SuperKEKB beam loss simulations in Xsuite

G. Broggi [1,2,3], R. Bruce [2], G. Iadarola [2], S. Redaelli [2], J. Salvesen [2], F. Van der Veken [2]

[1] Sapienza University of Rome, Italy [2] CERN, Meyrin, Switzerland [3] INFN-LNF, Frascati, Italy

With essential inputs and support from:
A. Abramov, M. Boscolo, A. Natochii, T. Ishibashi, S. Terui, F. Zimmermann

BELLE-II beam background meeting, 29/01/2025

About me

- **Giacomo Broggi** (email: giacomo.broggi@cern.ch)
  - Doctoral Student at CERN
    - Supervisor: **Dr. Roderik Bruce** (CERN)
  - PhD candidate in Accelerator Physics at Sapienza University of Rome
    - Advisor: **Dr. Manuela Boscolo** (Sapienza University of Rome and INFN-LNF)

- **Research focus**
  - Future Circular electron-positron Collider (FCC-ee) collimation system design
  - Development of simulation tools for collimation of lepton beams
    - Benchmark with measured data at operating lepton colliders (SuperKEKB, DAΦNE)

- **1 month exchange at KEK** (Jan-Feb 2024) in the frame of the **EAJADE exchange programme**
  - KEK supervisor: **Assoc. Prof. T. Ishibashi**
  - Participation in experimental activities: NLC system commissioning, background studies, …
  - Fruitful collaboration with KEK/BELLE-II colleagues to set up an Xsuite-based collimation simulation model of SuperKEKB (many thanks to A. Natochii for essential inputs and support!)

In this talk

- Beam loss simulations in Xsuite
- Setup of Xsuite-based collimation simulations with Xsuite model of SuperKEKB
- First SuperKEKB test simulations
    - Beam-gas loss distributions in the SuperKEKB LER

NOTE: The simulation results presented in this talk are not yet intended to provide quantitative conclusions. Instead, they are meant to demonstrate the capabilities of the Xsuite tool applied to SuperKEKB.

Outline

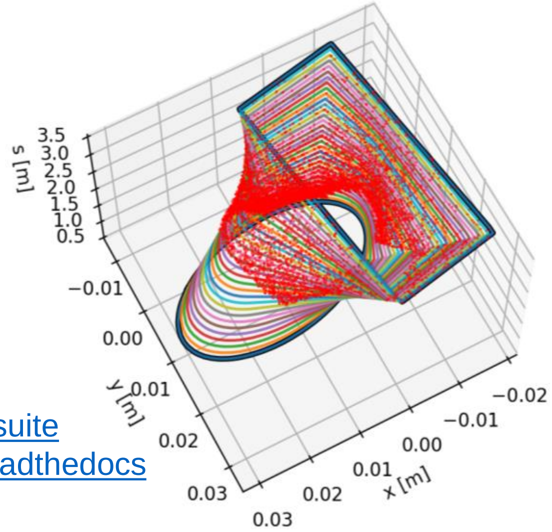
- **Introduction**
  - Beam losses and collimation simulations in Xsuite
  - Simulation tool benchmark: SuperKEKB is an ideal candidate
- **SuperKEKB aperture and collimator models**
- **Beam loss simulations**
  - Touschek scattering simulations
  - Beam-gas scattering simulations
- **First demonstrative SuperKEKB simulations with Xsuite**
  - SuperKEKB beam-gas losses
- **Outlook and next steps**

Outline

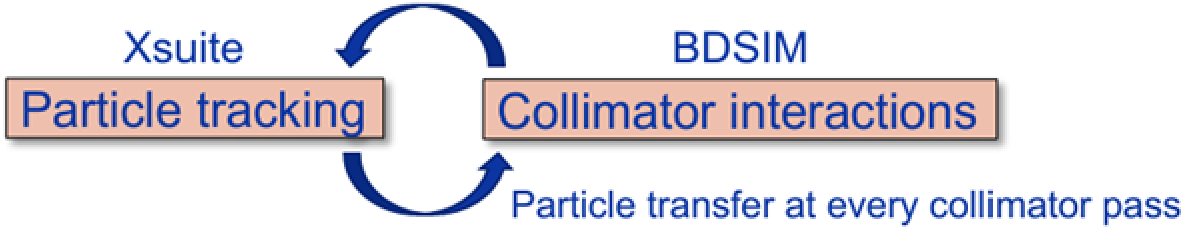
- **Introduction**
  - Beam losses and collimation simulations in Xsuite
  - Simulation tool benchmark: SuperKEKB is an ideal candidate
- **SuperKEKB aperture and collimator models**
- **Beam loss simulations**
  - Touschek scattering simulations
  - Beam-gas scattering simulations
- **First demonstrative SuperKEKB simulations with Xsuite**
  - SuperKEKB beam-gas losses
- **Outlook and next steps**

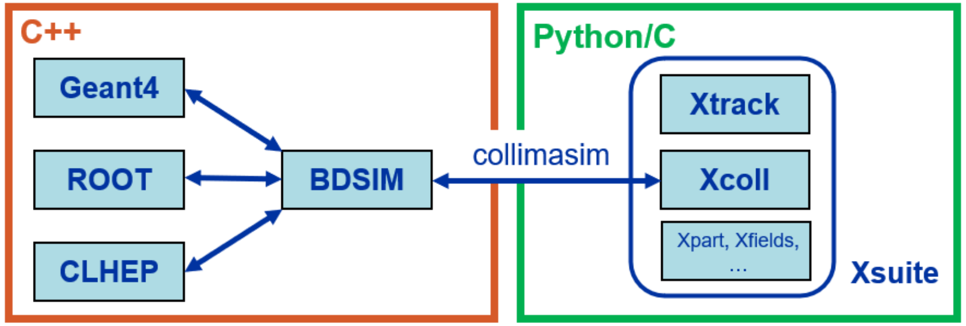
Beam losses and collimation simulations in Xsuite

- **Xsuite overview** (G. Iadarola - ICAP'24 talk, HB'23 paper)
  - Key modules: Xobjects, Xdeps, Xpart, Xtrack, Xfields, Xcoll
  - Seamless integration with accelerator-specific and general-purpose Python tools
  - Enables study of complex simulation scenarios
- **Xcoll module** (F. Van der Veken, ICAP'24 talk, HB'23 paper)
  - Dedicated module for collimation studies in particle accelerators
  - Integration of detailed aperture models with precise loss location identification
  - Integrates beam-matter interaction simulations in particle tracking with various scattering models (Everest-K2, FLUKA, Geant4/BDSIM)
- **Xsuite-BDSIM/Geant4 coupling** (A. Abramov, JINST paper)
  - Originally developed for the FCC-ee collimation simulation needs
  - Deployed in full production for FCC-ee collimation studies



