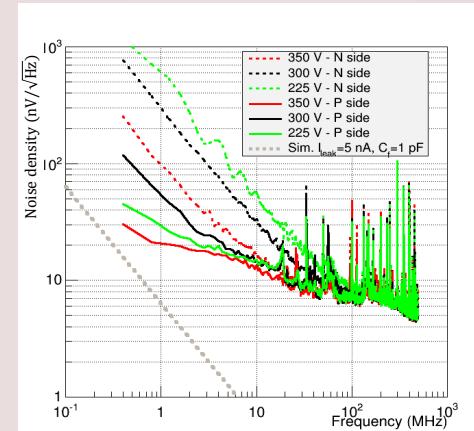
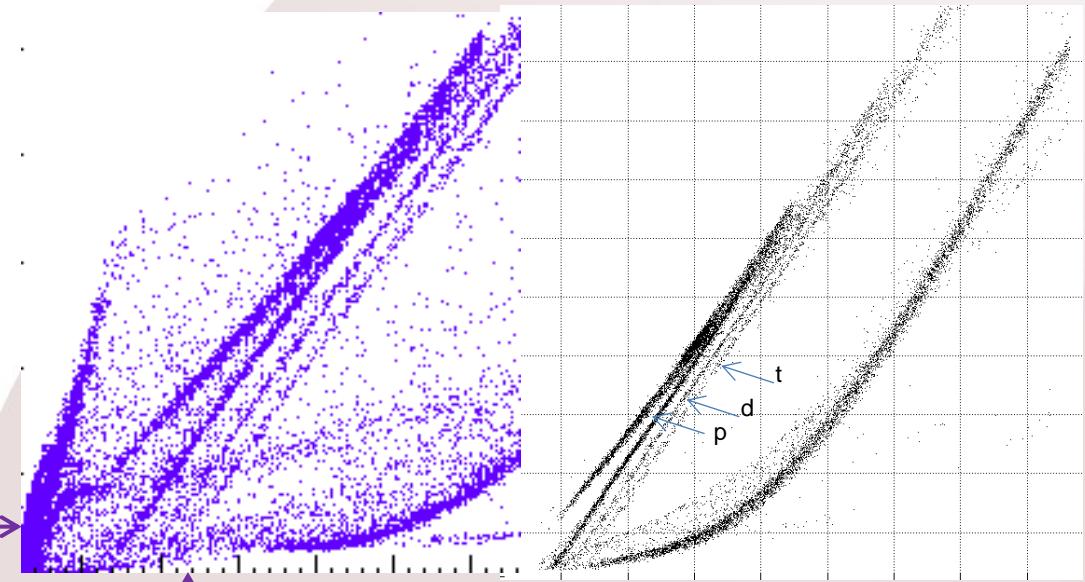
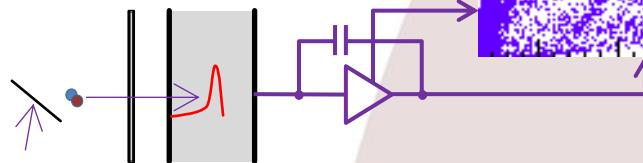
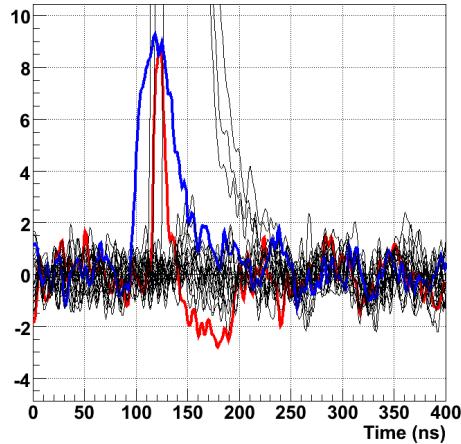


GASPARD: NOISE

ANALYSIS OF THE 2012 AND 2013 CAMPAIGNS AT IPNO'S TANDEM-ALTO



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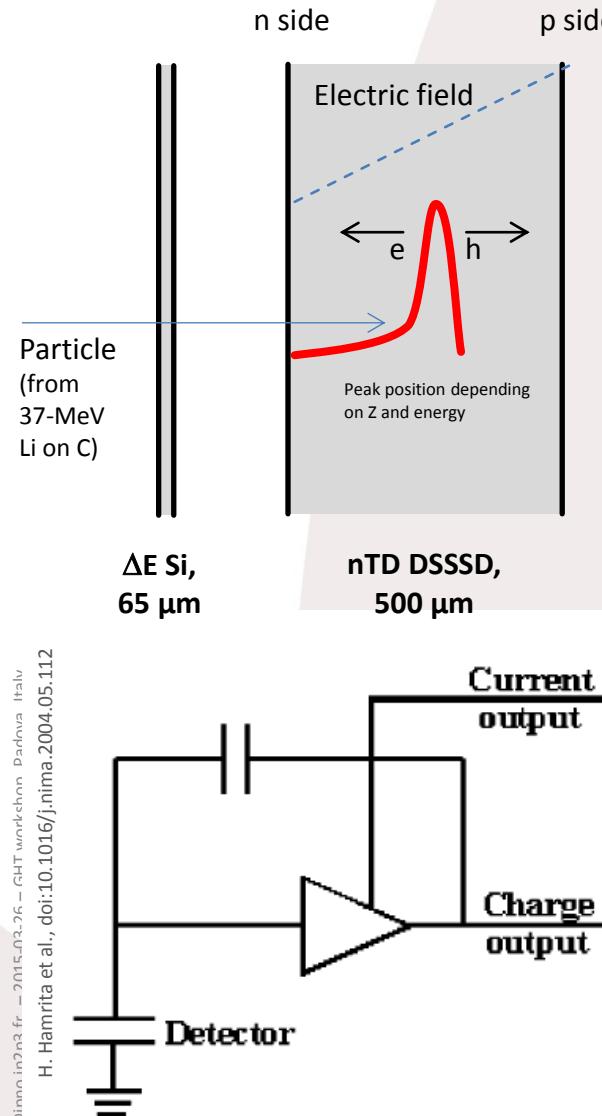
GASPARD-HYDE-TRACE workshop
Padova, March 25-27, 2015

OUTLINE

- Noise performance in the 2012 and 2013 campaigns
- Noise model
- Consequences of the noise on the dynamic range and on the time resolution
- Impact on the electronics

SETUP OF THE OCT 2012 CAMPAIGN

Campaign at [ALTO](#).



Detector

- 500- μm thick neutron Transmutation Doped (nTD) silicon detector
- Active area: 62.03×62.03 mm²
- Strips: on both side (X, Y directions), 485- μm pitch
- Particle injected into the rear side (benefit from the smaller velocity of holes for low-energy particles).
- Detector fully or partially depleted
- Total leakage current: < 500 nA @ 350 V (vendor data)

Front-end electronics

- PACI: preamplifier with current (i.e. low integration) and charge outputs. $C_f = 3.3 \text{ pF}$
- Current output: low integration / integration dominated by the detector capacitor: most of the fast component (electrons) is integrated. The response is not linear. Simulation by E. Rauli: rise time limitation of $\approx 8 \text{ ns}$ + tail around 30 ns.

Digitizer

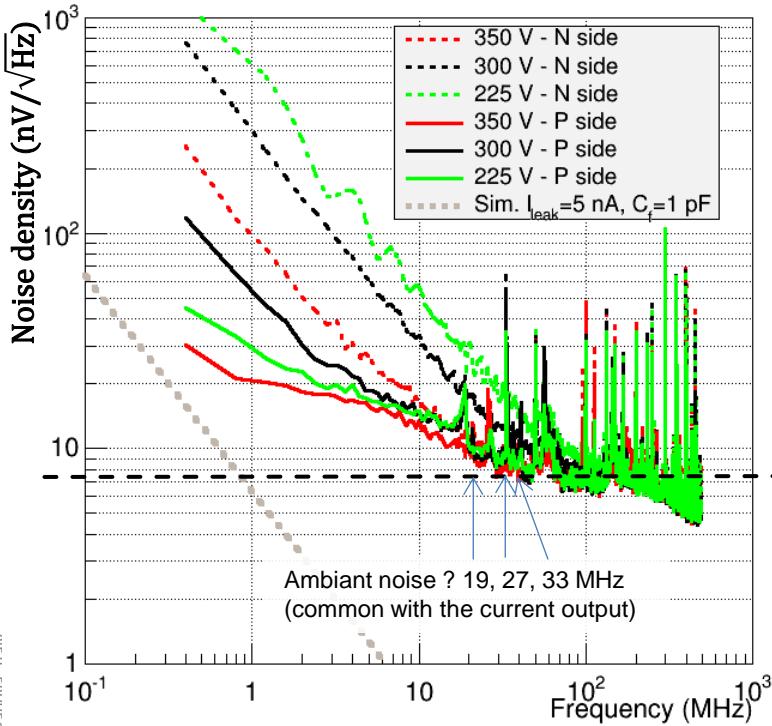
- [Matacq board](#)
- Version: [14-bit FADC](#) (input range = -1 to +1 V, 250- μV LSB)
- Sampling rate set to 1 GSPS
- Analog bandwidth: 300 MHz
- RMS noise < 175 μV (≈ 1 LSB)

