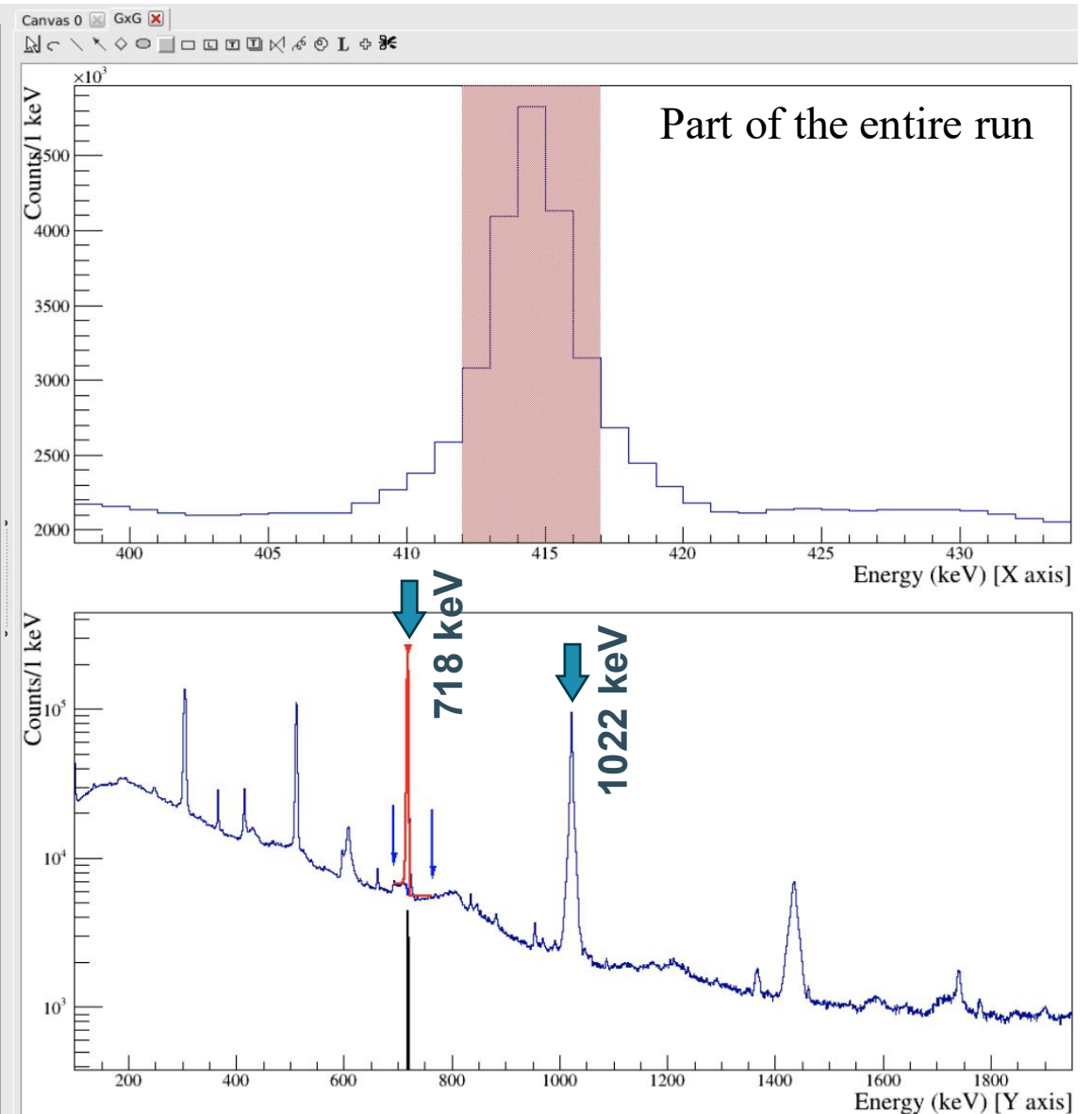
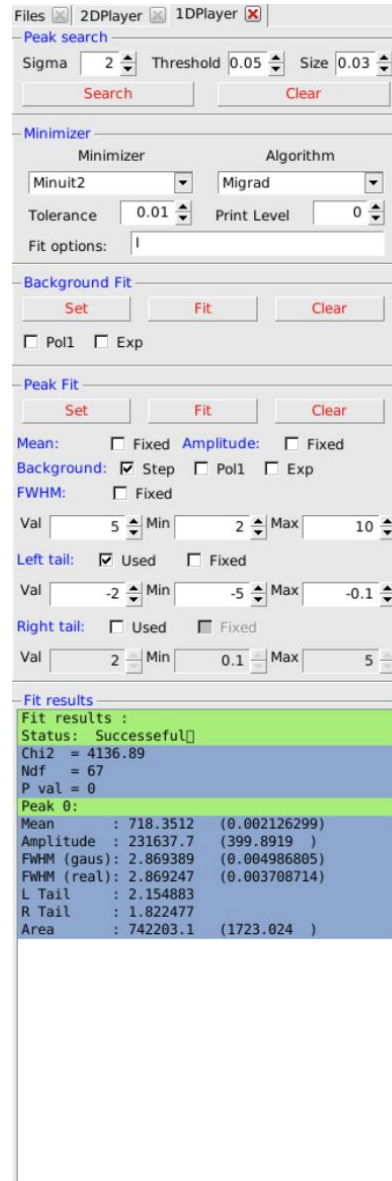
□ Statistical uncertainty of $N(1022)/N(718)$: 0.14%

