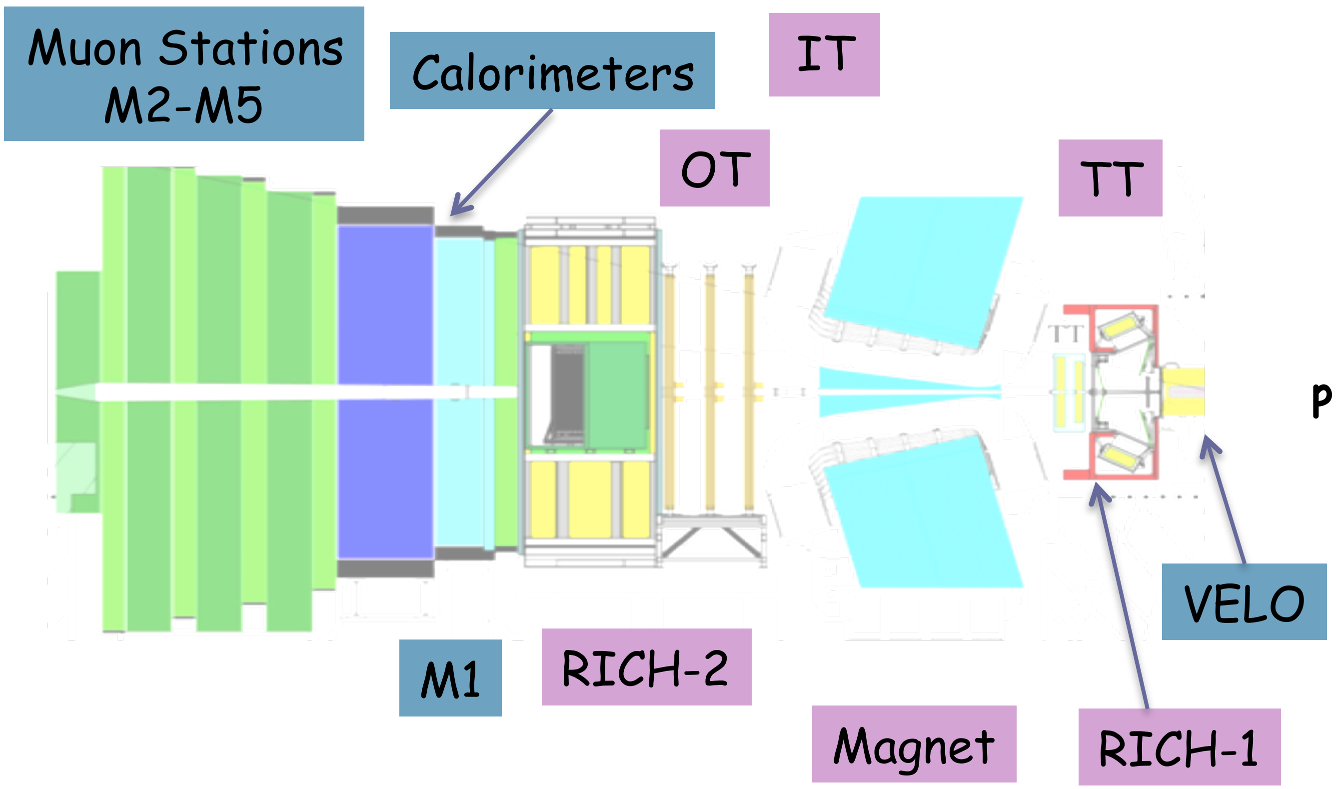
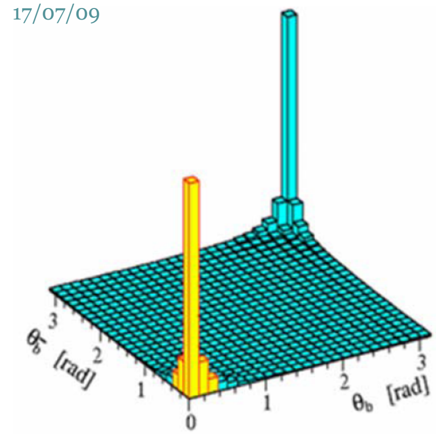
High Level Trigger for rare decays at LHCb

Kim Vervink
On behalf of the LHCb collaboration

17th of July 2009

LHCb detector





B decays mainly produced in the forward or backward direction

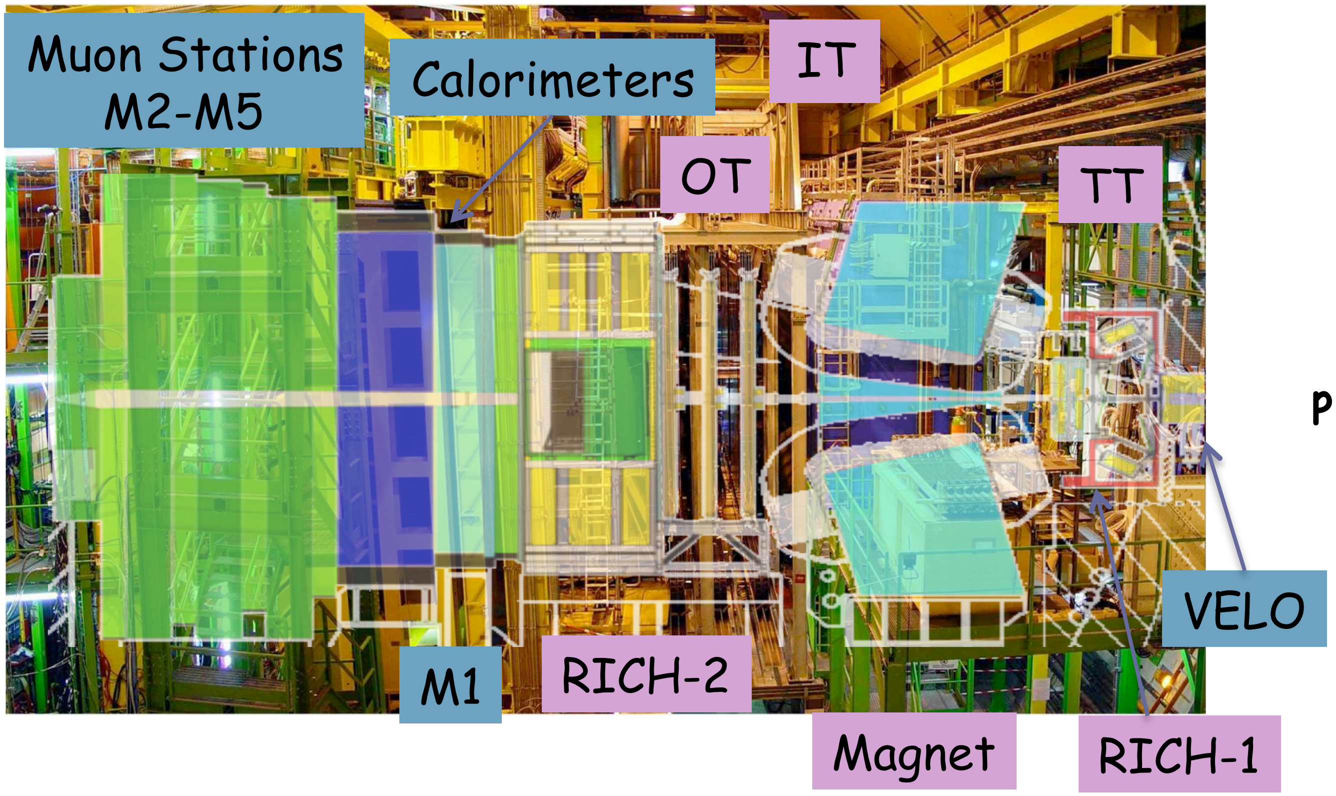
Sub detectors used in the first level of the trigger.

