A new timing detector for the CT-PPS project

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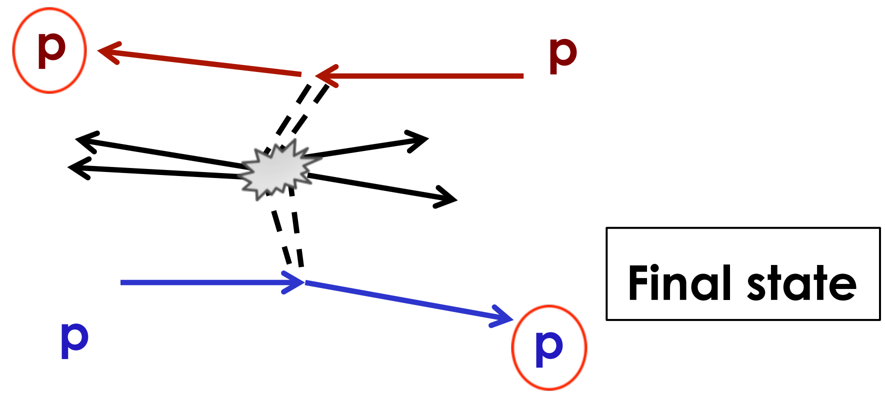
on behalf of the CMS and TOTEM collaborations

Outline

- Brief description of the project
- Timing detector: requirements
- UFSD for CT-PPS timing: proposal
  - Detector geometry and layout
  - Status of sensors production
  - Status of read-out processing chain
- Conclusion

CT-PPS: measures protons in the final state

The main physics goal of **CT-PPS** (CMS-TOTEM Precision Proton Spectrometer) is the study of central exclusive production at LHC. The distinctive signature of these events is to have two protons in the final state



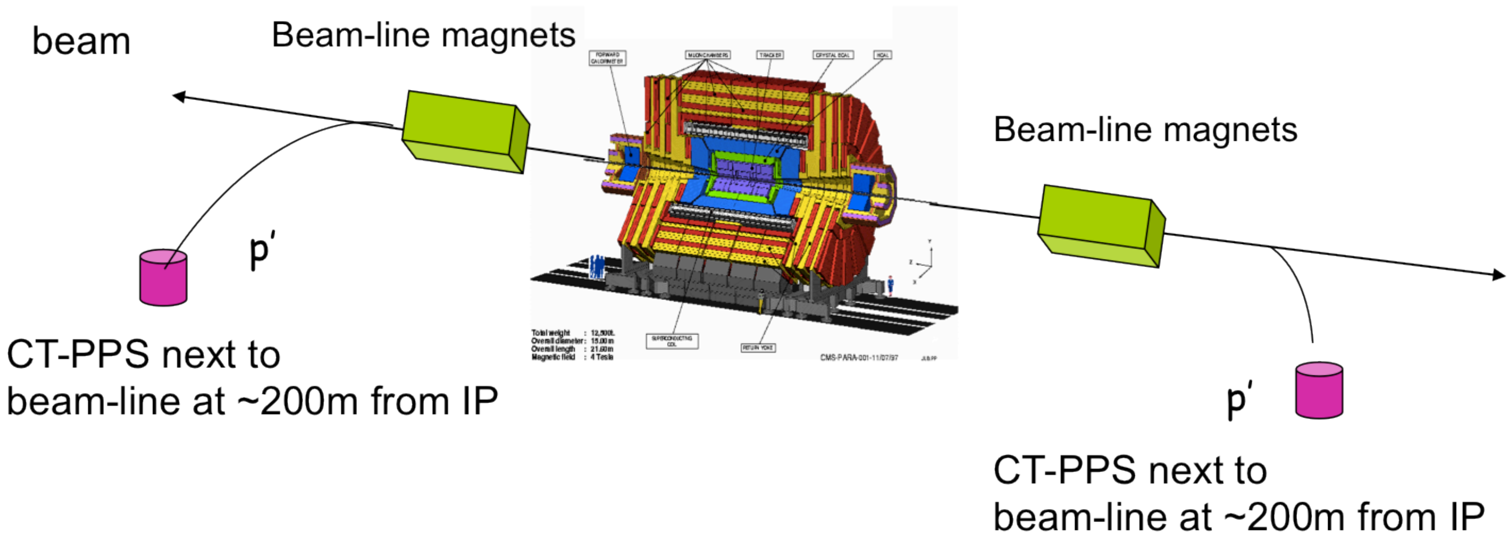
scattered at very small angles and to be detected close to the beam lines.

We need to measure with high precision **the momentum** and **timing** of the two ***protons in the very forward regions*** on both sides of CMS

CT-PPS: detector concept

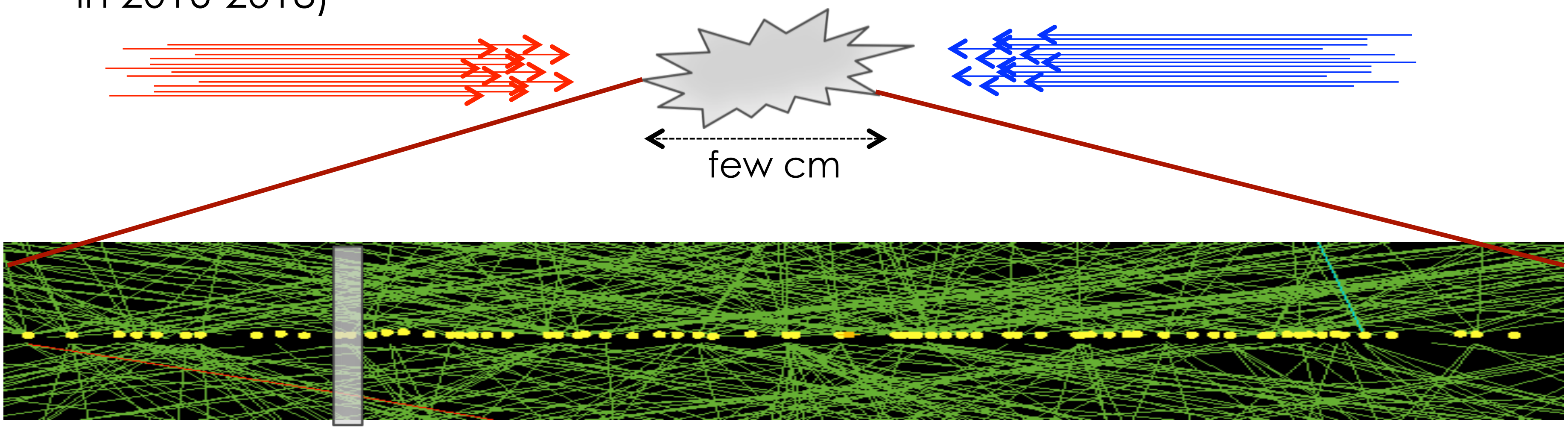
On both sides of the Interaction Point (IP5)

