Action soutenue par le Conseil Régional

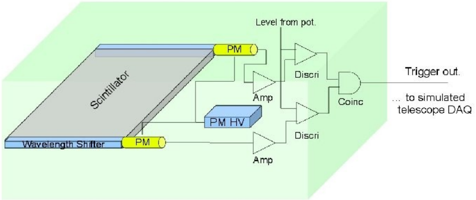
GATE prototype / demonstrator of Clock Distribution and Central Trigger for CTA (EAS Scintillator array)

Physicists: M. Punch, A. Djannati-Ataï, S. Pita, Y. Becherini

Engineers: C. Dufour, C. Boutonnet, B. Courty, S. Selmane, Ch. Olivetto

GATE team: A. Ménival, (P. Guillouët / A. Lafitte, for meca tbd)

Project Manager: Cédric Champion



Introduction (reminder)

Central trigger for unambiguous tagging of events

- Central Trigger by:
  - time pulses can tag coincidences to precision of signal transfer, which can vary by few ns with fibre movement/dilatation
  - time-tagged event labels depends on time-tagging precision which can be achieved
- 10ns tagging (easy to implement with clock distribution by optical fibre) is overkill already for reasonable rates (1kHz rate, 64 telescopes, rate of random coincidence 40Hz
  - ! But if single rate is 10kHz ⇒ 4kHz coincidence rate, so must use topology "neighbours" of 10 to bring back to ~100Hz
- $$R_{\text{sys,acc}} = M\,{}^{N}C_{M}\,R^{M}_{\text{single,acc}}\,T^{M-1}$$ N telescopes M-fold coinc.

R_{sys} (Hz)	$R_{tel,coinc}$ (Hz)	nCm	M coinc mult	N Tels	Coinc (ns)	$R_{single,acc}$ (Hz)
40.32	1.26	2016	2	64	10	1000
4032	126	2016	2	64	10	10000
600	48	300	2	25	10	10000
1200	96	300	2	25	20	10000
20	8	10	2	5	10	10000
160	64	10	2	5	80	10000

Introduction (philosophy)

For the stereoscopic triggering of the telescopes in CTA,
we favour an approach based on :

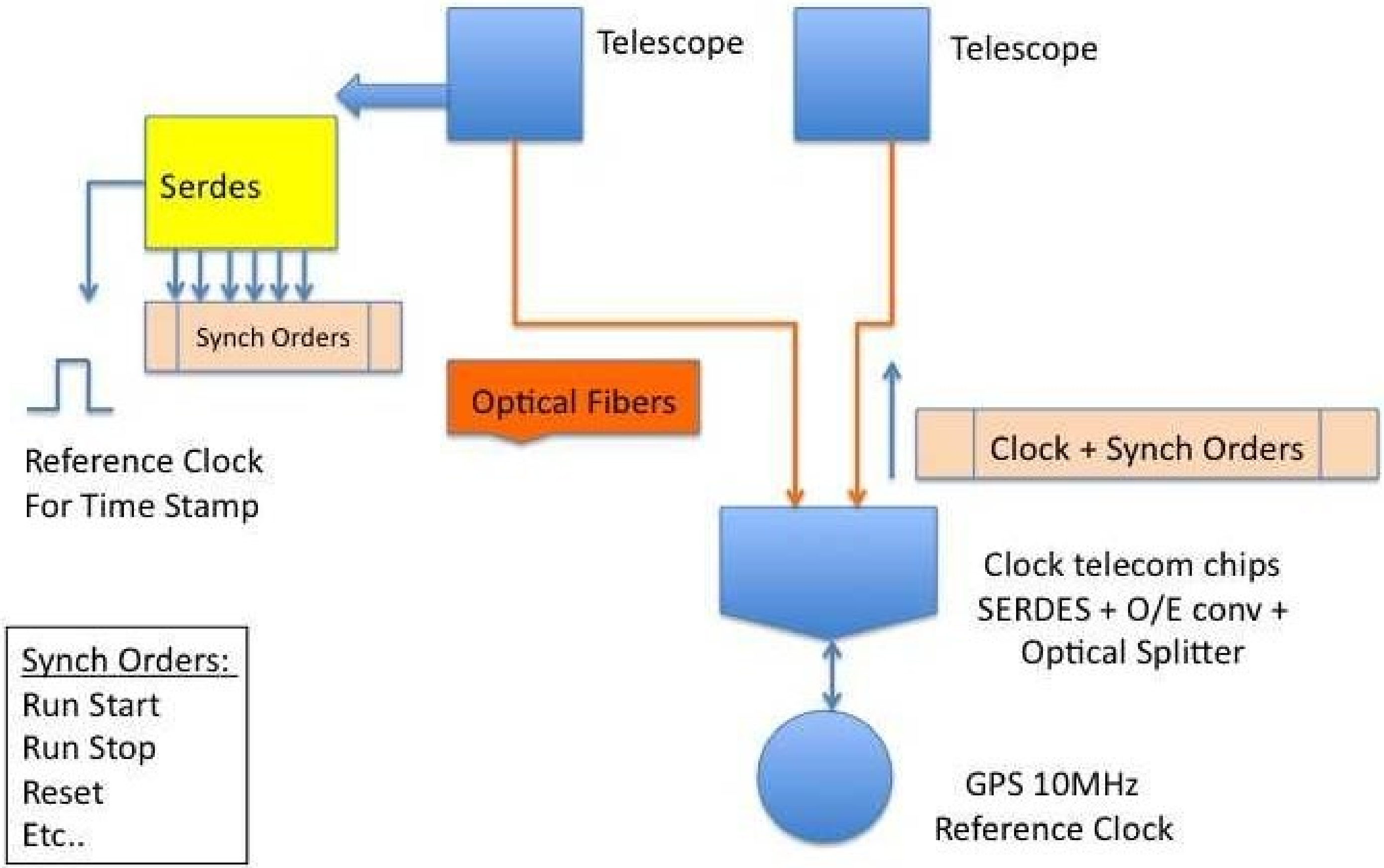
- Distribution of a high-precision clock from a central location (star-distribution)
- Time-tagging camera events (or partial events) using this clock
- Collecting streams of time-tags in a central trigger crate
  and checking for coincidence in software
- Then sending the streams of coinc. time-tags *either* (depending on bottleneck):
  - to the relevant cameras, to ask for the data to be sent to central, so reducing the stream of data to send over ethernet from telescope to central farm, *or*
  - to the central farm of processors which hold the events in memory, to identify the events to be written to disk and passed on for further processing

Other approaches possible:

- Sending of trigger pulses to central station to be put into time and checked for coinc. Complicated for large # of telescopes, difficult to avoid large dead-time
- All data to central, software search within data to extract time-tags & check for coincidences. Requires high processing capability and much bookkeeping (and needs clock-distribution in any case).

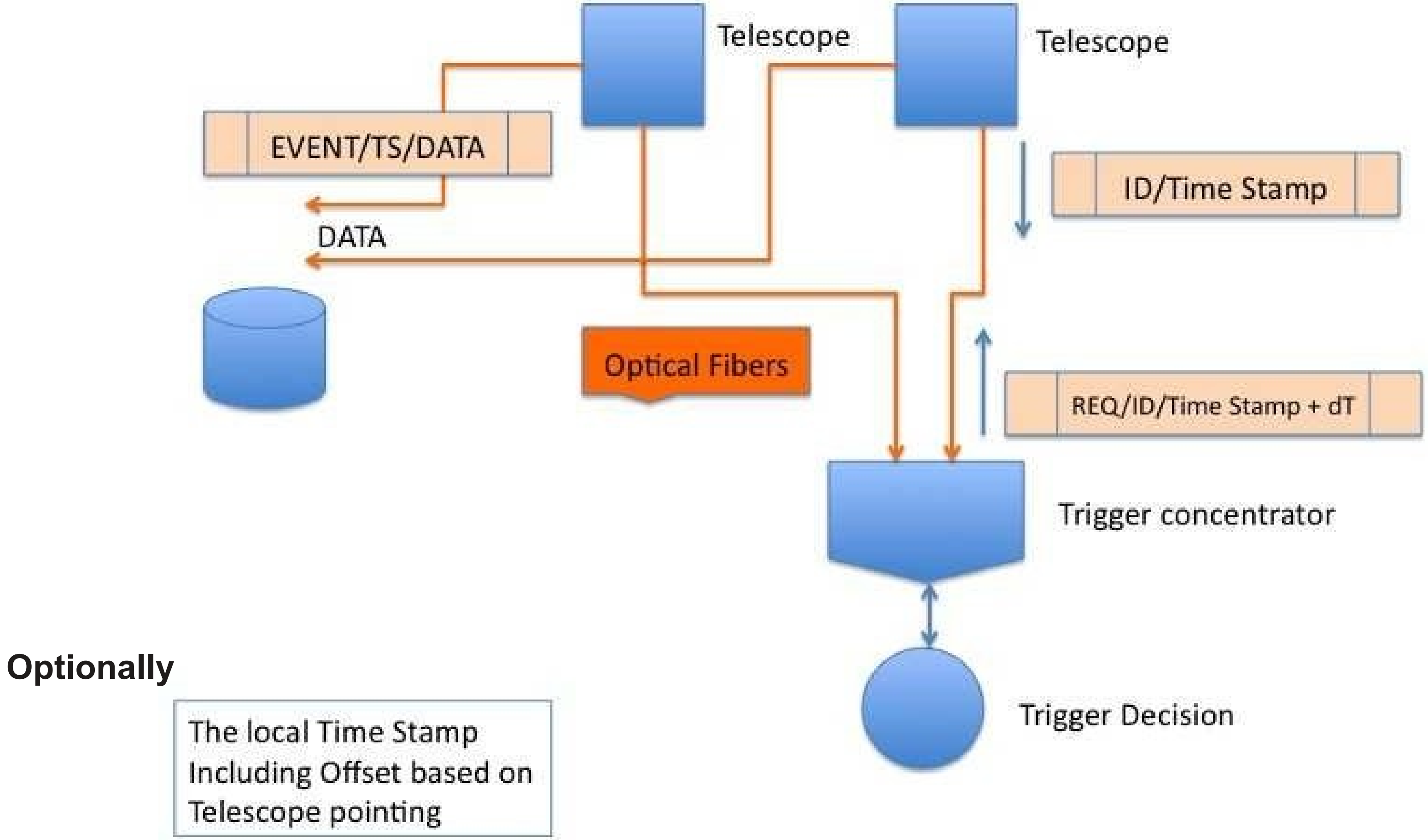
Inter-telescope Trigger; Clock Time-stamping topology

Distribution of reference clock and sync orders
from central location by dedicated fibre



Inter-telescope Trigger topology

Send telescope time-tags stream by dedicated fibre to central, return stream of coincident event time-tags to each telescope



Implementation of the Clock/Trigger solution

"MUTIN" Card
(multi-usage telescope interface), in PXI norm

A prototype board designed to test full functionality (Clock/Trigger)

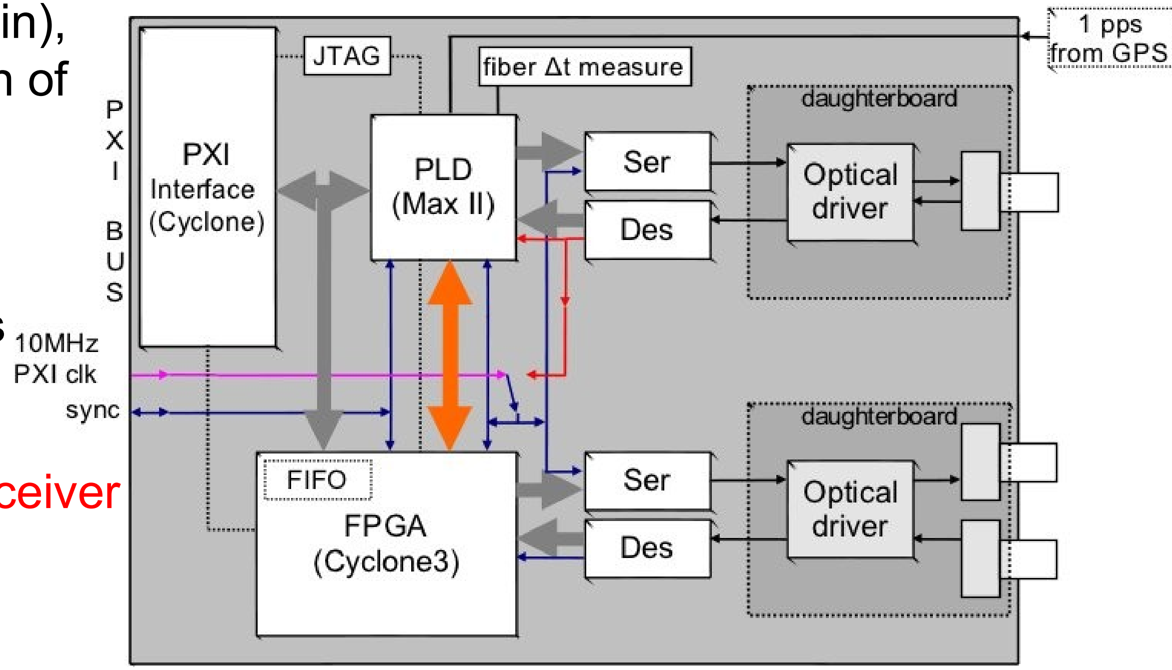
Flexible, with programmable logic (EPLD, 2x FPGA)

