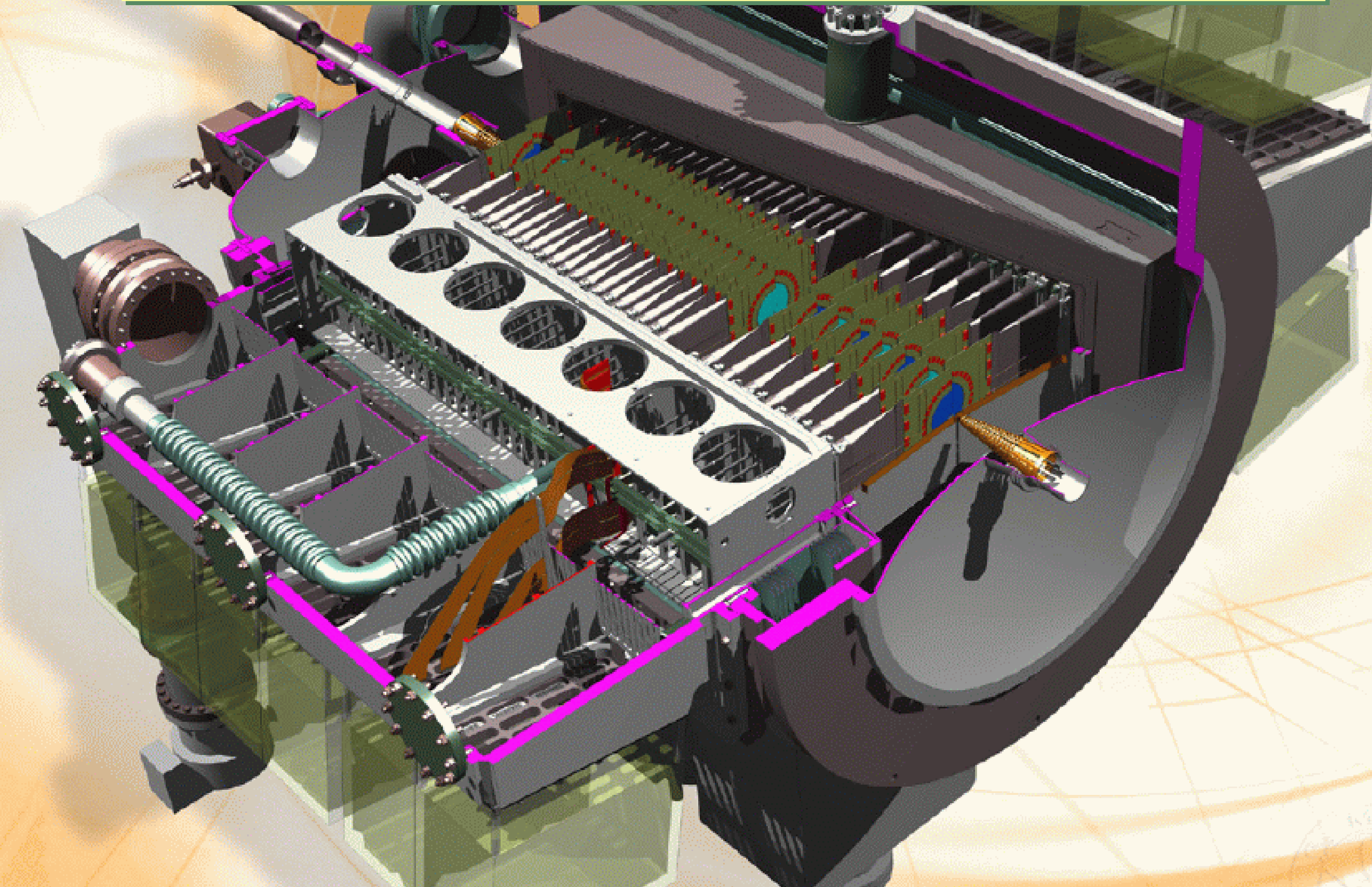
Luminosity Monitoring at LHCb

Massimiliano Ferro-Luzzi, CERN/EP

Geneva, December 2002



A Large Hadron Collider beauty experiment for precision measurements of CP violation and rare decays

Measure asymmetries:

$$A_{\bar{f}}(t) = \frac{R_{\bar{f}}(t) - \bar{R}_{\bar{f}}(t)}{R_{\bar{f}}(t) + \bar{R}_{\bar{f}}(t)}$$

from four rates

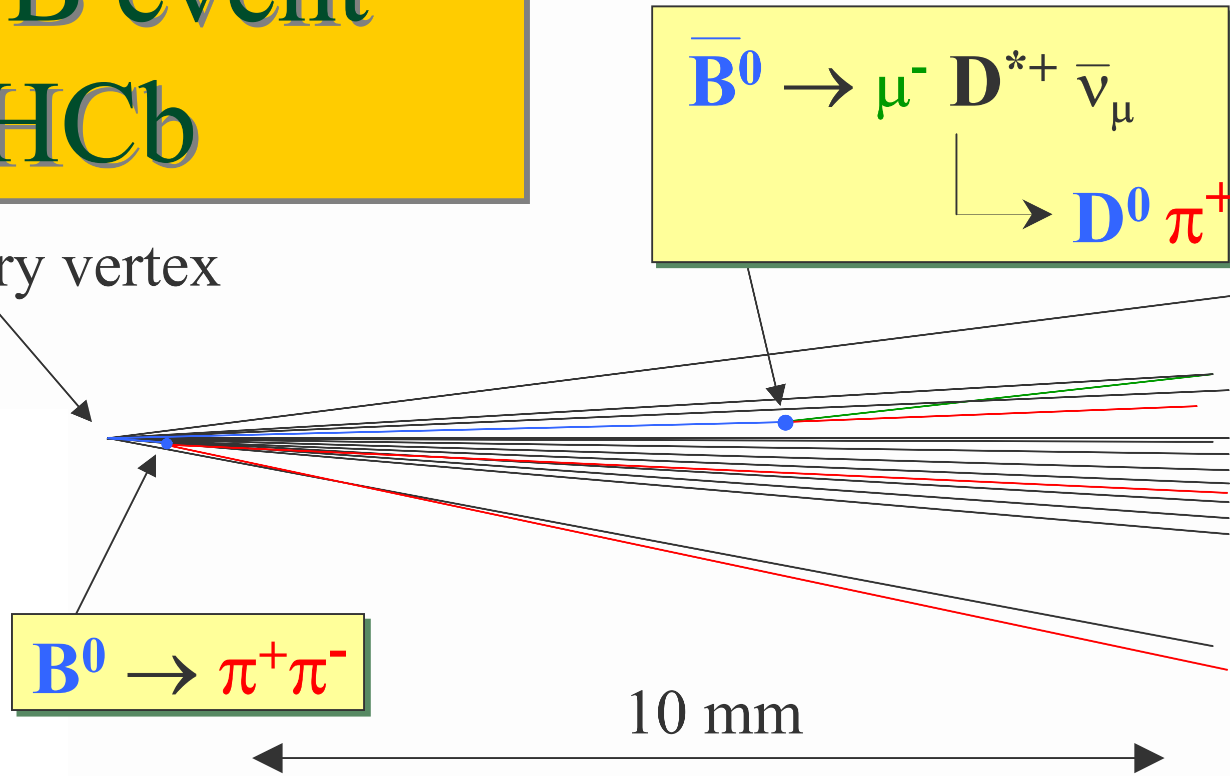
$\bar{R}_{\bar{f}}(t)$ = initial $\bar{B}$ decaying to final state $\bar{f}$

