Report on BEAMS-LC-CEPC:

1. First luminosity monitoring at SuperKEKB

(2. Beam halo characterization at ATF/ATF2 → backup slides)

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LAL-Orsay

On behalf of LAL SuperKEKB and ATF2 groups: *Chinese Scholarship Council

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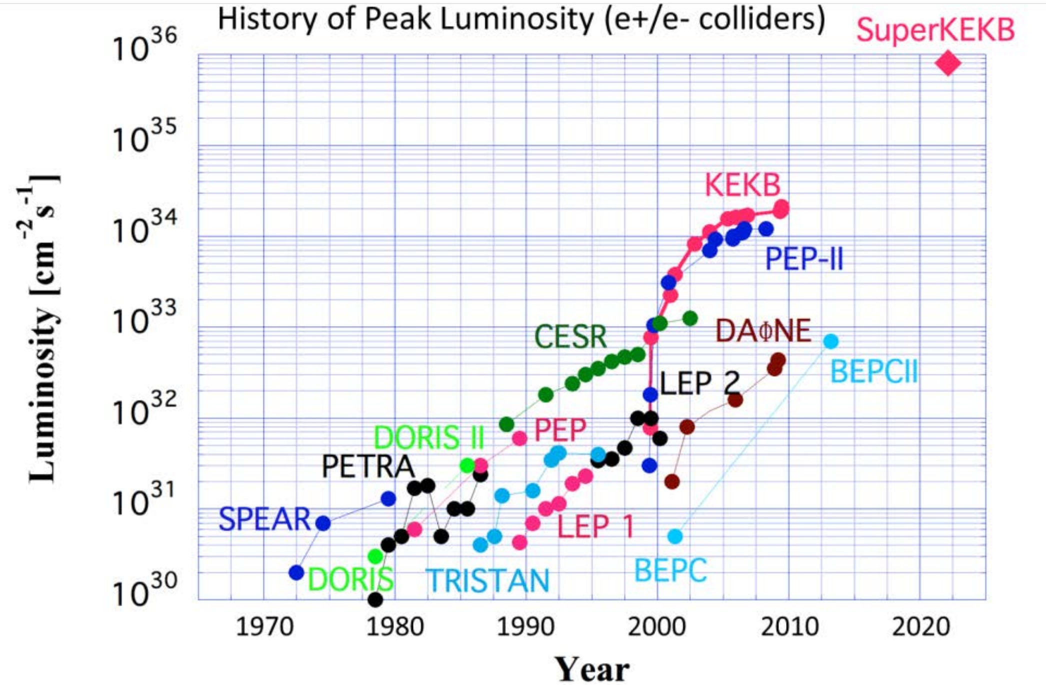
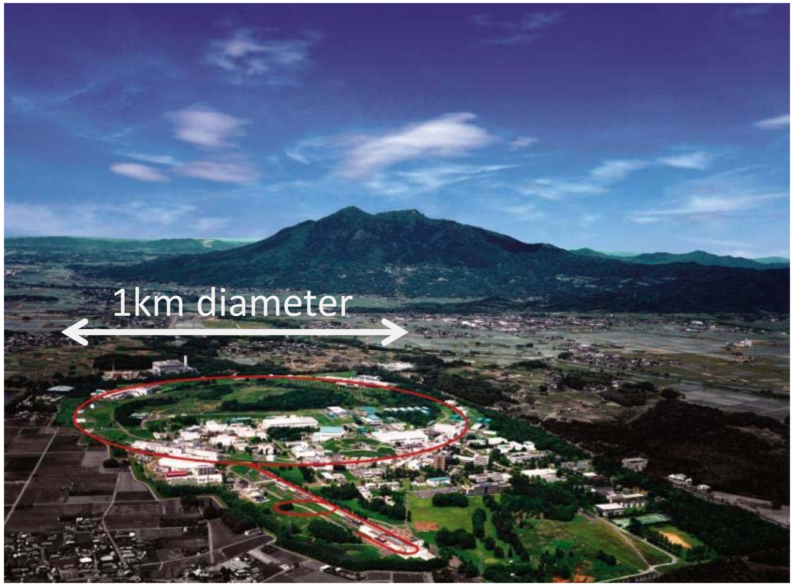
Collaboration with Chinese Institutes:

IHEP: Sha Bai, Jie Gao, Dou Wang, Yiwei Wang
Nanjing Univ.: Edna Cheung, Taifan Zheng (1st year PhD Student)

11th FCPPL workshop Marseille - France 22-25 May 2018

Exploring the luminosity frontier with SuperKEKB





KEKB
$2 \times 10^{34}/cm^2/s$

→

SuperKEKB
$8 \times 10^{35}/cm^2/s$

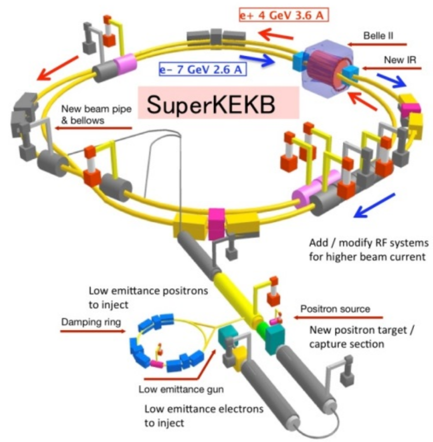
All future e+e– circular colliders use novel "nanobeam" collision scheme → being tried right now for 1st time at SuperKEKB in 2018

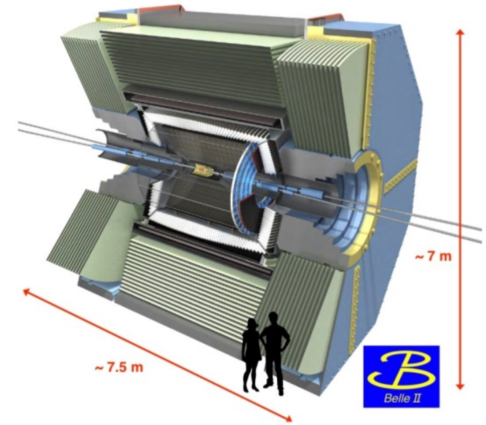
➔ essential validation + training for future CEPC / FCC-ee

SuperKEKB / Belle-II & "Machine-Detector Interface"

- Control beam induced backgrounds
- Luminosity monitoring & tuning

1) Phase 1 : 2016/Feb. → Jun.
   - single beam commissioning, vacuum scrubbing
   - no luminosity (no final focus), no detector
2) Phase 2 : 2018/Feb. → 2018/Jul.
   - colliding beam commissioning, no vertex detector
3) Phase 3 : ~ February 2019…
   - towards full luminosity for physics running

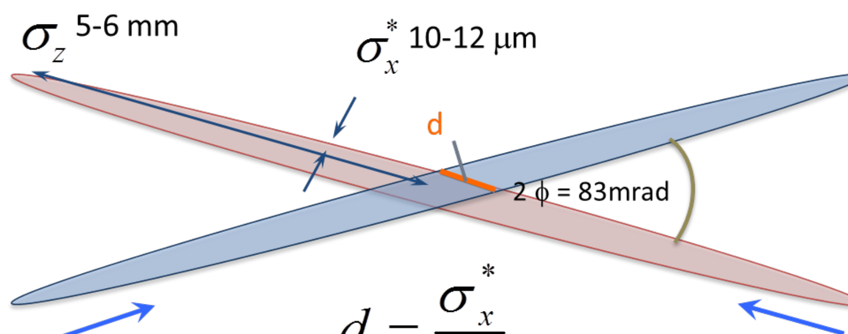




parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Half crossing angle	φ	11		41.5		mrad
# of Bunches	N	1584		2500		
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
→ Beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam param.	ξ_y	0.129	0.090	0.088	0.081	
Bunch Length	σ_z	6.0	6.0	6.0	5.0	mm
→ Horizontal Beam Size	σ_x^*	150	150	10	11	um
→ Vertical Beam Size	σ_y^*	0.94		0.048	0.062	um
Luminosity	**L**	**2.1×10^{34}**		**8×10^{35}**		$cm^{-2}s^{-1}$

→ **Luminosity × 40**

Nano-Beam Scheme SuperKEKB (design)



$$d = \frac{\sigma_x^*}{\phi}$$

Half crossing angle: ϕ

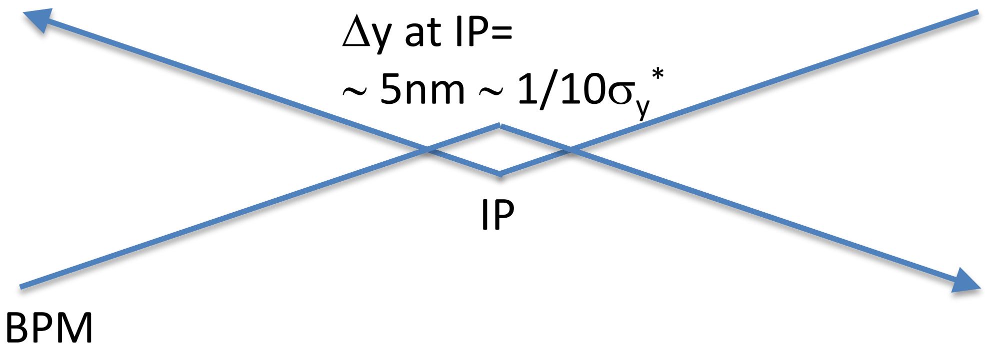
β_y = 300 μm   d ~ 300 μm

→ **mitigates beam-beam and hour-glass effects**

Luminosity

Fast & slow variations at IP require feedback corrections

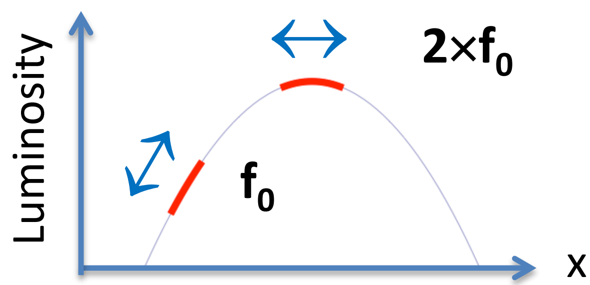
- Beam-beam deflection for fast vertical motion



Δy at BPM= ~ 1.3μm

Vertical vibration ~ 25-100 Hz
Sampling (BPMs) ~ 32 kHz

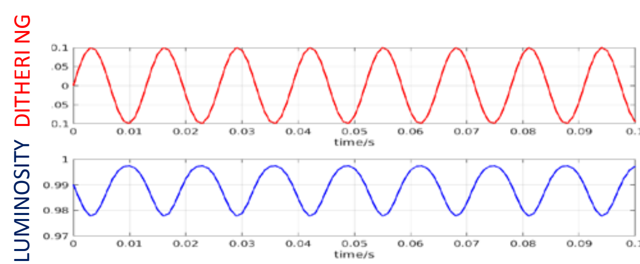
- Luminosity feedback by "dithering" for slower horizontal motion



Horizontal motion ~ few Hz
Modulation freq. f_0 ~ 77 Hz
Sampling (lumi. meas.) ~ 1 kHz

- minimize f_0 output component
- dithering × lumi. signal → phase

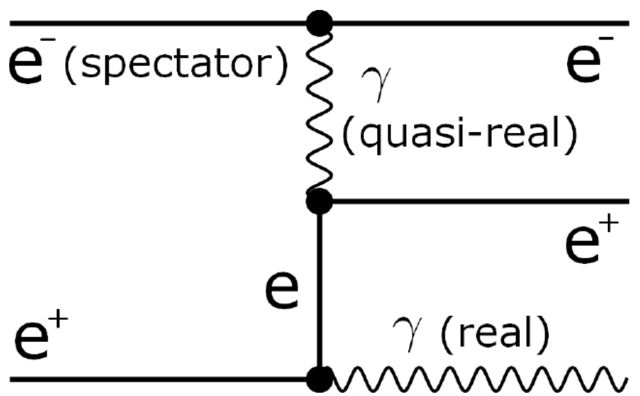
$$L(t) = \frac{f_{rev} N_1 N_2}{4\pi\sigma_x\sigma_y} e^{-(\frac{[q+p\sin(2\pi f t)]^2}{4})}$$



