

THE LHCb LEVEL-1 TRIGGER

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for the

LHCb collaboration



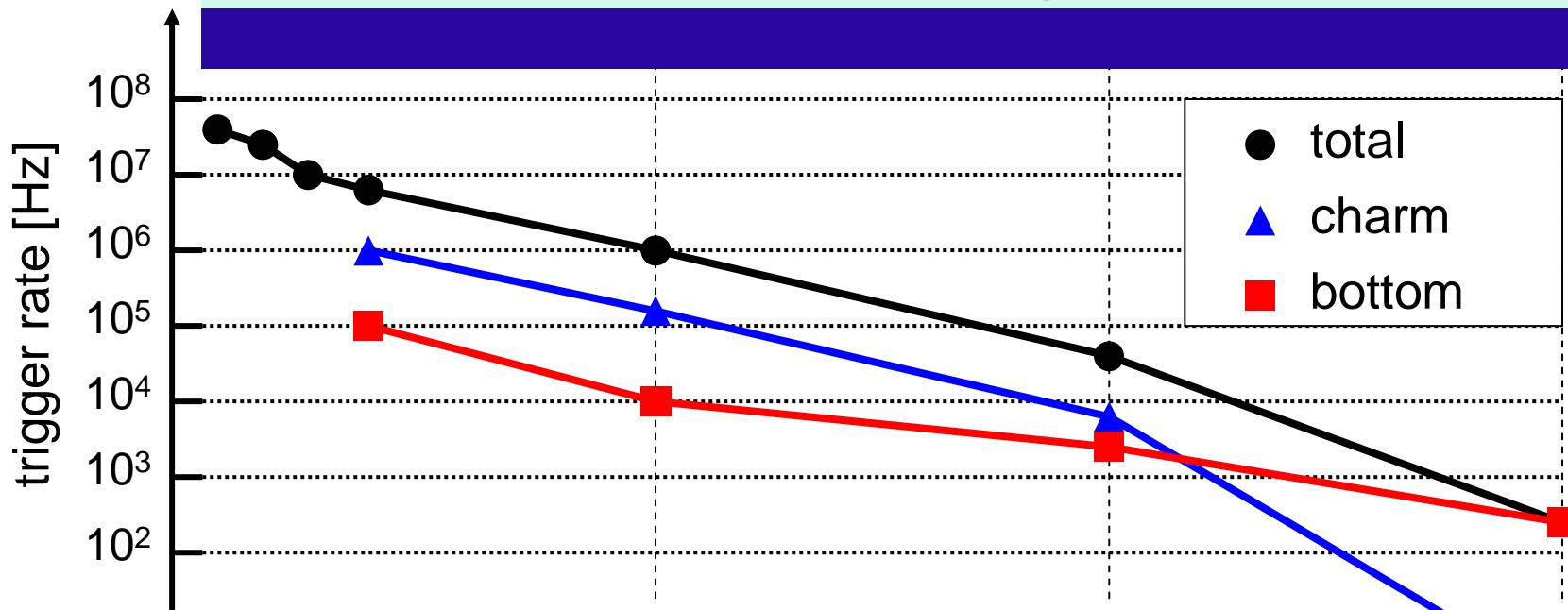
VERTEX 2003
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Lake Windermere, UK



LHCb IN NUMBERS

- Design Luminosity: $L = 2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1} = 200 \mu\text{b}^{-1}/\text{s}$
- $\sigma_{\text{total}} \approx 100 \text{ mb}$, $\sigma_{\text{inel}} \approx 80 \text{ mb}$, $\sigma_{\text{vis}} \approx 60 \text{ mb}$
⇒ 12 MHz total (visible) interaction rate
⇒ **10 MHz total (visible) event rate (pile-up)**
- Assumed $\sigma_{\text{bb}} \approx 500 \mu\text{b}$
⇒ **100 kHz B event rate!**
- But low branching fractions!
Expect (offline reconstructable events):
 - $B_d \rightarrow J/\psi(\mu^-\mu^+) K_S(\pi^-\pi^+)$: 1 per minute
 - $B_d \rightarrow \pi^-\pi^+$: 1 in two minutes
 - $B_s \rightarrow D_s^-(K^+K^-\pi^-) K^+$: 1 in six minutes
 - $B_s \rightarrow \mu^-\mu^+$: 1 per week (?)

LHCb TRIGGER OVERVIEW



Level-0:

- hardware
- $10 \text{ MHz} \rightarrow 1 \text{ MHz}$
- Uses:
 - calorimeters
 - muon chambers
 - pile-up veto (Si)

Level-1:

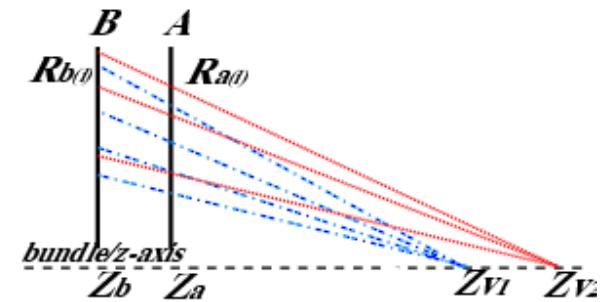
- software
- $1 \text{ MHz} \rightarrow 40 \text{ kHz}$
- Uses:
 - **vertices (Si)**
 - some tracking
 - L0 objects

High-Level:

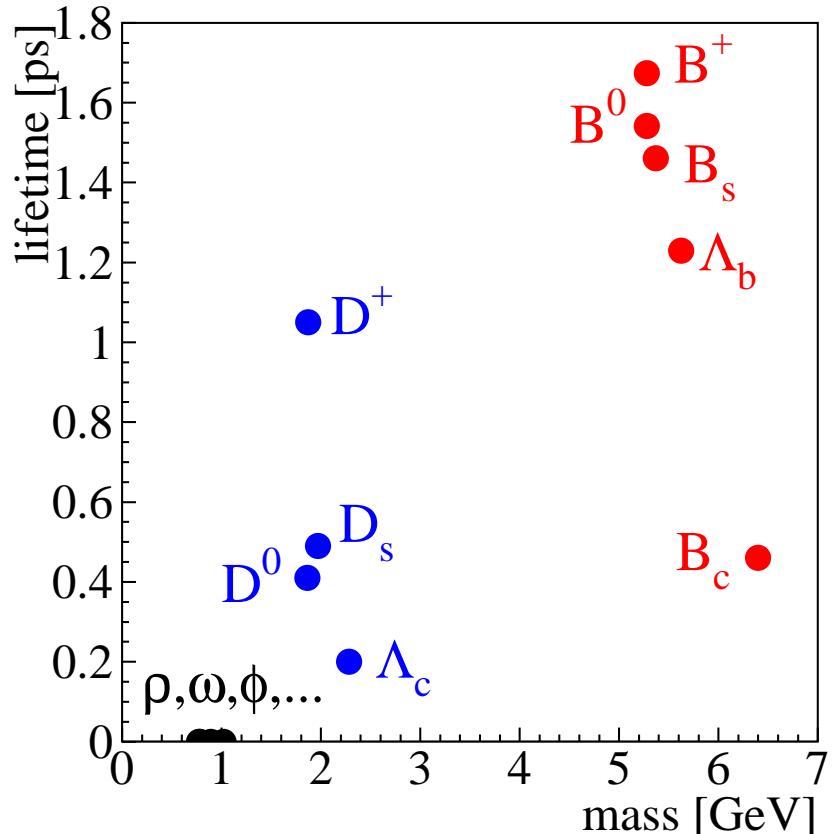
- software
- $40 \text{ kHz} \rightarrow 200 \text{ Hz}$
- Uses:
 - full event data

