Fast Luminosity Monitoring Using Diamond Sensor for SuperKEKB

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Outline

→ **Overview of the project: Aims & techniques**

→ **Luminosity measurement:**

- Radiative Bhabha at zero photon scattering angle & optimal position of sensors in LER (e^+)
- Status of HER (γ)
- Results with GEANT4 and design of the beam-pipe for phase 2

→ **Diamond sensors:**

- characteristics and tests
- DAQ layout and readout for Phase2 and 3

→ **Single beam losses at phase1**

- Data acquisition
- Data vs simulation

→ **Summary and next plans**

SuperKEKB

- Belle II @ SuperKEKB: e^+e^- collider (e^+ @ 4 GeV (LER) & e^- @ 7 GeV (HER)) , to study CP violation in the B meson sector and search for NP

  beyond the SM

- High Luminosity (design luminosity: 8 10^{35} cm^{-2} s^{-1})

→ Nano-beam scheme, very small beam sizes (60 nm),

  large crossing angle 2ϕ = 83 mrad

→ High currents (beams collide @ 0.25 GHz)

→ **Phases of commissioning**:

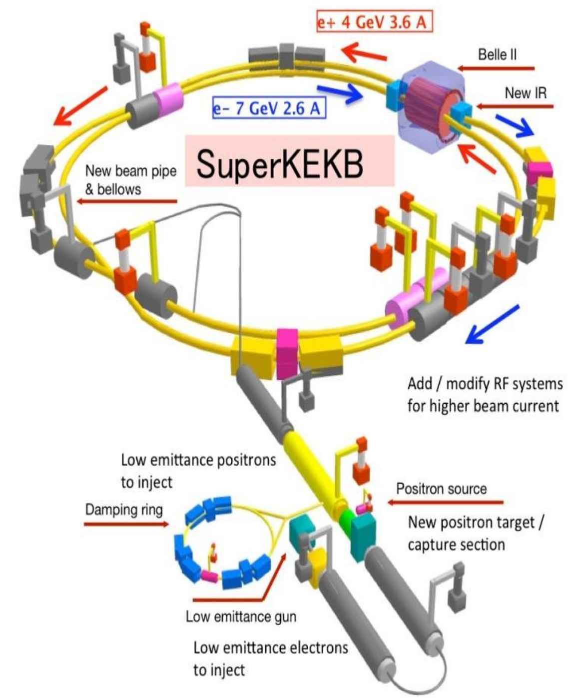
→ **Phase 1**: Single beam commissioning of LER and HER,

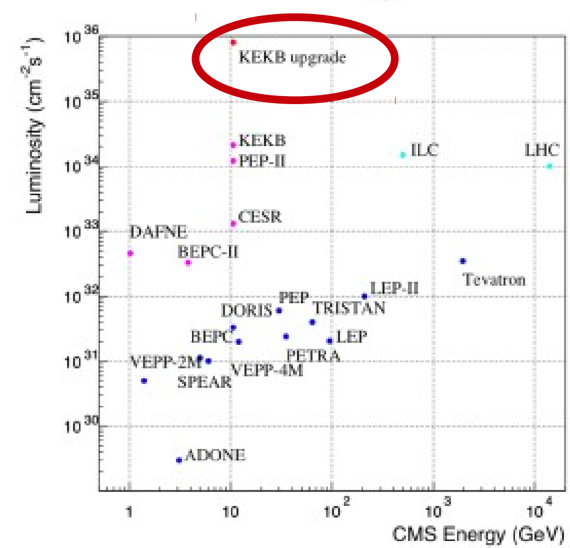
  NO COLLISION, NO LUMINOSITY (Feb-June 2016)

→ **Phase 2**: Insertion of High focusing quadrupoles,

  $\mathcal{L}$=10^{34} $cm^{-2}s^{-1}$

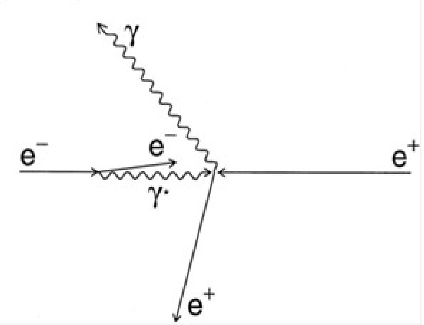
→ **Phase 3:** $\mathcal{L}$= 10^{35} $cm^{-2}s^{-1}$





Aims And Techniques

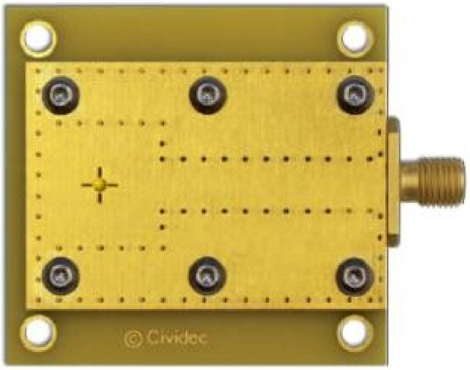
- Fast luminosity monitoring is required in the presence of dynamical imperfections, for feedback and optimization.
- Precision $\delta\mathcal{L}/\mathcal{L} = 10^{-3}$ in 1 to 10 ms
- Lumi monitoring for each bunch crossing: 2500 bunches, collide each 4 ns
- Measurement: Radiative Bhabha process at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



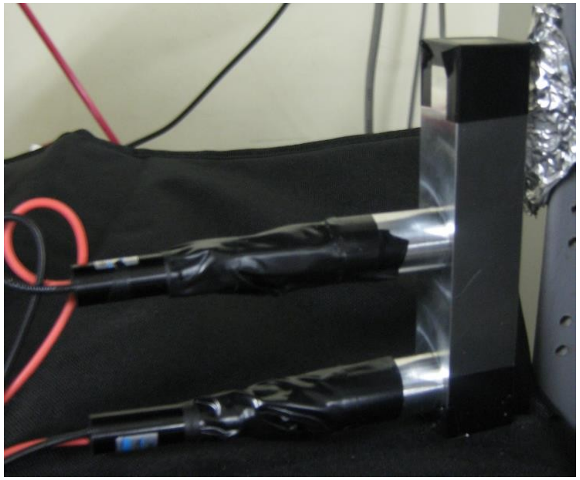
- Technologies: Sensors installed immediately outside beam

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

  -Scintillator + Cherenkov detectors

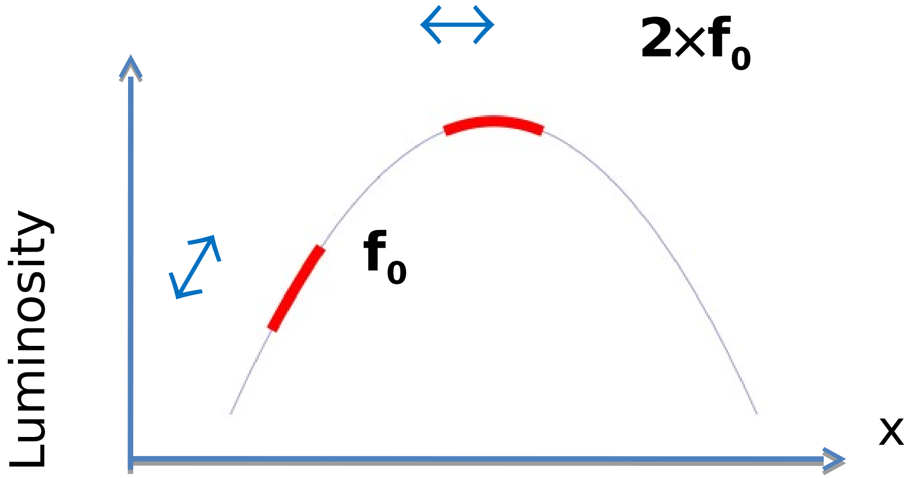


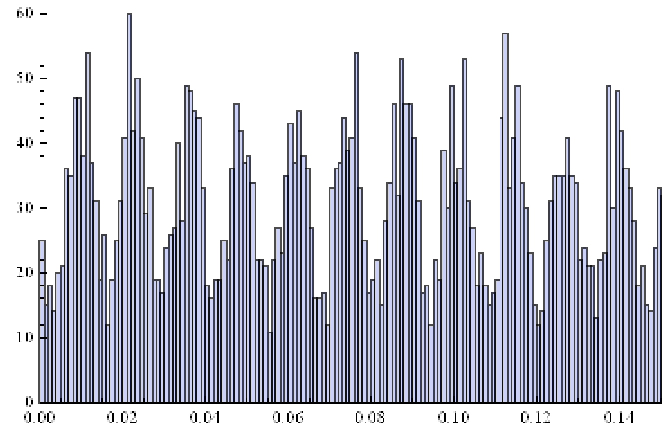
LAL group

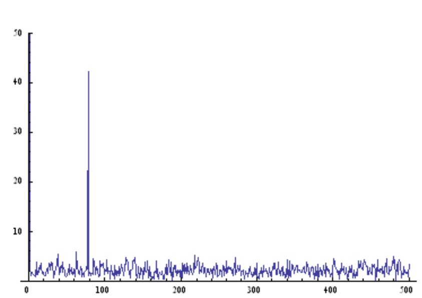


ZDLM group at KEK, S.Uehara San

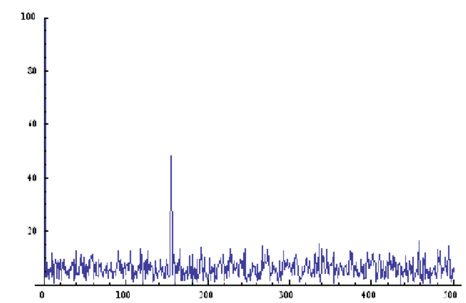
Specifications







Base frequency



Double frequency

→ **Dithering feedback for the horizontal alignment of the beams at IP, the necessary corrections are anticipated at a frequency ~ 1 Hz**

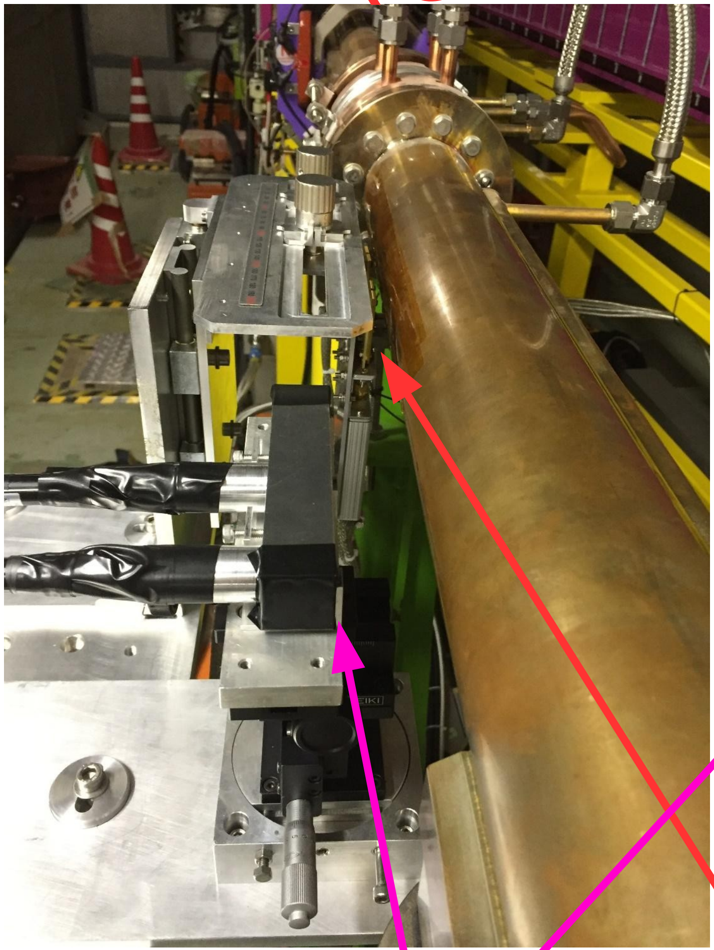
→ **Dithering frequency f_0= 77 Hz ; We sample ~ 10 times faster @ 1 KHz (each 1 ms)**

→ **Goal: minimize f_0 output component**

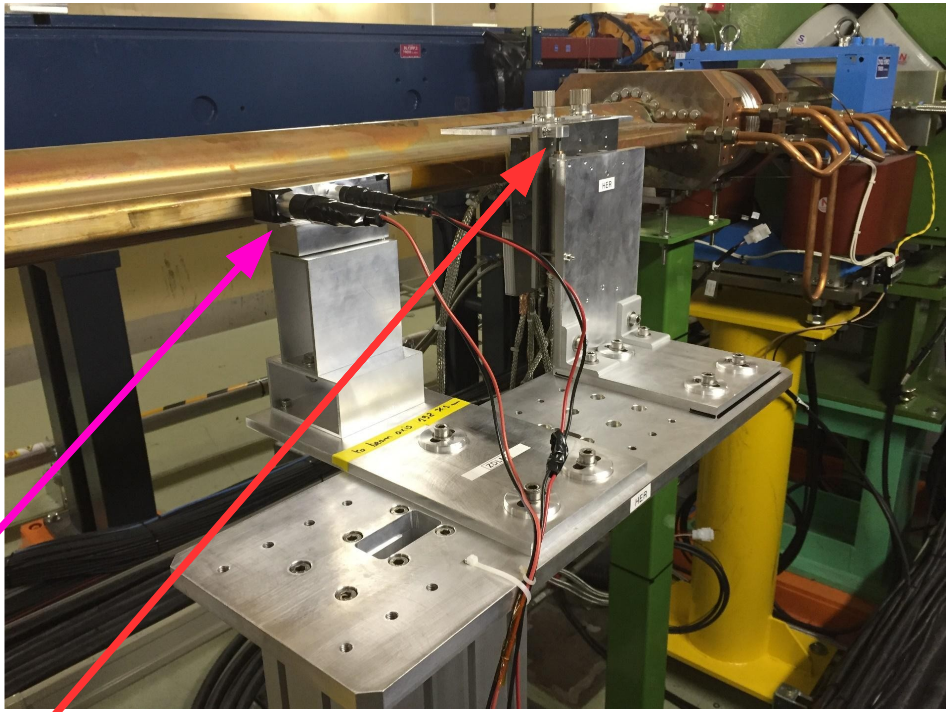
→ **Simulations done by S.Uehara at KEK show that a rate 400 KHz (precision ~ 10^{-3}) in 1 ms is enough for the feedback**

