Beauty 2023 @ Clermont-Ferrand

3-7 July, 2023

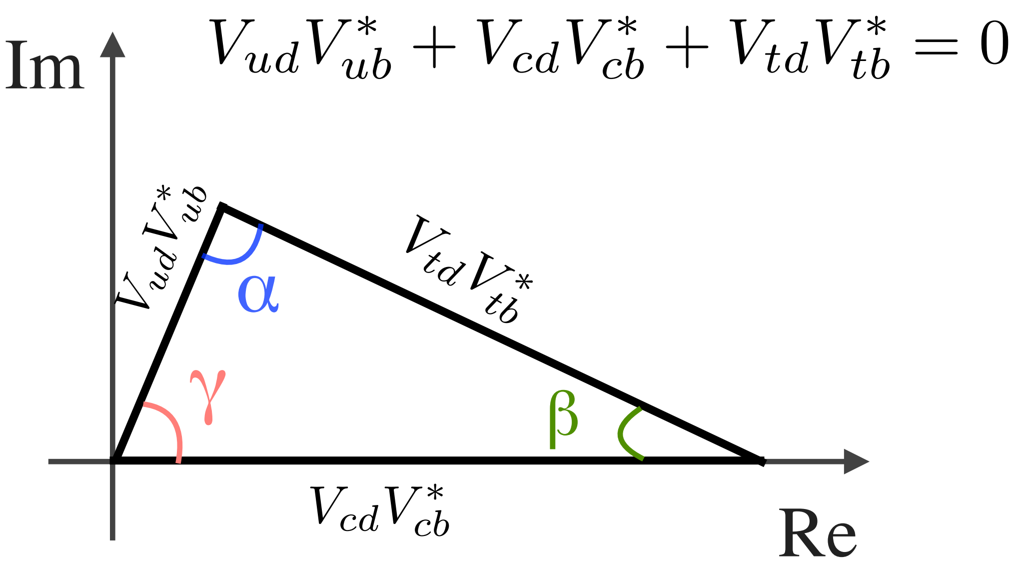
Measurements of ϕ_s and $\sin 2\beta$ at LHCb

Peilian Li
(on behalf of the LHCb collaboration)

CKM matrix

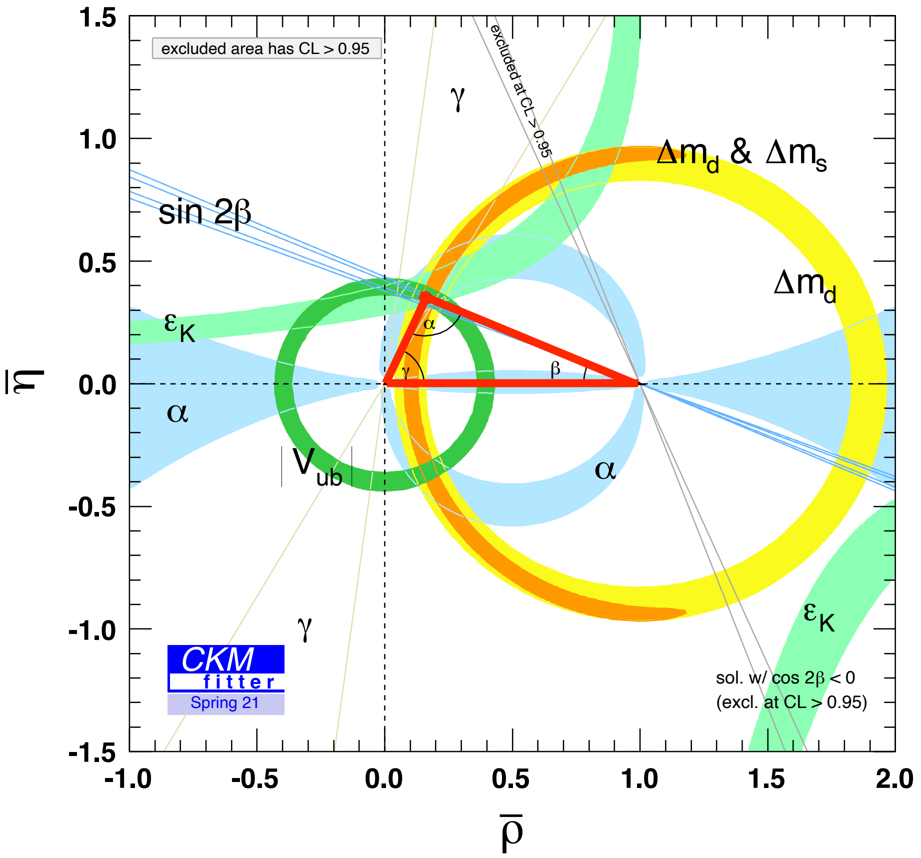
$$V_{CKM} = \begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}|e^{-i\gamma} \\ -|V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{i\beta_s} & |V_{tb}| \end{pmatrix} + \mathcal{O}(\lambda^5) \sim \begin{pmatrix} 1 & 0.2 & 0.004 \\ 0.2 & 1 & 0.04 \\ 0.008 & 0.04 & 1 \end{pmatrix}$$

- Key test of the SM: Verify unitarity of CKM matrix
  - Magnitudes: branching fractions or mixing frequencies
  - Phases: CP violation measurement



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

$$\alpha = \arg\left(-\frac{V_{td}V_{tb}^*}{V_{ud}V_{ub}^*}\right), \beta = \arg\left(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*}\right), \gamma = \arg\left(-\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right)$$



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- Key test of the SM: Verify unitarity of CKM matrix
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  - Phases: CP violation measurement
- Sensitive probe for new physics

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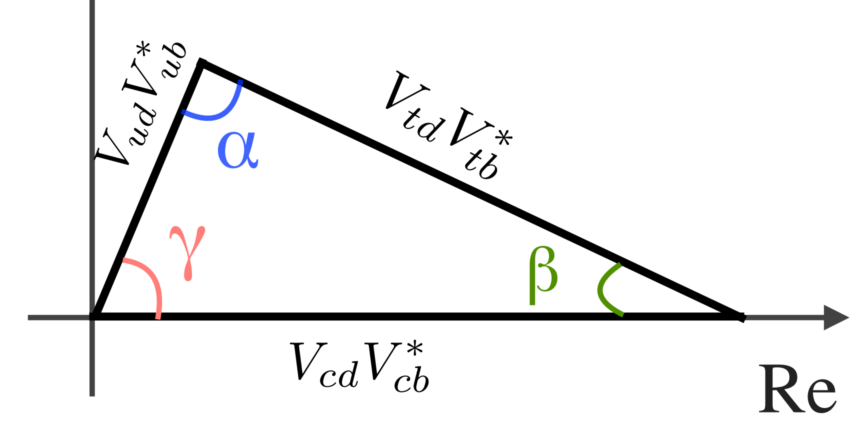

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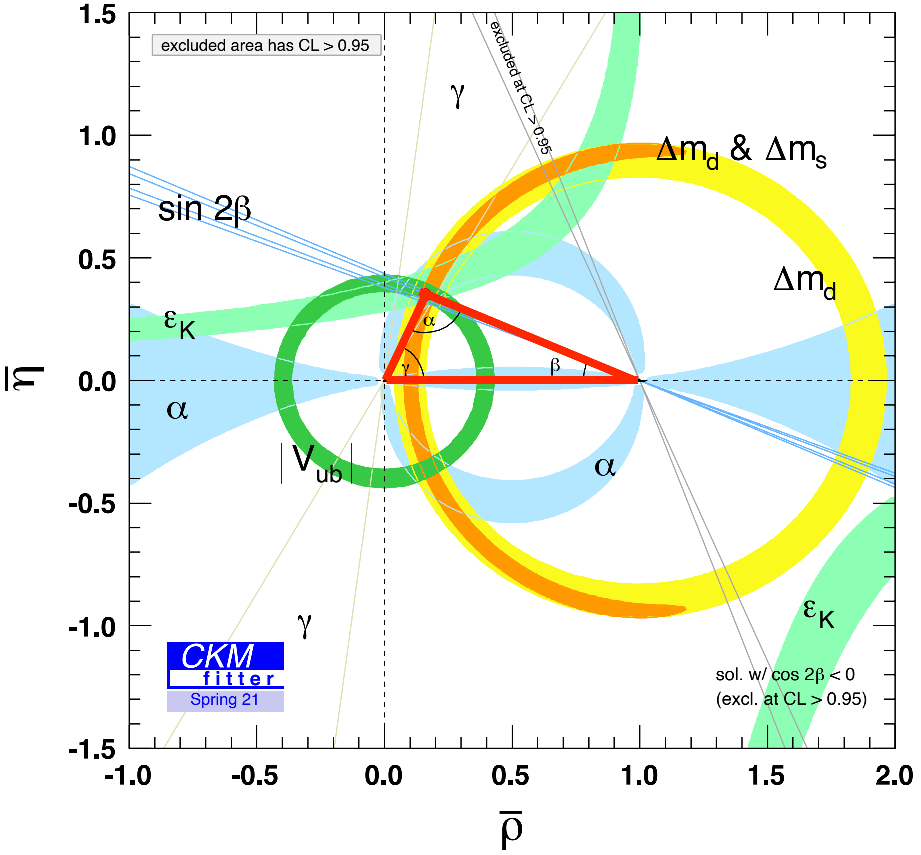
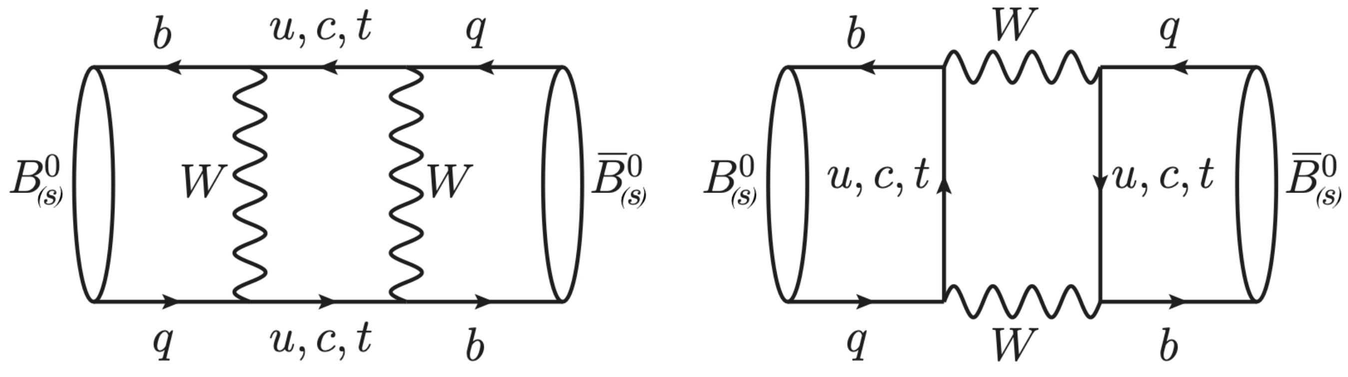
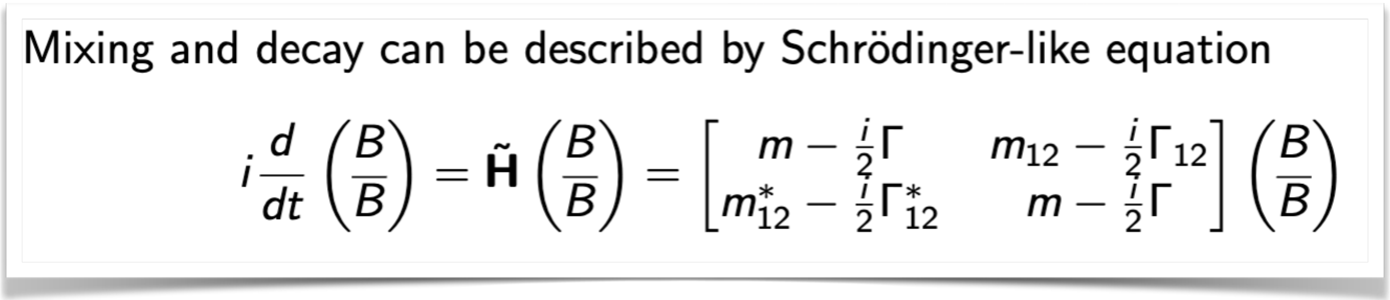


Neutral B meson oscillation

- Neutral B mesons can oscillate through box diagrams





Mixing and decay can be described by Schrödinger-like equation

$$i\frac{d}{dt}\begin{pmatrix} B \\ \overline{B} \end{pmatrix} = \tilde{\mathbf{H}}\begin{pmatrix} B \\ \overline{B} \end{pmatrix} = \begin{bmatrix} m - \frac{i}{2}\Gamma & m_{12} - \frac{i}{2}\Gamma_{12} \\ m^*_{12} - \frac{i}{2}\Gamma^*_{12} & m - \frac{i}{2}\Gamma \end{bmatrix}\begin{pmatrix} B \\ \overline{B} \end{pmatrix}$$

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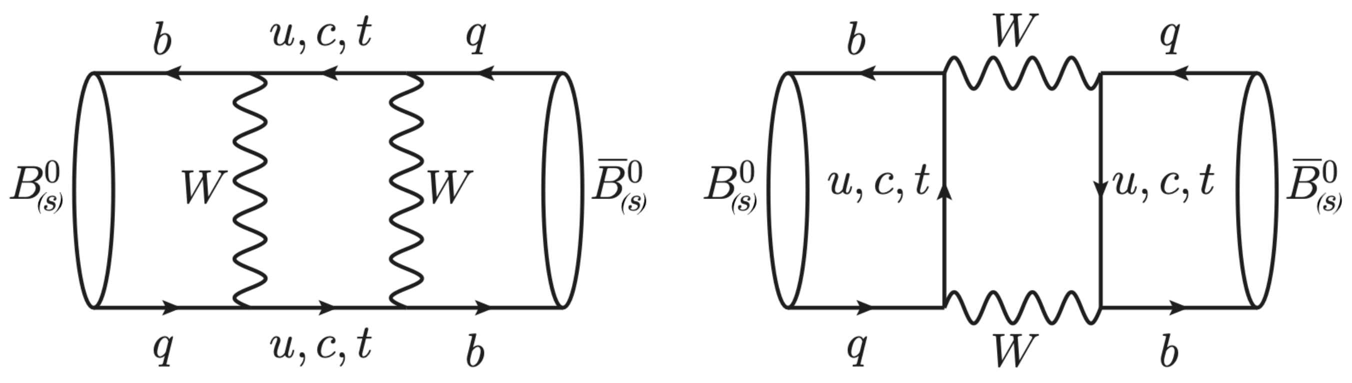

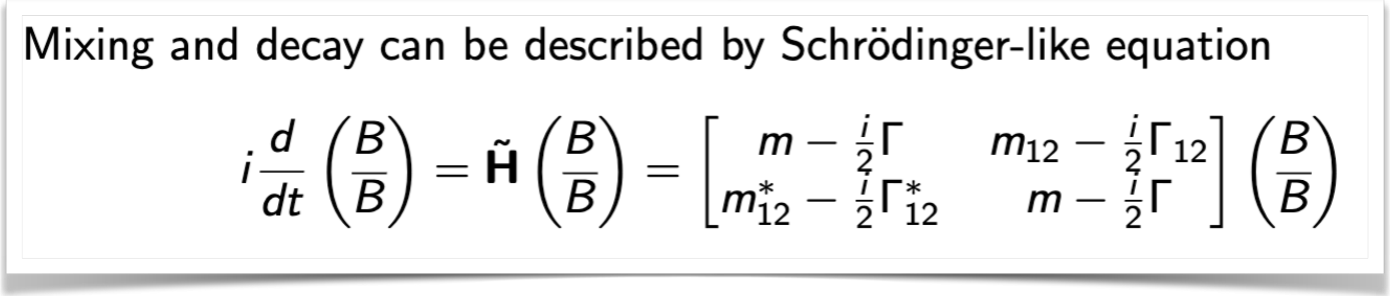
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- Decay rate of initial B or $\bar{B}$

$$|\langle f|H|B\rangle|^2 = \frac{1}{2}e^{-\Gamma t}|A_f|^2\left\{D\cosh\left(\frac{\Delta\Gamma}{2}t\right) + A_{\Delta\Gamma}\sinh\left(\frac{\Delta\Gamma}{2}t\right)\right.$$
$$\left.\pm C\cos(\Delta m t) \mp S\sin(\Delta m t)\right\}$$

direct *CP*   *CP* in mixing

- Mass difference $\Delta m_{(s)} = M_H - M_L = 2|M_{12}|$ → oscillation frequency!
- Decay-width difference $\Delta\Gamma_{(s)} = \Gamma_L - \Gamma_H = 2|\Gamma_{12}|cos\phi_{12}$

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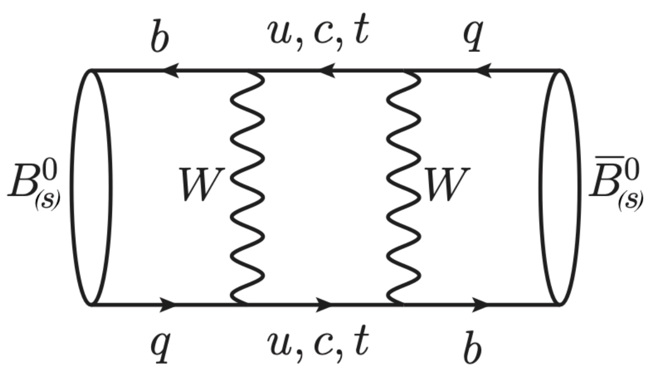

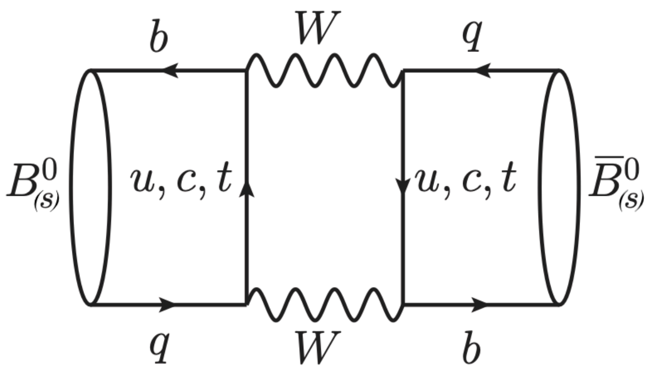

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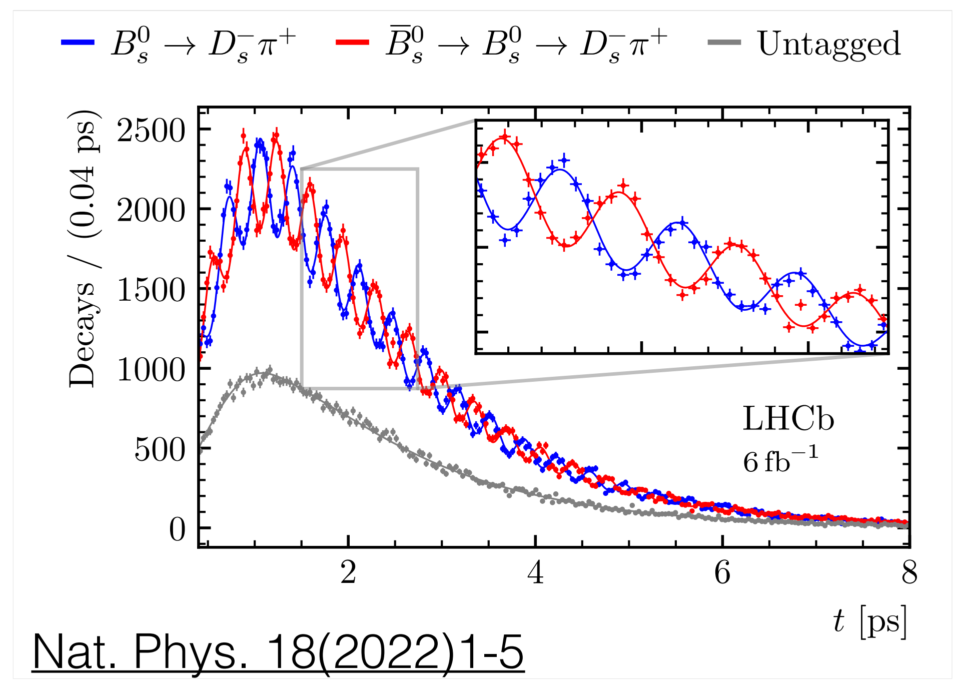

Nat. Phys. 18(2022)1-5

$$\Delta m_s = (17.7656 \pm 0.0057)\ ps^{-1}$$

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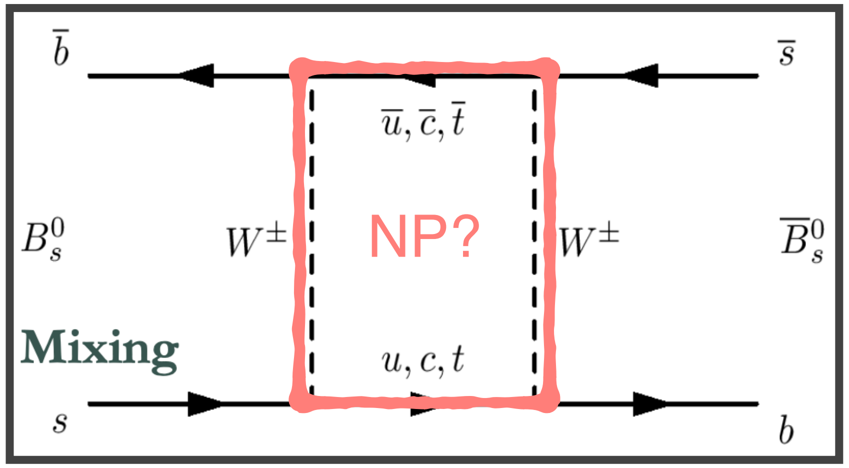
Opportunities for new physics



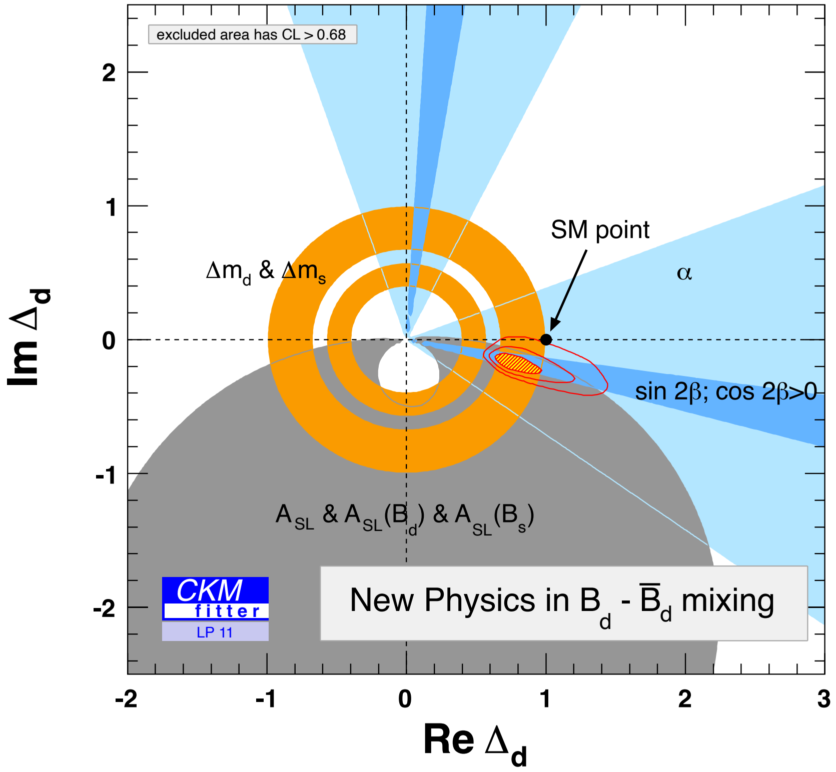
- New physics (NP) short-distance contributions can influence mixing

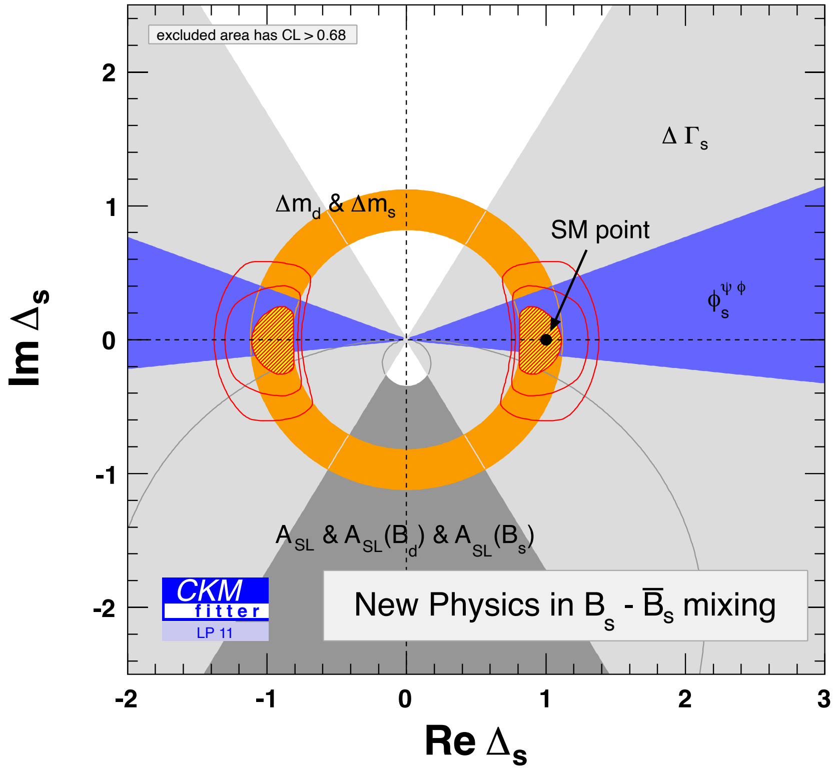
$$m_{12}^{q} = m_{12}^{SM,q} \cdot \Delta_q^{NP}$$

[PRD 86(2012)033008]

- Through B mixing, NP energy scales of up to 20 TeV for tree-level NP or 2 TeV for NP in loops can be probed

[PRD 89(2014)033016]





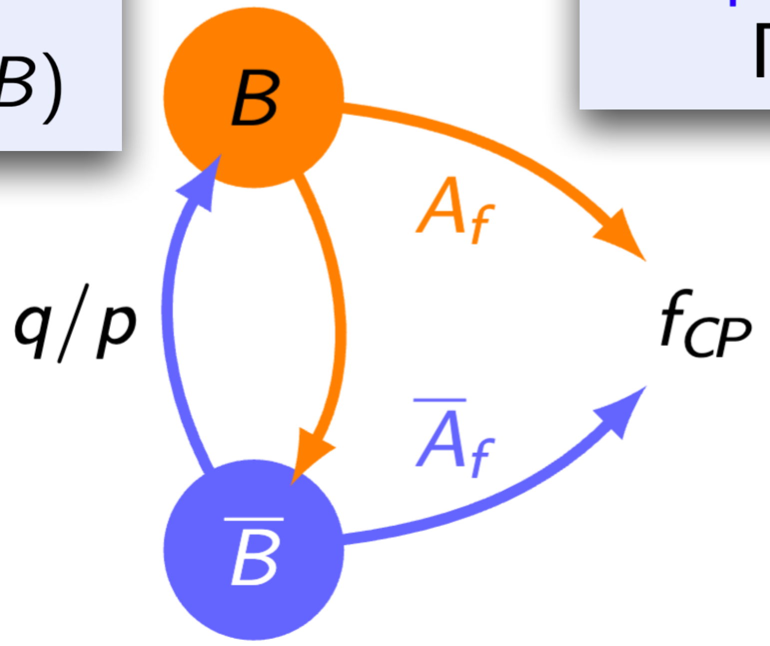
CP violation in B system

- CP violation requires two interfering amplitudes with different strong and weak phases
- For a $B^0_{(s)}$ decays to a CP eigenstate *f*, CP-violating effects depend on $\lambda = \frac{q}{p}\frac{\bar{A}_f}{A_f}$

CP violation in mixing

Unequal transition probabilities between flavour eigenstates

$$P(B \to \overline{B}) \neq P(\overline{B} \to B)$$



CP violation in decay

Unequal CP-conjugated decay rates

$$\Gamma(B \to f) \neq \Gamma(\overline{B} \to \overline{f})$$

CP violation in interference of decays with/without mixing

Time-dependent or time-integrated difference of decay rates of initial flavour eigenstates

$$\Gamma(B_{(\rightsquigarrow \overline{B})} \to f_{CP})(t) \neq \Gamma(\overline{B}_{(\rightsquigarrow B)} \to f_{CP})(t)$$

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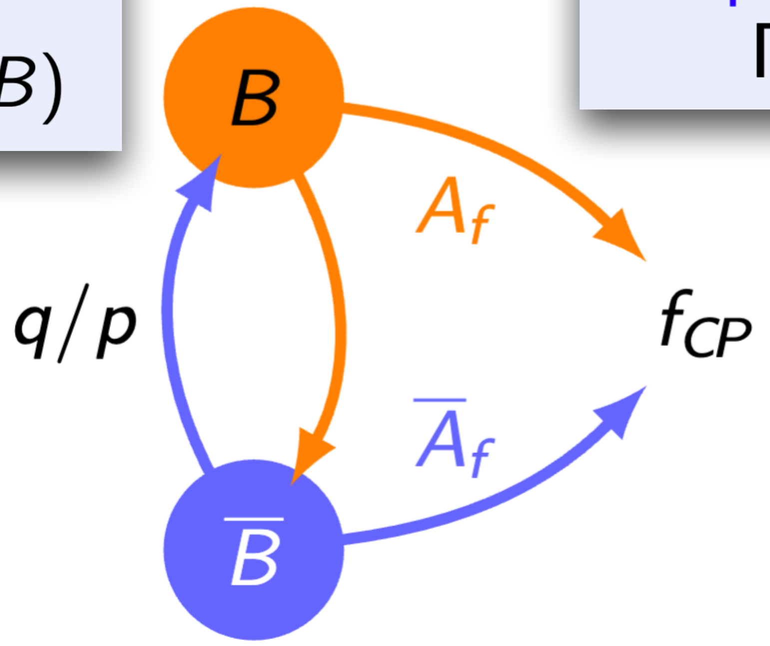

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ϕ_s & $\sin(2\beta)$

- $\sin(2\beta)$ in $B^0 \to \psi K_s^0$ (β ~22°)

$$\beta = arg(-\frac{V_{cd}V_{cb}^*}{V_{td}V_{tb}^*})$$

- $B^0 \to J/\psi(\mu^+\mu^-)K_s^0(\to \pi^+\pi^-)$
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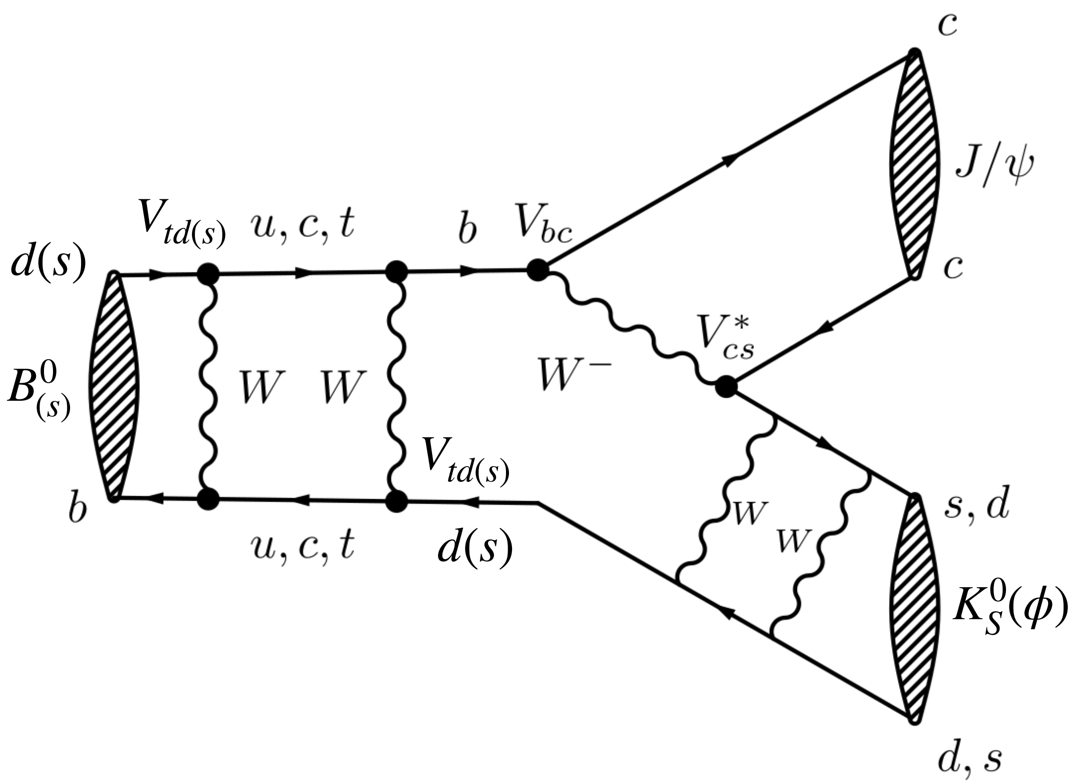