Dithering coil x 12

Radiative Bhabha at vanishing scattering angle

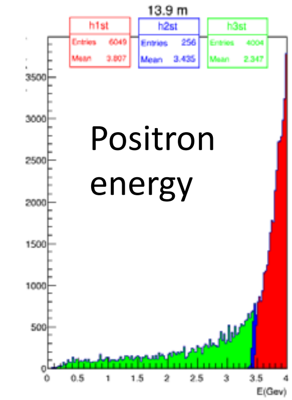
$\sigma \sim 250$ mbarn ($E_\gamma > 1\%\ E_{beam}$)



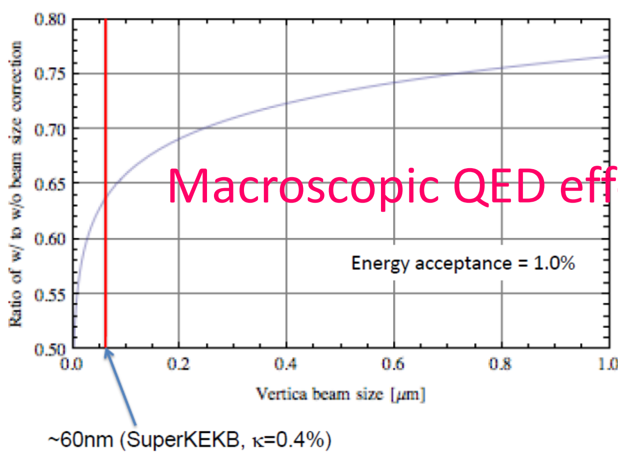
major background source from induced particle losses after IP

luminosity monitoring

LAL & KEK



Correction for cross section due to finite beam size



Macroscopic QED effect…

Luminosity monitoring specs

- Relative measurements
- 10^{-2} in 1 ms over all bunches ("dithering")
- 10^{-2} in ~ 1 s for each 2500 bunch → 4ns (for nominal luminosity)
- Non luminosity scaling contamination < 1% (e.g. beam gas bremstrahlung and Touschek losses)
- Should also work for initial luminosity

Y. Funakoshi (KEK), background workshop, Feb. 2012

Two complementary techniques

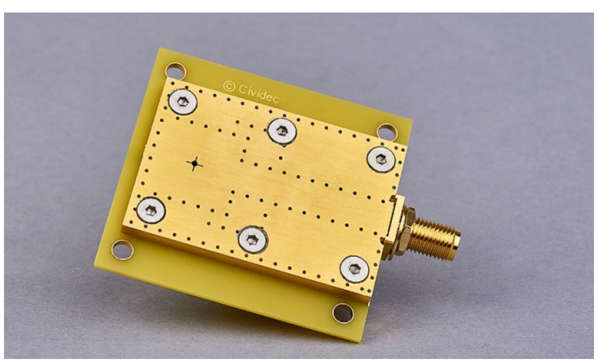
LumiBelle2
Luminosity Monitoring for Belle II

LumiBelle2 | **ZDLM (Zero Degree Luminosity Monitor)**

Both measure photons, recoiling electrons or positrons from the radiative Bhabha process at vanishing scattering angle → very large cross section.

LumiBelle2

- Diamond sensors;
- Digital electronics;
- $4 \times 4 \times 0.5/0.14\ mm^3$ single crystal CVD diamond sensors;
- Fast charge/current amplifiers.



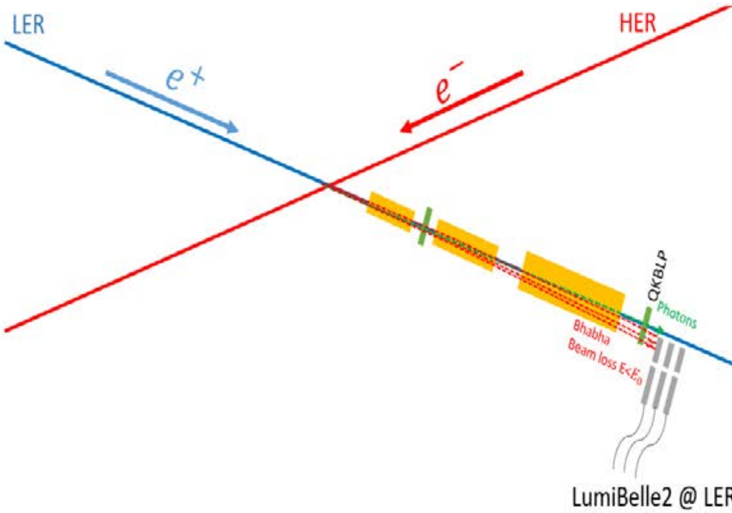
ZDLM (Zero Degree Luminosity Monitor)

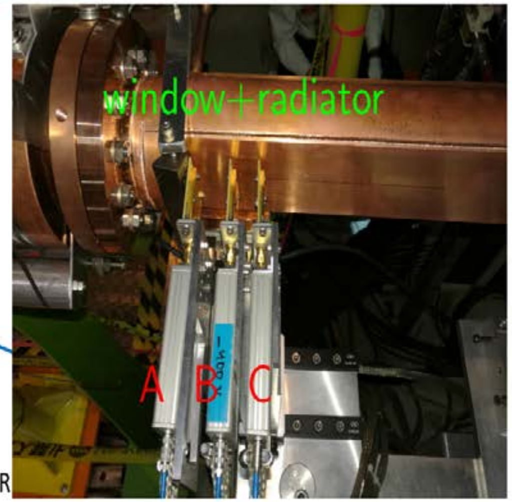
- Cherenkov and scintillator counters;
- Analog electronics;
- $15 \times 15 \times 64\ mm^3$ LGSO non-organic scintillator and ES-crystal (quartz);

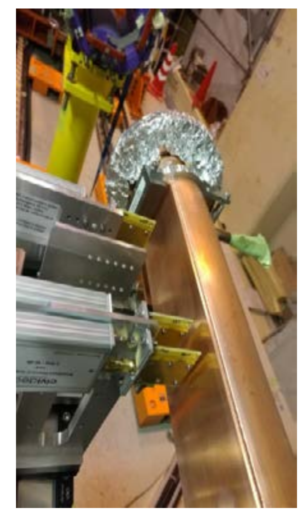


LER side

LumiBelle2
Luminosity Monitoring for Belle II





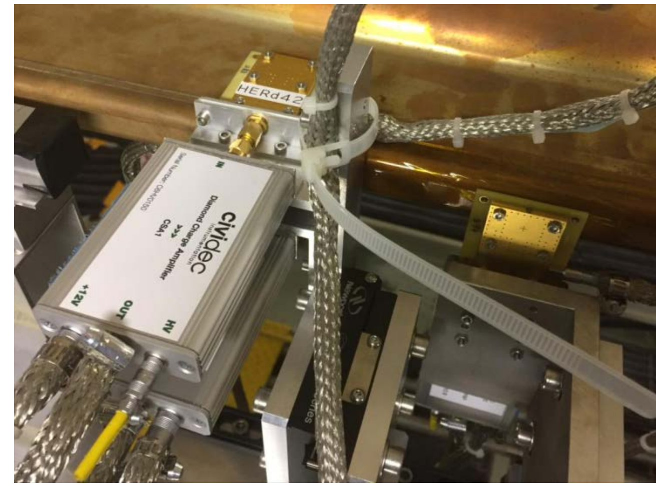


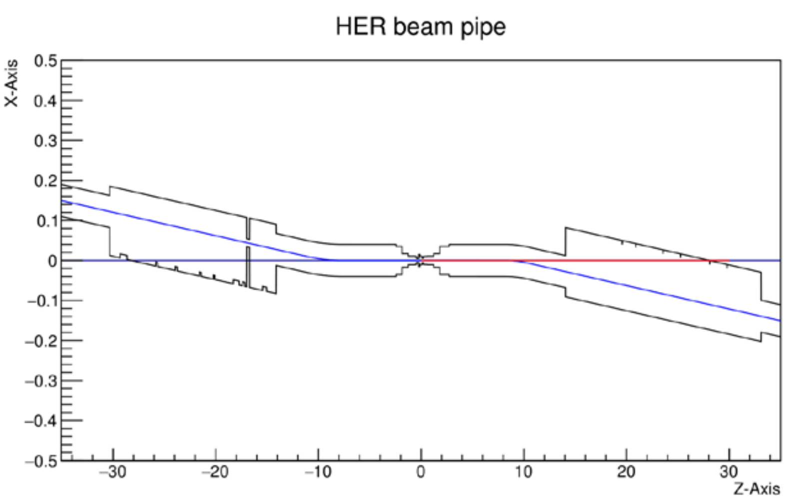
- Signal: Bhabha positrons
- Background: Bremsstrahlung and Touschek positrons
- Platform: 11 m after IP
- 3 sensors aligned
- Window + radiator

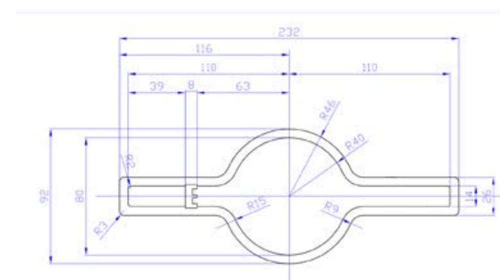
HER side

LumiBelle2
Luminosity Monitoring for Belle II

- Signal: Bhabha photons
- Background: Bremsstrahlung photons, Touschek electrons
- Platform: 30.5-30.8 m after IP
- 3 sensors: up, down, side

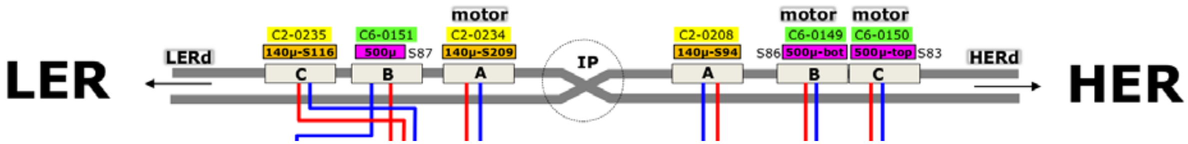


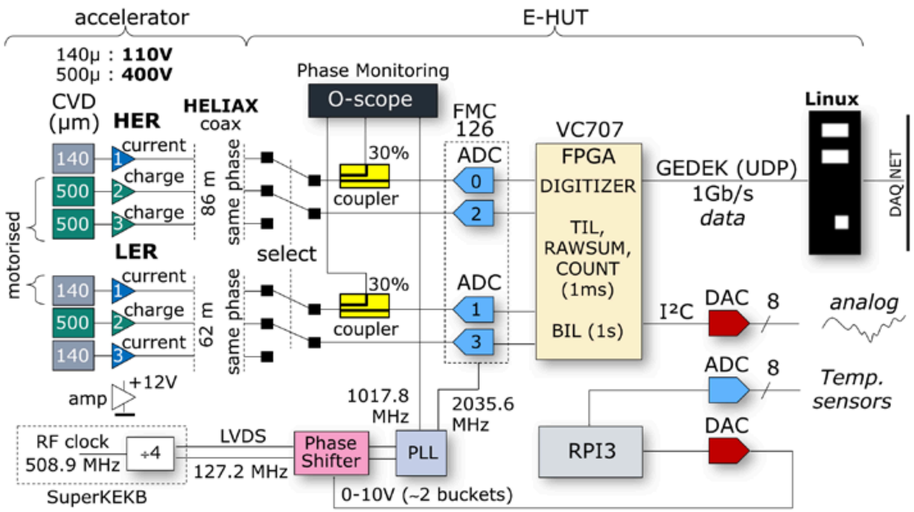


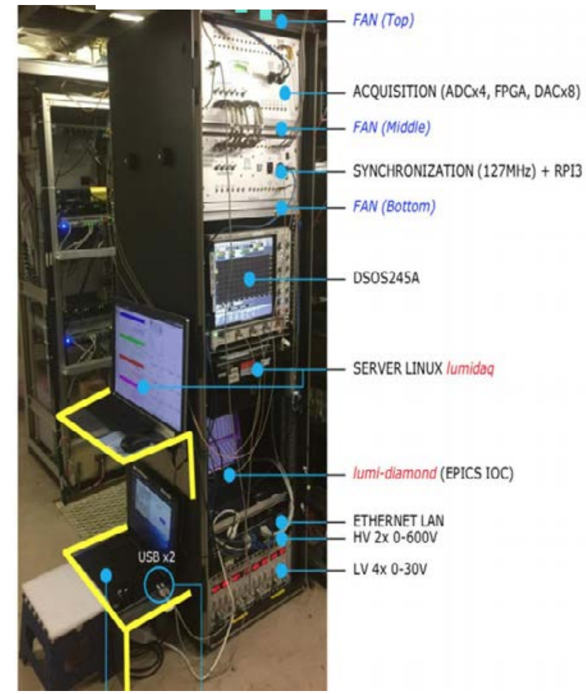


DAQ and online signal processing

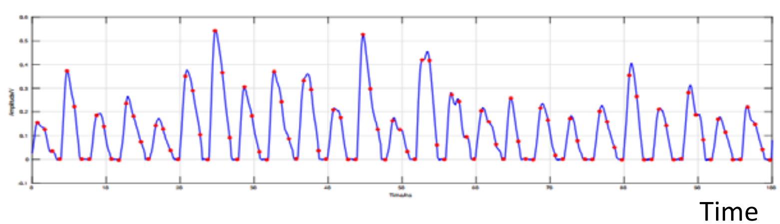
LumiBelle2
Luminosity Monitoring for Belle II







