CP Violation at LHCb

Marcel Merk

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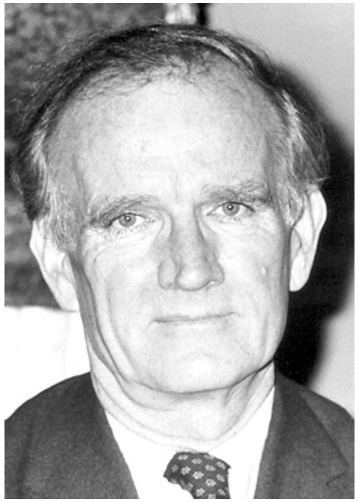
June 18 - 22, Groningen

A slide of History

- Charge Parity Violation in particle physics
  - **1964** (CCFT): Discovered in neutral Kaon beam
    "*indirect* CP violation"
    - Also called: *CPV in mixing*
    - Prob($K^0 \rightarrow \overline{K}^0$) ≠ Prob ($\overline{K}^0 \rightarrow K^0$)
      $|\varepsilon| = (2.228 \pm 0.011) \times 10^{-3}$ (PDG)
  - **1999** (NA48 & KTeV): Seen in Kaon decays
    "*direct* CP violation"
    - Also called: *CPV in decay*
    - Decay rates $\Gamma(K^0 \rightarrow \pi^+\pi^-) \neq \Gamma(\overline{K}^0 \rightarrow \pi^+\pi^-)$
      $Re(\varepsilon'/\varepsilon) = (1.65 \pm 0.26) \times 10^{-3}$ (PDG)
  - **2001** (Belle & Babar): Observed in B mesons decays
    "CP violation in *interference*"
    - Also called: *mixing induced CPV*
      $\sin 2\beta = 0.673 \pm 0.023$ (PDG)

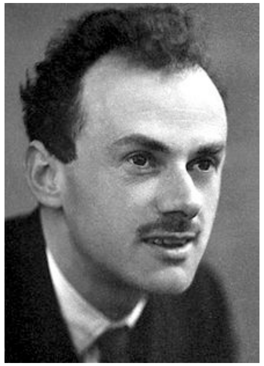
James Watson Cronin



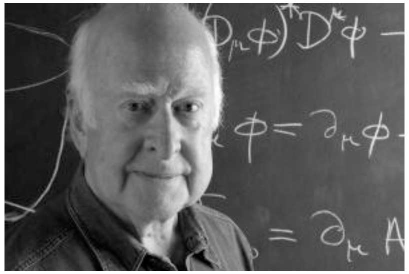
Val Logsdon Fitch

→ Nobel prize 1980

CP Violation in the Standard Model



Paul Dirac



Peter Higgs

Hideki Yukawa

$$\mathcal{L} = i\overline{\psi_L}\gamma_\mu D^\mu \psi_L + V(\phi) + Y_{ij}\left(\overline{\psi}^i_L \phi\right)\psi^j_R$$

- The Yukawa flavour couplings Y_{ij} make the theory CP violating if they are complex.
- After Spontaneous Symmetry Breaking the Yukawa terms give rise to quark masses.
- Expressing the quark *flavour eigenstates* in *mass eigenstates* leads to CP violating flavour changing charged currents.
- The origin of CP violation is related to the origin of mass and requires the existence of at least 3 generations

Interactions between Quarks

Cabibbo described "V-A" quark interactions with flavour changing charged currents:
➔ quark mixing

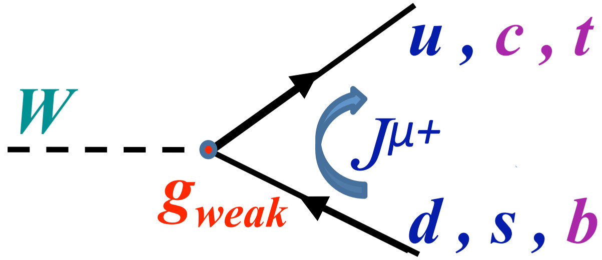
$$A = g_{weak}\, W^+_\mu\, J^{\mu +}$$

$$J^{\mu +} = \overline{\psi}_u\, \frac{1}{2}(1-\gamma^5)\, \gamma^\mu\, V_{CKM}\, \psi_d$$

Nicola Cabibbo

Makoto Kobayashi

Toshihide Maskawa



Particle →Antiparticle
$g_{weak} \rightarrow g^*_{weak}$

Kobayashi and *Maskawa* predicted in 1972 the 3rd quark generation to explain CP-Violation within the Standard Model
➔ Nobel Prize 2008 (shared with Nambu)

9 Coupling constants:
$g_{weak} \rightarrow g \cdot V_{CKM}$

The CKM Matrix V_{CKM}

$$
\begin{array}{c} \\ u \\ c \\ t \end{array}
\begin{array}{c}
\begin{array}{ccc} d & s & b \end{array} \\
\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}
\end{array}
$$

The CKM Matrix V_{CKM}

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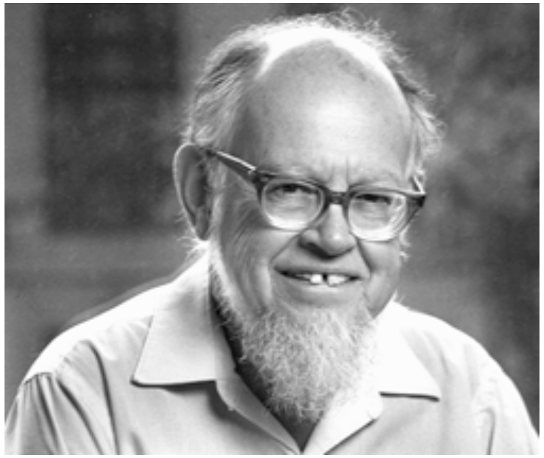

Wolfenstein parametrization: V_{CKM}

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

From unitarity ($V_{CKM}\ V^{\dagger}_{CKM}=1$)
CKM has four free parameters:
 3 real: λ (≈ 0.22) , A (≈ 1), ρ
 1 imaginary: $i\eta$

Particle → Antiparticle: $V_{ij} \rightarrow V_{ij}^*$
=> 1 CP Violating phase

The CKM Matrix V_{CKM}

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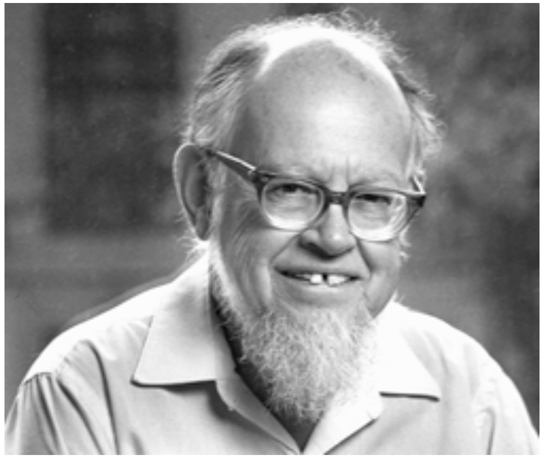
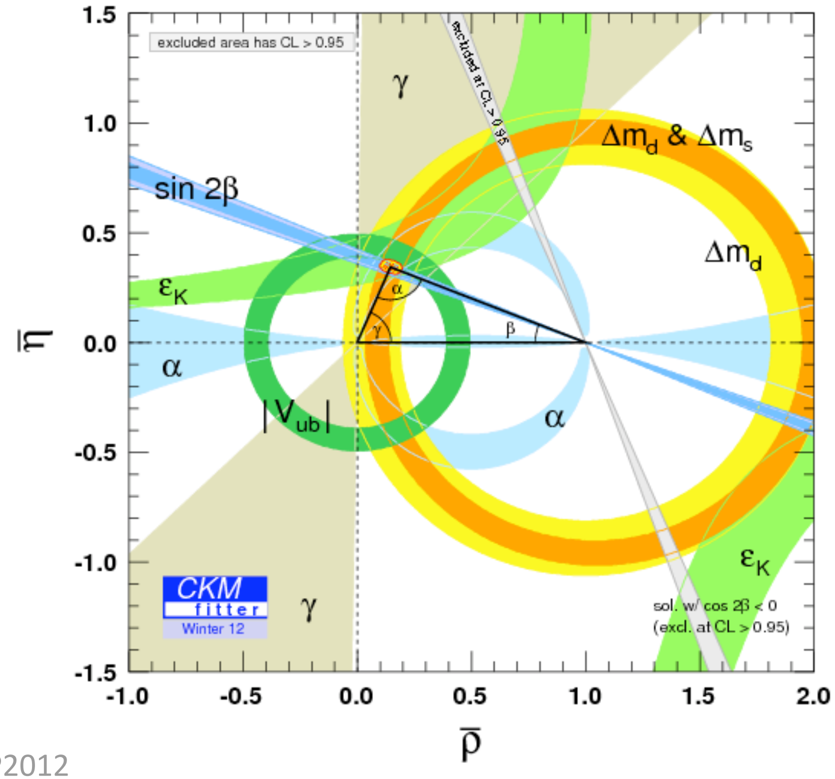


Wolfenstein parametrization: V_{CKM}

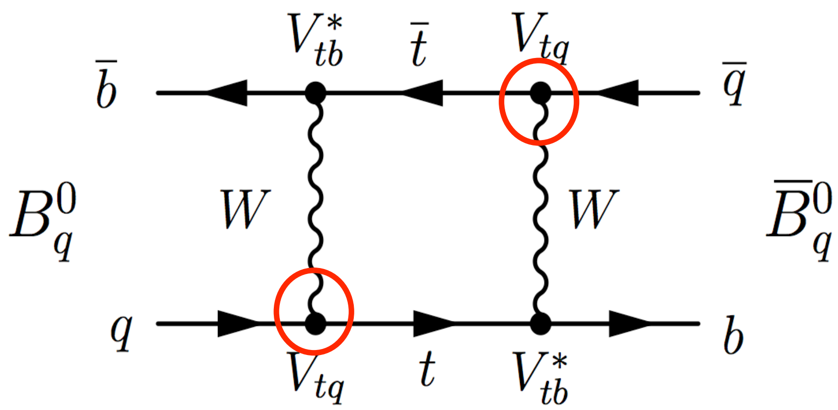
$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix}$$



Observing CP Violation in B decays

- CP Violation occurs in *interference of two quantum amplitudes* that have a different CP odd (as well as CP even) phase
  - Use the phenomenon of B-$\bar{B}$ mixing:
  - Interference of direct decay and decay via mixing leads to CP violation.

    Standard Model:
    - B^0-$\bar{B}^0$ phase $\phi_d = \arg(V_{td}) = 2\beta$
    - B_s-$\bar{B}_s$ phase $\phi_s = \arg(V_{ts}) = 2\beta_s$



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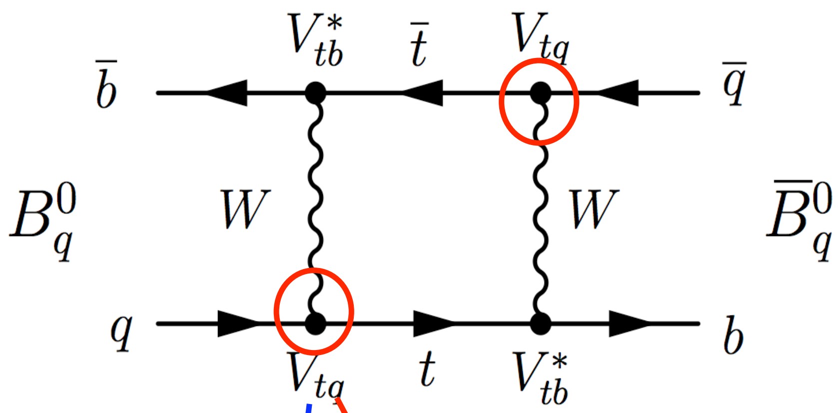
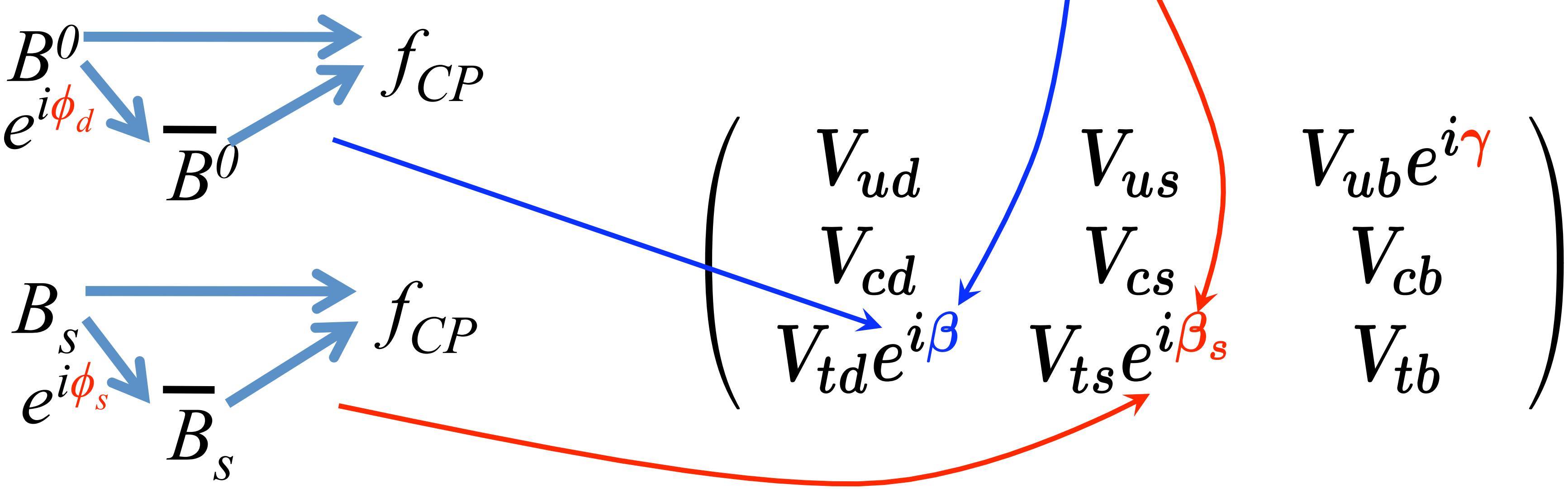


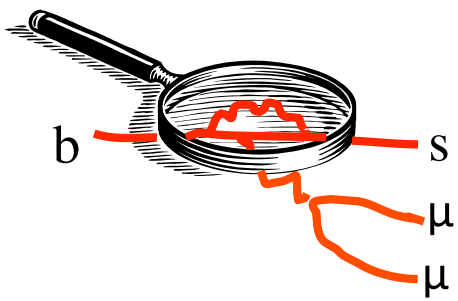


Probing new physics

- Flavour Physics: *indirect* search for new particles or interactions
  - Measure CP violation in many B, D decay modes
    - All observations should be consistent with a single CP phase
  - Measure branching rates of decays that are suppressed in SM
- Look for *interference* of CKM physics with New Physics
  - Expect sensitivity for new physics where SM amplitudes are suppressed: loop diagrams
  - Measure CP phases “with tree decays” and “with loops”

