Evidence for a high spin N* resonance in η photo-production in the extremely backward angle

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NSTART2019

Physics motivation

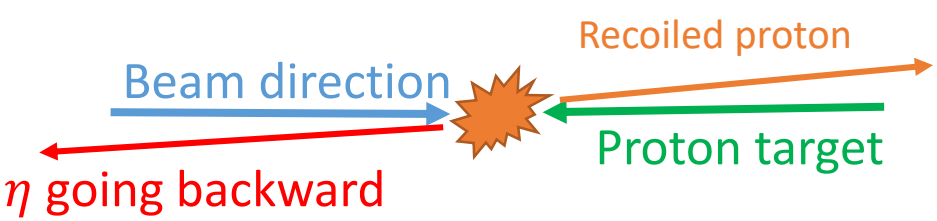
Missing resonance problem:

- The number of states predicted by Quark Model is too excessive
- Possible answers:
  - correct degrees of freedom?
  - simply escaped detection?

Nearly all baryons are confirmed by πN scattering

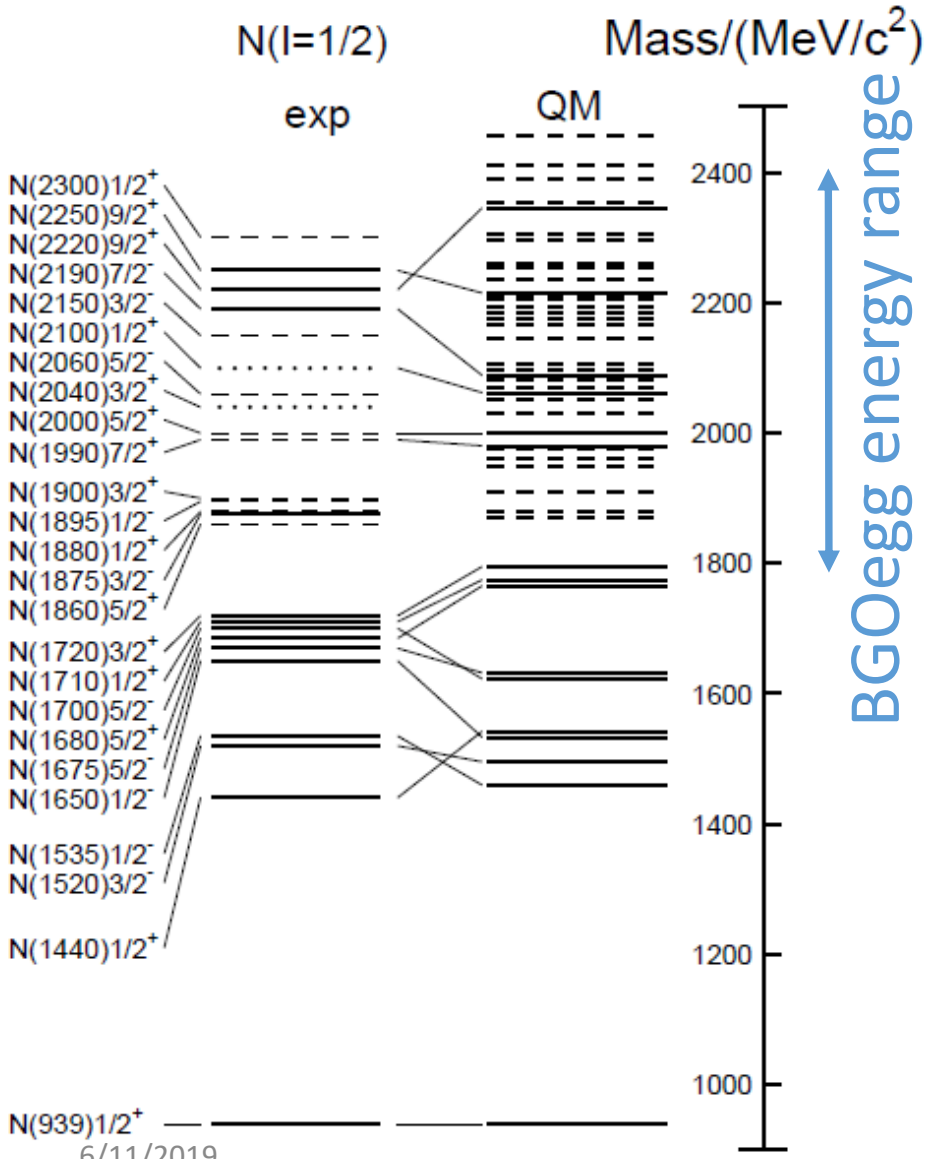
$$\pi + p \rightarrow X \rightarrow \pi + p$$

=> **We study** $\boldsymbol{\gamma + p \rightarrow X \rightarrow \eta + p}$ **at backward angles**



$$\boldsymbol{\cos\theta^{\eta}_{cm} < -0.9}$$

Physics motivation



Already confirmed states

Weak evident of existence

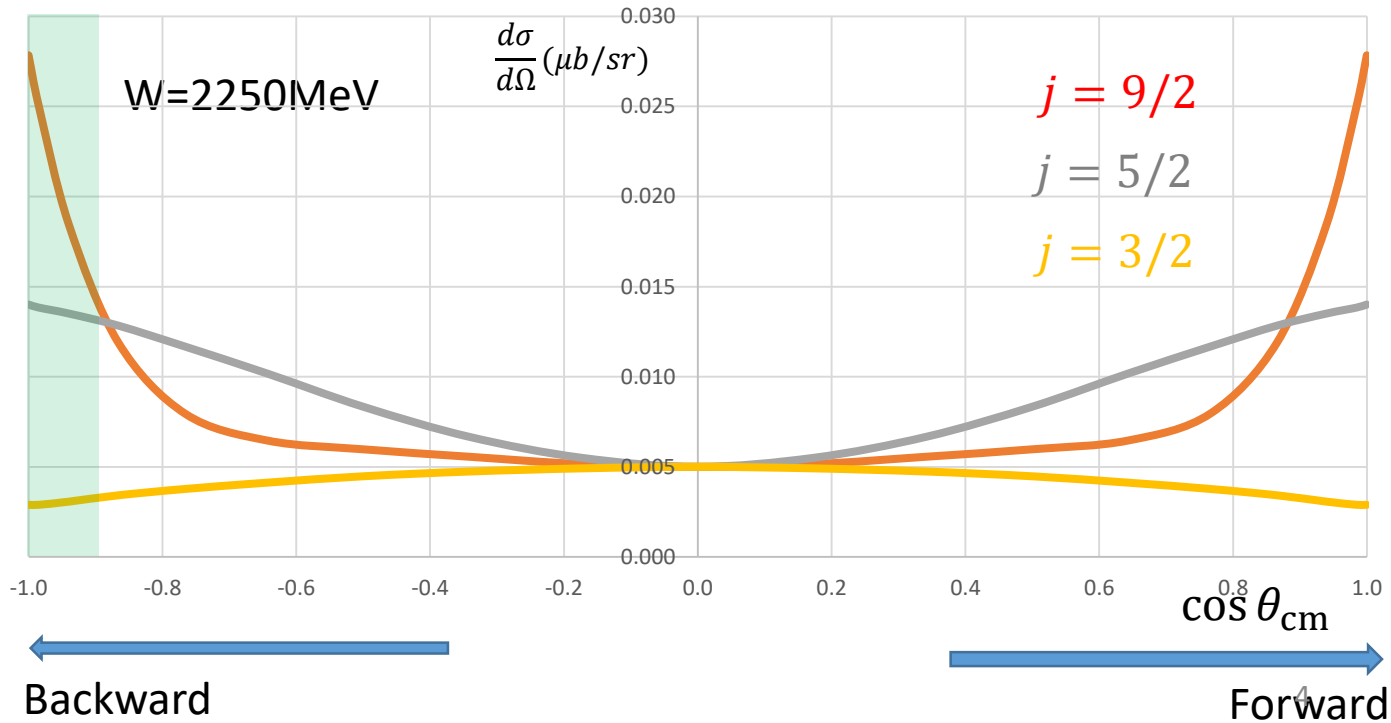
- Higher spin resonances appear in the higher energy area.
- In the photon-proton reaction, a decay product from high spin resonances will be enhanced in the backward angle
- Diffraction process is small at the backward angle

Why at backward angle?

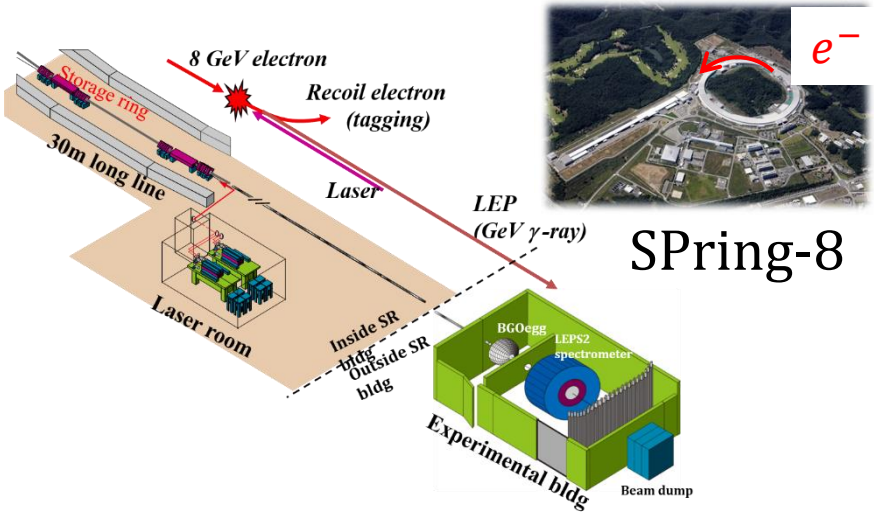
- Helicity is limited to $|h| \leq 3/2$ in photon–proton reaction => a resonance form from photon–proton reaction can not be in the helicity state $|h|$> 3/2.

=> If a resonance with $J \geq 5/2$ decays, the decay product is enhanced in the forward or backward angles.

At the backward angle, high-spin N* will dominate



LEPS2/BGOegg experiment in Japan

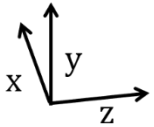


SPring-8

The photon beam is backward Compton scattering beam using polarized ultra violet laser, Catching recoiled electron with tagging detector

E_γ 1.3～2.4GeV

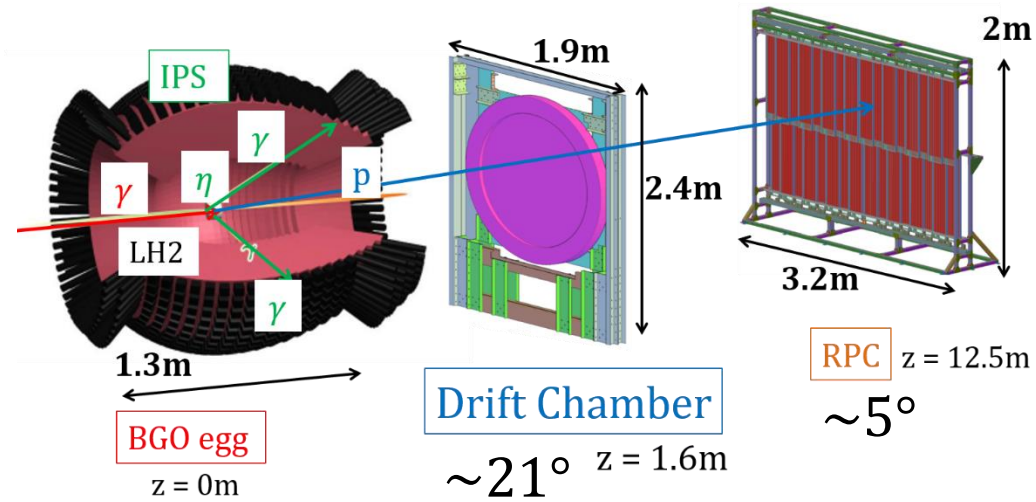
Tagger rate ～2Mcps



The target is Liquid Hydrogen target (LH2)

A single meson production, then decay to gamma in the final state, will be measured by BGOegg detector consisted of 1320BGO crystals

Recoiled proton is measured by DC and RPC



Cover 24°～144°

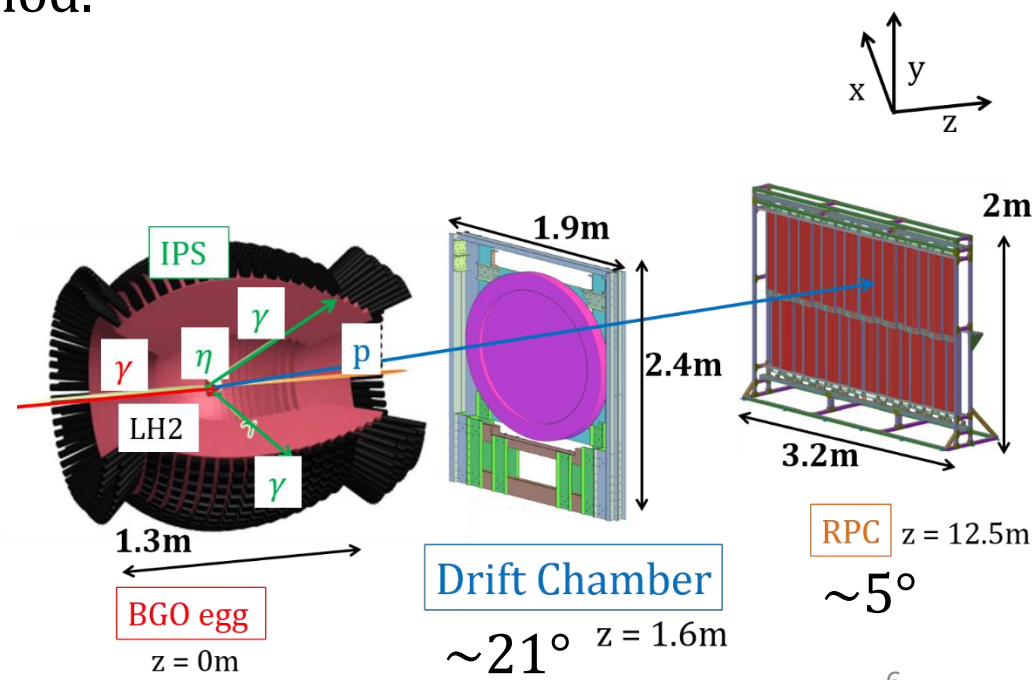
～21°

～5°

LEPS2/BGOegg experiment in Japan

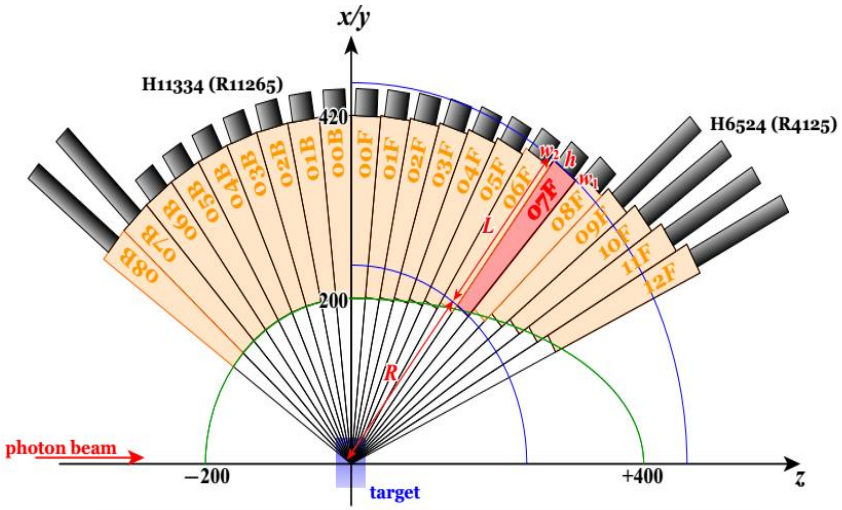
$$\gamma + p \rightarrow \eta + p \rightarrow 2\gamma + p$$

- All final state particles were detected,
- The momentum of proton in the extremely backward angles were measured by RPC,
- Kinematic fitting analysis method.



