The $B_s \to J/\Psi\Phi \to \mu\mu KK$ channel with CMS

Th.Speer, K.Prokofiev
Physik-Institut Universität Zürich, Switzerland

V.Ciulli, N.Magini,
Dipartimento di Fisica, Università degli Studi di Firenze, Italy

T.Ilicheva[1,2], S.Shulga[1,2]
[1]*LPP JINR Dubna, Russia*
[2]*Gomel State University, Belarus*

- Outline
  - The $B_s \to J/\Psi\Phi$ decay channel
  - Extraction of physical observables
  - Introduction to CMS detector at LHC
  - High Level Trigger Selection
  - Offline Selection and Analysis
  - Results

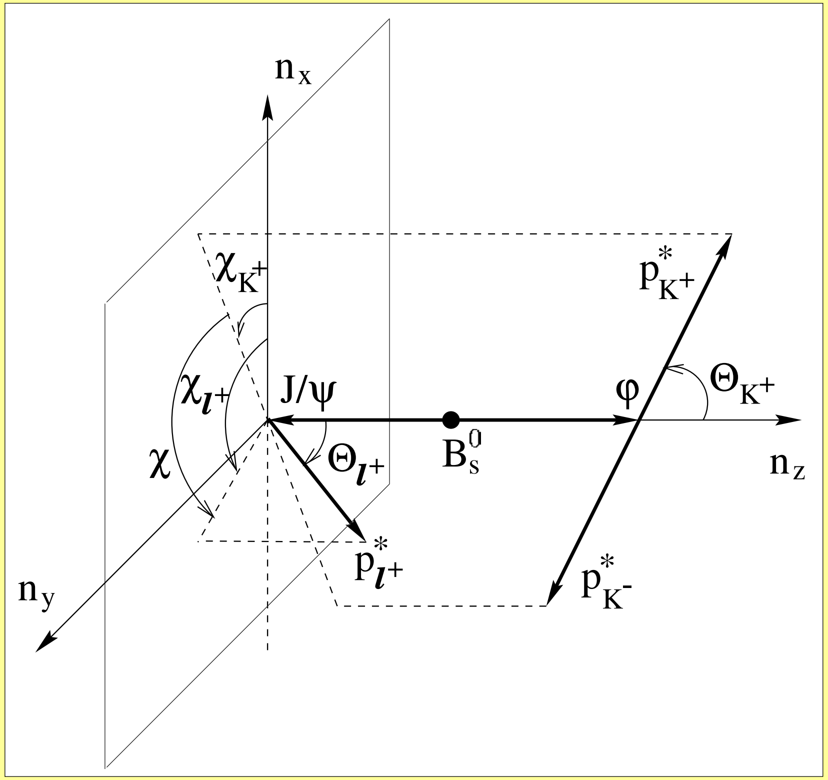
Beauty 2005, Assisi (Perugia), Italy, June 20-24, 2005

The $B_s \to J/\Psi\Phi \to \mu\mu KK$ decay channel (1)

- The $B_s \to J/\Psi\Phi \to \mu\mu KK$ decay
  - A "gold-plated" mode to extract the CP-violating weak phase $\phi_s \sim -2\lambda^2\eta$ (λ and η are Wolfenstein parameters)
  - Allows a measurement of parameters of the particle-antiparticle mixing in the B^0_s system:
    - Difference of widths of "heavy" and "light" mass eigenstates $\Delta\Gamma_s = \Gamma_H - \Gamma_L$
    - Difference of masses of "heavy" and "light" mass eigenstates Δm_s
    - Average width of mass eigenstates: $\bar{\Gamma} = \frac{\Gamma_H + \Gamma_L}{2}$
- Extraction of physical observables
  - Flavour-untagged sample:
    - Extraction of Γ_H and Γ_L is possible from the proper lifetime distribution using Max Likelihood method
    - Extraction of η, $\Delta\Gamma$, $\bar{\Gamma}$ is possible from the angular distributions of final state components using method of weight functions or Max. Likelihood method.
  - Flavour-tagged sample (same as for untagged sample +...):
    - Extraction of Δm_s is possible from angular distributions
    - Extraction of η is also possible from the time-dependent asymmetry of decay rates.

Extraction of physical observables (1)

- Angular analysis
  - The final state of the $B_s \to J/\Psi\Phi$ decay is an admixture of CP eigenstates.
  - The J/ψ and ϕ are massive neutral vector mesons ($J^{PC}=1^{--}$). Their zero-angular-momentum spectrum consists of states with orbital angular momentum L=0,1,2 (even, odd, even)
  - The decay amplitude can be decomposed into independent components, corresponding to linear polarizations of the final state vector mesons.
  - The angular dependencies of different of CP-odd and CP-even components are different and can be separated through the angular analysis
  - The angular distributions of the final state can be described with 3 angles
    - For example in the so-called helicity frame: Θ_{l+}, Θ_{K+}, χ:



Extraction of physical observables (2)

- In general, the angular distributions can be expressed in the following form:

$$f_0(\Theta_l,\Theta_K,\chi,t)=\frac{d^4\Gamma}{d\cos\Theta_l\, d\cos\Theta_K\, d\chi\, dt}\sim\sum_{i=1}^{6} b_i(t)\, g_i(\Theta_l,\Theta_K,\chi)$$

