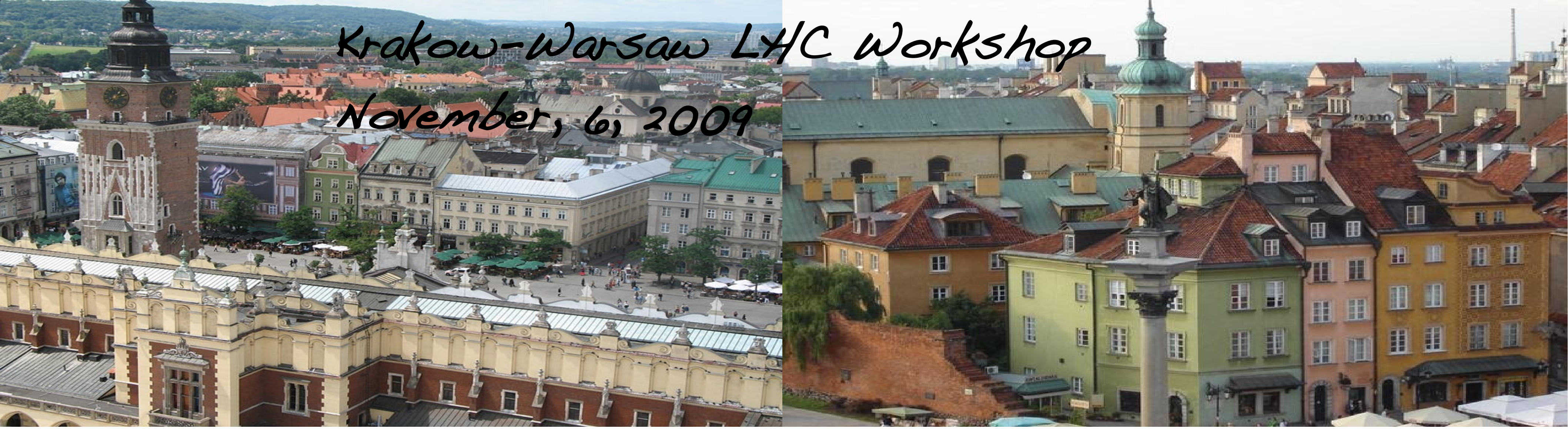


LHCb Trigger System and selection for $B_s \to J/\Psi(ee)\varphi(KK)$

Artur Ukleja
on behalf of LHCb Warsaw Group

Outline

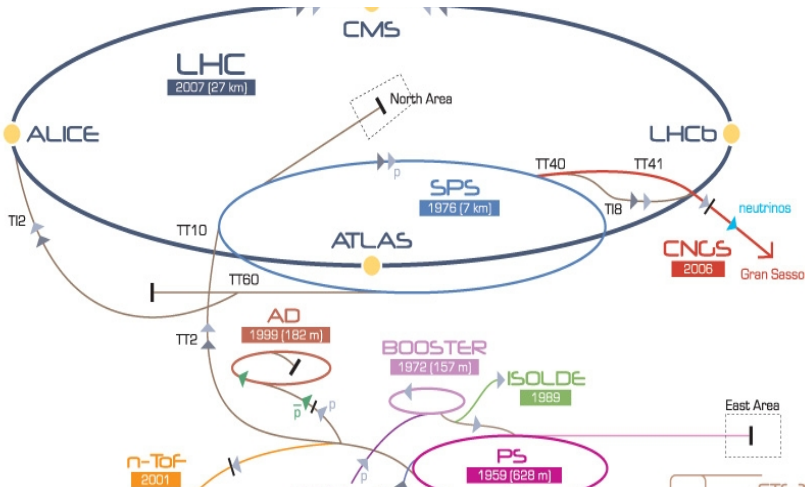
1. Motivation

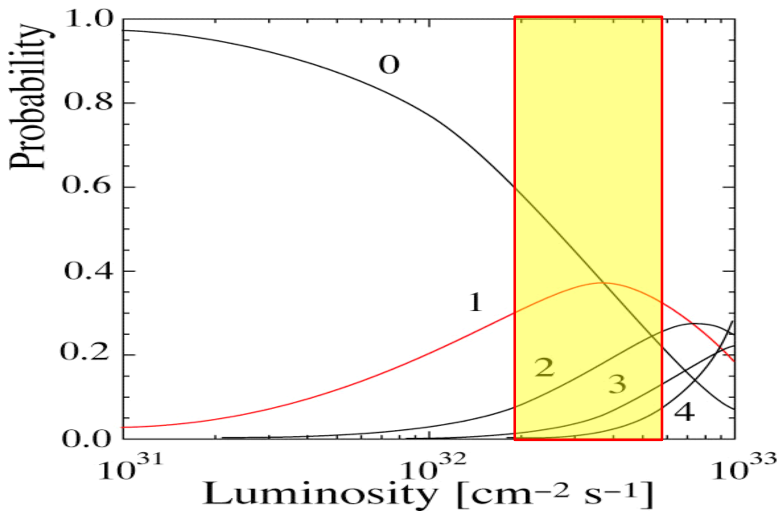
2. General scheme of LHCb trigger
   - Two trigger levels:
     – Level 0 (L0)
     – High Level Trigger (HLT)
   - Trigger rates division and efficiencies

3. High Level Trigger selection for $B_s \rightarrow J/\Psi(ee)\varphi(KK)$
   - selection of exemplary cut variables
   - final signal efficiency and Minimum Bias rate
   - acceptances for angles

4. Conclusions

Motivation





If **1 Interactions/Crossing** then **L~2x10^{32} cm^{-2}s^{-1}**

expected **100 kHz of bb-pairs**

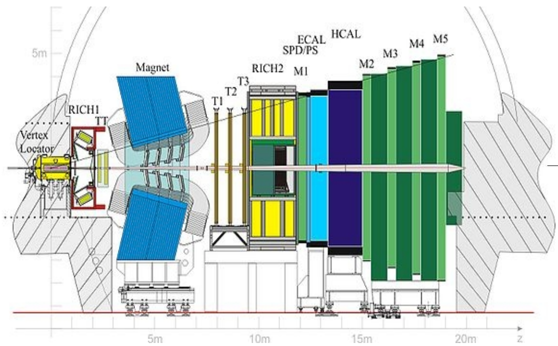
only 15% (15 kHz) of these events will include at least one B with all its decay products contained in LHCb acceptance

BR of interesting B decays: typically < 10^{-5} O(1)Hz

LHC Clock 40 MHz	→	Non empty beam crossing 30 MHz	→	Visible Events (≥2 tracks in LHCb) **~10 MHz**

Save: **2 kHz** (This 5000 reduction is achieved in two trigger levels)

Data flow



<u>~10 MHz</u> (≥2 tracks in acceptance)

4 subdetectors read out: VELO, ECAL, HCAL, Muon → **Level 0**

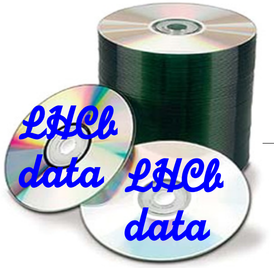
Hardware Trigger
– simple strategies but fast response
– decision synchronous with LHC clock

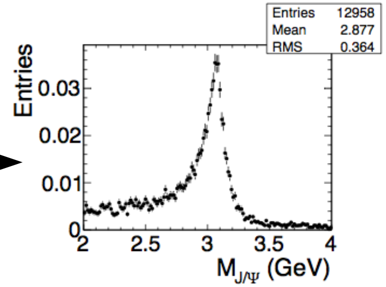
<u>~1 MHz</u>

Full detector information → **High Level Trigger**

Software Trigger
– time demanding sophisticated strategies
– asynchronous to LHC clock

