CHALLENGE:
Two Photon Physics In $B \to K^{(*)} \nu\nu$

Y. FAN, on behalf of kvv group

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Discrepancy between data and MC

$B^0 \rightarrow K^{*0}\,\nu\nu$ channel

Charged tracks:

> CDC acceptance, Pt>0.1 GeV/c, E<5.5 GeV,

> |dz|<3 cm, dr<0.5 cm (not for K_s^0's daughter)

Photons:

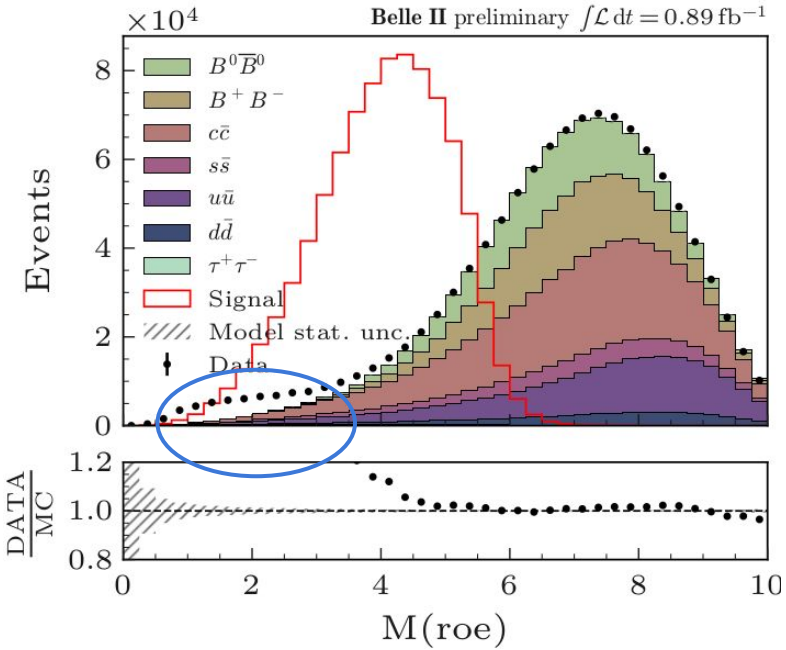
> Standard photon list , CDC acceptance,

> 0.1<E<5.5 GeV

Signal K*0->Kpi:
K, π: nPXDHits>0,KaonID>0.75, pionID>0.05,
K^{*0} vertex position and momentum is extracted from Treefit, 0.8<M<1.0 GeV

Two candidates with an MVA
(using M(K π), q^2 and vertex position in XY)

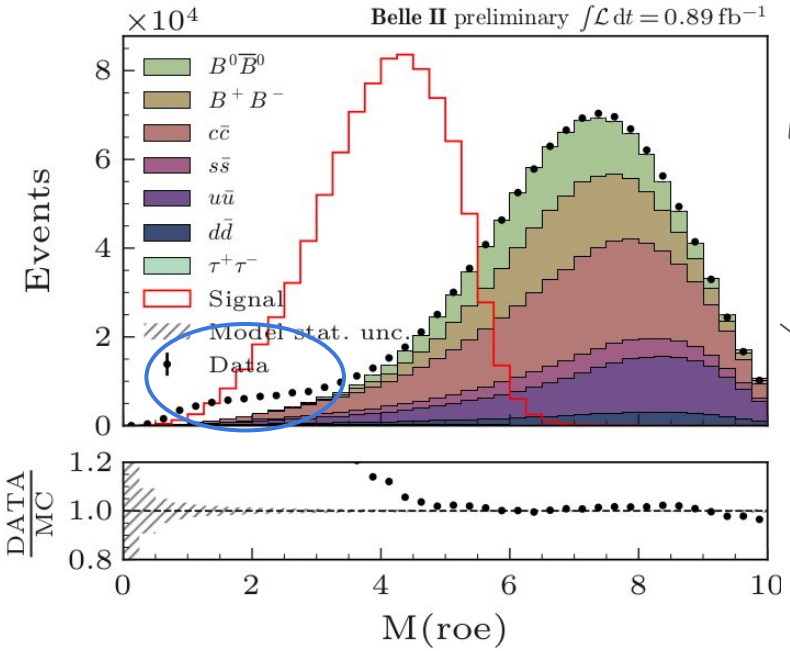
1% exp18 data and MC15RD, Luminosity normalized



