Simone Valdré
INFN – Sezione di Firenze
for the **FAZIA collaboration**

Charged particle identification using **time of flight** with FAZIA

FATA 2019
Acireale, September 3rd – 5th, 2019

FURBO project

FAZIA **U**pgrade for **R**adioactive **B**eam **O**peration

(INFN grant for new staff researchers)

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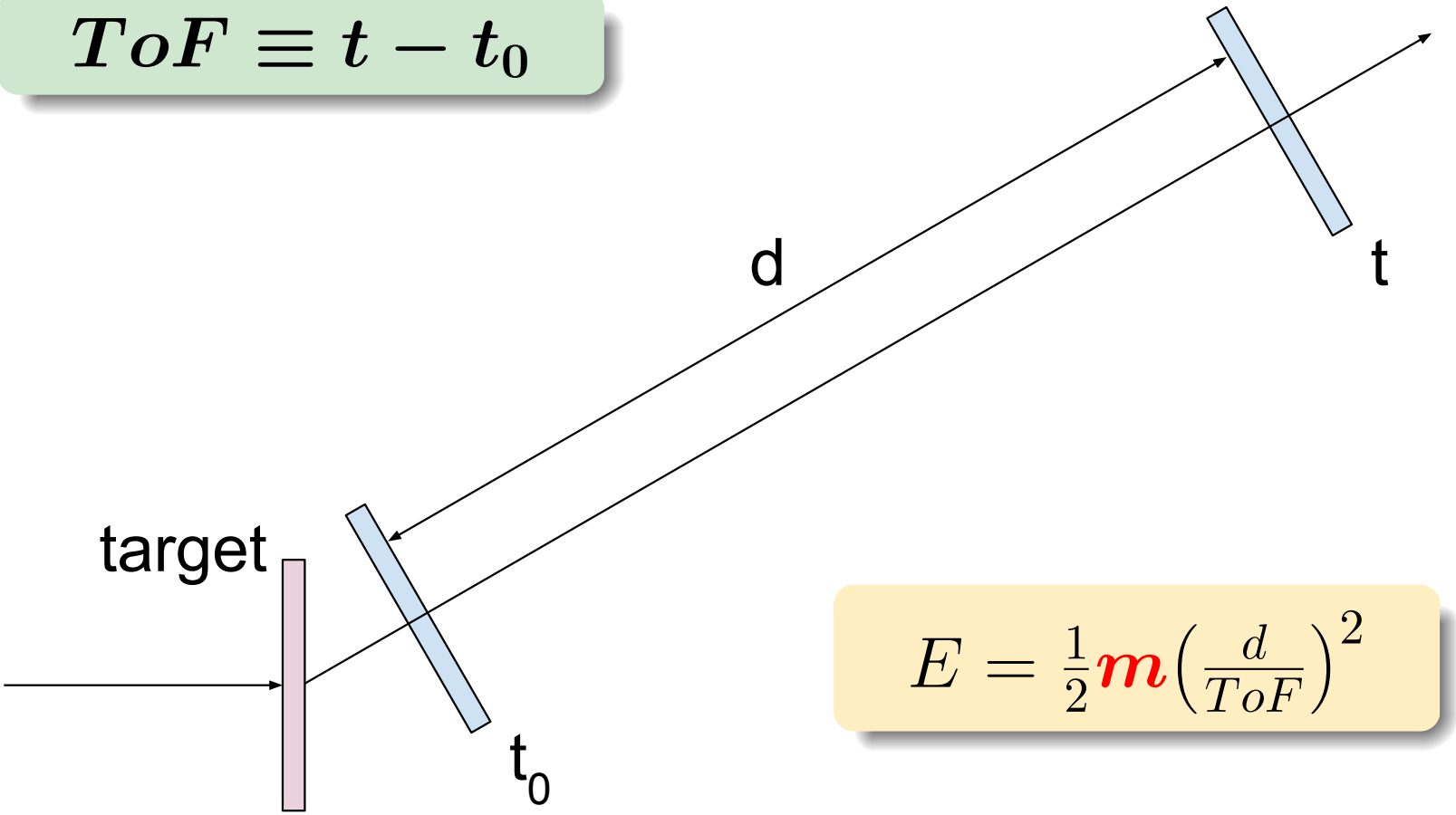
Reduction of identification thresholds

- Funtamental task to measure in future ISOL facilities (SPES, Spiral2,...)
- Physics of quasi-target
- Different possible solutions:
  - **time of flight** implementation (discussed here)
  - use of **thin** Si detectors as first stage
  - use of **alternative** detectors

Time of flight identification

$$ToF \equiv t - t_0$$



$$E = \frac{1}{2}\boldsymbol{m}\left(\frac{d}{ToF}\right)^2$$

Recover **mass** of particles from ToF and energy

Time of flight identification

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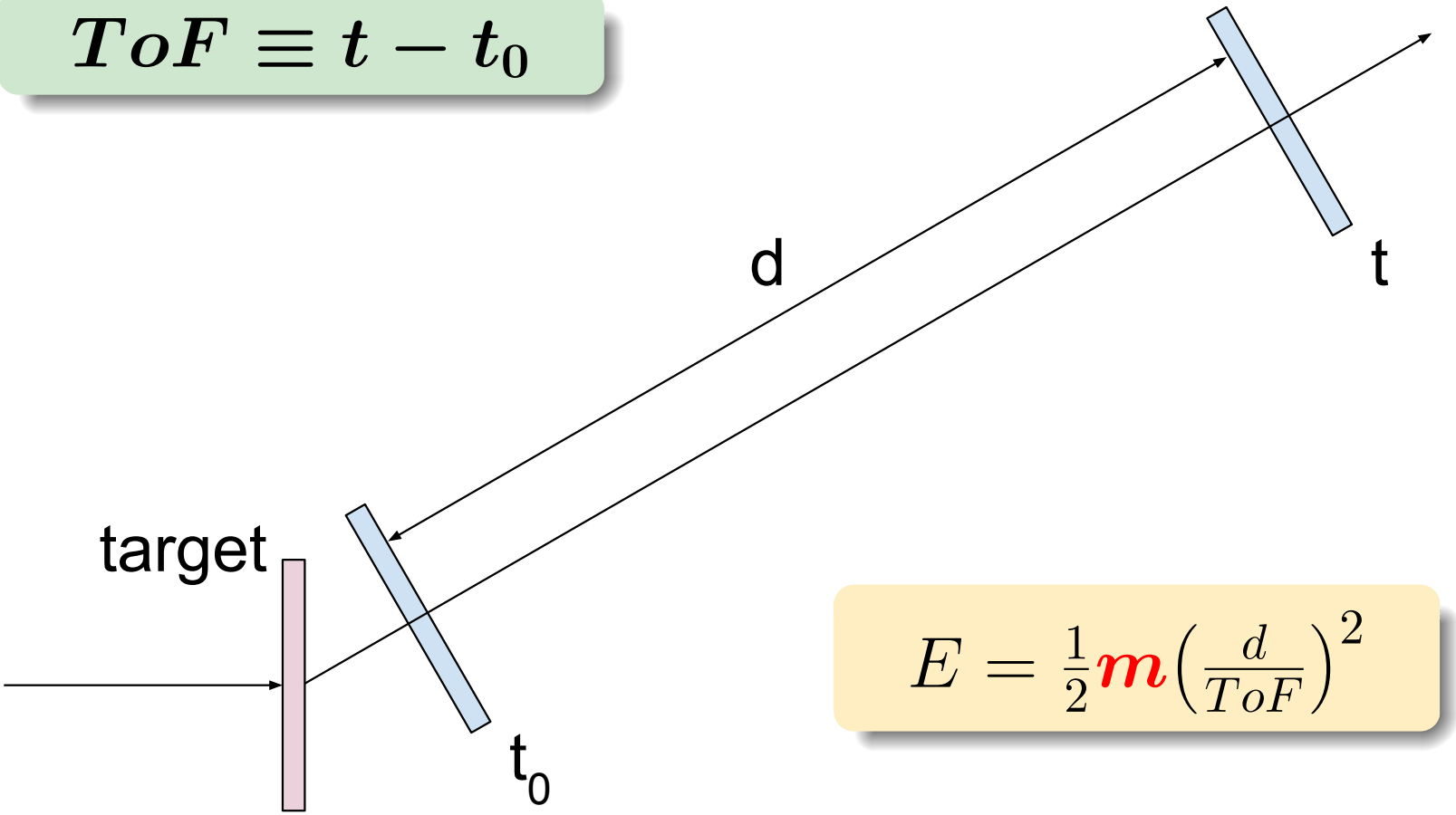
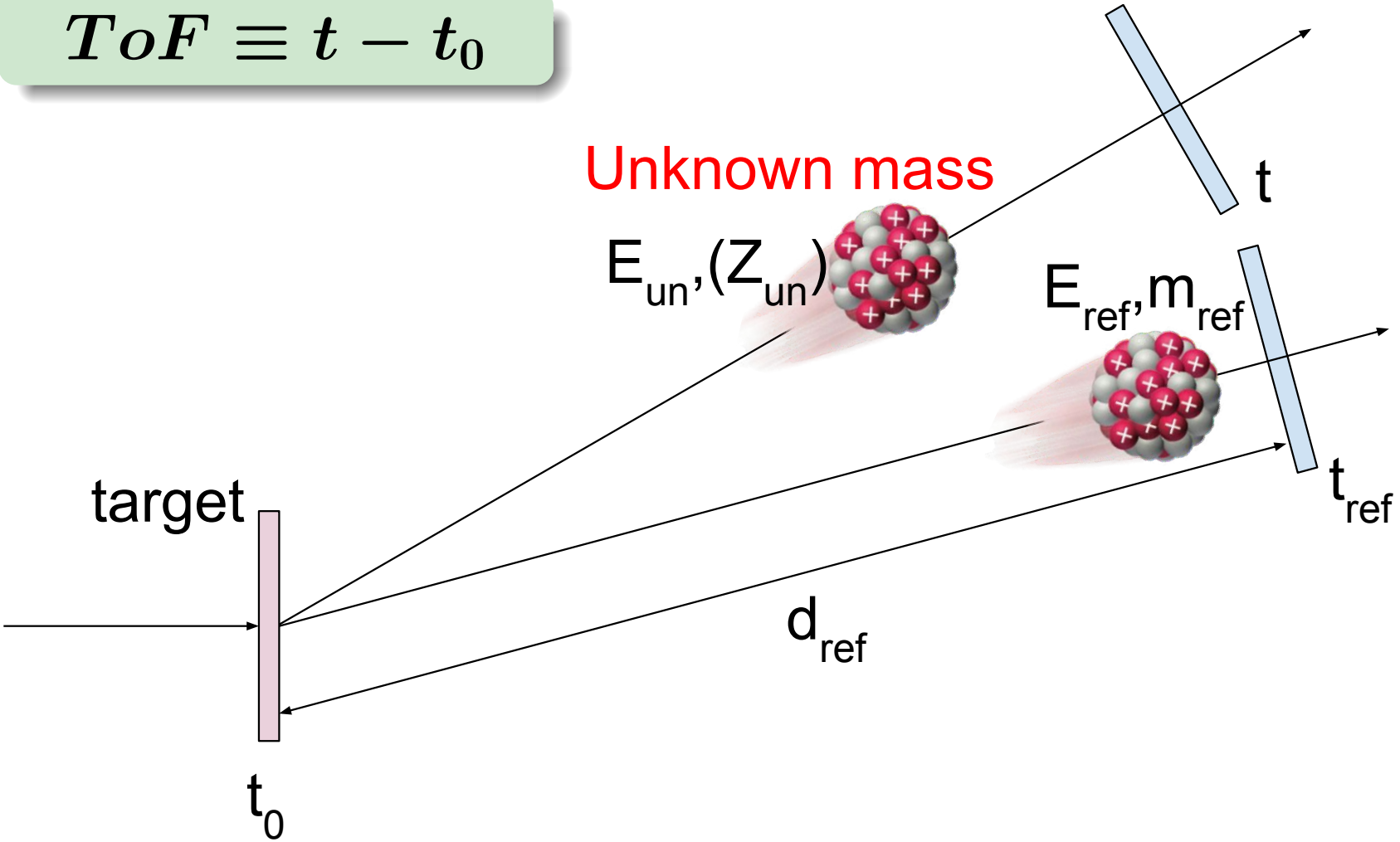


$$E = \frac{1}{2}m\left(\frac{d}{ToF}\right)^2$$

Start time mark needed!

Time of flight identification (only $M > 1$ events)

$$ToF \equiv t - t_0$$

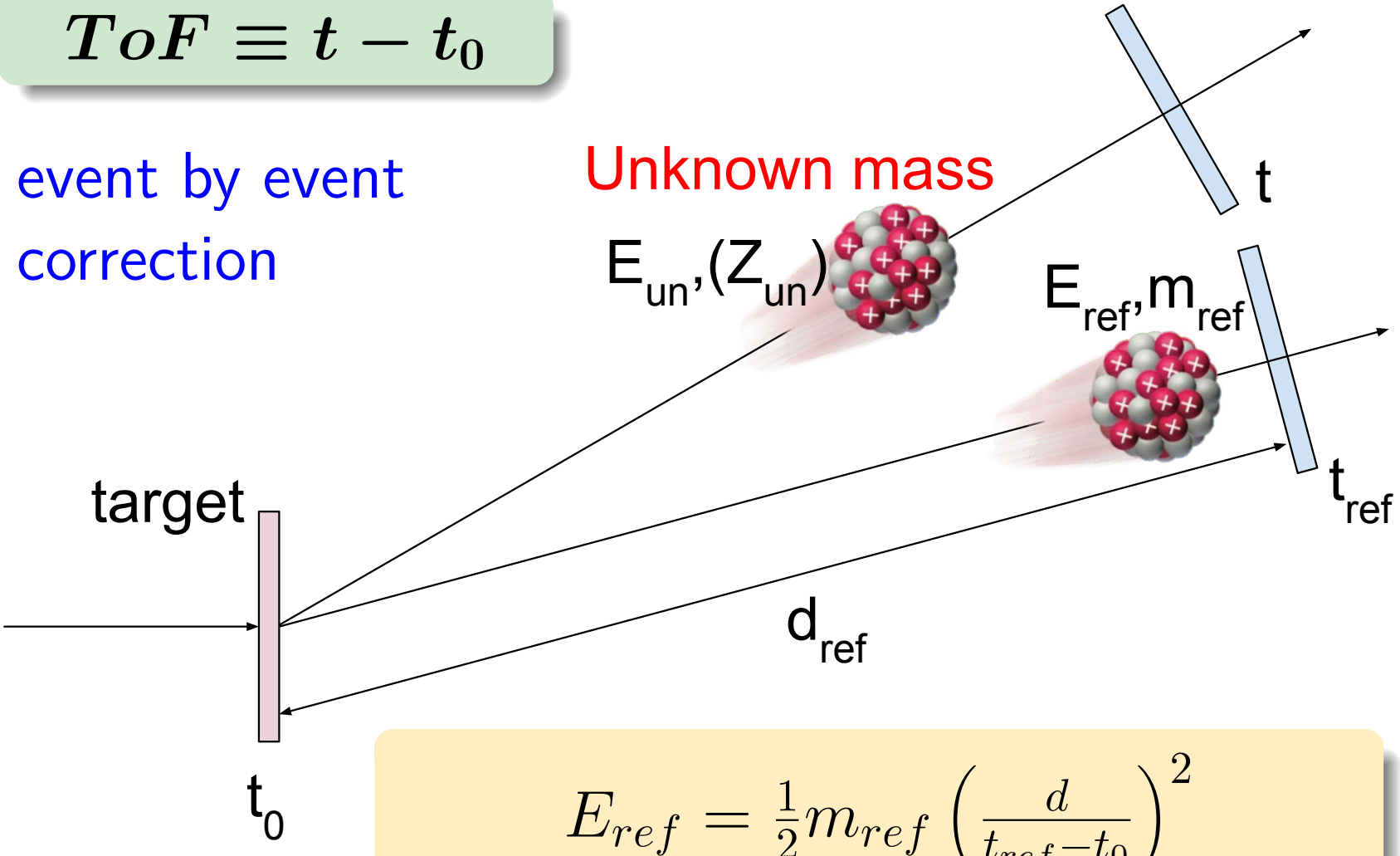


Proposed solution **without a start detector**

Time of flight identification (only $M > 1$ events)

