



中国科学院高能物理研究所  
*Institute of High Energy Physics*  
*Chinese Academy of Sciences*

# 2023年1-4月研究生考核报告

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# 目录

## ➤ BESIII 分析

- $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$  中  $X(2370)$  自旋宇称测量
- $\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \pi^+ \pi^- \eta'$  中  $\pi_1(1600)$  自旋宇称测量

## ➤ ATLAS 分析

- 电子和光子能量刻度修正
- Early Run3  $H \rightarrow \gamma\gamma$  衰变道基准截面测量
- 双光子顶点选择效率研究

# $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$ 中 X(2370) 自旋宇称测量

## ➤ 研究动机

- 用分波分析方法测量  $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$  过程中的胶球候选者 X(2370) 的自旋宇称

## ➤ 研究进展

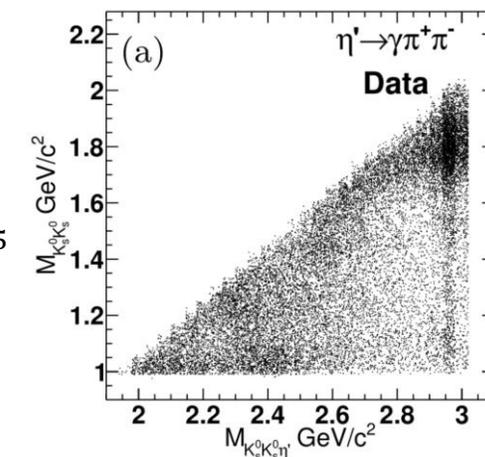
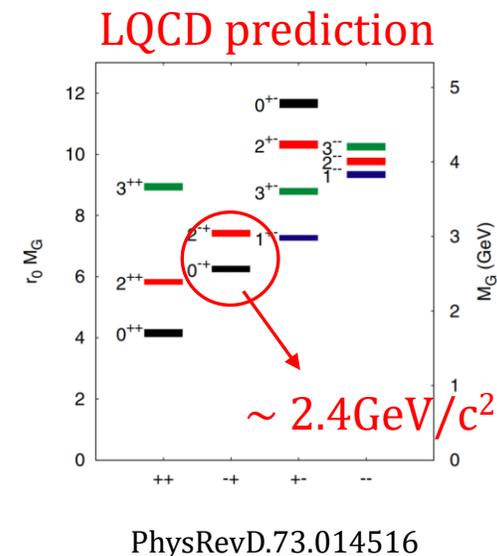
- 已经完成完成 Paper draft 并提交给 Referee Committee, 并根据目前收到的评论和建议, 对 draft 做了相应地更新和修改
- memo 和 draft 链接: [DocDB-1077](#), [HyperNews-BAM-00603](#)
- 在不同  $M_{K_S^0 K_S^0}$  cut 下测试了分波解的稳定性

## ➤ 研究进展 X(2370) 的测量结果

- $J^{PC} = 0^{-+}$
- $\text{Mass} = 2395_{-11}^{+11}(\text{stat.})_{-15}^{+11}(\text{syst.}) \text{ MeV}/c^2$ ,  $\text{Width} = 188_{-17}^{+18}(\text{stat.})_{-21}^{+12}(\text{syst.}) \text{ MeV}/c^2$
- $B[J/\psi \rightarrow \gamma X(2370), X(2370) \rightarrow f_0(980)\eta', f_0(980) \rightarrow K_S^0 K_S^0] = 1.32 \pm 0.22(\text{stat.})_{-0.25}^{+0.31}(\text{syst.}) \times 10^{-5}$

## ➤ 下一步

- 继续完善 Paper draft



# $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$ 中 X(2370) 自旋宇称测量

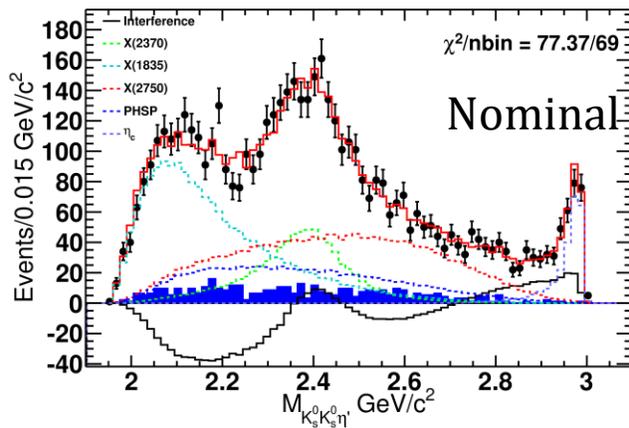
## ➤ 不同 $M_{K_S^0 K_S^0}$ cut 下的分波解

- 基于  $M_{K_S^0 K_S^0} < 1.10 \text{ GeV}/c^2$  的 Nominal 解, 在不同  $M_{K_S^0 K_S^0}$  cut 下进行分波分析, 测试了  $M_{K_S^0 K_S^0}$  cut 对 X(2370) 参数的影响。对  $M_{K_S^0 K_S^0} < 1.15 \text{ GeV}/c^2$  时的分波解的检查显示, 仍有显著性大于  $5\sigma$  的额外共振态, 需要进一步优化分波解。

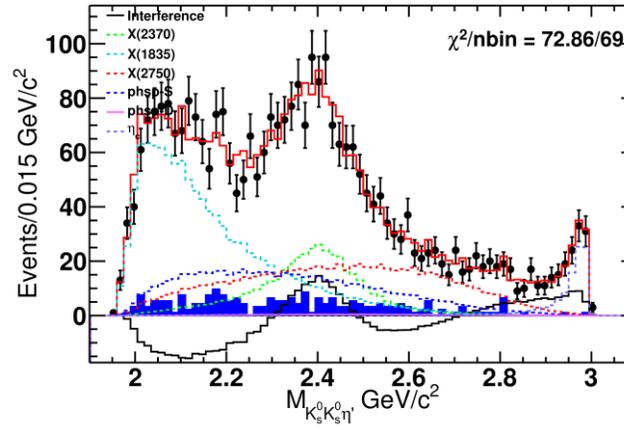
Cut	Changes of resonance parameters of X(2370)		
	$\Delta M \text{ (MeV}/c^2)$	$\Delta \Gamma \text{ (MeV}/c^2)$	$\Delta \mathcal{B}/\mathcal{B} \text{ (%)}$
$M_{K_S^0 K_S^0} < 1.05 \text{ GeV}/c^2$	+19	+9	+12.79
$M_{K_S^0 K_S^0} < 1.15 \text{ GeV}/c^2$	-11	+39	-32.11

