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

Dima El Khechen
Cécile Rimbault
Philip Bambade
Viacheslav Kubytskyi
Didier Jehanno

Outline

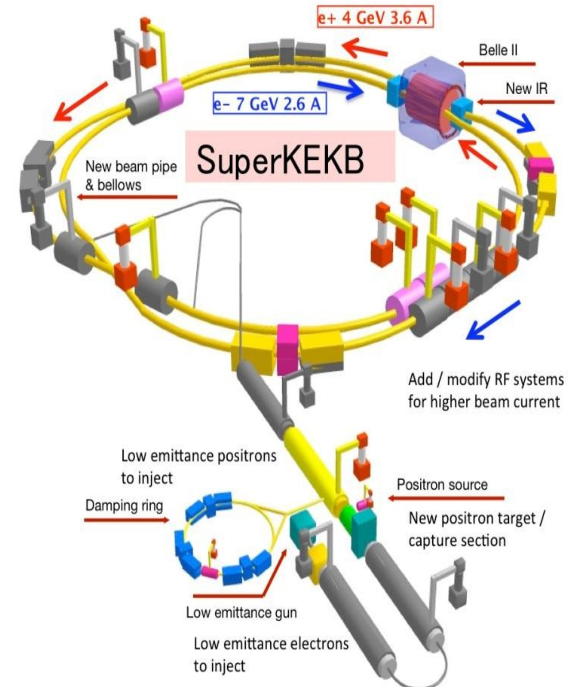
- Thesis activities and goals
- SuperKEKB: Definition and Status
- Fast luminosity monitoring:
  - ✓ Sensor location in LER
  - ✓ Geometry of the vacuum chamber
  - ✓ HER
- Preliminary results on Cherenkov and Scintillator detectors
- Readout and electronics
- Conclusion & Next Plans

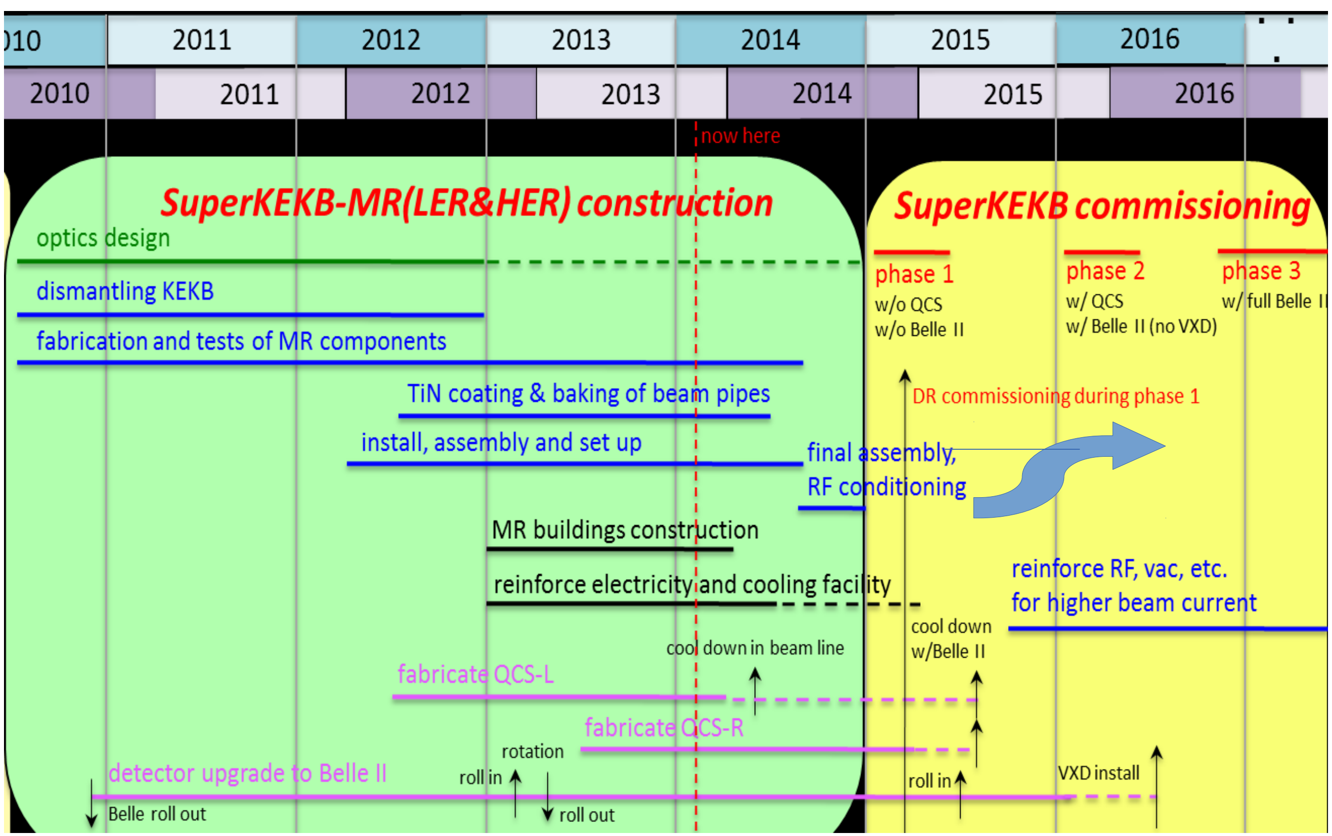
Thesis Activities And Goals

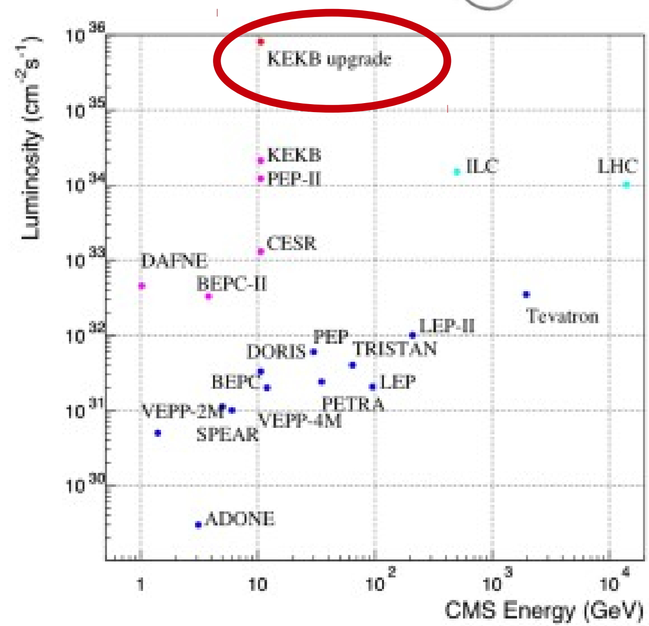
- Development of methodology for fast monitoring of the SuperKEKB high luminosity B meson factory
- Characterisation of diamond sensor technology
- Beam dynamics simulation to establish optimal measurement locations
- GEANT4 simulation to optimise mechanical set-up and define readout of the ZDLM of Belle II experiment at SuperKEKB
- Simulation of Background processes (ex: Beam-gas Bremsstrahlung)
- Installation and first tests at KEK during beam commissioning
- Development and implementation of fast analog electronic shaping and fast digitisation for on-line bunch-to-bunch and overall luminosity averaging