“Box” diagram: $\Delta B=2$

“Penguin” diagram: $\Delta B=1$



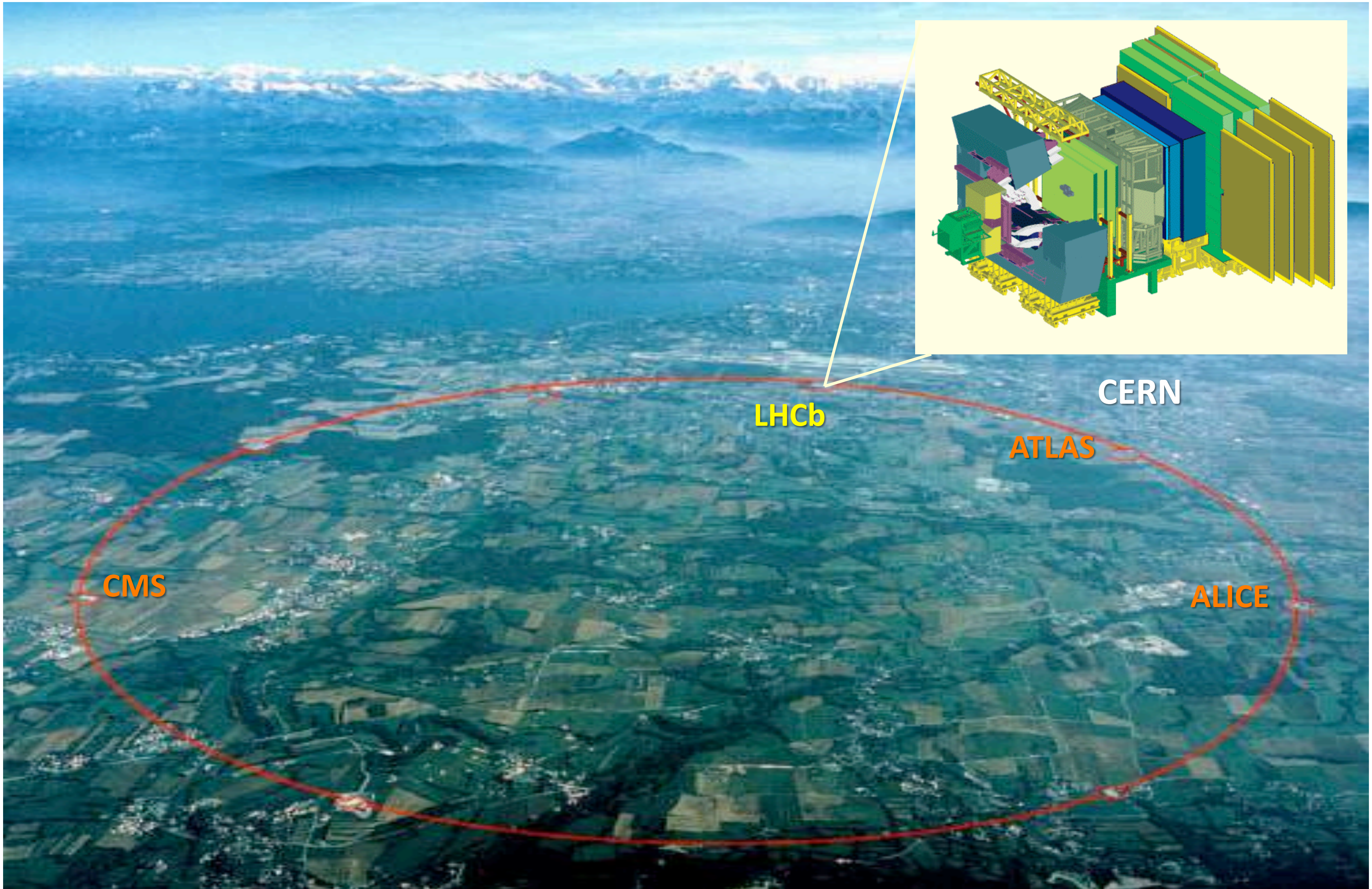
Classification of CP Violation Methods @ LHCb

- Many methods have been developed for B decays
- The classification *direct* and *indirect* is no longer sufficient
  - E.g.: methods with intermediate Charm states
- We use also experimental classifications
  - *"Time dependent"* vs *"Time independent"* methods
    - Observe CP Violation as function of B-decay time vs integrated over time
  - *"Tagged"* vs *"Untagged"* methods
    - Require knowledge of b-flavour at production or not
- I can't give a complete overview
  - Examples of several prominent ongoing analyses

CP Violation Measurements @ LHCb

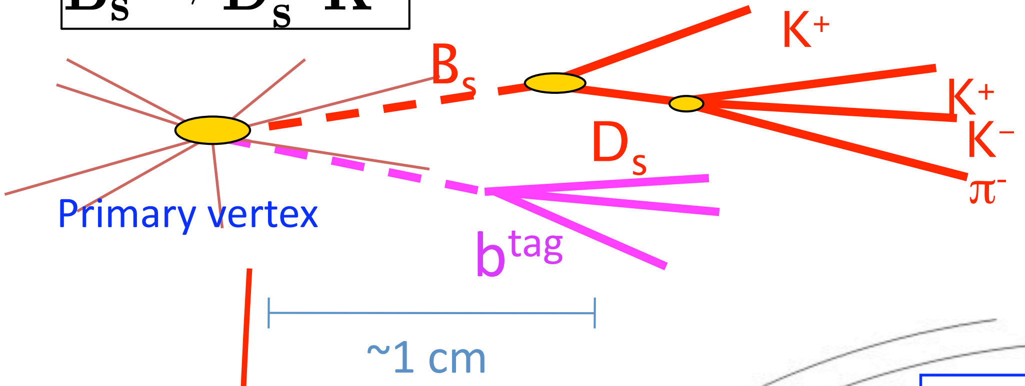
- *Time Integrated* measurements:
  - (1) Direct CP Violation in charmless decay $B_{(s)} \rightarrow K\pi$
    - Interference of trees with penguins
  - (2) CP Violation in charmed B decays: $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow D^0 \pi^-$
    - Measurement of " γ with trees" using ADS/GLW method
- *Time dependent* measurements (interference of mixing and decay):
  - (3) CP violation in charmless $B_{(s)}$ decays $B_s \rightarrow K^+K^-$ and $B \rightarrow \pi^+\pi^-$
    - Measurement of " γ with loops"
  - (4) CP Violation in charmed B_s Decays $B_s \rightarrow D_s K$
    - Measurement of "γ with trees"
  - (5) CP Violation in B_s decays to CP eigenstate $B_s \rightarrow J/\psi\ \phi$
    - Measurement of B_s mixing phase Φ_s (β_s)
- A charming surprise: CP Violation in charm
  - (6) CP Violation in two-prong hadronic D^0 decays
    - Measurement of ΔA_{CP}, difference of CP violation in $D^0 \rightarrow K^+K^-$ and $D^0 \rightarrow \pi^+\pi^-$

LHCb @ LHC



B Physics @ LHCb

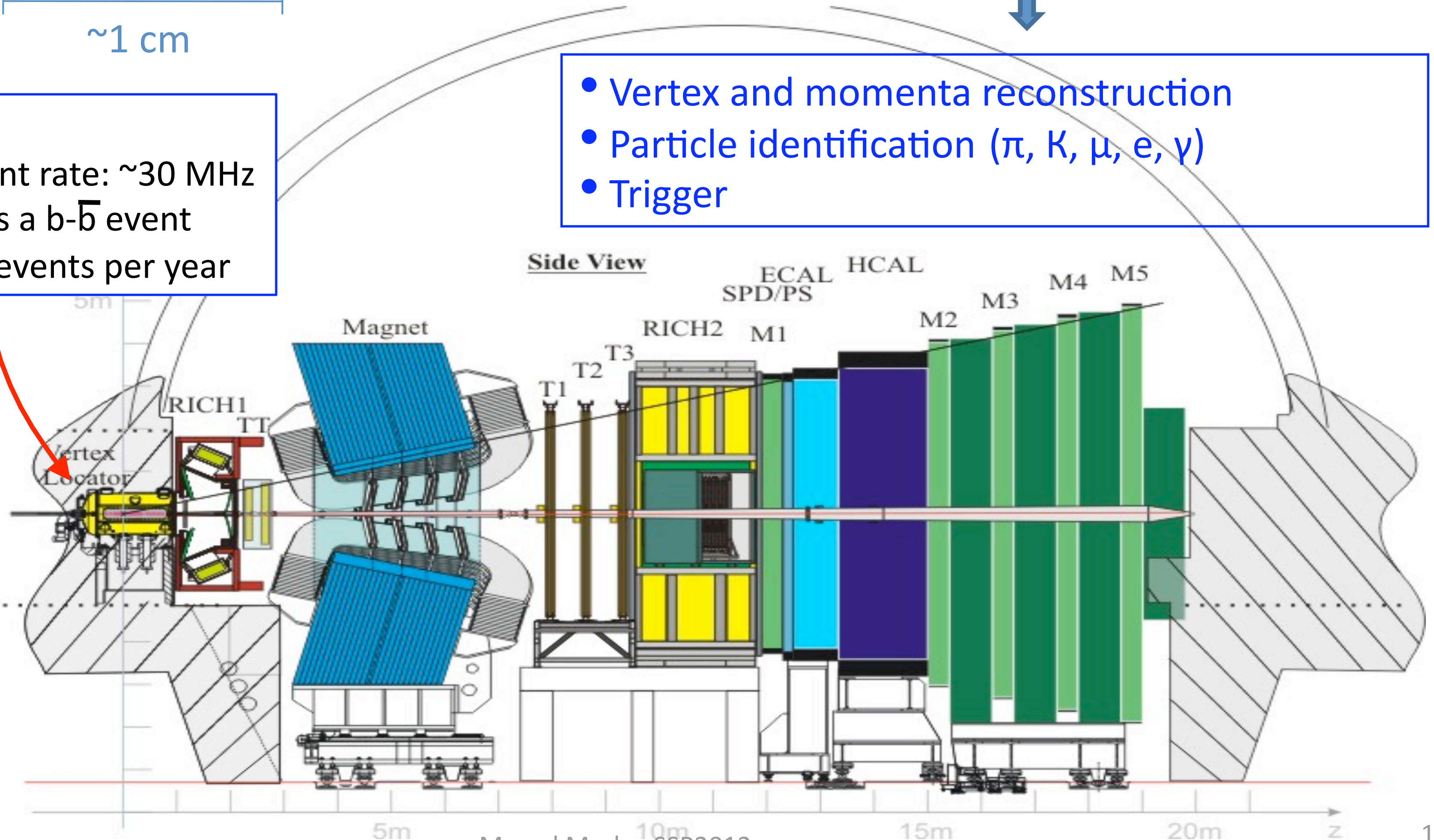
$B_s \rightarrow D_s^- K^+$



- Background Suppression
- Flavour tagging
- Decay time measurement

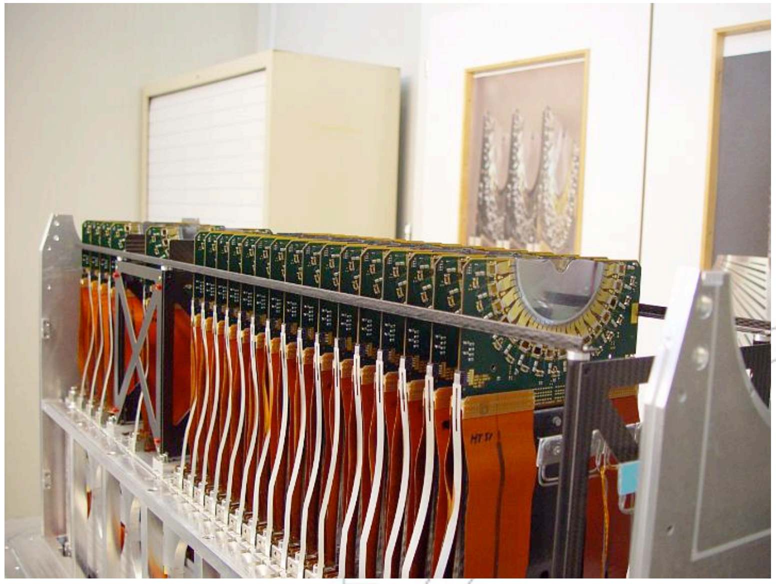
- Vertex and momenta reconstruction
- Particle identification (π, K, μ, e, γ)
- Trigger

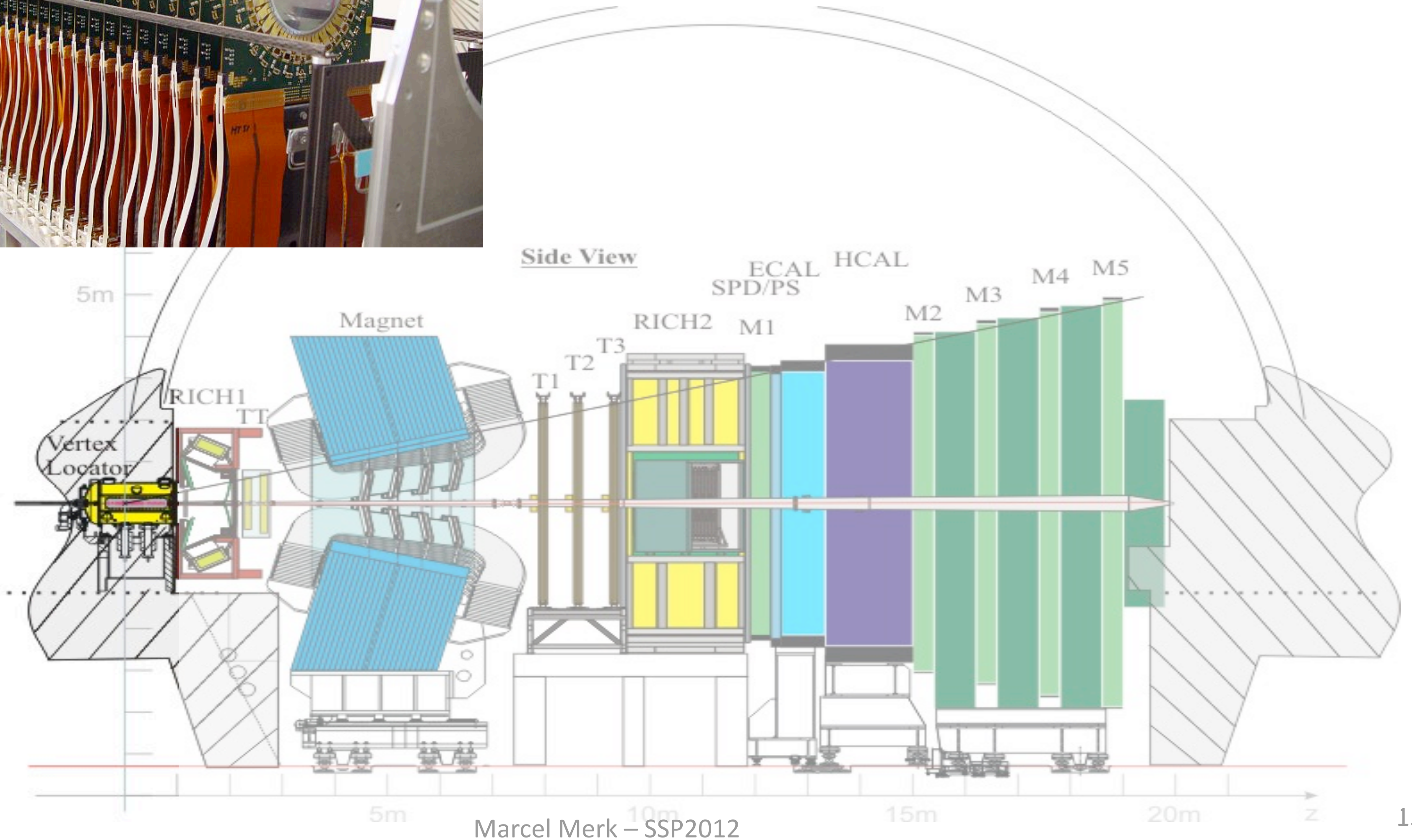
Design:
- LHCb event rate: ~30 MHz
- 1 in 160 is a b-$\bar{b}$ event
- 10^{12} b-$\bar{b}$ events per year



