Isospin violating decays of J/ψ

potentials in finding low-mass Z' boson

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Jiabao Zhang

张嘉宝

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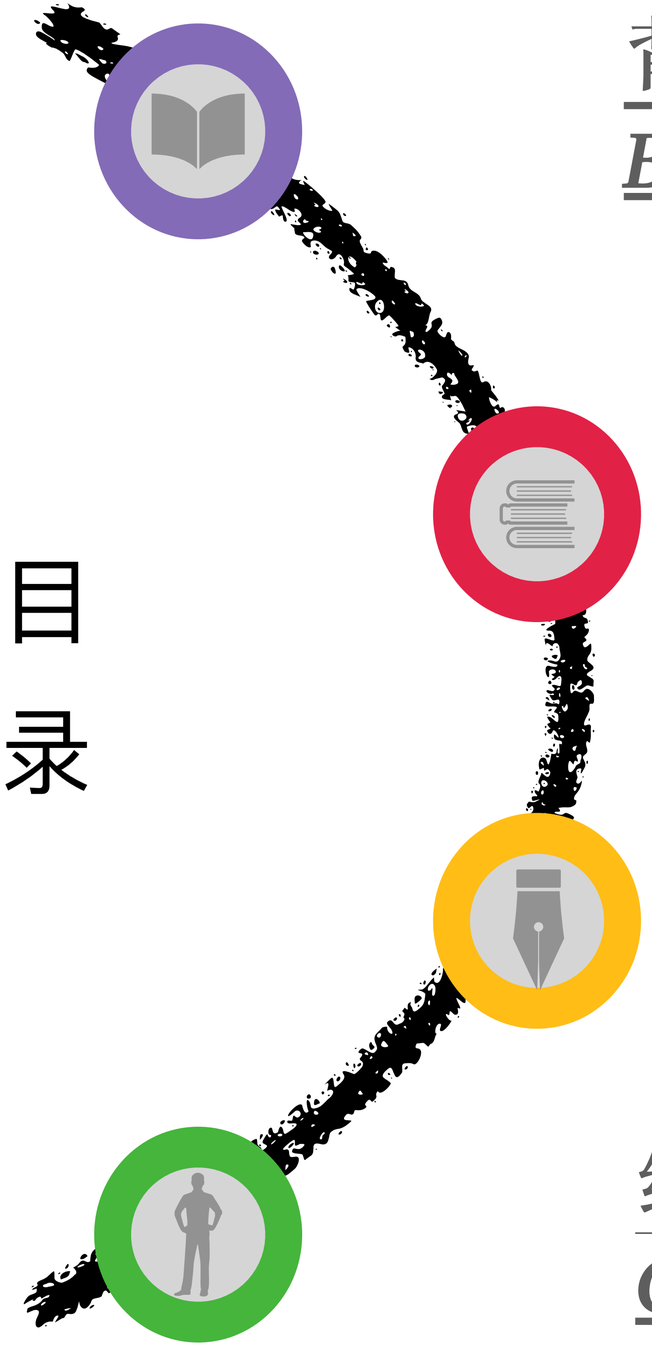

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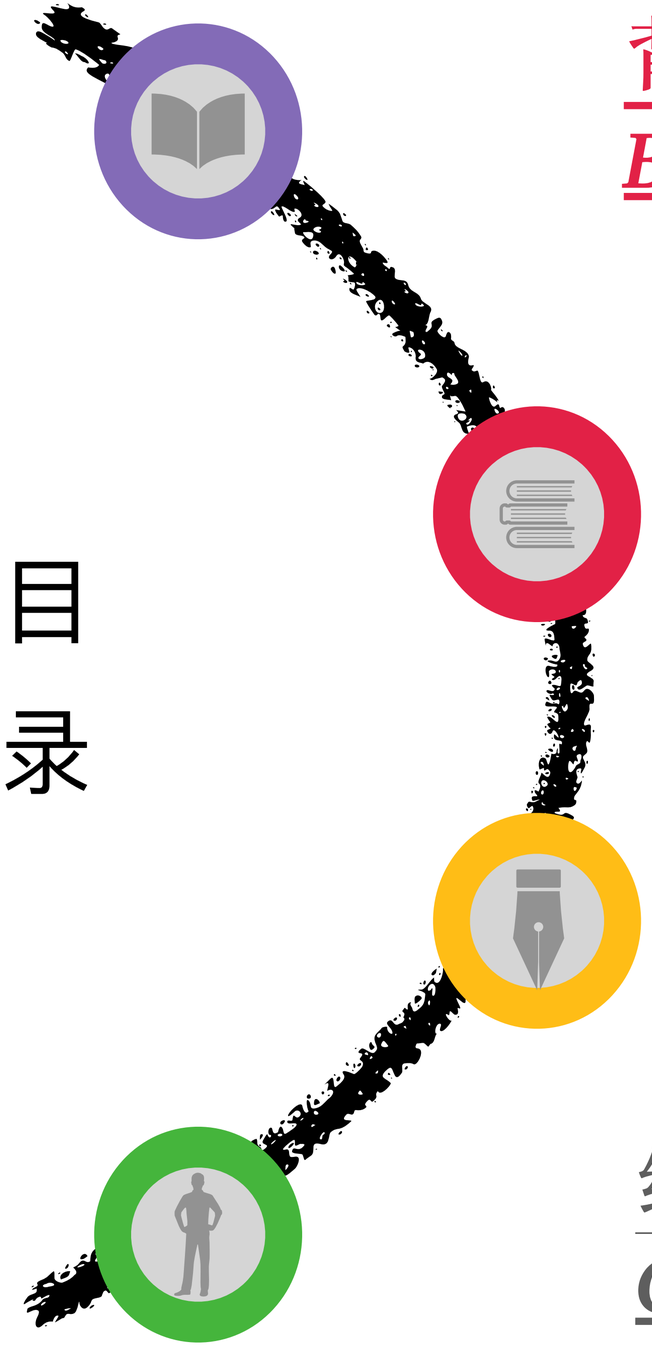


Background

[1] Study of $J/\psi \to p\bar{p}$ and $J/\psi \to n\bar{n}$, Phys. Rev. D 86, 032014 (2012)

[2] First observation of the isospin violating decay $J/\psi \to \Lambda\bar{\Sigma}^0 + c.c.$, Phys. Rev. D 86, 032008 (2012)

[3] Study of ψ decays to the $\Xi^-\bar{\Xi}^+$ and $\Sigma(1385)^{\mp}\bar{\Sigma}(1385)^{\pm}$ final states, Phys. Rev. D 93, 072003 (2016)

[4] Study of J/ψ and $\psi(3686)$ decay to $\Lambda\bar{\Lambda}$ and $\Sigma^0\bar{\Sigma}^0$ final states, Phys. Rev. D 95, 052003 (2017)

[5] Measurement of branching fractions of J/ψ and $\psi(3686)$ decays to Σ^+ and $\overline{\Sigma}^-$, JHEP 11, 226 (2021).

$N_{J/\psi} \approx 200$ Million

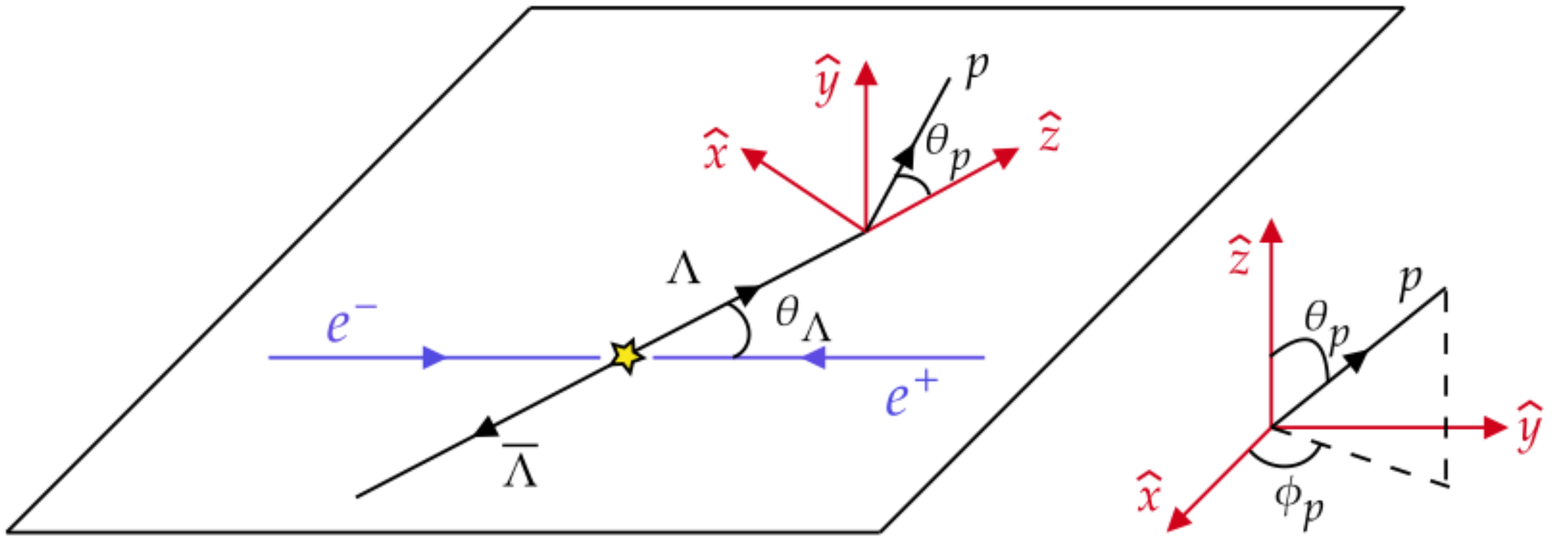
$N_{J/\psi} \approx 1$ Billion

$N_{J/\psi} \approx 10$ Billion

Background

[6] Precise Measurements of Decay Parameters and CP Asymmetry with Entangled $\Lambda - \bar{\Lambda}$ Pairs Pairs, Phys. Rev. Lett.129, 131801 (2022)

[7] Tests of CP symmetry in entangled $\Xi^0 - \bar{\Xi}^0$ pairs, Phys. Rev. D 108, L031106 (2023)



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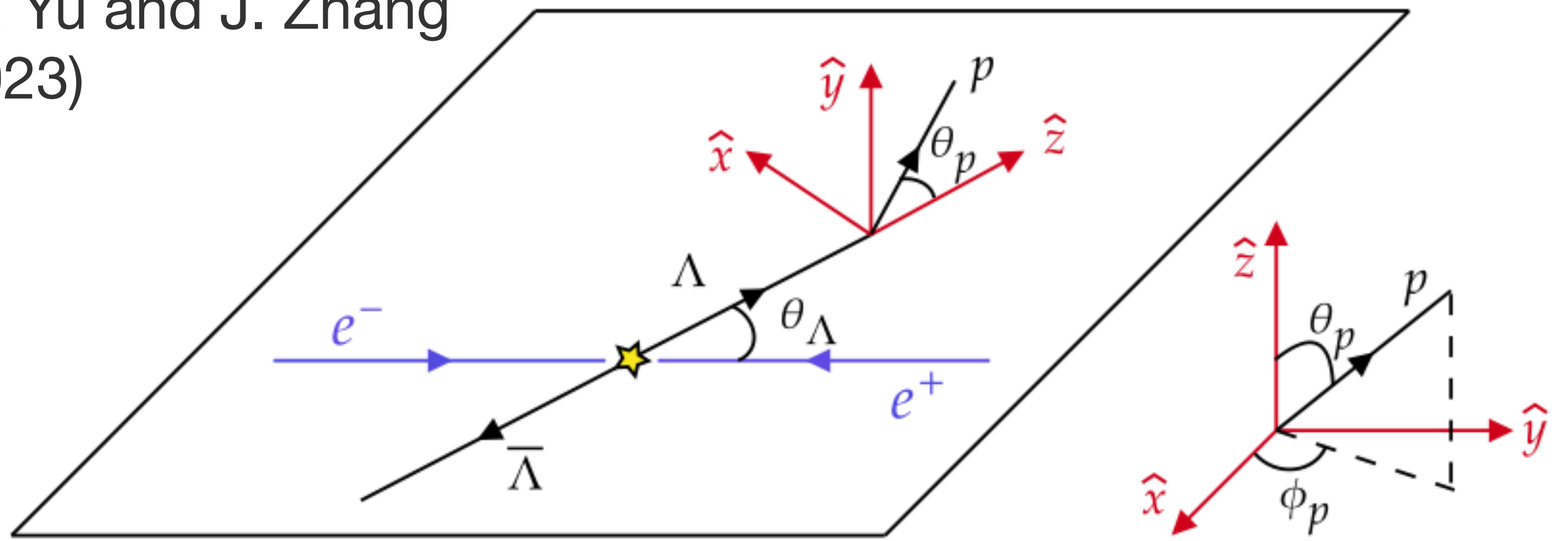
[7] Tests of CP symmetry in entangled $\Xi^0 - \bar{\Xi}^0$ pairs, Phys. Rev. D 108, L031106 (2023)

[8] Testing of P and CP symmetries with $e^+e^- \to J/\psi \to \Lambda\bar{\Lambda}$, X. G. He and J. P. Ma, Phys. Lett. B 839, 137834 (2023).

[9] Probing hyperon electric dipole moments with a full angular analysis, J. Fu, H. B. Li, J. P. Wang, F. S. Yu and J. Zhang Phys. Rev. D 108, L091301 (2023)