$$ToF \equiv t - t_0$$

event by event correction



$$E_{ref} = \frac{1}{2} m_{ref} \left(\frac{d}{t_{ref} - t_0} \right)^2$$

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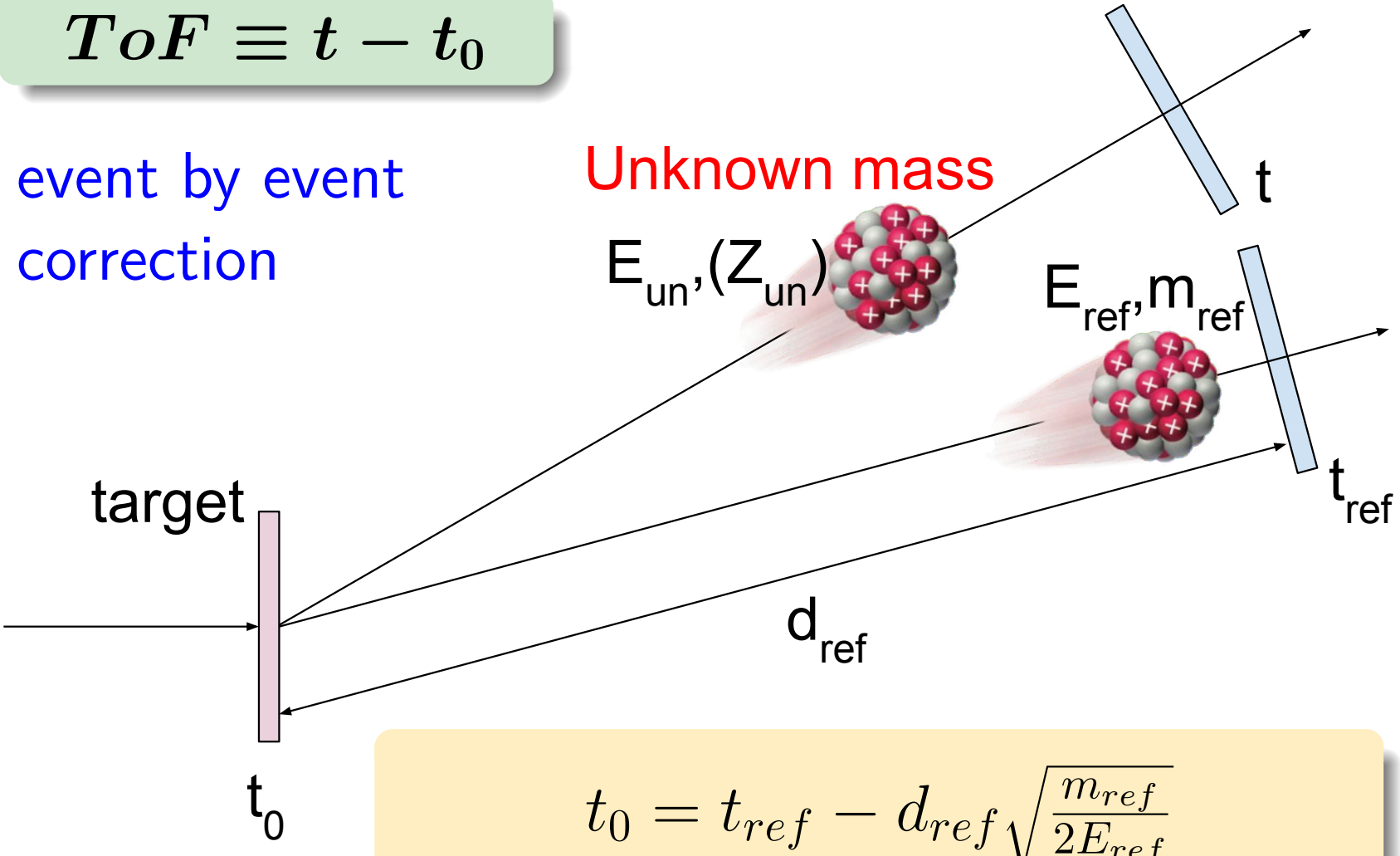

$$t_0 = t_{ref} - d_{ref}\sqrt{\frac{m_{ref}}{2E_{ref}}}$$

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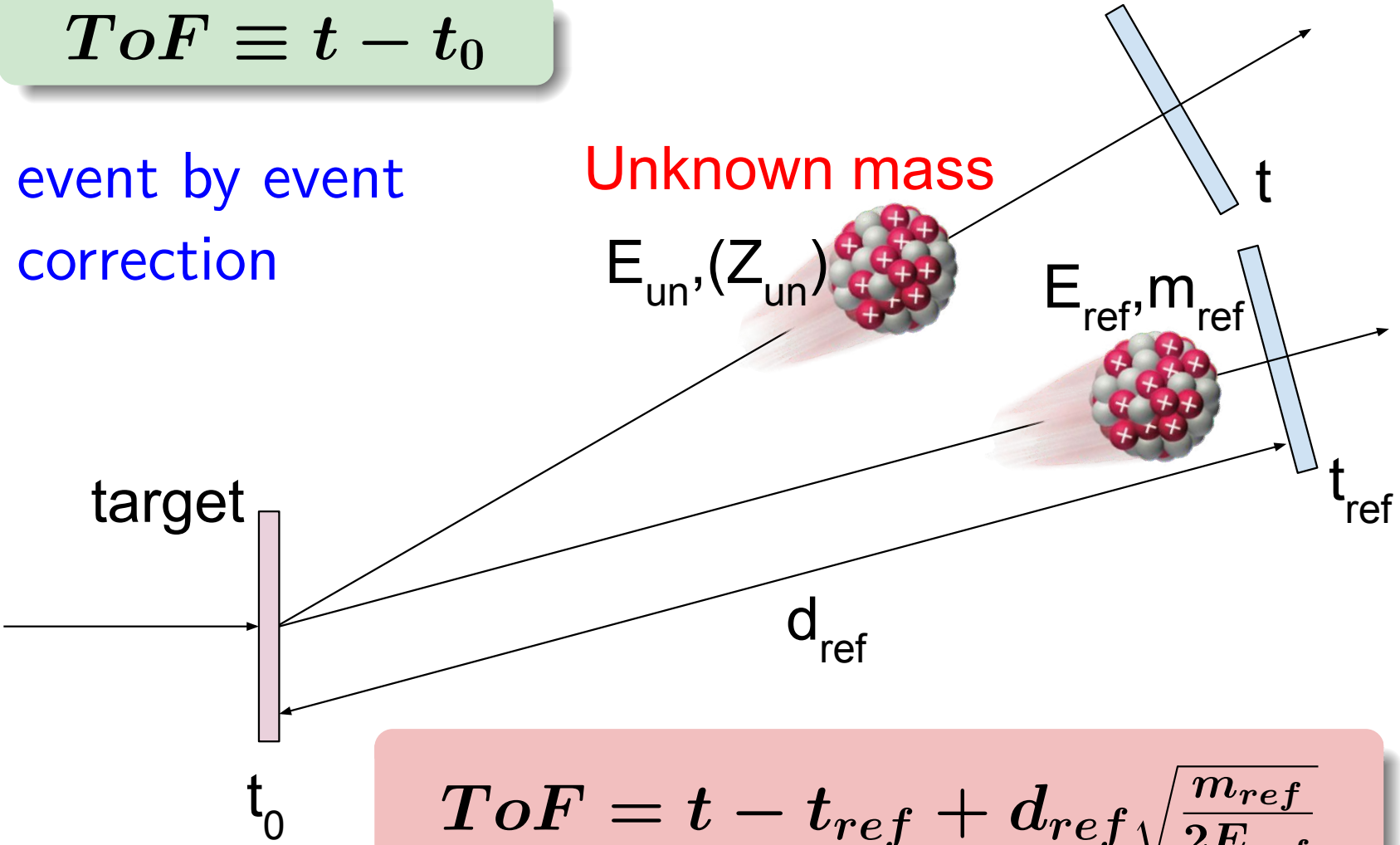
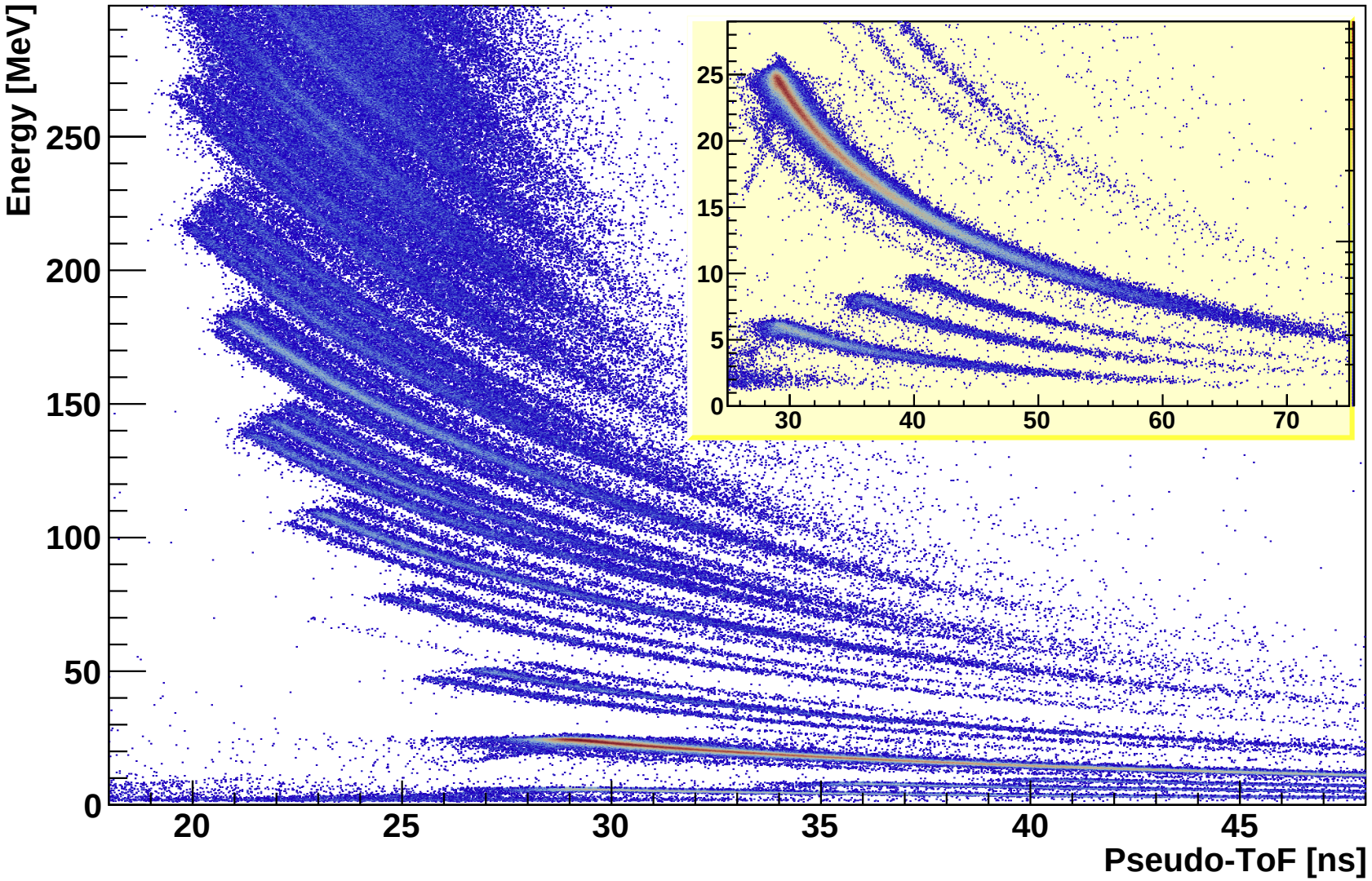


$$ToF = t - t_{ref} + d_{ref}\sqrt{\frac{m_{ref}}{2E_{ref}}}$$

Time of flight identification



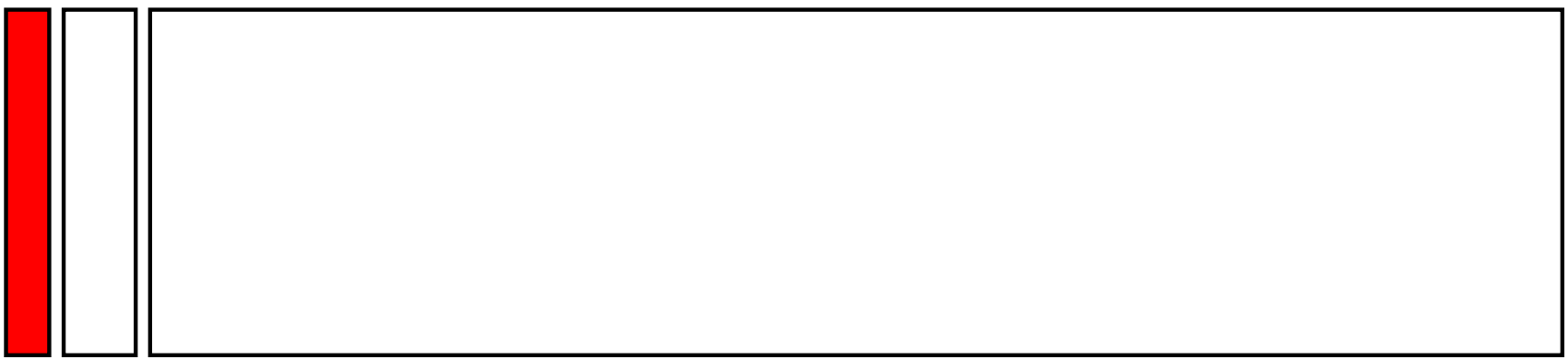
"Spoiler" of FAZIA discrimination capabilities

The FAZIA telescope

The telescope stages

1. 300 µm reverse-mounted Si detector;
2. 500 µm reverse-mounted Si detector;
3. 10 cm CsI(Tl) cristal read by a photodiode.

To achieve the best possible energy resolution and A and Z identification Si detectors come from a nTD ingot cut at random angle to avoid channeling effects.