LEVEL-0 TRIGGER

- Fully synchronous and pipelined hardware trigger
- ~10 MHz visible event rate (30 MHz bunch crossing)
- Global event variables (10 MHz → 7 MHz):
 - pile-up detector (two backward-looking silicon disks): reject events with multiple primary vertices
 - multiplicity in pile-up detector and SPDs in front of calorimeter (scintillator pad detectors for e/γ separation): reject too complicated events
 - minimum ΣE_T in all HCAL cells (avoid “empty” events)
- B signatures (7 MHz → 1 MHz):
 - high- p_T muons: track segments in muon chambers (MWPC)
 - high- E_T electrons, photons, π^0 : ECAL clusters (+SPD/PS)
 - high- E_T hadrons: HCAL clusters



LEVEL-1 STRATEGY



B hadrons are the **elephants** of the particle zoo:
they are **heavy** and **long-lived**

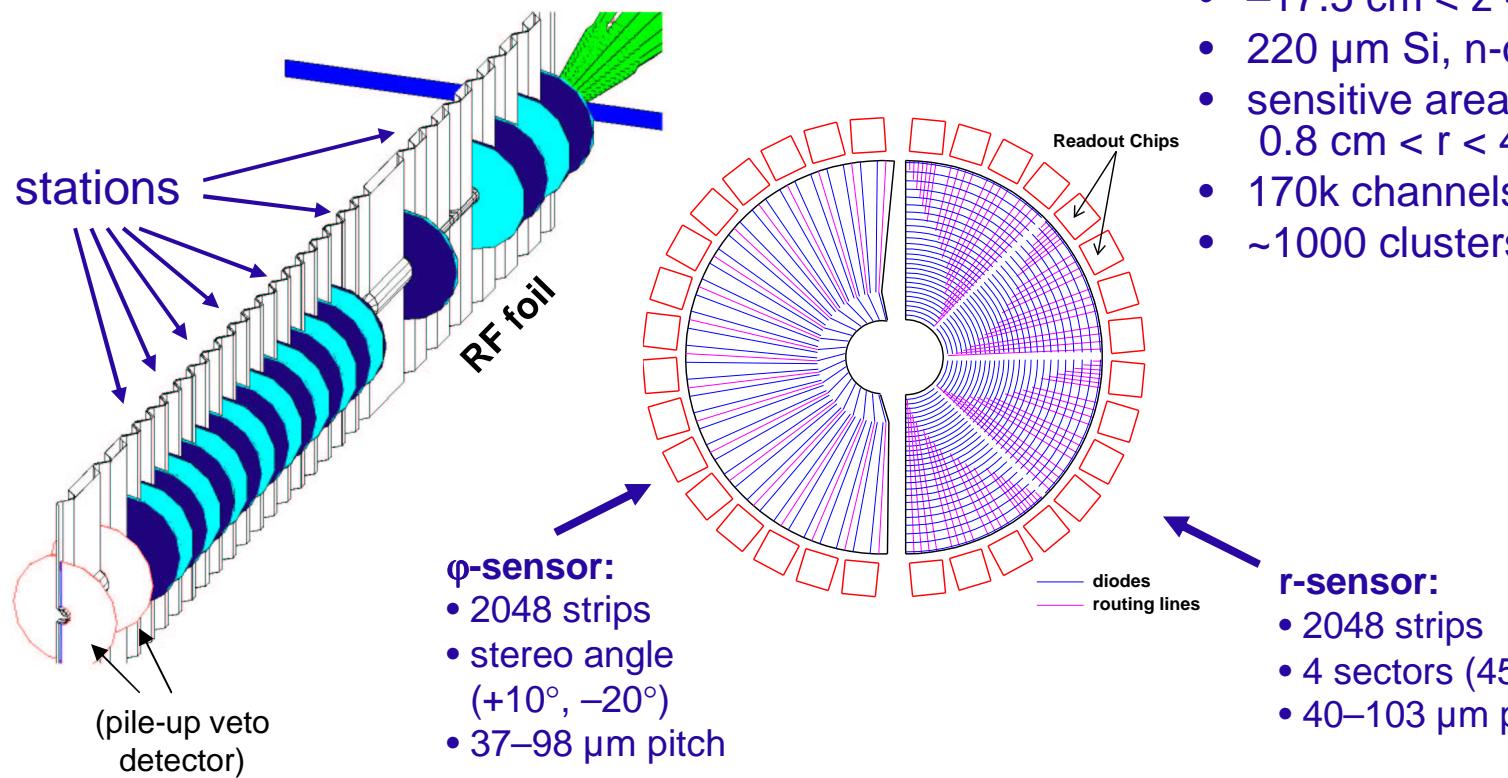
Approximation at trigger level:
look for tracks with both

- **high transverse momentum (p_T)
and**
- **high impact parameter**
(relative to primary vertex)

How do we measure impact parameters and p_T ?

IMPACT PARAMETER (1)

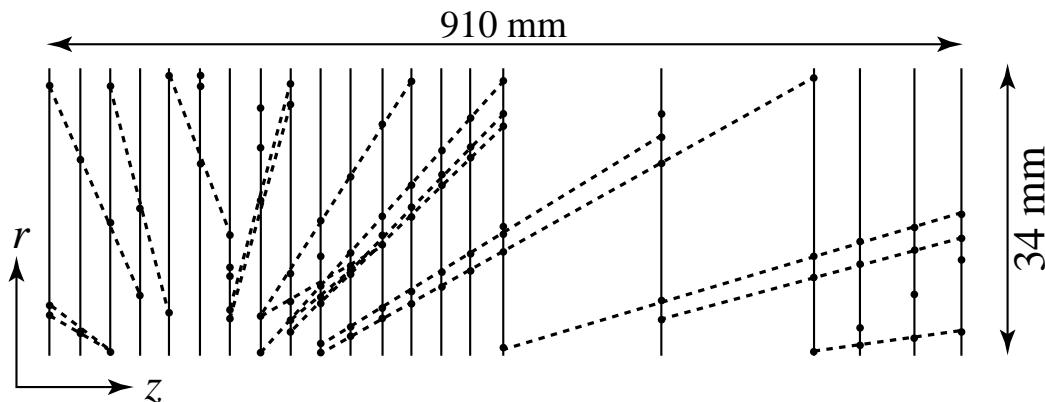
measure impact parameters with the
VErtex **L**Ocator:



IMPACT PARAMETER (2)

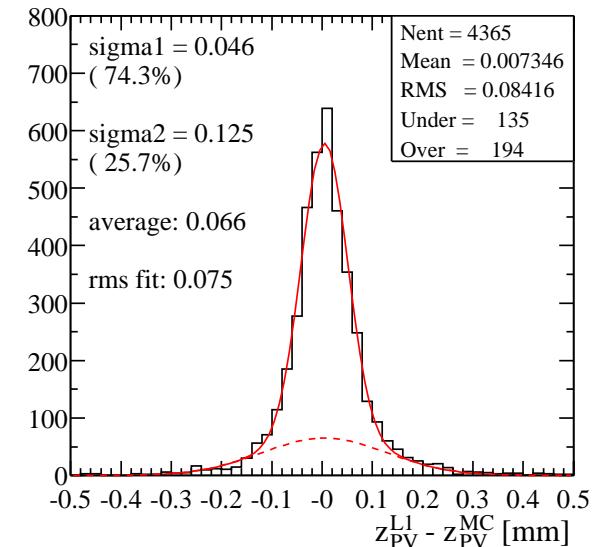
r-z projection contains most of the impact parameter information:

⇒ fast r-z tracking using only r-sensors
(straight-forward thanks to rather low occupancy in 45° sectors!)



