Search for New Physics in $B \to K\pi\pi\gamma$ with Belle-II data

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on behalf of the Belle-II collaboration

$b \to s\gamma$ transitions

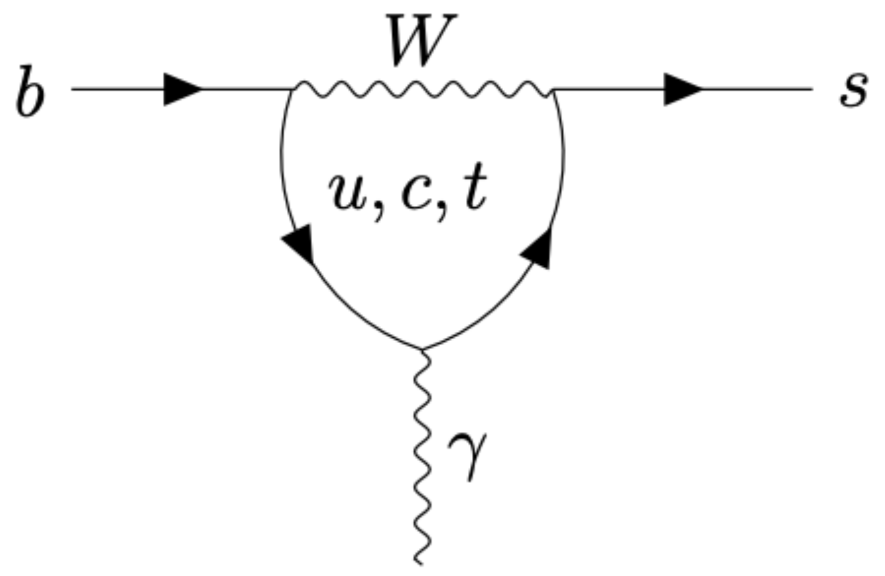
- $b \to s\gamma \Rightarrow$ absence of FCNC at the tree level in the SM $\Rightarrow$ Sensitive to BSM
- **SM photon polarisation:**
  - $b \to s\gamma \Rightarrow$ right-handed (left-handed for $\bar{b}$)

- **Time dependent CP asymmetry :**

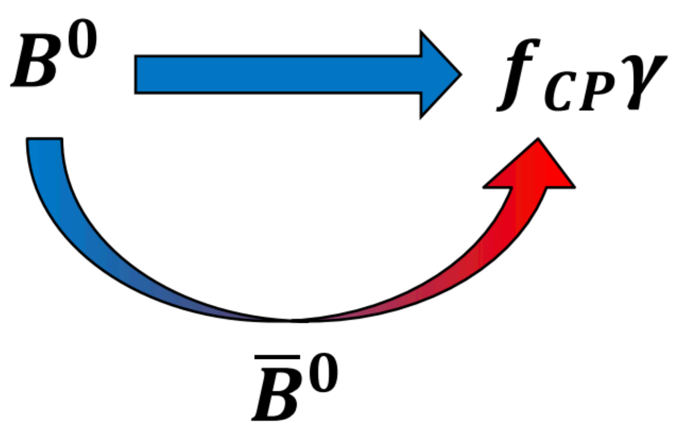
$$\mathcal{A}_{CP}(\Delta t) = \frac{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}\gamma) - \Gamma(B^0(\Delta t) \to f_{CP}\gamma)}{\Gamma(\bar{B}^0(\Delta t) \to f_{CP}\gamma) + \Gamma(B^0(\Delta t) \to f_{CP}\gamma)} = \mathcal{S}\sin(\Delta m \Delta t) - \mathcal{C}\cos(\Delta m \Delta t)$$

$$f_{CP} = K_S^0 \rho^0(\pi^{\pm}\pi^{\mp})$$

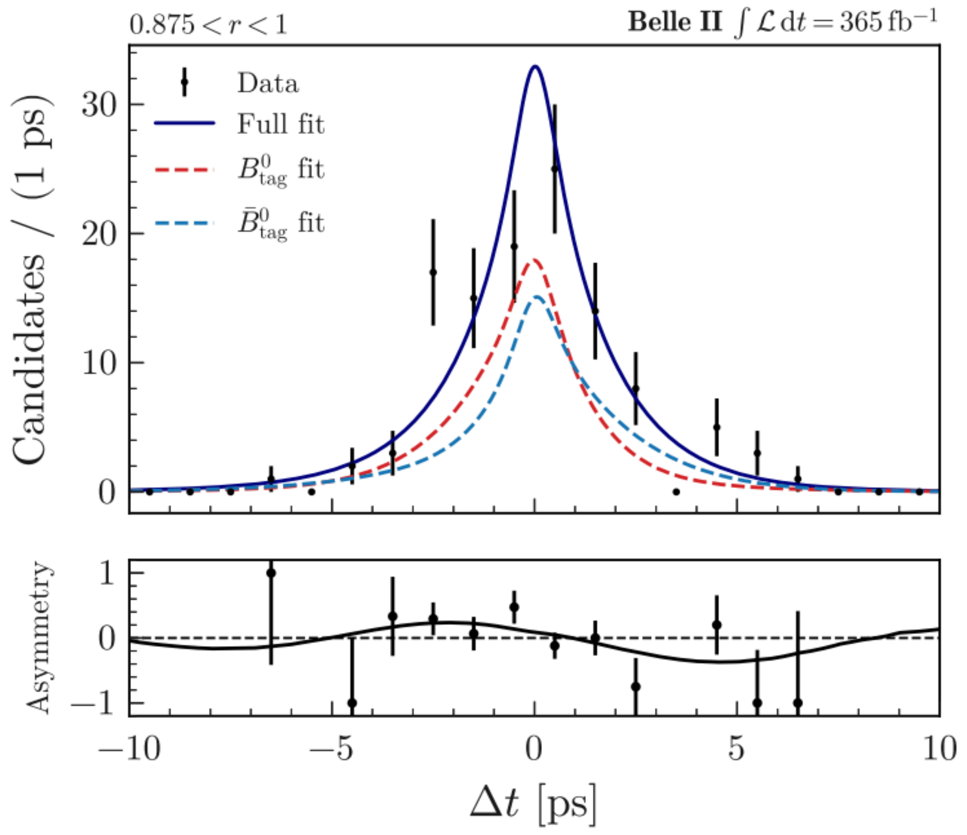
- If $\mathcal{S} \neq 0$, one can expect **BSM contributions**
- **Effective** $\mathcal{S}_{B^0 \to K_s^0 \pi\pi\gamma}$ measured with Belle and Belle-II data: **JHEP01(2026)134**