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)







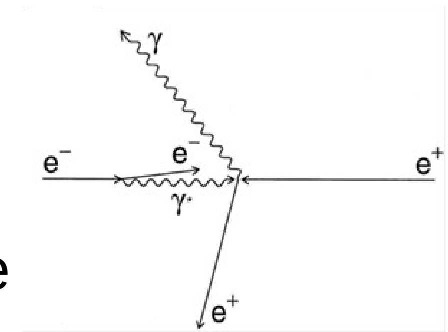
Fast Luminosity Monitoring

- 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

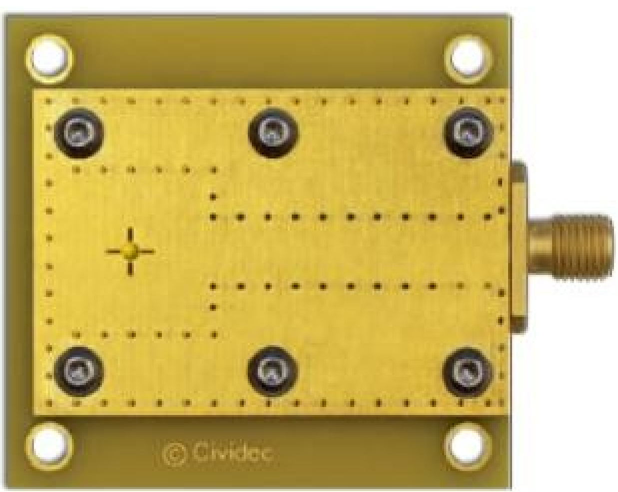
- Lumi monitoring for each bunch crossing: 2500 bunches, collide each 4 ns

- Measurement: Radiative Bhabha process at zero photon scattering angle , Large cross-section ~ 0.2 barn