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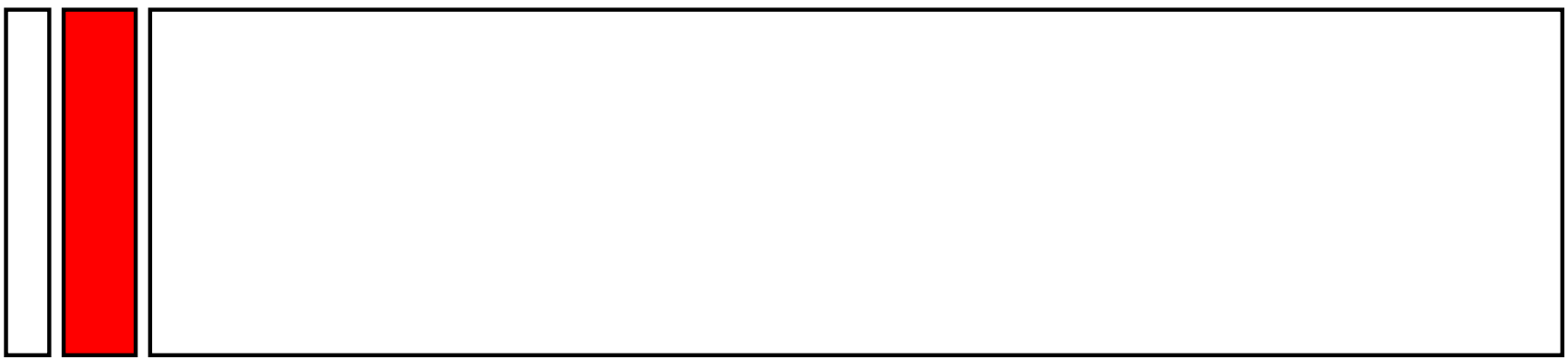

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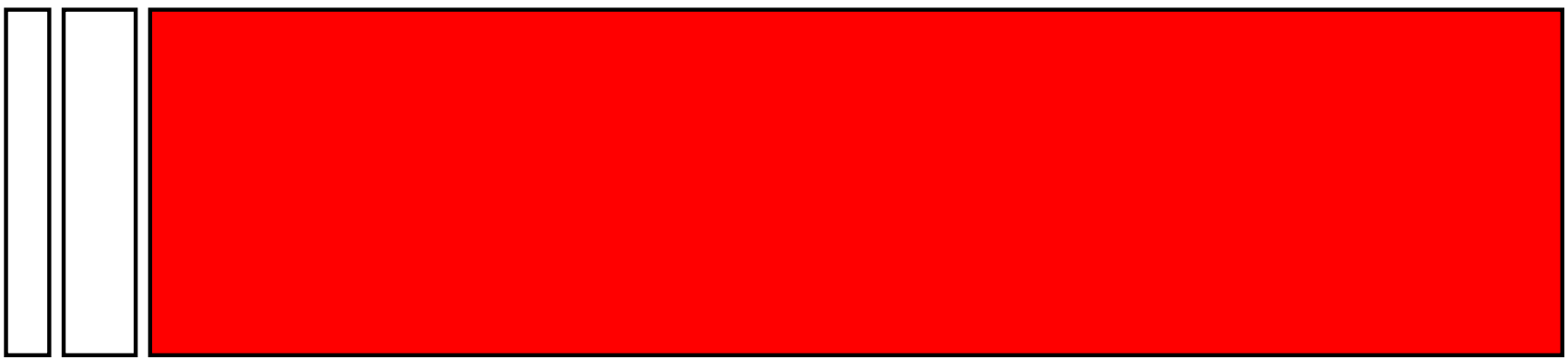
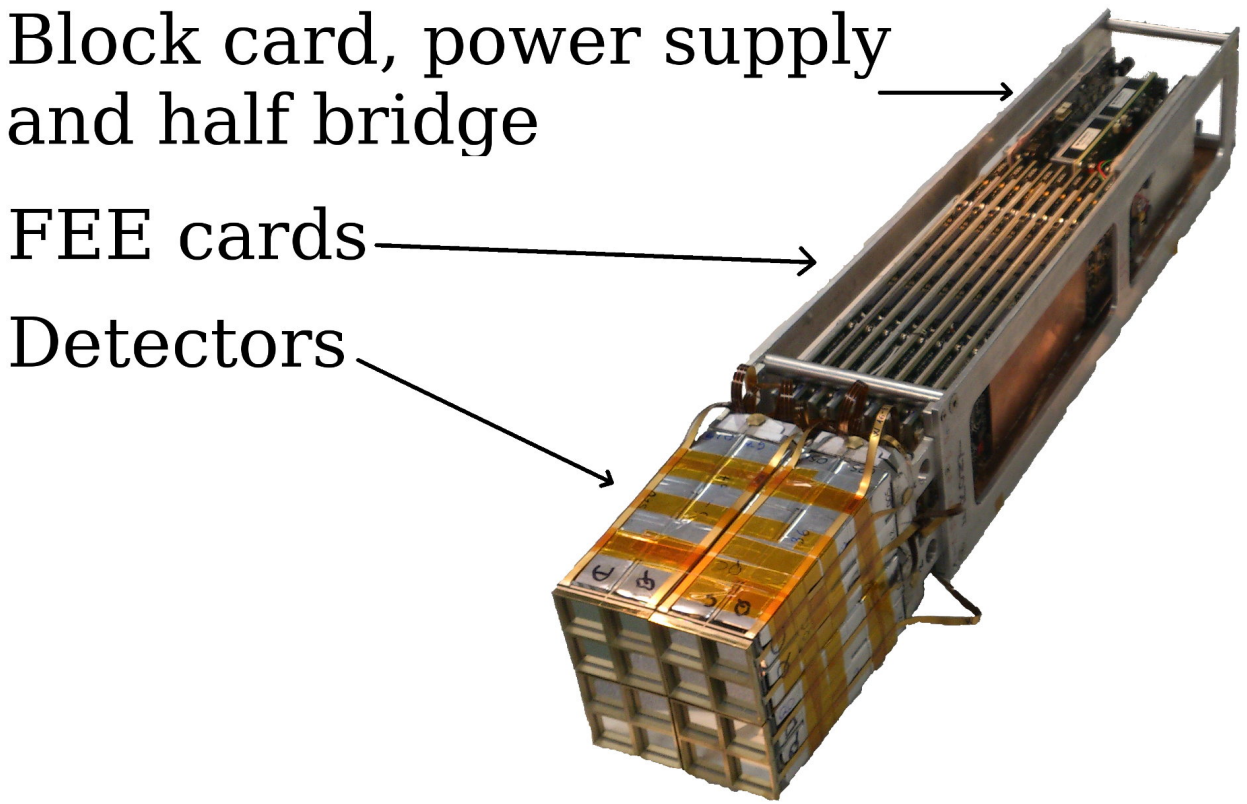


The FAZIA block



16 telescopes, *together with* ***front-end electronics***,
form a ***block*** *operating in* ***vacuum***.

FAZIA electronics

Front-end

- Analogue chain: charge preamplifiers and anti-aliasing filters

S. Valdré *et al*, Nucl. Instr. and Meth. A 930 (27), 2019

FAZIA electronics

Front-end

- Analogue chain: charge preamplifiers and anti-aliasing filters
- Signals are immediately digitized with **14-bit** ADCs:
  - energy resolution is better than 1 % from 5 MeV to 4 GeV
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- Compactness and modularity
- Very good isotopic discrimination capabilities
- Thresholds suited for Fermi energies (2–10 MeV/u)

S. Valdré *et al*, Nucl. Instr. and Meth. A 930 (27), 2019

Identification methods

$\Delta E - E$ correlation

- exploits the Bethe-Bloch energy loss relation
- identification threshold due to first layer thickness

Pulse Shape Analysis[a]

- charge collection depending on the impinging nuclei
- identification threshold corresponding to $\sim 50\,\mu m$ penetration

[a] N. Le Neindre *et al*, Nucl. Instr. and Meth. A 701 (145), 2013

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Pulse Shape Analysis[a]

- charge collection depending on the impinging nuclei
- identification threshold corresponding to $\sim 50\,\mu m$ penetration

$E - ToF$ correlation

- FAZIA implementation proposed here
- lowest identification threshold

[a] N. Le Neindre *et al*, Nucl. Instr. and Meth. A 701 (145), 2013

Time of flight with FAZIA

Not the first heavy-ion experiment to implement ToF[a]

[a] F. Amorini *et al*, IEEE T. Nucl. Sci. 55 (717), 2008

Time of flight with FAZIA

Not the first heavy-ion experiment to implement ToF[a]

Our challenges:

- **large area** ($2 \times 2\,\mathrm{cm}^2$), **reverse-mounted** Si detectors;
- signal slowed down by anti-aliasing filter;
- time mark extraction from 250 MS/s sampled signals;
- not using beam radiofrequency;
- 1 m flight base

[a] F. Amorini *et al*, IEEE T. Nucl. Sci. 55 (717), 2008

FAZIA time mark

For time mark extraction, after some tests we decided to adopt a **digital ARC-CFD**[a] with $t_{\mathrm{D}} = 20\,\mathrm{ns}$ and $f = 20\,\%$

[a] Even if the CFD is compensated, there is still a residual dependence on pulse shape, thus we discriminate both **mass** and **charge** of detected particles

FAZIA time mark

For time mark extraction, after some tests we decided to adopt a **digital ARC-CFD**[a] with $t_{\mathrm{D}} = 20\,\mathrm{ns}$ and $f = 20\,\%$

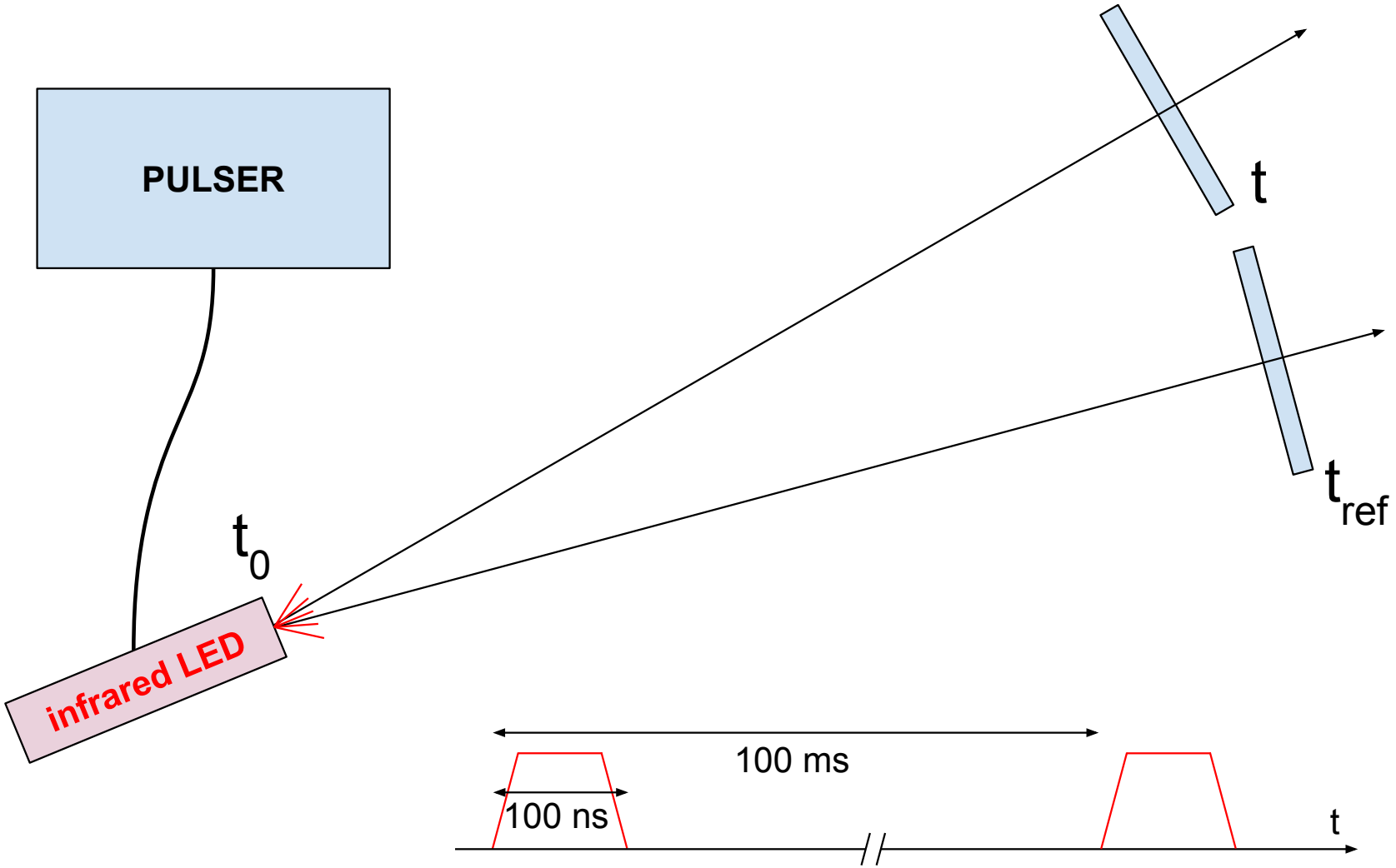
FAZIA time mark is digitally extracted from the acquired signal:

- we used the first layer **low range** signal ($\sim 300\,\mathrm{MeV}$ range, 14-bit @ $250\,\mathrm{MS/s}$);
- all signals are referred to the same validation time, which must be subtracted to obtain the true time mark:

$$t^{(\mathrm{ev,det})} = t^{(\mathrm{ev,det})}_{\mathrm{CFD}} - t^{(\mathrm{ev})}_{\mathrm{val}}$$