Vertex Topology

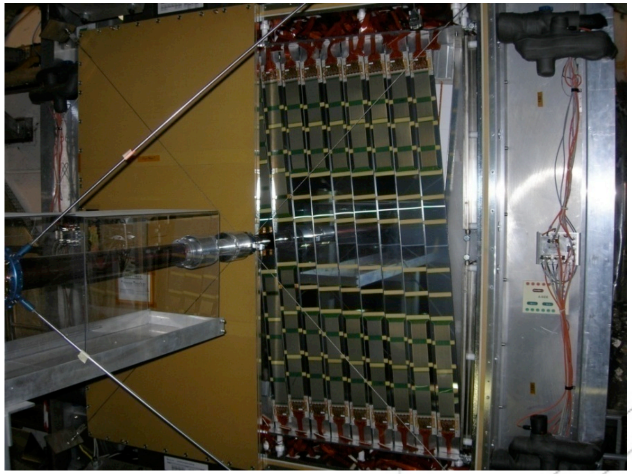
Vertex Locator



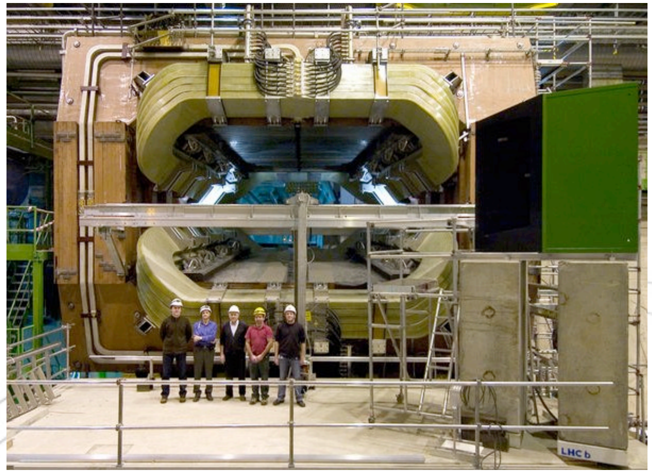


Momentum and Mass Reconstruction

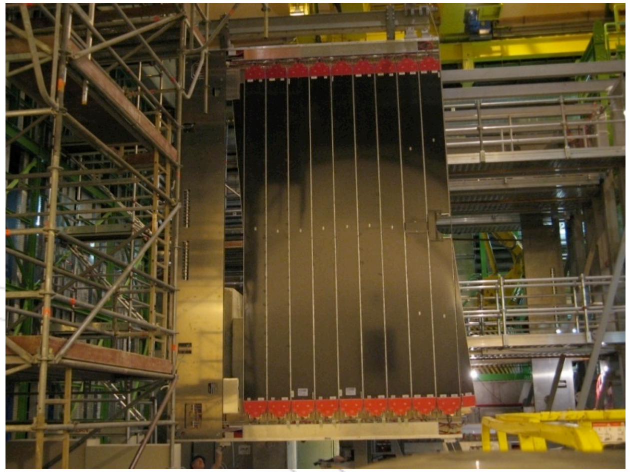
Trigger Tracker

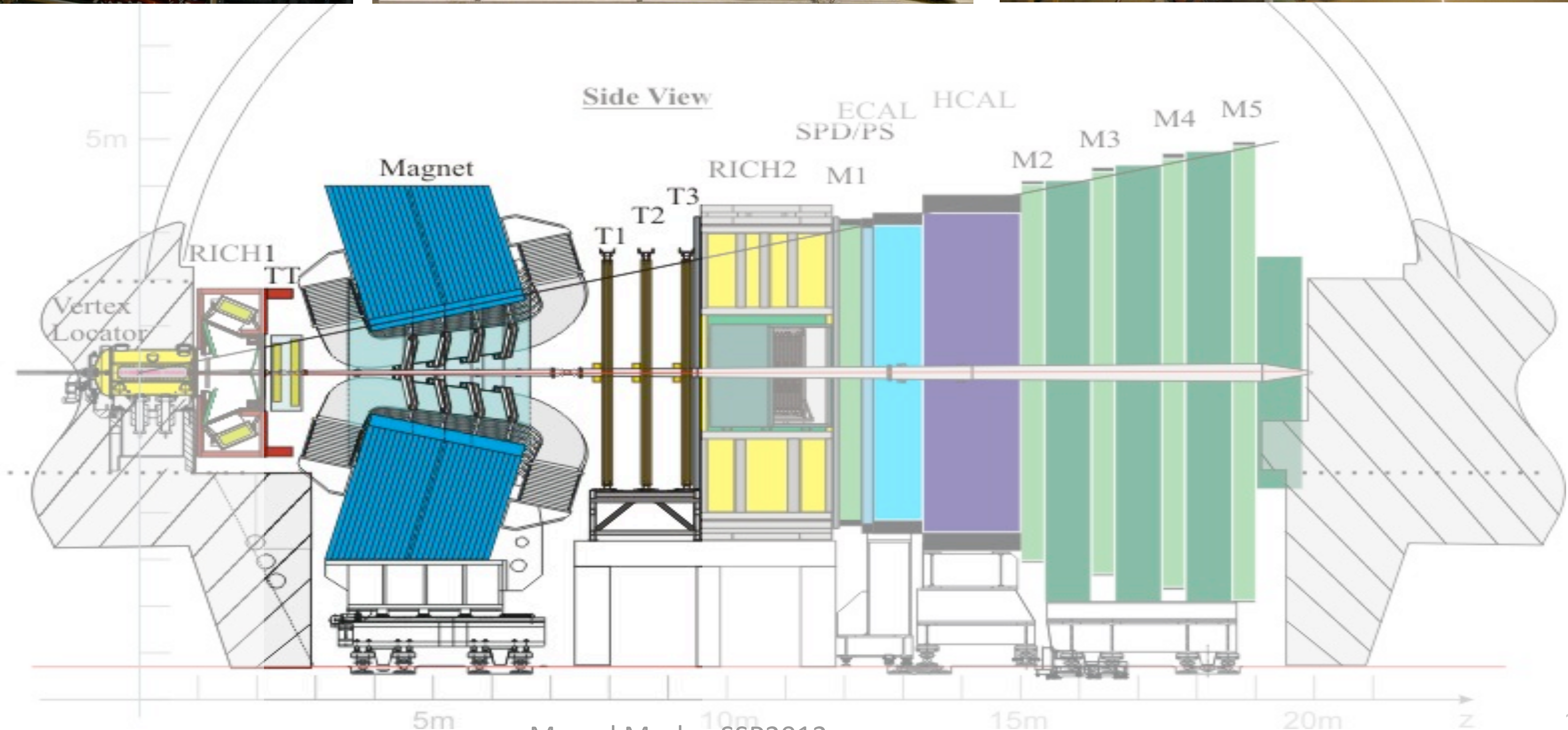


Magnet



Outer Tracker

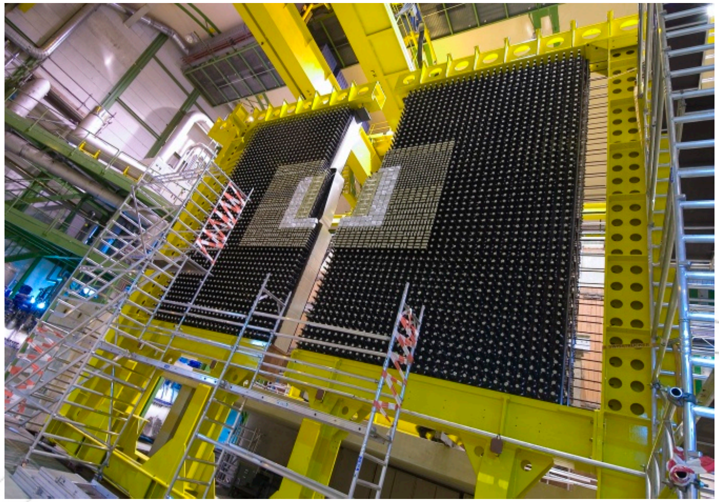




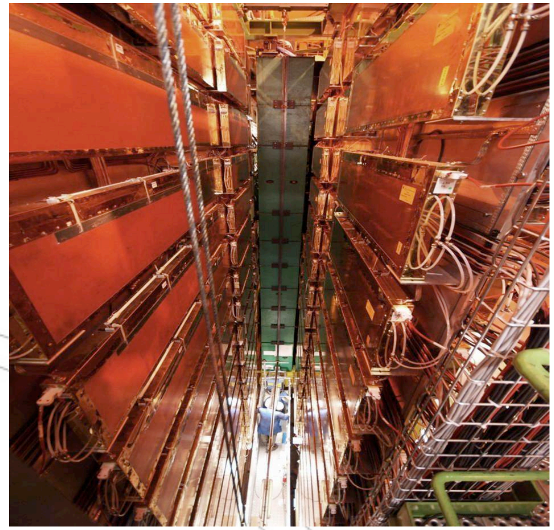
Particle Identification: π, K, μ, γ, e

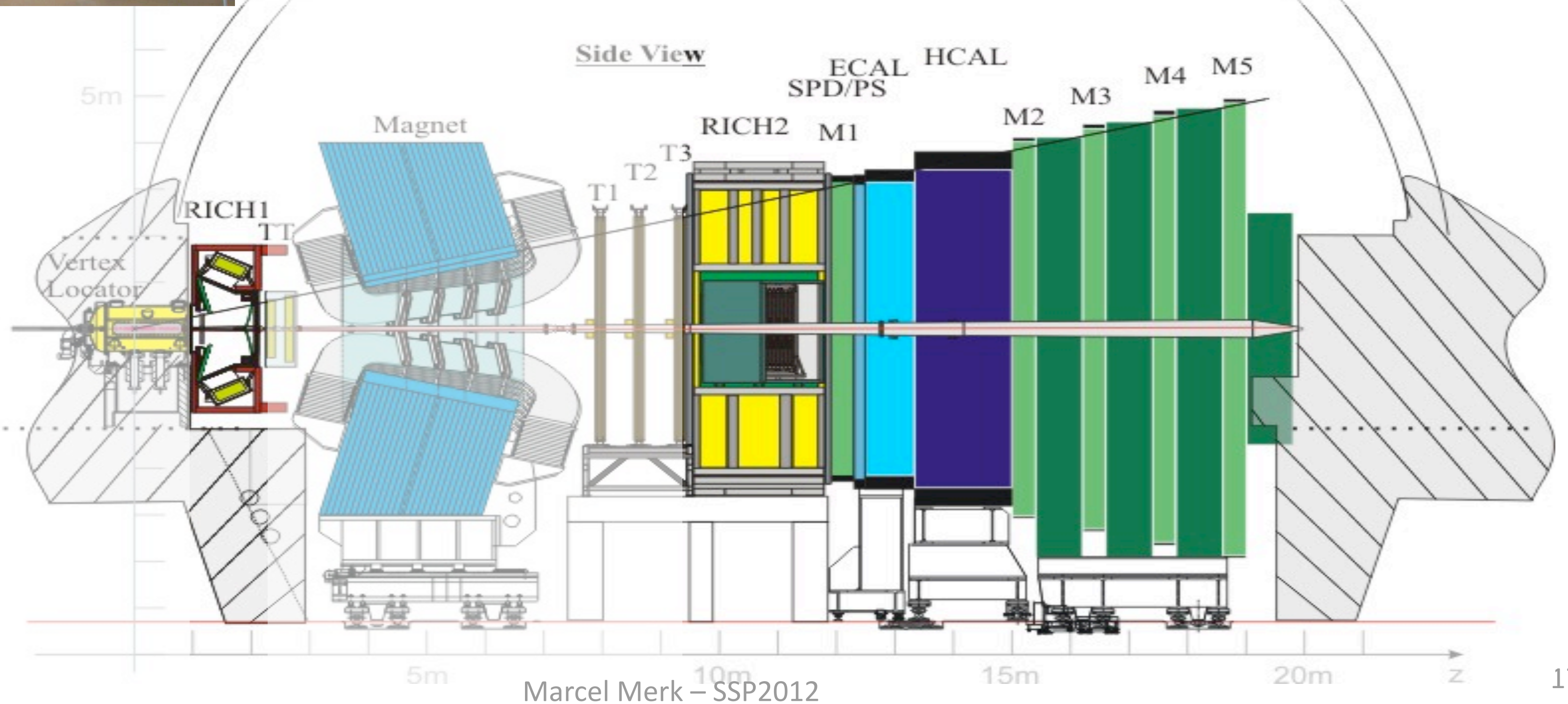
RICH

Calorimeter

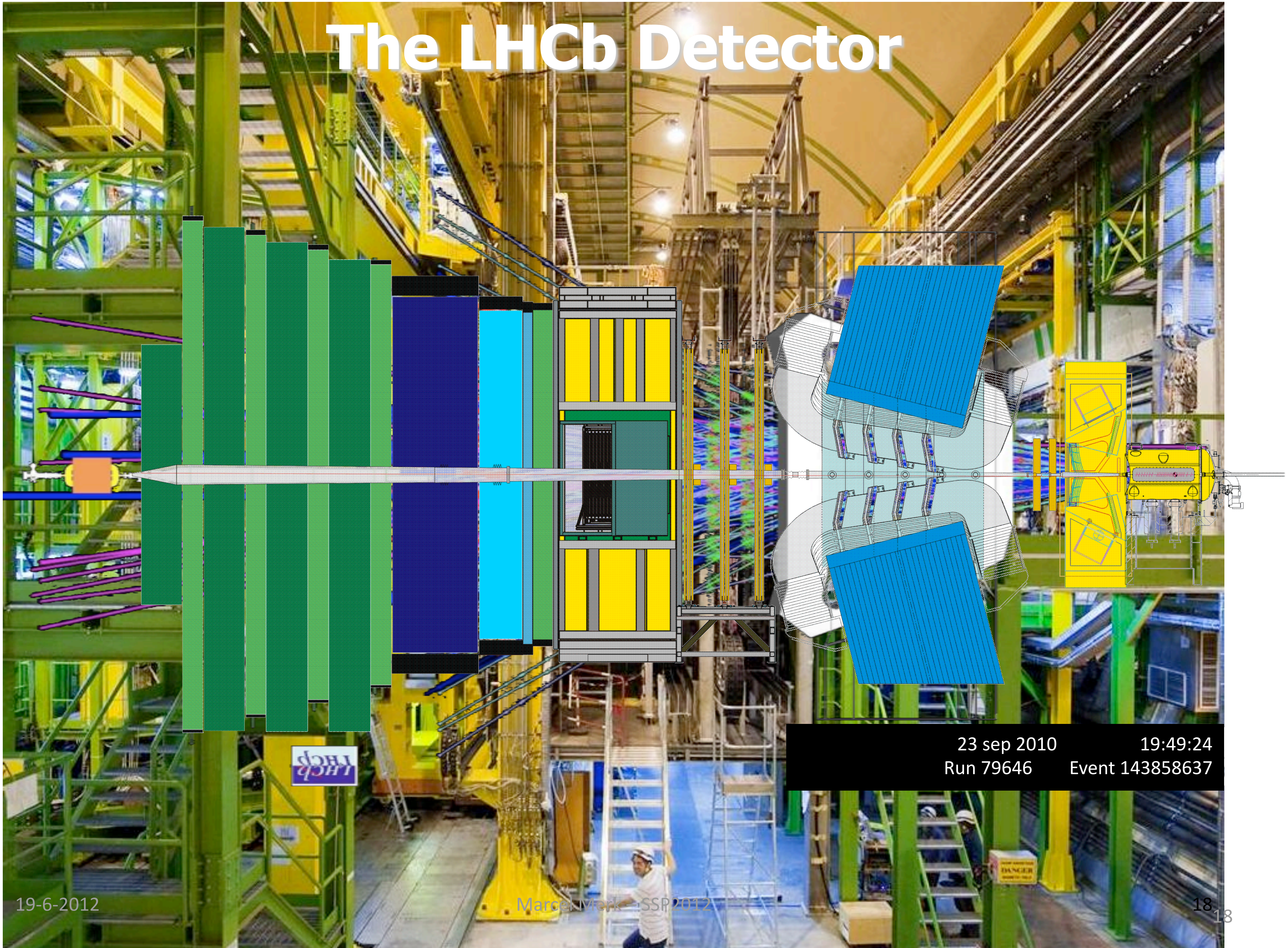


Muon

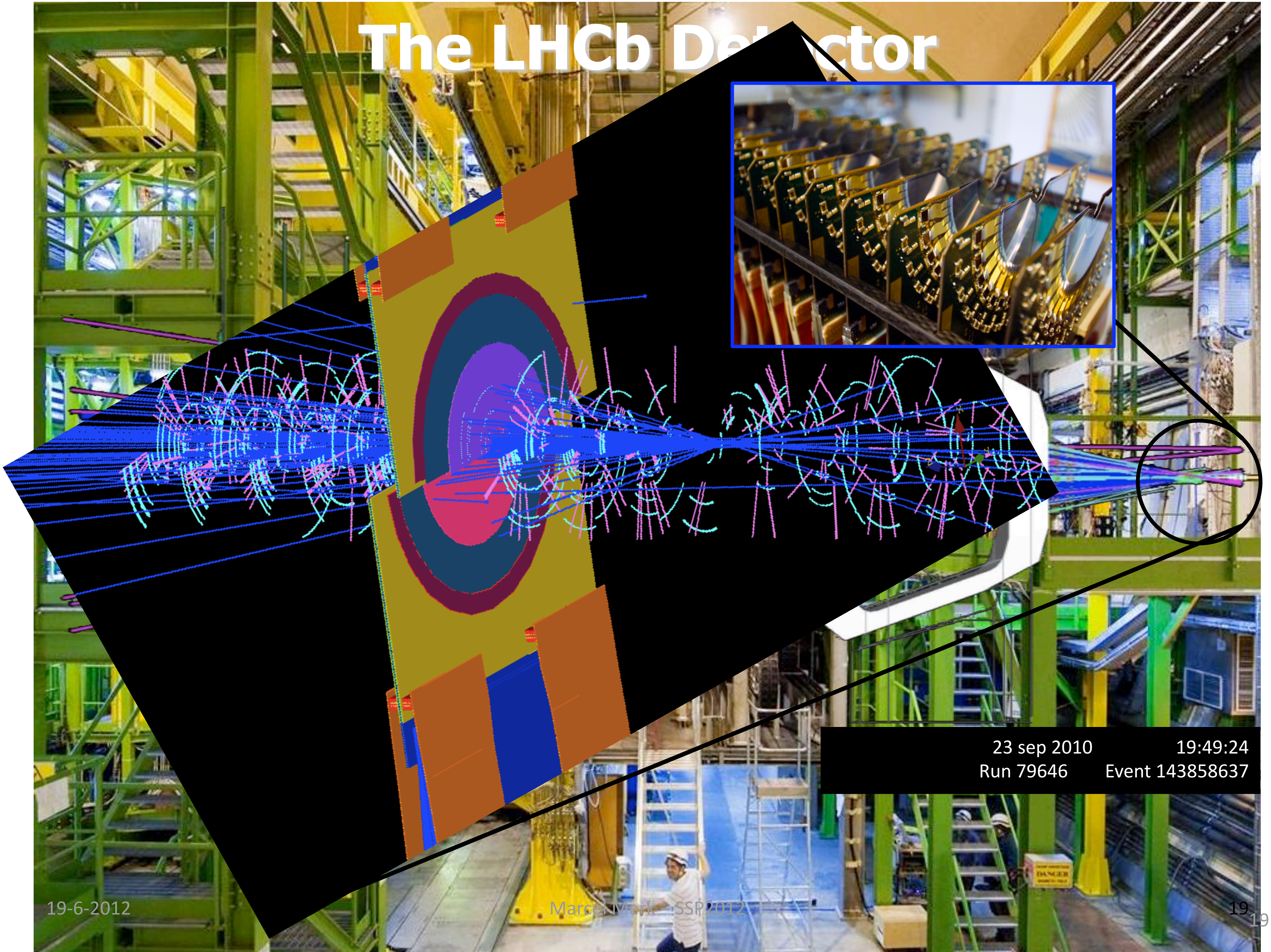




The LHCb Detector



The LHCb De ctor



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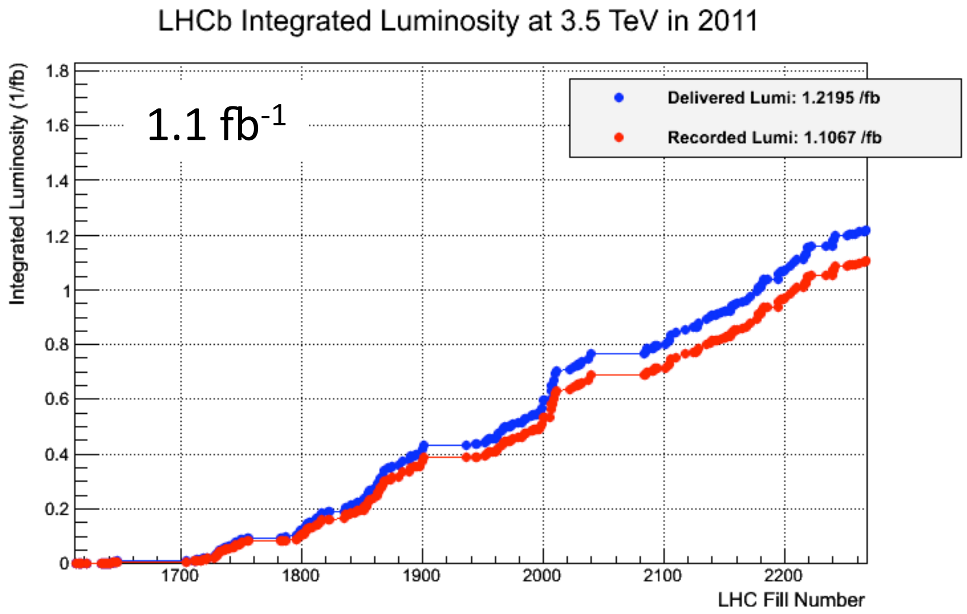
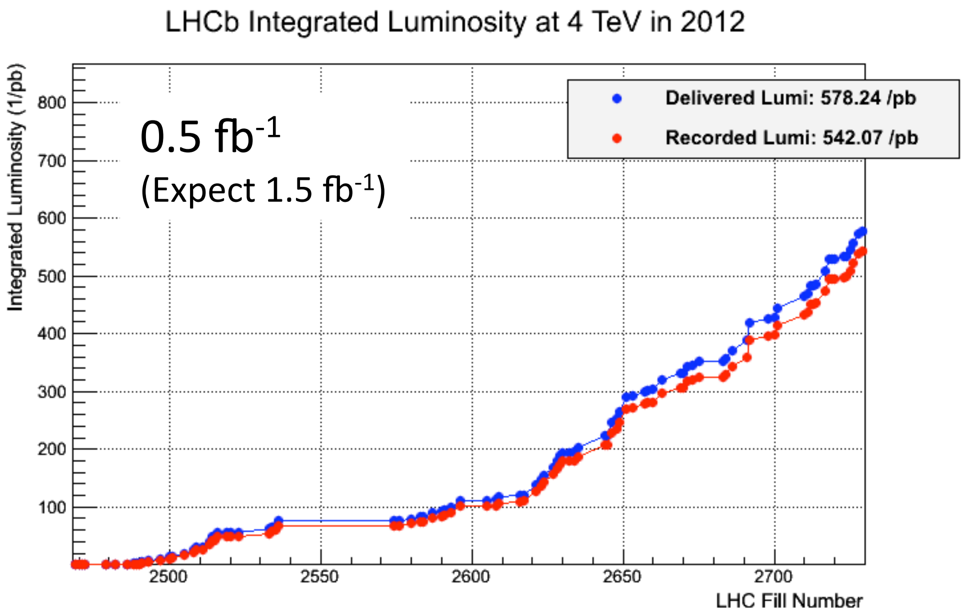
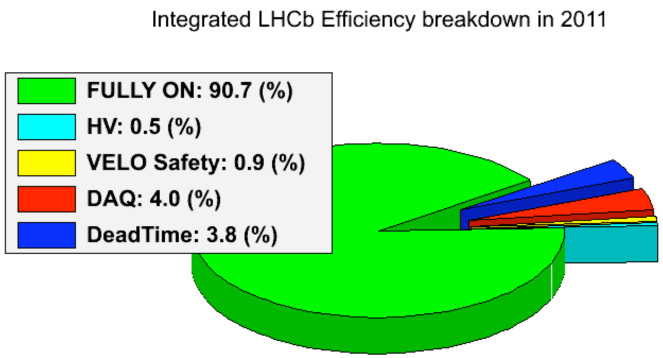
LHCb Running

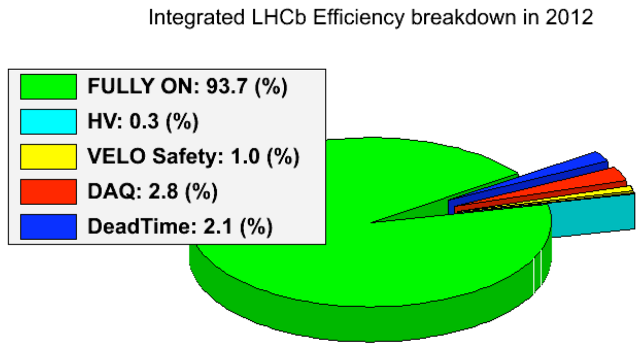
2011



2012



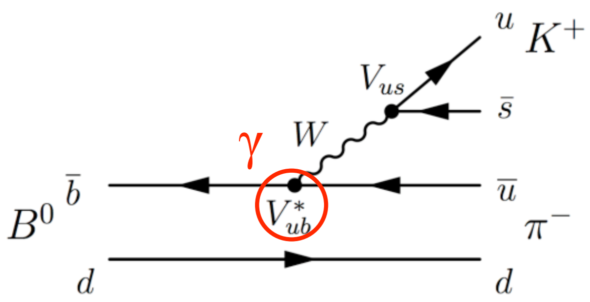




CP Violation Measurements @ LHCb

- Time Integrated measurements:
  - (1) Direct CP Violation in charmless decays $B_{(s)}$->Kπ.