Penguin diagram for $b \to s\gamma$



CP eigenstate



Time-dependent CP asymmetry

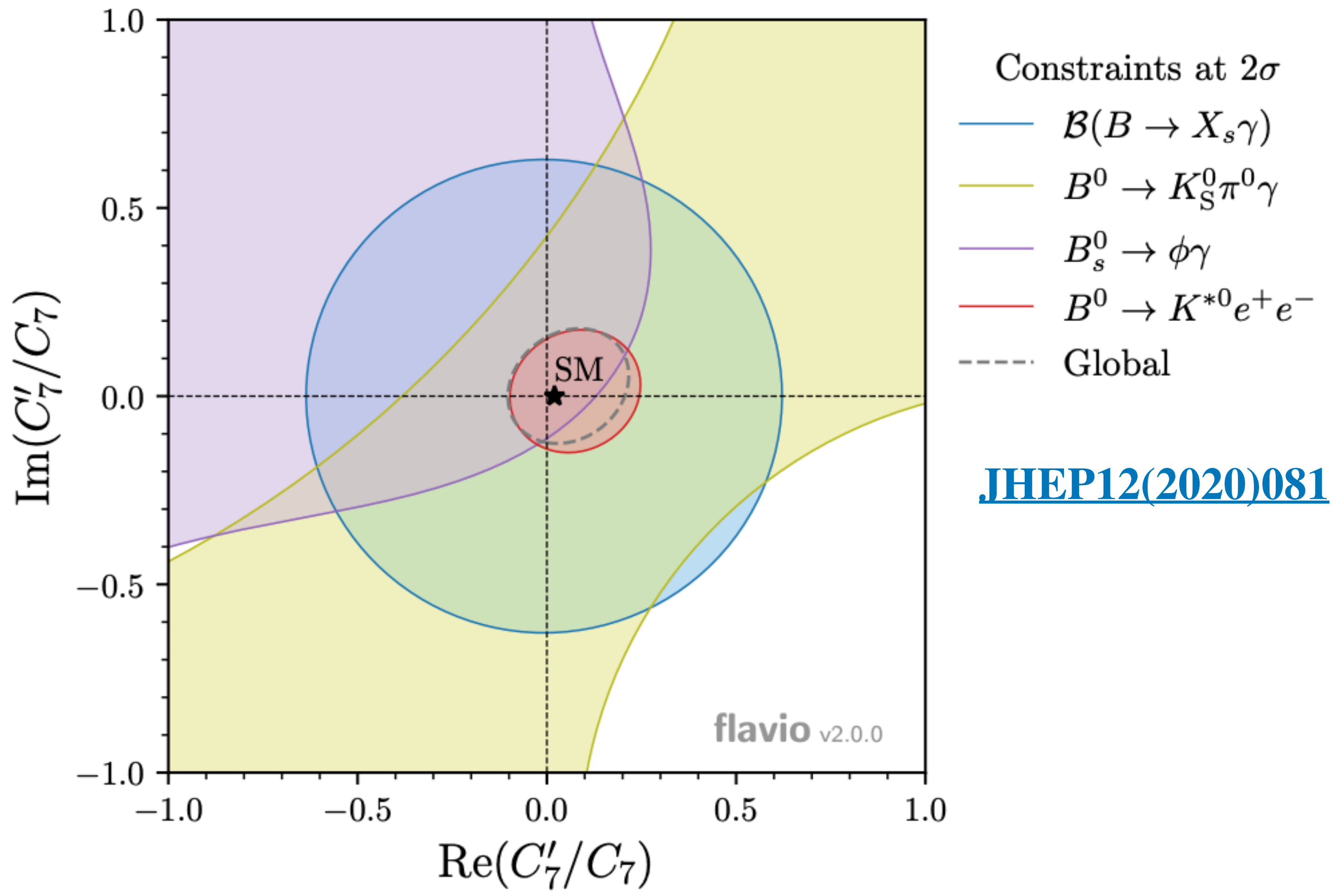
Contributions to the final state

$$\mathcal{S}_{B^0\to K_s^0\pi\pi\gamma} = \mathcal{D}\cdot\mathcal{S}_{f_{CP}}$$

Measured — *Dilution Factor* (Goal)

