Diamond detectors in FOPI

M.Ciobanu, M.Kis,
A.Schüttauf

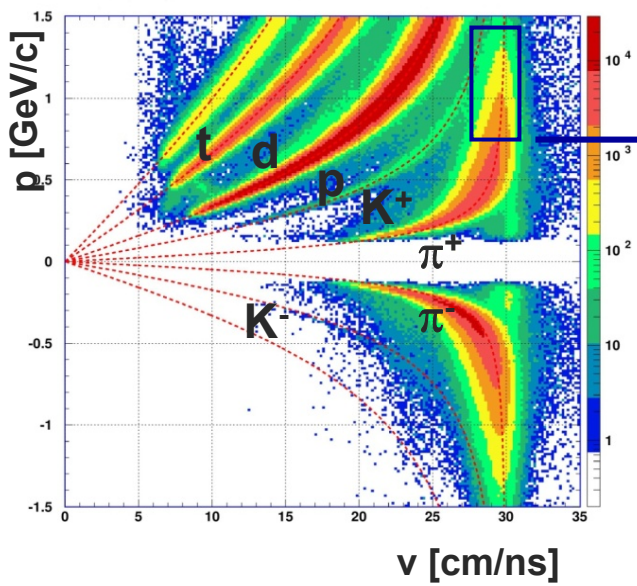
Outline

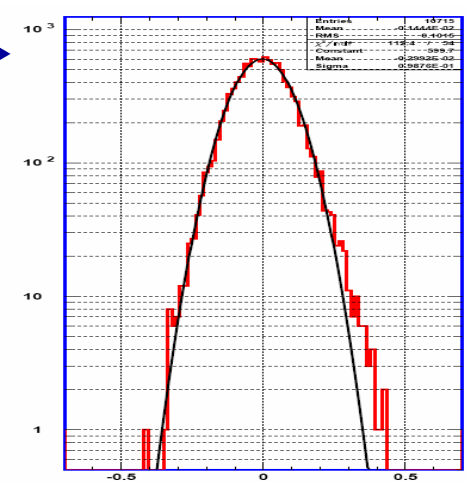
- FOPI's constrains on a start counter
- Timing relevant factors
- Diamond detectors
  - Heavy ion case Z>6
  - Proton case
- Summary and Outlook

FOPI's start counter

Heavy ion case:
For C-Au ions we need a start-counter better then **σ_{ts}< 50 ps**, with tails smaller 1 ‰ @ 1MHz.
To ensure the Pion-Kaon id up to 1 GeV/c.

Proton case:
The proton experiments hunt for rare event and will be operated at SIS space charge limit, with an estimated rate of 10 MHz.
For this an experiment a start resolution below **σ_{ts}< 70 ps** is needed.





σ_{tof}< 95 ps
for fast pions

Theory

What determines the timing ?

Diamond

Capacitance C_d
$\varepsilon_{(e-h)}$ ~13 eV
Thickness d
Size x·y
Type PCD,SCD

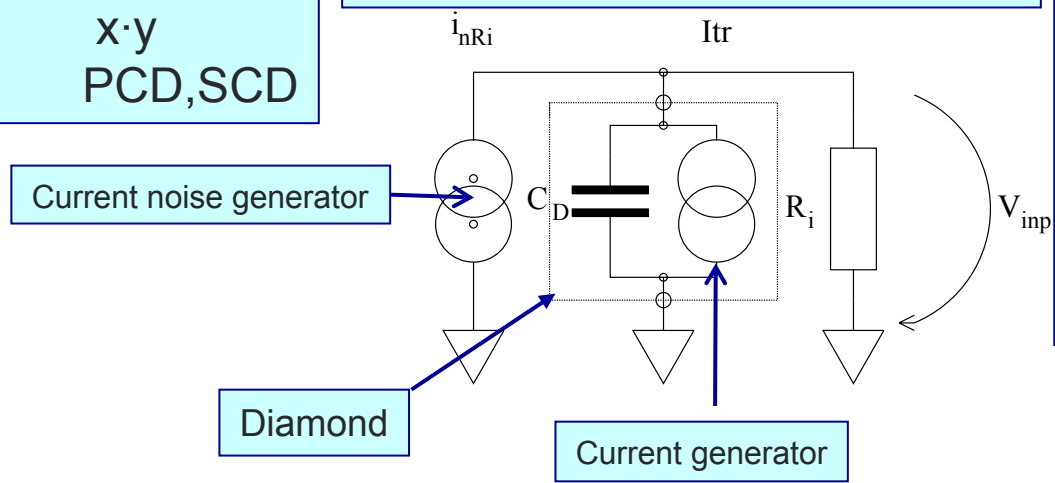
Interface

Capacitance C_p~0.3 pF/cm
Length l
Connector/Bond

Amplifier

Capacitance C_A
Gain G
Bandwidth BW_A
Noise N

Type CSA DC-coupled
BBA AC-coupled
MOS-follower
Trans. Amp.

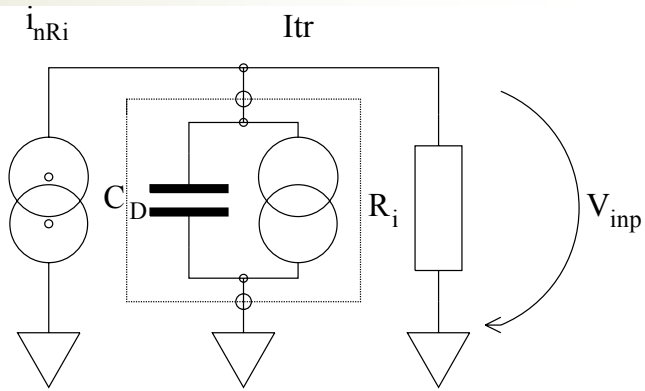


Simplest case a D+BBA

$$i^2_{nRi}/\Delta f = 4k \cdot T/Ri$$

$$i_{Tr}(t) = I_0 e^{-t/\tau}$$

$$i_{Tr}(t) = Qii(e,h)/\tau \cdot e^{-t/\tau}$$



$$S = V_{Sin} = i_{Tr}(0) \cdot R_i = Qii(e,h)/\tau \cdot R_i = Qii(e,h)/C_D$$

$$N^2 = V^2_{Nin} = i^2_{nRi}/\Delta f \cdot R^2_i \cdot f_u \pi/2 = 4k \cdot T \cdot R_i \cdot BW_N = k \cdot T/C_D$$

$$BW = f_u$$

$$BW_N = \pi/2 \cdot f_u$$

$$\sigma_t = \sigma_n/(dv/dt)$$

$$t_{rA} = 0.35/BW_A, dv/dt = 0.8 \cdot V_{Sin}/t_{rA} = 2.28 \cdot Q_{ii}(e,h)/C_D \cdot BW_A$$

Current noise generator	I^2_{nRI}
Frequency bandwidth	Δf
Relaxation time	τ
Time	t
Diamond charge	Q_{ii}
Temperature	T
Bolzman factor	k
Detector capacitance	C_D
Time resolution	σ_t
Thermal noise	σ_n
Resistance	R_i

Energy measurement: S/N

$$S/N = Qii(e,h)/\sqrt{k \cdot T \cdot C_D}$$

Timing measurement: N/(dv/dt)

$$\sigma_t = \frac{\sqrt{k \cdot T/C_D}}{2.28 \cdot Qii(e,h) \cdot BW_A/C_D} = \frac{\sqrt{k \cdot T \cdot C_D}}{2.28 \cdot Qii(e,h) \cdot BW_A}$$

A more realistic case in RF

Add a realistic noise factor F for RF applications:

F= Total noise/source resistor noise (Rs)

$$F = \frac{e^2_{nRS} + e^2_{neq}}{e^2_{nRs}} = 1 + \frac{i^2_{nA} \cdot R_S^{\ 2} + e^2_{nA}}{e^2_{nRs}}$$

$$i^2_{nA} \cdot R_s + e^2_{nA} = (F-1) \cdot e^2_{nRs}$$

$$i^2_{neq} = (F-1) \cdot i^2_{nRs}$$

$$i^2_{neq} / \Delta f = 4k \cdot T \cdot (F-1) / R_i$$

For good energy measurement we have to:

1) Minimize: C_D, T, F

2) Maximize: Q_{ii} → CSA

$$S/N = Qii(e,h) / \sqrt{k \cdot T \cdot (F-1) \cdot C_D}$$

For good timing measurement we have to:

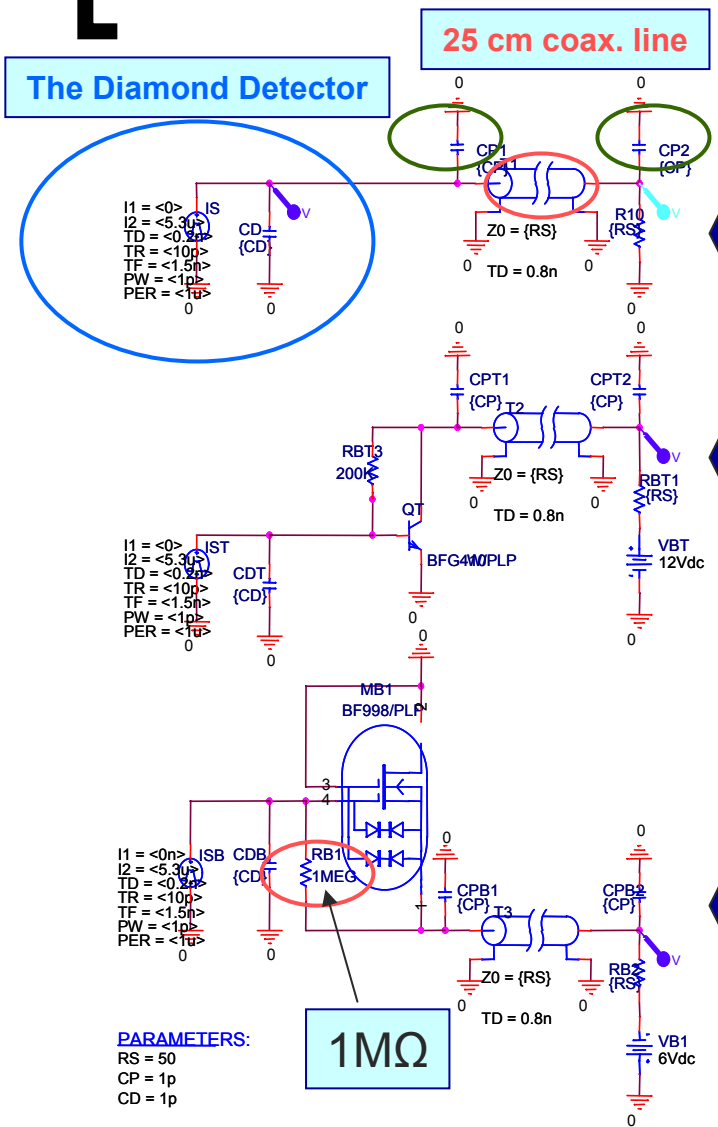
1) Minimize: C_D, T, F

2) Maximize: BW_A → BBA

$$\sigma_t = \frac{\sqrt{k \cdot T \cdot (F-1) \cdot C_D}}{2.28 \cdot Qii(e,h) \cdot BW_A}$$

Simulations

Three cases for simulations



50 Ω Load or 50 Ω Broadband Amplifier BBA like the DBA and FEE1.

