Picosecond timing of high energy heavy ions with semiconductor detectors

Vladimir Eremin*

O. Kiselev, I Eremin*, N. Egorov***, E.Verbitskaya***

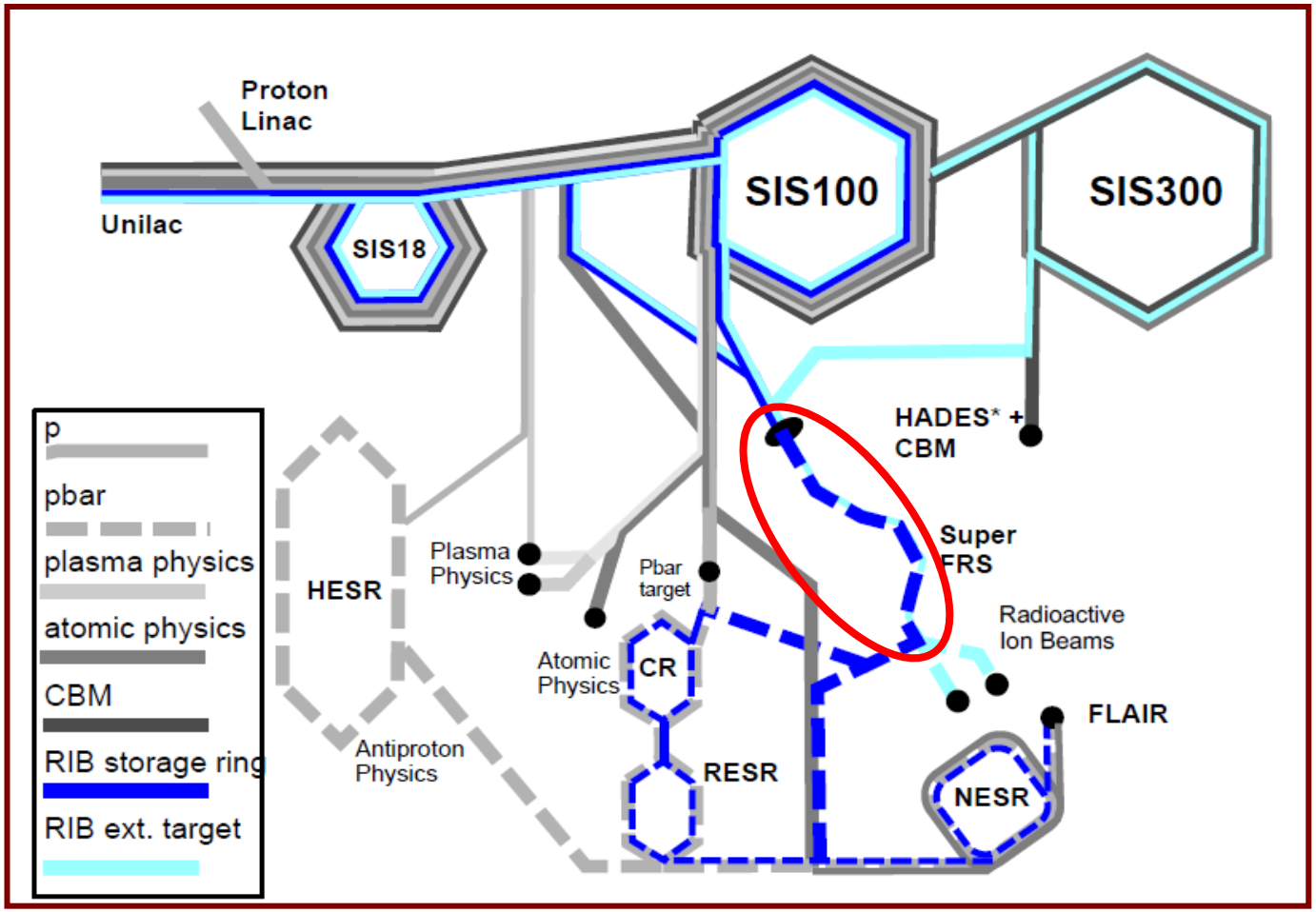
* Physical-Technical Institute, St.Petersburg, Russia
** GSI, Darmstadt,
*** RIMST, Zelenograd (Moscow), Russia