On-line results - continuous run

- ❑ Number of gamma rays at 718 and 1022 keV in the 414-keV coincidence spectrum

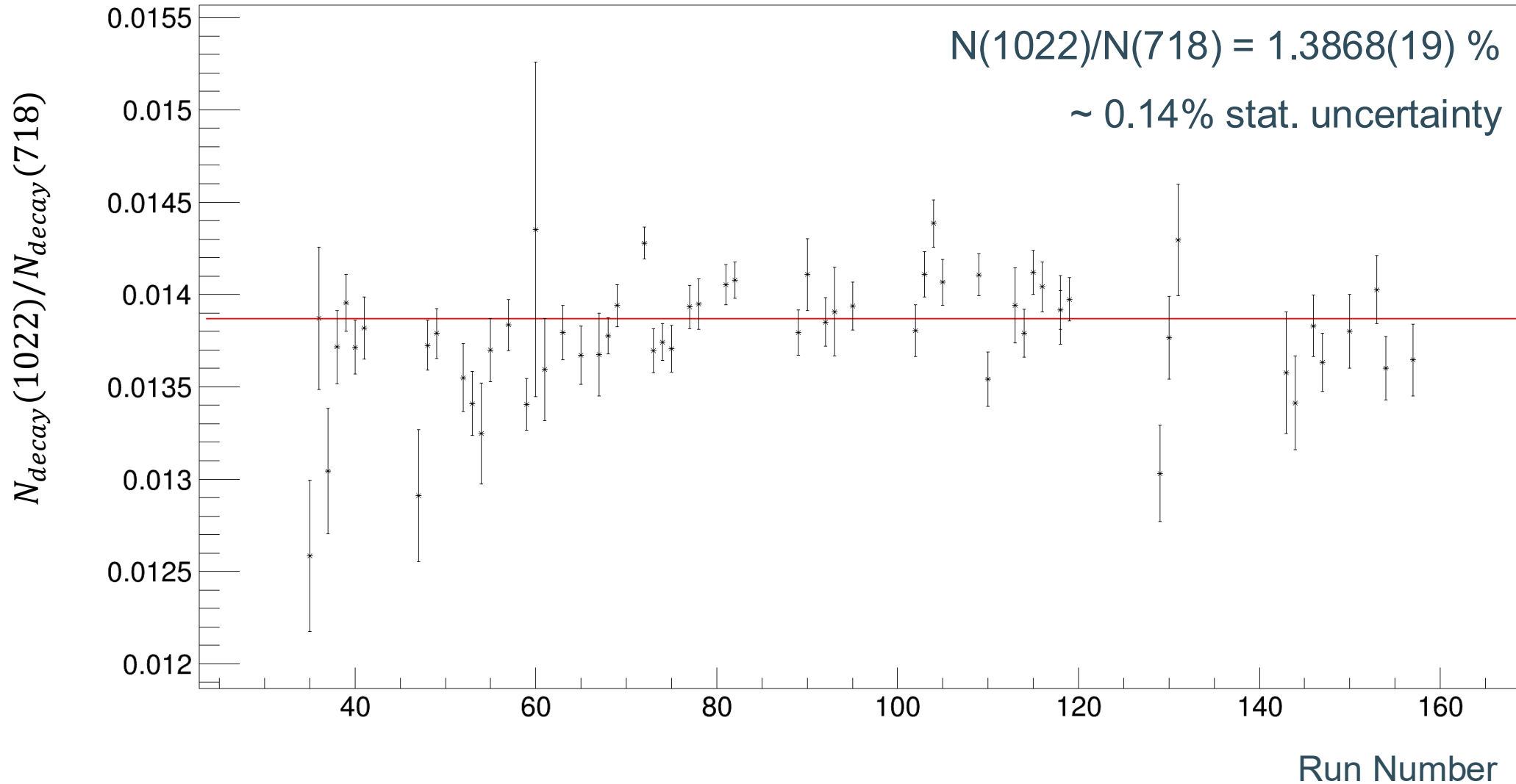
: $\sim 10^6$

- ❑ Statistical uncertainty from the efficiency ratio measurement
- : $\leq 0.15\%$



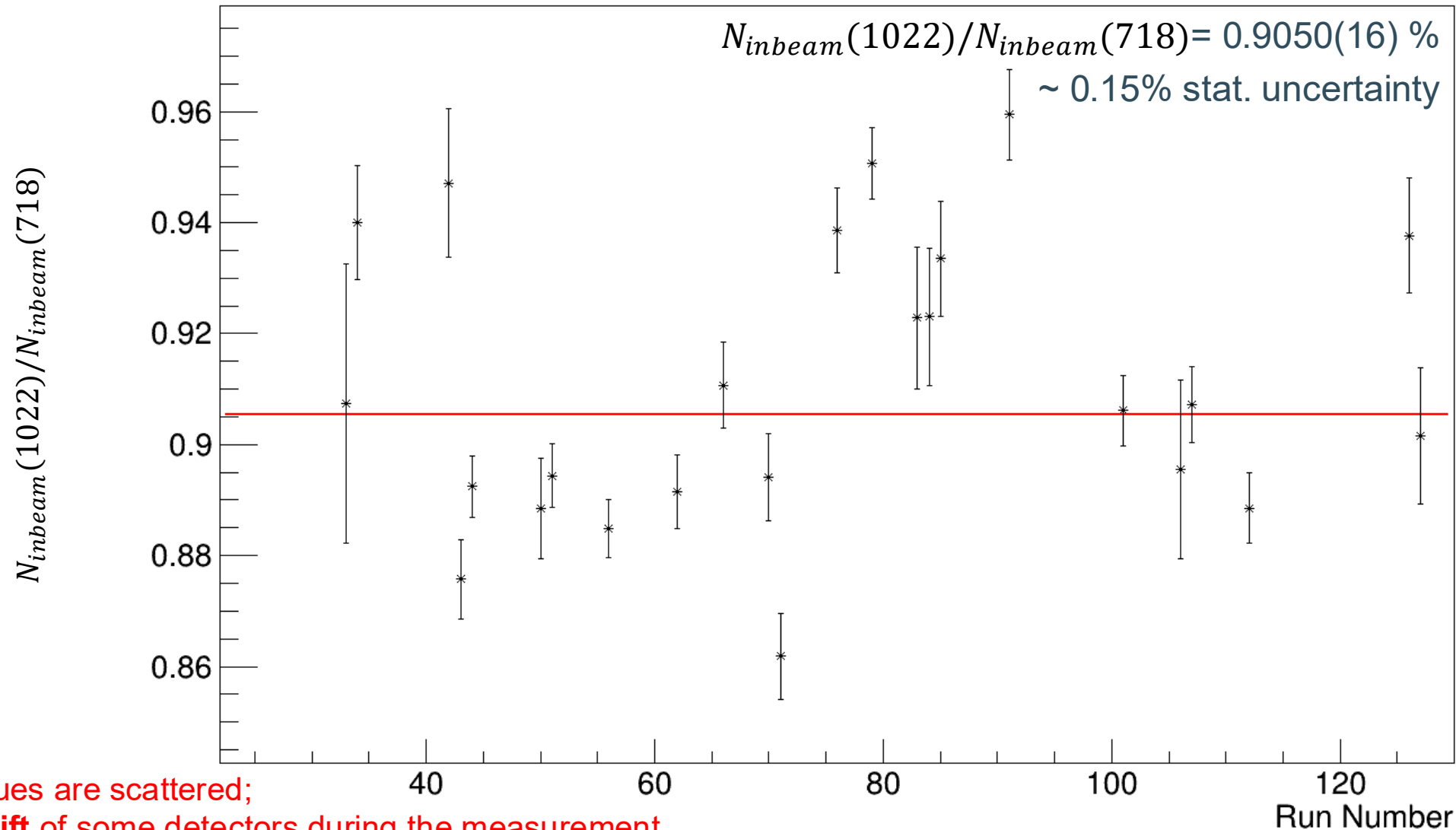
On-line results - count and efficiency ratios

