

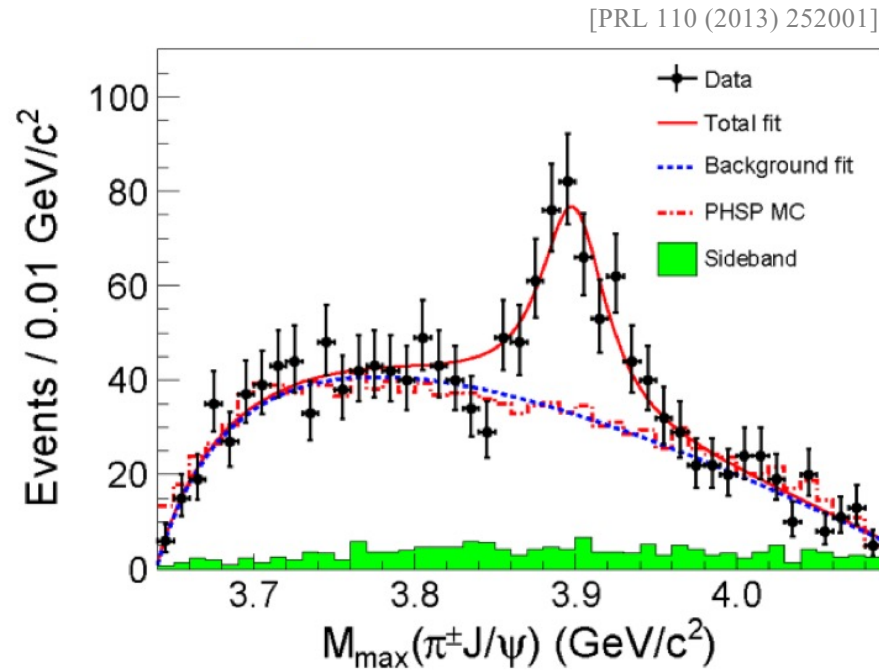
Search for the $Y(2175)$ in photoproduction at GlueX

Klaus Götzen and **Frank Nerling**
GSI Darmstadt, HFHF & GU Frankfurt
on behalf of the GlueX Collaboration

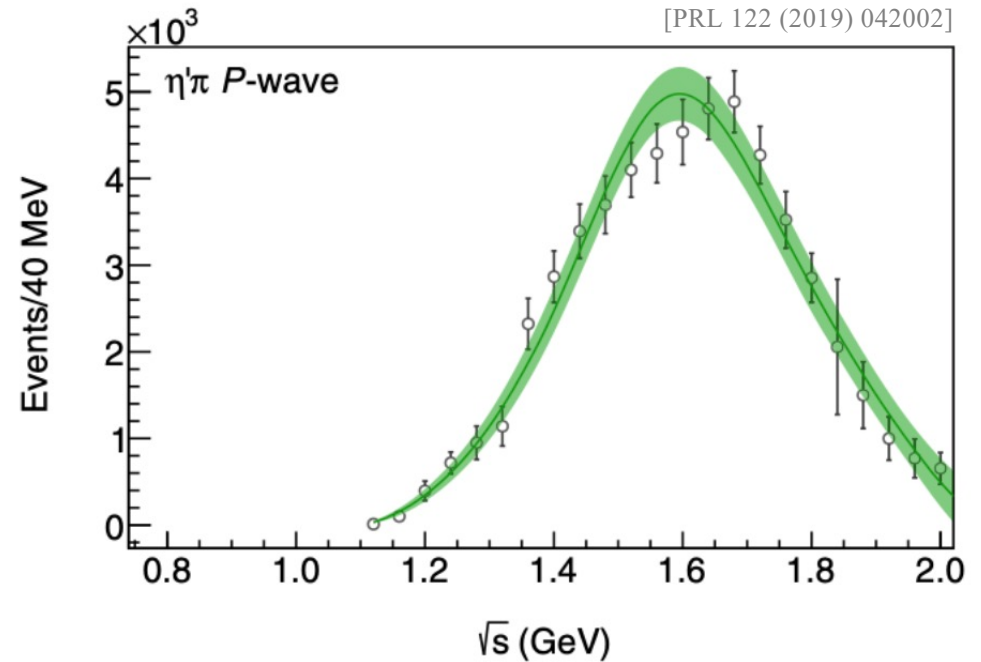
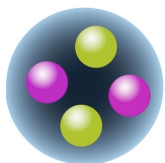
17th Intern. Workshop on Meson Physics – MESON2023,
June 22nd - June 27th 2023, KRAKÓW, Poland

Outline

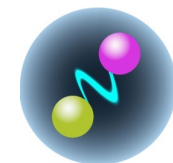
- **Introduction & motivation**
- **The GlueX experiment at JLab**
- **Analysis of $\gamma p \rightarrow \phi \pi^+ \pi^- p$**
 - Measurement of differential cross section
 - Search for $Y(2175)$
- **Summary**

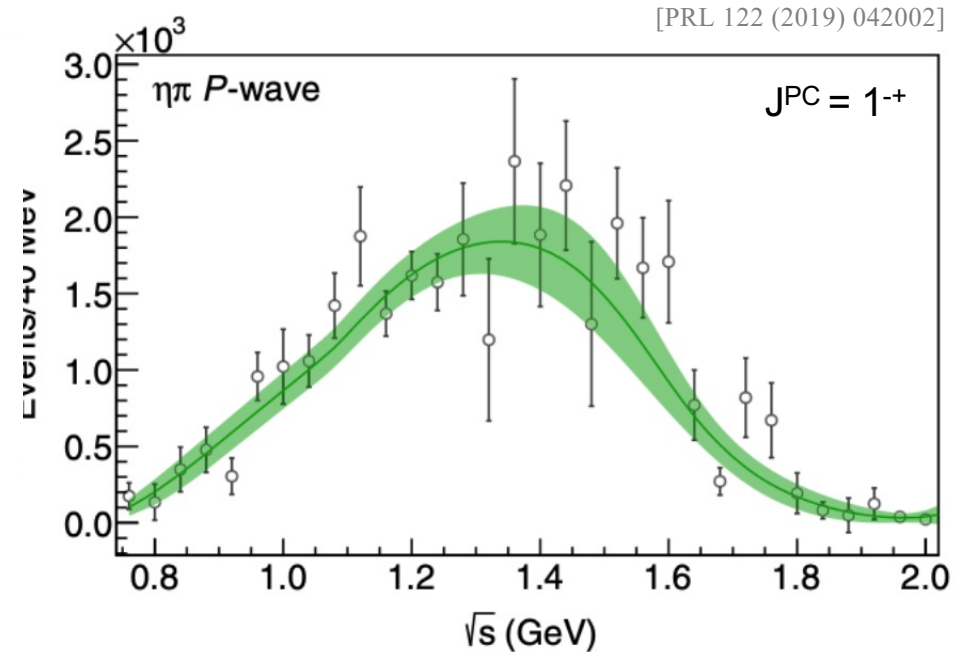
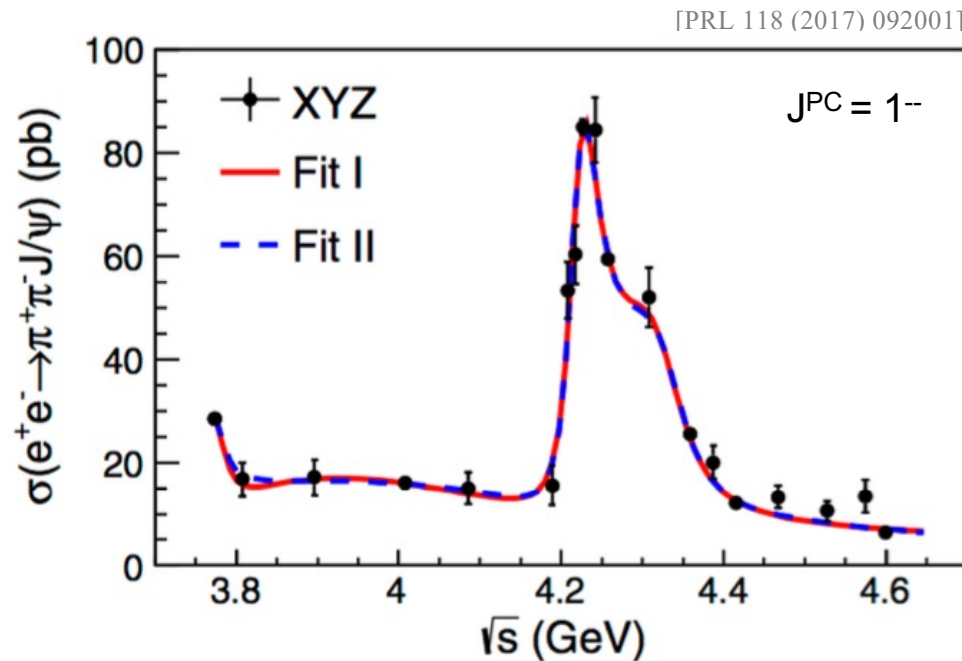


$$Z_c(3900)^{+/-} \rightarrow J/\psi \pi^{+/-}$$



$$\pi_1(1600) \rightarrow \eta'\pi$$



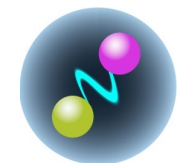
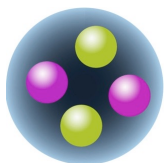


$Z_c(3900)^{+/-} \rightarrow J/\psi \pi^{+/-}$

$Y(4230) \rightarrow J/\psi \pi^+ \pi^-$

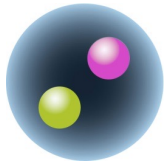
$\pi_1(1600) \rightarrow \eta' \pi$

$\pi_1(1400) = \pi_1(1600) \rightarrow \eta \pi$



Simple Quark model

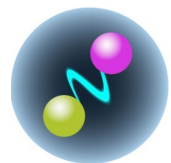
- Mesons: Color neutral $q\bar{q}$ systems



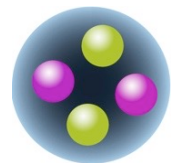
Conventional ($q\bar{q}$)

QCD

- Meson states beyond $q\bar{q}$



Hybrid ($q\bar{q}$) g

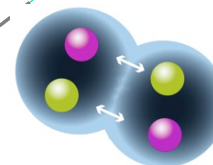


Tetraquark ($q\bar{q}q\bar{q}$)

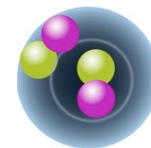


Glue-ball (gg) or (ggg)

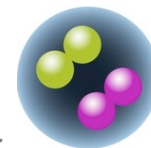
Alternative 4-quark configurations:



Molecule ($q\bar{q}$)($q\bar{q}$)

