



# Beam background detection at SuperKEKB/Belle II

**Peter M. Lewis** on behalf of the BEAST II Collaboration *University of Hawai'i at Mānoa* 

27 February 2017 INSTR-17

## Overview

#### This talk

- About BEAST II: a suite of detectors for measuring beam backgrounds at SuperKEKB during commissioning
- Preliminary BEAST II results from the first phase of SuperKEKB operation





### SuperKEKB

The super *B*-factory at KEK (2018 start)

- A planned **40-fold** increase in luminosity over KEKB (target: 8x10<sup>35</sup> cm<sup>-2</sup>s<sup>-1</sup> instantaneous, **50ab<sup>-1</sup>** integrated), due to major upgrades:
  - "Nano-beam" scheme (below)
  - Doubled beam currents
  - (large number of upgrades to RF, magnet, vacuum, damping systems)
- First turns Feb. 10, 2016! Exciting times!







Vertical beta function reduction (5.9 $\rightarrow$ 0.3 mm) gives x20

Beam Energies 8.0/3.5→7.0/4.0





### Commissioning of SuperKEKB





### Schedule: beam commissioning phases

Phase I (2016)

- Circulate both beams; **no collisions**
- Tune accelerator optics, etc.
- Vacuum scrub
- Beam studies

#### Phase II (2018)

- First collisions
- Develop beam abort
- Tune accelerator optics, etc. (nano-beam)
- Beam studies



### Commissioning requirements



#### SuperKEKB

- Real-time **monitoring** of beam conditions
- **Quantify** effects of tuning, collimators, etc., on beam loss
- Isolate the **type and source** of beam loss
- Inform beam loss **simulations** to optimize performance

#### Belle II

- Guarantee a **safe**-enough radiation environment for Belle II (beam backgrounds can be **dangerous** to detectors)
- **Mitigate** beam backgrounds (with physical shielding, electronic gating, magnet tuning, etc.) around interaction point
- Inform beam background **simulations** so they are properly accounted for in physics analysis (where they can cause **lower sensitivities**)

### Enter the BEAST

Primary detectors in BEAST II\* for phase I:

System	Institution	#	Unique measurement	
PIN diodes	Wayne St.	64	Neutral vs. charged dose rate	
Time Projection Chambers	U. Hawaii	4	Fast neutron flux and tracking	
Diamonds	INFN Trieste	4	Beam abort	
He3 tubes	U. Victoria	4	Thermal neutron rate	
CsI(Tl) crystals	U. Victoria	6	EM energy spectrum, injection backgrounds	
CsI+LYSO crystals	INFN Frascati	6+6		
BGO crystals	National Taiwan U.	8	Luminosity and EM rate	
CLAWS plastic scintillators	MPI Munich	8	Fast injection backgrounds	





Belle and the BEAST

Belle II will eventually roll in on a pair of railroad tracks







### BEAST operation in phase I

#### Completed

- 24/7 operation for 5 months (top)
- Throughout: beam scrubbing and tuning
- Two weeks of dedicated beam study runs
- Real-time background monitoring and feedback to SuperKEKB group (bottom)
- Dismantled BEAST II to make way for Belle II

#### In progress

- Preparing final results for publication (next slides)
- Working on phase II version of BEAST







### Preliminary BEAST II phase I results



#### Observable =?



How well can we *predict* beam backgrounds?

- We want simulation to match data
- How do we expect **detector observables** to behave as a function of **beam parameters**?
- There are **too many unknown parameters** in the beam to do this in terms of fundamental physics
- Instead we create a "heuristic model"
  - Composed of physics-motivated contributions from known background processes
  - Takes as inputs recorded beam conditions
  - Must explain variations in **observables** recorded by various BEAST detectors



#### Observable =



Beam-gas scattering

Includes (inelastic) Bremsstrahlung (Z is atomic number, *a* and *b* are parameters, I and P are current and pressure):

$$O_{brem} \propto I \cdot P \cdot Z^2 [log(\frac{a_b}{Z^{1/3}}) + b_b]$$

• Includes (elastic) **Coulomb** scattering:

$$O_{Cou} \propto I \cdot P \cdot Z^2 \left[ \frac{1}{a_C + (b_C Z^{1/3})^2} \right]^2$$





 $Observable = B \cdot IPZ_e^2$ 



Beam-gas scattering

- Call these both "**beam-gas background**" and parameterize them based on what we know
  - *B*: **beam-gas sensitivity** for each channel; can be measured in MC and data
  - *I*: Beam current
  - *P*: "Local" pressure
  - $\circ$   $Z_e$ : An "effective" atomic number taking into account the gas mixture recorded by a residual gas analyzer
- This is the **first term** in our heuristic model...





