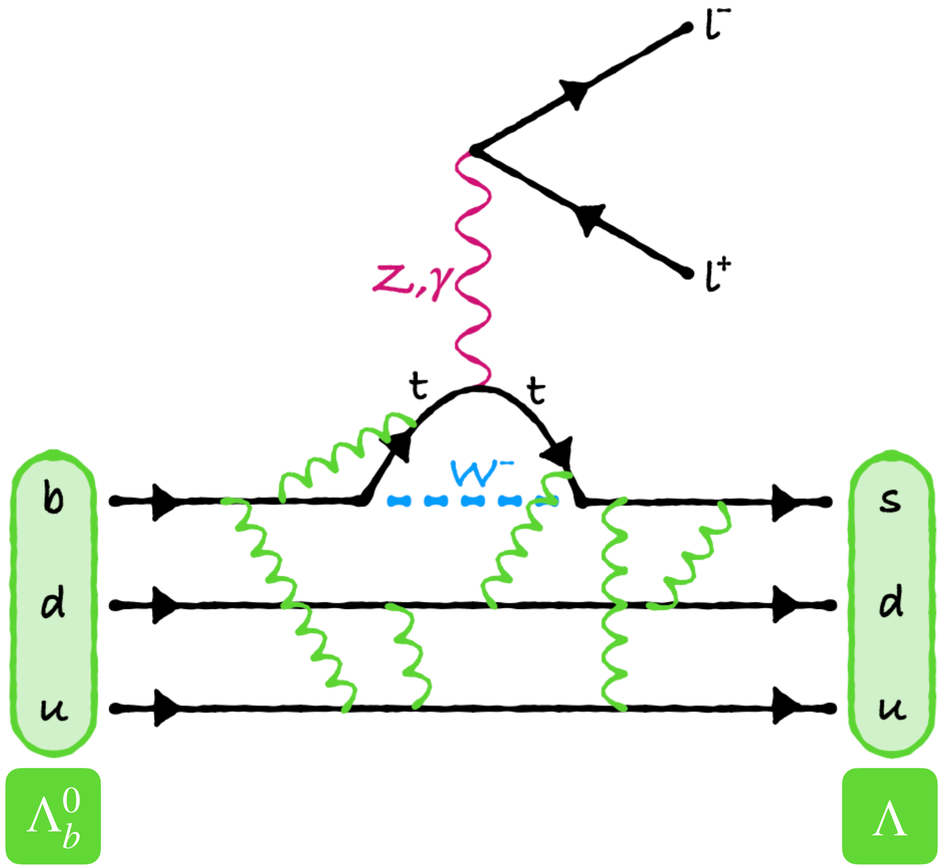
Polarized Lb baryons at FCC-ee

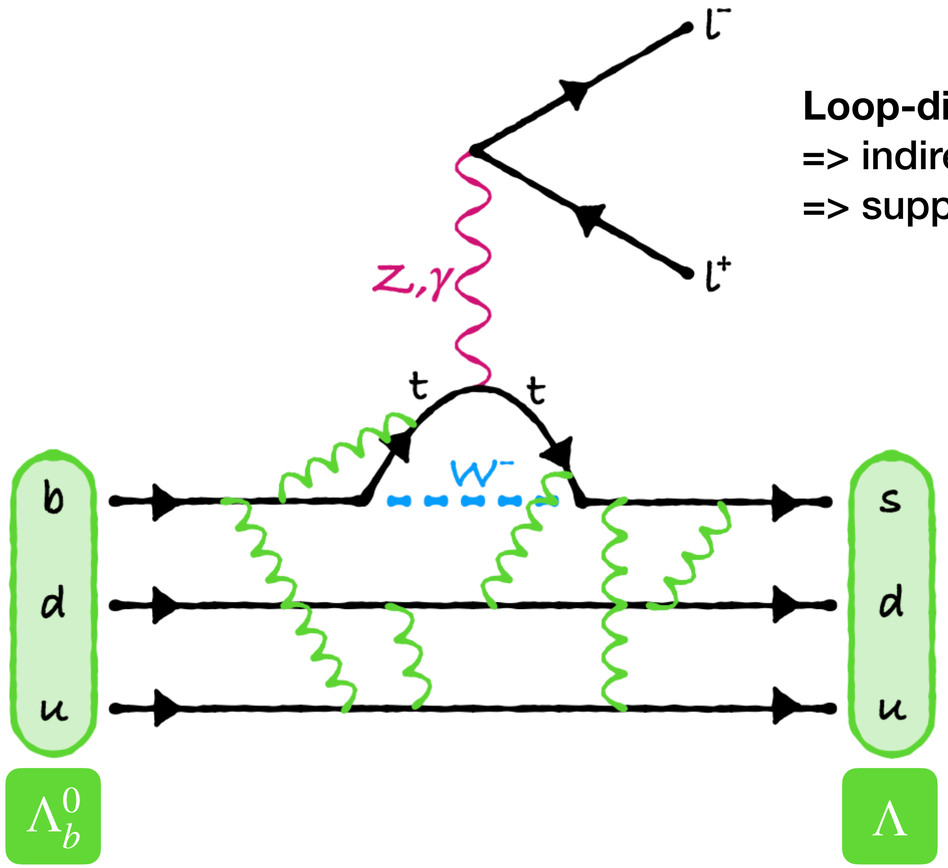
Anja Beck, Eluned Smith

FCC@MIT+Friends | 12-Sep-2025

Electroweak penguin decays

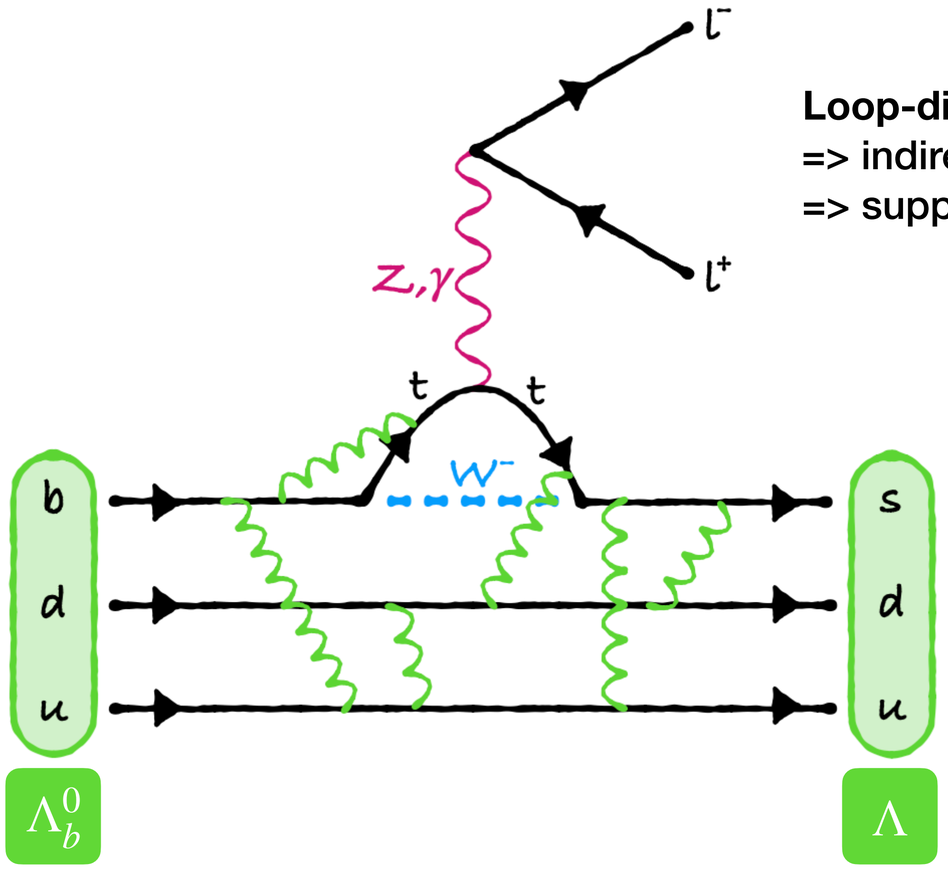


Electroweak penguin decays



Loop-diagram
=> indirect access to much higher scales than direct searches
=> suppressed in the SM, New Physics might be less diluted

Electroweak penguin decays



Loop-diagram
=> indirect access to much higher scales than direct searches
=> suppressed in the SM, New Physics might be less diluted

Hadronic effects
=> b hadronises before the decay
=> QCD effects complicate predictions

