THE LHCb LEVEL-1 TRIGGER

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for the

LHCb collaboration

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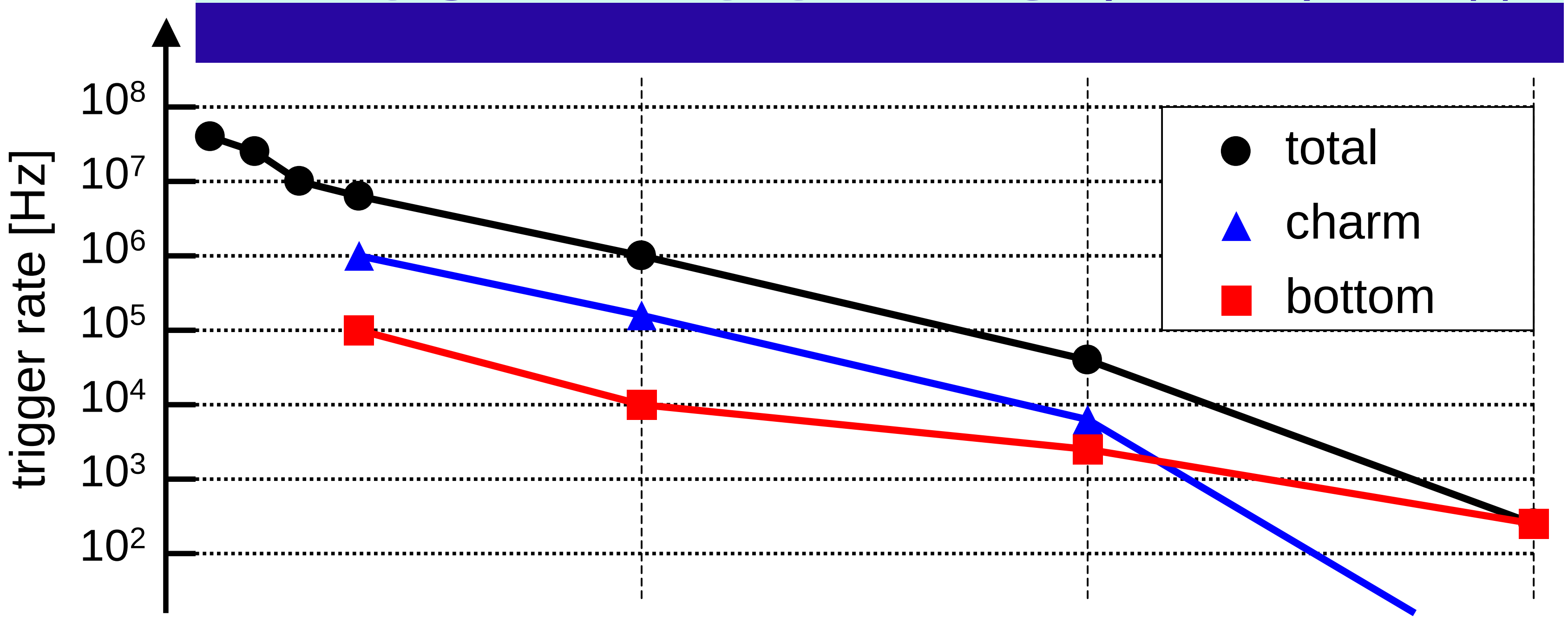
LHCb IN NUMBERS

- Design Luminosity: $L = 2 \times 10^{32}\ \mathrm{cm^{-2}\,s^{-1}} = 200\ \mu b^{-1}/s$
- $\sigma_{total} \approx 100$ mb, $\sigma_{inel} \approx 80$ mb, $\boldsymbol{\sigma_{vis} \approx 60}$ **mb**
  $\Rightarrow$ **12 MHz total (visible) event rate**
- Assumed $\boldsymbol{\sigma_{bb} \approx 500\ \mu b}$
  $\Rightarrow$ **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

