Particle Physics School Colloquium

2010/12/10

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Background studies for the Belle II experiment

- The Belle II experiment
- Physics at Belle
- Background

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

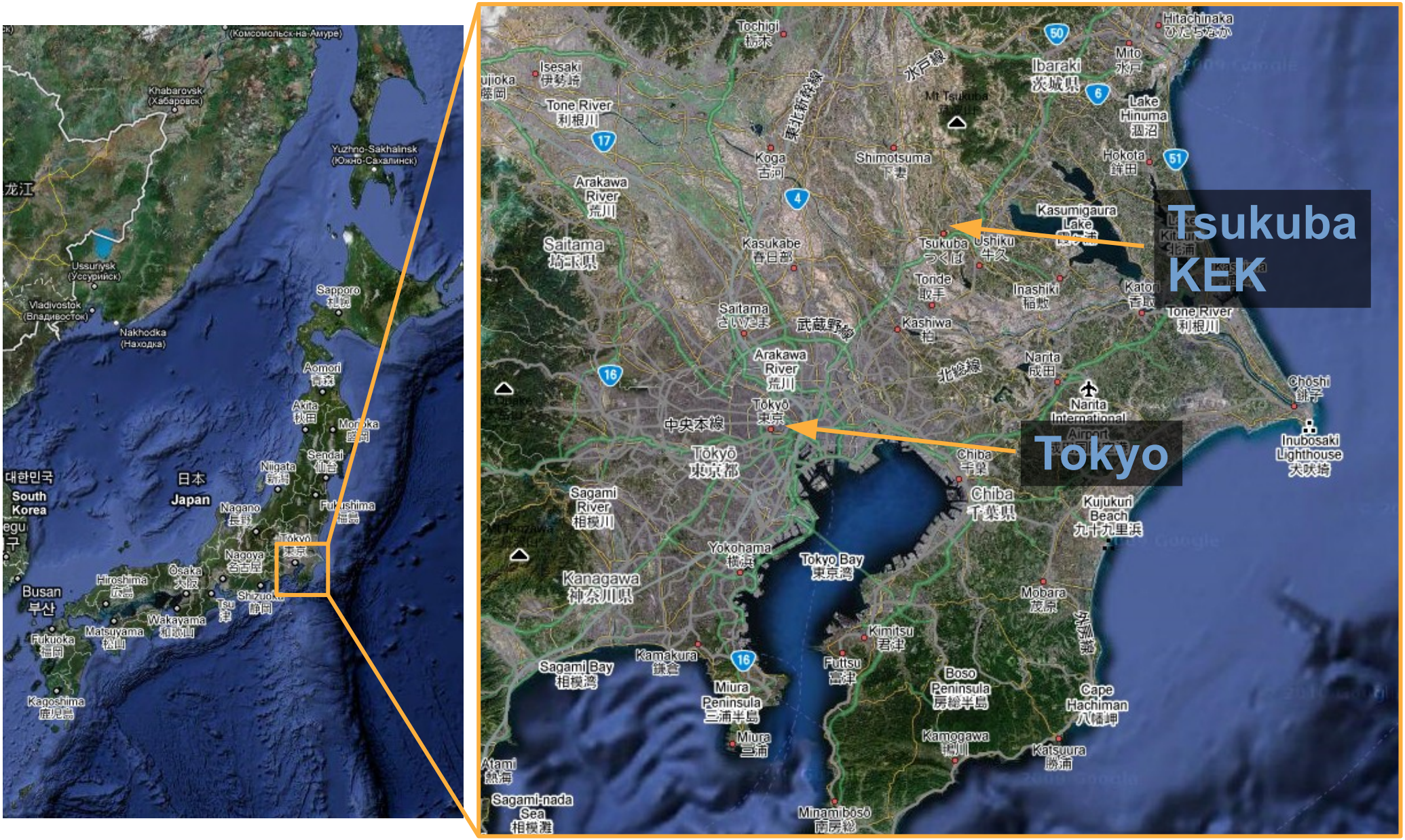
MAX-PLANCK-GESELLSCHAFT

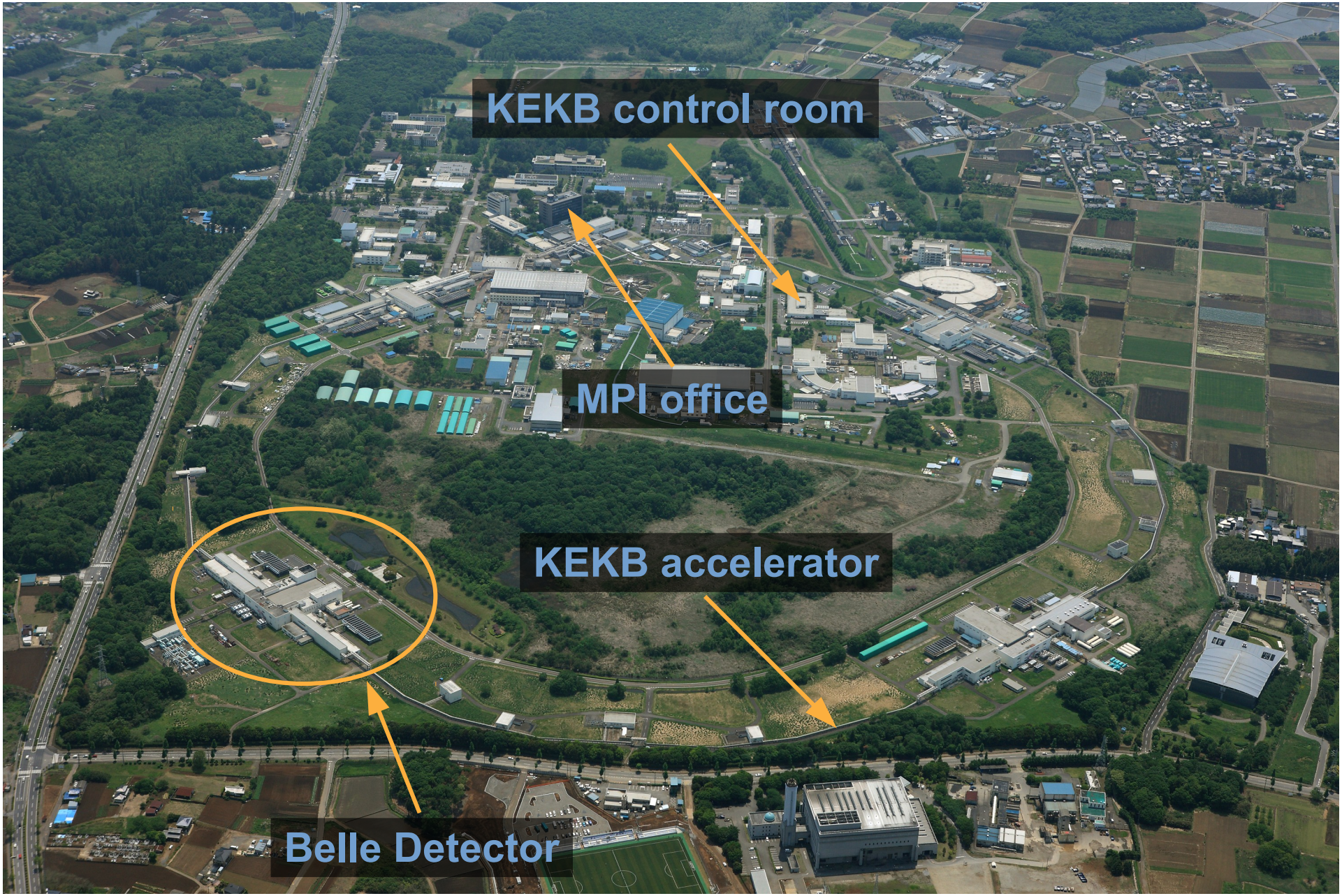
Belle II

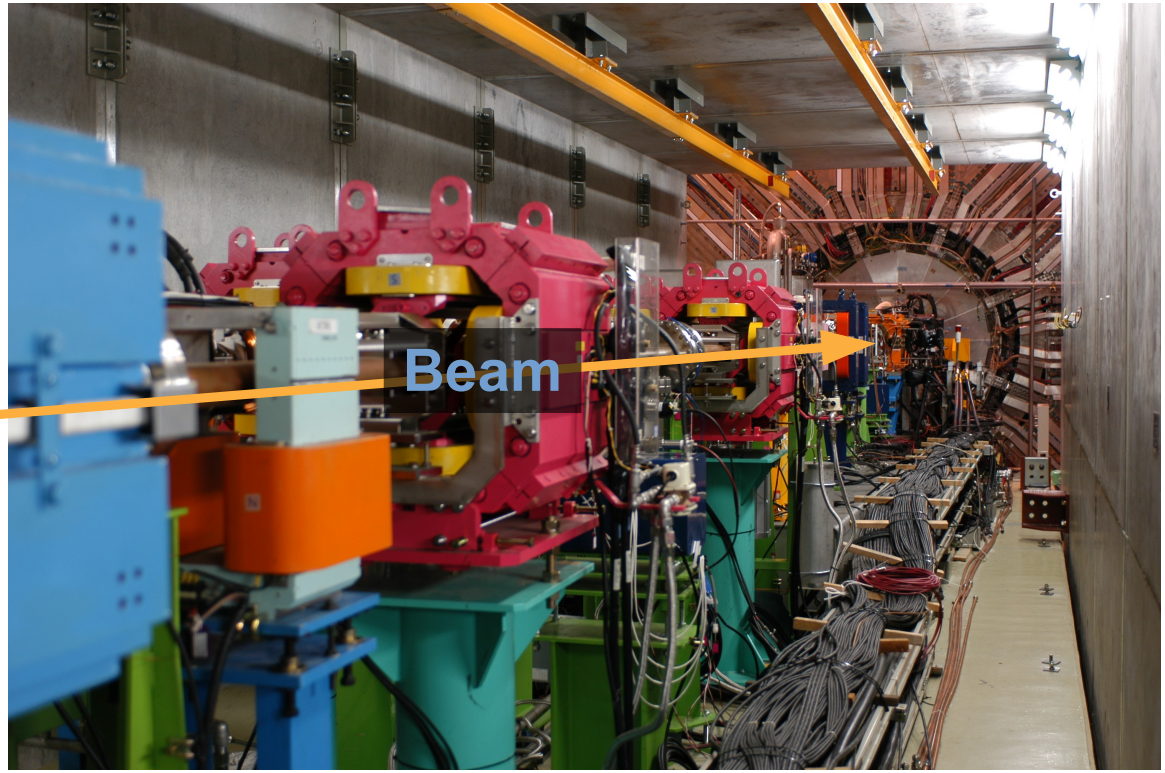
Excellence Cluster
Universe

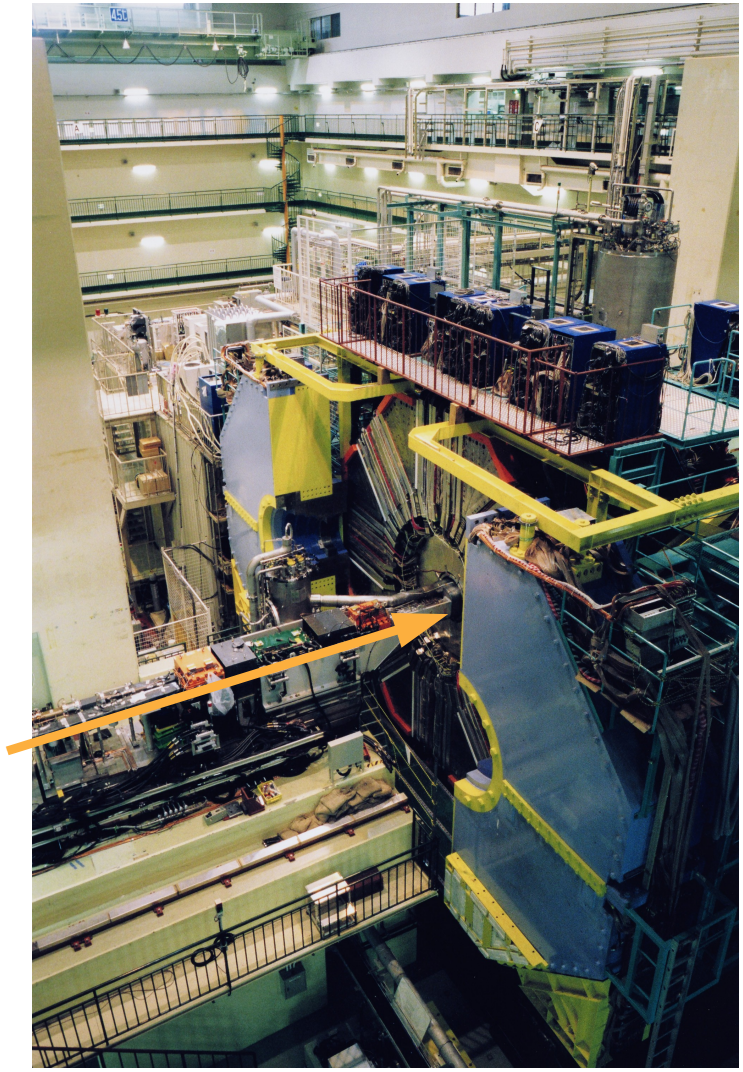
The Belle experiment is located at KEK in Tsukuba, Japan

KEK (**K**oh **E**nerugi kasokuki **K**enkyu kikou), High Energy Accelerator Research Organization



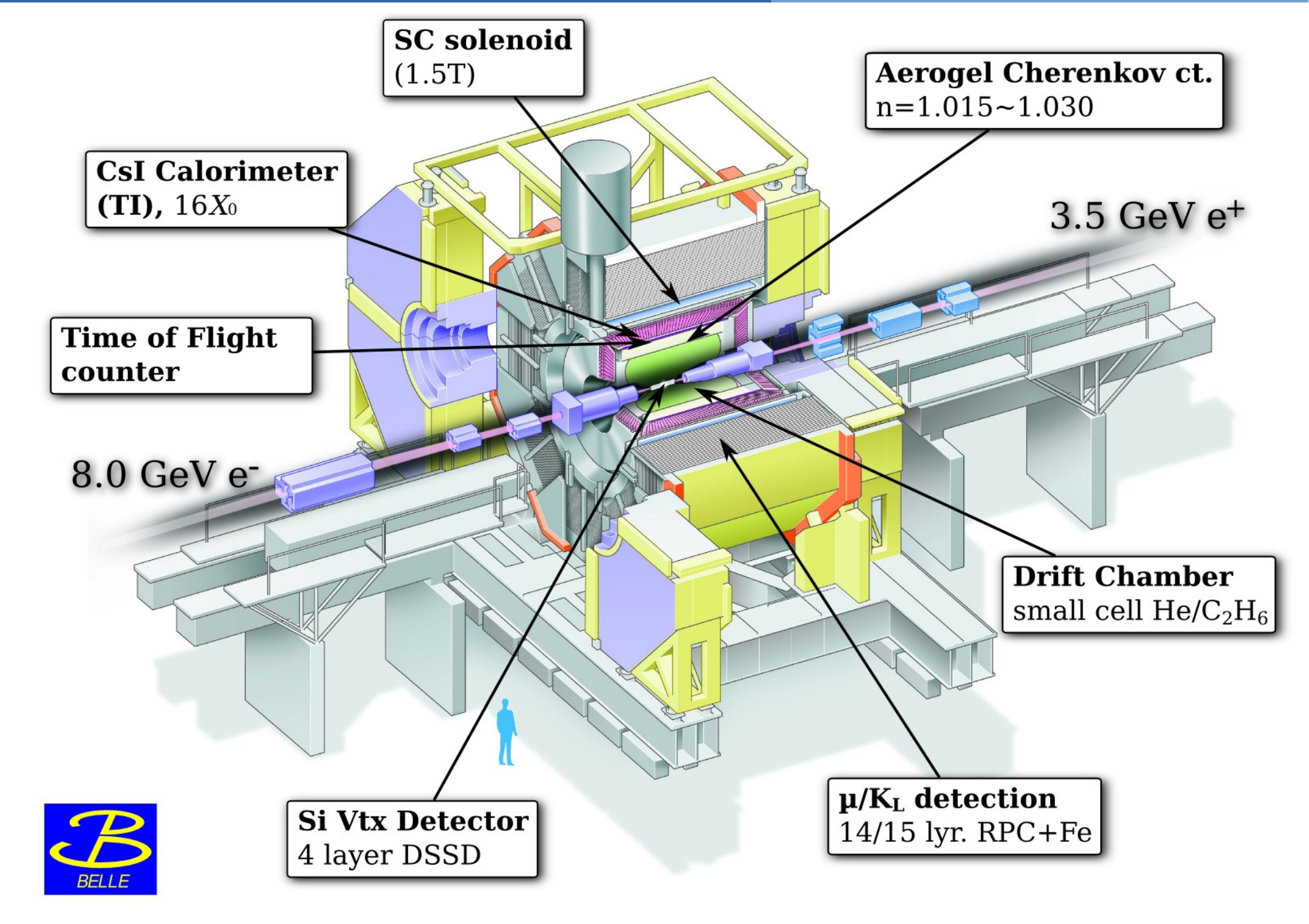

KEKB control room
MPI office
KEKB accelerator
Belle Detector





- **electron** – **positron** collider
  (running from 1999 to 13.06.2010)
- **asymmetric** energies: 8 Gev (e^-) and 3.5 GeV (e^+)
  mainly running at the $\Upsilon(4S)$ resonance (10.58 GeV)
- Holds the luminosity world record: **$L > 2.1 \cdot 10^{34}\ cm^{-2}\ s^{-1}$**
- Total accumulated luminosity: **1023 fb^{-1}** (~772 million $B\bar{B}$ pairs for $\Upsilon(4S)$)

B - Factory


SC solenoid
(1.5T)
Aerogel Cherenkov ct.
n=1.015~1.030
CsI Calorimeter
(TI), 16X_0
3.5 GeV e^+
Time of Flight
counter
8.0 GeV e^-
Drift Chamber
small cell He/C_2H_6
Si Vtx Detector
4 layer DSSD
μ/K_L detection
14/15 lyr. RPC+Fe
BELLE

Physics at Belle

CP Violation in Belle