 $Observable = B \cdot IPZ_e^2 + T \cdot \frac{T}{2}$ 



Touschek scattering

- Intra-beam Coulomb scattering
- Becomes dominant with highly compressed
   beams or bunches with a high density of particles
  - A **major concern** for SuperKEKB due to nano-beam scheme
- Depends on many factors; most of which do not vary during normal operation, except:
  - $\circ$   $\sigma_{v}$ : the vertical beam size
  - *I*: current
- The **touschek sensitivity** *T* is constant for each channel and can be measured in MC and data

### Testing the model

#### Size-sweep scans

 $\frac{Observable}{\text{QualityPolZinear fit validates } H = B + T \cdot \frac{I}{R Z^2 \sigma_y}$ 

Fit measures sensitivities *B* (offset) and T (slope)



### Comparison with MC

Ratios of sensitivities

- **Data/MC ratios** for beam-gas and Touschek sensitivities, right (1 is perfect agreement)
  - One point per detector channel
  - **Red**: positron beam
  - Blue: electron beam
- The conclusion: MC and data don't agree well at all!
  - (Not yet)
- We understand **some** of the disagreement but not all of it
  - This is *good*, it proves why we needed BEAST!
  - We're working hard on refining our understanding of SuperKEKB, BEAST and simulation so we can enter phase II with confidence



### Other results: injection

Injection backgrounds

- New charge is periodically injected into bunches
- These bunches are "dirty" for some time, showing short (~ns), medium (~µs) and long (~ms) time structure
- Not simulated and potentially dangerous, this **must be understood in detail**

Fast BEAST detectors

- Plastic and crystal scintillators
- Excellent (~ns) timing to see bunch-by-bunch structure
  - Bunch spacing: 6.3ns
  - Orbit time:  $10\mu s$



#### Injection time structure from



### Other results: injection



Injection time structure from crystals



20

### Other results: scrubbing



Cleaning new beam pipe

- A key goal of phase I was to "scrub" the beam pipes
  - High currents stimulate desorption of impurities from beampipe walls
  - Over time, vacuum improves, lowering beam-gas backgrounds
- BEAST quantified distinct improvements in beam-gas in phase I (right)
- Scrubbing **not yet** at final physics run quality



### Status and near future

#### Paper in progress

- It's going to be a beast!
- Many exciting results not shown today
- Look for publication in the summer

#### Phase II

- BEAST II and some Belle II detectors work together
- Phase I results suggest there will be no major surprises
- Many more questions to answer with narrower beams, collisions and final focusing magnets

