Diamond timing detectors for TOTEM and CT-PPS

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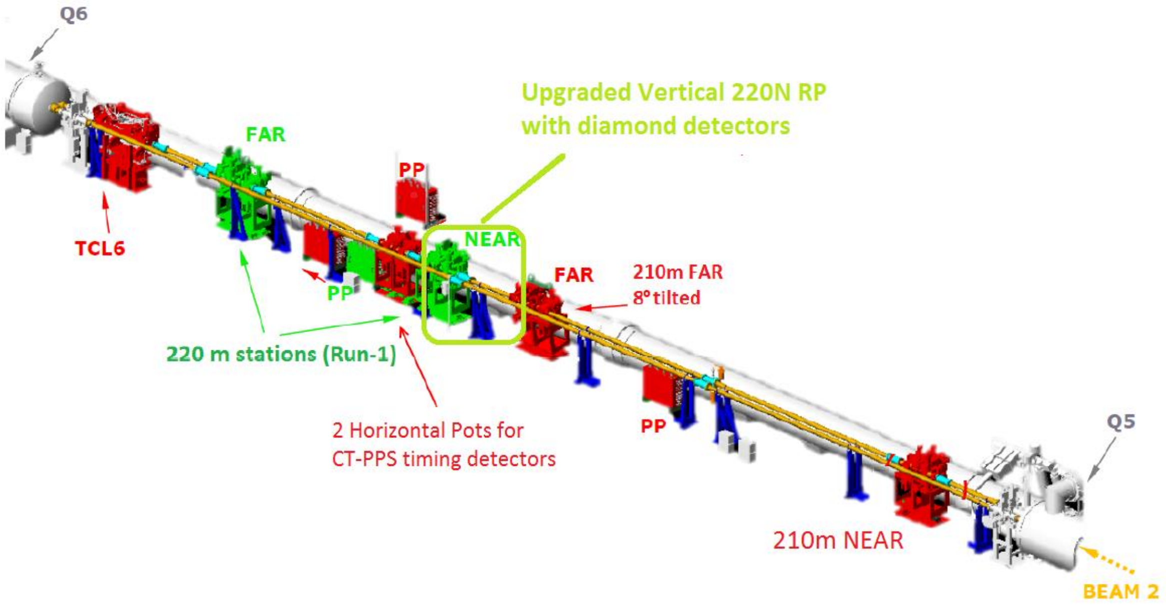
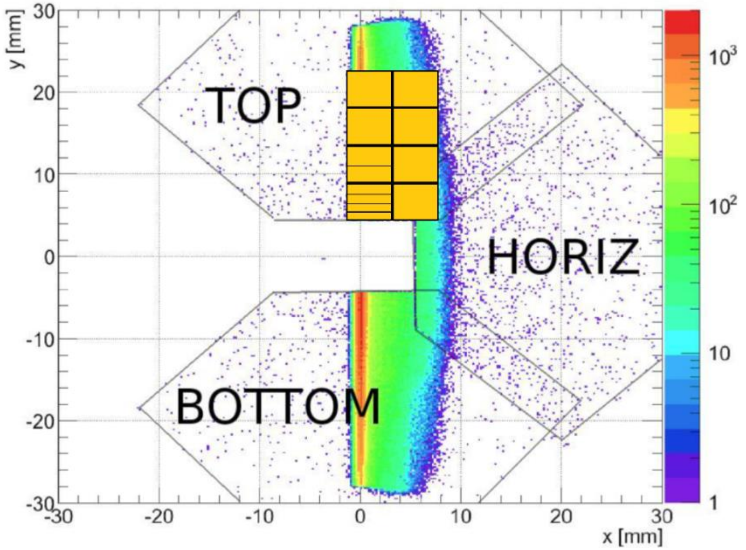
LHC Working Group on Forward Physics and Diffraction
CERN, 16/03/2016

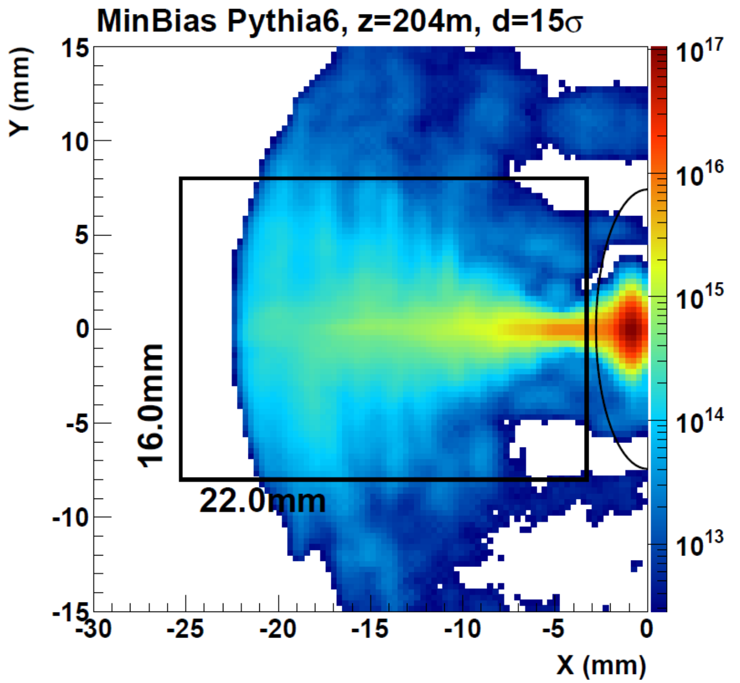
- Installation in the LHC of TOTEM diamond detectors in the vertical RPs
- Diamond detectors for CT-PPS: status and simulation studies

Reminder: diamond detectors for timing in the RPs

- The TOTEM / CT-PPS upgrade programme focuses on improving the experiments capability to explore and measure new physics in Central Diffractive (CD) processes: p+p -> p + X + p.
- The installation of proton Time-Of-Flight (TOF) detectors in the TOTEM Roman Pots allows to reconstruct the longitudinal vertex position and thus to assign the proton vertex to the proper vertex reconstructed by the CMS tracker, in presence of event pileup.

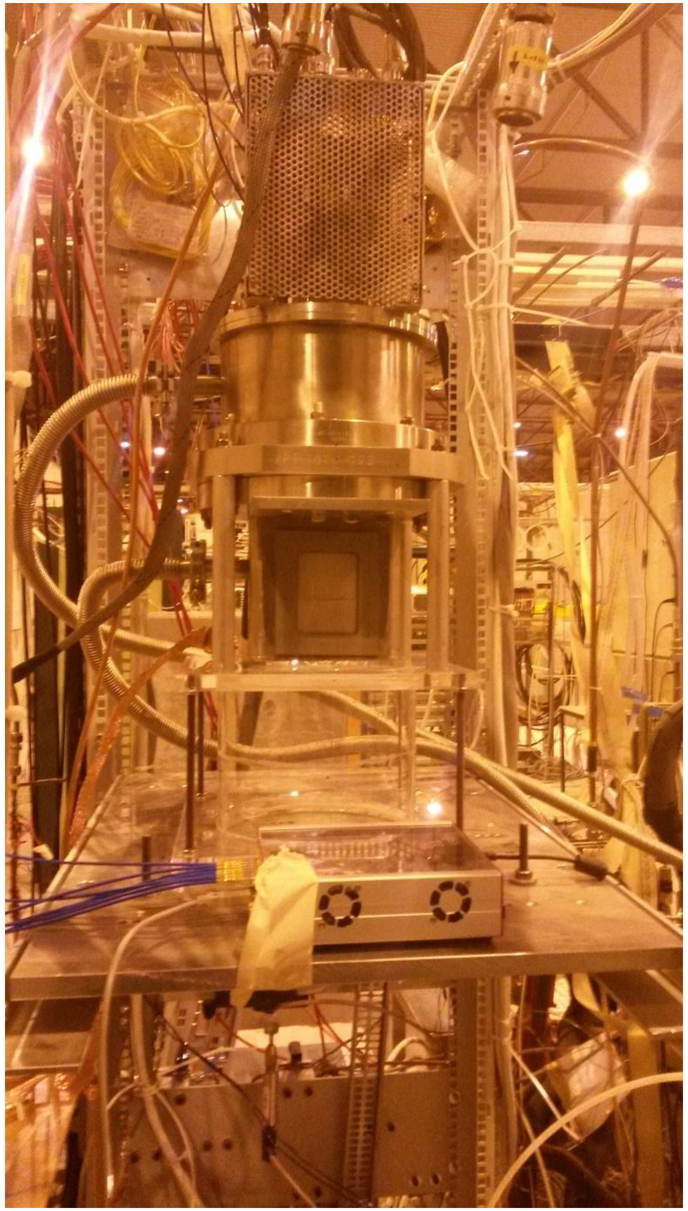






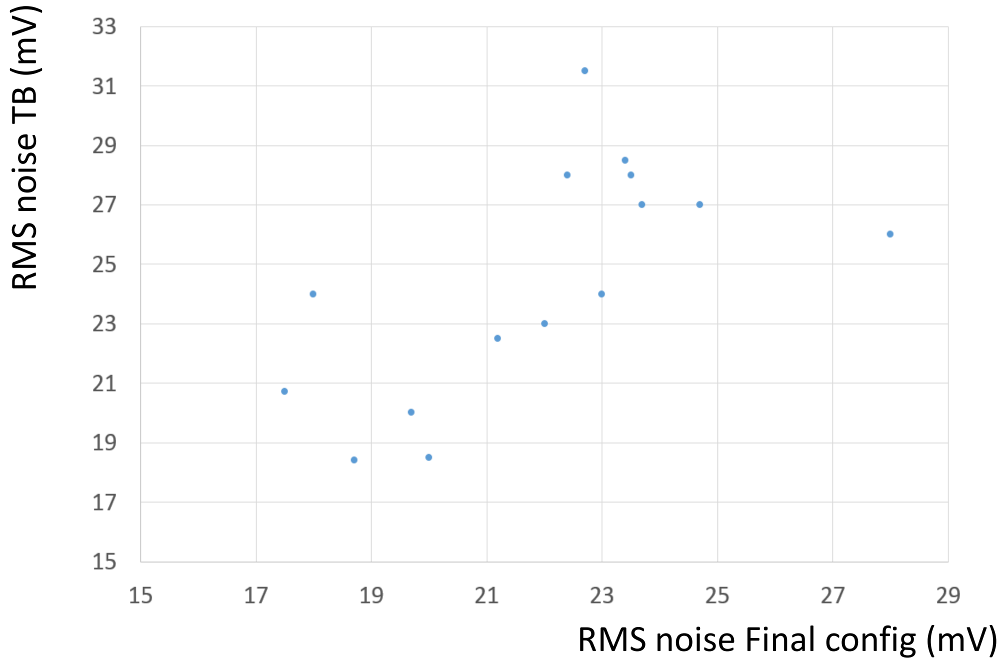
- High β, μ=1, 50 ps/arm, Rate/Pixel: 10 KHz.
- Low β, μ= 30, 10-30 ps/arm, Rate/Pixel: 1MHz.

Developments since the last October WG meeting:
1. Full test of diamonds detector in H8 with secondary vacuum and cooling



- The first tests in a secondary vacuum system were performed at T=-15 °C and P=30mb.
  - We found different working point/noise of the board
  - At 30 mb, we found discharge happening on the diamond board due to the HV.

- We set higher T (with a compatible pressure) and we found that at T>10 °C the system behaves as expected in term of noise.



- <u>In summary: noise/gain performance are dependent only on T while discharge probability depends only on P (see the next slide)</u>

Maximum P-Voltage allowed

- The most problematic thing was the HV ramp. The power supply, set at the maximum current limit of 1.5 μA (half of the value used in the TB) tripped already at about 450V for standard values of secondary vacuum.

- This discharges were found to damage the channels much more than the ones seen in standard P/T tests during previous TB.