在不同  $M_{K_S^0 K_S^0}$  cut 下的分波分析中都测得 X(2370) 自旋宇称为  $0^{-+}$

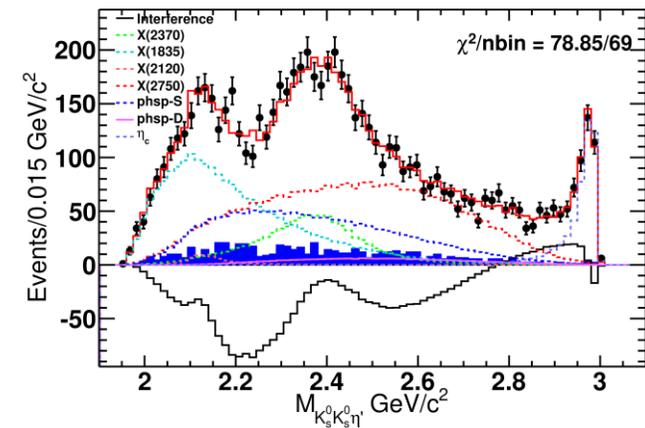
## ➤ 分波分析投影图



$$M_{K_S^0 K_S^0} < 1.10 \text{ GeV}/c^2$$



$$M_{K_S^0 K_S^0} < 1.05 \text{ GeV}/c^2$$



$$M_{K_S^0 K_S^0} < 1.15 \text{ GeV}/c^2$$

# $\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \pi^+ \pi^- \eta'$ 中 $\pi_1(1600)$ 自旋宇称测量

## ➤ 研究动机

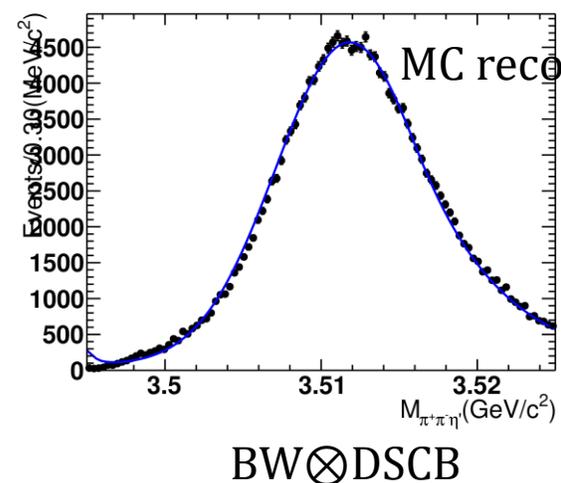
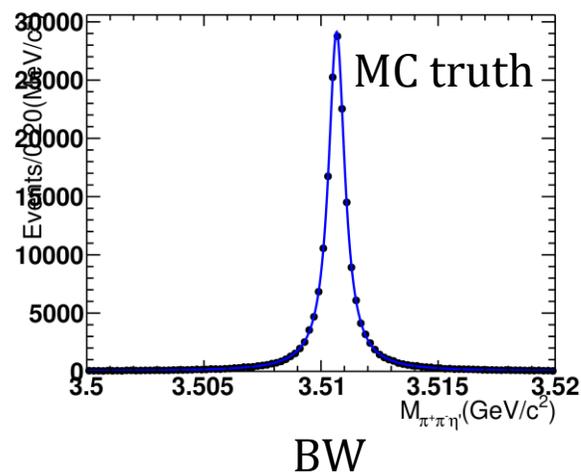
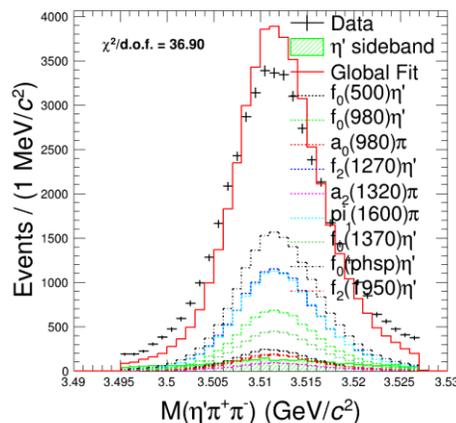
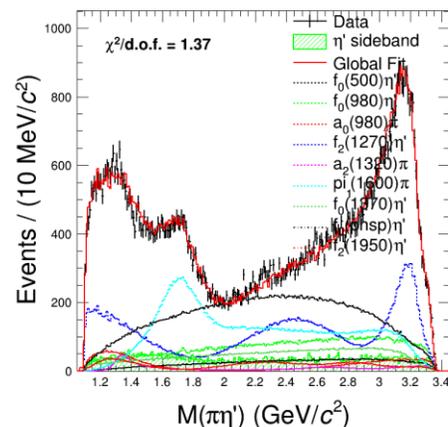
- 在  $\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \pi^+ \pi^- \eta'$  过程中测量混杂态候选者  $\pi_1(1600)$  的自旋宇称

## ➤ 研究进展

- 优化了  $\eta'$  候选者的选择方法
- $\pi_1(1600)$  自旋宇称的测量结果:  $J^{PC} = 1^{-+}$
- 正在撰写分析memo

## ➤ 下一步

- 目前的分波分析程序中没有考虑分辨, 准备通过拟合重建MC的  $\pi^+ \pi^- \eta'$  不变质量谱提取出分辨, 并在分波分析中加以考虑



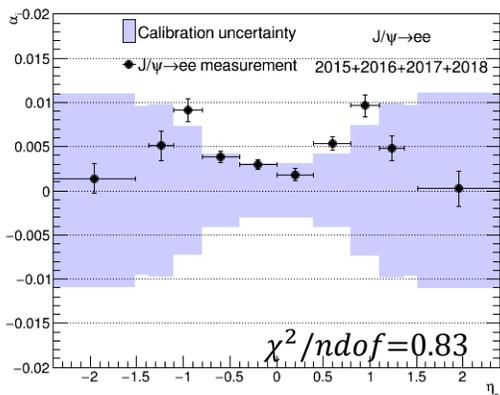
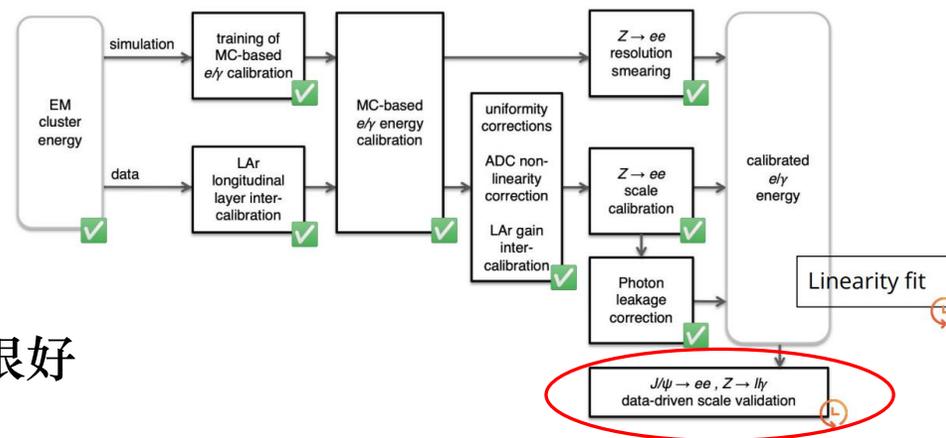
# Atlas: 电子和光子能量刻度修正

➤ 在最终的R21 precision recommendation版本下, 验证基于Zee的能量刻度

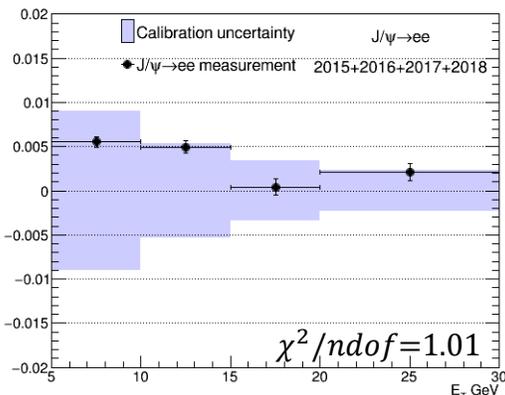
- 通过 $J/\psi \rightarrow ee$ 过程验证低横向动量区间下电子的能量刻度
- 通过 $Z \rightarrow ll\gamma$ 过程验证光子的能量刻度