<u>2 kHz</u>

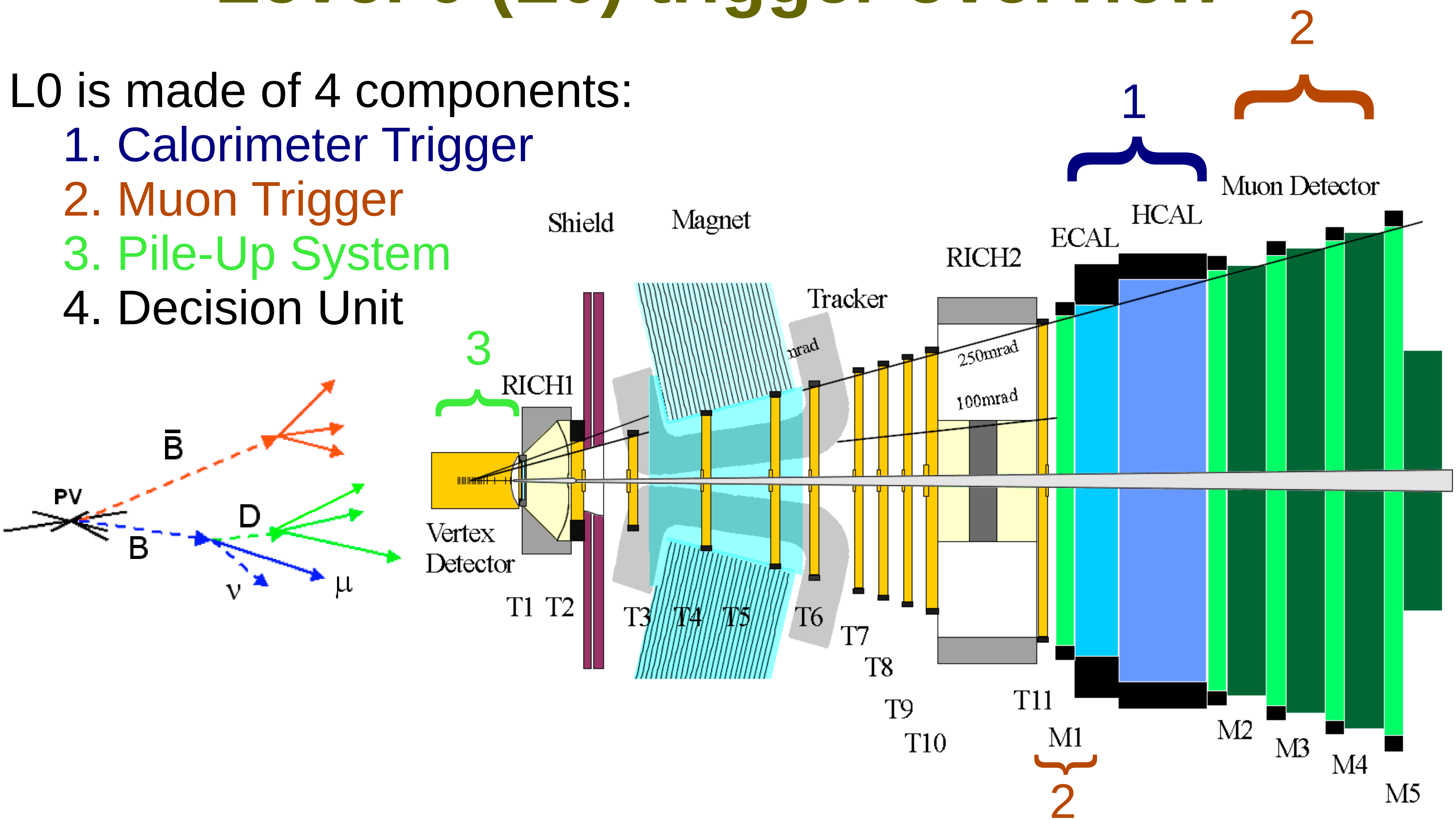




Level 0 (L0) trigger overview

L0 is made of 4 components:

1. Calorimeter Trigger
2. Muon Trigger
3. Pile-Up System
4. Decision Unit



Due to large mass of B, decays produce particles with large E_T (p_T)

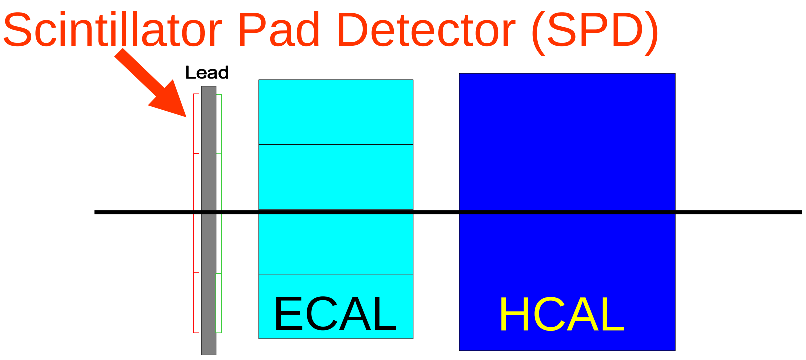
Particles with the high E_T (p_T) are selected

L0 Calorimeter Trigger

Zone 2x2 of calorimeter cells is used to form clusters (by adding E_T)

– large enough to contain most of E

– small enough to avoid overlap of various particles



The highest E_T candidate per type of particle

hadron, electron, γ, π^0

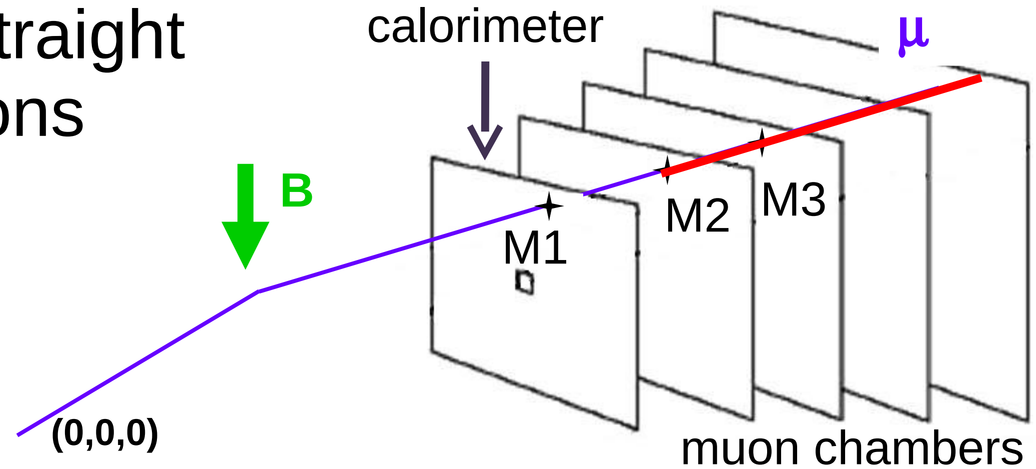
is selected and sent to the next stage

Required at least one cluster:

- in HCAL with E_T(hadron)>3.5 GeV
- or in ECAL with $E_T(e,\gamma,\pi^0)$>2.5 GeV

L0 Muon Trigger

Searches for hits defining a straight line through the 5 muon stations and interaction point



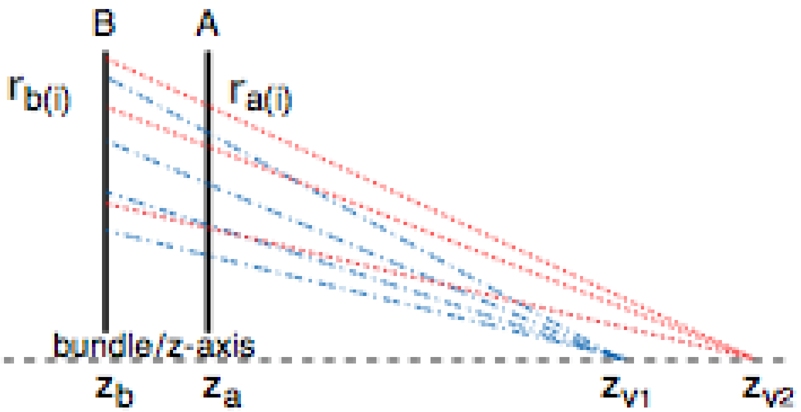
2 subtriggers:
- **L0 single muon**
- **L0 di-muon**

Decision is made requiring at least:
- single muon candidate with the largest p_T
  p_T>1.3 GeV
- or di-muon with the largest and the second largest p_T
  p_T of each > 0.1 GeV and sum of p_T>1 GeV

