Study of the Two-Photon QED Background in the Belle II Detector

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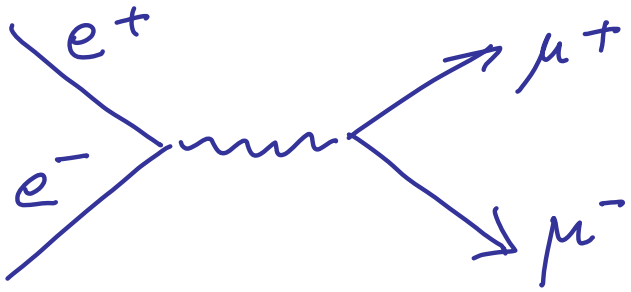
- Motivation for the Study
- Monte Carlo Generators
- Dedicated QED Experiments
- Data Analysis and Results
- Conclusions

QED Processes at SuperKEKB (Belle II)

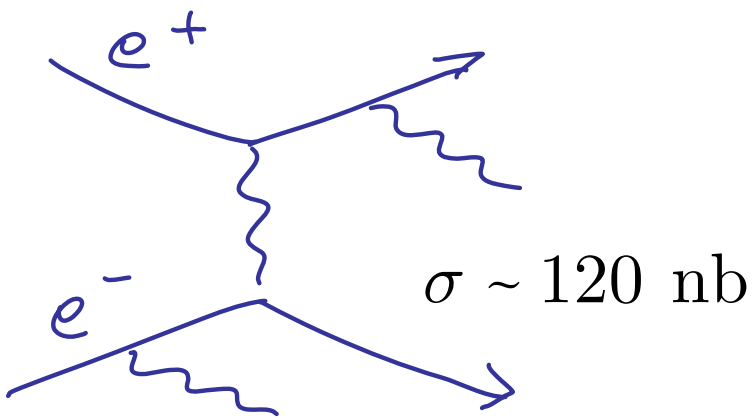
Cross sections for s-channel processes fall like 1/s



Rate ~ 600 ev/s

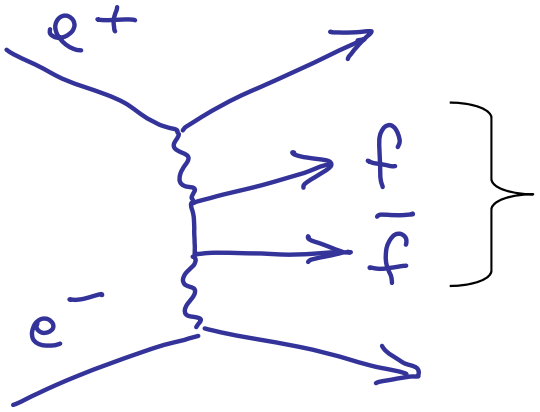
@10^3 / nb s

Cross sections for t-channel processes are largely independent of s



$\sigma \sim 120$ nb

Bhabha scattering

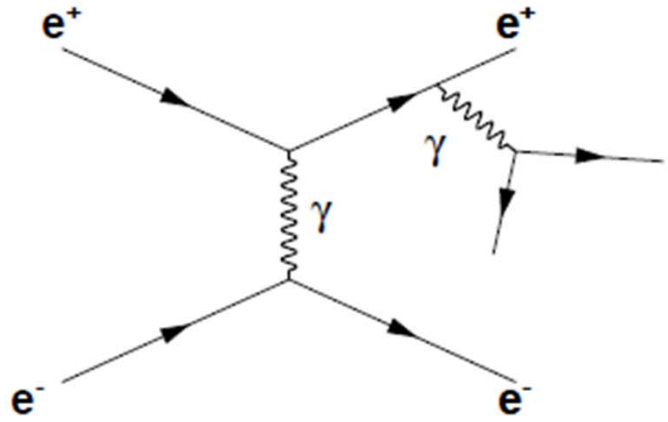


e^+e^- :

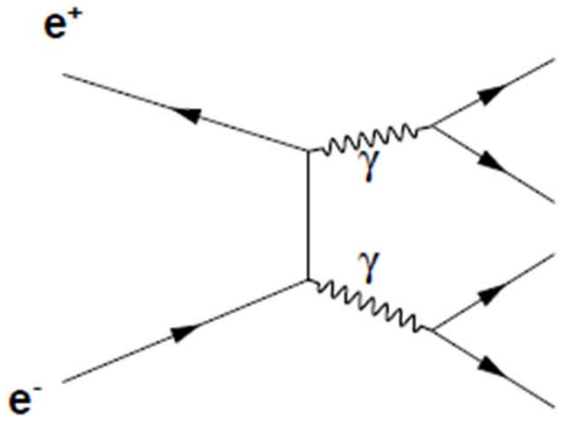
$\sigma \sim O(10^7\,\mathrm{nb})$

2-photon-processes

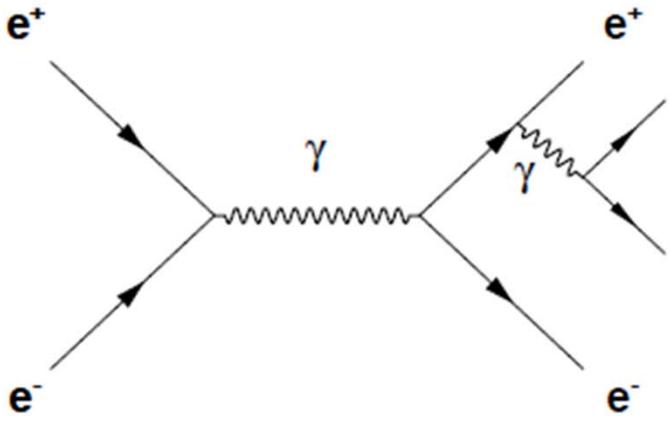
Four-Lepton QED Process



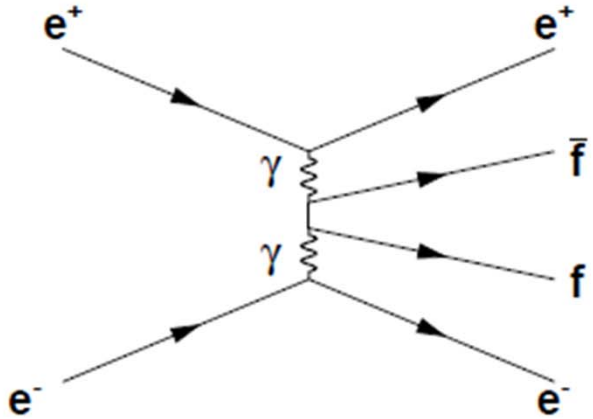
(a) Bremsstrahlung



(b) Conversion



(c) Annihilation



(d) Multiperipheral

Generators for 2γ - QED Processes

- 2-photon processes dominate by far

- Several generators:

  Diag36 („BDK“) (Berends-Daverfeldt-Kleiss, 1985)

  Grace (J.Fujimoto, et.al. Comp.. Phys. Comm. 100 (1997) 128)

  Racoon (A.Denner, S.Dittmaier, M.Roth, D.Wackeroth,
  Comp. Phys. Comm.. 153 (2003) 462)

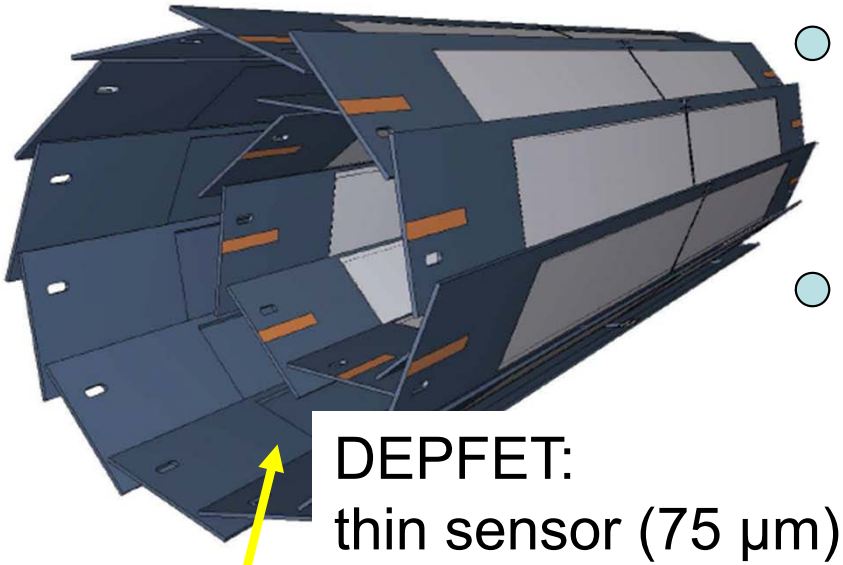
  KoralW (S. Jadach, W. Placzek, M. Skrzypek, B.F.L. Ward,
  CERN-TH/95-205, Jul 1995, CPC 94 (1996) 216 …)

- all done for symmetric e+e- machines (PETRA, LEP), all tested there!

Silicon Tracking System @ Belle II

SuperKEKB: Nano beam option, 1 cm radius of beam pipe

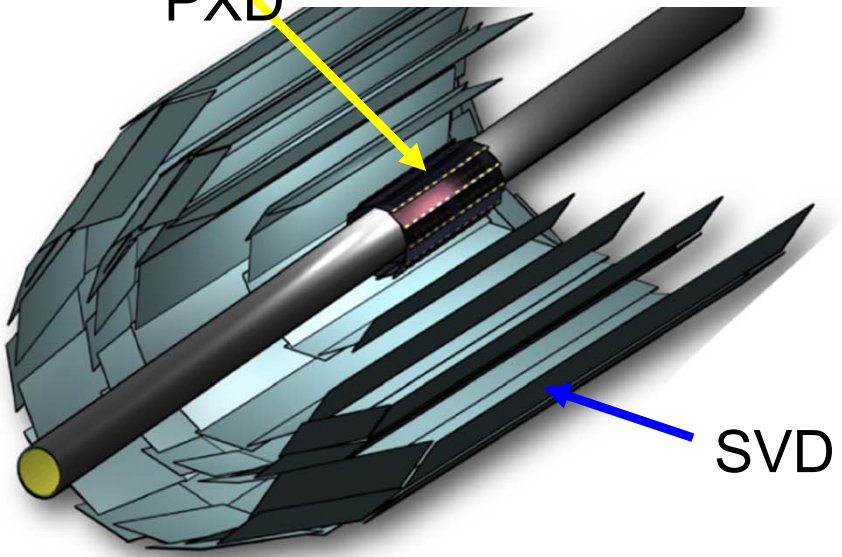
„PXD“



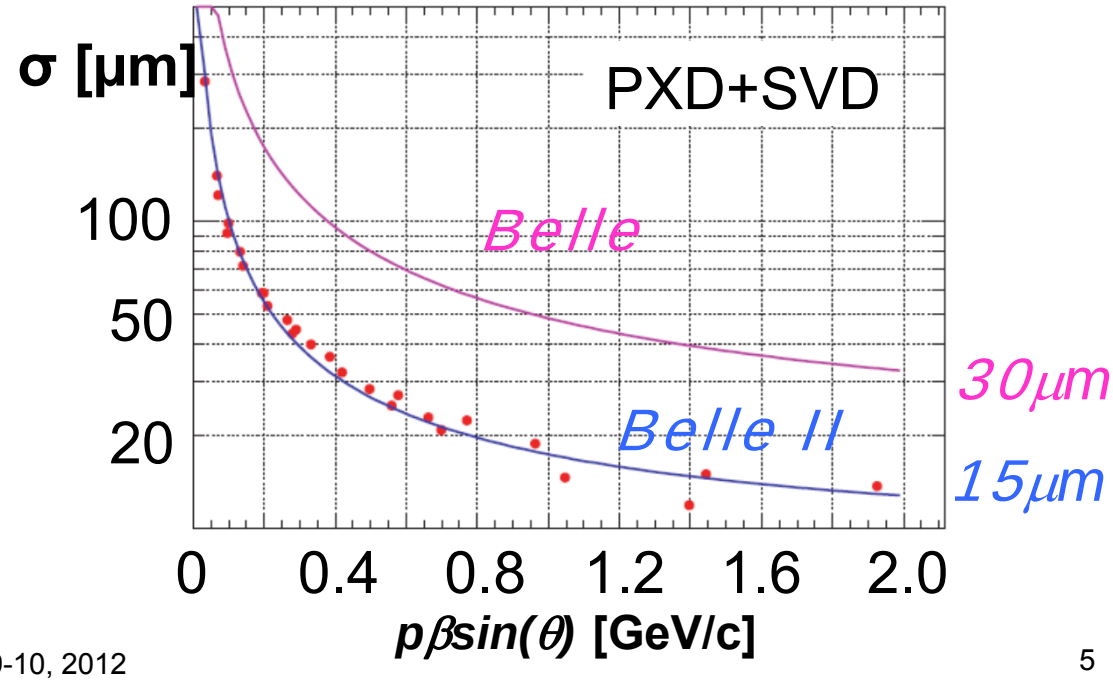
- 2 layer Si pixel detector (DEPFET technology)
  (R = 1.4, 2.2 cm) monolithic sensor
  thickness 75 µm (!), pixel size ~50 x 50 µm²
- 4 layer Si strip detector (DSSD) ← „SVD“
  (R = 3.8, 8.0, 11.5, 14.0 cm)

DEPFET:
thin sensor (75 µm)
unique worldwide

PXD



Significant improvement in z-vertex resolution



Motivation of the Study

- SuperB QED simulations (Frascati workshop 2009):

  10MHz/cm^2 @ 1.3 cm radius (BDK generator used)

  would yield 1.3 % occupancy for PXD (inner layer: 1.4 cm)