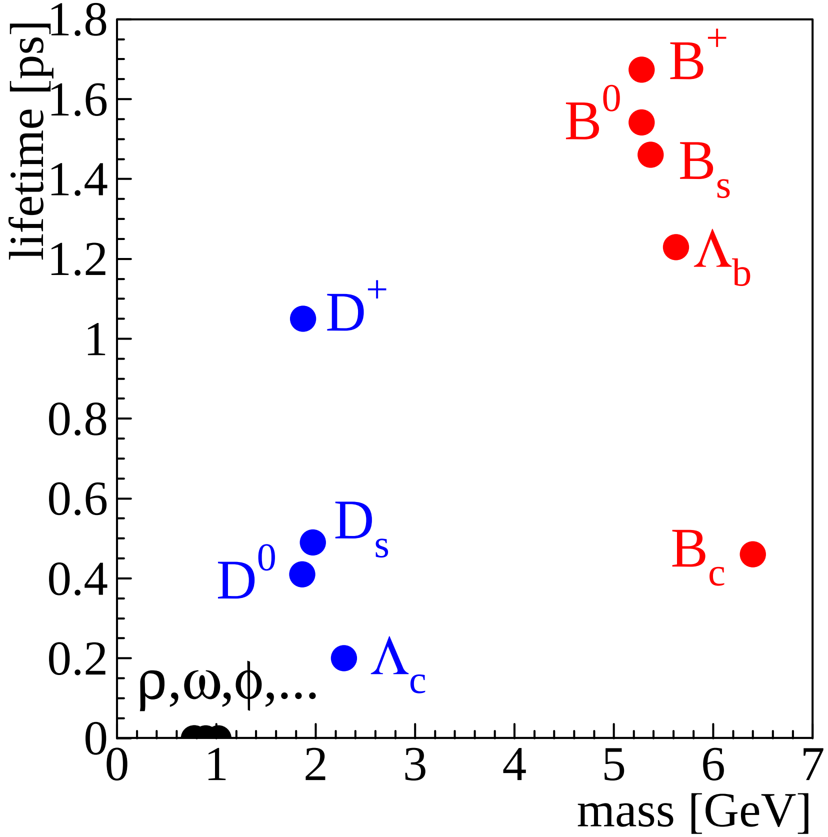


Level-0:
- hardware
- 12 MHz → 1 MHz
- Uses:
  - calorimeters
  - muon chambers
  - pile-up veto (Si)
- see previous talk!

Level-1:
- software
- 1 MHz → 40 kHz
- Uses:
  - vertices (Si)
  - some tracking
  - L0 objects

High-Level:
- software
- 40 kHz → 200 Hz
- Uses:
  - full event data

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)**

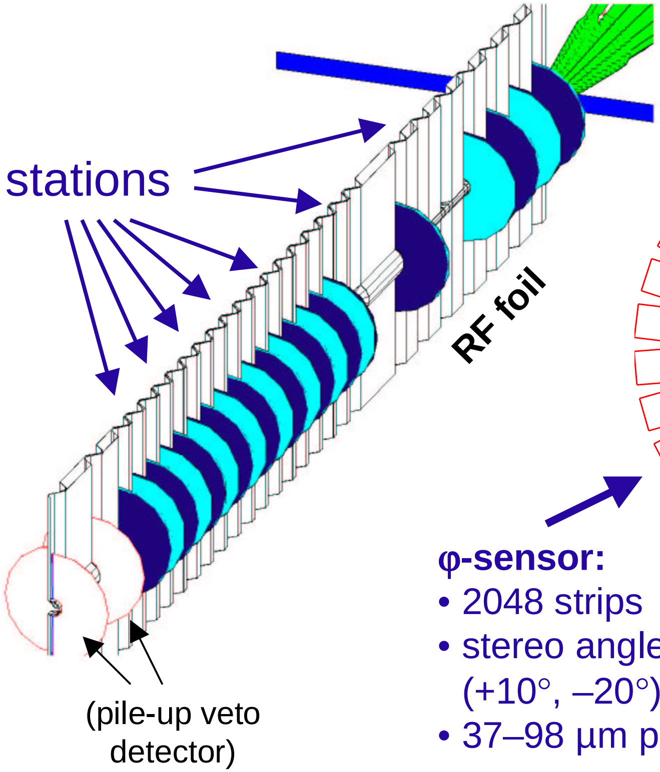
  and
- **high impact parameter** (relative to primary vertex)

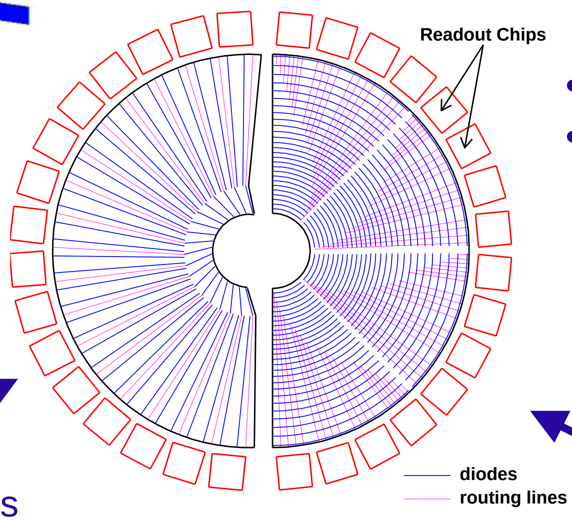
How do we measure impact parameters and p_T?