Beam on/off measurement



On-line results - count and efficiency ratios

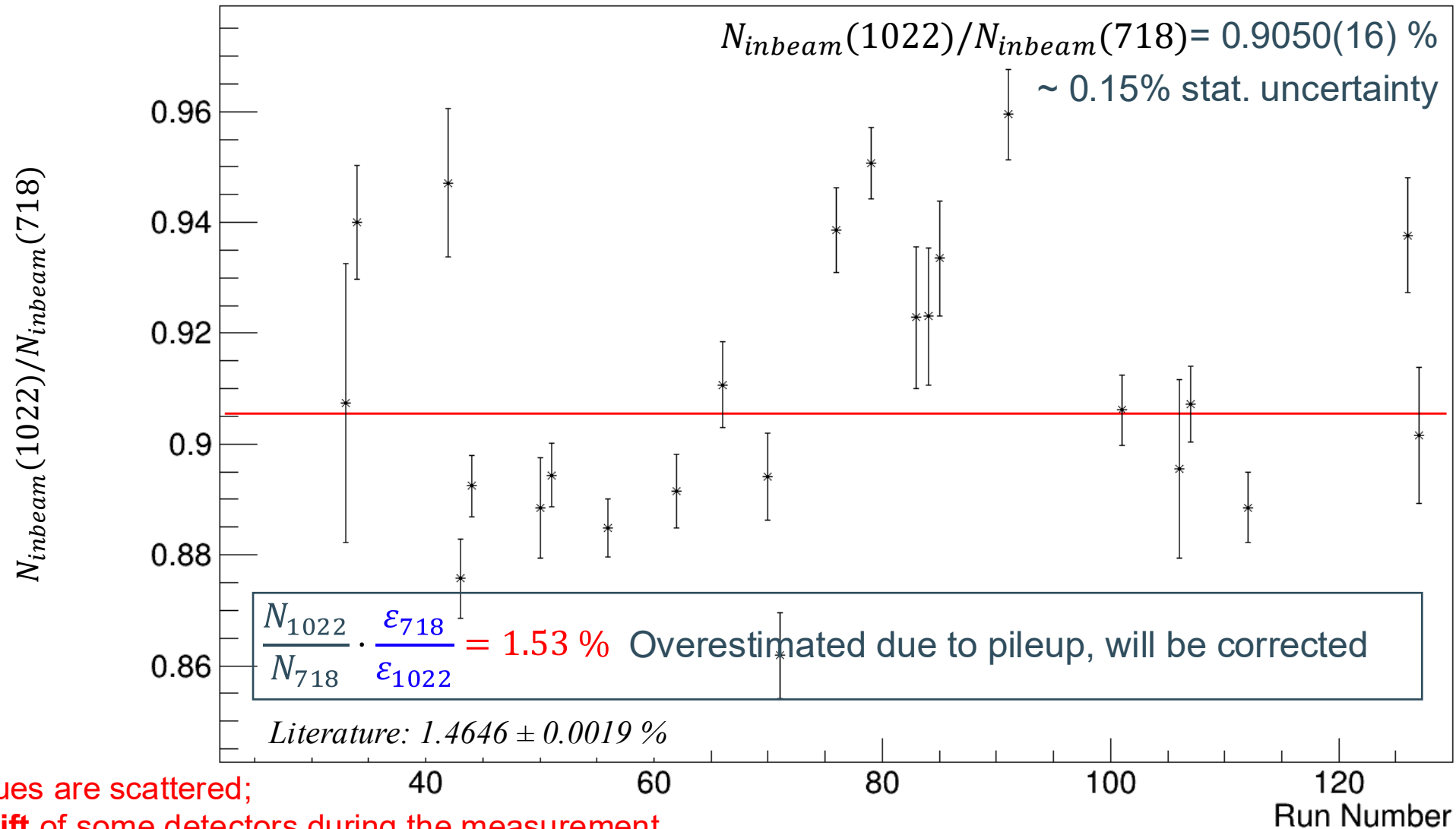
Continuous measurement



The values are scattered;
gain shift of some detectors during the measurement

On-line results - count and efficiency ratios

Continuous measurement



The values are scattered;
gain shift of some detectors during the measurement

Analysis

Neutron damage correction - some examples

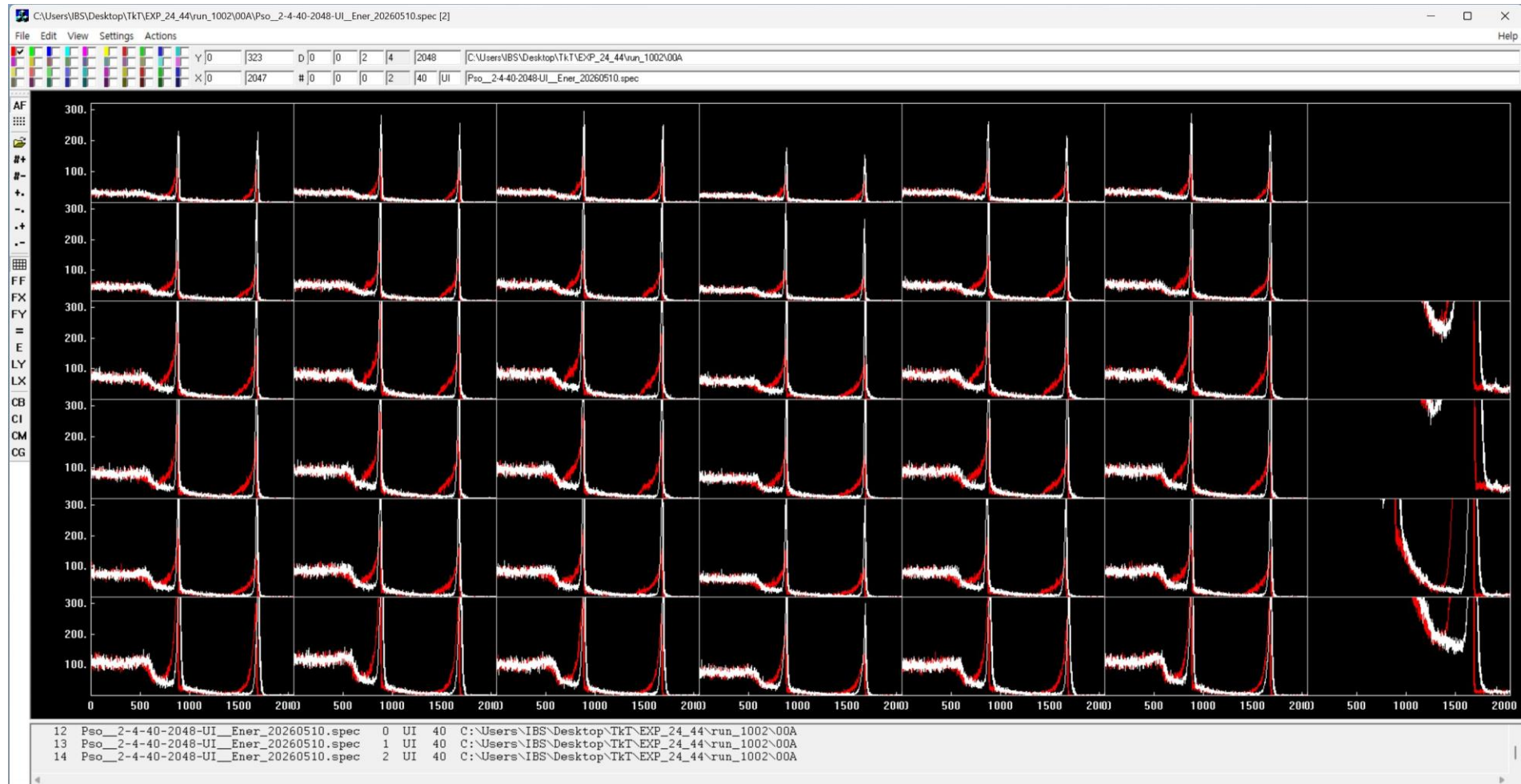
- 00A – original



Analysis

Neutron damage correction - some examples

- 00A – after the neutron damage correction



Analysis – next step