➤ 基于 $J/\psi \rightarrow ee$ 过程的电子能量刻度

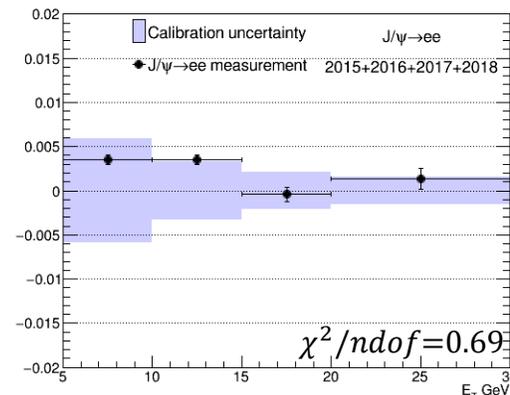
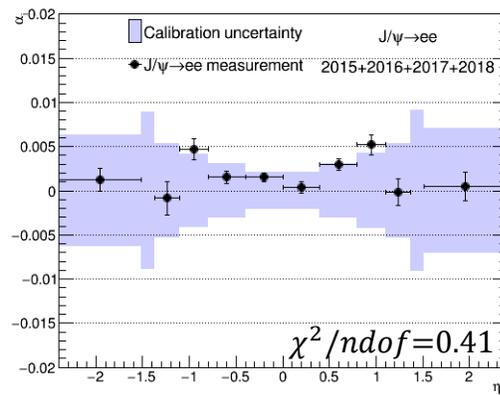
- 给出了电子的能量刻度修正因子随 $\eta$ 和 $E_T$ 的分布
- 更新了系统误差估计方法, 给出了系统误差测量结果
- 给出了考虑Linearity correction后的能量刻度修正因子
- 电子能量刻度修正因子与基于Zee的能量刻度的误差符合得很好
- 与之前版本precision recommendation相比, 变化符合预期



Nominal



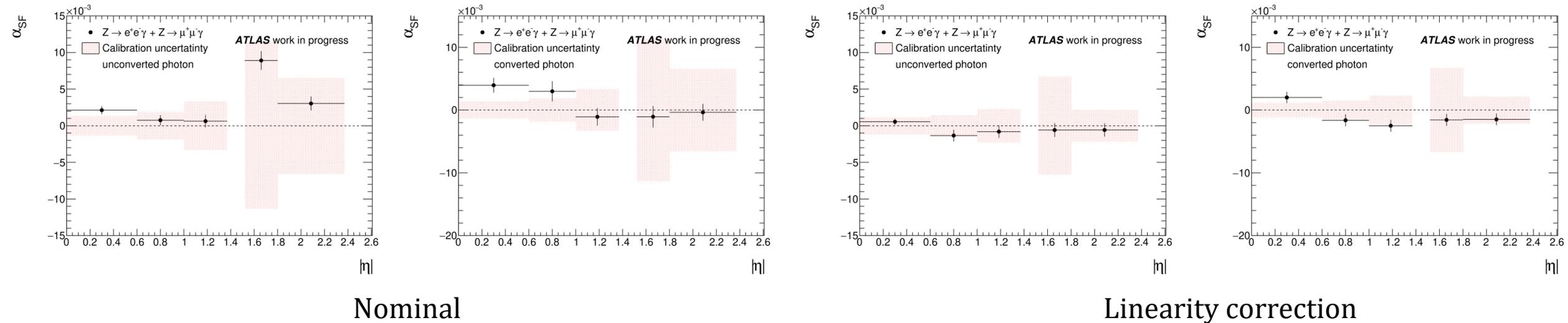
Linearity correction



# Atlas: 电子和光子能量刻度修正

## ➤ 基于 $Z \rightarrow l\bar{l}\gamma$ 过程的光子能量刻度修正

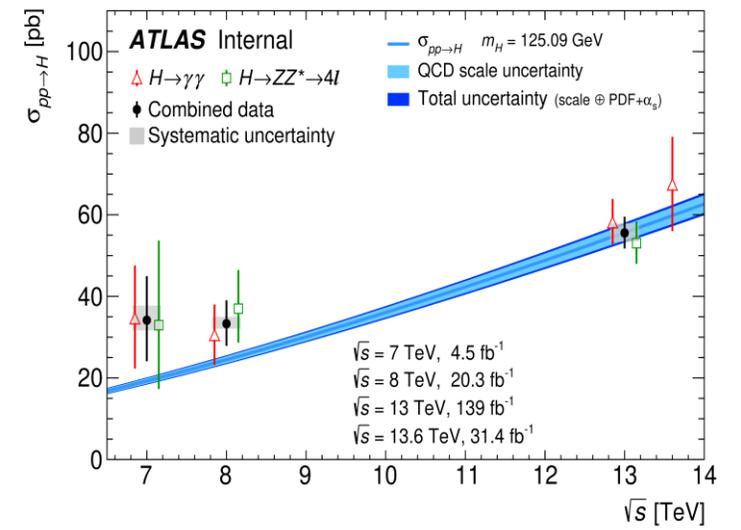
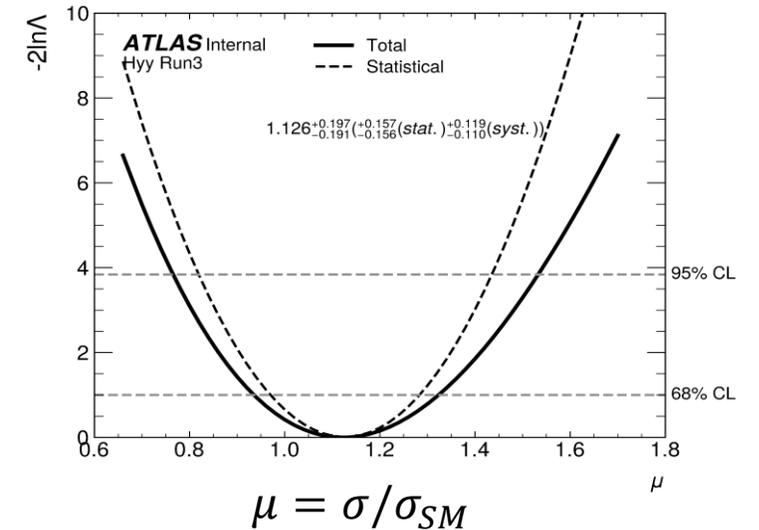
- 修复了分析包中pileup weight的计算错误
- 对 $Z \rightarrow ee\gamma$ 和 $Z \rightarrow \mu\mu\gamma$ 两个道联合测量，给出了转化光子、非转化光子的能量刻度修正的分布，并测量了系统误差
- 比较光子能量刻度修正因子与基于 $Zee$ 的能量刻度的误差
- 给出了考虑Linearity correction后的转化光子、非转化光子能量刻度修正因子



➤ 相关电子/光子能量刻度结果在[Egamma Calibration](#)会上给了7次报告，并将作为Full Run2 EGamma energy calibration 的交叉检验，预计今年发表文章

# Run3 $H \rightarrow \gamma\gamma$ 衰变道基准截面测量

- 研究动机:  $H\gamma\gamma$ 截面测量对研究希格斯玻色子的属性非常重要
- 本轮分析使用Run 3 data @ 13.6 TeV, 并且Athena 版本更新到Release 22, 测量结果与标准模型预测值一致:
  - $\sigma_{fid}(pp \rightarrow H \rightarrow \gamma\gamma) = 76_{-13}^{+14} fb$
  - $\sigma(pp \rightarrow H) = 67_{-12}^{+13} pb$
- 担任[supporting note](#)编辑; 验证了双光子顶点选择的效率[Report [link1,2](#)]; 在截面测量部分, 提供了基准截面的最终测量结果, 以及误差的拆分和估计[Report [link1,2](#)], 并在[Higgs Group Plenary Meeting](#)上报告了unblinded结果。
- 文章发表计划: 已经发表一篇[CONF note](#)