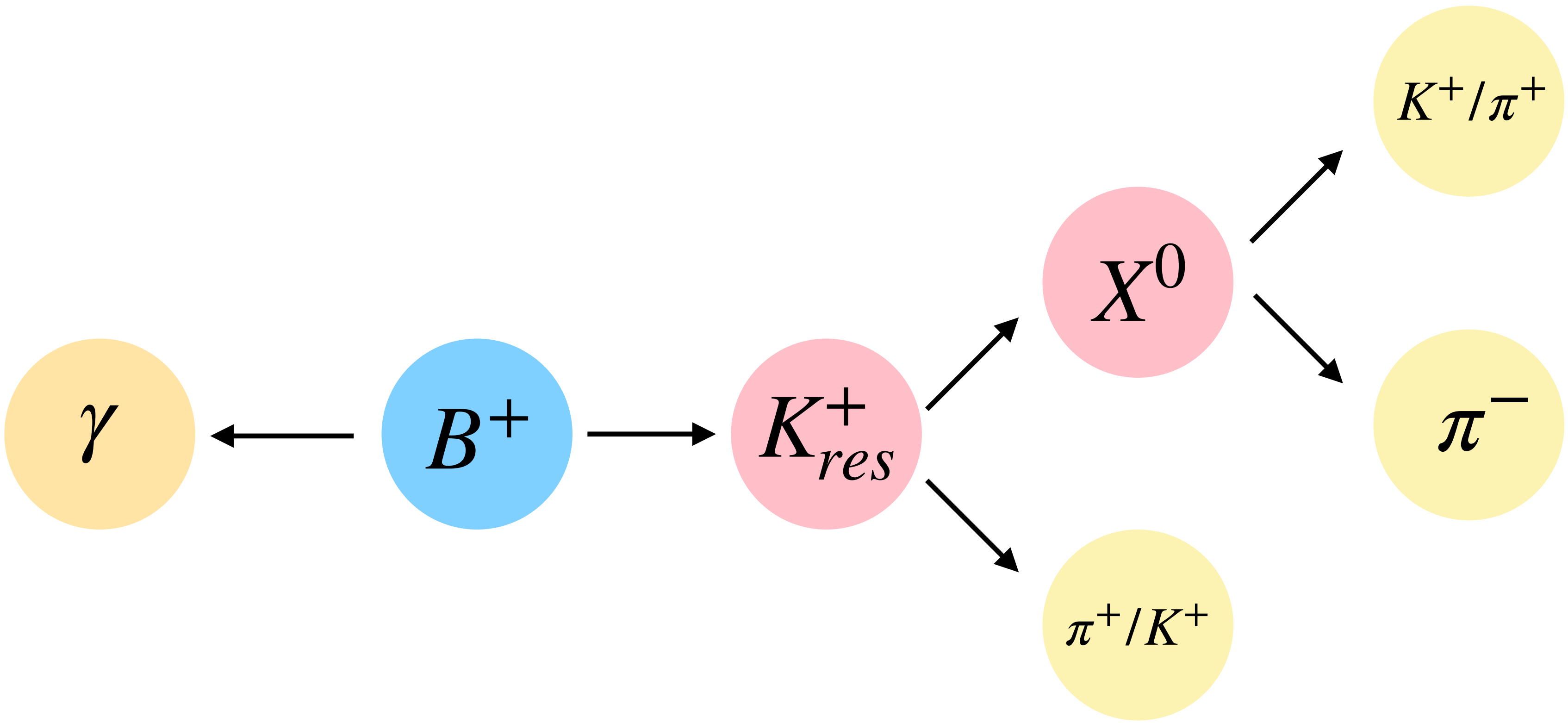
- $\mathcal{D}$ can be measured from the amplitudes of all intermediate contributions (*method in* - JHEP09(2019)034)
- $\mathcal{D}_{K_S^0\rho\gamma} = -0.78^{+0.19}_{-0.17}$ measured with few intermediate resonances [BaBar: 1512.03579]
- Measurement of dilution factor by **amplitude analysis** -
  - Obtain $\mathcal{S}_{f_{(CP)}}$ [marked in red in table]
  - Constrain Wilson co-efficients C_7'/C_7
- **Amplitude analysis** of isospin partner $B^+\to K^+\pi^+\pi^-\gamma$

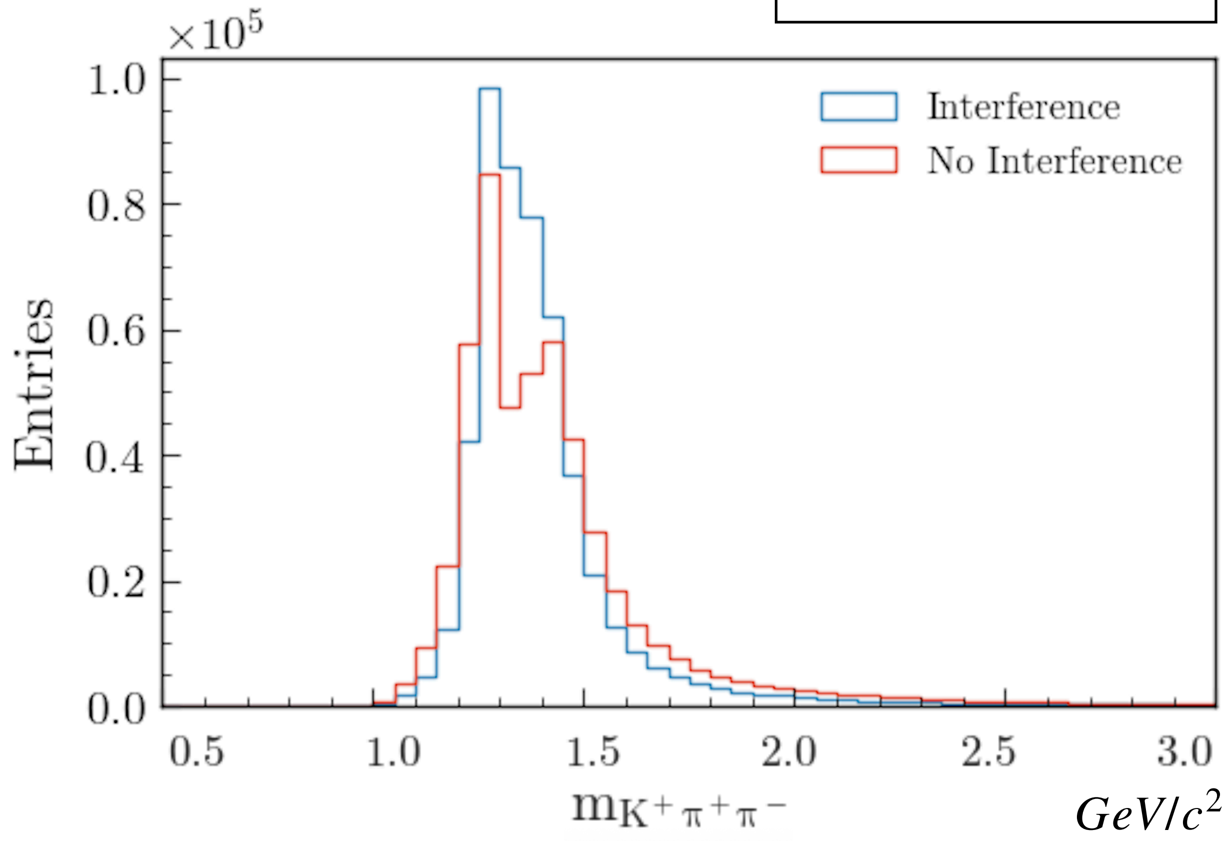
$\mathbf{J^P}$	Decay Mode
1^+	$K_1(1270)^+\to K^*(892)^0\pi^+$
	$K_1(1270)^+\to K^+\rho(770)^0$
	$K_1(1270)^+\to K^+\omega(782)^0$
	$K_1(1270)^+\to K^*(1430)^0\pi^+$
	$K_1(1400)^+\to K^*(892)^0\pi^+$
1^-	$K^*(1410)^+\to K^*(892)^0\pi^+$
	$K^*(1680)^+\to K^*(892)^0\pi^+$
	$K^*(1680)^+\to K^+\rho(770)^0$
2^+	$K_2^*(1430)^+\to K^*(892)^0\pi^+$
	$K_2^*(1430)^+\to K^+\rho(770)^0$
	$K_2^*(1430)^+\to K^+\omega(782)^0$
2^-	$K_2(1770)^+\to K^*(892)^0\pi^+$
	$K_2(1770)^+\to K^+\rho(770)^0$
	$K_2(1770)^+\to K_2^*(1430)^0\pi^+$
	$K_2(1770)^+\to K^+f_2(1270)^0$