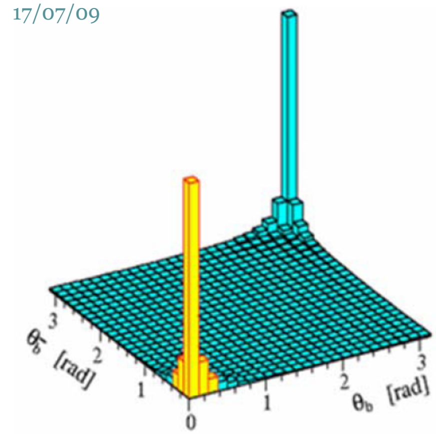
Detector fully equipped and commissioned.

Physics goal: search for New Physics in B decays in LHCb.

See also talk at plenary by A. Golutvin "LHCb"
- Wednesday 22nd at 14h30

LHCb detector





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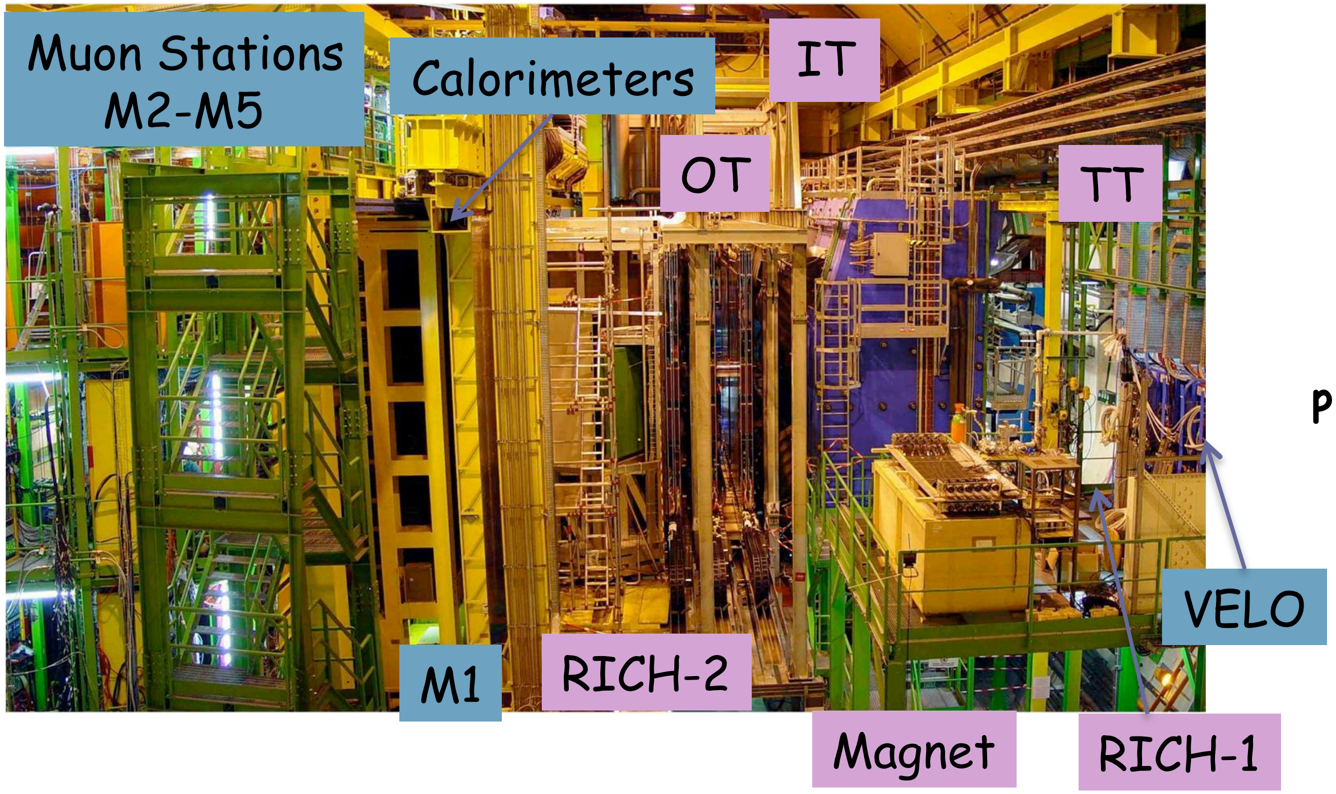

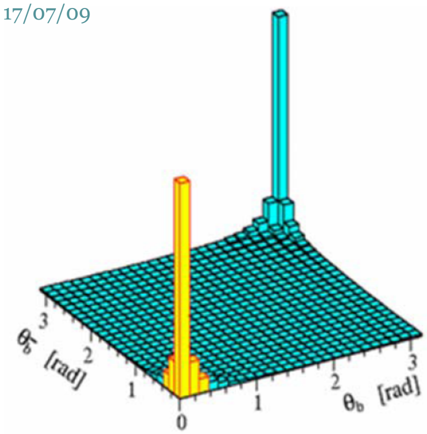

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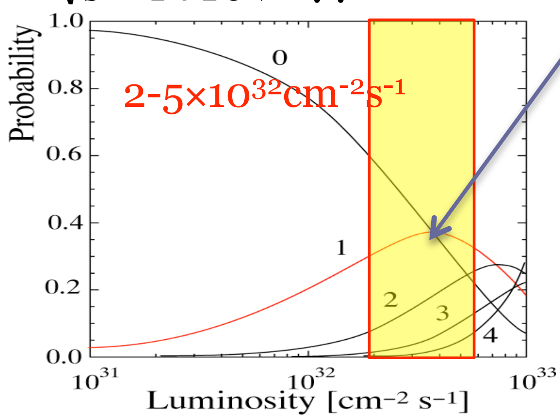
LHCb trigger environment

Production:

$\sqrt{s} = 14\,\text{TeV}$ **pp-collisions**



Tune luminosity: most probable is 1 interaction/X'ing

$\mathcal{L} = 2 \cdot 10^{32}\,\text{cm}^{-2}\text{s}^{-1}$

10^{12} $b\bar{b}$ per year or 10^5 per s.

$\sigma_{b\bar{b}} = 500\mu b$

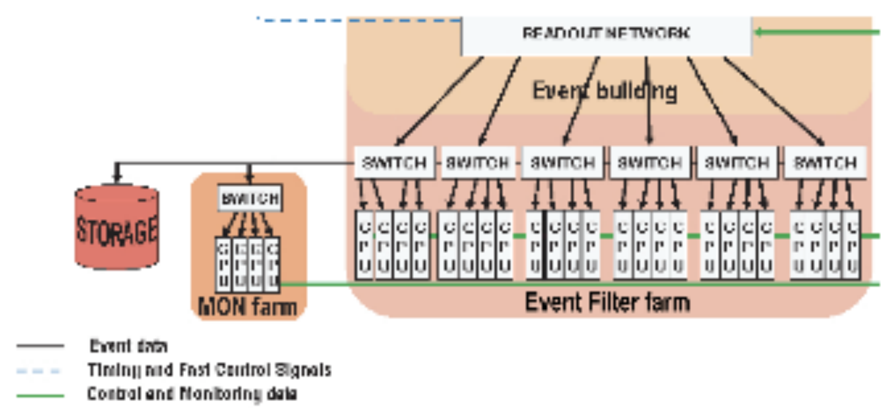
Corresponds to:	40MHz
Both bunches filled:	30MHz
>2 tracks in acceptance:	10MHz

15kHz of B decays with at least 1B in the acceptance
BR of interesting B decays: typically < 10^{-5} O(1)Hz

Trigger is essential!!!

