The SAMPIC chip for timing detectors

LHC Working Group on Forward Physics and Diffraction

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SAMpler for **PIC**osecond time pick-off : A read-out chip for the AFP timing detectors

- Application-Specific Integrated Circuit **(ASIC)** for picosecond timing measurement
- **New patented concept** based on Analog memory + Discriminator + Counter + Delay Locked Loops (DLL) + Analog to Digital Converter (ADC)
- 16 short Switch Capacitor Array (SCA), single-ended channels with embedded ADC and independant deadtime. Each is **self-triggerable**

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- 16 short Switch Capacitor Array (SCA), single-ended channels with embedded ADC and independant deadtime. Each is **self-triggerable**
- **Timing measurement**
  - TimeStamp Gray counter ($\simeq$ 6 ns step) sampling the external reference clock
  - DLL ($\simeq$ 150 ps step) defining a region of interest
  - Waveform shape (few ps RMS after interpolation) acquired on a 64-step analog memory

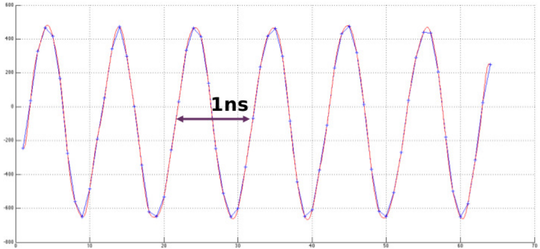
Design status

- **Two working prototype available now**
- 2 Mezzanine boards integrating SAMPIC with 16 acquisition channels available (MXC connectors)
- USB, Ethernet and Fiber Optic read-out
- 5V-1A supply required
- First tests gave satisfactory results (**3-4 ps RMS reached**)
  (see H. Grabas talk on http://qcdworkshop.ifj.edu.pl/)

Test status (1/2)

(see H. Grabas talk on http://qcdworkshop.ifj.edu.pl/)

- **Chip usable now to perform timing measurement**
  - Sample speed from 1 to 8.2 Gigasample/s (GSPS) on all the channels
  - Up to 10 GSPS on 8 channels
- Read-out error in a few cases and central trigger to correct
- **Already very good sampling quality**
  example of sampling of a sinus without any correction at 10 GSPS showed below



Test status (2/2)

- **2013:** Early tests
  see H. Grabas talk on http://qcdworkshop.ifj.edu.pl/

- **November-December 2013:** Signal attenuation and delay tests with a pulse generator (detailed in the next slides). Study of the "cross-talk" effect.

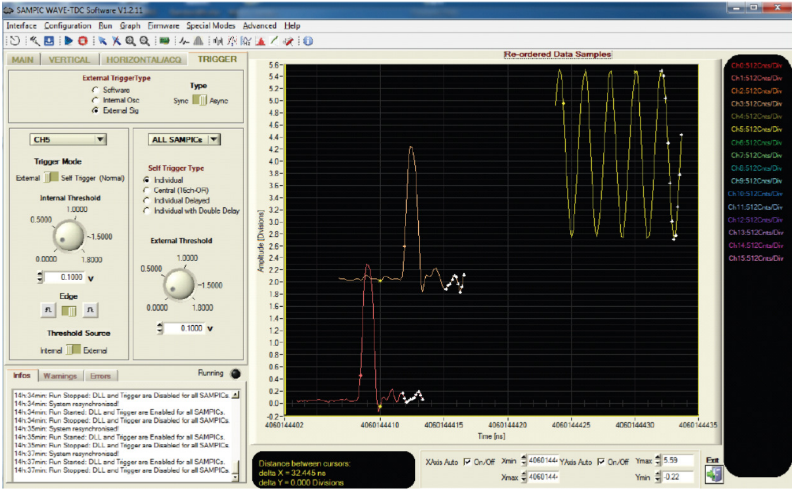
- **25-28 Feb. 2014:** Test-stand setup with TOTEM people at CERN. SAMPIC test with a pulser generator

- **July 2014 (to be confirmed):** Beam tests at the Paul Scherrer Institute (Switzerland) with low energy beams

- **October-December 2014 (to be confirmed):** Beam tests at CERN with the SPS (TOTEM beam test zone)

- **Manpower:** Yura, master student as of March to work on the SAMPIC software (9 months), money for 1 extra post-doc

