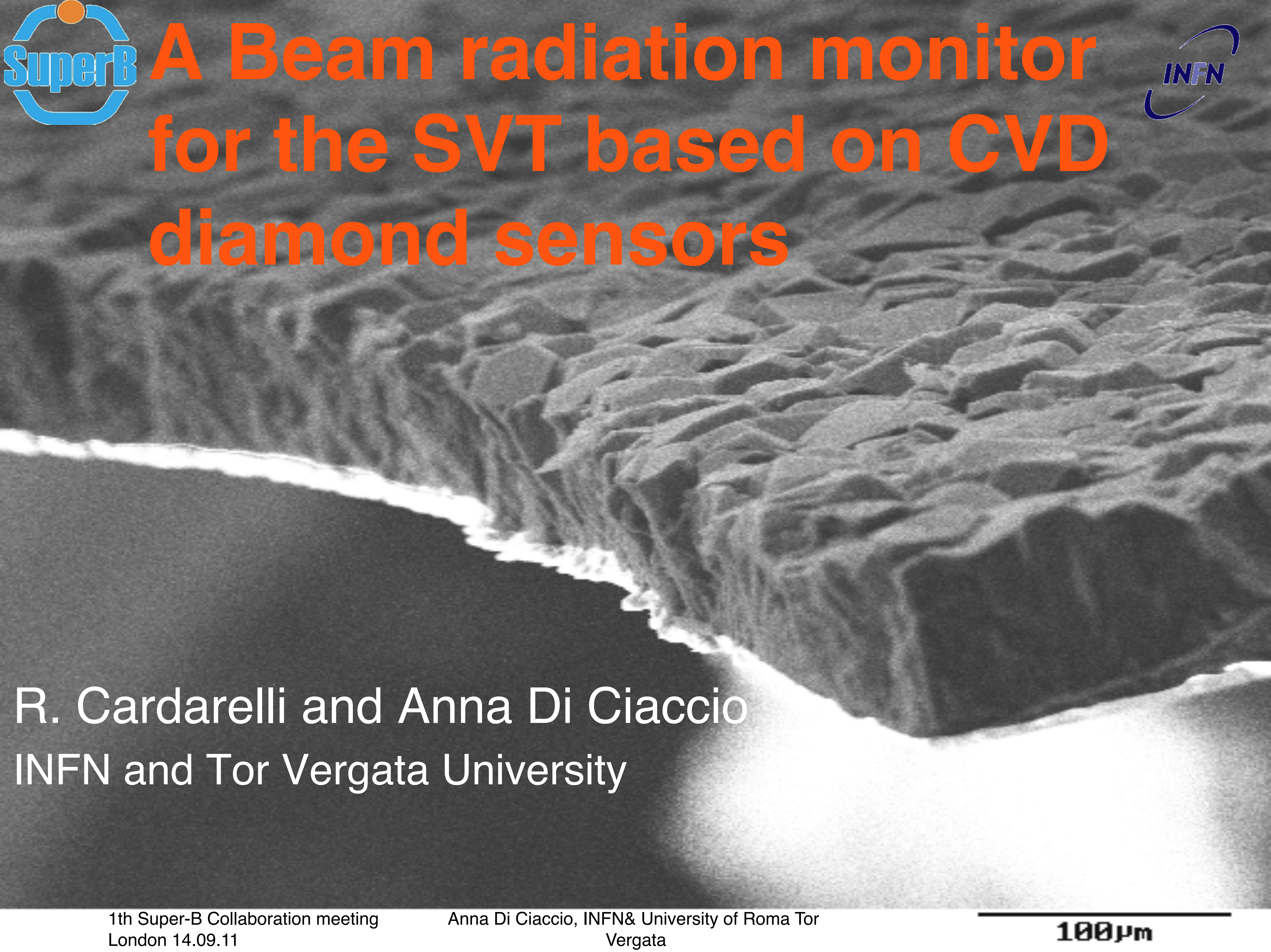
A Beam radiation monitor for the SVT based on CVD diamond sensors

R. Cardarelli and Anna Di Ciaccio
INFN and Tor Vergata University



Outline

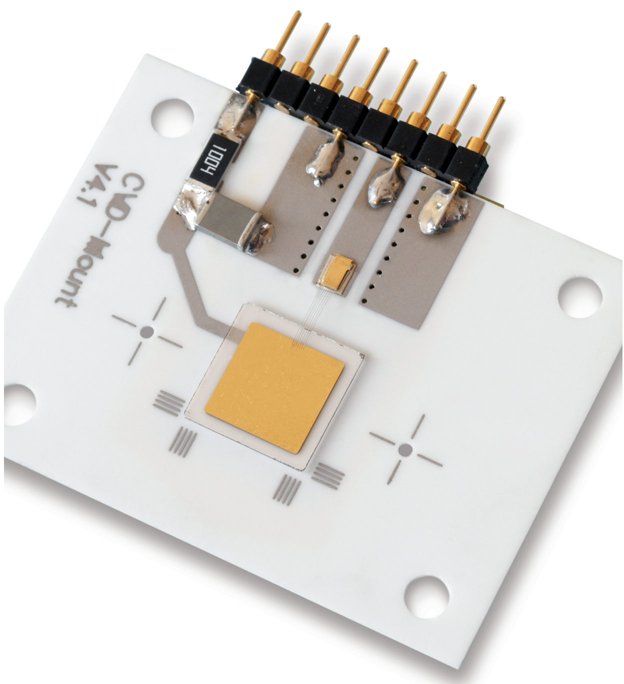
- Short review of CVD diamond sensors employed as beam monitoring in HEP
- First idea on a CVD beam radiation monitoring to protect the SVT
- Plan of activity for the next months

CVD Diamond Sensors as Radiation Monitor

- Radiation monitor crucial to protect the Silicon tracker from a high radiation dose due to i.e. beam losses or high background rates
  - Need to abort beam in presence of a current spike or a prolonged radiation dose letal for the SVT
- A fast, radiation hard detector with a low leakage currents is required
- In the past 5-6 years CVD diamond sensors employed as beam monitoring by the experiments
  - BaBar, Belle, CDF, ATLAS, CMS, LHC-b, ALICE
- R&D work done in the past 15 years by the RD42 experiment at CERN

CVD Diamond Properties

- Fast timing (1 ns)
- High Radiation tolerance (>1 MGy)
- Single-particle detection and current monitoring
- Efficiency for charged particles practically 100%
- 500 V @ 100 pA, so very low power consumption
- Leakage current (a few pA), do not increase with the accumulated dose
- insensitive to temperature variation