<u>General strategy</u>

1) First level hardware trigger (L0)
→ Readout netwerk
2) CPU farm (High Level Trigger):
→ Monitoring and storage



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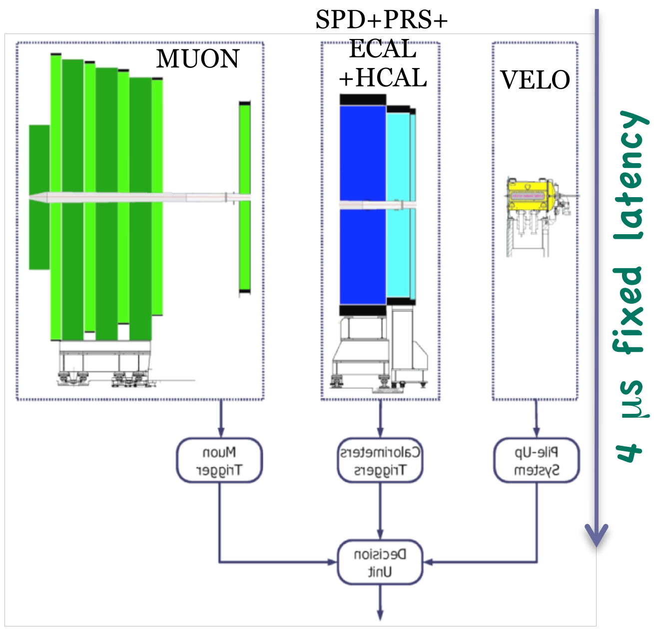
L0 trigger



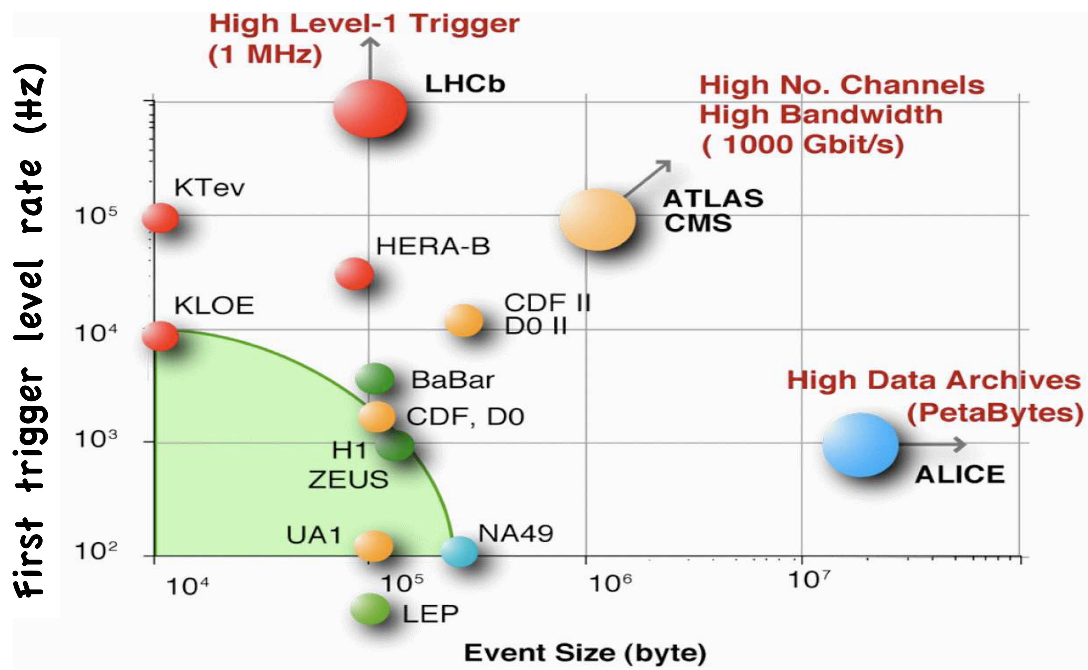
Custom Electronics

4 subdetectors read out and provide L0 trigger

- Velo: Pile-up system
- Ecal: single e/γ with p_T > 2.5 GeV → 200kHz
- Hcal: single hadron with p_T > 3.5 GeV → 700kHz
- Muon: single μ with p_T > 1.0 GeV → 200kHz

LHCb looks for B-mesons, lower mass (and p_T) than particles searched for by GPD's

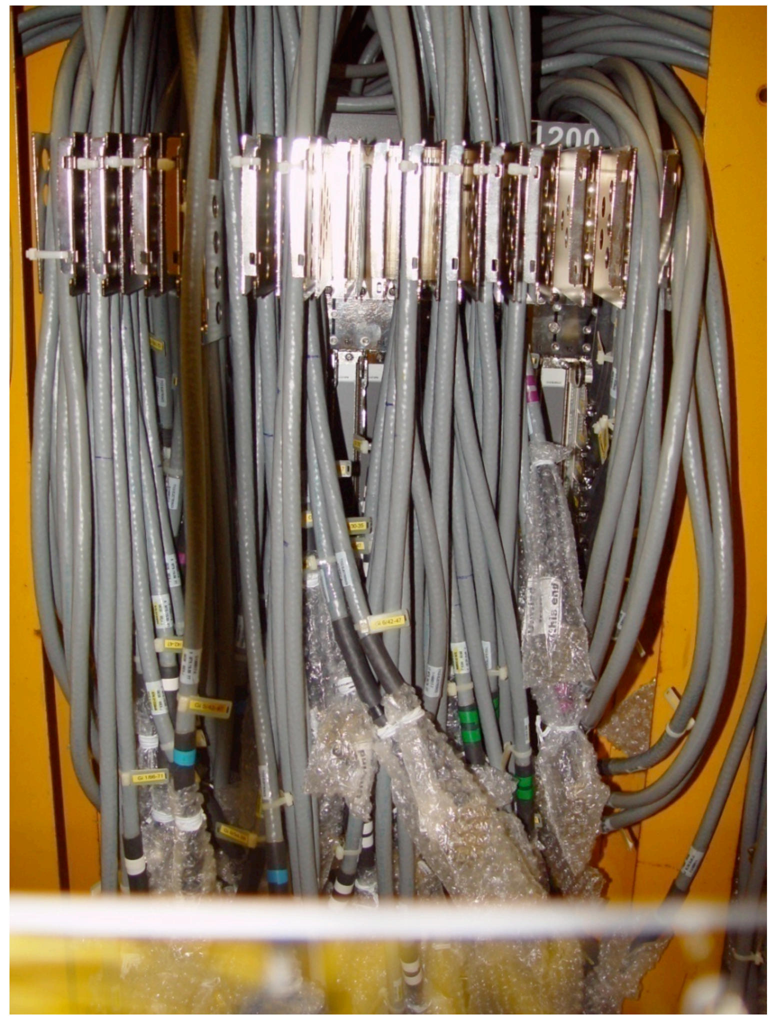
L0 output is large: 1 MHz



Pictures: Readout Network (Switch)

