Search for the decay $B_s^0 \rightarrow \mu^+\mu^-$ at CMS

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Flavour in the Era of LHC
CERN
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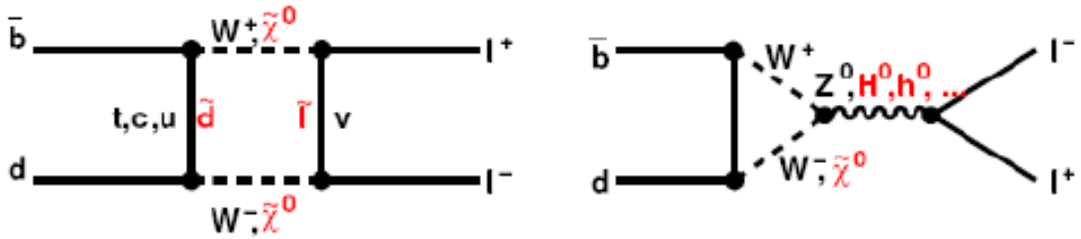
Introduction: The Decays $B^0 \to l^+l^-$

- FCNC forbidden at first order → higher orders

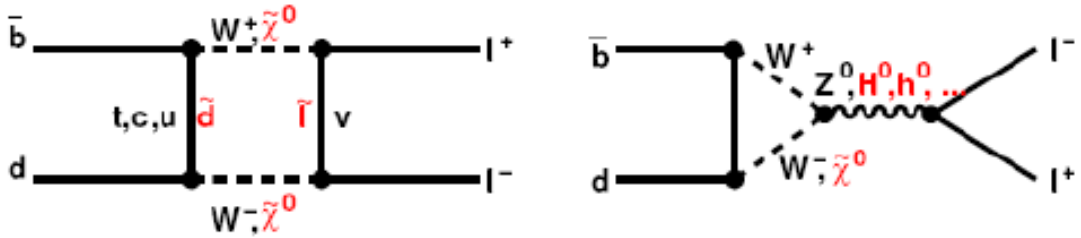


- Helicity suppression: width proportional to m_l^2
- B_d^0: suppression $(|V_{td}| / |V_{ts}|)^2$

Decay	SM prediction	Upper Limit	Exp.
$B_d^0 \to e^+e^-$	$2.4 \cdot 10^{-15}$	$8.3 \cdot 10^{-8}$	Babar
$B_s^0 \to e^+e^-$	$8.0 \cdot 10^{-14}$	$5.4 \cdot 10^{-5}$	CDF
$B_d^0 \to \mu^+\mu^-$	$1.0 \cdot 10^{-10}$	$3.9 \cdot 10^{-8}$	CDF + D0
$B_s^0 \to \mu^+\mu^-$	$3.5 \cdot 10^{-9}$	$1.5 \cdot 10^{-7}$	CDF + D0
$B_d^0 \to \tau^+\tau^-$	$3.1 \cdot 10^{-8}$	1.5%	Aleph
$B_s^0 \to \tau^+\tau^-$	$7.4 \cdot 10^{-7}$	5.0%	Aleph

Introduction: The Decays $B^0 \to l^+l^-$

- Contributions from non-Standard Model processes can be important:
  - Contributions of new diagrams
  - Contributions of new particles in existing diagrams:
    - Charged Higgs
    - SUSY particles
    - Fourth generation quarks



