Angular distributions for the process:

$$\Lambda_b \to \Lambda_J^*(pK^-)J/\psi(\ell^+\ell^-)$$

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In collaboration with Wei Wang and Zhi-Peng Xing.

The 8th China LHC Physics Workshop
2022-11-25

OutLine

Introduction

- Provide a platform for study of strong interactions.

• Lepton universality

- FCNC of $b \to s\ell^+\ell^-$ sensitive to srarches of physics of BSM ; $1.1 < q^2 < 6.0\ GeV^2/c^4$

$$R_K = \frac{\mathcal{B}(B \to K\mu^+\mu^-)}{\mathcal{B}(B \to Ke^+e^-)}$$

$$= 0.846^{+0.042+0.013}_{-0.039-0.012}$$

$$\boxed{< 1}$$

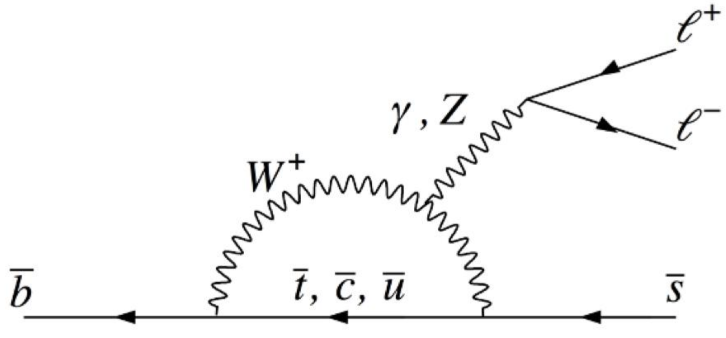
R. Aaij et al. [LHCb], JHEP 08, 055

$$R_{K^*} = \frac{\mathcal{B}(B \to K^*\mu^+\mu^-)}{\mathcal{B}(B \to K^*e^+e^-)}$$

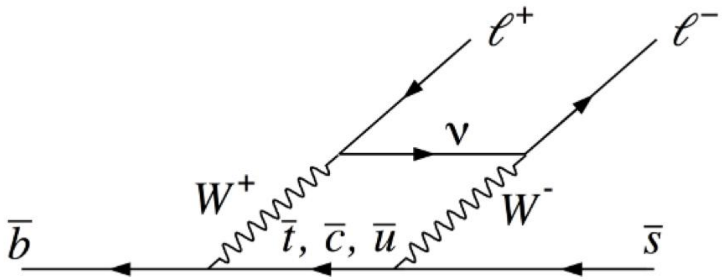
$$= 0.69^{+0.11}_{-0.07} \pm 0.05$$

$$\boxed{< 1}$$

R. Aaij et al. [LHCb], Nature Phys. 18, no.3



Penguin diagram



Box diagram

Introduction:Theoretical and Experimental

✓ Theoretical

✓Quark Model:

Light-Front Quark Model

Covariant Quark Model ....

✓QCD Sum rules(QCDSR)

✓Light-cone Sum rules(LCSR)

✓Lattice QCD (LQCD)

✓ Experimental

PRL **107,** 201802 (2011) PHYSICAL REVIEW LETTERS week ending 11 NOVEMBER 2011

Observation of the Baryonic Flavor-Changing Neutral Current Decay $\Lambda_b^0 \to \Lambda\mu^+\mu^-$

CDF collaboration; PRL 107,201802(2011)

JHEP PUBLISHED FOR SISSA BY SPRINGER

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Differential branching fraction and angular analysis of $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ decays

LHCb collaboration; JHEP 06 (2015), 115

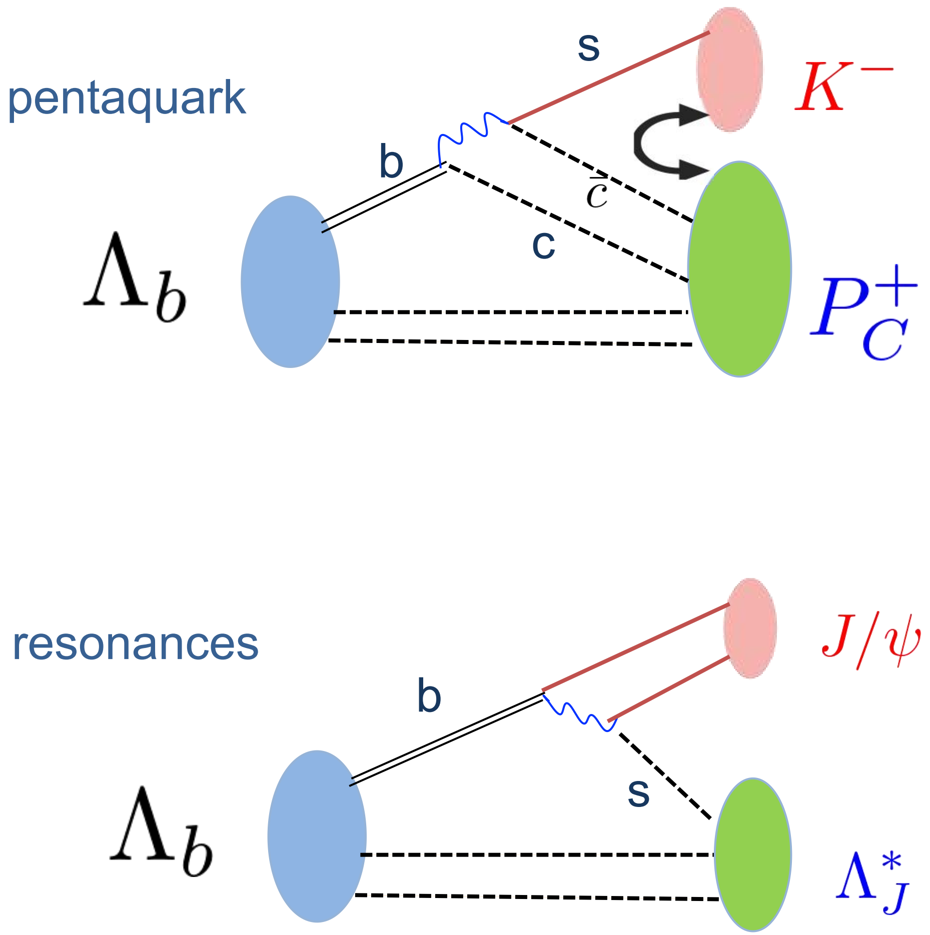
Angular moments of the decay $\Lambda_b^0 \to \Lambda\mu^+\mu^-$ at low hadronic recoil