Polarization and the angular decay rate

$$\frac{\mathrm{d}^6\Gamma}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{3}{32\pi^2}\Big($$

$$\begin{aligned}
&\big(K_1 \sin^2\theta_l + K_2 \cos^2\theta_l + K_3 \cos\theta_l\big) + \\
&\big(K_4 \sin^2\theta_l + K_5 \cos^2\theta_l + K_6 \cos\theta_l\big) \cos\theta_b + \\
&(K_7 \sin\theta_l \cos\theta_l + K_8 \sin\theta_l) \sin\theta_b \cos(\phi_b + \phi_l) + \\
&(K_9 \sin\theta_l \cos\theta_l + K_{10} \sin\theta_l) \sin\theta_b \sin(\phi_b + \phi_l) + \\
&\big(K_{11} \sin^2\theta_l + K_{12} \cos^2\theta_l + K_{13} \cos\theta_l\big) \cos\theta + \\
&\big(K_{14} \sin^2\theta_l + K_{15} \cos^2\theta_l + K_{16} \cos\theta_l\big) \cos\theta_b \cos\theta + \\
&(K_{17} \sin\theta_l \cos\theta_l + K_{18} \sin\theta_l) \sin\theta_b \cos(\phi_b + \phi_l) \cos\theta + \\
&(K_{19} \sin\theta_l \cos\theta_l + K_{20} \sin\theta_l) \sin\theta_b \sin(\phi_b + \phi_l) \cos\theta + \\
&(K_{21} \cos\theta_l \sin\theta_l + K_{22} \sin\theta_l) \sin\phi_l \sin\theta + \\
&(K_{23} \cos\theta_l \sin\theta_l + K_{24} \sin\theta_l) \cos\phi_l \sin\theta + \\
&(K_{25} \cos\theta_l \sin\theta_l + K_{26} \sin\theta_l) \sin\phi_l \cos\theta_b \sin\theta + \\
&(K_{27} \cos\theta_l \sin\theta_l + K_{28} \sin\theta_l) \cos\phi_l \cos\theta_b \sin\theta + \\
&\big(K_{29} \cos^2\theta_l + K_{30} \sin^2\theta_l\big) \sin\theta_b \sin\phi_b \sin\theta + \\
&\big(K_{31} \cos^2\theta_l + K_{32} \sin^2\theta_l\big) \sin\theta_b \cos\phi_b \sin\theta + \\
&\big(K_{33} \sin^2\theta_l\big) \sin\theta_b \cos(2\phi_l + \phi_b) \sin\theta + \\
&\big(K_{34} \sin^2\theta_l\big) \sin\theta_b \sin(2\phi_l + \phi_b) \sin\theta\Big)
\end{aligned}$$

Measured at LHCb
3D angular phase space

Only accessible for $P_{\Lambda_b^0} \neq 0$
5D angular phase space

Polarization and the angular decay rate

$$\frac{\mathrm{d}^6\Gamma}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{3}{32\pi^2}\Big($$

$$\begin{aligned}
&\big(K_1 \sin^2\theta_l + K_2 \cos^2\theta_l + K_3 \cos\theta_l\big) + \\
&\big(K_4 \sin^2\theta_l + K_5 \cos^2\theta_l + K_6 \cos\theta_l\big) \cos\theta_b + \\
&(K_7 \sin\theta_l \cos\theta_l + K_8 \sin\theta_l) \sin\theta_b \cos(\phi_b + \phi_l) + \\
&(K_9 \sin\theta_l \cos\theta_l + K_{10} \sin\theta_l) \sin\theta_b \sin(\phi_b + \phi_l) + \\
&\big(K_{11} \sin^2\theta_l + K_{12} \cos^2\theta_l + K_{13} \cos\theta_l\big) \cos\theta + \\
&\big(K_{14} \sin^2\theta_l + K_{15} \cos^2\theta_l + K_{16} \cos\theta_l\big) \cos\theta_b \cos\theta + \\
&(K_{17} \sin\theta_l \cos\theta_l + K_{18} \sin\theta_l) \sin\theta_b \cos(\phi_b + \phi_l) \cos\theta + \\
&(K_{19} \sin\theta_l \cos\theta_l + K_{20} \sin\theta_l) \sin\theta_b \sin(\phi_b + \phi_l) \cos\theta + \\
&(K_{21} \cos\theta_l \sin\theta_l + K_{22} \sin\theta_l) \sin\phi_l \sin\theta + \\
&(K_{23} \cos\theta_l \sin\theta_l + K_{24} \sin\theta_l) \cos\phi_l \sin\theta + \\
&(K_{25} \cos\theta_l \sin\theta_l + K_{26} \sin\theta_l) \sin\phi_l \cos\theta_b \sin\theta + \\
&(K_{27} \cos\theta_l \sin\theta_l + K_{28} \sin\theta_l) \cos\phi_l \cos\theta_b \sin\theta + \\
&\big(K_{29} \cos^2\theta_l + K_{30} \sin^2\theta_l\big) \sin\theta_b \sin\phi_b \sin\theta + \\
&\big(K_{31} \cos^2\theta_l + K_{32} \sin^2\theta_l\big) \sin\theta_b \cos\phi_b \sin\theta + \\
&\big(K_{33} \sin^2\theta_l\big) \sin\theta_b \cos(2\phi_l + \phi_b) \sin\theta + \\
&\big(K_{34} \sin^2\theta_l\big) \sin\theta_b \sin(2\phi_l + \phi_b) \sin\theta\Big)
\end{aligned}$$

Measured at LHCb
3D angular phase space

Only accessible for $P_{\Lambda_b^0} \neq 0$
5D angular phase space

Unpolarised beams (LEP)

Polarization and the angular decay rate

$$\frac{\mathrm{d}^6\Gamma}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{3}{32\pi^2}\Big($$

$$\begin{aligned}
&\big(K_1 \sin^2\theta_l + K_2 \cos^2\theta_l + K_3 \cos\theta_l\big) + \\
&\big(K_4 \sin^2\theta_l + K_5 \cos^2\theta_l + K_6 \cos\theta_l\big) \cos\theta_b + \\
&\big(K_7 \sin\theta_l \cos\theta_l + K_8 \sin\theta_l\big) \sin\theta_b \cos\left(\phi_b + \phi_l\right) + \\
&\big(K_9 \sin\theta_l \cos\theta_l + K_{10} \sin\theta_l\big) \sin\theta_b \sin\left(\phi_b + \phi_l\right) + \\
&\big(K_{11} \sin^2\theta_l + K_{12} \cos^2\theta_l + K_{13} \cos\theta_l\big) \cos\theta + \\
&\big(K_{14} \sin^2\theta_l + K_{15} \cos^2\theta_l + K_{16} \cos\theta_l\big) \cos\theta_b \cos\theta + \\
&\big(K_{17} \sin\theta_l \cos\theta_l + K_{18} \sin\theta_l\big) \sin\theta_b \cos\left(\phi_b + \phi_l\right) \cos\theta + \\
&\big(K_{19} \sin\theta_l \cos\theta_l + K_{20} \sin\theta_l\big) \sin\theta_b \sin\left(\phi_b + \phi_l\right) \cos\theta + \\
&\big(K_{21} \cos\theta_l \sin\theta_l + K_{22} \sin\theta_l\big) \sin\phi_l \sin\theta + \\
&\big(K_{23} \cos\theta_l \sin\theta_l + K_{24} \sin\theta_l\big) \cos\phi_l \sin\theta + \\
&\big(K_{25} \cos\theta_l \sin\theta_l + K_{26} \sin\theta_l\big) \sin\phi_l \cos\theta_b \sin\theta + \\
&\big(K_{27} \cos\theta_l \sin\theta_l + K_{28} \sin\theta_l\big) \cos\phi_l \cos\theta_b \sin\theta + \\
&\big(K_{29} \cos^2\theta_l + K_{30} \sin^2\theta_l\big) \sin\theta_b \sin\phi_b \sin\theta + \\
&\big(K_{31} \cos^2\theta_l + K_{32} \sin^2\theta_l\big) \sin\theta_b \cos\phi_b \sin\theta + \\
&\big(K_{33} \sin^2\theta_l\big) \sin\theta_b \cos\left(2\phi_l + \phi_b\right) \sin\theta + \\
&\big(K_{34} \sin^2\theta_l\big) \sin\theta_b \sin\left(2\phi_l + \phi_b\right) \sin\theta\Big)
\end{aligned}$$