  - (2) CP Violation in charmed decays $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow D^0 \pi^-$
- Time dependent measurements (interference of mixing and decay):
  - (3) CP violation in charmless $B_{(s)}$ decays $B_s \rightarrow KK$ and $B \rightarrow \pi\pi$
  - (4) CP Violation in charmed B_s decays $B_s \rightarrow D_s K$
  - (5) CP Violation in B_s decays to CP eigenstate $B_s \rightarrow J/\psi\ \varphi$
- CP Violation in mixing
  - (6) A charming surprise

(1) Direct CP Violation with $B_{(s)} \rightarrow K\pi$

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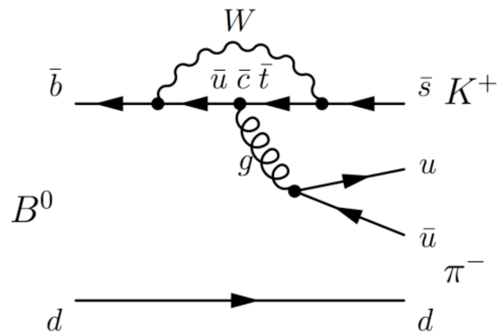


- Interference of trees and penguins
  - New physics can contribute to penguin loop
- Sensitive to V_{ub} phase: CKM angle γ
- Measure the *untagged* CP asymmetry for B^0 and B_s decays:

$$\mathcal{A}_{\mathcal{CP}} = \frac{\left(N_{\overline{B}\rightarrow\overline{f}} - N_{B\rightarrow f}\right)}{\left(N_{\overline{B}\rightarrow\overline{f}} + N_{B\rightarrow f}\right)} \qquad B \rightarrow f = \begin{cases} B^0 \rightarrow K^+\pi^- \\ B_s \rightarrow \pi^+K^- \end{cases}$$