$\epsilon = 98\%$ for B tracks

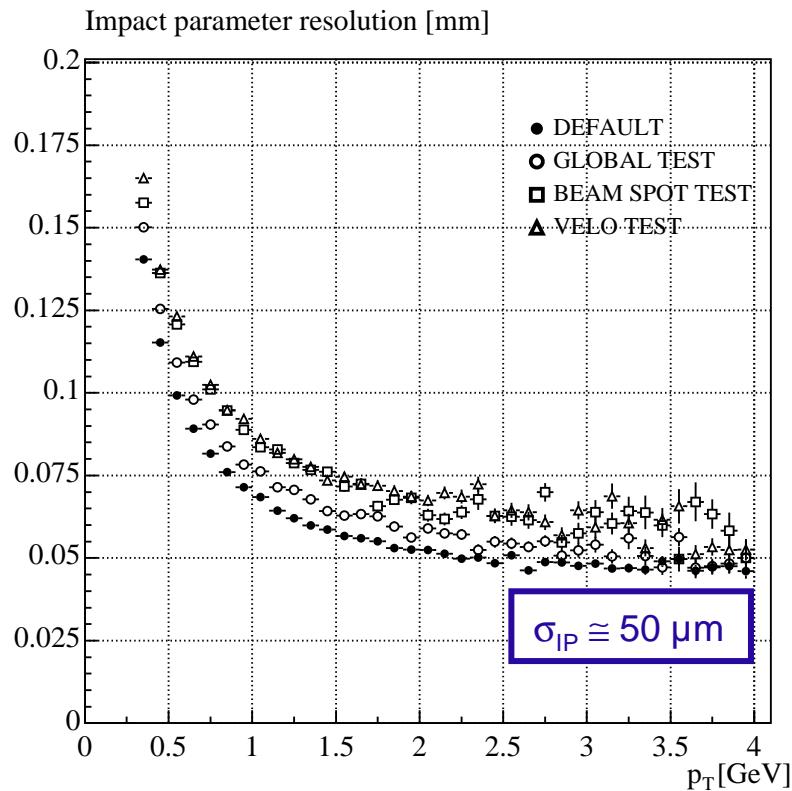
primary vertex resolution:



$$\sigma_z \approx 75 \mu\text{m}$$

IMPACT PARAMETER (3)

impact parameter resolution:
(also for various robustness scenarios...)



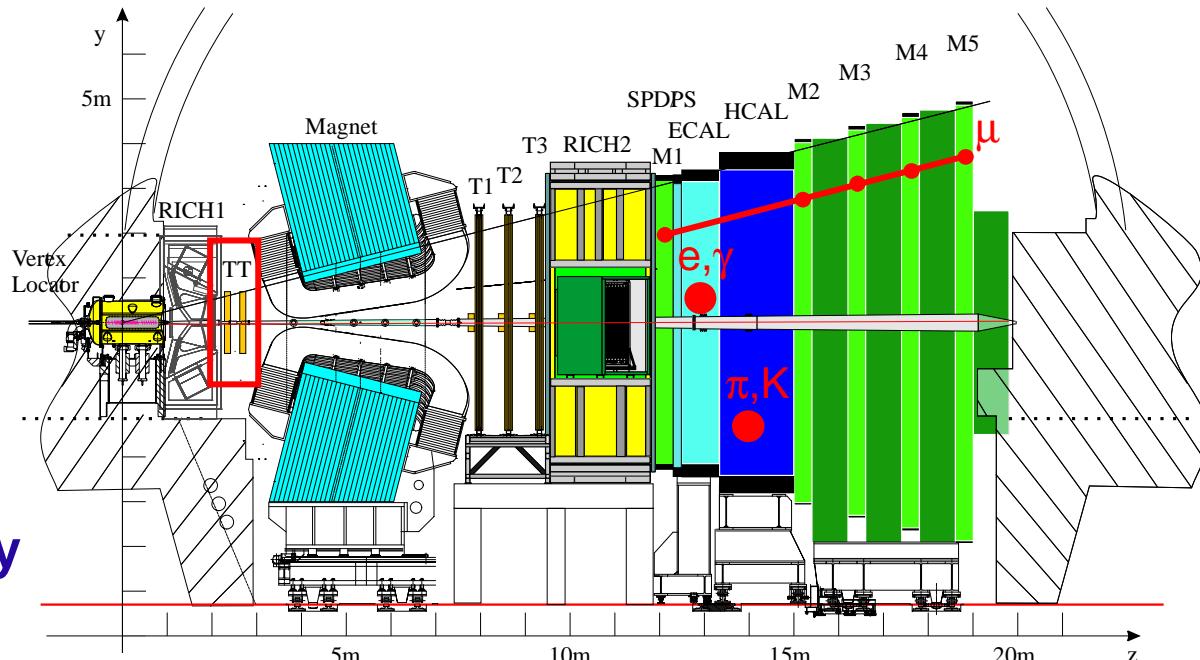
Good resolutions
are obtained with
(fast) 2D tracks!

But: p_T measurement via extra-
polation necessitates 3D tracks!
⇒ Reconstruct in 3D (ϕ -sensors)
only those tracks that have
large impact parameter!
(between 0.15 mm and 3 mm)

P_T MEASUREMENT

We must extrapolate tracks to some measurement that is influenced by the magnetic field!

Two complementary approaches:

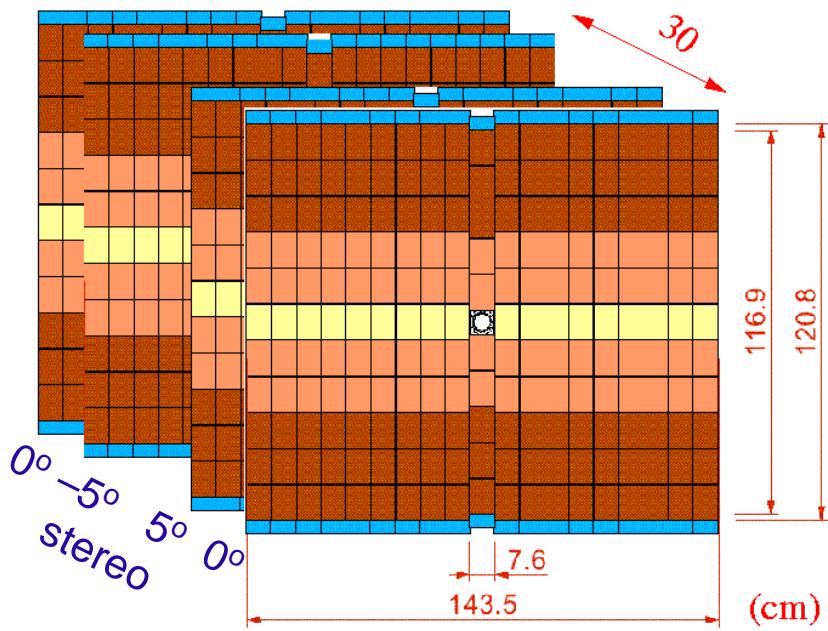


1) Fringe field before the magnet:
extrapolation to first tracking station,
TT (= **Trigger Tracker**), situated
between VELO and magnet
⇒ coarse momentum resolution but
high efficiency