Allows to "simulate" a telescope on one side
and the trigger part on the other

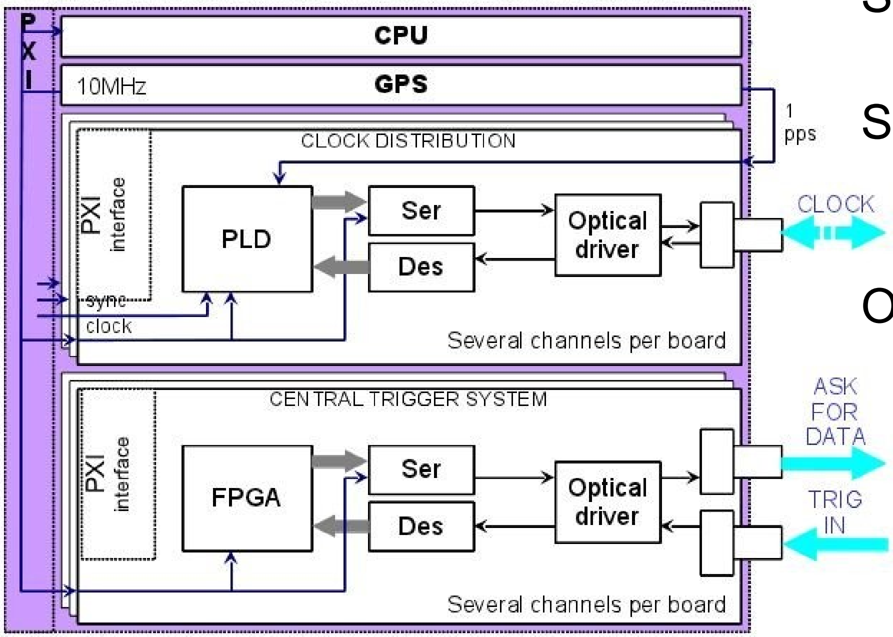
Optical daughter cards (2 per Mutin),
for the transmission / reception of
optical fibres' signals

Daughter cards allow to study
independently different
opto-electronics/fibre solutions

Latest, to be tested soon:
commercial bidirectional transceiver



Implementation foreseen for CTA



Several "Mutin" cards in central PXI crate, in multi-channel format

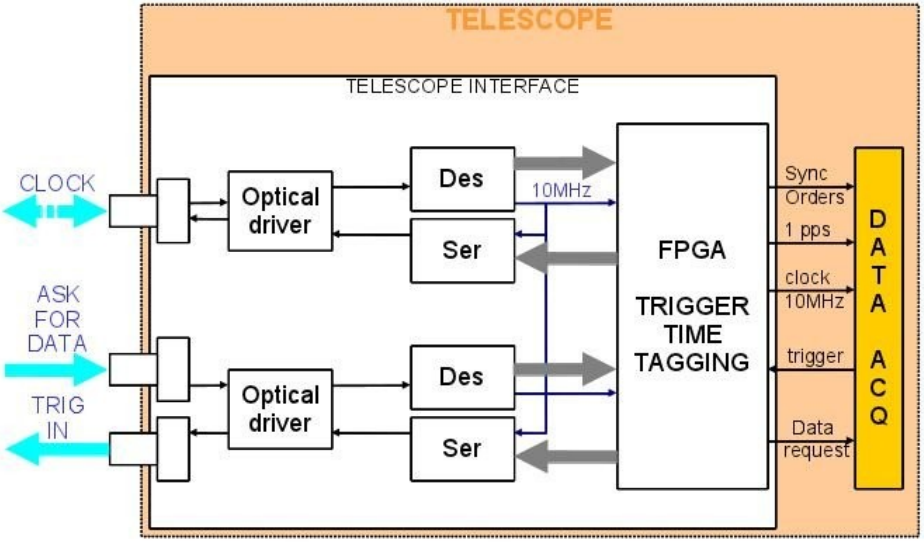
Some cards specialized for clock distribution (either with electronic + optical fan-out, or single bidirectional fibre per telescope)

Other cards specialized for the request / reception of time-tags

- polling over telescopes, at 100 Mbps with 1/8 fan-in for 64-bit tag → can cope with ~200kHz telescope rate, or
- single bidirectional fibre per telescope

"Mutin" card in each telescope (PXI or other norm)

Time-tagging signals (1pps, 10MHz) transferred to DAQ or Camera Trigger, or possibly tagging integrated in Mutin



Realisation using MUTIN Card

MUTIN card, current design specs
- Standard PXI: **100 x 160 mm**
- Consumption: **~2 Watts**

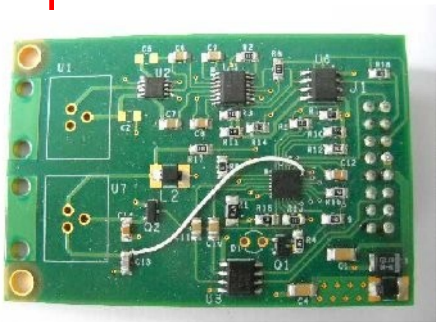
Daughter **Optics** cards:
- Consumption: 1.1W
- Standard Emitting diode power
  - 0.5mW →1mW peak
- Discrete Emitting diode power
  - 1.8mW →3mW peak

MUTIN Card in PXI crate

MUTIN + 2 Optics cards
- Total power consumption **~4.2W**
- Power supply, only **3.3 V** (+5V?)
- Cost (0.5+2x0.2)€ = **~ 1k€**
- Integration in PXI crate currently, but could make to other norm or standalone
- Connect to outside world via fibre
  - **≤ 3 fibres** (out of bundle of ~6) but could use single multi-mode fibre
- Connect to Camera preferably **LVDS**

Optics Cards

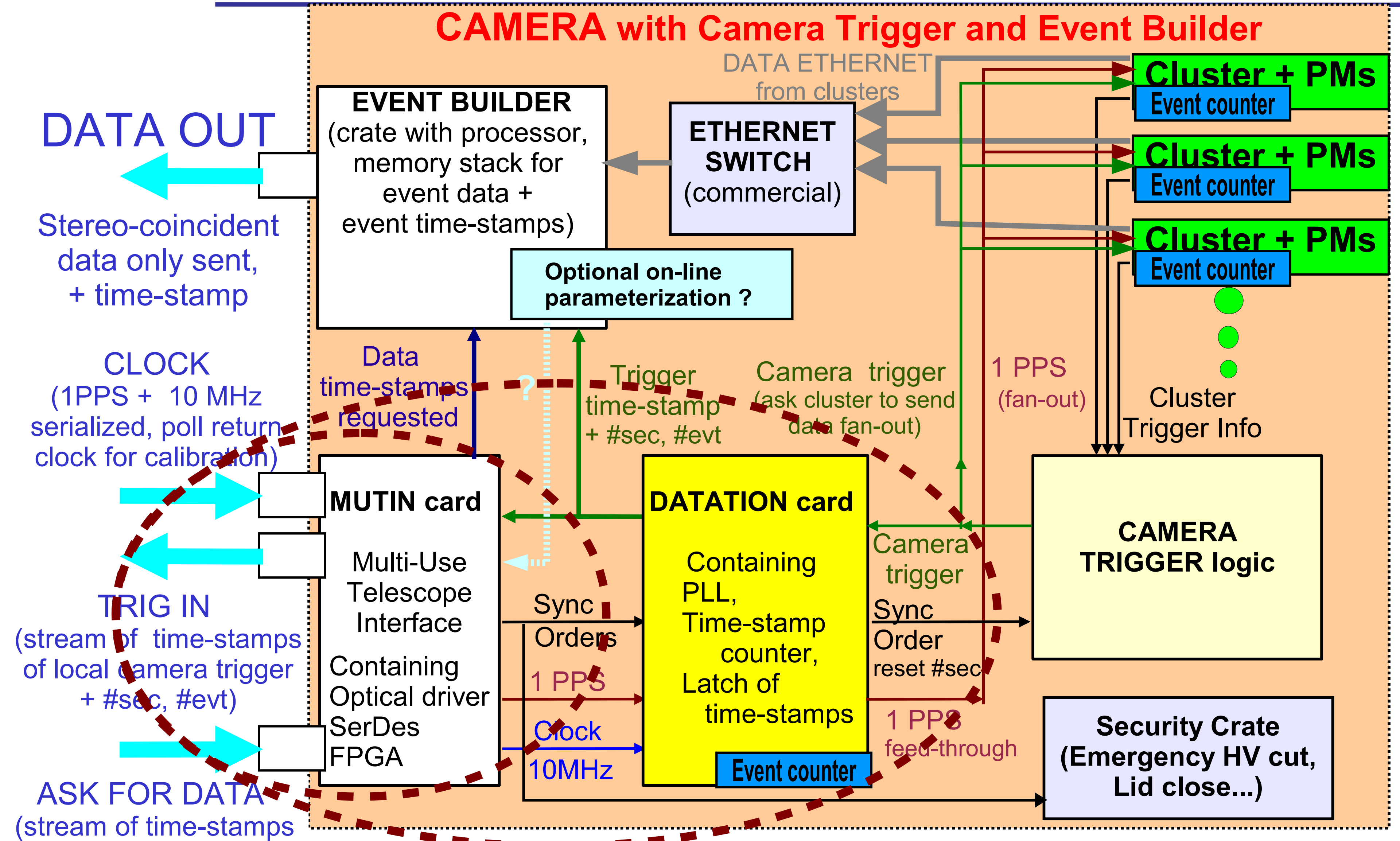
V1 with standard integrated components



V2 with discrete components, higher laser power possible

e.g. Commercial bidirectional tranceiver (tbd)

Ambitious option for Camera Architecture



Where **Event counter** is Counter of 1 PPS (reset by Sync order to Camera trigger) & Counter of Camera triggers (reset by 1 PPS)

GATE : How to field-test the Clock/Trigger

How to validate this scheme before CTA arrives ?

- PeV cosmic ray showers give particle reaching ground level
  - ⇒ pancake of particles, with similar timing characteristics to the Cherenkov light-front detected at lower energies by CTA
- Detection possible by an array of scintillators, separated by ~10m
- Can re-use the APC experience of “RELYC” (communication / outreach to schools), and PHEN-X (project for R&D after Simbol-X)
- A scintillator station is a CTA telescope “proxy”
- Functional verifications which are possible with this demonstrator:
  - verification of time-tagging of one station vs. the others
  - test the procedures of coincidence search (test of “particle-front” fit)
  - check for time-jumps, jitter, de-synchronisation ...
- What's not taken into account:
  - Event rate four orders of magnitude lower (~Hz per station, vs. 10kHz for CTA)

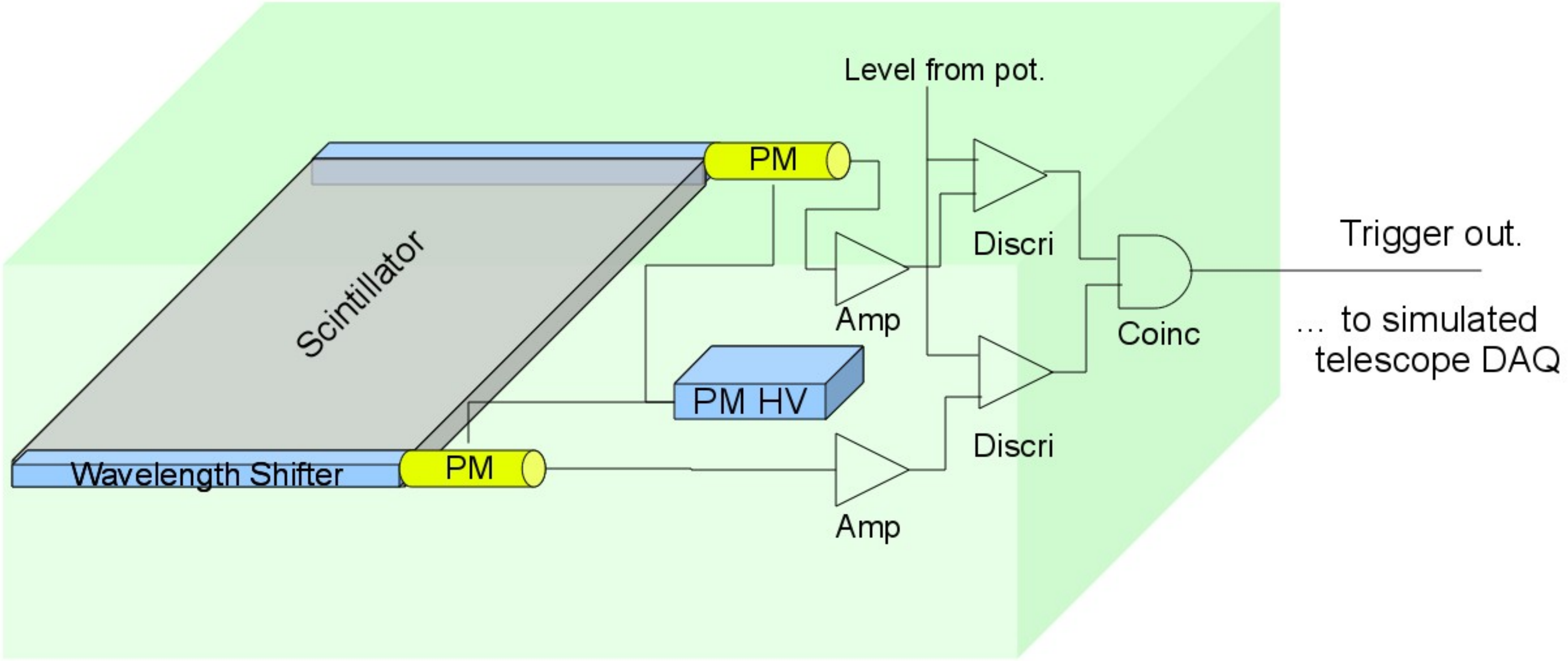
GATE : How to field-test the Clock/Trigger