Installation

LER (@ 11.9 m)



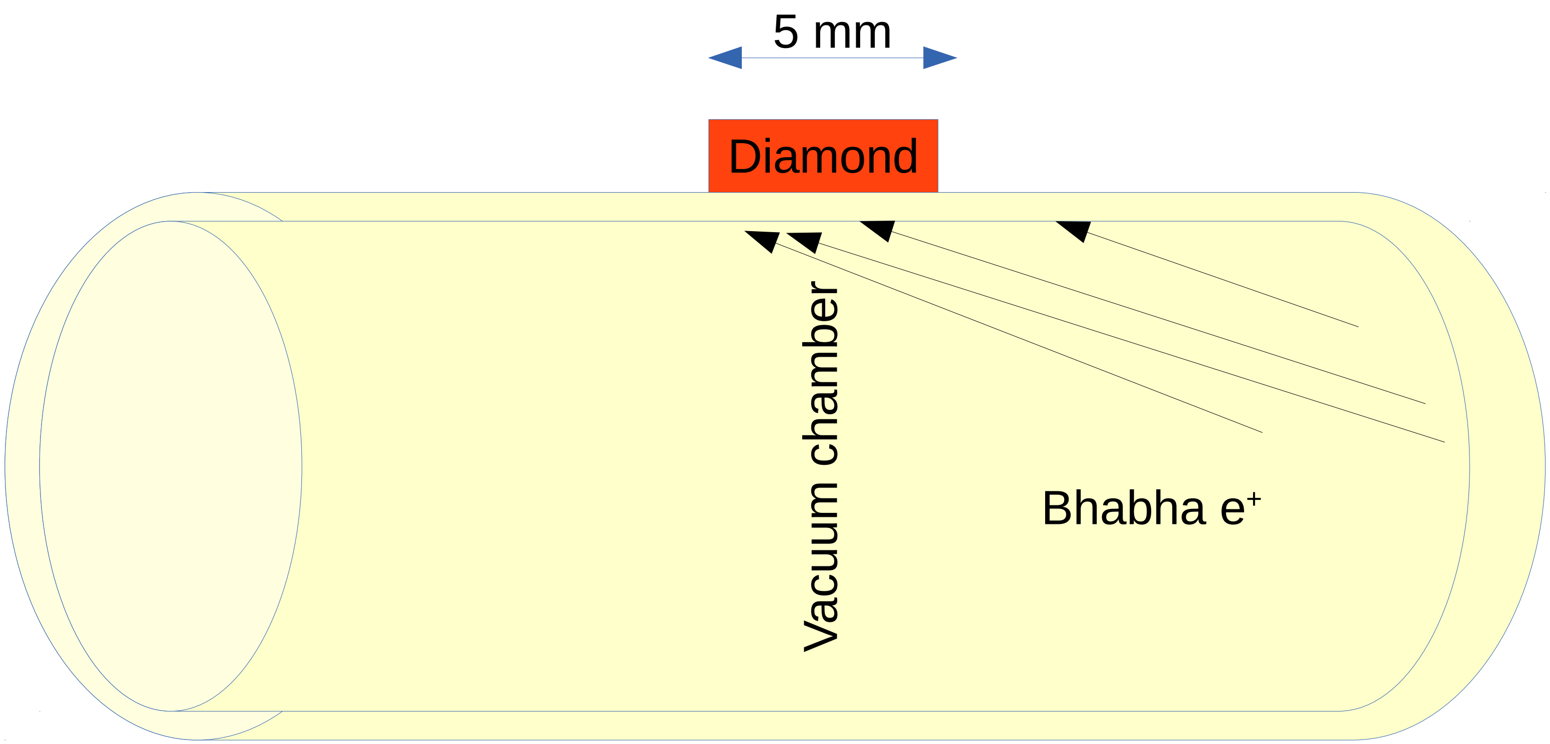
HER (@ 30 m)



Diamond sensors

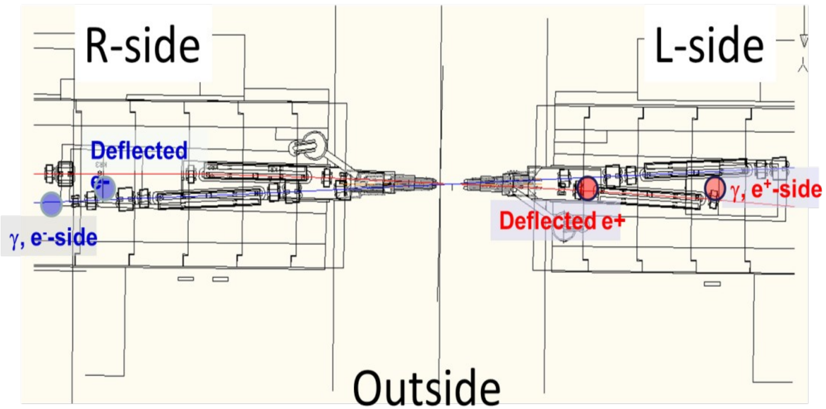
Cherenkov and crystal scintillator

Experimental Setup

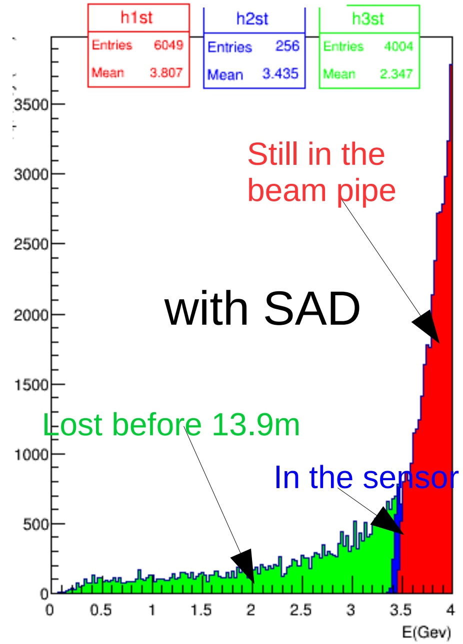


Status of LER

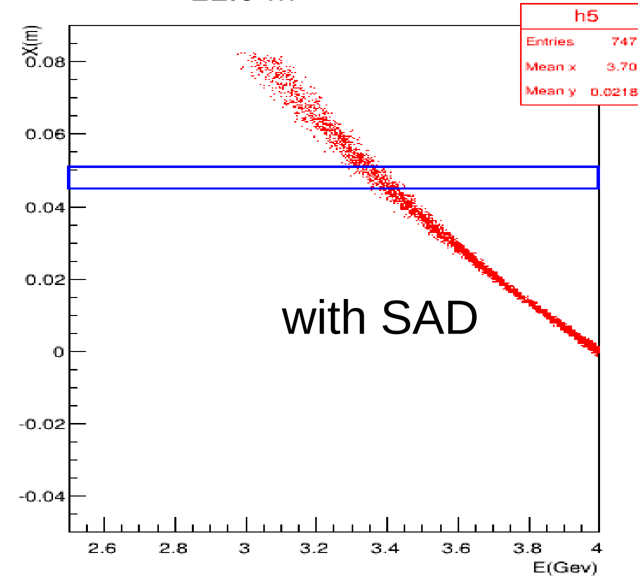
Radiative Bhabha at zero photon scattering angle at IP



11.9 m



11.9 m



→ Bhabha dynamics is generated by ***GuineaPIG++*** and tracked by ***SAD***

→ The low energy Bhabha positrons are lost downstream the IP (After bending magnets, quadrupoles, and in the drifts ….)

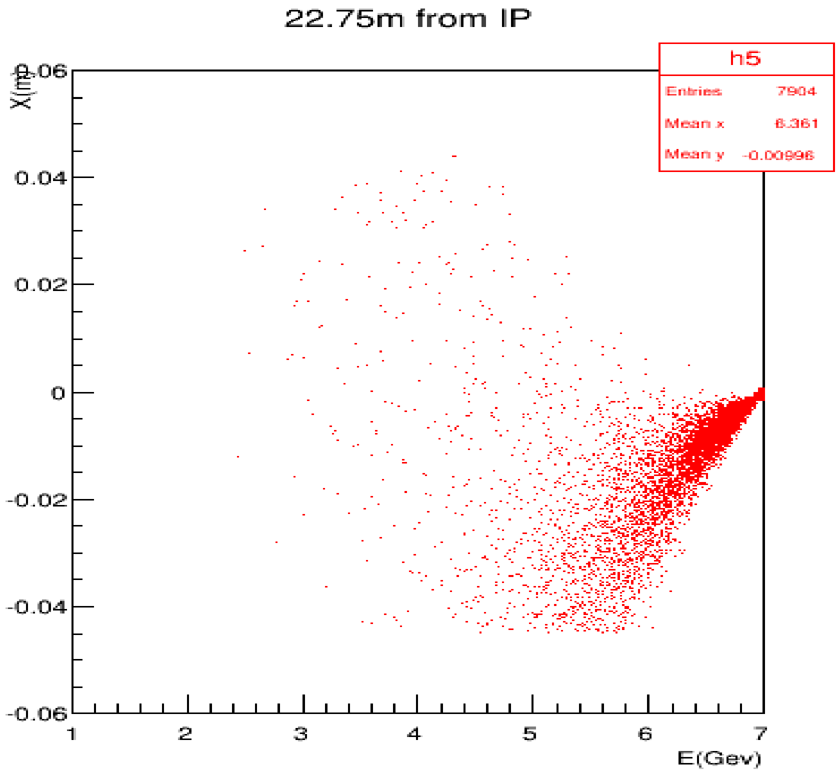
→ At 11.9 m, the fraction of lost Bhabha positrons (4.7% of the total cross-section) is sufficient, and the geometry is good to place the sensors (3m drift)

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}

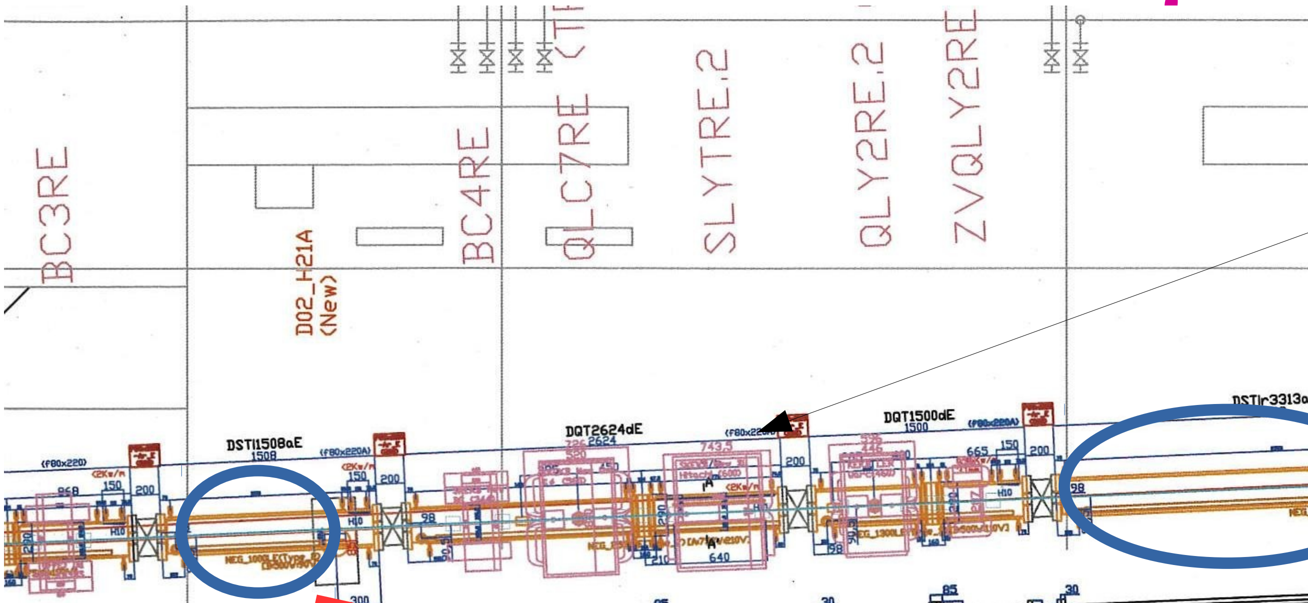
Status of HER

→ Unlike LER, the HER show non-linear distributions in the x-E plane, mainly due to chromaticity corrections, in addition to very low Bhabha rates