Glossy-Print

Real Life



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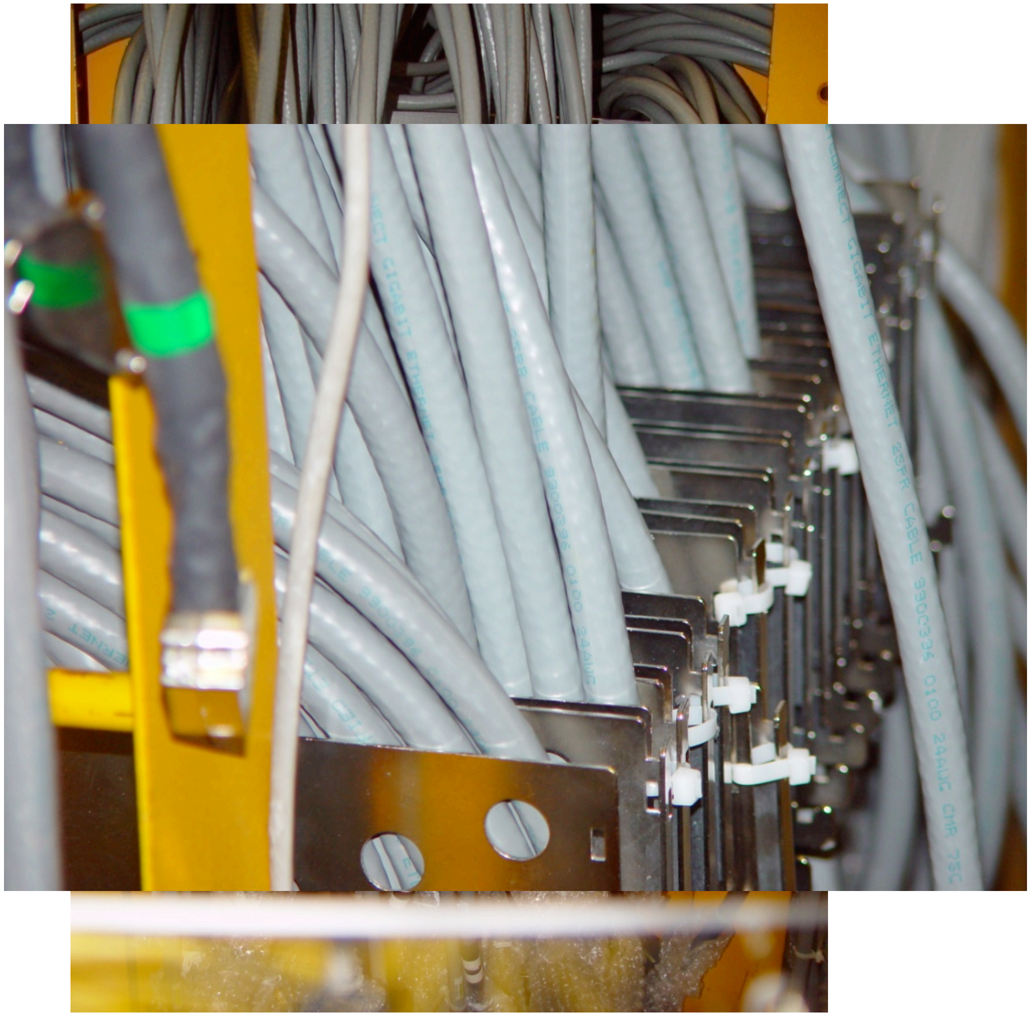

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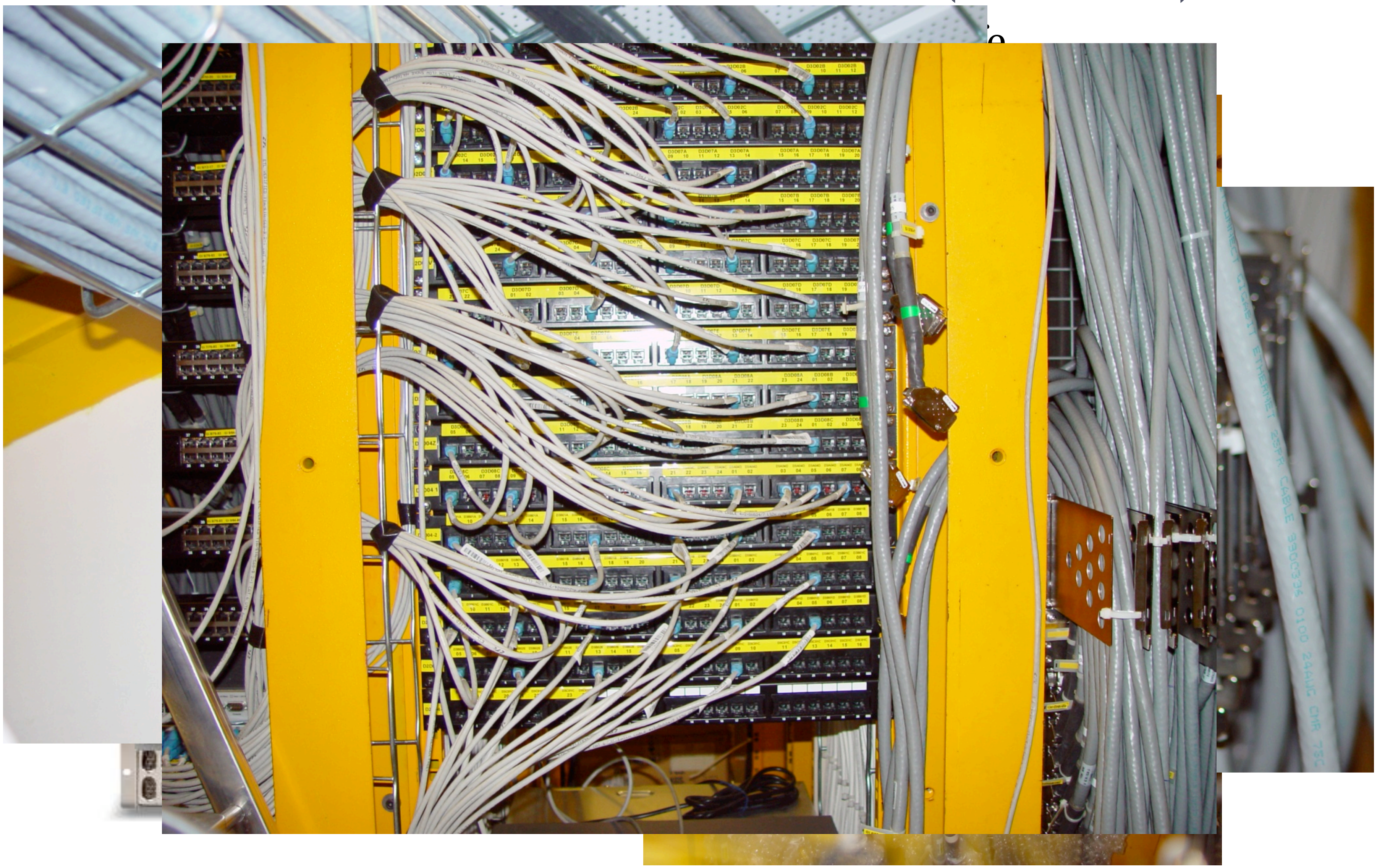
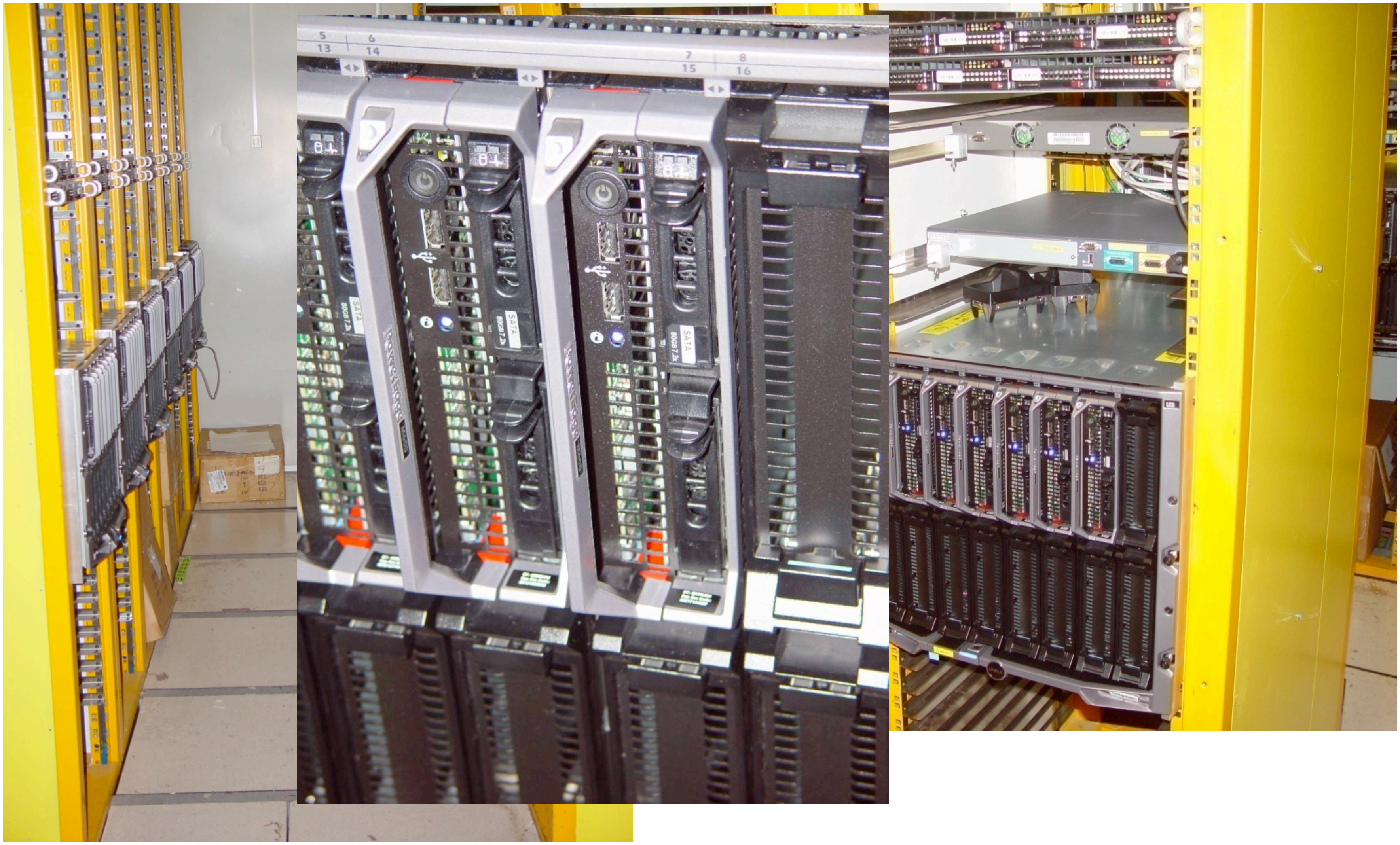
Pictures: Readout Network (Switch)