- Proton spectrometer making use of:
  - **machine magnets**
  - Two tracking stations with **pixel detectors**
- One station with **timing detectors**
- All detectors will be inserted in RomanPots (RP)

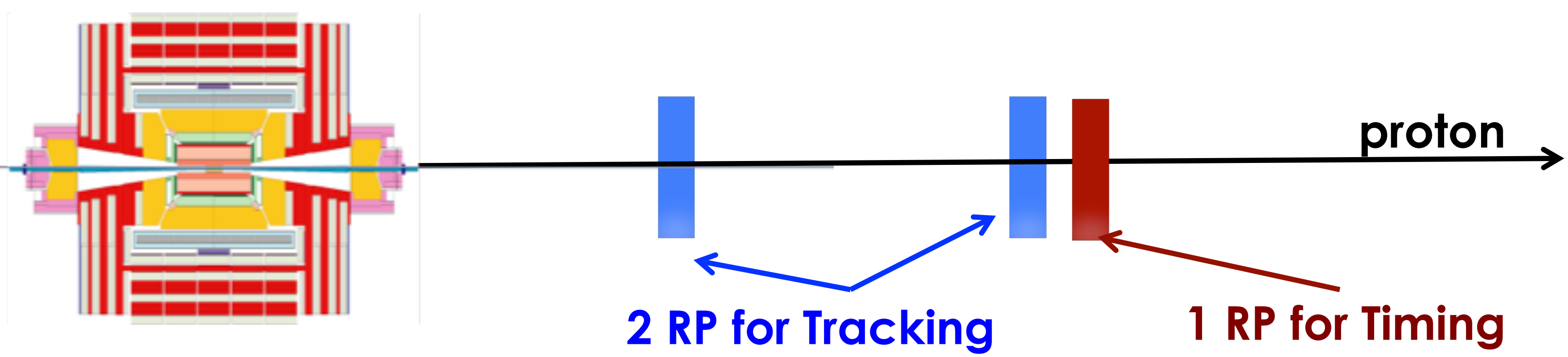


Why do we need timing?

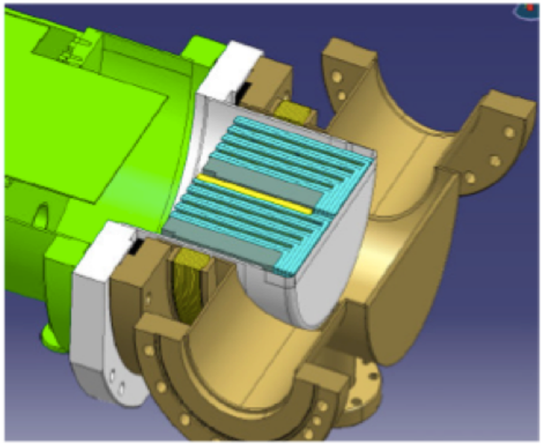
Pileup! At each bunch crossing, there will be many interactions (up to 50 in 2016-2018)



A precision of ~20 ps on the time of each proton will determine the vertex position with a precision of ~ 4.2 mm ("z-by-timing" resolution $\mathbf{\Delta z = c\,\Delta\,(t_1 - t_2)\,/2}$)



Timing detector: requirements

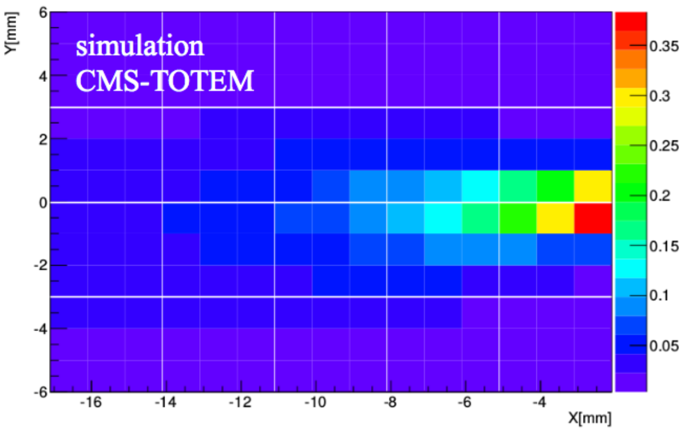


The timing detectors will be inserted in RomanPots developed by TOTEM, and brought as close as possible to the beam lines.

A small area detector (≤ few cm^2)

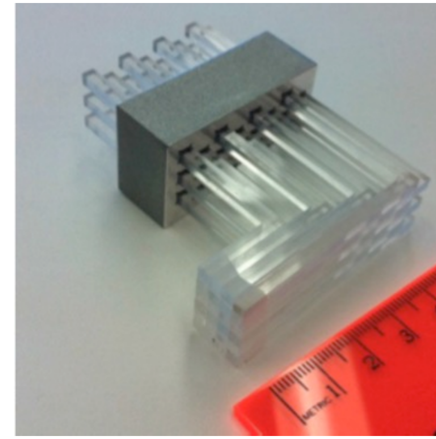
- with reduced dead region: edgeless towards the beam
- able to measure the time of passage of the proton with a resolution of 20 ps (vertex resolution of ~4.2 mm)
- segmented to cope with the high density of hits
- **Radiation hard:**
  - expected fluence ~$2 \cdot 10^{13}$ n_{eq}/cm^2 per fb^{-1} close to the beam

Detector occupancy per mm^2 at pile-up = 50



Timing detector with UFSD

CT-PPS TDR: QUARTIC detector →



4 identical modules made of quartz bars:

- Quartz Cherenkov bars of each Module (light guides) are connected to Hamamatsu SiPM 3x3 mm^2 photo-detectors

We'll start with diamonds detectors, early Summer 2016 **(see M. Berretti's Poster)**

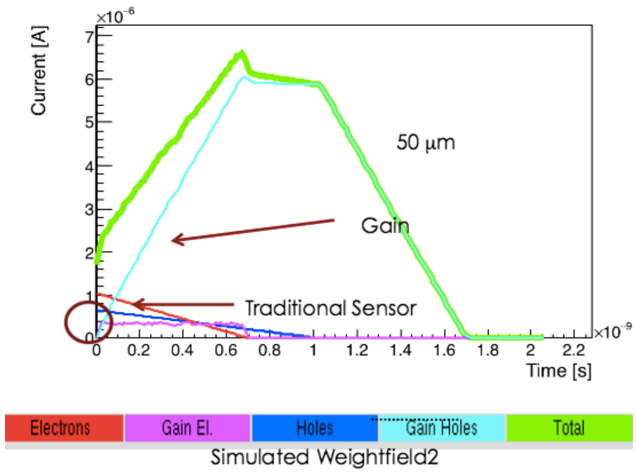
Alternative solution here presented:

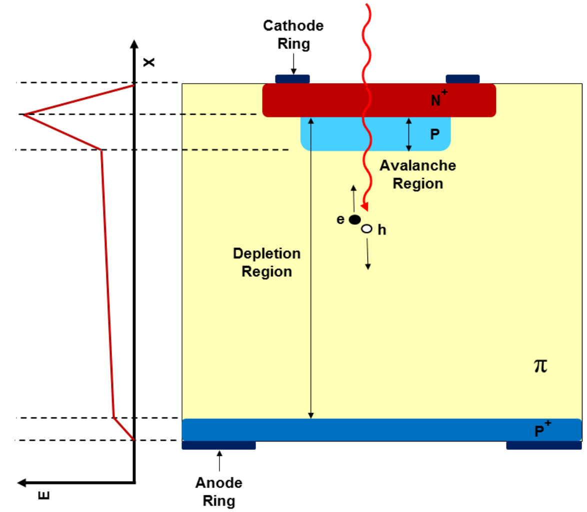
- use UFSD prototype (measuring only the time)

  Use planes of thin segmented LGAD* sensors, with adapted strip size → first demonstrator of UFSD

***Low Gain Avalanche Diodes**: H. Sadrozinski et al., NIM A730 (2013) 226-231
see N Wermes's talk, N. Cartiglia's talk

Timing detector with UFSD





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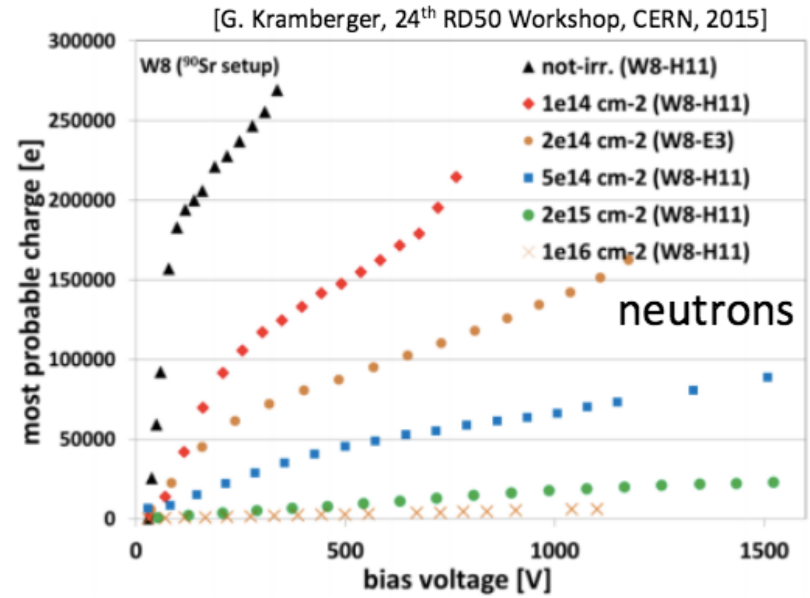
LGAD: radiation hardness status

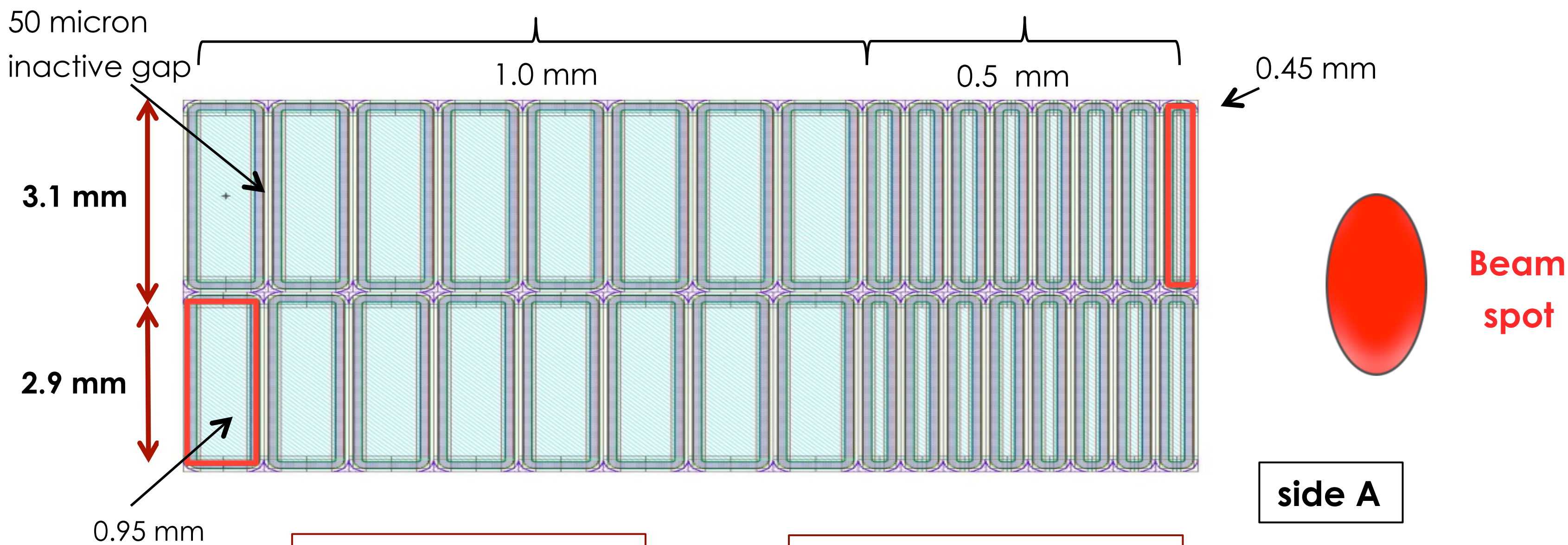
Highly irradiated LGADs show a decrease of signal amplitude.
Hypotheses:
1 acceptor (Boron of the gain layer) removal
-- trying with Gallium for gain layer
2 dynamic charge injection (high leakage current inducing n-type doping) which decreases the gain layer doping
-- thin, cold to reduce the leakage current

More studies under way (RD50, AIDA2020)



