# Measurement of $\Delta\Gamma_s$ in $B^0_s \rightarrow J/\psi\ \phi$ with CMS


Nicolò Magini


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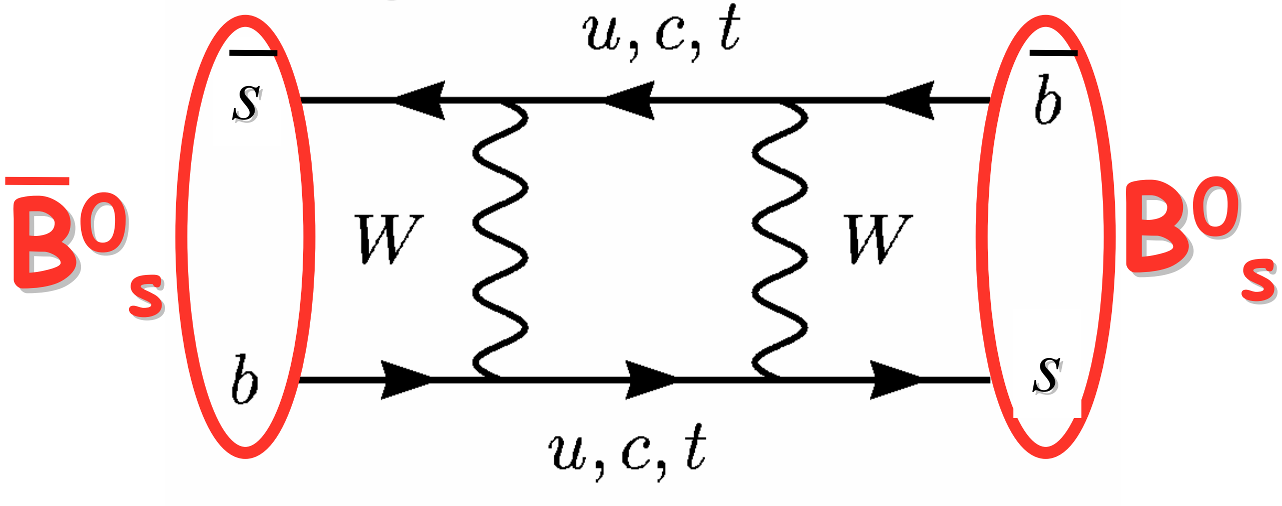
# Outline

- The $B^0_s \rightarrow J/\psi\ \phi$ decay
- Trigger selection
- Offline selection
- Angular analysis with the method of moments

# $B^0_s$ oscillations




$B_s$ are too heavy to be produced at *B factories*
→studied at hadron colliders

Standard Model predictions

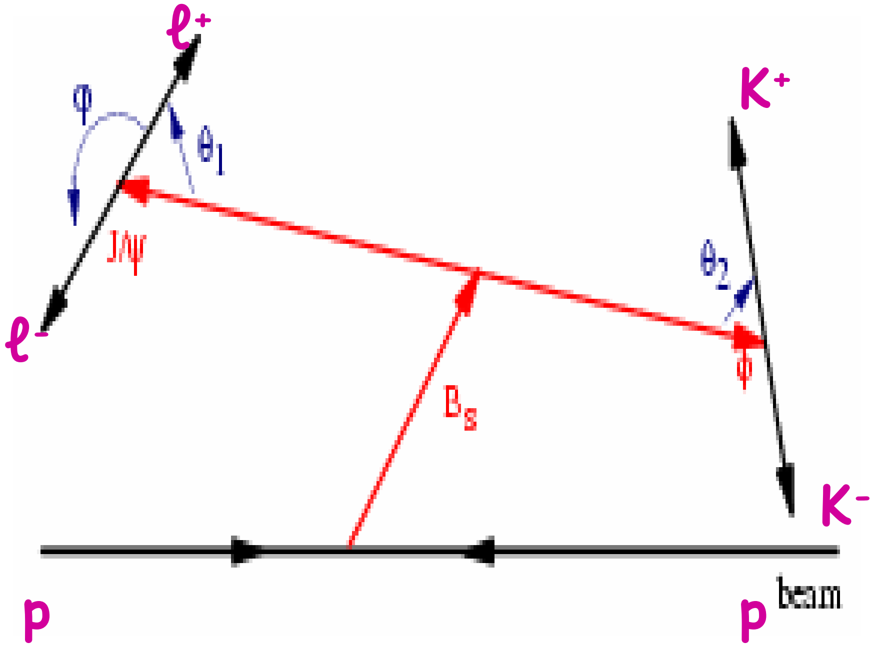
$\Delta m_S < 22.2 \times 10^{12}\ s^{-1}$ @ 95% CL , $\Delta\Gamma_s/\Gamma_s \sim 0.09$

PDG Experimental limits @ 95% CL

$\Delta m_S > 14.4 \times 10^{12}\ s^{-1}$, $\Delta\Gamma_s/\Gamma_s < 0.54$

Latest result by CDF : $\Delta\Gamma_s/\Gamma_s = (65^{+25}_{-33} \pm 1)\%$

# $B_s \to J/\psi\ \phi \to \mu^+\mu^- K^+K^-$

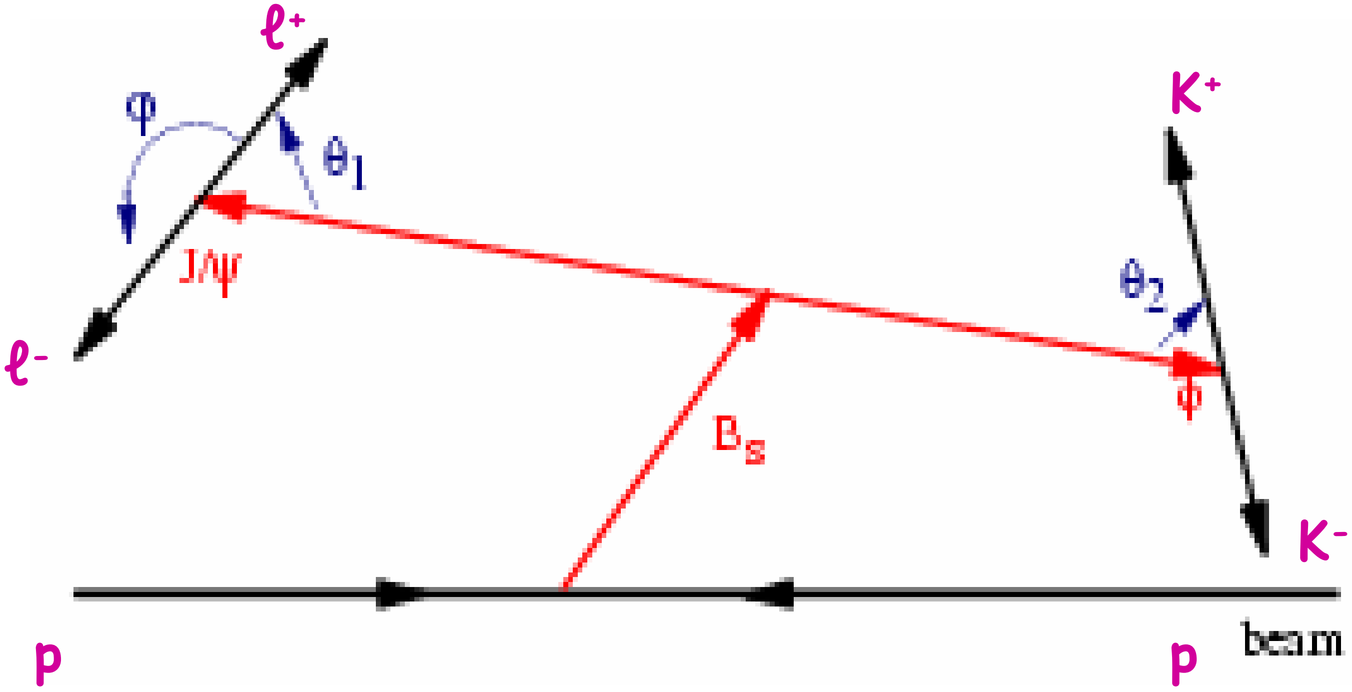



$BR(B_s \to J/\psi\ \phi) = (9.3 \pm 3.3) \times 10^{-4}$
$J/\psi \to \mu^+\mu^-$ (BR≈6%)
$\phi \to K^+K^-$ (BR≈49%)

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

Angular distributions of decay products depend on $\Gamma_s$, $\Delta\Gamma_s$, $\Delta M_s$ ($B^0_s$ mixing) and $\phi_s$ (CP Violation)

# $B_s \rightarrow J/\psi\ \phi$




$B_s$ decay products are both $J^{PC} = 1^{--}$ states

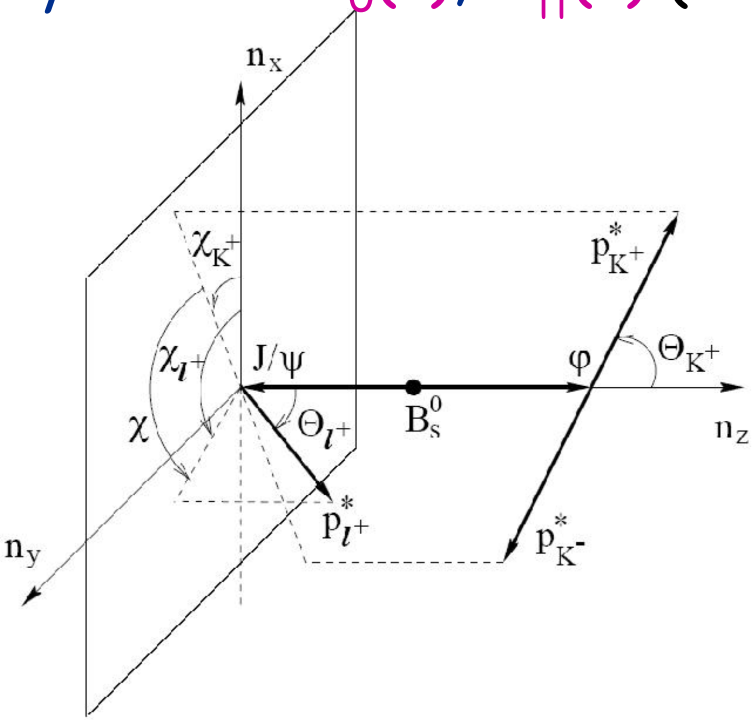
The final state has **CP = +1** if **L = 0,2** and **CP = -1** if **L = 1**

The two contributions with opposite CP can be separated with an *angular analysis* of the final decay products

# Angular distributions

$$W(t,\Omega) = \frac{d^3\Gamma}{d\cos\vartheta_1 d\cos\vartheta_2 d\varphi} = \frac{9}{64\pi}\sum_{i=1}^{6} b_i(t) g_i(\vartheta_1, \vartheta_2, \varphi)$$

Time evolution is a function of the *transversity amplitudes* $A_0(t)$, $A_{||}(t)$ (CP = +1) and $A_{\perp}(t)$ (CP = -1)




Known functions of the three *helicity angles* $\theta_1, \theta_2, \varphi$ describing decay product kinematics

# Angular distributions

$$b_1(t) = \frac{|A_0(0)|^2}{2}[(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_2(t) = \frac{|A_\parallel(0)|^2}{2}[(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_3(t) = \frac{|A_\perp(0)|^2}{2}[(1-\cos\phi_s)e^{-\Gamma_L t} + (1+\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_4(t) = |A_\parallel(0)||A_\perp(0)|\,[\frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_1 \sin\phi_s],$$

$$b_5(t) = \frac{1}{2}|A_0(0)||A_\parallel(0)|\cos(\delta_2-\delta_1)\cdot \\ [(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_6(t) = |A_0(0)||A_\perp(0)|\,[\frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_2 \sin\phi_s].$$