Hlt trigger: 2 layers

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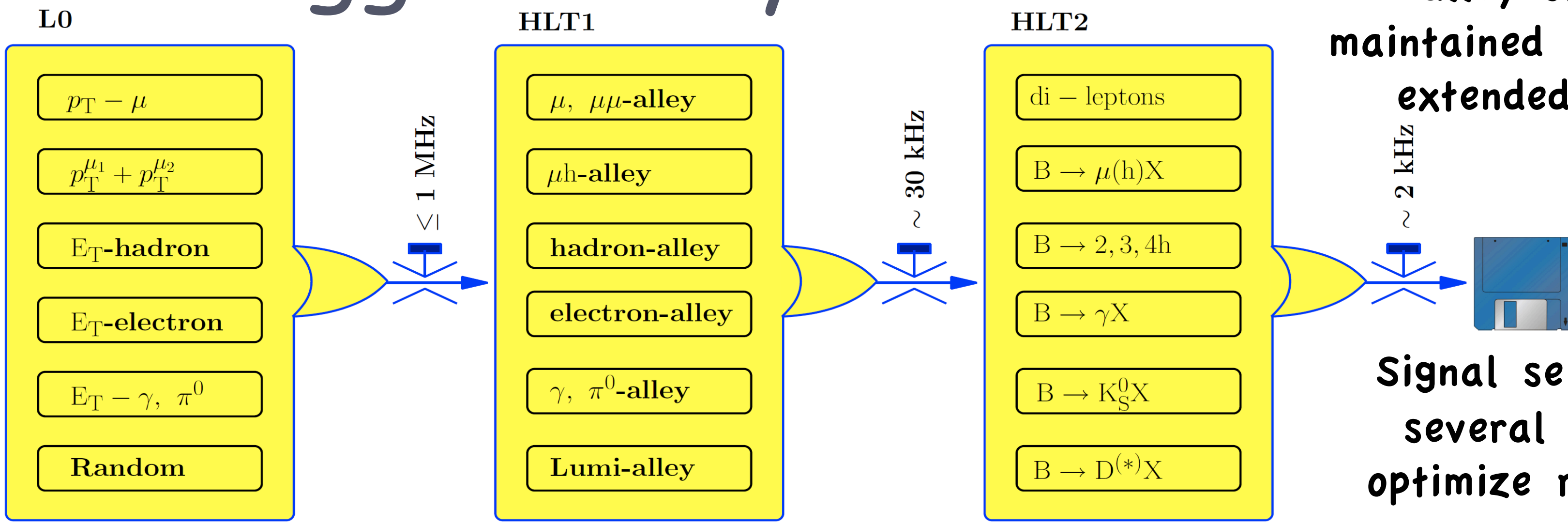


L0 alley structure is maintained in Hlt1 and extended in Hlt2

Signal selected by several triggers optimize robustness

~1 MHz

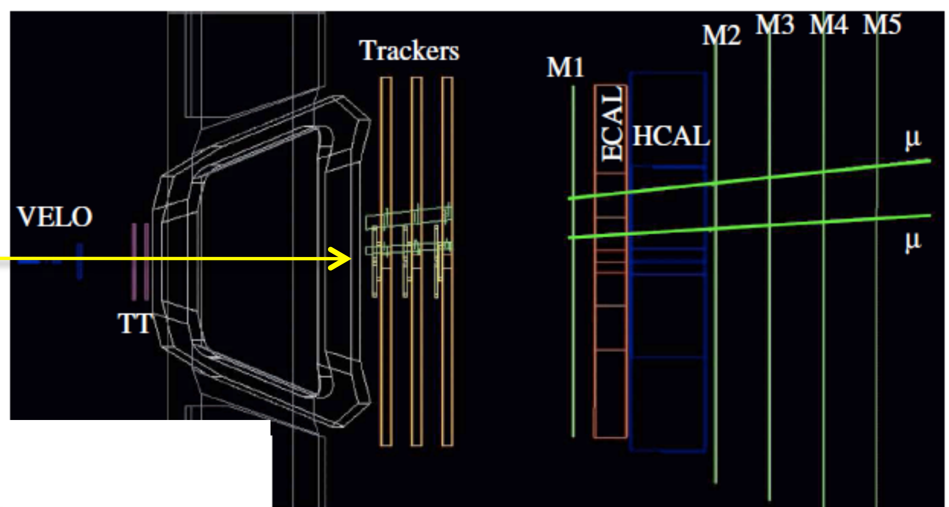
Hlt1:

confirmation of the L0 object

add information of T stations and Velo

search for tracks only in small window

~30 kHz



Hlt2: some additional inclusive trigger streams (K_s, ϕ) and a handful of exclusive selections (ex. $B_s \to \phi\gamma$).