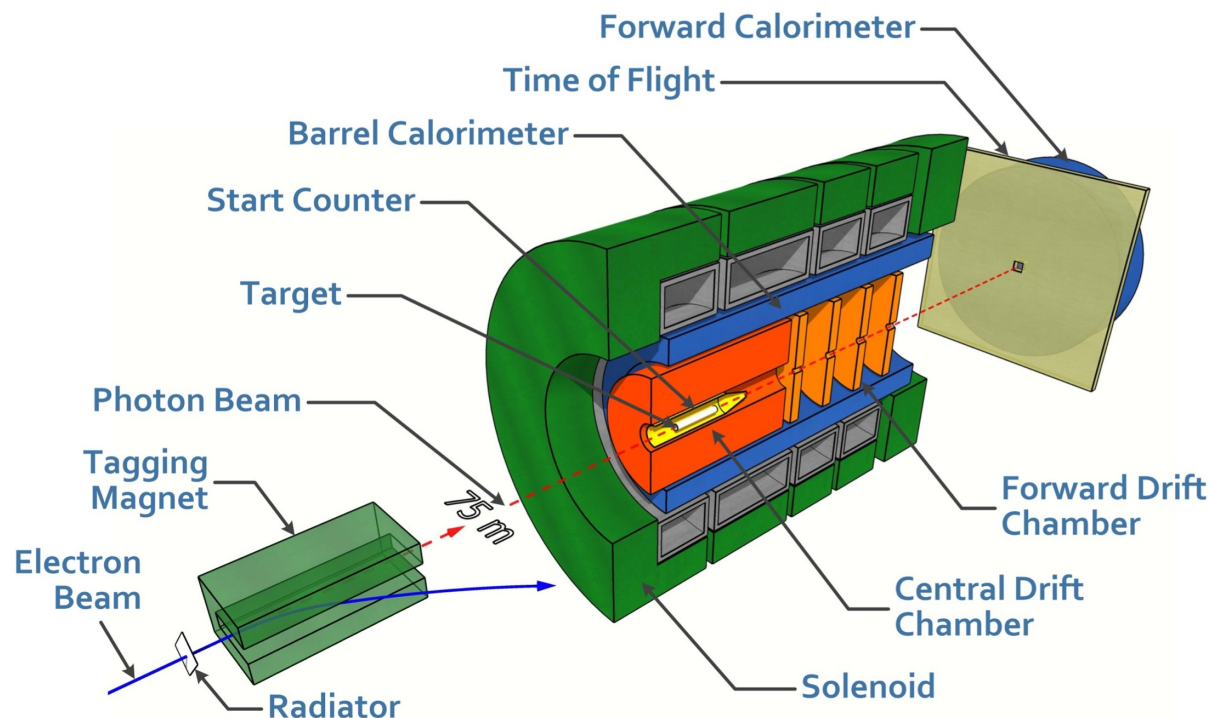
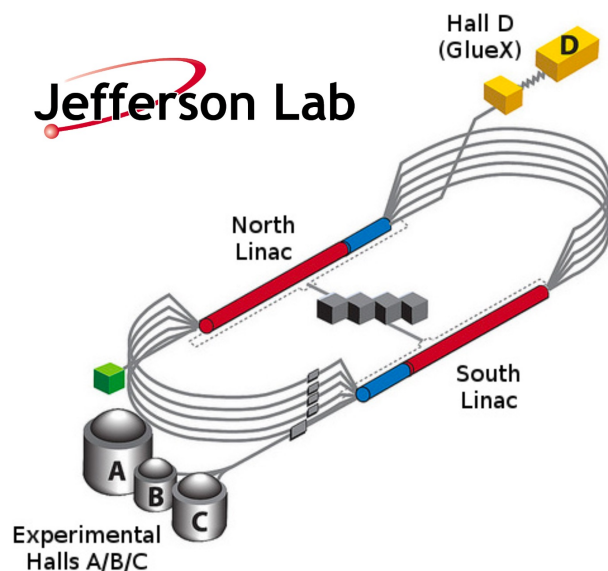


Hadro-quarkonium ($Q\bar{Q}$)($q\bar{q}$)

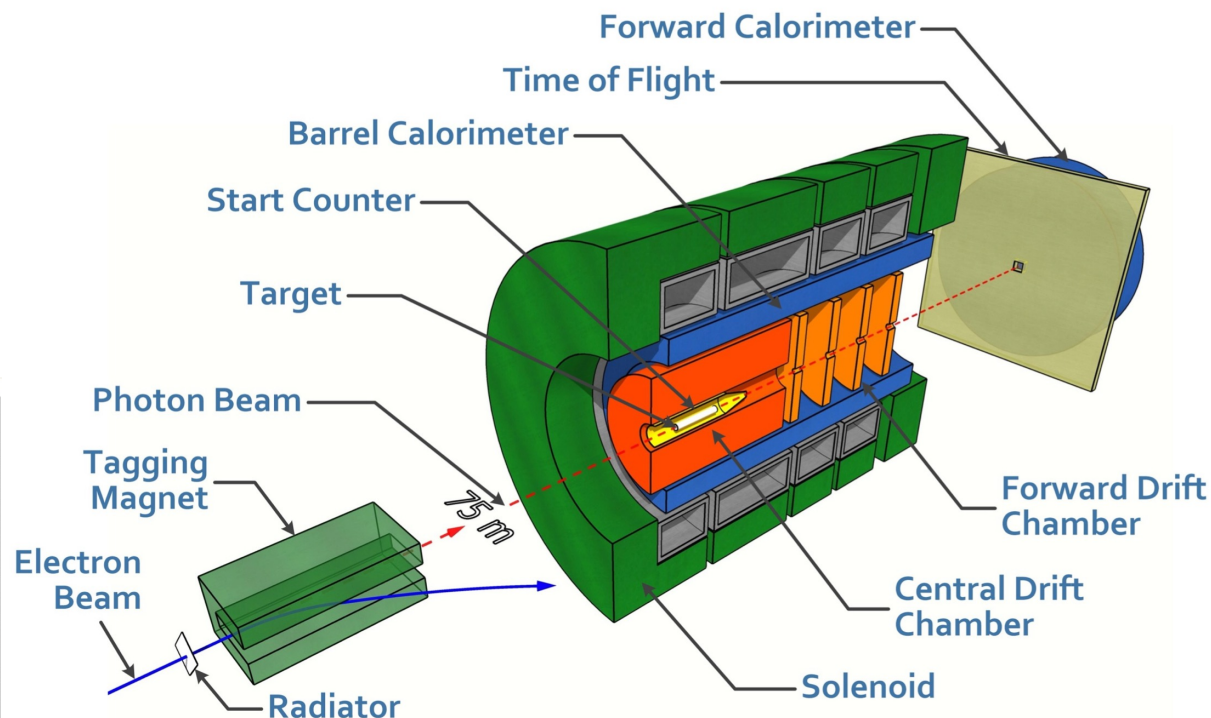
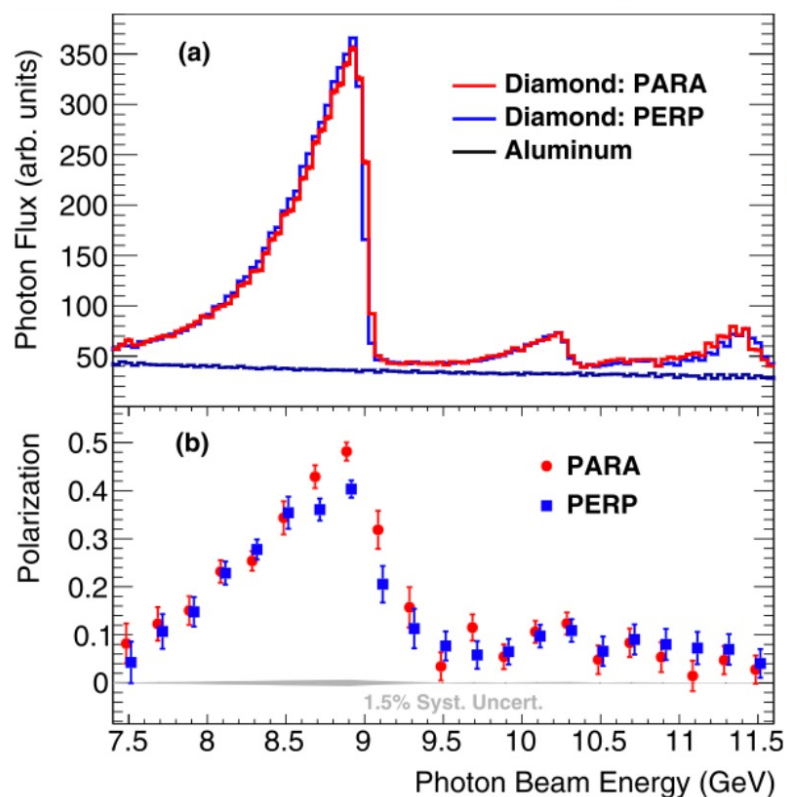
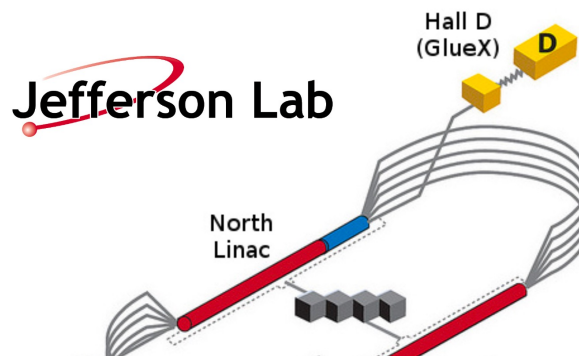


Di-quarkonium (qq)($\bar{q}\bar{q}$)

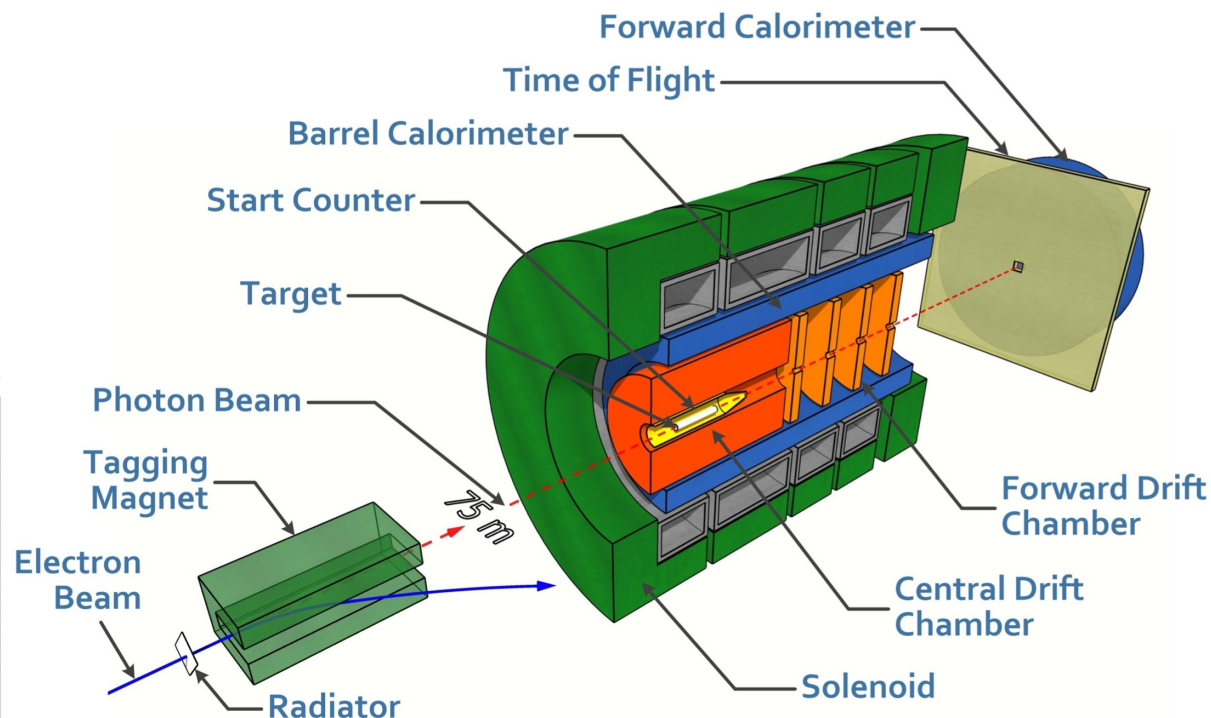
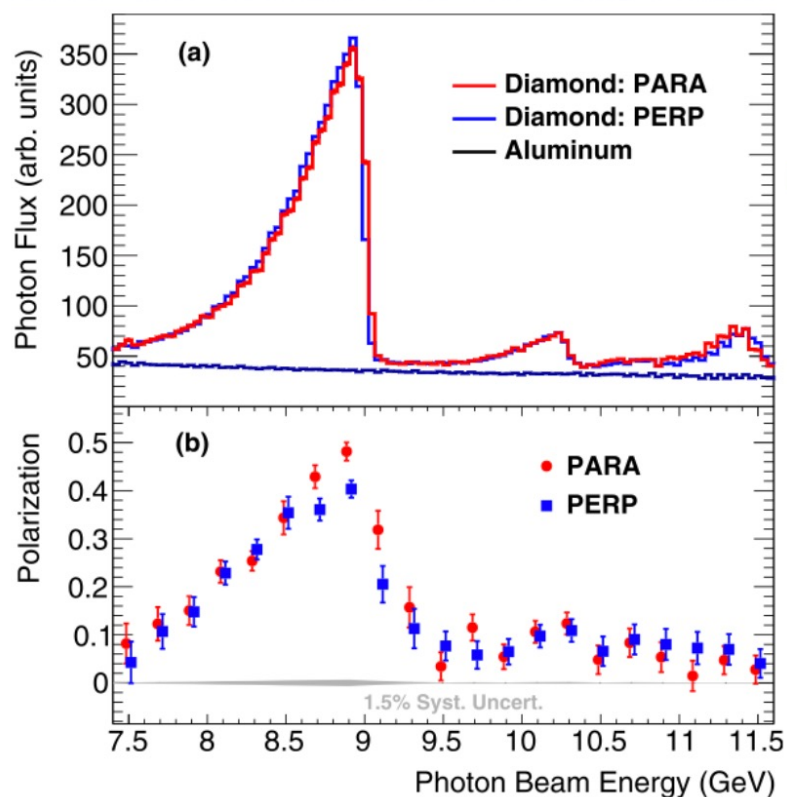
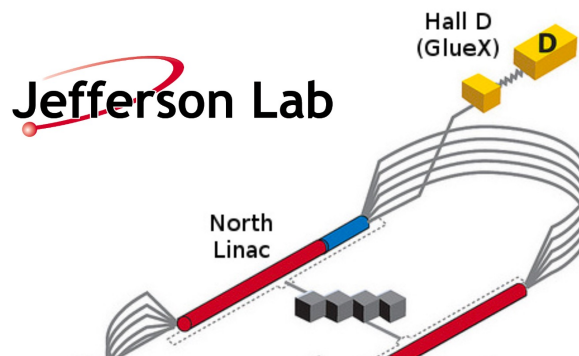