- ❑ Neutron damage correction and final energy recalibration are ongoing

Next step

- ❑ Gain correction over time



Development of the 511-keV pileup rejection algorithm

: segment-level information is very important

- number of connected, face-adjacent components (n_{comps})

if $n_{\text{comps}} = 1$, all of the hits are connected to a single event

if $n_{\text{comps}} \geq 2$, possibility of different photon origin

- Energy deposition of $n_{\text{comps}} = 2$

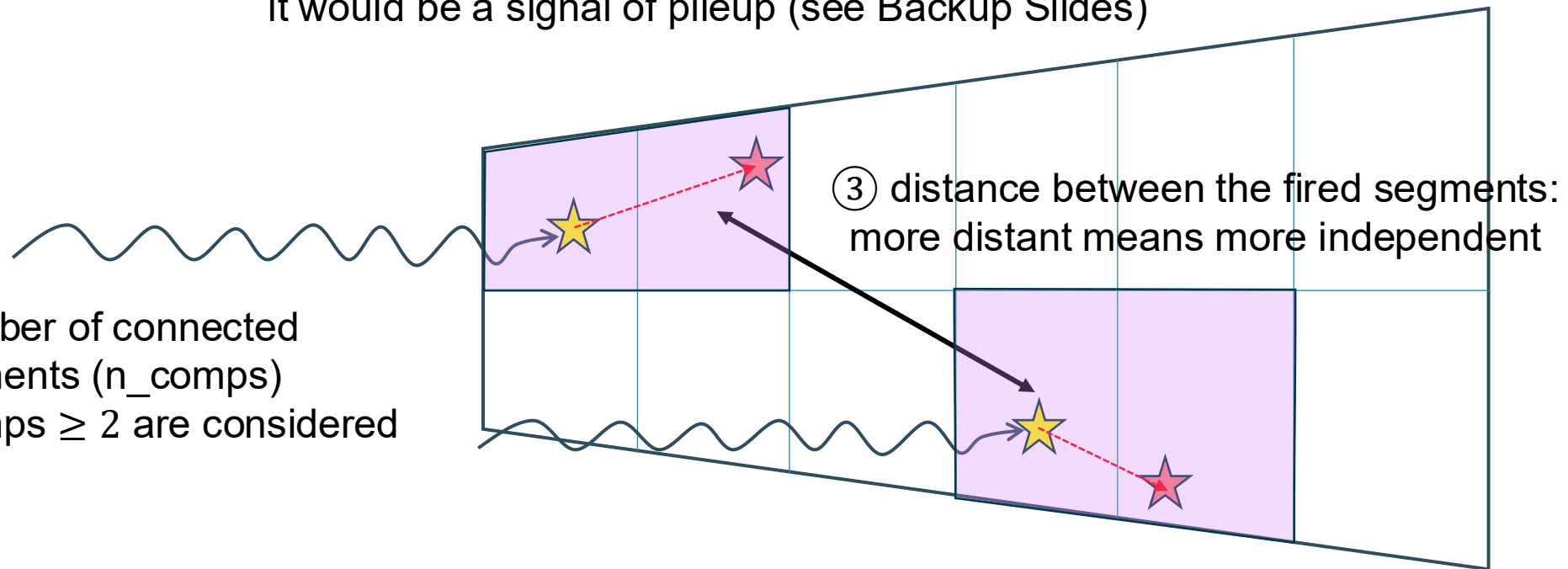
if $(E_{\text{dep1}}, E_{\text{dep2}}) = (511, 511)$ keV, the event is splitable; could be a pileup