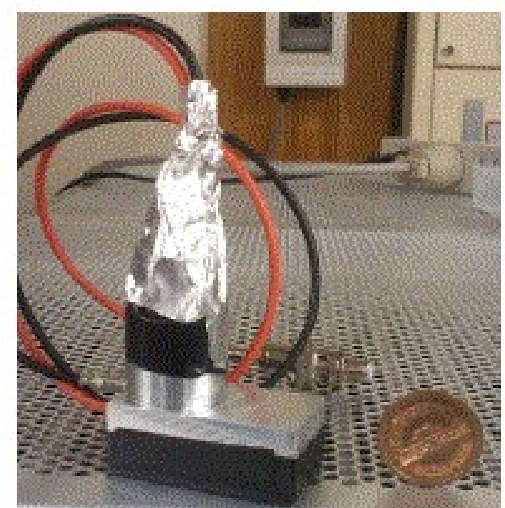


- Technologies: Sensors set immediately outside beam pipe

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



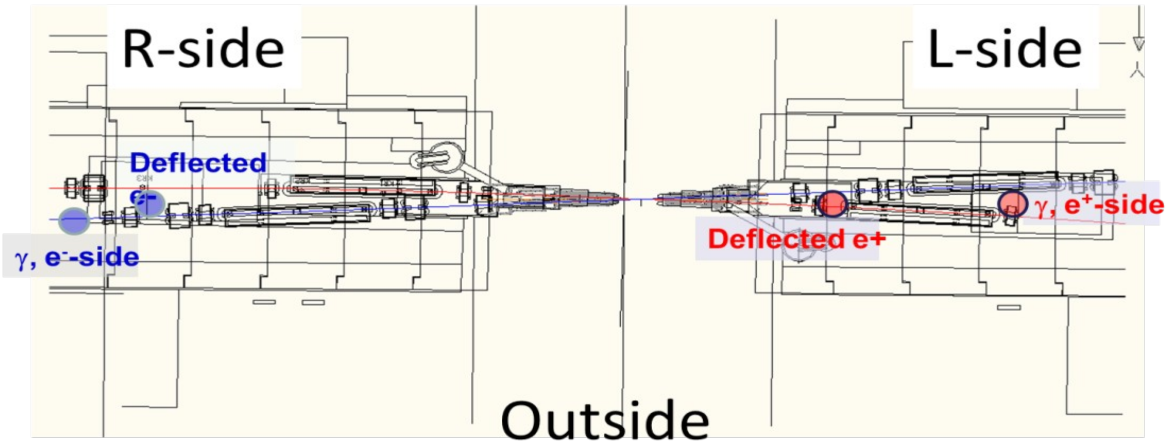
  -Scintillator + Cherenkov detector

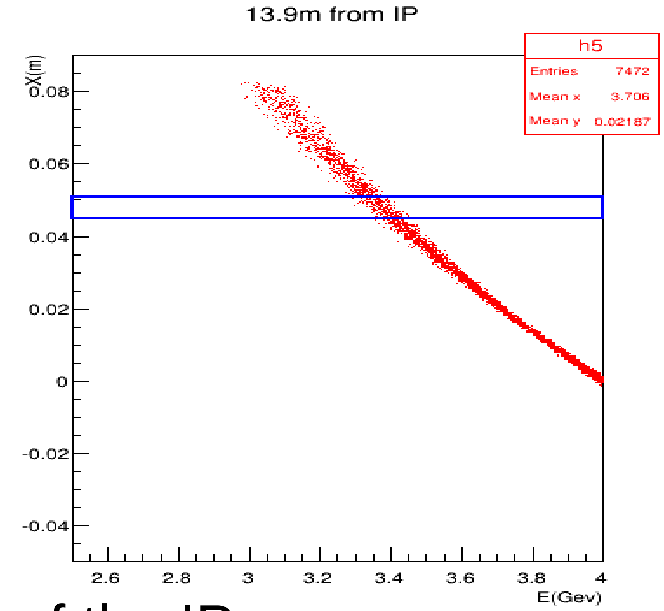


ZDLM group at KEK, S.Uehara San

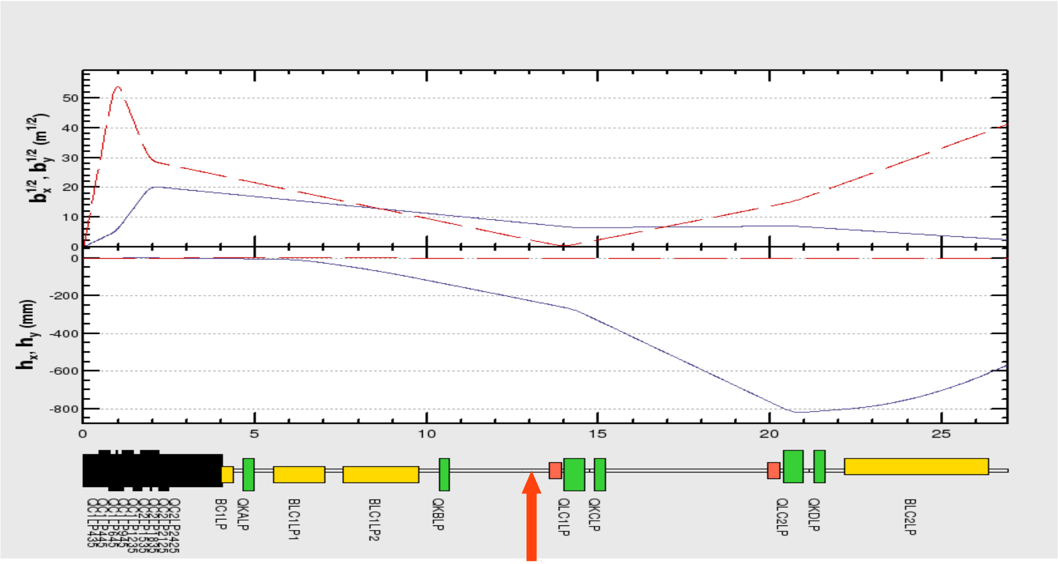
Sensor Location in LER

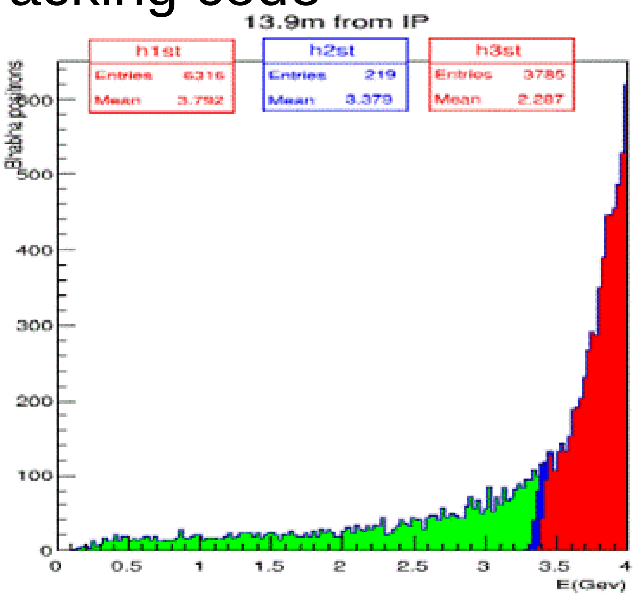
- Bhabha dynamics have been generated by GUINEA-PIG++





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





Sensor Location in LER

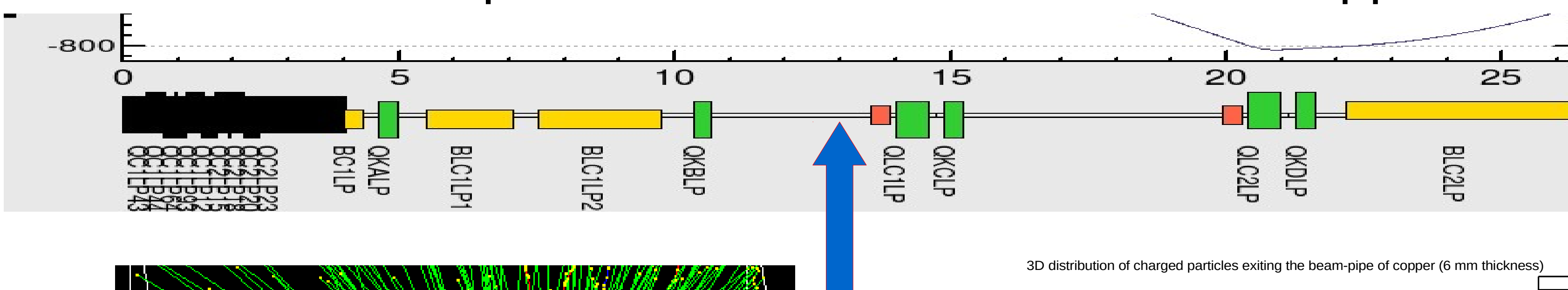
- To reach the aimed precisions, the following counting rates are required:

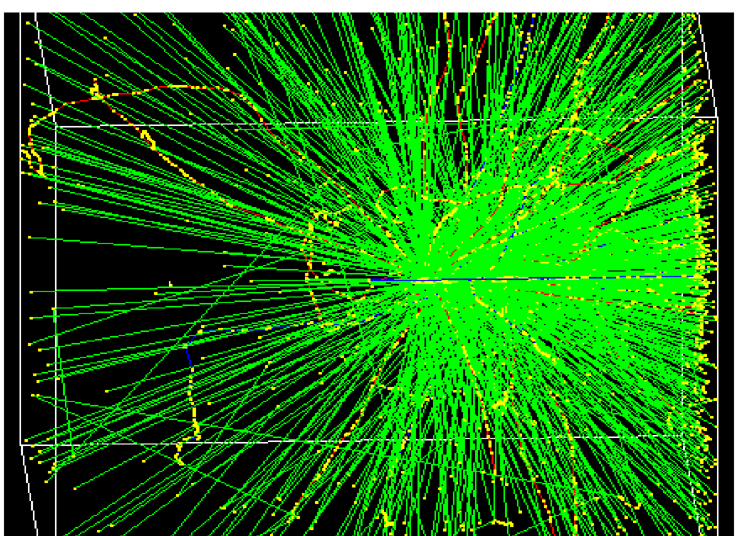
Luminosity ($cm^{-2} s^{-1}$)	Aimed precision (in 1 ms)	Required fraction of $\sigma_{ee \to ee\gamma}$
10^{34}	10^{-2}	2.1×10^{-3}
$8\ 10^{35}$	10^{-3}	2.6×10^{-3}

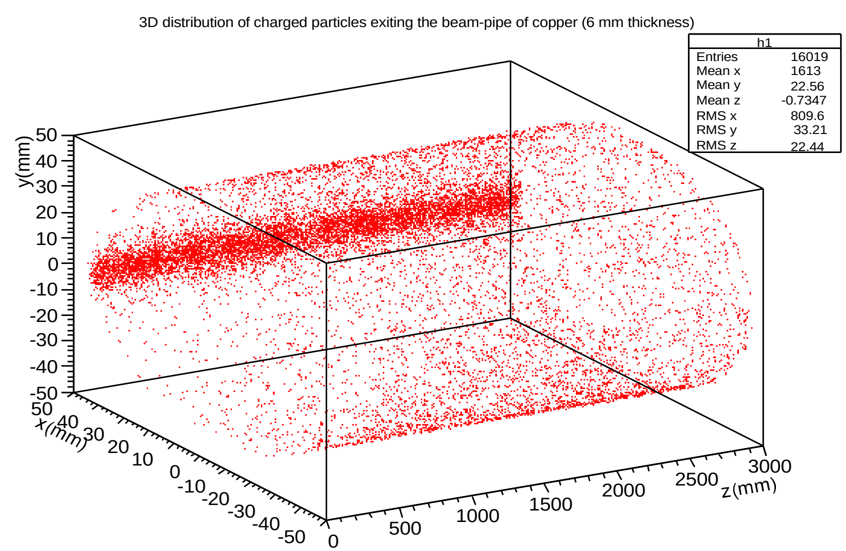
- The best candidate position is chosen to be at 13.9 meters from the IP:

✓ 3 meters drift , adequate to place our sensors

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

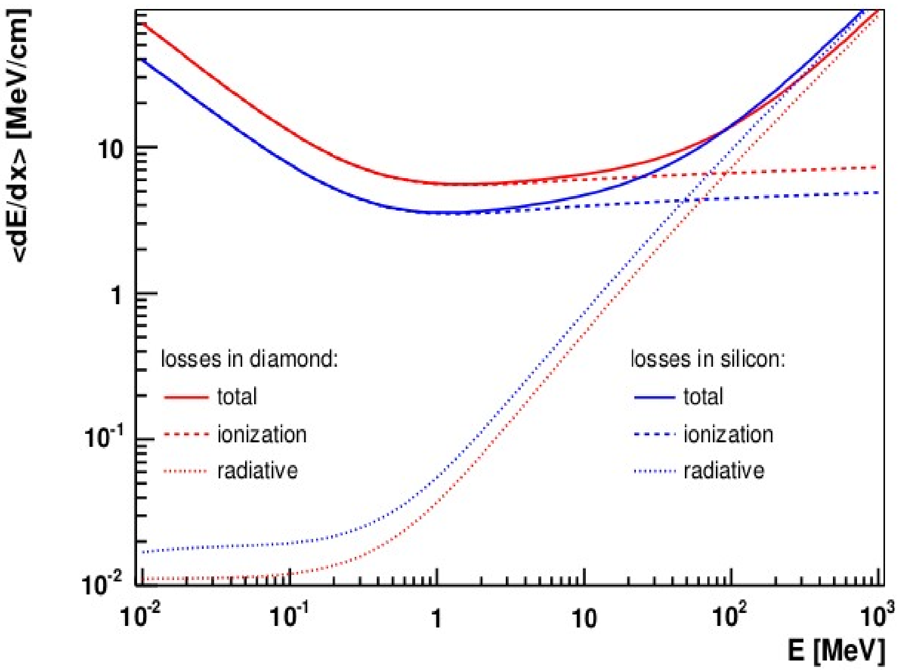






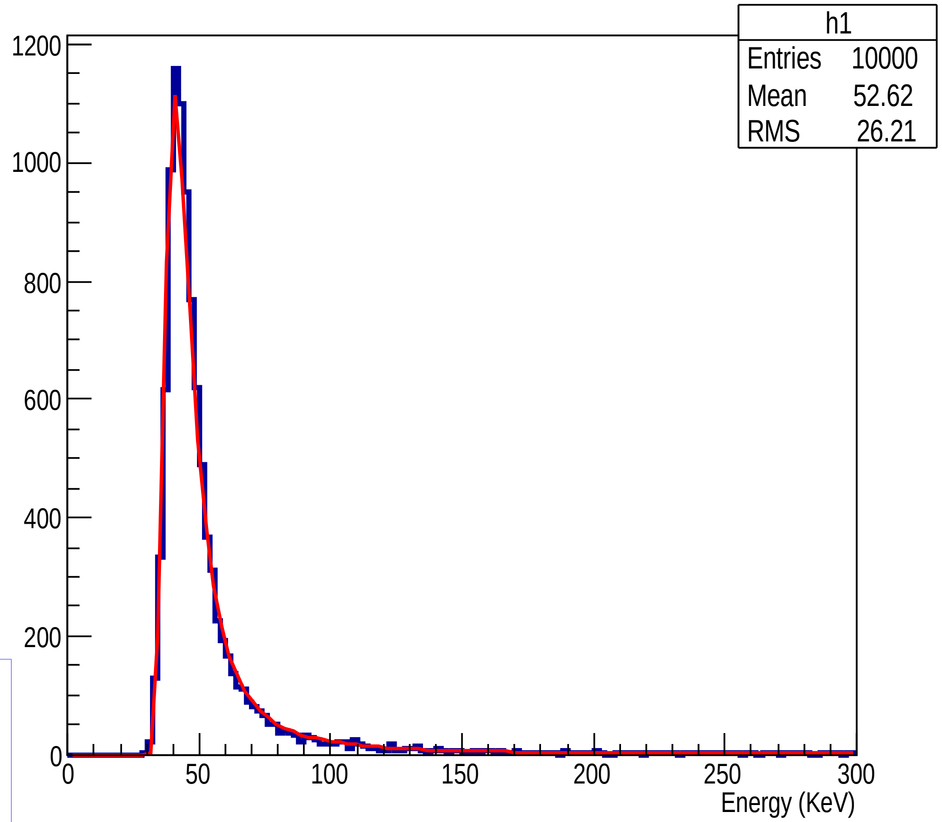
Energy Deposition of e+/e- in a 100um Diamond

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



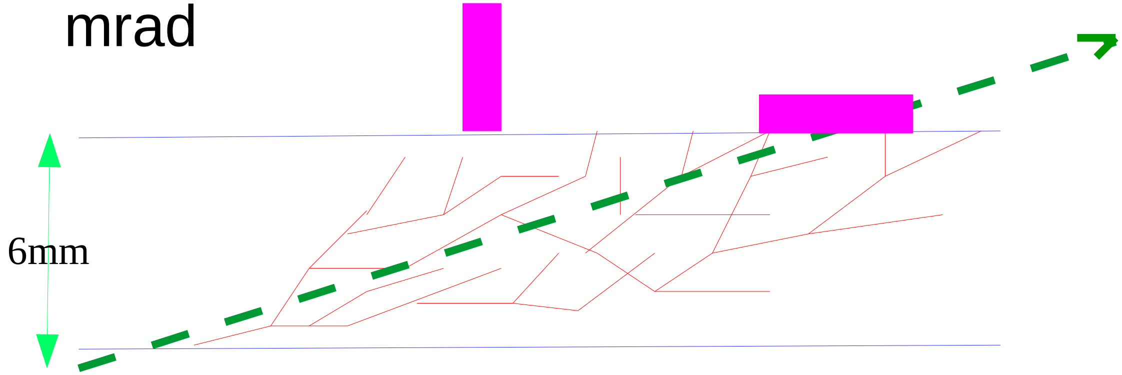
The mean energy losses of an electron in diamond (red curves) and silicon (blue curves)