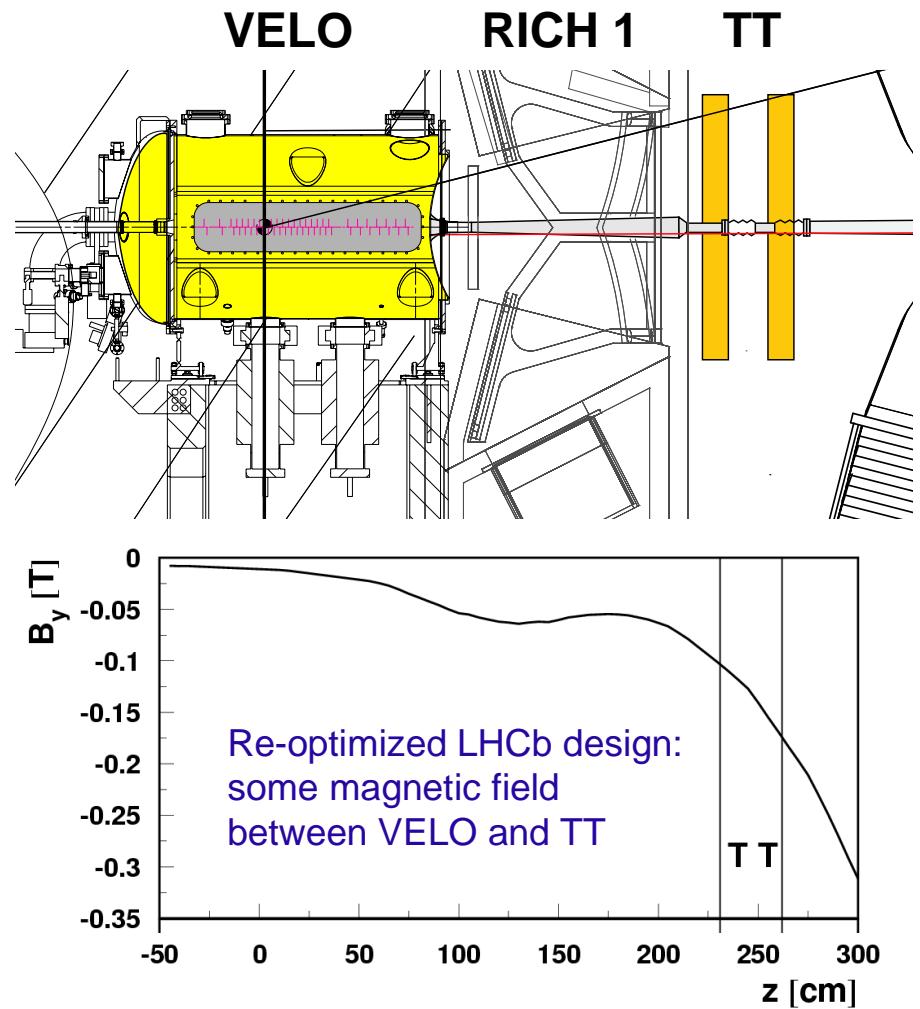
2) Full p_T kick after the magnet:
recycle calorimeter clusters and muon track
segments found by **Level-0**, try to match
them to VELO tracks!
⇒ better momentum resolution but low
over-all efficiency and low purity

P_T MEASUREMENT: TT

The Trigger Tracker (TT):

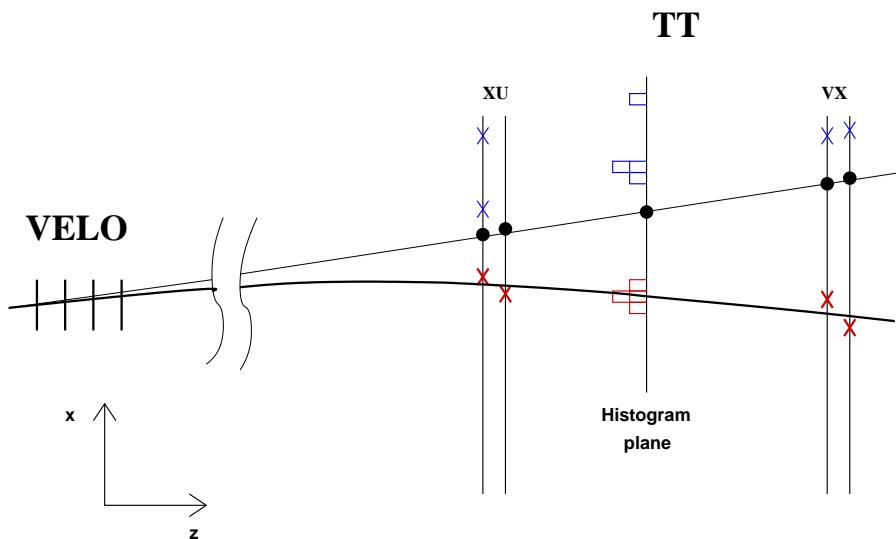


- 4 layers of Si (500 μm thick, 200 μm pitch)
- 836 sensors of $7.8 \times 11 \text{ cm}^2$ (7 m^2 total)
- ca. 400 clusters / event for Level-1

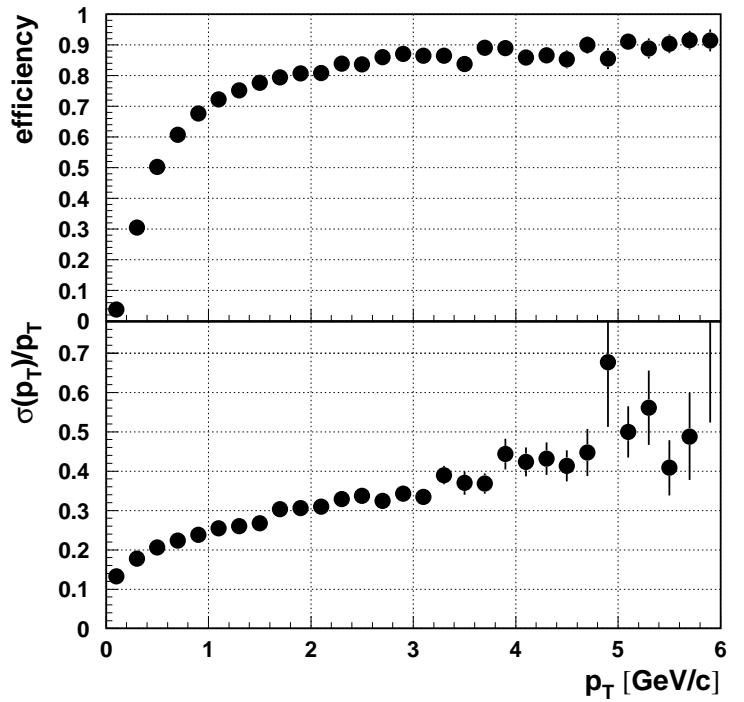


P_T MEASUREMENT: TT

integrated $Bd\ell \approx 115$ kG cm
⇒ 10-GeV track is deflected by
3.4 mm at TT



