Extracting the Cross Section of $(\gamma, \rho^- p)$ in Deuteron

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Workflow

$\gamma + d \rightarrow \rho^- + p + N_{miss}$

$\rho^- \rightarrow \pi^0 + \pi^-$

Raw Data → **Reconstruction** → Recon. Files (Version 2) → **Reaction Filter** → Physics ROOT (Version 6) → **Dslector** → Skimmed Files (Version 5) → **Filter** → Cut Files → 3D Hists → Fitting

Cuts

1. 51 cm < z <79 cm
2. $x^2+y^2 < 1\ cm^2$
3. 0.01 < CL
4. -1 < $m_{miss}^2 - m_p^2 < 1$
5. $p_{miss,kin} < 0.2$ GeV

$m_{2\pi}$ - y - z

y and z are variables

cos θ, t, s, $\sqrt{s}$, k

$$k = \frac{s - m_n^2}{2m_n}$$

Breit-Wigner Convolve with Gaussian

Old Version Simulation:

1M events

Non-relativistic Breit-Wigner

Fitting function for thrown:

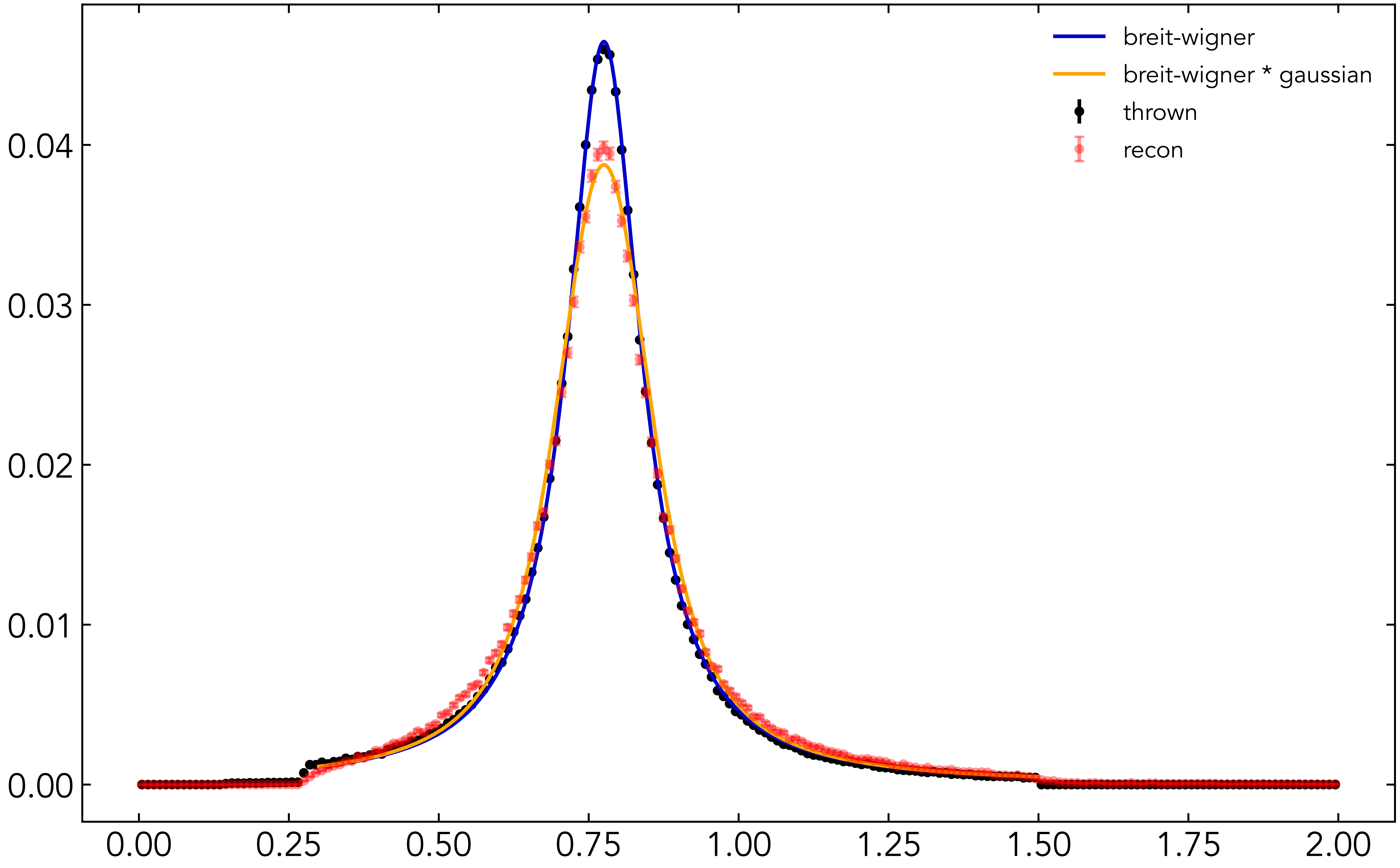
$$f(m_{2\pi}) \propto \frac{1}{(m_{2\pi} - M_\rho)^2 + \Gamma_0^2/4}$$

Fitting function for reconstructed:

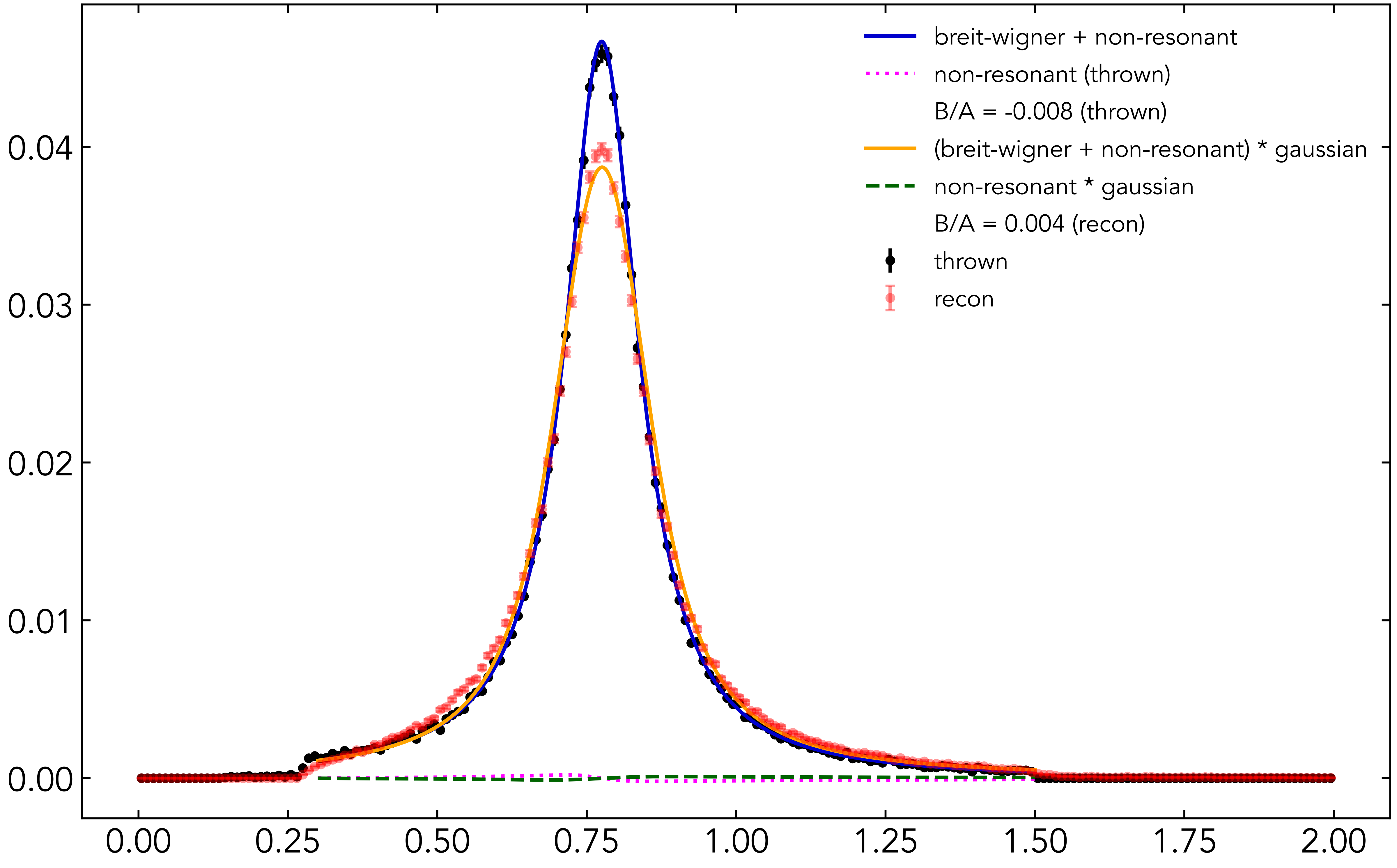
$$F(m_{2\pi}) \propto f * G = \int_{-\infty}^{\infty} f(m'_{2\pi}) G(m_{2\pi} - m'_{2\pi}; \sigma) dm'_{2\pi}$$

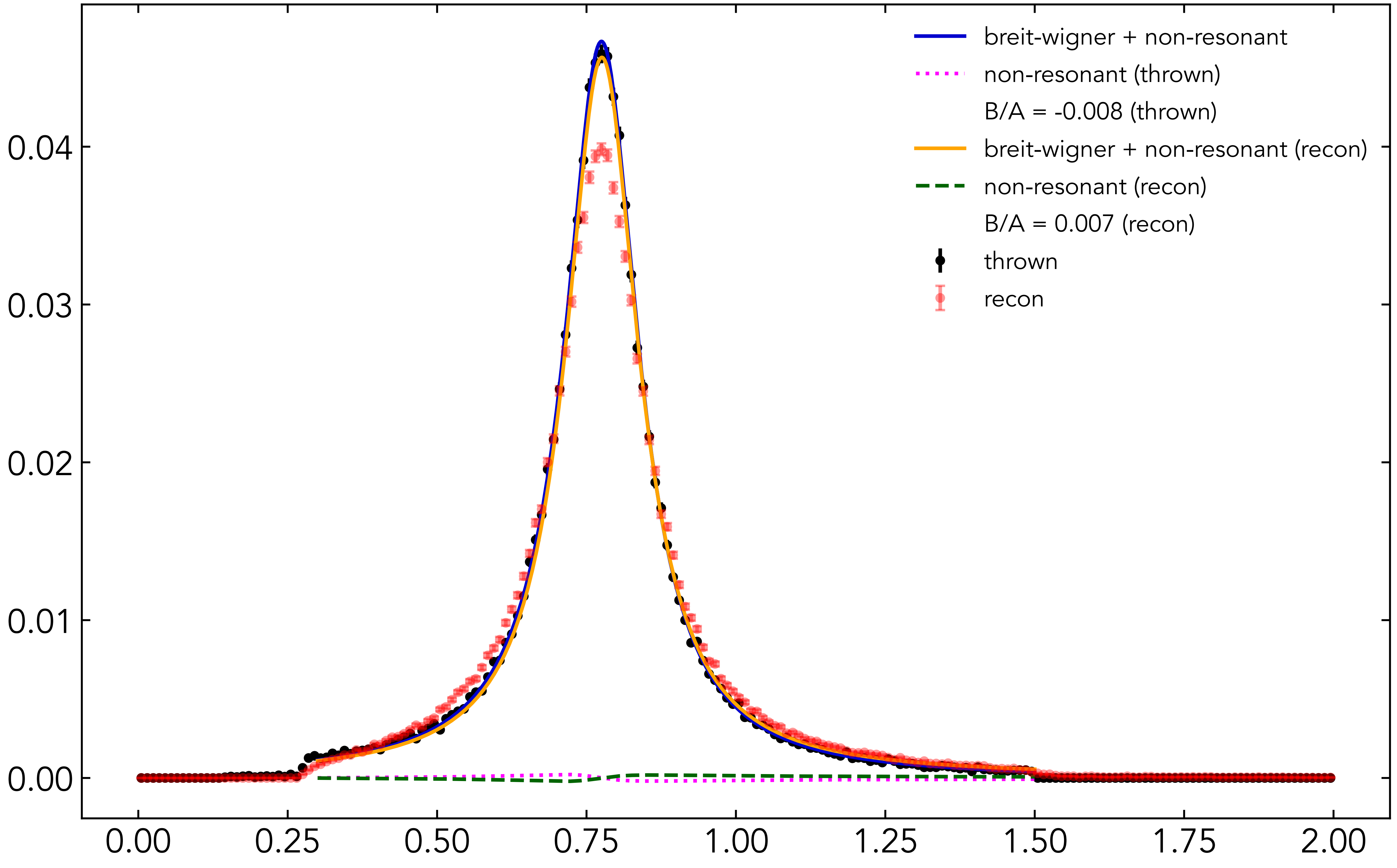
Breit-Wigner Convolve with Gaussian

$5.8 \leq E_\gamma < 11$ [GeV]
$\sigma = 0.038$ [GeV]