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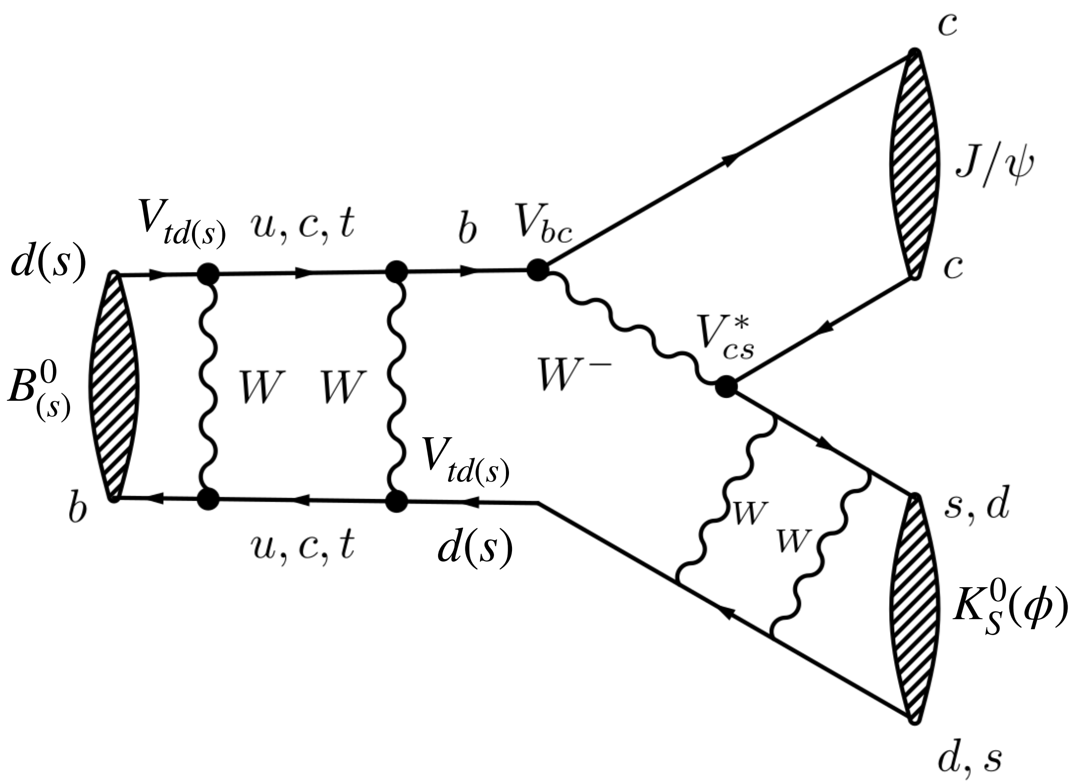

- ϕ_s in $B_s^0 \to J/\psi(\mu^+\mu^-)K^+K^-$

$$\phi_s^{SM} \approx -2\beta_s = 2arg(\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*})$$

(ignoring penguin contribution)

- Tree amplitude dominant

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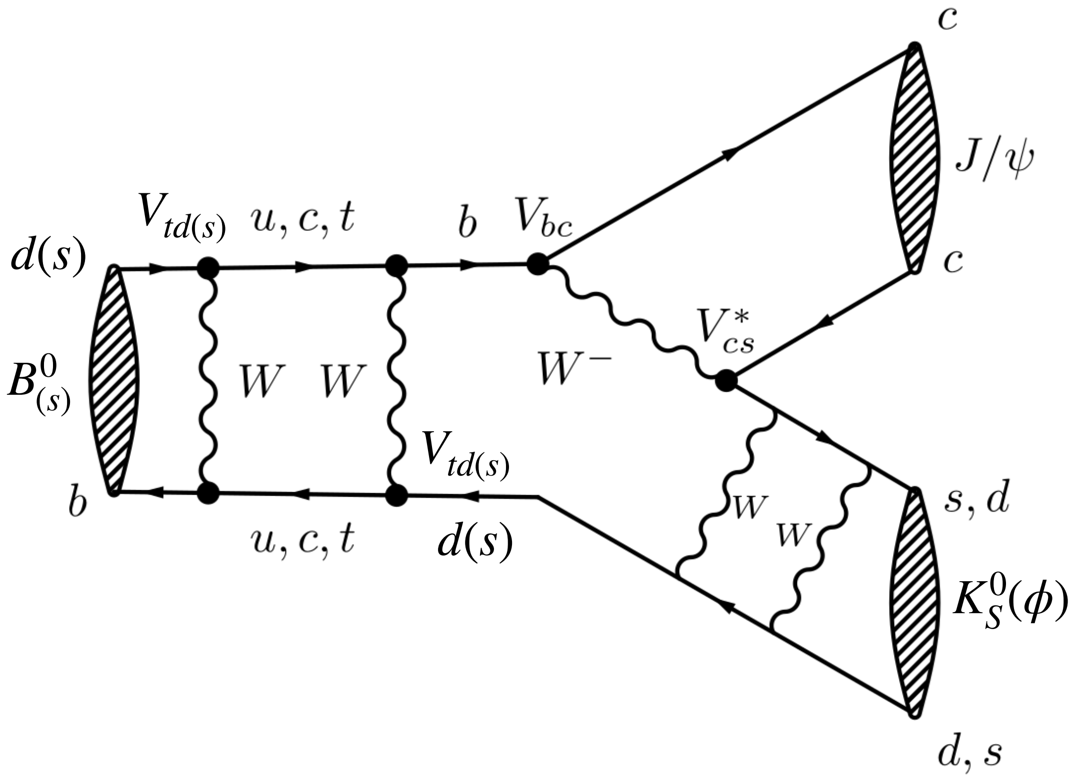

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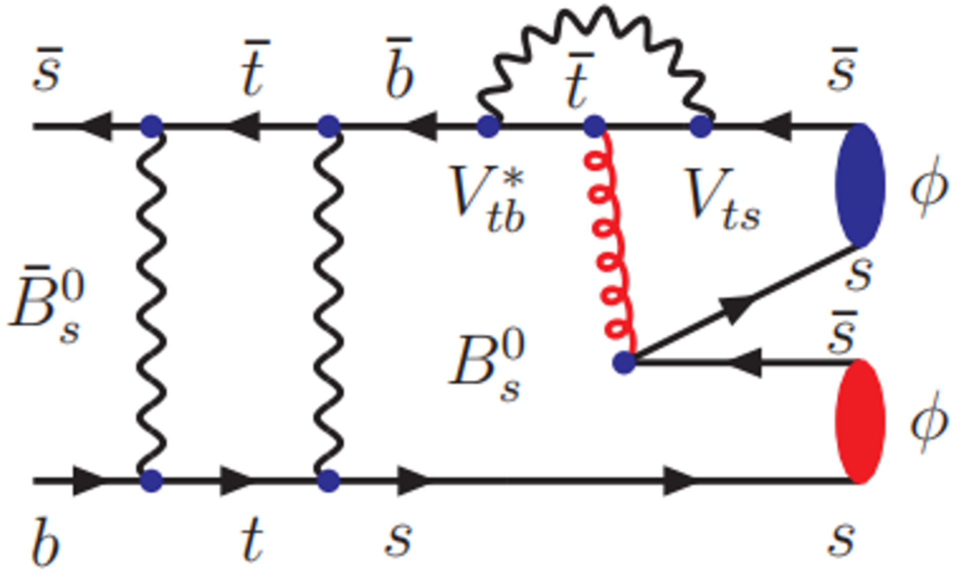
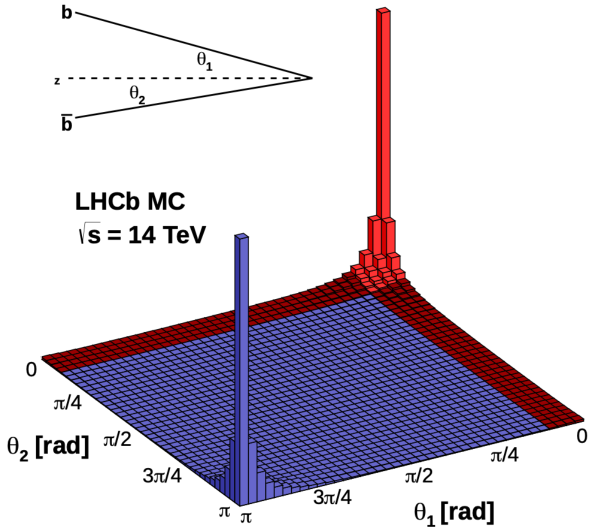
- $\phi_s^{s\bar{s}s}$ in $B_s^0 \rightarrow \phi(\rightarrow K^+K^-)\phi(\rightarrow K^+K^-)$
  - Penguin dominant

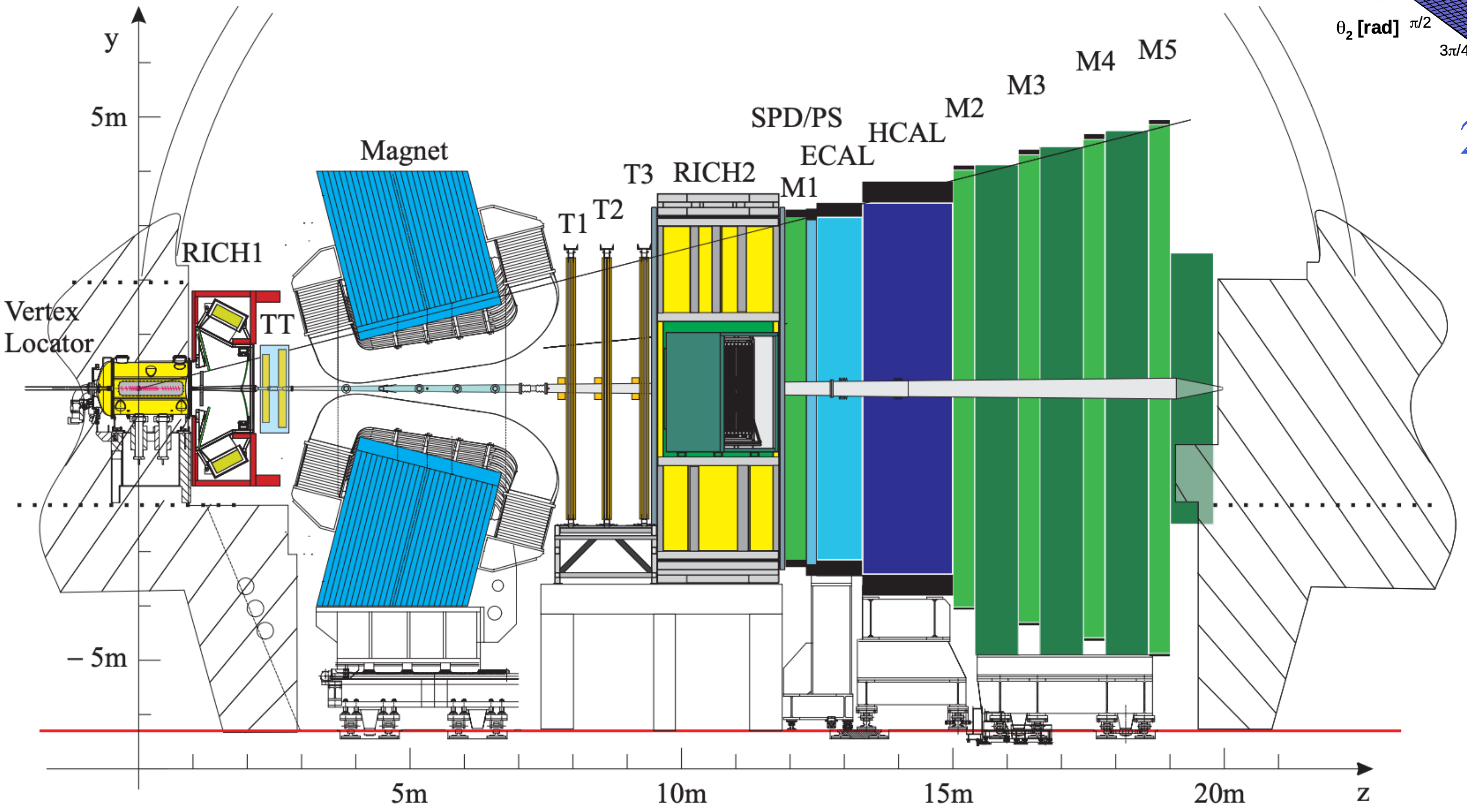


LHCb detector

General purpose detector specialised in beauty and charm hadrons



$2 < \eta < 5$



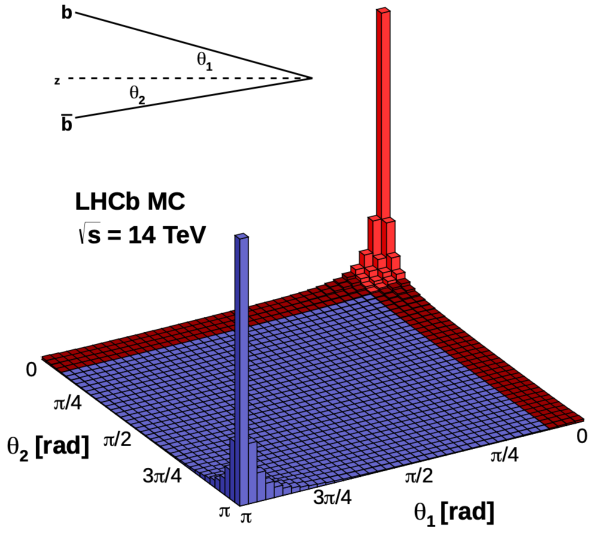
proton beam

LHCb performance:
JINST 14 (2019) P04013
Int. J. Mode. Phys. A30 (2015) 1530022

LHCb detector

General purpose detector specialised in beauty and charm hadrons

- Daughters of b & c hadron decays: $p_T \sim \mathcal{O}(1\ \mathrm{GeV}/c)$, flight distance L~1mm



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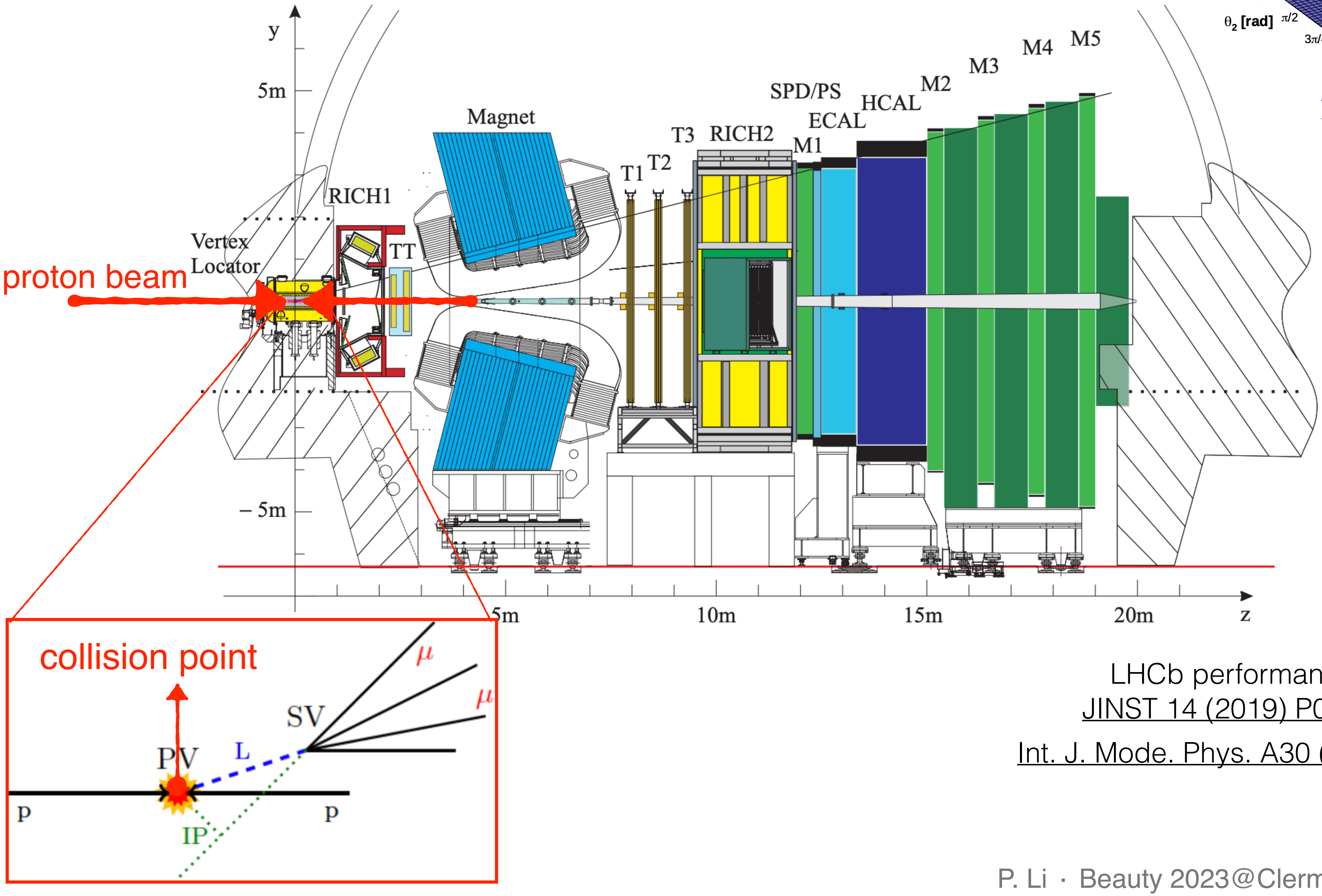

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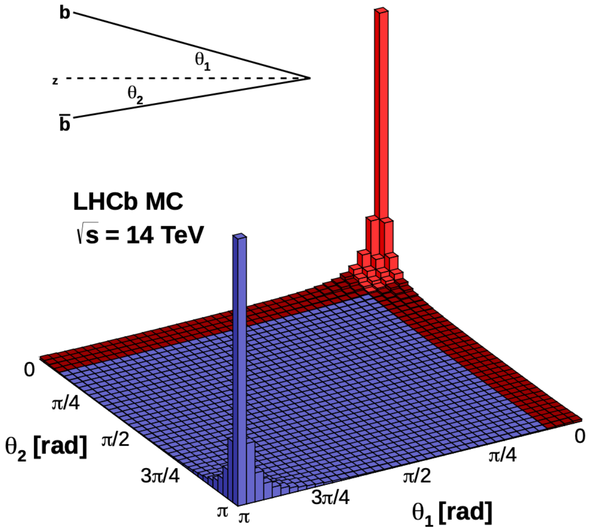

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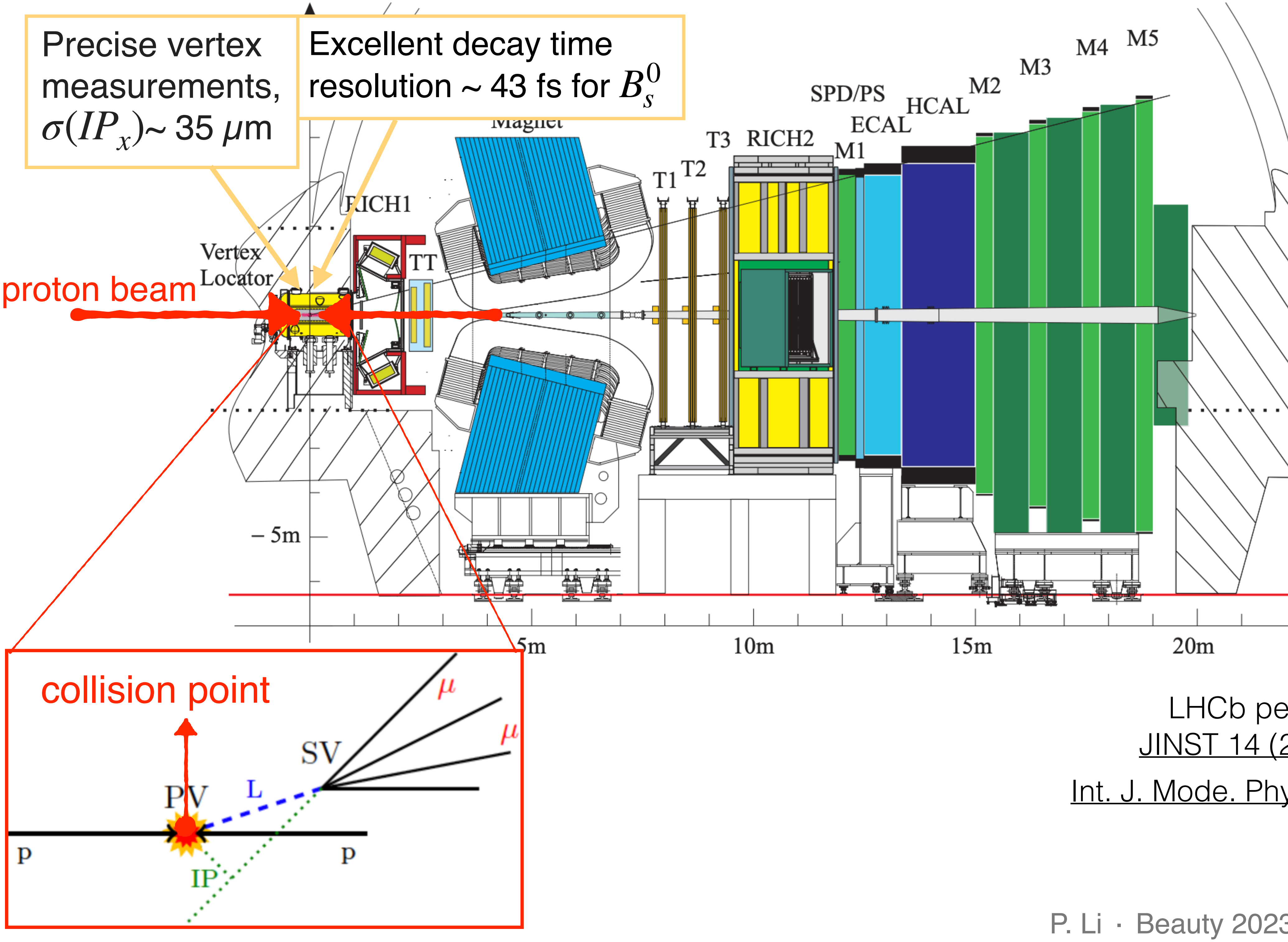

Precise vertex measurements, $\sigma(IP_x)$~ 35 μm

Excellent decay time resolution ~ 43 fs for B_s^0

proton beam

collision point

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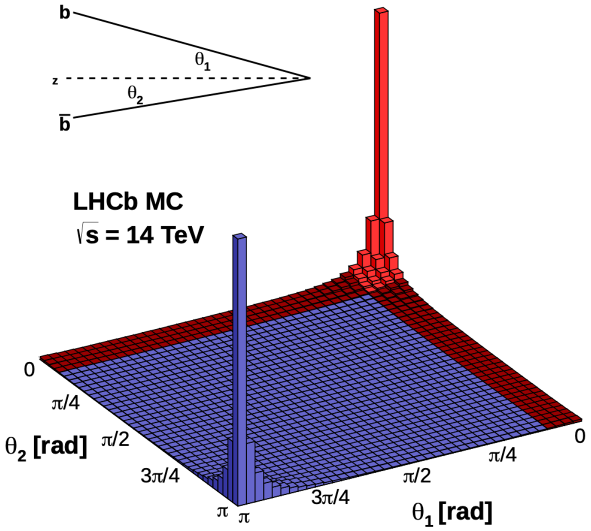

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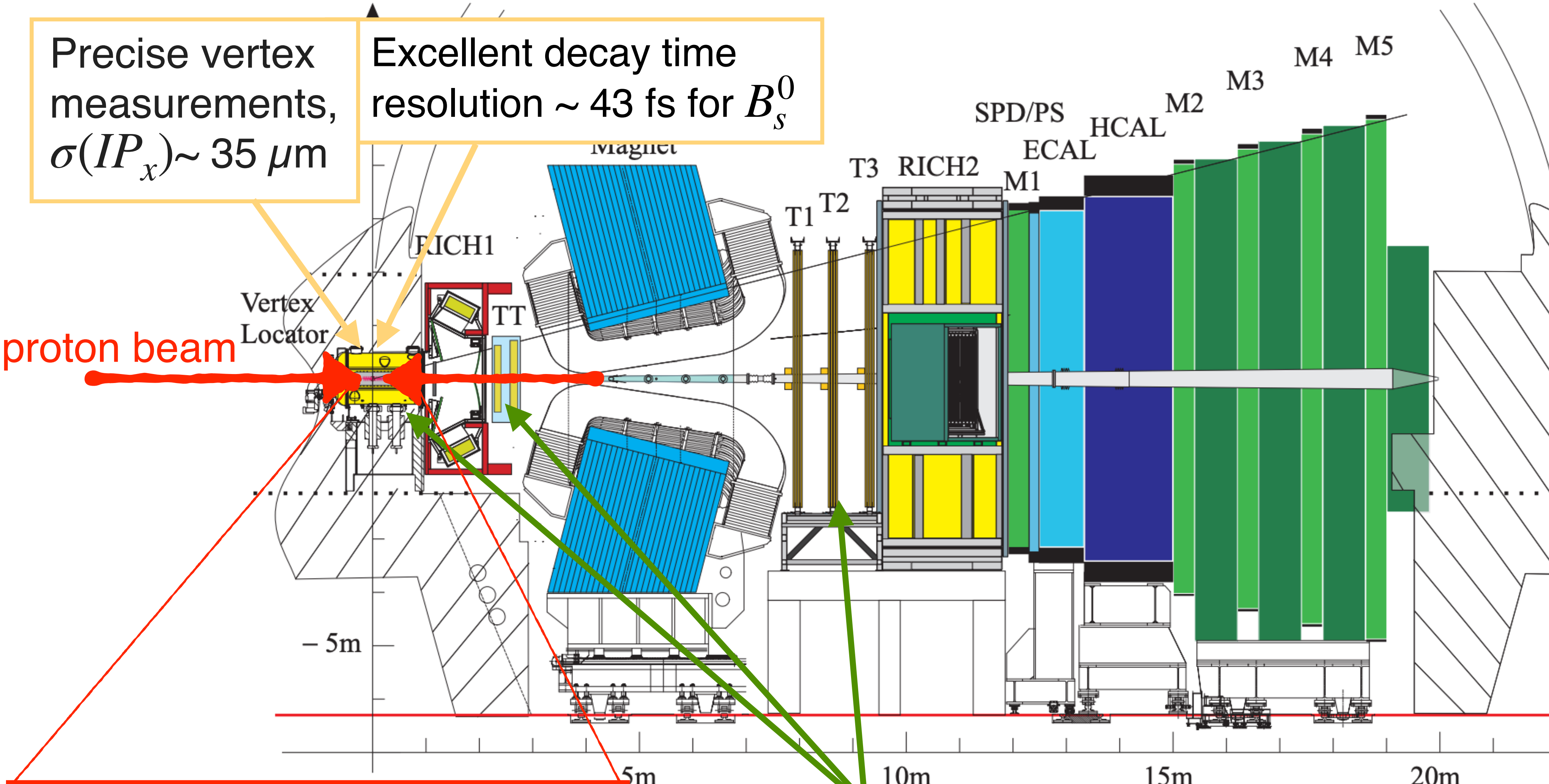

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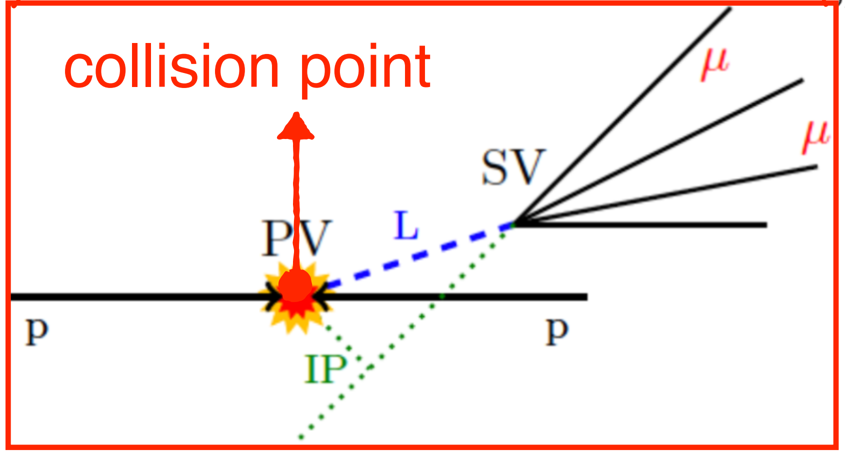

Excellent momentum resolution ~ 0.5%

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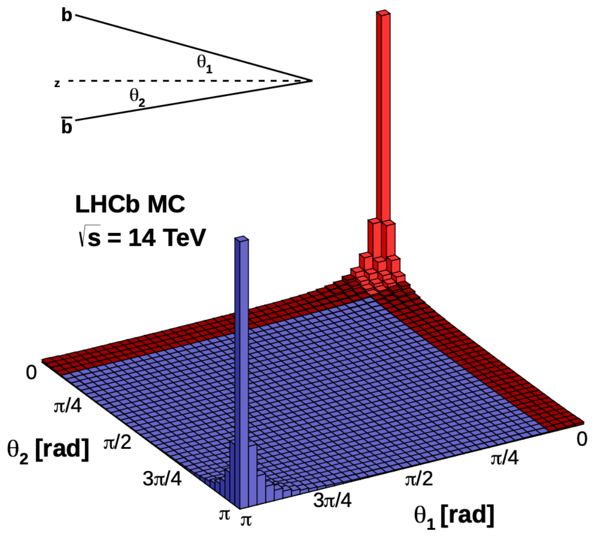

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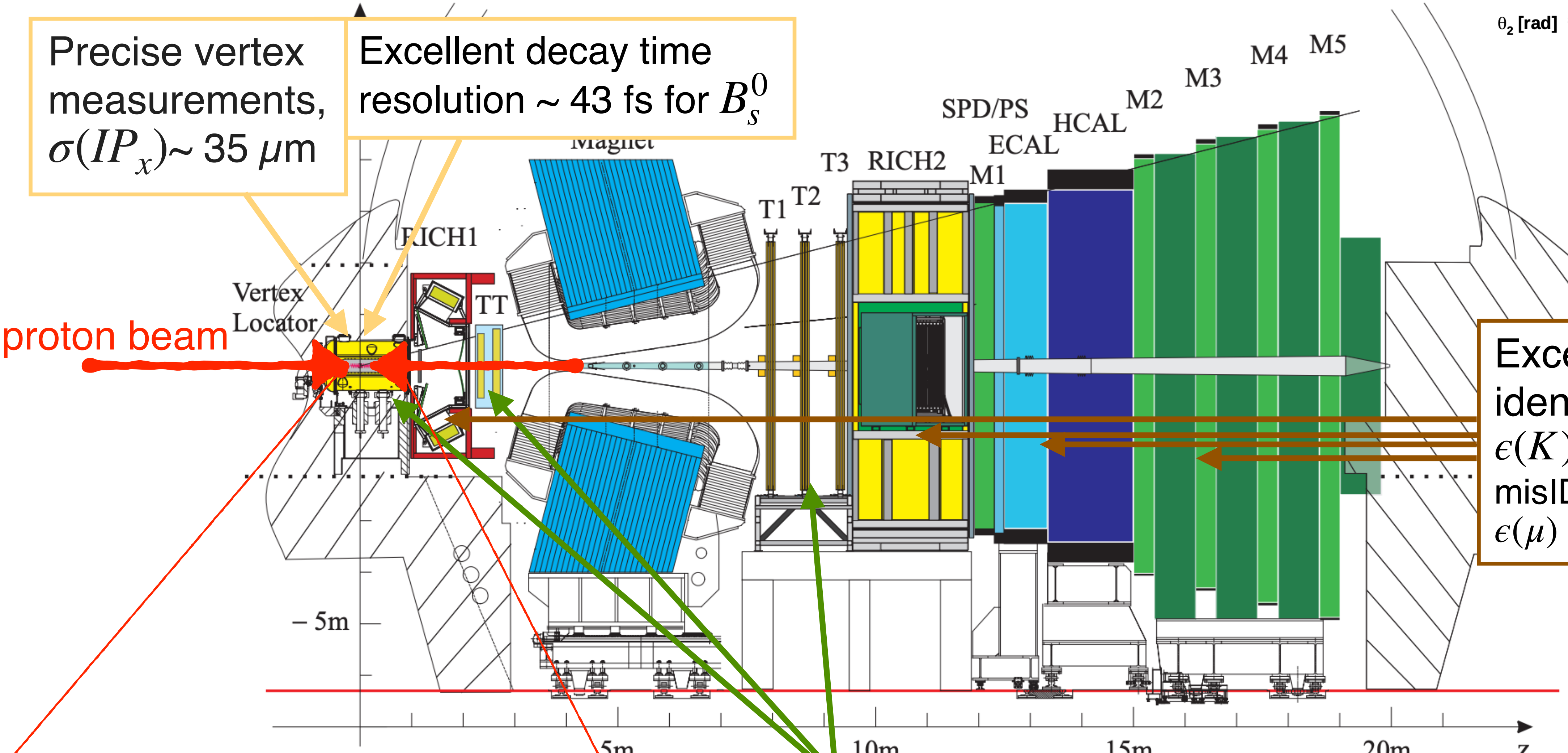
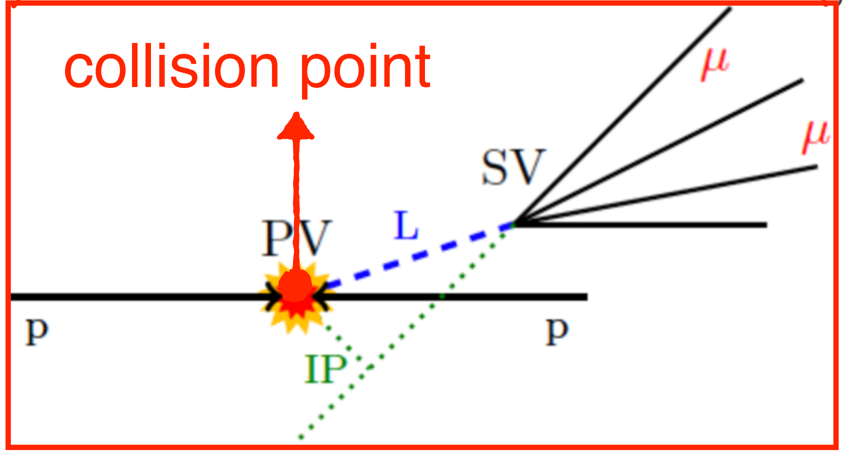


Precise vertex measurements, $\sigma(IP_x)$~ 35 μm

Excellent decay time resolution ~ 43 fs for B_s^0

Excellent particle identification
$\epsilon(K) \approx 95\,\%$
misID $p(\pi \to K) \approx 5\,\%$
$\epsilon(\mu) \approx 97\,\%$



