Fast Luminosity Monitoring Using Diamond Sensors For The Super Luminous Flavor Factory SuperKEKB

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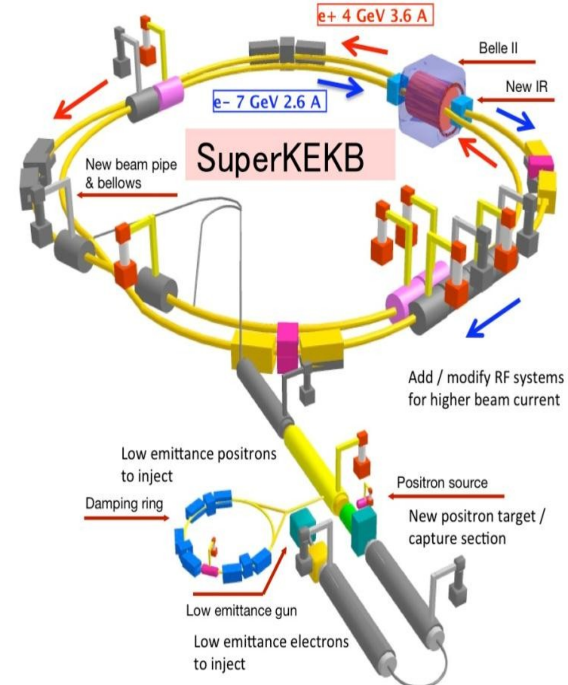
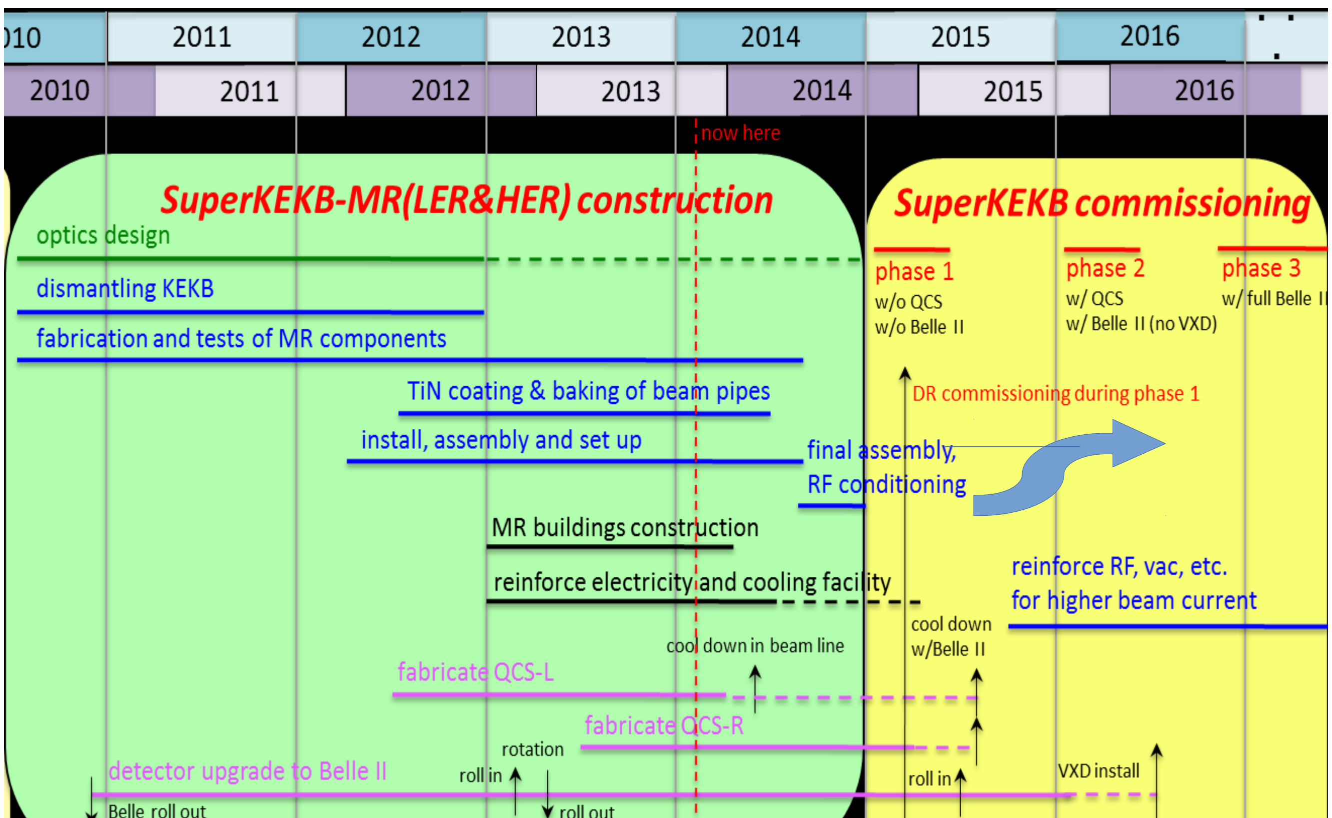
Outline

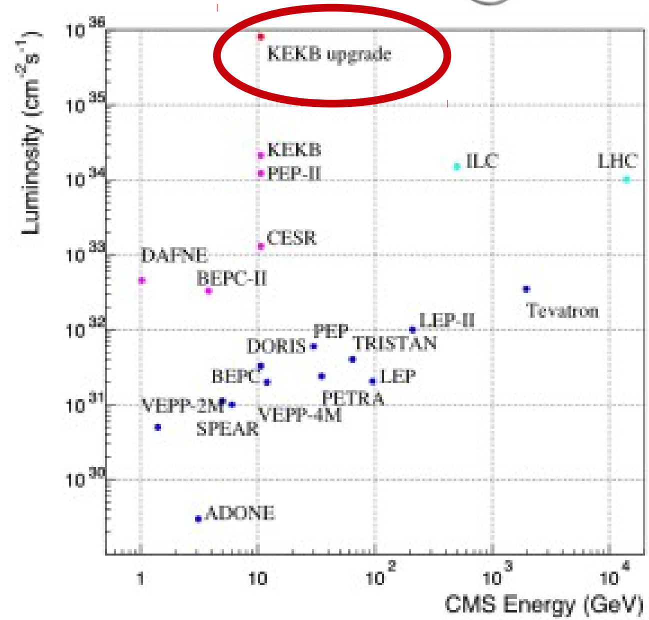
- SuperKEKB: Definition and Status
- Fast luminosity monitoring:
- ✓ Sensor location in LER
- ✓ Geometry of the vacuum chamber
- ✓ HER
- Readout and electronics
- Conclusion & Next Plans