SETUP OF THE OCT 2013 CAMPAIGN

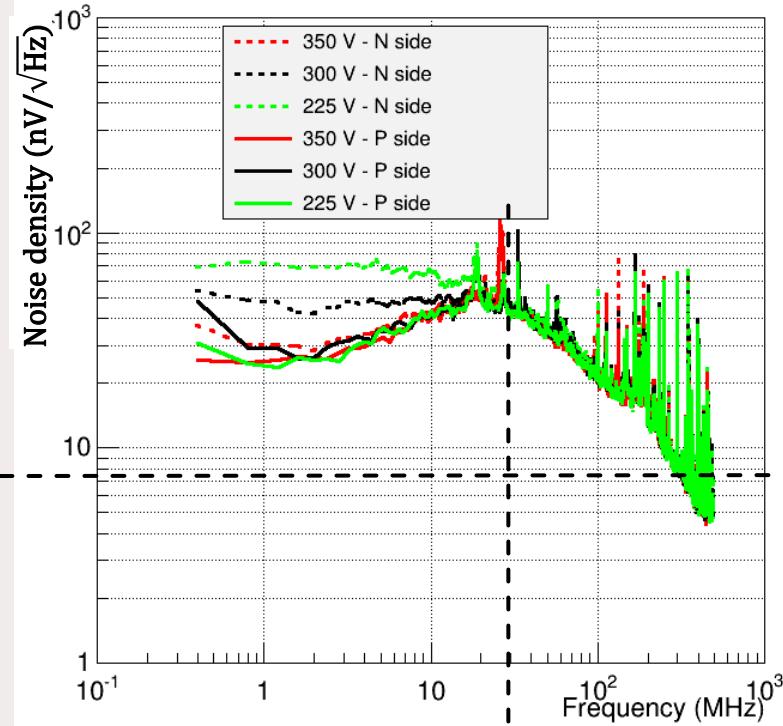
- Campaign at ALTO
- Measured in October 2013 ($d, {}^3\text{He}$ on mylar)
- Preamplifier: PACI
- Digitizer: [WaveCatcher](#) (12 bits, 1 LSB = μV ; noise = 700 μV RMS)
- Trigger start: beam sync. Signal
- Detector irradiated: total leakage current 3 μA @ 350 V

OBSERVED NOISE (OCT. 2012 DATA)

Charge output - trace



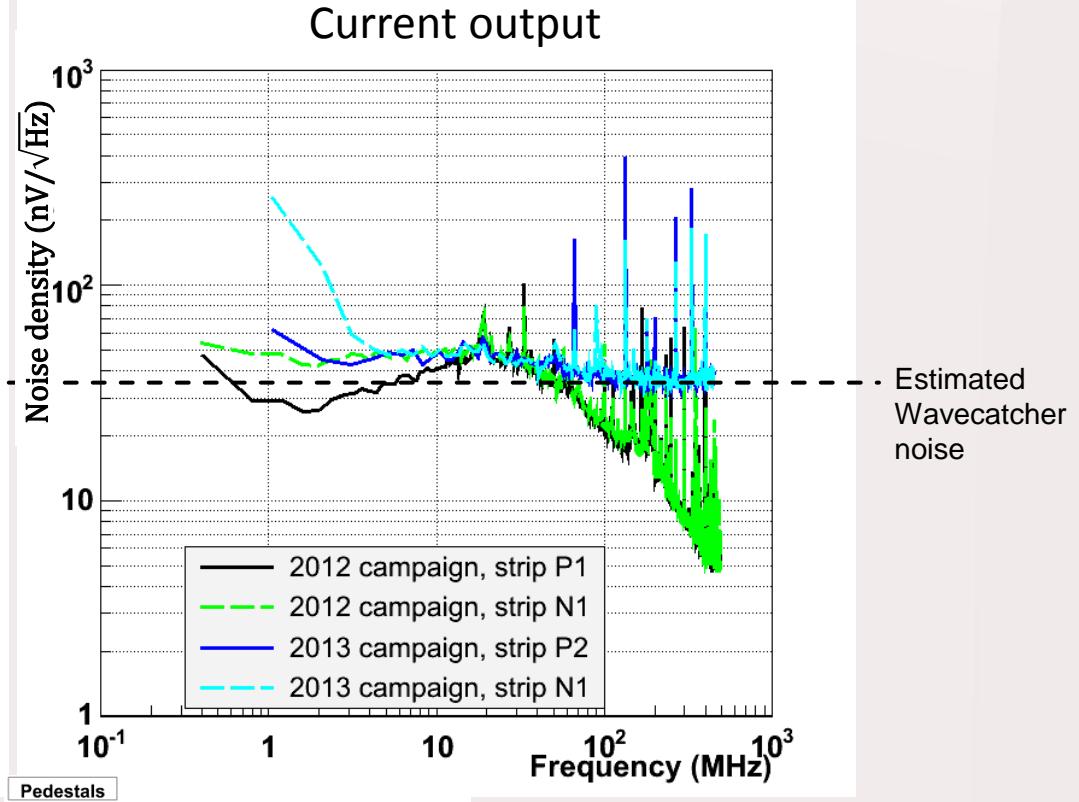
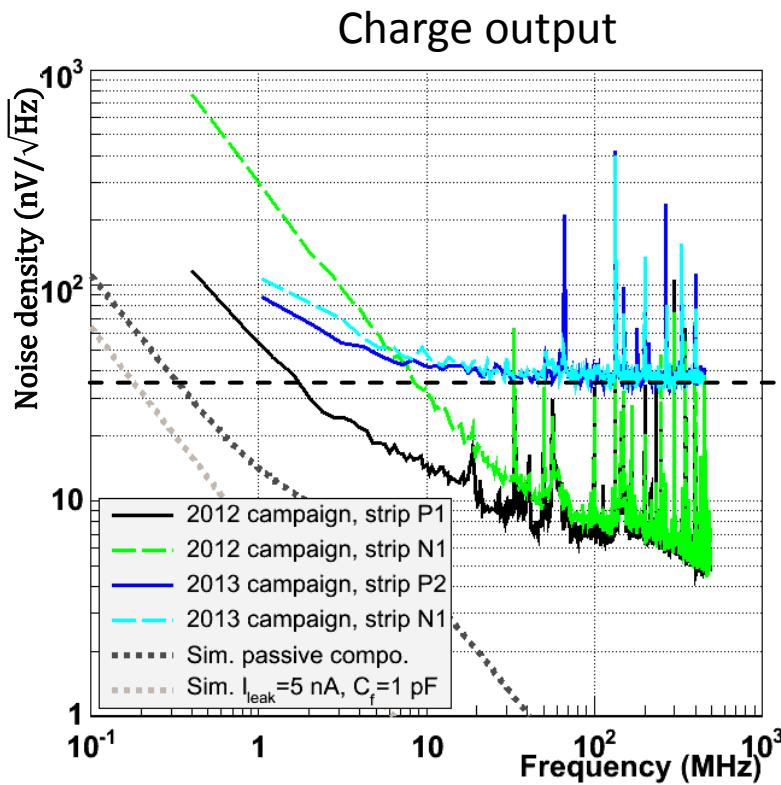
Current output - trace



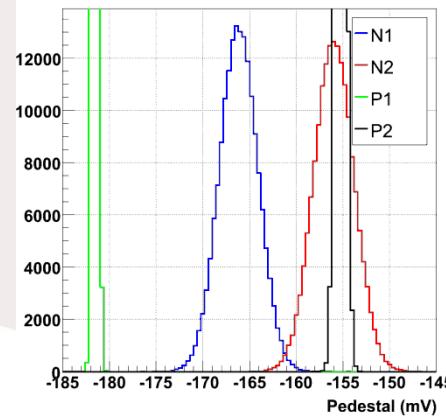
PACI current output cutoff frequency \approx 30 or 50 MHz?