- **Developped at LAL (Orsay, France)** by D.Breton and J.Maalmi
  - Windows software
  - Sets up SAMPIC and **acquires signals**. ASCII (tested) or binary (not tested) file outputs
  - Allows an **online vizualization** of the signals
  - Can perform different **calibrations**
  - Can perform **online time measurements**
- **Already usable for beam tests data acquisition**



SAMPIC WAVE-TDC Software V1.2.11
Interface Configuration Run Graph Firmware Special Modes Advanced Help
MAIN VERTICAL HORIZONTAL/ACQ TRIGGER
External TriggerType
Software
Internal Osc
External Sig
Type
Sync Async
CH5
ALL SAMPICs
Trigger Mode
External Self Trigger (Normal)
Internal Threshold
1.0000
0.5000
-1.5000
0.0000
1.8000
0.1000 V
Edge
Threshold Source
Internal External
Self Trigger Type
Individual
Central (16ch-OR)
Individual Delayed
Individual with Double Delay
External Threshold
1.0000
0.5000
-1.5000
0.0000
1.8000
0.1000 V
Infos Warnings Errors
Running
14h:34min: Run Stopped: DLL and Trigger are Disabled for all SAMPICs.
14h:34min: System resynchronised!
14h:34min: Run Started: DLL and Trigger are Enabled for all SAMPICs.
14h:34min: Run Stopped: DLL and Trigger are Disabled for all SAMPICs.
14h:35min: System resynchronised!
14h:35min: Run Started: DLL and Trigger are Enabled for all SAMPICs.
14h:35min: Run Stopped: DLL and Trigger are Disabled for all SAMPICs.
14h:37min: System resynchronised!
14h:37min: Run Started: DLL and Trigger are Enabled for all SAMPICs.
14h:37min: Run Stopped: DLL and Trigger are Disabled for all SAMPICs.
Re-ordered Data Samples
Amplitude [Divisions]
Time [ns]
4060144402
4060144410
4060144415
4060144420
4060144425
4060144430
4060144435
Ch0:512Cnts/Div
Ch1:512Cnts/Div
Ch2:512Cnts/Div
Ch3:512Cnts/Div
Ch4:512Cnts/Div
Ch5:512Cnts/Div
Ch6:512Cnts/Div
Ch7:512Cnts/Div
Ch8:512Cnts/Div
Ch9:512Cnts/Div
Ch10:512Cnts/Div
Ch11:512Cnts/Div
Ch12:512Cnts/Div
Ch13:512Cnts/Div
Ch14:512Cnts/Div
Ch15:512Cnts/Div
Distance between cursors:
delta X = 32.445 ns
delta Y = 0.000 Divisions
XAxis Auto On/Off Xmin 4060144 Xmax 4060144
YAxis Auto On/Off Ymax 5.59 Ymin -0.22
Exit

Calibrations performed by the software

- **Pedestals** : residual signals due to component defaults (5 mV RMS)

  acquisition with no signal on each channel for calibration

- **Analog to Digital Converter (ADC)** : non linearity of the transfer function, independant of the channel (1% RMS)

  acquisition of different static ramps for calibration

- **Timing Non Uniformity** : Jitter on the sampling time (3% RMS)

  acquisition of a sinusoid for calibration

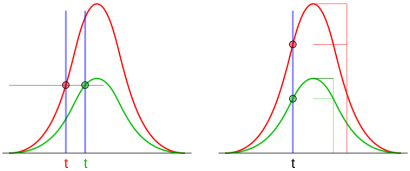
- Any other calibration can be implemented

SAMPIC Fast Analysis software

- **SPP/SEDI (Saclay, France) code** in C++ interfaced with ROOT for data analysis (developped by myself)
  - **Very light and adaptable code** in order to test easily several time measurement methods
  - **Convert ASCII data (offline) into a ROOT tree**
  - Robustness to test by confronting it to different data
- **Purpose**: make it usable for beam tests data analysis

Time measurement algorithms implemented in the software (1/2)

- **Constant Fraction Discriminator (CFD)**
  - Pulse maximum determined directly from datapoints (default) or with a spline interpolation
  - Fraction can be easily change, default is 50% of the maximum
  - Crossing time determined by linear or spline interpolation
  - CFD can theoritically be performed online by AFP
  - Sensible to baseline shifts and linearity of the pulse slope



Time measurement algorithms implemented in the software (2/2)