Energy deposited in 100 μm diamond



Geometry of Vacuum Chamber

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

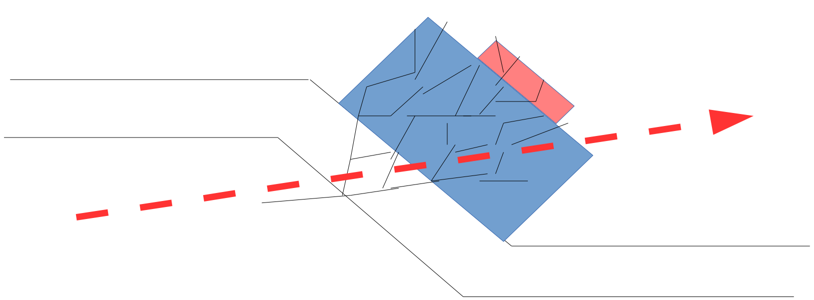


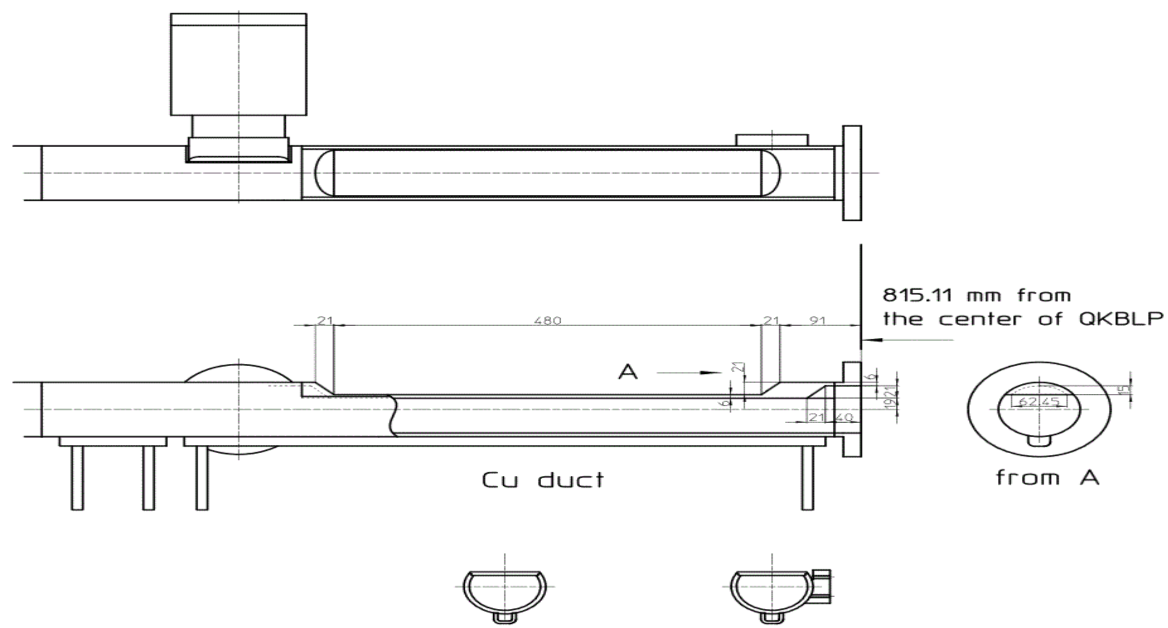
- The particle will cross 1.2 meters in the copper ~ 80 radiation lengths ➡