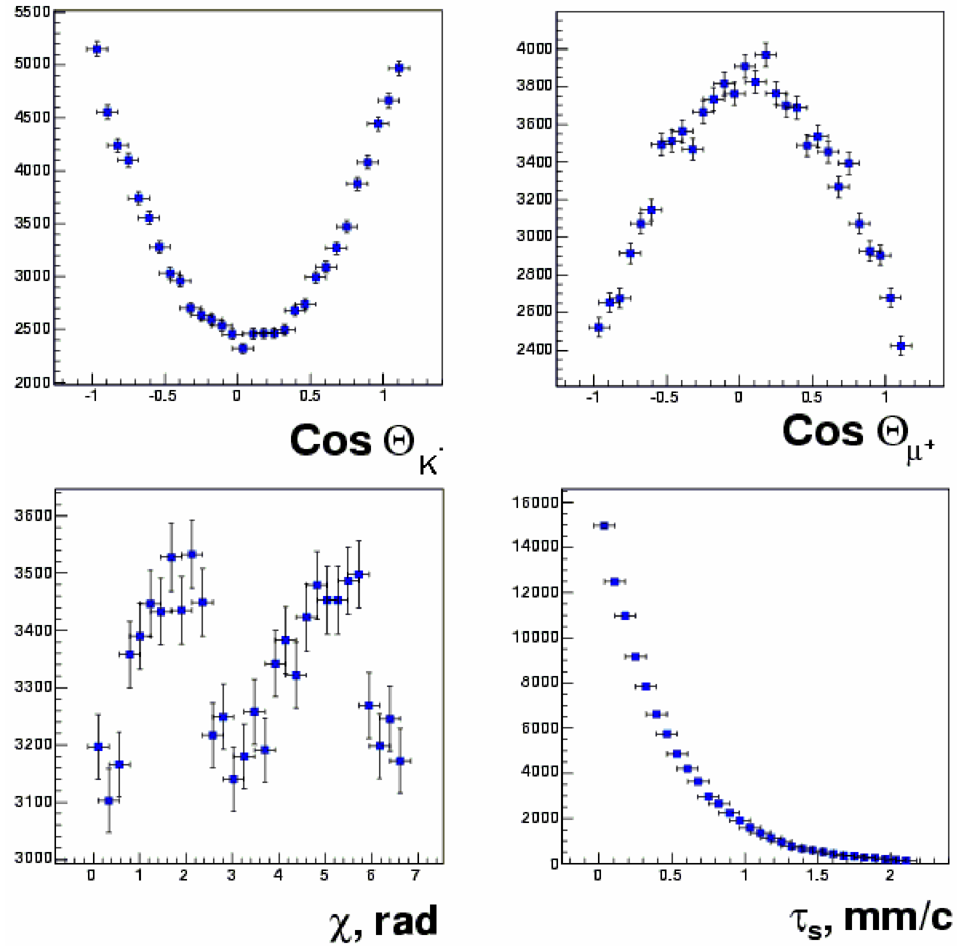
The distributions depend on

8 independent parameters

- Amplitudes $|A_{||}(0)|,|A_\perp(0)|$
- Strong phases $\delta_1$, $\delta_2$
- Width difference $\Delta\Gamma_s = (\Gamma_H - \Gamma_L)$
- Average width $\Gamma_s = (\Gamma_H+\Gamma_L)/2$
- Weak phase $\phi_s$
- *(Mass difference $\Delta M_s = x_s\Gamma_s$)*

# Generator

- Generator used: SIMUB
  - Developed by Dubna CMS group (Bel'kov, Shulga)
  - Needed to reproduce angular distributions of decay products (flat in PYTHIA)



# Main backgrounds

σ at LHC

- Signal $B^0_s \to J/\psi\ \phi \to \mu^+\mu^-\ K^+K^-$ 167 fb
- Exclusive bkg $B^0_d \to J/\psi\ K^* \to \mu^+\mu^-\ K\pi$ 900 fb
- Inclusive backgrounds :
- $b \to J/\psi\ X$ 51.4 nb
- Prompt $pp \to J/\psi\ X$ 310 nb
- In all samples : $p_T\,\mu > 2$ GeV/c
- In signal + $B_d$ bkg : $p_T\,\mu > 0.5$ GeV/c

# Main backgrounds

- Signal $B^0_s \to J/\psi\ \phi \to \mu^+\mu^-\ K^+K^-$ 200k ev
- Exclusive bkg $B^0_d \to J/\psi\ K^* \to \mu^+\mu^-\ K\pi$ 50k ev
  - Generated with SIMUB → full angular distributions

- Inclusive backgrounds :
- $b \to J/\psi\ X$ 200k ev
- Combinatorial $bb \to \mu\mu$ with $M(\mu\mu)$ 2.5-3.5 GeV/$c^2$ 100k ev
  - Generated with PYTHIA → no angular distributions
- Prompt $pp \to J/\psi\ X$ 50k ev
  - Generated with modified PYTHIA tuned on CDF $J/\psi$ production cross sections

- In all samples : $p_T\,\mu > 2$ GeV/c
- In signal + $B_d$ bkg : $p_T\,\mu > 0.5$ GeV/c

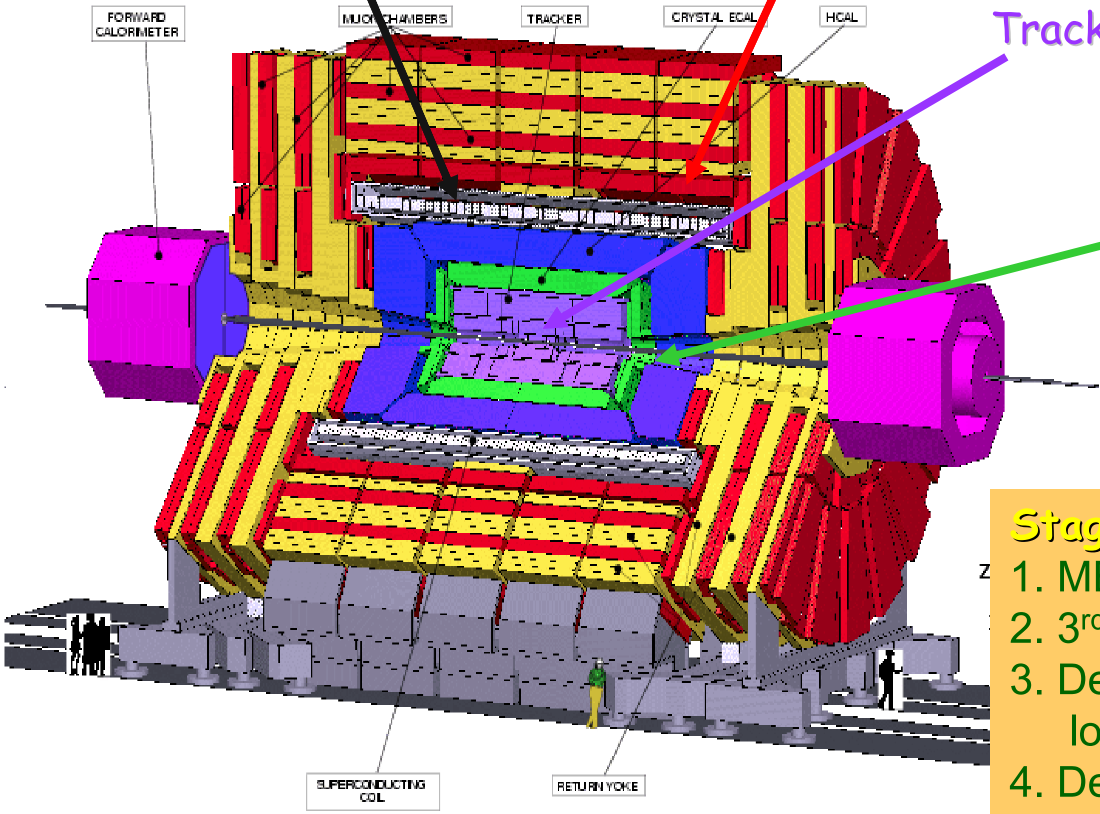
# The CMS detector

4 Tesla Solenoid

Muon system in return yoke

Tracker (Pixel + Silicon Microstrip)
$|\eta| < 2.4$

ECAL & HCAL
inside solenoid



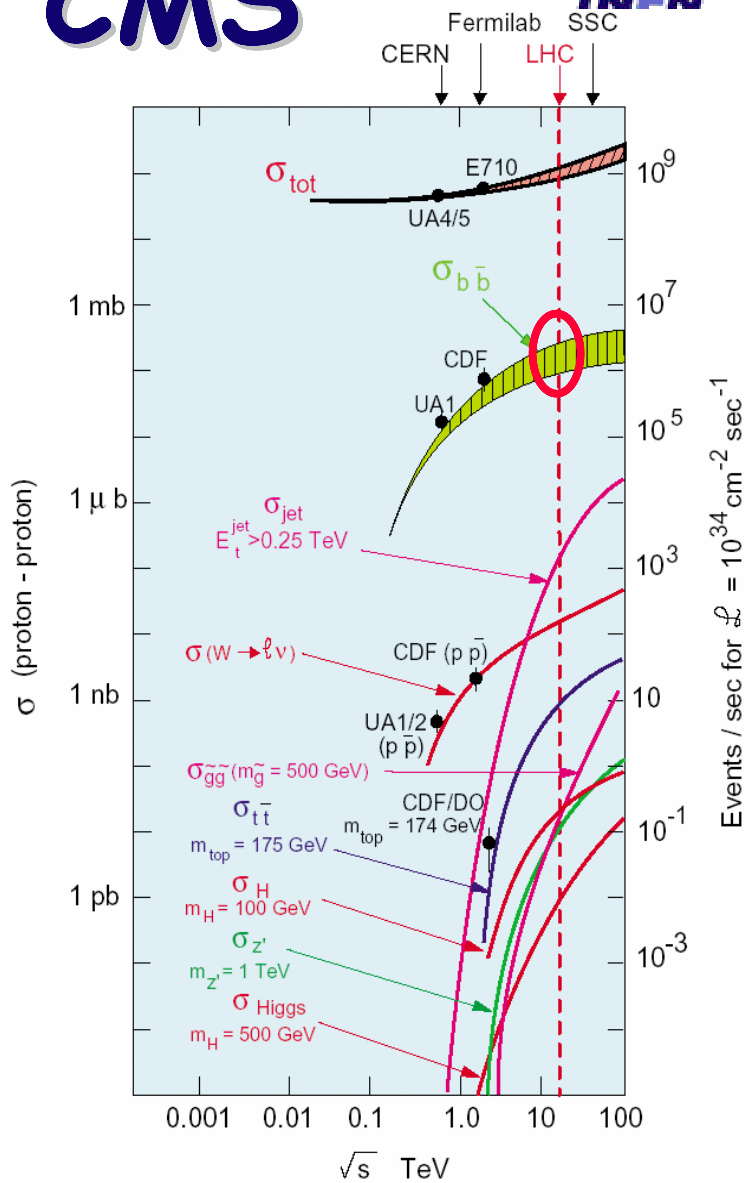

**Staged Scenario for start-up**

1. ME4 staged
2. 3rd forward pixel disks missing
3. Descoped HCAL (reduced no. of longitudinal samplings)
4. Descoped ME1/1a (3 ch in one, muon trigger up to $|\eta| = 2.1$)

