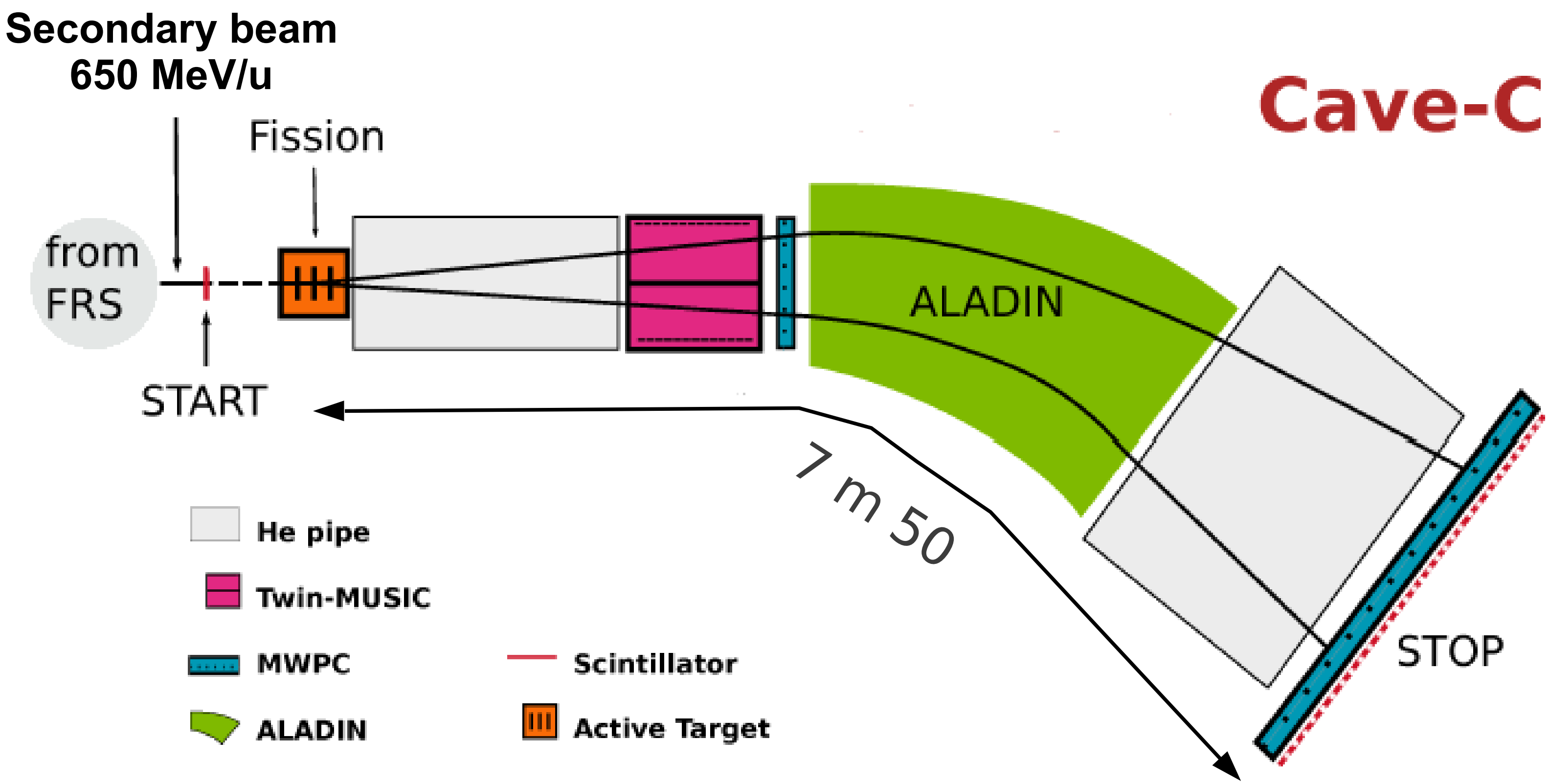
Picosecond resolution on Time-of-Flight measurement within the SOFIA experiment (S415)

G. Boutoux (CEA, DAM, DIF) **for the SOFIA collaboration**

Identification of the two fission fragments using the Bρ-ΔE-ToF technique



Time-of-Flight resolution better than 40 ps FWHM
is required to get resolved A over the full fission fragments mass range

Choice of the detector technology

Secondary beam spot size ≈ 20 mm → small-sized START detector

Dispersion of fission fragments in the dipole → 900x600 mm² STOP detector

The only option to study :
Plastic scintillators read-out by PMTs

DETECTION
- Plastic scintillators
- PMTs

ELECTRONICS
- Cables
- CFDs
- TACs or TDCs

Considerations on scintillation

Scintillator's light production

Plastic scintillator

Lowest light attenuation
+
Shortest scintillating time

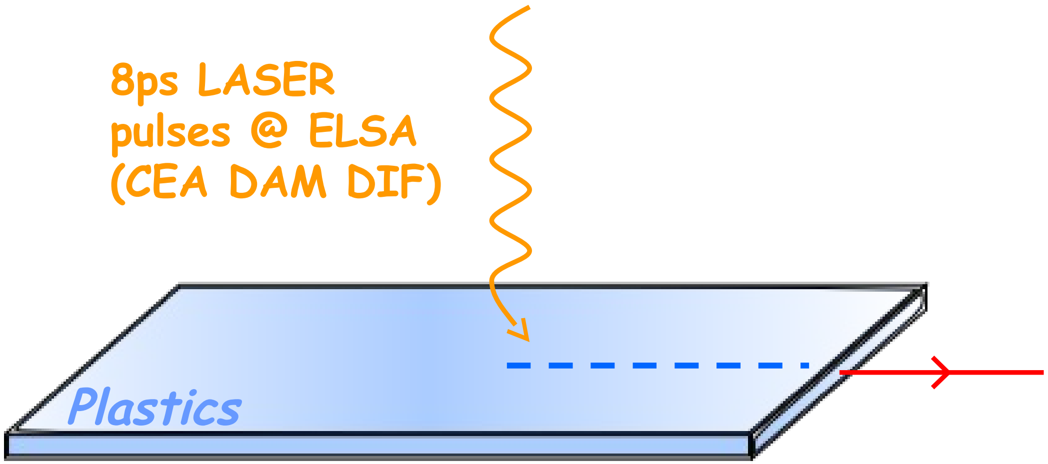
Fastest plastic scintillating materials from Saint-Gobain and Eljen Technology