What needs to be modified in the current test-bench

- Make a MUTIN card which works stand-alone, without PXI crate,
- Make a particle detection station ("suitcase") with:
  - Scintillator(s), ~1m^2
  - PMs for detection of scintillation light
  - High Voltages for the PMs
  - Wavelength shifter / Optical joint from scintillator to PMs
  - Electronics (amplifier, discriminator, coincidence)
- Concept:
  - Simplest possible box
  - Re-use previous APC developments (RELYC, PHEN-X)
  - Setting of gains, HTs by hand...
- Ensemble to be useful for outreach, student projects
  $\Rightarrow$ needs to be robust

Le schématique du « proxy télescope »

Modification / simplification de la « valise RELYC », en profitant des développements PHEN'X à l'APC



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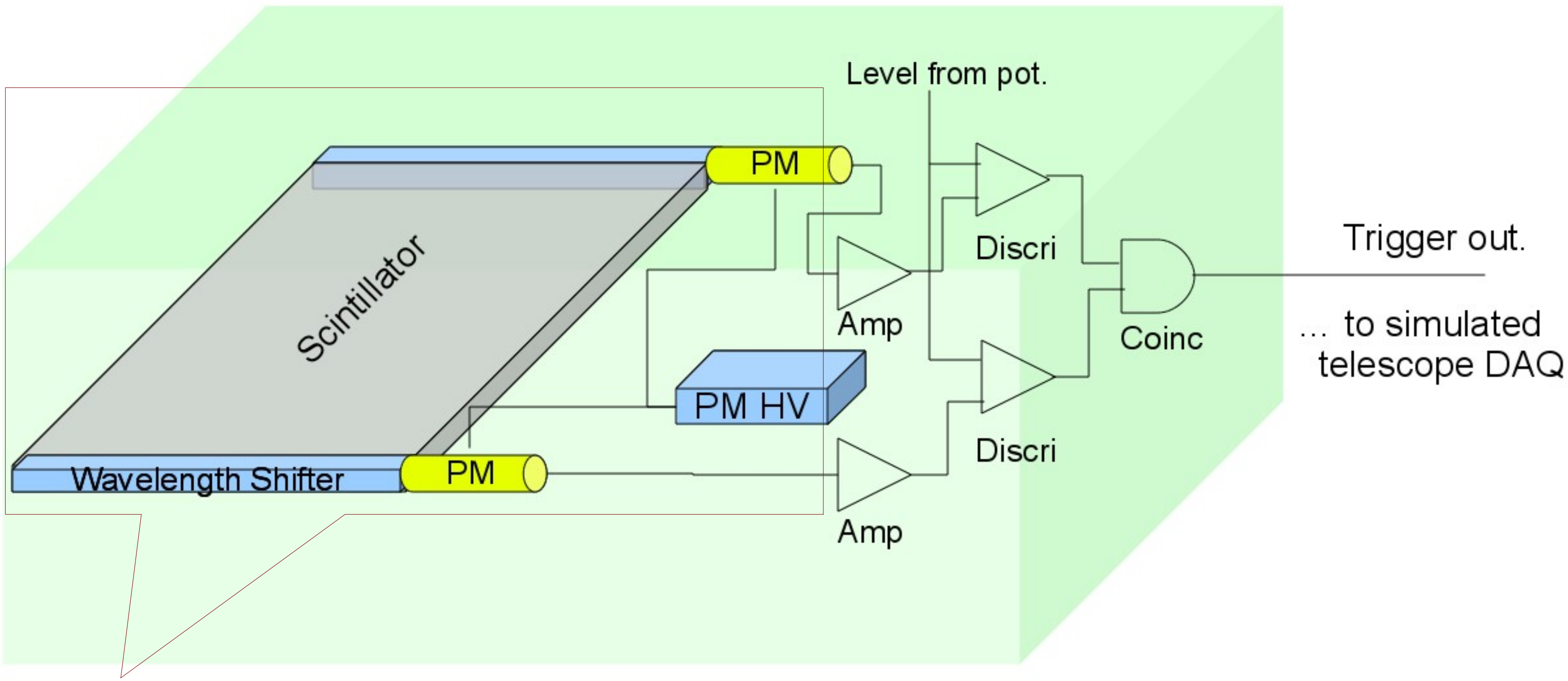

Partie à réaliser: commande, dessin, coupage, polissage, collage optique...

(demande de collaboration avec experts du CEA, envoyée Oct 2011)

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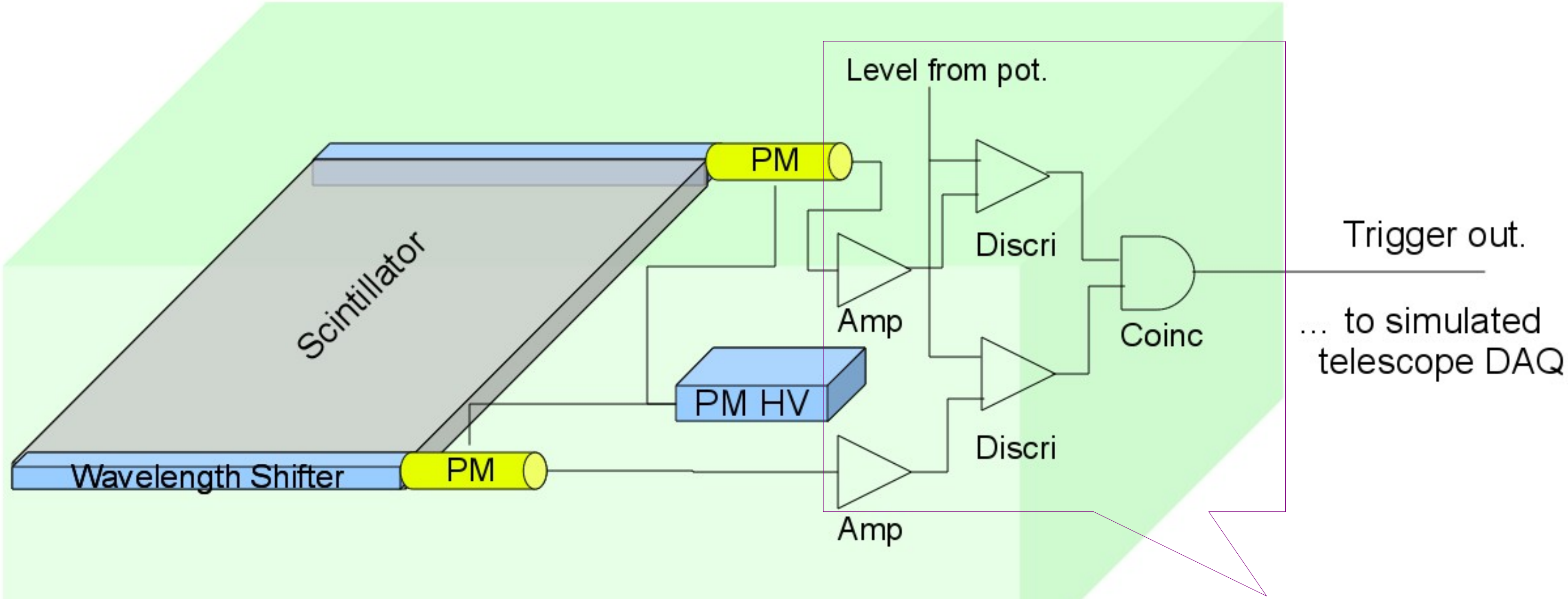


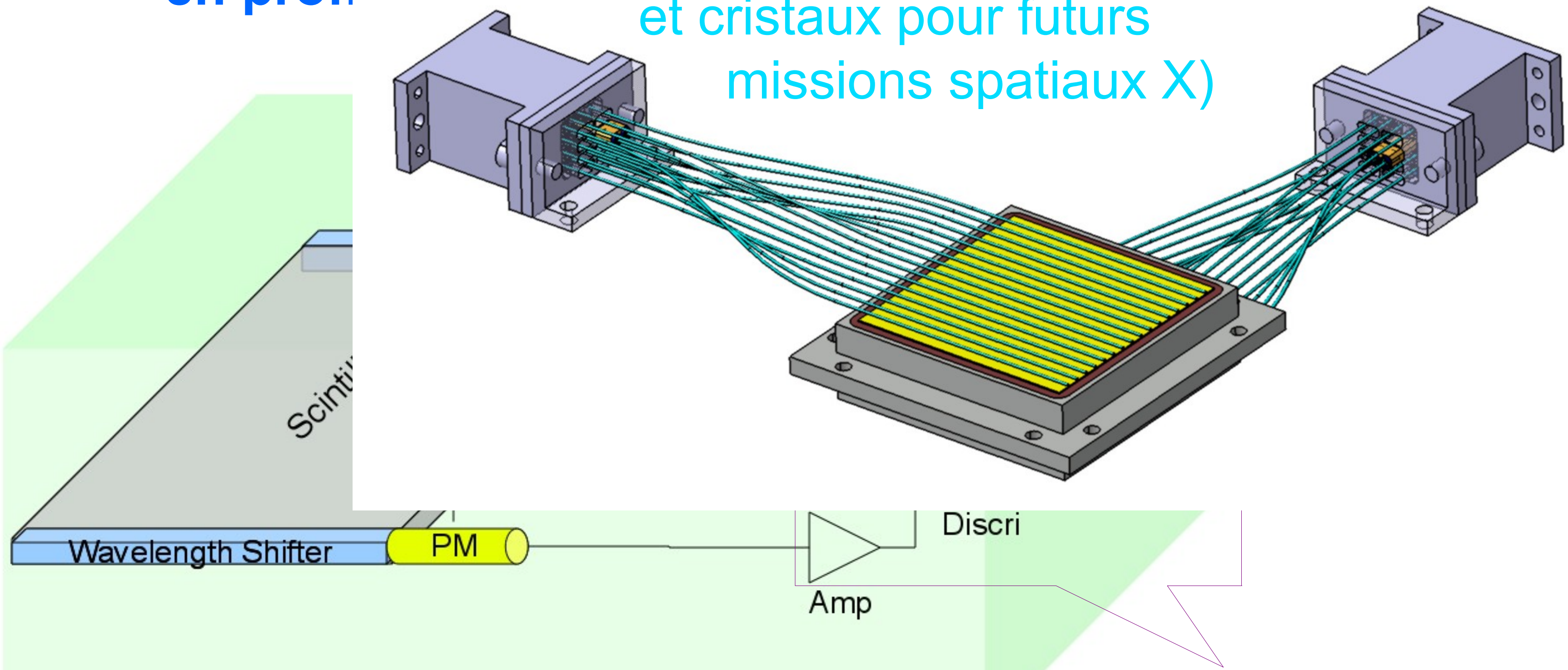
Partie à réaliser: adaptation/simplification d'une carte réalisé pour PHEN'X (ampli + intégrateur+shapeur+discri, 16 voies; C. Xiushan++), ajout de la coïncidence et sortie LVDS, câblage et test

(… ou bien, implementation de la coincidence dans la carte MUTIN?)

Le schématique du « proxy télescope »

Modification / ... en profi...

(Phen'X : tester des schémas d'anticoinc
et cristaux pour futurs
missions spatiaux X)