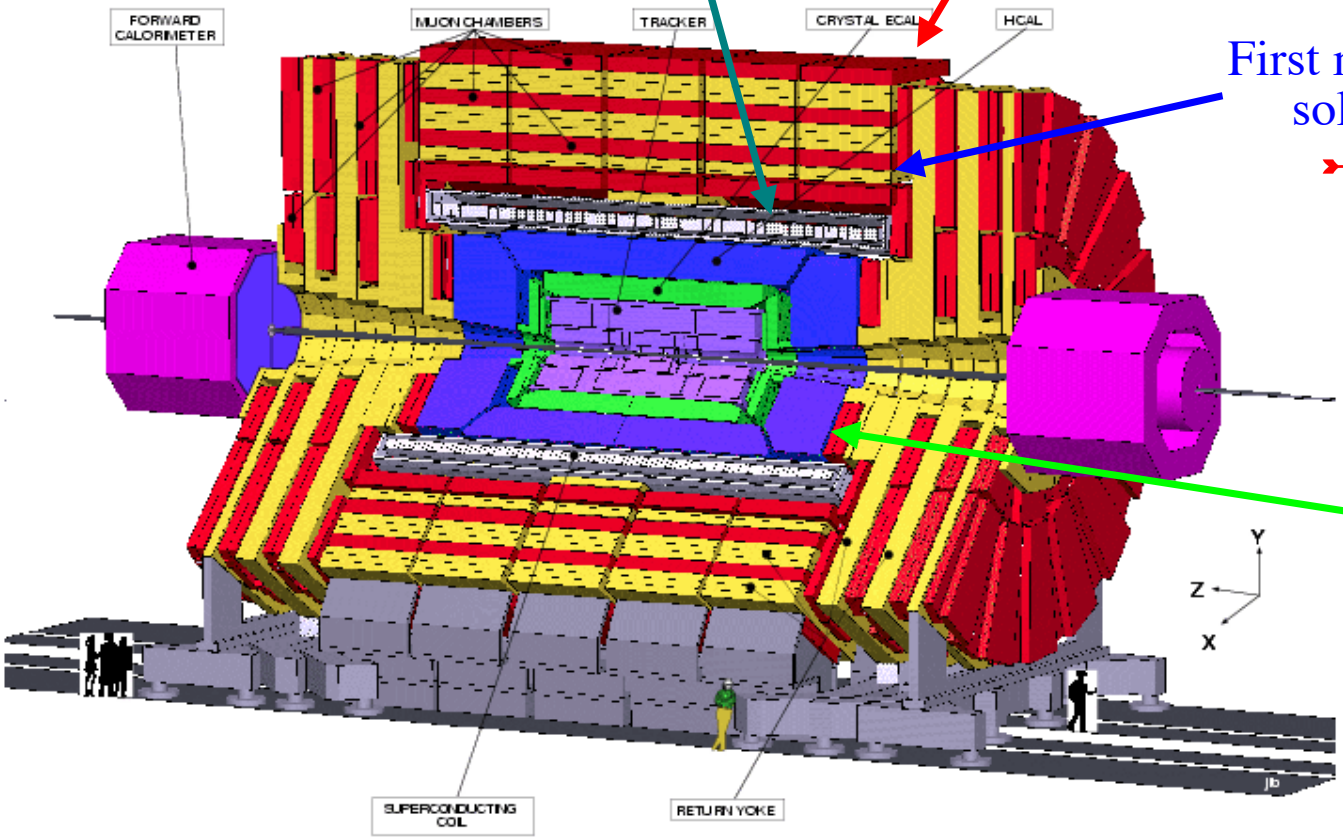
  - SUSY models: as high as $\mathrm{Br}(B_s^0 \to \mu^+\mu^-) \sim 10^{-6}$
  - Models with FCNC at first order:
    - $\mathrm{B}(B_d^0 \to l^+l^-) \sim \mathrm{Br(SM)} \times 20$
    - $\mathrm{B}(B_d^0 \to l^+l^-) \sim \mathrm{B(SM)} \times (300 - 400)$
  - Models with several Higgs doublets: $\mathrm{B}(B_d^0 \to l^+l^-) \sim \mathrm{B(SM)} \times 10$
  - B_d^0 suppression w.r.t. B_s^0 not the case in non-MFV models