→ Switch to study the Bhabha scattered photons in the HER at ~ 27 m from the IP

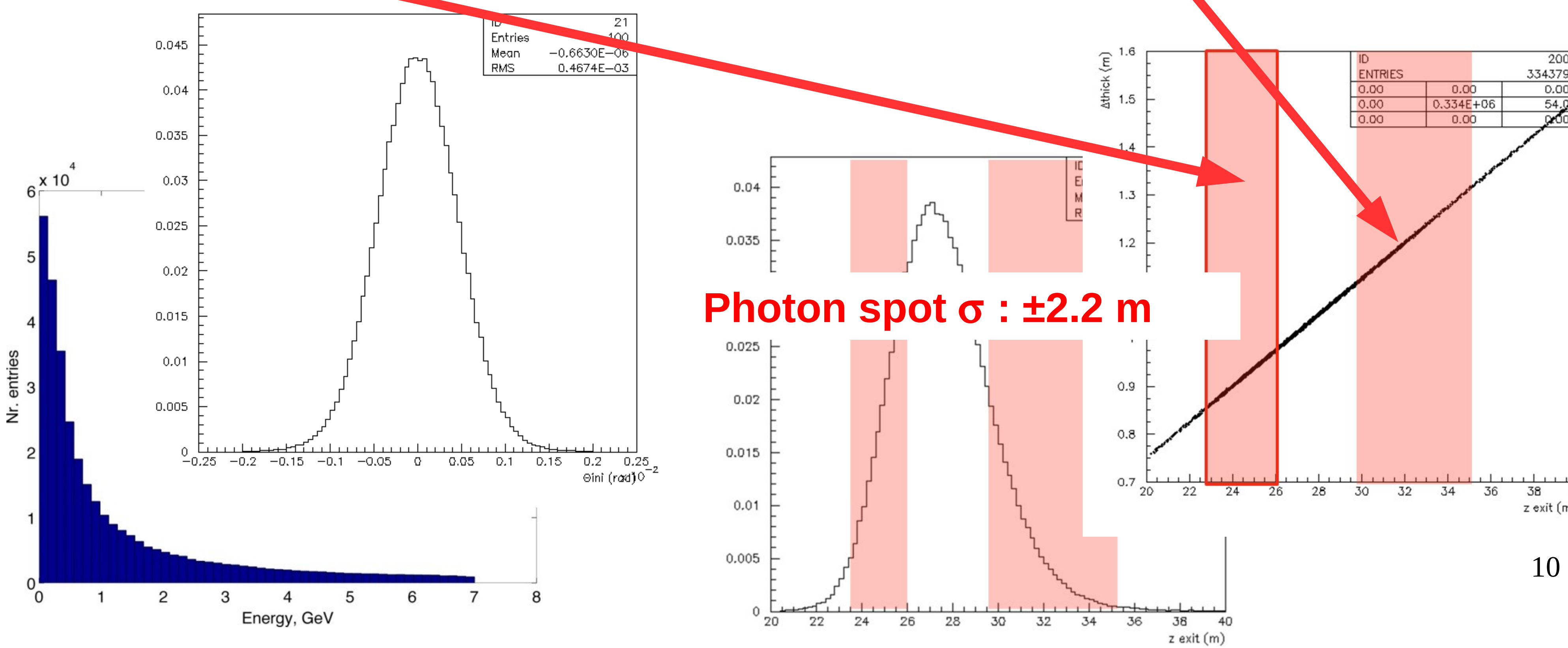


Sensor locations in HER : γ detection?



γ spot hits anti-chamber edge at SLYTRE2 (~ 27.4m downstream IP), with a mean angle of 5.9 mrad

Diamond sensors are chosen to be placed at 30 m



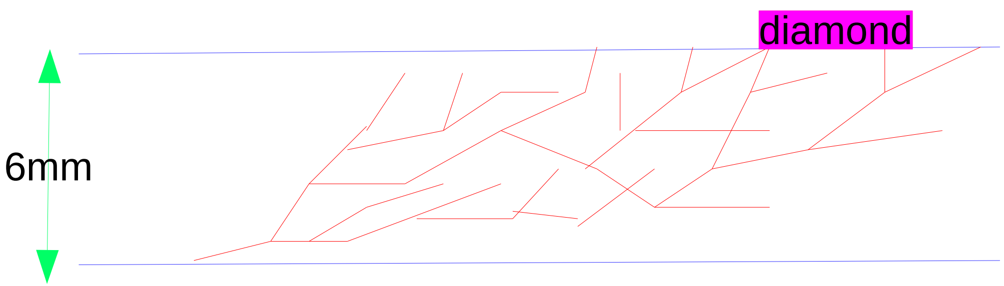
GEANT4 (signal in the detector) (LER)

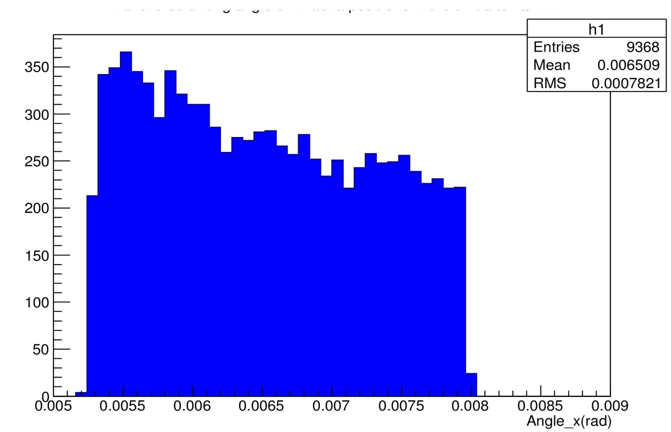
→**Geant4 simulations** taking into account the geometry and the material of the beampipe were performed

→ The positrons exit the 6mm Cu vacuum chamber at an average angle of 5 mrad

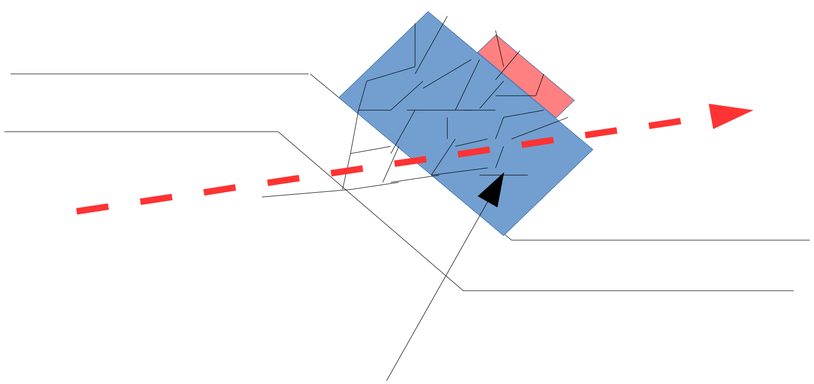
→As a result, the signal is very weak in the diamond (collection of the arm of the shower thanks to molière radius) (a weak precision ~ 7%)

→ Kanazawa san suggested a window at 45^0 at 11 meters to reduce the distance traveled in the material

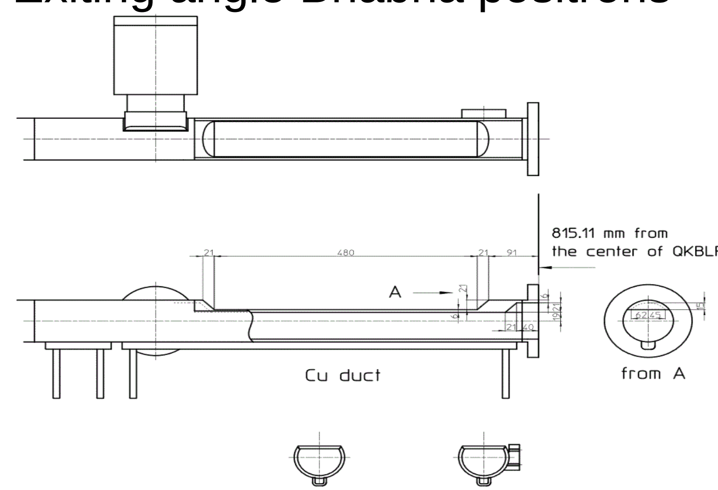




Exiting angle Bhabha positrons

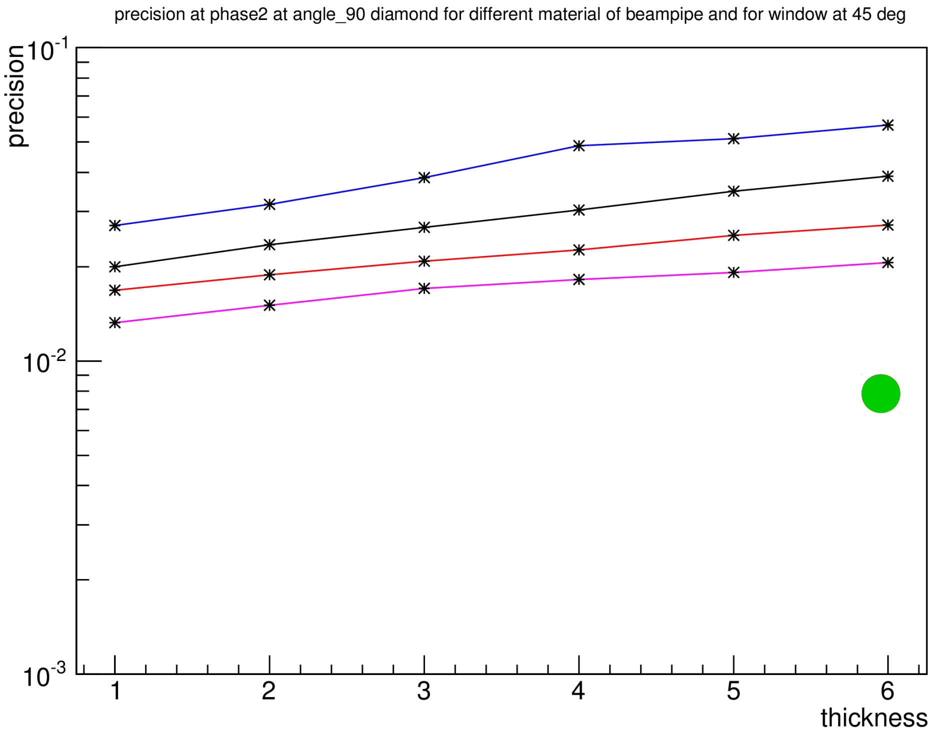


Radiator at shower max



Window suggested by Kanazawa san

Phase 2, the window will be installed



Copper, Aluminum, Beryllium, Titanium,
Cu window at 45^0 with Fe radiator at shower max

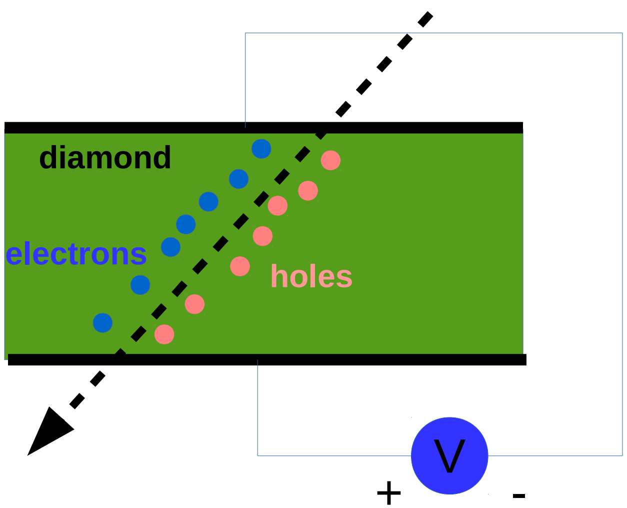
Beam pipe Design, diamond @ 90^0	Precision in 1 ms @ phase 2	Precision in 1 ms @ phase 3
Cu @ 1 mm	2.7×10^{-2}	4×10^{-3}
Al @ 1 mm	1.7×10^{-2}	2.5×10^{-3}
Ti @ 1 mm	2×10^{-2}	3×10^{-3}
Be @ 1 mm	1.3×10^{-2}	1.9×10^{-3}
Cu window at 45^0	7.5×10^{-3}	1.1×10^{-3}

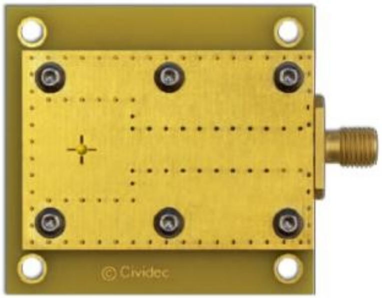
Diamond Sensor

- *Main characteristics :*

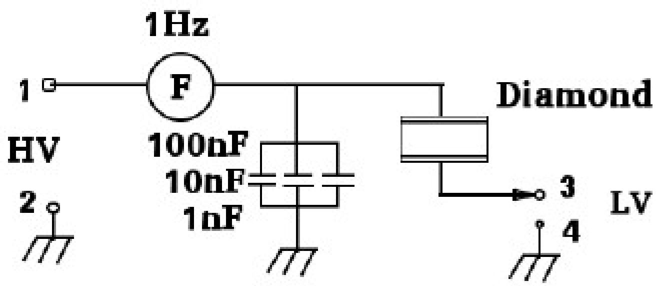
  → Large "band-gap" ----> **A weak leakage current**
  → High mobility -----> fast charge collection
  → High thermal conductivity
  → High binding energy -----> **radiation hardness**
  → very fast pulse -----> **few ns**

- *Functioning (very simple):*
  → A charged particle creates e^-/h pairs when crossing the diamond
  → An applied high voltage separates the charges
  → An amplified signal is read in an oscilloscope