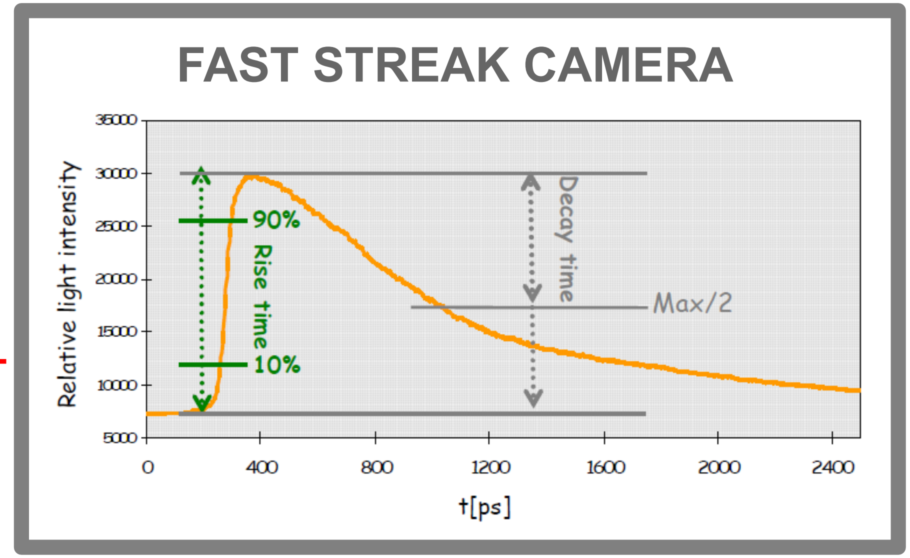
Saint-Gobain BC-422

Eljen Technology EJ-232

*The addition (0.25 or 0.5%) of a **quenching molecule** – the **Benzophenone** (BZ) – can be used to **reduce the light-pulse duration**.*

Plastic scintillating materials benchmarking





Shortest scintillating time

Eljen Technology EJ-232

Measured rise-times : 107 ps for non-quenched and 37-44 ps for quenched ones.

Light attenuation is huge in fast plastics and increases with quencher amount

Eljen Technology EJ-232

With or without quencher ?

→ *compromise between improving scintillating time and maximizing light collection*

STOP detector	START detector
Large 900x600 mm^2 ToF wall	Small-sized detector
Important light attenuation	*Low light attenuation*
Non-quenched plastic	**Quenched plastic 0.25% BZ is enough**

PMTs and Time resolution

PMTs

$$R_{PMT} \propto TTS / \sqrt{N_{p.e.}}$$

Time resolution (R_{PMT})

Transit Time Spread (TTS)

Number of photo-e^{-} produced ($N_{p.e.}$)

Choice of PMTs

PMTs

$$R_{PMT} \propto TTS / \sqrt{N_{p.e.}}$$

Time resolution

Transit Time Spread

Number of photo-e$^-$ produced

MCP-PMT

MCP-PMTs have the shortest TTS (< 25ps) but size is not adapted to a large ToF wall

Choice of PMTs

PMTs

$$R_{PMT} \propto TTS / \sqrt{N_{p.e.}}$$

Time resolution

Transit Time Spread

Number of photo-e$^-$ produced

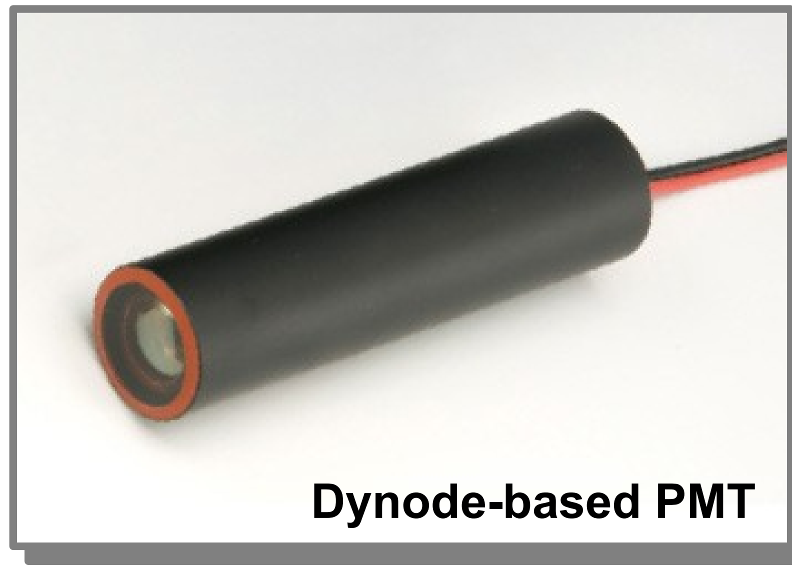
Dynode-based PMTs with the shortest TTS and optimized quantum efficiency (Q.E.)

Hamamatsu H6533 (TTS=160ps)
with « standard Bialkali » photocathode (Q.E=25 %)

Hamamatsu H10580 (TTS=270ps)
with « super Bialkali » photocathode (Q.E=35 %)

MCP-PMT

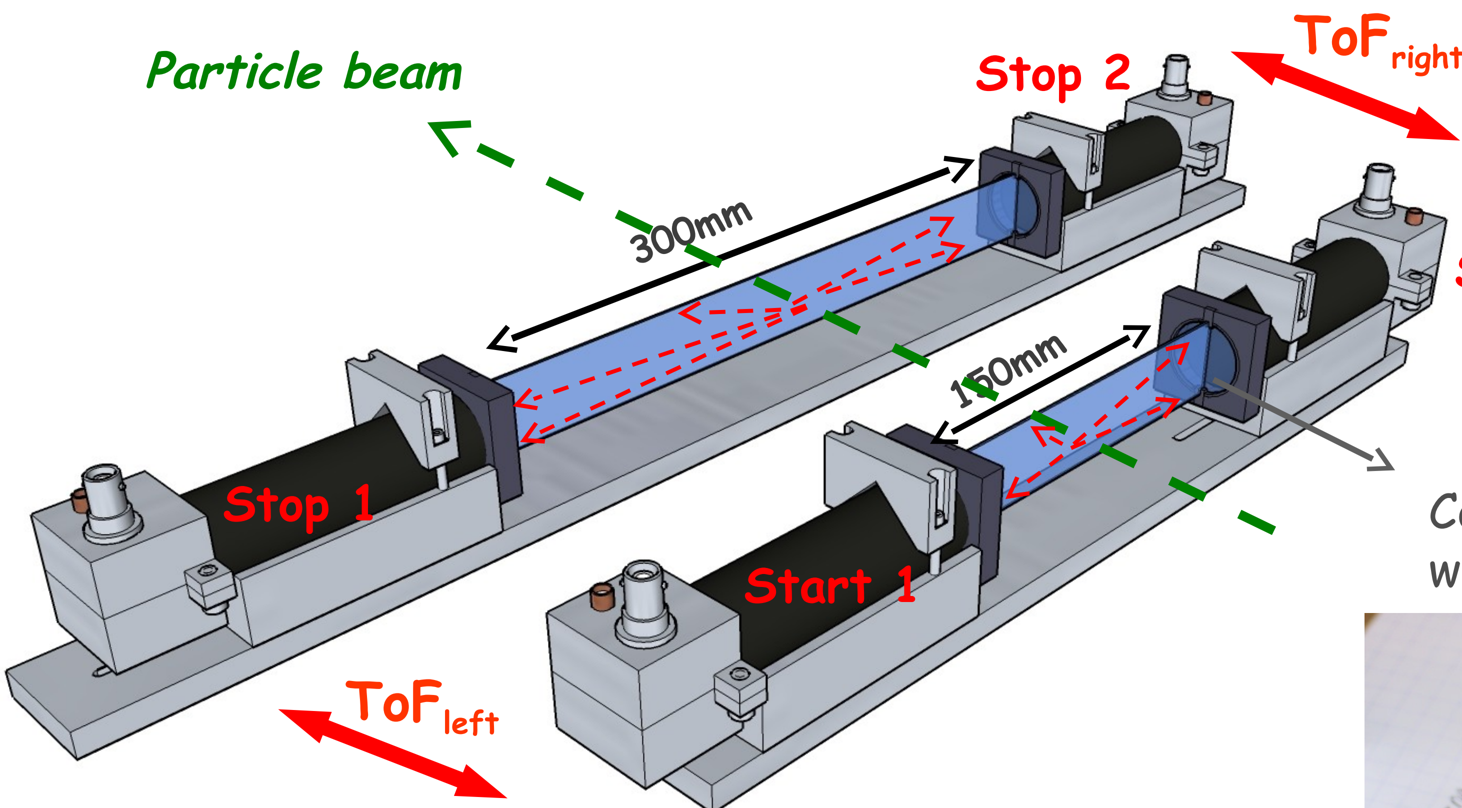
MCP-PMTs have the shortest TTS (< 25ps) but size is not adapted to a large ToF wall