- 12 GeV electron beam from CEBAF accelerator
- Coherent Bremsstrahlung on diamond radiator
- Linear polarization in peak at ~9 GeV: $P_\gamma \sim 40\%$
- Energy tagged by scattered electrons
- Beam intensity: $1 - 5 \cdot 10^7$ γ/s in peak



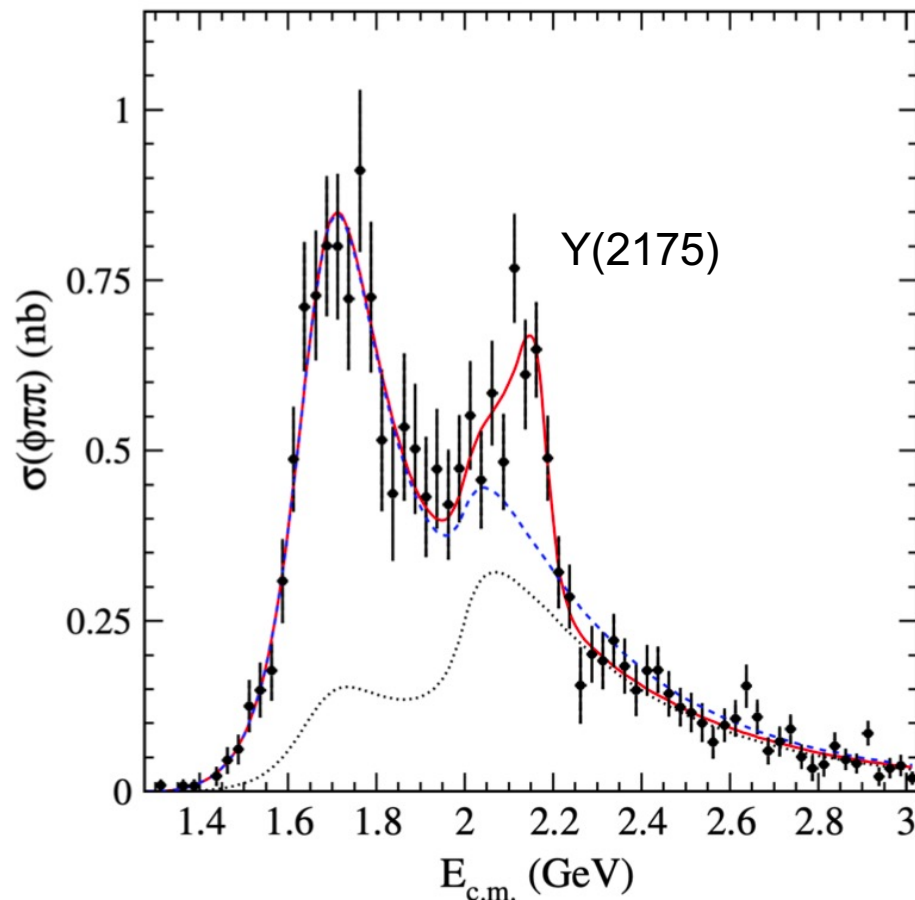
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- Coherent Bremsstrahlung on diamond radiator
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- Beam intensity: $1 - 5 \cdot 10^7$ γ/s in peak



- See GlueX plenary talk by M. Sheppard
- → more details & results

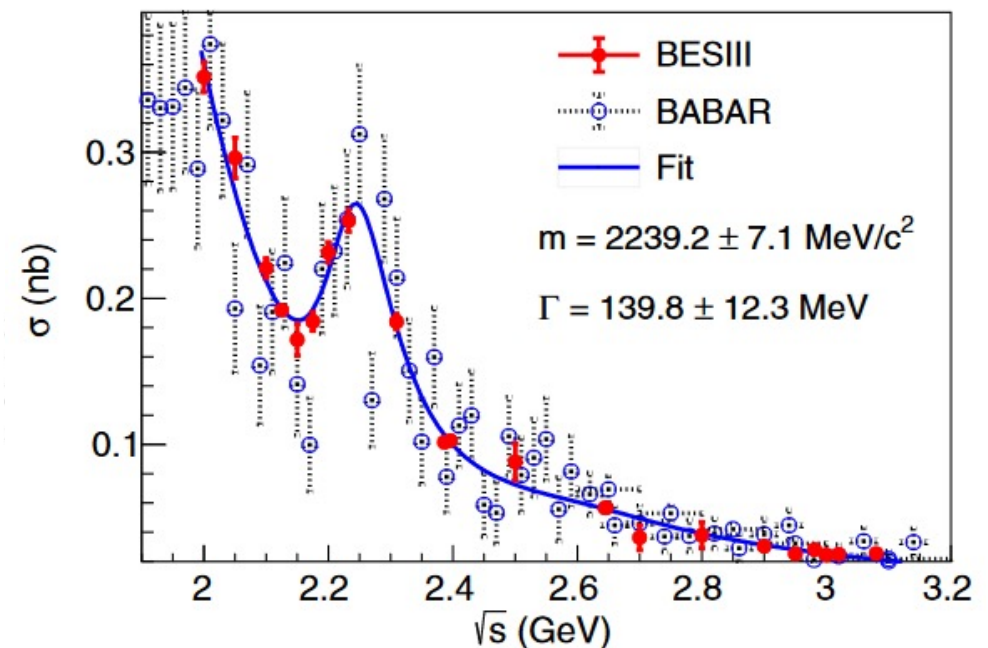
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[Phys. Rev. D. 74 (2006) 091103]



First observed in ISR, BaBar

[Phys. Rev. D 99, (2019) 032001]

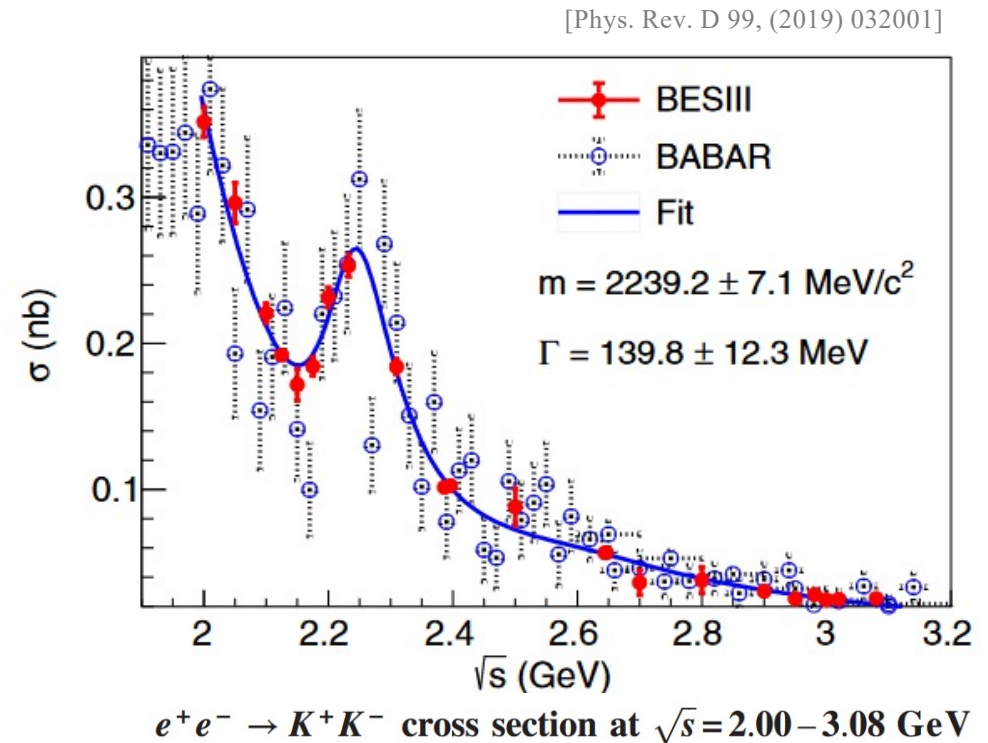
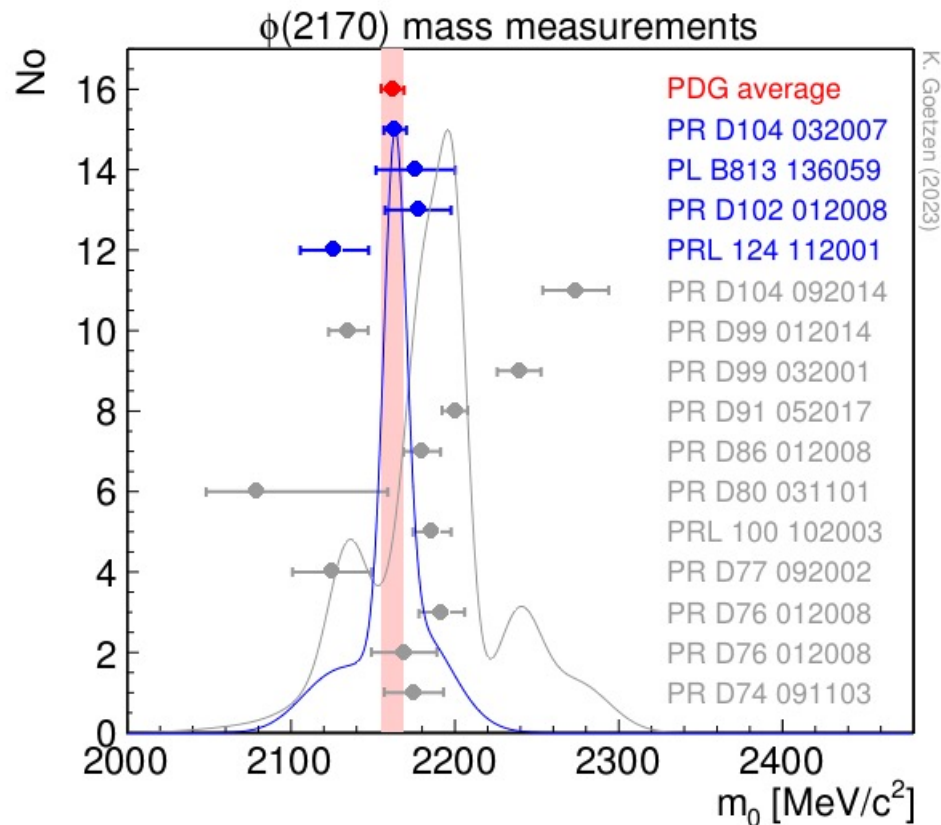