Sampling signal sequences at 1GHz



TIL: if $S[(i-1)\times 2+1] - S[(i-1)\times 2+3] > threshold$:

TIL $+= S[(i-1)\times 2+1] - S[(i-1)\times 2+3]$

RAWSUM: if $S(j) > threshold$:
Rawsum $+= S(j)$

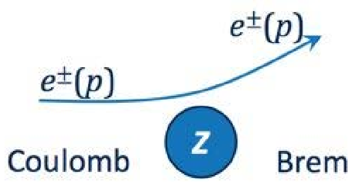
No trigger + Synchronization -----> Continuous monitoring, averaging at 1 kHz

TIL and RAWSUM are different ways of calculating the luminosity from the measured signal

Signal beam background

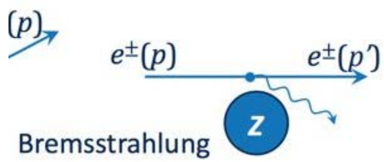
Coulomb

- Proportional to vacuum pressure and beam current
- Important globally but negligible for luminosity monitoring



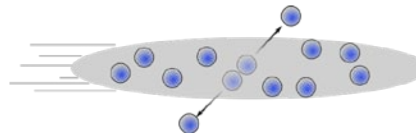
Bremsstrahlung → **dominant**

- Proportional to vacuum pressure and beam current
- Largest source of background in phase 2
- Photons measured at HER side
- Positrons measured at LER side



Touschek:

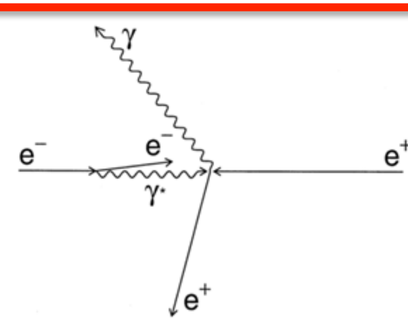
- Proportional to square of beam current
- Inversely proportional to beam size



Luminosity signal

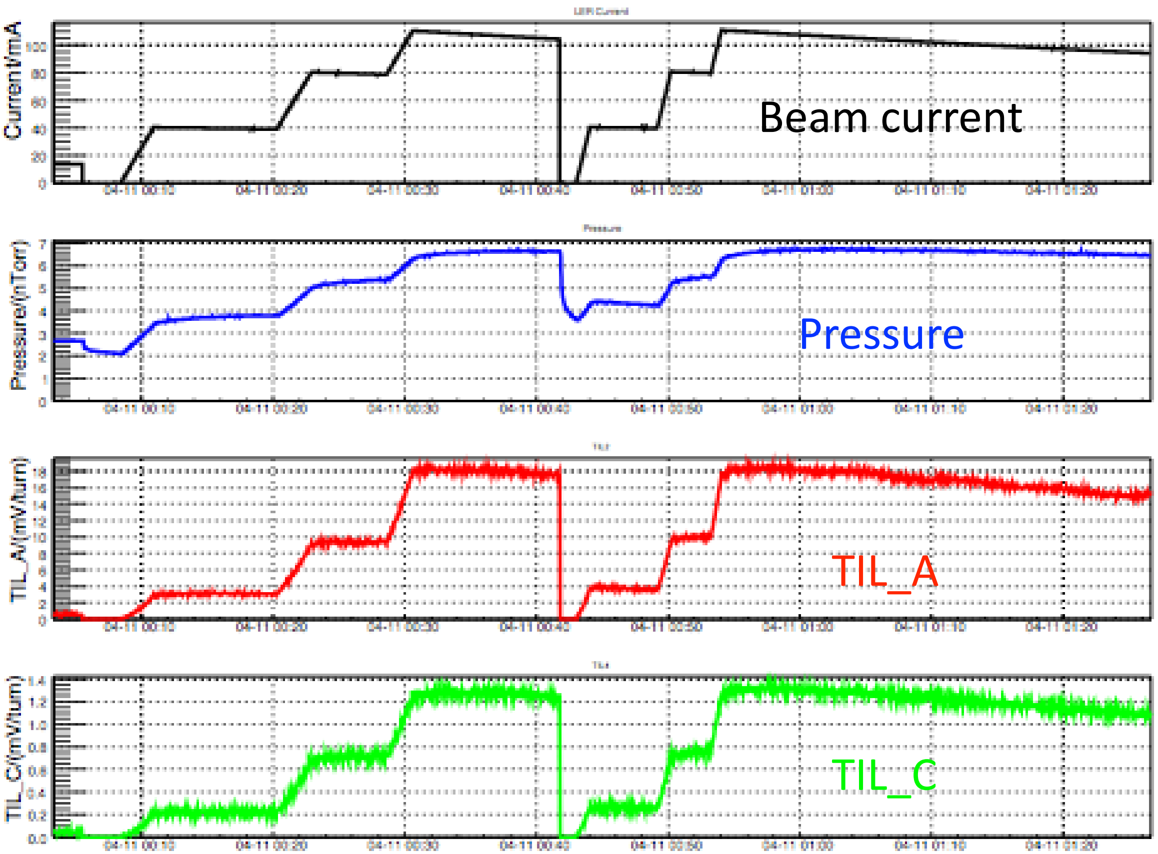
Radiative Bhabha process:

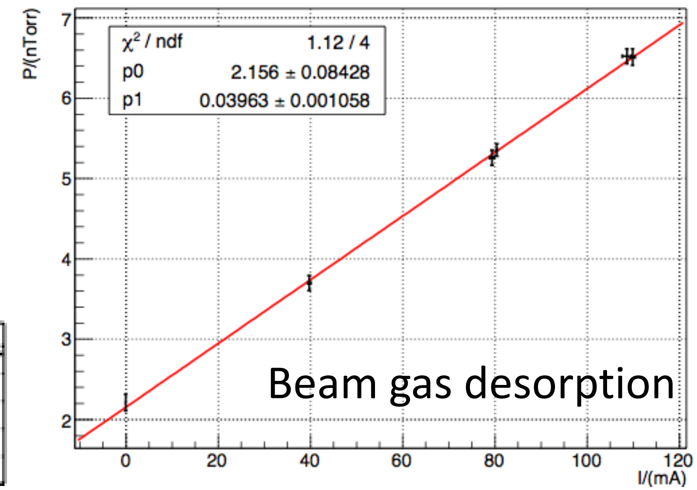
- Scattered @ IP
- Proportional to luminosity
- Large cross-section



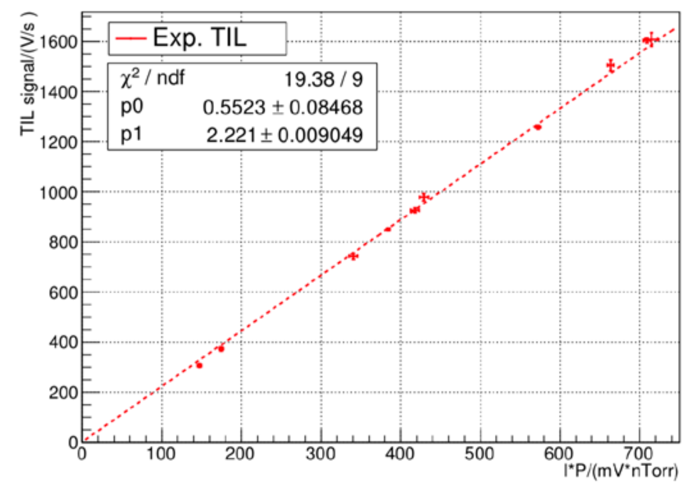
Background study (1)

- Background measurement:
  - ✦Bremstrahlung ∝ I*P   Dominant
  - ✦Touschek ∝ $I^2/(\sigma_x\sigma_y\sigma_z) \propto I \times P$





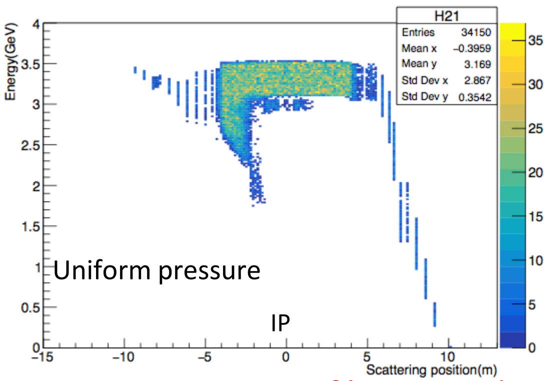
Pressure is proportional to current



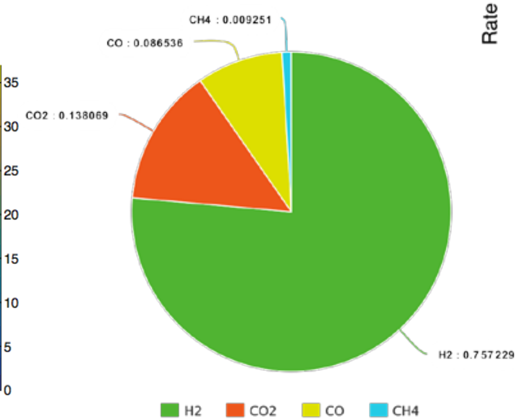
Background signal is proportional to product of beam current and pressure

Background study (2)