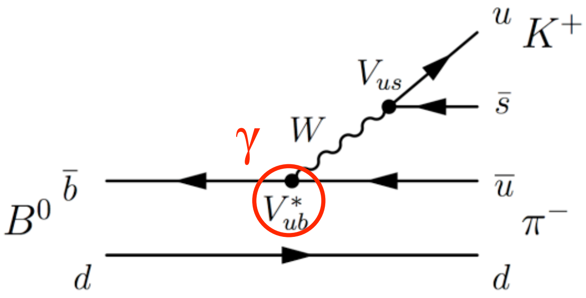
$$\mathcal{A}_{\mathrm{raw}} = \mathcal{A}_{\mathcal{CP}} + \mathcal{A}_{\mathrm{det}} + \kappa \cdot \mathcal{A}_{\mathrm{prod}}$$

(The correction factor is ~1%, measured from data)

Instrumental asymmetry

Mixing dilution times production asymmetry

(1) Direct CP Violation with $B_{(s)} \rightarrow K\pi$



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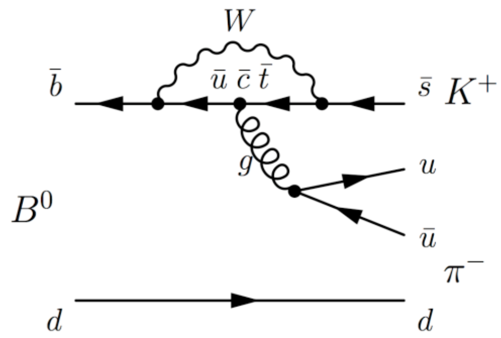
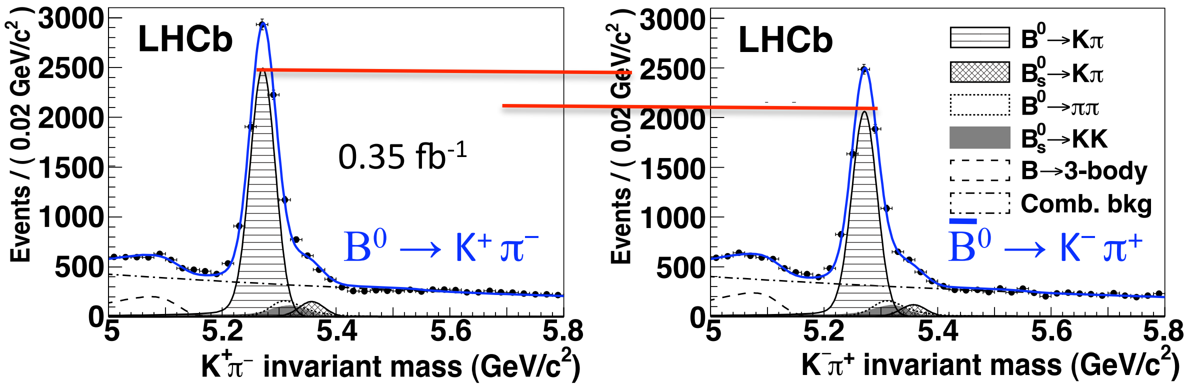


$B^0 \rightarrow K\pi$

PRL 108.201601

A_{CP} = -0.088 ± 0.011 ± 0.008

Most precise and first **5σ** observation of CP violation in a hadronic machine

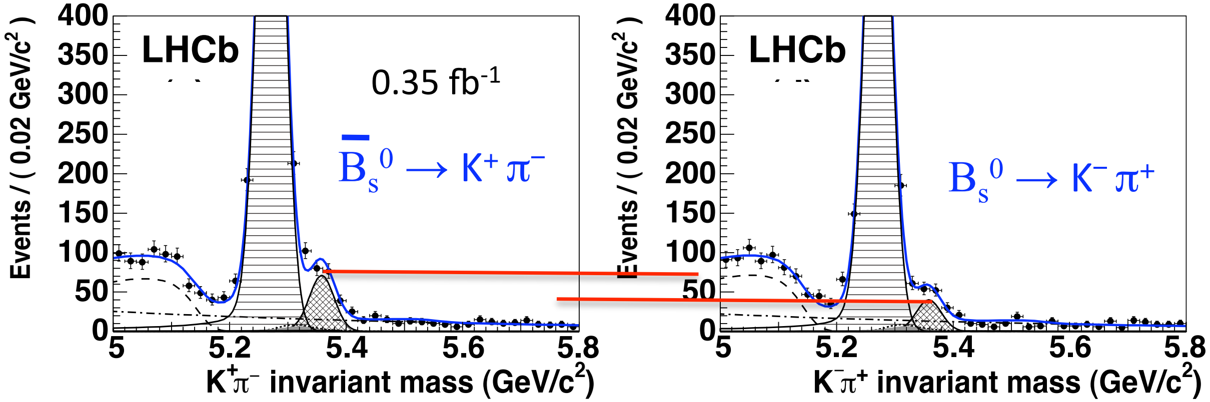


$B_s \rightarrow \pi K$

PRL 108.201601

A_{CP} = 0.27 ± 0.08 ± 0.02

First **3σ** evidence for CP asymmetry in B_s decays



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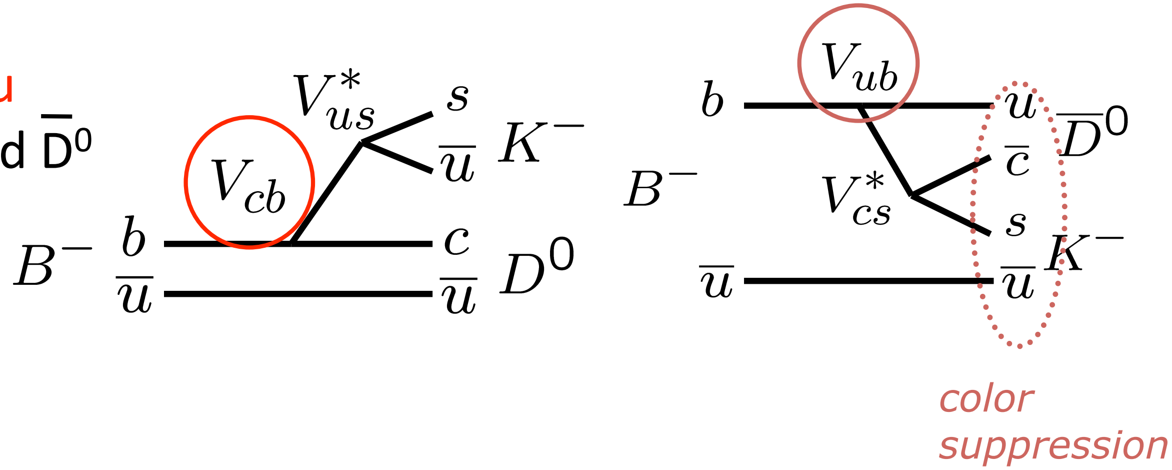
(2) The GLW/ADS method with B→DK and B→Dπ

- Interfere decays b→c with b→u to final states common to D^0 and $\overline{D}^0$

$$\frac{A(B^- \to \overline{D}^0 K^-)}{A(B^- \to D^0 K^-)} = r_B \, e^{i\delta_B} \, e^{-i\gamma}$$



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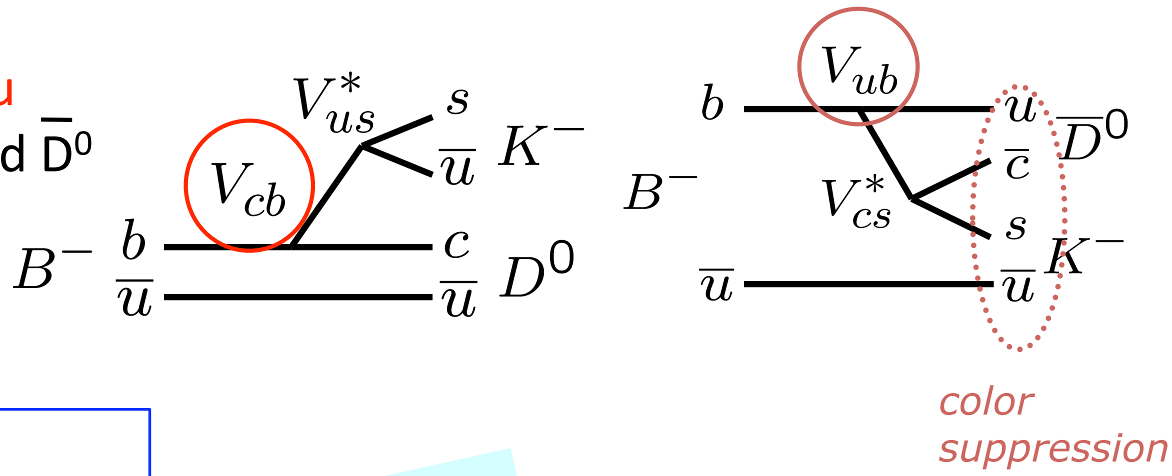


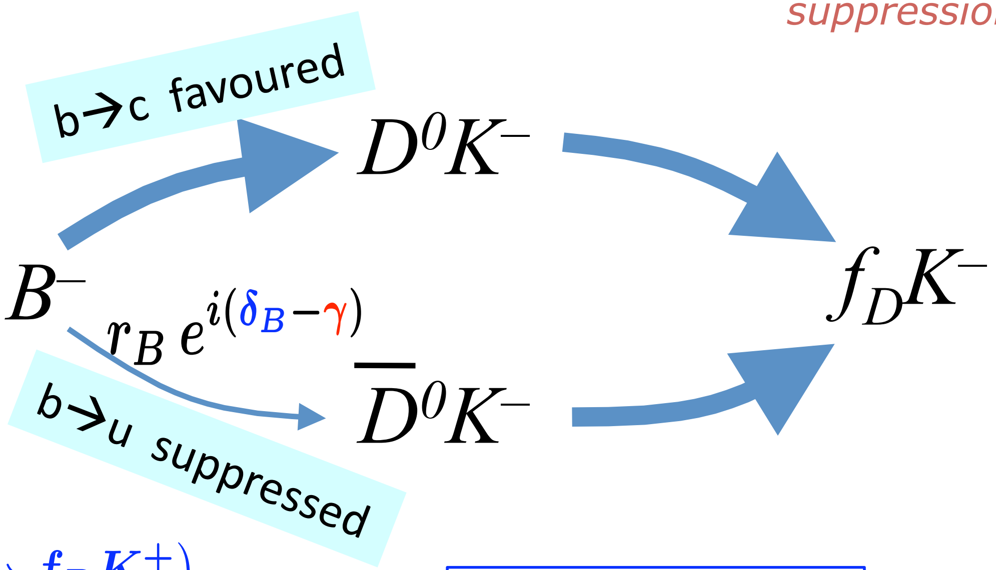
GLW method:

f_D is a CP eigenstate common to D^0 and $\overline{D}^0$: $f_D = K^+K^-, \pi^+\pi^-, \ldots$

Measure: $B \to D^0K$, $B \to \overline{D}^0K$, $B \to D_1K$

- Large event rate; small interference

Gronau, London, Wyler: Phys. Lett. B 265, 172 (1991)



Observables:

$$A_{CP+} = \frac{\Gamma(B^- \to f_D K^-) - \Gamma(B^+ \to f_D K^+)}{\Gamma(B^- \to f_D K^-) + \Gamma(B^+ \to f_D K^+)}$$

$$R_{CP+} = \frac{\Gamma(B^- \to f_D K^-) + \Gamma(B^+ \to f_D K^+)}{\Gamma(B^- \to D^0 K^+)}$$

Unknown phases:

Weak phase γ

Strong phase δ_B

(2) The GLW/ADS method with B→DK and B→Dπ

- Interfere decays b→c with b→u
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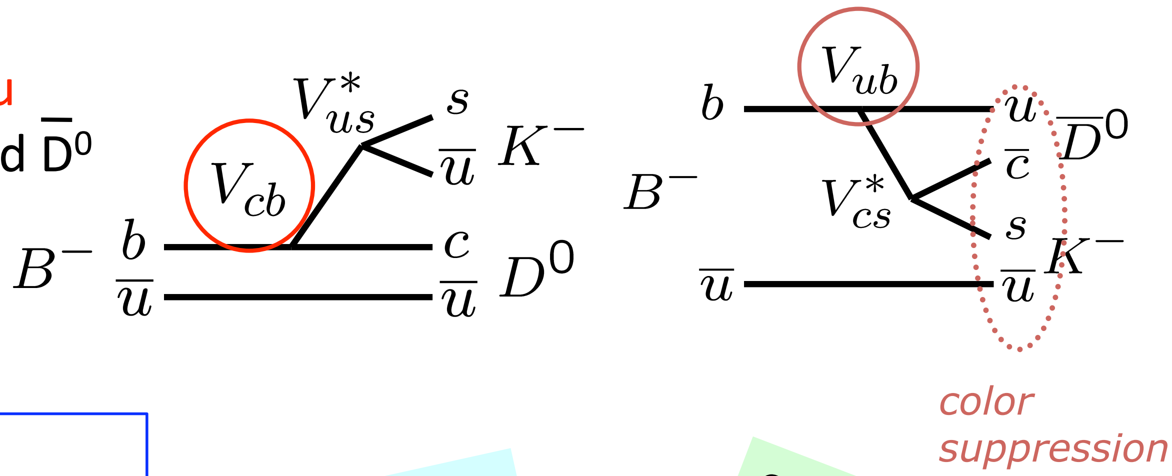
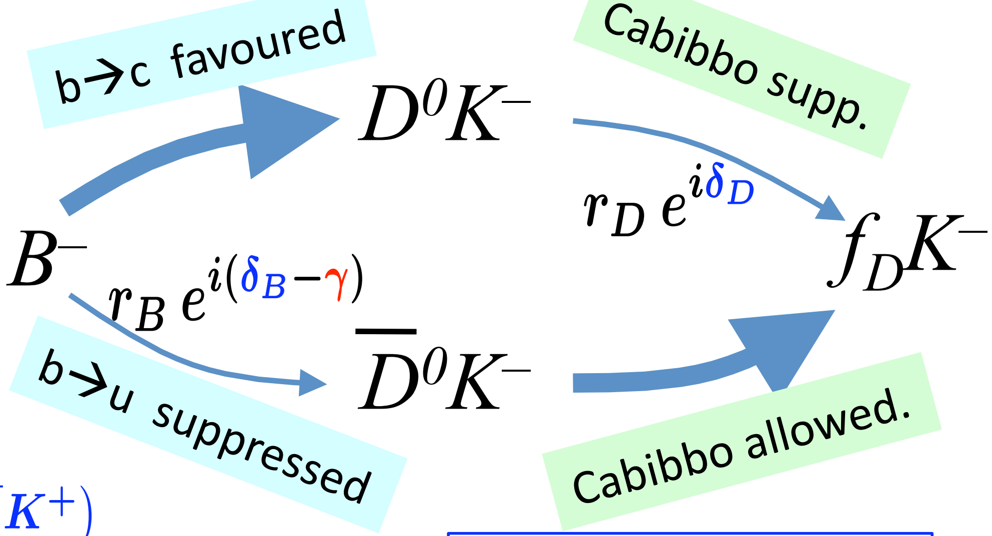