RESMDD-14, Florence, 8-10 Oct. 2014

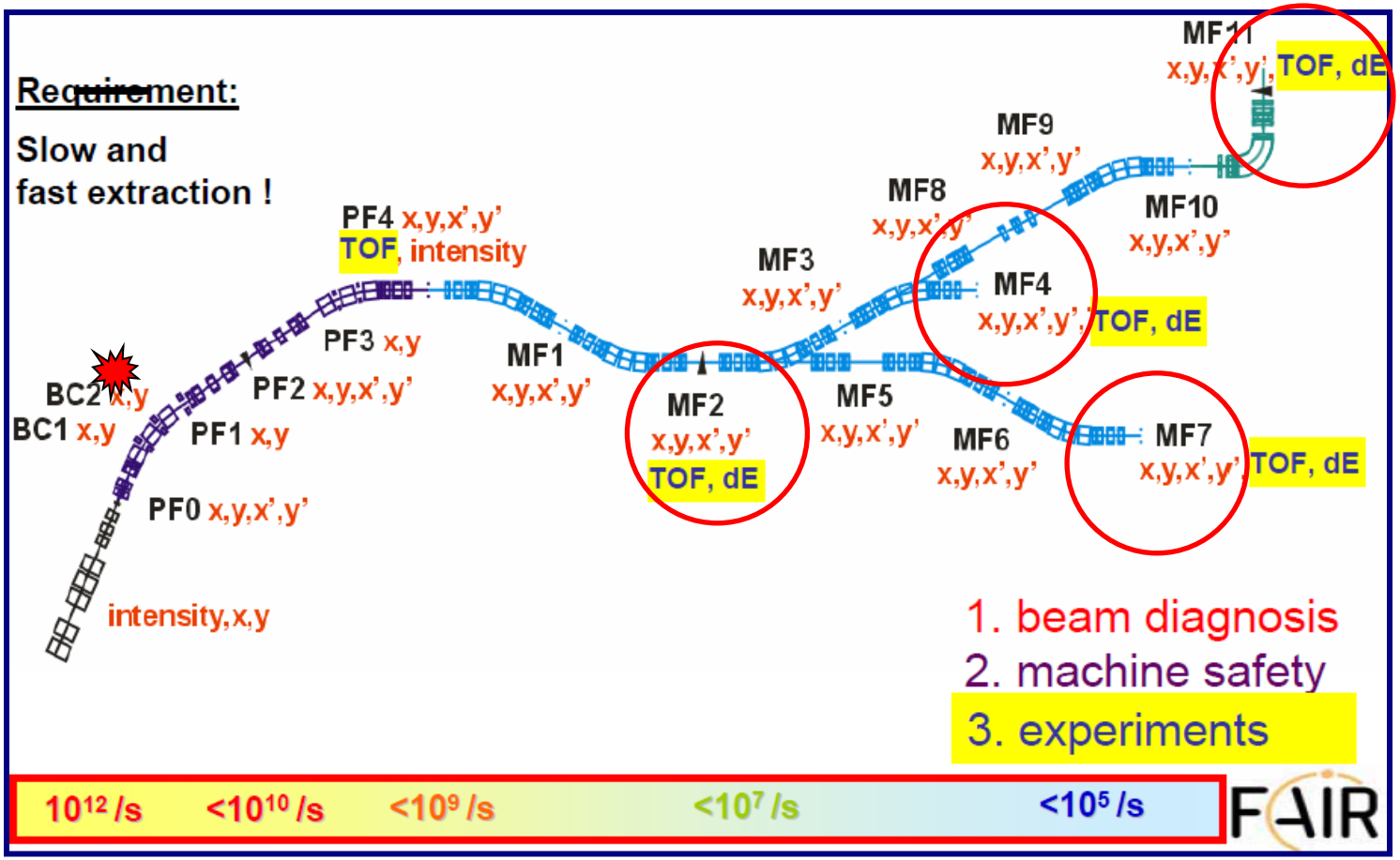
Outline

- Motivation
- Facility for Antiproton and Ion Research (FAIR)
- Physics of time resolution limit for:
  - MIPs
  - Short range ions
  - Long range ions
- Experiment
- Conclusions

FAIR project



Diagnostics in Super-FRS
and
Ioffe Physical –Technical Institute responsibilities



Specification
for TOF diagnostic of Super-Fragment Separator

6.1.10 Tof detectors (focal planes)

Physical parameters fixed	Design / engineering fixed	Integration / DMU check done	Procurement start	Procurement time

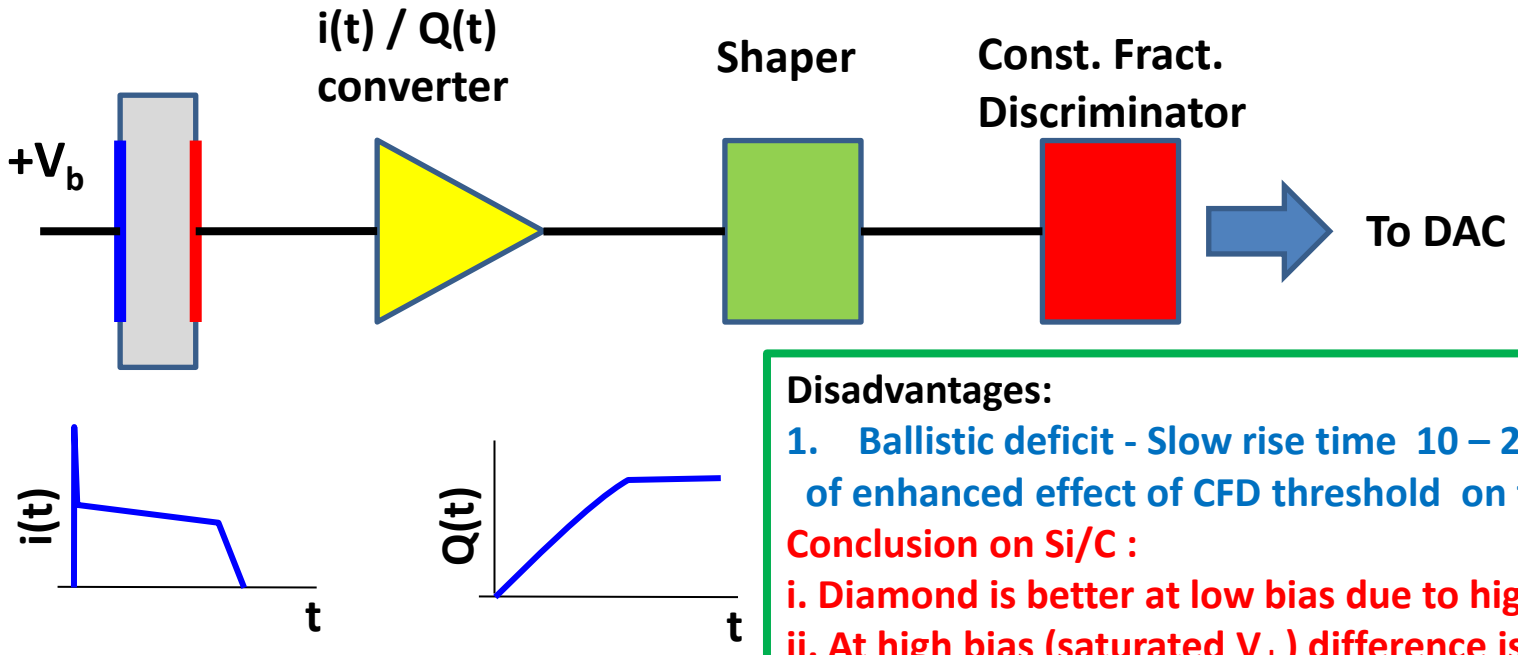
Quantity		4
Overall length	mm	200
Horizontal aperture	mm	400 (100)
Vertical aperture	mm	100 (50)
Time resolution	ps	<50
Rate	particles/spill	up to 10^7

Active area: 100 cm2

Dynamic range in Si (200um) Li/U (100-1500 MeV/u) = 0.03- 100 pC

Dynamic range in diamond (210um) Li/U (100-1500 MeV/u) = 0.006- 20 pC

Timing circuits with semiconductor detectors



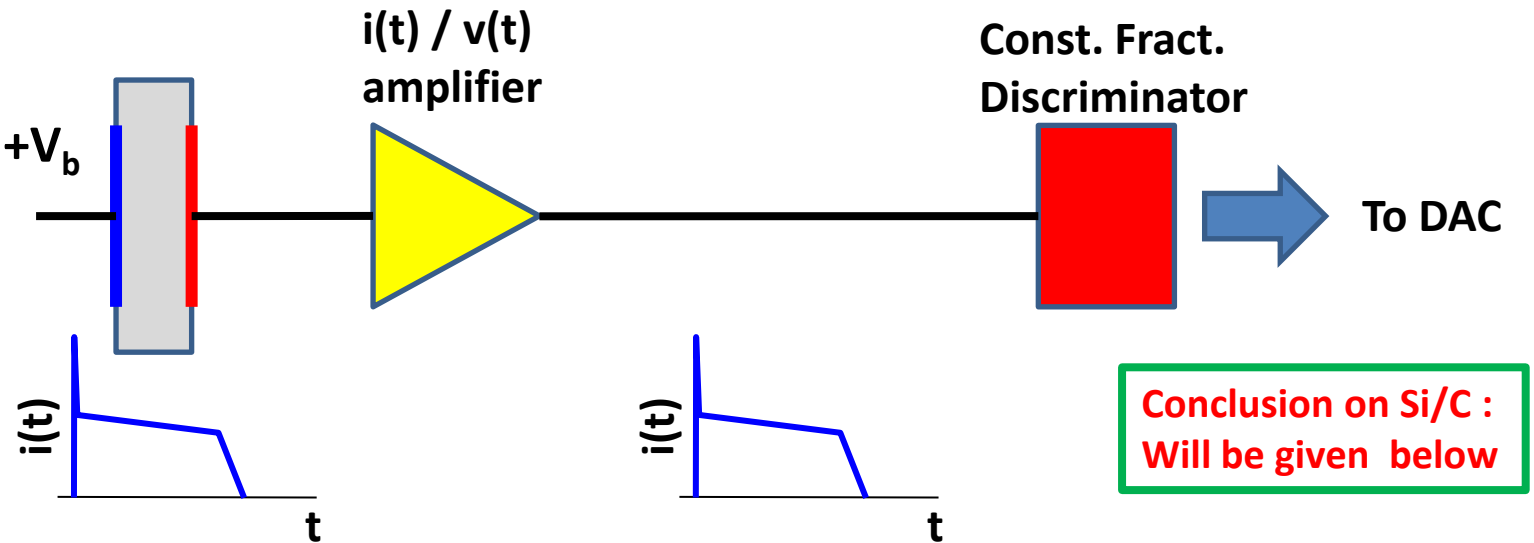
Disadvantages:

1. Ballistic deficit - Slow rise time 10 – 25 ns as a result of enhanced effect of CFD threshold on the time jitter

Conclusion on Si/C :

i. Diamond is better at low bias due to higher mobility

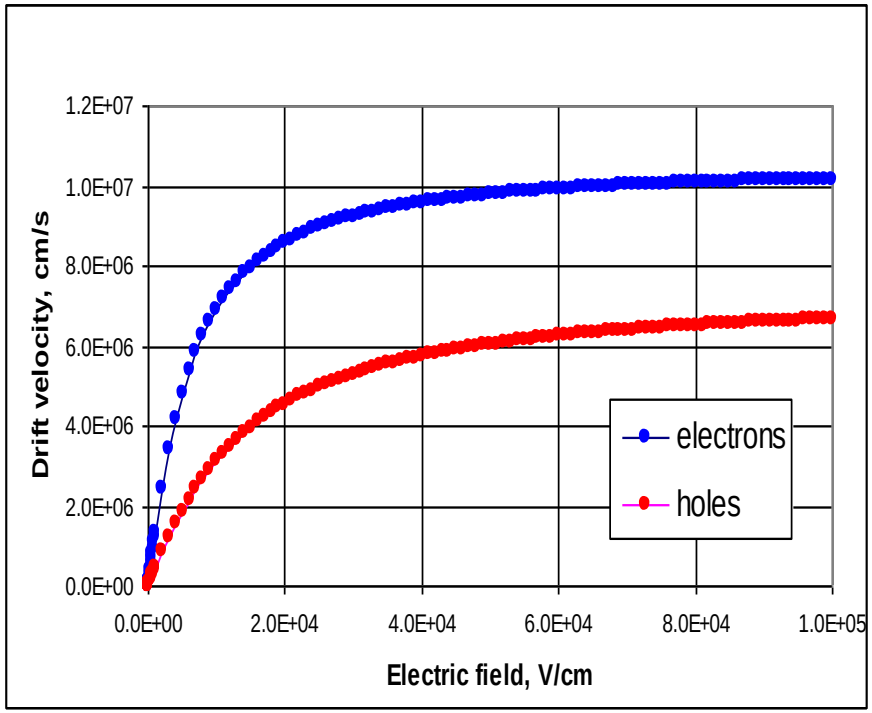
ii. At high bias (saturated V_{dr}) difference is negligible



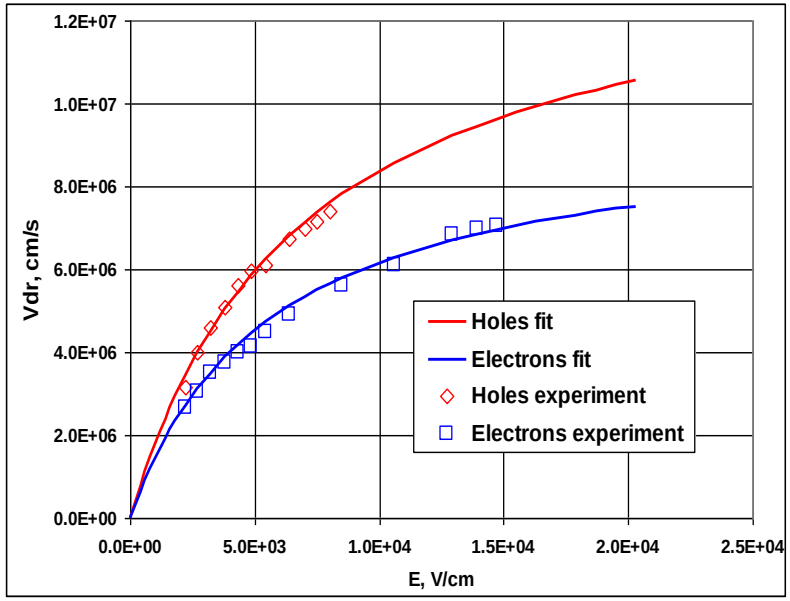
Conclusion on Si/C :
Will be given below