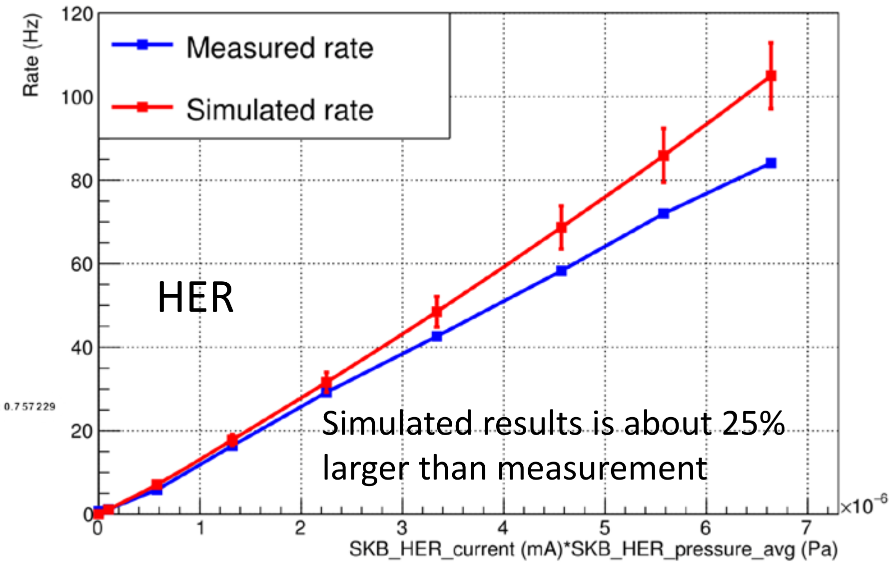
- Comparison with simulation



Scattering position of lost particles

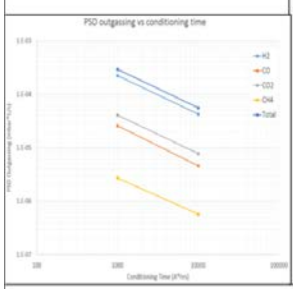


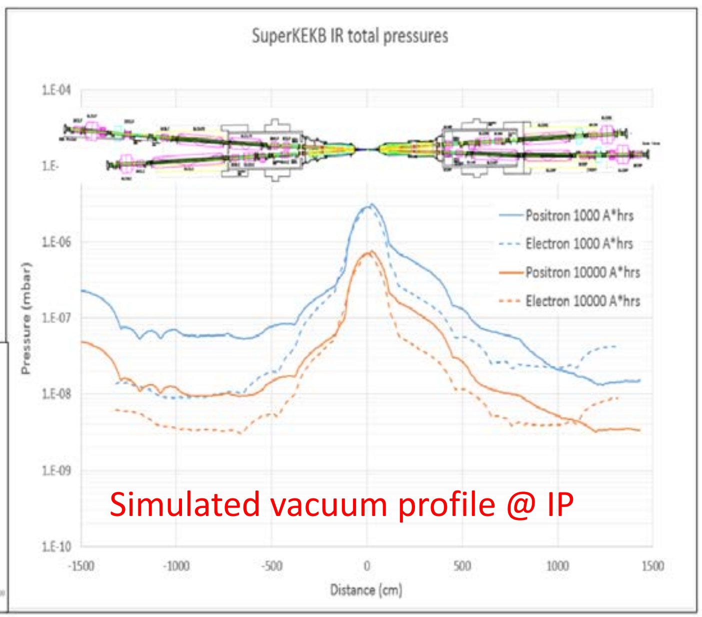
Z_{eff} =4.5

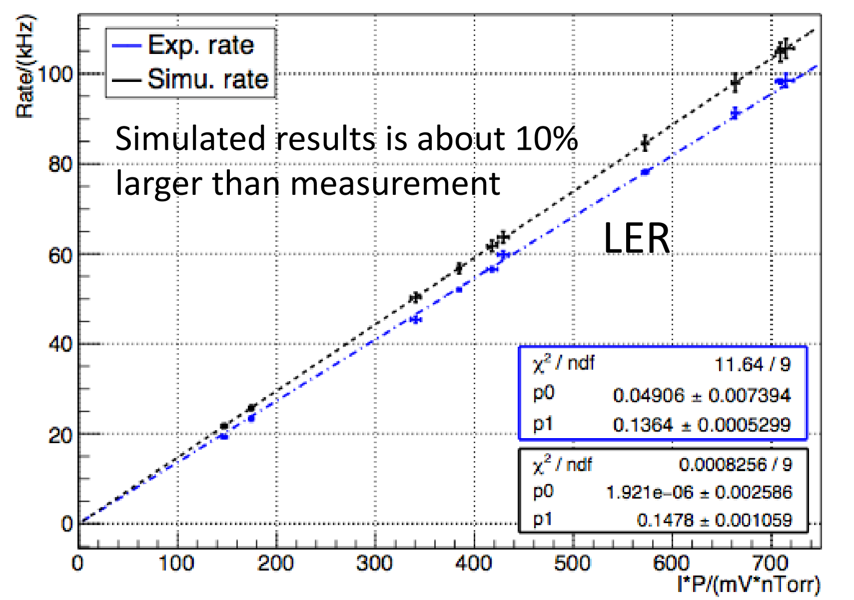


Total pressures at 1000, 10000 A*hrs, I = 3.6 A

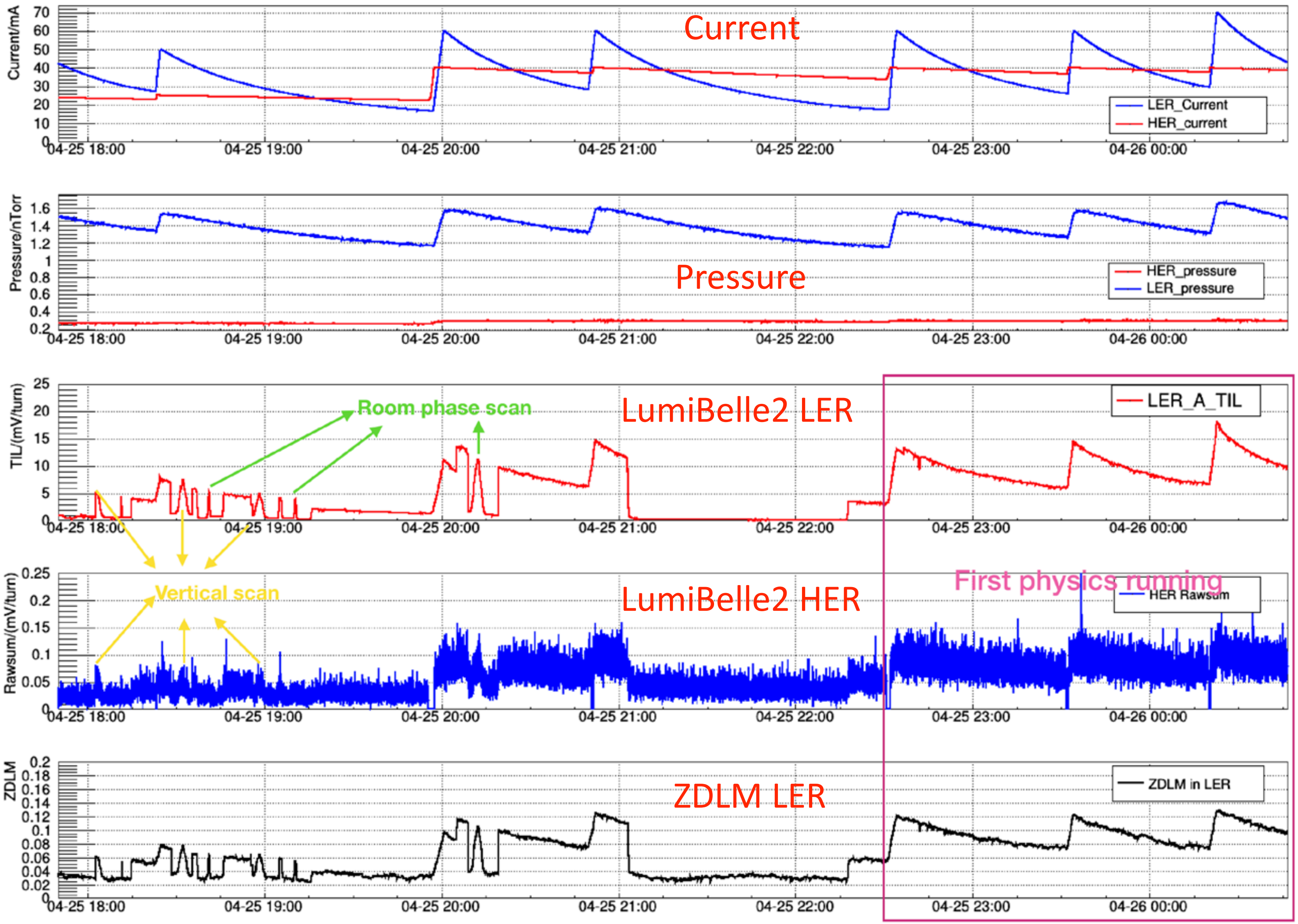
- Total indicates sum of H_2, CO, CO_2, and CH_4 partial pressures
- Asymmetric because of synchrotron radiation