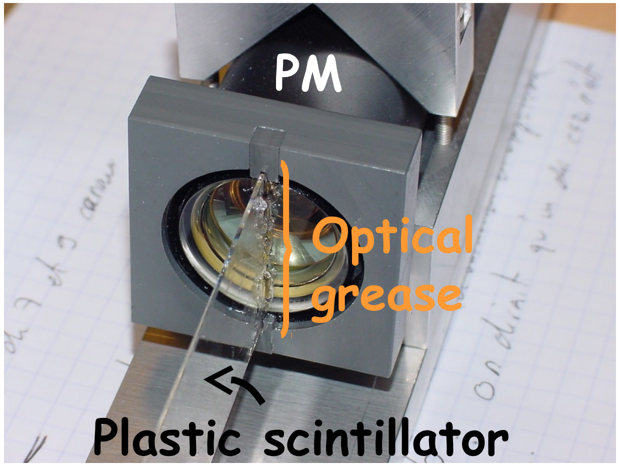
Dynode-based PMT

ToF measurements to confirm our technological choices

ToF measurement methodology



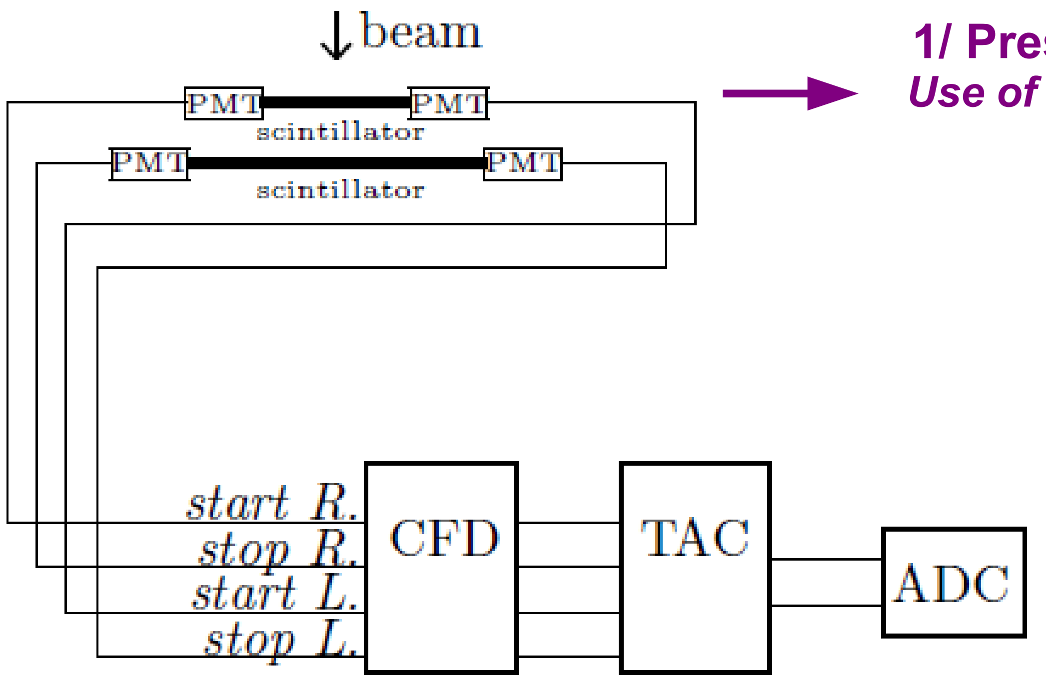
Contact plastic/PMT without light guides



Plastic scintillator 32 mm wide to match the PMTs diameter

$$TOF = \frac{TOF_{right} + TOF_{left}}{2}$$

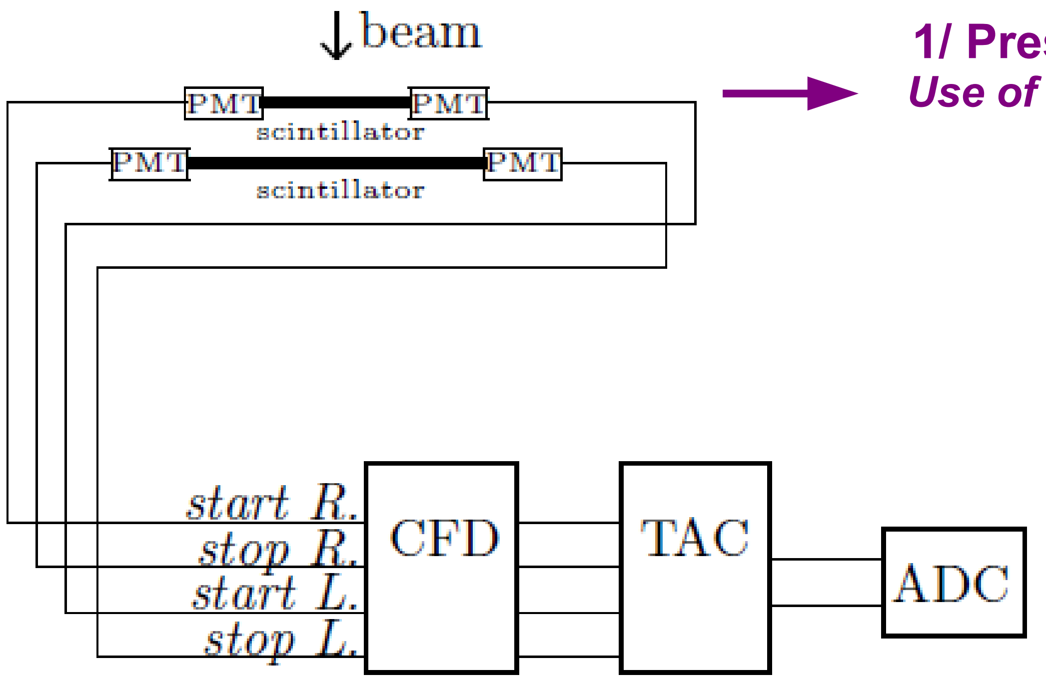
Definition of a proper front-end electronic chain