Discrepancy between data and MC in lower ROE-mass, (visible) transverse energy, …

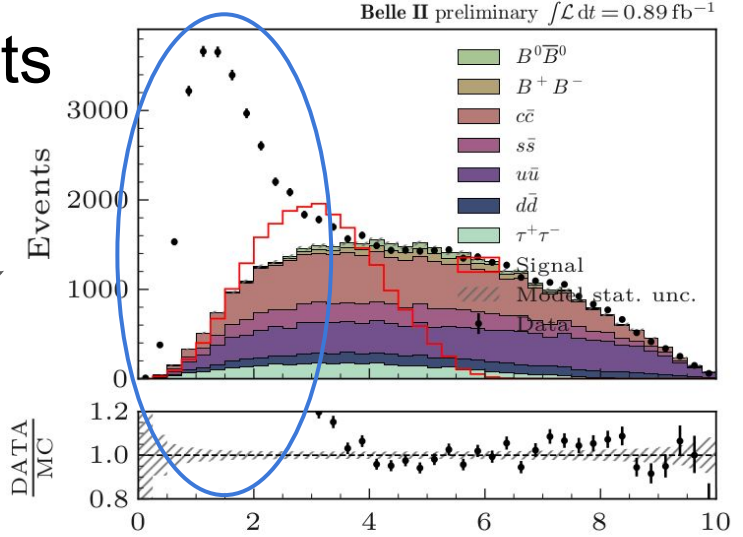
Discrepancy for low-multiplicity events

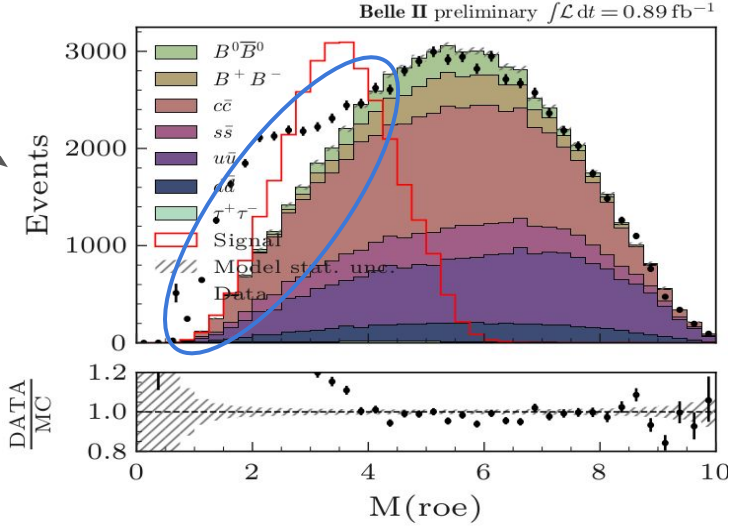
$B^0 \to K^{*0}\,\nu\nu$ channel



4 tracks

5 tracks

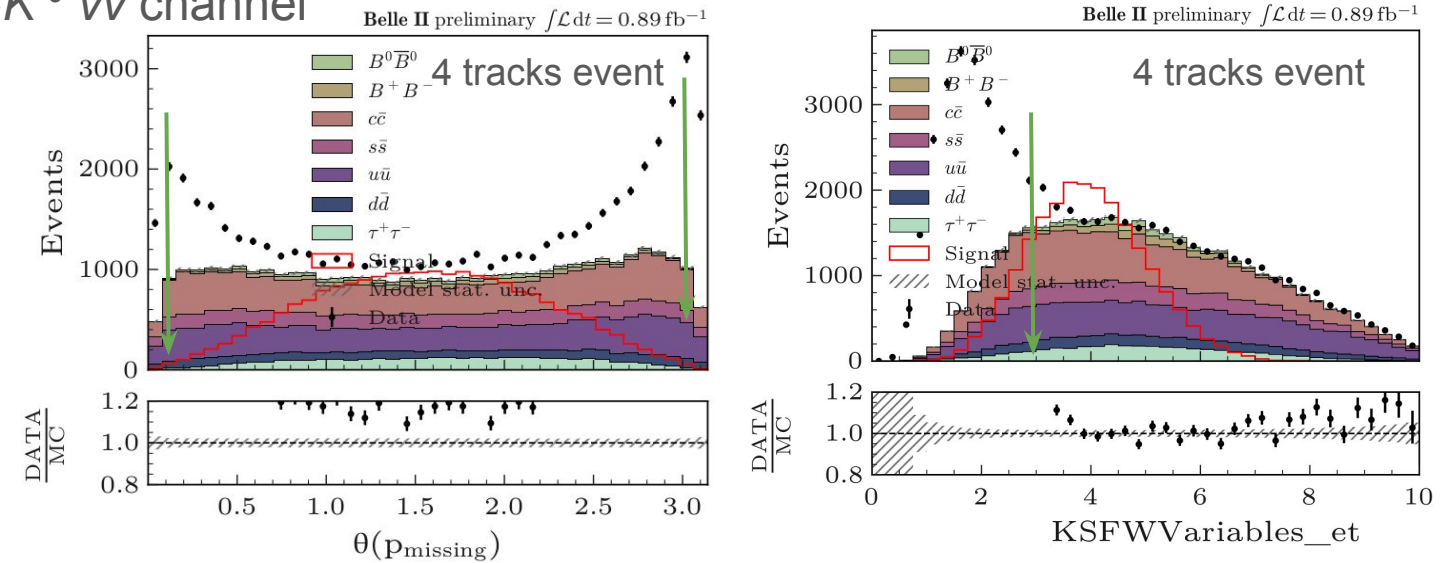




Main difference is from 4-6 track events