- Measured with the MATAcq 14 bits, during the Oct. 2012 campaign at ALTO. Selection of traces without events (P1 and N1), average over 250 traces.
- The noise on the P side seems to be dominated by the PACI + setup parasitic capacitances since the noise is independent from the high voltage, whereas for the N side, the noise seems to be more dependent on the detector capacitance (decreasing with the voltage, the minimum being the depletion voltage). Could not measure at lower frequency, where we expect to observe the effect of the leakage current as a function of the bias voltage.
- Main noise peaks: 19, 27 and 33 MHz (peak above 50 MHz: to be compared with the rise time, see next slides)
- The difference in ratio of the 27 and 33 MHz peaks in charge and current indicates that a current cutoff frequency around 30 MHz.

NOISE: COMPARISON WITH THE WAVECATCHER



Less pick-up noise with the 2013 setup?
 Greater pedestal RMS on N (2013 campaign):
 N1: 2.05 mV RMS
 N2: 2.12 mV RMS
 P1: 0.242 mV RMS
 P2: 0.479 mV RMS



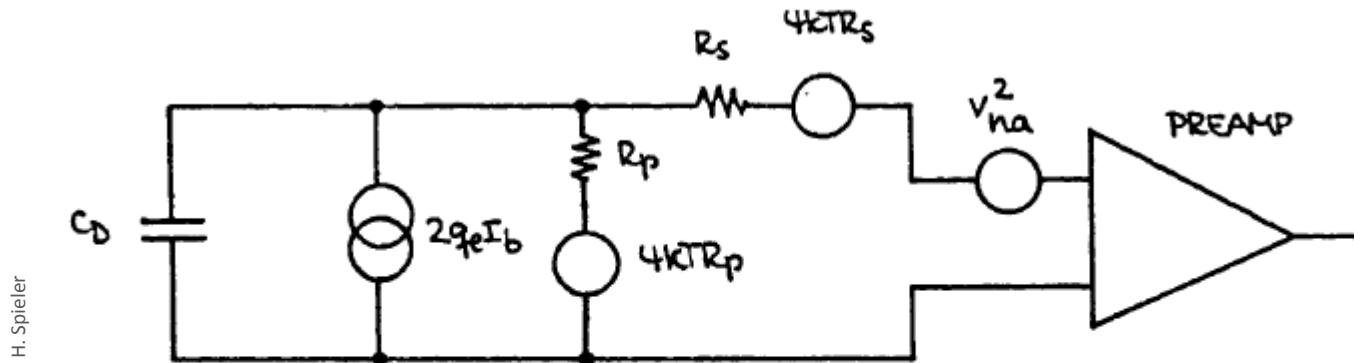
DETECTOR / NOISE MODEL

Noise sources

- Capacitor
- Leakage current: shot noise
- Thermal noise due to the resistivity
- Flicker noise (trapping and de-trapping)

Component values

- Range depending on the wafer processing (chemistry...)
- Bonding neglected (inductance) for the noise



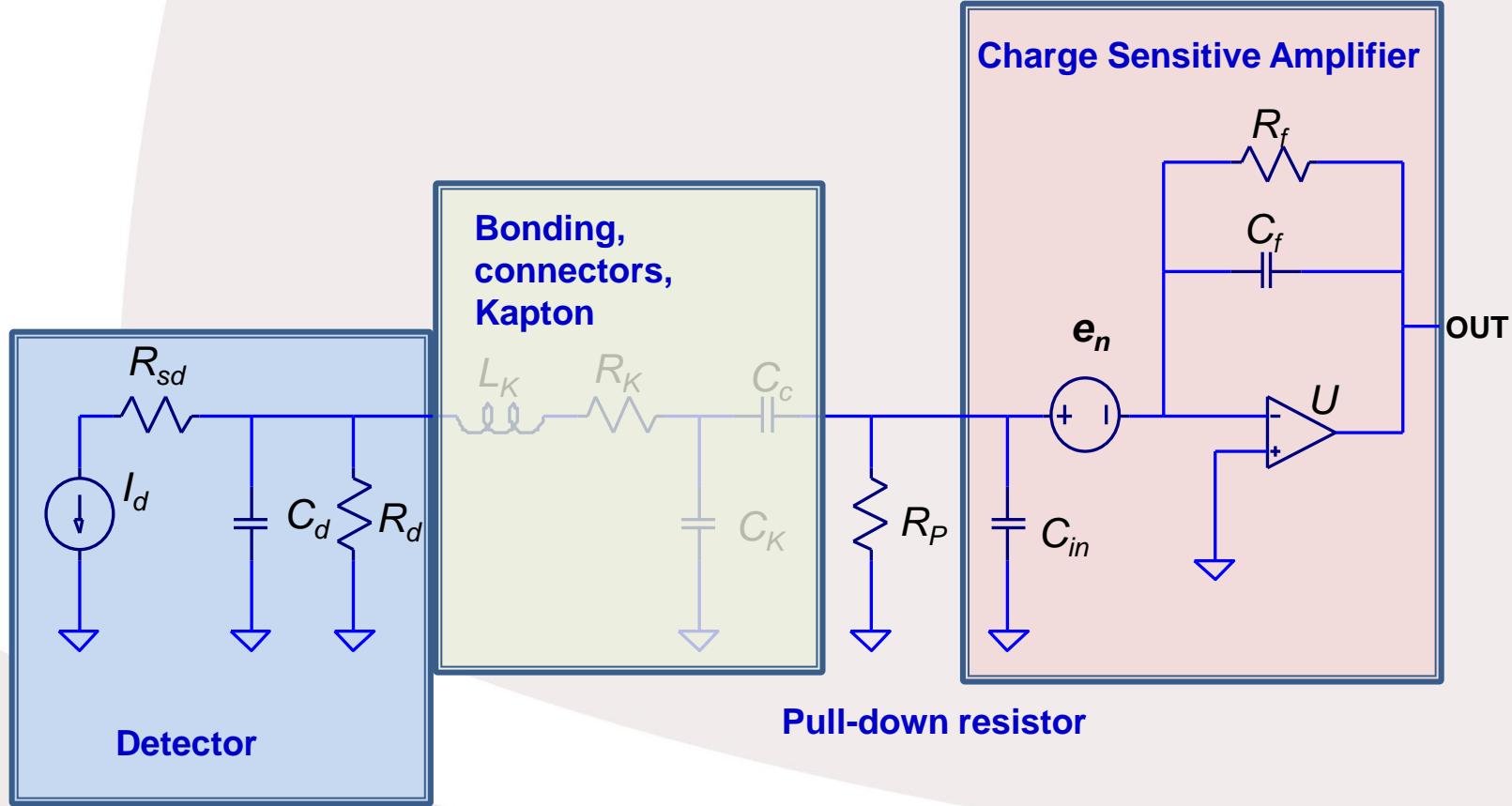
detector	bias current	shunt resistance	series resistance	equivalent input noise voltage of amplifier
	shot noise	thermal noise	thermal noise	

