BEAST phase1

H. Nakayama(KEK)
on behalf of
Belle2 Beam background group

Goals of Beam Background Group

- Overall goals: **Estimate, measure, mitigate, and protect against** beam backgrounds
- Background sources
  - Touschek effect (Beam size and energy)
  - Beam-gas interactions (current, pressure)
  - Synchrotron radiation
  - Radiative Bhabha scattering (Lum.)
  - 4-fermion final state QED process (Lum.)
  - Injection BG
- Can result in instantaneous damage, long term damage, or excess occupancy in Belle II
- Want to measure all backgrounds, **validate MC primarily during phase 1/2 (BEAST)**. Use MC to extrapolate to phase 3.

Beam BG Group

- LEADER, BEAST: **S. Vahsen** (Hawaii)
- BEAST KEK liaison, BG simulation: **H. Nakayama** (KEK)

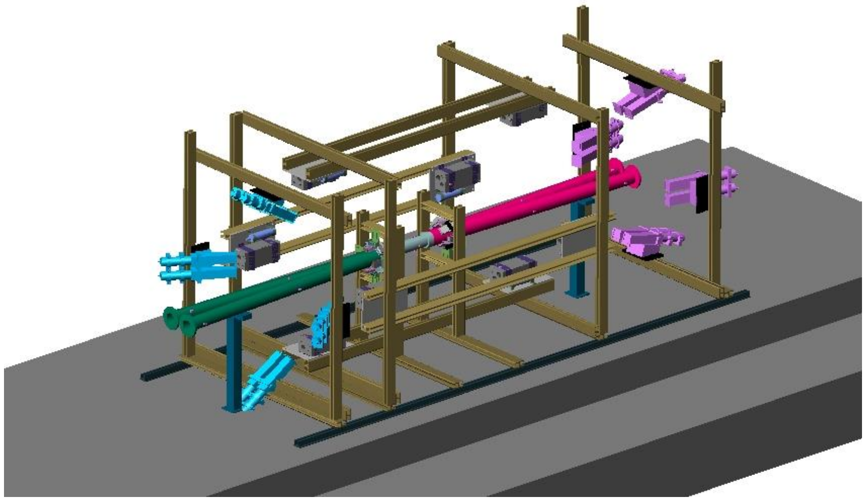
- Institutes:
  - KEK, Hawaii, Bonn, Trieste, MPI, Heidelberg, DESY, Wayne, NTU, IFCA, LAL, IPHC, etc..

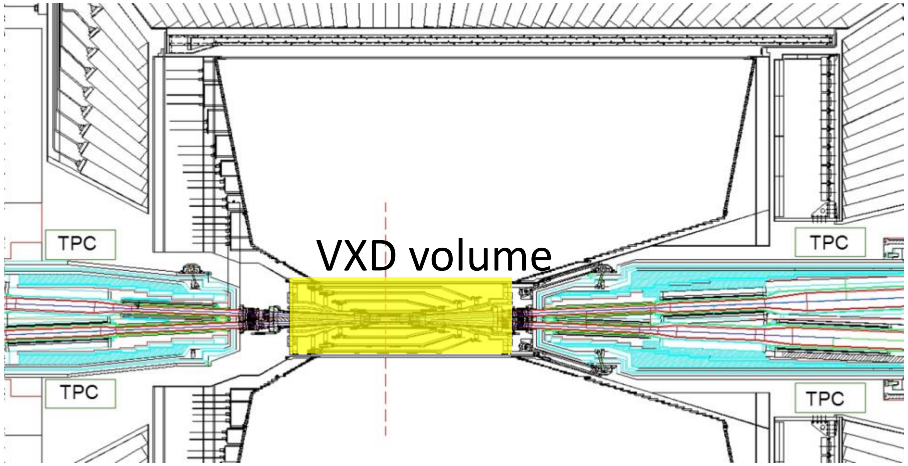
- Significant support from accelerator colleagues
  - Beam loss simulation by SAD
  - BEAST machine study operation

BEAST

SuperKEKB Commissioning Detector
BEAST II
獣
Belle II Collaboration

BEAST phase1/phase2





BEAST Phase 1: Jan-Jun 2016

- Vacuum scrubbing of beam pipe.
- No collisions. Belle will not roll-in.
- Variety of subsystems on fiberglass support structure
- **No Belle DAQ, only BEAST DAQ**

BEAST Phase 2: 2017 Autumn-

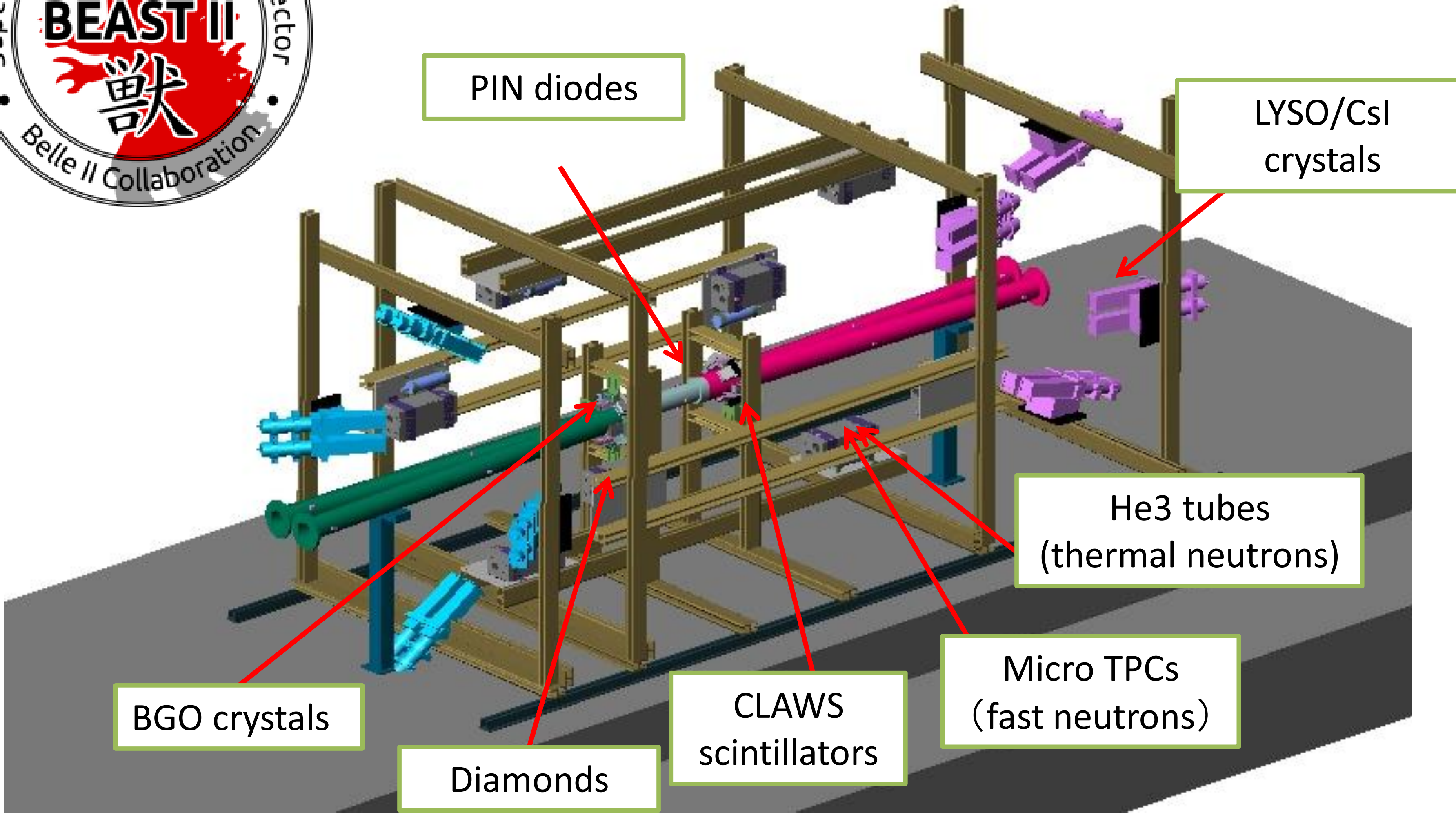
- Belle rolled in.
- VXD volume
  - Partial VXD ladders
  - + other BEAST phase2 sensors
- BEAST detectors in dock space and around QCS
- **BEAST DAQ + Belle DAQ**

BEAST phase1 sensors

- Measure BG levels near IP
  - X-rays, charged tracks, fast/thermal neutrons, dosimetry
  - online feedback to SuperKEKB
  - offline for analysis
- Test and calibration of diamond sensor for VXD beam abort in phase2/3
- First measurements of SuperKEKB injection BG
- First comparison of SuperKEKB beam-loss simulation with experimental data

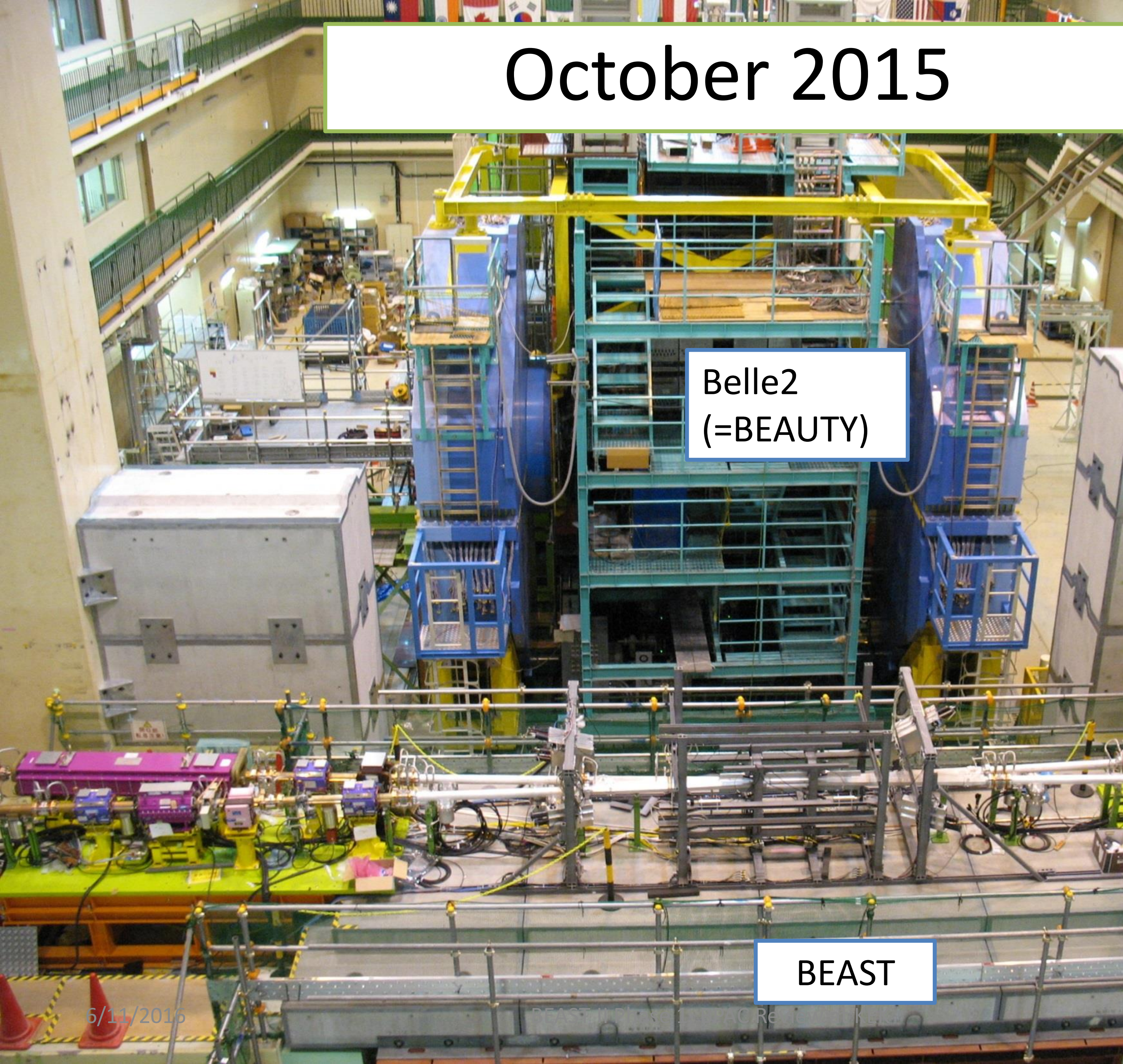
System	Detectors Installed	Unique Measurement
PIN Diodes (USA)	64	Neutral vs charged radiation dose
Diamonds (Torieste)	4	ionizing radiation dose
Micro-TPCs (Hawaii)	4	fast neutron flux++
He-3 tubes (Canada)	4	thermal neutron flux
Crystals (Italy, Canada)	6 CsI(Tl) 6 CsI 6 LYSO	EM energy spectrum, Injection BG
BGO crystal (Taiwan)	8	luminosity
“CLAWS” (Germany)	8	Injection BG

