The Trigger System of LHCb

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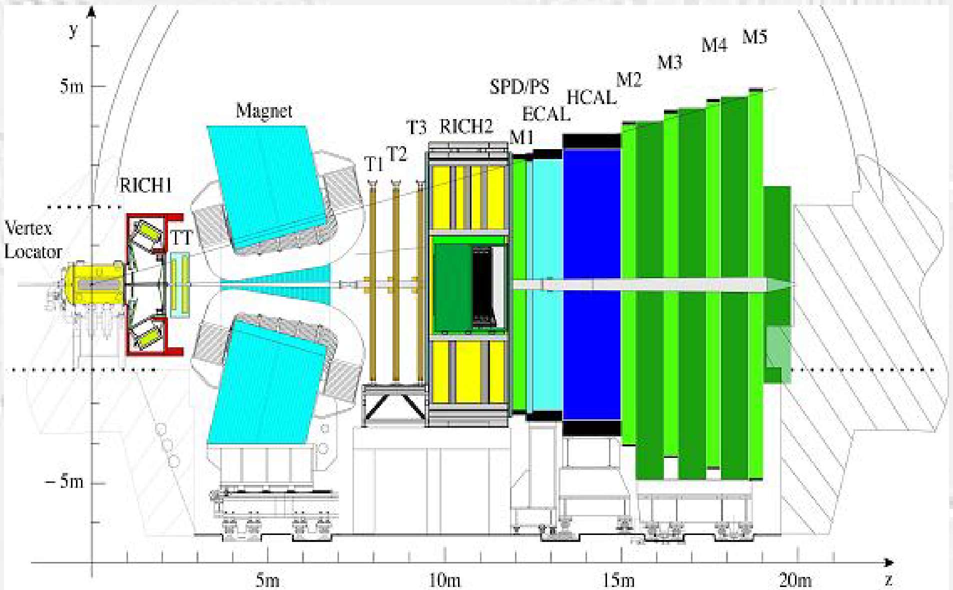
Marie Curie Fellowships

I. "Facts" of Physics and trigger strategy

II. Trigger overview



III. Level-0
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- decision unit
- status and performance

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- basic principles
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- status and performance

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- basic principles
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I. "Facts" of Physics ...

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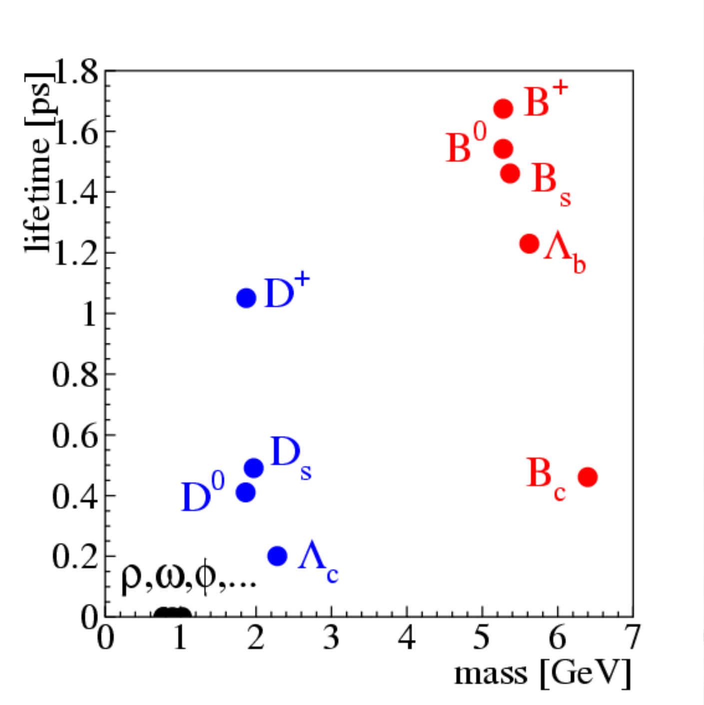
LHC environment

- pp collisions at E_{CM} = 14 TeV
- <L> = 2×10^{32} cm^{-2} s^{-1} = 2×10^{5} mb^{-1} s^{-1}
- Δt_{bunch} = 25 ns <-> bunch crossing rate = 40 MHz

Cross sections

Physical quantity	Value	Event rate	Yield / year
σ total	~ 100 mb		
σ visible	~ 60 mb	~ 12 MHz	
σ (c-cbar)	~ 3.5 mb	~ 700 kHz	~ 7×10^{12} pairs
σ (b-bbar)	~ 0.5 mb	~ 100 kHz	~ 10^{12} pairs



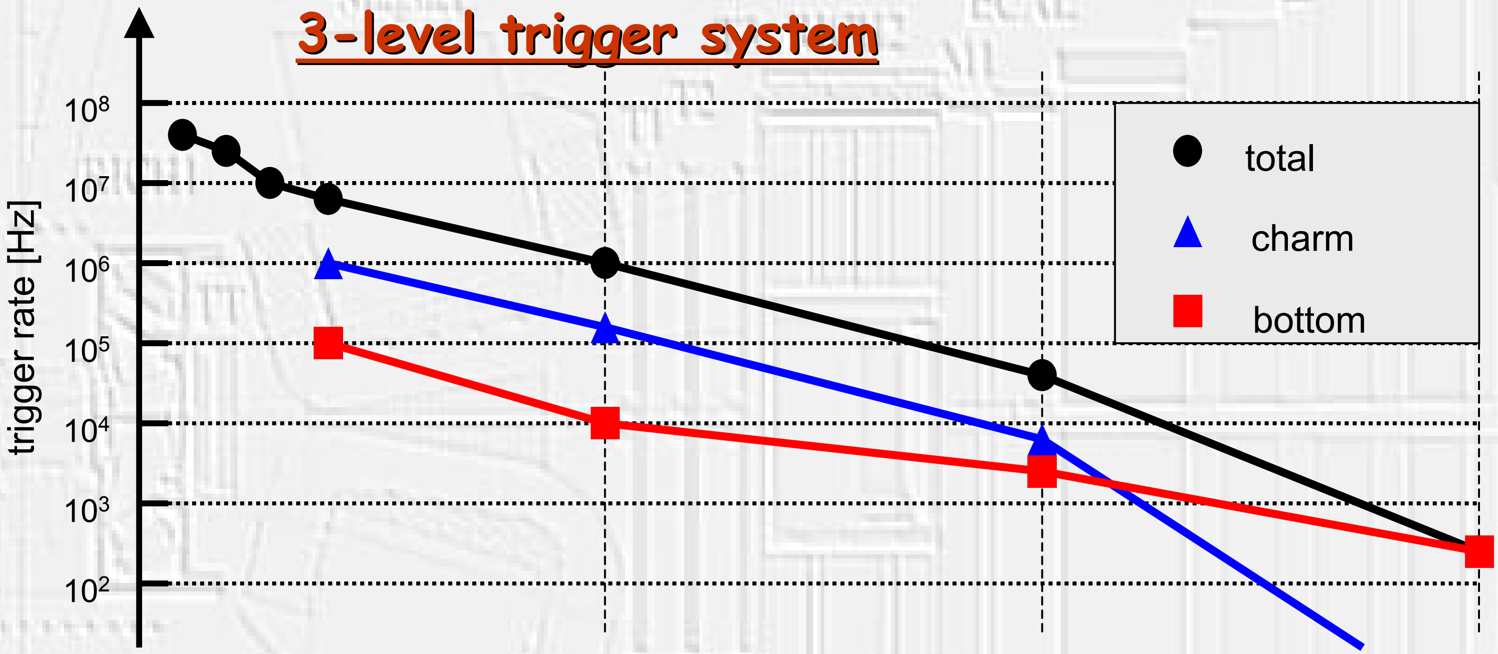
B-hadrons are heavy and long-lived !

Expected B-signal rates

- branching ratii ~ 10^{-9} – 10^{-4}
  - ➔ 10 – 10^{6} events / year ?

