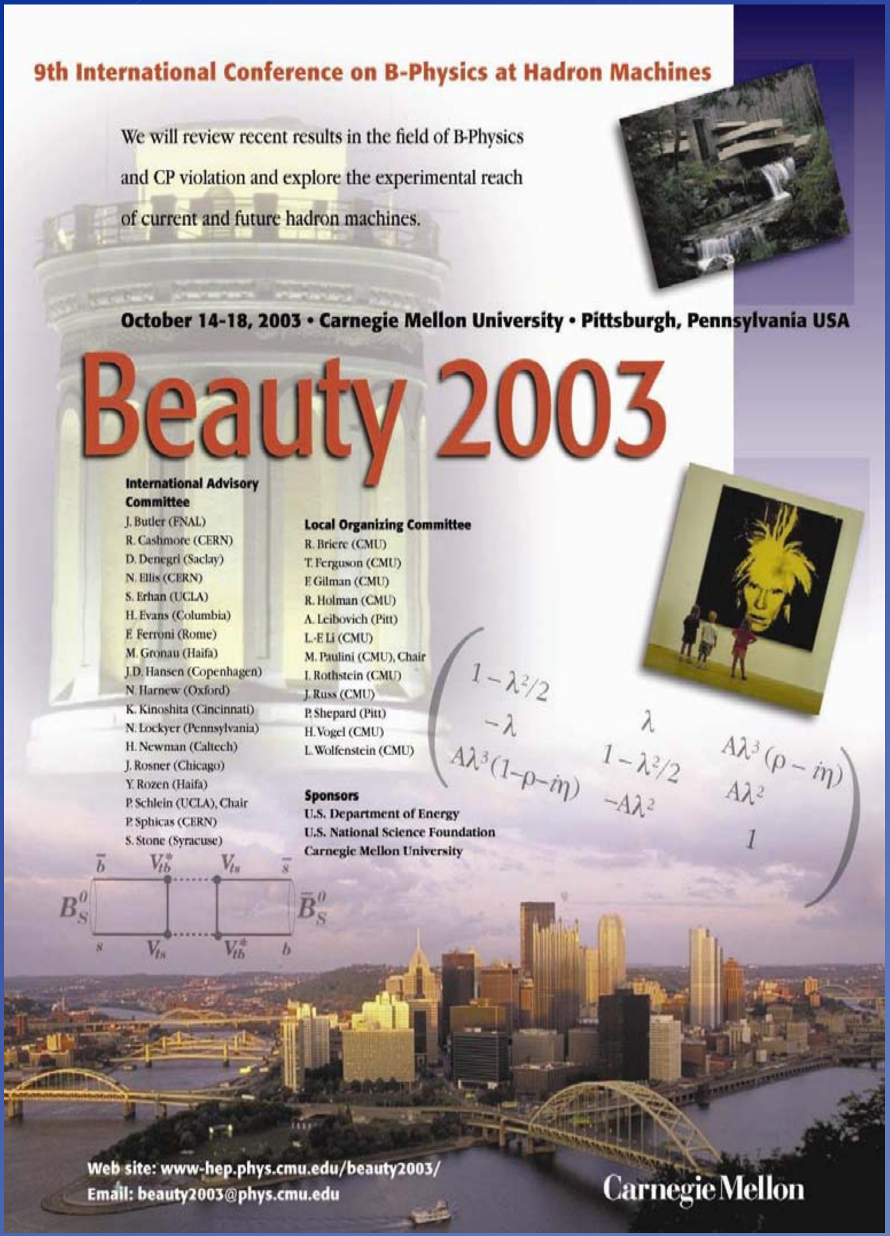

B Physics @ CMS

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IASA – Athens

On behalf of the CMS Collaboration

Beauty 2003

Oct 14-18 2003
Carnegie Mellon University
Pittsburg, Pennsylvania

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- Introduction
- Simulation/reconstruction software
- Trigger issues
- Some issues about Tracking
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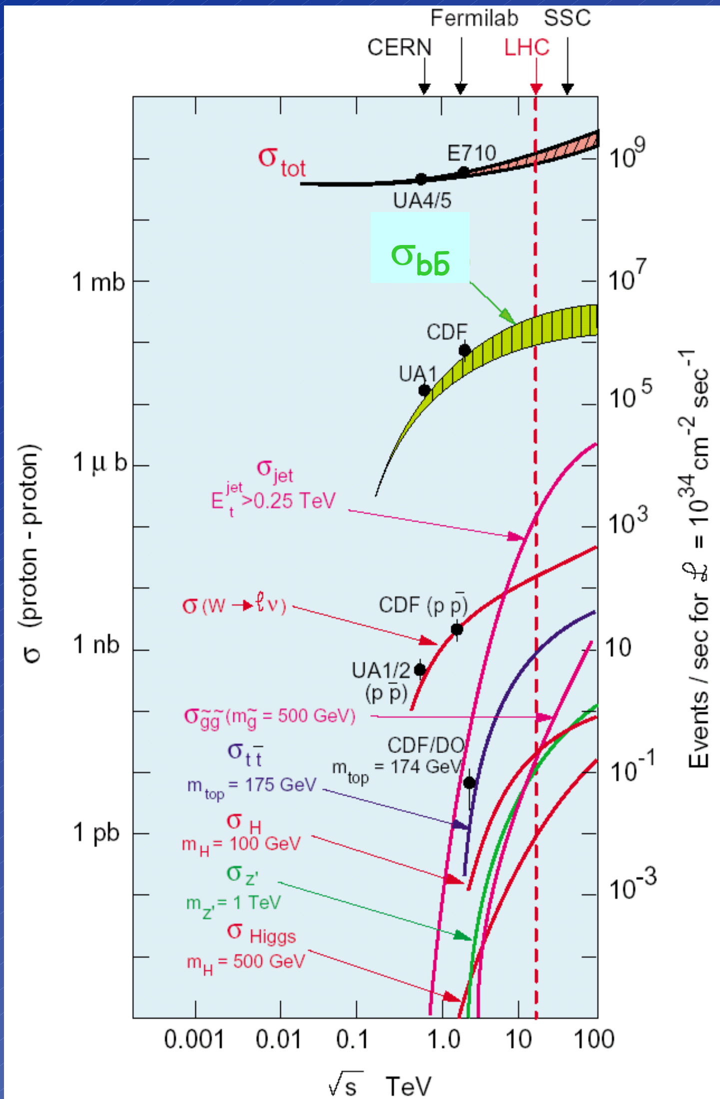
Introduction



b production at LHC

- Peak luminosity: 2×10^{33} cm^{-2}s^{-1} → 10^{34} cm^{-2}s^{-1}
- σ = 500 μb → O(10^5-10^6) b pairs/sec
- Only 100 ev/sec on tape for ALL interesting physics channels

