Revised strategy for determination of hyperon decay parameters

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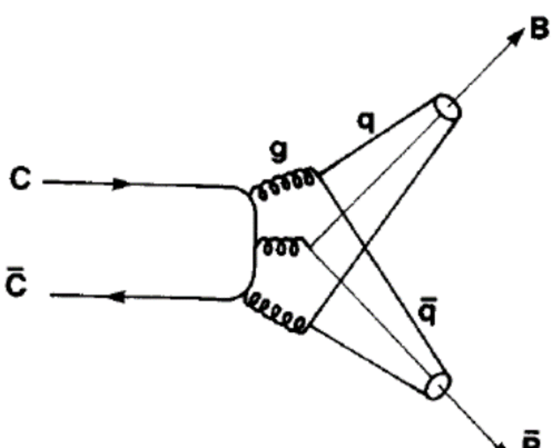
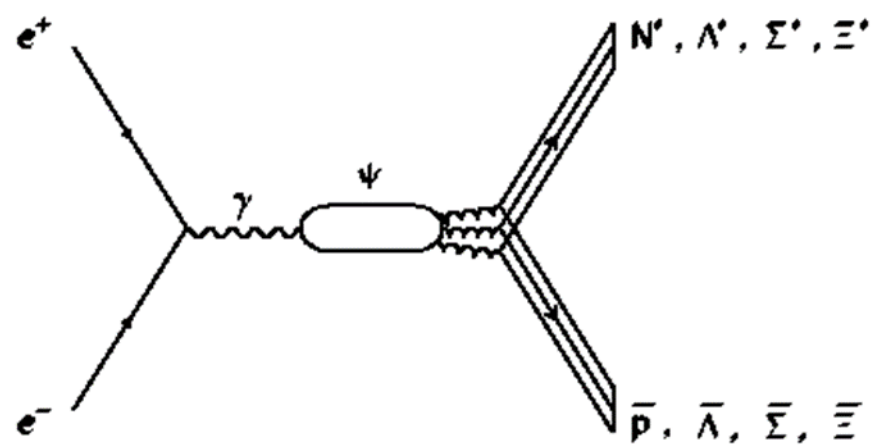
Assumption that baryons from J/ψ and ψ(3686) decays into baryon-antibaryon are unpolarized has to be revised:

Göran Fäldt, AK arXiv:1702.07288
Phys.Lett. B772 (2017) 16

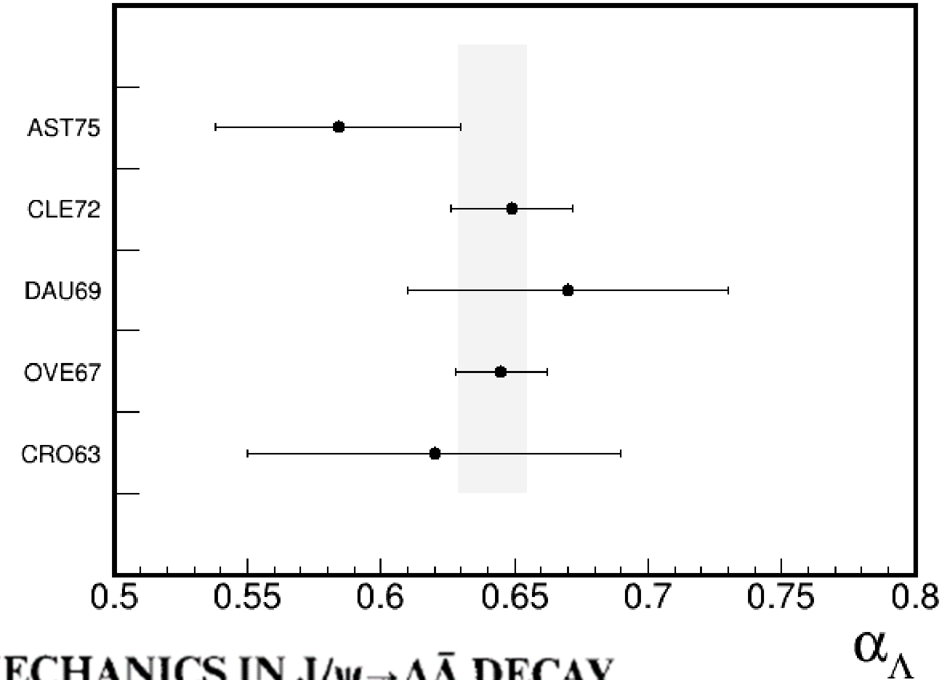
Nothing prevents hyperons from decays of 1^{--} states to be polarized orthogonally to the production plane





Lambda decay parameters

$$\alpha_\Lambda = 0.642 \pm 0.013$$



LOOKING AT *CP* INVARIANCE AND QUANTUM MECHANICS IN $J/\psi \to \Lambda\bar{\Lambda}$ DECAY

DM2 Coll. (1988) Phys. Lett. B 212, 523

BES, Phys.Rev. D81 (2010) 012003

$$A = \frac{\alpha_1 + \alpha_2}{\alpha_1 - \alpha_2}\left[= \frac{\alpha_\Lambda + \alpha_{\bar{\Lambda}}}{\alpha_\Lambda - \alpha_{\bar{\Lambda}}}\right]$$

	$\alpha_{\bar{\Lambda}}(\bar{\Lambda} \to \bar{p}\pi^+)$	A
DM2	-0.63 ± 0.13	0.01 ± 0.10
BES	$-0.755 \pm 0.083 \pm 0.063$	$-0.081 \pm 0.055 \pm 0.059$