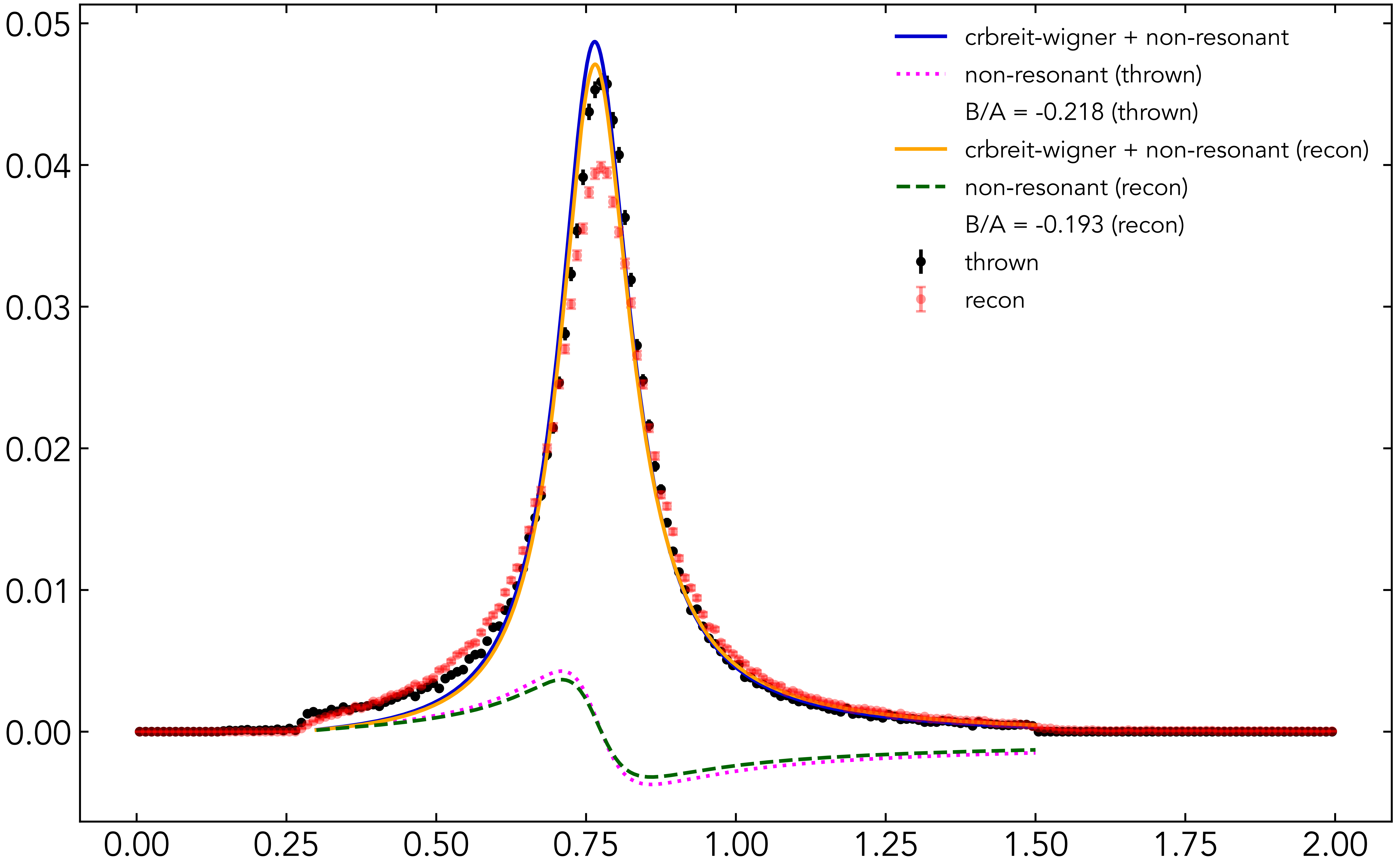


Convolution vs. w/o Convolution





Review Previous Result

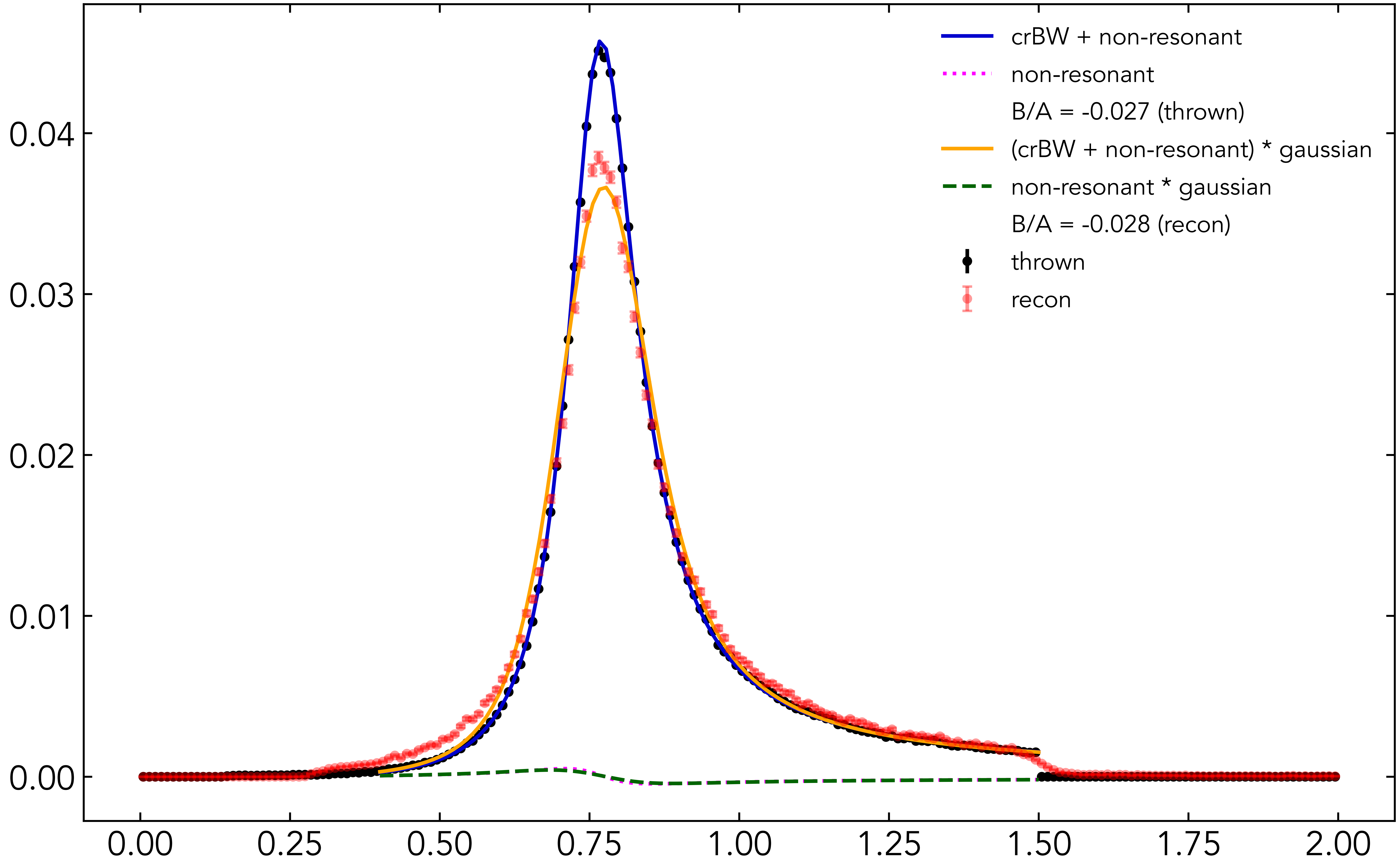


This plot shows we used improper fitting function to fit the simulation data which produced by BW.

In addition, we did not consider the detector resolution effect.