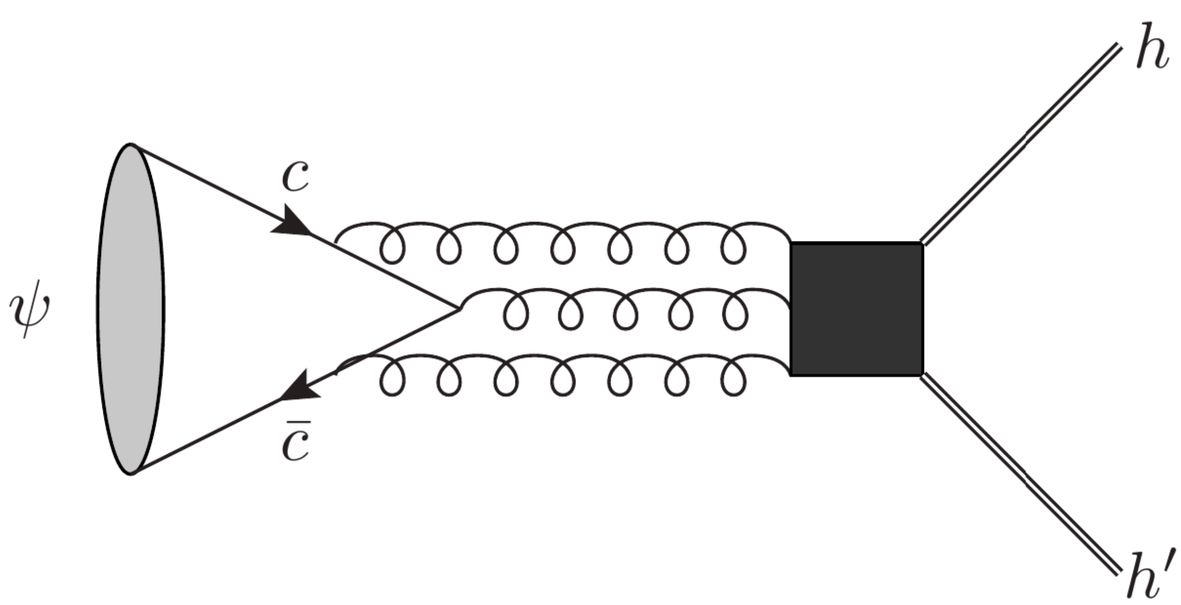


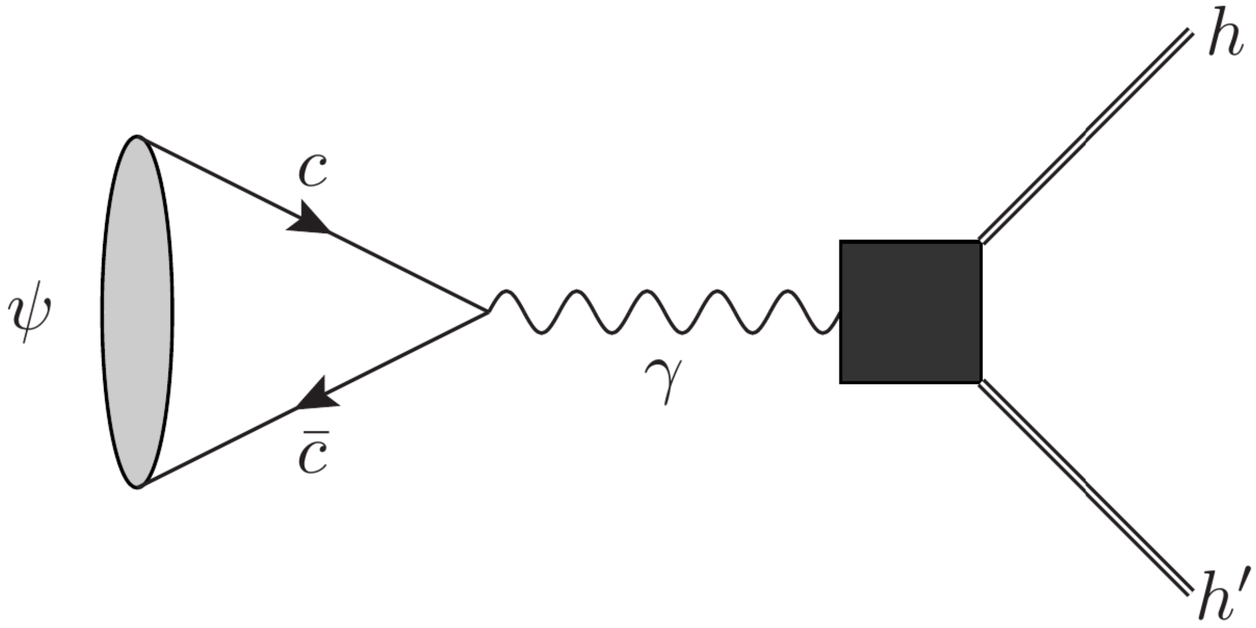
Motivations

ψ : J/ψ and $\psi(2S)$

$h(h')$: Octet baryon antibaryon

Isospin violating decays of vector charmonia





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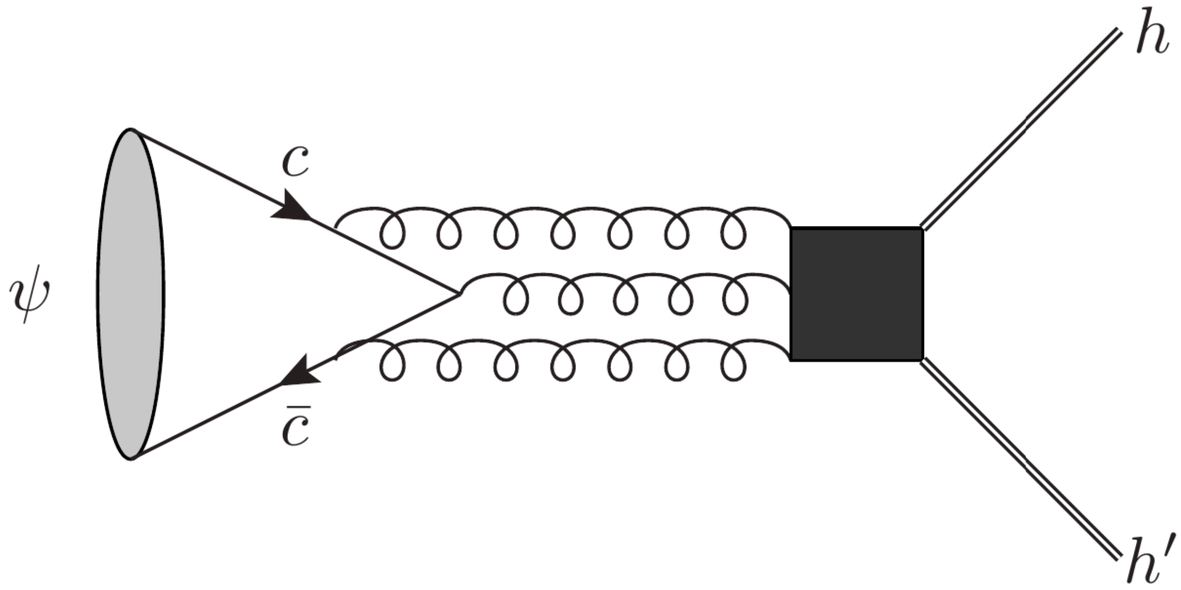
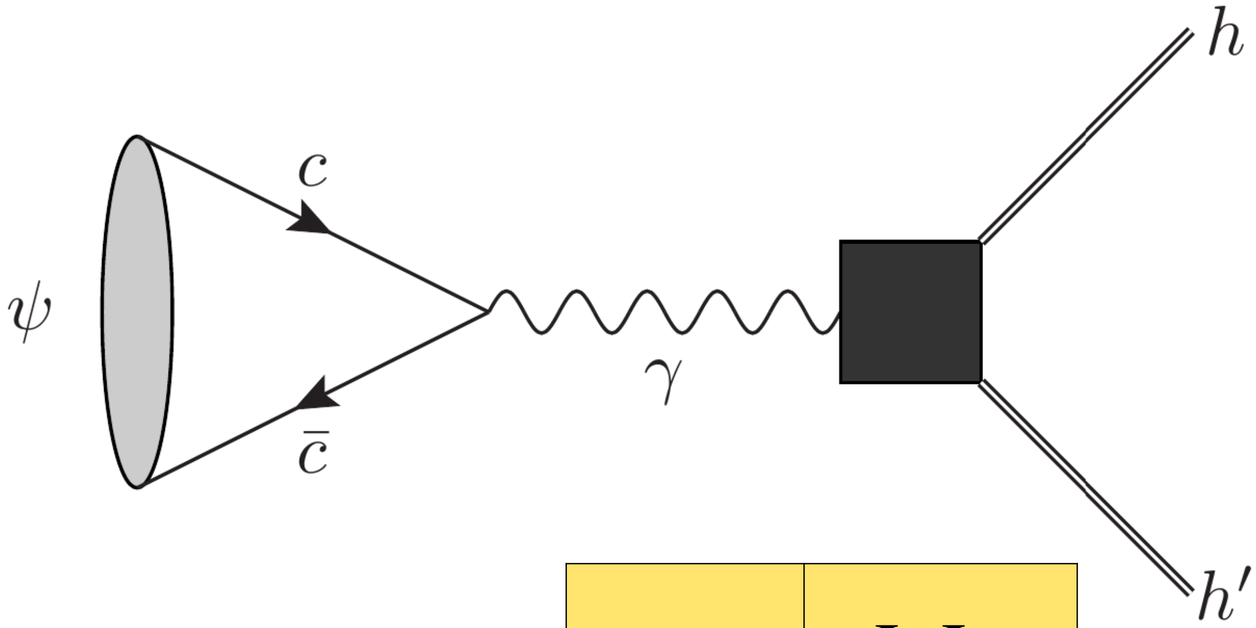




$$J/\psi \to \Lambda\overline{\Sigma}^0 + c.c.$$

	I, I_3
Λ	(0,0)
$\overline{\Sigma}^0$	(1,0)

Motivations

Isospin violating decays of vector charmonia

[2] First observation of the isospin violating decay $J/\psi \to \Lambda\bar{\Sigma}^0 + c.c.$,

Phys. Rev. D 86, 032008 (2012) $\mathcal{B}(J/\psi \to \Lambda\bar{\Sigma}^0 + c.c.) = 2.83(23) \times 10^{-5}$

[10] Measurements of the branching fractions of $\psi(3686) \to \bar{\Sigma}^0\Lambda + c.c.$ and $\chi_{cJ(J=0,1,2)} \to \Lambda\bar{\Lambda}$, Phys. Rev. D 103, 112004 (2021)

$\mathcal{B}(\psi(2S) \to \Lambda\bar{\Sigma}^0 + c.c.) = 1.6(7) \times 10^{-6}$

[11] Hyperon Form Factors & Diquark Correlations, Phys. Rev. D **96**, 092004 (2017)

$\mathcal{B}(\psi(2S) \to \Lambda\bar{\Sigma}^0 + c.c.) = 1.23(24) \times 10^{-5}$

Motivations

C. Q. Geng, C.-W. Liu, JZ. EPJC 83, 973 (2023)

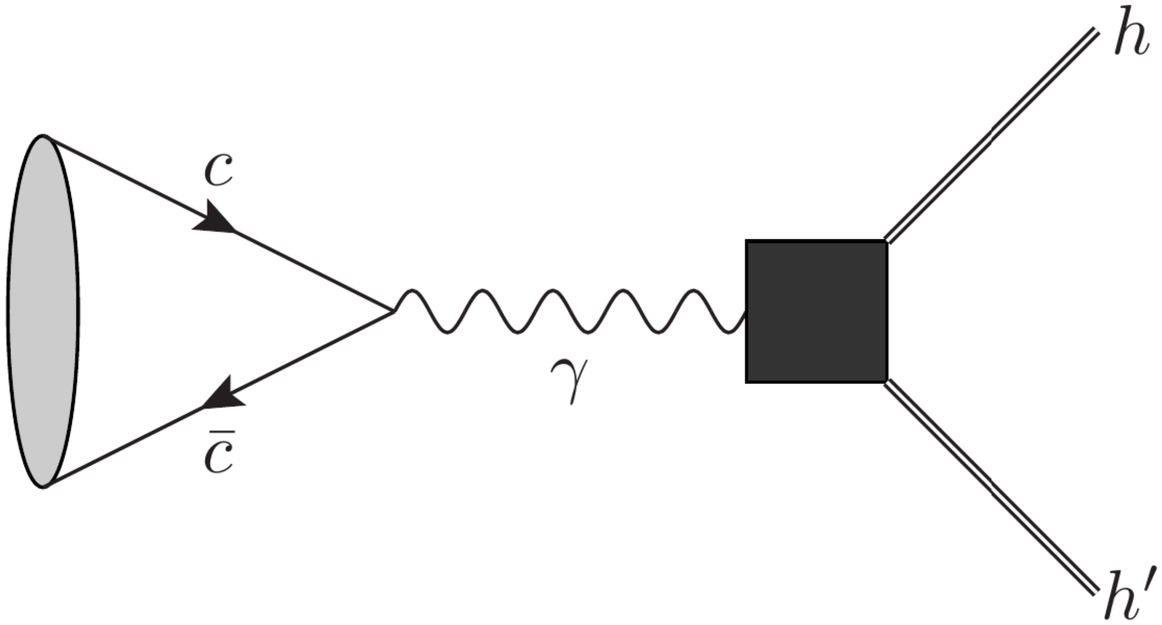
Isospin violating decays of vector charmonia

	Channels	$10^3\mathcal{B}$	α		Channels	$10^4\mathcal{B}$	α
	$p\bar{p}$	2.120(29)	0.595(19)		$p\bar{p}$	2.94(8)	1.03(7)
	$n\bar{n}$	2.09(16)	0.50(21)		$n\bar{n}$	3.06(15)	0.68(16)
	$\Lambda\overline{\Lambda}$	1.89(9)	0.469(26)		$\Lambda\overline{\Lambda}$	3.81(13)	0.824(74)
J/ψ	$\Sigma^0\overline{\Sigma}^0$	1.172(32)	$-0.449(20)$	$\psi(2S)$	$\Sigma^0\overline{\Sigma}^0$	2.35(9)	0.71(11)
	$\Sigma^+\overline{\Sigma}^-$	1.07(4)	$-0.5156(68)$		$\Sigma^+\overline{\Sigma}^-$	2.43(10)	0.682(32)
	$\Xi^0\overline{\Xi}^0$	1.17(4)	0.66(3)		$\Xi^0\overline{\Xi}^0$	2.3(4)	0.665(118)
	$\Xi^-\overline{\Xi}^+$	0.98(4)	0.586(16)		$\Xi^-\overline{\Xi}^+$	2.87(11)	0.693(69)

Motivations

New Signature of low mass Z' in J/ψ decays

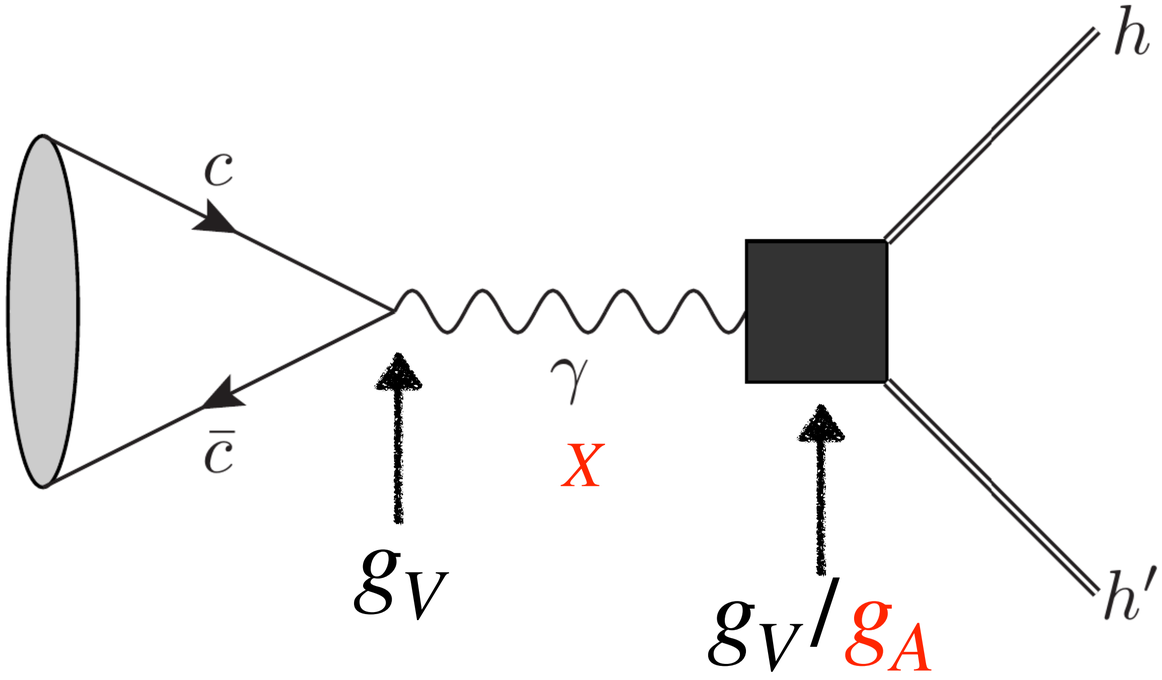
$$J/\psi \rightarrow \gamma^* \rightarrow \Lambda\overline{\Sigma}^0 + c.c.$$