BEAST Phase1 sensors at IP

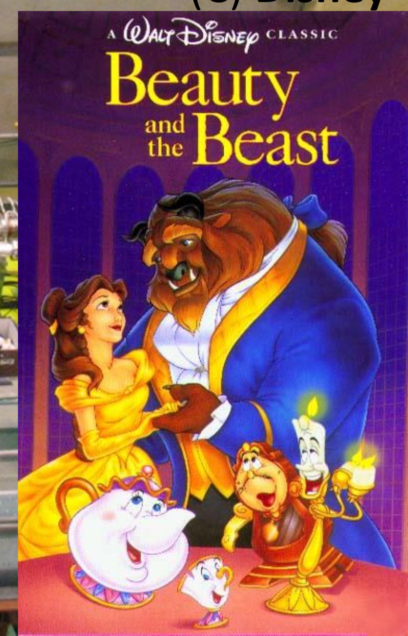


Various measurements (fast charged particle, high-energy photons, thermal/MeV neutron, dosimetry, etc..) to **validate beam loss simulation**

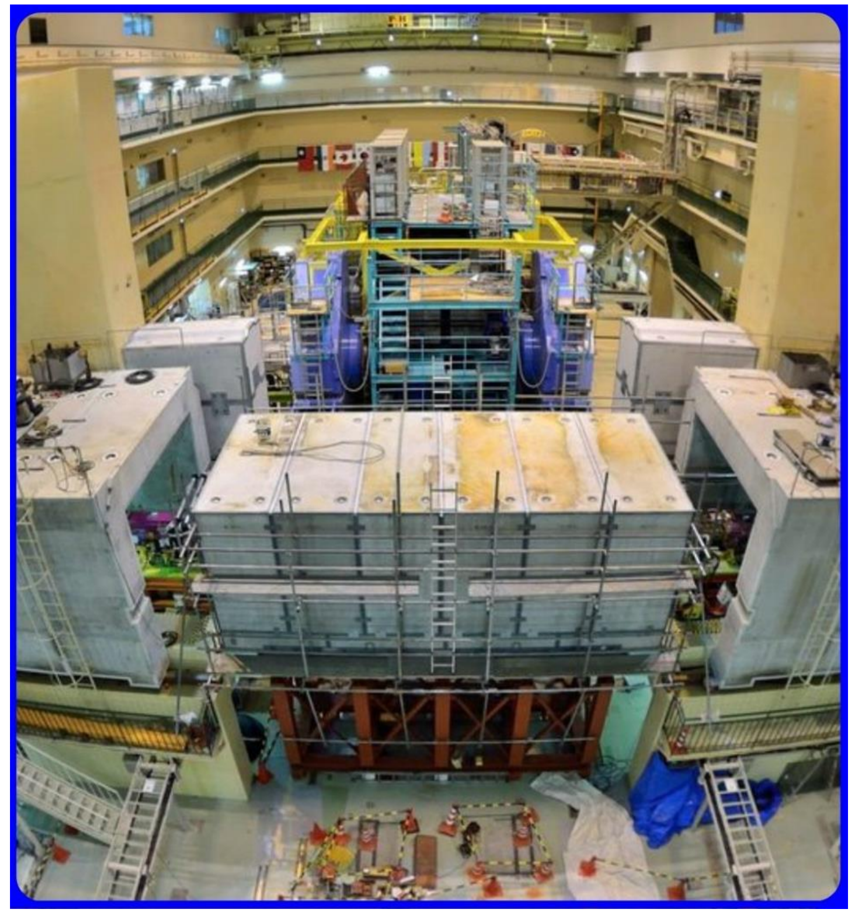
October 2015



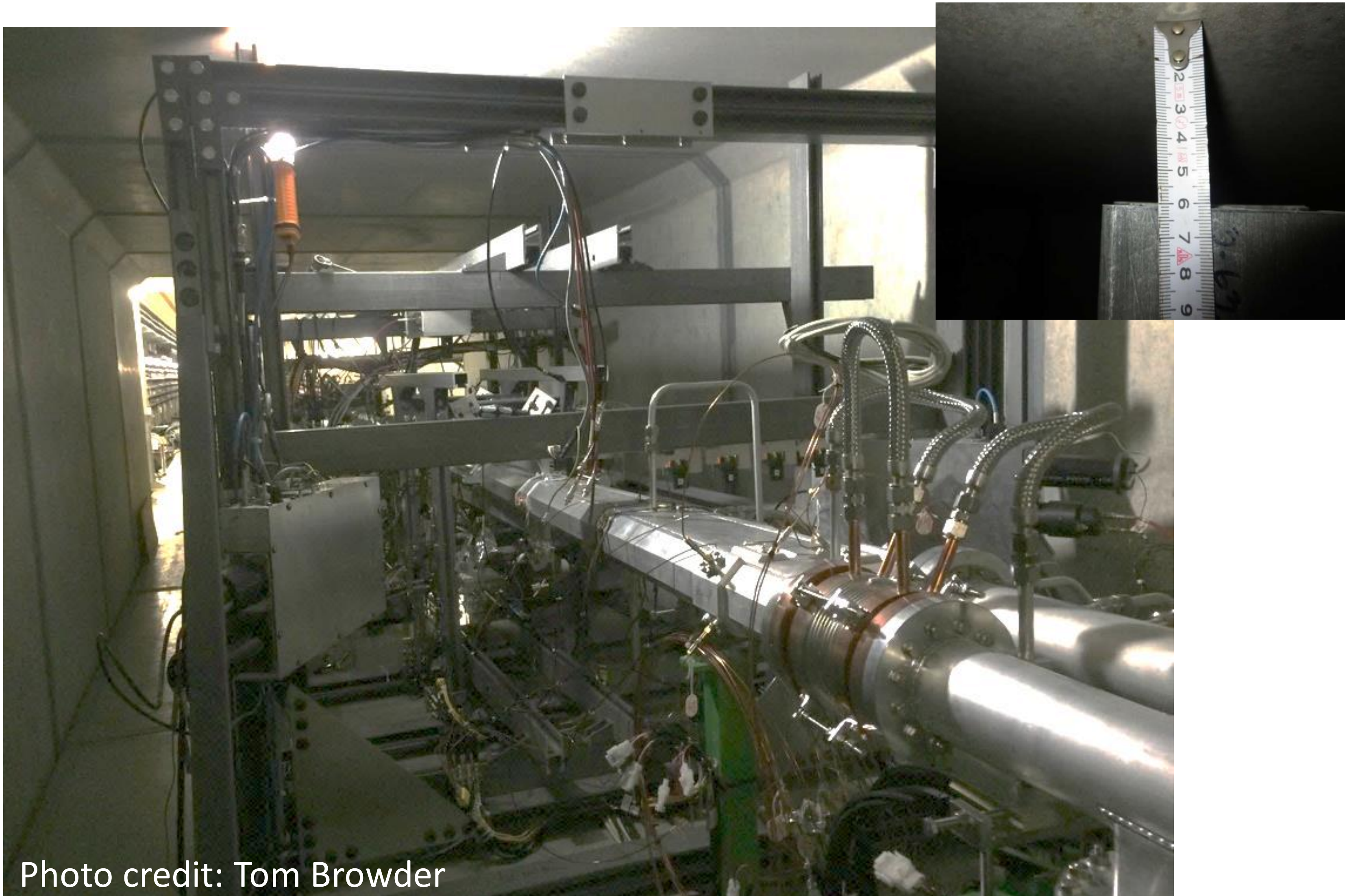
(C) Disney



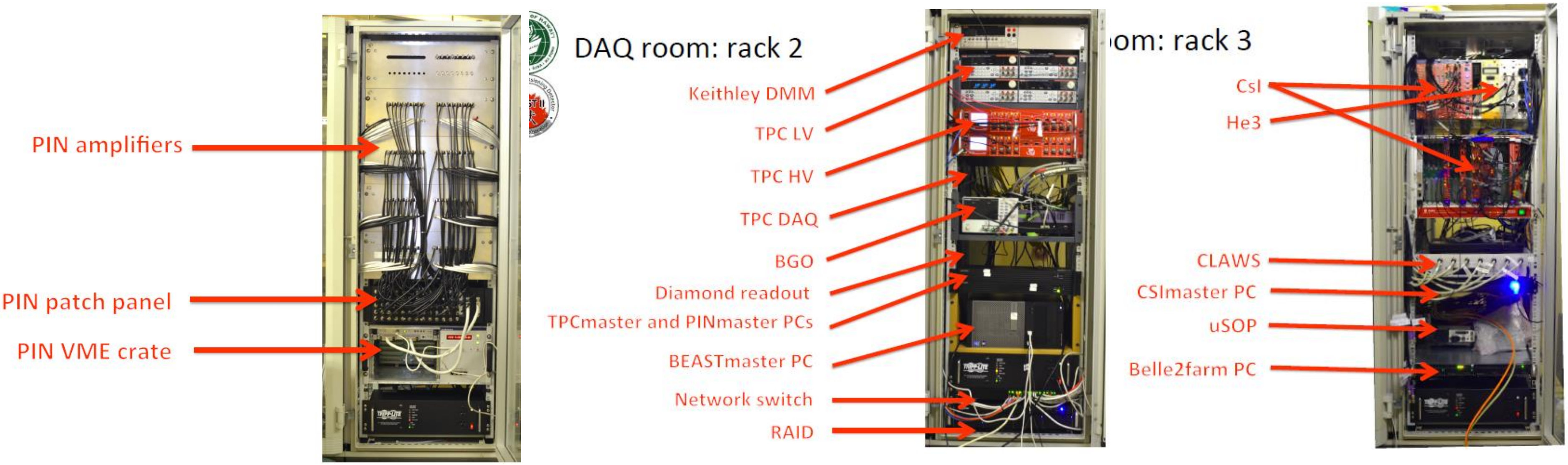
November, 2015
IP shield installation

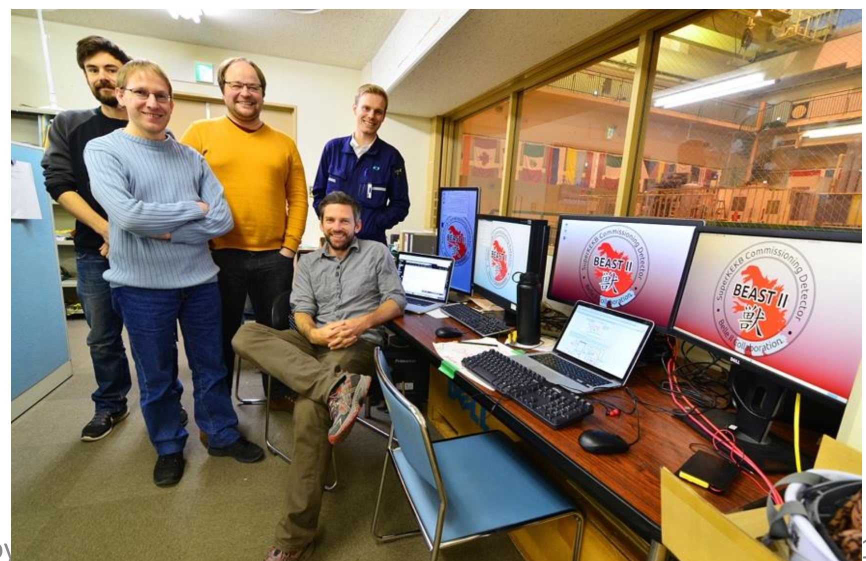


Snug fit in the BEAST cave



BEAST DAQ





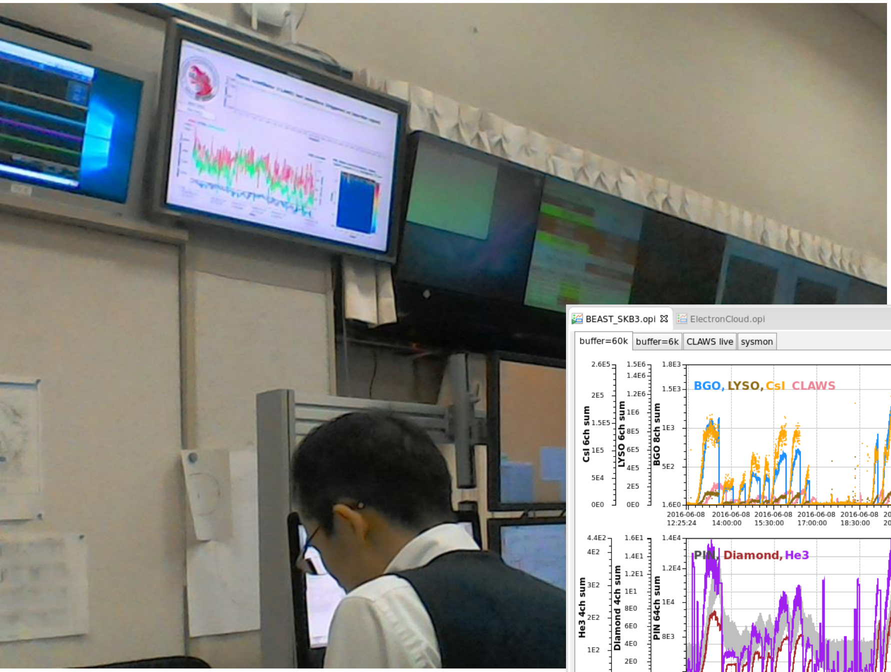
BEAST DAQ team

3 BEAST racks in B4 DAQ room, controlled from B3 BEAST booth

1 expert shift + 1 operator shift in B3

Up and running since Jan. 2016

BEAST display in SuperKEKB control

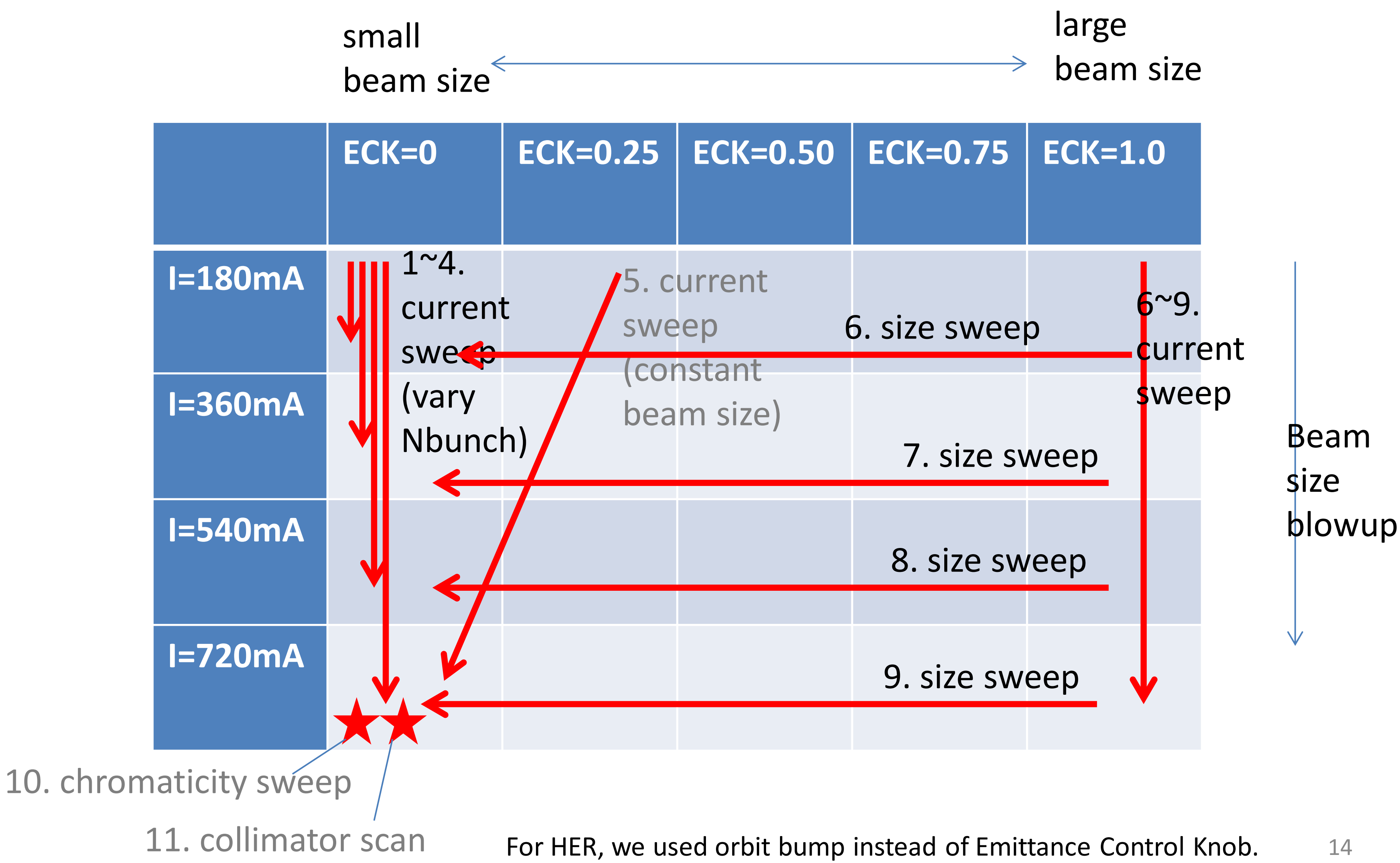


Provides BEAST sensor trend graph, Injection BG timing structure, etc…

BEAST machine studies in phase1