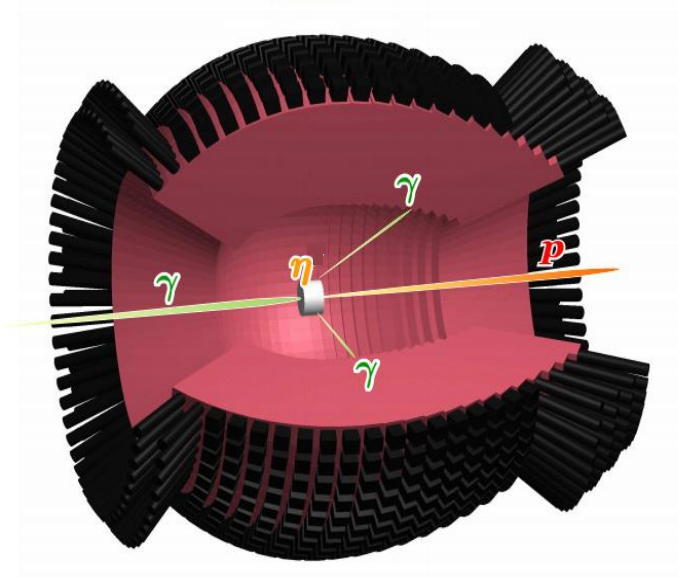
Cover 24°~144°

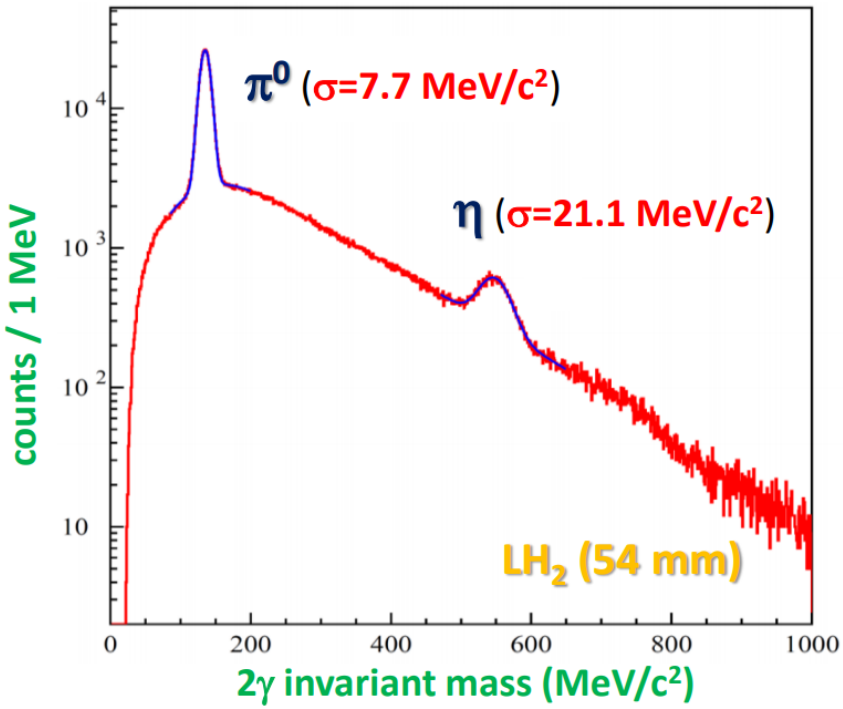
Large acceptance EM calorimeter BGOegg



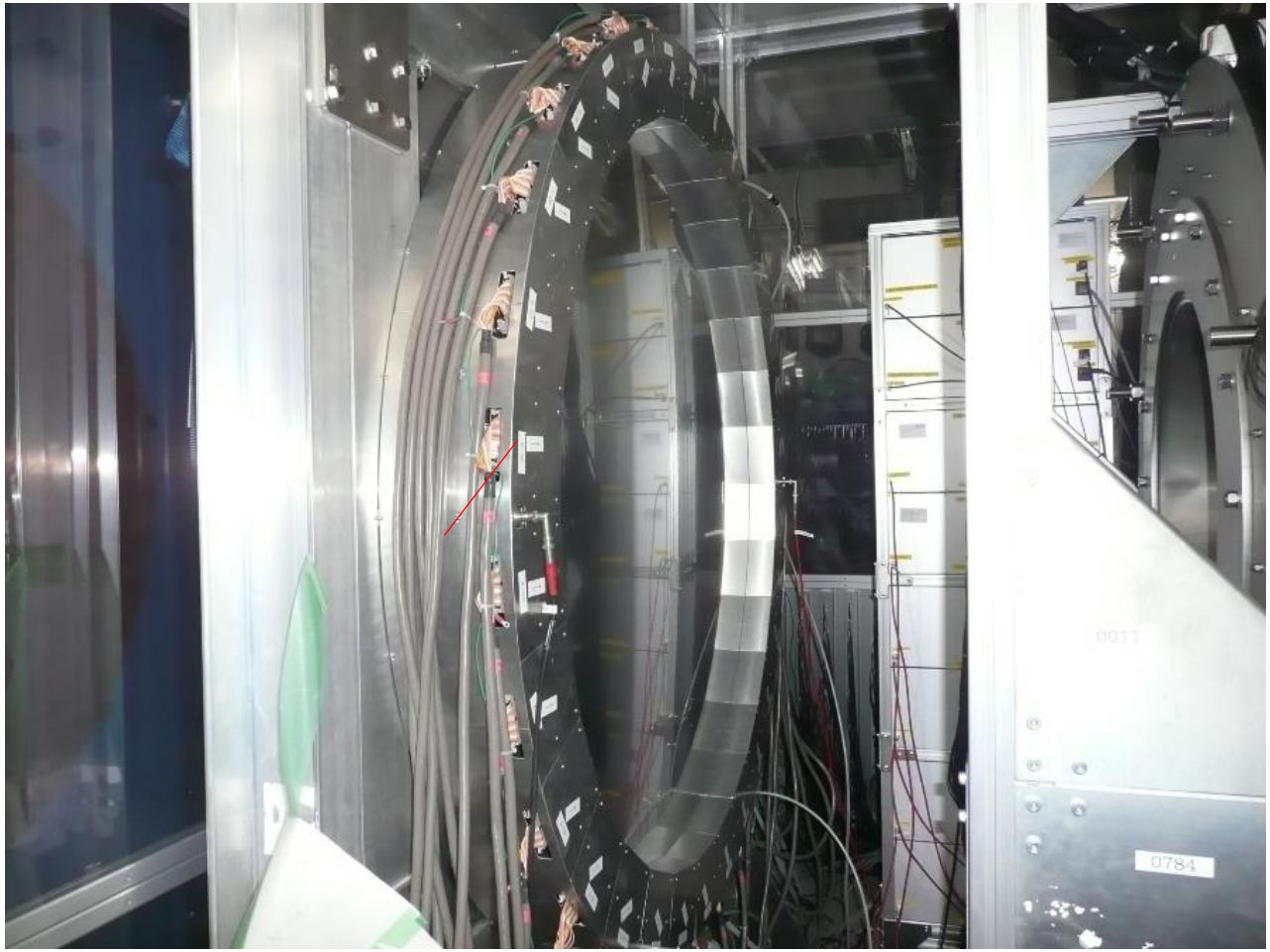
60 $Bi_4Ge_3O_{12}$ crystals x 22 layers covering $24^0 \sim 144^0$, $\boldsymbol{\sigma_E = 1.3\% @ 1\ GeV}$

Each BGO crystal cover 6^0in (θ, ϕ) with $L_{crystal} = 220mm = 20X_0$



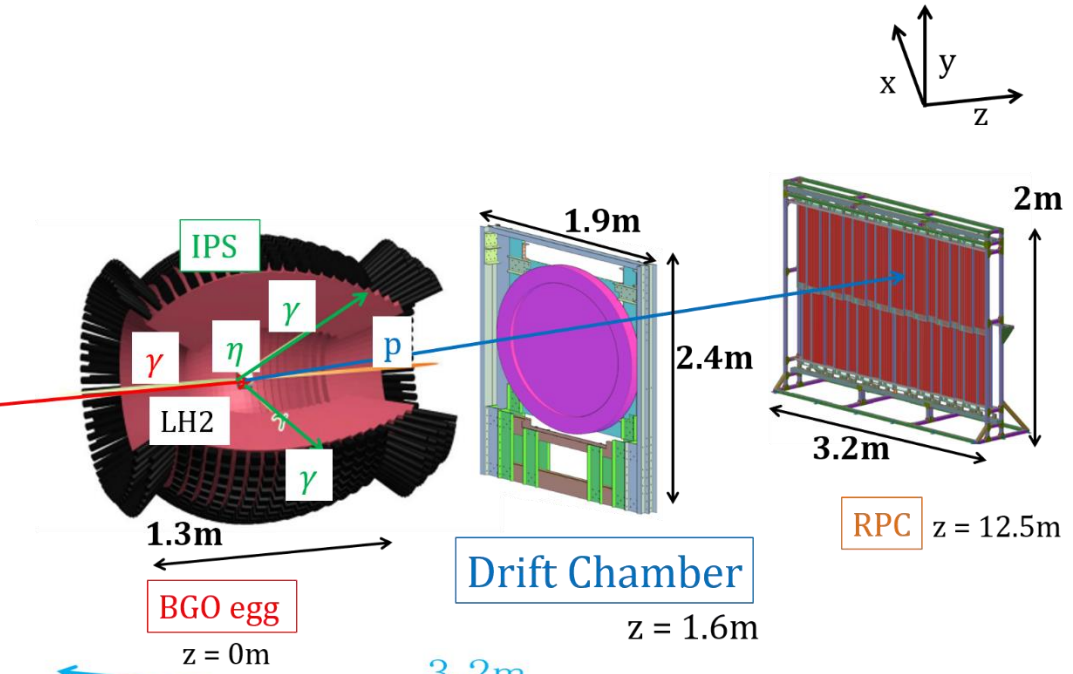


Drift Chamber (DC)

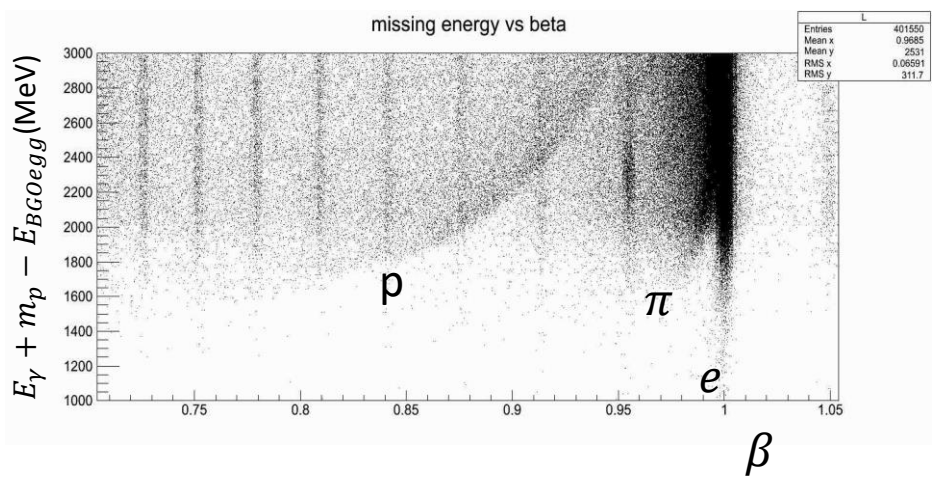


- Is the main forward charged particle detector.
- The distance from DC to target is $z = 1.6m$, the covering angle $\theta < 21^0$

Resistive Plate Chamber(RPC)



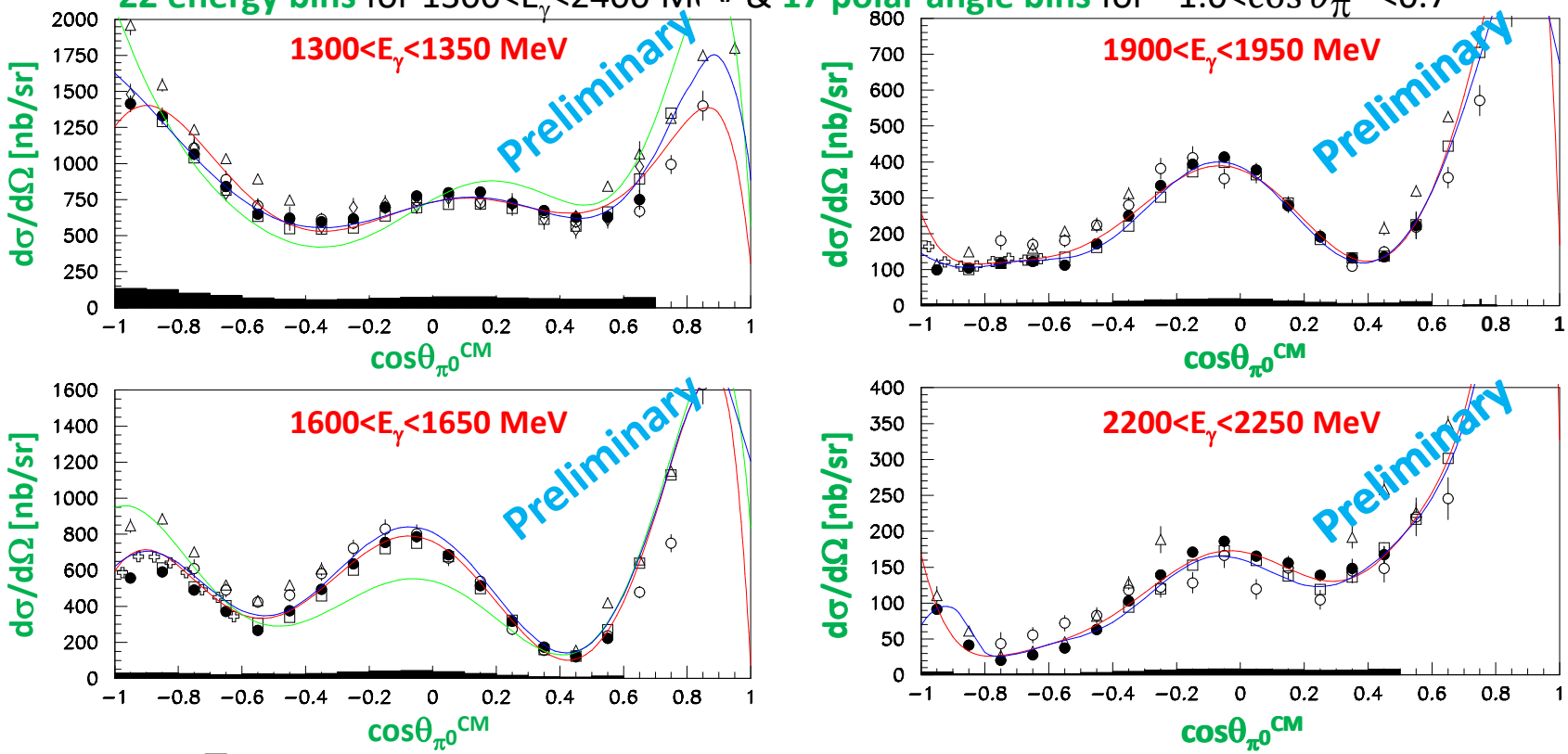
- Covering very small angle $\theta < 6$
- 12.5m distance from the target => only proton/pion/electron can be masured
- Using ToF method with Time resolution is 50-120ps



π^0 Differential cross section

In order to confirm the luminosity and the validity of the normalization factor, the differential cross section of π^0 was obtained.