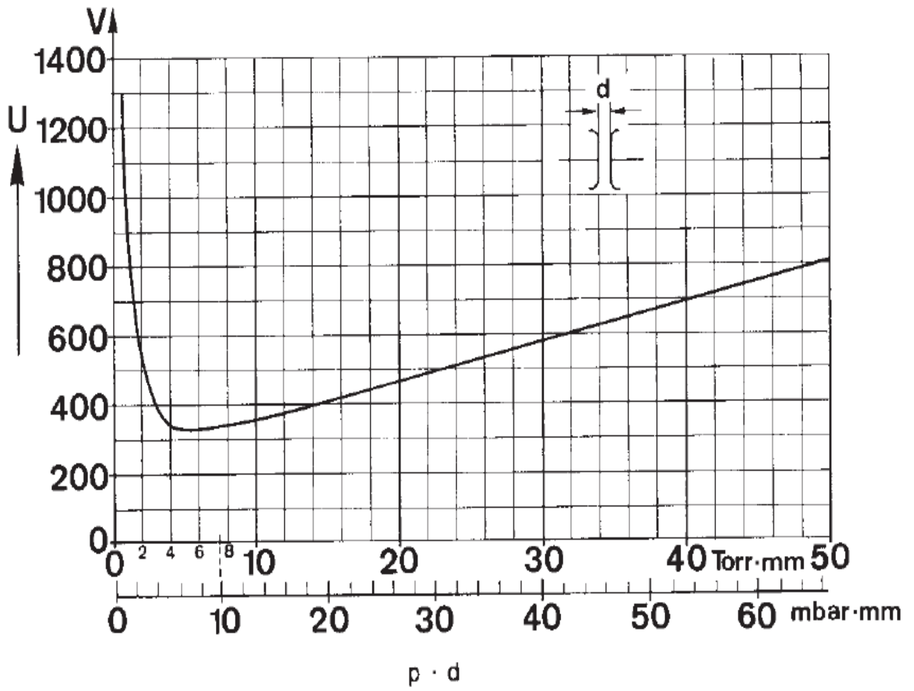


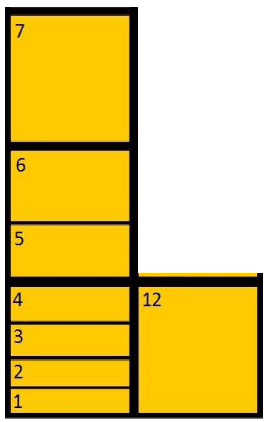
Fig. 9.18: Breakdown voltage U between parallel electrodes in a homogeneous electrical field as a function of gas pressure p distance between electrodes d (in mm) (Paschen curve), for air

Empirical V max, defined as the maximum voltage at which overcurrent is observed (Imax=1.5 μA)

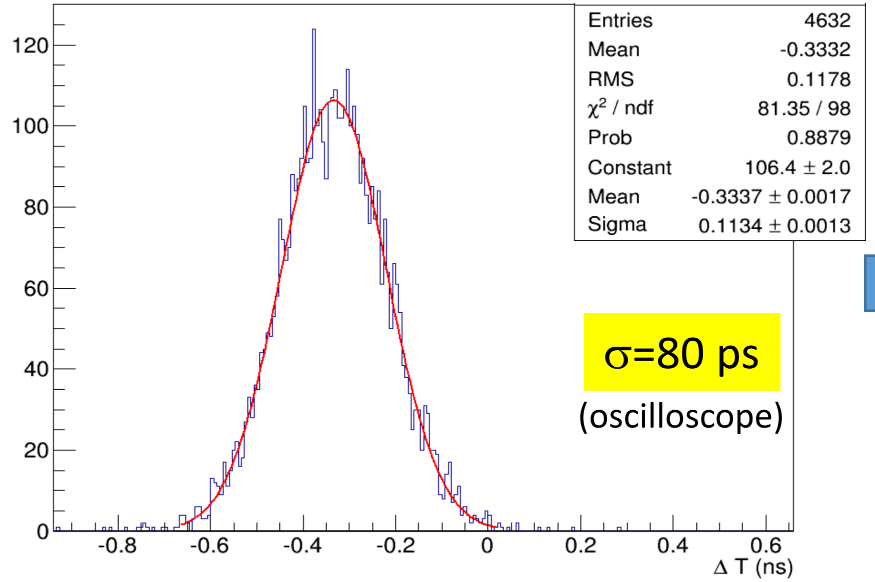
	V1 max	V2 max	V3 max	V4 max
P (mb)				
40	450	450	450	450
100	500	520	520	520
170	560	640	640	640
215	640	670	670	670

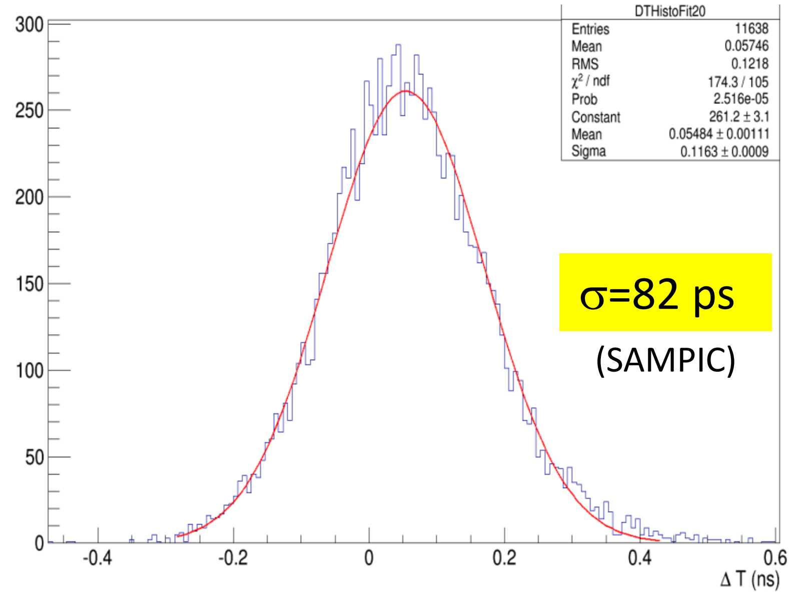
Test beam results with P=170 mb and HV=(560..640) V

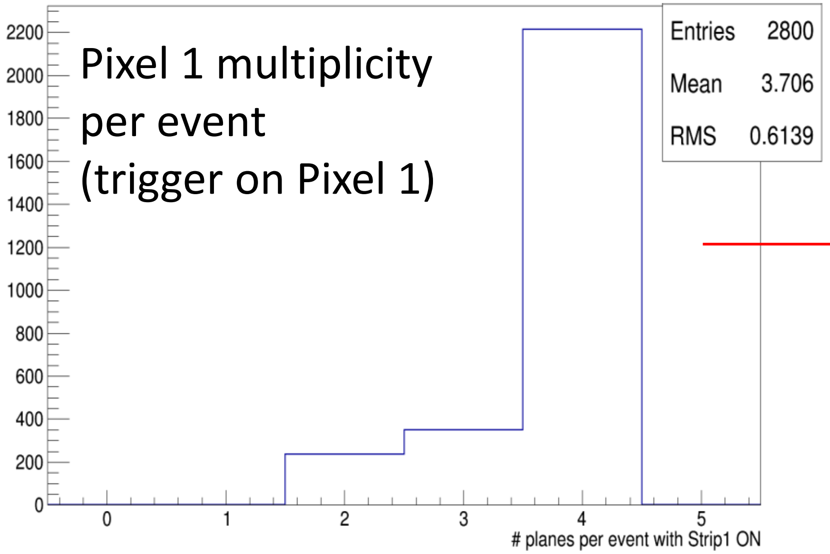
Channel Numbering:



- Pixel 3 was found to be aligned with the beam. Resolution measured with Oscilloscope and SAMPIC





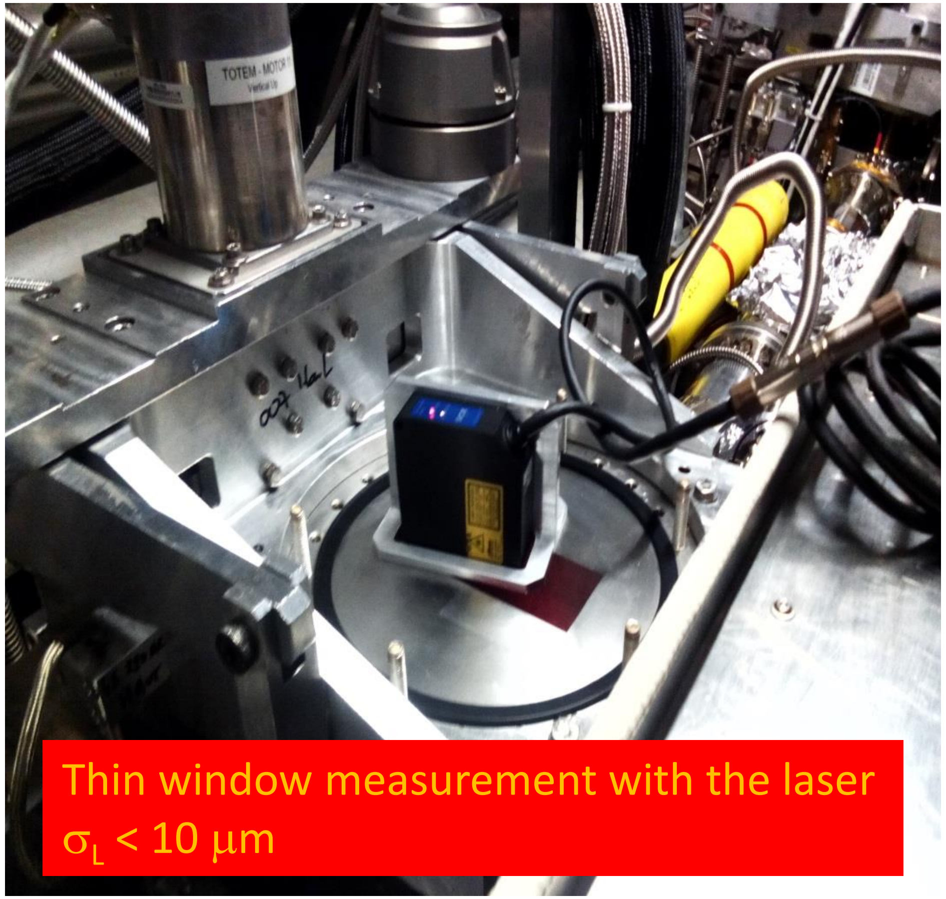


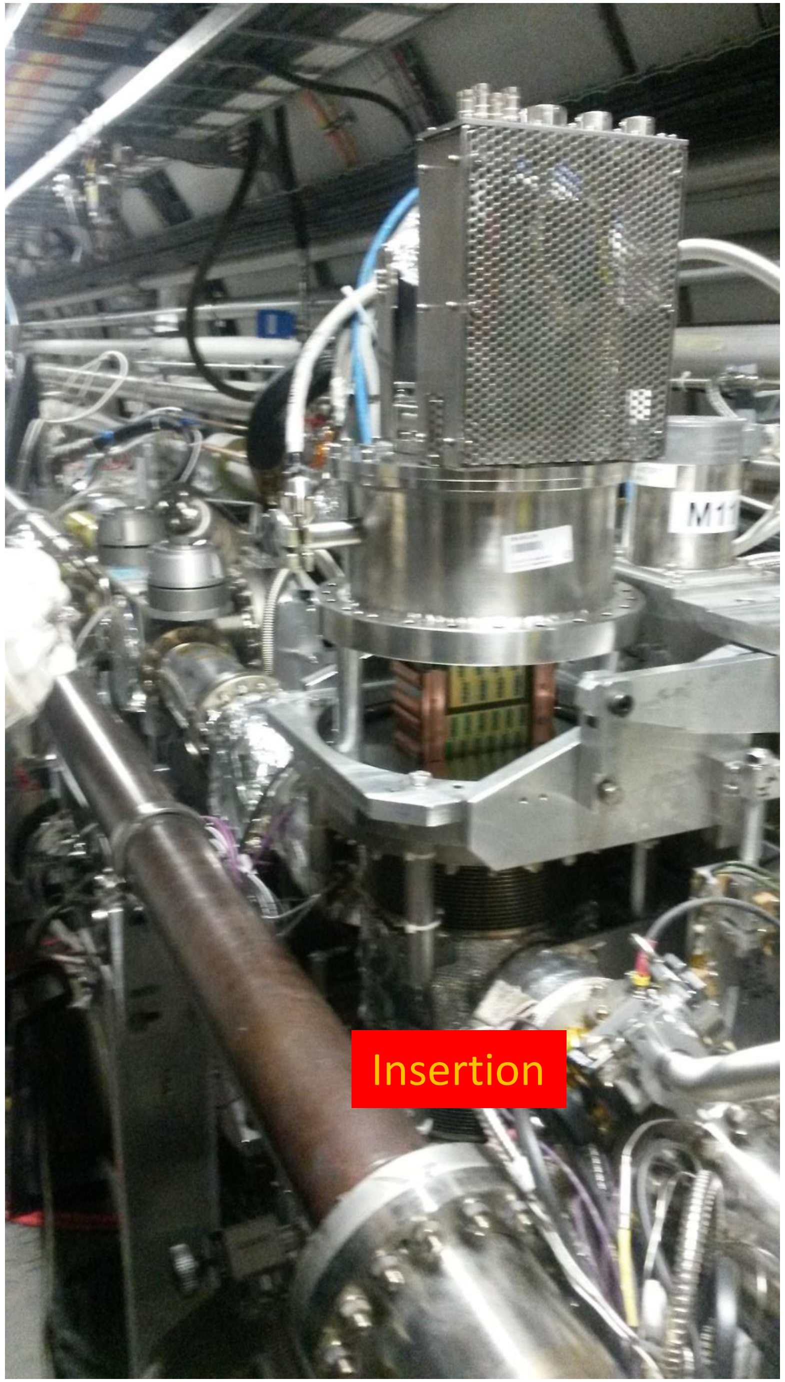
Compatible with misalignment

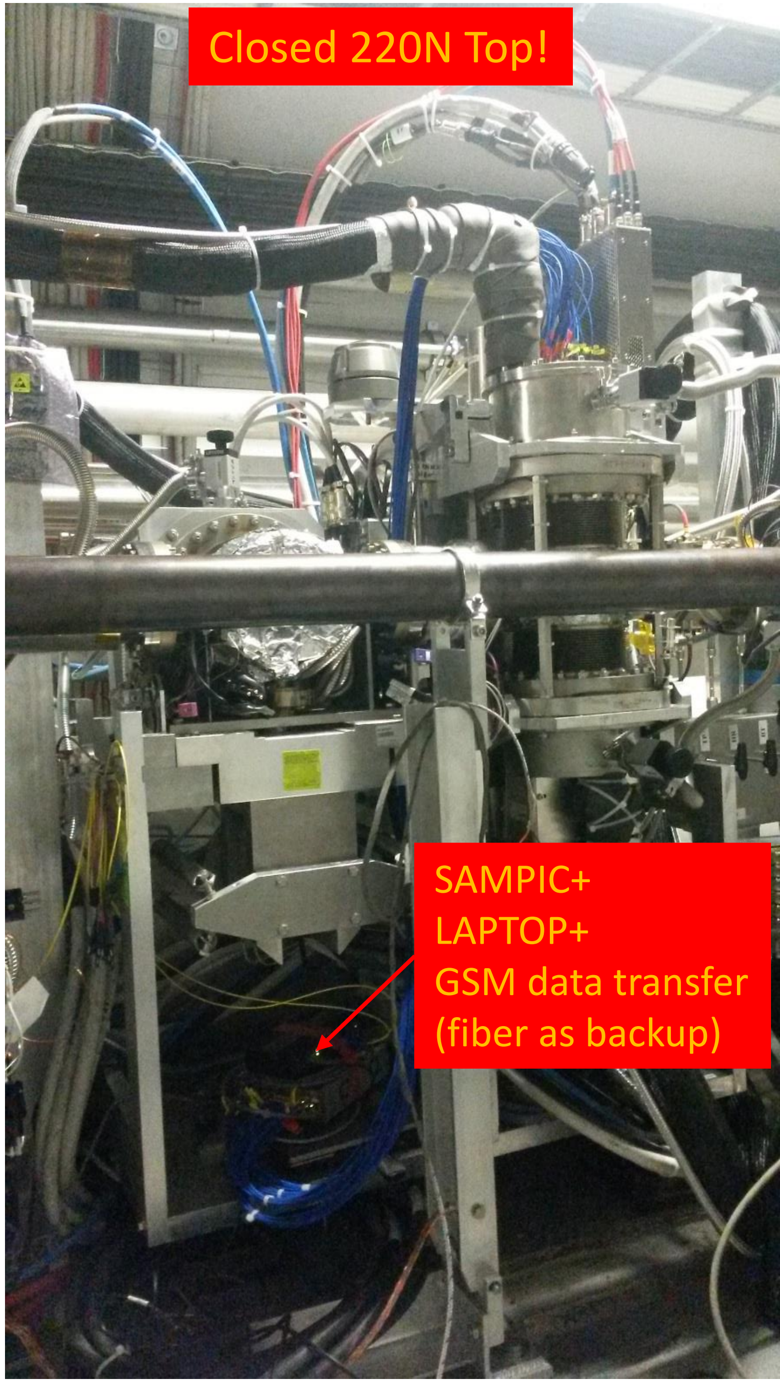
The time resolution was found to be better than in the previous TB at 700V (enhanced S/N)