SuperKEKB

- Belle II @ SuperKEKB: e^+e^- collider (e^+ @ 4 GeV (LER) & e^- @ 7 GeV (HER))
- High Luminosity (8 10^{35} cm^{-2} s^{-1})
  - Nano-beam scheme, very small beam sizes (60 nm)
  - High currents (beams collide @ 0.25 GHz)

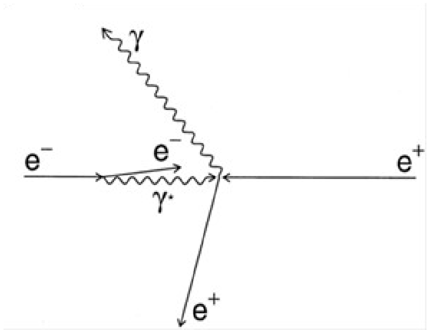






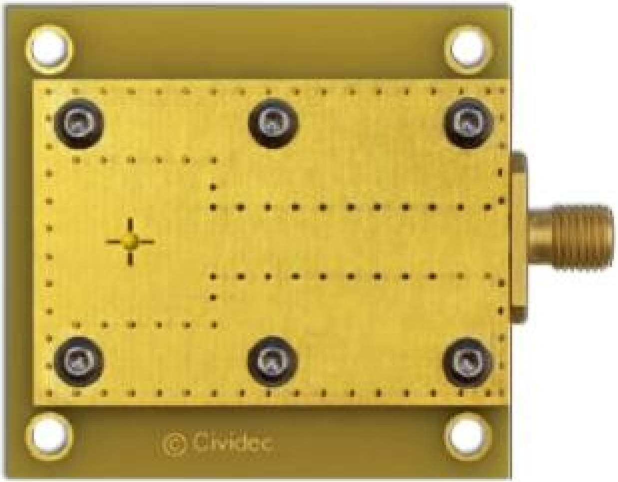
Fast Luminosity Monitoring

- Fast luminosity monitoring is required in the presence of dynamical imperfections, for feedback and optimization.
- Precision $\delta\mathcal{L}/\mathcal{L} = 10^{-3}$ in 1 ms
- Lumi monitoring for each bunch crossing: 2500 bunches, collide each 4 ns
- Measurement: Radiative Bhabha process at zero photon scattering angle , Large cross-section ~ 0.2 barn



- Technologies: Sensors set immediately outside beam pipe

  - 5x5 mm^2 diamond sensors (Radiation hardness, Fast charge collection)