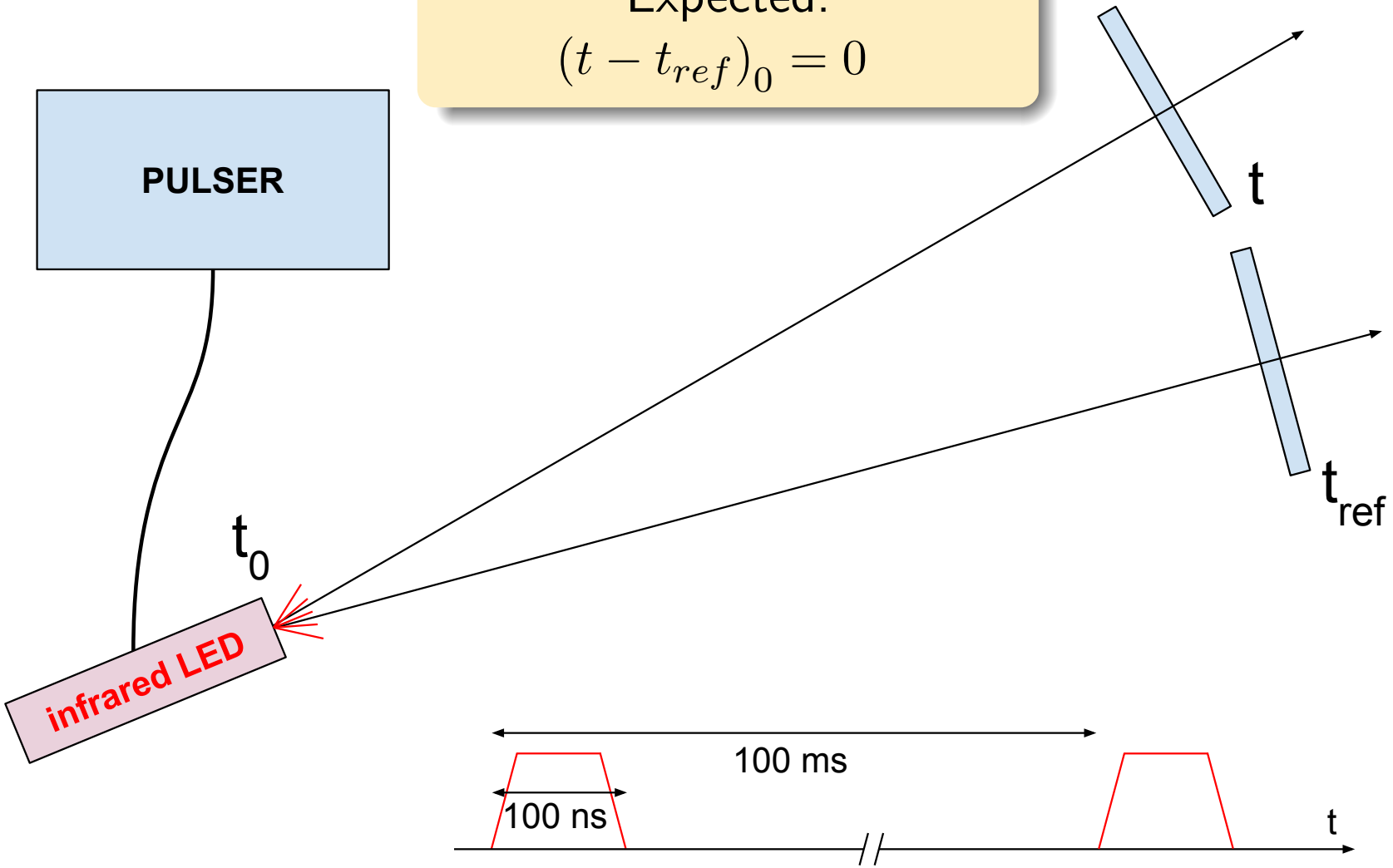
[a] Even if the CFD is compensated, there is still a residual dependence on pulse shape, thus we discriminate both **mass** and **charge** of detected particles

Timing accuracy test in Florence



Timing accuracy test in Florence

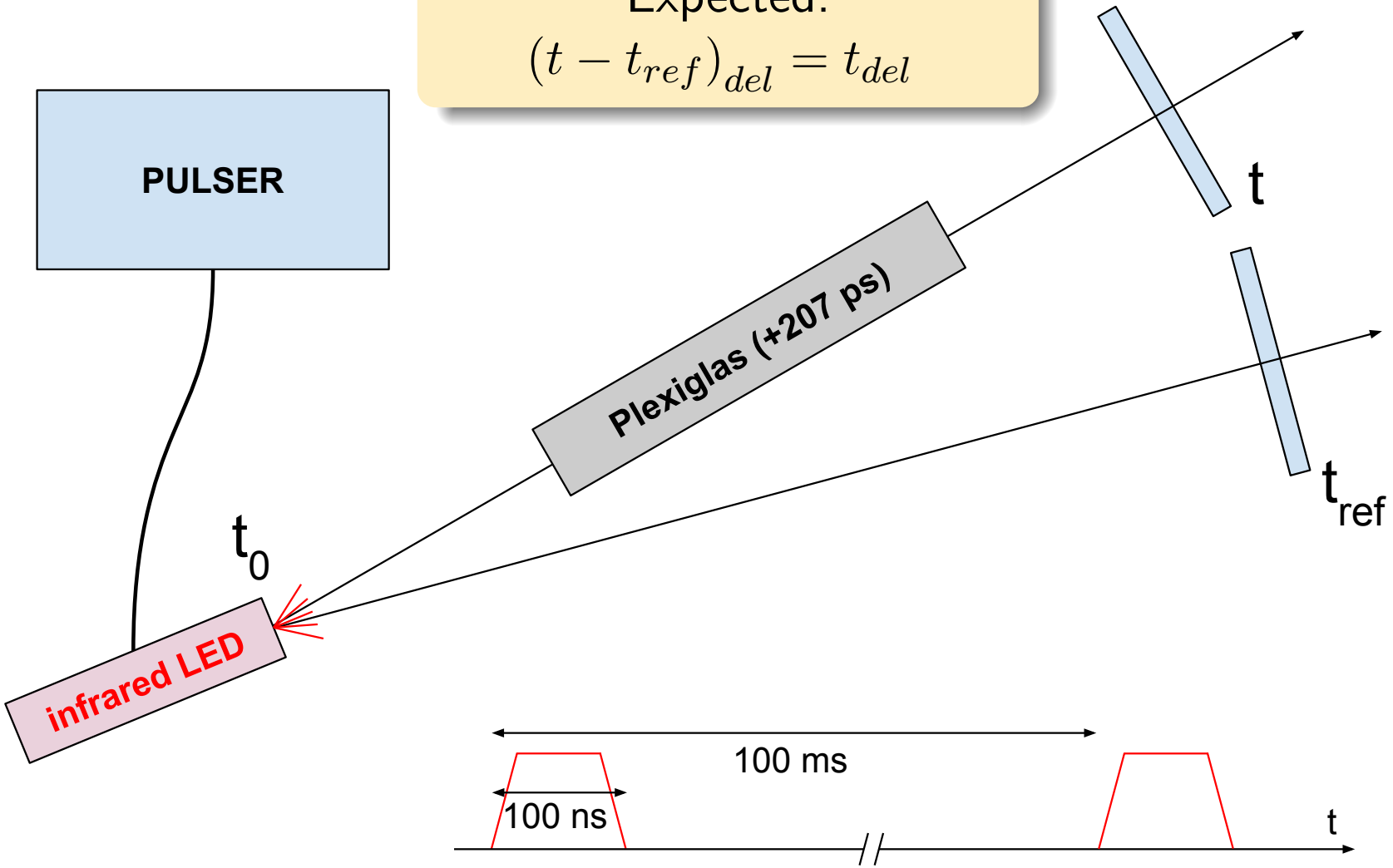
Expected:
$(t - t_{ref})_0 = 0$



Timing accuracy test in Florence

Expected:

$$(t - t_{ref})_{del} = t_{del}$$



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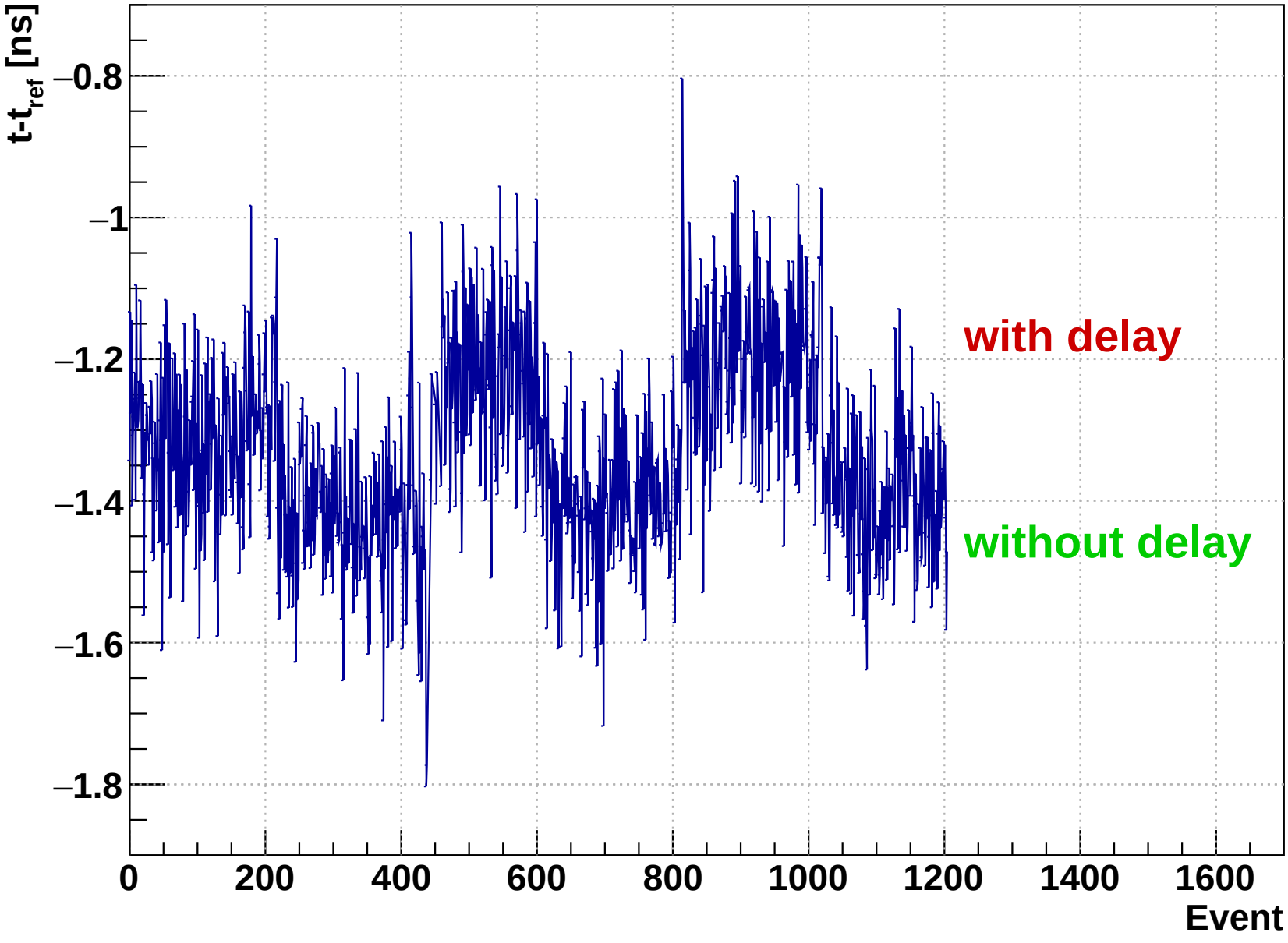

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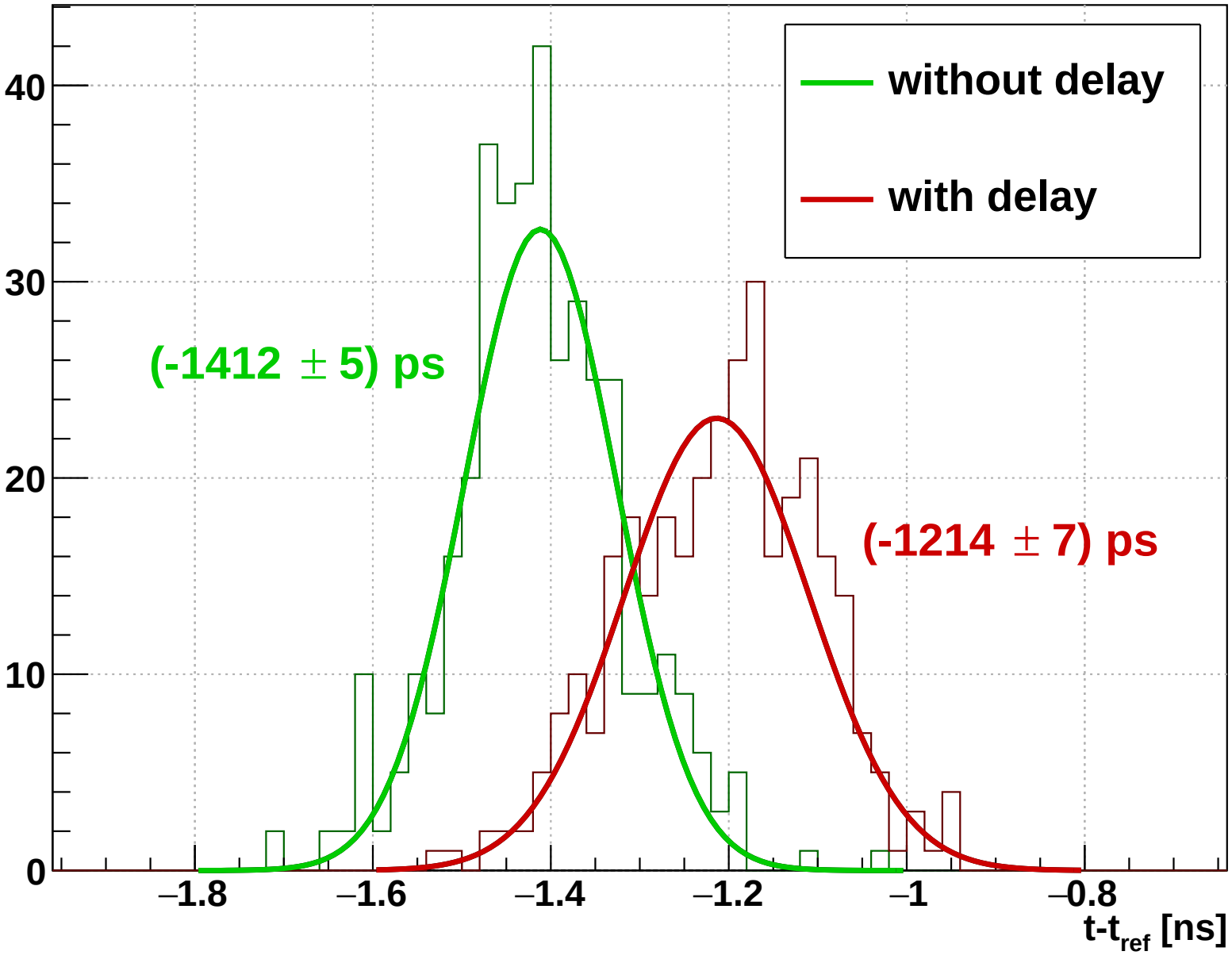