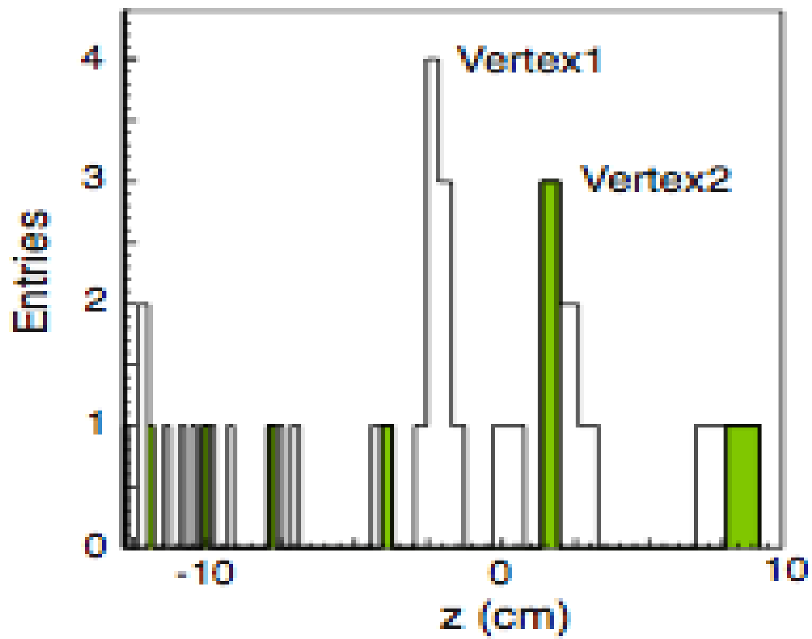
p_T can be measured with a resolution ~20%

L0 Pile-Up System

- Provides a rejection of events with multiple pp collisions through reconstruction of all primary vertices
- Consists of 2 VELO sensor planes (A,B)
- Hits of both planes are combined to find tracks
- Tracks are extrapolated to find vertices
- Cut is applied on number of tracks (3) coming from second vertex



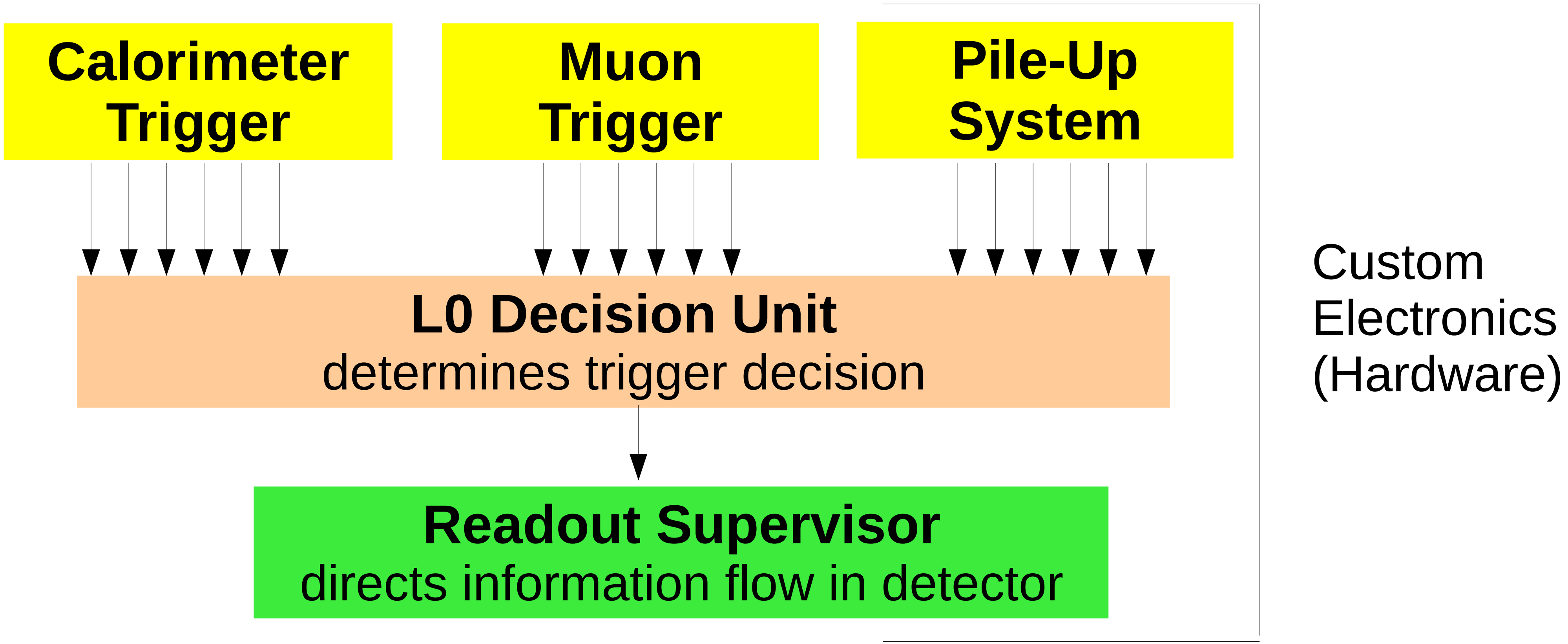
z_a, z_b – detector position
z_v – vertex position



L0 Decision Unit (DU)

DU collects all informations and derives final L0 decision

Detector: ~10 MHz

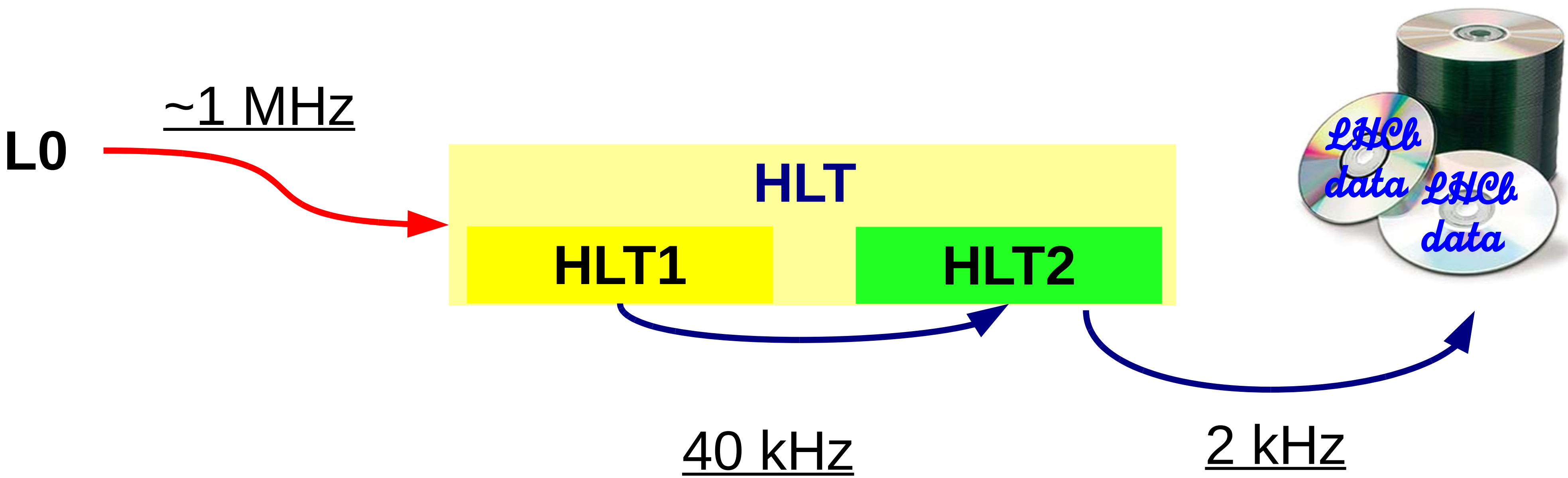


L0 output rate is large ~1 MHz and sent to next level (HLT)

High Level Trigger (HLT) overview

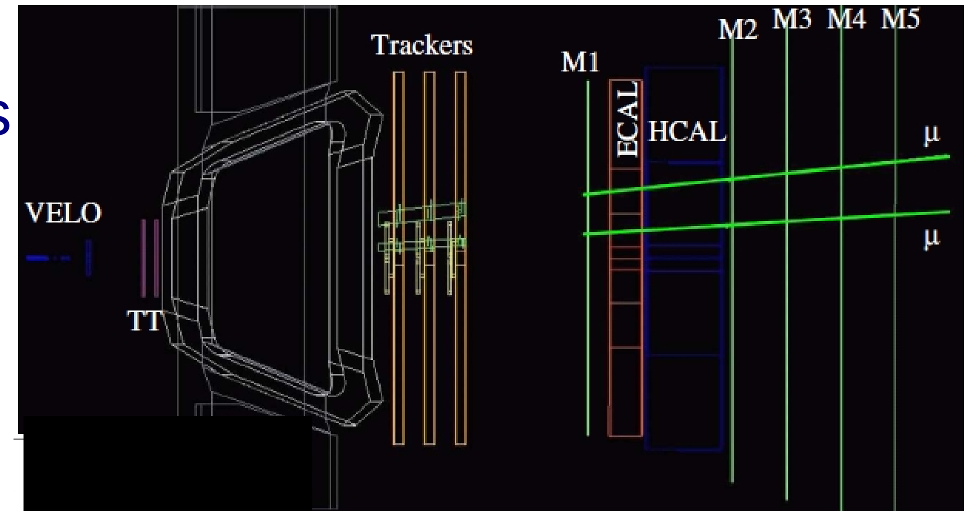
- The **software trigger** is based on c++ algorithms running in the Event Filter Farm (2000 processors)