Motivations

New Signature of low mass Z' in J/ψ decays

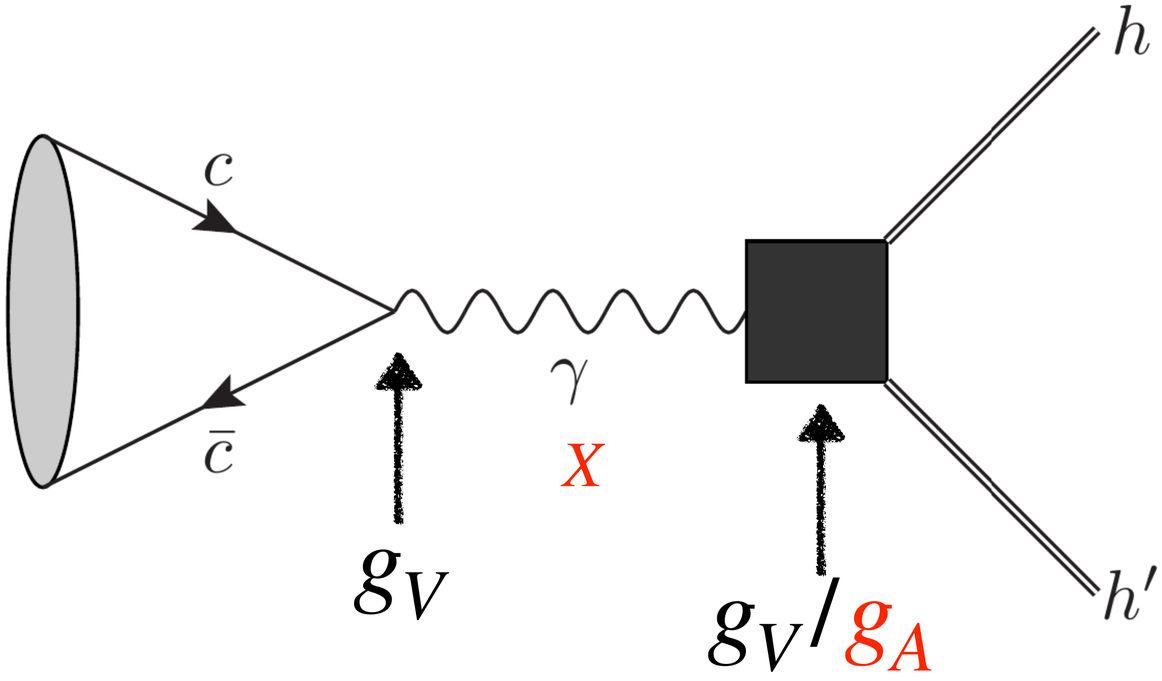
$$J/\psi \rightarrow X \rightarrow \Lambda\overline{\Sigma}^0 + c.c.$$



Motivations

New Signature of low mass Z' in J/ψ decays

$$J/\psi \rightarrow X \rightarrow \Lambda\overline{\Sigma}^0 + c.c.$$

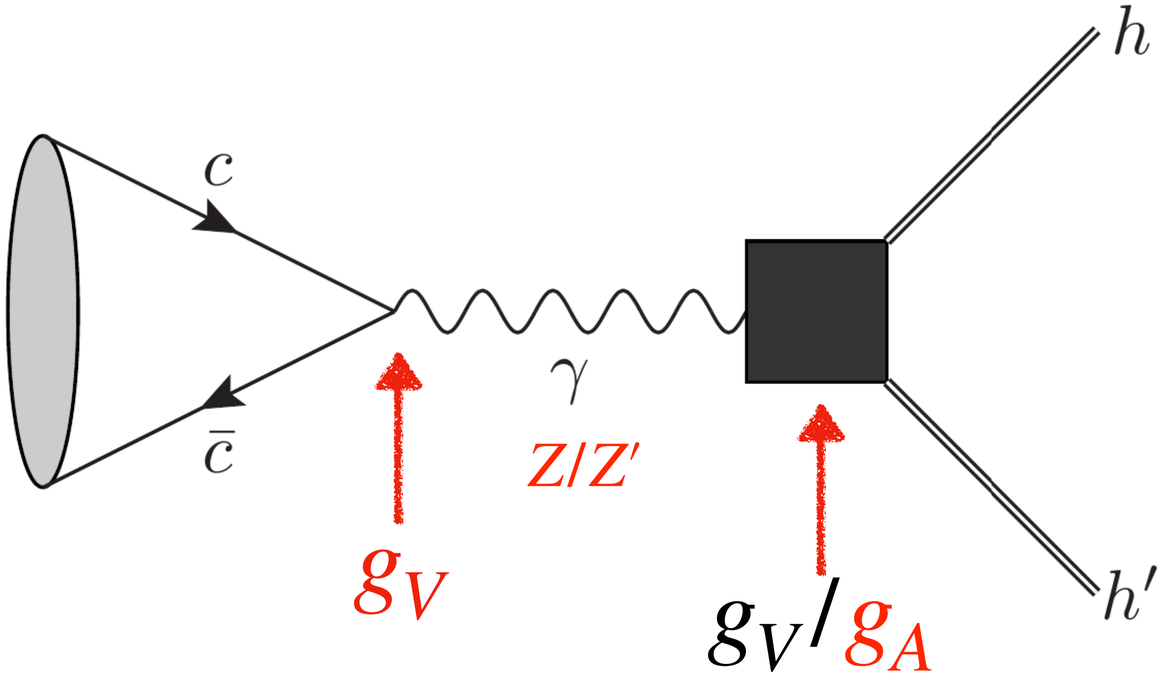


~~Dark Photon~~

Motivations

New Signature of low mass Z' in J/ψ decays

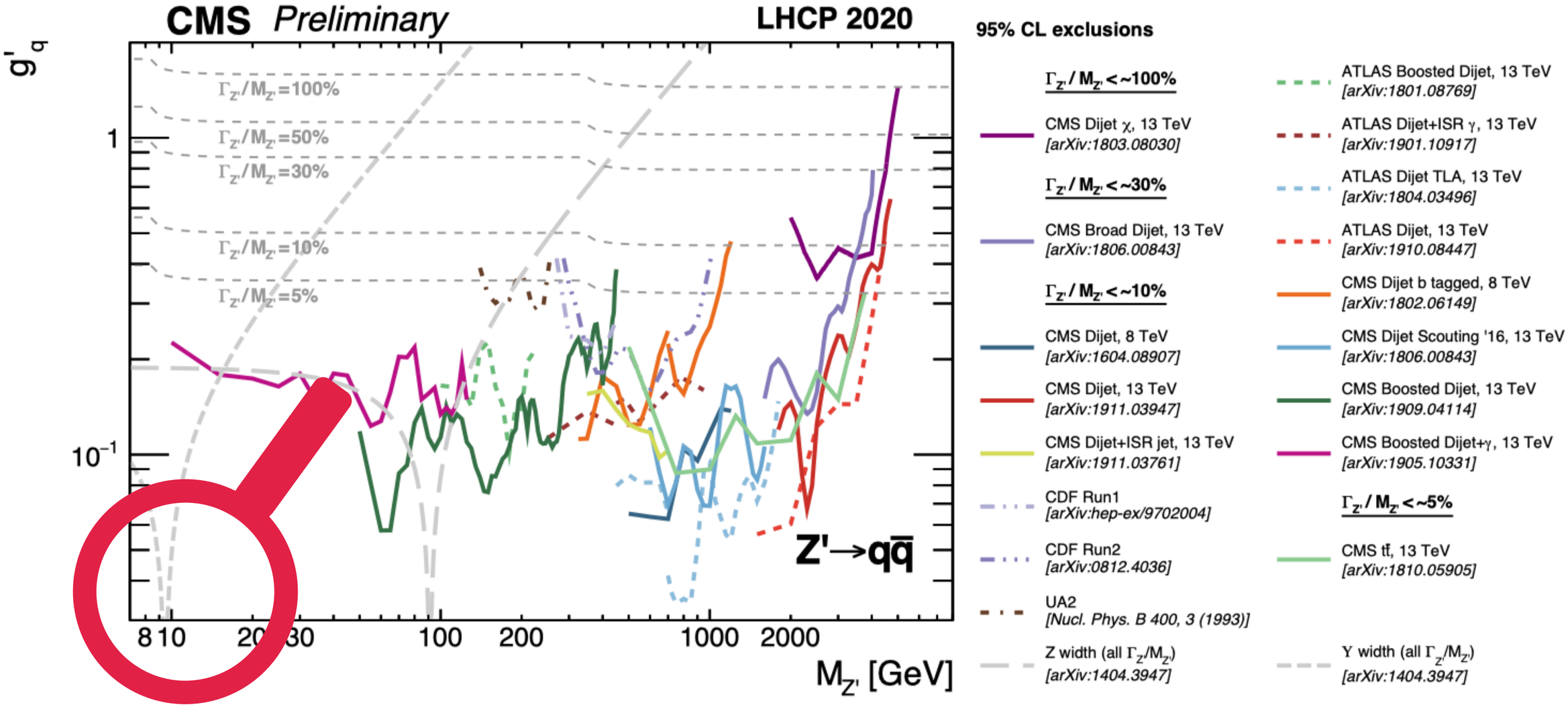
$$J/\psi \rightarrow Z/Z' \rightarrow \Lambda\overline{\Sigma}^0 + c.c.$$



Parity violation with SM $\sim 10^{-5}$

Motivations

New Signature of low mass Z' in J/ψ decays



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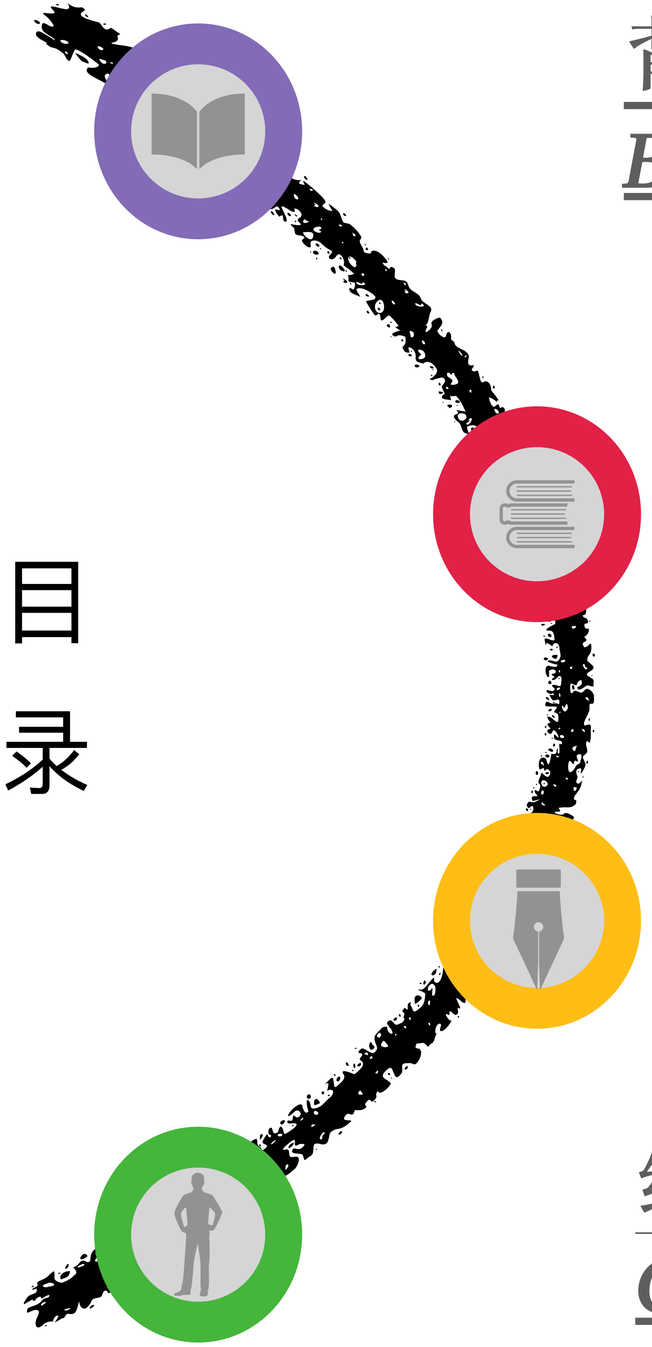
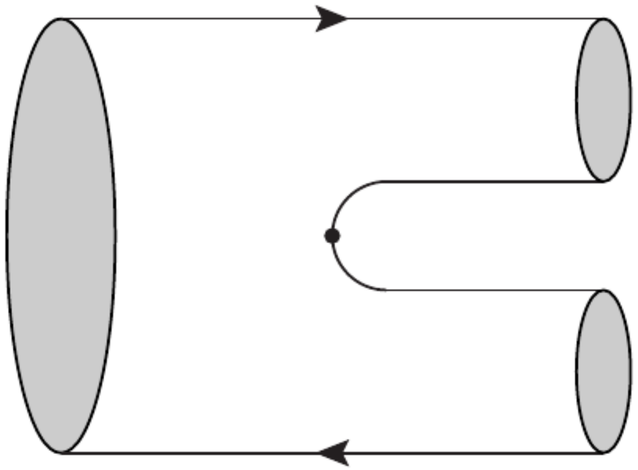
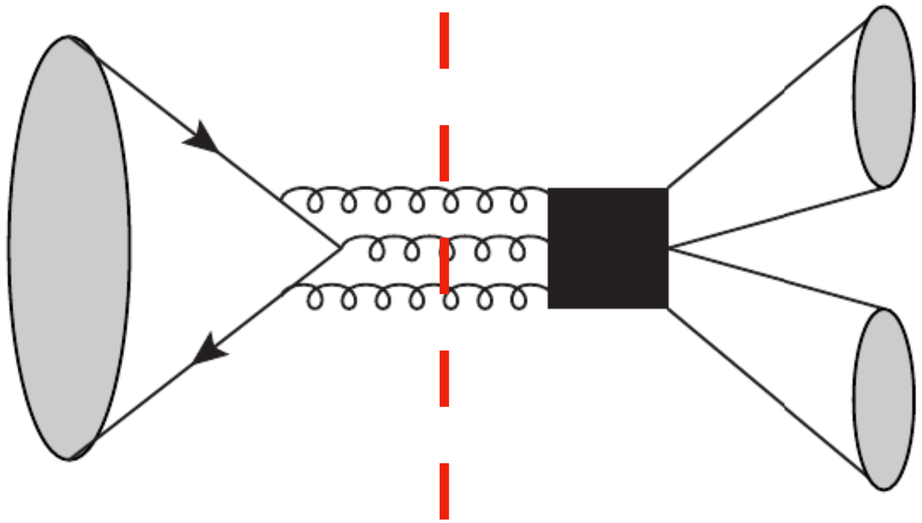


