Detecting the pure triangle singularity effect through the decay of ψ(2S)

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PRD 103 (2021) 1, 016014 arXiv: 2109.08349 [hep-ph]

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Content

- What is Triangle Singularity?
- Why Triangle Singularity interesting ?
- How to confirm Triangle Singularity?
- Our two proposals
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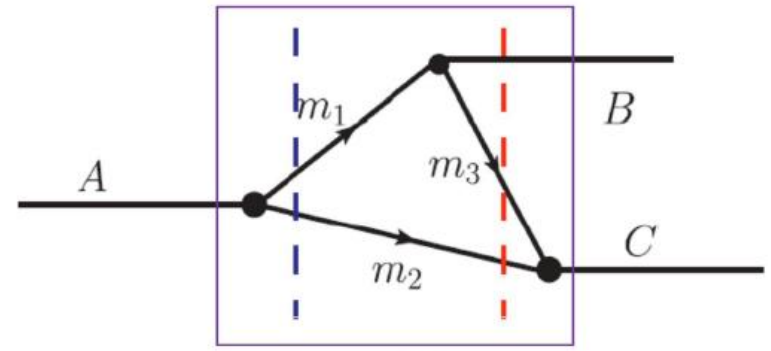
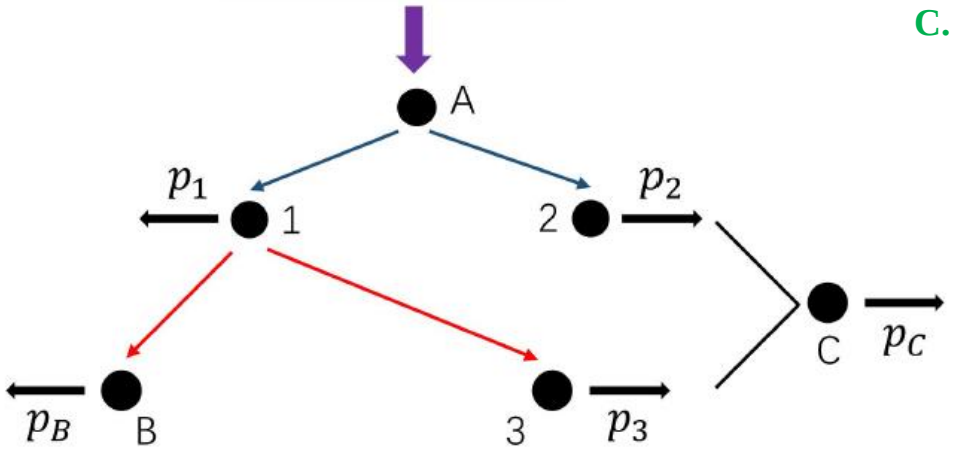
What is Triangle Singularity?





Actually Happened Process

(1) All particles are on mass-shell;

(2) Particle 3 catch up particle 2.

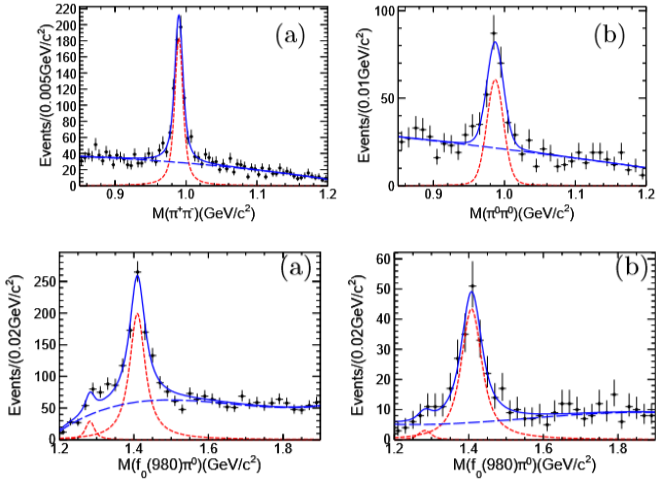
L. D. Landau, NP 13, 181 (1960)

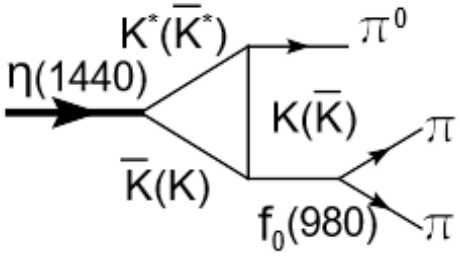
S. Coleman, R.E. Norton, Nuovo Cim. 38, 438 (1965)

R. Karplus, C.M. Sommerfield, E.H. Wichmann, PR 111, 1187 (1958).

J.D. Bjorken, Ph.D. Thesis, Stanford University, Stanford, CA, USA, (1959).

C. Schmid, PR 154, 1363 (1967)





BESIII collaboration,
PRL 108, 182001(2012)

Wu, Liu, Zhao, Zou
PRL, 108, 081803 (2012)

Why Triangle Singularity interesting ?

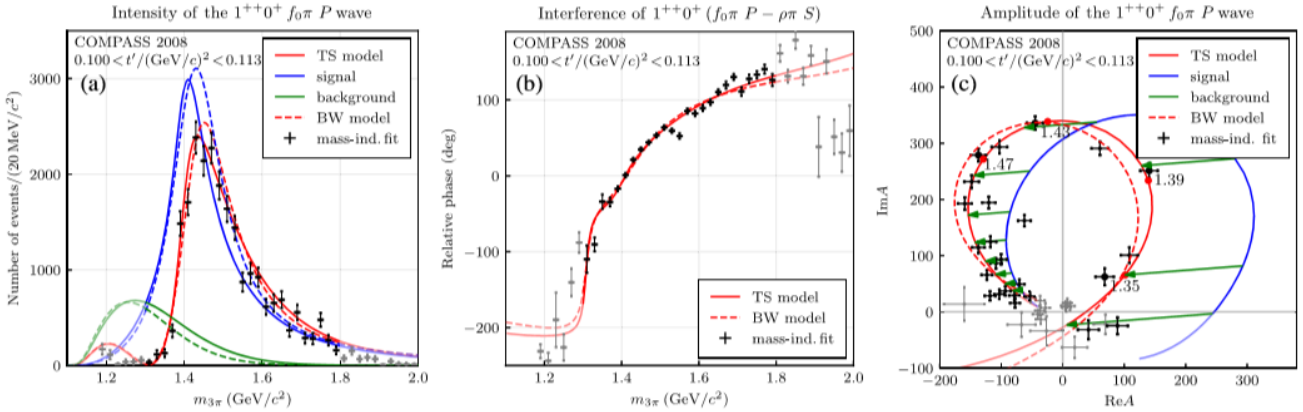
Guo, Liu, Sakai PPNP 112, 103757 (2020)