High frequency 22 GHz and low noise Transistor Amplifier (Tamp) BFG410W

N_F~1dB, C_e~ 0.4 pF, C_{re}~ 45fF (feedback C)

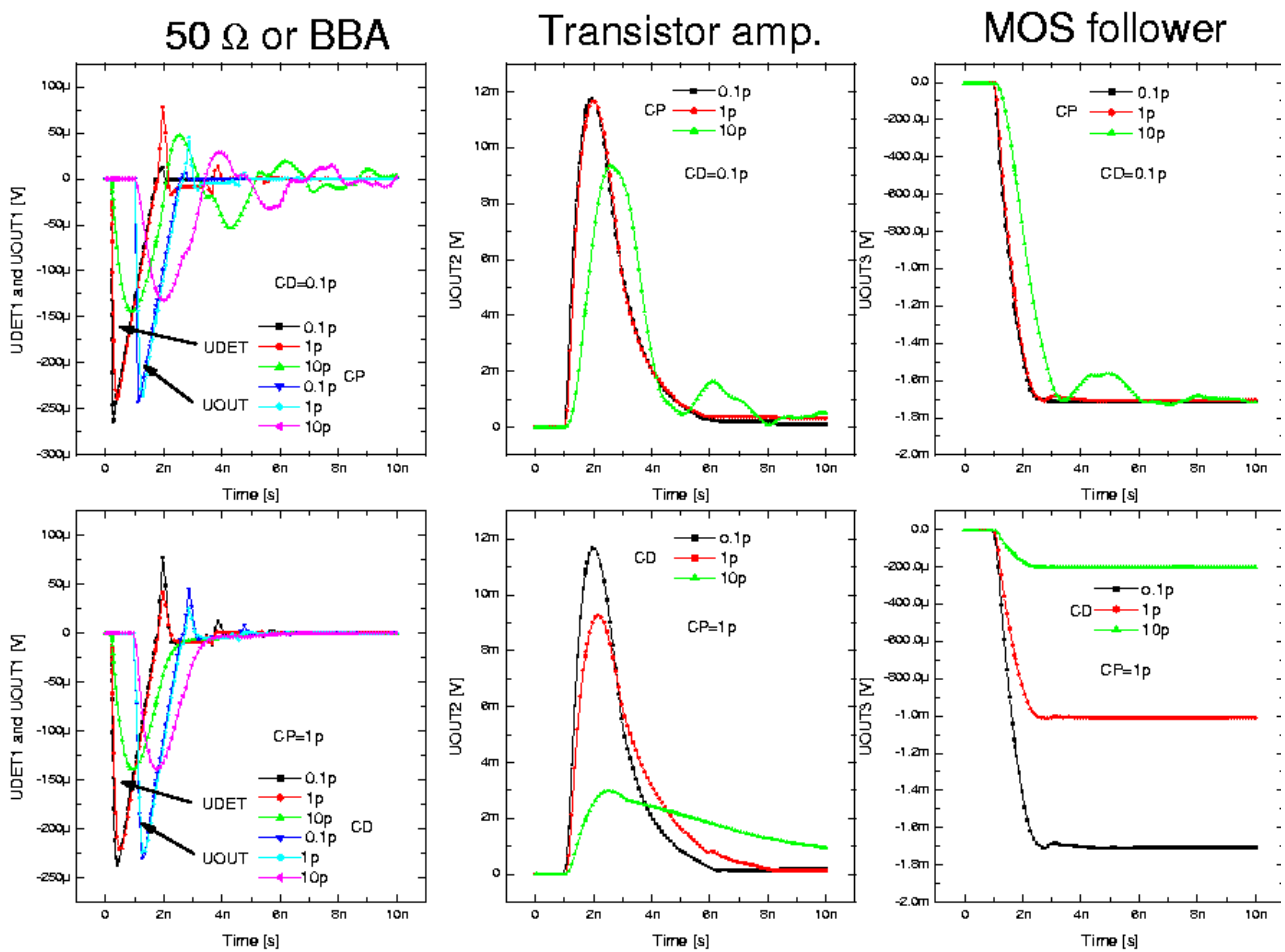
1GHz low noise MOS-follower based on a BF998 double gate MOSFET.

C_{G1-S}~ 2.1 pF, C_{rt}~ 25fF (reverse transfer C)

Simulations for signal shapes

C_d=const; 0.1pF
C_p=0.1/1.0/10 pF

C_p=const; 1pF
C_d=0.1/1.0/10 pF



As a result: "Keep C_d and C_p below 1 pF"

AC-simulations

Trans-impedance Z

Frequency f

$$Z = \frac{U_{out}}{I_{in}}; f = \frac{1}{2 \cdot \pi \cdot R \cdot C}$$

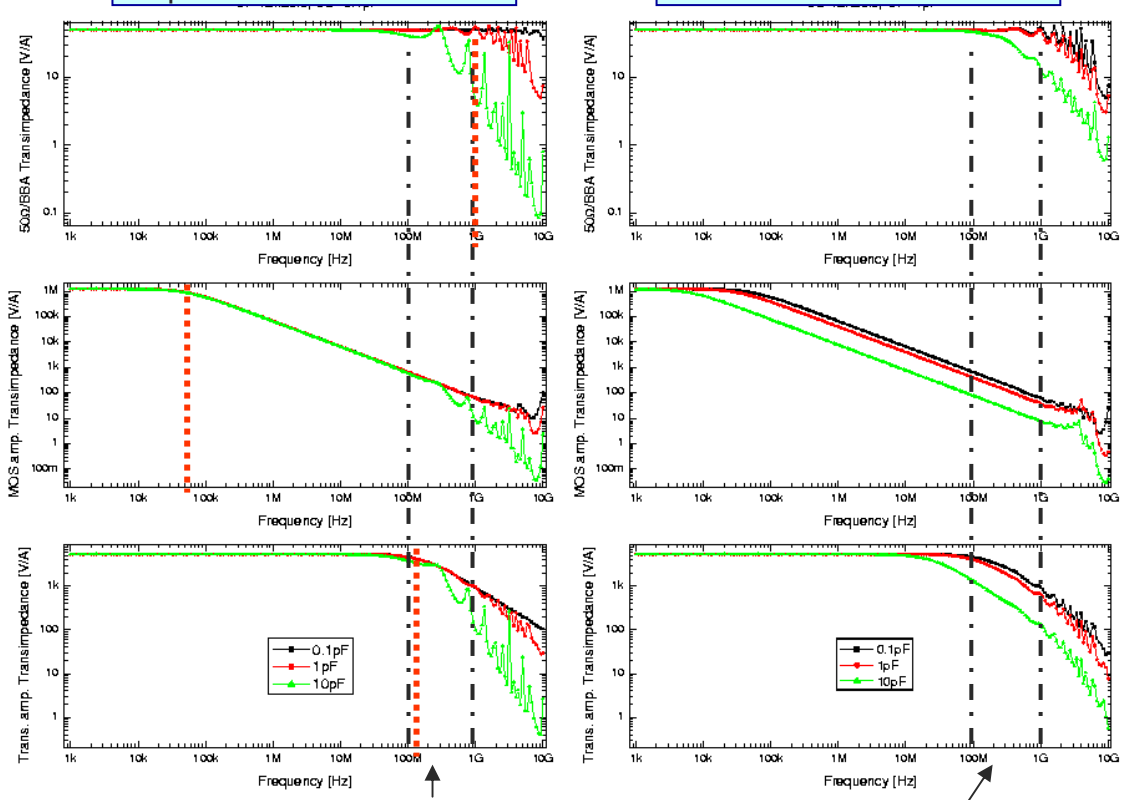
BBA
50 Ω with 2.9 pf
f=1.1 GHz

MOS-follower:
1 MΩ with 2.1 pF
f=79.3 kHz

TAmp:
4 kΩ with 0.4pF
f=104.2 MHz

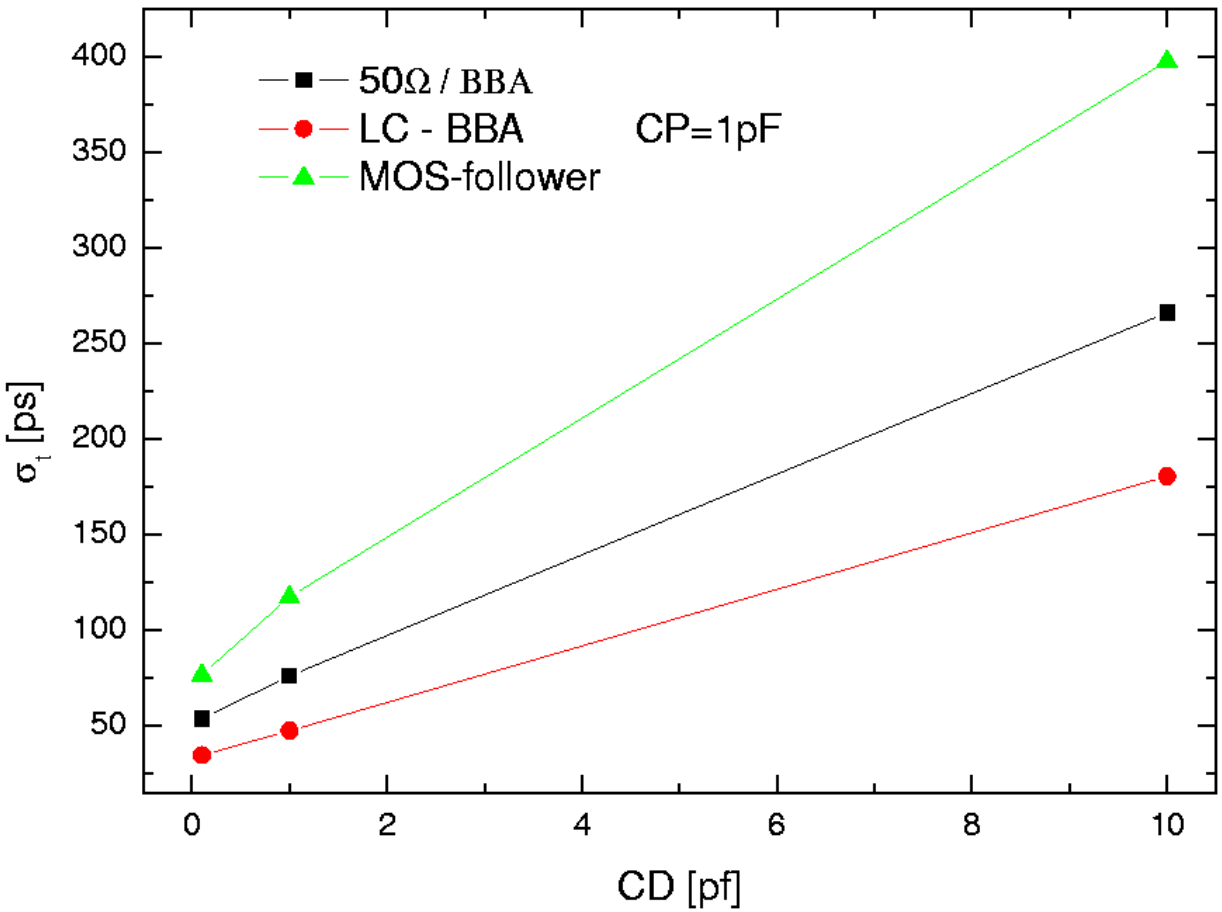
C_d=const; 0.1pF
C_p=0.1/1.0/10 pF

C_p=const; 1pF
C_d=0.1/1.0/10 pF



Timing relevant region

Simulations on the timing



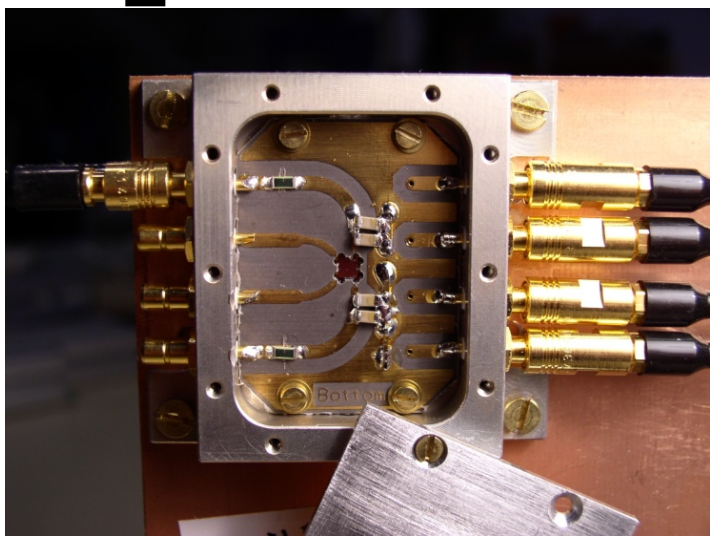
The simulation result Shows the expected result:

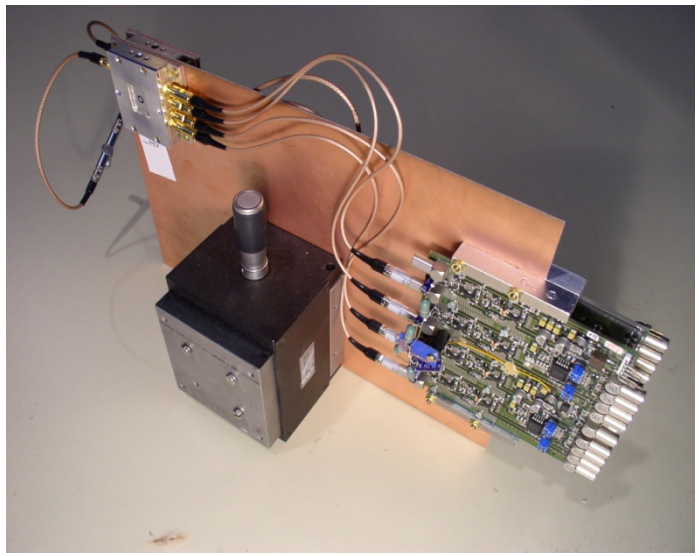
As smaller the detector capacitance as better.