Formalisms—$^3P_0$ model

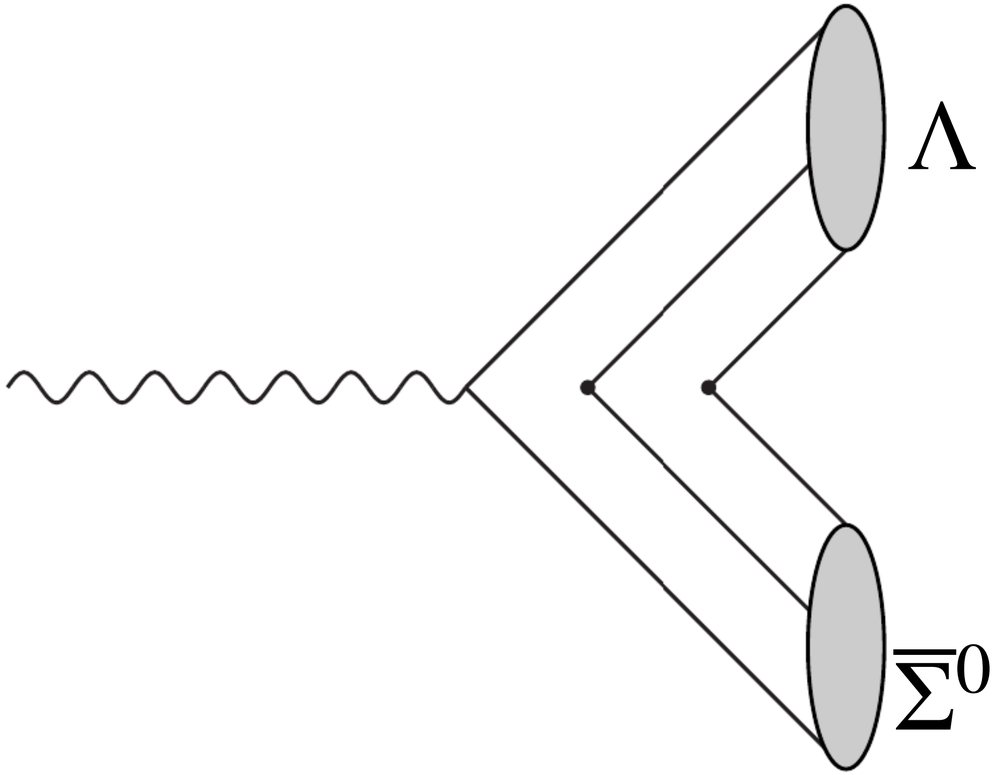


OZI-allowed decays



OZI-suppressed decays

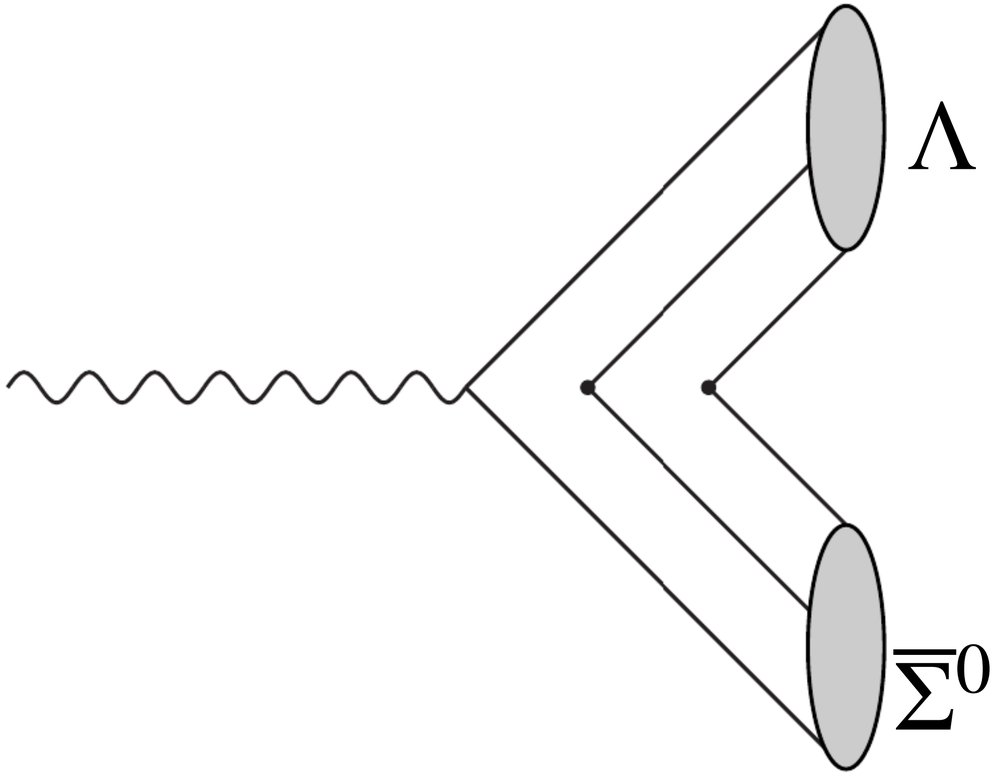
Formalisms—$^3P_0$ model



$$|\Lambda\rangle \propto u^{\dagger}_{a\alpha}(\vec{x}_u) d^{\dagger}_{b\beta}(\vec{x}_d) s^{\dagger}_{c\gamma}(\vec{x}_s)\,|0\rangle,$$

$$|\overline{\Sigma}^0\rangle \propto u_{a\alpha}(\vec{x}_u) d_{b\beta}(\vec{x}_d) s_{c\gamma}(\vec{x}_s)\,|0\rangle,$$

Formalisms—$^3P_0$ model



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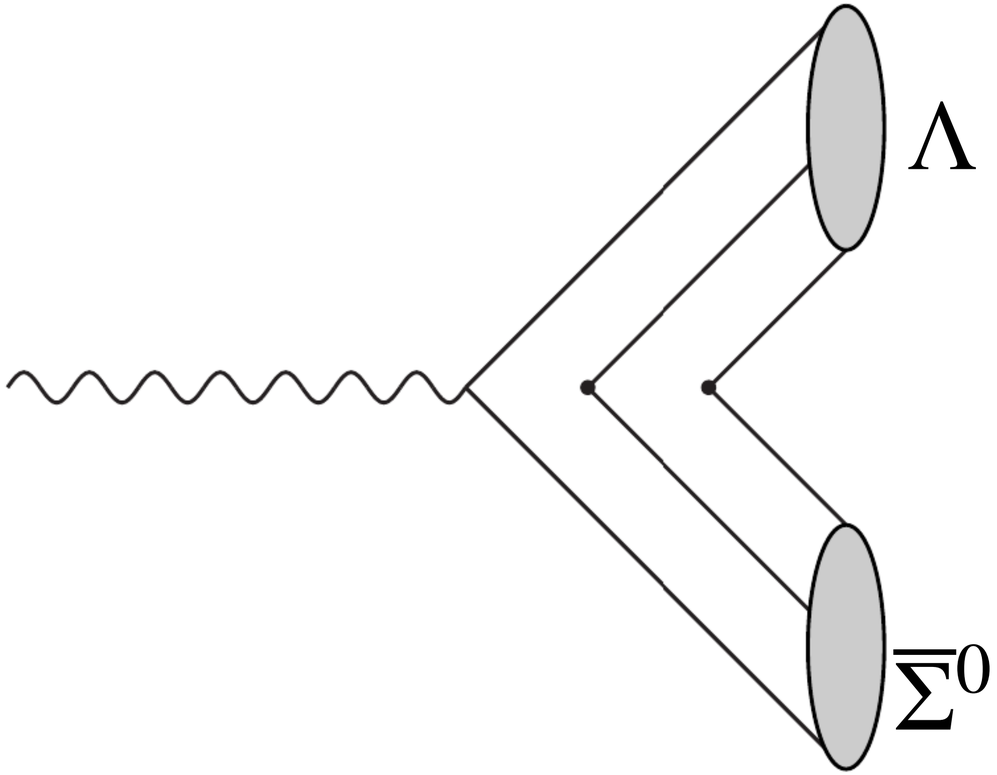
Homogeneous bag model (HBM)

$q^\dagger_{a\alpha}(\vec{x})$ is the field operator which only contain the creation operator of quarks

$q_{a\alpha}(\vec{x})$ is the field operator which only contain the creation operator of antiquarks

Formalisms—$^3P_0$ model



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$q^\dagger_{a\alpha}(\vec{x})$ is the field operator which only contain the creation operator of quarks

$q_{a\alpha}(\vec{x})$ is the field operator which only contain the creation operator of antiquarks

$$\epsilon_\mu \langle \lambda_\Lambda; \lambda_{\overline{\Sigma}^0} | \bar{u}\gamma^\mu u | 0\rangle \to 0 \quad \{q_{a\alpha}(\vec{x}), q^\dagger_{b\beta}(\vec{y})\} = 0$$

Formalisms—$^3P_0$ model

$$|\Lambda\rangle \propto u^\dagger_{a\alpha}(\vec{x}_u) d^\dagger_{b\beta}(\vec{x}_d) s^\dagger_{c\gamma}(\vec{x}_s)\,|0\rangle,$$

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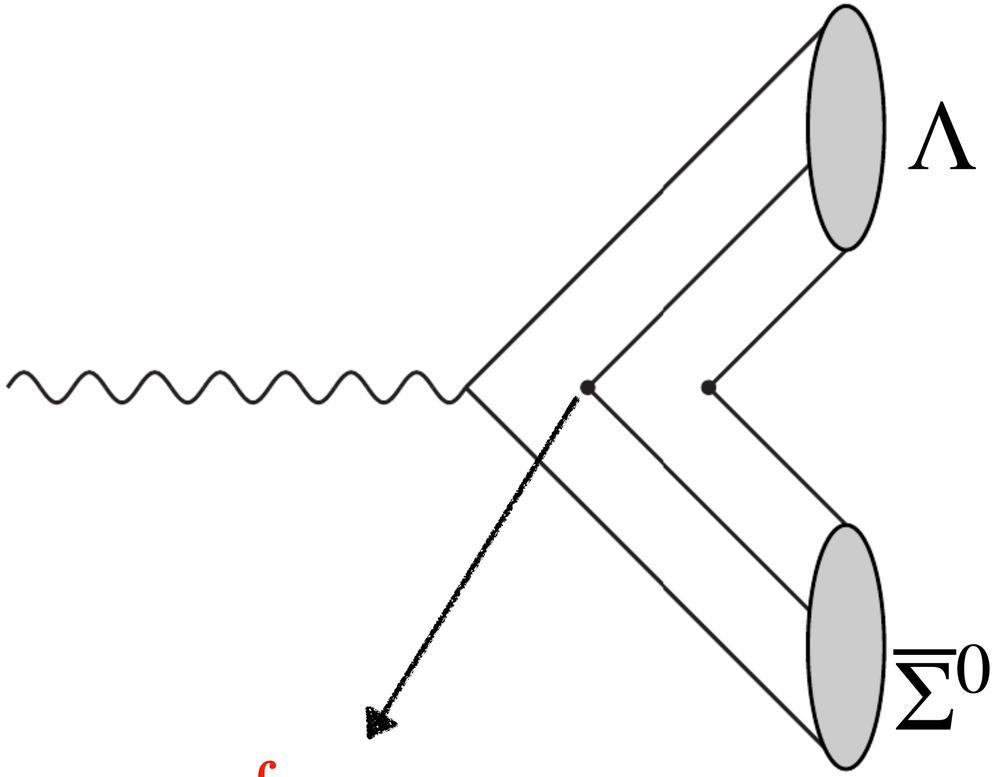


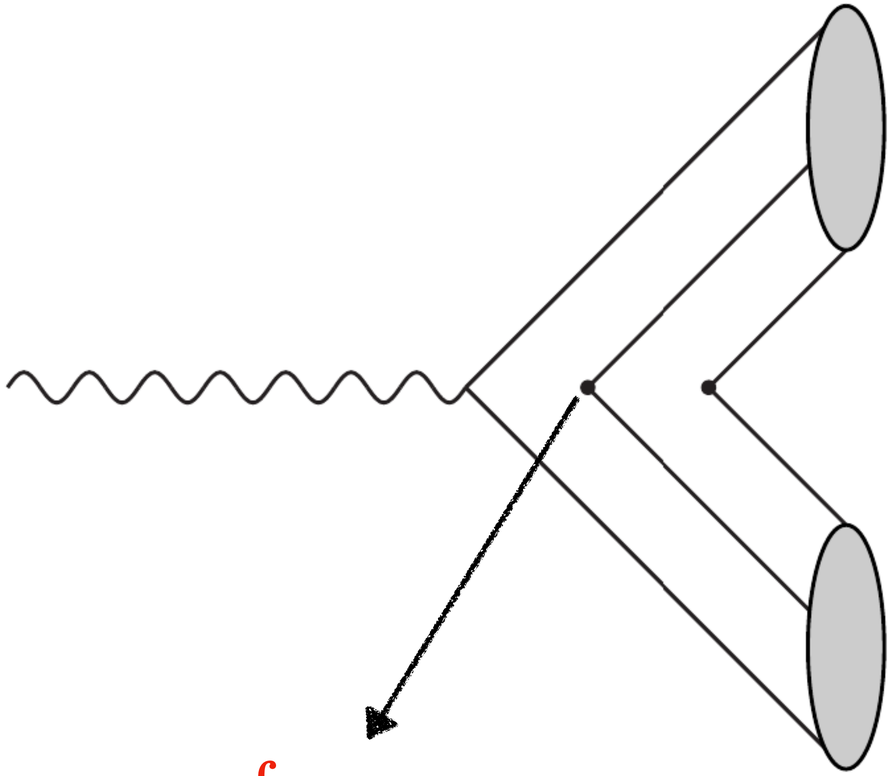
$q^\dagger_{a\alpha}(\vec{x})$ is the field operator which only contain the creation operator of quarks

$q_{a\alpha}(\vec{x})$ is the field operator which only contain the creation operator of antiquarks

$$T_q = \sqrt{3}\,\gamma_q \int d^3\vec{x}\ :\bar{q}(\vec{x})\,q(\vec{x}):$$

$$\epsilon_\mu \langle \lambda_\Lambda; \lambda_{\overline{\Sigma}^0}\,|\,\bar{u}\gamma^\mu T_d T_s u\,|\,0\rangle \equiv M^u_{\lambda_\Lambda \lambda_{\overline{\Sigma}^0}}$$

Formalisms—$^3P_0$ model



$$T_q = \sqrt{3}\,\gamma_q \int d^3\vec{x}\ \ :\bar{q}(\vec{x})\,q(\vec{x}):$$

dimensionless

may originates from gluon condensation

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Physics Letters B

Volume 218, Issue 3, 23 February 1989, Pages 267-271

Gluon and quark condensate induced $^3P_0$ quark pair creation

H.J. Weber [1]

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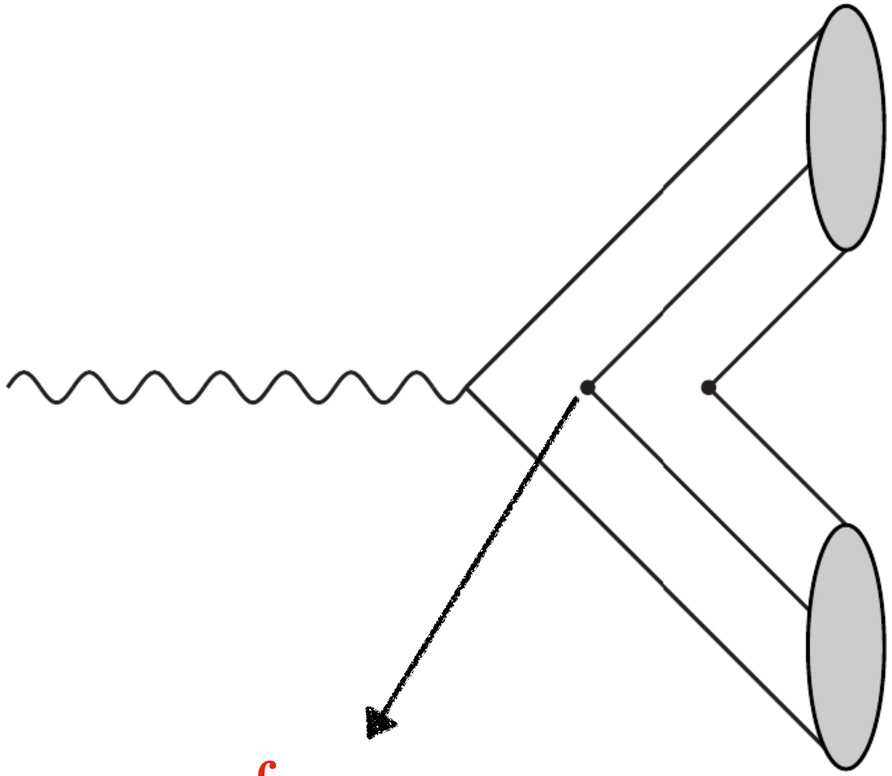