Beam monitoring with Diamonds

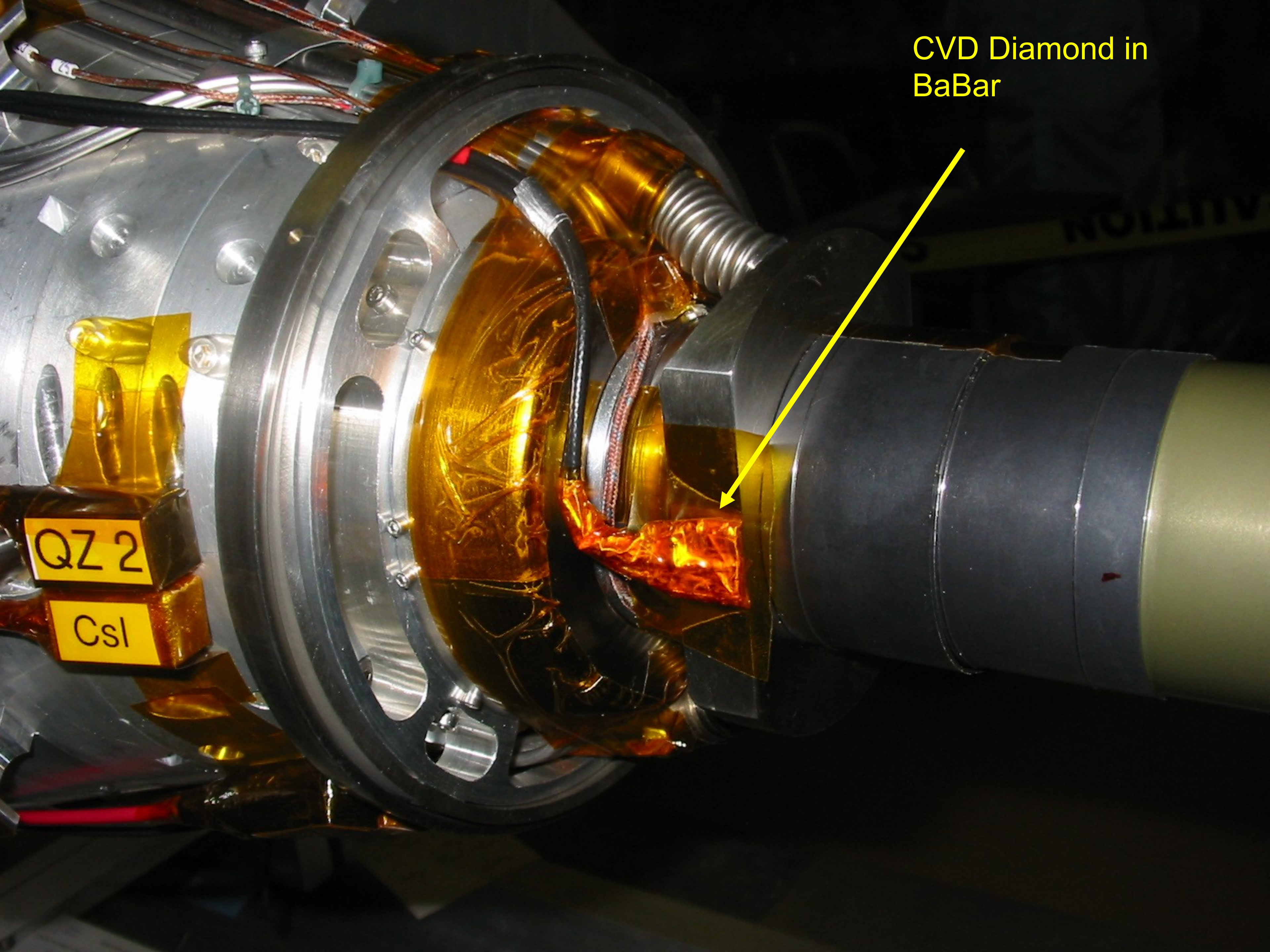
- Goal: measure interaction rate and background level in a high radiation enviroment near the IR
- Input to background alarm and beam abort

- **"DC current or dosimeter"**
  - Uses beam induced DC current to measure dose rate close to IP
  - Benefits from very low intrinsic leakage current of diamond
- **Simple DC (or slow amplification) readout**
  - Examples:Babar, Belle,CDF

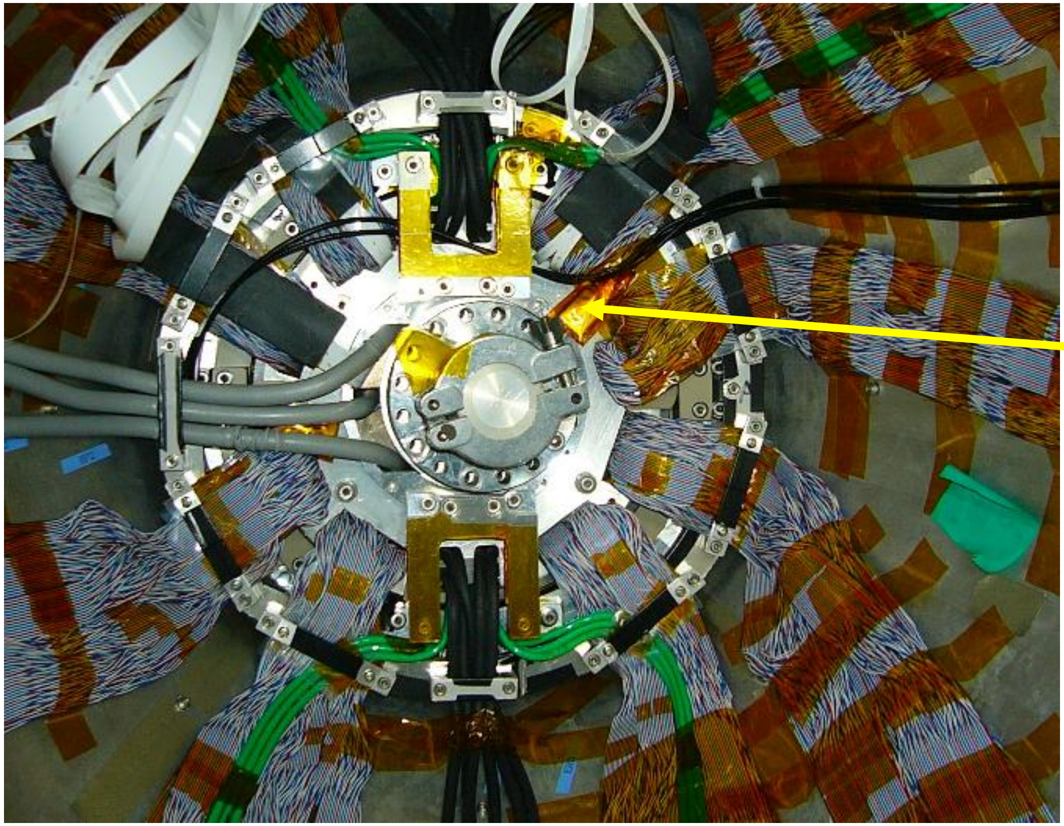
- **Single particle counting**
  - Detect min. ionizing particles
  - Benefits from fast diamond signal
  - Allows more sophisticated logic coincidences, timing measurements
- **Requires fast electronics with very low noise**
  - Example : ATLAS

Babar pCVD beam monitor

- BaBar initialy used 12 silicon PIN diodes ($1x1cm^2x300\ \mu m$), but leakage current increases 2nA/krad
  - After 100fb-1 typical current signal ≈10nA, noise1-2≈μA
- BaBar & Belle built successfully in 2004-05 the first pCVD radiation monitor
  - Typical signal current@1MRad ≈2-5 nA; Typical leakage noise < 1nA