B-physics program

- Rare decays
- CP violation
- B^0_s-$\bar{B}^0_s$ mixing

Trigger highly challenging

- $B_s \to \mu\mu$
- $B_s \to J/\psi\varphi \to \mu\mu$ KK
- $B_s \to D_s\pi \to$ KK ππ

Benchmark channels

Results from DAQ-TDR (CERN/LHCC 2002-26)

Simulation & Reconstruction Software

- Event Generation: PYTHIA 6.158
  - Interface to the user: CMKIN
  - Minimum bias event pile-up
  - Gluon splitting, heavy quark fusion, flavour excitation taken into account for $b\bar{b}$ events production
- Detector description and simulation: CMSIM based on Geant3
  - Geometry and material budget as in 2002
- Detector response:
  - Digitization, noise, effects due to pile-up, …
  - Level 1 trigger simulation
- Reconstruction:
  - Deposits in the calorimeters
  - Muons
  - Tracks
  - Primary and secondary vertices

Fortran based. Their equivalent C++ version is on the way …..

C++ Object Oriented
Same software for online and offline reconstruction and selection

L1 Trigger

Low Luminosity L1 Trigger Table (Prototype)

Trigger type	Threshold (ε=95%) (GeV)	Indiv. Rate (kHz)	Cumul rate (kHz)
1e/γ, 2e/γ	29, 17	4.6	4.3
1μ, 2μ	14, 3	3.6	7.9
1τ, 2τ	86, 59	3.2	10.9
1-jet,3-jets, 4-jets	177,86,70	3.0	12.5
Jet * MissE$_T$	88 * 46	2.3	14.3
e * jet	21 * 45	0.8	15.1
Min-bias		0.9	16.0

Designed to cover the widest possible range of physics for discovery

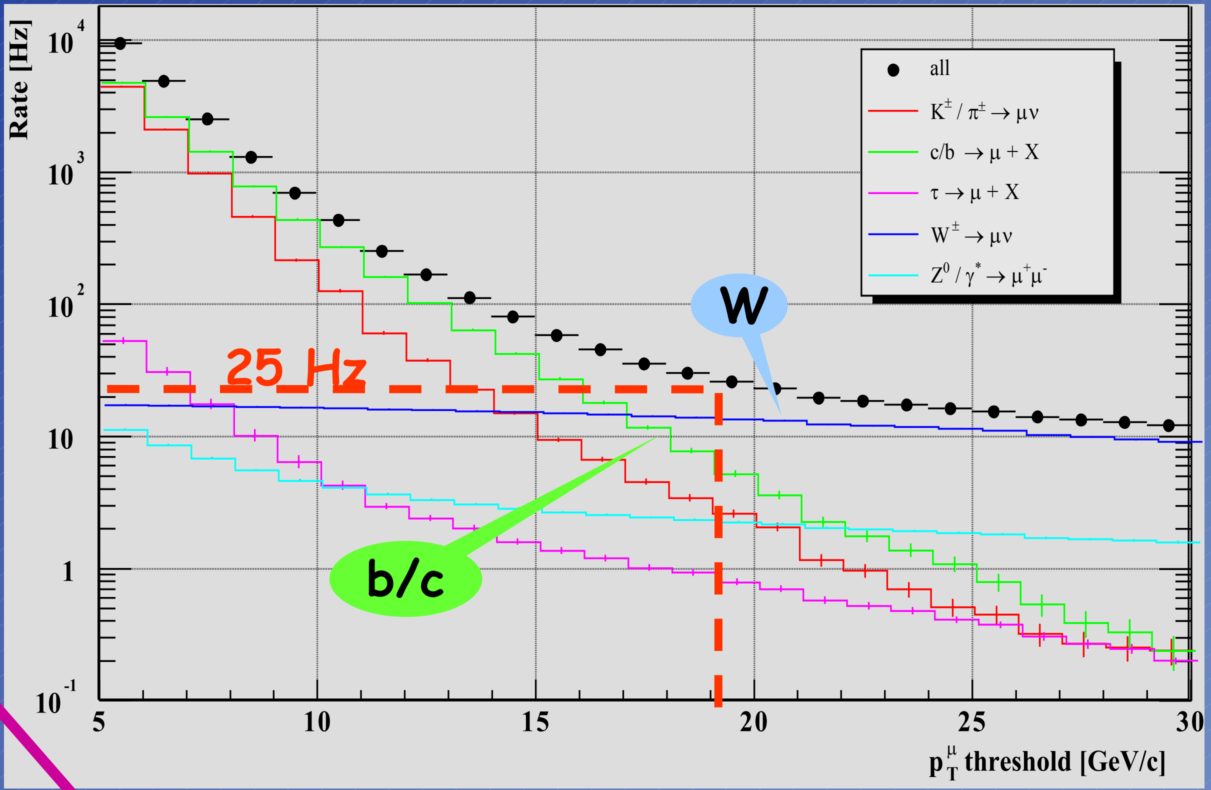
-Total L1 allocated rate-
50 KHz x 1/3 safety factor

- B Physics selection triggered @ L1 by single or di-muon triggers
- Particles from B decays have relatively soft spectrum
- Important keeping the L1 threshold as low as possible
- Muons are preferred to electron because of the lower trigger threshold

Muons in the High Level Trigger

- After HLT only 100Hz can be stored on tape
- 30Hz allocated to 1μ,2μ (25Hz+5Hz) ($P_T > 19GeV$, $P_T > 7GeV$)
- The content in b is too little (~ 5Hz for b/c)
- Need to push and select exclusive b events

Exploit the online tracking



1Hz → 10^7 evts/year @ low luminosity
Insufficient for processes with BR < 10^{-4}

High-Level Trigger Tracking

Limited amount of CPU time available for trigger decision:
- 500 ms on a 1GHz machine
- possibly 50 ms in 2007

