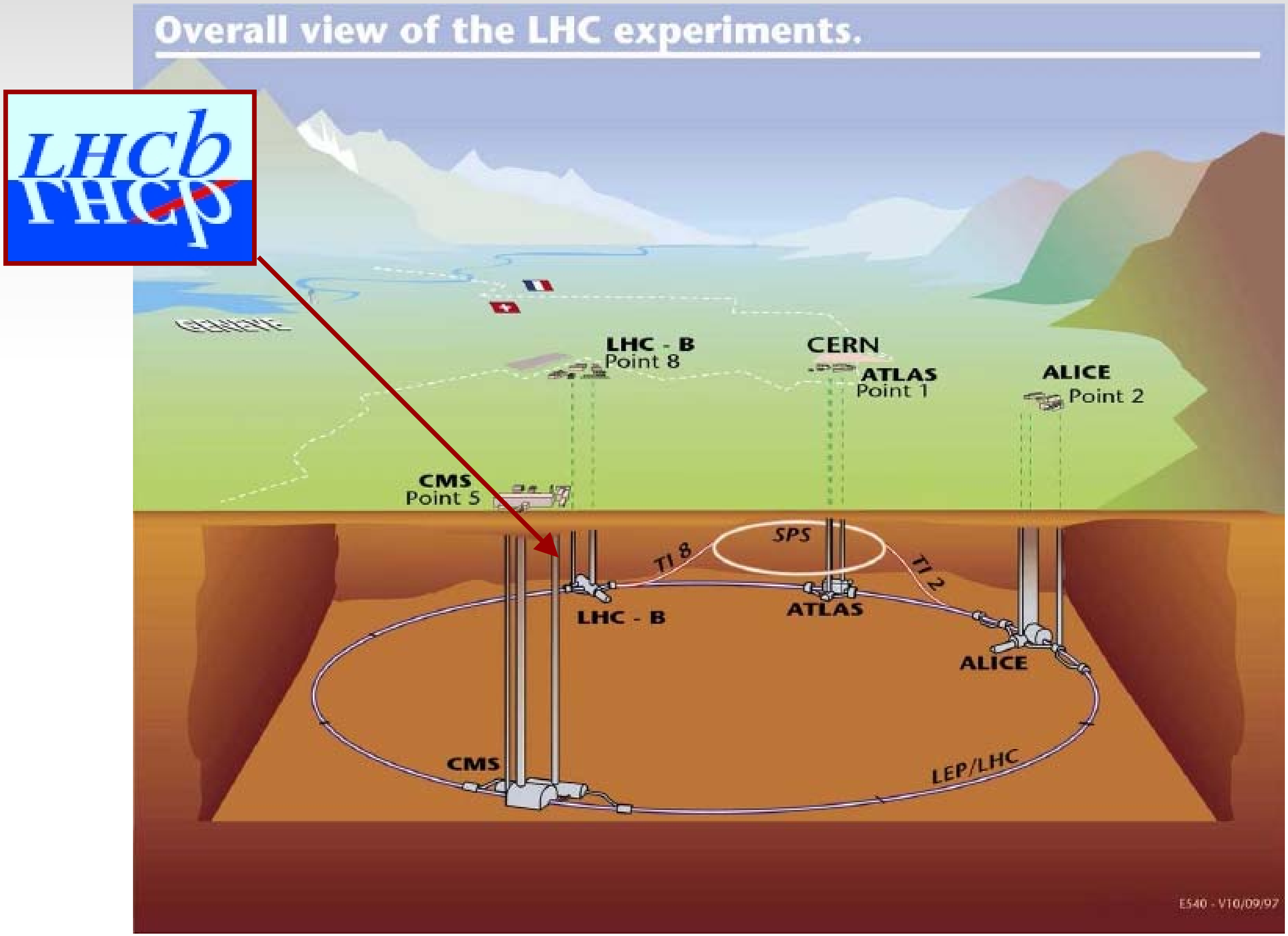
High Precision Standard Model Physics

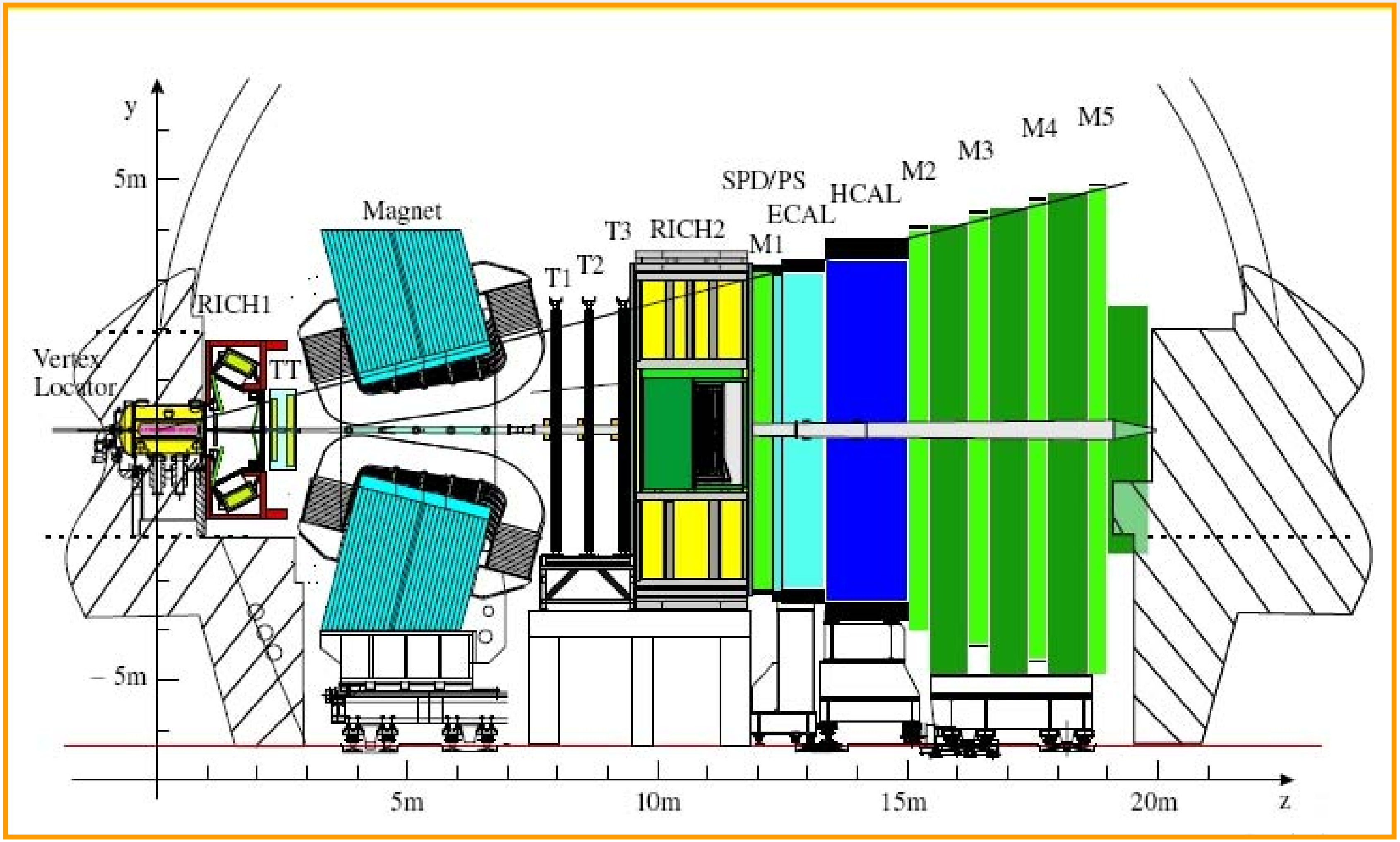
J. Magnin
Brazilian Center for Research in Physics
Rio de Janeiro - Brazil

Contents

LHCb


LHCb
Overall view of the LHC experiments.
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
E540 - V10/09/97

LHCb


y
5m
− 5m
Magnet
RICH1
Vertex Locator
TT
T1
T2
T3
RICH2
SPD/PS
ECAL
HCAL
M1
M2
M3
M4
M5
5m
10m
15m
20m
z

LHCb

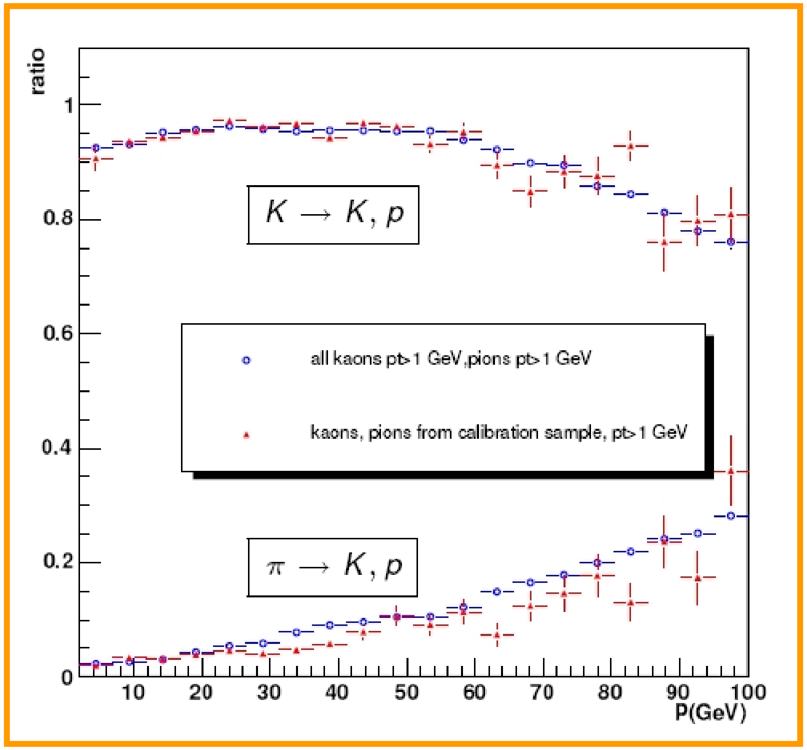
- Single arm detector
- Excellent vertexing and proper time resolution

~ 45 fs for secondary D^0

- Good tracking and momentum resolution

~ 6MeV D^0 mass

- Excellent K-π discrimination

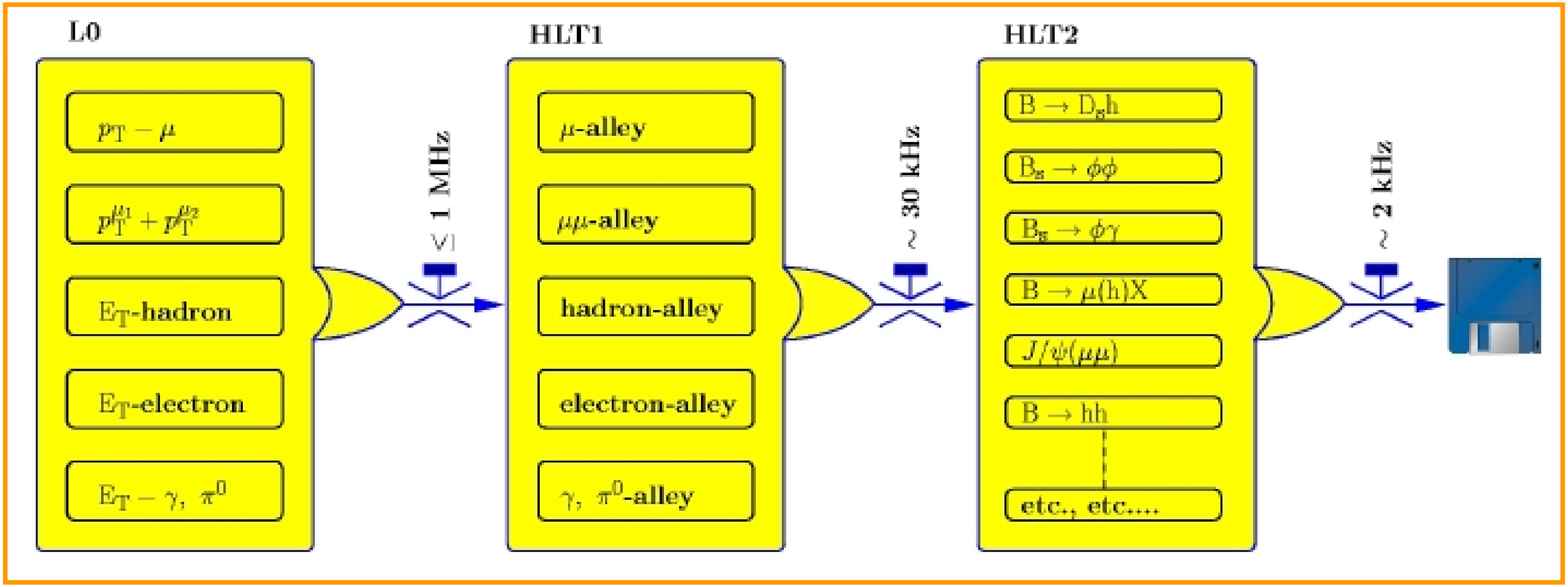


LHCb

- Two trigger levels:
  - L0 → hardware trigger designed to efficiently favors $b\bar{b}$ events (E_t > 3.5 GeV, $p_{t\mu}$ > 1.5 GeV) – Input 40 MHz – Output 1 MHz
  - HTL → software two stages trigger
    - HLT1: parallel trigger paths – partial reconstruction of limited detector information – confirms L0 using VeLo and tracking stations
    - HLT2: channels for specific analysis interest – final state candidate reconstruction – composite decay chain reconstruction