See also S. Terzo's talk

Sensor geometry for CT-PPS



16 Pixel ~ 3 mm²
Cap. Pixel ~ 6 pF

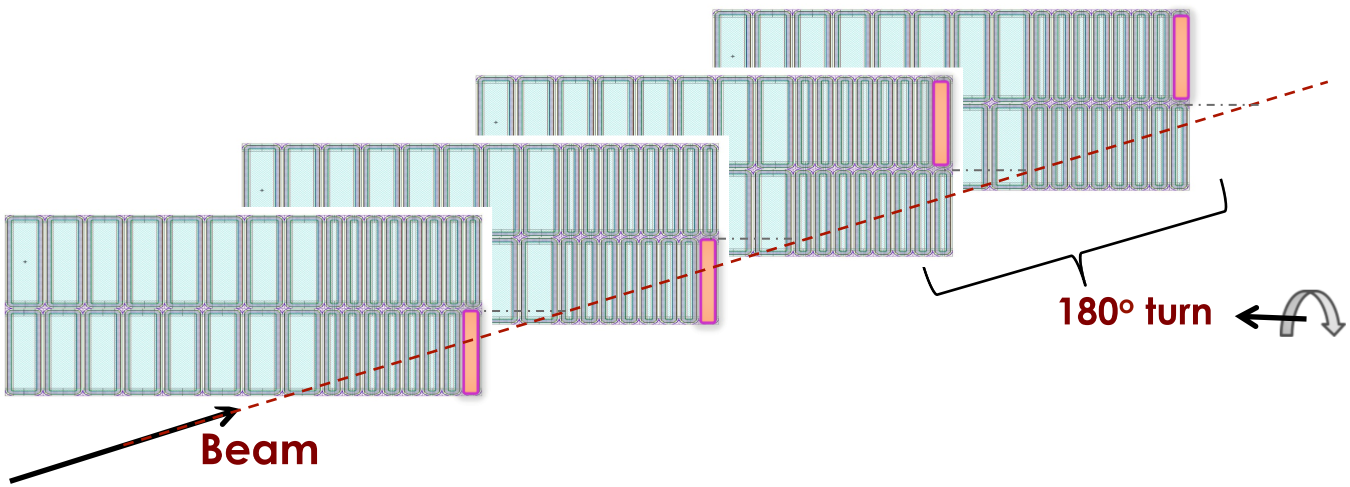
16 Pixel ~ 2 mm²
Cap. Pixel ~ 4 pF

Asymmetric design
Area = 12mm x 6mm;
Thickness = 50 um;
# of channels = 32 Gain ~ 15
Slim edge of ~200 um on side A

Expected time resolution: ~30 ps

Layout of detector planes

4 (6) planes per station (qualitative sketch):



No cracks aligned:
2 (3) planes facing the beam
2 (3) turned by 180°

UFSD for CT-PPS: Sensors production

Several new LGAD sensor productions geared towards this project are under way and will arrive in the next months.

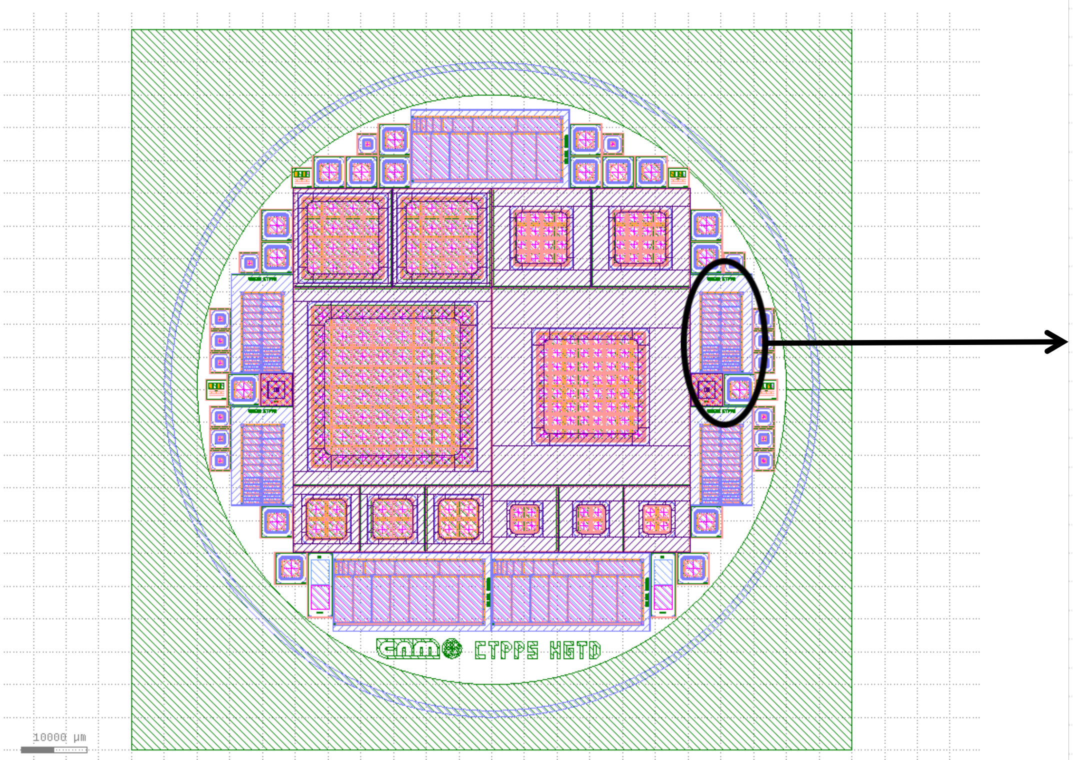
- Within RD50 collaboration, **CNM** is producing batches of various thicknesses, multiple geometries (pads/pixels/strips): 2 productions (SOI, EPI) dedicated to CT-PPS geometries, 50 microns thick.

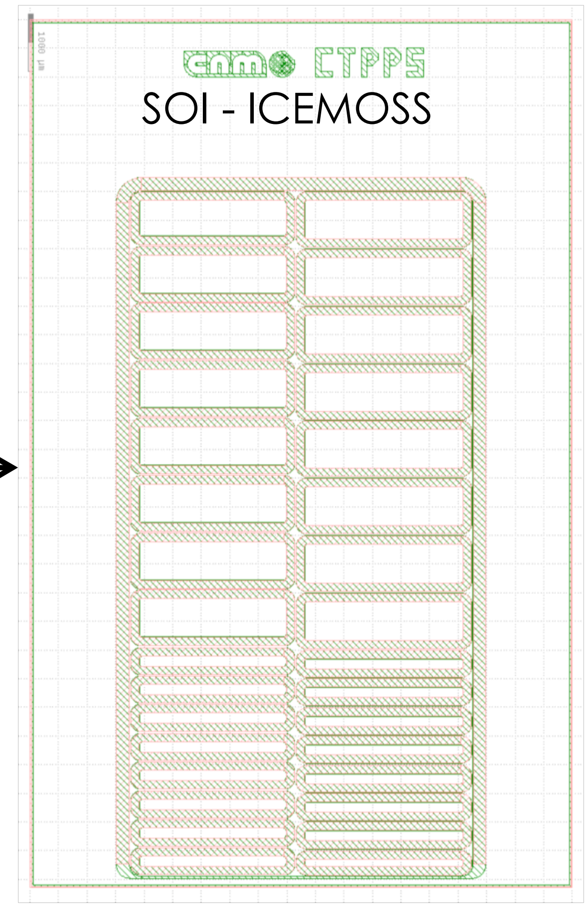
- In the framework of ERC-UFSD,INFN: **FBK**/Trento/Torino are also developing LGAD sensors:
  - first production, 300 microns thick, expected in Spring
  - 50-micron production with final CT-PPS design in early Summer (including some wafers with Gallium doping for radiation-hardness studies)