22 m long, 15 m diameter,
14.000 ton Detector

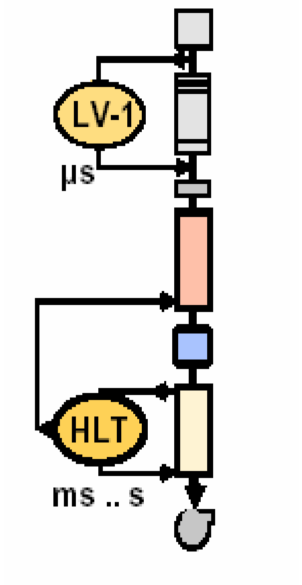
# B Physics at CMS

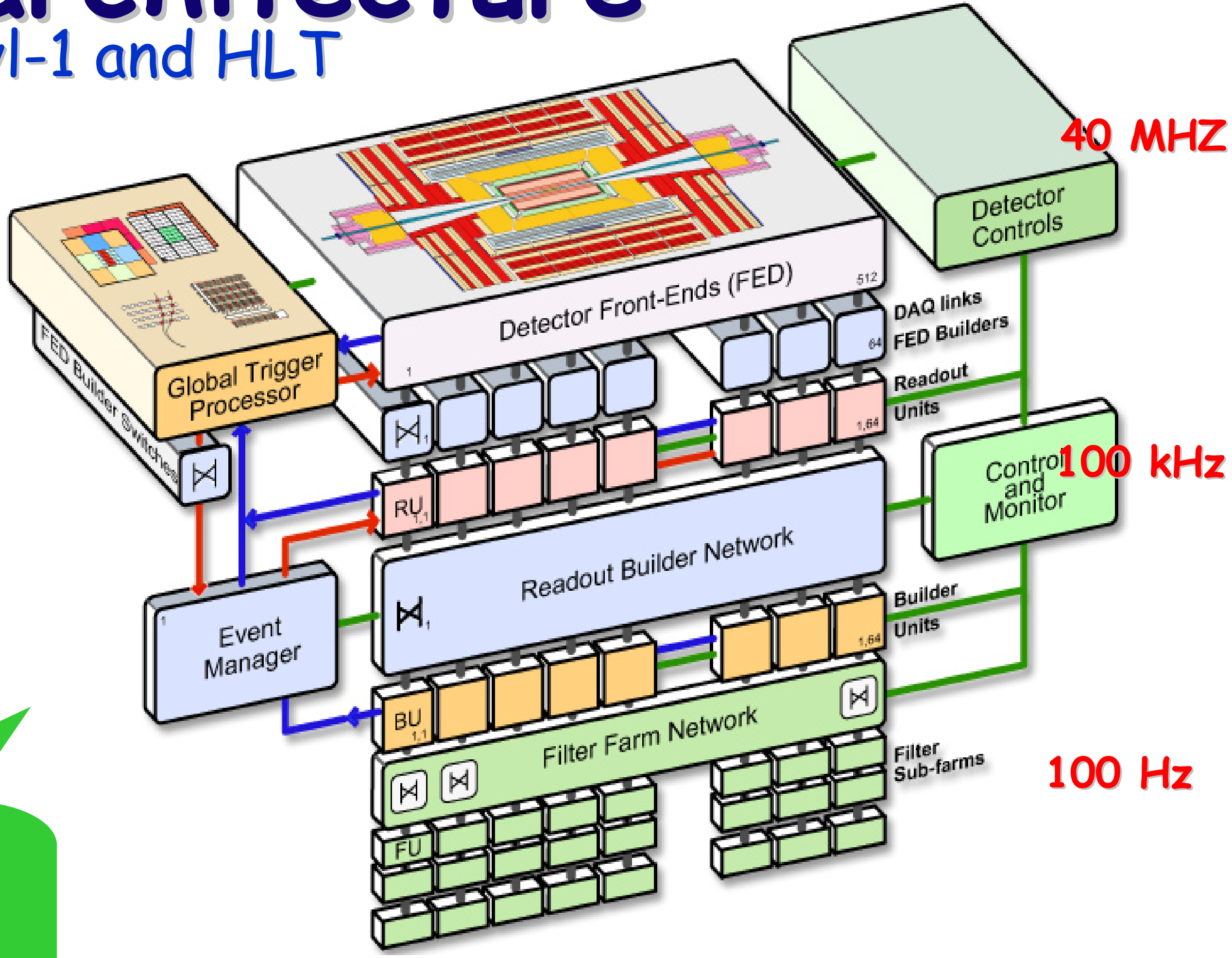
- b production at LHC
  - Starting luminosity: $2 \times 10^{33}\ cm^{-2}s^{-1}$
  - $\sigma = 0.5$ mb $\Rightarrow$ about $10^6$ b pairs/sec
  - only 100 ev/sec on tape for ALL interesting physics channels
- The trigger strategy is a great challenge