# 双光子顶点选择效率

## ➤ 研究动机

- $H \rightarrow \gamma\gamma$  系统不变质量的测量和初始顶点位置关系密切，因此正确地选择初始顶点至关重要。

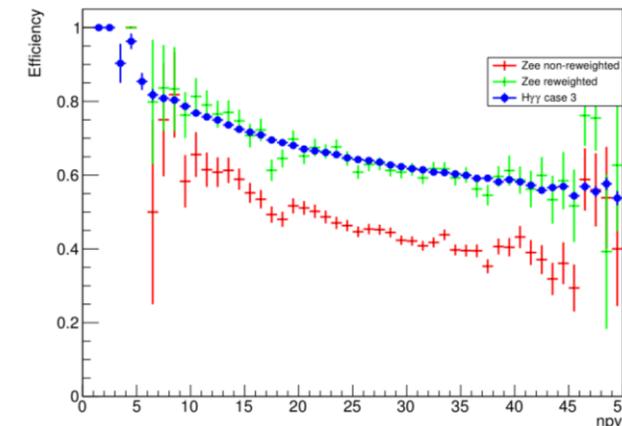
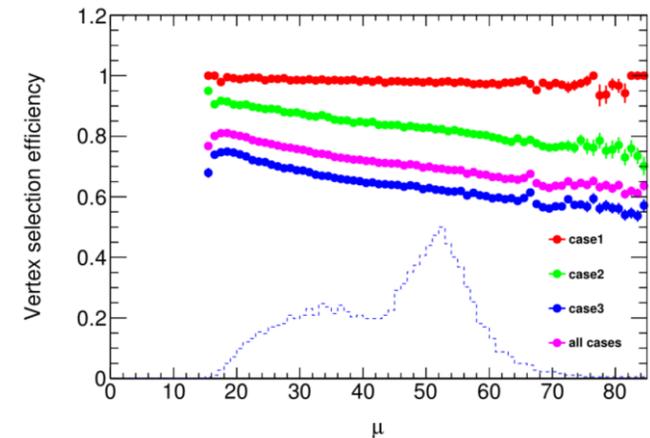
## ➤ 目前的顶点选择算法

- 将事例分为如下3类：
  - ✓ 至少一个光子转换为电子对，且径迹与重建初始顶点关联。(6%)
  - ✓ 至少有一个转换光子，其径迹在硅探测器中有击中点。(26%)
  - ✓ 两个光子均未转换。(68%)
- 对第一类事例，选择Hardest顶点作为初始顶点；第二、三类事例，用神经网络算法选出的顶点作为初始顶点。
- 测量了Higgs不同产生模式下顶点选择(Hardest和NN顶点)的效率，以及选择效率随事例堆叠的分布。

## ➤ 顶点选择算法的验证

- 利用  $Z \rightarrow ee$  过程的蒙特卡洛样本和真实数据模拟  $H \rightarrow \gamma\gamma$  过程，对重建算法进行了验证。
- 在对  $p_T^{ee}$  分布重新加权重后， $H \rightarrow \gamma\gamma$  和  $Z \rightarrow ee$  过程的选择效率分布符合得很好。

Production mode	Hardest vertex	NN vertex	Case1	Case2	Case3
ggF	52.16	71.54	98.17	84.15	64.52
VBF	67.34	75.96	98.00	83.53	71.21
$W^-H$	86.99	88.31	98.32	87.80	87.61
$W^+H$	87.76	88.67	98.60	87.83	88.07
$gg \rightarrow ZH$	89.64	89.81	98.80	88.88	89.36
$q\bar{q} \rightarrow ZH$	80.45	84.31	98.40	87.14	81.88
$t\bar{t}H$	99.55	95.21	99.00	90.85	96.41



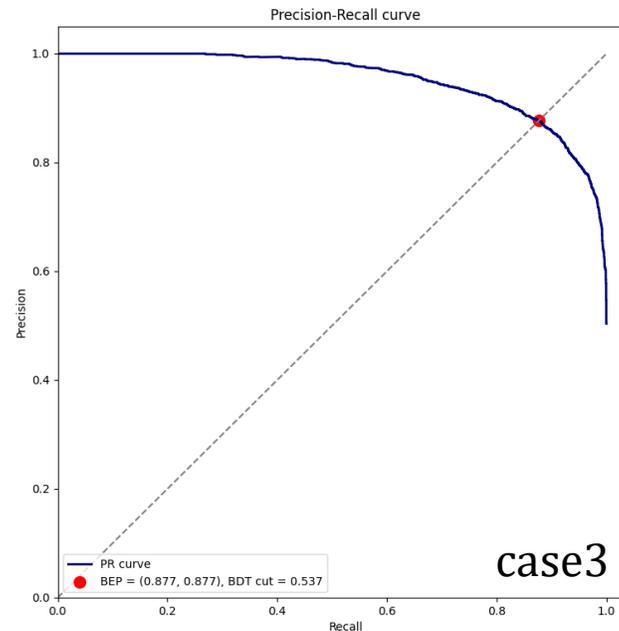
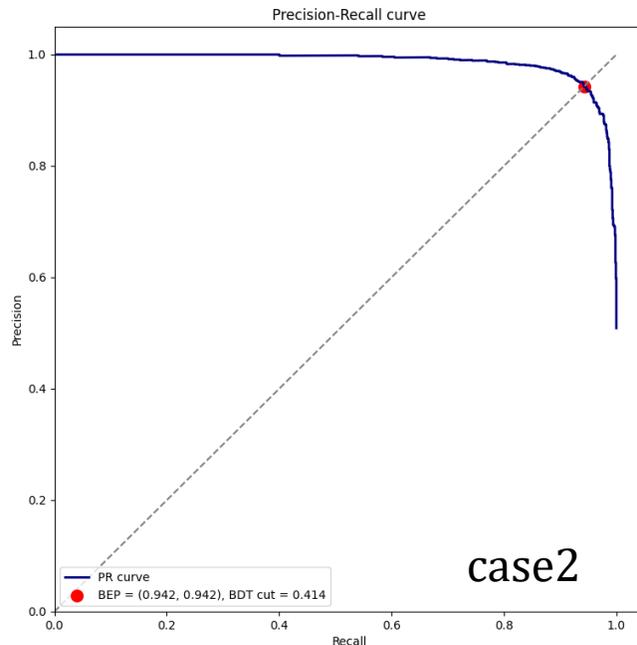
# 双光子顶点选择效率

## ➤ 双光子顶点选择的优化

- 目前 HGam 分析组使用的是基于 TMVA 的神经网络算法(NN)选择双光子顶点
- 尝试了新的训练方法(XGBoost, 添加其它训练变量等), 使用 Run3 数据进行训练
- 基于 XGBoost, 使用相同训练变量, 双光子顶点选择效率相比之前变化不大, 仍需进一步优化

$$\checkmark \epsilon = N(\Delta Z < 0.3 \text{ mm}) / N(\text{total})$$

$$\checkmark \Delta Z = Z_{PV}^{\text{selected}} - Z_{PV}^{\text{truth}}$$



XGBoost

	Efficiency	NN	XGBoost
Hardest case1		98.17%	
case2		84.15%	85.11%
case3		64.52%	63.98%
Inclusive		71.54%	71.52%

# 总结

## ➤ BESIII 分析

- $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$  中  $X(2370)$  自旋宇称的测量
  - ✓ 已经将Paper Draft提交给Referee Committee, 并根据收到的评论做出了相应修改([DocDB-1077](#))
- $\psi' \rightarrow \gamma \chi_{c1}, \chi_{c1} \rightarrow \pi^+ \pi^- \eta'$  中  $\pi_1(1600)$  自旋宇称测量
  - ✓ 正在撰写分析memo

## ➤ ATLAS 分析

- 电子和光子能量刻度修正
  - ✓ 基于最终的R21 precision recommendation, 给出了能量刻度修正, 结果将作为Full Run2 EGamma energy calibration 的交叉检验
- Run3  $H \rightarrow \gamma\gamma$  衰变道基准截面测量
  - ✓ 担任内部文章编辑, 提供了基准截面的最终测量结果, 已经发表一篇[CONF note](#)
- 双光子顶点选择效率
  - ✓ 测量了Higgs不同产生模式下基于神经网络的顶点选择的效率
  - ✓ 寻找其它训练变量, 优化训练模型, 提高顶点选择的效率