Corrected Simulation

GCF Generator
1M Events
crBW specturm



GCF Generator
1M Events
crBW spectrurm

↓

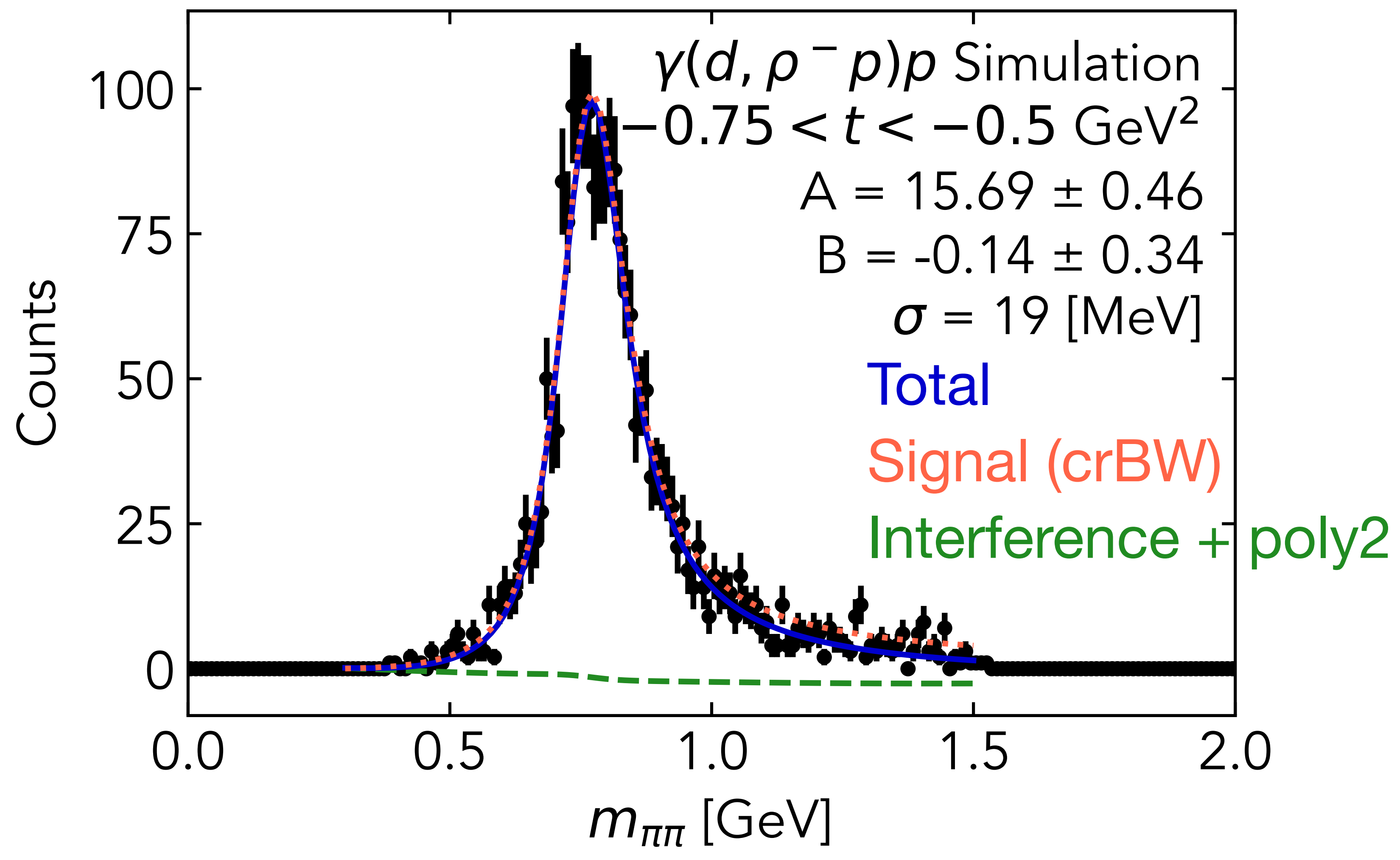
DSelector
Physical Cut

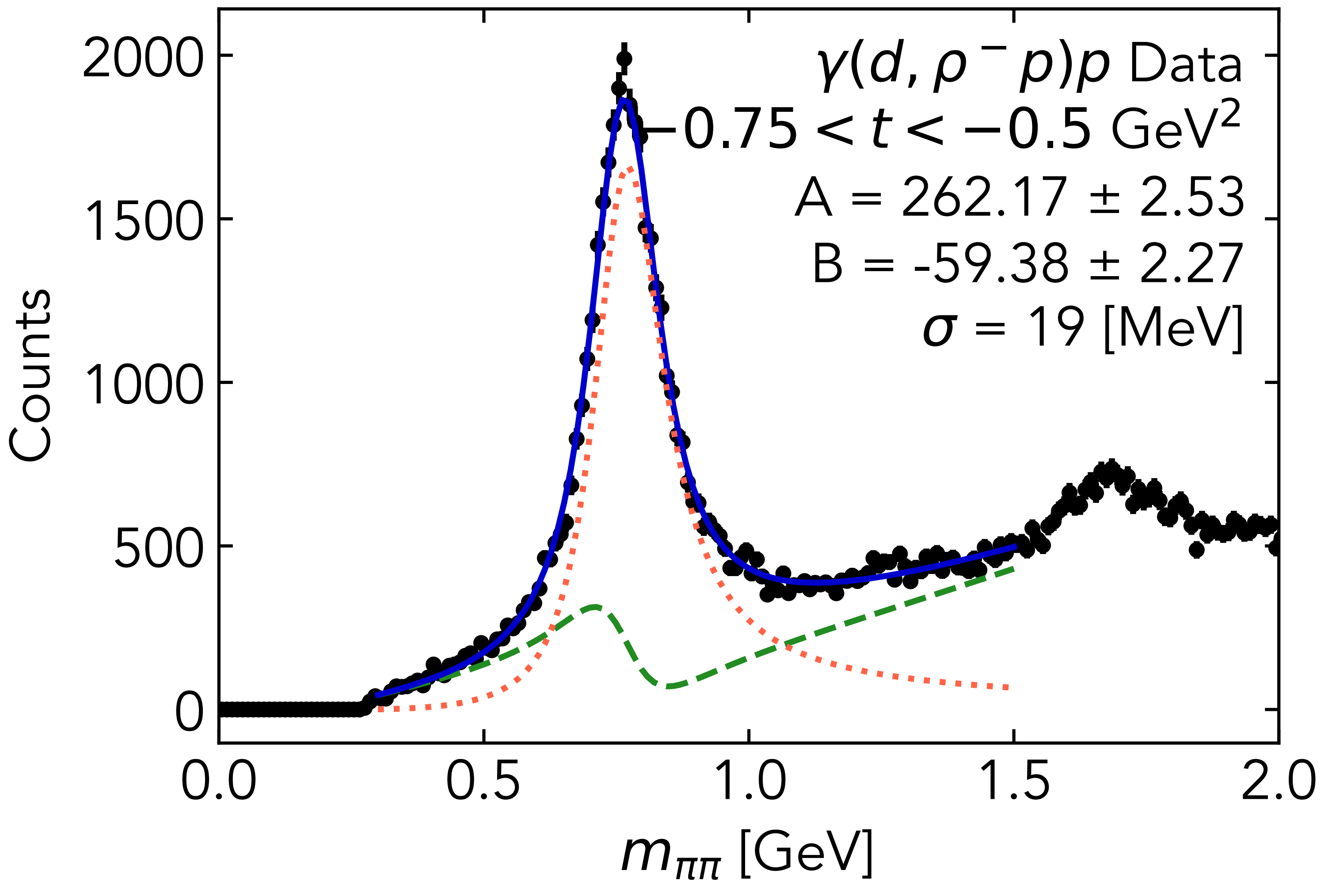
↓

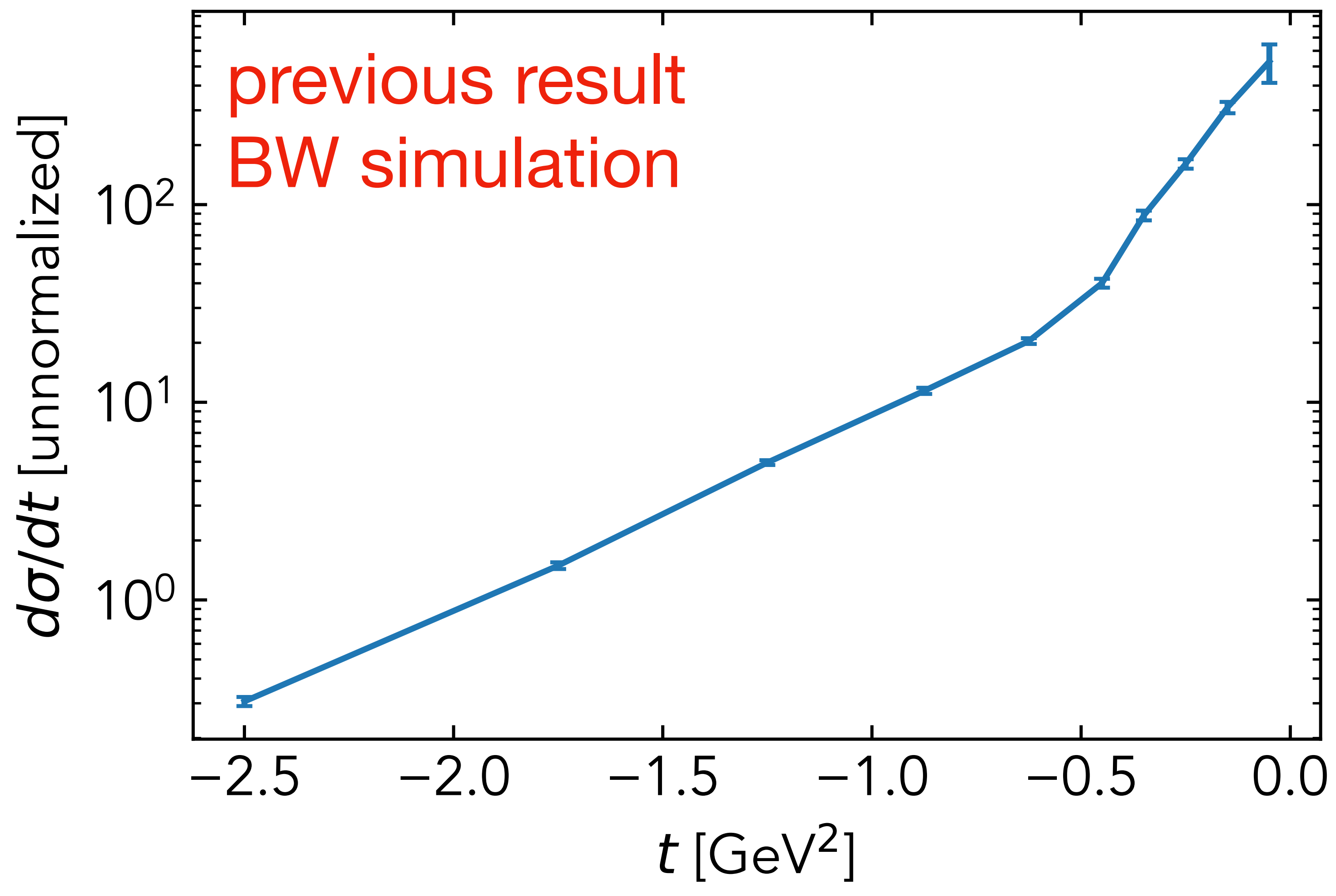
Fit Simulation First

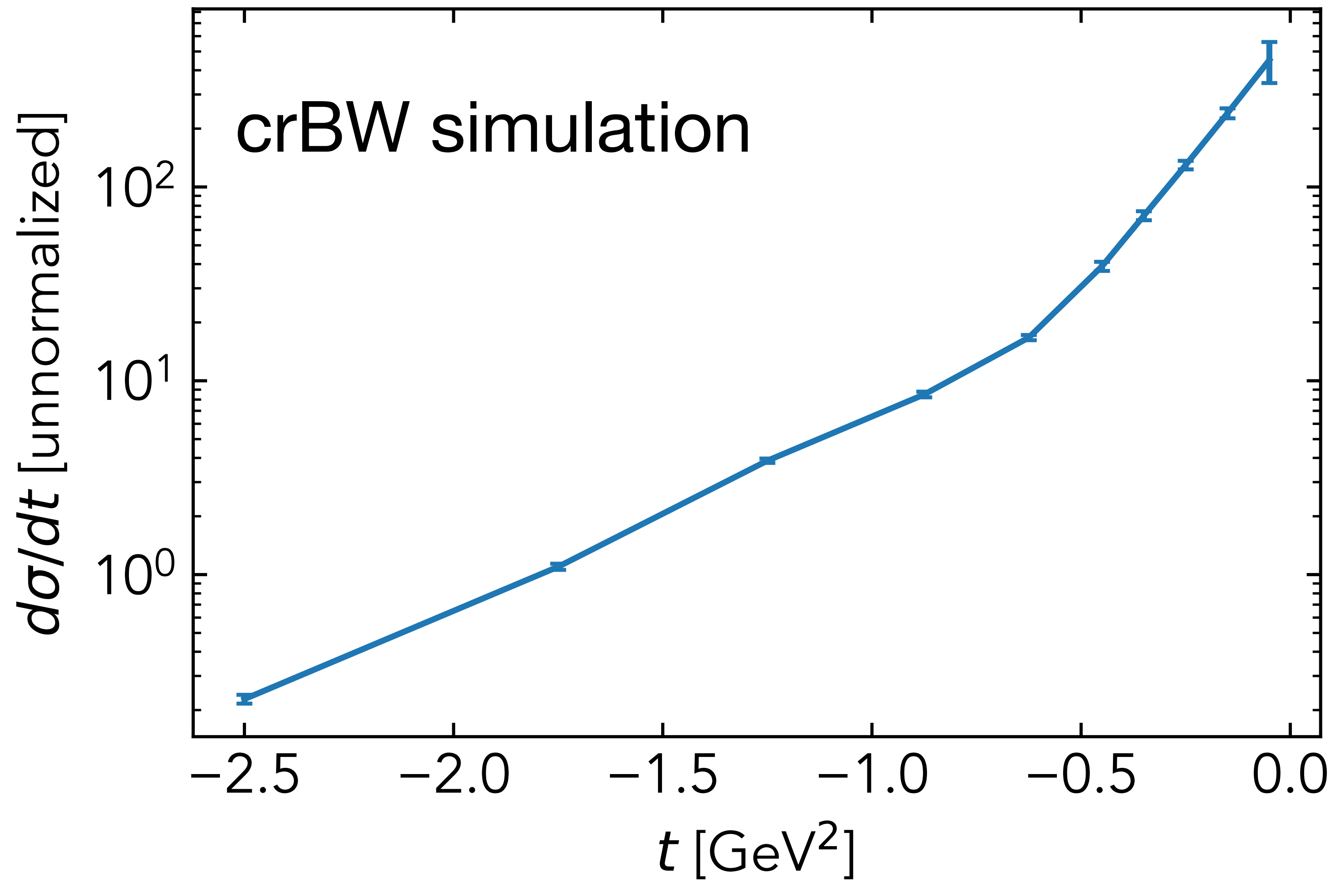
↓

Fit Data (fixed simga)





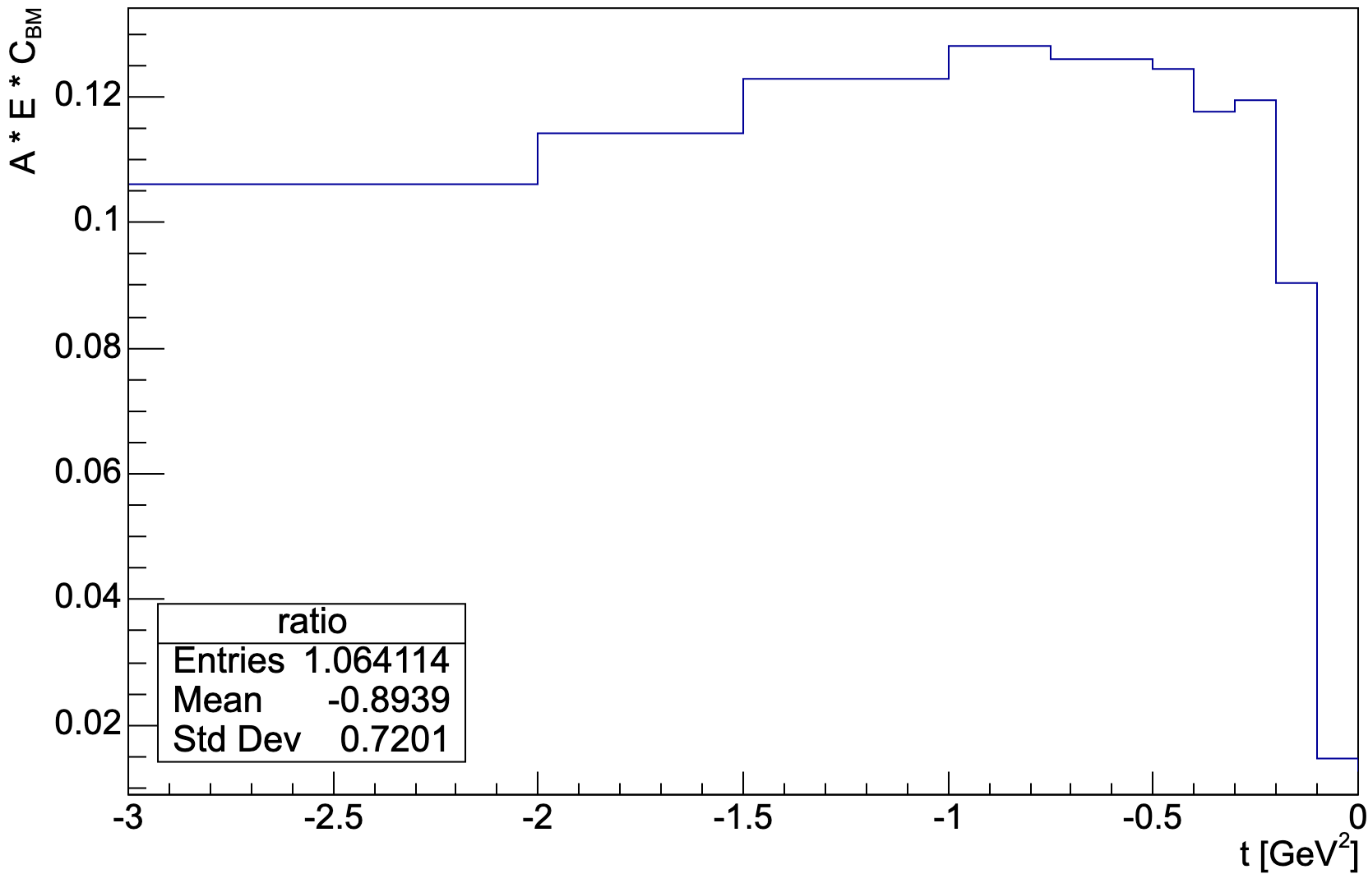




Nonresonant Contribution

Acceptance, Efficiency, and Bin Migration

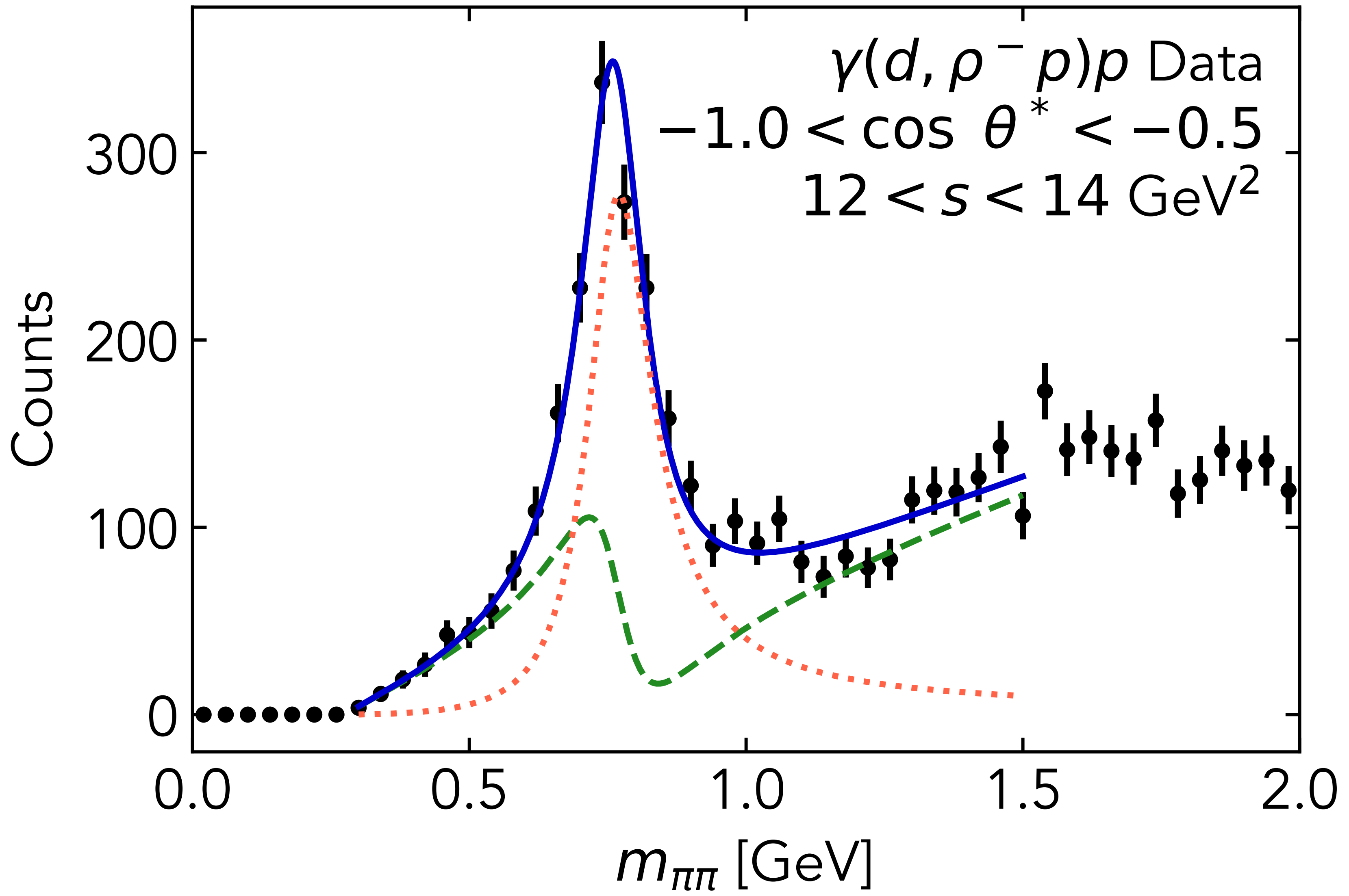
$$A \times \epsilon \times C_{BM} = \frac{\#\ accept}{\#\ thrown} \cdot \frac{\#\ detected}{\#\ accept} \cdot \frac{\#\ recon}{\#\ detected} \cdot \frac{\#\ skimmed}{\#\ recon}$$

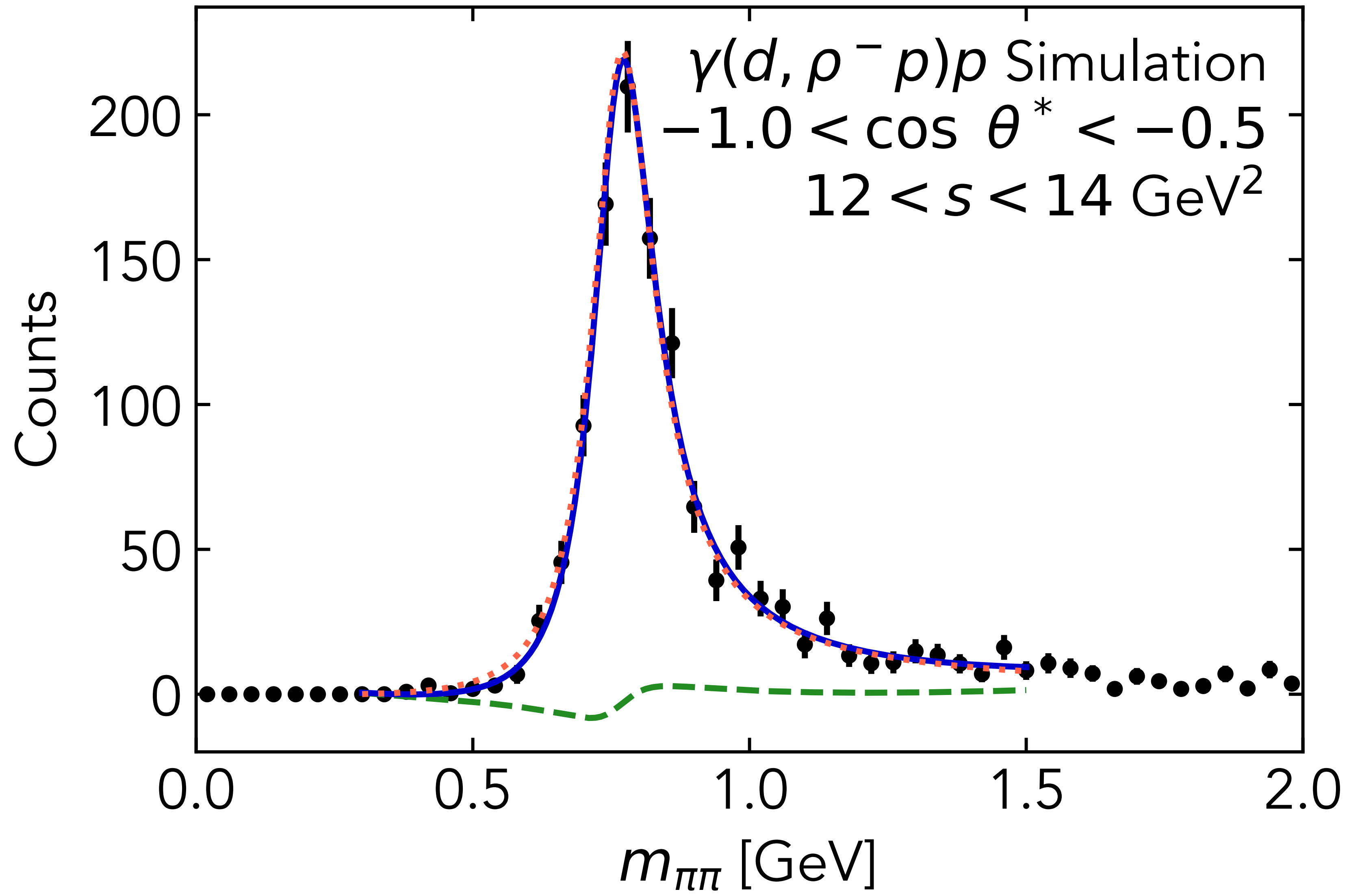


Back Up

The mass shift is from interference

- $$\frac{dN}{dM_{2\pi}} = A \cdot \frac{\Gamma_\rho M_\rho M_{2\pi}}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} + B \cdot \frac{2\sqrt{M_\rho M_{2\pi} \Gamma_\rho} \cdot (M_\rho^2 - M_{2\pi}^2)}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} + poly2$$
- $\Gamma_\rho = (q/q_0)^3 \cdot \Gamma_0 \cdot M_\rho / M_{2\pi}$
- q is the pion momentum in the center-of-mass frame, and q_0 for $M_{\pi^-\pi^0} = M_{\rho^-}$