# Trigger & DAQ architecture

Two level trigger: Lvl-1 and HLT

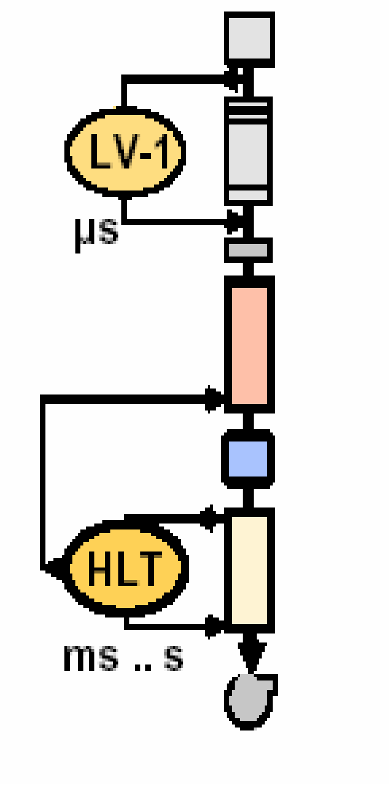


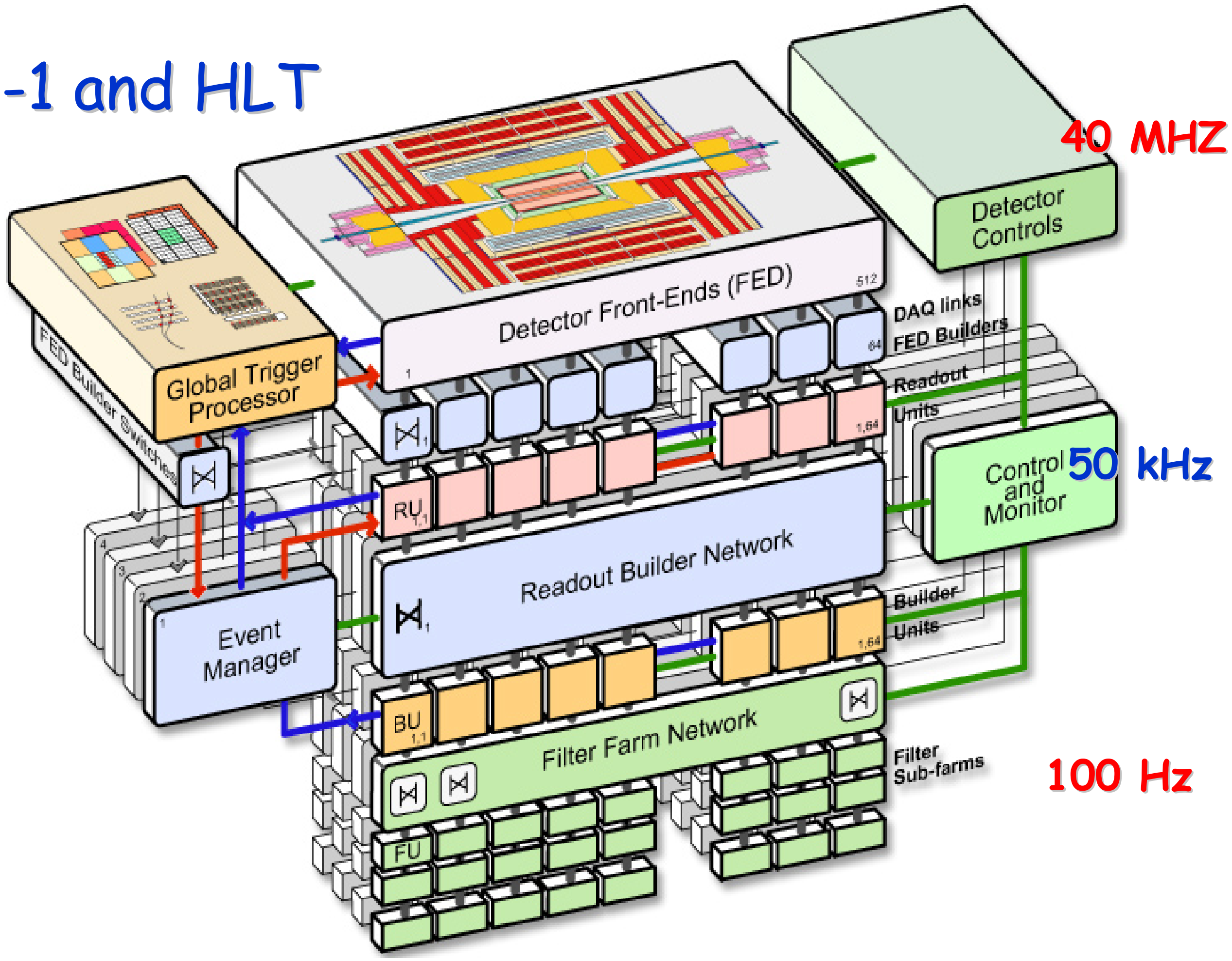




Several staging scenarios possible. Each slice allows 12.5 kHz

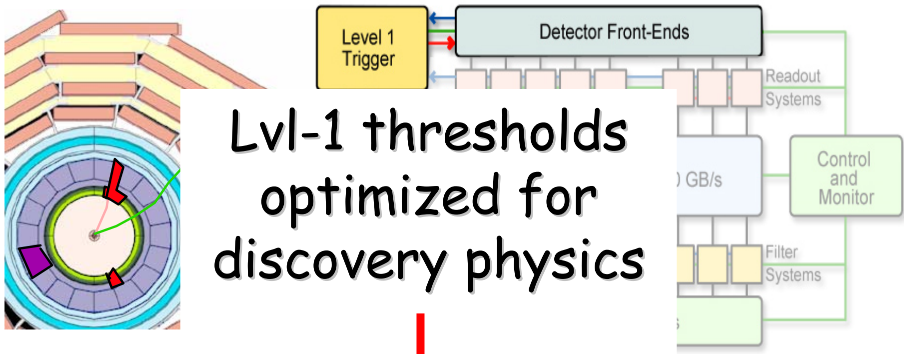
# CMS Trigger & DAQ

Two level trigger: Lvl-1 and HLT



# Level 1 Muon Trigger rates




Lvl-1 thresholds optimized for discovery physics

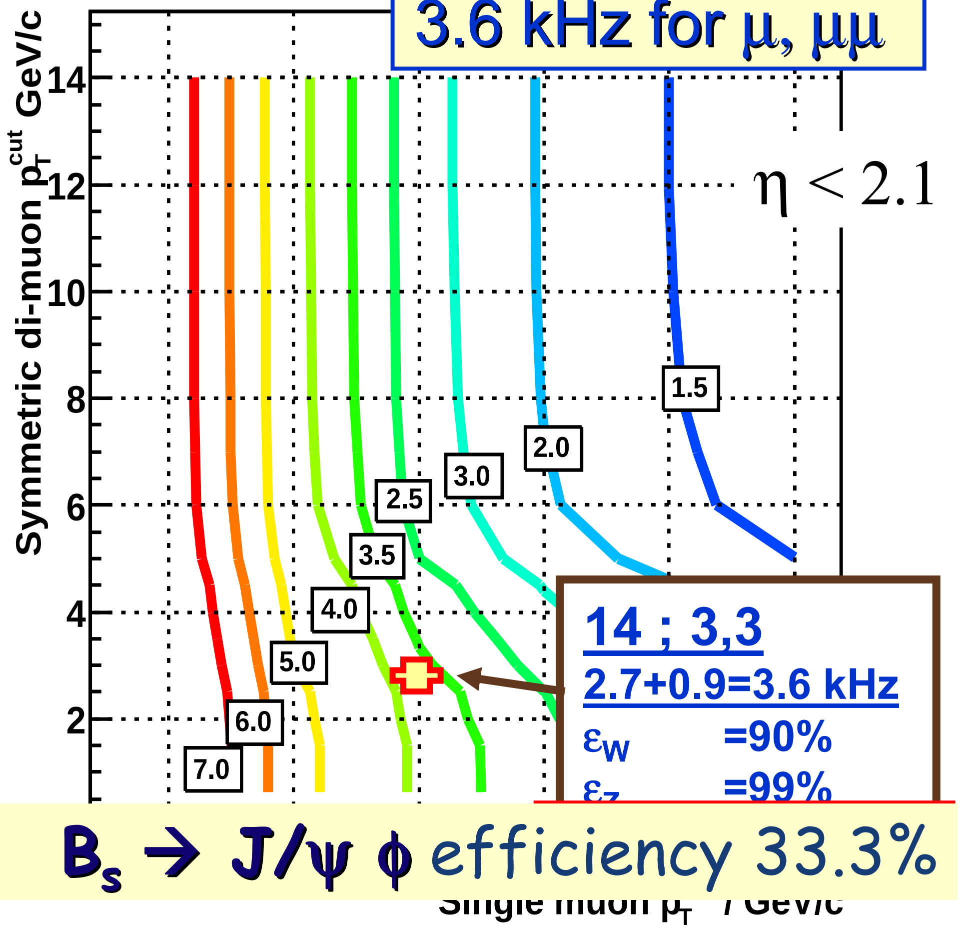
↓

High - $p_T$ processes are selected

b-jets are selected mainly by $1\mu$ and $2\mu$ trigger

Low Lumi

**16 kHz DAQ**
3.6 kHz for $\mu$, $\mu\mu$




**14 ; 3,3**
2.7+0.9=3.6 kHz
$\varepsilon_W$ =90%
$\varepsilon_Z$ =99%

**$B_s \rightarrow J/\psi\ \phi$ efficiency 33.3%**

# L1 Trigger

## L1 Global Muon Trigger - double $\mu$ cut $p_T^{\mu} \geq 3$ GeV/c

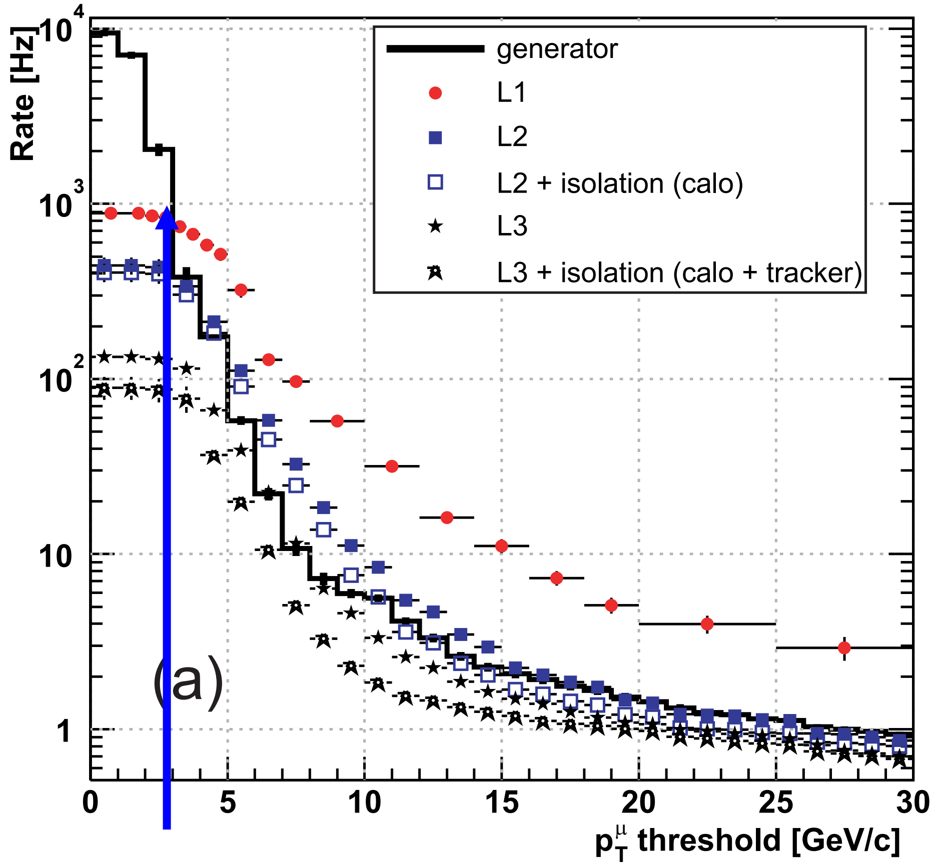
2$\mu$ extended to $|\eta| < 2.4$

DAQ TDR - Chapter 15

⇒ **Rate = 0.9 kHz**

+ Request that muons have opposite charge :

Signal efficiency 26.0%



# Using the Tracker at HLT

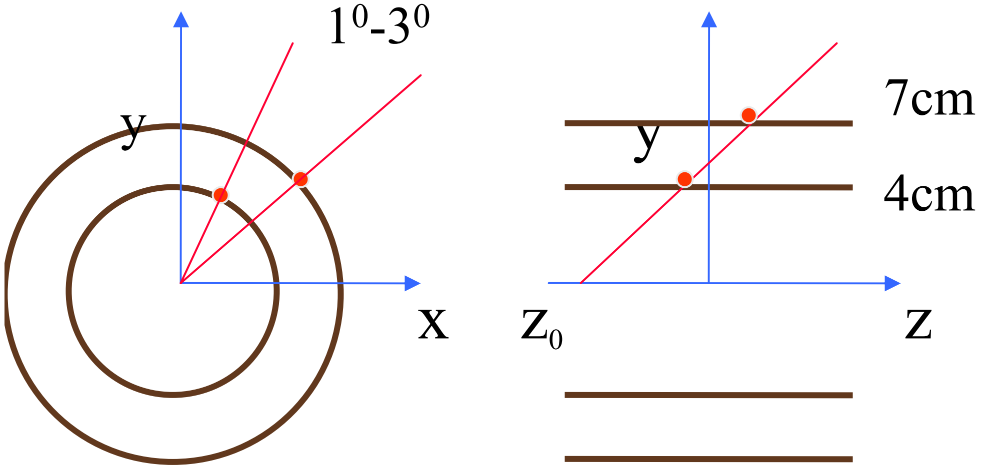
- Muon HLT stream optimized for high $p_T$ isolated muons → use the Silicon Tracker instead to reconstruct the decay chain at HLT
- HLT track reconstruction has to be fast but does not need to be global as the offline one, therefore it can be:
  - Regional
    - Restricted to some phase-space region defined from external Lvl-1 information (e.g. a cone around muon/jet direction or the set of tracks coming from a vertex or above a $P_T$ threshold )
  - Partial
    - Stopped after a number of hits have been assigned to the track
  - Conditional
    - Stopped when enough resolution is reached or on other condition

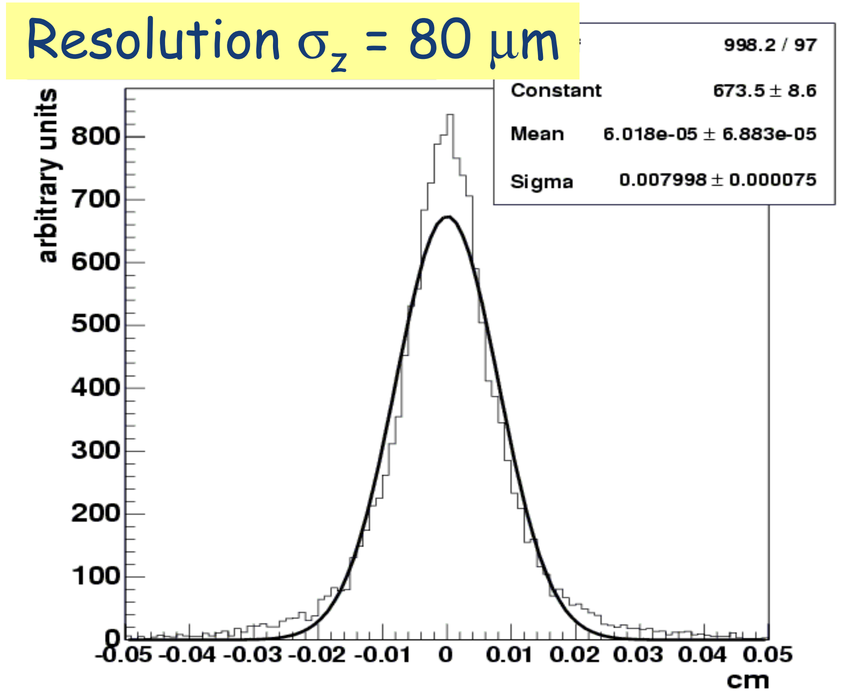
# HLT selection

- L2 $J/\psi$ reconstruction
  - Definition of Regions of Interest in Tracker
    - PV reconstruction
    - Direction from L1 muons
  - Fast reconstruction of tracks in pixel detector + first 2 layers of microstrip detectors

- L3 full decay chain reconstruction
  - Fast track reconstruction around $J/\psi$

# HLT PV reconstruction



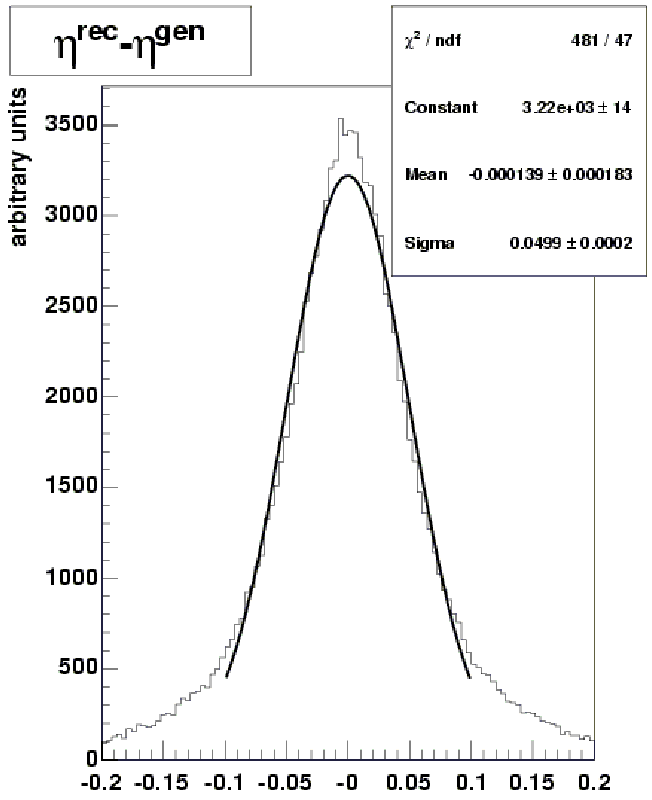

Z rec - Z sim (cm)

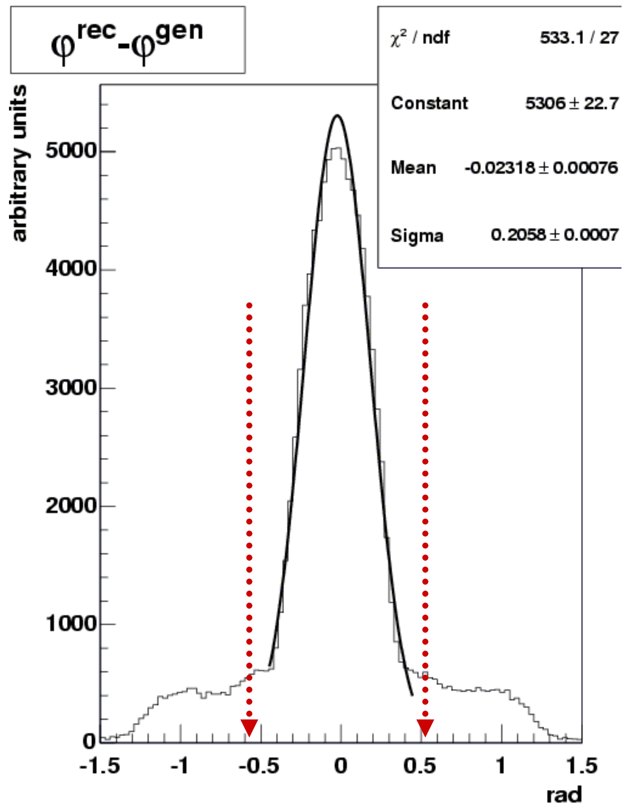
- Hit pairing with a straight line in rz
  - IP ≤ 1 mm
  - $p_T > 1$ GeV/c
- Matching with 3rd layer → track candidate
- PV candidate if ≥ 2 track cross z-axis
- Signal vertex from the highest $\Sigma\, p_T$ → eff. 96.9%