The Tamp should be better as the MOS follower as long as $C_{G1\text{-}S}$~2.1pF.

Setups
Electronics
Measurements

Setups for the MOS-follower





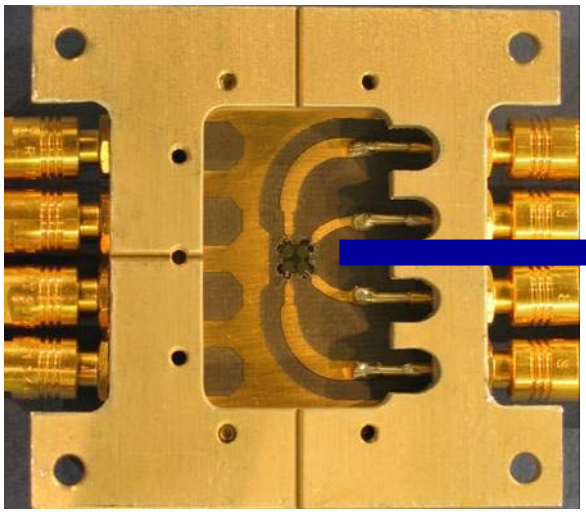
Two systems are prepared for a MIP (proton) measurement:

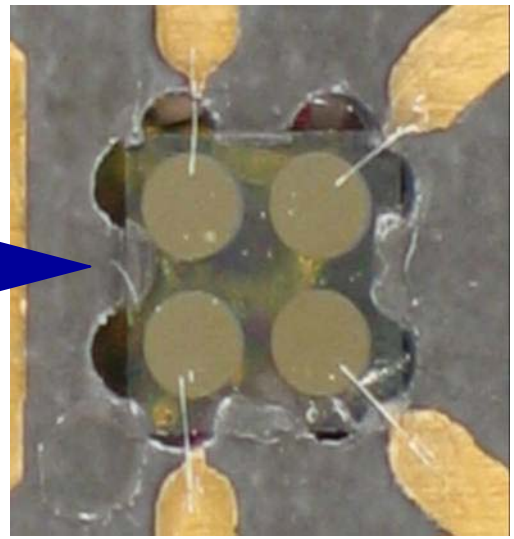
1) SC-DD, D=2mm, h=0.15mm, four quadrants, 4 capacitive buffers on each ensemble,
2) Two FEE1 are modified as a second stage for the analog data processing.

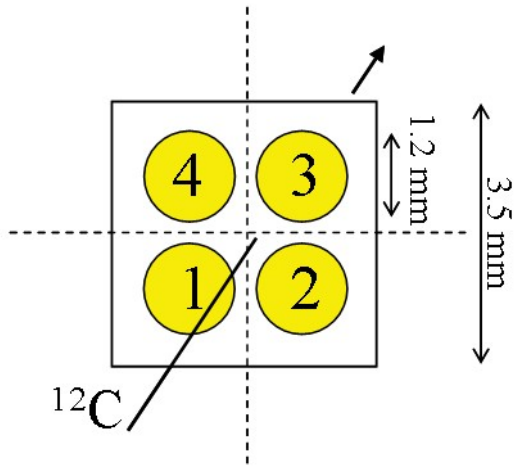
Waiting for beam and change the MOSFET to a lower C_{G1-S}<1pF !

SCD with PADI for rate tests

PADI = Preamplifer Discriminator
An ASIC based amplifier for timing measurements.