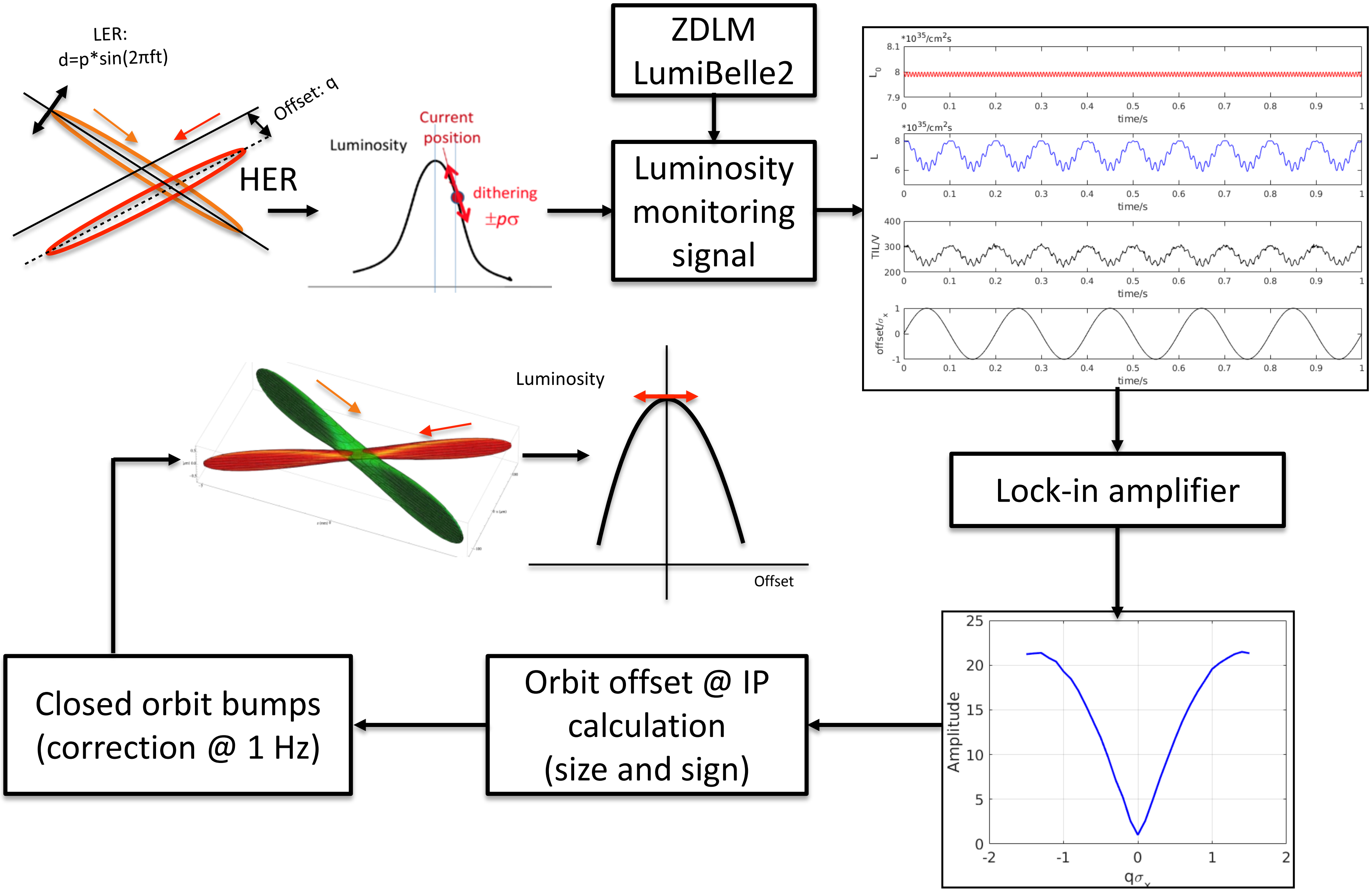




First collision – April 26, 2018

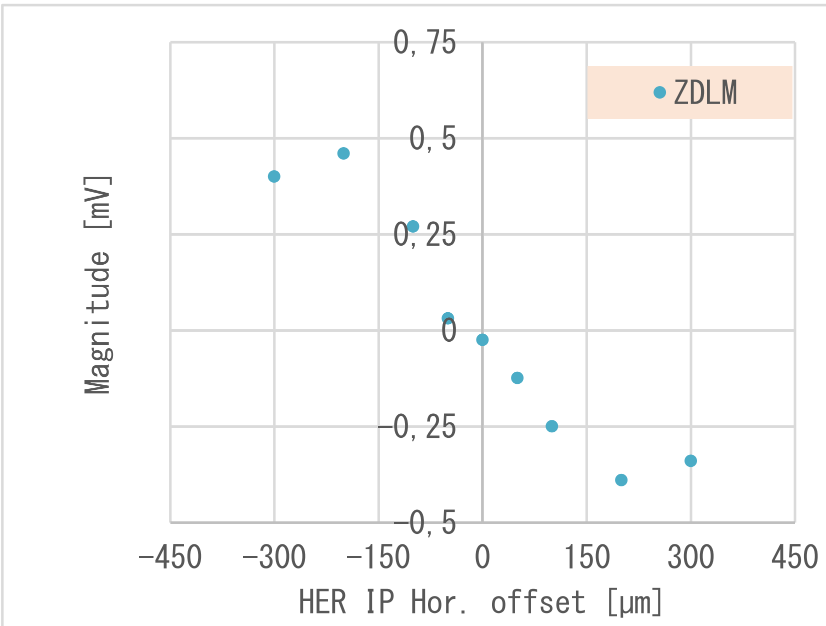


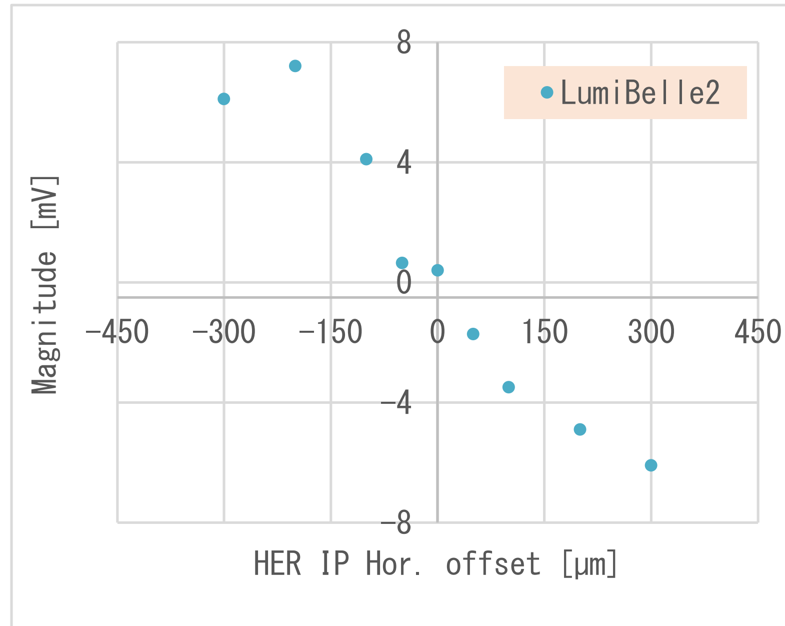
Dithering feedback algorithm



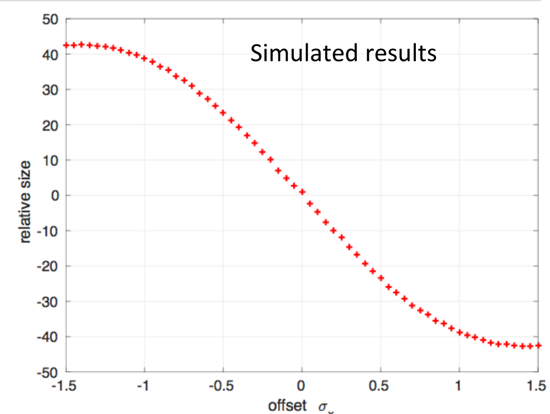
Dithering study with LumiBelle2 (1)

- Measurement with Lock-in amplifier



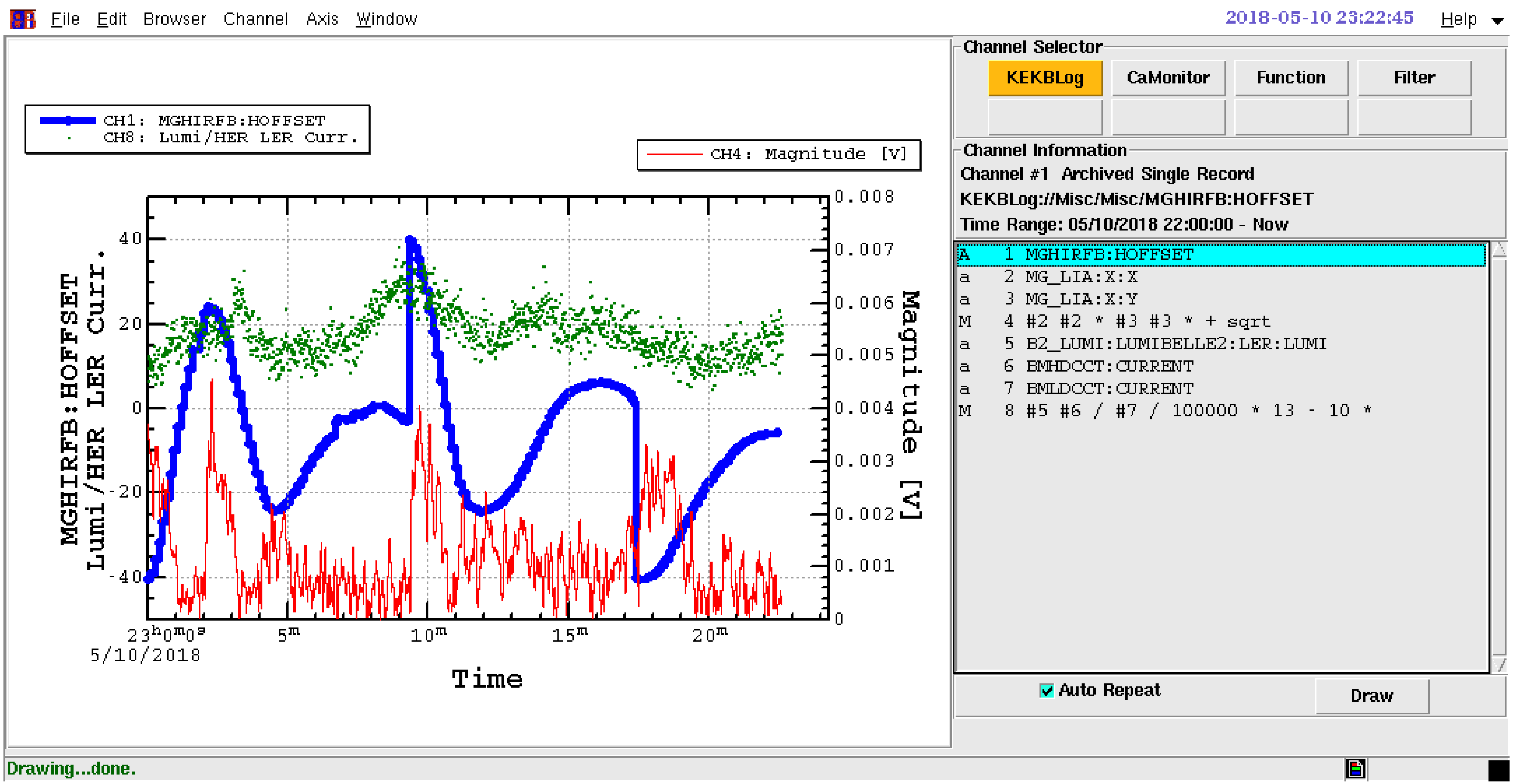


- Phase obtained by mixing dithering driven signal and luminosity monitoring signal
- Slope information can be obtained by several successive corrective moves
- Newton method is used to correct the beam orbit at 1 Hz



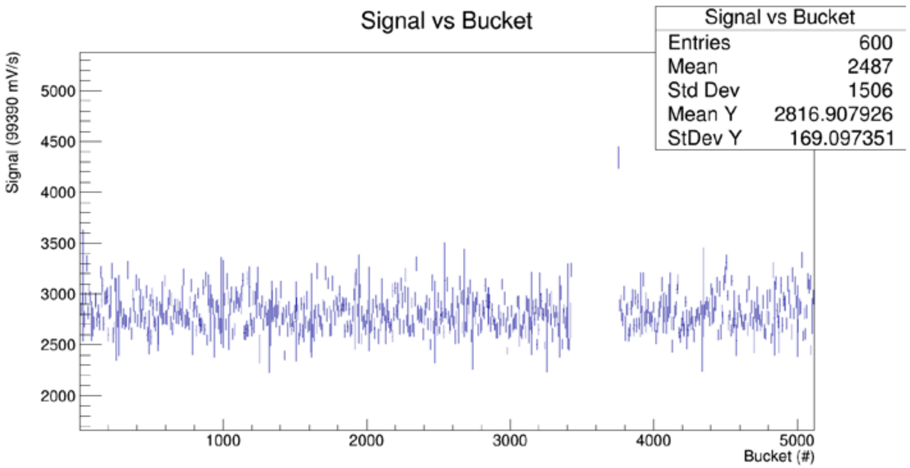
Dithering study with LumiBelle2 (2)

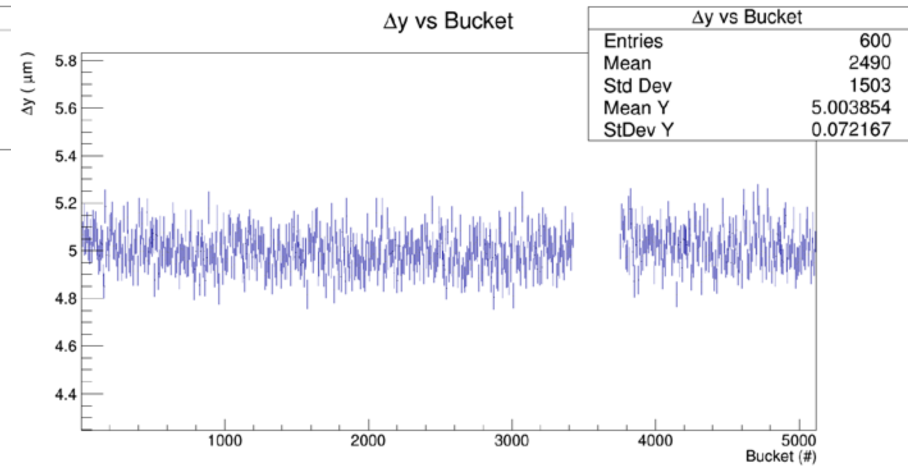
- Feedback shown to correct a deliberately introduced horizontal offset (after parameter tuning…)

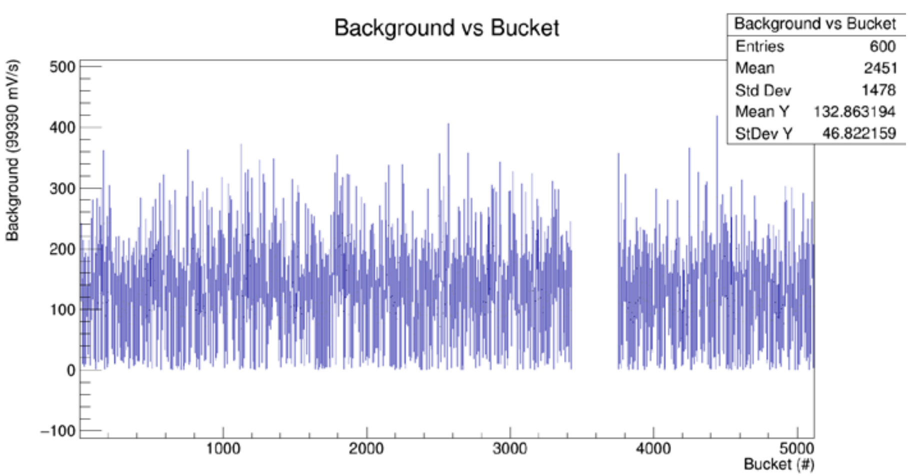


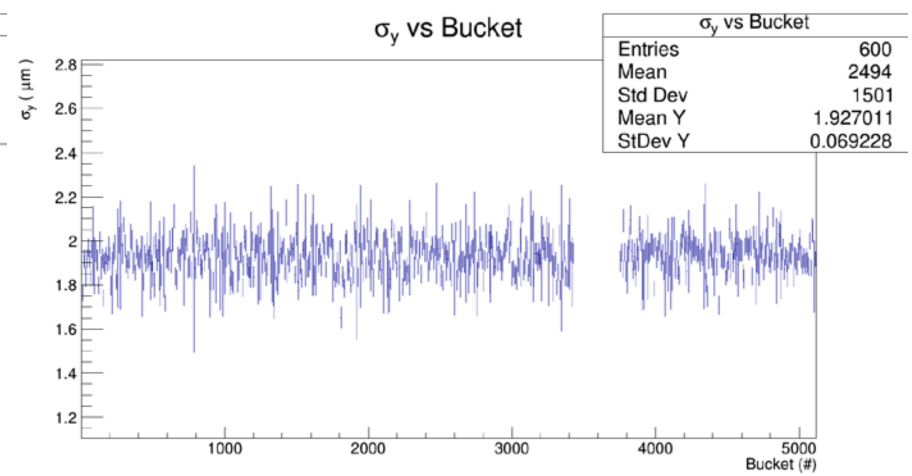
Bunch-by-bunch averaged LumiBelle2 measurements during vertical collision scanning