Standard Model (SM) very **successful**, yet cannot be the **complete** theory for example:

1) **Dark Matter exists**
(only 4% of the Universe accounted for by the SM)

2) **Neutrinos** do have mass

➡ but are massless in the Standard Model

3) **Asymmetry** in the amount of matter and antimatter in the universe

Big Bang produced an equal amount of matter and antimatter.

Today:

Baryons, electrons ⬅ Observation ➡ ~~antibaryons, positrons~~

➡ **CP Violation** is involved (Sakharov conditions)

- **C**harge conjugation (transforms particle ➡ antiparticle)
- **P**arity transformation (changes the **sign of space coordinates**)

The Standard Model (SM) with 3 families can **accommodate** the CP violation in weak interactions through the CKM (Cabibbo, Kobayashi, Masukawa) matrix.

The CKM Matrix "rotates" mass base into flavor base.

$$\underbrace{\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}}_{\text{flavor eigenstates}} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{V_{CKM}} \underbrace{\begin{pmatrix} d \\ s \\ b \end{pmatrix}}_{\text{mass eigenstates}}$$

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

unitary matrix: **4 free real parameters** (3 Euler angles and a phase)

Values not predicted by SM.

Wolfenstein parameterization

Expansion in powers of $\sin\theta_C = \lambda\,(\approx 0.226)$

CP conservation would imply $\eta = 0$

Phase introduces **imaginary terms** in the Standard Model Lagrangian inducing CP violation.