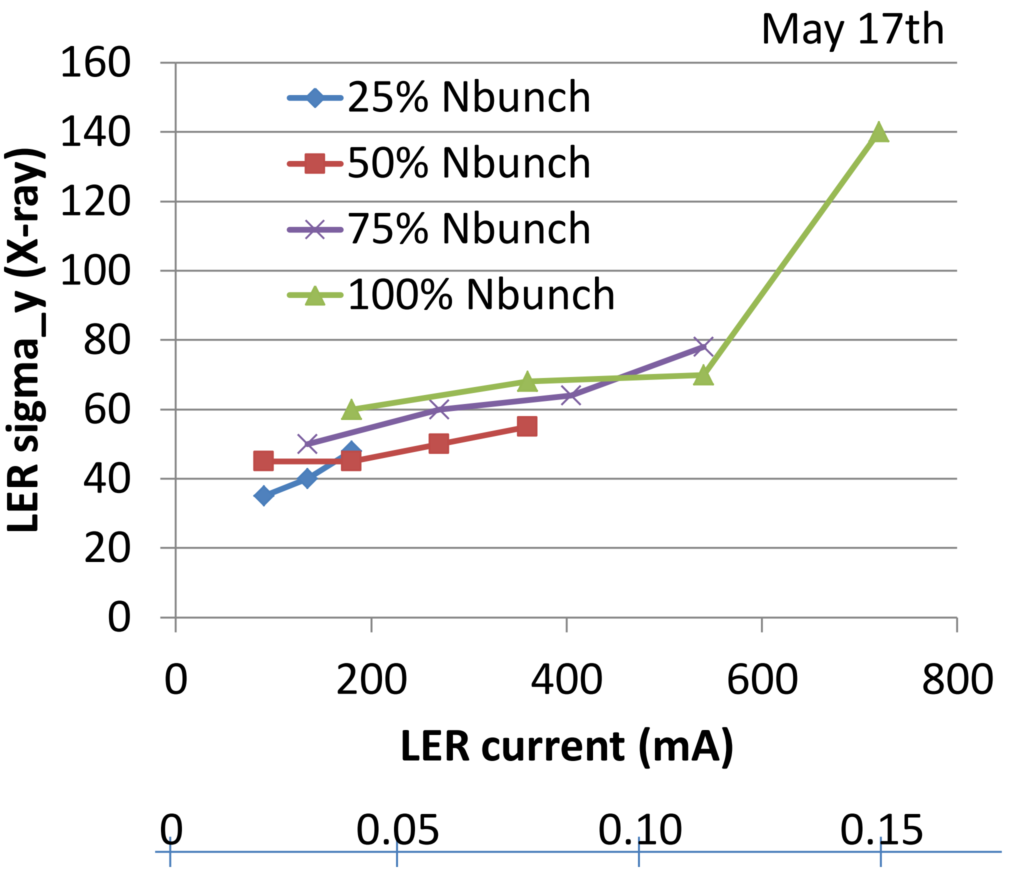
- May 16-18, 23-25 (~1.5 shift x 6days)
  1. Touschek study
     - beam size scan, N_bunch scan
  2. Vacuum bump study
     - NEG heating, increase pressure for x100~1000
  3. Collimator study
     - Impact on BEAST BG and beam life time
  4. Injection BG study
     - Time structure, dependence on injection parameters/efficiency

1. Touschek Study

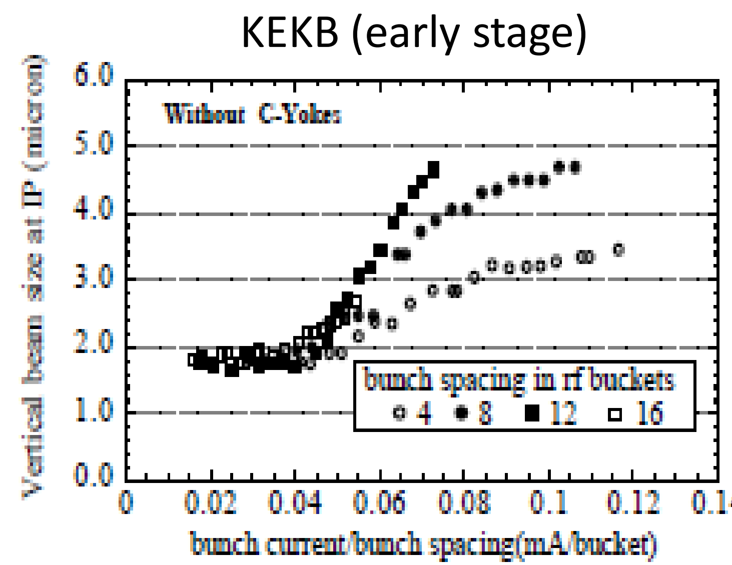


For HER, we used orbit bump instead of Emittance Control Knob.
For HER, we measured at 160,320,480,640mA.

LER beam size blow-up



Bunch current/ bunch spacing (mA/bucket)

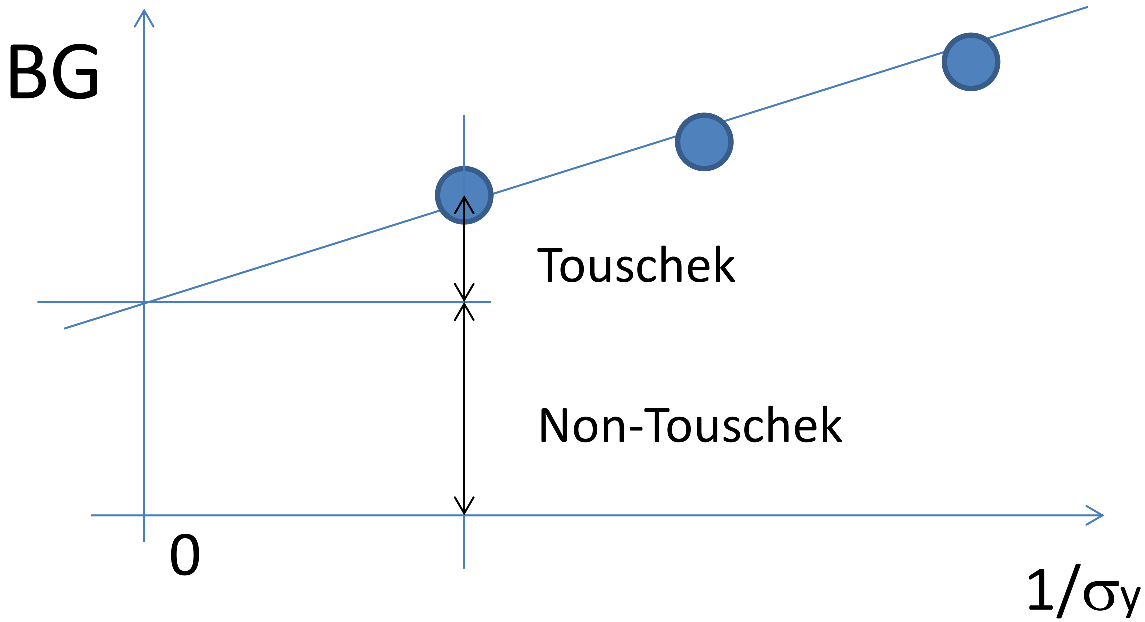


Early stage of KEKB: blow up at 0.04mA/bucket

KEKB after aging (2001): blow up at 0.12mA/bucket

SuperKEKB LER has achieved same level as KEKB(2001) in mid May.
Further mitigation has achieved by many permanent magnets installed in June.