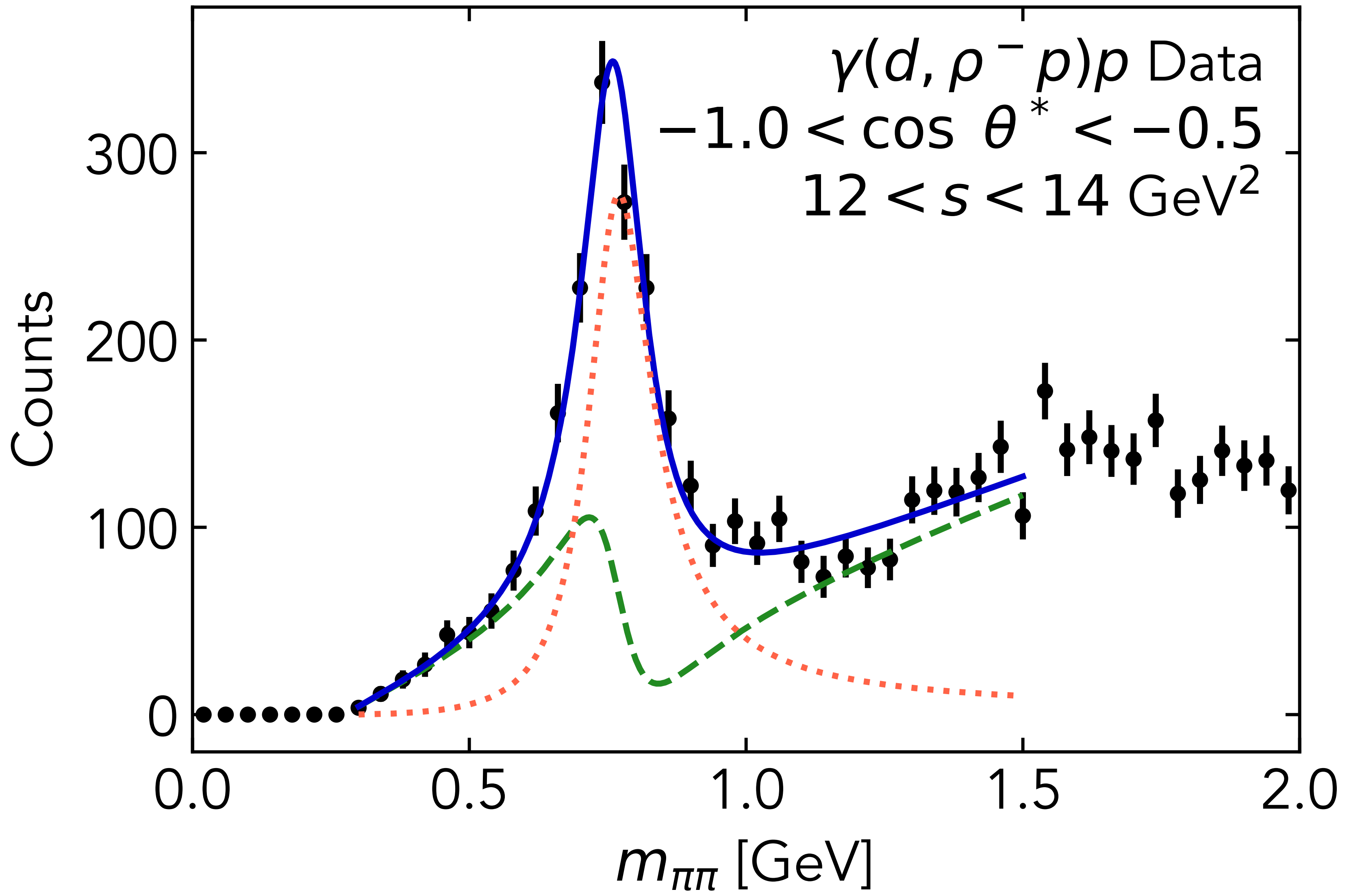


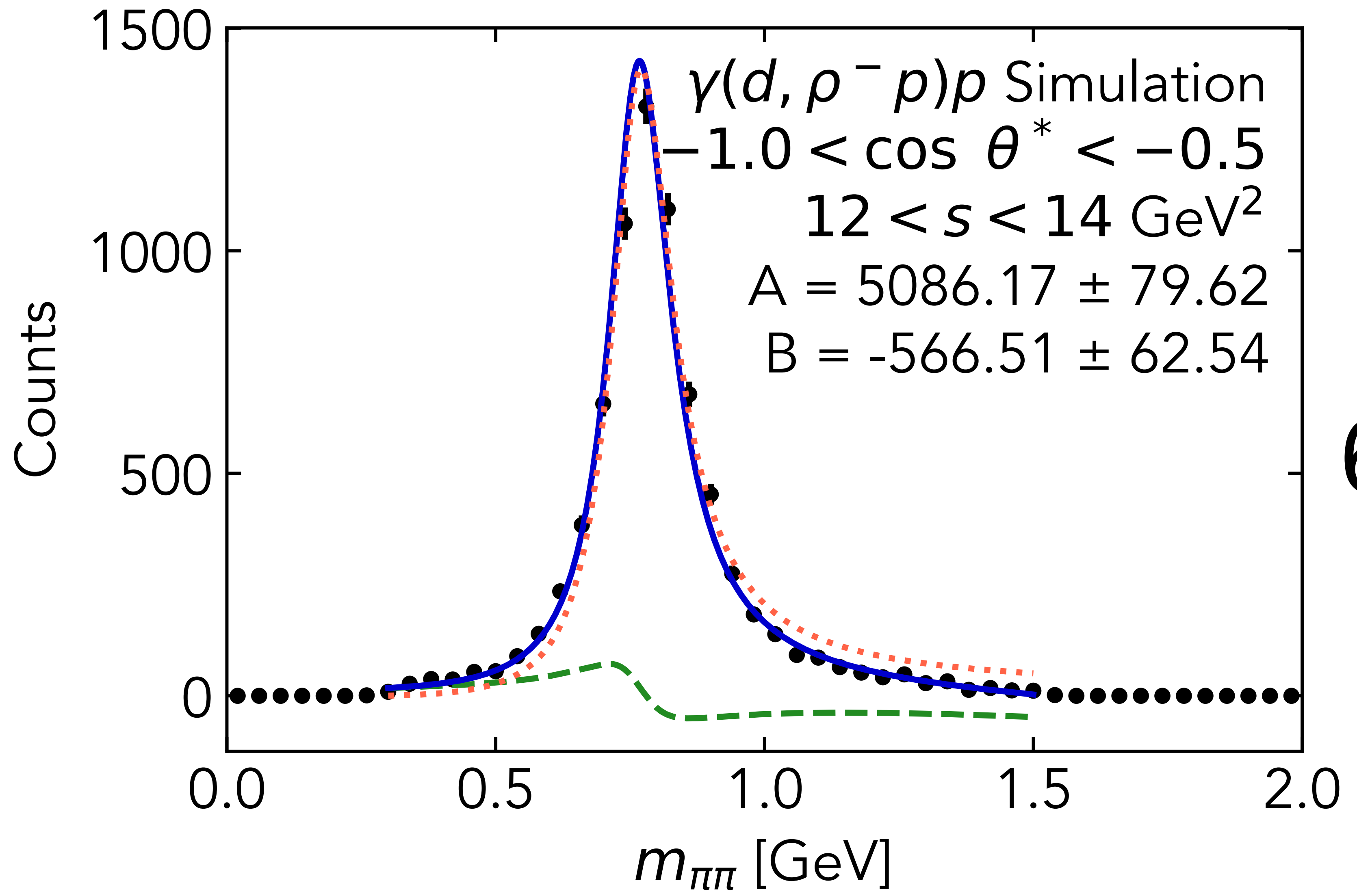


1M Simulation

The mass shift is from interference

- $$\frac{dN}{dM_{2\pi}} = A \cdot \frac{\Gamma_\rho M_\rho M_{2\pi}}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} + B \cdot \frac{2\sqrt{M_\rho M_{2\pi} \Gamma_\rho} \cdot (M_\rho^2 - M_{2\pi}^2)}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} + poly2$$
- $\Gamma_\rho = (q/q_0)^3 \cdot \Gamma_0 \cdot M_\rho / M_{2\pi}$
- q is the pion momentum in the center-of-mass frame, and q_0 for $M_{\pi^-\pi^0} = M_{\rho^-}$





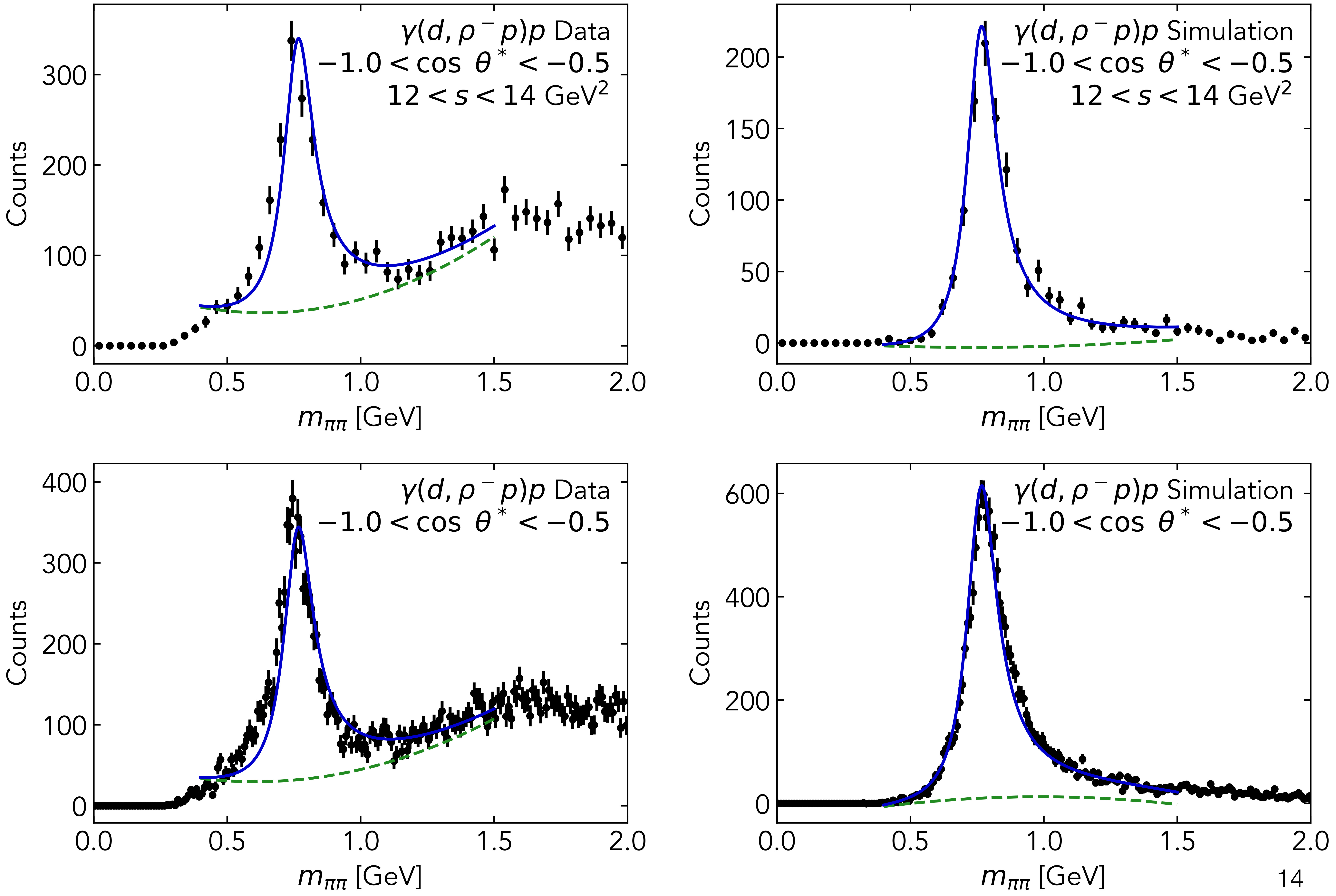
6M Simulation

Fitting Result

Fitting Function:

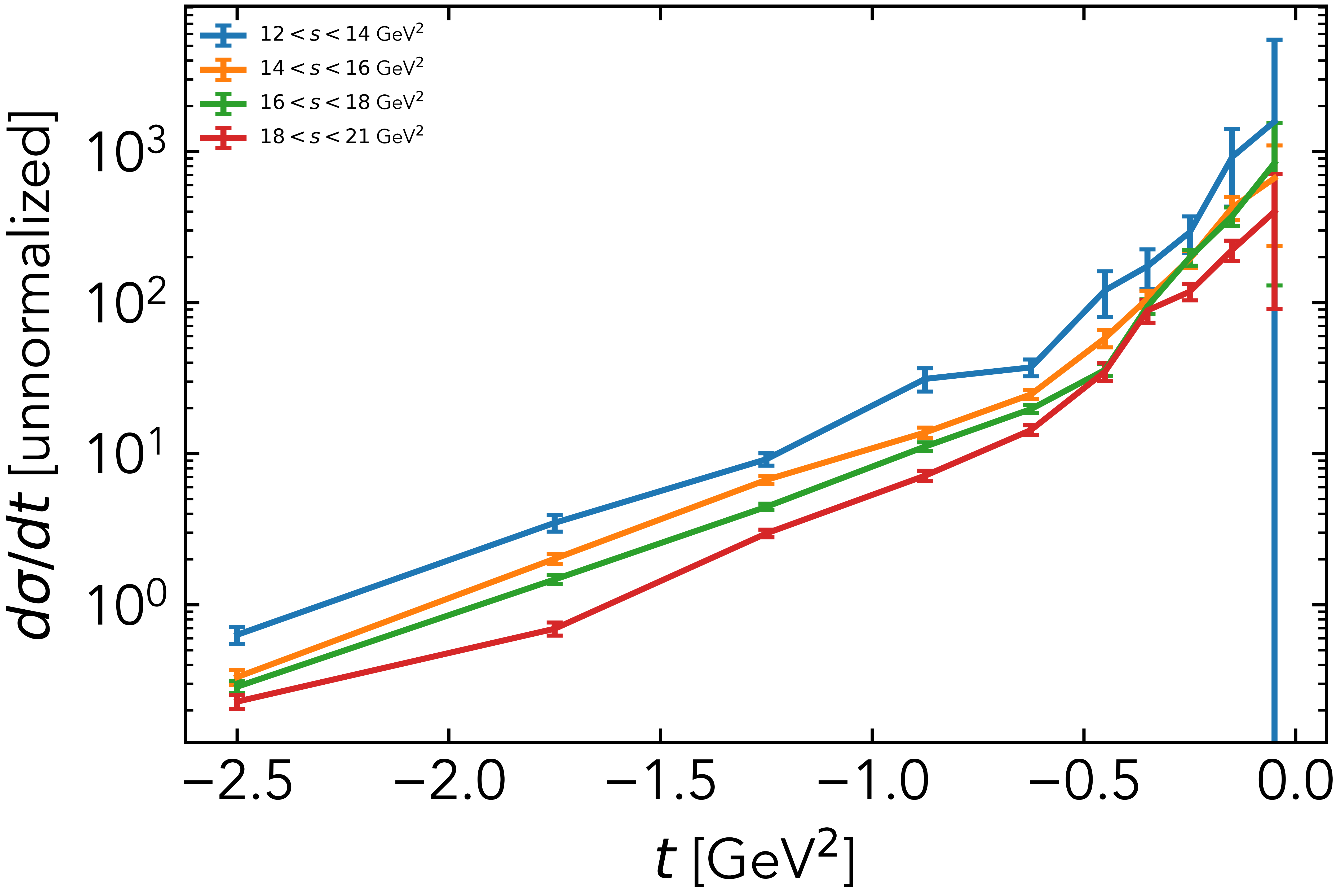
Relativistic Breit Wigner Distribution + poly2