- **Cross-correlation (CC)**
  - Possibility to add points to the original waveforms by spline interpolations before the CC computation
  - Maximum of the correlation function determined by spline interpolation
  - Less sensible to baseline shifts and linearity of the pulse slope
  - Signal must show a very good reproductibility

Further SAMPIC developments required for AFP

- Prototypes are not radiation-hard
  - not completely needed if SAMPIC is in the alcove
  - if inside the tunnel, full radiation-hardness required
- Ping-pong mode (= 2 channels connected to a single detector cell) required to handle LHC rates
- Checks/tests to perform to fully understand the chip
- Minor bugs corrections

Signal attenuation and Delay tests with a pulse generator **at 6.4 GSPS**

- Time measurement between **two shifted pulses**

- **Delay test**
  - SAMPIC Self-triggered
  - 1 pulse split into 2 pulses (simple T-junction) of the same amplitude
  - variable delays with different cables

- **Signal attenuation test**
  - SAMPIC Self-triggered
  - 1 pulse split into 2 pulses (simple T-junction)
  - varying amplitudes of the pulse with attenuators before splitting
  - little timing offset between the two pulses with cables to mimic real conditions

Characteristics of the circuit

- Pulse generator (Lecroy)
  - Amplitude: 5V (before splitting and attenuation)
  - Width: 0.90 ns
  - Frequency: 1 kHz
- Reducers
  - High bandwidth attenuator (Wavetek, **3GHz**) from 6 to 33 dB
  - or Low bandwidth reducer (Ferisol, **500MHz**) from 6 to 33 dB
- Delayer
  - Use of cables of different lengths

Delay tests (≃1.2 V pulse amplitude)

Visualization of the split pulses with the acquisition software

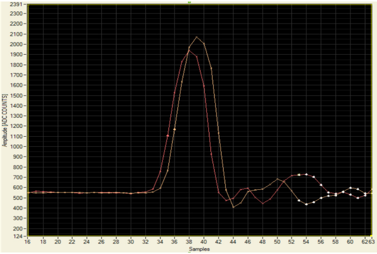


Figure : $\gamma\gamma$ production via γ exchanges

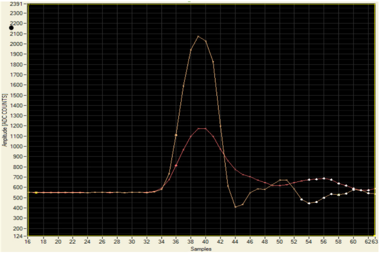
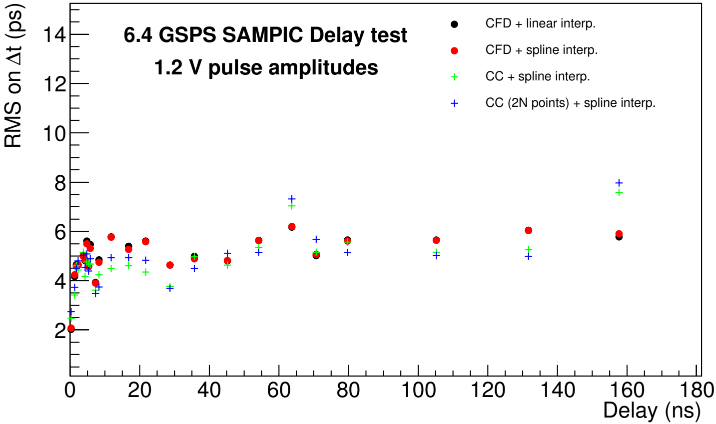


Figure : $\gamma\gamma$ production via gluon exchanges

- Signal distorsion and attenuation at high delay due to the increasing length of cables **(skin effect and limited bandwidth)**

Delay test results (≃1.2 V pulse amplitude)



- **Very low** σ, ranged between 1 and 6 ps
- No clear dependance versus delay
- CFD and CC comparable
- No delay : 1.4 ps RMS

Signal attenuation tests with a 3 GHz bandwidth reducer (4.73 ns delay)