- $g_i(\Theta_l,\Theta_K,\chi)$ Are the angular distributions, depending on the kinematics of the final state

- $b_i(t)$ are the time evolutions of physical observables (bilinear combinations of transversity amplitudes, corresponding to the linear polarizations of the final state): $|A_0(t)|^2$, $|A_\perp(t)|^2$, $|A_\parallel(t)|^2$, $\mathrm{Re}(A_0^*(t)A_\parallel(t))$, $\mathrm{Im}(A_\parallel^*(t)A_\perp(t))$, $\mathrm{Im}(A_0^*(t)A_\perp(t))$.
  - Include ϕ_s, Γ_L , Γ_H , Δm_s, two strong CP-conserving phases etc.

$$\begin{aligned}
|A_0(t)|^2 &= |A_0(0)|^2\left[e^{-\Gamma_L t}-e^{-\bar{\Gamma} t}\sin(\Delta mt)\delta\phi\right]\\
|A_\parallel(t)|^2 &= |A_\parallel(0)|^2\left[e^{-\Gamma_L t}-e^{-\bar{\Gamma} t}\sin(\Delta mt)\delta\phi\right]\\
|A_\perp(t)|^2 &= |A_\perp(0)|^2\left[e^{-\Gamma_H t}+e^{-\bar{\Gamma} t}\sin(\Delta mt)\delta\phi\right]\\
\Re(A_0^*(t)A_\parallel(t)) &= |A_0(0)||A_\parallel(0)|\cos(\delta_2-\delta_1)\left[e^{-\Gamma_L t}-e^{-\bar{\Gamma} t}\sin(\Delta mt)\delta\phi\right]\\
\Im(A_\parallel^*(t)A_\perp(t)) &= |A_\parallel(0)||A_\perp(0)|\left[e^{-\bar{\Gamma} t}\sin(\delta_1-\Delta mt)+\frac{1}{2}(e^{-\Gamma_H t}-e^{-\Gamma_L t})\cos(\delta_1)\delta\phi\right]\\
\Im(A_0^*(t)A_\perp(t)) &= |A_0(0)||A_\perp(0)|\left[e^{-\bar{\Gamma} t}\sin(\delta_2-\Delta mt)+\frac{1}{2}(e^{-\Gamma_H t}-e^{-\Gamma_L t})\cos(\delta_2)\delta\phi\right]
\end{aligned}$$

Extraction of physical observables (3)

- Extraction of observables
  - Likelihood fit of the angular distributions of the final state
  - Method of weight functions:
    - Finding a set of functions $w_i(\Theta_l, \Theta_K, \chi)$ such that:

$$\int d\cos\Theta_l \, d\cos\Theta_K \, d\chi \, w_i(\Theta_l, \Theta_K, \chi) \, g_j(\Theta_l, \Theta_K, \chi) \sim \delta_{ij}$$

    - Projecting out the physical observables:

$$b_i(t) = \int d\cos\Theta_l \, d\cos\Theta_K \, d\chi \, f_0(\Theta_l, \Theta_K, \chi, t) \, w_i(\Theta_l, \Theta_K, \chi)$$

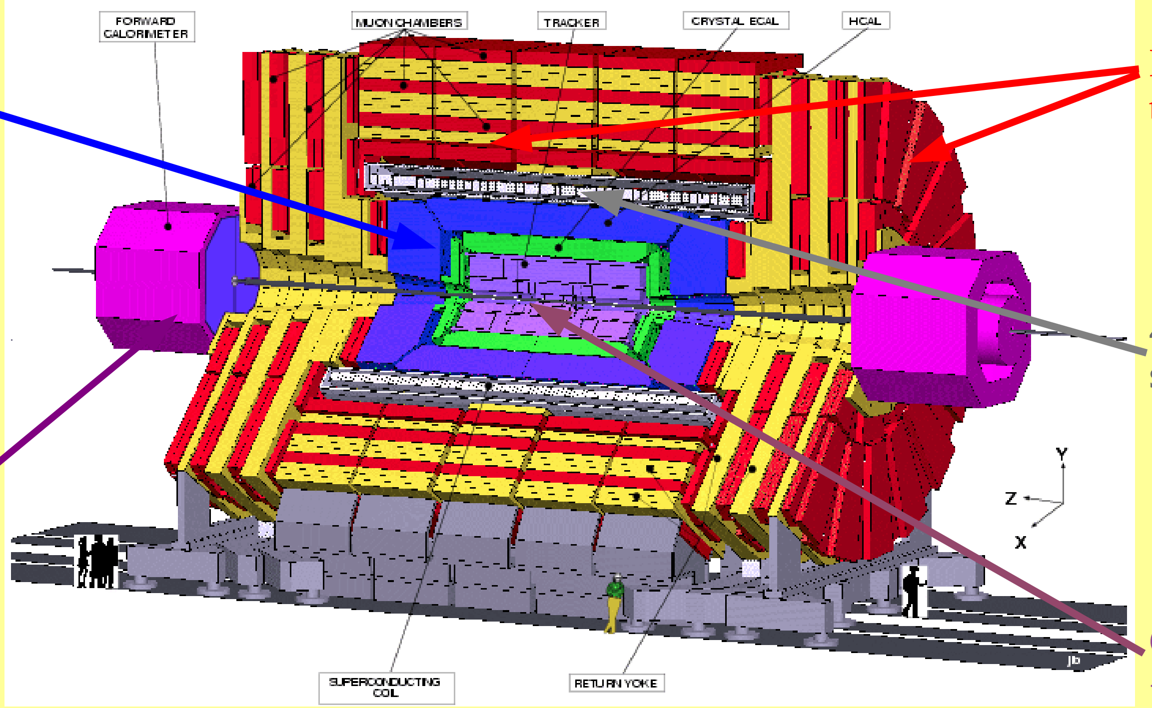
CMS Detector at LHC (1)