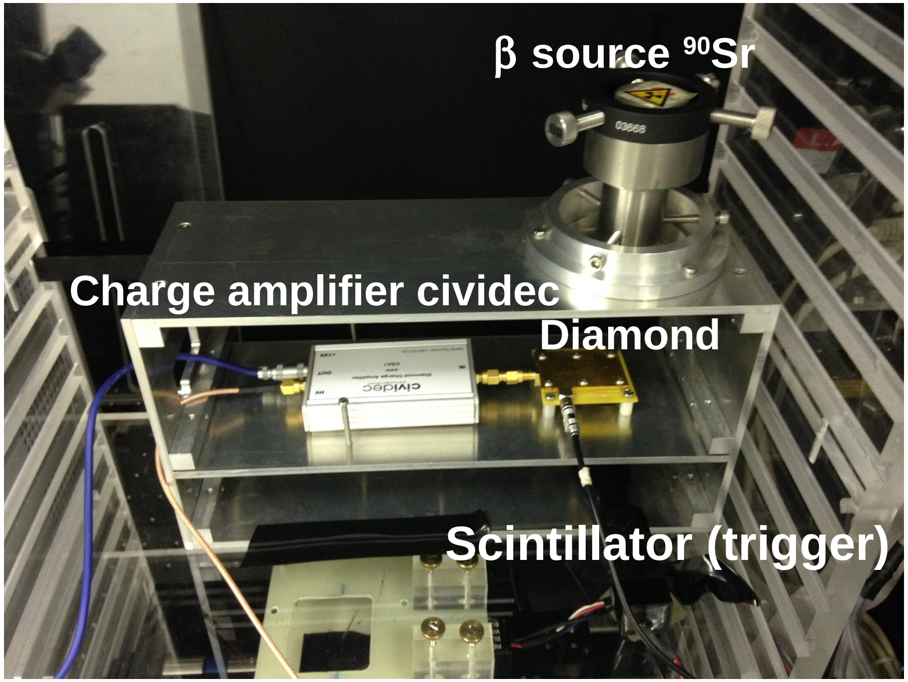


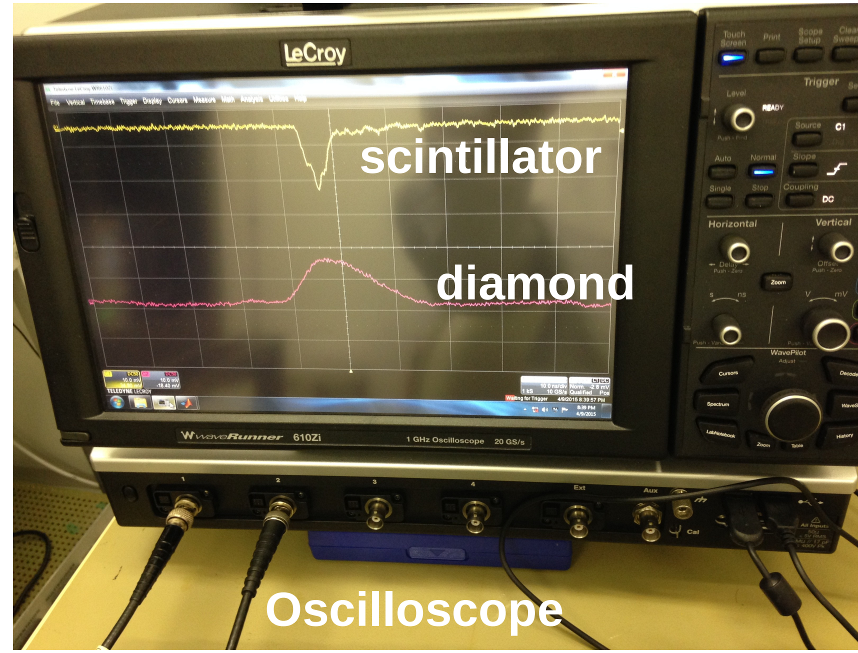


Diamond sensor cividec



Tests @ Clean room in LAL





__The goal of tests:__

→ Characterisation of Diamond (**Reconstruction of Landau**)

→ Characterisation of charge amplifier (σ=10 ns)(**Width of the signal, Position of the maximum of the signal**)

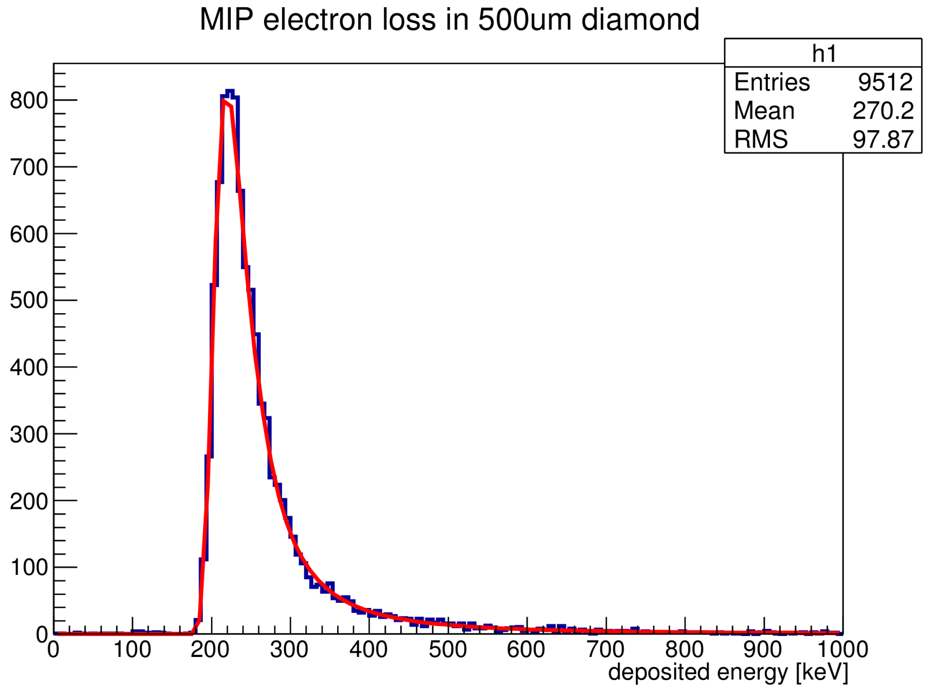
__Why?__

→We need to verify that the position of the maximum of the signal doesn't change significantly and doesn't depend on the maximum of the signal itself (sampling @ 1 GHz)

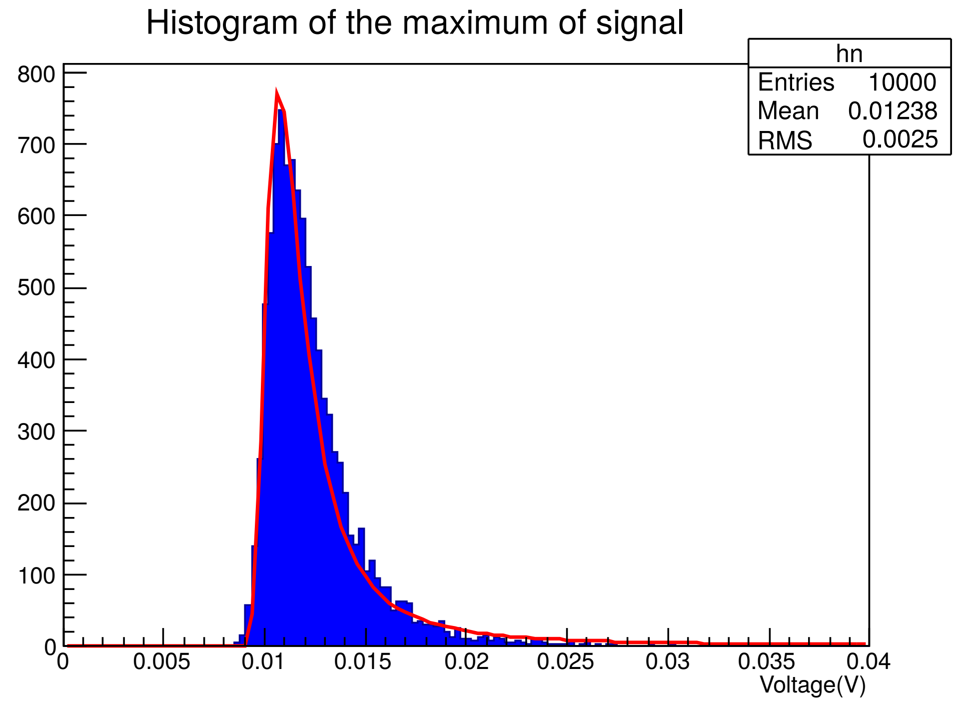
Signal of Diamond

→ The distribution of energy deposited is a **<u>'Landau'</u>**
→ 1 MIP creates 36 e^-/h pairs per μm
→ The width of the signal depends on the thickness of the diamond

Beta source ^{90}Sr (E_e = 0.546 MeV)



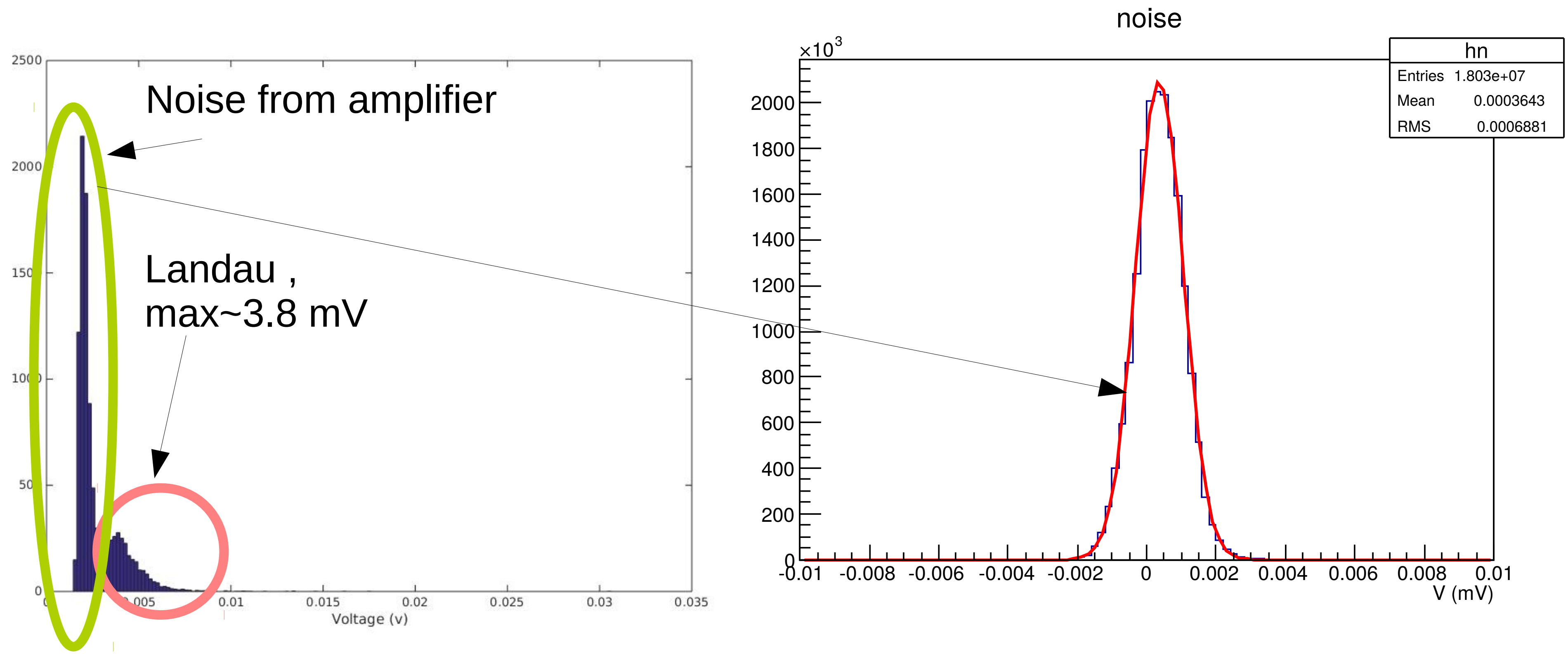
Simulation result (Geant4)



Tests in the clean room @ LAL

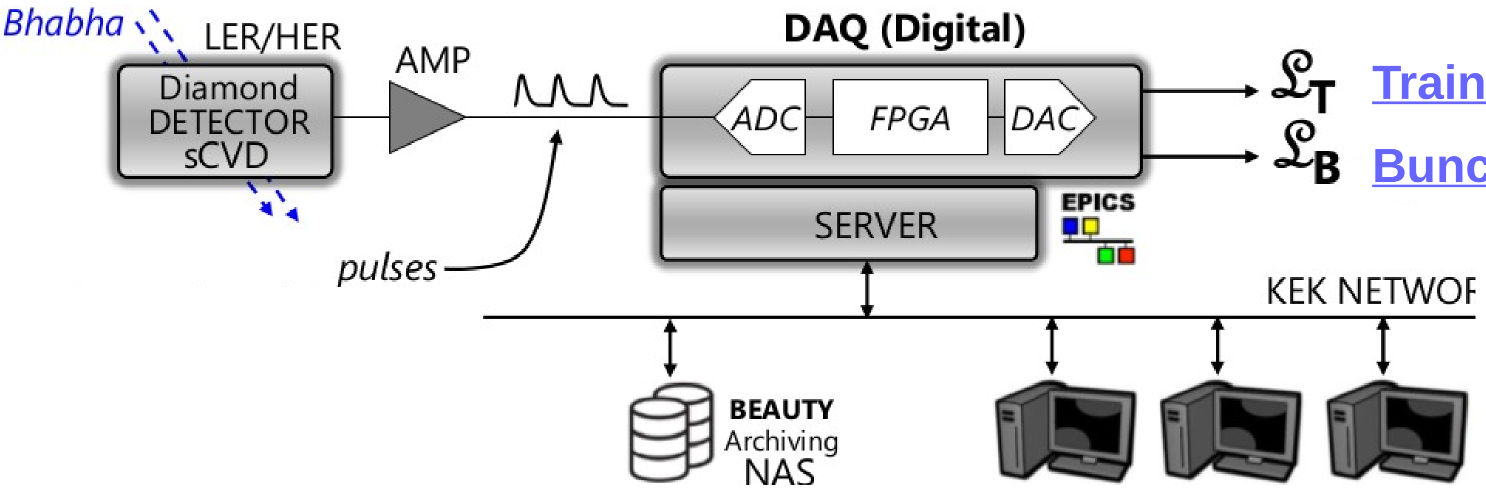
Analysis of the data

→ 140 μm , 5x5 mm² diamond sensor **(trigger on all the events in the scintillator) (V=-100 V)**



→ 1MIP corresponds to 5040 e⁻/h pairs ~ 0.8 fC ~ 3.2 mV

Readout And Electronics for Phases 2 and 3



The Set-up:

→ sCVD Diamond detector (500 µm for phase1 & 2, 140 µm for phase3) polarized by a high voltage (up to 400 V)

→ A cividec charge amplifier (Gain= 4mv/fC, σ= 10ns at phase 2 , faster at phase 3)

→ Heliax cables of very low attenuation (Estimation of 80/100 m)

→ DAQ (ADC-FPGA-DAC)

- 1GSPS sampling for the ADC (10 bits) and the DAC (16 bits)
- FPGA to calculate the train integrated luminosity L_T and the bunch integrated luminosity L_B

Backgrounds from Single Beam@ phase1

- **Goals of this study:**

  → Test our diamond sensors and calibrate it preparing for luminosity measurements at phase2