... and trigger strategy

3-level trigger system



Level-0	Level-1	HLT
✓ high E_T particles ✓ output 1 MHz ✓ custom hardware	✓ high E_T /IP particles ✓ output 40 kHz ✓ software	✓ full reconstruction ✓ output ~200 Hz ✓ software

II. Trigger overview

L0: **high E_T / P_T particles**

- hardware trigger with fixed latency
- pipelined operation, fixed latency of 4 μs
- rate reduction 40 MHz -> 1 MHz

L1: **high E_T / P_T & high impact parameter particles**

- software reconstruction on part of the data (from a few sub-detectors)
- algorithm runs on large PC farm, average latency of 1 ms
- rate reduction 1 MHz -> 40 kHz

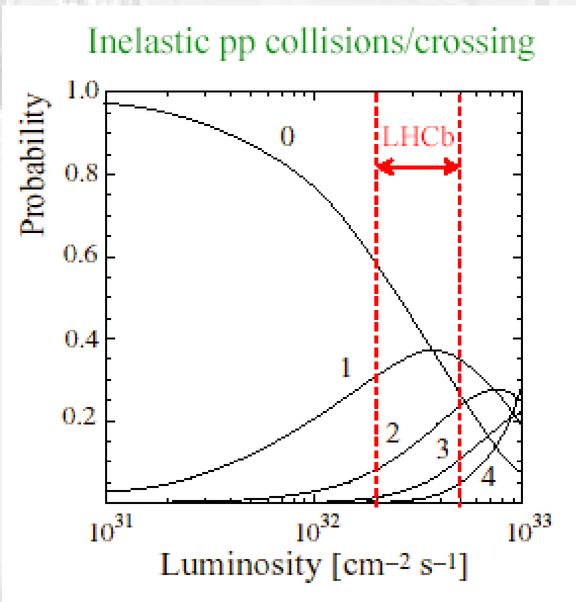
HLT: **high E_T / P_T & high IP particles & displaced vertices & B-mass & …**

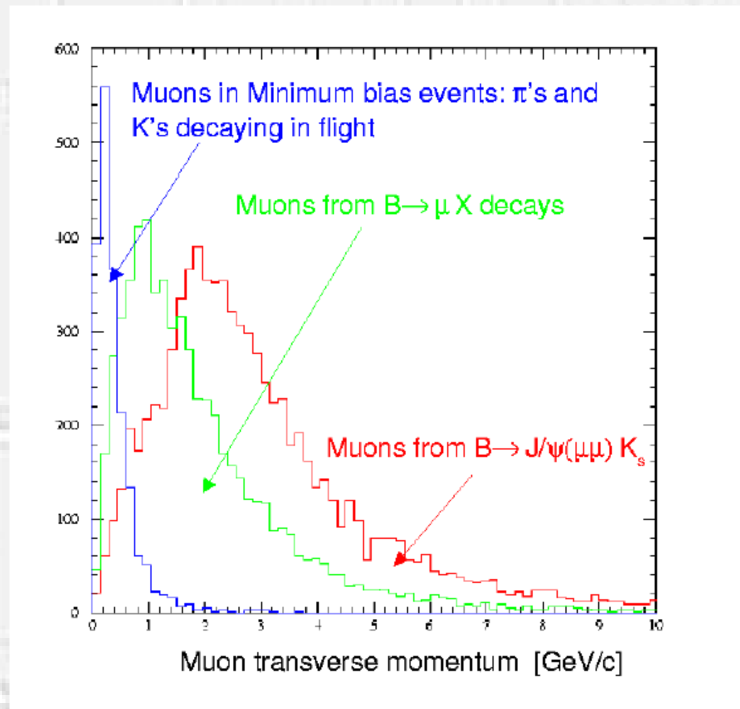
- software - full event reconstruction
  - tracking / vertexing with accuracy close to offline
- selection and classification of interesting physics events
  - inclusive / exclusive selections run
- algorithm runs on large PC farm (shared with L1)
- rate reduction 40 kHz -> ~ 200 Hz

III. Level-0

Goal

- select high E_T / P_T particles ⟵ **L0 thresholds on E_T / P_T of candidates**
  - ➥ hadrons / electrons / photons / π^0's / muons
- reject complex / busy / empty events ⟵ **global event variables**
  - ➥ more difficult to reconstruct in L1 & HLT
  - ➥ take longer to reconstruct in L1 & HLT
  - ➥ uninteresting for future analysis





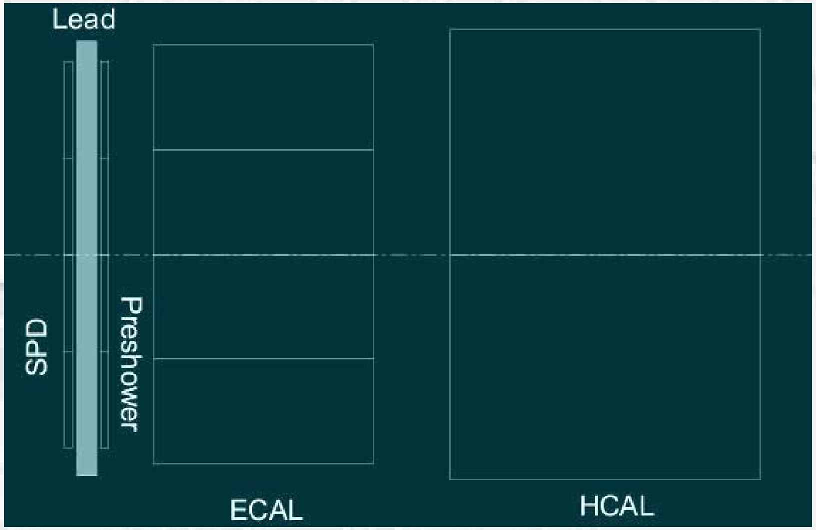
L0 calorimeter trigger

Detector components

- ECAL and HCAL
  - ➥ large energy deposits <-> E_T in 2x2 cells
- Scintillator Pad Detector (SPD) & Preshower (Prs)
  - ➥ used for charged / electromagnetic nature of clusters, respectively (PID)

Strategy

- identify hadrons / e / γ / π^0's using all 4 sub-detectors



Output for L0DU

- highest-E_T candidate of each type
  - ➥ hadron / e / γ / π^0 local & global
- global event variables
  - ➥ total E_T in HCAL <-> rejection of empty events
  - ➥ SPD hit multiplicity <-> rejection of busy events

L0 muon trigger

Detector components

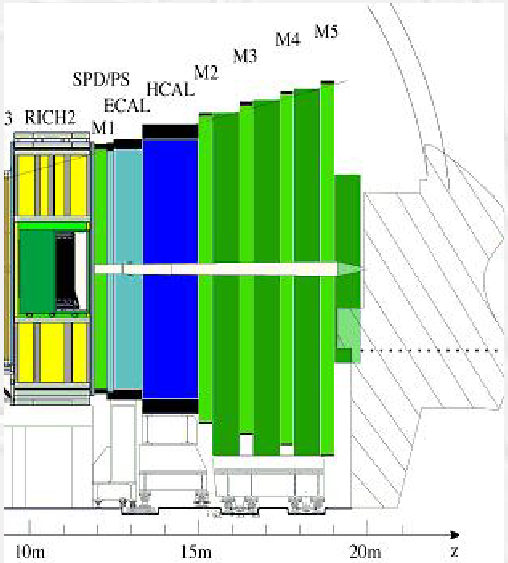
- M1 – M5 muon stations (4 quadrants each)

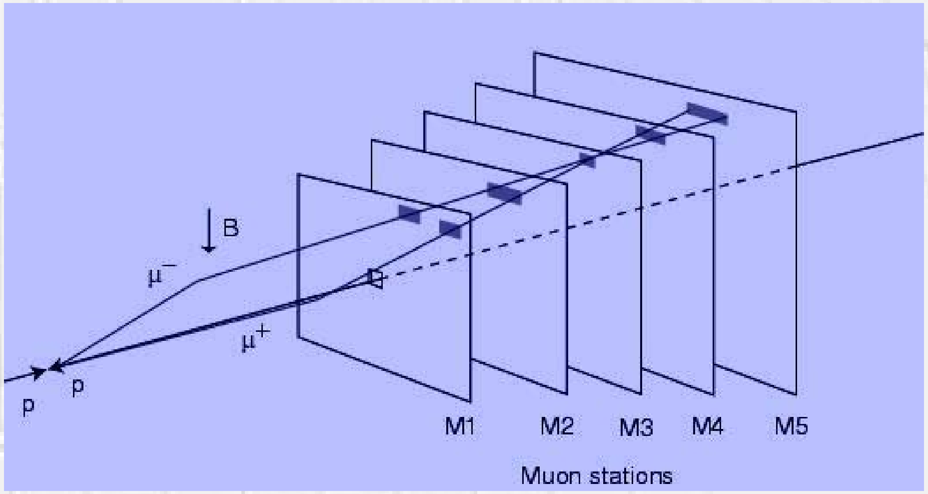
Strategy

- straight-line search in M2-M5
  and extrapolation to M1 for momentum determination
- momentum determination from M1-M2
  assuming muons from primary vertex
  (using a look-up table)