- LHC environment
  - 14 Tev pp collisions
  - 40 Mhz bunch crossing (every 25 ns)

- Design luminosity
  - Low luminosity run (first several years) L= $2 \cdot 10^{33}$ $cm^{-2}s^{-1}$ (~10 fb^{-1} per year)
    - ~3.5 Pile-Up events per bunch crossing
  - High luminosity run L= 10^{34} $cm^{-2}s^{-1}$ (~100 fb^{-1} per year)
    - ~20 Pile-Up events per bunch crossing

Electromagnetic & Hadron Calorimeters

Very forward calorimeters



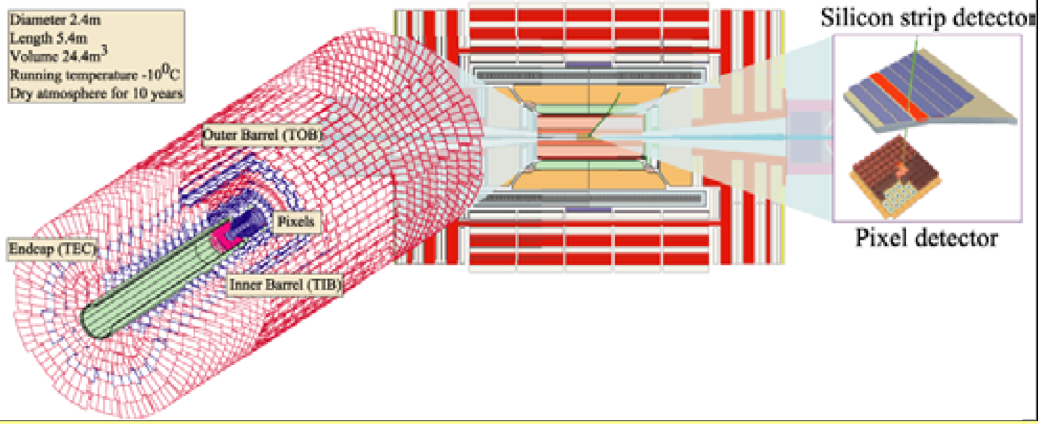
Muon cambers in the return yoke

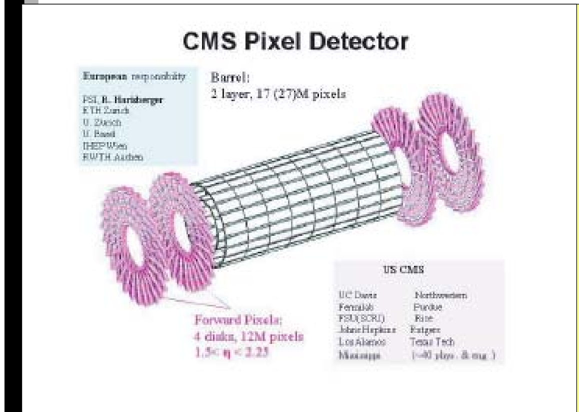
4 Tesla superconducting solenoid

Central tracker (Si pixel + Si strip detector)

CMS Detector at LHC (2)

- Central tracker
  - " All Silicon" Pixel+Microstrip detector
- For each reconstructed track:
  - 2-3 pixel hits + 10-14 SST hits





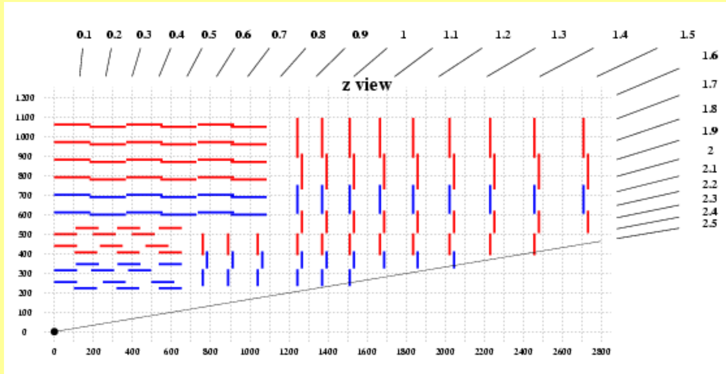
Pixel Detector: 3 barrel layers at radii of 4.4, 7.3, 10.2 cm; 2 pairs of endcap disks at z=34.5, 46.5 cm.