~2 kHz

Hlt2 trigger example: the inclusive ϕ alley

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~30 kHz

1. tracks from pattern recognition (no fitting) - apply "robust" cuts: P_T, distance to IP, ϕ mass...

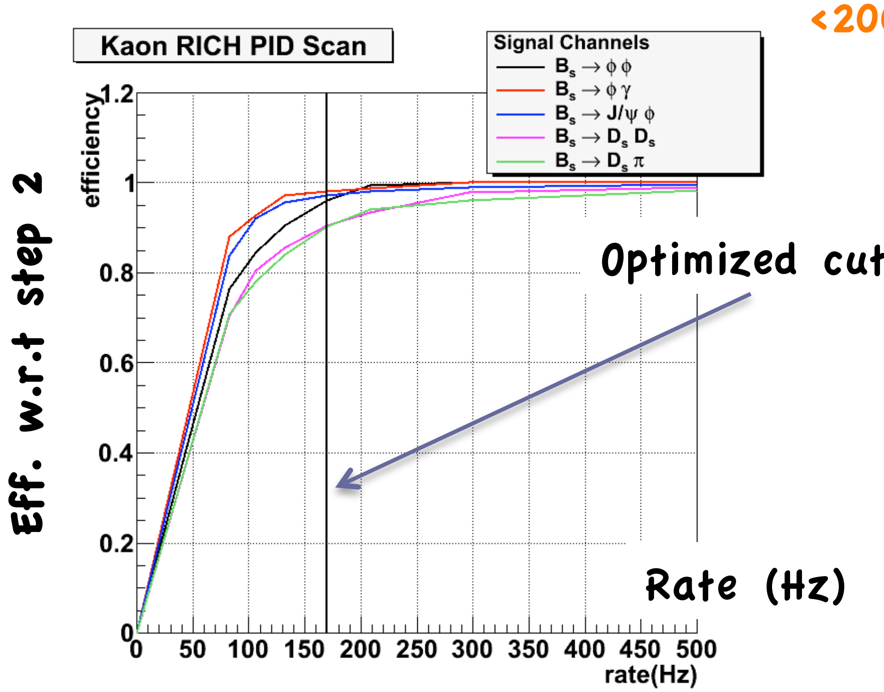
2000 Hz

2. fancier tracking algorithm applied on reduced rate: Kalman fit tracks and apply cuts on track and vertex resolutions.

800 Hz

3. Now with a reduced rate below 1000 Hz, we can apply the PID algorithm

<200 Hz



Hlt2 Incl. ϕ efficiency on offline selected events.

$B_s \to \phi\gamma$	75%
$B_s \to J/\psi(\mu\mu)\phi$	45%
$B_s \to J/\psi(ee)\phi$	55%
$B_s \to \phi\phi$	82%
$B_s \to D_s D_s$	40%
$B_s \to D_s \pi$	25%

Channels will also be triggered by other incl. trigger lines

Trigger performance on rare decays:

1.) $B^0 \rightarrow K^* \mu\mu$

2.) $B_s \rightarrow \phi\gamma$

See also: Search for New Physics at LHCb:
CP violation in Charm sector and rare decays of B hadrons
(M. H. Schune)
II Flavour Physics – Friday 17th at 10h00

NOTE: trigger efficiencies quoted for offline selected events.

$B^0 \rightarrow K^*\mu\mu$

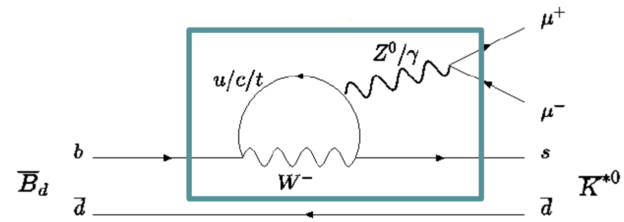
- FCNC decay which proceeds through a $b \rightarrow s$ transition. New Physics can enter in the loops of the diagram.

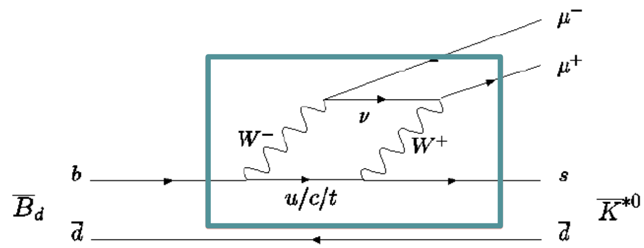
- Decay described by three angles (θ_l, ϕ, θ_K) and di-μ invariant mass q^2.

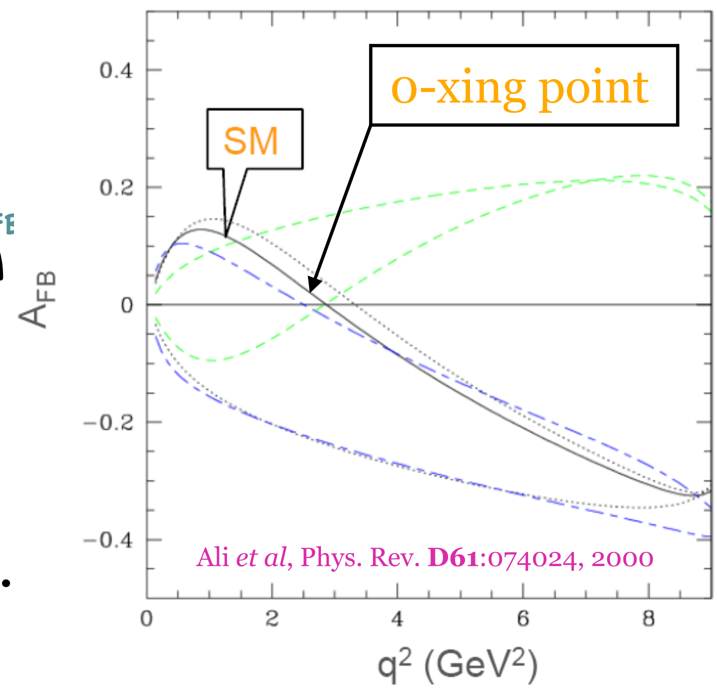
- By measuring angular distribution asymmetries, the uncertainty from $B^0 \rightarrow K^*\mu\mu$ transition form-factors cancel.

- Start with forward-backward asymmetry A_{FB} of θ_l distribution and compare with the SM prediction.

- Analysing simultaneously the three angular distributions as function of q^2 gives sensitivity to each of its Wilson coefficient.