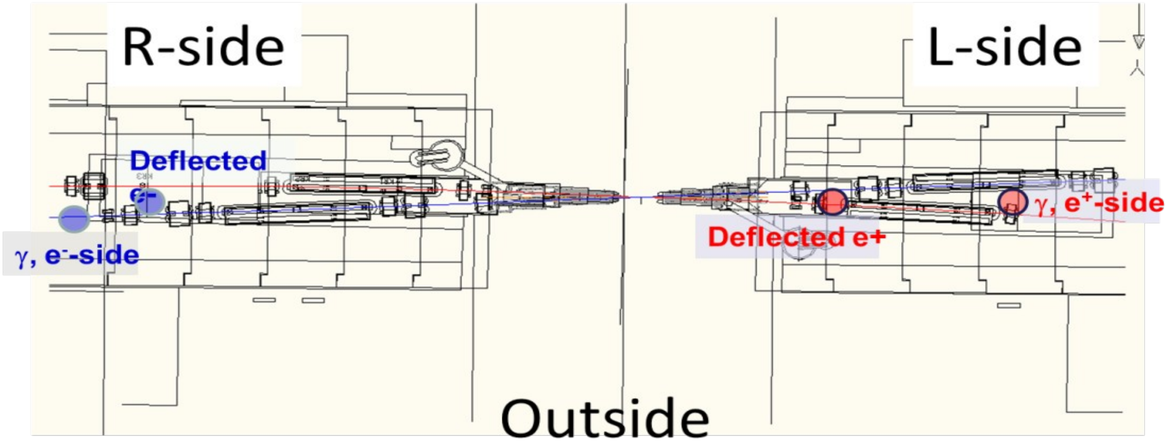


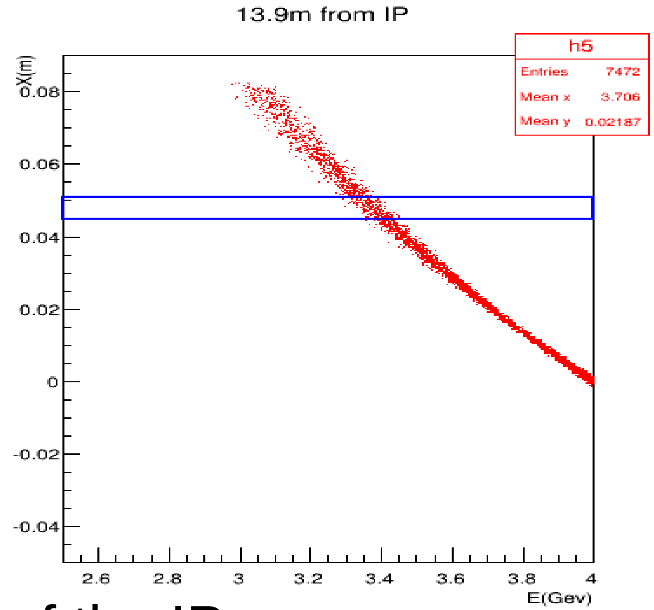
  -Scintillator + Cherenkov detector

ZDLM group at KEK, S.Uehara San

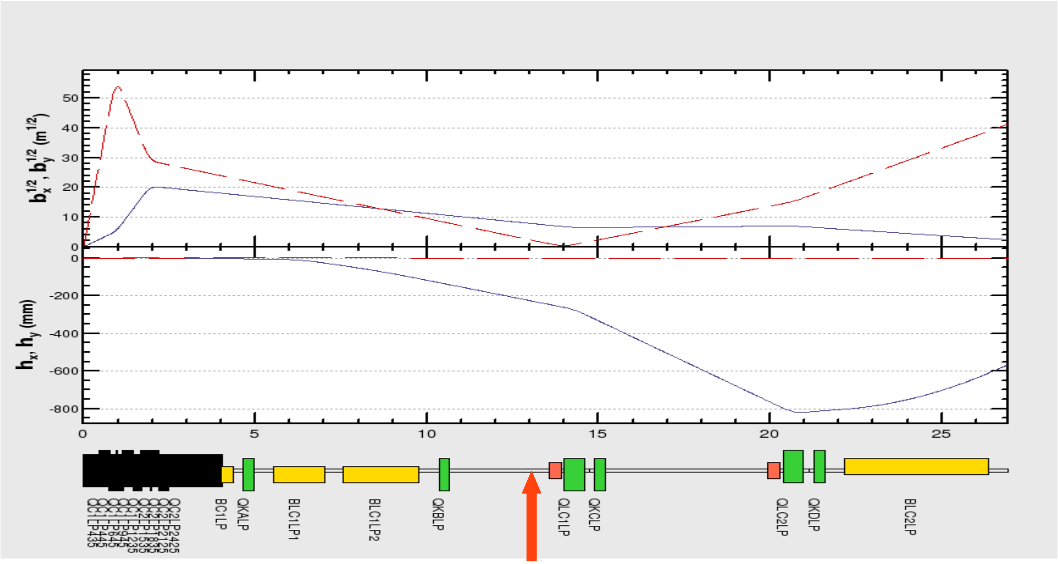
Sensor Location in LER

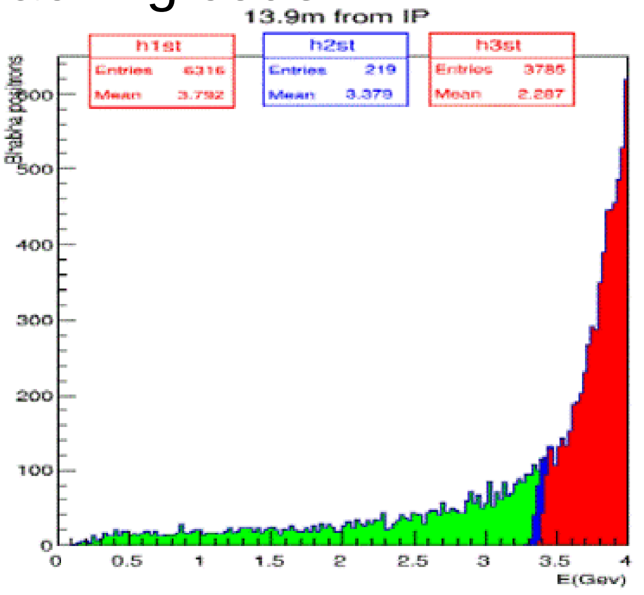
- Bhabha dynamics have been generated by GUINEA-PIG++





- Low energy e+/e- will be deflected downstream of the IP
- Exiting Bhabha rates are studied using SAD tracking code





Sensor Location in LER

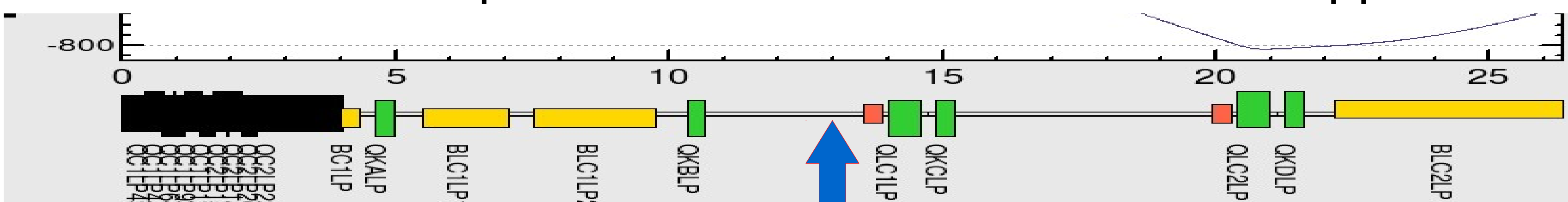
- To reach the aimed precisions, the following counting rates are required:

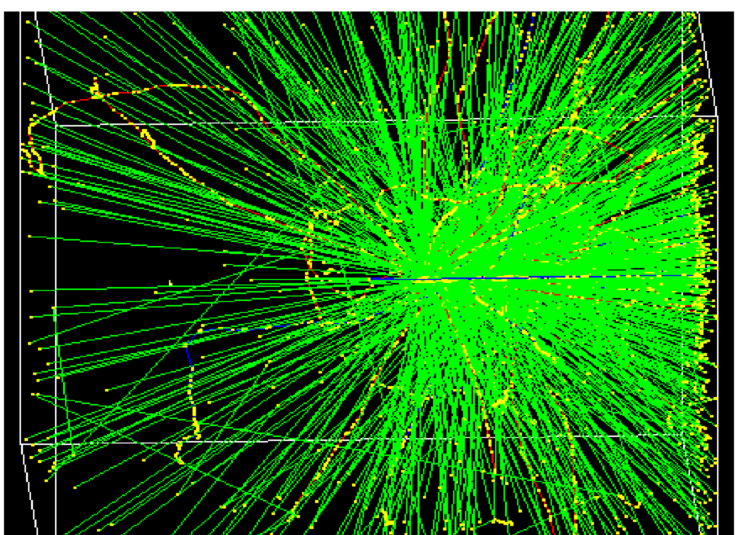
Luminosity ($cm^{-2} s^{-1}$)	Aimed precision (in 1 ms)	Required fraction
10^{34}	10^{-2}	2.1×10^{-3}
$8\ 10^{35}$	10^{-3}	2.6×10^{-3}

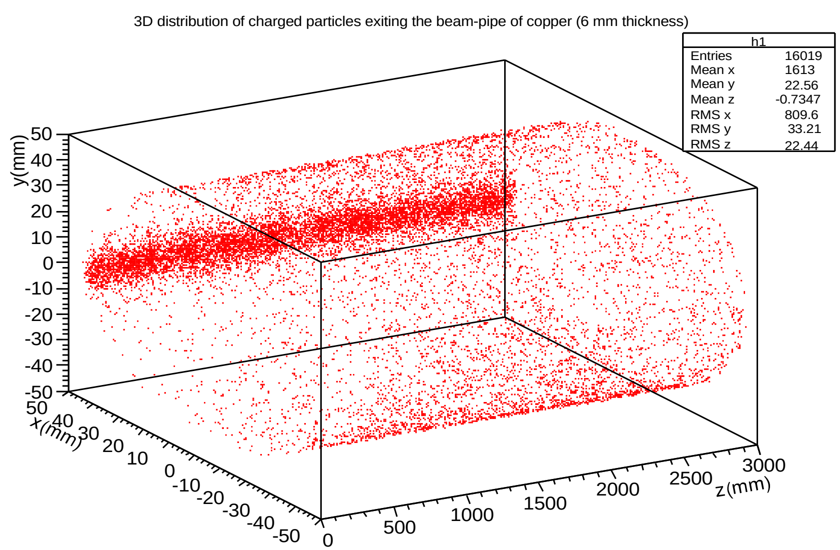
- The best candidate position is chosen to be at 13.9 meters from the IP:

✓ 3 meters drift , adequate to place our sensors

✓ 4.7% of Bhabha positrons will exit the 6 mm thick copper beam-pipe

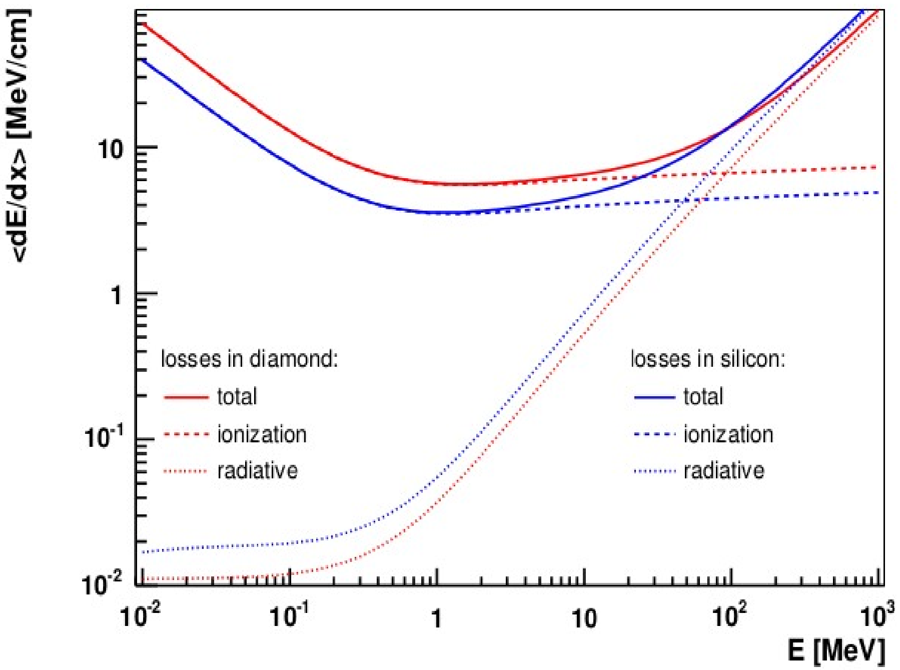




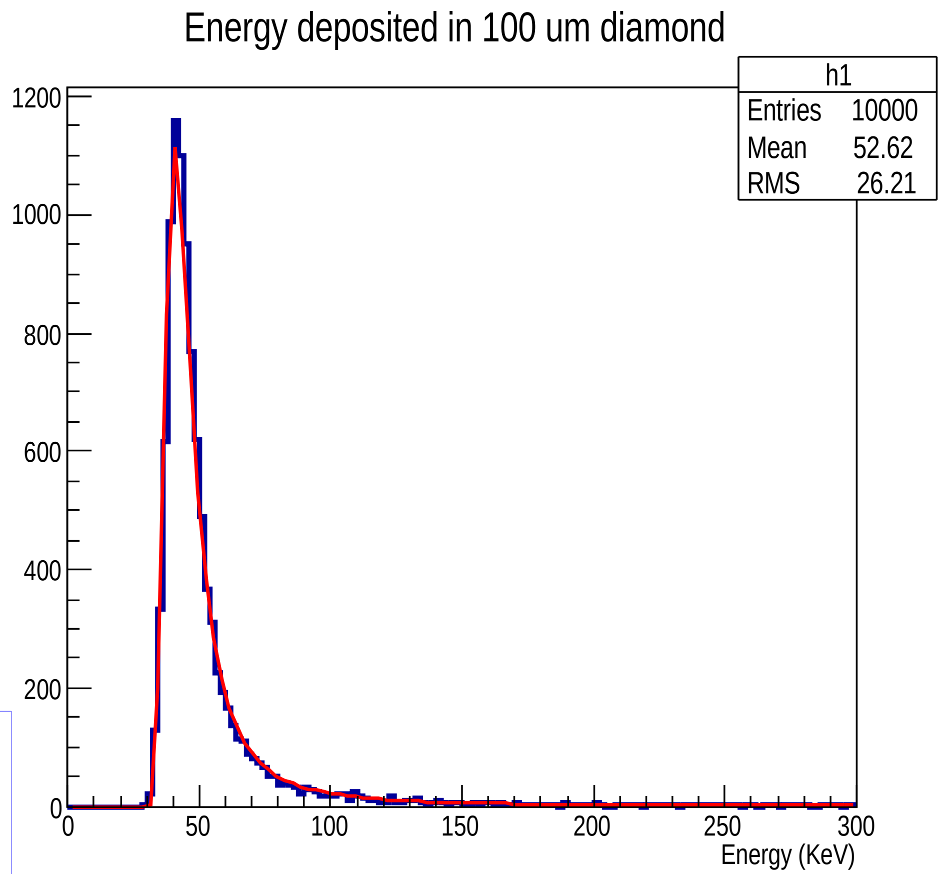


Energy Deposition of e+/e- in a 100um Diamond

- Charged particles like e^+ and e^- will deposit energy in the diamond sensor according to a “Landau” distribution

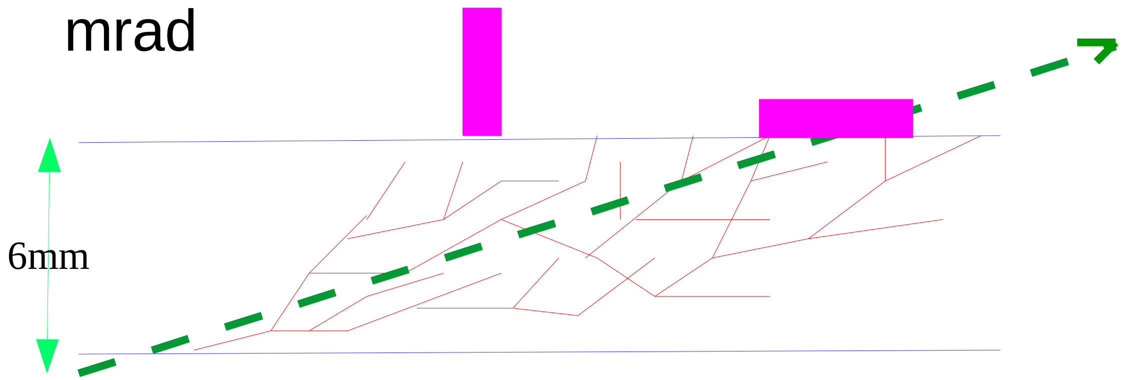


The mean energy losses of an electron in diamond (red curves) and silicon (blue curves)