JHEP12(2020)081

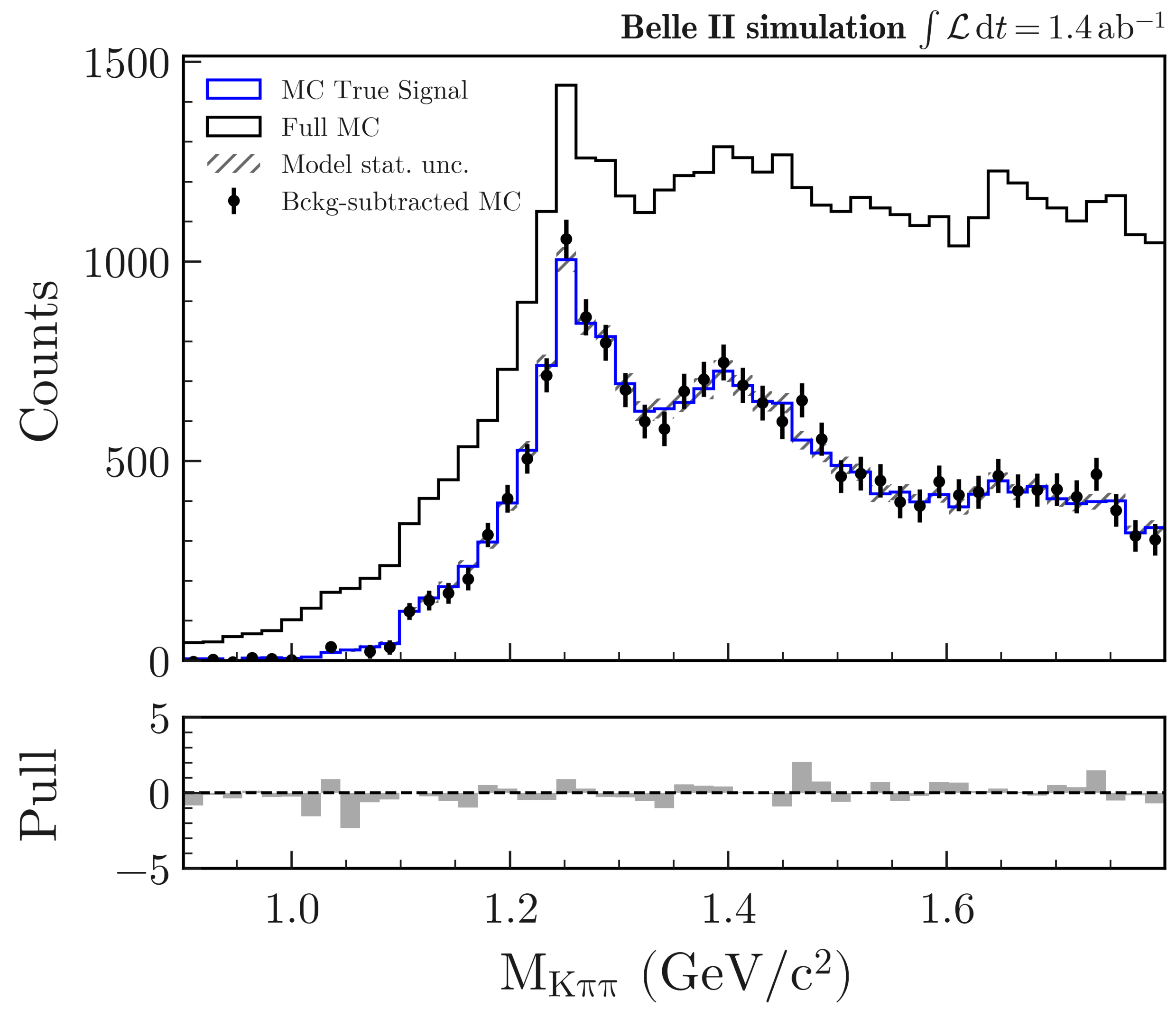
Amplitude study of $B \to K\pi\pi\gamma$





Effect of Interference in -
$K_1(1270) \to K^*(892)^0\pi^+$
$K_1(1400) \to K^*(892)^0\pi^+$

- First study in Belle-II, including interference and the proper angular structure of the decays.
  - Generation based on **AmpGen** with isobar decay model
- Same event reconstruction and selection as the published Belle II measurement for $\mathcal{S}_{B^0 \to K^0_S\pi\pi\gamma}$ - **JHEP09(2019)034**
- Background-subtracted distributions produced with **sPlot** based on $\Delta E = \frac{(p_B p_{e^+e^-} - s)}{2\sqrt{s}}$ discriminating variable



Background subtraction with sPlot (on Belle-II generic MC)