Xsuite readthedocs

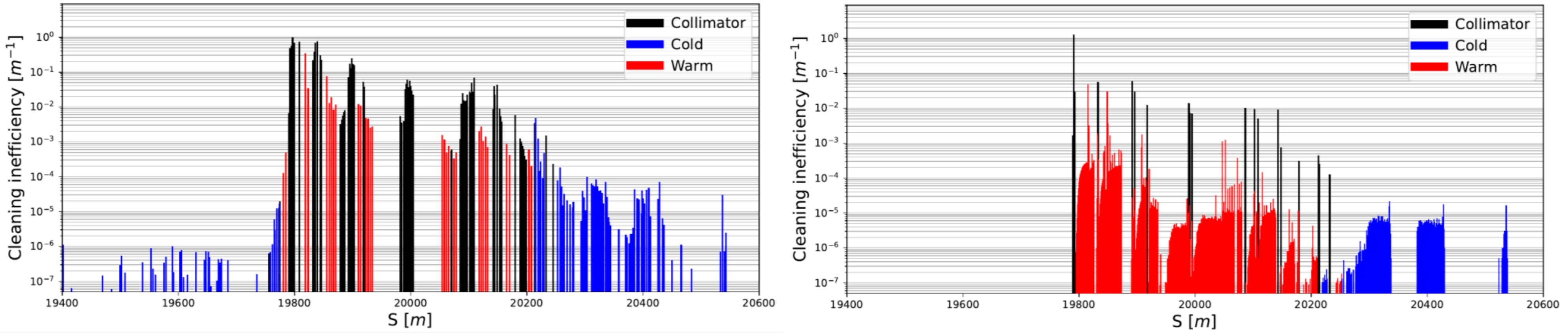




Simulation tool benchmark (1/2)

- **Xsuite-BDSIM** is used to quantify collimation performance in the FCC-ee
  - ➢ Important to benchmark simulations with measured data

- **Xsuite-BDSIM** coupling **already benchmarked** against:
  - ➢ **Existing tools**: MAD-X, PyAT-BDSIM, Sixtrack-FLUKA, Sixtrack-K2
  - ➢ **Measured data** from **proton machines**: PS, LHC



Betatron collimation losses in the LHC (IR7): measured (left) and simulated (right). From G. Broggi, master's thesis.

- For the FCC-ee needs this is **not fully satisfactory** (different particle type and energy)
  - ➢ **Benchmark with data from a lepton machine is needed**
  - ➢ **SuperKEKB** is an **excellent candidate** (DAΦNE is also being considered)

Simulation tool benchmark (2/2)

- An additional **benchmarked simulation tool** could also be **of interest for SuperKEKB/BELLE-II**
  - Could help in a better understanding of beam losses and overall machine performance
  - In general, good to have cross-checked simulation tools

- Ingredients for a successful benchmark:

J. Salvesen, previous talk

Xsuite-compatible SuperKEKB optics model
- Significant progress over the last ~6 months
- Detailed checks ongoing

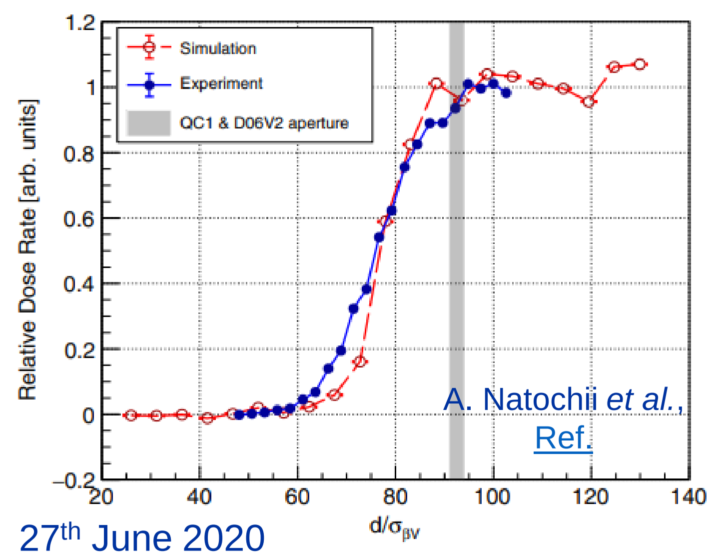
SuperKEKB aperture model
- Available in SAD model / BELLE-II Analysis Software Framework repository

SuperKEKB collimator data (geometry, opening, material)
- Provided by A. Natochii (many thanks!)

Capability to simulate background sources
(beam-gas, Touschek, luminosity, …)

Measured data to compare simulations with

Relative total dose rate for diamond detectors in the IR vs. D06V1 collimator aperture in units of σβV



A. Natochii *et al.*, Ref.

27th June 2020

Outline

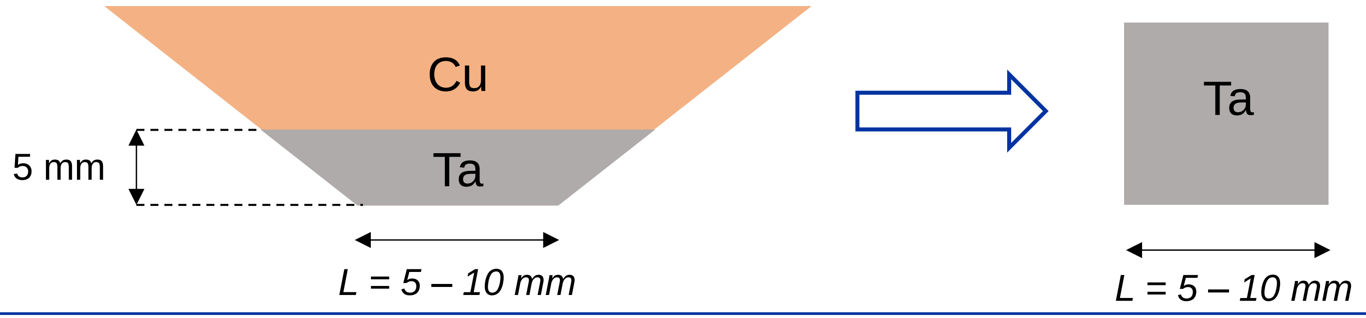
- **Introduction**
  - Beam losses and collimation simulations in Xsuite
  - Simulation tool benchmark: SuperKEKB is an ideal candidate
- **SuperKEKB aperture and collimator models**
- **Beam loss simulations**
  - Touschek scattering simulations
  - Beam-gas scattering simulations
- **First demonstrative SuperKEKB simulations with Xsuite**
  - SuperKEKB beam-gas losses
- **Outlook and next steps**

SuperKEKB aperture model in Xsuite

- **A first SuperKEKB** (LER) **aperture model has been included in the SuperKEKB Xsuite lattice**
  - IP aperture (5mm radius)
  - Final focus quadrupoles apertures from SAD
    - Information available for the quadrupole center (C) and exit (O) only!
    - **Current assumption**: aperture at the entry is the same as in the center