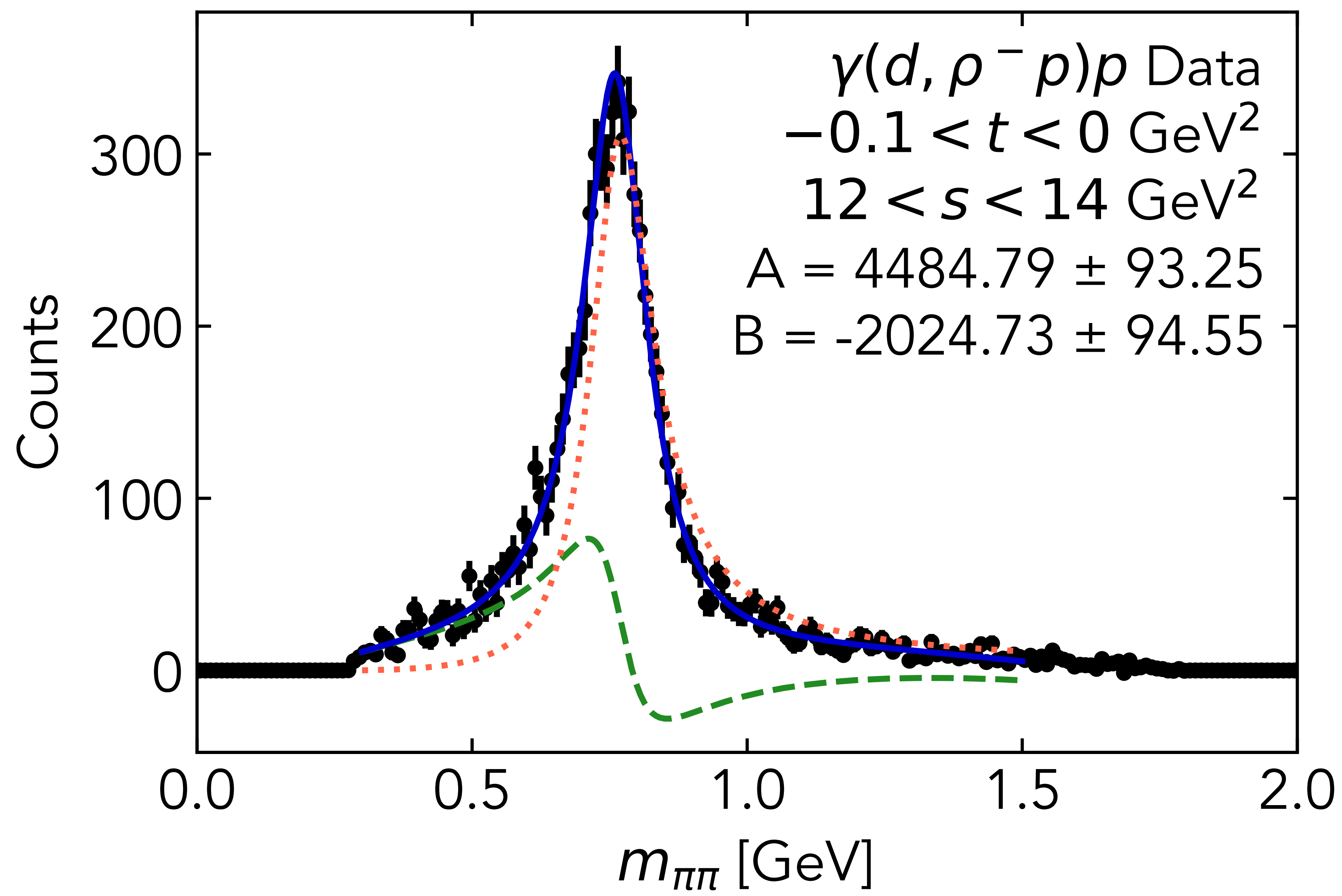
There is an apparent mass shift

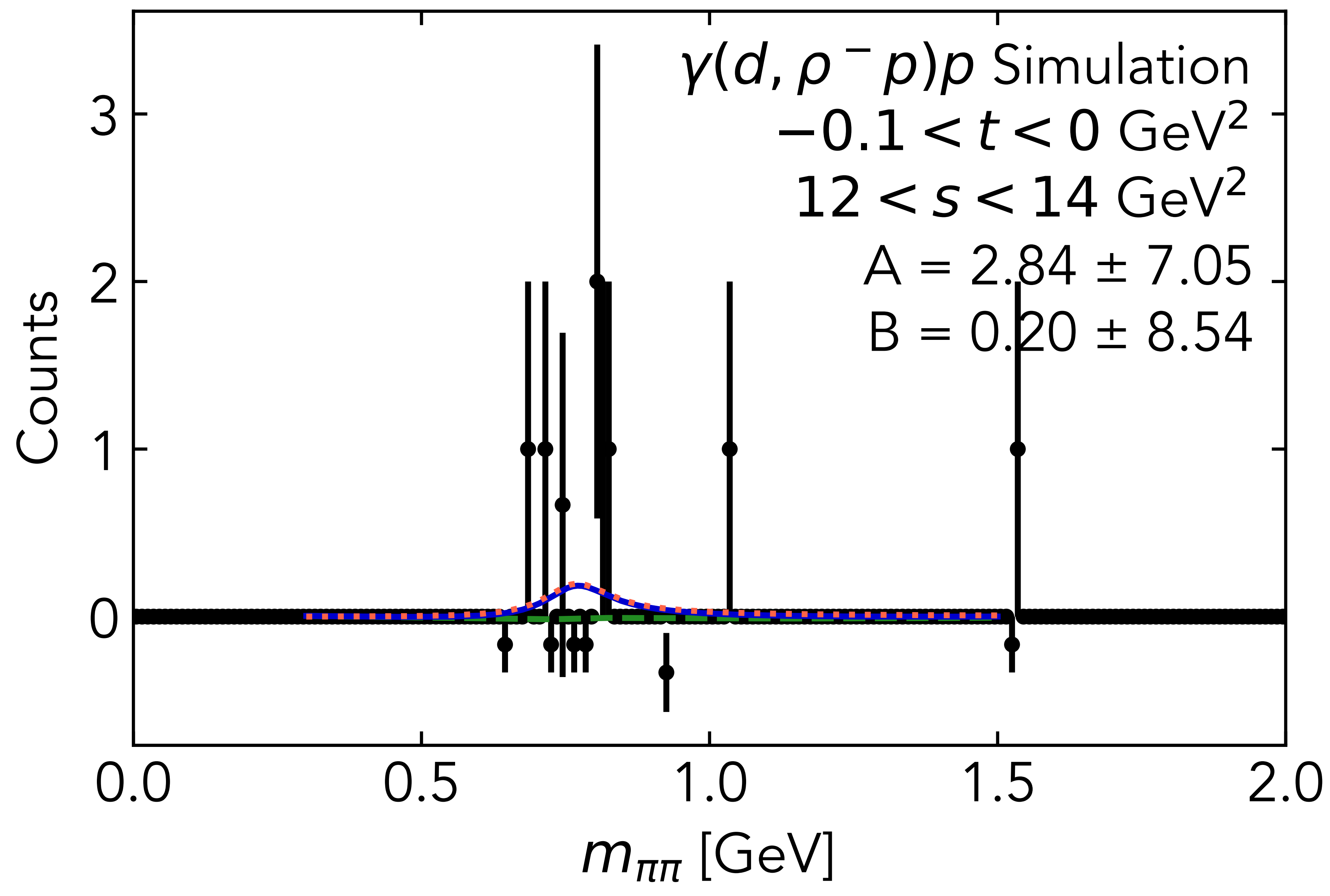


Preliminary Cross-section Distribution

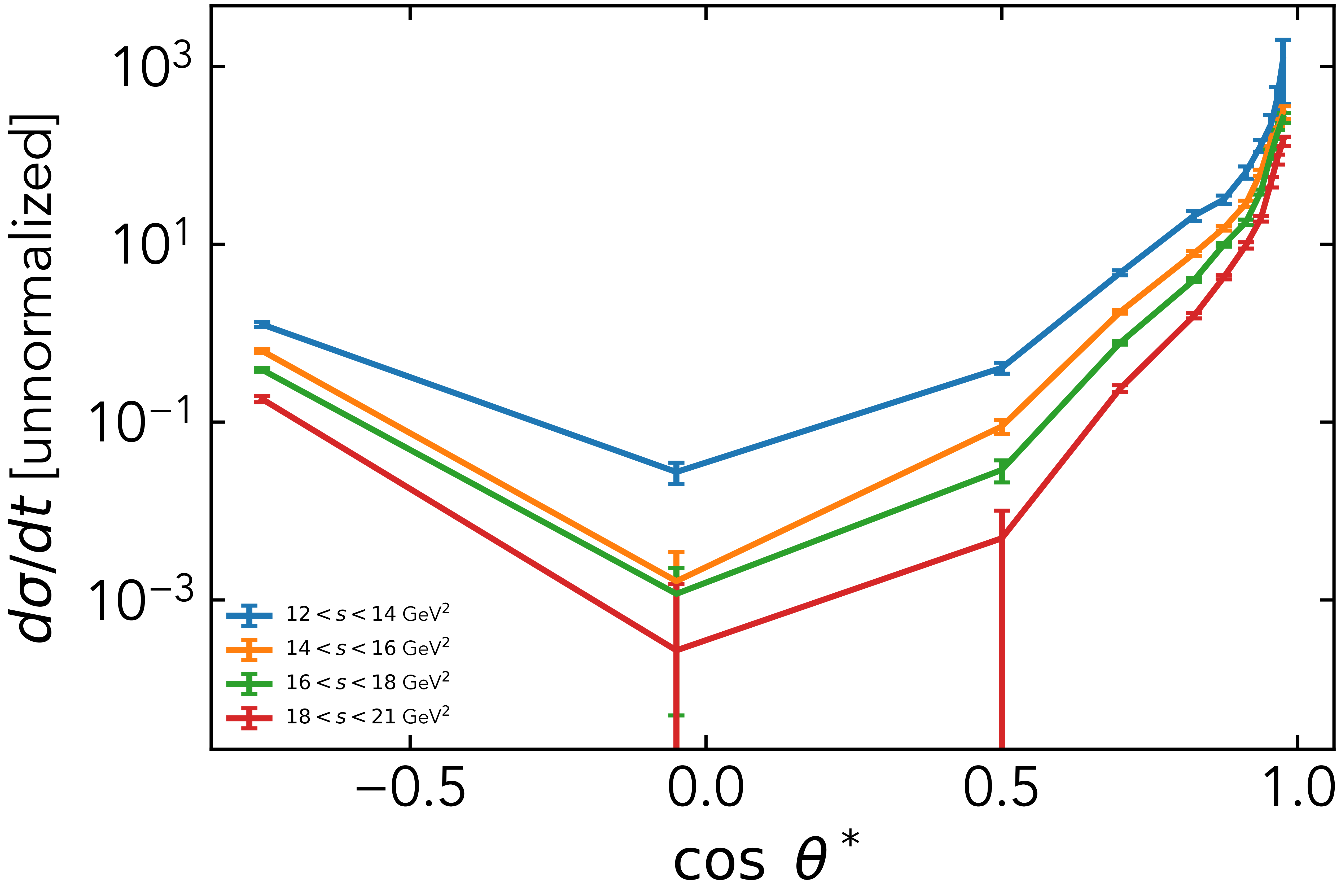
Large Error Bar

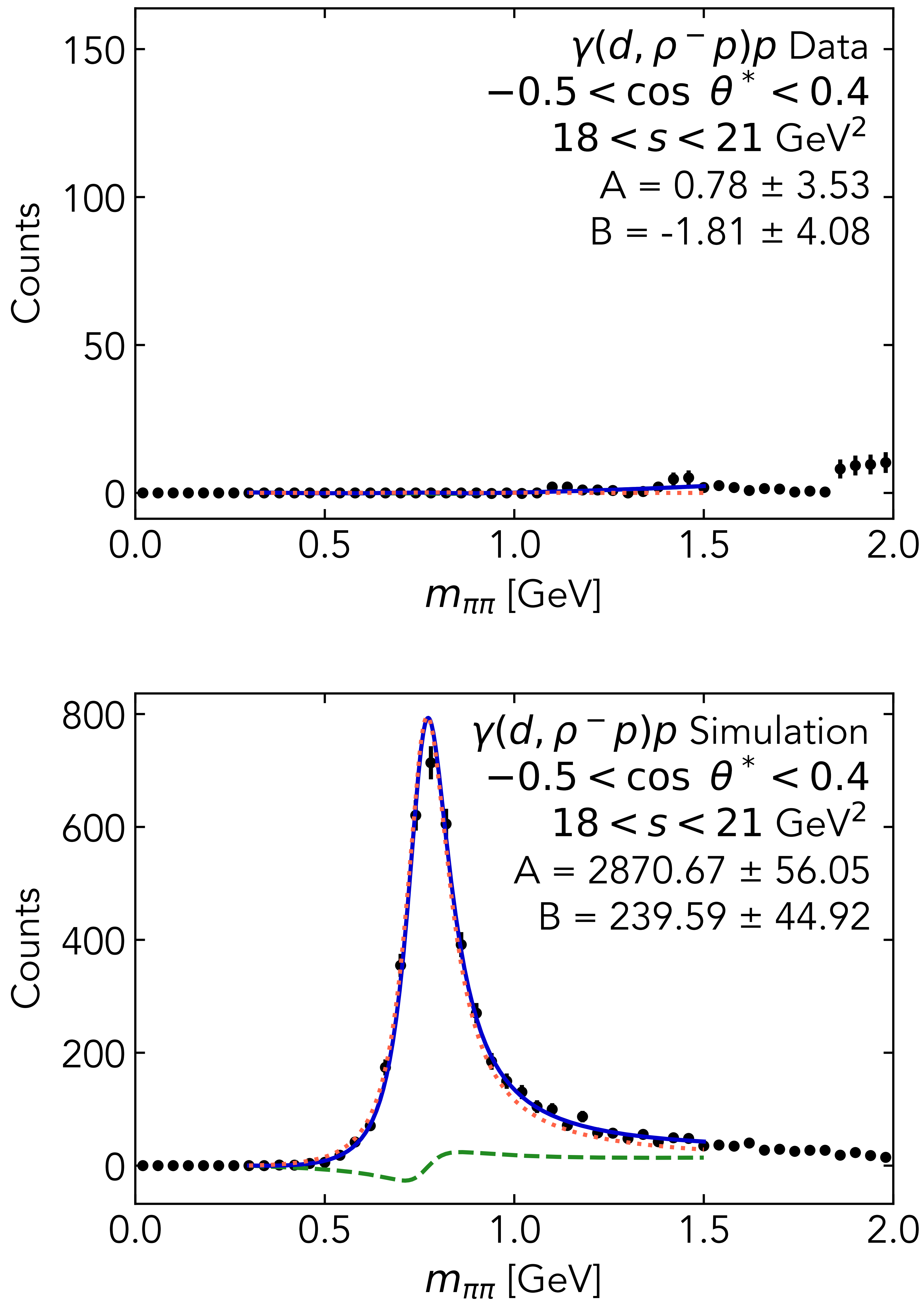




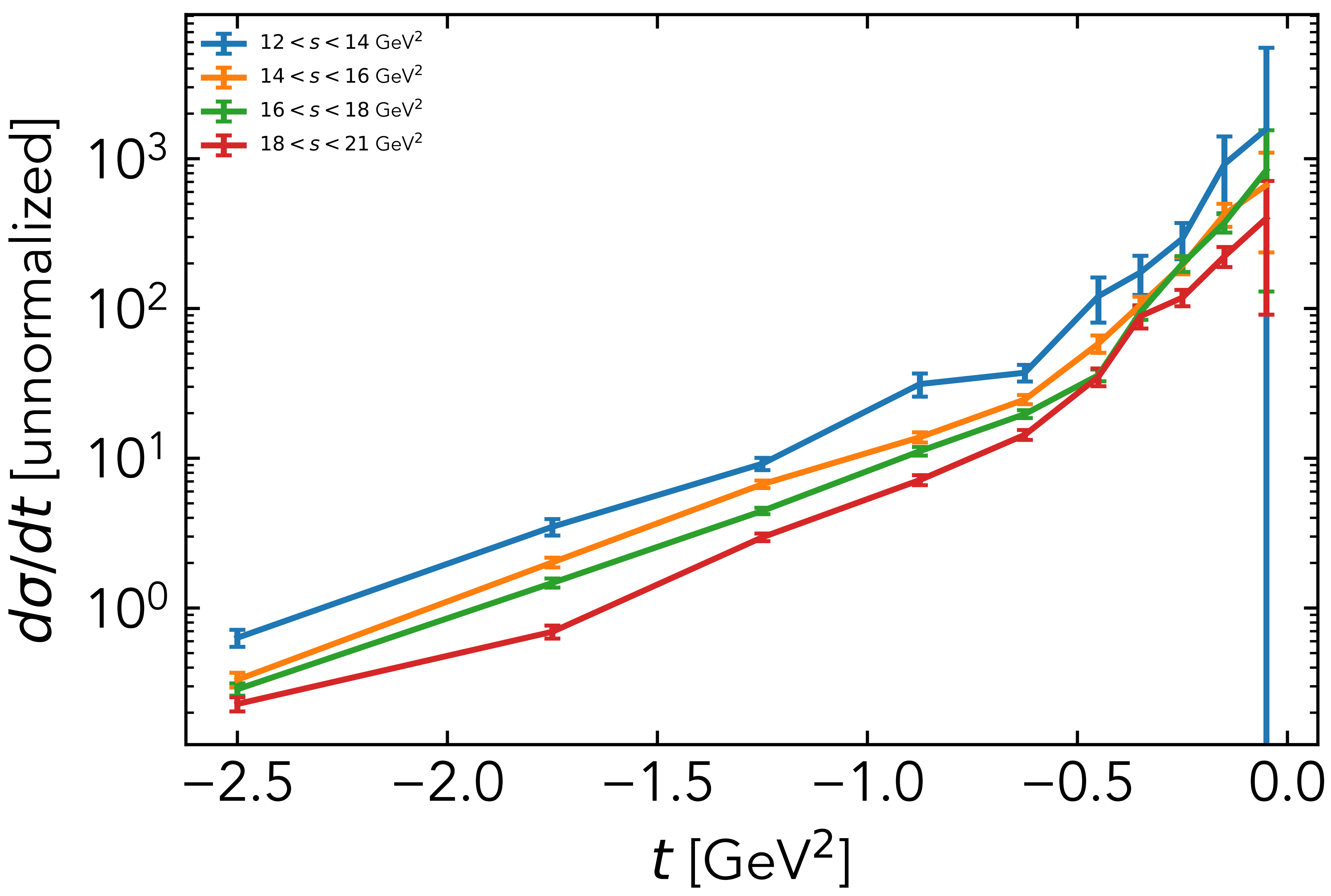


Large Error Bar

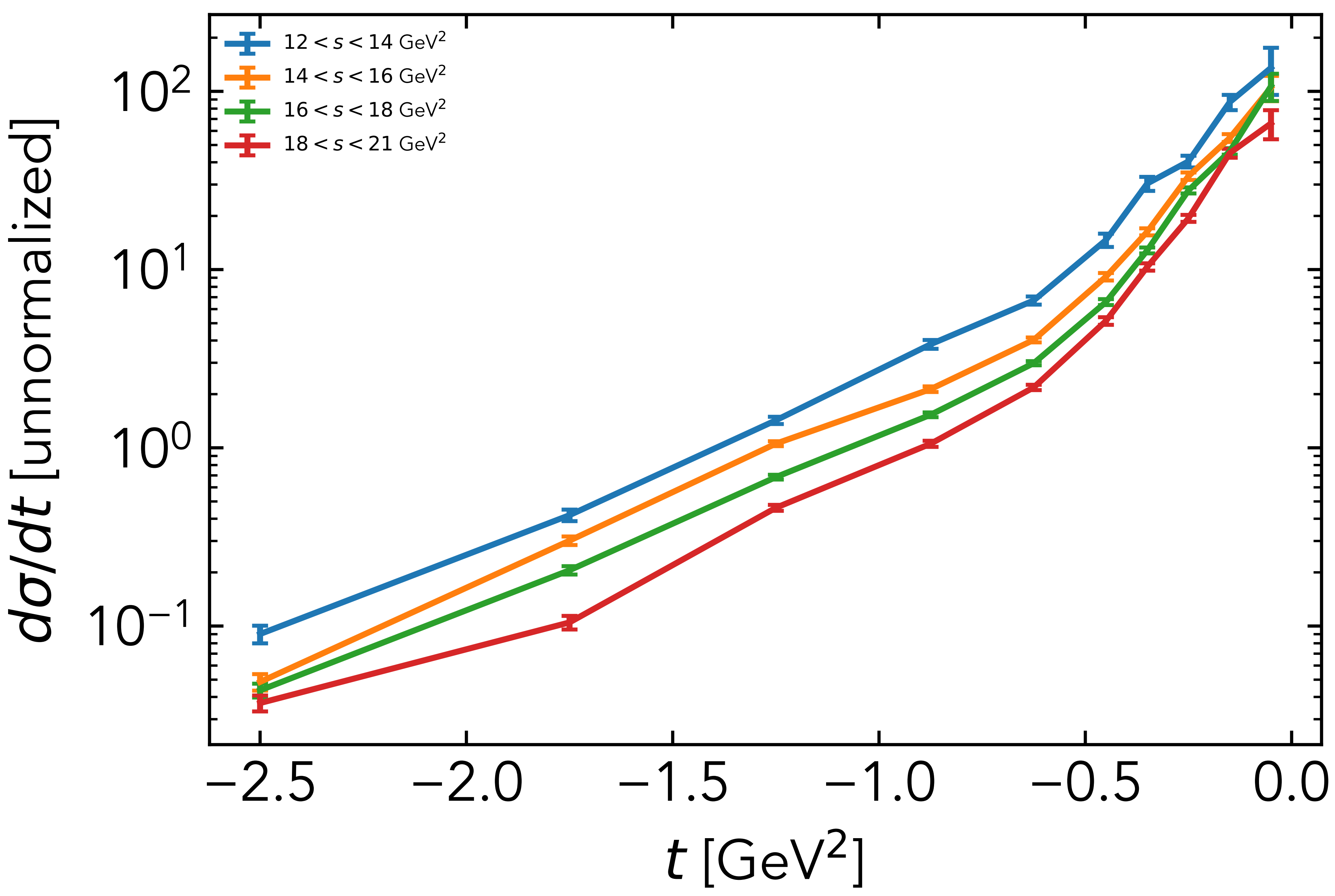




Comparsion



1M



6M

Normalization

$$\frac{d\sigma}{dt} = \frac{N_{exp}}{\Delta t} \times \frac{1}{L \cdot \epsilon \cdot A \cdot T \cdot Br}$$

$$\frac{\Delta N_{exp}}{\Delta t} = A_{exp} \cdot \int BW\ dM$$

$$\frac{\Delta N_{sim}}{\Delta t} = A_{sim} \cdot \int BW\ dM = N_{tot} \cdot \frac{\left(\frac{d\sigma}{dt}\right)_0}{\sigma_{tot}} \cdot \epsilon \cdot A$$

$$\frac{d\sigma}{dt} = \frac{A_{exp} \cdot \int BW\ dM}{L \cdot T \cdot Br \cdot A_{sim} \cdot \int BW\ dM} \cdot \frac{N_{tot} \cdot \left(\frac{d\sigma}{dt}\right)_0}{\sigma_{tot}} = \frac{A_{exp}}{A_{sim}} \times \frac{1}{L \cdot T \cdot Br} \cdot \frac{N_{tot} \cdot \left(\frac{d\sigma}{dt}\right)_0}{\sigma_{tot}}$$