22 energy bins for 1300<E_γ<2400 MeV & **17 polar angle bins** for $-1.0<\cos\theta_\pi^{CM}<0.7$

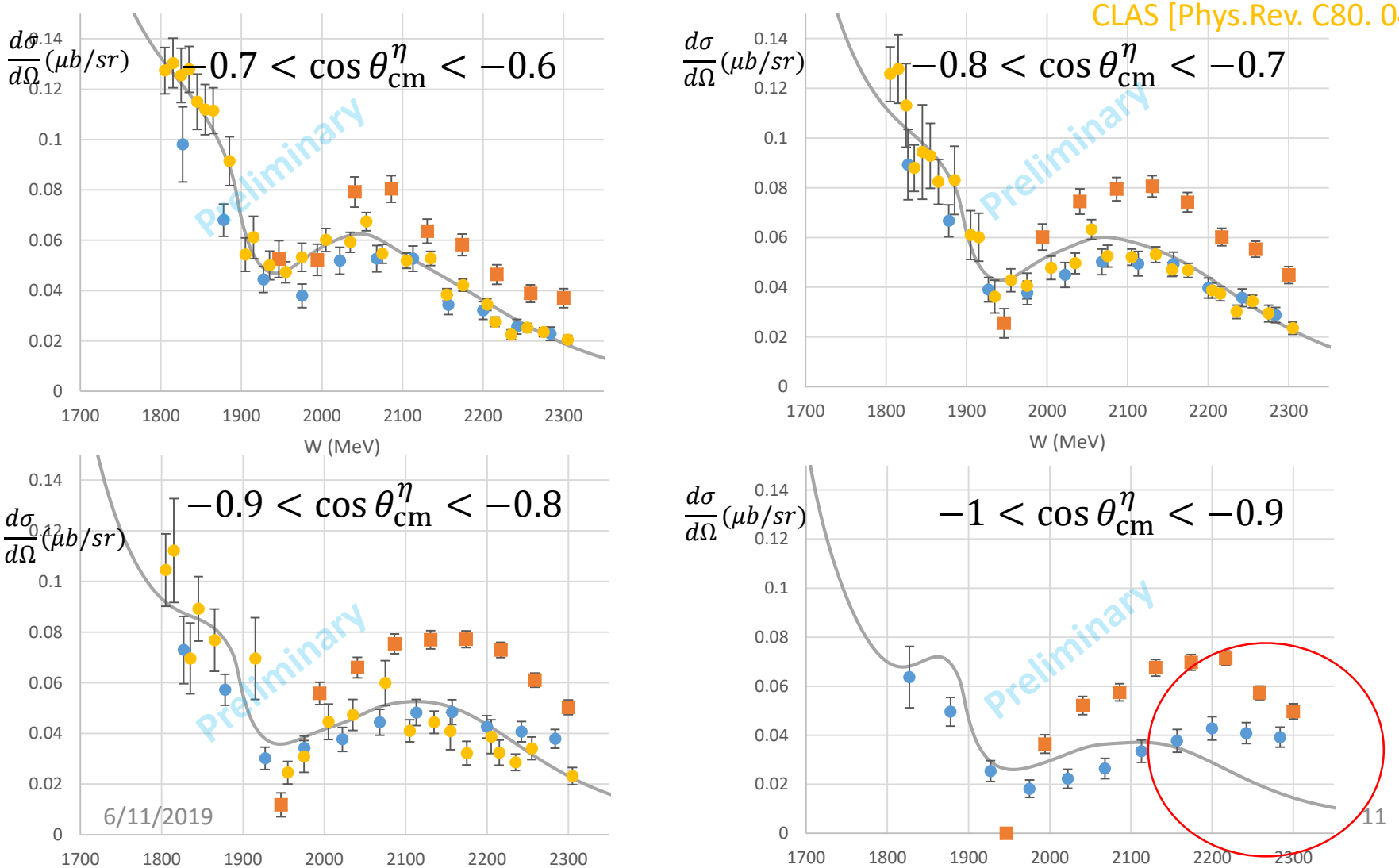


●: **this work (BGOegg)**, □: CLAS [PRC76 (2007) 025211],
○: CBELSA [PRL94 (2005) 012003], △: CBELSA [PRC84 (2011) 055203],
◇: GRAAL [EPJA26 (2005) 399], ✞ : LEPS [PLB657 (2007) 32]
Note: The histogram indicates the **systematic error** of the BGOegg meas.

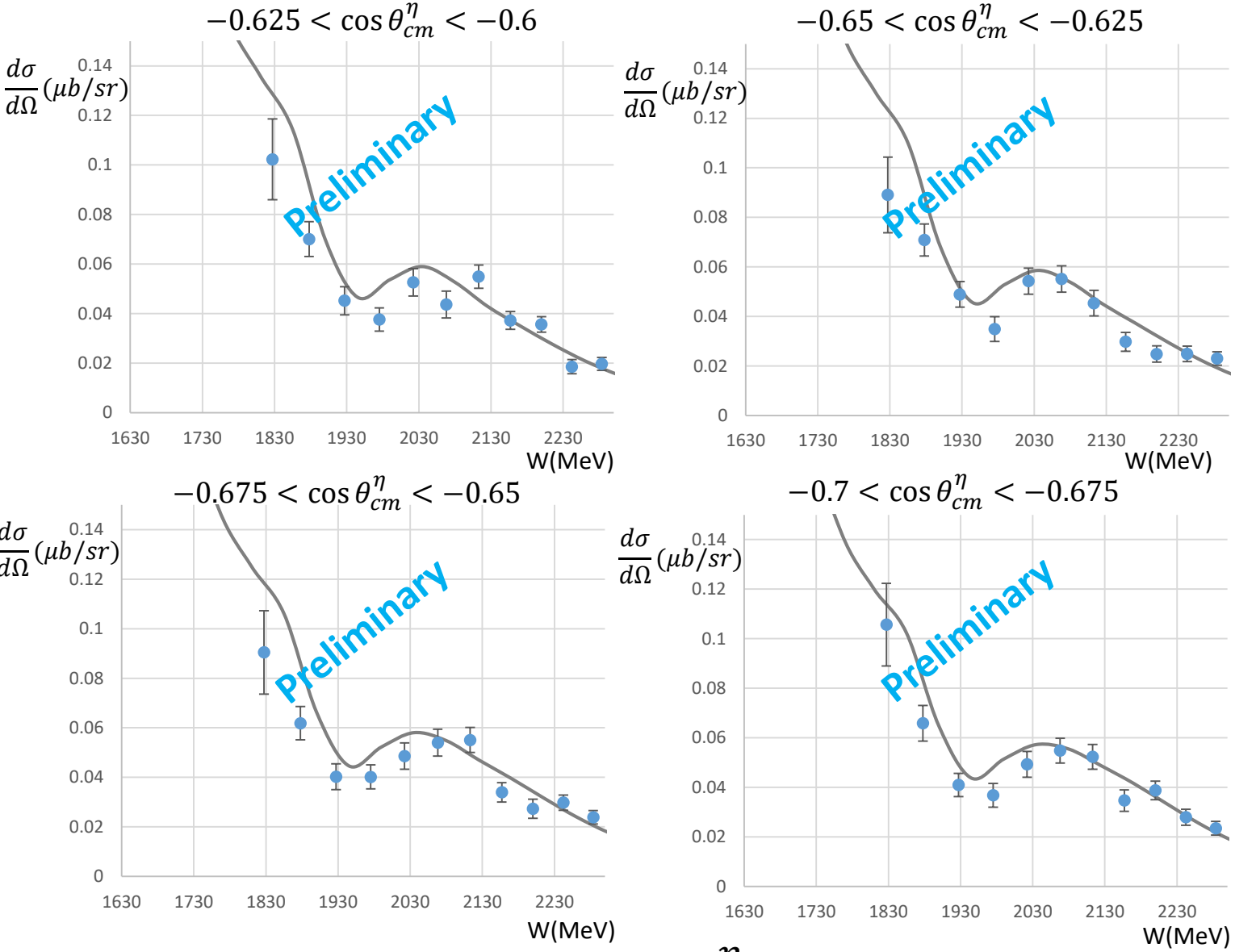
Bonn-Gatchina [https://pwa.hiskp.uni-bonn.de/BG2014_02_obs_int.htm]
GWU SAID [http://gwdac.phys.gwu.edu/analysis/pr_analysis.html]
ANL-Osaka [Prof. Sato (Osaka Univ.)]

Differential cross section $\gamma p \rightarrow \eta p$

etaMAID2018 prediction
BGOegg result
LEPS [PhysRevC.80.052201]
CLAS [Phys.Rev. C80. 045213]