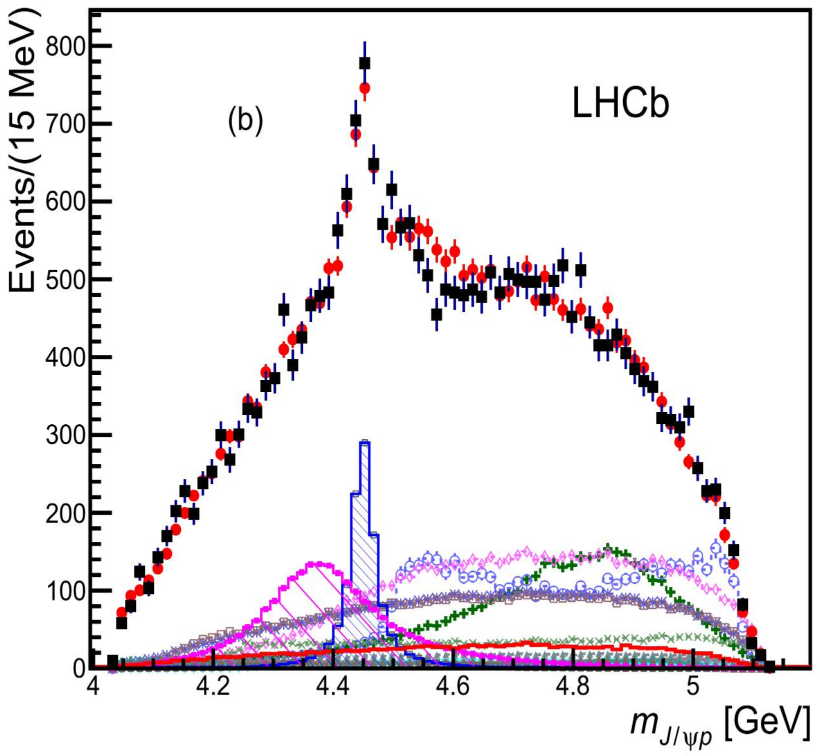
The LHCb collaboration

LHCb collaboration; JHEP 09 (2018), 146

Introduction: pentaquark

- pentaquark production





R. Aaij et al. [LHCb], Phys. Rev. Lett. 115, 072001

R. Aaij et al. [LHCb], Phys. Rev. Lett. 122, no.22, 222001

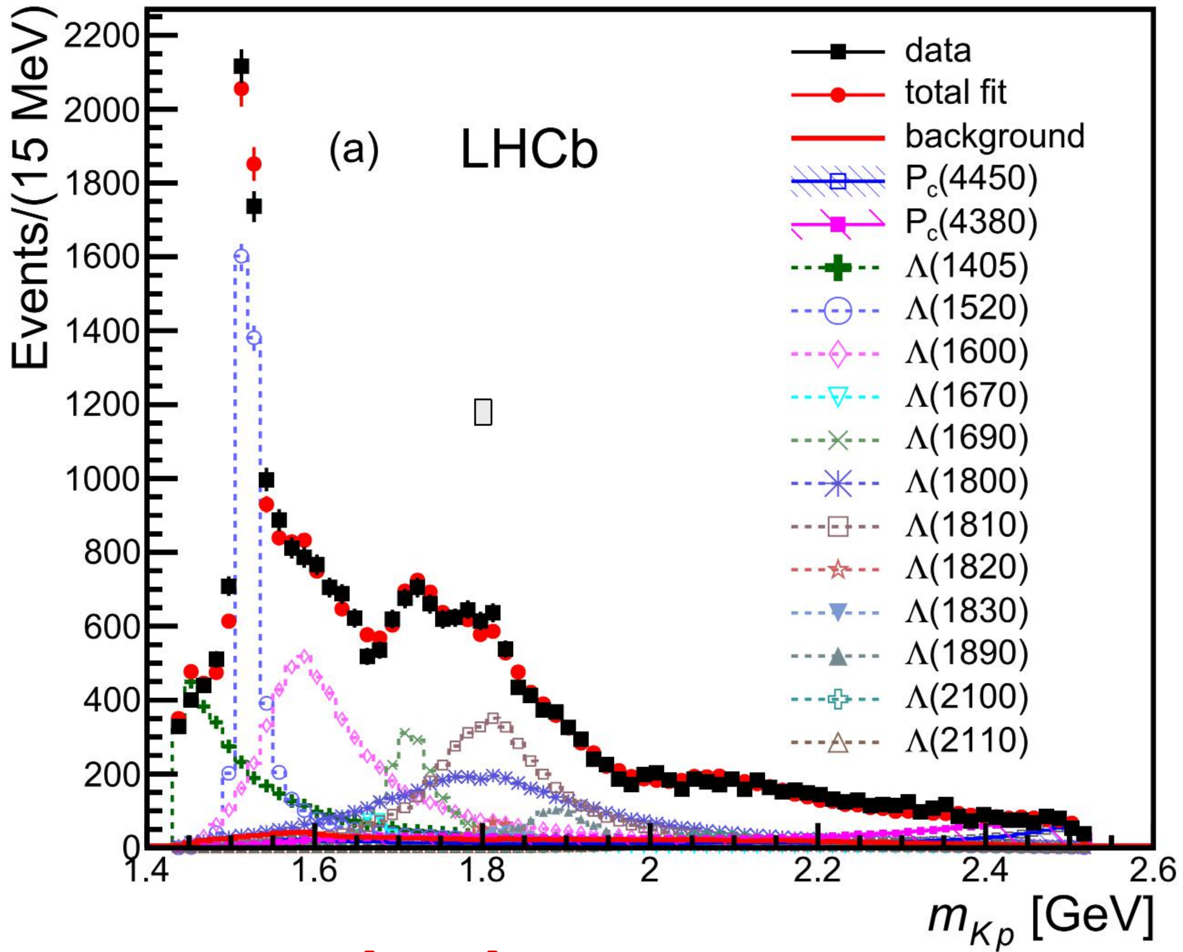
Introduction: Main background

$$\Lambda^*_{1405}, \Lambda^*_{1520}, \Lambda^*_{1600}, \Lambda^*_{1800}, \Lambda^*_{1810}$$

- The resonance decay to P K,
  $m_{\Lambda^*_{1405}} < m_p + m_K$

- Λ^*_{1800} is very close to Λ^*_{1810} , and will be treated together.