The CMS Experiment

13x6 m Solenoid: 4 Tesla Field

↣ Tracking up to η ~ **2.5**

Muon system in return yoke



First muon chamber just after solenoid

↣ extend lever arm for p_T measurement

ECAL & HCAL inside solenoid

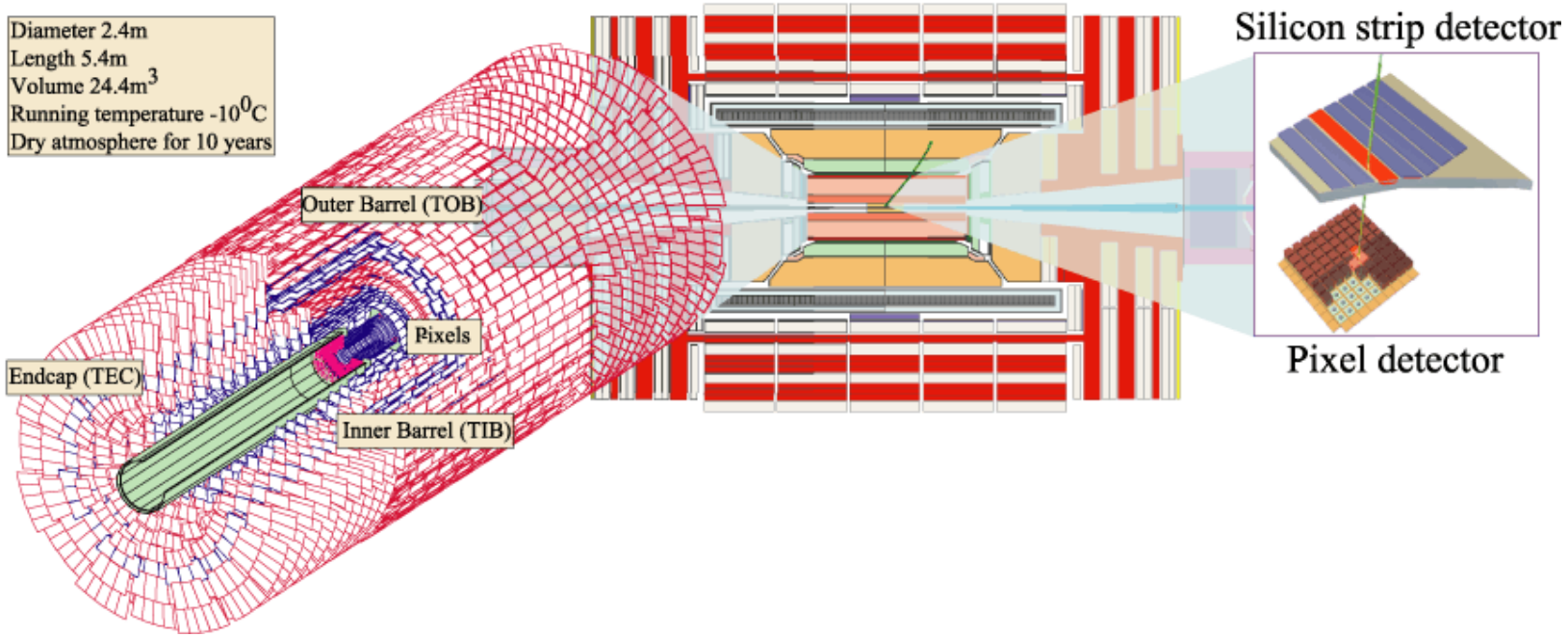
↣ 22m Long, 15m Diameter, 14'000 Ton Detector

The CMS Tracker

➳ CMS has chosen an all-silicon configuration

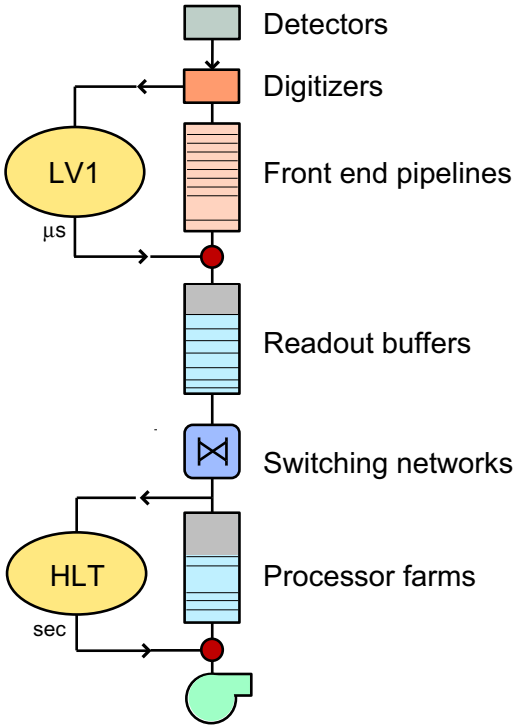
Rely on "few" measurement layers, each able to provide robust (clean) and precise coordinate determination:

- Pixel detector: 2 - 3 points
- Silicon Strip Tracker: 10 - 14 points



Trigger and DAQ

- Two level trigger architecture:
  - ➢ Level 1 trigger based on muon & calorimeters (40 MHz → ~100 kHz)
  - ➢ High Level trigger using similar reconstruction algorithms as offline (100 kHz → ~100 Hz)