1847 $\Lambda\bar{\Lambda}$

8997 $\Lambda\bar{\Lambda}$

$A = 0,$ => $\alpha_\Lambda = -\alpha_{\bar{\Lambda}} = 0.696 \pm 0.038$

Lambda decay parameters

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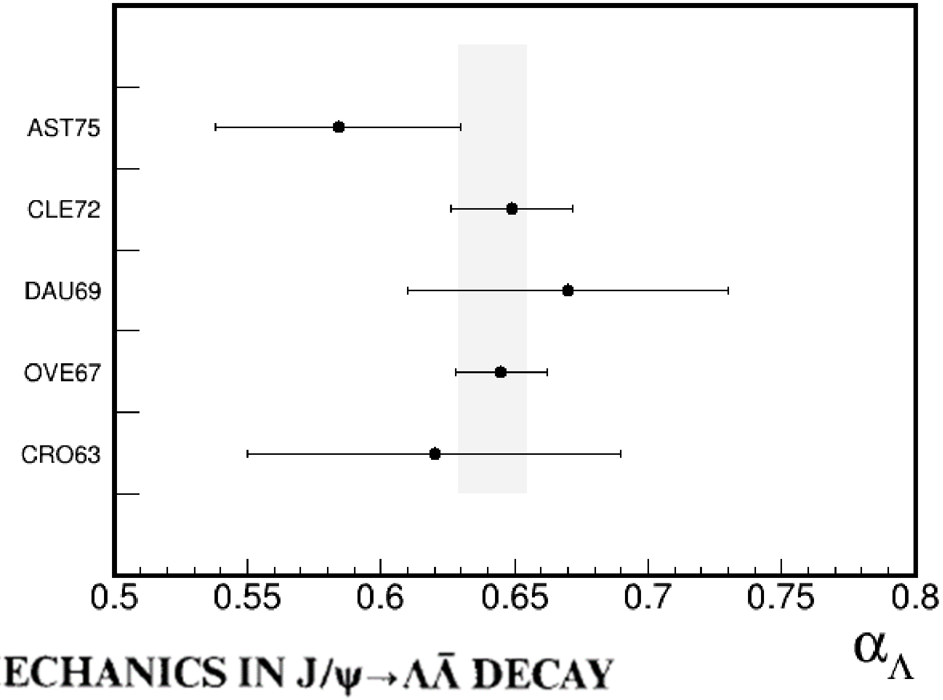

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BESIII $0.4 \cdot 10^6$

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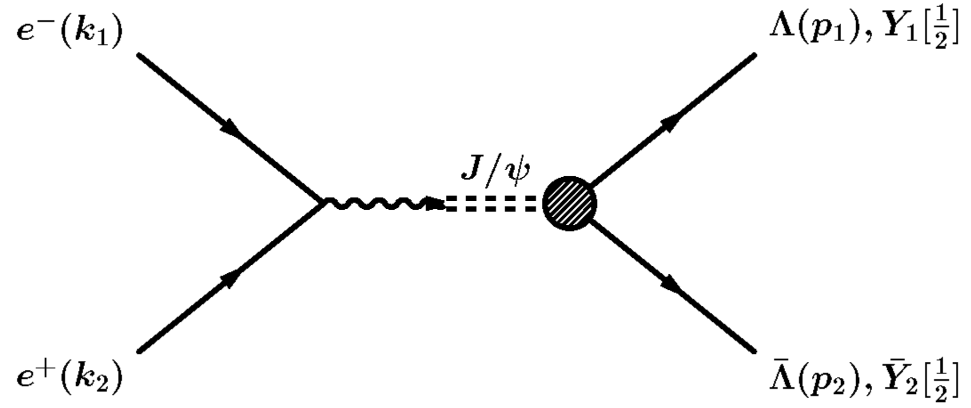
Formalism for $e^+e^- \to \gamma^* \to J/\psi \to \Lambda\bar{\Lambda}$



Special case of a well established formalism for baryon FFs

Dubnickova, Dubnicka, Rekalo
Nuovo Cim. A109 (1996) 241
Gakh, Tomasi-Gustafsson Nucl.Phys. A771 (2006) 169
Czyz, Grzelinska, Kuhn PRD75 (2007) 074026
Fäldt EPJ A51 (2015) 74; EPJ A52 (2016)141