Reduce
- # of track seeds
- # of operations per seed

Regional seed generation

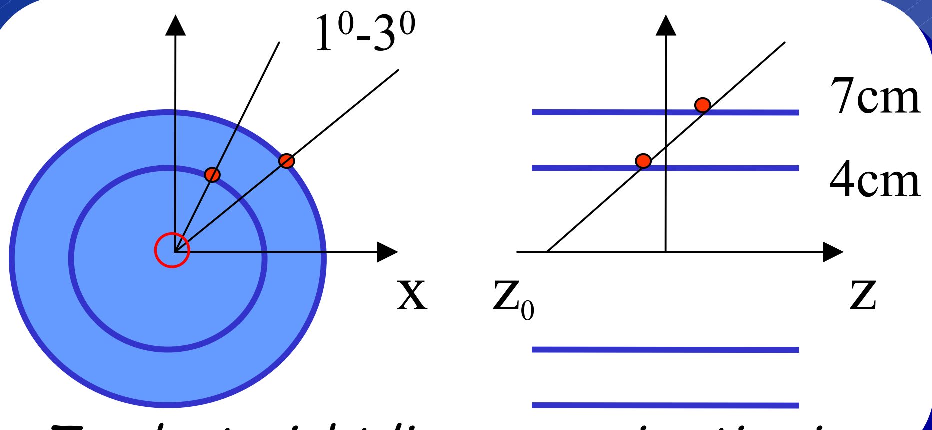
Limited to some region identified by Lvl1 objects (e.g. cone around μ direction)

Partial/Conditional Tracking

Stopped when:
- N hits are reconstructed
- P_T resolution > given threshold
- P_T value < given threshold
- ……………………………………..

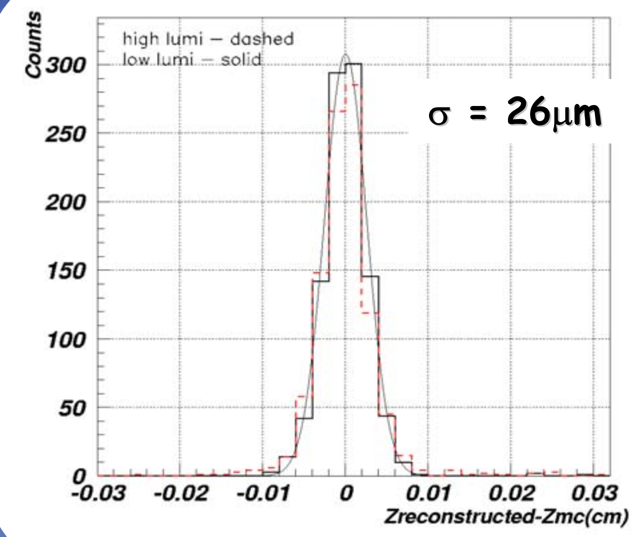
HLT Tracking does not need to be as accurate as in the offline

Primary vertex reconstruction



Track straight line approximation in z

Only Pixel Detector

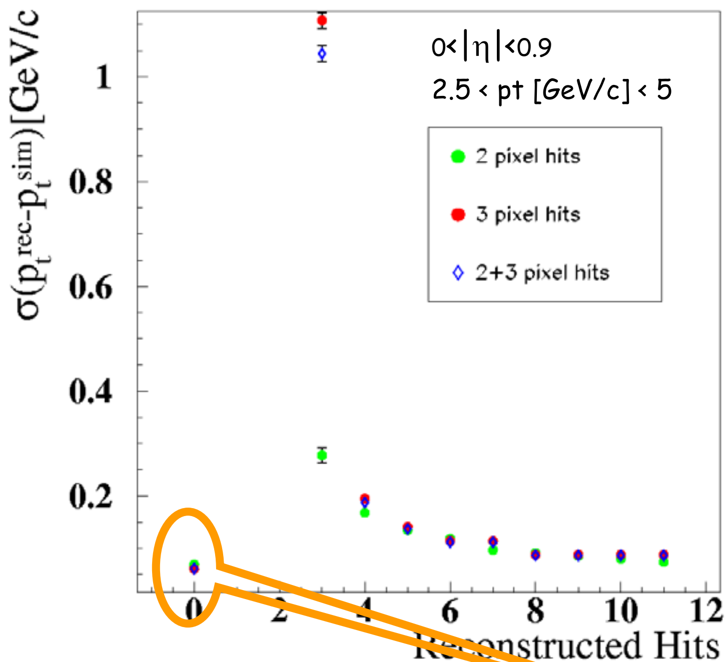


- Pixel hit pairing in R-z and R-φ
  - $d_0 \leq 1$ mm , $P_T > 1$ GeV
- Matching with 3rd layer → track candidate
- PV candidate if ≥ 3 track cross z-axis
- PV list → Signal vertex from ΣP_T and N_{tracks}
- Cleaning of tracks not pointing to PV

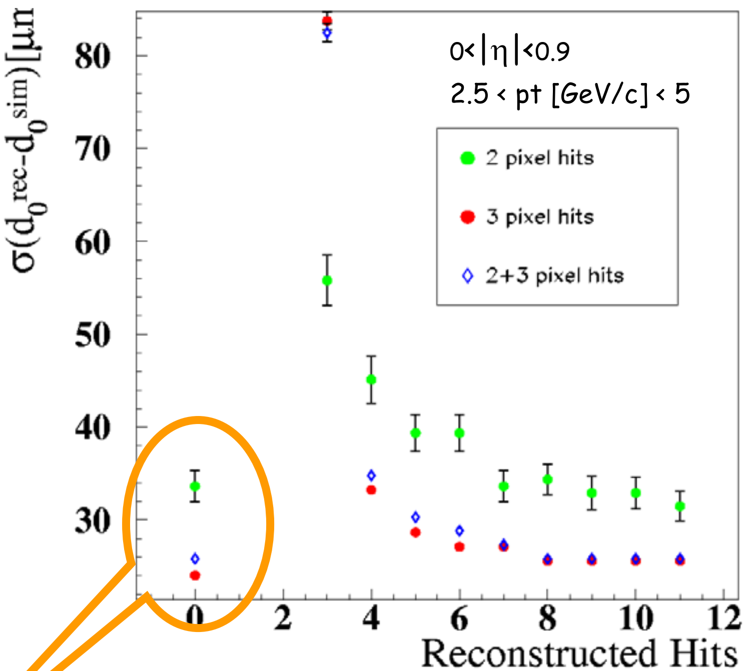
Average time:50msec @1 GHz

Partial Tracking

Transverse Momentum Resolution



Impact parameter Resolution



Full Tracker

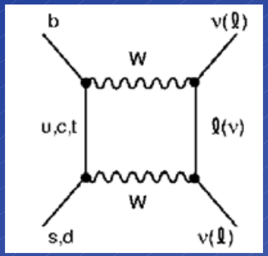
Tracking time proportional to the number of hits