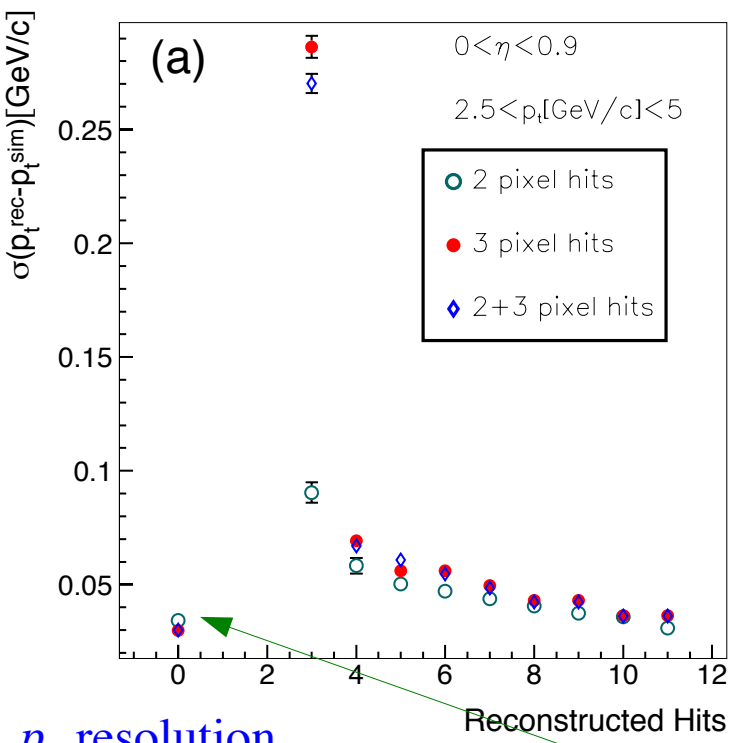
- Triggers for B-physics:
  - ➢ Level 1: Single-muon or dimuon trigger:
    - ➢ Single muon: $p_T > 14$ GeV/c
    - ➢ Dimuon: $p_T > 3$ GeV/c
  - ➢ HLT:
    - ➢ Inclusive b, c trigger: ~ 5 Hz (L1: high E_T jet)
    - ➢ Exclusive B decays:Partial reconstruction of decay products in the tracker in Region of Interest around the muons

Partial reconstruction

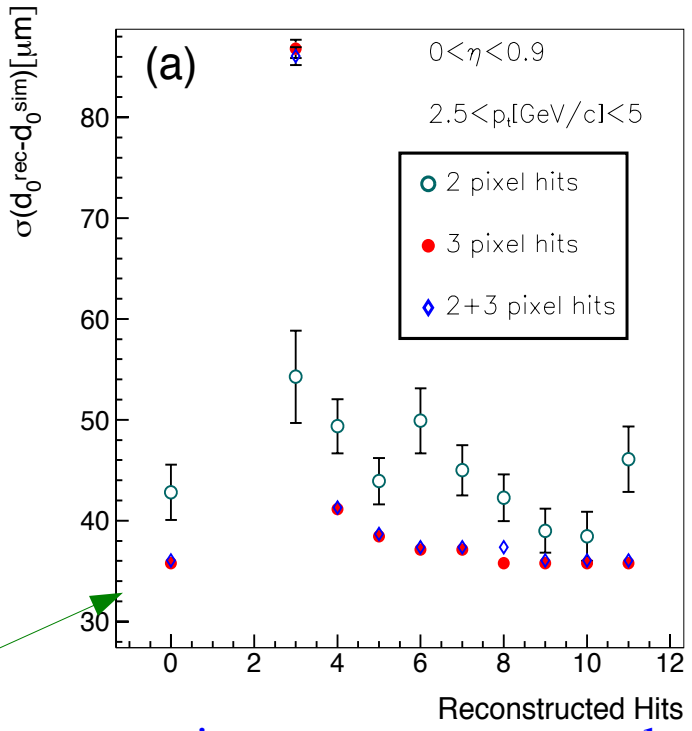
Partial reconstruction: stop track reconstruction once enough information is available to answer a specific question

➸ Track parameter resolutions reach an asymptotic value after using only first 5/6 hits