Beam size scan

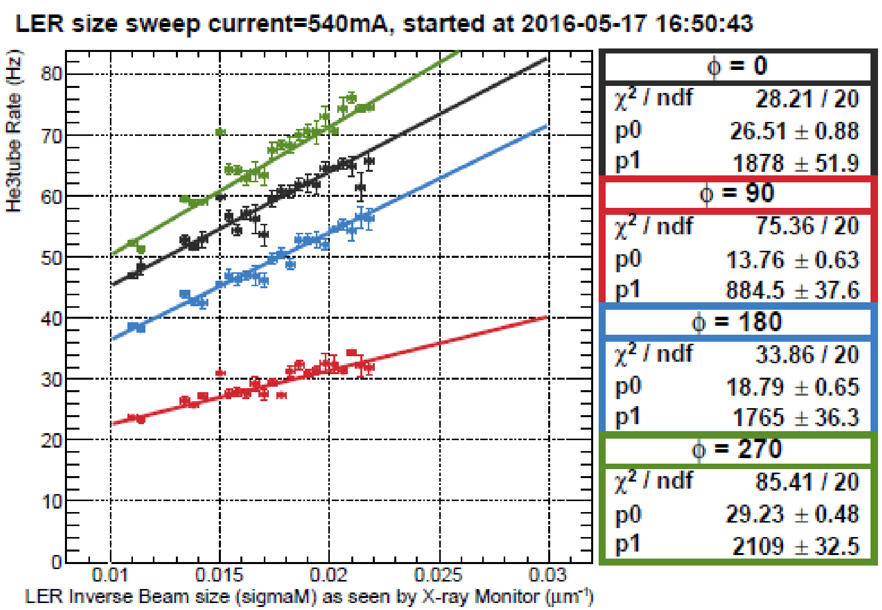


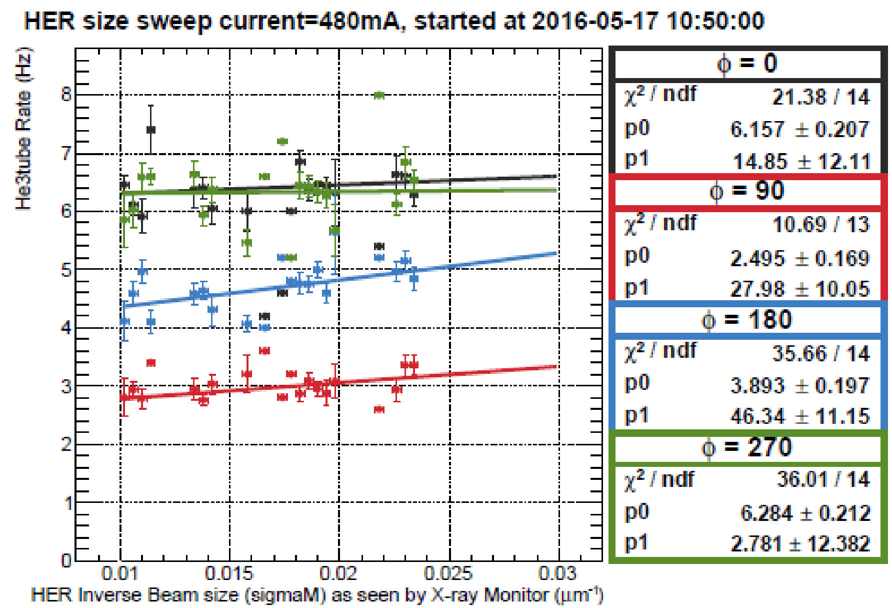
We can separately measure Touschek BG and other BG by fitting BG vs. $1/\sigma y$ plot with a linear function. Y-intercept of fitted line corresponds to non-Touschek BG component. ($1/\sigma y=0 \Leftrightarrow \sigma y=\mathrm{Inf.} \Leftrightarrow$ no Touschek)

Beam size scan (BEAST He3 tubes)

LER

HER





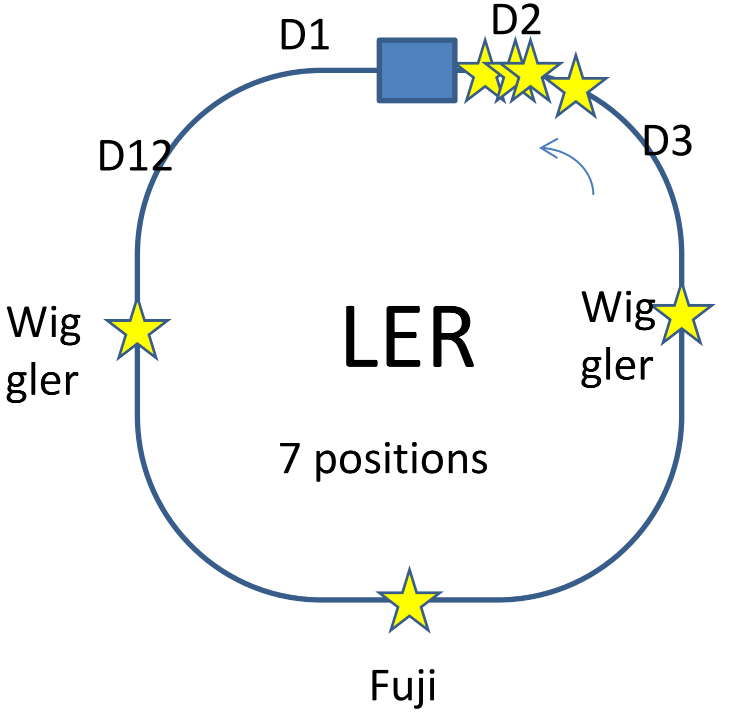
BG response on beam size clearly seen.

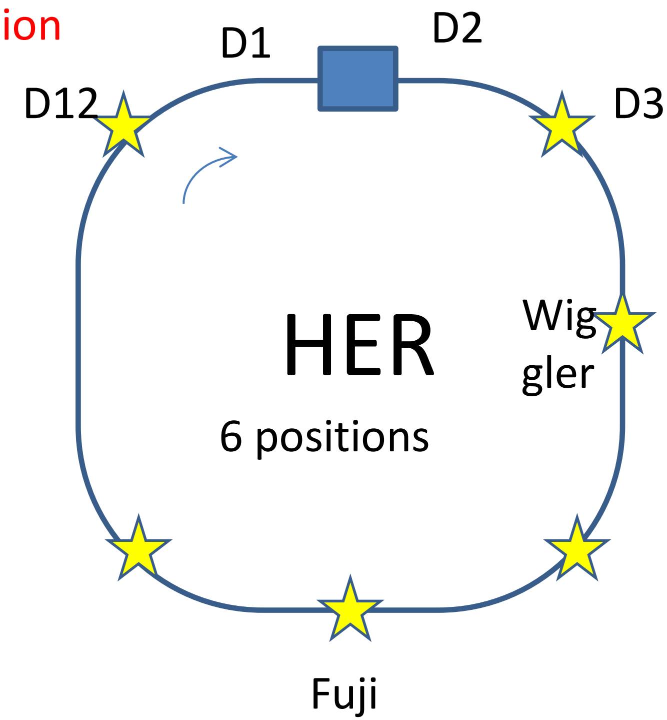
→ Evidence for Touschek BG contribution !

Quantitative comparison with SAD/GEANT4 simulation ongoing

2. Vacuum bump study

x100~1000 pressure
~1 hour/position





Short sections (4 sections) in D2
(need tunnel access each time)
Fuji straight section,
Oho/Nikko wiggler sections

4 arc sections,
Fuji straight section,
Oho wiggler section

Special thanks to SuperKEKB Vacuum group

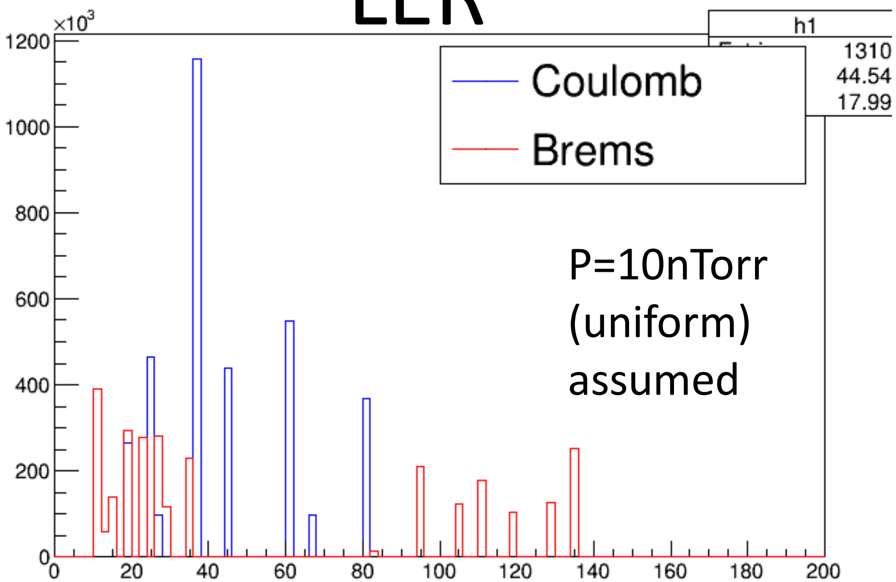
Vacuum bump study results

- ✓ LER: Vacuum bump in D02 sections has impact on BEAST BG, but other position did not.
- ✓ HER: Vacuum bump in all position has impact on BEAST BG.

- These observations are consistent with prediction by SAD simulation.

SAD prediction of Beam-gas BG

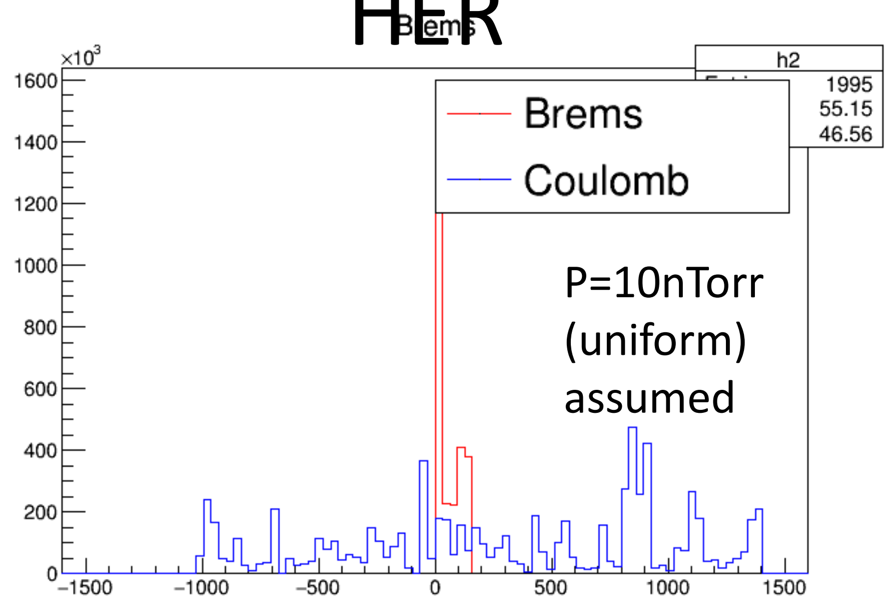
LER



P=10nTorr
(uniform)
assumed

Beam-gas scattered position
of IR beam loss [m]

HER



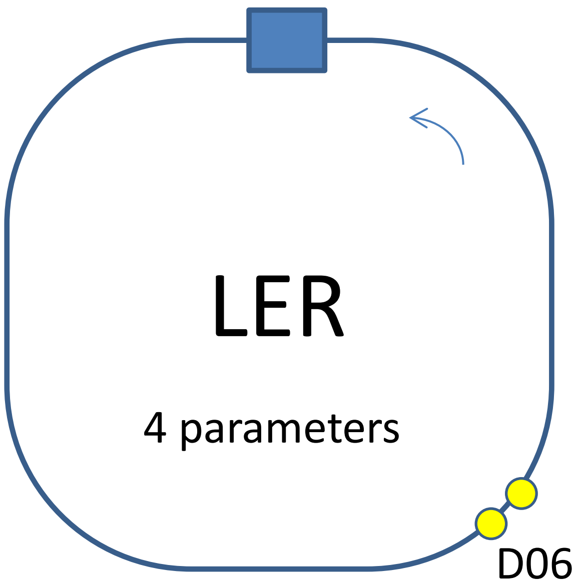
P=10nTorr
(uniform)
assumed

Beam-gas scattered position
of IR beam loss [m]

Coulomb: mainly from ~40m
Brems: mainly from ~20m and ~120m
No contribution from other positions

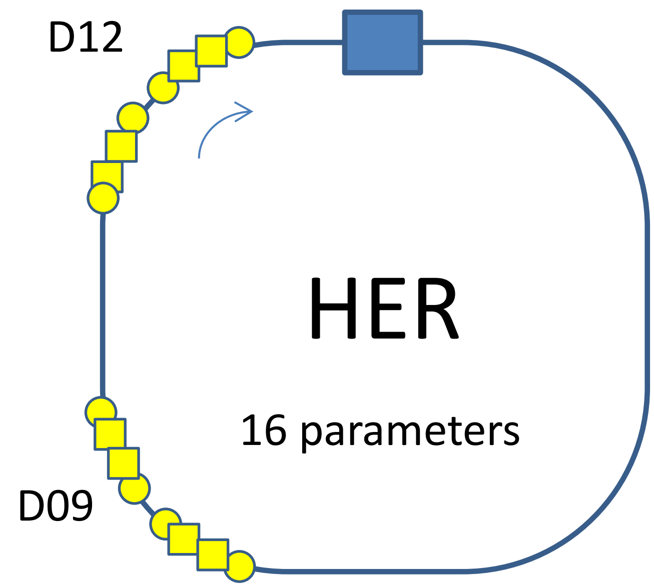
Coulomb: from whole ring
Brems: mainly from < 150m

