Using beauty to measure the difference between matter and antimatter

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Supervisor
Dr. A.Pellegrino

NIKHEF
LHCb

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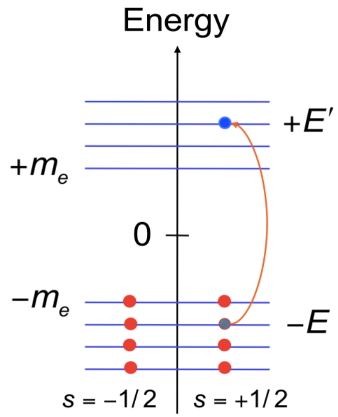
- The Dirac equation (1927)

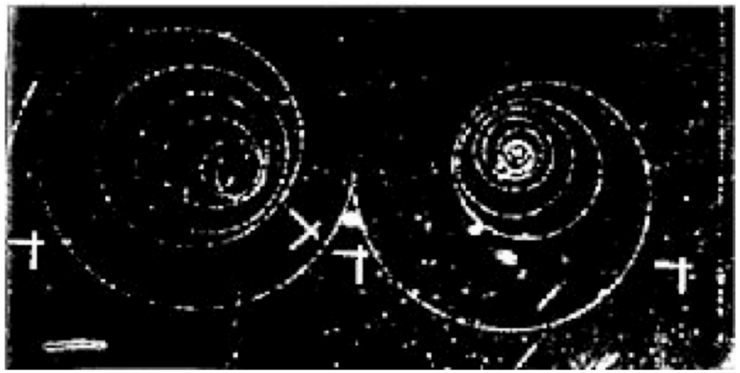
$$(i\gamma^{\mu}\partial_{\mu} - m)\psi(\vec{x},t) = 0$$

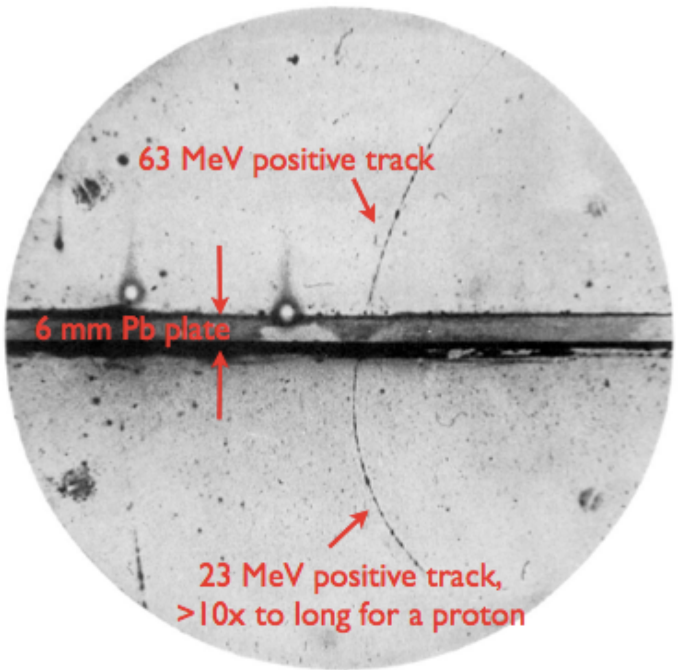
$$E = \pm\sqrt{\vec{p}^{2} + m^{2}}$$



- Anderson discovers positron (1931)

  - Confirmed with $\gamma \rightarrow e^{+}e^{-}$

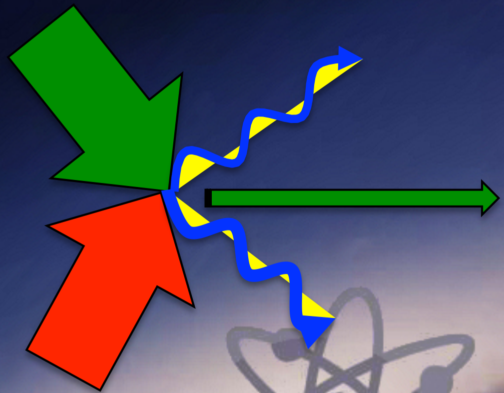




2

Annihilation

Matter + Antimatter = Light



3

Our Universe

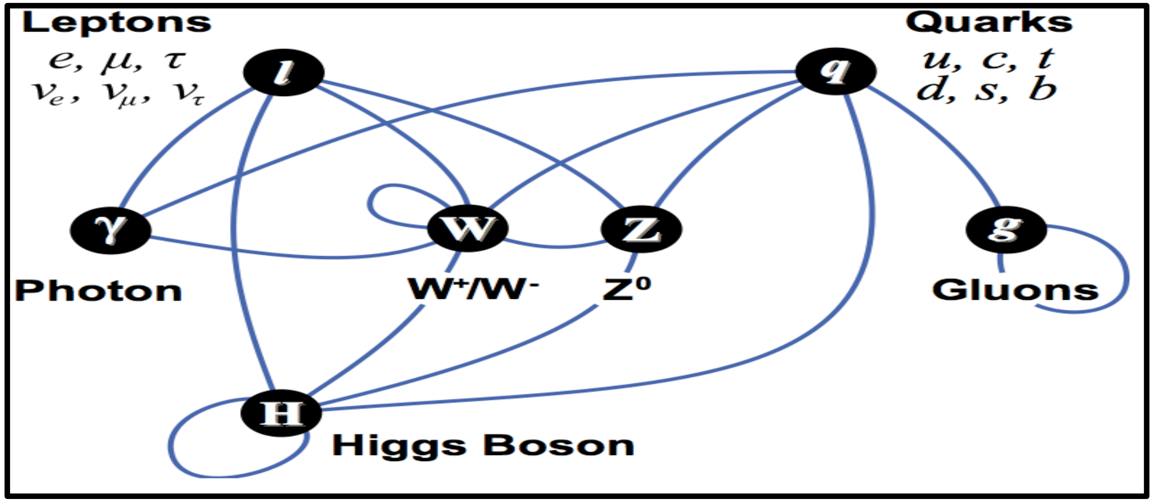
Matter dominates the universe

1

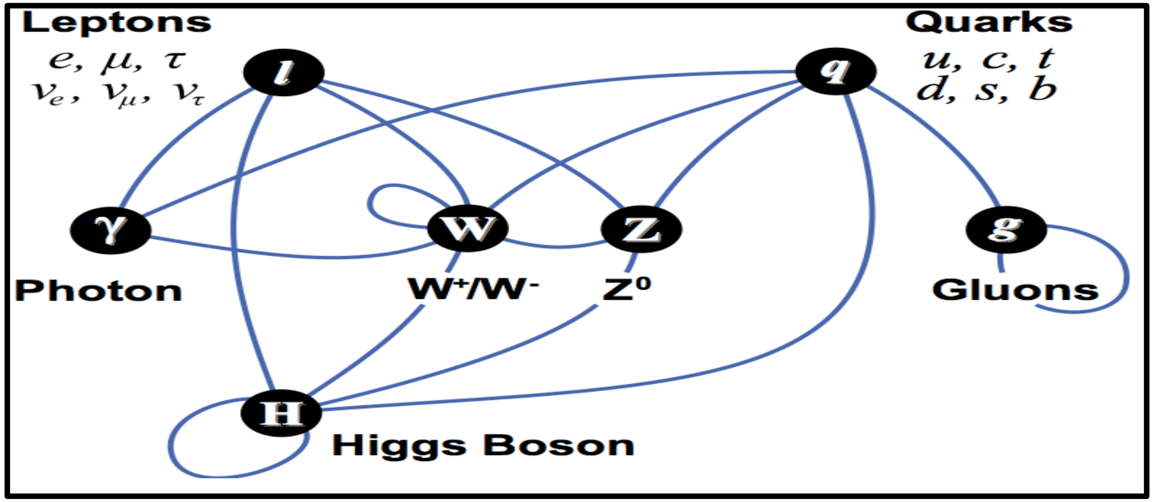
The Big Bang

The amount of matter equals the amount of antimatter.