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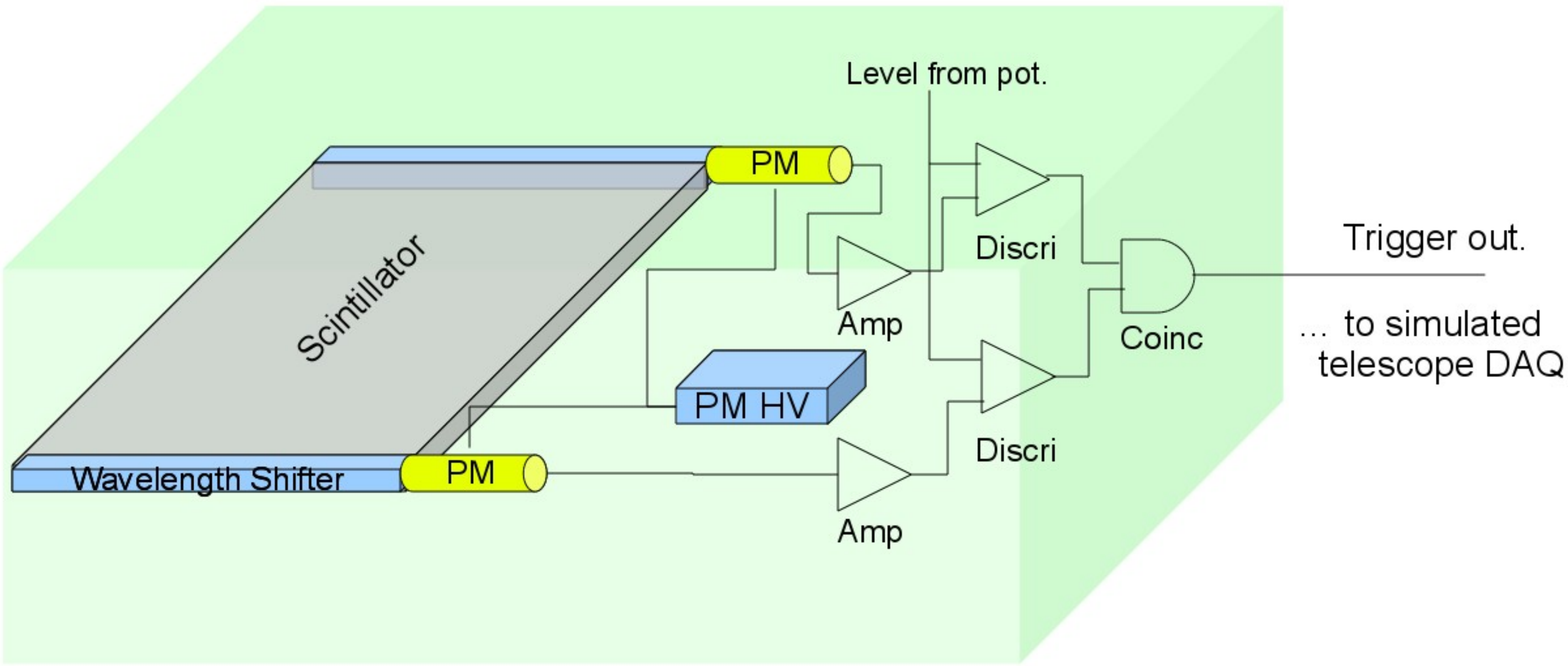
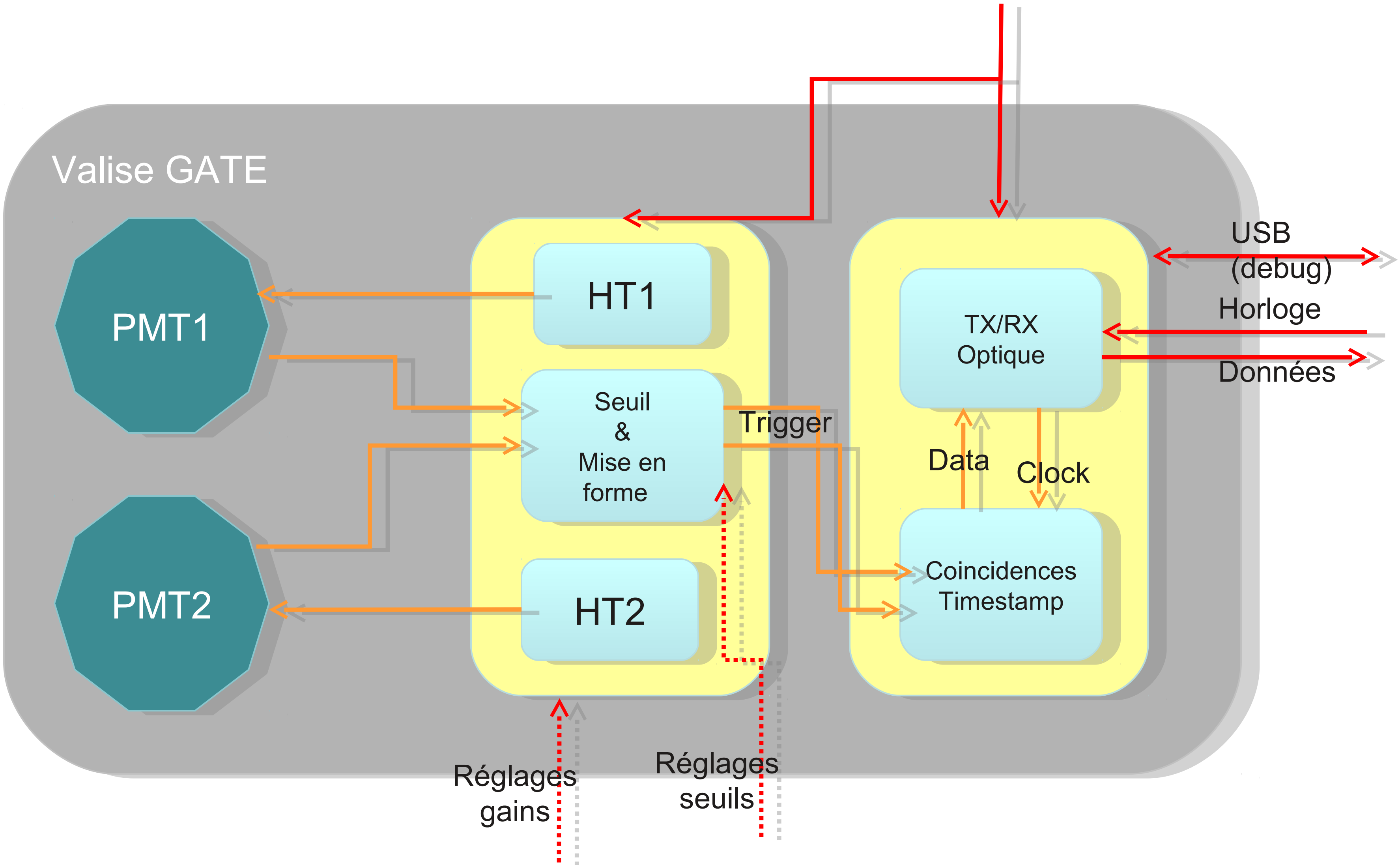


Partie à réaliser: intégration mécanique
de l'ensemble dans une « valise » et connectique

Achat de valise, scintillateur, shifter, PMs en Nov 11

Blocs fonctionnels valise GATE



La « valise »

Cahier de charge:

- Suffisamment large pour accueillir ~ 1m^2 de scintillateur
- Étanche a la lumière (donc noir!)
- Robuste et étanche au ruissellement

Solution trouvé: roll-case SKB-6022W

Modèle	Dimensions (mm) intérieures					Poids (kg)
	Longueur	Largeur	Hauteur totale	Hauteur Base	Hauteur Couvercle	
SKB-6022W	1530	565	152	76	76	16,0

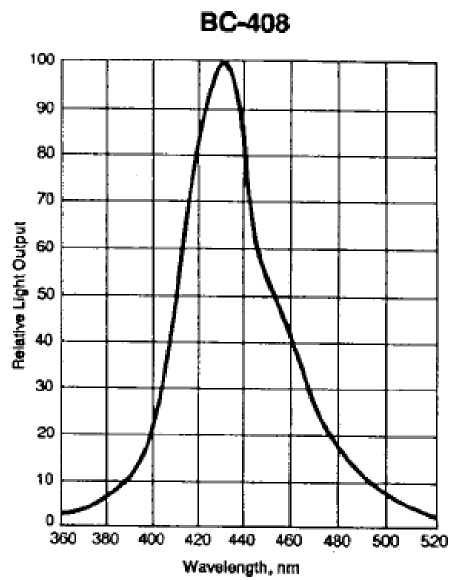
Achat en Nov 11, reçu en Dec 11

Le scintillateur et « wavelength shifter »

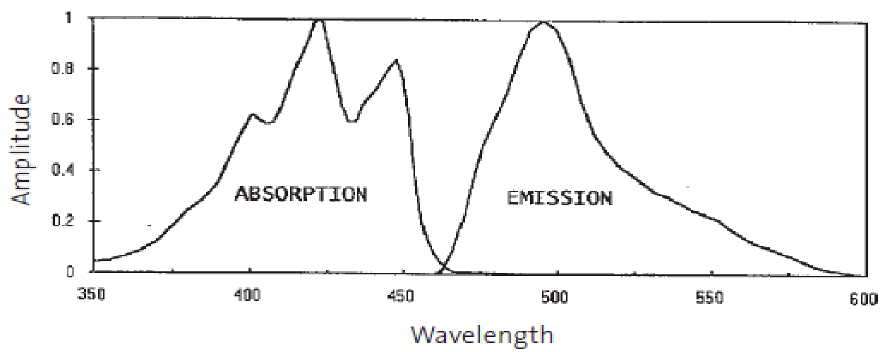
BC 408 en 125x55x10cm (η 1.49)

Scintillation Properties –

	BC-408
Light Output, %Anthracene	64
Rise Time, ns	0.9
Decay Time (ns)	2.1
Pulse Width, FWHM, ns	~2.5
Wavelength of Max. Emission, nm	425
Light Attenuation Length, cm*	210
Bulk Light Attenuation Length, cm	380



BC482A 10x10x125cm (η 1.59), et sa colle BC600 (η 1.56)



BC-482A Optical Spectra

Scintillation Properties –

	BC-482A Green
Decay Time, ns	12
Light Attenuation Length, cm	400
Absorption Peak, nm	420
Wavelength of Max. Emission, nm	494
Use with	BC-408 & 412

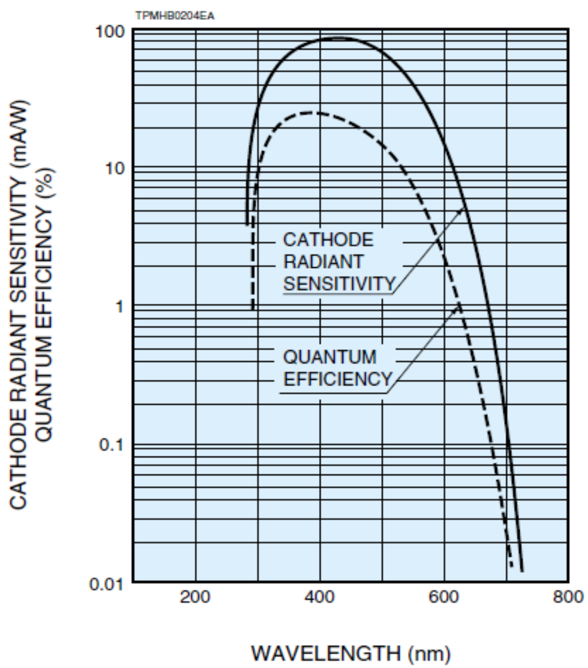
Achat en Nov 11, reception en Jan/Fév 12

Une proposition de Photomultiplicateur

Ne nécessite pas de caractéristiques contraignantes

- **R8619 ASSY,**
  25mm head on PMT for 300-650nm.
  semi-flexible leads.

- peut être fourni avec/sans
  pont diviseur et HT

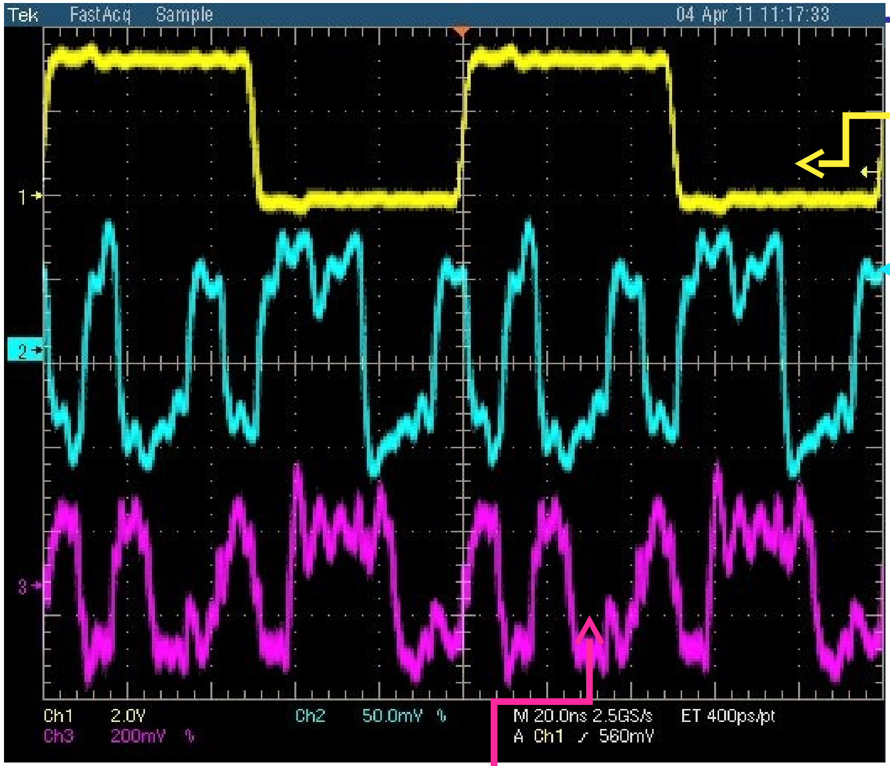


Key Specifications

Part Number	R8619
Type	Head on
Size	25mm
ActiveDia/L	22mm
Min λ	300nm
Max λ	650nm
Peak Sens.	420nm
Cathode Radiant Sensitivity	88mA/W
Window	Borosilicate
Cathode Type	Bialkali
Cathode Luminous Sensitivity	95μA/lm
Cathode Blue Sensitivity Index	11
Anode Luminous Sensitivity	190A/lm
Gain	2.0E+06
Dark Current after 30 min.	2nA
Rise Time	2.6ns
Transit Time	28ns
Number of Dynodes	10
Applied Voltage	1000V
Multi Anode	N
Power Supply	C3830 c9525-50 C9619
Amplifier	C7319 C6438 C5594 M7279 M8879

Achat en Nov 11, reçu en Dec 11

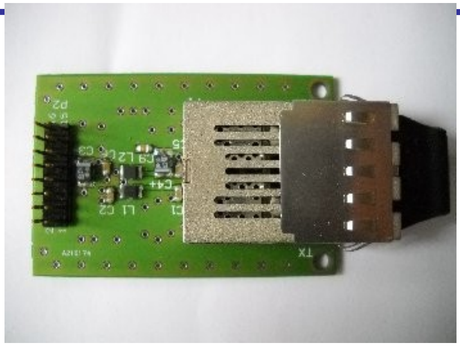
2010: Zeroth step with Integrated Optical Card