Fit model

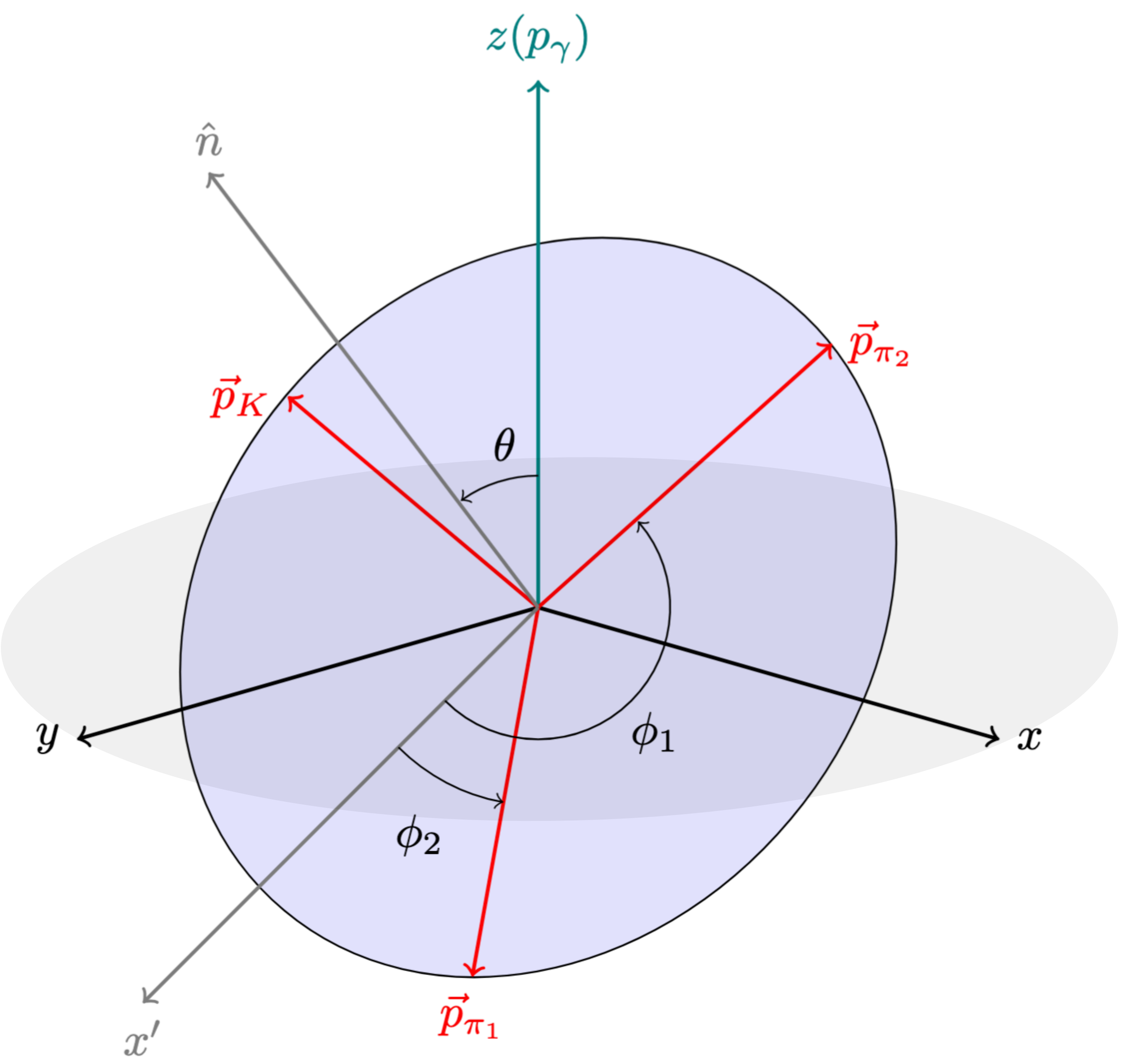
$$\mathcal{A}_{total}(P) = \sum_i a_i\, e^{-i\delta_i}\, \mathcal{A}_i(P)$$

5 fit variables: $\{m_{K^+\pi^+\pi^-},\ m_{K^+\pi^-},\ m_{\pi^+\pi^-},\ \cos\theta, \phi\}$

Note: $\phi = \frac{1}{2}(\phi_1 + \phi_2)$

$$\mathcal{A}(P) = S_B \cdot B_{L_B} \cdot T_{K_{res}} \cdot S_{K_{res}} \cdot B_{L_{K_{res}}} \cdot T_X \cdot S_X \cdot B_{L_X}$$

- *Angular momentum factors* $\Rightarrow S_i$
- *Barrier factors* $\Rightarrow B_i$
- *Lineshapes* $\Rightarrow T_i$
- S_B includes *radiative corrections*.
- $S_{K_{res}}$ are obtained from *tensor formalism*.