  → Compare simulation results to real measurements from the accelerator

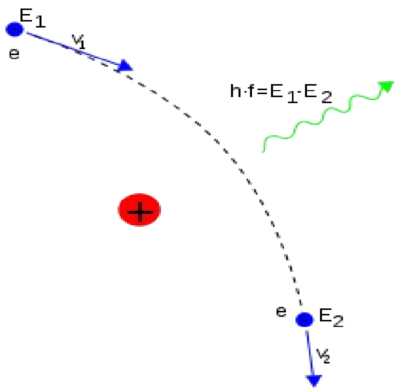
  → Make sure not to be contaminated by single beam backgrounds at phase 2

- **Backgrounds considered are :**

  1) Beam -gas Bremsstrahlung: Deceleration of a charged particle

  in the field of an atomic nucleus (losses proportional to the beam current

  and the vacuum pressure)



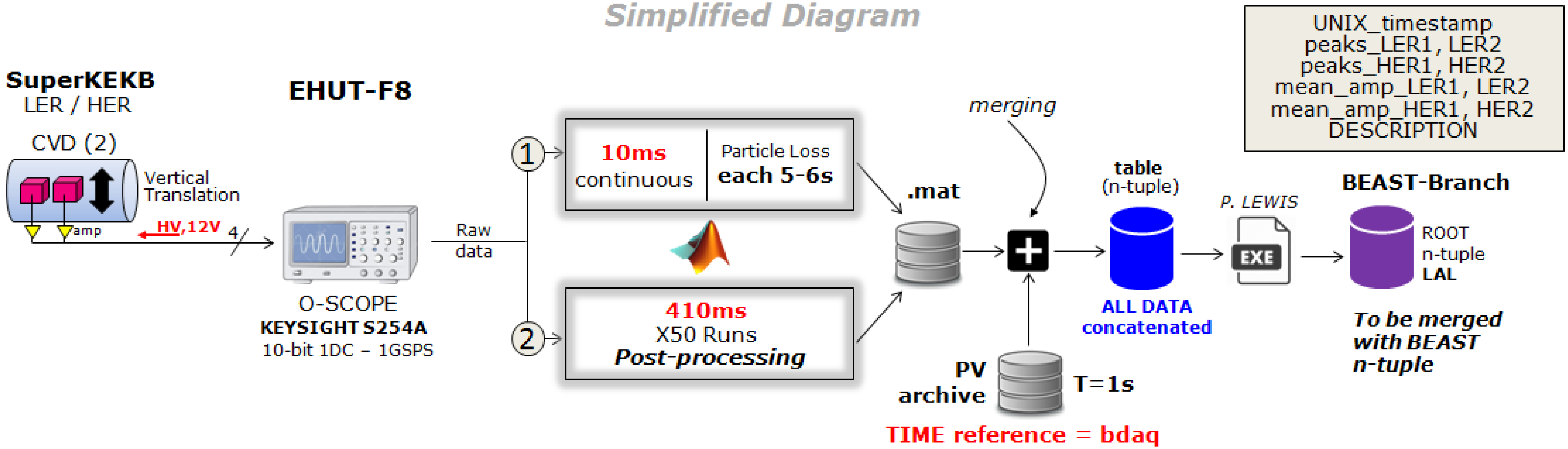
  2) Touschek effect: Coulomb scattering between particles in the same bunch, resulting in energy transfer from the transverse plane to the longitudinal plane due to relativistic effects, and thus the loss of the particles ..(losses are quadratic with beam current and inversely proportional to the beam size)

  3) Coulomb scattering: scattering of the bunch particles on the atomic electrons . (Similar as Touschek) (losses proportional to the beam current and the vacuum pressure)

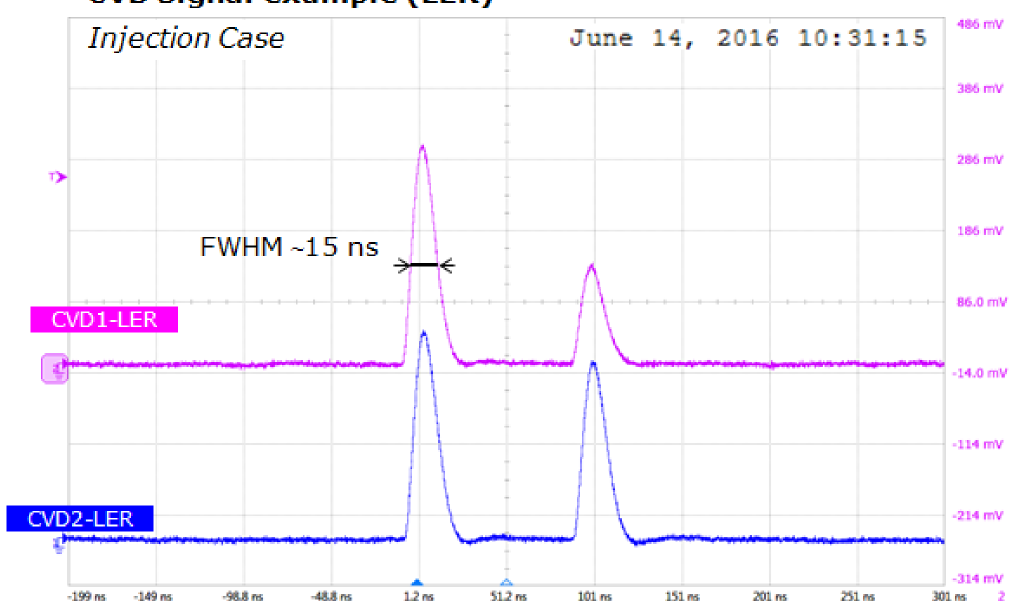
Data Acquisition

DATA ACQUISITION SETUP

Simplified Diagram



CVD Signal example (LER)



1 MIP = 3fC (18000 pairs e-/hole)

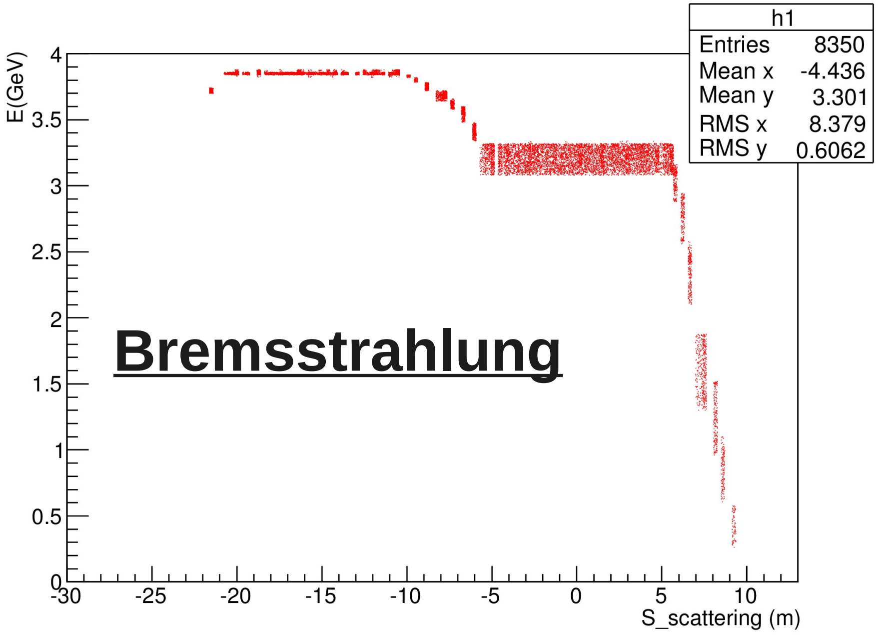
G → 1 MIP = **12mV**

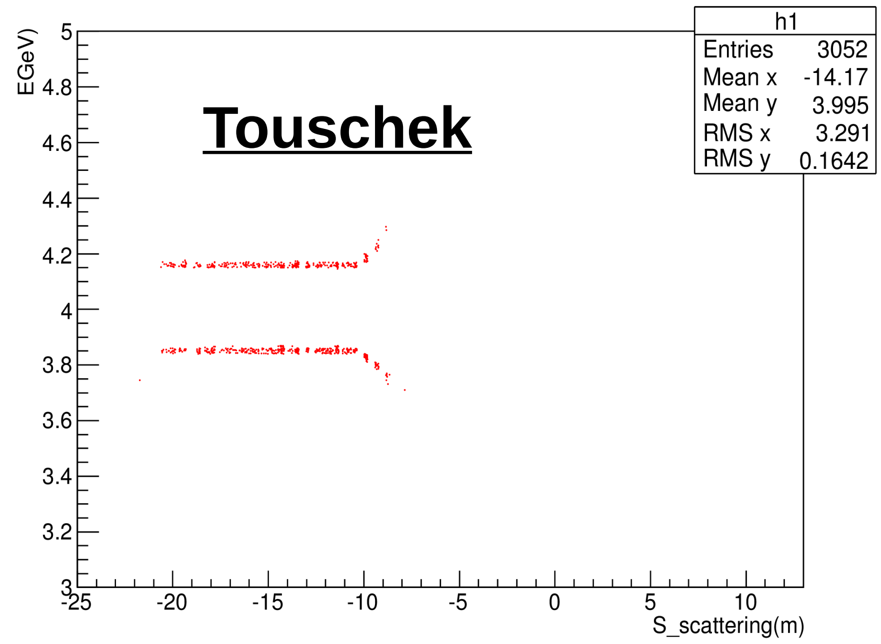
4mV/fC

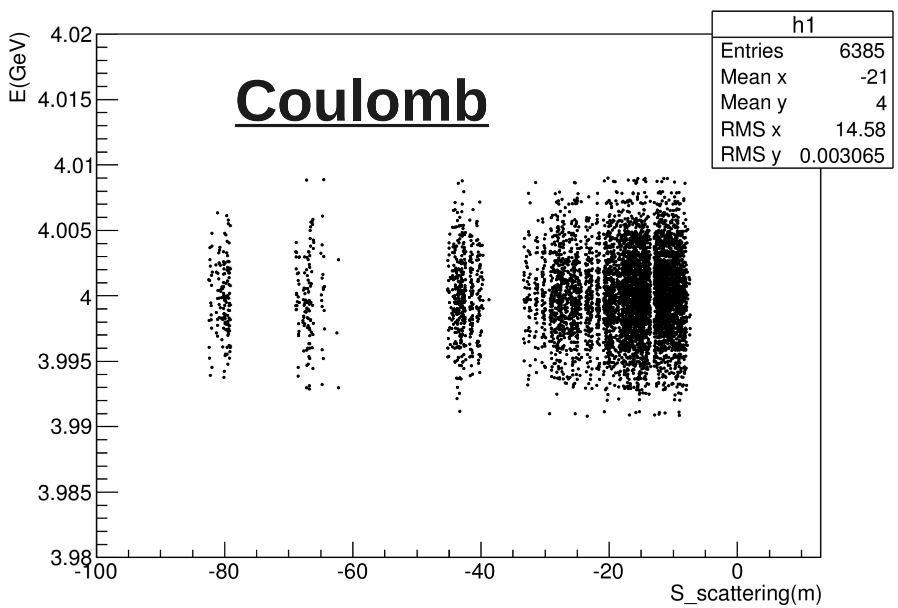
V_{Noise} = 0.73mVrms

SNR = 24 dB @1MIP

Simulations: SAD (LER)





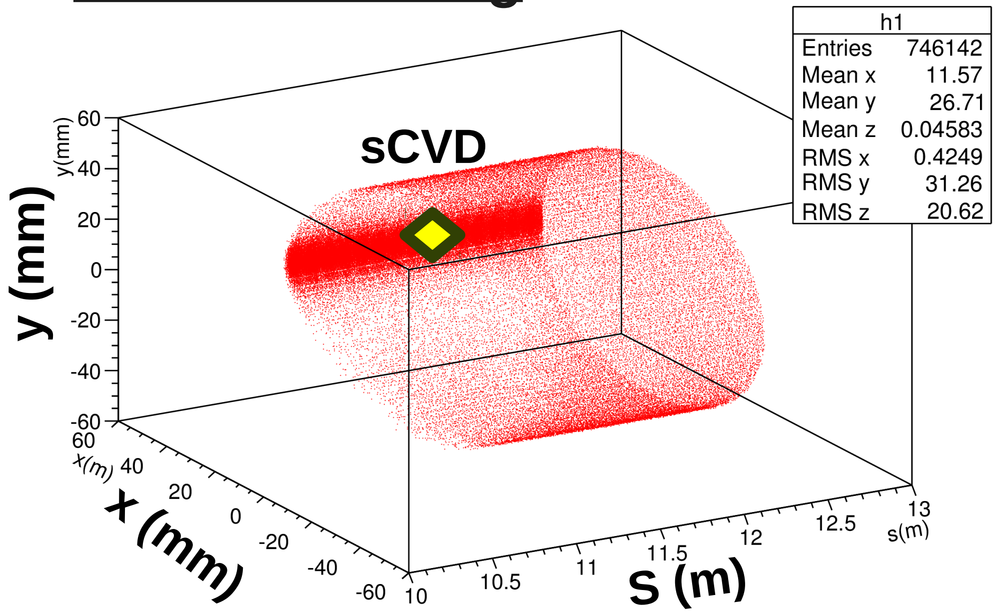


→ The simulations consider scattering the three processes (Beam-gas Bremsstrahlung, Touschek and Coulomb) each ~ 10 cm in the ring