$e^+e^- \rightarrow K^+K^-$ cross section at $\sqrt{s} = 2.00 - 3.08$ GeV

$$M = 2239.2 \pm 7.1 \pm 11.3 \text{ MeV}/c^2$$

$$\Gamma = 139.8 \pm 12.3 \pm 20.6 \text{ MeV}$$

PDG: Larger spread in individual resonance parameter measurements, e.g. above

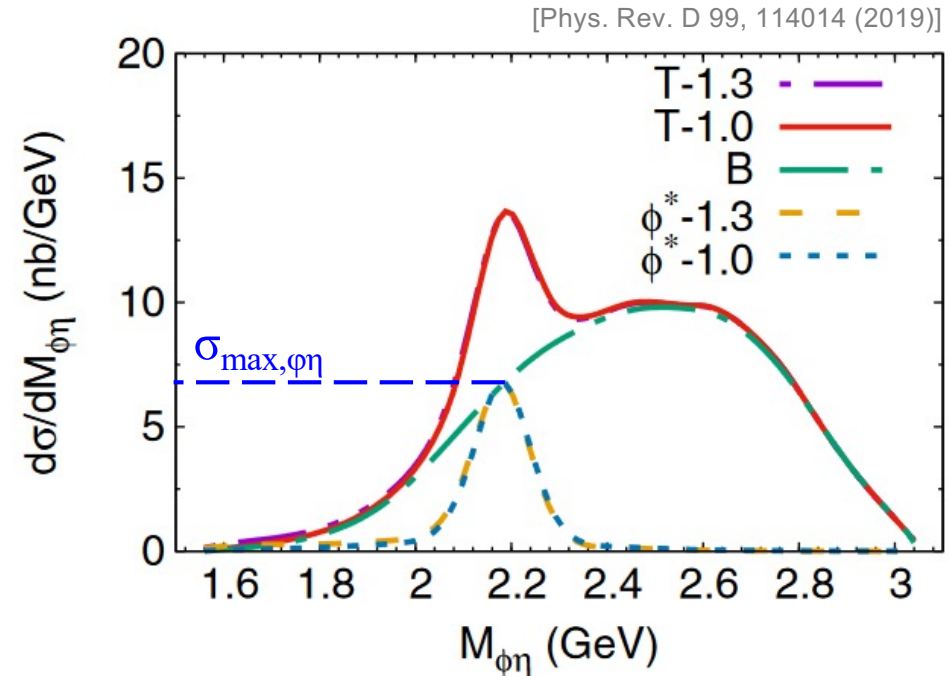
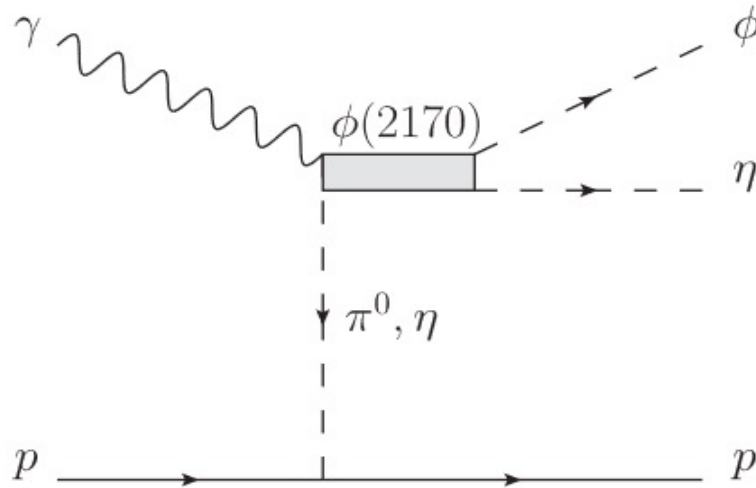


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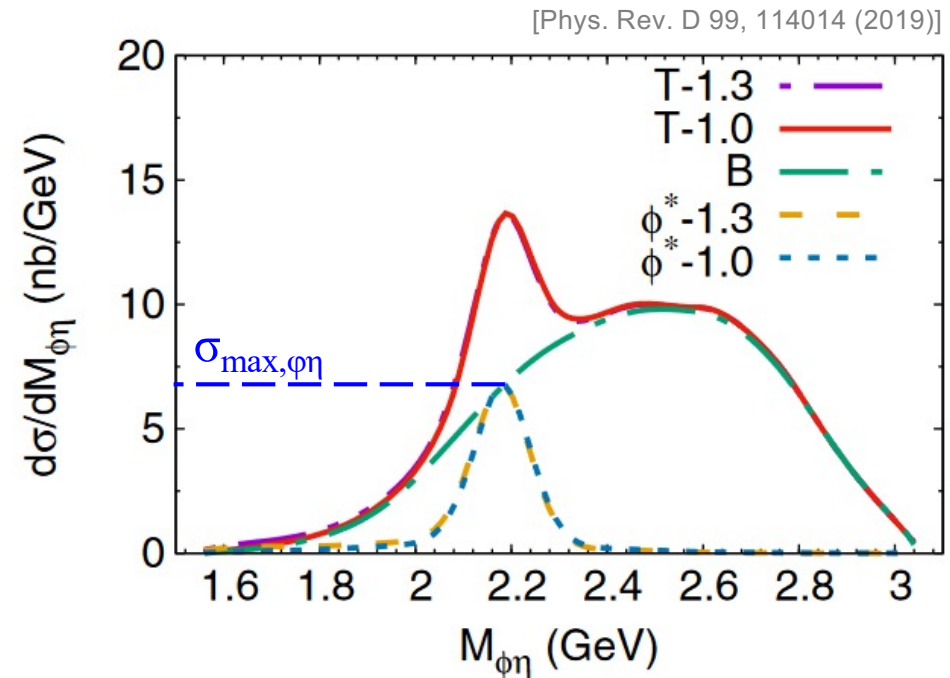
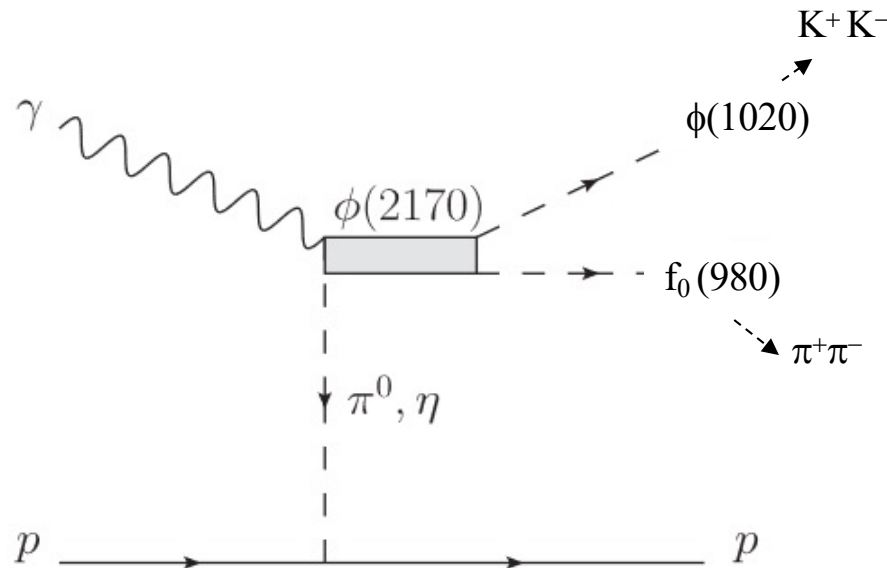
PDG: Larger spread in individual resonance parameter measurements, e.g. above

Prediction for photoproduction



- Investigation of reaction $\gamma p \rightarrow \phi \eta p$ @ $E_\gamma = 8$ GeV
- Assumption: $\Gamma(Y(2175) \rightarrow \phi \eta) \approx 6.6$ MeV (quark model)
- Peak integral: $\sigma_{\phi\eta} \approx 885$ pb (with $\sigma_{\max} \approx 7$ nb, $\Gamma = 83$ MeV/c²)

Study $\phi\pi\pi$ photoproduction



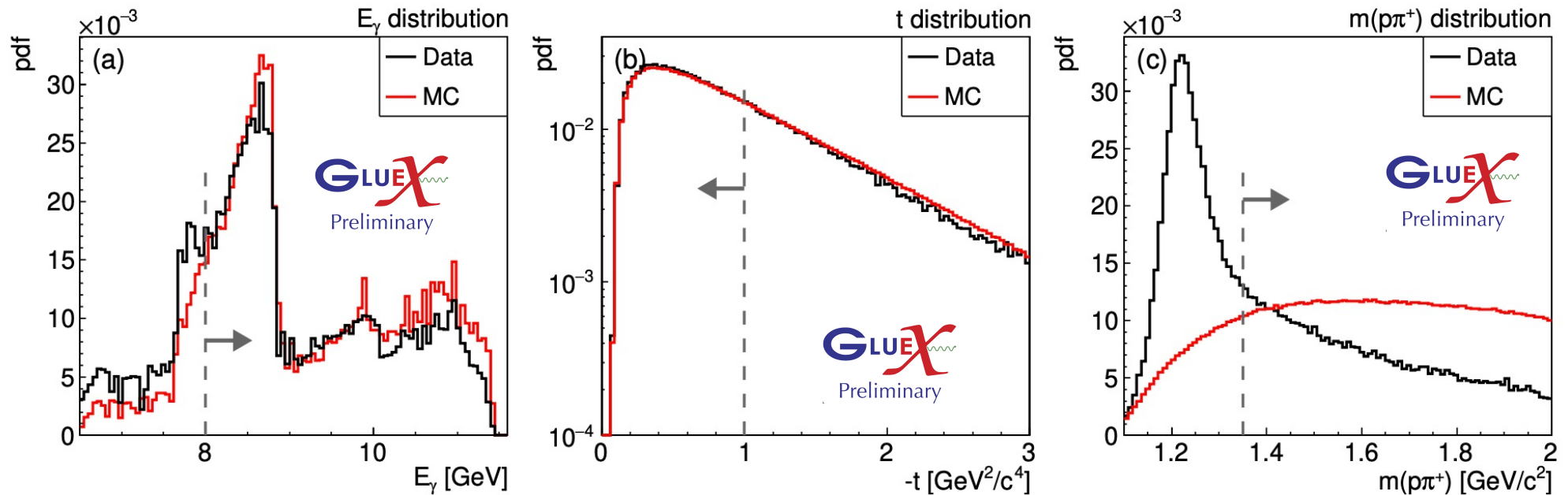
- Investigation of reaction $\gamma p \rightarrow \phi\eta p$ @ $E_\gamma = 8$ GeV
- Assumption: $\Gamma(Y(2175) \rightarrow \phi\eta) \approx 6.6$ MeV (quark model)
- Peak integral: $\sigma_{\phi\eta} \approx 885$ pb (with $\sigma_{\max} \approx 7$ nb, $\Gamma = 83$ MeV/c²)
- $\Gamma(Y(2175) \rightarrow \phi f_0(980) / \Gamma(Y(2175) \rightarrow \phi\eta)) \approx 1.37$
 - For $Y(2175) \rightarrow \phi f_0(980)$: $\sigma_{\phi f_0} \approx 1212$ pb

Timeline	$\int \mathcal{L}$ (pb ⁻¹)
2017	22
2018	103
2020	132
2023	
2024	

- I)
 - Apply loose PID selection (dE/dx, ToF)
 - Form $\gamma K^+K^-\pi^+\pi^- p$ candidates
 - Perform 4C of $K^+K^-\pi^+\pi^- p$ to γp_{target} system together with
 - Vertex fit of $K^+K^-\pi^+\pi^- p$ system

} event candidates
- II)
 - Apply beam energy cut $E_\gamma > 8 \text{ GeV}$
 - Apply momentum transfer cut $-t < 1 \text{ GeV}^2/c^4$ (fiducial)
 - Apply veto cut for $\Delta^{++}(1232): m > 1.35 \text{ GeV}/c^2$
 - Require $|MM^2| < 50 \text{ MeV}^2/c^4$ for missing mass squared
 - Require $\chi^2_{4C+vtx} < 70$