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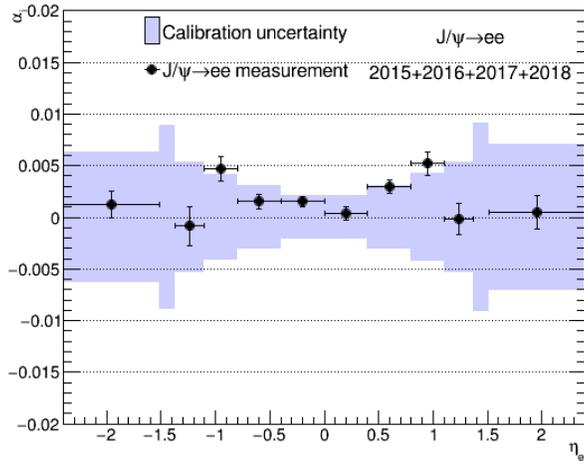
**Thanks!**

# $J/\psi \rightarrow ee$ : Scale results

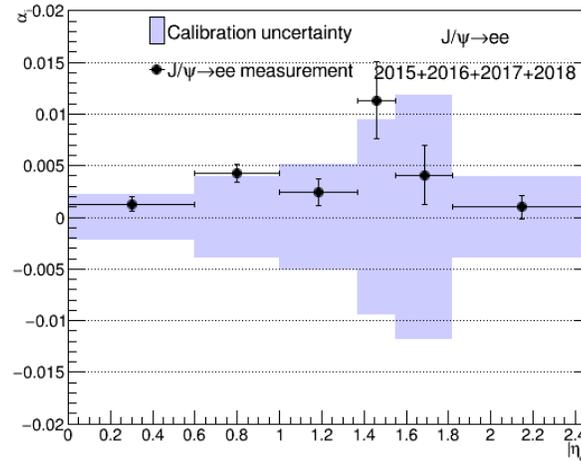
- Obtained the Energy scale factors w/o linearity correction as a function of the electron  $\eta$  or  $E_T$ 
  - The error bars on the black dots represent the total uncertainty