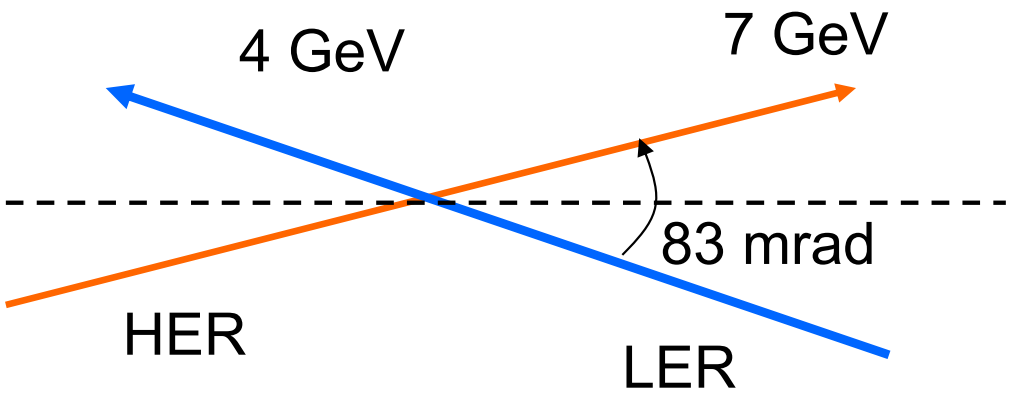
- Set of MCs studied (@MPI):

  KoralW, Grace, BDK give consistent results,
  but inconsistent with SuperB number

- Steps towards a resolution of the discrepancy:

  - some exchange of information (we: sent MC output (BDK),
    SuperB: sent change they made to BDK program)
  - check generators, detector simulations, and analysis

Kinematics at SuperKEKB



B-field direction

(Belle's symmetry axis)

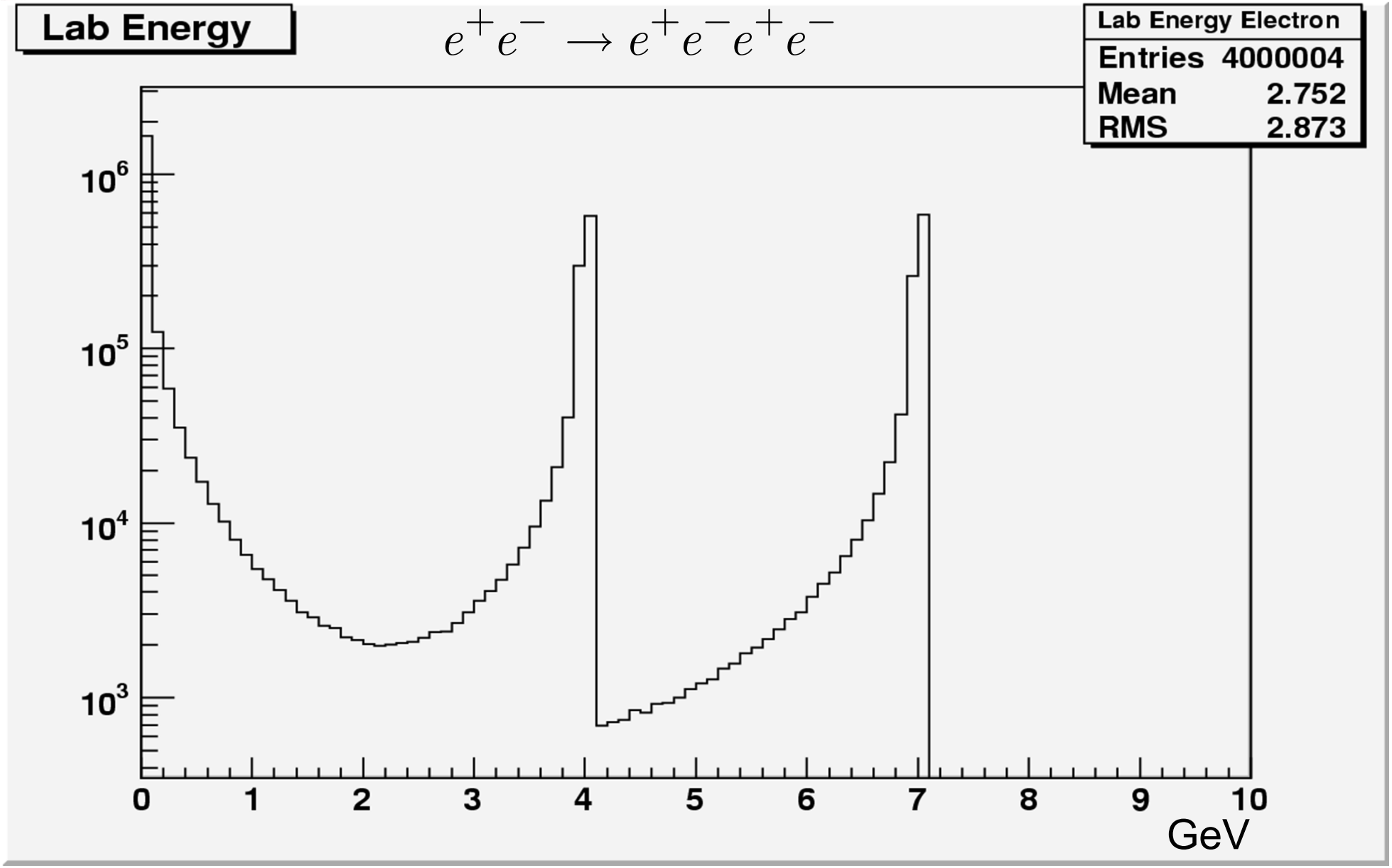
Procedure:

1M events per generator

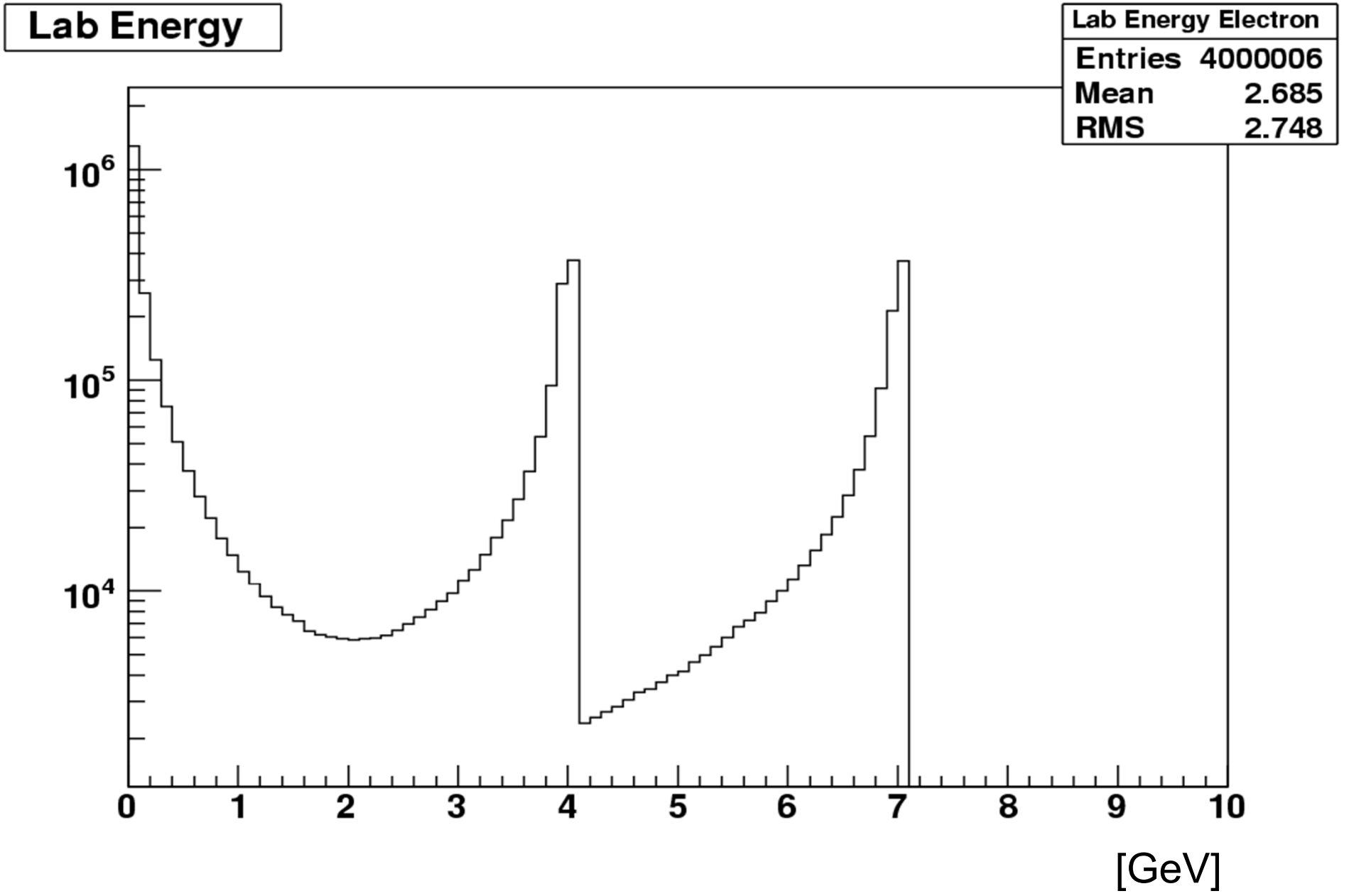
(less for BDK)

- generate events in CM system
- calculate boost from lab to CMS
- boost CMS to lab
- make acceptance cuts (p_T, θ) in the lab

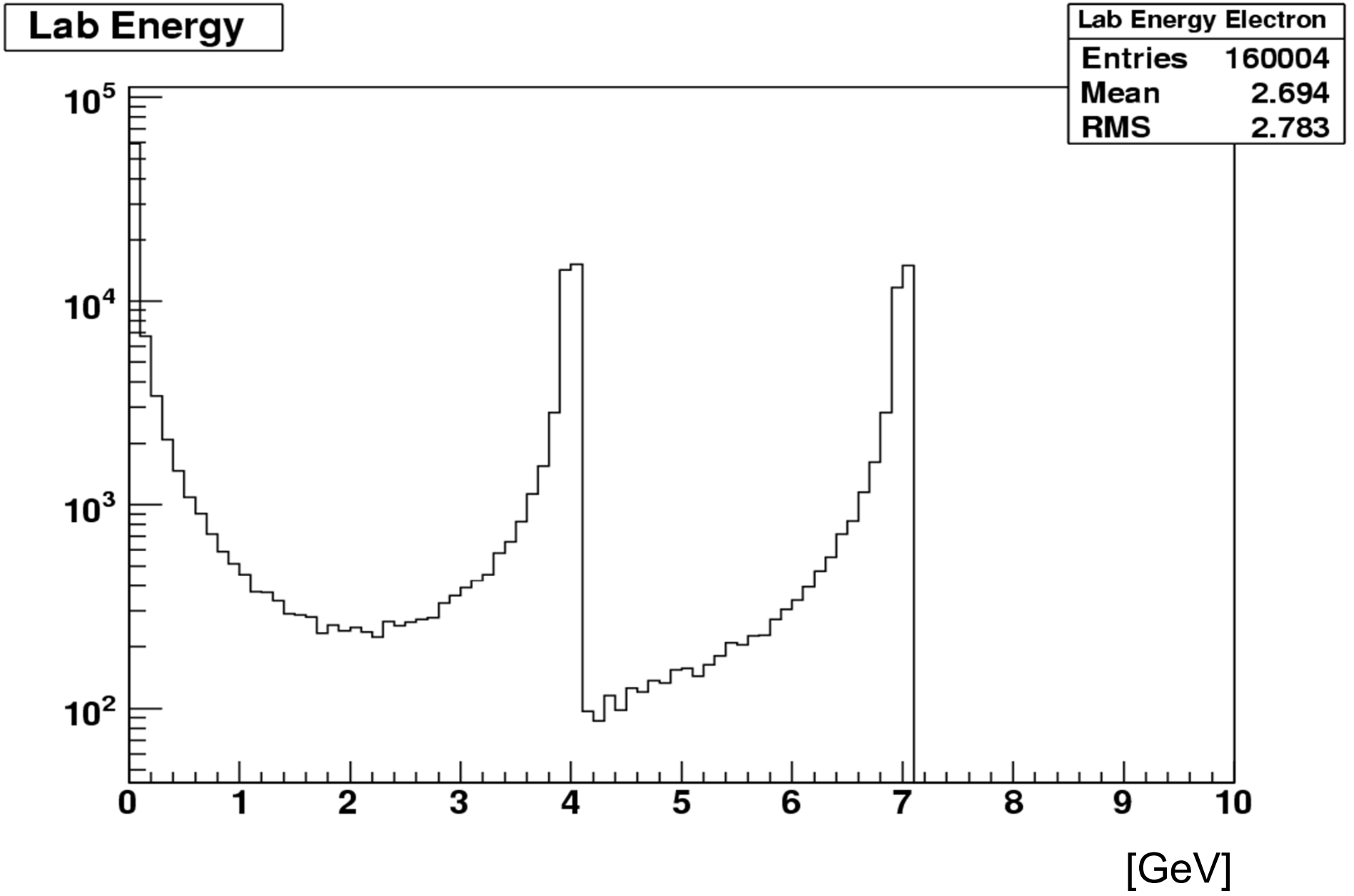
Berends-Daverfeldt-Kleiss (BDK)