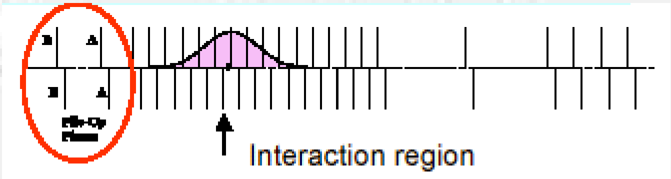
Output for L0DU

- 2 muon candidates per each of the 4 quadrants





L0 pile-up system

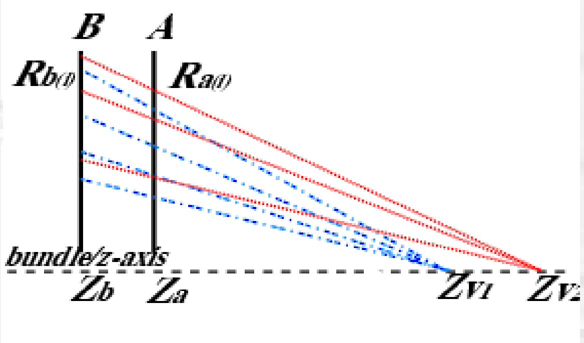


Detector components

- 2 silicon planes upstream of nominal IP

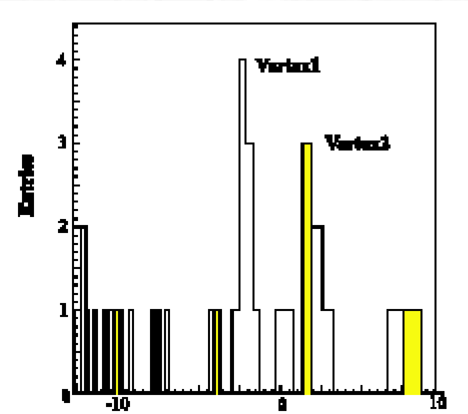
Strategy

- calculate z_{vtx} of vertices for all combinations of A and B
- find highest peak in histogram of z_{vtx}
- remove hits contribution to that peak
- find the second highest peak



Output for L0DU

- pile-up system multiplicity
- height of second peak (with sum of directly adjacent bins)
  - ➥ also the z-position is transferred, together with same info for 1st peak



L0 decision unit

Calorimeter

- SPD multiplicity
- total E_T in HCAL
- highest- E_T candidates: h, e, γ, π^0 local, π^0 global

Muon system

- 2 μ candidates per each of 4 quadrants

Pile-up system

- total multiplicity
- # tracks in second peak

L0 Decision unit

✓ cuts on global event variables
✓ thresholds on the E_T candidates

L0DU report

L0 decision unit

Global event variables applied first …

Global event cuts	Cut	Rate (MHz)	
ΣE_T	5.0 GeV	~ 8.3	~ 7
SPD multiplicity	280 hits	~ 13	
Tracks in 2nd vertex	3		
Pile-up multiplicity	112 hits		

… and then cuts on the **E_T / P_T candidates**

Trigger	Threshold (GeV)	Rate (kHz)	
Hadron	3.6	705	705
Electron	2.8	103	280
Photon	2.6	126	
π^o local	4.5	110	
π^o global	4.0	145	
Muon	1.1	110	160
Di-muon	1.3	145	

Di-muon trigger is special

- $P_T^{\mu\mu} = P_T^{\mu 1} + P_T^{\mu 2}$ with $P_T^{\mu 2} = 0$ possible
- "tags" clean B-signatures
- not subject to the global event selection

L0 status

Software

- packages up-to-date (honest simulation) and ready for DC'04
  - L0 Muon package re-written recently
  - new L0Checker package for performance checks and providing information for subsequent studies of L0

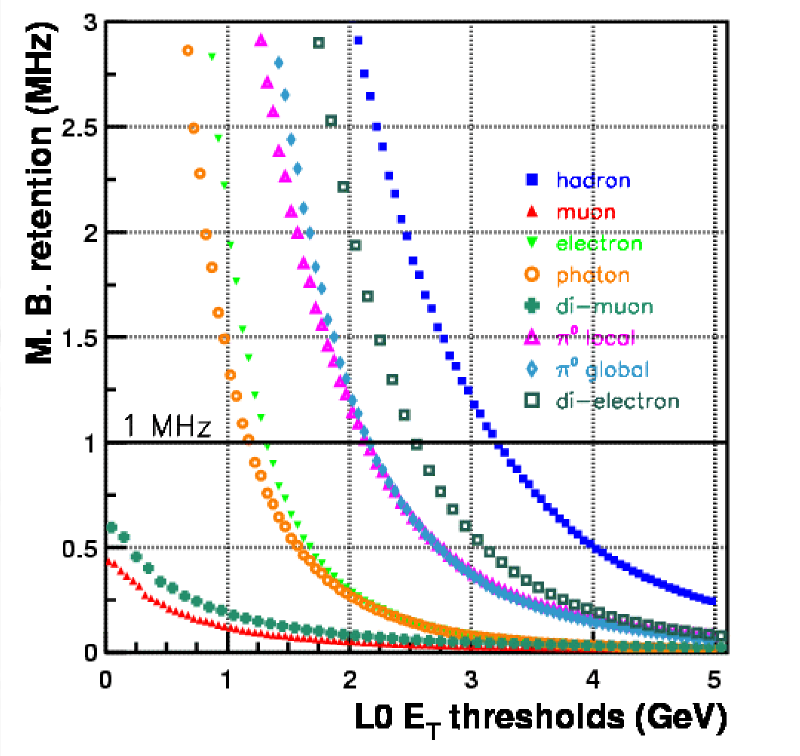
Optimization

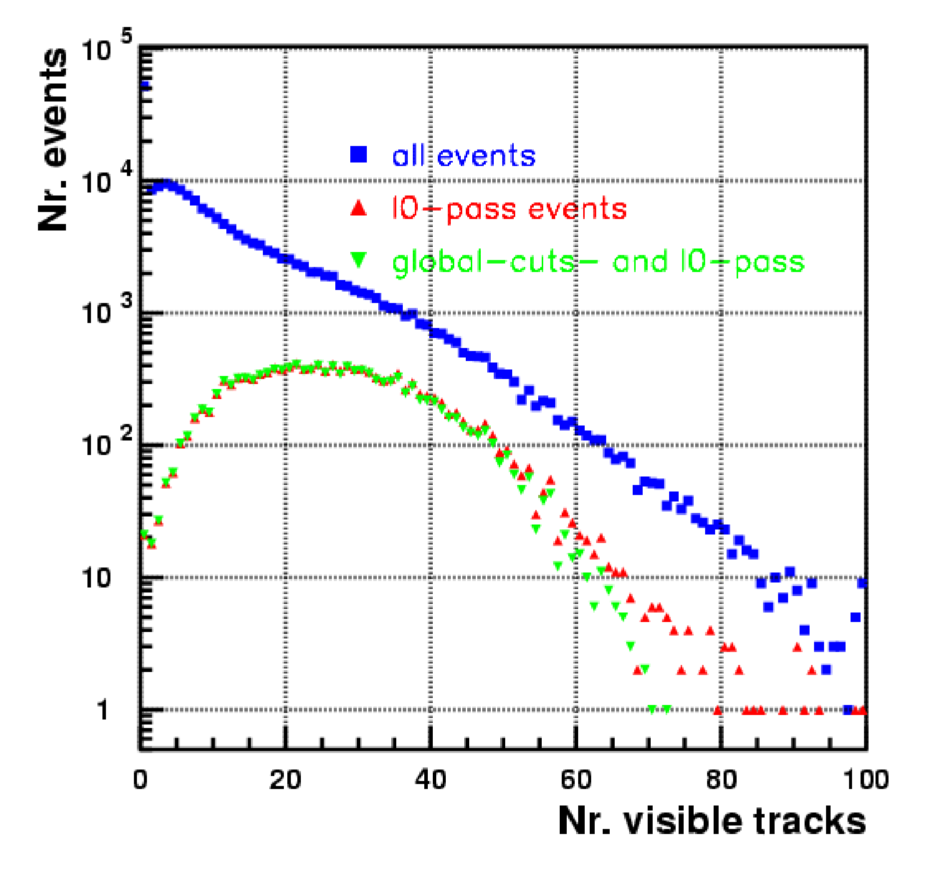
- L0 bandwidth division performed for the Trigger TDR
- DC'04 data will provide means for performance cross-checks and further studies

Performance

- hadronic channels: ε ~ 50 %
- electromagnetic channels: ε ~ 50-70 %
- muon channels: ε ~ 90 %