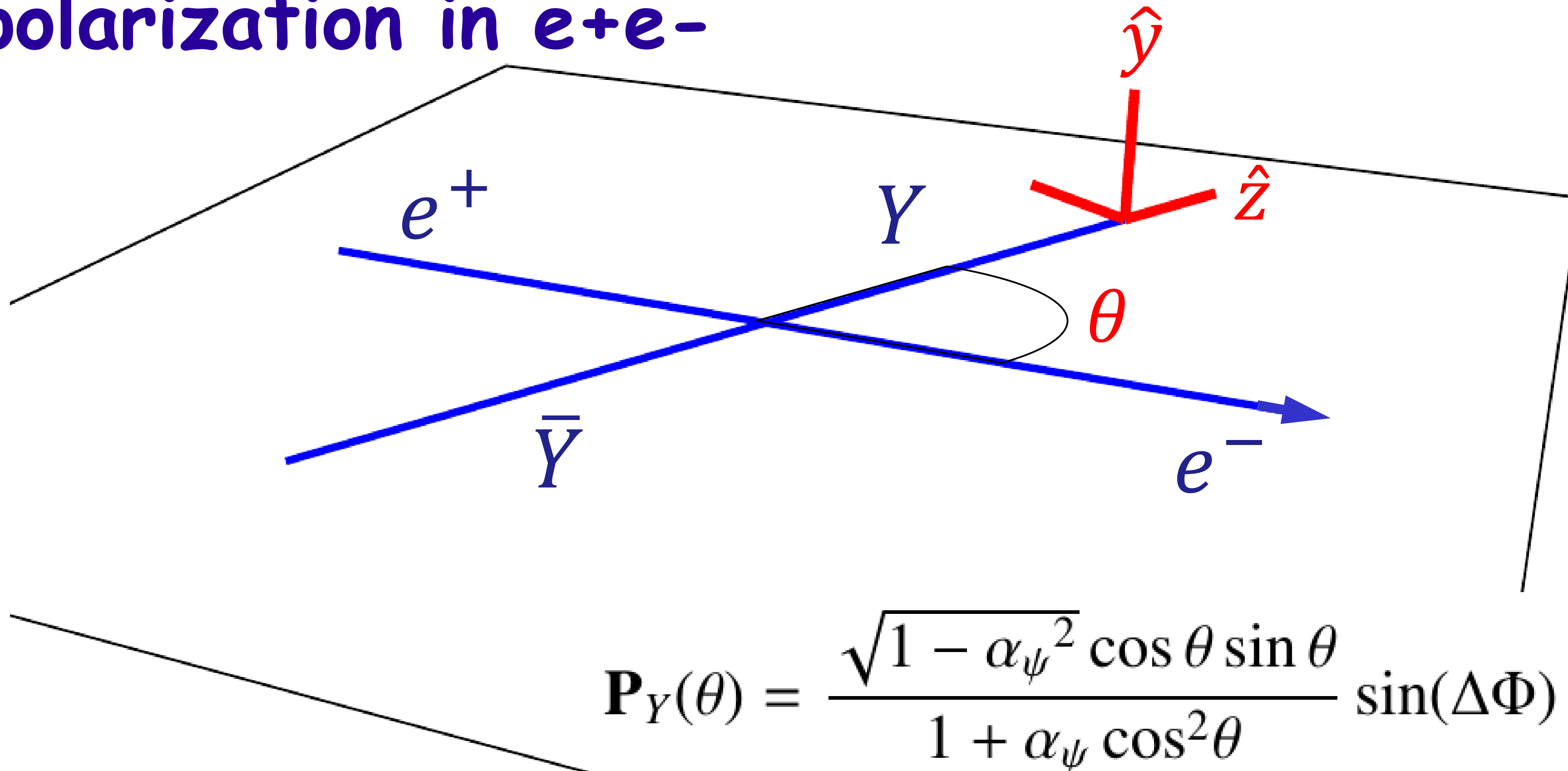
$$\Gamma^{\Lambda}_{\mu}(p_1, p_2) = -ie_g\Big[G^{\psi}_M\gamma_\mu - \frac{2M}{Q^2}(G^{\psi}_M - G^{\psi}_E)Q_\mu\Big]$$

$$Q = p_1 - p_2$$

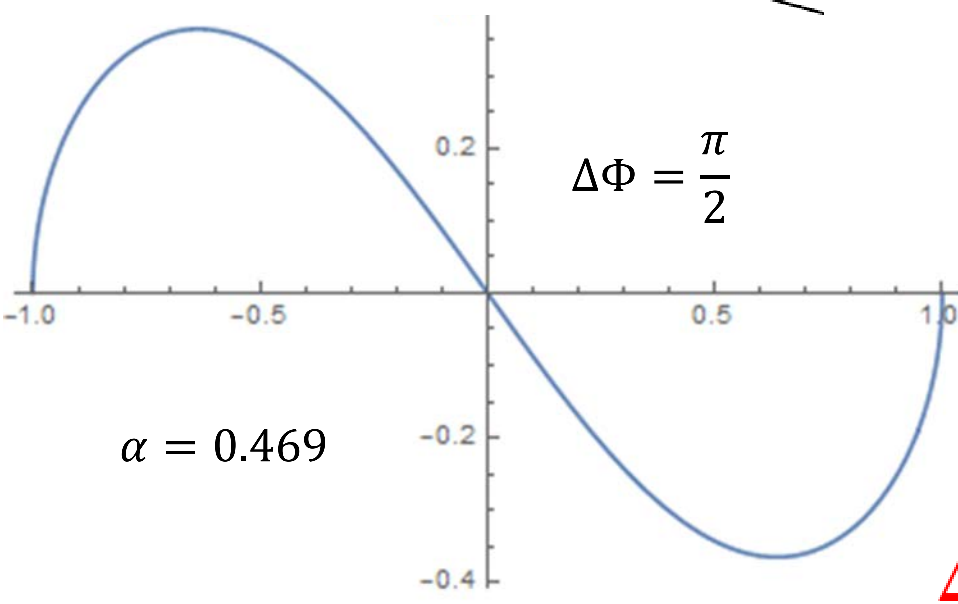
form factors: G^{ψ}_M and G^{ψ}_E $\quad G^{\psi}_E = \frac{\sqrt{s}}{2M_\Lambda}\sqrt{\frac{1-\alpha_\psi}{1+\alpha_\psi}}\, e^{i\Delta\Phi}\, G^{\psi}_M$

$$\frac{d\Gamma}{d\Omega} \propto 1 + \alpha_\psi \cos^2\theta \qquad -1 < \alpha_\psi < 1$$

Y polarization in e+e-



$$\mathbf{P}_Y(\theta) = \frac{\sqrt{1-\alpha_\psi{}^2}\cos\theta\sin\theta}{1+\alpha_\psi\cos^2\theta}\sin(\Delta\Phi)\,\hat{\boldsymbol{y}}$$