Geometry of Vacuum Chamber

- Bhabha positrons escape the beam pipe at an average angle of 5 mrad

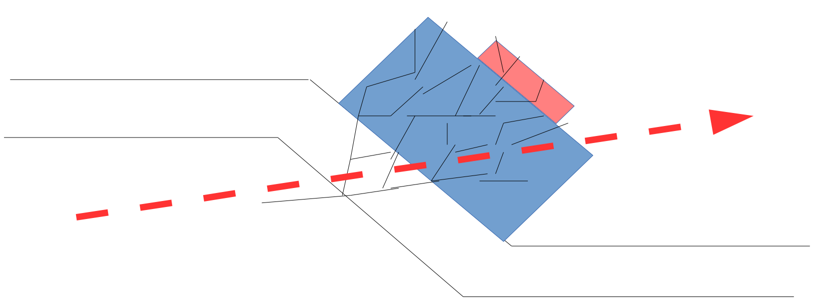


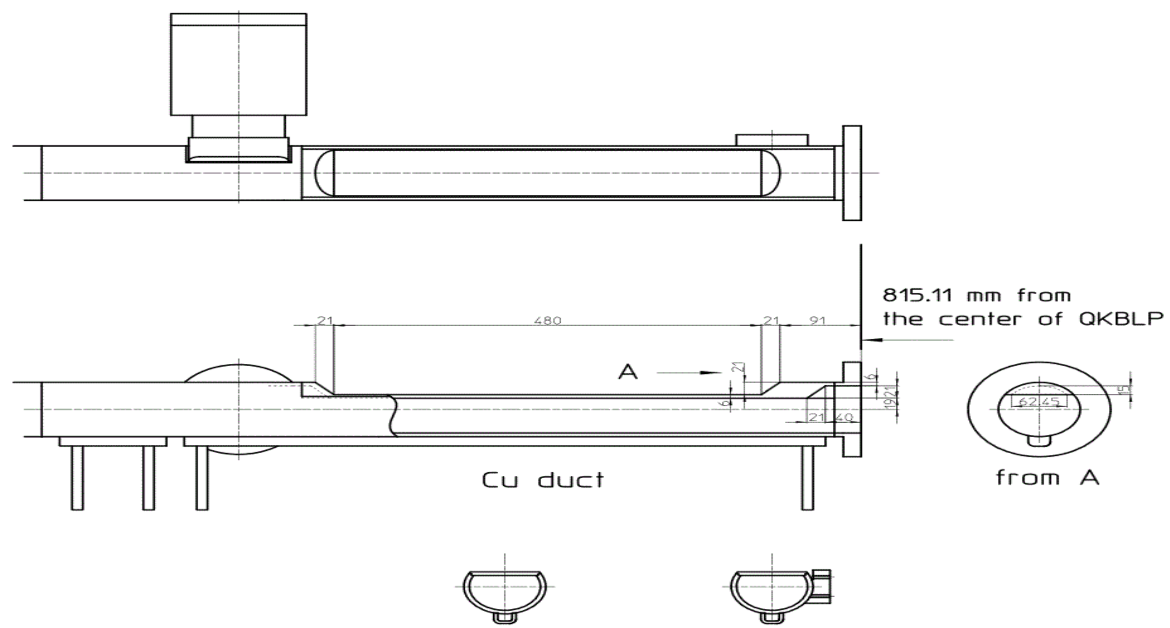
- The particle will cross 1.2 meters in the copper ~ 80 radiation lengths

  Absorption of shower particles in the beam-pipe

- Modification of the beam pipe is suggested to increase the probability of having exiting showers