L0 performance





each curve corresponds to considering separately the combination

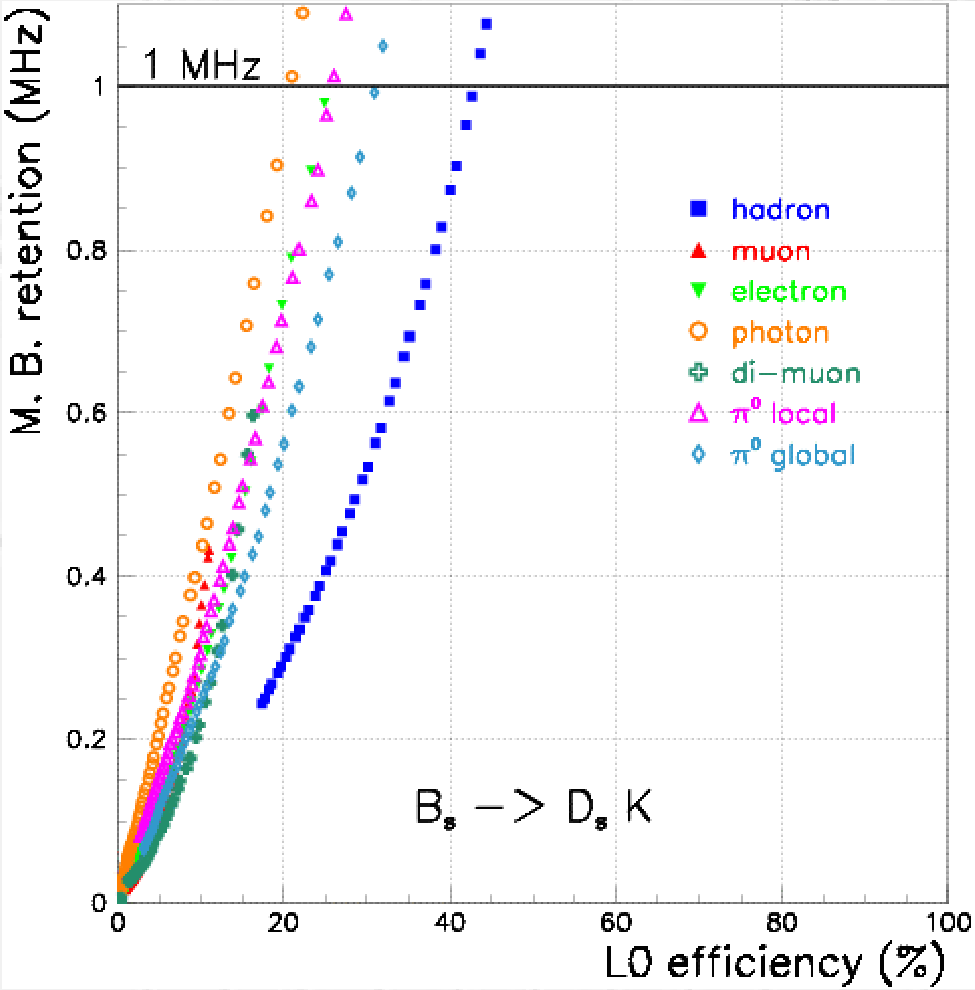
L0 trigger = sub-trigger

+ global event cuts

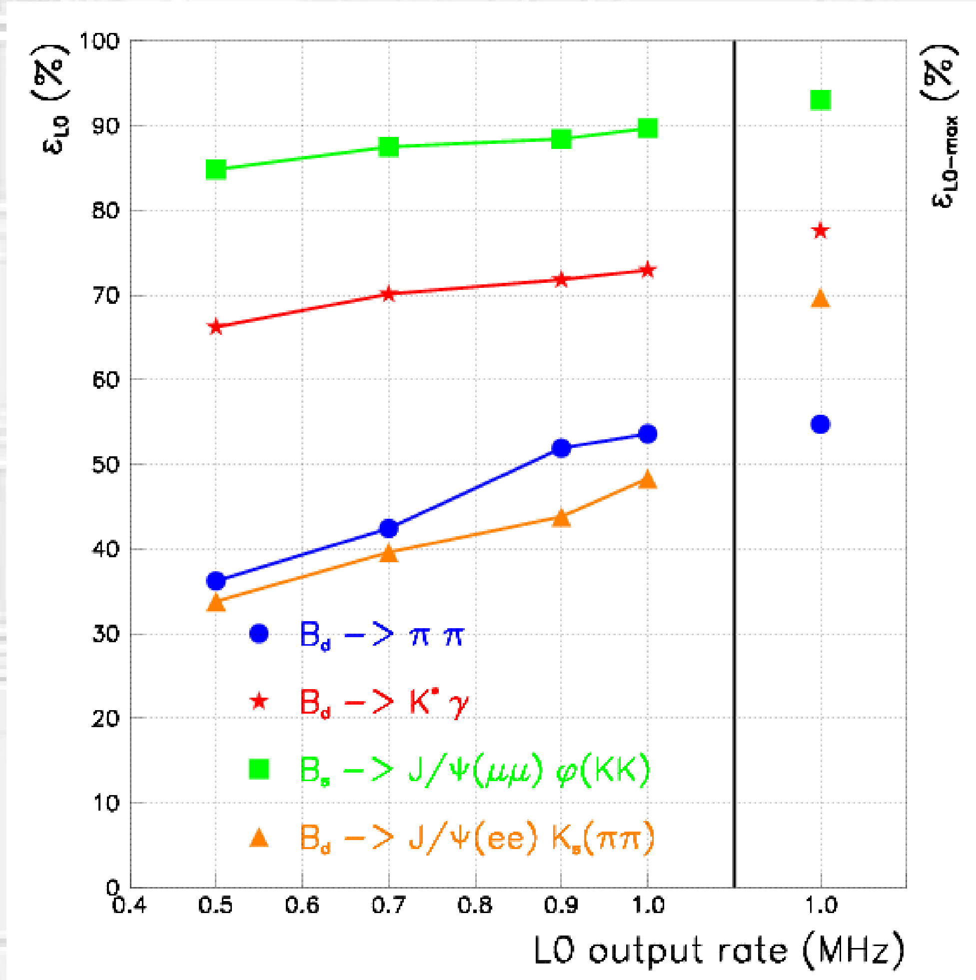
(di-electron trigger "à la di-muon trigger")

L0 performance

Single-channel inclusive curves



L0 bandwidth division optimization



IV. Level-1

Goal

- select events with long-lived particles and high P_T
  - multiple scattering can fake high impact parameters -> need P_T measurement as well

Detector components

- VELO and TT stations (+ L0 information)

Strategy

- fast 2D tracking in VELO (forward and backward tracks)
  - R-Z straight-line tracking (VELO R-sensors only)
- primary vertex reconstruction (VELO sector number is used as ϕ measurement)
- selection of tracks with large IP (IP $\in$ [0.15 , 3.0] mm)
- matching to L0 calorimeter and muon "objects"
- 3D tracking for those selected tracks
  - because P_T measurement from extrapolation to TT necessitates 3D tracks
- P_T measurement on selected tracks
- issue a L1 decision based on the $\log(P_{T1}) + \log(P_{T2})$ of these 2 tracks and on the "bonus" from the L0 matching

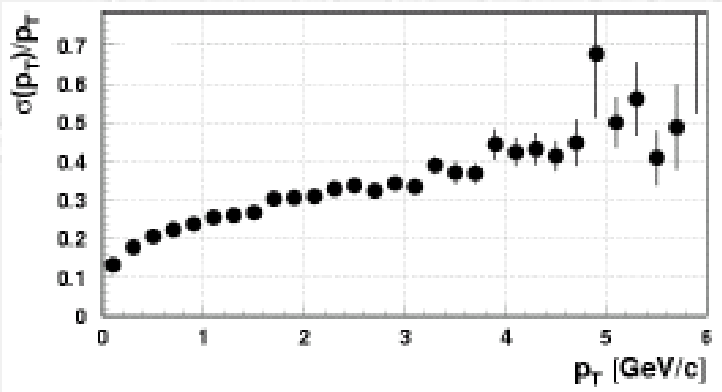
L1 reconstruction

Impact parameter measurement

- use VELO stations
  - ➥ R-Z projection contains most of the IP information

P_T measurement

- use TT for extrapolation of tracks and momentum determination
- $\sigma(P_T) / P_T \sim 30\%$



Clean B-signatures

- P_T can also be determined from a matching to L0 candidates!
  - ➥ VELO tracks are matched to L0 muons / calorimeter clusters
  - ➥ high E_T e / γ , high mass $\mu\mu$
- extra information used in the making of the L1 decision …

