Beam Background, Machine Detector Interface

Hiroyuki Nakayama(KEK, Belle2)

Beam Backgrounds…

1. Limit the lifetime of SuperKEKB
2. Determine survival time of Belle II detectors
3. Can lead to instantaneous damage
4. Increase Belle II hit occupancy
5. Result in non-negligible analysis background

- An underestimate of phase 3 beam backgrounds could have serious consequences.
- Our goal: use phases 1 and 2 to measure each individual background type, incl. scaling with beam parameters.

Beam BG sources at SuperKEKB

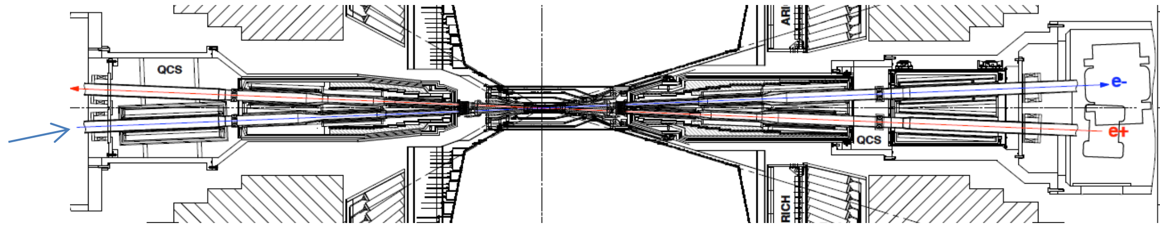
BG sources	Simulation Method
Touschek	Generate scattered particles with weights and SAD tracks them. Particles lost in IR are passed to GEANT4 fullsim.
Beam-gas Coulomb	
Beam-gas Bremsstrahlung	
Synchrotron Radiation	SR generator in GEANT4
Radiative Bhabha ($e^+e^- \rightarrow e^+ e^- \gamma$)	BBBrem/BHWide generator →GEANT4
QED 2-photon ($e^+e^- \rightarrow e^+e^-e^+e^-$)	aafh generator → GEANT4
Injection BG	Injected particles → SAD tracking→GEANT4

Single-beam BG (Touschek, Beam-gas Coulomb, Beam-gas Bremsstrahlung, Synchrotron Radiation)

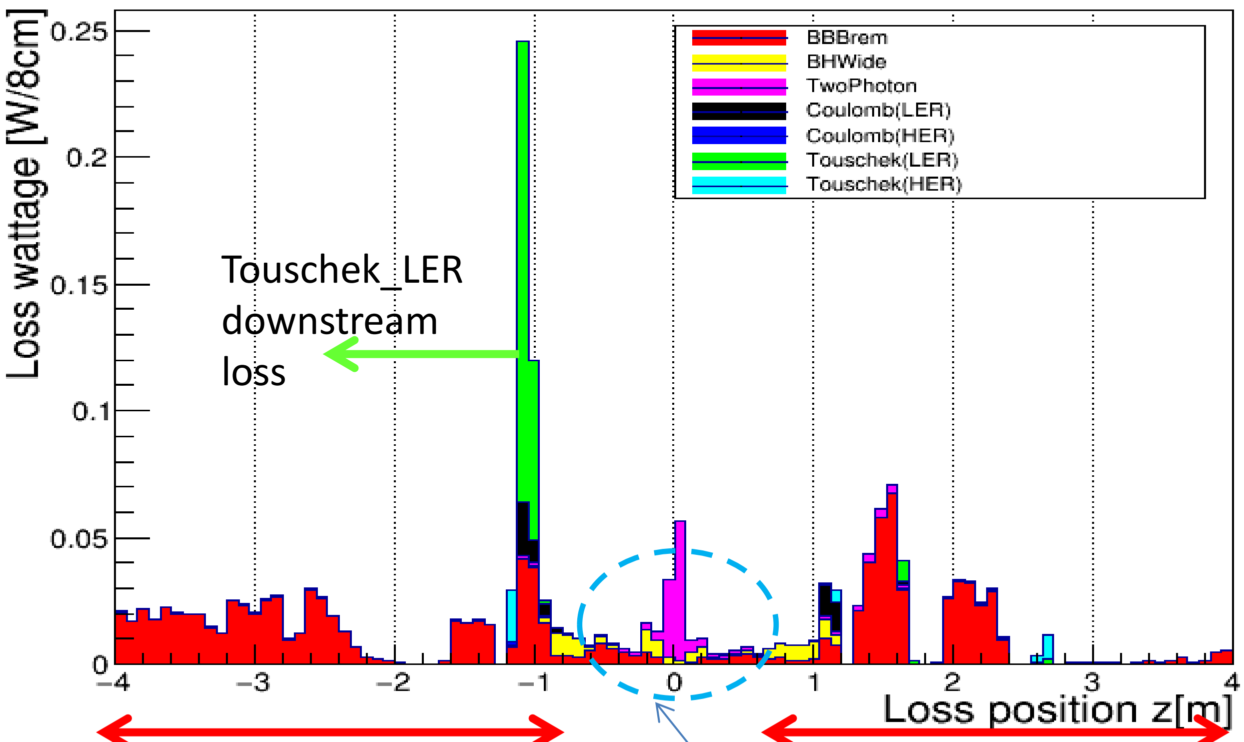
Luminosity BG (Radiative Bhabha, QED 2-photon)

Beam BG distribution

15th campaign
(for phase3)



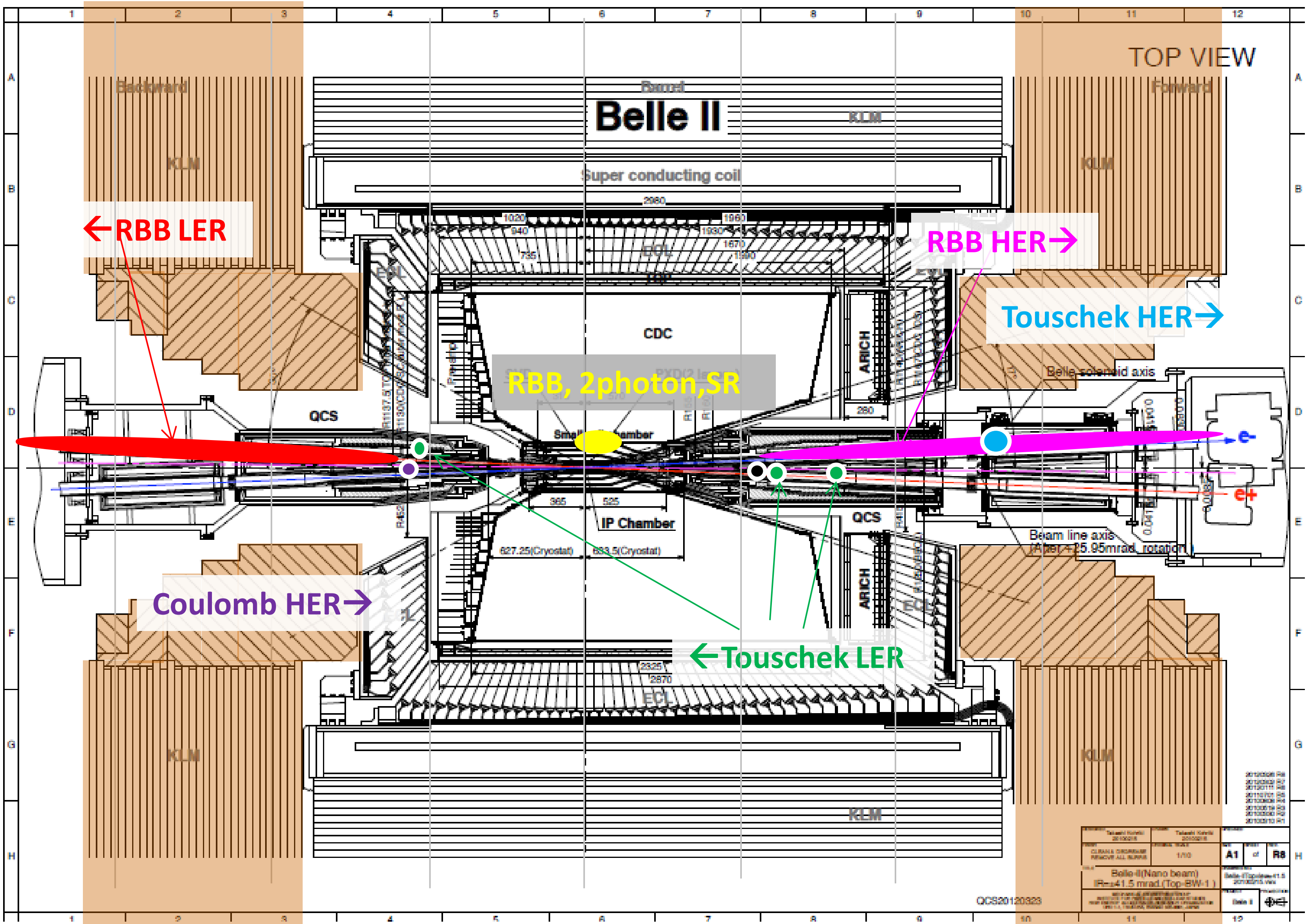
Loss wattage
= loss rate on beam pipe
* energy of loss particle