Measured at LHCb
3D angular phase space

Only accessible for $P_{\Lambda_b^0} \neq 0$
5D angular phase space

Unpolarised beams (LEP)

$0, \pm 1$

Z^0

Polarization and the angular decay rate

$$\frac{\mathrm{d}^6\Gamma}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{3}{32\pi^2}\Big($$

$$\begin{aligned}
&\big(K_1 \sin^2\theta_l + K_2 \cos^2\theta_l + K_3 \cos\theta_l\big) + \\
&\big(K_4 \sin^2\theta_l + K_5 \cos^2\theta_l + K_6 \cos\theta_l\big) \cos\theta_b + \\
&(K_7 \sin\theta_l \cos\theta_l + K_8 \sin\theta_l) \sin\theta_b \cos(\phi_b + \phi_l) + \\
&(K_9 \sin\theta_l \cos\theta_l + K_{10} \sin\theta_l) \sin\theta_b \sin(\phi_b + \phi_l) + \\
&\big(K_{11} \sin^2\theta_l + K_{12} \cos^2\theta_l + K_{13} \cos\theta_l\big) \cos\theta + \\
&\big(K_{14} \sin^2\theta_l + K_{15} \cos^2\theta_l + K_{16} \cos\theta_l\big) \cos\theta_b \cos\theta + \\
&(K_{17} \sin\theta_l \cos\theta_l + K_{18} \sin\theta_l) \sin\theta_b \cos(\phi_b + \phi_l) \cos\theta + \\
&(K_{19} \sin\theta_l \cos\theta_l + K_{20} \sin\theta_l) \sin\theta_b \sin(\phi_b + \phi_l) \cos\theta + \\
&(K_{21} \cos\theta_l \sin\theta_l + K_{22} \sin\theta_l) \sin\phi_l \sin\theta + \\
&(K_{23} \cos\theta_l \sin\theta_l + K_{24} \sin\theta_l) \cos\phi_l \sin\theta + \\
&(K_{25} \cos\theta_l \sin\theta_l + K_{26} \sin\theta_l) \sin\phi_l \cos\theta_b \sin\theta + \\
&(K_{27} \cos\theta_l \sin\theta_l + K_{28} \sin\theta_l) \cos\phi_l \cos\theta_b \sin\theta + \\
&\big(K_{29} \cos^2\theta_l + K_{30} \sin^2\theta_l\big) \sin\theta_b \sin\phi_b \sin\theta + \\
&\big(K_{31} \cos^2\theta_l + K_{32} \sin^2\theta_l\big) \sin\theta_b \cos\phi_b \sin\theta + \\
&\big(K_{33} \sin^2\theta_l\big) \sin\theta_b \cos(2\phi_l + \phi_b) \sin\theta + \\
&\big(K_{34} \sin^2\theta_l\big) \sin\theta_b \sin(2\phi_l + \phi_b) \sin\theta\Big)
\end{aligned}$$

Measured at LHCb
3D angular phase space

Only accessible for $P_{\Lambda_b^0} \neq 0$
5D angular phase space

Unpolarised beams (LEP)

$0, \pm 1$ $\quad -0.94$

Z^0 $\quad b$

Polarization and the angular decay rate

$$\frac{\mathrm{d}^6\Gamma}{\mathrm{d}q^2\,\mathrm{d}\vec{\Omega}} = \frac{3}{32\pi^2}\Big($$

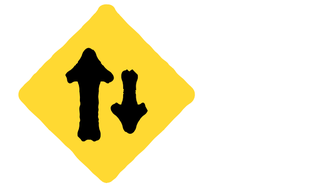
$$\begin{aligned}
&\big(K_1 \sin^2\theta_l + K_2 \cos^2\theta_l + K_3 \cos\theta_l\big) + \\
&\big(K_4 \sin^2\theta_l + K_5 \cos^2\theta_l + K_6 \cos\theta_l\big) \cos\theta_b + \\
&\big(K_7 \sin\theta_l \cos\theta_l + K_8 \sin\theta_l\big) \sin\theta_b \cos\left(\phi_b + \phi_l\right) + \\
&\big(K_9 \sin\theta_l \cos\theta_l + K_{10} \sin\theta_l\big) \sin\theta_b \sin\left(\phi_b + \phi_l\right) + \\
&\big(K_{11} \sin^2\theta_l + K_{12} \cos^2\theta_l + K_{13} \cos\theta_l\big) \cos\theta + \\
&\big(K_{14} \sin^2\theta_l + K_{15} \cos^2\theta_l + K_{16} \cos\theta_l\big) \cos\theta_b \cos\theta + \\
&\big(K_{17} \sin\theta_l \cos\theta_l + K_{18} \sin\theta_l\big) \sin\theta_b \cos\left(\phi_b + \phi_l\right) \cos\theta + \\
&\big(K_{19} \sin\theta_l \cos\theta_l + K_{20} \sin\theta_l\big) \sin\theta_b \sin\left(\phi_b + \phi_l\right) \cos\theta + \\
&\big(K_{21} \cos\theta_l \sin\theta_l + K_{22} \sin\theta_l\big) \sin\phi_l \sin\theta + \\
&\big(K_{23} \cos\theta_l \sin\theta_l + K_{24} \sin\theta_l\big) \cos\phi_l \sin\theta + \\
&\big(K_{25} \cos\theta_l \sin\theta_l + K_{26} \sin\theta_l\big) \sin\phi_l \cos\theta_b \sin\theta + \\
&\big(K_{27} \cos\theta_l \sin\theta_l + K_{28} \sin\theta_l\big) \cos\phi_l \cos\theta_b \sin\theta + \\
&\big(K_{29} \cos^2\theta_l + K_{30} \sin^2\theta_l\big) \sin\theta_b \sin\phi_b \sin\theta + \\
&\big(K_{31} \cos^2\theta_l + K_{32} \sin^2\theta_l\big) \sin\theta_b \cos\phi_b \sin\theta + \\
&\big(K_{33} \sin^2\theta_l\big) \sin\theta_b \cos\left(2\phi_l + \phi_b\right) \sin\theta + \\
&\big(K_{34} \sin^2\theta_l\big) \sin\theta_b \sin\left(2\phi_l + \phi_b\right) \sin\theta\Big)
\end{aligned}$$

Measured at LHCb
3D angular phase space

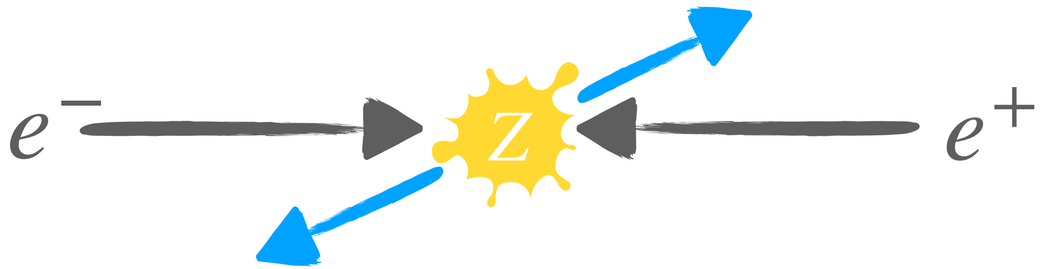
Only accessible for $P_{\Lambda_b^0} \neq 0$
5D angular phase space

Unpolarised beams (LEP)