1/ Preserve the PMT output signal's integrity

Use of doubly-shielded high-bandwidth (LMR-240) coaxial cables + SMA connectors

Definition of a proper front-end electronic chain



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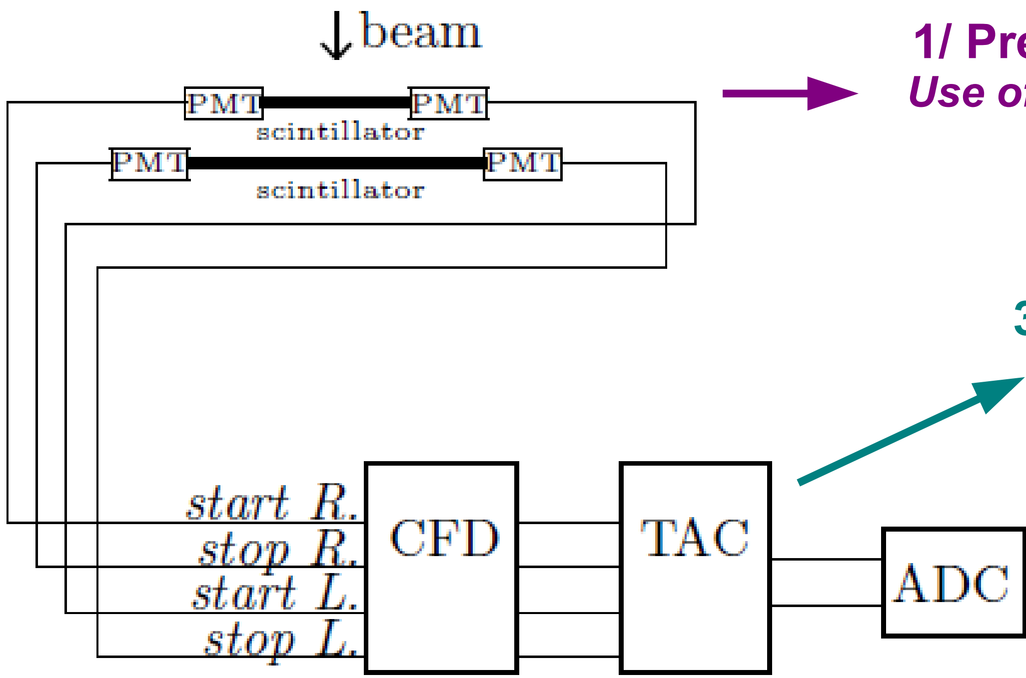
Use of doubly-shielded high-bandwidth (LMR-240) coaxial cables + SMA connectors

2/ Conversion into NIM logic signals by a CFD.

CFD (Philips Scientific 715) adapted to short rise-time signal (high analog bandwidth) + low jitter + well known walk effect (for time correction)

Definition of a proper front-end electronic chain



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3/ NIM signals feed a TAC (Ortec 566). The TAC output is digitalized by a 12-bit ADC (CAEN V785N).

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Electronic time resolution → 8 ps FWHM

ToF measurements and results

2008-2010
e^- beam @ ELSA
CEA DAM DIF

Many experiments with electron beam (8ps FWHM pulse) to mimic the interaction of a relativistic heavy ion

August 2009
^{56}Fe@400A.MeV
FRS

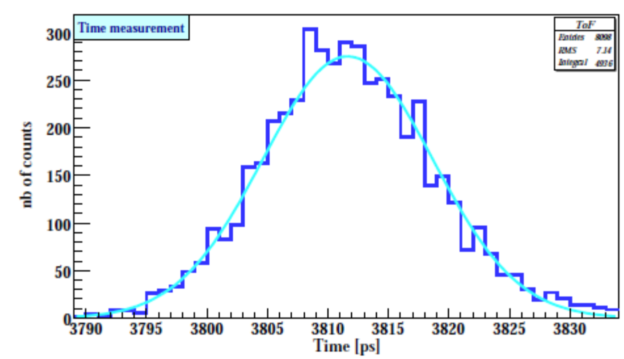
Use of 300 x 32 x 1 mm^3 EJ-232 as STOP + H6533 PMTs