Analysis – next step

Some ideas for the 511-keV pileup analysis (interacting with AI)

- ② Energy deposit in each segment (for $n_comps=2$):
if two 511-keV energy deposit are observed,
it would be a signal of pileup (see Backup Slides)

- ① number of connected
components (n_comps)
: $n_comps \geq 2$ are considered

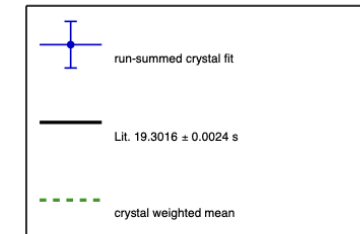
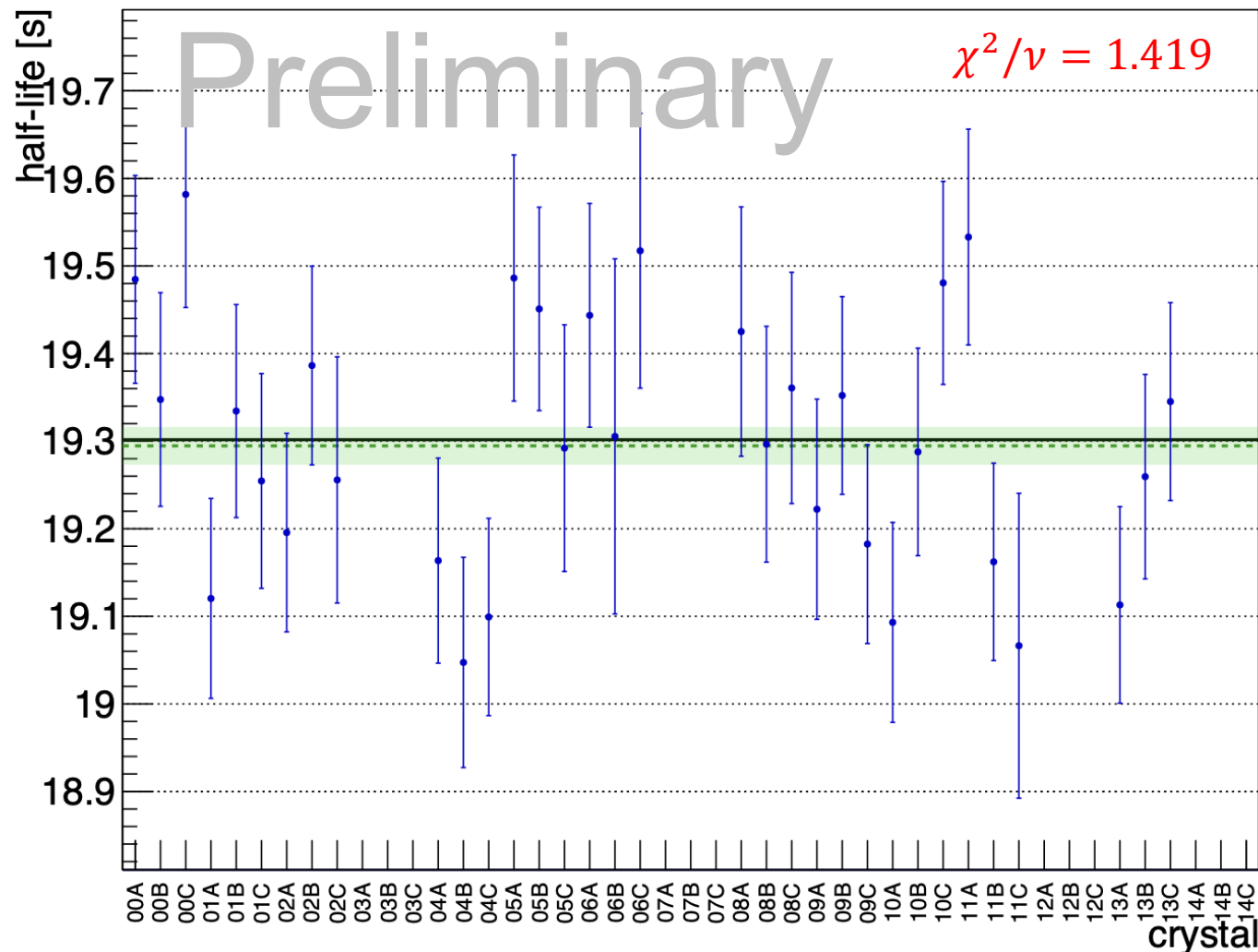