Good efficiency/ghost rate & resolution with just 5 hits

Exclusive B decay channels

Three decay channels chosen as benchmark

- $B_S \to \mu^- \mu^+$



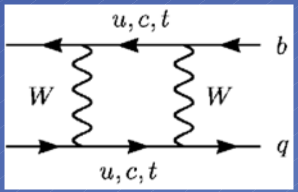
- FCNC $b \to s$, loop-level process in SM
- Indicator of possible new physics
- Observable before LHC only if drastically enhanced
- Unique signature…….but BR ~ O (10^{-9})

- $B_S \to J/\psi\ \varphi \to \mu^- \mu^+\ K^- K^+$

- Gold-plated decay mode for CP-violation
- Sensitive to new physics
- Won't be studied with big accuracy before LHC

Triggered @ L1 by the presence of 2μ

- $B_S \to D_S^- \pi^+ \to \varphi \pi^- \pi^+ \to K^- K^+\ \pi^- \pi^+$



- $B_S^0 - \overline{B}_S^0$ Mixing
- B_S flavour @ decay time unambiguously tagged by D_S sign

Triggered @ L1 by the presence of 1μ (from the semileptonic decay of the other b hadron in the event)

$B_s \to \mu^- \mu^+$

- @ L1:
  2μ trigger, $P_T > 3$ GeV, $|\eta| < 2.1$
- @ High Level Trigger:
  Regional tracking ➡ look for pixel seeds only in a cone around the 2μ, with $P_T > 4$ GeV and $d_0 < 1$mm, and compatible with PV

  Conditional tracking ➡ reconstruct tracks from good seeds
  - ✓ Stop reconstruction if $P_T < 4$ GeV @ 5σ
  - ✓ Keep only tracks with $\sigma(P_T)/P_T > 2\%$, $N_{hit} = 6$

  IF 2 Opposite Signs tracks found ➡
  Calculate the invariant mass
  Retain pairs with a) $|M_{\mu\mu} - M_{B_s}| < 150$ MeV
  b) Vertex $\chi^2 < 20$ & $d_0 > 150$ μm

Lvl-1 ε	HLT ε	Global ε	Events/ $10fb^{-1}$	Trigger Rate
15.2%	33.5%	5.1%	47	<1.7Hz

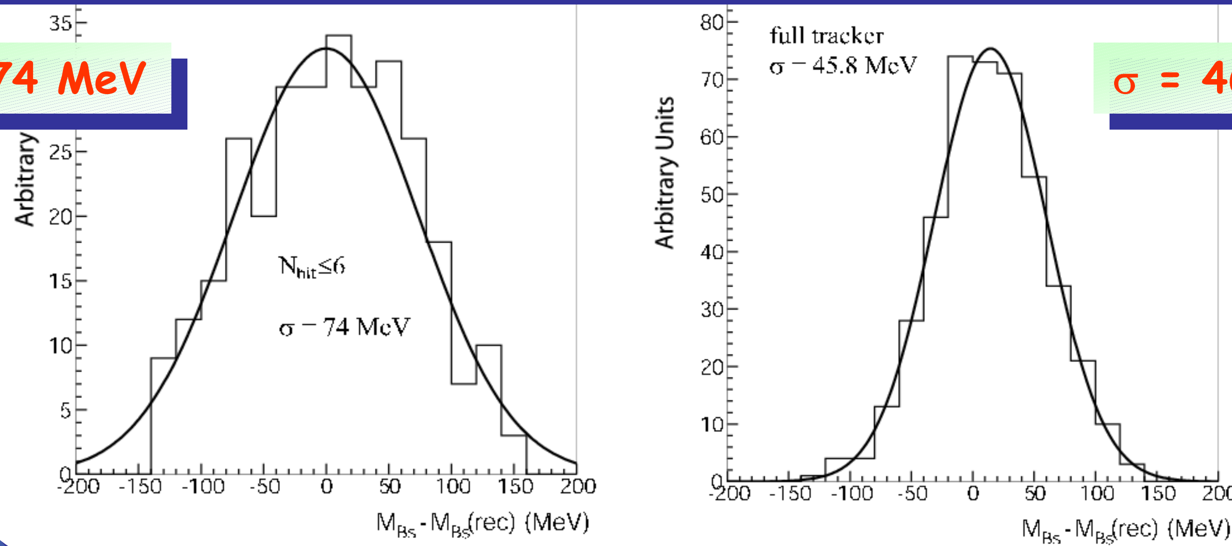
$B_s \to \mu^- \mu^+$

B_s Mass resolution

HLT | **Full Tracking**

σ = 74 MeV

σ = 46 MeV



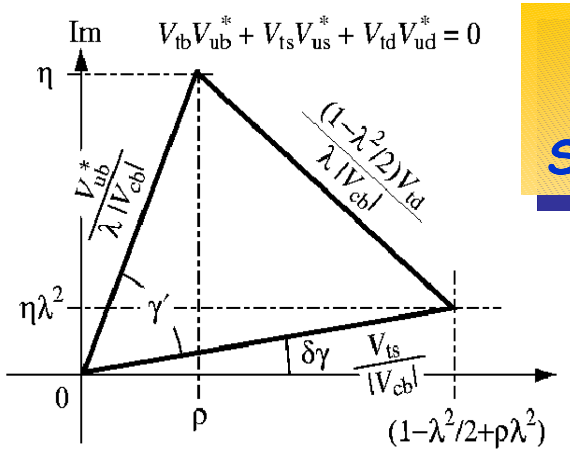
Old offline analysis (hep-ph/9907256 Jul 1999) predicts:

- ✓ 14 evts ± 2 bkg @ 90 C.L. with 20fb^{-1} (1 year @ 2x10^{33} cm^{-2}s^{-1})
- ✓ 5σ observation with 40fb^{-1} and feasibility @ high lumi too

……… But L1 is in $|\eta| < 2.4$ + slightly different kinematics cut

Update foreseen for the CMS Physics TDR

$B_s \to J/\psi\varphi \to \mu\mu$ KK



CP violation weak phase
$\phi_s = 2\delta\gamma = 2\lambda^2\eta$
SM predicts tiny CP asymmetry $\phi_s \sim O(0.03)$

$BR(B_s \to J/\psi\ \phi) = (9.3 \pm 3.3) \times 10^{-4}$
$BR(J/\psi \to \ell^+\ell^-) \approx 6\%$
$BR(\phi \to K^+K^-) \approx 49\%$