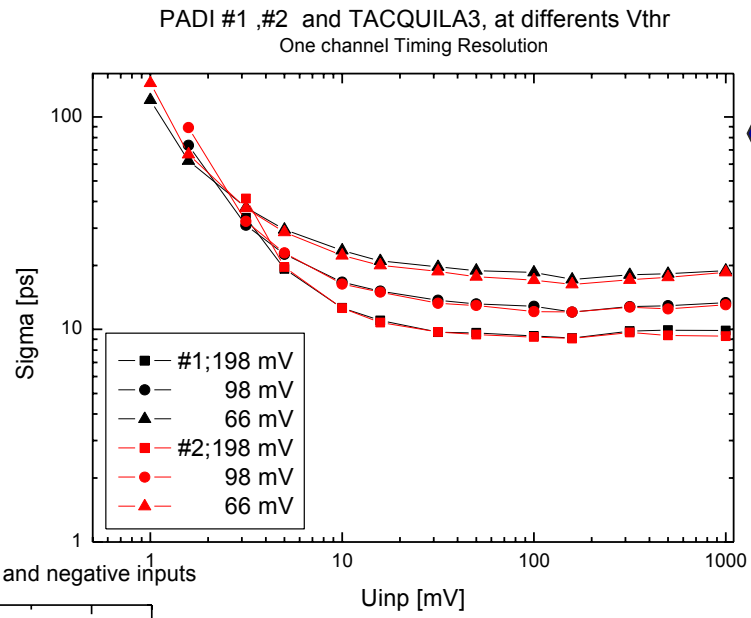




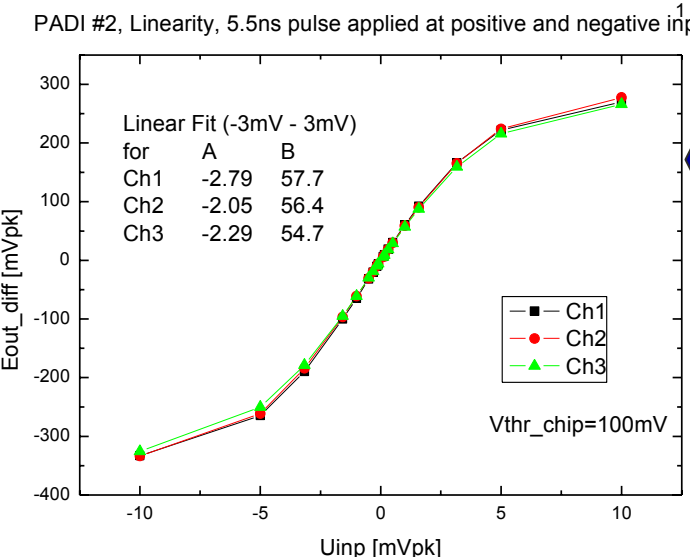
Diamond mounting case

SC Diamond with 4 pixels

PADI- pulser measurements

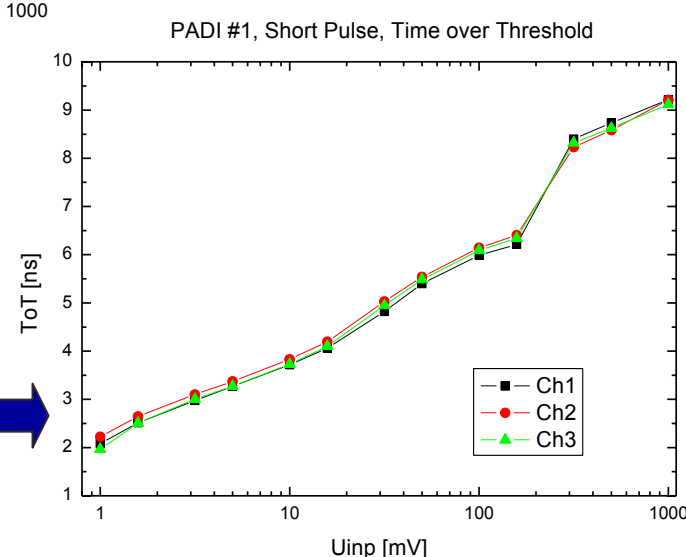


Timing < 20 ps
including the digitizer



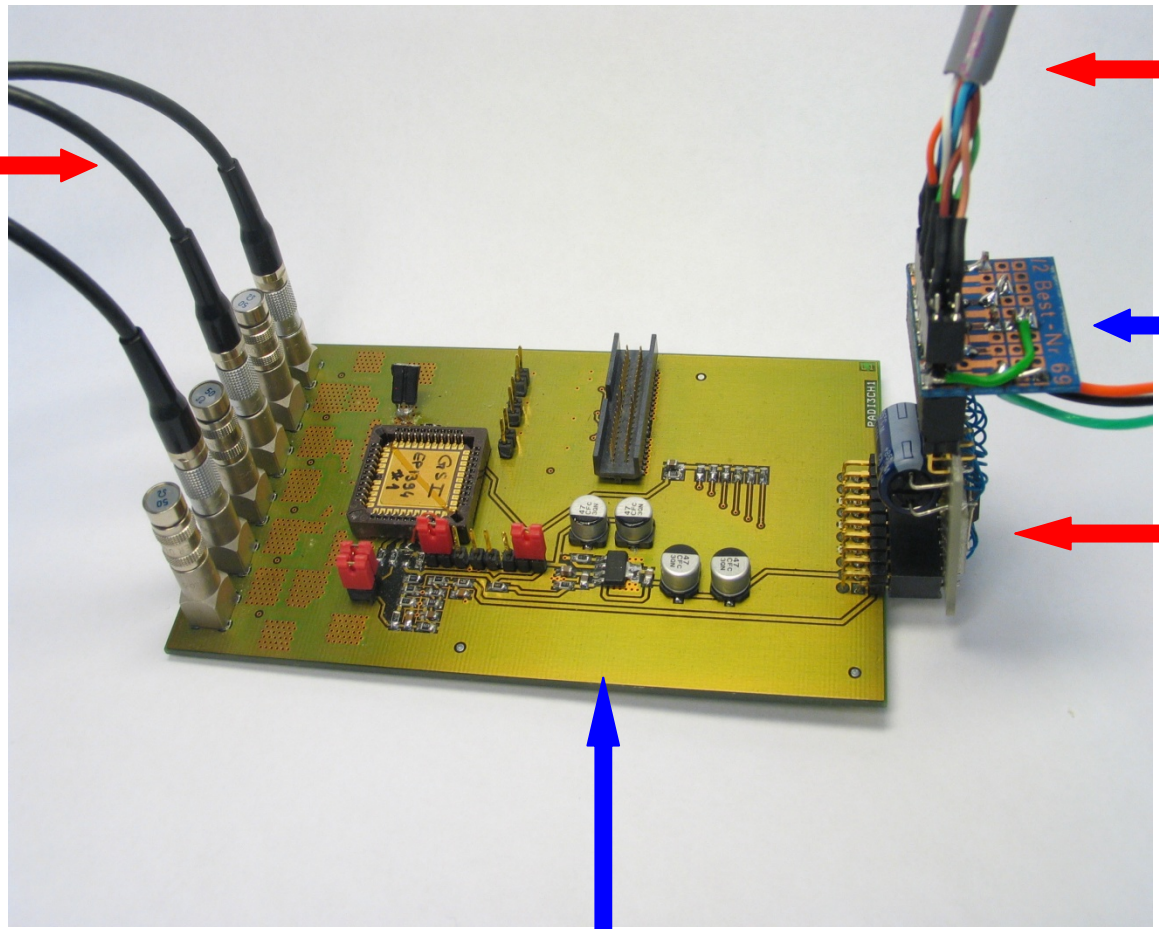
High uniformity
Large linear range

Time over Threshold
measurement ToT



First PADI PCB for SCD

Connection's with SC Diamond Pixel Detector



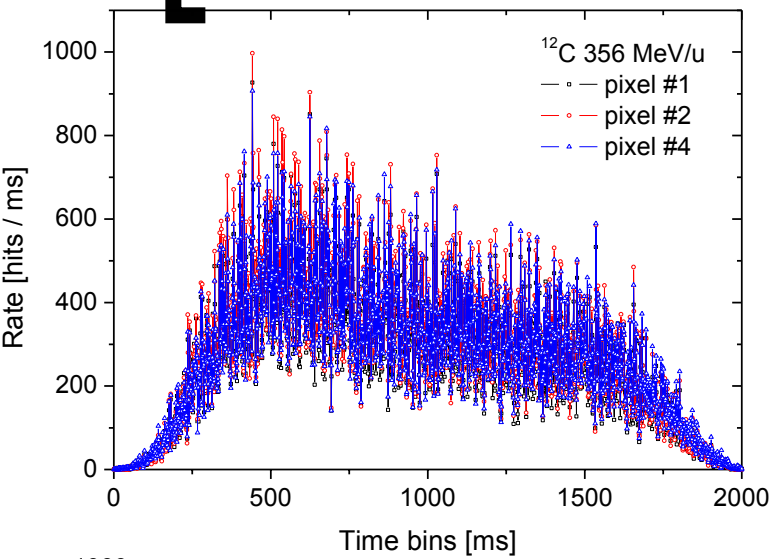
Time Output's LAN-K5 cable ~2.1m

Interface PCB +5V,GND,THR connections

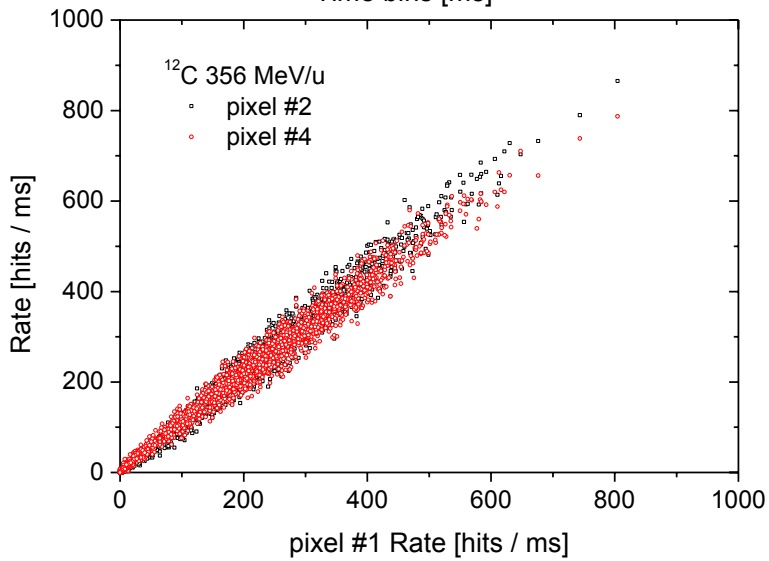
LVDS-PECL Converter PCB

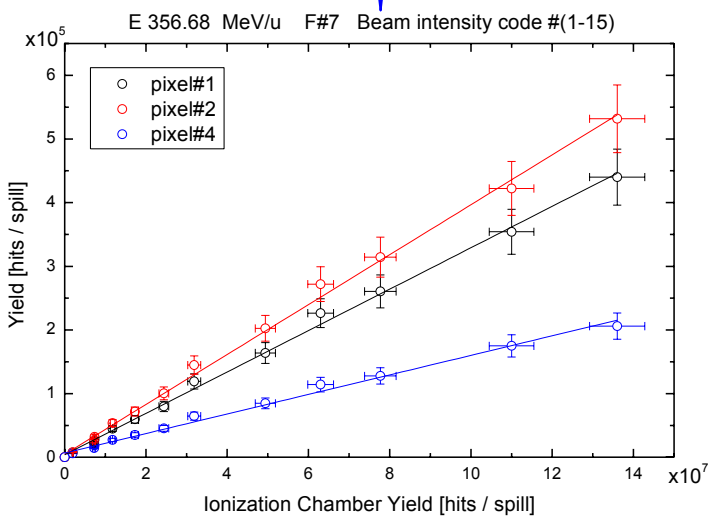
PADI test PCB

Rate dependence of PADI



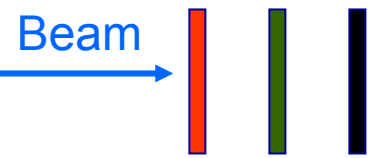
- **Time structure**
- **Pixels comparison**
- **Rate histogram**





The Heavy Ion case !

Setup I (test)

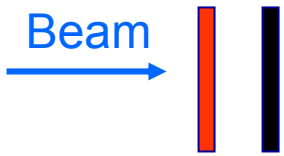


2 Pmt + Scintillator

150 µm PCD 2x2 cm² PADI

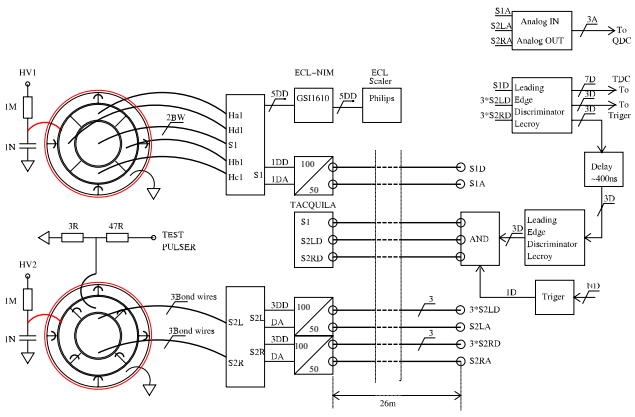
300 µm PCD 2x2 cm² FEE1

Setup II (Ni run 2008)

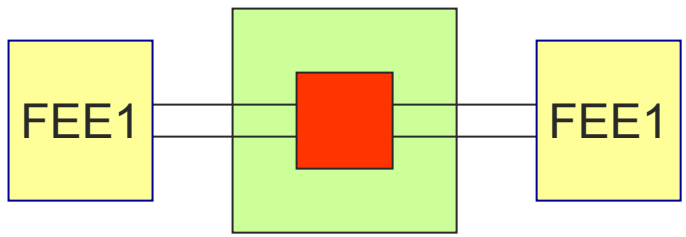


2 Pmt + Scintillator

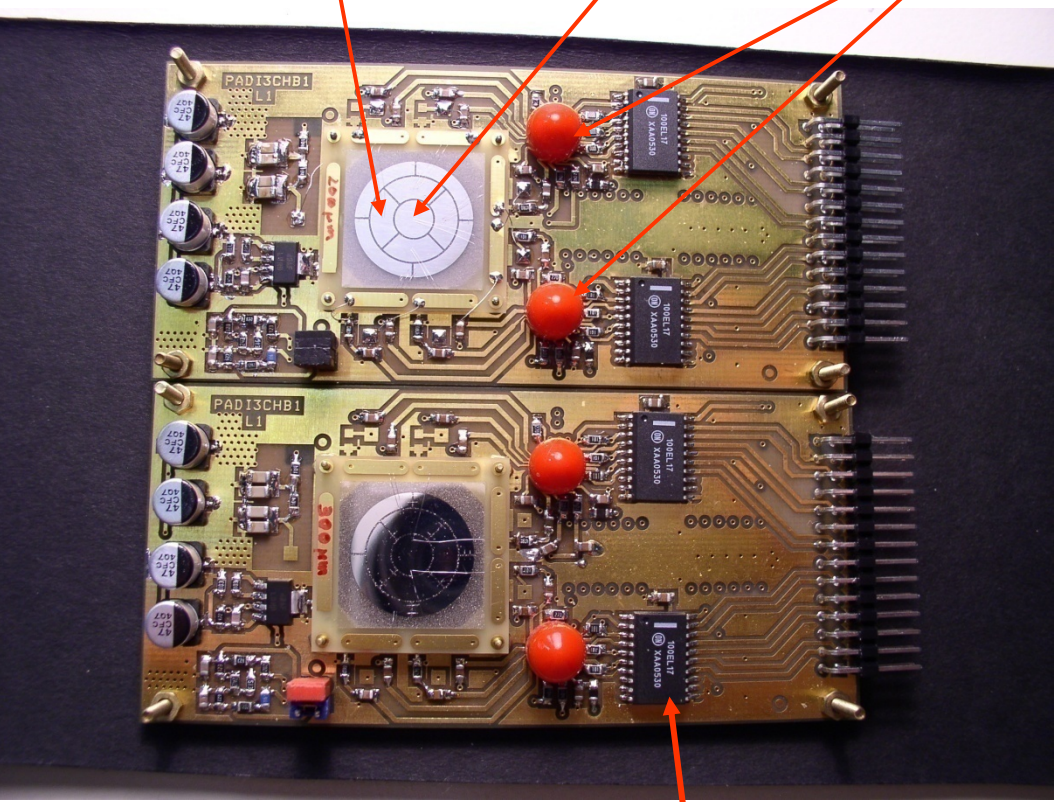
300 µm PCD 2x2 cm² FEE1

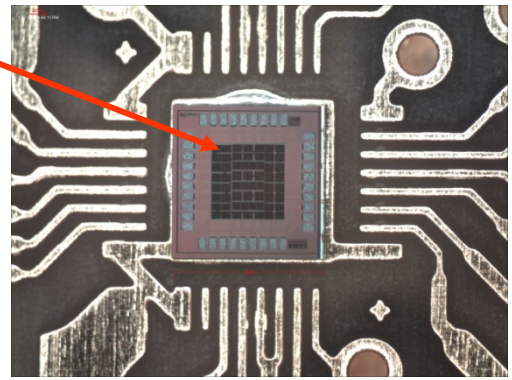


PCD schematics



A Diamond-PADI-Start



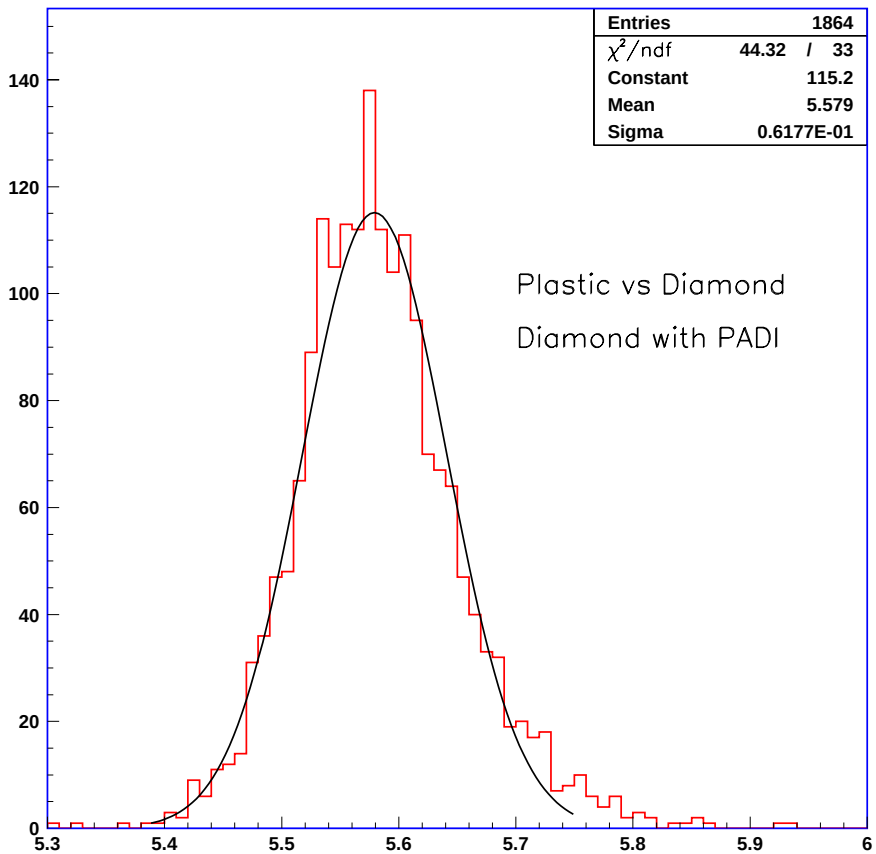


Diamond including the Start and HALO detector for beam monitoring. The readout is done by PADI.