# L2 Tracking regions

- Muon direction from L1 muon candidates

*Resolution on the direction of L1 muon candidates*

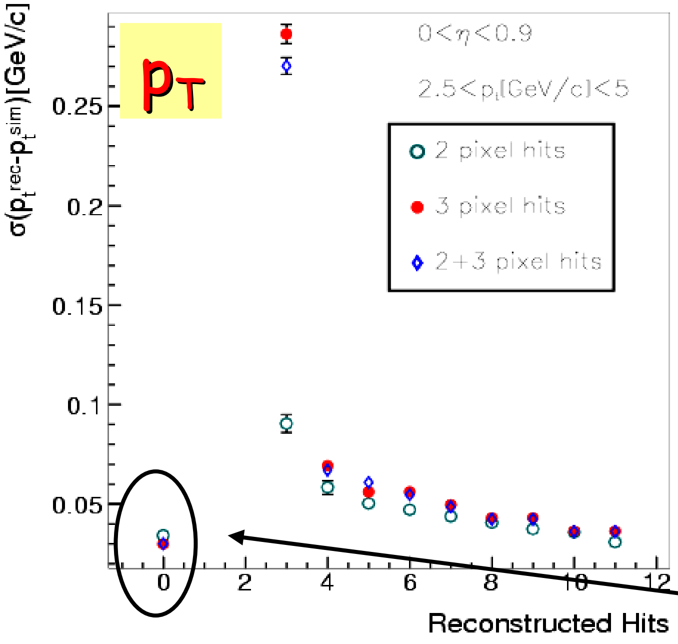


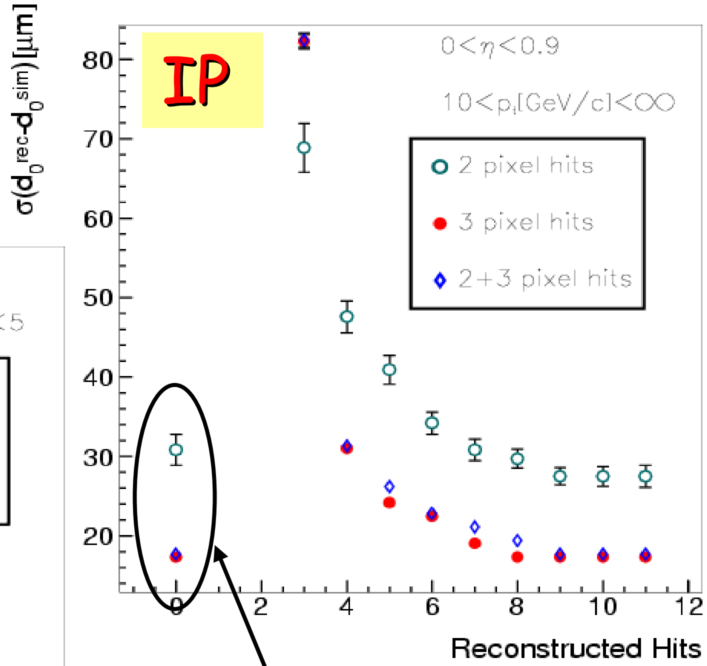




$|\Delta\eta| < 0.3$ $|\Delta\phi| < 0.5$

# Partial reconstruction

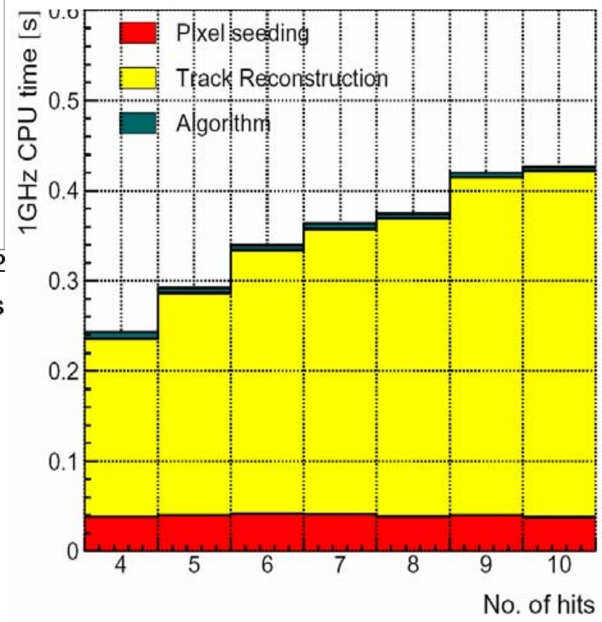
- Reconstruction of muon tracks in RoI
- Sufficient track parameter resolutions with 5 hits
- Half the time for full reconstruction needed



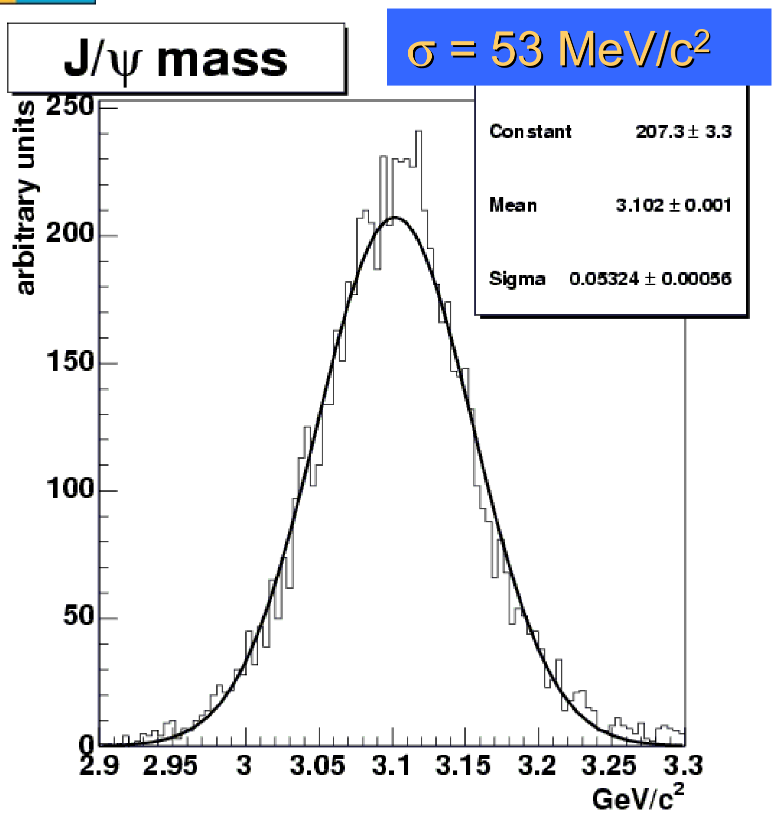



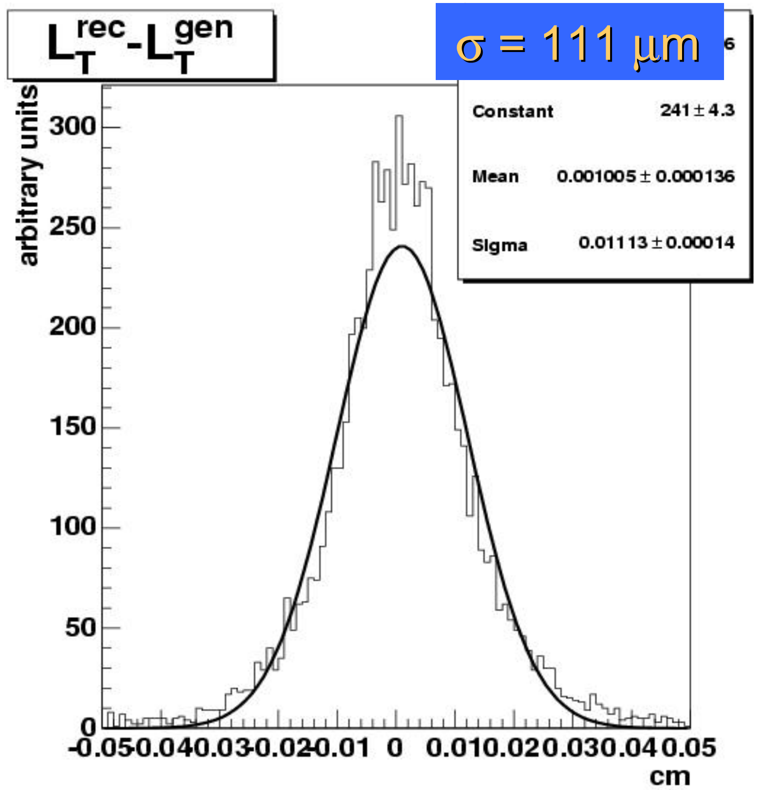

**Full tracker performance**

Time vs hits in 100 GeV/c b-jets



# L2 resolutions

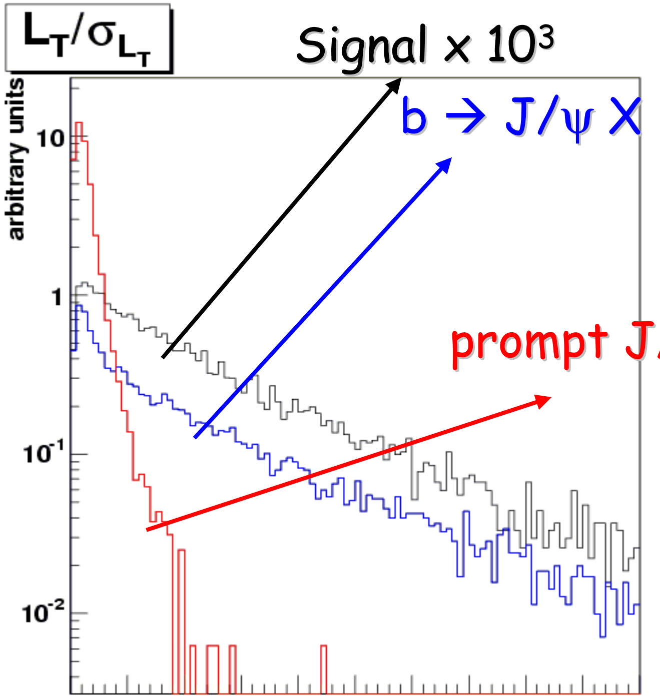



$\pm$ 150 MeV/$c^2$ around J/ψ mass

Secondary vtx fit : Transverse decay length resolution 111 μm

# L2 bkg rejection




$\chi^2 < 10$ and $L_T/\sigma(L_T) > 3$

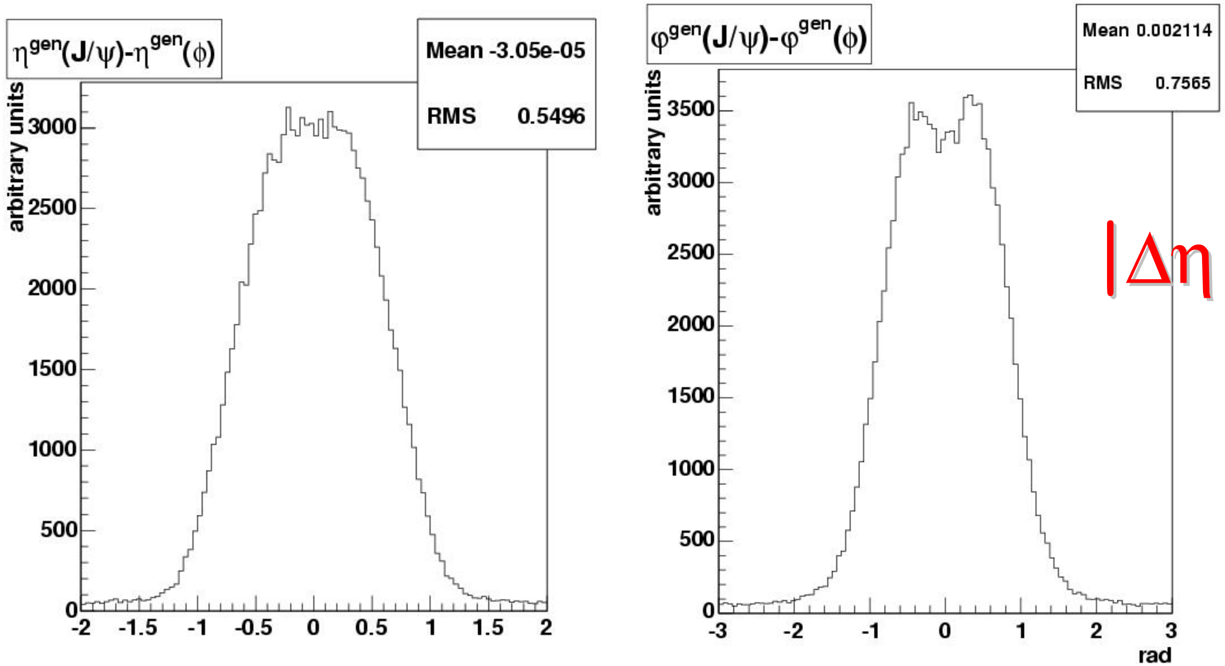
Rate = 10 Hz, <t> ~ 190 ms

~ 80% of L2 J/ψ are from b

| Event sample | $B_s^0 \to J/\psi\phi$ | Direct $J/\psi$ | $b \to J/\psi X$ | $B_d^0 \to J/\psi K^{*0}$ |
|---|---|---|---|---|
| $\sigma$ (nb) | 0.167 | 310 | 51.4 | 0.90 |
| L2 $\epsilon$ | $11.8\% \pm 0.2\%$ | $0.23\% \pm 0.02\%$ | $8.0\% \pm 0.1\%$ | $13.4\% \pm 0.2\%$ |
| L2 R (Hz) | $3.94(7) \cdot 10^{-2}$ | 1.44(13) | 8.2(1) | 0.241(4) |