Normalization

$$\frac{d\sigma}{dt} = \frac{A_{exp} \cdot \int BW\ dM}{L \cdot T \cdot Br \cdot A_{sim} \cdot \int BW\ dM} \cdot \frac{N_{tot} \cdot \left(\frac{d\sigma}{dt}\right)_0}{\sigma_{tot}} = \frac{A_{exp}}{A_{sim}} \times \frac{1}{L \cdot T \cdot Br} \cdot \frac{N_{tot} \cdot \left(\frac{d\sigma}{dt}\right)_0}{\sigma_{tot}}$$

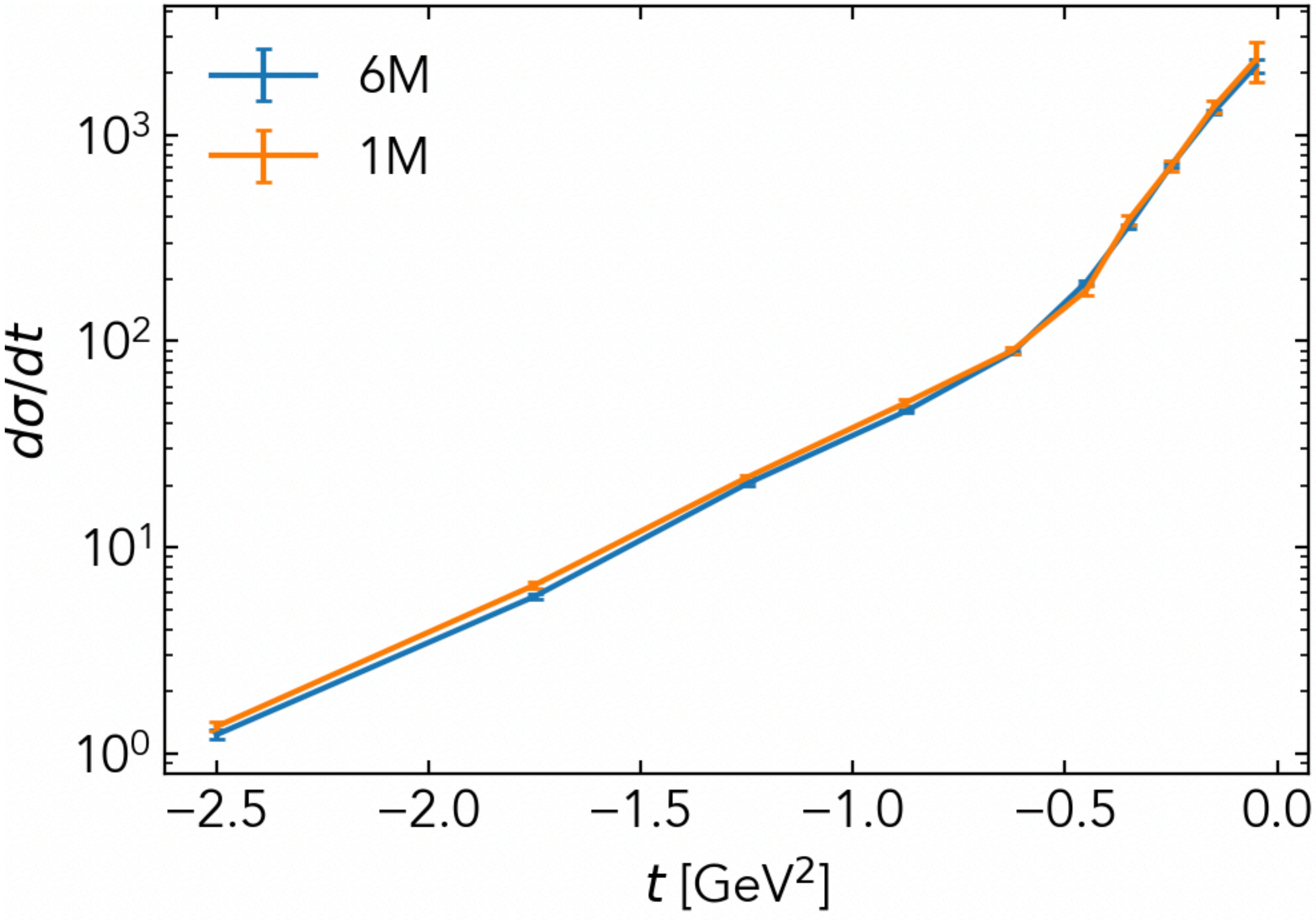
Jackson's Version

$$\begin{aligned} N_{tot} &= 10^6 \\ \left(d\sigma/dt\right)_0 &= 1\ \left[nb/GeV^2\right] \\ \sigma_{tot} &= 14.21847 \pm 0.00774\ [nb] \\ L_{exp} &= 17960\ [nb^{-1}] \\ Br &= Br(\pi^0 \to 2\gamma) \cdot Br(\rho^- \to \pi^- \pi^0) \\ &= 98.823\% \cdot 1 \end{aligned}$$

My Version

$$\begin{aligned} N_{tot} &= 6 \times 10^6 \\ \left(d\sigma/dt\right)_0 &= 1\ \left[nb/GeV^2\right] \\ \sigma_{tot} &= 14.51334 \pm 0.00704\ [nb] \\ L_{exp} &= 17960\ [nb^{-1}] \\ Br &= Br(\pi^0 \to 2\gamma) \cdot Br(\rho^- \to \pi^- \pi^0) \\ &= 98.823\% \cdot 1 \end{aligned}$$