We need a GEANT4 simulation to gain reliability of the analysis

Additional news from EXP. 22. 72

Beta-decay half-life measurement of ^{10}C – by crystal

Mu718 exponential TDGC (all), k=2.0: run-summed half-life by crystal



Mu718 exponential + mu2614 discrete TDGC

variant: all

gate: $718.38 \pm 2\sigma_{718}(t)$

background: $[700,708)+[732,740)$

N valid = 33

weighted mean = 19.294614 s

mean error = 0.021563 s

$\chi^2/\text{ndf} = 45.408/32$

reduced $\chi^2 = 1.4190$

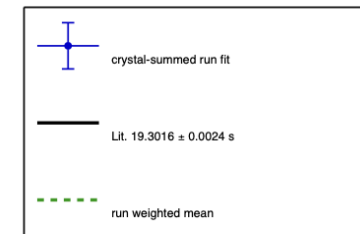
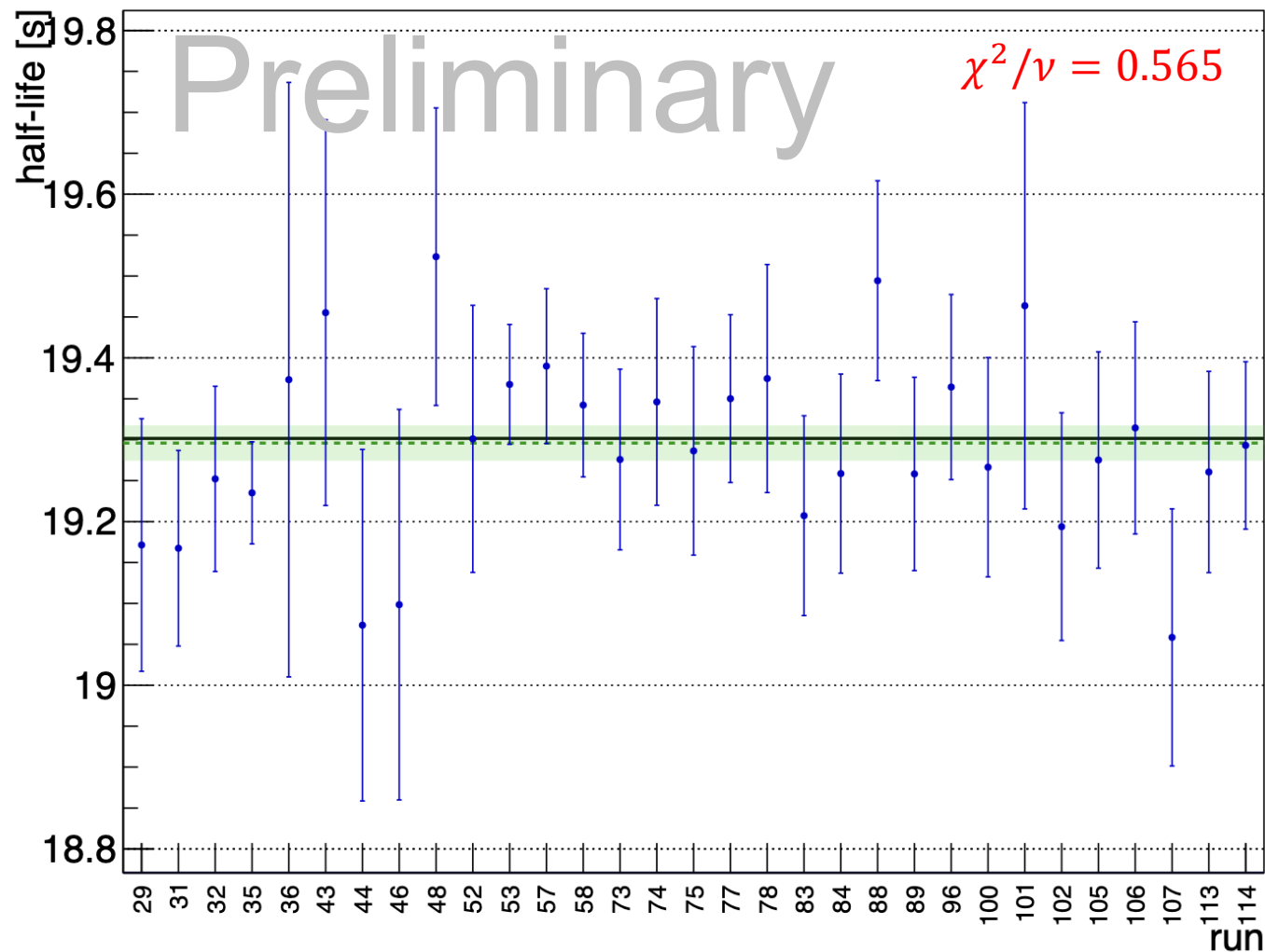
fit range: 10-112 s

Courtesy of Hyeonjin Lee

Additional news from EXP. 22. 72

Beta-decay half-life measurement of ^{10}C – by run

Mu718 exponential TDGC (all), k=2.0: crystal-summed half-life by run



Mu718 exponential + mu2614 discrete TDGC

variant: all

Preliminary result:

$$T_{1/2} = 19.2946 \pm 0.0216(\text{stat.}) \text{ s}$$

weighted mean = 19.295915 s

mean error = 0.021537 s

$\chi^2/\text{ndf} = 16.954/30$

reduced $\chi^2 = 0.5651$

fit range: 10-112 s

Courtesy of Hyeonjin Lee

Summary

^{10}C superallowed beta-decay BR measurement

Issues in EXP. 22. 72 $\rightarrow$ improvement of the setup

EXP. 24. 44 was performed in July-August 2025

Neutron damage correction, recalibration checked

Some ideas for the 511-keV pileup rejection algorithm

EXP. 22. 72 half-life measurement done, move to the BR measurement

Exp. 24. 44 Collaboration

Special thanks to: M. Loriggiola

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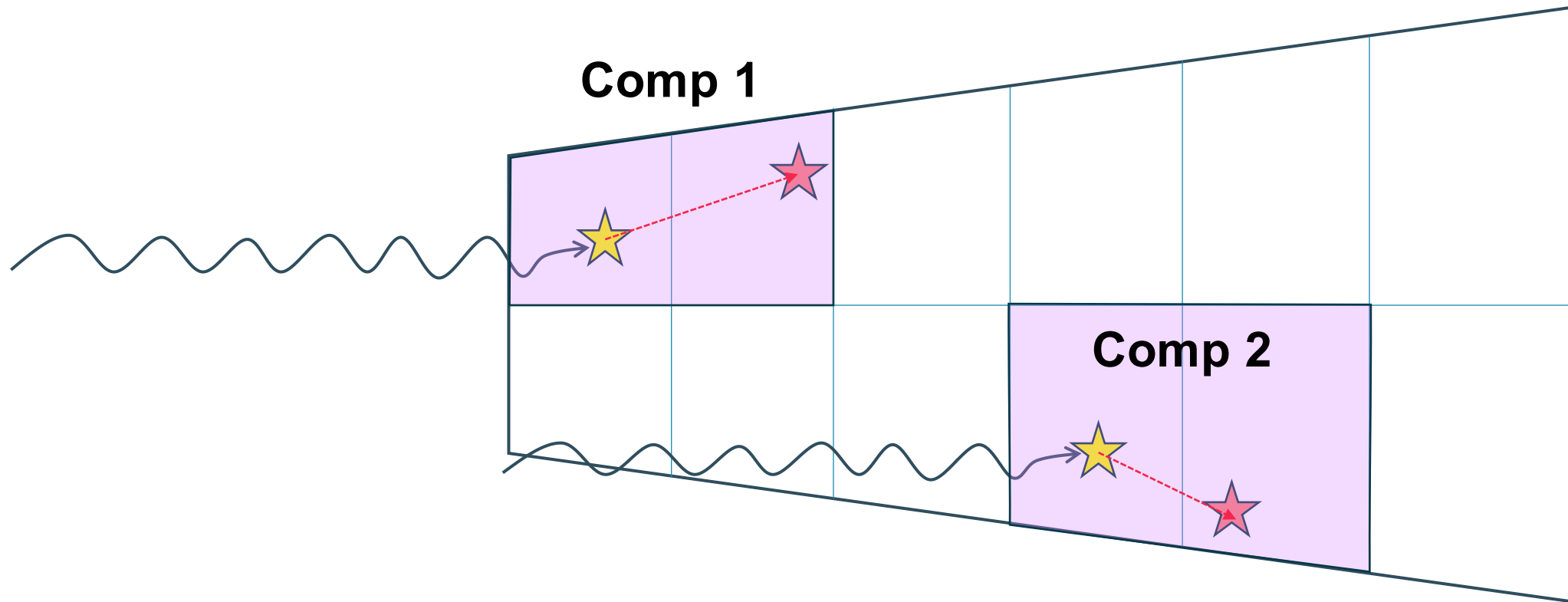
¹³INFN Sezione di Firenze, Firenze, Italy