CVD Diamond in
BaBar
QZ 2
CsI

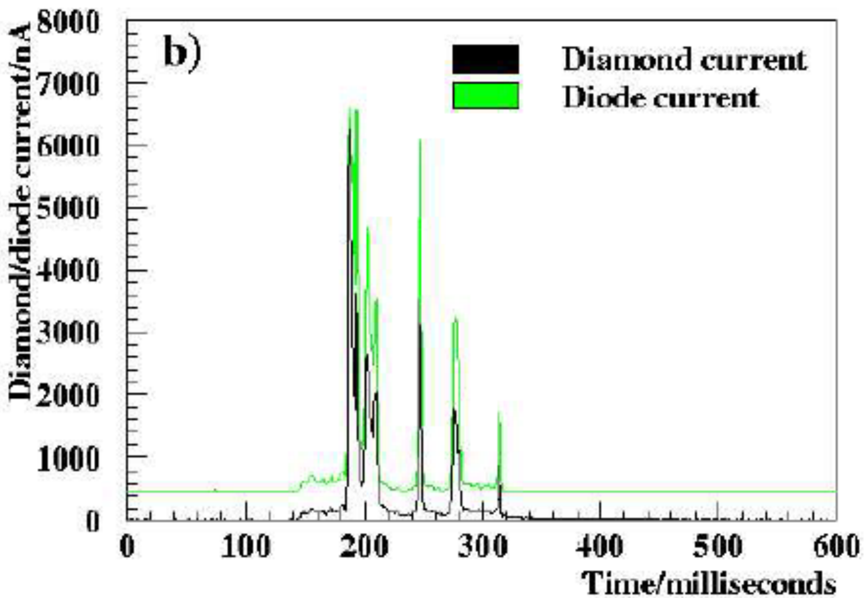
BELLE Diamond Beam Monitor

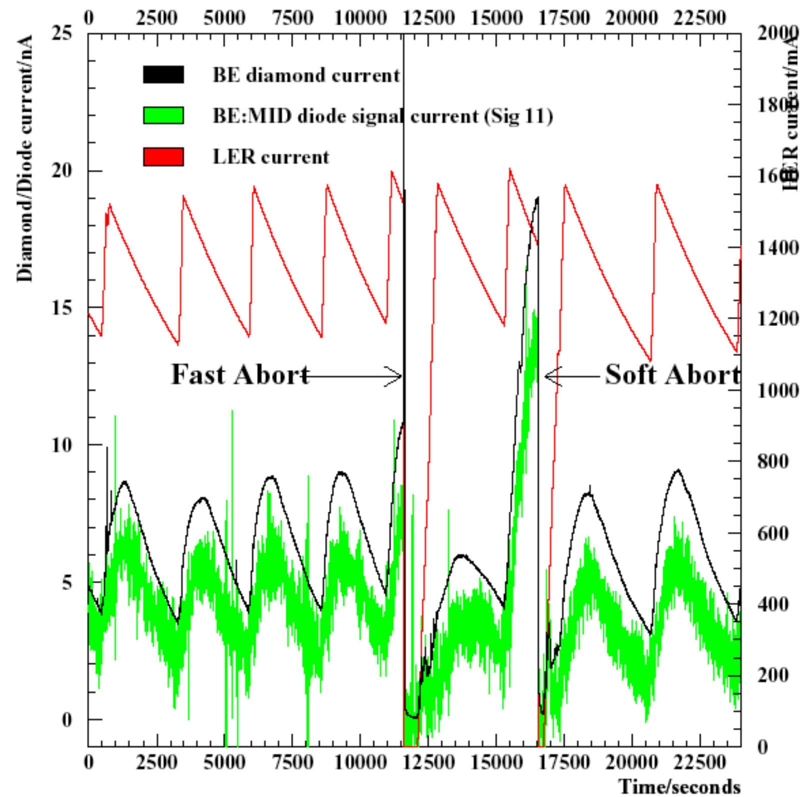


CVD diamond is installed outside the SVT

BaBar beam monitor

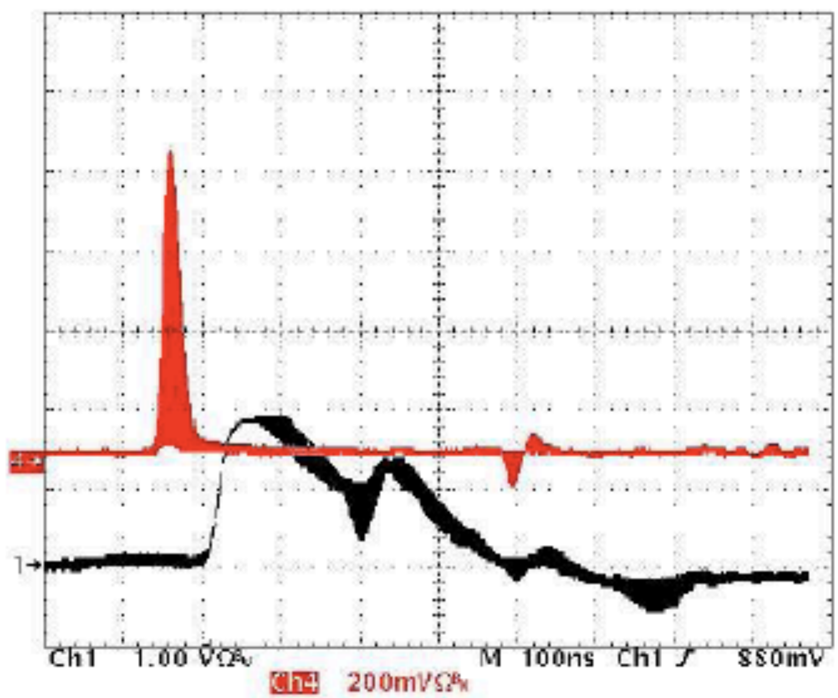
- Beam currents well traced by both devices
- Diamod sensor give a more precise measurements since is not affected by temperature variation





Very fast response

- Use a fast amplifier to look at PIN-diode and diamond signals
- Trigger on the PIN-diode signal
- Look at fast spikes: red = diamond, black = PIN-diode



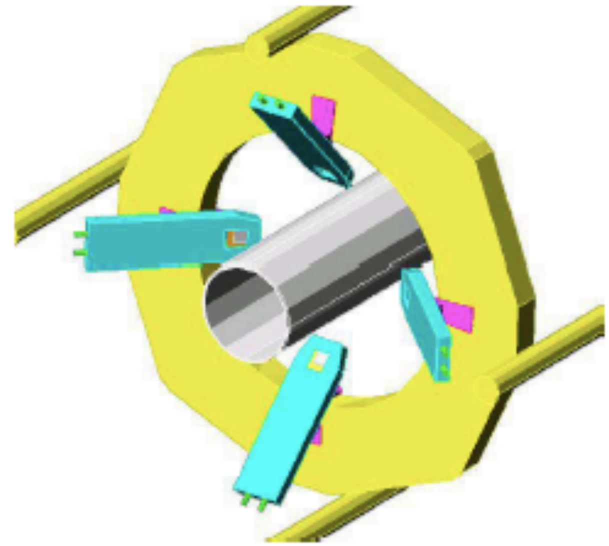
Time response on a spike of radiation < 20ns (limited by the amplifier bandwith)