L1 decision

Input from L1 reconstruction

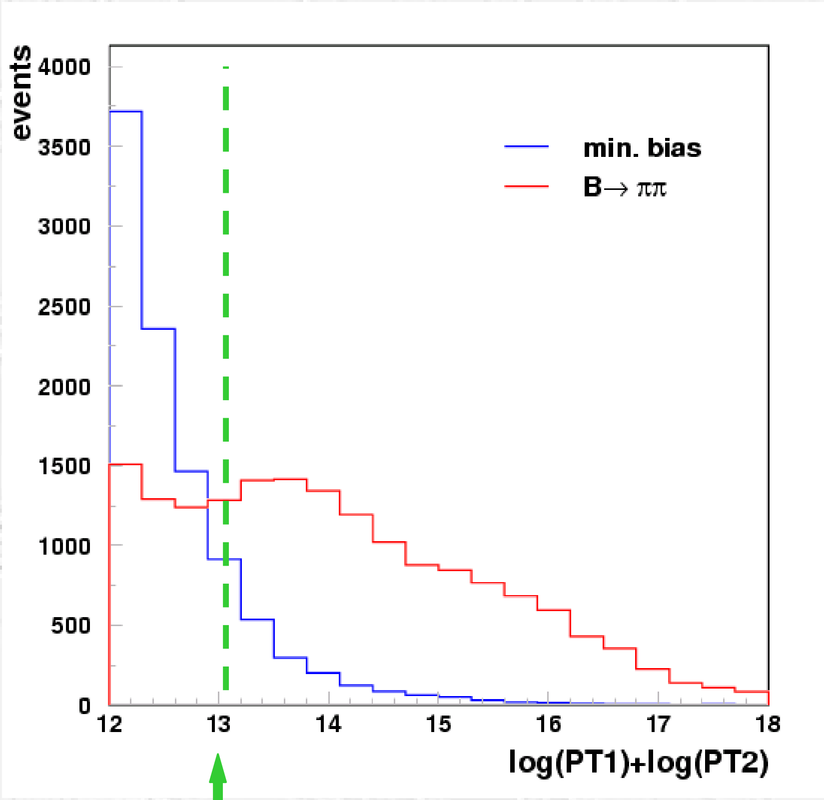
- P_T of 2 highest- P_T tracks among those with signed IP ∈ [0.15 , 3.0] mm
- “bonus” L0-matched objects

L1 Decision unit

↓

L1 score

- L1 decision based on a 1-dim. cut on $\log(P_{T1})+\log(P_{T2})$ (+ bonus)



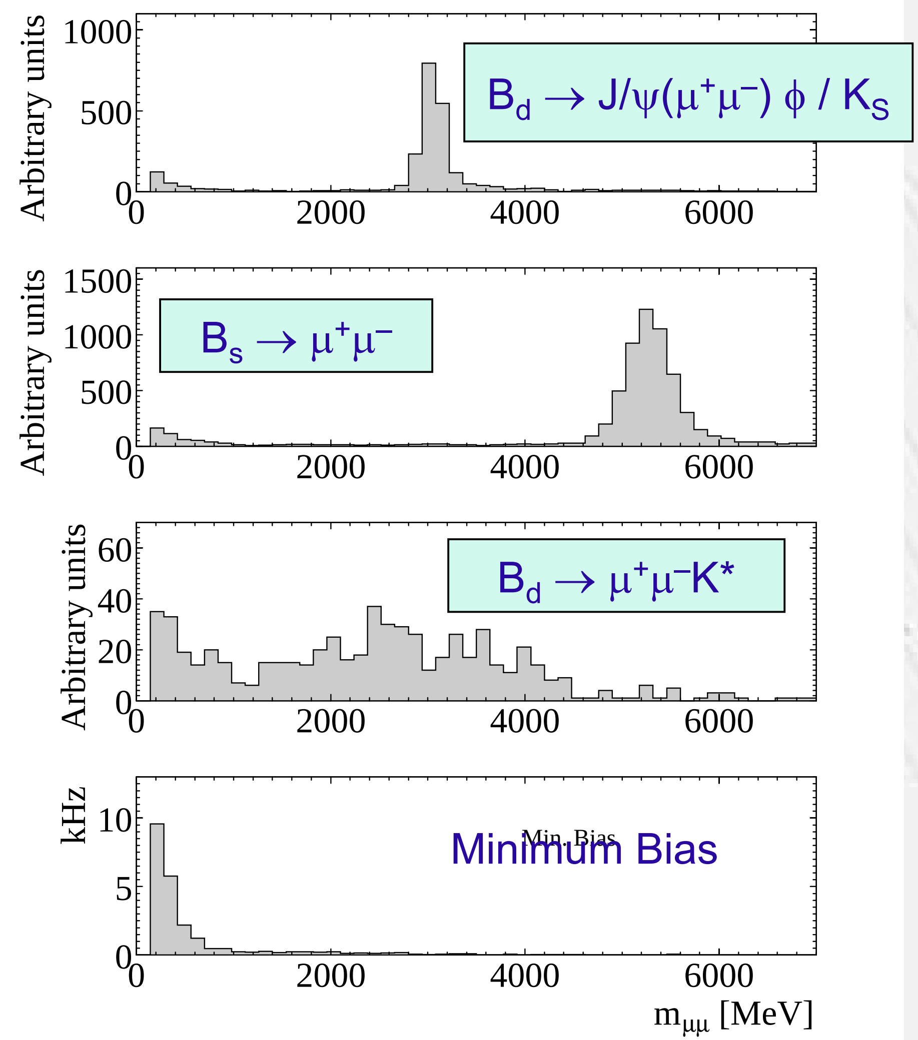
4% M. B. retention

L1 decision

Example of "bonus" …

Di-muon invariant mass @ L1

- J/Ψ peak visible
- B_s peak visible



L1 status

Software

- new version of whole L1 packages ready for DC'04
  - tracks reconstruction
  - primary vertex finder (also treatment of multiple PV)
  - decision package re-written (very modular <-> flexibility)

Optimization

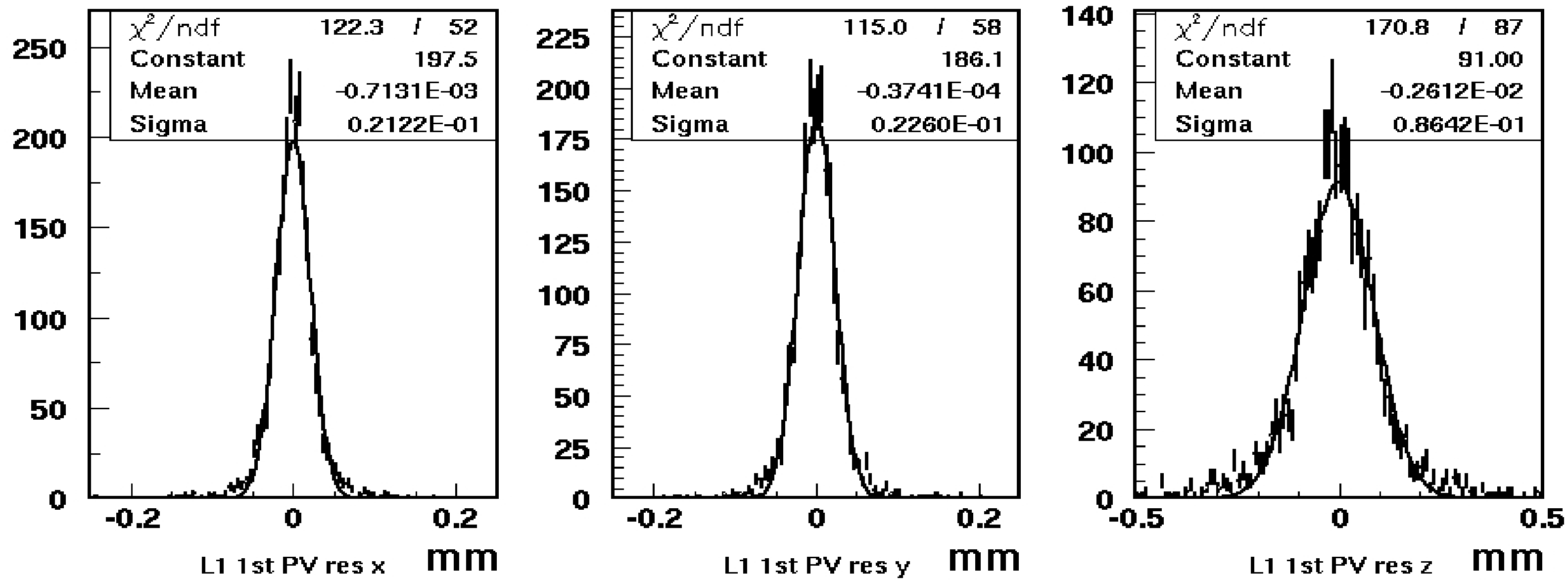
- whole reconstruction has been optimized/tuned on pre-production data
  - tracks reconstruction (track quality cuts, clone killing)
  - VELO-TT track matching (quality cuts)
  - vertex finder (cuts on min. # tracks, min. distance between vertices)