- 1^{st} step : J/ψ reconstruction → Retain muon pairs with $|M_{\mu\mu} - M_{J/\psi}| < 100$ MeV & Vertex $\chi^2 < 10$ & $d_0 > 200\ \mu m$

Rate = 15 Hz
<t>~260ms

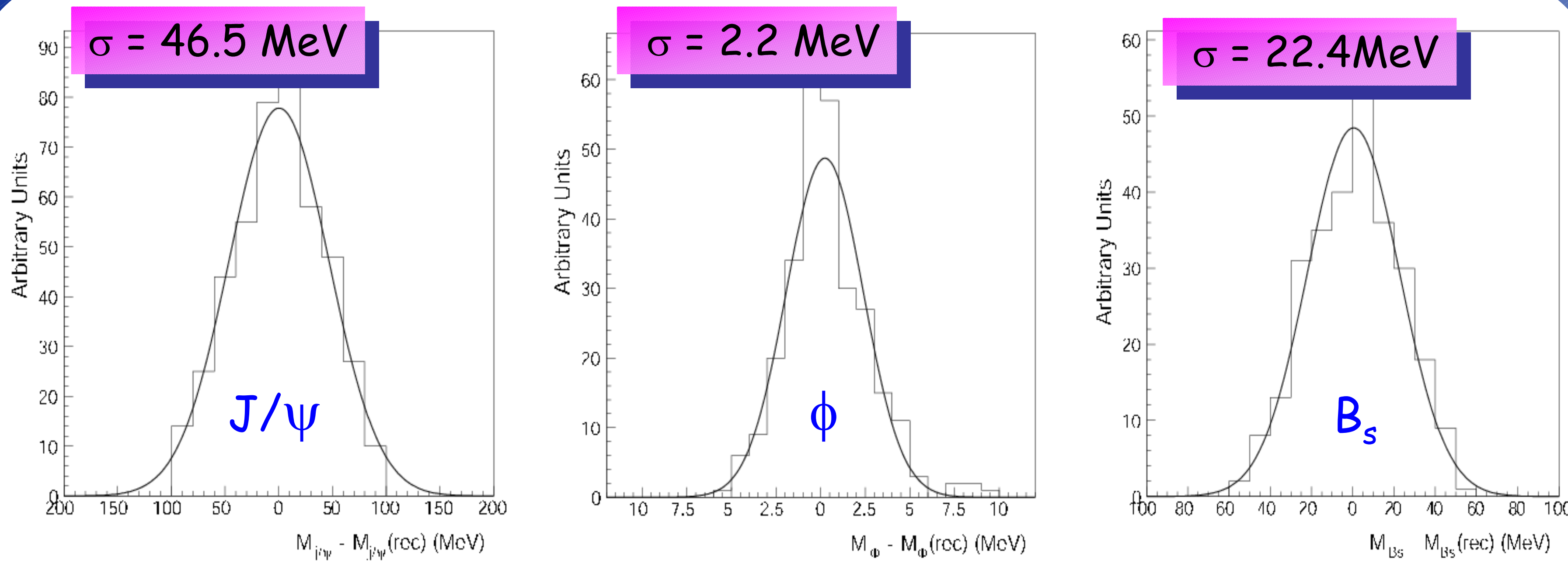
- 2^{nd} step: φ and B_s reconstruction
  Regional/conditional tracking around the J/ψ direction + $|M_{KK} - M_\varphi| < 10$MeV
  Then invariant mass $|M_{J/\psi\varphi} - M_{B_s}| < 60$ MeV + B_s vertexing

<t>~800ms

Lvl-1 ε	HLT step 1 ε	HLT step 1 Rate	HLT step 2 ε	HLT step 2 Rate	Events/ $10fb^{-1}$
16.5%	13.7%	14.5 Hz	8.7%	<1.7Hz	83800

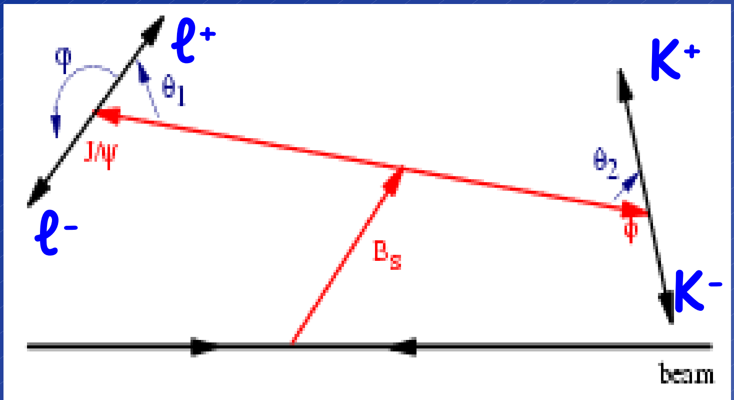
$B_s \to J/\psi\varphi \to \mu\mu\ KK$

HLT mass resolutions



The strong solenoid magnetic field → Good B_s mass resolution and lower background

$B_s \to J/\psi\varphi \to \mu\mu\ KK$

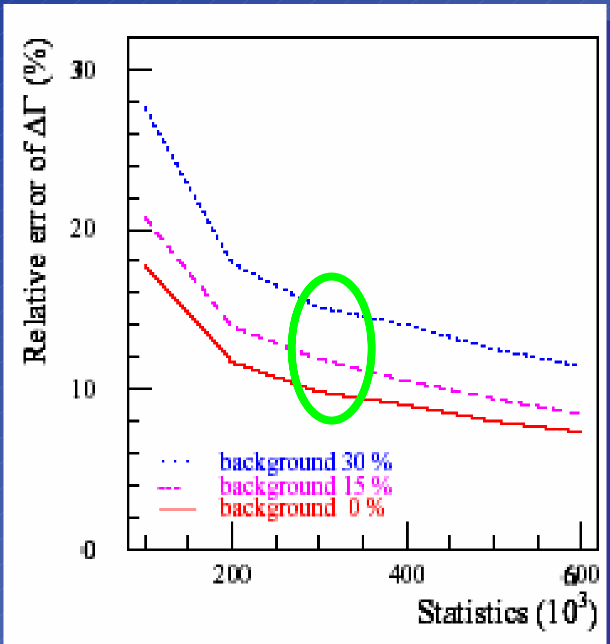


Old CMS analysis (CERN-2000-004) not updated yet

Angular distribution analysis
Expected number of signal evts ~600K (yield with 30fb^{-1})