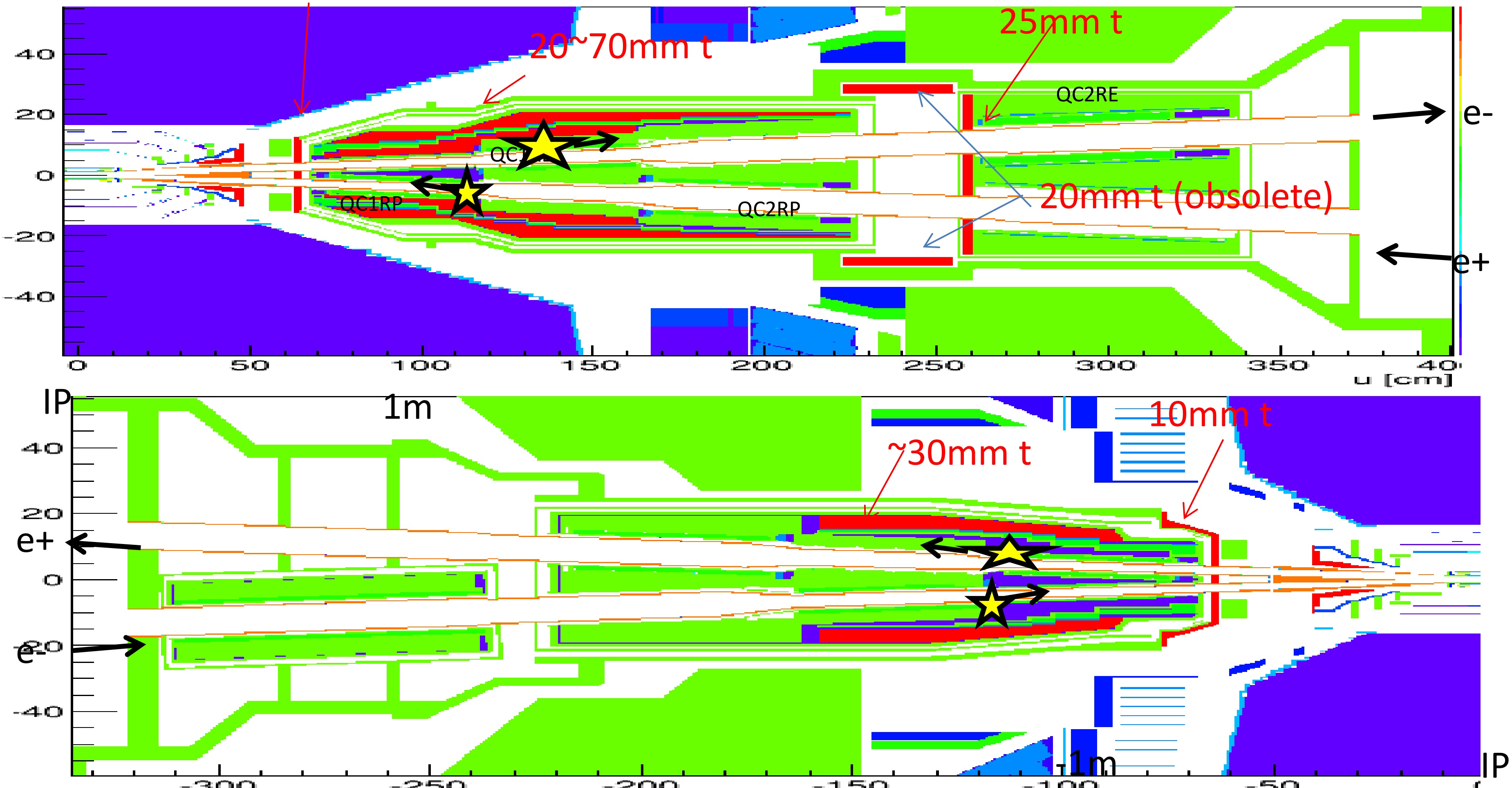
Rad. Bhabha loss at |z|>65cm are stopped by shield inside QCS

Lumi-dep. BG loss at |z|<65cm are dangerous for TOP PMT rate

Global views



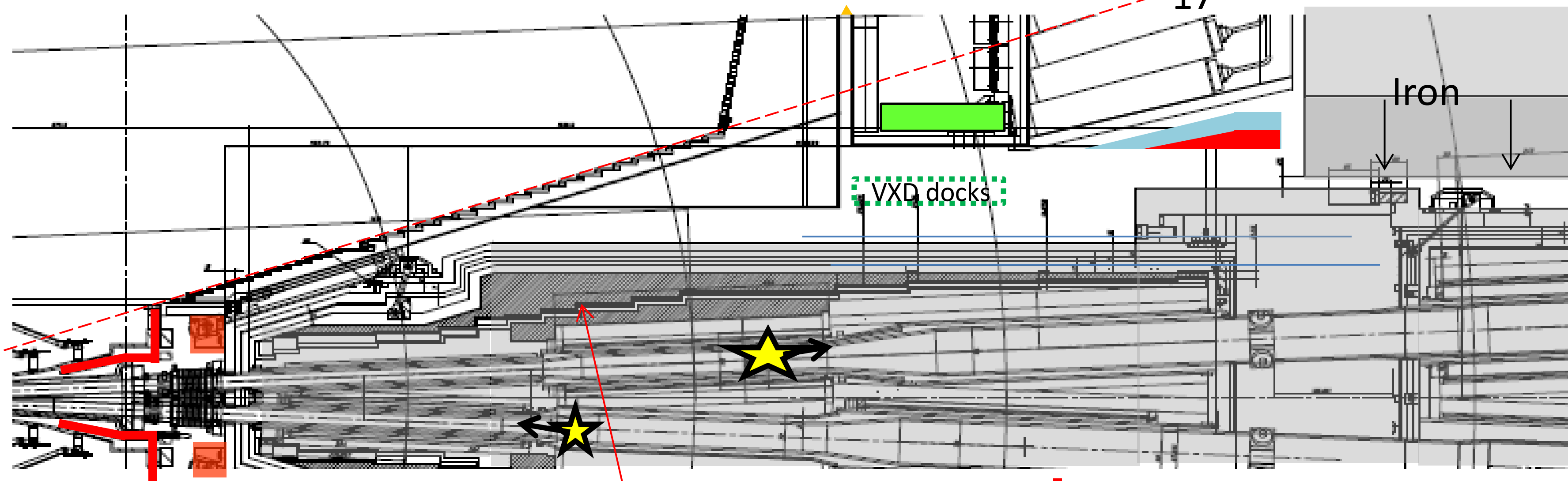
Tungsten shields (shown in red) inside QCS cryostat



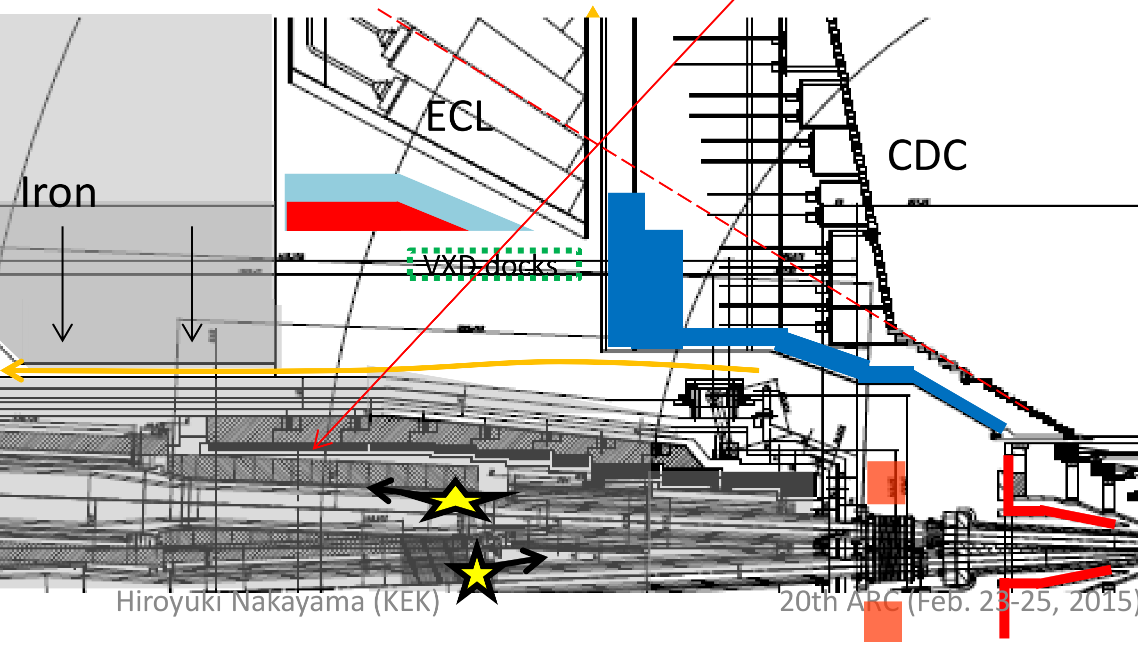
★→ Major beam loss position by Touschek or Beam-gas

Thick tungsten shields can significantly stop background showers originated from |s|>65cm.

BG shields outside QCS



Thick tungsten layers inside cryostat



Heavy metal shields to protect VXD from showers generated in cryostat

Neutron shield inside ARICH structure

Polyethylene neutron shield for CDC elec. board (planned)

ECL shield, included for ECL/ARICH simulation (Lead + Polyethylene)

RVC structure in front of QCS stops showers from RBB HER loss at z=60cm (6cm-thick SUS steel assumed)

Single-beam BG (1)