3. Collimator study



SuperKEKB-type

D06H3 IN/OUT
D06H4 IN/OUT



KEKB-type

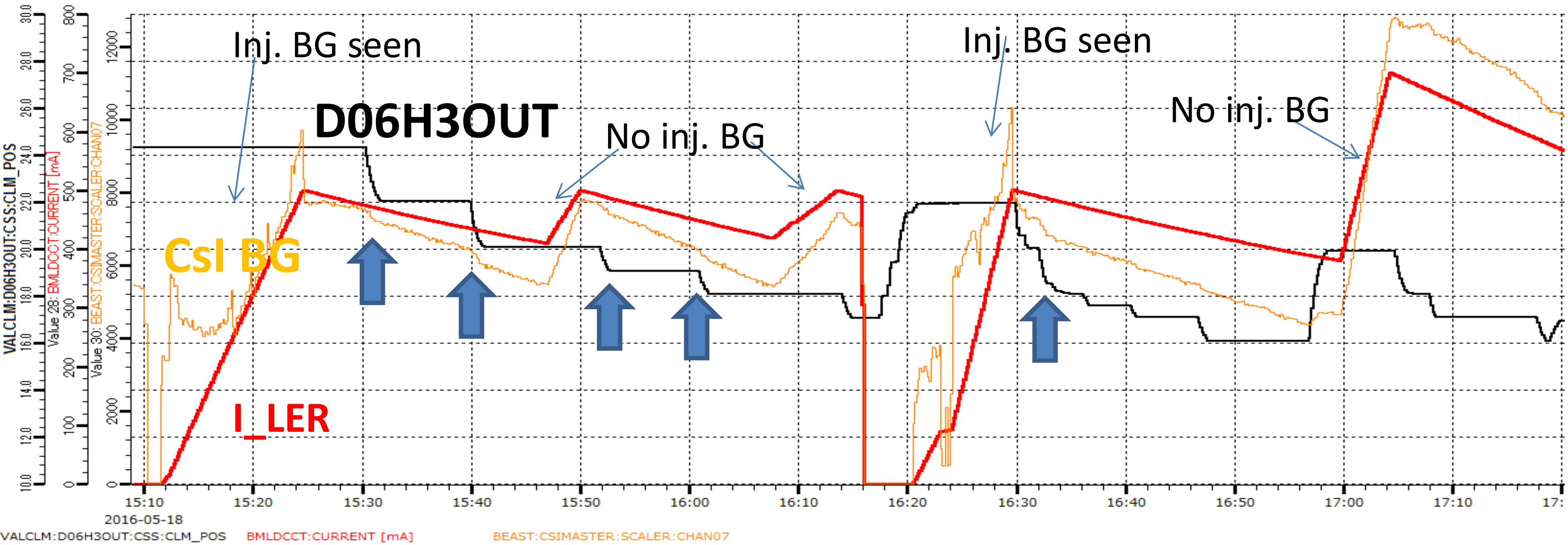
D12H1-4, V1-4
D09H1-4, V1-4

Special thanks to SuperKEKB Vacuum group

Collimator study results

- ✓ D06H3OUT is found to be effective to reduce BEAST BG
- ✓ This collimator is also effective to reduce injection BG
- ✓ HER collimators are not effective to reduce BEAST BG
- ✓ When HER collimator is too narrow, it even INCREASE the BEAST BG

LER collimator optimization



As we change D06H3OUT width from 24mm to 17mm,
BEAST CsI BG shows step-like decrease at every time collimator get narrower.

<u>This is the clear evidence of BG suppression by the collimator!</u>

When we make it further narrower, from 17mm to 16mm at 16:48,
we observed beam life time decreased. This should be the minimum width.
We optimize each collimator width like this.

4. Injection BG study

- Important for Belle2 Pixel detector
  - Veto window shape should be determined by injection BG time structure

✓ Compare good/bad injection efficiency

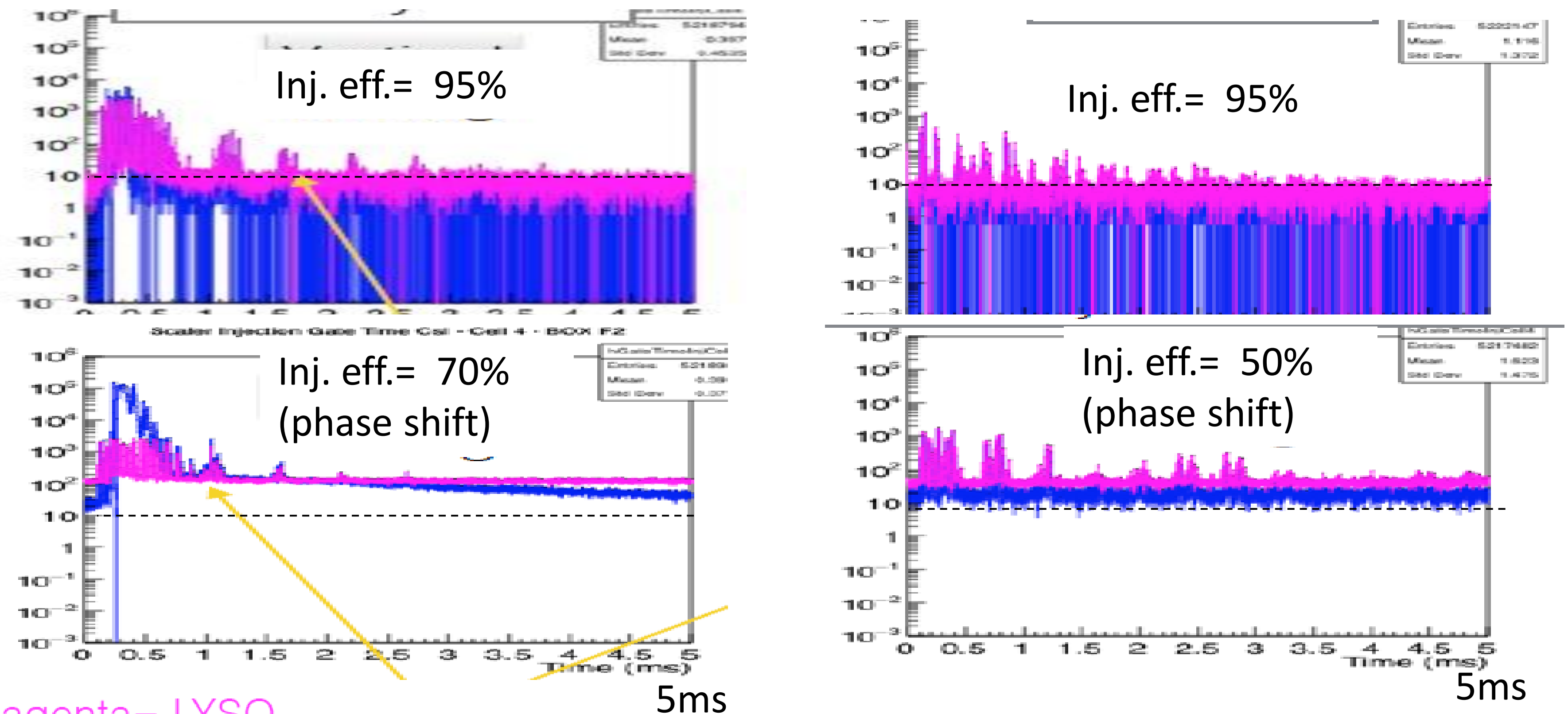
changing septum angle, vertical steering magnets, and injection phase to have bad injection efficiency

✓ CsI crystal/CLAWS scintillator observed interesting time structure

- Spikes at every ~0.5ms can be explained by synchrotron oscillation (~2kHz)

Injection BG on BEAST crystals

LER **HER**



Magenta= LYSO
Blue = CsI

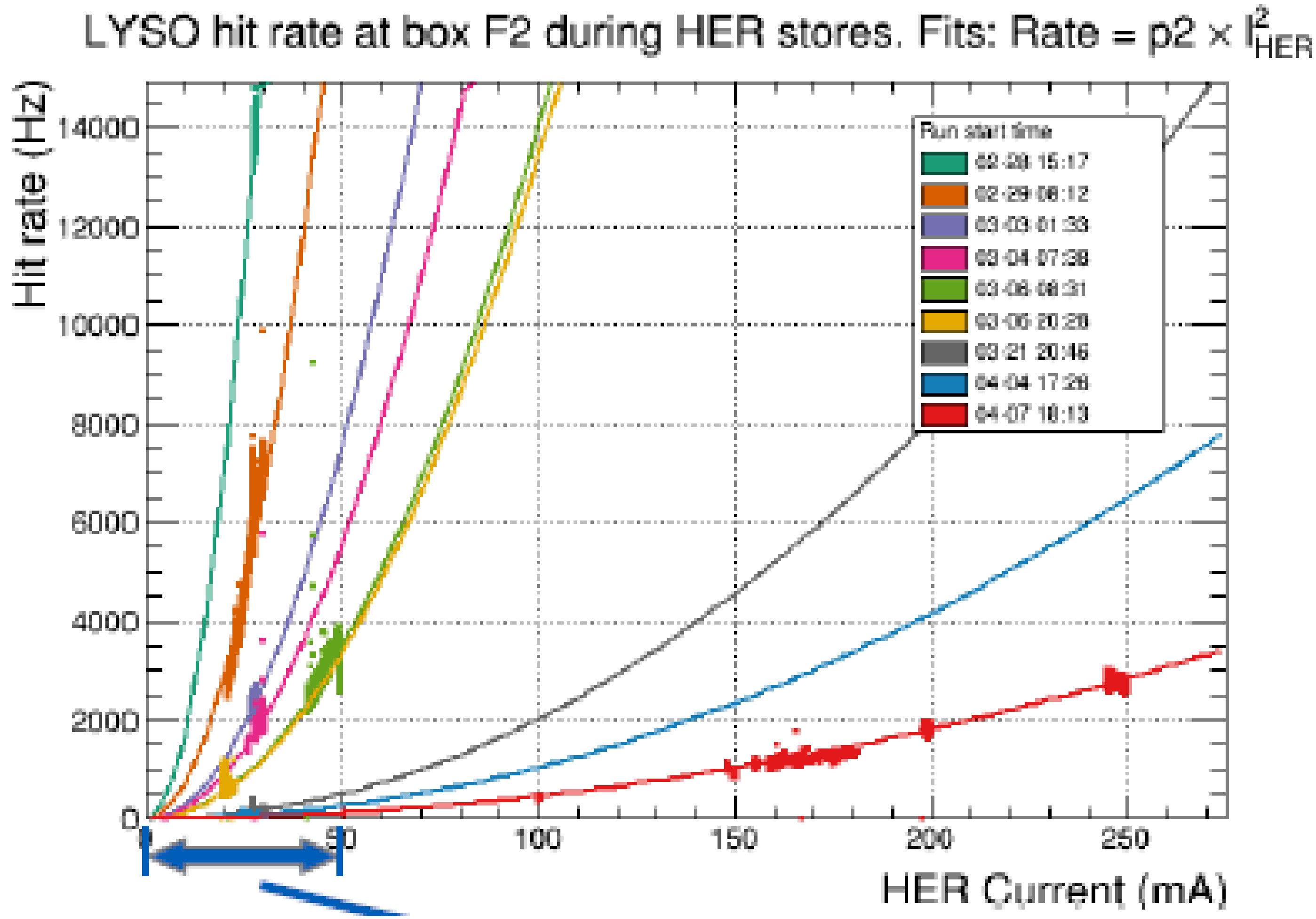
Live BEAST crystal waveforms are now available on SuperKEKB control panels. Please use it for injection tuning.