Visualization of the split pulses with the acquisition software

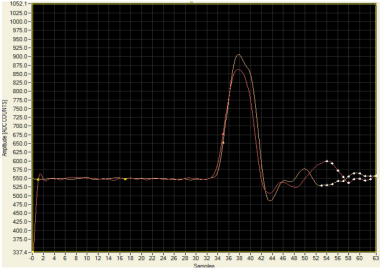


Figure : 12dB

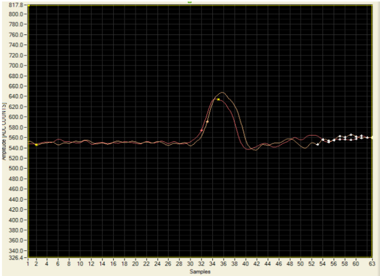
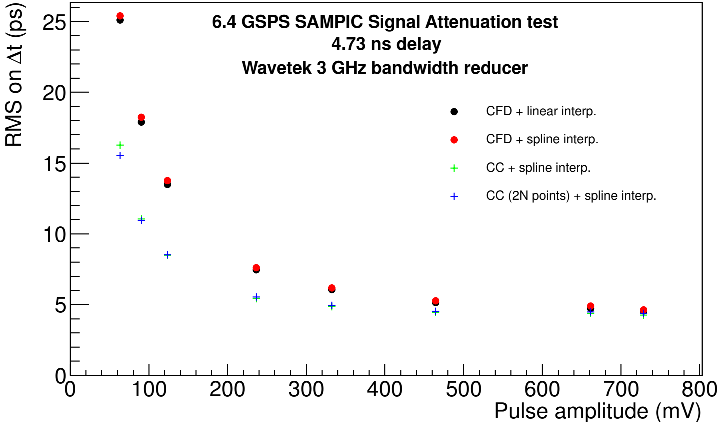


Figure : 24dB

- Rising edge of the slope : 1 ns
- Good signal reproductibility

Signal attenuation tests with a 3 GHz bandwidth reducer (4.73 ns delay)



- CFD = Constant Fraction Discriminator
- CC = Cross-Correlation, **gain a max factor of 1.5** at small amplitudes (smaller S/B)

Signal attenuation tests with a 500 MHz bandwidth reducer (4.73 ns delay)

Visualization of the split pulses with the acquisition software

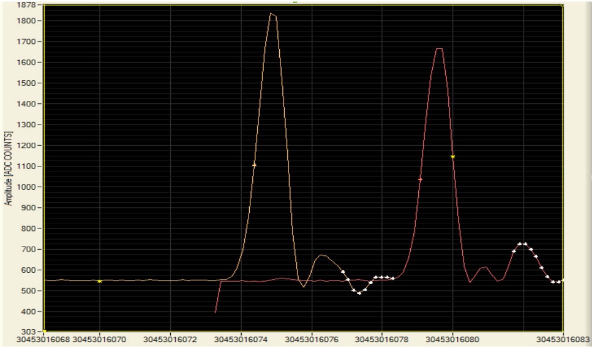
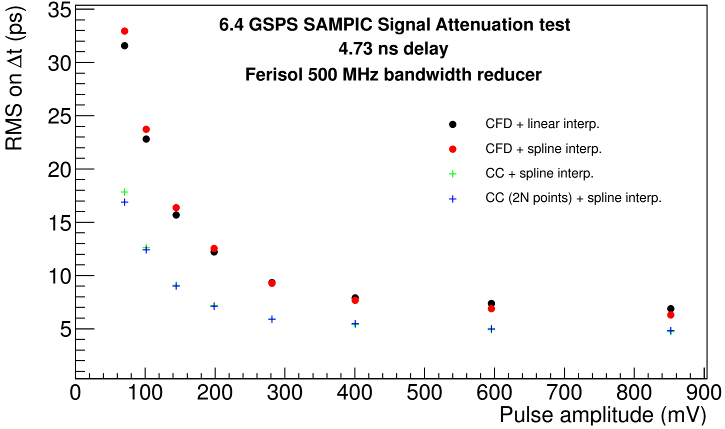


Figure : 0dB

- Rising edge of the slope lasts 1.5 ns (+50%)

Signal attenuation tests with a 500 MHz bandwidth reducer (4.73 ns delay)