FIRST MICLIGNETHICHEN OF DE FIRST MICLIGNET, A. BESNICH, J. BOSSICH, P. Branc, D. Cinnakevi, P. Cristandevi, S. de Jangevi, A. L. Bossich, T. D. Cinnakevi, P. Cristandevi, S. de Jangevi, C. La Lakie, A. L. C. La Lakie, A. L. Manner, P. R. McRancevi, H. Bacsar, T. C. La Lakie, A. L. Manner, P. R. Mark, M. Baczevi, M. Barren, M. Barren, M. Barren, M. Barren, M. Barren, Y. Solovievi, Y. Stetrungevi, M. Baczevi, M. J. Charlie, Y. Solovievi, Y. Stetrungevi, M. Baczevi, M. J. C. Wangevi, M. Starkevi, S. McLawara, Stechar Vision, C. Solovievi, Y. Stetrungevi, M. Saradavi, S. McL. Wangevi, M. Starkevi, S. Markevi, M. Saradavi, S. Barren, S. Barren, M. Barren, M. Barren, M. J. Barren, S. Solovievi, Y. Stetrungevi, M. Saradavi, S. McLawara, S. Solovievi, Y. Stetrugevi, M. Saradavi, S. McLawara, S. Saradavi, S. Saradavi, S. Saradavi, S. Saradavi, S. Barren, S. Saradavi, S	cam Back shini <sup>3</sup> , T. Bro Finocchiaro Ishibashi <sup>3</sup> , I. H. J. Lin <sup>9</sup> , JC. Roney <sup>5</sup> , A. B. S. Terui <sup>3</sup> , G. S. Terui <sup>3</sup> , G. S. Terui <sup>3</sup> , G. S. Terui <sup>3</sup> , G. S. J. H. Windel <sup>3</sup> , and Astronogy patter Engineers (EKX), husting and Astronogy patter Engineers (EKX), and and and aniguino (EKX). and Astronogy patter Engineers (EKX), and and aniguino (EKX). and aniguino (EKX) patter Engineers (EKX), and and aniguino (EKX). A scheduler and aniguino (EKX). A scheduler and aniguino (EKX). A scheduler and aniguino (EKX). A scheduler aniguino (EKX) and aniguino (EKX). A scheduler aniguino (EKX) aniguino (EKX). A scheduler aniguino (EKX) aniguino (EKX). A scheduler aniguino (EKX). A scheduler aniguino (EKX). A scheduler aniguino (EKX). A scheduler aniguino (EXX). A scheduler aniguino (EXX)	ground: wder <sup>4</sup> , A. I. Jaegle <sup>4</sup> , H. Lin <sup>9</sup> , A. M. tossi <sup>10</sup> , T. R. Tortone <sup>9</sup> , S. Nokoyau ke 85, 22607 <i>i</i> e Park, 34149 or 118440, G. 2007 <i>i</i> constraints, <i>i</i> <i>i</i> , 66, 123, Pere <i>i</i> , 118440, G. <i>i</i> , 66, 123, Pere <i>i</i> , 2007, <i>i</i> <i>i</i> , 66, 123, Pere <i>i</i> , 2007, <i>i</i> , <i>i</i> <i>i</i> , 66, 123, Pere <i>i</i> , 2007, <i>i</i> , <i>i</i> <i>i</i> , 66, 123, Pere <i>i</i> , 66, 123, Pere <i>i</i> , 66, 123, Pere <i>i</i> , 66, 123, Pere <i>i</i> , 66, 126, Pere <i>i</i> , 66, 126, Pere <i>i</i> , 66, 126, Pere <i>i</i> , 66, 105, Pere <i>i</i> , 65, 05, 506, <i>i</i> , <i>i</i> <i>i</i> , 65, 04, 500, exc <i>i</i> , 66, 126, Pere <i>i</i> , 66, 105, Pere <i>i</i> , 66, 105, Pere <i>i</i> , 65, 105, 506, <i>i</i> , <i>i</i> <i>i</i> , 85, exc <i>i</i> , 80, another <i>i</i> , 65, 105, 506, <i>i</i> , <i>i</i> <i>i</i> , 85, exc <i>i</i> , 80, another <i>i</i> , <i>i</i> ,	s al SUPPERCENS " hudano), G. Cautero', YT. Chen, Y. Walking, J. K. Golber, and R. J. F. Funskoshi, M. M. Gabriel, R. K. Golber, and Kulji, K. Kanzarawa, C. Kiselling, S. Koirab, K. K. K	Collaborati
University of Trieste, Department of	Physics, and In	PIN, YOU HOURT	io 2, 34127 Trieste, Italy	
"Ubieventy diversity of protect begreened of "Bioper Baar Evicencia, Department of Phy "Biope Baar Evicencia, Department of Phy Distract The high design luminosity of the SuperKEKB electron-po- backgrounds in the instruction region. As a result, proper success of the Belle II experiment. We report on messure solicetively knows as BEAST II, danging the so-called phy beam backgrounds observed, compare them with simulatic Knowodd:	sitron collide hy simulating thy simulating ments perfor see 1 run of t on, and discu	r is expecte g and supp rmed with the collider ss the impli	2. 34/27 Triese, http://dx.com/aid. M. Noruri & R. W. W. C.Z. Canada encode, Denois, M. 40202, LSA d to result in challenging levels of beam-induce easing these backgrounds will be critical to it system of dedicated commissioning detectors in 2016. We describe BEAST II, report on ti cations for Belle II.	 fed the ers, the