* Spokespersons of the experiment

Backup Slides

Conditions and scoring – probabilistic approach

1. Number of connected components: connection between the segments



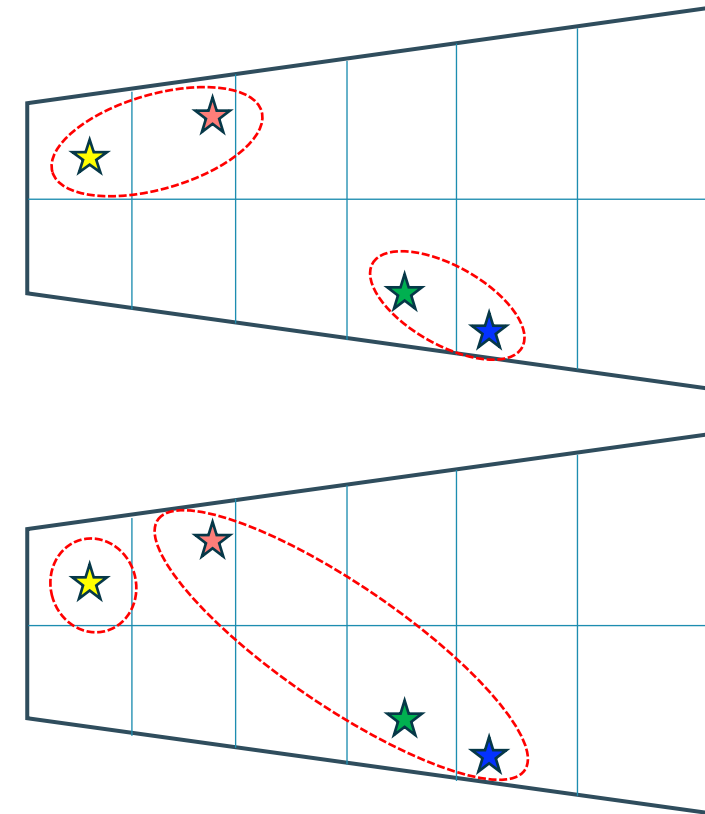
→ If the number of connected components is larger than one,
Give a large weight (+2) for the scoring

Conditions and scoring – probabilistic approach

1. Bi-partition approach: investigating all of the possible combinations for multi-hit cases

For example, if $E_A = 200$ keV, $E_B = 300$ keV, $E_C = 400$ keV, and $E_D = 122$ keV,

Split	E1 [keV]	E2 [keV]	Max. - 511 [keV]
{A} vs {B,C,D}	200	822	311
{B} vs {A,C,D}	300	722	211
{C} vs {A,B,D}	400	622	111
{D} vs {A,B,C}	122	900	389
{A,B} vs {C,D}	500	522	11 ✓
{A,C} vs {B,D}	600	422	89
{A,D} vs {B,C}	322	700	189



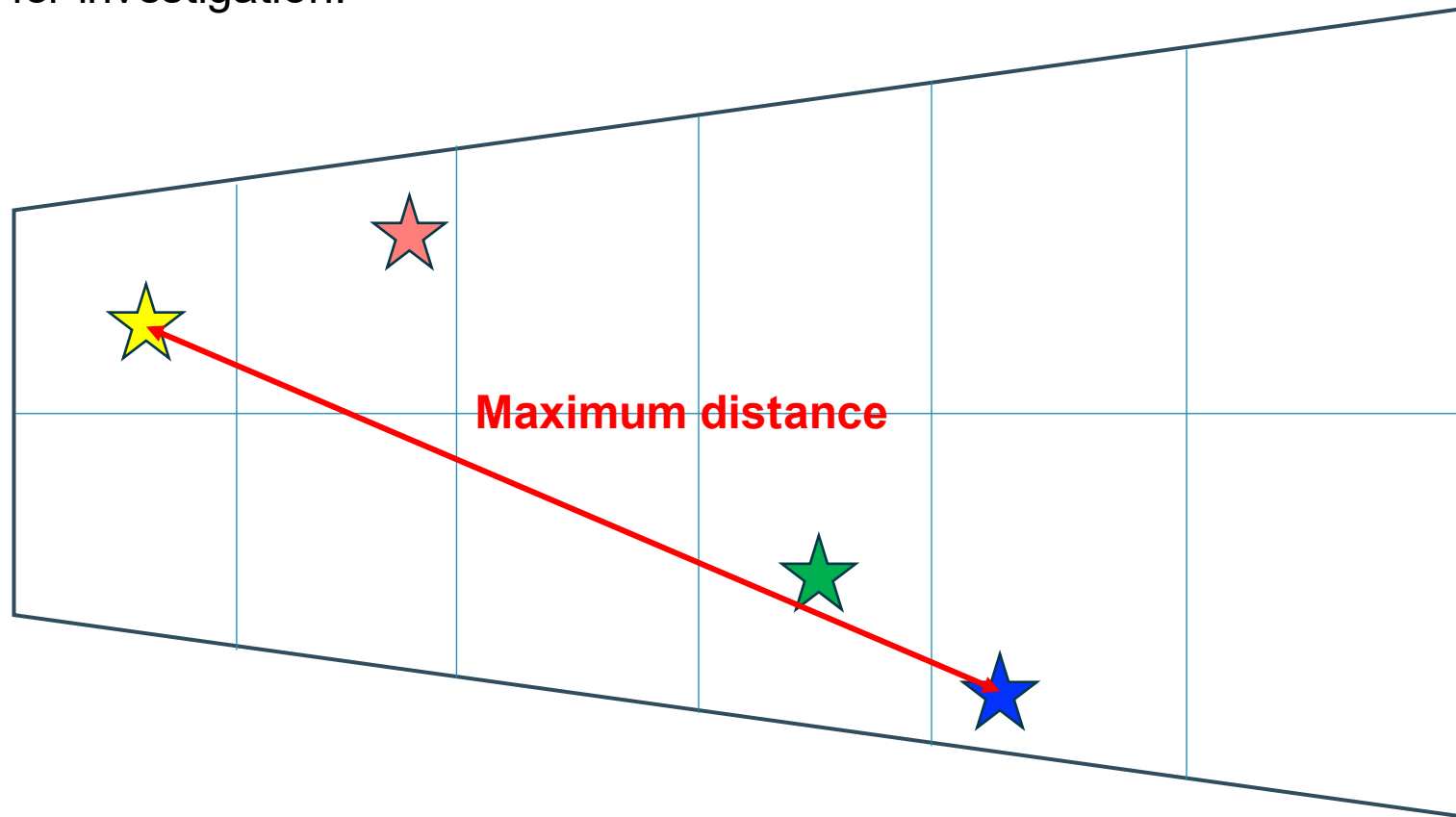
...