Drift velocity in Silicon and Diamond

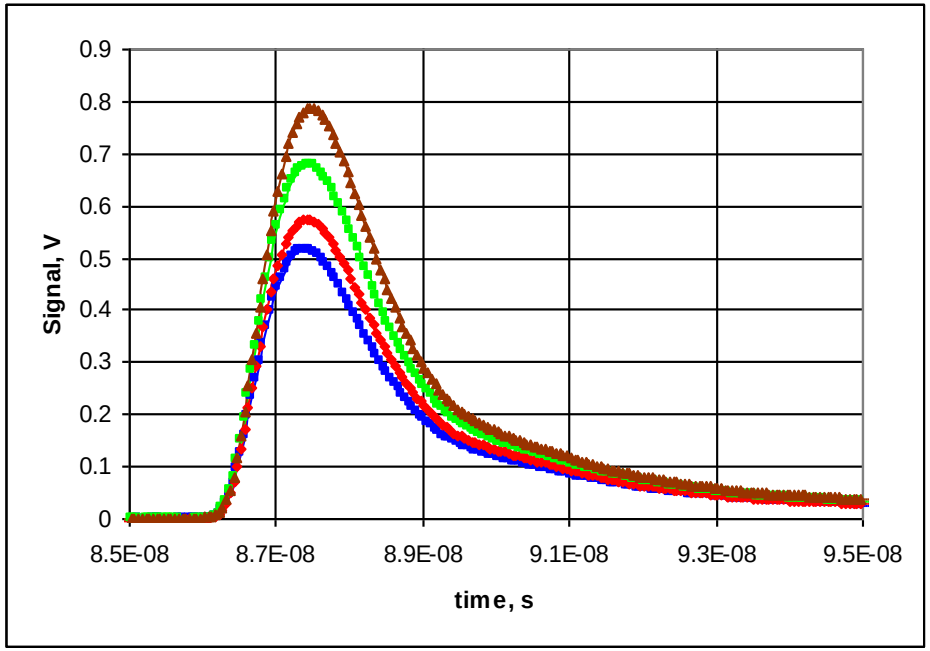
Si, 300K



scCVD , 300K

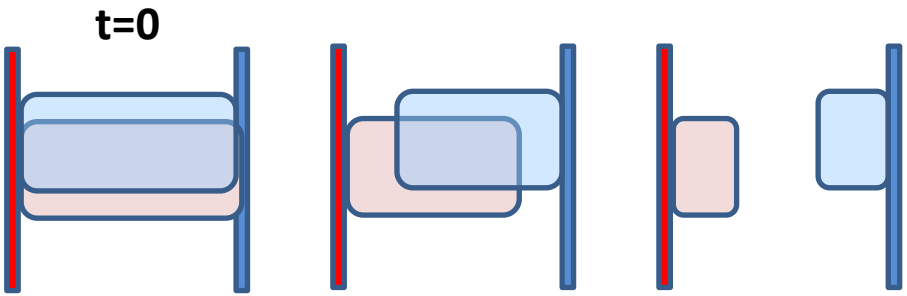


Current response for MIPs (low density track)



Conditions:

1. P-on-N planar detector
2. Area 25 mm^2
3. Thickness 300 um
4. Wavelenght – 1060 nm
5. Light pulse width – 50 ps
6. Amplifier BW – 0.5 GHz
7. OSC – analog BW - 3 GHz
8. R_{in} – 50 Ohm
9. 300K
10. The bias : 100, 150, 200, 300V.

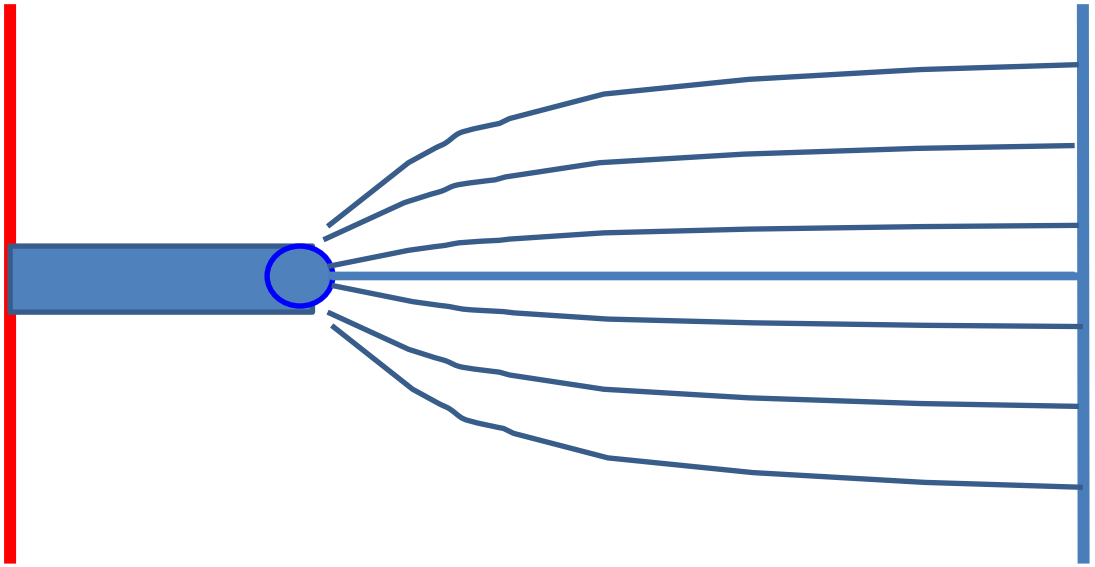


$i(t=0) = q^* (\langle v_{dr} \rangle_e + \langle V_{dr} \rangle_h)$

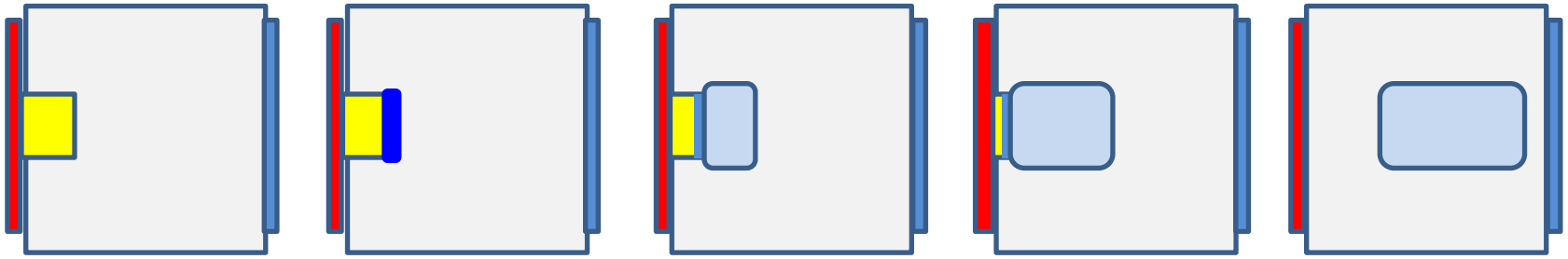
$t_r = 0$

- The response rise time is 640 ps
- No sensitivity to the bias voltage
- No sensitivity to the material.

SRP track in detector (high density short track)



Plasma effect for short range particles detection



t=0,
i(0) = 0,

Polarization charge & current

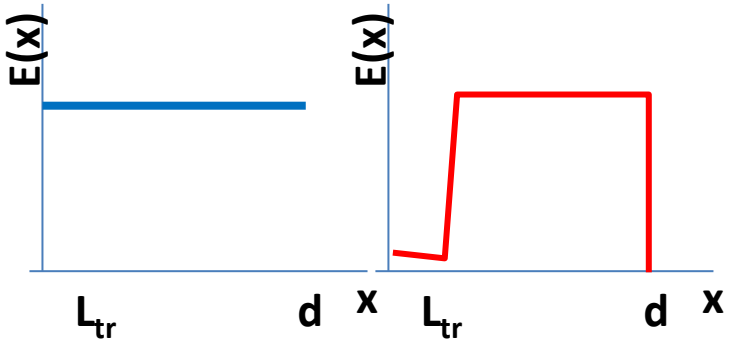
$t = t_{pol}$

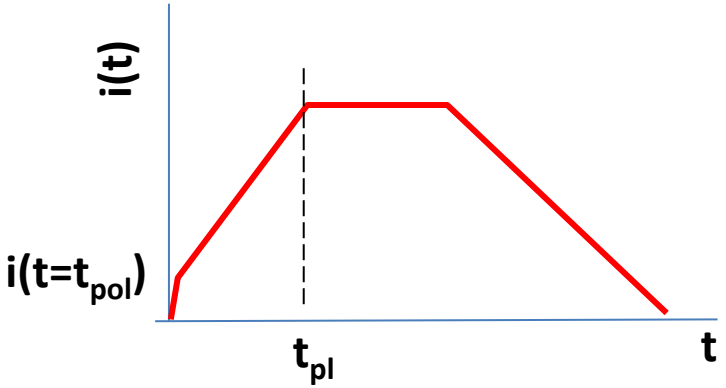
$q_{pol} = \Delta_{pol} * S_{tr} * n_{tr}$