- Tiny contribution
  Small integrated width → Λ^*_{1690}



R. Aaij et al. [LHCb], Phys. Rev. Lett. 115, 072001

Introduction: Main background

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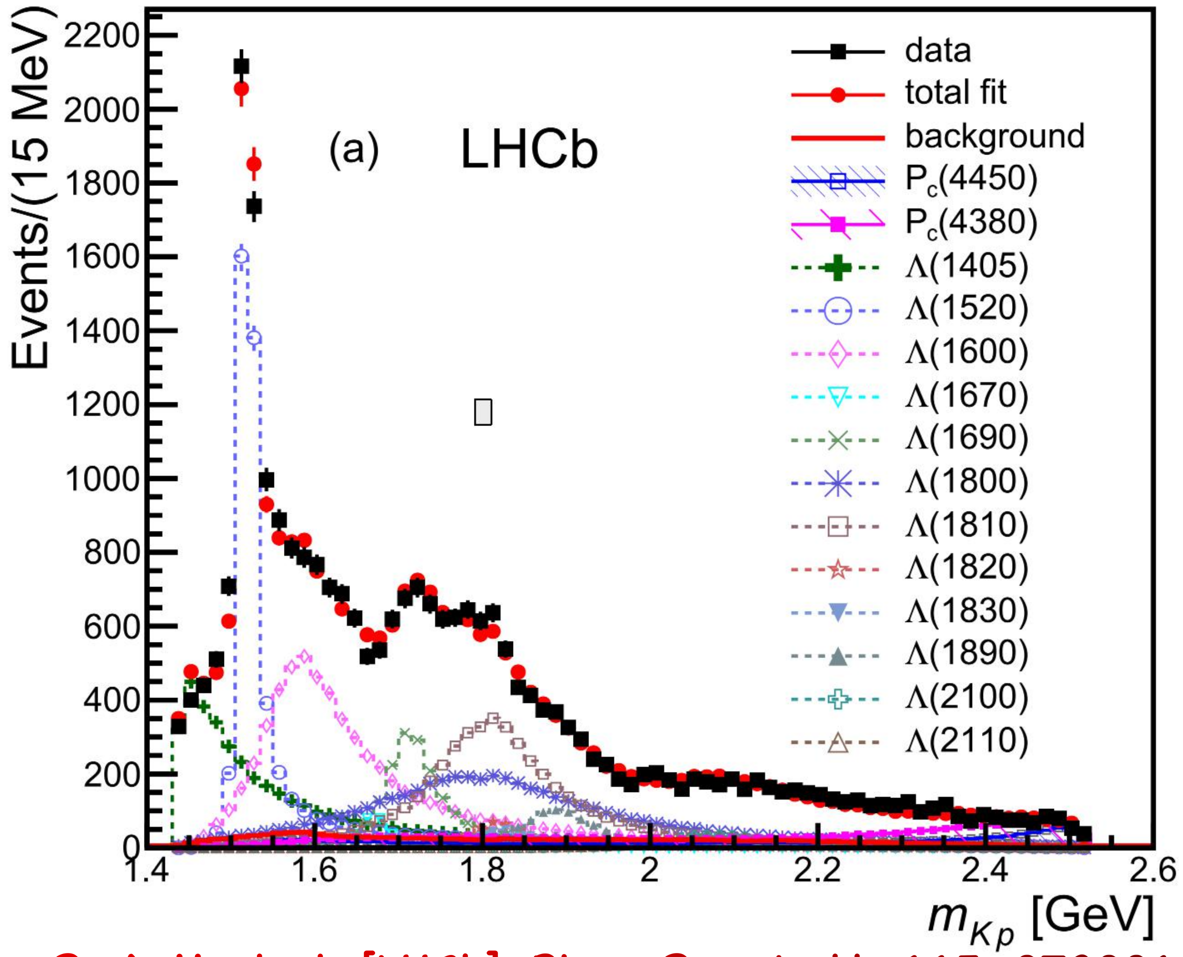
  Small integrated width $\Rightarrow$ Λ^*_{1690}



R. Aaij et al. [LHCb], Phys. Rev. Lett. 115, 072001

Introduction: Main background

$\cancel{\Lambda^*_{1405}}, \Lambda^*_{1520}, \Lambda^*_{1600}, \boxed{\Lambda^*_{1800}, \Lambda^*_{1810}}$

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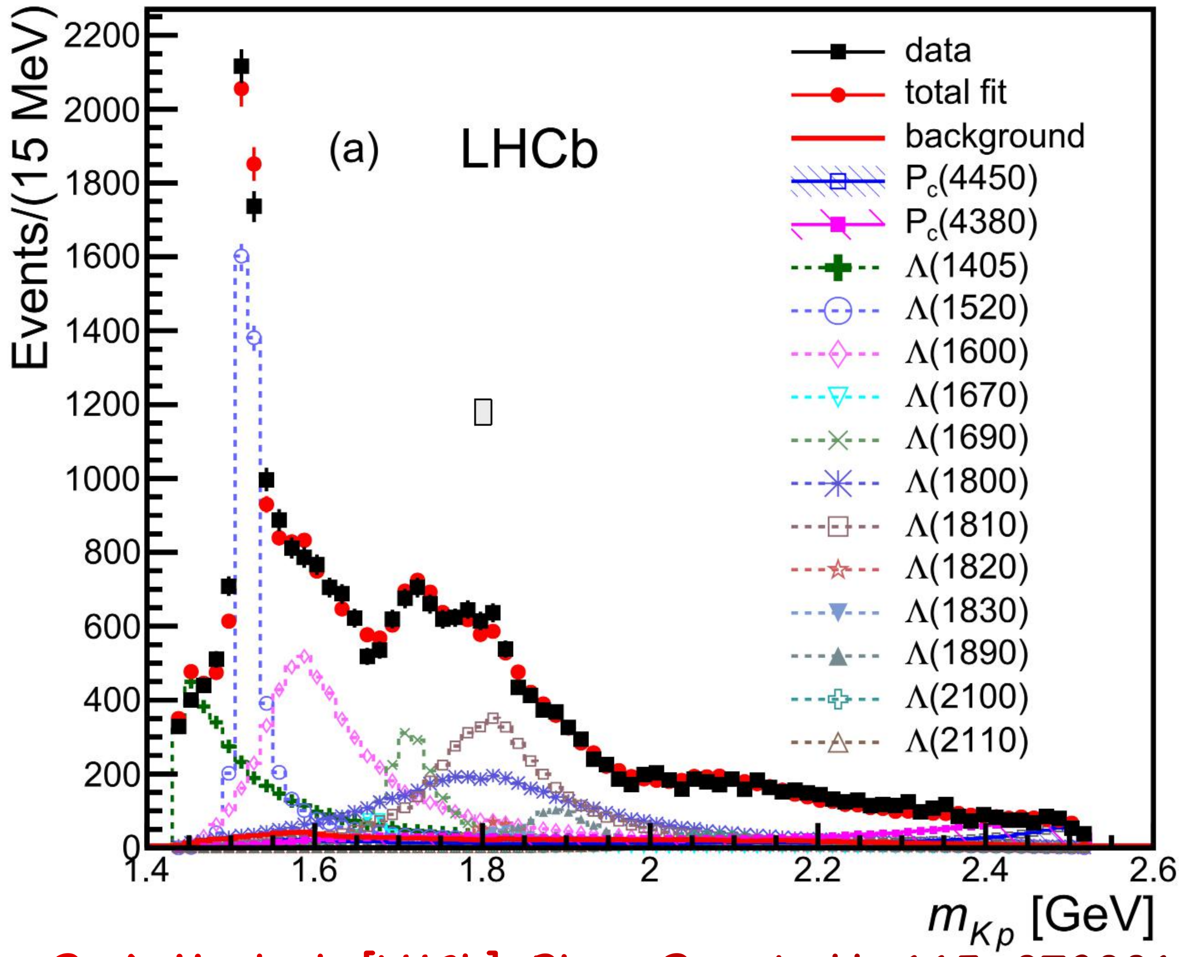