Final version of  
es2022\_R21\_Precision

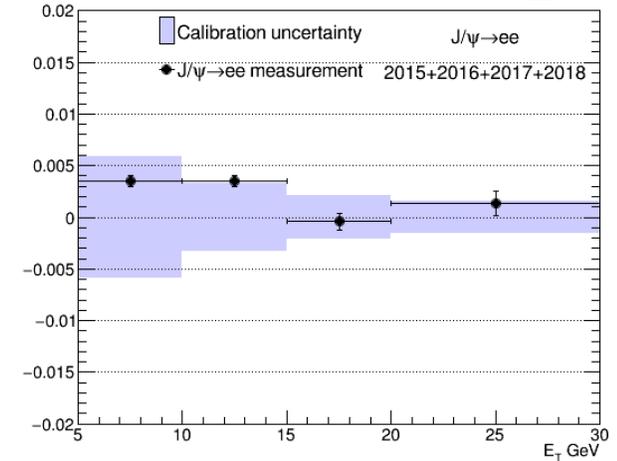
with  
Linearity  
correction



$\chi^2/ndof=0.41$

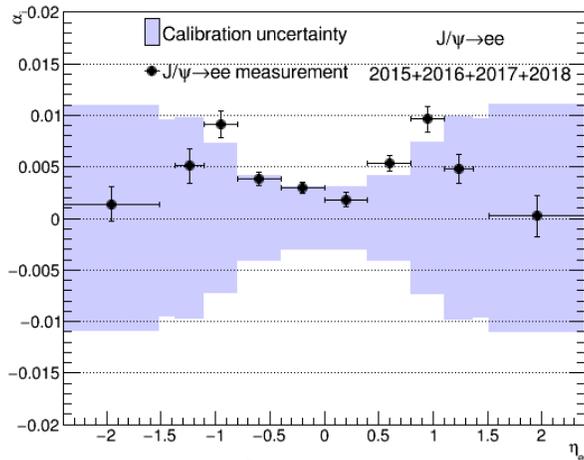


$\chi^2/ndof=0.63$

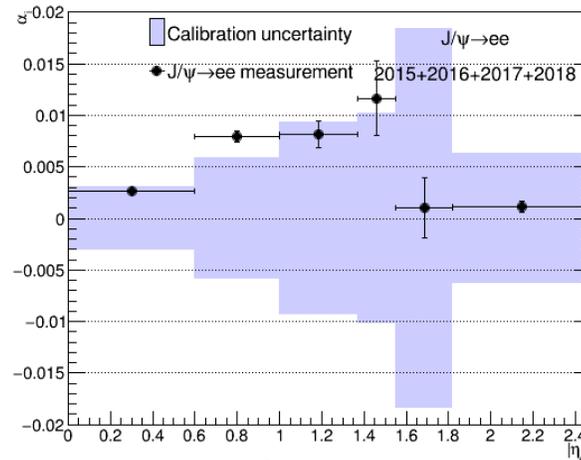


$\chi^2/ndof=0.69$

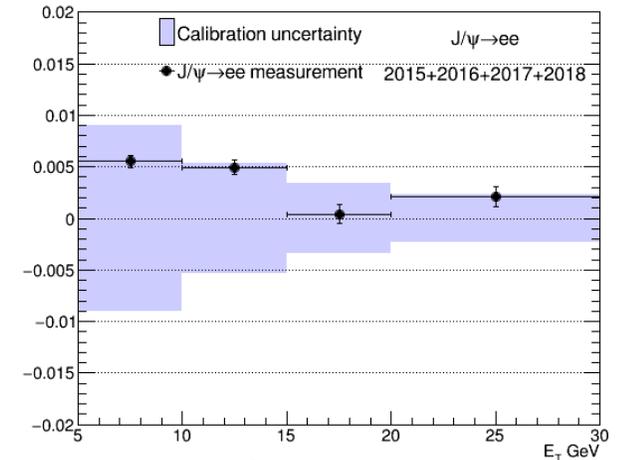
without  
Linearity  
correction



$\chi^2/ndof=0.83$



$\chi^2/ndof=0.89$

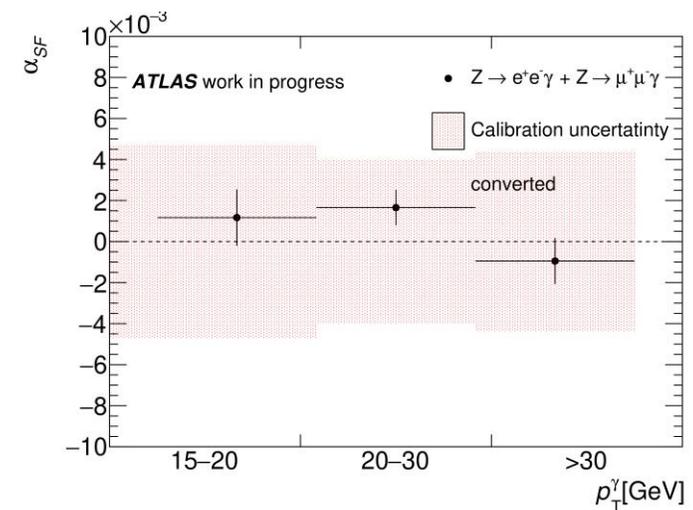
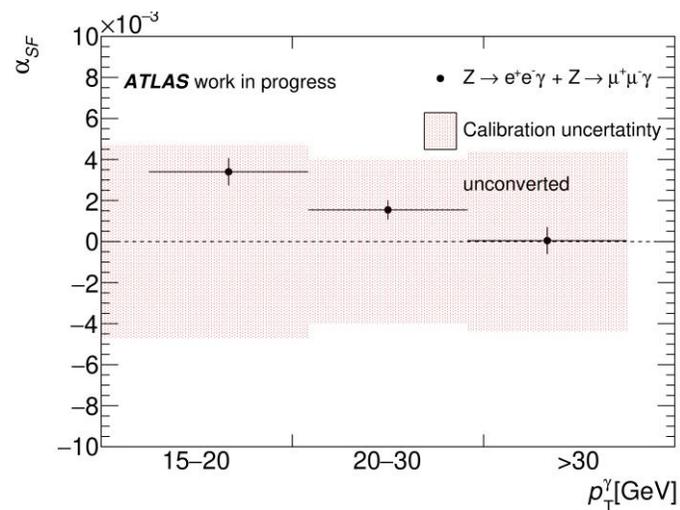
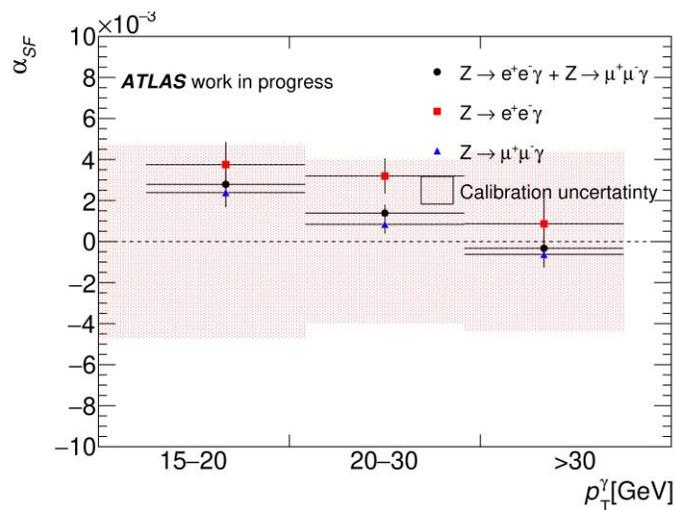
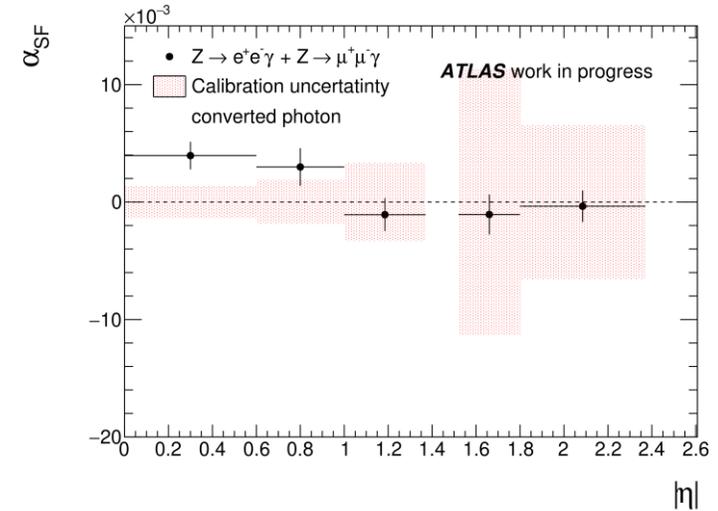
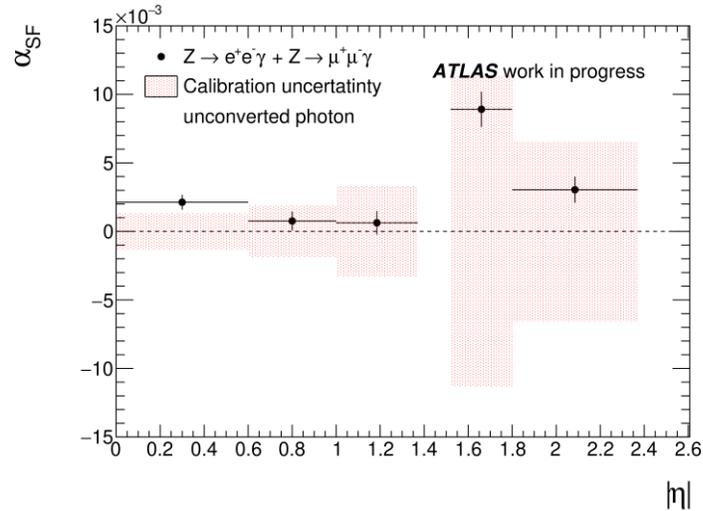
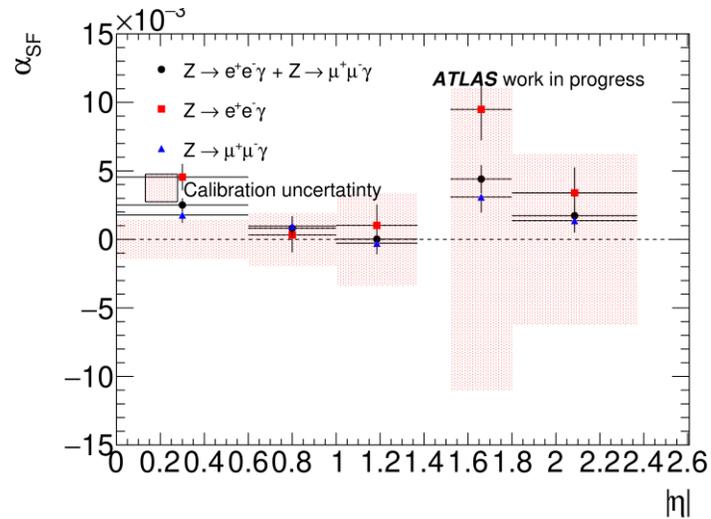