Production at CNM

Mask for the 50 µm-thick LGAD wafer is ready
→ first sensor expected on May (SOI)

10 wafer x 4 CT-PPS sensors

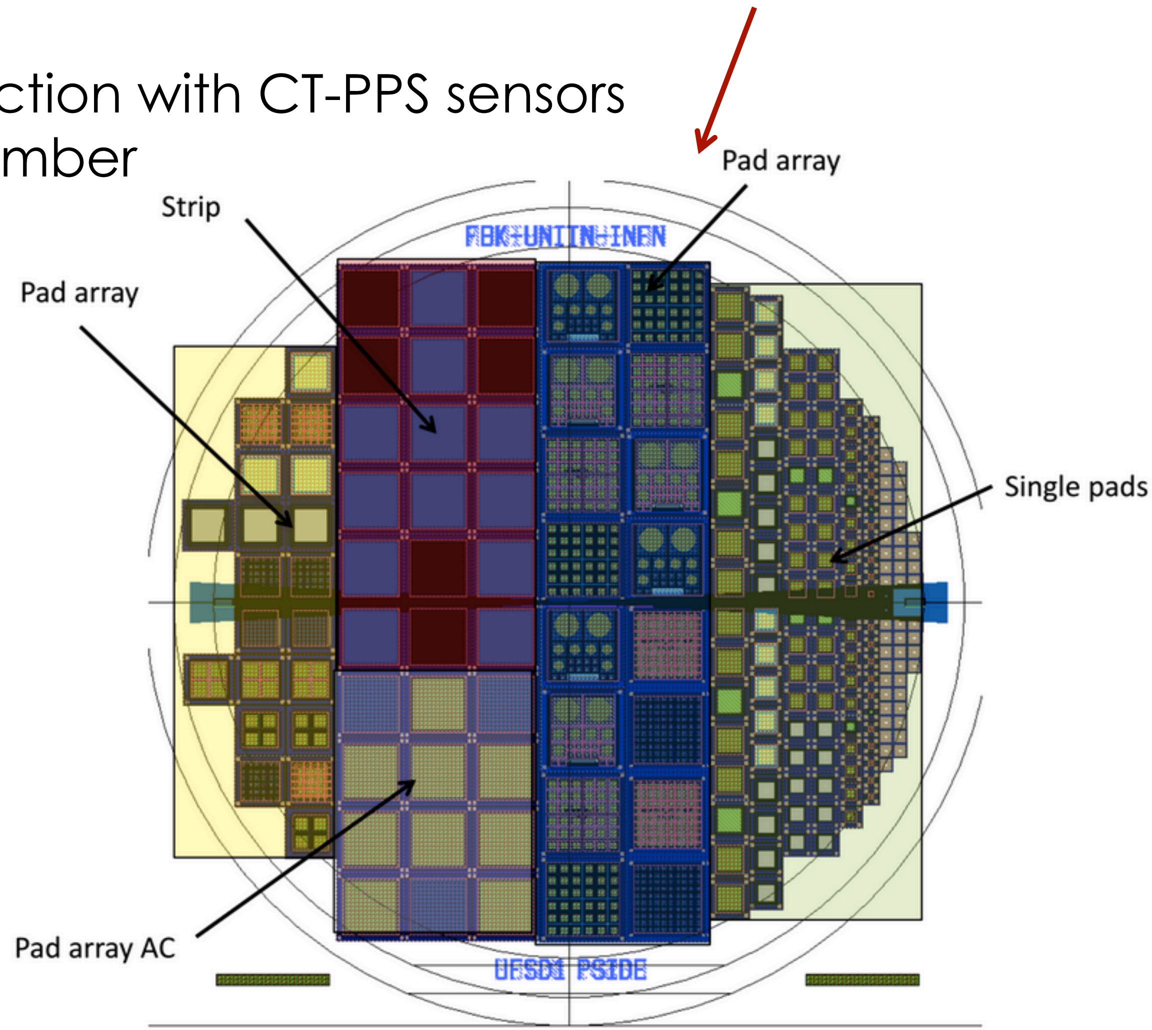




Production at FBK

- first LGAD (300 μm) sensors production ongoing
  → expected on March, multiple geometries (pad,strips)

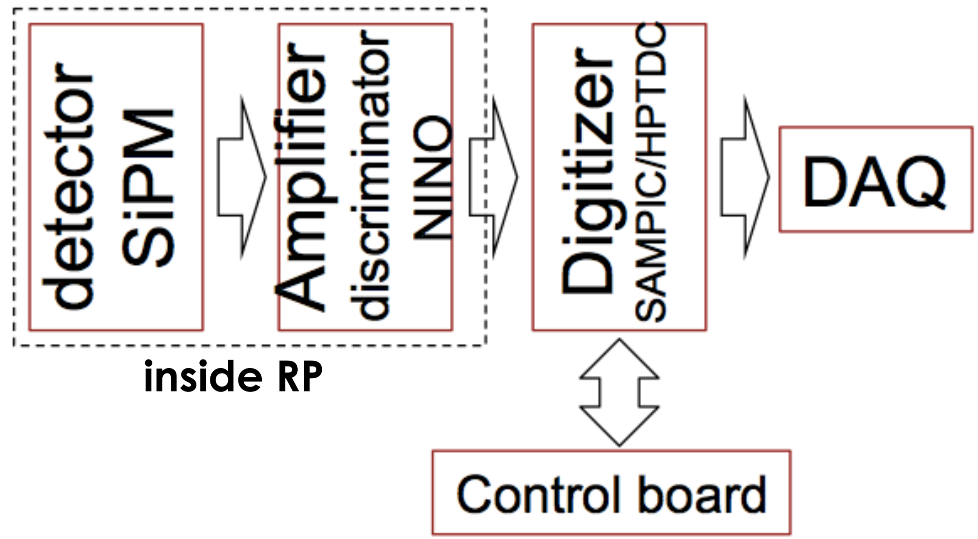
- 50 μm LGAD production with CT-PPS sensors
  → expected on September



Timing detector: read-out system

The current proposal is to be compatible with the signal processing chain prepared for Quartic:

- Amplifier
- Discriminator circuit (**NINO chip)**:
  - NINO chip with 32 differential inputs, LVDS outputs
  - Time resolution ~5 ps
- **Digitizer board**:
  - MotherBoard (MB) + mezzanine (for HPTDC)
  - LV powers/services
- interface to DAQ