R. Aaij et al. [LHCb], Phys. Rev. Lett. 115, 072001

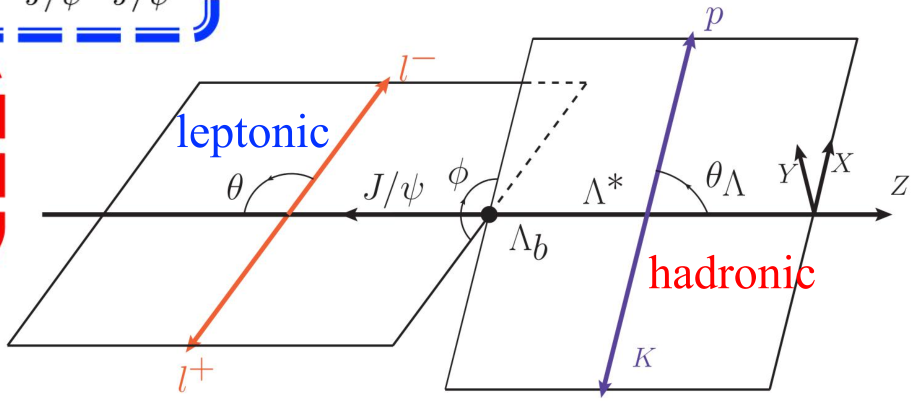
Helicity Amplitude

$$iM(\Lambda_b \to \Lambda_J^*(pK)J/\psi(\ell^+\ell^-)) = \sum_{\Lambda_J^*} \sum_{s_{\Lambda_J^*} s_{J/\psi}} iM(J/\psi \to \ell^+\ell^-)\frac{i}{q^2 - m_{J/\psi}^2 + i m_{J/\psi}\Gamma_{J/\psi}}$$

$$iM(\Lambda_b \to \Lambda_J^* J/\psi)$$ hadron I

$$\frac{i}{p_{\Lambda_J^*}^2 - m_{\Lambda_J^*}^2 + i m_{\Lambda_J^*}\Gamma_{\Lambda_J^*}} iM(\Lambda_J^* \to pK)$$

hadron II



$$\begin{aligned} iM(J/\psi \to \ell^+\ell^-) &= \\ &\langle \ell^+(s_+)\ell^-(s_-)| - igF^{\mu\nu}F'_{\mu\nu}|J/\psi(s_{J/\psi})\rangle \\ &= 2ieg \times \bar{u}(s_-)\gamma^\mu v(s_+)\epsilon_\mu(s_{J/\psi}) \\ &= 2ieg \times L_{s_-,s_+}^{s_{J/\psi}}(\theta,\phi), \end{aligned}$$

$$iM(\Lambda_J^* \to pK) = \boxed{\mathcal{A}_J} \times \left(D_{s_{\Lambda_J^*},s_p}^{J_{\Lambda_J^*}}(\phi_\Lambda,\theta_\Lambda)\right)^*$$

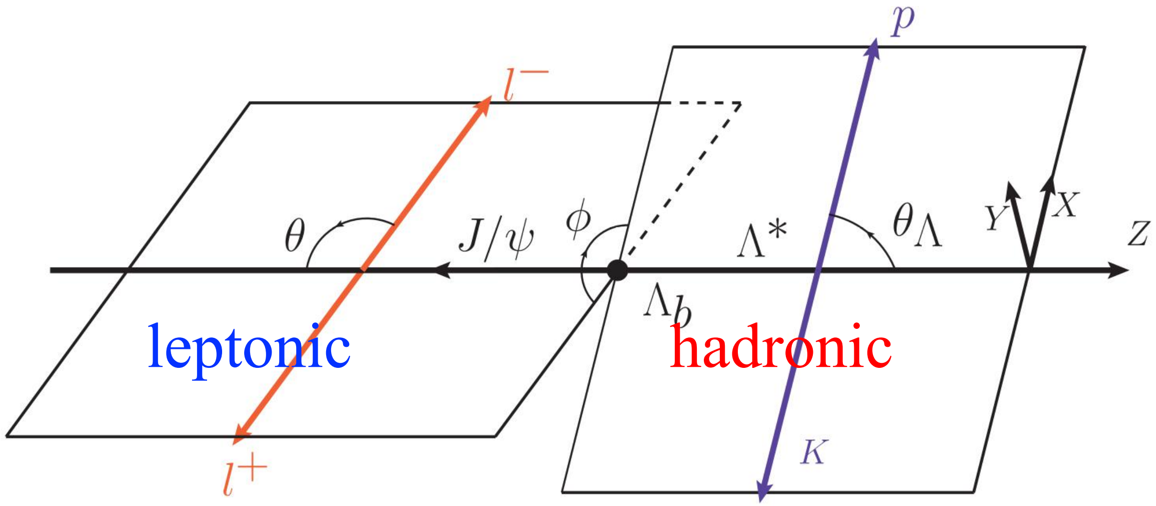
coupling constant

$$g^2 = \frac{3\Gamma(J/\psi \to \ell^+\ell^-)m_{J/\psi}^2}{4\alpha_{em}(m_{J/\psi}^2 + 2m_\ell^2)\sqrt{m_{J/\psi}^2 - 4m_\ell^2}}.$$

$$\mathcal{A}_J = \sqrt{\Gamma(\Lambda_J^* \to pK)16\pi m_{\Lambda_J^*}^2/|\vec{p}_p|}, \quad J = 1520$$

$$\mathcal{A}_J = \sqrt{\Gamma(\Lambda_J^* \to pK)8\pi m_{\Lambda_J^*}^2/|\vec{p}_p|}, \quad J = 1600, 1800$$

Phenomenological



$$\mathcal{M}(\Lambda_b \to \Lambda_J^* J/\psi) = \frac{G_F}{\sqrt{2}} V_{cb} V_{cs}^* a_2 f_{J/\psi} m_{J/\psi} \langle \Lambda_J^* | \bar{s}\gamma^\mu (1-\gamma_5) b | \Lambda_b \rangle \epsilon_\mu^*(s_{J/\psi}),$$

$$a_2 = C_1 + C_2/N_c, ,$$

$$C_1(m_b) = -0.248 \text{ and } C_2(m_b) = 1.107$$

Helicity Amplitude: Handronic matrix element

➢ Spin-1/2 baryon

$$\langle \Lambda_J^*(p', s')|\bar{s}\gamma^\mu b|\Lambda_b(p, s)\rangle \;=$$

$$\bar{u}(p', s')\big(\gamma_\mu f_1^p + \frac{p^\mu_{\Lambda_b}}{m_{\Lambda_b}} f_2^p + \frac{p^\mu_{\Lambda_J^*}}{m_{\Lambda_J^*}} f_3^p\big)u(p, s)$$

vector

$$\langle \Lambda_J^*(p', s')|\bar{s}\gamma^\mu \gamma_5 b|\Lambda_b(p, s)\rangle \;=$$

$$\bar{u}(p', s')\big(\gamma_\mu g_1^p + \frac{p^\mu_{\Lambda_b}}{m_{\Lambda_b}} g_2^p + \frac{p^\mu_{\Lambda_J^*}}{m_{\Lambda_J^*}} g_3^p\big)\gamma_5 u(p, s)$$

axial-vector

➢ MCN model

$$f(M_{pK}^2) = (a_0 + a_2 p_\Lambda^2 + a_4 p_\Lambda^4)\exp\left(-\frac{6m_q^2 p_\Lambda^2}{2\tilde{m}_\Lambda{}^2(\alpha_{\Lambda_b}^2 + \alpha_{\Lambda^*}^2)}\right)$$