Resolutions as a function of the number of hits used: (b-jets, $2.5<p_T<5$, $|\eta|<0.9$)



p_T resolution



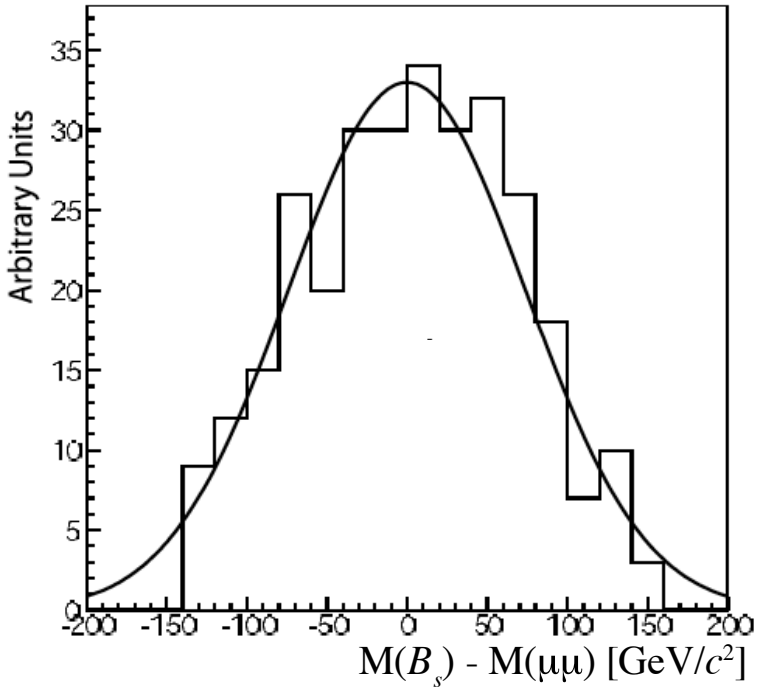
Transverse impact parameter resolution

("0 hits" indicates full track reconstruction!)

High-Level Trigger selection

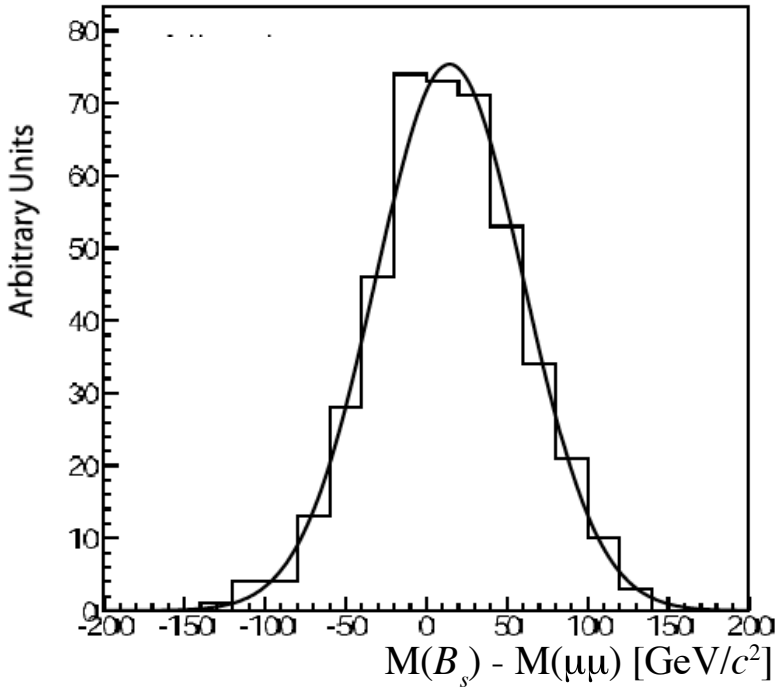
- Primary Vertex Reconstruction using only the pixel detector
  - ➢ Use 3 most probable PV found
- Regional, partial track reconstruction in cones around L1 muon candidates
  - ➢ Partial reconstruction up to 6 hits maximum
  - ➢ $p_T^{\mu} > 4$ GeV/c
  - ➢ $\sigma(p_T^{\mu})/p_T^{\mu} < 2\%$
- Track pairs with opposite charge: $|M(\mu\mu) - M(B_s)| < 150$ MeV/c^2
- Vertex Fit of track pairs:
  - ➢ $\chi^2<20$
  - ➢ Transverse decay length > 150 μm