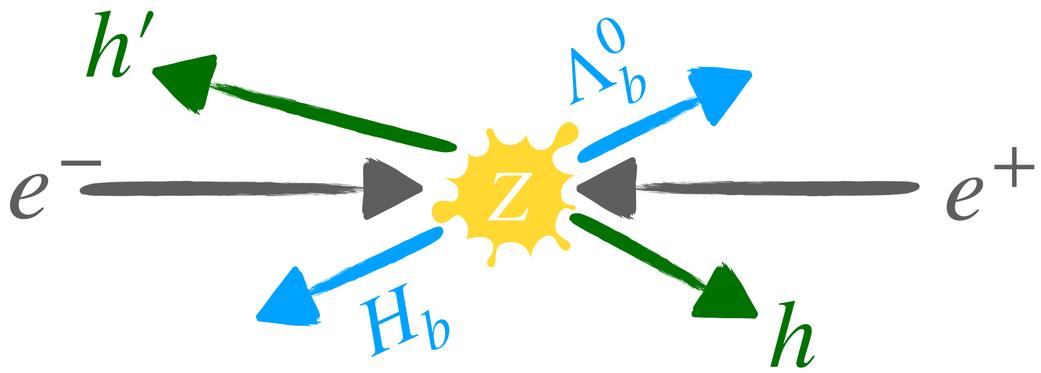
$0, \pm 1$	-0.94	-0.45
Z^0	b	Λ_b^0



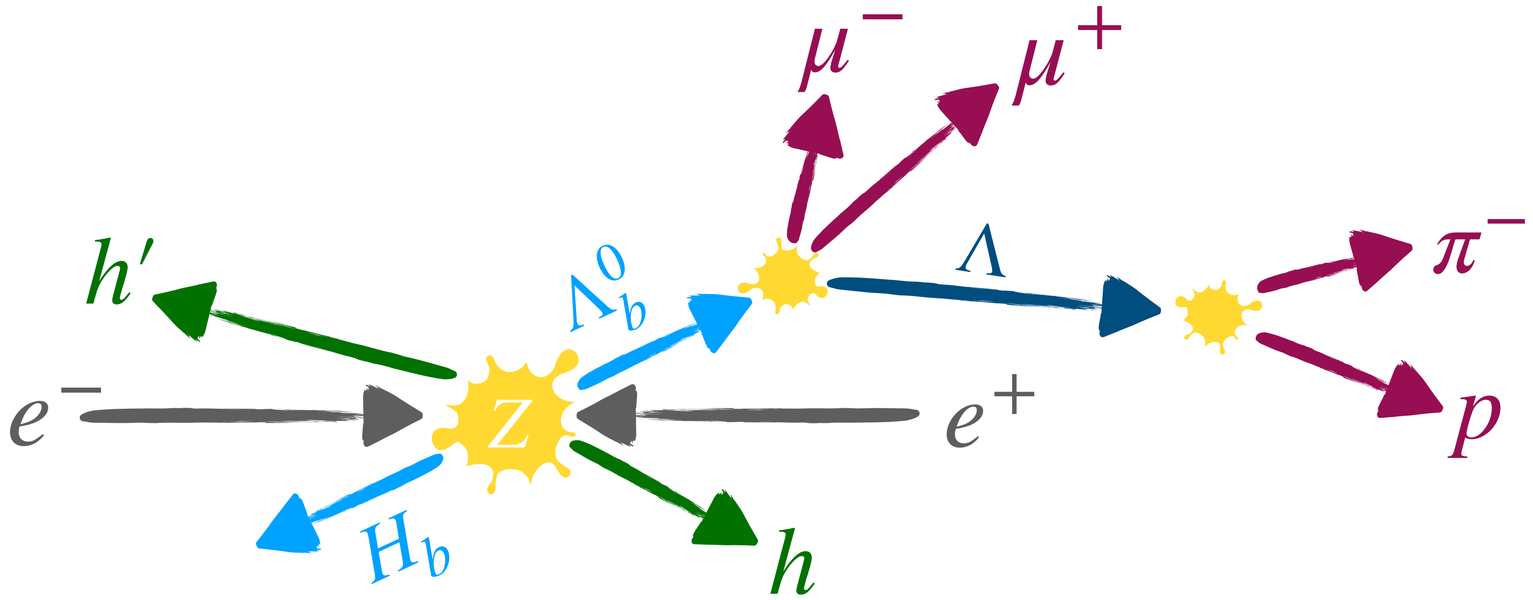
Geometry-based reconstruction



Geometry-based reconstruction



Geometry-based reconstruction



Geometry-based reconstruction

Reconstruction

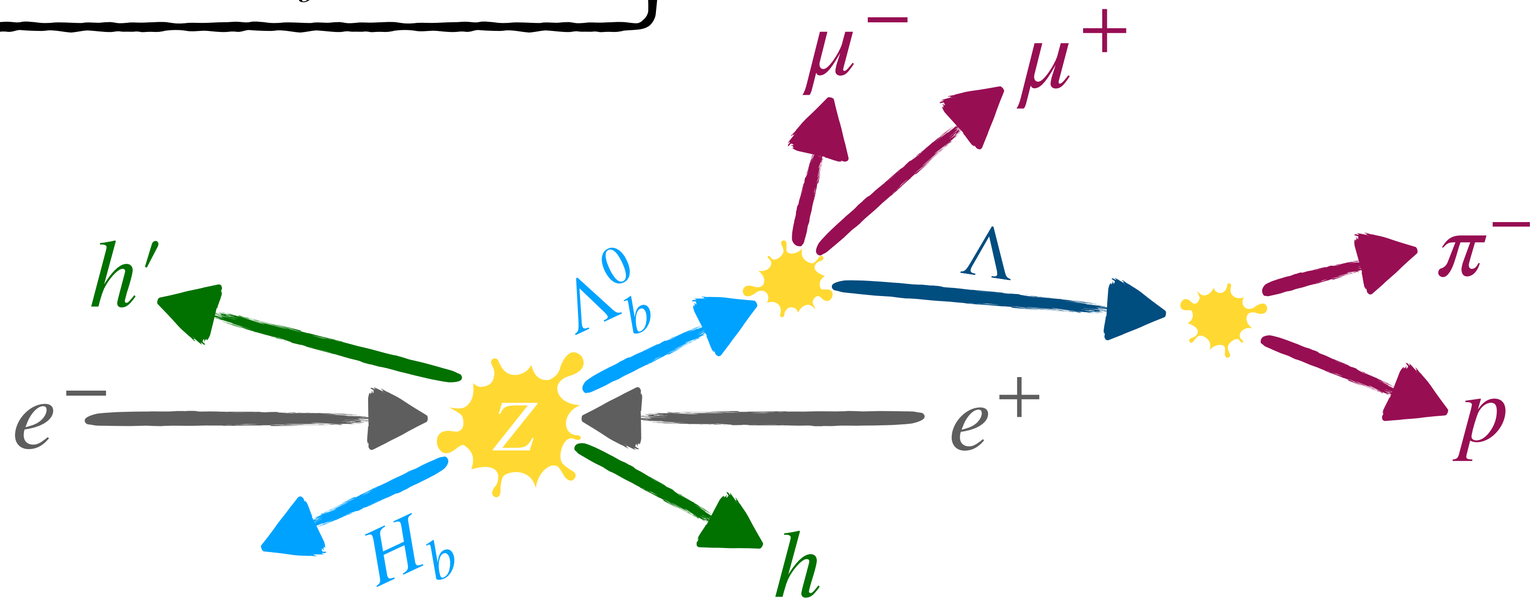
Tracking and vertex fit

Find all dimuon and dihadron vertices

Assign p and π mass based on distance to Λ mass

Find one of each:

- Λ_b^0 candidate: pair of pairs with smallest angle between Λ_b^0 and Λ directions
- $\overline{\Lambda_b^0}$ candidate: pair of pairs with smallest angle between $\overline{\Lambda_b^0}$ and $\overline{\Lambda}$ directions



Geometry-based reconstruction

Reconstruction

Tracking and vertex fit

Find all dimuon and dihadron vertices

Assign p and π mass based on distance to Λ mass

Find one of each:

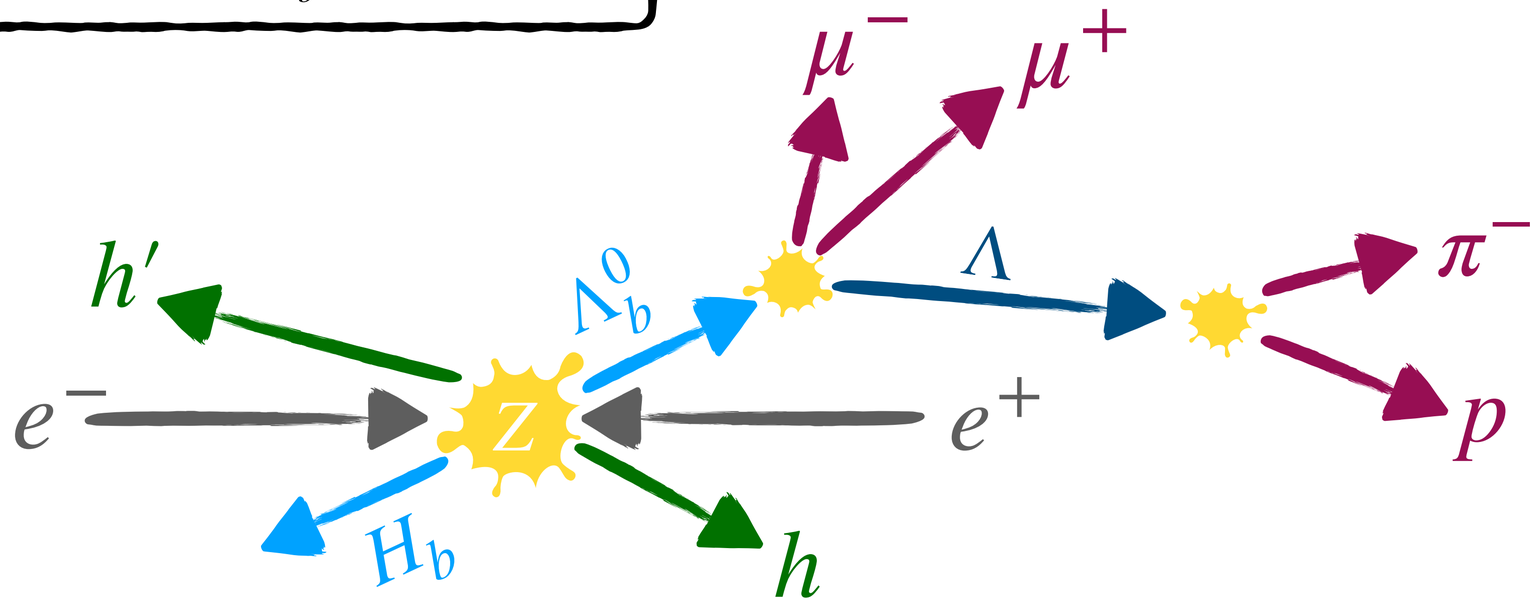
- Λ_b^0 candidate: pair of pairs with smallest angle between Λ_b^0 and Λ directions
- $\overline{\Lambda_b^0}$ candidate: pair of pairs with smallest angle between $\overline{\Lambda_b^0}$ and $\overline{\Lambda}$ directions

Selections

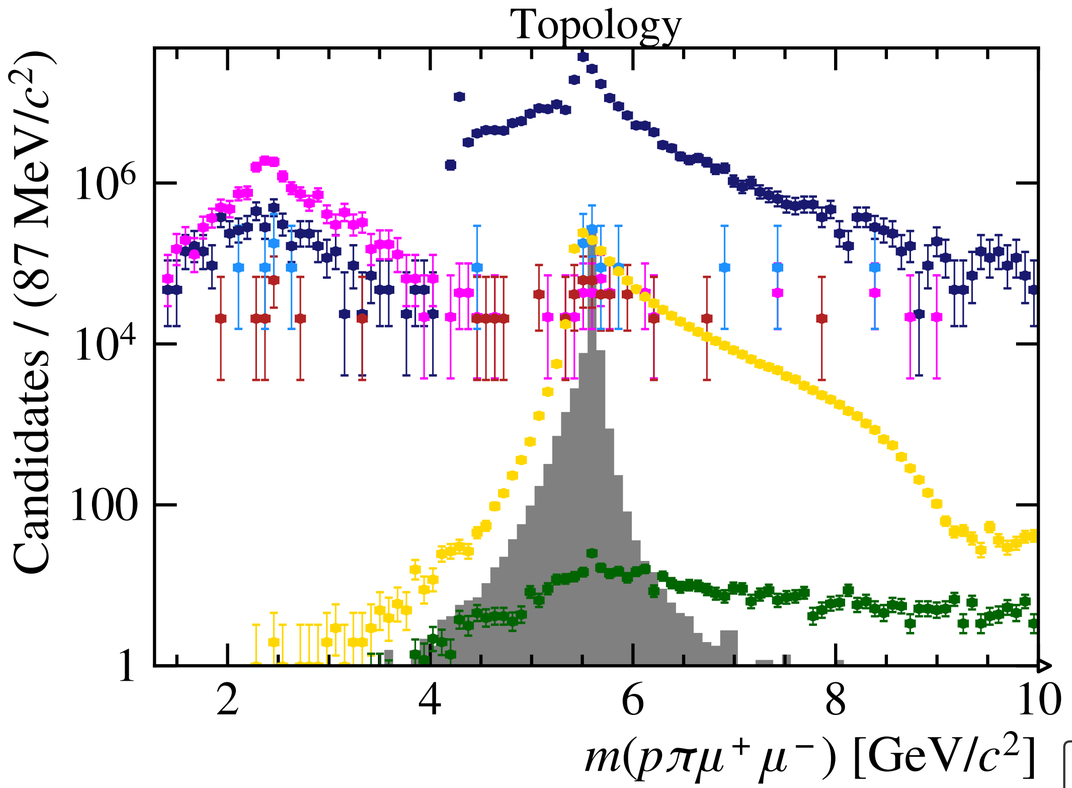
$\mathrm{IP}_{\mathrm{PV}}(\Lambda_b^0) < 100\ \mathrm{FD}(\Lambda_b^0)$

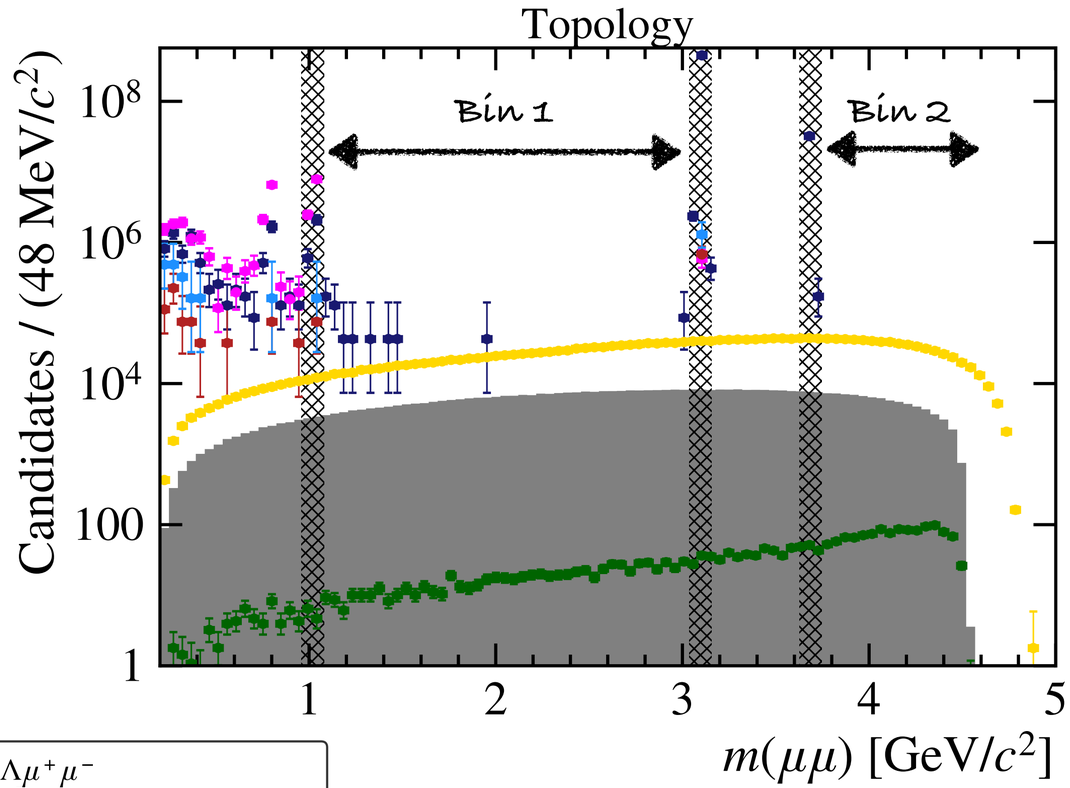
$10\ \mathrm{mm} < \mathrm{FD}(\Lambda)$

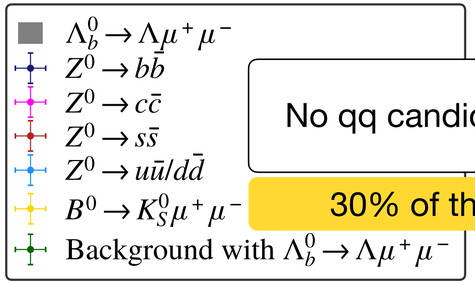
Tight windows around Λ_b^0, Λ, and $\mu^+\mu^-$ resonances



Backgrounds after selections (no windows)