  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



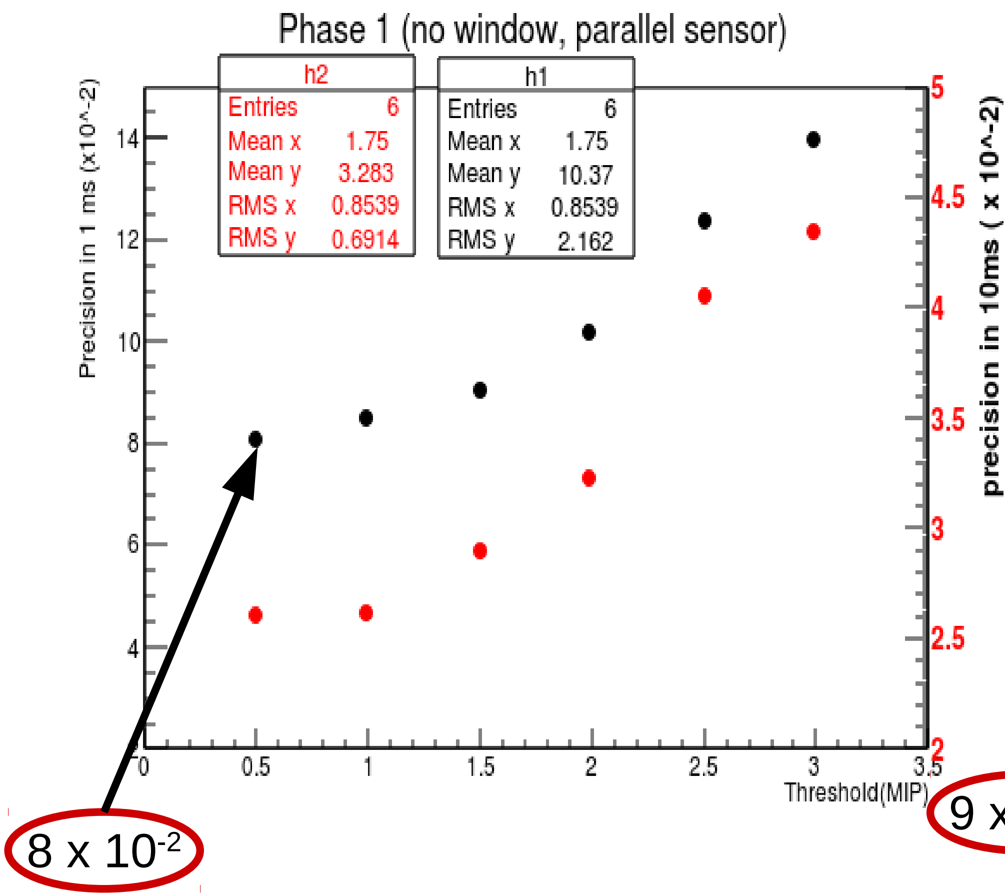


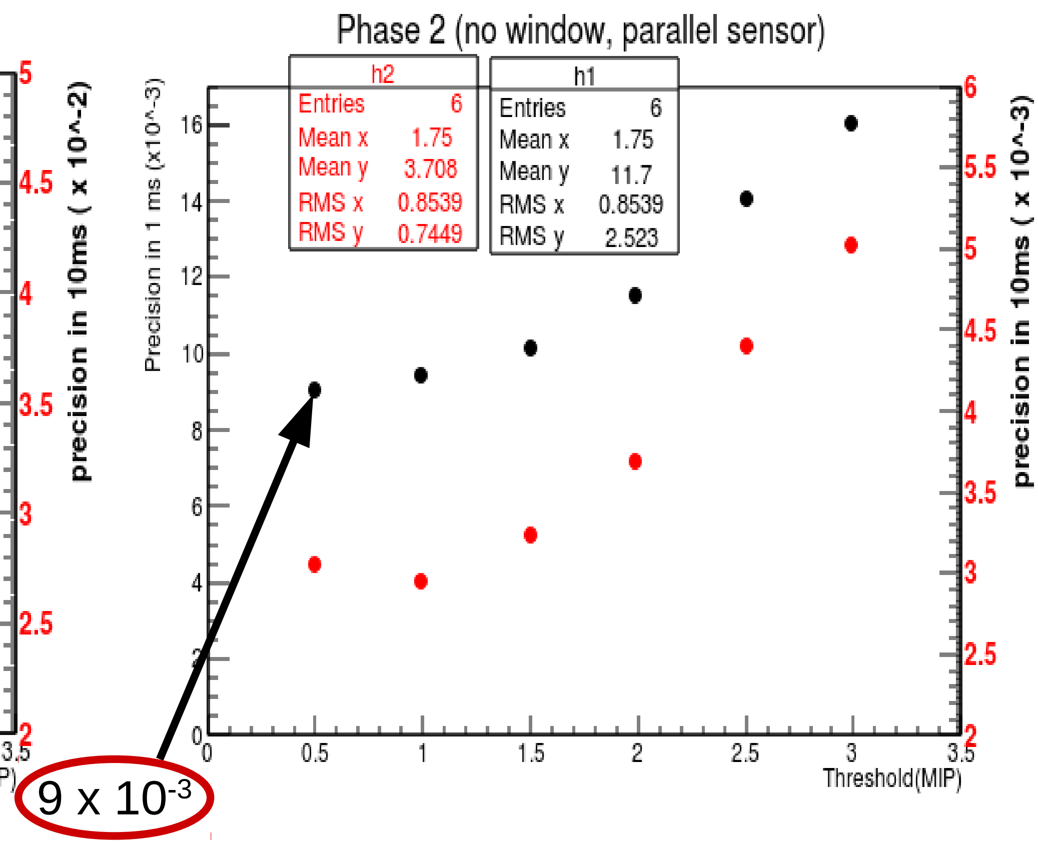
A Summary Table of collected secondaries

	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

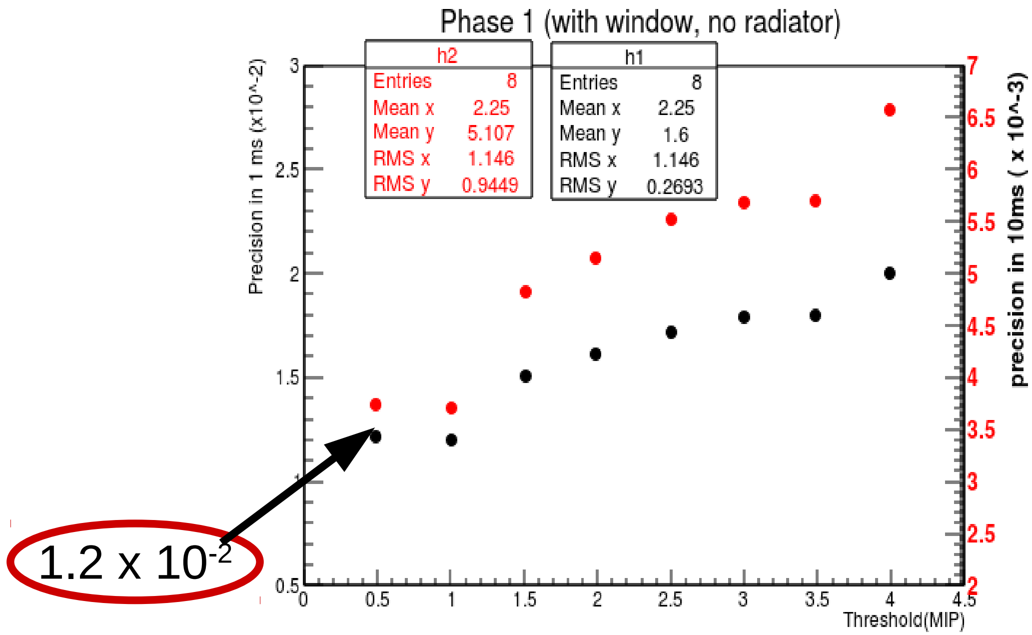


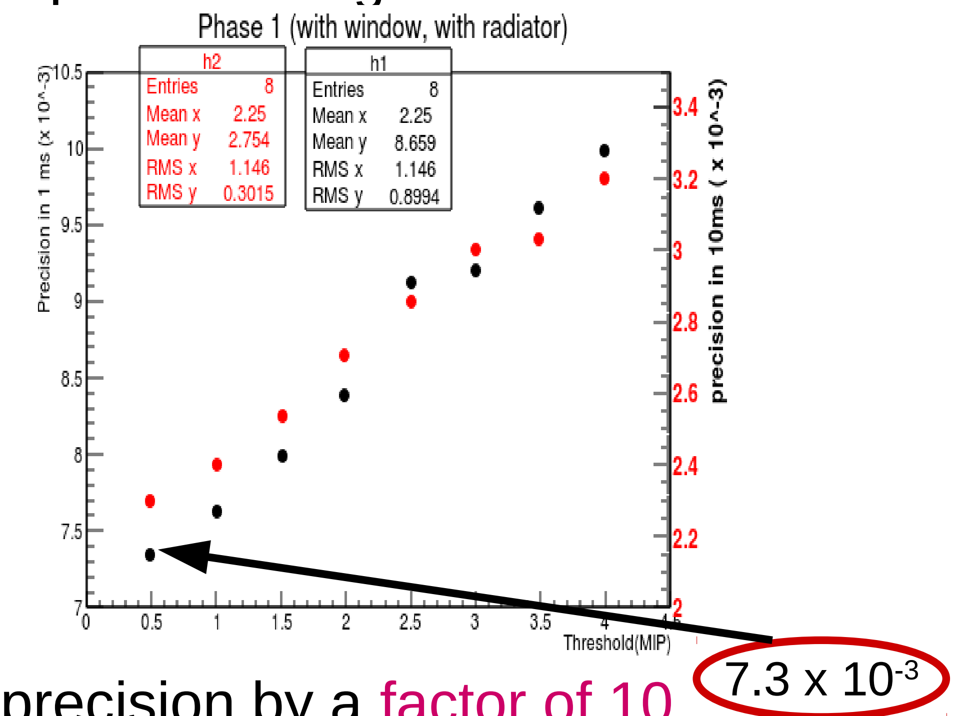


In the case of a normal cylindrical beam pipe, precisions are too far from the required one, even for the optimal luminosity (8 10^{35} cm^{-2} s^{-1})

GEANT4 Simulation Results

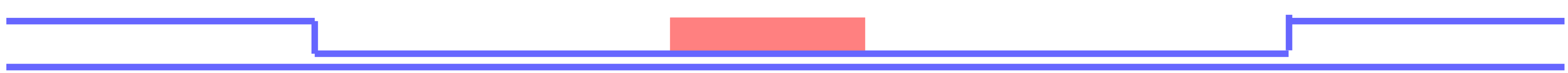
- Advantage of having a window at 45 degrees is the possibility of placing a radiator at shower max to improve the signal in the sensor.