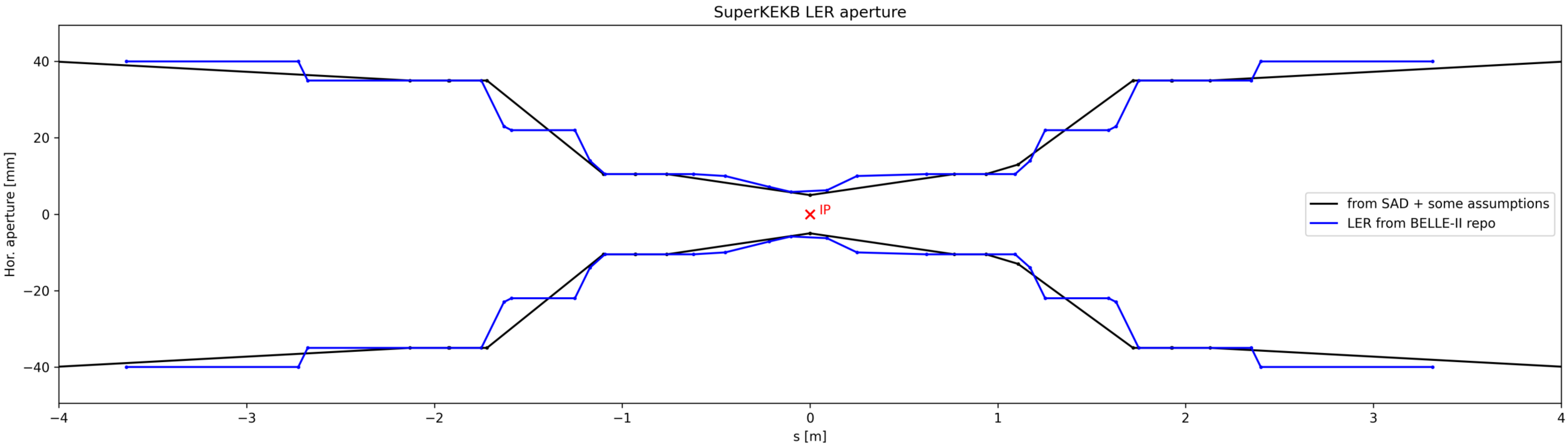
```
APERT  AQC1LC  =(AX =.01 AY =.0135 DY =.0015 )
       AQC1LO  =(AX =.013     AY =.0135 DY =.0015 )
       AQC2LC  =(AX =.035     AY =.035  DY =.0015 )
       AQC2LO  =(AX =.035     AY =.035  DY =.0015 )
       AQC2RO  =(AX =.035     AY =.035  DY =.001 )
       AQC2RC  =(AX =.035     AY =.035  DY =.001 )
       AQC1RO  =(AX =.013     AY =.0135 DY =.001 )
       AQC1RC  =(AX =.01 AY =.0135 DY =.001 )
```

  - IR beam pipe aperture (40 mm radius)
  - Beam pipe aperture elsewhere (45 mm radius)
  - Collimator apertures: set according to the scenario
  - Collimator geometry:



Only the collimator tip is presently modelled: this is most likely oversimplified for the SuperKEKB simulation needs!

SuperKEKB IR aperture model



- BELLE-II aperture model also available ([BELLE-II analysis software repository]())
  - Looks more detailed than SAD model
  - Should be implemented instead of the SAD model ?
  - Any recommendations ?

Outline

- **Introduction**
  - Beam losses and collimation simulations in Xsuite
  - Simulation tool benchmark: SuperKEKB is an ideal candidate

- **SuperKEKB aperture and collimator models**

- **Beam loss simulations**
  - Touschek scattering simulations
  - Beam-gas scattering simulations

- **First demonstrative SuperKEKB simulations with Xsuite**
  - SuperKEKB beam-gas losses

- **Outlook and next steps**

Beam loss simulations

- Different beam loss processes can be studied with Xsuite-based simulations:
  - **Generic beam halo losses**
    - Betatron losses, off-momentum losses, or combinations of the two

Slow losses on the collimation system

  - **Beam-gas beam losses**
    - Bremsstrahlung
    - Coulomb scattering

Focus of today's talk
(single beam background sources)

  - **Touschek scattering losses**
    - Under active development in the last month
    - First tests show good agreement with theory (Piwinski formula)

Soon available

  - **Beam losses from beam-beam interactions** (radiative Bhabha, beamstrahlung, beam-beam kicks)
    - Beam-beam models available in Xsuite (P. Kicsiny, PhD thesis)
    - Integrated beam-beam and collimation simulations already performed for:
      - FCC-ee (G. Broggi, BB'24 talk), LHC (F. Van der Veken, BB'24 talk)

  - With inputs to set up suitable models: losses due to fast instabilities, injection losses, failure scenarios, …
    - ➢ Fast instability losses being studied for the FCC-ee (G. Nigrelli, talk)

Touschek scattering simulations (1/2)

- A Monte Carlo routine to simulate Touschek scattering has been under active development in the last month
  - ➢ The routine follows the approach by A. Xiao and M. Borland (PRSTAB paper) implemented in ELEGANT

- An arbitrary number of Touschek scattering centers are placed along the lattice
  - At each Touschek scattering center, a Touschek scattered distribution is generated
  - To each simulated scattered particle is assigned a total scattering rate *Ri*

$$\boxed{R_i = \frac{r_i}{\sum r_i} \frac{R_{\mathrm{MC}}}{R_{\mathrm{P}}} \int R_{\mathrm{P}},}$$

$$\boxed{R_{\mathrm{MC}}(|\delta| > \delta_m) = \frac{V}{N} \sum_{i=1}^{M} \left[\frac{v^{*\prime}}{\gamma^2} \frac{d\sigma^{*\prime}}{d\Omega^{*\prime}} \sin\Theta^{*\prime} \rho(\vec{x}_1)\rho(\vec{x}_2) \right]_i = \sum_{i=1}^{M} r_i,}$$

ri: local scattering rate of the i-th particle
R_{MC}: local Touschek scattering rate from Monte Carlo
R_P: local Touschek scattering rate from Piwinski formula

V: phase-space volume
N: n. of simulated scattering events
M: n. of scattering events resulting in δ>δmin

v'*: velocity in the c.o.m frame after scatt.
Θ'*: scatt. angle in the c.o.m. frame
ρ: phase-space density