- HLT is divided in to **two steps:**
  HLT1 reduces rate to 40 kHz (25 times)
  HLT2 reduces rate to 2 kHz (written to discs)



HLT1 (called L0 confirmation)

- Confirms L0 objects by adding information from VELO & T-stations
- Consists of parallel sequences of algorithms (**alleys**) according to type of candidate on which L0 decision was taken
- **5 alleys** (details – Mariusz Witek talk): Muon, Muon+Track, Hadron, Electron and Photon



L0 objects: (Candidates per type of particle)

μ h EM

HLT1 alleys:

μ μ+t h e γ

Rates: **Σ 36.8** [kHz] 14.6 13.4 3.2 7

Event selected by at least one alley is sent to HLT2

HLT2

- Full reconstruction of event similar to offline analysis
  (there are differences with respect to offline tracking)
- Particle identification

- **2 types of selections** (HLT2 lines):
  – Inclusive – based on a few tracks,
  a full decay tree is not required
  higher rate
  – Exclusive – similar to offline selection but with loosen cuts
  requiring all decay product tracks
  produce a smaller rate

Possible scenario:

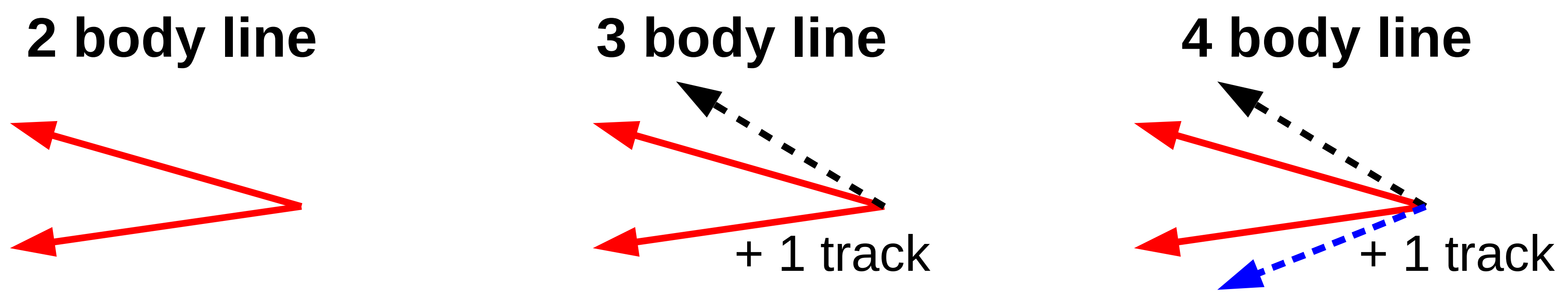
HLT2 output rate: 2 kHz → **Inclusive: 1900 Hz**
Exclusive: 100 Hz

Note: decision is not final!

HLT2 Lines

1. Inclusive
   - **Leptons**: di-muons, J/Ψ, single muons, muon+track
   - **Charm**: charm topological, D->X topological
   - **Topological**: all remaining topological
   - **Phi**: inclusive phi ($\varphi \to K^+K^-$)
2. Exclusive (e.g. $B_s \to J/\Psi\varphi$)

Topological trigger searches for 2, 3 and 4 body track combinations in a wide mass window (between 4 and 6 GeV).



Possible bandwidth division to distribute 2 kHz rate

Leptons	Charm	Topological	Phi	Exclusive
1200	200	400	100	<100

Example of trigger efficiencies

The Key Channels

	L0	HLT1	HLT2
B->hh	65%	79%	93%
B->μμ	98%	98%	97%
B_d->μμK*	91%	93%	92%
B_s->φγ	82%	72%	97%
B_s->J/Ψ(μμ)φ	94%	92%	98%
B_s->J/Ψ(ee)φ	52%	53%	69%

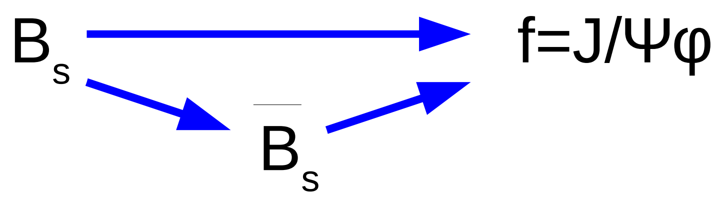
Efficiencies are good for most channels

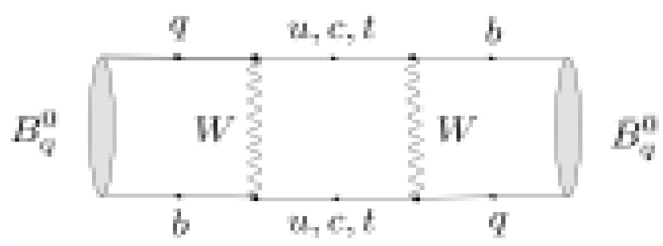
HLT2 selection for B_s->J/Ψ(ee)φ(KK)

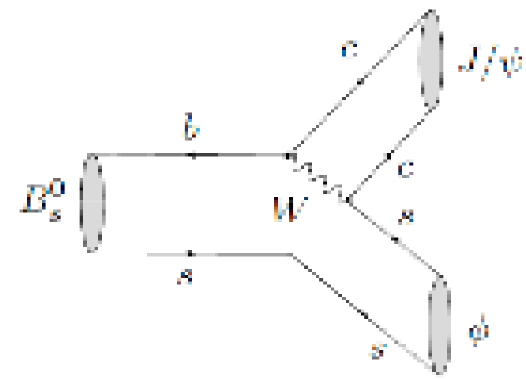
Interference between B_s decays to J/Ψφ with or without oscillation gives rise to a CP violating phase Φ_s.

J/Ψ->μμ
->ee

In SM: $\mathbf{\Phi_s = -2\beta_s}$
$\mathbf{\beta_s \approx 1^0}$







Exp.:$2\beta_s$=0.0368±0.0017

Measurement of Φ_s is one of the key goals of LHCb.

Although kinematics is the same for B_s->J/Ψ(ee)φ and B_s->J/Ψ(μμ)φ (if neglect mass difference between electron and muons) electrons are measured worse then muons (Bremsstrahlung photons).

Analysis was done with co-operation with A.Hicheur, EPFL, Lausanne
Results were presented for CPWG, August 2009

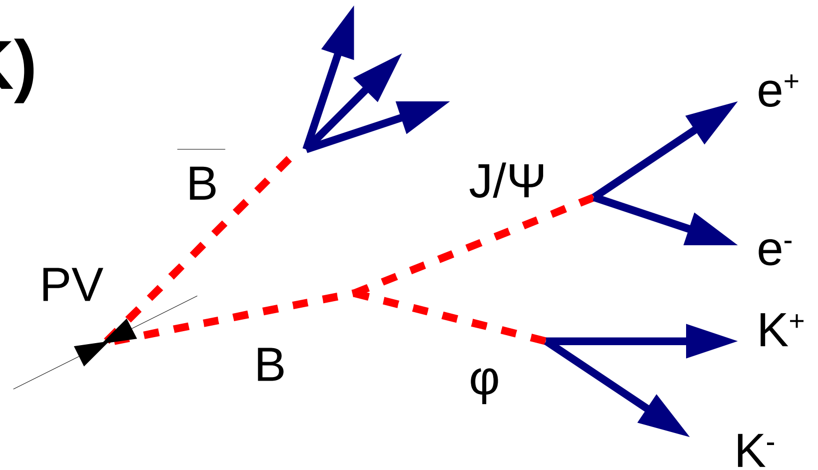
HLT2 selection

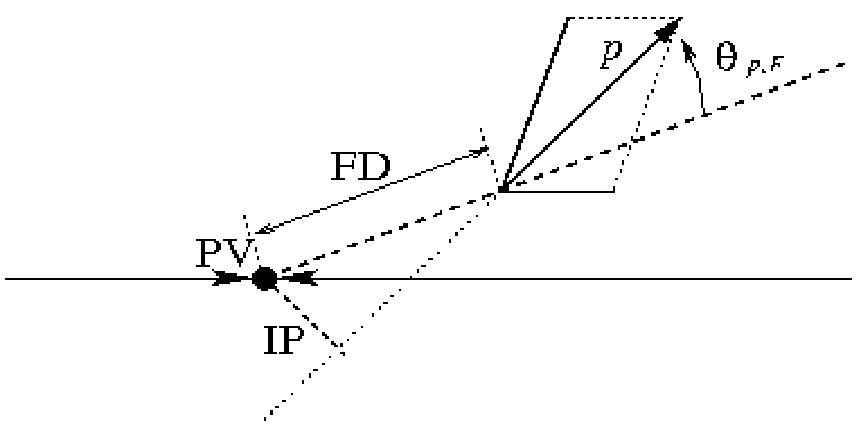
Each trigger selection is made according to the following rules:

1. Optimized to achieve the highest efficiency for the events selected in the offline analysis.
2. Rejecting uninteresting background events as strongly as possible.
3. Bandwidth limited to a few Hz (~10 Hz or below, not decided yet).

11 cuts to select $\mathbf{B_s \to J/\Psi(ee)\varphi(KK)}$

J/Ψ	$p_T(e)$>800MeV MIN IPS(e)>2 Vtx chi2/NDOF (J/Ψ)<25 **$2700<M_{J/\Psi}<3300$MeV**
φ	MIN IPS(K)>2 $p_T(\varphi)$>1GeV Vtx chi2/NDOF (φ)<25 **$1000<M_{\varphi}<1040$MeV**
B_s	**$4500<M_{Bs,pseudo}<6200$MeV** Vtx chi2/NDOF (B_s)<6 DIRA (B_s)>0.99

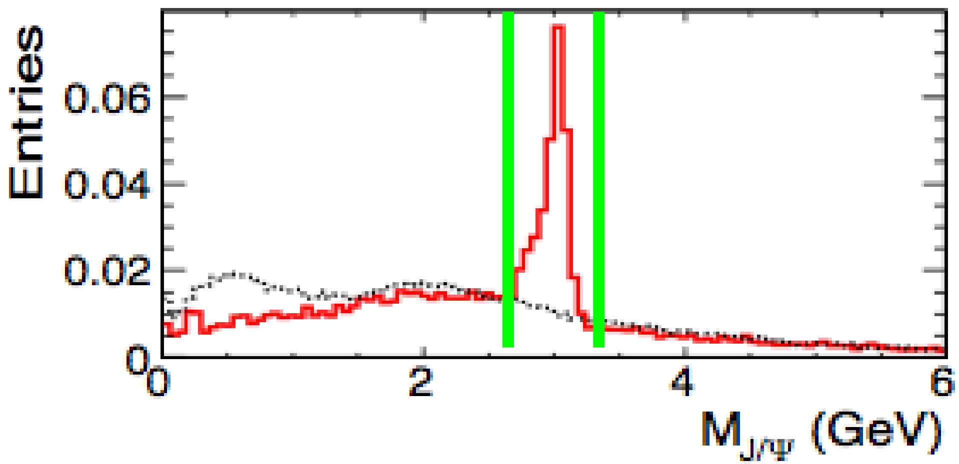


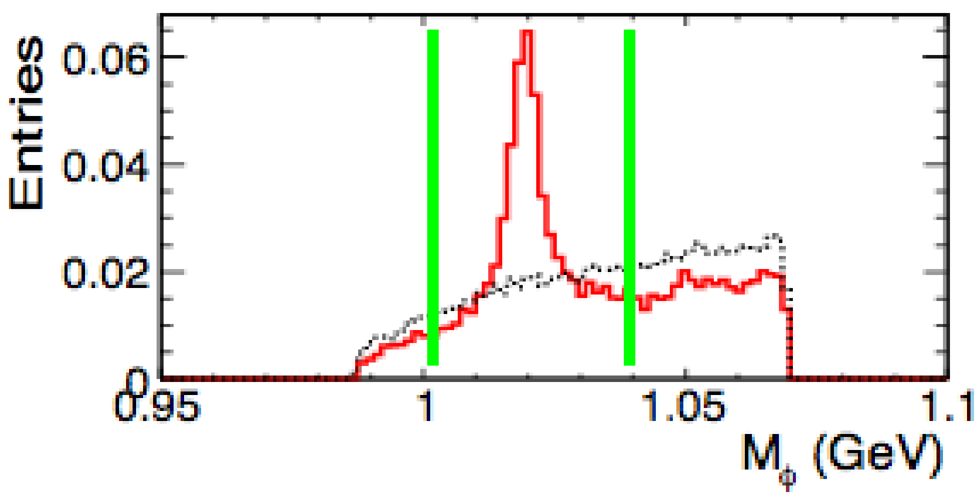


J/Ψ and φ reconstructions

J/Ψ is built from e^+e^- pairs and φ is built from K^+K^- pairs.

MB – dotted, Signal – full line





To separate signal and MB following cuts are done:

$2700 < M_{J/\Psi} < 3300$ MeV

It reduces: > 60 % MB
~ 5 % Signal events

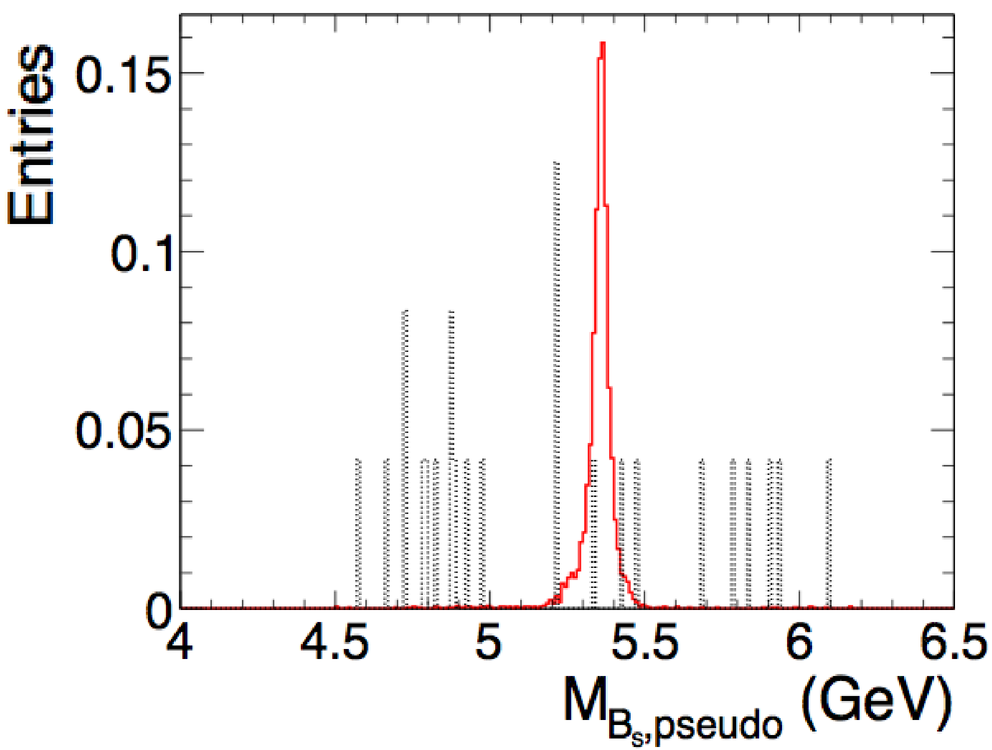
$1000 < M_{\varphi} < 1040$ MeV

It reduces: ~ 10 % MB
~ 2 % Signal events

Note: Comparison 1:1 (i.e. no scaling parameter)
in reality, signal is below MB

B_s reconstruction ($B_s \to J/\Psi\varphi$)

MB – dotted, Signal – full line



After all cuts (loosen M_{Bs}):

$4.5<M_{Bs,pseudo}<6.2$GeV

Signal eff.: 70±0.5 %

MB rate: 19 Hz (24 B_s cand.)