"University of Proxim, Representation "Report Data Strategies and Providence of Pro- "Report Data Strategies and Pro- Hostract The high design luminosity of the SupperKEKB electrone op- buckgrounds in the interaction region. As a result, pro- success of the Belle II experiment. We report on measure collectively known is BEAST II, danging the so-called phy- beam backgrounds observed, compare them with simulatic Keywords:	sitron collide hy simulating ments perfor use 1 run of t n, and discur	rr is expecte g and supp rrmed with the collider ss the impli	<ul> <li>a JAI27 Draw, Buy</li> <li>Consolid</li> <li>Consolid</li> <li>Consolid</li> <li>M 40302, E3A</li> <li>d to result in rehalfenging levels of boson-induces</li> <li>system of foddiardo commissioning detector</li> <li>system of foddiardo commissioning detector on til</li> </ul>	ed the rs, the
"University of Proxim, Department of "Neurons of Provin, Department of Pro- "Neuron Example, Department of Pro- backgrounds in the interaction region, As a result, proper backgrounds in the interaction region. As a result, proper soccess of the Belle I experiment. We report on measure collectively known as BEAST II, during the so-called phy been backgrounds observed, compare them with simulatic <i>Exponents</i> :	Project, and to Astronomy, 3 sites and Astronomy sitron collide thy simulating ments perfor ase 1 run of 1 m, and discus	r is expecte g and supp rmed with the collider ss the impli	e.2. 34/27 Prove. Roy Mark 2007 Biology Constant work: Proves. Mit #2010, COA d to result in challenging levels of beam-induce essing these backgrounds will be critical or system of dedicated commissioning detector in 2016. Ne describe BEAST II, report on the automs for Belle II. Overview and motivation	red the rs, the 6
"Unerent", diversity of these, Dependent "Ngose Date University, Dependent of Phy Ngose Date University, Dependent of Phy Date Date University of the SuperKEKB electron-po Sackgrounds in the interaction region. As a result, proper occess of the Belle II experiment. We report on measure ollectively known as BEAST II, during the so-called phy arm backgrounds observed, compare them with simulatic Grywords: Zontents Introduction	Project, and its Project, and its siltron collide fly simulating ments performants used 1 run of to n, and discur	r is expecte g and suppr rmg 666 W H	e 2. 34/27 Priore, Inly M. Wordt BC, WP/CC, Consid M. Wordt BC, WP/CC, Consid M. Stark, St	ed heb me 6 7 7
"beeners" of Works of Practic Dependence of "Bione Date Determing, Department of Physics "Bione Date Determing, Department of Physics betract Determined the State Determing, Department of Physics Determined Determined Department of Physics Determined	Project, and its Project, and its siltron collide siltron collide ty simulating ments perform use 1 run of to n, and discur 2 3	r is expecte g and supp me, 666 W. H r is expecte g and supp med with the collider ss the impli	e2_J4/27 Process, Bay second, Promess, May Consult waves, Promess, MA 42020, E3A et al. The second second second second ensing these backgrounds will be entitled to the system of dedicated commissioning detector in 2016. We describe BEAST II, report on the automs for Belle II. Overview and motivation	red bes the f f f f f f f f f f f
"Internet of trans. Department of "Rope Date University. Department of Physics "Rope Date University. Department of Physics betract The high design luminosity of the SuperKEKB electron-po ackgrounds in the interaction region. As a result, proper occess of the Belle III experiment. We report on measure solectively known as BEAST II, during the so-called phy an backgrounds observed, compare them with simulatic <i>cynords</i> : <b>Introduction</b> <b>The BEAST II system</b> 2.1 BEAST .	Project, and its and Aaronneng. States and Aaronne sittron collide thy simulating ments perfor see 1 run of to n, and discur 2 3 3	r is expecte g and supp rms, 666 W. H r is expecte g and supp rmsed with the collider ss the impli	e 2. 34/27 Prose, hby the stream of the str	ed he rs, 6 7 7 7 8