# HLT L3 strategy

Fast tracking with $p_T$ min = 0.5 GeV/c around $J/\psi$ direction

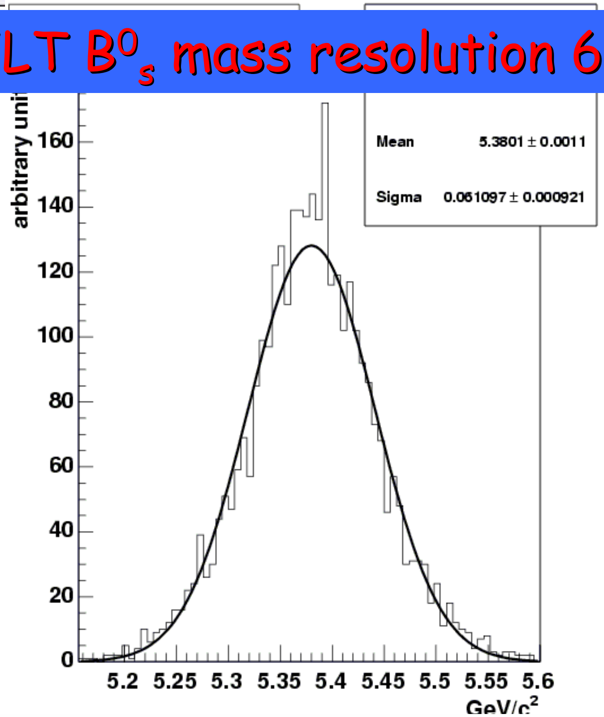



$|\Delta\eta|<1.0$, $|\Delta\phi|<1.0$

Eff. for $\phi$ reco WRT L2 is 46.8%

# L3 reconstruction

HLT $B^0_s$ mass resolution 61 MeV/$c^2$




Fast tracking around $J/\psi$ direction

$\phi$ mass $\pm$ 20 MeV/$c^2$

$B^0_s$ mass $\pm$ 200 MeV/$c^2$

+

Vertex selection repeated on 4 track vertex

bkg rate 0.05 Hz

| Event sample | $B^0_s \to J/\psi\phi$ | Direct $J/\psi$ | $b \to J/\psi X$ | $B^0_d \to J/\psi K^{*0}$ |
|---|---|---|---|---|
| $\sigma$ (nb) | 0.167 | 310 | 51.4 | 0.90 |
| L3 $\epsilon$ | $5.3\% \pm 0.1\%$ | $< 6.1 \cdot 10^{-5}$ | $(3.9 \pm 0.7) \cdot 10^{-4}$ | $(2.4 \pm 0.7) \cdot 10^{-3}$ |
| L3 R (Hz) | $1.78(3) \cdot 10^{-2}$ | $< 3.7 \cdot 10^{-2}$ | $4.0(8) \cdot 10^{-2}$ | $4.2 \pm 1.2 \cdot 10^{-3}$ |

# Offline reconstruction

- Full reconstruction of tracks in tracker
  - $p_T$ min = 0.5 GeV/c
- Combinatorial decay chain reconstruction
  - μ/K mass assignment
  - Loose mass/$p_T$ cuts to reduce number of combinations
- Kinematic fitting

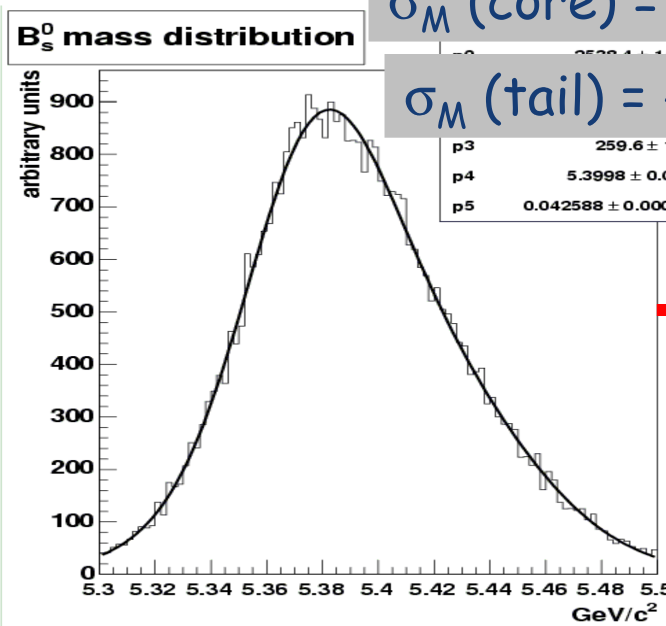
# Kinematic fitting

## Constraints applied

- Common 4 track vertex
- $J/\psi$ mass constraint
- *Vertex pointing constraint*

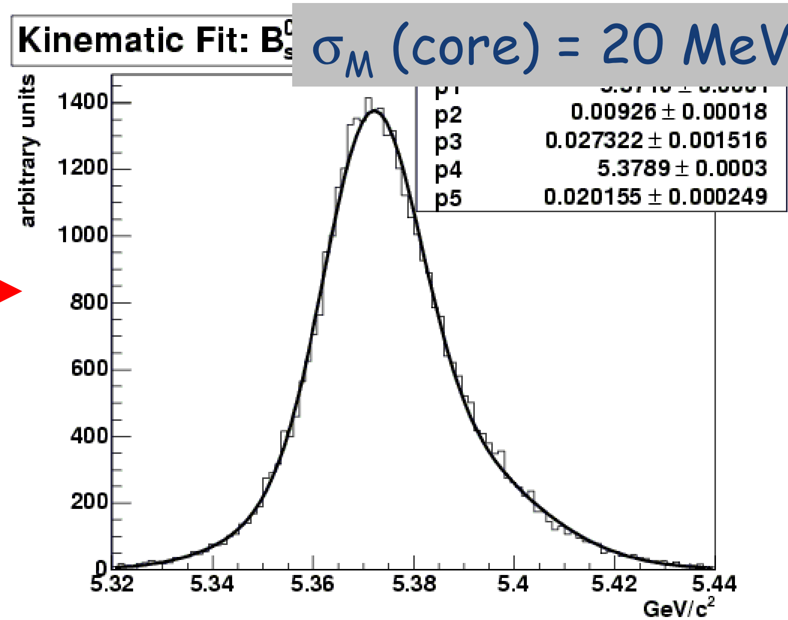
$\sigma_M$ (core) = 24 MeV/$c^2$

$\sigma_M$ (tail) = 42 MeV/$c^2$



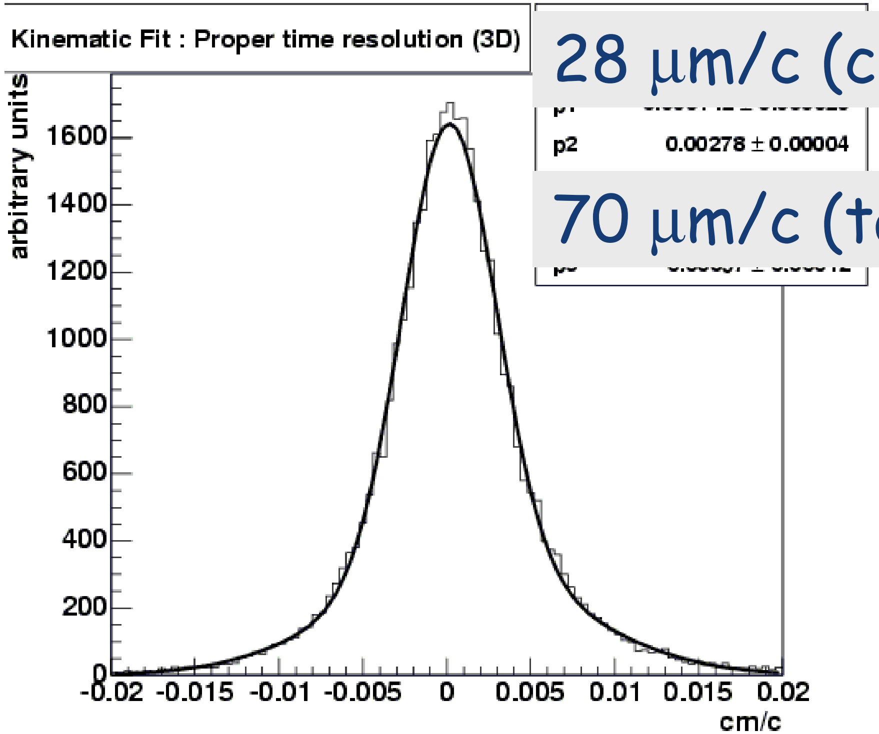

$\sigma_M$ (core) = 9 MeV/$c^2$

$\sigma_M$ (core) = 20 MeV/$c^2$



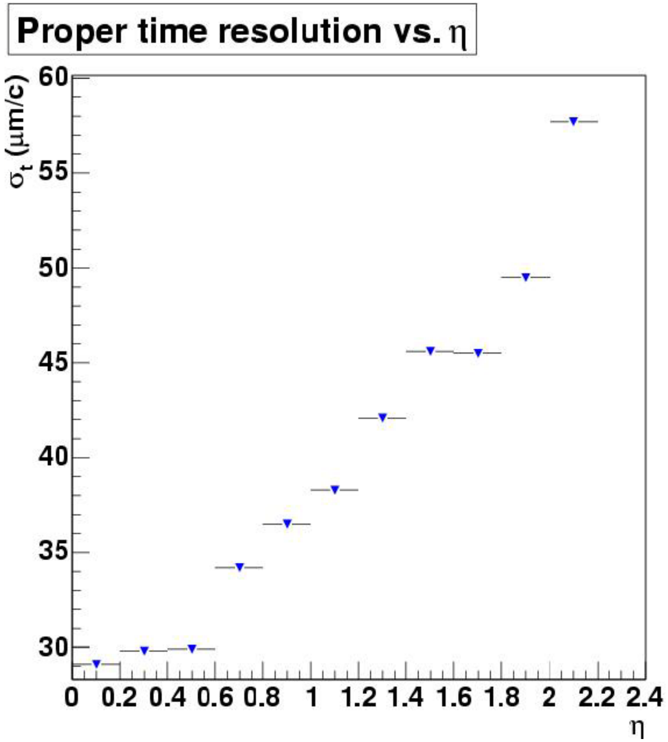

## Mass resolution improvement

# Kinematic fit : vertex




28 μm/c (core)

70 μm/c (tail)




- σ proper time 28 – 57 μm/c (93 – 190 fs) vs. η
  - Will be investigated for improvements

# Offline selection

Selection cuts optimized to minimize the statistical error on the angular observables

$$\sigma(A_S) \propto \frac{\sqrt{S+B}}{S} \oplus \frac{B}{S} \cdot \sigma(A_B)$$

Stat + syst

- No gain from additional vtx cut
- $\Delta m\ B^0_s < 33\ \mathrm{MeV}/c^2$
- $\Delta m\ \phi < 8\ \mathrm{MeV}/c^2$

# Results

- No additional vtx cut
- $\Delta m\ B^0_s < 33\ MeV/c^2$
- $\Delta m\ \phi < 8\ MeV/c^2$

- Events selected per 10 $fb^{-1}$

| Data sample | $B_s^0 \to J/\psi\phi$ | $b \to J/\psi X$ | $B_d^0 \to J/\psi K^*$ |
|---|---|---|---|
| $\sigma$ (nb) | $0.167 \pm 0.062$ | $51.4 \pm 4.8$ | $0.90 \pm 0.08$ |
| $\epsilon$ | $3.81\% \pm 0.08\%$ | $(9 \pm 3) \cdot 10^{-5}$ | $(3.6 \pm 0.8) \cdot 10^{-4}$ |
| $N_{SEL}$ | $(64 \pm 24) \cdot 10^3$ | $(45 \pm 13) \cdot 10^3$ | $(3.2 \pm 0.8) \cdot 10^3$ |

- Estimated S/B = 4/3, but very limited stat. for backgrounds

# Analysis

# Method of moments

- In very few words: observables extracted from the average of a function on data, e.g.:
  - assume differential cross section is:

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta} = a + b\cos^2\theta$$

  - b/a can be obtained as

$$\frac{b}{a} = \frac{5(3\overline{\cos^2\theta} - 1)}{3 - 5\overline{\cos^2\theta}}$$

# Angular distributions

The angular distributions of interest are much more complicated:

$$W(t,\Omega) = \frac{d^3\Gamma}{d\cos\vartheta_1 d\cos\vartheta_2 d\varphi} = \frac{9}{64\pi}\sum_{i=1}^{6} b_i(t) g_i(\vartheta_1,\vartheta_2,\varphi)$$