Oct. TB (ps): (B12,B13,B23) = (87,92,94)
This Test (ps): (B12,B13,B23) = (80, 90,87)

Tunnel installation (Nov. 2015)



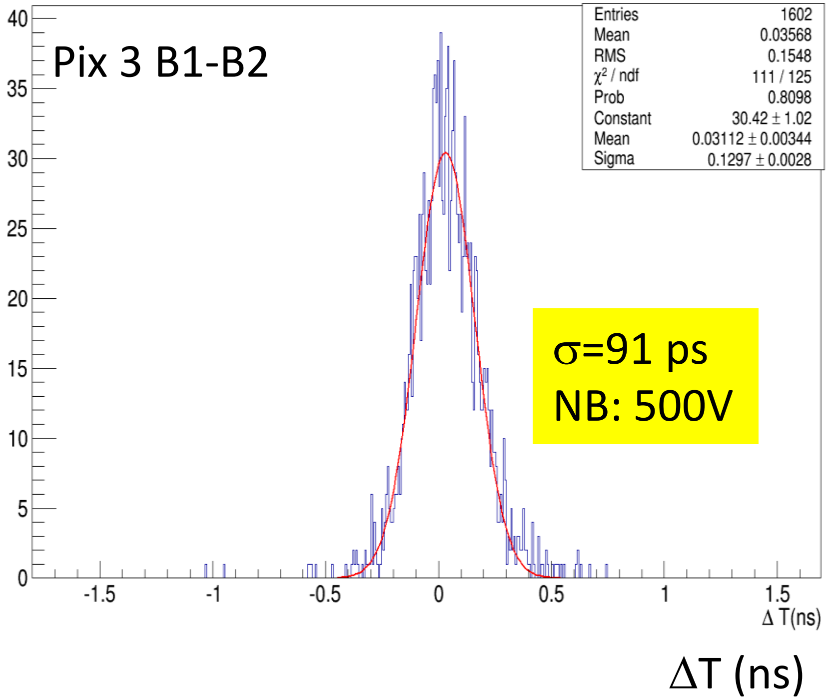


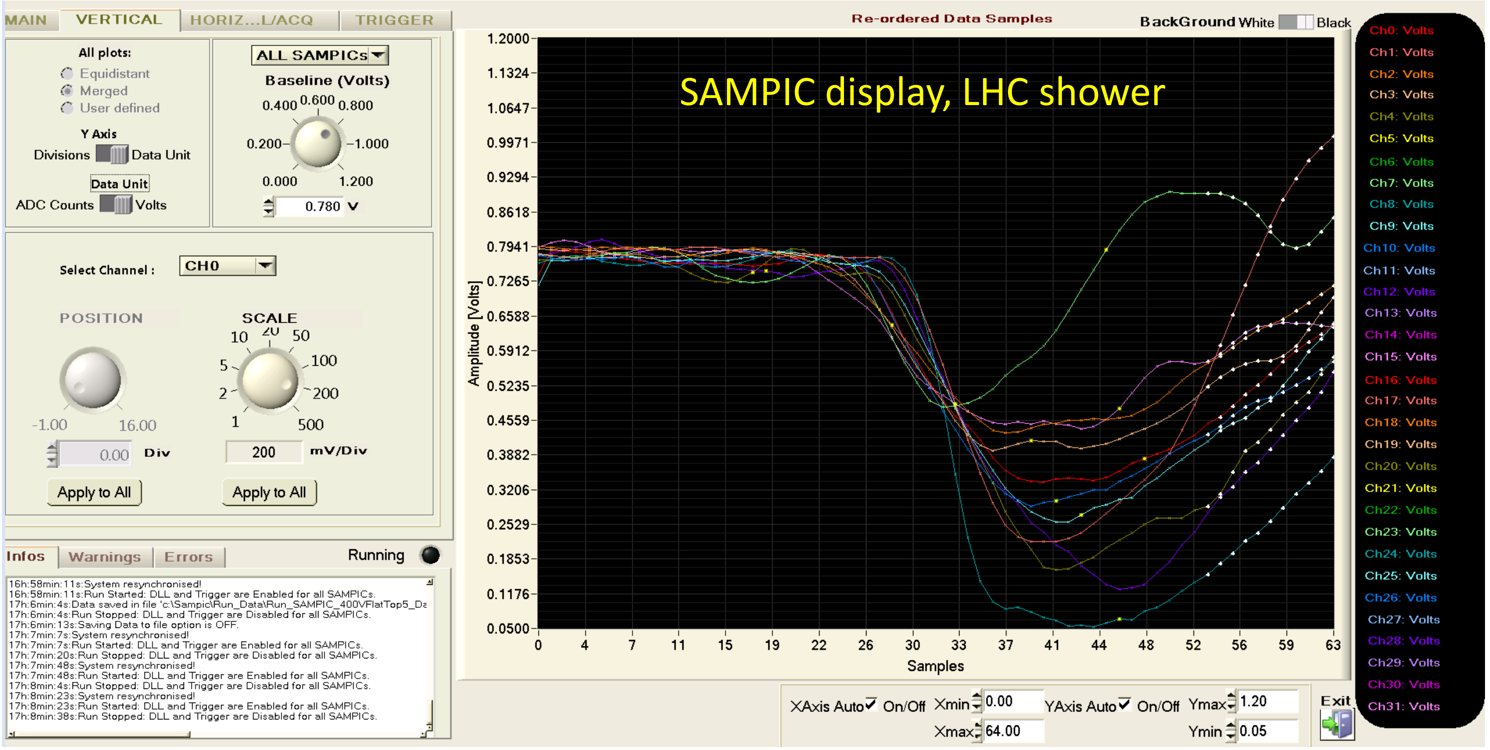


Many thanks also to:
R. Stefanovitch, A. Baud, X. Pons, L. Kottelat…

Tunnel results

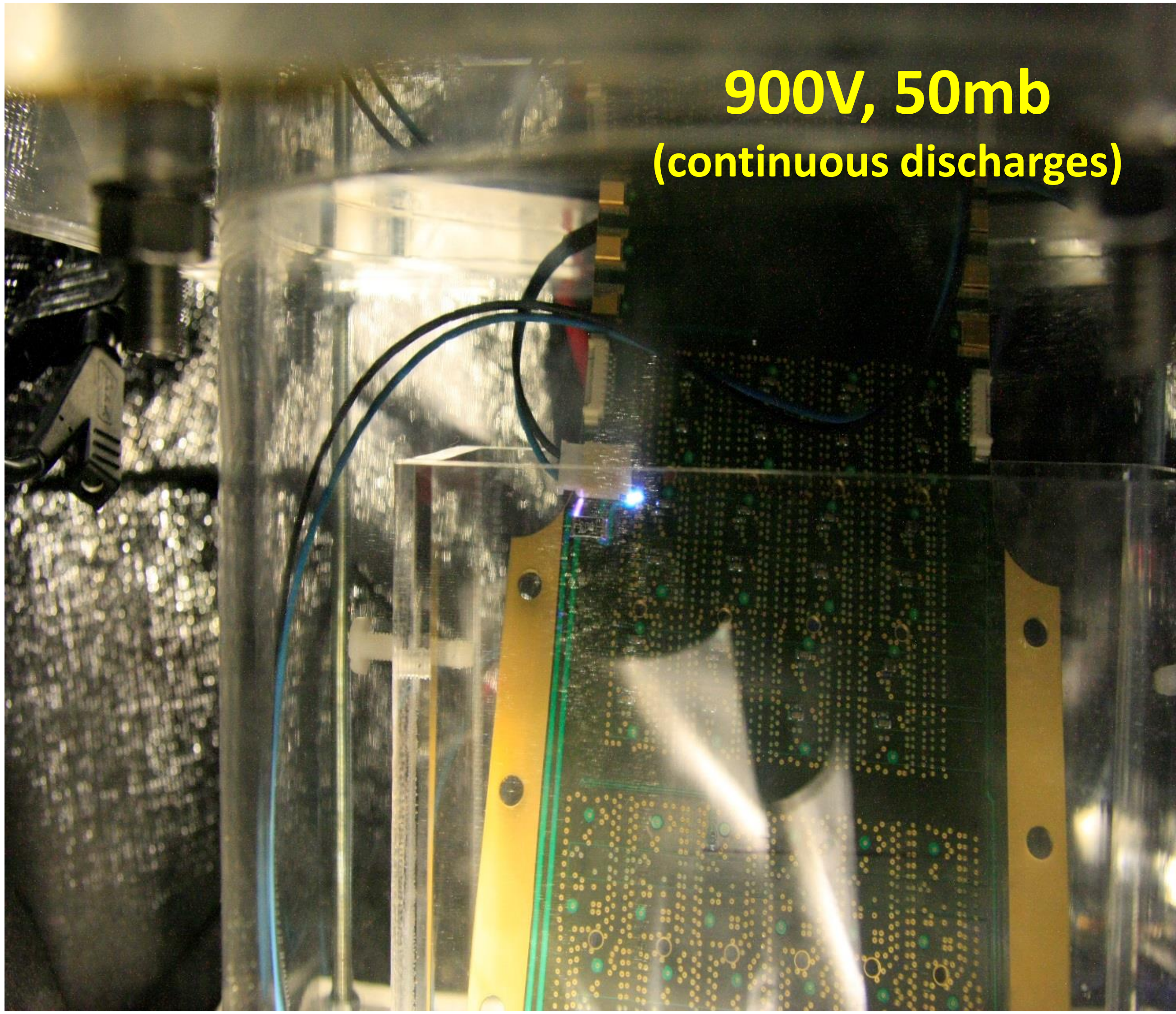
- The system have been tested inside the tunnel at hybrid T=20 C and P=200mb.
- *The noise was found to be identical to the one measured in H8.*
- *The T/P were stable for all the data taking period ~20h.*
- RP was in garage position, only showers arrived at a low rate <10 Hz.
- A more conservative current limit was set (0.5 μA), which allowed to ramp the system only up to 500V.
- *No extra dead channels (9 in total) was produced during the tunnel exercise.*



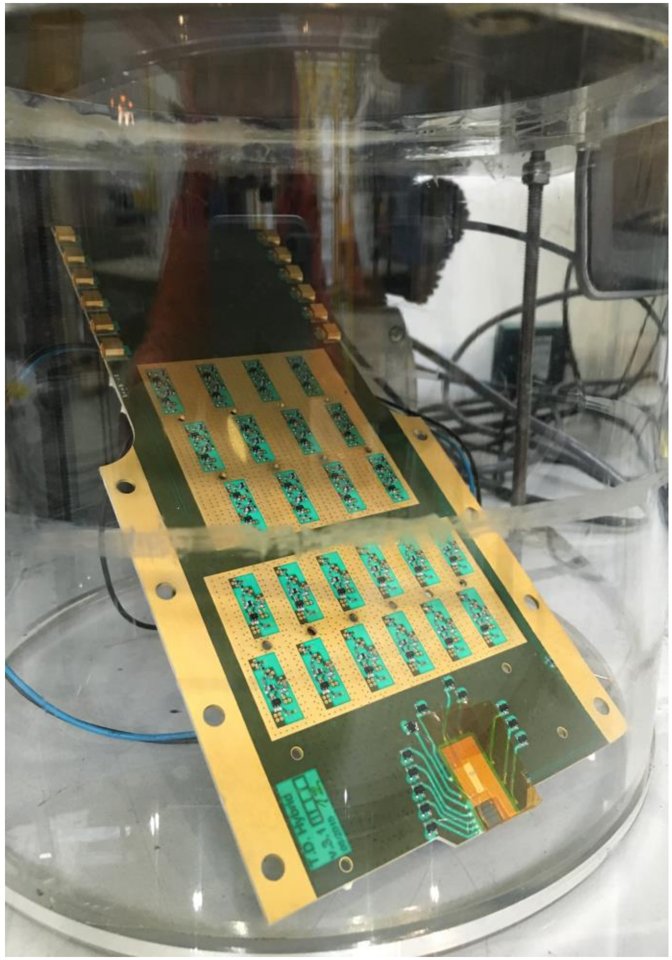


HV tests of the hybrid in vacuum

- First tests have been done by using the hybrid board without any diamond attached.
- The systems, in P=50mb, shown the first discharges at V=720V.
- By coating the HV distribution with Polyurethane the maximum voltage reached is 820V.
- The weak point of the board was found to be the diamond+ bonding (discharge started at about 450 V)

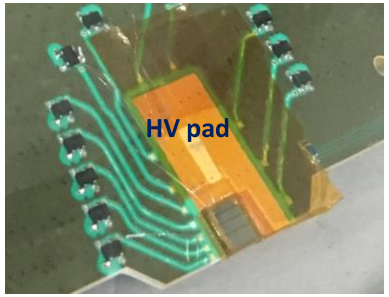


TOTEM diamond detectors for CT-PPS



- Big effort has been done in order to avoid discharge in secondary vacuum.
- Diamond board tested down to 10 mb pressure and position of the eventual discharges and weak points were identified.