Trigger was NOT optimized

	$\Delta\Gamma_s$	$\phi_s(x_s=20)$	$\phi_s(x_s=40)$
Value	$0.15\times\Gamma_s$	0.04	0.04
Error	8.0%	0.014	0.03



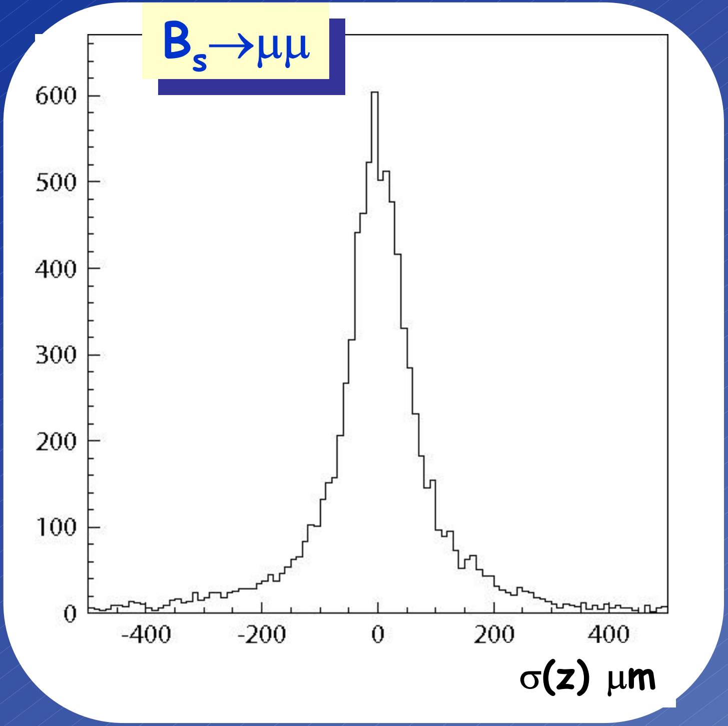
Expected yields from HLT: ~300K with 40fb^{-1}

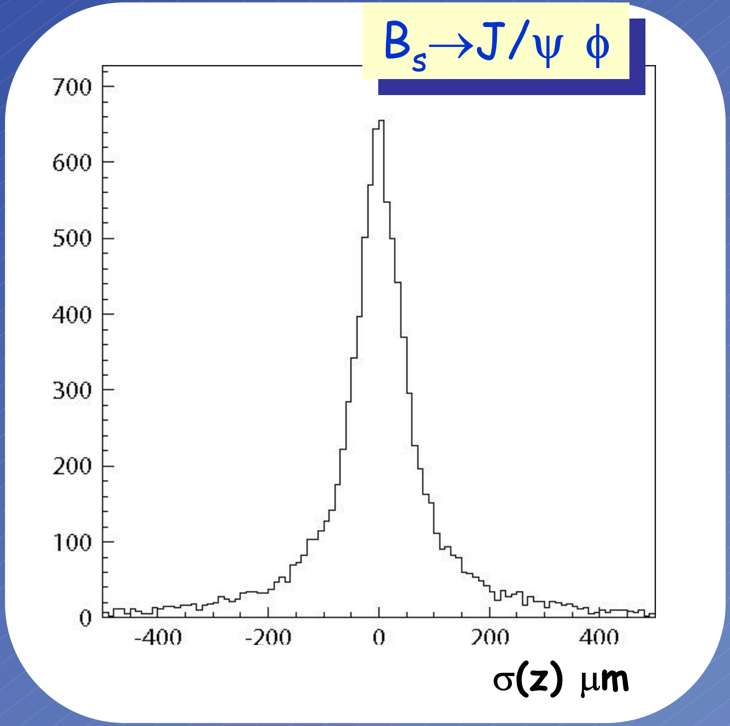
$\sigma(\Delta\Gamma_s)/\Delta\Gamma_s \sim$ 12%

$\delta\phi_s(x_s=20) \sim$ 0.02 rad

$\delta\phi_s(x_s=40) \sim$ 0.04 rad

Secondary vertex reconstruction





	$B_s \to \mu\mu$	$B_s \to J/\psi\ \phi$
σ(x) μm	47.5 ±3.63	55.3 ±0.95
σ(z) μm	71.5 ± 1.3	72.7 ±1.4
CPU time msec	1.9	3

$B_s \to D_s\pi \to \varphi\pi\pi \to KK\ \pi\pi$

Current W.A.: B_s^0-$\bar{B}_s^0$ mixing: $\Delta M_s \geq 14.4\ ps^{-1}$ @95%CL
SM prediction: $14.8 \leq \Delta M_s \leq 25.9\ ps^{-1}$ @ 99%CL

@ L1:
single μ ($P_T > 14$ GeV) or low-P_T μ + low-E_T jet (various threshold scenarios possible). The μ also serves for tagging the B_s flavour @ production time

@ HLT:
Pixel Primary vertex reconstruction
Partial Tracking: Seeds with $P_T > 0.7$ GeV, 3 Hits (2 pixels + 1SST) & $z \pm 1$ mm from PV
Topological cuts: $\Delta R(KK) < 0.3$, $\Delta R(\varphi\ \pi) < 1.2$, $\Delta R(D_s\pi) < 2.0$, $\Delta\varphi(B_s,\mu) > 0.6$

Kinematical cuts: $P_T(\varphi) > 2$GeV, $P_T(D_s) > 4$GeV, $P_T(B_s) > 5$GeV

Mass reconstruction: $\Delta M_\varphi < 15$MeV, $\Delta M_{Ds} < 75$MeV, $\Delta M_{Bs} < 270$MeV