(a bar stands for “CP conjugate”)

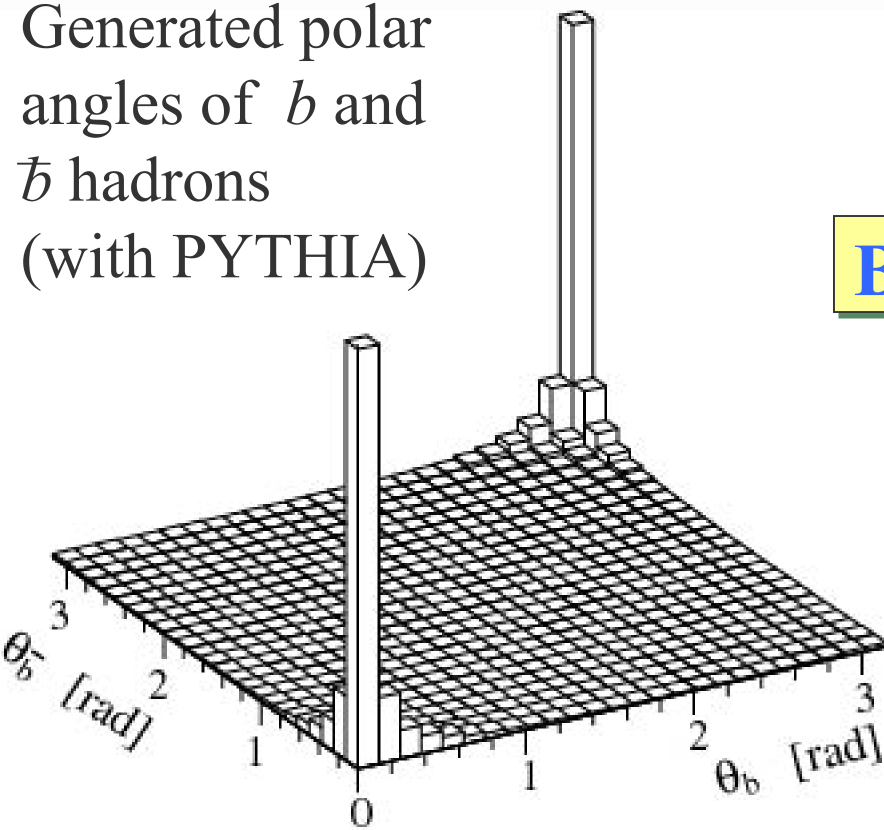
e.g. (semi)leptonic FCNC B-decays.

…always possible to measure rates relative to other channels

Typical B event at LHCb



Generated polar angles of b and $\bar{b}$ hadrons (with PYTHIA)



Aims for offline:

decay distance resolution ≈ 120 μm

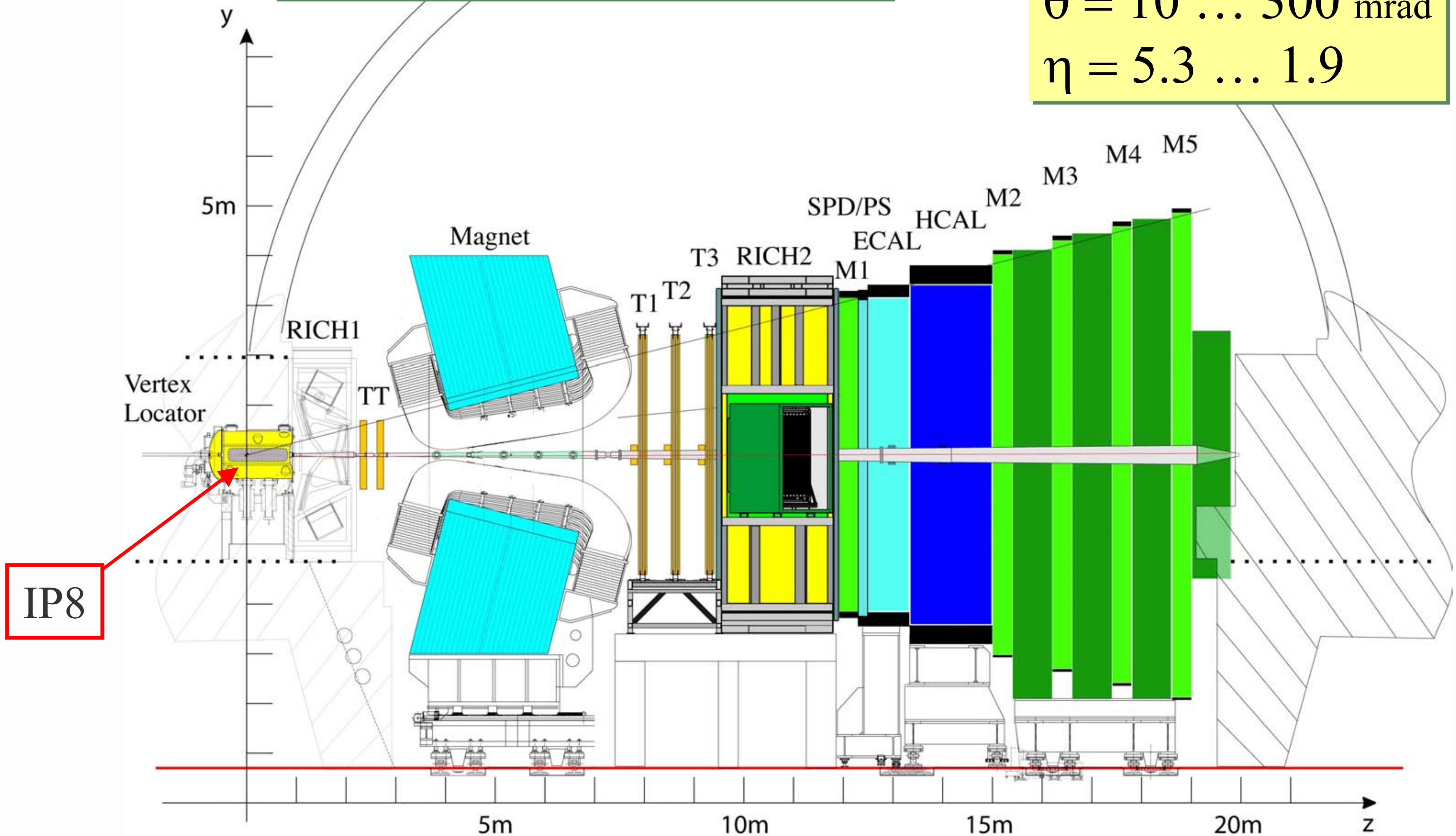
proper decay time resolution ≈ 0.04 ps

LHCb Detector

Acceptance:

$\theta = 10 \ldots 300$ mrad

$\eta = 5.3 \ldots 1.9$



LHCb Trigger

SICB monte-carlo (PYTHIA)

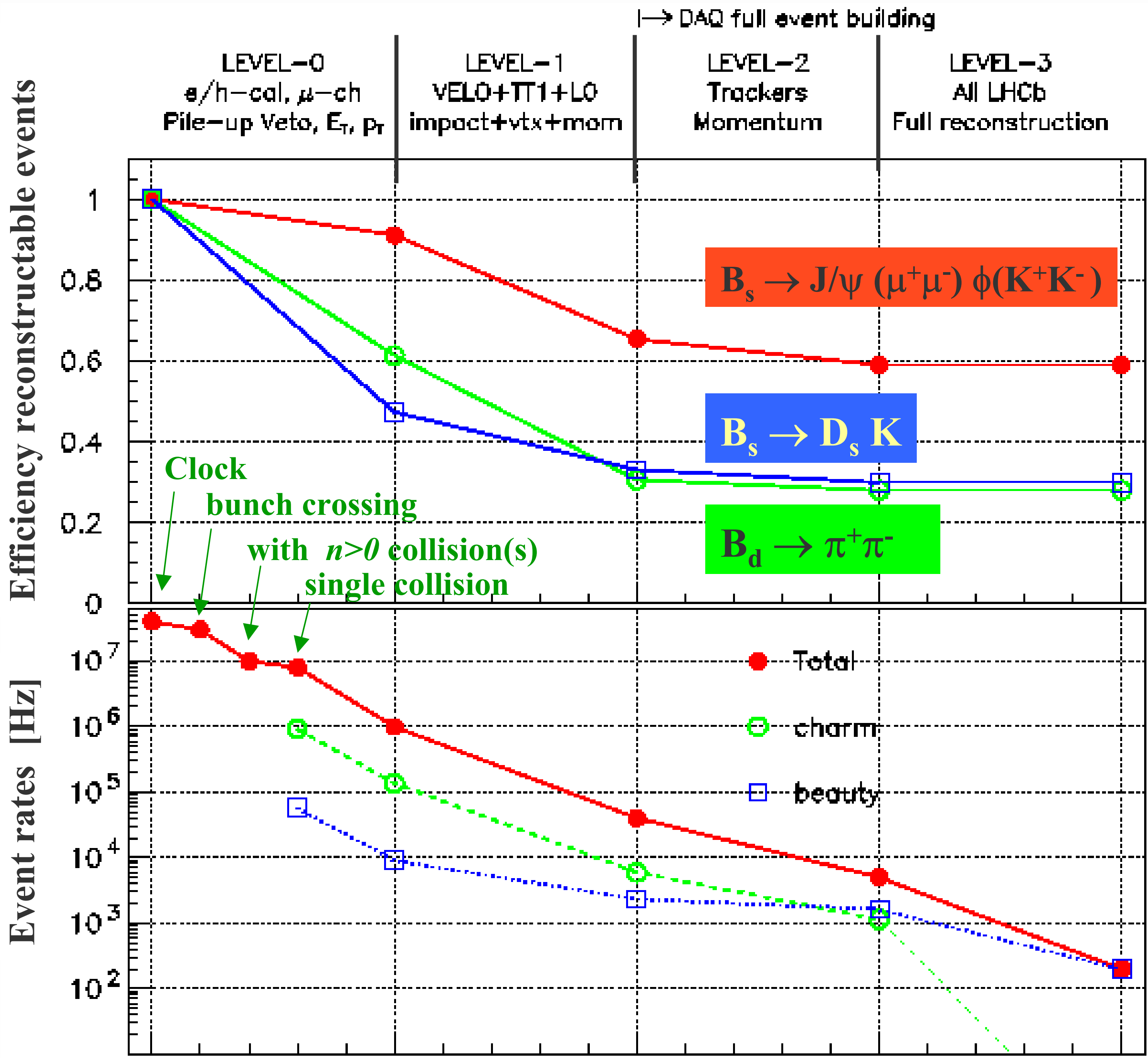
$\sigma_{total} \approx 100$ mb

$\sigma_{beauty} \approx 0.5$ mb

To tape:

~ 3×10^6 B_d evts/yr

~ 1×10^6 B_s evts/yr



Why a Pile-Up Detector ?

- Level-1 is based on finding displaced vertices and becomes problematic when there is more than 1 collision in a bunch crossing
- Level-0 (p_T cut, output at 1 MHz) is less “beauty-selective” for events with $n>1$ collisions.
- Physics analysis is cleaner with $n=1$ collision.

→ **LHCb wants and is designed for single-interaction bunch crossings !!**

Thus, find and veto crossings with $n>1$ collisions at level-0 and give more bandwidth to crossings with $n=1$ collision.