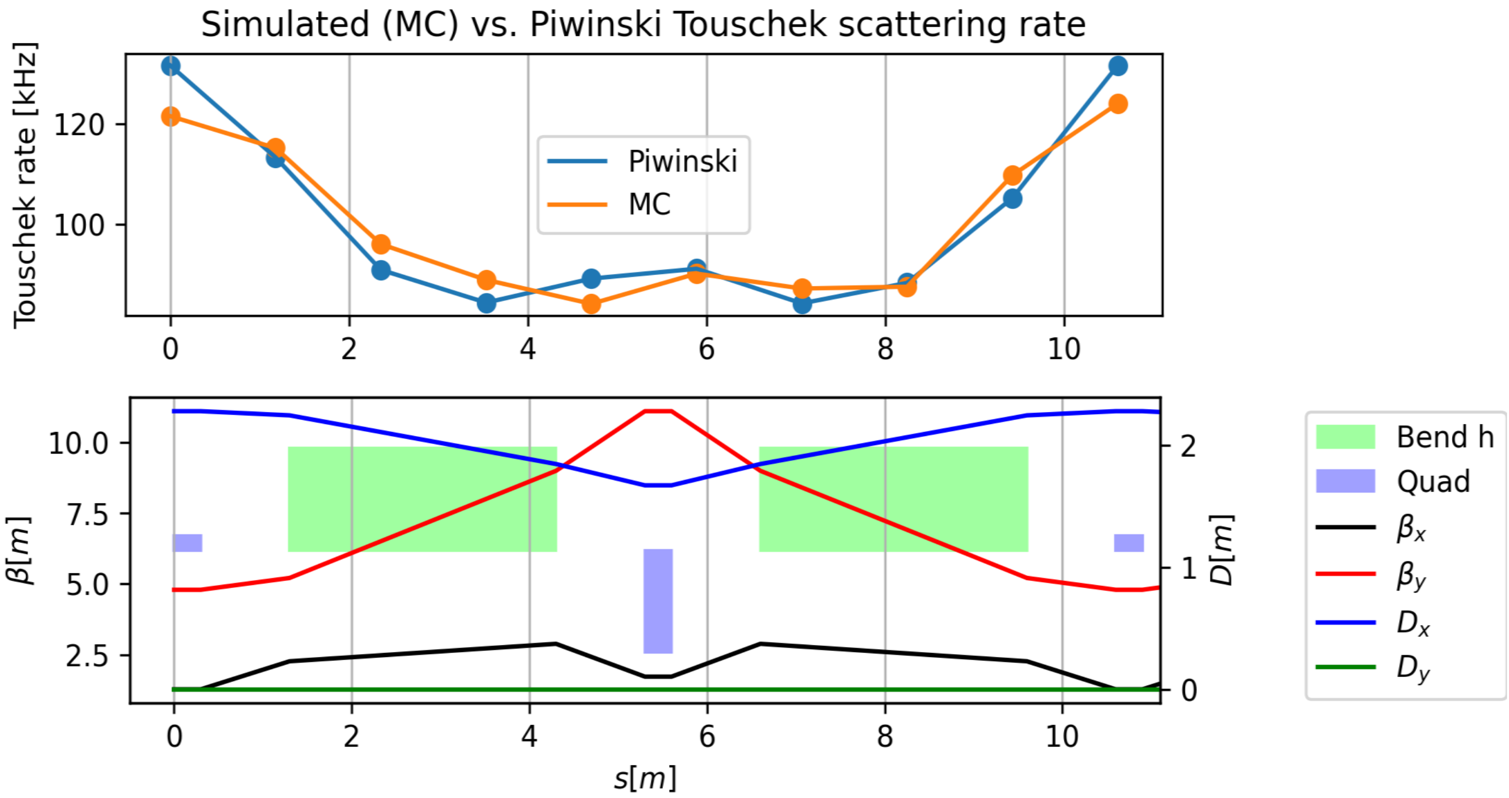
$$\boxed{\frac{d\sigma^*}{d\Omega^*}(\Theta^*, \Psi^*) = \frac{r_e^2}{4\gamma^{*2}} \left[\left(1 + \frac{1}{\beta^{*2}}\right)^2 \frac{4 - 3\sin^2\Theta^*}{\sin^4\Theta^*} + \frac{4}{\sin^2\Theta^*} + 1 \right],}$$

Møller DCS

  - For a Gaussian-distributed bunch $R_{MC}/R_P \approx 1$
  - The integral of R_P is taken over each section upstream of each Touschek scattering center, starting from the previous scattering center: the simulated scattered particles accurately represent the scattering rate from the entire upstream section

Touschek scattering simulations (2/2)

- The beam-loss rate and location can then be calculated tracking with Xsuite the Touschek-scattered particles through the lattice and recording all lost particles
  - ➢ The total loss rate will be the sum of *Ri* for all the particles lost at any location.



- Good agreement between simulated (MC) and Piwinski Touschek scattering rate for a Gaussian-distributed beam

- Full simulations with tracking Touschek scattered particles yet to be performed

Beam-gas simulations (1/3)

- A scattering routine to simulate beam-gas interactions while tracking in Xsuite has been recently developed

- **Physics models** (DCS: Differential Cross Section):

Bremsstrahlung

- Z<5: DCS in complete screening with radiation logarithms computed using the Dirac-Fock model of the atom (Thomas-Fermi model not accurate at low Z)
- Z>5: DCS with Tsai analytical screening functions
- Coulomb correction
- NO LPM

As implemented in Geant4 (G4eBremsstrahlungRelModel.cc, G4ModifiedTsai.cc)

↓

Rejection sampling of Δpx, Δpy, δ

Coulomb scattering

- Wentzel-Mott DCS
  - Rutherford DCS + Wenztel corr. + Mott corr.
  - Wenztel: screening of the nuclear charge by atomic electrons
  - Mott: magnetic moment interaction between e+/e- and target nucleus

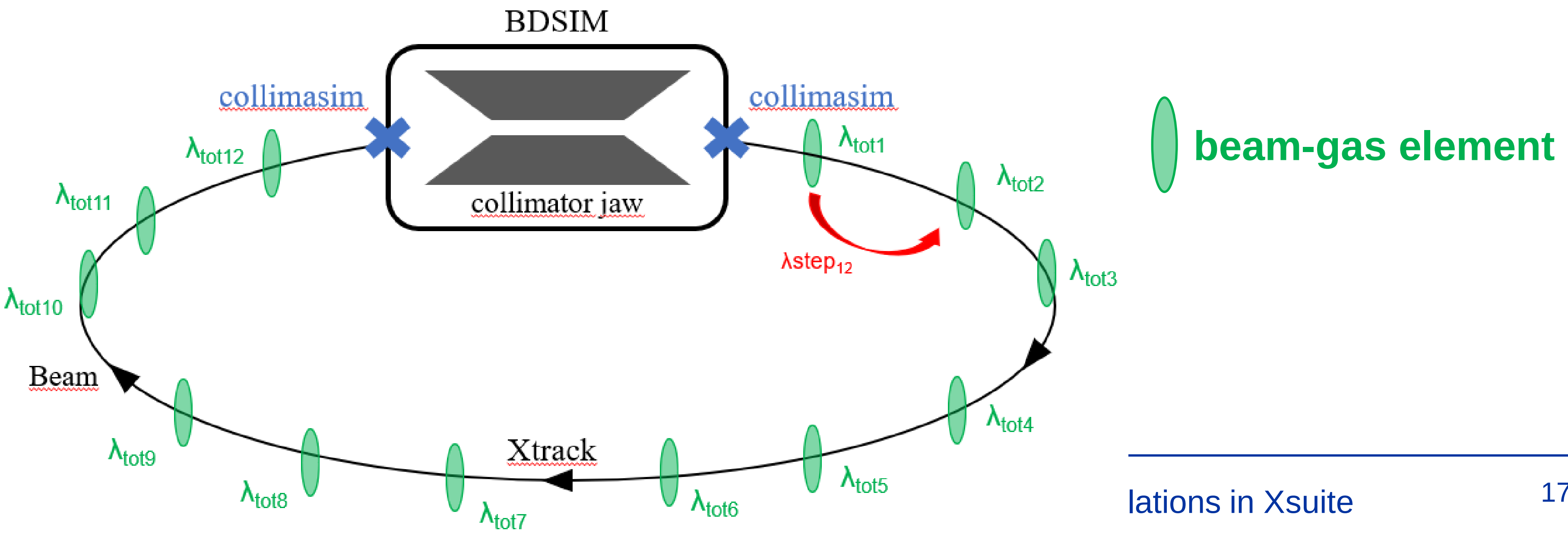
As implemented in Geant4 (G4ScreeningMottCrossSection.cc – FAST computation)