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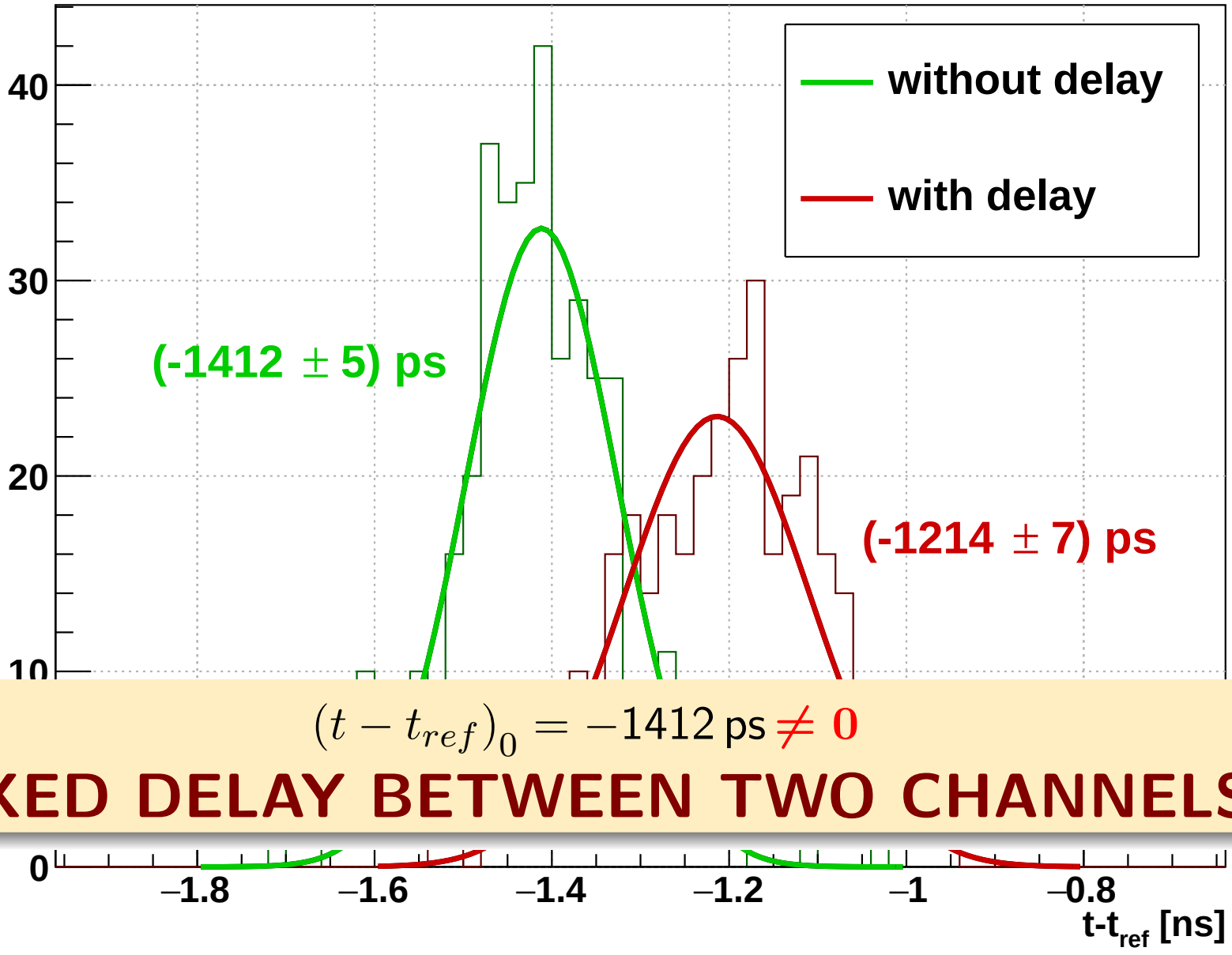
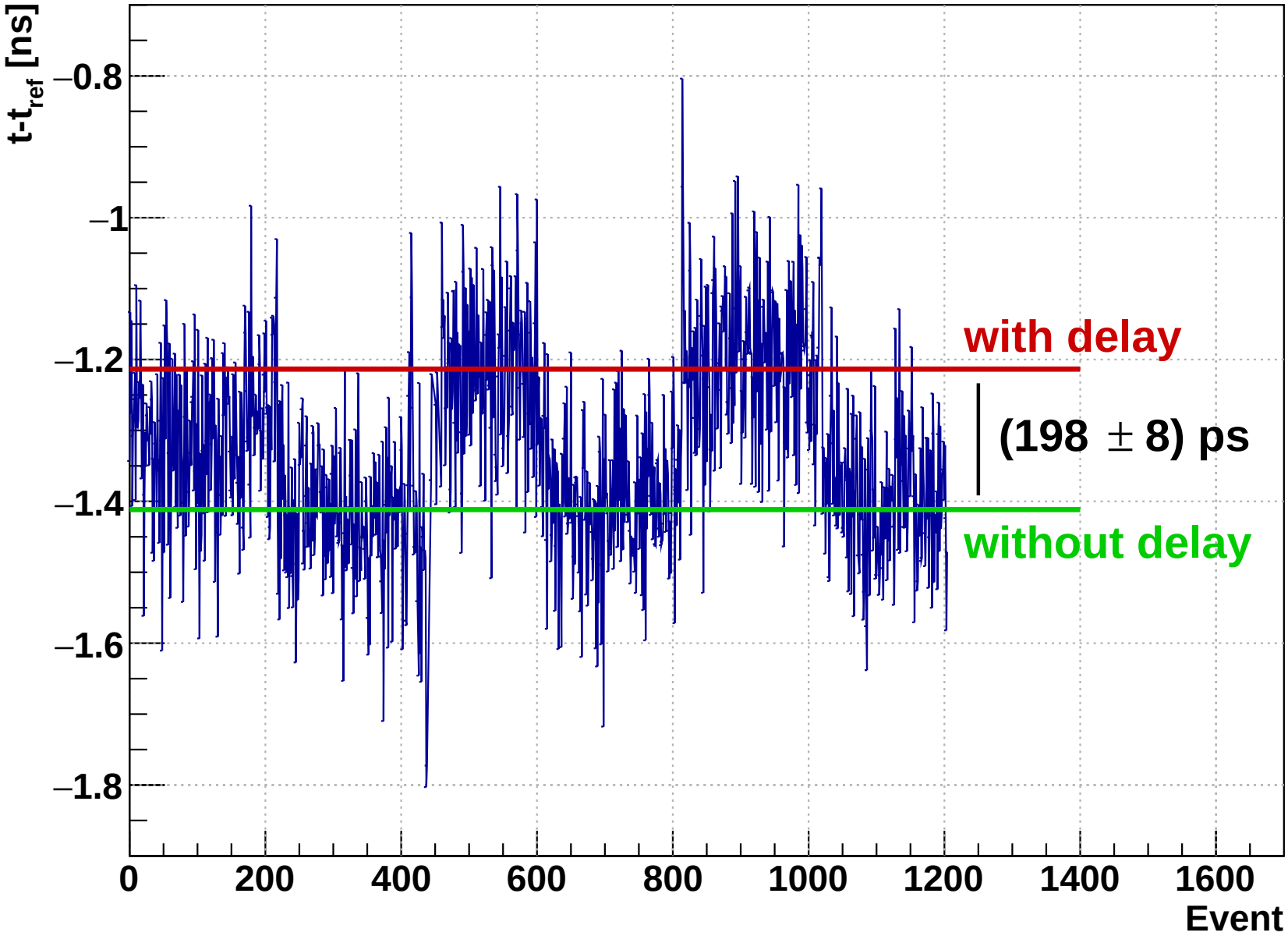


$$(t - t_{ref})_0 = -1412\,\text{ps} \neq 0$$

FIXED DELAY BETWEEN TWO CHANNELS

Timing accuracy test in Florence



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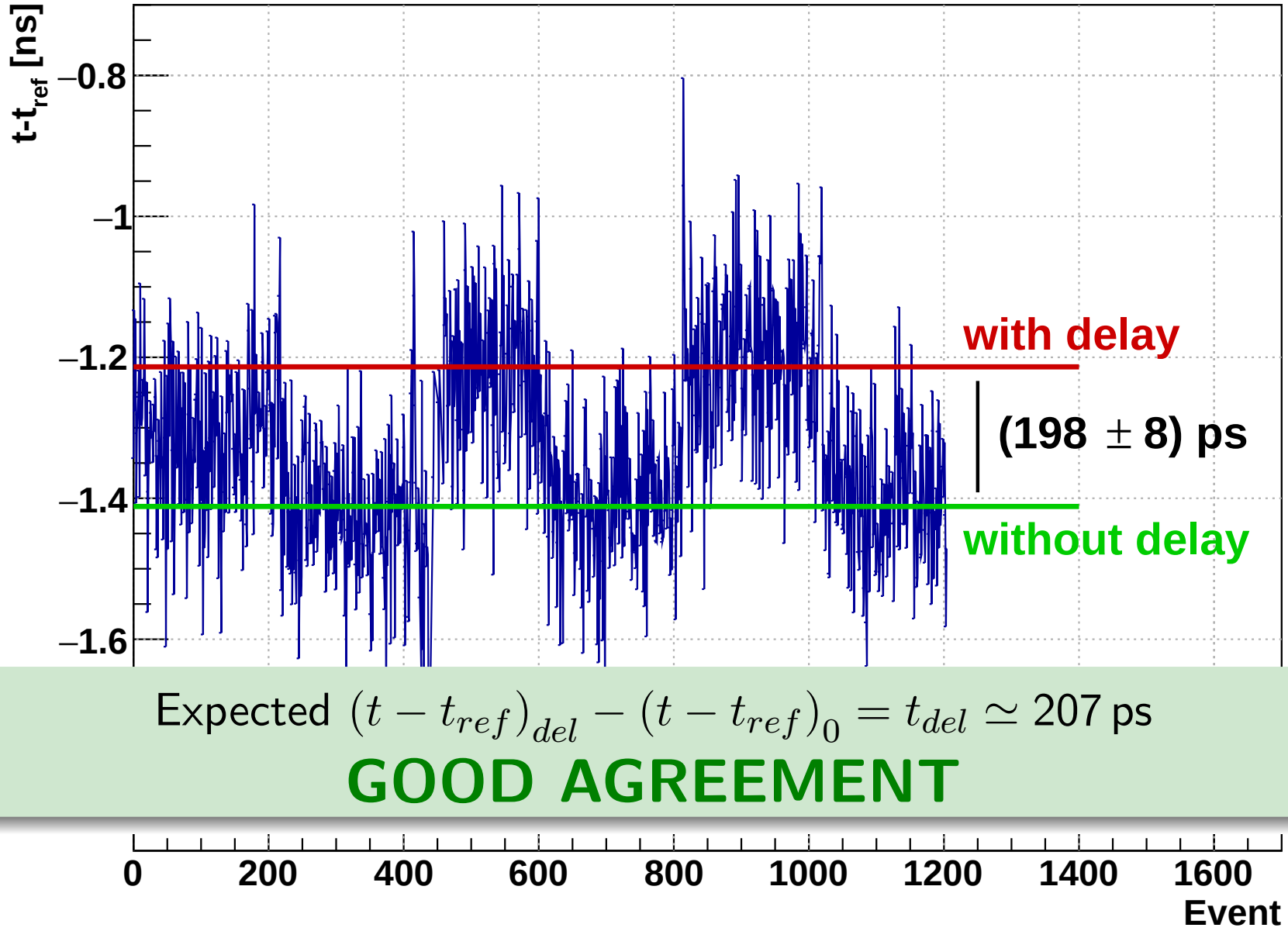

Expected $(t - t_{ref})_{del} - (t - t_{ref})_0 = t_{del} \simeq 207$ ps

GOOD AGREEMENT

FAZIAPRE experiment at LNS

$$^{40,48}\mathrm{Ca} + {}^{12}\mathrm{C}\ @\ 25,40\,\mathrm{AMeV}\ (6\ \mathrm{FAZIA\ blocks})$$

Timing test

The same timing test performed on the test bench was repeated during the mounting of FAZIAPRE experiment at LNS giving a measured delay of (203 ± 13) ps *(added delay was nominally* 207 ps*)*

FAZIAPRE experiment at LNS

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Timing test

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Permanent infrared LED

During the FAZIAPRE experiment, the infrared LED was mounted inside the scattering chamber and was kept on during all the shift (at a 0.1 Hz *rate) to trace channel delays*

FAZIAPRE experiment at LNS

Results of LED analysis:

FAZIAPRE experiment at LNS

Results of LED analysis:

- fixed delays up to 4 ns between channels **(NOT EVENT DEPENDENT)**:

$$t^{(\mathrm{ev,det})} = t^{(\mathrm{ev,det})}_{\mathrm{CFD}} - t^{(\mathrm{ev})}_{\mathrm{val}} + \delta t^{(\mathrm{det})}$$

FAZIAPRE experiment at LNS

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- delays remain almost **stable** (within 200 ps) after a full restart of the electronics
- simple production of a **delay map** to correct time marks:

$$t^{(\mathrm{ev,det})}_{\mathrm{adj}} = t^{(\mathrm{ev,det})}_{\mathrm{CFD}} + \Delta^{(\mathrm{det})}$$

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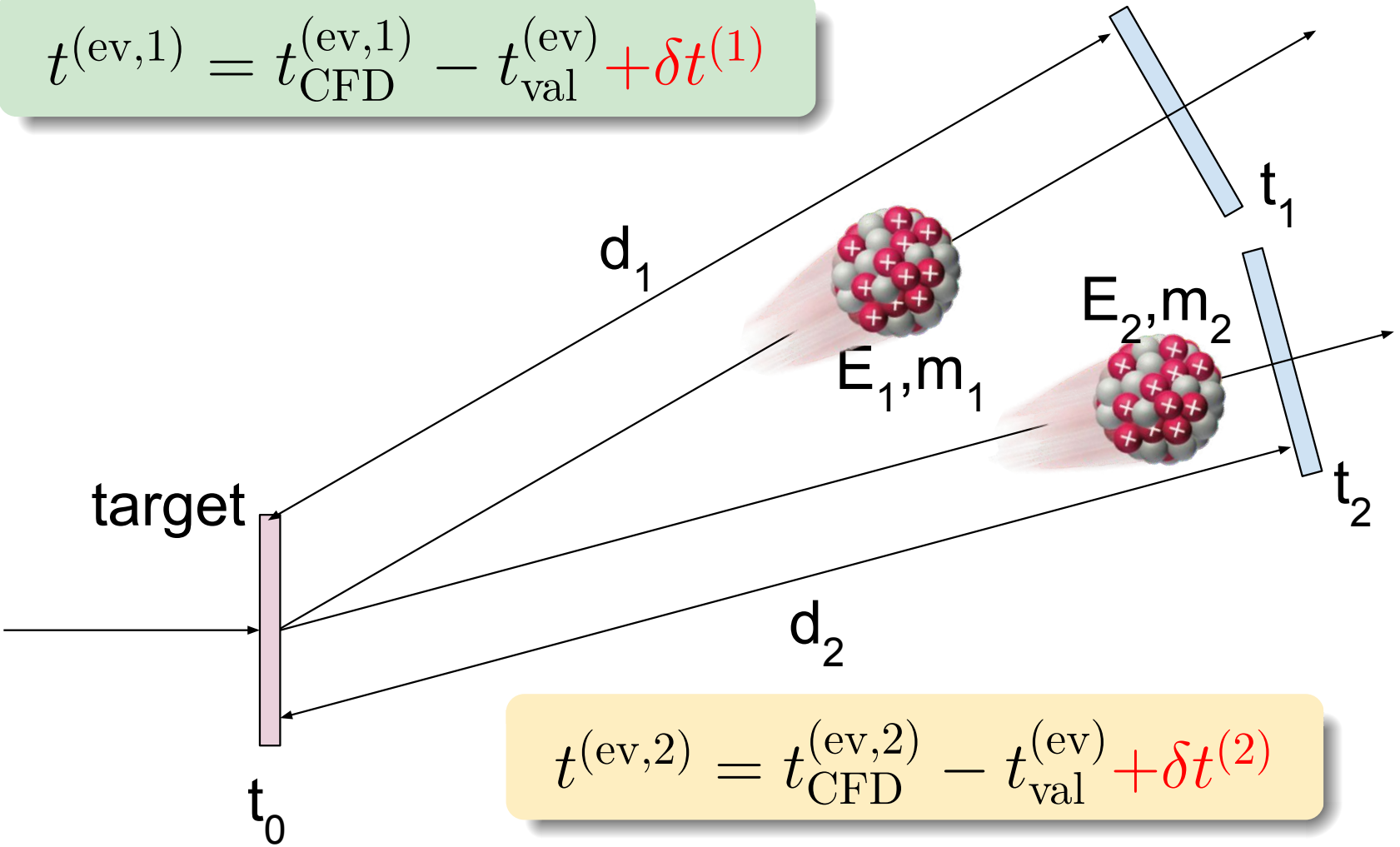
- simple production of a **delay map** to correct time marks:

$$t_{\mathrm{adj}}^{(\mathrm{ev,det})} = t_{\mathrm{CFD}}^{(\mathrm{ev,det})} + \Delta^{(\mathrm{det})}$$