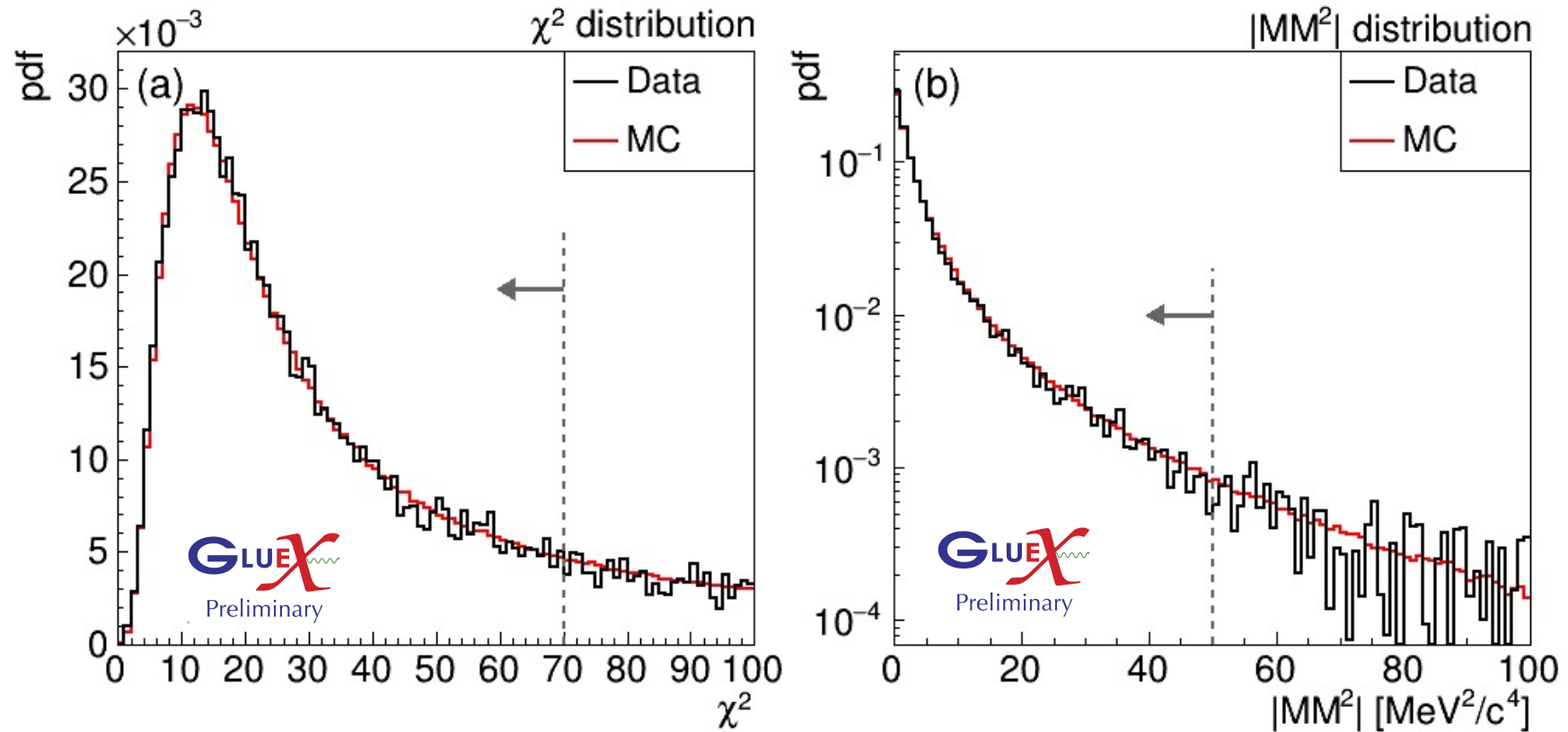
} event selection cuts
- III)
 - Determine $\phi(1020)$ yield using a Voigtian fctn.



- Photon energy:
 $E_\gamma > 8 \text{ GeV}$

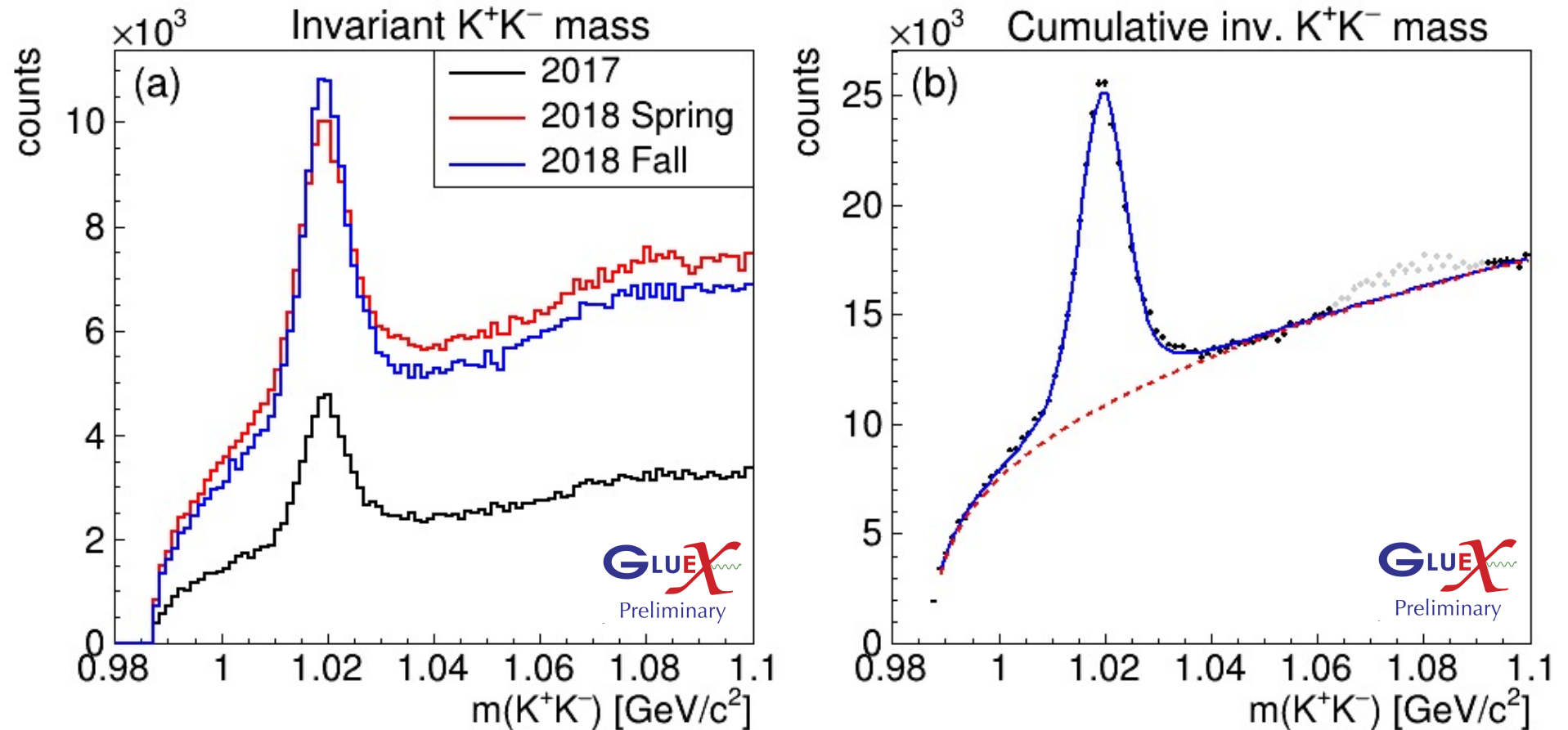
- Momentum transfer:
 $-t < 1 \text{ GeV}^2/c^4$

- Veto $\Delta(1232)^{++}$:
 $m(\pi^+\pi^-) > 1.35 \text{ GeV}/c^2$



- 4C and vertex fit quality:
 $\chi^2 < 70$ (ndf = 11)

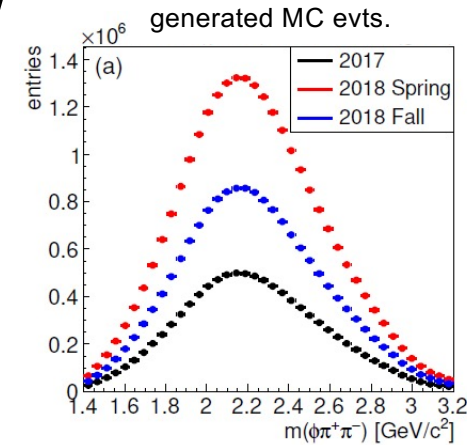
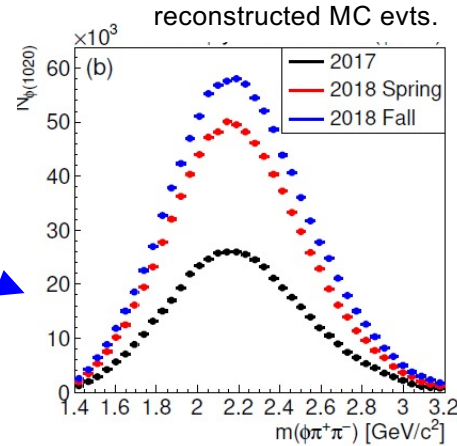
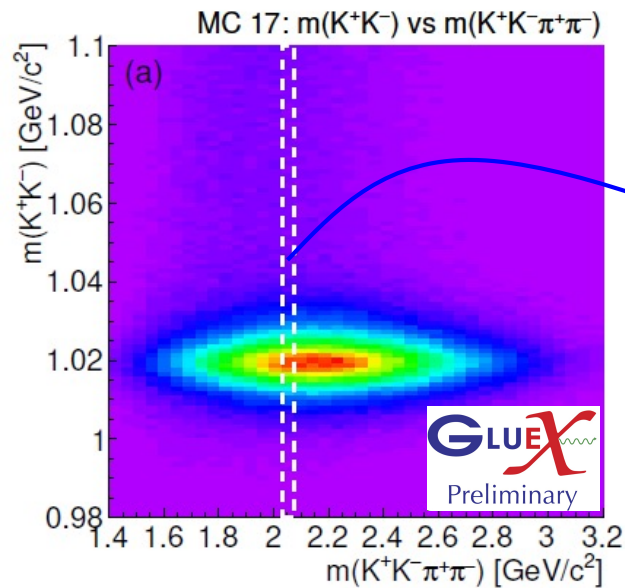
- Missing mass:
 $|MM^2| < 50 \text{ MeV}^2/c^4$



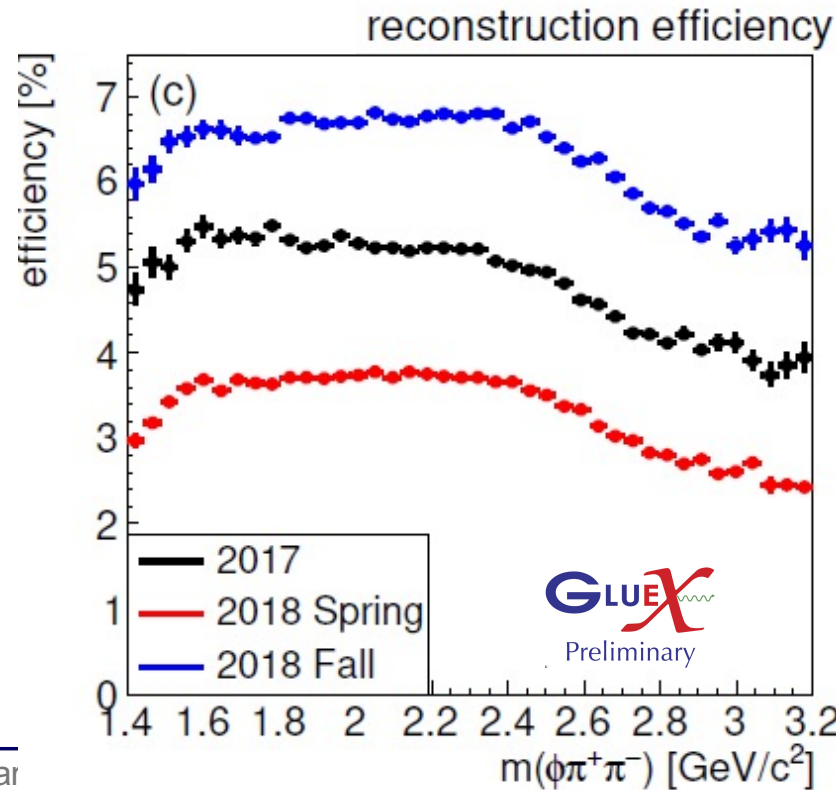
- Fit signal with function (V = Voigtian):