the BIG BANG THEORY

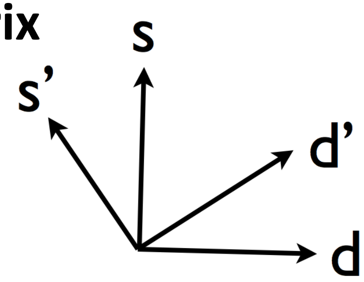


$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}$$
$$+ i\bar{\psi}\not{D}\psi + h.c.$$
$$+ \psi_i y_{ij}\psi_j\phi + h.c.$$
$$+ |D_\mu\phi|^2 - V(\phi)$$



$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c. + \psi_i y_{ij}\psi_j\phi + h.c. + |D_\mu\phi|^2 - V(\phi)$$

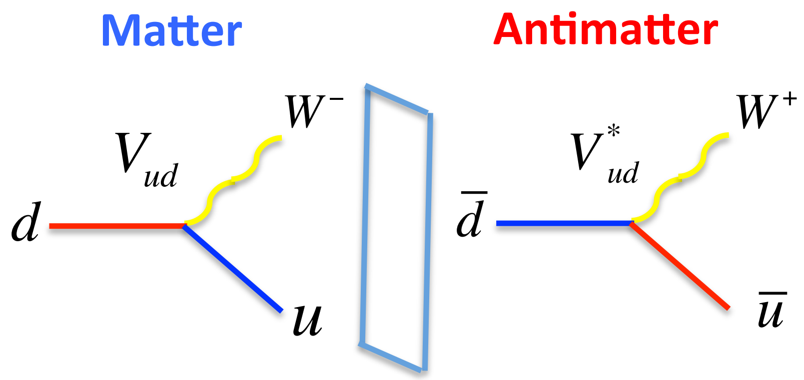
Cabbibo-Kobayashi-Maskawa matrix



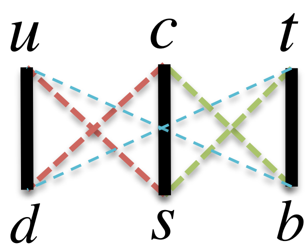
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

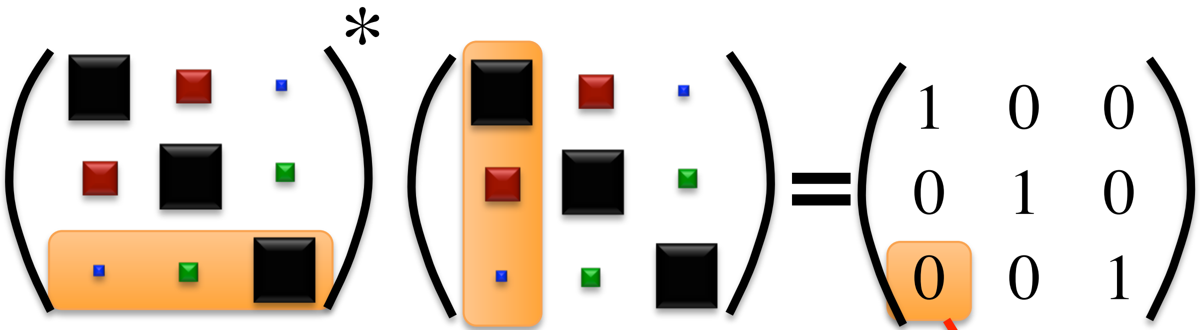
CKM matrix

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



Unitarity

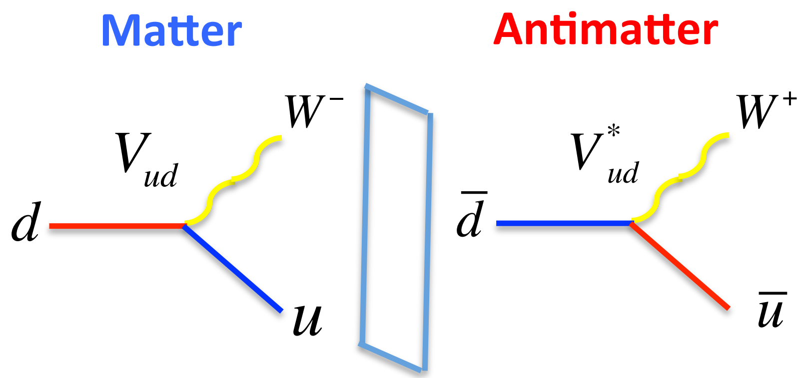




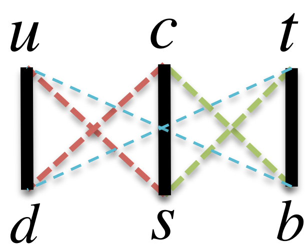
$$V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td} = 0$$