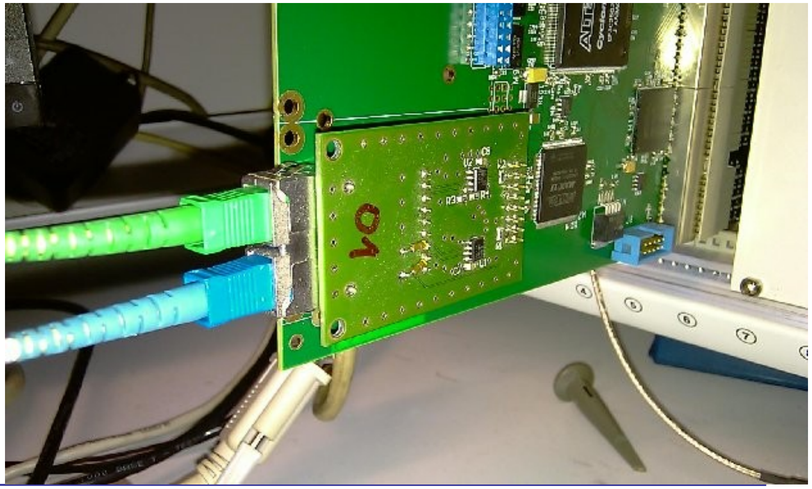
10Mhz Clock "reconstituted"

Emission (TD+) 10bit word sent

Reception (RD+) 10bit word received

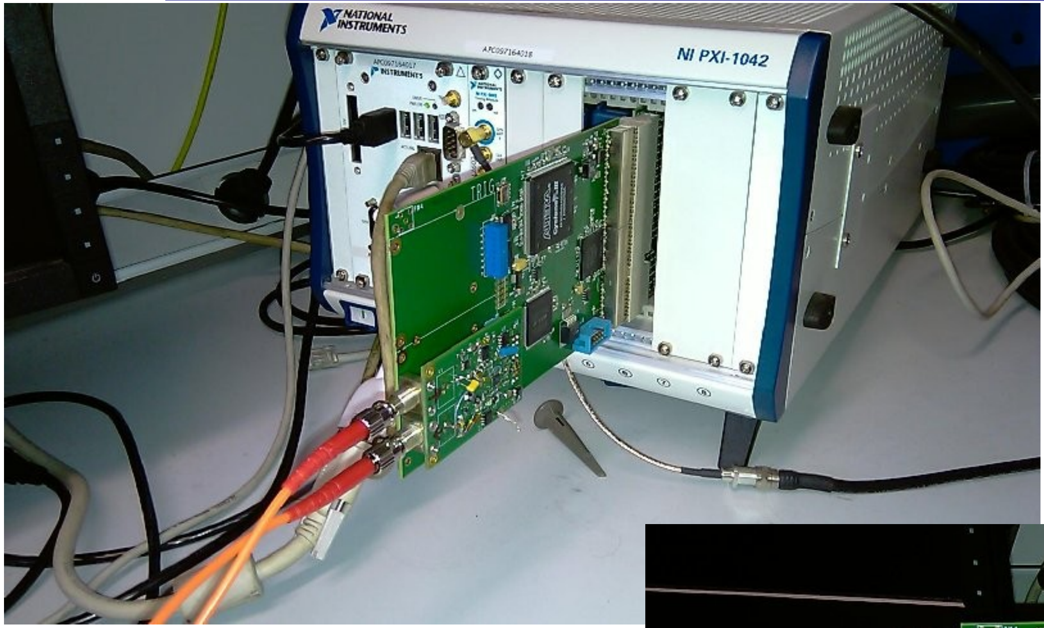


Optical Transmission (using commercial optical modules) 100 mbps, 850nm
(loop on single Mutin card)



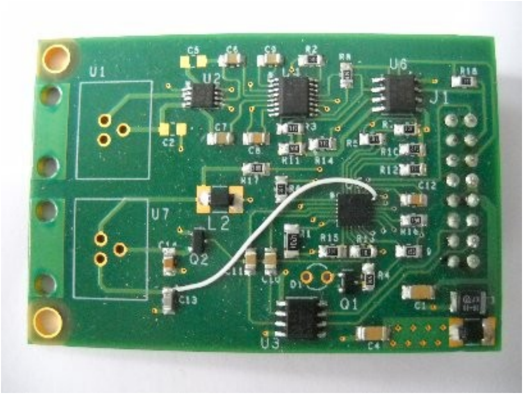
"By eye", jitter of order ~1ns
(depends on SerDes quality)
→ measurements were t.b.d.

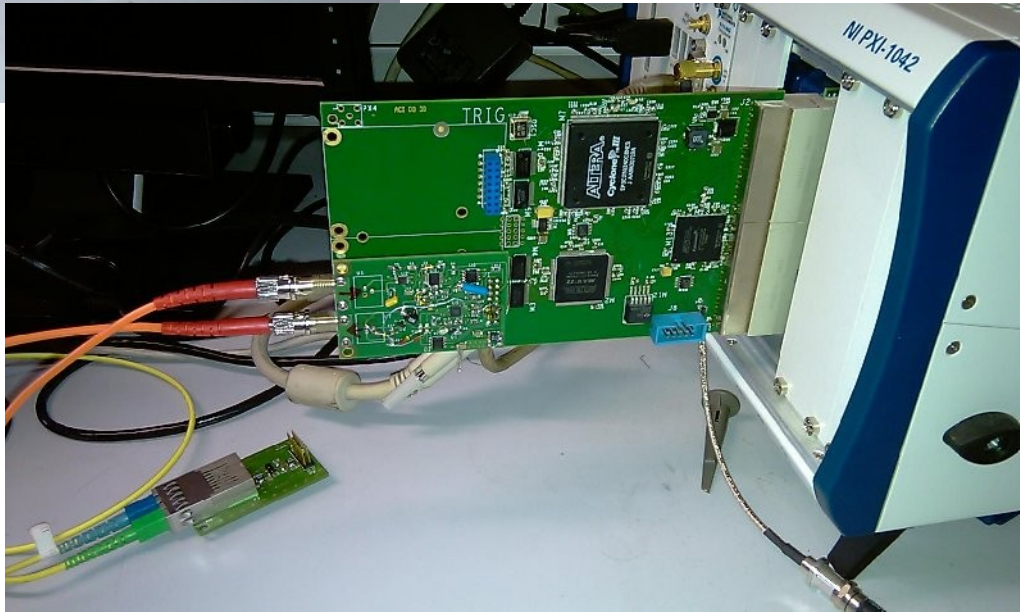
Next step, Optical card with more power



Optical Transmission (discrete components module) 100 Mbps, 850nm

Version V1 (noise problem, transmission perturbed depending on the word sent)
Version V2 (working – Oct. 2011)

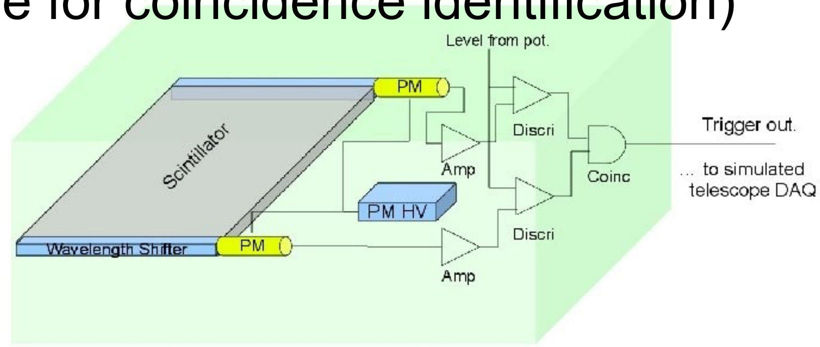




Near/medium future developments

List as presented in Madrid, April 2011 (with developments in colour)

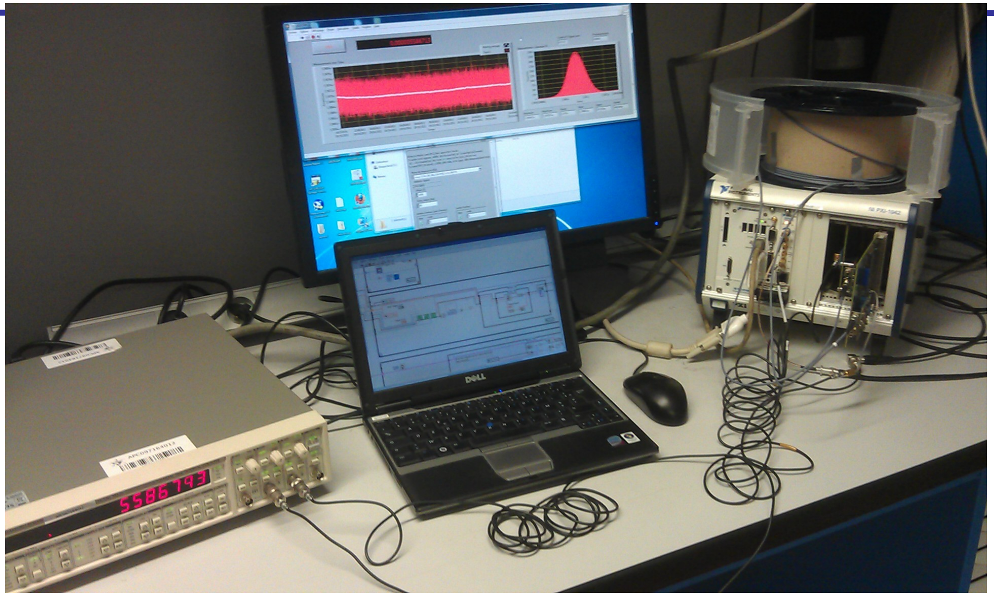
- Verify version V2 of optical card (OK)
- Test link type central ↔ telescope using 2 Mutin cards (OK)
- Implement optical splitting of signal to multi-telescopes (determine multiplicity of splitting achievable) (TBD, or keep to simpler solution of two bidirectional fibres per telescope)
- Purchase and test commercial bi-directional optical card (TBD)
- Implement PLLs on the EPLD or FPGA of the Mutin card, to create a time-stamp from the received 10MHz + 1PPS (expected 800MHz achievable → 1.25 ns precision) (TBD, collaboration to start with ISMO, Orsay)
- Test the “array trigger” using scintillator array as proxy telescope array (incl. development of real-time software for coincidence identification) (APC part of GATE project – *Gamma-ray Telescope Elements*) (TDB 2012/13)

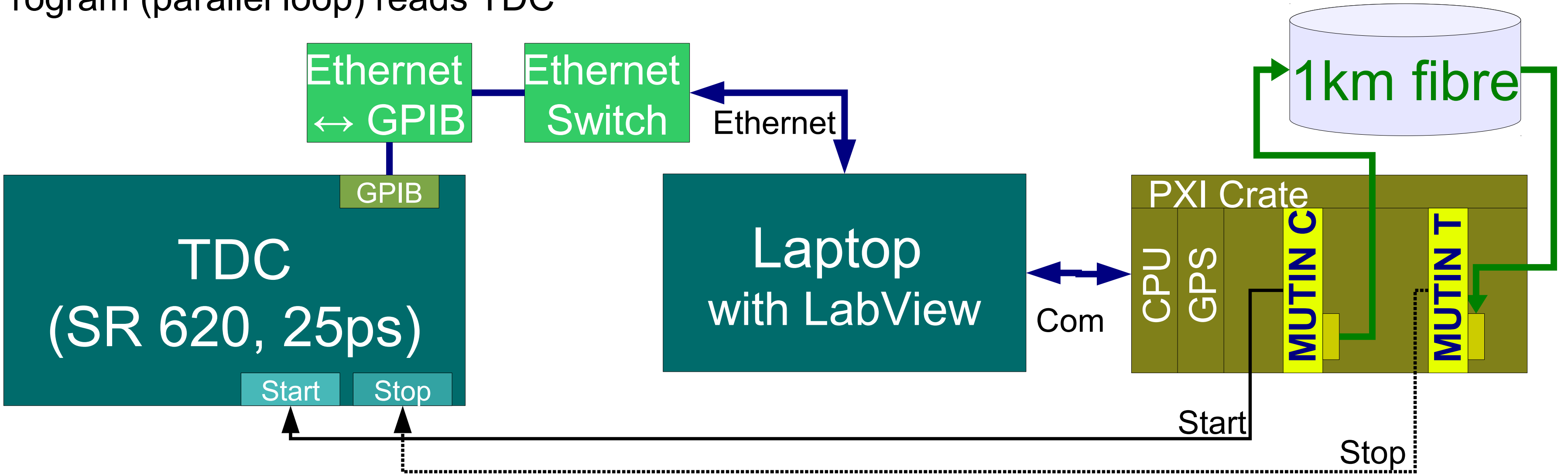


Test Bench of Mutin/Optical cards

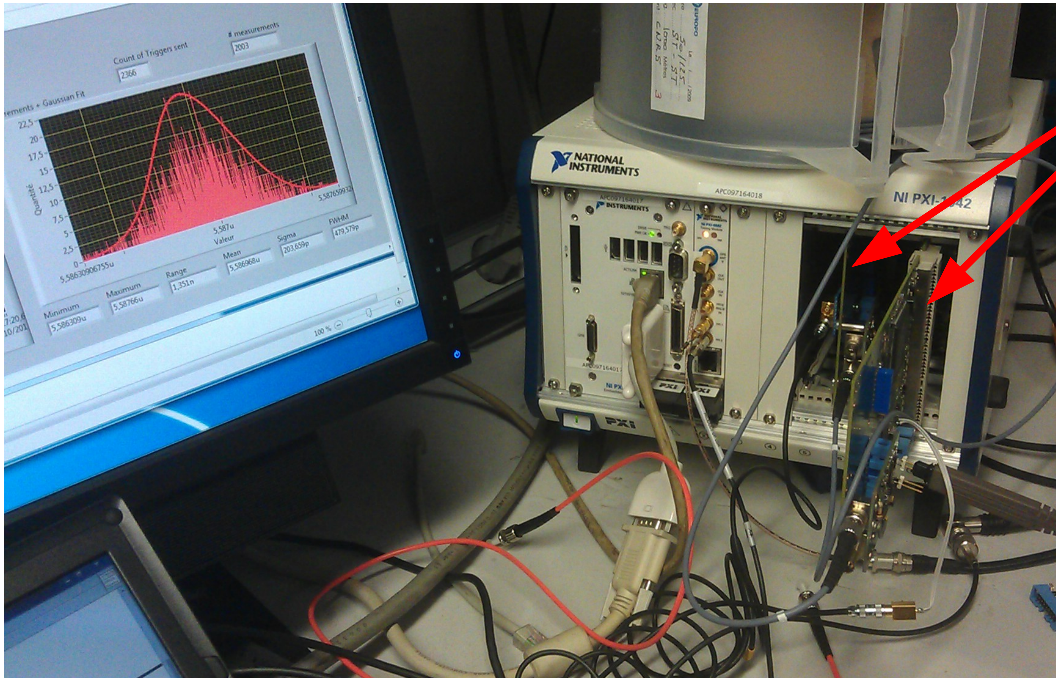
Test of time stability / jitter:

- Program sends start order (8-bit) to Mutin_C
- Mutin_C Altera receives and interprets
- Generates “Start” on Lemo output (to TDC)
- Sends-on order to Mutin_T
  via SerDes optical cards + fibre
- Mutin_T receives & interprets order
- Generates “Stop” on Lemo output (to TDC)
- Program (parallel loop) reads TDC



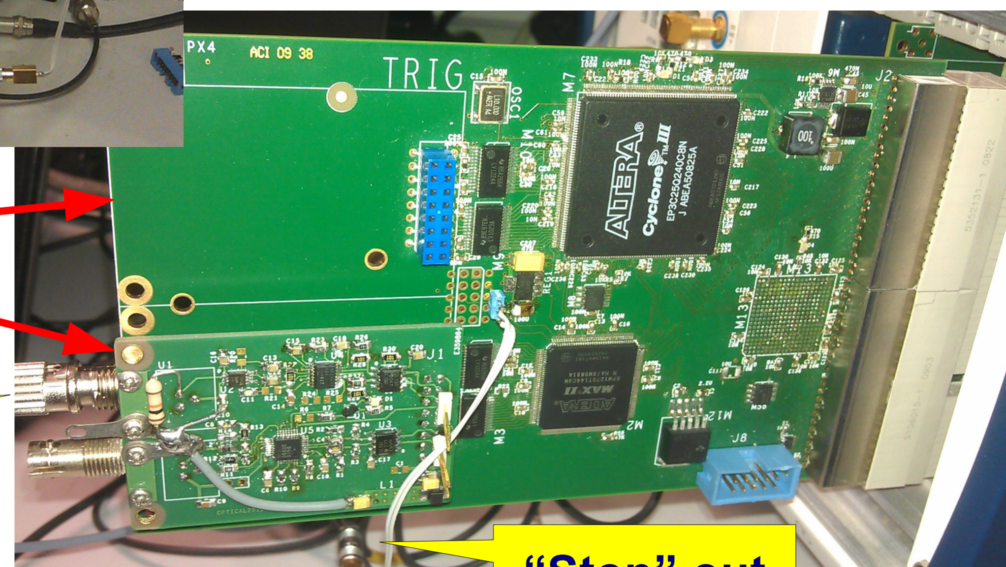


Test Bench of Mutin/Optical cards (zooms)



Zoom on PXI & Mutin Cards:
Mutin_C, emitter with PXI interface
Mutin_T, receiver, no PXI control (on extender board)

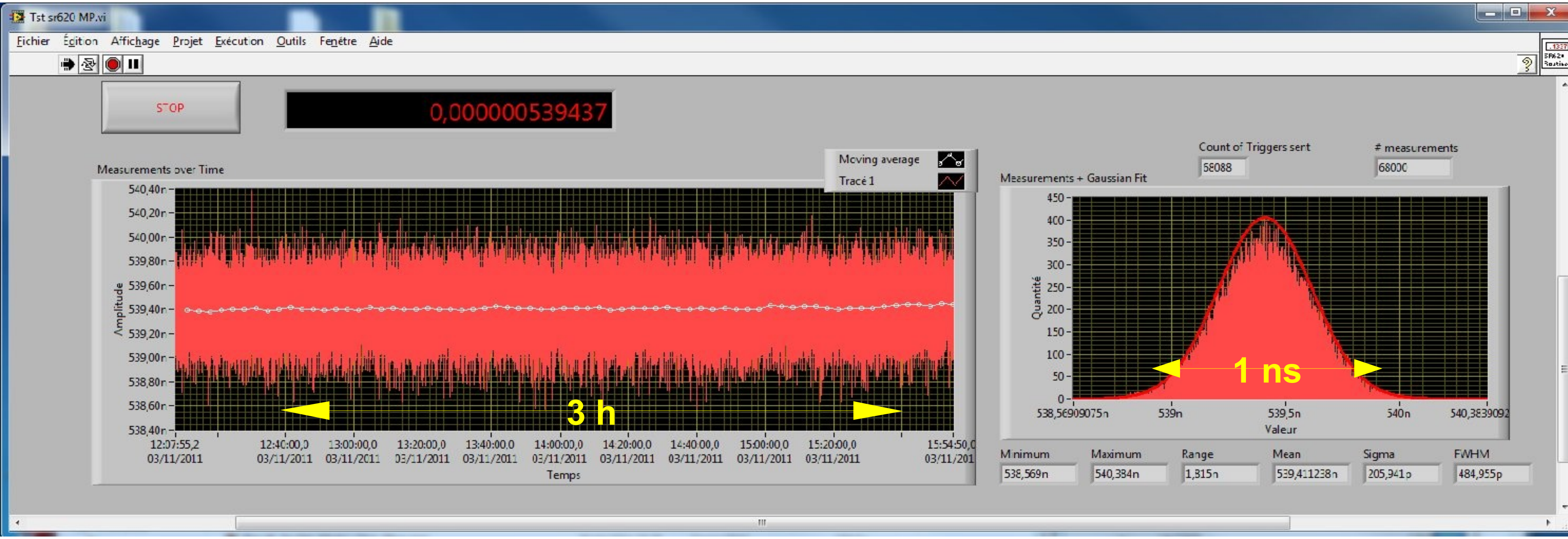
Zoom on Mutin Card and daughter Optical Card:



Fibre in

"Stop" out

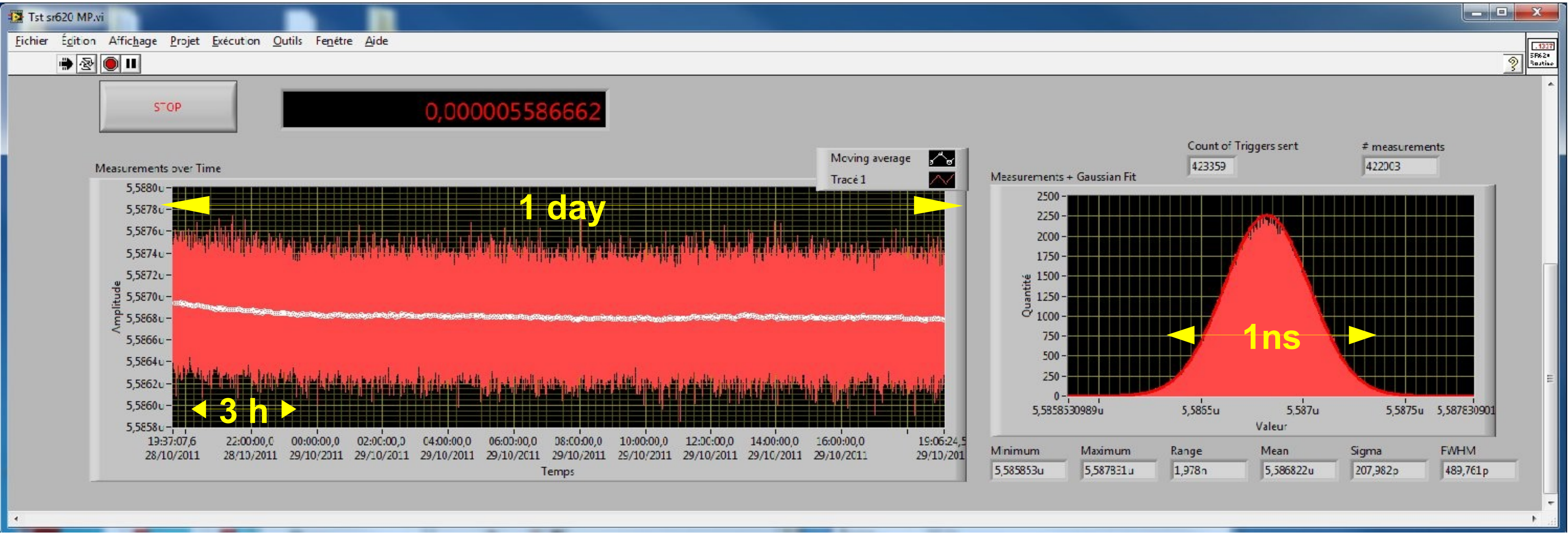
Results of Test Bench of Mutin/Optical cards



Test with 30 cm fibre / stable temperature:

- **Nice Gaussian distribution**
  - **206 ps sigma, 485 ps FWHM**
  - **Max excursion 1.8 ns**
  - **Transit time 538.4 ns**

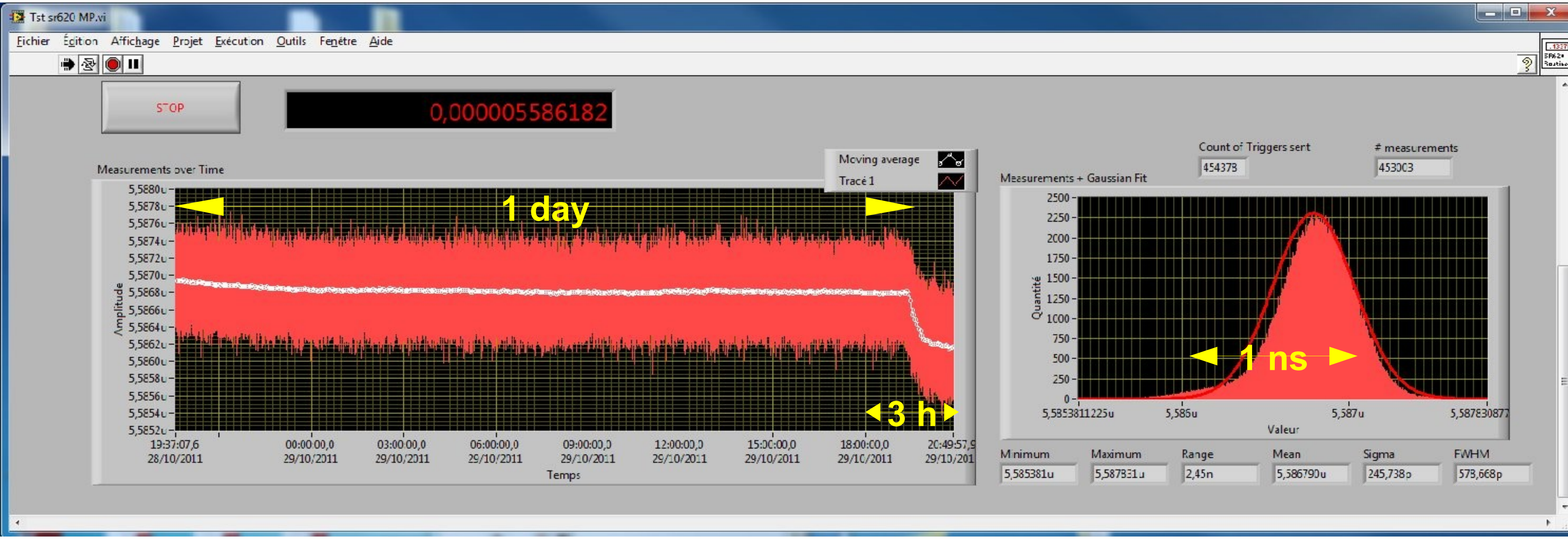
Results of Test Bench of Mutin/Optical cards



Next test with 1km fibre / stable temperature:

- **Nice Gaussian** (some temperature variation at start?)
  - **208 ps sigma, 490 ps FWHM**
  - **Max excursion 1.98 ns**
  - **Transit time 5586.8 ns** (i.e., for 1km – 30cm, time 5048.4ns, or 5.05ns/m)

Results of Test Bench of Mutin/Optical cards



Test with 1 km fibre / temperature variation

(moved fibre coil from PXI crate exhaust!):