$Q_{pol} = q_{pol} * \Delta_{pol} / d$

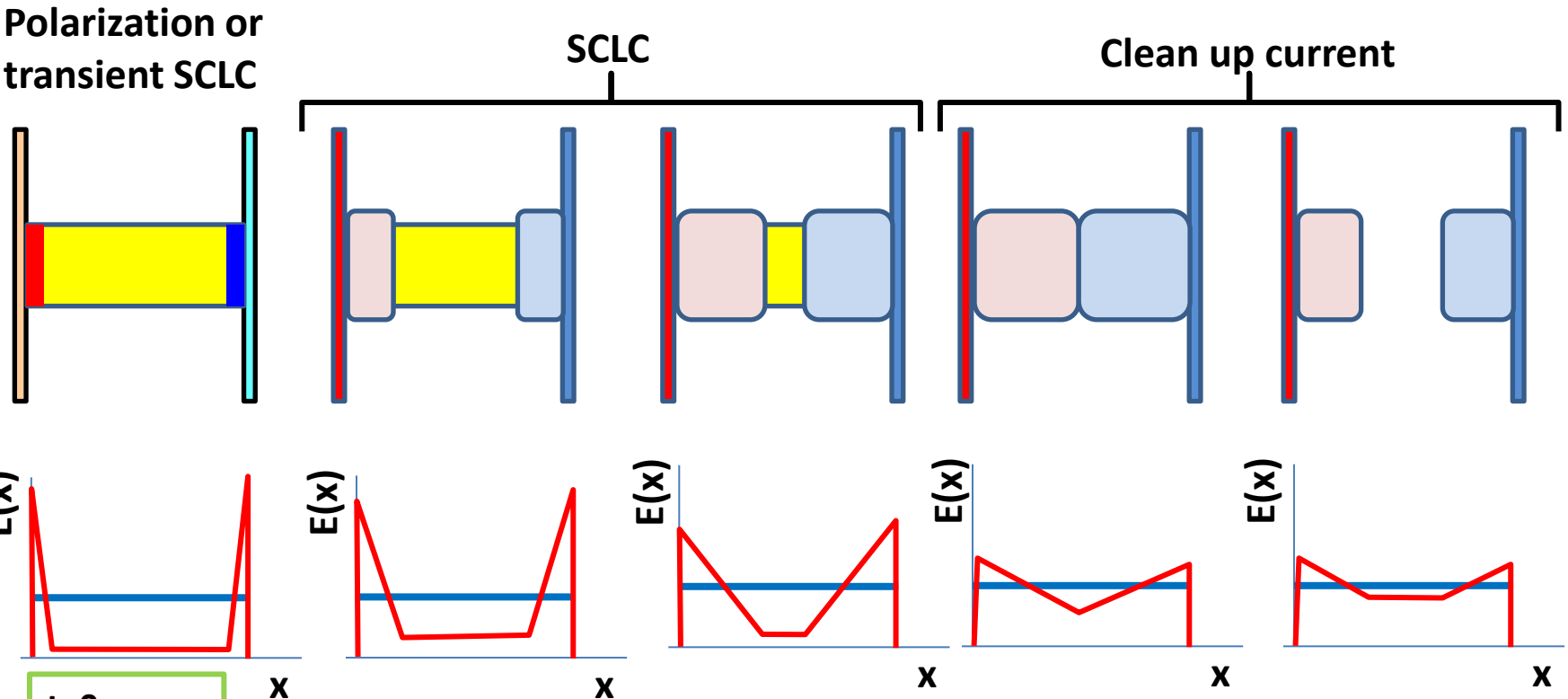
$I_{pol} = q_{pol} * v_{dr}\ 1/d$

- current response rise time is t_{pl}
- t_{pl} is sensitive to the bias voltage
- t_{pl} is sensitive to the material.





Plasma effect for LONG range heavy particles detecti



t=0,
Q(0) = 0

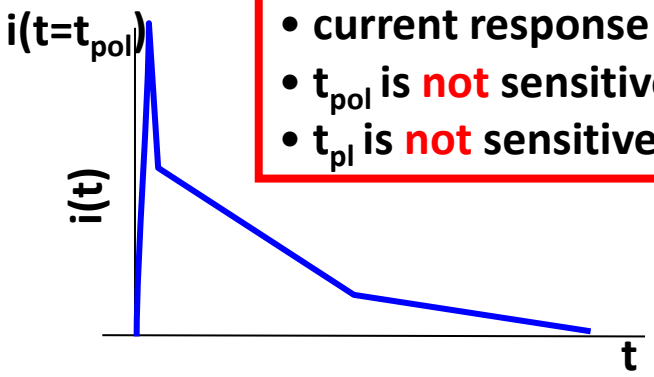
Polarization charge & current

$t = t_{pol}$

$q_{pol} = \Delta_{pol} * S_{tr} * n_{tr}$

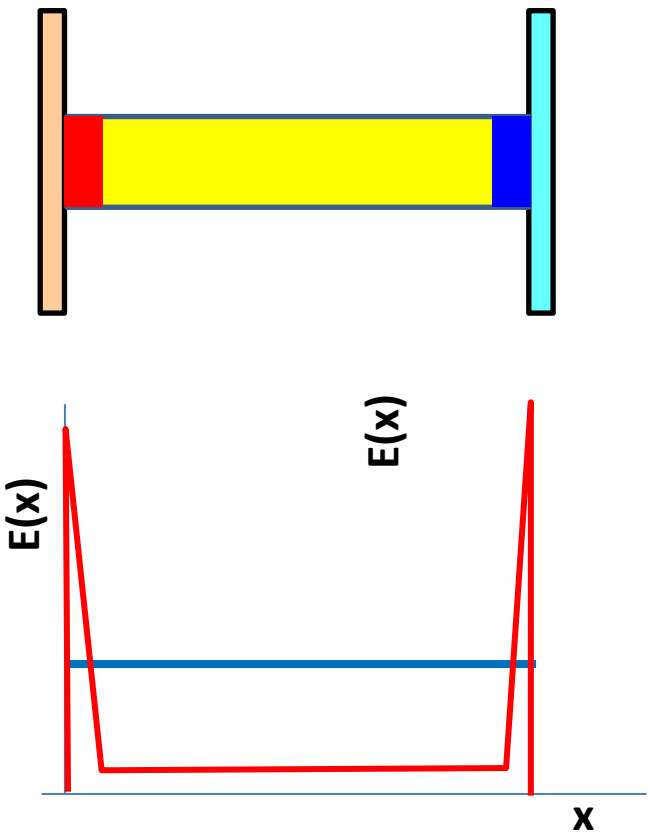
$Q_{pol} = 2 * q_{pol} * \Delta_{pol}\, d/d$

$I_{pol} = 2 * q_{pol} * v_{dr}\, d/d$



- current response rise time is t_{pol}
- t_{pol} is not sensitive to the bias voltage
- t_{pl} is not sensitive to the material.