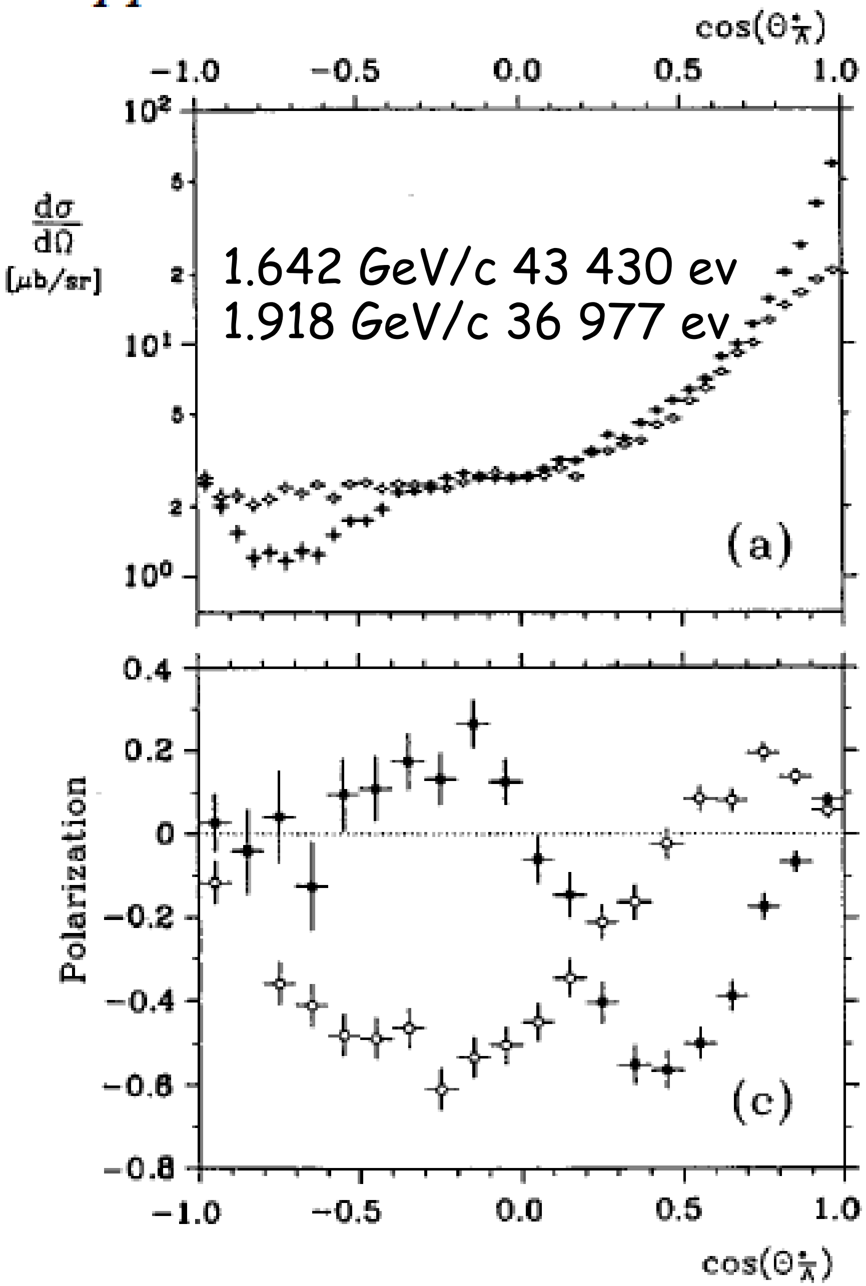
$$\boldsymbol{P}_Y(\theta) = -\boldsymbol{P}_Y(\pi-\theta) = -\boldsymbol{P}_{\bar{Y}}(\theta)$$

$$\boldsymbol{P}_Y(0) = \boldsymbol{P}_Y(\pi/2) = \boldsymbol{P}_Y(\pi) = \mathbf{0}$$

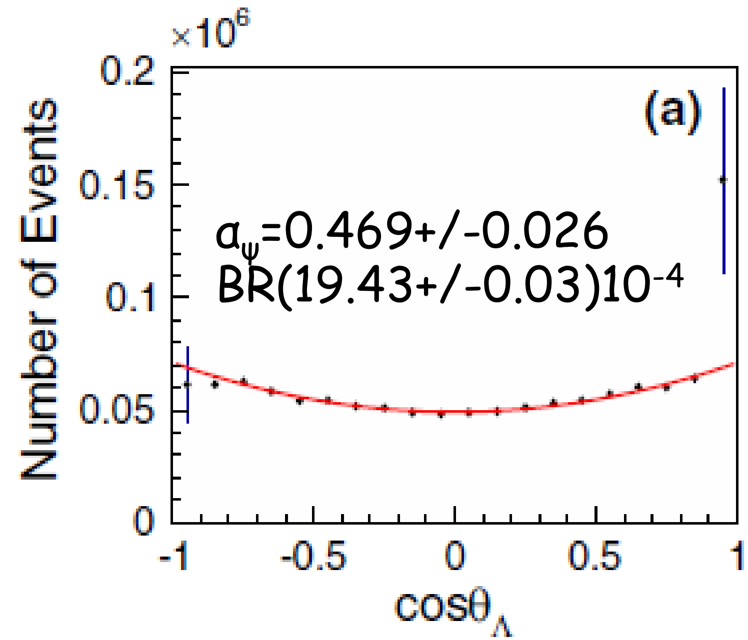
$$\langle\boldsymbol{P}_Y(\theta)\rangle = \mathbf{0}$$

$$\Delta\Phi \neq 0 \;\Rightarrow\; \boldsymbol{P}_Y(\theta) \neq 0\ !$$

$\bar{p}p \to \bar{\Lambda}\Lambda$



$e^+e^- \to \gamma^* \to J/\psi \to \Lambda\bar{\Lambda}$



?