Structures	Processes	Loops	I/F	Refs.
2.1 GeV [141]	$\gamma p^+ \to N^*(2030) \to K^+\Lambda(1405)$	$K^*\Sigma\pi$	I	[142]
2.1 GeV	$\pi^- p^+ \to K^0\Lambda(1405)$, $pp \to pK^+\Lambda(1405)$	$K^*\Sigma\pi$	I	[143]
1.88 GeV	$\Lambda_c^+ \to \pi^+\pi^0\pi\Sigma$	$\bar{K}^*N\bar{K}$	I	[144, 145][a]
$N(1700)$ [10]	$N(1700) \to \pi\Delta$	$\rho N\pi$	I	[146]
$N(1875)$ [10]	$N(1875) \to \pi N(1535)$	$\Sigma^*K\Lambda$	I	[147]
$\Delta(1700)$ [148–150]	$\gamma p \to \Delta(1700) \to \pi N(1535) \to p\pi^0\eta$	$\Delta\eta p$	I	[151]
2.2 GeV [152]	$\Lambda_c^+ \to \pi^0\phi p$	$\Sigma^*K^*\Lambda$	F	[153]
1.66 GeV [154, 155]	$\Lambda_c^+ \to \pi^+K^-p$	$a_0\Lambda\eta, \Sigma^*\eta\Lambda$	F	[156]
$P_c(4450)$ [35]	$\Lambda_b^0 \to K^-J/\psi p$	$\Lambda(1890)\chi_{c1}p$	F	[157–160][b]
		$N(1900)\chi_{c1}p$	F	[159]
peaks relevant for P_c	$\Lambda_b^0 \to K^-J/\psi p$	$\bar{D}_{sJ}\Lambda_c^{(*)}\bar{D}^{(*)}$	F	[36, 158]

Structures	Processes	Loops	I/F	Refs.
$\rho(1480)$ [78, 79]	$\pi^- p \to \phi\pi^0 n$	$K^*\bar{K}K$	I	[80, 81]
$\eta(1405/1475)$ [82–86]	$\eta(1405/1475) \to \pi f_0$	$K^*\bar{K}K$	I	[87–91][a,b]
$f_1(1420)$ [92]	$f_1(1285) \to \pi a_0/\pi f_0$	$K^*\bar{K}K$	I	[89, 93–95][b]
$a_1(1420)$ [96, 97]	$a_1(1260) \to f_0\pi \to 3\pi$	$K^*\bar{K}K$	I	[97–99]
1.4 GeV [100]	$J/\psi \to \phi\pi^0\eta/\phi\pi^0\pi^0$	$K^*\bar{K}K$	I	[101][b]
1.42 GeV	$B^- \to D^{*0}\pi^- f_0(a_0), \tau \to \nu_\tau\pi^- f_0(a_0)$	$K^*\bar{K}K$	I	[102, 103]
	$D_s^+ \to \pi^+\pi^0 f_0(a_0), \bar{B}_s^0 \to J/\psi\pi^0 f_0(a_0)$	$K^*\bar{K}K$	I	[104, 105]
$f_2(1810)$ [10]	$f_2(1640) \to \pi\pi\rho$	$K^*\bar{K}^*K$	I	[106]
1.65 GeV	$\tau \to \nu_\tau\pi^- f_1(1285)$	$K^*\bar{K}^*K$	I	[107]
1515 MeV	$J/\psi \to K^+K^- f_0(a_0)$	$\phi\bar{K}K$	I	[108]
2.85 GeV, 3.0 GeV	$B^- \to K^-\pi^- D_{s0}^*/K^-\pi^- D_{s1}$	$K^{*0}D^{(*)0}K^+$	I	[109, 110]
5.78 GeV	$B_c^+ \to \pi^0\pi^+ B_s^0$	$\bar{K}^{*0}B^+\bar{K}$	F	[111]
[4.01, 4.02] GeV	$[\bar{D}^{*0}D^{*0}] \to \gamma X$	$D^{*0}\bar{D}^{*0}D^0$	I	[112]
4015 MeV	$e^+e^- \to \gamma X$	$D^{*0}\bar{D}^{*0}D^0$	I	[113, 114]
4015 MeV	$B \to KX\pi$, $pp/p\bar{p} \to X\pi$+anything	$D^{*0}\bar{D}^{*0}D^0$	I	[115, 116]
$\Upsilon(11020)$ [117, 118]	$e^+e^- \to Z_b\pi$	$B_1(5721)\bar{B}B^*$	I	[119, 120]
3.73 GeV	$X \to \pi^0\pi^+\pi^-$	$D^{*0}\bar{D}^0D^0$	F	[121]
[4.22, 4.24] GeV	$e^+e^- \to \gamma J/\psi\phi/\pi^0 J/\psi\eta$	$D_{s0(s1)}^*\bar{D}_s^{(*)}D_s^{(*)}$	F	[122]
[4.08, 4.09] GeV	$e^+e^- \to \pi^0 J/\psi\eta$	$D_{s0(s1)}^*\bar{D}_s^{(*)}D_s^{(*)}$	F	[122]
$Z_c(3900)$ [31, 32]	$e^+e^- \to J/\psi\pi^+\pi^-$	$D_1\bar{D}D^*$	F	[119, 123–127][c]
		$D_0^*(2400)\bar{D}^*D$	F	[128, 129]
$Z_c(4020, 4030)$ [33, 130]	$e^+e^- \to \pi^+\pi^- h_c(\psi')$	$D_{1(2)}\bar{D}^{(*)}D^{(*)}$	F	[125]
$X(4700)$ [131, 132]	$B^+ \to K^+J/\psi\phi$	$K_1(1650)\psi'\phi$	F	[133]
$Z_c(4430)$ [30, 134]	$\bar{B}^0 \to K^-\pi^+ J/\psi$	$\bar{K}^{*0}\psi(4260)\pi^+$	F	[135]
$Z_c(4200)$ [136, 137]	$\bar{B}^0 \to K^-\pi^+\psi(2S)$	$\bar{K}_2^*\psi(3770)\pi^+$	F	[135]
	$\Lambda_b^0 \to p\pi^- J/\psi$	$N^*\psi(3770)\pi^-$	F	[135]
$X(4050)^\pm$ [138]	$\bar{B}^0 \to K^-\pi^+\chi_{c1}$	$\bar{K}^{*0}X\pi^+$	F	[139]
$X(4250)^\pm$ [138]	$\bar{B}^0 \to K^-\pi^+\chi_{c1}$	$\bar{K}_2^*\psi(3770)\pi^+$	F	[139]
$Z_b(10610)$ [34]	$e^+e^- \to \Upsilon(1S)\pi^+\pi^-$	$B_J^*\bar{B}^*B$	F	[128]