ADS method:

Use common flavour state $f_D=(K^+\pi^-)$

Note: decay $D^0 \to K^+\pi^-$ is double Cabibbo suppressed

- Lower event rate; large interference



Atwood, Dunietz, Soni:
Phys Rev Lett 78, 3257 (1997)
Phys Rev D 63, 036005 (2001)

Observables:

$$A_{ADS} = \frac{\Gamma(B^- \to f_D K^-) - \Gamma(B^+ \to \overline{f_D} K^+)}{\Gamma(B^- \to f_D K^-) + \Gamma(B^+ \to \overline{f_D} K^+)}$$

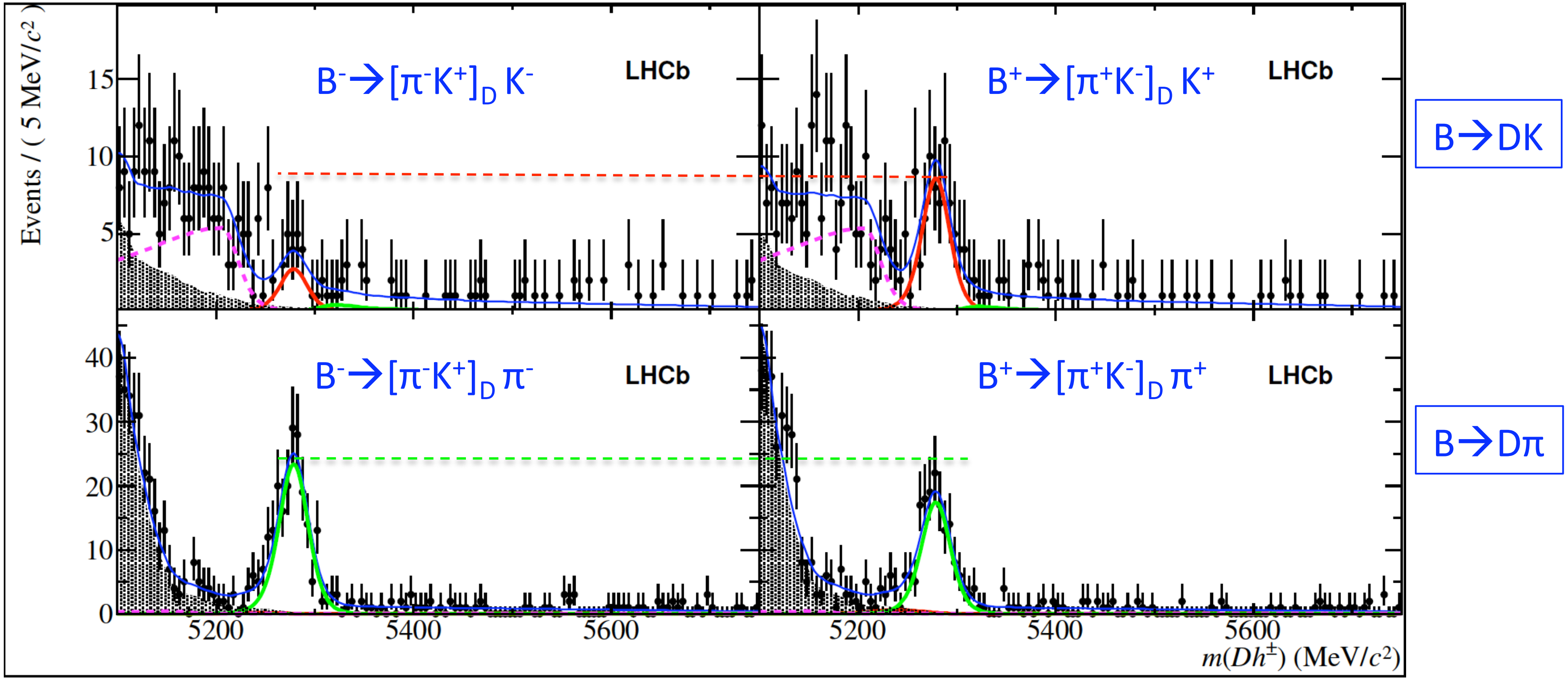
$$R_{ADS} = \frac{\Gamma(B^- \to f_D K^-) + \Gamma(B^+ \to \overline{f_D} K^+)}{\Gamma(B^- \to \overline{f_D} K^-) + \Gamma(B^+ \to f_D K^+)}$$

Unknown phases:
Weak phase γ
Strong phase δ_B , δ_D

(2) The GLW/ADS method with B→DK and B→Dπ

Observe ADS mode $B^- \to [\pi^- K^+]_D K^-$ with 10 σ significance

arXiv:1203:3662
LHCb: 1.0 fb^{-1}



B→DK shows ***4.0 σ evidence*** of CPV:

$A_{ADS}(K)$ = -0.52 +- 0.15 +- 0.02
$R_{ADS}(K)$ = 0.015 +- 0.002 +- 0.000

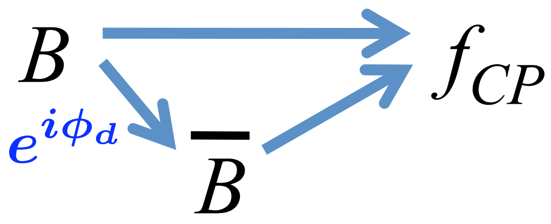
B→Dπ shows ***2.4σ hint*** of possible asym:

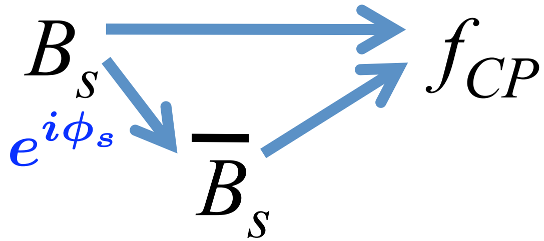
$A_{ADS}(\pi)$ = 0.14 +- 0.06 +- 0.01
$R_{ADS}(\pi)$ = 0.0041 +- 0.0003 +- 0.0001

CP Violation Measurements @ LHCb

- Time Integrated measurements:
  - (1) Direct CP Violation in charmless decays $B_{(s)}$->Kπ.
  - (2) CP Violation in charmed decays $B^- \rightarrow D^0 K^-$ and $B^- \rightarrow D^0 \pi^-$
- Time dependent measurements (interference of mixing and decay):
  - (3) CP violation in charmless $B_{(s)}$ decays $B_s \rightarrow KK$ and $B \rightarrow \pi\pi$ ⬅
  - (4) CP Violation in charmed B_s decays $B_s \rightarrow D_s K$
  - (5) CP Violation in B_s decays to CP eigenstate $B_s \rightarrow J/\psi\ \varphi$
- CP Violation in mixing
  - (6) A charming surprise

Time Dependent CP Violation



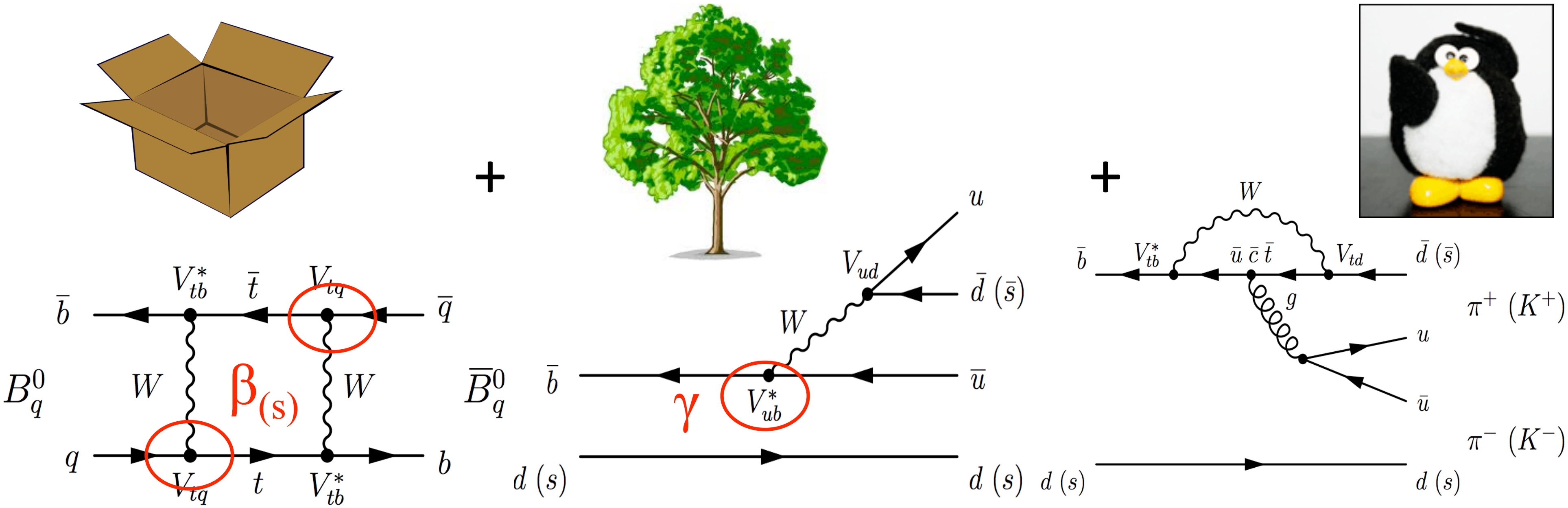


$$\mathcal{A}_{CP}(t) = \frac{\Gamma_{\overline{B}\to f}(t) - \Gamma_{B\to f}(t)}{\Gamma_{\overline{B}\to f}(t) + \Gamma_{B\to f}(t)} = \frac{\mathcal{A}^{dir}\cos(\Delta \mathrm{M t}) + \mathcal{A}^{mix}\sin(\Delta \mathrm{M t})}{\cosh\left(\frac{\Delta\Gamma}{2}\mathrm{t}\right) - \mathcal{A}^{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma}{2}\mathrm{t}\right)}$$

$$\left(\mathcal{A}^{dir}\right)^2 + \left(\mathcal{A}^{mix}\right)^2 + \left(\mathcal{A}^{\Delta\Gamma}\right)^2 = 1$$

- Extraction of $\mathcal{A}^{dir}$ and $\mathcal{A}^{mix}$ require flavour tagging: knowing the flavour of the B-meson at production

(3) Charmless $B_{(s)}$ decays $B \rightarrow \pi^+\pi^-$ and $B_s \rightarrow K^+K^-$



<u>A measurement of "γ with loops"</u>

(Fleisher: Phys.Lett.B459:306-320,1999)

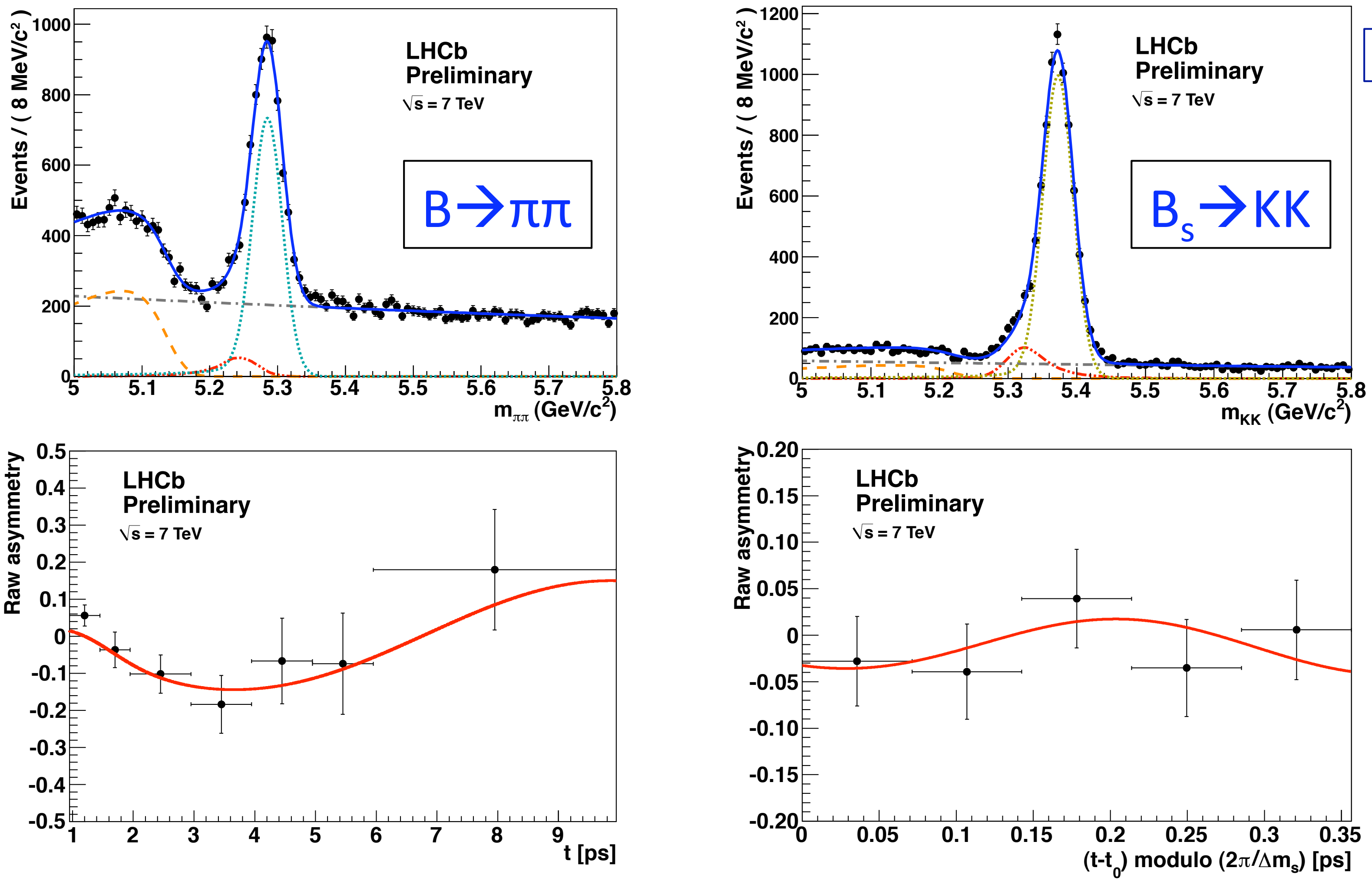
- Sensitivity to new physics enters via the penguin loop
- Combined analysis of $B \rightarrow KK$, $B \rightarrow \pi\pi$ with $B \rightarrow K\pi$
  - Make use of U-spin flavour symmetry to extract common hadronic factors

$$\mathcal{A}_{\pi\pi}^{mix} \sim 2\beta + 2\gamma \qquad \mathcal{A}_{KK}^{mix} \sim 2\beta_s + 2\gamma$$

$$\mathcal{A}_{\pi\pi}^{dir} \sim 2\gamma \qquad \mathcal{A}_{KK}^{dir} \sim 2\gamma$$