Summary

- BEAST phase1 machine study very successful
- Detailed analysis ongoing to give comparison with SAD+GEANT4 simulation
- We will repeat similar studies in phase2 with BELLE detector + BEAST phase2 sensors, and extrapolate it toward phase3

backup

HER Vacuum scrubbing progress

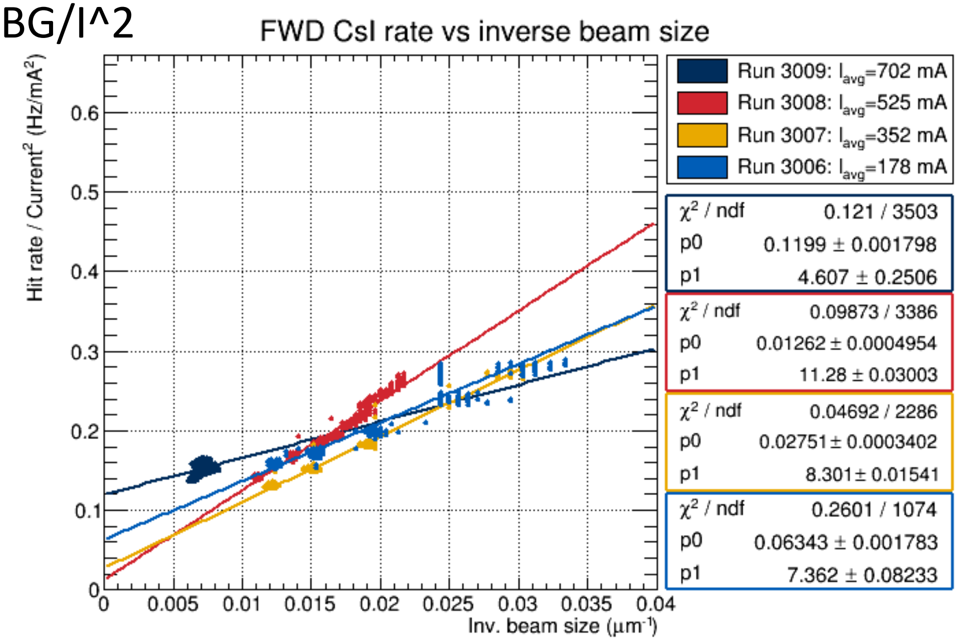


Beam size scan (BEAST CsI crystal)

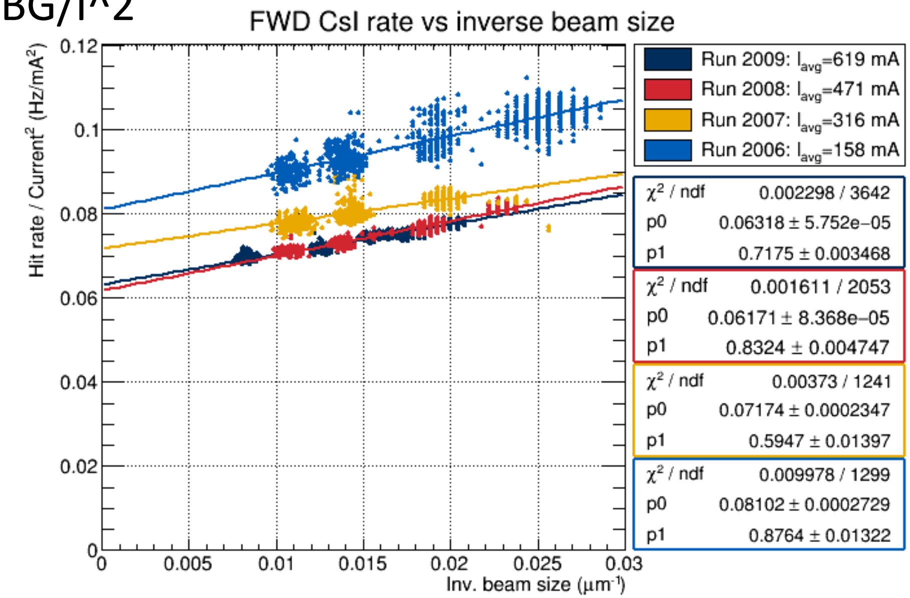
LER

HER

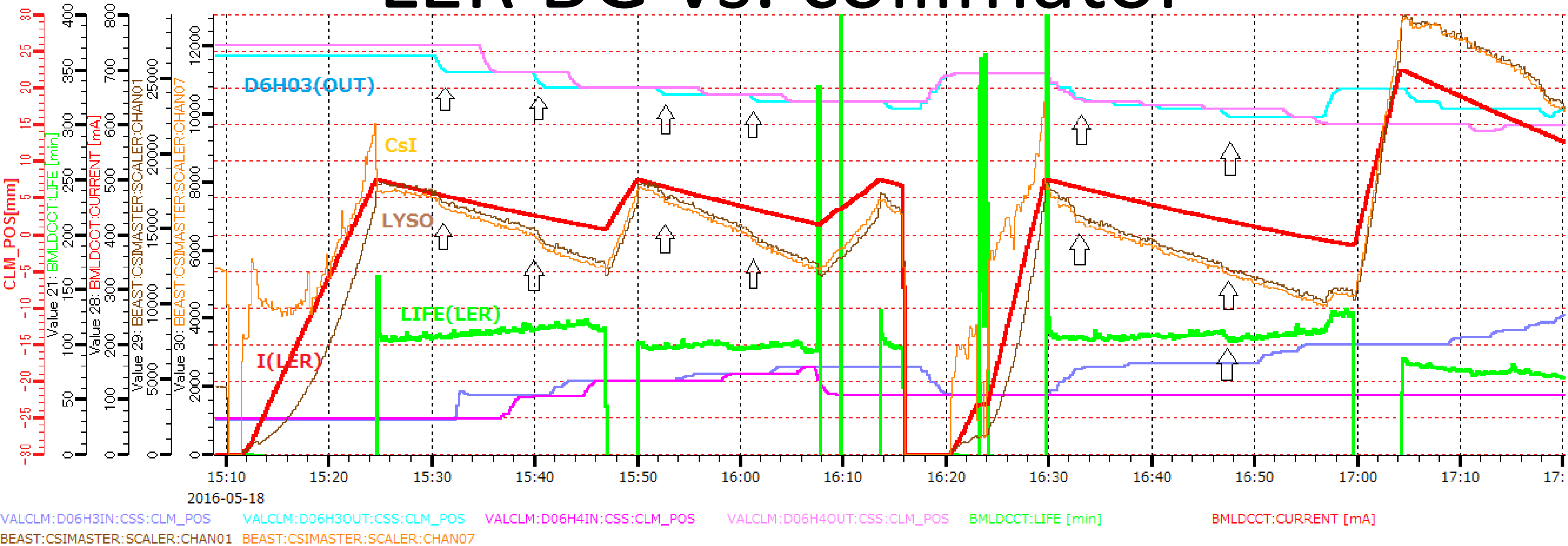
BG/I^2



BG/I^2



LER BG vs. collimator

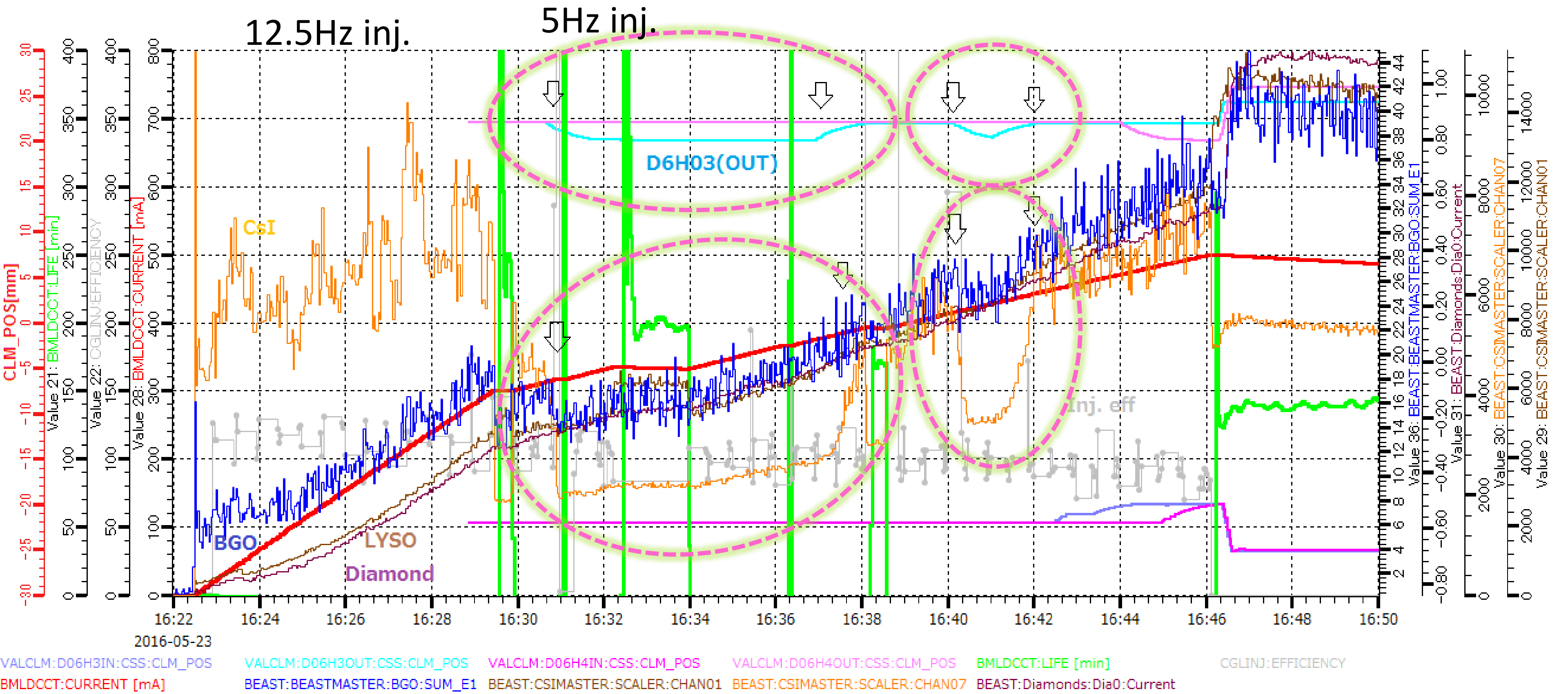


As we change D06H3OUT width from 24mm to 17mm,
LYSO/CsI BG shows step-like decrease at every time collimator get narrower.

<u>This is the clear evidence of BG suppression by the collimator!</u>

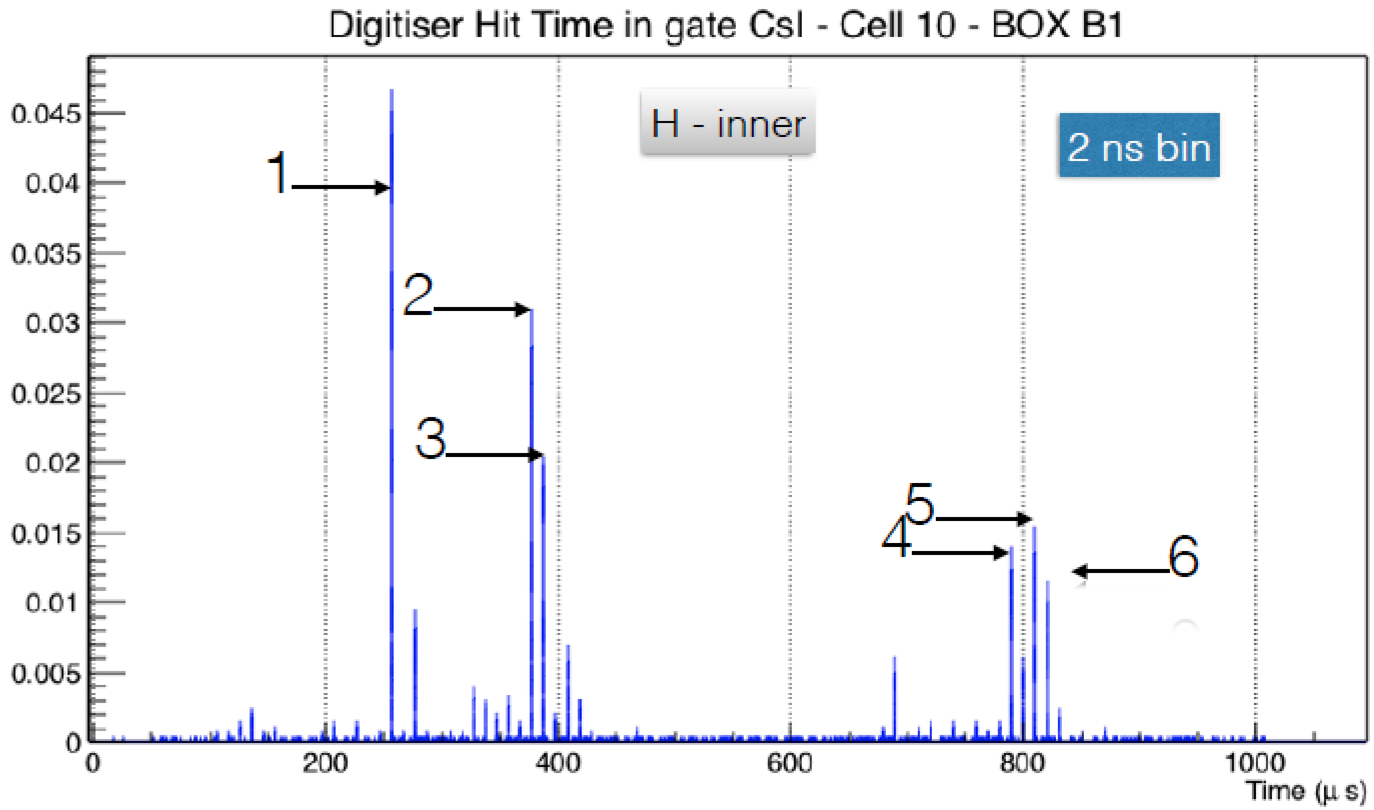
When we make it further narrower, from 17mm to 16mm at 16:48,
we observed beam life time decrease.
Which means this should be the minimum collimator width for D06H3OUT.

LER Injection BG vs. collimator



Run #5006 was meant to find a effective collimator to mitigate injection BG.
We found D6H03OUT is effective to suppress injection BG on CsI crystal.
Actually, it is the same collimator which is effective to suppress BG
from the stored beam.