BB13 500 µm:
20 pF/cm² @350 V
→ 5 to 10 pF/strip

BB13 500 µm:
500 nA @350 V / 3 µA after irrad.
→ 1 to 100 nA / strip

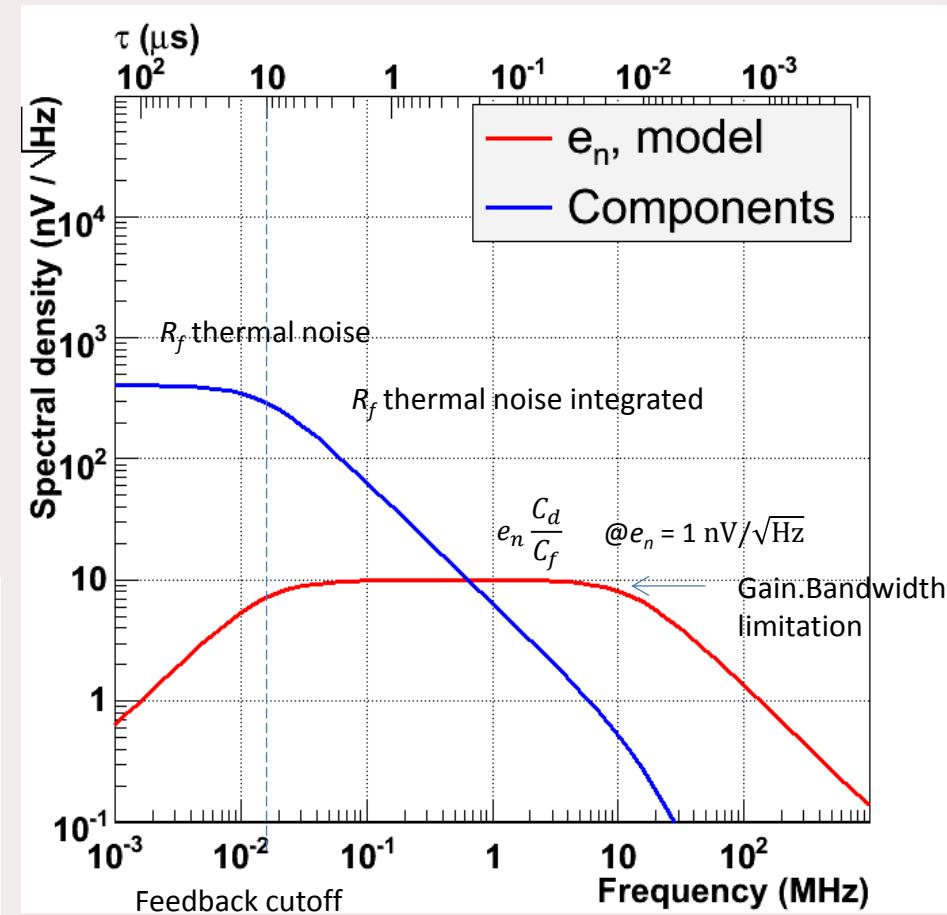
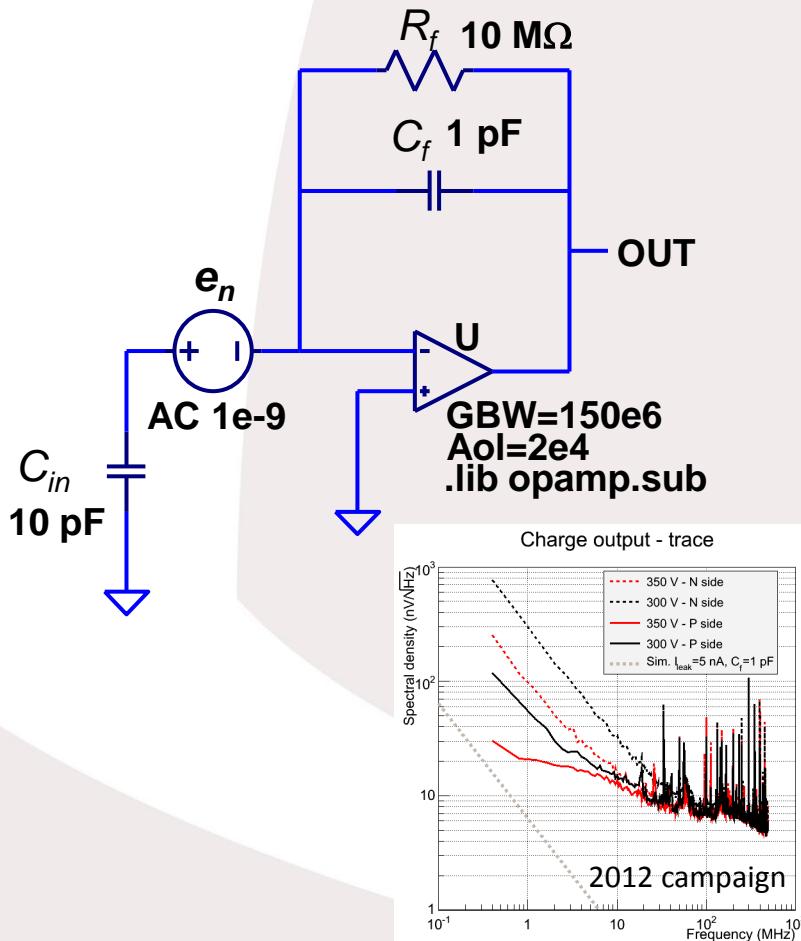
MODEL

- Simplified model
- Checked in the literature to what extent an “aggregated” model can be used of the silicon
- Aggregated model correct up to ≈ 160 MHz
- SPICE simulation with [LT SPICE](#) (interface to SPICE), equivalent results with [SIMetrix](#) (allows less nodes, different interface).
- Kapton model: use calculations of L. Leterrier for MUST 2 (total: / see next slides)
- Coupling = 47 nF, pull-down = 10 M Ω
- PACI input: see next slide



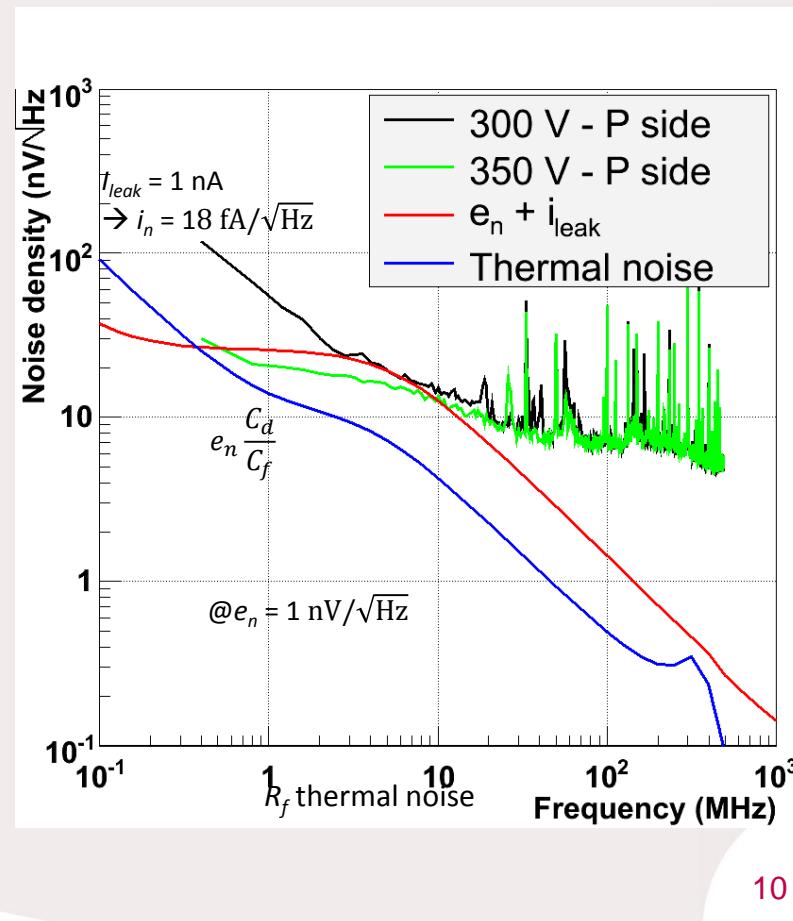
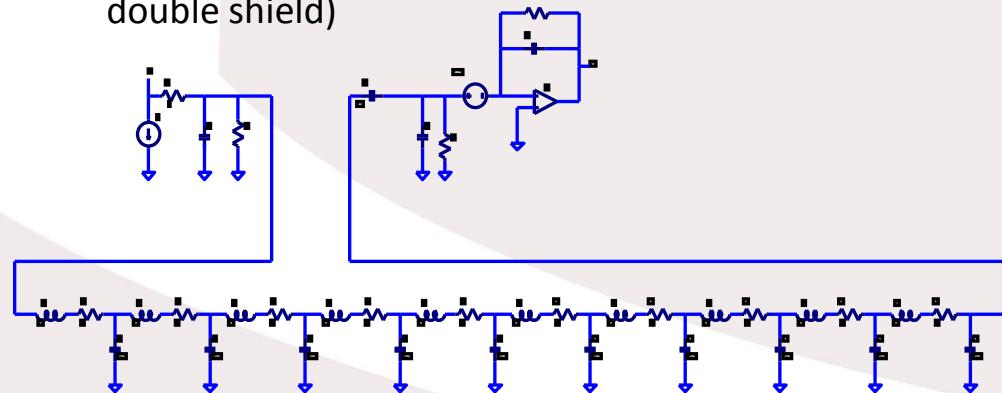
PACI MODEL

- Did not represent the gain following the integration stage since the main contribution to the noise is the first stage (i.e. mostly the input transistor)
- Value: resistor = E. Rauly, capacitor = according to the gain
- Input model (capa + RMS): values at 1 MHz from the data sheet of the input transistor ([BF862](#))
- The Gain.bandwidth limitation affects the behavior. Value does not seem correct, rather incompatible with the feedback cutoff frequency.