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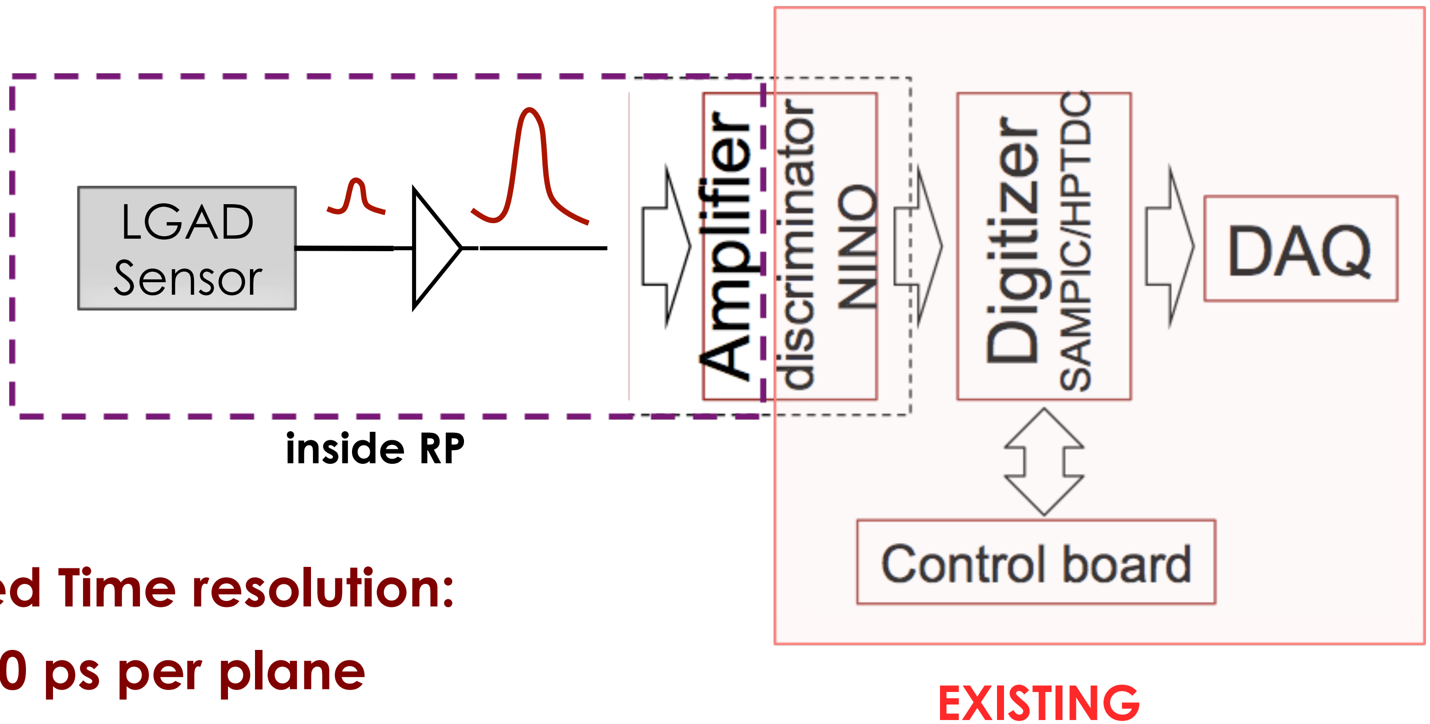
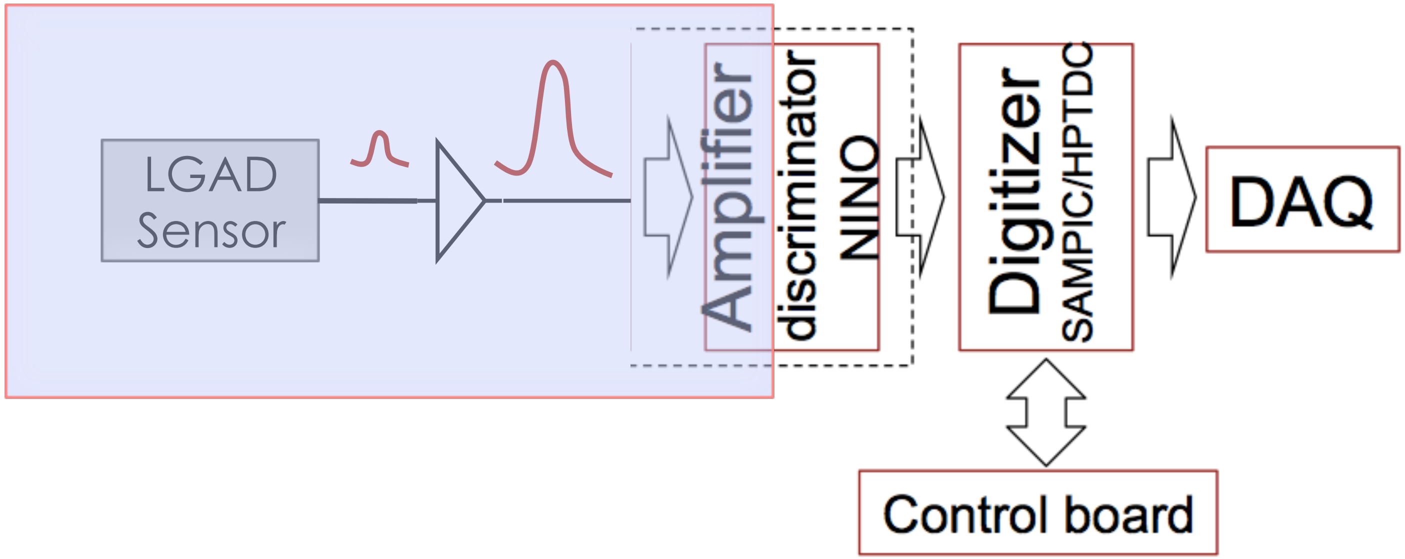


Expected Time resolution:

40-50 ps per plane

(including NINO and HPTDC)

UFSD read-out system



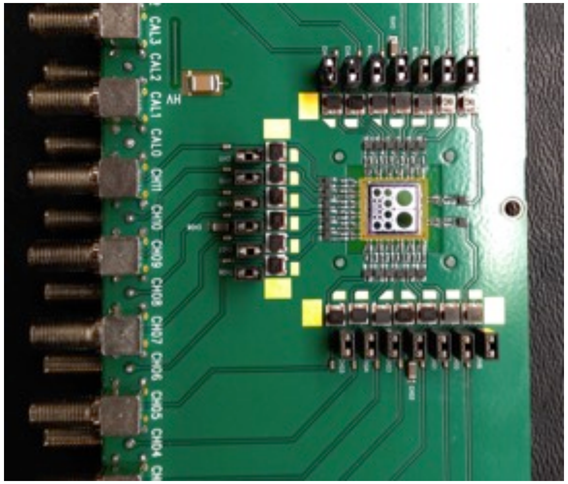
For the first stage: two alternatives pursued