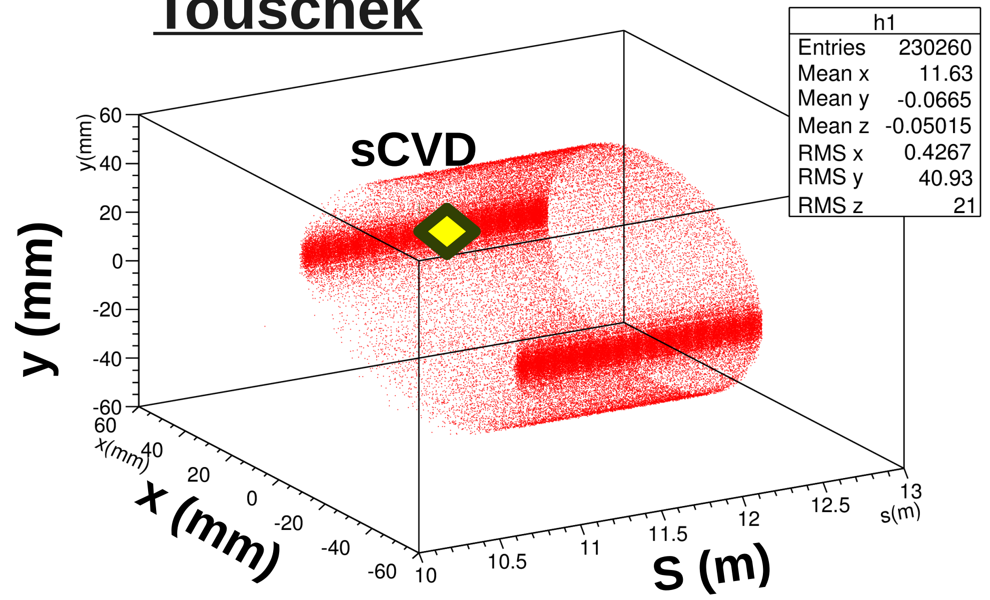
→ The figures show the energy and the position of scattering of the particles from the three processes lost in the drift at 11.9 meters in the LER

Simulations: Geant4 (LER)

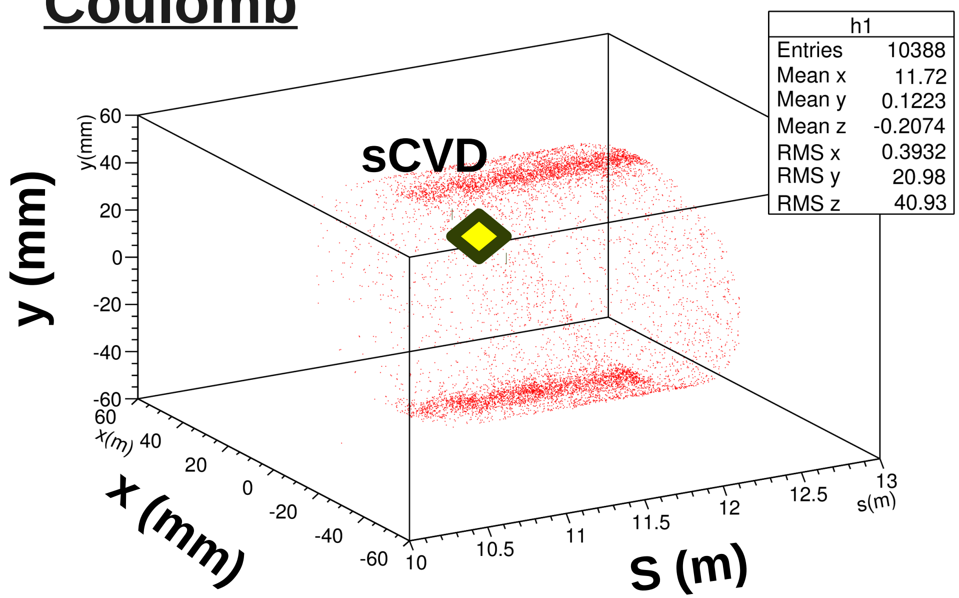
Bremsstrahlung



Touschek



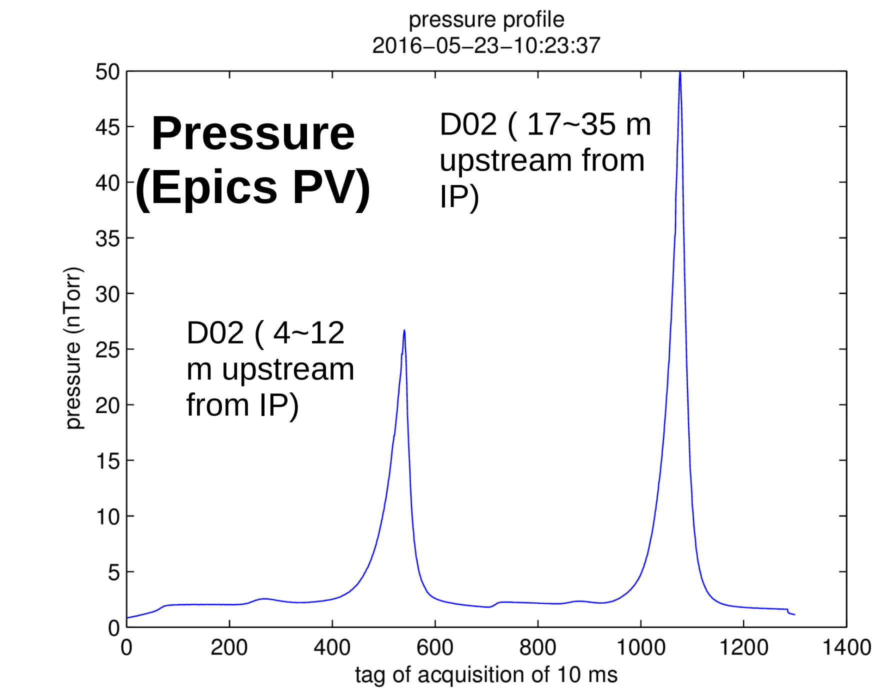
Coulomb

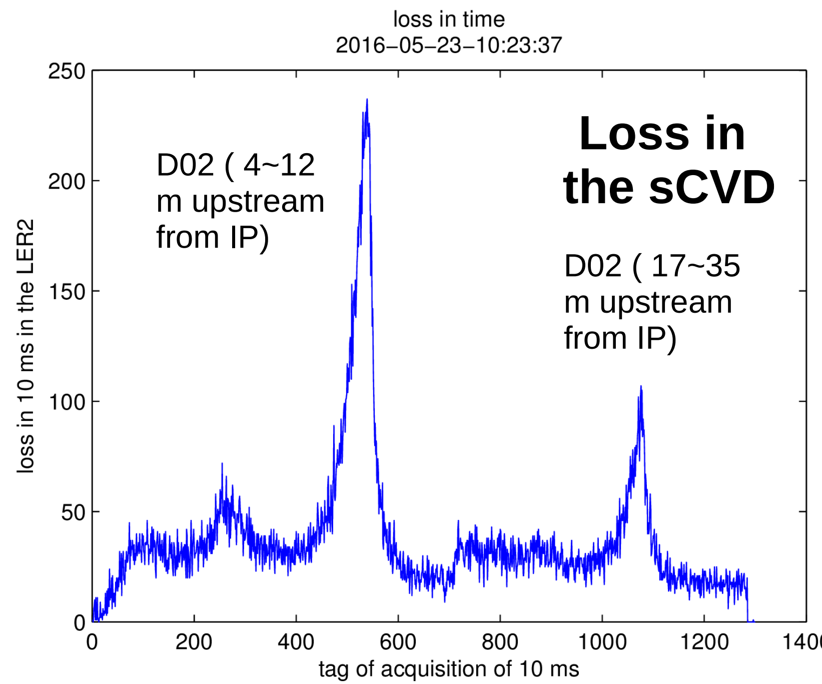


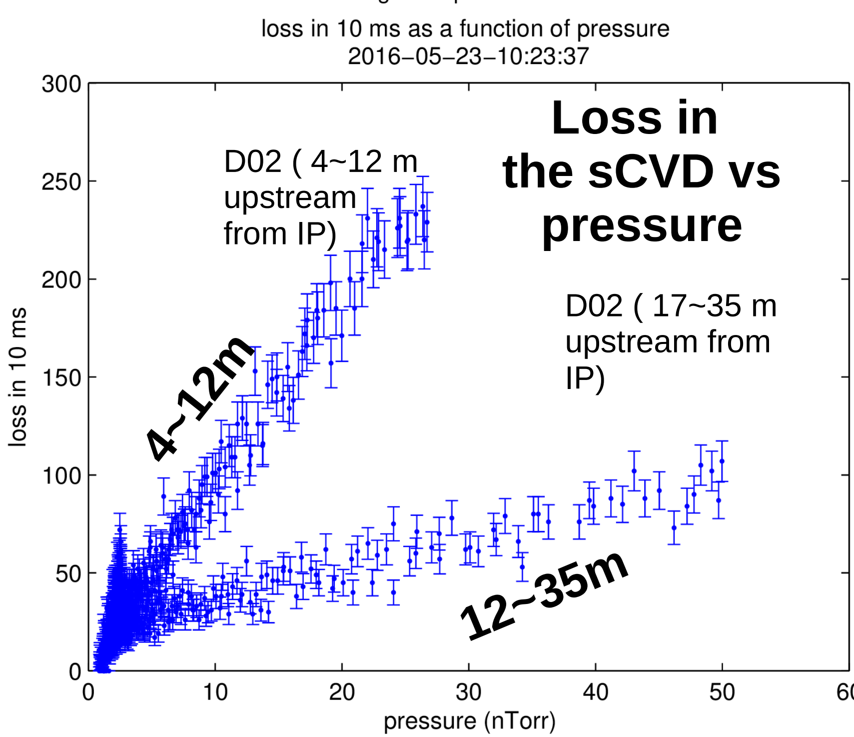
→ From simulations:

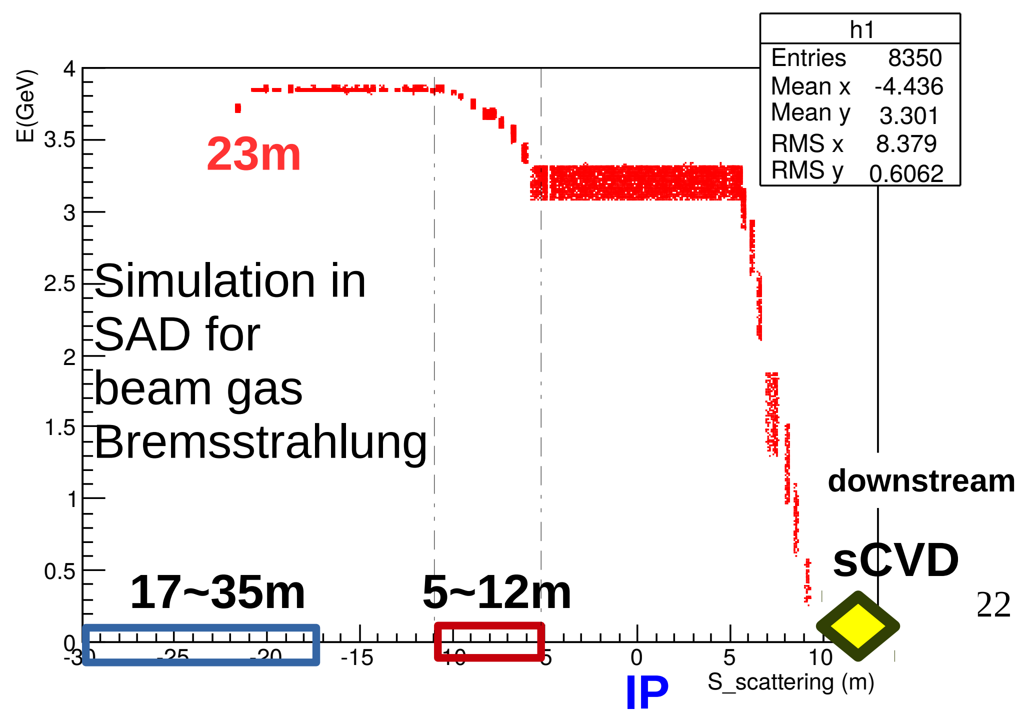
- The events in the sCVD are mainly from beam-gas Bremsstrahlung and Touschek
- We have no losses in our sCVDs from Coulomb process (losses are mainly in the vertical plane)

Losses in the sCVD during vacuum bumps in LER









Data analysis for different beam sizes (LER)

→ Study: Change the vertical beam size for the same current by varying the emittance control knob (change x-y coupling)

→ Repeat the same study for different currents (180, 360, 540,720,900,1000 mA)

→ Fit the losses in the diamond sensor as a function of $1/\sigma_y$ at each current

→ At σ_y → infinity ($1/\sigma_y=0$), No losses from Touschek , only Bremsstrahlung in the sensor

→ To compare Touschek to the simulation:

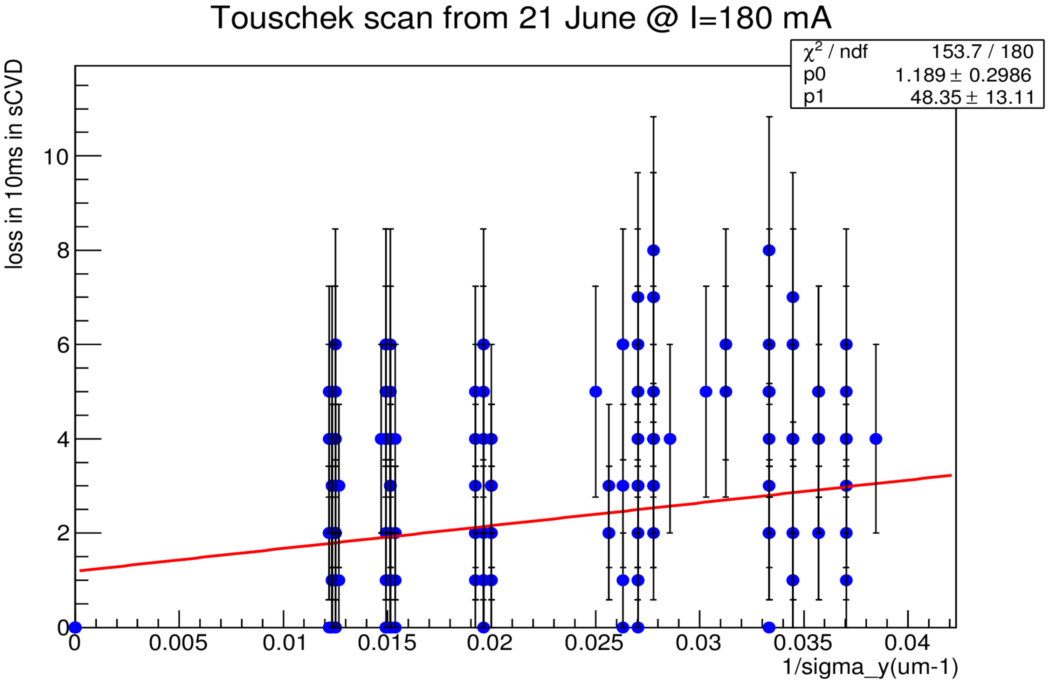
Data :