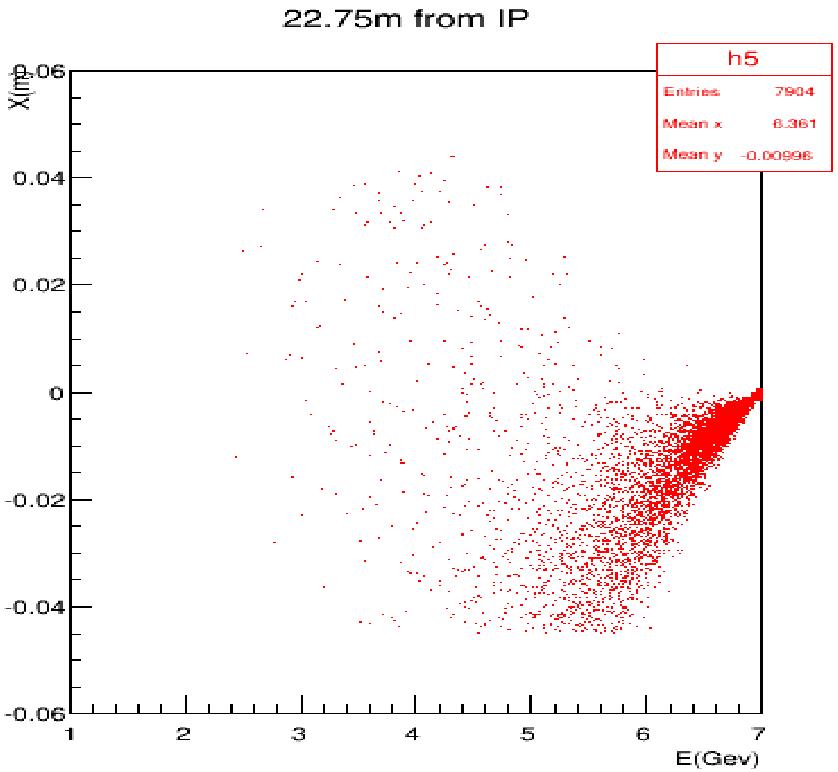
- Presence of a window improves the precision by a factor of 10

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



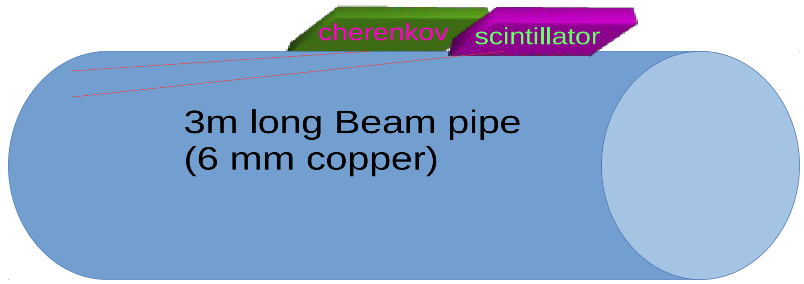
Study Of HER

- 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”



Preliminary Results on Cherenkov And Scintillator Detectors

- 15 mm x 15 mm x 50 mm
- Charged particles of path length λ >15 mm are considered
- Cherenkov : Pure Quartz SiO_2 , density= 2.7 g/cm^3
- Scintillator: LGSO : $Lu_{1.8}Gd_{0.2}SiO_5$, density= 7.3 g/cm^3



- Detectors are simulated in two manners

1) Independently (events in each detector separately)

2) In coincidence (Poisson distribution)

Preliminary Results

Independently

Luminosity ($cm^{-2} s^{-1}$)	Precision in 1 ms	Precision in 10 ms
10^{34}	2×10^{-2}	6.5×10^{-3}
10^{35}	6.5×10^{-3}	2.04×10^{-3}

In coincidence

Luminosity ($cm^{-2} s^{-1}$)	Precision in 1 ms	Precision in 10 ms
10^{34}	0.2	6.3×10^{-2}
10^{35}	2.2×10^{-2}	6.9×10^{-3}

→ Precisions are 4 times better than the case of 5x5 mm^2 diamond for independent detectors

→ Precisions are 2.5 times worse than the case of 5x5 mm^2 diamond for coincidence case

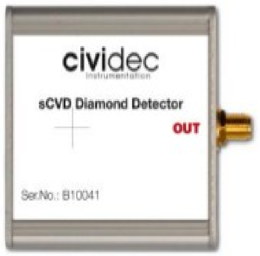
Diamond Sensors

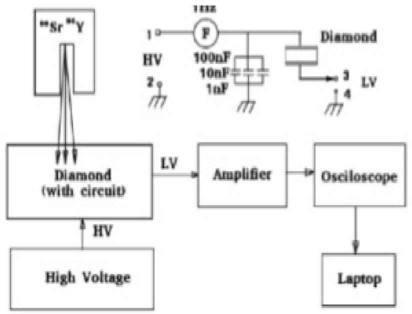
- Diamond sensor technology already exists at LAL since 2012 for Beam-halo study at ATF2 (prototype of ILC final focus)
- For SuperKEKB: signal width <1-2 ns,

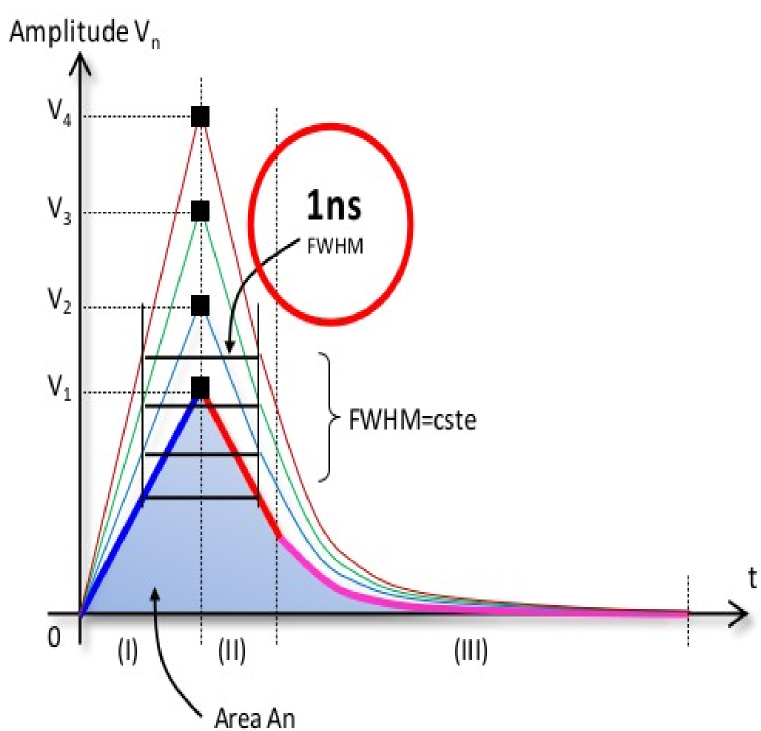
  since bunch spacing is 4 ns
- Charge amplifier : $\sigma = 10$ ns (shaping time)