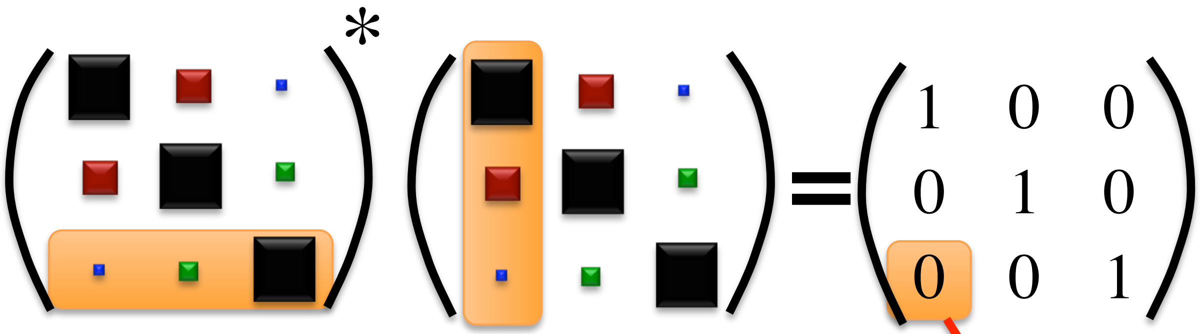
CKM matrix

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

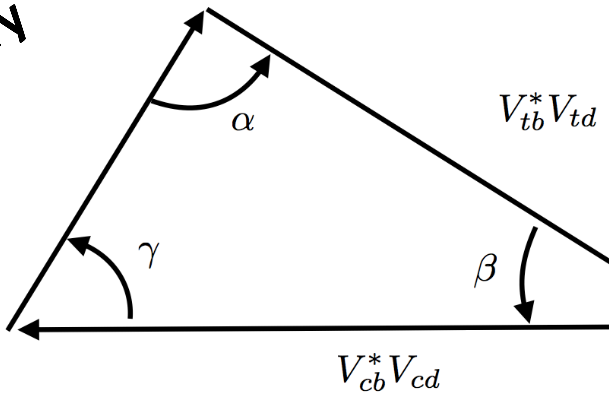


Unitarity



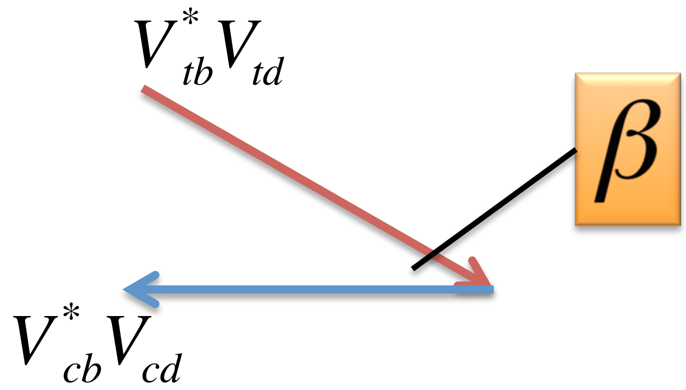


The Unitary triangle



$$V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td} = 0$$

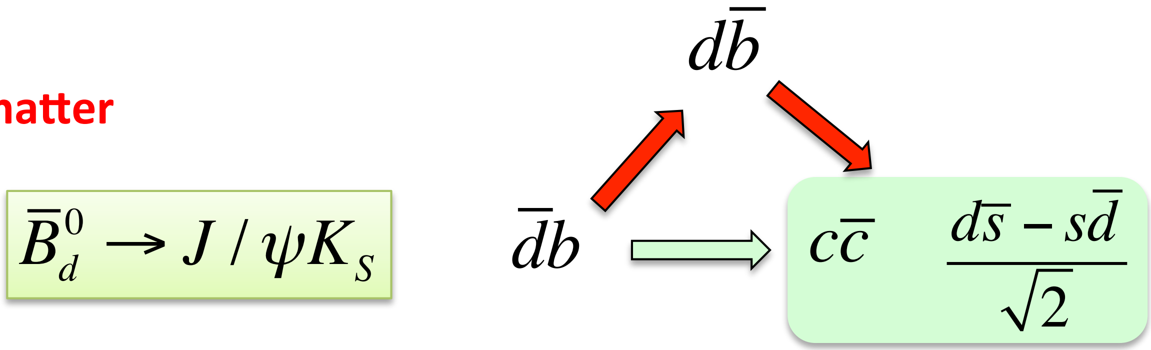
β



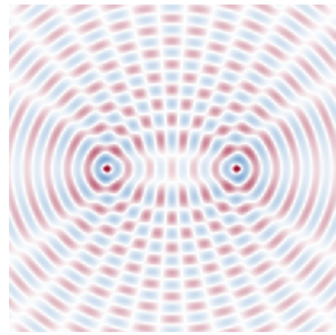
beauty ↔ top ↔ down

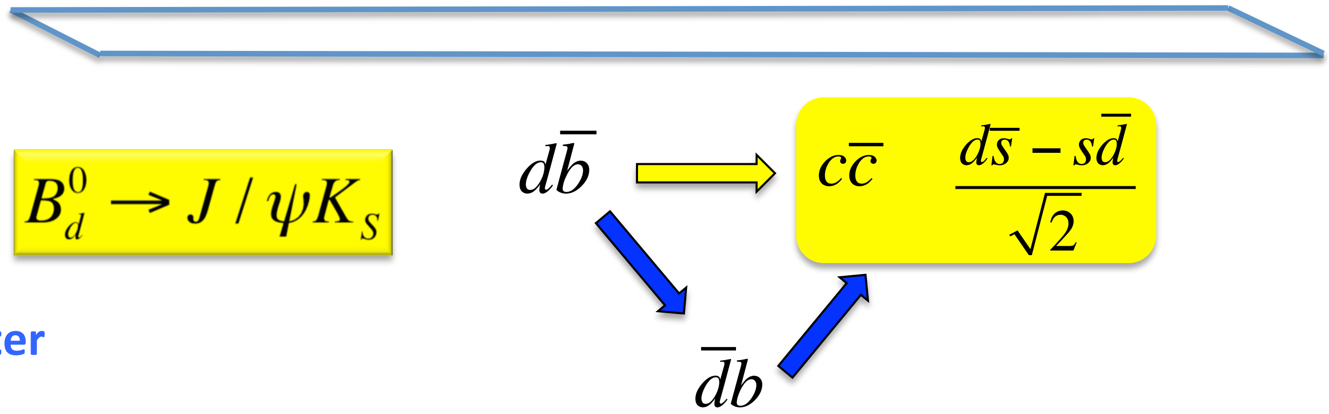
down ↔ charmed ↔ beauty

Antimatter

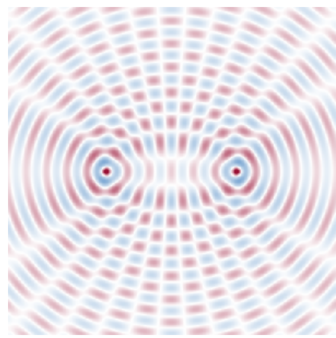


Interference

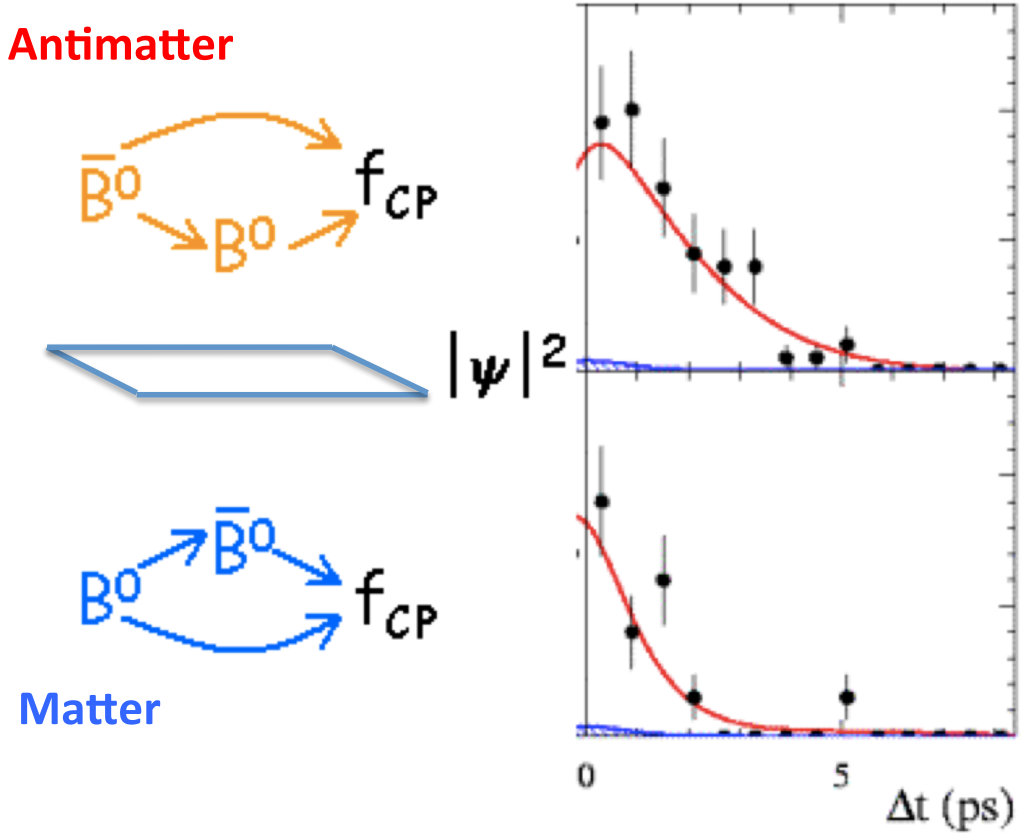




Matter



Interference



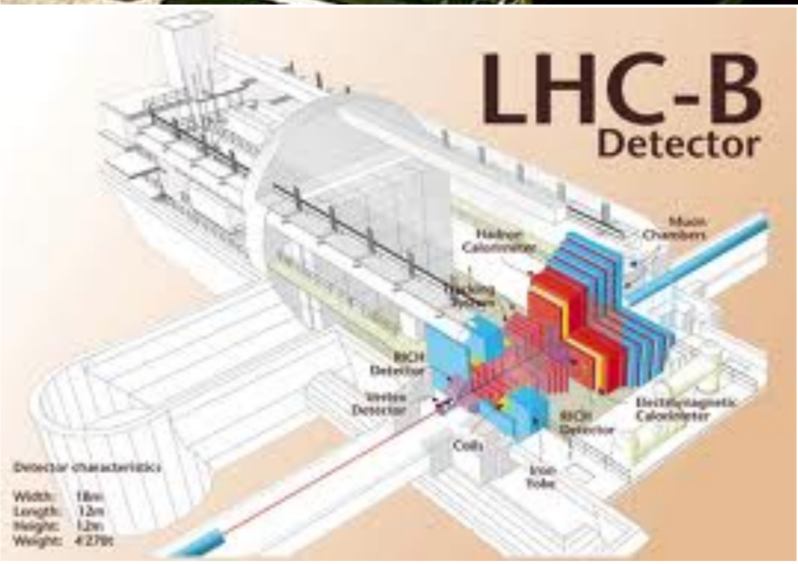
Decay rates are proportional to:

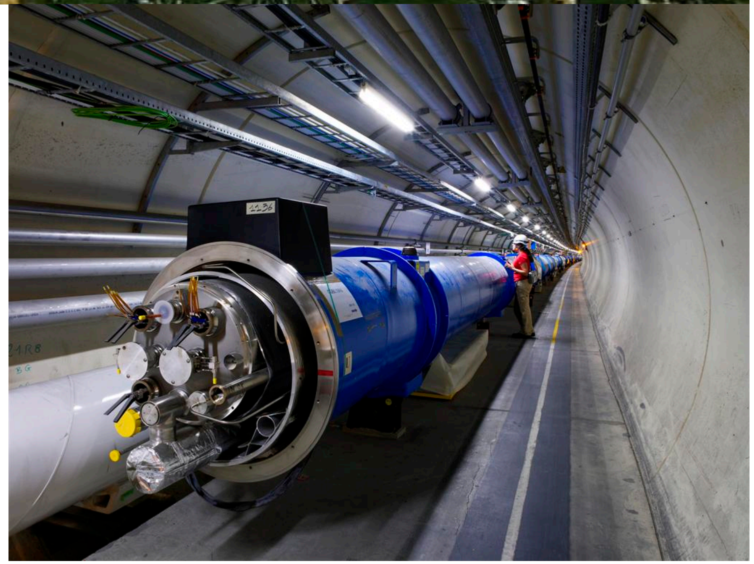
$$e^{-\Gamma|\Delta t|}(1+\sin(2\beta)\sin(\Delta m\Delta t))$$

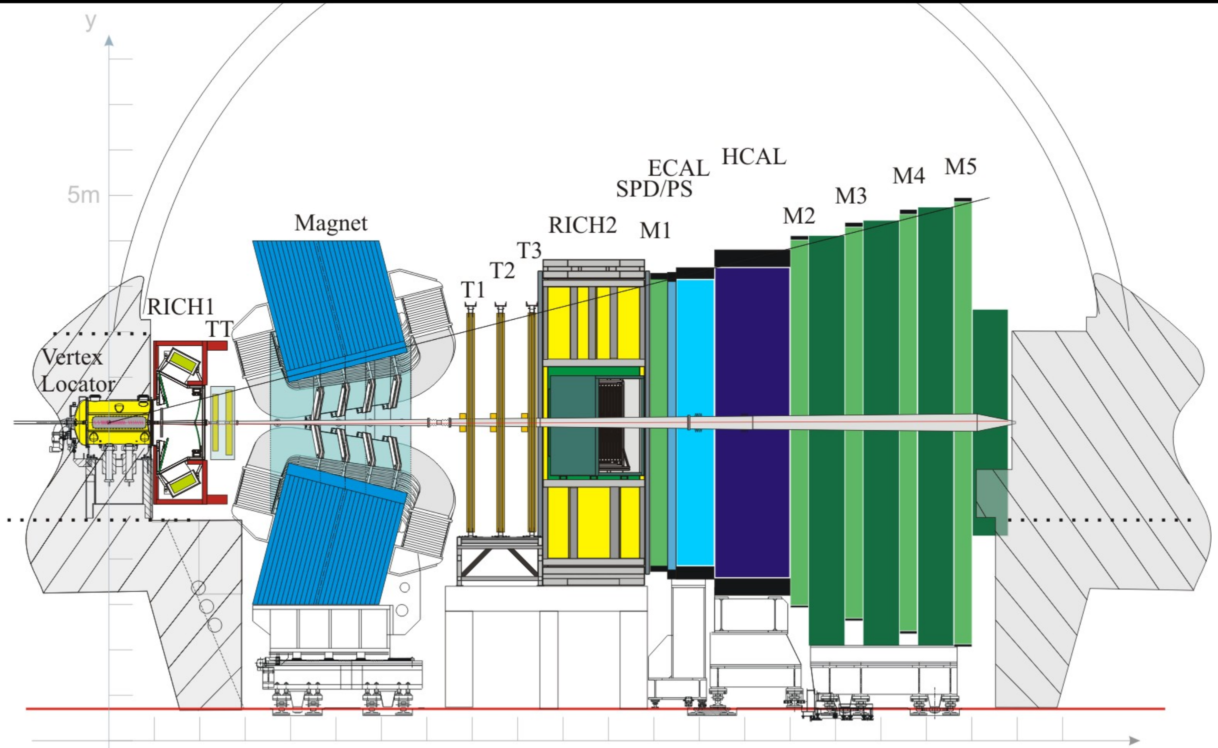
$$e^{-\Gamma|\Delta t|}(1-\sin(2\beta)\sin(\Delta m\Delta t))$$

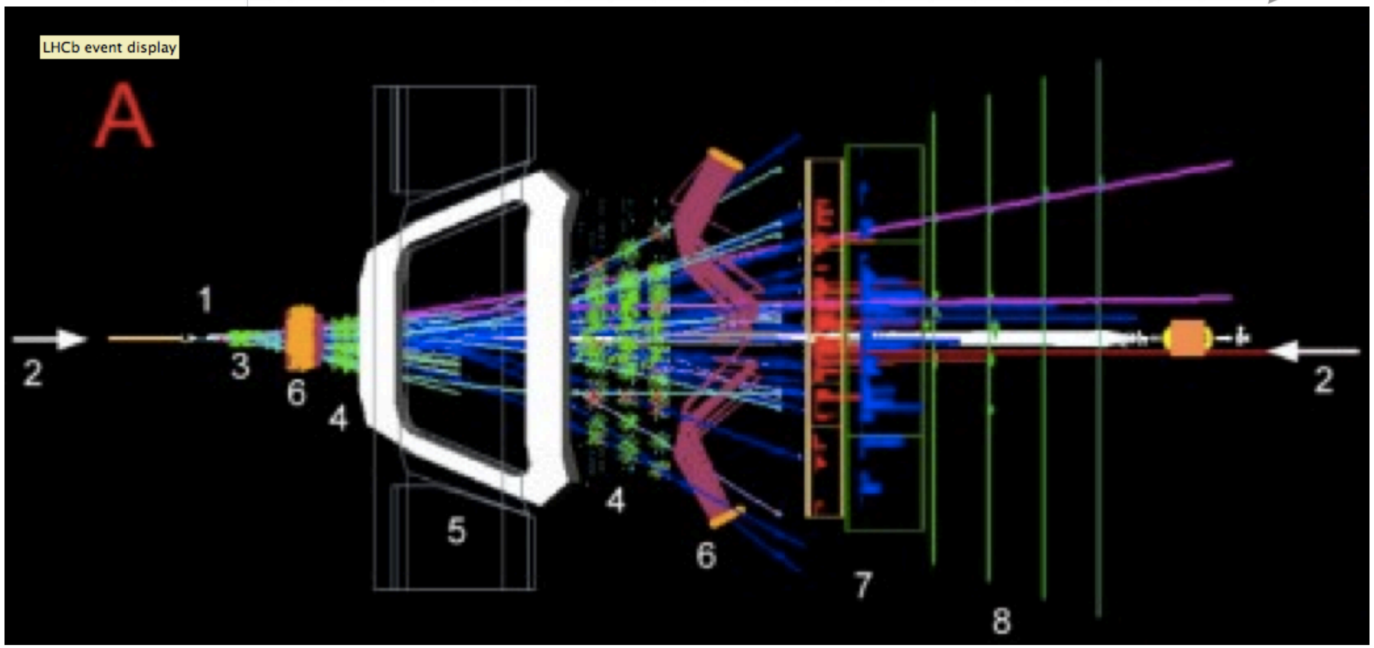
$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B^0} \to J/\psi K_S) - \Gamma(B^0 \to J/\psi K_S)}{\Gamma(\overline{B^0} \to J/\psi K_S) + \Gamma(B^0 \to J/\psi K_S)} = \sin(2\beta)\sin(\Delta m t)$$