1.It is a pure kinematic effect –> Model independent
2.The effect of Loop –> Understand hadronic loop contribution
3.Provide a peak structure –> May mixing with resonance
4.Extract the nature of hadron –> Study the coupling at the energy point
5. ……

$$\pi p \to a_1(1420) \to f_0(980)\pi \to 3\pi$$



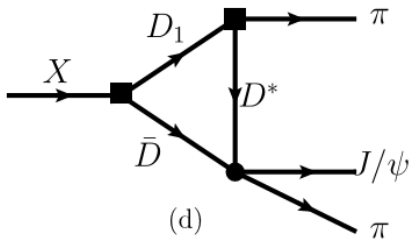
Mikhasenko, Ketzer, Sarantsev
PRD 91, 094015 (2015)

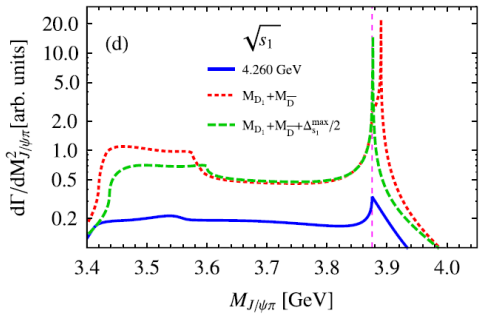
COMPASS Collaboration PRL 127, 082501 (2021)

But not confirm yet …

How to confirm Triangle Singularity?

1.Threshold

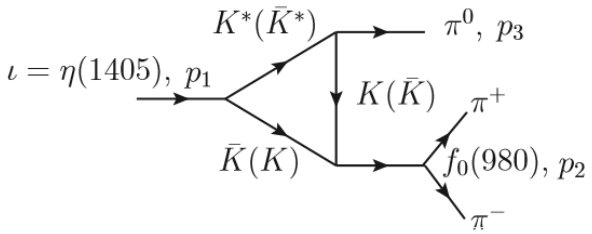


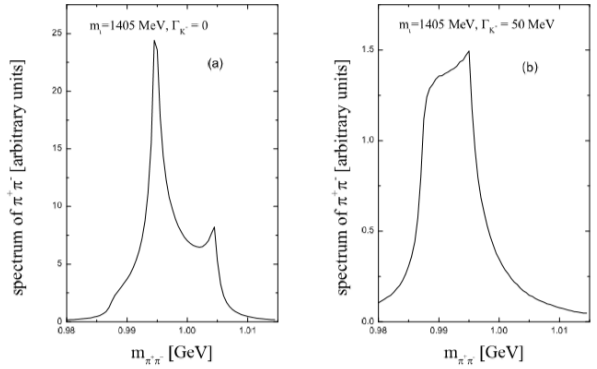


The corresponding values are listed in Table 1. The ATS peak will then stay close to the normal threshold, as illustrated in Fig. 4(d). In this sense, it would be difficult to distinguish the ATS peak from the pole structure in the invariant mass of the $J/\psi\pi$. We shall come back to the relevant issue later in this Section. It should be

X. H. Liu, M. Oka and Q. Zhao,
PLB 753, 297-302 (2016)

2.Width of the internal particle of the loop



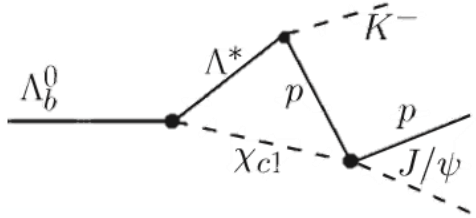


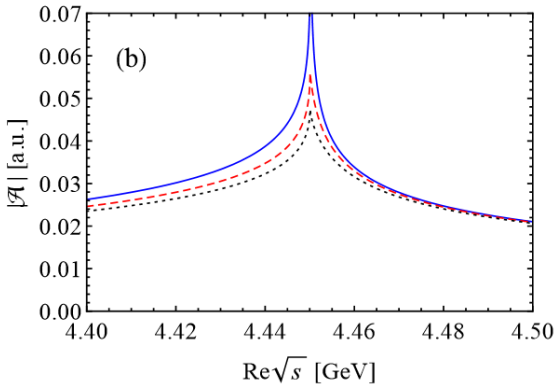
Achasov, Kozhevnikov, Sobolev IM, Shestakov PRD 92 (2015) 3, 036003

3.Unknow vertex

Guo, Meißner, Wang, Yang, PRD92, 071502 (2015)

$$\Lambda_b \to (c\bar{c})\Lambda^* \to (c\bar{c})\Lambda\, K^- \to J/\psi p K^-$$