30 ps FWHM

November 2010
^{238}U@600A.MeV
FRS

Use of 600 x 32 x 4 mm^3 EJ-232 as STOP
Test of both H6533 and H10580 PMTs

PMTs	Time resolution [ps]
H6533	17 ps FWHM
H10580	21 ps FWHM



Results

Extraplation of the ToF resolution
for heavy fission fragments @ 600A.MeV

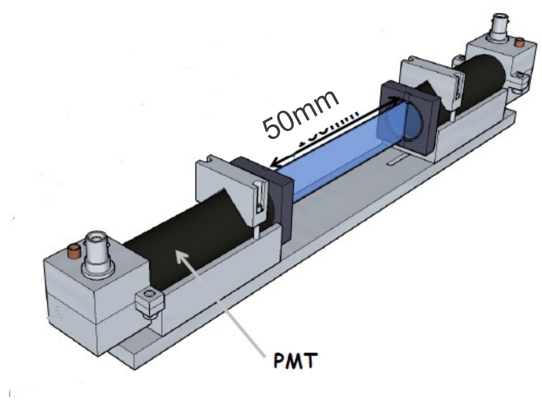
↓

27 ps FWHM with H6533 PMTs
33 ps FWHM with H10580 PMTs

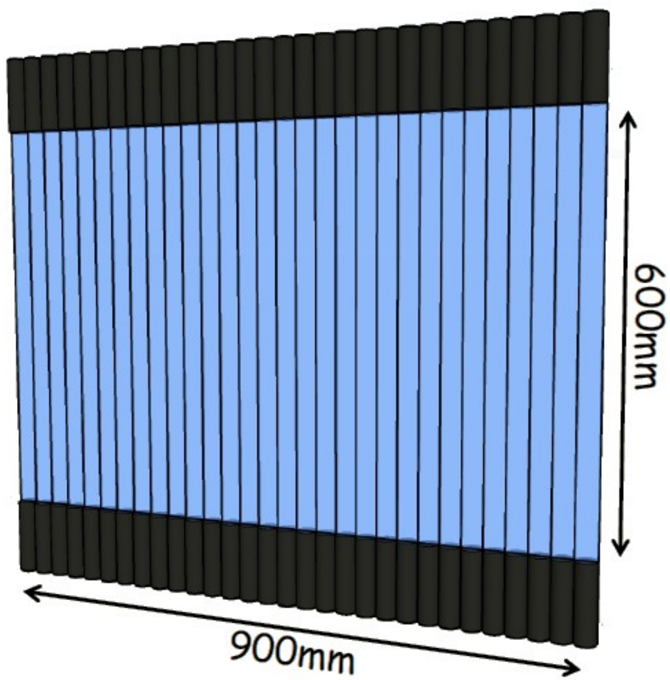
↓

Better than the 40 ps FWHM
needed for the SOFIA experiment

SOFIA final design



START : 50 x 32 x 1.5 mm^3 EJ-232
with 0.25 % MBZ quencher + H6533 PMTs

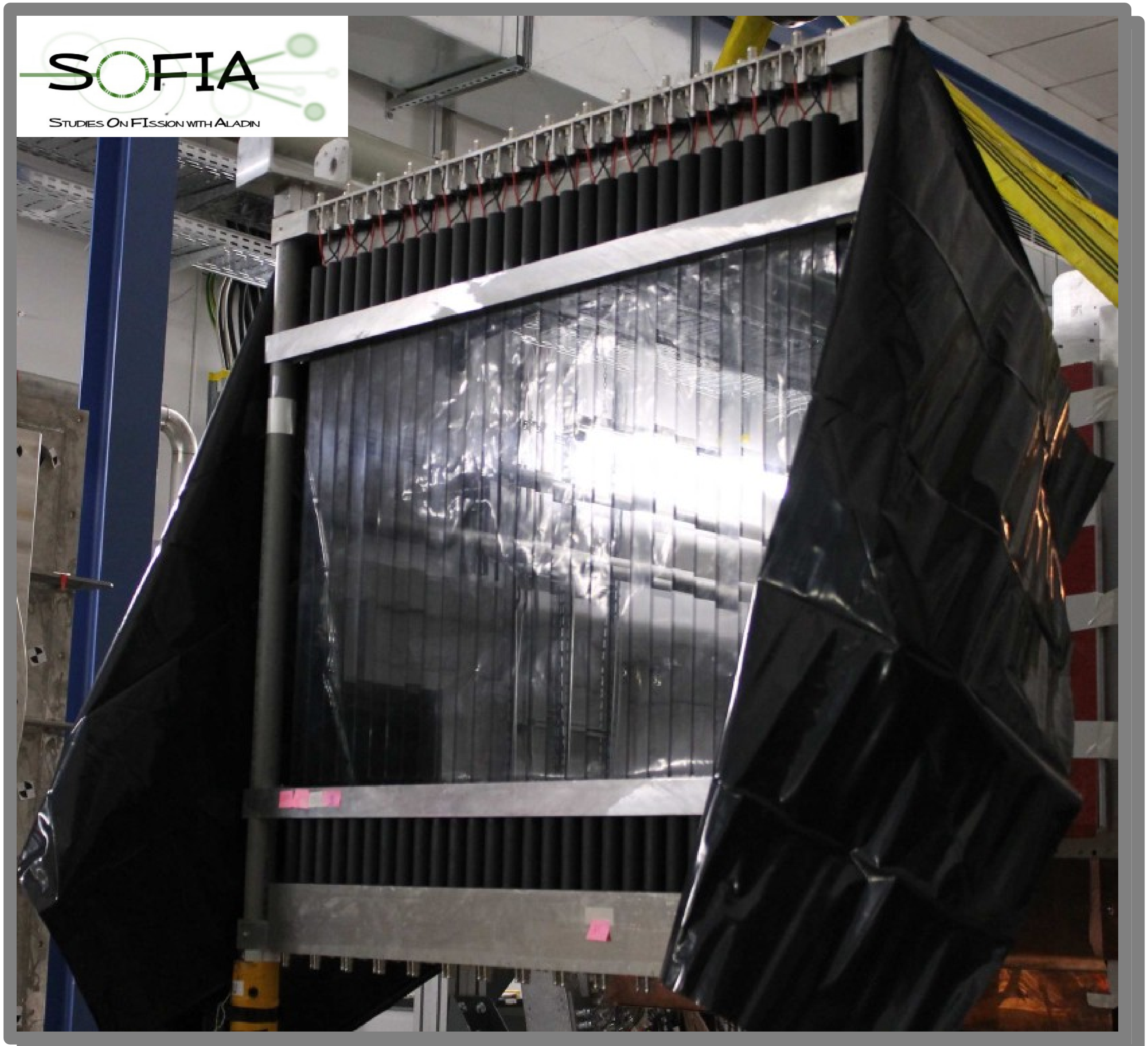


STOP : 600 x 32 x 5 mm^3 EJ-232
non-quenched

28 plastic slats

16 x H6533 PMTs on the center
38 x H10580 PMTs on the edges
(60 % less expensive)

Pictures - SOFIA



ToF wall

VME FPGA-based TDC with picosecond resolution

56 PMTs for our ToF set-up → we need a lot of TACs !!!

ALTERNATIVE SOLUTION FOR SOFIA – Studies On FIssion with ALADIN

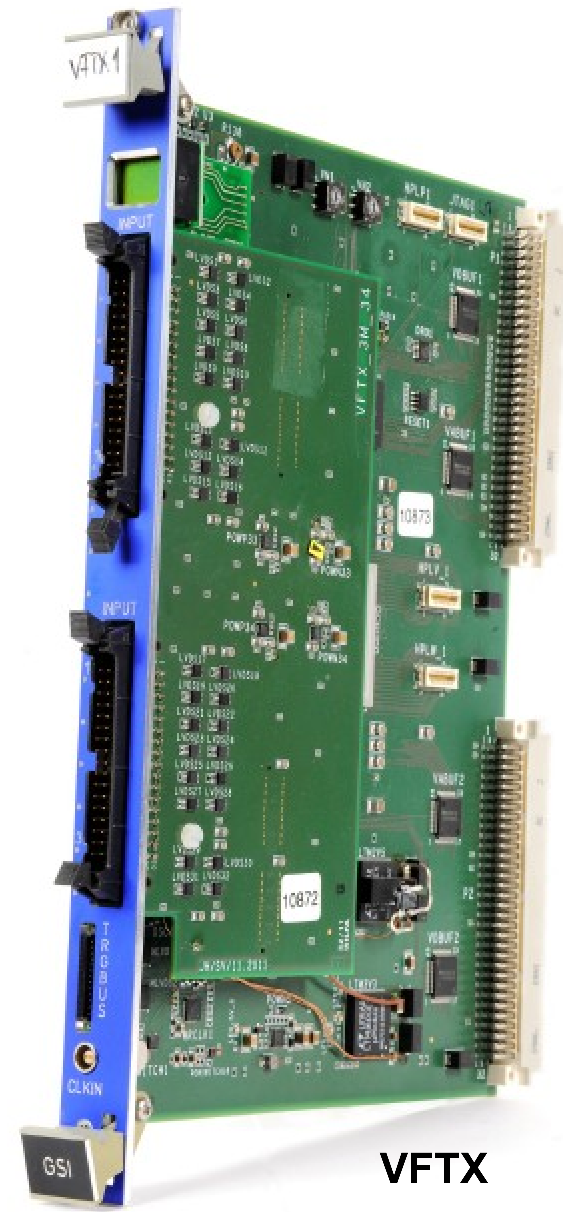
New 16-channels VME TDCs
with a resolution below 20 ps FWHM maximum

Developed by EE department @ GSI

Wave Union algorithm

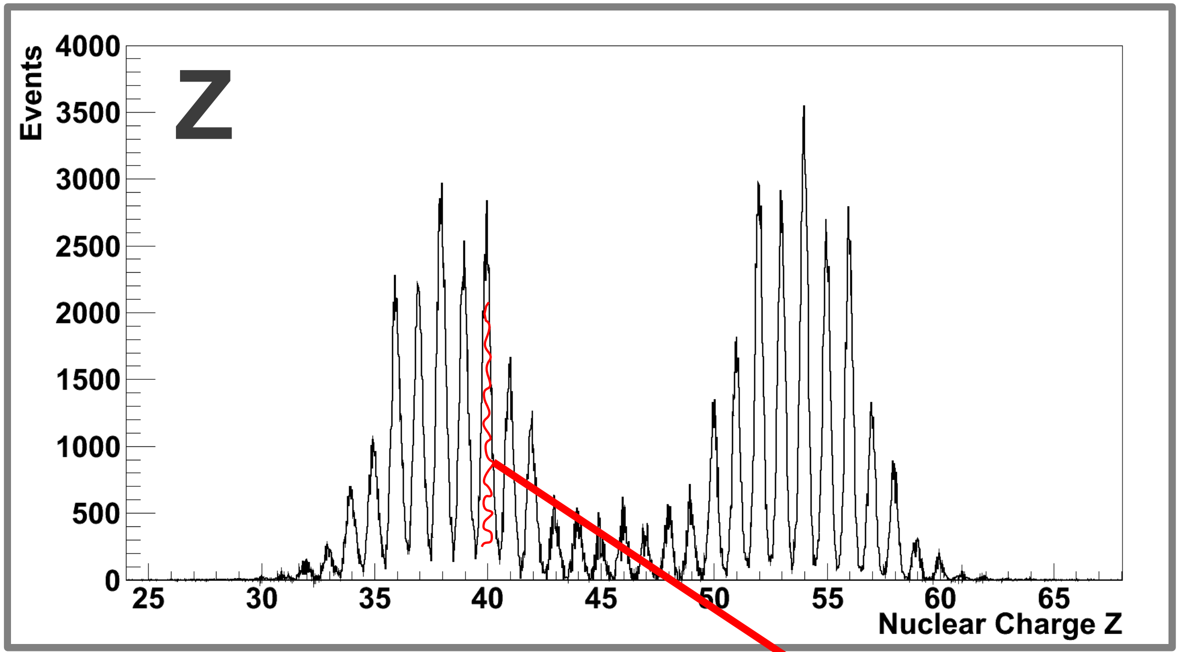
Implemented in the FPGA of the GSI logic module VFTX