Excellent momentum resolution ~ 0.5%

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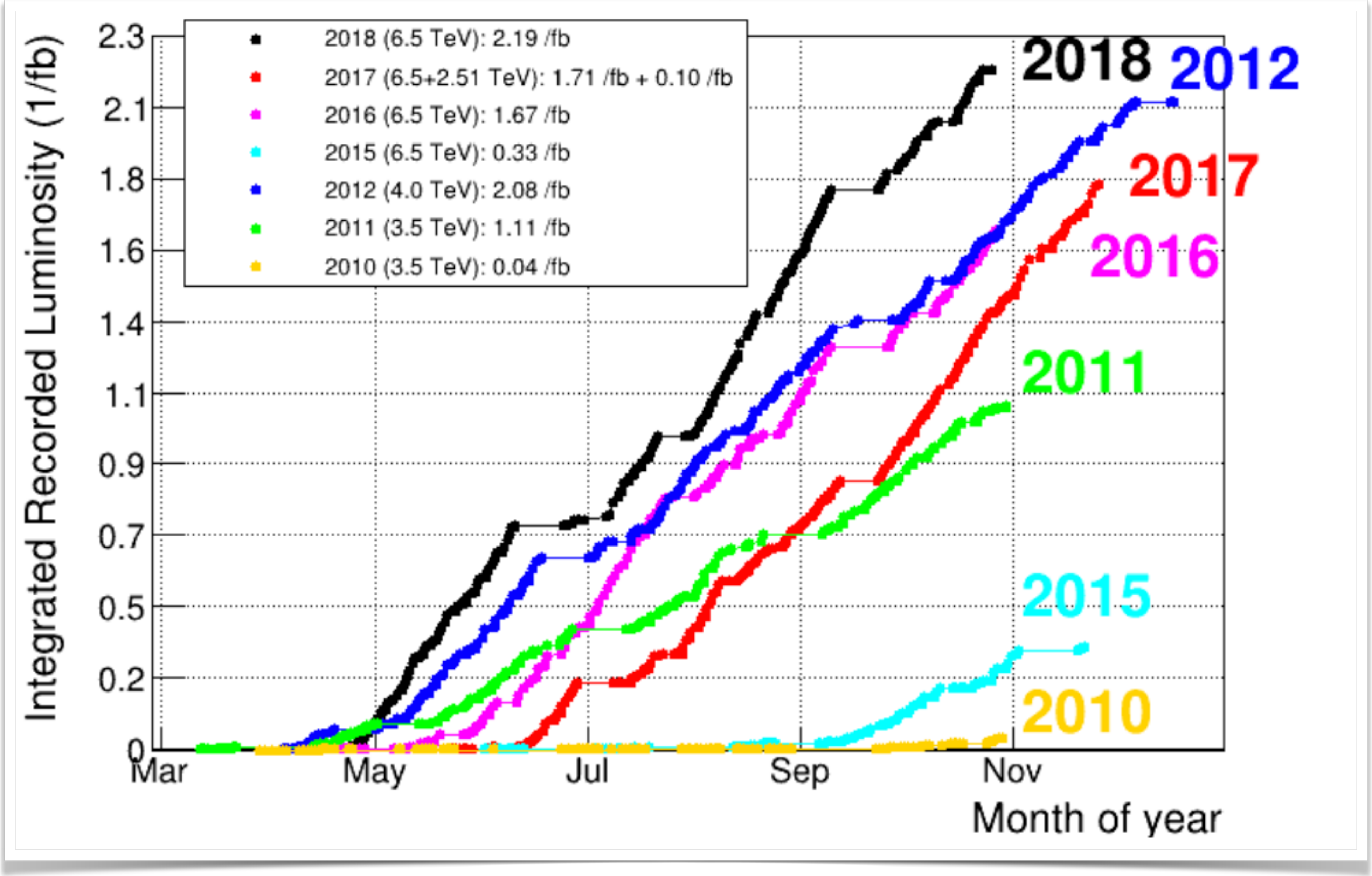
Luminosity



- Run 1(2011+2012): 3 fb^{-1} + Run 2 (2015-2018): 6 fb^{-1}
- Large number of beauty hadrons:

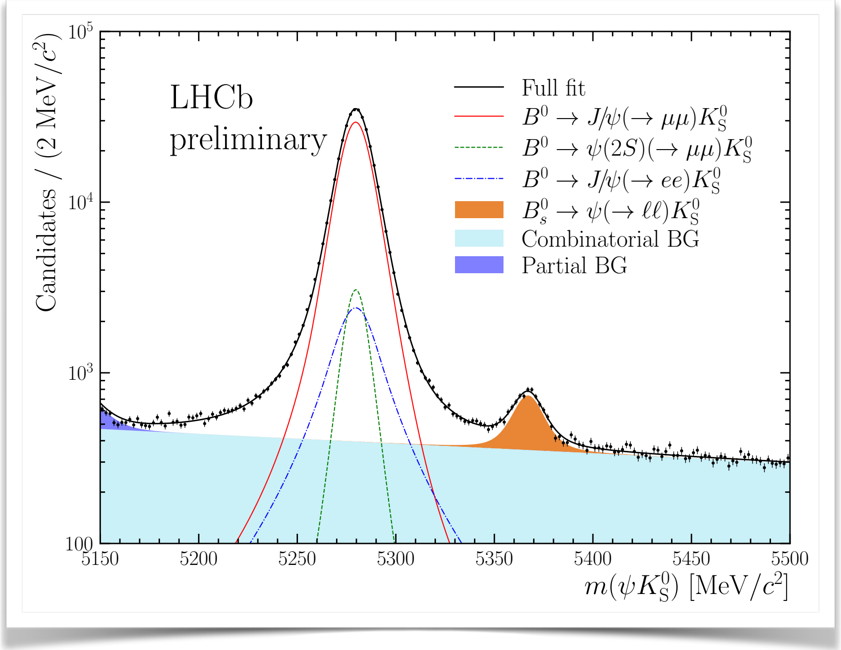
[PRL118(2017)052002]

$\sigma(b\bar{b})(7TeV) = 72.0 \pm 0.3 \pm 6.8\ \mu\mathrm{b}$, $\sigma(b\bar{b})(13TeV) = 144 \pm 1 \pm 21\ \mu\mathrm{b}$ in 2<η<5

Mass fit

- *sPlot technique* to subtract combinatorial background:
  → perform fits to invariant mass distribution

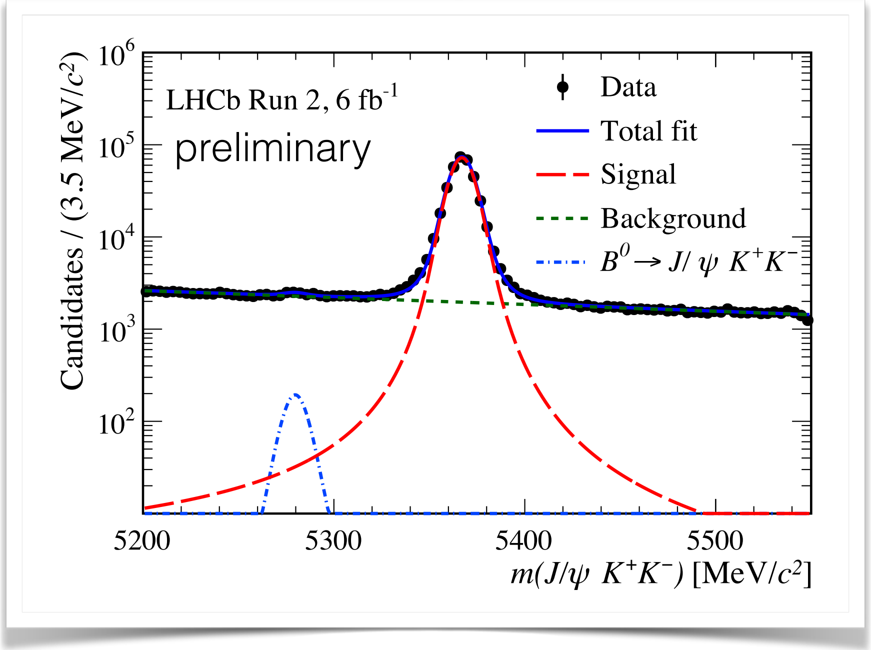
- $B^0 \to J/\psi(\mu^+\mu^-)K_s^0$ (85%)
- $B^0 \to J/\psi(e^+e^-)K_s^0$ (12%)
- $B^0 \to \psi(2S)(\mu^+\mu^-)K_s^0$ (6%)



Total signal candidates
~306090 + 42700 + 23560

LHCb-PAPER-2023-013
In preparation

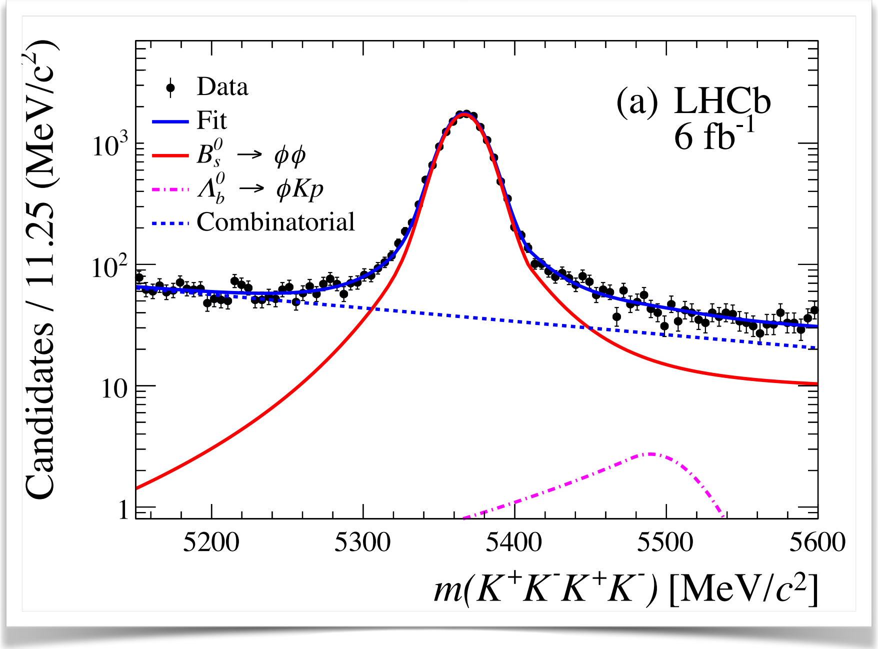
- $B_s^0 \to J/\psi K^+K^-$



Total signal candidates
~349000

LHCb-PAPER-2023-016
In preparation

- $B_s^0 \to \phi\phi$



Total signal candidates
~15840

LHCb-PAPER-2023-001

CP asymmetry

- Time-dependent CP asymmetry: $A_{CP}(t) = \frac{\Gamma(\bar{B}^0_{(s)} \to f) - \Gamma(B^0_{(s)} \to f)}{\Gamma(\bar{B}^0_{(s)} \to f) + \Gamma(B^0_{(s)} \to f)} = \eta_f \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$
  - ➡ Experimentally

$$A_{CP}(t) \propto \eta_f \cdot e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2} \cdot (1 - 2\omega) \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$$

- Tagging of $B^0_{(s)}$ flavor at production: probability of wrong tag ω
- Excellent decay-time resolution $\sigma_t \sim 43 \text{ fs}$
- CP eigenvalue of the final state η_f

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- Time-dependent CP asymmetry: $A_{CP}(t) = \frac{\Gamma(\bar{B}^0_{(s)} \to f) - \Gamma(B^0_{(s)} \to f)}{\Gamma(\bar{B}^0_{(s)} \to f) + \Gamma(B^0_{(s)} \to f)} = \eta_f \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$
  - ➡ Experimentally

$$A_{CP}(t) \propto \eta_f \cdot e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2} \cdot (1 - 2\omega) \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$$

  - Tagging of $B^0_{(s)}$ flavor at production: probability of wrong tag ω
  - Excellent decay-time resolution $\sigma_t \sim 43\ \mathrm{fs}$
  - CP eigenvalue of the final state η_f

- $B^0 \to \psi(\to \ell^+\ell^-)K^0_S(\to \pi^+\pi^-)$: CP-odd component only

CP asymmetry

- Time-dependent CP asymmetry: $A_{CP}(t) = \dfrac{\Gamma(\bar{B}^0_{(s)} \to f) - \Gamma(B^0_{(s)} \to f)}{\Gamma(\bar{B}^0_{(s)} \to f) + \Gamma(B^0_{(s)} \to f)} = \eta_f \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$
  - ➡ Experimentally

$$A_{CP}(t) \propto \eta_f \cdot e^{-\frac{1}{2}\Delta m_s^2 \sigma_t^2} \cdot (1 - 2\omega) \cdot \sin 2\beta_{(s)} \cdot \sin(\Delta m_{(s)} t)$$

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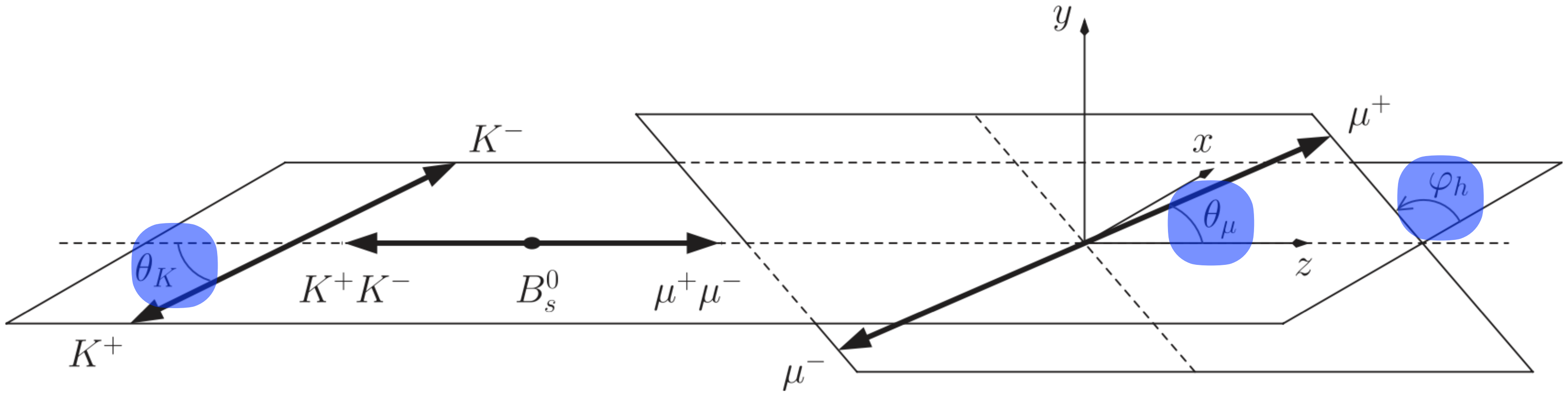
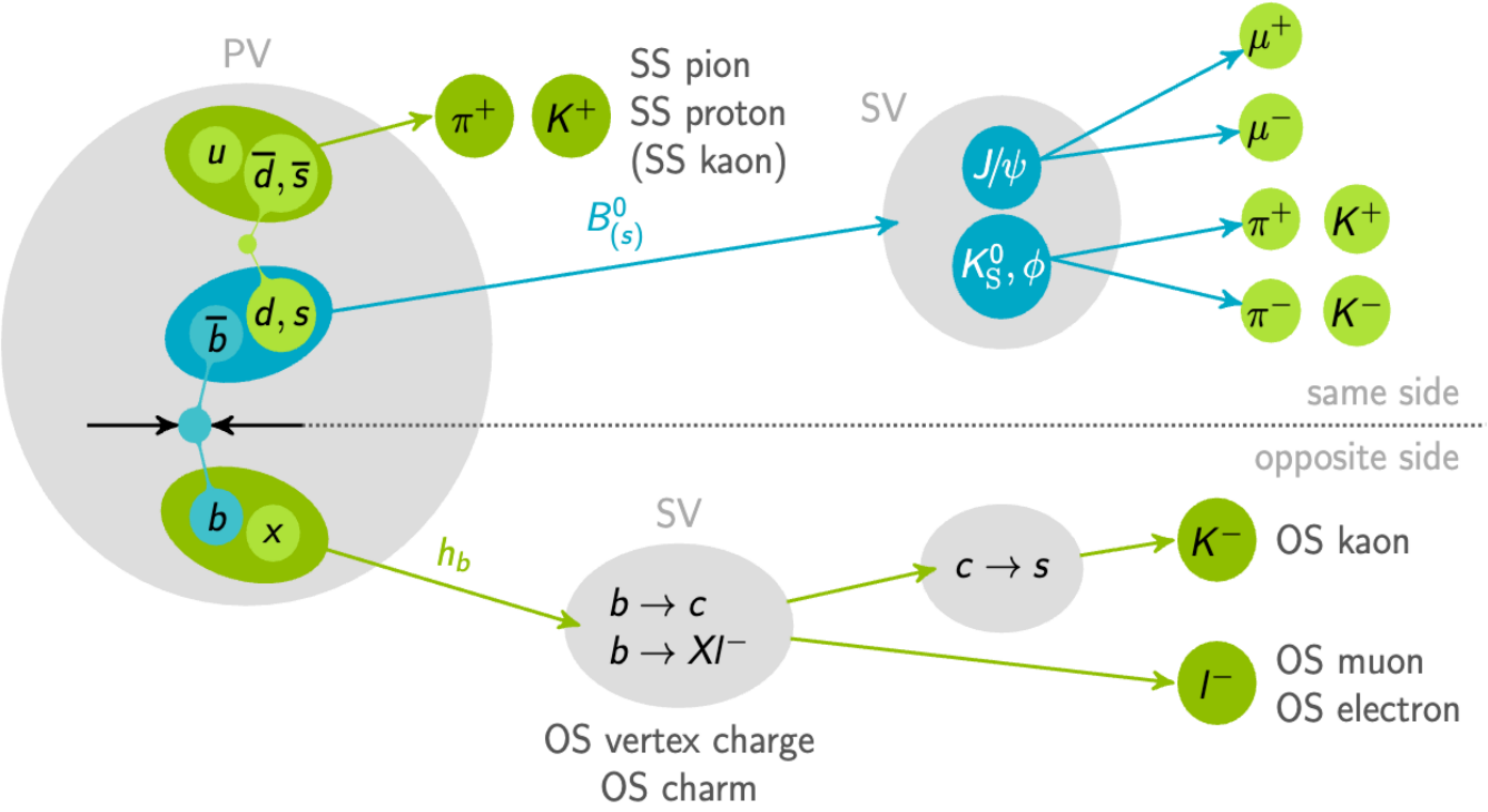
- $B^0 \to \psi(\to \ell^+\ell^-)K^0_S(\to \pi^+\pi^-)$: CP-odd component only
- $B^0_s \to J/\psi(\to \mu^+\mu^-)\phi(\to K^+K^-) + B^0_s \to \phi(KK)\phi(KK)$:
  - ➡ a mixture of CP-even ($L = 0,2$) & CP-odd ($L = 1$) components

→ Angular analysis needed



Flavor tagging

$$\mathcal{A}^{CP} = \frac{\Gamma(\overline{B}^0_{(s)} \to f_{CP}) - \Gamma(B^0_{(s)} \to f_{CP})}{\Gamma(\overline{B}^0_{(s)} \to f_{CP}) + \Gamma(B^0_{(s)} \to f_{CP})}$$



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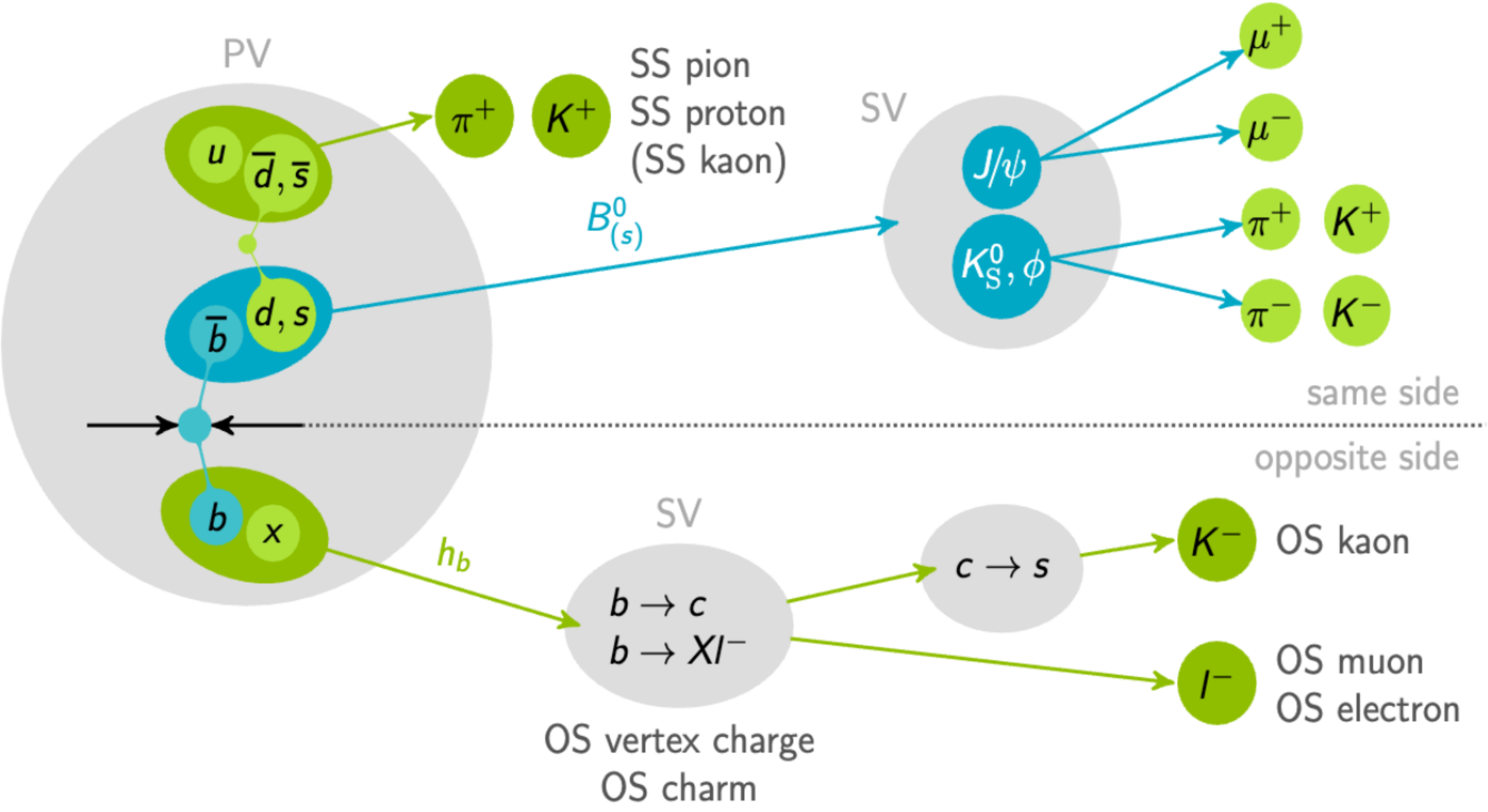

- Same-side (SS) tagging: Use charge of kaon produced in the fragmentation

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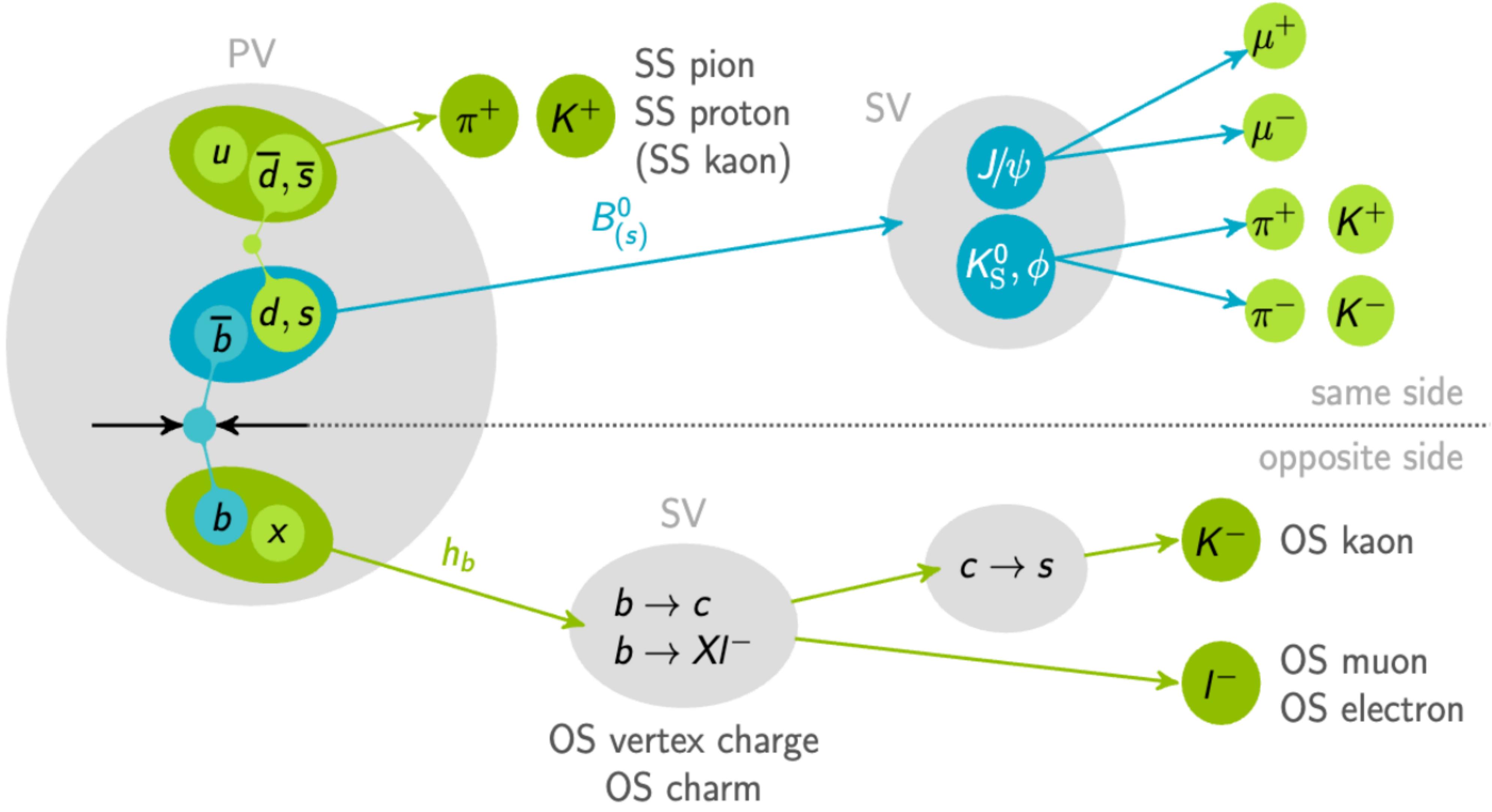
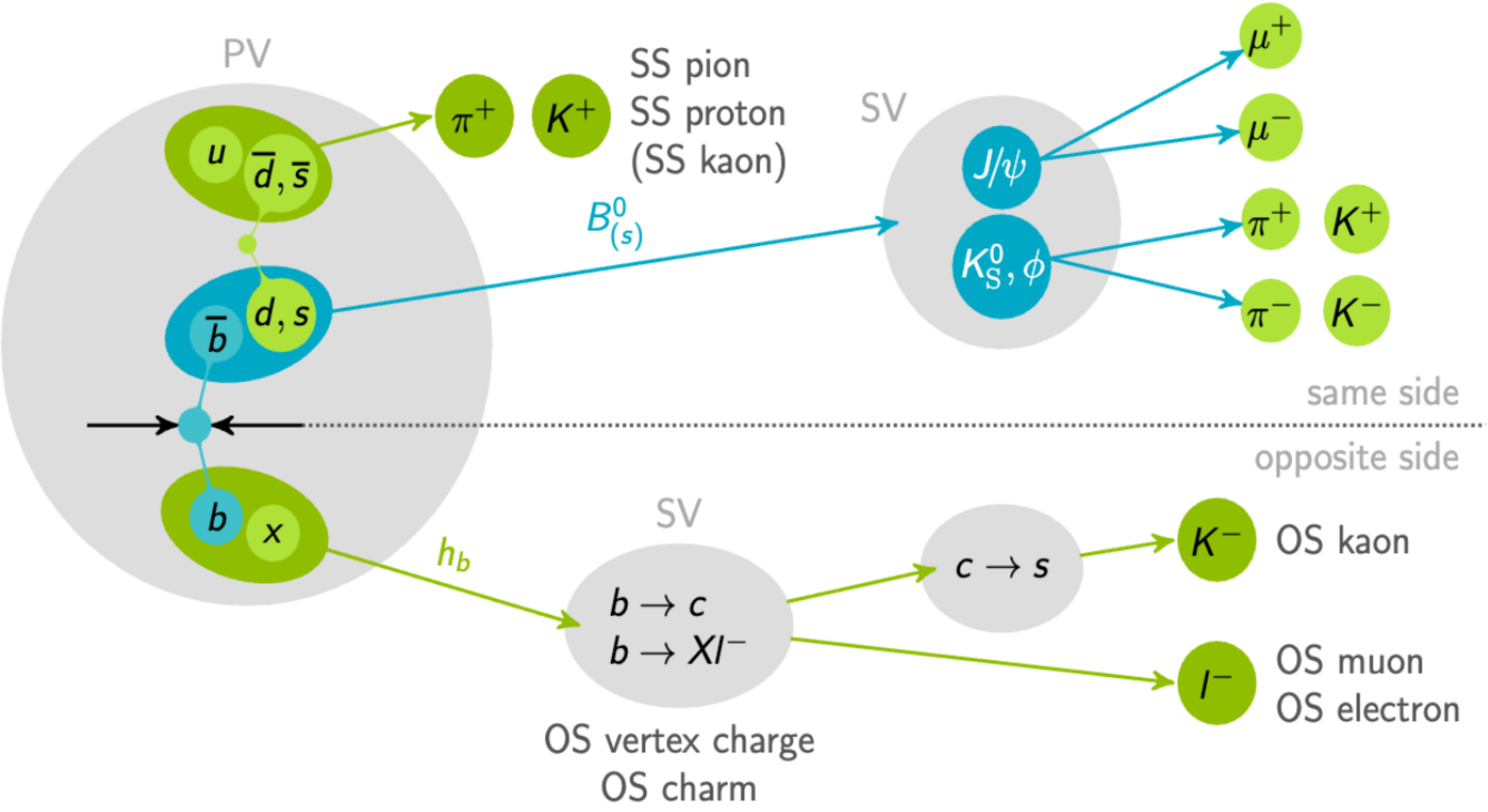


- Same-side (SS) tagging: Use charge of kaon produced in the fragmentation
- Opposite-side (OS) tagging: charge of leptons or hadrons from the decay of the other *b* hadrons

Flavor tagging

$$\mathcal{A}^{CP} = \frac{\Gamma(\overline{B}^0_{(s)} \to f_{CP}) - \Gamma(B^0_{(s)} \to f_{CP})}{\Gamma(\overline{B}^0_{(s)} \to f_{CP}) + \Gamma(B^0_{(s)} \to f_{CP})}$$

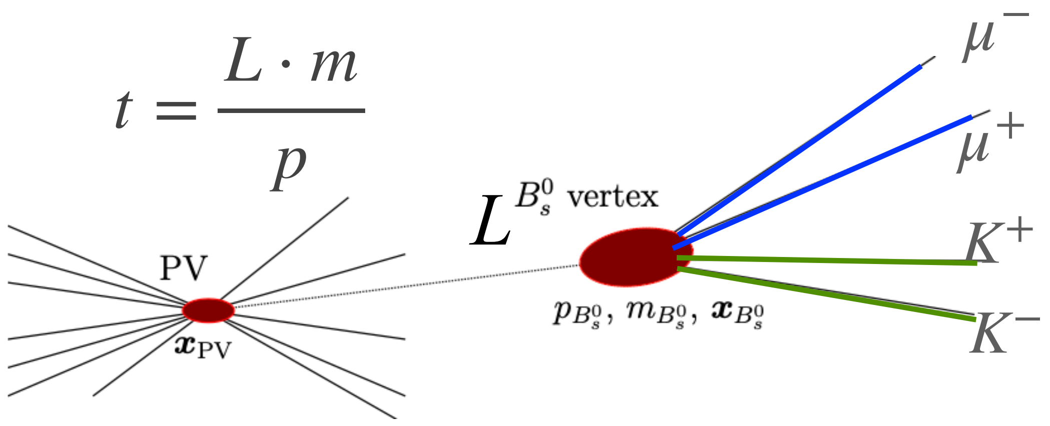


Tagging power	$B^0 \to \psi K^0_S$	$B^0_s \to J/\psi KK$	$B^0_s \to \phi\phi$
$\epsilon_{\text{tag}}(1-2\omega)^2$	(4-6)%	4.3%	6%

tagging efficiency ϵ_{tag} mistag rate ω

Decay-time resolution

- Decay time resolution dilutes oscillations, $\mathscr{D} = exp(-\frac{1}{2}\sigma_{\text{eff}}^2\Delta m_s^2)$
- Significant for B_s^0 system, negligible for B^0



$$t = \frac{L \cdot m}{p}$$

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  - $B^0 \to \psi K_S^0$: $\sigma_{MC} \sim 60$ fs
  - $B_s^0 \to J/\psi KK$ & $B_s^0 \to \phi\phi$

$$\delta_t^2 = (\frac{m}{p})^2 \underset{\substack{\downarrow \\ \sim 200\ \mu\mathrm{m}}}{\sigma_L^2} + (\frac{t}{p})^2 \underset{\substack{\downarrow \\ \sigma_p/p \sim 0.4\,\%}}{\sigma_p^2}$$