Discrepancy of data and simulation in low multiplicity events

$B^0 \to K^{*0}\,\nu\nu$ channel



Visible data/mc discrepancy in low range of roe-mass / transverse-energy / visible-energy, … with missing momentum pointing in forward/backward direction

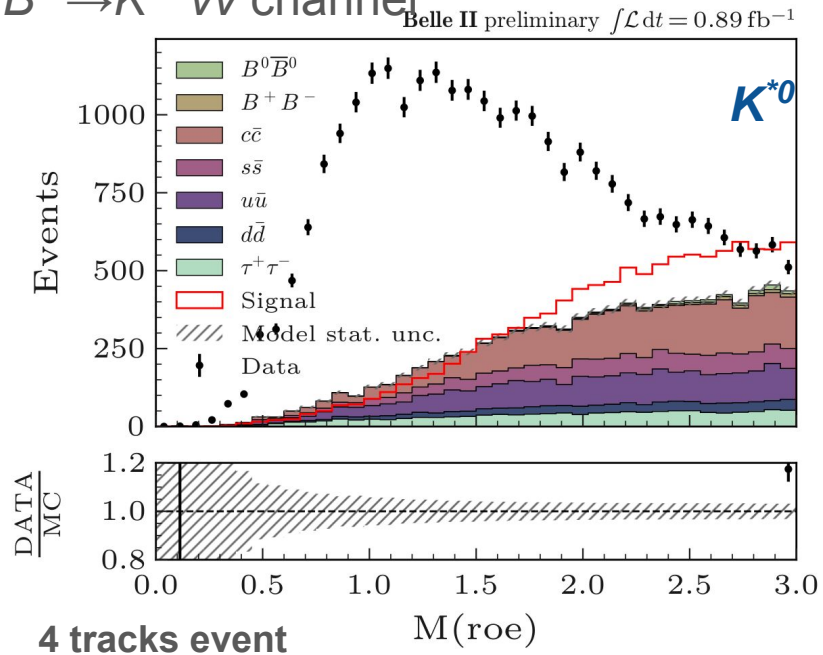
Veto in K^*/K_S channel: θ(Pmiss) in (0.1, 3.0) and transverse energy >2.8 GeV