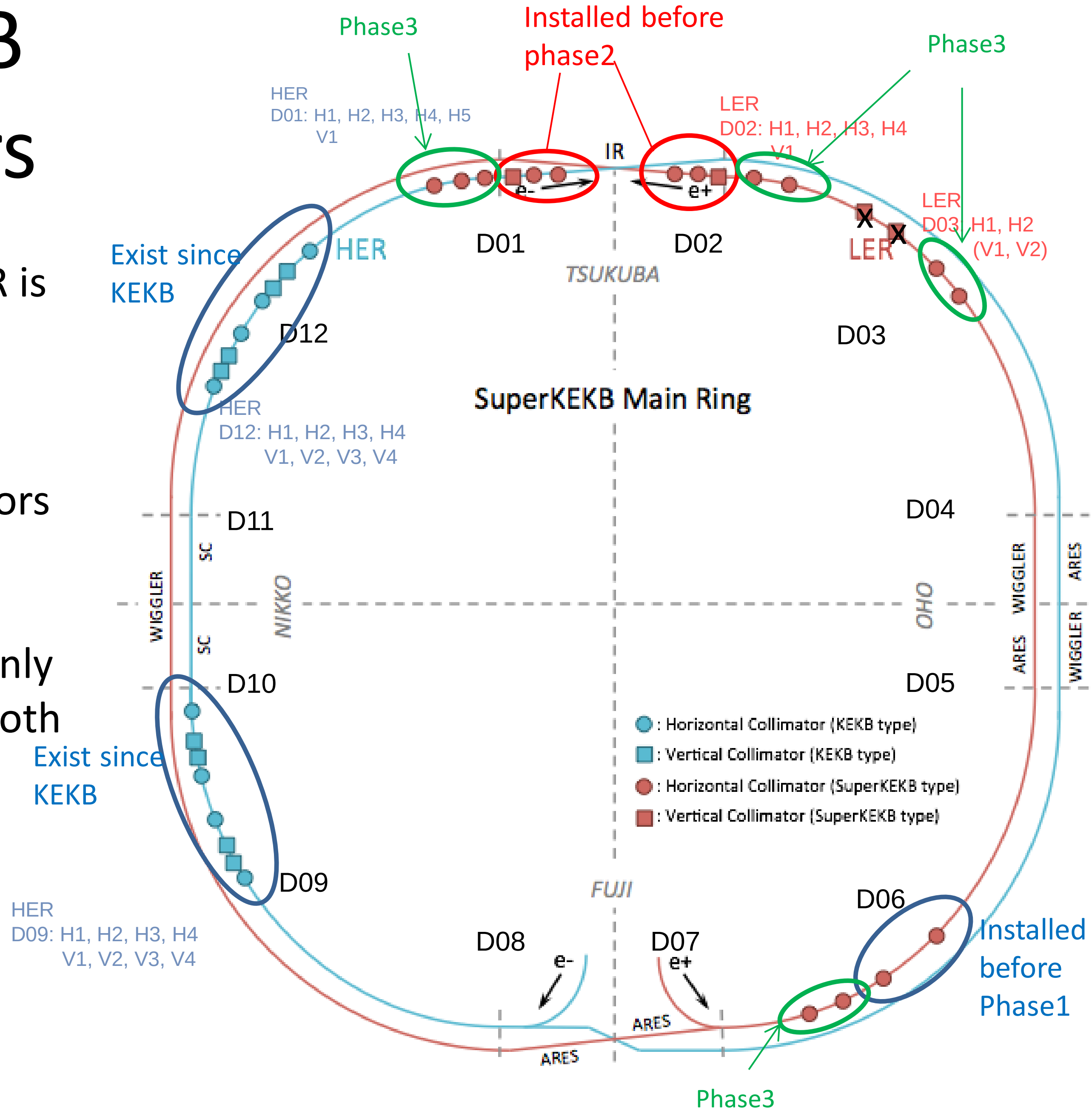
Touschek, Beam-gas

- Well suppressed by movable collimators
- Horizontal collimators near IP
  - effective for Touschek & Beam-gas Bremsstrahlung
- Narrow(~2mm) vertical collimator
  - effective for Beam-gas Coulomb
  - however, we can install only one such collimator per ring (*)
- Need careful collimator adjustment during operation
  - Miss-operation might result in x100~x1000 beam loss in the detector
- Less number of collimators installed in phase2
  - but the BG rate is acceptable (detuned optics)

(*) H. Nakayama, et. al., ``Small-Beta Collimation at SuperKEKB to Stop Beam-Gas Scattered Particles and to Avoid Transverse Mode Coupling Instability,'' Conf.Proc. C1205201 (2012) 1104

SuperKEKB Collimators

- Collimators near IR is important
- One narrow vert. collimator per ring
- Phase2 IR collimators
  - 2 horizontal
  - 1 vertical
- KEKB type: inner only
- SuperKEKB type: both



Single-beam BG (2)

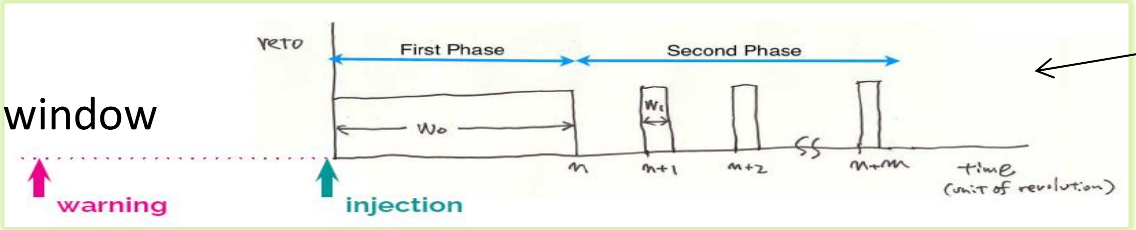
Synchrotron Radiation

- SR fans from QCS magnets might reach VXD detectors
  - Simulated level is acceptable both in phase2/phase3
  - Beam pipe misalignment effect is also considered

Injection BG

- Belle II trigger veto while injection BG is busy
  - To avoid PXD high occupancy
  - Veto window time structure determined by injection BG
- Important measurement in Phase2 (with damping ring)

Veto window

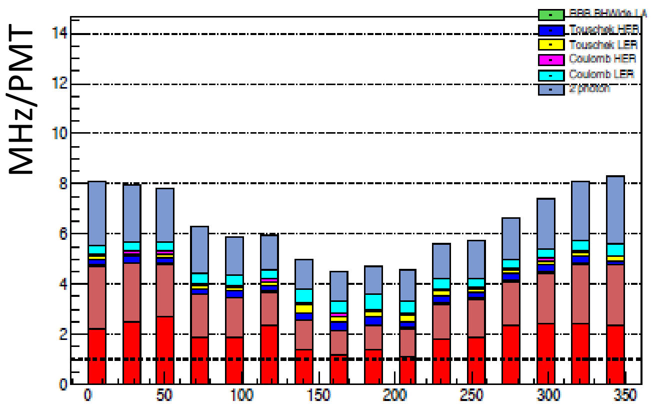


window shape determined by measurement

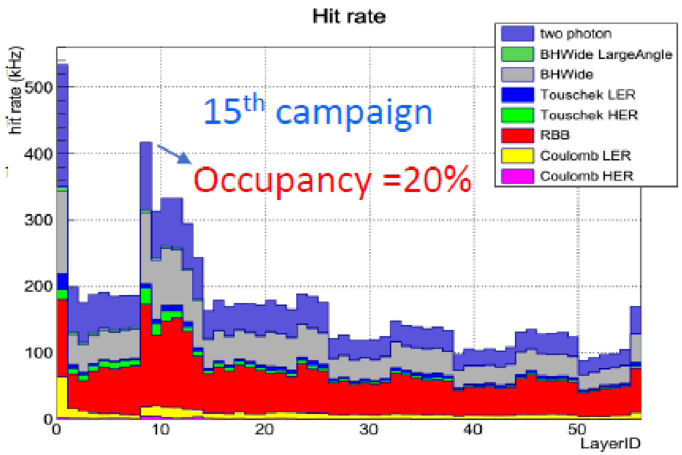
15th campaign

Simulated sub-Detector BG levels

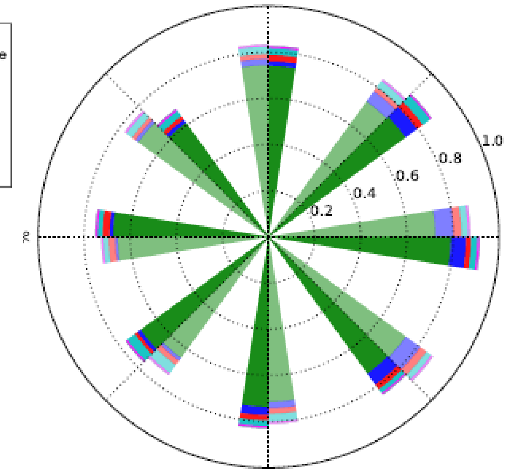
TOP PMT rate



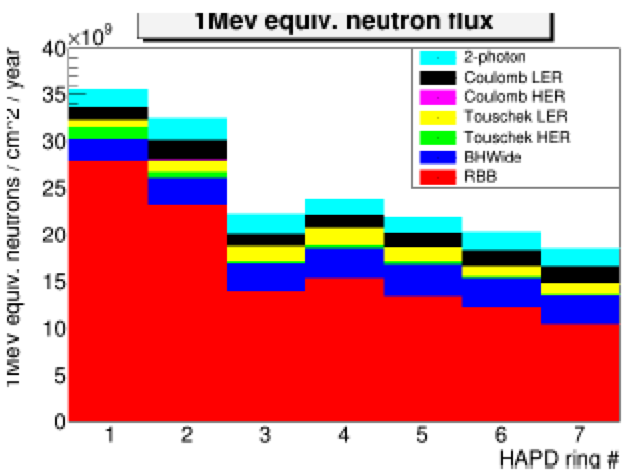
CDC wire rate



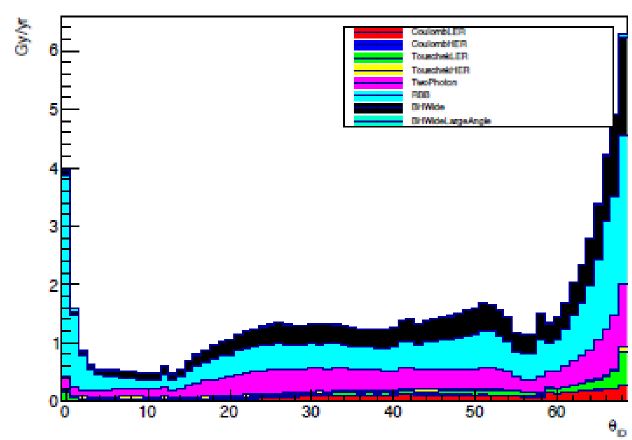
PXD occupancy



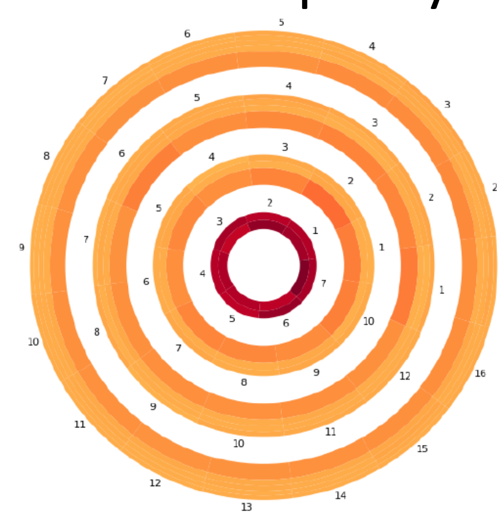
ARICH neutrons



ECL crystal dose



SVD occupancy



See more details in Background parallel session

https://kds.kek.jp/indico/event/23336/session/27/?slotId=0#20170208

Summary for 15^{th} campaign

listing SF<5 only
SF=Safety Factor

	15^{th} campaign result	criteria	SF
PXD occupancy	2photon:0.9% , SR:~0.2% (10th)	< 3%	3
CDC wire hit rate	400kHz at layer#8	<200kHz	1.3
CDC Elec.Borad n-flux* (averg.)	2.5	<1	1.3
CDC Elec.Board dose	250 Gy/yr	<100 Gy/yr	1
TOP PMT rate	5-8 MHz/PMT	<1 MHz/PMT	0.3
TOP PCB n-flux*	0.35	<0.5	3
ARICH HAPD n-flux*	0.3	<1	3
ECL crystal dose	6 Gy/yr in BWD	<10 Gy/yr	2
ECL diode n-flux*	?	<1	4
ECL pile-up noise	?	0.8 at Belle-I	?