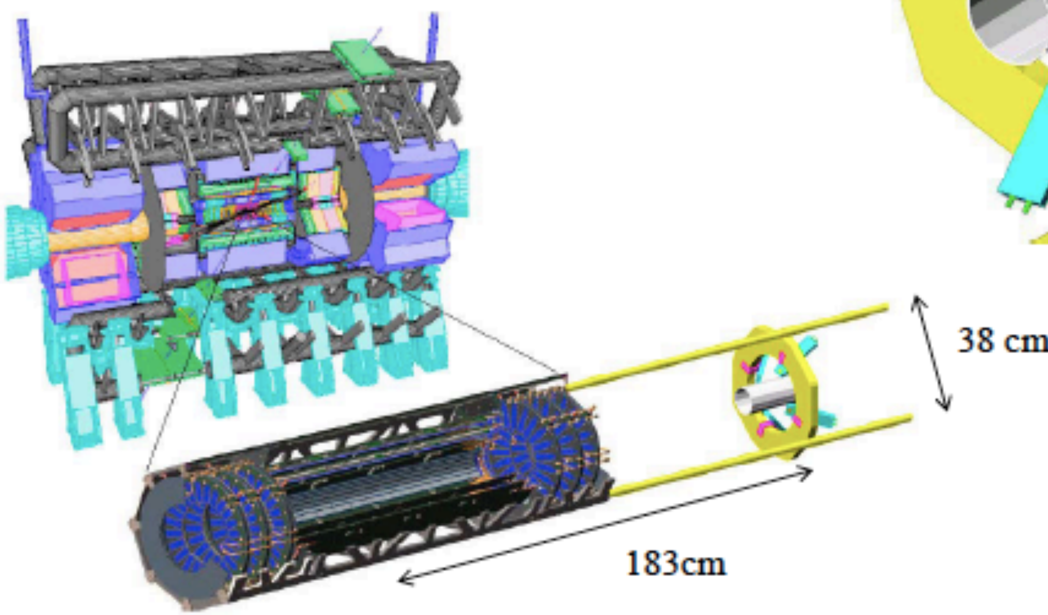
Beam loss and conditions monitor for CMS and Atlas

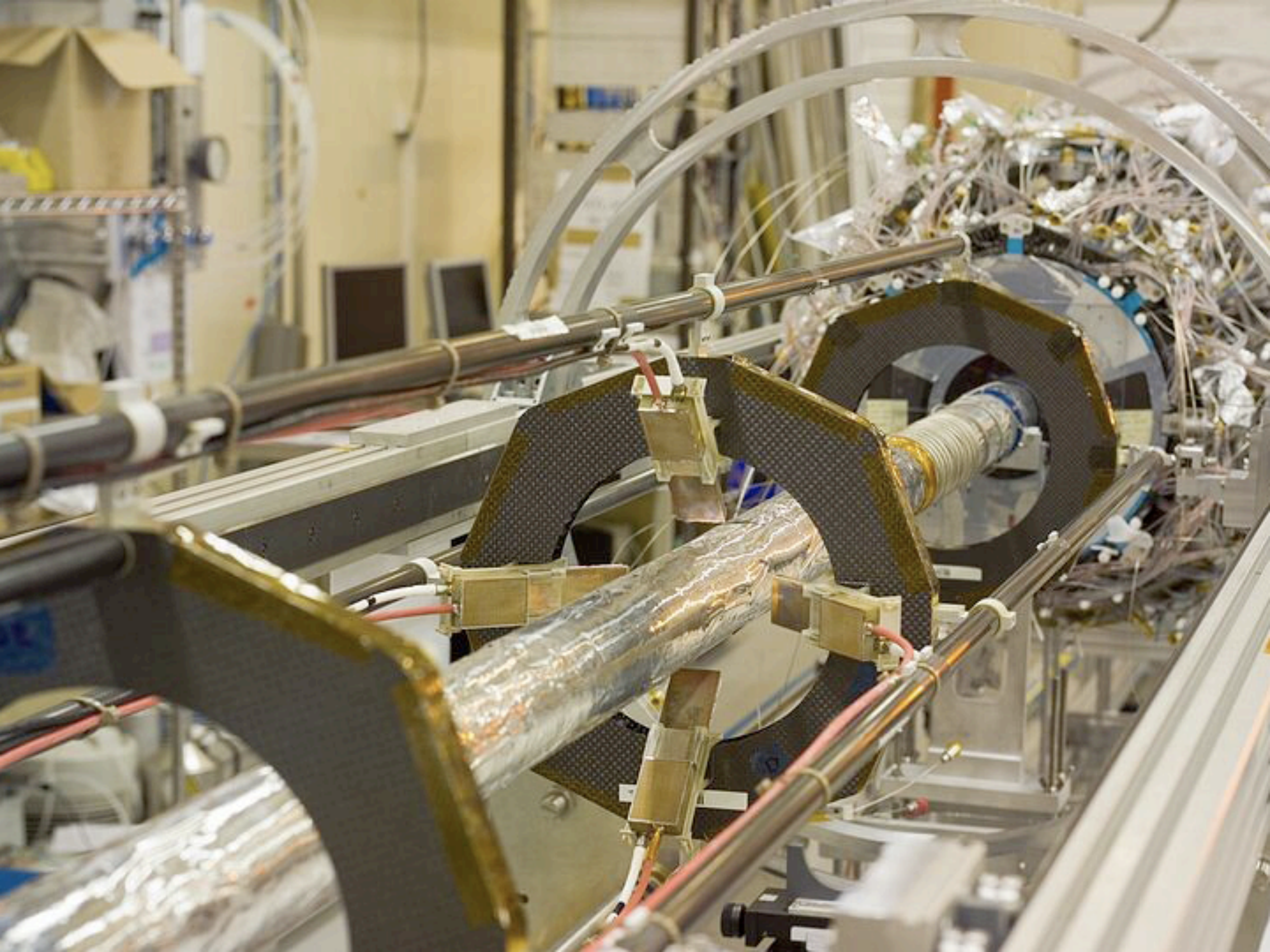
- ATLAS and CMS use also diamond as a sensor for beam loss measurements and beam monitor conditions close to the beam pipe.
- Same type of device considered by CMS & Atlas inside their trackers
  - CMS: ~ $z=\pm1.8$m and $r=4$cm
  - Atlas: ~ $z=\pm1.9$m $r=5.5$cm
- the beam monitor address the following issues:
  - Allow to protect the Si trackers during instabilities / accidents
  - Providing feedback to the machine helping them to routinely provide optimum conditions
  - Monitor the instantaneous dose during operation

ATLAS beam monitor

- 4 BCM stations on each side of the Pixel detector
  - Mounted on Pixel support structure at z = +/- 183.8 cm and r = 7 cm
  - Each station: 1cm² detector element + Front-end analog readout