→Keep 95-98% signal in K* and K_S channel

→Residual correction to MC using off-resonance data (BDT_C)

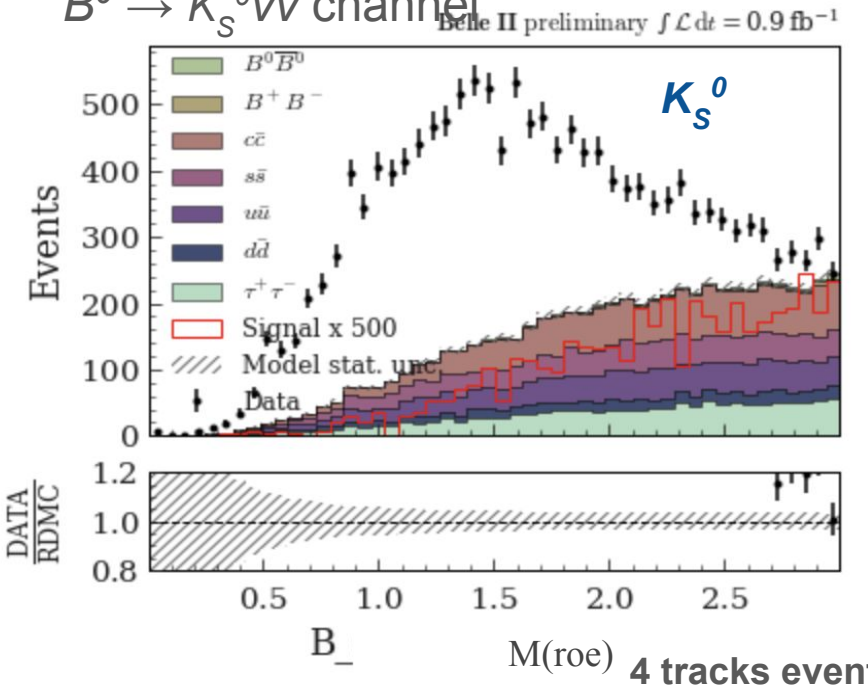
Different impact for different channels

$B^0 \to K^{*0}\nu\nu$ channel



4 tracks event

$B^0 \to K_S^0\nu\nu$ channel



4 tracks event

Possible decays:

Two-photon process with missing one or two electrons, e.g,

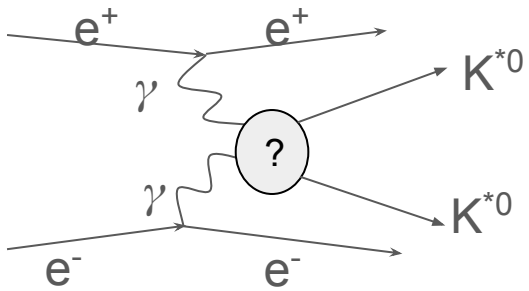
$\gamma\gamma \to K^{*0}K^{*0}/\ K^{*+}K^{*-}/\ K_SK_S$, …

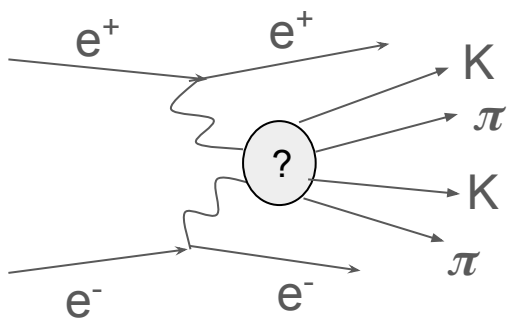
$\to K^{*0}\ K\pi$, $K\pi K\pi$,...