Performance

- efficiencies expected to be ~10% better compared to TDR !
  - improvements mainly due to faster and better reconstruction (improved tracking, bug fixed in handling of vertices)
- fast algorithm within the design time budget: ~ 4.7 ms (compared to ~ 8 ms @ TDR time)

L1 performance

Primary vertex resolution (of only the 1st PV)



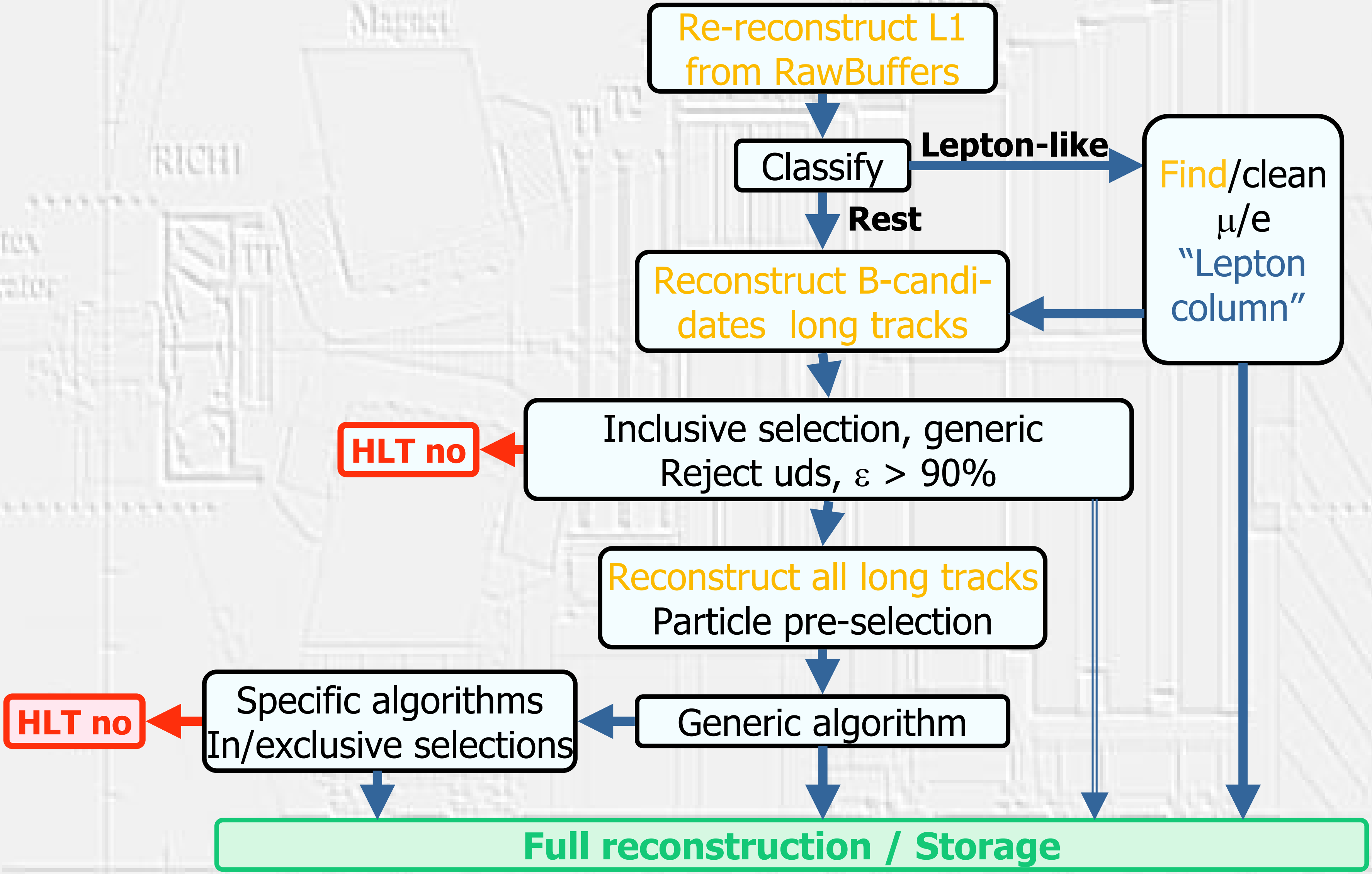
σ_x = 21 μm

σ_y = 23 μm

σ_z = 86 μm

(Slightly worse than for TDR)

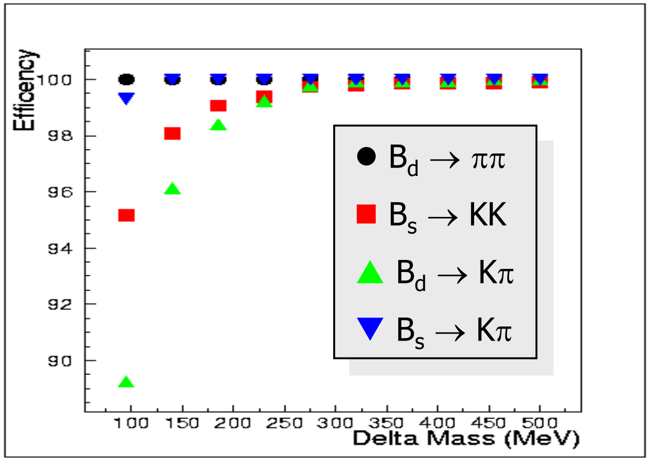
V. HLT - High Level Trigger

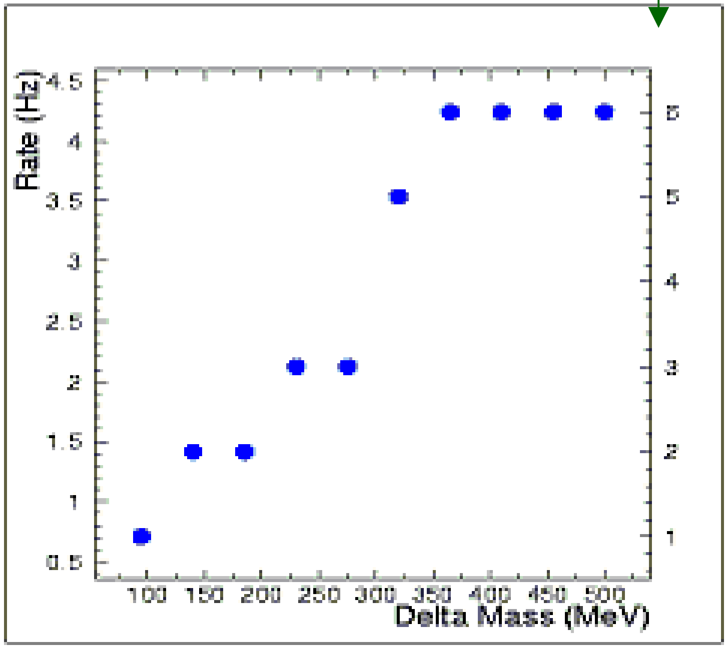


HLT – exclusive selections

Case of $B^0 \to h\ h$

Efficiency: offline selected





events

Half window

- offline selections were used as baseline, applied after L0xL1
- offline tracks and vertices used
- unique set of HLT (loose) cuts for the 4 "hh" channels