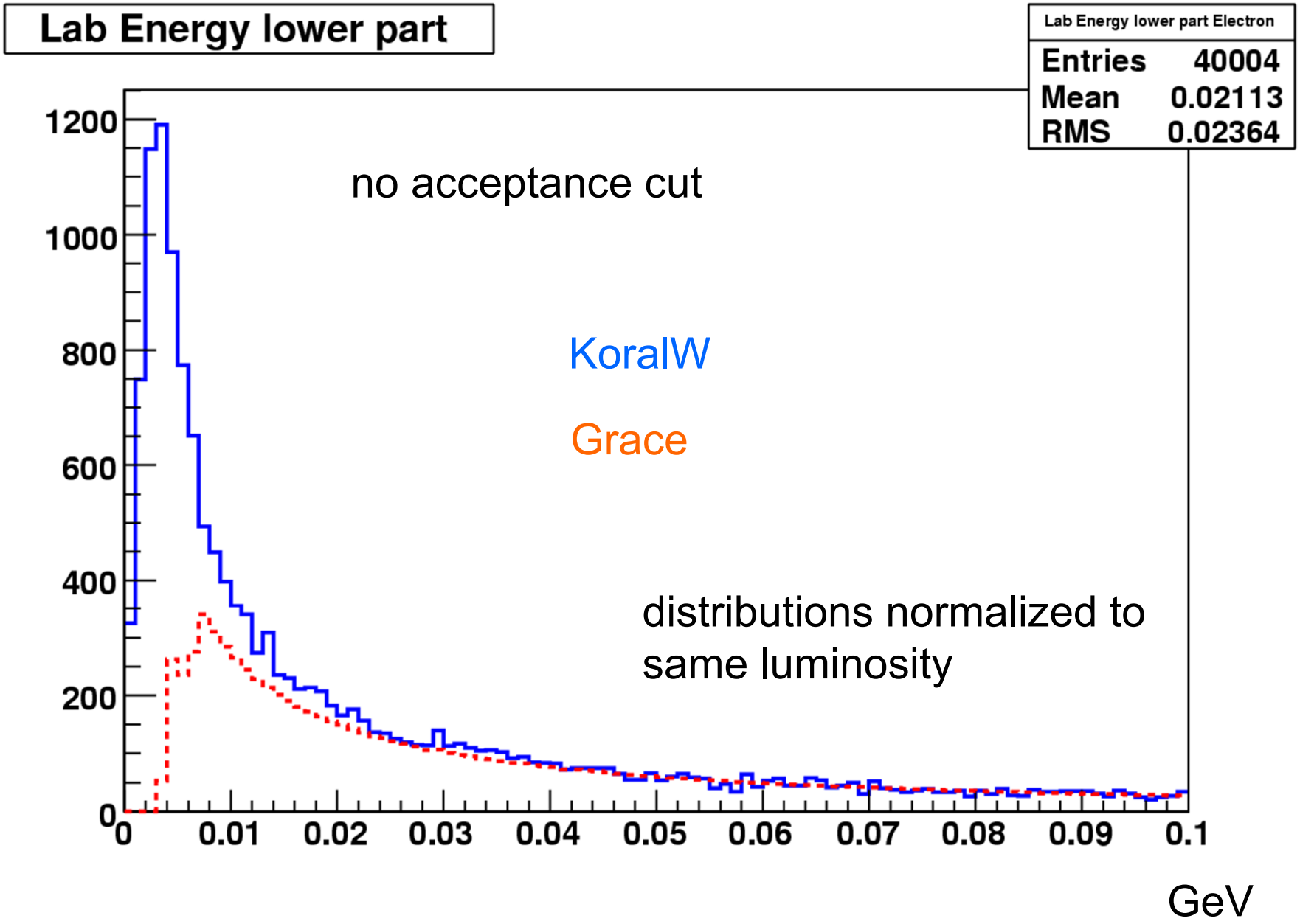
Grace


Lab Energy
Lab Energy Electron
Entries 4000006
Mean 2.685
RMS 2.748
10^6
10^5
10^4
0 1 2 3 4 5 6 7 8 9 10
[GeV]

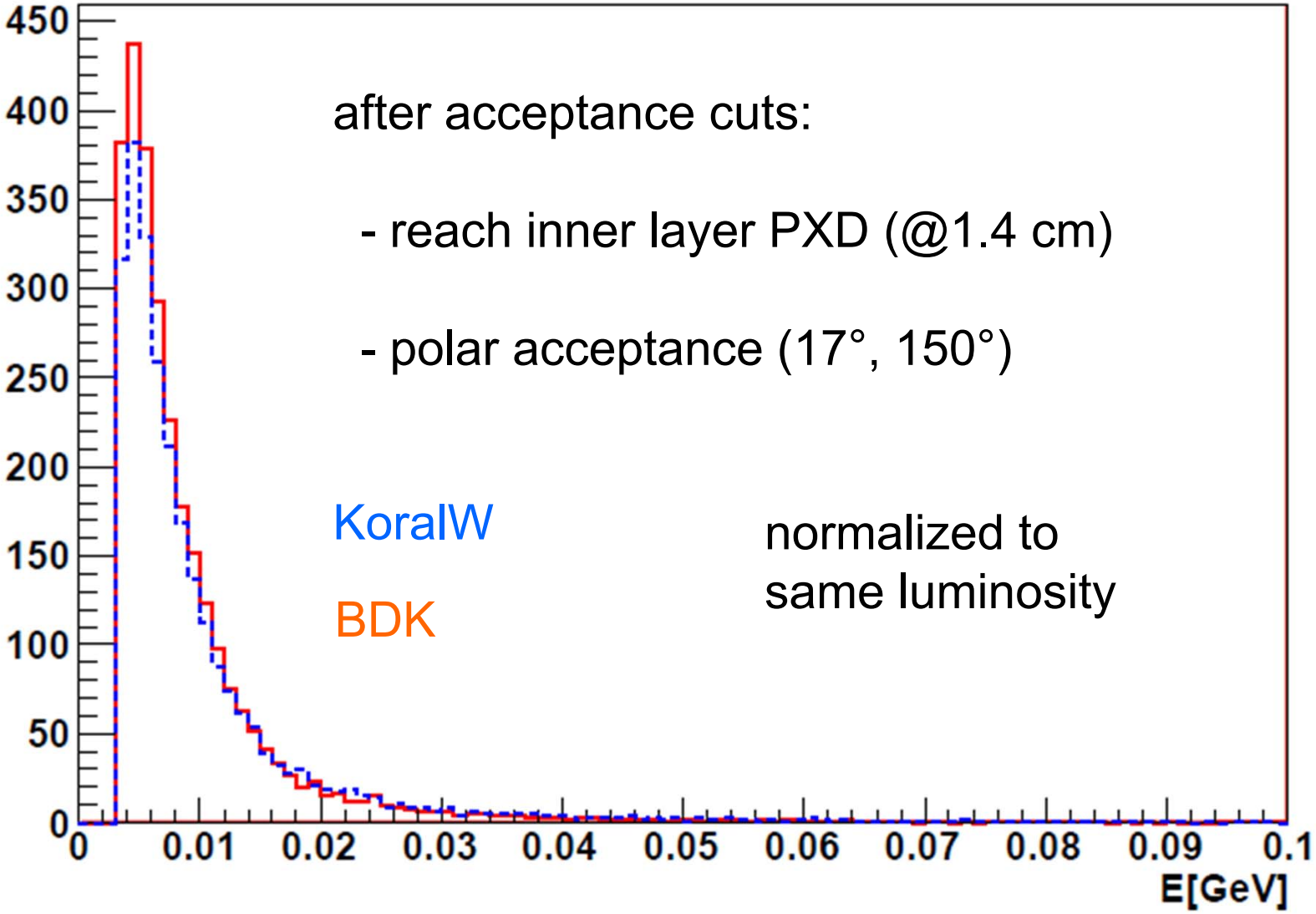
KoralW


Lab Energy
Lab Energy Electron
Entries 160004
Mean 2.694
RMS 2.783
10^5
10^4
10^3
10^2
0 1 2 3 4 5 6 7 8 9 10
[GeV]

Compare Grace to KoralW



Compare BDK to KoralW



Estimates for expected QED rates (I)

BDK: $\sigma = 7.3 \times 10^6 \left[\mathrm{nb}\right]$ (no cut)

KWc: $\sigma = 4.6 \times 10^5 \left[\mathrm{nb}\right]$ (3 MeV cut in momentum)

$$N_{\mathrm{tr}}(\mathrm{bg}) = N_{\mathrm{tr}}^{\mathrm{acc}}(\mathrm{MC}) \cdot \frac{\sigma_{\mathrm{QED}} \cdot L}{N_{\mathrm{ev}}(\mathrm{MC})}$$

ε

DEPFET readout time

$$L = \int \mathcal{L}\, dt = \mathcal{L} \cdot \Delta t = 10^3 \left[\frac{1}{n\mathrm{b}\, s}\right] \times 2 \times 10^{-5} \left[s\right]$$

$N_{\mathrm{ev}}(\mathrm{MC}) = 10^6$ **BDK:** $\varepsilon = 0.146$

$N_{\mathrm{ev}}(\mathrm{MC}) = 4 \times 10^4$ **KW:** $\varepsilon = 0.23$

Estimates for expected QED rates

background tracks per event:

BDK: $N_{\mathrm{tr}}^{\mathrm{bg}} = 2630$

KW: $N_{\mathrm{tr}}^{\mathrm{bg}} = 2519$

Expectation from SuperB MC:

$N_{\mathrm{tr}}^{\mathrm{bg}} = 13800$

This is a factor 5.5 more !!!

Naive estimate of occupancy:

Nr of pixels: $250 \times 1600 \times 8 = 3.2 \times 10^6$

(assume each track lights up 3 pixels)

$0.24\ \%$ ⟷ $1.3\ \%$

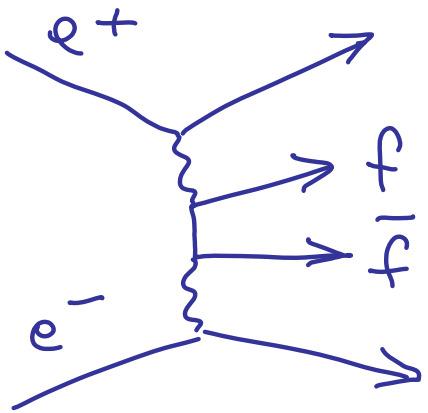
Our number

„SuperB“ number

How to find out what is going on?

- Two-photon processes (and MC) have been tested so far only at high momentum transfers (PETRA, PEP, LEP …)

  single tag,
  double tag,
  no-tag with high pt secondaries



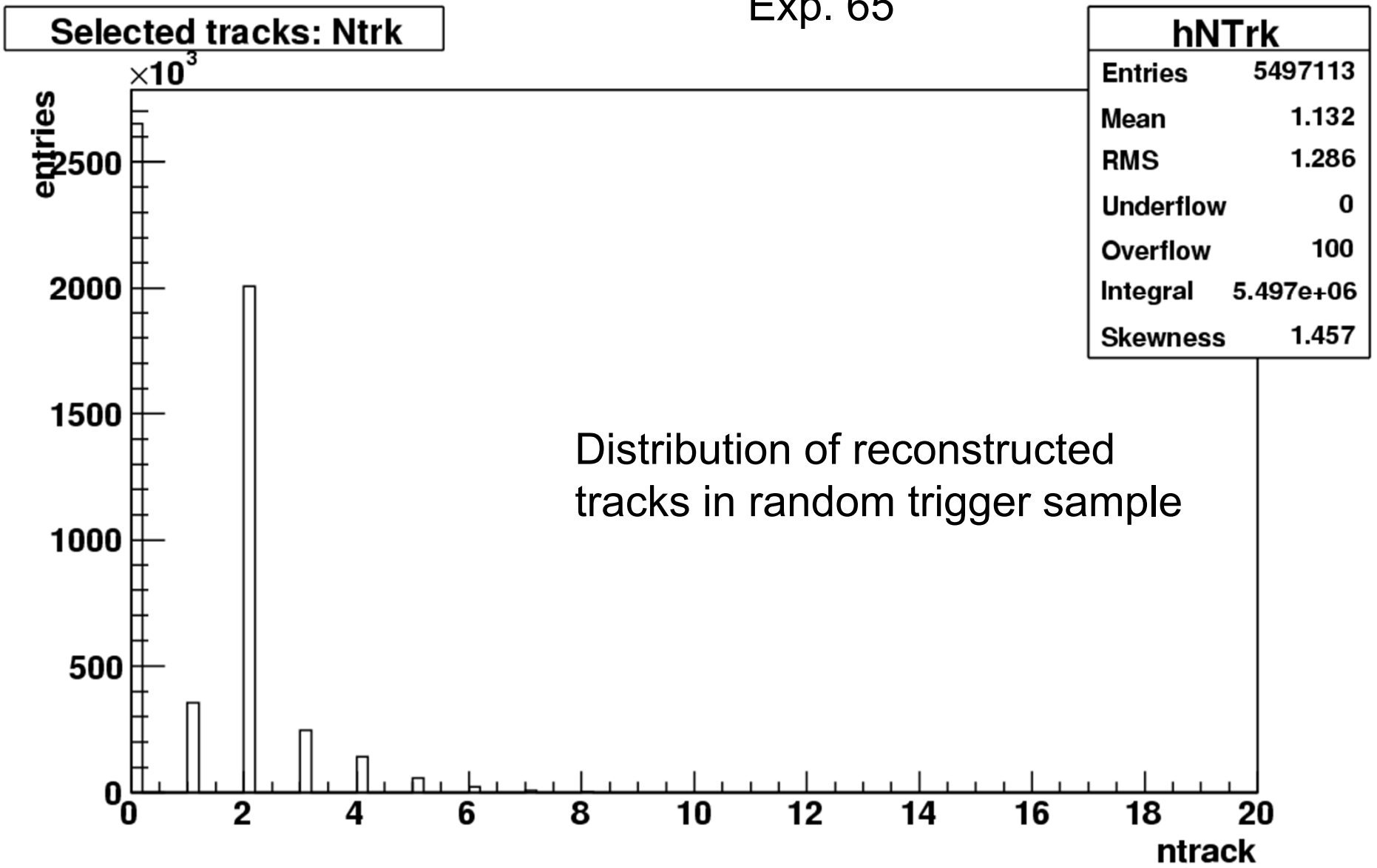
- Are the MC‘s correct at our low energy ?
  (never tested for our case!)