Time evolution is a function of the *transversity amplitudes* $A_0(t)$, $A_{||}(t)$, $A_\perp(t)$ which contain the parameters of interest

→ A set of 6 weighting functions $w_i(\theta_1,\theta_2,\varphi)$ is defined to separate the 6 $b_i(t)$ components

Known functions of the three *helicity angles* $\theta_1,\theta_2,\varphi$ describing decay product kinematics

# Method of moments

$$b_1(t) = \frac{|A_0(0)|^2}{2}[(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_2(t) = \frac{|A_\parallel(0)|^2}{2}[(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_3(t) = \frac{|A_\perp(0)|^2}{2}[(1-\cos\phi_s)e^{-\Gamma_L t} + (1+\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_4(t) = |A_\parallel(0)||A_\perp(0)|\,[\frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_1 \sin\phi_s],$$

$$b_5(t) = \frac{1}{2}|A_0(0)||A_\parallel(0)|\cos(\delta_2-\delta_1)\cdot \\ [(1+\cos\phi_s)e^{-\Gamma_L t} + (1-\cos\phi_s)e^{-\Gamma_H t}],$$

$$b_6(t) = |A_0(0)||A_\perp(0)|\,[\frac{1}{2}(e^{-\Gamma_H t} - e^{-\Gamma_L t})\cos\delta_2 \sin\phi_s].$$

$$w_1 = \frac{1}{12}[28\cos^2\Theta_{K^+}\sin^2\Theta_{l^+} - 3\sin^2\Theta_{K^+}(1+\cos^2\Theta_{l^+})],$$

$$w_2 = -\frac{1}{8}[4\cos^2\Theta_{K^+}\sin^2\Theta_{l^+} - 29\sin^2\Theta_{K^+}(1-\sin^2\Theta_{l^+}\cos^2\chi) \\ +21\sin^2\Theta_{K^+}(1-\sin^2\Theta_{l^+}\sin^2\chi)],$$

$$w_3 = -\frac{1}{8}[4\cos^2\Theta_{K^+}\sin^2\Theta_{l^+} + 21\sin^2\Theta_{K^+}(1-\sin^2\Theta_{l^+}\cos^2\chi) \\ -29\sin^2\Theta_{K^+}(1-\sin^2\Theta_{l^+}\sin^2\chi)],$$

$$w_4 = -\frac{25}{8}\sin^2\Theta_{K^+}\sin^2\Theta_{l^+}\sin 2\chi,$$

$$w_5 = \frac{25}{4\sqrt{2}}\sin 2\Theta_{K^+}\sin 2\Theta_{l^+}\cos\chi,$$

$$w_6 = \frac{25}{4\sqrt{2}}\sin 2\Theta_{K^+}\sin 2\Theta_{l^+}\sin\chi.$$

- The angular distributions of interest are much more complicated: define a set of 6 weighting functions $w_i$ to separate the 6 $b_i$ components

# Statistical Error

- Results on 64k generator level events

| | Input generator value | Measured value | Statistical error | (Relative) |
|---|---|---|---|---|
| $\Gamma_s$ | 2.2784 $c$/mm | 2.24 $c$/mm | 0.03 $c$/mm | 1.4% |
| $\Delta\Gamma_s$ | -0.4557 $c$/mm | -0.43 $c$/mm | 0.06 $c$/mm | 14% |
| $\Delta\Gamma_s/\Gamma_s$ | -0.2 | -0.192 | 0.028 | 15% |

  - number of events selected per L = 10 $fb^{-1}$
  - *but no selection bias on kinematics and MC truth used*

$$\sigma\left(\frac{\Delta\Gamma_S}{\Gamma_S}\right) = \frac{6.9}{\sqrt{S}} \quad \xrightarrow{B\neq 0} \quad \sigma\left(\frac{\Delta\Gamma_S}{\Gamma_S}\right) = 6.9\frac{\sqrt{S+B}}{S}$$

S/B=4/3 $\Rightarrow$ $\sigma(\Delta\Gamma/\Gamma)$ = 0.036 for 10 $fb^{-1}$

# Statistical Error

- Results on 64k generated events
  - ( = number of events selected per L = 10 $fb^{-1}$)

| | Input generator value | Measured value | Statistical error | (Relative) |
|---|---|---|---|---|
| $\Gamma_s$ | 2.2784 $c$/mm | 2.24 $c$/mm | 0.03 $c$/mm | 1.4% |
| $\Delta\Gamma_s$ | -0.4557 $c$/mm | -0.43 $c$/mm | 0.06 $c$/mm | 14% |
| $\Delta\Gamma_s/\Gamma_s$ | -0.2 | -0.192 | 0.028 | 15% |

- *"Optimal" statistical error:*
  - *Background = 0*
  - *Detector resolution not included*
  - *No selection bias on kinematics*

# Experimental effects

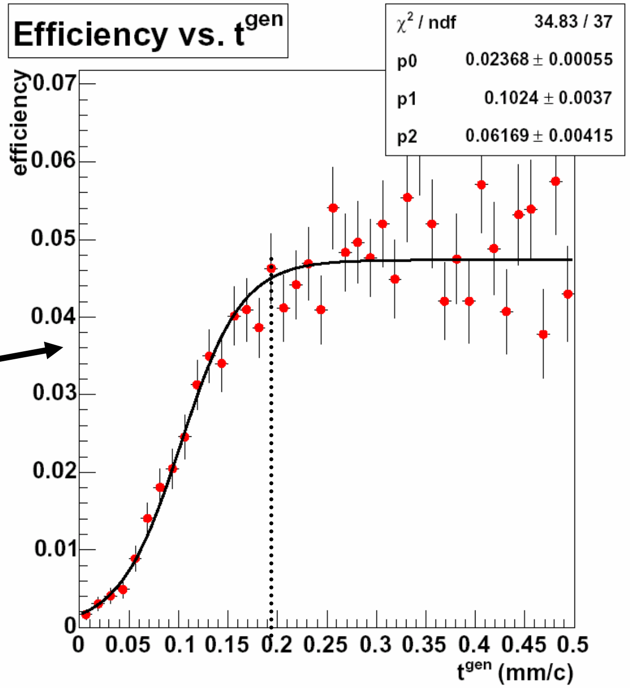
## The previous "ideal" error is increased by

- **Background contamination**

$$\sigma\left(\frac{\Delta\Gamma_S}{\Gamma_S}\right) = \frac{6.9}{\sqrt{S}} \quad \xrightarrow{B\neq 0} \quad \sigma\left(\frac{\Delta\Gamma_S}{\Gamma_S}\right) = 6.9\frac{\sqrt{S+B}}{S}$$

S/B = 4/3 ⇒ $\sigma(\Delta\Gamma/\Gamma)$ = 0.028 → 0.036

- **Detector resolution**
  - negligible compared to statistical error
- **Selection efficiency bias**
  - Strongly correlated to decay length cuts
  - Could be taken into account reweighting the events




$t_{min}$ = 0.2 mm/c ⇒ $\sigma(\Delta\Gamma/\Gamma)$ = 0.036 → **0.043**
**(comparable with the predicted final result of CDF/D0 at Tevatron Run II)**

# Comparison with other experiments

•

Tevatron Run II potential (2 $fb^{-1}$)
CDF 4k events → σ = 0.04
D0 · 6k events
First year of LHC (20 $fb^{-1}$)
CMS 180k evt → σ = 0.03
ATLAS 200k → s =
LHCb 100k evt (2 $fb^{-1}$) → σ = 0.018

# Detector resolutions

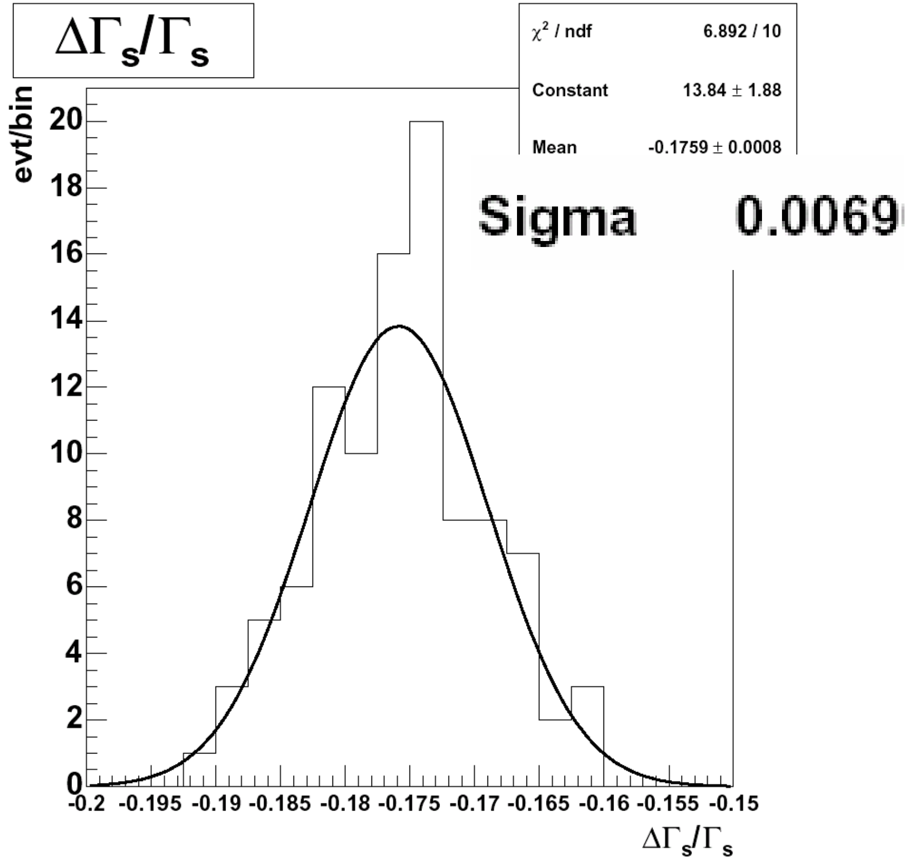
- Analytical propagation of average resolutions on angles and proper time:

| Events analyzed | Resolution error | (Relative) | Statistical error | (Relative) |
|---|---|---|---|---|
| 10000 | 0.01 | 5.0% | 0.069 | 31% |
| 40000 | 0.005 | 2.5% | 0.036 | 21% |
| 70000 | 0.0038 | 1.9% | 0.026 | 13% |
| 100000 | 0.0032 | 1.6% | 0.022 | 11% |

- Scales with statistics
- Negligible compared to statistical error
- Cross-checked with toy Monte Carlo