Unitary triangle in the **B system**

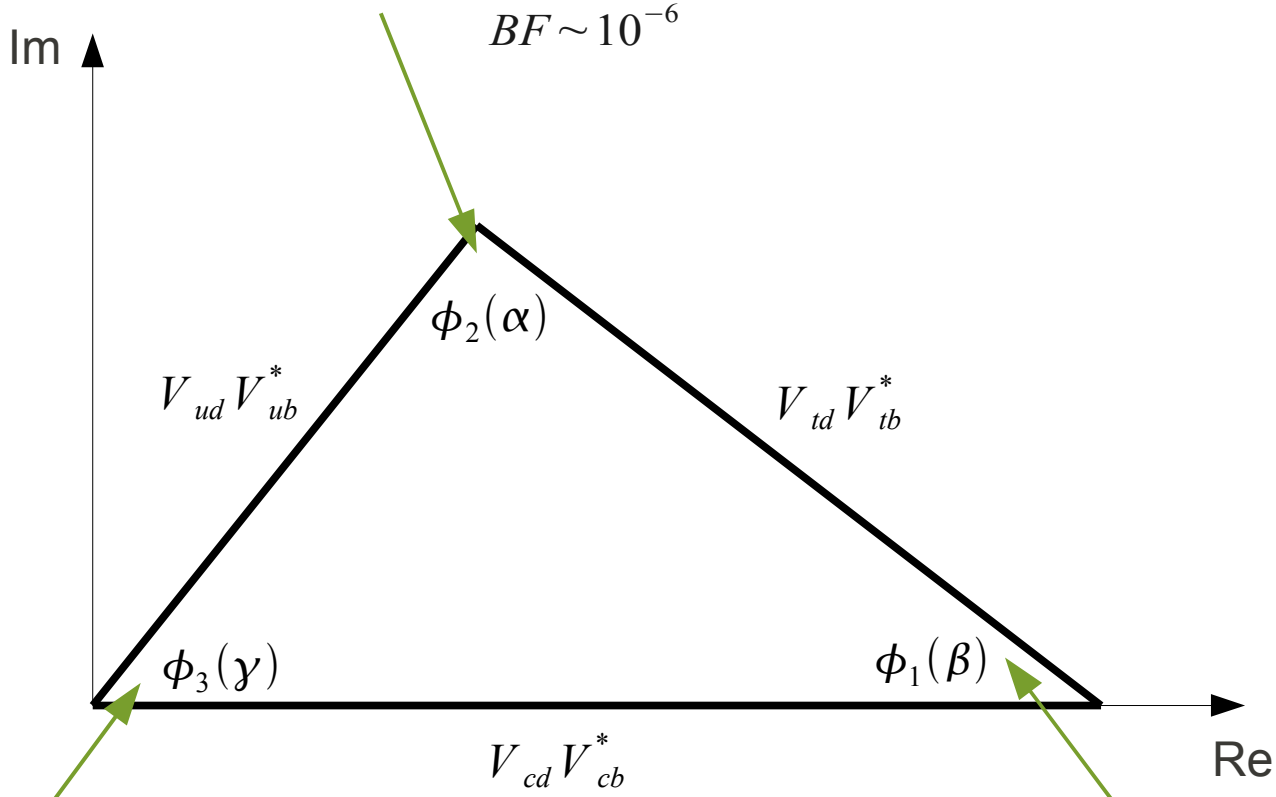
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

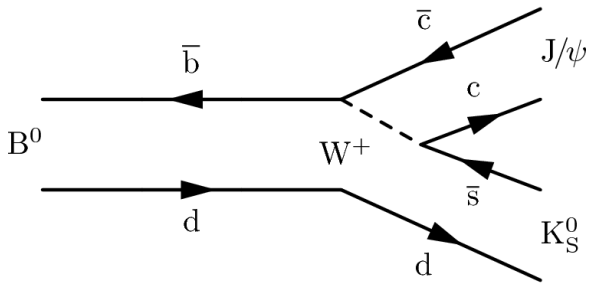
$$\underbrace{V_{ud}V_{ub}^*}_{O(\lambda^3)} + \underbrace{V_{cd}V_{cb}^*}_{O(\lambda^3)} + \underbrace{V_{td}V_{tb}^*}_{O(\lambda^3)} = 0$$

Big CP violation

$B^0 \to \pi\pi, a_1\pi, \rho\rho$ **MPI group**

$BF \sim 10^{-6}$





$B^0 \to DK^{(*)}, DK_S^0, K\pi, D^*\pi$

$BF \sim 10^{-5}$

$B^0 \to J/\psi K_S^0$

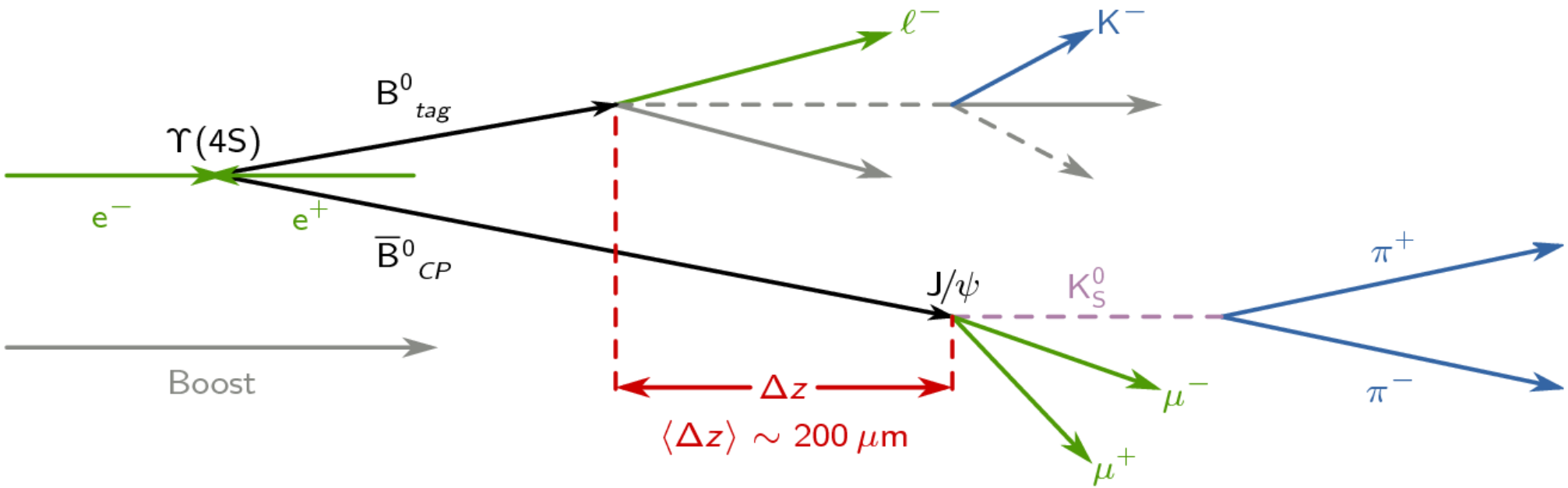
$BF \sim 10^{-4}$

Production of B mesons at the $\Upsilon(4S)$ resonance (10.58 GeV)

$$e^+ e^- \to \Upsilon(4S) \to B^0 \bar{B}^0$$

Produced in a quantum-entangled state

Flavor eigenstate



Asymmetric beam energies: "convert" time to distance

$$\Delta z = \beta \gamma c \Delta t$$

Some state f ($\bar{f}$) or CP eigenstate e.g. J/ψ K_S

Good vertex resolution needed.

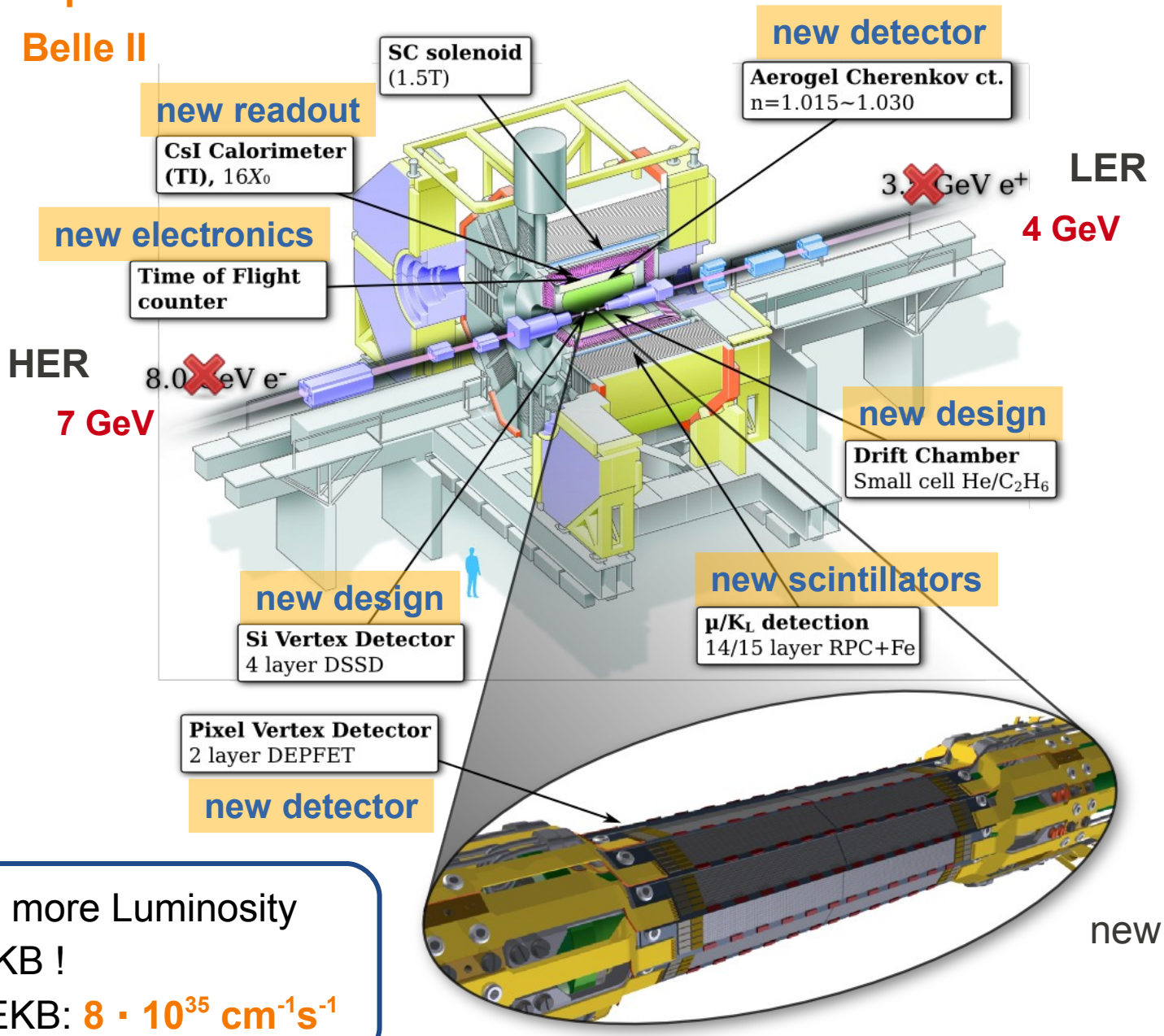
Belle II

The next generation

Belle was shutdown on **13.06.2010**: Construction of an upgraded accelerator & detector started.

KEKB ➡ SuperKEKB

BELLE ➡ Belle II



40 times more Luminosity than KEKB !