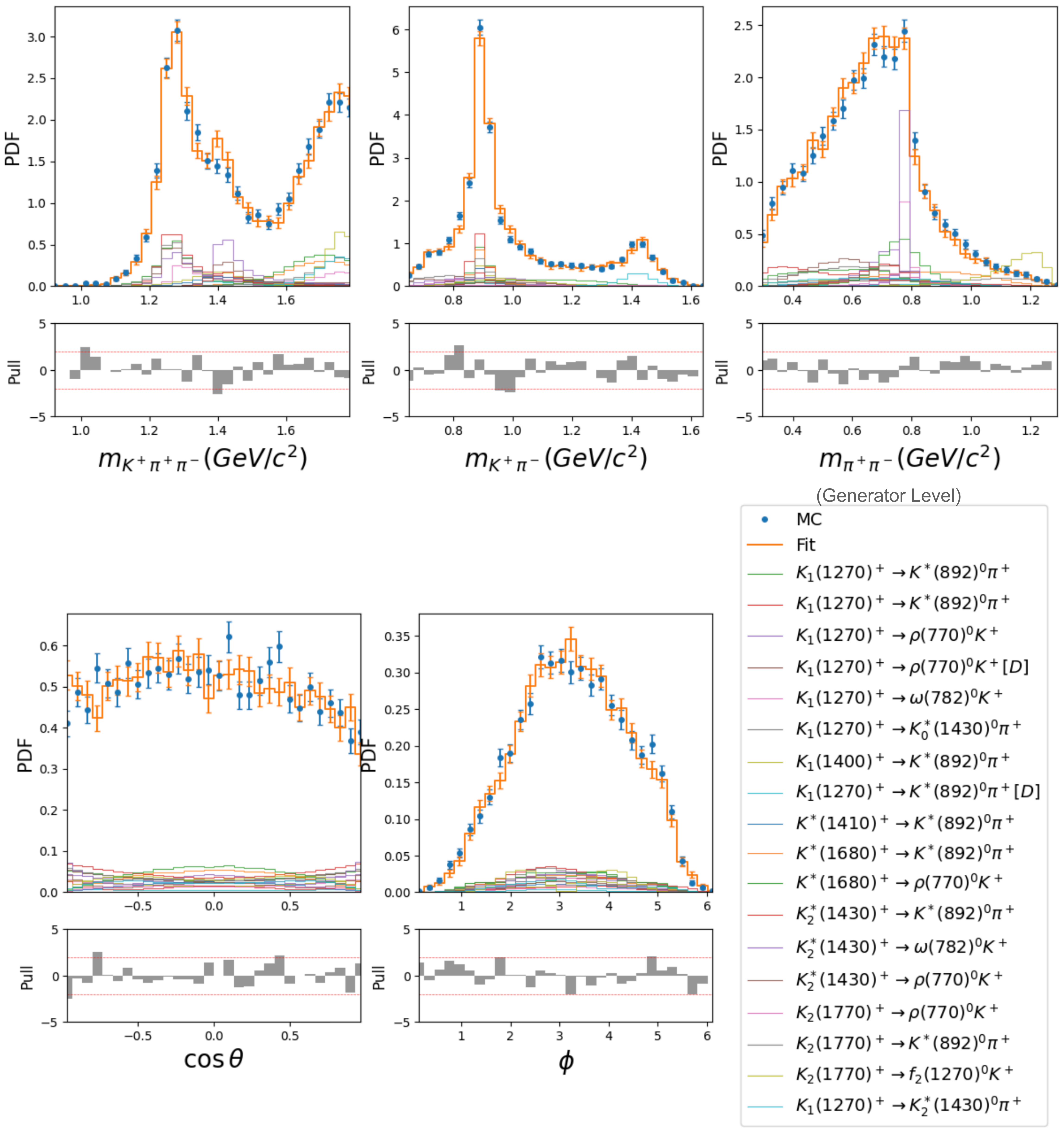


Decay kinematics

Fit example

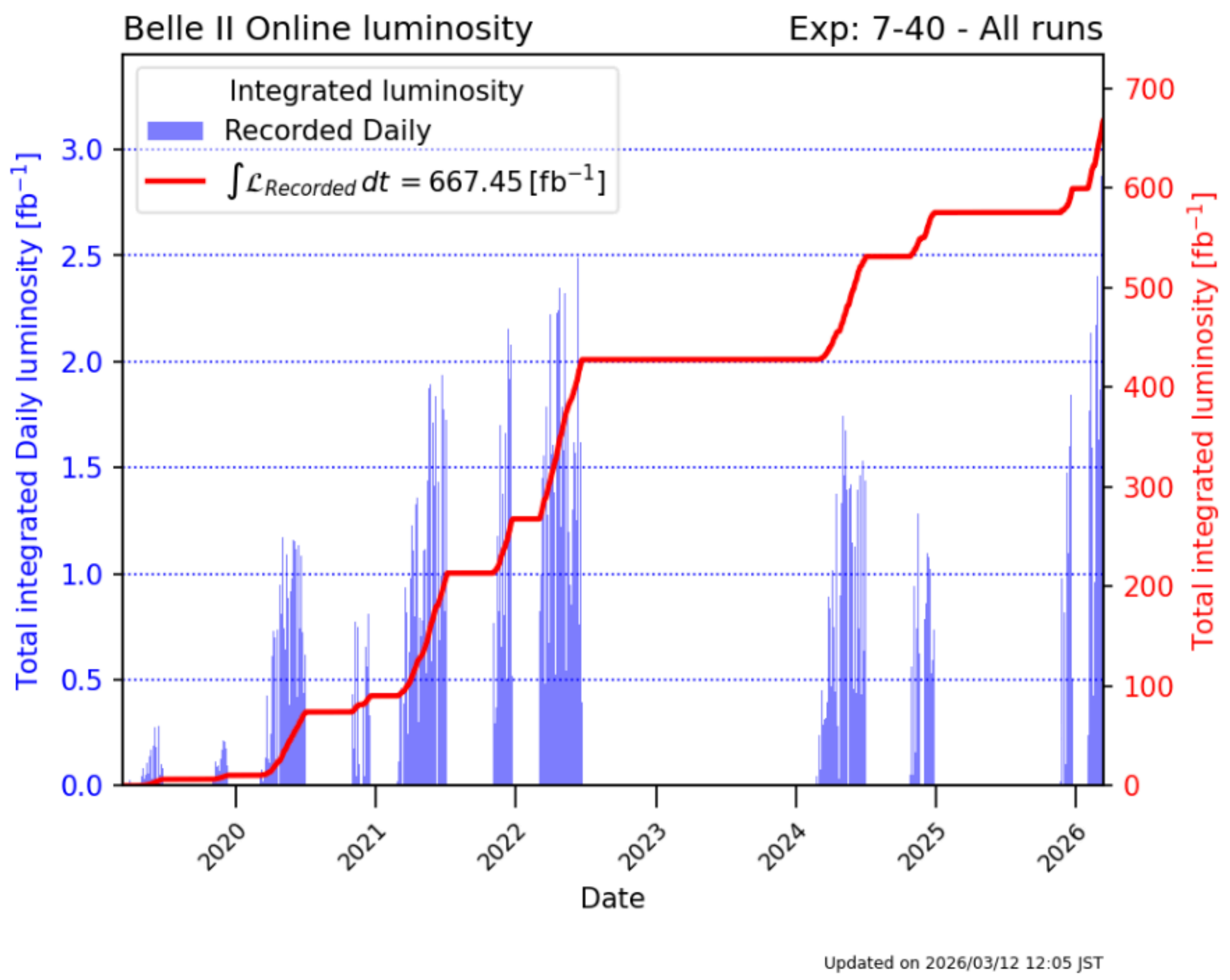
- Fit for a_i and δ_i for each channel.
- Pole masses and widths of the resonances fixed
- Unbinned negative log likelihood fit

MC Simulation



Prospects

- Currently on-going
- This analysis is expected to be the first publication on the amplitude analysis of $B \rightarrow K\pi\pi\gamma$ decays in Belle-II.
- Expected additional results: Branching ratios of less studied intermediate K_{res} decays
- Result planned with latest processed data