  → enough for phase 1 (average

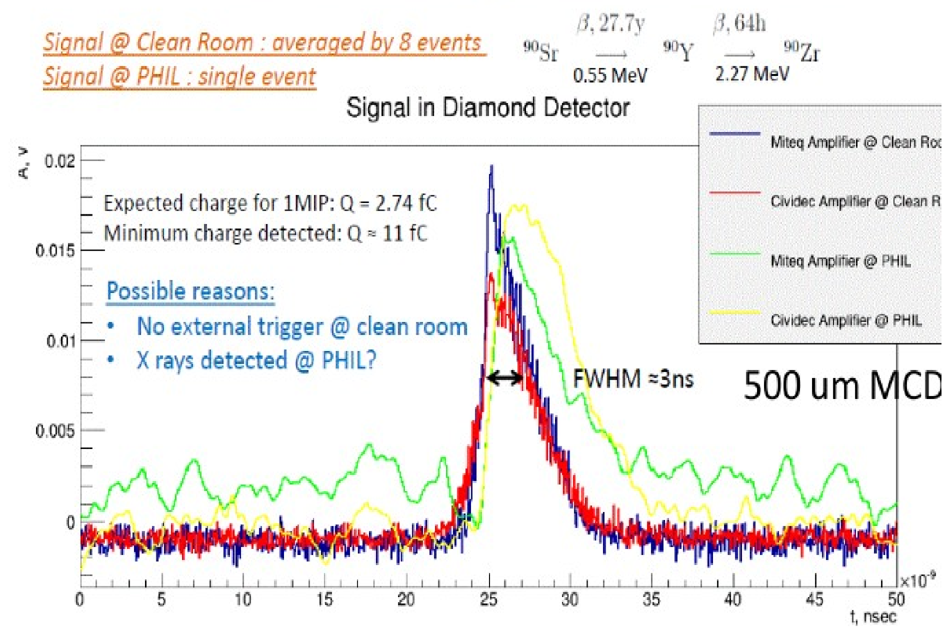
  signal rate < 1 Bhabha per b.c)







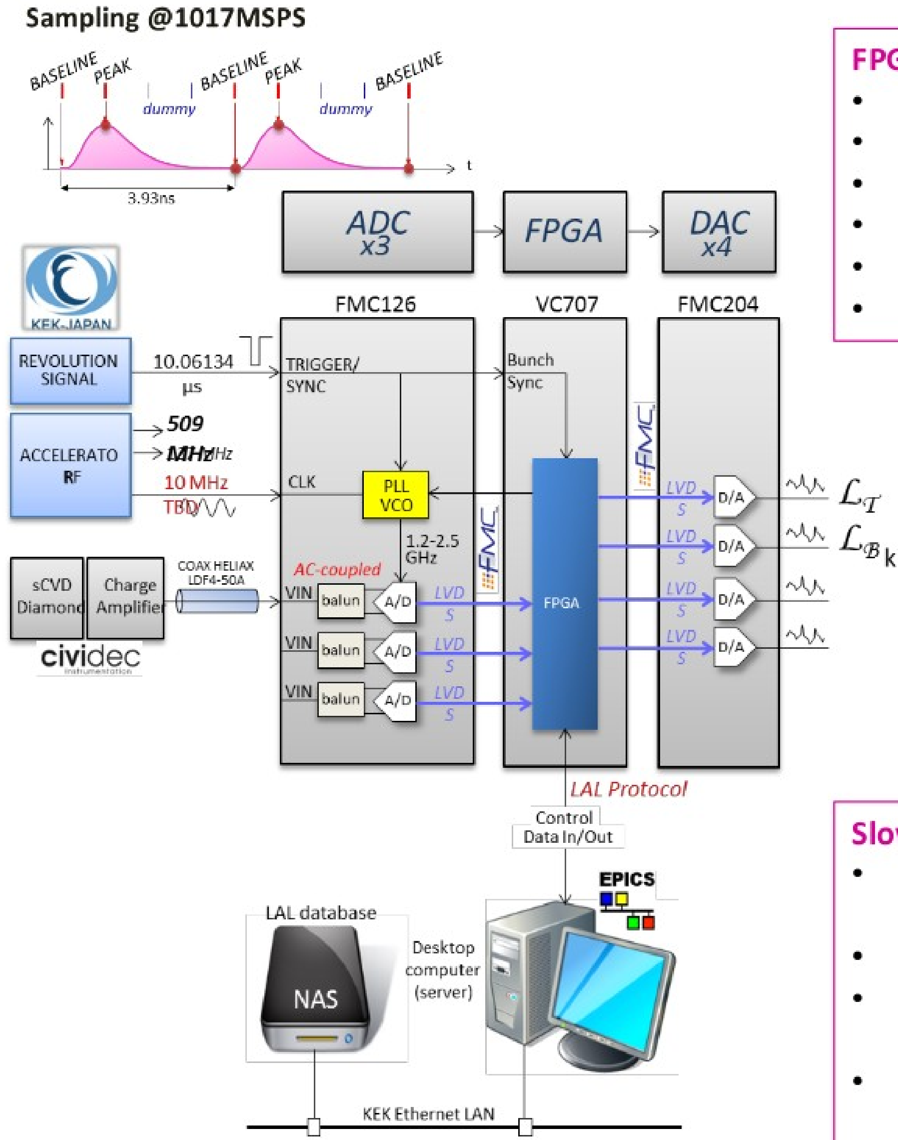
Minimum Signal Detection



S. Liu (ATF2 group)

Readout

Work carried on by Didier Jehanno



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
- Study of the Cherenkov and Scintillation detectors to be improved (yet not a priority of our work)
- 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 of SuperKEKB project, 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 studies
- 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 !!!

Explanations & precisions

- Total number of positrons that exit the beam-pipe over 3 m is 971 → 4.7% of the total cross-section
- Average number of positrons is 75.4 —Averaging→ 75.4 / 971 = 0.078
- Number of signals per b.c is $\nu = 3 \times 0.078 \times 4.7\% = 0.01$ (each 4 ns)
- Number of signals in the sensor in 1 ms is N= 2500
- Precision is 1/sqrt(N)

➢ Detectors in coincidence implies to have at least one signal in both at the same time from the same bunch crossing

➢ Poisson distribution is given as $P(n,\nu)=\frac{\nu^n e^{-\nu}}{n!}$, probability to get n signals in the sensors for the case of an average of ν signals

➢ $P_1=P_2= P(0,0.01)= 0.99$; $P'_1=P'_2= 1- P_1=0.01$ (is the probability to have at least one signal in one of the two counters)

➢ $P_1' \times P_2' = 1- P(0,\nu)$, **ν=??** → Obtain precision from by calculating an effective number of signals corresponding to the coincidence