Polarization current



^{197}Au, E=920 GeV

E_{dep} = 1 GeV/ 300 um (silicon)

Pairs concentration n = 10^{17} pairs *cm-3

V= 300 V

Polarization charge

φ_{pol} = 150 V

Δ_{pol} = 3 um

$q(t_{pol}) = \Delta_{pol} * S_{tr} * n_{tr}$

^{197}Au at 750 MeV/u – 920 MeV,

Polarization time

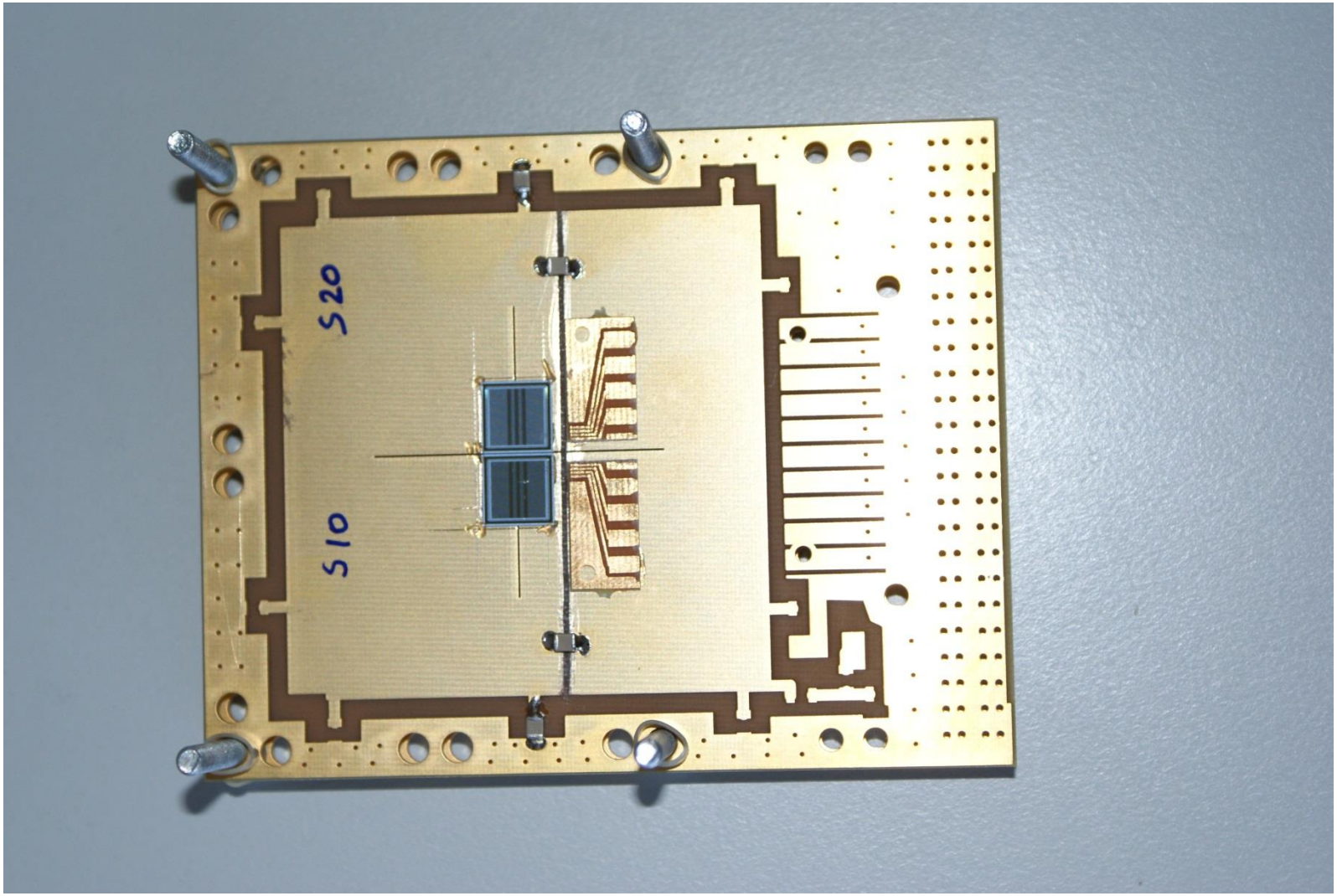
$t_{pol} = \frac{\varepsilon \cdot \varepsilon_0}{e \cdot \mu \cdot n_{tr}}$ = Maxwell relaxation time