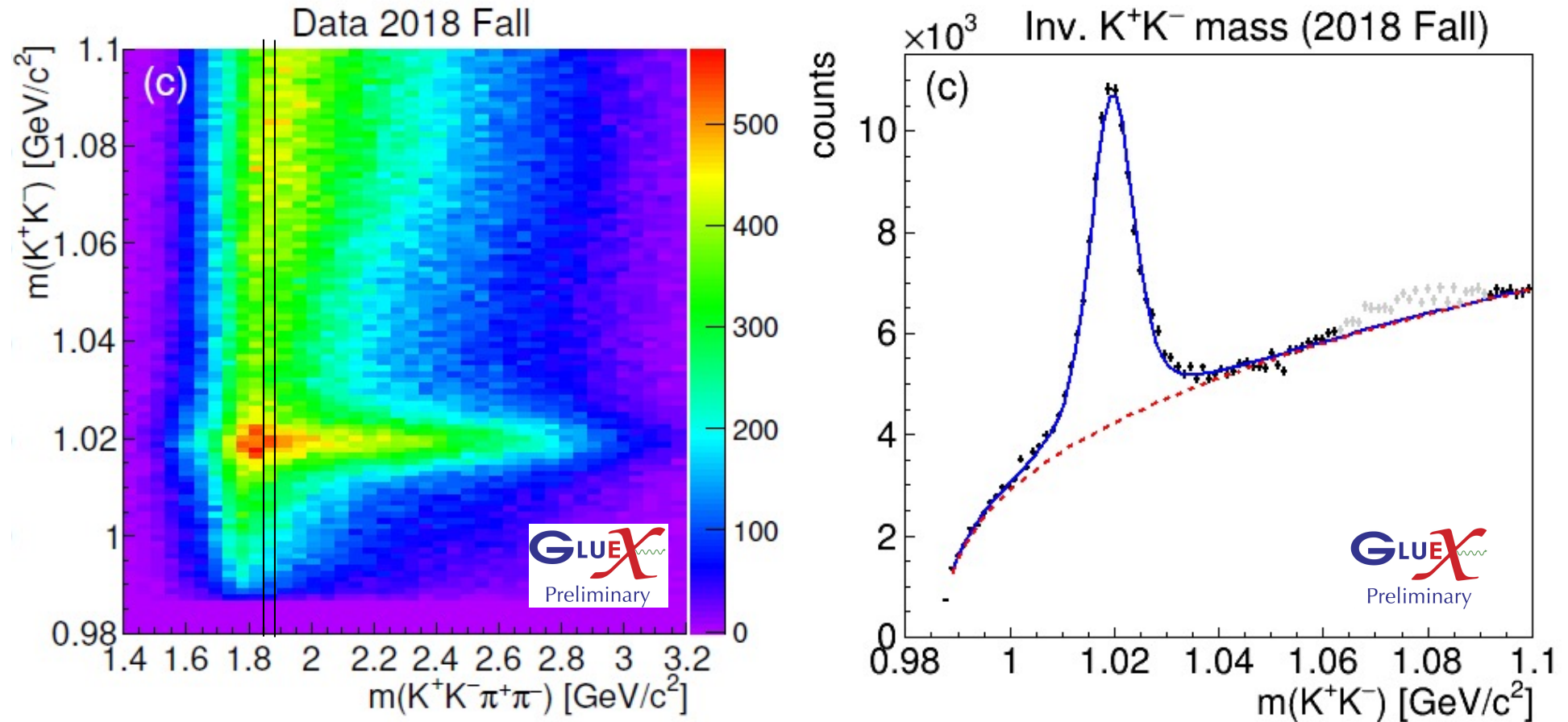
$$f(m) = V(m; m_0, \Gamma_0, \sigma_{\text{res}}) + |m - m_t|^p \cdot e^{-\lambda m} \quad \text{for } m > m_t,$$

- Fix ϕ -shape parameters to extract distributions slice-wise

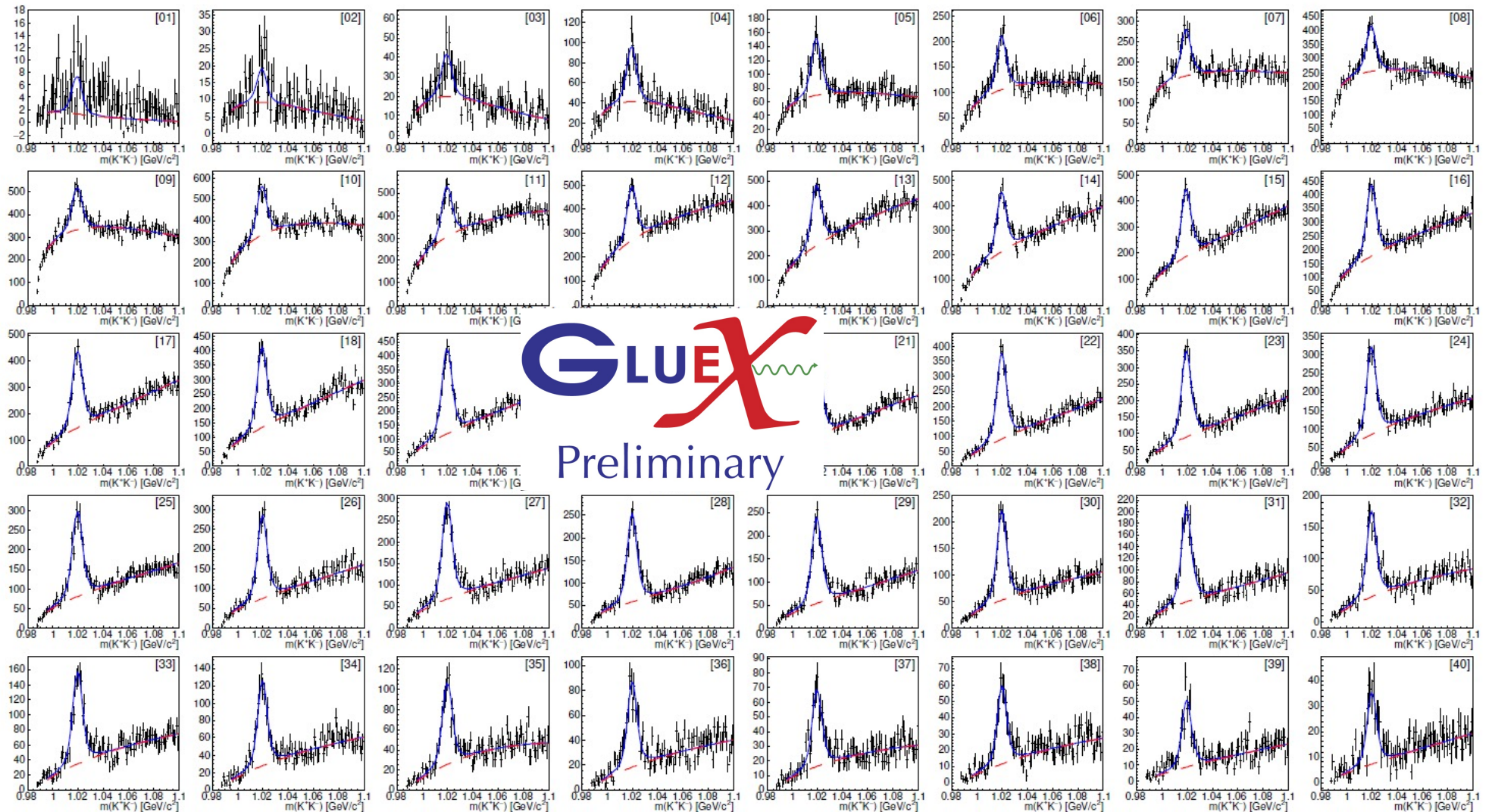


=>





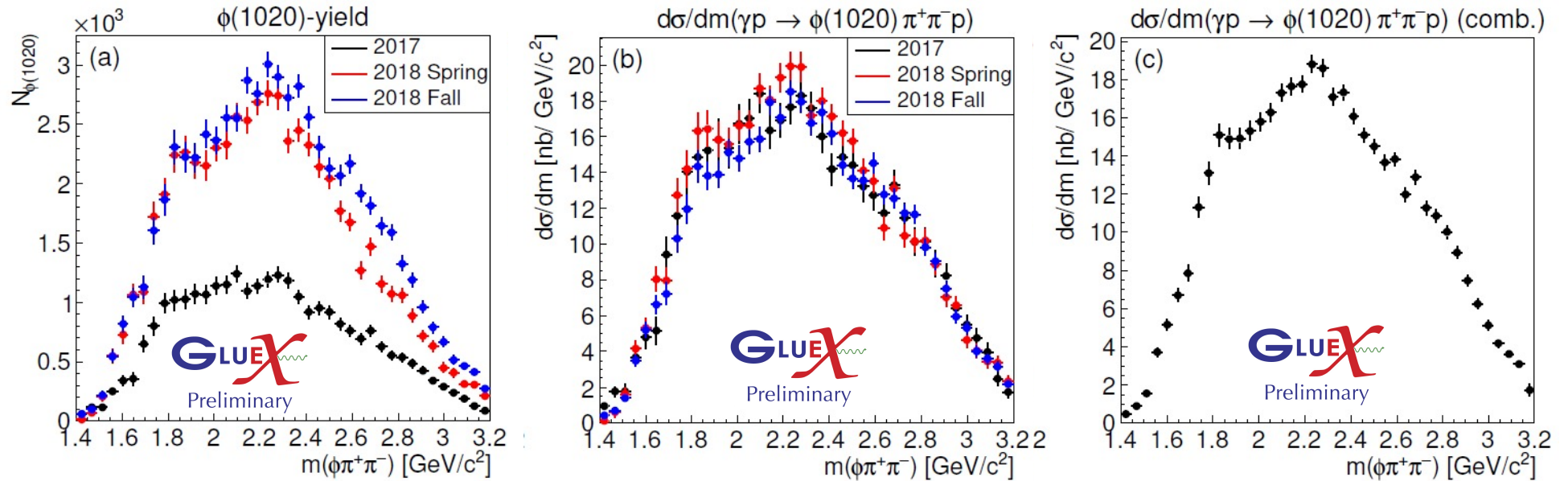
- Fit yields in **45 MeV slices** in 4-body mass with **fixed signal shape**
- Signal shape parameters m and σ_{res} determined from data (coarse scan)



- Single slice fits data (here for 2018 Fall)

- Determine mass-dependent cross section:

$$\frac{d\sigma}{dm}(m_i) = \frac{N_\phi(m_i)}{\varepsilon(m_i) \cdot F \cdot d_{\text{target}} \cdot \mathcal{B}(\phi(1020) \rightarrow K^+ K^-)}$$