Possible implementations: 1. Total energy in calorimeters
2. Time-of-flight clusters
our choice ! → 3. Look for primary vertices → Pile-Up VETO detector

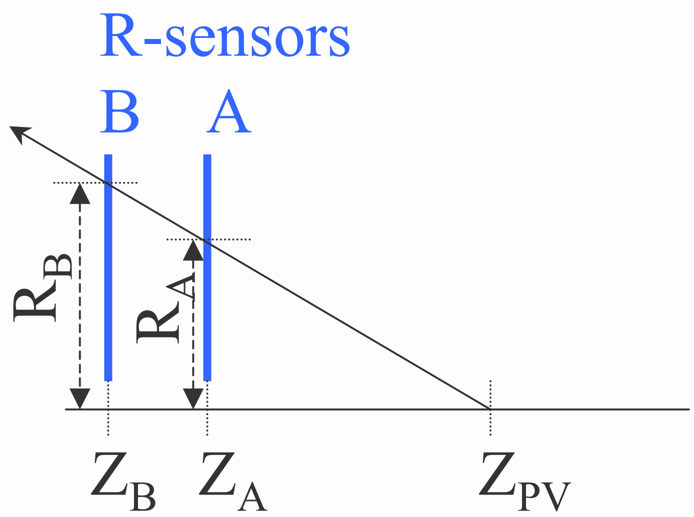
Probability P_n to have n (inelastic) collisions in a bunch crossing:

$$P_n = \frac{\mu^n}{n!} e^{-\mu} \qquad \text{with} \qquad \mu = \sigma_{in} L / f$$

Luminosity
Bunch crossing frequency ≈ 30 MHz
(inelastic) cross-section

Pile-Up Detector: principle

See N. Zaitsev's PhD Thesis Univ. van Amsterdam

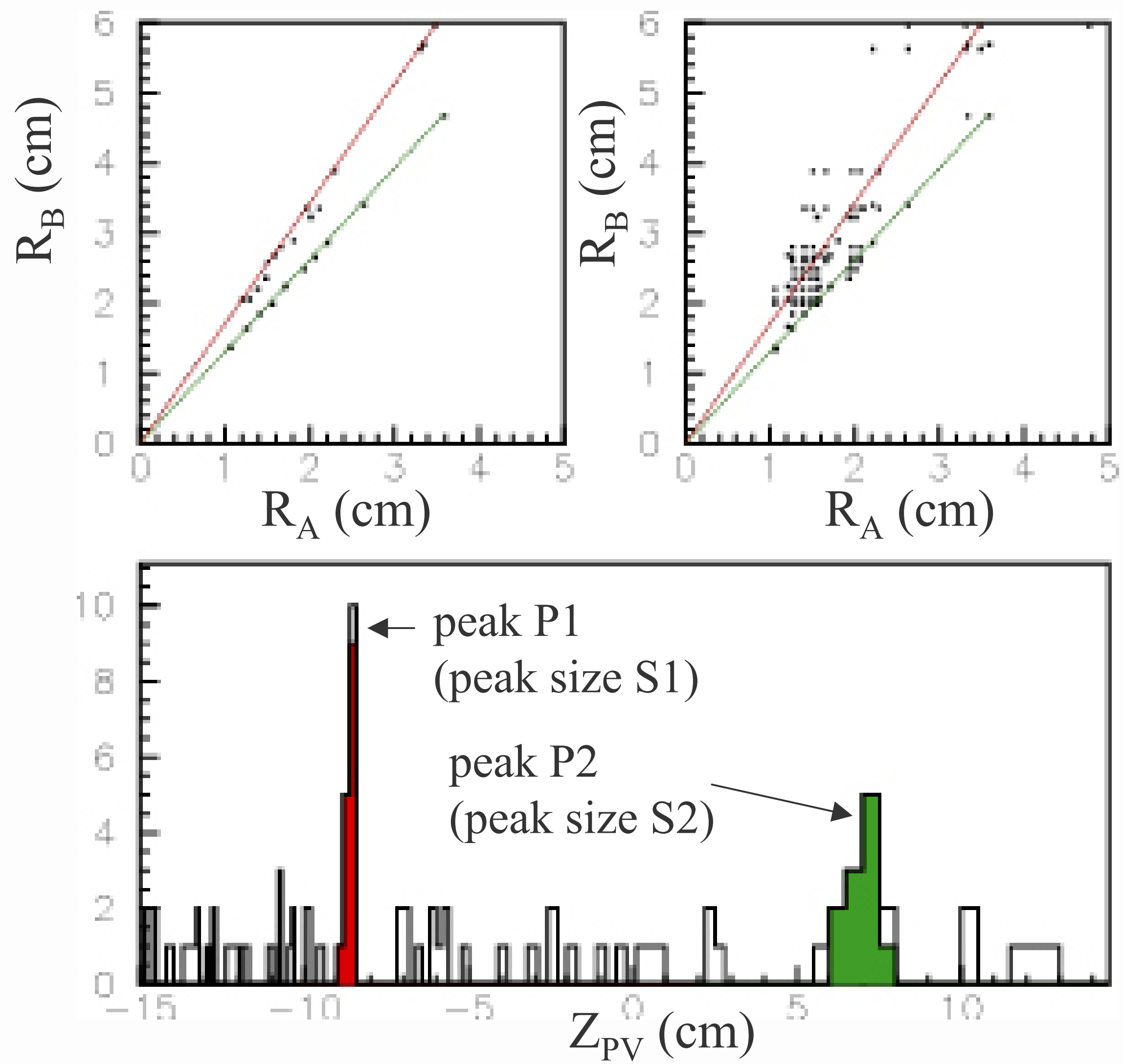


If hits are from the same track:

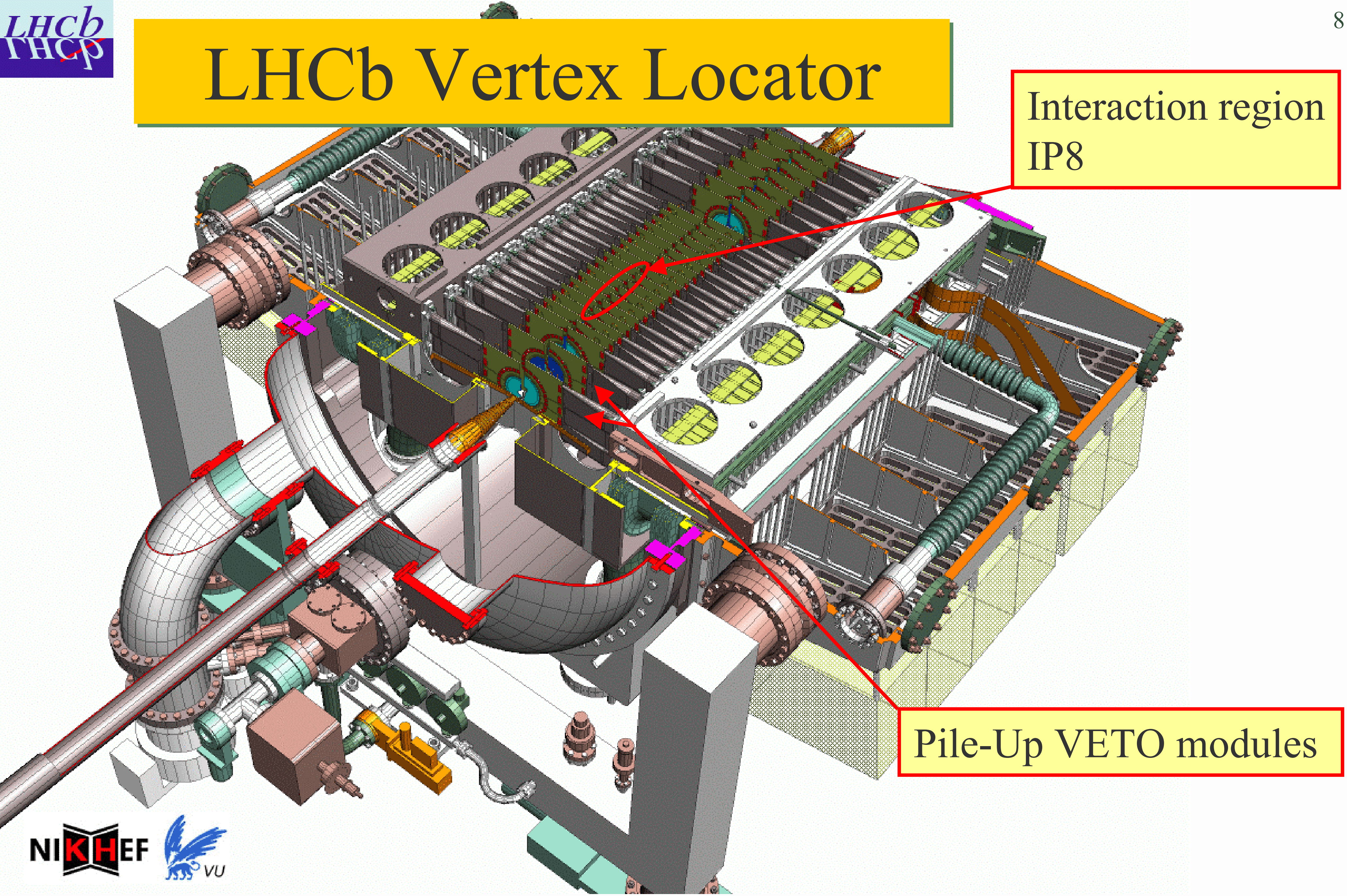
$$k \equiv \frac{R_A}{R_B} = \frac{Z_{PV} - Z_A}{Z_{PV} - Z_B}$$