$\gamma p \rightarrow \eta p$ differential cross section

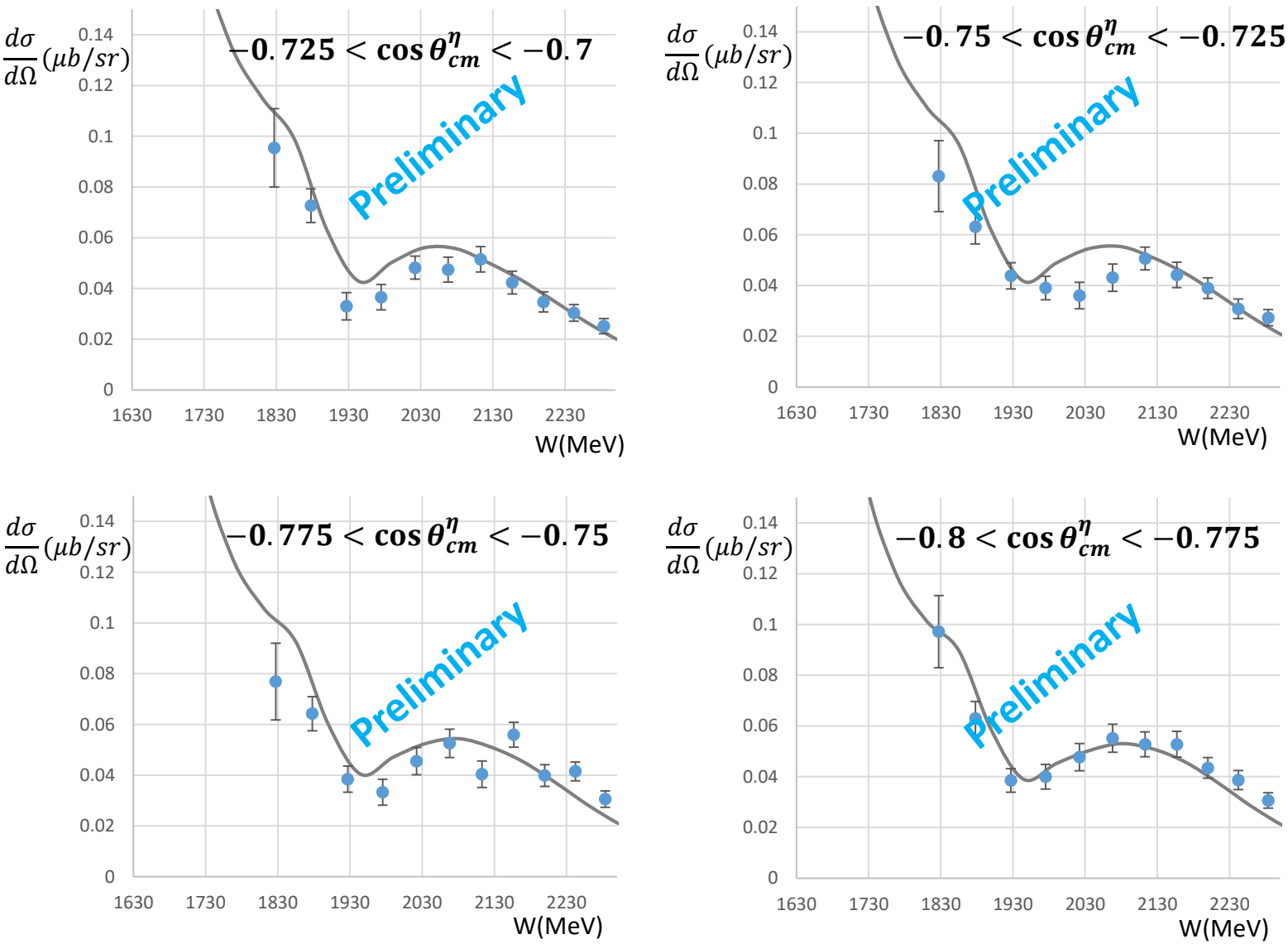


BGOegg Data

Eta-MAID 2018

$$\Delta \cos\theta^{\eta}_{cm} = 0.025$$

$\gamma p \rightarrow \eta p$ differential cross section



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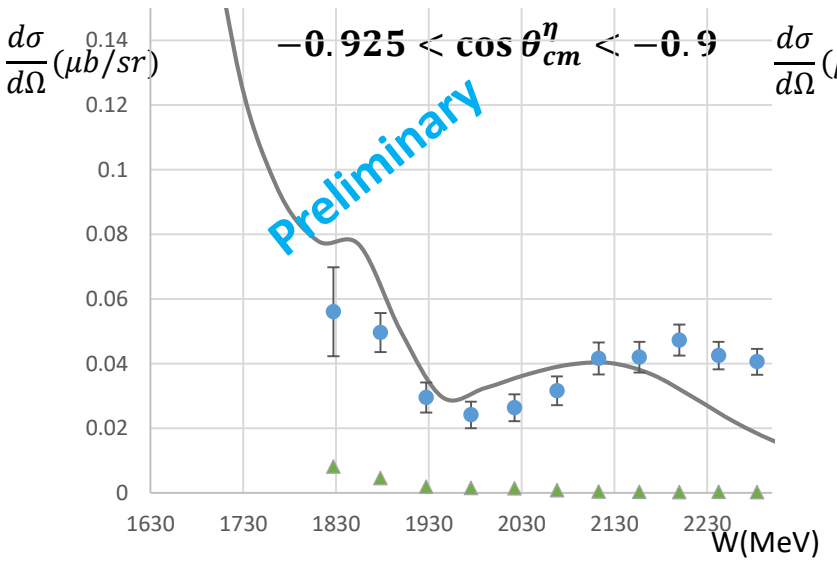
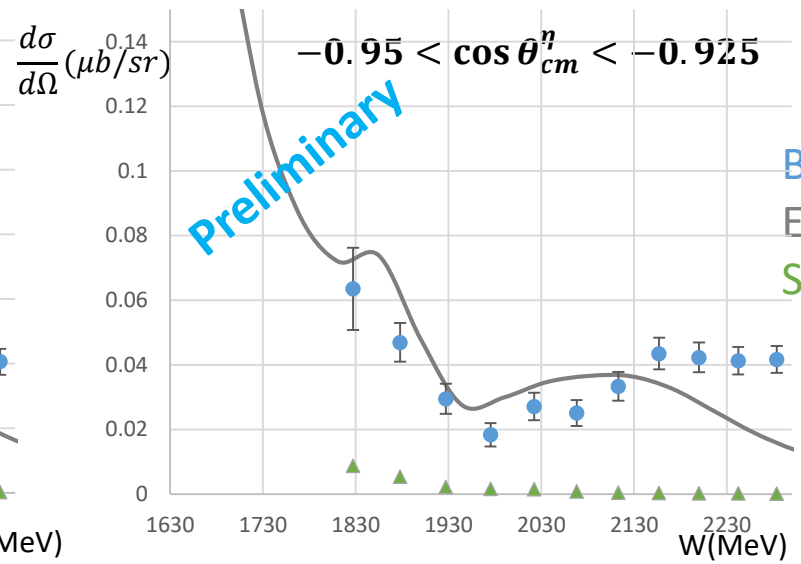
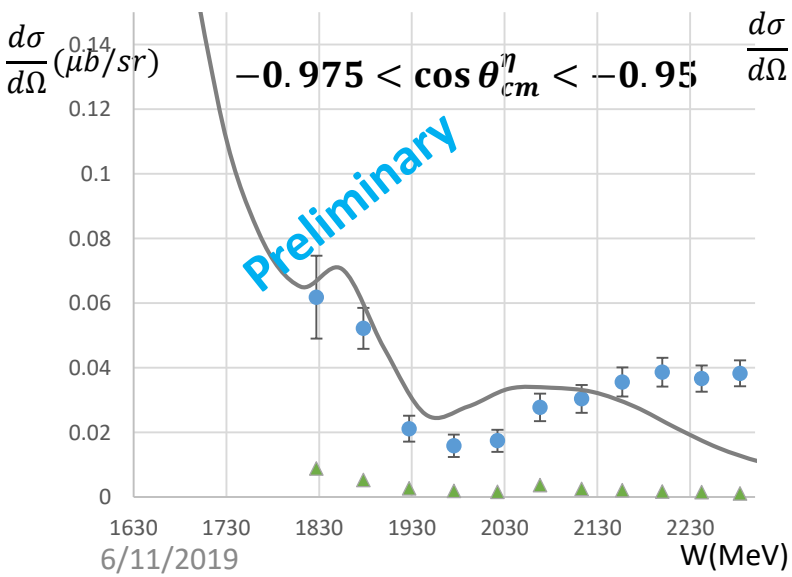


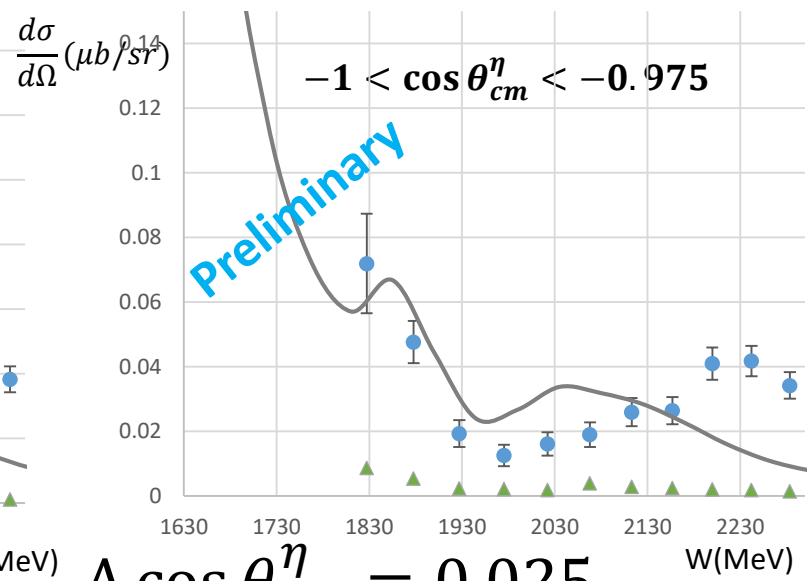


BGOegg Data

Eta-MAID 2018

Systematic error

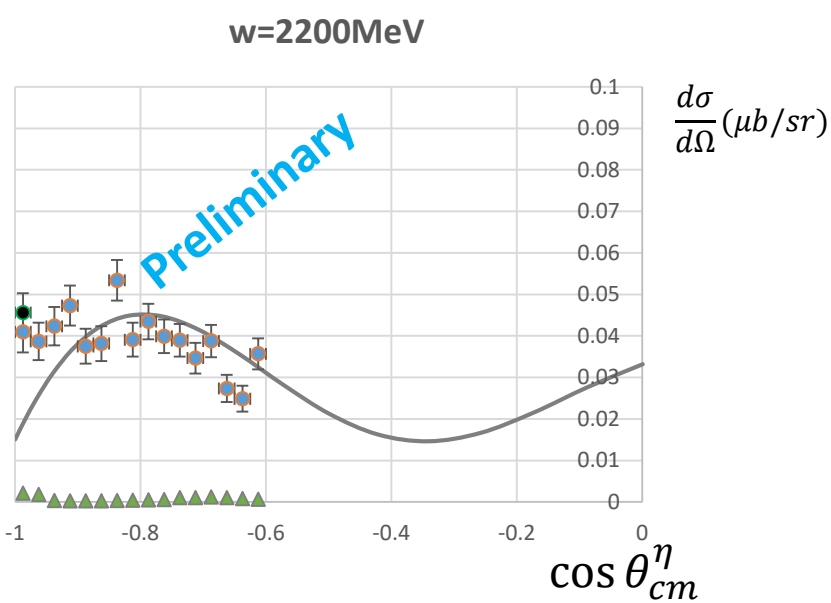


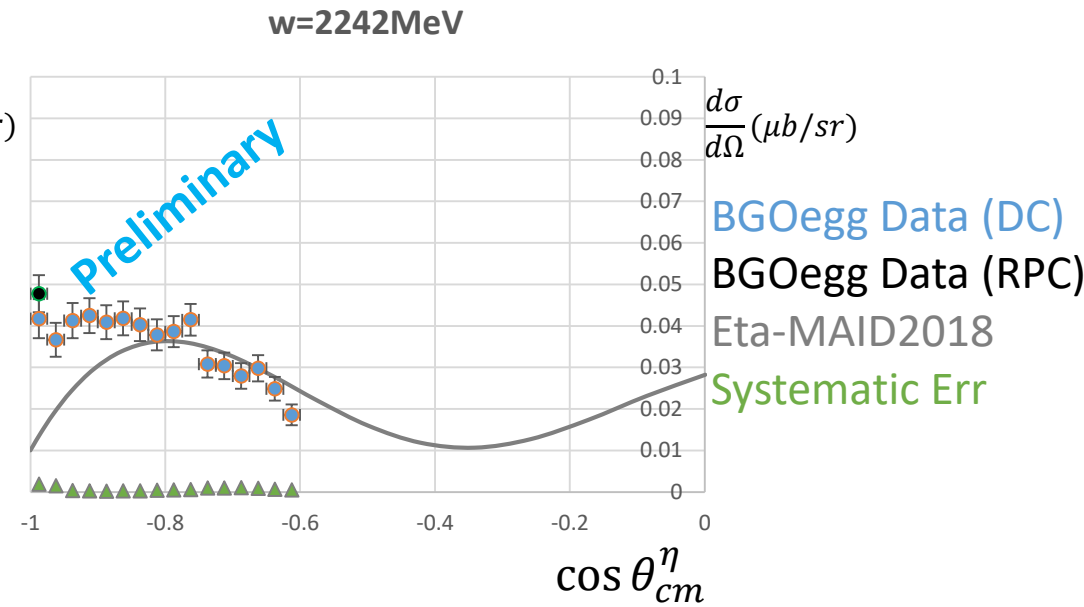


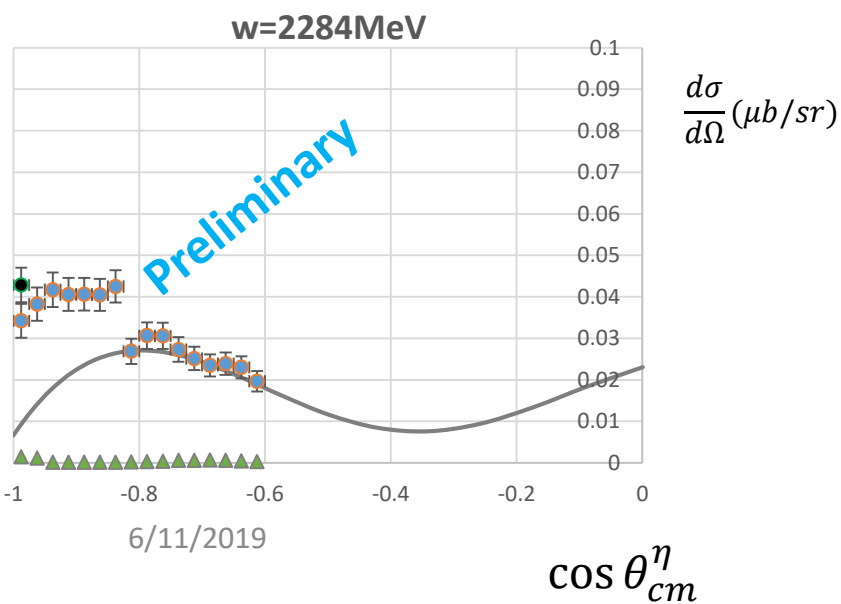
Up-to-date exp. data in this angle is rather lacking

$$\Delta \cos\theta^{\eta}_{cm} = 0.025$$

$\gamma p \rightarrow \eta p$ differential cross section







- The world experimental data at the backward angle is lacking high quality data.
- The disagreement between data and prediction is an indication that there could be another source of contribution.
- this contribution may come from a resonance, this resonance should have spin $\geq 5/2$ and mass around 2.23GeV

Particle J^P	overall	Status as seen in $N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$
N $1/2^+$	****										
$N(1440)1/2^+$	****	****	****	****	***						
$N(1520)3/2^-$	****	****	****	****	**	****					
$N(1535)1/2^-$	****	****	****	***	*	****					
$N(1650)1/2^-$	****	****	****	***	*	****	*				
$N(1675)5/2^-$	****	****	****	****	***	*	*	*			
$N(1680)5/2^+$	****	****	****	****	***	*	*	*			
$N(1700)3/2^-$	***	**	***	***	*	*			*		
$N(1710)1/2^+$	****	****	****	*		***	**	*	*	*	
$N(1720)3/2^+$	****	****	****	***	*	*	****	*	*	*	
$N(1860)5/2^+$	**	*	**		*	*					
$N(1875)3/2^-$	***	**	**	*	**	*	*	*	*	*	
$N(1880)1/2^+$	***	**	*	**	*	*	**	**		**	
$N(1895)1/2^-$	****	****	*	*	*	****	**	**	*	*	****
$N(1900)3/2^+$	****	****	**	**	*	*	**	**		*	**
$N(1990)7/2^+$	**	**	**			*	*	*			
$N(2000)5/2^+$	**	**	*	**	*	*				*	
$N(2040)3/2^+$	*		*								
$N(2060)5/2^-$	***	***	**	*	*	*	*	*	*	*	
$N(2100)1/2^+$	***	**	***	**	**	*	*		*	*	**
$N(2120)3/2^-$	***	***	**	**	**		**	*		*	*
$N(2190)7/2^-$	****	****	****	****	**	*	**	*	*	*	
$N(2220)9/2^+$	****	**	****			*	*	*			
$N(2250)9/2^-$	****	**	****			*	*	*			
$N(2300)1/2^+$	**		**								
$N(2570)5/2^-$	**		**								
$N(2600)11/2^-$	***		***								
$N(2700)13/2^+$	**		**								

**** Existence is certain.
*** Existence is very likely.
** Evidence of existence is fair.
* Evidence of existence is poor.