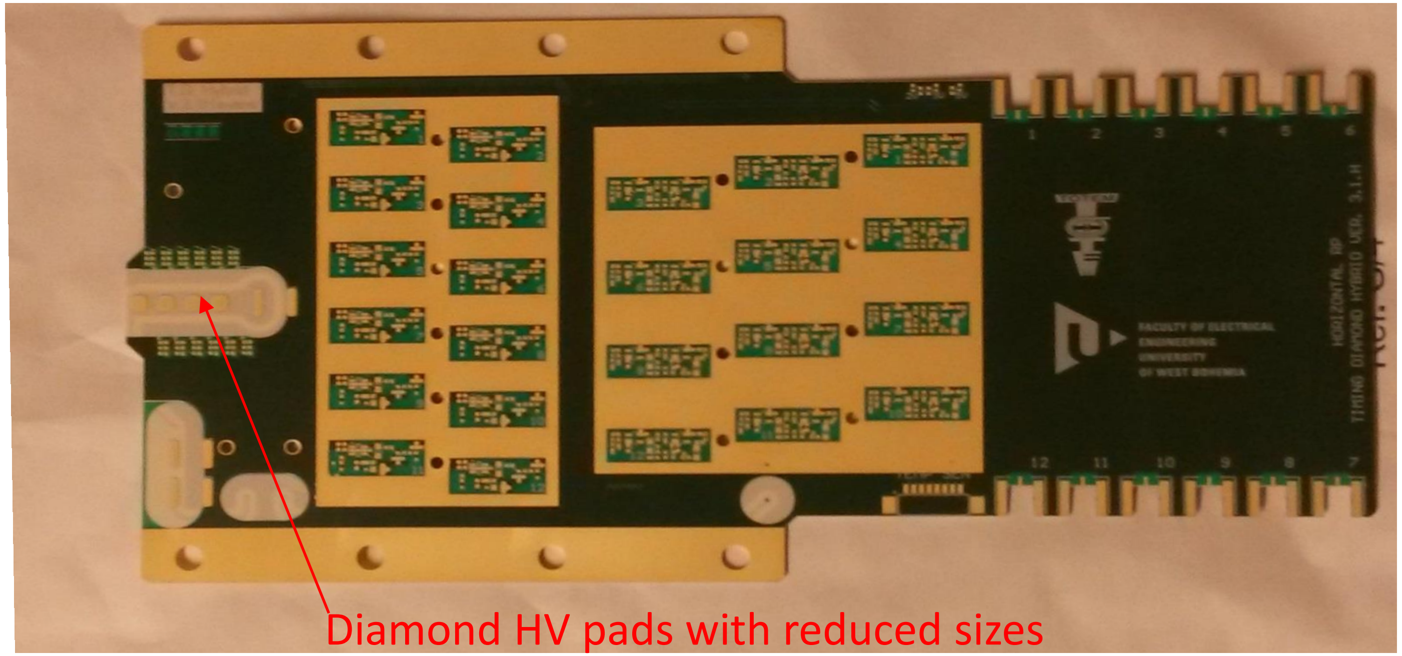
- **Action taken to achieve nominal HV (700V) in secondary vacuum:**
    - **Redesign the board**
        - **Discharges on the board itself**
            - **Simulation of discharges: Old board gave discharges at ~600V (new design OK @ 900V)**
    - **Coating and larger size wire bonding (weakest point)**
        - **Reduce the HV gluing pads not to have uncovered HV spots**
        - **Passivation of the uncovered spots**
            - **Kapton glued on top (done), special resins (done, to be tested),bigger bonding wires (done, to be tested)**



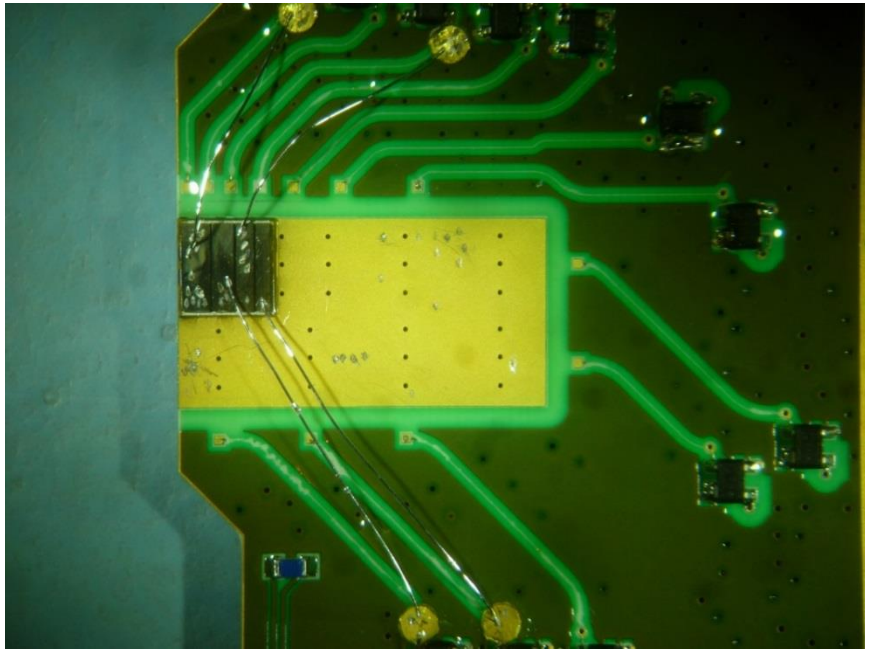
→The tests done with the Kapton on the old board gave good results, but quite complicated to be implemented.

Horizontal board coating

- PCB with special geometry for the horizontal RP and with better HV tolerance in vacuum already produced (population next 2 weeks)



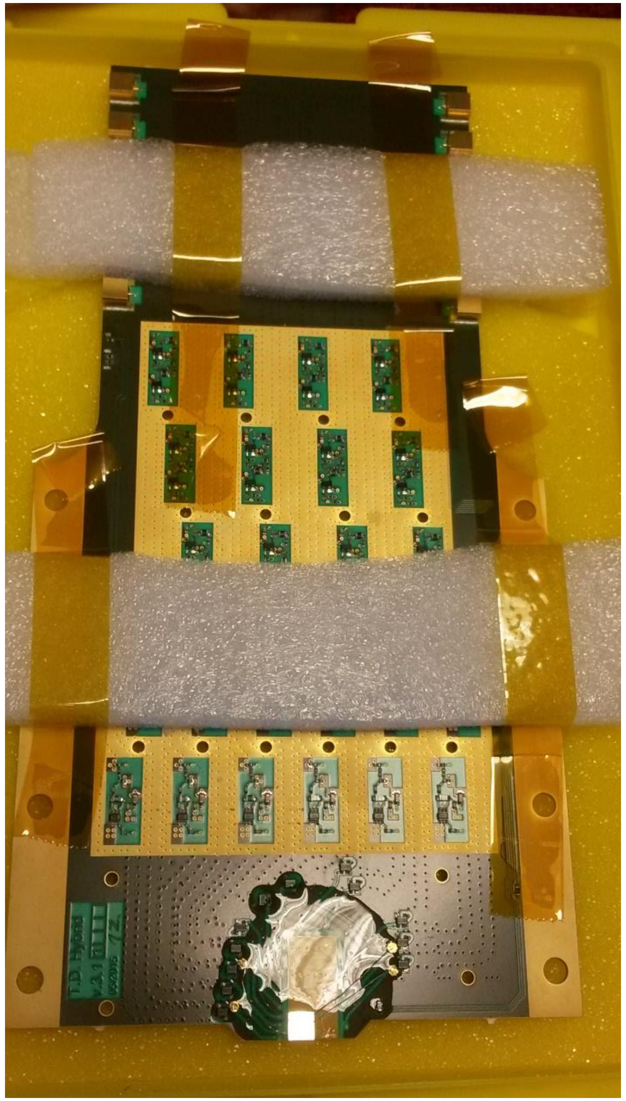
- One old board was sent to a company for coating and large wire bonding: better for field reduction and reduced impedance for the signal

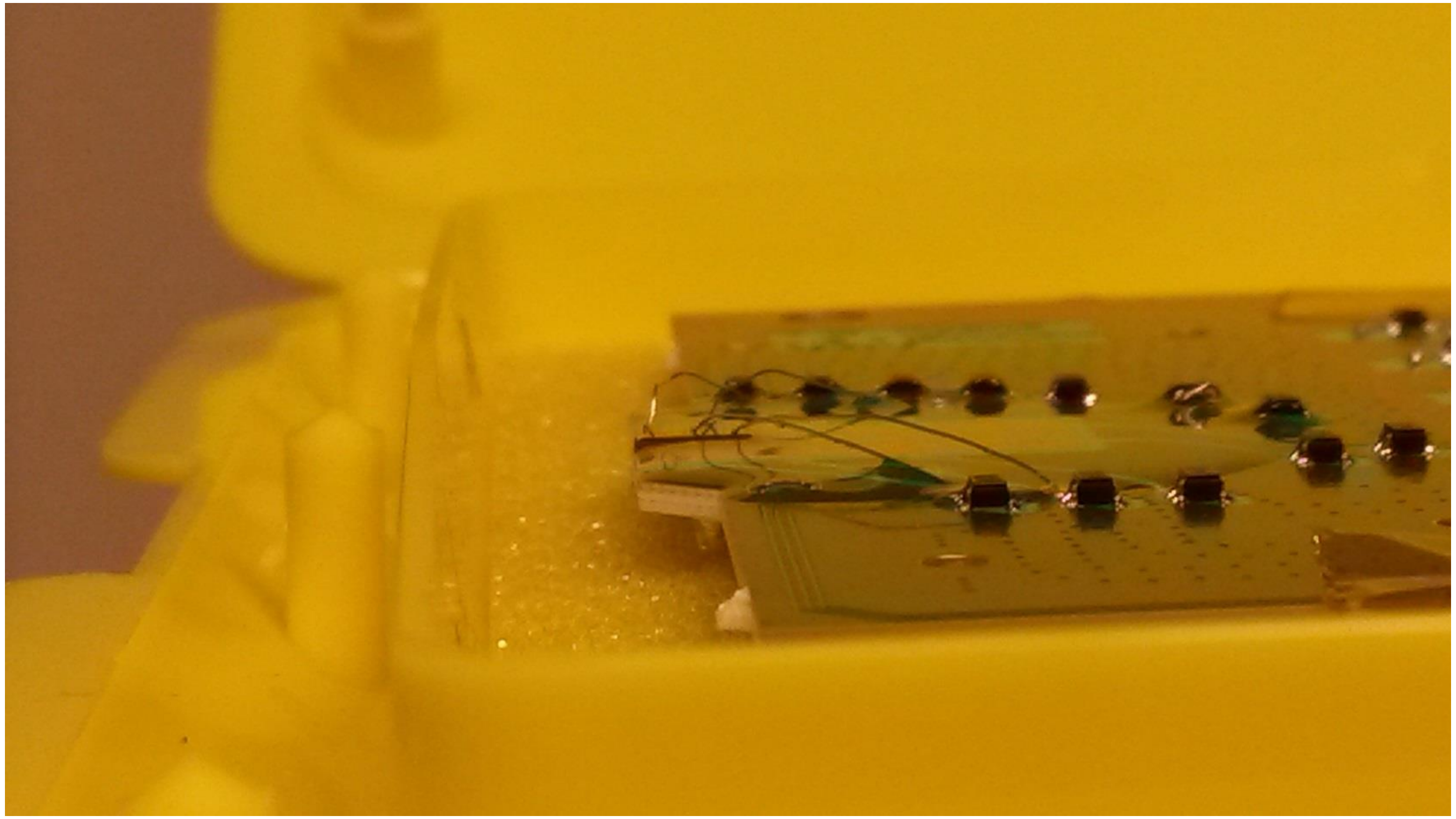


- Silicon-based coating, $R_V = 3 \cdot 10^{15}$ Ωcm
- 150 μm wire bonding

- First tests seems that the problem has been fixed (up to 840V at 60 mb)
- NB: for tracking diamonds can be operated at ~400V → NO PROBLEM

MIPOT board with coating and large wire arrived this morning.