- Fitting of vertical beam sizes and relative offsets bunch-by-bunch
- Presently16 ns bunch separation, in Phase 3 → 4 ns (LHC has 25 ns)







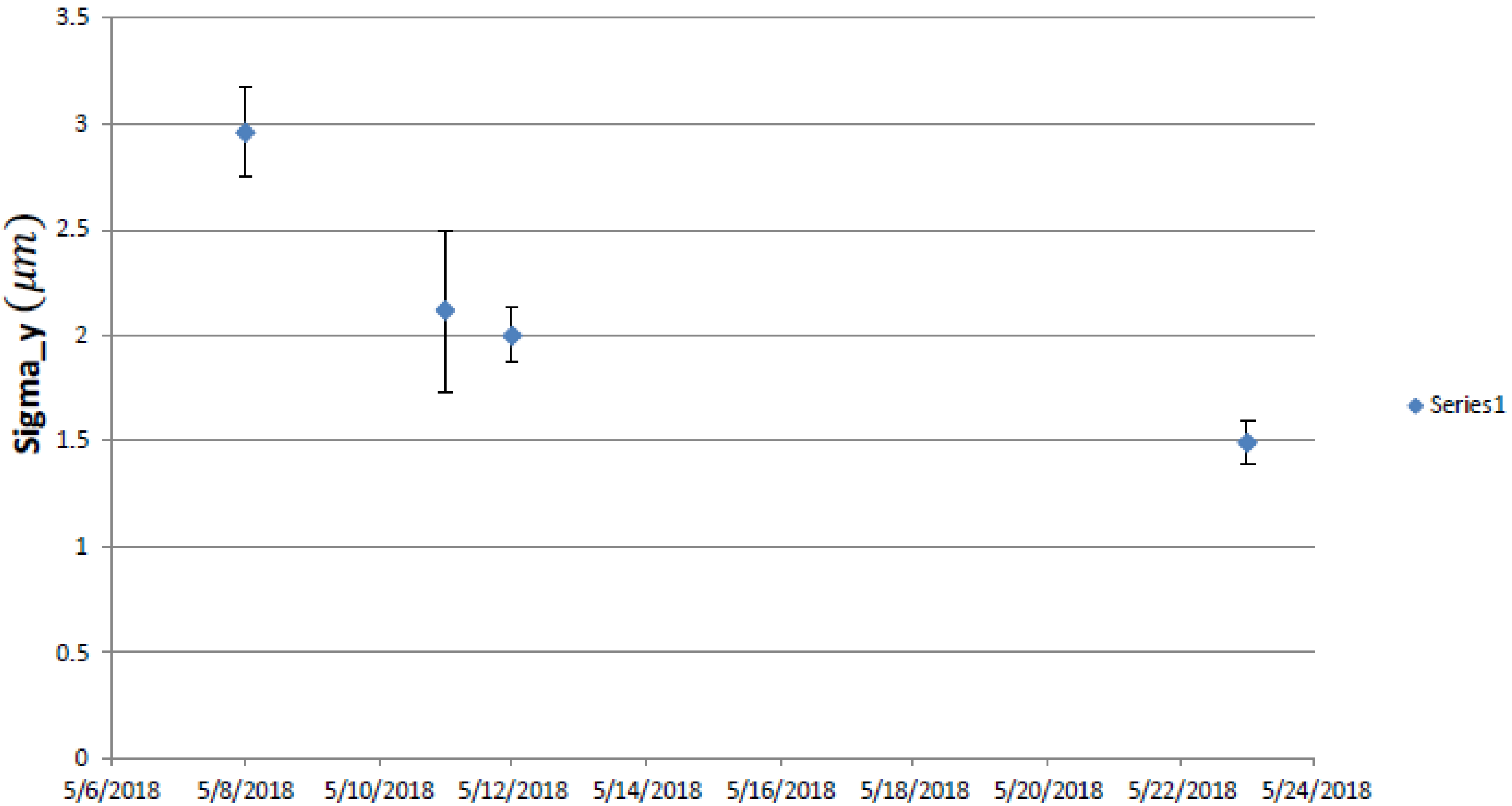


Signals and backgrounds need normalization by bunch-by-bunch currents

Individual bunch vertical sizes and relative offsets are determined to a few percent

σ_y (offset scans) squeezing

- σ_y is estimated for each monitor and average is given;
- Estimation from luminosity only during vertical offset scans;



Conclusions & future prospects

- **SuperKEKB**: 1st trial in 2018 of new "**nanobeam**" collision scheme promises a breakthrough in luminosity ($\times$ 40 increase)
- Latest instantaneous luminosity with 2.1.1 optics $\sim 10^{33}$ cm^{-2} s^{-1}
- Challenge for beams controls and tuning, including backgrounds
- Successful test of LumiBelle2 fast luminosity monitor during 2018 colliding beam commissioning at KEK:
  - several channels for 1kHz % level luminosity precision over 3 orders of magnitude
  - successful test of horizontal feedback based on LumiBelle2 by dithering technique
  - bunch-by-bunch luminosities and vertical beam sizes / relative offsets

→ Impact on future circular e+e– collider design work

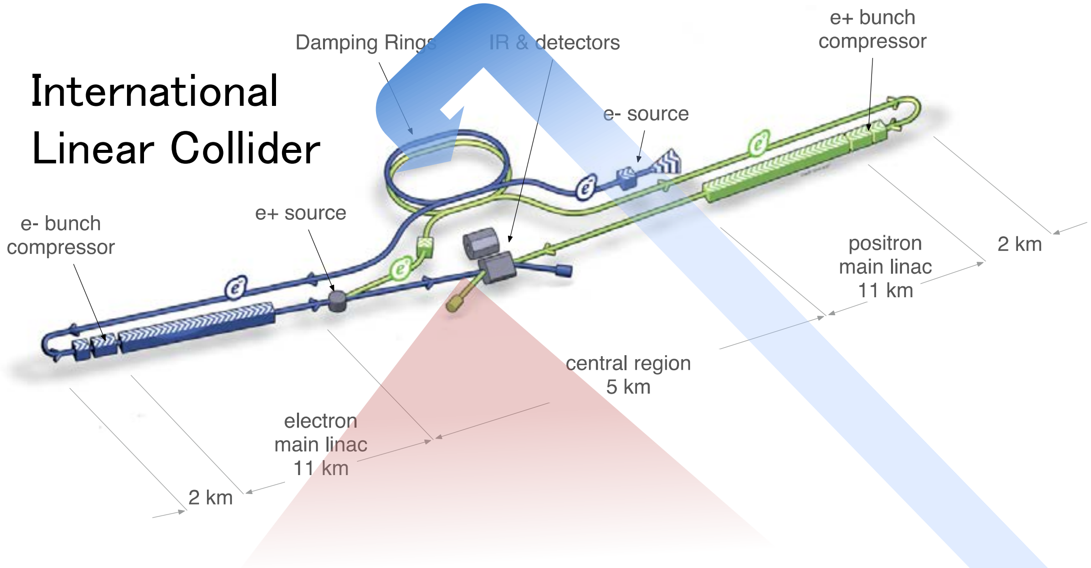
→ Rare, almost once in a life time, hands-on experience starting up a major HEP accelerator project, especially for junior scientists

→ IN2P3 (LAL & IPHC) has joined Belle II
  - LumiBelle2 activity moving to Belle II as long-term technical service task
  - prepare LumiBelle2 for sustainable long-term operation with more limited HR

→ New perspectives for France-China collaboration

Backup slides
(ATF beam halo studies)

International
Linear Collider



Accelerator Test Facility

Energy: 1.3 GeV, Repetition: 3.12 Hz
Intensity: 1×10^{10} e-/bunch (max. 2×10^{10}), 1~20 bunches/pulse
Emittance: Design, 1 nm(H)/ 10 pm(V),
Achieved 4 pm(V)

Advanced Beam Instruments R&D

ATF2 beamline

Nano-meter beam R&D

Final focus system development

Technologies to maintain the luminosity at ILC

Goal 1: validate ILC-like final focus → $\sigma_y \sim 40$ nm
Goal 2: nm-level IP beam stability via feedback

Damping Ring (~140m)

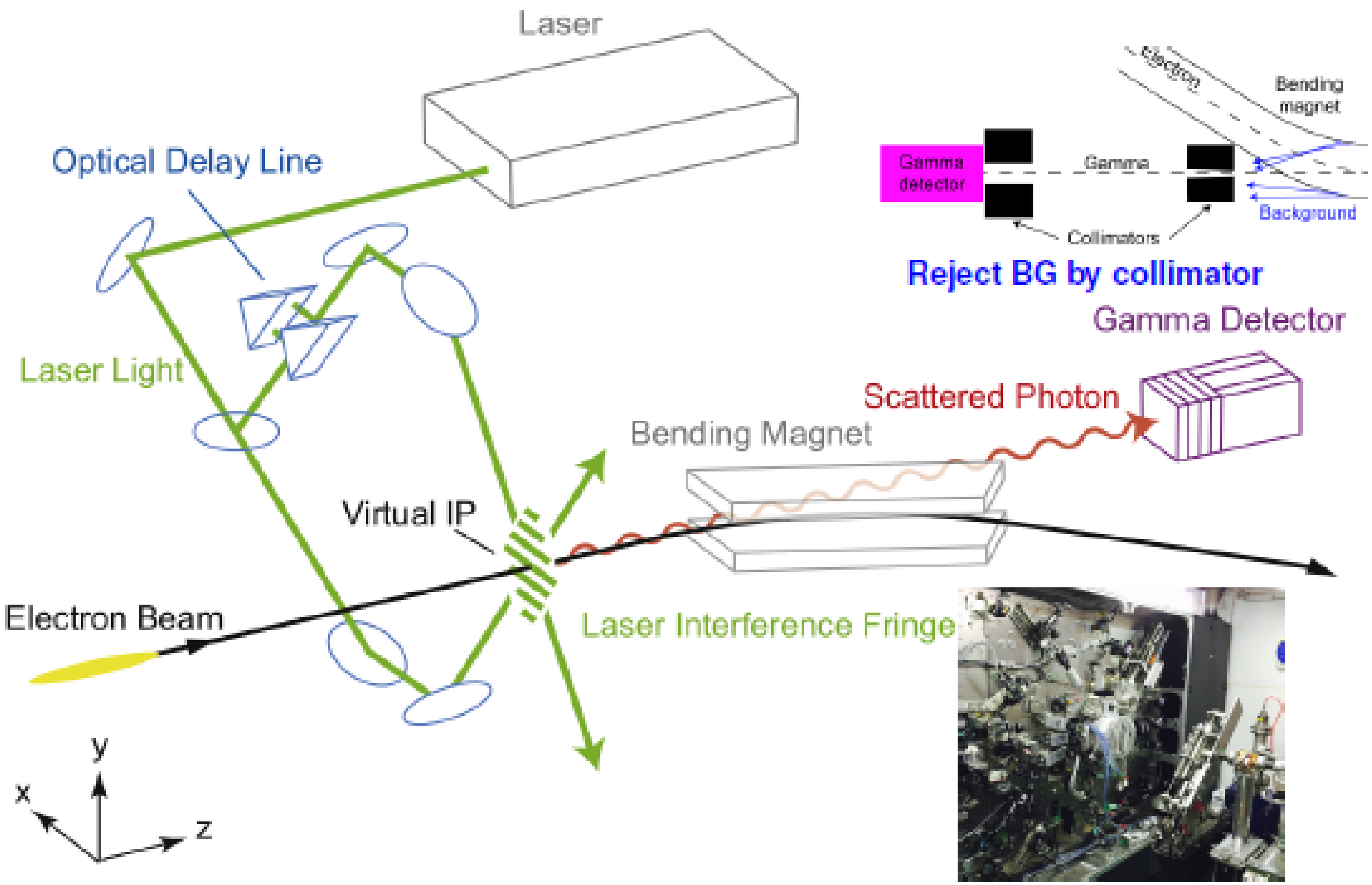
Low emittance beam

Cs_2Te Photocathode RF Gun

1.3 GeV S-band Electron LINAC (~70m)

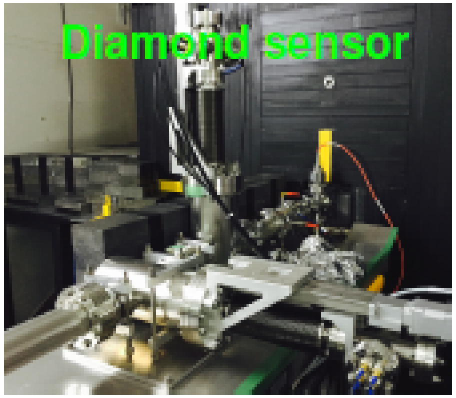
Motivation of halo study at ATF

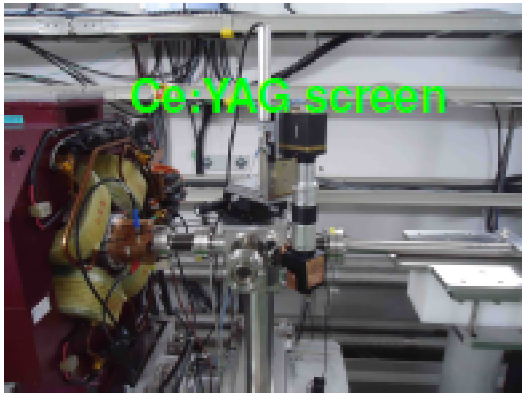
- Background induced by halo particles loss upstream of IP might reduce the modulation resolution of *Shintake* monitor
- Essential to understand the genesis of halo and its distribution !