SuperKEKB: $8 \cdot 10^{35}\ cm^{-1}s^{-1}$

new subdetector **PXD** **(MPI, HLL)**

? Which background

How much background

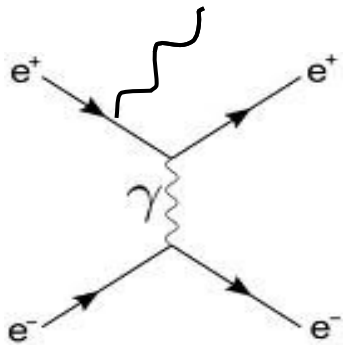
Two kinds of background are expected for Belle II

Machine background

- ✓ Beam/gas scattering (Bremsstrahlung and Coulomb scattering)
- ✓ Touschek effect (intra bunch scattering)
- ✓ Synchrotron radiation

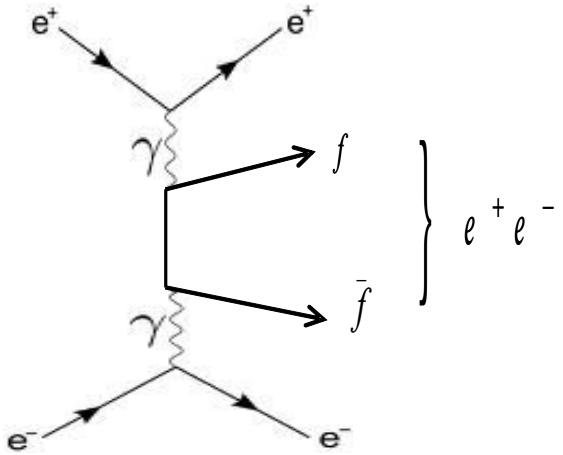
Luminosity related background

Radiative Bhabha scattering



$\sigma \approx 50\,nb$

Gamma/Gamma reactions

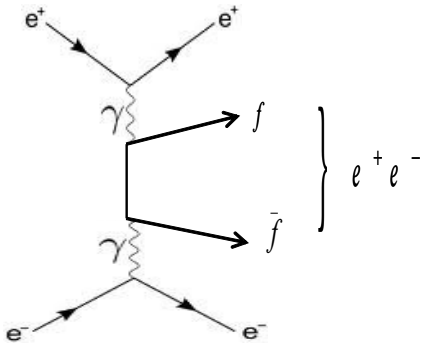


$\sigma \approx O(10^7\,nb)$

Expected rate increase of:

Machine	Luminosity related
	factor of **40** due to luminosity

Dominating QED background: **2 photon processes**



Expected occupancy of PXD

	SuperB (private communication)	**BDK** (Simulation)	**KW** (Simulation)
Tracks	13800	~800	~800
Occupancy	1.3 %	0.07 %	0.1 %

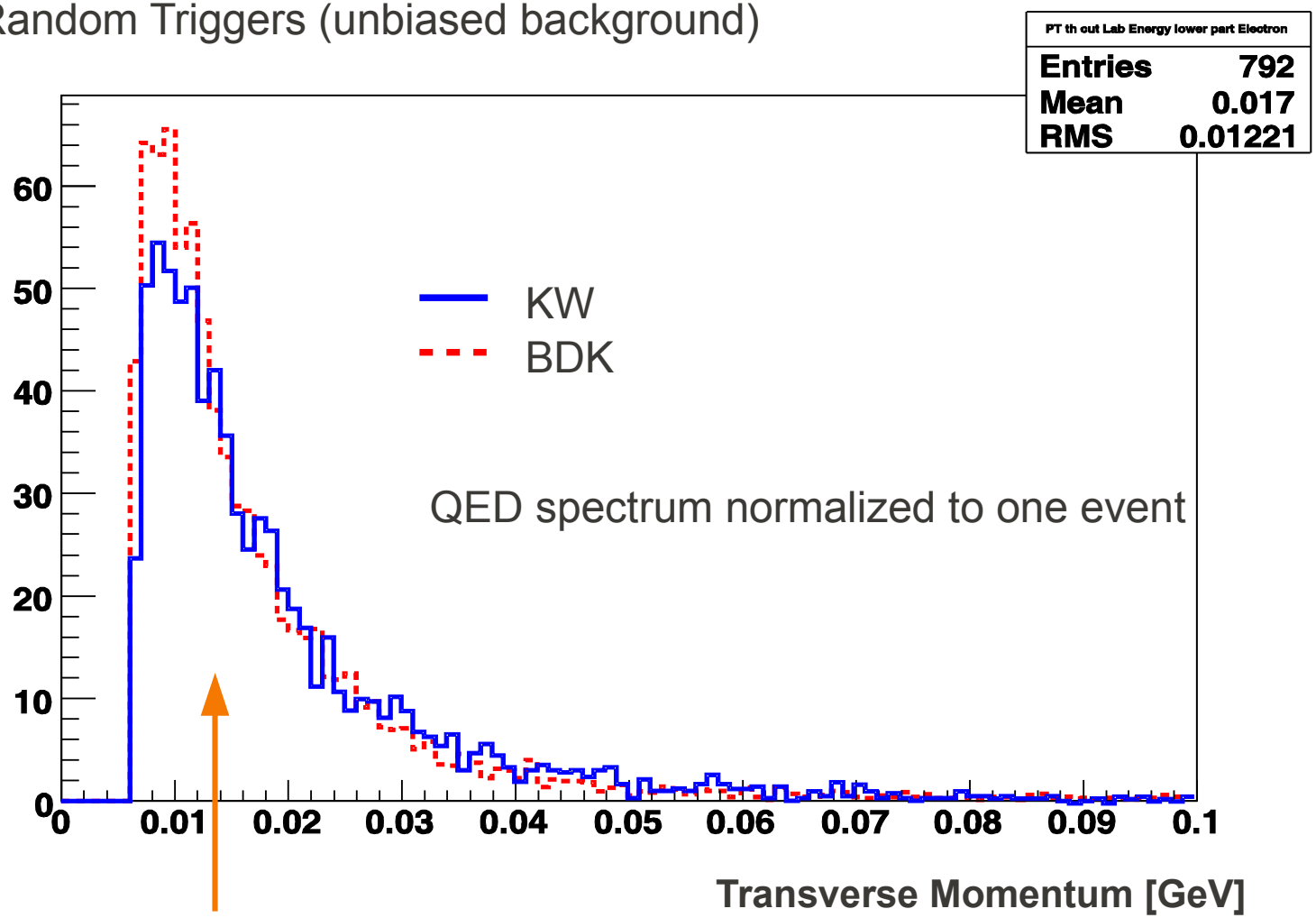
BDK: Berends – Daverfeldt – Kleiss
KW: S.Jadach et al.

Real data to clarify situation: Special QED runs taken at **May 28th** on Belle

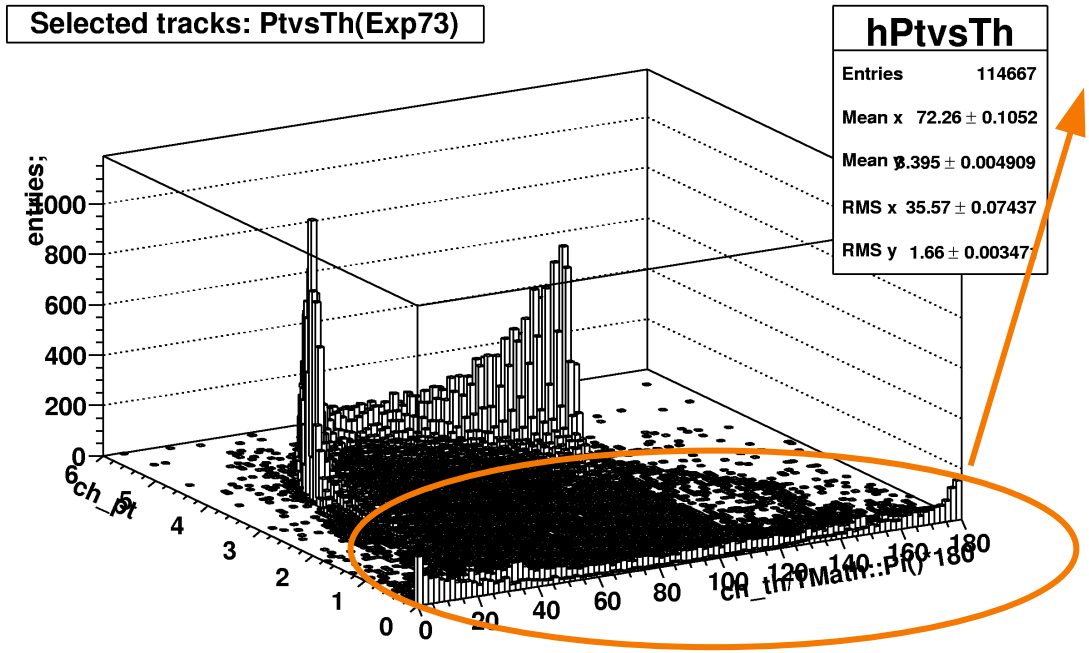
Idea: Measure QED background

Problem: Events consisting of tracks with a few MeV cannot be triggered at Belle

Solution: Random Triggers (unbiased background)



high rate at very low momentum
(~ 5 – 20 MeV)