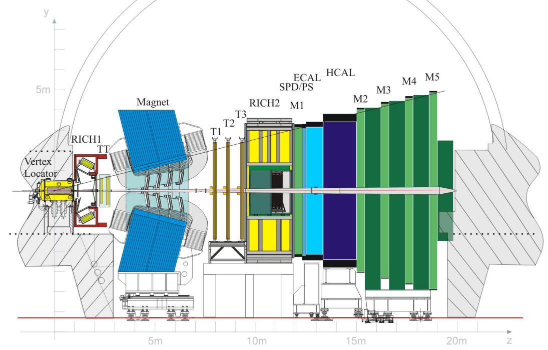

ALICE
CMS
ATLAS
LHCb

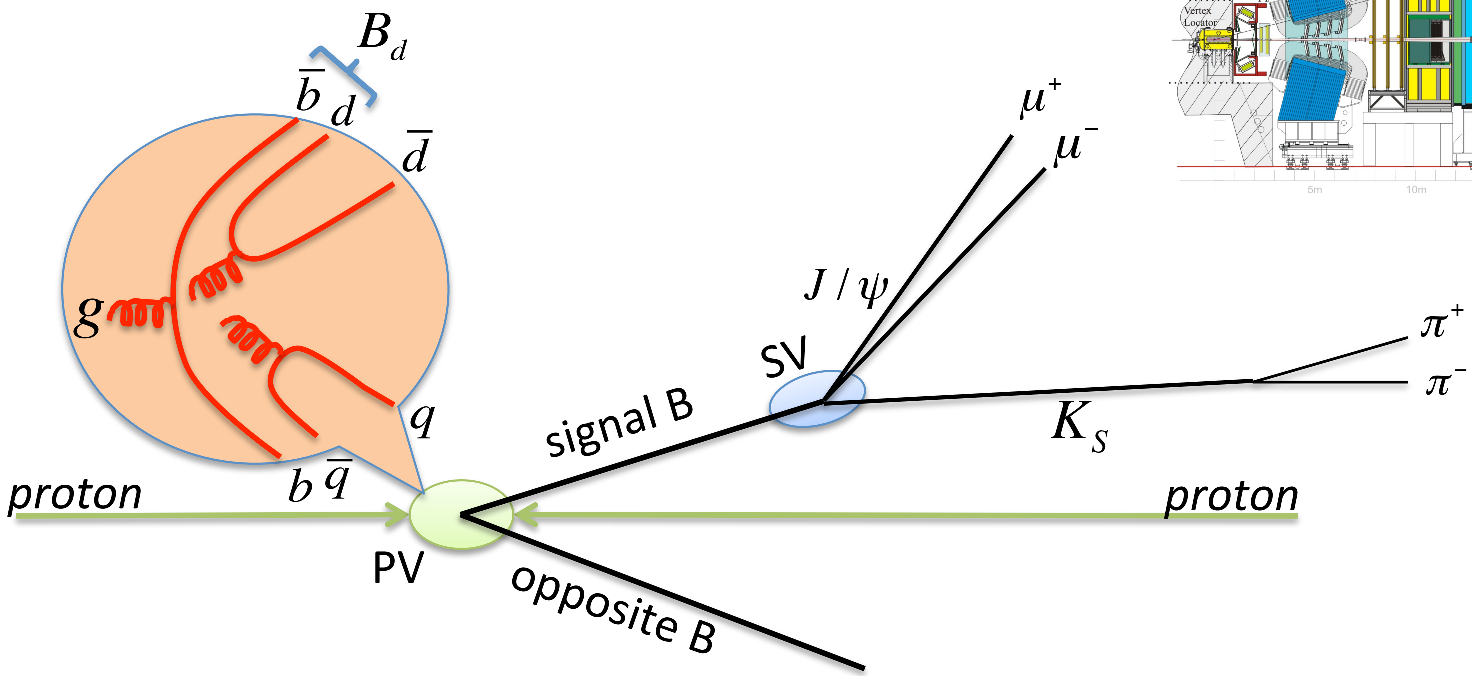

LHC-B
Detector

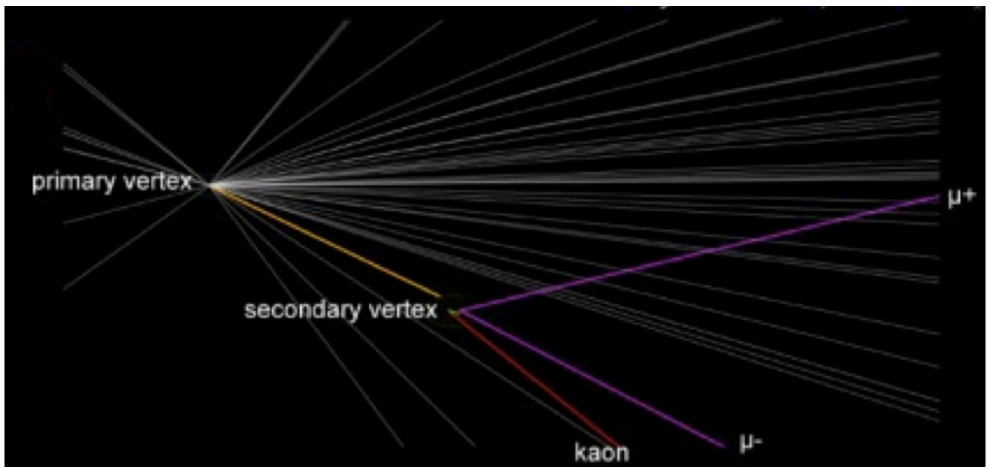


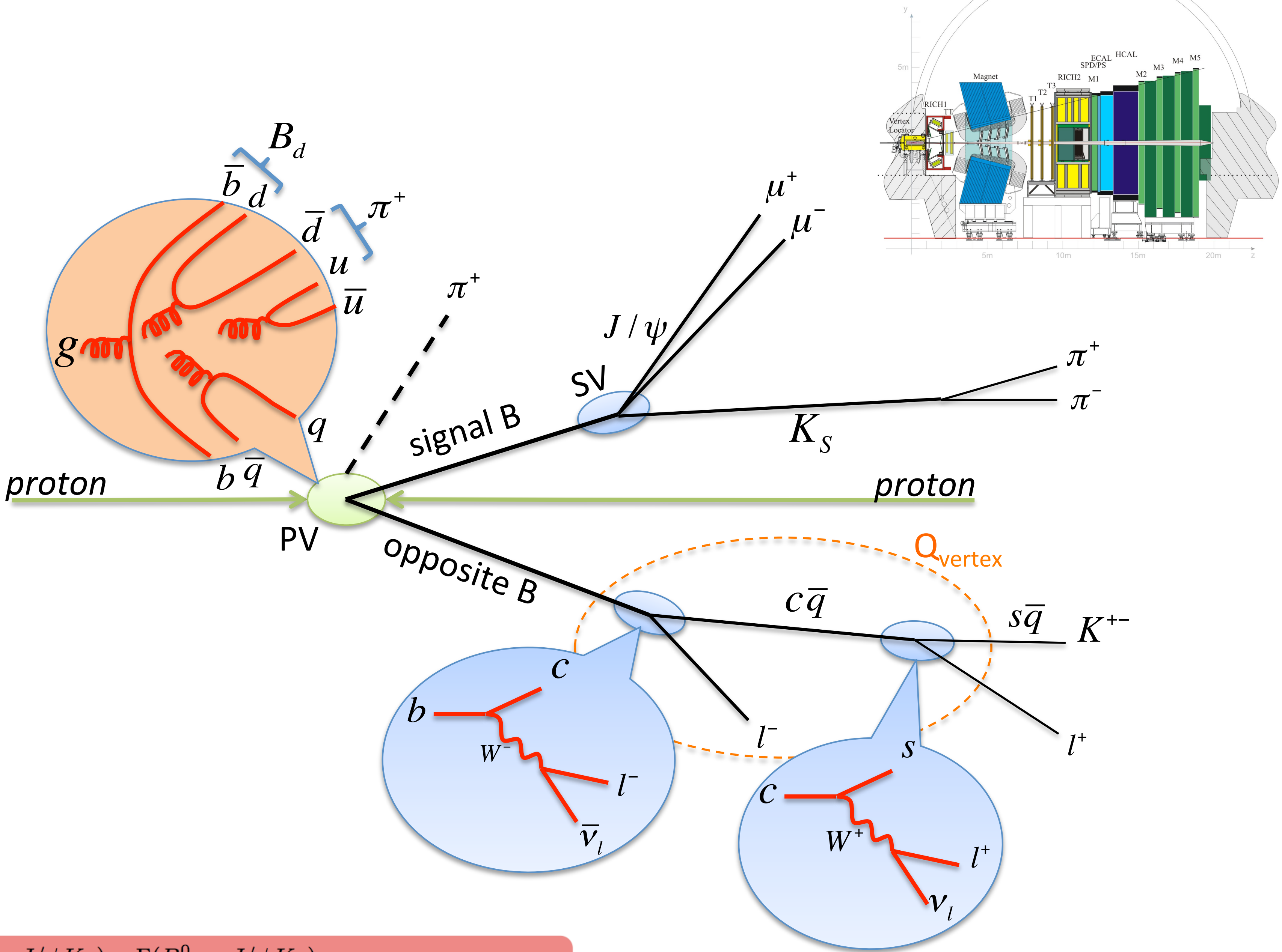

y
5m
Magnet
RICH1
TT
Vertex
Locator
T1
T2
T3
RICH2
M1
SPD/PS
ECAL
HCAL
M2
M3
M4
M5


LHCb event display
A
1
2
3
6
4
5
4
6
7
8
2


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


B_d
$\bar{b}$
d
$\bar{d}$
g
q
b
$\bar{q}$
proton
PV