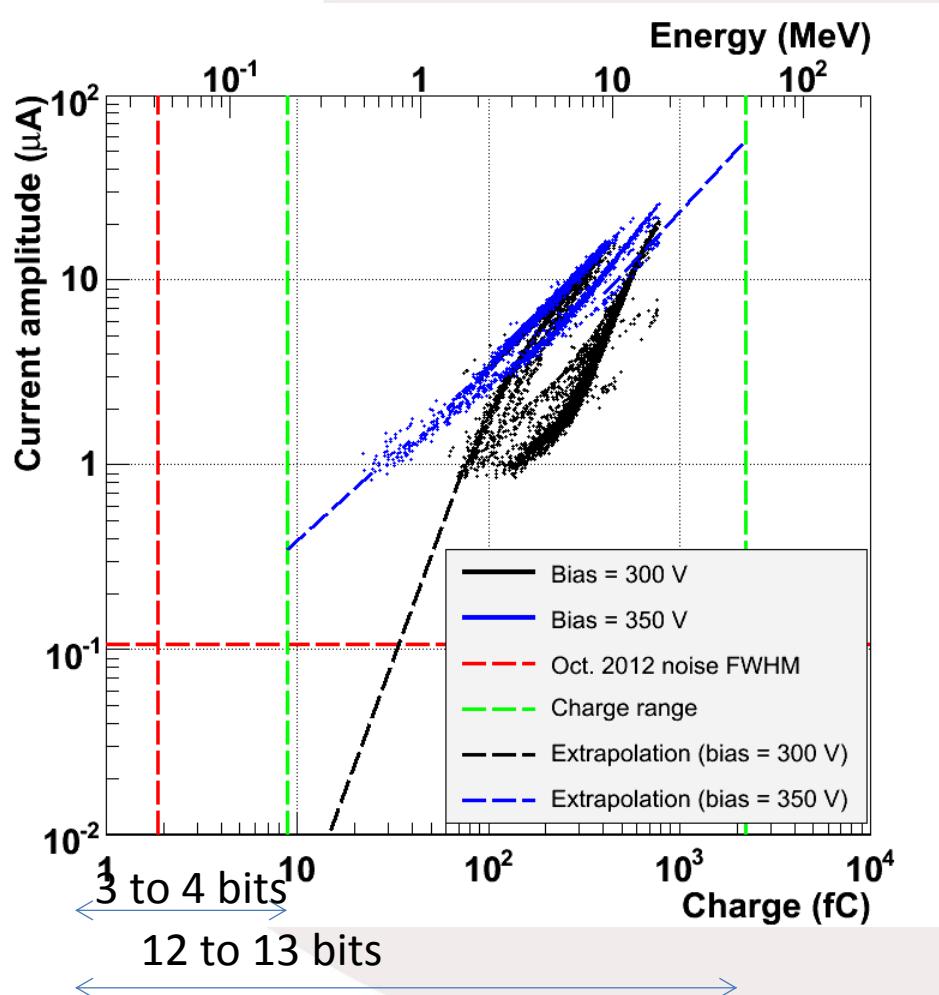


KAPTON CONNECTION

- Model:
 - At low frequency (wavelength in medium >> circuit size): integrate the components = 30 nH, 25 Ω series, 15 pF parallel
 - At high frequency (wavelength in medium << circuit size): guided propagation = noiseless impedance
 - Between those limits: use several cells
- Orders of magnitude:
 - 10 cm, in Kapton: tenth of the wavelength corresponds to 160 MHz
 - Need to split in at least 10 to have a more realistic simulation
 - At 1-nA leakage current and present gain-bandwidth limitation, the capacitance noise dominates between 0,5 to 5 MHz: below = R_f thermal noise, above = cut by the bandwidth limitation and dominated by the ADC noise
 - Final version of GASPARD Kapton: great line length dispersion, expected greater capacitance (more layers, double shield)



IMPACT ON THE DYNAMIC RANGE



Calibration for the amplitude: calculate
 $Q/(t_{FWHM}/2/0.9)$, fit with the amplitude
 $\rightarrow i(\mu\text{A})=0.035+114v(V)$ (if strictly
7000V/A, this would be 143)

- Data from the Oct. 2012 campaign
- Difficult to extrapolate the upper limit of the range / the directions per element seem to be parallel
- 300-V bias, the detector is not depleted and the low-energy signals will not be correctly collected (not enough field → possibly more noise due to charge recombination) + need greater dynamic range and much greater gain
- With the present electronics, it will be a real issue to measure 100-keV pulses (poor signal-to-noise ratio in amplitude and charge).

iPACI: 12.8 bits ENOB (simulated → J.-J. Dormard's talk)

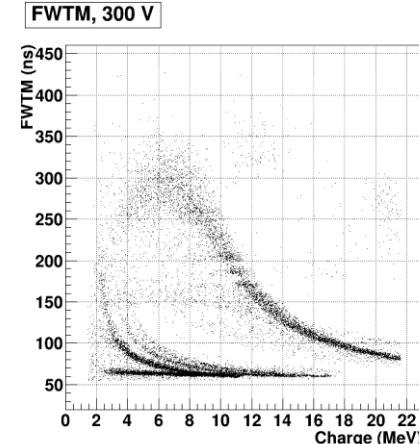
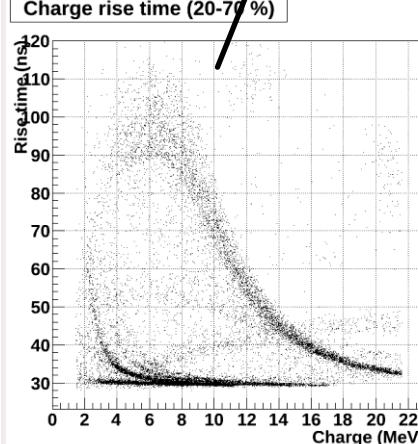
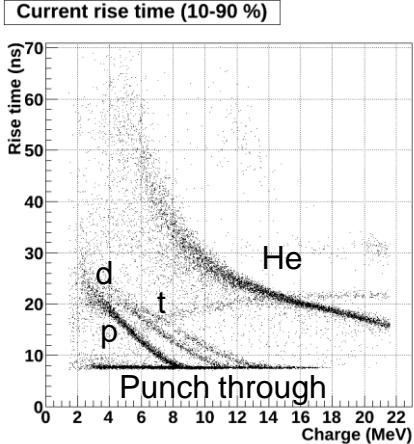
RISE TIME AND SHAPE FACTOR

Campaign at ALTO October 2012 (Li on C)

Full depletion = 330 V

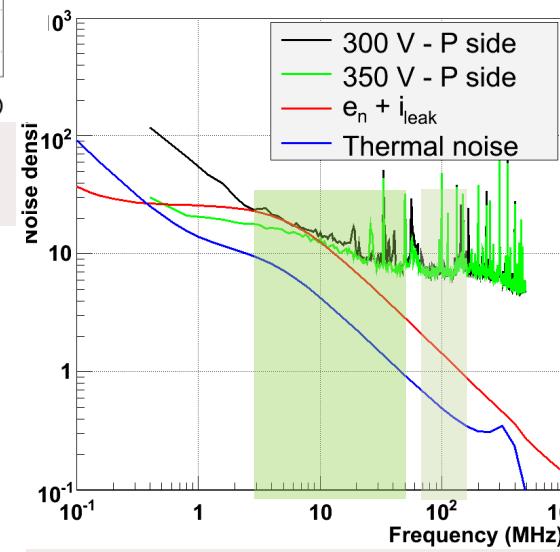
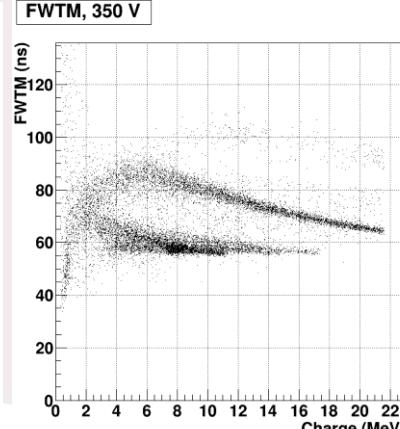
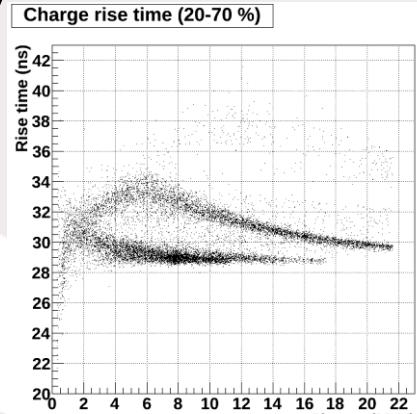
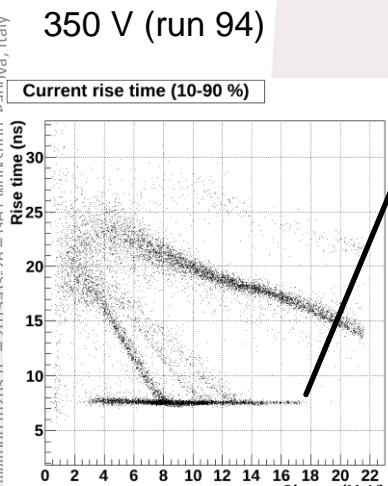
300 V (run 157)