IMPACT PARAMETER (1)

measure impact parameters with the **VE**rtex **LO**cator:

- 21 stations, each with 2 r- and 2 φ-sensors
- –17.5 cm < z < 75 cm
- 220 µm Si, n-on-n
- sensitive area: 0.8 cm < r < 4.2 cm
- 170k channels
- ~1000 clusters/event to L1





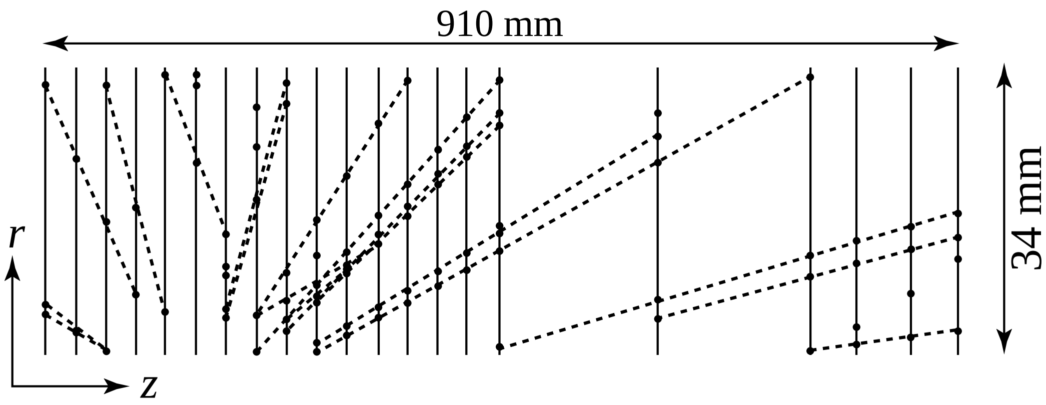
φ-sensor:
- 2048 strips
- stereo angle (+10°, –20°)
- 37–98 µm pitch

r-sensor:
- 2048 strips
- 4 sectors (45°)
- 40–103 µm pitch

IMPACT PARAMETER (2)

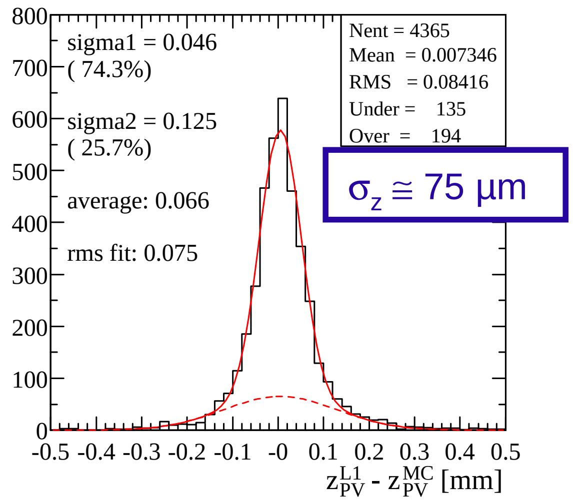
r-z projection contains most of the impact parameter information:

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



ε = 98% for B tracks

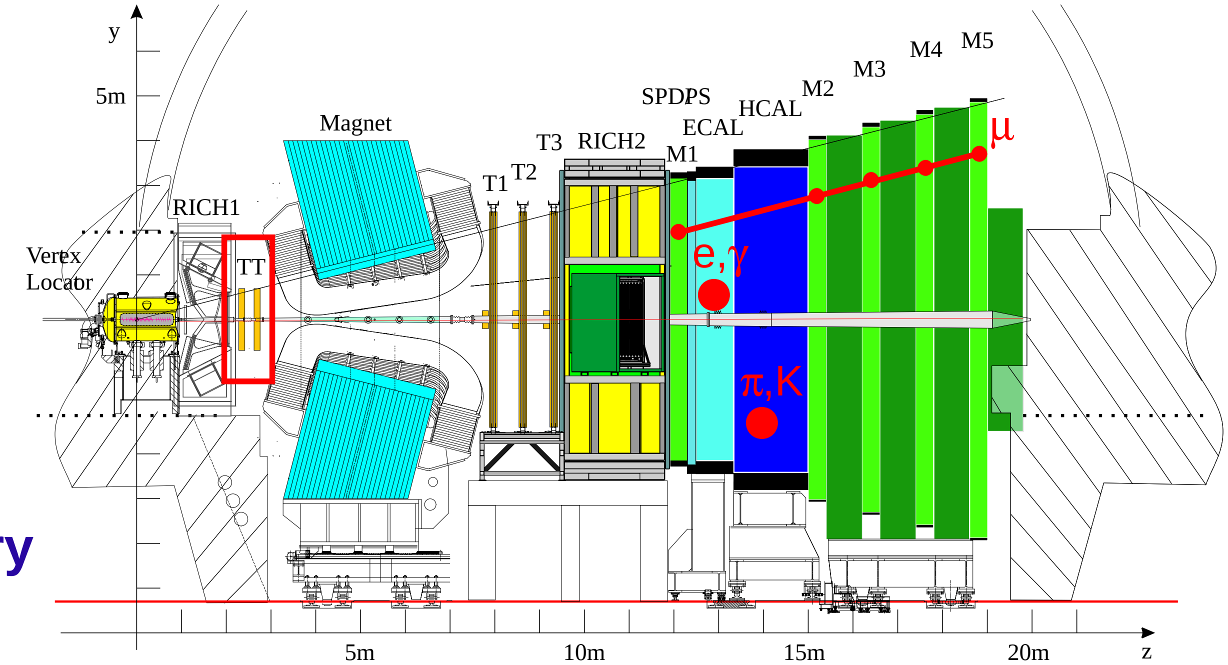
primary vertex resolution:



However: p_T measurement via extra-polation necessitates 3D tracks!
⇒ Reconstruct in 3D (φ-sensors) **only** those tracks that have **large impact parameter!** (between 0.2 mm and 3 mm)

P_T MEASUREMENT

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



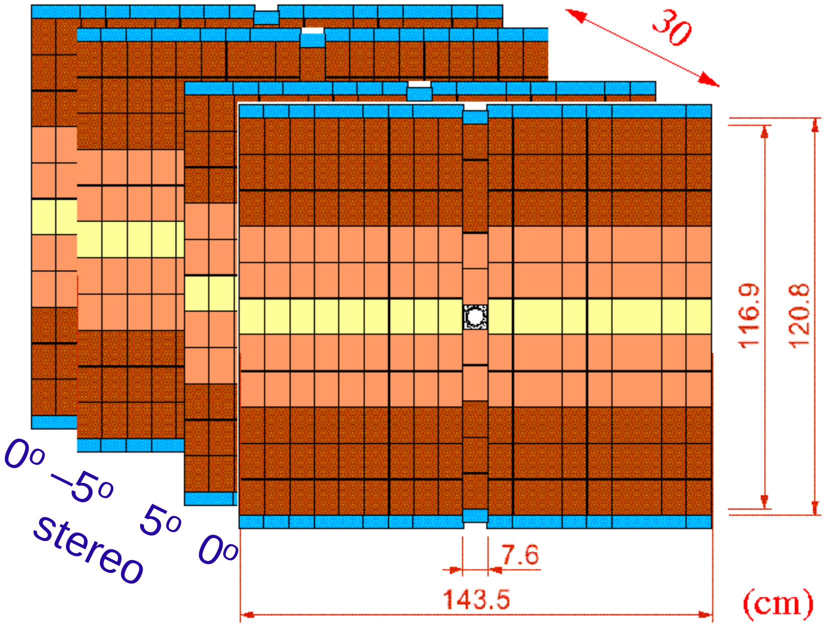
Two complementary approaches:

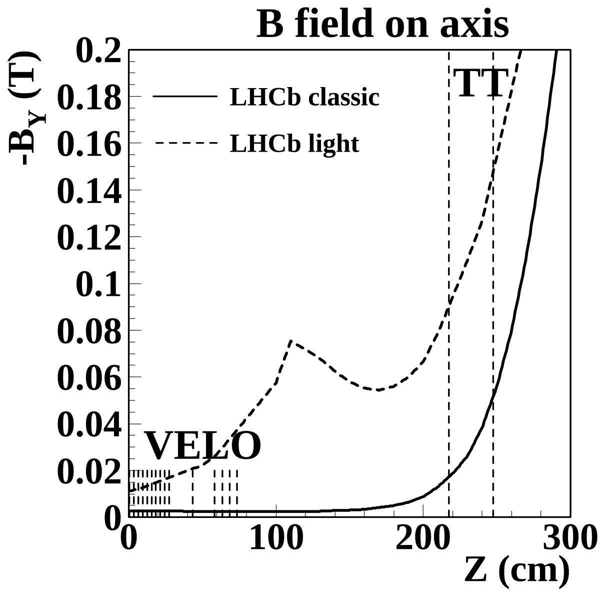
1) Fringe field before the magnet:
extrapolation to first tracking station, **TT** (= **Trigger Tracker**), situated between VELO and magnet
⇒ coarse momentum resolution but high efficiency