  B-factories:
  no-tag with **low pt** secondaries (no trigger!)

- Proposal: do a dedicated experiment at KEKB with
  random triggers (performed on May 28, 2010)

Study of Random Triggers in Bellel

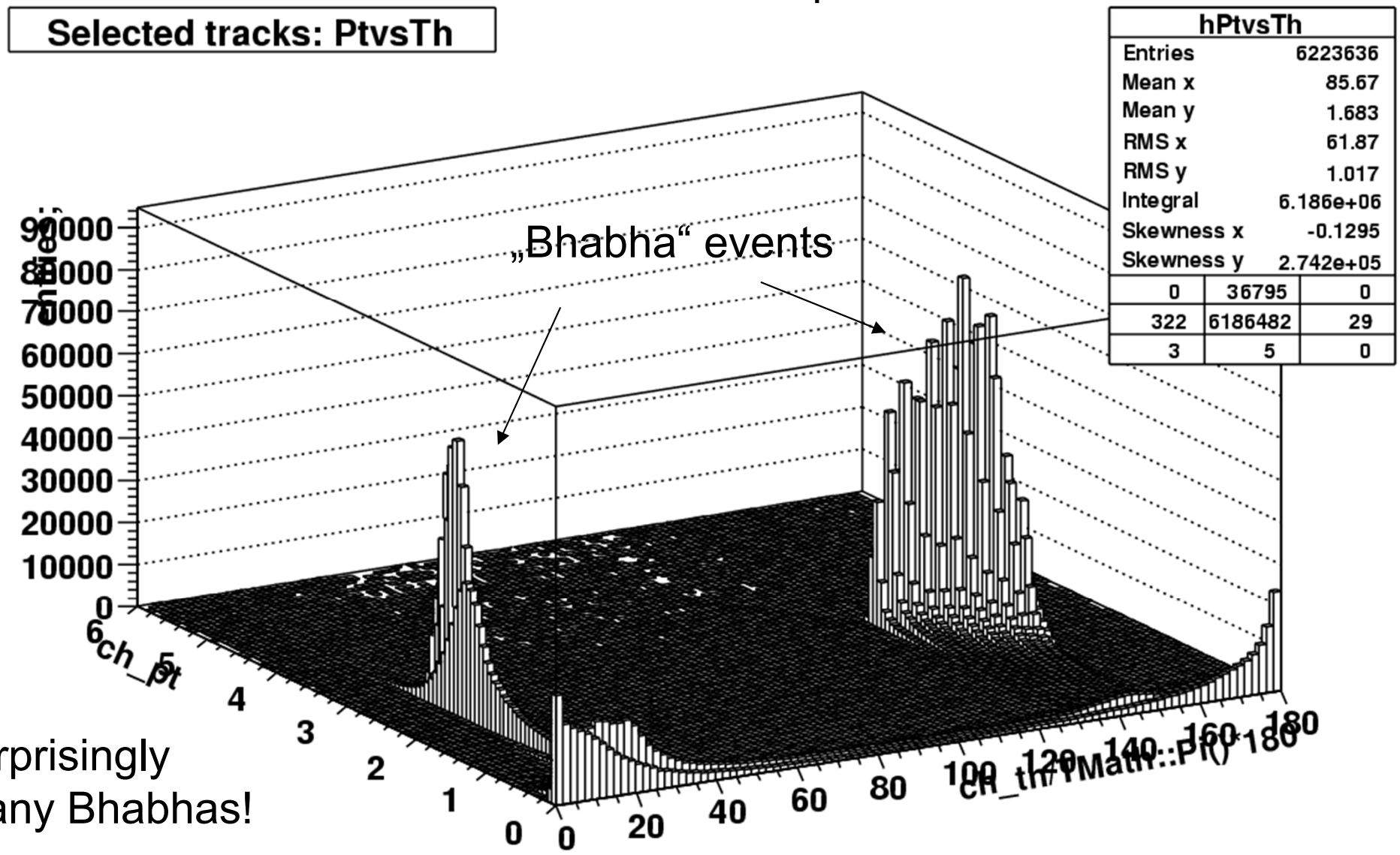
Exp. 65



Distribution of reconstructed tracks in random trigger sample

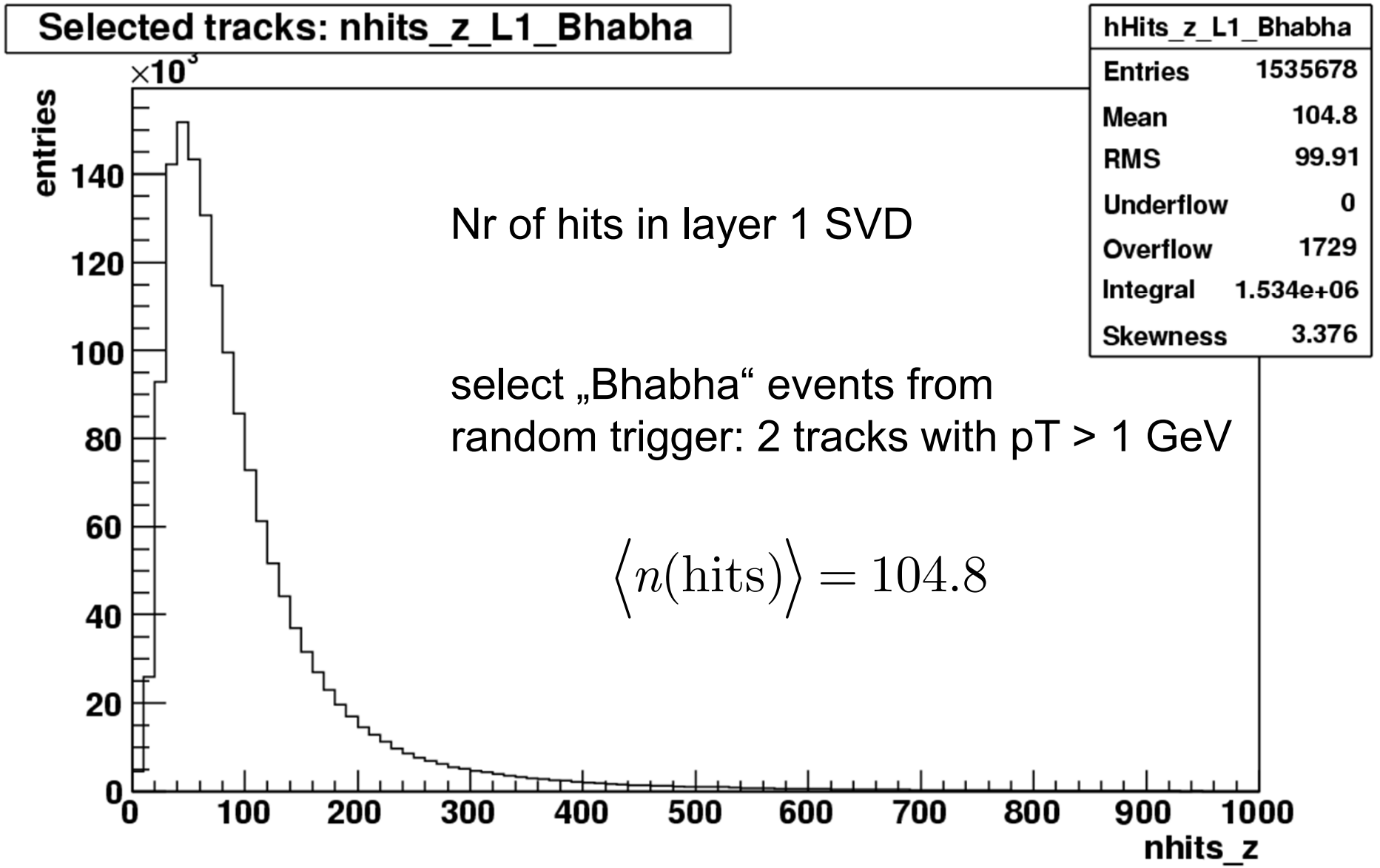
Random Triggers: Polar angle vs pT

Exp. 65



surprisingly
many Bhabhas!