or $$Z_{PV} = \frac{Z_A - k\,Z_B}{1 - k}$$

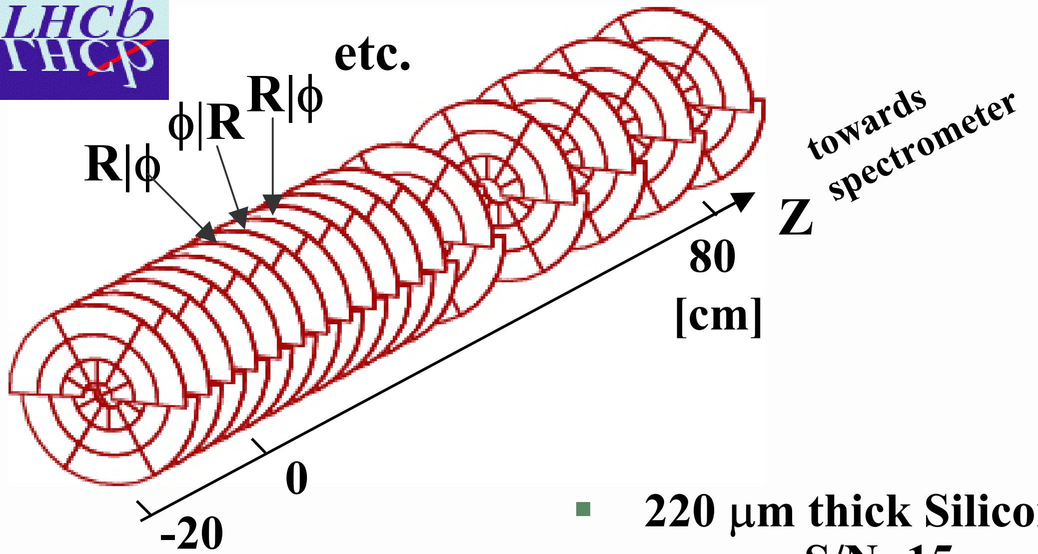
→ allows locating *pp* collisions



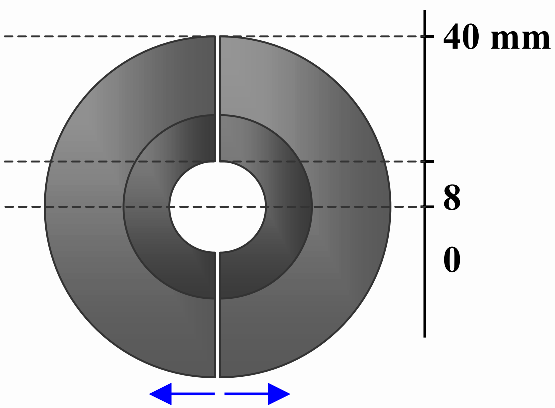
LHCb Vertex Locator



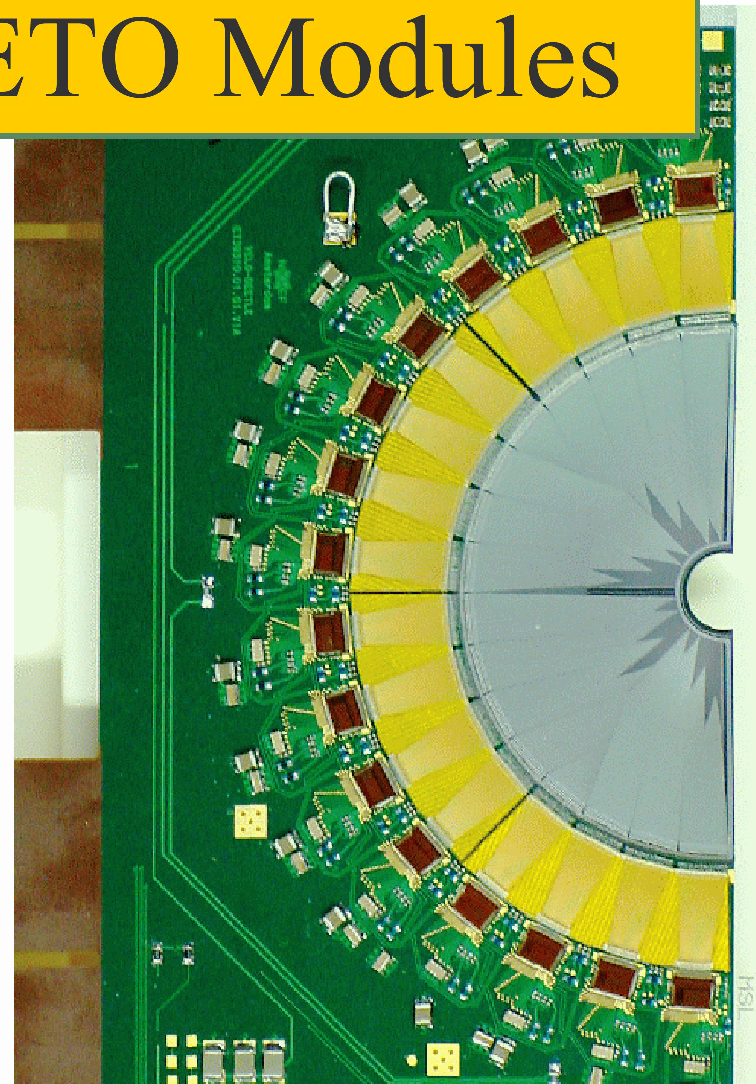
VELO and PU-VETO Modules



- 220 μm thick Silicon single-side *n*-on-*n*, S/N=15
- **42 VELO modules:**
  - R and ϕ measuring planes
  - Varying pitch: ~ 20…120 μm
  - Beetle front-end chip
  - 170 k channels, analog, L1-Trigger
- **4 Pile-Up VETO modules:**
  - Only R measuring planes
  - Velo pitch / 4
  - Beetle front-end chip, use comparator
  - 2 k channels, binary (+analog), L0-Trigger



retract by ± 3 cm during beam filling/tuning



R-sensor prototype

Pile-Up VETO: Implementation

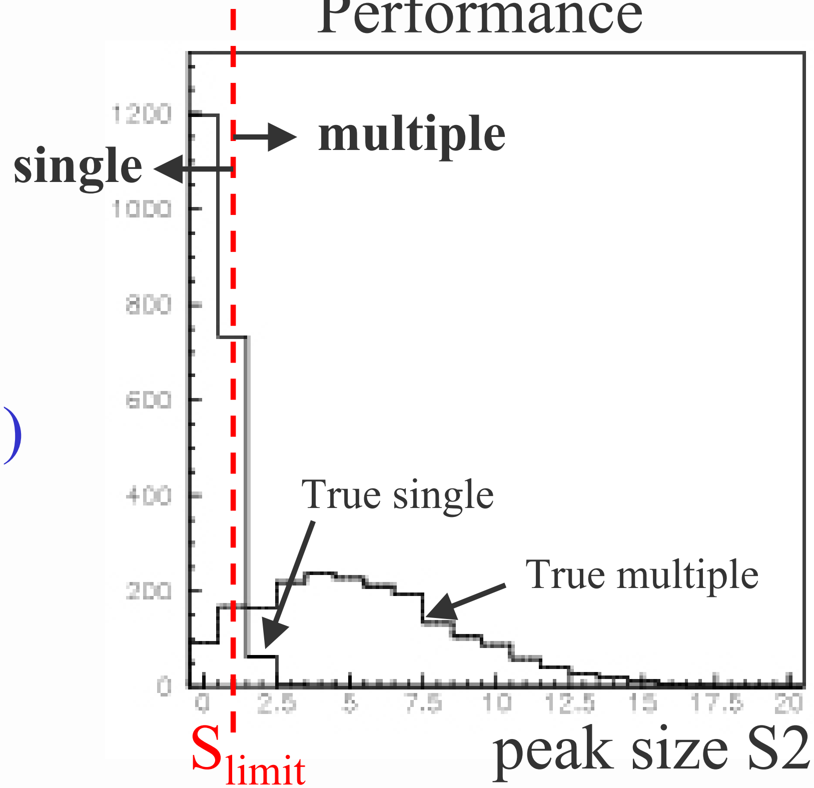
- VELO: add upstream two "R-only" modules, the pile-up VETO
- Read out for trigger level-0 (rest of VELO enters only in level 1)
- Histogramming algorithm to distinguish **single** and **multiple** *pp* collisions.

Schematically:

(0) build a Z_{PV} histogram
(1) search highest peak P1 (peak size S1)
(2) mask hits belonging to P1
(3) search next highest peak P2 (peak size S2)
(4) classify: if $S2 < S_{limit}$ then **single,**
else **multiple**

S_{limit} sets efficiency and purity.

Performance



Pile-Up Detector as Lumi-Monitor

- Most LHCb subsystem data are analysed after highly biased trigger
- Pile-up: read out at level-0 (≈ unbiased)
  - large acceptance
  - high and stable efficiency
  - knows how many collisions in a bunch crossing

    (distinguishes bunch crossings with $n=0$, $n=1$ and $n>1$ collisions)

Note: use of this feature increases statistical accuracy but systematics can arise from erroneous assignments between the various classes .

(mostly between classes $n=1$ and $n>1$;
typical : (n=1)-efficiency ≈ 90% and (n>1)-fraction in (n=1)-class ≈12%)

μ - Estimators

<u>The following estimators were studied:</u>

(ε_0, ε_1, $\varepsilon_{n>1}$= fractions of bunch crossings classified as having n= 0, n=1 and n>1 collisions)

1/0 ratio estimator $\mu = \varepsilon_1 / \varepsilon_0$

0-collision estimator $\mu = -ln(\varepsilon_0)$

Does not need to know misassignments between n=1 and n>1 !!
Uses "*either* $n=0$ *or* $n>0$" logic
→ low systematic uncertainties

non-0-coll. estimator $$\chi^2 = \left[\frac{\varepsilon_1 - P_1}{\Delta\varepsilon_1}\right]^2 + \left[\frac{\varepsilon_{n>1} - P_{n>1}}{\Delta\varepsilon_{n>1}}\right]^2$$

full sample estimator $$\chi^2 = \left[\frac{\varepsilon_0 - P_0}{\Delta\varepsilon_0}\right]^2 + \left[\frac{\varepsilon_1 - P_1}{\Delta\varepsilon_1}\right]^2 + \left[\frac{\varepsilon_{n>1} - P_{n>1}}{\Delta\varepsilon_{n>1}}\right]^2$$