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 efficiency

P_T MEASUREMENT: TT

The Trigger Tracker (TT):





Reoptimized LHCb design: some magnetic field between VELO and TT

integrated Bdl ≈ 115 kG cm
⇒ 10-GeV track is deflected by
3.4 mm at TT

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

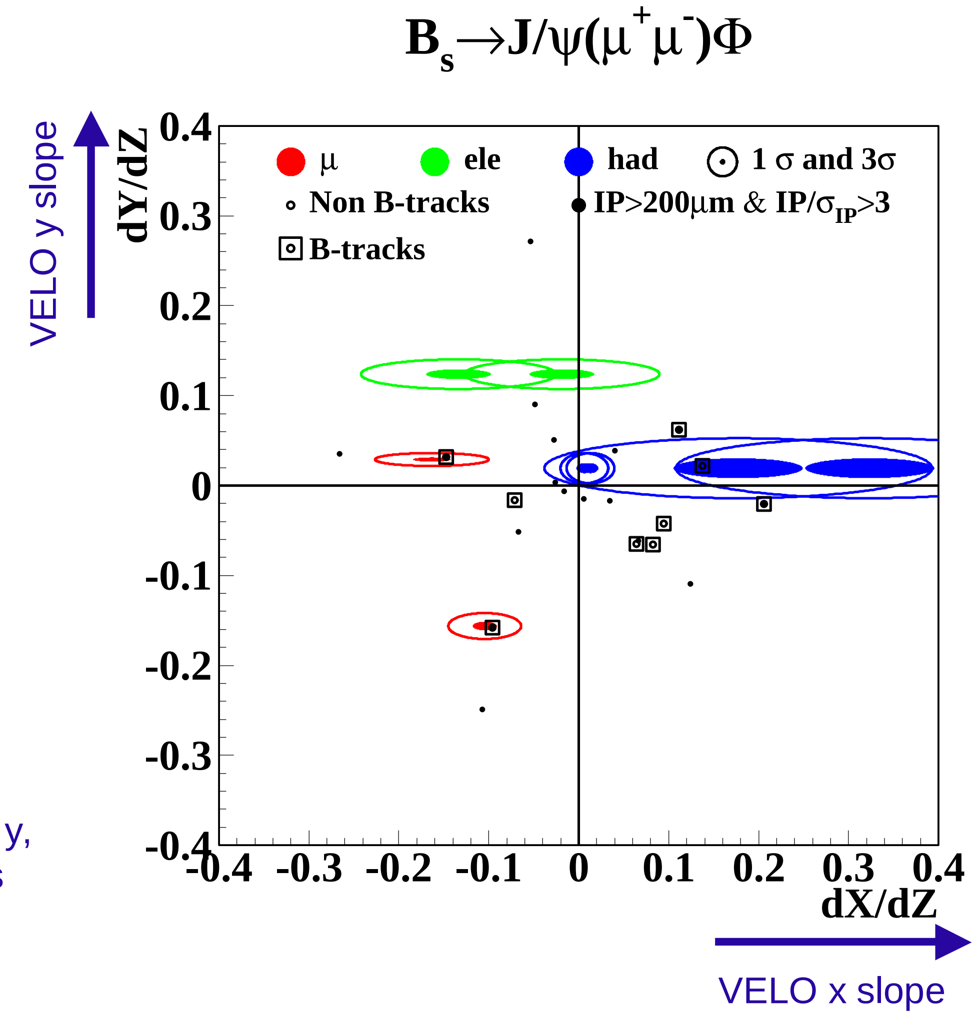
Momentum resolution: 20–40%

P_T MEASUREMENT: L0

Complementary approach:

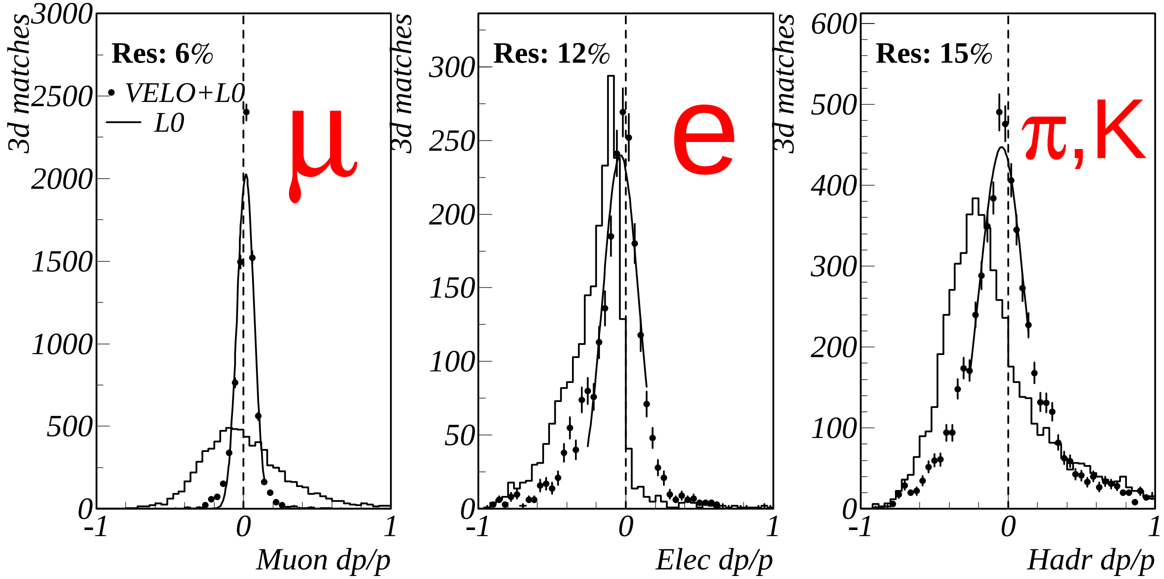
Try to match tracks found in the VELO to **high-p_T objects found by Level-0:**

- 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: L0



momentum resolution:	**6%**	**12%**	**15%**
matching efficiency:	**95%**	**94%**	**93%**
purity:	**52%**	**32%**	**27%**

P_T MEASUREMENT: L0

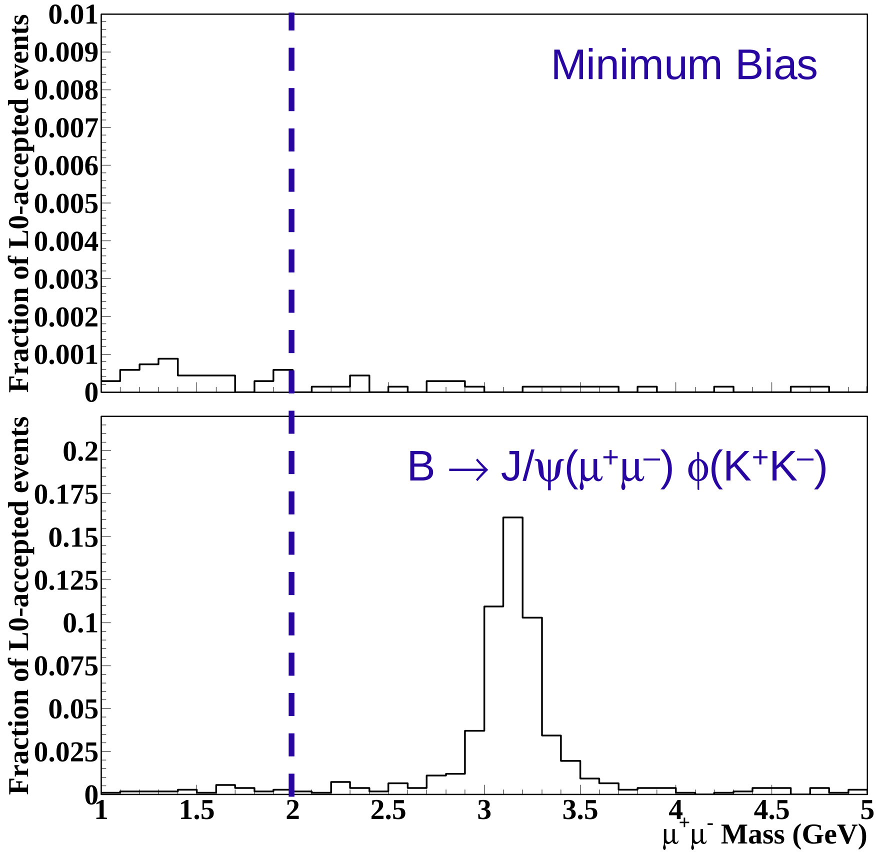
Example:

μμ **invariant mass** available at Level-1!