Random Triggers: Bhabha selection

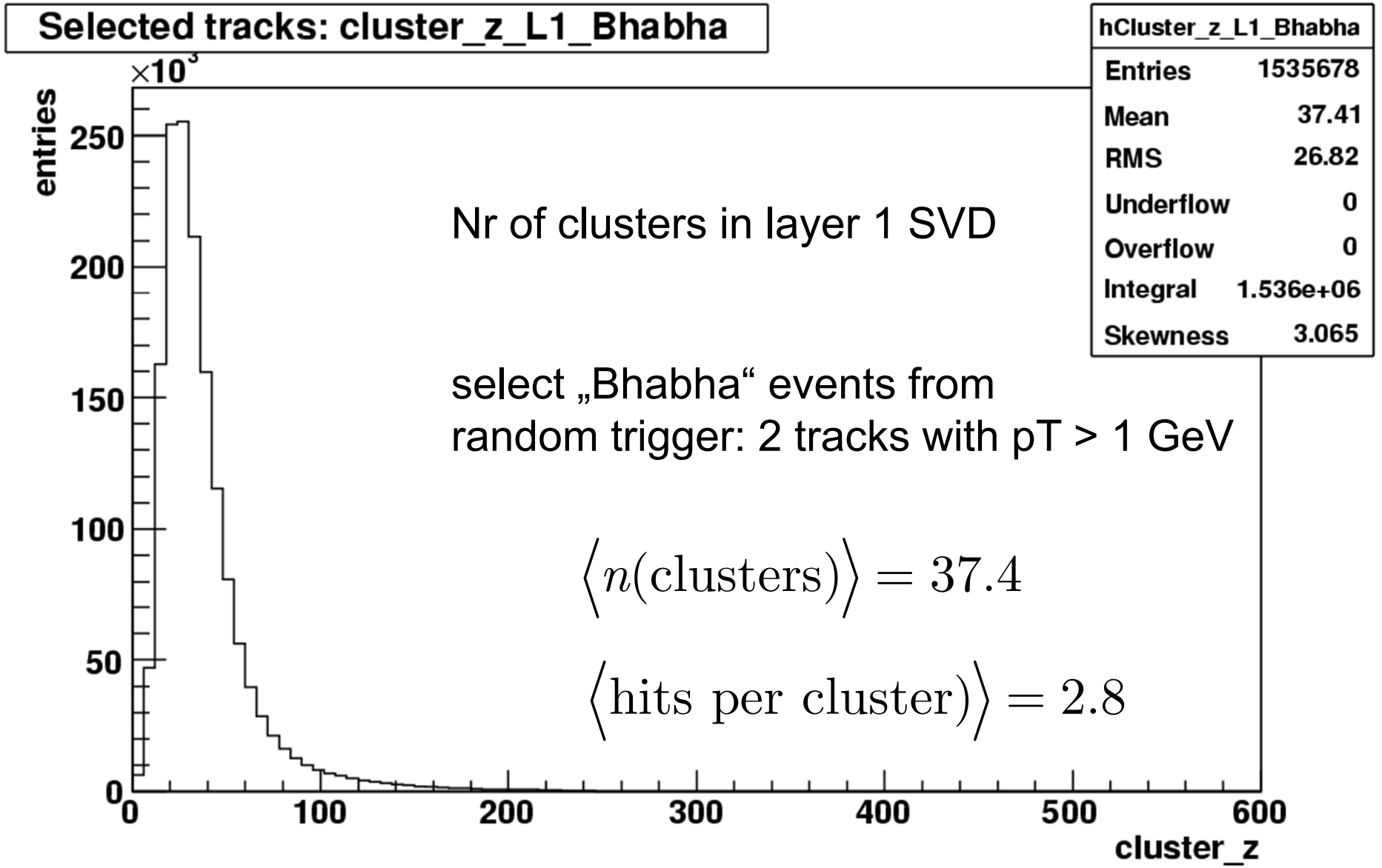


Nr of hits in layer 1 SVD

select „Bhabha“ events from
random trigger: 2 tracks with pT > 1 GeV

$$\langle n(\text{hits}) \rangle = 104.8$$

Random Triggers: Bhabha selection



Nr of clusters in layer 1 SVD

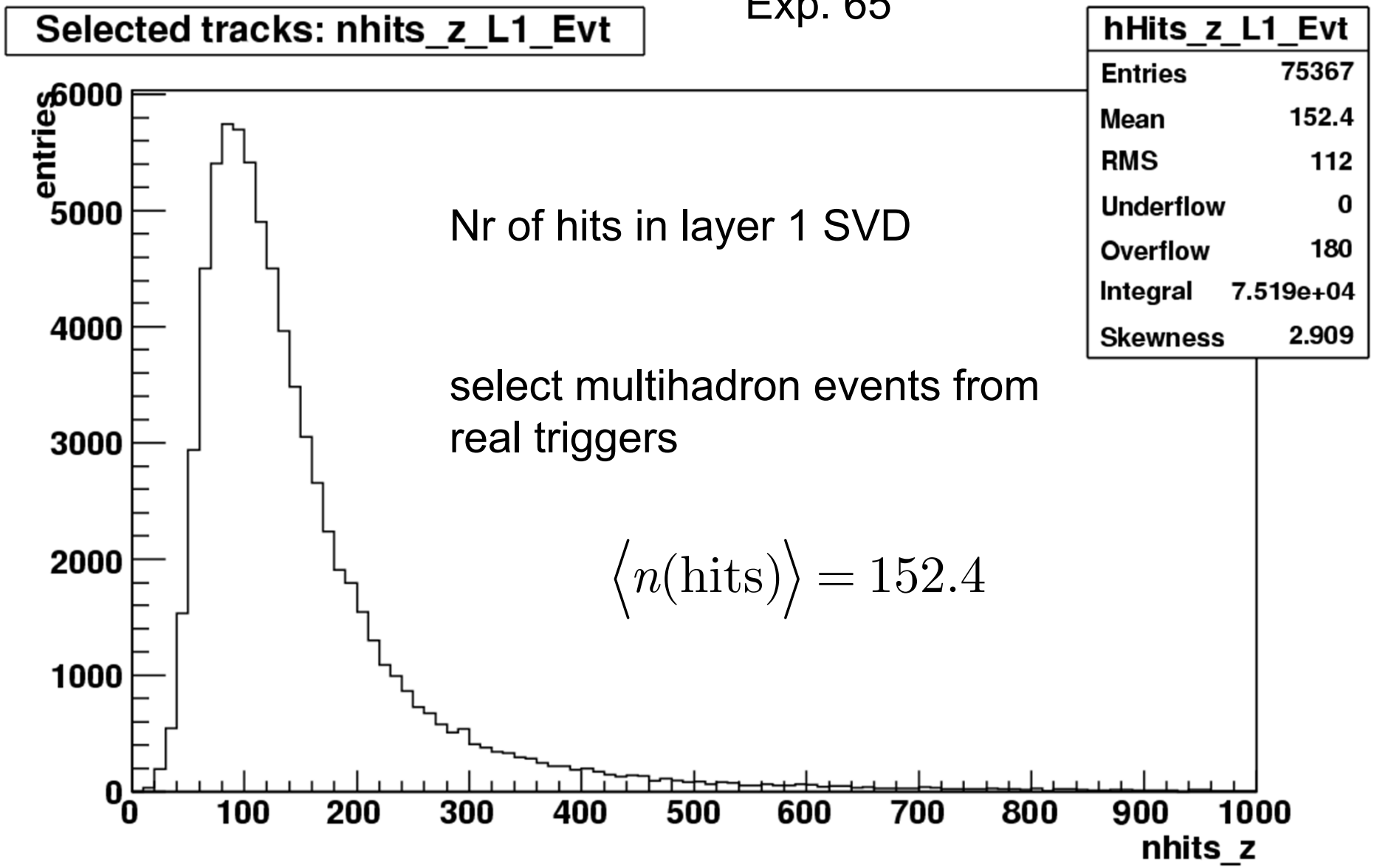
select „Bhabha“ events from
random trigger: 2 tracks with pT > 1 GeV

$$\left\langle n(\text{clusters}) \right\rangle = 37.4$$

$$\left\langle \text{hits per cluster} \right\rangle = 2.8$$

Control Sample: Multihadron events

Exp. 65

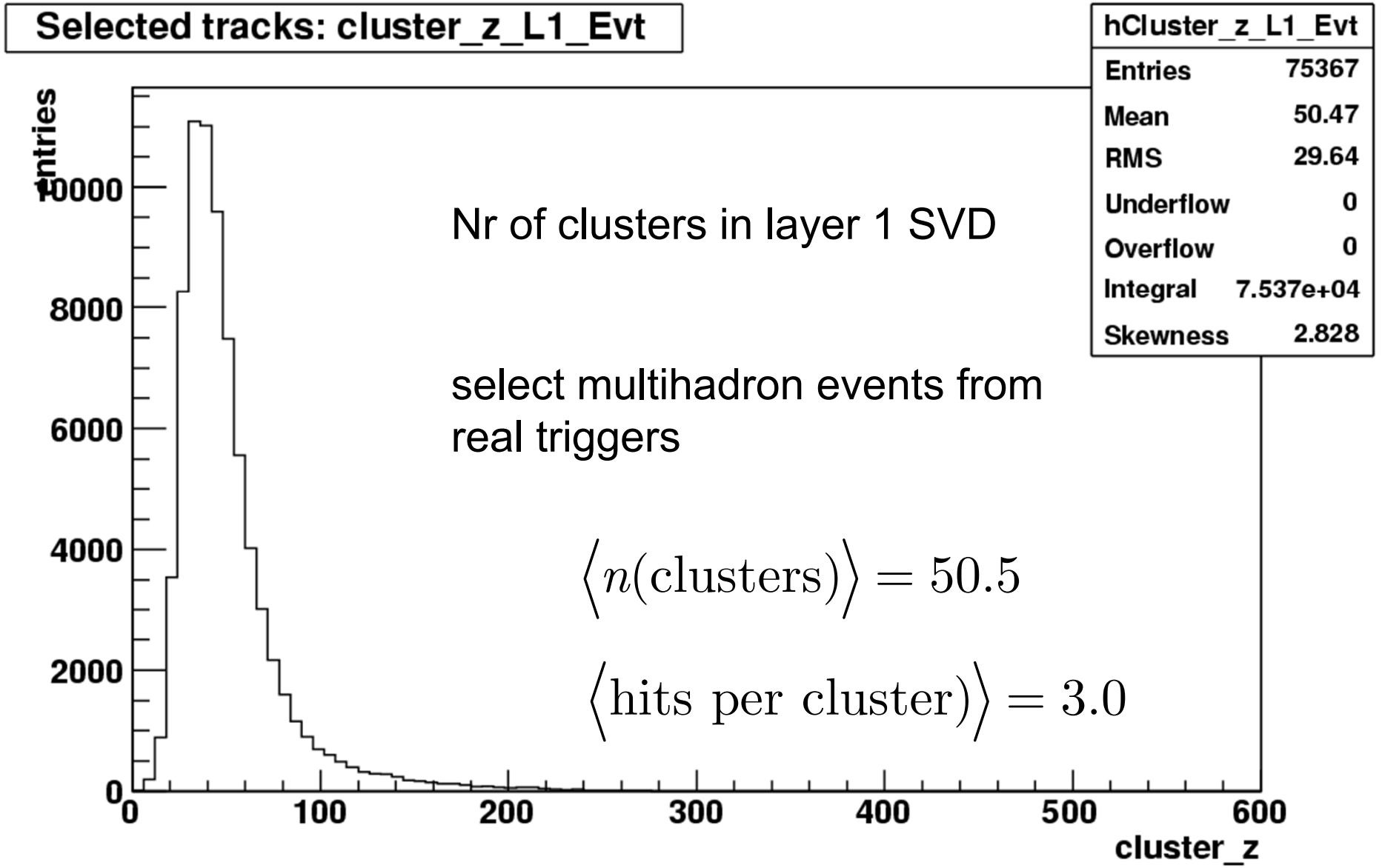


Nr of hits in layer 1 SVD

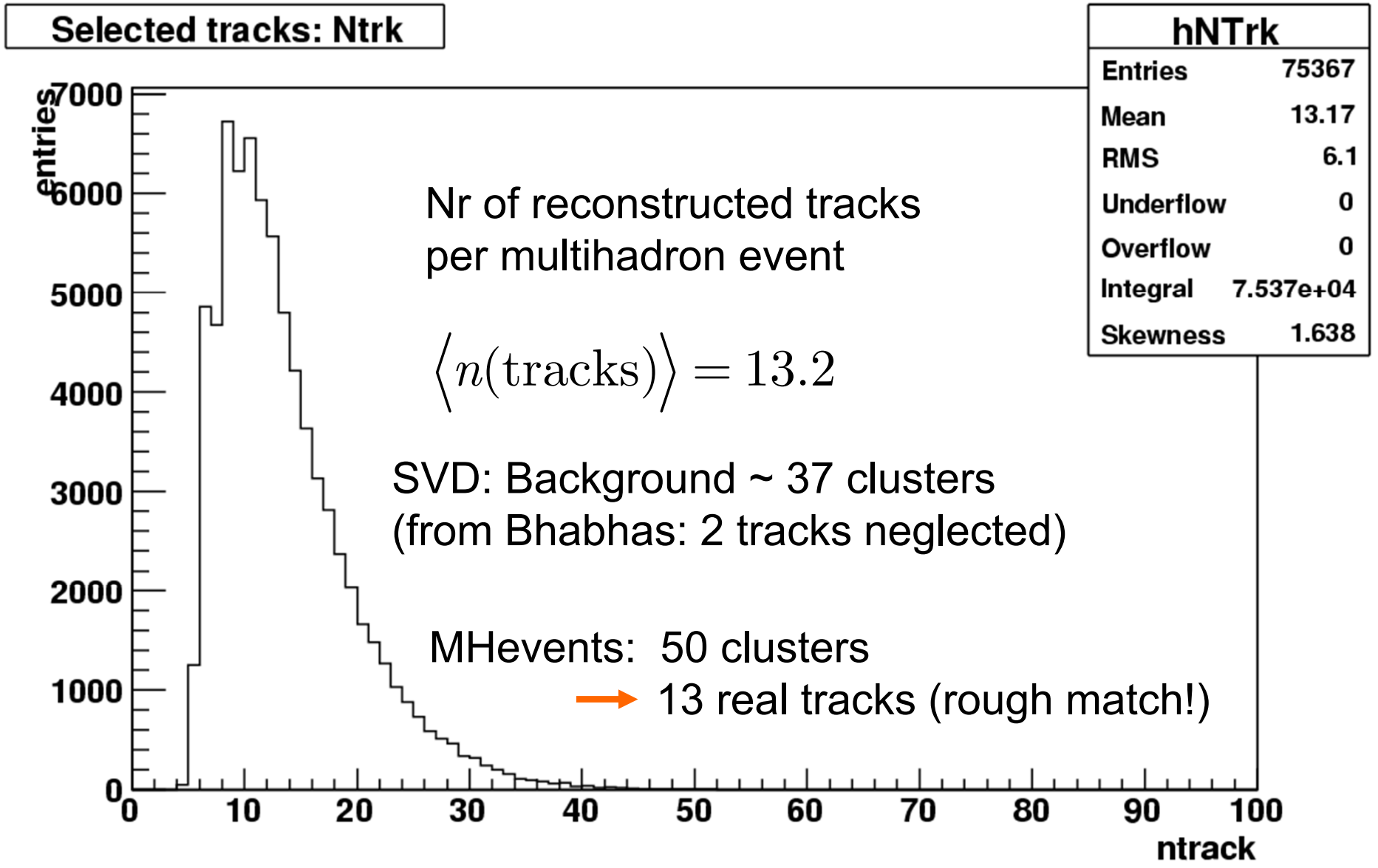
select multihadron events from real triggers

$$\langle n(\text{hits}) \rangle = 152.4$$

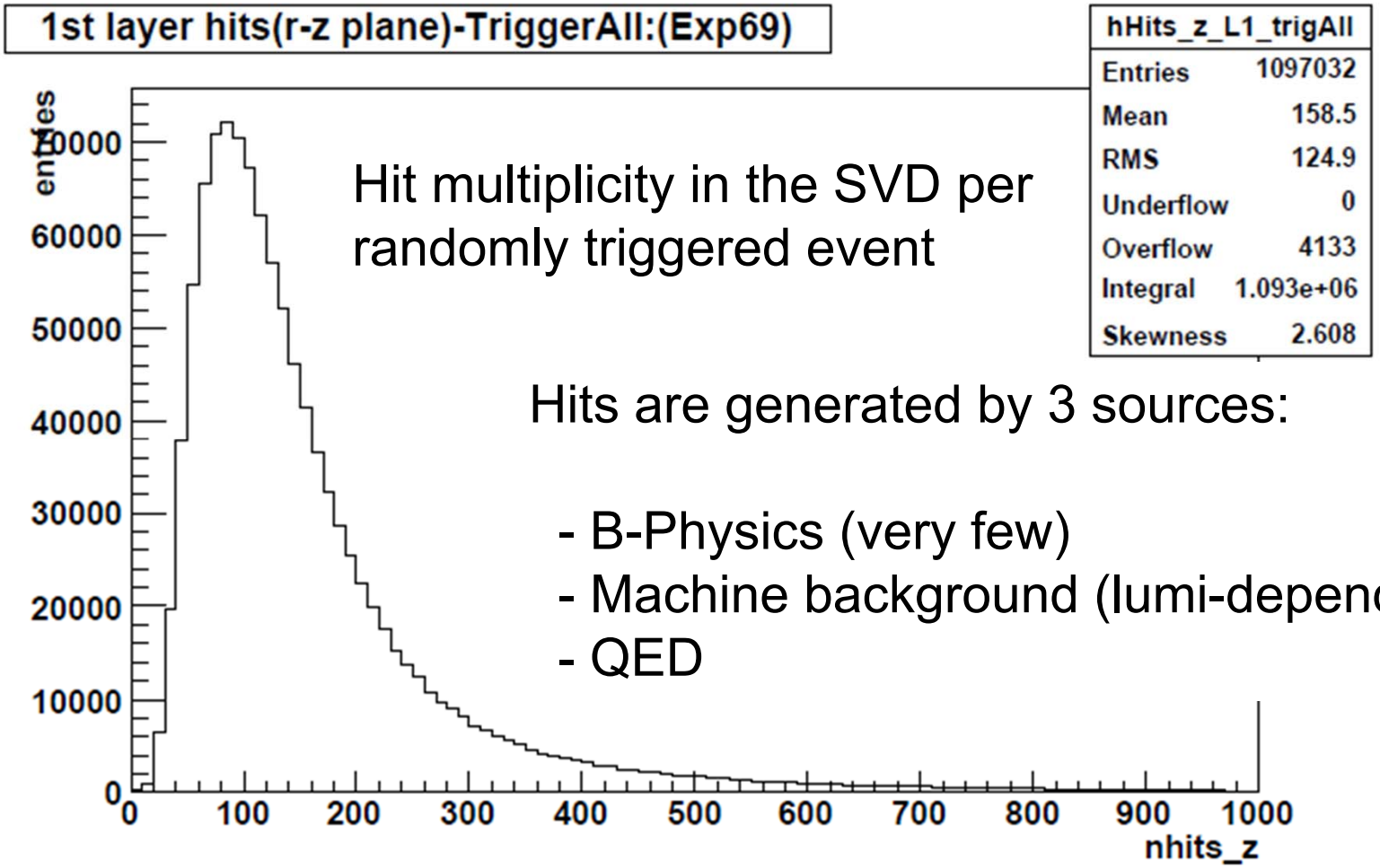
Control Sample: Multihadron events



Control Sample: Multihadron events



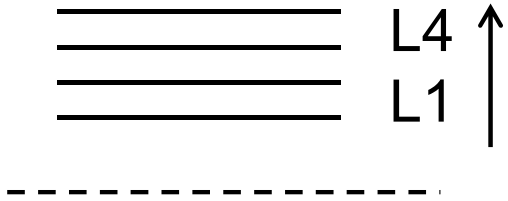
„Measurement“ of QED



Hit multiplicity in the SVD per randomly triggered event

Hits are generated by 3 sources:

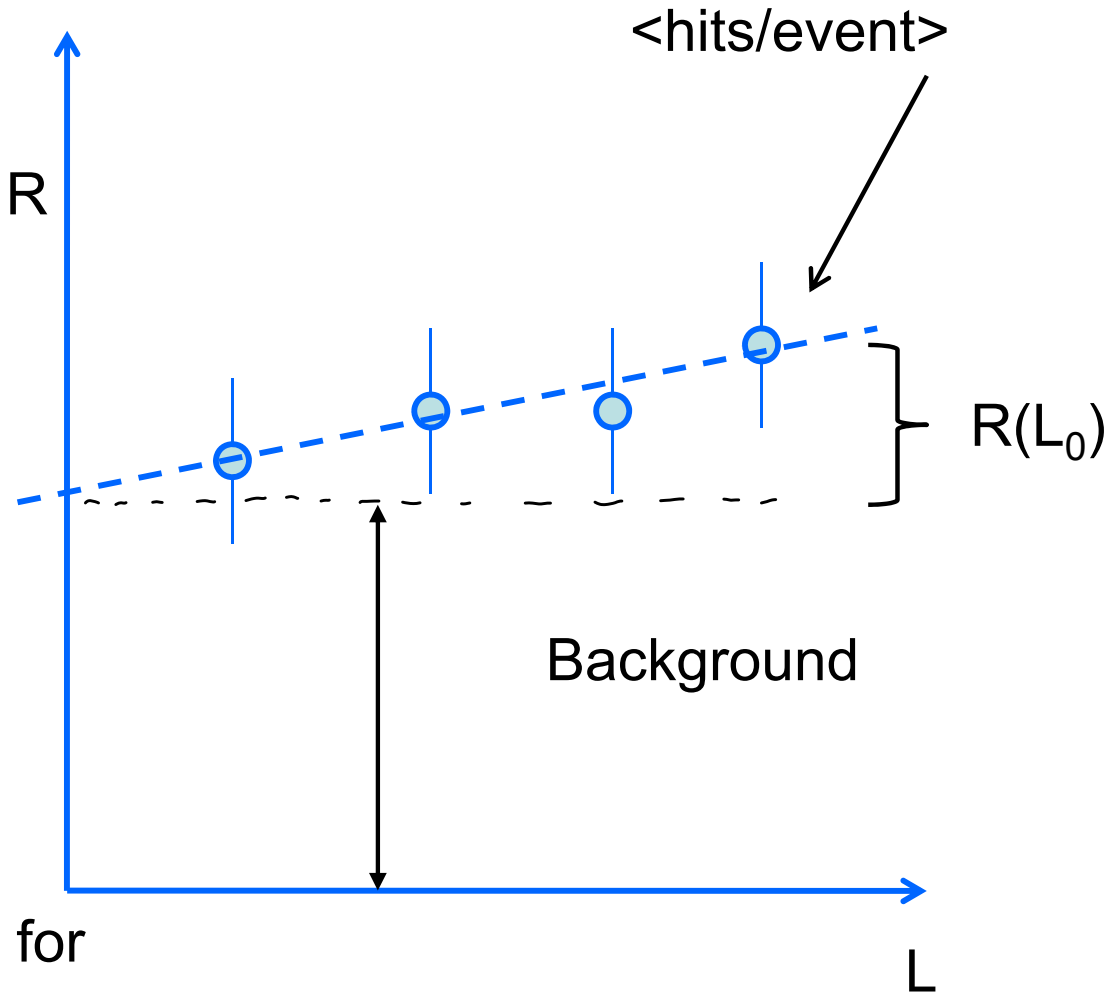
- B-Physics (very few)
- Machine background (lumi-dependent?)
- QED



Task: try to separate the three sources by measuring <hit/event> as function of L

Simple-Minded SVD Hit Analysis

- Measure R=<hits/event> as function of luminosity (given by Bhabha events)
- Extrapolate to L=0 to get „non-QED“ background
- Difference = QED rate
- Vary the luminosity in different ways to control the systematics.
- Check outer detector (CDC) for non-QED (2γ) contributions



What Do We Expect ?

SuperKEKB Simulation: ~2500 tracks per PXD frame
(~13800, if SuperB number is right)

L ~ 1000 / nb s
Integration time = 20 µs

Scale to KEKB:

L ~ 10 / nb s
Integration time = 2 µs

our simulation
1st layer of SVD
(radius corrected)

~ factor 1000 less: 1.2 tracks / SVD frame

=> 3.7 hits / frame on average

(radius correction included)

(20, if SuperB number is right)

Runs on May 28, 2010

Random trigger rate: 400 Hz (new, truely random trigger !)

Bhabha trigger rate: 50 Hz moderate start luminosity (~ 10/nbs)

Each experiment started with a run ~10 /nb s („default“)

Run unit: 500 k triggers at 400 Hz = 30 min (including beam setup)

vary luminosity in steps of 2/nb s

10, 8, 6, 4 /nb s
about 500 k triggers per run

Together with setup for triggers / beams: 17 hours (8:00 – 1:00 (Saturday)

QED Runs and Data Sample

- Exp. B (increase vertical beam size in HER)

  Run 401 – 411 (each run 500 k triggers)

  $$\sigma(y) \in [2.10 - 2.83]\mu m$$

- Exp A (separate the beams vertically)

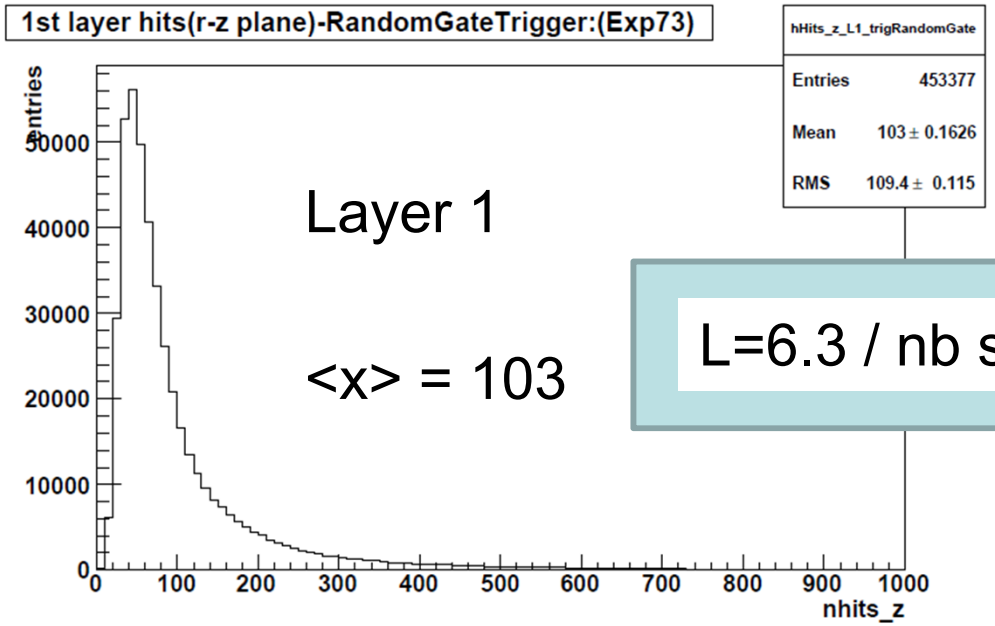
  Run 415 – 420 (each run 500 k triggers)

- Exp C (change bunch currents by stopping injection)

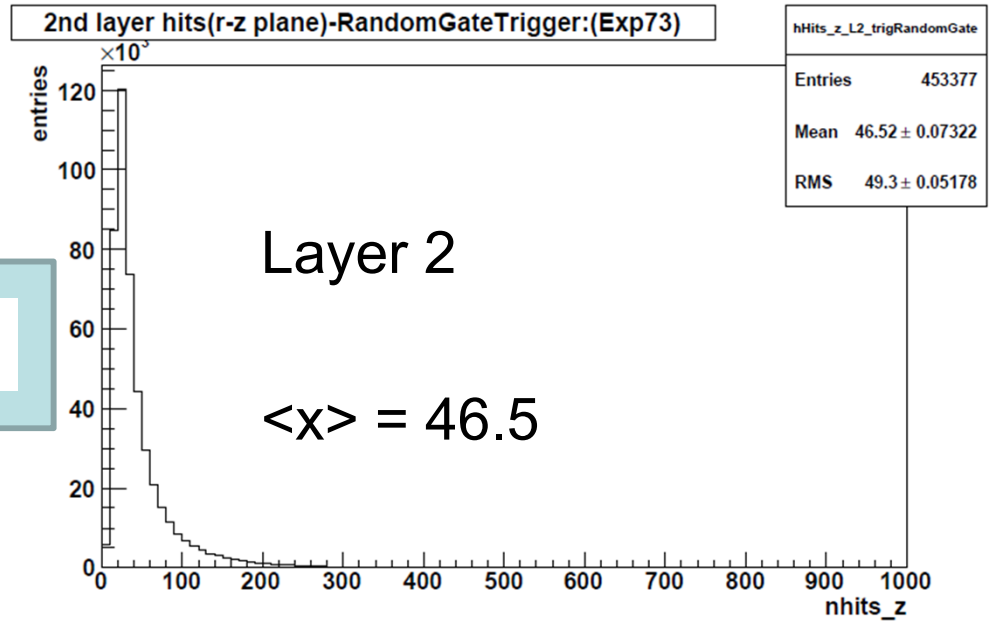
  Run 421 – 427 (each run 10 min)

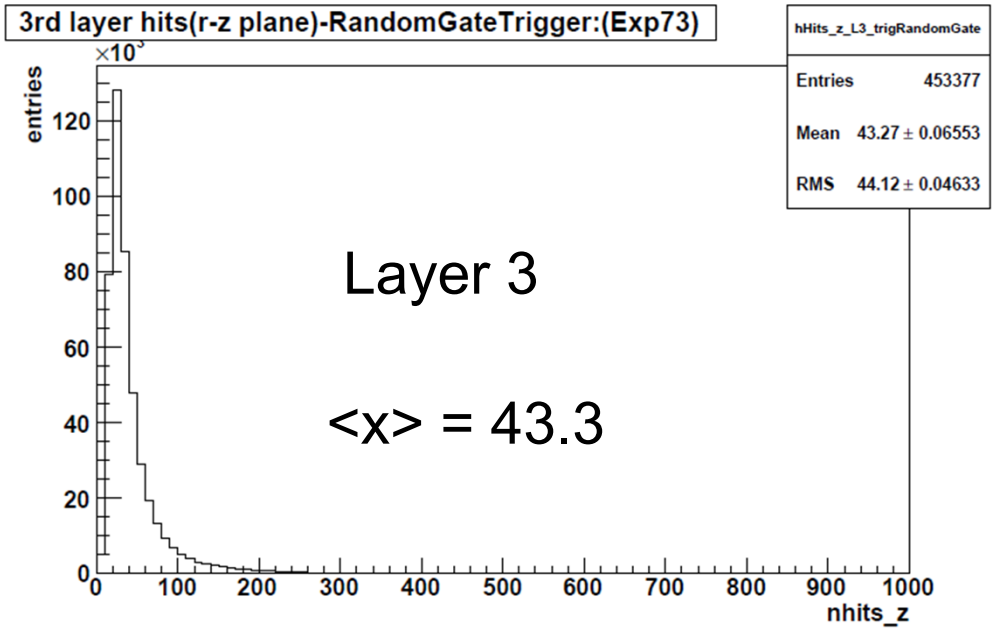
  Total amount of triggers / exp ~ 2 Million