Intrinsic TDC time resolution
→ 18 ps FWHM



VFTX

Preliminary results on mass reconstruction - SOFIA



Example :

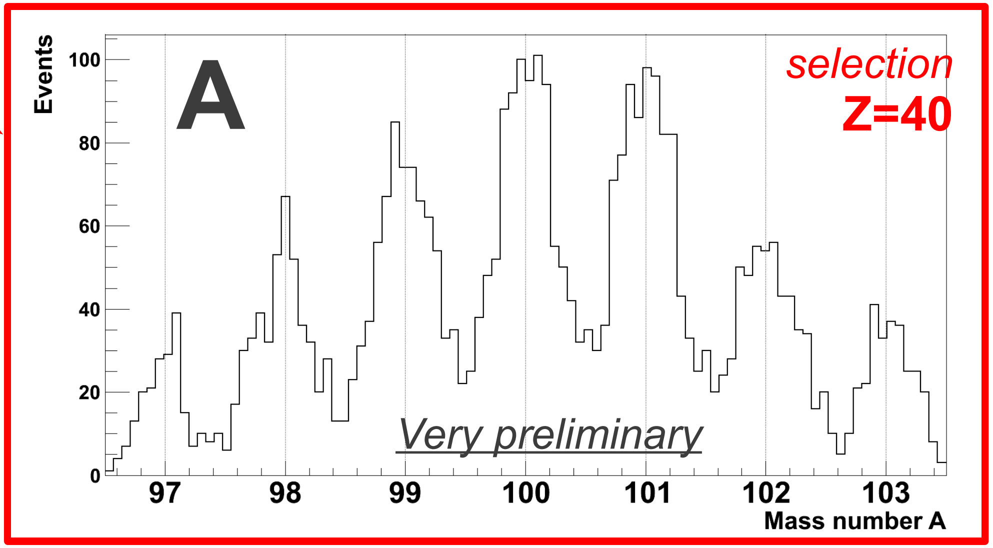
$^{235}U^*$

coulex-induced fission

SOFIA
STUDIES ON FISSION WITH ALADIN

Very preliminary results :
Rough correction of the walk effect

Mean mass A resolution for Z=40 :
→ 0.6 FWHM
… that corresponds to
50 ps FWHM ToF resolution
(preliminary)
(will be better after proper time corrections)



Conclusion

Development of a new large ToF set-up based on plastic scintillators read-out by dynode-based PMTs for the SOFIA experiment

Unprecedented ToF resolution using relativistic ions beams

Two test experiments @ FRS :
using ^{56}Fe@400A.MeV → 30 ps FWHM
using ^{238}U@600A.MeV → 17 ps FWHM

Final design for optimizing ToF performance with relativistic (600A.MeV) heavy fission fragments → 27 ps FWHM

SOFIA
STUDIES ON FISSION WITH ALADIN

Time resolution better than the 40 ps FWHM needed for the SOFIA experiment → confirmed by our preliminary results on mass reconstruction

DE LA RECHERCHE À L'INDUSTRIE

Backup slides

Choice of the detector technology

Secondary beam spot size ≈ 20 mm → small-sized START detector

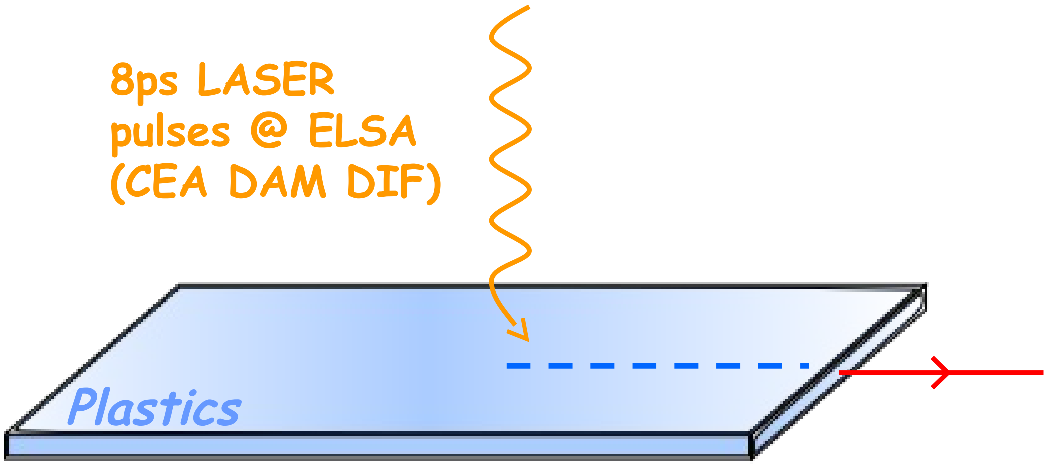
Dispersion of fission fragments in the dipole → 900x600 mm² STOP detector

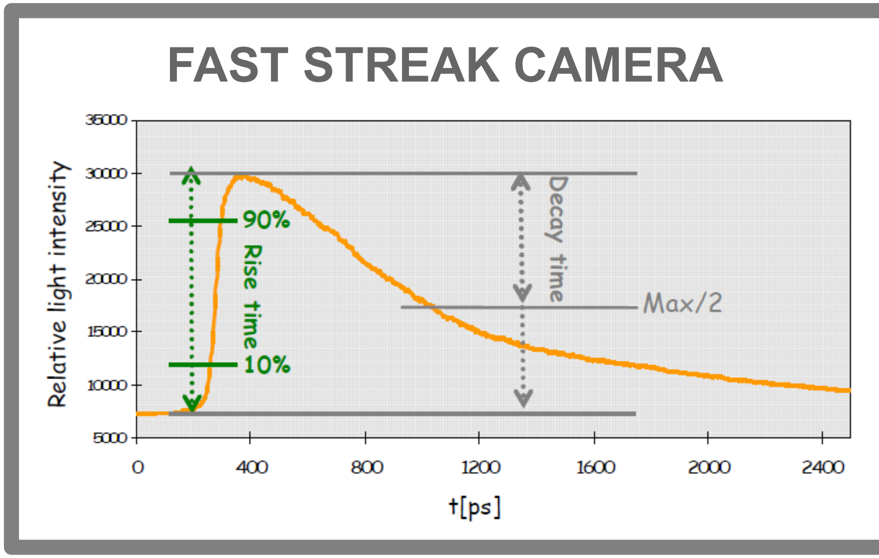
2 options

tRPCs		Plastic scintillators + PMTs	
MIPs	50 ps RMS in ALICE *[Akindinov et al., NIMA 602 (2009) 709]* 75 ps RMS in HADES *[Blanco et al., NIMA 602 (2009) 691]*	MIPs	Usually 100 ps RMS
1 GeV/u U beam	68 ps RMS *with small-sized tRPCs* *[Paradela et al., IEEE Conference (2011)]*	95 MeV/u ^{40}Ar beam	10 ps RMS *with small-sized detectors* *[Nishimura et al., NIMA 510 (2003) 377]*
		80 MeV/u ^{124}Xe beam	10 ps RMS *using MCP-PMTs (LYCCA)* *[Hoischen et al., NIMA 654 (2011) 354]*