extrapolation of VELO track to TT clusters,
matching with histogramming method



Momentum resolution: 20–40%

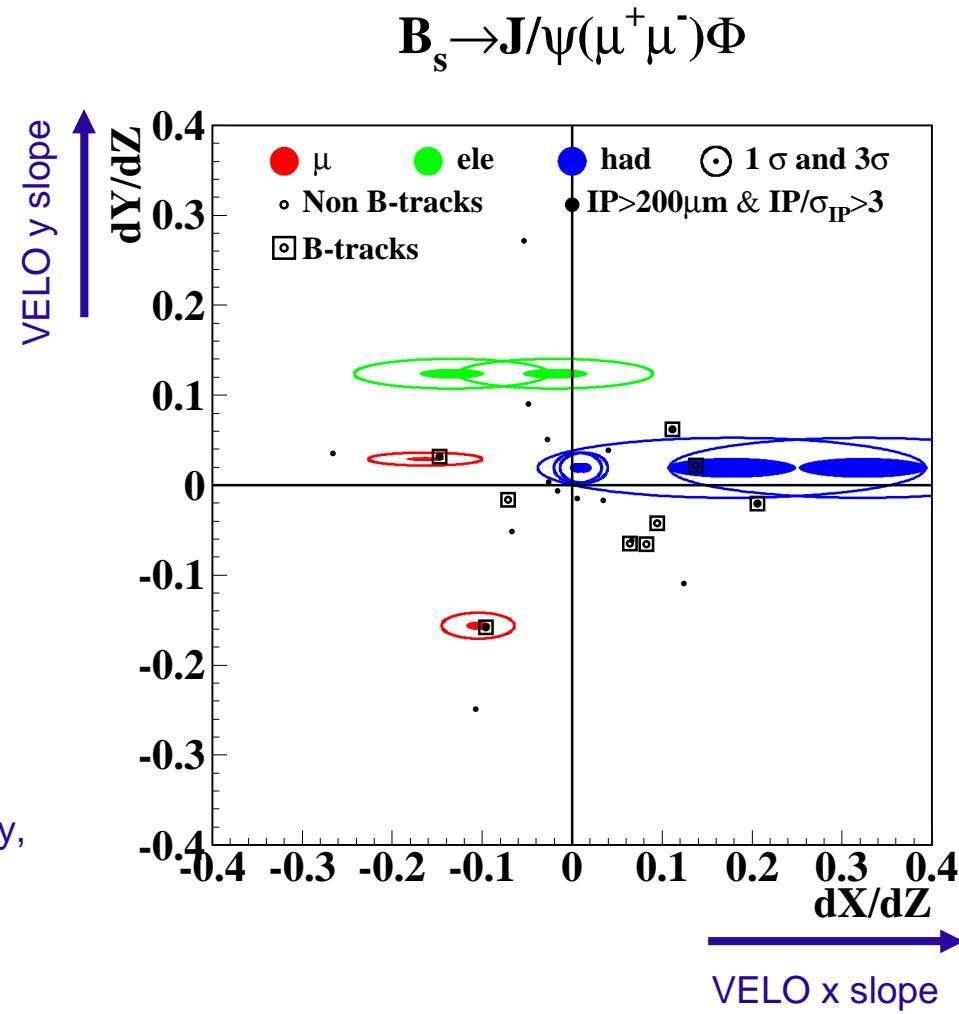
P_T MEASUREMENT: L0

Complementary approach:

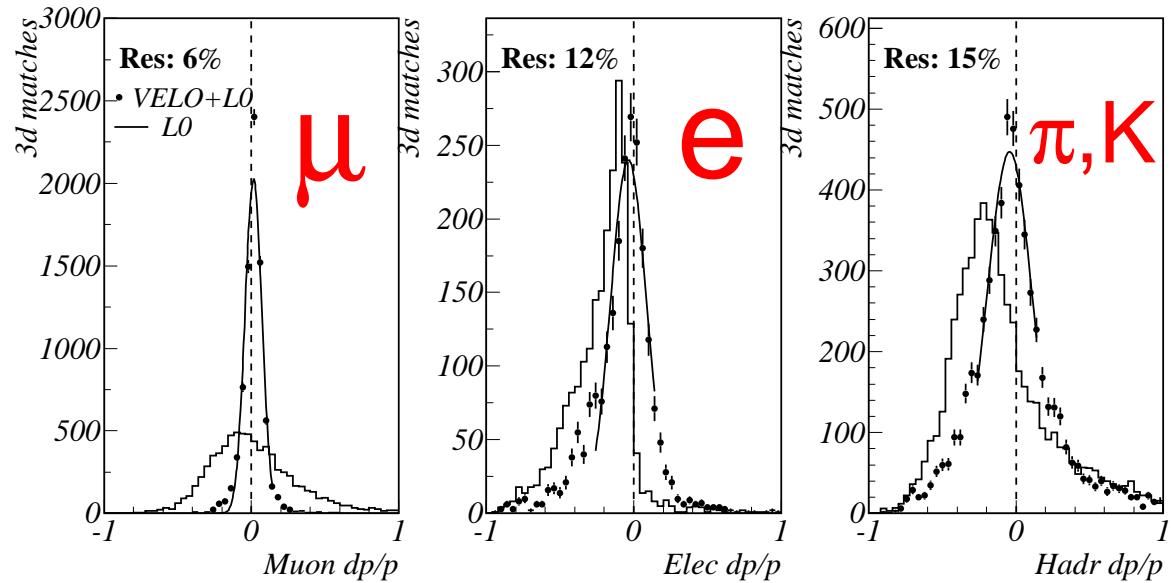
Try to match tracks found in the VELO to **high- p_T objects found by Level-0**:

- muon track segments
- calorimeter clusters (ECAL and HCAL)

Example: VELO slopes in x and y, comparison between predictions from Level-0 objects and actual VELO tracks



P_T MEASUREMENT: LO



**momentum
resolution:**

6%

12%

15%

**matching
efficiency:**

95%

96%

93%

purity:

51%

33%

27%

P_T MEASUREMENT: LO

Example:

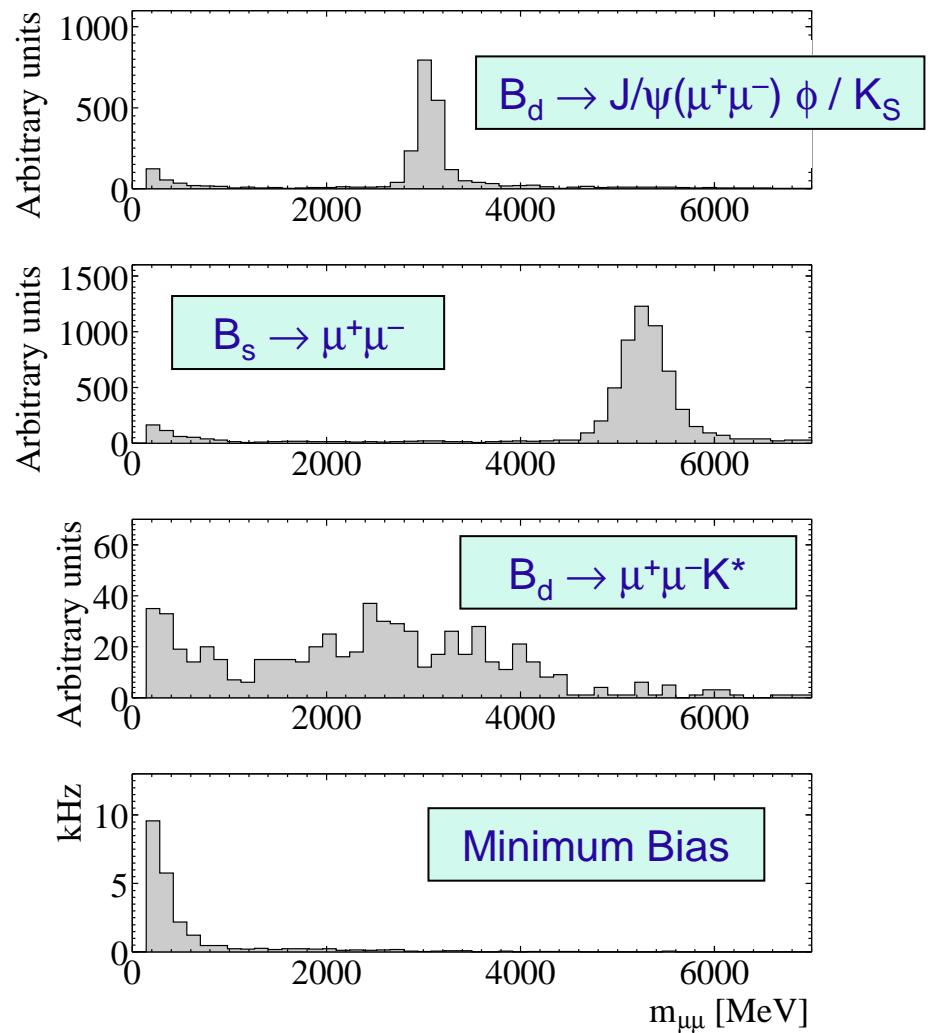
$\mu\mu$ invariant mass available at

Level-1!

⇒ can boost dimuon channels
at small cost in bandwidth!

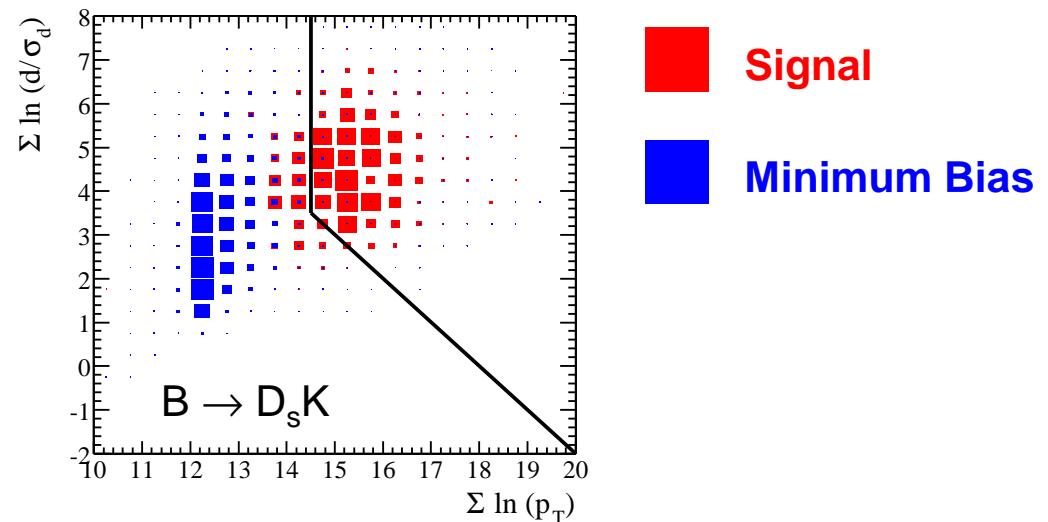
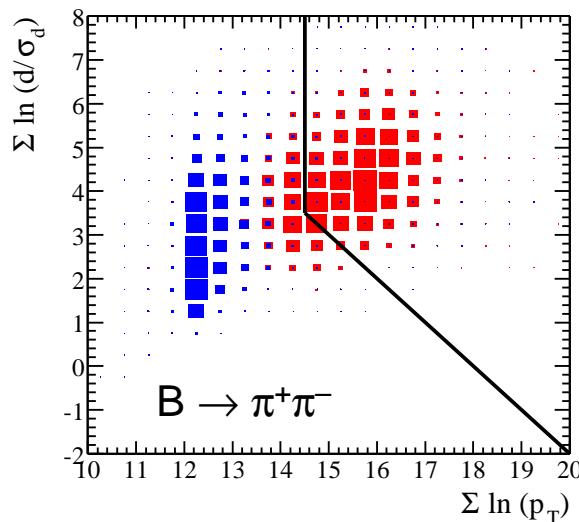
- $B \rightarrow J/\psi(\mu^+\mu^-)X$ channels
- $B \rightarrow \mu^+\mu^- K^*$
- $B \rightarrow \mu^+\mu^-$

More knobs to turn...,
under study!