signal B
SV
J/ψ
μ^+
μ^-
π^+
π^-
K_S
opposite B
proton


primary vertex
secondary vertex
μ+
μ-
kaon

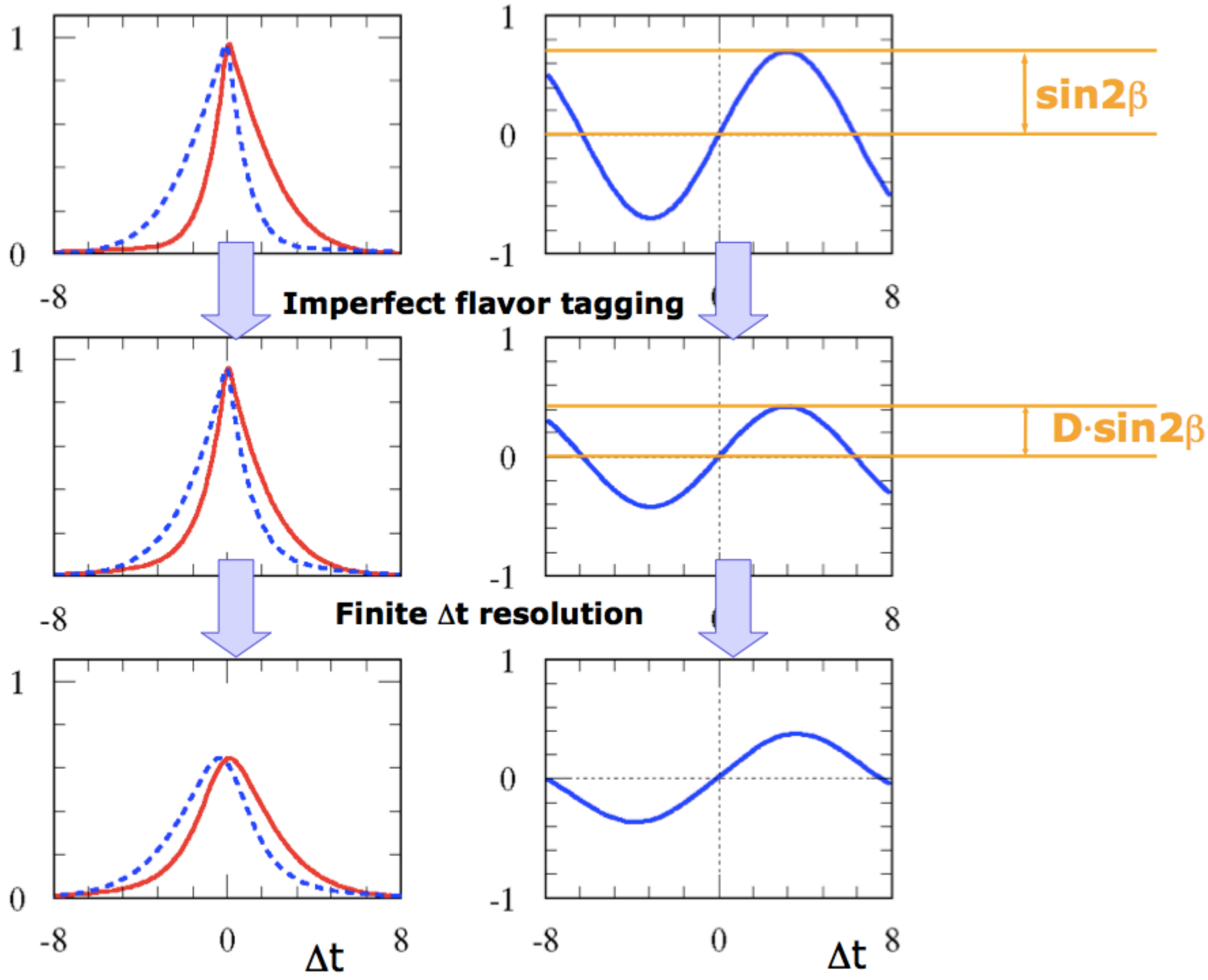


$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B^0} \to J/\psi K_S) - \Gamma(B^0 \to J/\psi K_S)}{\Gamma(\overline{B^0} \to J/\psi K_S) + \Gamma(B^0 \to J/\psi K_S)} = \sin(2\beta)\sin(\Delta m t)$$

$$\frac{N_{\bar{B}} - N_B}{N_{\bar{B}} + N_B}$$

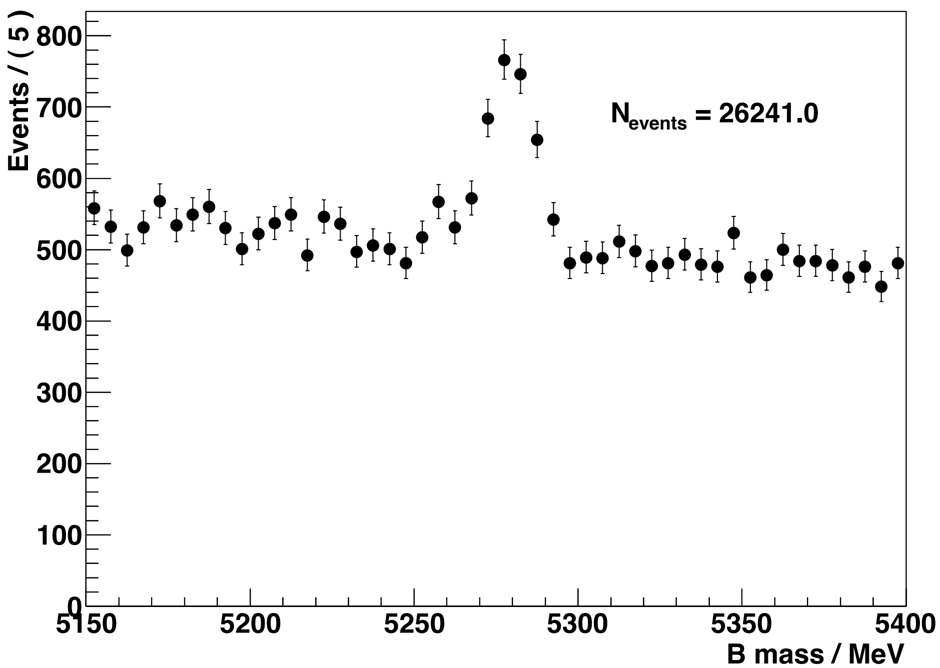
Asymmetry(t)