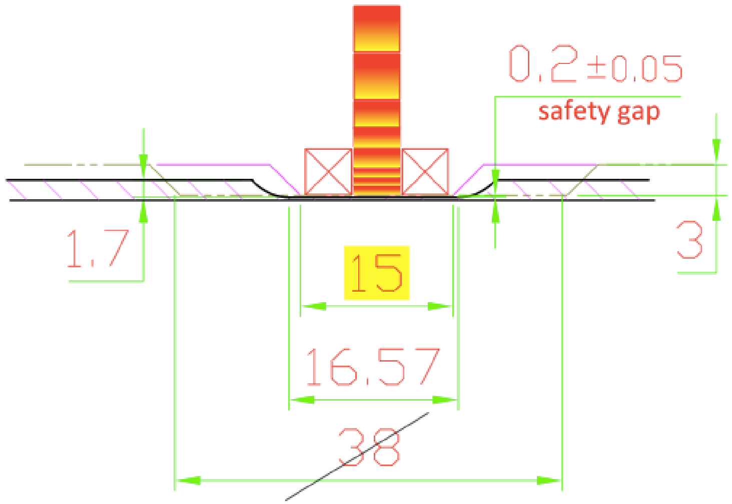




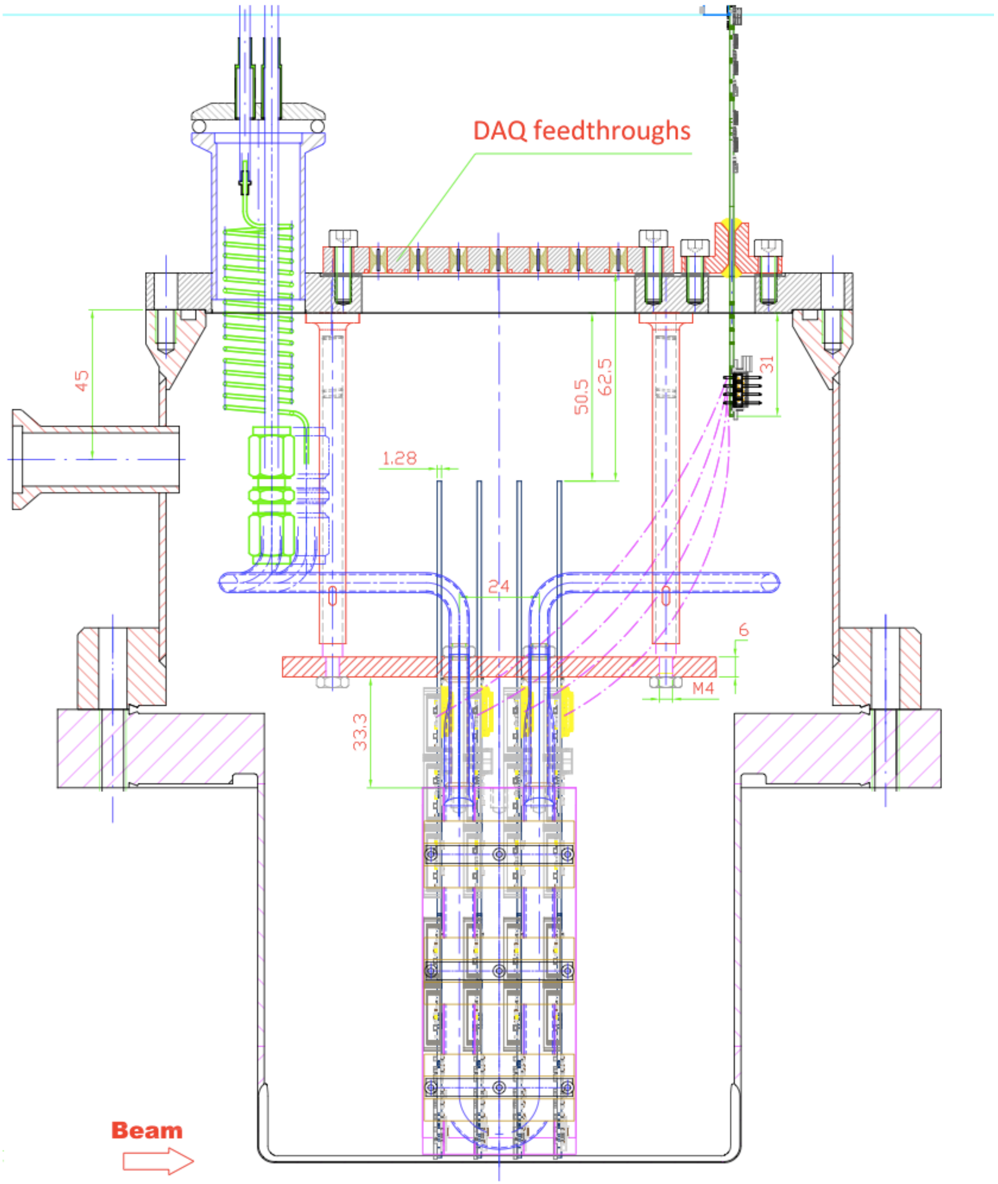
Diamond detectors for CT-PPS (1)

Minimal mechanical/cooling adaptation needed:

- Thin window profile adapted to the hybrid



- Apart from this, champignon and cooling system is exactly the same of the vertical one

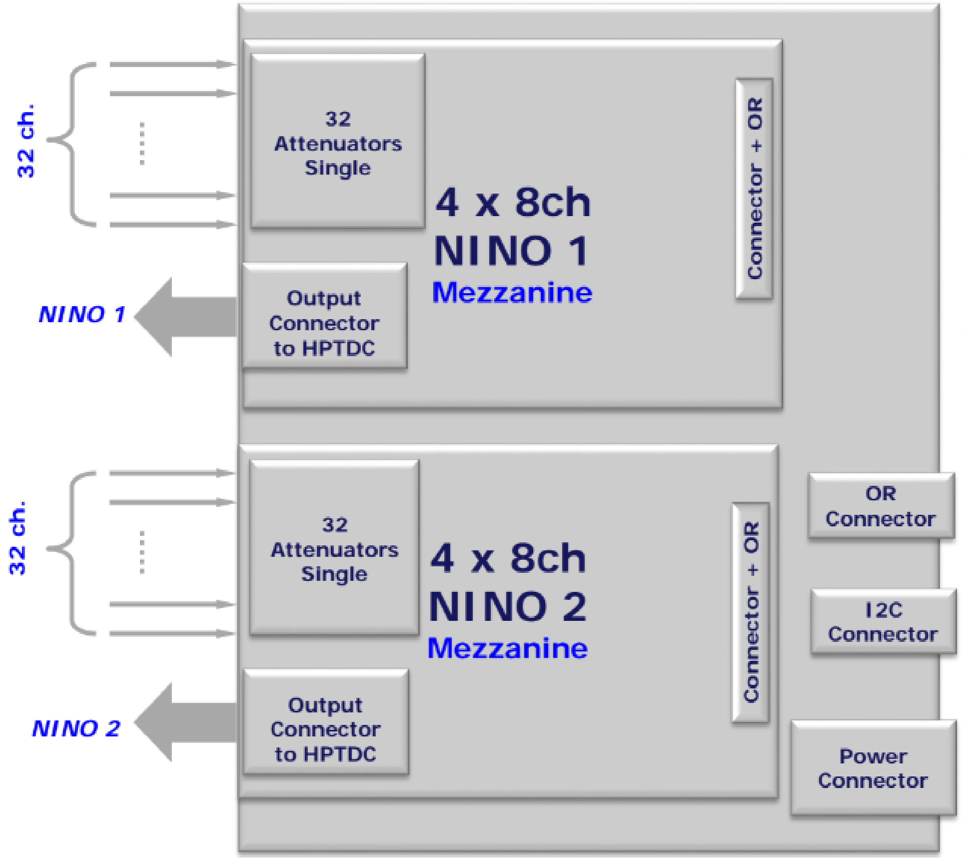


Diamond detectors for CT-PPS (2)

Biggest change: different digitizer

- Unfortunately the Sampic cannot be used as we expect order of 3MHz per channel (Sampic tested safely for 350 KHz/8 channels) . Version 3 (not yet in production) can fix this problem by introducing a buffer for LS1 selection.
- For the June installation, we will use the NINO+HPTDC, but the performance of this solution has to be verified.
- The NINO board will be mounted externally as a mezzanine on the final digitizer board.

G. Antchev, Totem collaboration meeting

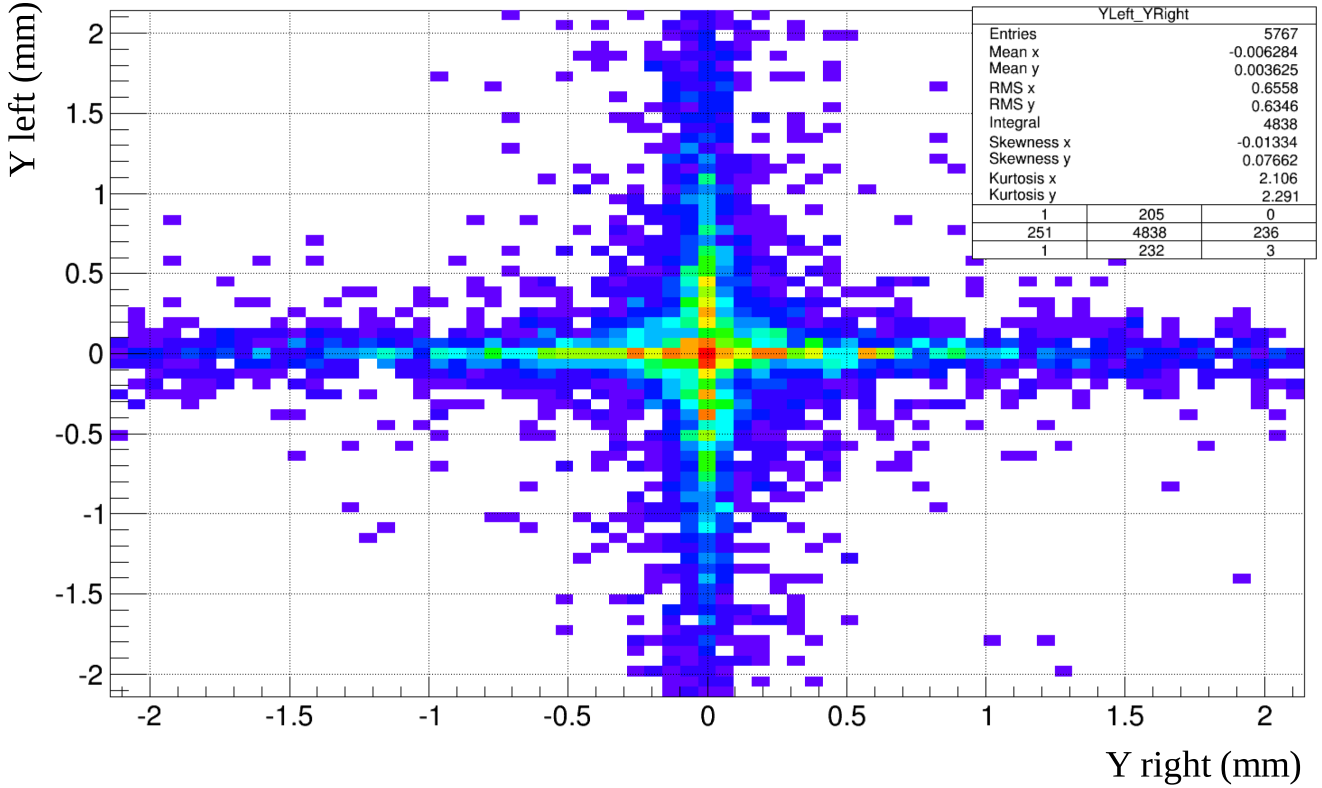


- 64 channels (2 x 32)
- Board in CTPPS cassette slot
- Same mechanics
- New front panel
- 2 x NINO mezzanines
- Power from 2.5V channel
- I²C connector
- Flat cables to HPTDC

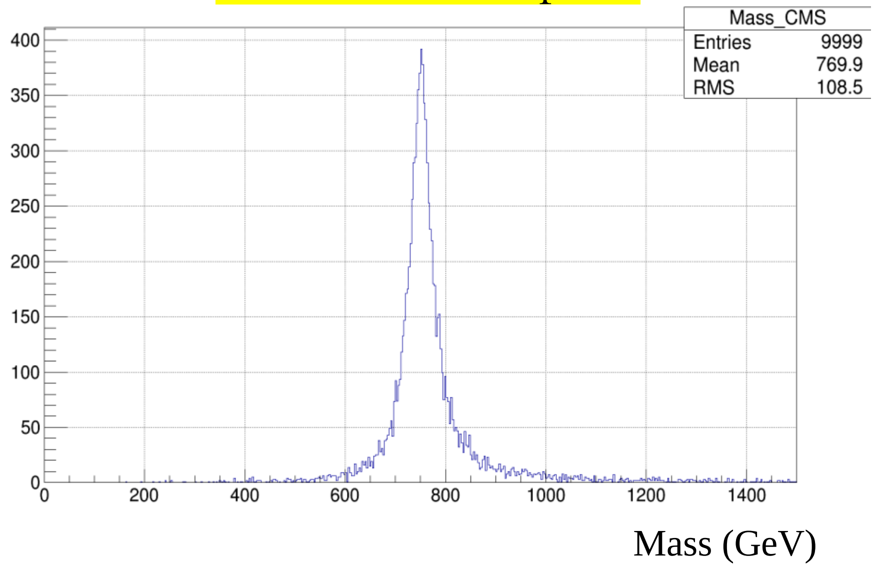
Diamond geometry for CT-PPS: simulation results (1)

- FPMC simulation (thanks to C. Royon) has been used to optimize the diamond geometry
  - ➢ *It is enough one single diamond row (metallized width 4.2 mm).*