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

Beam BG まとめ

- TOP PMTの半数は、Phase3のfull-lumi数年で交換が必要
  - QCS と VXD の隙間からのロスが要因で、これ以上の低減は困難
- その他の検出器はほぼOK (ただしmarginは少ない)
- Phase2ではコリメータの数が少ないが、大丈夫
- 入射BGは見積もりに含まれていないので注意
  - Phase2 での実測(damping ringあり)が重要
- Phase2でもBG machine studyを予定
  - Beam-size scan, vacuum bump, collimator study
  - Luminosity scan
  - Injection study (with damping ring)

MDI communication

<u>Topics covered</u>
- Beam Abort
- Operational flags for injection control
- Injection timing signal
- EPICS communication

1. Beam abort

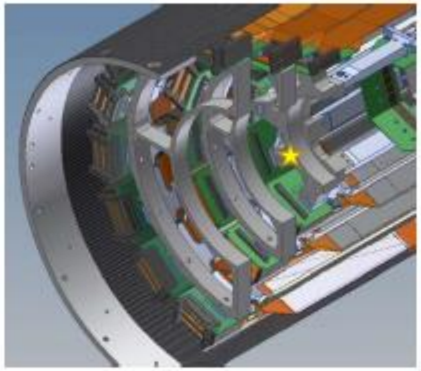
- Beam abort should be sent via hard-wired connection
- “Fast abort” sources
  - VXD diamond sensors
  - Can abort LER and HER separately
- “Slow abort” sources
  - Solenoid quench, EH power outage
  - Other environmental sensors
    - Beam pipe temperature error, cooling system error, etc..
  - Collected by ‘Uehara’ logger and give a combined abort signal
  - Always abort both rings

➢ Accelerator abort timing signal send back to VXD abort module
  - for offline abort diagnosis

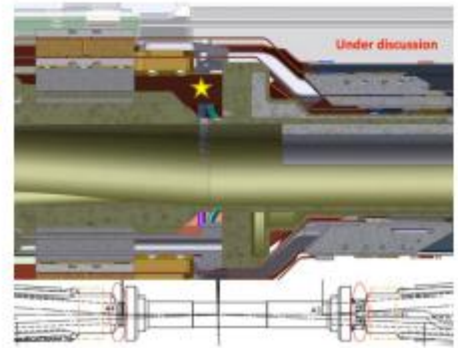
Belle-II

VXD abort sensors

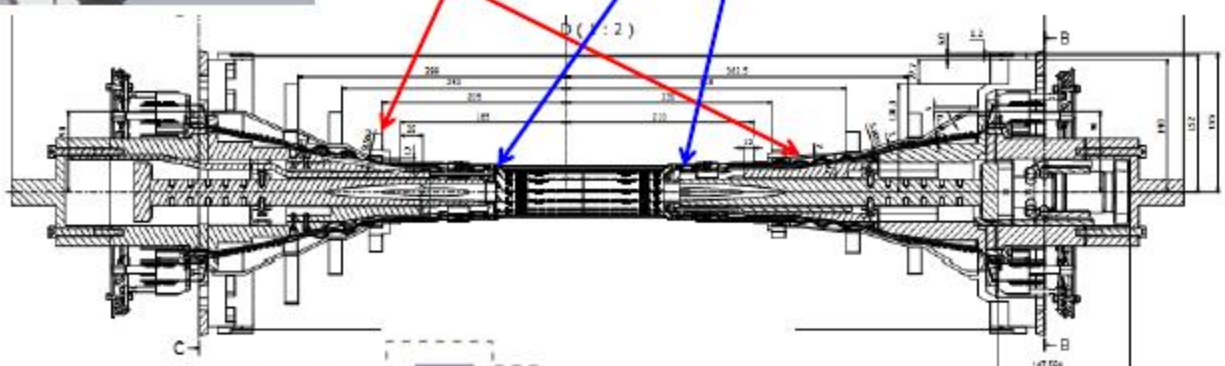
Torieste group



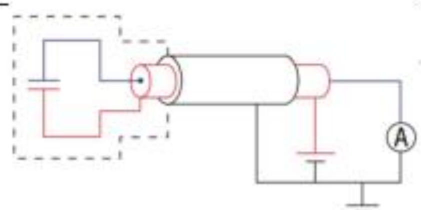
4 + 4 sensors
PXD-beam pipe



6 + 6 sensors
on SVD support cone
close to L3 rings



Shielded
diamond
sensors



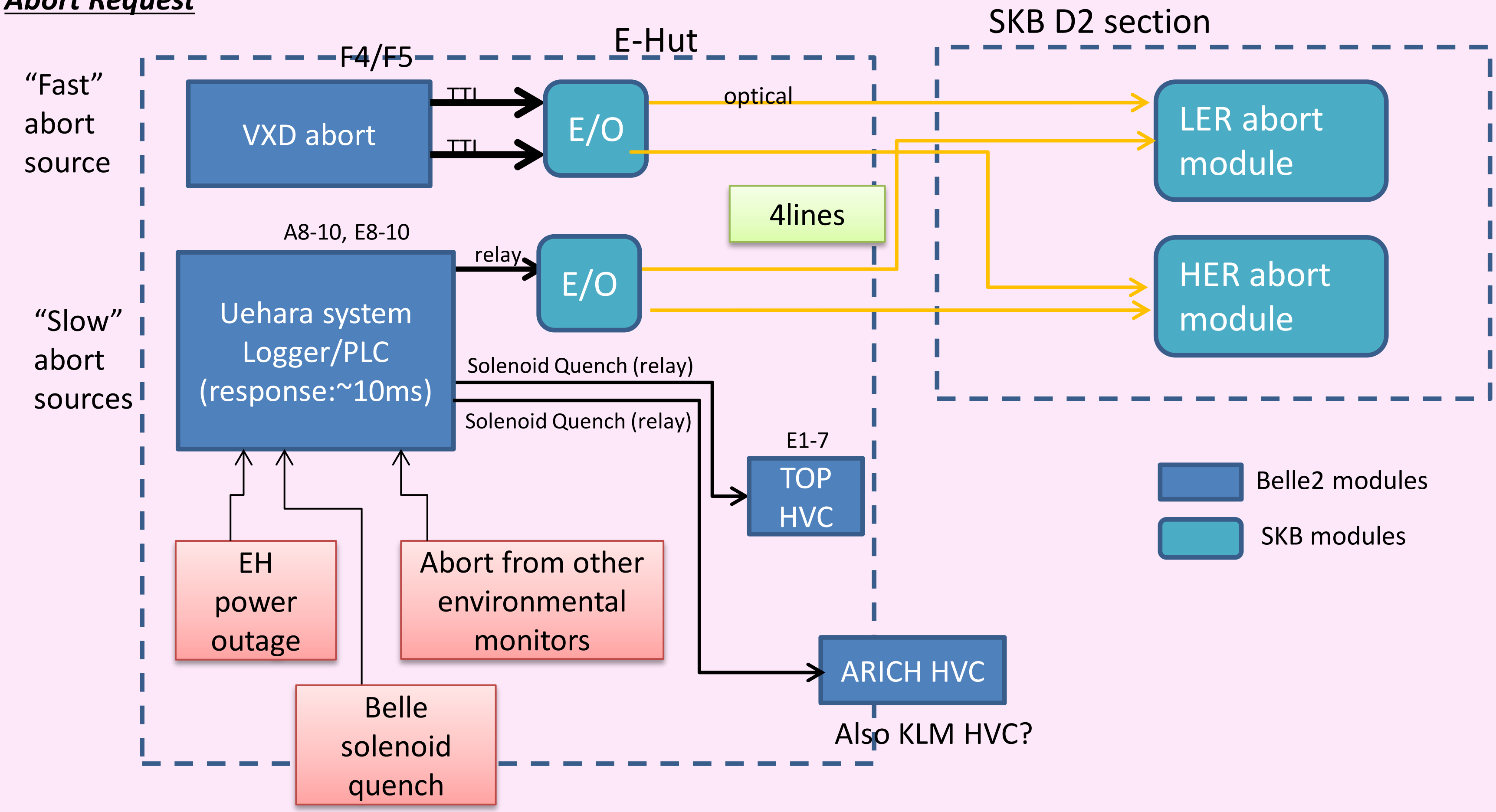
3+15 m (3+40 m) cables
Voltage sources (150÷500 V)
picoAmmeters

4

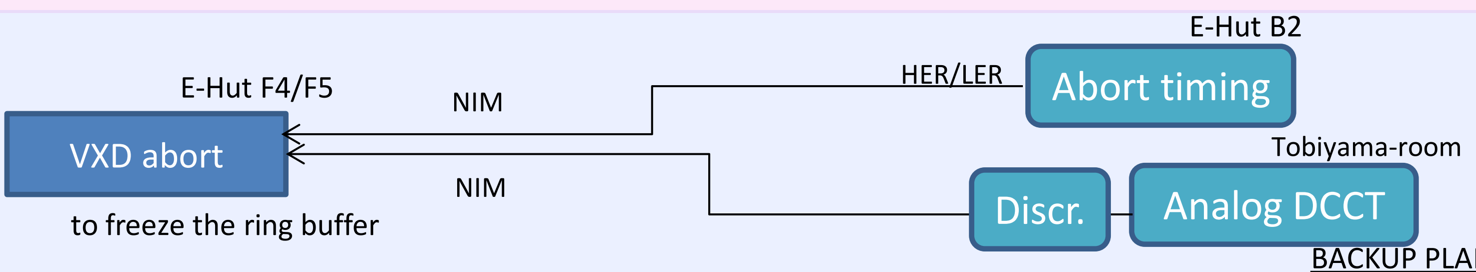
Beam Abort Diagram

H. Nakayama
ver. 2017.6.30

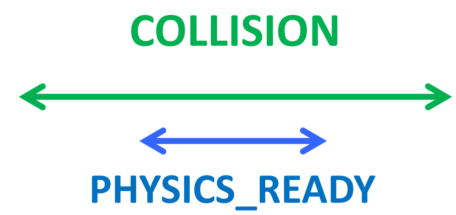
Abort Request



Abort Timing
(for abort diagnosis)