Λ^*_{1600}			
form factor	a_0	a_2	a_4
f_1^+	0.467	0.615	0.0568
f_2^+	-0.381	-0.2815	-0.0399
f_3^+	0.0501	-0.0295	-0.00163
g_1^+	0.114	0.300	0.0206
g_2^+	-0.394	-0.307	-0.0445
g_3^+	-0.0433	0.0478	0.00566
$\alpha_{\Lambda*(1600)} = 0.387$			

L. Mott and W. Roberts, Int. J. Mod. Phys. A 27, 1250016 (2012)

Helicity Amplitude: Handronic matrix element

➤ Spin-3/2 baryon:Helicity-base

$$\langle \Lambda^*_{1520}(p', s')|\bar{s}\gamma^\mu b|\Lambda_b(p, s)\rangle \; =$$

$$\bar{u}_\lambda(p', s')\Bigg(f_0^{3/2}\frac{m_{\Lambda^*_{1520}}}{s_{p+}}\frac{(m_{\Lambda_b} - m_{\Lambda^*_{1520}})p^\lambda q^\mu}{q^2}$$

$$+f_+^{3/2}\frac{m_{\Lambda^*_{1520}}}{s_{p-}}\frac{(m_{\Lambda_b} + m_{\Lambda^*_{1520}})p^\lambda(q^2(p^\mu + p'^\mu) - q^\mu(m^2_{\Lambda_b} - m^2_{\Lambda^*_{1520}}))}{q^2 s_{p+}}$$

$$+f_\perp^{3/2}\frac{m_{\Lambda^*_{1520}}}{s_{p-}}(p^\lambda\gamma^\mu - \frac{2p^\lambda(m_{\Lambda_b}p'^\mu + m_{\Lambda^*_{1520}}p^\mu)}{s_{p+}})$$

$$+f_{\perp'}^{3/2}\frac{m_{\Lambda^*_{1520}}}{s_{p-}}(p^\lambda\gamma^\mu - \frac{2p^\lambda p'^\mu}{m_{\Lambda^*_{1520}}} + \frac{2p^\lambda(m_{\Lambda_b}p'^\mu + m_{\Lambda^*_{1520}}p^\mu)}{s_{p+}} + \frac{s_{p-}g^{\lambda\mu}}{m_{\Lambda^*_{1520}}})\Bigg)u(p, s)$$

vector

➤ LQCD

$$f(M^2_{pK}) = F + A(\omega - 1)$$

Lattic QCD		
form factor	F	A
$f_0^{3/2}$	3.54(29)	−14.7(3.3)
$f_+^{3/2}$	0.0432(64)	1.63(19)
$f_\perp^{3/2}$	−0.068(18)	2.49(35)
$f_{\perp'}^{3/2}$	0.0461(18)	−0.161(27)
$g_0^{3/2}$	0.0024(38)	1.58(17)
$g_+^{3/2}$	2.95(25)	−12.2(2.9)
$g_\perp^{3/2}$	2.92(24)	−11.8(2.8)
$g_{\perp'}^{3/2}$	−0.037(14)	0.09(25)

S. Meinel and G. Rendon, Phys. Rev. D 105, no.5, 054511 (2022)

Phenomenological

$$\frac{d\Gamma(\Lambda_b \to \Lambda_J^*(pK)J/\psi(\ell^+\ell^-))}{d\cos\theta d\cos\theta_\Lambda d\phi dM_{pK}^2} = \frac{3\sqrt{\lambda}|\vec{p}_p|}{16384\pi^4 m_{\Lambda_b}^3 m_{\Lambda_J^*}(m_{J/\psi}^2 + 2m_\ell^2)}$$

$$\times \frac{1}{2} \sum_{s_{\Lambda_b}, s_p, s_+, s_-} \mathcal{B}(J/\psi \to \ell^+\ell^-) \underbrace{|L_{s_-,s_+}^{s_{J/\psi}}(\phi,\theta)}_{\text{leptonic}} \underbrace{\mathcal{A}_{s_p,s_{J/\psi}}^{s_{\Lambda_b}}(\theta_\Lambda)|^2}_{\text{hadronic}}$$

$$= \mathcal{P}\Big(L_{11} + \cos\theta_\Lambda L_{12} + \cos 2\theta_\Lambda L_{13} + \cos 2\phi(L_{21} + \cos 2\theta_\Lambda L_{22})$$

$$+ \cos 2\theta(L_{31} + \cos\theta_\Lambda L_{32} + \cos 2\theta_\Lambda L_{33}) + \sin 2\theta \cos\phi(\sin\theta_\Lambda L_{41} + \sin 2\theta_\Lambda L_{42})$$

$$+ \cos 2\phi \cos 2\theta(L_{51} + \cos 2\theta_\Lambda L_{52}) + \sin 2\theta \sin\phi(\sin\theta_\Lambda L_{61} + \sin 2\theta_\Lambda L_{62})$$

$$L_{11} = \frac{1}{16}(9\boxed{|H^{\frac{3}{2}}_{\frac{1}{2},\frac{3}{2}}|^2 + 16|H^{\frac{1}{2}}_{\frac{1}{2},\frac{1}{2}}|^2} + 10|H^{\frac{3}{2}}_{\frac{1}{2},\frac{1}{2}}|^2 + 15|H^{\frac{3}{2}}_{\frac{1}{2},-\frac{1}{2}}|^2 + 24|H^{\frac{1}{2}}_{\frac{1}{2},-\frac{1}{2}}|^2) + \ldots$$

$$L_{21} = \frac{\sqrt{3}}{8}(4\hat{m}_\ell^2 - 1)\boxed{\mathcal{R}_e(H^{\frac{3}{2}}_{\frac{1}{2},\frac{3}{2}} H^{\frac{3}{2}*}_{\frac{1}{2},-\frac{1}{2}})} + \quad \ldots$$

Phenomenological

➢ differential decay width:

$$d\Gamma(\Lambda_b \to \Lambda_J^*(pK)J/\psi(\ell^+\ell^-))/dM_{pK}^2 \;=\; \mathcal{P}\frac{8\pi}{9}\left(9L_{11} - 3L_{13} - 3L_{31} + L_{33}\right)$$