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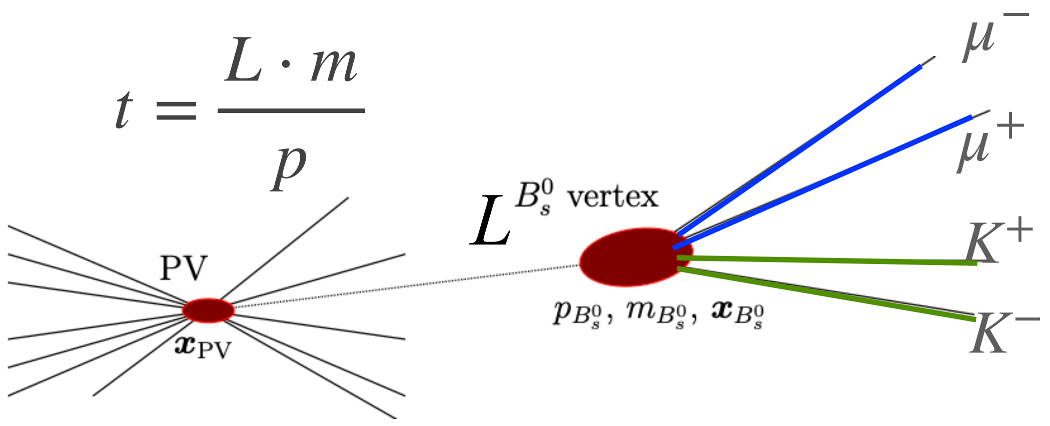

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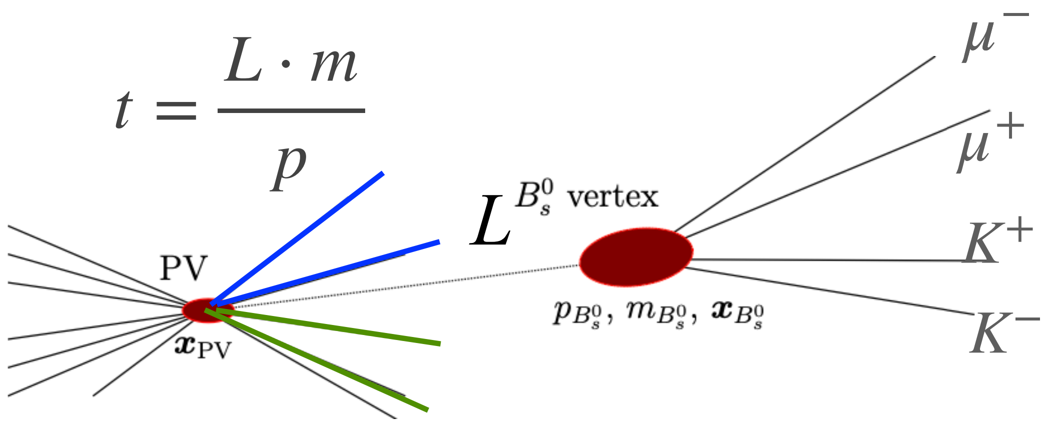

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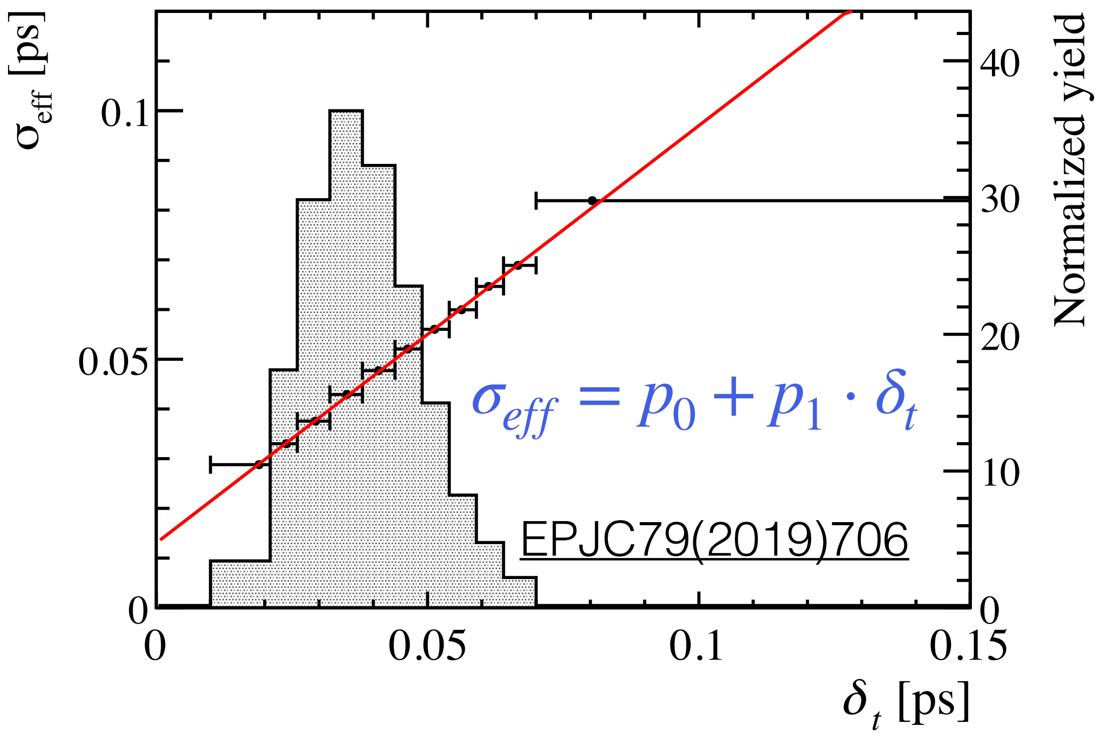
✓ Effective Gaussian resolution model:

σ_{eff} as a function of per-event δ_t (11 bins)



$\sigma_{eff} = p_0 + p_1 \cdot \delta_t$

EPJC79(2019)706

Decay-time resolution

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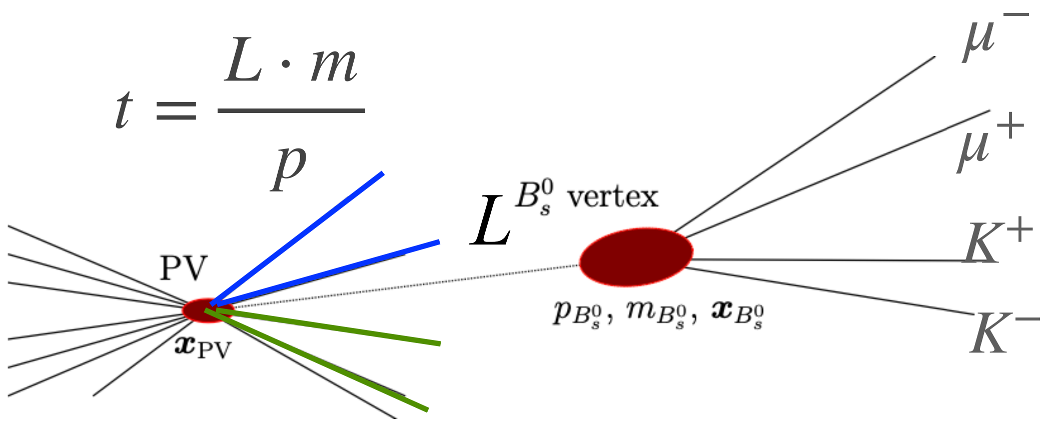
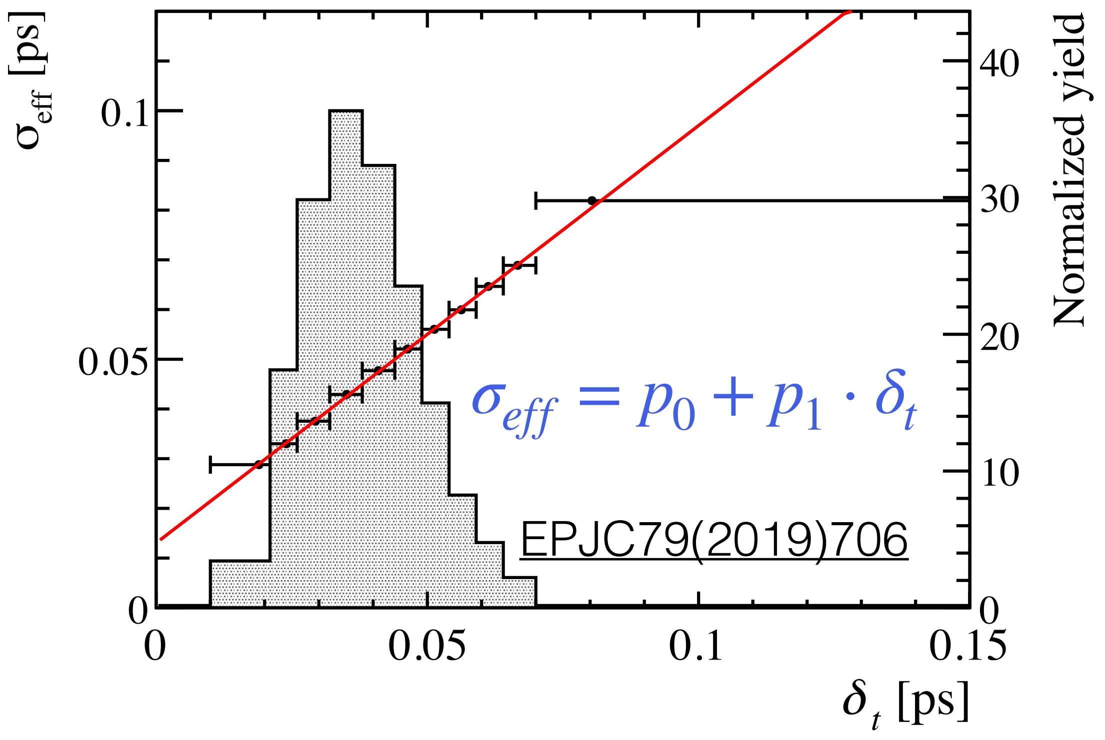


$$t = \frac{L \cdot m}{p}$$

$$\delta_t^2 = (\frac{m}{p})^2 \sigma_L^2 + (\frac{t}{p})^2 \sigma_p^2$$

$\sim 200\ \mu$m $\qquad \sigma_p/p \sim 0.4\,\%$



$\sigma_{eff} = p_0 + p_1 \cdot \delta_t$

EPJC79(2019)706

✓ Effective Gaussian resolution model:
σ_{eff} as a function of per-event δ_t (11 bins)

$$\sigma_{eff} \sim 42(3)\ \text{fs} \rightarrow \mathscr{D} = 0.757$$

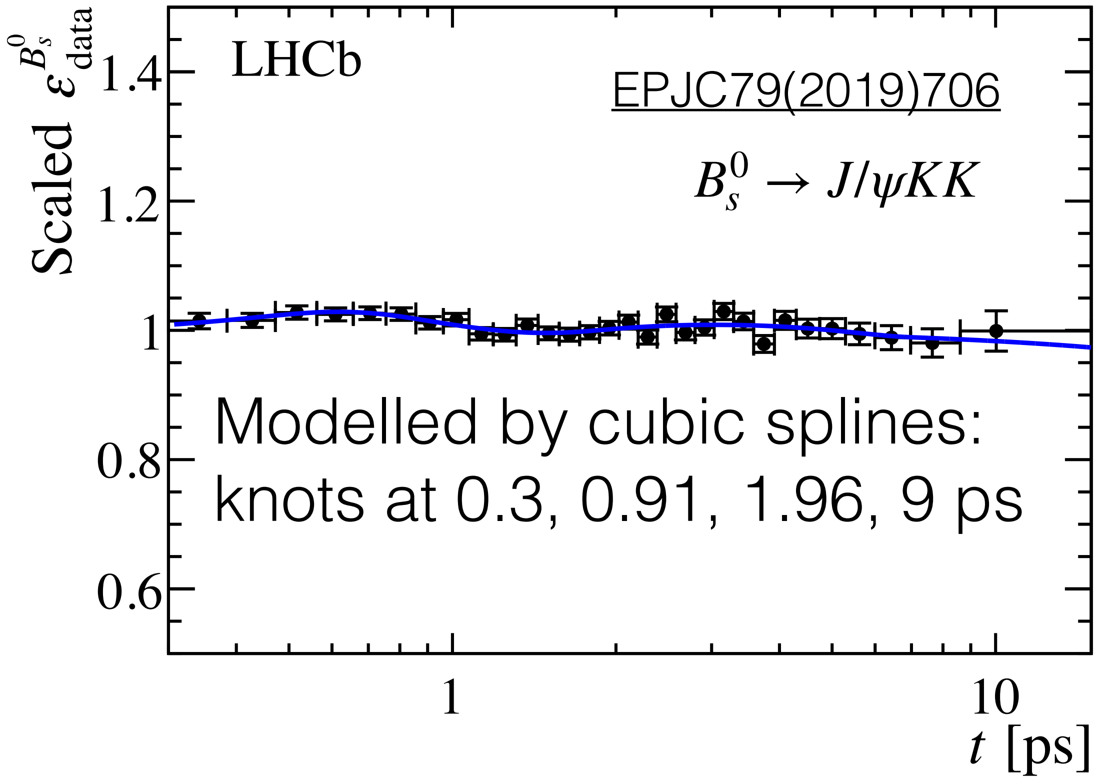
Decay time & angular efficiencies

- Reconstruction and selection criteria introduce non-uniform efficiency

- Decay-time efficiencies:

  Data driven method

$$\varepsilon_{\rm data}^{B_s^0}(t) = \varepsilon_{\rm data}^{B^0}(t) \times \frac{\varepsilon_{\rm sim}^{B_s^0}(t)}{\varepsilon_{\rm sim}^{B^0}(t)}$$



Modelled by cubic splines:
knots at 0.3, 0.91, 1.96, 9 ps

$$f(t) \propto \varepsilon(t) \cdot e^{-t/\tau} \otimes G(0,\sigma_t)$$

Decay time & angular efficiencies

- Reconstruction and selection criteria introduce non-uniform efficiency

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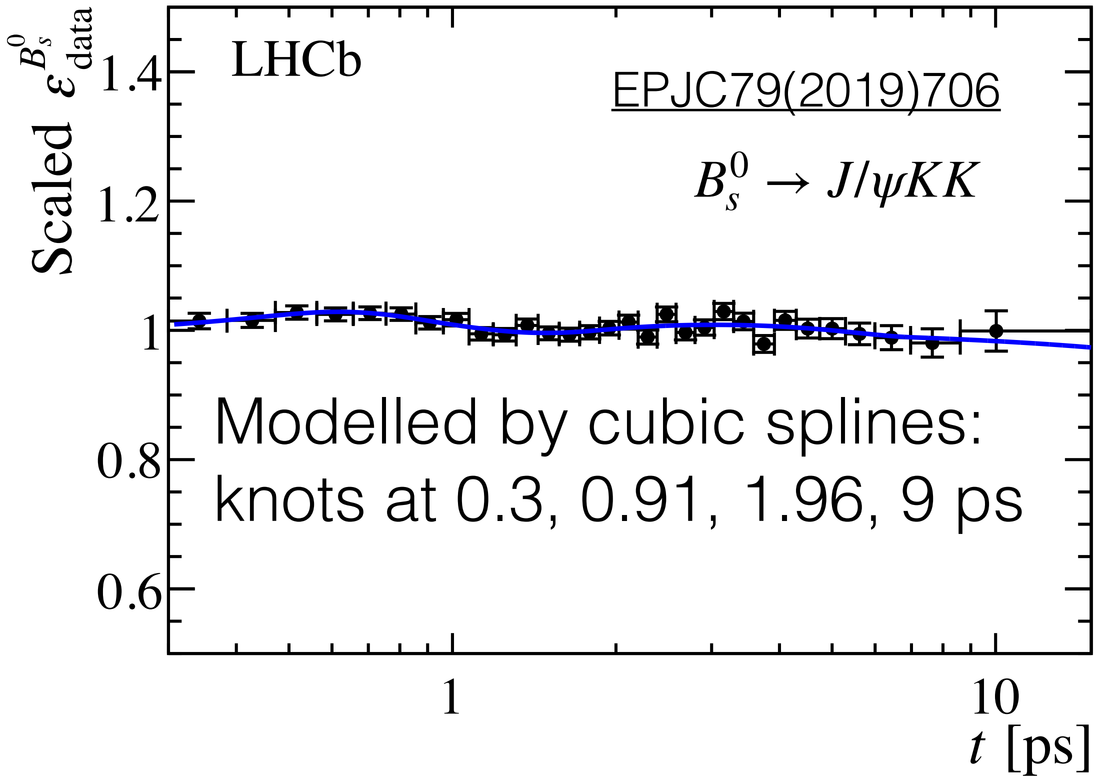

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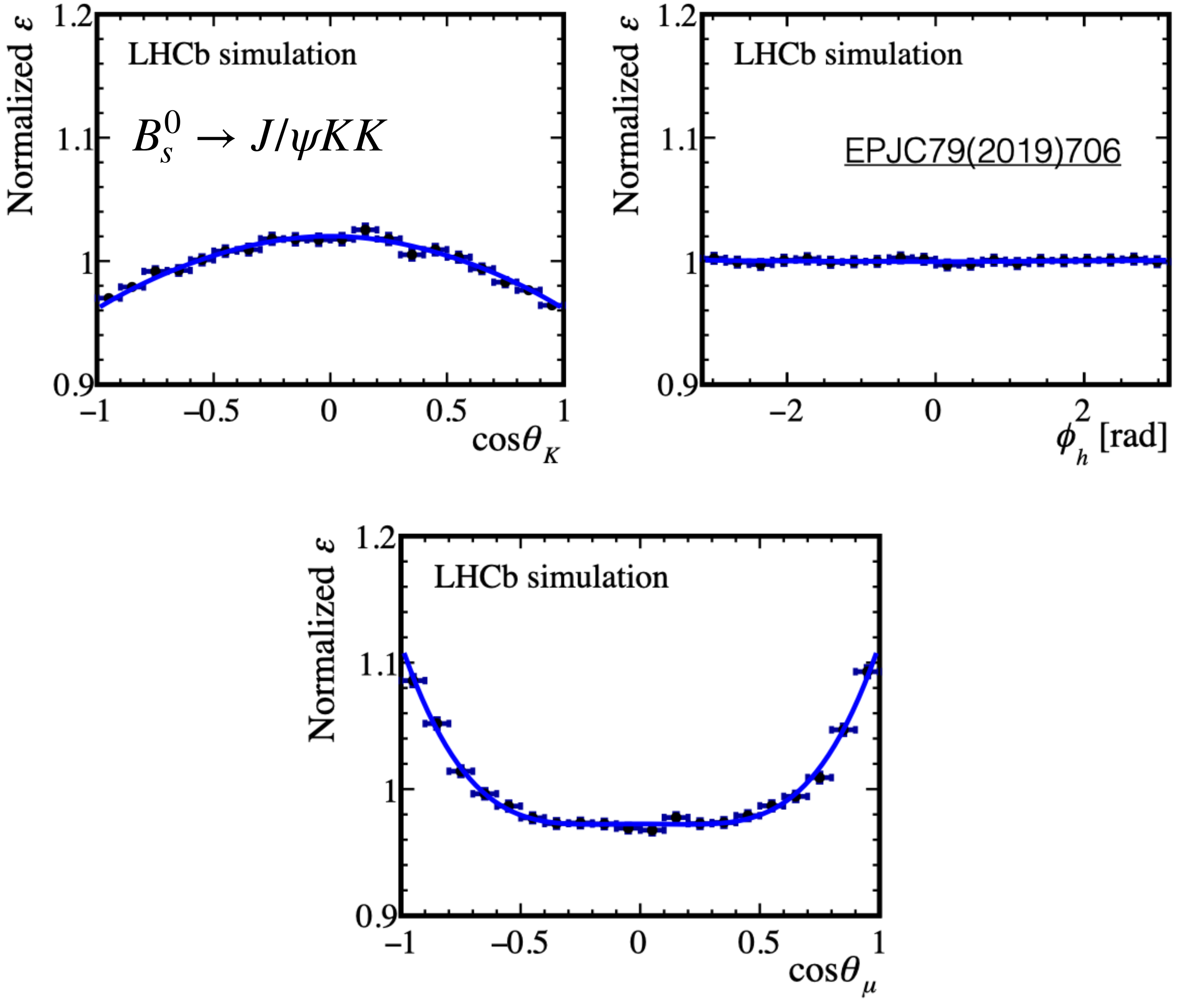
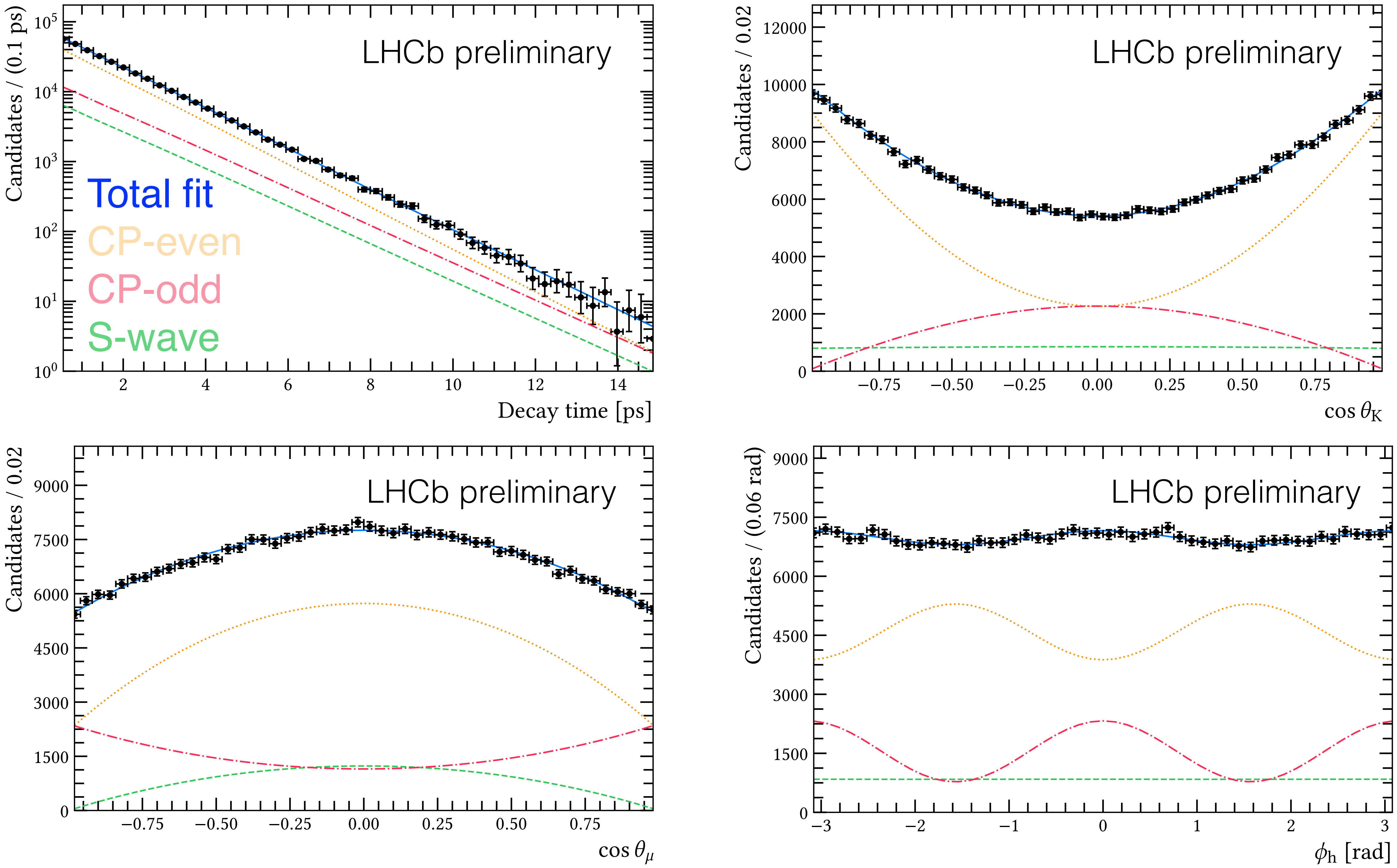
- Angular efficiencies for B_s^0 decays estimated with simulation



ϕ_s in $B_s^0 \to J/\psi KK$

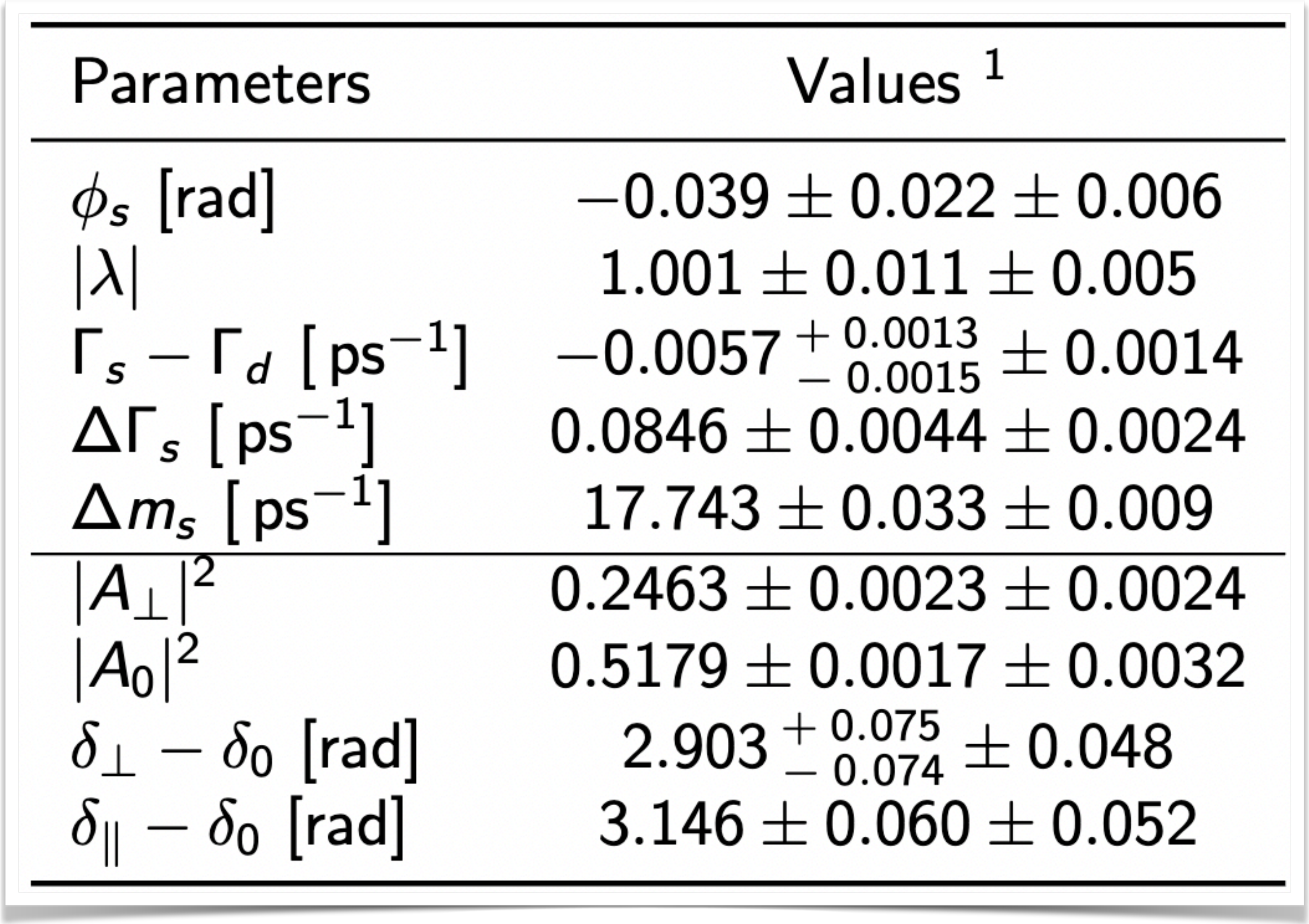
LHCb-PAPER-2023-016
In preparation

$$\mathscr{P}(t, \theta_K, \theta_\mu, \phi_h \,|\, \delta_t) \propto \sum_{k=1}^{10} N_k h_k(t) f_k(\theta_K, \theta_\mu, \phi_h) \quad \to \phi_s,\ \Delta m_s,\ \Delta\Gamma_s,\ \Gamma_s - \Gamma_d$$



ϕ_s in $B_s^0 \to J/\psi KK$

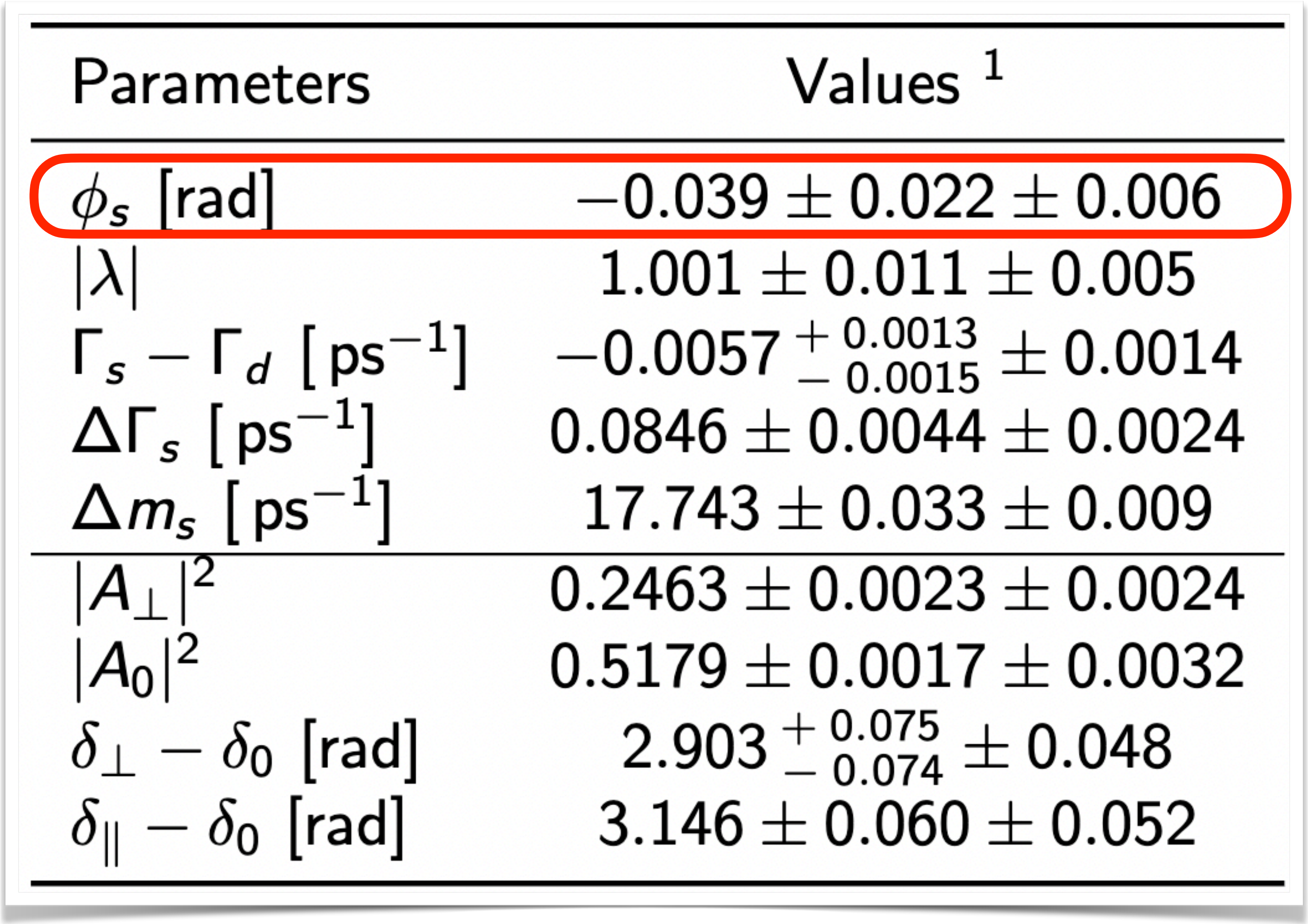
LHCb-PAPER-2023-016
In preparation



Parameters	Values [1]
ϕ_s [rad]	$-0.039 \pm 0.022 \pm 0.006$
$\lvert\lambda\rvert$	$1.001 \pm 0.011 \pm 0.005$
$\Gamma_s - \Gamma_d$ [ps^{-1}]	$-0.0057\,^{+\,0.0013}_{-\,0.0015} \pm 0.0014$
$\Delta\Gamma_s$ [ps^{-1}]	$0.0846 \pm 0.0044 \pm 0.0024$
Δm_s [ps^{-1}]	$17.743 \pm 0.033 \pm 0.009$
$\lvert A_\perp\rvert^2$	$0.2463 \pm 0.0023 \pm 0.0024$
$\lvert A_0\rvert^2$	$0.5179 \pm 0.0017 \pm 0.0032$
$\delta_\perp - \delta_0$ [rad]	$2.903\,^{+\,0.075}_{-\,0.074} \pm 0.048$
$\delta_\parallel - \delta_0$ [rad]	$3.146 \pm 0.060 \pm 0.052$

ϕ_s in $B_s^0 \to J/\psi KK$

LHCb-PAPER-2023-016
In preparation



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$\delta_\parallel - \delta_0$ [rad]	$3.146 \pm 0.060 \pm 0.052$