0-event μ - Estimator

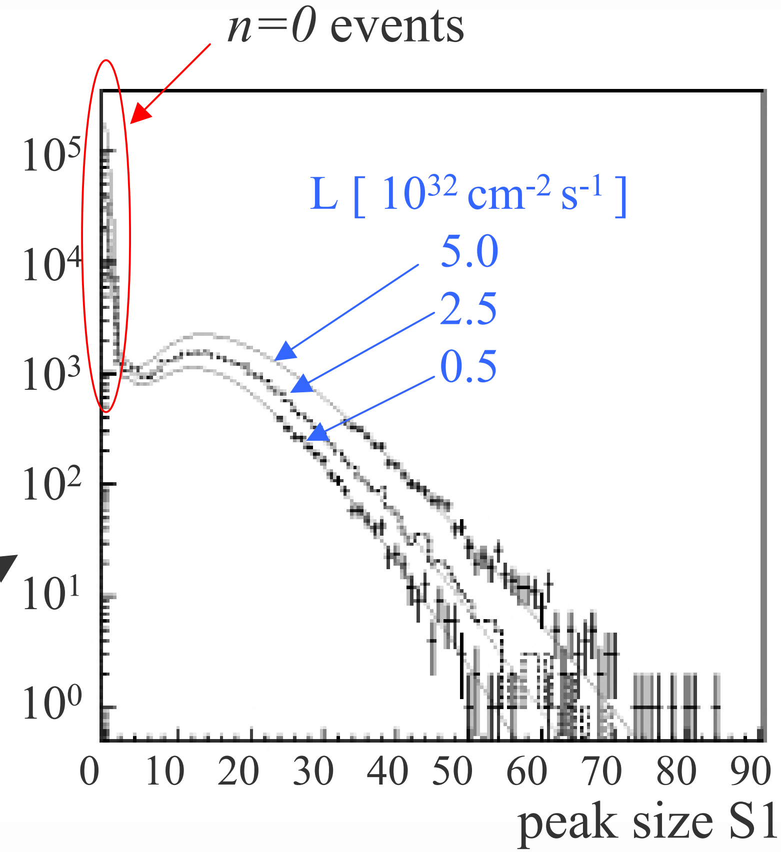
Misassignment of a class *n>0* event into a class *n=0* event will cause a shift of μ towards lower values.

$$P_{0,meas} = P_0 + \sum_{n>0} \alpha_n P_n$$

Monte-carlo: $\alpha_1 = 0.094 \pm 0.002$

$\alpha_{n>1}$ negligible at LHCb luminosities

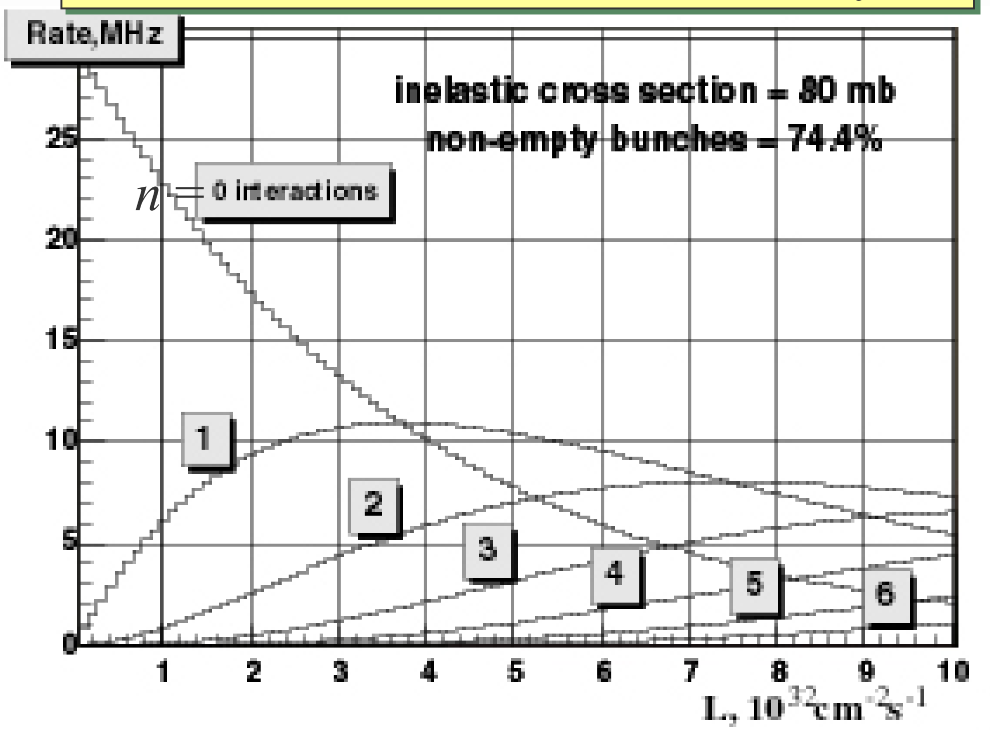
- mix 0, 1, … 6 collisions (PYTHIA) in Poisson proportions to simulate events
- add noise (to simulate beam-gas collisions, activity of detectors, etc.)
- fit distribution of largest peak size S1 to extract μ



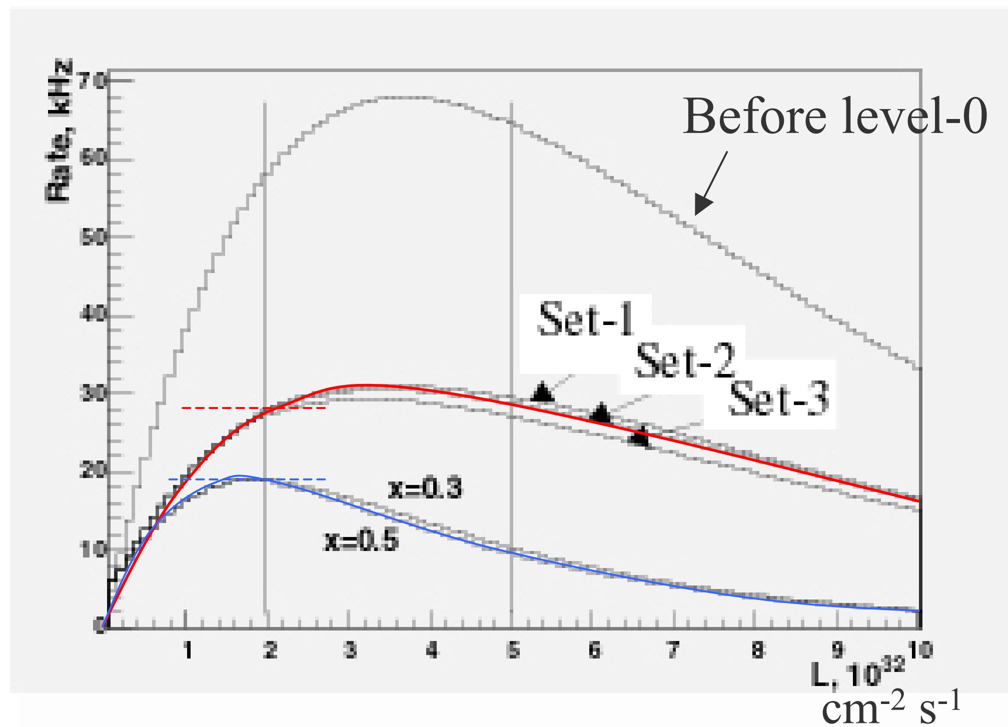
Statistics are close to infinite …
Measure individual bunch-bunch (relative) luminosities with ~0.5% statistical accuracy in about 20 seconds