Taken **background events** consist of

- B – physics (few)
- Machine background
- QED

Scales with luminosity

Take runs with varying luminosity to subtract machine background

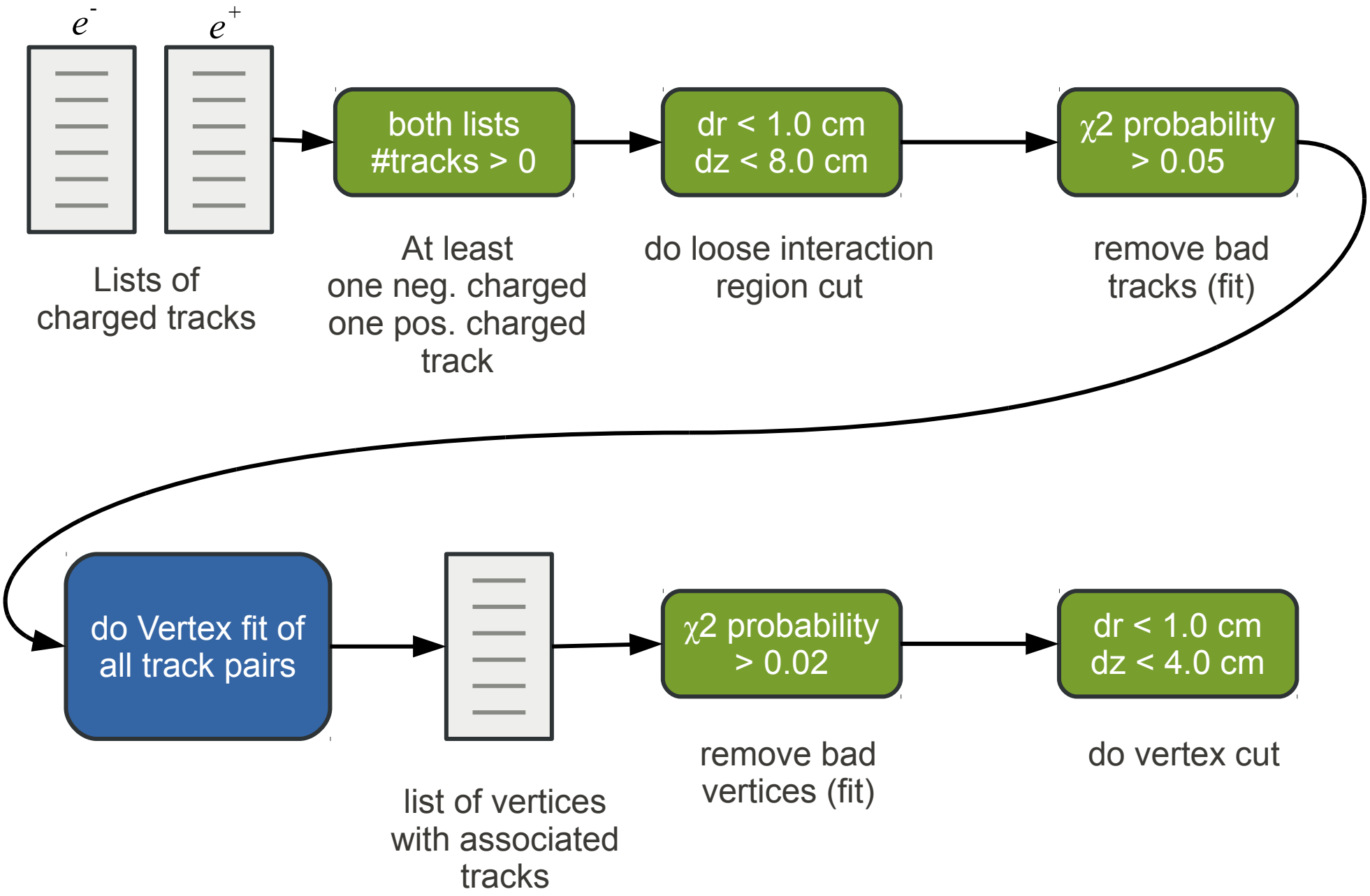
Analysis follows two paths:

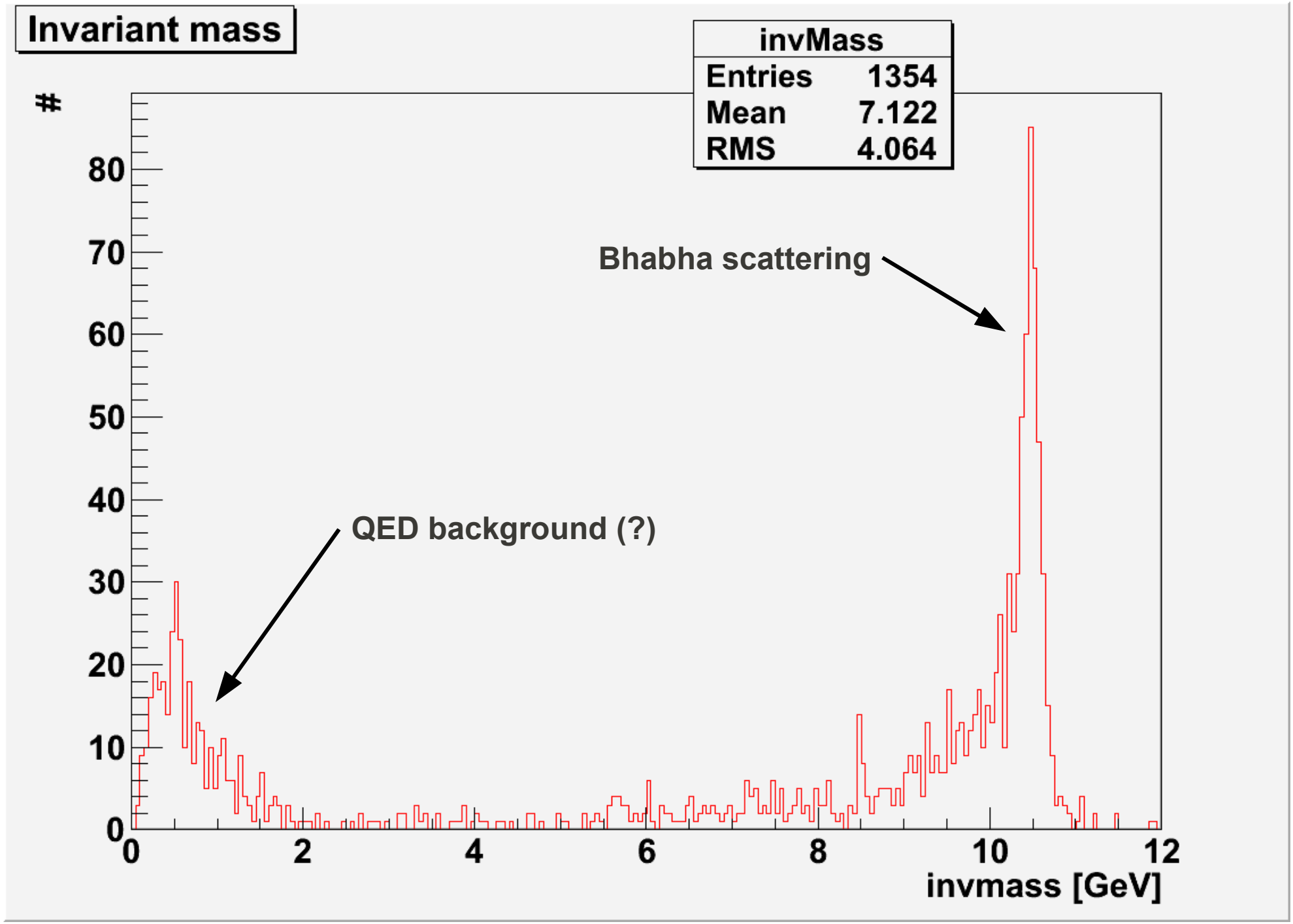
QED run data

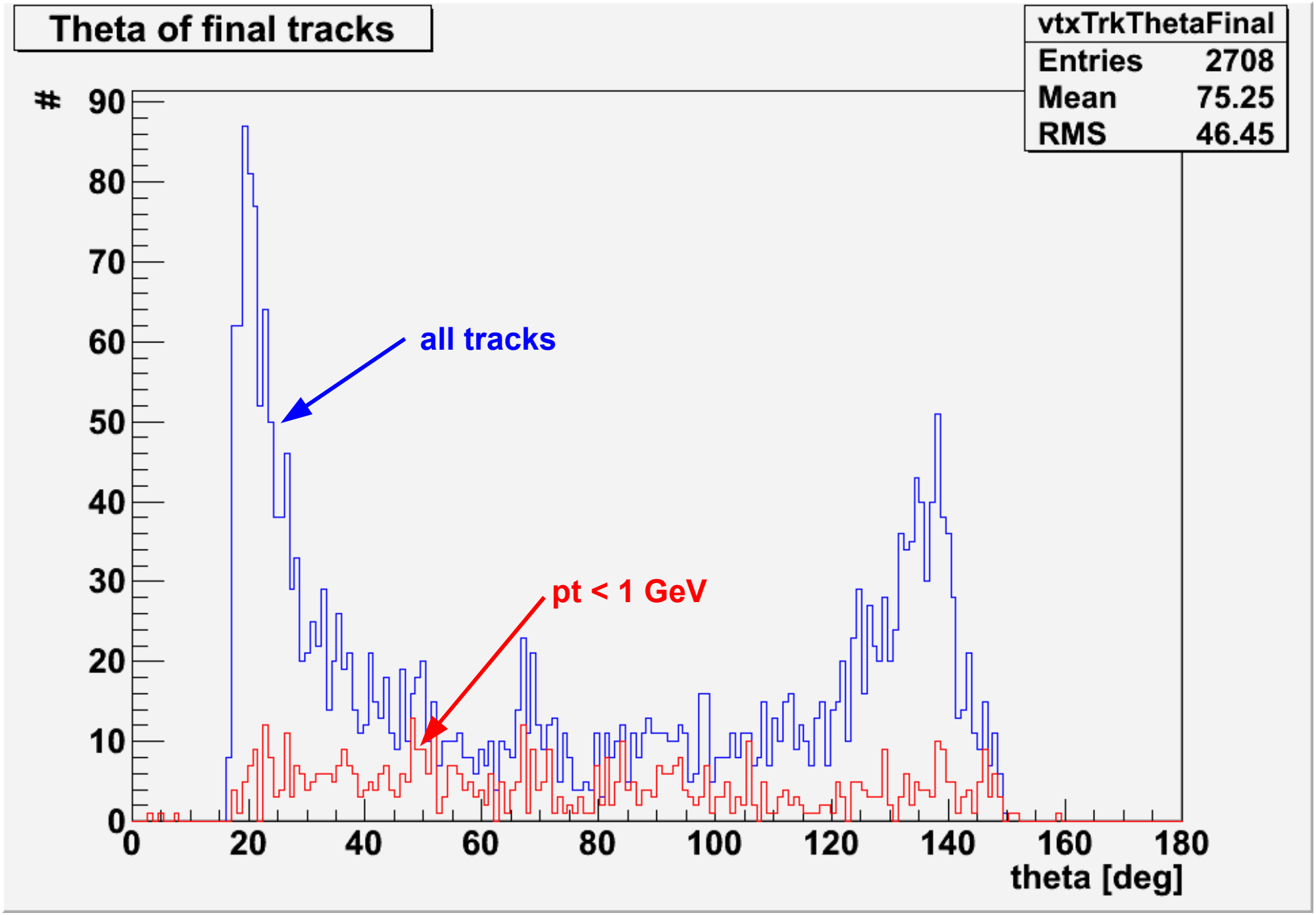
Study hit distributions in SVD and CDC (*done by Elena Nedelkovska, see talk at last Young Scientist Ringberg meeting*)

Study reconstructed tracks (*done by me*)

Search for two track events




Invariant mass
invMass
Entries 1354
Mean 7.122
RMS 4.064
#
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
invmass [GeV]
Bhabha scattering
QED background (?)


Theta of final tracks
vtxTrkThetaFinal
Entries 2708
Mean 75.25
RMS 46.45
#
90
80
70
60
50
40
30
20
10
0
all tracks
pt < 1 GeV
0
20
40
60
80
100
120
140
160
180
theta [deg]

Machine background

Touschek

Touschek is a single Coulomb scattering effect of two particles

- ✓ Transforms a small transverse momentum into a large longitudinal momentum
- ✓ Particles leave the nominal beam orbit
- ✓ If energy deviation of the particles leads to violation of accelerator parameters
  both particles are lost !