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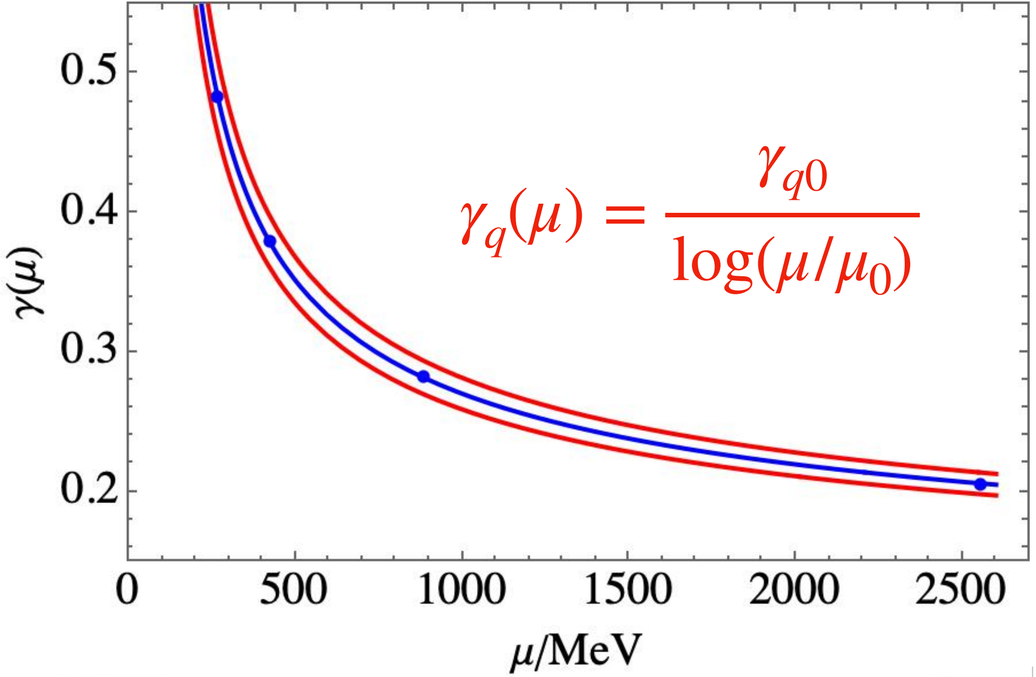

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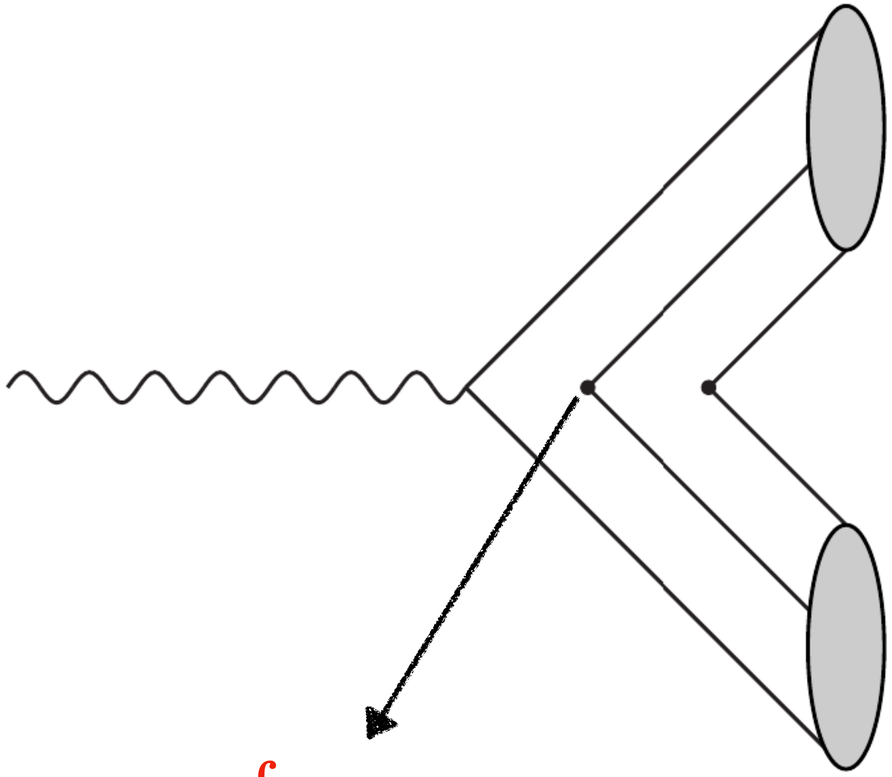
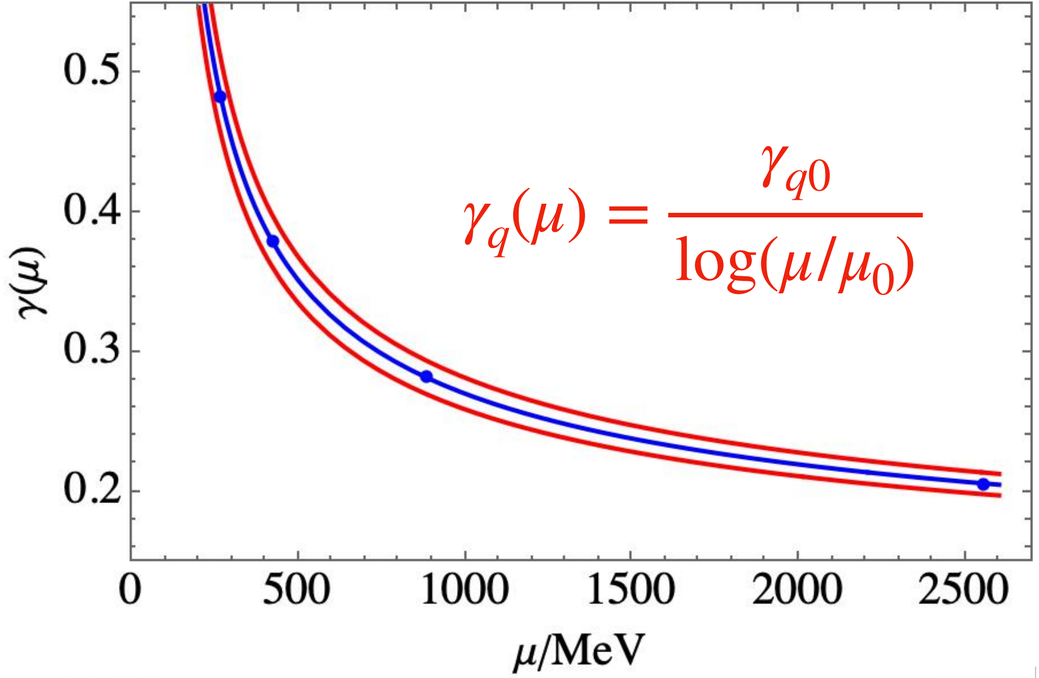


$$\alpha_s(\mu) = \frac{b_0^{-1}}{\log(\mu^2/\Lambda^2)}$$

$$T_q = \sqrt{3}\,\gamma_q \int d^3\vec{x}\ \ :\bar{q}(\vec{x})\,q(\vec{x}):$$

dimensionless

may originates from gluon condensation



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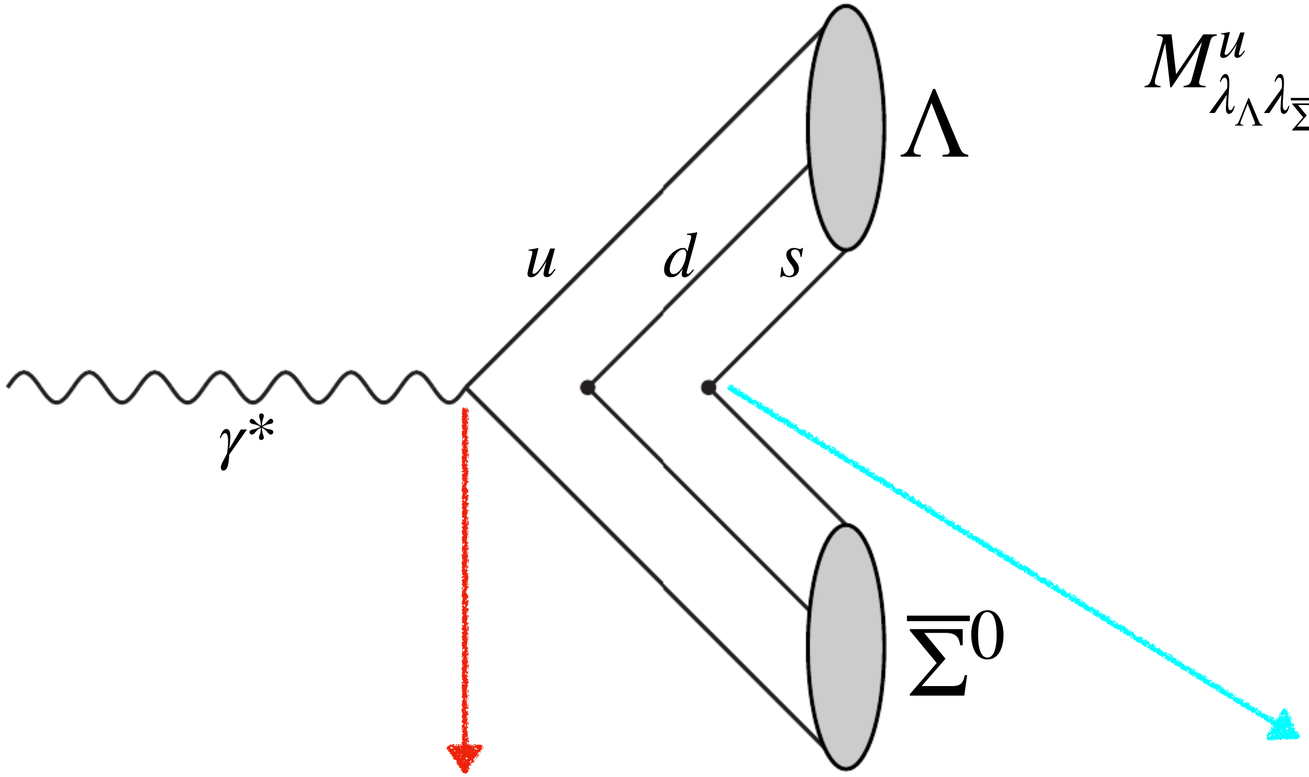


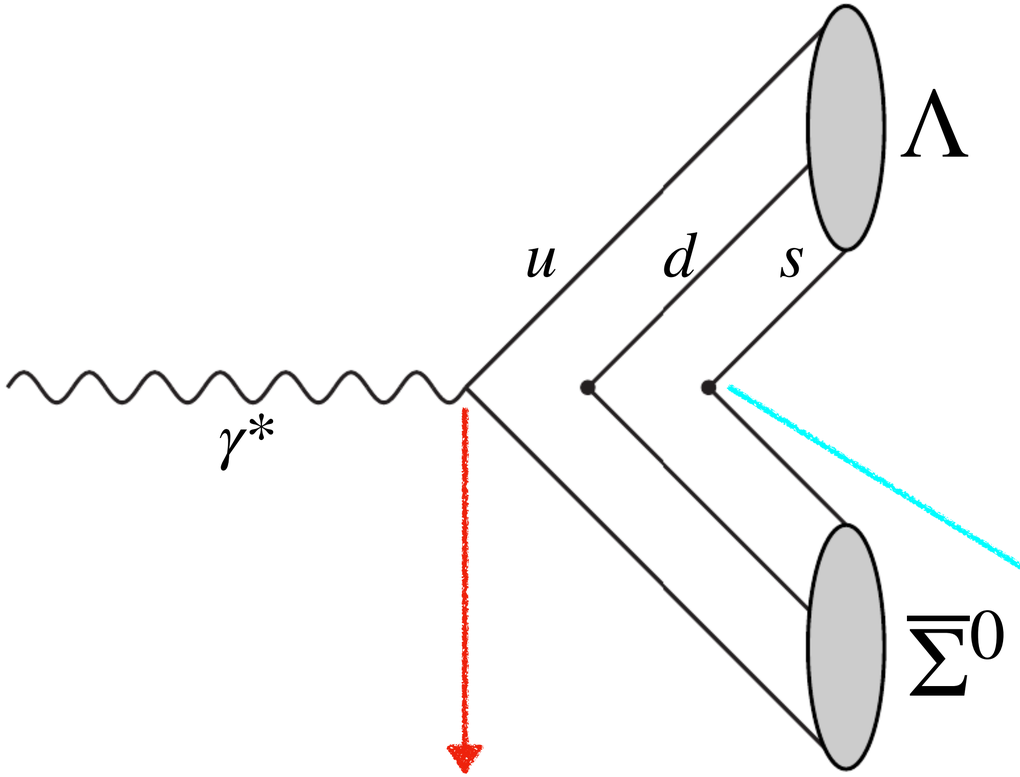
$$M^{u}_{\lambda_\Lambda \lambda_{\bar{\Sigma}0}} = \epsilon_\mu \langle \lambda_\Lambda; \lambda_{\bar{\Sigma}0} \,|\, \bar{u}\gamma^\mu u T_d T_s \,|\, 0 \rangle$$

$$\propto \left\langle \Gamma^{\lambda_\psi}_{\lambda_u \lambda_{\bar{u}}}(\vec{x}_\Delta) E_{\lambda_d \lambda_{\bar{d}}}(\vec{x}_\Delta) E_{\lambda_s \lambda_{\bar{s}}}(\vec{x}_\Delta) \right\rangle$$

$E_{\lambda_q \lambda_{\bar{q}}}$: vertex function for $^3P_0$ vertex

$\Gamma^{\psi}_{\lambda_u \lambda_{\bar{u}}}$: vertex function for QED vertex

Formalisms—$^3P_0$ model & HBM



$$M^{u}_{\lambda_\Lambda \lambda_{\bar{\Sigma}0}} = \epsilon_\mu \langle \lambda_\Lambda; \lambda_{\bar{\Sigma}^0} \,|\, \bar{u}\gamma^\mu u T_d T_s \,|\, 0 \rangle$$

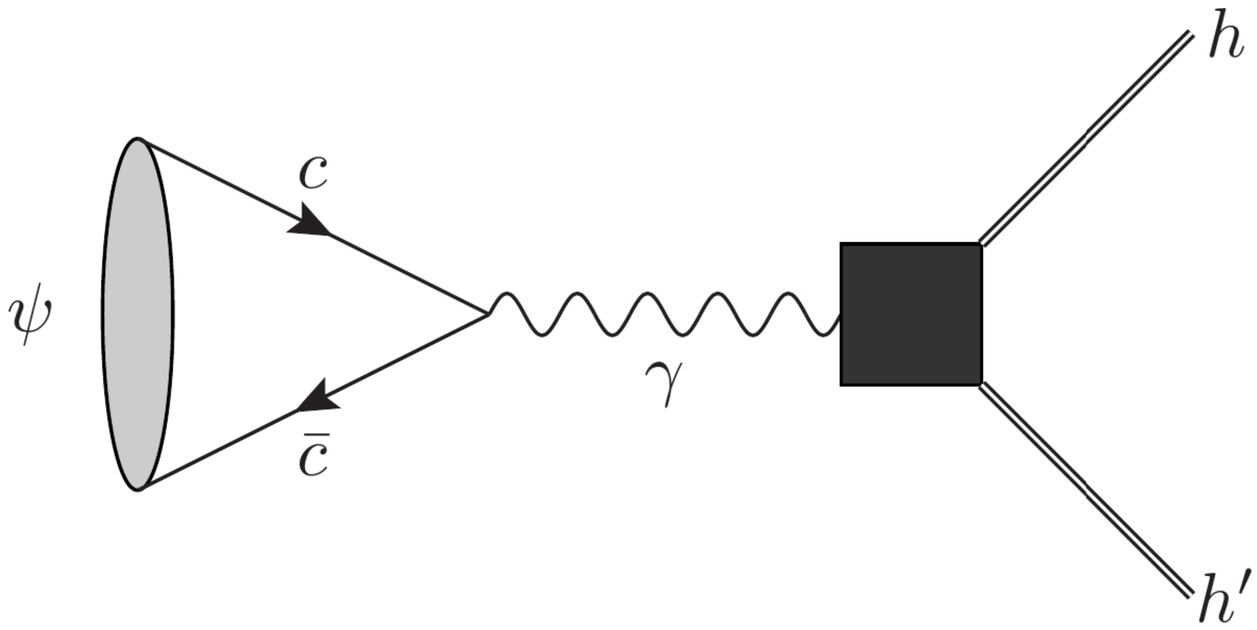
$$\propto \left\langle \Gamma^{\lambda_\psi}_{\lambda_u \lambda_{\bar{u}}}(\vec{x}_\Delta) E_{\lambda_d \lambda_{\bar{d}}}(\vec{x}_\Delta) E_{\lambda_s \lambda_{\bar{s}}}(\vec{x}_\Delta) \right\rangle$$