Total rate for all excl. ~ 100 Hz

Possible scenario:

$5.2<M_{Bs,pseudo}<5.5$ GeV

DIRA>0.995

Sig.eff.=70 %

MB rate= 2 Hz

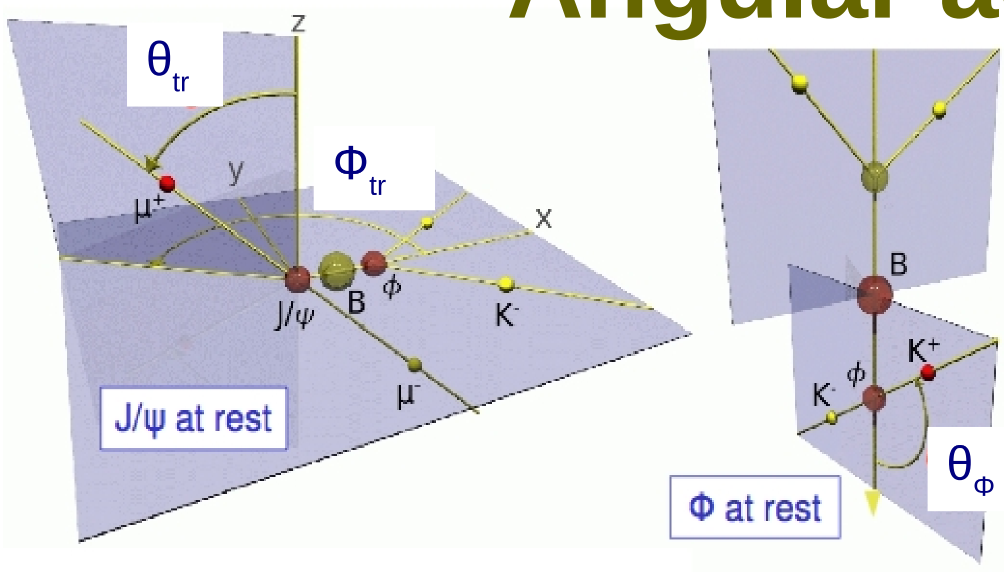
Pseudo-mass of B_s obtained by replacing measured $M_{J/\Psi}$ by true $M_{J/\Psi}$

Additional cuts are introduced, not only on $M_{J/\Psi}$ and M_φ

was checked:

no significant bias for angular distributions and lifetime

Angular acceptance



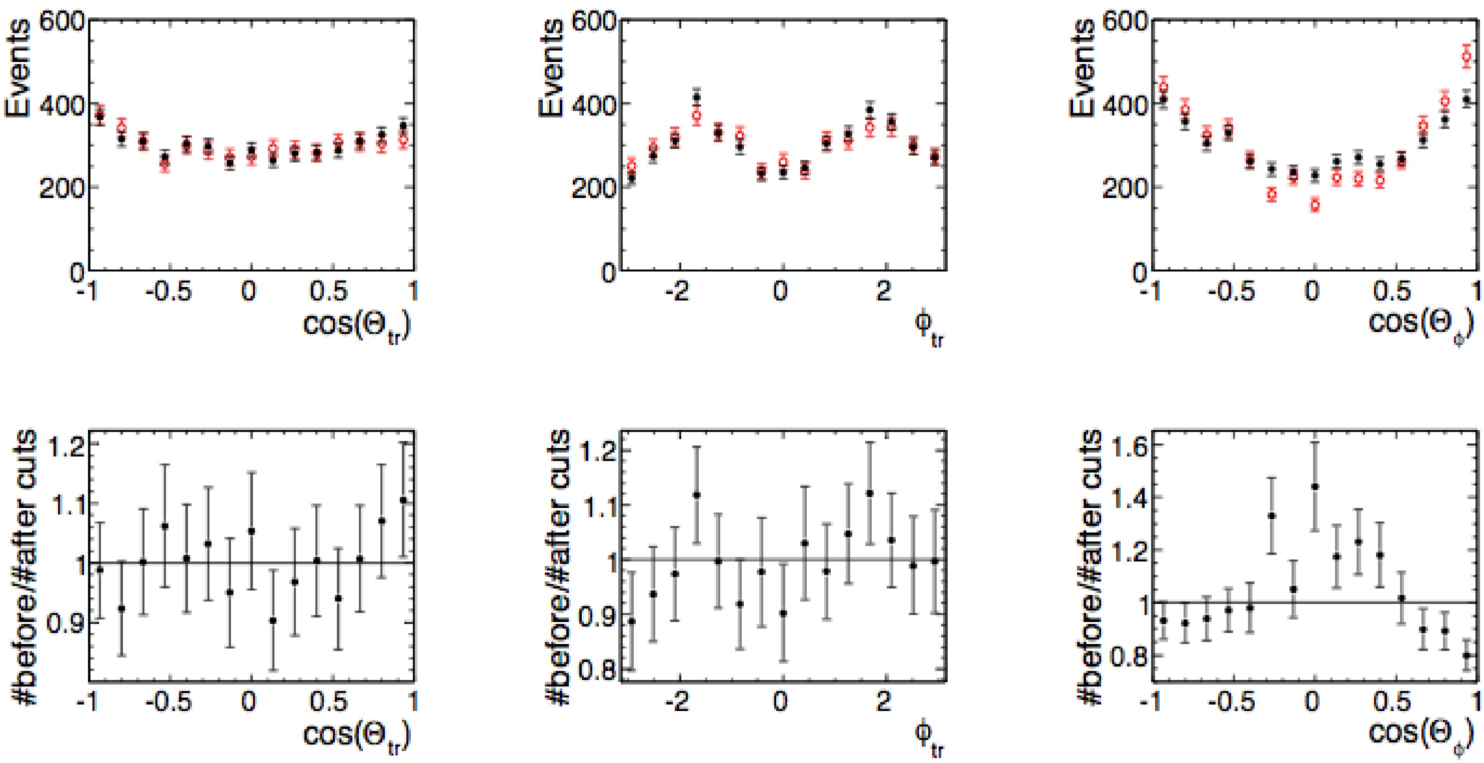
θ_{tr} – polar angle of positive lepton in J/Ψ rest frame and z axis

Φ_{tr} – azimuthal angle of positive lepton in J/Ψ rest frame

θ_{Φ} – formed by positive kaon and x' axis in φ rest frame

before cuts – full dots

after all cuts – open dots



No significant biases for angular distributions after all cuts are seen

Summary and conclusions

- **LHCb has very efficient and robust trigger**
  – consists of two parts (L0, HLT)
  – reduces rate up to 2 kHz

- **Trigger selection for B_s->J/Ψ(ee)φ is proposed**
  – wider mass window $4.5<M_{Bs}<6.2$ GeV
  signal efficiency≈70% and MB rate=19 Hz
  – if necessary: MB rate maybe reduced by tighten M_{Bs} window
  to 2 Hz (signal efficiency≈70%)

Back-up

HLT2 lines – rates division

Three trigger scenarios to distribute 2kHz rate between categories depending on physics emphasis

Trigger line	Trigger scenarios [Hz]		
	Leptonic	Hadronic	Charming
Leptons	**1200**	400	600
Charm	**200**	200	800
Topological	**400**	1100	400
Phi	**100**	200	100
Exclusive	< **100**	< 100	< 100
Total	**2000**	2000	2000

Example of trigger efficiencies

Signal	L0	Hlt1	Hlt2/1
B2HH	65%	79%	93%
B2MuMu	98%	98%	97%
Bc2JpsiMuNu	100%	99%	96%
Bc2JpsiPi	99%	98%	97%
Bd2DstarMu	84%	87%	64%
Bd2JpsiMuMuKs	95%	93%	96%
Bd2MuMuKstar	91%	93%	92%
Bd2eeKstar	57%	67%	70%
Bs2DsH	55%	71%	85%
Bs2JpsiPhi	94%	92%	98%
Bs2JpsiPhiBiased	94%	94%	97%
Bs2JpsieePhi	52%	53%	69%
Bs2KstarKstar	51%	67%	76%
Bs2PhiGamma	82%	72%	97%
Bs2PhiPhi	43%	57%	95%
Bu2D0K_KsHH	55%	64%	49%