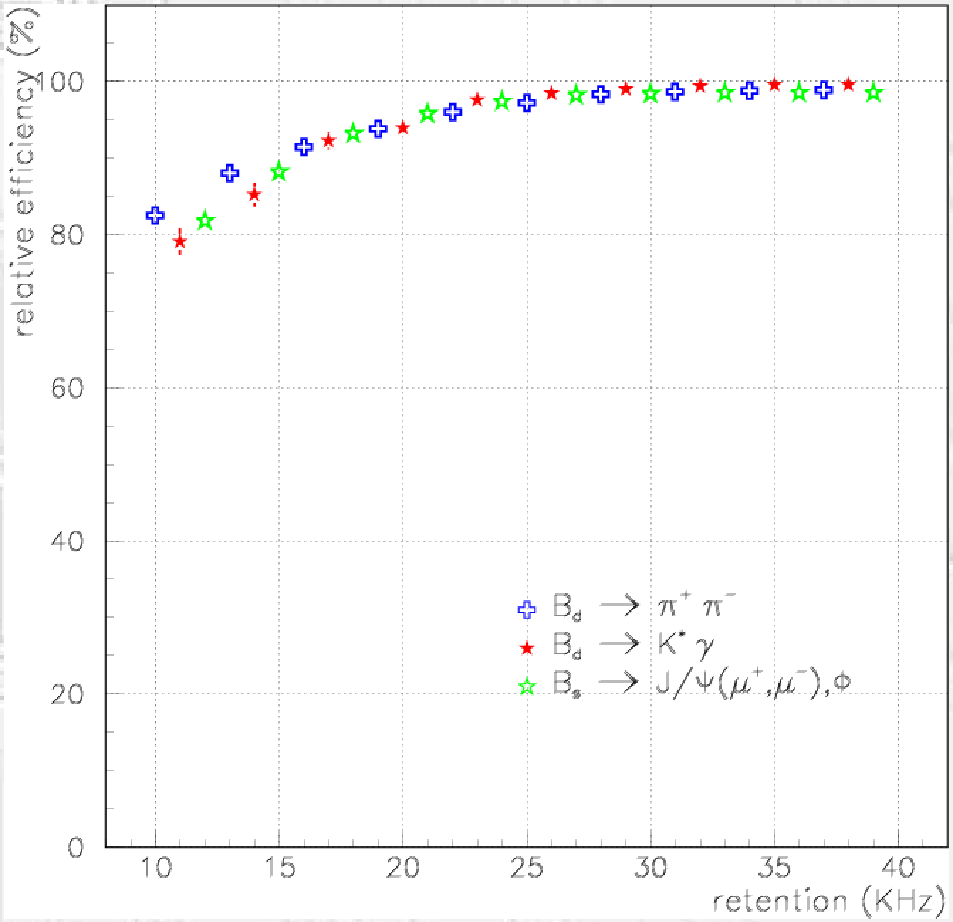
HLT – L1 confirmation

Idea

- re-do the L1 algorithm @ HLT
  - ➥ with improved tracking (σ(p)/p ~ 0.6%)

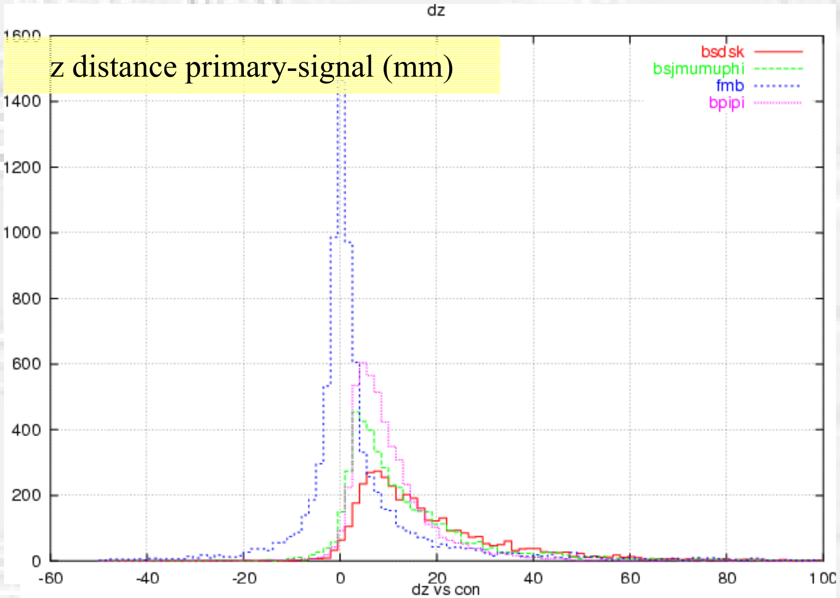
Performance

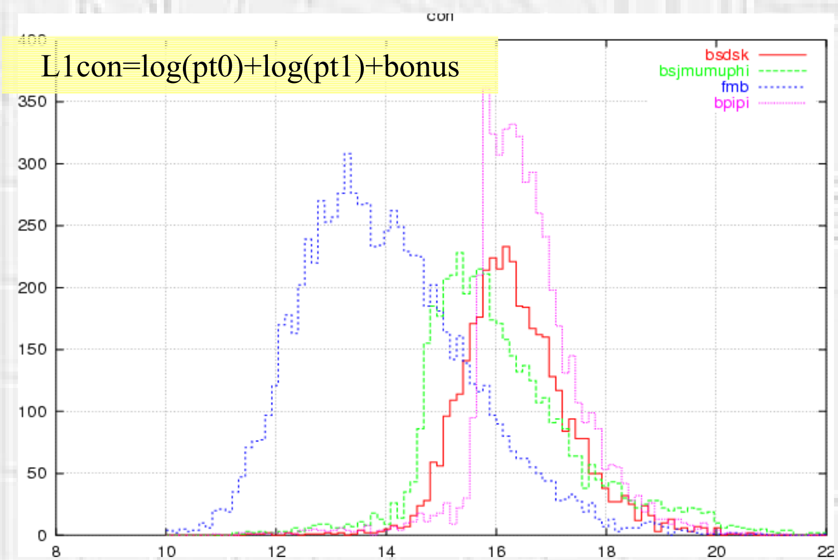
- ~ 5% efficiency loss for ½ minimum bias retention (i.e. @ 20kHz)

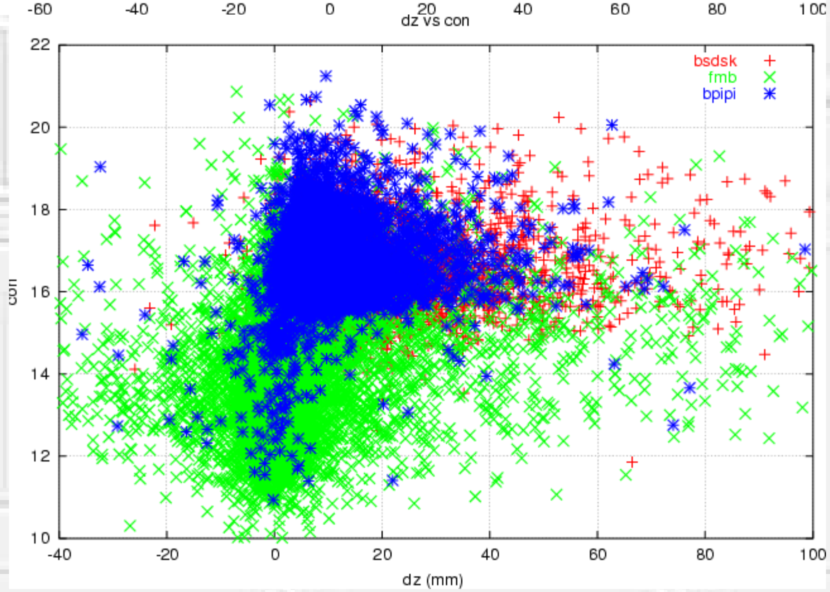


HLT – generic algorithms

- The discriminating variables:
  - **Kinematics:**
    - l1con = log(pt0)+log(pt1)+bonus
      - pt0,pt1 from T1-T3 measurements
      - Bonus = function from L0 objects
        - E_T from cal (gamma,e)
  - **Geometry**
    - Z- Flight distance:
      - Between primary and secondary vertex