Frequency min: 2 MHz



350 V (run 94)

Frequency max: 50 MHz / PACI limitation



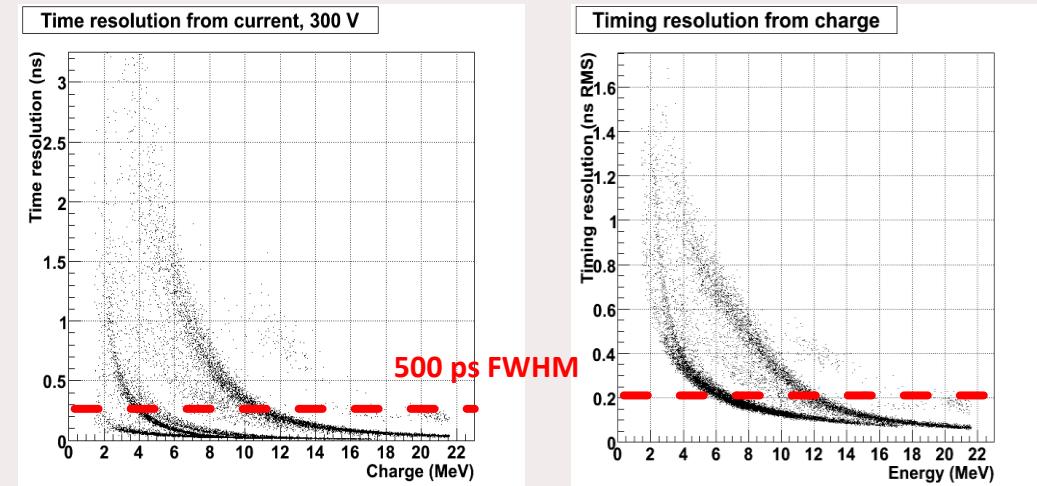
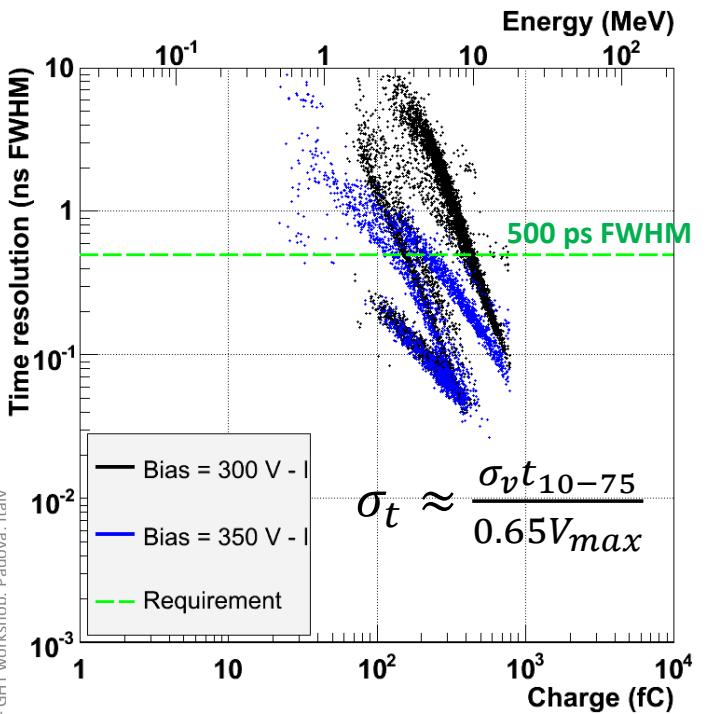
Dominant noise = ADC

$$\sigma_t \approx \frac{\sigma_v}{\frac{\partial v}{\partial t}}$$

TIME RESOLUTION

Campaign at ALTO October 2012 (Li on C)

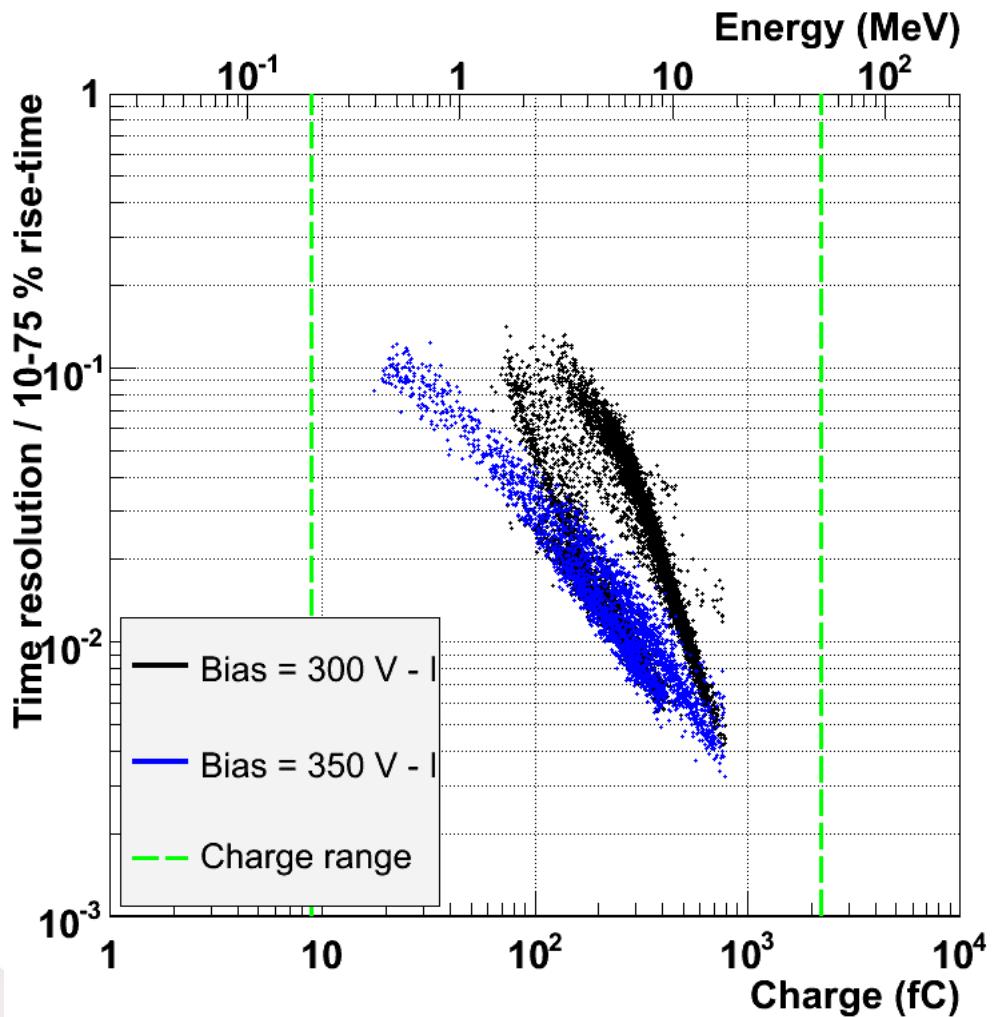
- Expected poor resolutions at the lowest energies (greater slope)
- Dedicated slow shaper for the timing (compromise between the rise time and the noise)



The measurements of October 2012 show that 500-ps FWHM resolution can be reached provided **the detector is well depleted** (350 V). Below depletion (300 V), the charge signal gives the best results (<1.5 ns RMS above 4 MeV).

The current RMS noise is 340-350 μ V RMS i.e 40 nA RMS at the input (on a 300 MHz bandwidth).