LHCb

- Two trigger levels:



L0

$p_T - \mu$

$p_T^{\mu_1} + p_T^{\mu_2}$

E_T-hadron

E_T-electron

$E_T - \gamma,\ \pi^0$

≤ 1 MHz

HLT1

μ-alley

$\mu\mu$-alley

hadron-alley

electron-alley

$\gamma,\ \pi^0$-alley

~ 30 kHz

HLT2

$B \rightarrow D_s h$

$B_s \rightarrow \phi\phi$

$B_s \rightarrow \phi\gamma$

$B \rightarrow \mu(h)X$

$J/\psi(\mu\mu)$

$B \rightarrow hh$

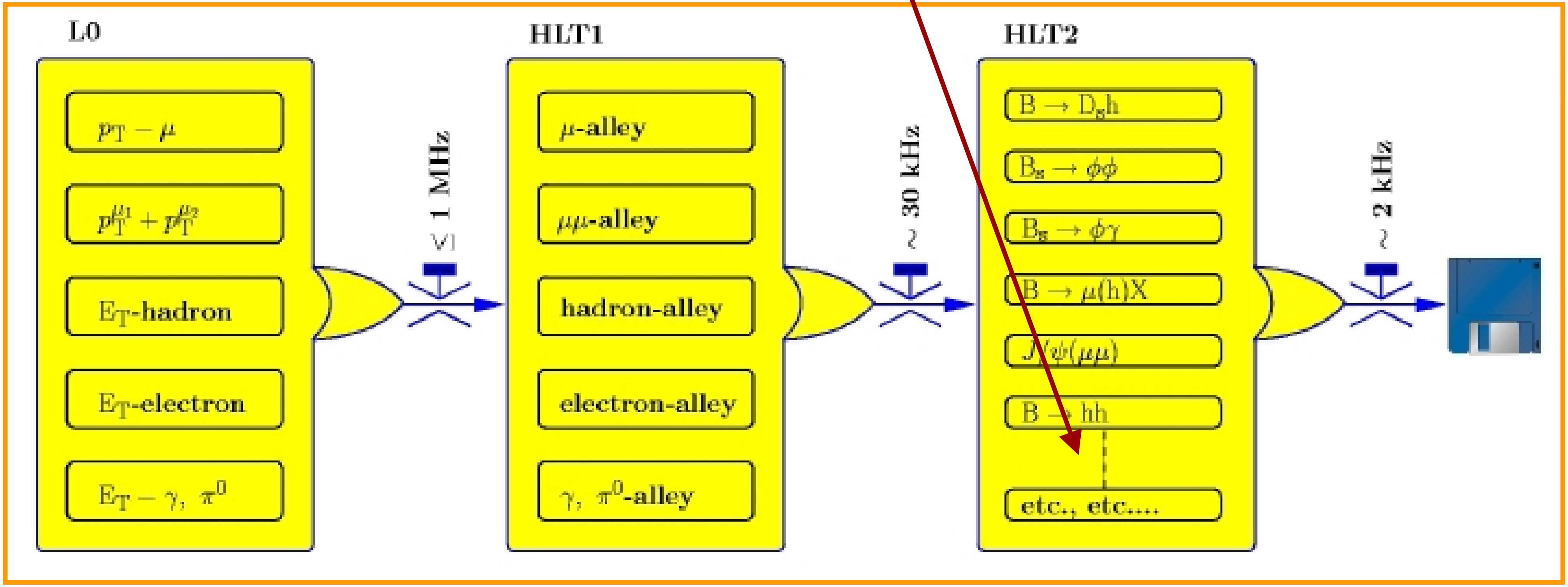
etc., etc....

~ 2 kHz

LHCb

- Two trigger levels:

$B \rightarrow (D^* \rightarrow (D^0 \rightarrow hh) + \pi) + X$



The CKM Matrix

- SU(3) x SU(2) x U(1) gauge symmetry of SM does not allow for leptons and quarks masses
- Fermion masses are dynamically generated in the spontaneous symmetry breaking due to the Yukawa coupling among fermions and Higgs fields

$$M_i = \frac{v g_i}{\sqrt{2}}$$

i = u → up-type quarks
d → down-type quarks
e → massive leptons

The CKM Matrix

- Move from the flavor (electroweak) basis to the mass eigenstates basis performing the transformation

$$U_{u(d,e)} M_{u(d,e)} \tilde{U}^{\dagger}_{u(d,e)} = \begin{pmatrix} m_{u(d,e)} & 0 & 0 \\ 0 & m_{c(s,\mu)} & 0 \\ 0 & 0 & m_{t(b,\tau)} \end{pmatrix}$$

The CKM Matrix

- The neutral current part of the Lagrange density remains unchanged but the charged current part is modified by a factor

$$\boxed{V = U_u U_d^\dagger = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}$$

$$\boxed{VV^\dagger = \mathrm{I}}$$

The CKM Matrix

- The neutral current part of the Lagrange density remains unchanged but the charged current part is modified by a factor

$$\boxed{V = U_u U_d^\dagger = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}$$

CKM-Matrix

$$\boxed{VV^\dagger = \mathrm{I}}$$

The CKM Matrix

- The neutral current part of the Lagrange density remains unchanged but the charged current part is modified by a factor

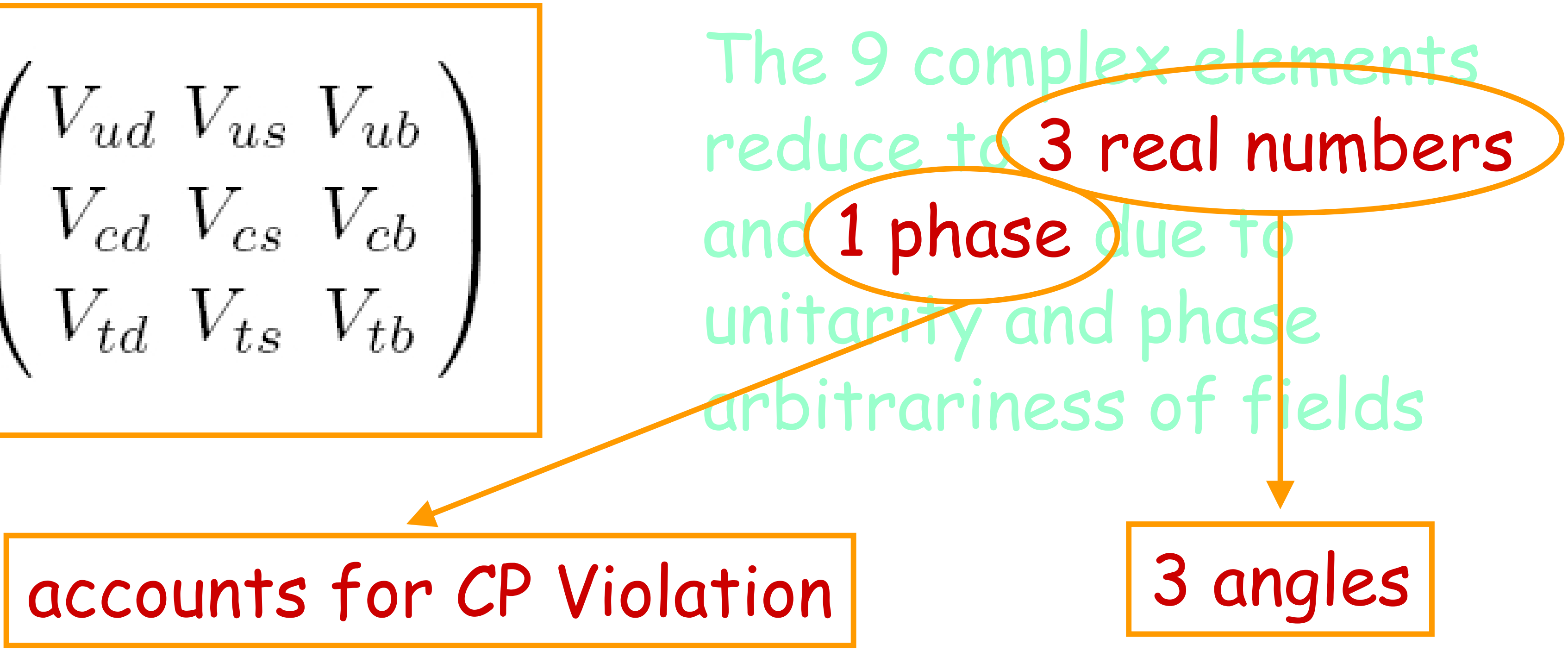
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

The 9 complex elements reduce to 3 real numbers and 1 phase due to unitarity and phase arbitrariness of fields

The CKM Matrix

- The neutral current part of the Lagrange density remains unchanged but the charged current part is modified by a factor

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



The 9 complex elements reduce to 3 real numbers and 1 phase due to unitarity and phase arbitrariness of fields

accounts for CP Violation

3 angles

The CKM Matrix

- There are several parameterizations for V:
  - Standard parameterization

$$V = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13} \end{pmatrix}$$

$$c_{ij} = \cos\theta_{ij},\ s_{ij} = \sin\theta_{ij} \ \text{ for } i < j = 1, 2, 3$$

- product of three rotation matrices and one phase
- rotations are characterized by the Euler angles θ_{ij}
- θ_{ij} mixing angles between generations

The CKM Matrix

- There are several parameterizations for V:
  - Wolfenstein parameterization

$$V = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & \lambda^3 A(\rho - i\eta) \\ -\lambda & 1 - \frac{1}{2}\lambda^2 & \lambda^2 A \\ \lambda^3 A(1 - \rho - i\eta) & -\lambda^2 A & 1 \end{pmatrix}$$

- $\lambda \sim V_{us} \sim 0.22$ is the expansion parameter
- $s_{23} = A\lambda^2$
- $s_{13}e^{-i\delta} = A\lambda^3(\rho - i\eta)$

The Unitary Triangle

- CKM unitarity ➔ six triangles in the complex (ρ,η) plane obtained from all the possible products among different columns.

- 4 flat and 2 non flat and quasi degenerated corresponding to the B meson system ➔ taken as indicative of large CP-violating asymmetries.

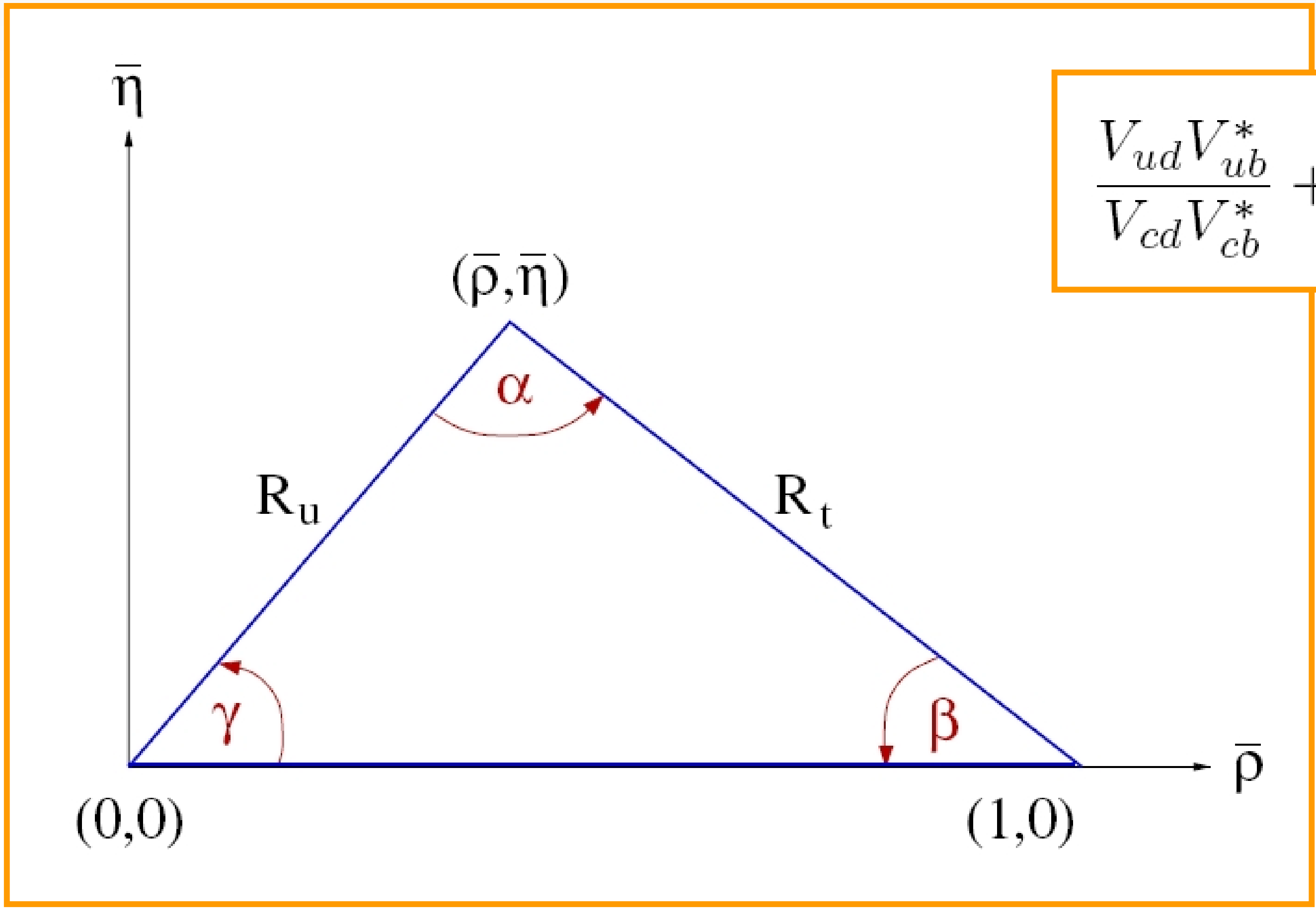
The Unitary Triangle

- The product of the 1st and 3rd columns gives (B-meson system)

$$\boxed{\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}+\frac{V_{cd}V_{cb}^*}{V_{cd}V_{cb}^*}+\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}=0}$$