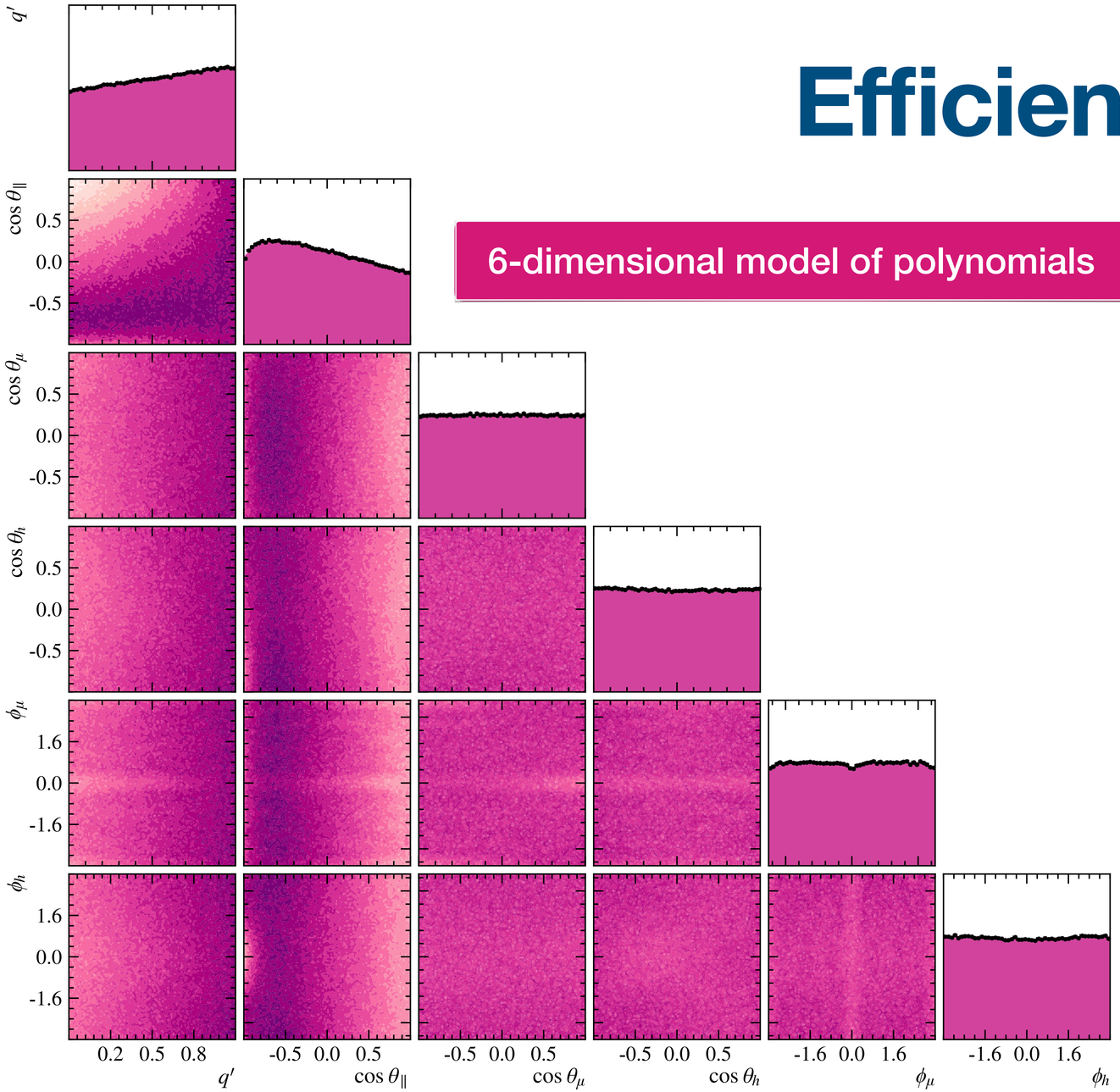


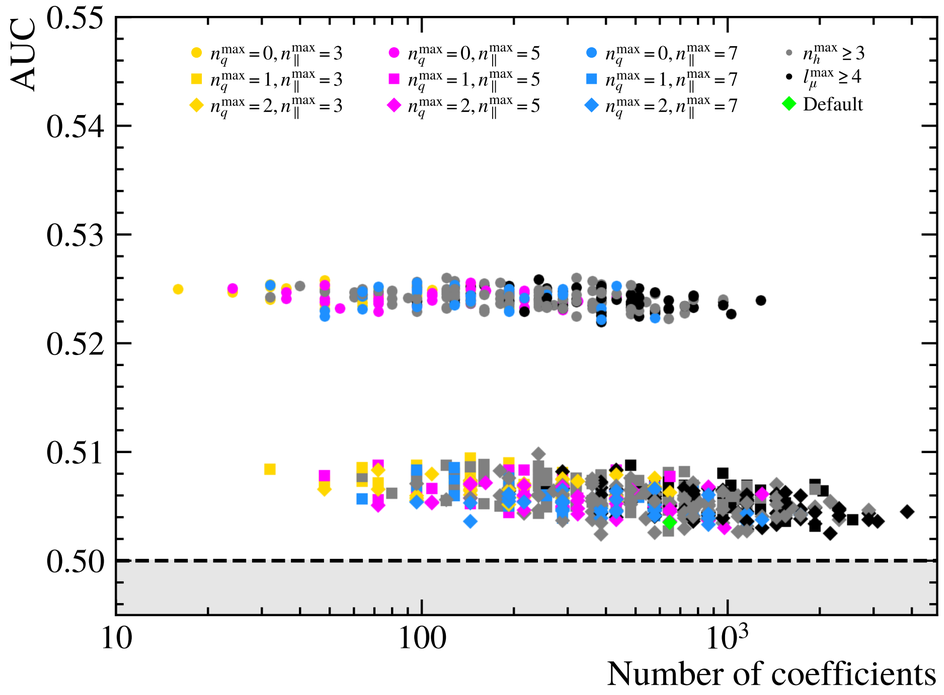
No qq candidates remain after selections