Two photon physics

$\gamma\gamma \to K^{*0}K^{*0}$

$\gamma\gamma \to K\pi K\pi$





- The scattered e+e- final states **predominantly stay inside the beam pipe**
- quasi-two-body vector final state: $\gamma\gamma$->VV' ,V has same J^{PC} as the photon, therefore *VV'* can be produced in relative S-wave.
- **Hadronic physics, not well modeled from first principles**

Measurement of two-photon process

Huge amount of measurements done

D Morgan et al 1994 J. Phys. G: Nucl. Part. Phys. 20 A1

CERN–LEP–ALEPH	
$\gamma\gamma \to jets$	Buskulic *et al* 1993 *Phys. Lett.* **313B** 509
CERN–LEP–OPAL	
$\gamma\gamma \to hadrons$	Akers *et al* 1994 *Z. Phys. C* **61** 199
CESR–CLEO	
$\gamma\gamma \to \bar{p}p$	Artuso *et al* 1993 *CLNS Preprint* 93/1245
DESY–DORIS–ARGUS	
$\gamma\gamma \to K^+K^-$	Albrecht *et al* 1989 *Z. Phys.* C **48** 183
$\gamma\gamma \to \bar{p}p$	Albrecht *et al* 1989 *Z. Phys.* C **42** 543
$\gamma\gamma \to \bar{p}p\pi^0$, etc.	Albrecht *et al* 1989 *Z. Phys.* C **42** 543
$\gamma\gamma \to \Delta^{++}\bar{p}\pi^- + \text{c.c.}$	Albrecht *et al* 1989 *Z. Phys.* C **42** 543
$\gamma\gamma \to \Delta^0\bar{\Delta}^0$, etc.	Albrecht *et al* 1989 *Z. Phys.* C **42** 543
$\gamma\gamma \to \pi^+\pi^-\pi^0\pi^0$	Albrecht *et al* 1989 *Phys. Lett.* **217B** 205
$\gamma\gamma \to K^+K^-\pi^+\pi^-$	Albrecht *et al* 1987 *Phys. Lett.* **198B** 255
$\gamma\gamma \to 2K_s^0\pi^+\pi^-$, $K_s^0K^-\pi^0\pi^+ + \text{c.c.}$	Albrecht *et al* 1988 *Phys. Lett.* **212B** 528
$\gamma\gamma \to 2\pi^+2\pi^-\pi^0$	Albrecht *et al* 1987 *Phys. Lett.* **196B** 101
$\gamma\gamma \to 2\pi^+2\pi^-2\pi^0$	Albrecht *et al* 1987 *Phys. Lett.* **198B** 577
$\gamma\gamma \to K^+K^-\pi^+\pi^-\pi^0$	Albrecht *et al* 1988 *Phys. Lett.* **210B** 273
$\gamma\gamma \to \rho^0\rho^0$, etc.	Albrecht *et al* 1991 *Z. Phys.* C **50** 1
$\gamma\gamma \to \rho^+\rho^-$	Albrecht *et al* 1991 *Phys. Lett.* **267B** 535
$\gamma\gamma \to \rho^0\omega$	Albrecht *et al* 1987 *Phys. Lett.* **196B** 101
$\gamma\gamma \to \omega\omega$, etc.	Albrecht *et al* 1987 *Phys. Lett.* **198B** 577
$\gamma\gamma \to K^{*+}K^{*-}$	Albrecht *et al* 1988 *Phys. Lett.* **212B** 528
$\gamma\gamma \to K^{*0}\overline{K}^{*0}$, etc.	Albrecht *et al* 1987 *Phys. Lett.* **198B** 255
$\gamma\gamma \to \phi\rho^0$	Albrecht *et al* 1987 *Phys. Lett.* **198B** 255
$\gamma\gamma \to \omega\phi$, etc.	Albrecht *et al* 1988 *Phys. Lett.* **210B** 273
DESY–DORIS–CRYSTAL-BALL	
$\gamma\gamma \to \pi^0\pi^0$	Marsiske *et al* 1990 *Phys. Rev.* D **41** 3324
$\gamma\gamma \to \pi^0\pi^0$	Bienlein 1992 *San Diego Workshop* [10f]
$\gamma\gamma \to \pi^0\eta$	Antreasyan *et al* 1986 *Phys. Rev.* D **33** 1847
$\gamma\gamma \to 3\pi^0$	Antreasyan *et al* 1990 *Z. Phys.* C **48** 561