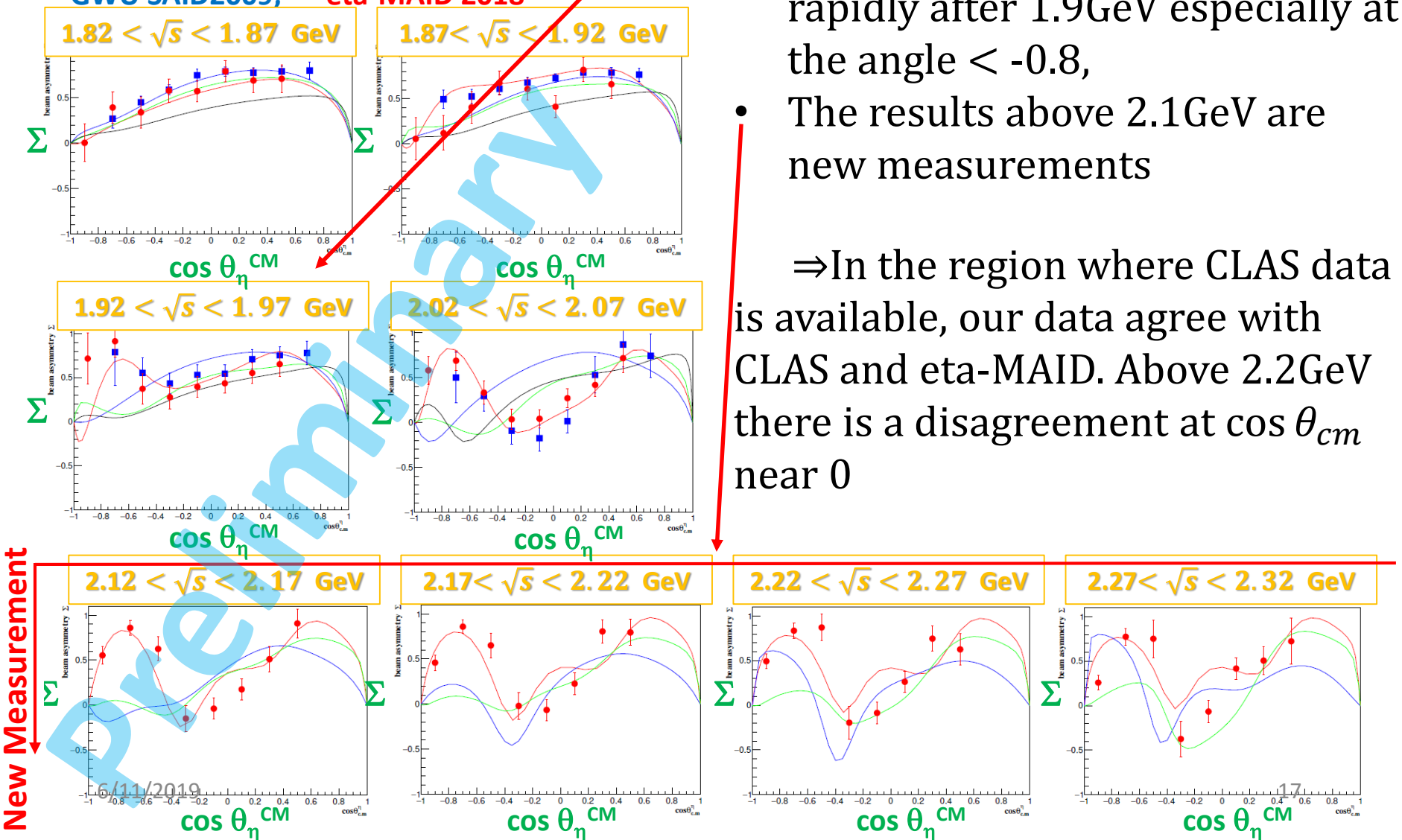
Accessible

- 2 resonances may match with our observation
  N(2220) 9/2+ and N(2250)9/2-
- Both with the evidence in the ηN channel is only 1-star **=>our data may indicate strong couplings of the state(s) to eta meson**
- **Or new high-spin state which couple to η strongly**

M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018) (page 759)

η beam asysmetry

● BGOegg, ■ CLAS [PLB 771 (2017) 213]
— ANL-Osaka, — Bonn-Gatchina2014
— GWU SAID2009, — eta-MAID 2018



- Strong angular dependence above 1.9GeV,
- The angular dependence change rapidly after 1.9GeV especially at the angle < -0.8,
- The results above 2.1GeV are new measurements

⇒In the region where CLAS data is available, our data agree with CLAS and eta-MAID. Above 2.2GeV there is a disagreement at cos θ_{cm} near 0

Summary

- BGOegg experiment started data taking from 2013, and the first results of eta photo-production in backward angles from a proton was presented.
- A bump structure at the energy around 2.2GeV at the angle $-1 \leq \cos\theta_{CM}^{\eta} < -0.975$ was observed. This structure disagrees with the prediction from eta-MALD.
- The data indicate strong eta coupling of N(2220) and/or N(2250) OR existence of a new high-spin resonance.

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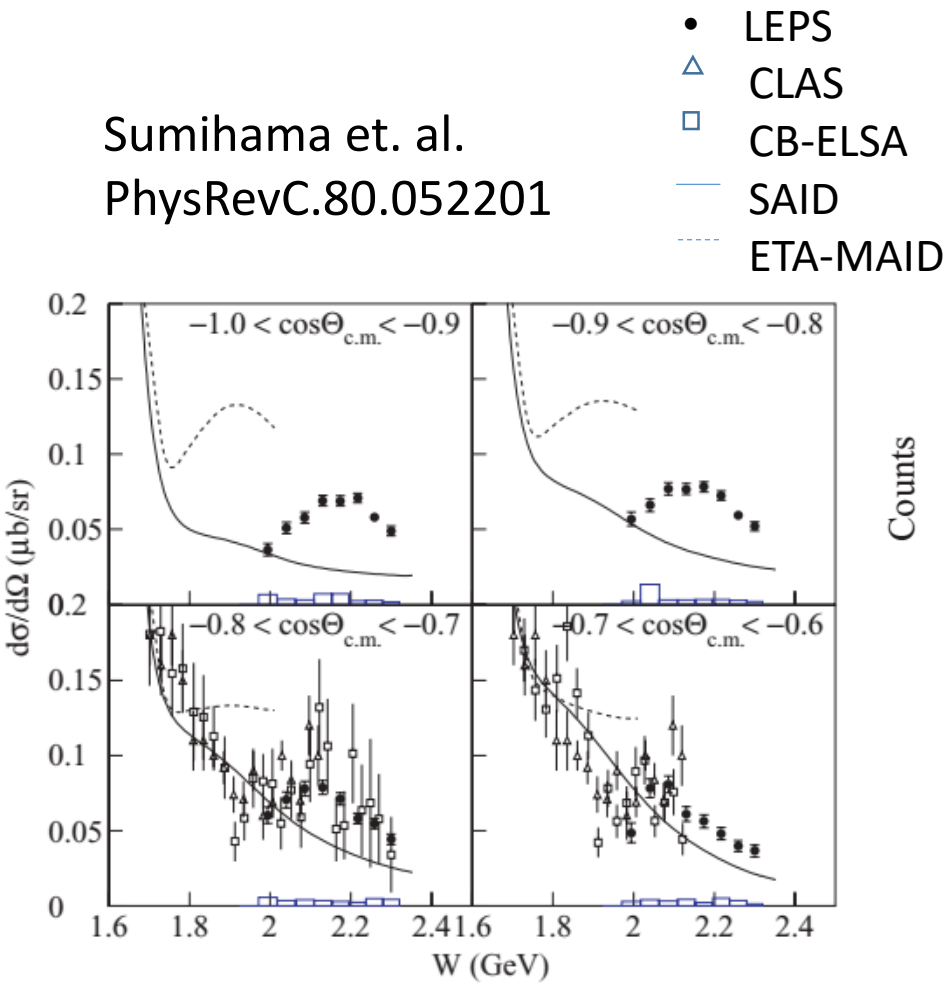
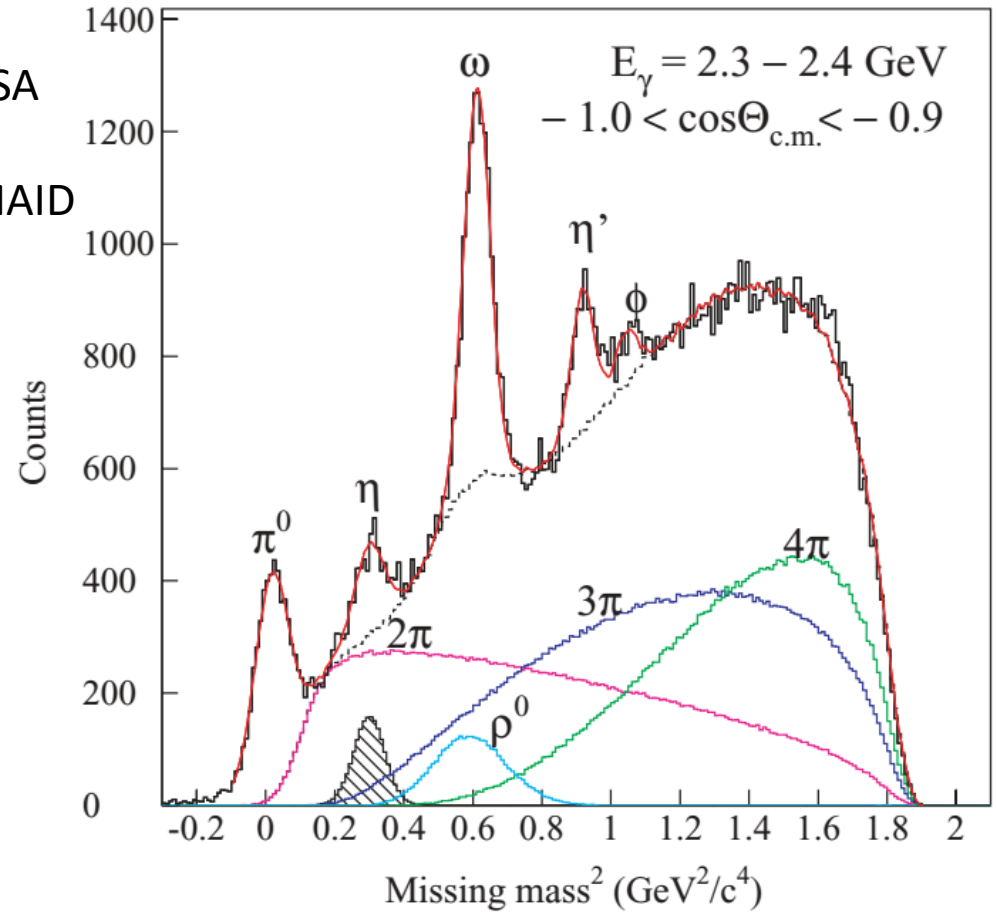
Thank you for listening

Back up

Physics motivation

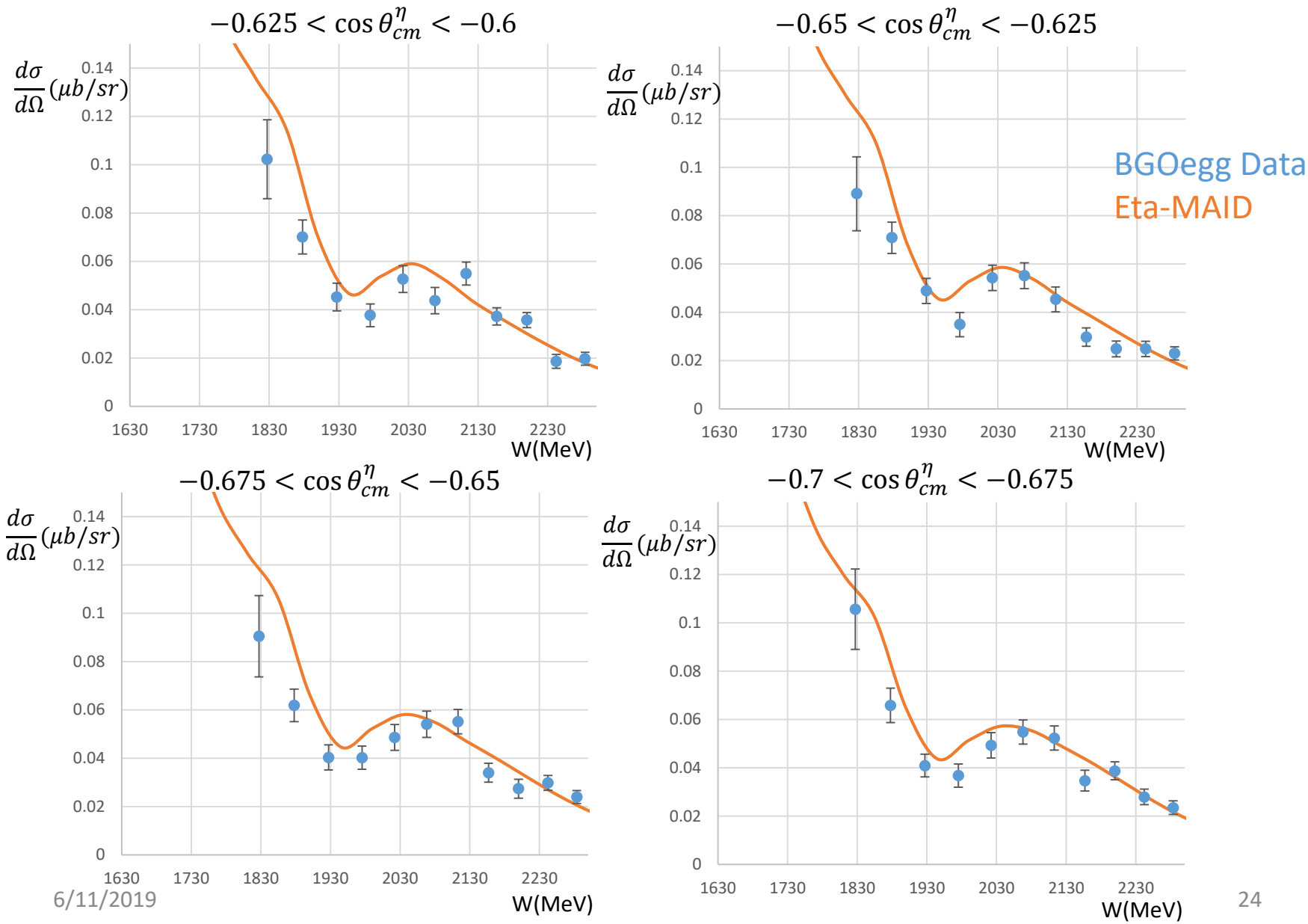
Sumihama et. al.
PhysRevC.80.052201





- ✓ η : large $s\bar{s}$ & isospin 0 => $N^* \rightarrow \eta p$ will have isospin 1/2
- ✓ Small t-channel contribution at the backward angle