High-Level Trigger selection



B_s mass residual,using 6 hits

σ = 74 MeV



B_s mass residual, using the full tracker

σ = 45.8 MeV

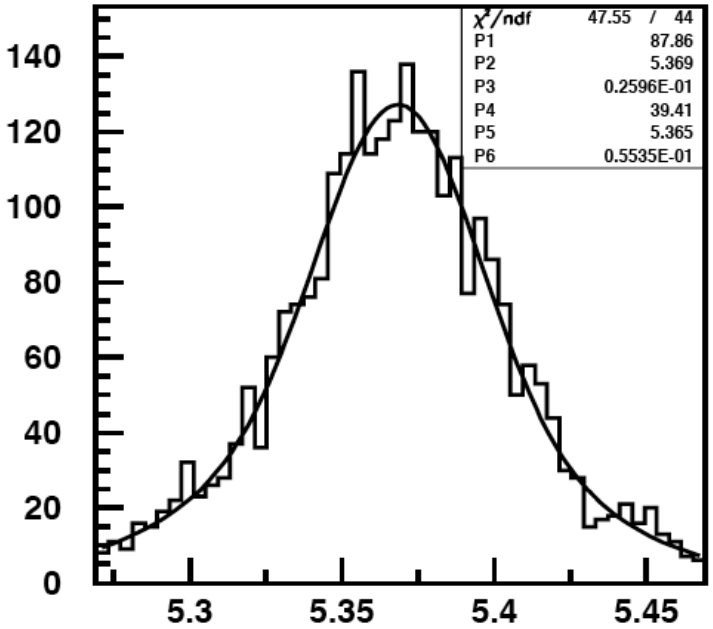
- Efficiency: 5.1% (w.r.t to decays with p_T (μ) > 2 GeV/c, |η|< 2.4)
  - ➢ Level 1 efficiency: 15.2 %
  - ➢ HLT efficiency: 33.5 %
- Events/10fb^{-1}: 47
- HLT accept rate: < 1.7 Hz

Offline selection study

- Signal and background events generated with
  - $p_T(\mu) > 4.3$ GeV/c , $|\eta| < 2.4$
  - $p_T(\mu\mu) > 12$ GeV/c
  - $0.4 < \Delta R(\mu\mu) < 1.2$
- Full simulation of the detector at low luminosity ($\sim 10^{33}$ cm^{-2}s^{-1})
- No HLT simulation, assumed to be fully efficient with these cuts at low-luminosity
- Background: QCD 2 or 3-jet processes with $b\bar{b} \rightarrow \mu^+\mu^-$
  - Main contribution to background: gluon splitting
  - Events simulated for offline study: 10'000 events (after cuts)
- Events assumed to pass HLT, kinematic cuts
  - Signal: 66 events /10fb^{-1}
  - Background: $2.9 \cdot 10^7$ events /10fb^{-1}
- Extrapolation for high luminosity ($\sim 10^{34}$ cm^{-2}s^{-1}): no detector simulation

The offline selection

- Track reconstruction: Combinatorial KF, with $p_T > 0.9$ GeV/c
- Track pairs with opposite charge: $|M(\mu\mu) - M(B_s)| < 40$ MeV/c^2