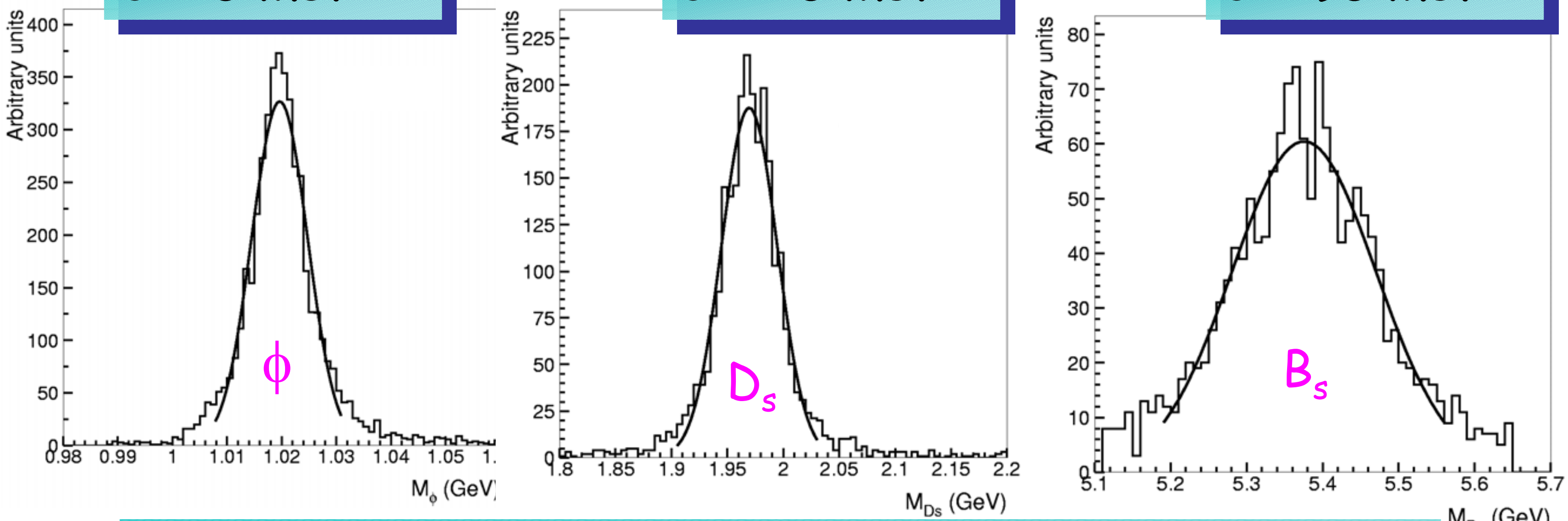
HLT efficiency ~ 9%, <t> = 640 msec

$B_s \rightarrow D_s\pi \rightarrow \varphi\pi\pi \rightarrow KK\ \pi\pi$

σ = 5 MeV

σ = 25 MeV

σ = 95 MeV



HLT Mass resolutions (only 3 hits used for Tracking)

# of signal evts depends on the L1 B.W. allocated to the channel
Assuming 1KHz allocated @ L1 (5Hz @ HLT)

300-400 signal events/year ⟷ sensitivity to Δm_s up to 20 ps^{-1}
1000 evts needed to cover the whole SM allowed range $\Delta m_s \leq 26$ ps^{-1}
(CMS NOTE 2000/038,CMS NOTE 2002/045)

$B_s \to D_s\pi \to \varphi\pi\pi \to KK\ \pi\pi$

Machine conditions/instantaneous luminosity ⇨ might allow lowering the L1 thresholds below the nominal value

Trigger rates (KHz) vs cuts on the muon P_T and jet E_T

HLT (Lvl-1)

$P_T\mu$ \ $E_T$jet	0 GeV	20GeV	30Gev
4GeV	0.27 (50)	0.15 (15)	0.08 (5.7)
5GeV	0.19 (33)	0.10 (11)	0.06 (4.2)
6GeV	0.16 (26)	0.082 (8.5)	0.055 (3.6)
7GeV	0.11 (18)	0.062 (6.2)	0.045 (2.7)
10GeV	0.037 (6.4)	0.021 (2.5)	0.014 (1.3)
14GeV	0.017 (3.2)	0.010(1.3)	0.008 (0.7)

High Level Trigger Table @ Low Luminosity

Trigger type	Threshold (e=90-95%) (GeV)	Indiv. Rate (Hz)	Cumul. rate (Hz)
1e, 2e	29, 17	34	34
1γ, 2γ	80, (40*25)	9	43
1μ, 2μ	19, 7	29	72
1τ, 2τ	86, 59	4	76
Jet * MissE_T	180 * 123	5	81
1-jet, 3-jet, 4-jet	657, 247, 113	9	89
e * jet	19 * 52	1	90
Inclusive b-jets	237	5	95
Calibration/ other		10	105

B-Physics is missing ....

- Bandwith for B-physics @ LHC start-up will depend on:
- Luminosity
  - ✓ Lower luminosity → larger bandwith
- Background conditions
  - ✓ The safety factor of 3 might be pessimistic → lower thresholds, add trigger types, exploit the full B.W.
- In addition a possible strategy is to introduce B-triggers as the luminosity drops during the fill (2 drops expected)

Conclusions

- LHC huge $b\bar{b}$ statistics will allow first observations (e.g. $B_s \to \mu^- \mu^+$) and very accurate studies (e.g. determination of $\Delta\Gamma_s$ from $B_s \to J/\psi\varphi$)

- Although CMS design is not B-physics specific, it can support a competitive B-physics program

- Fast Tracking is a key point in B-decay selection at High Level Triggers as demonstrated for few benchmark channels in the DAQ TDR

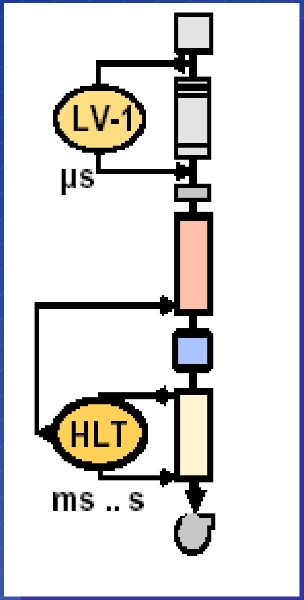
- LHC operating conditions, especially at start-up are critical: Low luminosity for a while ⇒ lots of B physics