  A window at 45 degrees is suggested



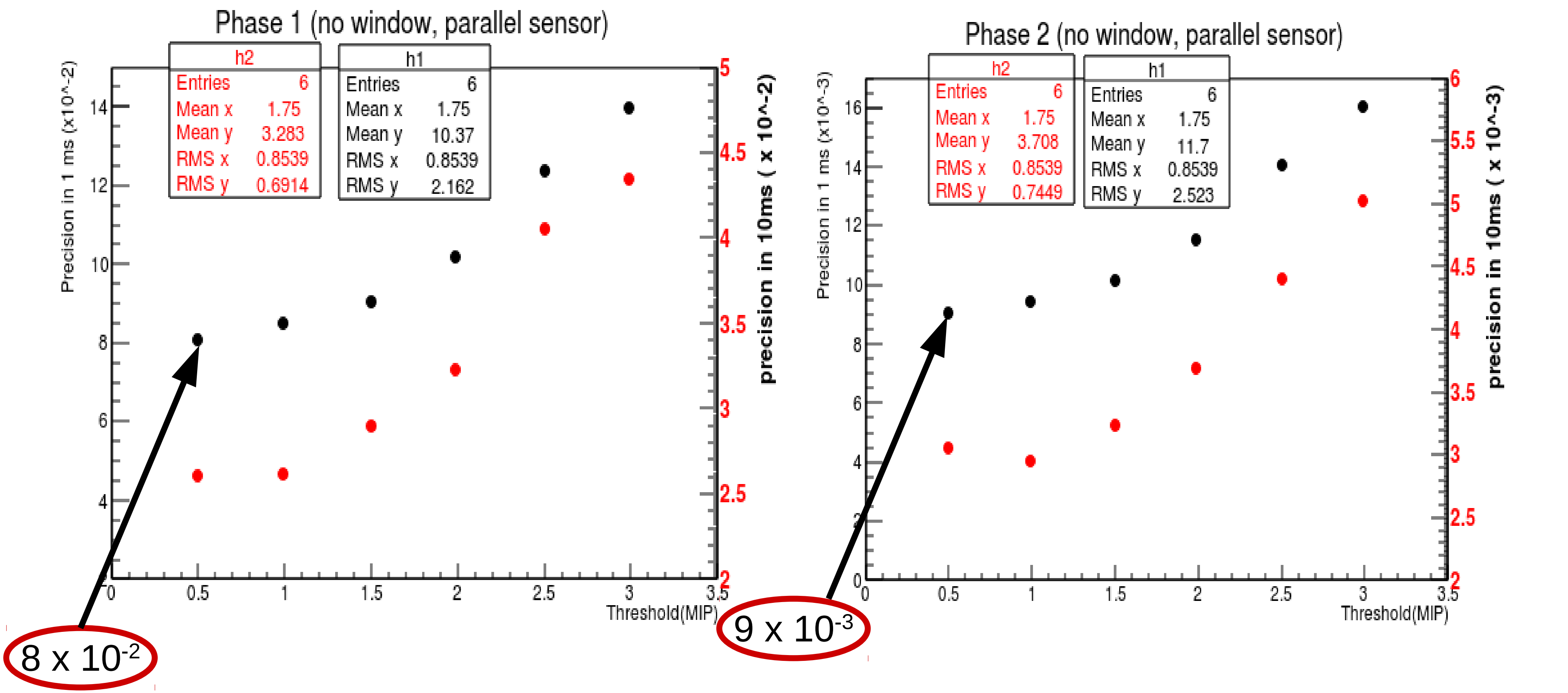


A Summary Table of collected secondaries

	Luminosity ($cm^{-1} s^{-1}$)	Required Precision in 1 ms (Nb of particles)	Number of particles collected in 1 ms	Number of particles per bunch crossing
No window	10^{34}	10^{-2} (> 10^{4} part)	1.4 10^{2}	0.00056
No window	8 10^{35}	10^{-3} (> 10^{6} part)	1.3 10^{4}	0.052
Window	10^{34}	10^{-2} (> 10^{4} part)	4.4 10^{3}	0.0176
Window	8 10^{35}	10^{-3} (> 10^{6} part)	3.5 10^{5}	1.4
Window+Radiator	10^{34}	10^{-2} (> 10^{4} part)	1.5 10^{4}	0.06
Window+Radiator	8 10^{35}	10^{-3} (> 10^{6} part)	1.2 10^{6}	4.8

GEANT4 Simulation Results

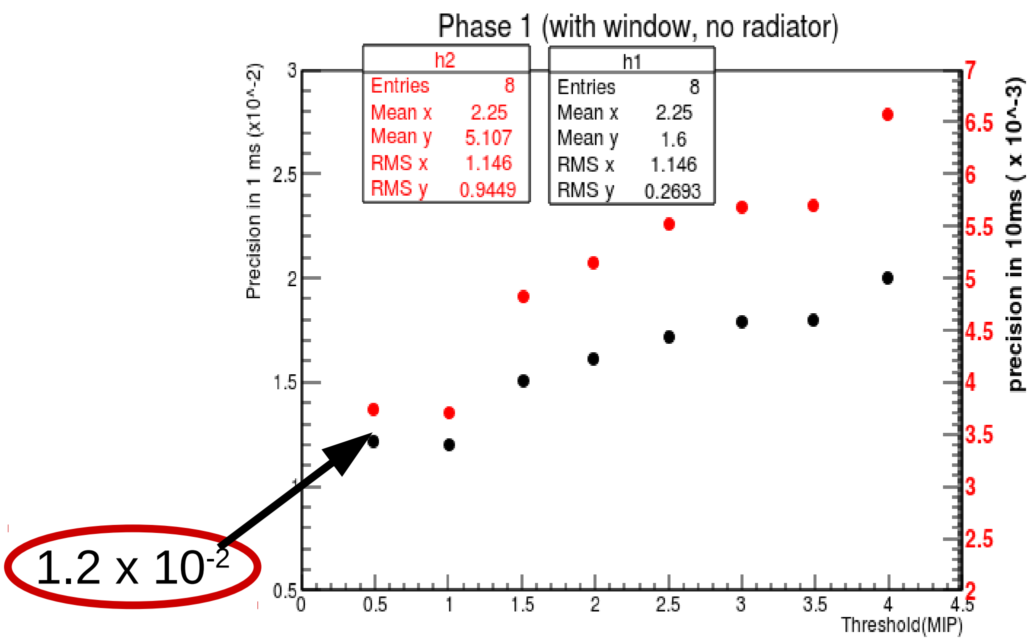
- Geant4 simulations were performed, considering the material and the beam pipe geometry, to estimate the actual signals in the sensors

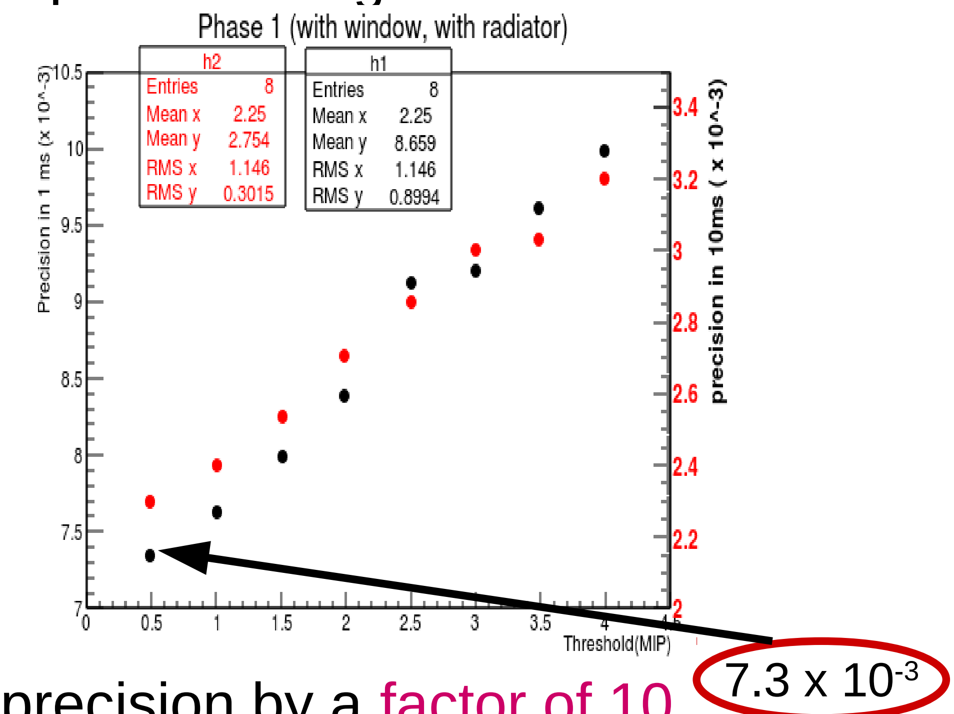


In the case of a normal cylindrical beam pipe, precisions are too far from the required one, even for the optimal luminosity (8 10^{35} cm^{-2} s^{-1})

GEANT4 Simulation Results

- Advantage of having a window at 45 degrees is the possibility of placing a radiator at shower max to improve the signal in the sensor.