DECISION ALGORITHM

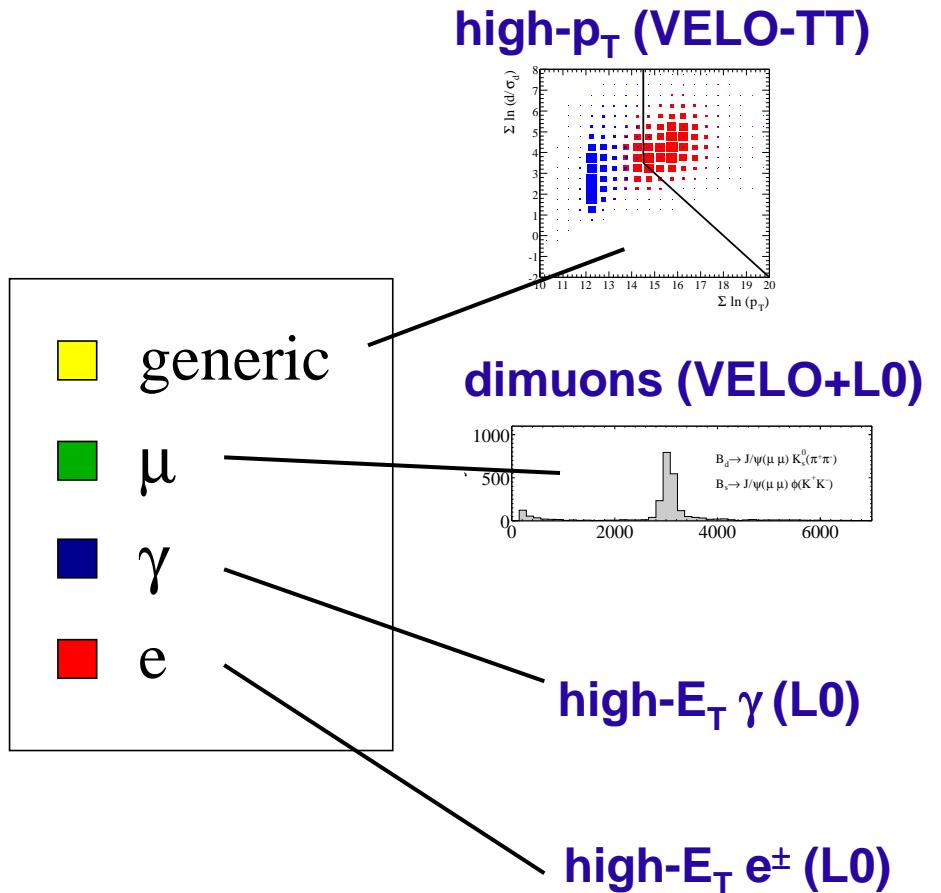
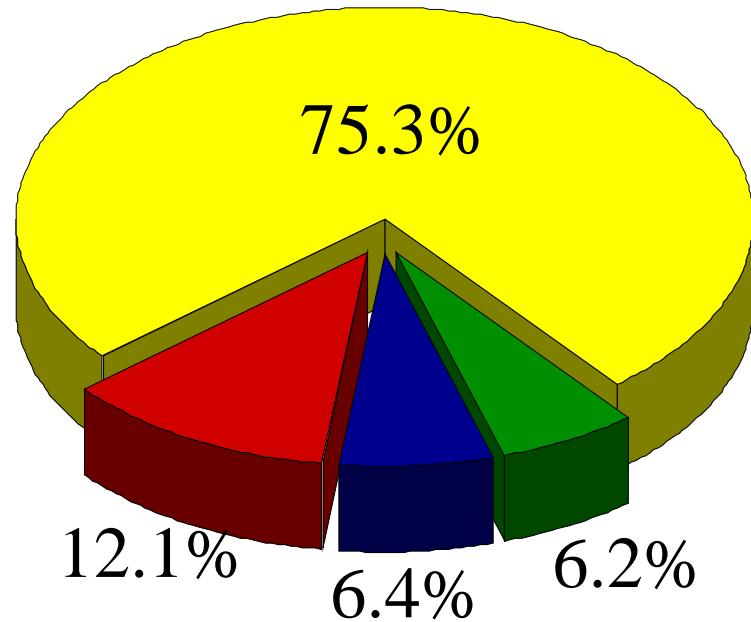
- among the tracks with high impact parameter [0.15 – 3 mm], select the **two with the highest p_T**
- using the measured p_T 's estimate the **significances of the impact parameters** of the two tracks (d/σ_d)
- apply a **2D cut** in the plane $\Sigma \ln(p_T)$ vs $\Sigma \ln(d/\sigma_d)$



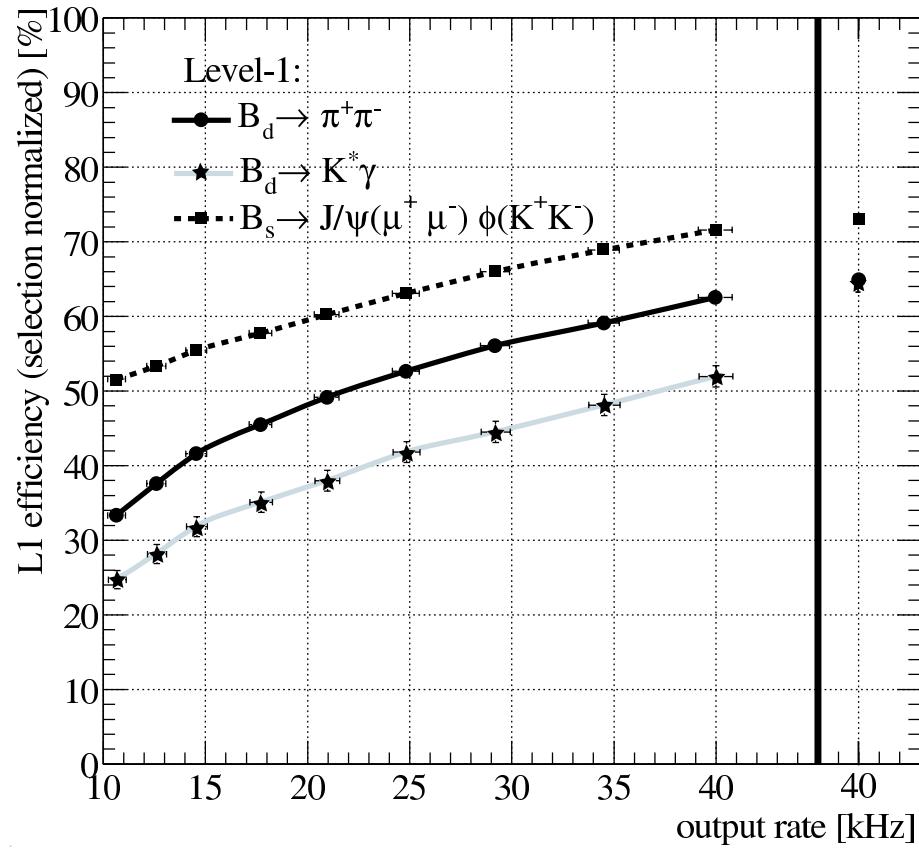
- **relax** the cut in the presence of **specific signatures**: dimuon mass, high- p_T photons and electrons from L0

BANDWIDTH DIVISION

Applied for “TDR Trigger”:



PERFORMANCE



$B \rightarrow$	ϵ_{L1}	$\epsilon_{L0 \times L1}$
$\pi^+\pi^-$	62.7%	33.6%
$D_s^-K^+$	62.6%	29.5%
$J/\psi(\mu^+\mu^-) K_S$	67.7%	60.5%
$J/\psi(e^+e^-) K_S$	54.9%	26.5%
$J/\psi(\mu^+\mu^-) \phi$	71.4%	64.0%
$K^{*0} \gamma$	51.9%	37.8%

IMPLEMENTATION

- Level-1 is a **software trigger**
 - maximum flexibility at an early stage!
- Level-1 farm now a part of the LHCb online farm:
 - larger L1 event size (with TT data, possibly more tracking stations)
 - smaller global event size due to detector re-optimization
 - ⇒ L1 and global event sizes not so different anymore!
- 1800 processors foreseen for the entire LHCb farm
 - flexible allocation between offline reconstruction and triggers (L1 and HLT), currently planning on 1000 processors for L1 and 400 for HLT
 - ⇒ average processing time of **1 ms per event** (1 MHz input rate)
- Level-1 buffer holds 58k events ⇒ **> 50 ms latency**
(Quad Data Rate SRAM)