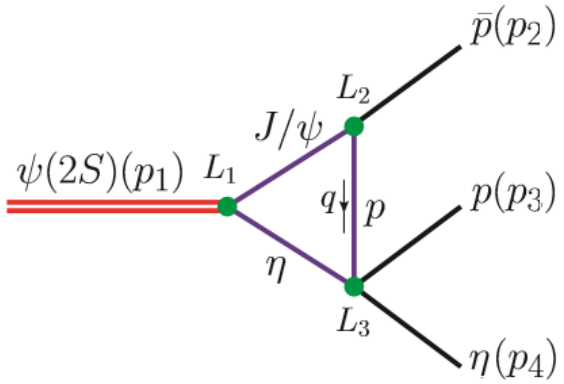




First proposal

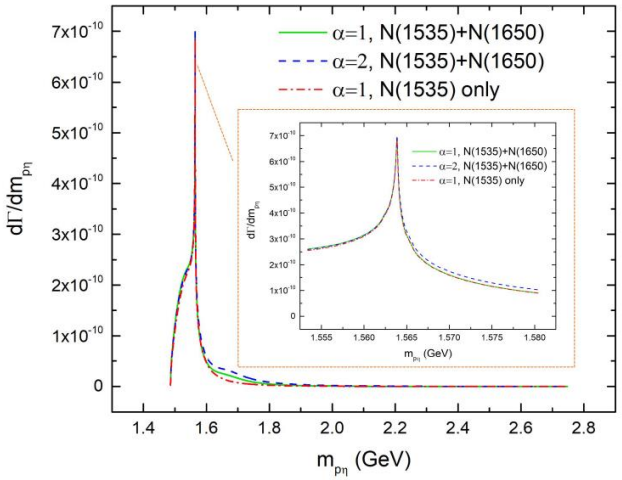
1.Threshold

Far away from pη threshold. Singularity point is 1.563 GeV of p η invariant mass.