- The most precise measurement in single channel to date
- Compatible with prediction assuming the SM
- No evidence of CP violation
- Consistent and combined with Run 1 measurement:

$$\phi_s = -0.043 \pm 0.020 \text{ rad}$$

ϕ_s combinations in $b \to c\bar{c}s$ transition

Previous World Average:

$$\phi_s^{c\bar{c}s} = -0.049 \pm 0.019 \text{ rad}$$

$$\phi_s^{J/\psi KK} = -0.070 \pm 0.022 \text{ rad}$$

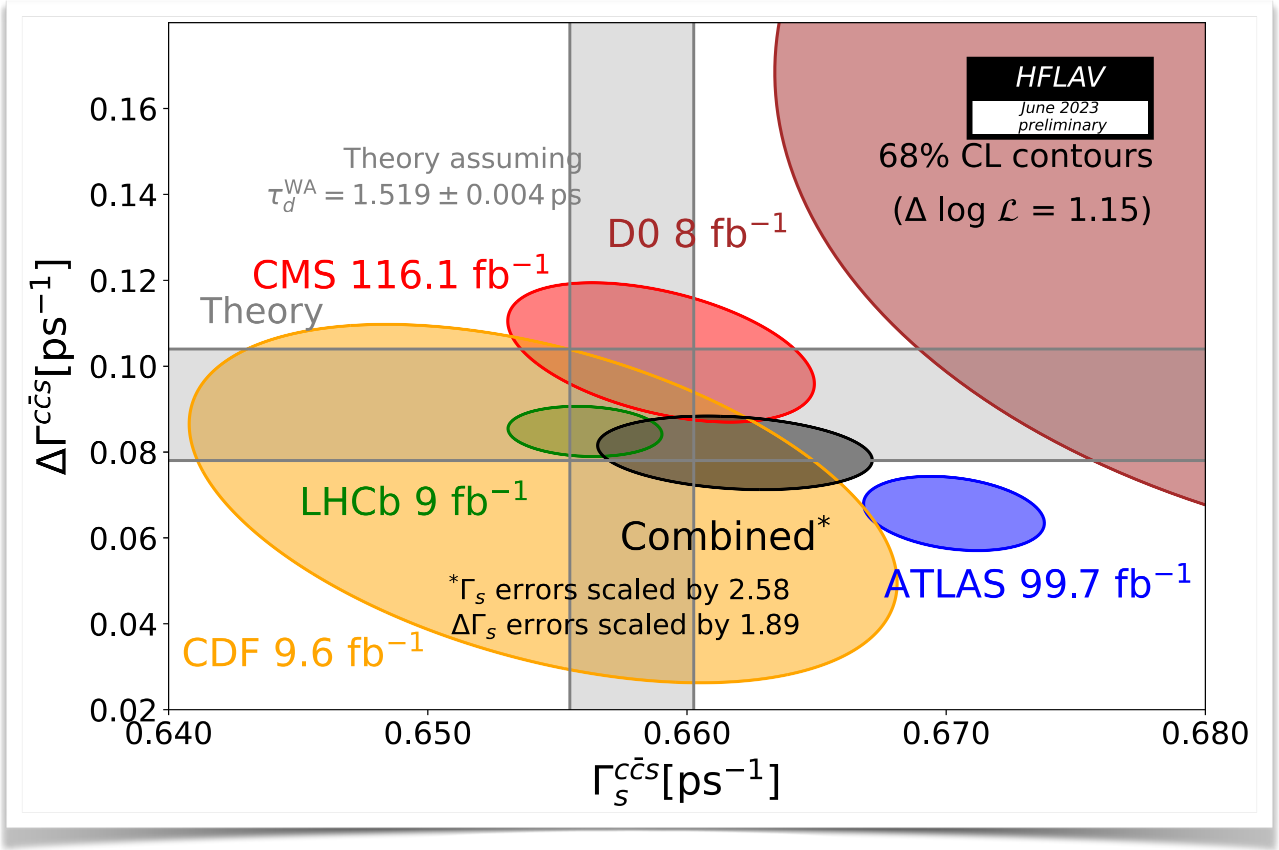
New World Average: (preliminary)

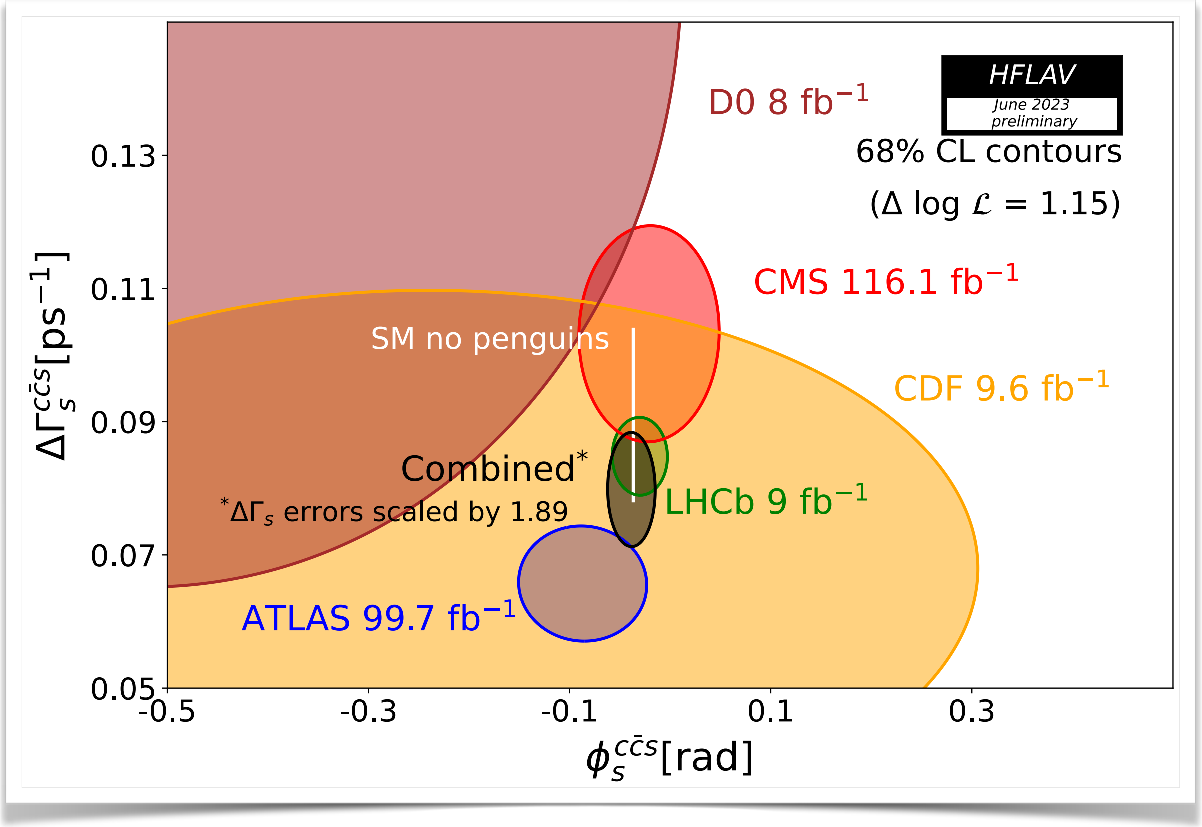
$$\phi_s^{c\bar{c}s} = -0.050 \pm 0.016 \text{ rad } (16\%)$$

$$\phi_s^{J/\psi KK} = -0.039 \pm 0.017 \text{ rad } (23\%)$$

- Consistent with the Global fits with SM assumption

$$\phi_s^{\text{CKMFitter}} \approx -2\beta_s = (-0.0368^{+0.0006}_{-0.0009}) \text{ rad} \qquad \phi_s^{\text{UTFitter}} = (-0.0370 \pm 0.0010) \text{ rad}$$





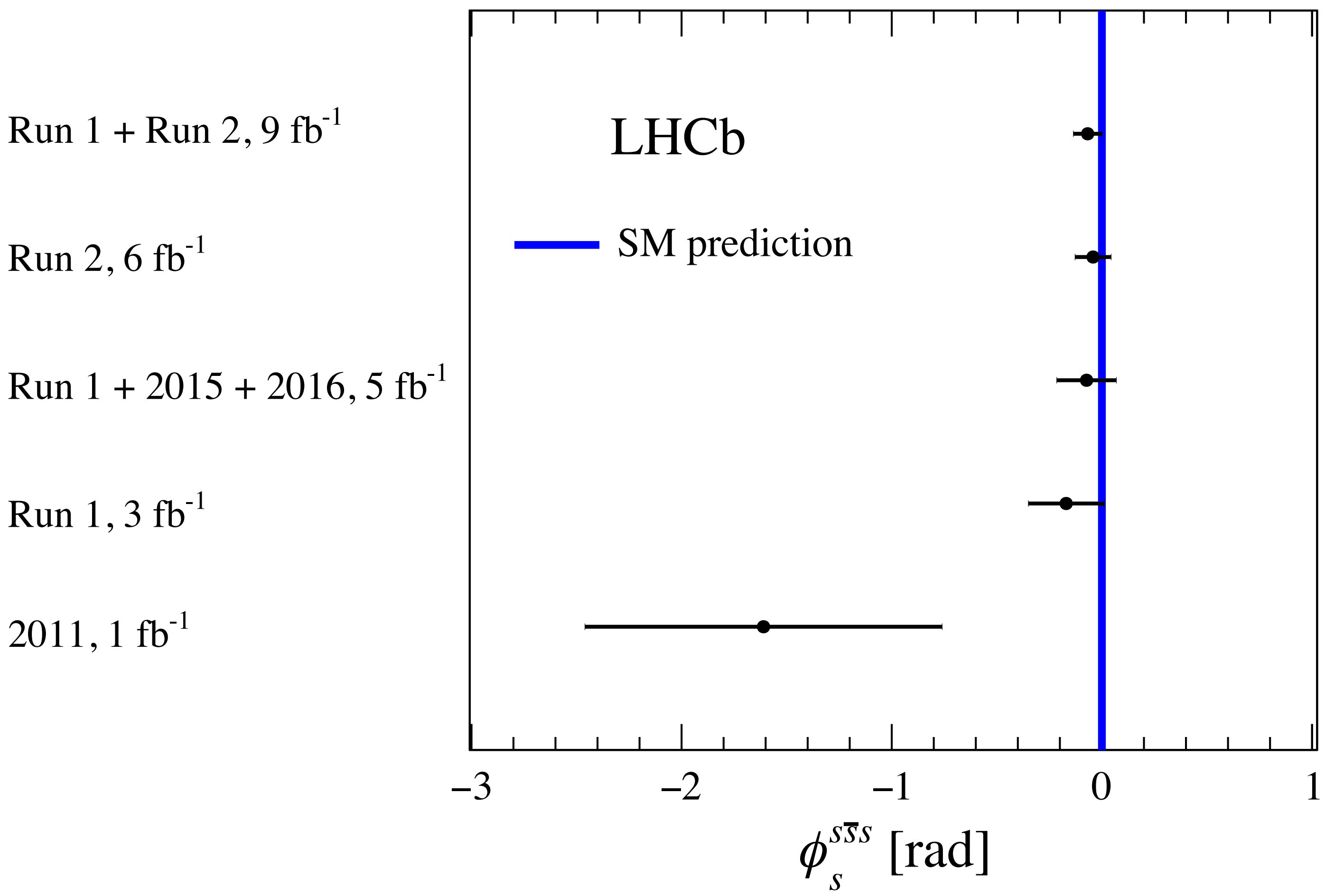
ϕ_s in $b \to s\bar{s}s$ transition

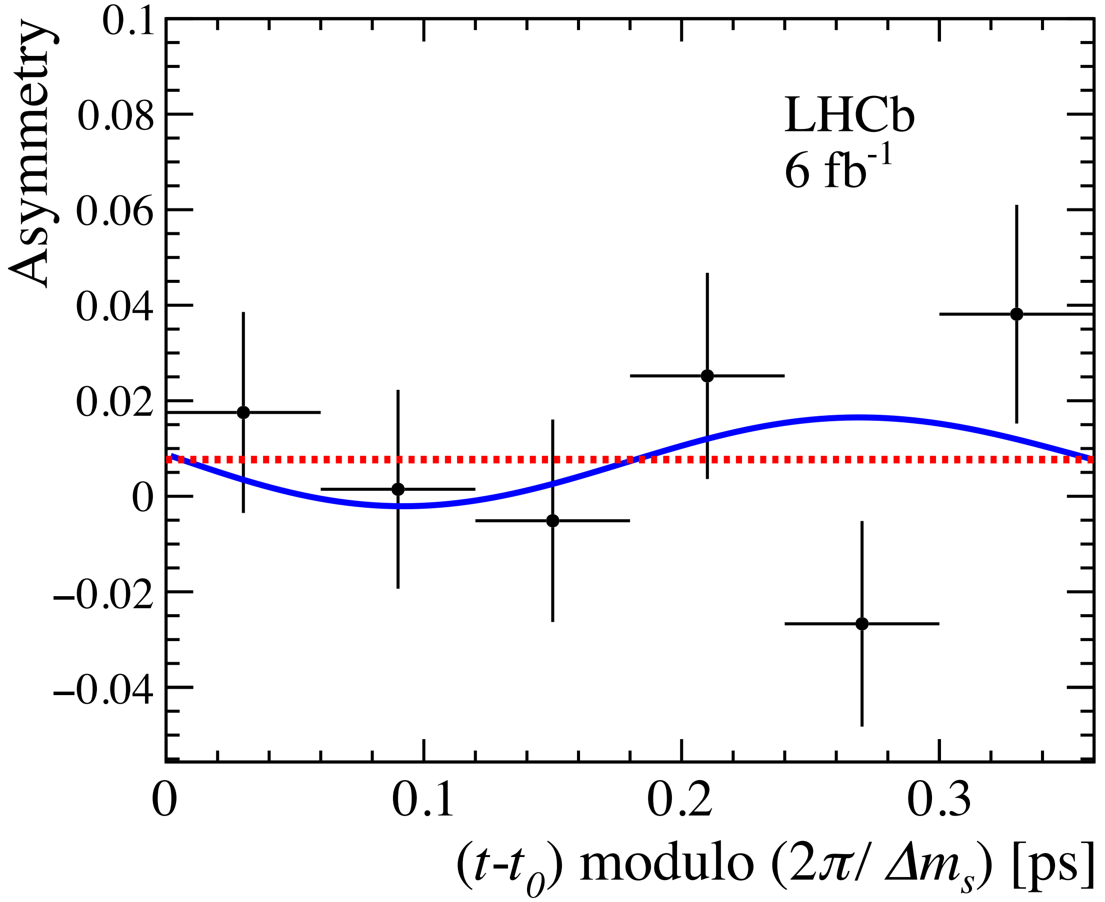
LHCb-PAPER-2023-001

$$\phi_s^{s\bar{s}s} = -0.042 \pm 0.075 \pm 0.009 \text{ rad}$$

$$|\lambda| = 1.004 \pm \pm 0.030 \pm 0.009$$

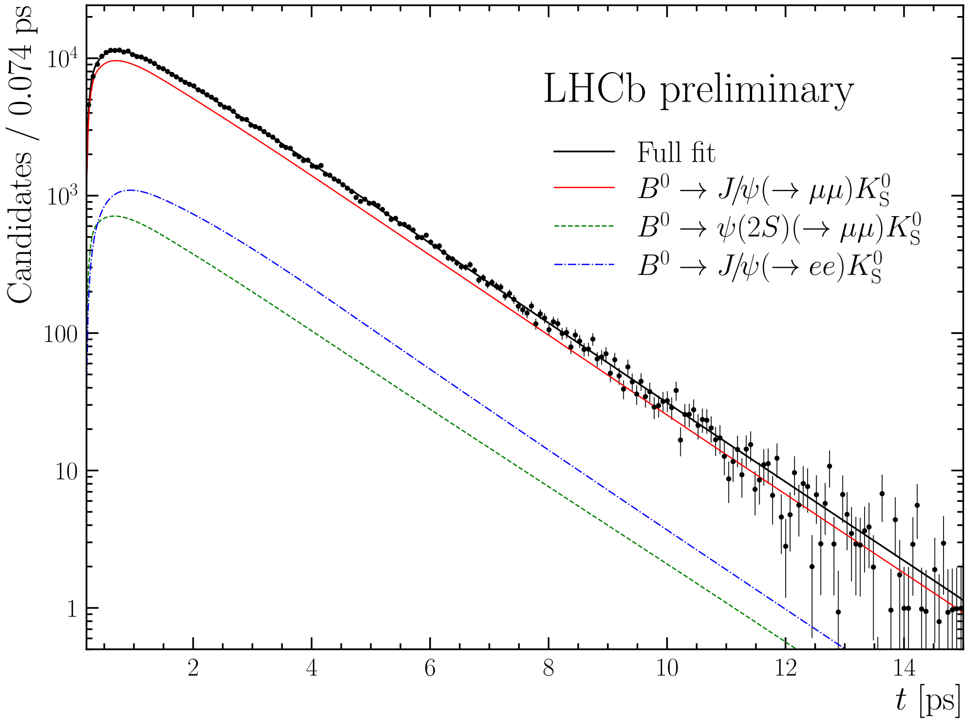
- The most precise measurement in any penguin dominated B decays
- No polarisation dependence is observed

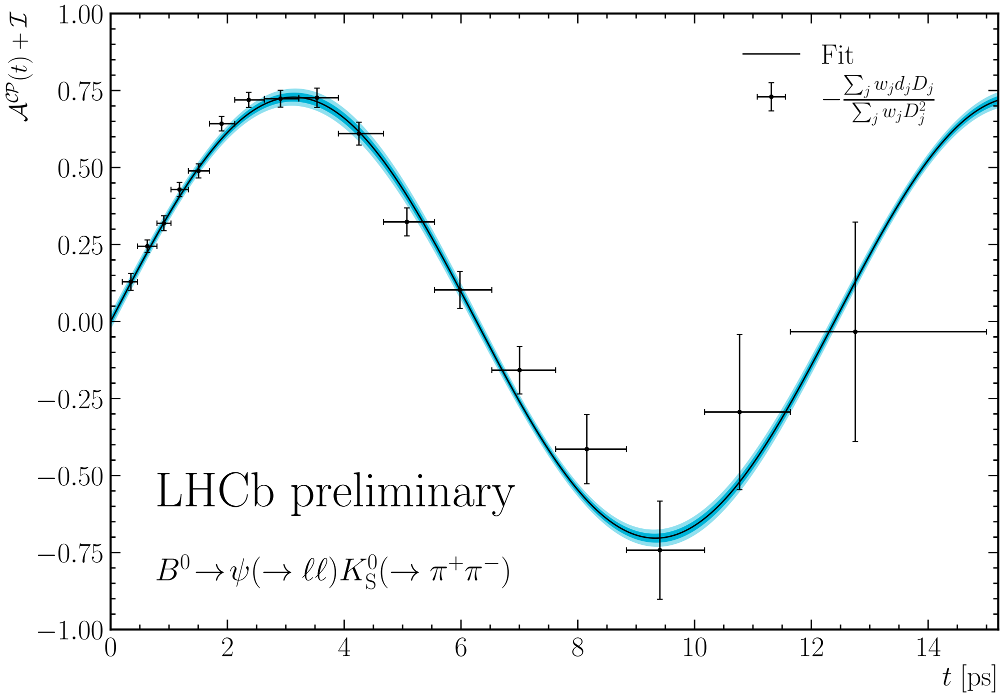




$\sin 2\beta$ in $B^0 \to \psi K_S^0$

LHCb-PAPER-2023-013
In preparation



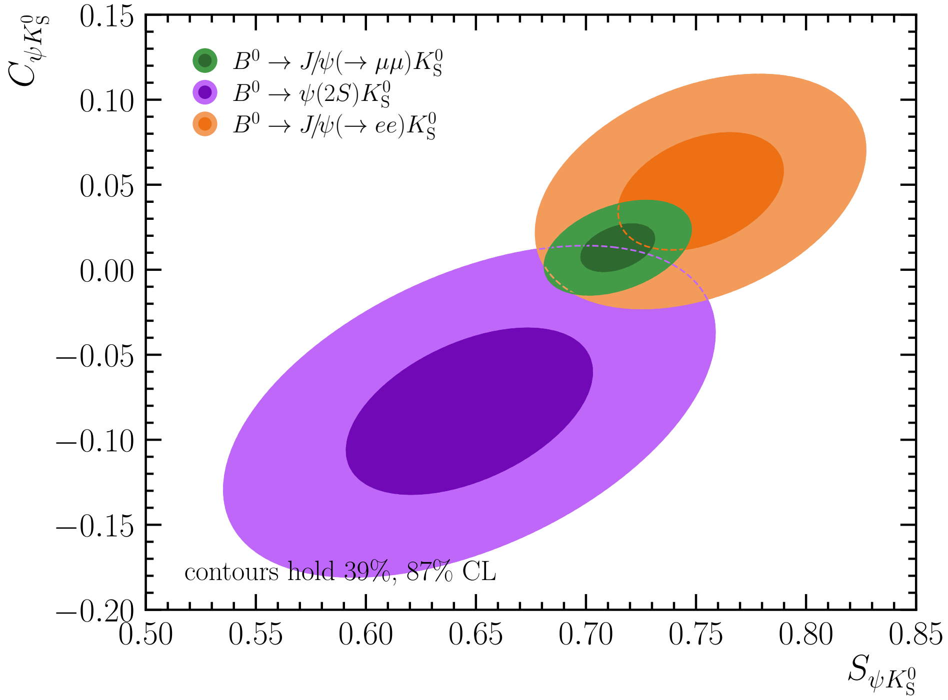


Combined fit result

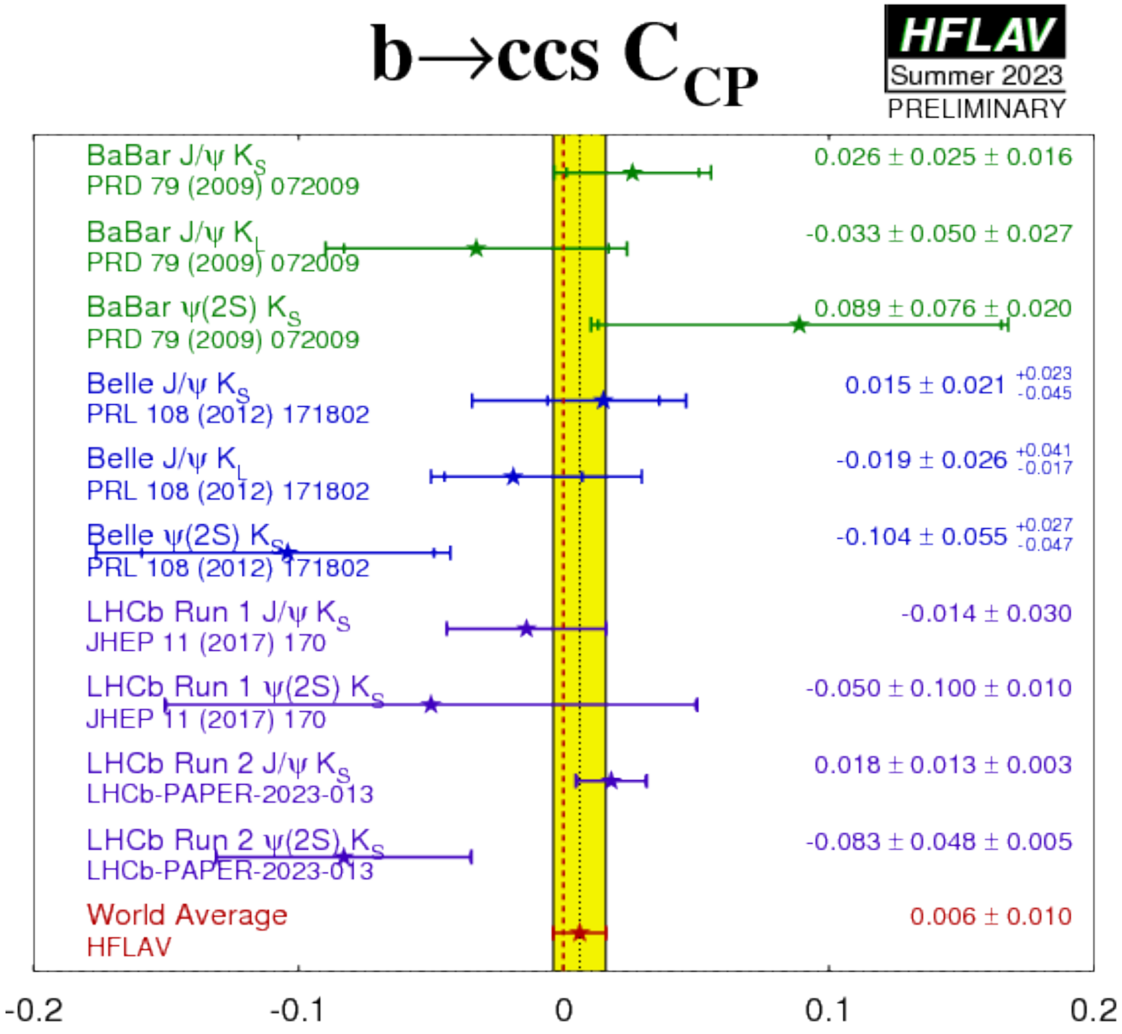
$$S_{\psi K_S^0}^{\text{Run 2}} = 0.716 \pm 0.013\,(\text{stat}) \pm 0.008\,(\text{syst})$$

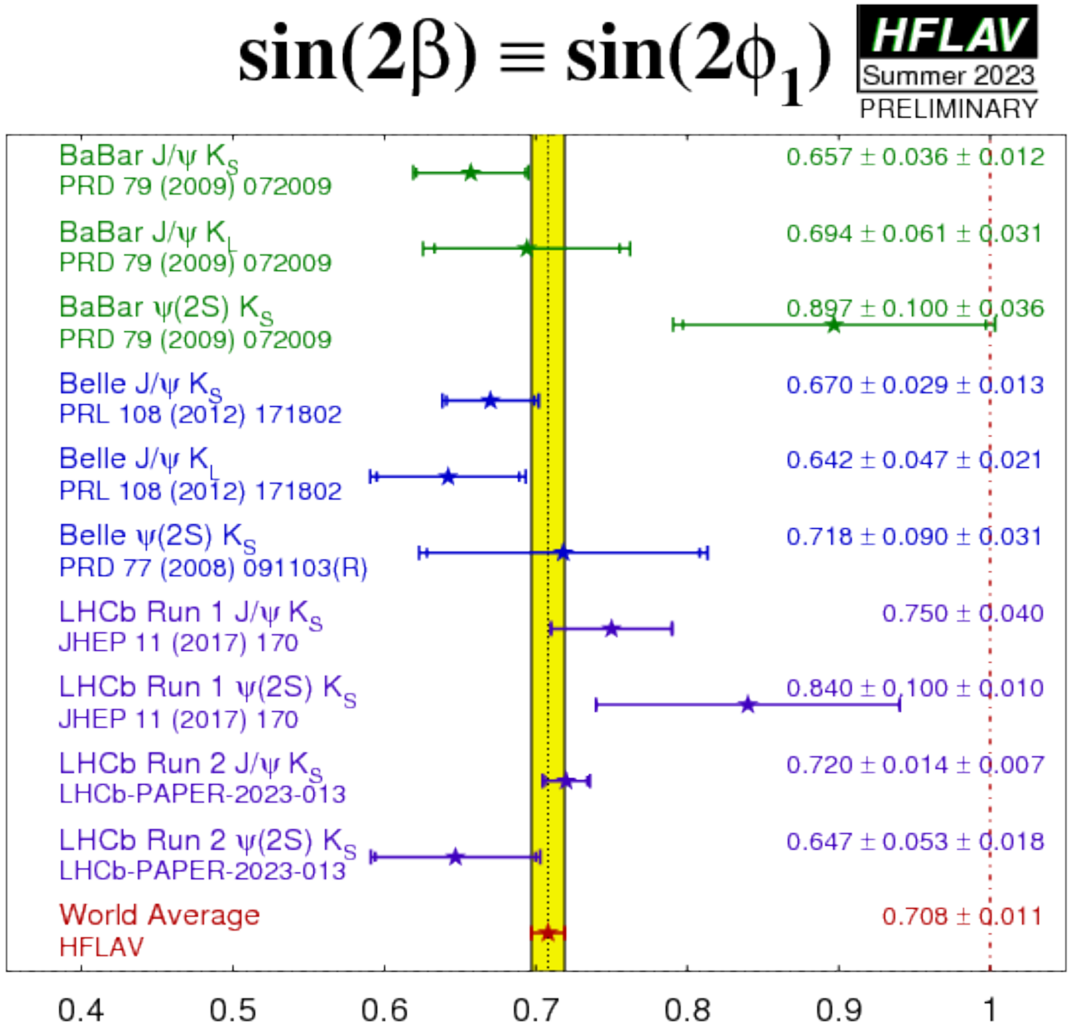
$$C_{\psi K_S^0}^{\text{Run 2}} = 0.012 \pm 0.012\,(\text{stat}) \pm 0.003\,(\text{syst})$$