therease "or the sector of them. Development of      "Bigme Stare University. Department of      "Bigme Stare University. Department of Phys     bitract bitract bitract bitract bitract bit interaction region. KRKB electrons po     keymonds in the interaction region. RA a result, program     more sector of the sector o	Project, and its and Auronomy. Side and Auroneous sitteen collide thy simulating ments perfort sets 1 run of 1 nn, and discus 2 3 3 3 3	r is expecte g and support r is expected g and supp rmed with the collider ss the impli	e2_J4/27 Process, Bay second, Parmin, Mr 49302, E3A d to result in challenging levels of Denam-induce wring these backgrounds will be critical to the system of dedicated commissioning detector in 2016. We describe BEAST II, report on the automs for Belle II. Overview and motivation	
*Uneranty of Human Department of *Bione Stare University, Department of Physics *Bione Stare University, Department of Physics bstract the high design luminosity of the SuperKEKB electron-po- ckgrounds in the interaction region. As a result, proper coses of the Belle II experiment. We report on measure illectively known as BEAST II, during the u-called phy an background-observed, compare them with simulatic gwords: southers Introduction The BEAST II system 2.1 BEAST I. 2.1 PLN diades 2.3 CLAWS	Project, and its and Annovemp. States and Annovemp. sitron collide thy simulating ments perfort and discur- 2 3 3 3 3 3	r is expecte g and supp rmed with the collider ss the impli	e 2. 34/27 Prose, hay di, term all 27 prose, hay di, term all 27 proses, hay di to result in challenging levels of beam-induce essing these backgrounds will be critical get of system of dedicated commissioning system of and system of dedicated commissioning system of and system of dedicated commissioning and proversion and motivation	ed be rs, he 6 7 7 7 7 7 8 9 9 10
Schemmer of Neurosci for Tomosci Augument of "Bigue State Distances", Department of Physics "Bigue State Distances, Department of Physics bistract bigle State Distances, Department of Physics bigle State Distances, D	Project, and its of Annoweng. I defined and Annoweng sittee annoweng sitte	r is expecte g and support r is expecte g and support r is expected g and support r is expected g and support r is expected g and support r is expected g and support 2.5.1 2.5.2 2.5.3 2.5.4 2.5.5 2.6 TPC 2.6.1 2.6.2 2.6.3	e2_J4/27 Proses, they constant and the second secon	ed be ex- be 6 7 7 7 7 8 8 9 10
Subserved of them. Development of them. Development of the them. Development of the them. Development of the "None base Datentist, Department of Physics Base District State of the SuperKEKB electron-pockgrounds in the interaction region. As a result, proper occess of the Belle II experiment. We report on measure blecking the so-called physics and baseling of the SuperKEKB electron-pockgrounds in the interaction region. As a result, proper occess of the Belle II experiment. We report on measure blecking the so-called physics and baseling of the SuperKEKB electron-pockgrounds in the interaction of the SuperKEKB electron-pockground between the source of the SuperKEKB electron-pockground between the SuperKEKB electron-pockground between the source of the source of the SuperKEKB electron-pockground between the source of the SuperKEKB electron-pockground between the source of the source of the SuperKEKB electron-pockground between the source of the SuperKEKB electron-pockground between the source of the source of the source	Project and as of Annovem, 1 sitro and Annovem sitron collide by simulating memts perform ase 1 run of t m, and discur 2 3 3 3 3 4 4	100 Pieuring ang. 666 W. H ris expecte g and supp rmed with the collider ss the impli	e 2. 34/27 Prose, høy (k. 107) Ersten, høy konst, Porons, Mit #202, EGA d to result in challenging levels of beam-induce essing these backgrounds will be critical of system of dedicated commissioning detoto in 2016. Ne describe BLAST II, report on ti ations for Belle II. Overview and motivation	ed be rs, he 6 7 7 7 7 7 8 9 9 9 10 10 12