⇒ can boost dimuon channels at small cost in bandwidth!

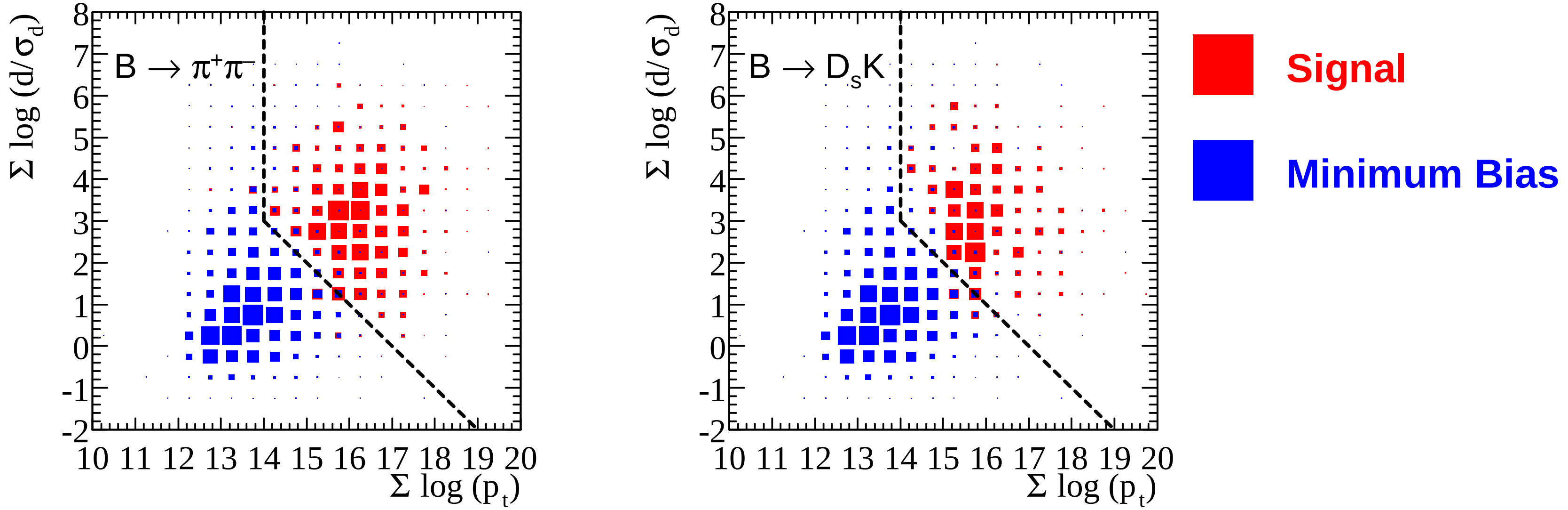
- $B \rightarrow J/\psi(\mu^+\mu^-)X$ channels
- $B \rightarrow K^*\mu^+\mu^-$
- $B \rightarrow \mu^+\mu^-$

Many more knobs to turn…, under study!