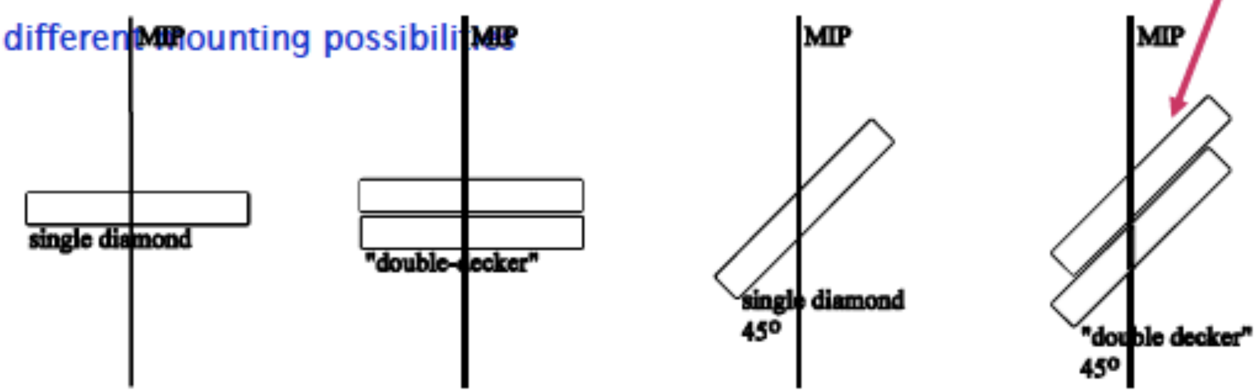




ATLAS beam monitor

Many tests already done:

- beam-test measurements
  - evaluation of prototypes of detectors and FE electronics
  - Boston beam-test: May 2004
  - SPS CERN beam-test: November 2004
  - KEK test beam
- bench-tests
  - Sr-90 based tests of setups
  - evaluation of prototypes of detector boxes with FE
  - evaluation of back-end electronics
  - QA of final detectors
- different mounting possibilities



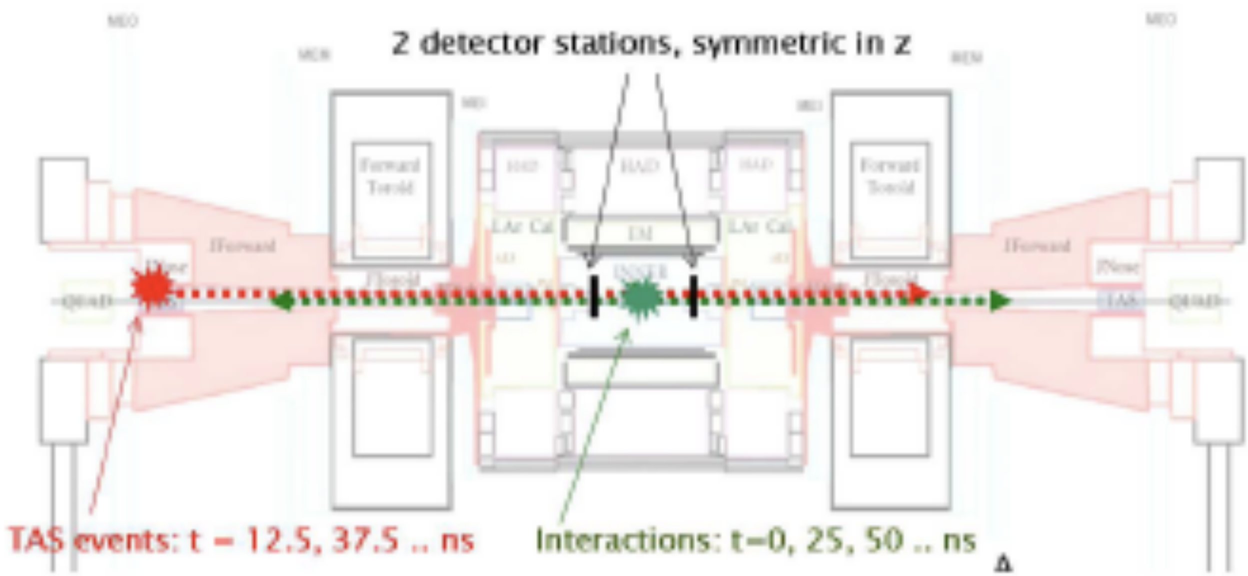
- irradiations of components

This one chosen

To maximize the collected charge

ATLAS beam monitor

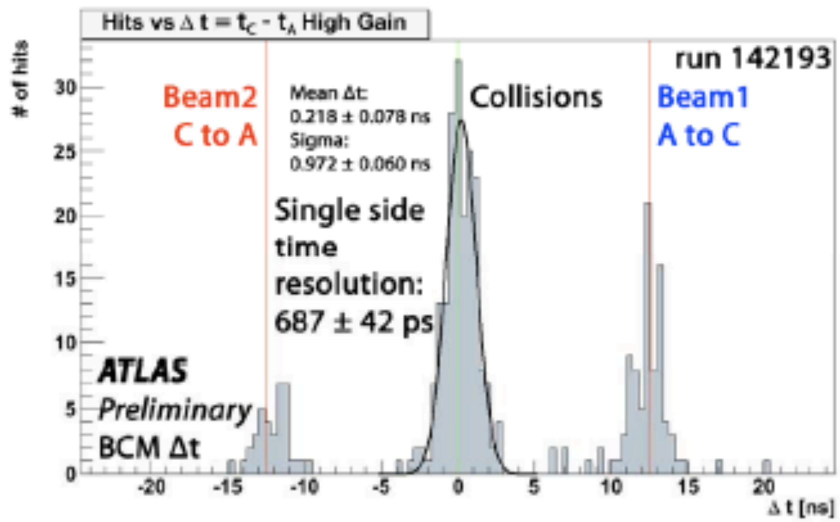
Idea: Time of flight measurement to distinguish collisions from background



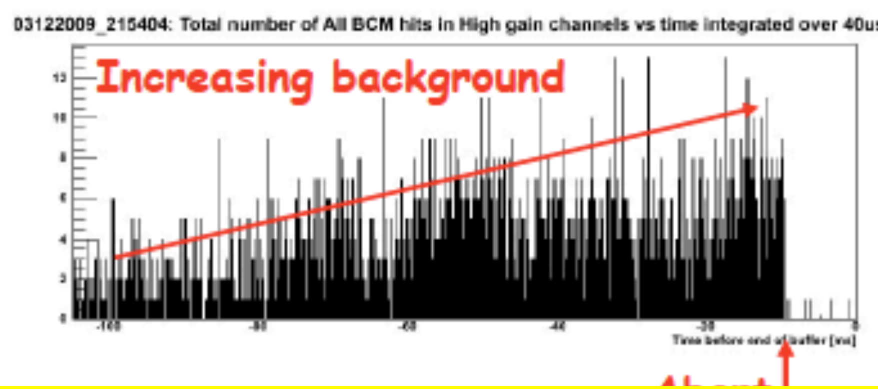
- Detectors placed at $z = \pm$ 1.9m and r = 55mm ($\eta \sim 4.2$, Δt = 12.3ns)
- Detectors must be able to withstand ~50Mrad in 10yrs
- Detectors plus electronics must have excellent time resolution (~1ns rise time, 2-3ns pulse width, 10ns baseline restoration)

ATLAS BCM performance

- BCM achieved 687ps timing
- BCM can distinguish real collisions from background