Lattice QCD:

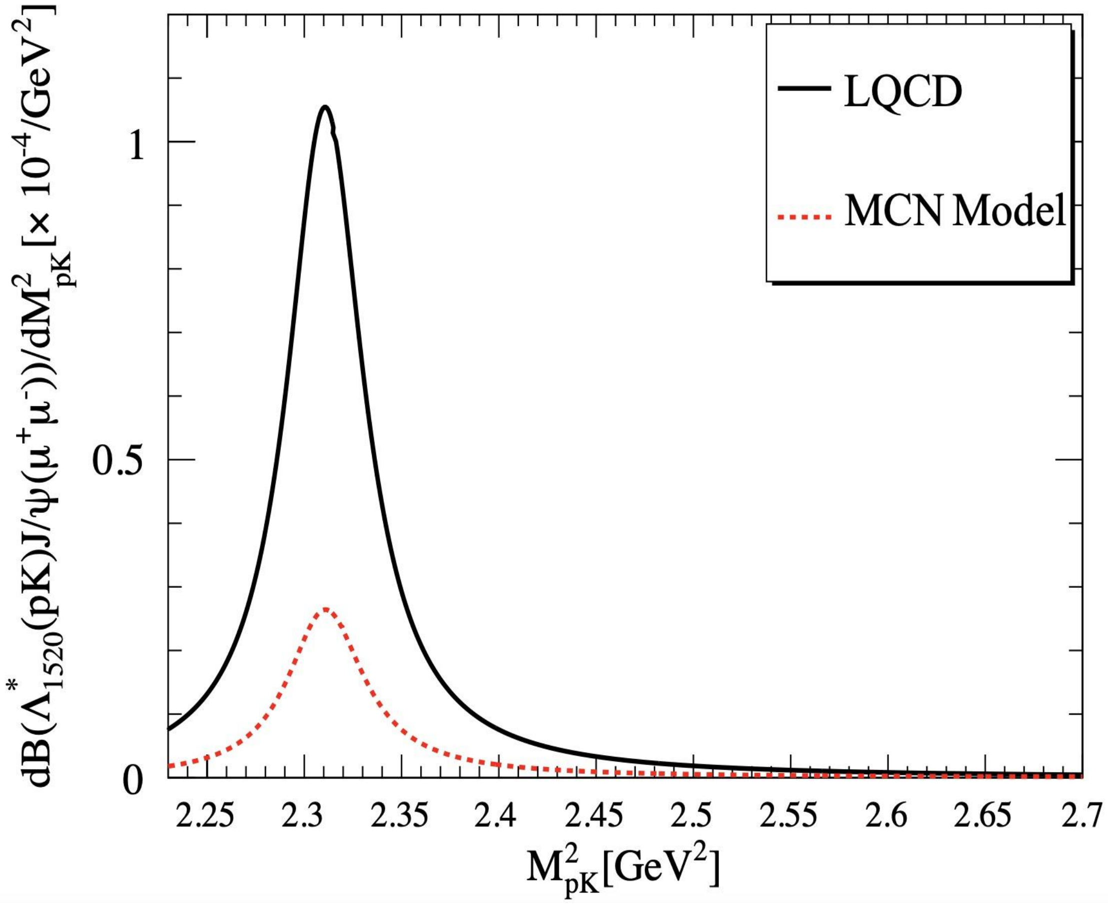
$$\mathcal{B}(\Lambda_b \to \Lambda_{1520}^*(pK)J/\psi(\mu^+\mu^-)) = (7.22 \pm 2.53) \times 10^{-6}$$

MCN model:

$$\mathcal{B}(\Lambda_b \to \Lambda_{1520}^*(pK)J/\psi(\mu^+\mu^-)) = \;1.904 \times 10^{-6}$$

$$\mathcal{B}(\Lambda_b \to \Lambda_{1600}^*(pK)J/\psi(\mu^+\mu^-)) = 1.11 \times 10^{-6}$$

$$\mathcal{B}(\Lambda_b \to \Lambda_{1800}^*(pK)J/\psi(\mu^+\mu^-)) = 3.87 \times 10^{-6}$$



Phenomenological

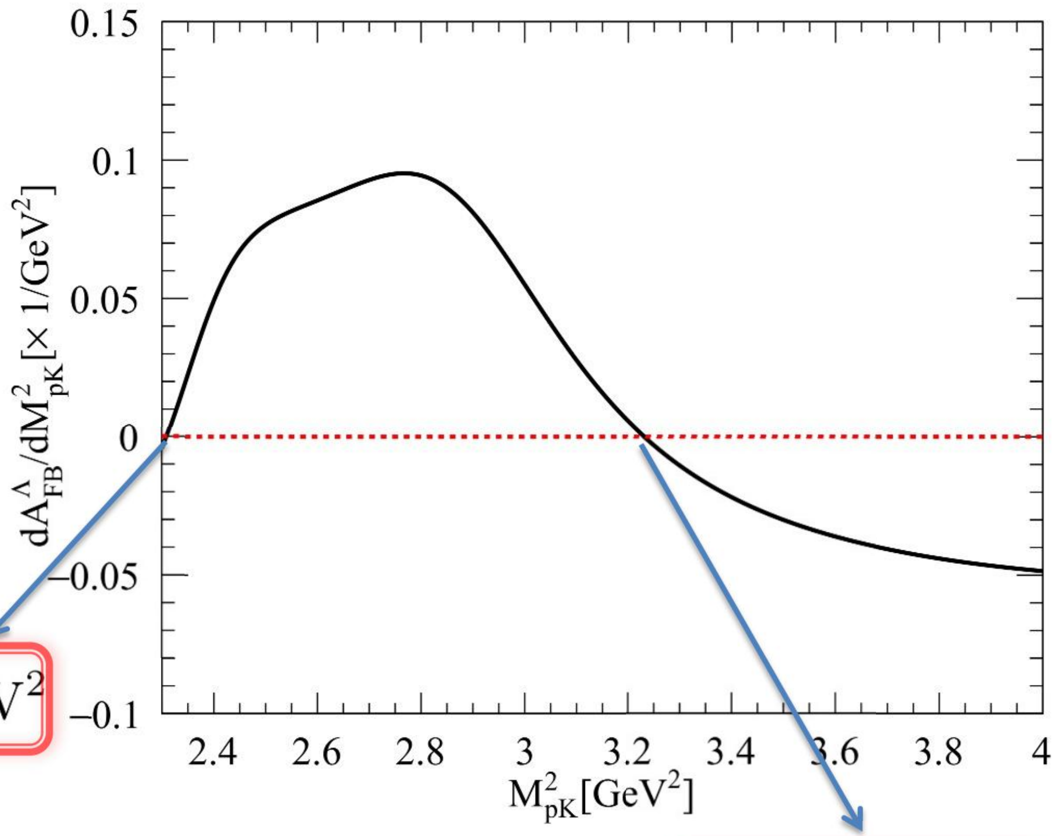
$$A_{FB}^{\Lambda} = \frac{\left[\int_0^1 - \int_{-1}^0\right] d\cos\theta_\Lambda \frac{d^2\Gamma}{dM_{pK}^2 d\cos\theta_\Lambda}}{\left[\int_0^1 + \int_{-1}^0\right] d\cos\theta_\Lambda \frac{d^2\Gamma}{dM_{pK}^2 d\cos\theta_\Lambda}}$$