- The most precise measurement in single measurement to date

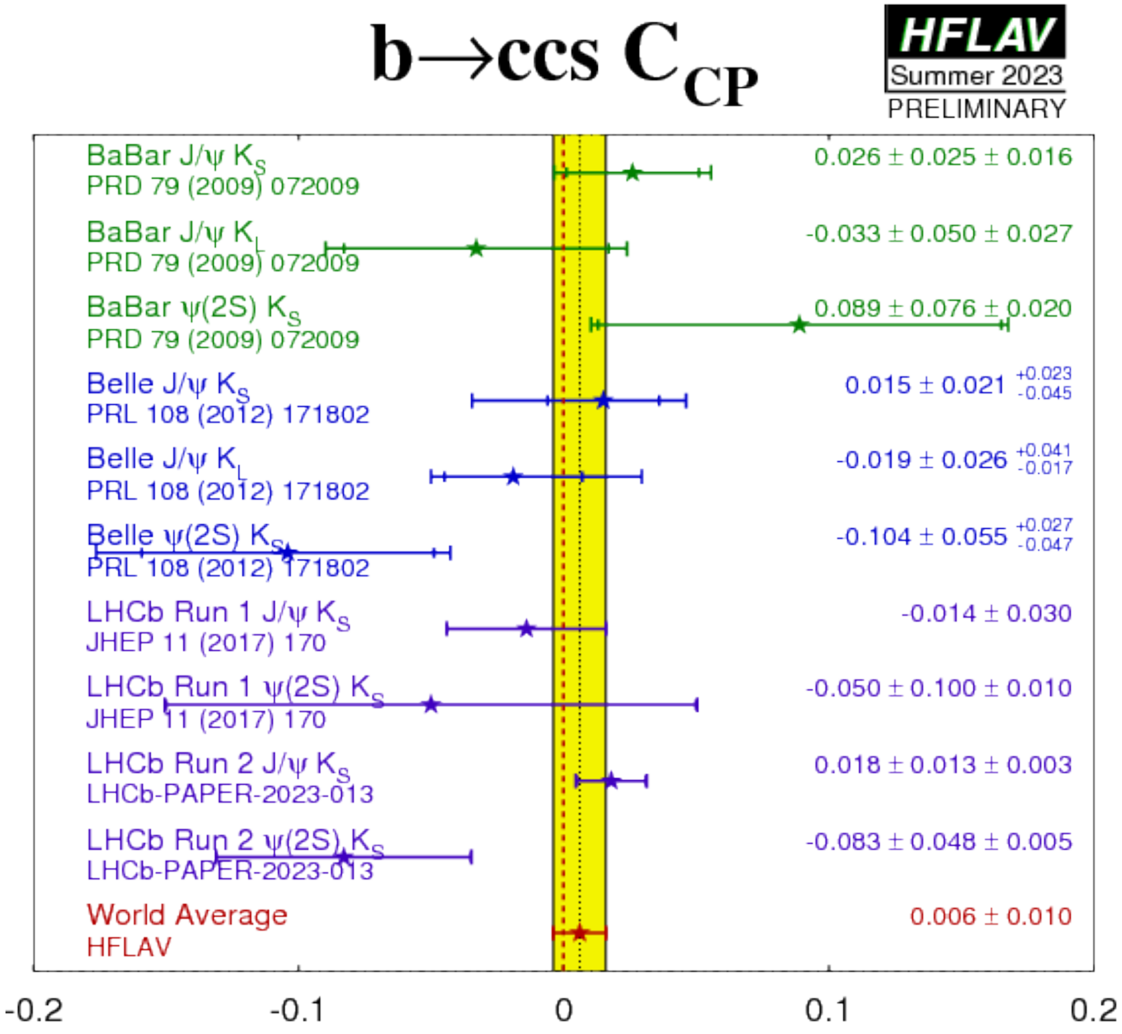


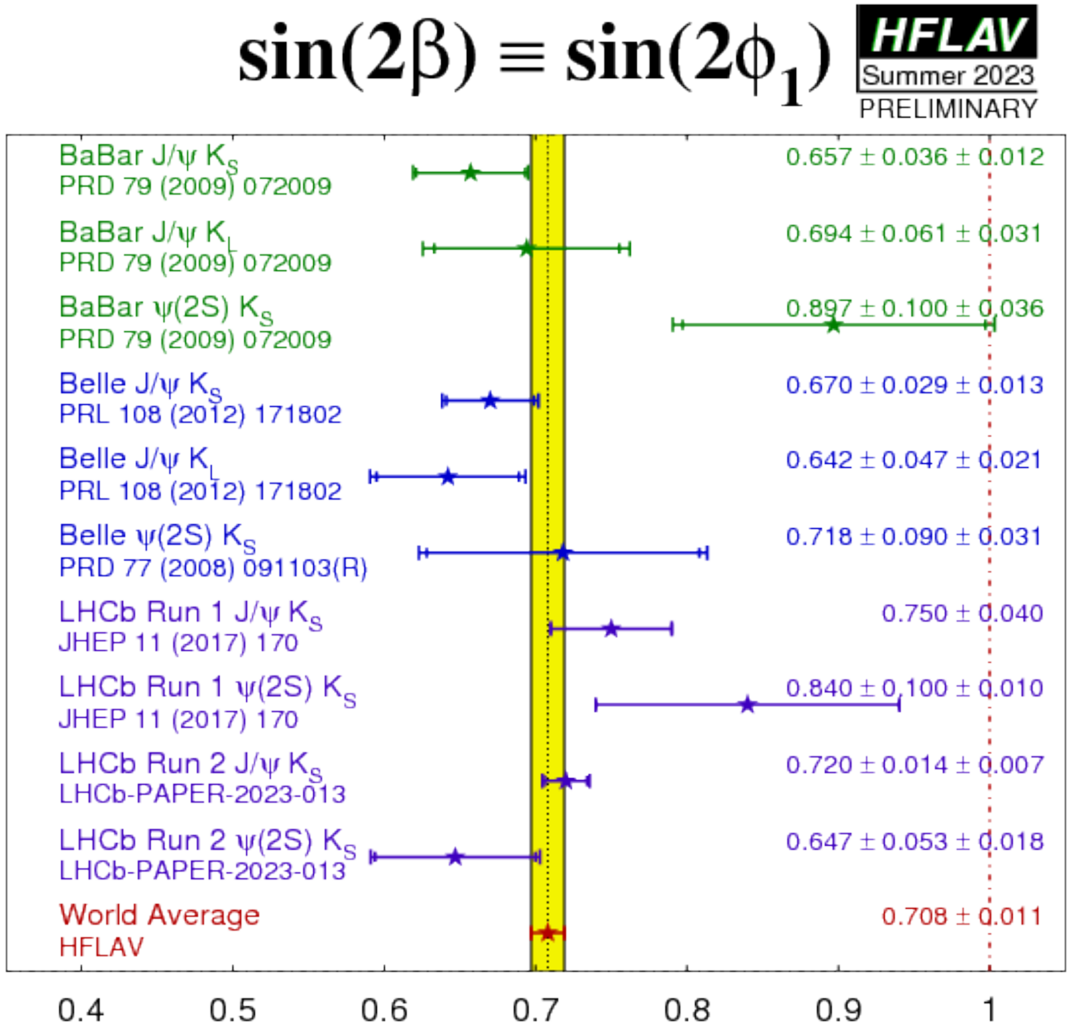
$\sin 2\beta$ combinations





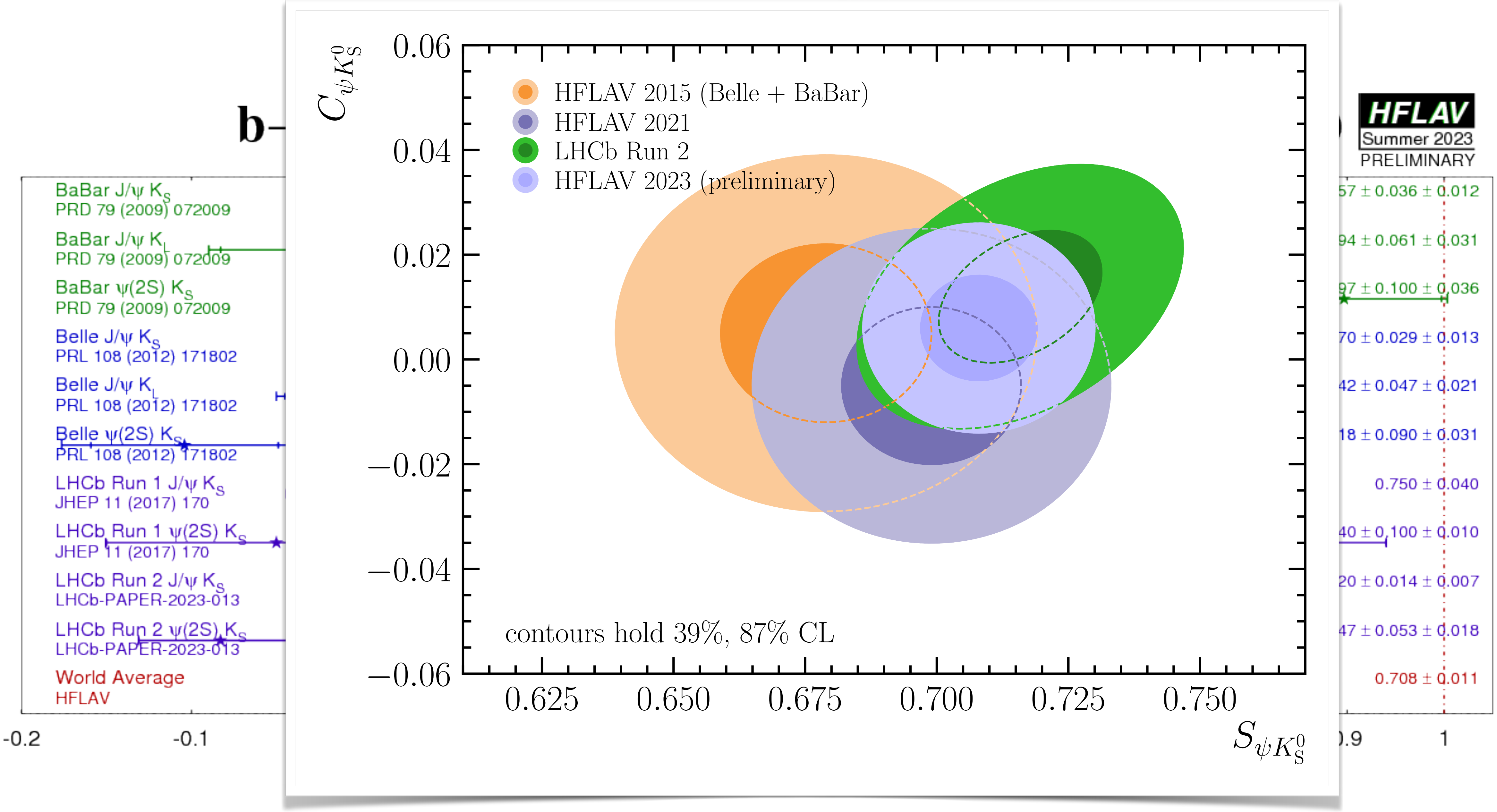
$\sin 2\beta$ combinations





- Consistent with other measurements, still statistical uncertainty limited
- Dominant contribution to the World Average

$\sin 2\beta$ combinations



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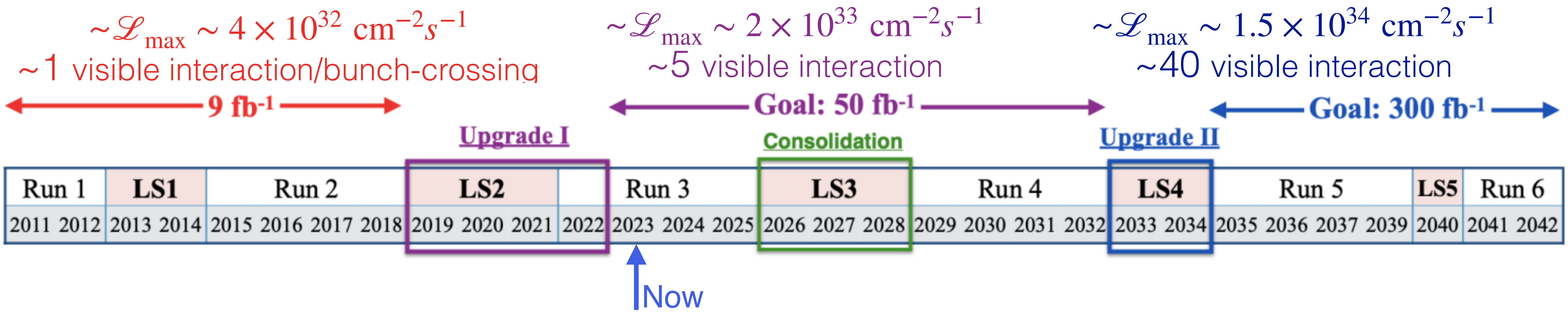
Looking at Run 3 and beyond



$\sim\mathscr{L}_{\max} \sim 4 \times 10^{32}\ \mathrm{cm}^{-2}s^{-1}$

$\sim$1 visible interaction/bunch-crossing

$\sim\mathscr{L}_{\max} \sim 2 \times 10^{33}\ \mathrm{cm}^{-2}s^{-1}$

$\sim$5 visible interaction

$\sim\mathscr{L}_{\max} \sim 1.5 \times 10^{34}\ \mathrm{cm}^{-2}s^{-1}$

$\sim$40 visible interaction

9 fb^{-1}

Goal: 50 fb^{-1}

Goal: 300 fb^{-1}

Upgrade I

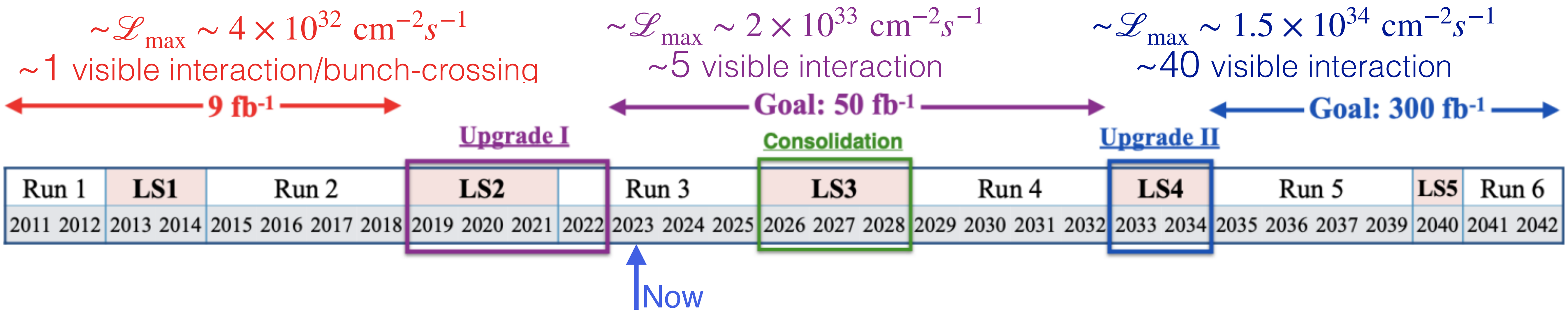
Consolidation

Upgrade II

Run 1	LS1	Run 2	LS2		Run 3	LS3	Run 4	LS4	Run 5	LS5	Run 6
2011 2012	2013 2014	2015 2016 2017 2018	2019 2020 2021	2022	2023 2024 2025	2026 2027 2028	2029 2030 2031 2032	2033 2034	2035 2036 2037 2039	2040	2041 2042

Now

Looking at Run 3 and beyond



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Upgrade II

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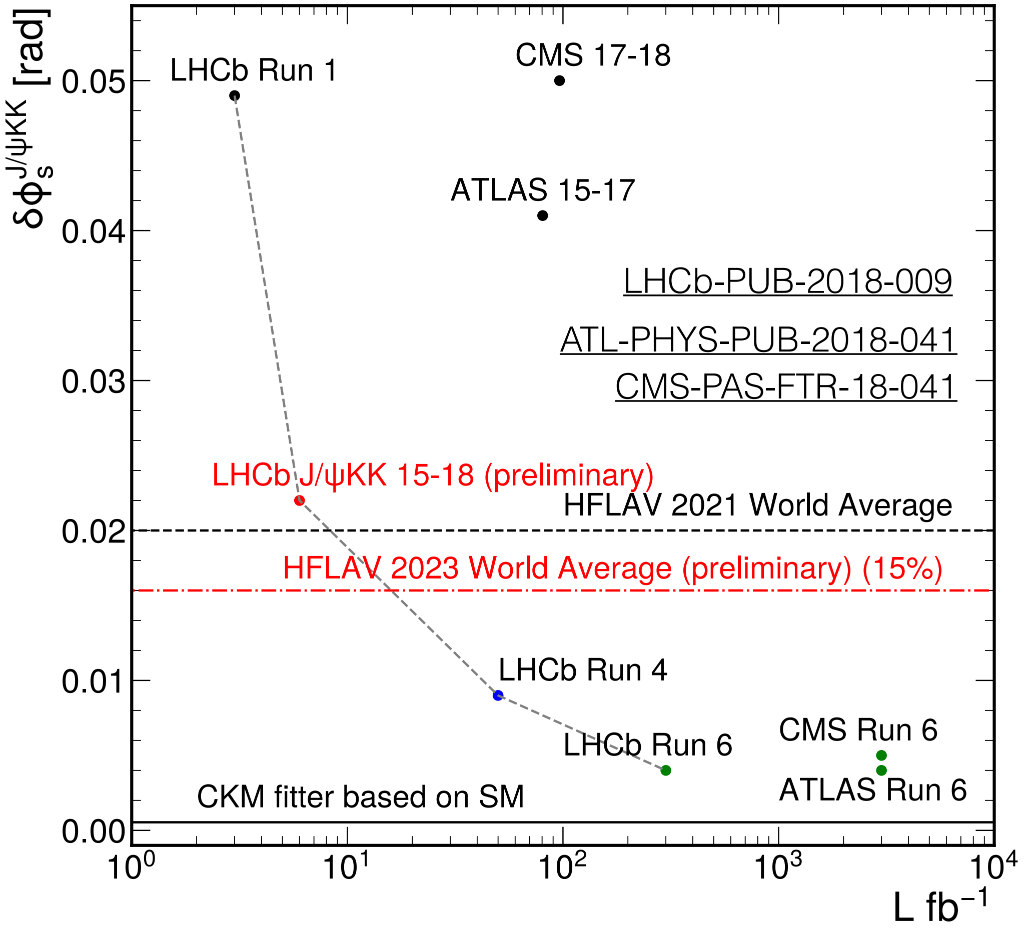
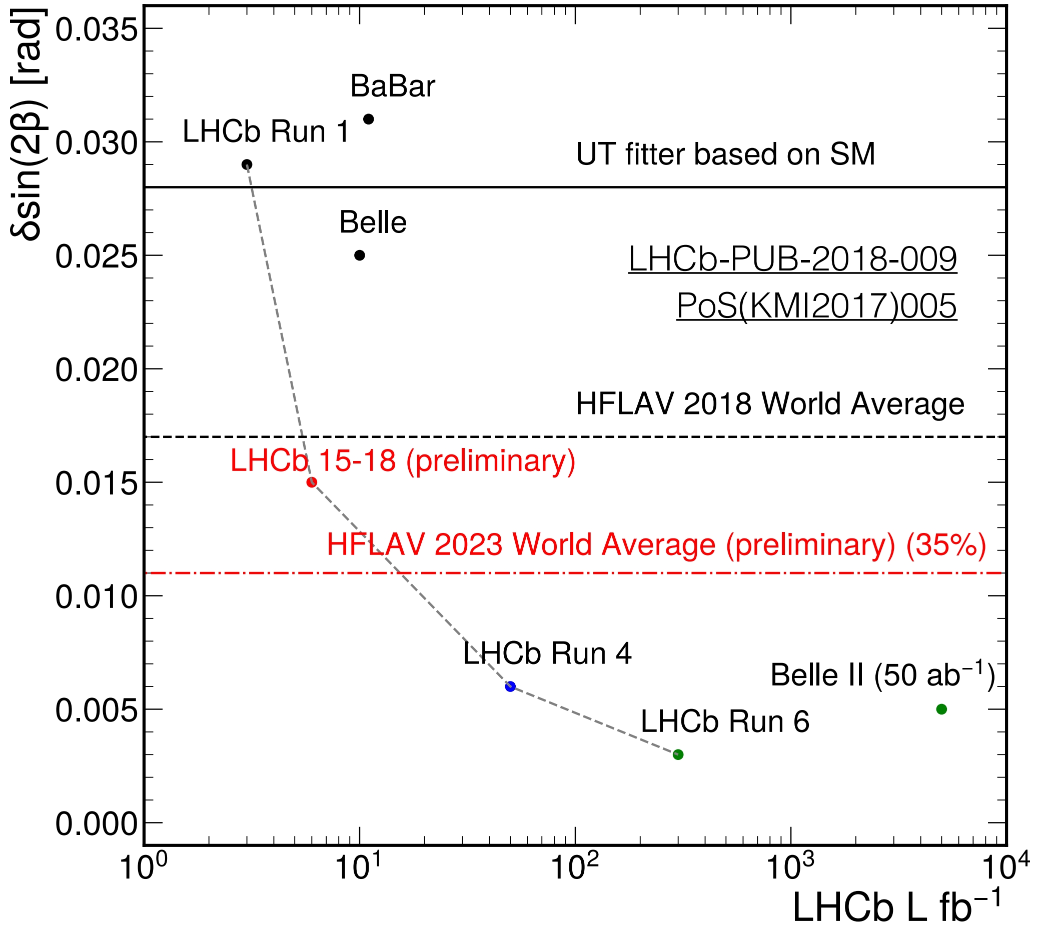
Now

- Further precision improvement with more data
- Great opportunities to search for NP indirectly, up to > TeV scale





Summary

- ✓ LHCb dominates the world average of many CPV measurements
- ✓ Flag-ship time-dependent measurements of CP violation in B-meson decays with full LHCb data sample, providing the most precise results for
  - ✓ ϕ_s in $b \to c\bar{c}s$ transition, $\sigma(\phi_s) \sim 20$ mrad
  - ✓ $\phi_s^{s\bar{s}s}$ in penguin dominant B decays
  - ✓ $\sin 2\beta = 0.716 \pm 0.013(\text{stat.}) \pm 0.008(\text{syst.})$
- ✓ Looking forward to further test of the SM and search for new physics with more data from Upgrade I & II

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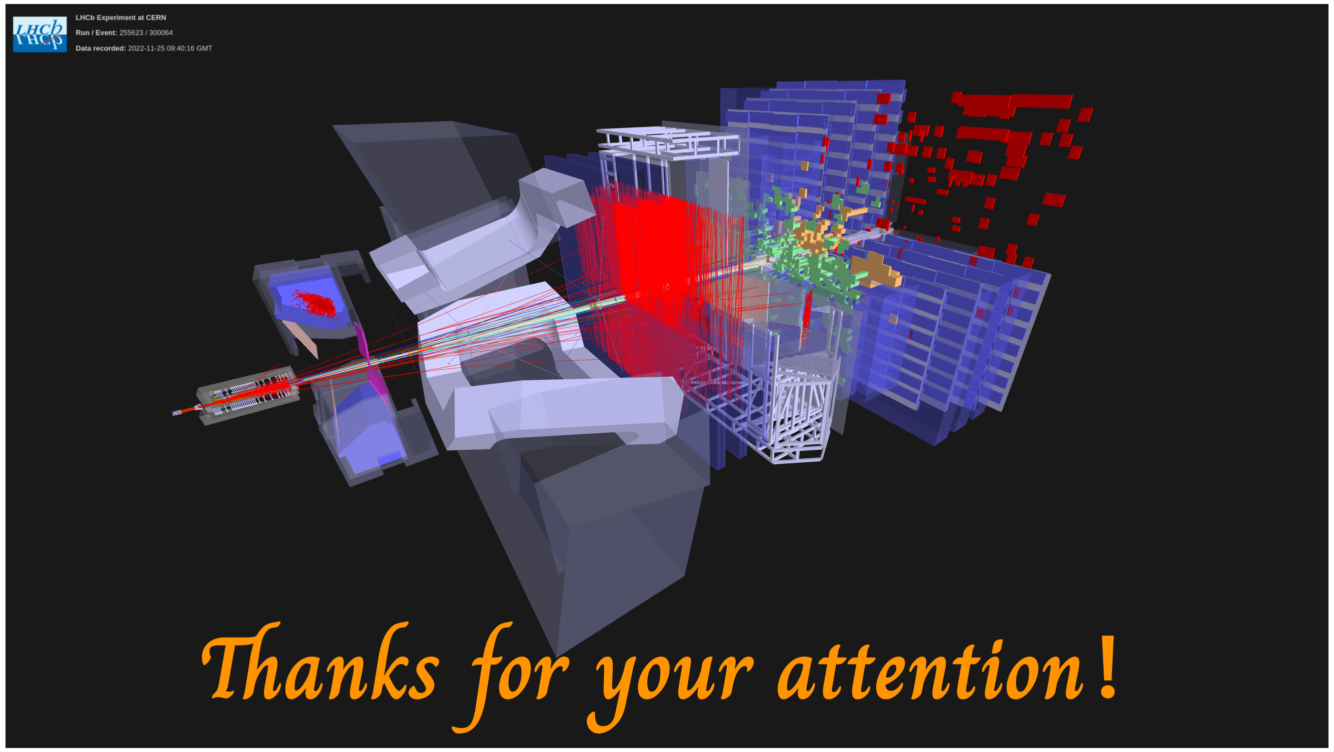

Back up slides

Flavor tagging calibration

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- Statistical process, the tag is not always right → knowledge of mistag rate ω
- Not all selected candidates can be tagged → knowledge of tagging efficiency ϵ_{tag}
- Data-driven method to calibration the performance

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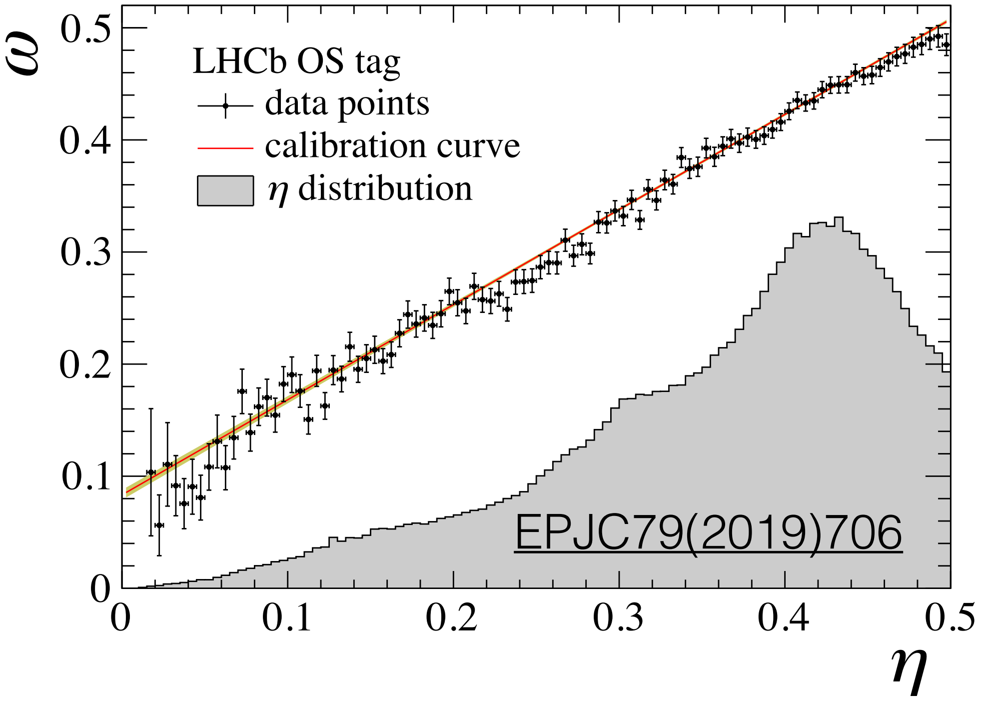

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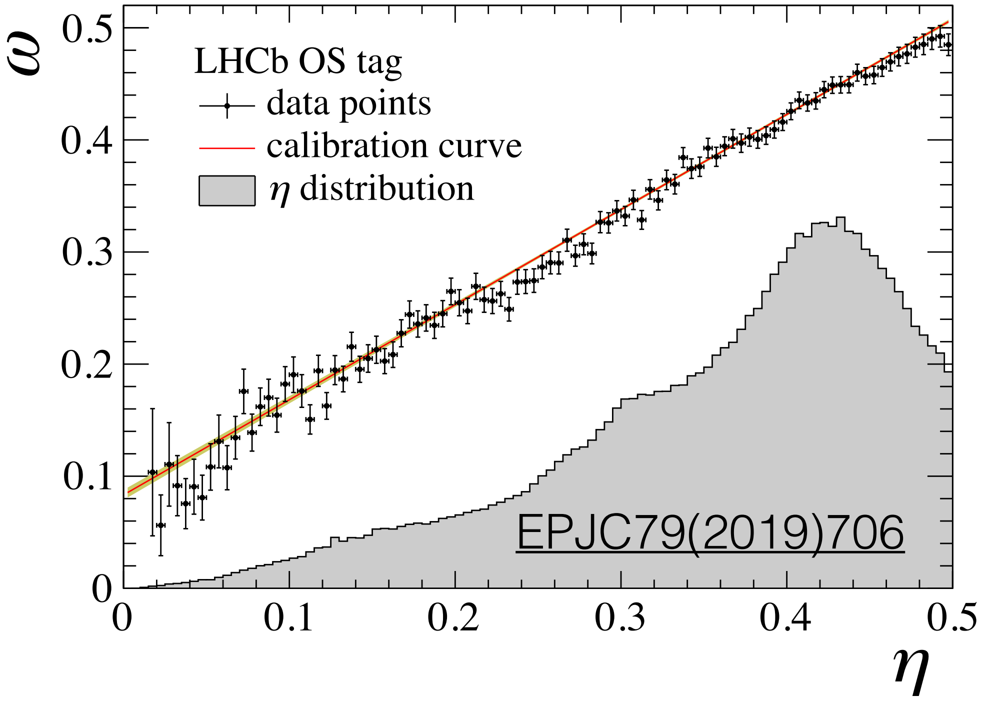
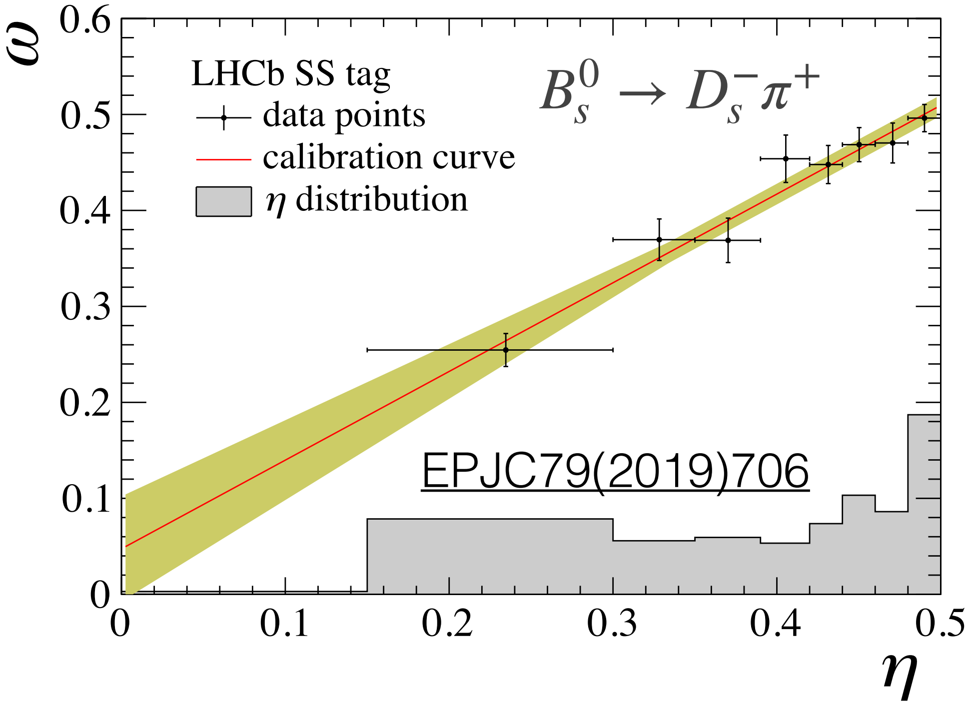


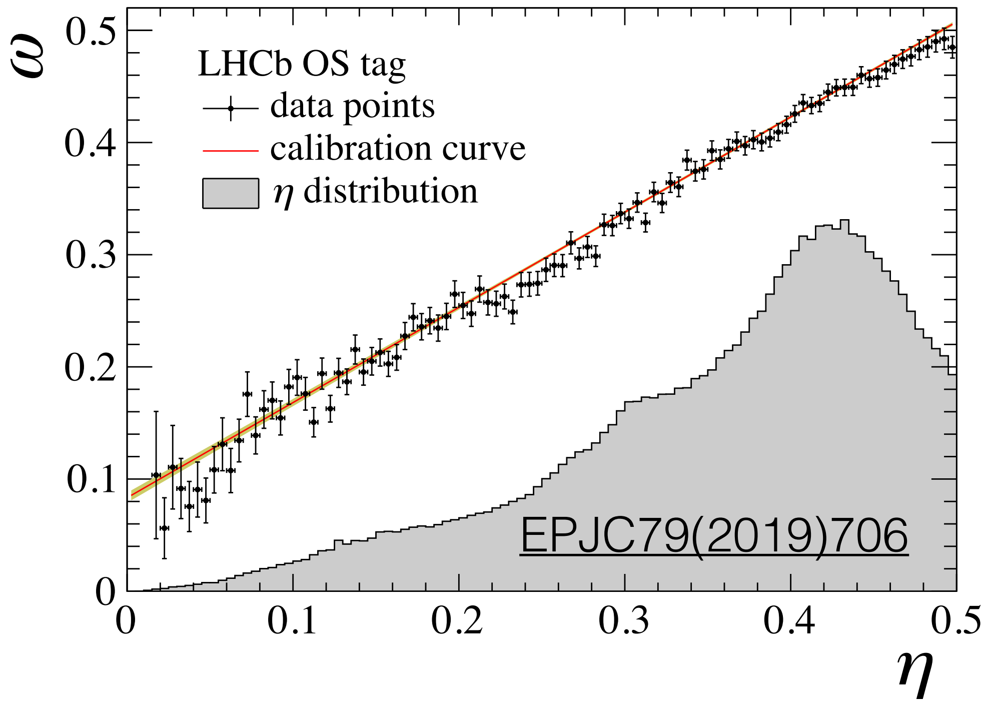
- SS tagging for B_s^0: $B_s^0 \to D_s^- \pi^+$
- SS tagging for B^0: $B^0 \to J/\psi K^*$



Flavor tagging calibration

- Statistical process, the tag is not always right → knowledge of mistag rate ω
- Not all selected candidates can be tagged → knowledge of tagging efficiency $\epsilon_{\rm tag}$
- Data-driven method to calibration the performance

- OS tagging: $B^+ \to J/\psi K^+$



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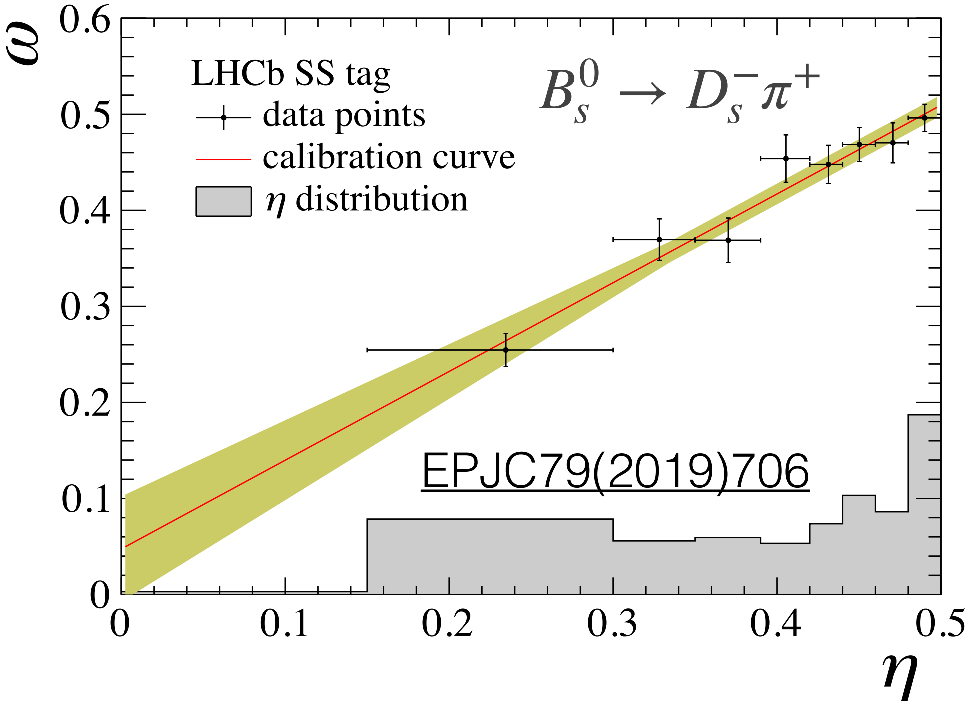

Tagging power	$B^0 \to \psi K_S^0$	$B_s^0 \to J/\psi KK$	$B_s^0 \to \phi\phi$
$\epsilon_{\rm tag}(1-2\omega)^2$	(4-6)%	4.3%	6%

ϕ_s polarisation dependent fit

- New physics effects can vary in different polarisation states
  - Allow $|\lambda|$ and ϕ_s differ in polarisation states
  - Shows no evidence for any polarisation dependence

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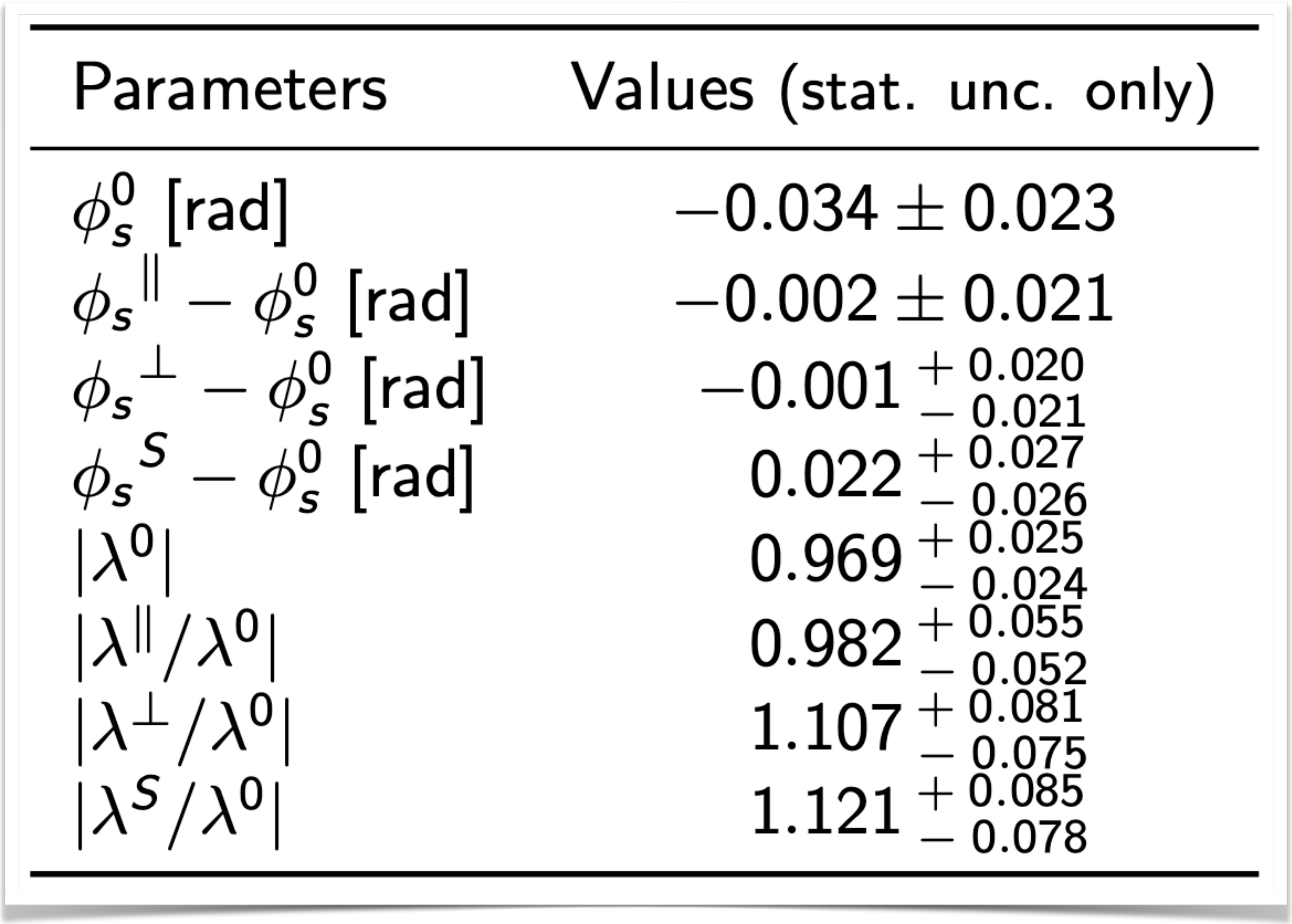