Pixel size: 100x150µm; Hit Resolution in r ~10µm, in r-z ~20µm;

Pseudorapidity coverage: |η|<2.2 (3 hits in the entire coverage assumed)

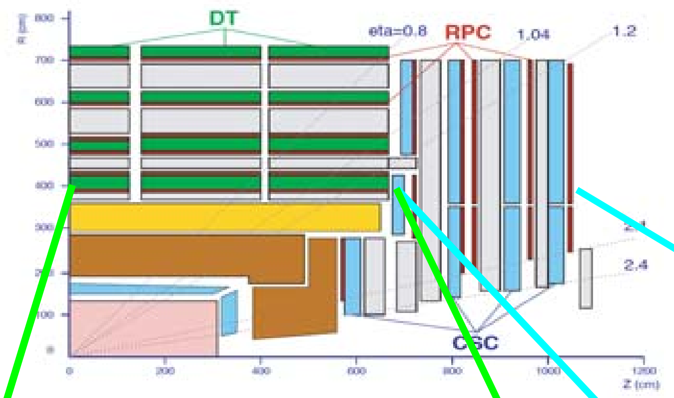
Silicon Strip Tracker: 4 layers inner barrel, 6 layers outer barrel, 3 inner and 9 outer pairs of endcap discs. Pseudorapidity coverage |η|<2.5

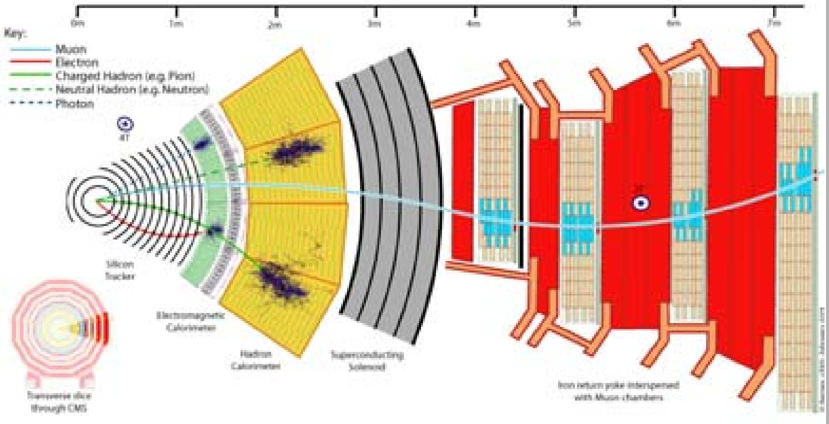
Red: single side detectors; Blue: double side detectors



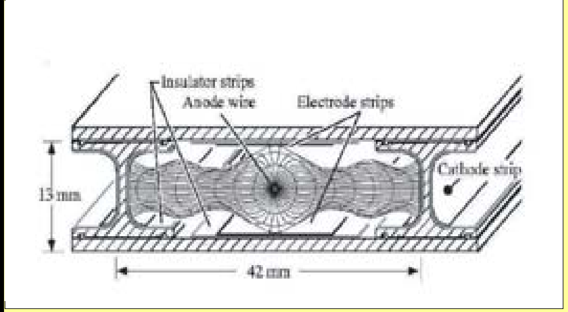
CMS Detector at LHC (3)

3 detector technologies used: DT, CSC, RPC

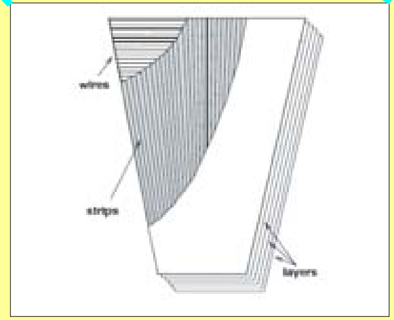




Drift tubes

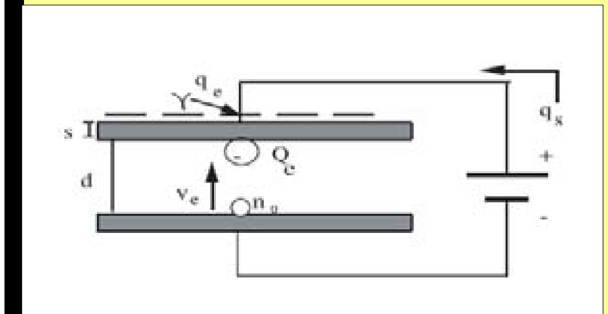


Cathode strip chambers



In the barrel region the drift tube chambers are used. Spatial resolution: $\sigma_{R\varphi}$~100µm per cell.

In the endcaps the Cathode Strip Chambers are used. Spatial resolution: $\sigma_{R\varphi}$~100-240µm per strip measurement