DV v24r1p1

L0 – L0 eff
HLT1 – HLT1 eff. when L0 on
HLT2/1 – HLT2 eff. when L0 and HLT1 on

HLT2 efficiencies

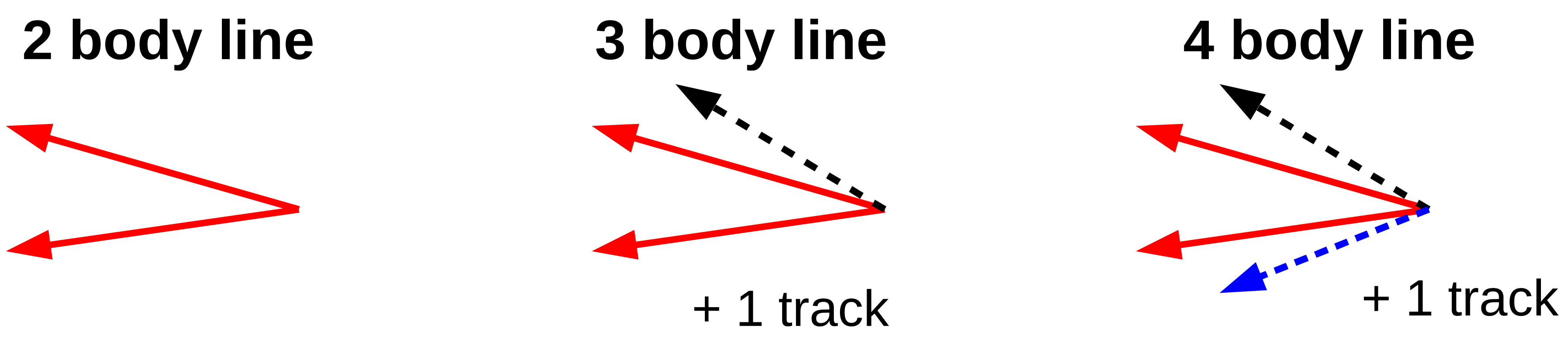
Signal	Hlt2/1	Best Sel	2nd Sel	3rd Sel
B2HH	93%	B2HH: 87 %	TopoTF2BodyReq2Yes: 81 %	TopoTF3BodyReq2Yes: 54 %
B2MuMu	97%	UnbiasedBmm: 92 %	BiasedDiMuonMass: 91 %	IncMuTrackMid: 81 %
Bc2JpsiMuNu	96%	UnbiasedJPsi: 81 %	B2JpsiX_MuMu: 71 %	BiasedDiMuonMass: 62 %
Bc2JpsiPi	97%	UnbiasedJPsi: 86 %	BiasedDiMuonMass: 84 %	IncMuTrackMid: 68 %
Bd2DstarMu	64%	IncMuTrackMid: 47 %	TopoTF4BodyReq3Yes: 28 %	TopoTF3BodyReq3Yes: 27 %
Bd2JpsiMuMuKs	96%	UnbiasedJPsi: 92 %	BiasedDiMuonMass: 78 %	IncMuTrackMid: 53 %
Bd2MuMuKstar	92%	IncMuTrackMid: 79 %	TopoTF3BodyReq3Yes: 65 %	TopoTF4BodyReq3Yes: 64 %
Bd2eeKstar	70%	TopoTF3BodyReq3Yes: 54 %	TopoTF4BodyReq3Yes: 53 %	TopoTF4BodyReq4Yes: 43 %
Bs2DsH	85%	TopoTF4BodyReq3Yes: 74 %	TopoTF3BodyReq3Yes: 72 %	TopoTF4BodyReq4Yes: 56 %
Bs2JpsiPhi	98%	UnbiasedJPsi: 91 %	BiasedDiMuonMass: 78 %	Bs2JpsiPhiDetached: 70 %
Bs2JpsiPhiBiased	97%	UnbiasedJPsi: 85 %	BiasedDiMuonMass: 80 %	Bs2JpsiPhiDetached: 72 %
Bs2JpsieePhi	69%	IncPhi: 59 %	TopoTF4BodyReq4Yes: 33 %	TopoTF4BodyReq3Yes: 33 %
Bs2KstarKstar	76%	TopoTF3BodyReq3Yes: 67 %	TopoTF4BodyReq3Yes: 65 %	TopoTF4BodyReq4Yes: 48 %
Bs2PhiGamma	97%	PhiGamma: 93 %	IncPhi: 85 %	KstGamma: 77 %
Bs2PhiPhi	95%	IncPhi: 89 %	TopoTF4BodyReq4Yes: 60 %	TopoTF4BodyReq3Yes: 50 %
Bu2D0K_KsHH	49%	TopoTF3BodyReq3Yes: 39 %	TopoTF4BodyReq3Yes: 35 %	TopoTF4BodyReq4Yes: 24 %

HLT2/1 – HLT2 eff. when L0 and HLT1 on

DV v24r1p1

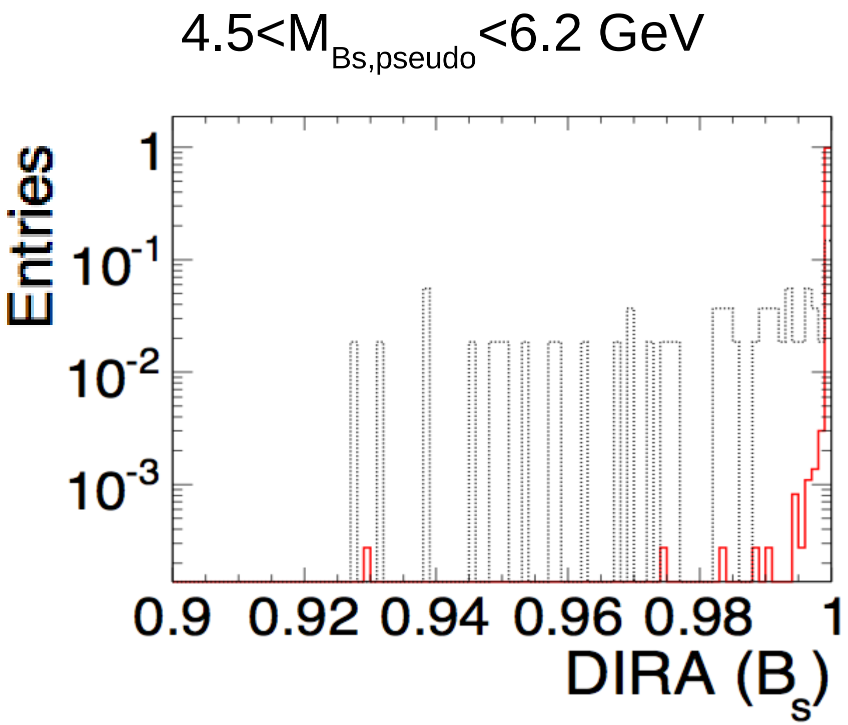
HLT2 Topological lines

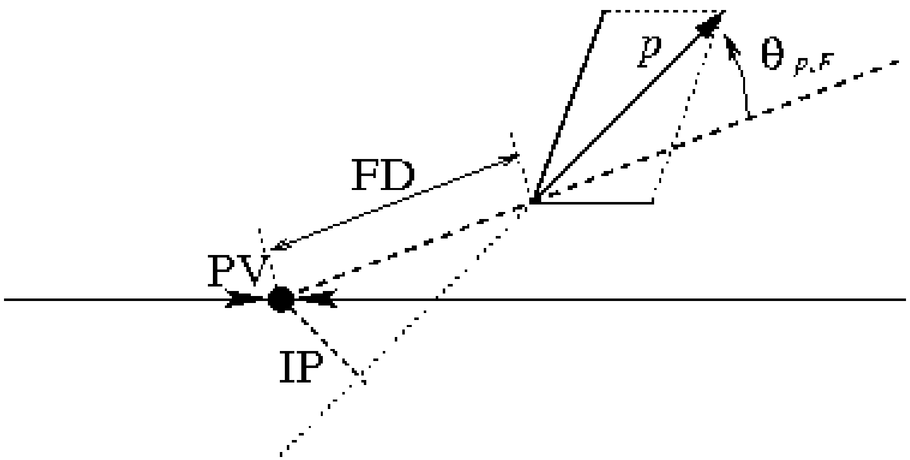
It searches for 2, 3 and 4 body track combinations in a wide mass window (between 4 and 6 GeV).