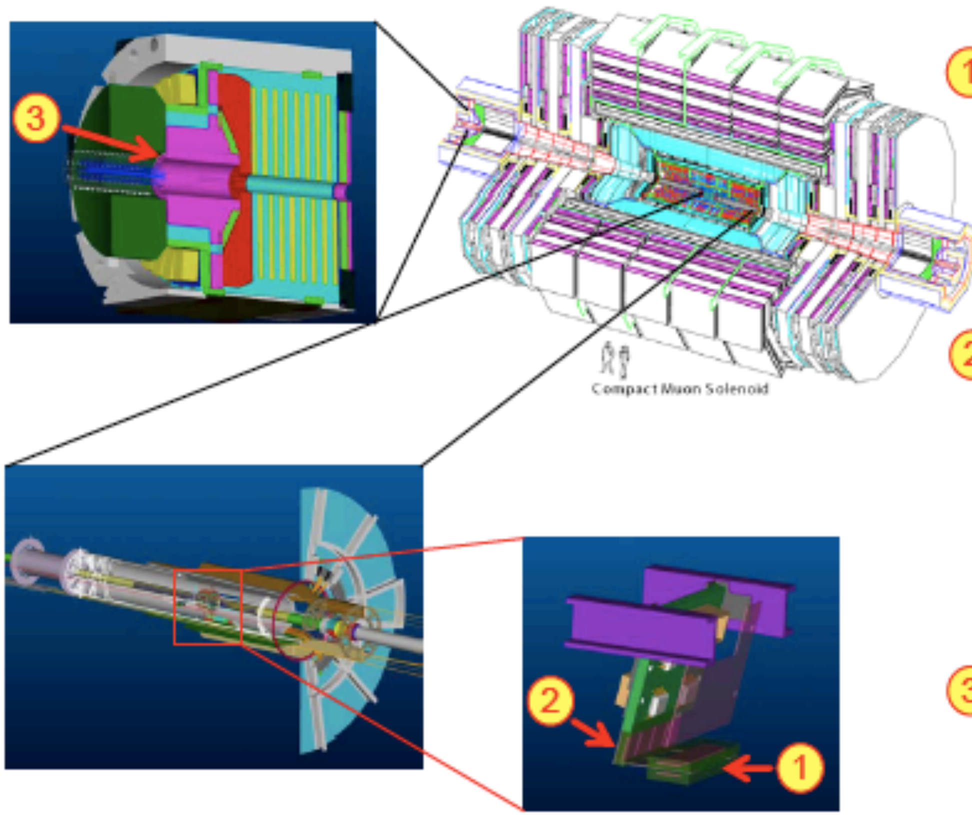


- BCM stores a record of 1177+100 orbits
- BCM sensitive enough to abort the beams



For Super-B 100ps time resolution are needed (detectors place at 100-150mm distance)

CMS



2 Sensor Locations, 2 Monitoring Timescales

CMS BCM Units

1. **Leakage current monitor**
   Location: z=±1.9m, r=4.5cm
   4 stations in θ
   Sensor: 1cm^2 PCVD Diamond
   Readout: 10kHz

2. **Fast BCM unit**
   Location: z=±1.9m, r=4.3cm
   4 stations in θ
   Sensor: Single Crystal Diamond
   Electronics: Analog+ optical
   Readout: bunch by bunch

3. **Leakage current monitor**
   Location: z=± 14.4m, r=29cm
   8 stations in θ
   Sensor: 1cm^2 PCVD Diamond
   Readout: 10kHz

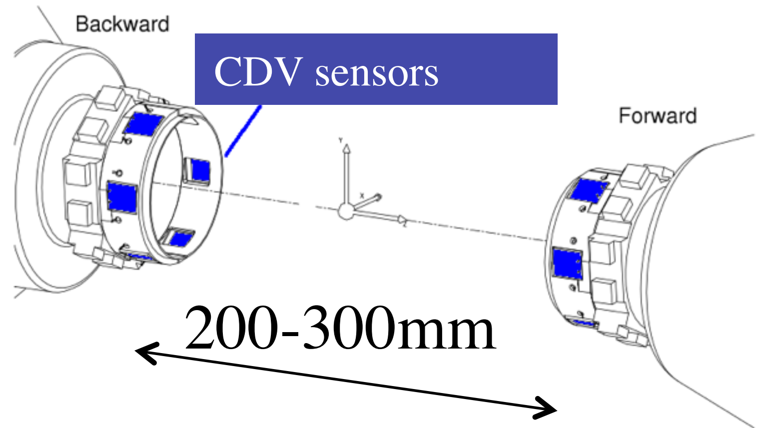
Sensors shielded from IP

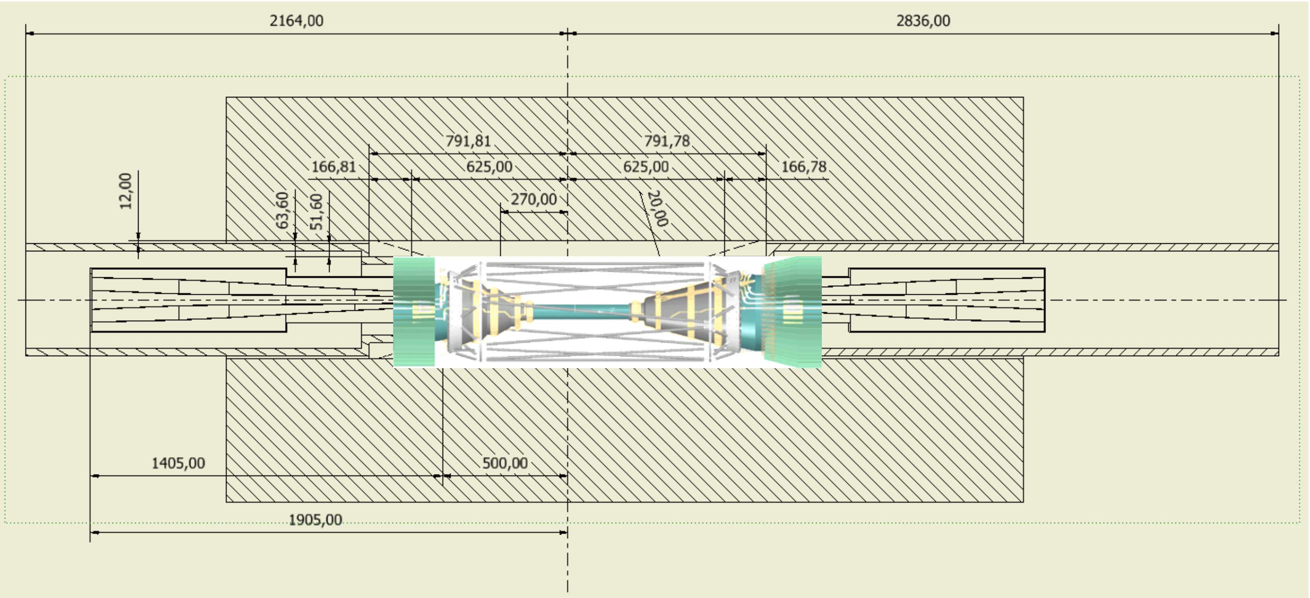
Work plan for the SuperB SVT radiation monitor

- Identification of the best location for the sensors (help from F. Bosi)
- MC Geant4 simulation of the Radiation monitor to evaluate the expected background in the planned location and optimization of the geometry
- Design the system specifications (type/dimensions of sensors, read-out electronics, etc)
- Test of a few sensors (pCVD vs sCVD) with a new fast amplifier developed in Roma Tor Vergata by R. Cardarelli for a diamond sensor.