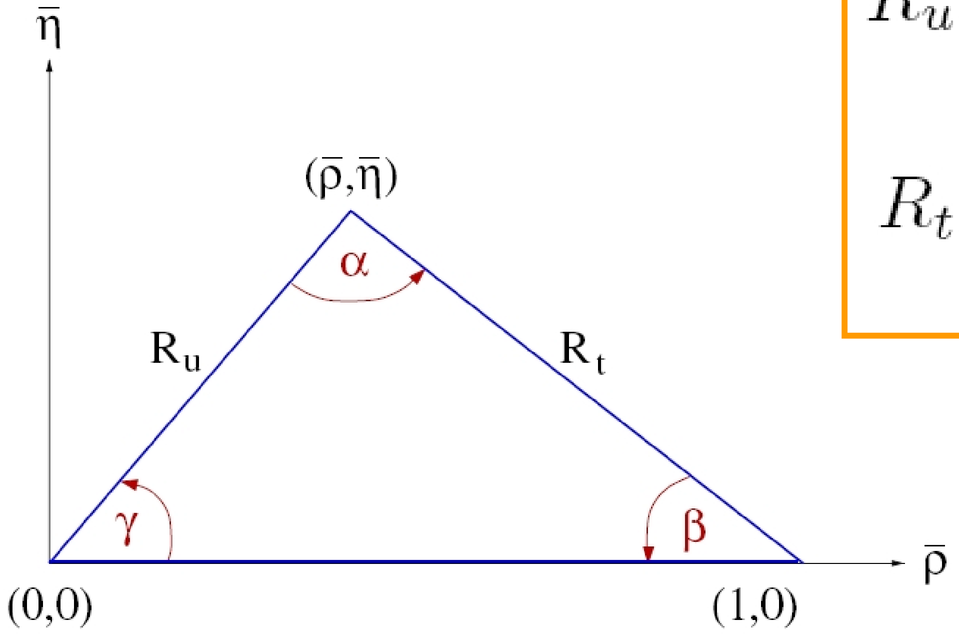
The Unitary Triangle

- The product of the 1st and 3rd columns gives (B-meson system)



$$\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*} + \frac{V_{cd}V_{cb}^*}{V_{cd}V_{cb}^*} + \frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*} = 0$$

The Unitary Triangle



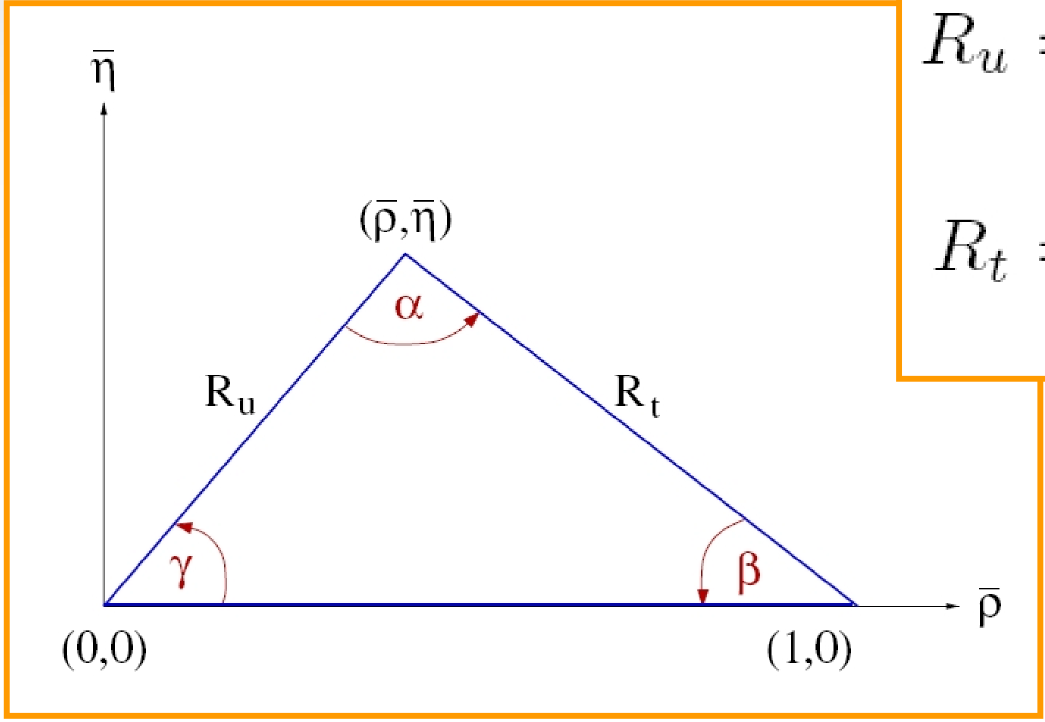
$$R_u = \left| \frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \right| = \sqrt{\overline{\rho}^2 + \overline{\eta}^2} \ ,$$

$$R_t = \left| \frac{V_{td} V_{tb}^*}{V_{cd} V_{cb}^*} \right| = \sqrt{(1 - \overline{\rho})^2 + \overline{\eta}^2}$$

$$\overline{\rho} + i\overline{\eta} \equiv - \frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*}$$

$$\rho + i\eta = \frac{\sqrt{1 - A^2\lambda^4}(\overline{\rho} + i\overline{\eta})}{\sqrt{1 - \lambda^2}\left[1 - A^2\lambda^4(\overline{\rho} + i\overline{\eta})\right]}$$

The Unitary Triangle



$$R_u = \left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| = \sqrt{\bar\rho^2+\bar\eta^2}\ ,$$

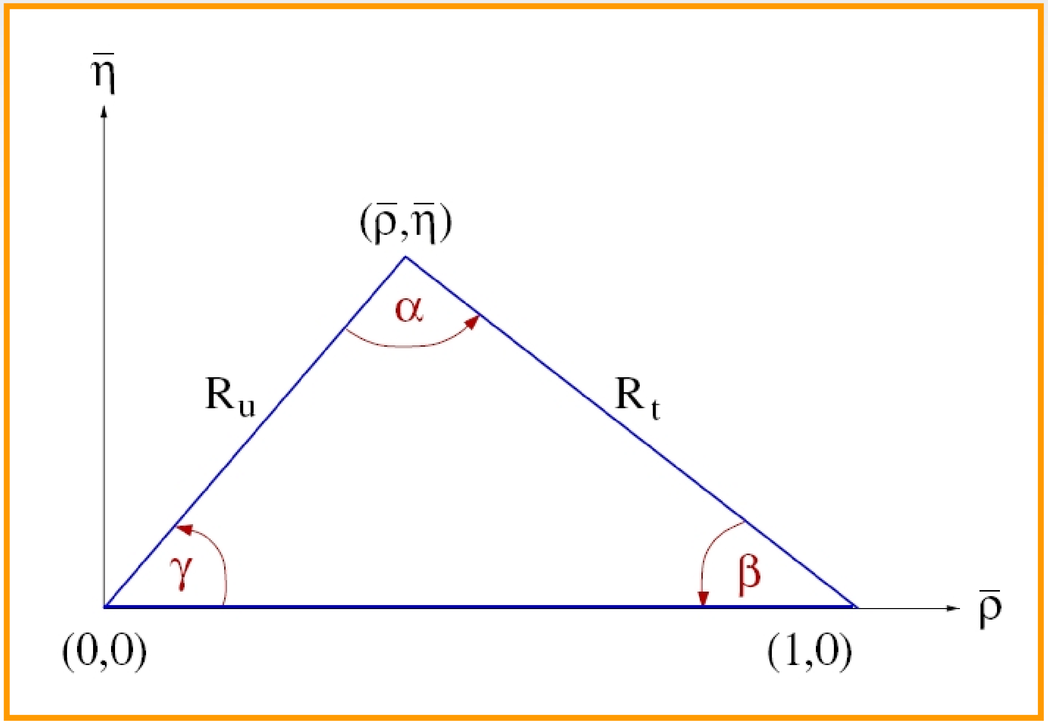
$$R_t = \left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| = \sqrt{(1-\bar\rho)^2+\bar\eta^2}$$

$$\bar\rho + i\bar\eta \equiv -\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}$$

to all orders in λ

$$\rho + i\eta = \frac{\sqrt{1-A^2\lambda^4}(\bar\rho+i\bar\eta)}{\sqrt{1-\lambda^2}\left[1-A^2\lambda^4(\bar\rho+i\bar\eta)\right]}$$

The Unitary Triangle

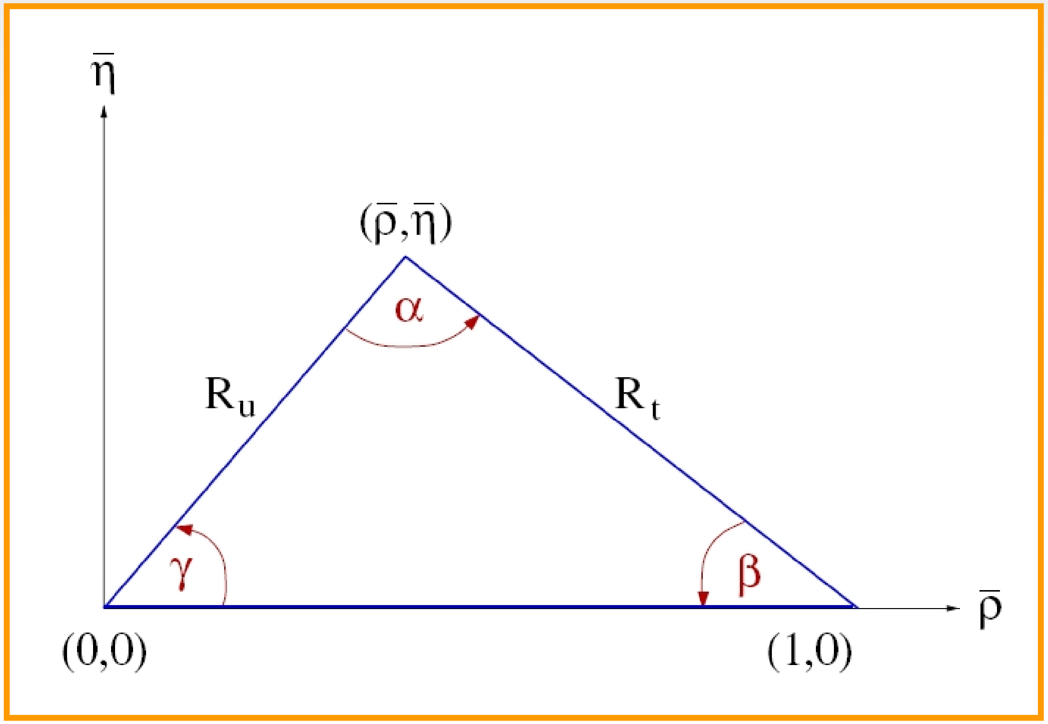


$$\boxed{\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]}$$

$$\boxed{\beta = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]}$$

$$\boxed{\gamma = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]}$$

The Unitary Triangle



$$\alpha = \arg\left[-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right]$$