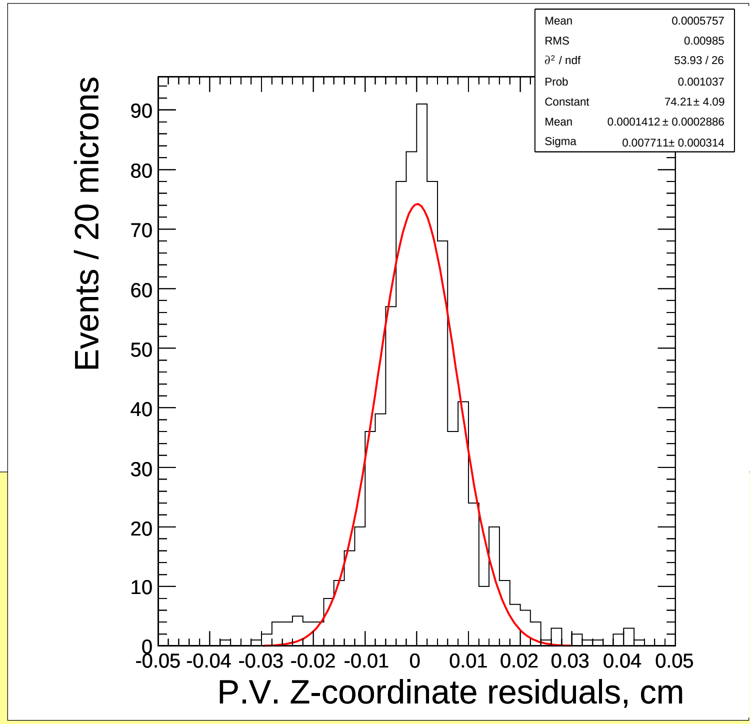
Resistive Plate chambers are used for the L1 muon trigger (σ_T~1ns). Muons are reconstructed using a pattern comparator logic; the parameters (p_t,η,φ) are assigned via look up tables

The High Level Trigger Selection (1)

- Based on the Level 1 dimuon trigger:
  - Hardware-based trigger (combined partial DT, CSC, RPC information is used)
  - Returning up to 4 best muon candidates per pileUp event.
  - The P_t, η, ϕ of the candidate are assigned through the Look-Up Table mechanism, only muon candidates with P_t>3GeV are reconstructed
  - Opposite charge muon pairs are selected for further analysis

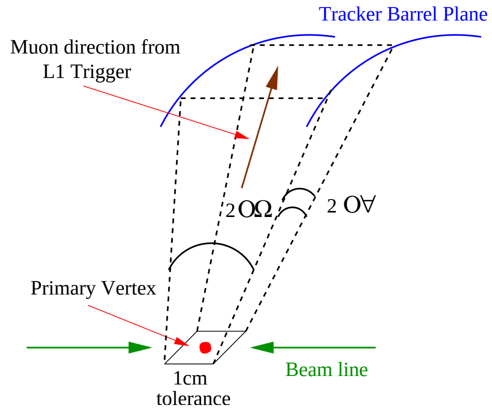
The High Level Trigger Selection (2)

- HLT Level 2
  - Primary vertex reconstruction using pixel detector only.
  - 3 most probable vertex candidates are kept for further analysis.
  - A resolution on the Z-coordinate of the Primary vertex is around 70 µm

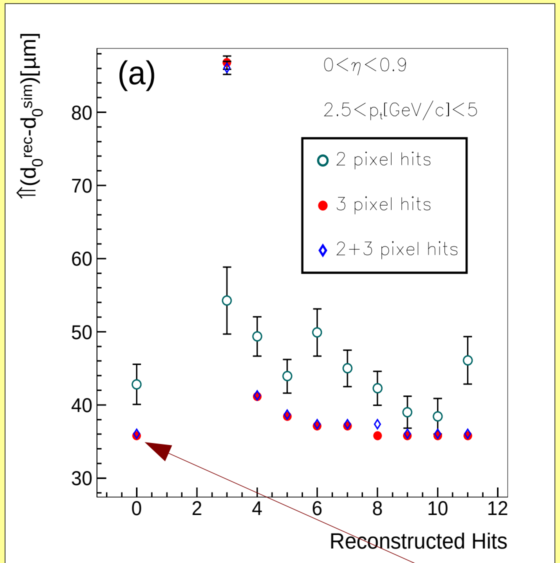


The High Level Trigger Selection (3)

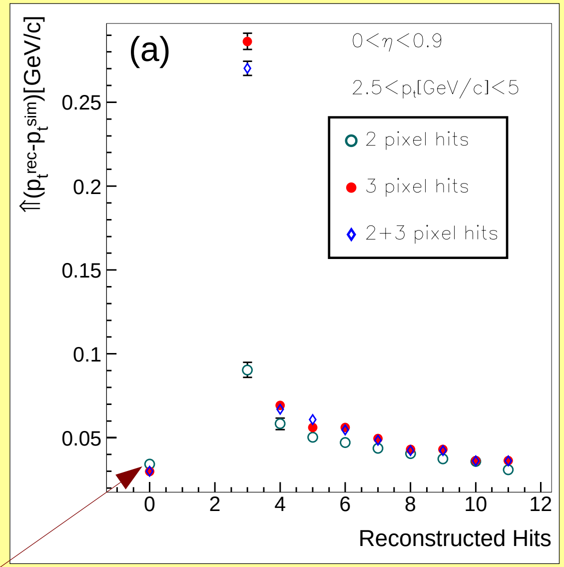
- Regional track reconstruction in rectangular (η, Φ) region:
  - The region is centered in the Primary Vertex
  - Direction is defined by the momentum of Level 1 muon candidate
  - Partial track reconstruction (up to 6 hits) with pixel and inner layers of tracker.