2.Width of the internal particle of the loop

All narrow internal particles, J/psi, p, η

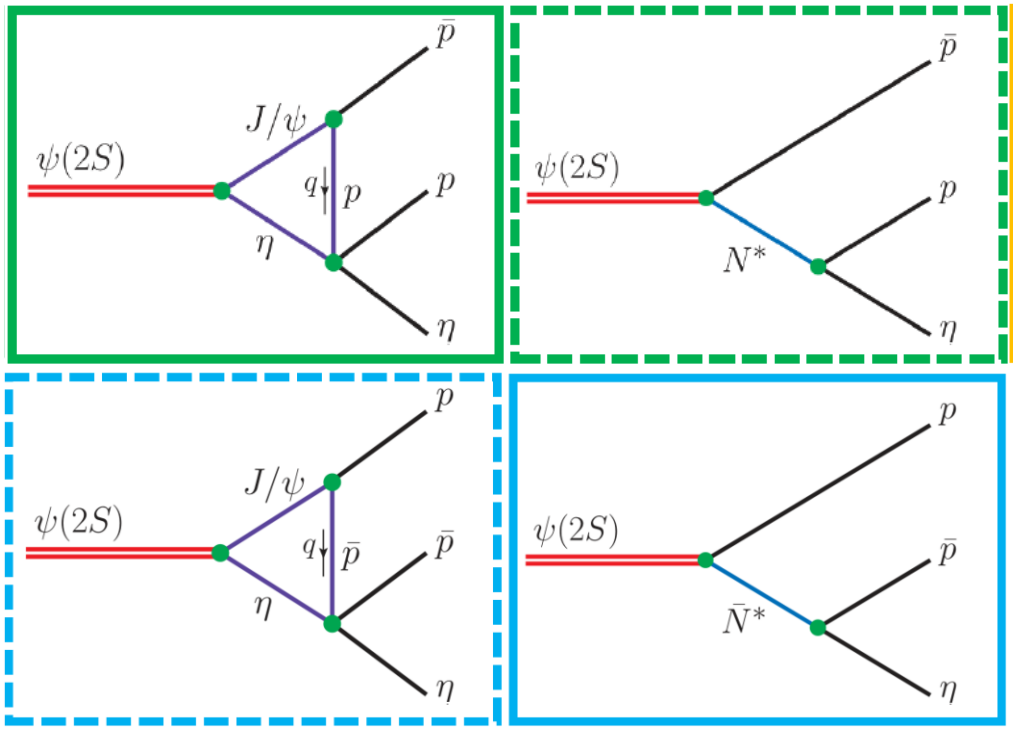


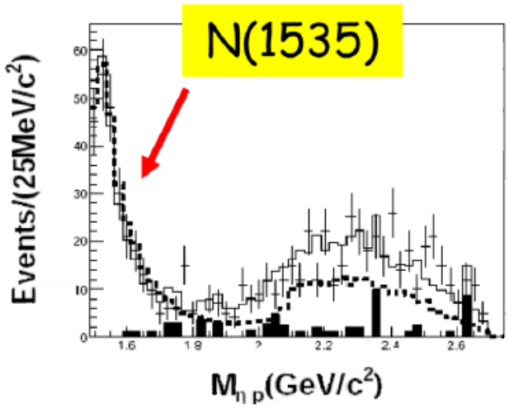
3.Unknow vertex

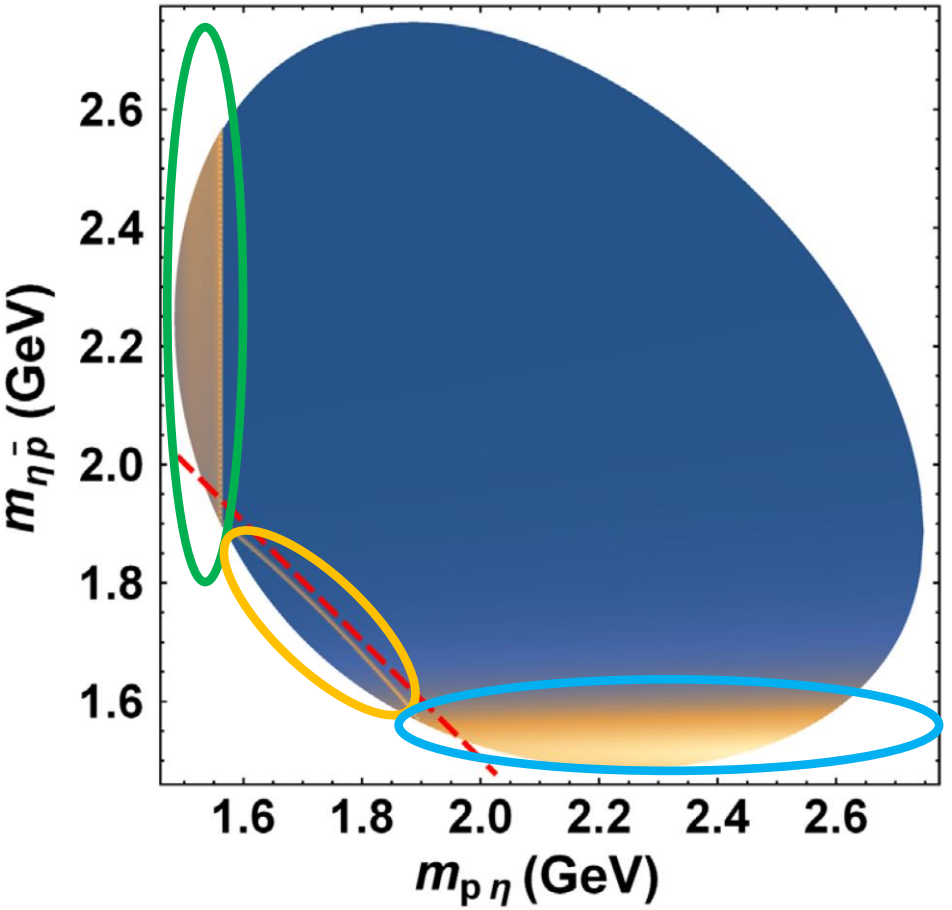
All vertices are constrained from experimental data

First proposal

Signal + Background







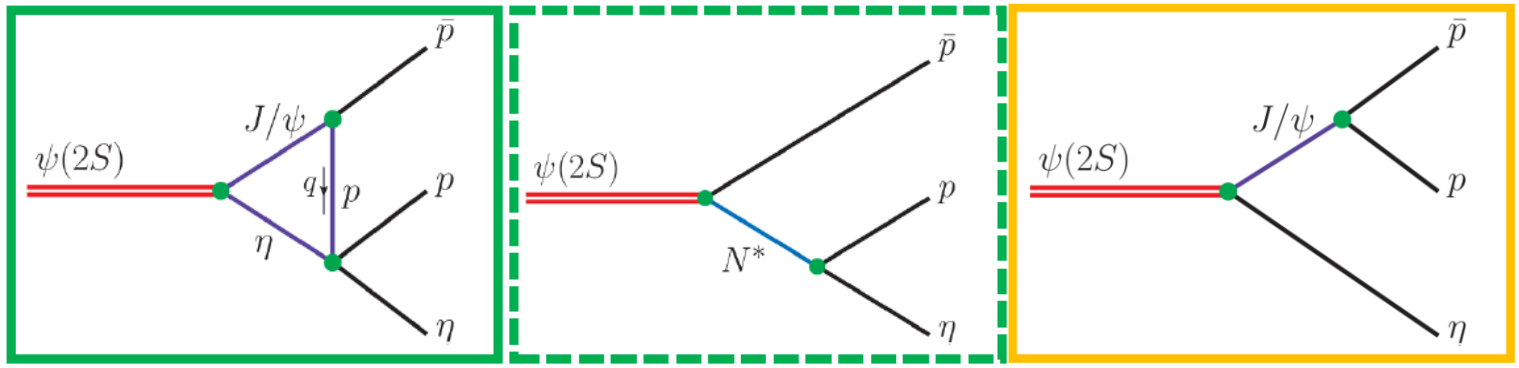
Take a cut to remove the contribution of J/ψ tree diagram as done in BESIII

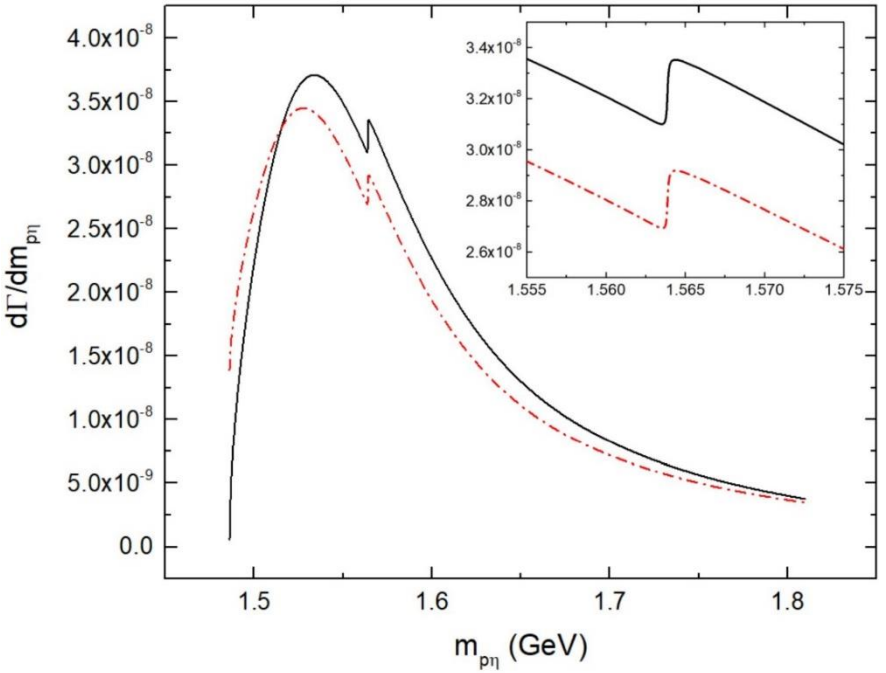
$m_{p\bar{p}} < 3.067$ GeV

BESIII PRD 88, 032010 (2013)

First proposal

Signal + Background





1.There exists a visible enhancement at the right shoulder of N(1535).