$\gamma p \rightarrow \eta p$ differential cross section



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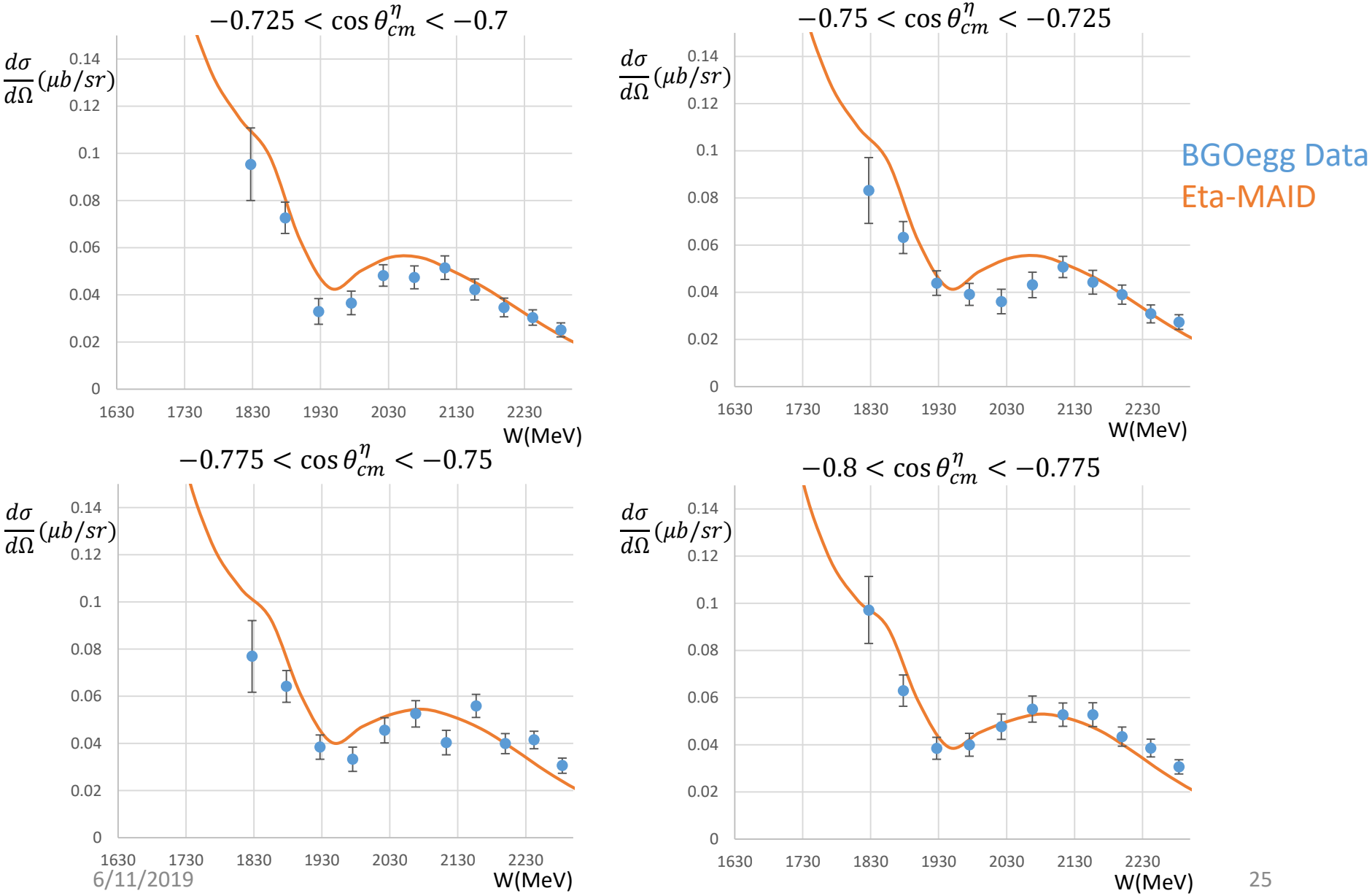

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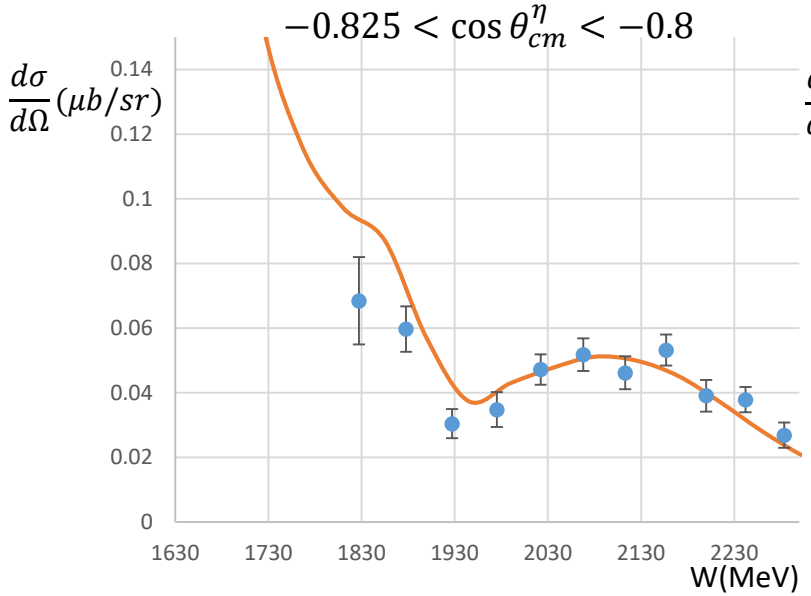
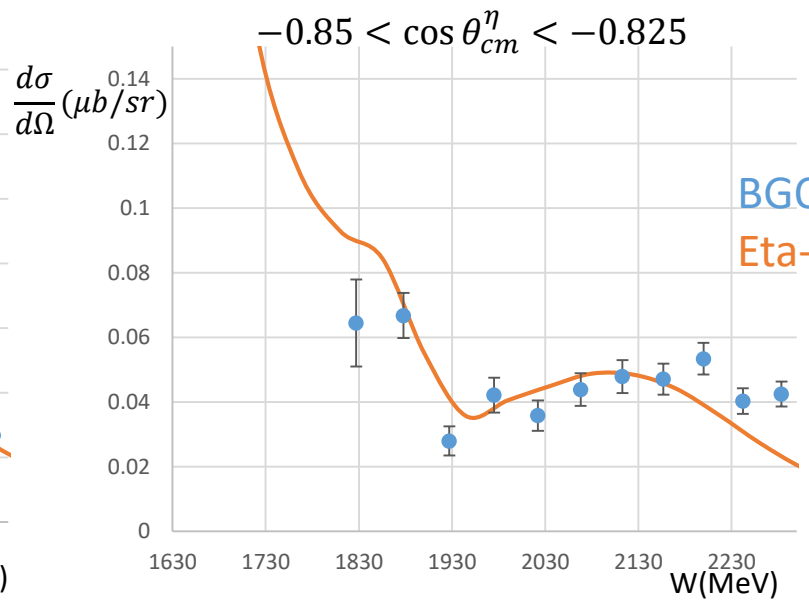
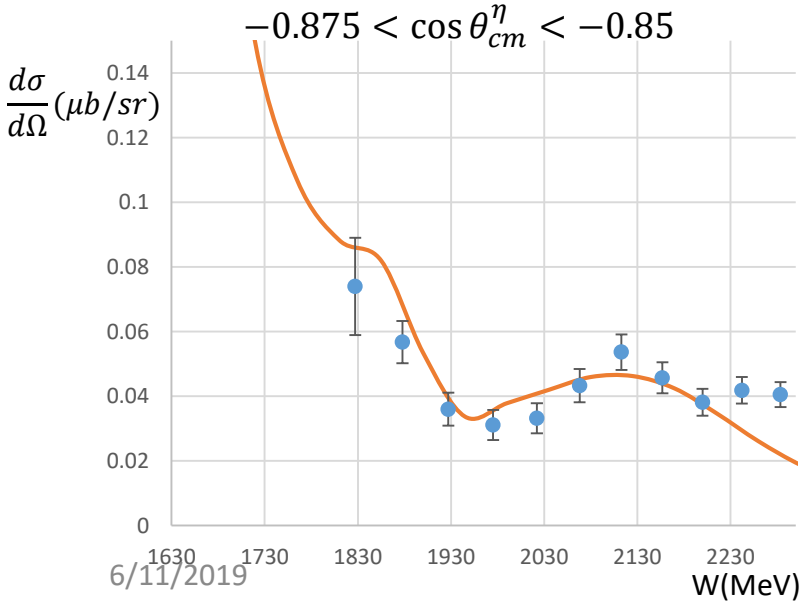
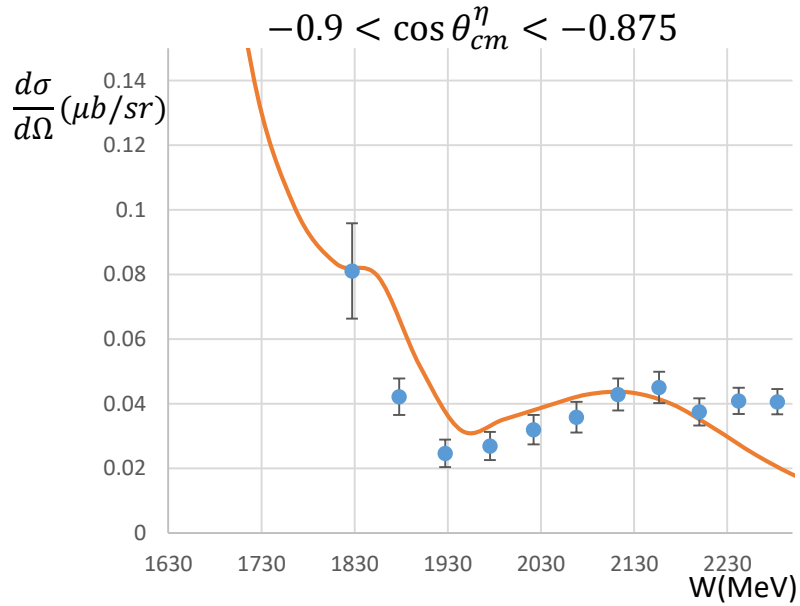




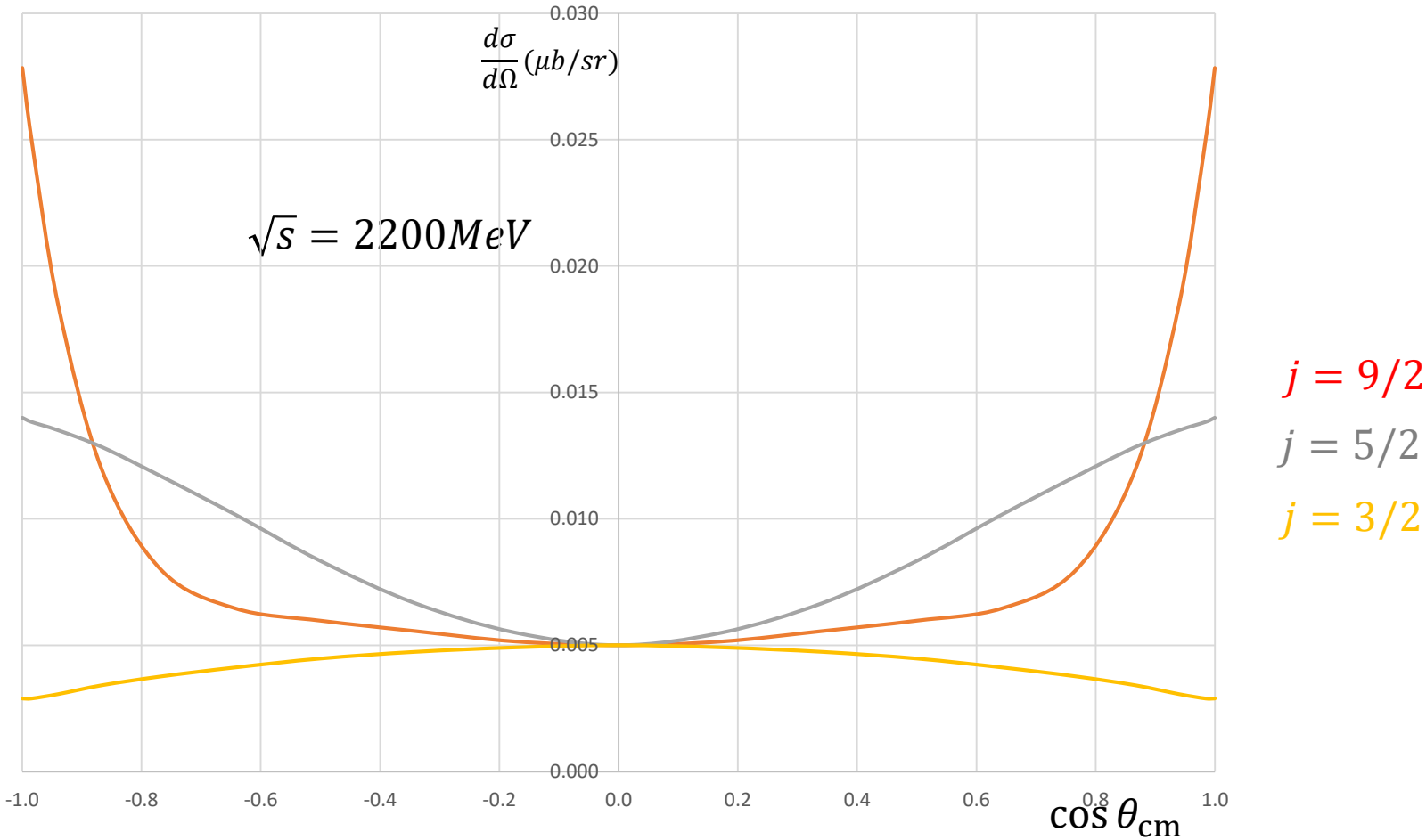
BGOegg Data

Eta-MAID





Differential cross section (single N* mode)



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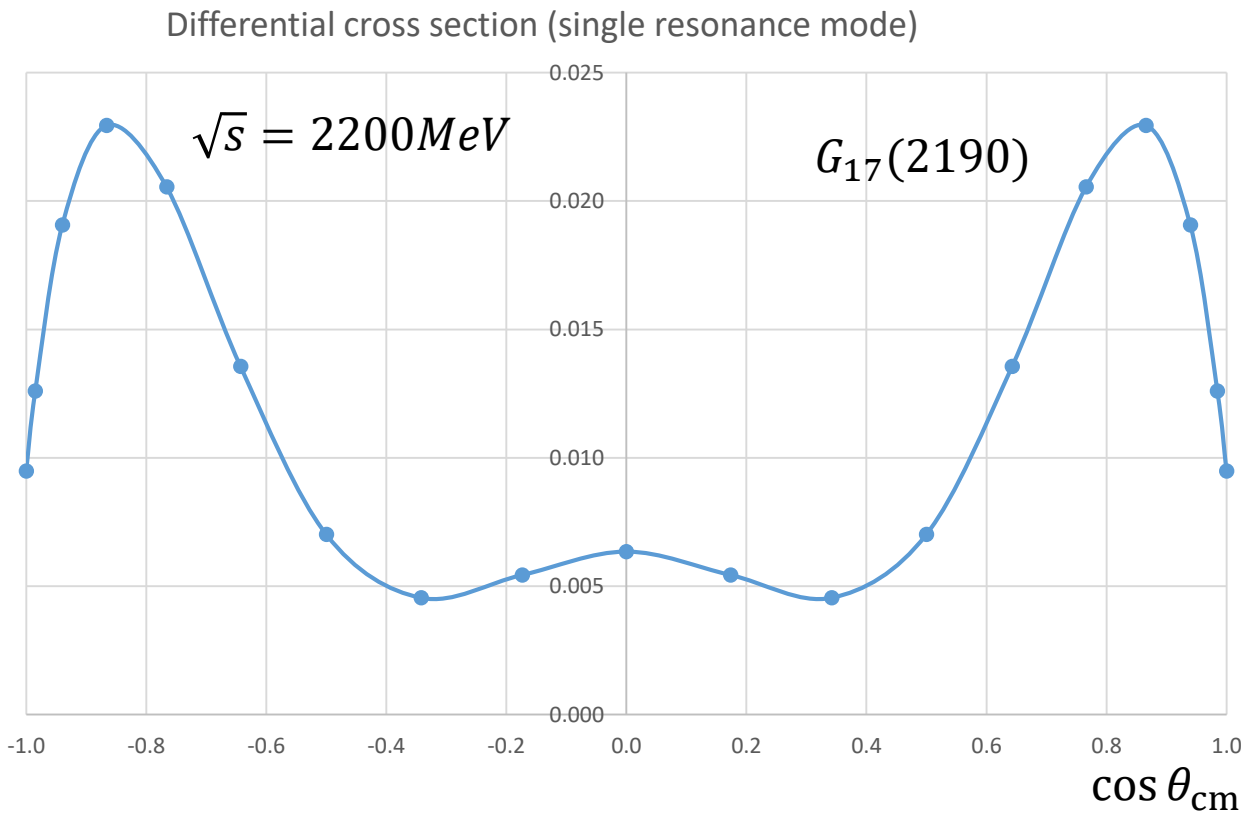