- Tracker resolution as function of number of hits used in reconstruction



Transverse IP resolution

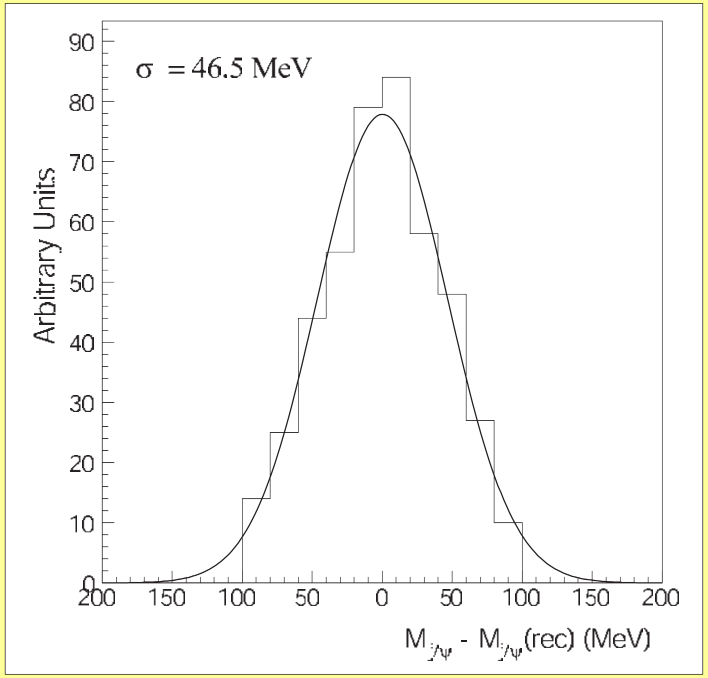


Transverse momentum resolution

0 hits indicates full track reconstruction

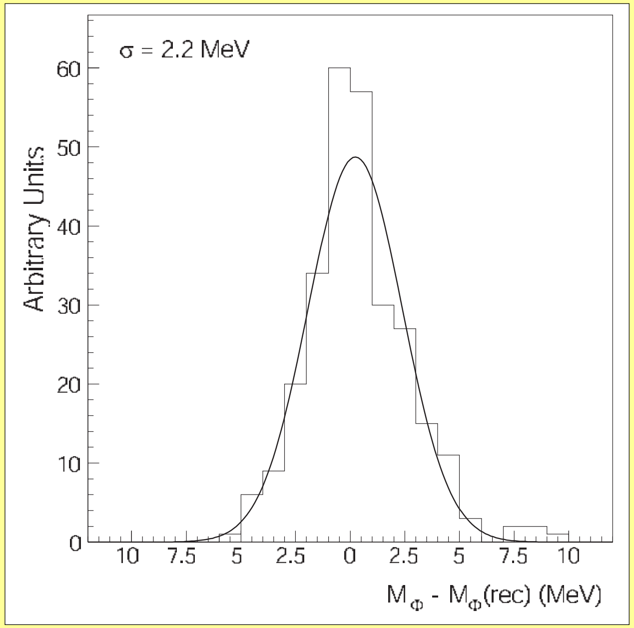
The High Level Trigger Selection (4)

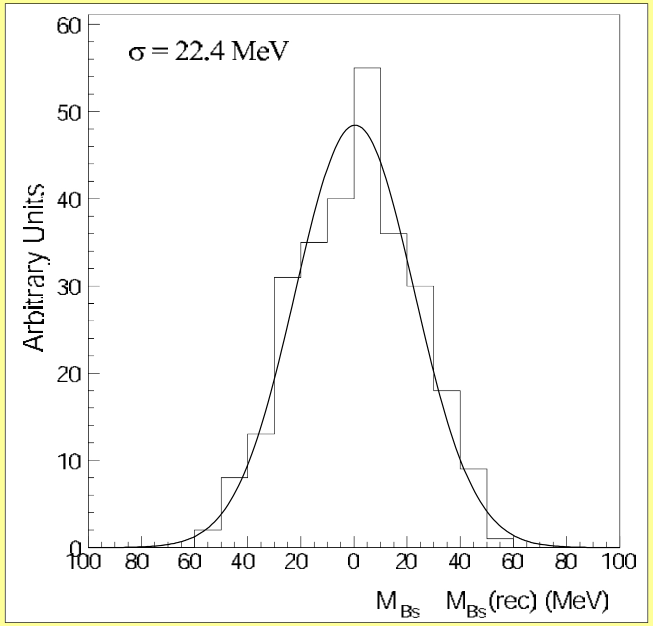
- Suppression of combinatorial background
  - Vertex reconstruction, candidates with $\chi^2<10$ are selected
  - Transverse decay length significance cut $L_T/\sigma_T > 3$
- Muon mass is assigned to the candidate tracks, an invariant mass of J/Ψ is reconstructed
- Candidates with $|\Delta M(J/\Psi)|<100$MeV, $P_t(\mu) > 2.0$GeV are selected
  - Correct μμ combinations



The High Level Trigger Selection (5)

- HLT Level 3: The $B_s \to J/\Psi\Phi \to \mu\mu KK$ reconstruction
  - Partial track reconstruction (Pixel + inner tracker layers) in the narrow cone around J/Ψ direction
  - Suppression of combinatorial background
    - Reconstruction of 4-track secondary vertex candidate
    - Candidates with $\chi^2<10$ are selected
    - Transverse decay length
- The kaon mass is assigned to the tracks, masses of Φ candidates are calculated
  - Opposite charge pairs with $|\Delta M(\Phi)|<10$ MeV are selected
- Candidates with $|\Delta M(B_s)|<60$ MeV are selected