Proton Y-left vs Y-right for 2γ simulation at 13 TeV and β=0.8m



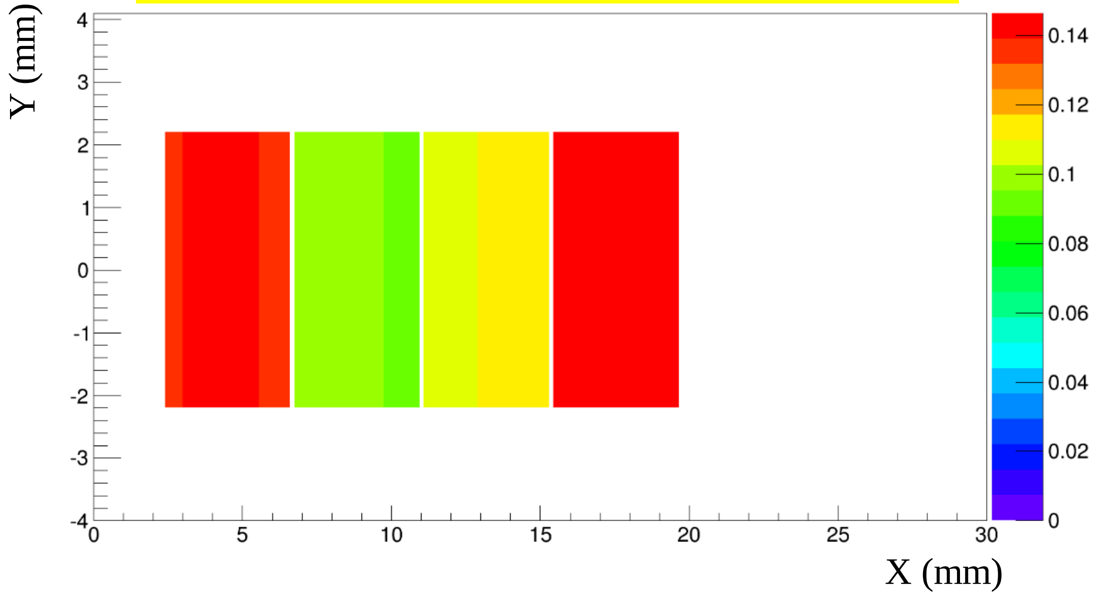
FPMC mass output



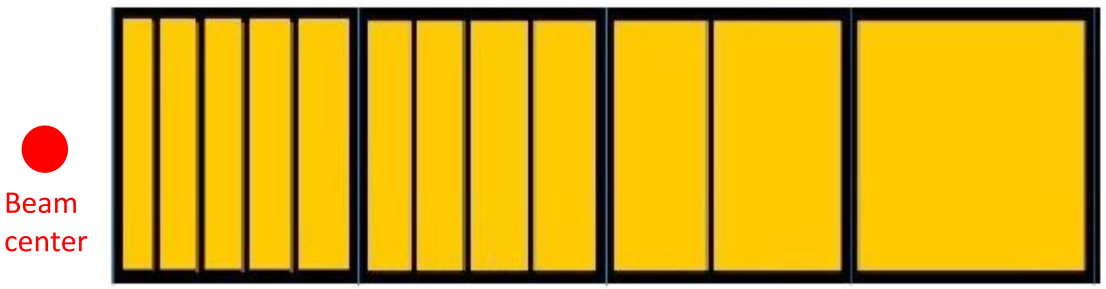
Diamond geometry for CT-PPS: patterns

- Board for CT-PPS has been produced with 12 channels around a single raw in the X direction (4 diamonds):

Occupancy simulation
(including Physics and beam background, μ=30)



4 diamonds/plane with this pattern
(metallizations ongoing)



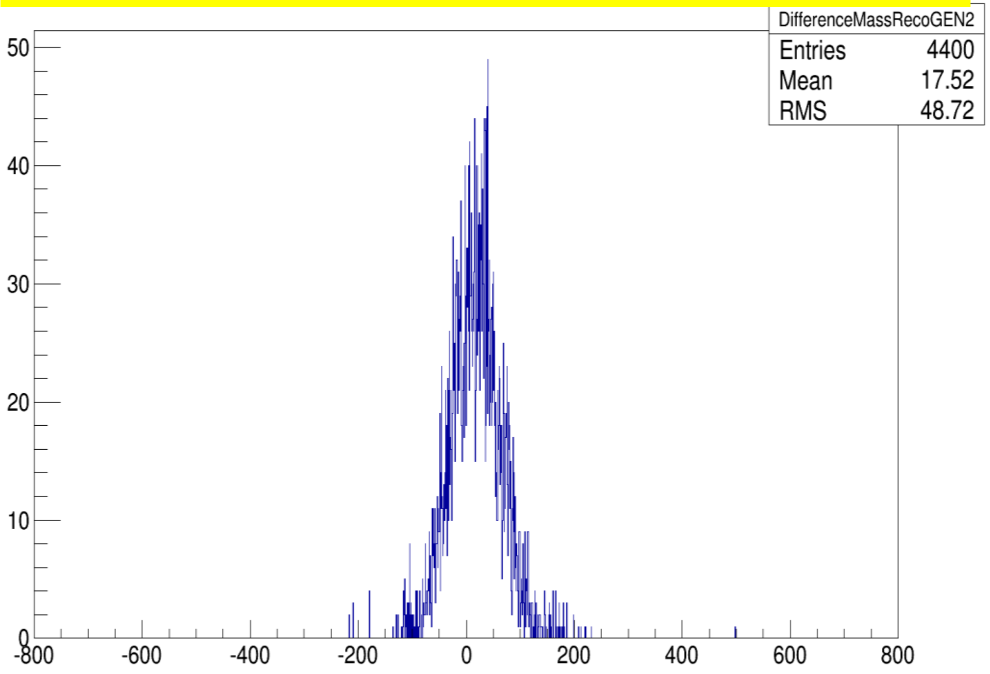
- Due to the time constraint the patterns with (1,2,4)-strips from the diamonds in the vertical RPs have been also used.

- The diamond closer to the beam has instead a new pattern with higher granularity, optimized for a low occupancy.

Diamond detector mass reconstruction capability

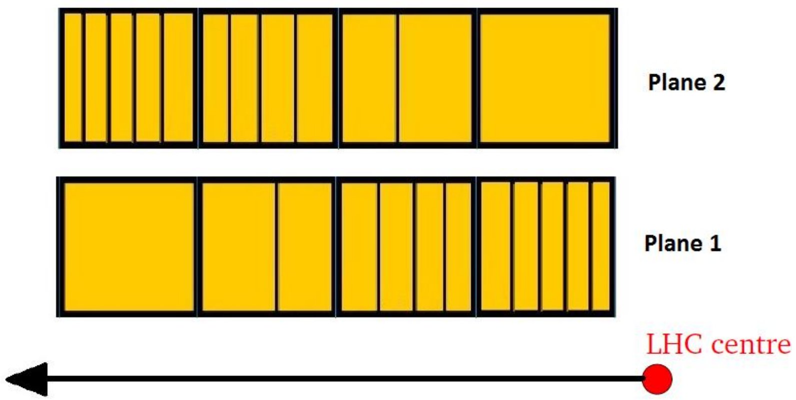
- By using the approximated relation x ~ Dξ it is possible to determine the mass of the system from the 2 protons: $M = \sqrt{s\ \varepsilon_1 \varepsilon_2}$
- A resolution of about 50 GeV can be obtained with the current design (excluding misalignment effects etc.)
- Because of the $x_L - x_R$ correlation it can be improved only by having a layer with inverted segmentation.

Generator mass – Reconstructed mass



ΔM (GeV)

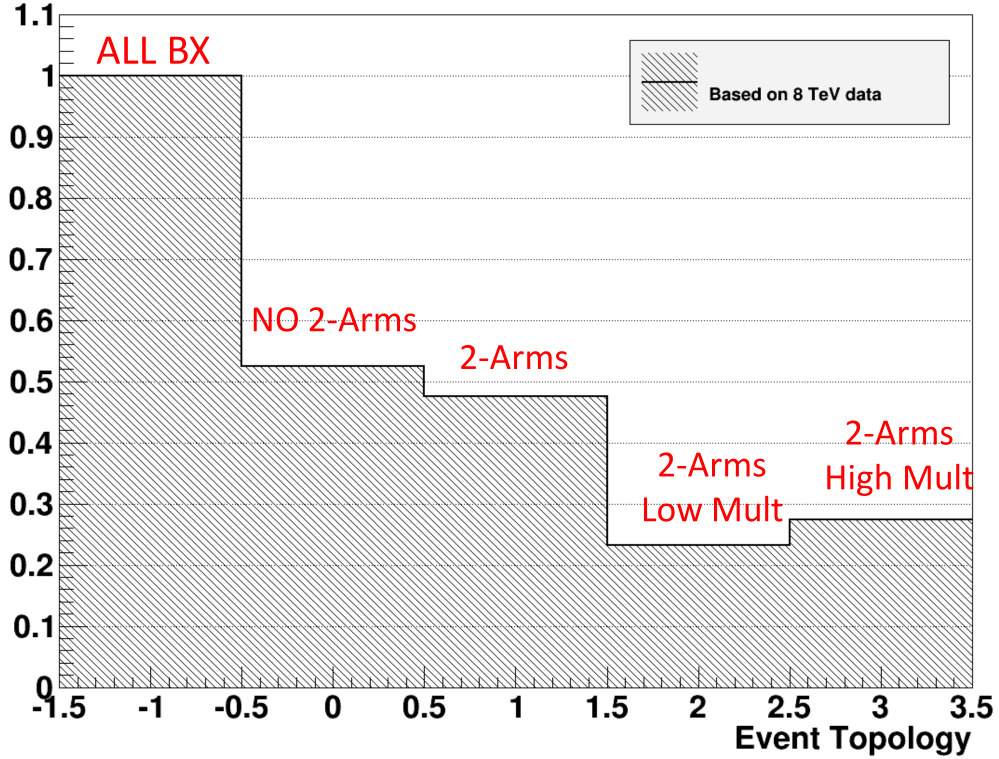
Possible to improve it by ~30% by swapping the pixellization in one plane



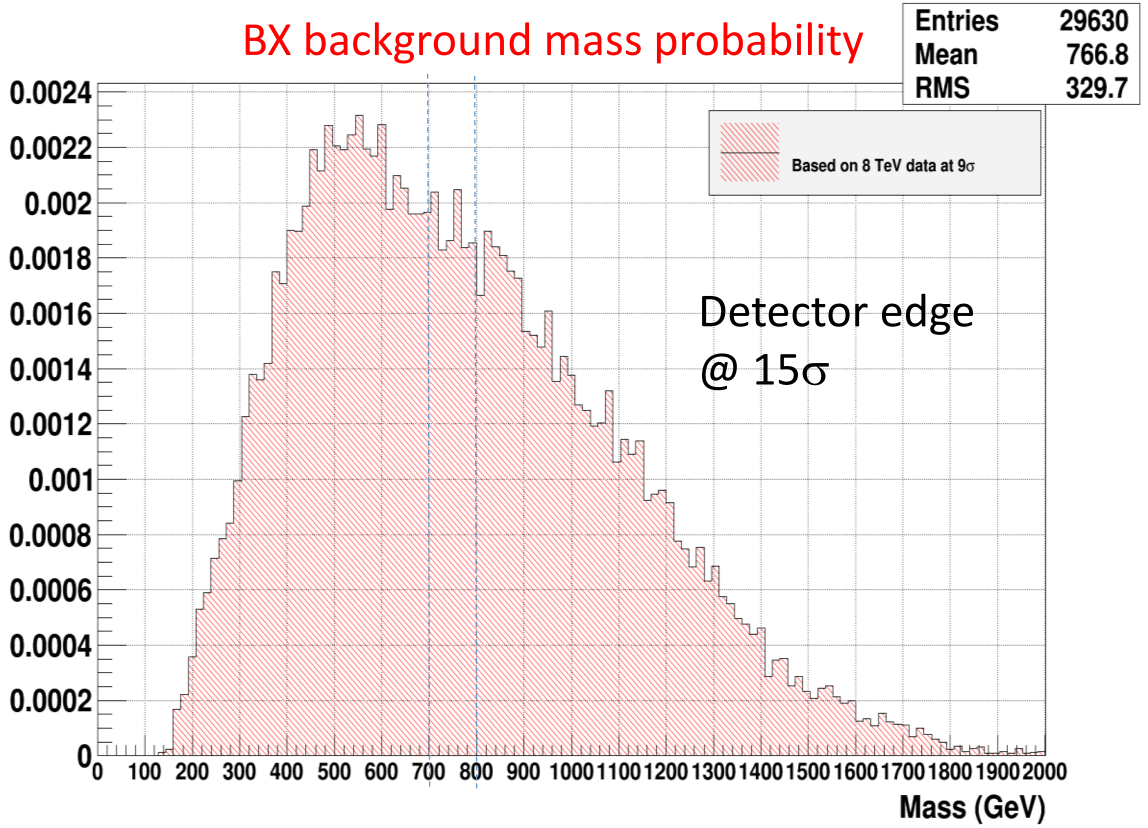
2γ analysis and background reduction with the diamonds (1)

- $\gamma\gamma$ -> X(750 GeV) -> $\gamma\gamma$ signal is generated with FPMC (assumed ~4-5 signals in acceptance in 25 fb^{-1})
- Main background is given by inclusive $\gamma\gamma$+ proton pileup, σ=230 fb^{-1} for P_t >50 GeV (http://arxiv.org/pdf/1312.5153.pdf)
- Pileup has been simulated by Sherpa and pile-up protons from soft Phys. Beam back has been added