Comparsion

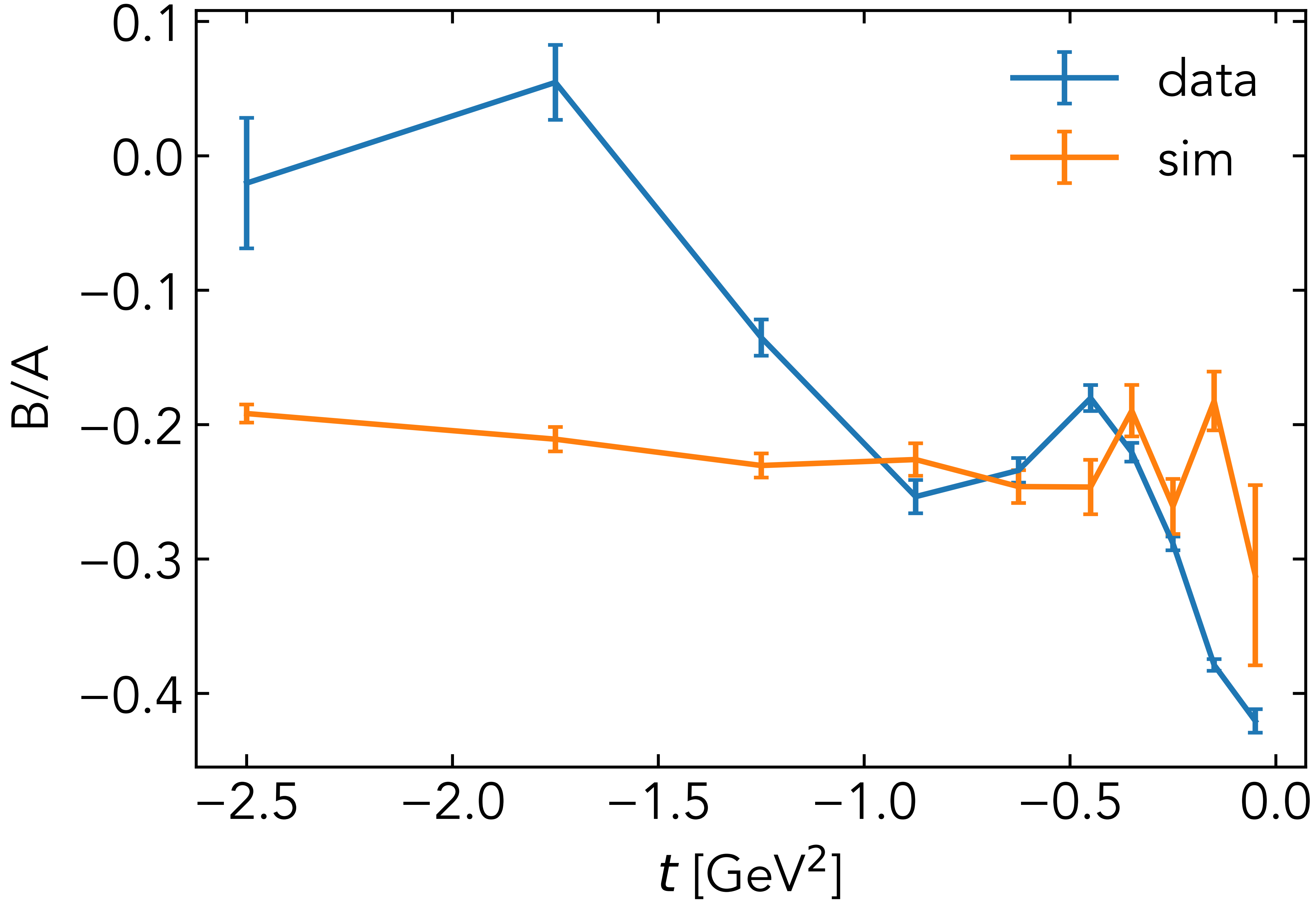


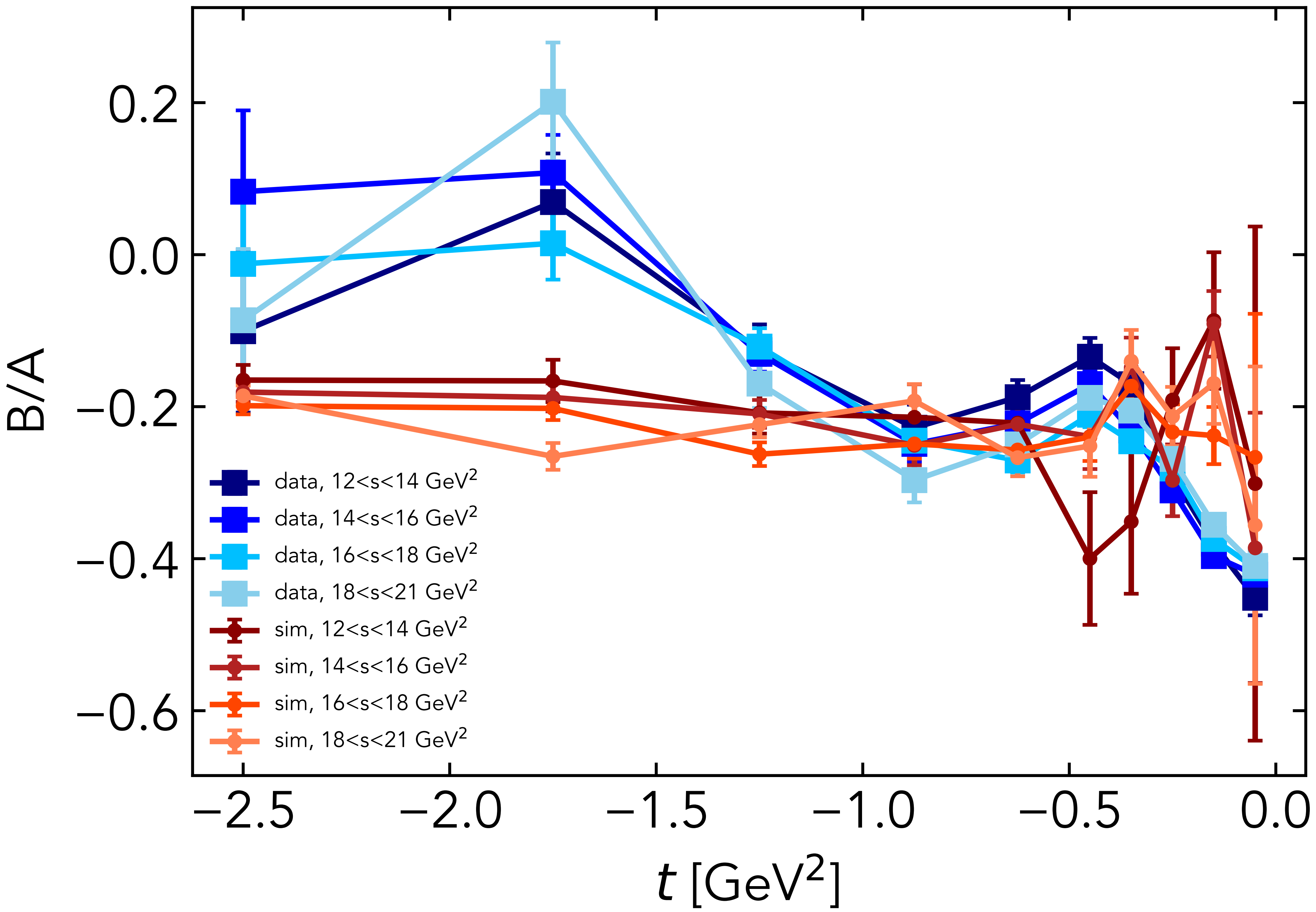
Nonresonant Contribution

$$\frac{dN}{dM_{2\pi}} = A \cdot \frac{\Gamma_\rho M_\rho M_{2\pi}}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} + B \cdot \frac{2\sqrt{M_\rho M_{2\pi} \Gamma_\rho} \cdot (M_\rho^2 - M_{2\pi}^2)}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} + poly2$$

$$\Gamma_\rho = (\sqrt{q/q_0})^3 \cdot \Gamma_0 \cdot M_\rho / M_{2\pi}$$

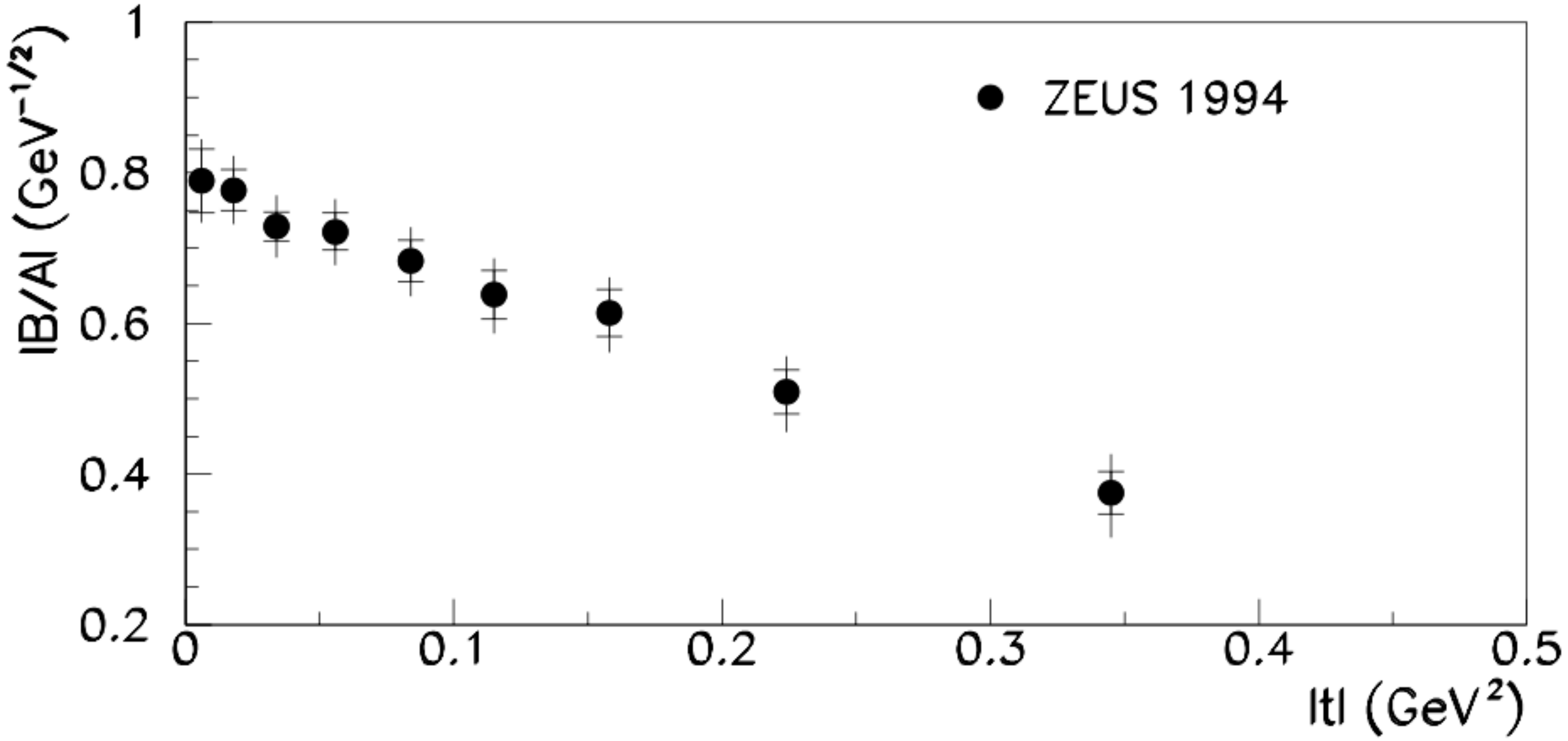
The interference strength |B/A| decreases as high t