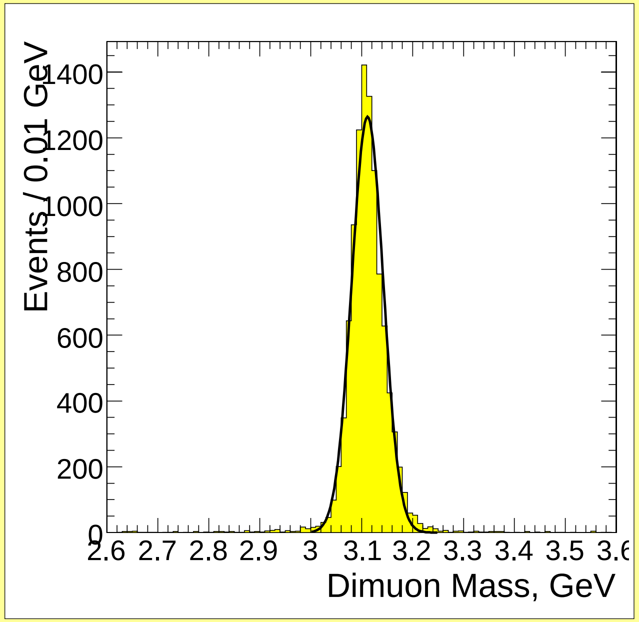


The High Level Trigger Selection (6)

- Overall signal efficiency after L3 is 8.7%
- Generator level kinematic cuts:
  - Signal muons $P_t > 2.0$GeV
  - Hadrons $P_t > 0.5$ GeV
- Expected cross section $97 \cdot 10^3$ fb
- A yield of some ~83'800 events is expected with 10 fb^{-1} (one year of the low luminosity run L $= 2 \cdot 10^{33}$ $cm^{-2}s^{-1}$)
- Level 3 background rate are <1.7 Hz

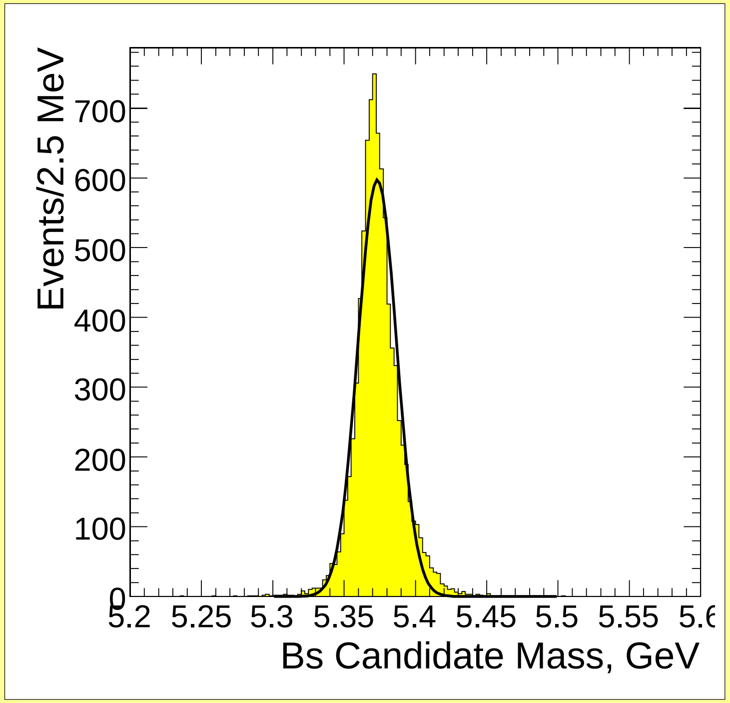
Offline Selection (1)

- Based on muon reconstruction using combined information Tracker+Muon chambers
- Two reconstruction strategies are available:
  - L3 Muon reconstructor Uses the L1 hardware trigger to produce muon seeds, combines the information from muon chambers with the tracker response
  - Global Muon Reconstructor Uses “internal” seeds: look for hit multiplets in muon chambers (Flexible P_t threshold), combines the information from muon chambers with the tracker response
- A combination of two strategies with cleaning (50% of shared hits):
- Combinatorial J/Ψ reconstruction:
  - Muons with P_t>2Gev are selected.
  - Opposite charge muon pairs are created, their invariant mass is calculated



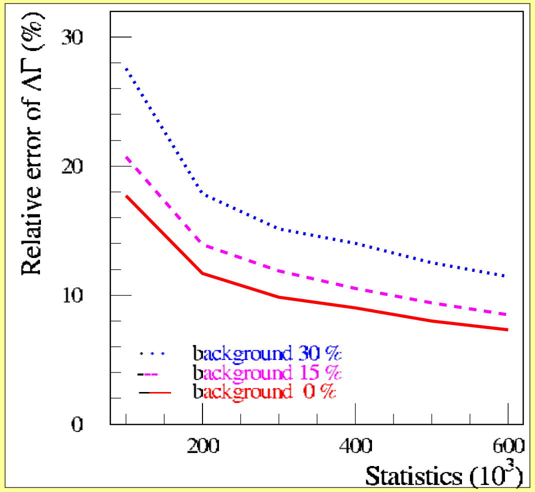
Offline Selection (2)