BX event topology in the RP



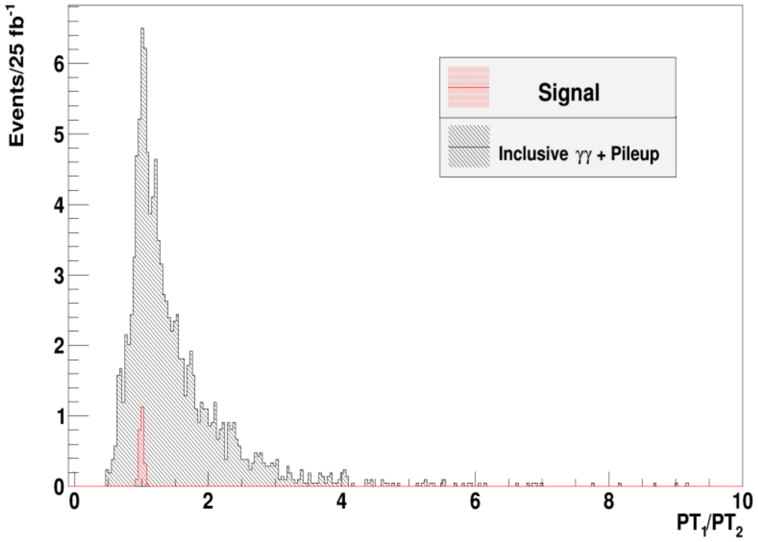
BX background mass probability

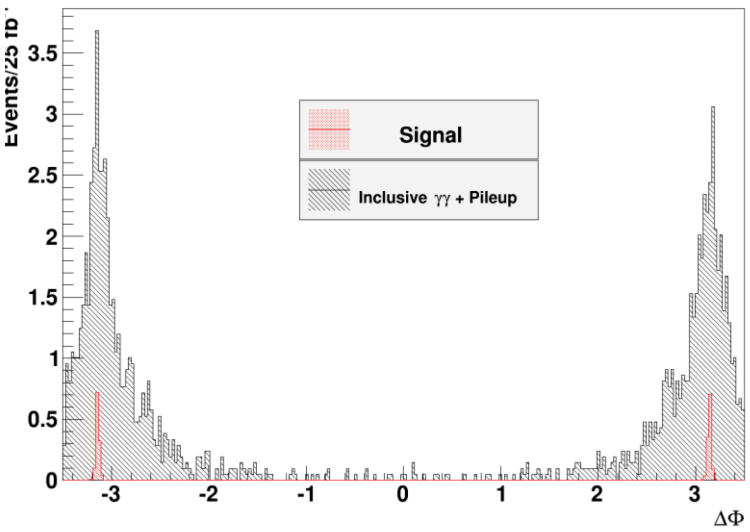


- 2% (4%) of BX has a mass coincidence in the 700-800 GeV region, assuming low (all) track multiplicity in the RP

2γ analysis and background reduction with the diamonds (2)

- Background can be also reduced by introducing a cut in the γ energy, γ P_T balance and in the γγ Δϕ:





- Data reduction and background suppression:

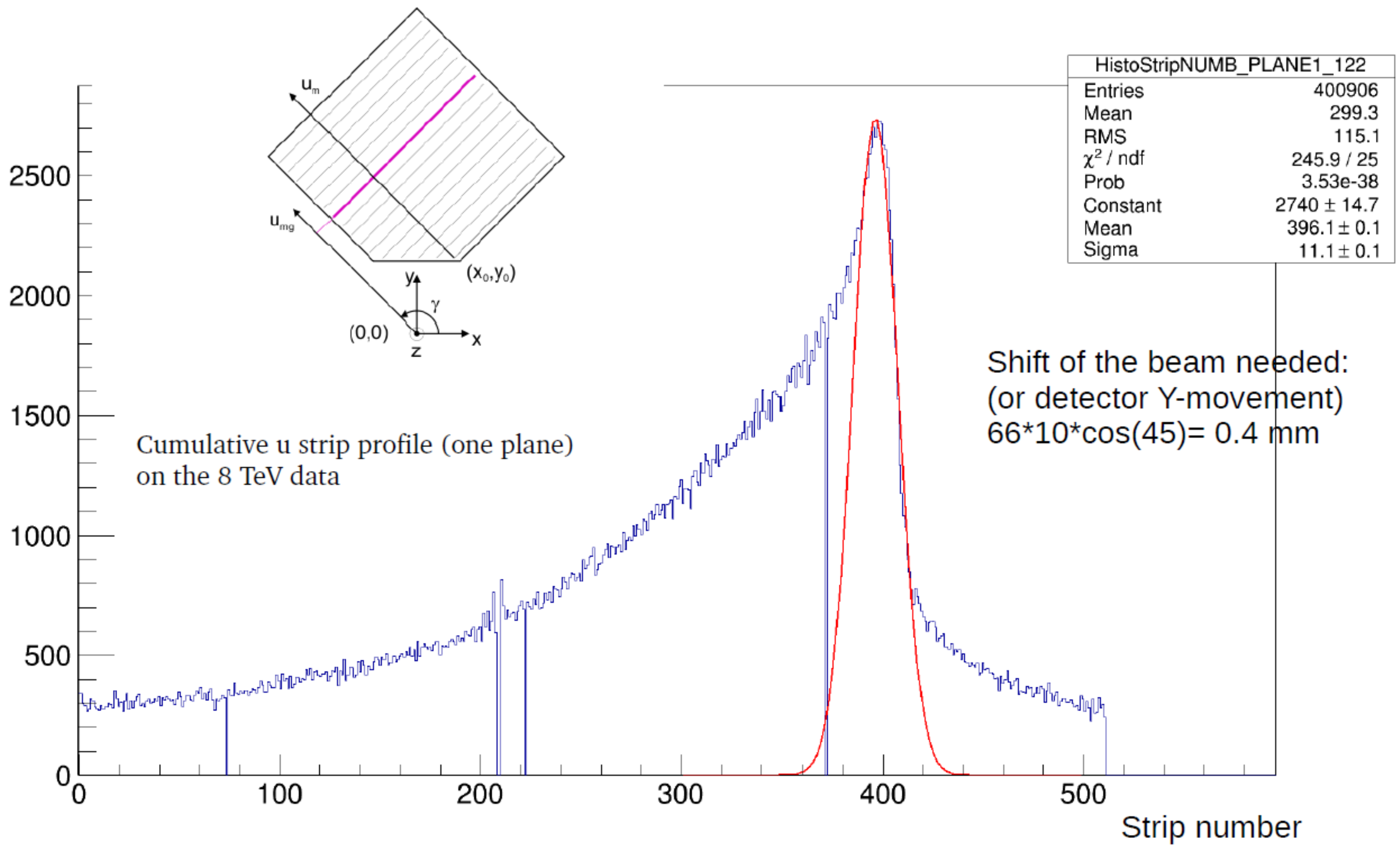
		Main background (γγ + Proton pileup)	Signal
	Events in 25 fb-1 ($p_{T1,2}$>50 GeV, M> 500 GeV)	5625	8
	$\|1-P_T\gamma_1/P_T\gamma_2\|<8\%$	225	8
	$\Delta\Phi(\gamma\gamma)< 5°$	28.13	8
Diamond Only	Double proton in RP, ΔM<110 GeV , Δη<1	1.13	4.5
Silicon Only	Double proton in RP, ΔM<35 GeV , Δη<0.15	0.17	4.5

To be confirmed according to the final LHC optics setting

Radiation hardness

Silicon radiation hardness

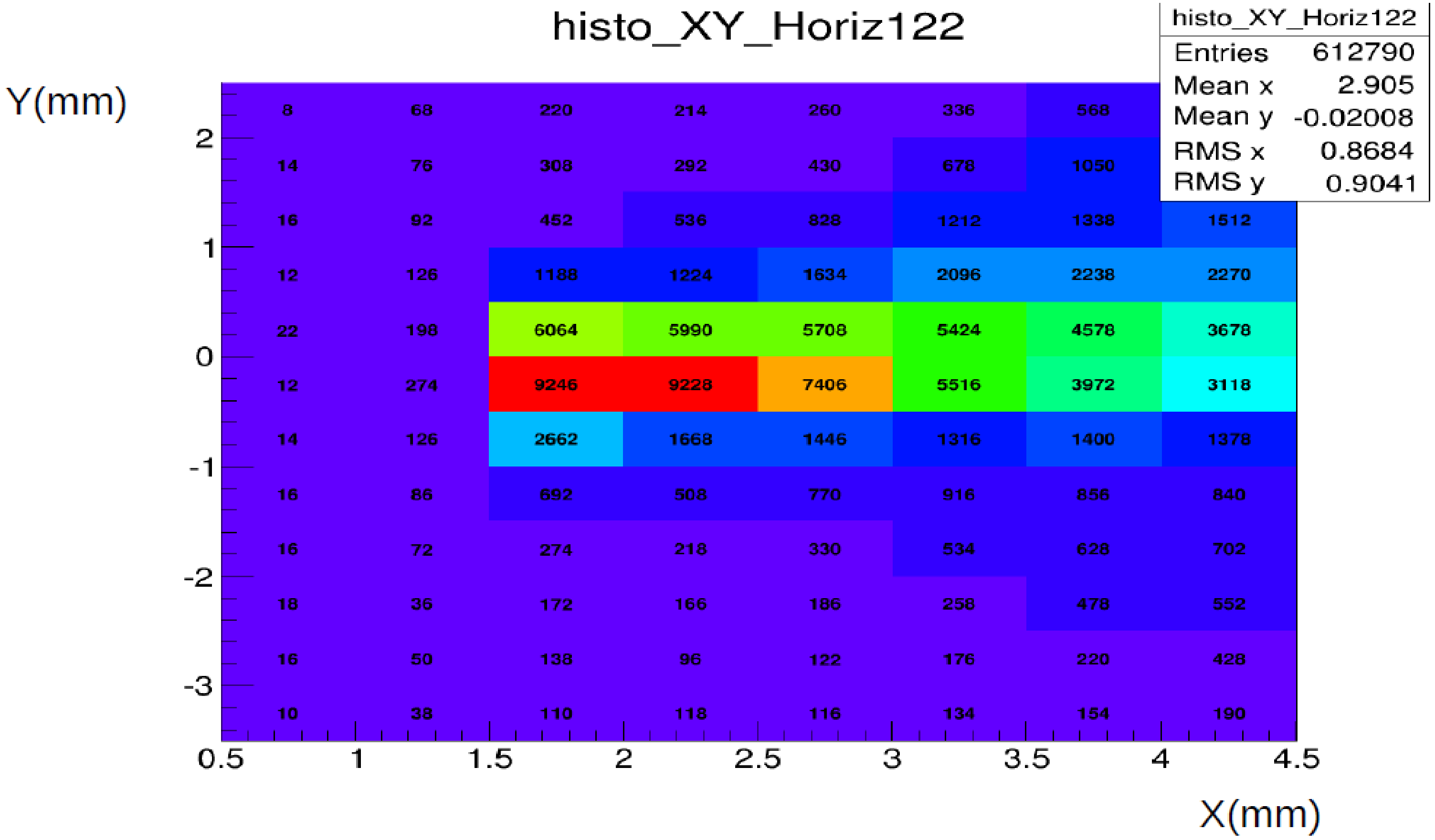
13 TeV and 8 TeV analysis shown that is not wise to rely on big shift of the beam over Y (u,v strips quite well overlapped)



- Looking at the 8 TeV we see only few planes with strip shifted
- No big shifts found in 13 TeV data (but there diffractive peak very weak due to collimation set.)
- A shift of the plane/beam around the Y axis of about 0.4 mm can do the job.

Silicon radiation hardness

- Effective edge distance ~15σ (σ=0.12mm) at 8 TeV (1.8mm).
- Particle BX/mm^2 :Hot spot (scaled by Pileup μ=25): 9.2K*2.8*4/600K=0.17 p/mm^2
- Due to ghost tracks we can expect real rate of 0.14 p/mm^2
- I assume the same RP distance to the beam axis. This is not far from the13 TeV running conditions (optimistic case).



Silicon radiation hardness

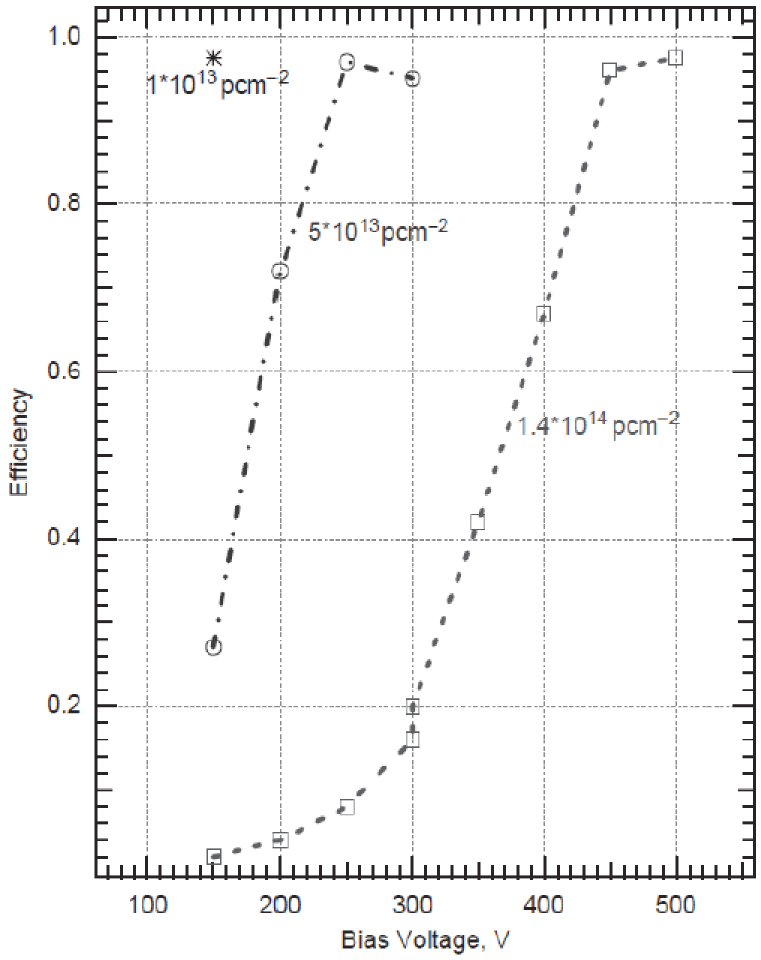


Fig. 6. Efficiency of irradiated edgeless detectors with CTS at the working temperature of −18 °C. The efficiency has been calculated by comparing the hits in the irradiated detector with the hits in a non-irradiated detector placed in front, along the beam axis.

- **I assume** 50% efficiency is good for our purposes. Extrapolation: 2.5×10^{14} protons/cm^2 at 50% efficiency and 500V. Assumed 3×10^{14} at lower T. and (current RP detector in very good shape).