first observation of two photons to $K^{*0}K^{*0}$

L = 234.3 pb^{-1}

Decay	cross-section (nb)
$\gamma\gamma \to K^-\pi^+K^-\pi^+$	2.4±0.9
$\gamma\gamma \to K^{*0}K^-\pi^+$	2.0±0.7
$\gamma\gamma \to K^{*0}\bar{K}^{*0}$	1.3±0.4

measurement of K*K*bar in two-photon interaction

Belle Ks pair production in ST two-photon process

Belle Ks pair production in two-photon process(zero tag)

Measurement of two-photon process

Two-photon result from Belle, from Uehara-san's talk

process	W (GeV)	L (fb-1)	papers published by Belle	year
$\pi^0\pi^0$	0.6-4.0	95	PRD 78, 052004	2008
	0.6-4.0	223	PRD 79, 052009	2009
$\pi^+\pi^-$	0.8-1.5	86	PRD 75, 051101	2007
	0.8-1.5	86	JSPJ 76, 074102	2007
	2.4-4.1	88	PLB 615,39	2005
K^+K^-	1.4-2.4	67	EPJC 32, 323	2004
	2.4-4.1	88	PLB 615,39	2005
$K^0_SK^0_S$	2.4-4.0	398	PLB 651, 15	2007
	1.05-4.0	972	PTEP 2013, 123C01	2013
$\eta\eta$	1.1-3.8	393	PRD 82, 114031	2010
$\eta\pi^0$	0.84-4.0	223	PRD 80, 032001	2009
$4\pi/4K/2K2\pi$	2.4-4.1	395	EPJC 53, 1	2008
$\eta'\pi^+\pi^-$	1.4-3.4	673	PRD 86, 052002	2012
$\eta'\pi^+\pi^-,\eta_c(1S),\eta_c(2S)$	1.4-3.8	941	PRD 98, 072001	2018
D Dbar	3.7-4.3	395	PRL 96, 082003	2006
$\gamma J/\psi$	3.2-3.8	33	PLB 540,33	2002
$\phi J/\psi$	4.2-5.0	825	PRL 104, 112004	2010
$\omega J/\psi$	3.9-4.2	694	PRL 104, 092001	2010
$\omega\omega/\phi\phi/\omega\phi$	1.5-4.0	870	PRL 108, 232001	2012
ppbar	2.03-4.0	89	PLB 621,41	2005
$ppbarK^+K^-$	3.2-5.6	980	PRD 93, 112017	2016
π^0	0.6-4.0	759	PRD 86, 092007	2012
$\pi^0\pi^0$	0.5-2.1	759	PRD 93, 032003	2016
$K^0_SK^0_S$	1.0-2.6	759	PRD 97, 052003	2018

Two-photon process in BELLE II

Easiest but crude way: remove/veto in data, use off-resonance to fix remaining discrepancies (for B-physics)
→may need dedicated optimization for each decay channel

Modeling: **TREPS** in BELLE II, however supported decays are only
pp, K^+K^-, $\pi^+\pi^-$

→Extend modeling to other final states (e.g. K*K*, also beyond 4-tracks)
→Dedicated measurements to improve modeling (?)

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MODELING: PRIMARY STAGE

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Modeling $\gamma\gamma \rightarrow K_S^0 K_S^0$

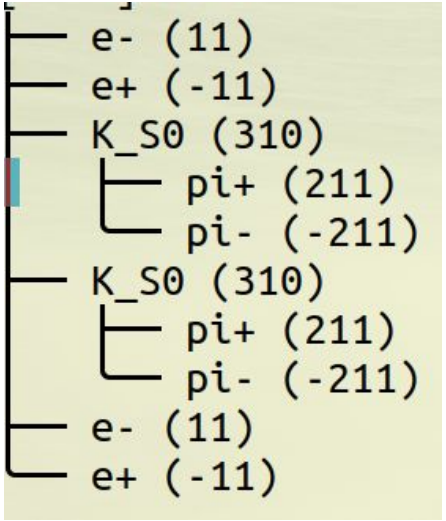
TREPS(Two-photonic REsonance Production Simulator)