2. Injection control
- Operation flags -



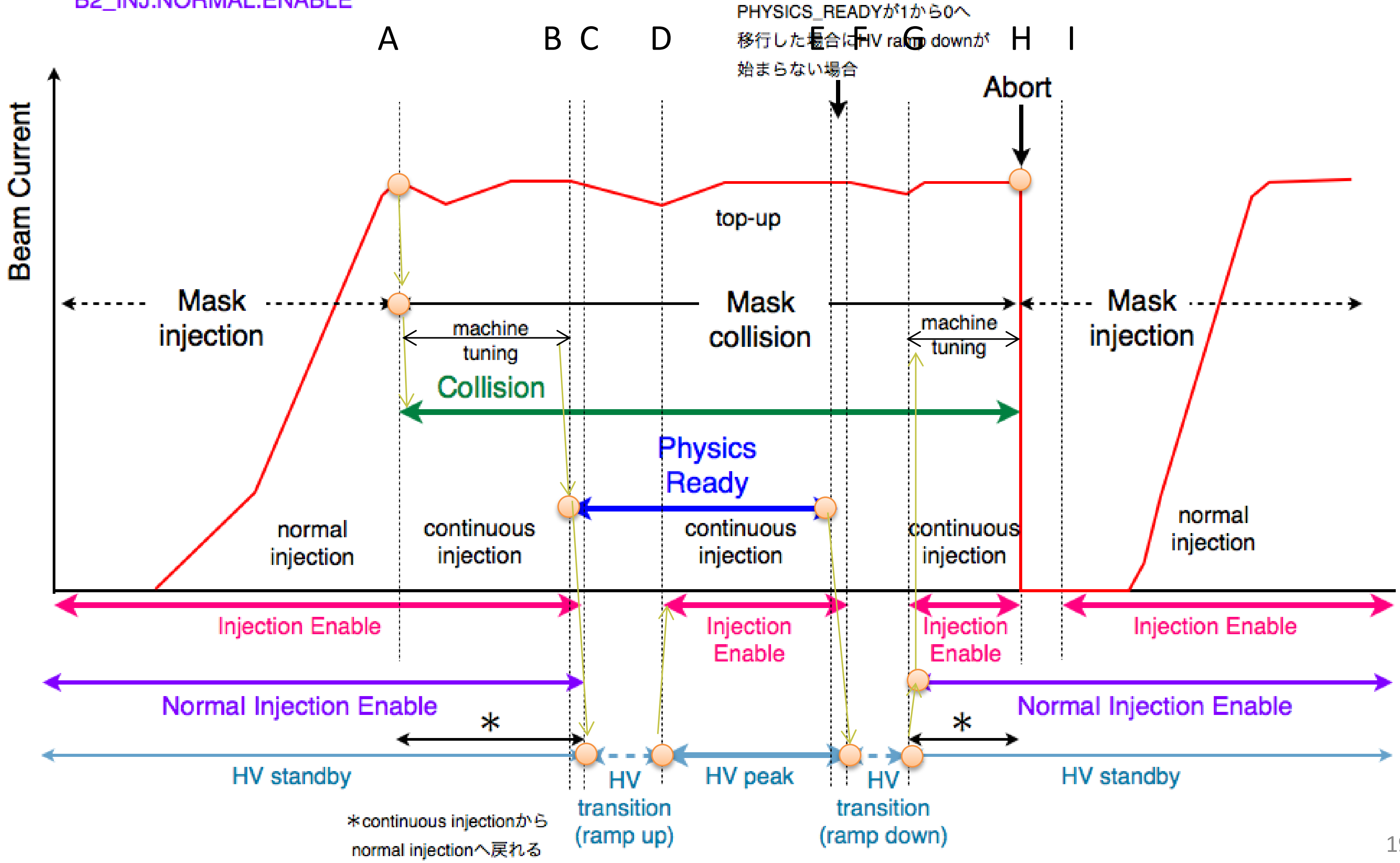
- Accelerator status
  - COLLISION
    - Yes= continuous injection, No= normal injection
    - Collimator mode depends on this flag
  - PHYSICS_READY(can be 1 only when COLLISION is 1)
    - Accelerator promises not to go back to normal injection mode without detector permission

- Detector status
  - NORMAL_INJECTION_ENABLE
    - Allow normal(initial/accumulating) injection (and wild machine tuning)
    - TRUE when HV is STANDBY (no control from BG level assumed)
  - (Continuous) INJECTION_ENABLE
    - Allow continuous (trickle/top-up) injection
    - TRUE when (HV=PEAK or STANDBY)&&(no local run)&&(safe BG level)

CG_OPR:COLLISION
CG_OPR:PHYSICS_READY
B2_INJ:INJECTION:ENABLE
B2_INJ:NORMAL:ENABLE

Physics ReadyはCollisionのサブセット
Collisionでは、Maskは基本的に"Collision"