2.The width of the peak is enlarged to 5 MeV.

3.The enhancement of the peak VS the tree diagram is about 10%.

4 billion $\psi(2S)$ ⇒ about 120 events.

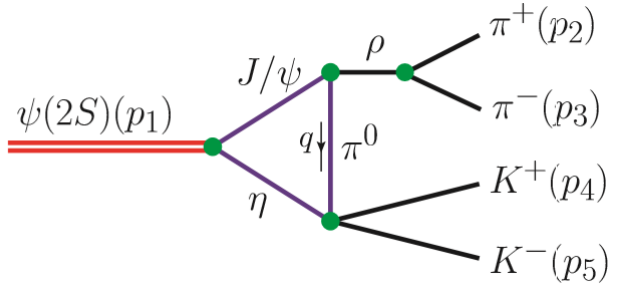
Weakness:

1. Ask for high resolution, 2-3 MeV,
2. Generated from interference between TS and BG with an assumption that phase is 0.

Second proposal– Moving Triangle singularity

1.Threshold

Far away from $\pi\eta$ threshold. Singularity point is from 1.158-1.181 GeV of KK invariant mass with the width of ρ.

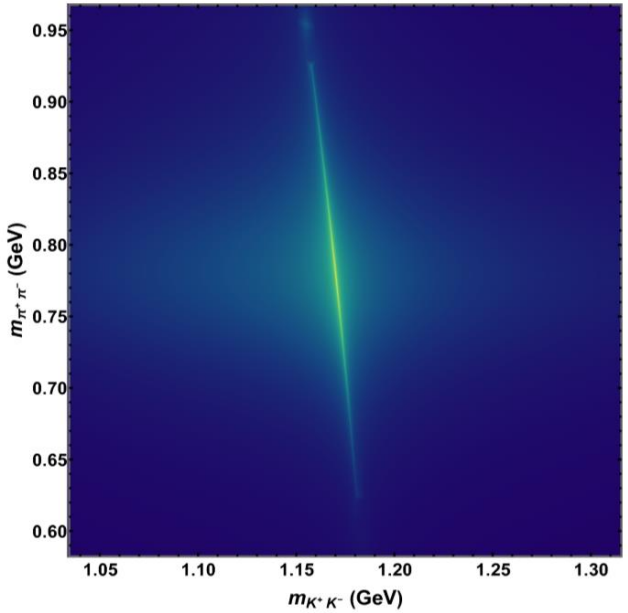


2.Width of the internal particle of the loop

All narrow internal particles, J/ψ, π, η

3.Unknow vertex

All vertices are constrained from experimental data



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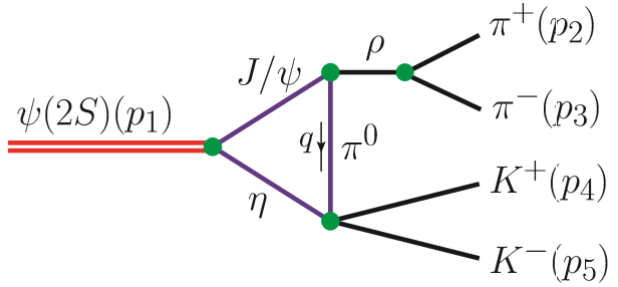

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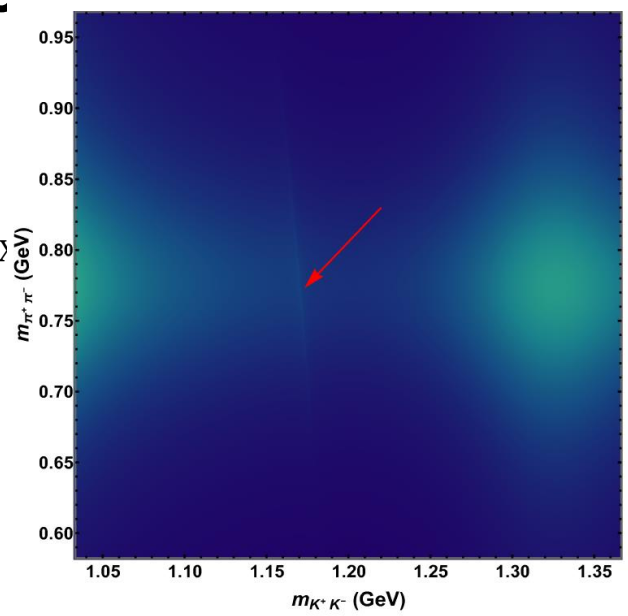
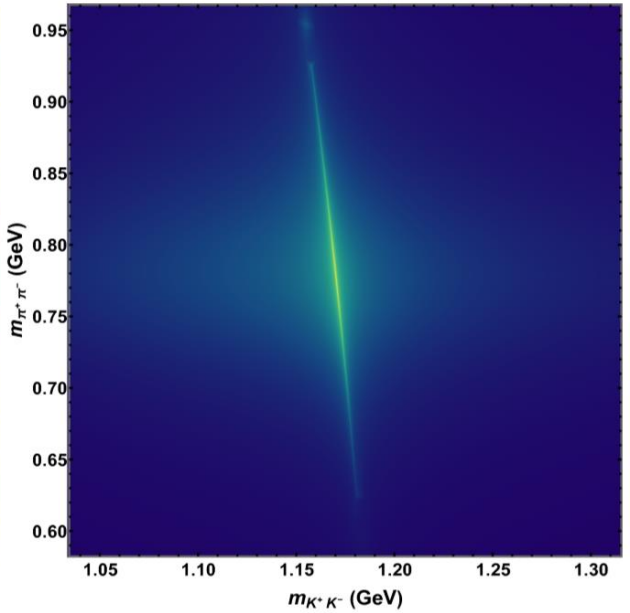
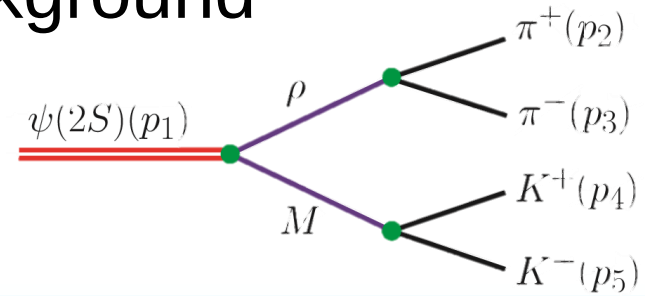
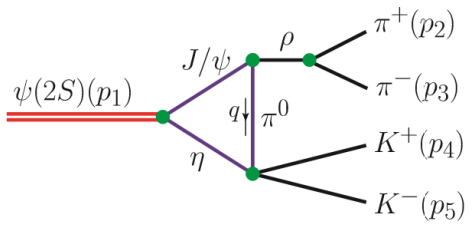