$J/\psi \to \Lambda\bar{\Lambda}$ $440,675 \pm 670$

BESIII,Phys. Rev. D 95, 052003 (2017)

PS185, PRC54 (1996) 1877

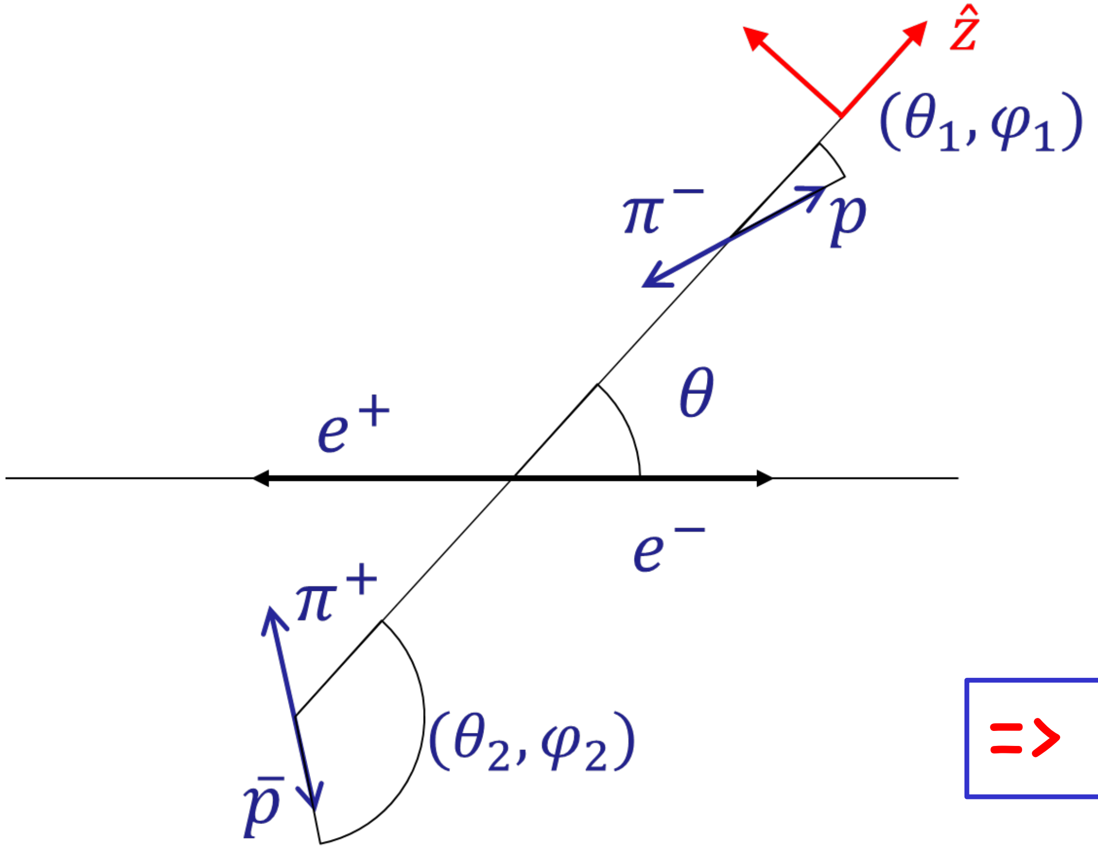
Single tag decay distributions

$$\frac{d\Gamma}{d\cos\theta d\Omega_1} \propto \left(1 + \alpha_\psi \cos^2\theta\right) \{1 + \alpha_1 P_\Lambda(\theta) \sin\theta_1 \sin\phi_1\}$$

$\Lambda \rightarrow p\pi^-$: $\Omega_1 = (\cos\theta_1, \phi_1)$

$\alpha_\Lambda = \alpha_1$

proton direction: spherical coord in Λ rest frame



Use max log likelihood to fit $\Gamma(\theta, \theta_1, \phi_1)$

=> α_ψ $\alpha_1 \sin(\Delta\Phi)$

Double tag decay distributions

$$e^+e^- \rightarrow (\Lambda \rightarrow p\pi^-)(\bar{\Lambda} \rightarrow \bar{p}\pi^+)$$

EPJ A52 (2016)141
arXiv:1702.07288

$$d\sigma \propto \mathcal{W}(\boldsymbol{\xi})\ d\cos\theta\ d\Omega_1 d\Omega_2$$

$\Lambda \rightarrow p\pi^-$: $\Omega_1 = (\cos\theta_1, \phi_1)$ $\alpha_\Lambda = \alpha_1$

$\bar{\Lambda} \rightarrow \bar{p}\pi^+$: $\Omega_2 = (\cos\theta_2, \phi_2)$ $\alpha_{\bar{\Lambda}} = \alpha_2$

ξ : $(\cos\theta, \Omega_1, \Omega_2)$

Spin correlations

$$\begin{aligned}\mathcal{W}(\boldsymbol{\xi}) =& 1 + \alpha_\psi \cos^2\theta \\ &+ \alpha_1\alpha_2 \left(\mathcal{T}_1(\boldsymbol{\xi}) + \sqrt{1-\alpha_\psi^2}\cos(\Delta\Phi)\mathcal{T}_2(\boldsymbol{\xi}) + \alpha_\psi \mathcal{T}_6(\boldsymbol{\xi}) \right) \\ &+ \sqrt{1-\alpha_\psi^2}\sin(\Delta\Phi)\ \sin\theta\cos\theta\ (\alpha_1 \sin\theta_1 \sin\phi_1 + \alpha_2 \sin\theta_2 \sin\phi_2)\end{aligned}$$

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DM2 Coll. (1988) Phys. Lett. B 212, 523

$$\mathcal{W}^{\mathcal{B}}(\xi) = 1 + \alpha_\psi \mathcal{G}_1(\xi) + \alpha_1\alpha_2\, \mathcal{G}_2(\xi) + \alpha_\psi\alpha_1\alpha_2\, \mathcal{G}_3(\xi)$$