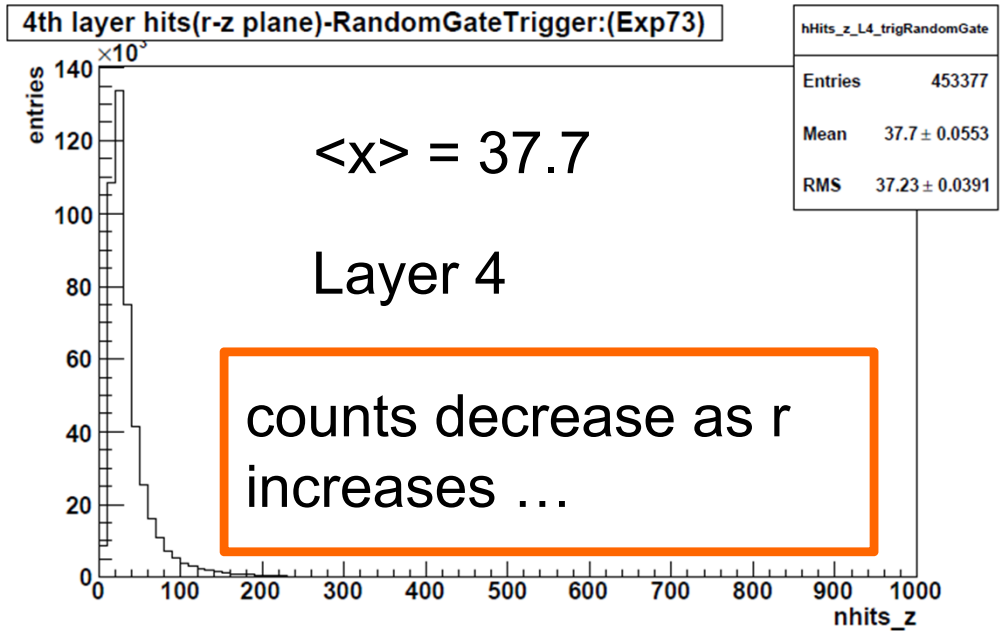
Run 408 Exp B z-strips (similar for φ strips)



L=6.3 / nb s

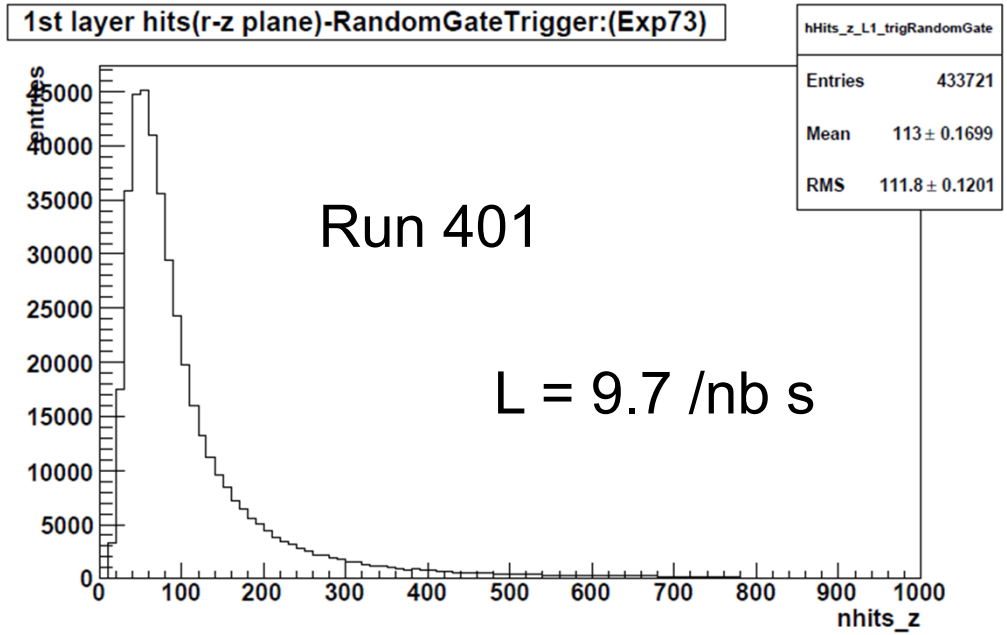


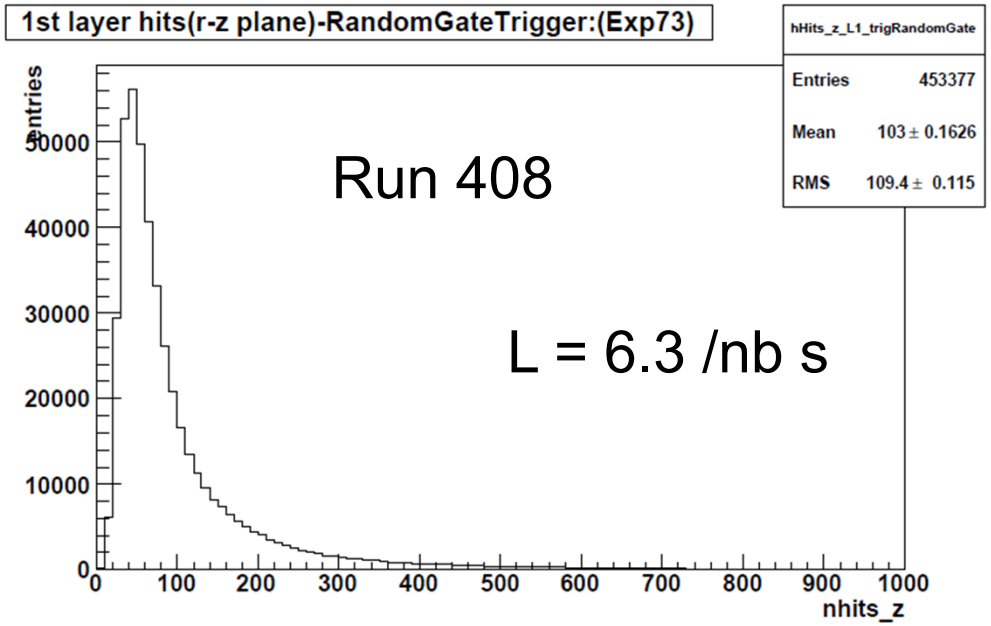




counts decrease as r increases …

Data Sample: Changing Luminosity …





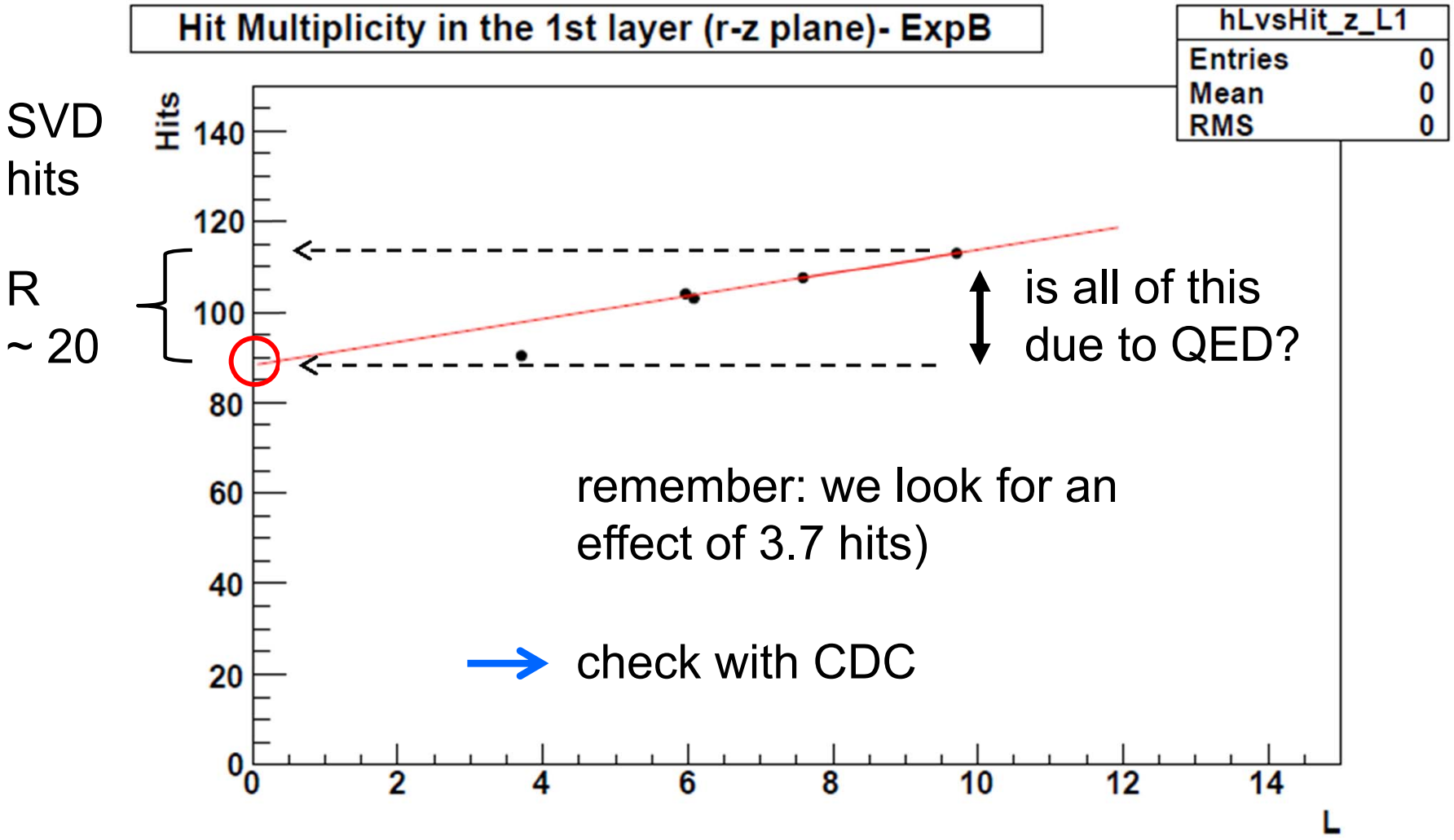
First SVD layer:

$R = \langle n_{hits} \rangle = 113$

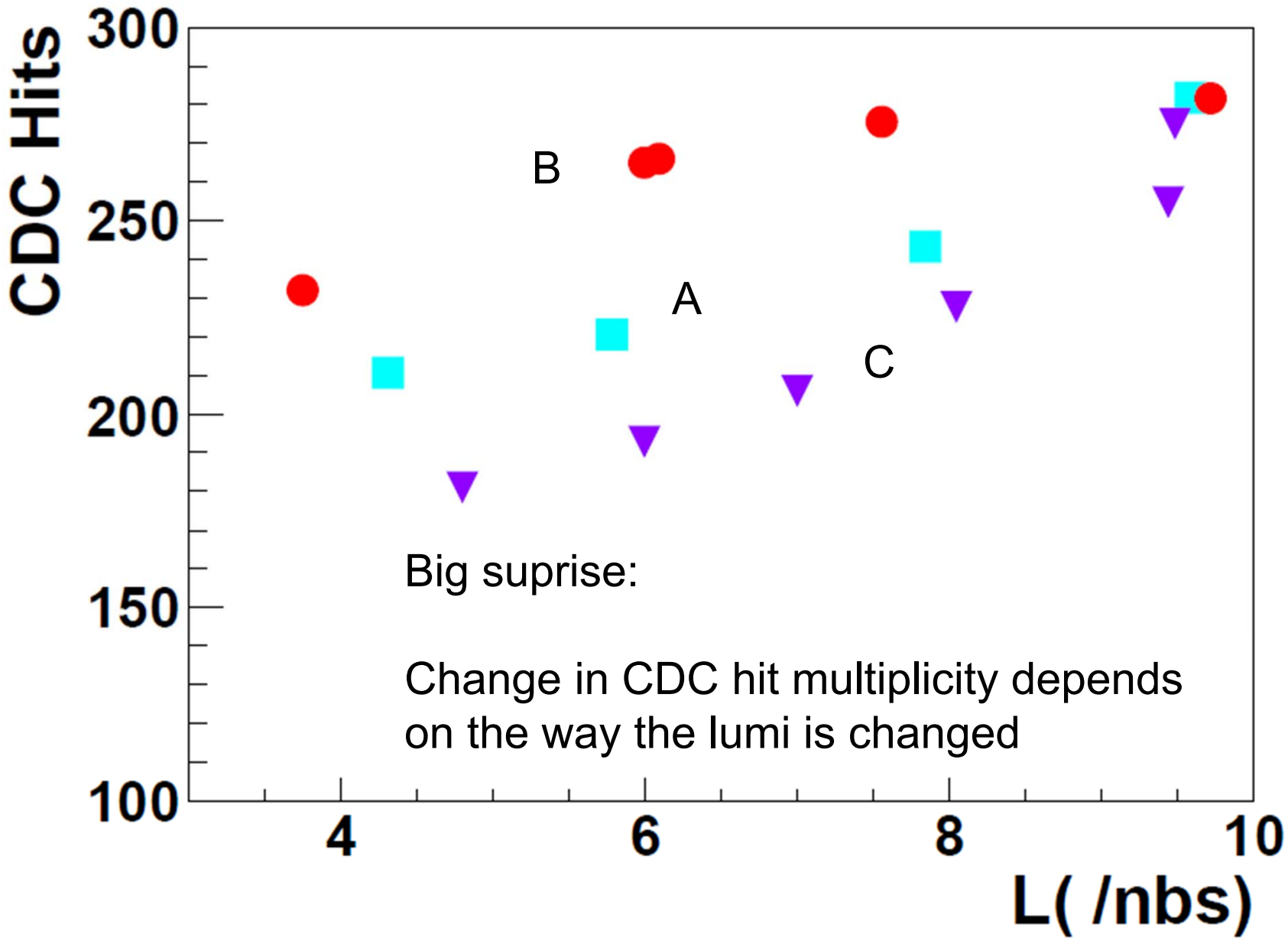
Hits indeed decrease !