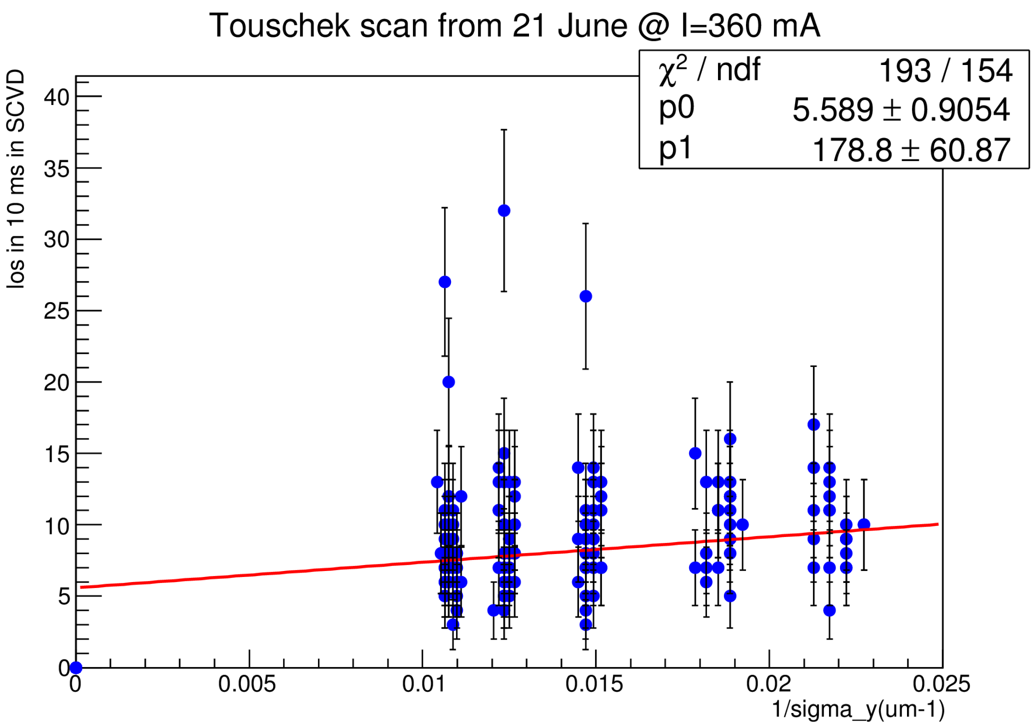
* Extrapolate slopes (and their errors) of the fit of the losses with $1/\sigma_y$ to one current (1A)
* Calculate the weighted arithmetic mean of the extrapolated slopes and errors

Simulation:

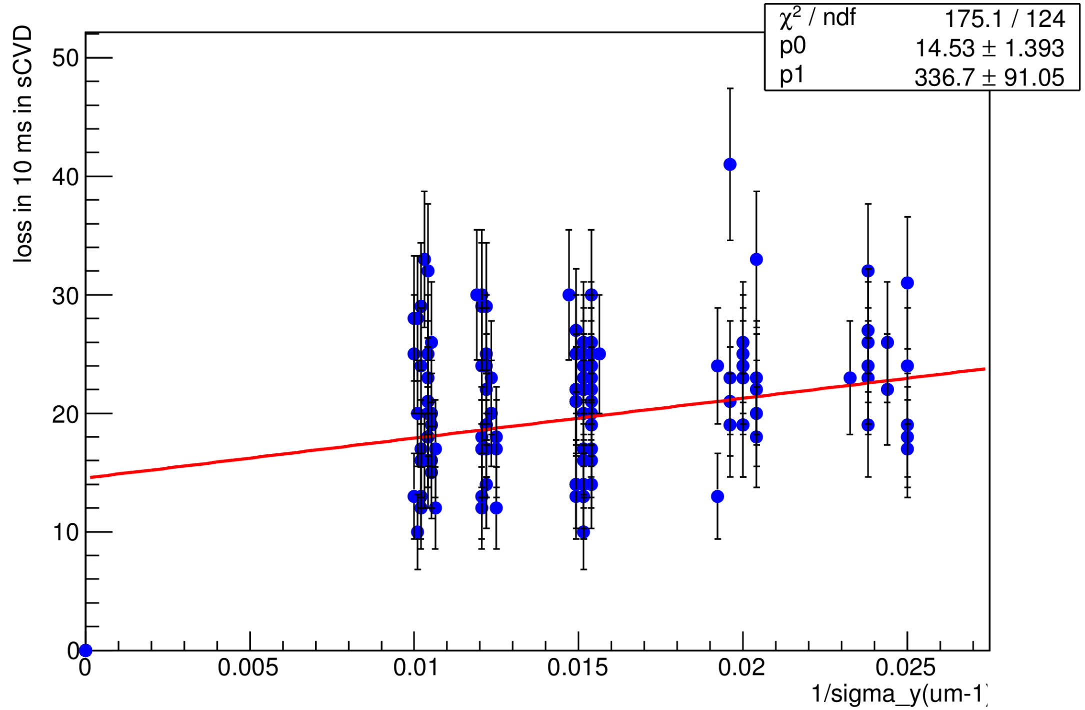
* Perform simulation @ 1 A at different σ_y (change the value of the x-y coupling → change ε_y)
* Fit the obtained losses linearly as $1/\sigma_y$, then compare to the data

Fit of the loss in the sCVD as a function of the inverse vertical beam size, for different currents