BES, Phys.Rev. D81 (2010) 012003

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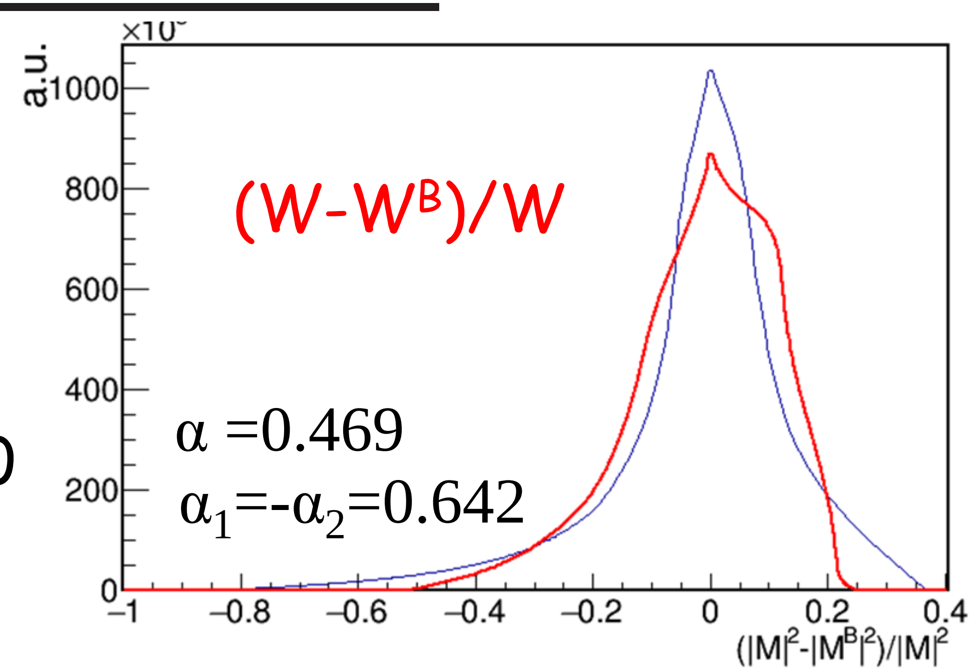
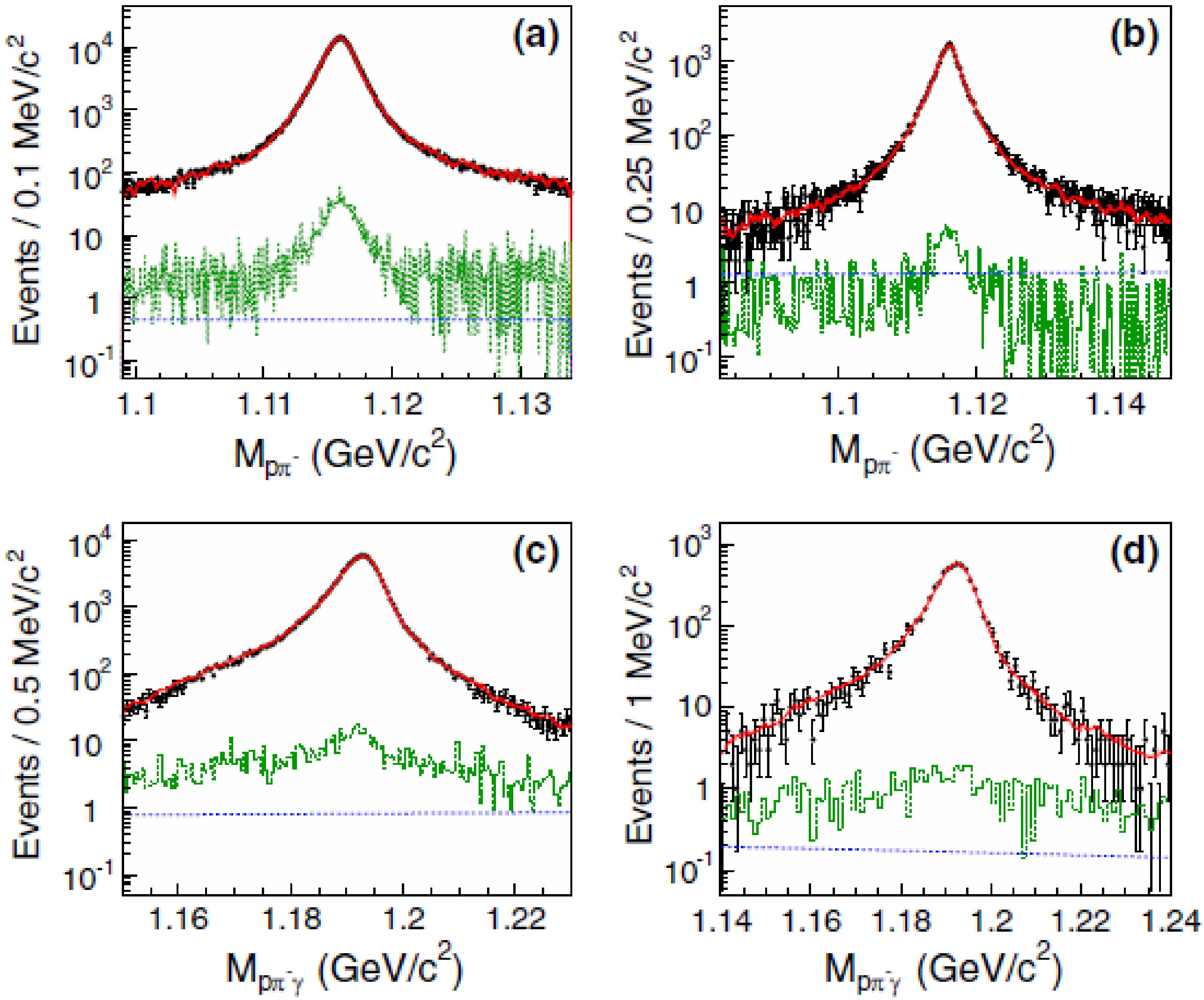
- Only two parameters:

  $\alpha_\psi \quad \alpha_1 \cdot \alpha_2$
- Λ unpolarized
- W^B and W differs even for $\Delta\Phi$=0



BESIII,Phys. Rev. D 95, 052003 (2017)



Channel	N_{obs}
$J/\psi \to \Lambda\bar{\Lambda}$	440, 675 ± 670
$J/\psi \to \Sigma^0\bar{\Sigma}^0$	111, 026 ± 335
$\psi(3686) \to \Lambda\bar{\Lambda}$	31, 119 ± 187
$\psi(3686) \to \Sigma^0\bar{\Sigma}^0$	6, 612 ± 82