K*μμ through the trigger: μ and hadron alley

- The muon alleys are main trigger line but beware of soft muon signal.
- Cuts on P_T affects the angular distribution.

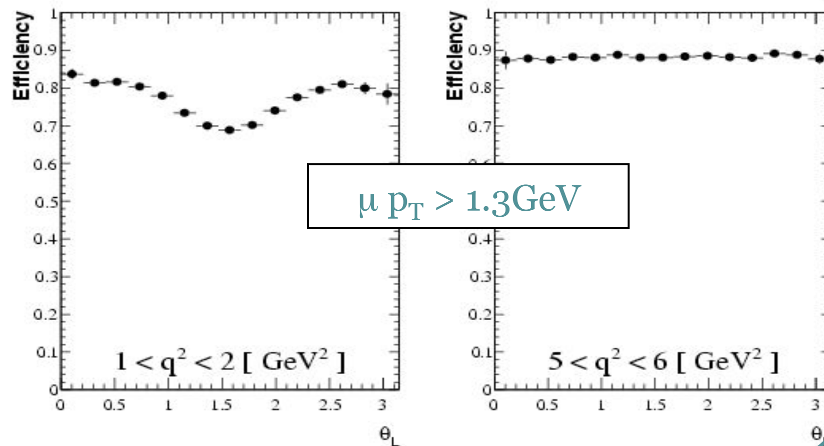
Level 0

Single muon: - P_T muon > 1.3 GeV
- only required for 1 muon

Di-muon: - P_T of each > 0.1 GeV
- sum of P_T>1.0 GeV

Hadron

L0 efficiency: ~90%



Hlt 1 + 2

		Hlt1	Hlt2t
(Di) Muon alley:	- P_T cut, IP (and di-muon mass)	eff: ~83%	eff: 80%
Muon + track alley:	- 2nd μ can have low P_T	eff: ~80%	eff: 85%
Hadron alley:		eff: ~20%	eff: 80%

L0 x Hlt1 x Hlt2 efficiency on offline selected events: 80%.

Distortion of acceptance function

Trigger and offline selection and the detector resolution affects the angular distribution θ_l.

- Zero-crossing point of A_{fb} stays intact!!

Parameterize the acceptance function

1. MC simulation: The momentum distribution of B_d needs to be accurately generated.
   Cross check with $B^0 \to J/\psi\ K^*$.
2. Control sample: $B^0 \to J/\psi\ K^*$: triggered and selected by the same filters as the signal -- but 20 times more statistics and no A_{fb} asymmetry.

2fb^{-1}:

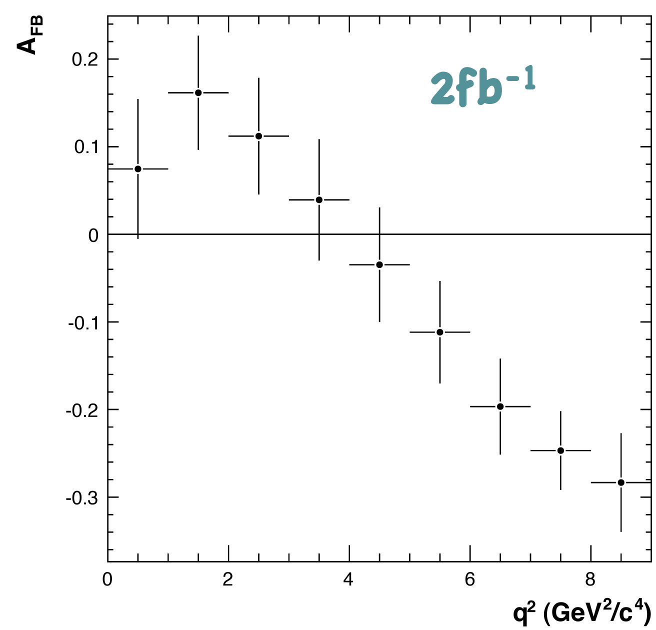
Expected number of signal events: 4300

Precision on determining the zero-crossing: ±0.5 GeV^2

Statistical uncertainty on $A_{fb}(q^2)$: ~0.6 GeV^2

BELLE has ~230 K^*ll events (657M BB) [1]

CDF ~20 $K^*\mu\mu$ events (0.9fb^{-1}) [2]



[1] arXiv:0810.0335v1

[2] arXiv:0804.3908v1

Trigger performance on rare decays:

1.) $B^0 \rightarrow K^* \mu\mu$

2.) $B_s \rightarrow \phi\gamma$

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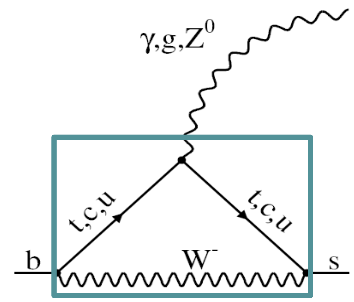


Probe New Physics in loop which would modify the photon polarisation.

- Measure the time-dependent decay rate:

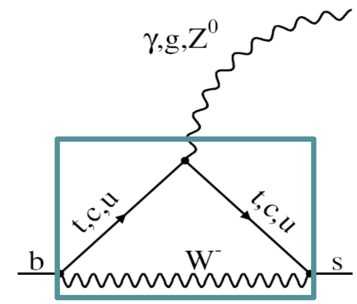
$$\Gamma(\overset{(-)}{B}_s \rightarrow \phi\gamma) = |A|^2 e^{-\Gamma_s t}\left[\cosh(\Delta\Gamma_s t/2) + A_s^{\Delta}\sinh(\Delta\Gamma_s t/2) \pm C_s\cos(\Delta m_s t) \mp S_s\sin(\Delta m_s t)\right]$$

$$C_s \approx 0 \qquad S_s \approx \sin 2\psi \sin 2\phi \approx 0$$

$$\sin\varphi_s \overset{SM}{\approx} 0$$

- Decay described by proper-time (t) but not by tagging
- Reliable theoretical prediction at NNLO

$B_s \to \phi\gamma$



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- Measure the time-dependent decay rate:

$$\Gamma(\overset{(-)}{B}_s \to \phi\gamma) = |A|^2 e^{-\Gamma_s t}\left[\cosh(\Delta\Gamma_s t/2) + A_s^\Delta \sinh(\Delta\Gamma_s t/2)\right]$$

$$A_s^\Delta \approx \sin 2\psi \cos 2\phi \approx \sin 2\psi$$

$$\tan\psi \equiv \left|\frac{A(\bar{B}_s \to \phi\gamma_R)}{A(\bar{B}_s \to \phi\gamma_L)}\right|^{SM} \approx 0.1$$

- Decay described by proper-time (t) but not by tagging
- Reliable theoretical prediction at NNLO

$B_s \to \phi\gamma$ through the trigger: γ and hadron alley

Level 0

Photon alley: eff*: ~72%

-$E_T(\gamma)$ > 2.3 GeV, $E_T(e)$ > 2.6 GeV, $E_T(\pi^0)$> 4.3 GeV

Hadron alley: E_T > 3.5 GeV eff*: ~36%

L0 efficiency: ~82%

Hlt 1

Photon alley = photon + 1 or 2 track(s): eff*:~60%

- fast p^0/γ separator algorithm
- track: requirements on p_T, IP distance, vertex quality