- 2 and 3 body lines explore combinations of π and K
- 4 body line excluded because of unbearable timing from huge number of combinations

Tighten MB rate by DIRA (B_s) cut





DIRA (direction angle)
cosine of angle between momentum of particle and direction of flight from PV to decay vertex

cut	Events / Candidates for B_s		
	signal	signal eff. [%]	MB
DIRA (B_s)>0.99	3 153 / 3 704	70	19 Hz / 24
DIRA (B_s)>0.995	3 151 / 3 700	70	14 Hz / 15
DIRA (B_s)>0.995 5.2<$M_{Bs,pseudo}$<5.5 GeV	3 140 / 3 611	70	**2 Hz** / 2

Cut summaries for New Trigger Selection

	cut	Signal efficiency[%]	MB rate [Hz]
0	Standard Di-electron: Hlt2Electrons P_t(e)>800 MeV Vtx chi2 J/Ψ<25 $M_{J/\Psi}$<6 GeV Non-standard φ: NoCutKaons (~~Hlt2GoodKaons~~) Vtx chi2 φ<25 $\|M_\varphi\|$<PDG±50MeV B_s: all built candidates	100	9 642
1	$P_t(\varphi)$>1 GeV	98	8 538
2	1000<M_φ<1040 MeV	96	7 006
3	2700<$M_{J/\Psi}$<3300 MeV	90	2 639
4	MIN IPS (e)>2	81	523
5	MIN IPS (K)>2	74	260
6	Vtx chi2 B_s<6	70	88
7	4500<$M_{B,pseudos}$<6200 MeV	70	71
8	DIRA (B_s)>0.99	70	19

Unbiased Pt Selection
(above cuts without MIN IPS(e) and MIN IPS(K))
for prescaling=0.01 MB rate=7 Hz

for:
DV **v23r1** and **OLD** reference sample (Roadmap, Feb.2009)

Curiosity

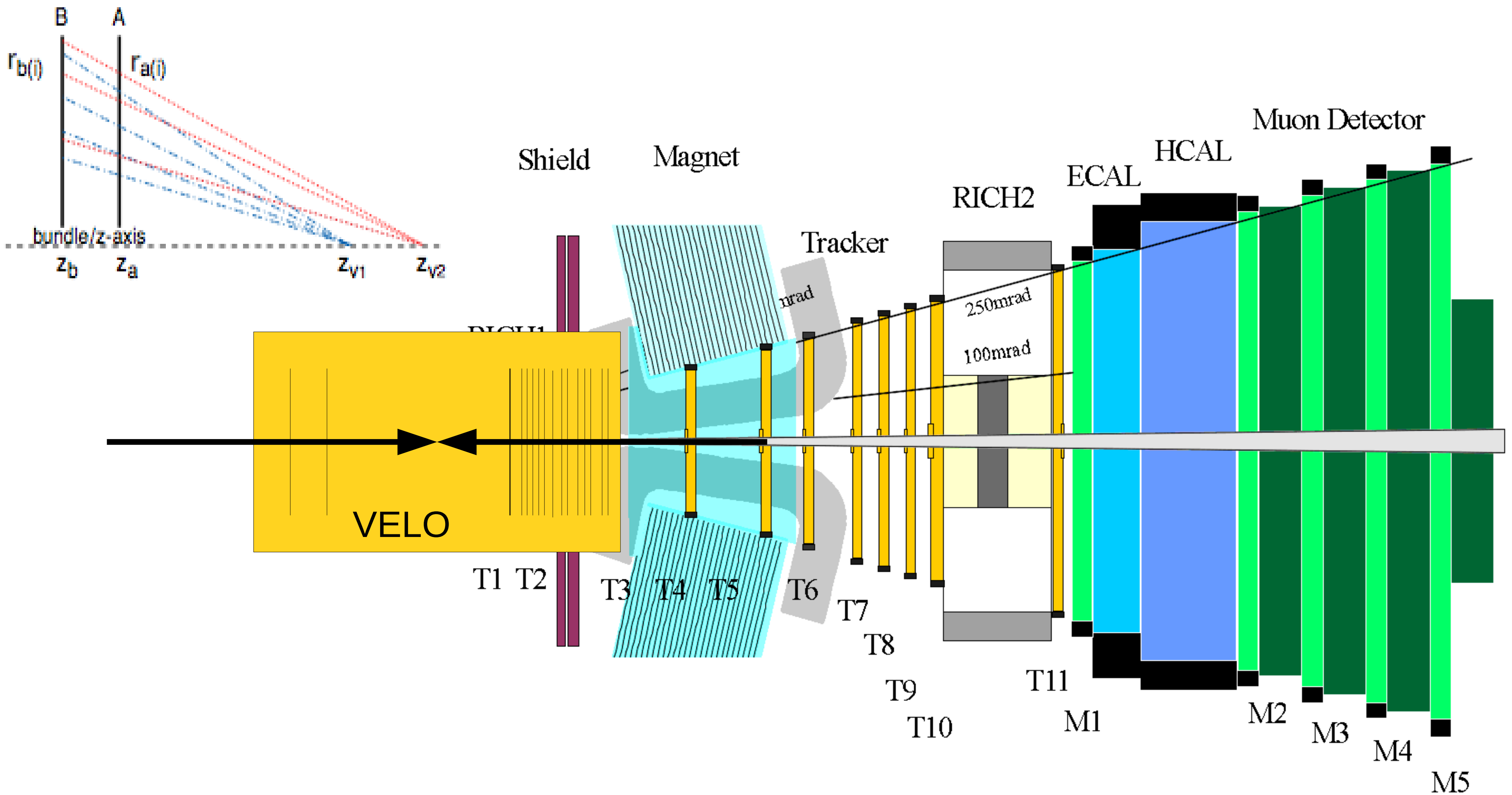
1 event ~ 35 kB

HLT2: 2 kHz -> 2 kHz x 35 kB= 70 MB/s

1 minute 4.2 GB (120kevents)

Standard DVD every one minute

Pile-Up system (VELO)



Pile-Up trigger rejects good B meson candidates
(events with two vertexes: 1. pp interac. 2. B decay vertex)

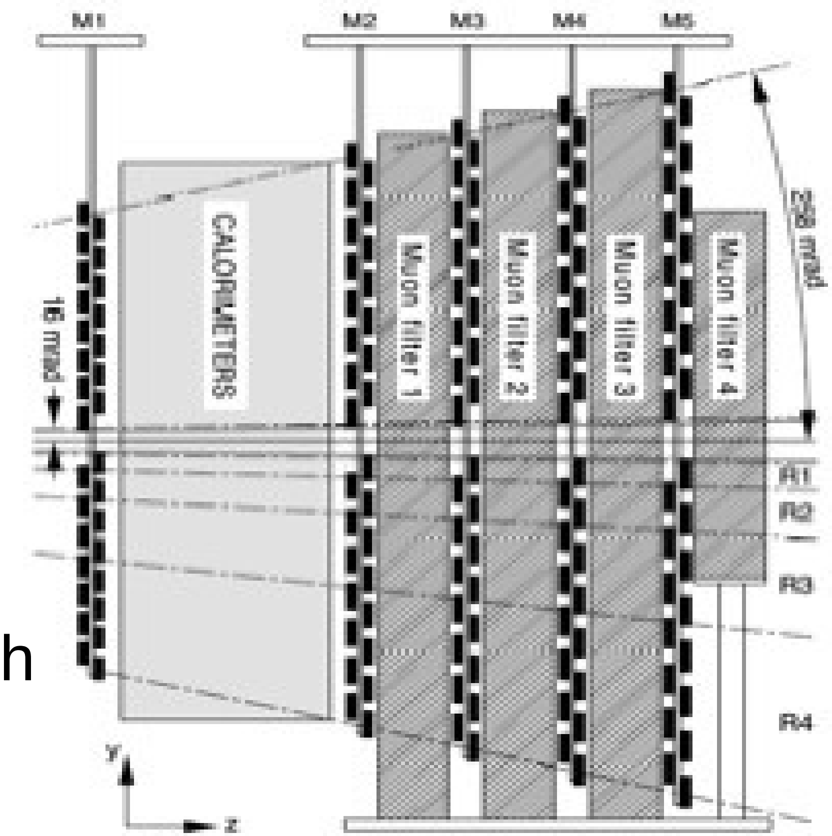
but on opposite side of detector

Track finding algorithm (L0 muon trigger)

It is implemented using
only logical operations.

It starts in M3.

For each logical pad hit in M3,
    an extrapolated position
    is set in M2, M4, M5
    along the straight line passing through
    the hit in M3 and interaction point.



Pad hits are looked for M2, M4, M5 closed to the extrap. position.

Track position in M1 is determined by making straight line extrapolation from M3 and M2, and identifying the pad hit closest to extrapolation point.