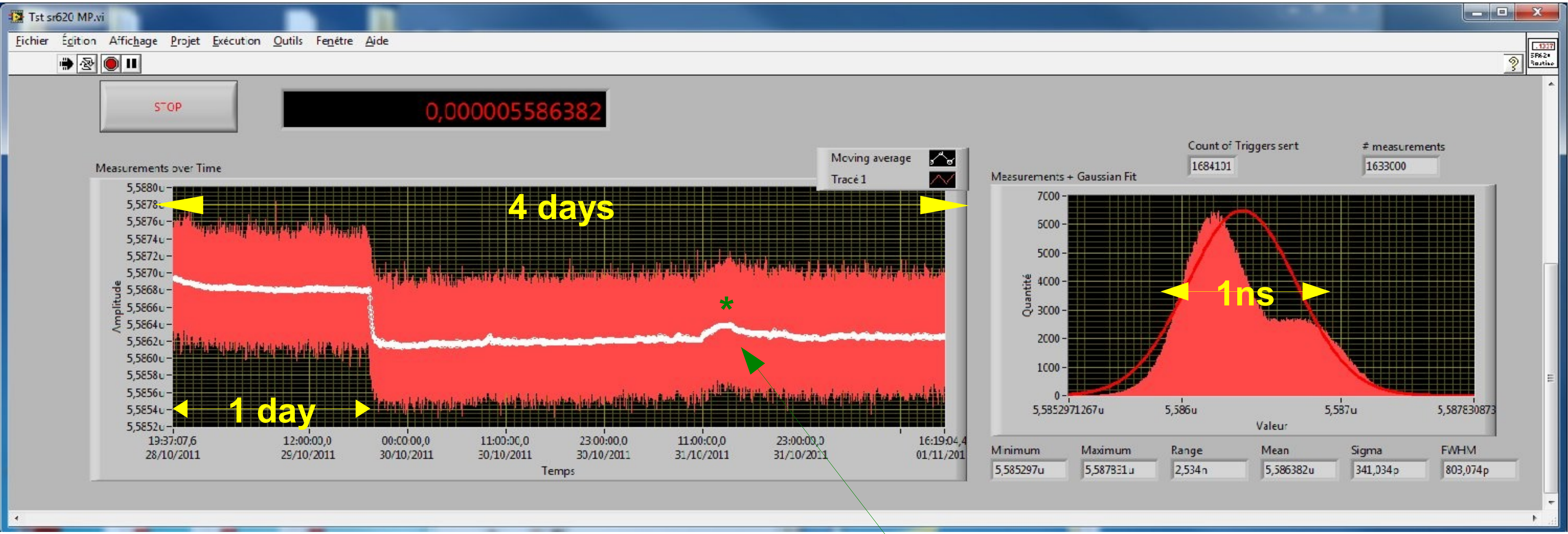
Minimal Shift of baseline (by ~0.7 ns) with exponential decay

Decay time constant is ~ 5 min (by eye)

Fused silica n= 1.4585, delta 1.28×10^{-5}/°C

→ 0.7 ns for 16° in 1 km (lower delay for temp ↓)

Results of Test Bench of Mutin/Optical cards



Test with 1 km fibre / temperature variation

(moved fibre coil from PXI crate exhaust ... continued data-taking):

Nice double Gaussian appears (separation ~0.7 ns)

Some variation (~0.2 ns) seen at noon on 31/10 (*)

(south-facing window, sunny day)

Next steps for Test Bench

a) Investigate temperature variation

- Not significant, but nice to understand
- Is this due to changes in fibre or electronics?

b) Measure “Return Journey” time

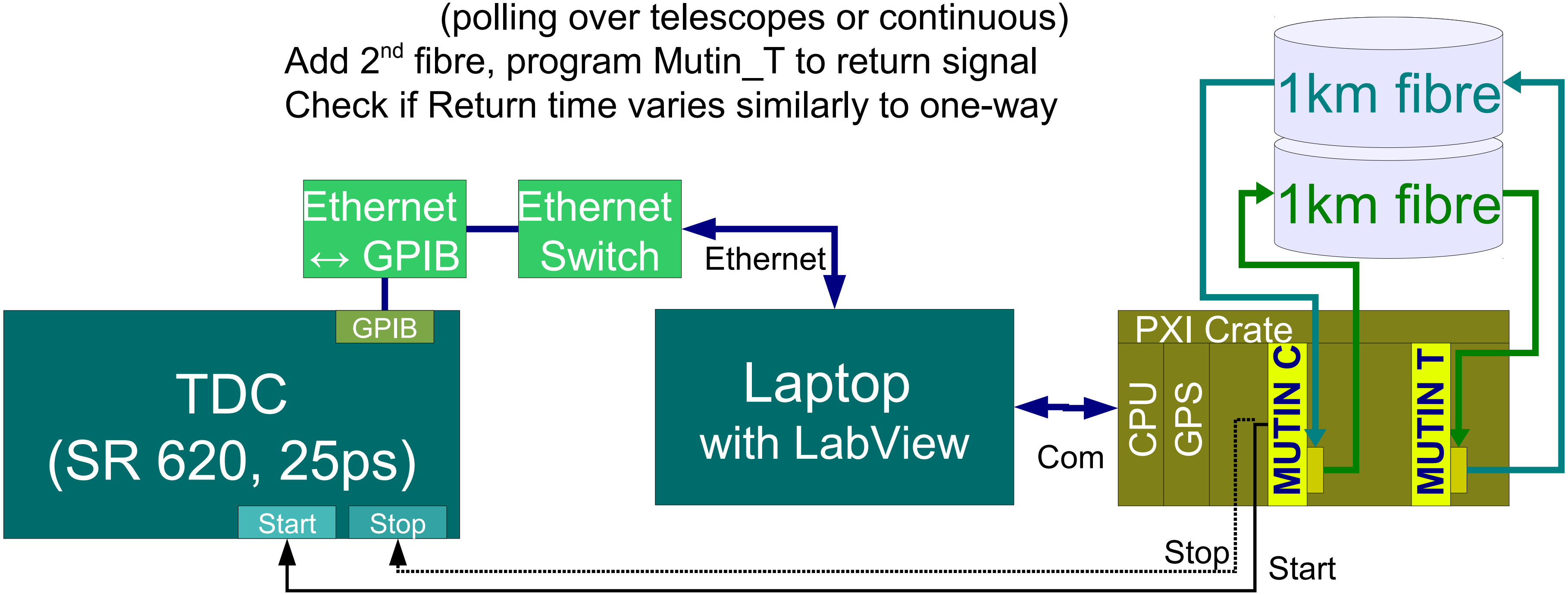
If this time is reliable

→ we can calibrate time variation

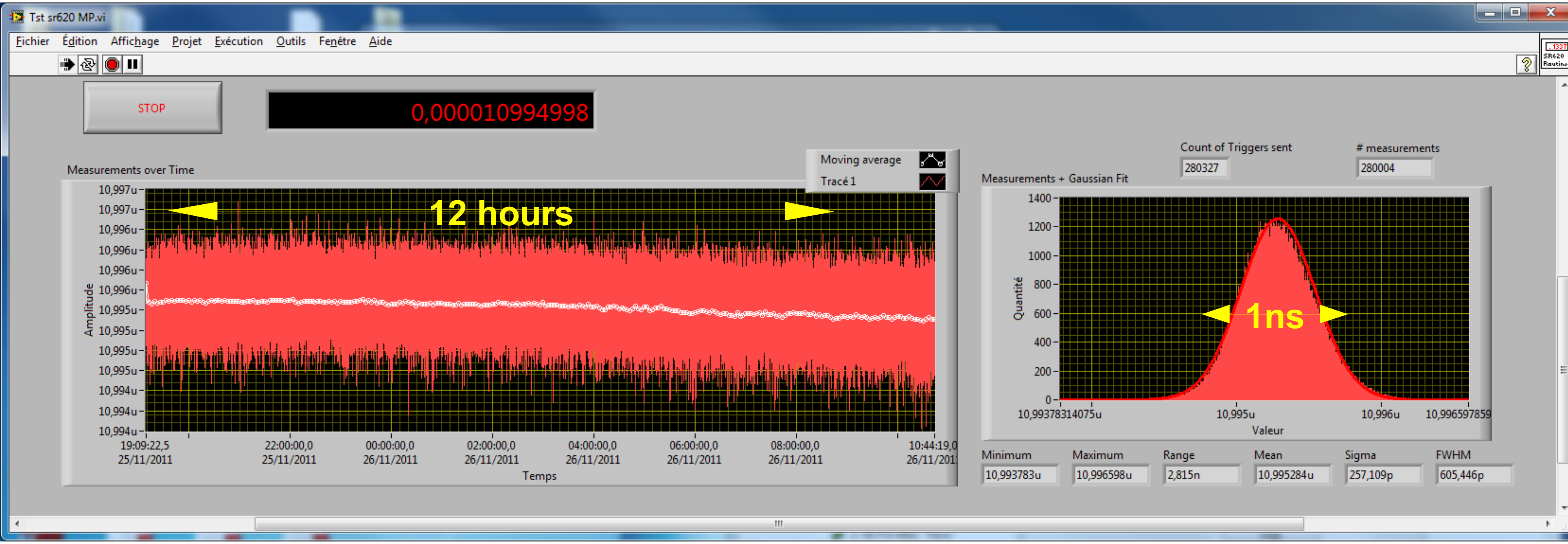
(polling over telescopes or continuous)

Add 2nd fibre, program Mutin_T to return signal

Check if Return time varies similarly to one-way



Results of Test Bench of Mutin/Optical cards



Return Journey Time Test with 1 km + 1 km fibre

(measurement of return journey time ÷ 2 → calibration of variation)

Some temperature variation seen overnight

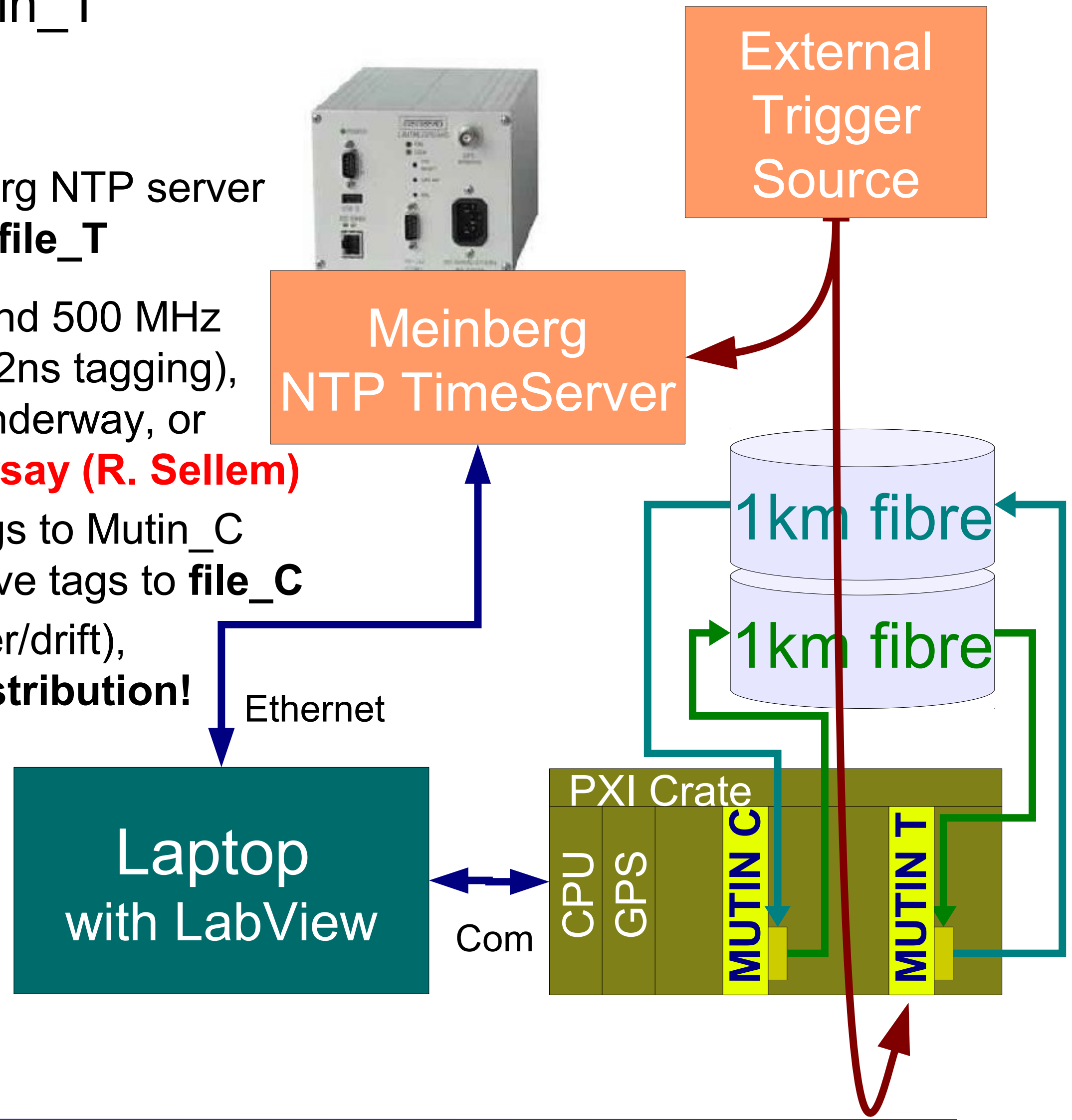
Still nice Gaussian, 257 ps sigma

→ We can reliably calibrate the fibre!