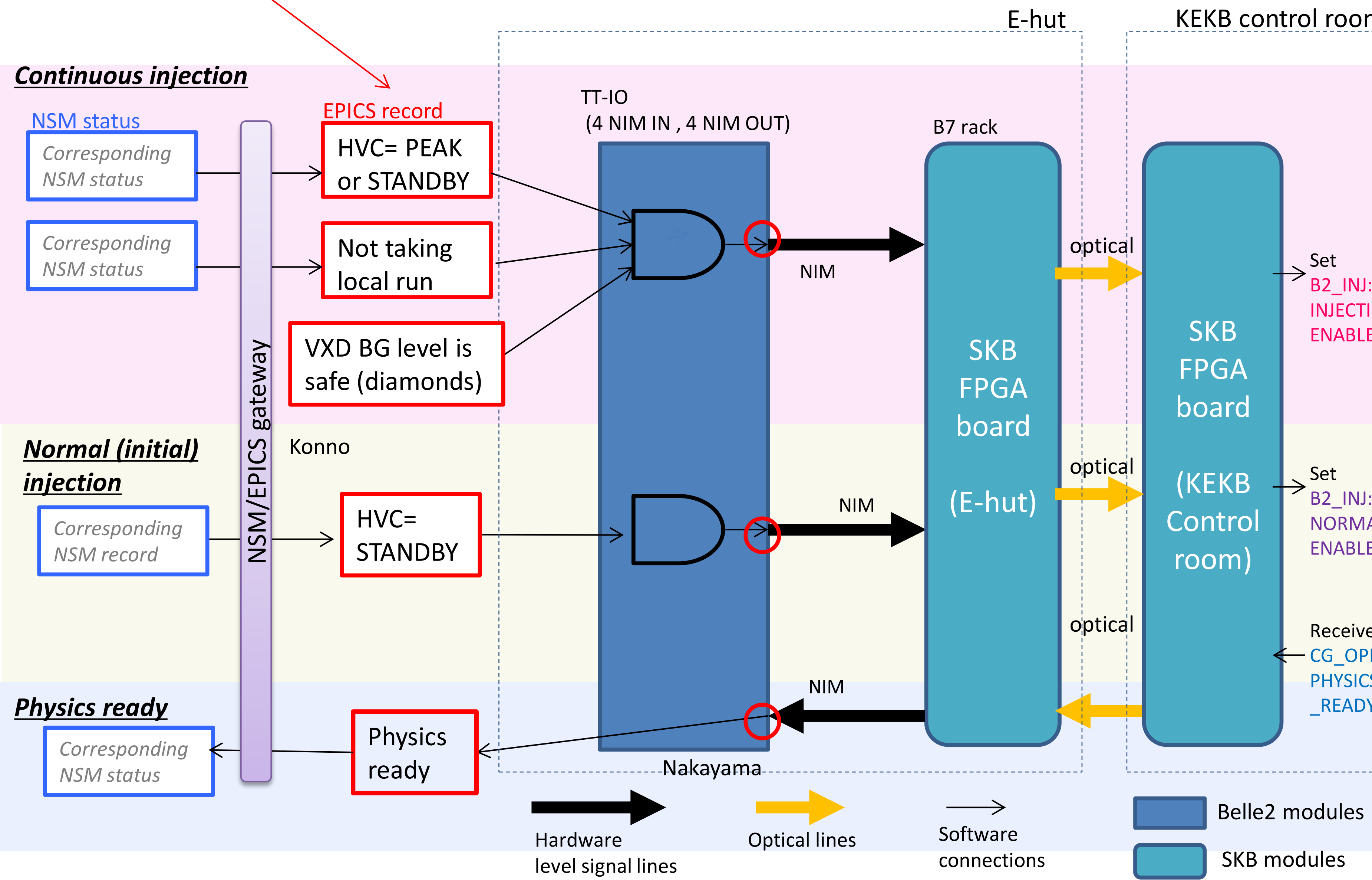
Belle II Local Run
→ Injection disable



These EPICS records should be readable from KEKB EPICS via CA gateway

Injection control diagram

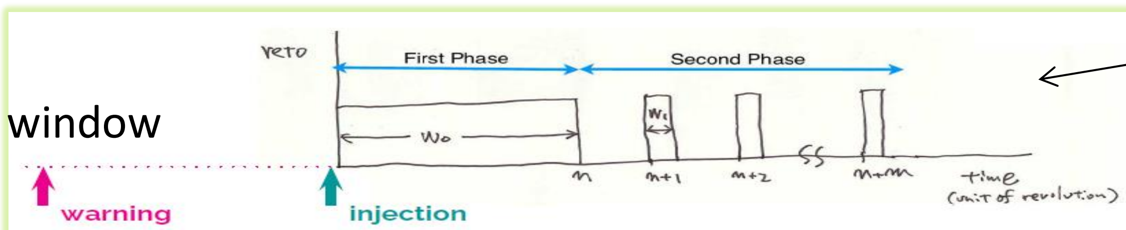
H. Nakayama
ver. 2017.1.30



3.Injection timing signal

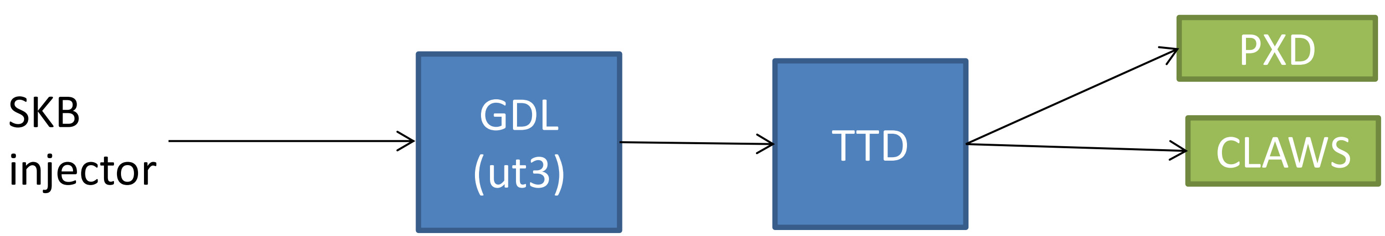
- SKB beam injection timing is delivered as <u>“Event Data”</u>
  - serial link, Xilinx Rocket IO, 20bit info (timing info + α), 50Hz
  - “in-advance” signal (well before injected bunch arrival)
- Belle2 GDL receives “Event Data” on ut3 board
  - Then TTD delivers “injection veto” to sub-detectors (PXD, etc..)
  - PXD goes insensitive after each injection to avoid BG saturation

Veto window



window shape determined by measurement

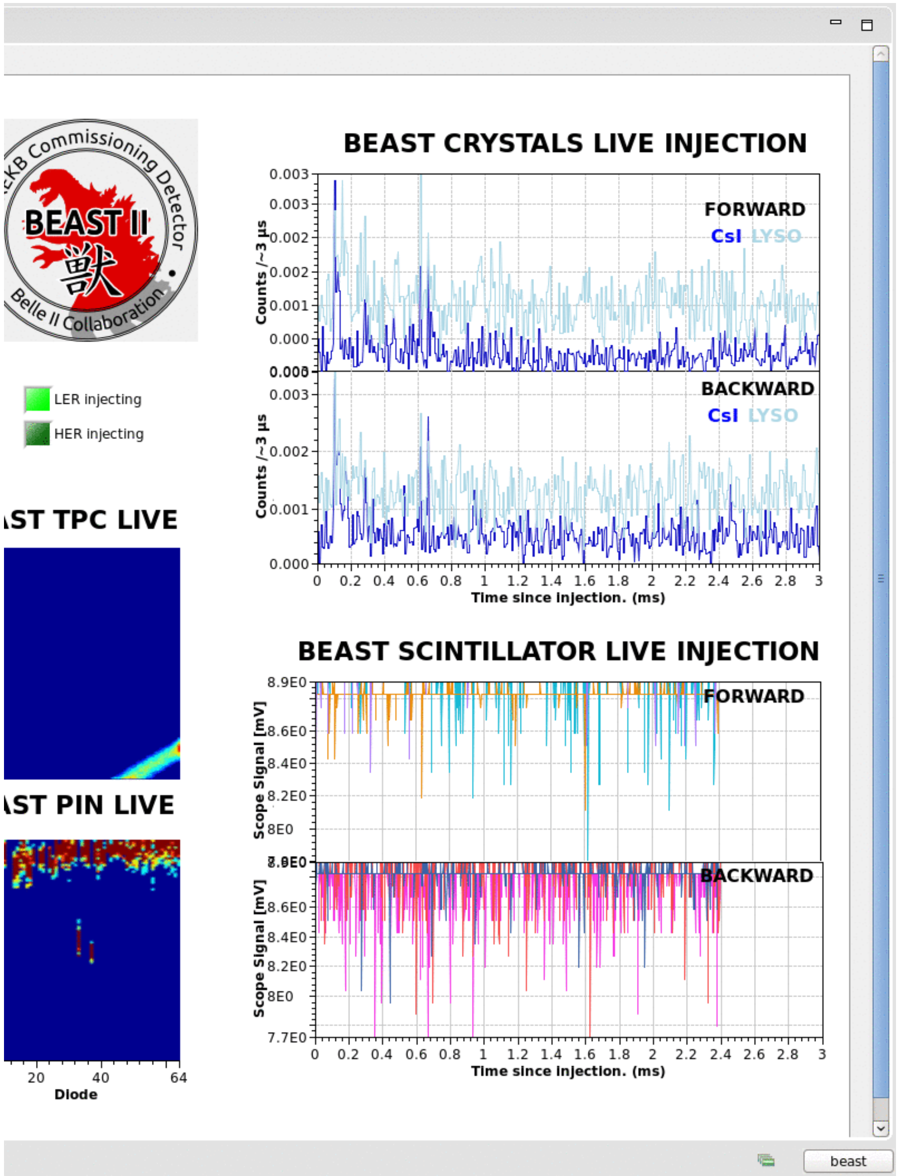
- Receiving test by ut3 ongoing (Y. Iwasaki)



4. EPICS communication

- Belle2-SKB communication is based on EPICS
  - Except several important hard-wired connection
- SKB→Belle2
  - Machine parameters, vacuum levels, injection parameters, …
  - Most of them already prepared in phase1
- Belle2→SKB
  - Luminosity, vertex position, bunch luminosity, etc.. (for machine tuning)
  - Injection BG timing structure (for injection tuning)
    - See next slide
  - BG rates measured by sub-detectors/BG sensors (for collimator tuning)
    - z/phi/theta distribution of BG hits give insight on which BG we see, and which collimator we should squeeze

LIVE display of injection BG in phase1



- BEAST phase1 CsI crystal/CLAWS
- Waveforms sent by EPICS, updates every few seconds
- Provide BG time structure for 3ms after injection

- This display helps SKB operator to improve injection efficiency (periodical spikes implies bad injection phase, etc..)

- We need similar displays at phase2/3

MDI まとめ

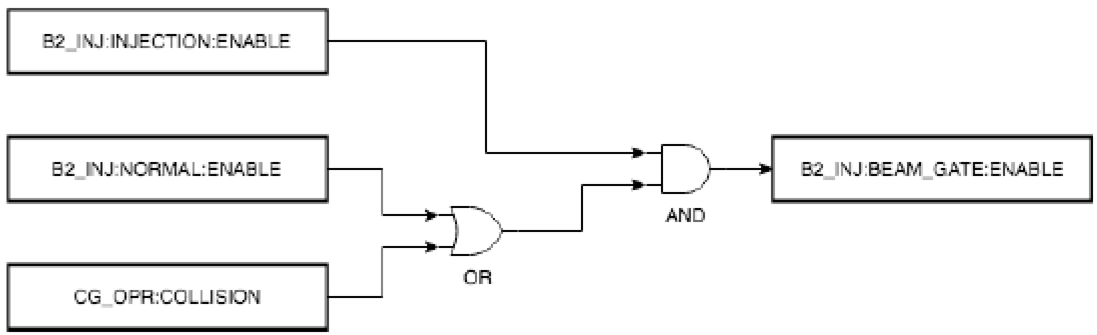
- Hard-wiredのアボート信号：配線済み　　佐々木氏・小林氏
  - アボートタイミング信号も配線済み
- Hard-wiredの入射コントロール信号：配線済み
- 入射タイミング信号(Event system)
  - Belle2 TRG/DAQグループが受信テスト中
- それ以外の情報はEPICSで共有

backup

Y. Ohnishi (July 11th, 2017)

Belle II Beam Gate Enable

Belle IIによる 入射許可	HV Transitionでない Local runでない radiation dose OK	B2_INJ:INJECTION:ENABLE
Belle IIによる ノーマル入射許可	HV Standby等	B2_INJ:NORMAL:ENABLE
加速器からの 衝突状態示唆	Normal injectionと Continuous injection	CG_OPR:COLLISION