This setup needs more R&D to optimize the bonding, impedance and signal transport.

Too ambitious but the right way!!

Results with PADI

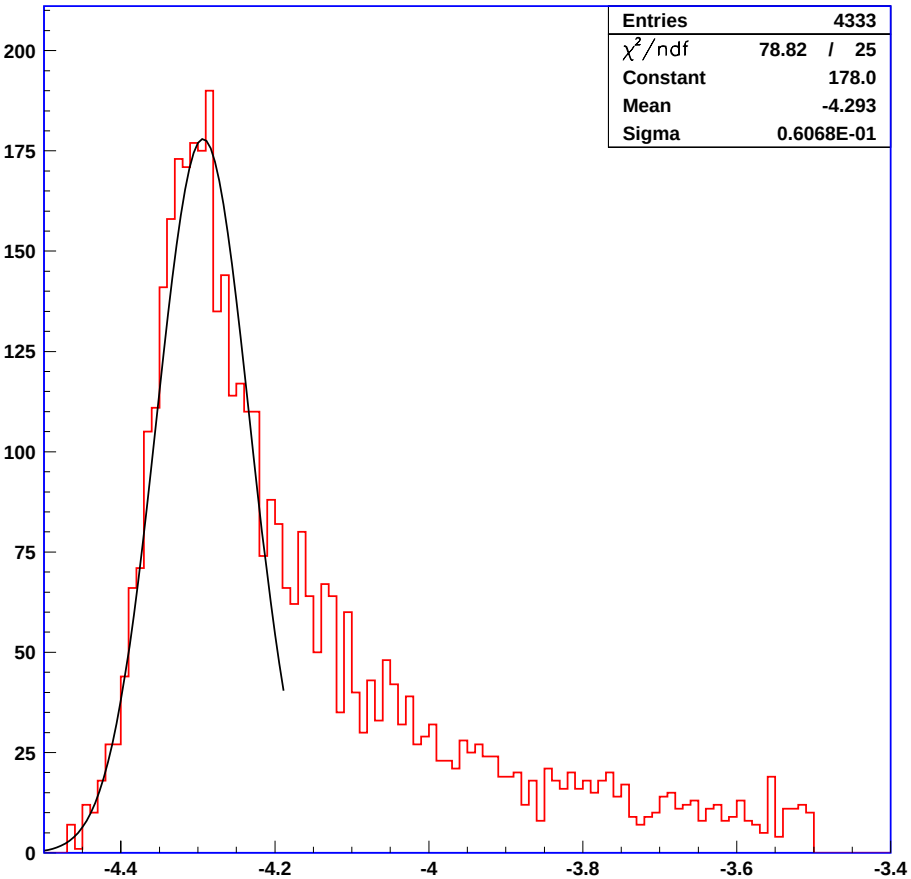


(D1+D2/)2-(P1+P2)/2 (ns)

Pros:
Using PADI to read out a PCD, we reached **σ_{td} < 45 ps** in relation to a plastic scintillator.

Cons:
The connection (bonding) is critical and introduced impedance problems which have to be solved In the next step.
Up to now, low rate only (1 kHz)!

Results with FEE1 (test'08)



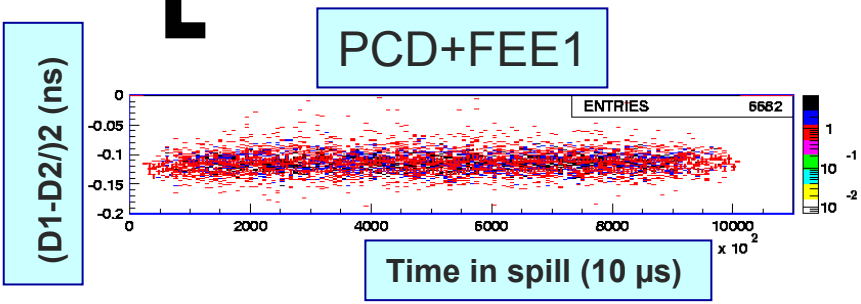
(D1+D2/)2-(P1+P2)/2 (ns)

Pros:
Using FEE1 to read out a PCD, we reached **σ_{td} < 41 ps** in relation to a plastic scintillator.

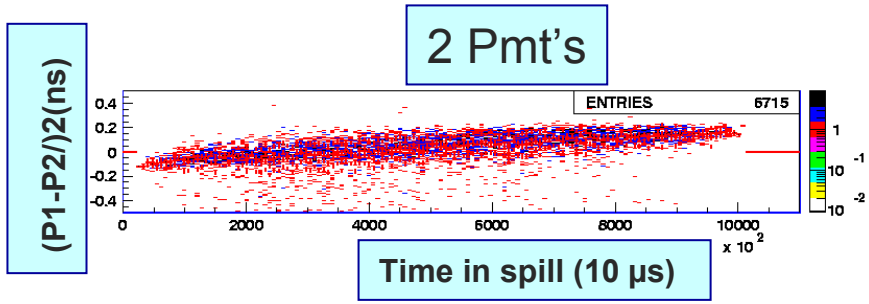
Cons:
The FEE1 is not suitable for MIPs. At higher rates we see the tail from the plastic (>5kHz).

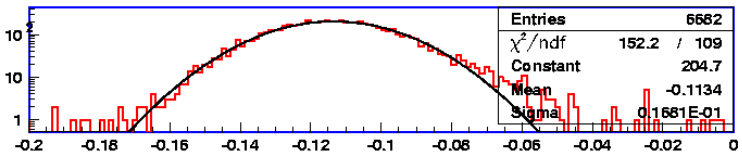
Results with FEE1 (run '08)

PCD+FEE1

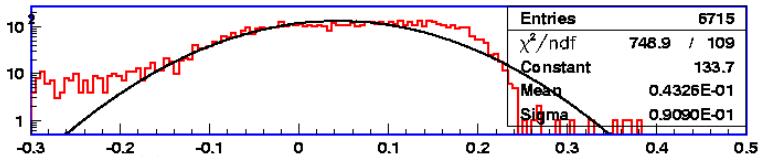


2 Pmt's

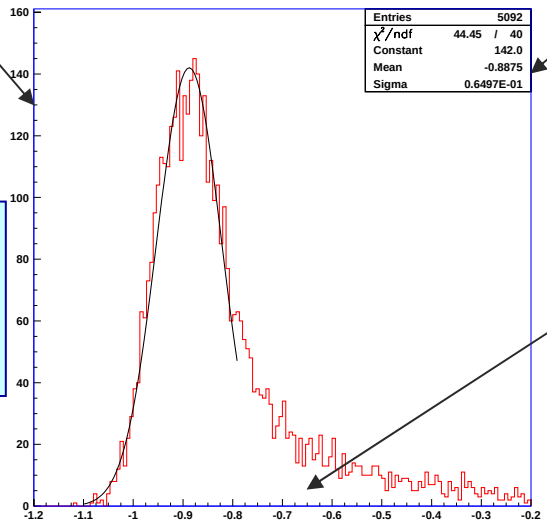




(D1-D2/)2 (ns)



(P1-P2/)2 (ns)



(D1+D2/)2-(P1+P2)/2 (ns)

The combined resolution:

$\sigma_{tdp} < 61$ ps

$\sigma_{td} < 45$ ps

Tails from plastics at 250 kHz
NI+Ni @ 1.9 AGeV

How to build a MIP start ?

Diamond:

A SC diamond with a 5x5mm^2 metallization at a thickness of d=0.4 mm has capacitance of C_D=3 pF.

We can decrease the detector capacitance by dividing the diamond into NxN pixels:

N	2	3	**4**
C_D pixel	0.75pF	0.33pF	**0.187pF**

For other d, for example d1=d/2, the capacitances are two times higher.

Electronics:

- **TAmp which HADES used (BFG410W) with a 22 GHz BW: N_F~1dB, C_e~0.4pF, C_{re}~50fF.**
- **MOS-Follower to be used in the FOPI Proton tests (BF998) has: C_{G1-S}~2.1pF, C_{rt}~25fF (reverse transfer capacitance) and the frequency domain 1GHz.**
- **NINO-Low Capacity (LC) in 130 µm technology.**
- **PADI-LC in 180 µm technology.**

NINO-LC for a pixel start

130 nino circuits

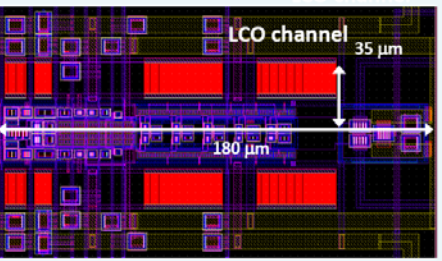
- **2 versions of NINO architecture implemented in a 0.13 µm technology**

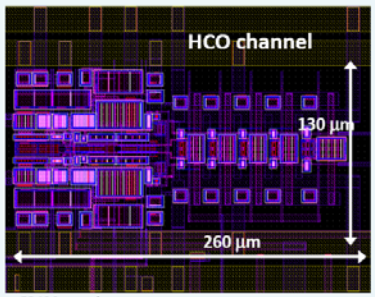
LCO version (for Cin ~ 200 fF)

- Noise < 1000 e- rms
- Rising time < 500 ps rms
- Power consumption : 300 µW
- Tunable threshold (0 to 4 fC)
- Differential output

HCO version (for Cin ~ 10 pF)

- Noise < 4000 e- rms
- Rising time < 200 ps rms
- Power consumption : 3 mW
- Tunable threshold (0 to 20 fC)
- Differential output





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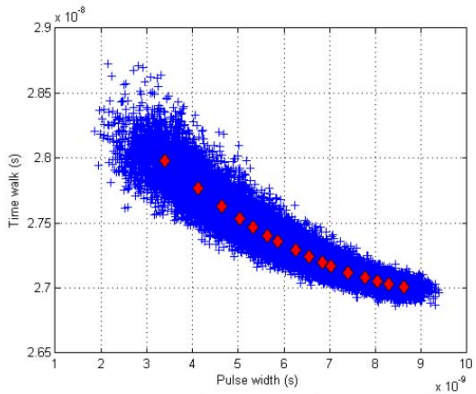
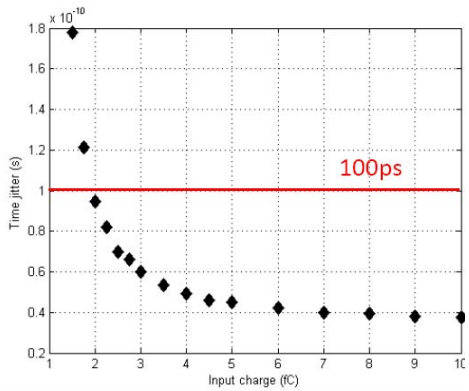
P.Jarron CERN PH

Using a timing ASIC for a silicon readout !