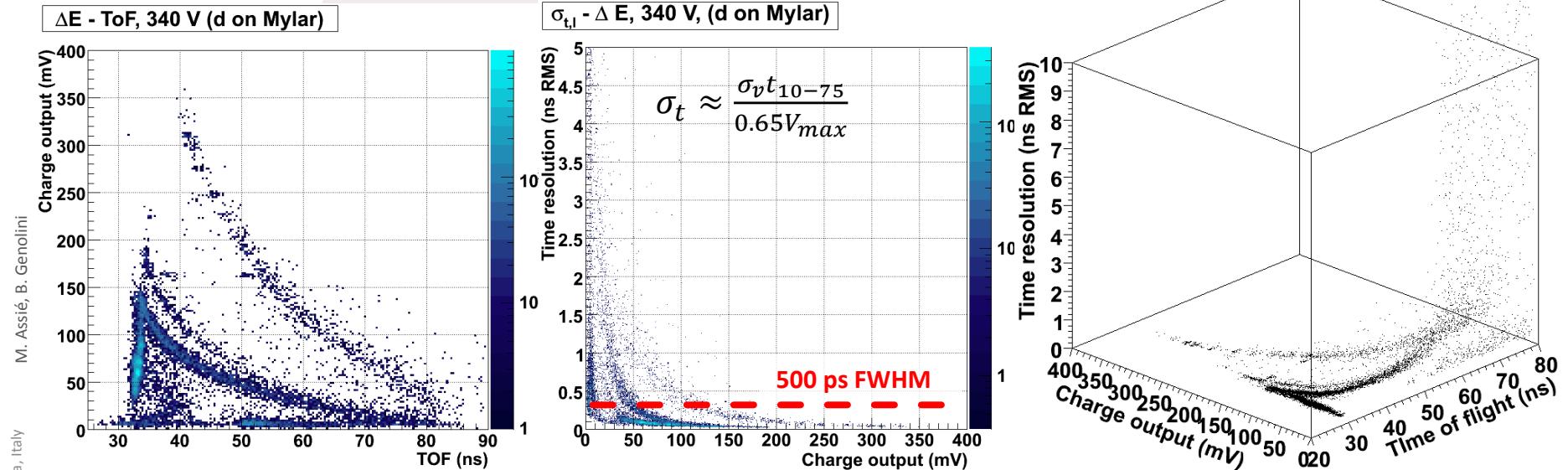
TIME RESOLUTION (RELATIVE)



Requirement ?

Change with 300-μm thickness
(smaller rise time)

TIME RANGE (OCT 2013 CAMPAIGN)



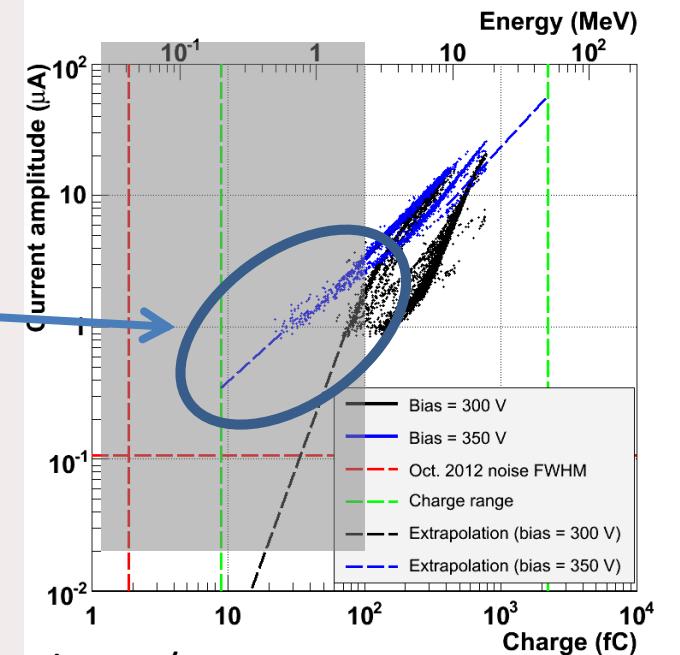
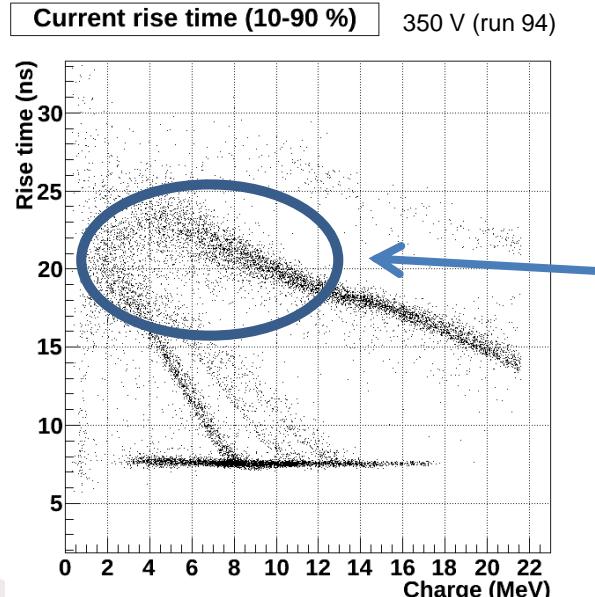
$^3\text{He}/^4\text{He}$ discrimination

(lack of statistics for this run – preliminary data; particle identification validated from other detectors)

Resolution correct for relatively high energy He isotopes, but not sufficient at the lowest energies without filtering. The noise is greater compared to the Matacq.

WHY USE AN ANALOG DISCRIMINATOR?

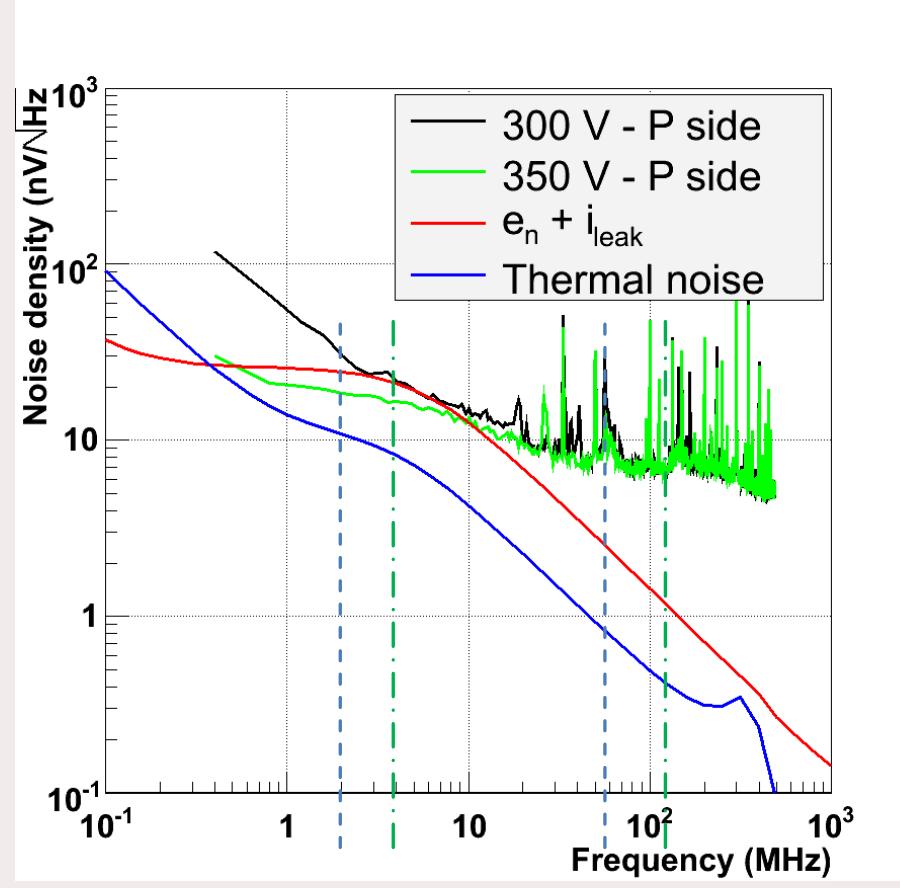
- At the lowest energies, the PSA is more difficult: at 350 V, could not separate well H and He isotopes below 4 MeV
- At low energies for H and He, the rise times are the greatest ($t_{\text{rise}} > 15 \text{ ns}$): can implement a dedicated filter on a reduced bandwidth (**20 MHz**) to achieve a better signal-to-noise ratio
- Ageing: implement a tunable rise time N. Demaria et al., NIMA, 447(2000), [doi:10.1016/S0168-9002\(00\)00182-0](https://doi.org/10.1016/S0168-9002(00)00182-0)
- Digitized signals: need 5 samples to make a good time measurement on those I, i.e. a signal amplitude $> 4\sigma_{\text{noise}} + 5\nu_{\text{LSB}}$, oversampling difficult to achieve ?