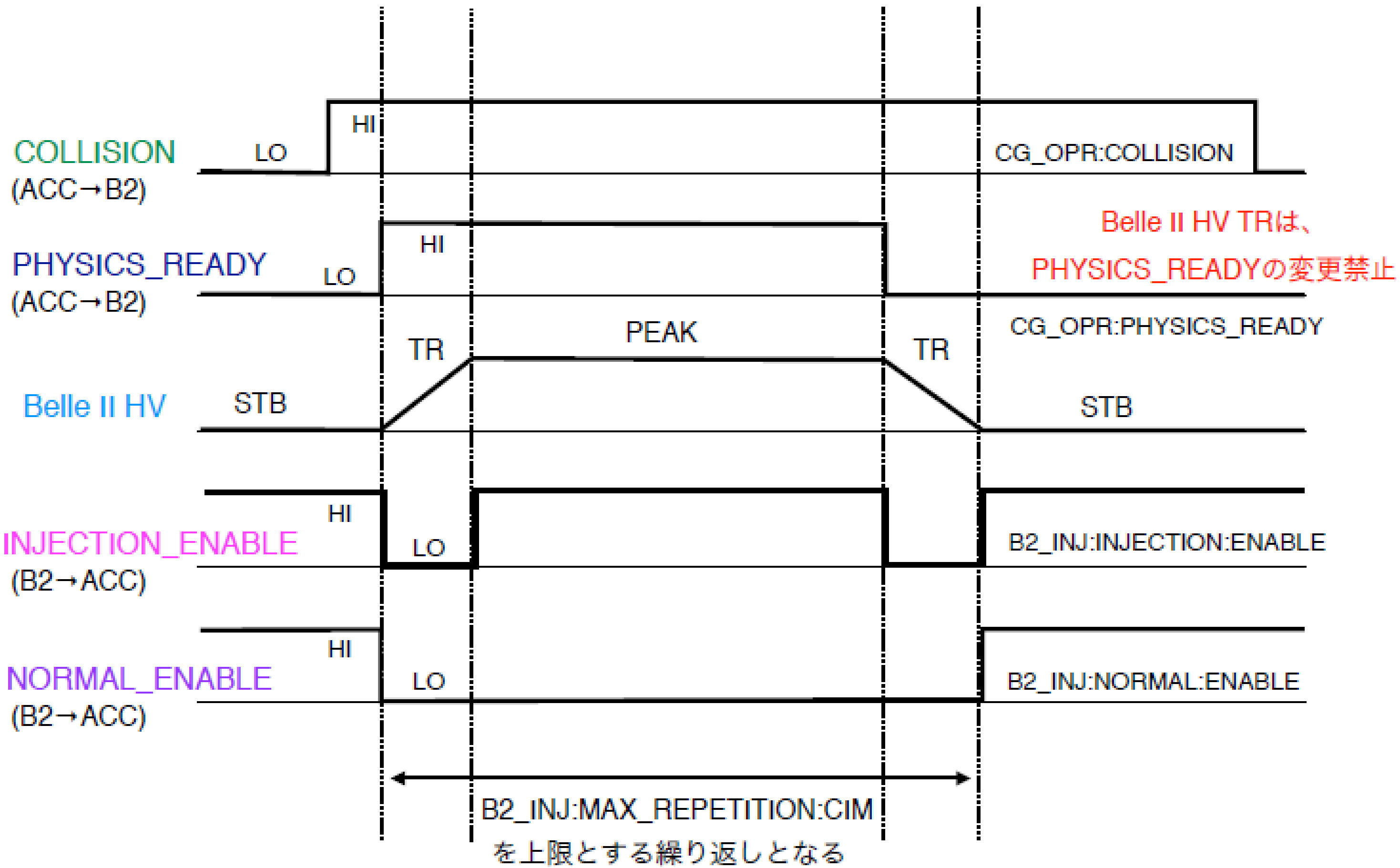


operation	Normal Injection			Continuous Injection					
Mask	Injection Mode			Collision Mode					
CG_OPR:COLLISION	**0**			**1**					
CG_OPR:PHYSICS_READY	0			0			1		
B2_INJ:NORMAL:ENABLE	**1**	0	**0**	**1**	0	**0**	**1**	0	**0**
B2_INJ:INJECTION:ENABLE	**1**	**0**	1	**1**	**0**	**1**	**1**	**0**	**1**
Belle II HV	Standby	**Transition**	**Peak**	Standby	**Transition**	**Peak**	Standby	**Transition**	**Peak**
B2_INJ:BEAM_GATE:ENABLE	1	0	0	1	0	1	1	0	1
Comment	OK	禁止	禁止	OK	PHYSICS_READYを1から0に変更した直後は、可能性あり		OK	PHYSICS_READY: 0→1	OK

Y. Ohnishi (July 11th, 2017)

Belle II Injection Enable

Belle II HVは、PHYSICS_READY信号と連動.



EPICS RECORD

レコード名	信号の流れ	信号の種類
CG_OPR:COLLISION	ACC → Belle II	ソフトウエア
CG_OPR:PHYSICS_READY	ACC → Belle II	ハードワイヤー CO_CCCS:RPV132:PHYSICS:READY
B2_INJ:INJECTION:ENABLE	Belle II → ACC	ハードワイヤー CO_CCCS:RPV132:INJECTION:ENABLE
B2_INJ:NORMAL:ENABLE	Belle II → ACC	ハードワイヤー CO_CCCS:RPV132:NORMAL:INJECTION
B2_INJ:MAX_REPETITION:CIM	Belle II → ACC	ソフトウエア
?	Belle II → ACC	ソフトウエア

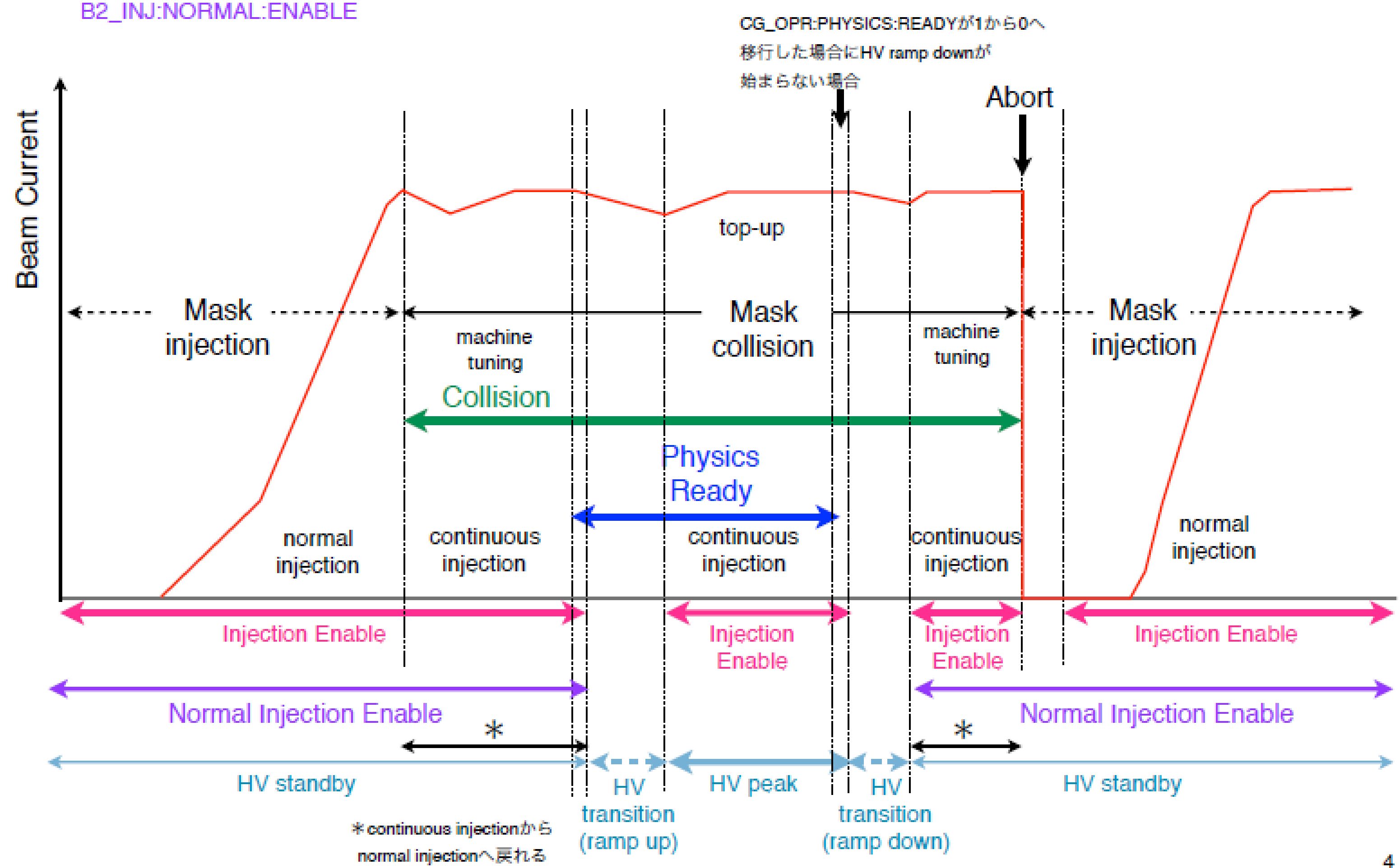
Belle IIのHV状態を示すレコードが必要 (0:Transition, 1:STB, 2:PEAK)
PHYSICS_READYをHV Transition状態では変更できないようにするため.

Y. Ohnishi (July 11th, 2017)

Beam Operation

CG_OPR:COLLISION
CG_OPR:PHYSICS:READY
B2_INJ:INJECTION:ENABLE
B2_INJ:NORMAL:ENABLE

Physics ReadyはCollisionのサブセット
Collisionでは、Maskは基本的に"Collision"



Typical Run Cycle Scenario

Case study for Beam abort during Belle HV standby

A. Enough current accumulated. KCG issues “COLLISION=1” and switches to continuous injection. BCG switch collimators to “COLLISION” mode. KCG starts machine tuning. Since “Normal Injection Enable” flag from Belle2 is still 1, KCG can go back to COLLISION=0 if needed.

B. KCG finishes machine tuning and issues “PHYSICS_READY=1”.

C. Belle2 receives “PHYSICS_READY=1” and Belle2 HV starts ramp up. Any injection inhibited.

D. Belle2 HV reaches peak. Belle2 issues “Injection Enable=1” and continuous injection is now allowed.

E. KCG issues “PHYSICS_READY=0” because machine tuning needed (beams get instable, etc.). Note that normal injection will not start until Belle2 allow to do so (by issuing normal injection enable)

F. Belle2 HV starts to ramp down.

G. Belle2 HV becomes standby. Belle2 issues ”NORMAL_INJECTION_ENABLE=1”. Continuous injection resume. Now KCG can start machine tuning. (If needed, KCG switch to normal injection and BCG switch collimators to “Injection” mode)

H. Beam aborted during machine tuning. Note that abort is issued during Belle HV standby, in this case. KCG issues “COLLISION=0”. BCG switch collimators to “Injection” mode. If abort was issued by high BG level, continuous injection is not allowed until BG get smaller.

I. BG becomes safe and continuous injection is enabled. Normal injection can start now.

SuperKEKB EPICS records we need for BEAST studies

- Accelerator status
- LER/HER optics version (emittance, tune, chromaticity, steering magnet values, etc..)
- Beam currents, bunch numbers, bunch currents, beam lifetime, beam sizes, emittance-control bump size (for Touschek study)
- Vacuum pressure, partial pressure of CO, H2,.. using Q-mass (for Beam-gas study)
- Beam position/beam size/phase at each collimators, width of each collimator, BLM(Beam Loss Monitor) info at each collimator (for Collimator study)
- Injection mode, injected beam, injection rates, injection efficiency, injected bunch number? (for Injection study)
- Beam separation, etc.. (for lumi-BGstudy)

- Any others?

Mainly needed for background machine study, collimator study
Red: not used in KEKB . For other request items, corresponding parameter in the KEKB list (in following slide) are underlined

Sven Vahsen(Hawaii)

Lessons learned in phase 1?