Final step for Test Bench

c) Implement time-tagging in Mutin_T

- Implement trigger input on Mutin_T
- Trigger with external random triggers
- Time-Tag triggers at source with Meinberg NTP server
  → save tags to **file_T**
- Implement resettable counters 1 PPS and 500 MHz
  (upscaled from 10 Mhz of SerDes → 2ns tagging),
  Simulation of this code for Altera is underway, or
  begin collaboration with ISMO, Orsay (R. Sellem)
- Mutin_T sends stream of trigger time-tags to Mutin_C
  where they are read by Laptop → save tags to **file_C**
- If **file_C** & **file_T** comparable (check jitter/drift),
  we will have implemented clock distribution!



Implementation for GATE

Mode 1-Mutin each per "Telescope"

Distribute clock (synchronized by PXI back-plane) from each Mutin_C

Measure return journey time regularly for calibration

Receive time-tags to each Mutin_C

Collect tags and search for coincidences

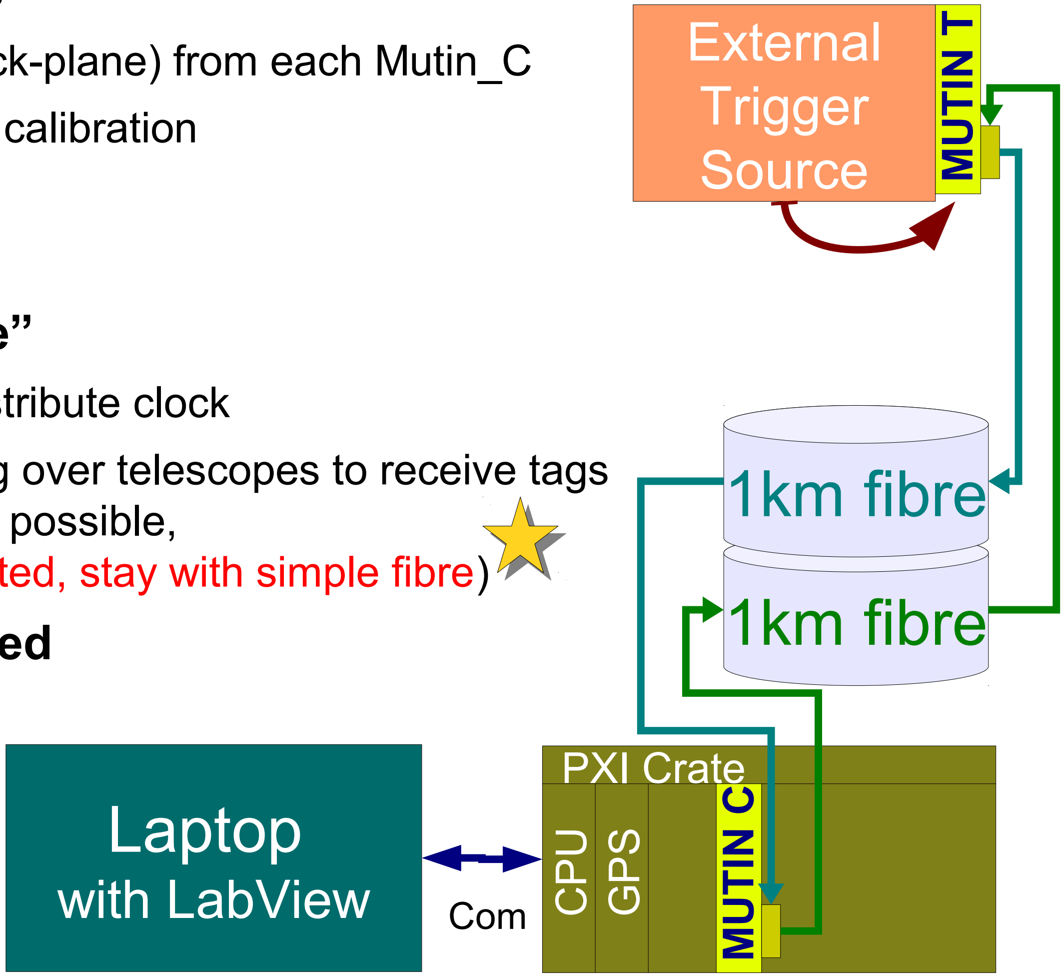
Mode 1-Mutin per "Multi-Telescope"

Optical splitter at output of Mutin_C to distribute clock

Optical splitter at input of Mutin_C, polling over telescopes to receive tags
(will need to test how much splitting is possible,
may be unnecessarily complicated, stay with simple fibre)

For CTA, mixed-mode will be needed to cope with ~60 tels

or add more channels per MUTIN card



CTA Clock Distribution & Central Trigger

- Clock distribution and central trigger by time-stamp seems the most flexible implementation
- The MUTIN card provides a
  - low cost (~1k€ on telescope side) and
  - low power-consumption (4.2W)
- Interface to Central trigger by ≤ 3 multimode fibres
  (2 if bidirectional, 1 clock distrib + return, 1 trigger time-tags)
  (note 2.8dB/km for fibre at 850nm measured)
- Interface to Camera Trigger by LVDS, perhaps ethernet ?
- Currently using PXI and LVDS standards,
  but can adapt to the trigger logic requirements
- Development now proceeding after some hitches
- **Should be able to start "field-testing" next year!**
  » **GATE 1st proto in Spring, 1st series in Autumn**

Budget prévisionnel

Initialement estimations / offres de février/mars 2010

Première prototype de Valise scintillateur

	Euros	Quantité	Euros
Valise (Roll-Case SKB6022W)	325.60	1	326
Scintillator (BC408 St Gobain)	1295.75	1	1296
Wavelength shifter (WLS BC482A)	125.38	2	251
Accessoires pr WLS, emballage	670.14	1	670
Photomultiplicateur R1924a Hama	395.00	2	790
PM Base pont diviseur E2924	112.00	2	224
PM Haute Tension HT C4900	127.00	2	254
Carte Phen-X modifie + alims	600.00	2	1200
Carte Mutin adapte + alims	600.00	2	1200
Somme			*6210*
Aléas de 10%			*621*

Sérié de ... 11

supposant 20% de rabais dans le cas ou le prix de série n'est pas connu

Valise (Roll-Case SKB6022W)	277.50	11	3053
Scintillator (BC408 St Gobain)	1092.81	11	12021
Wavelength shifter (WLS BC482A)	77.93	22	1714
Photomultiplicateur R1924a Hama	324.00	22	7128
PM Base pont diviseur E2924	93.38	22	2054
PM Haute Tension HT C4900	105.00	22	2310
Carte Phen-X modifie + alims	500.00	11	5500
Carte Mutin adapte + alims	500.00	11	5500
Somme			*39280*
Aléas de 10%			*3928*

Cout totale en équipement **50039**

Budget prévisionnel

Estimations / offres revisées ou achats (TTC!)

Première prototype de Valise scintillateur

	Euros	Quantité	Euros	Payé (HT)	Qty	Payé (HT)	Taxe	
Valise (Roll-Case SKB6022W)	325.60	1	326	364.32	1	364.32	71.41	
Scintillator (BC408 St Gobain)	1295.75	1	1296	1389.00	1	1389.00	272.24	
Wavelength shifter (WLS BC482A)	125.38	2	251	254.00	2	508.00	99.57	
Accessoires pr WLS, emballage	670.14	1	670	396.00	1	396.00	77.62	Ciment optique, ruban adhesive noir+reflet.
Photomultiplicateur R1924a Hama	395.00	2	790	395.80	2	791.60	155.15	R8619 Hama +mu metal
PM Base pont diviseur E2924	112.00	2	224	188.00	2	376.00	73.70	
PM Haute Tension HT C4900	127.00	2	254			*254.00*	*49.78*	*(pas encore acheté)*
Carte Phen-X modifie + alims	600.00	2	1200			*1200.00*	*235.20*	*(pas encore acheté)*
Carte Mutin adapte + alims	600.00	2	1200			*1200.00*	*235.20*	*(pas encore acheté)*
Frais de port +douanes Scintillateur+WLS				760.00	1	760.00	148.96	
Frais de port +douanes ciment optique				130.00	1	130.00	25.48	
Somme			*6210*			7368.92	1444.31	**8813.23**
Aléas de 10%			*621*					

Série de …	**11**			Série de	8			
supposant 20% de rabais dans le cas ou le prix de série n'est pas connu								
Valise (Roll-Case SKB6022W)	277.50	11	3053	*327.89*	*8*	*2623.10*	*514.13*	
Scintillator (BC408 St Gobain)	1092.81	11	12021	*1111.20*	*8*	*8889.60*	*1742.36*	
Wavelength shifter (WLS BC482A)	77.93	22	1714	*203.20*	*16*	*3251.20*	*637.24*	
Accessoires pr WLS, emballage	670.14	1	670	*316.80*	*8*	*2534.40*	*496.74*	
Photomultiplicateur R1924a Hama	324.00	22	7128	*316.64*	*16*	*5066.24*	*992.98*	
PM Base pont diviseur E2924	93.38	22	2054	*150.40*	*16*	*2406.40*	*471.65*	
PM Haute Tension HT C4900	105.00	22	2310	*101.60*	*16*	*1625.60*	*318.62*	
Carte Phen-X modifie + alims	500.00	11	5500	*500.00*	*8*	*4000.00*	*784.00*	
Carte Mutin adapte + alims	500.00	11	5500	*500.00*	*8*	*4000.00*	*784.00*	
Tranceivers BiDi Commericales				*200.00*	*16*	*3200.00*	*627.20*	
Frais de port +douanes Scintillateur+WLS				*760.00*	*1*	*760.00*	*148.96*	
Frais de port +douanes ciment optique				*130.00*	*1*	*130.00*	*25.48*	
Somme			*39950*			*38487*	*7543*	
Aléas de 10%			*3995*			*3849*	*754*	
Cout totale en équipement			**50777**			**49704**	**9742**	**59446.13** TTC avec aléas

Budget prévisionnel par année

Estimations / offres revisées ou achats (TTC!)

Première prototype de Valise scintillateur

	Payé (HT)	Qty	Payé (HT)	Taxe	
Valise (Roll-Case SKB6022W)	364.32	1	364.32	71.41	
Scintillator (BC408 St Gobain)	1389.00	1	1389.00	272.24	
Wavelength shifter (WLS BC482A)	254.00	2	508.00	99.57	
Accessoires pr WLS, emballage	396.00	1	396.00	77.62	
Photomultiplicateur R8619 Hama	395.80	2	791.60	155.15	
PM Base pont diviseur E2924	188.00	2	376.00	73.70	
Frais port+douanes Scint.+WLS	760.00	1	760.00	148.96	
Frais port+douanes ciment optique	130.00	1	130.00	25.48	
Somme 2011			4714.92	924.12	**5639.04**
PM Haute Tension HT C4900	127.00	2	*254.00*	*49.78*	
Carte Phen-X modifie + alims	600.00	2	*1200.00*	*235.20*	
Carte Mutin adapte + alims	600.00	2	*1200.00*	*235.20*	
Série de		8 '=4+4			
supposant 20% de rabais dans le cas ou le prix de série n'est pas connu					
Valise (Roll-Case SKB6022W)	*327.89*	*8*	*2623.10*	*514.13*	
Scintillator (BC408 St Gobain)	*1111.20*	*8*	*8889.60*	*1742.36*	
Wavelength shifter (WLS BC482A)	*203.20*	*16*	*3251.20*	*637.24*	
Accessoires pr WLS, emballage	*316.80*	*8*	*2534.40*	*496.74*	
Photomultiplicateur R1924a Hama	*316.64*	*16*	*5066.24*	*992.98*	
PM Base pont diviseur E2924	*150.40*	*16*	*2406.40*	*471.65*	
PM Haute Tension HT C4900	*101.60*	*16*	*1625.60*	*318.62*	
Carte Phen-X modifie + alims	*500.00*	*8*	*4000.00*	*784.00*	
Carte Mutin adapte + alims	*500.00*	*8*	*4000.00*	*784.00*	
Tranceivers BiDi Commericales	*200.00*	*16*	*3200.00*	*627.20*	
	760.00	*2*	*1520.00*	*297.92*	
	130.00	*2*	*260.00*	*50.96*	
Somme réstant			*42031*	*8238*	
Aléas de 10%			*4203*	*824*	
Cout totale en équipement			**50949** avec aléas	**9986**	**60934.43**

Economies possibles sur Scintillateur/WLS si polissage « maison » ?

Frais de port x2

	Prix/Payé HT	Taxe	TTC
2011	4714.92	924.12	5639.04
2012	22342.27	4379.09	26721.36
2013	19688.27	3858.90	23547.17
Totale sans aléas	46745.46	9162.11	55907.57
avec aléas	50948.52		

Calendrier prévisionnelle

Calendrier révise en novembre 2011

Equipement E4 : Demonstrateur Distribution Horloge et Trigger Central	2011	2012	2013
Commande des scintillateurs			
Modification des cartes PHEN-X pour faire une version à 2 voies			
Modification de la carte MUTIN en version « stand-alone »			
Production de la série de ~10 stations scintillateur			
Tests en profondeur du réseau : développement et tests d'algorithmes de mise en temps, fit de front de particules, tests de timing relatif entre les stations (précision, jitter, sauts), tests de la fiabilité dans le temps du système.			
Transfert de connaissances du système vers les équipes d'enseignement et les responsables de stage.			

The end …