The only option to study :
Plastic scintillators read-out by PMTs

Plastic scintillating materials benchmarking





Supplier	Type	Quencher	Rise-time [ps]	Decay-Time [ps]	L [cm]
Saint-Gobain	BC-422	0.5%BZ	68	592	< 8
Eljen-Technology	EJ-232	0.5%MBZ	37	1374	6
		0.25%MBZ	44	1502	
		0%	107	2543	17

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1/ Measured rise-times 107ps for non-quenched and 37-44ps for quenched ones.

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4/ Attenuation length is very important for fast timing plastics

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2/ The shortest rise-time has been obtained for Eljen Technology EJ-232

3/ The decay-time decreases with quencher amount

4/ Attenuation length is very important for fast timing plastics

5/ Light attenuation becomes worst with quencher amount

Supplier	Type	Quencher	Rise-time [ps]	Decay-Time [ps]	L [cm]
Saint-Gobain	BC-422	0.5%BZ	68	592	< 8
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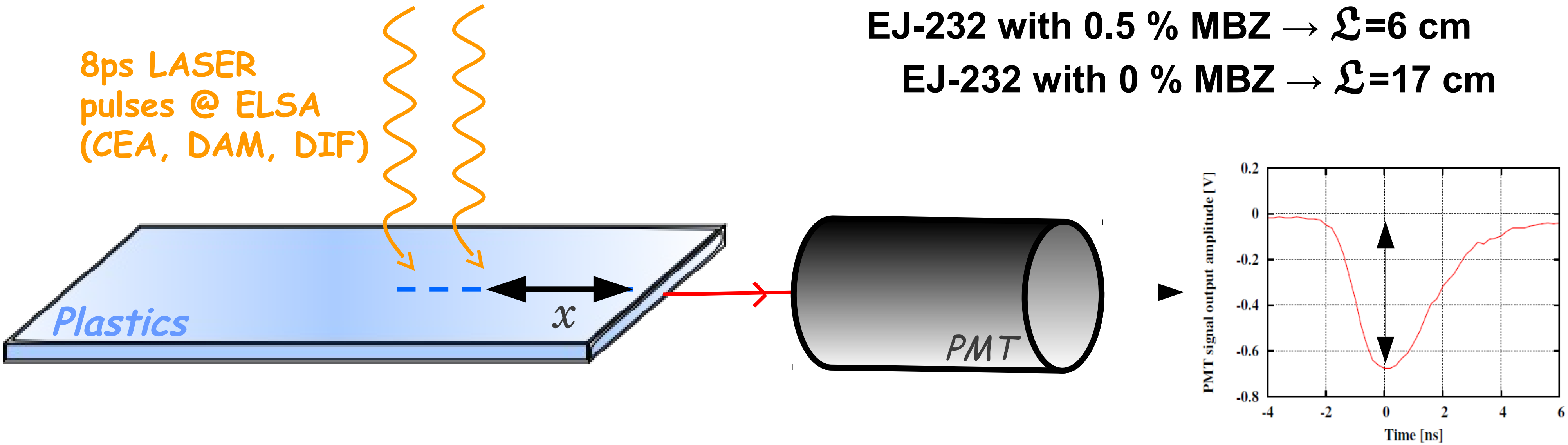
		0.25%MBZ	44	1502	
		0%	107	2543	17

Study of attenuation length $\mathfrak{L}$*

* Due to self-absorption, the light output is half-reduced after a propagation length equal to $\mathfrak{L}$.

EJ-232 with 0.5 % MBZ → $\mathfrak{L}$=6 cm

EJ-232 with 0 % MBZ → $\mathfrak{L}$=17 cm



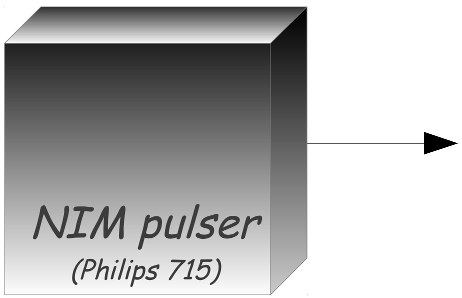
Rather short attenuation lengths !! (Standard plastics materials → $\mathfrak{L}$>100 cm)

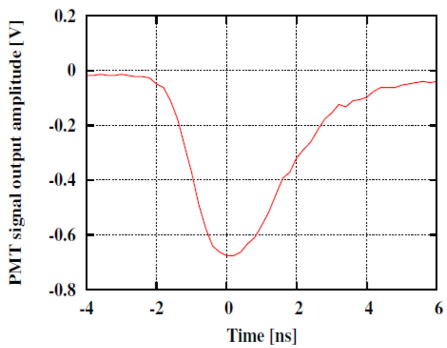
The addition of quencher strongly decreases the attenuation length.

Find a compromise between rising time and light production (weak attenuation)

This prevent us from using quencher in 600 mm long scintillator slats

Definition of a proper front-end electronic chain





Typical PMT output :
Rise-time → 2 ns
Decay-time → 3 ns

Preserve the PMT output signal's integrity
Use of doubly-shielded high-bandwidth (LMR-240) coaxial cables + SMA connectors

Conversion into NIM logic signals by a CFD.
CFD (Philips Scientific 715) adapted to short rise-time signal (high analog bandwidth) + low jitter

Time walk effect → 200 ps shift for a variation of 10 on the input signal amplitude
Known for each CFD – Essential to correct for the time walk effect

NIM signals feed a TAC (Ortec 566).
The TAC output is digitalized by a 12-bit ADC (CAEN V785N).