SVTRadMon location

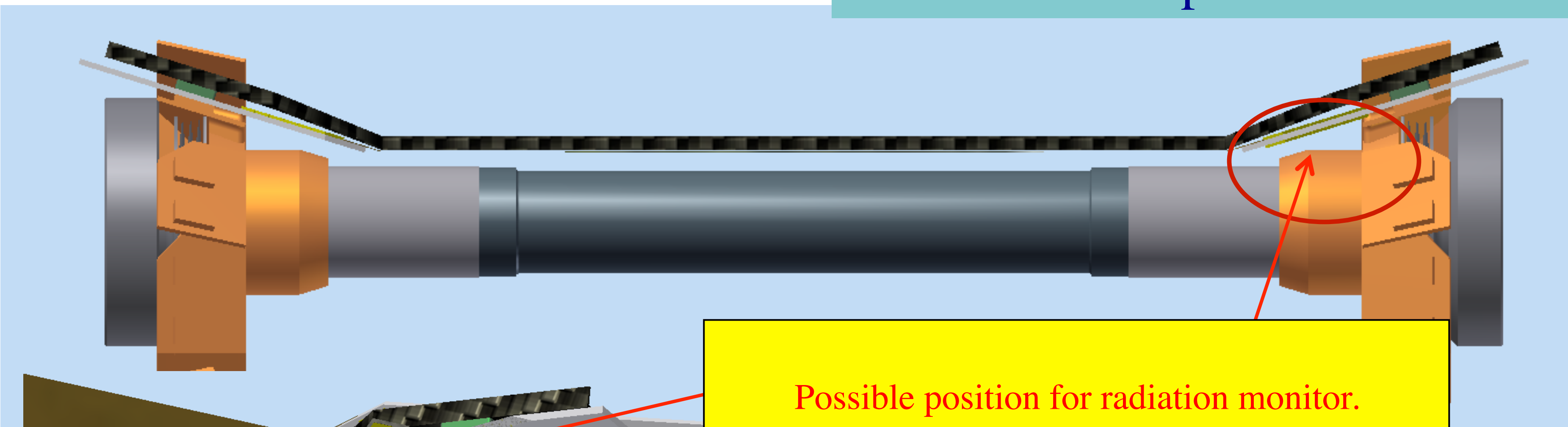
- Study the position and the geometry of the CVD sensor near inner tracking in Super-b
  - First contact with F.Bosi (space limitation is an issue)

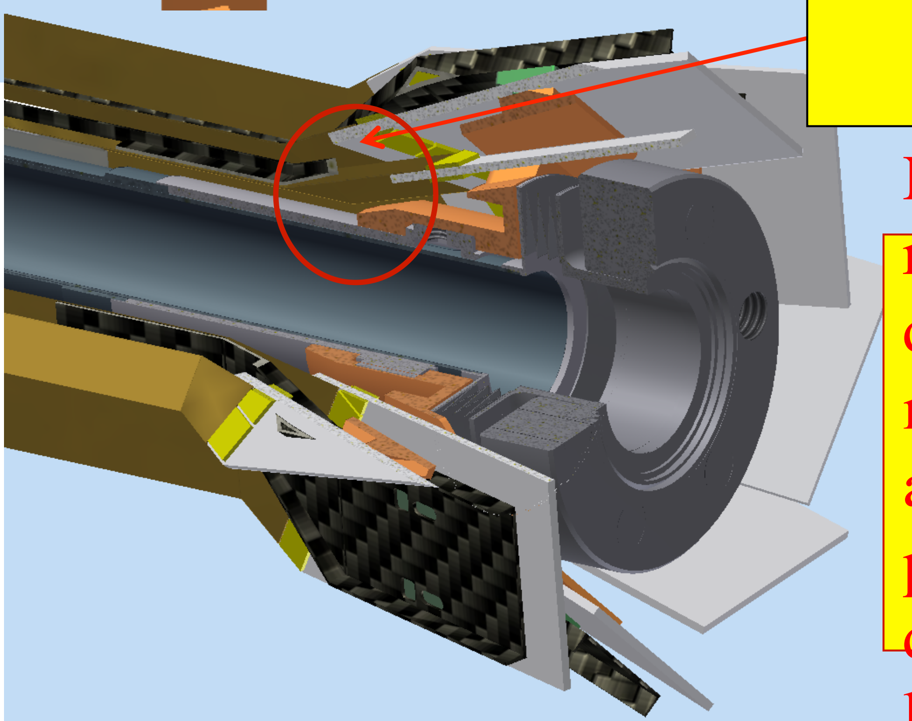




Radiation Monitor position

From F. Bosi's presentation





Possible position for radiation monitor.

Not yet defined the position of radiation monitor, its design depends still by definition of many other I.R. components, anyway we will try as soon as possible, to place the overall dimension on the general layout.