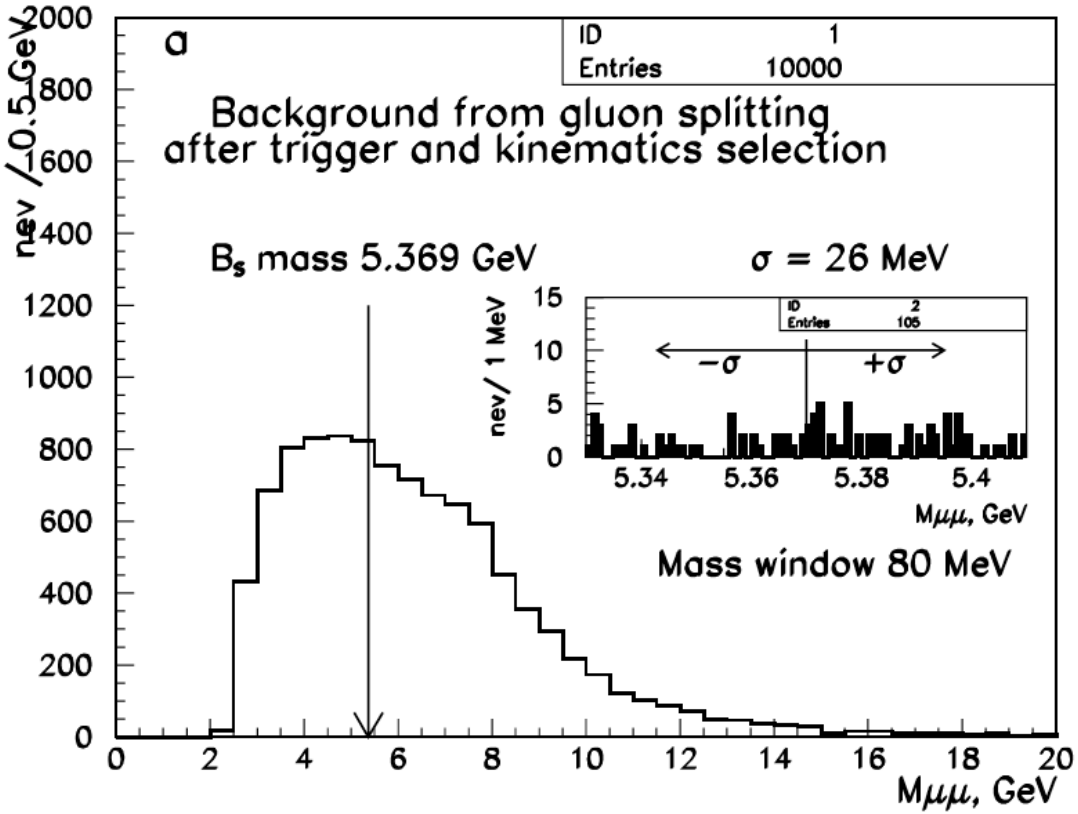
Reconstructed B_s mass(signal) [GeV/c^2]