$\langle \ldots \rangle = \int d^3\vec{x}_\Delta \ldots$ integrates the bag center over the entire space

$E_{\lambda_q \lambda_{\bar{q}}}$: vertex function for $^3P_0$ vertex

$\Gamma^{\psi}_{\lambda_u \lambda_{\bar{u}}}$: vertex function for QED vertex

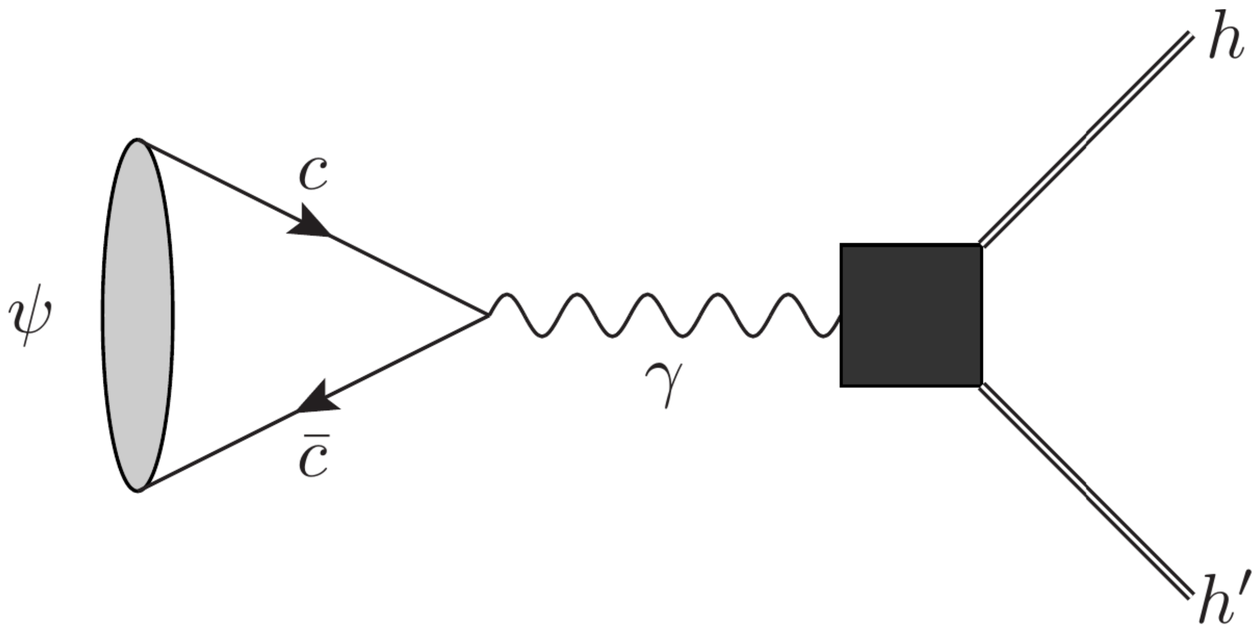
Formalisms—Observables



$$M^{q}_{\lambda_\Lambda \lambda_{\bar{\Sigma}0}} = \epsilon_\mu \bar{u} \left[G_M(q^2)\gamma^\mu + \frac{M_+}{q^2}(G_M(q^2) - G_E(q^2))q^\mu \right] v,$$

$$\mathscr{A}_T = \sqrt{2(M_\psi^2 - M_-^2)}G_M(s),\ \mathscr{A}_L = \frac{M_+}{M_\psi}\sqrt{M_\psi^2 - M_-^2}G_E(s)$$

Formalisms—Observables



$$\mathscr{B}(\psi \to hh') = \frac{1}{3}\frac{|\vec{p}_h|}{8\pi M_\psi^2 \Gamma_\psi} \sum_{\lambda_h,\lambda_{h'}} |\mathscr{A}_{\lambda_h\lambda_{h'}}|^2,$$

$$\frac{d\Gamma}{d\cos\theta} \propto 1 + \alpha\cos^2\theta,$$

$$\alpha = \frac{|\mathscr{A}_T|^2 - 2|\mathscr{A}_L|^2}{|\mathscr{A}_T|^2 + 2|\mathscr{A}_L|^2},$$

$$M^q_{\lambda_\Lambda \lambda_{\bar{\Sigma}0}} = \epsilon_\mu \bar{u}\left[G_M(q^2)\gamma^\mu + \frac{M_+}{q^2}(G_M(q^2) - G_E(q^2))q^\mu\right] v,$$

$$\mathscr{A}_T = \sqrt{2(M_\psi^2 - M_-^2)}G_M(s),\ \mathscr{A}_L = \frac{M_+}{M_\psi}\sqrt{M_\psi^2 - M_-^2}G_E(s)$$

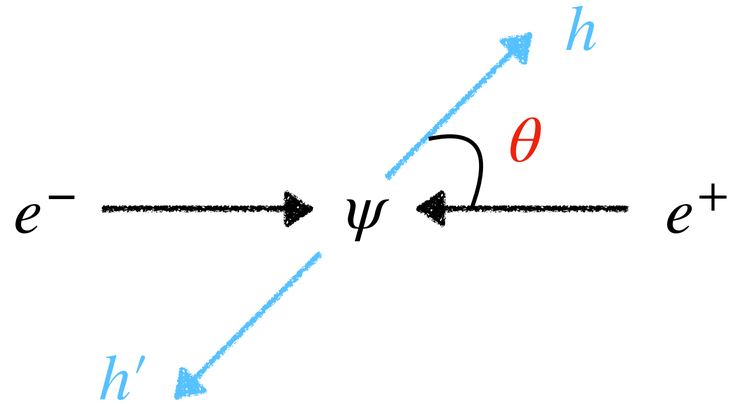


TABLE OF COTENT

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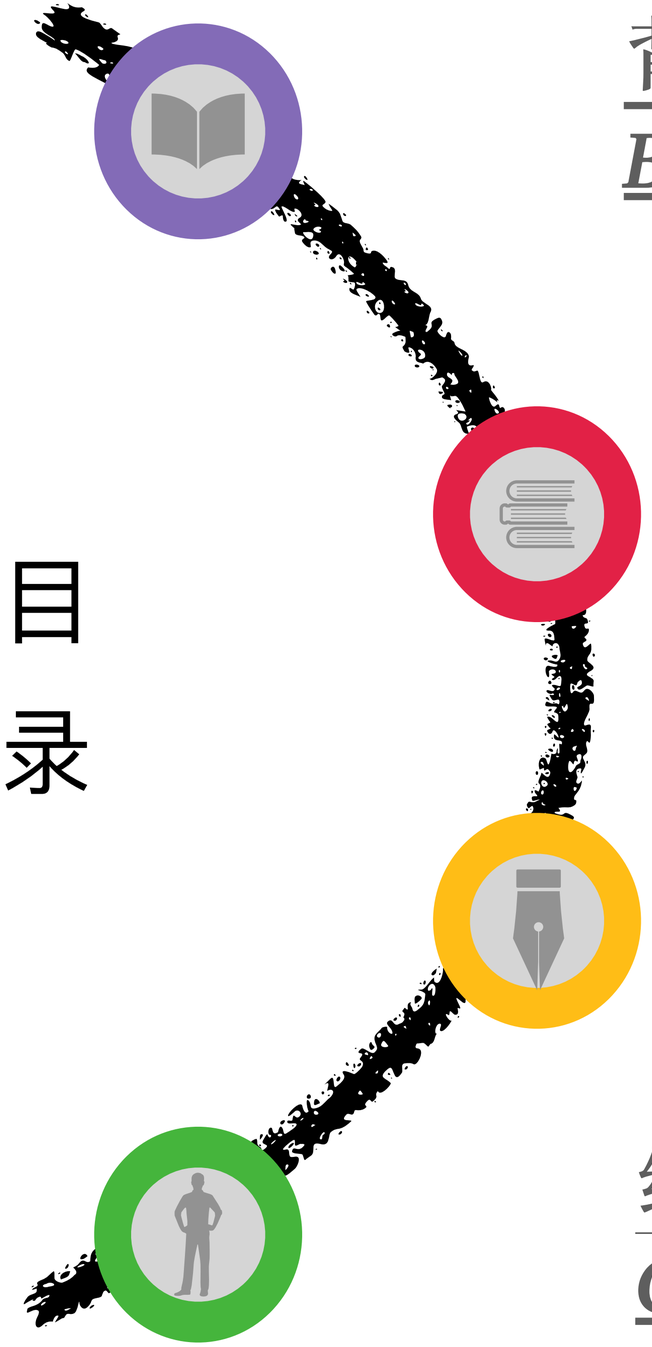


Formalisms—Z' model

$$\langle \Lambda \overline{\Sigma}^0 \,|\, (\bar{u}\gamma_\mu\gamma_5 u - \bar{d}\gamma_\mu\gamma_5 d) \,|\, Z' \rangle \langle Z' \,|\, \bar{c}\gamma^\mu c \,|\, \psi \rangle$$

$$Z'_\mu \left[g_A \left(\bar{u}\gamma^\mu\gamma_5 u - \bar{d}\gamma^\mu\gamma_5 d \right) + g_V \bar{c}\gamma^\mu c \right] + \ldots$$

Formalisms—Z' model

Parity violation $\langle \Lambda\overline{\Sigma}^0 | (\bar{u}\gamma_\mu\gamma_5 u - \bar{d}\gamma_\mu\gamma_5 d) | Z' \rangle \langle Z' | \bar{c}\gamma^\mu c | \psi \rangle$

$$Z'_\mu \left[g_A \left(\bar{u}\gamma^\mu\gamma_5 u - \bar{d}\gamma^\mu\gamma_5 d \right) + g_V \bar{c}\gamma^\mu c \right] + \ldots$$

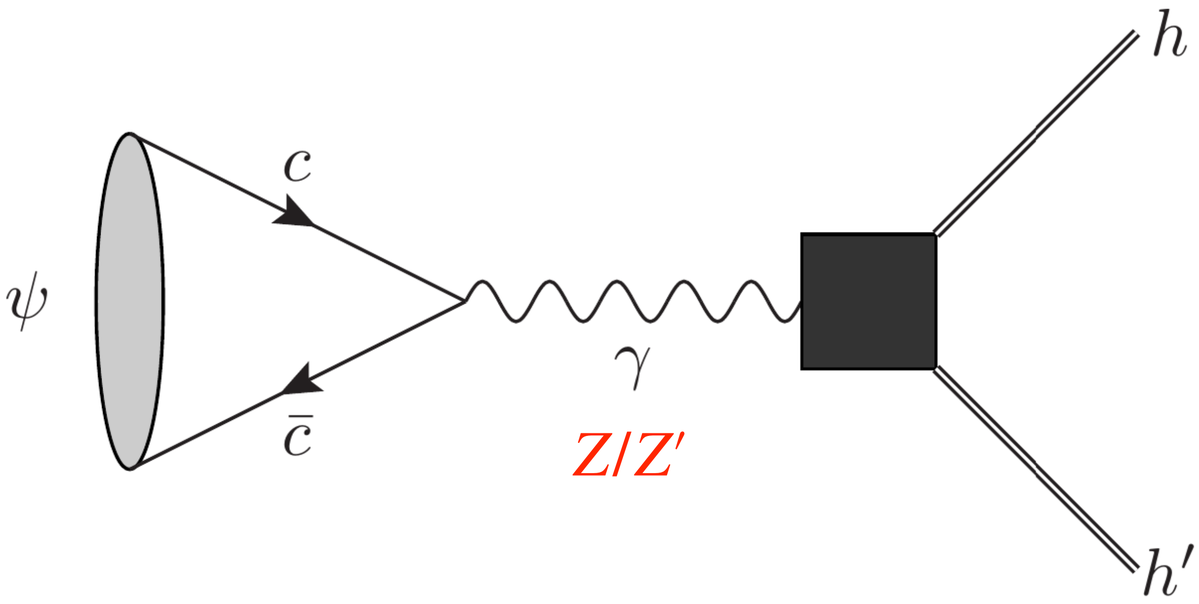
Formalisms—Z' model

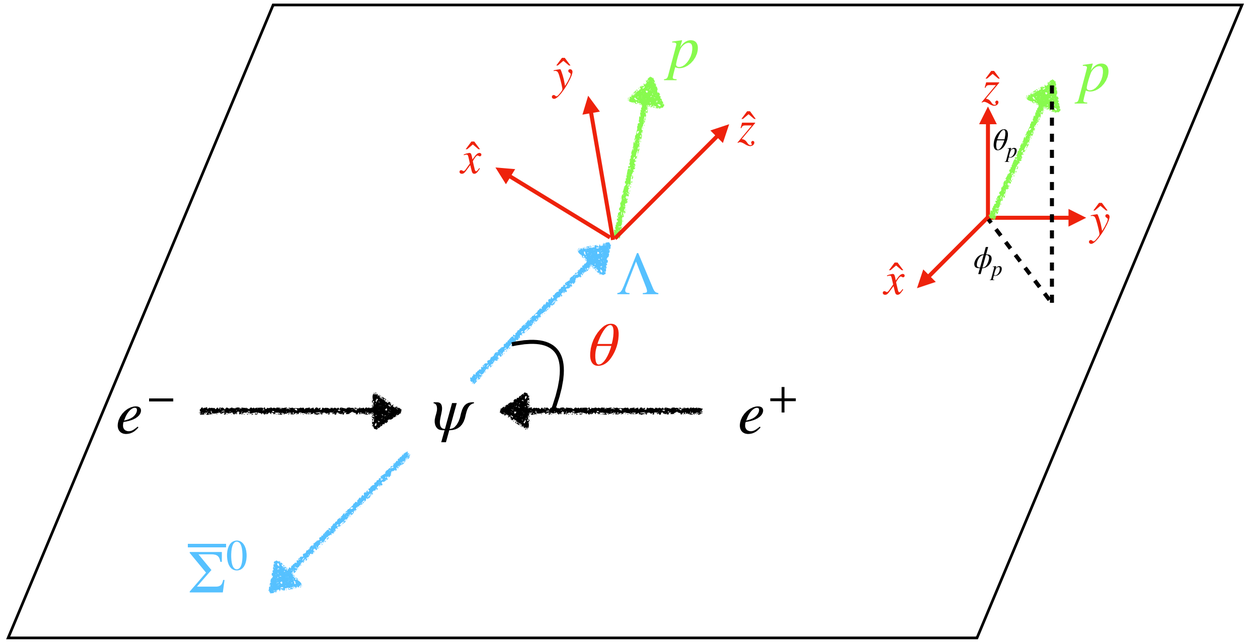
Parity violation $\langle \Lambda\overline{\Sigma}^0 | (\bar{u}\gamma_\mu\gamma_5 u - \bar{d}\gamma_\mu\gamma_5 d) | Z' \rangle \langle Z' | \bar{c}\gamma^\mu c | \psi \rangle$

$$Z'_\mu \left[g_A \left(\bar{u}\gamma^\mu\gamma_5 u - \bar{d}\gamma^\mu\gamma_5 d \right) + g_V \bar{c}\gamma^\mu c \right] + \ldots$$