- Max #BX in the hot spot that can be tolerated: $3*10^{12}$ p/mm^2 / (0.14 p/mm^2) = $2*10^{13}$ BX

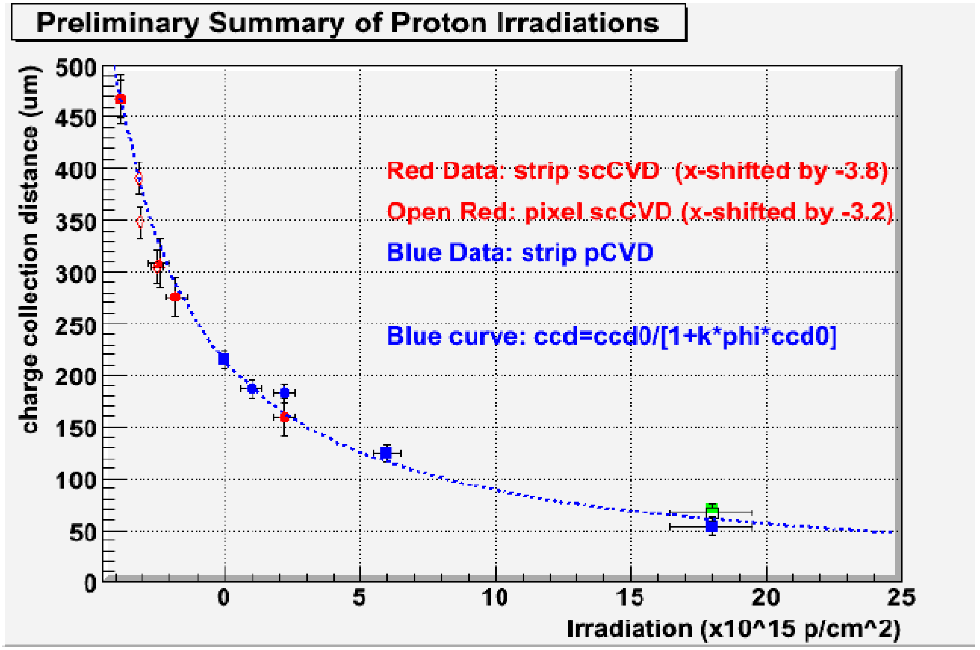
- 28 days are needed to collect 20 fb^{-1} (6.3×10^{13} BX)
- Max number of BX in the hot spot was 2×10^{13}

NEEDS ~3 detector packages in the worst case of fixed beam spot (NB:other solutions already found)

Diamond radiation hardness: from William Trischuk (RD42)

24 GeV Proton Irradiations

- Have irradiated:
  - pCVD samples to 1.8×10^{16} p/cm^2
  - scCVD samples to 5×10^{15} p/cm^2
- Characterise signal at intermediate fluences



- Default $E = 1$ V/μm
- Green at $E = 2$ V/μm
- Align by shifting -3.8×10^{15} p/cm^2

This pCVD material $\equiv$ scCVD material **after** $\approx 3.8 \times 10^{15}$ p/cm^2

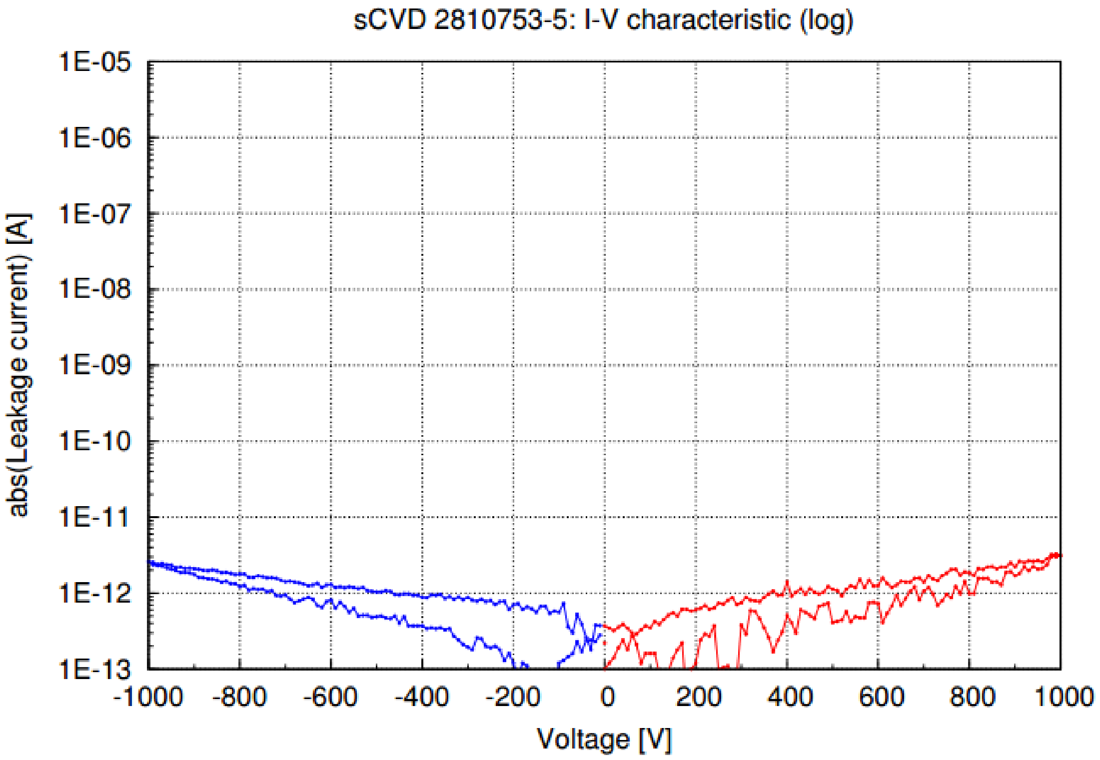
- pCVD and scCVD follow same damage curve:

$$1/\mathrm{d} = 1/\mathrm{d}_0 + k\phi$$

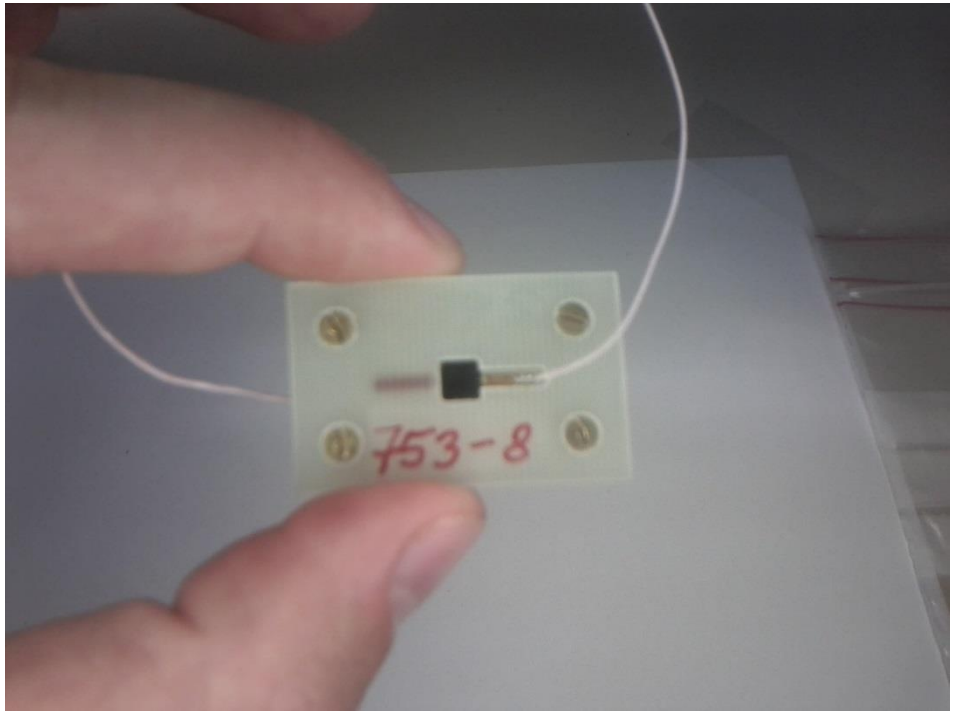
$$k \approx 0.7 \times 10^{-18}\ \mu\mathrm{m}^{-1}\ \mathrm{cm}^2$$

scCVD:
- @ 4×10^{15} p/cm^2 expected worsening of S/N of a factor 2 (still good efficiency)
- At least factor 20 better than RP silicons

Preparing for new planes production: Improved HV tests for diamond selection

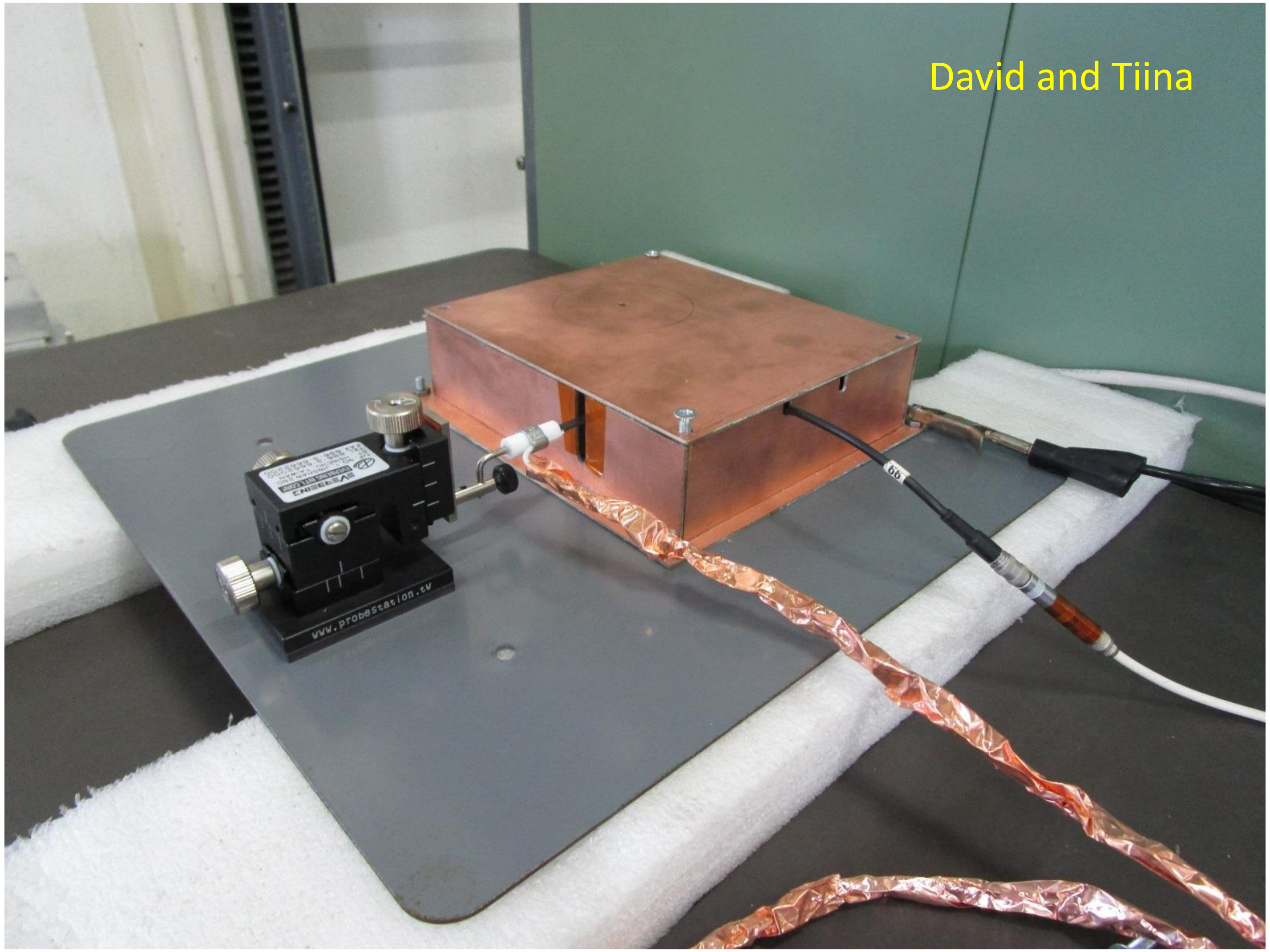


Test performed in Desy (Thanks to W. Lohman and M. Hempel)



- Selection of High quality diamonds (leakage<10 pA) at 1 kV to be patterned.
- Both leakage current and rate under source measured.

Improved HV tests for diamond selection



- Setup built also at CERN and Helsinki
- We try to use spring probe instead of bonding to have a system ready to use at each arrival of the diamonds
- Finalization of the system at CERN expected in 2 weeks
- *All diamonds for CT-PPS have been measured in terms of leakage current performance.*

Short term plan:

- Enough diamonds are metallized (under metallization) to equip 2 cylindrical RPs in June with 4 planes/side
- Intense work ongoing to be sure that the pressure/temperature problems are fixed
- Almost continuous TOTEM/CT-PPS test beam ongoing from 25 April to TS1, preparation of the experimental area
- Production of the NINO+HPTDC+ digitized card and its interface ongoing/under testing (big effort/challenging)

Conclusions:

- Simulation studies show that very good background suppression can be achieved with standard RP tracking capability while diamonds can help due to the superior radiation hardness even with lower mass resolution. Spare silicon packages available from TOTEM in case of rad-hard will be an issue. Possible to cover the 20 fb^{1} with 2/3 exchanges. Further studies are ongoing, beam or vertical detector movement of about 0.5 mm would be enough.

- New geometry for CT-PPS studied based on 2γ signal. Board produced and optimized for CT-PPS needs, diamonds/boards on schedule (even with tight margins for additional delays).

- Final physics capability to be reviewed according to the final optics (dramatic dependence).

Thanks