➡ Reduces beam lifetime

Rate of Touschek scattering is proportional to E^{-3} (E beam energy)
scales linearly with the bunch dimensions

SuperKEKB:

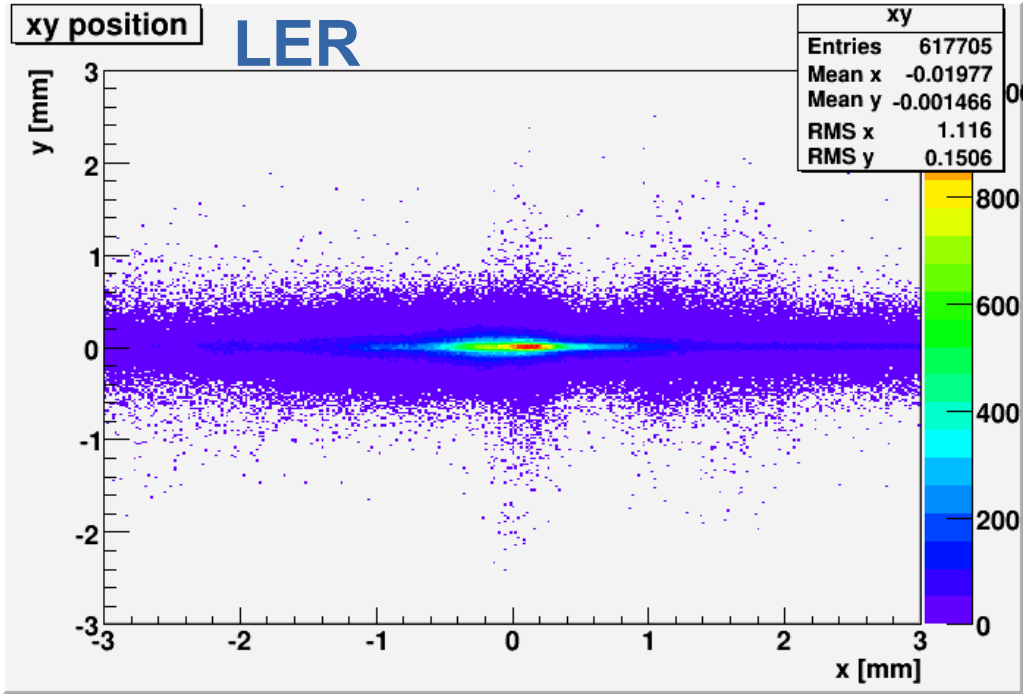
➡ Very small beams horizontal beam size **10.2 μm** (LER), **7.75 μm** (HER)
vertical beam size **59 nm** (LER), **59 nm** (HER)

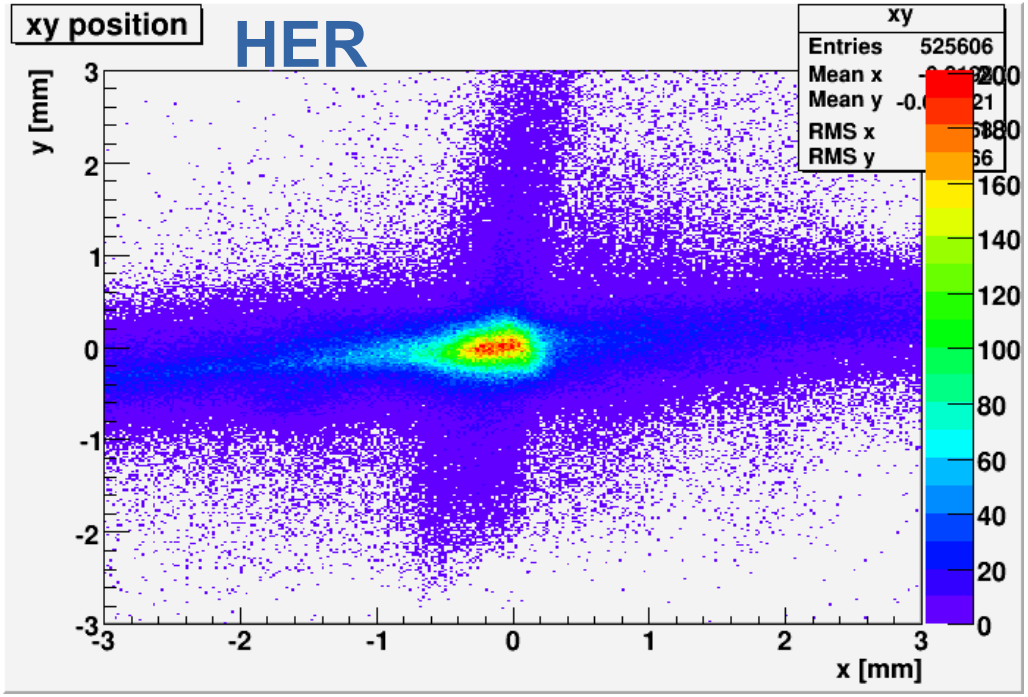
Touschek is the main source of background at Belle II

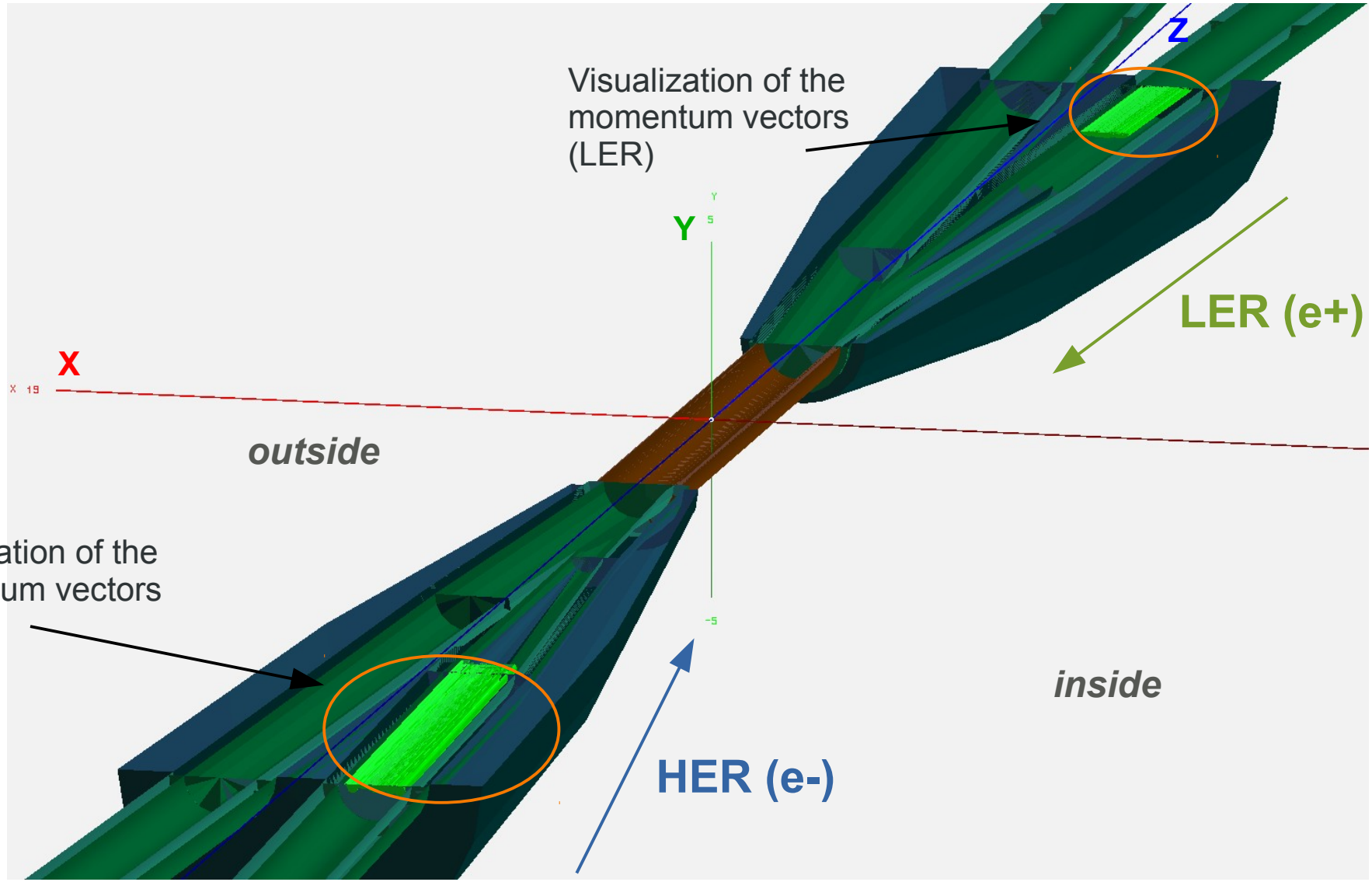
First Touschek background events were simulated:

- **KEKB** beam parameters and magnetic field
- Scattering positions were taken **randomly** along the ring (equally distributed)
- Particle was **transported** through the magnetic field of the ring
- Particles leaving the ring or hitting slits were **removed**
- Particle flux at **±50cm** from the IP was written out