Electronic time resolution → 8 ps FWHM

ToF measurement with electrons @ ELSA (CEA, DAM, DIF)

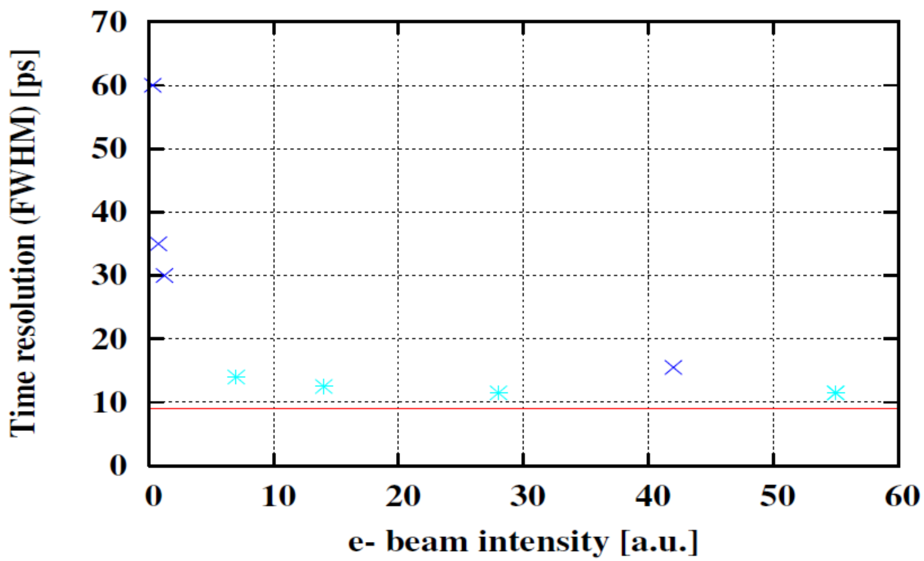
About electron beam @ ELSA

8ps FWHM electron pulse duration → mimic the interaction of a relativistic heavy ion
Adjustement of the intensity of the electron beam → modulation of the energy loss
Restriction to 0.5 mm plastic thickness because of electron beam divergence

Our set-up (2008)

START : 150 x 32x 0.5 mm^3 BC-422 with 0.5 % BZ quencher + H6533 PMTs
STOP : 150 or 300 x 32 x 0.5 mm^3 BC-422 with 0.5 % BZ quencher + H6533 PMTs

Results



Conclusion

The resolution appears to improve strongly when increasing the beam intensity

Intrinsic time resolution the ToF detector can be as low as few ps for very high energy in the detector

Time resolution significantly degrades when increasing the scintillator's length (strong light attenuation)

Counting rates

Counting rates at S2 → 2 MHz (SOFIA)

↓

New PMTs for SOFIA-2 (2014)

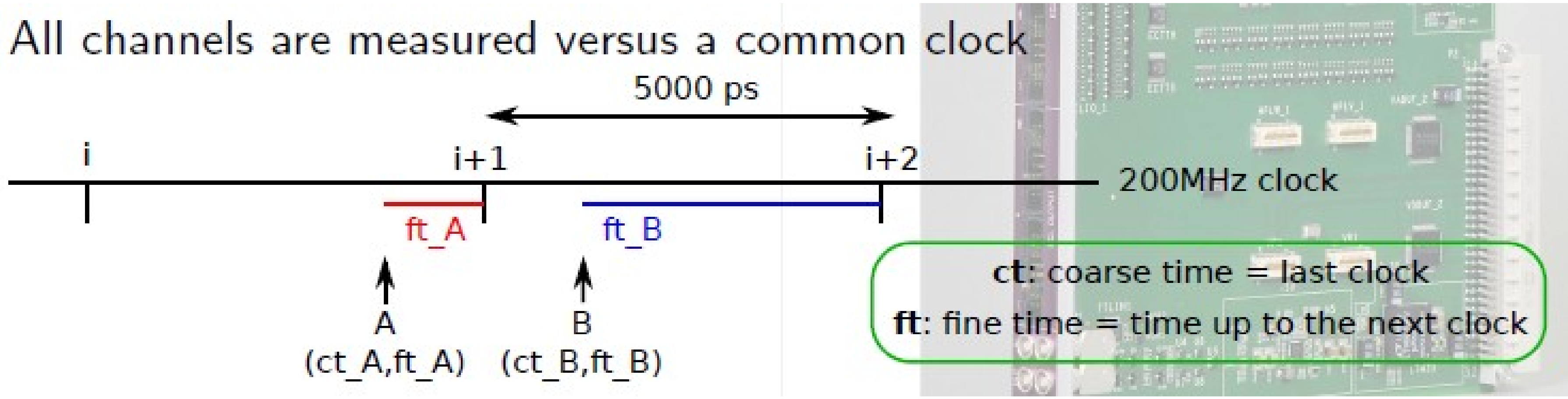
→ modified resistive bridge between dynodes to support higher intensities

↓

Expected counting rates at S2 → 10 MHz

VFTX (1/2)

Principle : use the logic gate transit (~ 3-5 ps) to provide a precise time measurement.

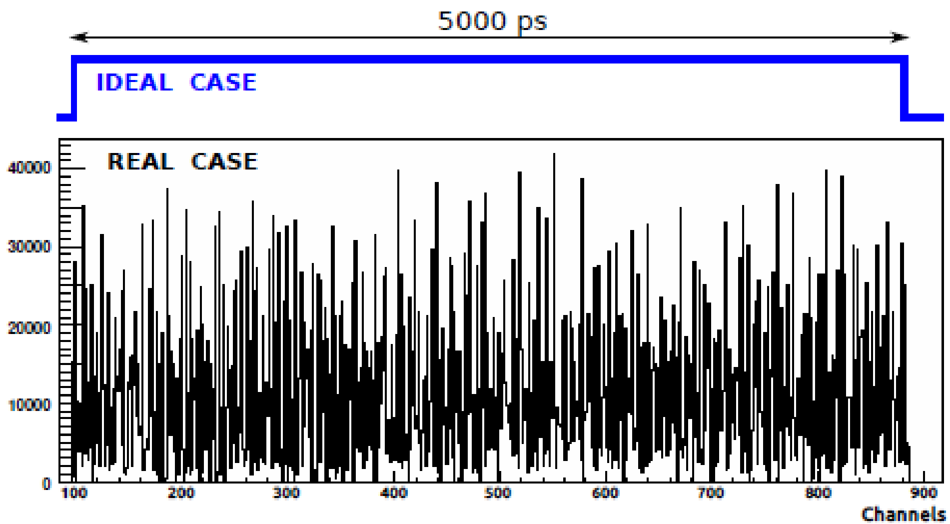


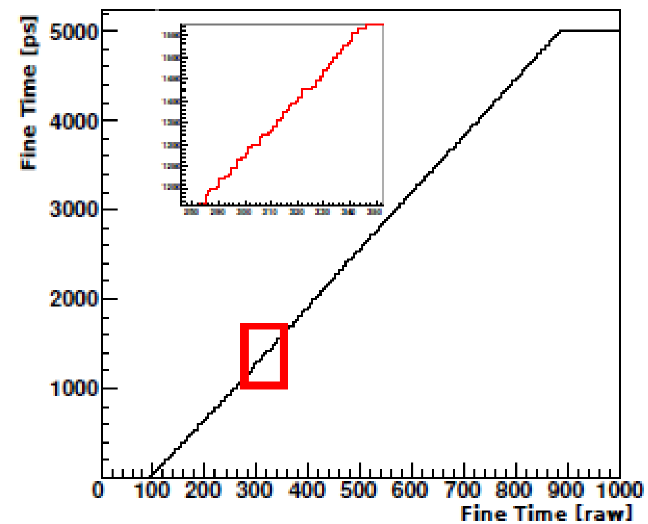
Necessity to have a very stable clock @ 200 MHz

Large intrinsic non-linearity of the ne time which needs to be corrected
→ easy to correct and stable in time.

VFTX (2/2)

Calibration of the fine time





Intrinsic resolution using a pulser

Δt<5μs → same coarse time

$\sigma_{VFTX} \approx 8ps$ RMS

Δt<5μs → different coarse time

$\sigma_{VFTX} \approx 12ps$ RMS