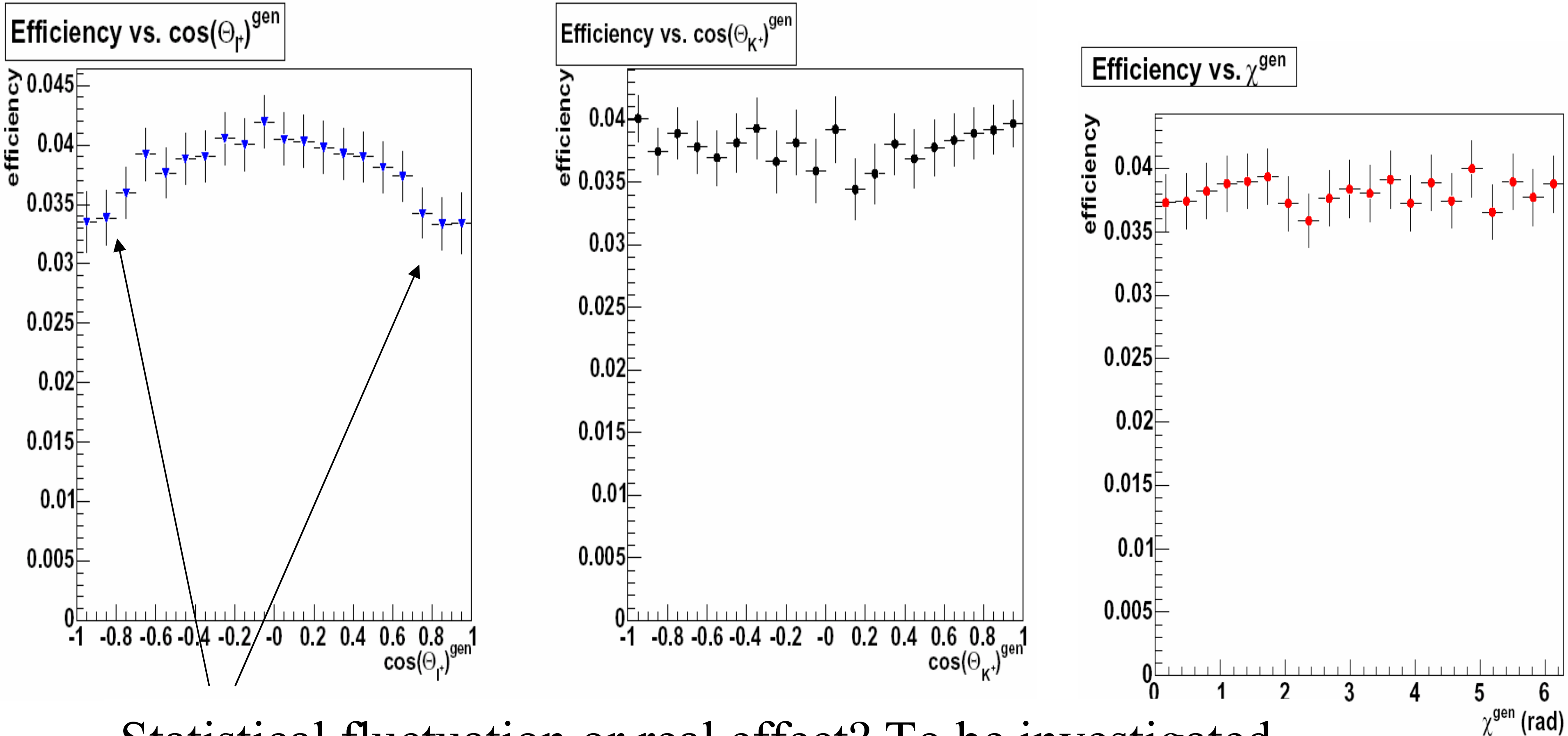
# Detector resolutions - 2

- Cross check using a toy MC with 100k events
- 86 μm random smearing applied to decay length in r-$\phi$
- $\sigma(\Delta\Gamma/\Gamma) = 0.007$ instead of 0.003
  - factor 2 acceptable given the method



# Reconstruction efficiencies

- Almost flat for angles




Statistical fluctuation or real effect? To be investigated…

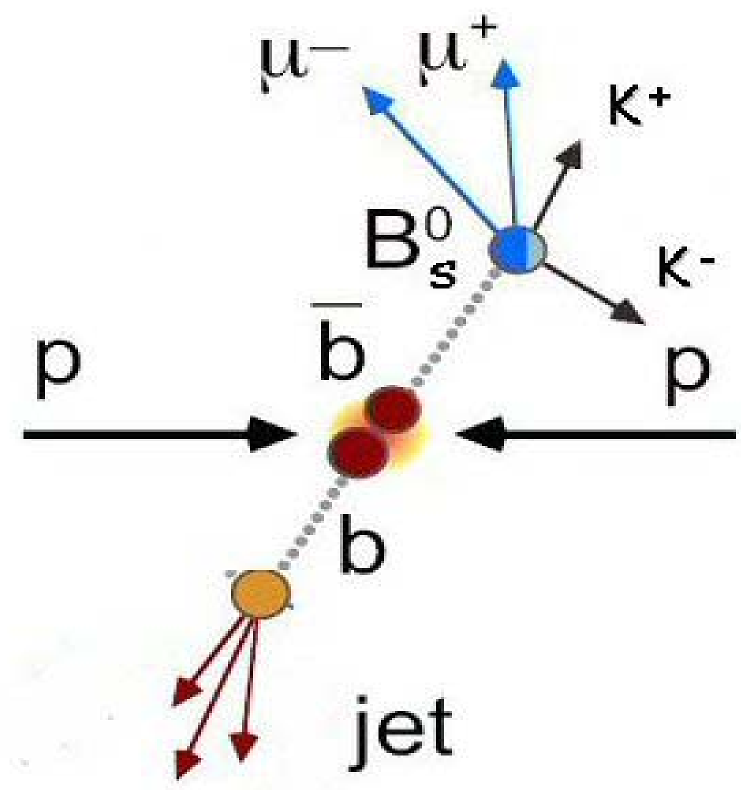
# Efficiency vs proper time

# Conclusions

- A statistical precision of 0.018 on $\Delta\Gamma_s/\Gamma_s$ is expected with 60 $fb^{-1}$
  - Please note : a detailed estimate of systematics will be performed when larger MC statistics is available
- CMS can compete with other experiments on selected B physics channels
- Low $p_T$ di-muon trigger and fast tracking at HLT are essential

# Generated $B_s \to J/\psi\ \phi$

200k events generated with SIMUB




$J/\psi \to \mu^+ \mu^-$

- $p_t^{\mu} > 2$ GeV/c
- $|\eta^{\mu}| < 2.5$

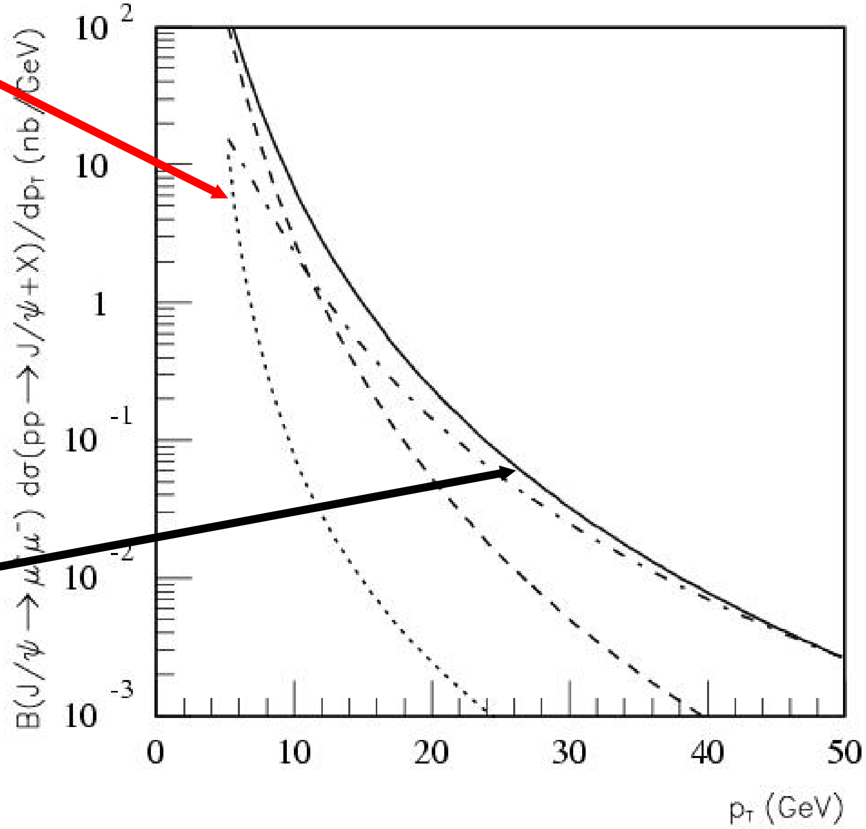
$\phi \to K^+K^-$

- $p_t^{K} > 0.5$ GeV/c
- $|\eta^{K}| < 2.5$

$\sigma$ = 167000 fb

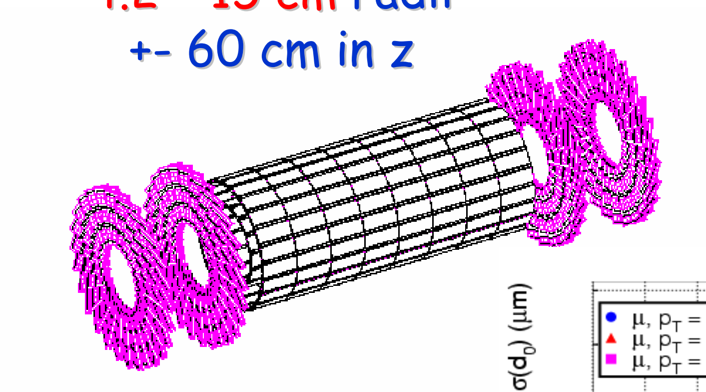
# JPsi2mu

- PYTHIA (color singlet) underestimates pp→ J/ψ X cross section by orders of magnitude (ref. CDF)
- Modified PYTHIA version including color octet processes

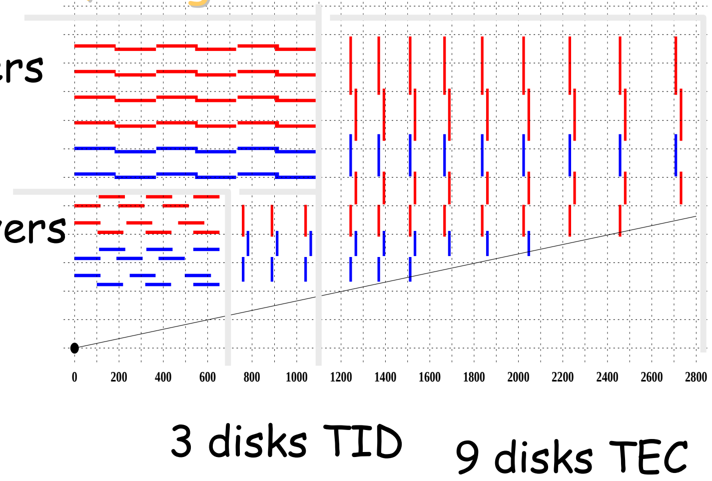


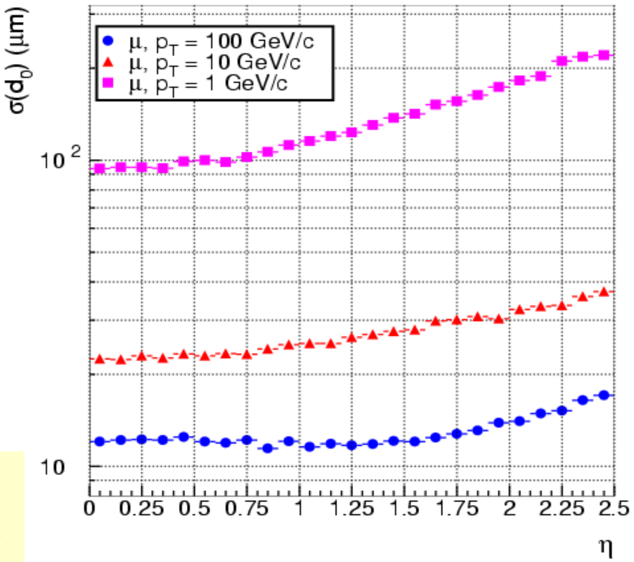
# CMS Tracker

Pixel detector: 3 layers
4.2 – 15 cm radii
+- 60 cm in z

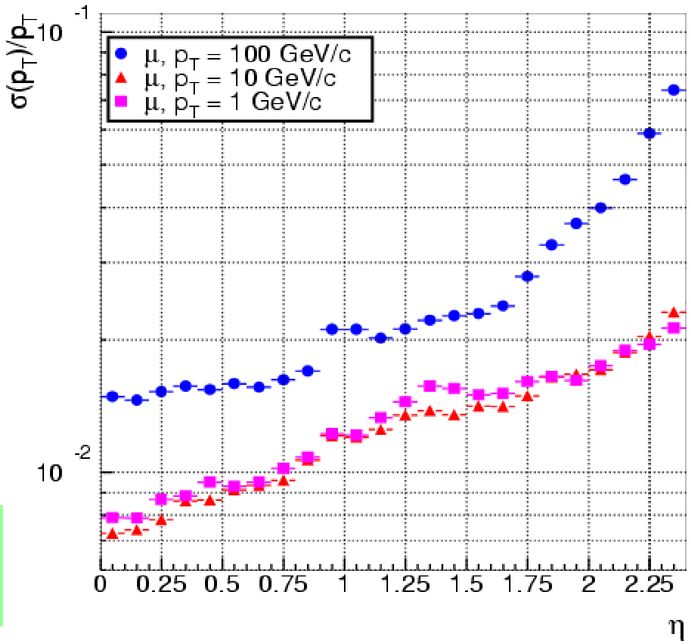


Radius ~ 110cm, Length/2 ~ 270cm




Transverse IP resolution ~ 20 $\mu$m for tracks with $P_t$ ~ 10GeV




Occupancy ~ $10^{-4}$
Pixel is used for seeding

Silicon strip : $\sigma_{R\varphi}$ = 10-60 $\mu$m, cell size ~ 10 cm$^2$
Pixel: $\sigma_{R\varphi, z}$ = 10-20 $\mu$m, cell size ~ 150 $\mu$m$^2$