$\chi^2/ndof=1.01$

# $Z \rightarrow ll\gamma$ : Differential photon energy scale factor

## ➤ Differential photon energy scale factor

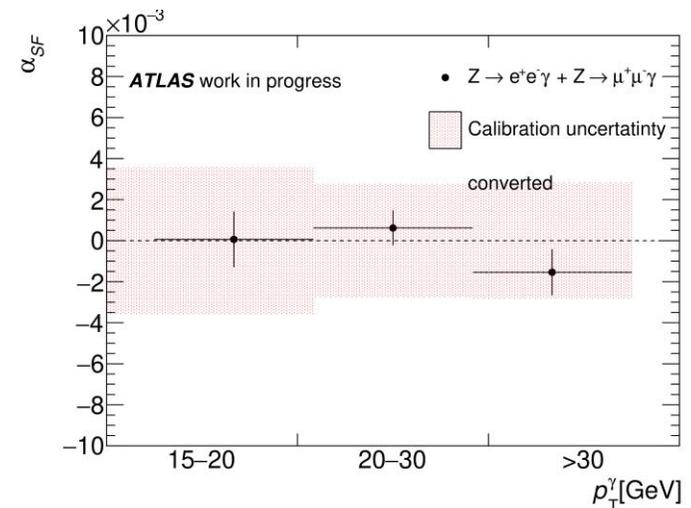
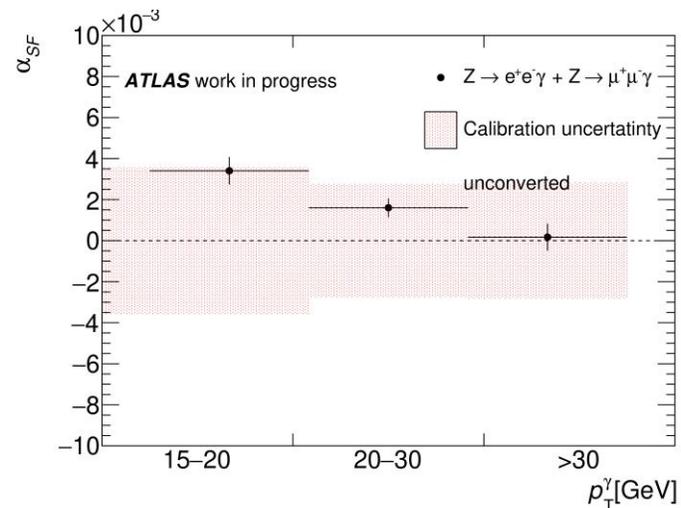
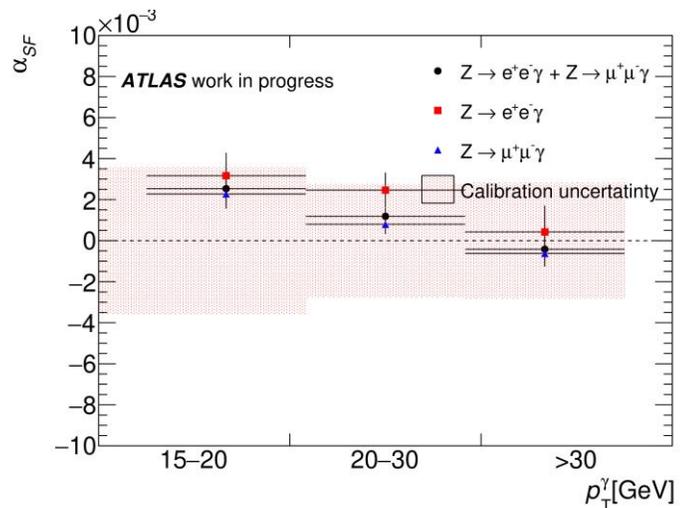
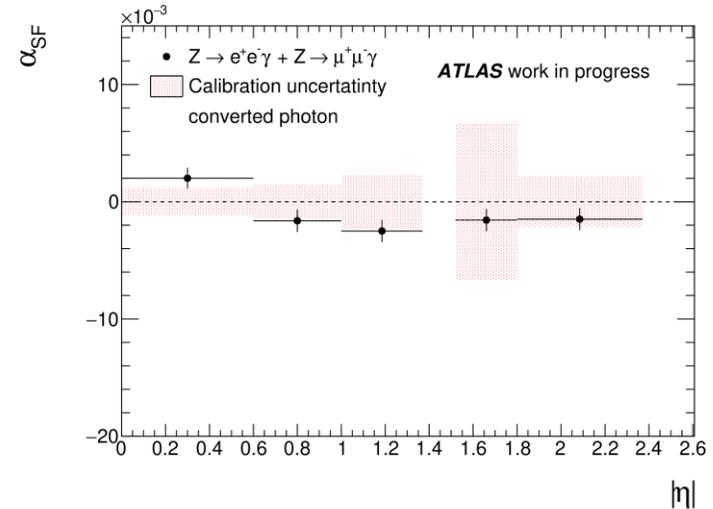
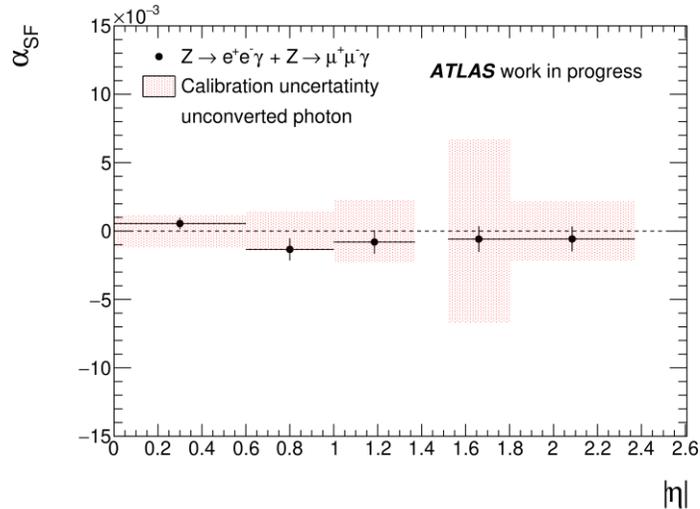
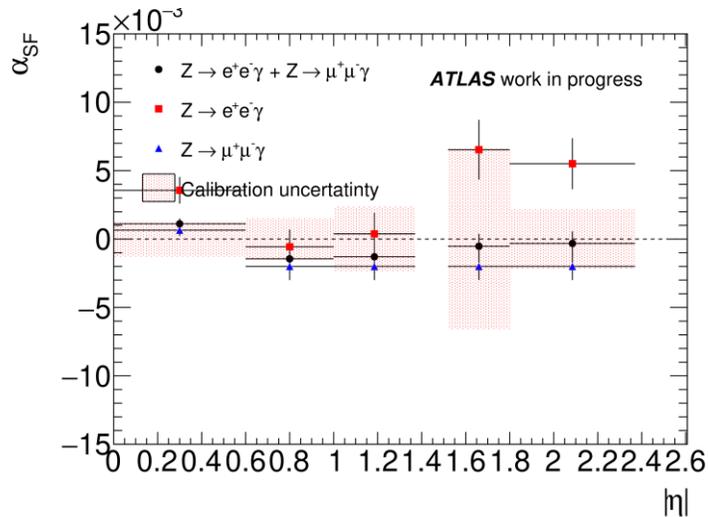
without  
Linearity  
correction



# $Z \rightarrow ll\gamma$ : Differential photon energy scale factor

## ➤ Differential photon energy scale factor

with  
Linearity  
correction



# $J/\psi \rightarrow \gamma K_S^0 K_S^0 \eta'$ 分析

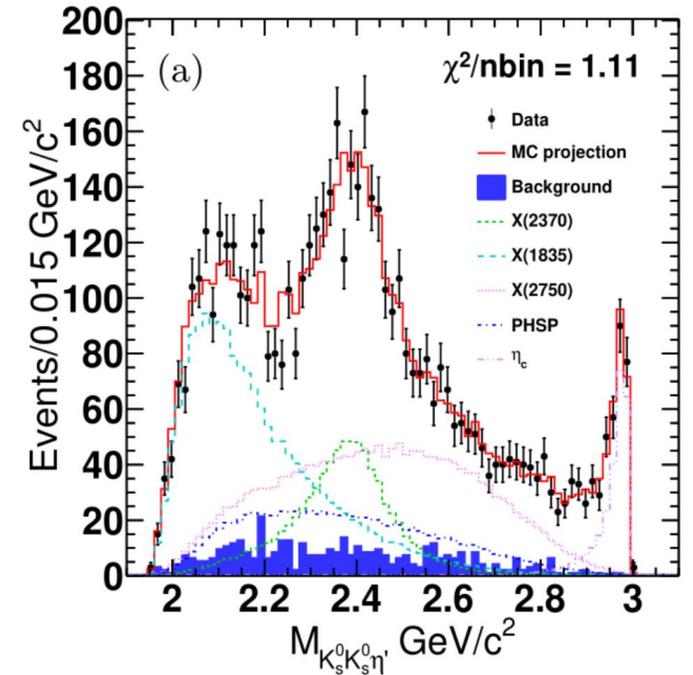
## ➤ 目前的分波解

state	$J^{PC}$	Decay mode	Mass ( $MeV/c^2$ )	Width ( $MeV/c^2$ )	Significance
X(2370)	$0^{-+}$	$f_0(980)\eta'$	$2395^{+11}_{-11}$	$188^{+18}_{-17}$	$14.9\sigma$
X(1835)	$0^{-+}$	$f_0(980)\eta'$	1844	192	$> 20\sigma$
X(2750)	$0^{-+}$	$f_0(980)\eta'$	$2799^{+52}_{-48}$	$660^{+180}_{-116}$	$16.4\sigma$
$\eta_c$	$0^{-+}$	$f_0(980)\eta'$	2983.9	32.0	$> 20.0\sigma$
PHSP	$0^{-+}$	$\eta'(K_S^0 K_S^0)_{S-wave}$	---	---	$9.0\sigma$
		$\eta'(K_S^0 K_S^0)_{D-wave}$	---	---	$16.3\sigma$