➡ Particles lost: **LER 39 %**, **HER 48 %**



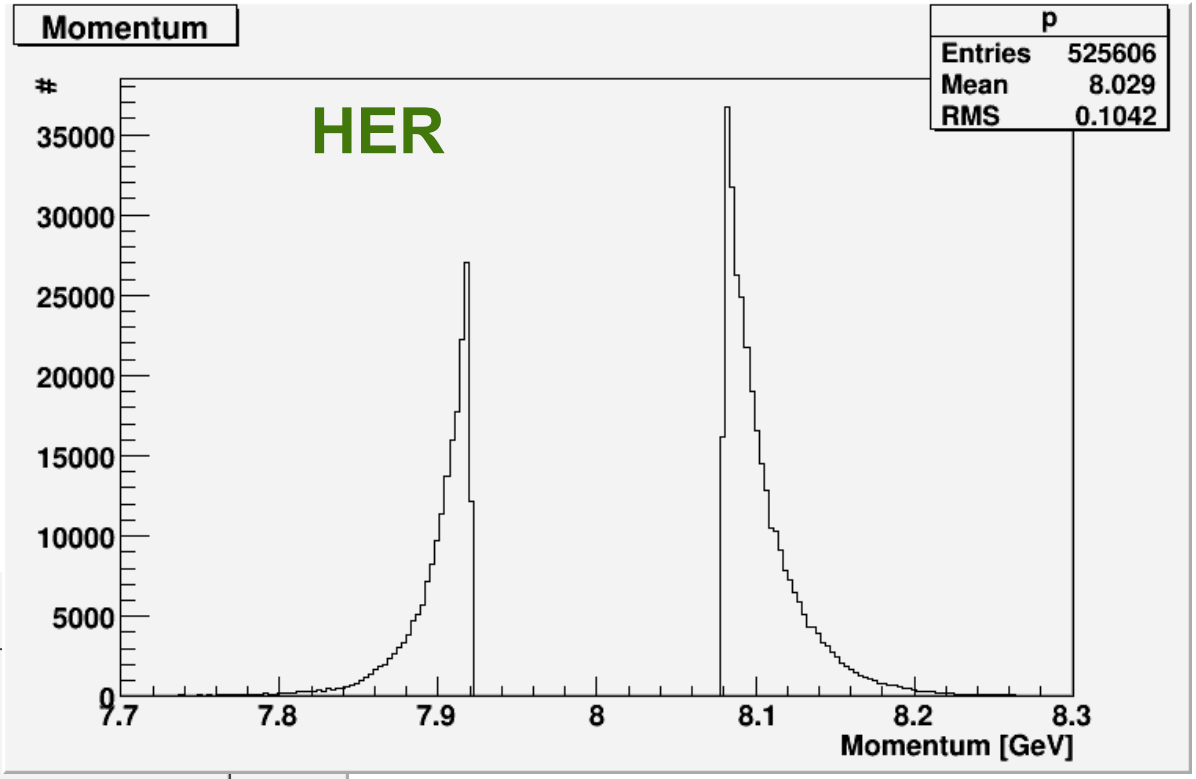


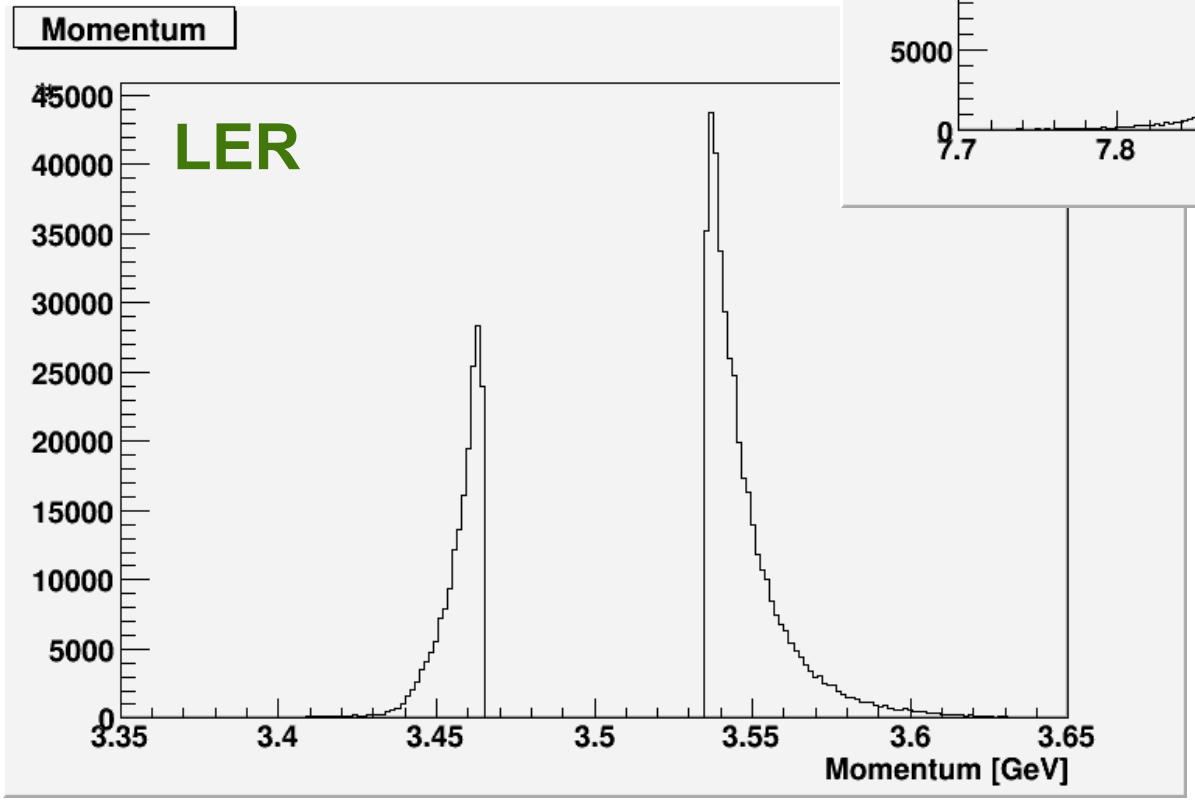

Visualization of the momentum vectors (LER)
Z
Y
X
LER (e+)
outside
Visualization of the momentum vectors (HER)
inside
HER (e-)

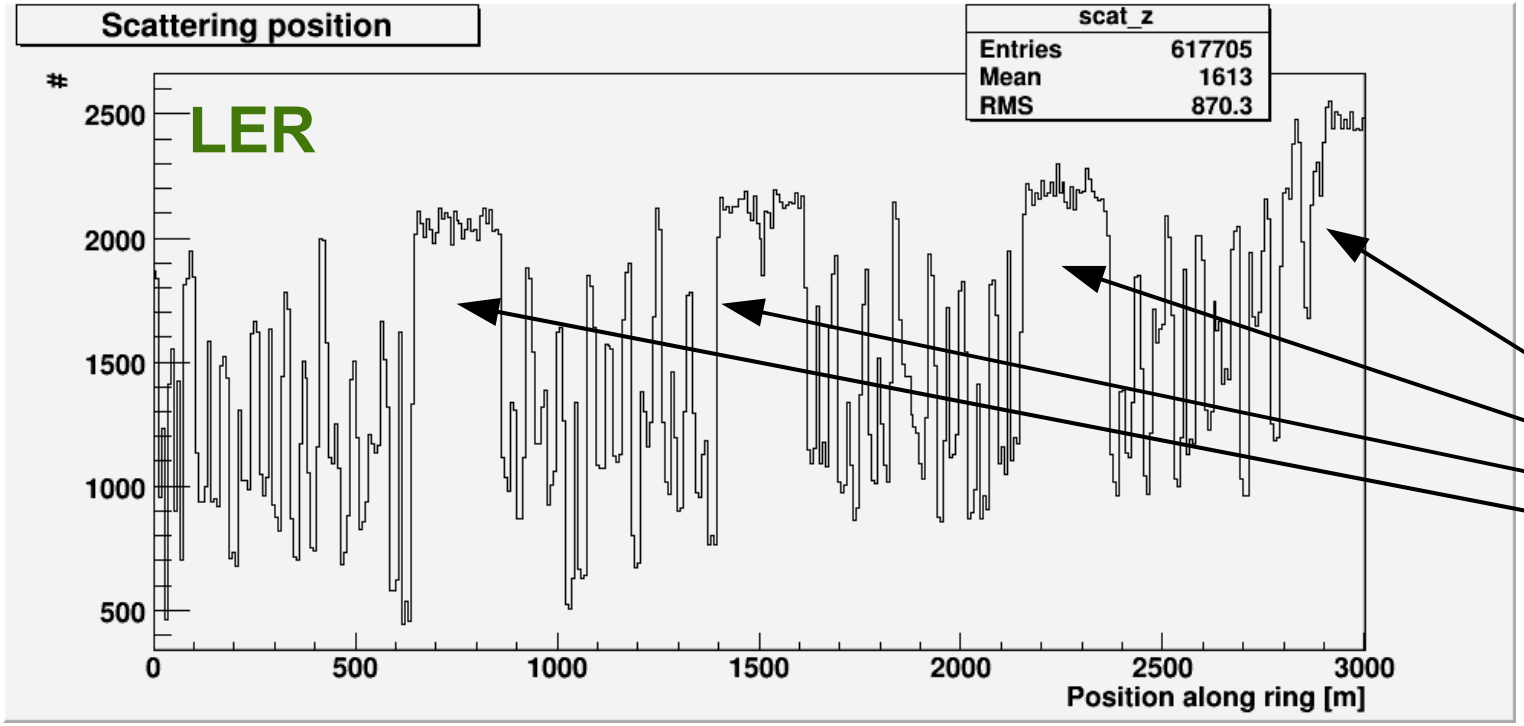
Momentum

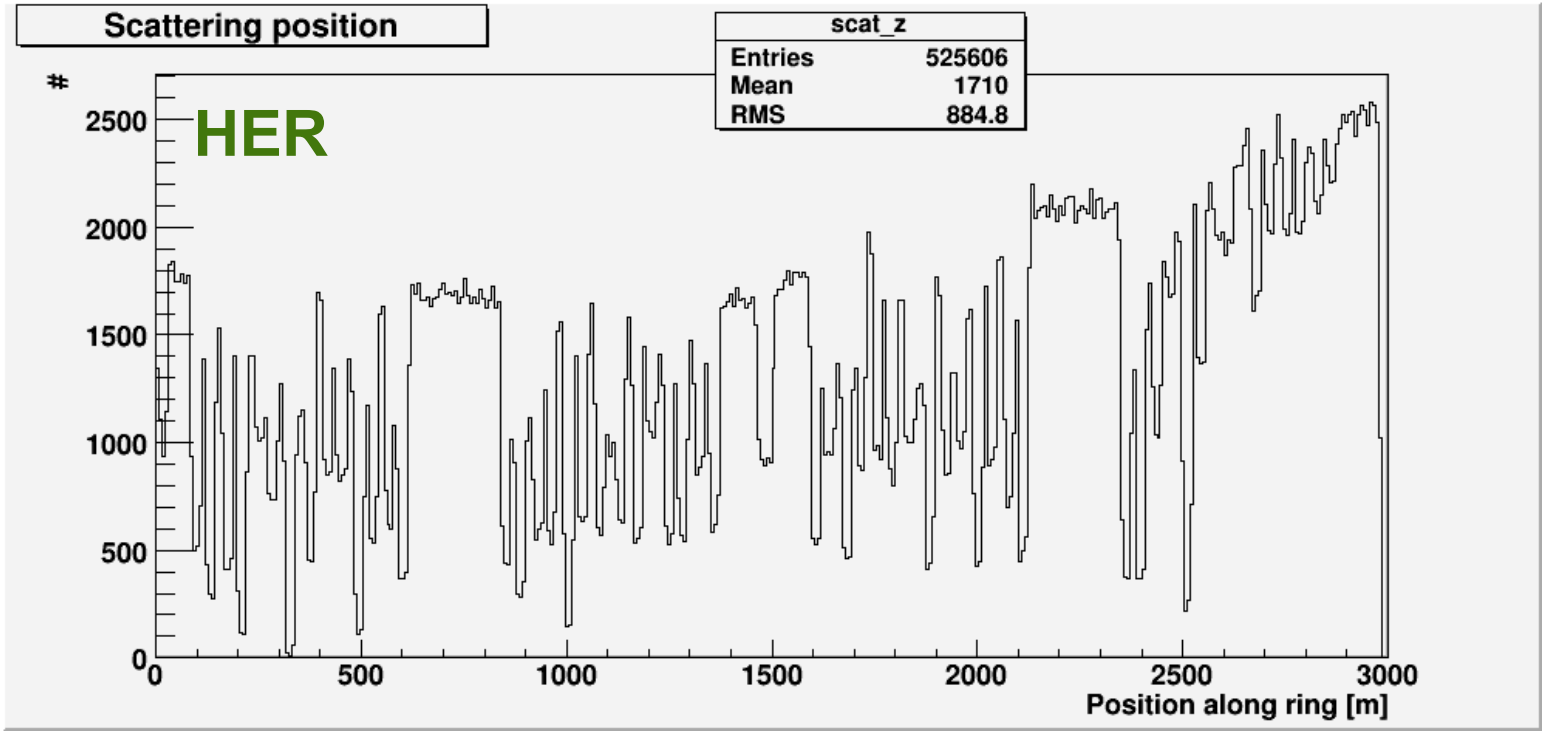
The momentum of the particle is increased/decreased by at least **1%** of its nominal energy