30% of the signal yield without PID

Efficiency

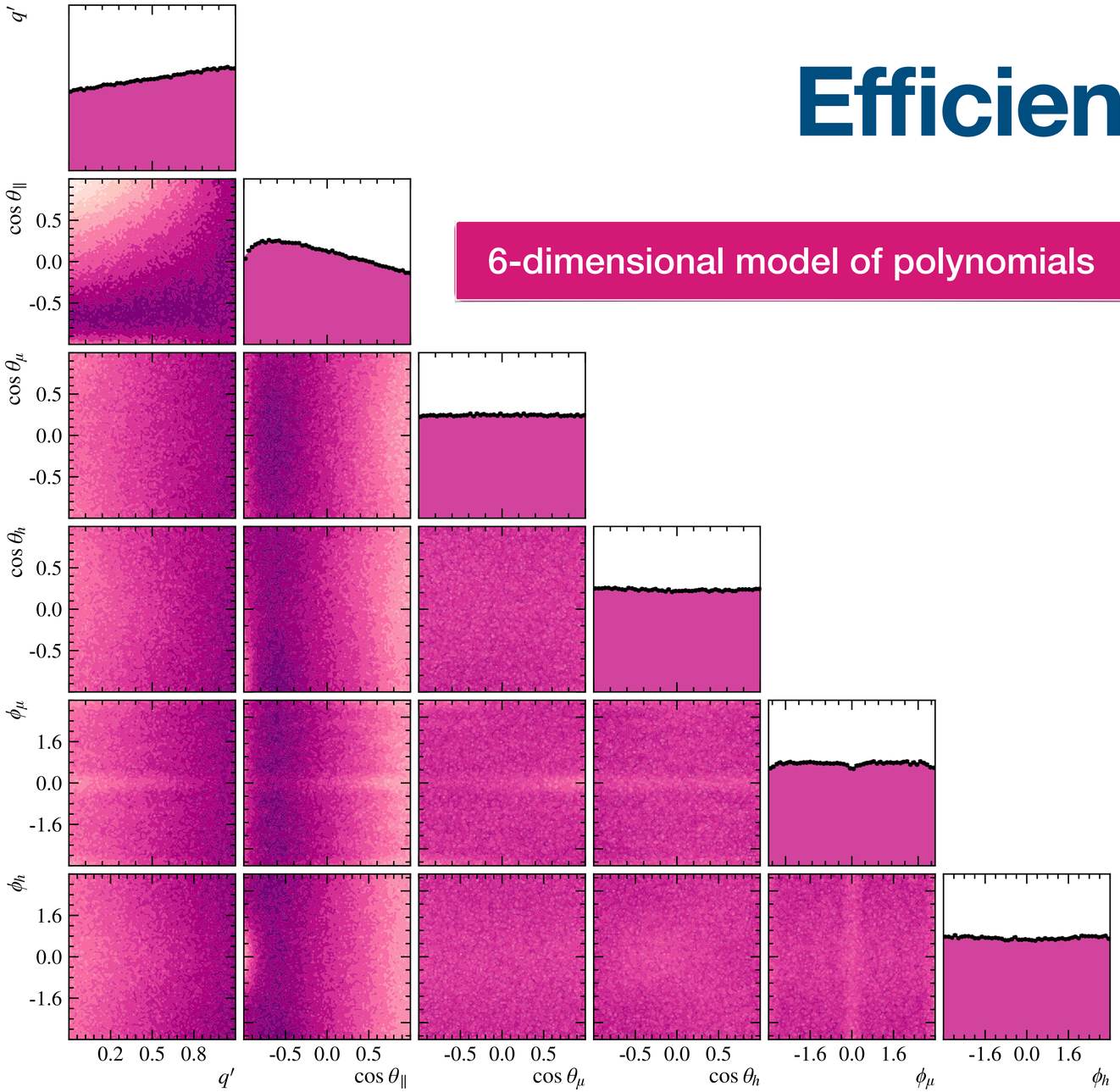
6-dimensional model of polynomials



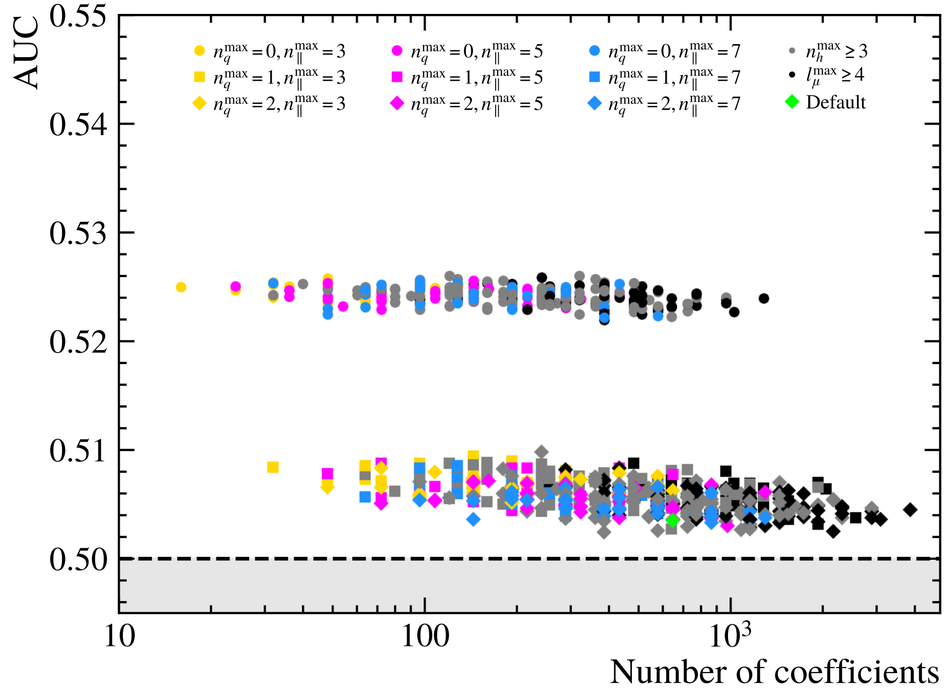


Efficiency

6-dimensional model of polynomials



Quality assessment via AUC score comparing model and simulation



Angular fit in two bins

Yield is similar to LHCb Upgrade 1

Setup
Unextended maximum likelihood fit
Signal-only
Weighted samples (physics weight and efficiency)

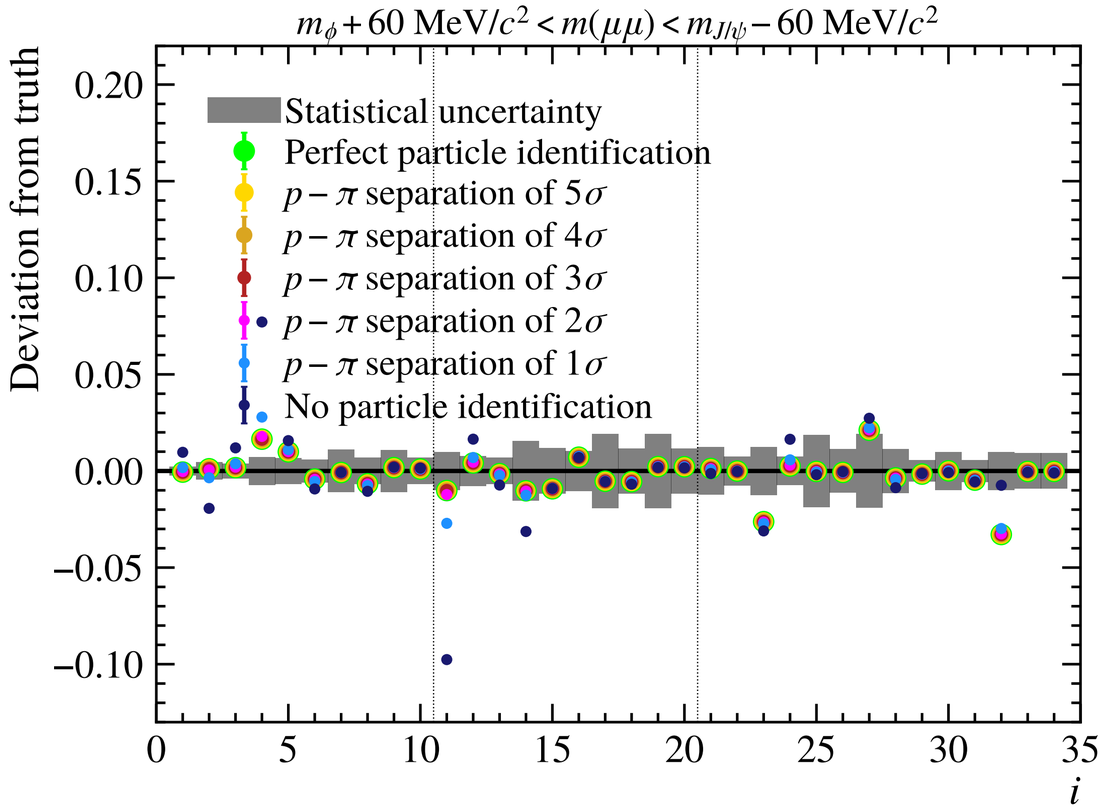
Stat. uncertainty: mean uncertainty in toys
Syst. uncertainty: deviation from truth in large sample

Angular fit in two bins

Yield is similar to LHCb Upgrade 1

Setup
Unextended maximum likelihood fit
Signal-only
Weighted samples (physics weight and efficiency)

Stat. uncertainty: mean uncertainty in toys
Syst. uncertainty: deviation from truth in large sample