→ Give a large weight (+2) for the scoring

Conditions and scoring – probabilistic approach

2. Maximum distance between the fired segments

We set 55 mm for investigation.



Give a moderate weight (+1) when the distance $d > 55$ mm;
it would imply that the hit pattern comes from two different photons

Conditions and scoring – probabilistic approach

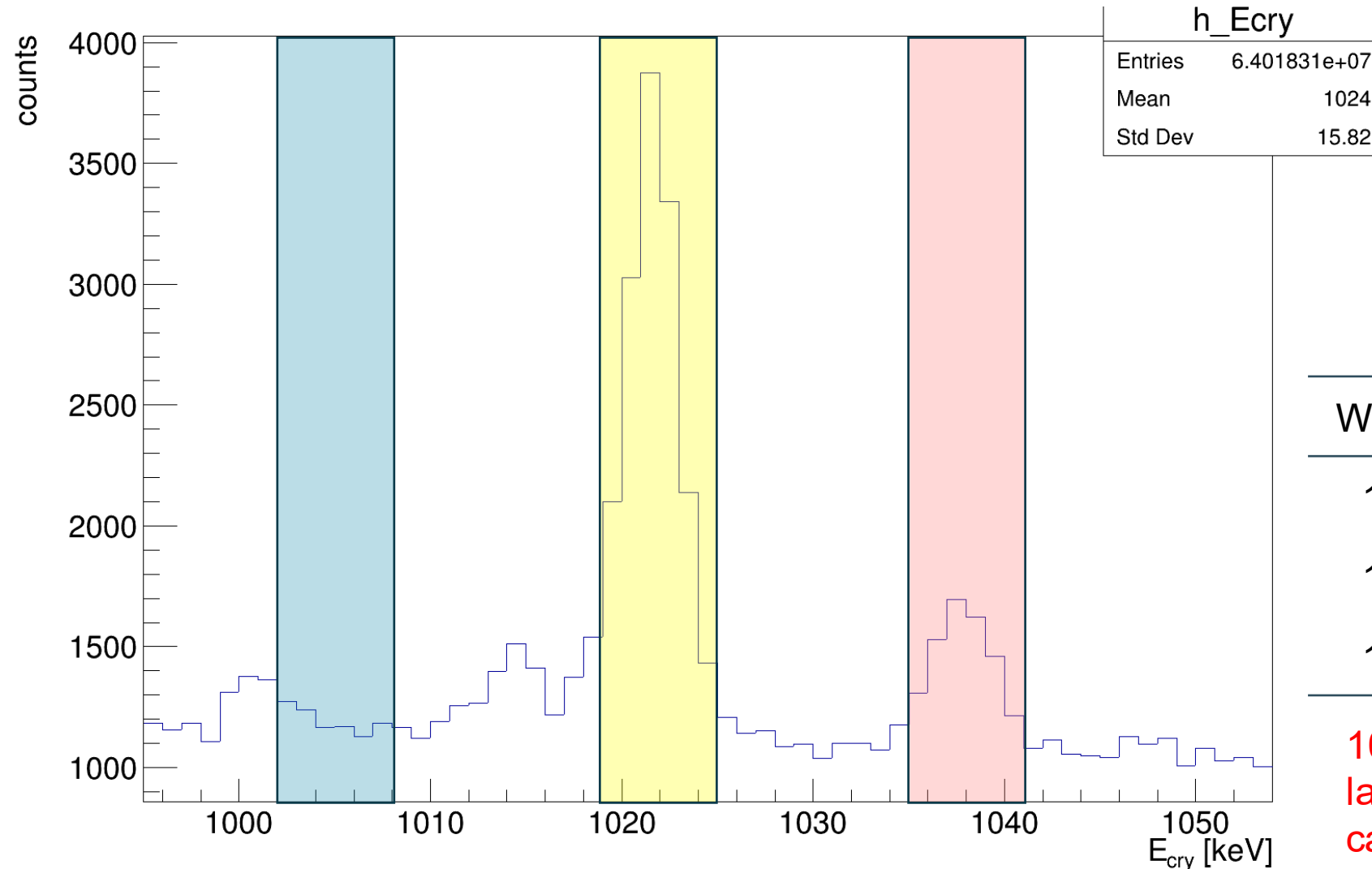
Scoring system

Score	Condition
0	bipartition gate fail (bipart_penalty > 60 keV)
1	Spatial distance condition (> 55 mm) or n_comps $\geq$ 2
2	bipartition gate pass (bipart_penalty < 30 keV), or n_comps $\geq$ 2
3	...
4	...
5	bipartition gate pass (bipart_penalty < 30 keV), Spatial distance condition (> 55 mm), and n_comps $\geq$ 2

Score = 5 support the pileup case

Conditions and scoring – probabilistic approach

Fraction of score = 5 cases



Window [keV]	Fraction
1002-1008	1.73(15)%
1035-1041	1.85(14)%
1019-1025	2.63(13)%

1022 keV shows significantly larger fraction than the other cases