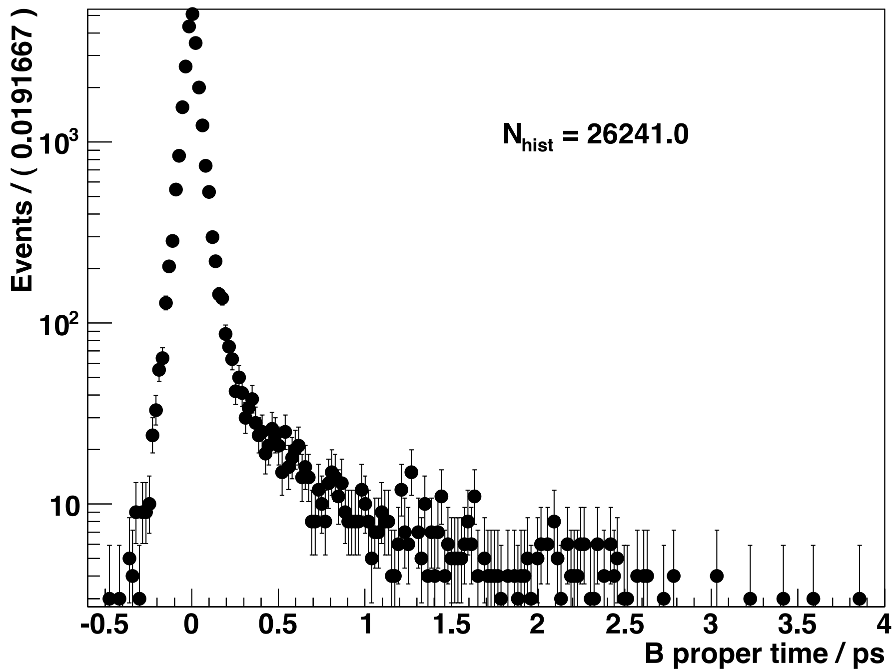
$B^0(\Delta t)$ $\overline{B^0}(\Delta t)$ $A_{CP}(\Delta t) = \sin 2\beta \cdot \sin(\Delta m_d \Delta t)$



$$Pdf(m,t \mid tag, mistag) = \left\{ Signal(m,t \mid tag, mistag) + Bkg(m,t) \right\} \otimes \mathrm{Resolution(t)}$$

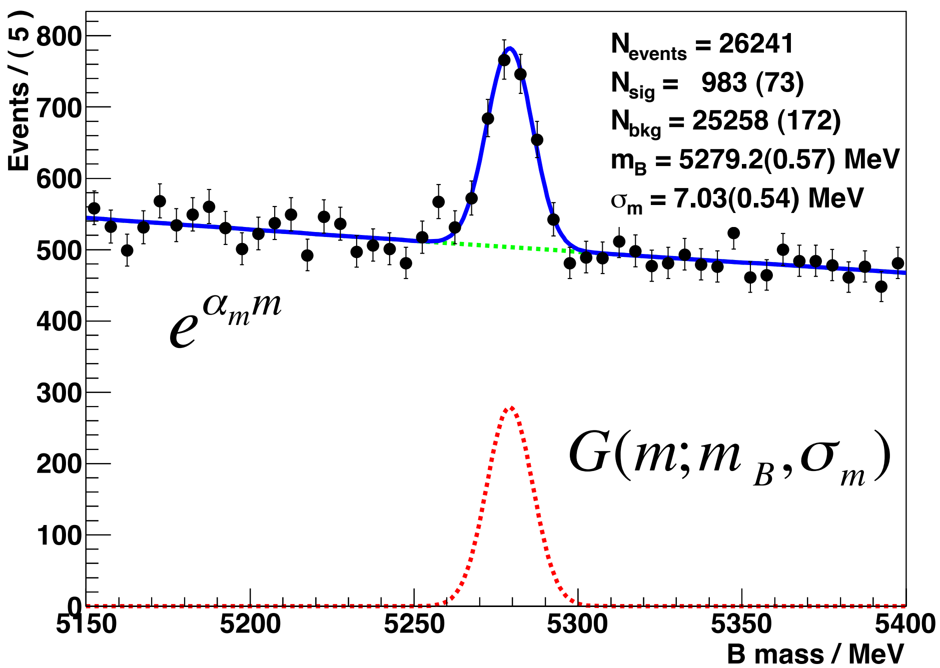
$$Pdf(m,t \mid tag, mistag) = Pdf(m) \times Pdf(t \mid tag, mistag)$$