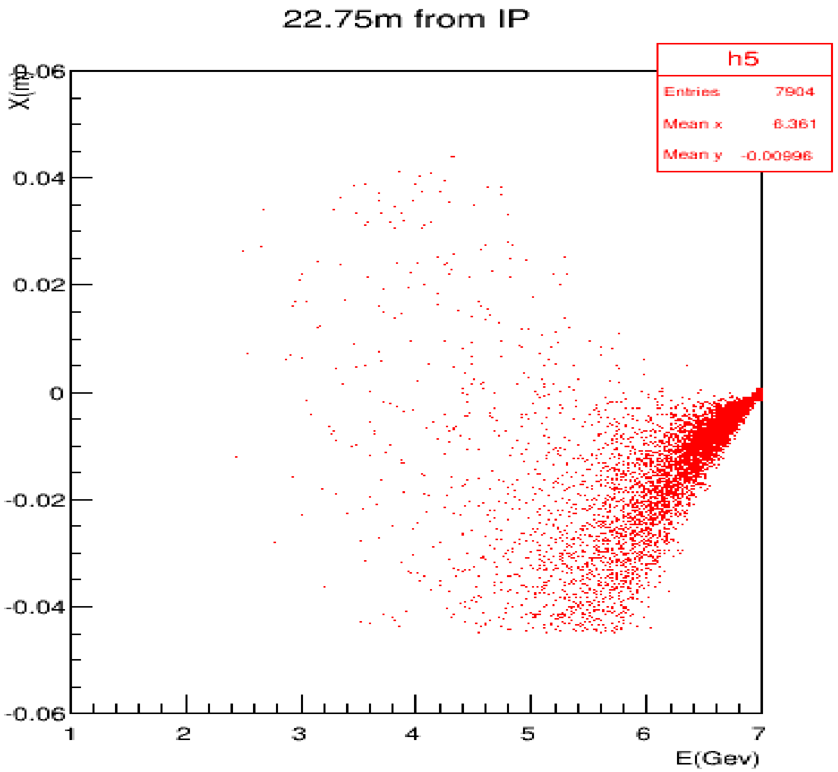


- Presence of a window improves the precision by a factor of 10

BUT such window may be costly and may introduce wakefields thus affecting the beam stability .. A new design is under discussion, it consists of a thinner beam pipe in the drift chosen to put our diamond sensors

Study Of HER

- Unlike LER, the HER showed non-linear distributions in the x-E plane, mainly due to chromaticity corrections, in addition to very low Bhabha rates
- No candidate place for our sensor is yet considered
- Search for a candidate place will be on going as an internship work subject by Oleg Shkola, National University of “Kiev-Mohyla academy”



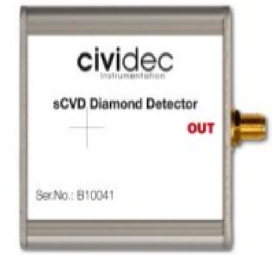
Diamond Sensors

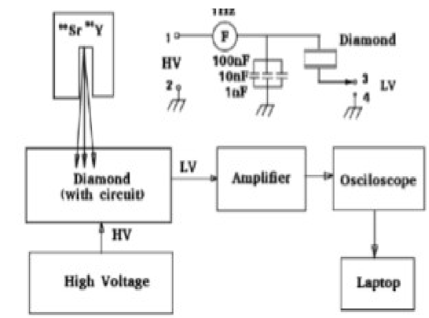
- Diamond sensor technology already exists at LAL since 2012 for Beam-halo study at ATF2 (prototype of ILC final focus) (Presentation of Viacheslav Kubytskyi)
- For SuperKEKB: signal width <1-2 ns,

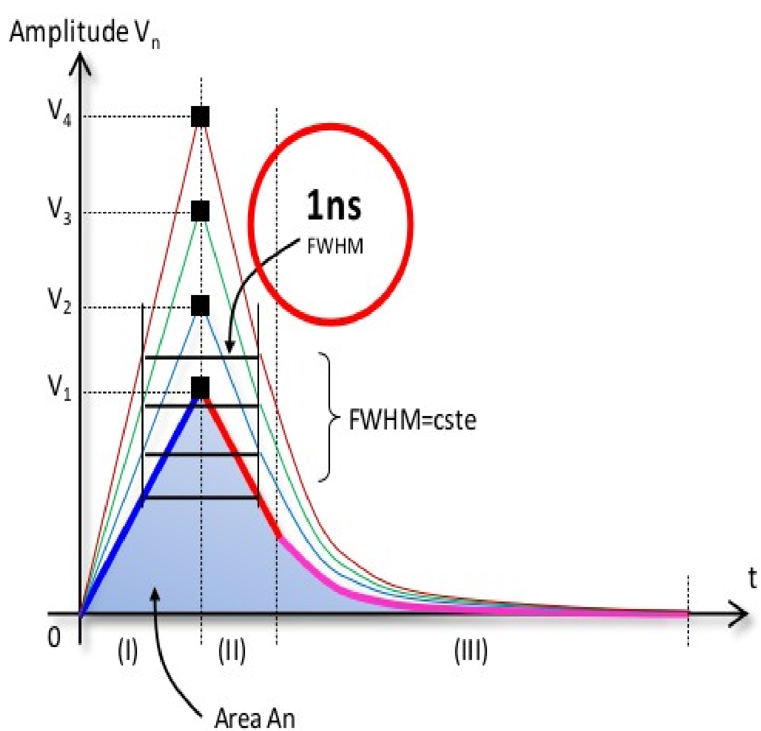
  since bunch spacing is 4 ns
- Charge amplifier : $\sigma = 10$ ns (shaping time)