Input parameters, differential cross-section,
number of generated events per invariant-mass interval(W):
basf2/generators/treps/data/

New-channel configuration:
basf2/generators/scripts/low_multiplicity_sorcery/constants.py
basf2/generators/scripts/low_multiplicity_sorcery/utils.py

```
generators.add_treps_generator(
    path,
    finalstate = 'e+e-KS0KS0',
)
```

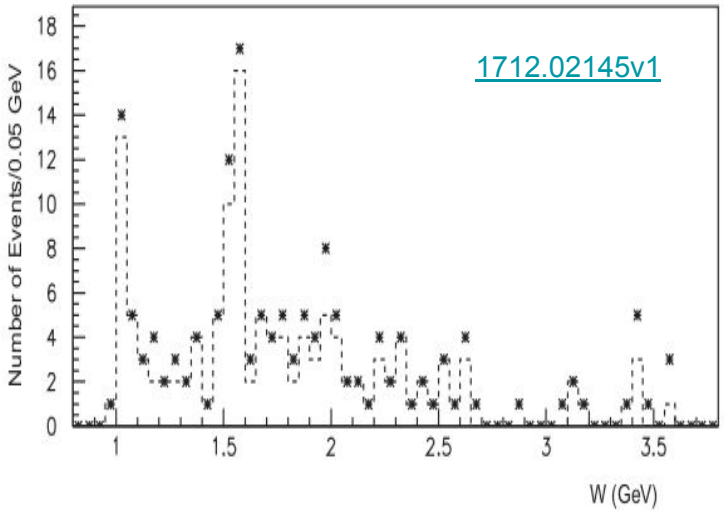
Final state particle: 2
Physics model : 202
Form-factor model:0