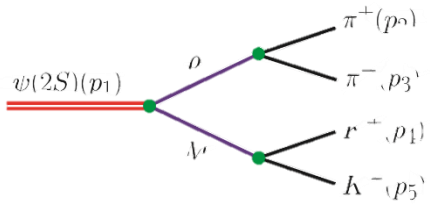


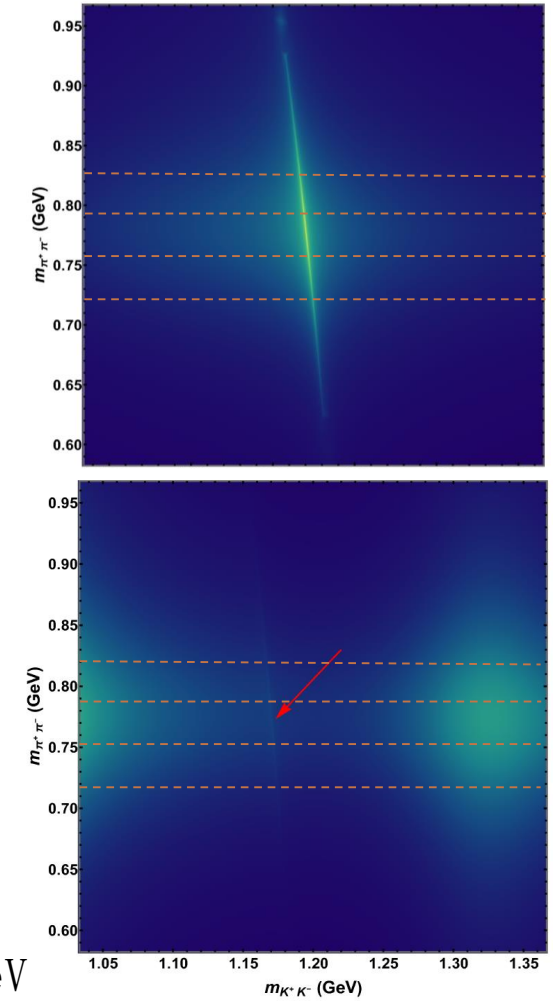
Background

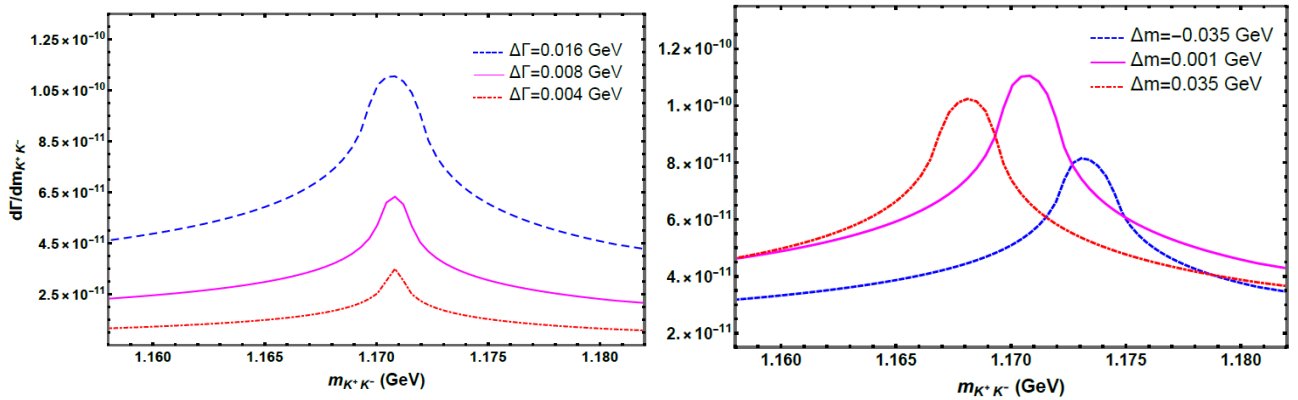


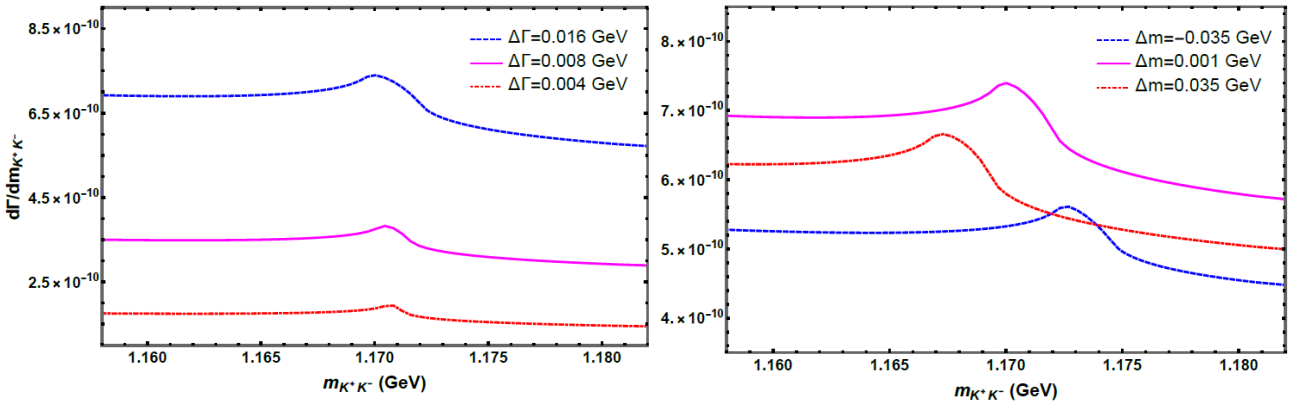
Second proposal– Moving Triangle singularity











4 billion $\psi(2S)$
→ about 10 events/MeV

Two important parameters,
$\Delta\Gamma$: the width of bin; Δm: the distance from the center mass of ρ.

Summary

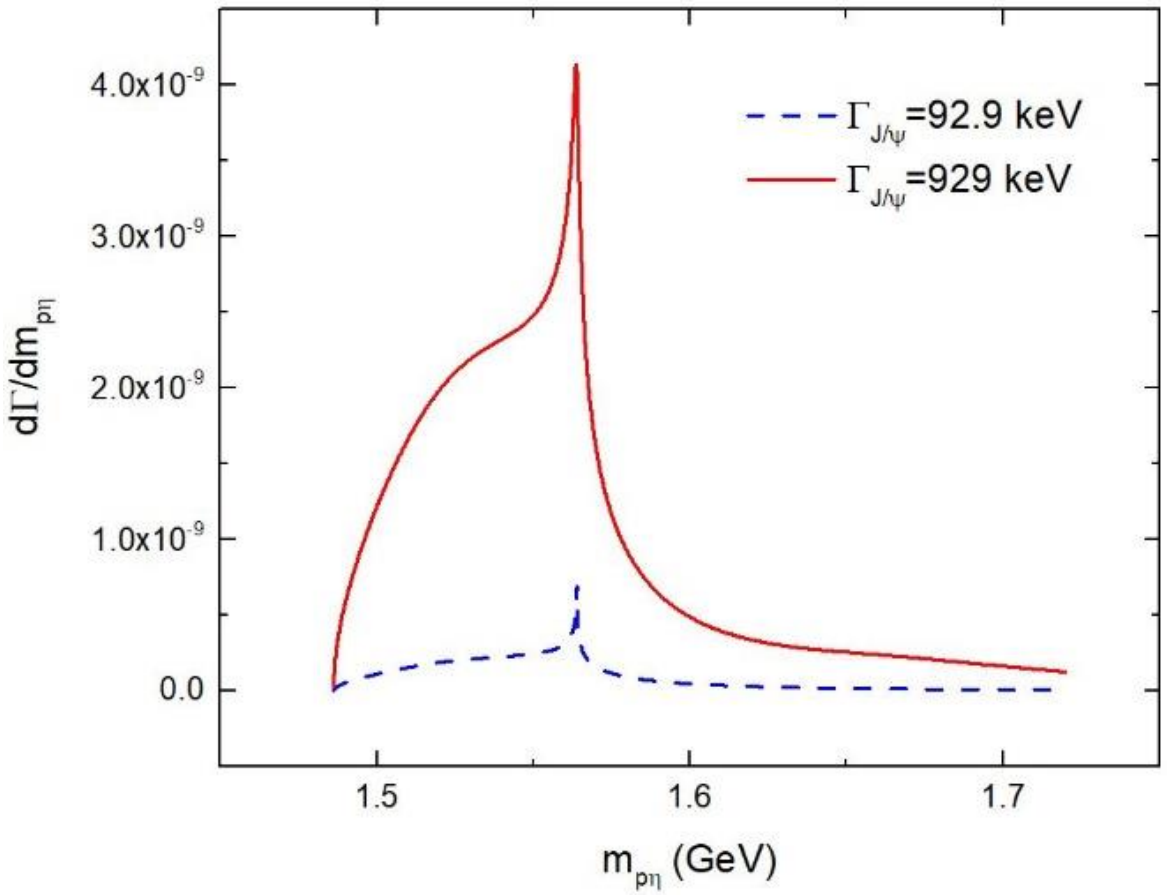
We discuss how to confirm the Triangle Singularity, we should consider the following three points,