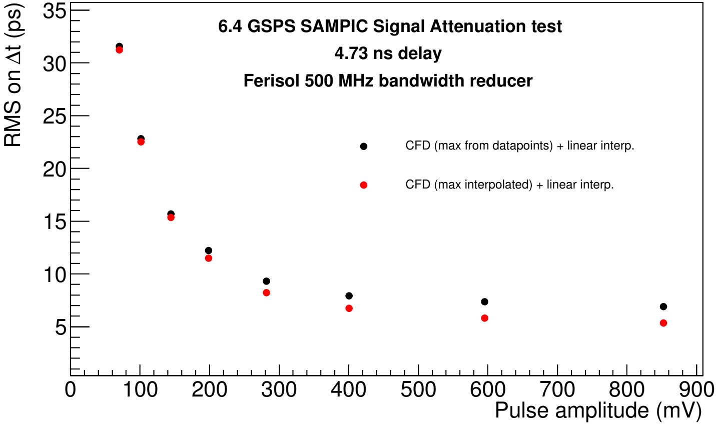


- CFD results degraded by a factor $\simeq 1.5$ at low amplitude
- **Linearity interpolation still show good results**
- **CC results not degraded**

Elegant way to measure the jitter noise

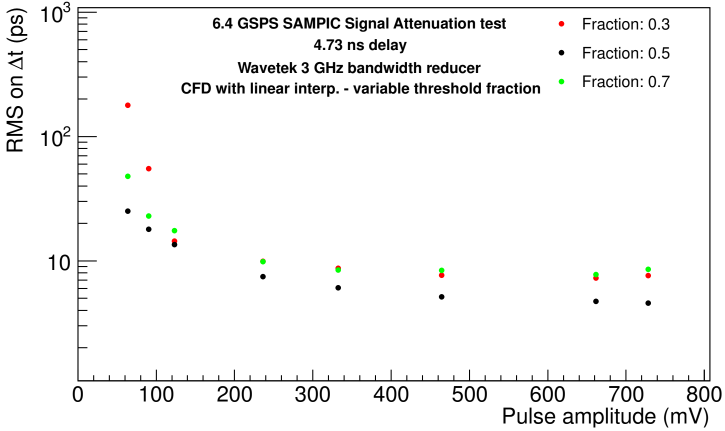
- the RMS on the time measurement of 1 pulse is the quadratic sum of the jitter noise σ_t and a term proportional to the rising edge of the pulse
  - Rising edge of the pulse inversely proportional to the amplitude (constant width pulses)
  - $RMS\ (2\ pulses) = \sqrt{2}\ RMS(1\ pulse) = \sqrt{\sigma_t^2 + (\frac{K}{A})^2}$
- **Jitter noise expected to be a few ps** if the design is correct
- Results of the fit for the two attenuators
  with CC 2N points + spline interp. method
  - 3 GHz bandwidth: σ_t = 3.0 ps, K = 657 s.mV, χ^2 = 0.03
  - 500 MHz bandwidth: σ_t= 3.3 ps, K= 807 s.mV, χ^2=0.04
- **First validation of the SAMPIC design**

Extra : CFD with fraction from interpolated maximum



- Peak value from interpolation improves results when S/B ratio is high enough
- Makes almost no difference at low S/B ratio

Extra : CFD algorithm performance against fraction



- Fraction of 0.5 shows the best performance (slope is highest)

Conclusion

- **Good performance of SAMPIC confirmed**
  - **2 to 4 ps resolution achieved** with a pulse generator and a basic CFD method
  - **Jitter noise measurement (3 ps) validates SAMPIC design**
  - Calibrations can still be improved
  - Data acquisition can still be optimized (a few outliers were detected)

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- First test of the fast analysis C++/ROOT code and different time measurement algorithms
  - **A simple CFD with maximum value picked from datapoints + linear interpolation is enough to give very good results**
  - CFD ratio of 0.5 shows the best performance
  - CC improves the results but it might not be the case for real signals (reproductibility issue)

Plans for the SAMPIC fast analysis code

- **Pre-treatment algorithm** to isolate the main peak of the pulse to be coded
- **Signal template** to be built from data
- Use of **binary data** instead of ASCII data (faster acquisition time)
- **Cross-talk** effect to be studied
- Outliers to be looked at