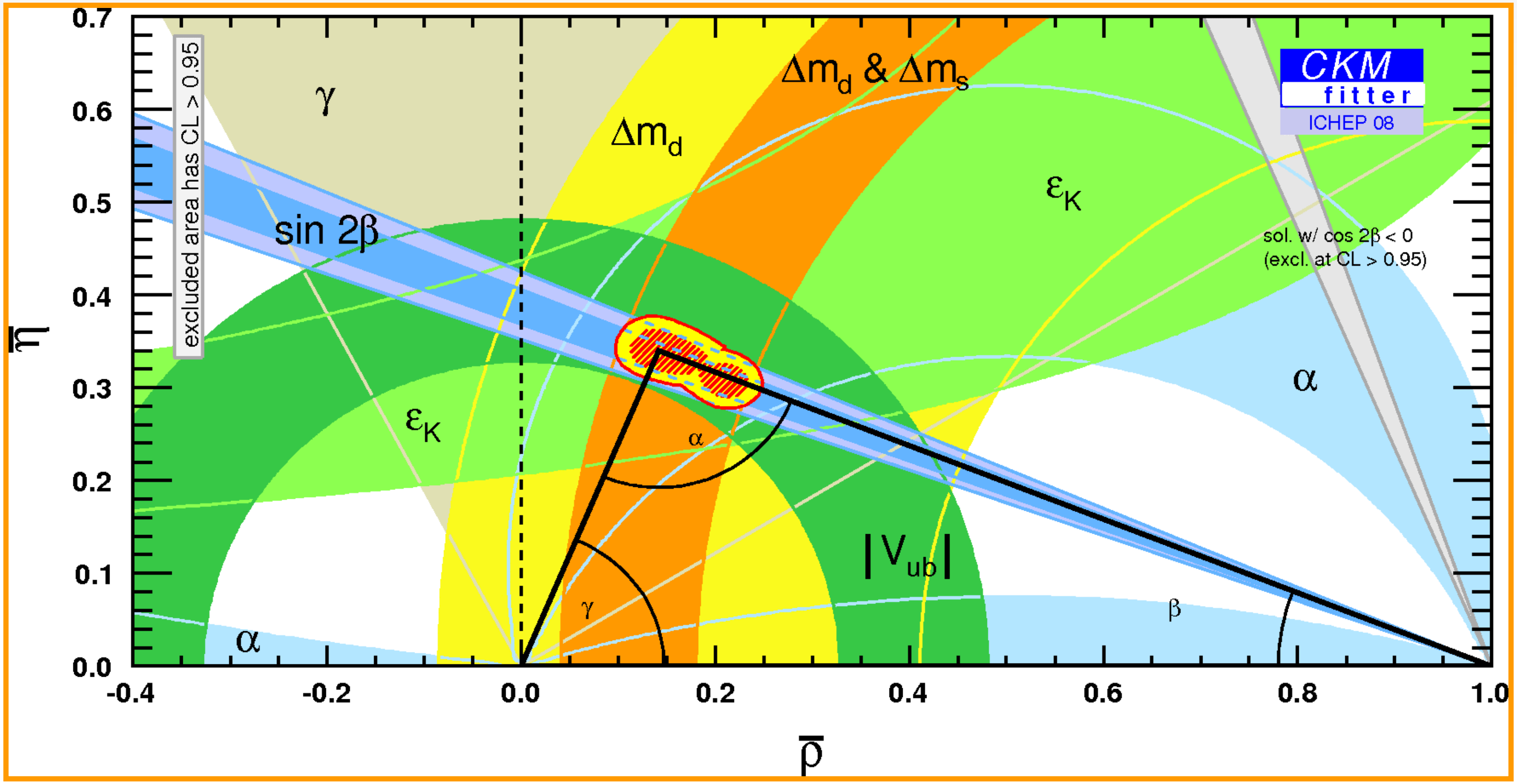
$$\beta = \arg\left[-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right]$$

$$\gamma = \arg\left[-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right]$$

There are also other ingredients constraining the UT: ε_k, Δm_d, Δm_s, $B \rightarrow \tau\nu$, etc.

The Unitary Triangle

Current status



The Unitary Triangle

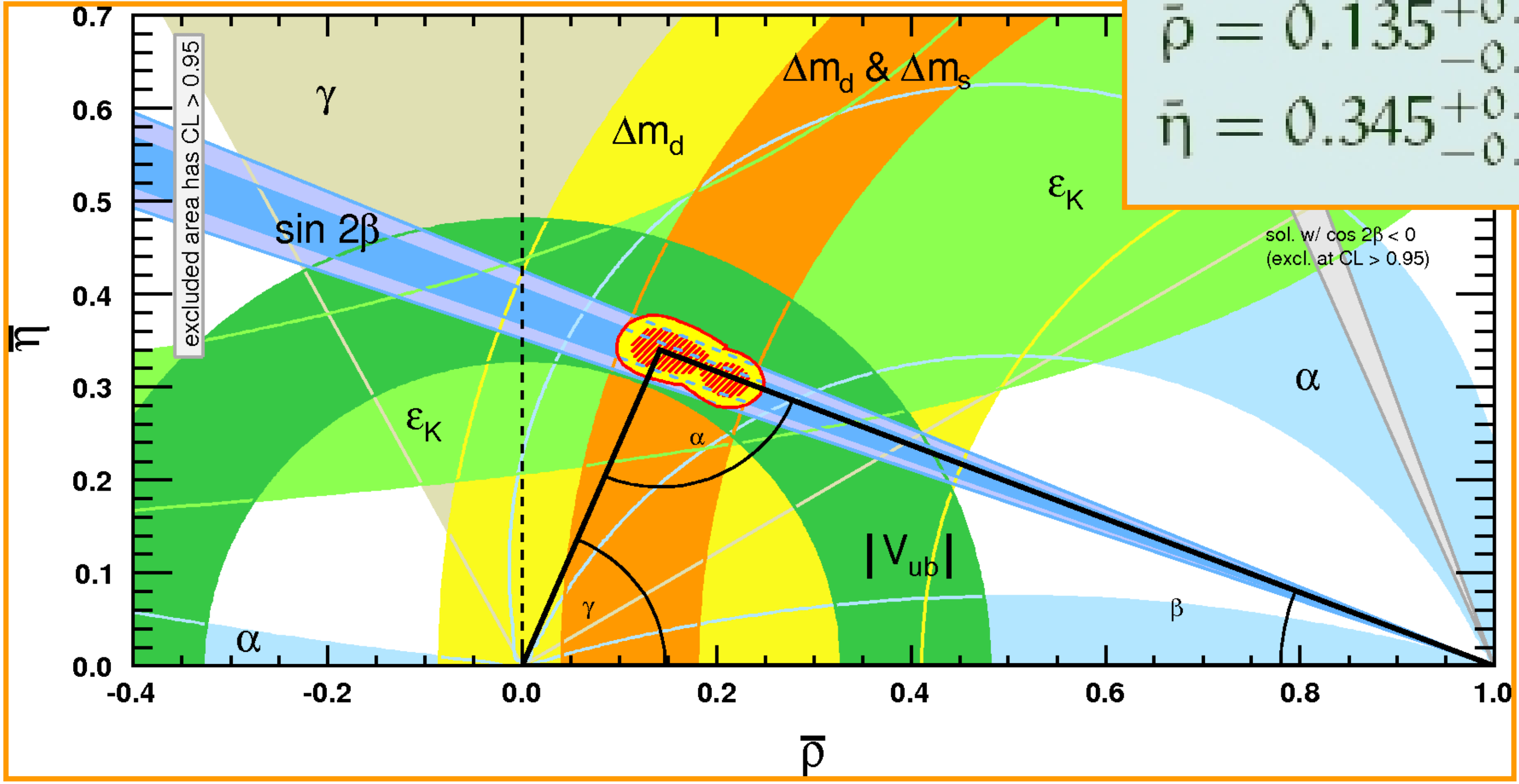
Current status

$$A = 0.795^{+0.025}_{-0.015}$$

$$\lambda = 0.2252 \pm 0.0008$$

$$\bar{\rho} = 0.135^{+0.033}_{-0.016}$$

$$\bar{\eta} = 0.345^{+0.015}_{-0.018}$$



What's next?

- Goal: high precision measurements of the CKM coefficients
- Why ?
  - precise determination of CKM coefficients to look for deviations of SM predictions

  - look for New Physics via CP violating phases and/or rare decays

What's next?

- Goal: high precision measurements of the CKM coefficients
- How ?
  - consistency check of UT → more statistics, improvements in γ, etc.
  - comparison of different measurements of the same quantity, one sensitive and another insensitive to NP
  - $|\Delta F|=1$ and $|\Delta F|=2$ FCNC rare decays and mixing resp.
  - etc.

Beauty Physics examples

Measurements of CP asymmetries in the proper time distribution of B^0s going to a common final state → direct information on the angles of UT

$$\boxed{A_{CP} = \frac{\Gamma(\overline{B}^0(t) \rightarrow f) - \Gamma(B^0(t) \rightarrow f)}{\Gamma(\overline{B}^0(t) \rightarrow f) + \Gamma(B^0(t) \rightarrow f)}}$$

B^0 → charmonium + K^0: cleanest modes

$A_{CP} \propto \sin(2\beta)\sin(\Delta m t)$

α from $B_d \to \pi^+\pi^-\pi^0$

Current value: $\alpha = (88^{+6}_{-5})^\circ$

CKMFitter

- Assume that $B_d \to \pi\pi\pi$ proceeds mainly through $\rho \to \pi\pi$
- Six interfering modes ($B_d \to \rho^+\pi^-$, $B_d \to \rho^-\pi^+$, $B_d \to \rho^0\pi^0$ and c.c.)
- Tree and penguin transitions contribute to each mode

- Proper time evolution of tagged Dalitz distributions provides enough information to determine simultaneously α and the relative amplitudes and strong phases between all the transitions
- Clean extraction of α in the $[0,\pi]$ range

- LHCb @ 2 fb^{-1} → $\sigma(\alpha) < 10^\circ$

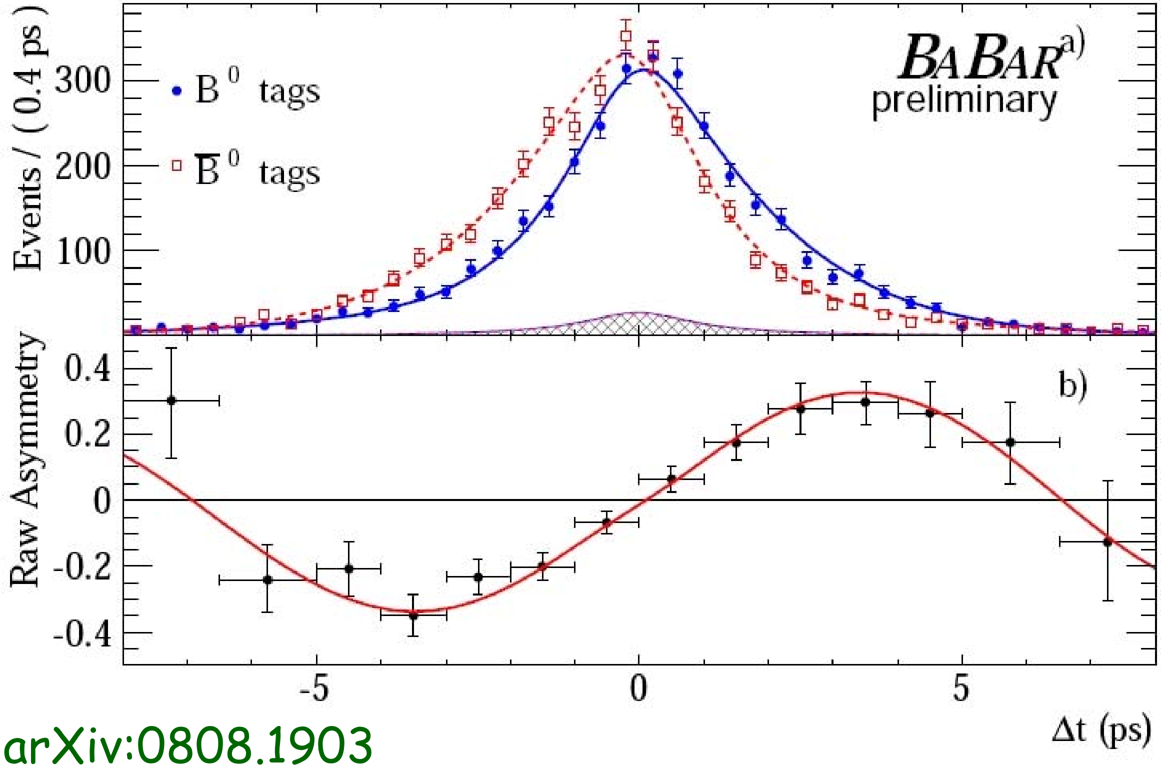
sin(2β) from $B^0 \rightarrow J/\Psi\ K_s$

world average (HFAG): sin(2β) = 0.676 ± 0.026

β = (21.2 ± 1.0)°

Dominated by BaBar and Belle

LHCb:
236K events / 2 fb^{-1}
σ[sin(2β)] ~ 0.020
(σ ~ 0.025 in
B-factories)