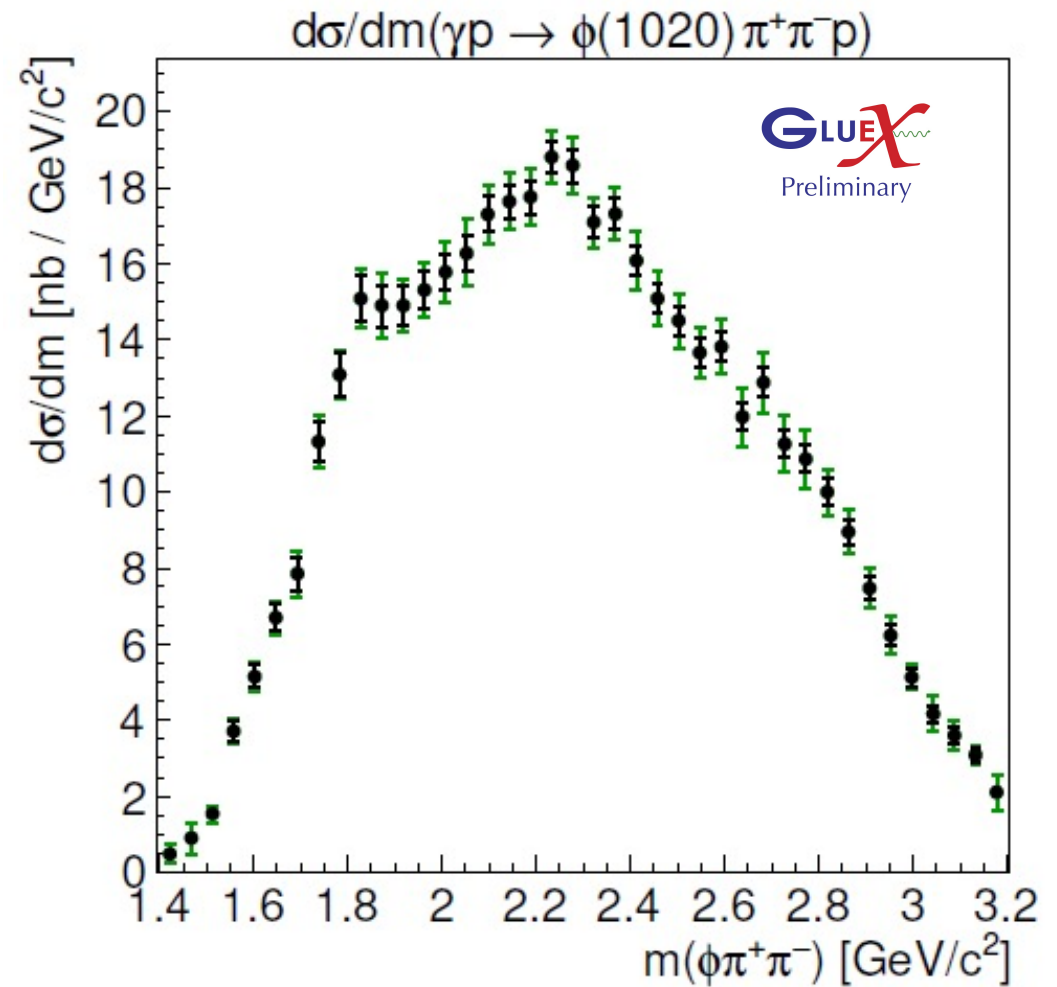


- Combine results by bin-wise via „weighted average“ method:

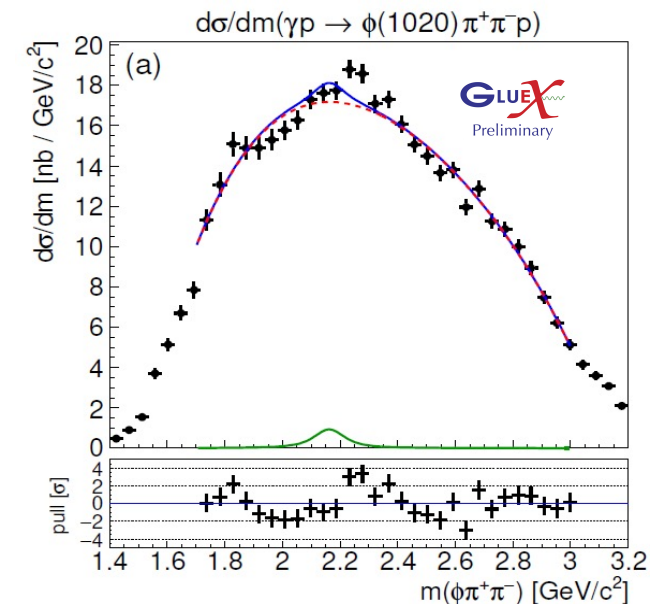
$$\hat{x} \pm \delta\hat{x} = \frac{\sum_i w_i x_i}{\sum_i w_i} \pm \left(\sum_i w_i^2 \right)^{-1/2} \quad \text{with } w_i = 1/\delta x_i^2$$

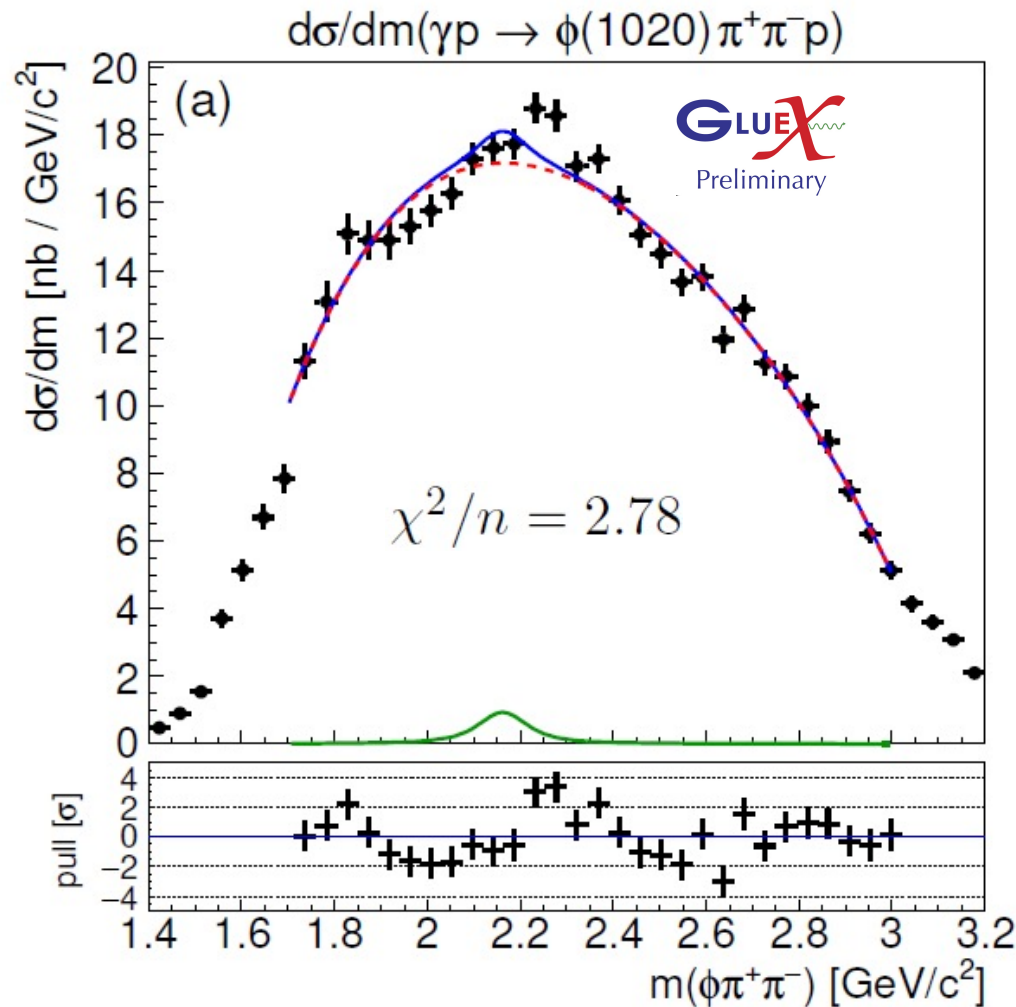
=> Take differences in cross section of default vs. varied fit as systematics

Source	$\delta_{\text{sys,avg}}$ [%]
$\phi(1020)$ branching fraction	1.0
χ^2 requirement	0.9
MM^2 requirement	0.4
Accidentals	0.5
K^+K^- binning	0.7
$\Delta(1232)^{++}$ veto	2.8
$\phi(1020)$ fit model data	0.8
$\phi(1020)$ fit model MC	0.7
$\phi(1020)$ fit range	1.6
$\phi(1020)$ veto range MC	0.5
$\phi(1020)$ integral range MC	0.1
$\phi(1020)$ param. interpolation	0.5
Total systematic uncertainty	4.7



- Fit signal + background in **combined spectrum**
 - 1 Res.: $f(m) = V(m; m_1, \Gamma_1, \sigma_{\text{res}}) + T_4(m)$
 - 2 Res.: $f(m) = V_1(m; m_1, \Gamma_1, \sigma_{\text{res}}) + V_2(m; m_2, \Gamma_2, \sigma_{\text{res}}) + T_4(m)$
 - V = Voigtian, $T_4 = 4^{\text{th}}$ order Chebyshev polynomial
- Use **weighted mass resolution** from MC ($\sigma_{\text{res}} = 24.6 \text{ MeV}/c^2$)
- Repeat for each **systematic variation**
- Systematic uncertainty: Difference to nominal result
- Additional systematics are:
 - $m(\phi\pi\pi)$ fit range
 - $m(\phi\pi\pi)$ fit model (degree of bkgd polynomial)
 - $\phi(2170)$ mass m_0 (by $\pm 1\sigma$)
 - $\phi(2170)$ width Γ_0 (by $\pm 1\sigma$)
- And we take the (larger) difference as systematic uncertainty





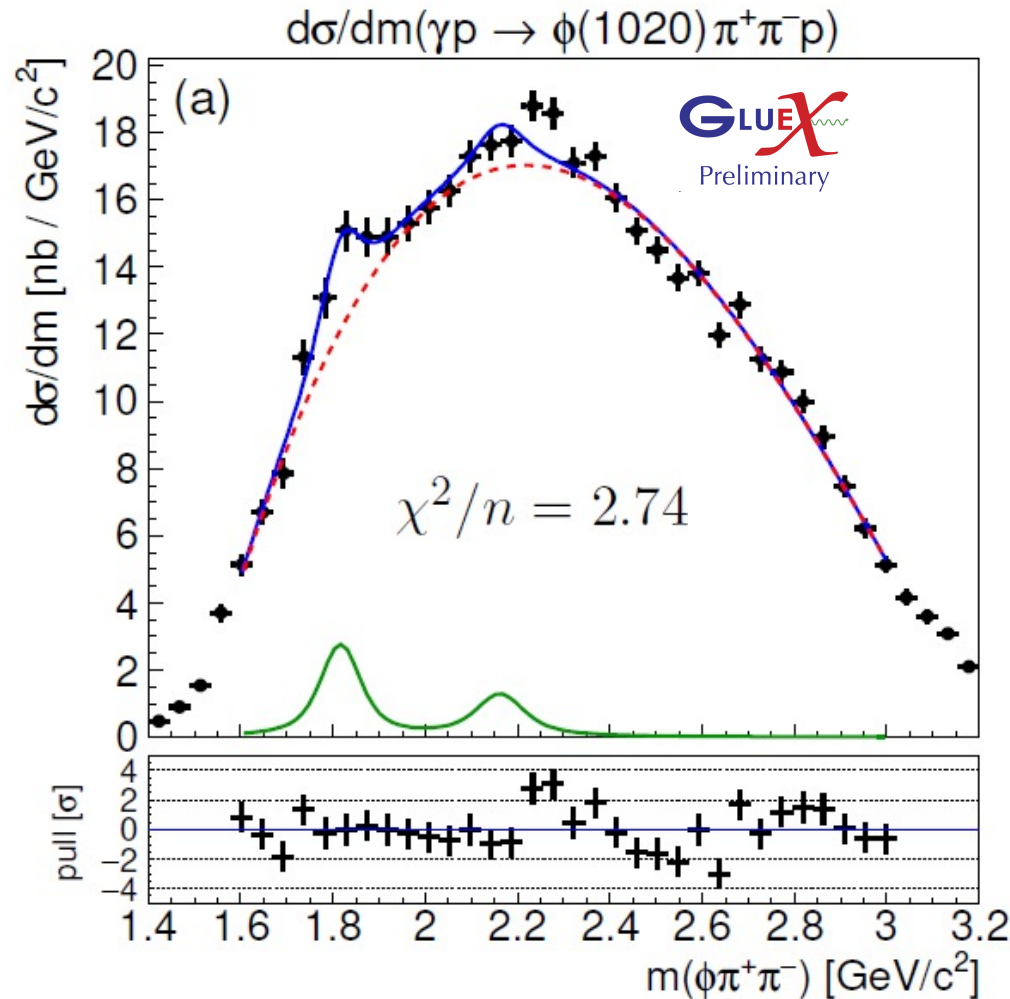
R1: Fixed PDG parameters Y(2175)