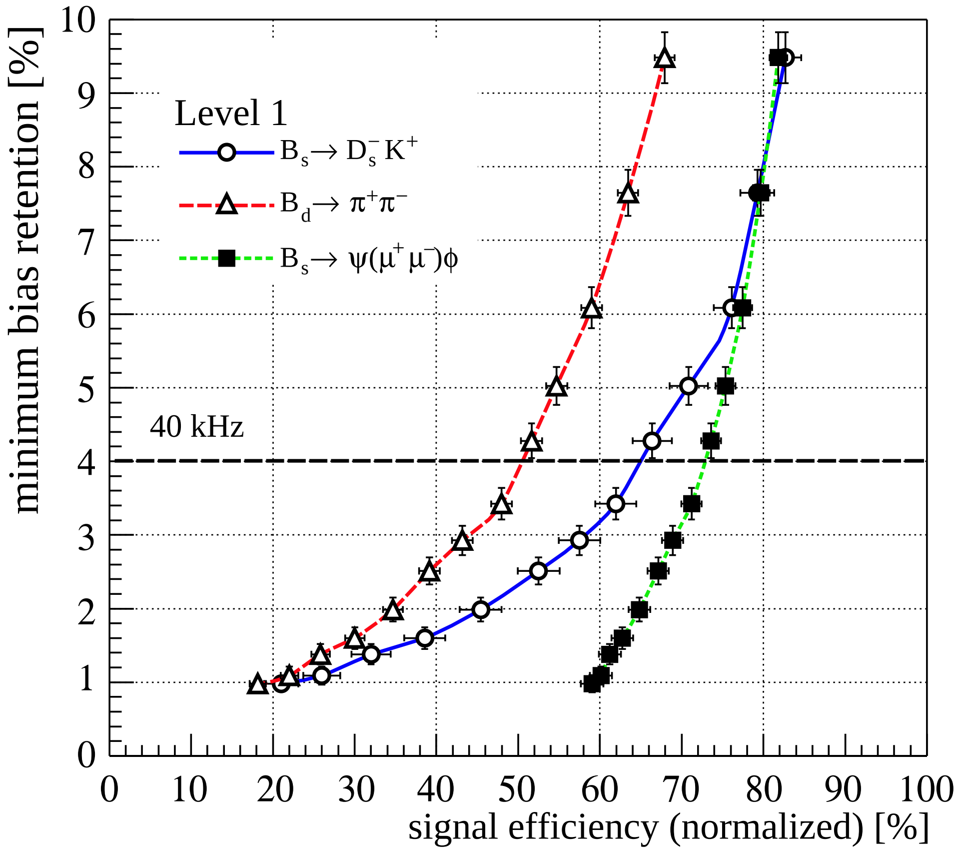
DECISION ALGORITHM

- among the tracks with high impact parameter [0.2 – 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 $\Sigma\log(p_T)$ vs $\Sigma\log(d/\sigma_d)$



- relax the cut in the presence of **specific signatures** (dimuon mass, high-p_T photons from L0 etc.)

PERFORMANCE



$B \to$	ε_{L1}	$\varepsilon_{L0\times L1}$
$\pi^+\pi^-$	50.5%	30.9%
$D_s^- K^+$	65.4%	28.6%
$J/\psi(\mu^+\mu^-)\ K_S$	71.1%	64.8%
$J/\psi(\mu^+\mu^-)\ \phi$	73.1%	67.9%
$K^{*0}\gamma$	32.7%*	26.7%

* before use of L0 photon

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 reoptimization (LHCb-light)
  - ⇒ L1 and global event sizes not so different anymore!

- 1200 processors foreseen for triggers (L1 and HLT)
  - flexible allocation between L1 and HLT, currently planning on 800 processors for L1
  - ⇒ average processing time of **800 μs per event** (1 MHz input rate)

- Level-1 buffer holds 58k events ⇒ **> 50 ms latency**

TIMING

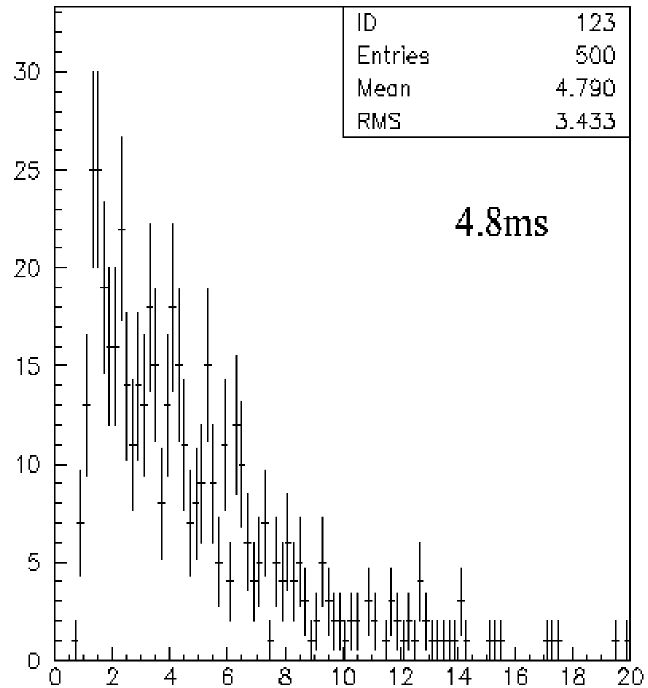
(preliminary studies)

2D tracking	~60%
primary vertex	~10%
3D tracking*	~10%
p_T measurement* (match to TT+L0)	~20%

* selected tracks only

- **on average ~7 ms / event for complete L1 decision measured with 2002 CPUs**
- **expect a factor 7–8 in CPU power between 2002 and 2007 (PASTA* report)**

⇒ we are already in the right ballpark! (many optimizations still to come)



tracking only: ~4.8 ms

* **PASTA** = The LHC Technology Tracking Team for **P**rocessors, Memory, **A**rchitectures, **ST**orage and **TA**pes

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** } (p_T)
- Preliminary studies show satisfactory physics performance **within time budget**
- More detailed studies for **Technical Design Report**, due in September '03