(3) Charmless $B_{(s)}$ decays $B \to \pi^+\pi^-$ and $B_s \to K^+K^-$

LHCb-CONF-2012-007



$\mathcal{A}^{dir}_{\pi\pi} = 0.11 \pm 0.21(\mathrm{stat}) \pm 0.03(\mathrm{sys})$

$\mathcal{A}^{mix}_{\pi\pi} = -0.56 \pm 0.17(\mathrm{stat}) \pm 0.03(\mathrm{sys})$

$\mathcal{A}^{dir}_{KK} = 0.02 \pm 0.18(\mathrm{stat}) \pm 0.04(\mathrm{sys})$

$\mathcal{A}^{mix}_{KK} = 0.17 \pm 0.18(\mathrm{stat}) \pm 0.05(\mathrm{sys})$

First (preliminary) evidence of mixing induced CP violation seen at hadron collider (3.2σ)

CP Violation Measurements @ LHCb

- Time Integrated measurements:
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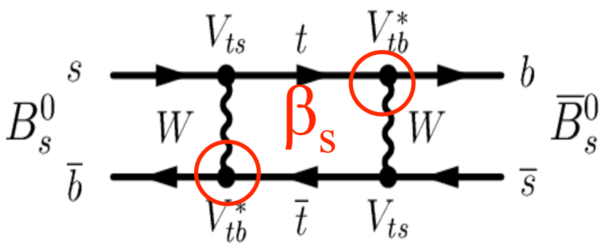
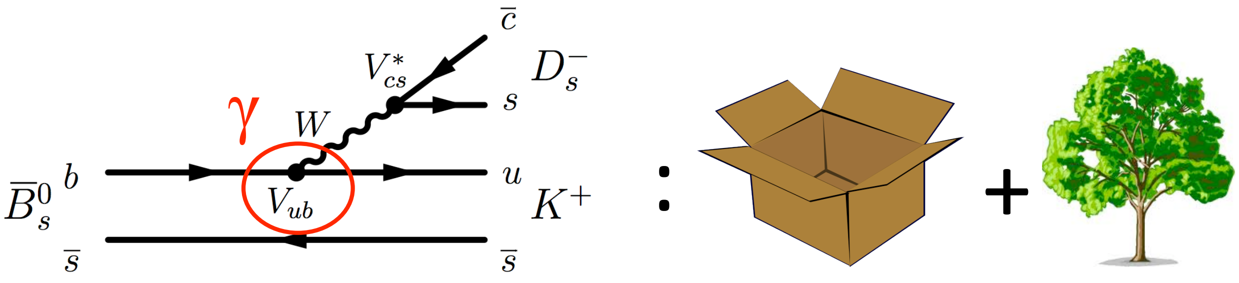
- Time dependent measurements (interference of mixing and decay):
  - (3) CP violation in charmless $B_{(s)}$ decays $B_s \rightarrow KK$ and $B \rightarrow \pi\pi$
  - **(4) CP Violation in charmed B_s decays $B_s \rightarrow D_s K$** ⟸
  - (5) CP Violation in B_s decays to CP eigenstate $B_s \rightarrow J/\psi\ \varphi$
- CP Violation in mixing
  - (6) A charming surprise

(4) Charmed B_s decays: $B_s \rightarrow D_s K$

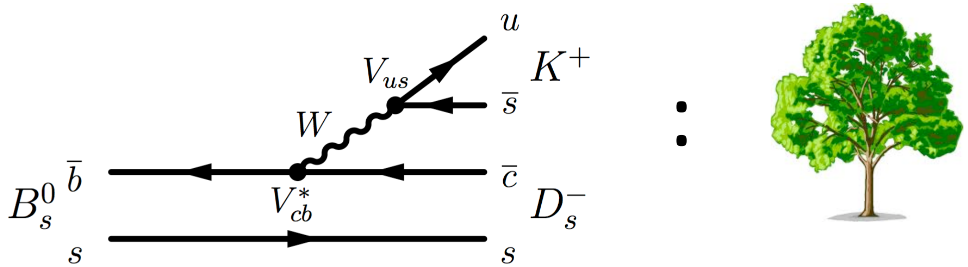
Two decay amplitudes to the same final state:

1) via mixing $B_s \rightarrow \overline{B}_s \rightarrow D_s^- K^+$:

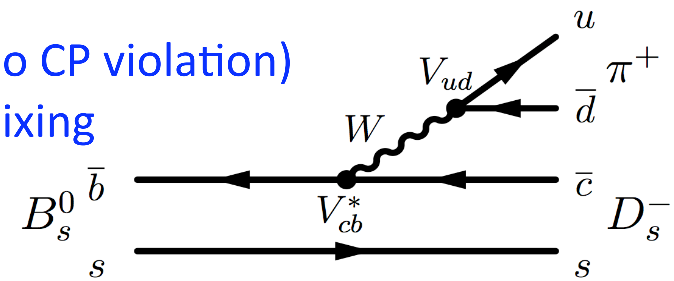




2) direct: $B_s \rightarrow D_s^- K^+$:

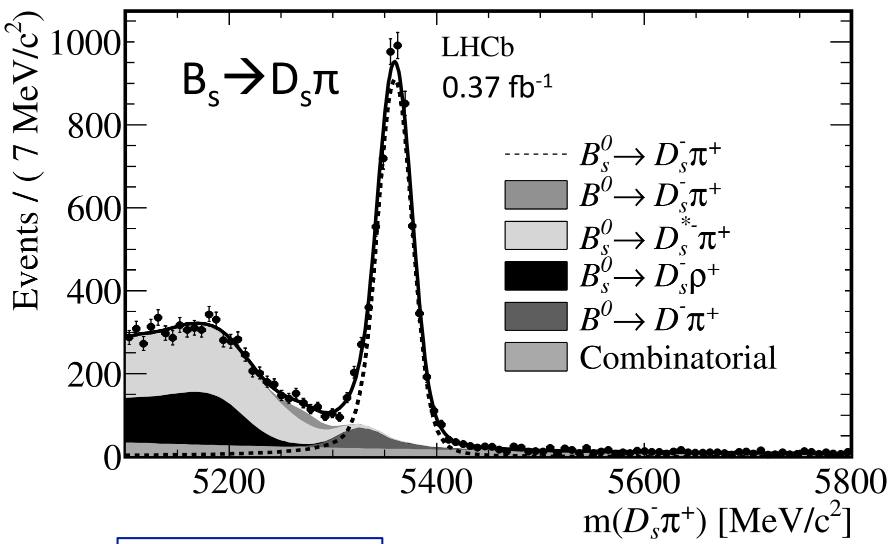


- Golden mode for a time dependent measurement of "γ with trees"
  - Hadronic uncertainties small
- Sensitivity to new physics enters via the mixing loop: expected to be small
- Combined analysis of $B \rightarrow D_s K$ with $B_s \rightarrow D_s \pi$:
  - For $B_s \rightarrow D_s \pi$ only decay amplitude 2) is possible (no CP violation)
  - Use $B_s \rightarrow D_s \pi$ decay as a calibration process for B mixing

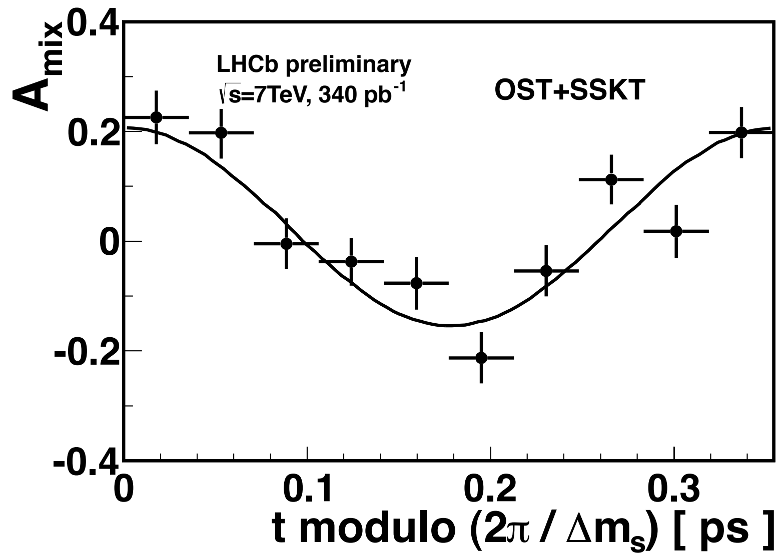


(4) Charmed B_s decays: $B_s \to D_s K$

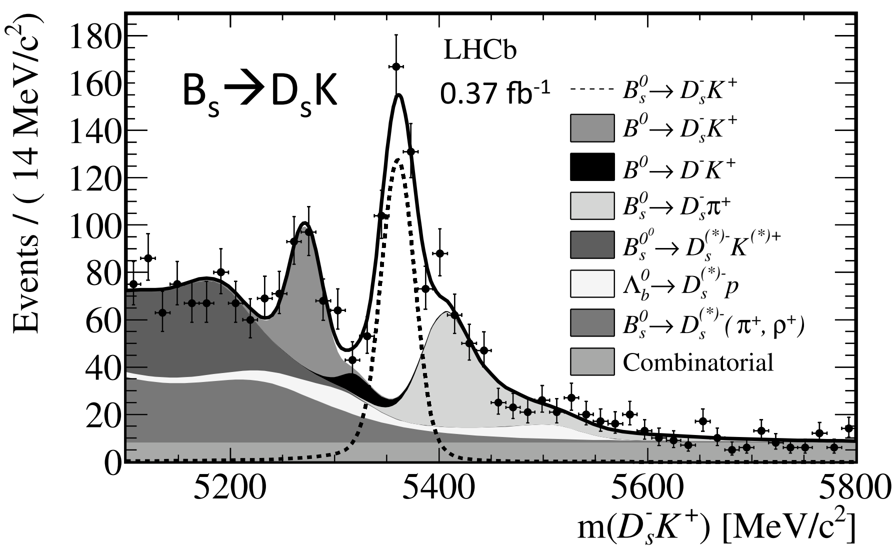
arXiv:1204.1237



LHCb-CONF-2011-050



arXiv:1204.1237



- $B_s \to D_s\pi$ — LHCb-CONF-2011-050 and arXiv:1112.4311
  - Flavour tagging:
    - Opposite side: $\varepsilon D^2 = 3.2 \pm 0.8$ %
    - Same side: additional power
  - Measurement of B_s mixing:
    - $\Delta m_s = 17.63 \pm 0.11 \pm 0.02\ ps^{-1}$
- $B_s \to D_s K$ — arXiv:1204.1237
  - Branching ratio:
    - BR = $(1.90 \pm 0.12 \pm 0.18) \times 10^{-4}$

CP Violation Measurements @ LHCb

- Time Integrated measurements:
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- Time dependent measurements (interference of mixing and decay):
  - (3) CP violation in charmless $B_{(s)}$ decays $B_s \rightarrow KK$ and $B \rightarrow \pi\pi$
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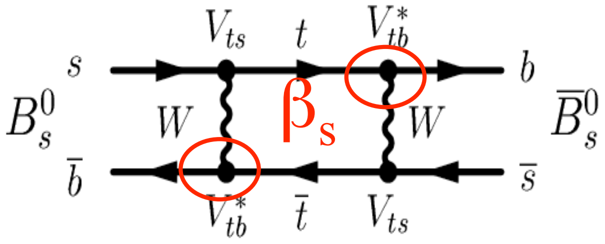
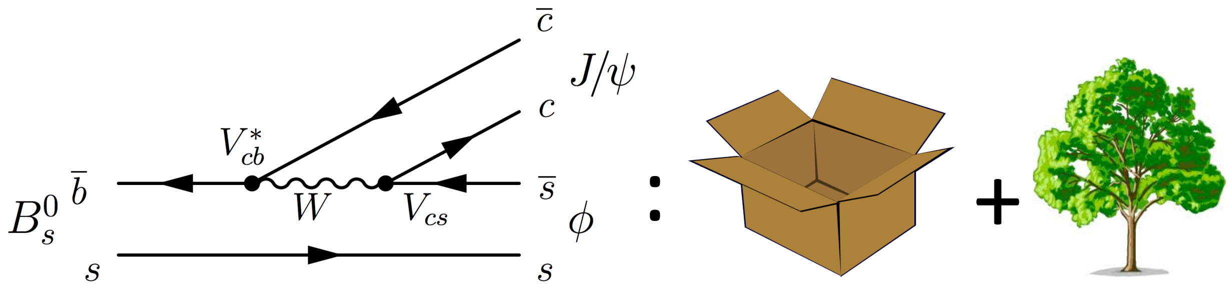
  - (5) CP Violation in B_s decays to CP eigenstate $B_s \rightarrow J/\psi\ \varphi$ ⬅
- CP Violation in mixing
  - (6) A charming surprise

(5) B_s decays to a CP eigenstate: $B_s \rightarrow J/\psi\phi$

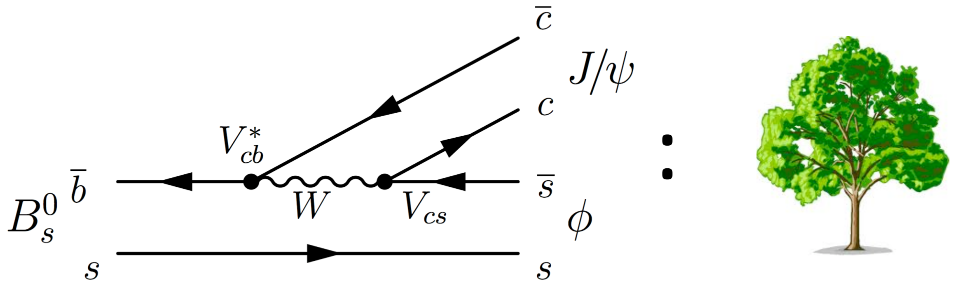
Two decay amplitudes to the same CP eigenstate final state.