↓

Rejection sampling of Δpx, Δpy

Beam-gas simulations (2/3)

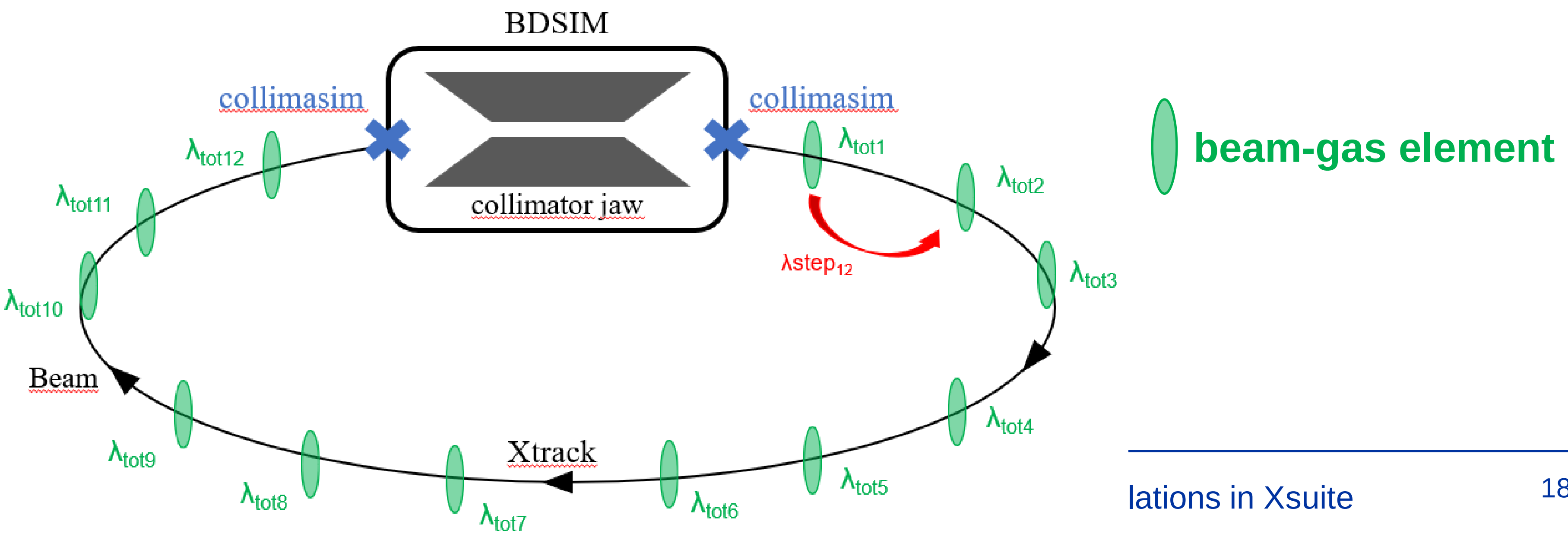
- An arbitrary number of **beam-gas elements** (Xsuite custom elements) are placed along the lattice
  - Each beam-gas element embed information about the local gas parameters (pressure, composition, …) taken from a measured (or simulated) pressure profile
  - At each **beam-gas element** the mean free path is computed from cross sections and local gas densities
  - When tracking in Xsuite, a random number is generated for each particle to represent the distance travelled by that particle in units of mean free paths (mfp): $n_\lambda = -\log(random(0,1))$
  - The number n_λ is compared with mfp step $n_{\lambda,\,ij} = \frac{\Delta s_{ij}}{\lambda_{tot\,j}}$ between two consecutive beam-gas elements:
    - $n_\lambda - n_{\lambda,\,ij} \leq 0$: **interaction** → a new n_λ is sampled for further tracking
    - $n_\lambda - n_{\lambda,\,ij} > 0$: **NO interaction** → n_λ is updated as $n'_\lambda = n_\lambda - n_{\lambda,\,ij}$ for further tracking



Beam-gas simulations (3/3)

- When the **interaction condition** is satisfied, **which interaction** (eBrem or CoulombScat) and **with which gas species** is decided by sampling among all the possibilities with probabilities given by the cross-sections and the local gas densities

- Once an interaction is selected, the **effect of the interaction** is applied to the interacting particle:
  - ➢ $px \rightarrow px + \Delta px$, $py \rightarrow py + \Delta py$, $\delta \rightarrow \delta_0 + \delta$
- Cross section biasing is necessary to perform simulations with reasonable computing time
  - Biasing choice: cross sections are scaled up such that $\lambda mfp = 1$ turn
    - ➢ $(1 – 1/e) \cong 63.2\%$ simulated particles interact on the first turn
    - ➢ Constraint: a simulated particles cannot interact twice



Disclaimer on Touschek and beam-gas routines

- At the moment, the Touschek and beam-gas scattering routines are not part of the Xsuite framework
    - They are presently custom routines that have been developed in the context of collimation tracking in Xsuite with a focus on the FCC-ee/SuperKEKB/DAΦNE simulation needs
    - In the longer term, upon generalization, testing, and agreement with the lead developers, they will embedded in Xsuite (Xfields/Xcoll modules)

Outline

- **Introduction**
  - Beam losses and collimation simulations in Xsuite
  - Simulation tool benchmark: SuperKEKB is an ideal candidate
- **SuperKEKB aperture and collimator models**
- **Beam loss simulations**
  - Touschek scattering simulations
  - Beam-gas scattering simulations
- **First demonstrative SuperKEKB simulations with Xsuite**
  - SuperKEKB beam-gas losses
- **Outlook and next steps**

SuperKEKB beam-gas losses

Configuration from 27/06/2020 background study
[A. Natochii et al., PRAB paper]