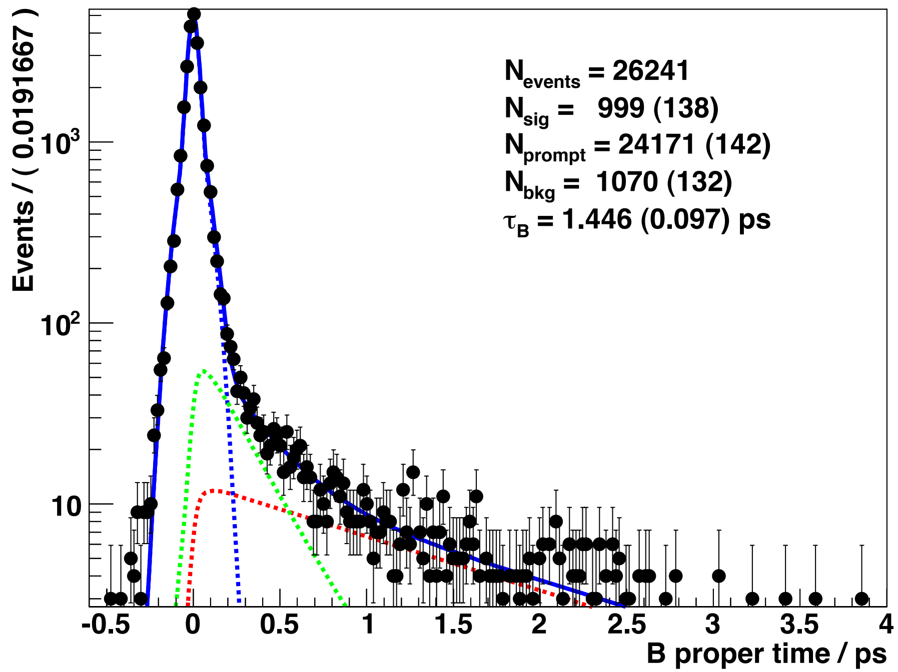


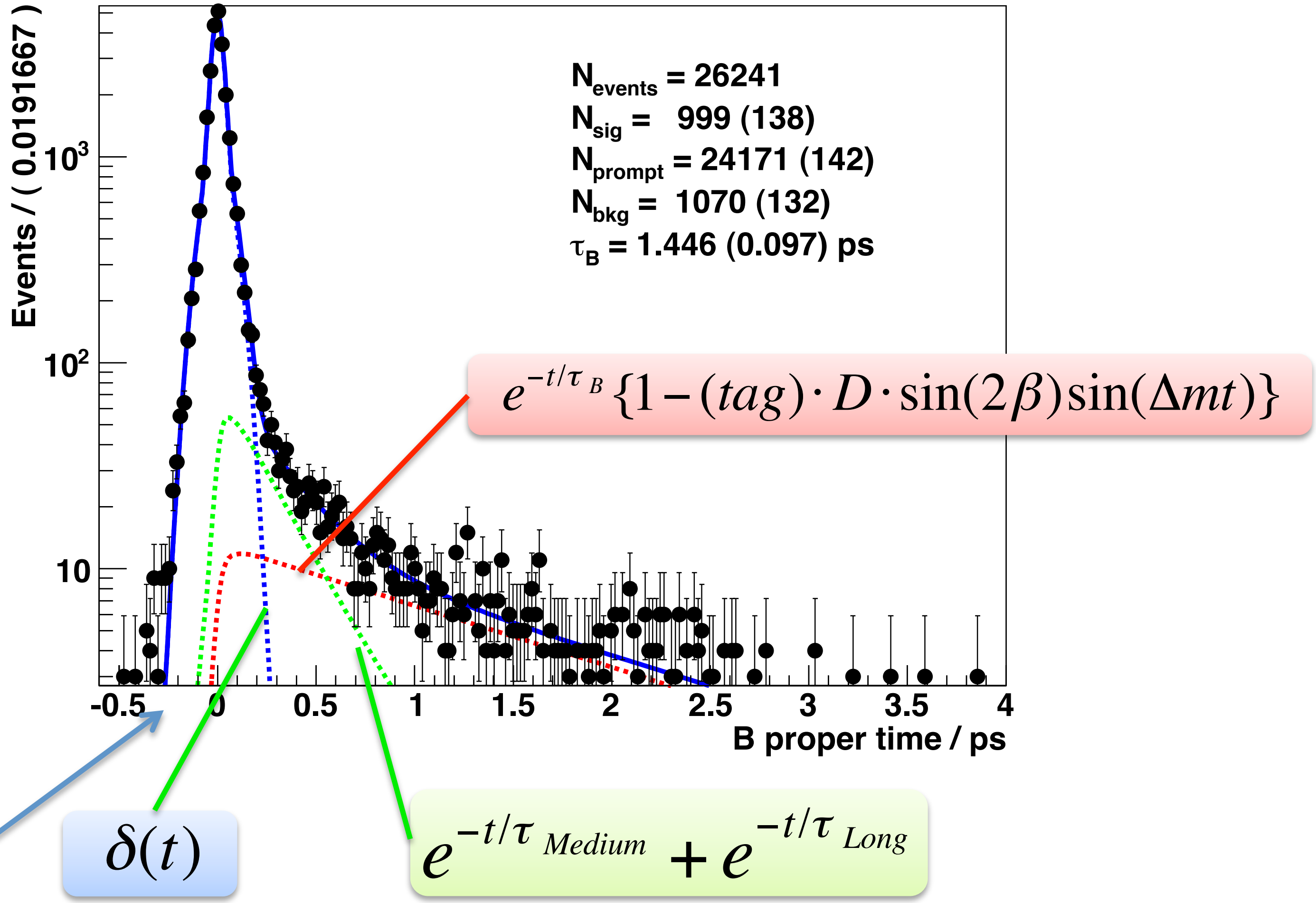


$$Pdf(m,t \mid tag,mistag) = \left\{ Signal(m,t \mid tag,mistag) + Bkg(m,t) \right\} \otimes \mathrm{Resolution(t)}$$

$$Pdf(m,t \mid tag,mistag) = Pdf(m) \times Pdf(t \mid tag,mistag)$$



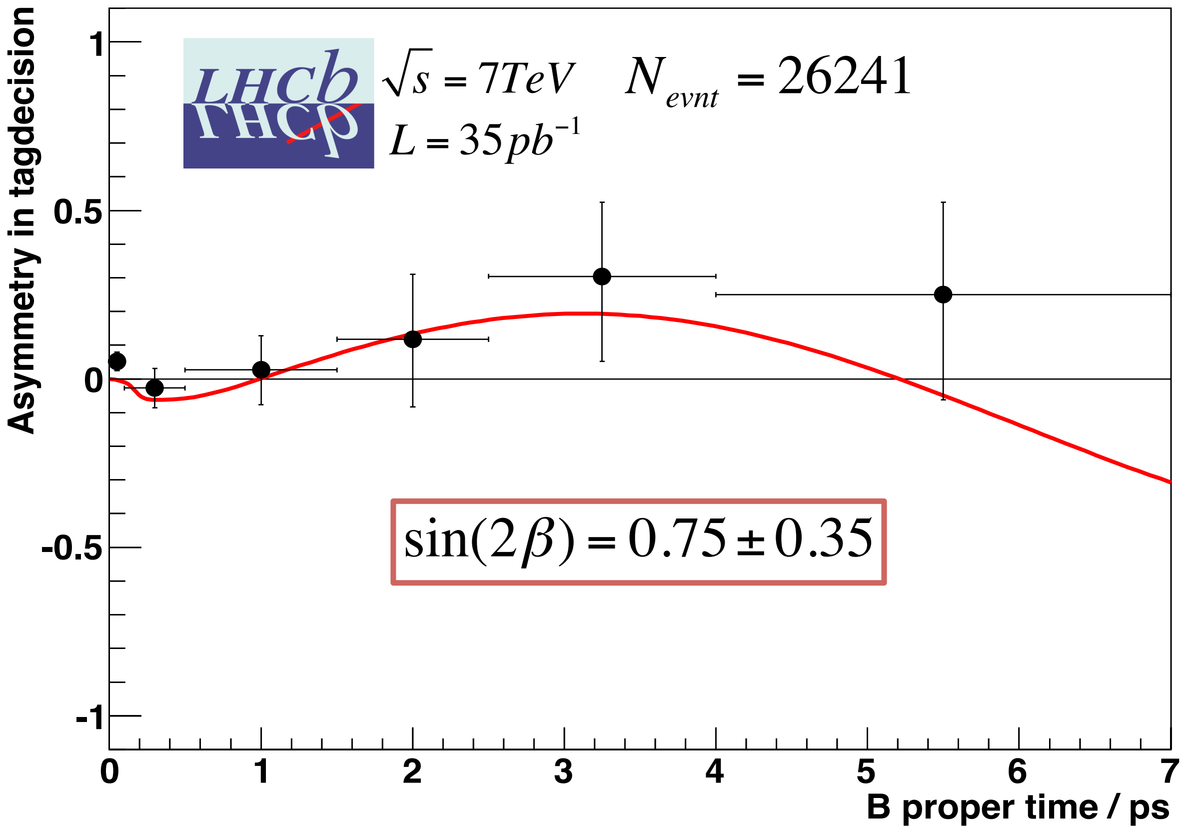




$$\text{Resolution(t)} = G_1(t;0,\sigma_1) + G_2(t;0,\sigma_2) + G_3(t;0,\sigma_3)$$

$B_d^0 \to J/\psi K_S$

$$\mathcal{A}_{CP} = \frac{\Gamma(\overline{B^0} \to J/\psi K_S) - \Gamma(B^0 \to J/\psi K_S)}{\Gamma(\overline{B^0} \to J/\psi K_S) + \Gamma(B^0 \to J/\psi K_S)} = \sin(2\beta)\sin(\Delta m t)$$



B and anti-B mesons do behave differently!

My result: $\sin(2\beta) = 0.75 \pm 0.35$

World average: $\sin(2\beta)_{WorldAvr} = 0.673 \pm 0.023$

- Based on the data taken during the last year
- Not the main measurement what LHCb was built for
- Crucial benchmark for LHCb before more difficult measurements
- Confirmation of the previous results (BaBar&Belle)
- Impact on world average expected next year.