Systematic Error

Tran Nam

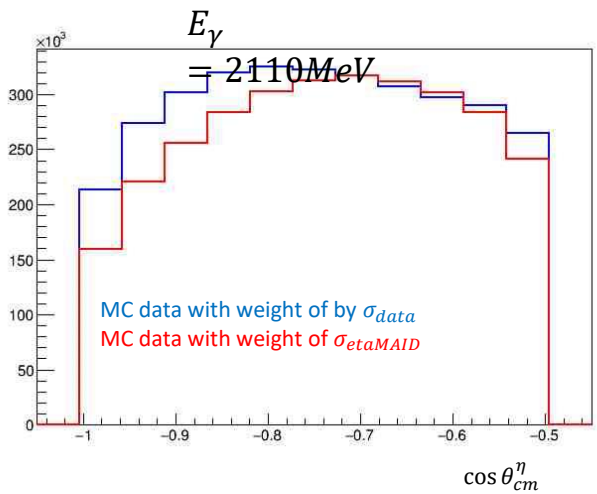
Contributions of the systematic error

Source	Contribution (%)
Acceptance	<3%
Kinematic fitting	<3%
Branching ratio	0.2%
Target length	1.3%
Transmission factor	<3%
Background contamination	<6.24%

the systematic error of acceptance

- The reason for this sizeable uncertainty is the fact that the acceptance calculation requires experiment to be simulated as detailed as possible, which certainly cannot reproduce data fully.
- To estimate the contribution from the acceptance, 2 sets of MC data were generated:
  - 1st MC set: a distribution **weighted etaMAID cross section**
  - 2nd MC set: a distribution **weighted by real data cross section**
- The cross section obtained from the acceptances determined by 2 MC data set will then be compared.

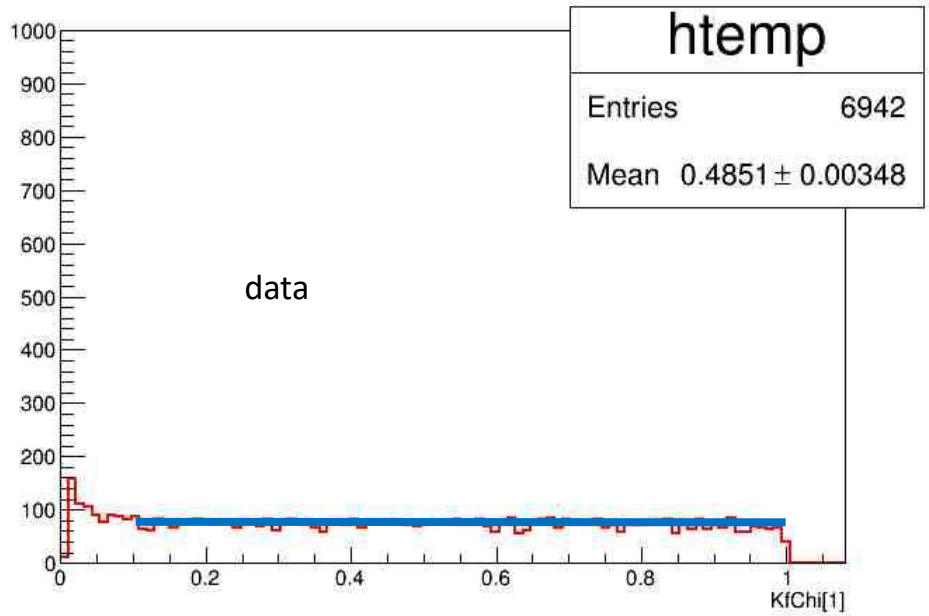
the systematic error of acceptance

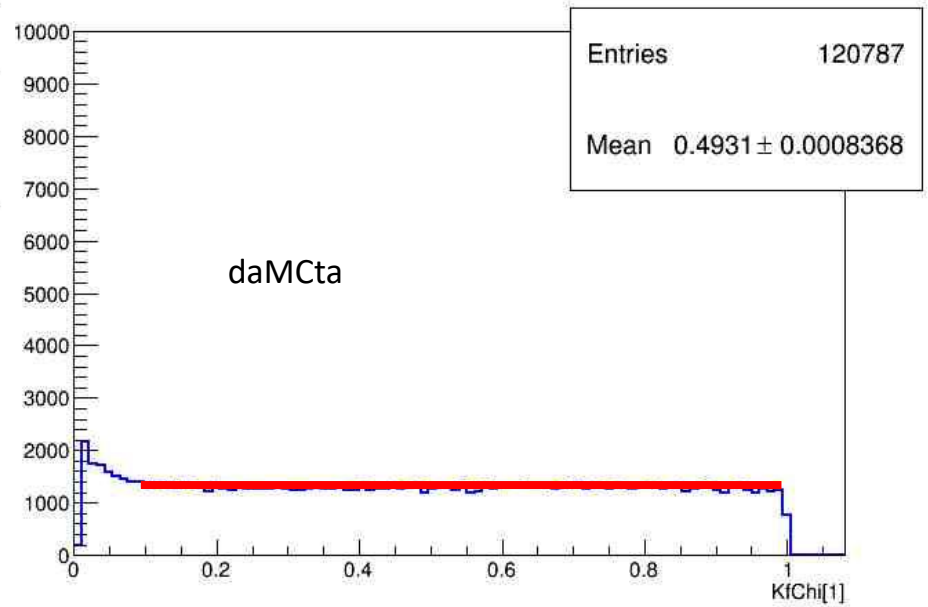


E_γ (MeV)	$\cos\theta^{\eta}_{cm}$															
	-0.9875	-0.9625	-0.9375	-0.9125	-0.8875	-0.8625	-0.8375	-0.8125	-0.7875	-0.7625	-0.7375	-0.7125	-0.6875	-0.6625	-0.6375	-0.6125
1310	0.50	0.66	2.47	-0.56	0.34	0.17	0.85	0.23	0.73	0.13	-0.44	1.93	0.71	1.83	2.16	0.11
1410	-1.50	-1.25	-2.17	-1.52	-1.57	-0.52	-1.08	-1.89	-1.58	-1.41	-1.11	-1.90	-1.57	-2.81	-1.80	-0.47
1510	-2.14	0.19	-1.12	-1.28	-1.73	0.43	-1.82	-1.49	-1.51	-0.64	-2.22	-0.42	-0.68	-1.47	0.30	-0.77
1610	-0.62	-0.83	-2.35	-0.06	0.76	-0.72	-2.44	0.10	-0.26	-0.03	-0.96	-0.15	-1.89	-1.28	-0.16	-1.12
1710	0.49	-0.81	-0.06	-0.23	-0.76	-0.08	-1.16	-0.54	-1.00	-0.31	-1.09	-1.35	0.71	-0.81	-1.16	-1.31
1810	-1.59	-1.63	-0.25	0.74	-1.89	-0.41	-0.10	-0.96	-1.21	-1.33	-0.23	-0.89	-1.36	-0.69	-0.81	-0.97
1910	-1.28	-1.01	-0.31	-0.12	-0.96	-0.24	-1.20	-0.38	-0.44	-0.70	-1.28	-2.54	-0.79	-0.44	-0.80	-1.76
2010	-0.92	-0.43	-1.34	-1.84	-1.25	-0.70	-1.21	-0.50	-0.74	-1.74	-1.06	-1.29	-0.62	-0.87	-1.02	-2.68
2110	-0.80	0.45	0.04	-1.86	-0.24	-0.65	-0.16	-2.14	-1.57	-0.01	-0.31	-0.13	-0.64	-0.24	-1.15	-0.51
2210	-1.19	-2.88	-0.71	-1.29	-0.56	-1.91	-1.08	0.32	-1.44	-0.89	-0.73	-1.87	-1.84	0.65	-1.46	-0.75
2310	-1.62	0.14	-0.24	-0.51	-1.32	0.13	-1.47	-0.96	-0.33	-1.84	0.00	-2.43	-0.67	-0.01	-1.63	-2.36

The difference in % of the cross section calculated from acceptance of 2 MC data sets is shown in above table

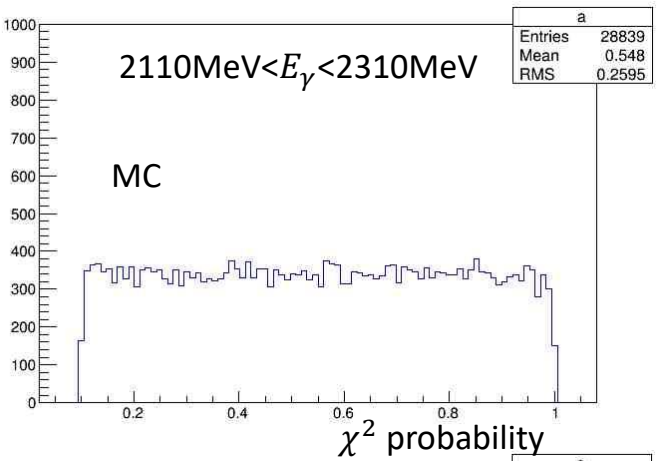
The systematic error of kinematic fitting and Background contamination

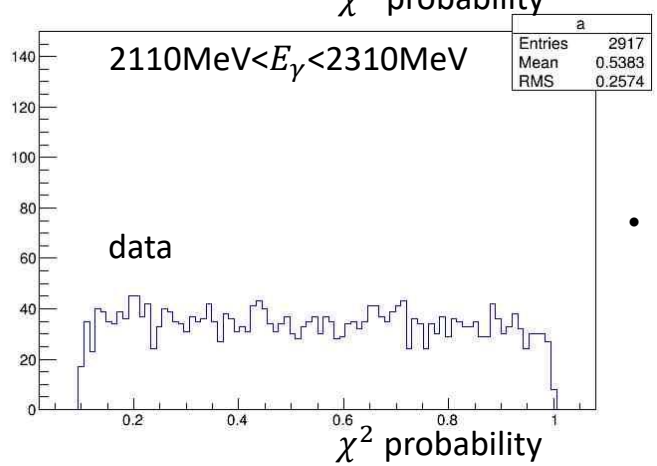




As can be seen, above 0.1 or 10% confident level, the χ^2 probability distribution on both data and MC are flat.
Below 0.1 , there is a rise in the region below 0.1 on both distributions, the reason is because of the non- Gaussian of the input resolution, in addition, background contamination on data is also possible.
Both of kinematic fitting cut and background contribute to the total systematic error.

The systematic error of kinematic fitting





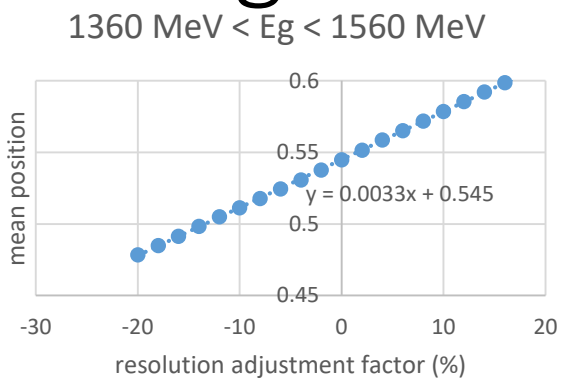
The mean position of the χ^2 probability distribution of MC and data is compared after the cut at 10% confident level to remove the potential BG contamination in data

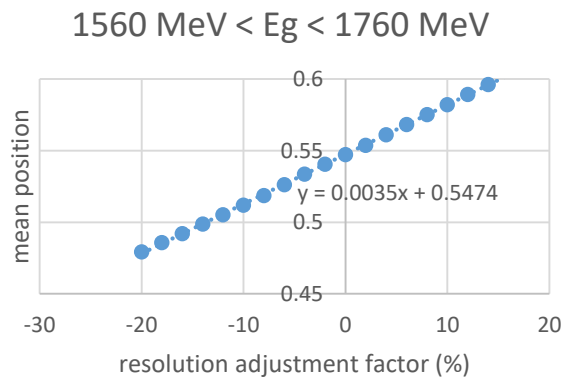
The resolution input of KF on MC then was adjusted by a factor ($\pm 2\%$, $\pm 4\%$, $\pm 6\%$ …) to obtain the mean position similar to data.

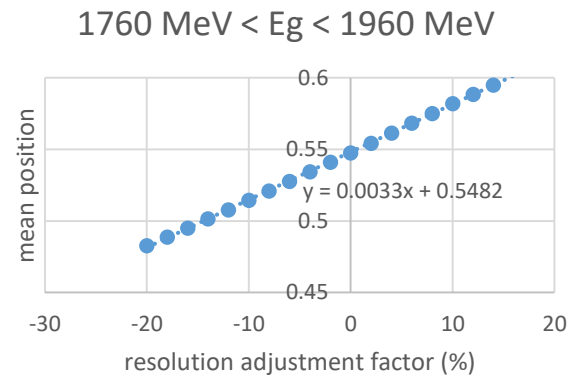
- The systematic error for the kinematic fitting is obtained after recalculating the acceptance using new resolution input on MC.

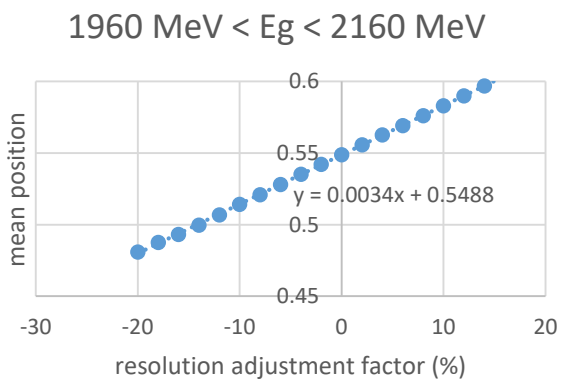
E (MeV)	Mean position on data	Mean position on MC
1410	0.5216	0.5447
1610	0.5438	0.5473
1810	0.5462	0.5475
2010	0.5537	0.5488
2210	0.5383	0.5480

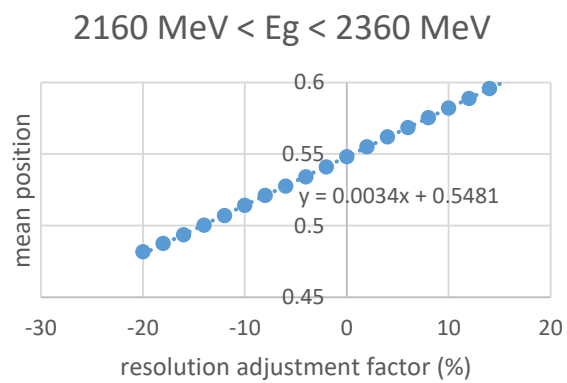
The systematic error of kinematic fitting











The changing of the mean position as a function of % changing of resolution input.
For example: changing resolution by $\pm 2\%, \pm 4\%, \pm 6\%$ … then plot the % of changing vs the mean position on MC χ^2 probability distribution.
The resolution input of KF on MC is adjusted so that the mean position is same with data.