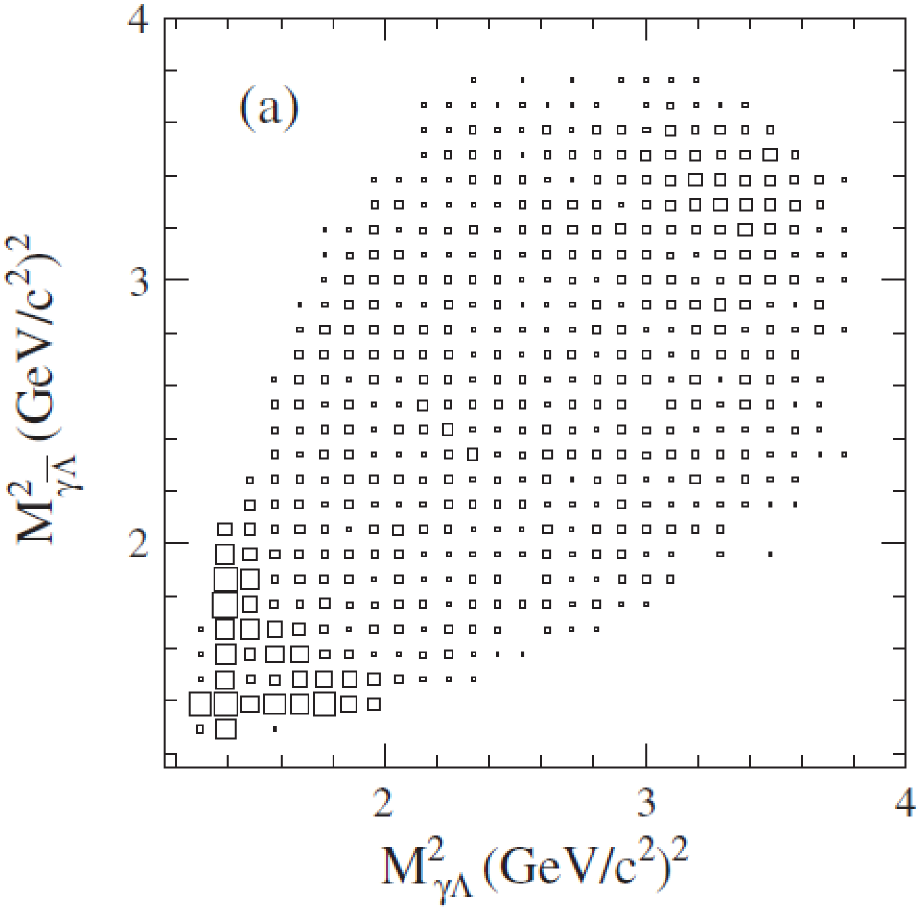
Determine ΔΦ for each decay

for Σ^0
Λ polarized longitunally

$P_\Lambda = (P_\Sigma) \cos\theta_{\Sigma\Lambda}$

$J/\psi \to \Sigma^+\bar{\Sigma}^-$	$\Sigma^+(uus)$	$p\pi^0$ (51.6%)
$\psi(3686) \to \Sigma^+\bar{\Sigma}^-$		$n\pi^+$ (48.3%)

Modes	N_S	N_B
$J/\psi \to \bar{\Lambda}\Sigma^0(\Sigma^0 \to \gamma\Lambda)$	308 ± 24	105 ± 10
$J/\psi \to \Lambda\bar{\Sigma}^0(\bar{\Sigma}^0 \to \gamma\bar{\Lambda})$	234 ± 21	95 ± 9



BESIII, Phys. Rev. D 86, 032008 (2012)
225×10^6 J/ψ

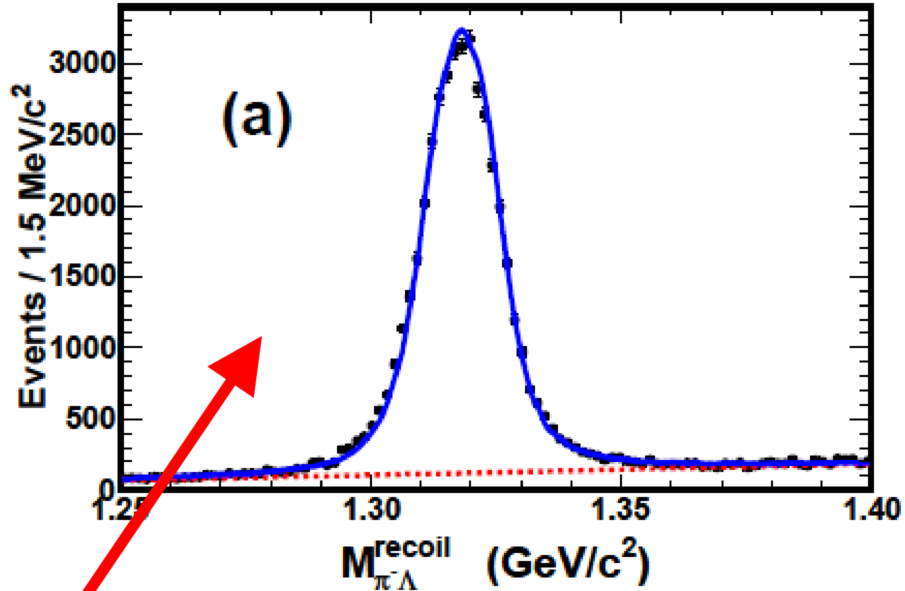
(now 1.31×10^6 J/ψ)

Determine $\Delta\Phi$ for $\Lambda\Sigma^0$ transition form factor...