- Φ candidates selection
- All tracks, having the angular difference to J/Ψ direction of $\Delta R = \sqrt{\Delta\eta + \Delta\Phi} < 2$ at their transverse impact point state are fully reconstructed with tracker.
- The kaon mass is assigned, invariant mass of all the opposite charge pairs is calculated.
- Tracks with P_t>0.5 GeV are selected for analysis
- Candidates with |ΔM(Φ)|<12 MeV are selected
- Kinematic fitting and B^0_s reconstruction
  - For every candidate the joint 4-track vertex is fitted, the dimuon mass is constrained to be equal to the mass of the J/Ψ meson. The χ^2 probability of the fit is calculated
  - The χ^2 probability threshold of $5\cdot10^{-4}$ is applied
  - B_s candidates with $|\Delta M(B_s)|$<67 MeV are selected

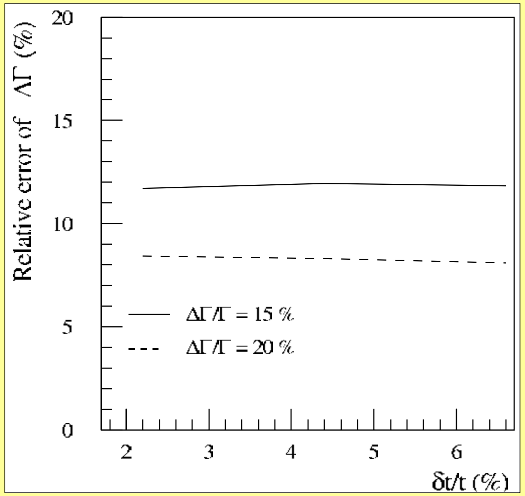


Offline Selection (4)

- Combined HLT+offline efficiency is ~5%
- A yield of some ~145'000 events is expected with 30 fb^{-1}
  (two to three years of the low luminosity run L $=2\cdot10^{33}\ cm^{-2}s^{-1}$)
- The background is <10%, dominated by:
  - $B_d \rightarrow J/\Psi K^*$, $b \rightarrow J/\Psi X$
- Expectations with time-dependent angular analysis (Max. Likelihood method):
- Expected relative error on $\Delta\Gamma$ as a function of accumulated statistics



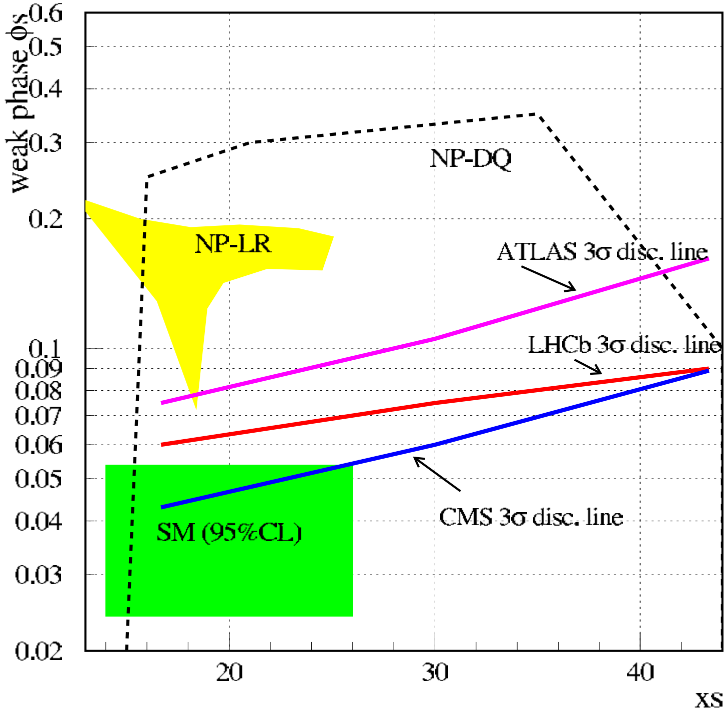
Expected relative error on $\Delta\Gamma$ as a function of relative error on proper lifetime



- CMS expects a relative uncertainty on $\Delta\Gamma$~16 % for $\Delta\Gamma/\Gamma = 0.15$

Sensitivity to CP-violation effects

- Allowed regions for the CP-violating weak phase ϕ_s as a function of $x_s = \frac{\Delta m_s}{\bar{\Gamma}_s}$



- An expected statistical uncertainty for ϕ_s is ~0.028 for x_s = 20.
- The result is obtained with the angular analysis using Max. Likelihood fit

Conclusion

- High level trigger, offline selection and analysis strategies for the $B_s \to J/\Psi\Phi \to \mu\mu KK$ decay channel were developed in CMS
- CMS expects to select several hundreds of thousands of $B_s \to J/\Psi\Phi \to \mu\mu KK$ events during first years of the LHC run.
- The background level is expected to be <10%
- An relative uncertainty on $\Delta\Gamma$ is expected to be ~16%
- The statistical error on the CP-violating weak phase ϕ_s is expected to be ~0.028 for $x_s = 20$