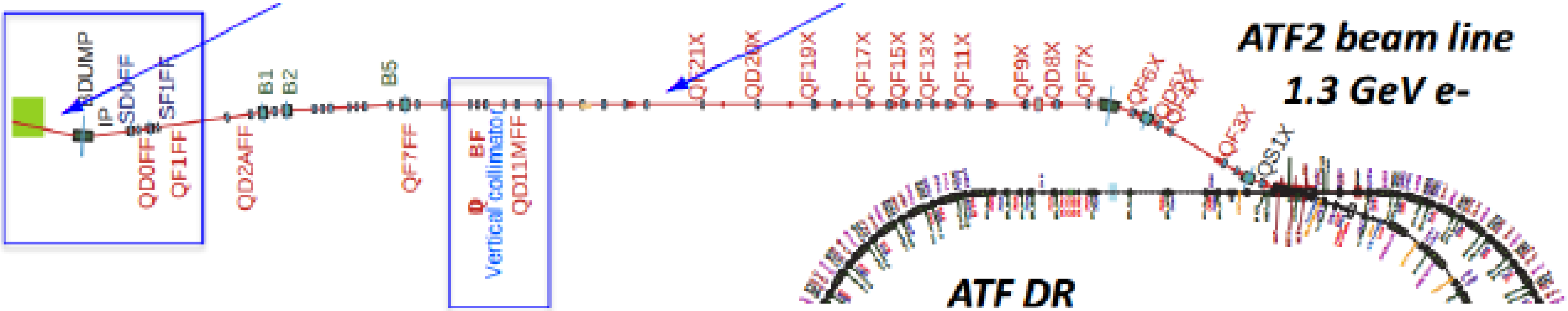


Instrumentations for beam halo diagnostics

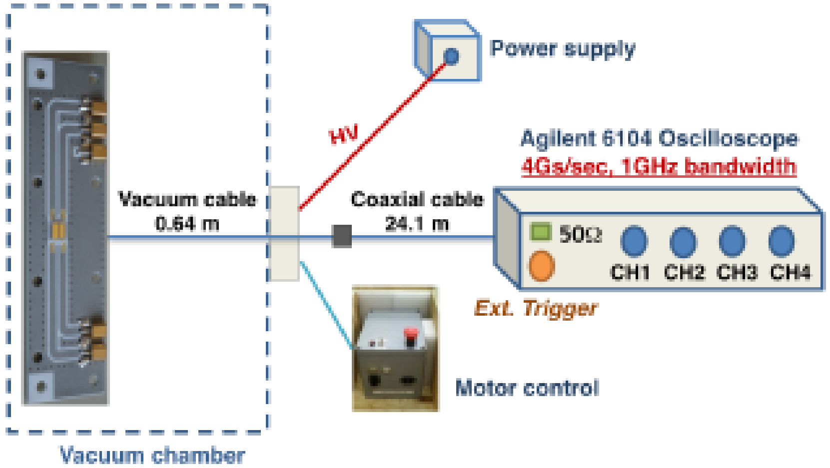
- First measurement: wire scanners at the previous EXT line, 2005
- New diagnostics: diamond sensor (DS) detector and YAG/OTR monitor

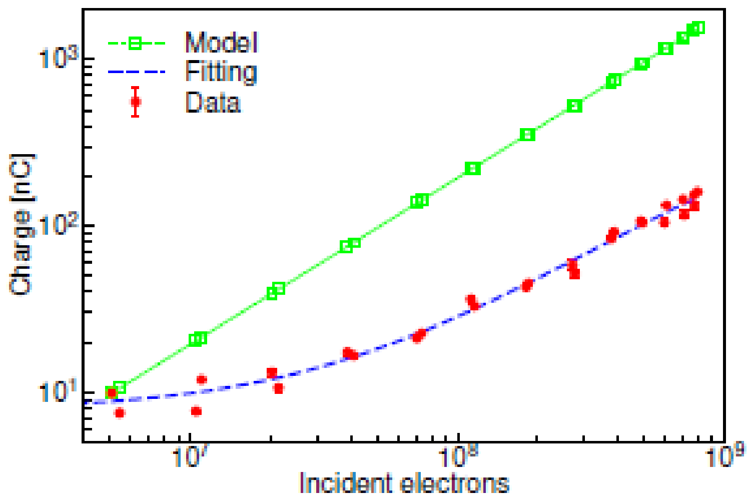






in vacuum diamond sensor detector



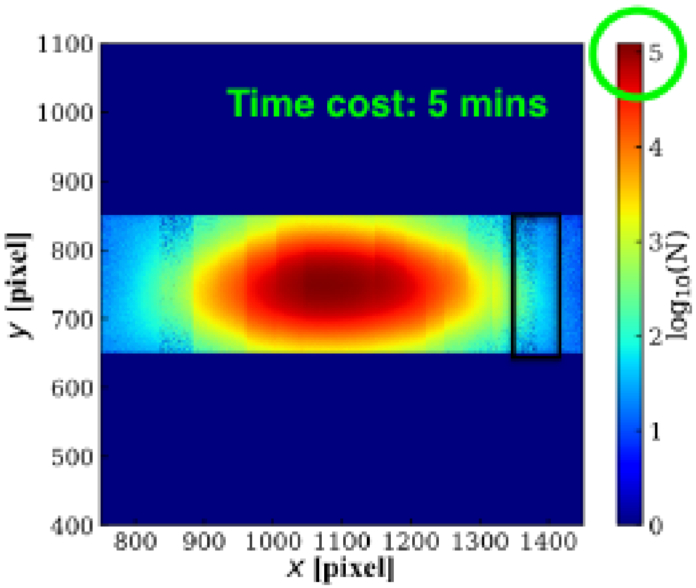


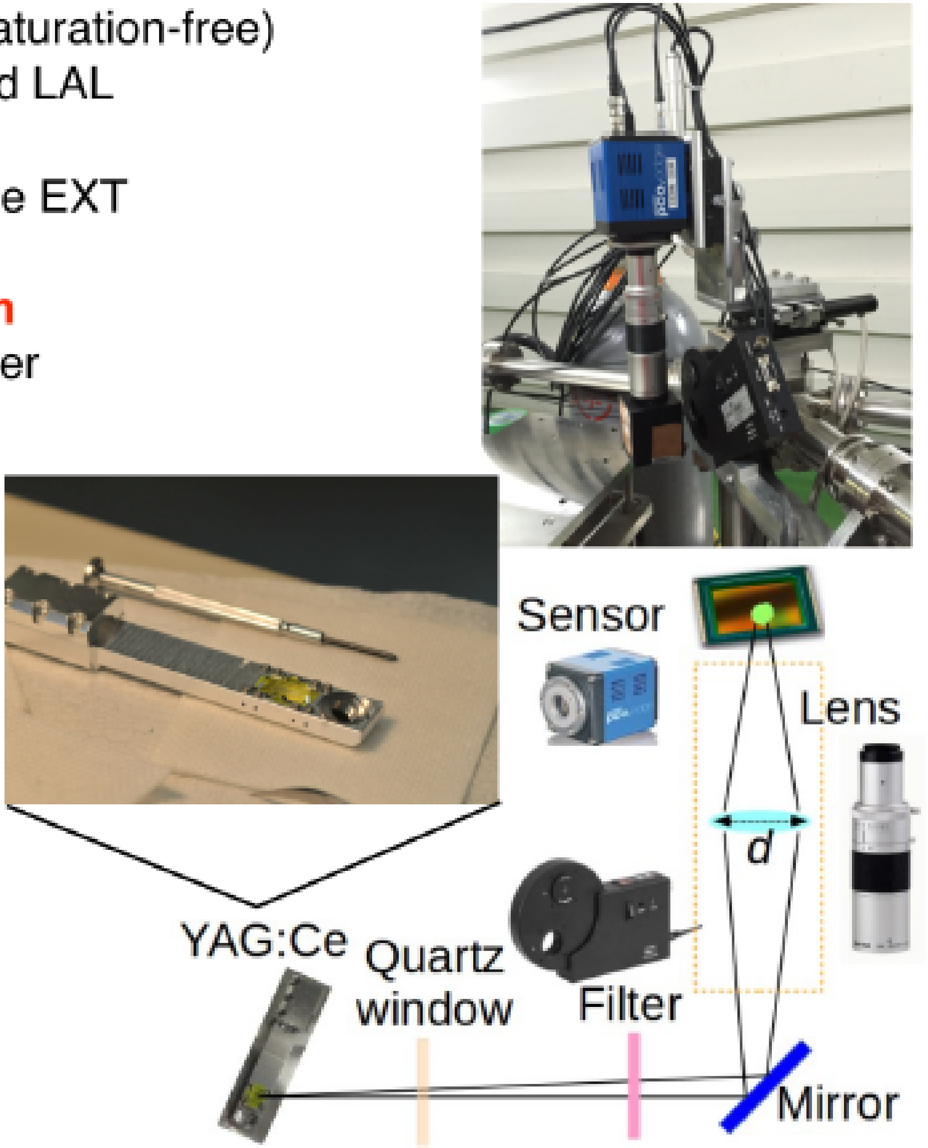
- Two 1.5 mm$\times$4 mm and two 0.1 mm$\times$4 mm sCVD DS strips
- Dynamic range $d_R \approx 10^5$
  * Lower limit: induction current/noise level
    $> 2 \times 10^{-3}$ nC (>$1\times10^3 e$)
  * Upper limit: charge collection saturation
    $\sim 1 \times 10^2$ nC
- Signal of core is re-scaled by "self-calibration" thanks to WS upstream of DS
  * Approximating charge collected in the core by extrapolating WS measurement
  * Re-scaling factor
    $\kappa(n_e) = Q_{exp}/Q_{meas}$

[1] S. Liu, et al., NIMA, 832 (2016)

A novel Ce:YAG/OTR monitor

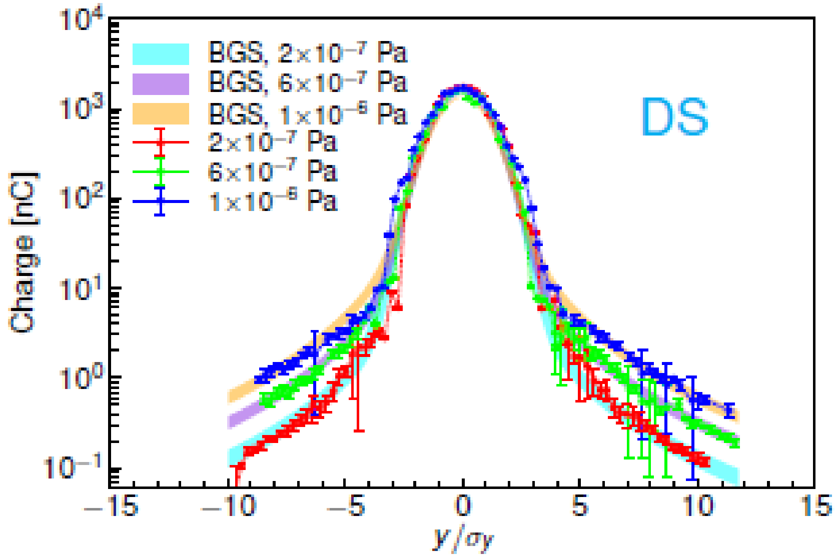
- YAG —> core/halo; OTR —> core (saturation-free)
- Collaboration among KEK, CERN and LAL
- Dispersion-free or large dispersion
  —> Adjusted using QS1X/QS2X in the EXT
- Critical Performance:
  DNR > 10^5 and resolution < 10 μm
- Scanning (x or y) using YAG + ND filter
  —> avoiding the blooming effect
- Multi-shot measurements
  —> Position/beam size jitter < 5%