Mean = 5.369 GeV

σ(core) = 26 MeV

σ(tail) = 55 MeV

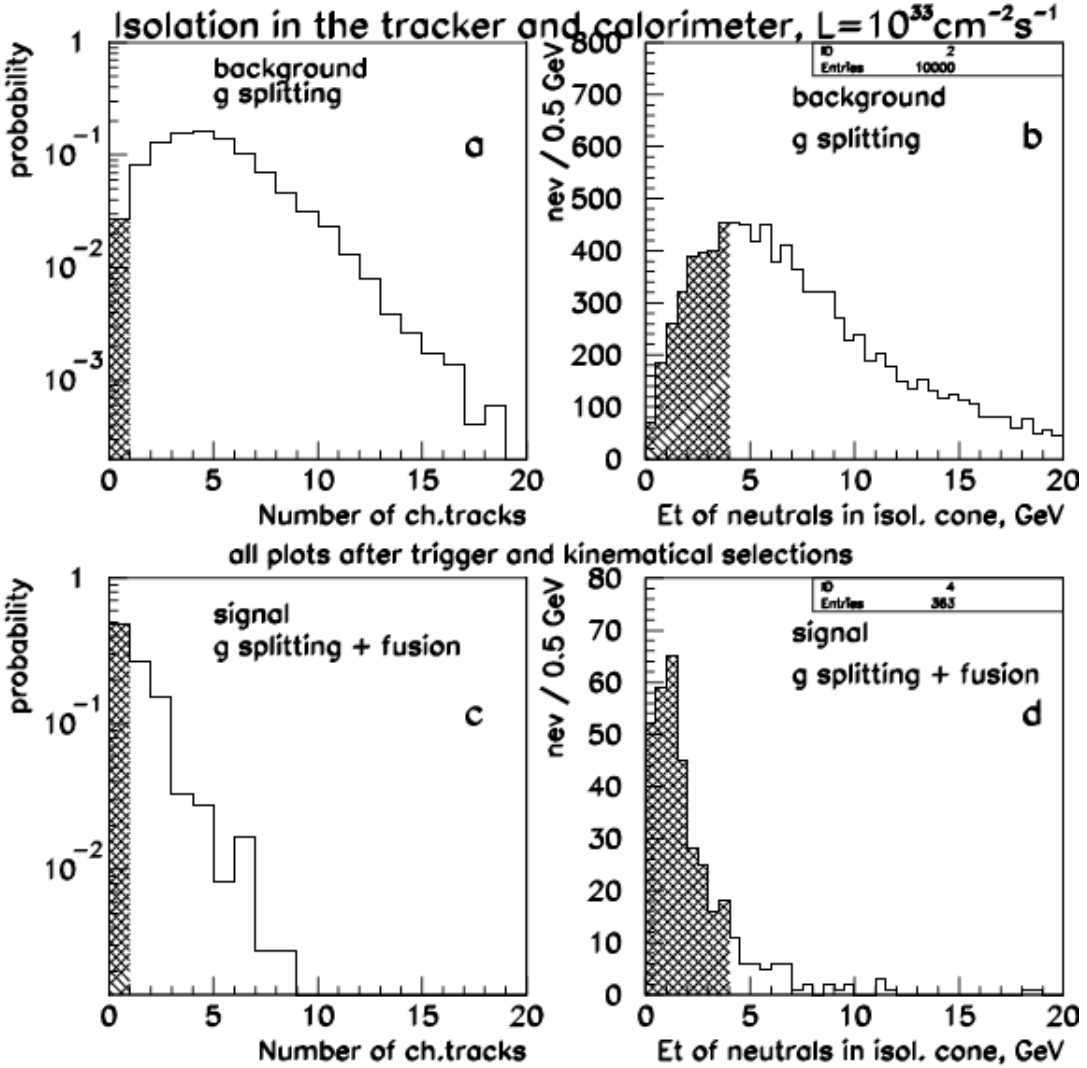
Efficiency: 72 %



Background: Dimuon invariant mass [GeV/c^2]

The offline selection

- Tracker Isolation:
  - ➢ No charged track in cone of $\Delta R < 0.5 \cdot \Delta R(\mu\mu) + 0.4$ around reconstructed dimuon momentum
- Calorimeter isolation (EM+HAD, same ΔR):
  - ➢ Et < 4 GeV (low lumi)
  - ➢ Et < 6 GeV (high lumi)
- Efficiency:
  - ➢ Signal: 0.46 (low lumi)
    0.31 (high lumi)
  - ➢ Bckgr.: $1.3 \cdot 10^{-2}$ (low lumi)
    $0.87 \cdot 10^{-2}$ (high lumi)



The offline selection

- Vertex Fit of dimuon pairs:
  - ➢ Minimal distance between muon tracks: $d < 50$ μm
  - ➢ Significance on min. dist. : $d/\sigma(d) < 2$
  - ➢ Transverse decay length significance : $L_{xy}/\sigma(L_{xy}) > 12$ (15 at high lumi)
  - ➢ Uncertainty on Transverse decay length : $\sigma(L_{xy}) < 80$ μm
  - ➢ Cosine of angle (momentum/decay length) > 0.9
- Efficiency:
  - ➢ Signal: 0.32 (low lumi)
    0.18 (high lumi)
  - ➢ Background : $< 2.3 \cdot 10^{-4}$ (no event remaining)

The offline selection

Events after all offline requirements:

- Low luminosity 10 fb^{-1} ~1 year at 10^{33} $cm^{-2}s^{-1}$
  - ➢ Signal: 7.0
  - ➢ Background: < 1.0
- High luminosity 100 fb^{-1} ~1 year at 10^{34} $cm^{-2}s^{-1}$
  - ➢ Signal: 26.0
  - ➢ Background: < 6.4
- 4σ observation should be possible with 30 fb^{-1} (3 years low-lumi)
- 6.3σ observation should be possible with 130 fb^{-1} (3 years low-L +1 high-L)
- A new study is now undertaken to study full selection, HLT & Offline

Conclusion

- CMS well suited for *B* physics
  - ➢ Large *b* production cross section
  - ➢ High luminosity (even at the initial "*low luminosity*"!)
- Powerful Muon system, used also for Level-1 Trigger
- Robust and versatile tracker and track reconstruction algorithms
  - ➢ Good performance at HLT
- CMS capable of observing decay $B_s^0 \rightarrow \mu^+\mu^-$ (even with SM branching ration!)
  - ➢ New physics?
  - ➢ Constraints on models beyond SM
- Selection of rare decay should also be possible at high luminosity
- Can expect high yield of other rare decays $B_s^0 \rightarrow \mu^+\mu^-\phi$, $B \rightarrow \mu^+\mu^- K$, $B \rightarrow \mu^+\mu^- K^*$