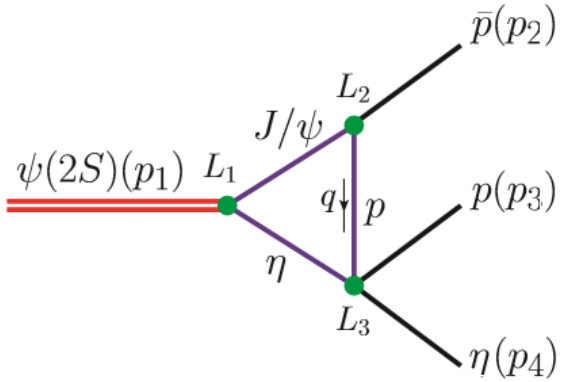
1. Threshold
2. Width of the internal particle of the loop
3. Unknow vertex

Then we propose two processes $\psi(2s) \to p\,\bar{p}\,\eta$ through J/ψ, p, η loop and $\psi(2s) \to \rho\,KK \to \pi\pi\,KK$ through J/ψ, π, η loop.

But the signals of both two processes are not very stronger. ☹

More discussion





$$\sim \sqrt{\Gamma_{J/\psi\to p\bar{p}}}\ \ln \Gamma_{J/\psi}$$

V. R. Debastiani1, S. Sakai, E. Oset EPJC 79, 69 (2019)

We will continue to find some broader states with width around 10 MeV.

Thanks for attention!