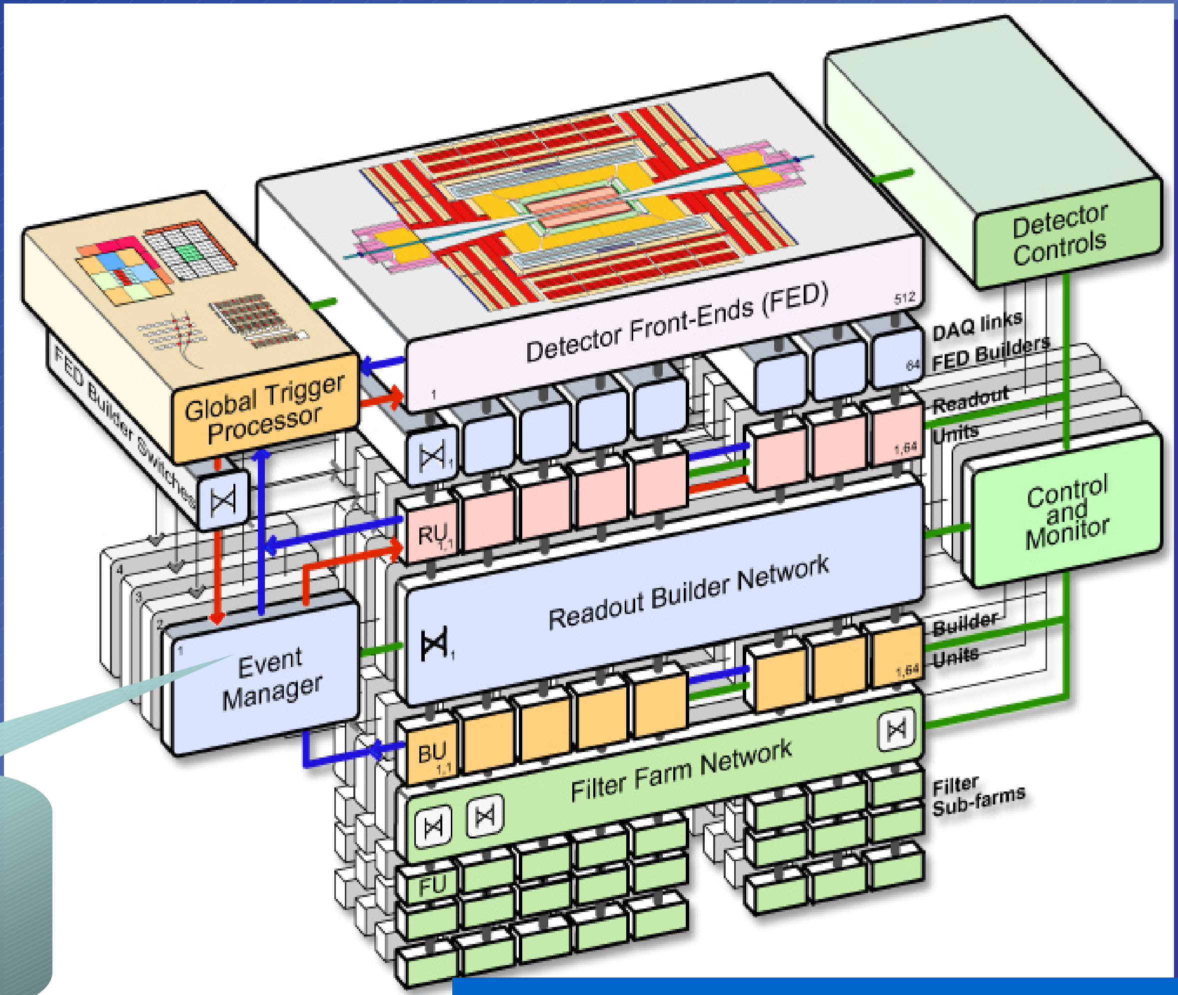
- The Physics TDR, due in the next few years, will address in more details the CMS B-physics potential, turning the attention from the HLT selection to detailed offline analysis

Backup material

Trigger & DAQ architecture

Two level trigger: Lvl-1 and High Level Triggers





40 MHz

100 KHz
(50 KHz)

100 Hz

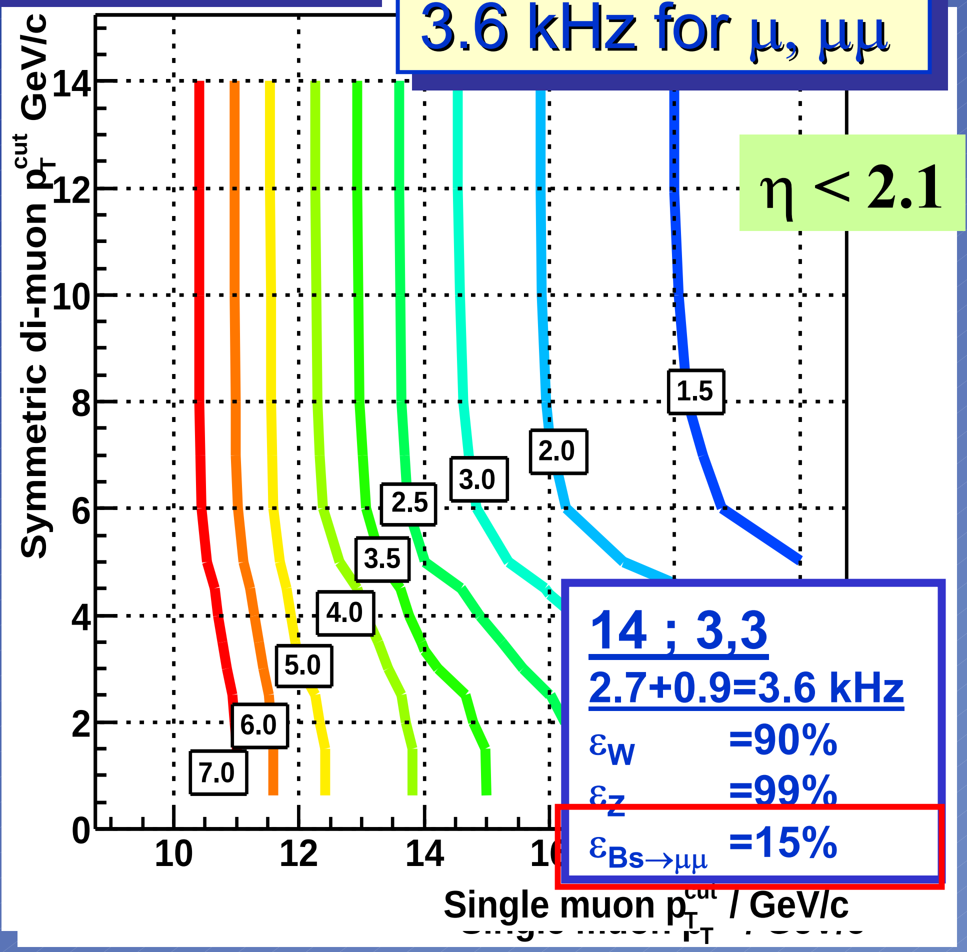
Several staging scenarios possible. Each slice allows 12.5 KHz

4 DAQ slices at start-up => 50 KHZ

Lvl-1 Trigger: Muon Stream

Low Luminosity

16 kHz DAQ
3.6 kHz for μ, μμ



$\eta < 2.1$

14 ; 3,3
2.7+0.9=3.6 kHz

ε_W =90%
ε_Z =99%
$\varepsilon_{Bs\to\mu\mu}$ =15%