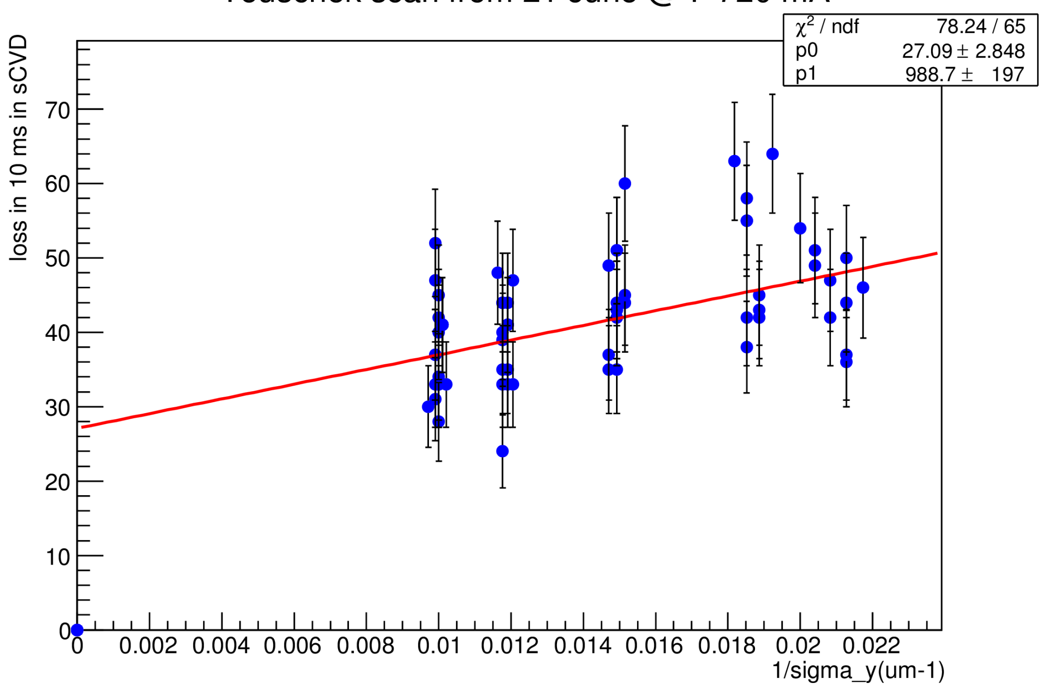


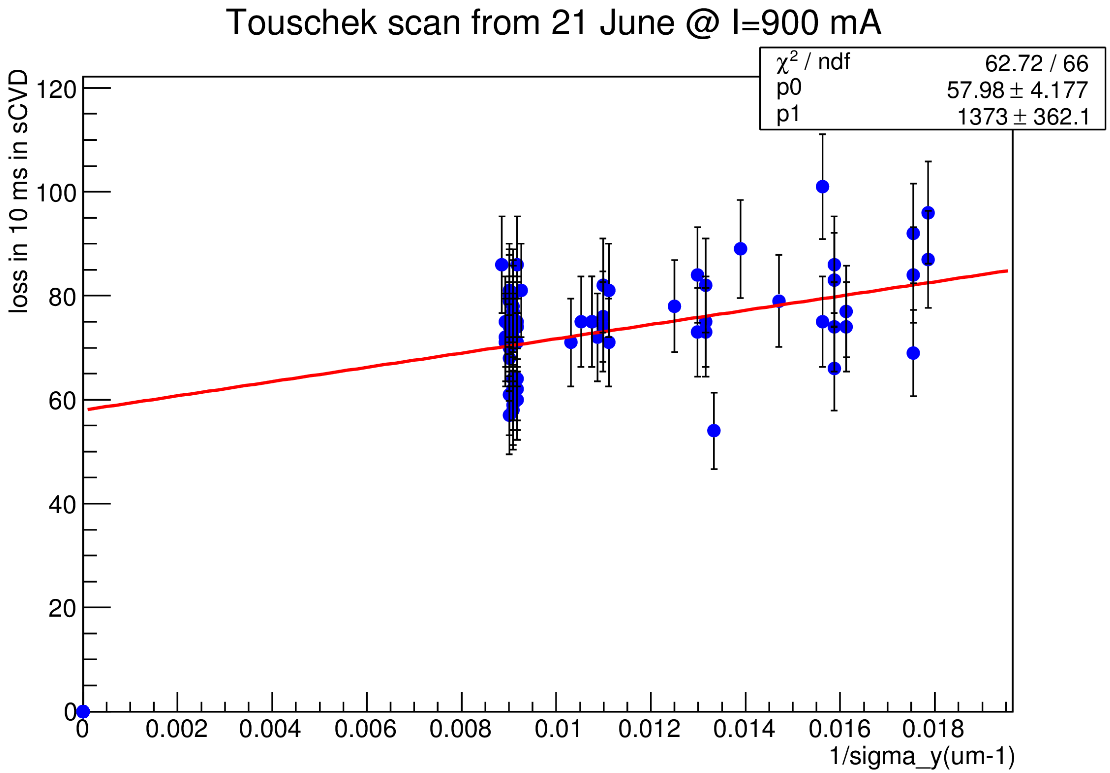


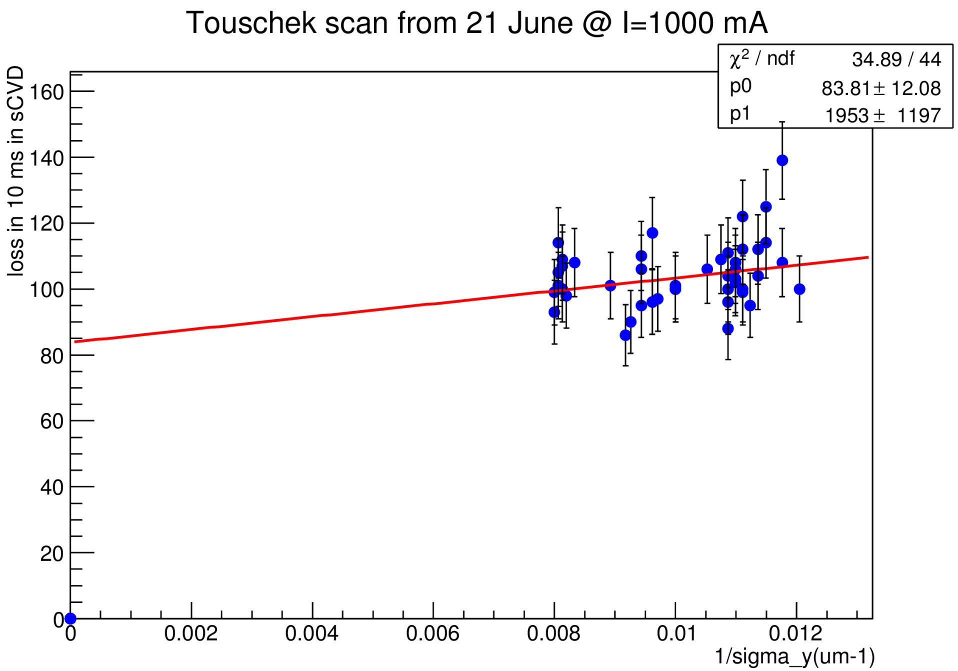
Touschek scan from 21 June @ I=540 mA



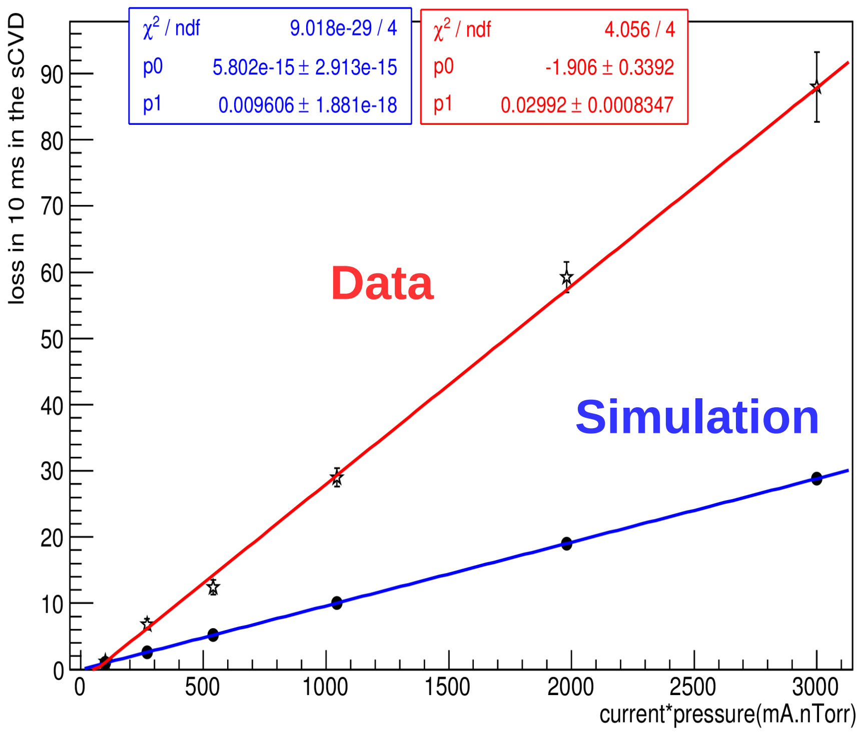
Touschek scan from 21 June @ I=720 mA

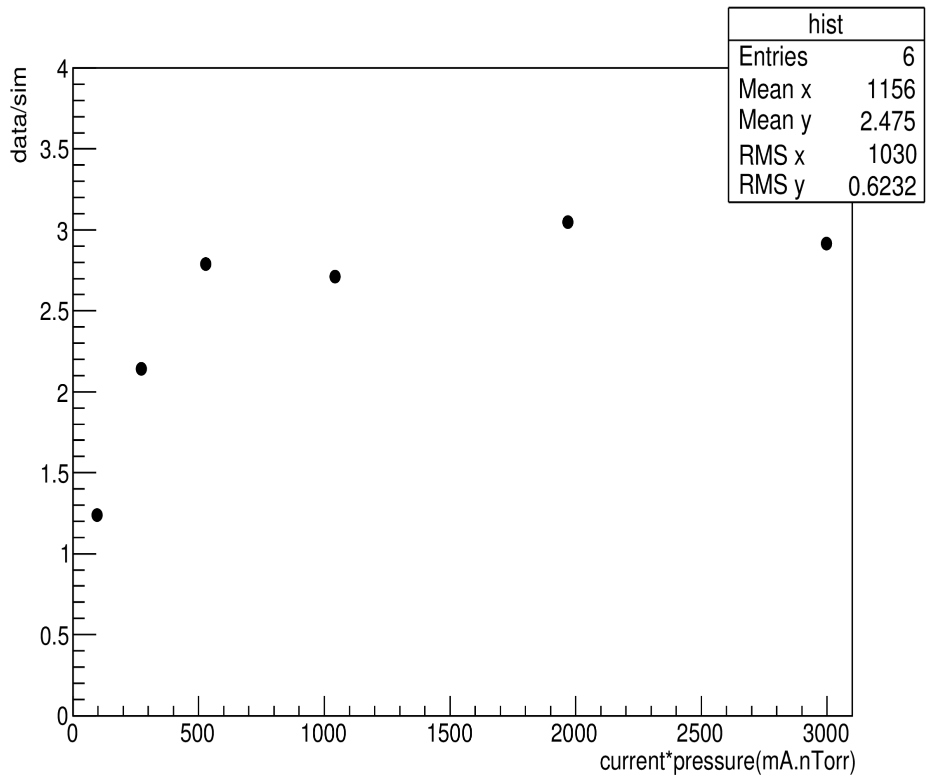



Touschek scan from 21 June @ I=900 mA
χ^2 / ndf 62.72 / 66
p0 57.98 ± 4.177
p1 1373 ± 362.1
loss in 10 ms in sCVD
1/sigma_y(um-1)


Touschek scan from 21 June @ I=1000 mA
χ^2 / ndf 34.89 / 44
p0 83.81 ± 12.08
p1 1953 ± 1197
loss in 10 ms in sCVD
1/sigma_y(um-1)

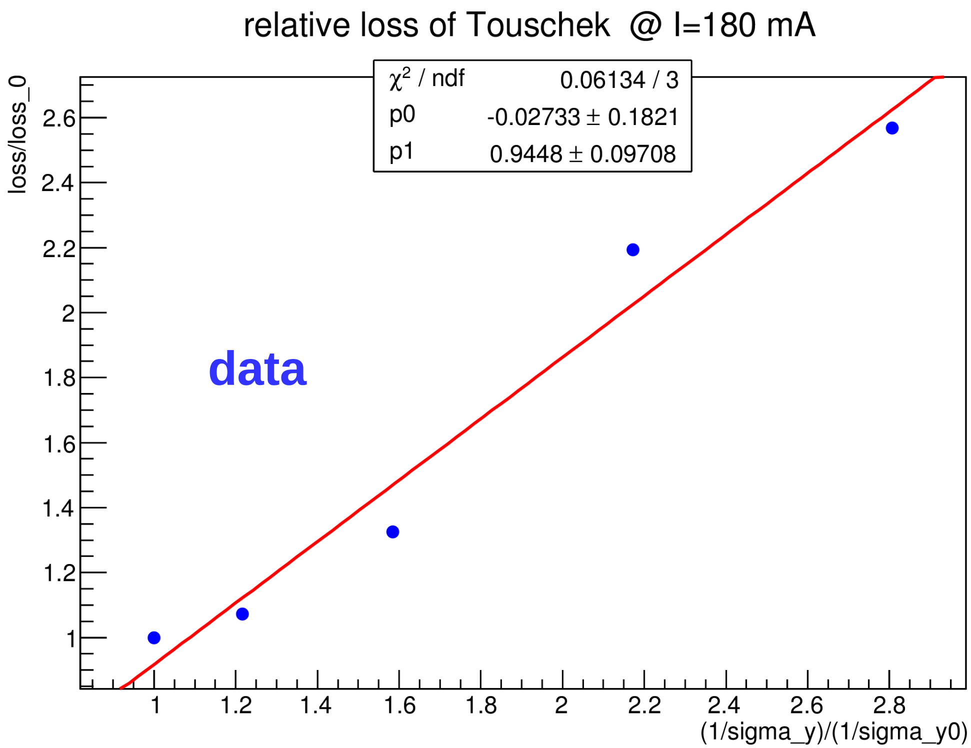
Contribution from Bremsstrahlung

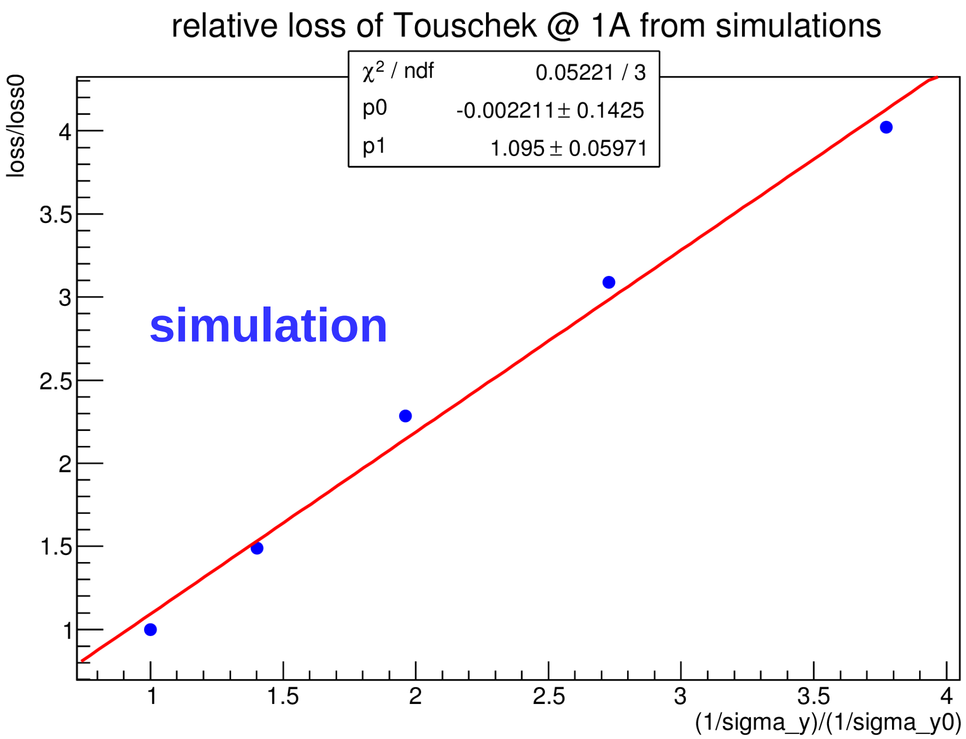




From the above analysis, we can find the factor 3 of data to simulation, which is explained by the fact that the measured pressure value from the CCG should be multiplied by a factor of 3 to approximate an actual CO equivalent pressure in the ring .

Contribution from Touschek





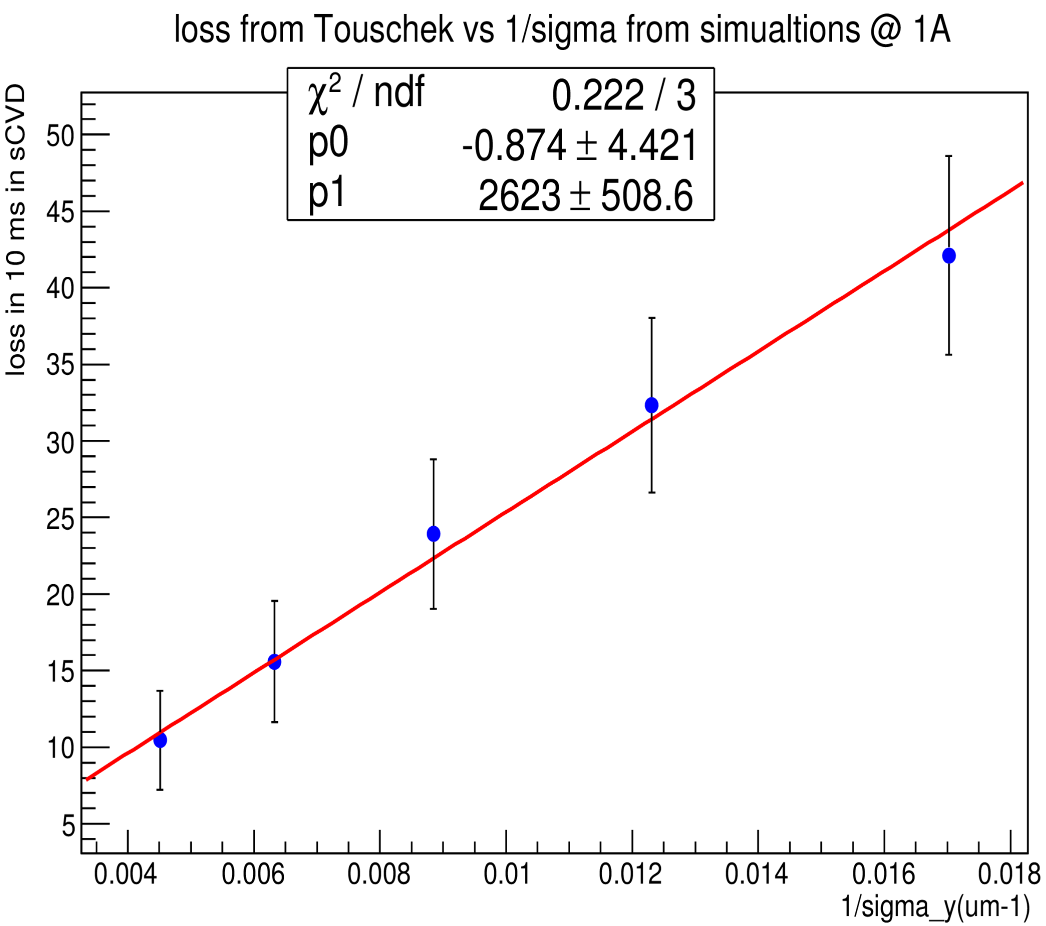
From this plot, we can clearly see the linear dependence of the Touschek on $1/\sigma_y$

The data and simulation show the direct proportionality of the losses from Touschek with the inverse of the vertical beam size for the same current

Touschek: Data vs Simulation

→ Simulation : **$Touschek_{simu}$ =(2623 +/- 508.6)x($1/\sigma_y$)**

→ Data : **$Touschek_{data}$= (1530.24 +/- 172.5)x($1/\sigma_y$)**



→ After the above mentioned analysis, the factor **simu/data= 1.7 +/- 0.37**

→ **Explain the factor?**

+ The Touschek losses are proportional to *$1/\sigma_y$x $1/\sigma_x$*, σ_y=sqrt(ε_y.β_y) and σ_x=sqrt(ε_x.β_x)

In the simulation, ε_y=κ*ε_x, κ is the value of the x-y coupling → simulation is proportional to 1/ ε_x

→ ($\varepsilon_{x(sim)}$ > $\varepsilon_{x(machine)}$) (No good measurement of the horizontal beam size at SuperKEKB)

→**<u>It is believed that there is no error on the measurement of the vertical beam size because it is very consistent with the estimated value from the optics corrections.</u>**

Conclusions and next plans

→ Fast luminosity monitoring is very important for feedback and optimisation.
→ Simulations show that the window at 45^o is very essential to obtain the aimed precisions.
→ Characterisation of the diamond sensor was performed successfully in the clean room at LAL
→ Installation of the experimental setup was accomplished and data taking took place successfully during the single beam commissioning of SuperKEKB
→ Data and simulations in the LER are consistent for Bremsstrahlung, while for Touschek we believe the factor is due to inconsistency in the horizontal emittance between the data and the simulation
→ The analysis of the data taken in the HER is on-going

Next Plans:
→ Installation of the window for phase 2
→ Preparation of the DAQ system for phase 2
→ Ongoing simulations to study the signal in the DS from the Bhabha photons in the HER
→ A new PhD student will continue my work starting from October 2016

Back up slides