The systematic error of kinematic fitting

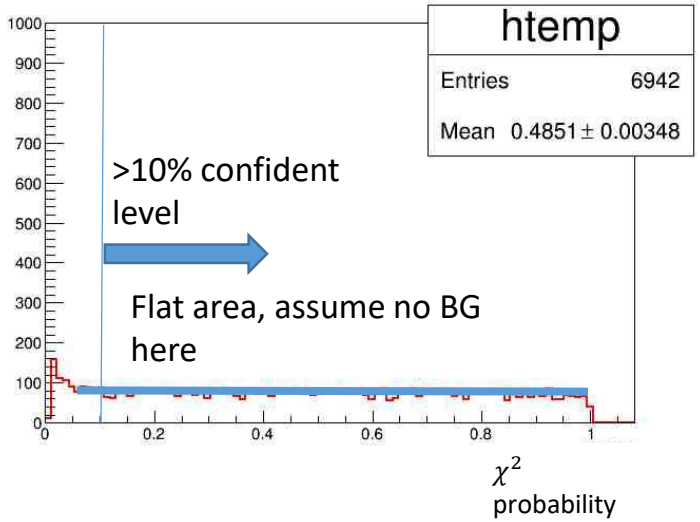
E (MeV)	Adjustment factor for the resolution on MC
1410	-7%
1610	-1%
1810	-0.6%
2010	+1.44%
2210	-2.88%

The % of cross section changed before and after applying new resolution

Eg (MeV)	$\cos\theta_{cm}^{\eta}$															
	-0.9875	**-0.9625**	**-0.9375**	**-0.9125**	**-0.8875**	**-0.8625**	**-0.8375**	**-0.8125**	**-0.7875**	**-0.7625**	**-0.7375**	**-0.7125**	**-0.6875**	**-0.6625**	**-0.6375**	**-0.6125**
1310	2.04	2.39	2.65	2.62	2.47	2.55	2.32	2.03	2.20	1.95	2.07	1.92	1.98	1.77	1.59	1.49
1410	2.05	2.13	2.55	2.16	2.27	2.17	2.17	2.01	1.85	1.78	2.08	1.82	1.79	1.56	1.70	1.61
1510	-0.11	1.45	1.27	1.03	1.51	1.29	1.13	1.23	1.02	0.98	1.16	0.98	1.06	0.99	1.08	0.88
1610	0.81	0.45	0.34	0.27	0.28	0.28	0.21	0.19	0.28	0.15	0.25	0.25	0.19	0.30	0.22	0.19
1710	0.77	0.18	0.39	0.49	0.17	0.31	0.20	0.26	0.31	0.22	0.17	0.28	0.28	0.19	0.14	0.18
1810	0.12	0.17	0.55	0.48	0.10	0.17	0.17	0.41	0.19	0.17	0.28	0.21	0.22	0.20	0.20	0.21
1910	0.06	-0.13	0.61	0.24	-0.42	-0.14	-0.28	-0.10	-0.02	0.04	0.03	-0.05	-0.01	-0.05	0.01	0.01
2010	-0.19	-1.02	-0.32	-0.30	-0.25	-0.71	-0.22	-0.32	-0.19	-0.21	-0.23	-0.28	-0.16	-0.18	-0.27	-0.18
2110	0.17	0.21	0.38	-0.13	0.34	0.10	-0.12	-0.08	0.08	0.26	0.16	0.07	0.09	0.13	0.10	0.12
2210	1.63	0.92	0.74	1.52	0.70	0.84	0.19	0.52	0.44	0.33	0.36	0.60	0.44	0.37	0.40	0.33
2310	0.49	-0.13	0.73	1.49	0.65	0.92	0.88	0.47	0.47	0.42	0.54	0.63	0.42	0.73	0.39	0.41

Background contamination

- BG contamination can be checked by increasing the cut point in the χ^2 probability distribution from 1% -> 10% confident level cut.
- Above 10% confident level cut point on data, the distribution is flat, we assume that events with >10% confident level contain no BG.



To reduce the statistical fluctuation, the data sample was separated in 2 energy region only, E_γ<1.8 GeV and E_γ>1.8 GeV .

Background contamination

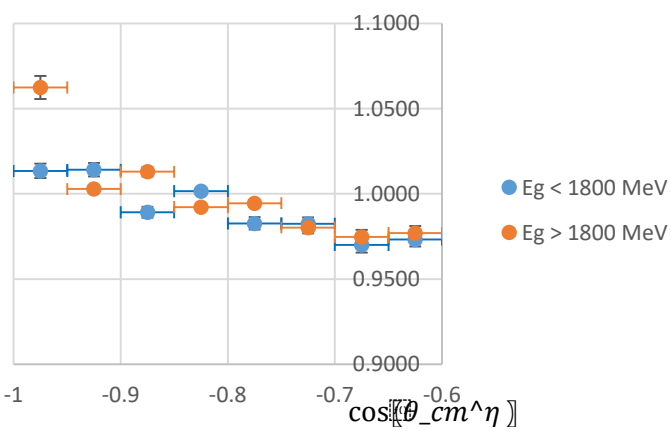
$E_\gamma < 1800MeV$

CL cut (%)	-0.975	-0.925	-0.875	-0.825	-0.775	-0.725	-0.675	-0.625
1	762	899	1068	1206	1307	1351	1445	1533
2	757	909	1067	1209	1296	1348	1436	1525
3	755	911	1061	1208	1290	1344	1427	1513
4	759	909	1055	1211	1287	1337	1424	1514
5	765	902	1053	1204	1282	1328	1428	1514
6	771	904	1053	1211	1286	1319	1425	1508
7	776	904	1058	1202	1294	1324	1424	1515
8	772	904	1062	1210	1291	1321	1422	1503
9	774	904	1060	1209	1283	1326	1422	1503
10	772	912	1057	1208	1285	1328	1401	1492

$E_\gamma > 1800MeV$

CL cut(%)	-0.975	-0.925	-0.875	-0.825	-0.775	-0.725	-0.675	-0.625
1	1360	1710	1768	1783	1770	1597	1480	1335
2	1366	1711	1757	1774	1776	1595	1463	1332
3	1370	1712	1758	1764	1763	1590	1460	1341
4	1392	1709	1757	1767	1761	1592	1459	1327
5	1392	1714	1770	1768	1751	1590	1454	1322
6	1407	1717	1782	1770	1753	1589	1451	1310
7	1421	1716	1785	1774	1753	1584	1451	1306
8	1425	1707	1791	1778	1759	1566	1449	1305
9	1438	1713	1792	1768	1760	1571	1443	1302
10	1445	1714	1790	1769	1761	1565	1443	1304

The largest difference is between 1% cut and 10% cut in the region $E_\gamma > 1800\ MeV$ (red color).



The figure on the left shows the ratio between 1% and 10% cut which is also the largest difference . The statistical errors are included.

Background contamination

$E_\gamma < 1800MeV$

CL cut (%)	-0.975	-0.925	-0.875	-0.825	-0.775	-0.725	-0.675	-0.625
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	-0.64	1.02	-0.16	0.25	-0.84	-0.26	-0.62	-0.52
3	-0.85	1.32	-0.67	0.13	-1.35	-0.53	-1.23	-1.32
4	-0.42	1.08	-1.26	0.40	-1.51	-1.06	-1.46	-1.22
5	0.43	0.32	-1.42	-0.19	-1.96	-1.68	-1.17	-1.21
6	1.15	0.46	-1.40	0.39	-1.60	-2.39	-1.36	-1.60
7	1.85	0.50	-0.95	-0.33	-1.01	-2.04	-1.40	-1.19
8	1.33	0.48	-0.62	0.29	-1.20	-2.21	-1.54	-1.97
9	1.62	0.56	-0.80	0.26	-1.82	-1.87	-1.56	-1.96
10	1.34	1.41	-1.08	0.16	-1.73	-1.75	-3.00	-2.68

$E_\gamma > 1800MeV$

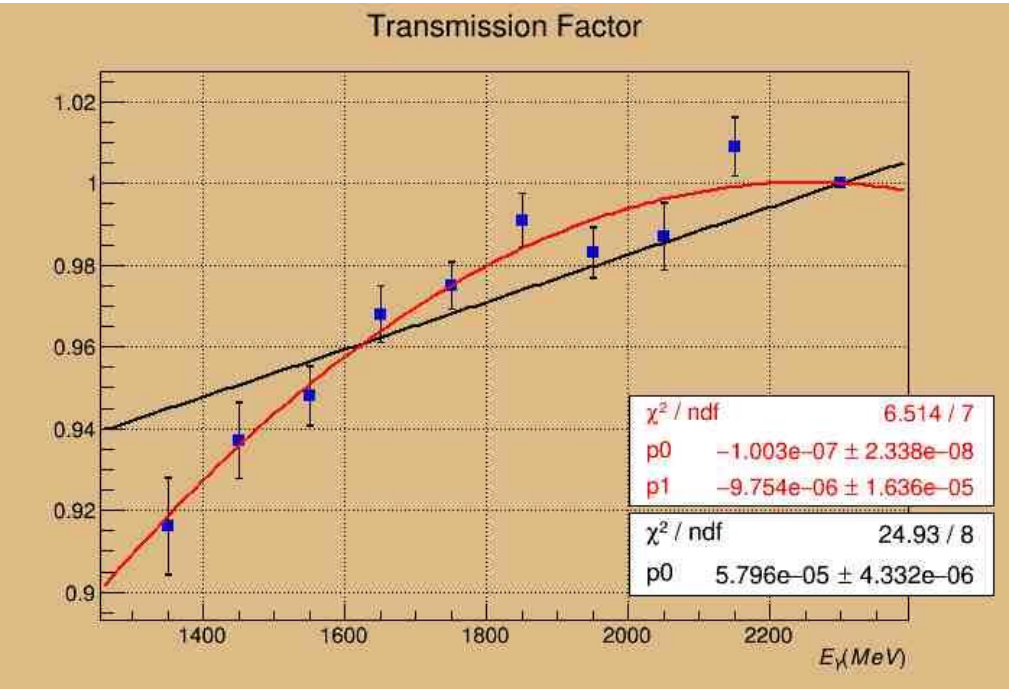
CL cut (%)	-0.975	-0.925	-0.875	-0.825	-0.775	-0.725	-0.675	-0.625
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.44	0.10	-0.58	-0.54	0.33	-0.10	-1.20	-0.19
3	0.72	0.15	-0.53	-1.09	-0.39	-0.40	-1.40	0.45
4	2.38	-0.01	-0.61	-0.95	-0.50	-0.30	-1.46	-0.57
5	2.37	0.27	0.14	-0.86	-1.10	-0.39	-1.78	-0.96
6	3.43	0.46	0.82	-0.73	-1.00	-0.48	-1.96	-1.82
7	4.52	0.39	1.00	-0.50	-1.00	-0.77	-1.97	-2.15
8	4.75	-0.15	1.30	-0.30	-0.65	-1.89	-2.13	-2.24
9	5.72	0.21	1.36	-0.87	-0.56	-1.61	-2.49	-2.47
10	6.24	0.28	1.30	-0.78	-0.55	-1.97	-2.53	-2.31

The difference in % of different cut point compare to 1% cut point (top 2 tables) and associated statistical error (bottom 2 tables)

%	-0.975	-0.925	-0.875	-0.825	-0.775	-0.725	-0.675	-0.625
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.29	0.34	0.12	0.14	0.25	0.14	0.21	0.18
3	0.33	0.38	0.25	0.10	0.32	0.20	0.29	0.29
4	0.24	0.35	0.34	0.18	0.34	0.28	0.32	0.28
5	0.24	0.19	0.36	0.12	0.39	0.35	0.28	0.28
6	0.39	0.23	0.36	0.18	0.35	0.42	0.31	0.32
7	0.49	0.24	0.30	0.16	0.28	0.39	0.31	0.28
8	0.42	0.23	0.24	0.15	0.30	0.40	0.33	0.36
9	0.46	0.25	0.27	0.15	0.37	0.37	0.33	0.36
10	0.42	0.40	0.32	0.12	0.36	0.36	0.46	0.42

%	-0.975	-0.925	-0.875	-0.825	-0.775	-0.725	-0.675	-0.625
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.18	0.07	0.18	0.17	0.14	0.08	0.28	0.12
3	0.23	0.09	0.17	0.25	0.15	0.16	0.31	0.18
4	0.42	0.03	0.19	0.23	0.17	0.14	0.31	0.21
5	0.42	0.13	0.09	0.22	0.25	0.16	0.35	0.27
6	0.50	0.16	0.22	0.20	0.24	0.17	0.36	0.37
7	0.58	0.15	0.24	0.17	0.24	0.22	0.36	0.40
8	0.59	0.09	0.27	0.13	0.19	0.34	0.38	0.41
9	0.65	0.11	0.28	0.22	0.18	0.32	0.41	0.43
10	0.68	0.13	0.27	0.21	0.18	0.35	0.41	0.42

Transmission factor



The reason for the energy dependence of the transmission is still uncertain.

The systematic error for this transmission factor is obtained by using different fitting function to this dependence, in this case, pol2 and linear function.

Event though the χ^2/ndf of the pol2 function is better than the linear function but since the reason of this dependence is still unknown, fitting with linear function is also reasonable.

The cross section calculated using both fitting functions is compared to check the systematic error

Transmission factor

Eg (MeV)	Error (%)
1350	-1.98
1450	-0.96
1550	-0.19
1650	0.35
1750	0.68
1850	0.79
1950	0.70
2050	0.41
2150	-0.08
2300	-1.18

The cross section difference (in %) using 2 fitting function is shown in the above table

Other contributions

- There is an error associated with the value used for the $\eta \rightarrow 2\gamma$ decay branch, which is taken from the error determined by the experimental measurements used to produce the branching ratio PDG values. The error is 0.2%
- The length of the liquid hydrogen target used in the current experiment is 54 cm with 1% contribution to the uncertainty in the calculation of the target area density.
- The photon flux determination is relate to the deadtime of the data acquisition system, the deadtime is calculated from the scalers and assume to have in-significant contribution to the uncertainty due to high precision of the scalers.