t_{pol} = 5*10^{-14} s

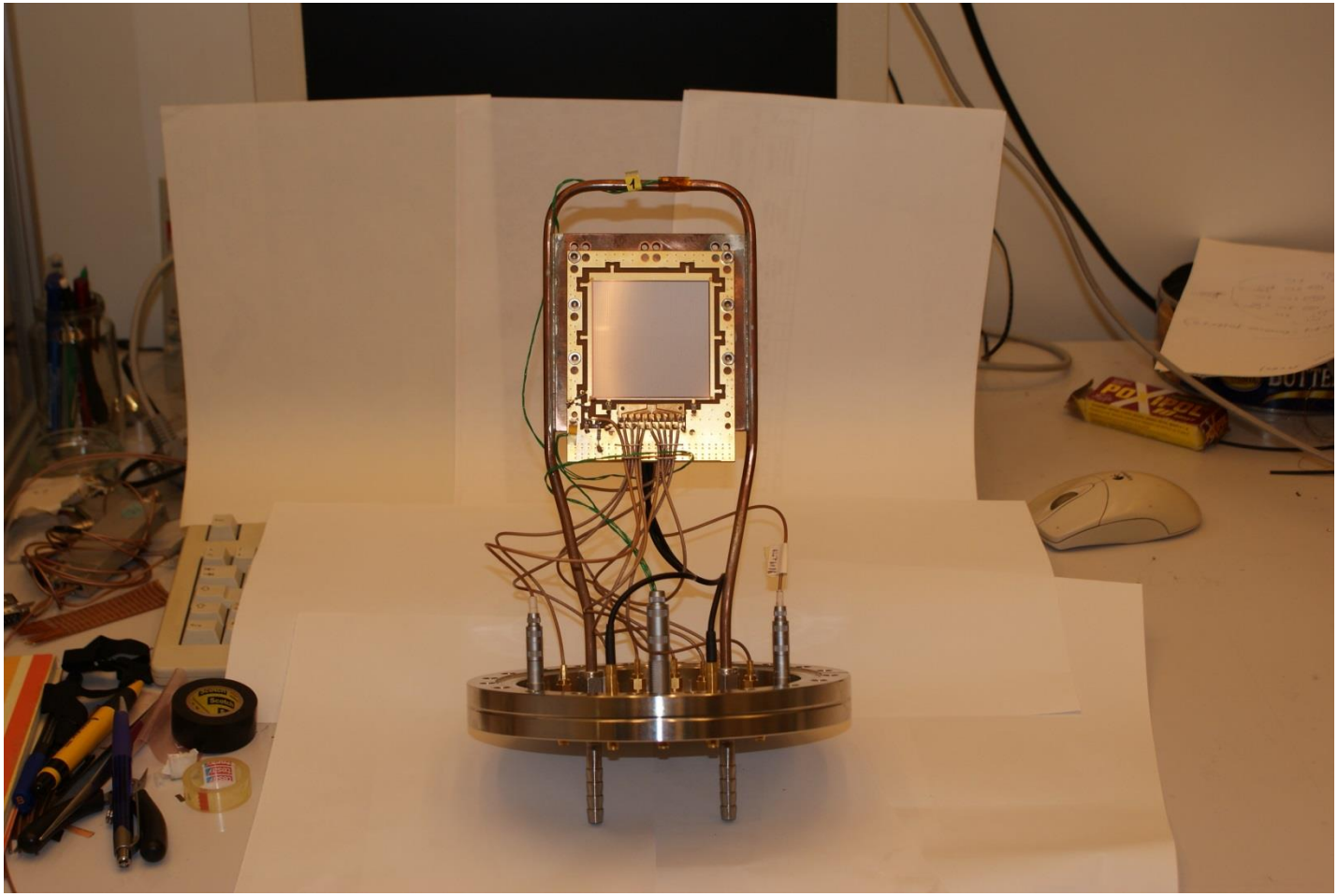
Polarization current

$i_{pol} = q_{pol} * 1 / t_{pol}$

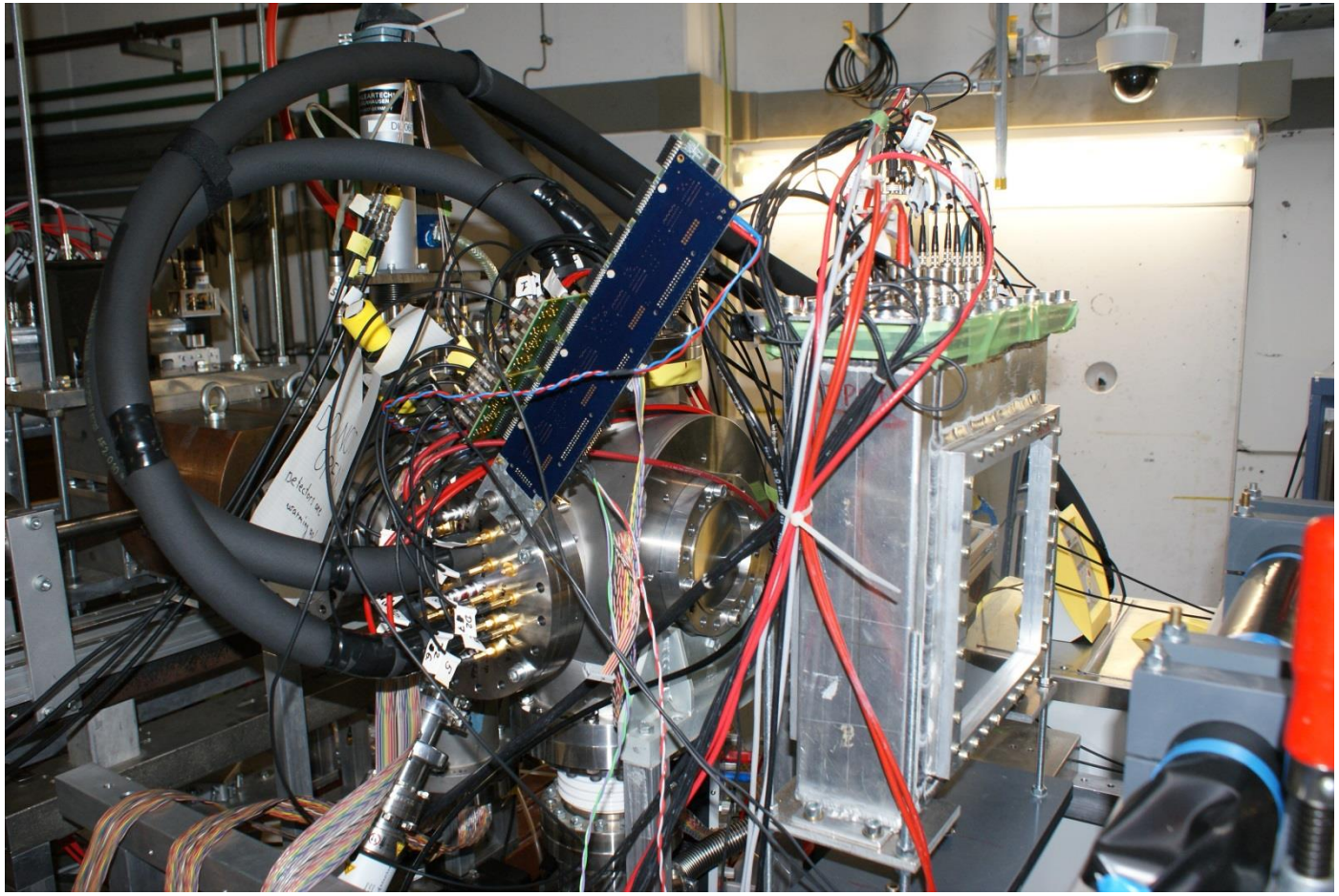
Two mini-strip Si detectors installed on the cooling PCB.