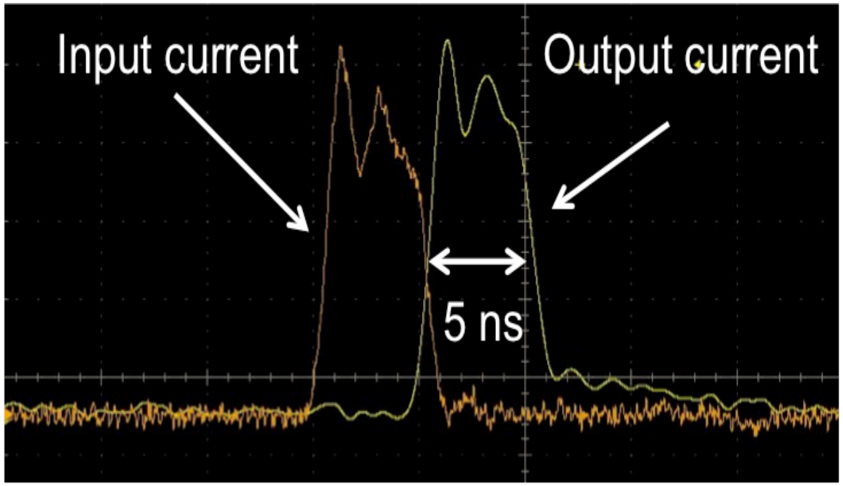
A "preAmp+NINO" : surface mounted pre-amplifier that matches NINO inputs – under development in Santa-Cruz

B "ACC" (Analog-Comparator Chip)**:** custom analog ASIC for the amplification and discriminator stage – under development in Torino/Lisbon

A: preAmp + NINO

Discrete components:
First prototype board of a low noise, distortion-free BroadBand amplifier done by Santa-Cruz (PSA4-5043 monolithic amplifier)





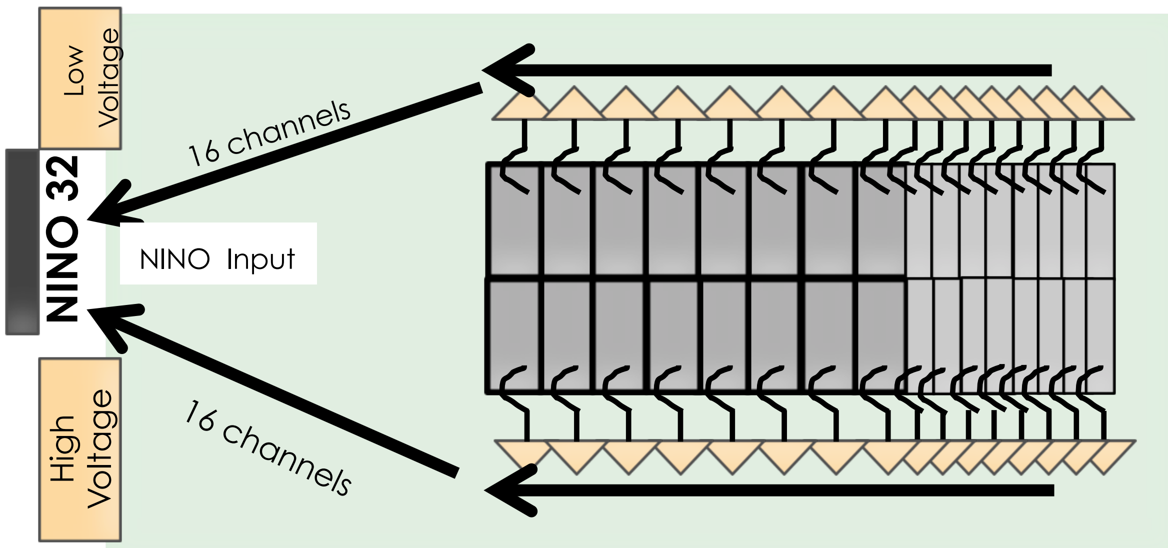
Comparison between the input and output signals (output attenuated by 13), measured with a high-precision oscilloscope

A: preAmp + NINO

CT-PPS version ~ spring 2016.

Challenge: the sensor has a pitch of 500 microns, at the very limit of using a front-end board made of discrete components..

Bond wire: 0.8 nH/mm.
Max. length: 2-3 mm

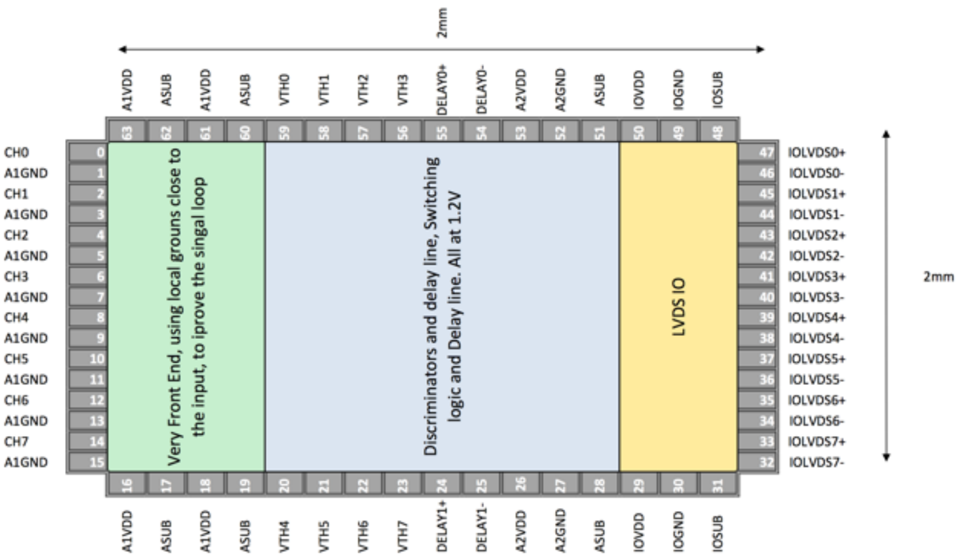


Inside the secondary vacuum of the Roman Pot

B: ACC

Torino-Lisbon micro-electronics groups: developing a low noise Analog-Comparator Chip (ACC), to replace **the amplifier and the NINO.**

- Noise performance: ~ 500 ENC for 6pF detector (slope 50 ENC/pF)
- Design of the comparator completed
- Implementation of Time Over Threshold for time walk compensation
- Submission date: May (130 nm)
- Ready in July



Conclusion

An alternative solution for the timing detector of CT-PPS has been presented.