Subserver of trans. Development of "Bigner Start Diversity. Department of Phys. "Bigner Start Diversity. Department of Phys. bitract bright design huminosity of the SupperKEKB electrons pose keyrounds in the BELAST II, during the so-called phys. ann backgrounds observed, compare them with simulatic govords: Introduction The BEAST II system 2.1 BLAST. 2.2 PIN diodes. 2.3 CLAWS Region - 2.3 CLAWS Redoot and Acalysis. 2.3 CLAWS Frager. 2.3 CLAWS Redoot and Acalysis. 2.3 CLAWS Redoot	Project, and as of Annovem, 1 sitro and Annovem sitron collide ty simulatin memts perform see 1 run of f an, and discur 2 3 3 3 3 3 4 4 4 5	100 Flower may, 666 W. H g and suppermed with the collider ss the impli	e2_J4/27 Dress, Bay second, Zeronia, Markan Constant second, Zeronia, Markan Constant ending these backgrounds will be critical to the system of dedicated commissioning detector in 2016. We describe BEAST II, report on the automs for Belle II. Overview and motivation	ed be e. be 6 7 7 7 8 9 9 10 10 12 12
Subserved of Totals. Development of      Subserved of Totals. Development of      "Bigue State University. Department of Phys     "Bigue State University. Department of Phys     bitract  bitract bitract bitract bitract list experiment. We report on measure bicetively known as BEAST II. during the to-called phys multicetively known as a state of the top physical during the top physical duri	2 3 3 3 3 4 4 5 5 2 2 3 3 3 3 4 4 5 5	1900 Faverry, my, 666 W. H g and supp rmed with the collider s the impli	e 2. 34/27 Prose, høy (2. 34/27 Prose, høy	ed ber es, her 6 7 7 7 7 8 9 9 9 9 10 10 10 12 12 12
therms of trains. Destined of trains. Destined of the second	2 3 3 3 3 3 4 4 5 5 5	1800 Faverer; my, 666 W H g and supp rmed with 1 the collider ss the impli	e2_J4/27 Dress, hby constant of the second	red be to the to
Chemen Of Vision Description     Control of Vision     Control of	sitron collide sitron collide to and Astronomy 3 sitron collide the simulating ments performed as 1 nun of 1 as 3 3 3 3 3 3 4 4 5 5 5 5	100 Favory, my 666 W fb g and supp rmed with the collider ss the impli	e 2. 34/27 Prose, høy (2. 34/27 Prose, høy	ed be rs, he 6 7 7 7 7 7 7 7 8 9 9 9 10 10 10 12 12 12 12 12 13
Characteristic Characteristics of Protect Descriptions of Protect Description of Prote	sitron collide sitron collide the and Atronom site and At	1800 Faverery, my, 666 W B g and supp rmed with the collider ss the impli	e2_JVI27 Dress, hby constitution of the second sec	ed bes, s. be be s. be 6 6 7 7 7 7 8 9 9 9 10 10 10 10 10 10 10 10 10 10 10 10 10
Chemen 24 North SuperKEKB electron- Provide SuperKEKB electron-po- keyne SuperKEKB electron- po- keyne SuperKEKB electron- po- keyne SuperKEKB electron- po- keyne SuperKEKB electron- po- keyne SuperKEKB electron- po- keyne SuperKEKB electron- po- keyne SuperKEKB electron- po-	sitron collide sitron collide sitron collide ty simulatin ments performed set 1 run of 1 n, and discus 2 3 3 3 3 4 4 5 5 5 5 5 5 5 6	1800 Faveray, my, 666 W H g and suppg rmed with the collider ss the impli	e 2. 34/27 Prose, høy (2. 34/27 Prose, høy	ed bee rs, he 6 7 7 7 7 7 7 8 9 9 9 9 10 10 10 12 12 12 12 12 12 13 13 13

mmissio

(This is the view ~right now at KEK: final focusing magnet commissioning at IP) Photo courtesy R. Mussa





### Additional slides





### BEAST II: the commissioning detector

Primary detectors in BEAST II for phase **II**:

System	Institution	#	Unique measurement
PIN diodes	КЕК	64	Neutral vs. charged dose rate
"Micro" Time Projection Chambers	U. Hawaii	48	Fast neutron flux and tracking
Diamonds	INFN Trieste	48	Ionizing radiation rate
He3 tubes	U. Victoria	4	Thermal neutron rate
CLAWS plastic scintillators	MPI Munich	82 ladders	Fast injection backgrounds

...continued





### BEAST II: the commissioning detector

Primary detectors in BEAST II for phase **II**:

System	Institution	#	Unique measurement
Belle II PXD	U. Bonn	2 ladders	Radiation tolerance for final physics runs
Belle II SVD	KEK	4 ladders	Radiation tolerance for final physics runs
FANGS	U. Bonn	15	Silicon pixel sensors (synchrotron x-ray spectrum)
PLUME	Strasbourg	2 ladders	Silicon pixel sensors (collimator adjustment)