NINO Electronic Jitter < 40 ps



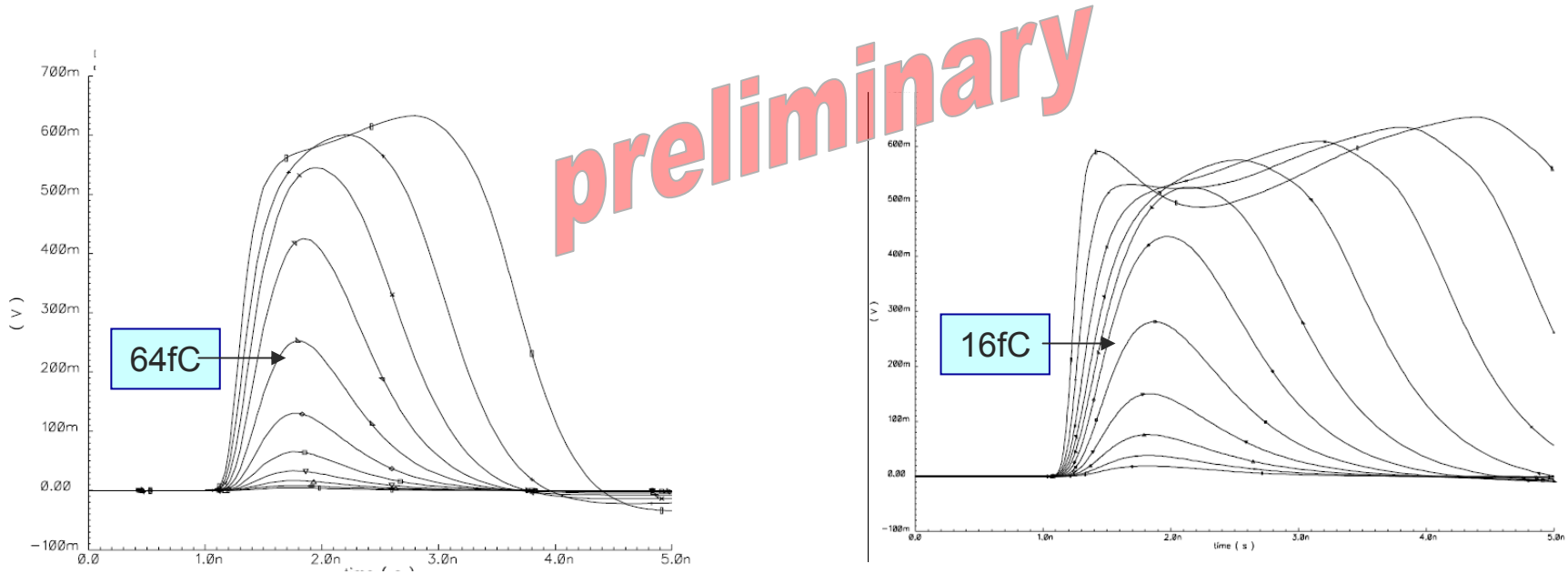
Scatter plot of time jitter versus pulse width



Jitter vs. input charge

100fF calibration capacitance,

PADI-Low Capacitance (LC)

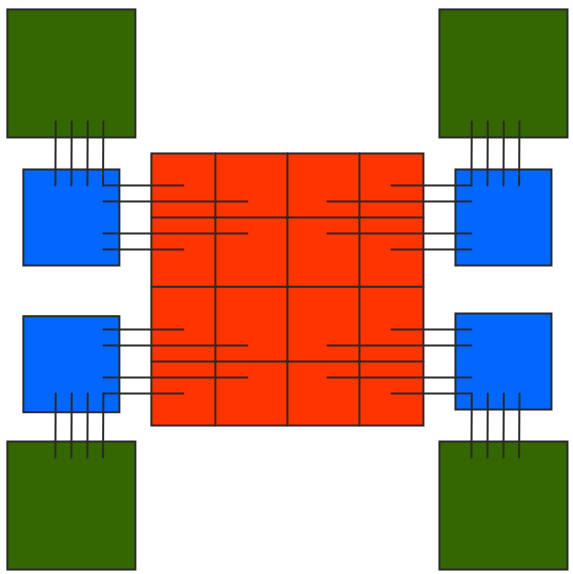


The existing PADI-4Ch.
Q_{IN}=1 – 1024 fC
Noise @ output: 2.3mV
Z_{in}=50 Ω

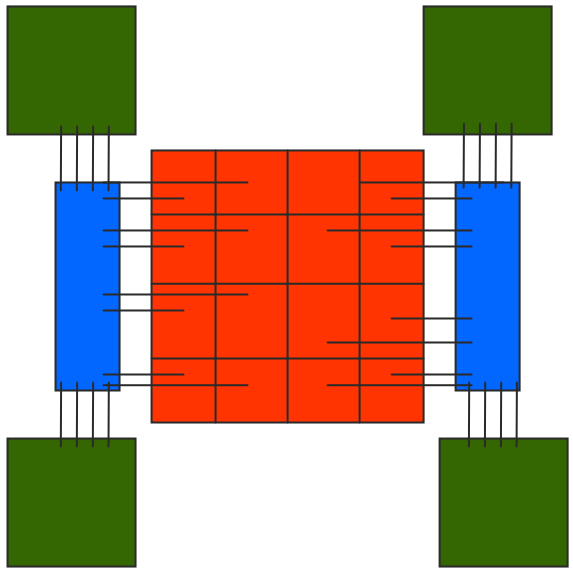
4 times higher sensitivity only 1.6 higher noise

The new PADI-LC
Q_{IN}=1 – 1024 fC:
Noise @ output: 3.6mV
Z_{in}=380 Ω

A possible MIP diamond start



4x4 pixel SCD
4 PADI (LC)
4 DANTE



4x4 pixel SCD
2 NINO (LC)
4 DANTE

Summary & Outlook

Summary

- In our current understanding we need a low capacitance (<0.2 pF) diamond followed by a low capacitance amplifier (<0.4 pF).
- In simulations we understand our timing behavior within the current setups.
- We tested different electronic readout concepts during 3 years:

	PCD	SCD
A) FEE1 (DBA)	40	450
B) CSA		250
C) MOS-follower	(40)	(80)
D) PADI	45	?

- In real experimental conditions the diamonds are not fully understood but timing ~ 50 ps !
- SC diamonds died during runs frequently !!
- The main conclusion from the experimental runs:

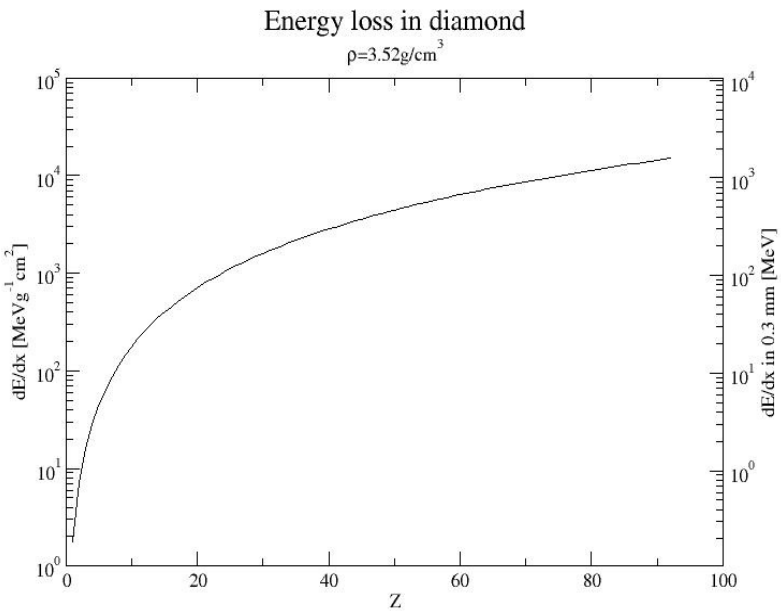
Don't make it to complicated !!!

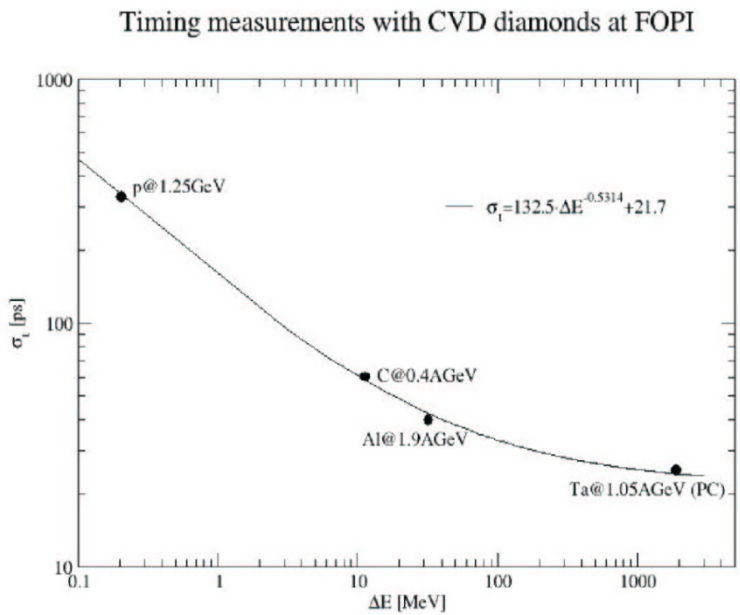
Outlook

- From the latest simulations and the most recent ASIC developments at CERN (NINO-LC) and GSI (PADI-LC) the development of an Diamond-ASIC is possible and should be done.
- For FOPI an 4x4 pixel SC-Diamond (5x5 mm^2) with an C_D of 0.18 pF is reasonable.
- PADI is in principle capable to be redesigned, at the amplifier stage, to have 16 times higher sensitivity at a 3-5 times higher noise level.
- Using DANTE as a digitizer we could be compatible for CBM as well.

We would like to thank the whole detector–lab crew for the support and help in preparing the diamonds and in participating their beam-times.

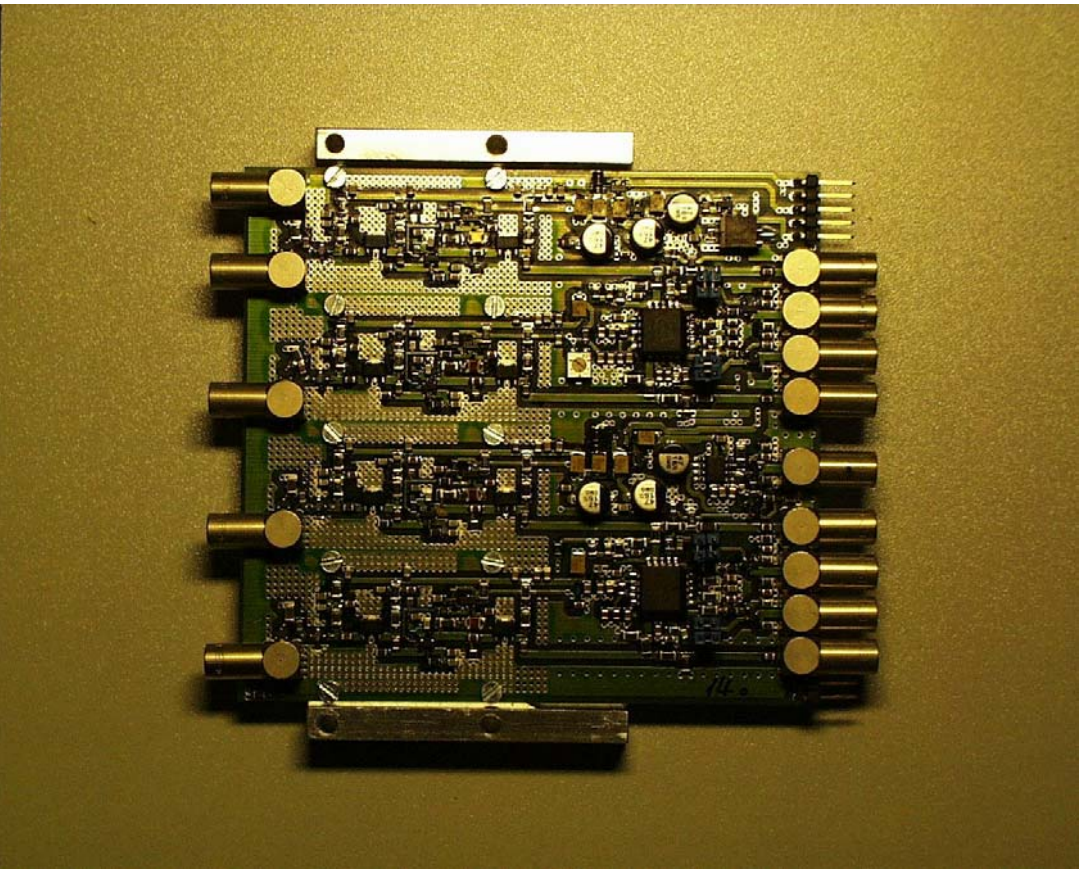
Old stuff





- Timing measurements with CVD diamonds, Tomica Porobić, RBI Zagreb, Croatia, for FOPI collaboration, talk at NORHDIA Meeting, Sept.2006