I also studied an alternative synchronization method which can be used **without LED pulses**

Auto-synchronization

$$t^{(\mathrm{ev},1)} = t^{(\mathrm{ev},1)}_{\mathrm{CFD}} - t^{(\mathrm{ev})}_{\mathrm{val}} + \delta t^{(1)}$$



$$t^{(\mathrm{ev},2)} = t^{(\mathrm{ev},2)}_{\mathrm{CFD}} - t^{(\mathrm{ev})}_{\mathrm{val}} + \delta t^{(2)}$$

Take events with (at least) 2 well known particles

Auto-synchronization

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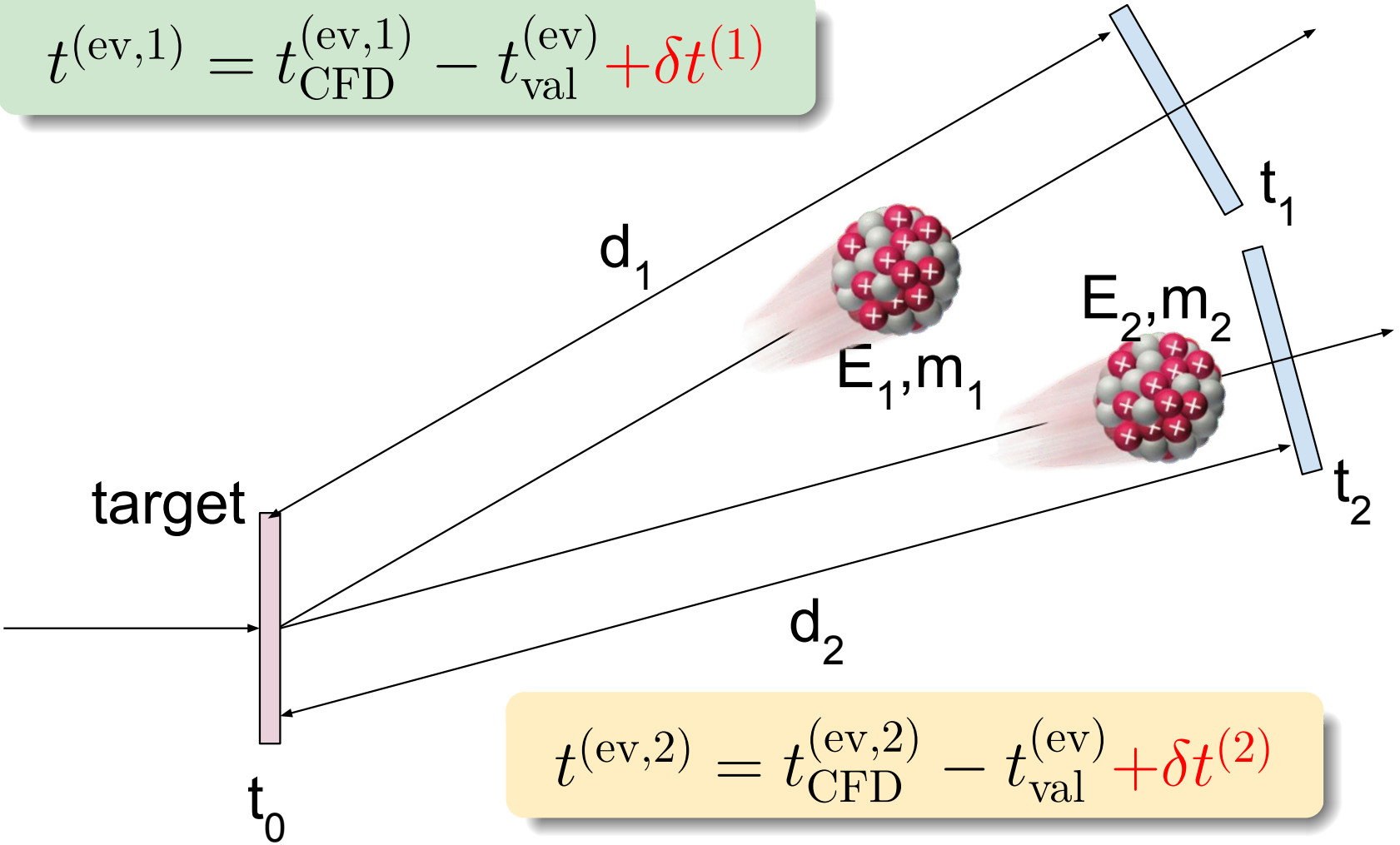

$$t^{(\mathrm{ev},2)} = t^{(\mathrm{ev},2)}_{\mathrm{CFD}} - t^{(\mathrm{ev})}_{\mathrm{val}} + \delta t^{(2)}$$

$$\Delta^{(1,2)} \equiv \delta t^{(2)} - \delta t^{(1)} = t^{(\mathrm{ev},2)} - t^{(\mathrm{ev},2)}_{\mathrm{CFD}} - t^{(\mathrm{ev},1)} + t^{(\mathrm{ev},1)}_{\mathrm{CFD}}$$

Auto-synchronization (or LED)

Now we have a **delay map** $\Delta^{(\mathrm{i})} \equiv \delta t^{(\mathrm{i})} - \delta t^{(\mathrm{ref})}$

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$$\Downarrow$$

$$t^{(\mathrm{ev},2)} - t^{(\mathrm{ev},1)} = t^{(\mathrm{ev},2)}_{\mathrm{CFD}} + \delta t^{(2)} - t^{(\mathrm{ev},1)}_{\mathrm{CFD}} - \delta t^{(1)}$$

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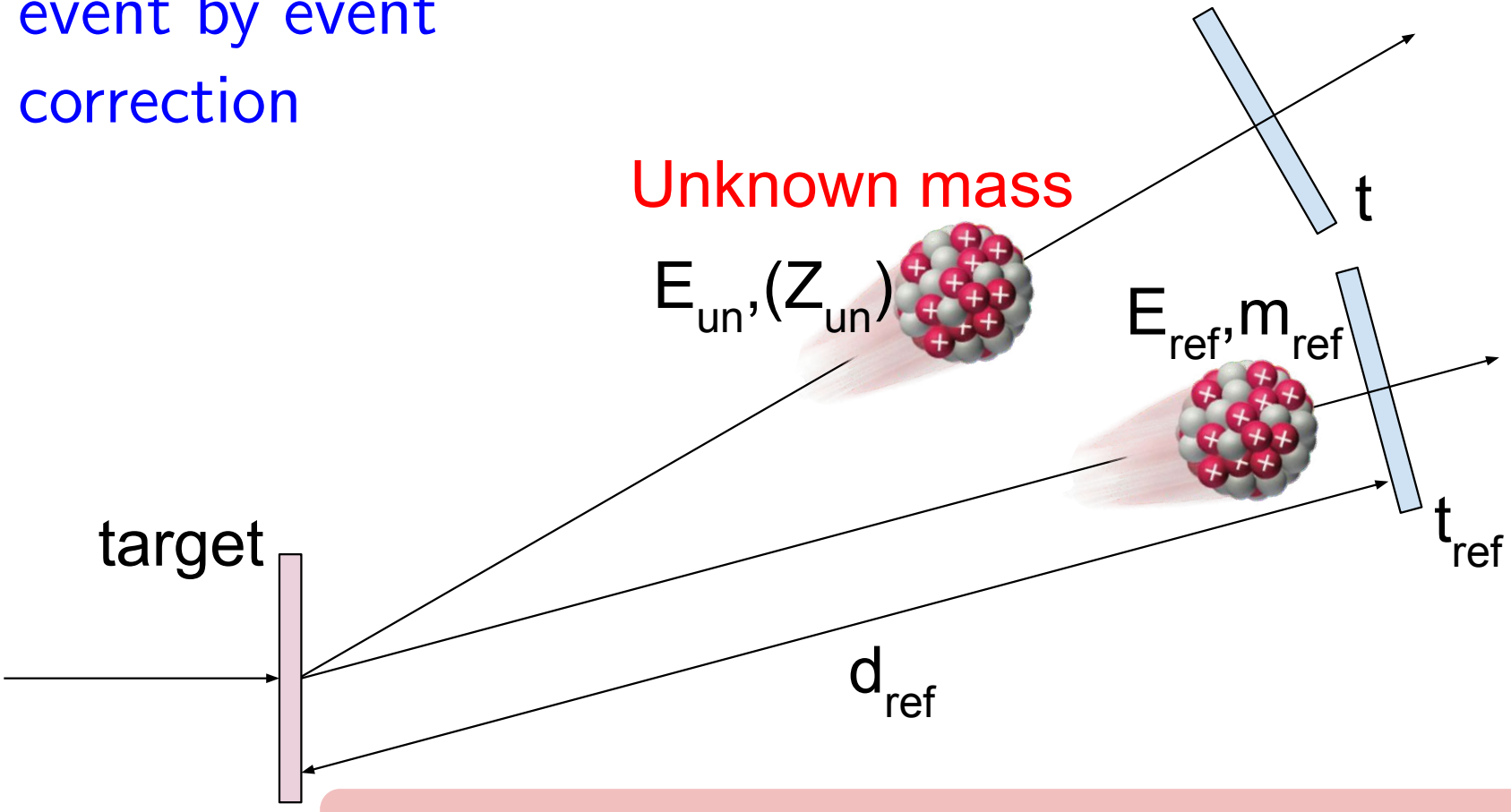
$$t^{(\mathrm{ev},2)} - t^{(\mathrm{ev},1)} = t^{(\mathrm{ev},2)}_{\mathrm{adj}} - t^{(\mathrm{ev},1)}_{\mathrm{adj}}$$

Time of flight identification (only $M > 1$ events)

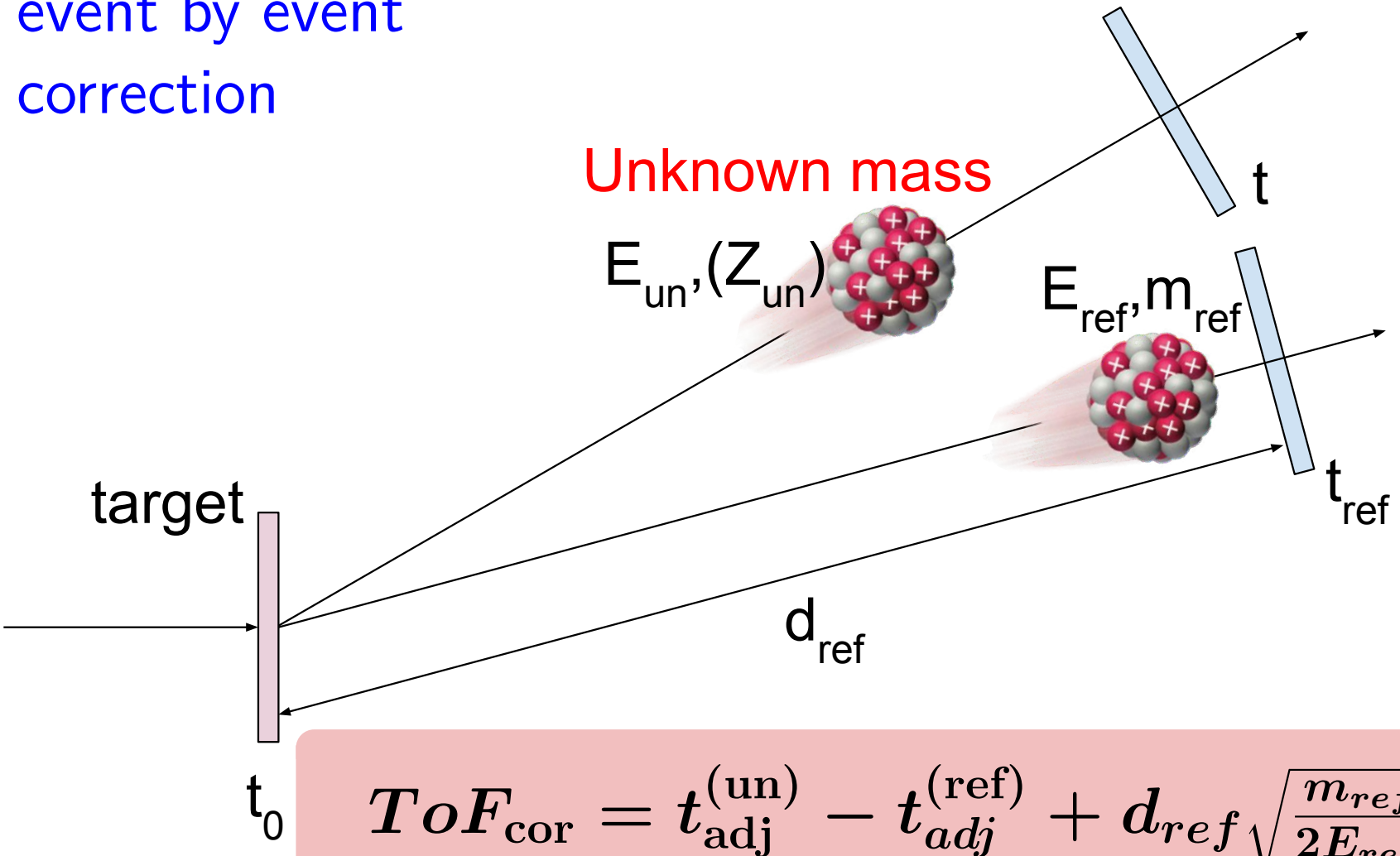
event by event correction



$$ToF_{\mathrm{RAW}} = t^{(\mathrm{un})}_{\mathrm{CFD}} - t^{(\mathrm{ref})}_{CFD} + d_{ref}\sqrt{\frac{m_{ref}}{2E_{ref}}}$$