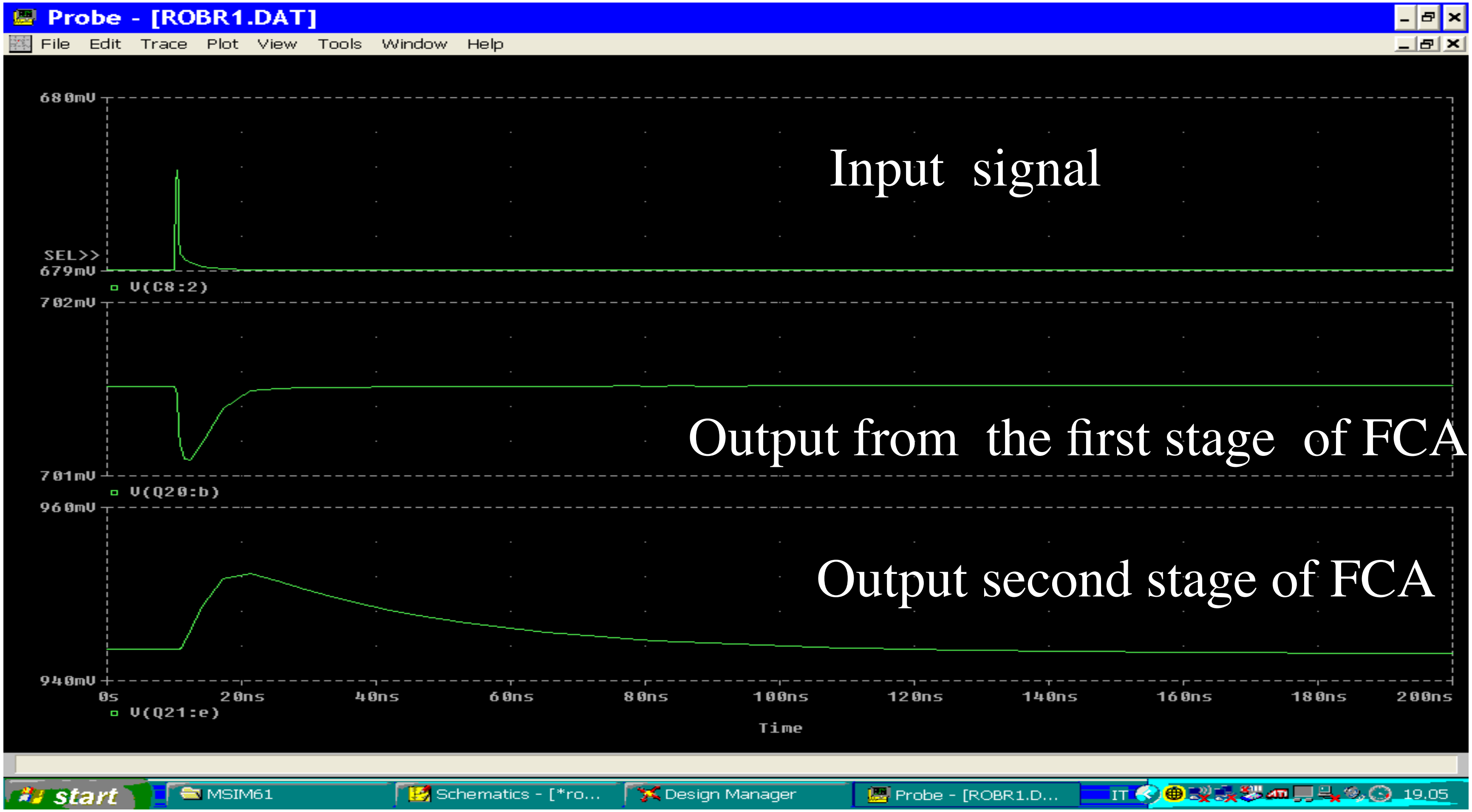
A new front end

- A fast charge amplifier (FCA) for a CVD diamond detector has already been developed for neutron spectroscopy application (ITER project) and tested at JET tokamak and at the 14 MeV Frascati neutron generator
  - M.Angelone, et al : IEEE, vol 57,N6,2010.
- The detector signal was transported to the FCA by a high frequency cable 100m long.
- The successful results suggests the application of the same circuit to the beam monitor of the SVT

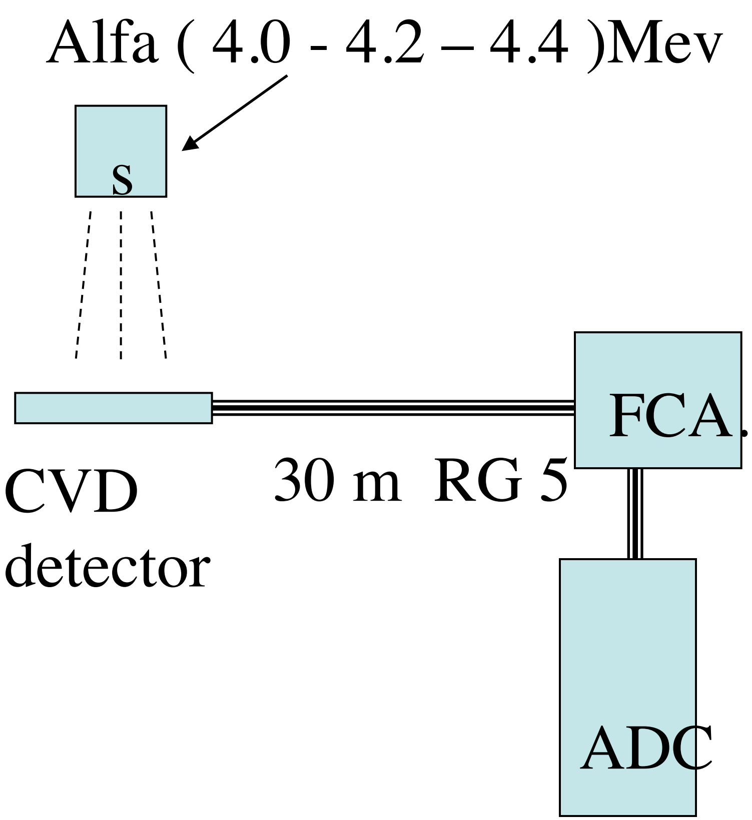
FCA electronics performance

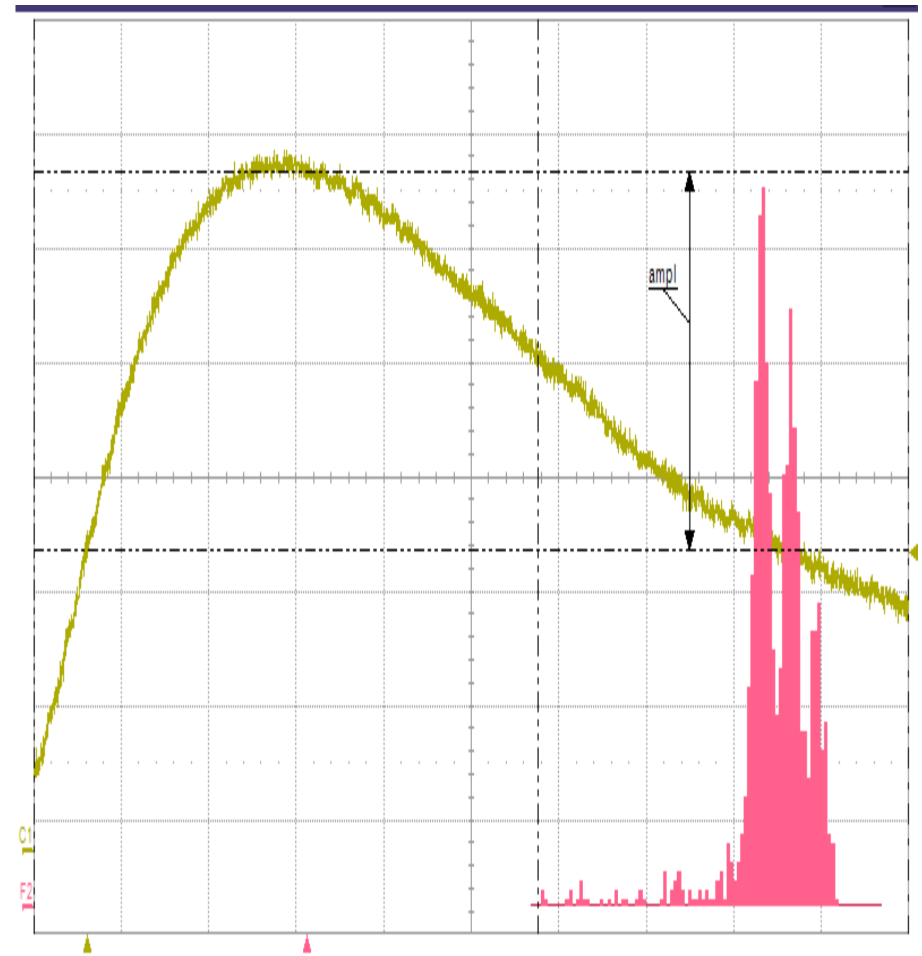
- Sensitivity 1.5 mV/fC
- Noise 2 fC RMS
- Latch capability 100 ps
- Bandwidth 10-100 MHz
- Power consumption 6 mW
- Tunable input impedance from a few ohm to 100 Ohm (to match the cable impedence)

SPICE Simulate amplifier pulse response



Test with alfa particles





Energy resolution ≈ a few%

Conclusions

- Roma Tor Vergata group is interested to built a radiation monitor for the SVT based on CVD diamond sensors
- Several issues to be studied in the next months:
  - Location of detectors (in collaboration with F.Bosi)
  - Expected background rates
  - Choice of technology:
    - polycrystalline CVD diamond vs Mono-crystalline CVD diamond
      - Weaknesses of polycrystalline CVD diamond: many grain boundaries -> defects, non-uniformity of collection properties
      - Mono-crystalline CVD diamond : No grain boundaries -> less defects , uniform collection properties
- FE optimization
  - test-beam with CVD sensors planned with different incident particles (n,e,γ)