$$\frac{dA_{FB}^{\Lambda}}{dM_{pK}^2} \propto \sum_{s_{\Lambda_b}, s_{\Lambda_J^*} = \pm\frac{1}{2}} (2\hat{m}_\ell^2 + 1) \boxed{\mathcal{R}_e(H^{\frac{3}{2}}_{s_{\Lambda_b}, s_{\Lambda_J^*}} H^{\frac{1}{2}*}_{s_{\Lambda_b}, s_{\Lambda_J^*}})}$$

neglect Λ^*_{1600} contribution

$$\frac{dA_{FB}^{\Lambda}}{dM_{pK}^2} \propto \mathcal{R}_e(L_{\Lambda^*_{1520}} L_{\Lambda^*_{1800}})$$

$$\frac{dA_{FB}^{\Lambda}}{dM_{pK}^2} \propto \underline{(M_{pK}^2 - m^2_{\Lambda^*_{1520}})(M_{pK}^2 - m^2_{\Lambda^*_{1800}})} = 0$$



$\boxed{s_0^1 = 2.307\mathrm{GeV}^2}$

$\boxed{s_0^2 = 3.231\mathrm{GeV}^2}$

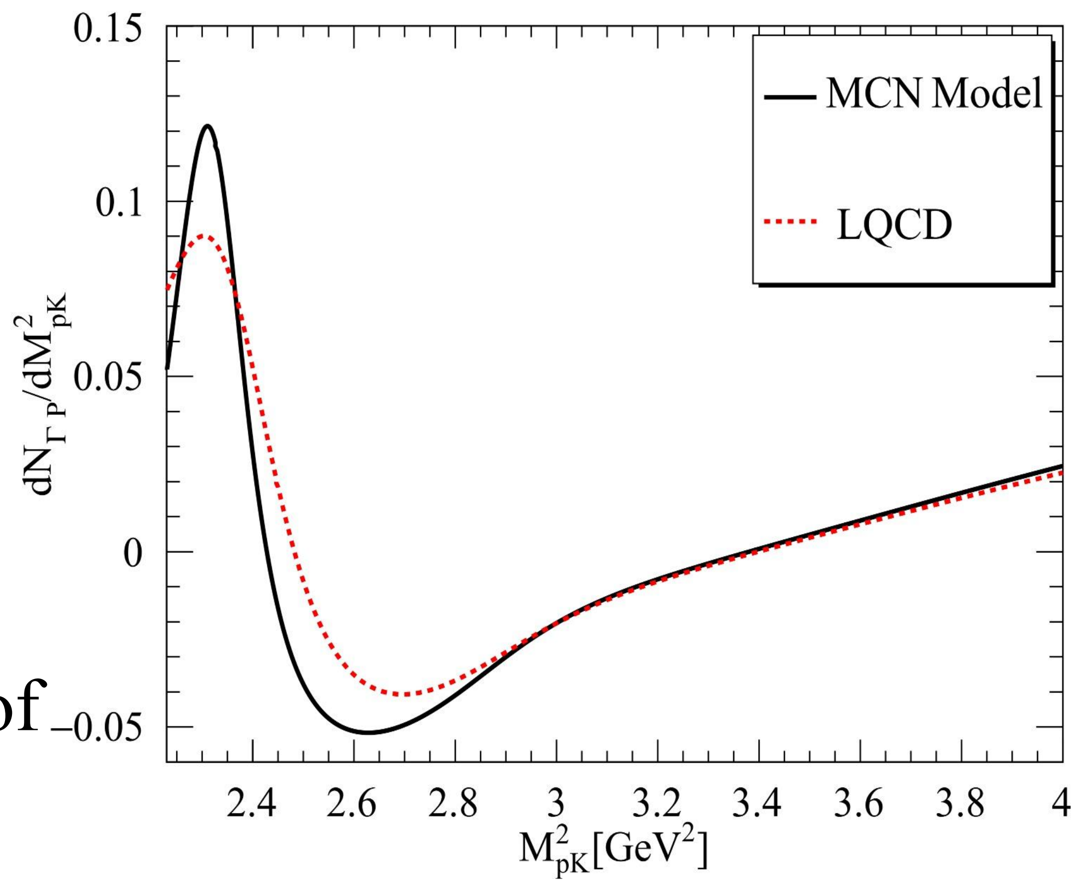
Phenomenological

- normalized polarised decay width

$$\frac{dN_{\Gamma_P}}{dM_{pK}^2} = \frac{\frac{d\Gamma(\frac{1}{2})}{dM_{pK}^2} - \frac{d\Gamma(-\frac{1}{2})}{dM_{pK}^2}}{\frac{d\Gamma(\frac{1}{2})}{dM_{pK}^2} + \frac{d\Gamma(-\frac{1}{2})}{dM_{pK}^2}}$$