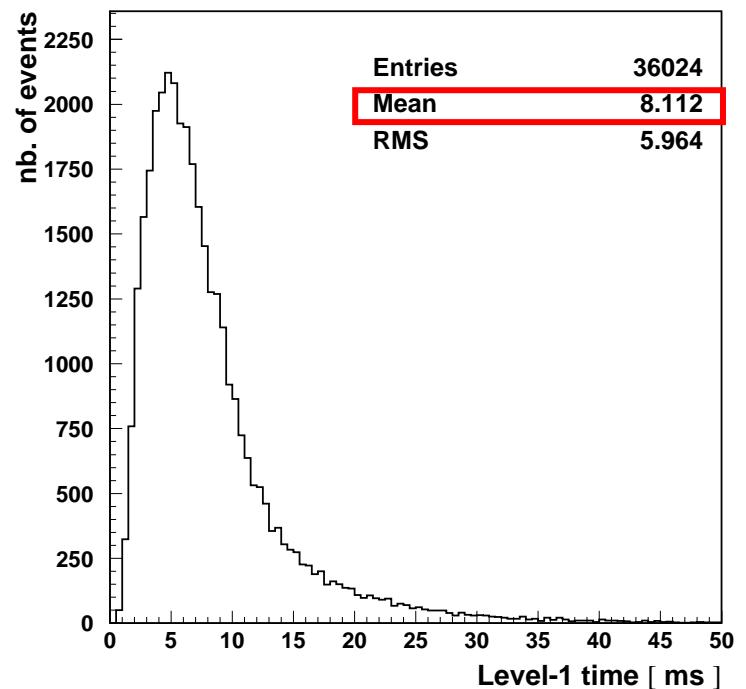
TIMING

initialization	~13%
2D tracking	~45%
primary vertex	~6%
3D tracking*	~20%
p_T measurement*	~16%
(match to TT+L0)	

* selected tracks only

- on average ~8 ms / event for complete L1 decision measured with 2002 CPUs
- expect a factor ~6 in CPU power between 2002 and 2007 (PASTA* report)
⇒ we are already in the right ballpark! (many optimizations still to come)

(TDR studies)



* PASTA = The LHC Technology Tracking Team for Processors, Memory, Architectures, Storage and TApes

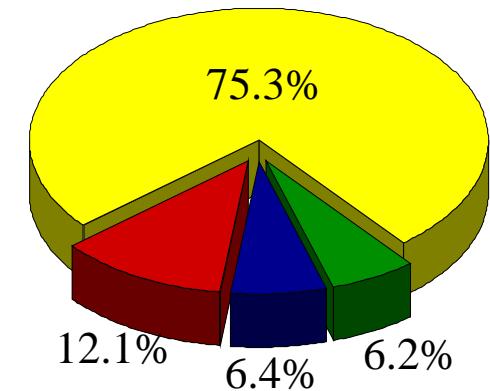
HIGH-LEVEL TRIGGER

- A second layer of **software trigger** for final decision on whether to write event to storage (~200 Hz foreseen)
- **Full detector information available** at this level (except RICH)
- Algorithms are **still under development**; current strategy:
 - 1) **Confirmation of Level-1 decision** with momentum resolution from all tracking stations (T1–T3): 40 kHz → 20 kHz
 - 2) **Full reconstruction** of (long) tracks.
 - 3) **Exclusive selection** of priority channels (simplified offline selections): 10–20 Hz per channel
 - 4) **Inclusive selection** of other channels (exploit common features in offline selections): fill remaining bandwidth

⇒ **hadron colliders force us to run the physics selection algorithms in the trigger!**

SUMMARY

- The LHCb Level-1 trigger is a **software trigger**
- Selection of events containing b hadrons by searching for **high impact parameter** and **high transverse momentum** of daughter tracks
- detector input from:
 - **VErtex LOcator** (impact parameter)
 - **Trigger Tracker**
 - **L0 decision unit**
- Extensive studies show satisfactory physics performance **within time budget**
- **Technical Design Report** for the LHCb Trigger System has just appeared! See there for more details.



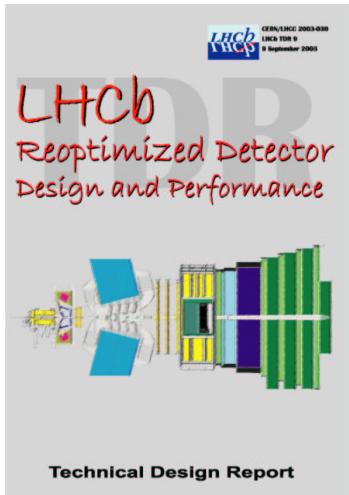
TRIGGER TDR

CERN / LHCC 2003-31

9 September 2003

together with:

Reoptimized Detector Design and Performance TDR



LHCb
FHCb

Thomas Schietinger (Lausanne)

LHCb Level-1 Trigger

VERTEX 2003



LHCb Trigger System

Tigritornis, -oid, n. s. Name of *Tanysiptera*.
-Tigrid, adj., of tigers; tigerish.
Tigritornis (Linnæus). Name of a species of
birds of prey, *Tanysiptera*, which resembles the
Tigritornis (Linnæus). Name of a species of
birds of prey, *Tanysiptera*, which resembles the
tiger in coloration.

Sticker. 17. *Wetmore*, p. 8, figs. 2, 3. *Wetmore*, 17. *Wetmore*, ad. *The trooper*, 1, 1940, p. 101, fig. 1. *trooper*, 1940, p. 101, fig. 1. *Trooper*. The form *trooper* occurs in *Wetmore*, but *Wetmore* remained his usual name down to 1940, and it is still in student use from *Souland* to the *Singling* *Wetmore*.

3. A movable catch or lever the pulling or pressing of which releases a device or spring, and so causes some form of mechanism to act. *E.g.* spring, trap.

The Washington Post, Wagner says, tried to keep the news from breaking, a little better than this newspaper did. "They had more resources, more coverage and speed of beat," he says. "But the big difference was that they had no reporter in the White House." Tidbits has a 200-word "Washington Wrap" 1½ times a day, which is a fraction of what the Post's 100-plus-word "Washington Post" does. "It's like the difference between my basement and the White House," he says. "I can't compete with them." The Post's reporter in the White House, though, is a good friend of Tidbits' editor. "He's a very nice guy," says Tidbits' editor. "He's been a tremendous resource for us." In fact, the Post reporter, Michael Sparer, has been a guest on Tidbits' radio show. "He's a very nice guy," says Tidbits' editor. "He's been a tremendous resource for us." In fact, the Post reporter, Michael Sparer, has been a guest on Tidbits' radio show.

2. Mr. F. M. Hayes of St. Louis, Mo., has the following to say concerning the Traders to be used in government contracts: "This is my New England home, and I have been here all my life. I am a native of Boston, and a son of a man who was a member of the Legislature, and a member of the State Board of Education. My father died in 1870, and my mother died in 1875. I have drawn the sum of \$100,000.00 from the Wm. M. Waite Fund, and I have given away \$100,000.00.

b. A lever or snib in a crossbow the pulling or pressing of which releases the string.

288. *Gymnophyllum* s. v. 28, no. 404, just as when a Crossbow is made by pulling down the Trigger. — 288 R. H. M. Attorney to 287. (Rutherglen) The string is drawn by the Trigger or button, and remains so, because it is strained thus until the trigger of the crossbow suggestion.

In the drawing of

trigger, in a moment, instantaneously. Quick as

Technis

Technique

el-1 Trigger

el- / trigger

Technical Design Report

PTFX 2003