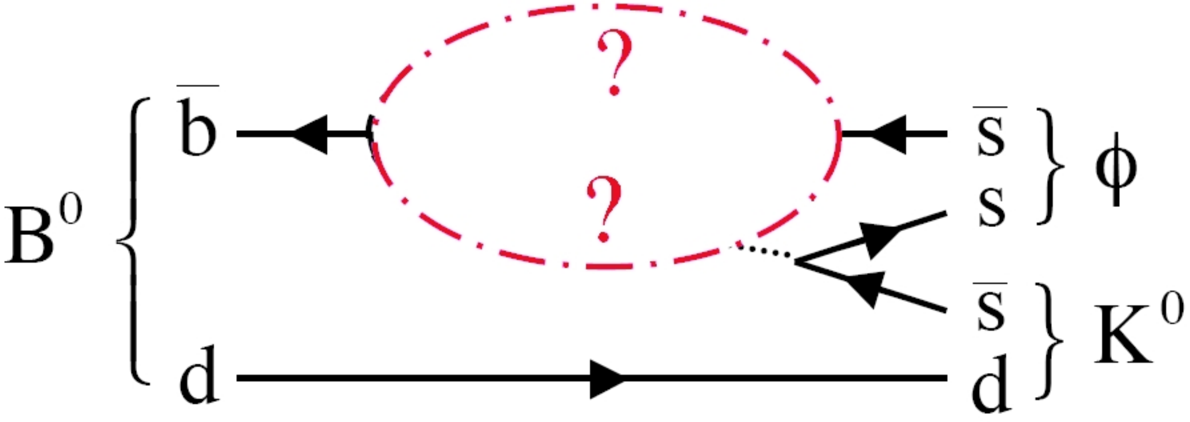
arXiv:0808.1903

sin(2β) from $B^0 \to J/\Psi\ K_s$ vs $B^0 \to \phi K^0$

world average (HFAG): sin(2β) = 0.676 ± 0.026

β = (21.2 ± 1.0)°

Compare with sin(2β) extracted from $B^0 \to \phi K^0 \to$ NP in penguin diagrams leading to observable deviations from SM predictions



New particles might appear as virtual particles in loops

measurements of γ

Current value: $\gamma = (72^{+34}_{-30})^{\circ}$

CKMFitter

measurements of γ

Current value: $\gamma = (72^{+34}_{-30})^\circ$

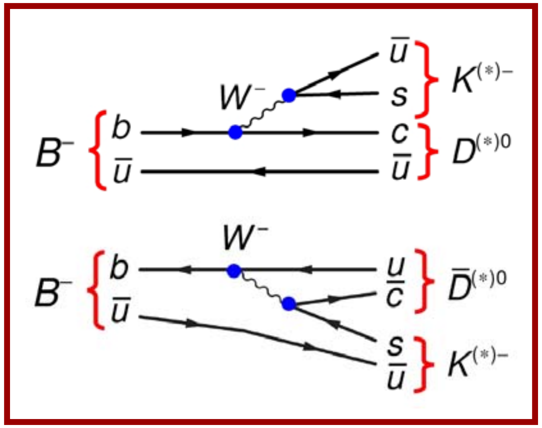
Large errors

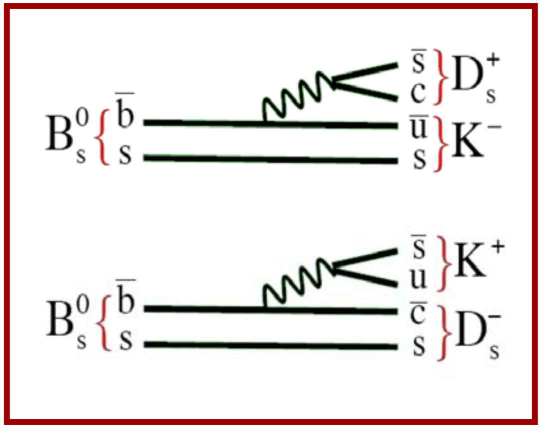
Several possibilities

$B^+ \rightarrow D^{(*)0} K^{(*)+}$

$B_s \rightarrow D_s K$

...

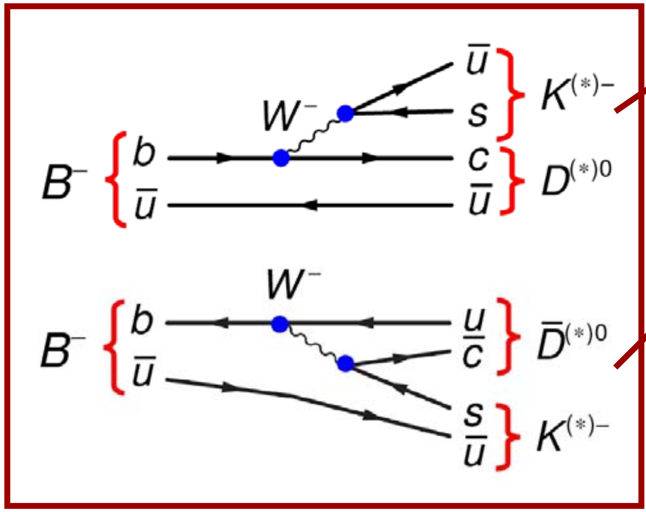




measurements of γ

Current value: $\gamma = \left(72^{+34}_{-30}\right)^{\circ}$

$B^+ \to D^{(*)0} K^{(*)+}$



b → c, dominant ($B^- \to D^0 K^-$)

b → u, color suppressed ($B^- \to \bar{D}^0 K^-$)

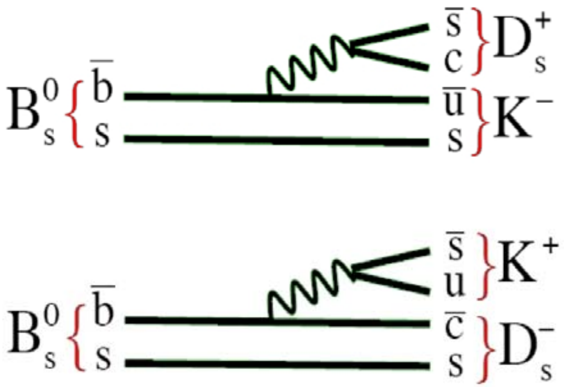
- Reconstruct D in final states accessible to both, D^0 and $\bar{D}^0$ ($K\pi$, KK, $\pi\pi$, $K_s\pi\pi$, etc).
- Use several methods (ADS – D → CP eigenstates), GLW – D → flavor states, GGSZ – interference in Dalitz Plot).
- Involves tree decays only.
- $\sigma_{stat}(\gamma) \sim 9^{\circ}$ for 2 fb^{-1} in LHCb.

measurements of γ

Current value: $\gamma = (72^{+34}_{-30})^{\circ}$

$B_s \rightarrow D_s K$

Tree decays b → c and b → u interfering via B_s mixing

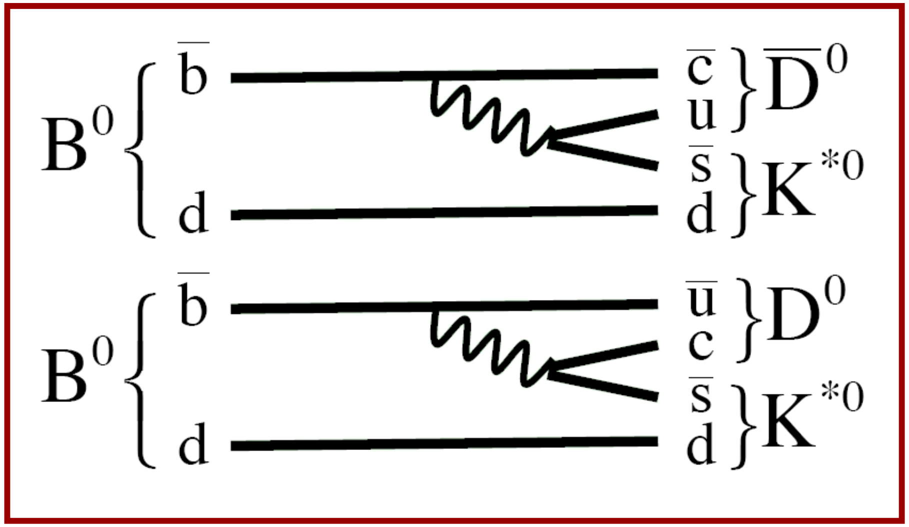


- Determine $2\beta_s + \gamma$ ➔ γ in a clean way.
- The two decay amplitudes are ~ λ^3 ➔ the ratio can be extracted from data.
- LHCb expects 6200 / 2 fb^{-1} – $B_s \rightarrow D_s\pi$ background ~ 15 % thanks to the excellent PID – $\sigma(2\beta_s+\gamma) \sim (9 - 12)^{\circ}$ with $\Delta m_s \sim 20\ ps^{-1}$
- 8-fold ambiguity resolved (→ 2-fold) if $\Delta\Gamma_s$ large enough.

measurements of γ

Current value: $\gamma = \left(72^{+34}_{-30}\right)^\circ$

Other modes: $B^0 \rightarrow D^0 K^{*0}$

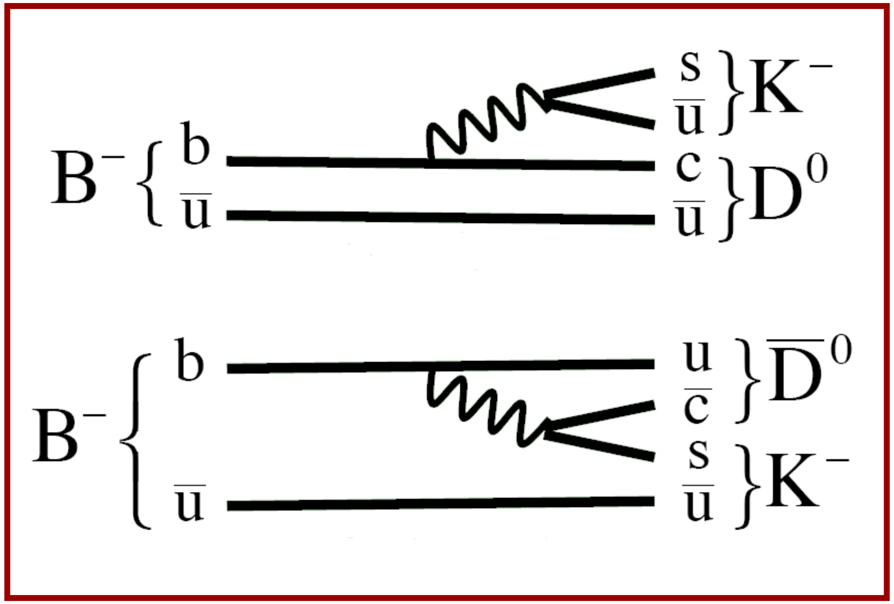


- Two color suppressed diagrams interfering via D^0 mixing
- Six decay rates to be measured depending on the D^0 decay ($K^+\pi^-$, $K^-\pi^+$, K^+K^- and c.c.)
- LHCb expectation: $\sigma(\gamma) \sim 8^o$ in one year

measurements of γ

Current value: $\gamma = \left(72^{+34}_{-30}\right)^\circ$

Other modes: $B^\pm \rightarrow D^0 K^\pm$



- measure the relative rates for $B^- \rightarrow D^0K^-$ and $B^+ \rightarrow \bar{D}^0K^+$
- Use the ADS (Atwood, Dunietz, Soni) method
- Candidate for the most precise determination of γ in LHCb: $\sigma(\gamma) \sim 5^\circ$ in one year

B_s mixing phase ($b \to c\bar{c}s$)

Golden $b \to c\bar{c}s$ mode is $B_s \to J/\psi\,\phi$

B_s mixing phase in SM:

$\beta_s = -\arg(V_{ts}{}^2) = -2\lambda\eta^2 \sim -0.04$

$$A_{CP}(t) = \frac{-\eta_f \sin 2\beta_s \sin(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2) - \eta_f \cos 2\beta_s \sinh(\Delta\Gamma_s t/2)}$$

$$2\beta_s = -0.57^{+0.24}_{-0.30}\ , \quad \Delta\Gamma_s = 0.19 \pm 0.07\ ps^{-1}$$

D0 Collaboration – arXiv:0/802.2255

B_s mixing phase ($b \rightarrow c\bar{c}s$)

Golden $b \rightarrow c\bar{c}s$ mode is $B_s \rightarrow J/\psi\ \phi$

B_s mixing phase in SM:

$\beta_s = -\arg(V_{ts}^2) = -2\lambda\eta^2 \sim -0.04$

LHCb sensitivity @ 2 fb^{-1}:

~130 k-events $B_s \rightarrow J/\psi(\mu\mu)\ \phi$

$\sigma_{stat}(2\beta_s) \sim 0.023$

$\sigma_{stat}(\Delta\Gamma_s/\Gamma_s) \sim 0.009$

$$A_{CP}(t) = \frac{-\eta_f \sin 2\beta_s \sin(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2) - \eta_f \cos 2\beta_s \sinh(\Delta\Gamma_s t/2)}$$

$$2\beta_s = -0.57^{+0.24}_{-0.30}\ , \quad \Delta\Gamma_s = 0.19 \pm 0.07\ ps^{-1}$$

D0 Collaboration – arXiv:0/802.2255

B_s mixing phase ($b \rightarrow c\bar{c}s$)

Golden $b \rightarrow c\bar{c}s$ mode is $B_s \rightarrow J/\psi\ \phi$

B_s mixing phase in SM:

$\beta_s = -\arg(V_{ts}^2) = -2\lambda\eta^2 \sim -0.04$

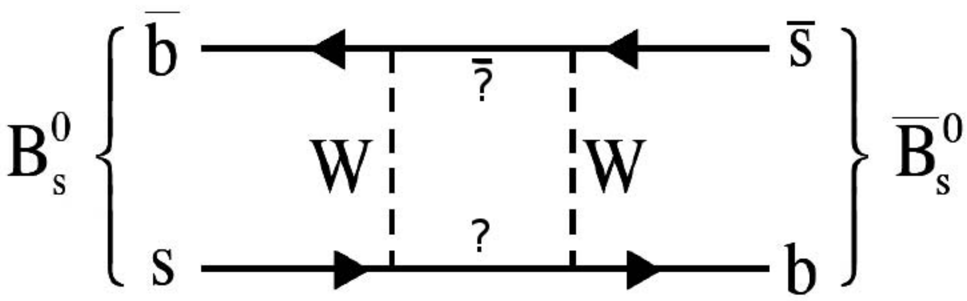
LHCb sensitivity @ 2 fb^{-1}:

$\sim$130 k-events $B_s \rightarrow J/\psi(\mu\mu)\ \phi$

$\sigma_{stat}(2\beta_s) \sim 0.023$

$\sigma_{stat}(\Delta\Gamma_s/\Gamma_s) \sim 0.009$

Sensitive probe of NP



e.g. larger contribution in presence of a 4th generation.