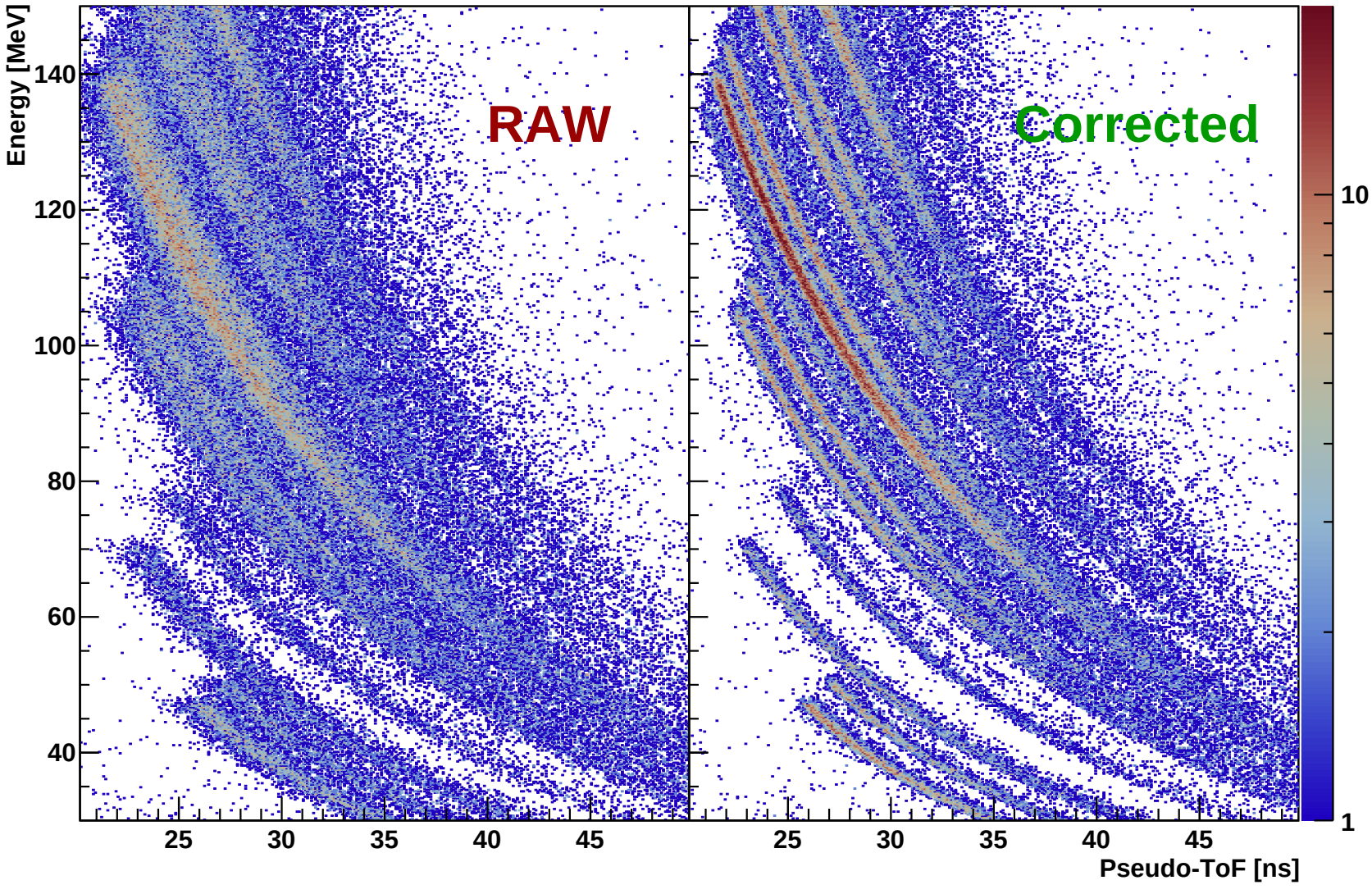
Time of flight identification (only $M > 1$ events)

event by event correction

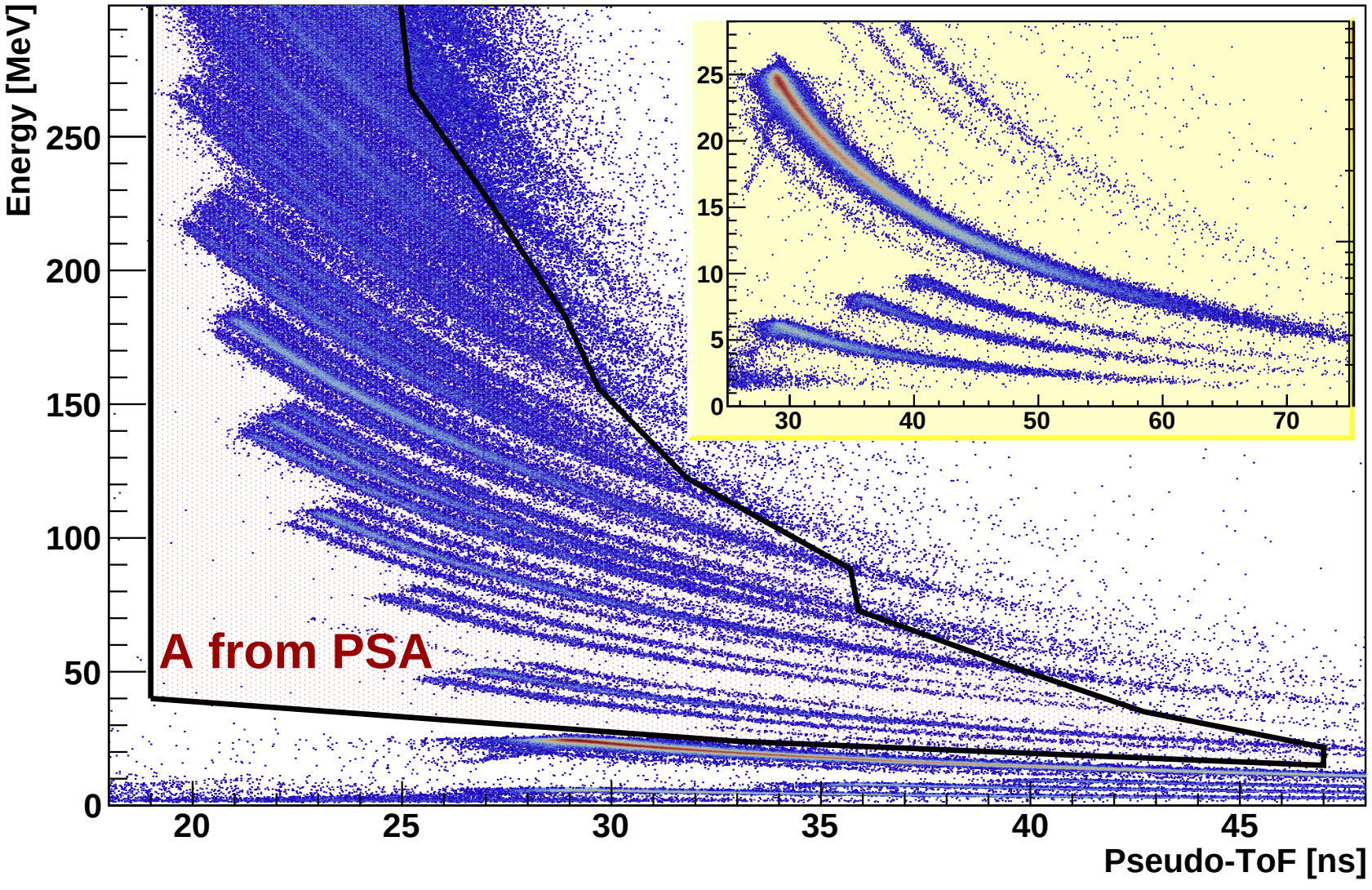


$$ToF_{cor} = t_{adj}^{(un)} - t_{adj}^{(ref)} + d_{ref}\sqrt{\frac{m_{ref}}{2E_{ref}}}$$

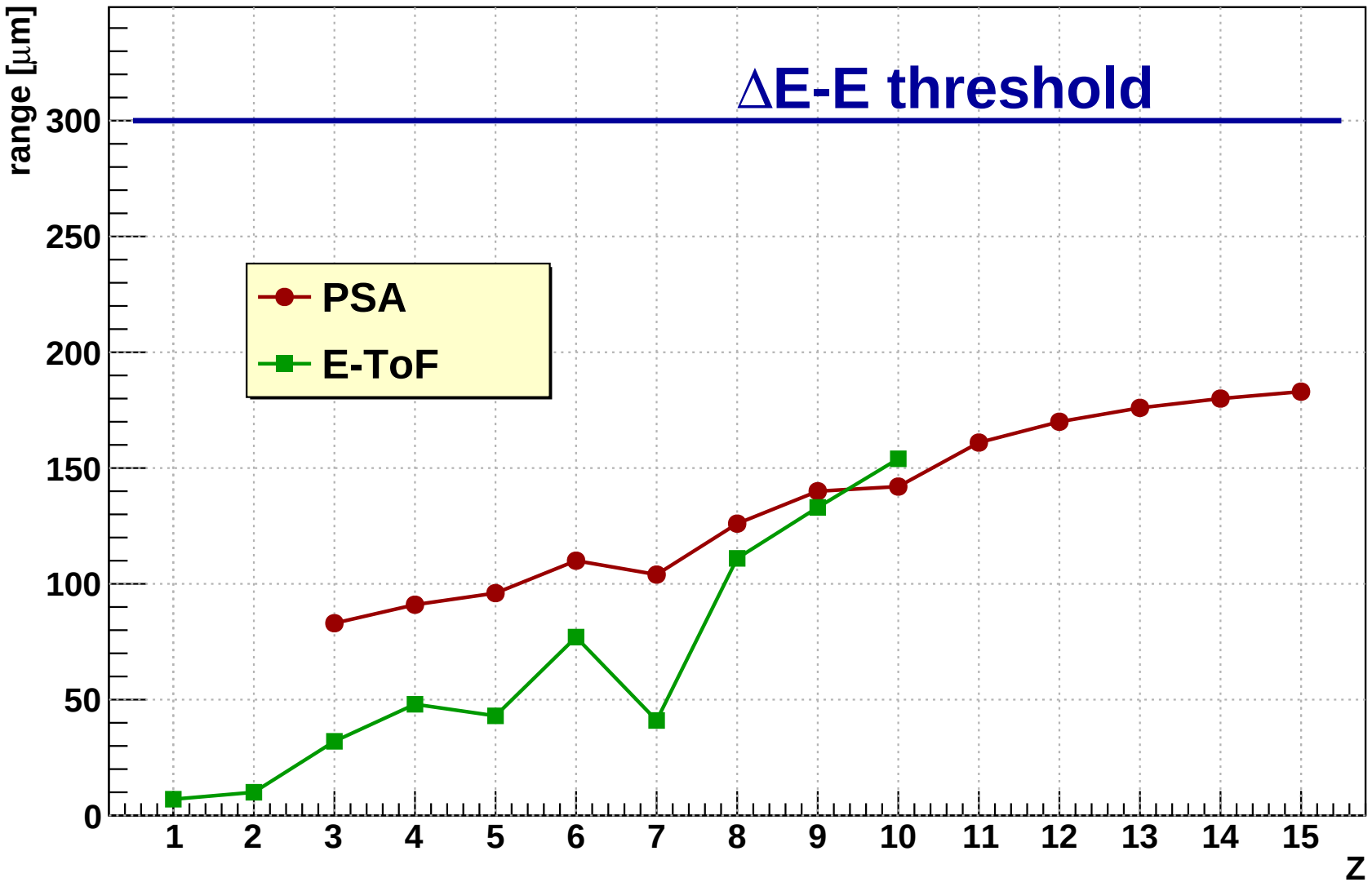
Delay correction (LED or auto-sync)



Final $E - ToF$ correlation



Improvement of isotope discrimination



Summary and conclusions

- Possibility to perform precise time measurements with FAZIA:
  - time mark jitter from $\sim 100\,\text{ps}$ to $\sim 1\,\text{ns}$ depending on impinging particle
  - observed sampling delays between channels up to 4 ns

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  - very accurate methods (error on delay correction $\sim$10 ps)
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  - observed sampling delays between channels up to 4 ns
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  - very accurate methods (error on delay correction $\sim$10 ps)
  - trace possible variations of the channel delay during the run (less than $\sim$200 ps)
- $E - ToF$ correlation to reduce energy threshold for mass ID:
  - $Z = 1, 2$ isotopes separated at all energies **(not seen in PSA!)**
  - threshold clearly reduced for $Z = 3 - 8$
  - non perfectly homogeneous detectors fully recovered

Summary and conclusions

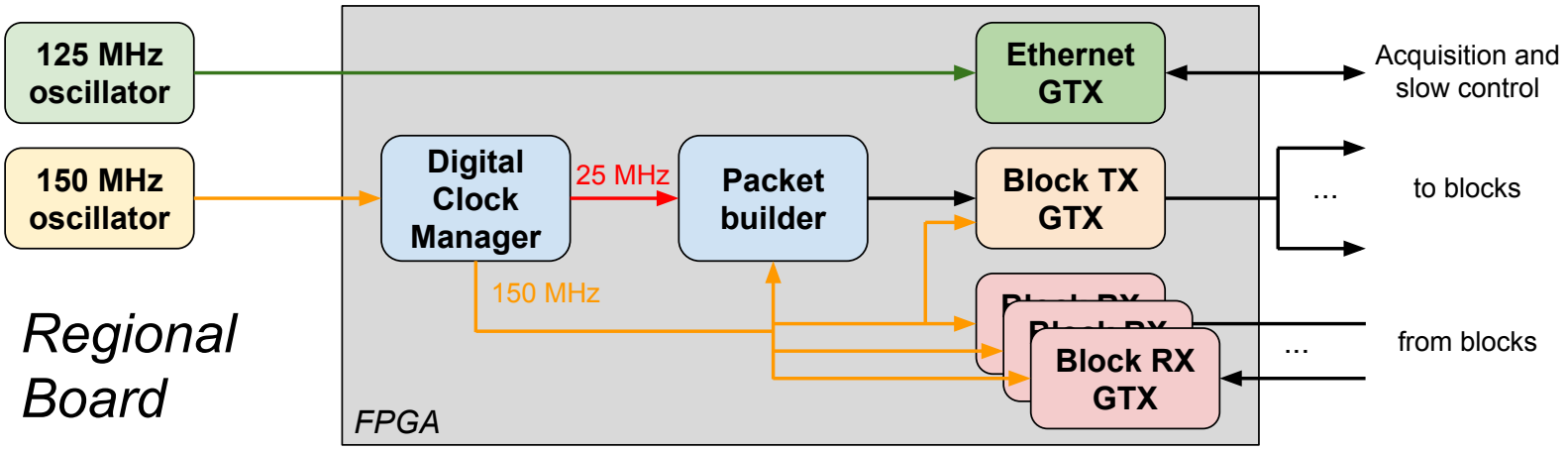
- Possibility to perform precise time measurements with FAZIA:
  - time mark jitter from $\sim$ 100 ps to $\sim$ 1 ns depending on impinging particle
  - observed sampling delays between channels up to 4 ns
- Auto-correlations or LED pulses to synchronize Si1 channels:
  - very accurate methods (error on delay correction $\sim$10 ps)
  - trace possible variations of the channel delay during the run (less than $\sim$200 ps)
- $E - ToF$ correlation to reduce energy threshold for mass ID:
  - $Z = 1, 2$ isotopes separated at all energies **(not seen in PSA!)**
  - threshold clearly reduced for $Z = 3 - 8$
  - non perfectly homogeneous detectors fully recovered
- Opening the door to QT physics with FAZIA.