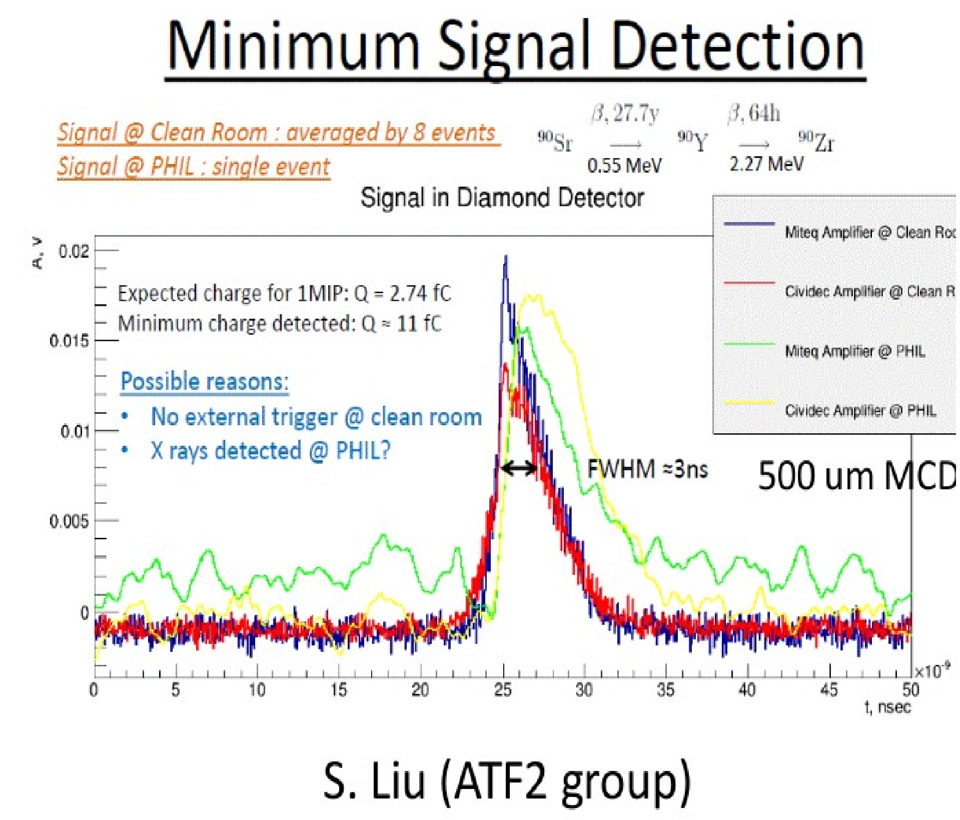
  → enough for phase 1 (average

  signal rate < 1 Bhabha per b.c)

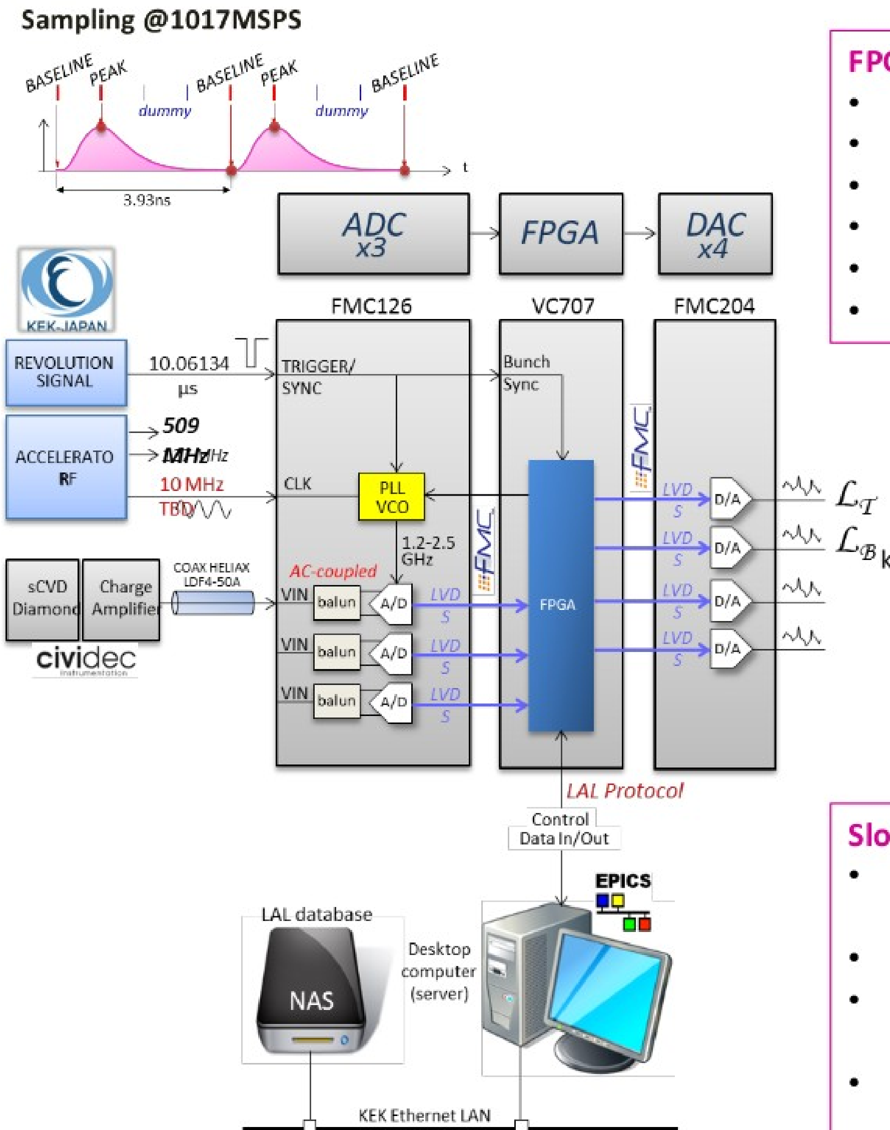








Readout



FPGA-based digital acquisition
- Synchronized to acc. RF Clock @ 10MHz
- Sampling every 1ns
- Phase adjustment by the ADC board
- Peak value acquisition : determines Bhabha events nb
- 2015 : signal FWHM 10ns (140µm diamond thickness)
- 2016 : signal FWHM ~2ns (100µm diamond thickness)

Outputs
- Train Integrated Luminosity over 1ms
- Bunch Integrated Lumi over 1ms : 2500 values @254 MHz

Slow Control / Interface
- Sampling controlled by local Linux machine (LM) connected to FPGA board
- TIL and BIL directly computed by FPGA and read by LM
- EPICS protocol installed on LM and provides TIL + BIL to EPICS users in real time (1ms)
- DAQ also comes with 4 Analog outputs
  Controlled by EPICS users
  Used for tests, debug and orbit feedback

Conclusions & Next Plans

- Fast Luminosity monitoring is very important for a feedback system and for optimization
- Optimal position of the sensor is to be at 13.9 meters from the IP in the LER …. For the HER, to be studied in the coming two months
- Simulations in Geant4, results in the necessity of having a window to increase our signals in the diamond
- A deep study of the design of a new vacuum chamber is taking place , using GEANT4
- Fast readout and electronics are under development to be able to monitor bunch by bunch luminosity
- Characterization tests of the 140 μm, 4x4 mm^2 diamond sensor with the fast 10 ns charge amplifier using α and β sources will take place in the clean room at LAL
- Due to delayed schedule, no beam-beam collision will take place during my thesis → A simulation study and measurements of the Bremsstrahlung process will take place in the context of background estimations
- Installation of the whole set-up will take place at KEK with the start of single beam commissioning at the end of 2015

THANK YOU !!!