1) via mixing $B_s \rightarrow \overline{B}_s \rightarrow J/\psi\phi$:





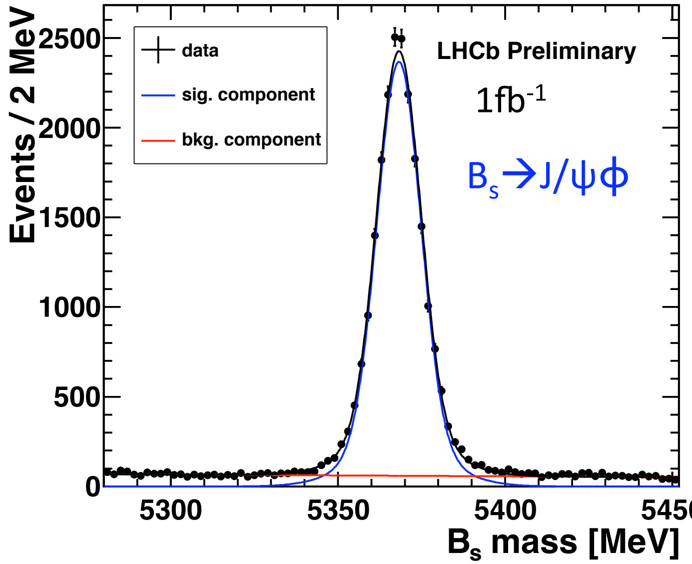
2) direct: $B_s \rightarrow J/\psi\phi$:

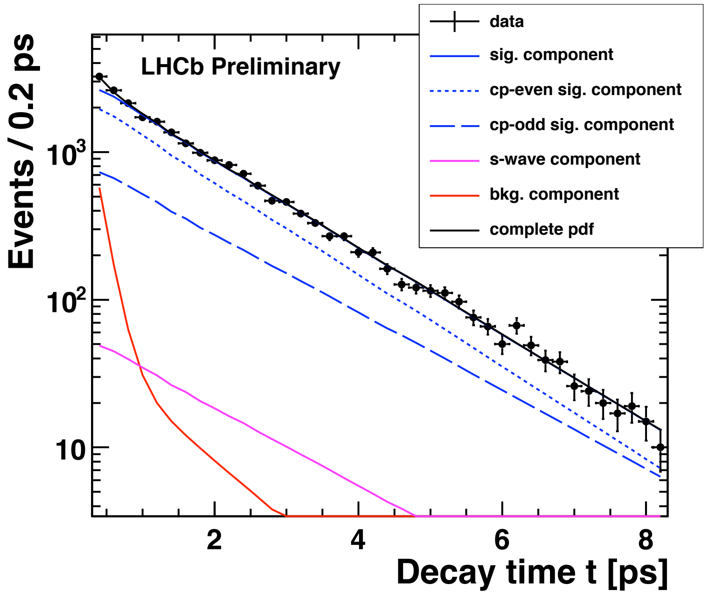


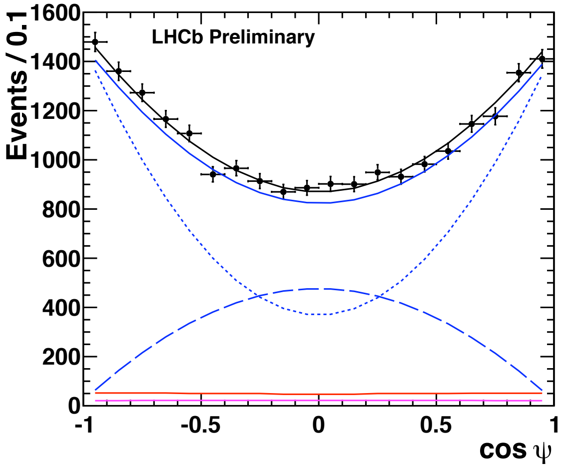
- Golden mode for a time dependent measurement of "β_s via mixing diagram"
  - Hadronic uncertainties small
- High sensitivity to new physics that enters via the mixing loop
- B_s is a *speudoscalar* (s=0) while J/ψ and ϕ are *vector* particles (s=1)
  - Final state is superposition of CP even (L=0 and L=2) CP odd (L=1)
  - Requires angular analysis to disentangle

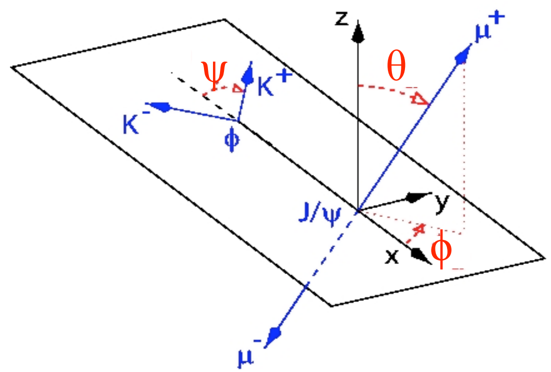
- Alternative analysis in pure CP odd eigenstate $B_s \rightarrow J/\psi\ f_0(980)$

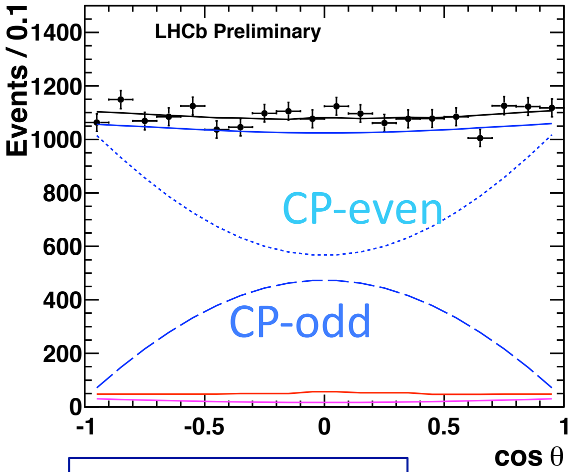
(5) B_s decays to a CP eigenstate: $B_s \to J/\psi\phi$

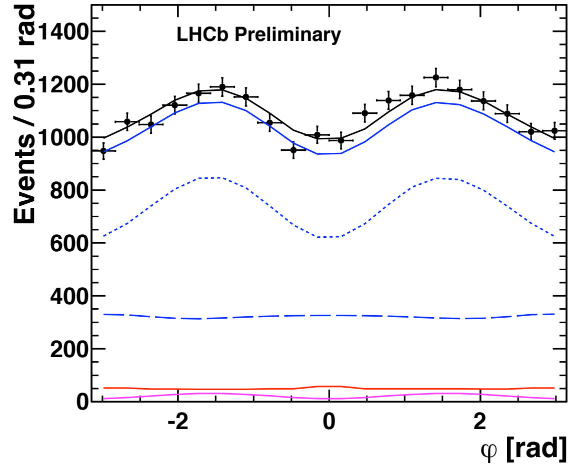












LHCb-CONF-2012-002

Preliminary:

$\phi_s = -0.001 \pm 0.101 \pm 0.027$ rad

$\Delta\Gamma_s = 0.116 \pm 0.018 \pm 0.006\ ps^{-1}$

$\phi_s = 2\beta_s$

Consistent with no CP violation as predicted in SM

CP Violation Measurements @ LHCb

- Time Integrated measurements:
  - (1) Direct CP Violation in charmless decays $B_{(s)}$->Kπ.
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  - (5) CP Violation in B_s decays to CP eigenstate $B_s \rightarrow J/\psi\ \varphi$
- CP Violation in mixing
  - (6) A charming surprise ⬅

(6) CP Violation in mixing: A Charming Surprise

- CP Violation in charm:
  - The mixing amplitude is small.
    - Expect no significant interference between mixing and decay
    - Difference $D \rightarrow \overline{D}$ and $\overline{D}$->D expected to be very small → $O(10^{-4})$
  - Direct CP violation (in decay)
    - Expected negligible in Cabibbo favoured modes ("Trees")
    - In Cabibbo suppressed mode "plausible" up to $O(10^{-3} - 10^{-4})$
  - Expectation: observation of any CP asymmetry in charm is a sign of New Physics…

(6) CP Violation in mixing: A Charming Surprise

- CP asymmetry from charm decays:

$$\mathcal{A}^{f}_{CP}(t) = \frac{\Gamma_{D\to f}(t) - \Gamma_{\overline{D}\to f}(t)}{\Gamma_{D\to f}(t) + \Gamma_{\overline{D}\to f}(t)}$$

- Measure time integrated CP asymmetries in D→$\pi^+\pi^-$ and D→K^+K^-
  – Use decays $D^{*\pm}\to D\,\pi_s^{\pm}$ to tag the flavour of the D (D or $\overline{D}$) using the charge of the slow pion π_s

M.Gersabeck et. al., J.Phys. G39 (2012) 045005

$$A^{f}_{CP} = a^{dir}_{CP}(f) + \frac{\langle t\rangle}{\tau} a^{ind}_{CP}$$

- Observed asymmetry includes detector effects and possible production asymmetry of D^*

$$A_{raw}(f) = A_{CP}(f) + A_D(f) + A_D(\pi_s) + A_P(D^{*+})$$

- Cancel these to first order by measuring *difference* between D→$\pi^+\pi^-$ and D→K^+K:

$$\Delta A_{CP} \equiv A_{raw}(KK) - A_{raw}(\pi\pi) = A_{CP}(KK) - A_{CP}(\pi\pi)$$

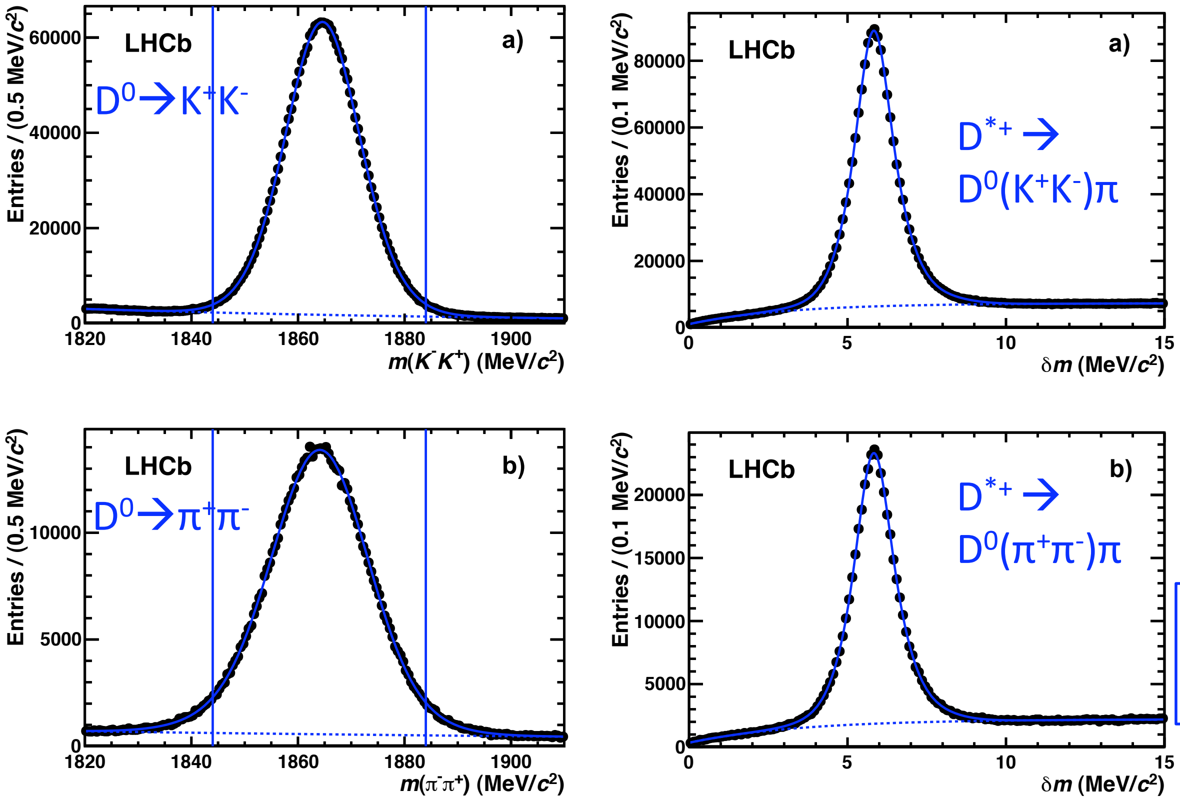
$$= \left[a^{dir}_{CP}(KK) - a^{dir}_{CP}(\pi\pi)\right] + \frac{\Delta\langle t\rangle}{\tau} a^{ind}_{CP}$$

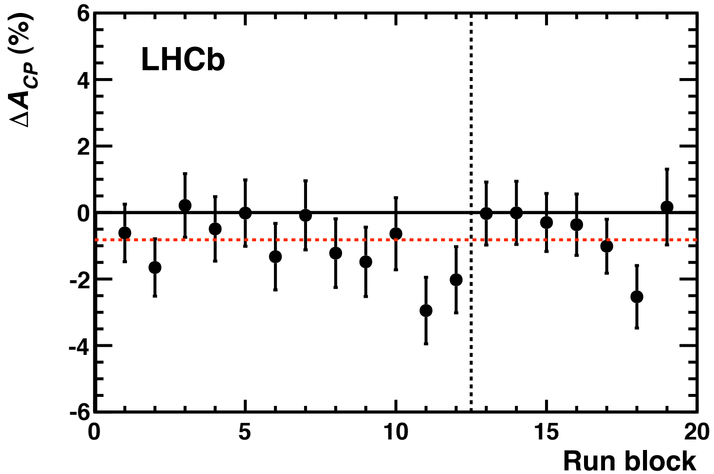
- Contribution from possible indirect CP violation term small

Signal Yields

1.4 M tagged $D^0 \rightarrow K^+K^-$ and
0.4M tagged $D^0 \rightarrow \pi^+\pi^-$

LHCb, 0.6 fb^{-1}, PRL 108, 111602 (2012)





ΔA_{CP} =(-0.82±0.21(stat)±0.11(sys))%
3.5 σ deviation from zero.

- Value is larger than was expected from SM before measurement was available
- *Postdiction*: general agreement that we cannot yet exclude that it is caused by hadronic uncertainties…
  - Currently hot activity in experiment and in theory.

Summary & Conclusions

- CP Violation:
  - ***1964*** CP Violation with K^0
  - ***2001*** CP Violation with B^0
  - ***2011*** Evidence for CP Violation with B_s and CP Violation with D^0

- LHCb carrying out full physics program
  - Collected 1.5 fb^{-1} by now
  - Backgrounds well under control
  - Expect to collect 5 fb^{-1} before upgrade

- Time dependent and time integrated CP observables for B decays
  - Towards measurements of CKM angle "γ with trees"
  - Towards measurements of CKM angle "γ with loops"
  - World best measurement of B_s mixing phase ϕ_s (consistent with SM β_s)

- CP violation in charm
  - Evidence for CP violation in ΔA_{CP}.
  - Hadronic effects to be clarified.

- LHCb upgrade in 2018
  - Higher luminosity: expect to collect 50 fb^{-1} in the upgrade
  - New 40 MHz Trigger
    - Extend the physics program