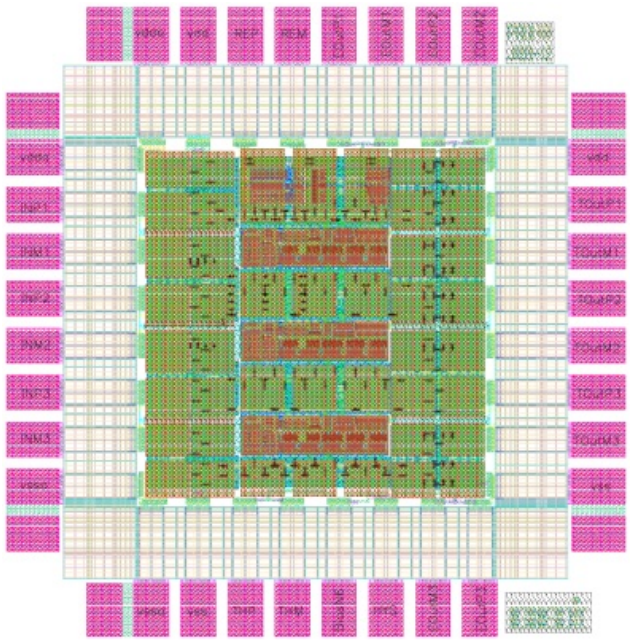
FEE1



FOPI-FEE1

1. 4 Channels
   AC Amp., LE Disc., 4*OR,
   THR and GAIN man. adj.
2. +6V, +12V, -6V 1.85 W/Ch.
3. Dim.: 110mm * 95mm
4.INP.: 4 LEMO 1 LEMO TEST
5.OUT.:4 NIM for TIME
4 LEMO Amplitude 1 LEMO OR
6.AC: - GAIN ~ 0-200
- Bandwidth ~ 1GHz
- Noise ~ 20μV
- Rise Time ~ 350ps
7. Disc.:- Noise ~ 40μV
- Rise Time ~ 500ps
- Res. Jitter ~4.8ps
8. Time Res.: 30-10-5-4-4 [ps]

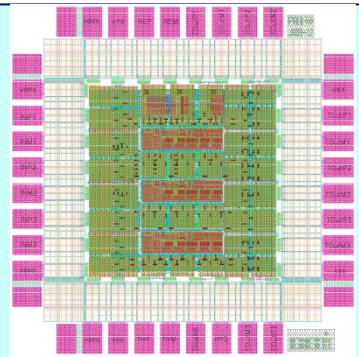
PADI



CBM-PADI

- Time res.(@10mV) [ps] < 10
- Gain ~ 60
- Bandwidth [MHz] ~ 180
- Linear range [mV] ~ -5 to 5
- CTRR [dB] ~ 26 - 40
- CMRR [dB] > 40
- Input impedance [Ω] ~ 48 - 58
- Power [mW/Ch] ~ 31

PADI-parameter



- **DC Power Consumption:** **31[mW/ch]**

- **DC Threshold Calibration:**
  The transfer characteristics from the threshold voltage applied to PADI terminals to energy output is: 0.334 (σ=0.022)

- **Input impedance measurements:** **Z_{INP}[Ω]**

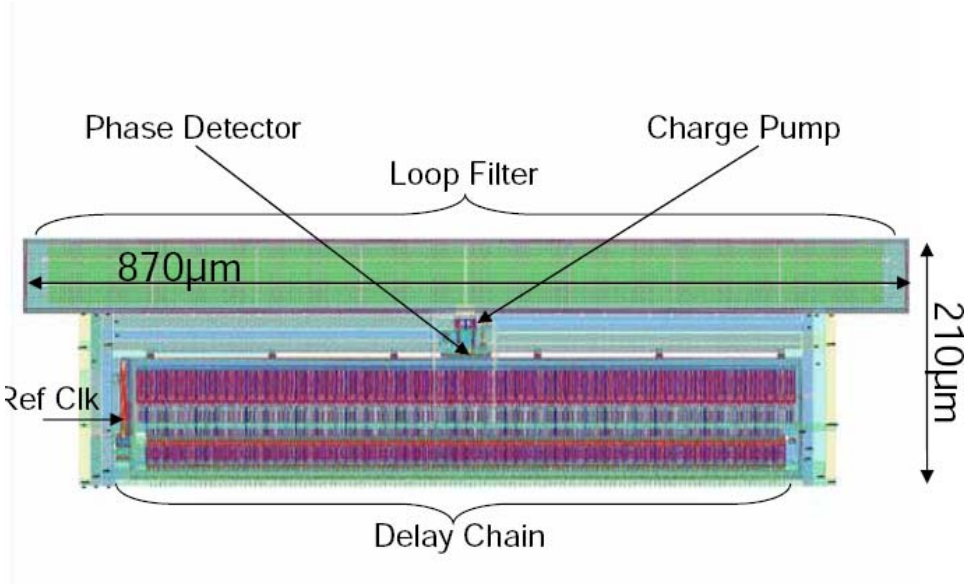
1. AC method : Questionable!	27-96
2. TDR method adapted for low level signals, with "T"	35-67
3. TDR adapted for low level signals, with a directional coupler	42-59
4. Short pulse method for low level signals, directional coupler	48-58

- **Crosstalk measurements:**

	CTRR32	**CTRR31**
PADI (AC @75MHz) [dB]	25-30	22-27
PADI Pulse Meas. [dB]	>40	

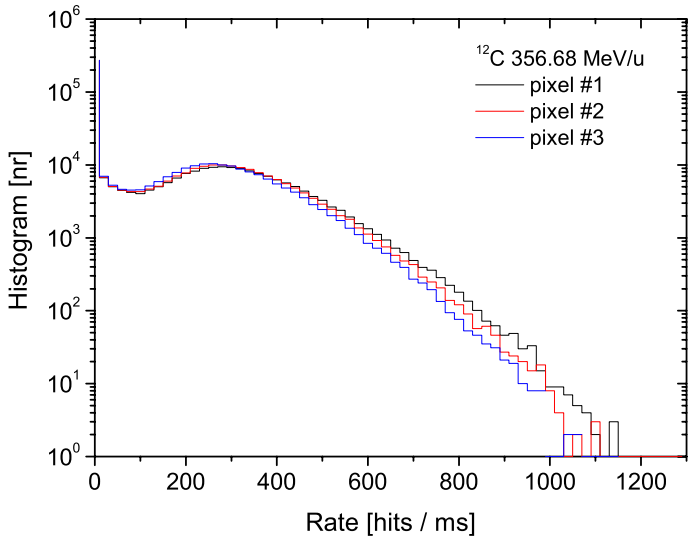
- **Common Mode Rejection Ratio Measurement**
  PADI Pulse Meas. [dB] 26-40

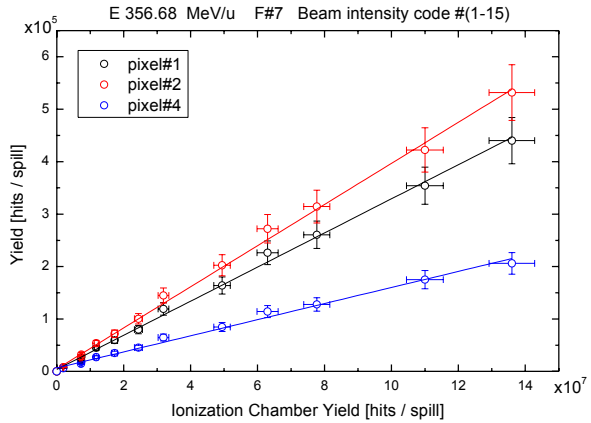
DANTE (Double DLL)

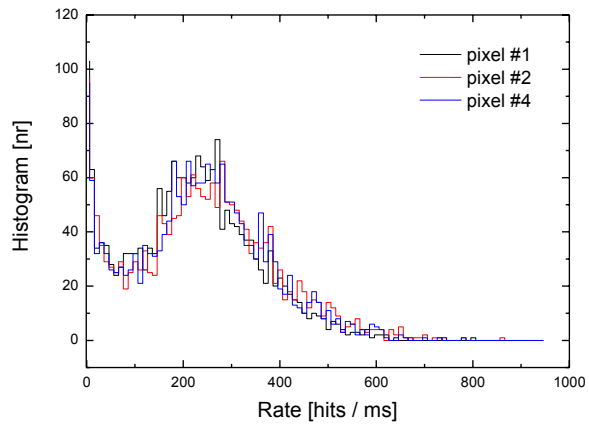


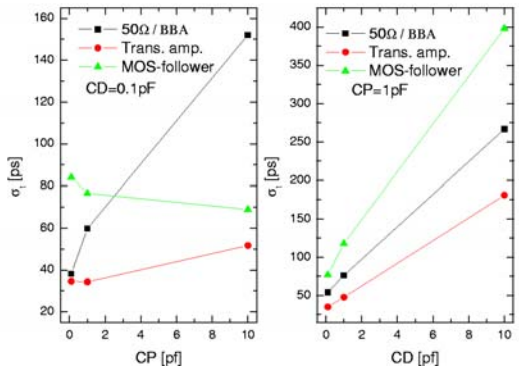
- CBM-TDC
- Double DLL core **DANTE@156.25 MHz**
- Bin width **50 ps ➔ 14.4 ps**
- Process: **UMC 0.18 µm**
- 4-16 channels
- LVDS input
- Multi-hit with no DT
- DP: **3.2 ns**
- ToT: min. width **50 ps**
- DT: **0**
- CT: ?
- INL: < **0.5 LSB (25 ps)**
- Power con.: **30 mW/ch**

Rate dependence II









To use the new NINO developed at CERN is a good idea, but we must be carefully with the input impedance; if the new NINO has 50Ohms like the old NINO, I am not very sure of success.