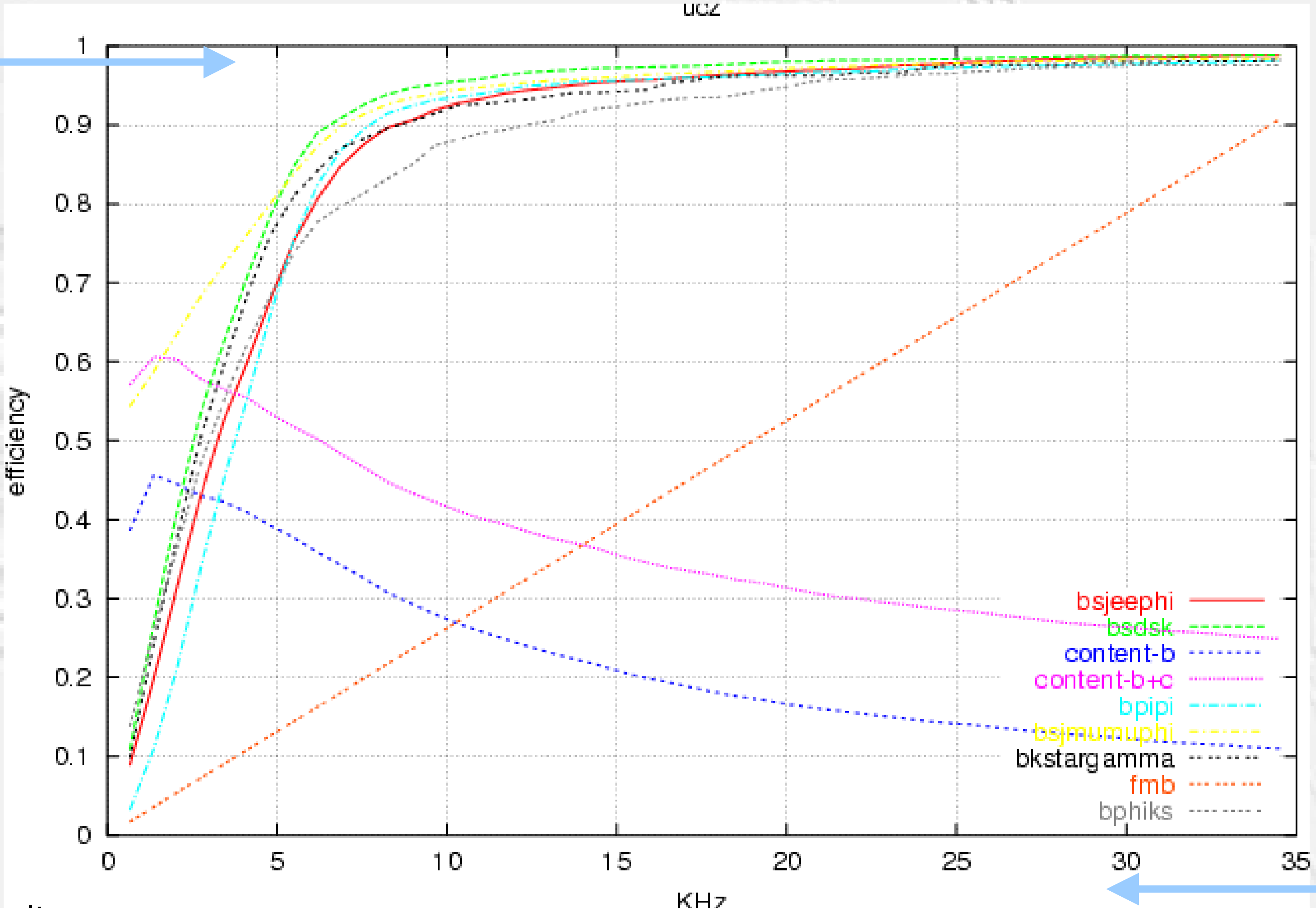






HLT – generic algorithms

generic



inclusive

- Results:
  - Relax scenario: cuts{'ip'=1.5mm,'chi2'=2.5}
  - Output rate 10kHz = 8 (generic) +2 (dimuon) at >90% efficiency
  - Point of view: *Inclusive: from right, Generic: from Left*

HLT status

Software

- new version of whole Trg packages has just been released for DC'04
  - tracking
  - primary vertex finder

Optimization

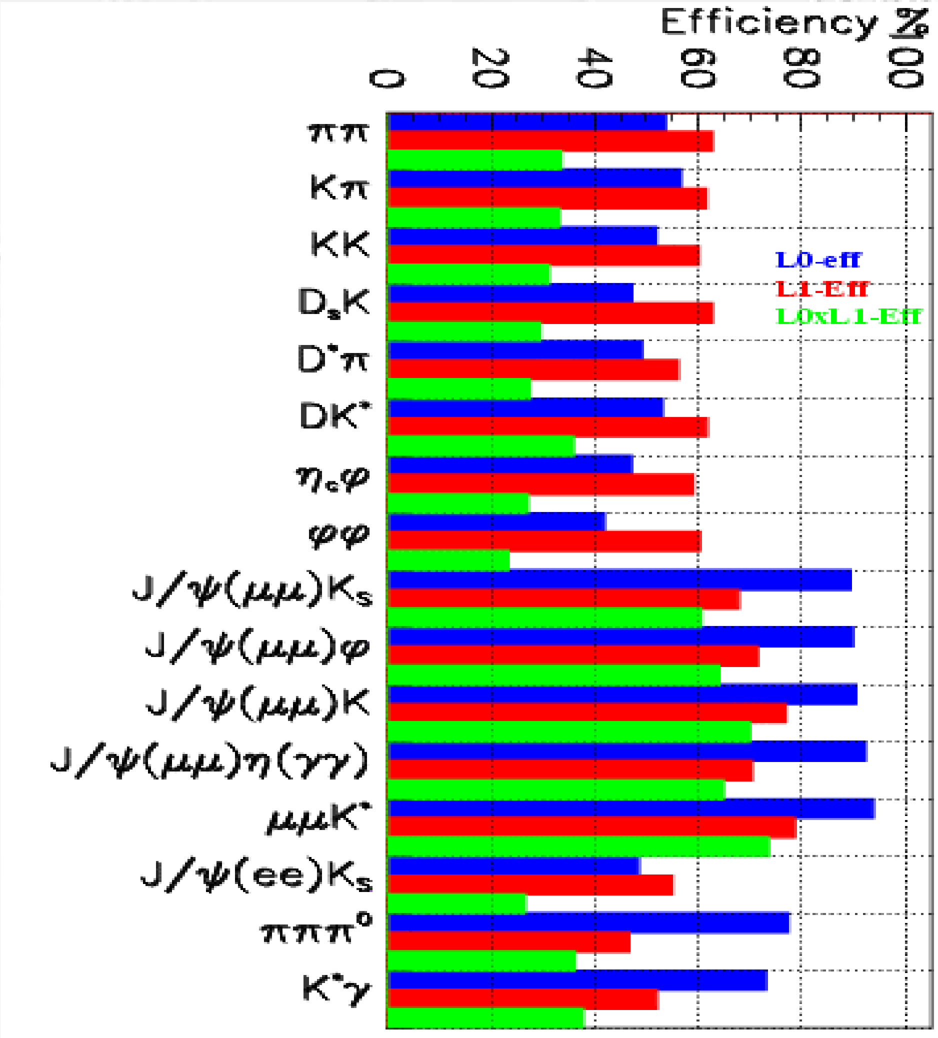
- to be done with DC'04 data
  - tracking optimization done to some extent on "old" data

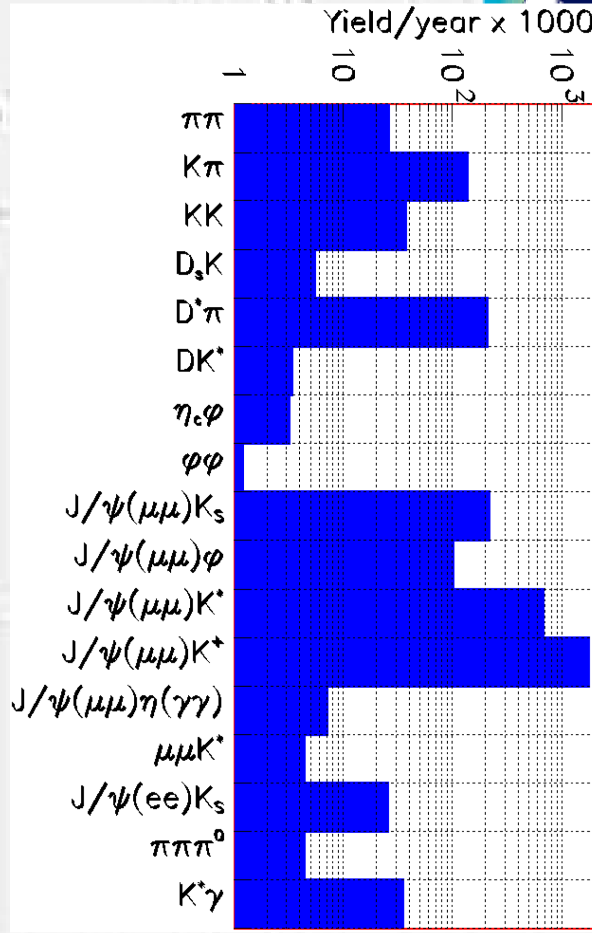
Performance

- the best possible …
- fast algorithms within the design time budget
- exclusive selections show that individual signal channels give HLT rates ~ 10 Hz for $\varepsilon > 95\%$

VI. Summary

TDR performances





Event composition	b-bbar (%)	c-cbar (%)
generated	1.1	5.6
after L0	3.0	10.6
after L1	9.7	14.2

VII. Open questions ongoing studies

Level-0

- implementation of di-electrons
- monitoring / performance from real data

Level-1

- L1 decision strategy
- improved usage of L0 muon and calorimeter information
- treatment of events with multiple primary vertices
- nature of minimum-bias / signal events passing L1

HLT

- development of reconstruction
- development of generic / exclusive selections
- RICH information @ HLT -> improvement in physics reach from PID?
  - main use: K/ π separation for similar final states (e.g. B^0 -> $\pi\,\pi$, $K\,\pi$)
  - lower rates of channels with high rates without K/ π separation
  - efficient reconstruction of inclusive decays (e.g. B -> K^* X))