## ➤ X(2370)的测量结果

- $J^{PC} = 0^{-+}$
- Mass =  $2395^{+11}_{-11}(\text{stat.})^{+11}_{-15}(\text{syst.}) MeV/c^2$ , Width =  $188^{+18}_{-17}(\text{stat.})^{+12}_{-21}(\text{syst.}) MeV/c^2$
- $B[J/\psi \rightarrow \gamma X(2370)] * B[X(2370) \rightarrow f_0(980)\eta'] * B[f_0(980) \rightarrow K_S^0 K_S^0] = 1.32 \pm 0.22(\text{stat.})^{+0.31}_{-0.25}(\text{syst.}) \times 10^{-5}$

Projection of combined channel:  
 $\eta' \rightarrow \pi^+ \pi^- \eta$  and  $\eta' \rightarrow \gamma \rho^0$



# Diphoton vertex

## ➤ Categorization and training variables

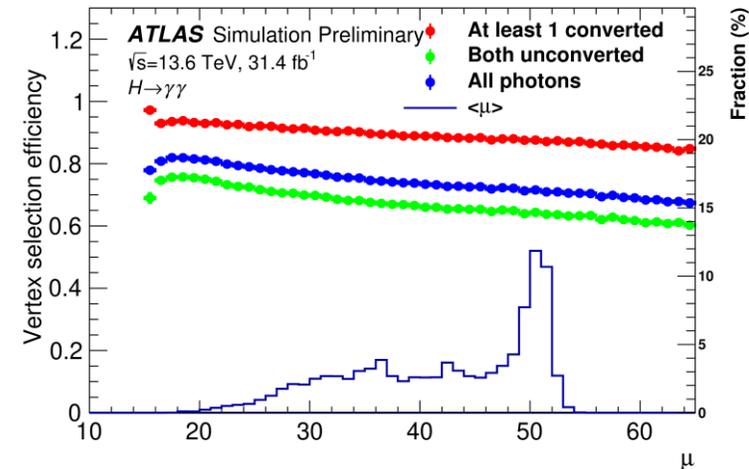
The events are categorized into 3 cases by following algorithm:

- Case1: At least one photon converting into  $e^+e^-$  pairs and leading to tracks that are associated to a reconstructed primary vertex. (The fraction of such events in the total events is 6%)
- Case2: At least one converted photon with tracks containing hits in the silicon detectors. (26%)
- Case3: Both photons unconverted or associated to tracks containing only hits in the TRT. (68%)

## ➤ NN selection:

### • Variables:

- ✓  $(Z_{common} - Z_{vertex})/\sigma_Z$ , where  $Z_{vertex}$  is the position of the primary vertex;  $\sigma_Z$  is the associated error.
- ✓  $\Delta\phi(\gamma\gamma, vertex)$ , the azimuthal angle between the diphoton system and system defined by the vector sum of the tracks associated to the vertex.
- ✓  $\log(\Sigma p_T)$ , the scalar sum of transverse momenta of the tracks associated to the vertex.
- ✓  $\log(\Sigma p_T^2)$ , idem with  $p_T^2$  instead of  $p_T$



# Diphoton vertex selection efficiency

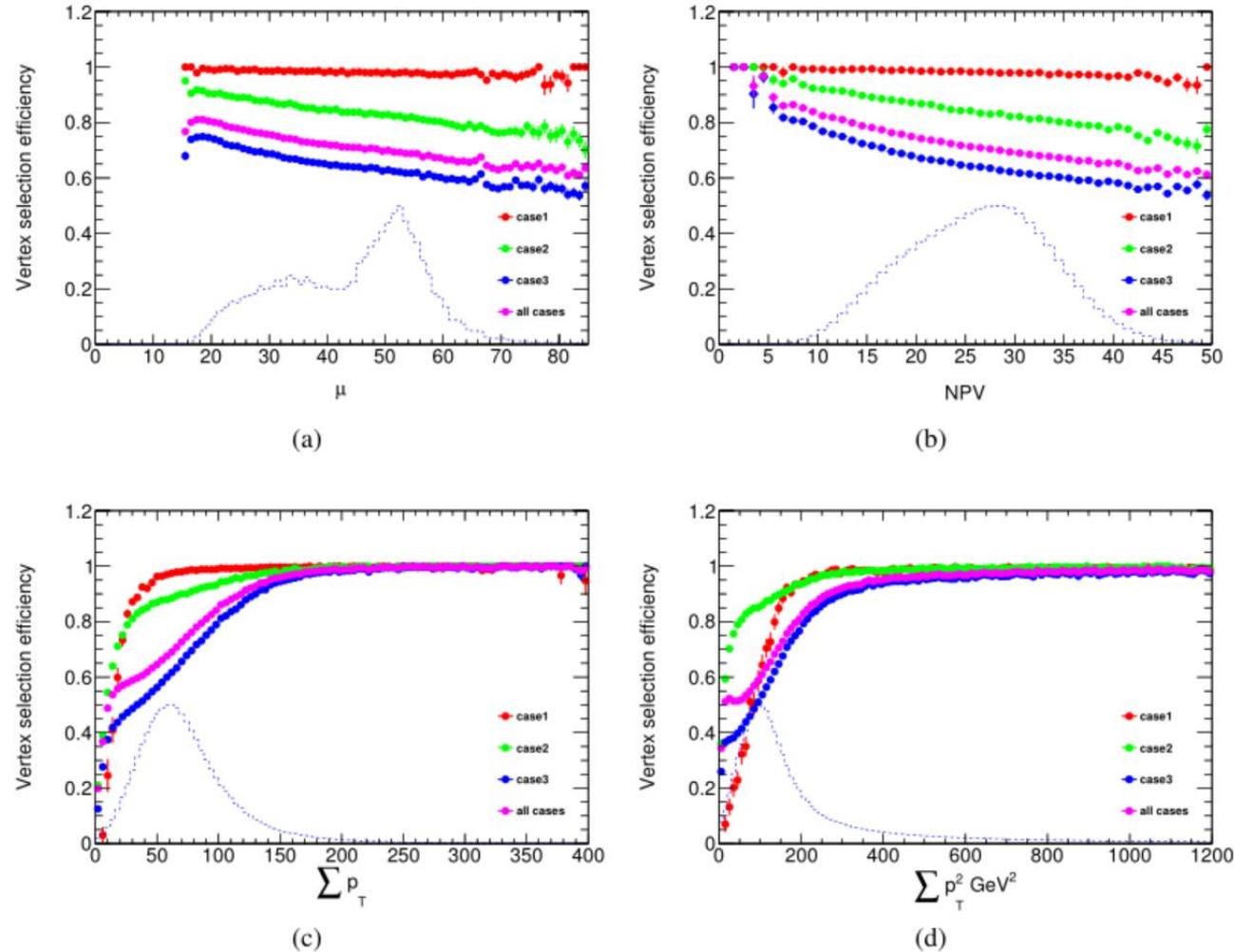


Figure 3.1: Efficiencies for selecting the correct primary vertex as a function of (a) pile-up, (b) number of primary vertices, (c) the  $\sum p_T$  and (d)  $\sum p_T^2$  when considering neural network algorithm. In each plot, the dashed blue histogram shows the distribution of the variable. Case1/2/3 are defined in the text.

# Ranking plots

- Largest systematic uncertainty is spurious signal
- Photon ID uncertainty is second largest uncertainty
  - Photon ID uncertainty significantly larger in Run 3, expected from EGamma pre-recommendations

SM cross-section [prediction](#) (theory):

- $\sigma_{fid}(pp \rightarrow H \rightarrow \gamma\gamma) = 67.5 \pm 3.4 \text{ fb}$
- $\sigma(pp \rightarrow H) = 59.8 \pm 2.6 \text{ pb}$