FAZIA collaboration

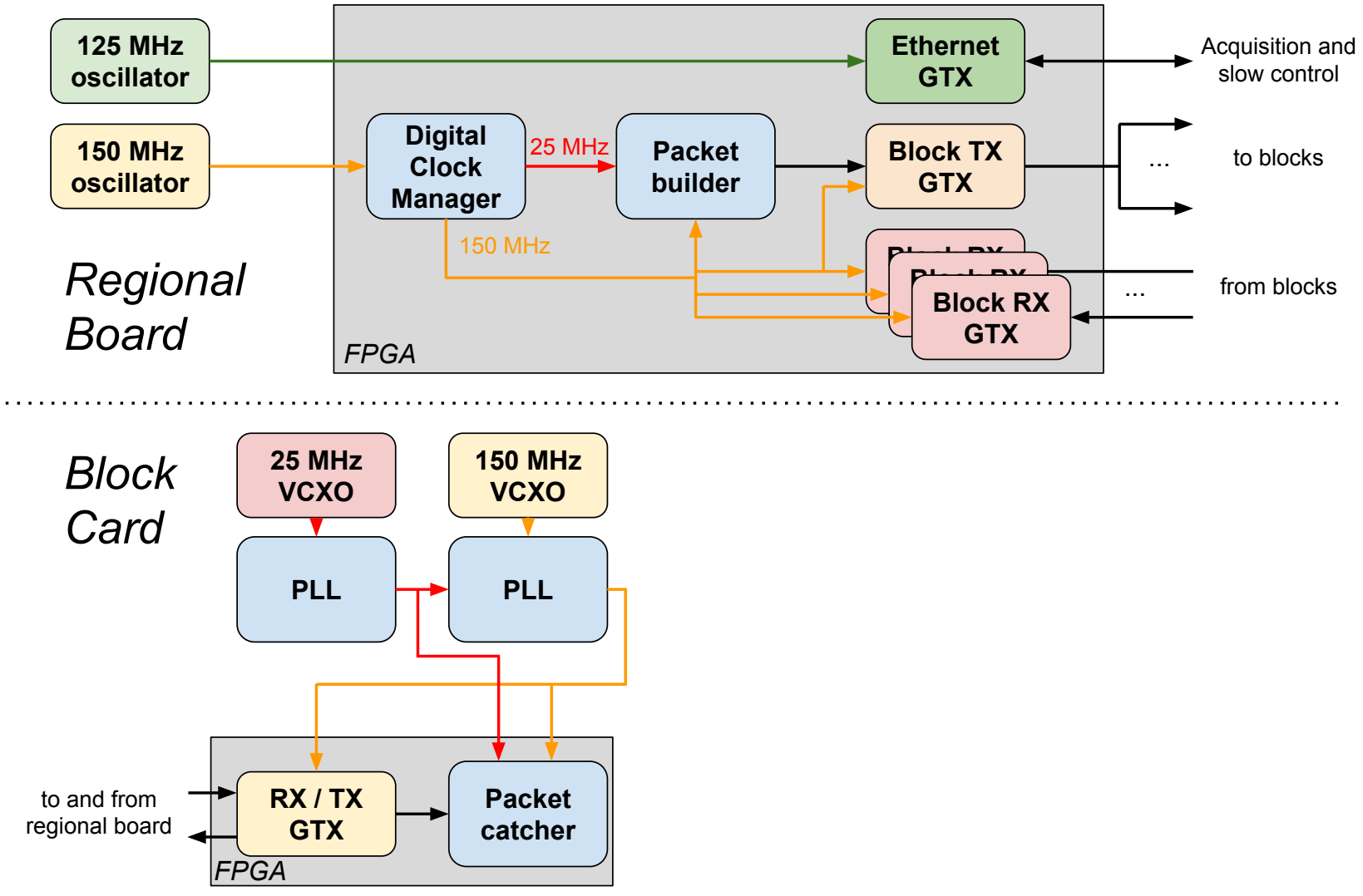
Thanks for your attention

Backup slides

Clock tree


125 MHz oscillator
150 MHz oscillator
Regional Board
Digital Clock Manager
25 MHz
150 MHz
Packet builder
Ethernet GTX
Block TX GTX
Block RX GTX
FPGA
Acquisition and slow control
to blocks
from blocks

Clock tree


125 MHz oscillator
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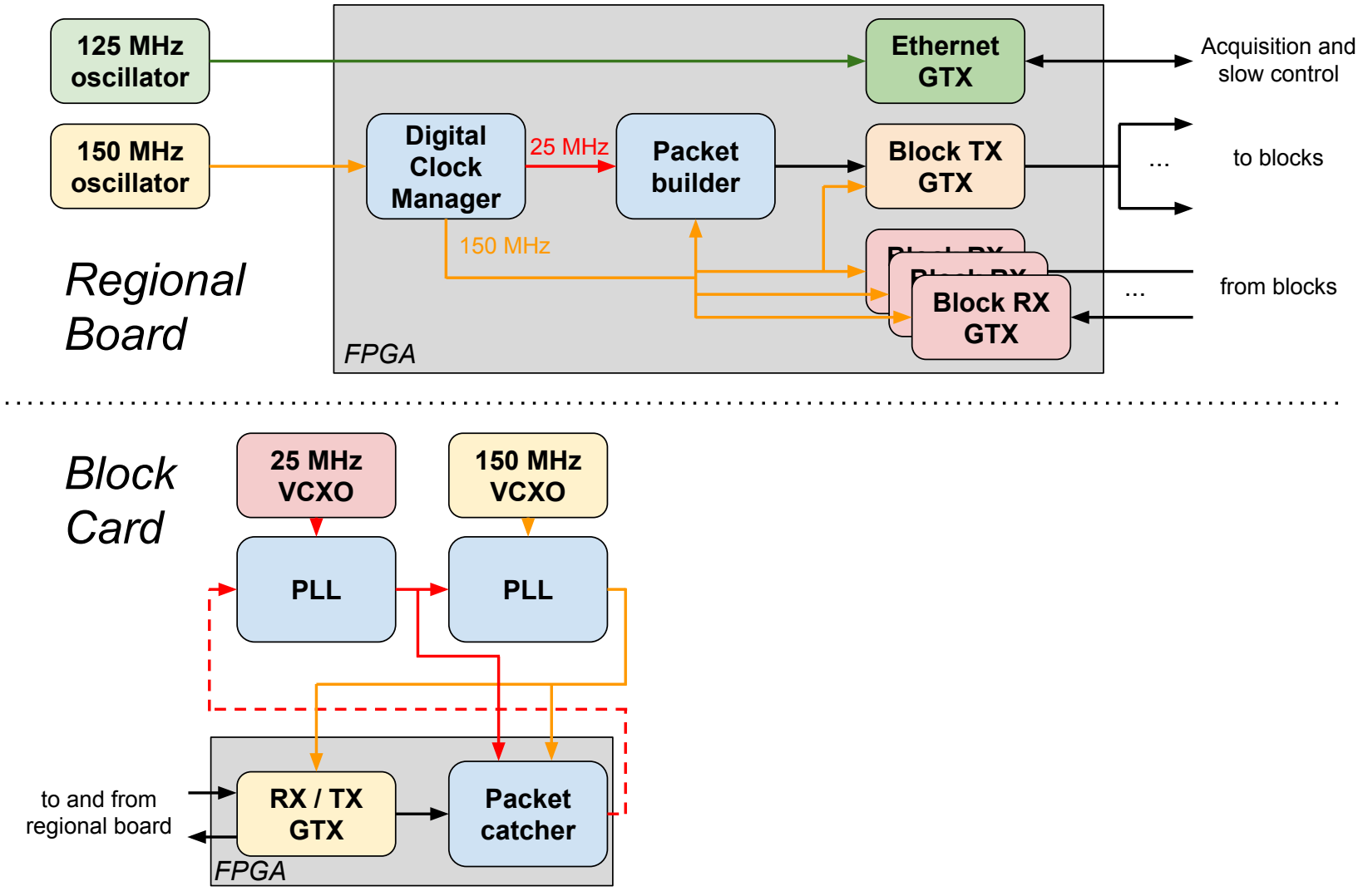
Digital Clock Manager
25 MHz
150 MHz
Packet builder
Ethernet GTX
Block TX GTX
Block RX GTX
Acquisition and slow control
to blocks
from blocks
Regional Board
FPGA
Block Card
25 MHz VCXO
150 MHz VCXO
PLL
PLL
RX / TX GTX
Packet catcher
to and from regional board
FPGA

Clock tree


125 MHz oscillator
150 MHz oscillator
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25 MHz
150 MHz
Packet builder
Ethernet GTX
Block TX GTX
Block RX GTX
...
Acquisition and slow control
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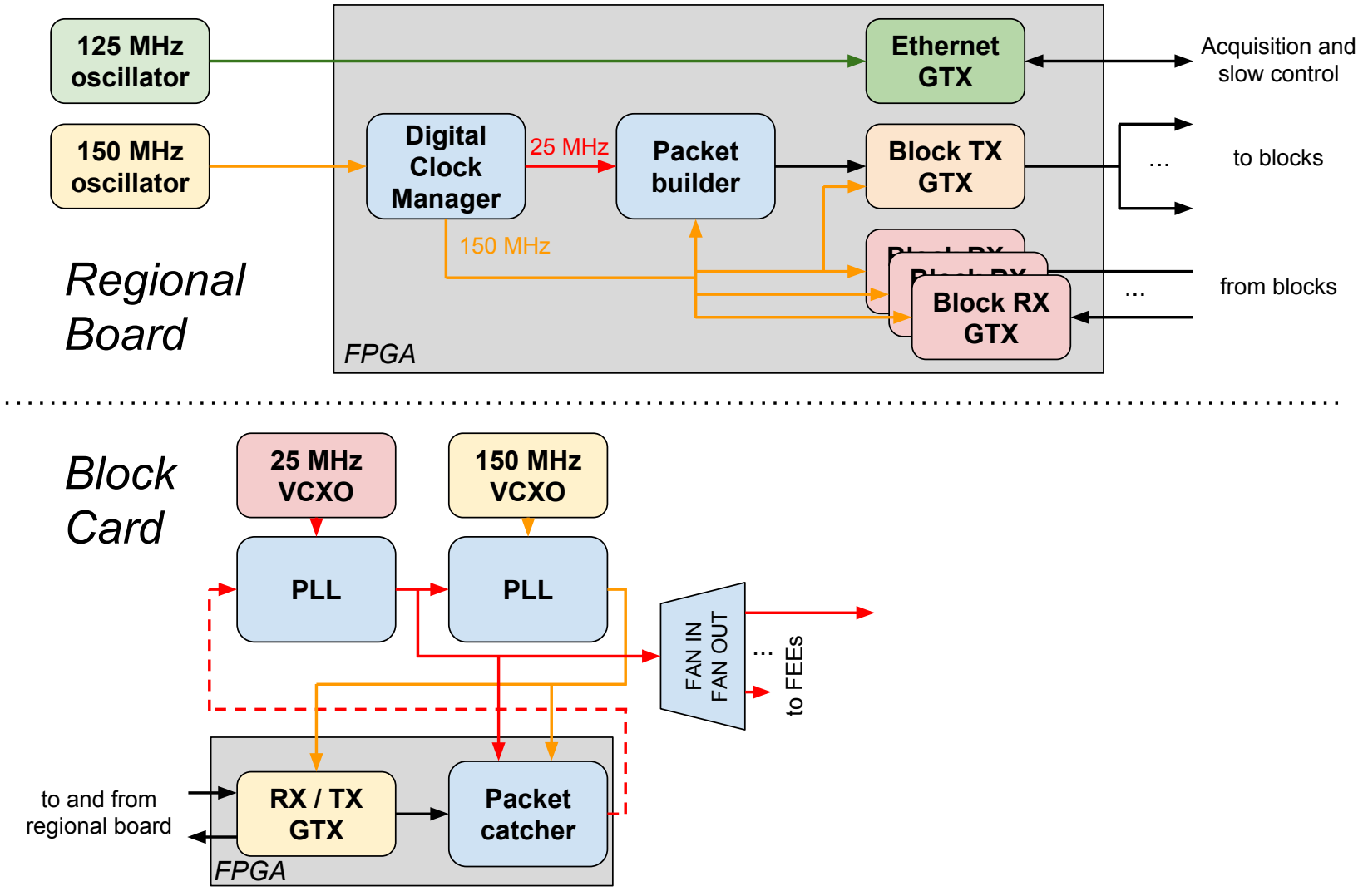
Clock tree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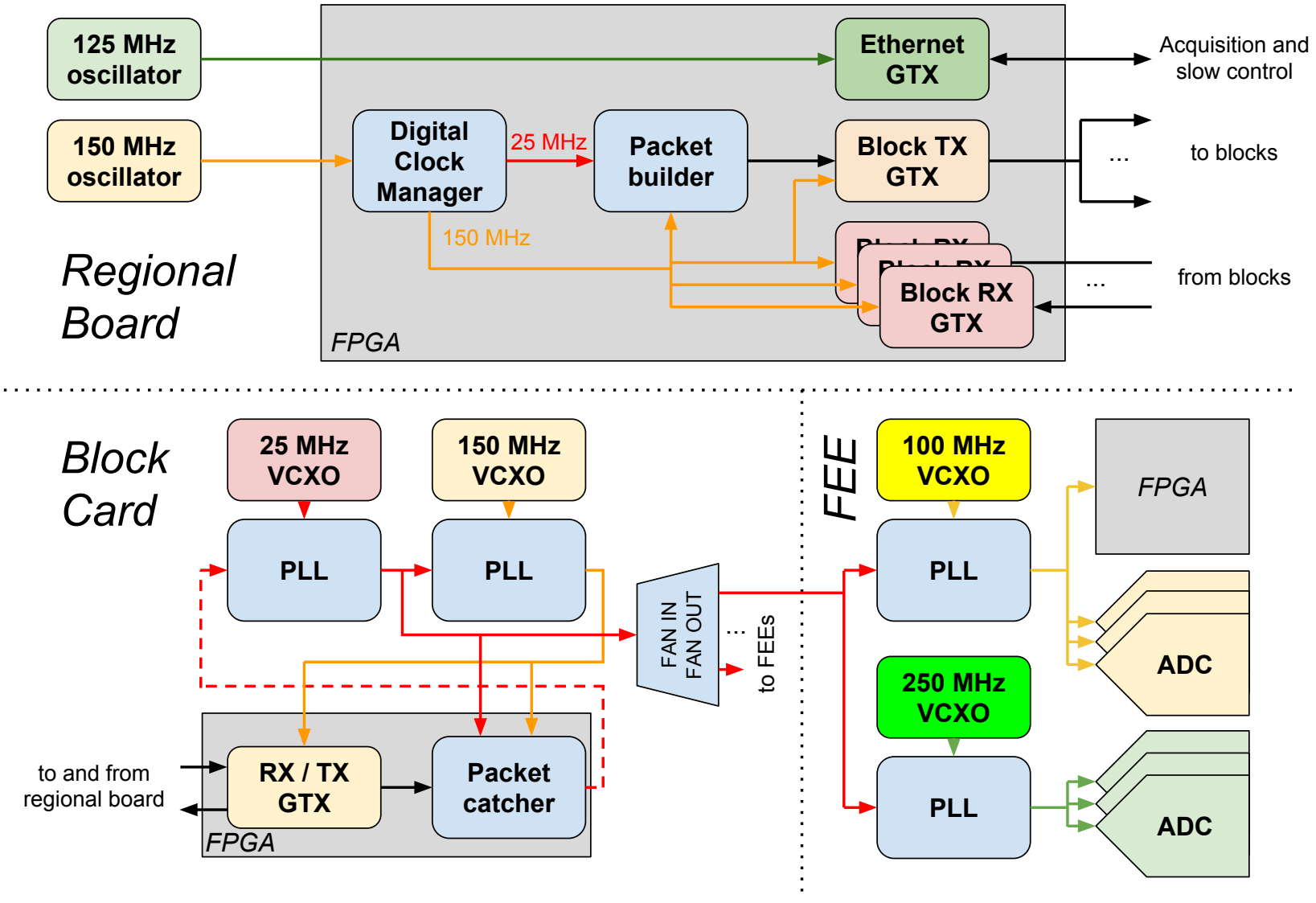
150 MHz VCXO
PLL
PLL
FAN IN
FAN OUT
to FEEs
to and from regional board
RX / TX GTX
Packet catcher
FPGA

Clock tree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to and from regional board
RX / TX GTX
Packet catcher
FPGA
FEE
100 MHz VCXO
250 MHz VCXO
PLL
PLL
FPGA
ADC
ADC

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