RUN 9 - Digitiser Data



The same excited bunch appears after several turns

BEAST Phase2 sensors

BEAST Phase2 study

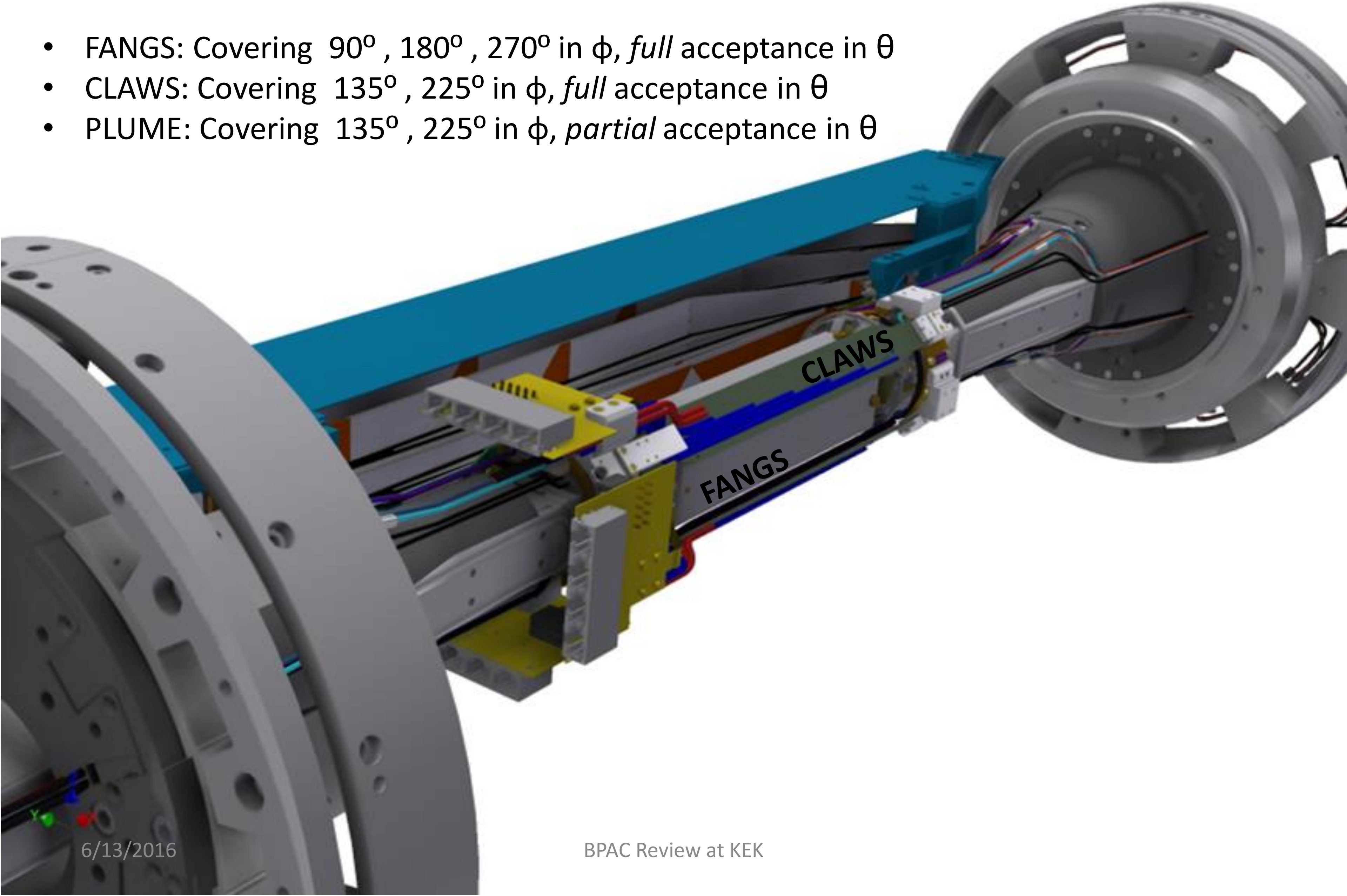
- **Phase2 is most similar to phase3, but still different**
  1. “Detuned” optics with smaller IR beta functions (less SR, Toucheck, Beam-gas)
  2. Worse vacuum level (more Beam-gas)
  3. Smaller luminosity (less RBB/2-photon)
  4. VXD ladders at phi ≠ 0 is missing in phase2
- **We need some extrapolation**
  - For 1, simulation/measurement comparison with detuned optics tells us how much we can believe simulation with final optics
    - Collimator secondary shower effect can be measured at phase2.
  - For 2. and 3. extrapolation is rather straightforward.
  - For 4, beast sensor measurements at phi≠0 is important.
- **Separate measurement of each BG sources** is important
  - Vary **beam size , vacuum level , luminosity** to disentangle Touschek, BeamGas, RBB and 2photon (same approach with 2010 BG study)
  - Validate simulation results with measurement

BEAST Phase2 study

- **Need all sub-detectors DAQ running** (at random trigger)
  - global Belle II DAQ (partial VXD, CDC, TOP, ARICH,BKLM,EKLM, TRG)
  - Extrapolate measured each sub-detector BG level to phase3
  - Sub-detector DQM records are useful for analysis
- **Other commissioning items during phase2 period**
  - Slow control (EPICS) communication, timing signals connection btw SuperKEKB-Belle2, beam abort/injection interlock
  - VXD CO2 cooling, injection noise damping-time measurement, PXD ROI finding etc…
  - **Collimator optimization study**
    - Simulation/measurement comparison with various collimator settings
    - Develop strategy how to reach optimal collimator setting

VXD Detector Systems in phase 2

- FANGS: Covering 90º , 180º , 270º in ϕ, *full* acceptance in θ
- CLAWS: Covering 135º , 225º in ϕ, *full* acceptance in θ
- PLUME: Covering 135º , 225º in ϕ, *partial* acceptance in θ



VXD Detector Systems in phase 2

- FANGS: Covering 90º , 180º , 270º in ϕ, *full* acceptance in θ
- CLAWS: Covering 135º , 225º in ϕ, *full* acceptance in θ
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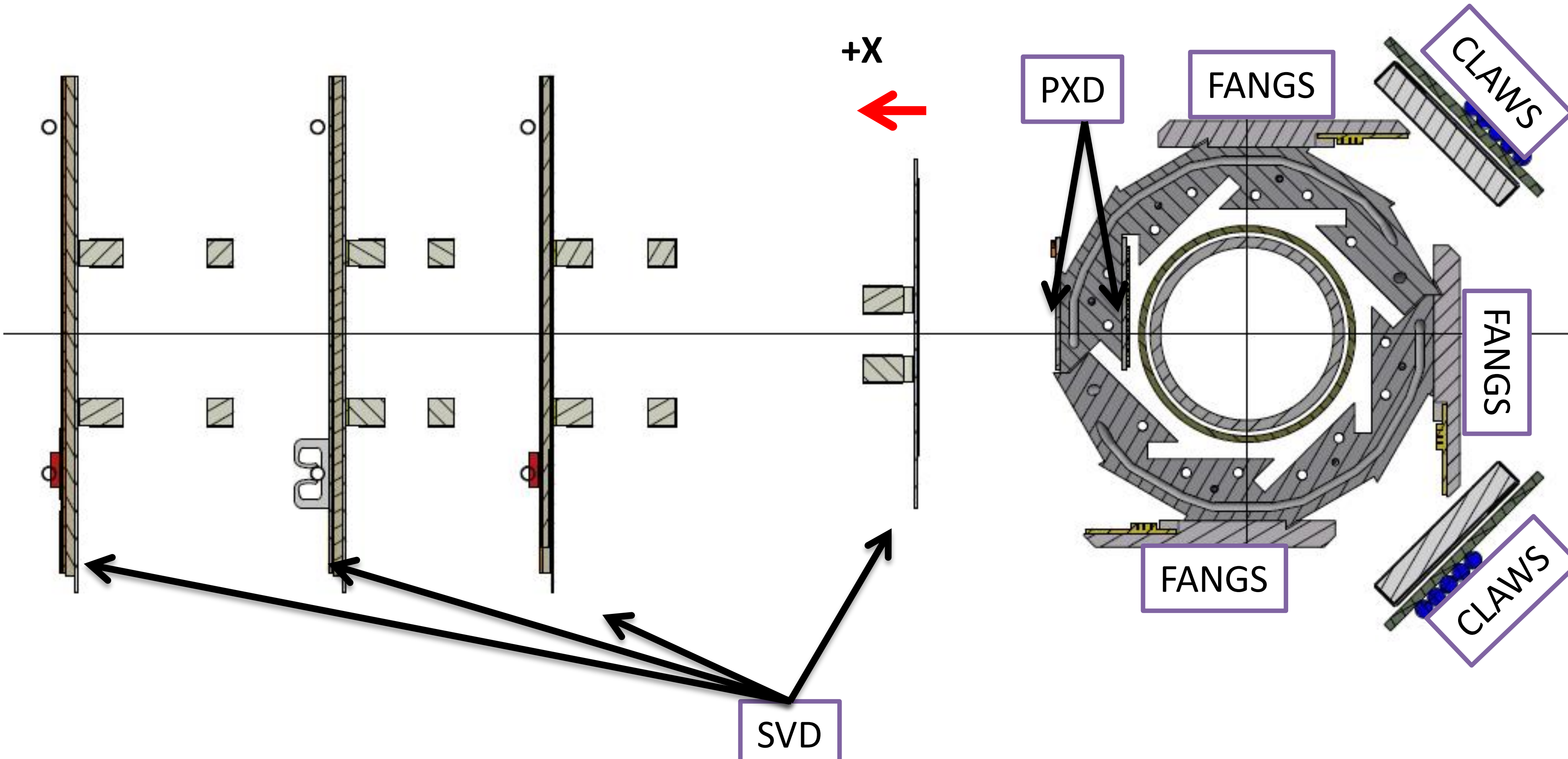
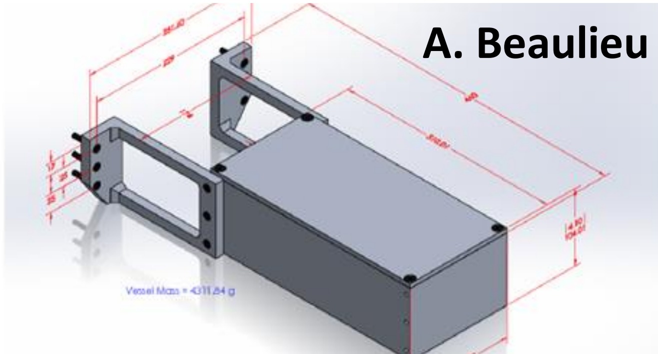


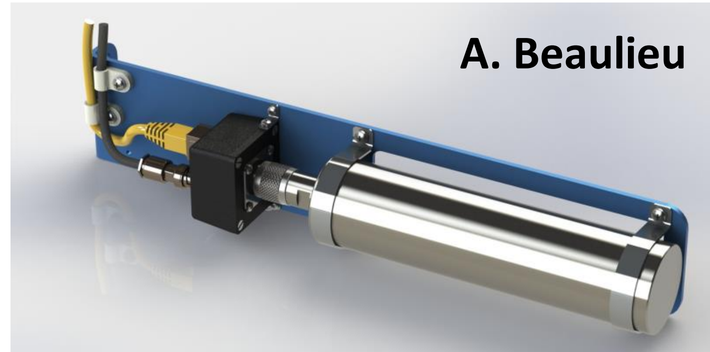
Phase2 Background Detectors

sensor	contact p.	number	location	DAQ	unique measurement	Tasks/ Priority
Belle II PXD	C. Marinas	2 ladders	VXD	Belle II / VXD EPICS	**in-situ occupancy, full Belle II tracking, vertexing**	**1,2** (4)
Belle II SVD	K. Nakamura	4 ladders	VXD	Belle II / VXD EPICS		
diamond sensors	L. Vitale	8 diamonds	VXD	Belle II monitor DB & BEAST EPICS	ionizing dose in VXD → **BEAM abort**	**1,2** (4)
FANGS "LHC style" silicon pixel sensors	C. Marinas	3 arms 15 chips	VXD	BEAST EPICS	MIPs & x-rays > 10 keV @ 40 MHz → **Synchrotron x-ray spectrum**	**1,2,4**
CLAWS Scintillators w/ SiPMTs	F. Simon	2 ladders	VXD	BEAST EPICS	X-rays or track counting w/ 1-ns timing → **injection background**	**1,2** (4)
PLUME "ILC style" silicon pixels sensor	I. Ripp-Baudot	2 ladders	VXD	BEAST EPICS	Two-sided silicon pixels → **tracklets w/ pointing**	**(2),** 4
Scintillators + PIN diodes	H. Nakayama K. Nakamura	40+40	around QCS	BEAST EPICS	X-ray and total loss distribution versus position, → **collimator adjustment**	**3**
Micro-TPC nuclear recoil detectors	S. Vahsen	8	VXD dock	BEAST EPICS	**fast neutrons:** rate, directional & spectral information	**4**
He-3 tube neutron detectors	S. De Jong	4	VXD dock	BEAST EPICS	**thermal neutrons:** rate	**4**