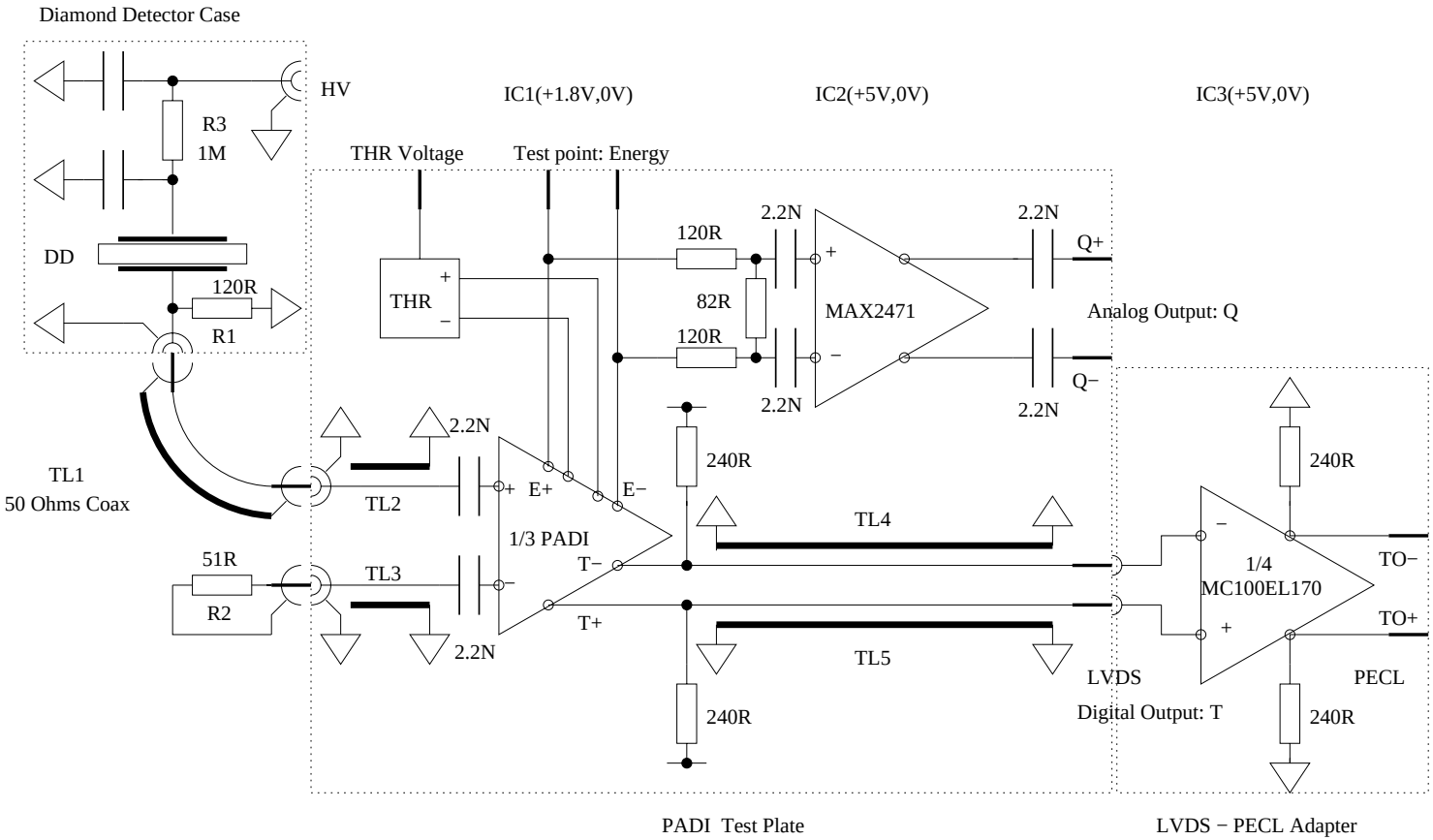
- The MOS used in FOPI Proton tests and in MOS-follower simulations (BF998) has: CG1-S~2.1pF, Crt~25fF (reverse transfer capacitance) and the frequency domain 1GHz.
- The transistor used in simulations (BFG410W) is a 24GHz transistor having: NF~1dB, Ce~0.4pF, Cre~50fF

- In the FOPI Proton tests we used a SC DVD diamond (5x5mm^2) and a metallization of 2.6x2.6mm^2.

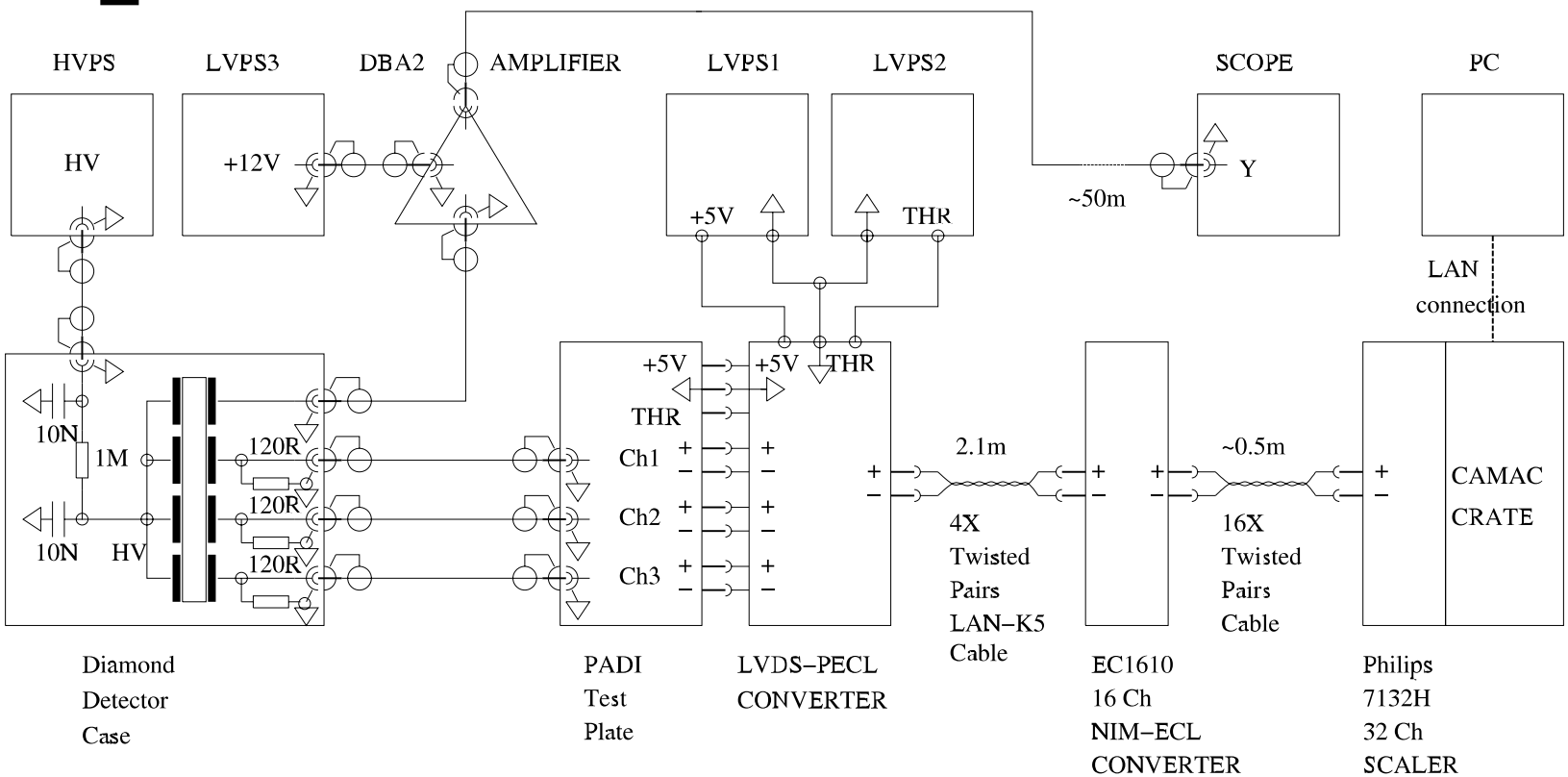
With this configuration we have a C_D~ 1pf and the parasitic capacitance at the input of CSA of C_P~ 5.5pf.

In comparison the HADES case he detector capacitance is 4 times smaller C_D~ 0.25 pf .

Schematic view of the board



Schematic view of the setup

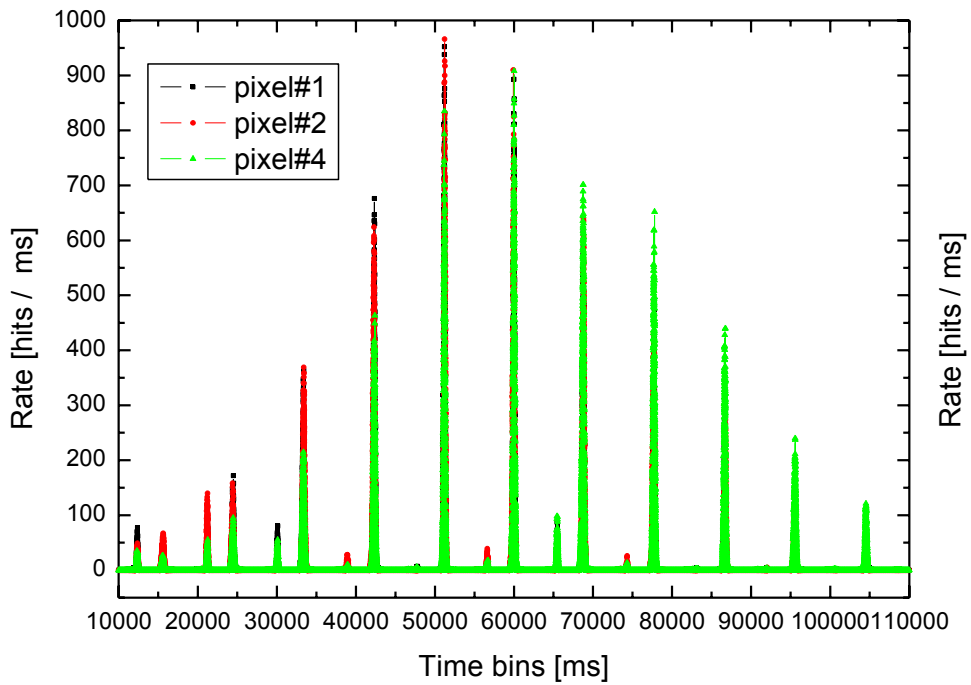


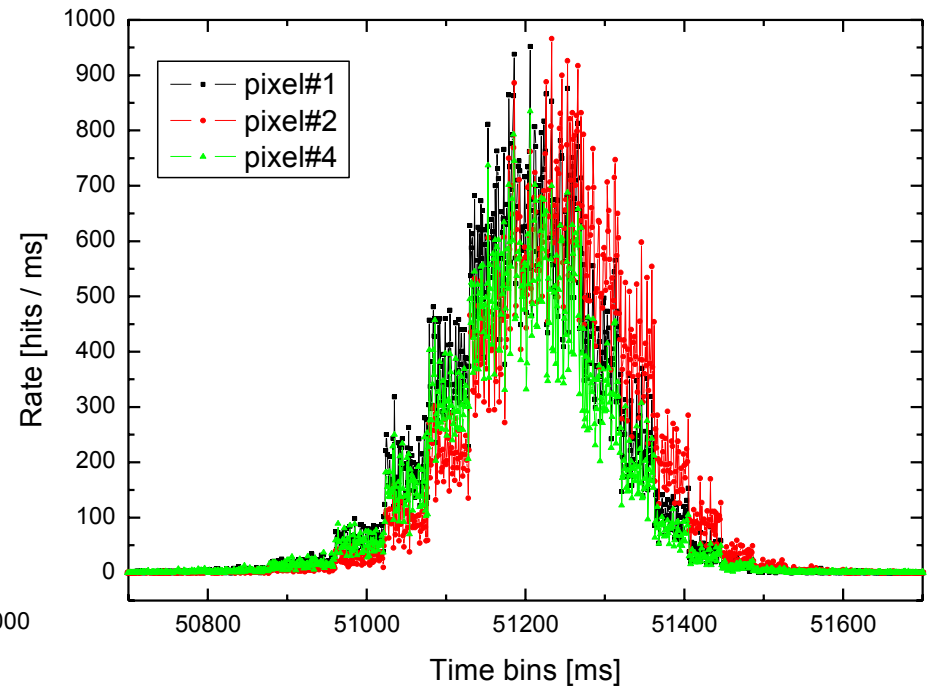
The scaler was programmed to measure rates in 1ms time slices.

The setup was optimized for high rate measurements:

For each channel the maximal rate is 1.5 x 10^8 [hits/s]

A beam sweep with C^{12} ions





The carbon ions have an initial energy of 88.83MeV/u with constant focus (#7) and intensity (#1).
The sweep covered an area of 120mm x 20mm with 671 points