$R = \langle n_{hits} \rangle = 103$

Exp B: Changing Luminosity …



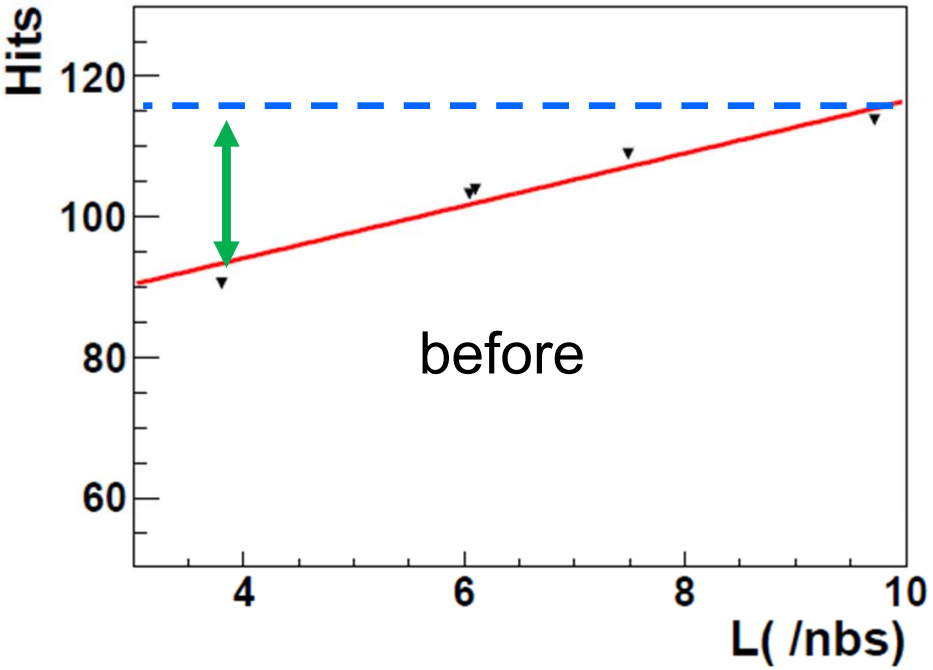
Changing Luminosity: CDC Hit Mult.



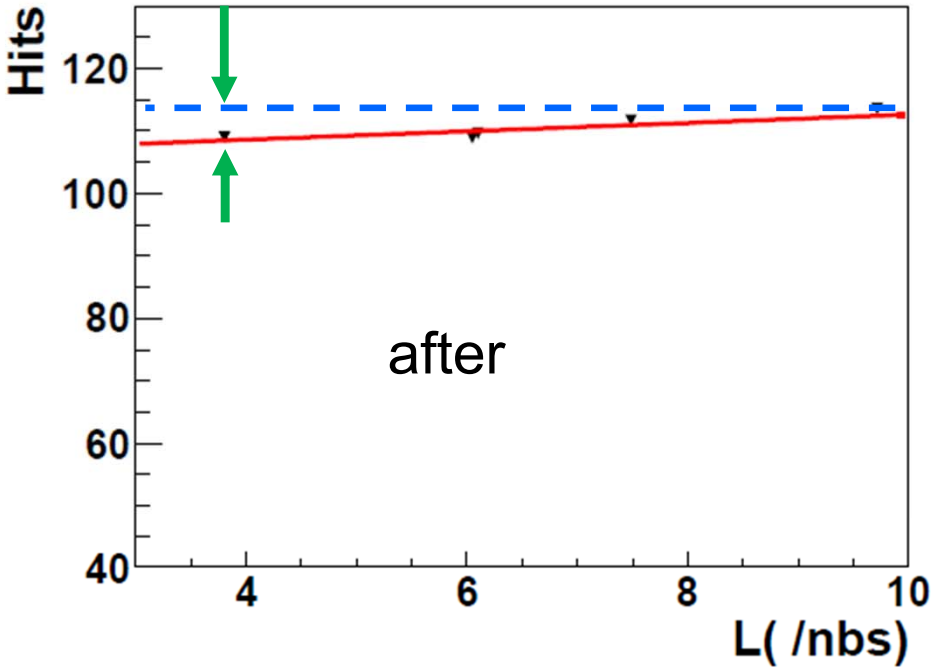
Background Correction

For each experiment, each data point:

$$N^{SVD}_{hits\_corr}(L_i) = N^{SVD}(L_i) \times \frac{N^{CDC}(L_{max})}{N^{CDC}(L_i)}$$

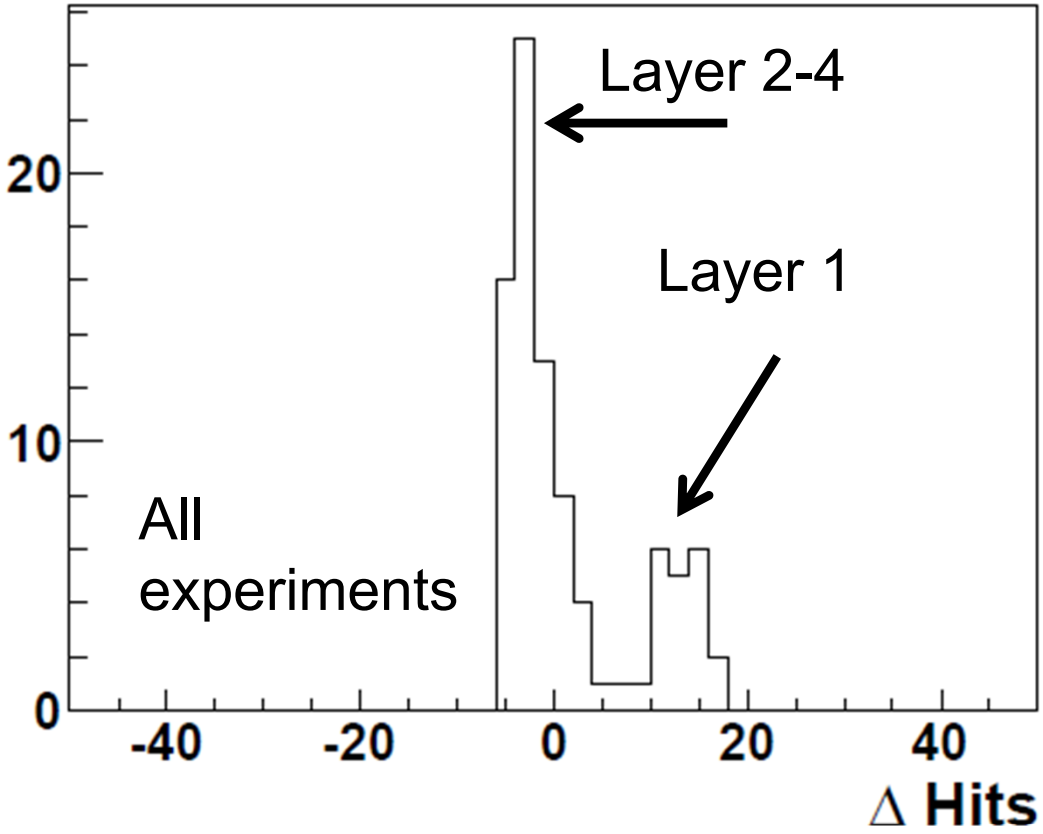


(a) exp.(B)



(b) exp.(B)

Results



1st layer hit hardest,

higher layers much less

consistent with full Monte Carlo simulation

Full Monte-Carlo simulation: 3 x naive expectation: **curlers !**

Experiment	SVD layers	Hits	QED hits	KoralW	SuperB(BDK)
Belle	1	~ 100	13.3 ± 2.6	11.31	62.2
	2 - 4	~ 45	-2.9 ± 2.1	2.38	13.1
Belle II	Occupancy (1st PXD)			0.7%	4.0%

(details: see Belle Note)

Conclusions

- Two-photon process dominant source of background at SuperKEKB, potentially dangerous for a pixel detector (occupancy)
- (Our) calculations, using 3 different generators, indicate that background is NOT exceeding a critical limit for the PXD
- This is in contrast to the SuperB number („10 MHz/cm^2“):
  We extract a track rate of 1.8 MHz/cm^2“)
- Dedicated experiments carried out at KEKB (just before the shutdown).
- Simple-minded counting model employed to extract surplus hits from 2-photonQED over other backgrounds (CDC used for correction)
- Our simulations are in agreement with experiment
- PXD‘s innermost layer seems safe, despite 20 µs integration time

BACKUP

BDK initialize

```
********** Parameters from input card **********
 Process number =  5
 Beam energy =      5.290 GeV
Fractional momentum for e- beam =   0.00000   0.00000   1.00000
Fractional momentum for e+ beam =   0.00000   0.00000  -1.00000
 W(minimum) =      0.001 GeV
 Theta of the produced particles =     0.00 -   180.00 deg
 Rejection scheme =  2
 Estimated maximum of the weight =   1.00
 Estimated maximum of the FT     =   3.50
 WAP =   1.0000E+00  1.0000E+00  1.0000E+00  1.0000E+00
 WBP =   1.0000E+00  1.0000E+01  1.0000E+04  1.0000E+04
 ( optional input parameters )
 Mass of the L =      1.400 GeV
 Particle code of L =  4
 Charge of the L =    0.667
 Random-number INIRAN param. =          1
 ************************************************************

0PROCESS NUMBER    5 HAS BEEN SELECTED
```

Trip to Krakow in Feb. 2010

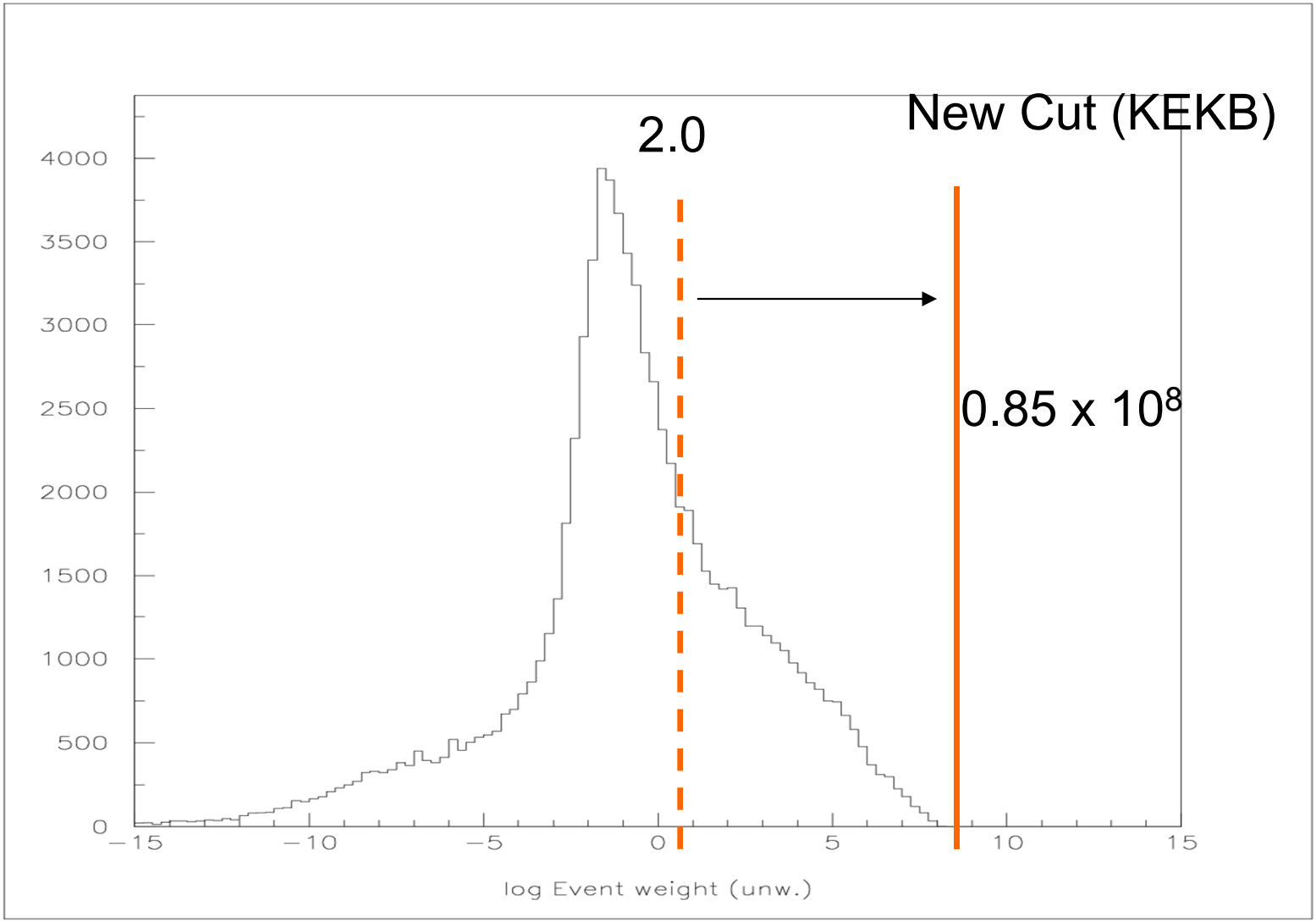
- Direct contact with authors for almost 2 days
- Many tests of the program at large (LEP) and small (KEKB) energies studying the various cutoffs (using WEIGHTED events, fast, recommended by the authors)
- Conclusions:

  to the surprise of the authors, the program seems to behave well even at very small cutoffs.

  When turning to the UNWEIGHTED events, however, a problem‘ was dicovered with the maximum weight

  this needed to be adjusted for the new energies!

The Weight Problem



Old Cut (OK for LEP)