B_s mixing phase ($b \rightarrow c\bar{c}s$)

Golden $b \rightarrow c\bar{c}s$ mode is $B_s \rightarrow J/\psi\ \phi$

B_s mixing phase in SM:

$\beta_s = -\arg(V_{ts}^2) = -2\lambda\eta^2 \sim -0.04$

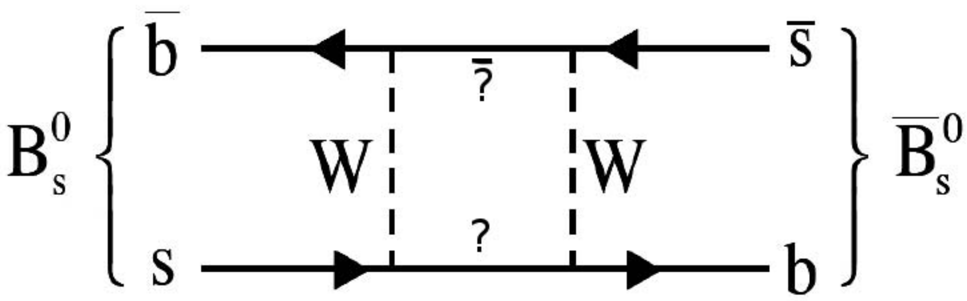
LHCb sensitivity @ 2 fb^{-1}:

~130 k-events $B_s \rightarrow J/\psi(\mu\mu)\ \phi$

$\sigma_{stat}(2\beta_s) \sim 0.023$

$\sigma_{stat}(\Delta\Gamma_s/\Gamma_s) \sim 0.009$

Sensitive probe of NP



e.g. larger contribution in presence of a 4th generation.

then $\beta_s \neq \beta_s^{SM} = -\arg(V_{ts}^2)$

$\Delta m_s \neq \Delta m_s^{SM} \propto |V_{ts}^2|$

B_s mixing phase ($b \to c\bar{c}s$)

Golden $b \to c\bar{c}s$ mode is $B_s \to J/\psi\, \phi$

B_s mixing phase in SM:

$\beta_s = -\arg(V_{ts}{}^2) = -2\lambda\eta^2 \sim -0.04$

LHCb sensitivity @ 2 fb^{-1}:

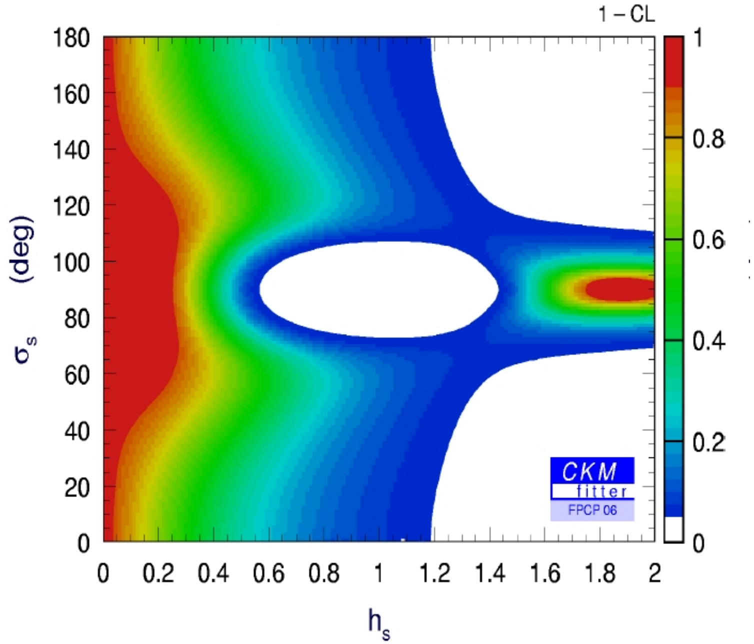
~130 k-events $B_s \to J/\psi(\mu\mu)\,\phi$

$\sigma_{stat}(2\beta_s) \sim 0.023$

$\sigma_{stat}(\Delta\Gamma_s/\Gamma_s) \sim 0.009$

Representing amplitudes as

$$M_{12} = \left(1 + h_s e^{2i\sigma_s}\right) M_{12}^{SM}$$



then $\beta_s \neq \beta_s^{SM} = -\arg(V_{ts}{}^2)$

$\Delta m_s \neq \Delta m_s^{SM} \propto |V_{ts}{}^2|$

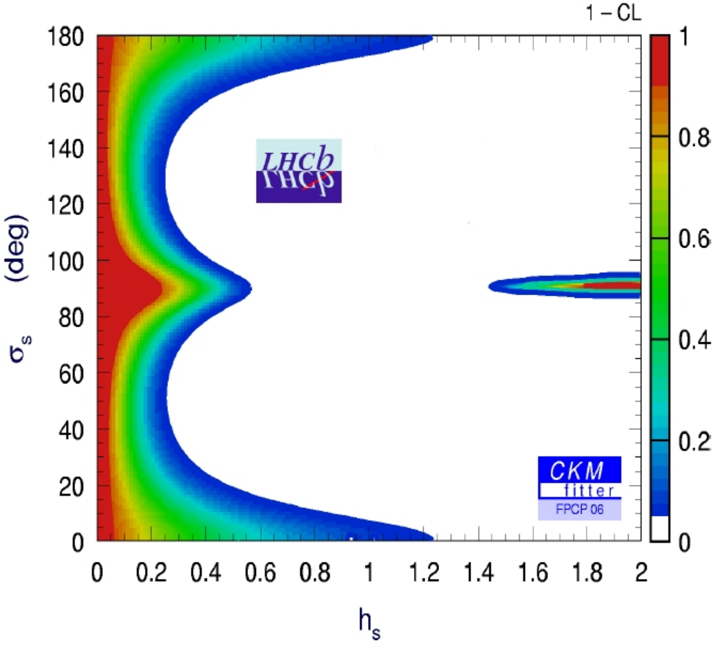
B_s mixing phase ($b \to c\bar{c}s$)

Golden $b \to c\bar{c}s$ mode is $B_s \to J/\psi\,\phi$

B_s mixing phase in SM:

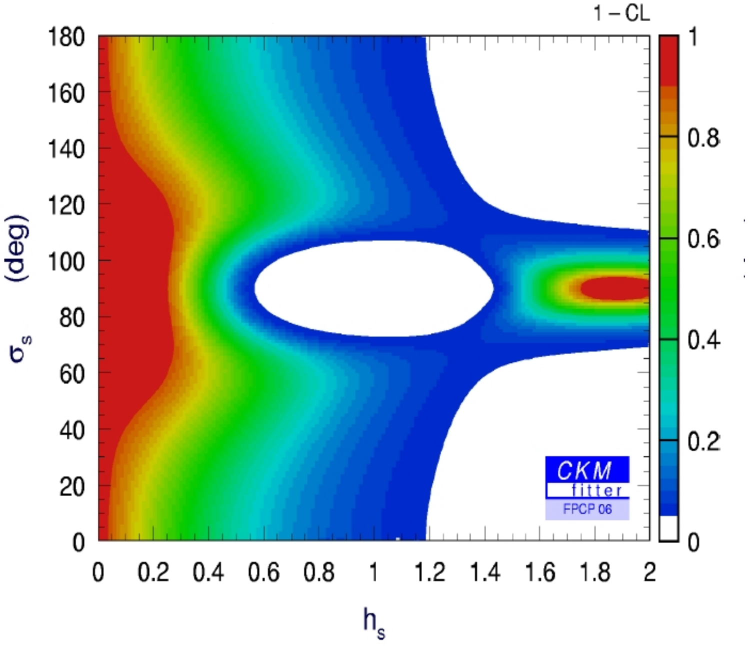
$\beta_s = -\arg(V_{ts}^2) = -2\lambda\eta^2 \sim -0.04$

LHCb @ 0.2 fb^{-1} / $\sigma(2\beta_s) \sim 0.1$



Representing amplitudes as

$$M_{12} = \left(1 + h_s e^{2i\sigma_s}\right) M_{12}^{SM}$$



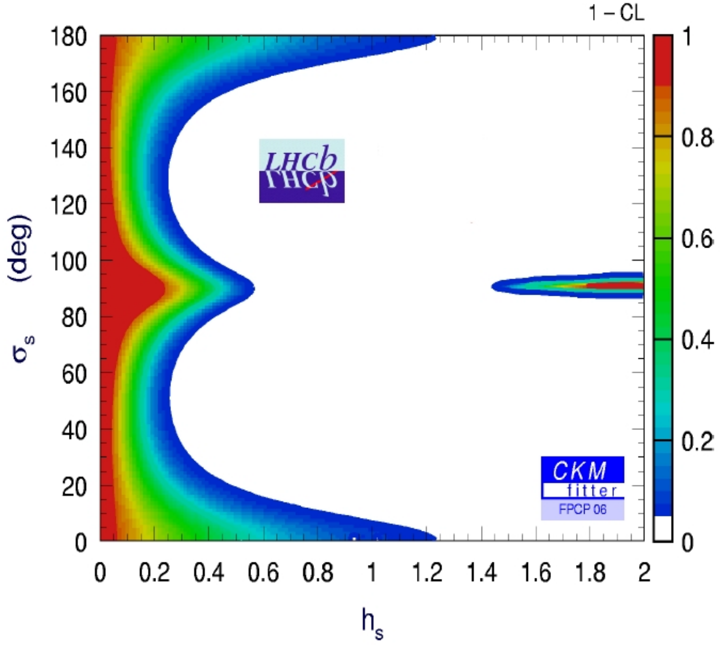
B_s mixing phase ($b \rightarrow c\bar{c}s$)

Golden $b \rightarrow c\bar{c}s$ mode is $B_s \rightarrow J/\psi\, \phi$

B_s mixing phase in SM:

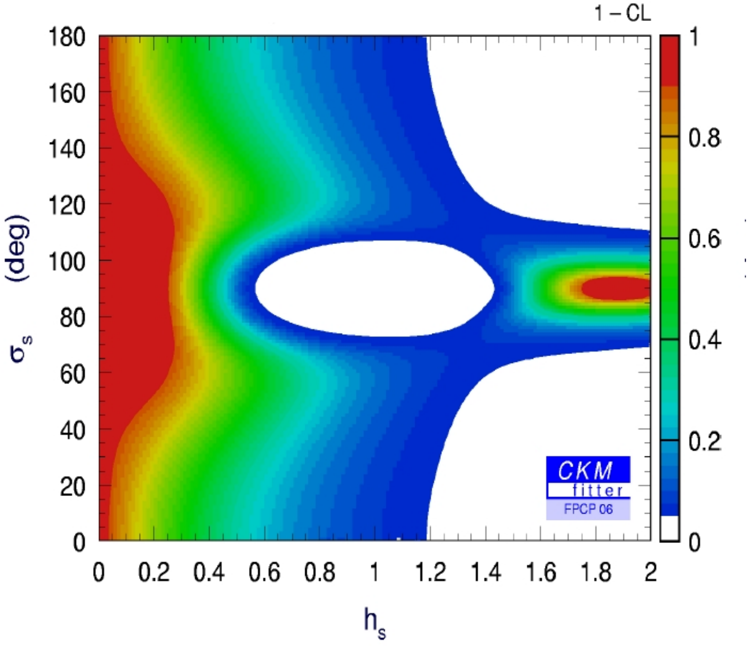
$\beta_s = -\arg(V_{ts}^2) = -2\lambda\eta^2 \sim -0.04$