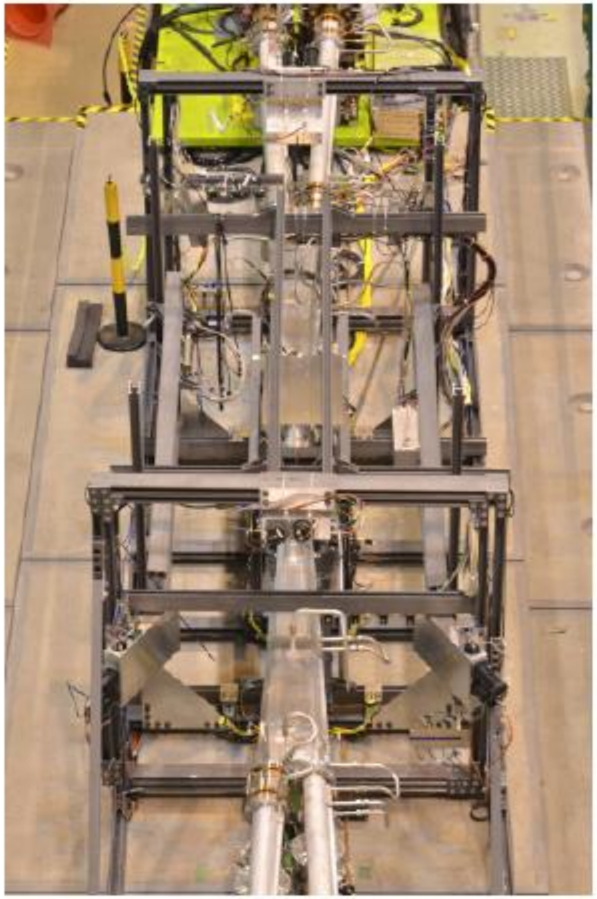
(implications for phases 2 and 3 ?)

- Vacuum scrubbing successful, but not complete
- Safe to install Belle II + BEAST phase 2
  - Total dose in phase 1: A few hundred krad near beampipe
  - < 2krad for R > 30 cm
  - <1.7 krad from from SR
  - Beam abort system calibrated and sensitive
- A plethora of phase 1 analysis results now exist, written up in a > 80 page Belle II note
- SAD modifications resulting from this work have already led to modified BG predictions for phase 3
- It will take at least 1 more month to ensure all analyses are consistent, digest the implications, and extrapolate to phases 2/3
- A number of sophisticated BG sensors have been demonstrated their utility in phase 1, and are ready for phase 2
- With data processing and analysis procedures in place, phase 2 data interpretation should be significantly faster than phase 1

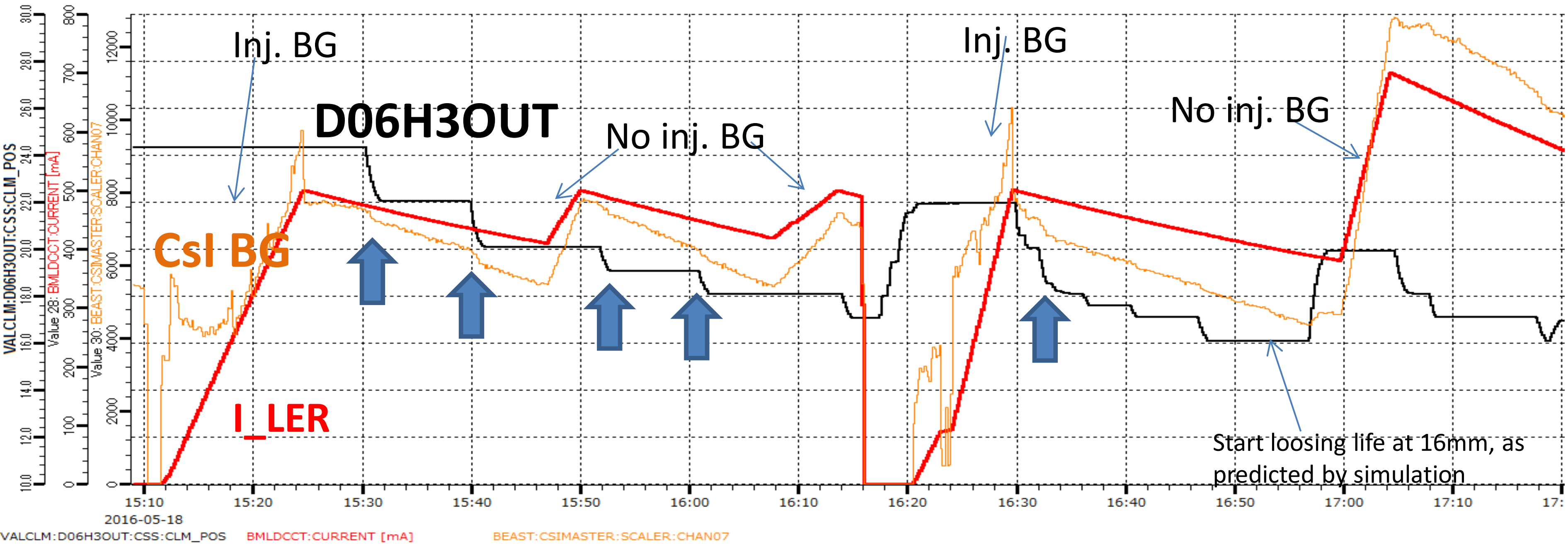
BEAST II Phase 1

- Collection of detectors aimed at studying beam backgrounds
- Independent detectors, no global event building

System	Detectors Installed	Unique Measurement
PIN Diodes	64/64	neutral vs charged radiation dose
Diamonds	4/4	ionizing radiation dose
Micro-TPCs	4/4	directional fast neutron flux
He-3 tubes	4/4	thermal neutron rate
Crystals	6/6 Csi(Tl) 6/6 Csi 6/6/ LYSO	EM energy spectrum
BGO	8/8	EM dose rate
"CLAWS"	8/8	Inj. BG
Scintillator	4/4	EM particle rate



3. LER collimator vs. BEAST BG



As we change D06H3OUT width from 24mm to 17mm,

BEAST CsI BG shows step-like decrease at every time collimator get narrower.

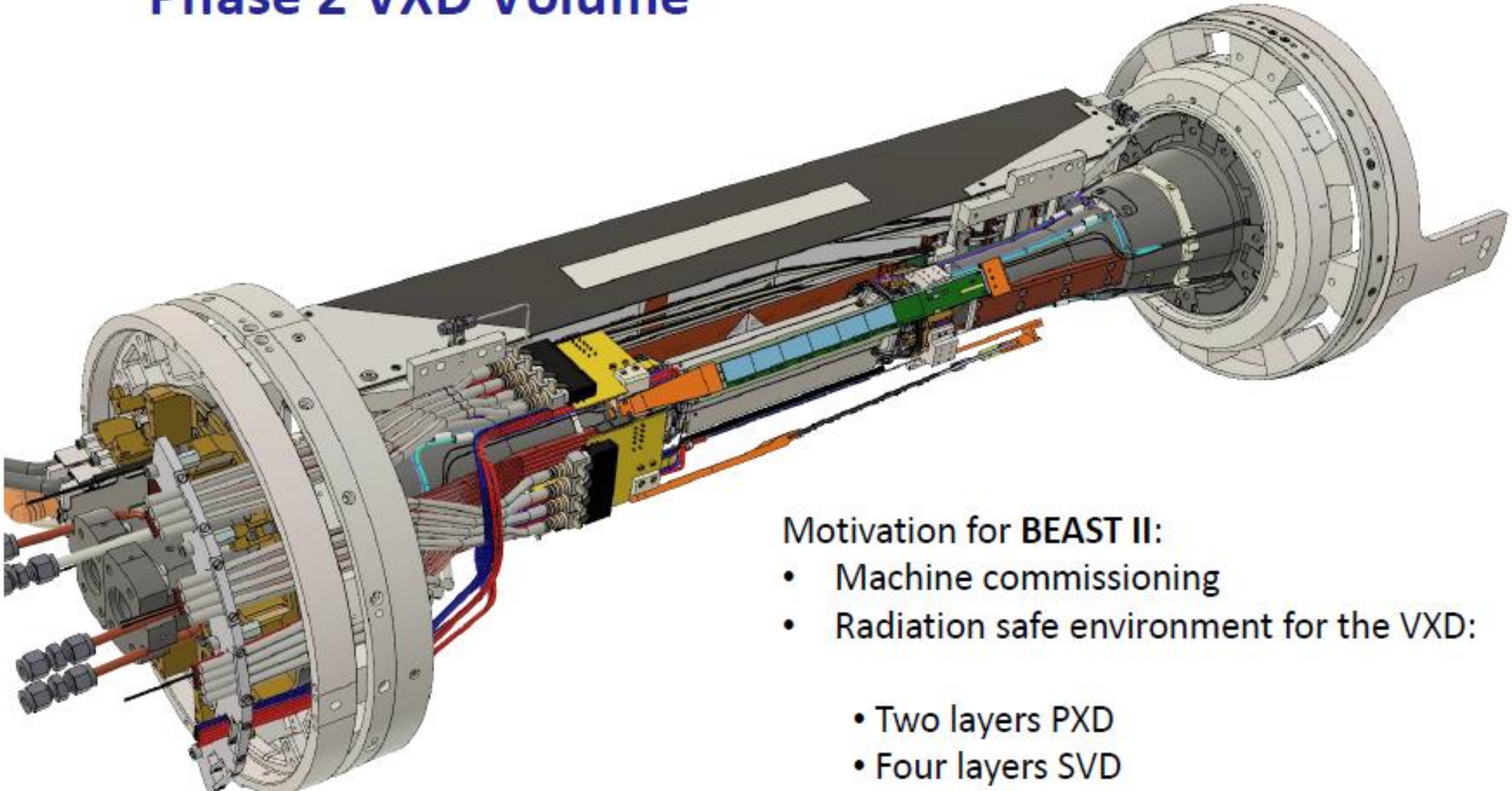
<u>This is the clear evidence of BG suppression by the collimator!</u>

We also observe that

<u>injection BG is completely stopped by the same collimator!</u>

(at <=20mm)

Phase 2 VXD Volume



Motivation for **BEAST II**:

- Machine commissioning
- Radiation safe environment for the VXD:
  - Two layers PXD
  - Four layers SVD
  - Dedicated radiation monitors
    FANGS, CLAWS, PLUME

cmarinas@uni-bonn.de