Backup

Amplitude Model

- **Frame of reference** $\Rightarrow K_{res}$ rest frame
  - *Coordinates:* $\vec{z} = \vec{p}_\gamma$, $\vec{y} = \vec{p}_\gamma \times (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$
  - *Degrees of freedom:* 16 (4 x 4 $\vec{p}$) - 4 (masses) - 4 ($\vec{p}_{K_{res}} = 0$) - 3 (rotations) $\Rightarrow$ **5**
- **Phase Space:** $d\Phi \sim \dfrac{m_{01}m_{12}(m_B^2 - m_{012}^2)}{m_{012}} dm_{012}dm_{12}dm_{01}d\cos\theta d\phi$
- **Conversion between momenta and 5 observables:**
  - $m_{K^+\pi^+} = \left(m^2_{K^+\pi^+\pi^-} + m^2_{K^+} + m^2_{\pi^+} + m^2_{\pi-} - m^2_{K^+\pi^-} - m^2_{\pi^+\pi^-}\right)^{\frac{1}{2}}$
  - $|\vec{p}_i| = \dfrac{\left[\left(m^2_{ijk} - (m_j + m_k)^2\right)\left(m^2_{ijk} - (m_j - m_k)^2\right)\right]^{\frac{1}{2}}}{2m_{ijk}}, |\vec{p}_\gamma| = \dfrac{m_B^2 - m^2_{ijk}}{2m_{ijk}}, E_i = \left(m_i^2 + |\vec{p}_i|^2\right)^{\frac{1}{2}}$
  - $\delta = \cos^{-1}\left(\dfrac{m^2_{\pi^+} + m^2_{\pi^-} + 2E_{\pi^+}E_{\pi^-} - m_{\pi^+\pi^-}}{2|\vec{p}_{\pi^+}||\vec{p}_{\pi^-}|}\right),\ \phi_\pm = \phi \mp \dfrac{\delta}{2}$, *if* $\phi_+ < 0,\ \phi_+ \to \phi_+ + 2\pi$ *and* $\phi_- > 0,\ \phi_- \to \phi_- - 2\pi$
  - $\vec{p}_{\pi^\pm} = |\vec{p}_{\pi^\pm}|(\cos\theta\cos\phi_\pm,\ \sin\phi_\pm\ \sin\theta\cos\phi_\pm)$
  - $\vec{p}^+_K = -\left(\vec{p}_{\pi^+} + \vec{p}_{\pi^-}\right)$
  - $\vec{p}_\gamma = (0, 0, E_i)$

B-decay Angular Factors

$$\Lambda^{ab} = \left(i \frac{(SO_3)_x \cdot p_{(\gamma)x} + (SO_3)_y \cdot p_{(\gamma)y} + (SO_3)_z \cdot p_{(\gamma)z}}{|\vec{p}_\gamma|} \right)^{ab}$$

$B^+ \to K^+_{res}(1^+)\gamma$

$$\left(-i\varepsilon_{\mu\nu\alpha\beta}\left[\Lambda^{\mu\delta}\epsilon^*_\delta(p_{(\gamma)})p^\alpha_{(R)}p^\beta_{(\gamma)}\right] + \left(\epsilon^*_\nu(p_{(\gamma)})p^\alpha_{(R)}p_{(\gamma)\alpha} - \epsilon^*_\delta(p_{(\gamma)})p^\delta_{(R)}p_{(\gamma)\nu}\right)\right)\epsilon^{*\nu}(p_{(R)})$$

$B^+ \to K^+_{res}(1^-)\gamma$

$$\left(-i\varepsilon_{\mu\nu\alpha\beta}\left[\epsilon^{*\mu}(p_{(\gamma)})p^\alpha_{(R)}p^\beta_{(\gamma)}\right] + \left(\Lambda_{\nu\mu}\epsilon^{*\mu}(p_{(\gamma)})p^\alpha_{(R)}p_{(\gamma)\alpha} - \Lambda_{\mu\delta}\epsilon^{*\mu}(p_{(\gamma)})p^\delta_{(R)}p_{(\gamma)\nu}\right)\right)\epsilon^{*\nu}(p_{(R)})$$

$B^+ \to K^+_{res}(2^+)\gamma$

$$\left(-i\varepsilon_{\mu\nu\alpha\beta}\left[\epsilon^{*\mu}(p_{(\gamma)})p_{(R)\delta}p^\alpha_{(R)}p^\beta_{(\gamma)}\right] + \left(\Lambda_{\nu\alpha}\epsilon^{*\alpha}(p_{(\gamma)})\left(p_{(R)}\cdot p_{(\gamma)}\right)p_{(\gamma)\delta} - \Lambda_{\mu\alpha}\epsilon^{*\alpha}(p_{(\gamma)})p^\mu_{(R)}p_{(R)\delta}p_{(\gamma)\nu}\right)\right)\epsilon^{*\nu\delta}(p_{(R)})$$