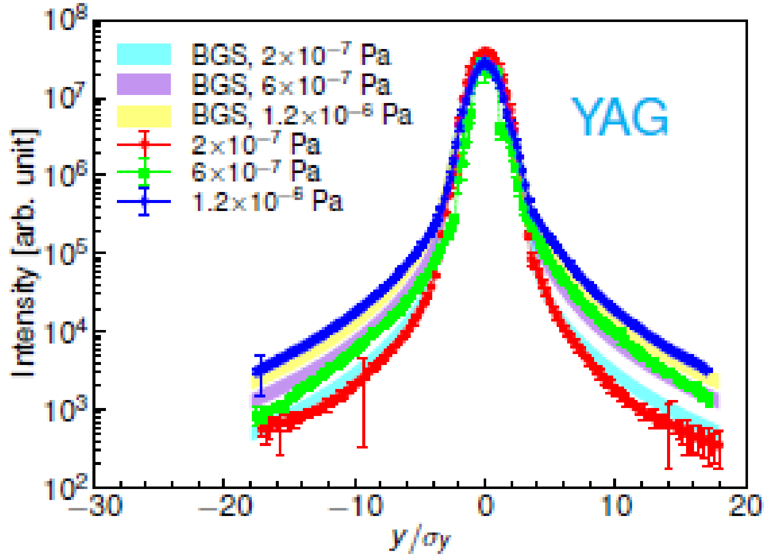




Vertical beam halo due to BGS

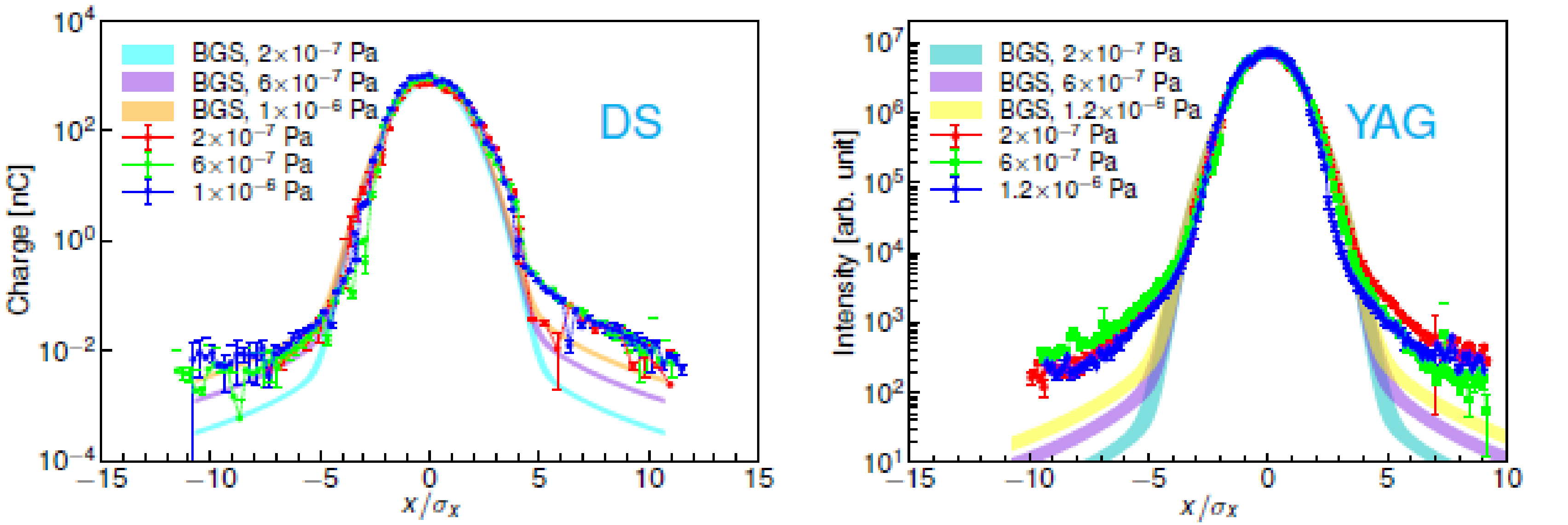
- Beam profiles measured by DS after re-scaling and that by YAG monitor are in good agreement with the numerical predictions
- Higher tail for the worsened vacuum: 2×10^{-7} Pa $\rightarrow$ 1×10^{-6} Pa
- Vertical beam halo is dominated by elastic BGS!





Horizontal profile measurements

- Measurements are higher than the numerical predictions (BGS)
- Asymmetric distribution, more particles on the high energy side
- No significant change for the degraded vacuum
- Other dominating mechanisms (Touschek scattering?)

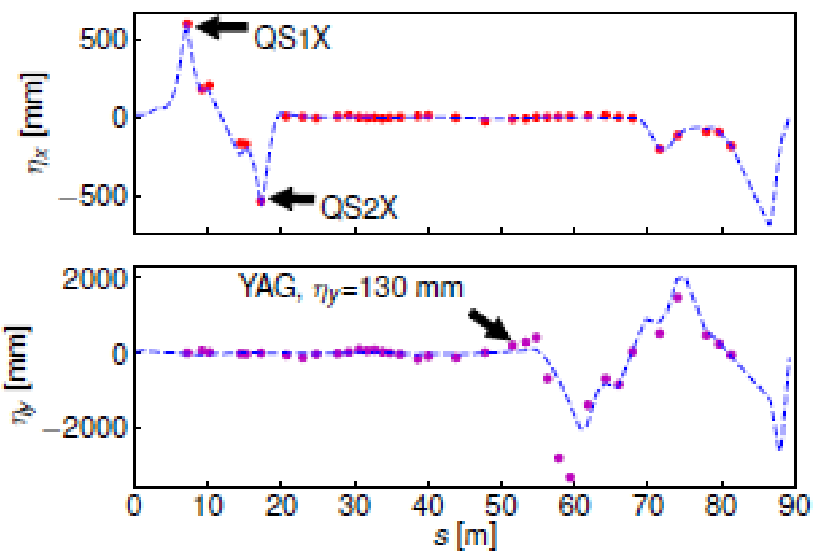


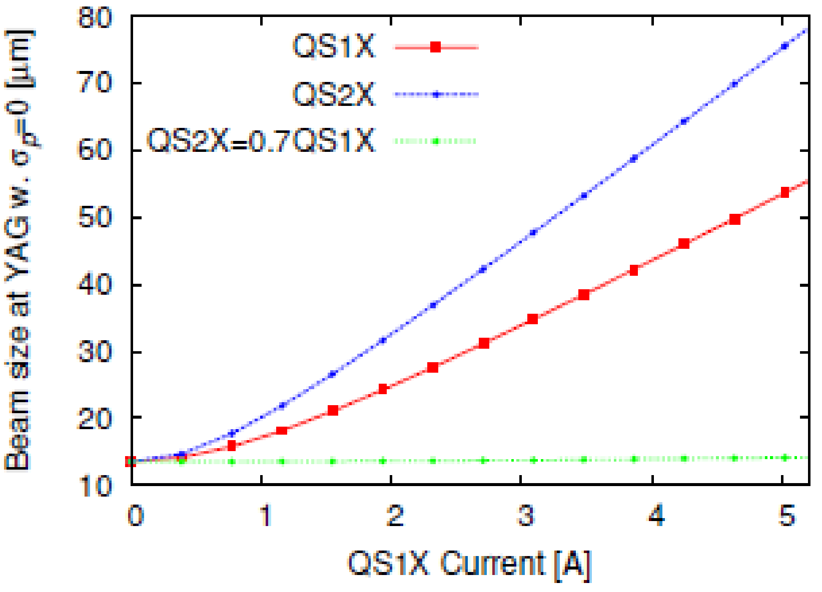
Design of energy spectrum measurement (1)

- Min. distinguishable energy deviation

$$\delta_{m,\text{sep}} \geq 2\sqrt{\epsilon\beta}/\eta$$

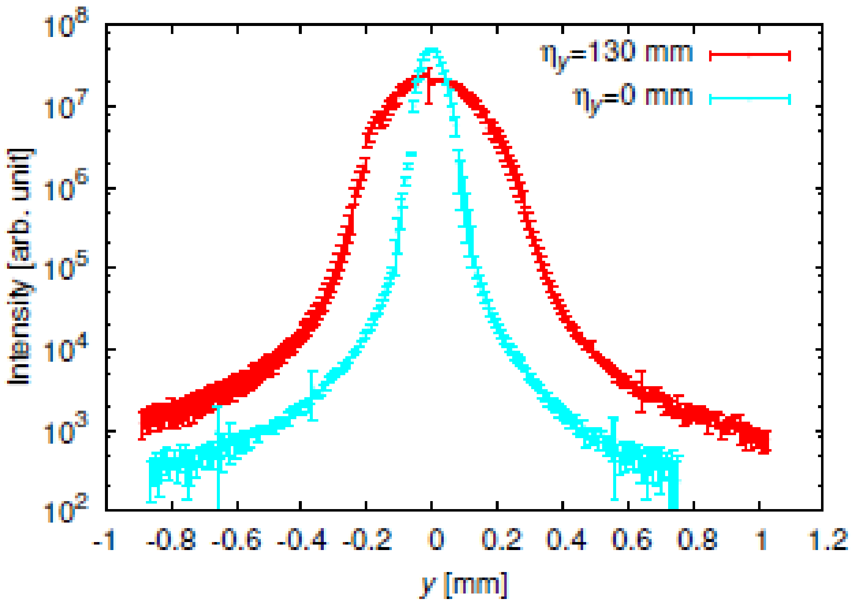
- Small β and large η, but $\epsilon_x \approx 100\epsilon_y$ –> vertical observation is superior!
- Vertica dispersion blowing up:
  - Adjusting η_y by tuning QS1X/QS2X with specific ratio, e.g., 10:7
  - Ver. profile <— energy spectrum if η_y is large enough (>150 mm)

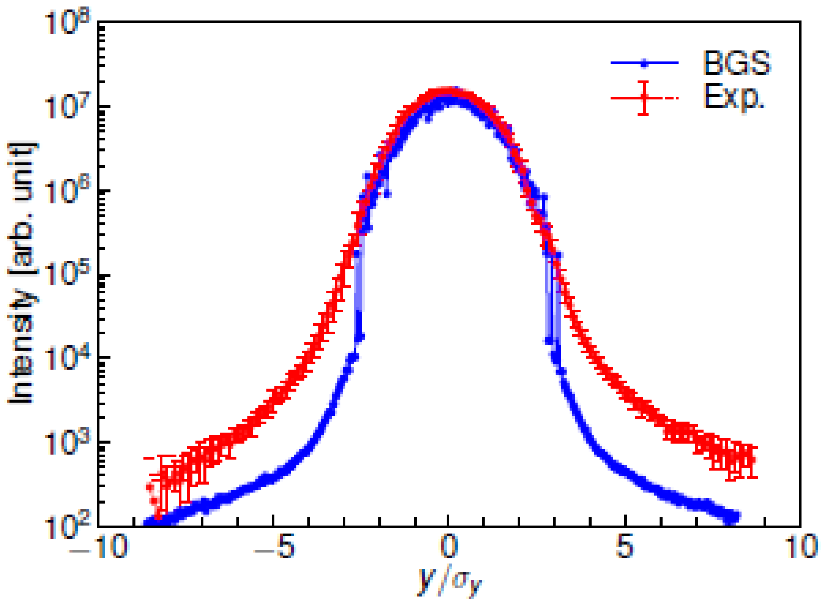




First observation of energy spectrum

- Simulations with the measured vertical betatron profile at EXT kicker
- For $\eta_y = 200$ mm, the measured vertical tail is higher than the prediction by at least a factor of 4 –> Momentum profile!?





- Influence of the betatron halo (BGS) and xy coupling terms? Due to Touschek scattering?