Large area 64x64 strip detector on the cooling board and installed on flange

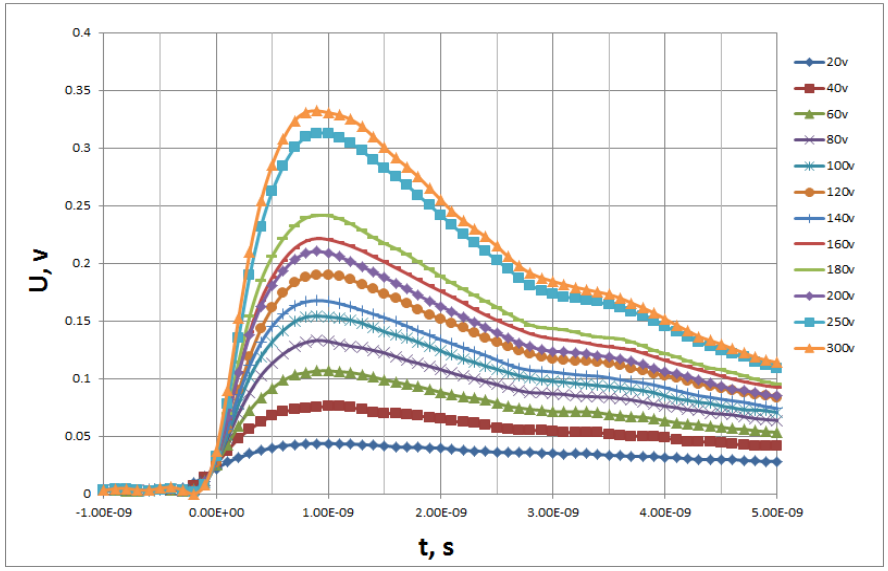


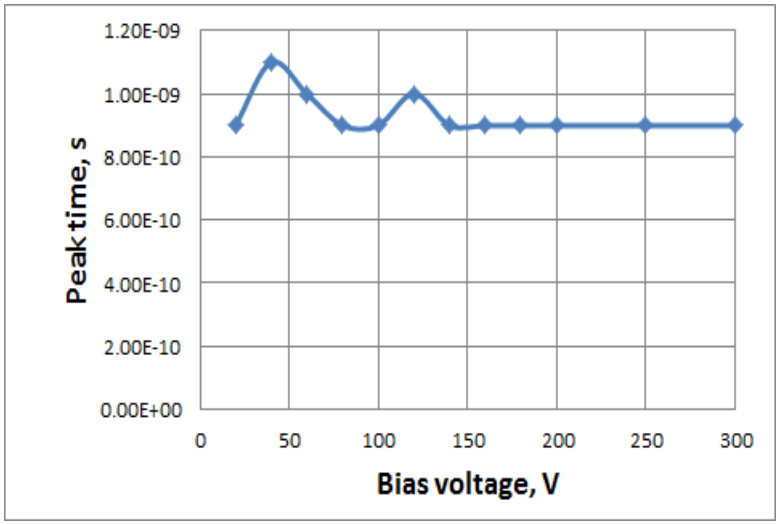
The flange with detectors installed on the vacuum chamber and connected with the wide band electronics



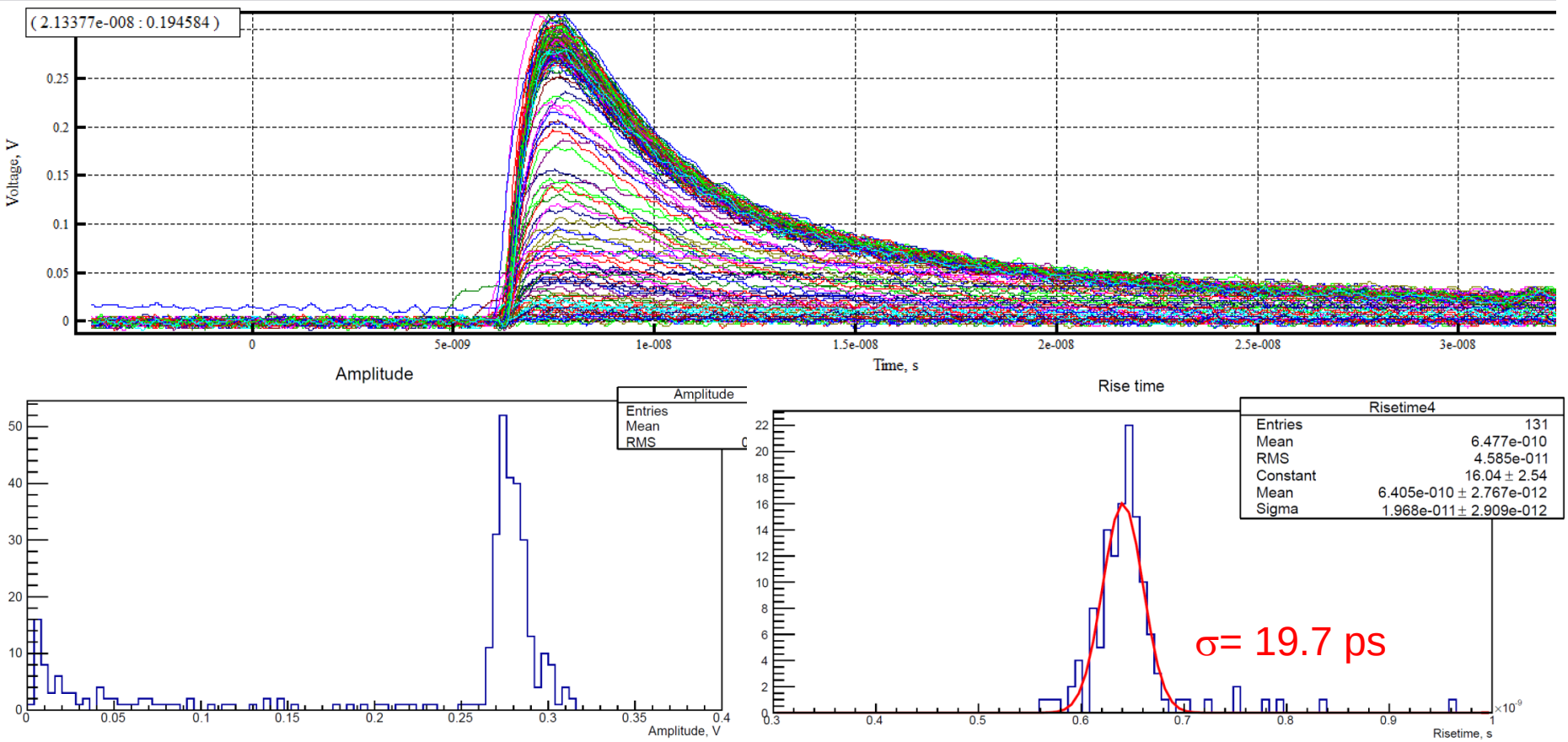
Voltage scan of Si detector current response

^{197}Au, E=920 GeV
Detector thickness - 300 um
Voltage range 20 – 300 V





Time resolution



Conclusions

1. The rise time of current pulse is not sensitive to the density of e-h pairs in plasma inside the track
2. The rising edge amplitude is defined by the track polarization
3. The physical limit for the current pulse rise time is a Maxwell relaxation time.
4. In the experiments it is limited by the input RC and front – end electronics.
5. Effect of the detector material on the detector time resolution in current operational mode is negligible
6. Readout of fast component of current response allows to increase the maximum radiation fluence for semiconductor detectors based on any material.
7. Si detectors provide time resolution < 20 ps for heavy relativistic ions (better than required for SFRS diagnostics)

8. **With these conclusions the detector technology (reproducibility, fabrication time, trimming to the requirements) and the detector price become the major criteria for technical decision.**

Acknowledgement

This work was supported by the Program of Russian Academy of Sciences, Part 15.24, and RF President Grant # SS-347.2014.2.

The authors express deep gratitude to A. Gorbatiuk for discussion and simulations.

Thank you for attention!