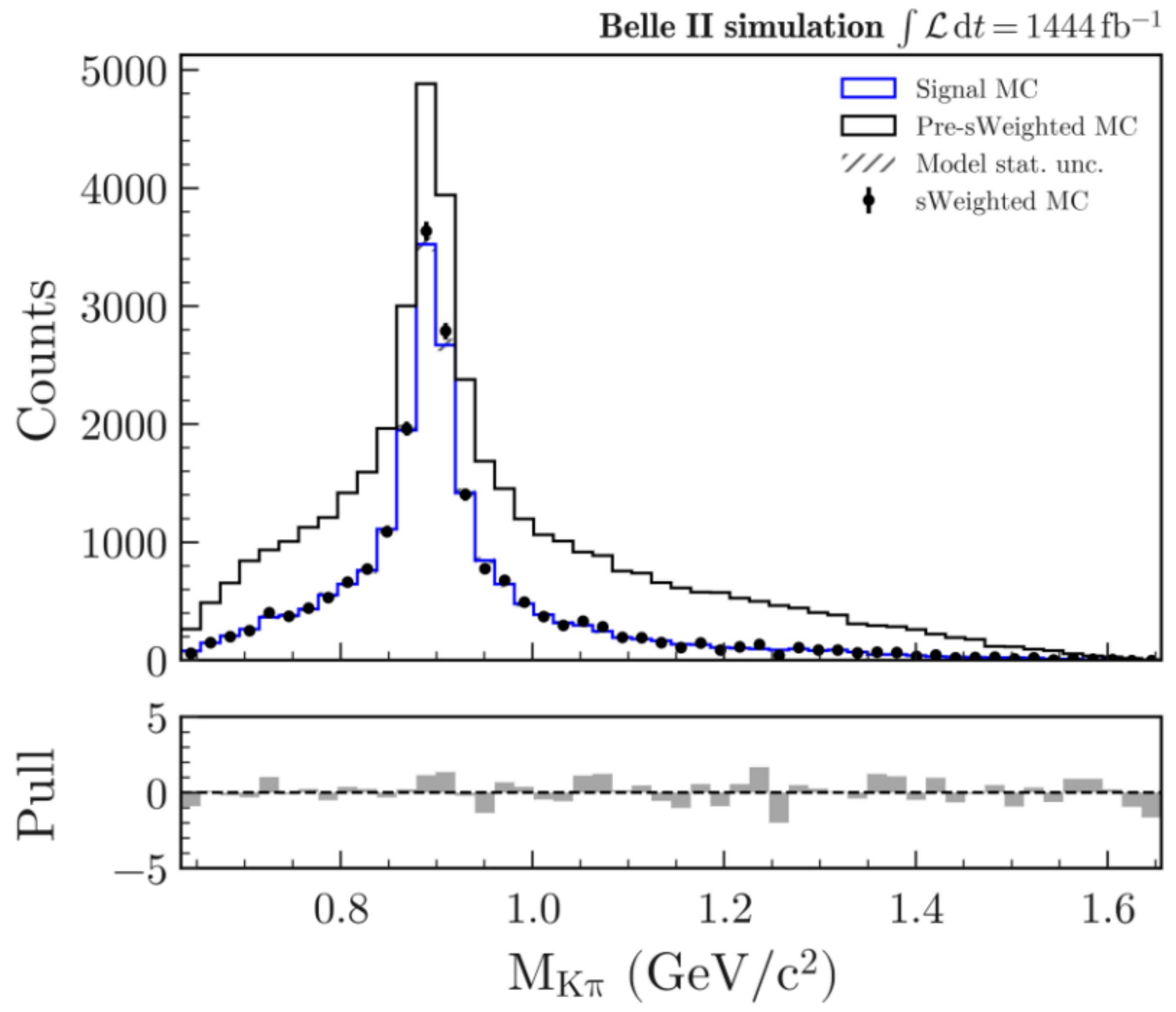
$B^+ \to K^+_{res}(2^-)\gamma$

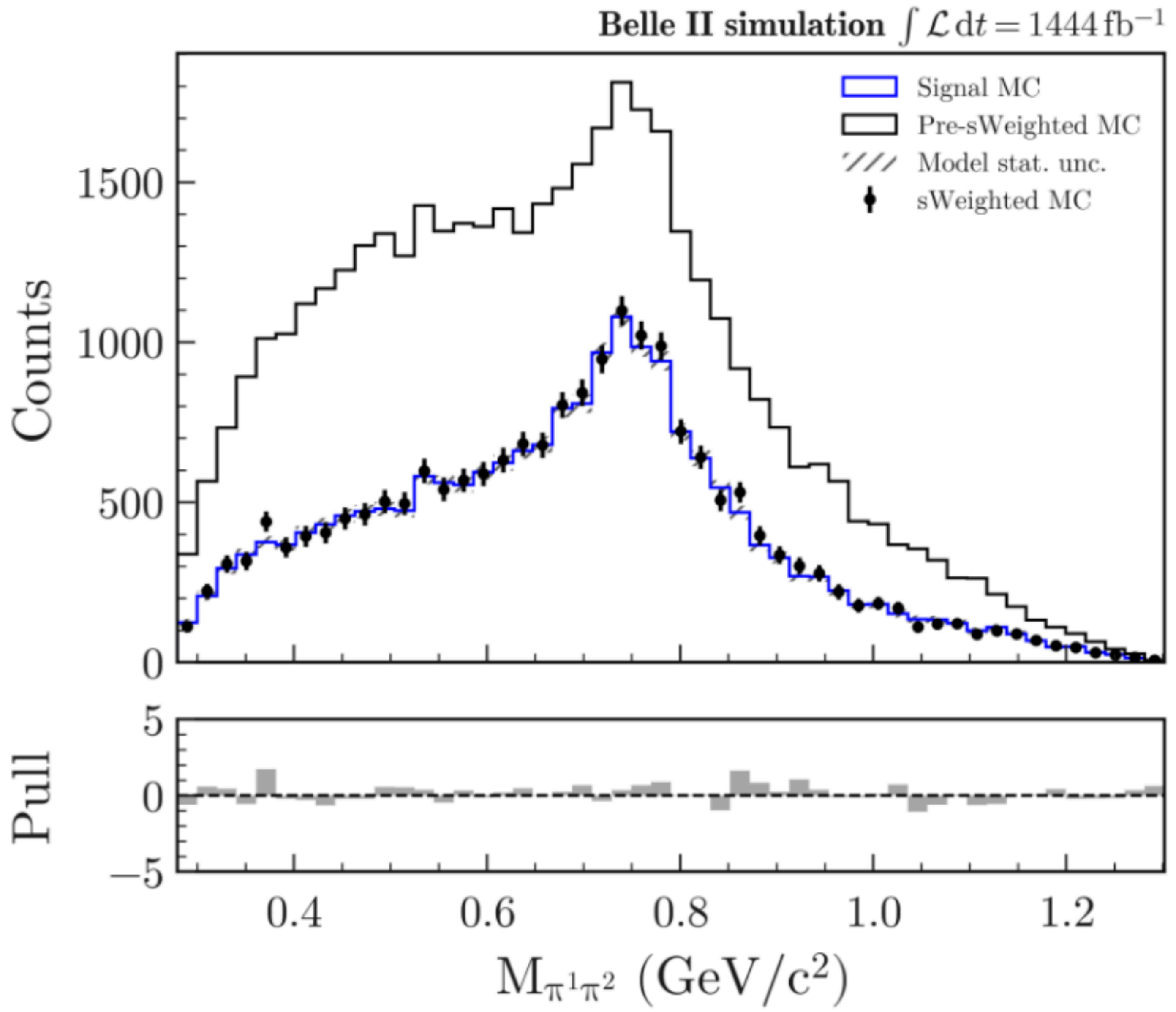
$$\left(-i\varepsilon_{\mu\nu\alpha\beta}\left[\Lambda^{\mu\chi}\epsilon^*_\chi(p_{(\gamma)})p_{(R)\delta}p^\alpha_{(R)}p^\beta_{(\gamma)}\right] + \left(\epsilon^*_\nu(p_{(\gamma)})\left(p_{(R)}\cdot p_{(\gamma)}\right)p_{(\gamma)\delta} - \epsilon^*_\alpha(p_{(\gamma)})p^\alpha_{(R)}p_{(R)\delta}p_{(\gamma)\nu}\right)\right)\epsilon^{*\nu\delta}(p_{(R)})$$

Background Subtraction

- sFit Method : Create background subtracted distribution
  - Obtain signal only samples to perform our amplitude model fit
- Strategy : Use ΔE and Mbc as discriminating variables to compute the sWeights for the m($K\pi\pi$)/m($K\pi$)/m($\pi\pi$) control variables (so far)
  - Check that no correlations between discriminating and control variables

Correlation to	ΔE
m($K\pi\pi$)	-0.3 %
m($K\pi$)	-1.9 %
m($\pi\pi$)	2.6 %





Plots by: M. Maushart