Very first data of LHCb can exclude a significant region the (σ_s, h_s) plane



Representing amplitudes as

$$M_{12} = \left(1 + h_s e^{2i\sigma_s}\right) M_{12}^{SM}$$

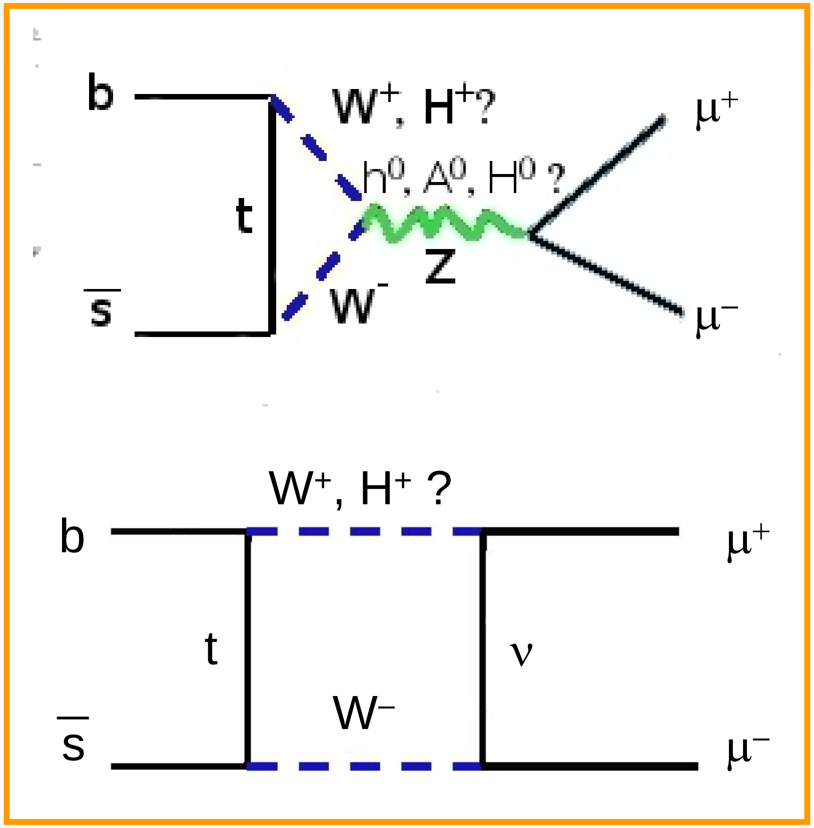


Rare decays: $B^0_s \to \mu^+\mu^-$

- SM rate suppressed by ~ $m_\mu^2/m_B^2 \to BR = 3.4 \times 10^{-9}$
- Possible enhancement in MSSM → New virtual particles in loops

See e.g.
- JHEP11 (2001) 001,
- Phys. Rev. Lett. 84 (2000) 228,
- Phys. Lett. B 546 (2002) 96,
- etc.

Current limits from Tevatron:
- CDF → $BR < 5.8 \times 10^{-8}$ @ 95% CL
- D0 → $BR < 9.3 \times 10^{-8}$ @ 95 CL

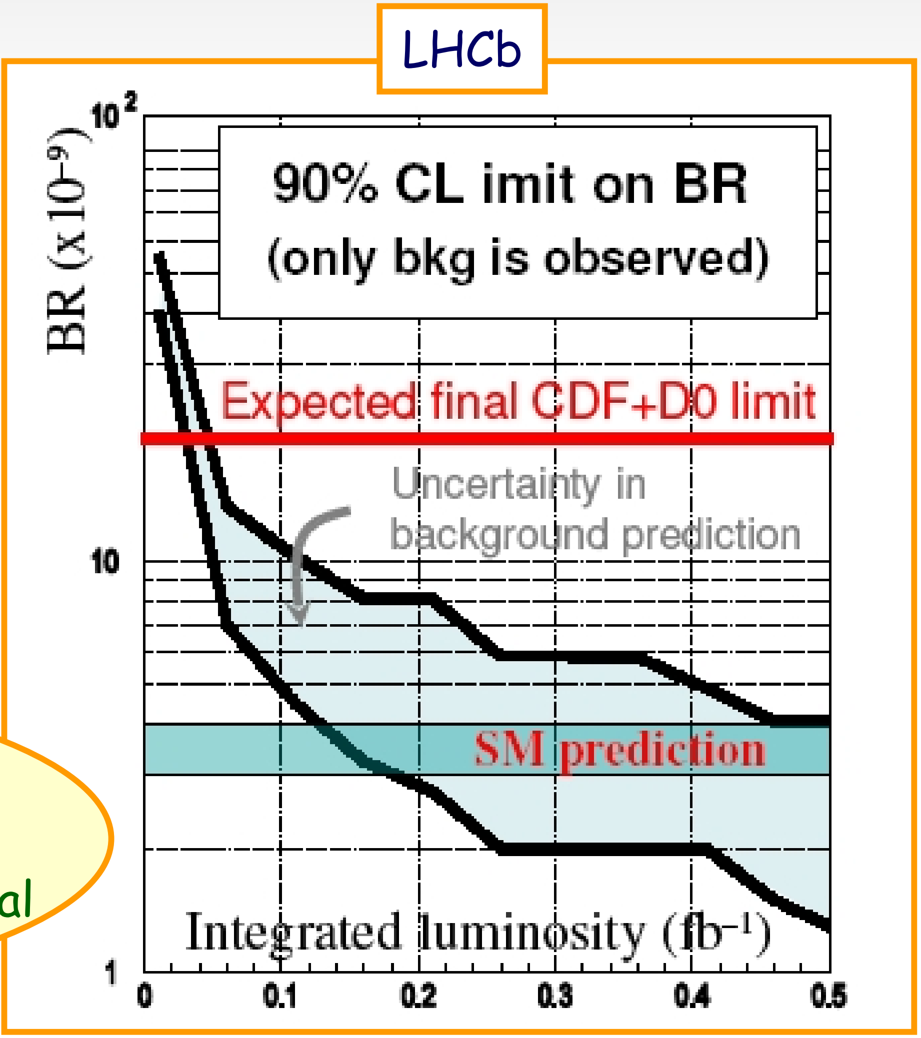


Rare decays: $B^0_s \rightarrow \mu^+\mu^-$

- SM rate suppressed by ~ m_μ^2/m_B^2 → BR = 3.4×10^{-9}
- Possible enhancement in MSSM → New virtual particles in loops

See e.g.
- JHEP11 (2001) 001,
- Phys. Rev. Lett. 84 (2000) 228,
- Phys. Lett. B 546 (2002) 96,
- etc.

Current limits from Tevatron:
- CDF → BR < 5.8×10^{-8} @ 95% CL
- D0 → BR < 9.3×10^{-8} @ 95 CL



$0.05\ fb^{-1}$ → better than CDF + D0
$0.5\ fb^{-1}$ → exclude BR down to SM
$6.0\ fb^{-1}$ → 5σ observation of SM signal
T'Jampens – Beach08

Conclusions-I (B-physics)

- LHC will pursue an extensive program in B-Physics
- LHCb has the potential to give answers to several questions from the very beginning (2 fb^{-1} ~ 1 year of data taking)
  - Remarks about LHCb:
    - excellent PID (K-π separation over a 100 GeV/c momentum range), mass (16 MeV/c^2 for $B_s \rightarrow J/\psi\,\phi$) and decay-time resolution (~ 40 fs)
    - robust trigger dedicated to B-physics
- Limits on NP scenarios will appear in the first months
- 5 years of data taking: clear view of the impact of NP on B-physics

Bonus track: Charm Physics

- B-mesons decay to (D^* + anything) with BR=22.5 %
- $D^* \rightarrow D^0 + \pi$ with BR ~ 60 something %
  - $BR(D^{*0} \rightarrow D^0\pi^0) = (61.9\pm2.9)$ %
  - $BR(D^{*+} \rightarrow D^0\pi^+) = (67.7\pm0.5)$ %
  - $BR(D^{*+} \rightarrow D^+\pi^0) = (30.7\pm0.5)$ %
- Then LHCb is also a large source of D^* (and hence of D^0) which can be used for charm physics and,
- As a mater of fact, LHCb has a dedicated trigger for the decay chain $B \rightarrow (D^* \rightarrow (D^0 \rightarrow hh) + \pi) + X$

Bonus track: Charm Physics

- The $D^* \rightarrow D^0 + \pi$ will be also used for PID (RICH) calibration
- D^0 and $\overline{D}^0$ tagged by using the π in the $D^* \rightarrow D^0 + \pi$

D^0 tagged signal yields @ 2 fb^{-1}

$D^0 \rightarrow K^-\pi^+$ (RS)	~	50×10^6
$D^0 \rightarrow K^+\pi^-$ (WS)	~	0.2×10^6
$D^0 \rightarrow K^+K^-$	~	5×10^6
$D^0 \rightarrow \pi^+\pi^-$	~	2×10^6

Only from B-mesons, also prompt charm

Similar number of prompt D* expected

Bonus track: Charm Physics

D^0 tagged signal yields @ 2 fb^{-1}

$D^0 \rightarrow K^-\pi^+$ (RS) ~ 50×10^6

$D^0 \rightarrow K^+\pi^-$ (WS) ~ 0.2×10^6

$D^0 \rightarrow K^+K^-$ ~ 5×10^6

$D^0 \rightarrow \pi^+\pi^-$ ~ 2×10^6

Several analysis are possible

- Time integrated and time dependent CP-Violation searches
  - Two body $D^0 \rightarrow K\pi$, K^-K^+ and $\pi^-\pi^+$ modes
  - Semileptonic decays $D^0 \rightarrow Kl\nu$
- Three body charged and neutral decays
  - $D^0 \rightarrow K_s\pi^+\pi^-$, $K_sK^+K^-$, $K_sK\pi$
  - $D^+ \rightarrow K^+K^-\pi^+$, $K\pi\pi$ from $D^{*+} \rightarrow D^+\pi^0$ (BR ~ 30 %)
- Four body decays
  - $D^0 \rightarrow K^+K^-\pi^+\pi^-$, $K\pi\pi\pi$

$D^0 - \overline{D}^0$ mixing

In absence of CP violation $D^0 - \overline{D}^0$ mixing described by

$$x = \frac{m_1 - m_2}{\Gamma} = \frac{\Delta m}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} = \frac{\Delta\Gamma}{2\Gamma}$$

The time-dependent WS decay rate is

$$r_{\mathrm{WS}}(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}\,y'(\Gamma t) + \frac{1}{2}R_M(\Gamma t)^2\right)$$

$$\begin{aligned} x' &\equiv x\cos\delta + y\sin\delta \\ y' &\equiv y\cos\delta - x\sin\delta \end{aligned}$$

$D^0 - \bar{D}^0$ mixing

In absence of CP violation $D^0 - \bar{D}^0$ mixing described by

$$x = \frac{m_1 - m_2}{\Gamma} = \frac{\Delta m}{\Gamma} \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma} = \frac{\Delta\Gamma}{2\Gamma}$$

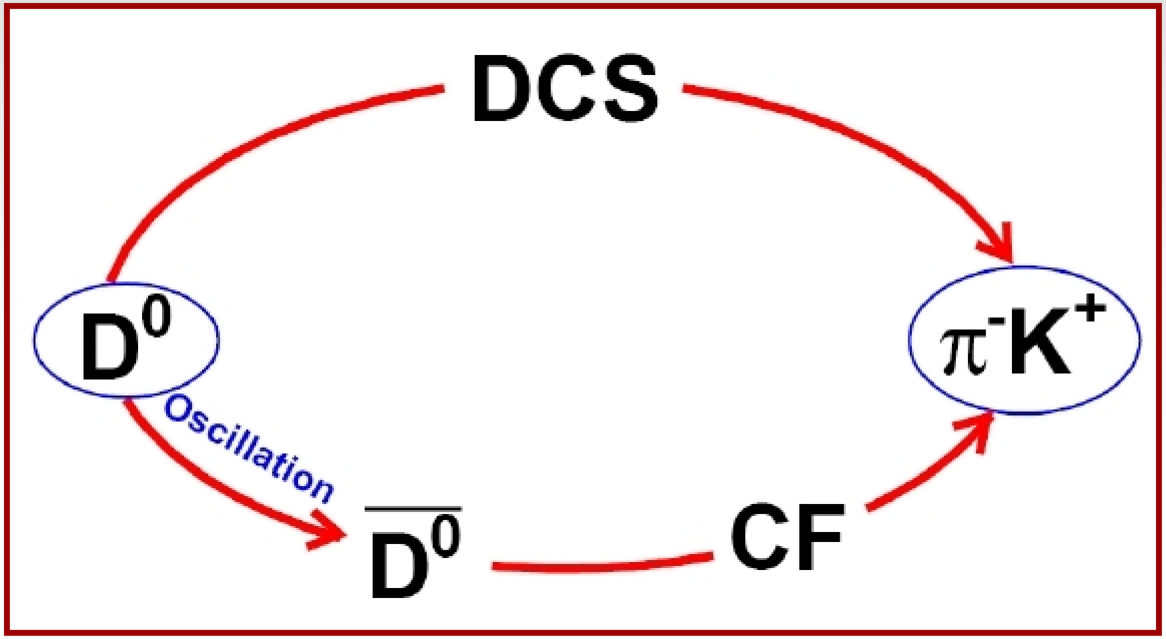
The time-dependent WS decay rate is

$$r_{\mathrm{WS}}(t) \propto e^{-\Gamma t} \left(R_D + \sqrt{R_D}\, y'(\Gamma t) + \frac{1}{2} R_M (\Gamma t)^2 \right)$$