- First SuperKEKB **test simulations** have been set up
  - SuperKEKB LER 2020 lattice (βx^* = 60 mm, βy^* = 0.8 mm, CW)
  - IR solenoid not yet included
  - NO X-Y coupling (i.e., NO vertical offset of sextupoles added)
  - Initial conditions: εx=2.1 nm, εy=2.1 pm, σz = 5 mm
  - Aperture model from SAD
  - Collimator settings from 27/06/2020 background study
    - D06V1 at ~60sigma
  - Simplified collimator geometries modelled in BDSIM/Geant4
  - Extrapolated pressure profile at I = 0.477 A
    - Z=7 equivalent gas (from KEKB/SuperKEKB experience)

LER
INJ

	DIF_POS [mm]	beta_x [m]	nu_x	eta_x [m]	Nsigma (BSC)	Nsigma (beta)	Nsigma (eta)	LM
D06H1OUT	10.49	24.2	25.01	0.7	18.2	46.4	19.8	0.02
D06H1IN	-10.53	24.2	25.01	0.7	18.3	46.6	20.0	
D06H3OUT	10.79	24.2	26.23	0.7	18.8	47.8	20.5	0.00
D06H3IN	-10.82	24.2	26.23	0.7	18.9	47.9	20.5	
D03H1OUT	10.89	29.0	38.44	0.8	17.2	44.2	18.7	0.03
D03H1IN	-11.11	29.0	38.44	0.8	17.6	45.0	19.1	
D02H1OUT	7.97	22.6	42.26	0.2	29.7	36.5	51.2	0.00
D02H1IN	-8.06	22.6	42.26	0.2	30.1	37.0	51.8	
D02H2OUT	10.48	39.2	42.74	0.6	19.1	36.4	22.5	0.00
D02H2IN	-10.46	39.2	42.74	0.6	19.3	36.7	22.7	
D02H3OUT	12.41	40.9	43.46	-0.9	16.9	42.3	18.4	0.01
D02H3IN	-12.58	40.9	43.46	-0.9	17.1	43.0	18.7	
D02H4OUT	8.06	26.4	44.24	-0.4	19.6	34.2	24.0	0.00
D02H4IN	-8.02	26.4	44.24	-0.4	19.5	34.1	23.9	
QC1(1.18m)	10.5	41.7	44.28			35.5		

4=Abort
>3.00
>1.50
>0.70

31.7
Dia QCSFW

	DIF_POS [mm]	beta_y [m]	nu_y	Nsigma (beta)	LM
D06V1TOP	2.25	67.3	28.86	59.4	1.61
D06V1BTM	-2.20	67.3	28.86	58.8	
D06V2TOP	1.93	20.6	30.50	92.9	0.02
D06V2BTM	-2.00	20.6	30.50	96.1	0.02
	0.23				
D02V1TOP	1.55	18.4	44.87	78.9	0.03
D02V1BTM	-1.50	18.4	44.87	76.1	
	0.15				
QC1 (1.12m)	13.5	977.8	46.34	94.2	

31.7
Dia QCSFW

beta_y*[mm]	beta_x* [mm]
0.8	60.0

20200623_0.8x60CW40_0.8x60CW80_sler_202

emit_x [nm]	2.10
emit_y [nm]	0.021
emit_y [nm] by XRM	0.053
Sigmay by XRM [um]	60.6
current [mA]	477

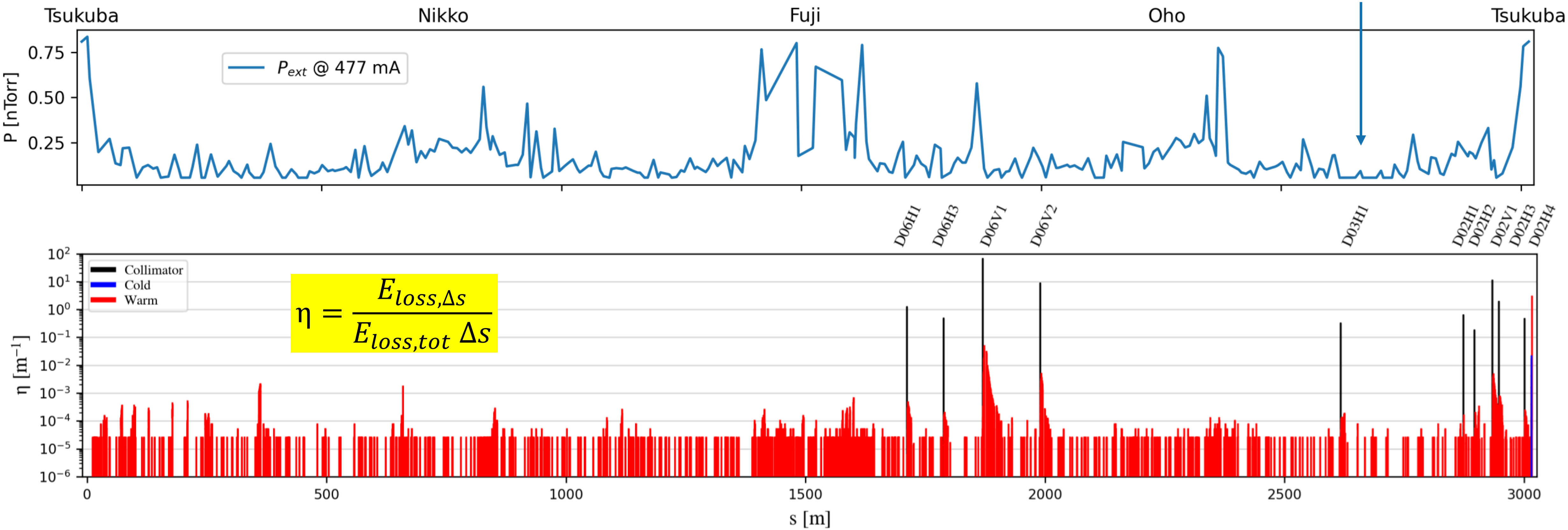
- 1429 equispaced (~2 m spacing) beam-gas elements to model beam-gas interactions (eBrem or CoulombScat)
  - $1x10^6$ particles tracked 1 turn with biased beam-gas interactions ON + 999 turns with interactions OFF
  - SR emission ON (damping + quantum excitations)

SuperKEKB beam-gas losses: Coulomb scattering

- Simulation output returns a record of all simulated particles, including information like:
  - Particle type, 6D coordinates (x, px, y, py, zeta, δ)
  - State (alive, lost on aperture, lost on collimator, …), loss location (s-coordinate), lost at turn #, …

- Distribution of lost particles can be presented in loss maps:

Extrapolated pressure profile @ 477 mA used in simulation



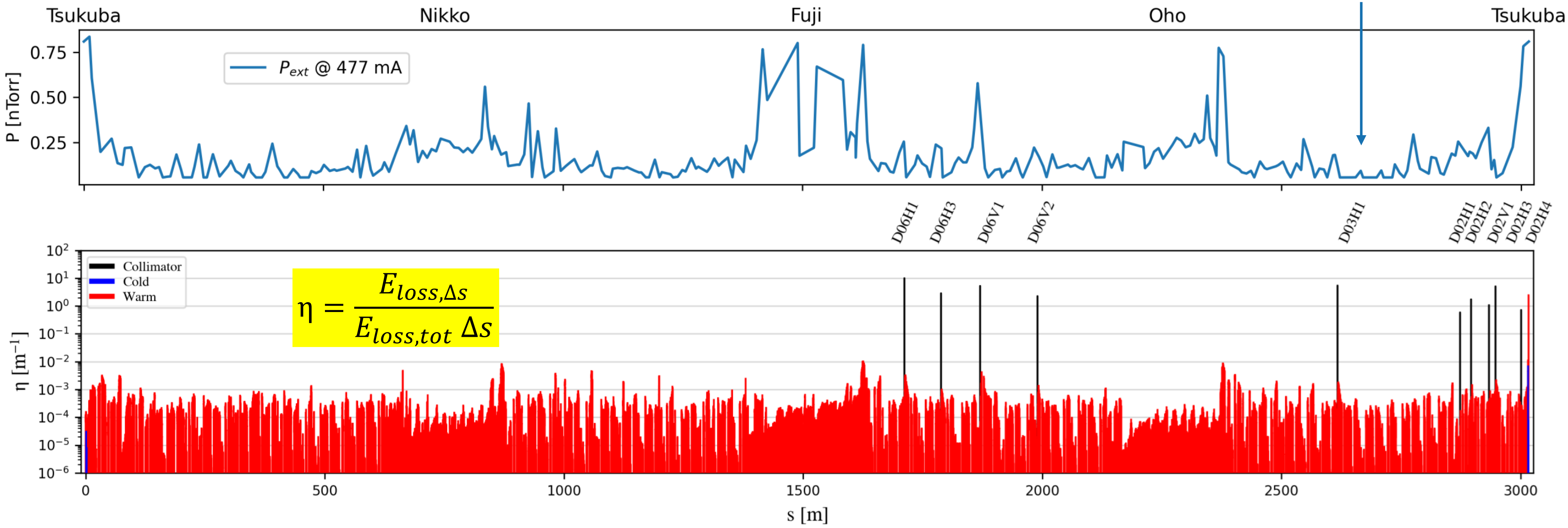
$$\eta = \frac{E_{loss,\Delta s}}{E_{loss,tot}\ \Delta s}$$

SuperKEKB beam-gas losses: bremsstrahlung

- Simulation output returns a record of all simulated particles, including information like:
  - Particle type, 6D coordinates (x, px, y, py, zeta, δ)
  - State (alive, lost on aperture, lost on collimator, …), loss location (s-coordinate), lost at turn #, …

- Distribution of lost particles can be presented in loss maps:

Extrapolated pressure profile @ 477 mA used in simulation



$$\eta = \frac{E_{loss,\Delta s}}{E_{loss,tot}\ \Delta s}$$

Additional output from simulations

- Simulation output also returns:

  - **Impact table**: table containing a record of the particle impacts on each collimator
    - ➢ Very useful to retrieve impacting distributions on each collimator (example on next slide)

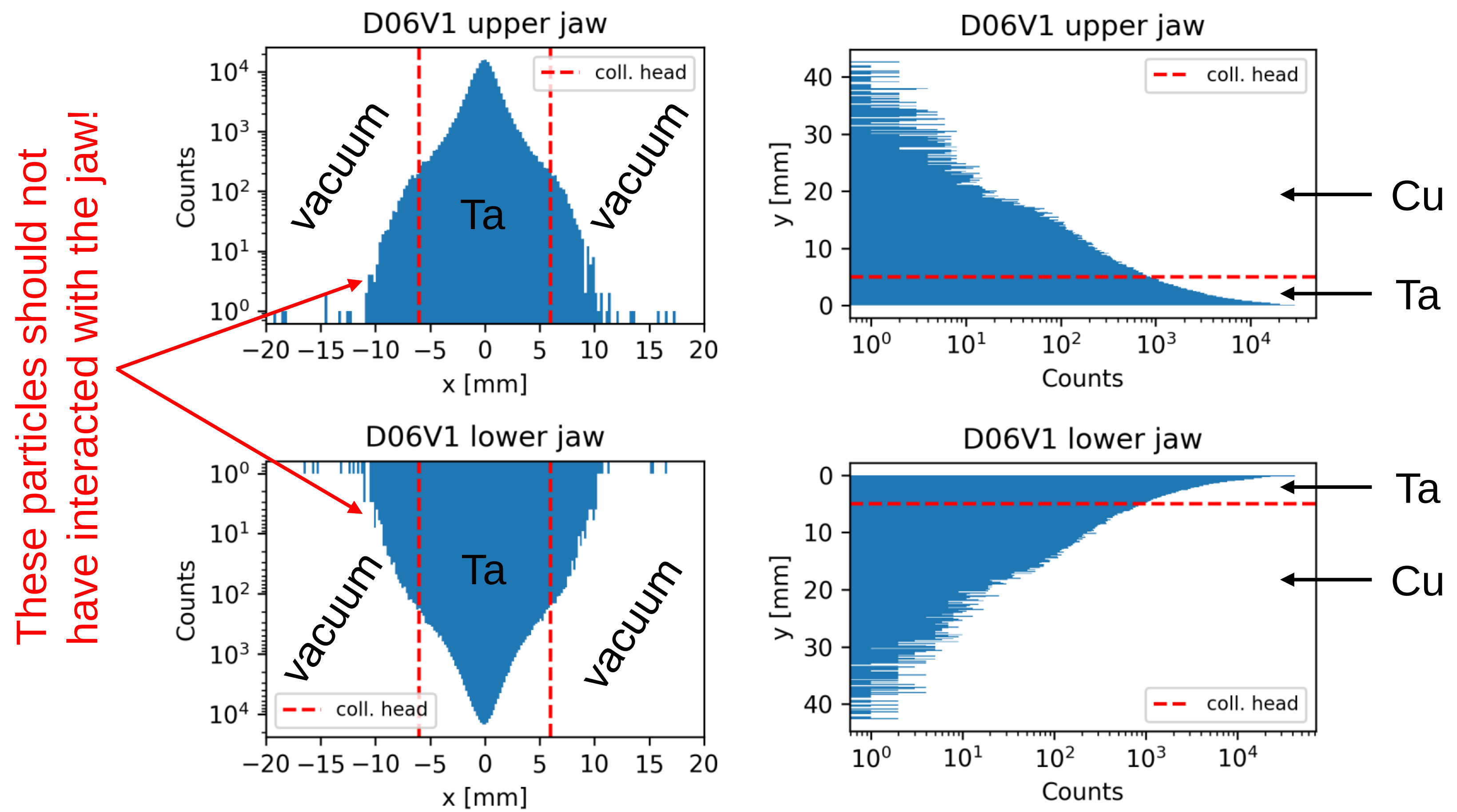
turn	collimator	interaction_type	id_before	s_before	x_before	px_before	y_before	py_before	zeta_before	delta_before	energy_before	mass_before	charge_before
0	pmd06v2	Enter Jaw R	121	0.0	2.758376e-03	0.000762	-0.001984	0.000310	0.002288	-0.000844	3.996622e+09	510998.9375	1
0	pmd06v2	Enter Jaw R	329	0.0	4.988879e-04	0.000327	-0.000792	0.000133	-0.006344	-0.000236	3.999054e+09	510998.9375	1
0	pmd06v2	Enter Jaw R	352	0.0	1.537153e-03	0.000326	0.000775	-0.000181	-0.001554	-0.000552	3.997790e+09	510998.9375	1
0	pmd06v2	Enter Jaw L	455	0.0	8.516428e-04	0.000366	-0.000050	0.000032	0.002967	-0.000385	3.998460e+09	510998.9375	1
0	pmd06v2	Enter Jaw L	725	0.0	5.278703e-03	0.001025	0.000594	-0.000064	0.003924	-0.000114	3.999544e+09	510998.9375	1