➡ Gap around nominal energy



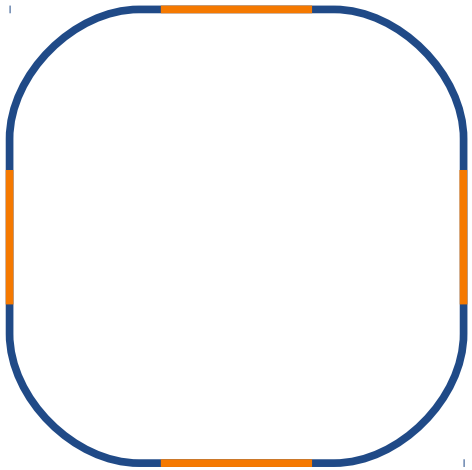






Position of the scattering along the beampipe

The **straight sections** of the KEKB ring



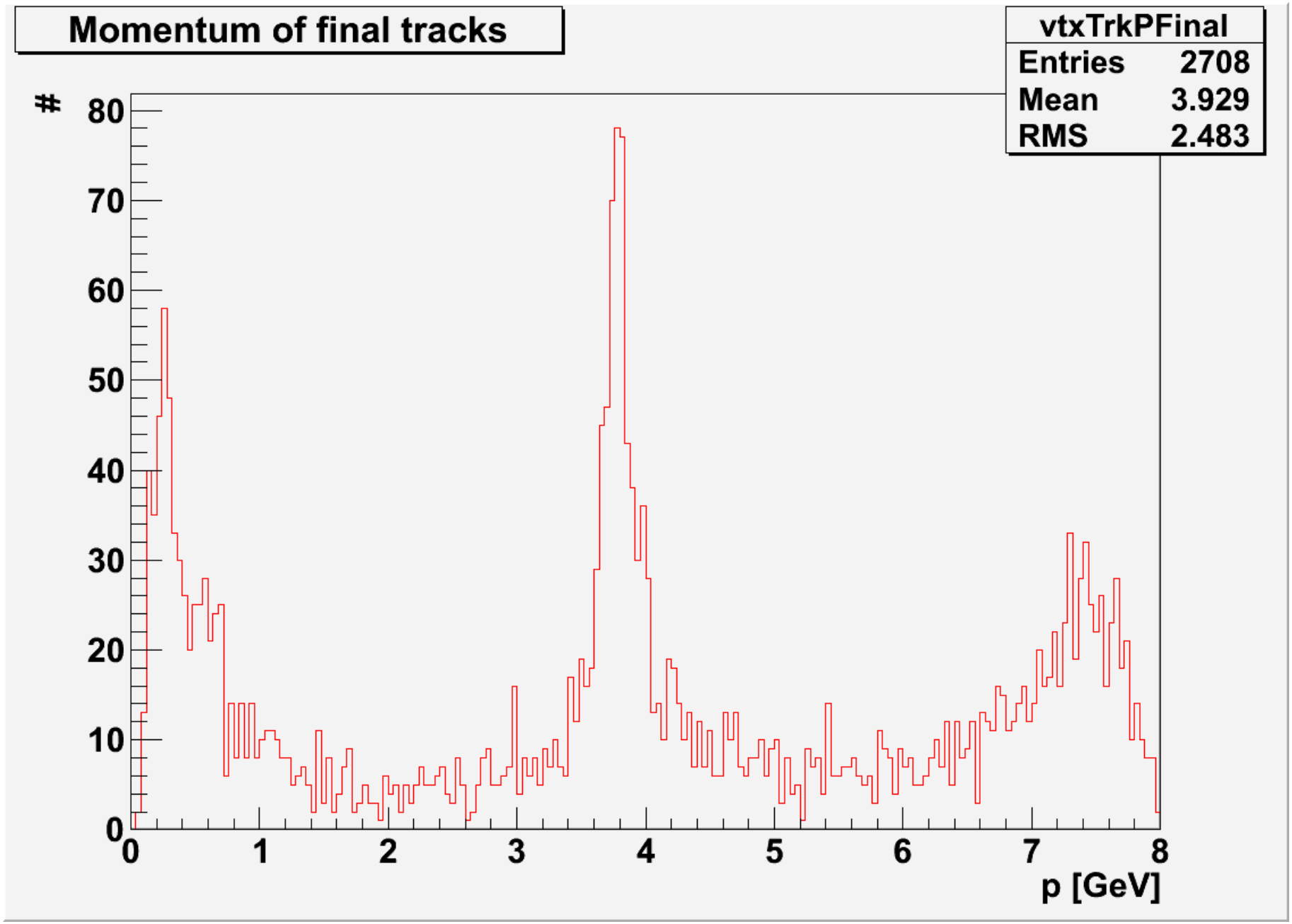
- The Belle Experiment and CP Violation
- Upgrade of the accelerator requires new background studies
- Two types of background: machine and luminosity related
- QED background track studies started. Next step: compare data to MonteCarlo
- Touschek background

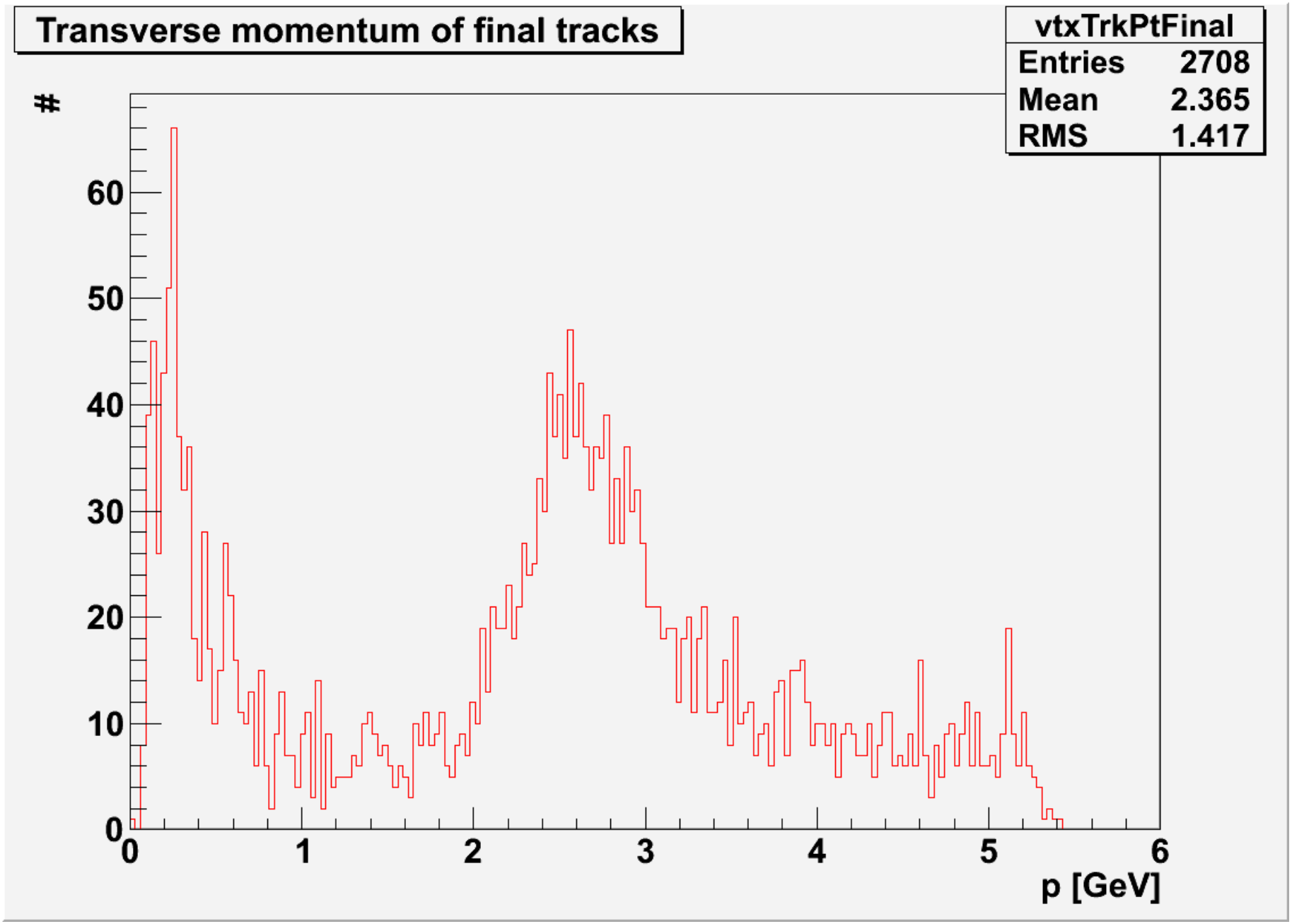
  Dominating background at Belle II
  Next step: Simulate Touschek with SuperKEKB parameter

Merry Christmas
&
Happy new year

Backup

Things I couldn't show


Momentum of final tracks
vtxTrkPFinal
Entries 2708
Mean 3.929
RMS 2.483
#
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
p [GeV]


Transverse momentum of final tracks
vtxTrkPtFinal
Entries 2708
Mean 2.365
RMS 1.417
#
60
50
40
30
20
10
0
0
1
2
3
4
5
6
p [GeV]