R_D → ratio of the DCS to CF decay rates

$R_M = (x^2 + y^2)/2 = (x'^2 + y'^2)/2$ mixing rate

$D^0 - \overline{D}^0$ mixing



$$r_{\mathrm{WS}}(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}\, y'(\Gamma t) + \frac{1}{2} R_M (\Gamma t)^2\right)$$

R_D → ratio of the DCS to CF decay rates

$R_M = (x^2 + y^2)/2 = (x'^2 + y'^2)/2$ mixing rate

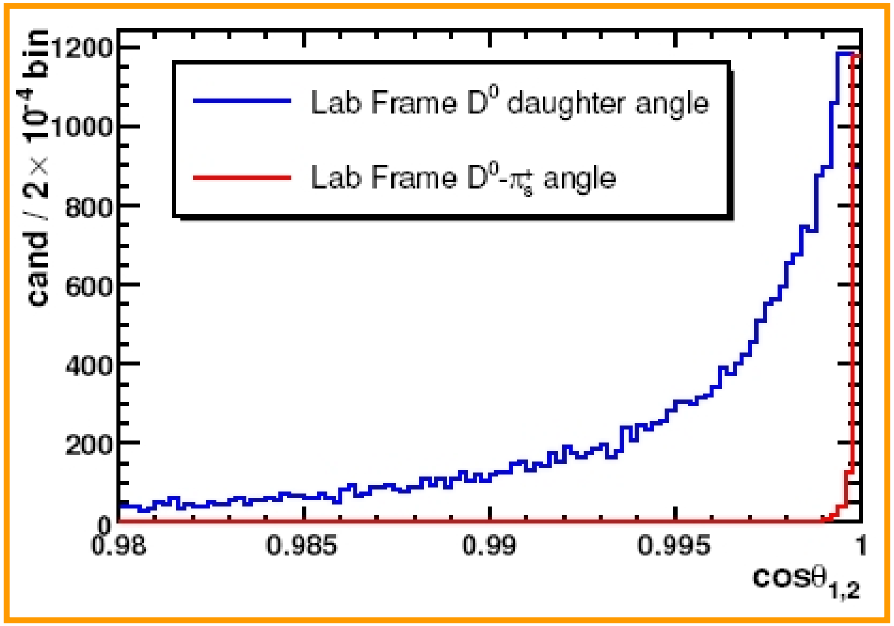
$D^0 - \overline{D}^0$ mixing

$$r_{WS}(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}y'(\Gamma t) + \frac{1}{2}R_M(\Gamma t)^2\right)$$

- $D^0/\overline{D}^0$ candidates tagged at the birth vertex
- Analysis requires a precise measurement of the decay time
  - the birth vertex of D^0 poorly determined (π and D^0 are almost collinear)

D^0 flight distance @ 60 GeV

$\beta\gamma c_\tau$ ~ 4 mm



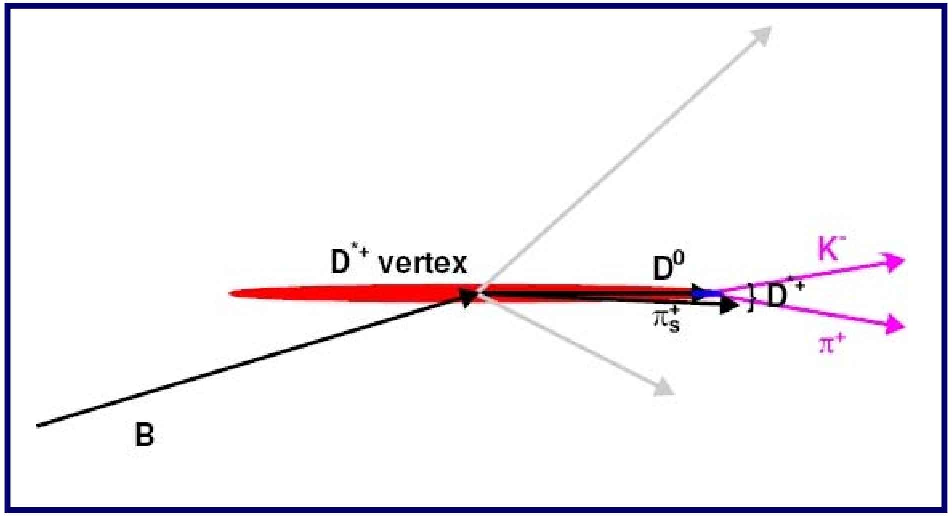
$D^0 - \bar{D}^0$ mixing

$$r_{\mathrm{WS}}(t) \propto e^{-\Gamma t}\left(R_D + \sqrt{R_D}\,y'(\Gamma t) + \frac{1}{2}R_M(\Gamma t)^2\right)$$

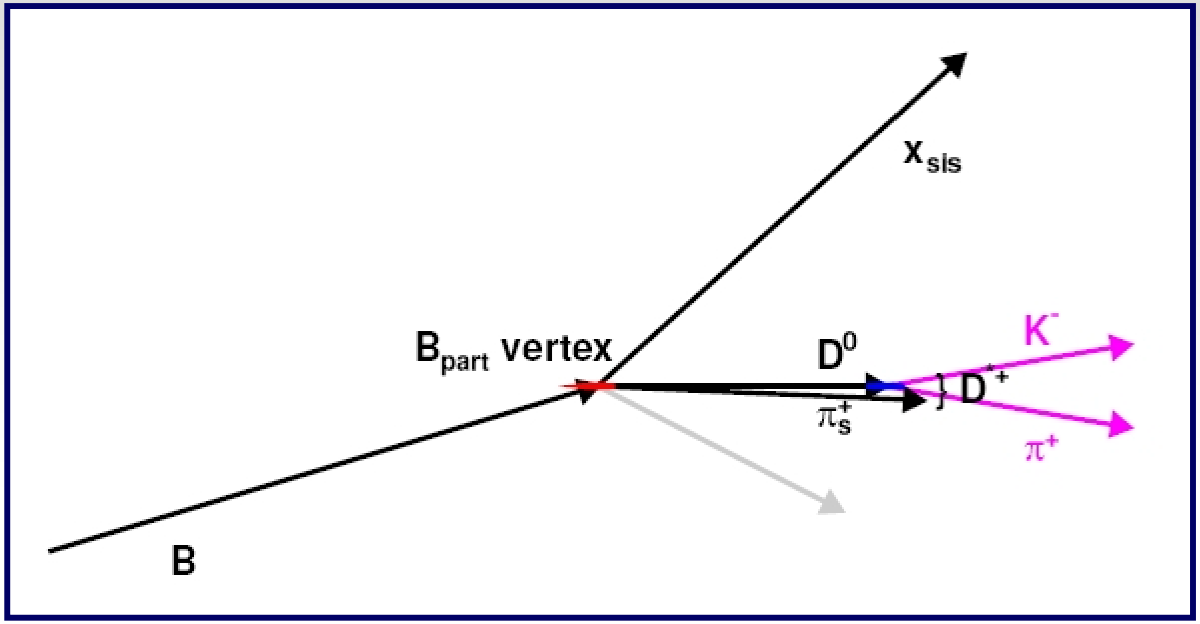
- $D^0/\bar{D}^0$ candidates tagged at the birth vertex
- Analysis requires a precise measurement of the decay time
  - the birth vertex of D^0 poorly determined (π and D^0 are almost collinear)
  - needs new techniques to improve resolution of the birth vertex

D^0 flight distance @ 60 GeV

$\beta\gamma c_\tau \sim 4$ mm



$D^0 - \bar{D}^0$ mixing

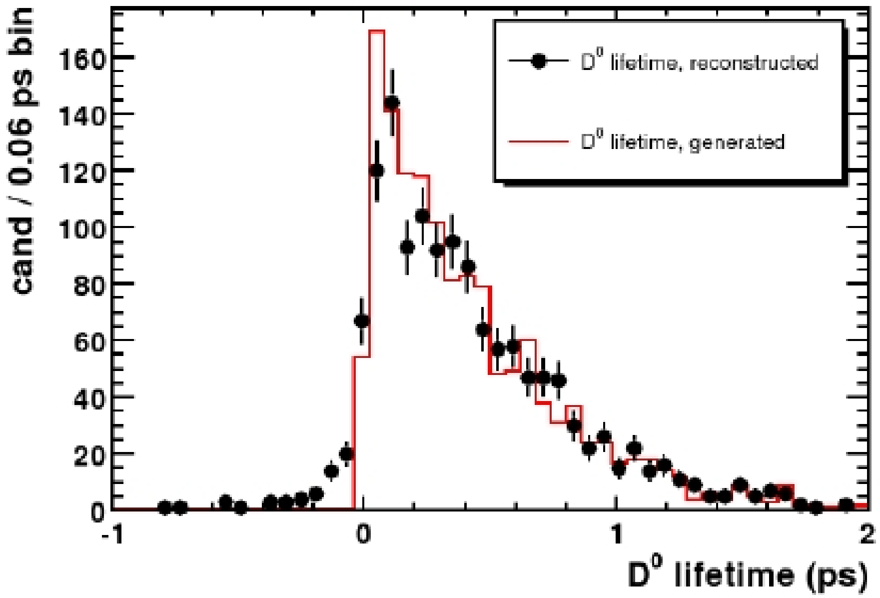


Improvement of the D^0 birth vertex

- partial reconstruction of the mother B-meson
- use de decay vertex do B-meson as the birth vertex of the D^0

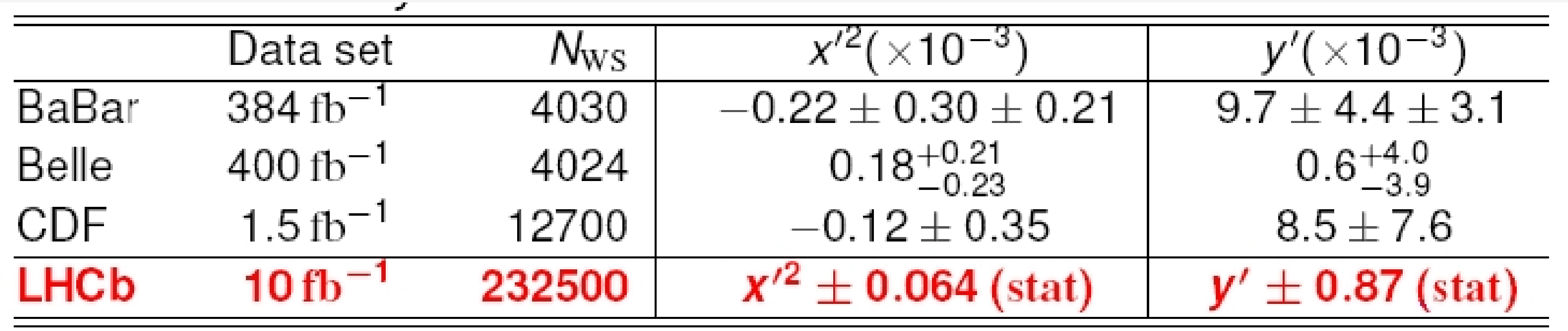
	D^0	D^{*+}	B_{part}
x	21.6 μm	187. μm	18.1 μm
y	16.9 μm	144. μm	18.4 μm
z	257. μm	4232. μm	237. μm

proper time resolution
0.465 ps → 0.045 ps



$D^0 - \bar{D}^0$ mixing

LHCb sensitivity



	Data set	N_{WS}	$x'^2 (\times 10^{-3})$	$y' (\times 10^{-3})$
BaBar	384 fb^{-1}	4030	$-0.22 \pm 0.30 \pm 0.21$	$9.7 \pm 4.4 \pm 3.1$
Belle	400 fb^{-1}	4024	$0.18^{+0.21}_{-0.23}$	$0.6^{+4.0}_{-3.9}$
CDF	1.5 fb^{-1}	12700	-0.12 ± 0.35	8.5 ± 7.6
LHCb	**10 fb^{-1}**	**232500**	$x'^2 \pm 0.064$ **(stat)**	$y' \pm 0.87$ **(stat)**

Current status:

- BaBar, Belle and CDF reported evidence of mixing
- No evidence of CP-Violation in mixing

Conclusions –II (Charm physics)

- LHCb will record an impressive amount of charm events
- LHCb has an exciting potential for charm physics
- The dedicated D^* trigger will provide ~ 10^8 tagged $D^0 \rightarrow hh$ / 2 fb^{-1} ➔ unprecedent sensitivity to search for D^0-$\overline{D}^0$ mixing and CP-Violation
- Previous measurements can be greatly improved
- x, y ~$O(10^{-3})$ in SM. If bigger values ➔ NP ?
- Multi-body D decay studies are also possible

Conclusions

- LHCb has an interesting potential for B-physics but also for Charm-physics
- Even in the first months / year of data taking, LHCb could produce interesting results concerning NP / limits to NP