1. Generation-independent couplings. $\Leftarrow$ evade FCNC constraints
2. Leptophobic $\Leftarrow$ evade e^+e^- collision experimental constraints
3. Violate isospin & parity $\Rightarrow$ $g_A = (g_u^R - g_d^R)/4 \neq 0,\ g_V = (g_u^R + g_u^L)/2 \neq 0$

Formalisms—Observables





$$\frac{1}{\Gamma}\frac{\partial\Gamma}{\partial\cos\theta_p} = 1 + \alpha_{\mathrm{NP}}\alpha_\Lambda\cos\theta = 1 + \alpha\cos\theta_p\,,$$

$$\alpha_{\mathrm{NP}} = \frac{|h_{++}|^2 + |h_{+-}|^2 - |h_{-+}|^2 - |h_{--}|^2}{|h_{++}|^2 + |h_{+-}|^2 + |h_{-+}|^2 + |h_{--}|^2}\,.$$ Nonzero value ⇒ large parity violation

TABLE OF COTENT

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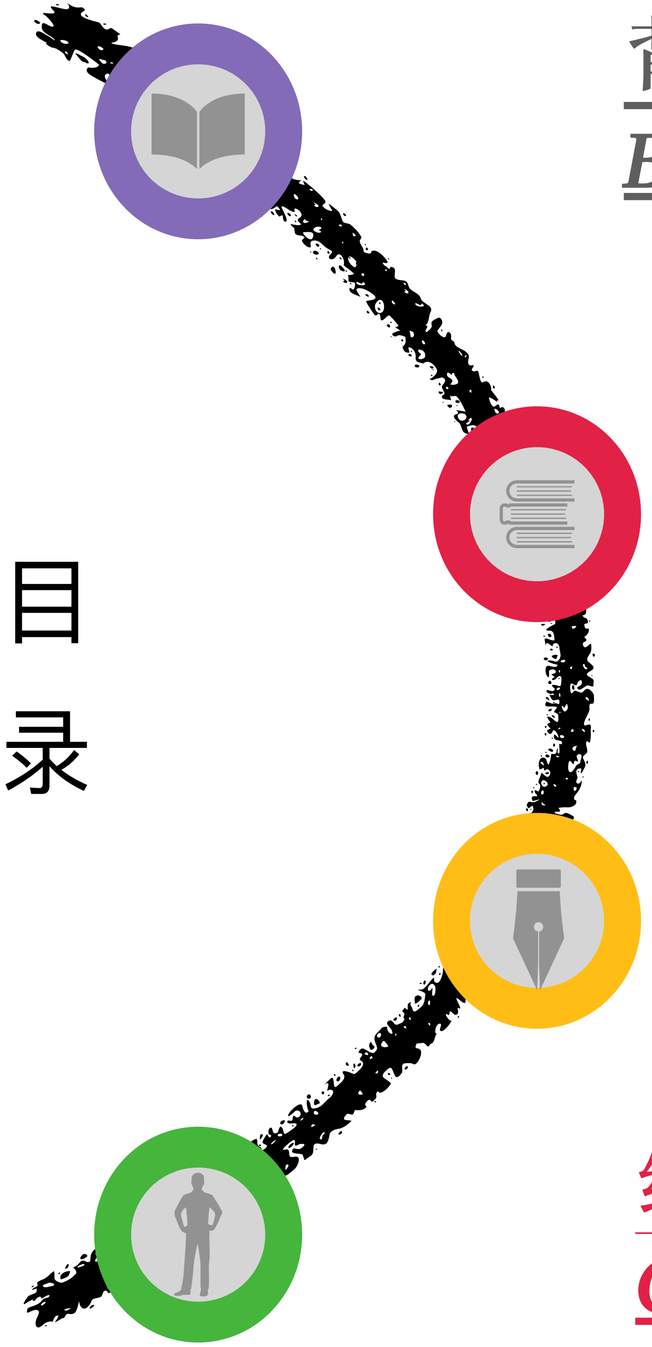


Isospin violating decays of vector charmonia

C. Q. Geng, C.-W. Liu, JZ. EPJC 83, 973 (2023)

Channels	$10^5\mathcal{B}$			α_ψ		
	This work	Exp.		This work	Exp.	
$J/\psi \to \Lambda\overline{\Sigma}^0 + c.c.$	2.40 ± 0.40	2.83 ± 0.23	[1]	0.314	0.418 ± 0.030	[4]
$\psi(2S) \to \Lambda\overline{\Sigma}^0 + c.c.$	0.30 ± 0.05	0.16 ± 0.07	[2]	0.461		
		1.23 ± 0.24	[3]			

[1] M. Ablikim *et al.* [BESIII], Phys. Rev. D **86**, 032008 (2012).

[2] M. Ablikim *et al.* [BESIII], Phys. Rev. D **103**, 112004 (2021).

[3] S. Dobbs, K. K. Seth, *et al*, Phys. Rev. D **96**, 092004 (2017).

[4] M. Ablikim *et al.* [BESIII], arXiv:2309.04139.

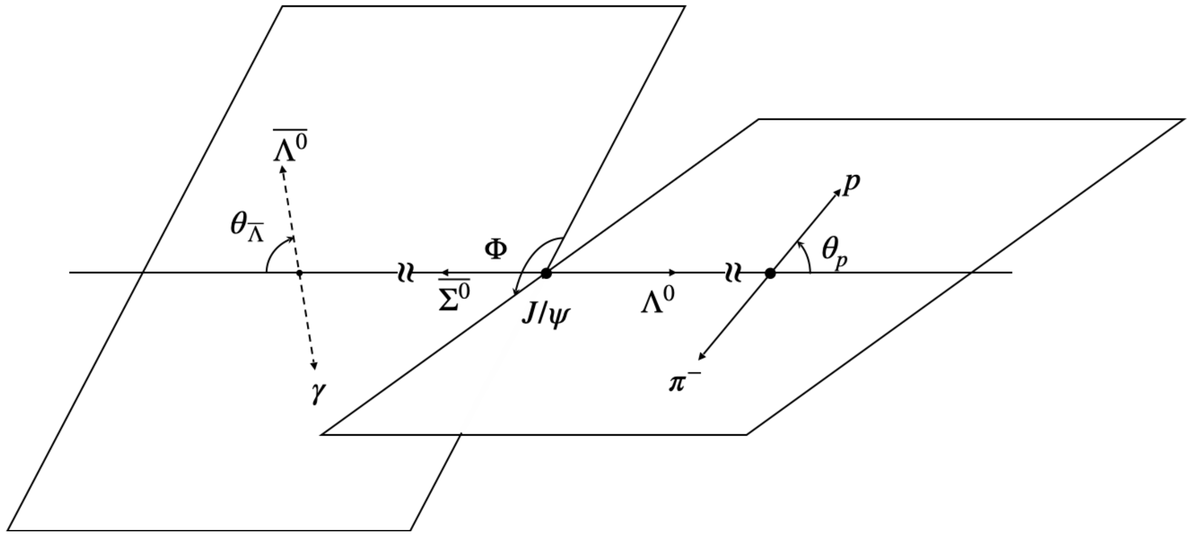
Special Thanks to

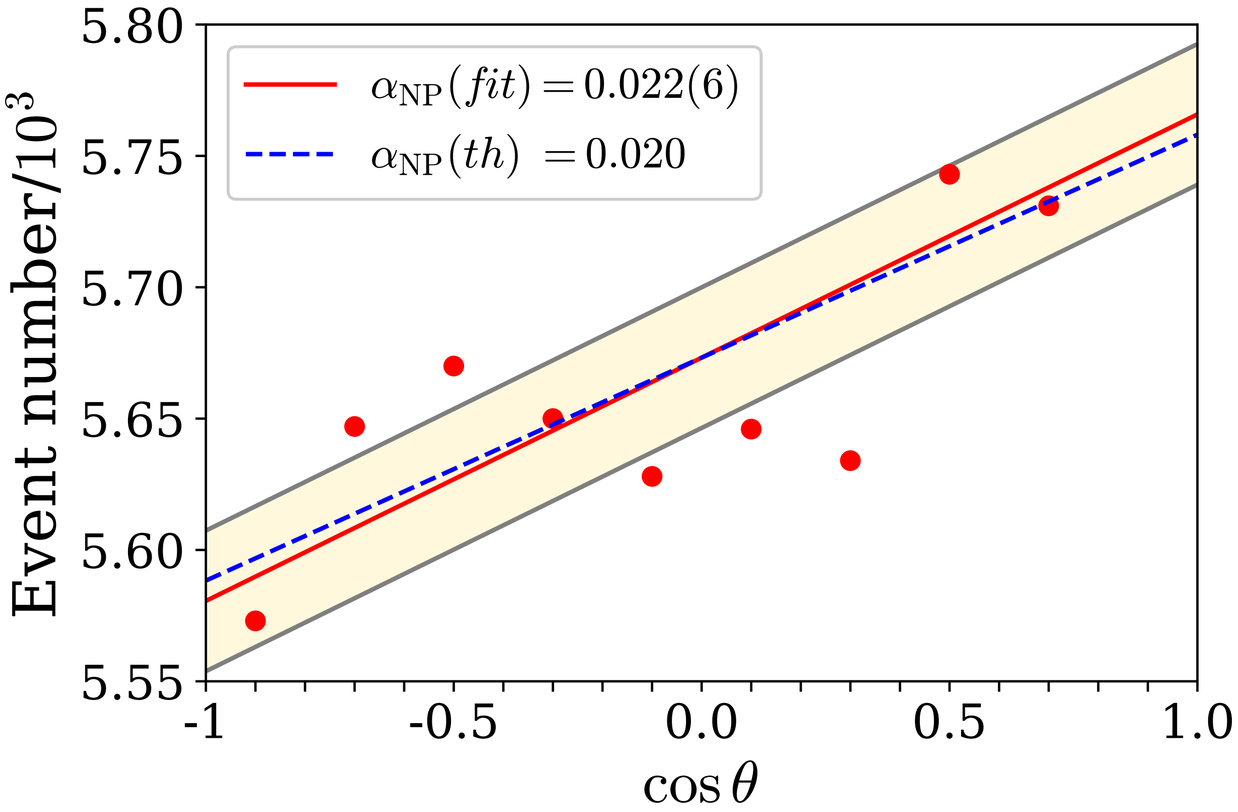
Prof. 周小蓉 & Dr. 贾泽坤

from USTC!

New Signature of low mass Z′ in J/ψ decays

Submitted to PLB, under review





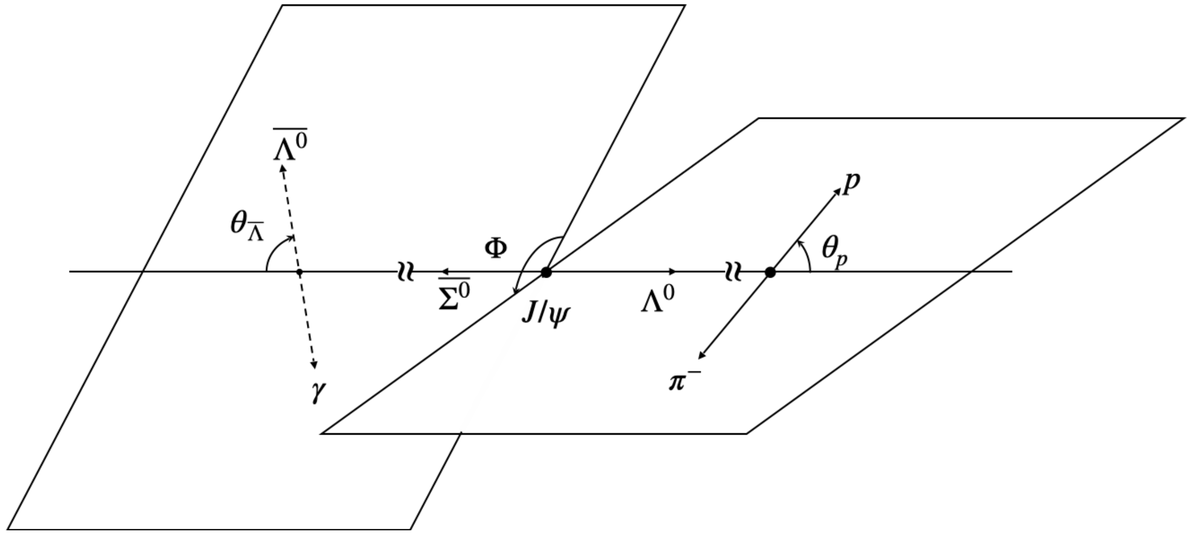
$N_{\rm event} = N_{J/\psi} \times \mathscr{B}_{\Lambda\overline{\Sigma}^0+c.c} \times \epsilon$ We take $\epsilon = 20\,\%$

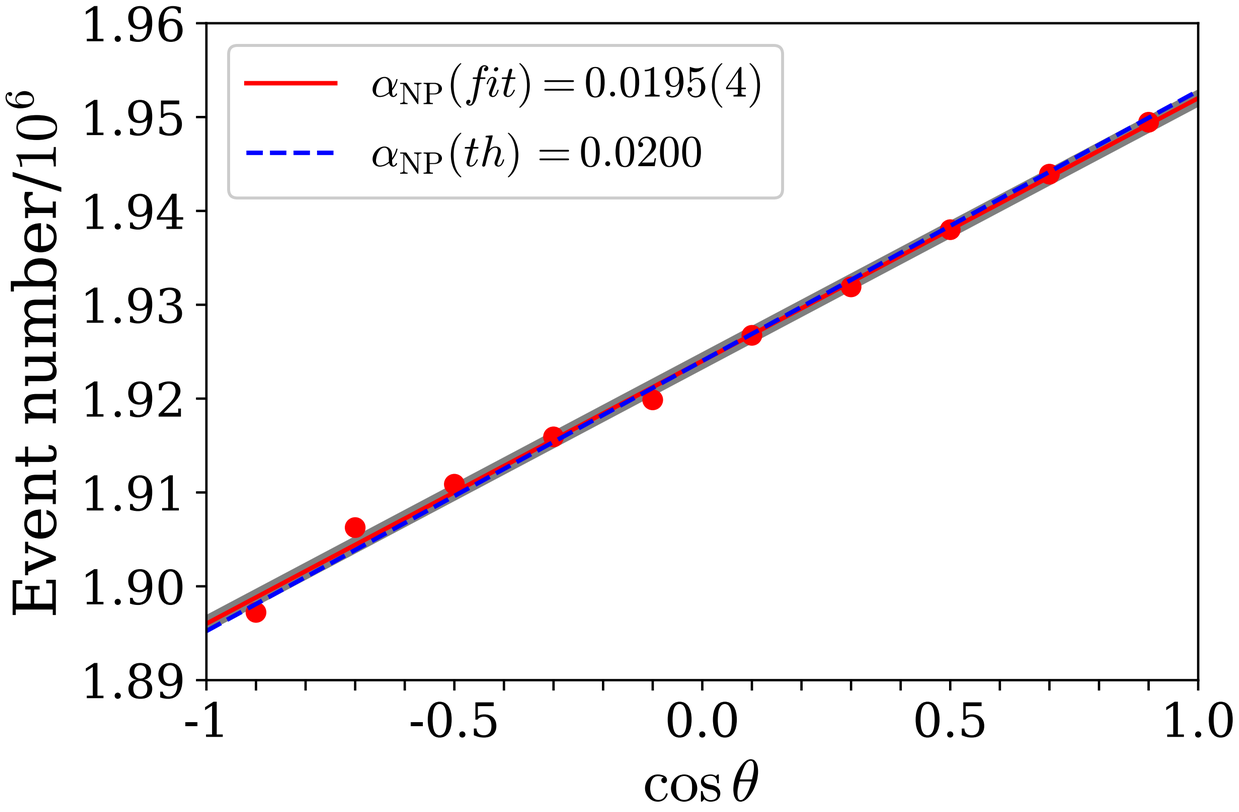
$N_{J/\psi} = 10^{10}$ for BESIII

$$\frac{1}{\Gamma}\frac{\partial\Gamma}{\partial\cos\theta_p} = 1+\alpha_{\rm NP}\alpha_\Lambda\cos\theta_p\,,$$