Λ polarized longitunally

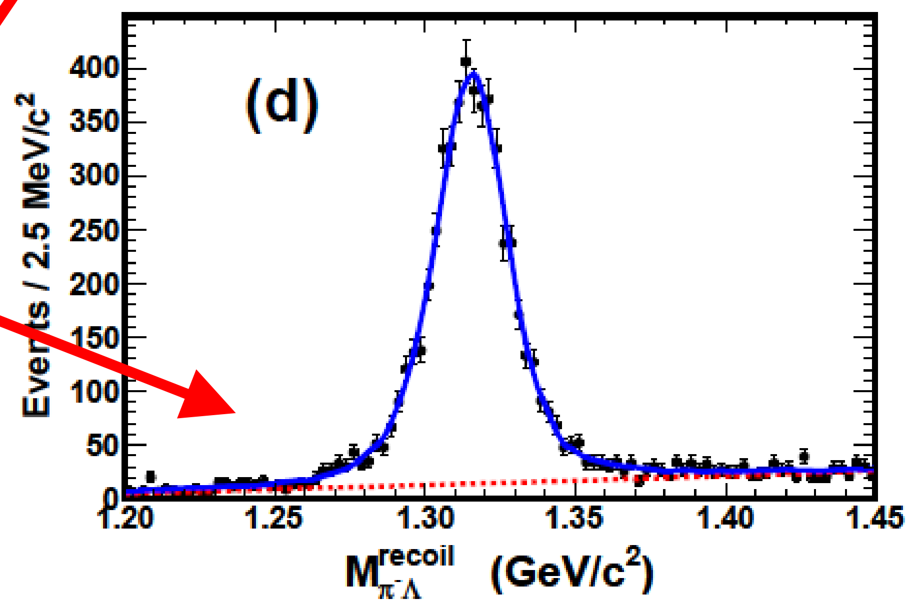
$P_\Lambda = (P_\Sigma) \cos\theta_{\Sigma\Lambda}$

BESIII
Phys. Rev. D 93, 072003 (2016)



Determine ΔΦ for J/ψ and ψ(3686)+ all decay parameters?

Channel	N_{obs}
$J/\psi \to \Xi^-\bar{\Xi}^+$	42810.7 ± 231.0
$J/\psi \to \Sigma(1385)^-\Sigma(1385)^+$	42594.8 ± 466.8
$J/\psi \to \Sigma(1385)^+\bar{\Sigma}(1385)^-$	52522.5 ± 595.9
$\psi(3686) \to \Xi^-\bar{\Xi}^+$	5336.7 ± 82.6
$\psi(3686) \to \Sigma(1385)^-\bar{\Sigma}(1385)^+$	1374.5 ± 97.8
$\psi(3686) \to \Sigma(1385)^+\bar{\Sigma}(1385)^-$	1469.9 ± 94.6

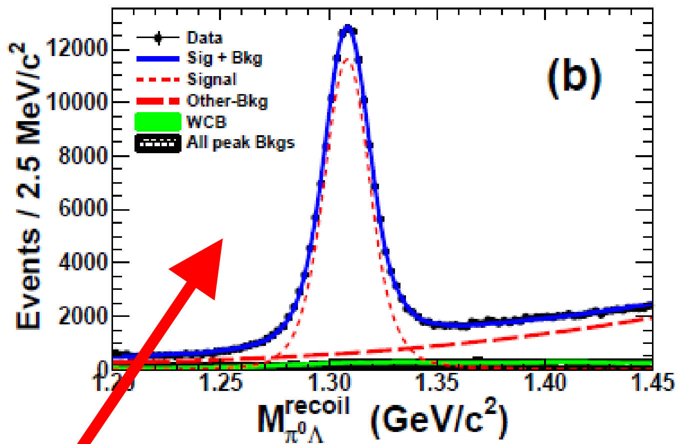


$\Xi^-(dss) \mid \Lambda\pi^-$ (99.8%)

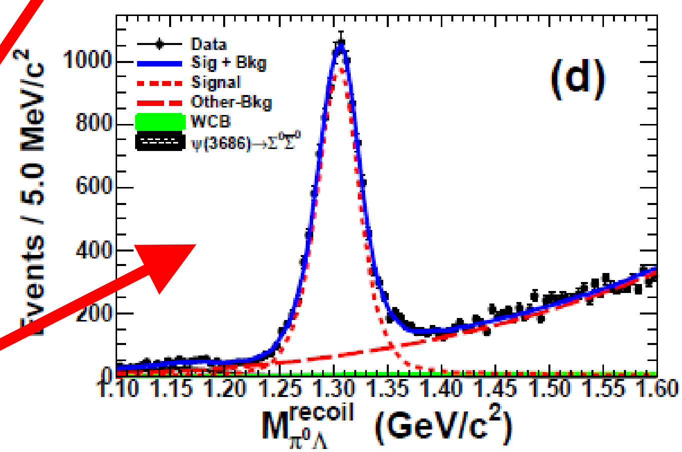
BESIII Phys.Lett. B770 (2017) 217
arXiv:1612.08664

$\Xi^0(uss)$ | $\Lambda\pi^0$ (99.5%)

Determine ΔΦ for J/ψ and ψ(3686)+ all decay parameters?



Channel	N_{obs}
$J/\psi \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	102762 ± 852
$J/\psi \to \Xi^0\bar{\Xi}^0$	134846 ± 437
$\psi(3686) \to \Sigma(1385)^0\bar{\Sigma}(1385)^0$	2536 ± 185
$\psi(3686) \to \Xi^0\bar{\Xi}^0$	10839 ± 123



Conclusions/outlook

Well established general formulas for
$e^+e^- \rightarrow \gamma^* \rightarrow B_{1/2}\, \bar{B}_{1/2}$ are applied to J/ψ and ψ(3686)

Access to decay parameters even using single tag mode
if corresponding $\Delta\Phi \neq 0$.

Charmonia: determine $\Delta\Phi$ for J/ψ and ψ(3686) $Y\bar{Y}$ decays
[including $\bar{\Lambda}\,\Sigma^0$]

Too simplified helicty amplitude formalism for weak decays...