Difficulties on the shape / SNR
 →analog time measurement

CONCLUSIONS

- Over the signal bandwidth, the noise is dominated by the ADC for the fastest signals (provided we suppress the lowest frequencies) = explains the best results with a (fast) bipolar filter
- For slower signals, the series noise has a non negligible contribution
- We expect the series noise to be dominated by the Kapton capacitance
- → if we have difficulties with the smallest signals, we may have to consider full analog processing with a discriminator to use the time of flight to get rid of the FADC digitization noise and reduce the series noise



PACI

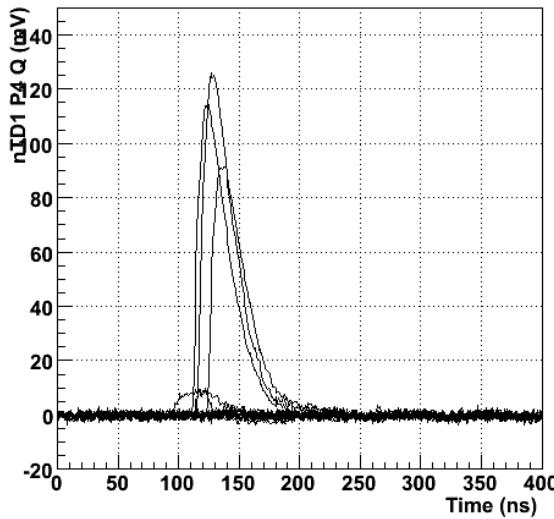
iPACI

BACK-UP

ILLUSTRATION OF THE DYNAMIC RANGE

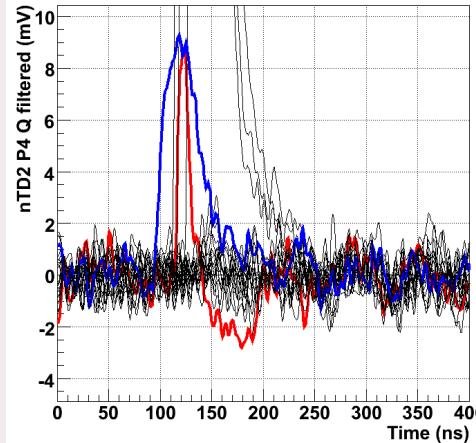
Campaign at ALTO October 2013 ($d, {}^3\text{He}$ on Mylar)

`visu(nTD1 P4, I)`



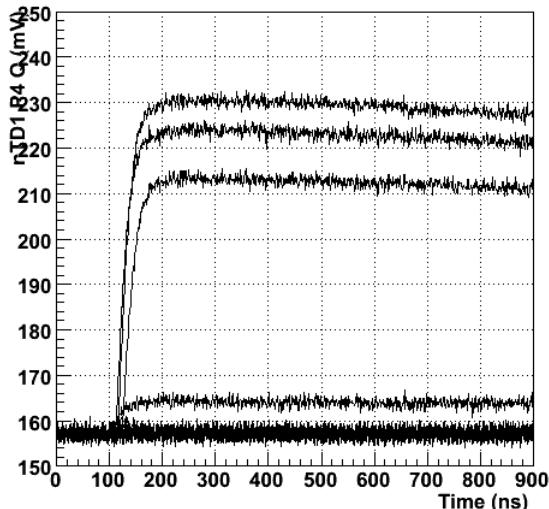
20 first « current » (fast shaper) signals on P4: many zeros.

`visu(filter(BLsub(nTD1 P4, I)))`

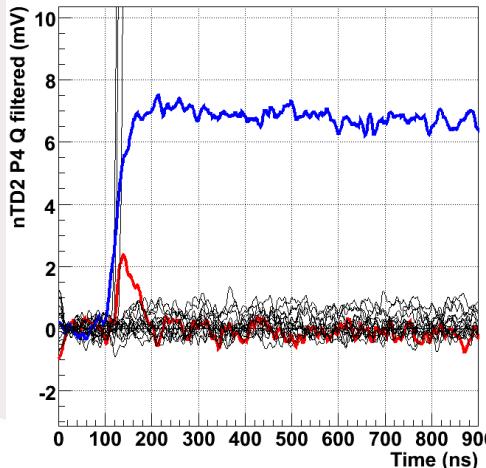


Zoom after base line subtraction and slight smoothing: **small « standard » pulse (blue)** and **small « bipolar » pulse (red)**.
(due to coupling with neighbor or charge sharing between several strips)

`visu(nTD1 P4, Q)`



`visu(filter(BLsub(nTD1 P4, Q)))`

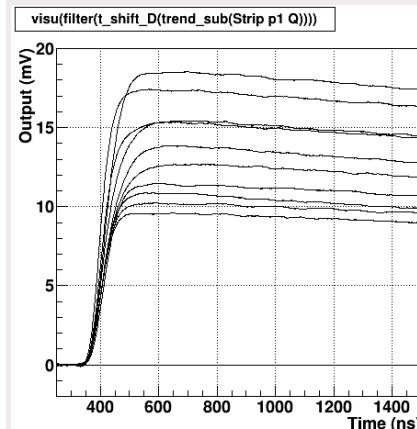
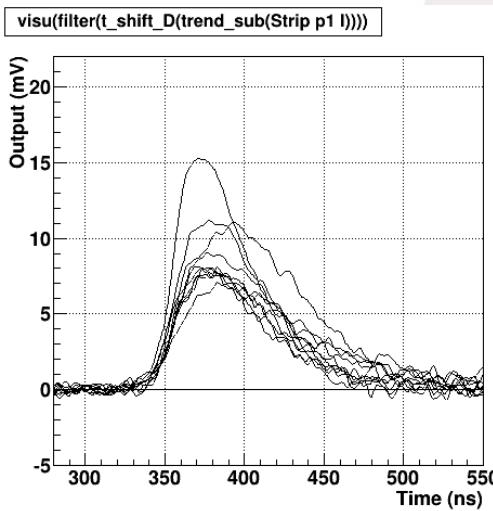


Associated « charge » (slow shaper) signals on P4.

Right = after base line subtraction and slight smoothing

LOW END OF THE DYNAMIC RANGE

Campaign at ALTO October 2012 (Li on C)

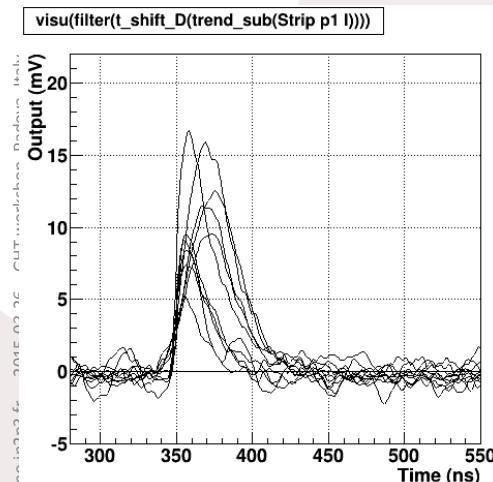


300 V: (left: current, right: charge; 15 mV on Q \approx 2 MeV)

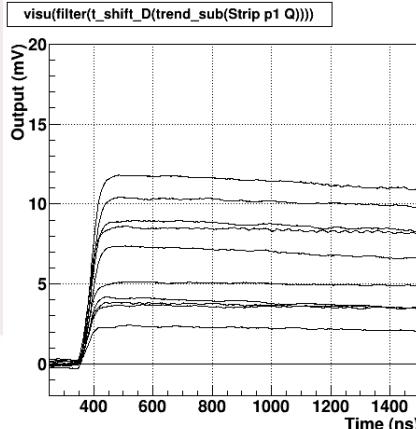
Filter on the current signal: trapezoidal (5-ns edge, 2-ns flat top)
Filter on the charge signal: moving average (50-ns)

2 MeV

I used these time constants (rising and falling edges) to calculate the minimum peak current. We could reduce the dynamic range by an important factor by not working below depletion.



350 V: (left: current, right: charge; 15 mV on Q < 2 MeV)



Greater noise due to oscillation (27 MHz, picked up?), and fall time still compatible with the early detector signal simulation and the PACI fall time, 30 ns (signal width = 20-ns collection).