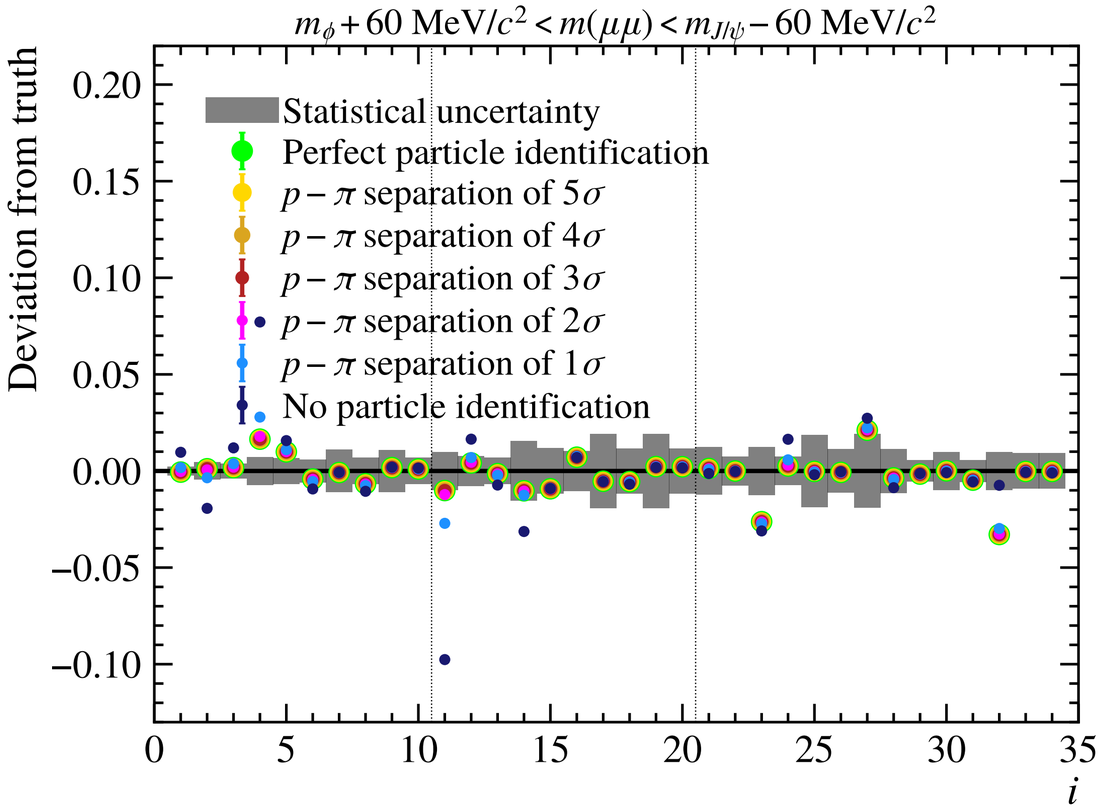


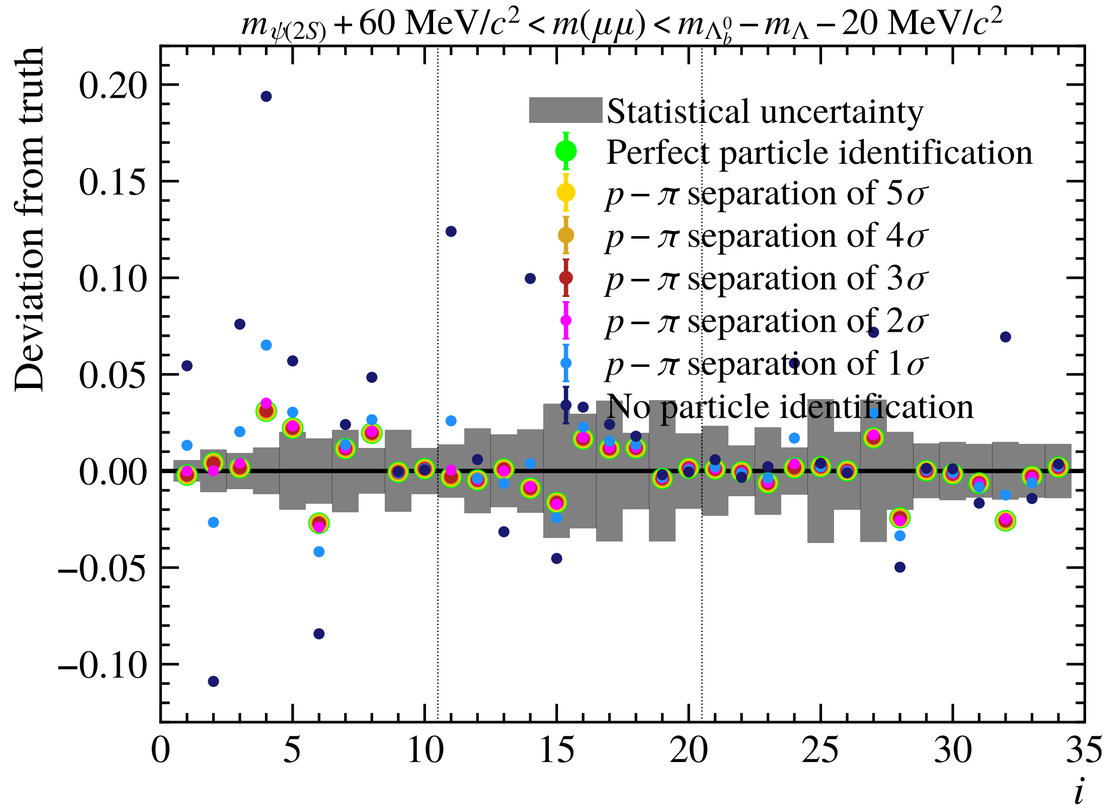
Angular fit in two bins

Yield is similar to LHCb Upgrade 1

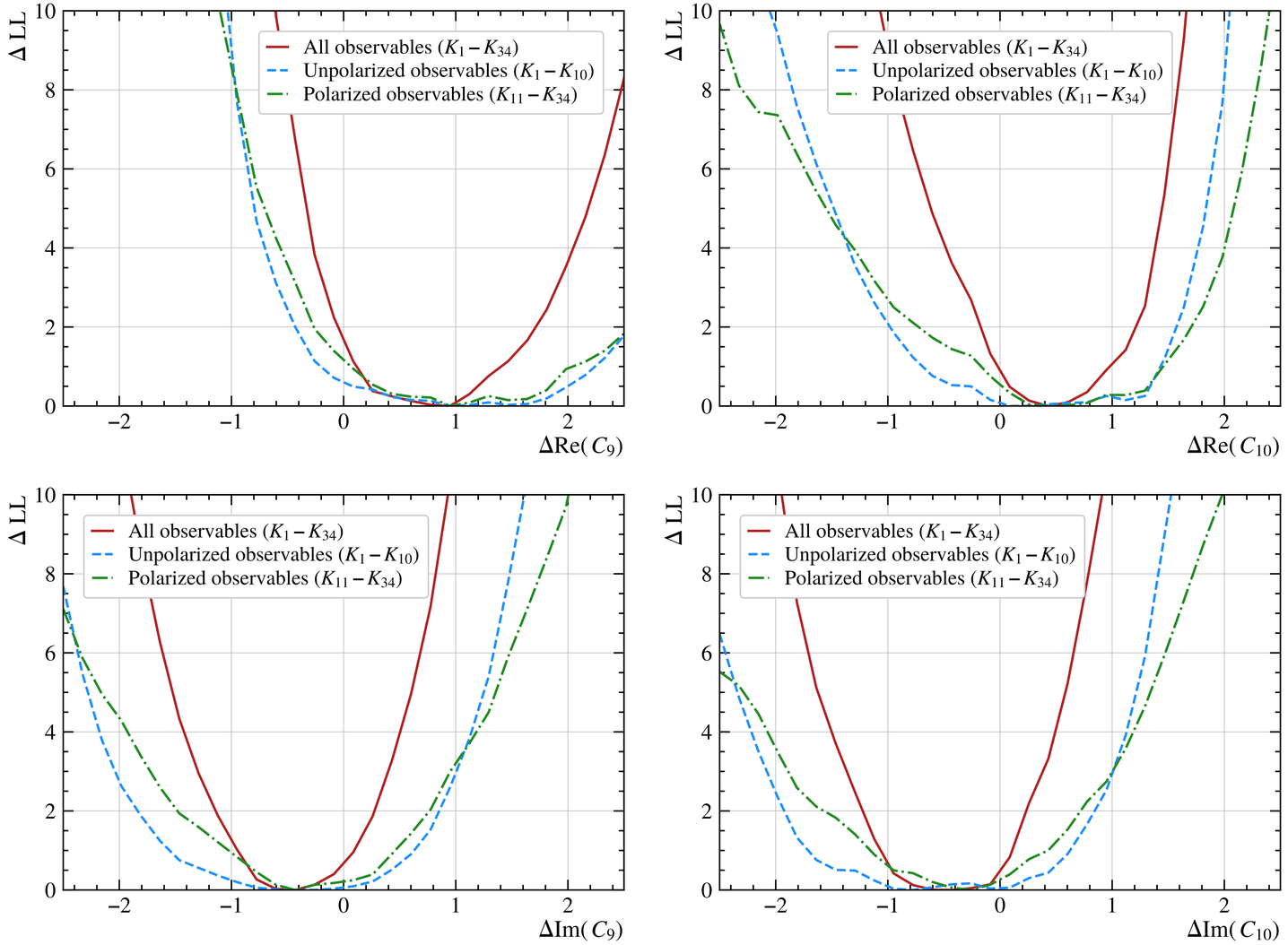
Setup
Unextended maximum likelihood fit
Signal-only
Weighted samples (physics weight and efficiency)

Stat. uncertainty: mean uncertainty in toys
Syst. uncertainty: deviation from truth in large sample





Sensitivity to the Wilson Coefficients



Shift from 0 due to different operator models in simulation and theory fitter

Sensitivity improvement when adding the polarized observables
No “most relevant” observable