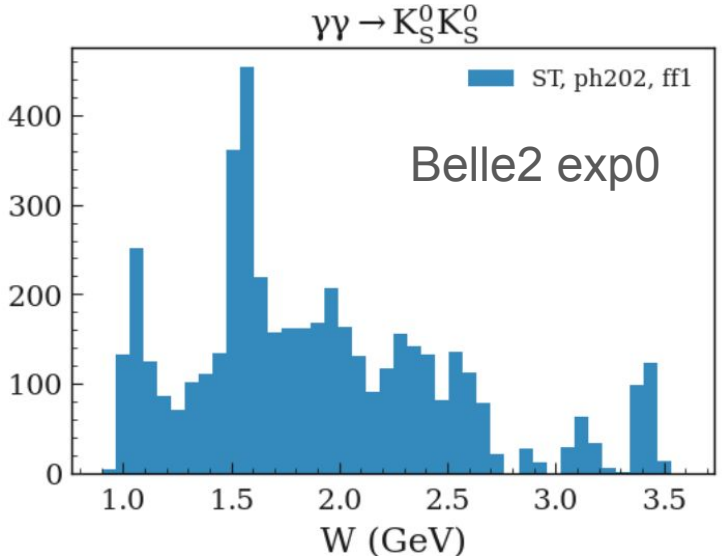


Modeling $\gamma\gamma \rightarrow K_S^0 K_S^0$

π: thetaInCDCAcceptance
$0.45<(K_S^0)<0.55$

Belle, single tag

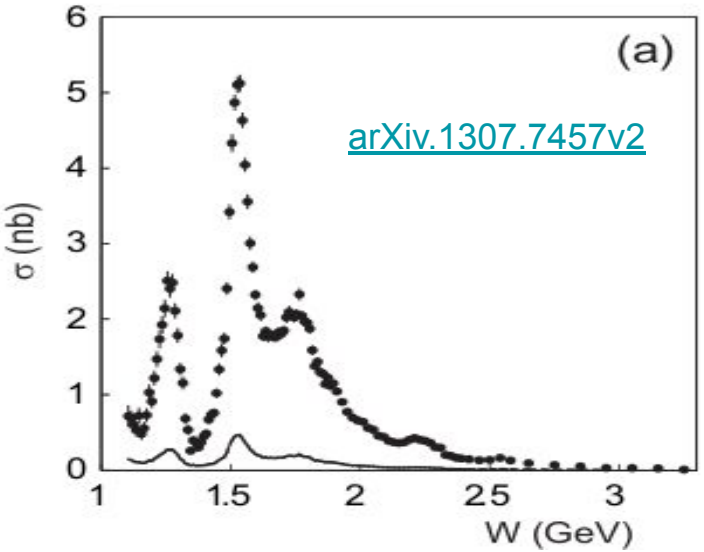


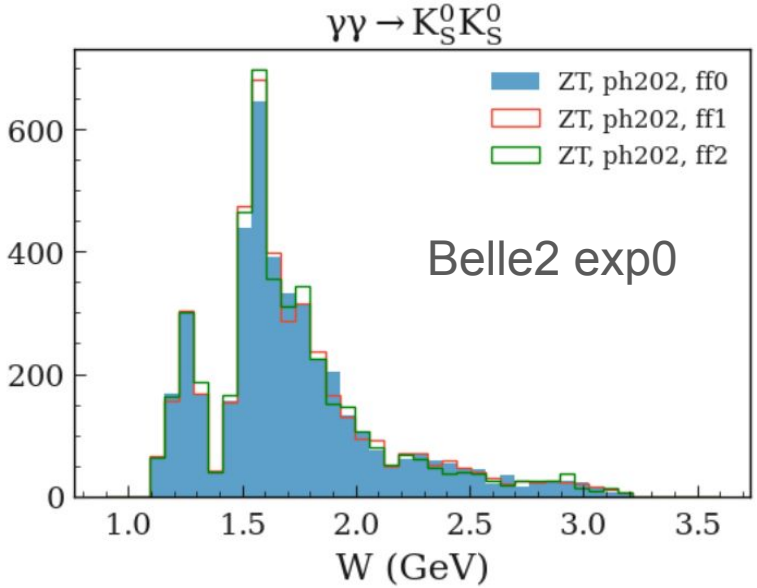


Modeling $\gamma\gamma \rightarrow K_S^0 K_S^0$

π: thetaInCDCAcceptance
$0.45<(K_S^0)<0.55$

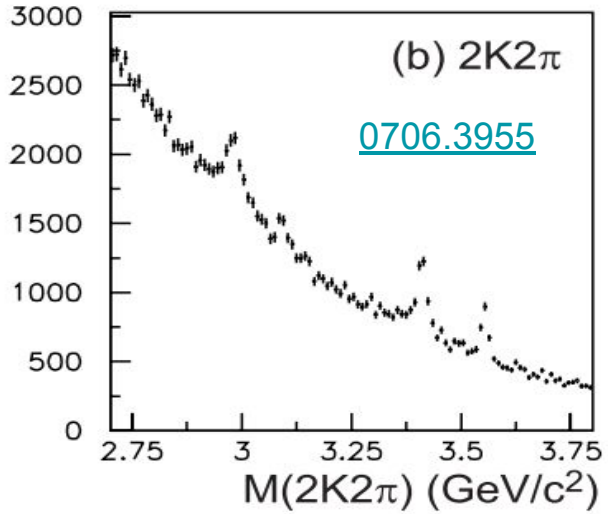
Belle, zero tag, $|\cos\theta^*|<0.8$





Modeling $\gamma\gamma \rightarrow KK\pi\pi$

M(KKππ)<2.75 ?



- Extract KKππ, Kπππ, KKKK, ππππ differential cross-section from Belle II data

- Differential cross-section
  w>2.7: Implement the angular distribution based on previous measurement
  w<2,7: (a). Implement the angular distribution based on theory model, tuning to data-shape
  (b). PWA in Belle II data

No idea of how to model vector production events
Generator group ?