$$m_{\phi(2170)} = 2162 \pm 7 \text{ MeV}/c^2$$

$$\Gamma_{\phi(2170)} = 100^{+31}_{-21} \text{ MeV}/c^2$$

$$\sigma_{\phi(2170)} = 174 \pm 69 \text{ (stat.)} \pm 218 \text{ (sys.) pb}$$

$$\sigma_{\phi(2170)} < 499 \text{ pb (CL90)} [Z = 1.6\sigma (2.1\sigma)]$$



R1: Fixed PDG parameters Y(2175)

$$m_{\phi(2170)} = 2162 \pm 7 \text{ MeV}/c^2$$

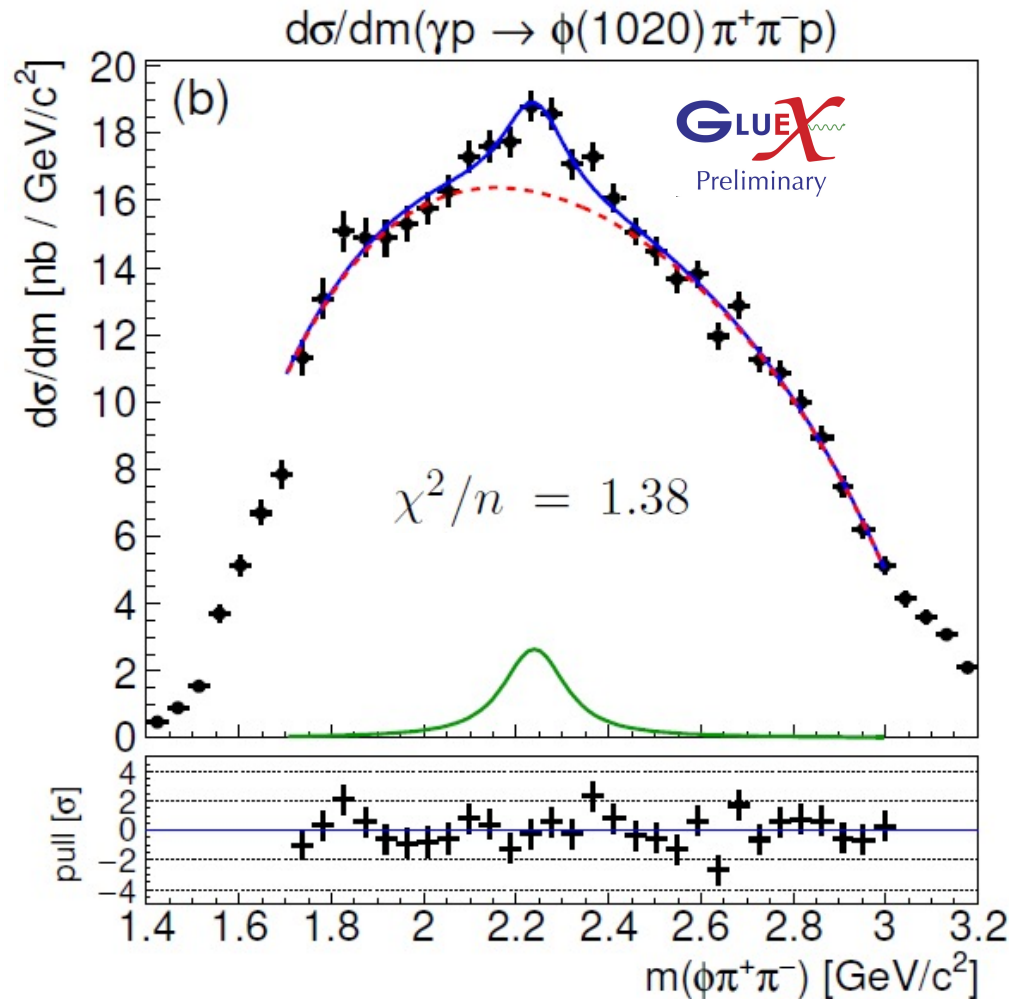
$$\Gamma_{\phi(2170)} = 100^{+31}_{-21} \text{ MeV}/c^2$$

R2: Possible structure at $m \sim 1.8 \text{ GeV}$

$$\sigma_{X(1800)} < 615 \text{ pb (CL90)}$$

$$\sigma_{\phi(2170)} = 232 \pm 68 \text{ (stat.)} \pm 91 \text{ (sys.) pb}$$

$$\sigma_{\phi(2170)} < 379 \text{ pb (CL90)} [Z = 1.5\sigma (1.8\sigma)]$$

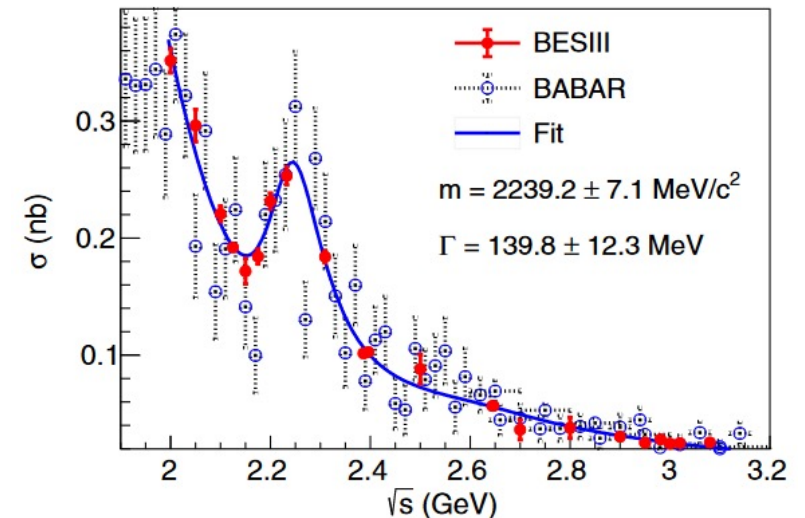


R1: Fixed parameters Y(2239)

$$m_{Y(2239)} = 2239.2 \pm 13.4 \text{ MeV}/c^2$$

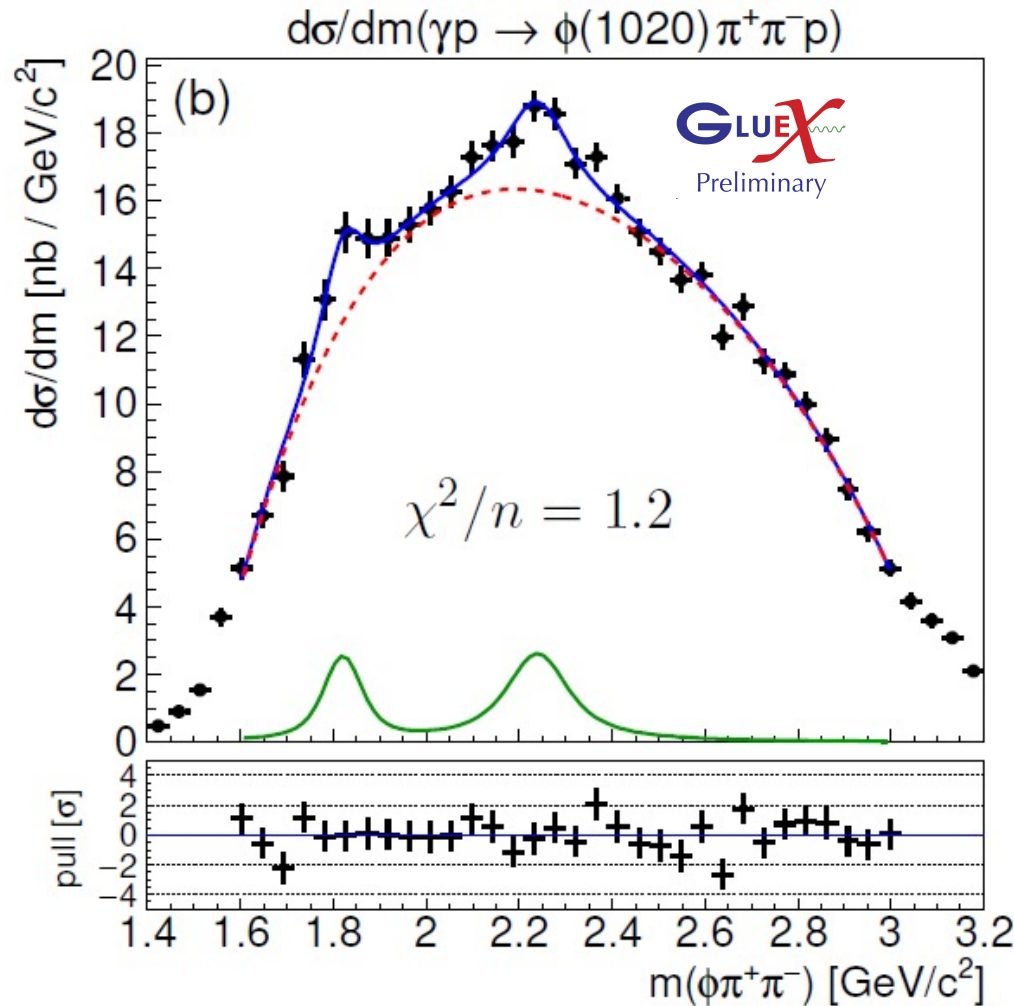
$$\Gamma_{Y(2239)} = 139.8 \pm 24.0 \text{ MeV}/c^2$$

[Phys. Rev. D 99, (2019) 032001]



$$\sigma_{Y(2239)} = 641 \pm 82 \text{ (stat.)} \pm 181 \text{ (sys.) pb}$$

$$\sigma_{Y(2239)} < 896 \text{ pb (CL90)} \quad [Z = 5.7\sigma \text{ (6.0}\sigma)]$$



R1: Fixed parameters Y(2239)

$$m_{Y(2239)} = 2239.2 \pm 13.4 \text{ MeV}/c^2$$

$$\Gamma_{Y(2239)} = 139.8 \pm 24.0 \text{ MeV}/c^2$$

R2: Possible structure at $m \sim 1.8$ GeV):

$$\sigma_{X(1800)} < 701 \text{ pb (CL90)}$$

$$\sigma_{Y(2239)} = 629 \pm 83 \text{ (stat.)} \pm 130 \text{ (sys.) pb}$$

$$\sigma_{Y(2239)} < 826 \text{ pb (CL90)} \quad [Z = 4.7\sigma \text{ (5.1}\sigma)]$$

- Analysis of reaction $\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p$
- Measurement of differential $\phi \pi^+ \pi^-$ production cross section $\sigma(\gamma p \rightarrow \phi \pi^+ \pi^- p)$
- Search for $Y(2175)$ + other resonances gives

Case	Cross Section [pb]	UL [pb]	Z_{stat}	Z_{tot}
Fit a_1 : $Y(2175)$ fixed	$174 \pm 69 \pm 218$	499	2.1	1.6
Fit a_2 : $Y(2175)$ fixed	$232 \pm 68 \pm 91$	379	1.8	1.5
Fit b_1 : $Y(2239)$ fixed	$641 \pm 82 \pm 181$	896	6.0	5.7
Fit b_2 : $Y(2239)$ fixed	$629 \pm 83 \pm 130$	826	5.1	4.7

- Fit with $Y(2175)$ PDG parameters $\rightarrow$ no evidence ($Z < 3\sigma$)
- Alternative fits with $Y(2239)$ parameters (fixed) $\rightarrow$ evidence/observation ($Z > 3$)
- Signal strength of $Y(2239)$ in ball-park of predicted $\sigma \approx 1200$ pb
- Find 2nd structure at around $m \approx 1.8$ GeV/ c^2
 - UL(CL90): $\sigma < 615$ pb (fit a_2) and $\sigma < 701$ pb (fit b_2)

- Analysis of reaction $\gamma p \rightarrow K^+ K^- \pi^+ \pi^- p$
- Measurement of differential $\phi \pi^+ \pi^-$ production cross section
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Thank you!

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- Find 2nd structure at around $m \approx 1.8$ GeV/c²
 - UL(CL90): $\sigma < 615$ pb (fit a_2) and $\sigma < 701$ pb

**Under internal review for publication
 $\rightarrow$ paper submission to journal soon**