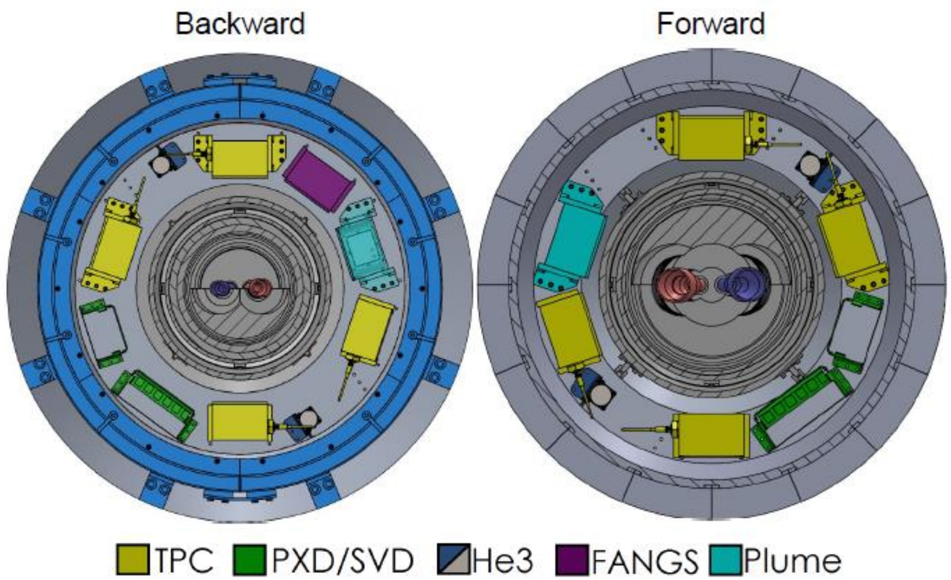
Neutron Detectors in Dock Space



8 x TPC fast neutron detector



4 x He-3 thermal neutron detectors

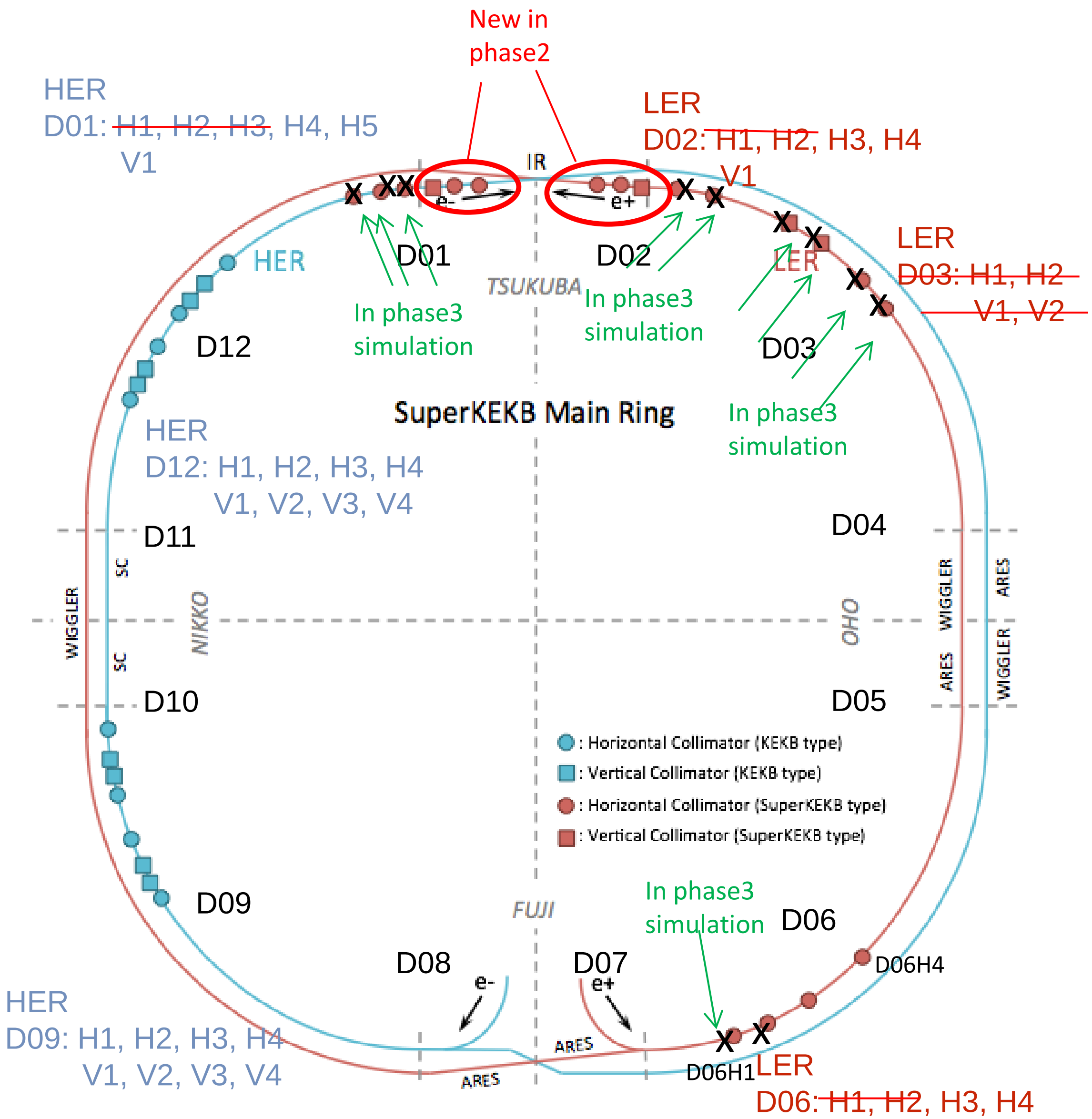


<u>Ahead of / on schedule:</u>

- 4 He-3 tubes in hand already for phase 1.
- Six more TPCs (in addition to those in phase 1) ~ to be completed by April 2016.

Phase2 collimators

Phase-II collimators



Phase1

LER: D06H3, D06H4

HER: (D09[H/V]*, D12[H/V]*)

Reuse collimators from KEKB

Newly installed btw phase1/2

D02H4, D02H3; D02HV1

D01H5, D01H4; D01HV1

These are crucial to protect Belle2 in phase2 and perform collimator study

Newly installed before phase3?

D02H2, D02H1

D03H2, D03H1; D03V2, D3V1

D01H4, D01H5, D01HV1

Phase2 collimators

- Because of severe budgetary limitation, we cannot install all collimators before phase2
- We have concluded that:

  install only horizontal x2(nearest) and verticalx1 (for each ring)
- These are still sufficient to protect phase2 detectors and to perform collimator study
  - BG loss estimation for phase2 sensor
    - Touschek BG: tolerable (OK even without any collimator)
    - Coulomb BG: tolerable (V width should be same width phase3)
    - Injection BG: don't know yet, H collimators should be effective
  - Phase2 Collimator study to confirm our strategy
    - Secondary scattering from nearest H collimator
    - Feedback from detector BG levels

Final number of phase3 collimators is under study
(Hx2 +Vx1 is not sufficient)

SAD Simulation results

LER sler_1689.sad, sler_1689_d4-8.sad	Touschek (|s|<4m)	Touschek (|s|<30m)	Coulomb (|s|<4m)
Phase3 (all collimators)	0.16 GHz	2.7 GHz	0.32 GHz
Phase3 (Hx2, Vx1)	4.76 GHz	111 GHz	-
Phase2 (Hx2, Vx1)	0.09 GHz	2.45 GHz	0.03 GHz
Phase2 (Full open)	0.15 GHz	0.17 GHz	2.48 GHz

HER sher_5775.sad, sher_5767_d4-8.sad	Touschek (|s|<4m)	Touschek (|s|<30m)	Coulomb (|s|<4m)
Phase3 (all collimators)	0.05 GHz	0.64 GHz	0.001 GHz
Phase3 (Hx2, Vx1)	3.50 GHz	21.5 GHz	-
Phase2 (Hx2, Vx1)	0.01 GHz	0.07 GHz	0.01 GHz
Phase2 (Full open)	0.16 GHz	0.23 GHz	0.91 GHz

>1GHz loss in |s|<4m is too dangerous

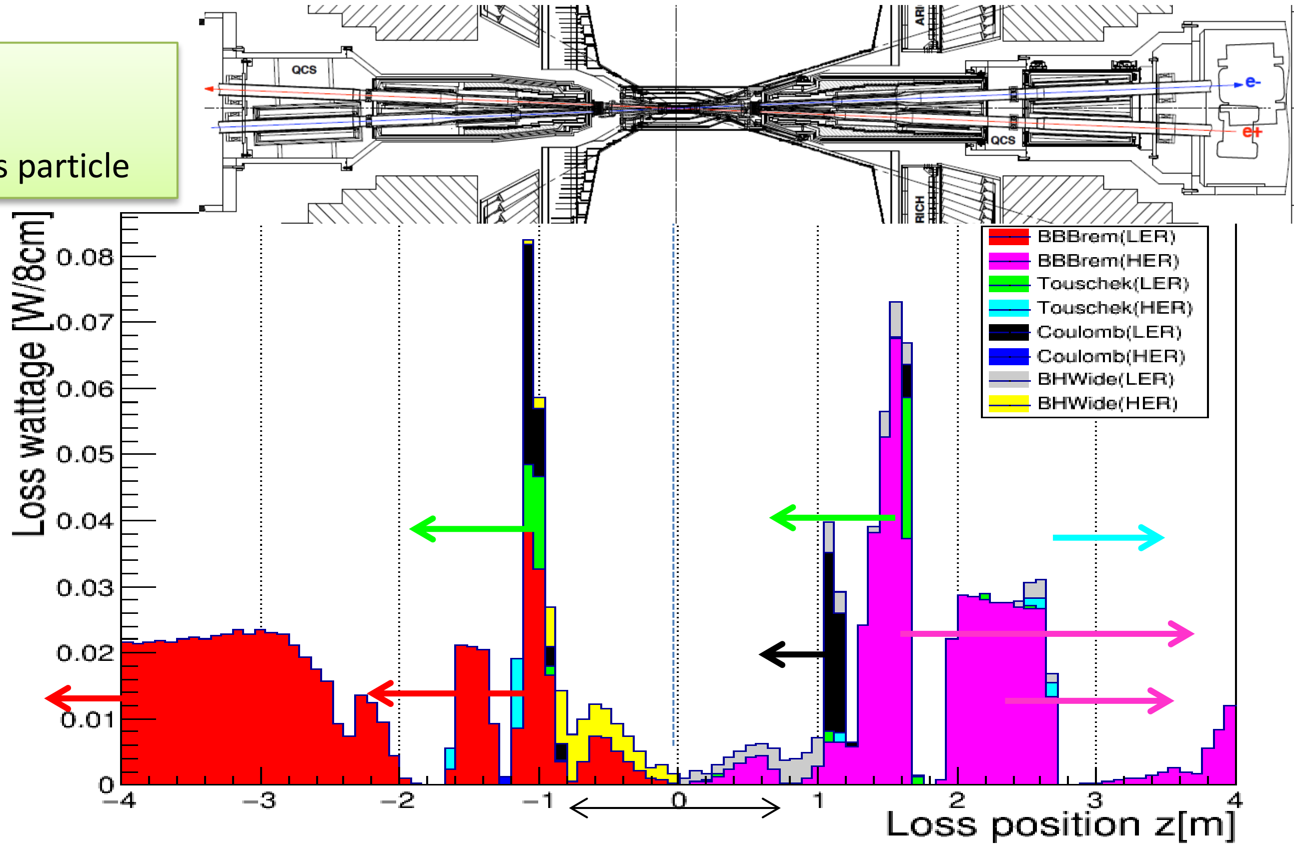
Phase3 background

Ver. 2015.6.15
(12th campaign)

BG loss distribution

Loss wattage
= loss rate
 * energy of loss particle

HER
(e-)



LER
(e+)

1GeV ,1GHz
= 0.16W

	LER (4GeV e+)	HER (7GeV e-)
Rad. Bhabha (BHWide)	0.06 W (0.09GHz)	0.05 W (0.05GHz)
Rad. Bhabha (BBBrem)	0.67 W (eff. 1.0GHz)	0.56W (eff. 0.50GHz)
Touschek	0.05 W (0.08GHz)	0.02 W (0.02 GHz)
Coulomb	0.10 W (0.16GHz)	0.001W (0.001GHz)

Summary for 12th campaign

listing SF<5 only
SF=Safety Factor

	12th campaign result	limit	SF
PXD occupancy	2photon:0.9% , SR:~0.2% (10th)	< 3%	3
CDC wire hit rate	170kHz	<200kHz	1.3
CDC Elec.Borad n-flux* (averg.)	~0.8	<1	1.3
CDC Elec.Board dose	100 Gy/yr	<100 Gy/yr	1
TOP PMT rate	3.5MHz/PMT	<1 MHz/PMT	0.3
TOP PCB n-flux*	0.15	<0.5	3
ARICH HAPD n-flux*	0.3	<1	3
ECL crystal dose	4.5 Gy/yr	<10 Gy/yr	2
ECL diode n-flux*	0.23	<1	4
ECL pile-up noise	4.3/5.8 MeV	0.8 at Belle-I	?

KLMs studies are not included

With "combined" shield at inner ECL

*neutron flux in unit of 10^{11} neutrons/cm2/yr, NIEL-damage weighted