Parameters	Values (stat. unc. only)
ϕ_s^0 [rad]	-0.034 ± 0.023
$\phi_s{}^{\parallel} - \phi_s^0$ [rad]	-0.002 ± 0.021
$\phi_s{}^{\perp} - \phi_s^0$ [rad]	$-0.001 \, {}^{+\,0.020}_{-\,0.021}$
$\phi_s{}^{S} - \phi_s^0$ [rad]	$0.022 \, {}^{+\,0.027}_{-\,0.026}$
$\lvert\lambda^0\rvert$	$0.969 \, {}^{+\,0.025}_{-\,0.024}$
$\lvert\lambda^{\parallel}/\lambda^0\rvert$	$0.982 \, {}^{+\,0.055}_{-\,0.052}$
$\lvert\lambda^{\perp}/\lambda^0\rvert$	$1.107 \, {}^{+\,0.081}_{-\,0.075}$
$\lvert\lambda^{S}/\lambda^0\rvert$	$1.121 \, {}^{+\,0.085}_{-\,0.078}$

Results of the parameters for S-wave

$$
\begin{aligned}
|A_S^1|^2 &= 0.472 \pm 0.024 \pm 0.027, \\
|A_S^2|^2 &= 0.042 \pm 0.005 \pm 0.010, \\
|A_S^3|^2 &= 0.0029^{+0.0013}_{-0.0009} \pm 0.023, \\
|A_S^4|^2 &= 0.0037^{+0.0025}_{-0.0019} \pm 0.032, \\
|A_S^5|^2 &= 0.0508 \pm 0.007 \pm 0.027, \\
|A_S^6|^2 &= 0.151 \pm 0.011 \pm 0.051, \\
\delta_S^1 - \delta_\perp &= 2.05^{+0.12}_{-0.14} \pm 0.19\,\mathrm{rad}, \\
\delta_S^2 - \delta_\perp &= 1.62^{+0.19}_{-0.19} \pm 0.41\,\mathrm{rad}, \\
\delta_S^3 - \delta_\perp &= 1.16^{+0.37}_{-0.29} \pm 0.19\,\mathrm{rad}, \\
\delta_S^4 - \delta_\perp &= -0.15^{+0.12}_{-0.15} \pm 0.31\,\mathrm{rad}, \\
\delta_S^5 - \delta_\perp &= -0.637^{+0.068}_{-0.076} \pm 0.17\,\mathrm{rad}, \\
\delta_S^6 - \delta_\perp &= -1.013^{+0.074}_{-0.083} \pm 0.07\,\mathrm{rad}.
\end{aligned}
$$

Systematics for ϕ_s

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* Uncertainties (×0.01) Dominated sys. Sub-dominated sys. Stat. limited

Source	$\lvert A_0\rvert^2$	$\lvert A_\perp\rvert^2$	ϕ_s [rad]	$\lvert\lambda\rvert$	$\delta_\perp-\delta_0$ [rad]	$\delta_\parallel-\delta_0$ [rad]	$\Gamma_s-\Gamma_d$ [ps^{-1}]	$\Delta\Gamma_s$ [ps^{-1}]	Δm_s [ps^{-1}]
Mass parametrization	0.04	0.03	0.03	0.02	0.15	0.12	0.02	0.04	0.03
Mass: shape statistical	0.04	0.04	0.05	0.09	0.62	0.33	0.02	0.01	0.11
Mass factorization	0.11	0.10	0.42	0.19	0.54	0.60	0.12	0.16	0.18
B_c^+ contamination	0.04	0.05	—	0.02	—	0.17	(0.07)	(0.03)	—
D–wave component	0.04	0.04	0.02	—	0.07	0.13	0.01	0.03	0.02
Bkgcat 60	0.07	0.04	0.02	0.10	0.18	0.18	0.02	—	0.01
Multiple candidates	0.01	—	0.27	0.22	0.90	0.41	0.01	0.01	0.24
Particle identification	0.06	0.09	0.27	0.27	1.31	0.51	0.05	0.15	0.46
C_{SP} factors	—	0.01	0.01	0.03	0.73	0.41	—	0.01	0.04
DTR model portability	—	—	0.08	0.03	0.26	0.09	—	—	0.09
DTR calibration	—	—	0.03	0.02	0.11	0.07	—	—	0.05
Time bias correction	0.04	0.05	0.06	0.05	0.77	0.11	0.03	0.05	0.44
Angular efficiency	0.05	0.14	0.25	0.32	0.42	0.44	0.01	0.02	0.13
Angular resolution	0.01	0.01	0.02	0.01	0.02	0.08	—	0.01	0.02
Kinematic weighting	0.24	0.09	0.01	0.01	0.98	0.86	0.02	0.03	0.31
Momentum uncertainty	0.08	0.04	0.04	—	0.07	0.11	0.01	—	0.13
Longitudinal scale	0.07	0.04	0.04	—	0.10	0.09	0.02	—	0.31
Neglected correlations	—	—	—	—	4.20	4.96	—	—	—
Total sys. unc.	0.32	0.24	0.6	0.5	4.8	5.2	0.14	0.24	0.9
Stat. unc.	0.17	0.23	2.2	1.1	7.5	6.0	0.14	0.44	3.3

- ϕ_s, $\lvert\lambda\rvert$, $\Delta\Gamma_s$, Δm_s are statistically limited

Systematics for $\phi_s^{s\bar{s}s}$

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Source	$\phi_s^{s\bar{s}s}$	$\lvert\lambda\rvert$	$\lvert A_0\rvert^2$	$\lvert A_\perp\rvert^2$	$\delta_\parallel - \delta_0$	$\delta_\perp - \delta_0$
Time resolution	4.9	2.6	0.8	0.8	0.1	3.4
Flavor tagging	4.8	4.7	0.9	1.3	1.2	9.7
Angular acceptance	3.9	4.9	1.4	1.7	4.7	1.2
Time acceptance	2.3	1.7	0.1	0.1	5.6	0.7
Mass fit & factorization	2.2	4.4	1.9	2.3	2.3	2.5
MC truth match	1.1	0.2	0.1	0.1	0.2	0.3
Fit bias	0.8	0.7	0.9	0.3	3.6	0.7
Candidate multiplicity	0.3	0.2	0.1	0.8	0.2	0.1
Total	8.8	8.6	2.7	3.3	8.5	10.7

Parameter	Result
$\phi_s^{s\bar{s}s}$ [rad]	$-0.042 \pm 0.075 \pm 0.009$
$\lvert\lambda\rvert$	$1.004 \pm 0.030 \pm 0.009$
$\lvert A_0\rvert^2$	$0.384 \pm 0.007 \pm 0.003$
$\lvert A_\perp\rvert^2$	$0.310 \pm 0.006 \pm 0.003$
$\delta_\parallel - \delta_0$ [rad]	$2.463 \pm 0.029 \pm 0.009$
$\delta_\perp - \delta_0$ [rad]	$2.769 \pm 0.105 \pm 0.011$

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Systematics for $\sin 2\beta$

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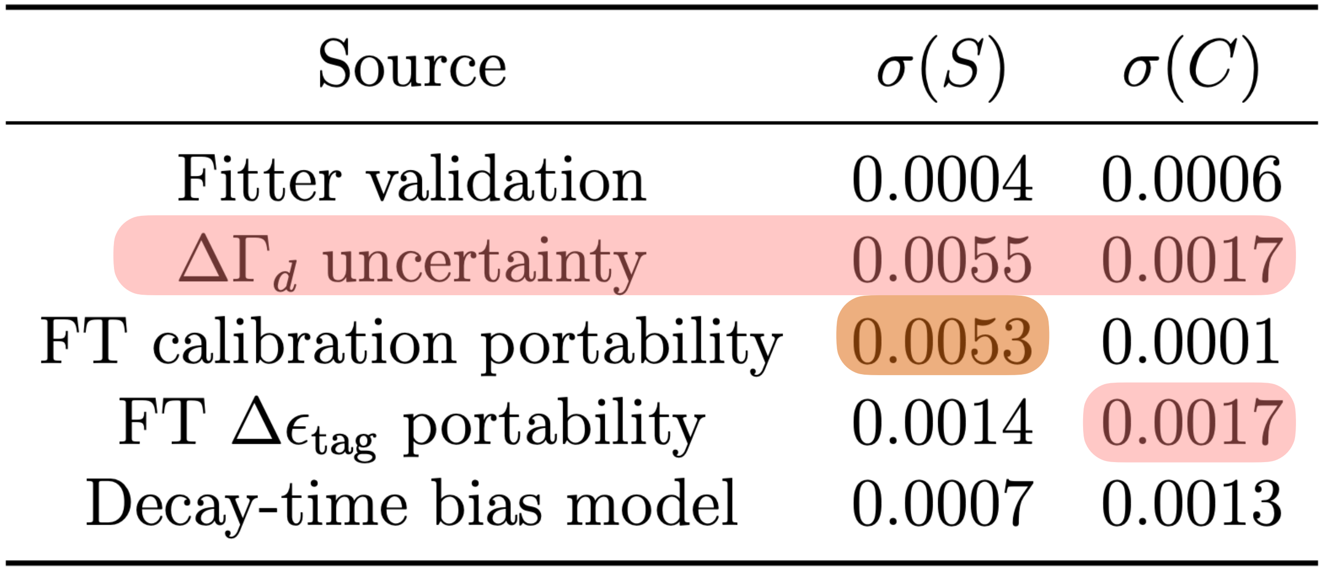
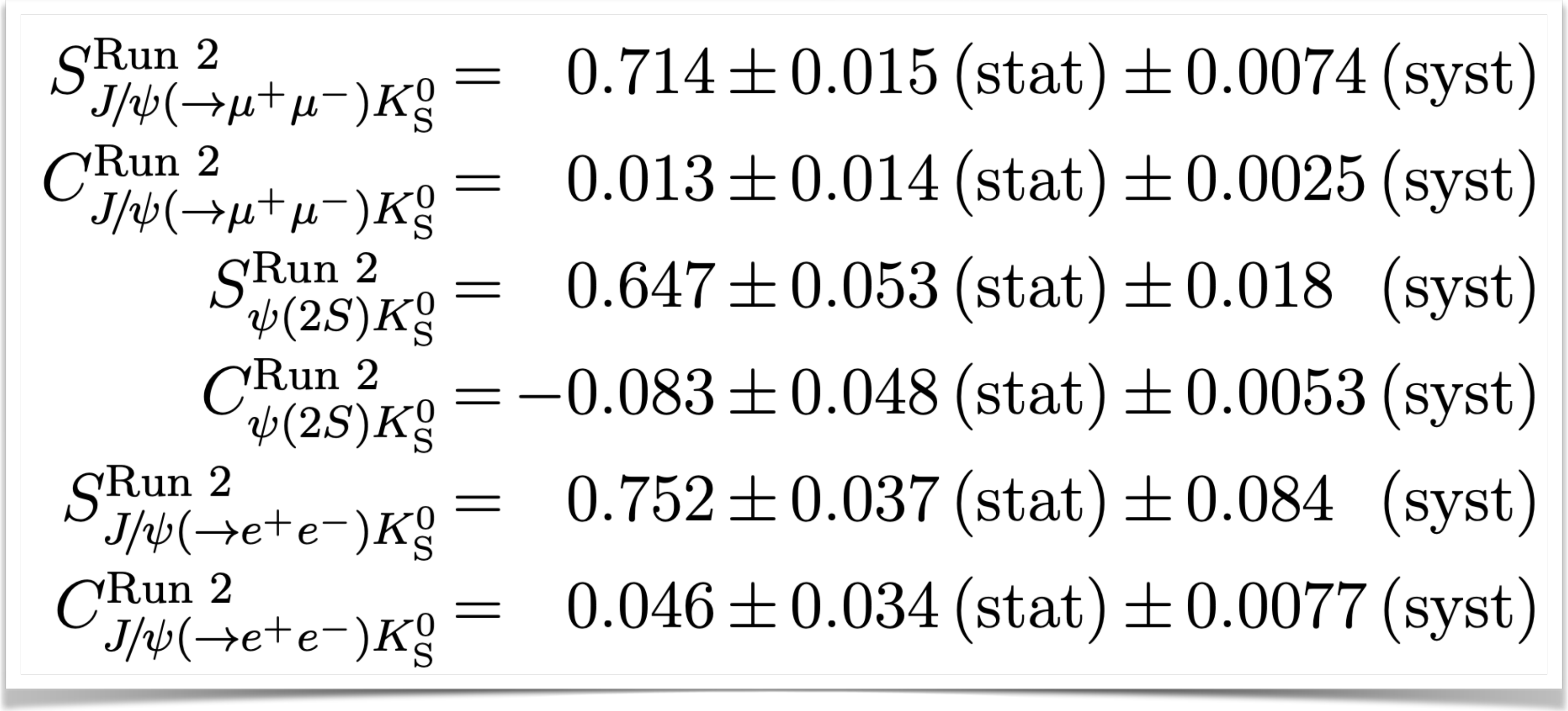


Source	$\sigma(S)$	$\sigma(C)$
Fitter validation	0.0004	0.0006
$\Delta\Gamma_d$ uncertainty	0.0055	0.0017
FT calibration portability	0.0053	0.0001
FT $\Delta\epsilon_{\text{tag}}$ portability	0.0014	0.0017
Decay-time bias model	0.0007	0.0013



$$\begin{aligned}
S^{\text{Run 2}}_{J/\psi(\to\mu^+\mu^-)K^0_{\text{S}}} &= 0.714 \pm 0.015\,(\text{stat}) \pm 0.0074\,(\text{syst})\\
C^{\text{Run 2}}_{J/\psi(\to\mu^+\mu^-)K^0_{\text{S}}} &= 0.013 \pm 0.014\,(\text{stat}) \pm 0.0025\,(\text{syst})\\
S^{\text{Run 2}}_{\psi(2S)K^0_{\text{S}}} &= 0.647 \pm 0.053\,(\text{stat}) \pm 0.018\,(\text{syst})\\
C^{\text{Run 2}}_{\psi(2S)K^0_{\text{S}}} &= -0.083 \pm 0.048\,(\text{stat}) \pm 0.0053\,(\text{syst})\\
S^{\text{Run 2}}_{J/\psi(\to e^+e^-)K^0_{\text{S}}} &= 0.752 \pm 0.037\,(\text{stat}) \pm 0.084\,(\text{syst})\\
C^{\text{Run 2}}_{J/\psi(\to e^+e^-)K^0_{\text{S}}} &= 0.046 \pm 0.034\,(\text{stat}) \pm 0.0077\,(\text{syst})
\end{aligned}$$

Time-dependent angular fit

EPJC79(2019)706

$$\mathscr{P}(t, \theta_K, \theta_\mu, \phi_h \,|\, \delta_t) \propto \sum_{k=1}^{10} N_k h_k(t) f_k(\theta_K, \theta_\mu, \phi_h) \quad \rightarrow \phi_s, \Delta m_s, \Delta\Gamma_s, \Gamma_s - \Gamma_d$$

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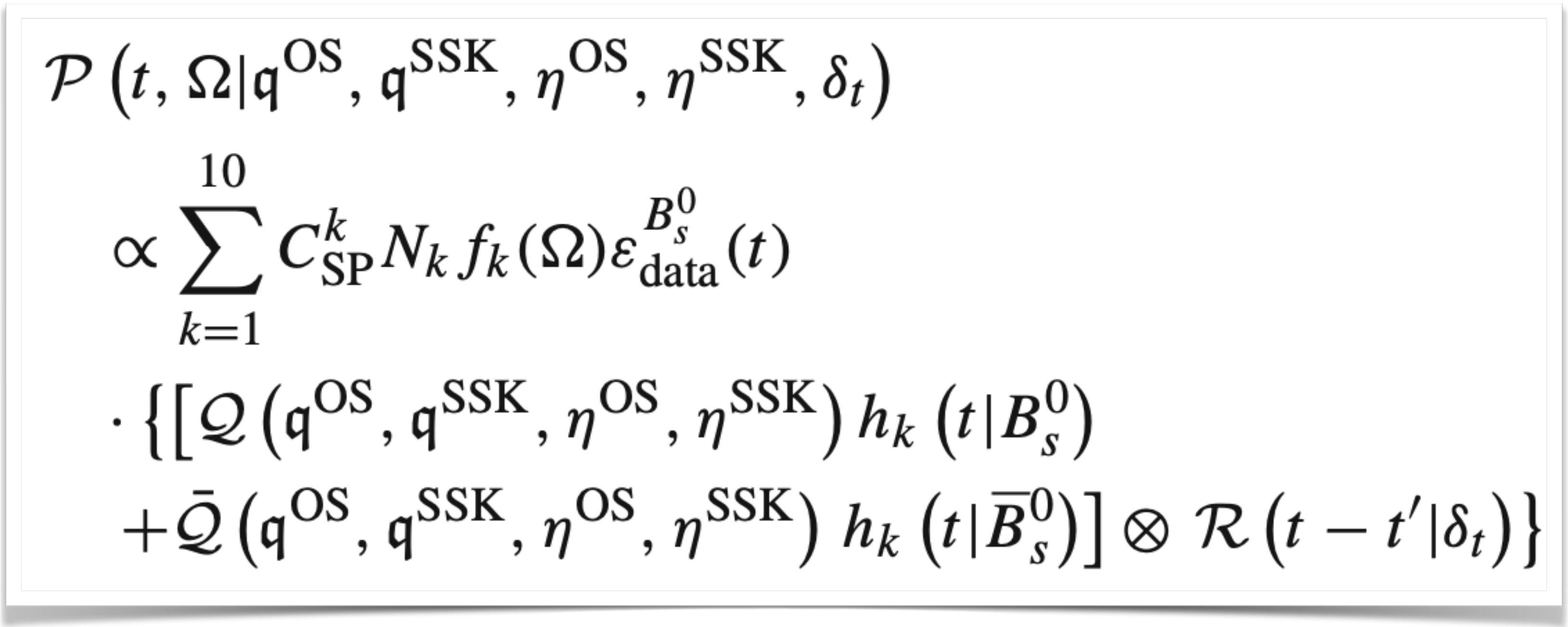

$$\begin{aligned}&\mathcal{P}\left(t,\Omega|\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\delta_t\right)\\ &\quad\propto \sum_{k=1}^{10} C_{\mathrm{SP}}^{k} N_k f_k(\Omega)\varepsilon_{\mathrm{data}}^{B_s^0}(t)\\ &\quad\cdot\left\{\left[\mathcal{Q}\left(\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|B_s^0\right)\right.\right.\\ &\quad\left.\left.+\bar{\mathcal{Q}}\left(\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|\overline{B}_s^0\right)\right]\otimes\mathcal{R}\left(t-t'|\delta_t\right)\right\}\end{aligned}$$

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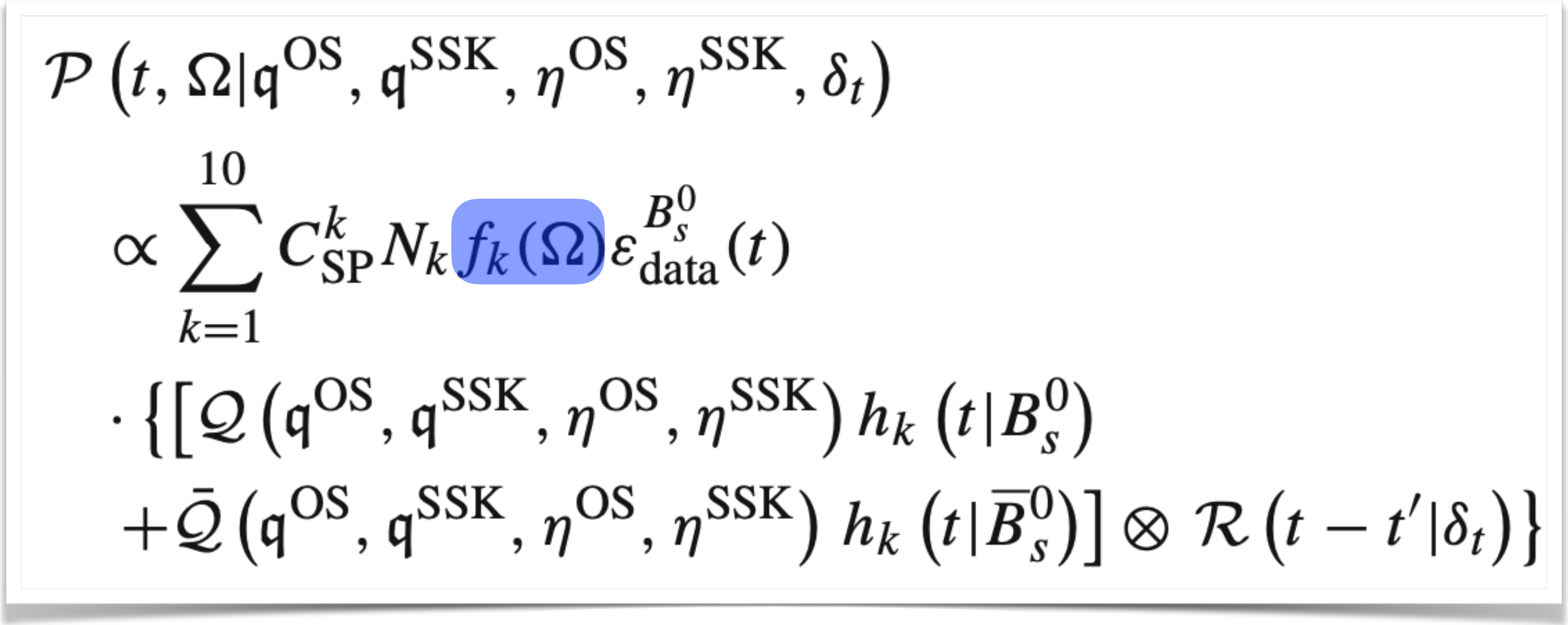

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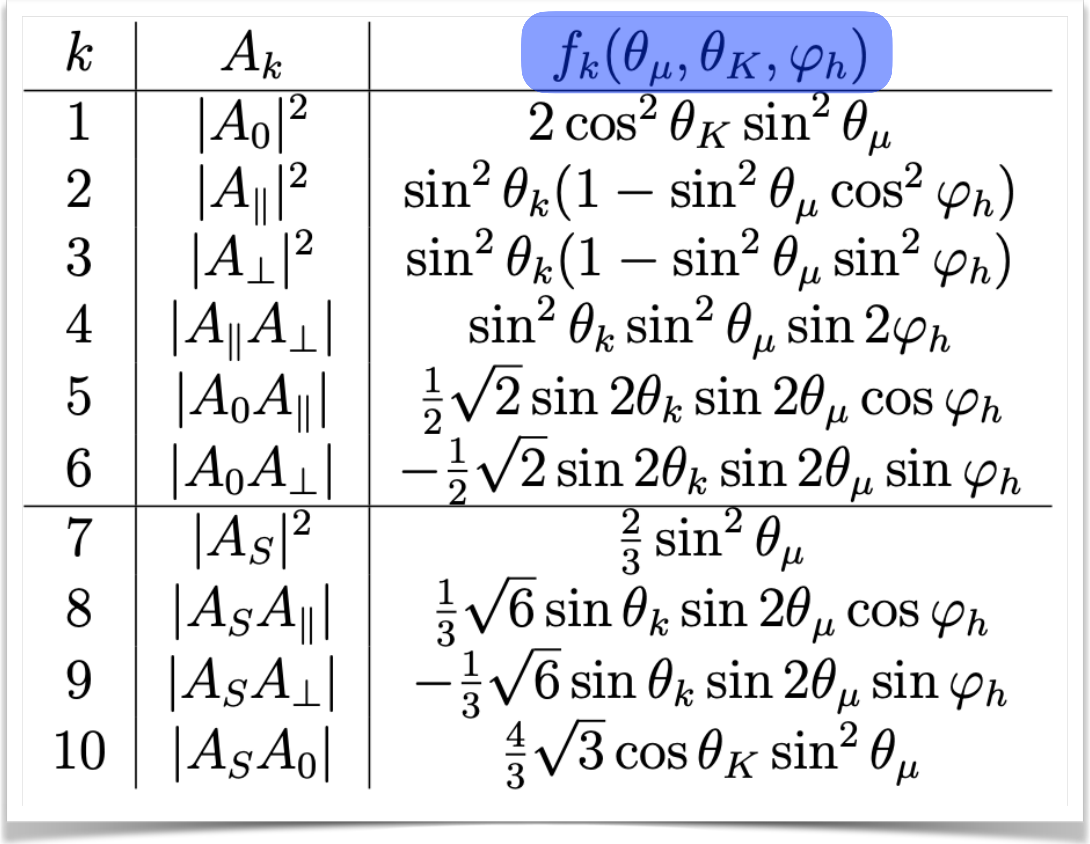
Angular amplitudes

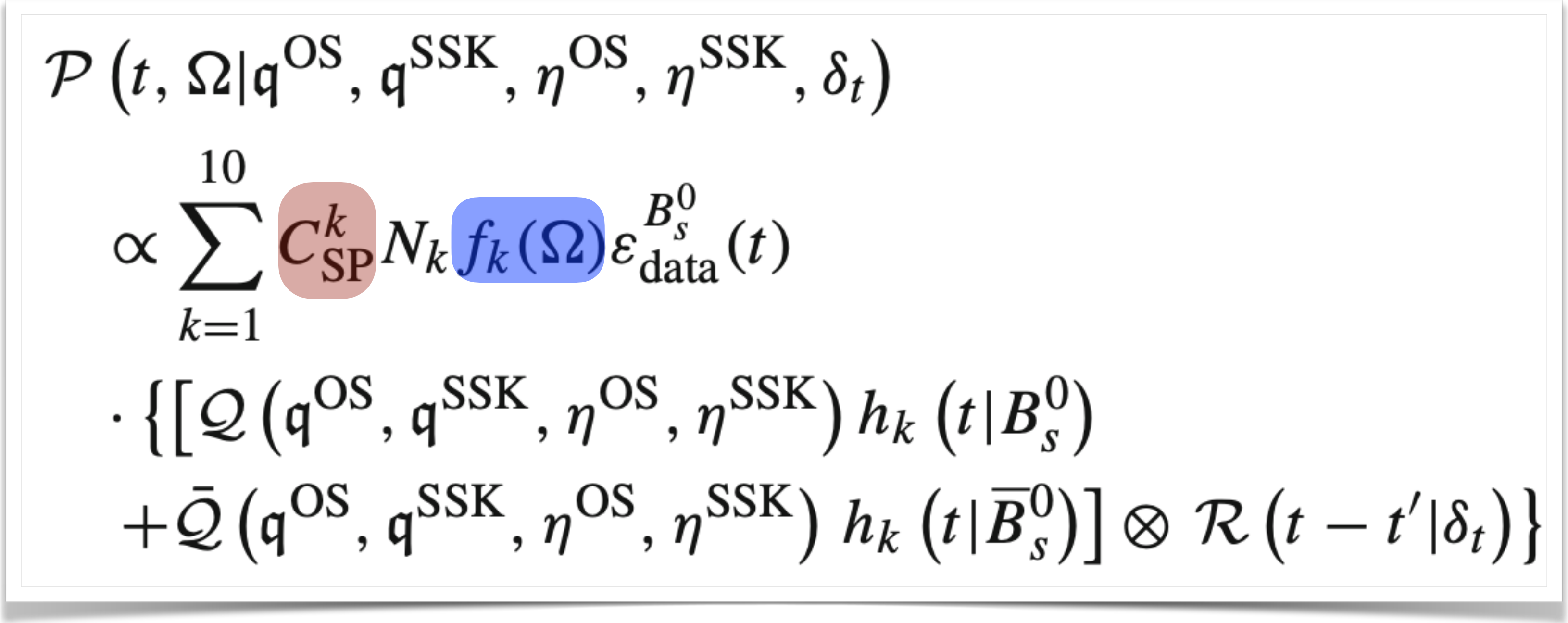


k	A_k	$f_k(\theta_\mu,\theta_K,\varphi_h)$
1	$\lvert A_0\rvert^2$	$2\cos^2\theta_K\sin^2\theta_\mu$
2	$\lvert A_\parallel\rvert^2$	$\sin^2\theta_k(1-\sin^2\theta_\mu\cos^2\varphi_h)$
3	$\lvert A_\perp\rvert^2$	$\sin^2\theta_k(1-\sin^2\theta_\mu\sin^2\varphi_h)$
4	$\lvert A_\parallel A_\perp\rvert$	$\sin^2\theta_k\sin^2\theta_\mu\sin 2\varphi_h$
5	$\lvert A_0 A_\parallel\rvert$	$\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\cos\varphi_h$
6	$\lvert A_0 A_\perp\rvert$	$-\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\sin\varphi_h$
7	$\lvert A_S\rvert^2$	$\frac{2}{3}\sin^2\theta_\mu$
8	$\lvert A_S A_\parallel\rvert$	$\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\cos\varphi_h$
9	$\lvert A_S A_\perp\rvert$	$-\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\sin\varphi_h$
10	$\lvert A_S A_0\rvert$	$\frac{4}{3}\sqrt{3}\cos\theta_K\sin^2\theta_\mu$

Time-dependent angular fit

EPJC79(2019)706

$$\mathscr{P}(t,\theta_K,\theta_\mu,\phi_h\,|\,\delta_t) \propto \sum_{k=1}^{10} N_k h_k(t) f_k(\theta_K,\theta_\mu,\phi_h) \;\rightarrow \phi_s,\ \Delta m_s,\ \Delta\Gamma_s,\ \Gamma_s-\Gamma_d$$



$$\mathcal{P}\left(t,\Omega|\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\delta_t\right)$$
$$\propto \sum_{k=1}^{10} C_{\mathrm{SP}}^{k} N_k f_k(\Omega)\varepsilon_{\mathrm{data}}^{B_s^0}(t)$$
$$\cdot\left\{\left[\mathcal{Q}\left(\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|B_s^0\right)\right.\right.$$
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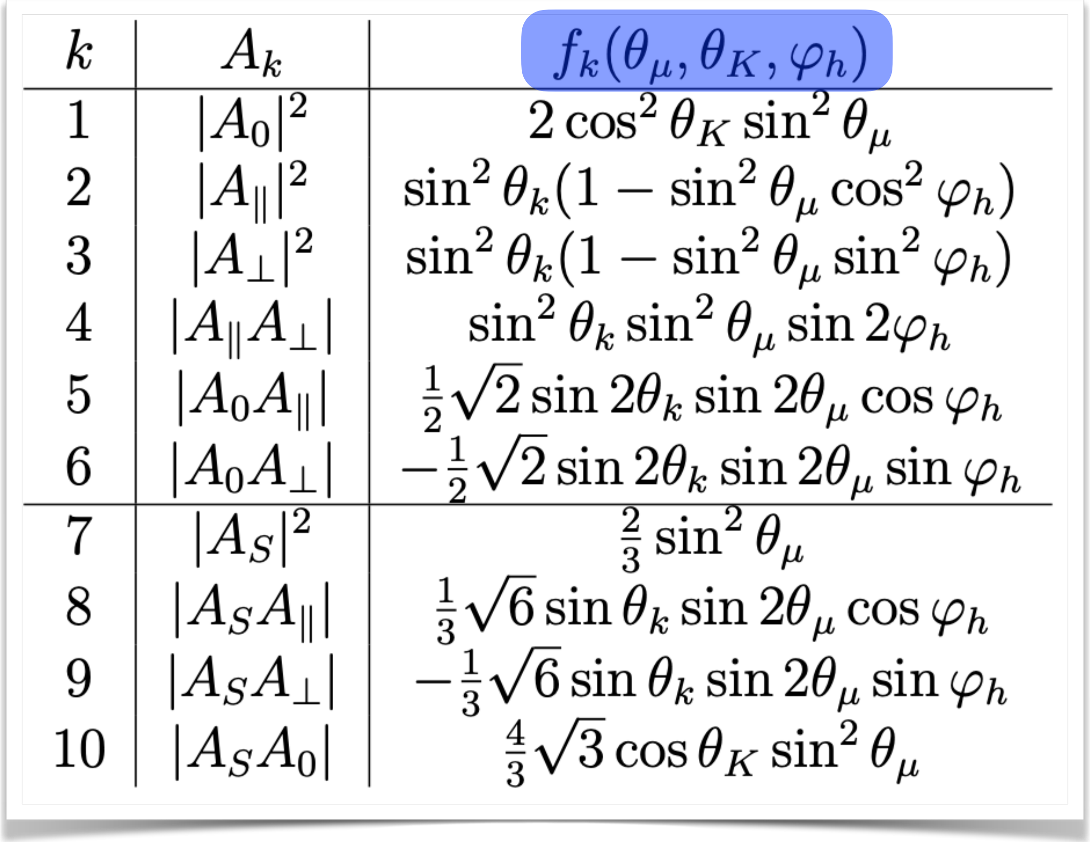
Angular amplitudes