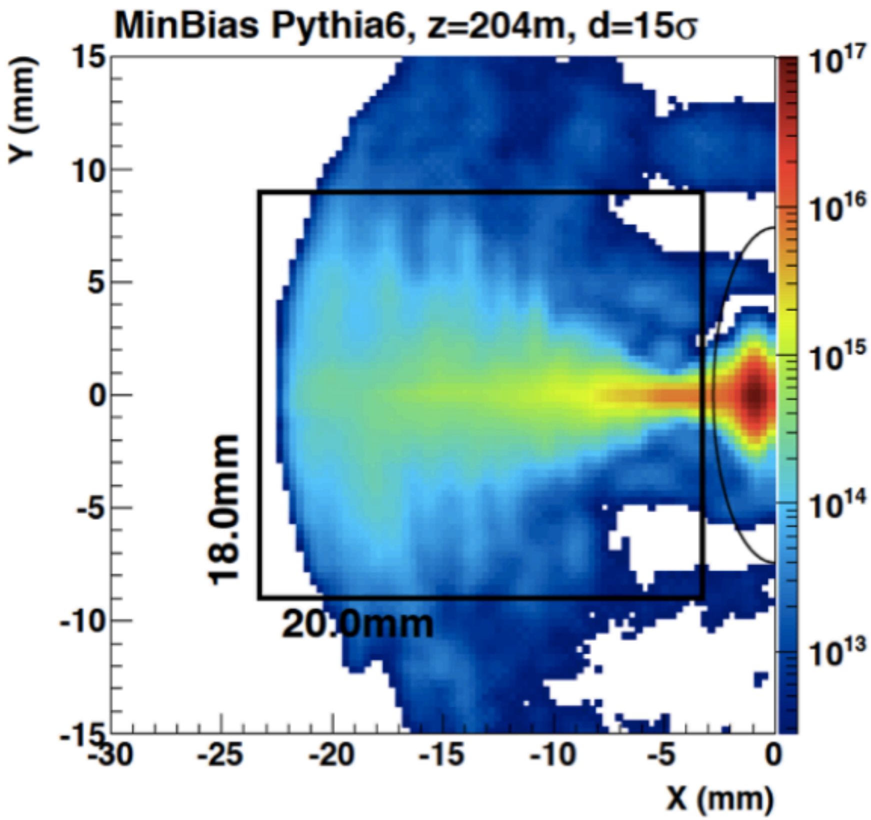
It is based on the recently conceived LGAD technology (UFSD project), still in R&D phase, which looks very promising:

- time resolution ~30 ps for 50um thick sensors with G~15
- radiation hardness under study, current design working up to 10 fb^{-1}

Lots of developments ongoing, on both sensors and front-end electronics. The next 6 months will be hectic and determine the success of this first application of UFSD.

Backups

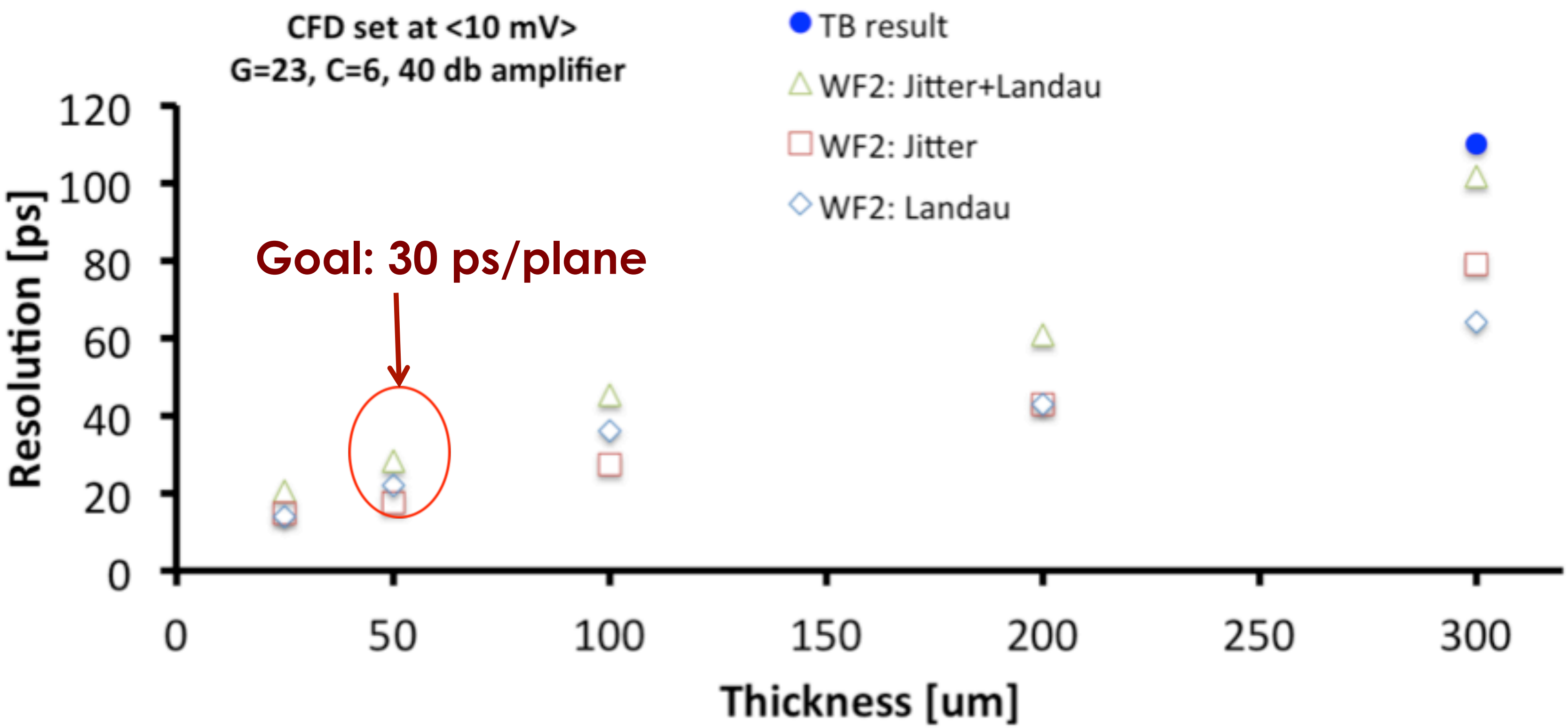
Radiation level in detector



Per 100 fb^{-1}:

- Proton flux up to 5.10^{15} cm^{-2} in the **pixel detectors**
- 10^{12} neq/cm^2 and 100 Gy in **photosensors** and **readout electronics**

LGAD in Testbeam: results and extrapolation



WF2 = Weightfield2, simulation program.

Contribution of the Jitter and Landau parts to the total time resolution as a function of the sensor thickness.