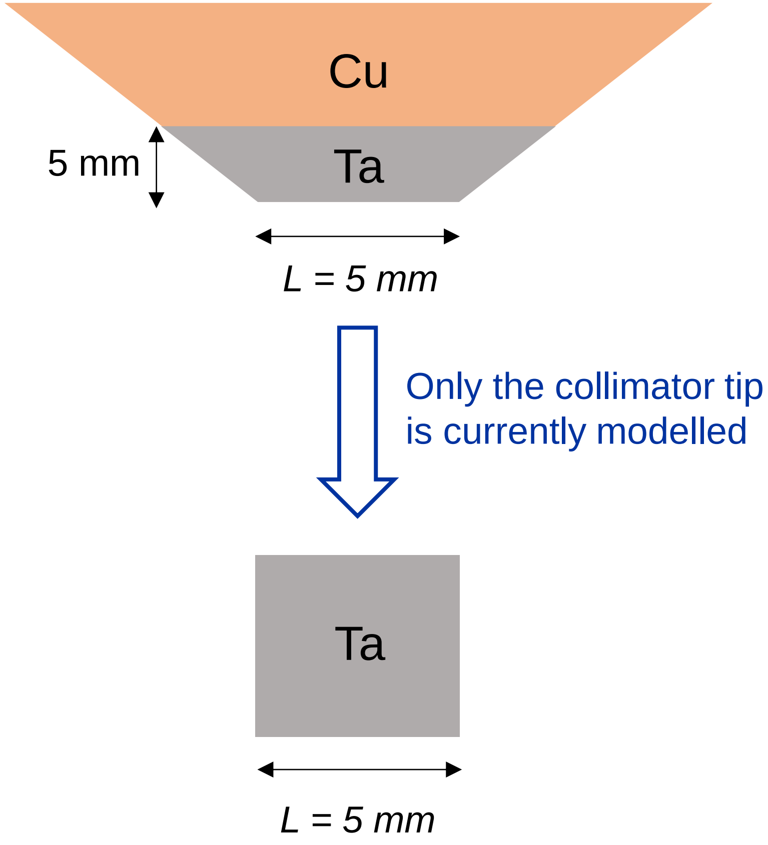
  - **Beam-gas log**: table containing the history of the beam-gas interactions that took place in the simulation

name	s	particle_id	interaction
beam_gas_0	0.000000	[1099, 1132, 2400, 2445, 4601, 5503, 6598, 826...	[N_eBrem, N_eBrem, N_eBrem, N_eBrem, N_eBrem, ...
beam_gas_1	2.111415	[338, 1663, 3373, 3374, 3813, 4415, 5826, 7581...	[N_eBrem, N_eBrem, N_eBrem, N_eBrem, N_eBrem, ...
beam_gas_2	4.222829	[3743, 4303, 4912, 5554, 6659, 7280, 7600, 764...	[N_eBrem, N_eBrem, N_eBrem, N_eBrem, N_eBrem, ...
beam_gas_3	6.334244	[2423, 4111, 4971, 6001, 9161, 9326]	[N_eBrem, N_eBrem, N_eBrem, N_eBrem, N_eBrem, ...
beam_gas_4	8.445658	[1531, 3174, 4181, 4480, 5120, 5642, 6110, 622...	[N_eBrem, N_eBrem, N_eBrem, N_eBrem, N_eBrem, ...
...	...	...	...

SuperKEKB beam-gas losses: impacts on D06V1

- Example: distribution impacting D06V1 collimator because of Coulomb scattering interactions





- Collimator impacts show that the presently assumed collimator geometry is too simplified!

Outline

- **Introduction**
  - Beam losses and collimation simulations in Xsuite
  - Simulation tool benchmark: SuperKEKB is an ideal candidate
- **SuperKEKB aperture and collimator models**
- **Beam loss simulations**
  - Touschek scattering simulations
  - Beam-gas scattering simulations
- **First demonstrative SuperKEKB simulations with Xsuite**
  - SuperKEKB beam-gas losses
- **Outlook and next steps**

Outlook

- **Ongoing effort to perform SuperKEKB beam loss simulations with Xsuite**
  - GOAL: benchmark Xsuite-BDSIM with SuperKEKB background studies (27th June 2020 – PRAB paper)
  - Xsuite could be of interest for SuperKEKB/BELLE-II
    - Integrated scattering engines (Geant4/BDSIM, FLUKA)
    - Online processing of detailed aperture models with precise identification of lost particle locations
    - We are happy to contribute to SuperKEKB/BELLE-II collimation and background studies!

  - A lot of progress in the latest months:
    - Optics model development (many thanks to J. Salvesen, G. Iadarola, KEK colleagues !!)
    - First simplified SuperKEKB aperture and collimator models
    - Development of beam-gas and Touschek scattering routines
    - First test simulations successfully ran: while still purely demonstrative, show the possibility of simulating collimation in SuperKEKB with Xsuite!

Next steps

- Include full IR (with solenoid) in the model: this is already possibile! (J. Salvesen, previous talk)
- Refine the aperture and collimator geometry models
- Beam loss simulations with the recently developed Touschek scattering routine
- Perform qualitative (first) and quantitative (i.e., tracking IR losses in the BELLE-II detector) collimator scans

- Upcoming publication (IPAC'25):

COMPARISON OF XSUITE SIMULATIONS WITH MEASURED BACKGROUNDS AT SUPERKEKB

G. Broggi[1,2,3*], A. Abramov[2], M. Boscolo[3], R. Bruce[2], G. Iadarola[2], T. Ishibashi[4]
A. Natochii[5], S. Redaelli[2], J. Salvesen[2], S. Terui[4], F. Van der Veken[2]
[1]Sapienza University of Rome, Italy [2]CERN, Meyrin, Switzerland [3]INFN-LNF, Frascati, Italy
[4]KEK, Tsukuba, Ibaraki, Japan [5]Brookhaven National Laboratory, Upton, NY, USA

➢ Goal is to present a benchmark of Xsuite simulations with 27th June 2020 background study (PRAB paper)

Any support from your side is much welcome! ☺

Thank you!

Backup