C_{SP}^{k} account for the interference between P- and S- wave



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5	$\lvert A_0 A_\parallel\rvert$	$\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\cos\varphi_h$
6	$\lvert A_0 A_\perp\rvert$	$-\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\sin\varphi_h$
7	$\lvert A_S\rvert^2$	$\frac{2}{3}\sin^2\theta_\mu$
8	$\lvert A_S A_\parallel\rvert$	$\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\cos\varphi_h$
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Time-dependent angular fit

EPJC79(2019)706

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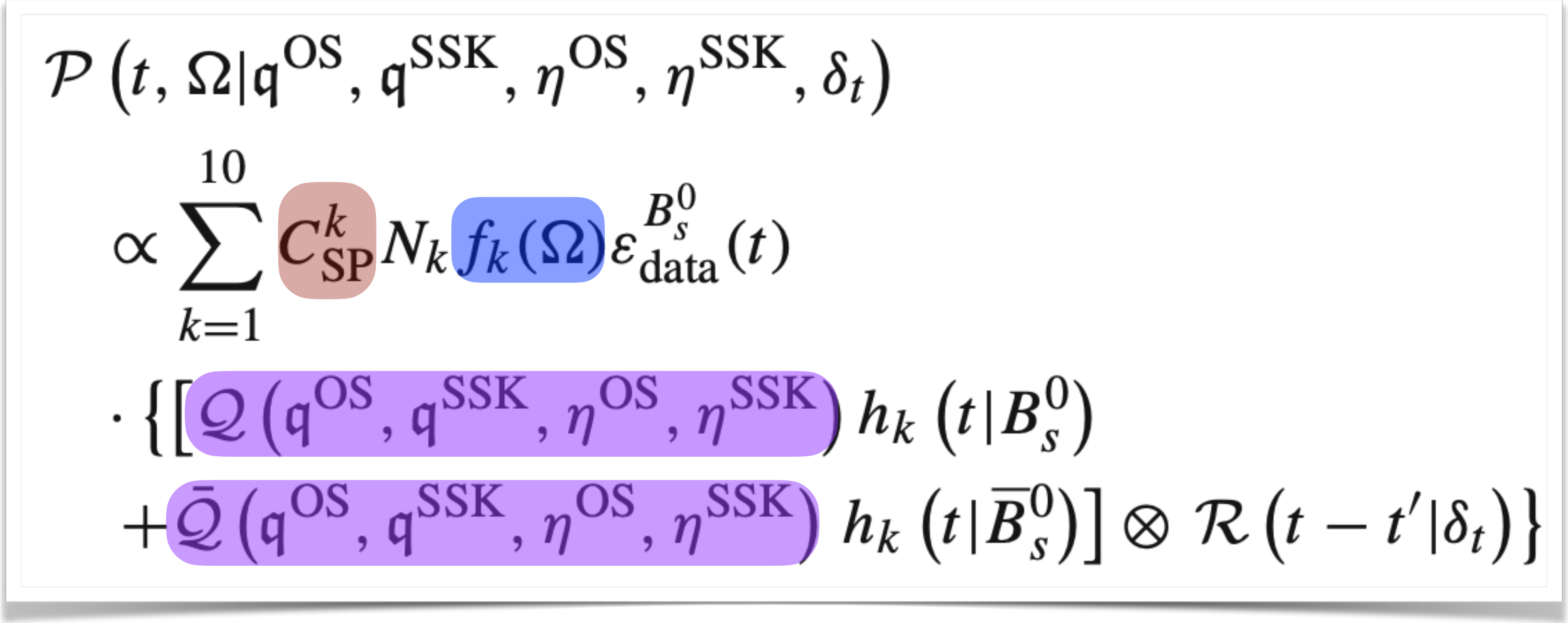

$$\mathcal{P}\left(t,\Omega|\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\delta_t\right)$$
$$\propto \sum_{k=1}^{10} C^k_{\mathrm{SP}} N_k f_k(\Omega)\,\varepsilon^{B^0_s}_{\mathrm{data}}(t)$$
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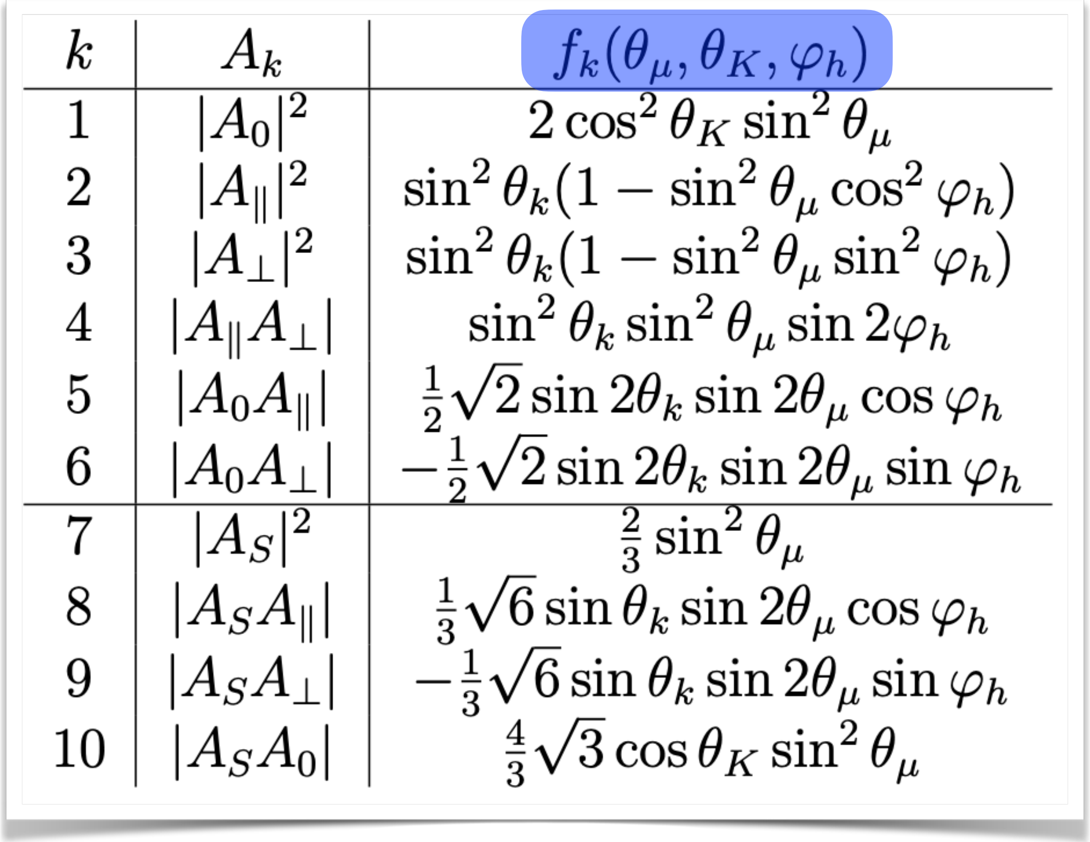
C^k_{SP} account for the interference between P- and S- wave

flavor tagging



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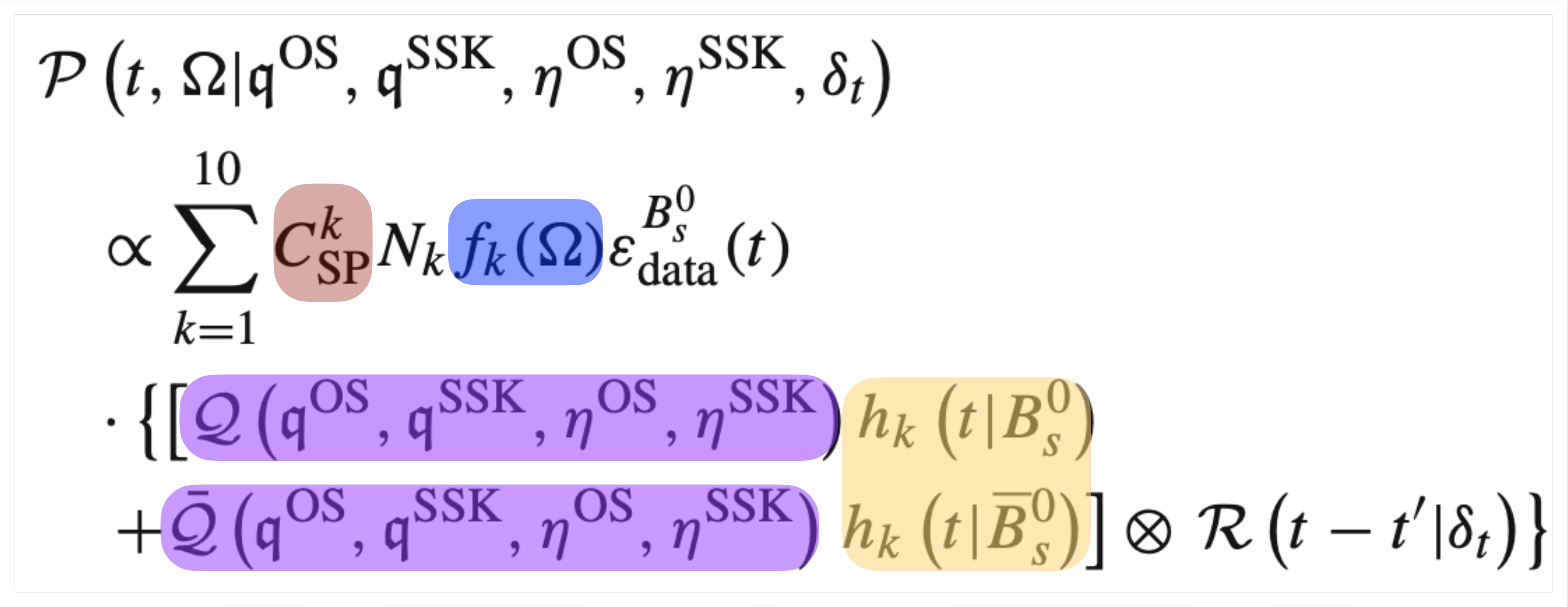
6	$\lvert A_0 A_\perp\rvert$	$-\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\sin\varphi_h$
7	$\lvert A_S\rvert^2$	$\frac{2}{3}\sin^2\theta_\mu$
8	$\lvert A_S A_\parallel\rvert$	$\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\cos\varphi_h$
9	$\lvert A_S A_\perp\rvert$	$-\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\sin\varphi_h$
10	$\lvert A_S A_0\rvert$	$\frac{4}{3}\sqrt{3}\cos\theta_K\sin^2\theta_\mu$

Time-dependent angular fit

EPJC79(2019)706

$$\mathscr{P}(t,\theta_K,\theta_\mu,\phi_h\,|\,\delta_t) \propto \sum_{k=1}^{10} N_k h_k(t) f_k(\theta_K,\theta_\mu,\phi_h) \;\rightarrow\; \phi_s,\ \Delta m_s,\ \Delta\Gamma_s,\ \Gamma_s-\Gamma_d$$



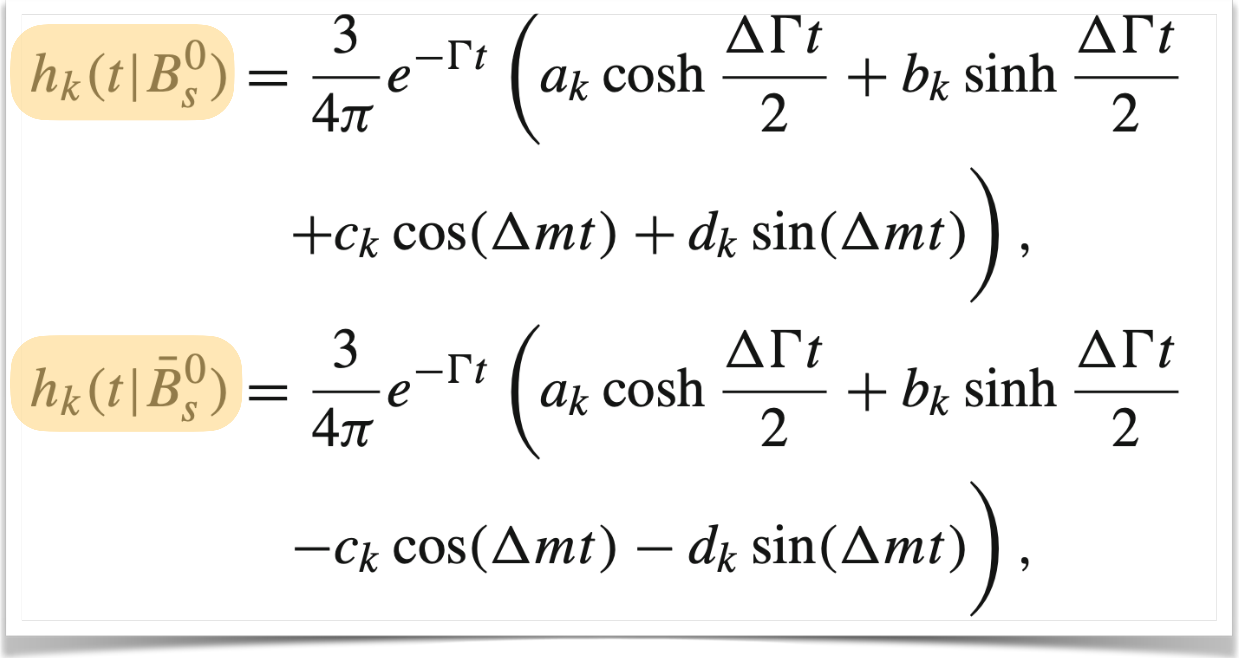
$$\mathcal{P}\left(t,\Omega|\mathrm{q}^{\mathrm{OS}},\mathrm{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\delta_t\right)$$
$$\propto \sum_{k=1}^{10} C_{\mathrm{SP}}^{k} N_k f_k(\Omega)\varepsilon_{\mathrm{data}}^{B_s^0}(t)$$
$$\cdot\left\{\left[\mathcal{Q}\left(\mathrm{q}^{\mathrm{OS}},\mathrm{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|B_s^0\right)\right.\right.$$
$$\left.\left.+\bar{\mathcal{Q}}\left(\mathrm{q}^{\mathrm{OS}},\mathrm{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|\bar{B}_s^0\right)\right]\otimes\mathcal{R}\left(t-t'|\delta_t\right)\right\}$$

Angular amplitudes

C_{SP}^{k} account for the interference between P- and S- wave

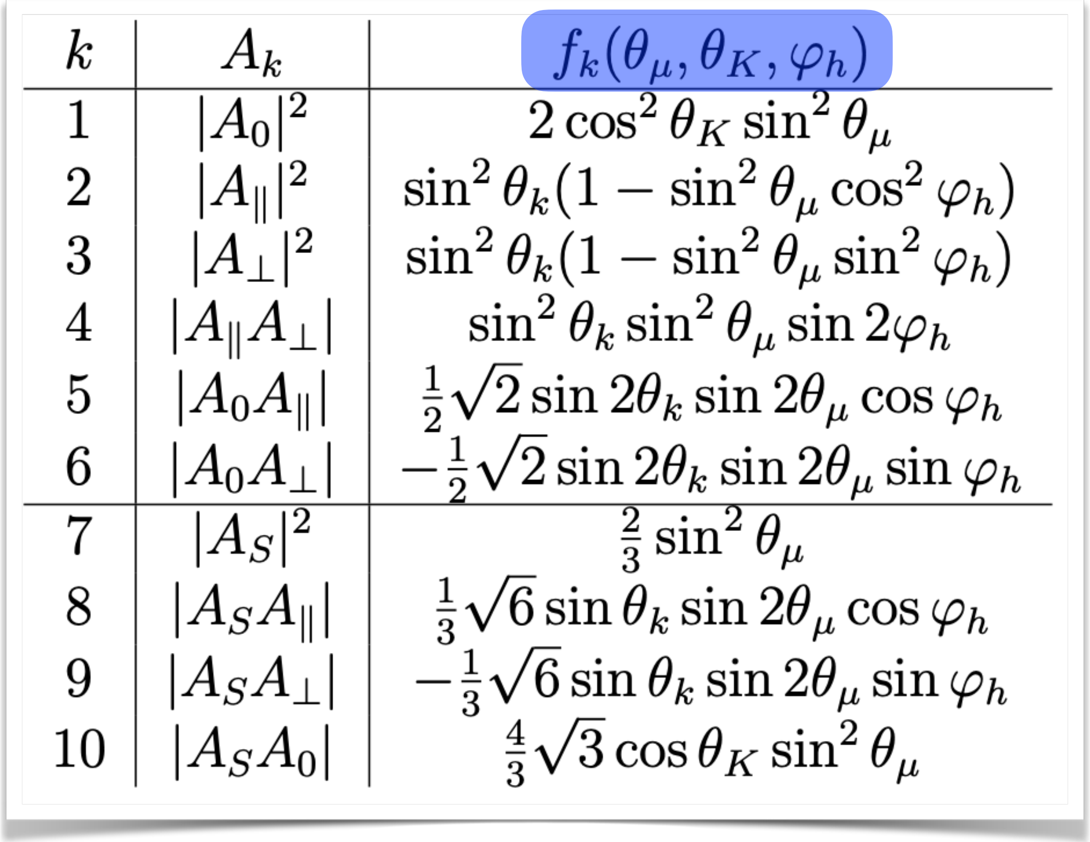
flavor tagging

time-dependent oscillation



$$h_k(t|B_s^0) = \frac{3}{4\pi}e^{-\Gamma t}\left(a_k\cosh\frac{\Delta\Gamma t}{2}+b_k\sinh\frac{\Delta\Gamma t}{2}\right.$$
$$\left.+c_k\cos(\Delta m t)+d_k\sin(\Delta m t)\right),$$
$$h_k(t|\bar{B}_s^0) = \frac{3}{4\pi}e^{-\Gamma t}\left(a_k\cosh\frac{\Delta\Gamma t}{2}+b_k\sinh\frac{\Delta\Gamma t}{2}\right.$$
$$\left.-c_k\cos(\Delta m t)-d_k\sin(\Delta m t)\right),$$

a_k, b_k, c_k, d_k involve strong and weak phases (δ,ϕ_s) of each component

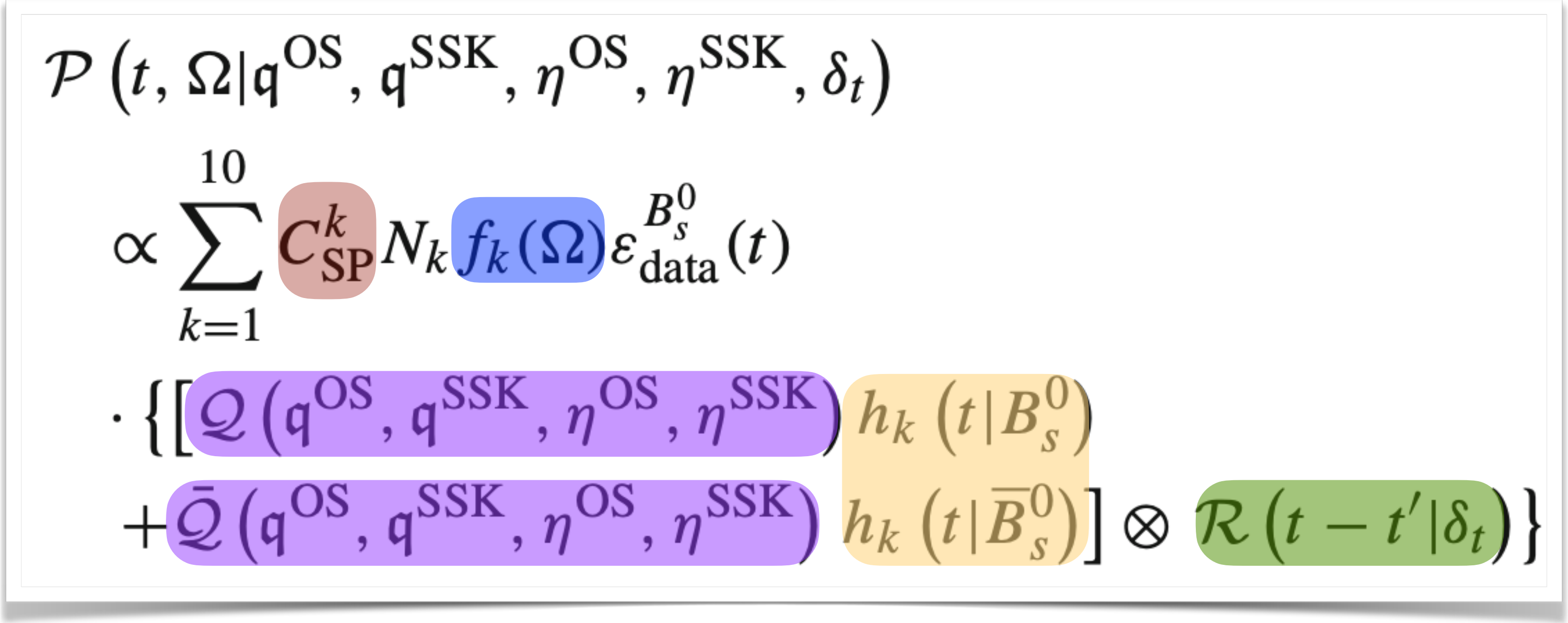


k	A_k	$f_k(\theta_\mu,\theta_K,\varphi_h)$
1	$\|A_0\|^2$	$2\cos^2\theta_K\sin^2\theta_\mu$
2	$\|A_\parallel\|^2$	$\sin^2\theta_k(1-\sin^2\theta_\mu\cos^2\varphi_h)$
3	$\|A_\perp\|^2$	$\sin^2\theta_k(1-\sin^2\theta_\mu\sin^2\varphi_h)$
4	$\|A_\parallel A_\perp\|$	$\sin^2\theta_k\sin^2\theta_\mu\sin 2\varphi_h$
5	$\|A_0 A_\parallel\|$	$\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\cos\varphi_h$
6	$\|A_0 A_\perp\|$	$-\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\sin\varphi_h$
7	$\|A_S\|^2$	$\frac{2}{3}\sin^2\theta_\mu$
8	$\|A_S A_\parallel\|$	$\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\cos\varphi_h$
9	$\|A_S A_\perp\|$	$-\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\sin\varphi_h$
10	$\|A_S A_0\|$	$\frac{4}{3}\sqrt{3}\cos\theta_K\sin^2\theta_\mu$

Time-dependent angular fit

EPJC79(2019)706

$$\mathscr{P}(t,\theta_K,\theta_\mu,\phi_h\,|\,\delta_t) \propto \sum_{k=1}^{10} N_k h_k(t) f_k(\theta_K,\theta_\mu,\phi_h) \;\rightarrow \phi_s,\ \Delta m_s,\ \Delta\Gamma_s,\ \Gamma_s-\Gamma_d$$



$$\begin{aligned}&\mathcal{P}\left(t,\Omega|\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\delta_t\right)\\ &\propto \sum_{k=1}^{10} C^k_{\mathrm{SP}} N_k f_k(\Omega)\varepsilon^{B^0_s}_{\mathrm{data}}(t)\\ &\cdot\left\{\left[\mathcal{Q}\left(\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|B^0_s\right)\right.\right.\\ &\left.\left.+\bar{\mathcal{Q}}\left(\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|\bar{B}^0_s\right)\right]\otimes\mathcal{R}\left(t-t'|\delta_t\right)\right\}\end{aligned}$$

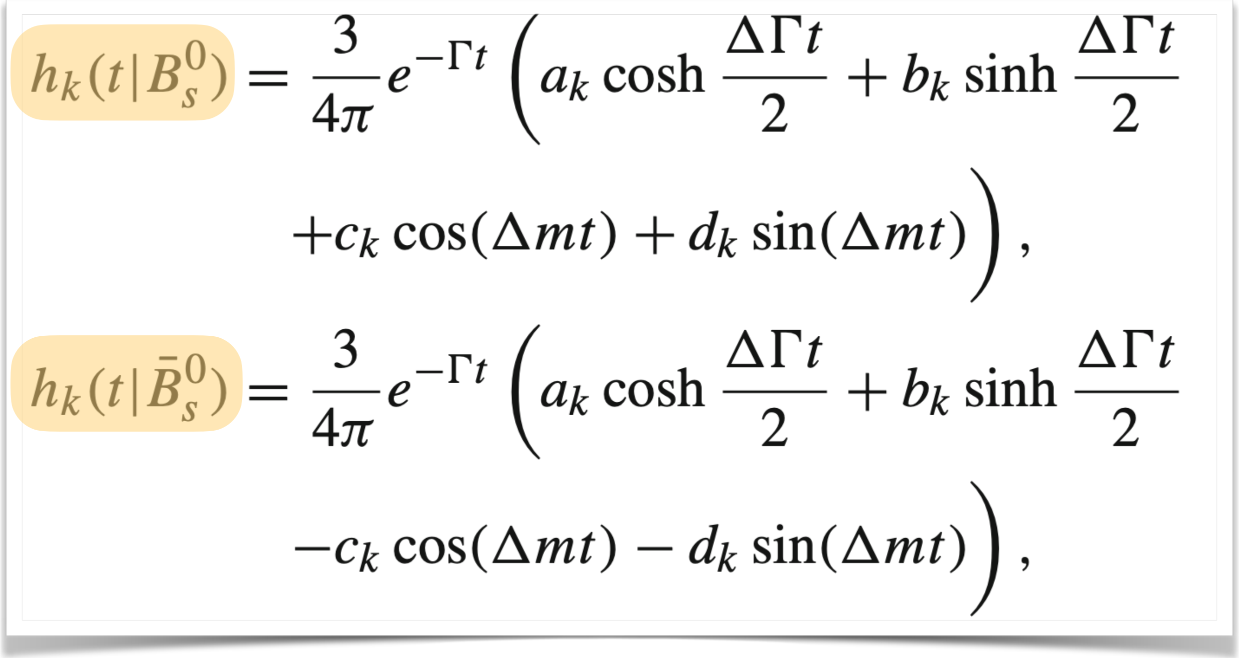
Angular amplitudes

C^k_{SP} account for the interference between P- and S- wave

flavor tagging

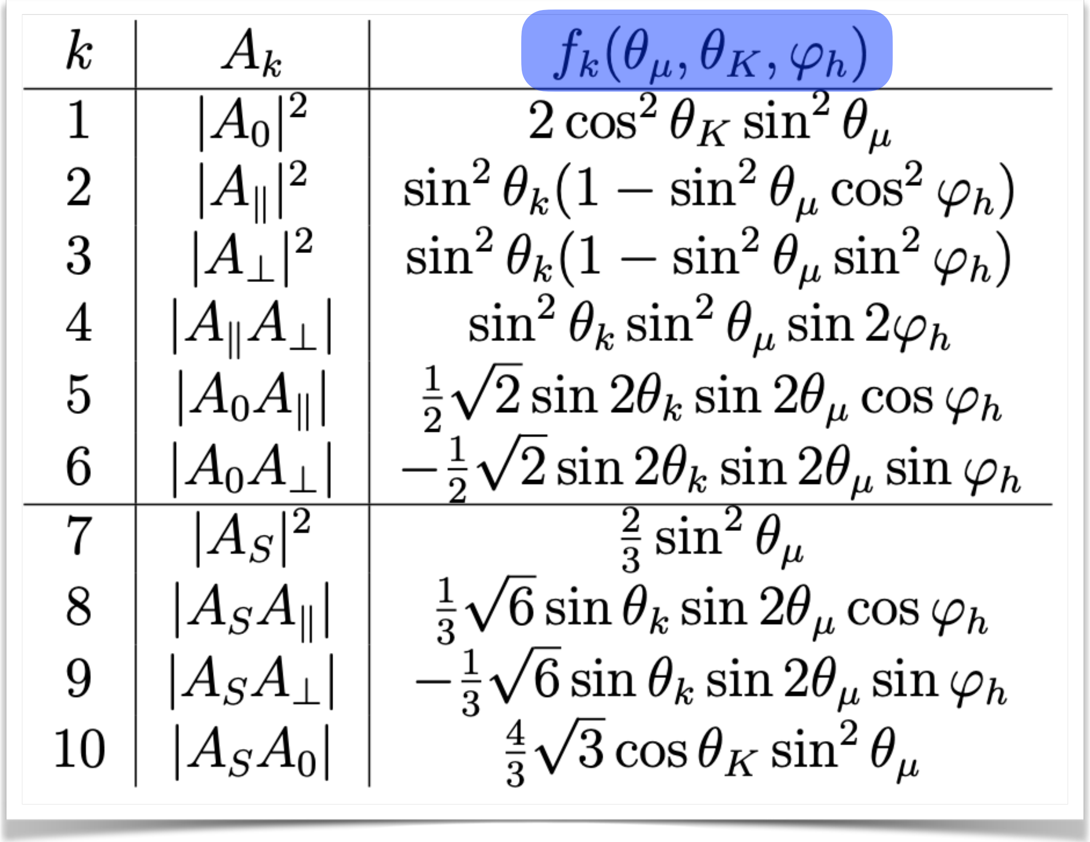
time-dependent oscillation

decay-time resolution



$$h_k(t|B^0_s) = \frac{3}{4\pi}e^{-\Gamma t}\left(a_k\cosh\frac{\Delta\Gamma t}{2}+b_k\sinh\frac{\Delta\Gamma t}{2}\right.$$
$$\left.+c_k\cos(\Delta m t)+d_k\sin(\Delta m t)\right),$$
$$h_k(t|\bar{B}^0_s) = \frac{3}{4\pi}e^{-\Gamma t}\left(a_k\cosh\frac{\Delta\Gamma t}{2}+b_k\sinh\frac{\Delta\Gamma t}{2}\right.$$
$$\left.-c_k\cos(\Delta m t)-d_k\sin(\Delta m t)\right),$$

a_k, b_k, c_k, d_k involve strong and weak phases (δ,ϕ_s) of each component



k	A_k	$f_k(\theta_\mu,\theta_K,\varphi_h)$
1	$\lvert A_0\rvert^2$	$2\cos^2\theta_K\sin^2\theta_\mu$
2	$\lvert A_\parallel\rvert^2$	$\sin^2\theta_k(1-\sin^2\theta_\mu\cos^2\varphi_h)$
3	$\lvert A_\perp\rvert^2$	$\sin^2\theta_k(1-\sin^2\theta_\mu\sin^2\varphi_h)$
4	$\lvert A_\parallel A_\perp\rvert$	$\sin^2\theta_k\sin^2\theta_\mu\sin 2\varphi_h$
5	$\lvert A_0A_\parallel\rvert$	$\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\cos\varphi_h$
6	$\lvert A_0A_\perp\rvert$	$-\frac{1}{2}\sqrt{2}\sin 2\theta_k\sin 2\theta_\mu\sin\varphi_h$
7	$\lvert A_S\rvert^2$	$\frac{2}{3}\sin^2\theta_\mu$
8	$\lvert A_SA_\parallel\rvert$	$\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\cos\varphi_h$
9	$\lvert A_SA_\perp\rvert$	$-\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\sin\varphi_h$
10	$\lvert A_SA_0\rvert$	$\frac{4}{3}\sqrt{3}\cos\theta_K\sin^2\theta_\mu$

Time-dependent angular fit

EPJC79(2019)706

$$\mathscr{P}(t,\theta_K,\theta_\mu,\phi_h\,|\,\delta_t) \propto \sum_{k=1}^{10} N_k h_k(t) f_k(\theta_K,\theta_\mu,\phi_h) \rightarrow \phi_s,\ \Delta m_s,\ \Delta\Gamma_s,\ \Gamma_s-\Gamma_d$$

$$\begin{aligned}
&\mathcal{P}\left(t,\Omega|\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}},\delta_t\right)\\
&\propto \sum_{k=1}^{10} C_{\mathrm{SP}}^{k} N_k f_k(\Omega)\varepsilon_{\mathrm{data}}^{B_s^0}(t)\\
&\cdot\left\{\left[\mathcal{Q}\left(\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|B_s^0\right)\right.\right.\\
&\left.\left.+\bar{\mathcal{Q}}\left(\mathfrak{q}^{\mathrm{OS}},\mathfrak{q}^{\mathrm{SSK}},\eta^{\mathrm{OS}},\eta^{\mathrm{SSK}}\right)h_k\left(t|\bar{B}_s^0\right)\right]\otimes\mathcal{R}\left(t-t'|\delta_t\right)\right\}
\end{aligned}$$

Angular amplitudes

C_{SP}^{k} account for the interference between P- and S- wave

flavor tagging

time-dependent oscillation

decay-time efficiency

decay-time resolution

$$\begin{aligned}
h_k(t|B_s^0) = \frac{3}{4\pi}e^{-\Gamma t}\bigg(&a_k\cosh\frac{\Delta\Gamma t}{2}+b_k\sinh\frac{\Delta\Gamma t}{2}\\
&+c_k\cos(\Delta m t)+d_k\sin(\Delta m t)\bigg),\\
h_k(t|\bar{B}_s^0) = \frac{3}{4\pi}e^{-\Gamma t}\bigg(&a_k\cosh\frac{\Delta\Gamma t}{2}+b_k\sinh\frac{\Delta\Gamma t}{2}\\
&-c_k\cos(\Delta m t)-d_k\sin(\Delta m t)\bigg),
\end{aligned}$$

a_k, b_k, c_k, d_k involve strong and weak phases (δ, ϕ_s) of each component

k	A_k	$f_k(\theta_\mu,\theta_K,\varphi_h)$
1	$\lvert A_0\rvert^2$	$2\cos^2\theta_K\sin^2\theta_\mu$
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4	$\lvert A_\parallel A_\perp\rvert$	$\sin^2\theta_k\sin^2\theta_\mu\sin 2\varphi_h$
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7	$\lvert A_S\rvert^2$	$\frac{2}{3}\sin^2\theta_\mu$
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9	$\lvert A_S A_\perp\rvert$	$-\frac{1}{3}\sqrt{6}\sin\theta_k\sin 2\theta_\mu\sin\varphi_h$
10	$\lvert A_S A_0\rvert$	$\frac{4}{3}\sqrt{3}\cos\theta_K\sin^2\theta_\mu$