Pile-Up VETO: performance

Occurrence rate of crossings with
n inelastic collisions vs luminosity



Rate of "single-collision" B-events
as a function of luminosity



Note:

Evt type	Geom. Acc.	Cross Sec.
Elastic	0.0 %	22 mb
1- (2-) diffractive	46.7 (55.8) %	25 mb
Other inelastic	99.94 %	55 mb

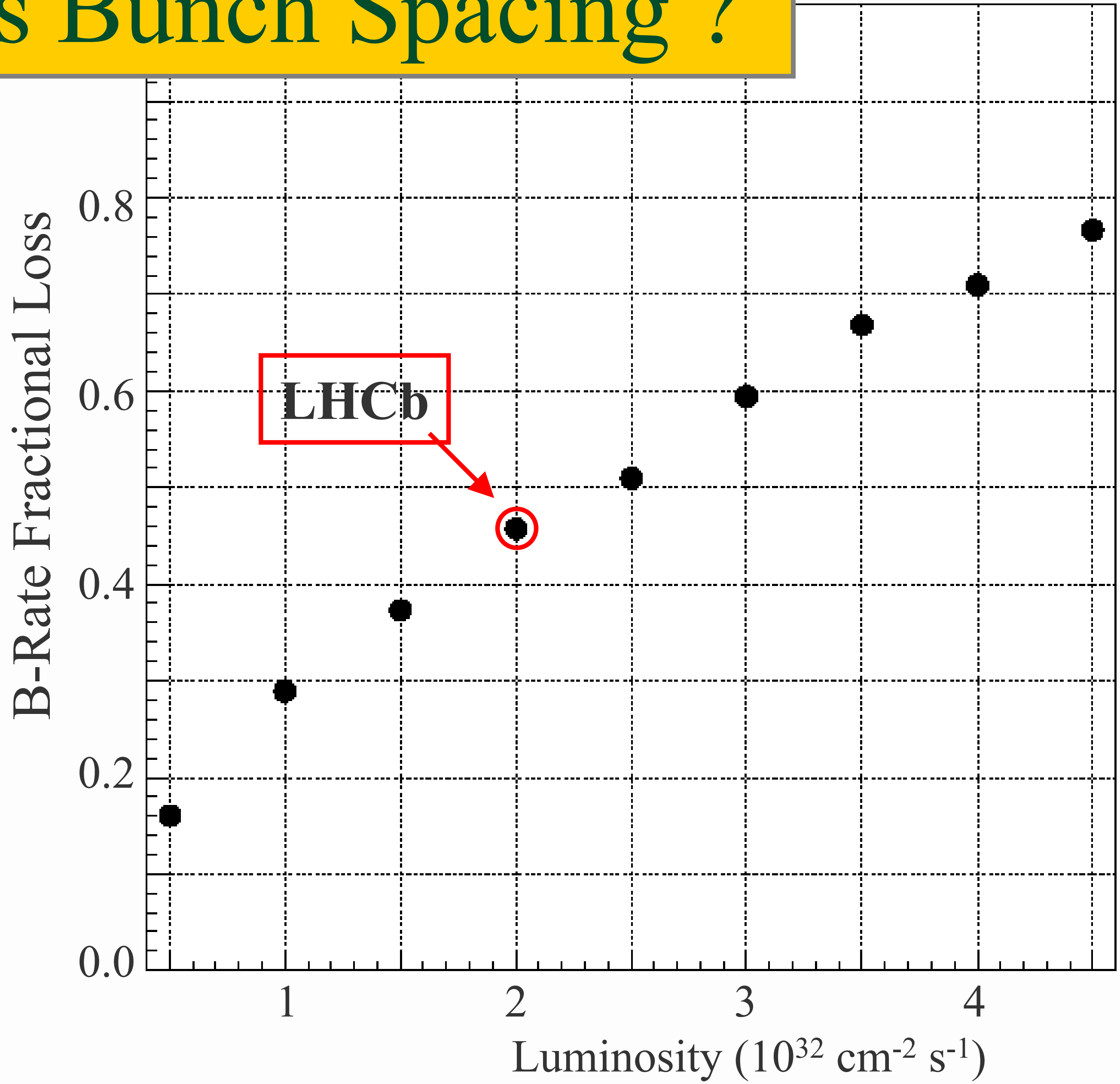
After level-0: without and with Pile-up veto
→ gain factor of at least 1.4 in B-event rate
at the same nominal luminosity (2×10^{32})

25 to 75 ns Bunch Spacing ?

LHCb was designed for

- **single-collision events**
- **at 2×10^{32} cm^{-2} s^{-1}**

Thus, with 75 ns, we get an average loss of 50% in the B-rate !!



Summary

- LHCb is an experiment for studying CP-violation (asymmetries) and rare decays (BR) in the B-meson sector (10 mrad < θ < 300 mrad)
- Preliminary studies for relative luminosity monitoring were carried out for the Pile-Up detector:
  - zero-event estimator is simplest, with lowest systematics
  - precision limited by knowledge of acceptance to diffractive events
  - we can expect a (systematic) uncertainty down to ~0.5 % for relative luminosity
  - statistics are ± infinite … enough to measure individual bunch-bunch luminosities with ~0.5% statistical accuracy in about 20 seconds
- Absolute normalization will be done by using *calibrated processes* (*TOTEM* ?)

LHCb needs single-collision bunch crossings, hence **25 ns** and **not 75 ns** .

With 75 ns we lose a factor 2 on B-rates (on average) !

25 to 75 ns Bunch Spacing ?

LHCb was designed for

- **single-collision events**
- **at 2 × 10^{32} cm^{-2} s^{-1}**

Thus, with 75 ns, we get an average loss of 50% in the B-rate !!