Hadron alley eff*:~15%

L0 x Hlt1 efficiency: ~60%

Hlt 2

Exclusive B_s -> $\phi\gamma$ line: eff*: ~88%

- offline selection procedure with relaxed cuts

Inclusive phi alley: eff*: ~83%

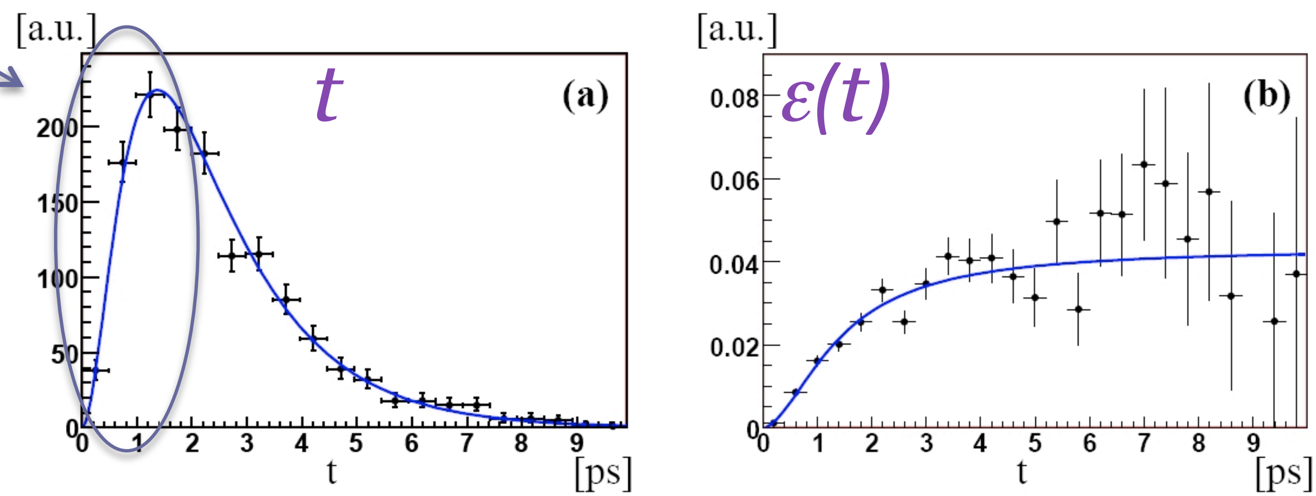
-P_T (K and ϕ) and PID, IP, mass window

L0 x Hlt1 x Hlt2 efficiency: ~57%

* on offline selected events (which passed L0 (+ Hlt1) trigger)

Distortion of the proper-time distribution

- Both trigger selection and offline selection cut on IP distance of ϕ to reduce the prompt background.
- Affects the B_s proper-time distribution



- Acceptance function: $\varepsilon=\varepsilon(t)$
  - Use control sample $B^0 \to K^*(K^+\pi^-)\gamma$
  - Follows the same trigger flow as the signals.
    - Statistics are ~factor 6 higher.

2 fb^{-1}

Expect 11×10^3 selected signal events
stat. error on A^Δ = ~0.2

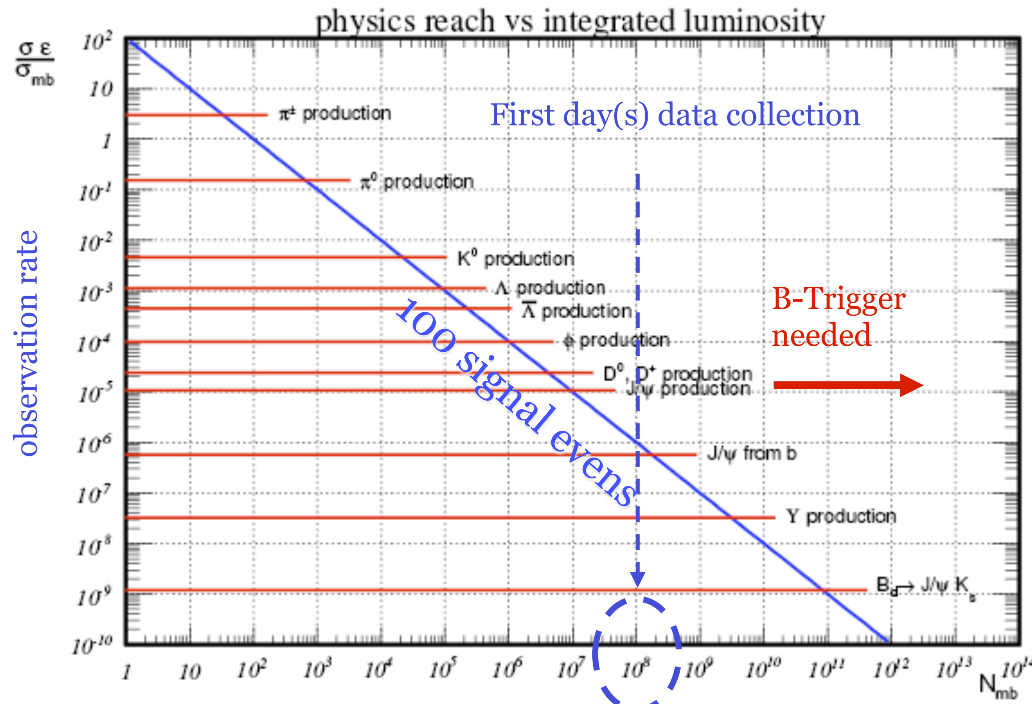
Belle [1]:
18^{+6}_{-5} signal events on 24 fb^{-1}
BF $(B_s \to \phi\gamma) = 57^{+18}_{-15}(stat)^{+12}_{-11}(syst)\ 10^{-6}$

[1]PRL 100, 121801 (2008)

Trigger during first data

Trigger settings has to allow for trigger commissioning

1. Random event selector trigger
   - Monitor the distributions at L0 entrance
2. L0 trigger + Random event selector in Hlt1:
   - Monitor the distributions of variables we will cut on in Hlt
3. Events passing the full trigger:
   - Monitor the online environment using offline reconstruction
   - Trigger efficiencies vs. offline



« Minibias statistics to perform a 10% measurement »

Summary

- Critical aspect of LHCb is isolating rare decays in the LHC environment.
- Trigger consist of
  - a hardware trigger which search for high P_T events.
  - and a software "High Level Trigger" based on software algorithms in a CPU farm.
- Trigger efficiencies of 80% and 60% for $B^0 \rightarrow K^*\mu\mu$ and $B_s \rightarrow \phi\gamma$ respectively are obtained.
- With control samples we can study and correct for the introduced biases on acceptance function or lifetime distribution.
- Finally strategy for trigger commissioning is discussed

We are ready for data...

Other LHCb talks at EPS

- Commissioning and performance of LHCb vertex detector (T. Bowcock)
  - IV Detectors & accelerators – Thursday 16th at 10h00
- Measurements of CP violation and CKM matrix at LHCb (M. Calvi)
  - II Flavour Physics – Thursday 16th at 11h30
- New Physics sensitivity of the rare decay mode $B \to K l^- l^+$ (T. Hurth)
  - II Flavour Physics – Friday 17th at 9h30
- Search for New Physics at LHCb: CP violation in Charm sector and rare decays of B hadrons (M. H. Schune)
  - II Flavour Physics – Friday 17th at 10h00
- Nonleptonic charmless Bc decays and their search at LHCb (S. Descotes Genon)
  - II Flavour Physics – Saturday 18th at 10h05
- LHCb (A. Golutvin) –
  - Plenary session – Wednesday 22nd at 14h30