New Signature of low mass Z′ in J/ψ decays

Submitted to PLB, under review





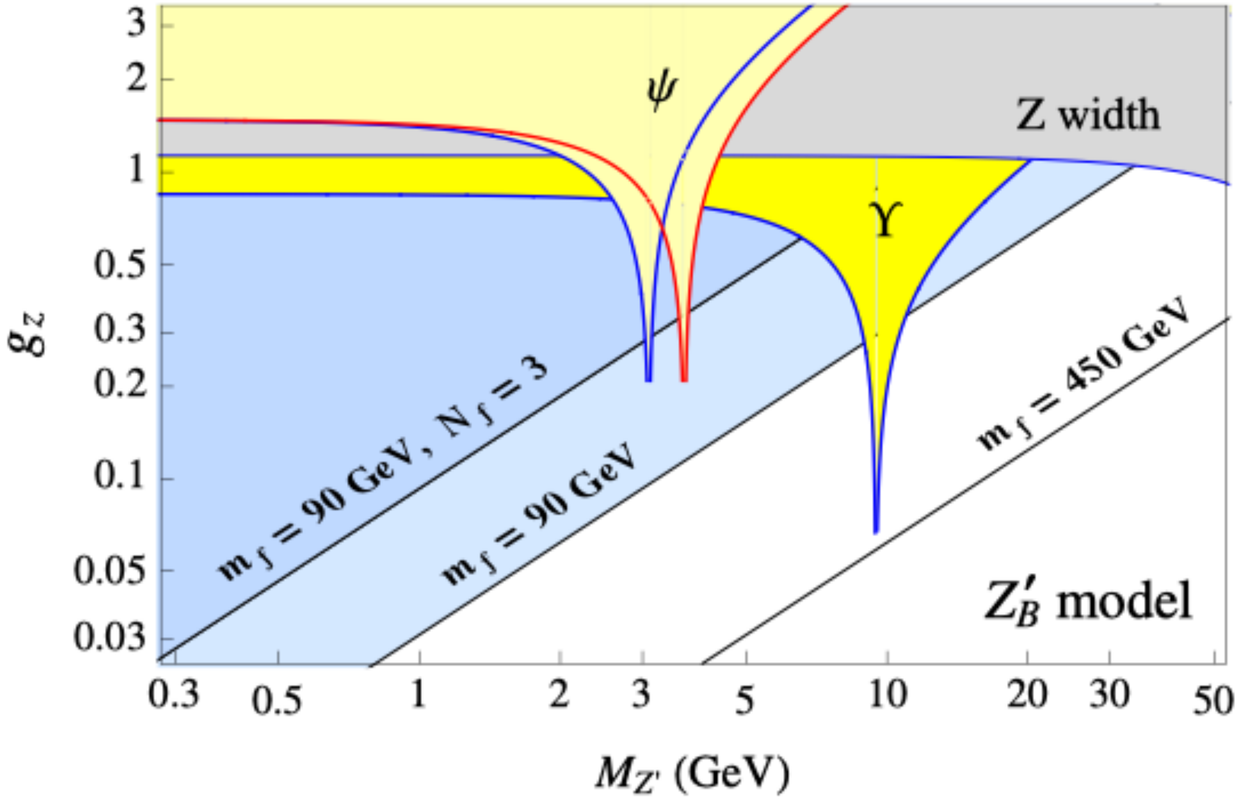
$N_{\rm event} = N_{J/\psi} \times \mathcal{B}_{\Lambda\overline{\Sigma}^0+c.c} \times \epsilon$ We take $\epsilon = 20\,\%$

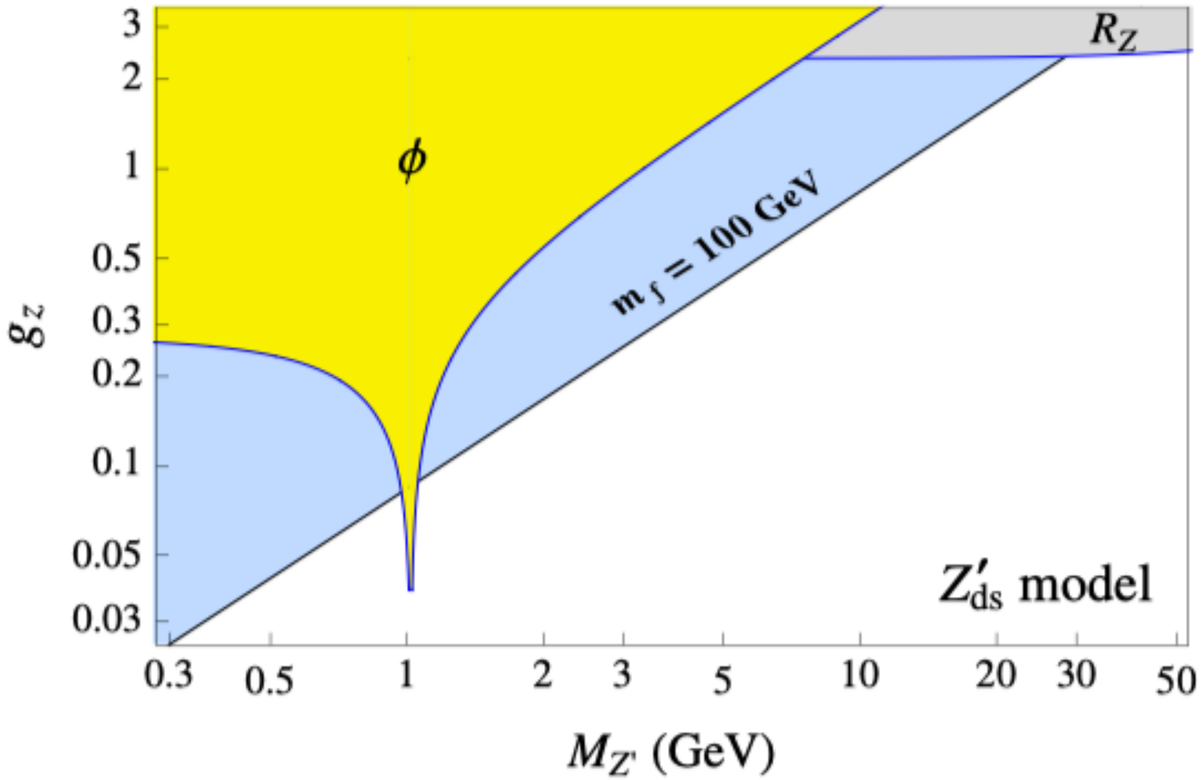
$N_{J/\psi} = 3.4 \times 10^{12}$ for STCF

$$\frac{1}{\Gamma}\frac{\partial\Gamma}{\partial\cos\theta_p} = 1+\alpha_{\rm NP}\alpha_\Lambda\cos\theta_p\,,$$

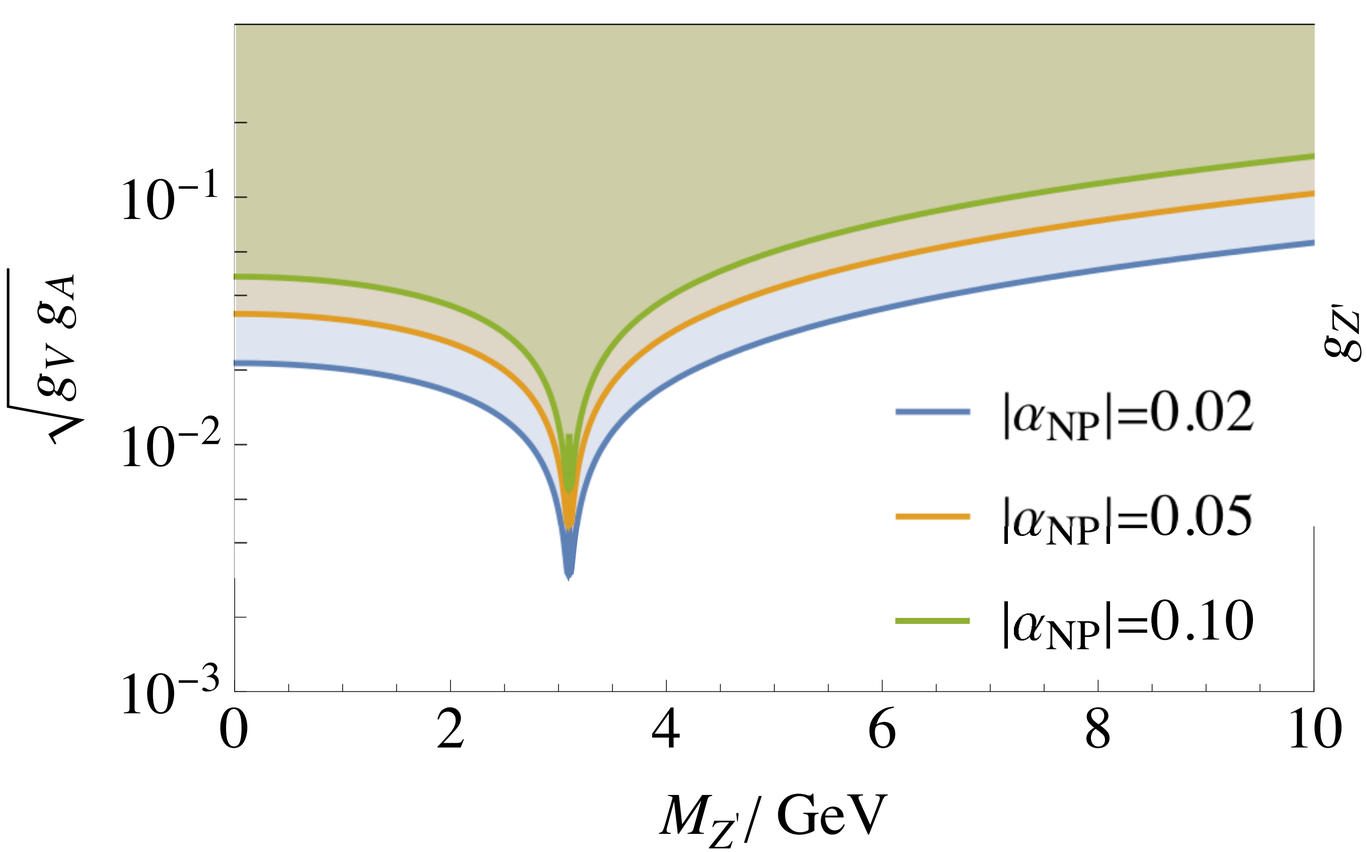
感谢聆听！

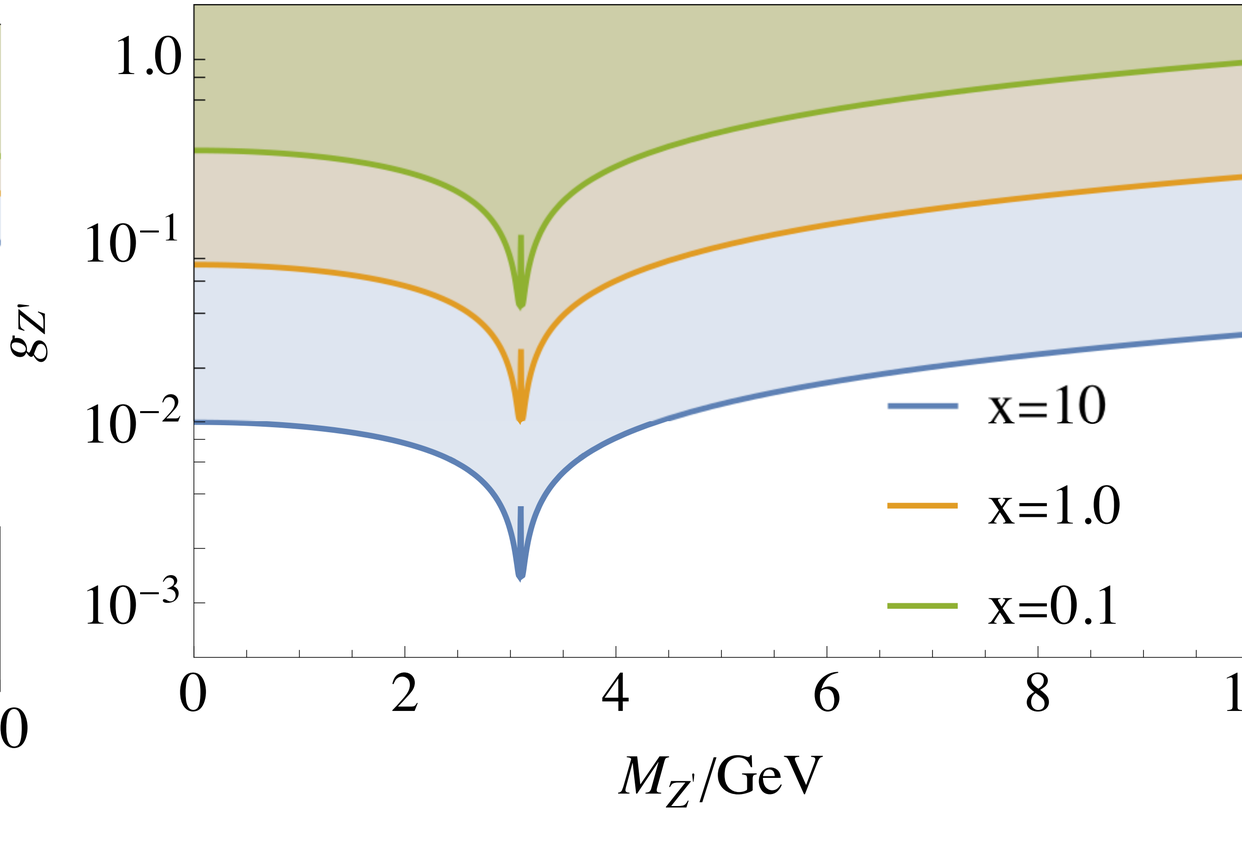
Backup


3
2
1
0.5
0.3
0.2
0.1
0.05
0.03
g_Z
ψ
Υ
Z width
$m_{f} = 90$ GeV , $N_f = 3$
$m_{f} = 90$ GeV
$m_{f} = 450$ GeV
Z'_B model
0.3
0.5
1
2
3
5
10
20
30
50
$M_{Z'}$ (GeV)


3
2
1
0.5
0.3
0.2
0.1
0.05
0.03
g_Z
ϕ
R_Z
$m_{f} = 100$ GeV
Z'_{ds} model
0.3
0.5
1
2
3
5
10
20
30
50
$M_{Z'}$ (GeV)

Backup


$\sqrt{g_V\, g_A}$
10^{-1}
10^{-2}
10^{-3}
0
2
4
6
8
10
$M_{Z'}$/ GeV
$|\alpha_{\rm NP}|$=0.02
$|\alpha_{\rm NP}|$=0.05
$|\alpha_{\rm NP}|$=0.10


$g_{Z'}$
1.0
10^{-1}
10^{-2}
10^{-3}
0
2
4
6
8
$M_{Z'}$/GeV
x=10
x=1.0
x=0.1