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Back-up

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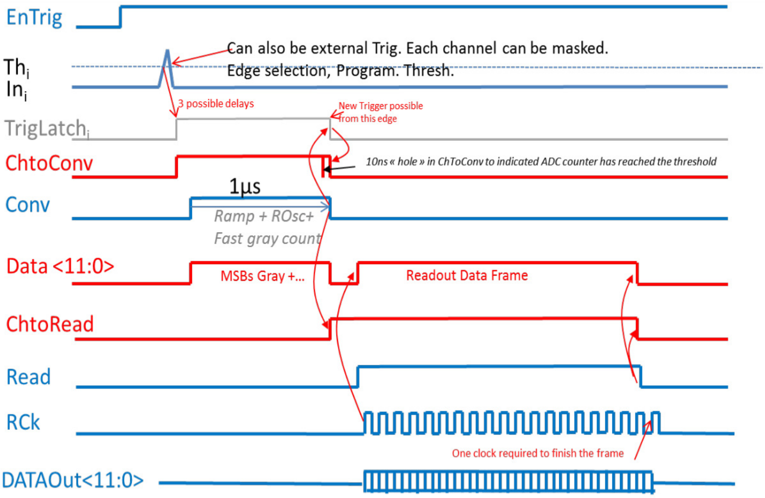
Austria Micro System 0.18 μm CMOS kit

- Based on IBM0.18m : IBM quality & documentation
- Good Standard Cells Library
- Good lifetime foreseen (HV module, automotive)
- 1.8V power supply: nice for analog design/ high dynamic range
- Reasonable leakages
- Good noise properties (already checked with IdefX chips for CdTe)
- Reasonable radiation hardness
- Less complex (and less expensive) than IBM 0.13m
- AMS high quality Design Kit
- Easy access (CMP, Europractice, AMS)

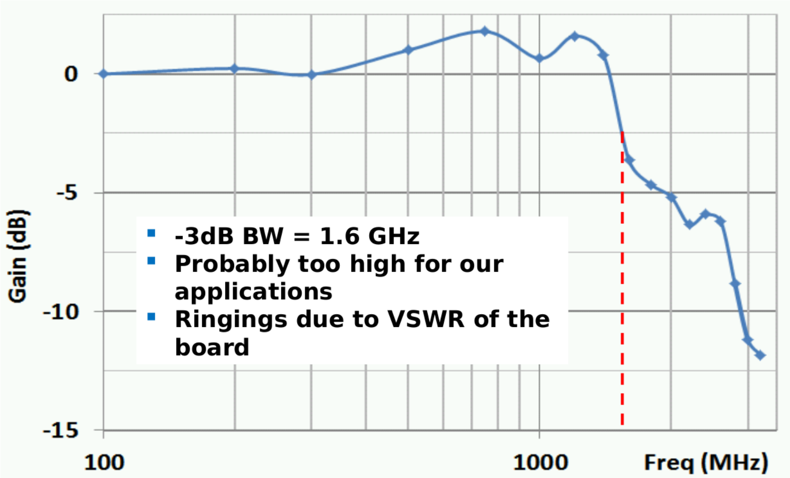
Operation



FROM SAMPIC to FPGA

TO FPGA from SAMPIC

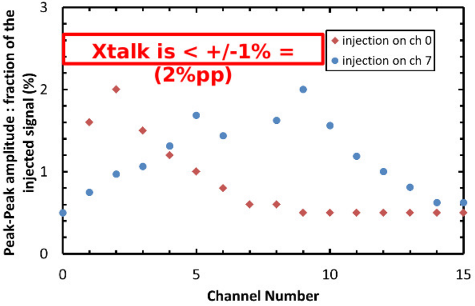
Bandwidth


Gain (dB)
0
-5
-10
-15
100
1000
Freq (MHz)
-3dB BW = 1.6 GHz
Probably too high for our applications
Ringings due to VSWR of the board

Cross-talk (E. Delagnes)

SAMPIC0: XTALK measurement

- 800mV, 1ns FWHM, 300ps risetime and falltime injected on channel 7
- Signal measured on the other channels
- Xtalk = derivative and decrease as the distance to the injection channel
- Xtalk signal is bipolar with ~ equal positive and negative lobe
- Same plot, but shifted if injection in another channel



Cross-talk (E. Delagnes)

SAMPIC0: Is it really derivative XTALK ?

- Instead of a short pulse, we send a longer pulse. Then we see that the Xtalk is not really derivative:
- The edge (green) triggers a damped oscillation with ~ 1.2 GHz frequency (yellow). With a short input pulse , we only see the first period of the sinewave
- This resonance frequency is the same for all the channels and unchanged if we change the sampling frequency
- Consistent with the resonance seen in frequency domain

Cross-talk (E. Delagnes)

SAMPIC0: XTALK in the frequency domain