- s=1/2 is larger than s=-1/2 in low range

- mainly contributed by the interference of vector and axial-vector



polarized decay width is important observable for study hadron matrix element

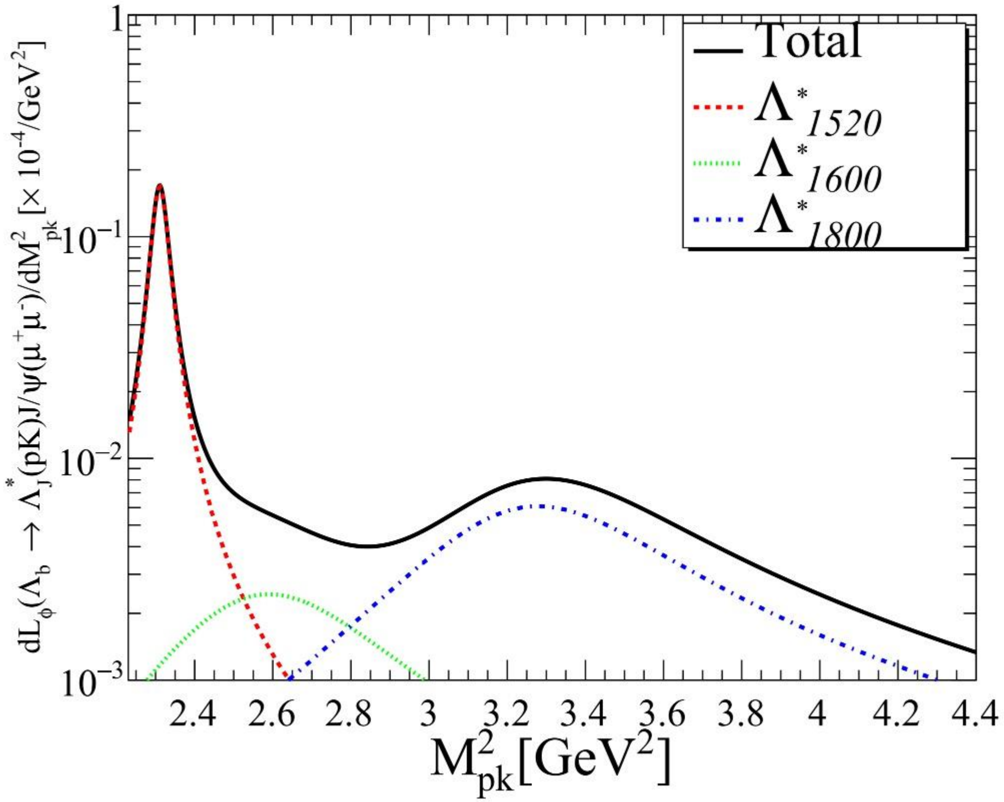
Summary

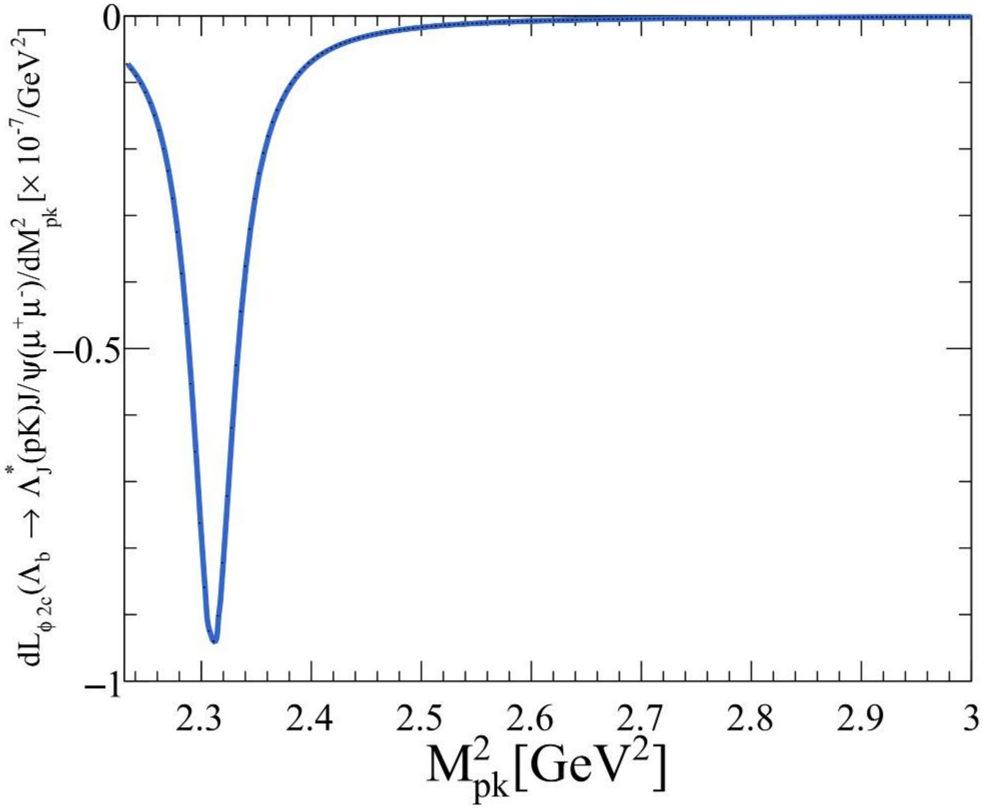
- We have derived the angular distribution with three resonances;
- Obtain phenomenological results: partial decay width, forward-backward asymmetry, polarisation;
- Serve as a calibration for the study of $b \to s\bar{\mu}\mu$ decay in Λ_b decays.

Thanks!

Backup

Phenomenological

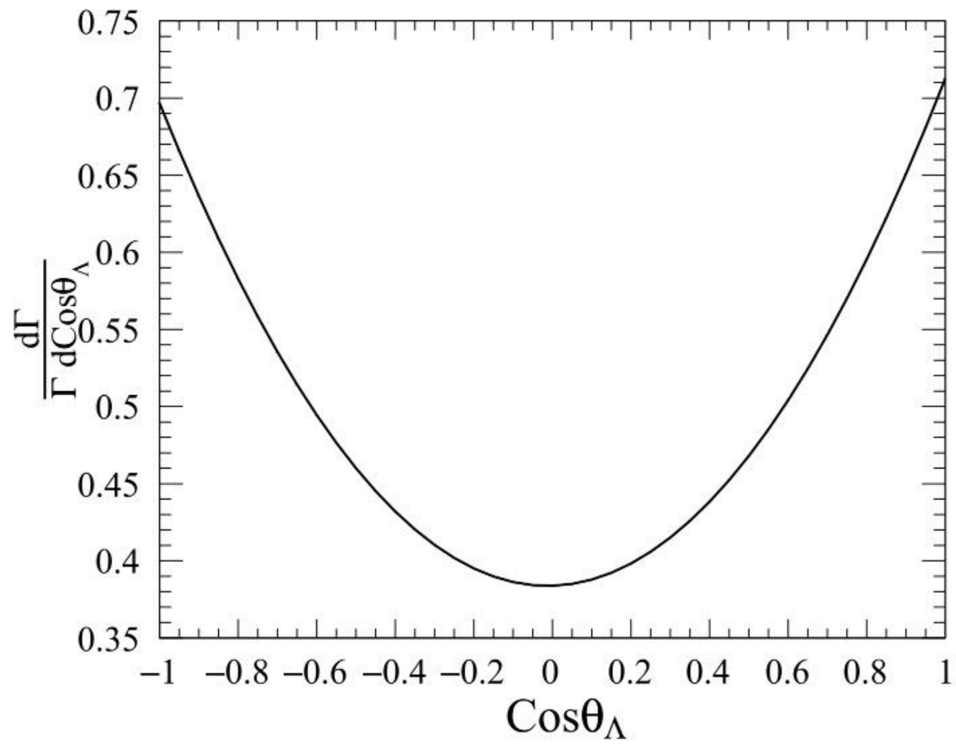




Phenomenological

$$\frac{d\Gamma(\Lambda_b \to \Lambda_J^*(pK)J/\psi(\ell^+\ell^-))}{\Gamma dM_{pK}^2 d\cos\theta_\Lambda} =$$

$$\left(L_\Lambda + L_{\Lambda c}\cos\theta_\Lambda + L_{\Lambda 2c}\cos 2\theta_\Lambda\right)/\Gamma$$



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