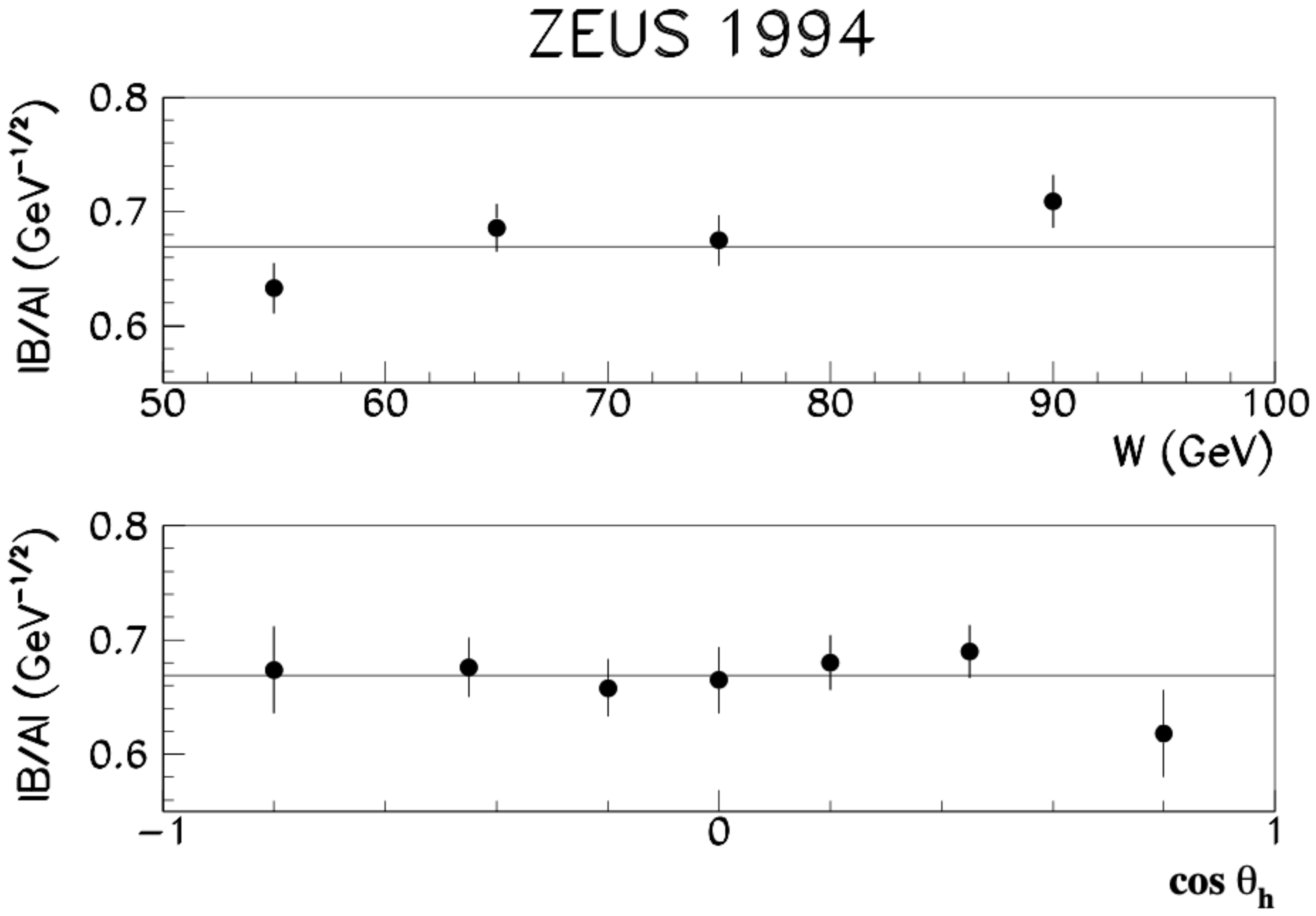




ZEUS Result

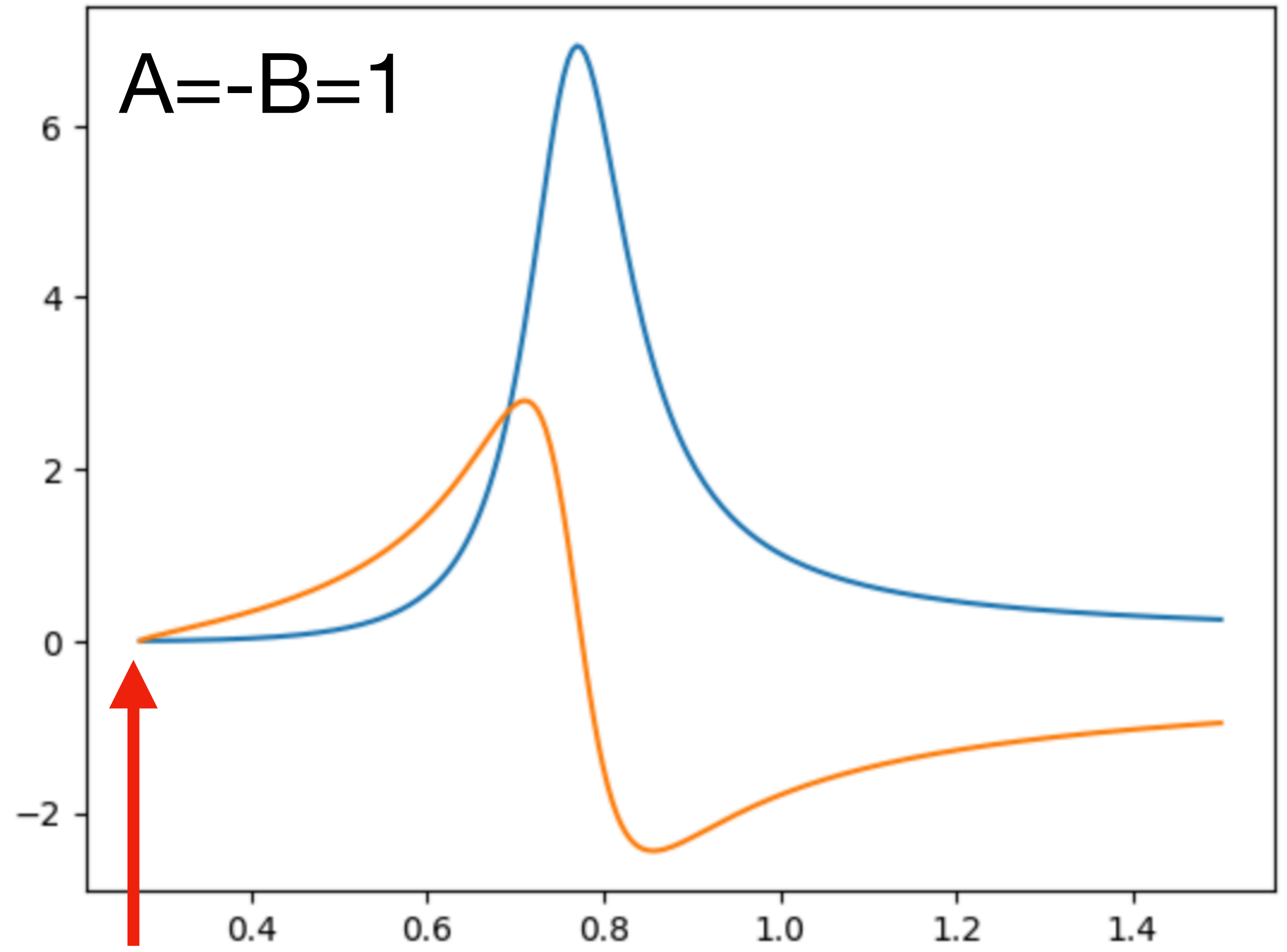
$$50 < \sqrt{s} < 100\ GeV$$



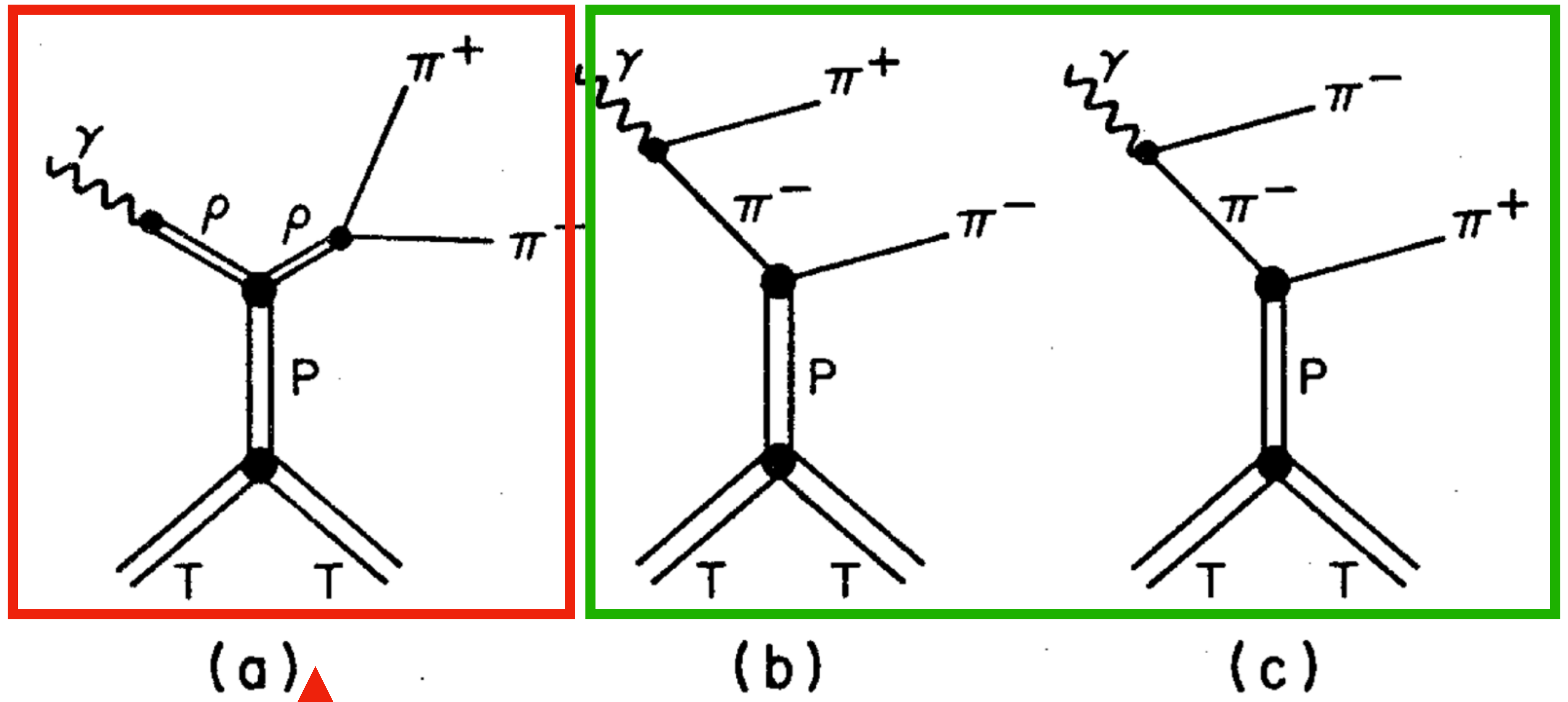


ZEUS Collaboration, “Elastic and proton dissociative ρ^0 photoproduction at HERA”, *Eur. Phys. J. C* **2** (1998) 247

Non-resonance ππ interfere the signal



$m_{\pi^0} + m_{\pi^-}$



$$\frac{dN}{dM_{2\pi}} = \left| A \cdot \frac{\sqrt{\Gamma_\rho M_\rho M_{2\pi}}}{(M_\rho^2 - M_{2\pi}^2) + iM_\rho \Gamma_\rho} + B \right|^2$$

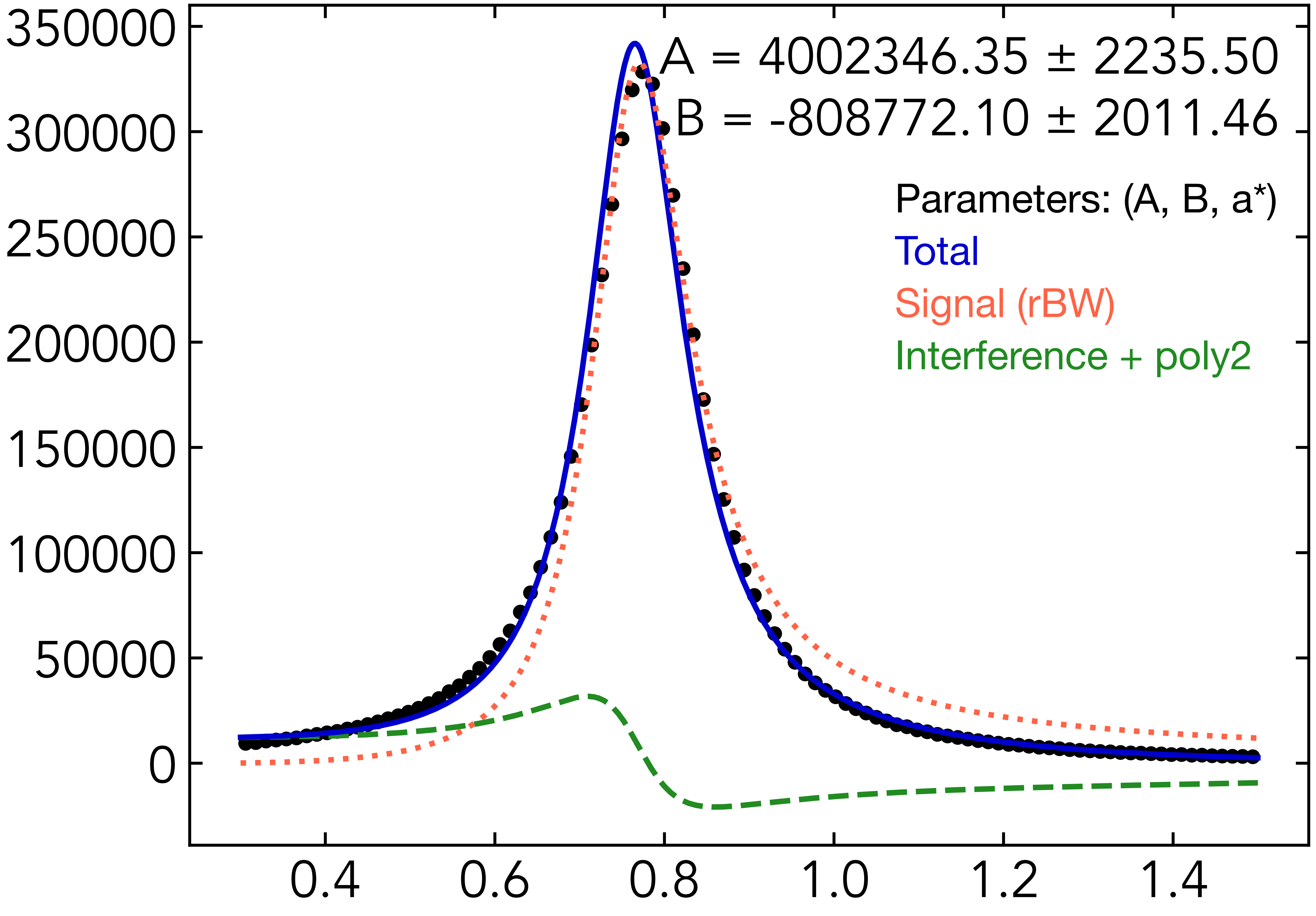
$$\frac{dN}{dM_{2\pi}} = A \cdot \frac{\Gamma_\rho M_\rho M_{2\pi}}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} + B \cdot \frac{\Gamma_\rho M_\rho M_{2\pi}}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2} \cdot \frac{2(M_\rho^2 - M_{2\pi}^2)}{\sqrt{M_\rho M_{2\pi} \Gamma_\rho}}$$

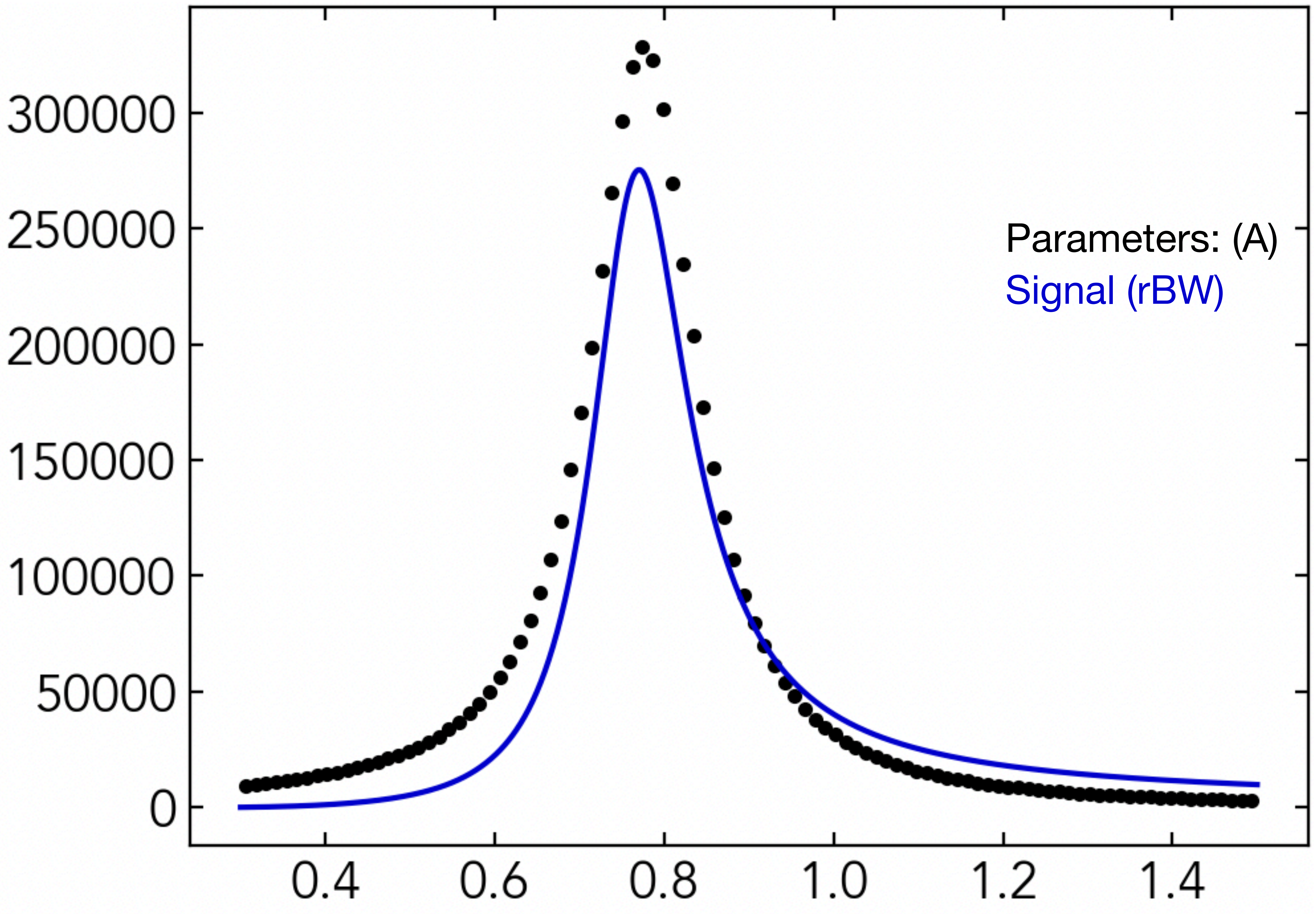
When $M_{2\pi} \to m_{\pi^0} + m_{\pi^-}, \Gamma_\rho \to 0$

Giese, R. (SLAC) Photoproduction of rho Mesons from Hydrogen and Deuterium from 9-GeV to 16-GeV
P.Soding,"On the apparent shift of the ρ meson mass in photoproduction",Phys.Lett. 19 (1966) 702

Thrown simulation

GCF Generator
6M Events
BKG: random trigger
Fixed ρ^- mass and width





Thrown simulation

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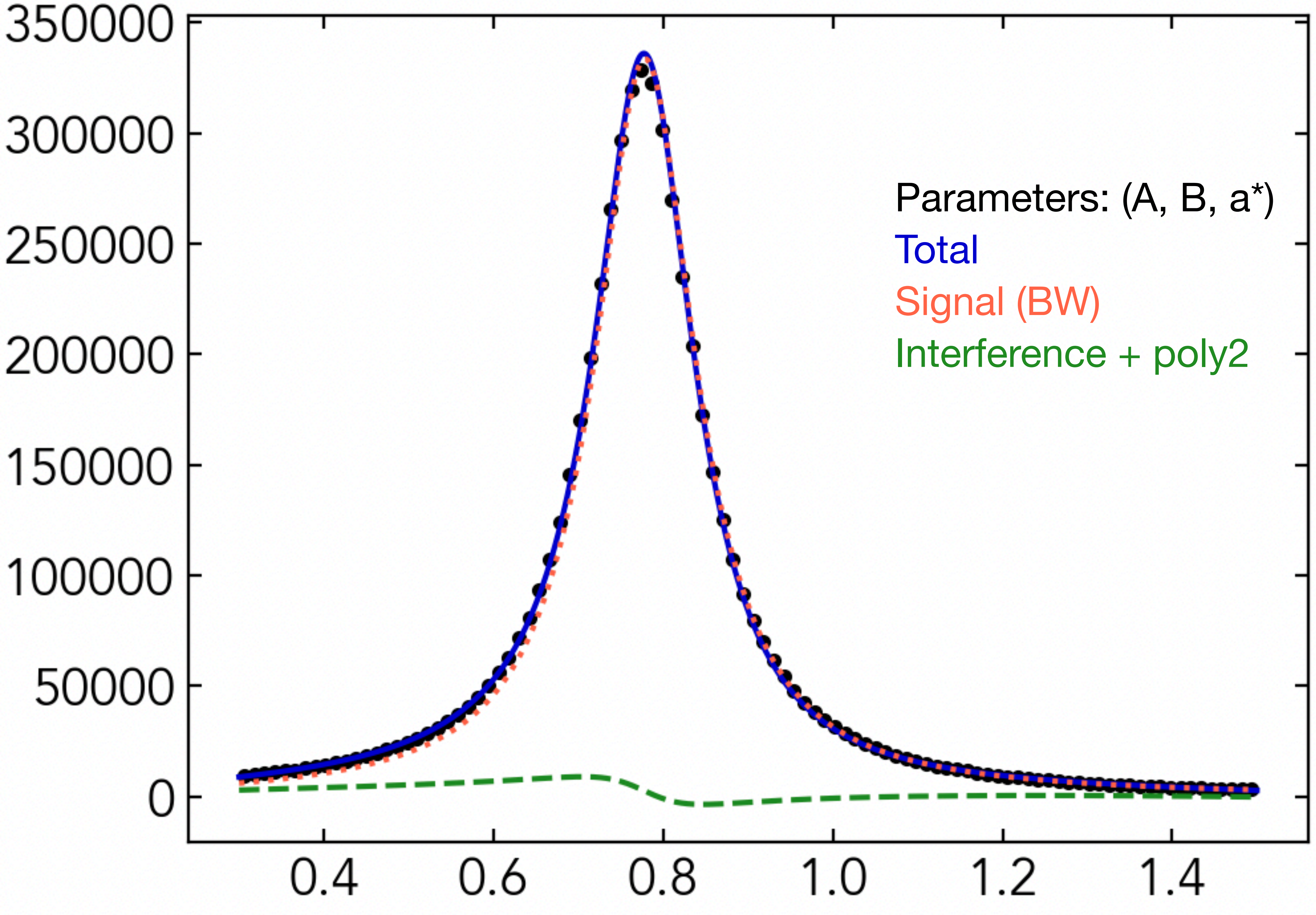

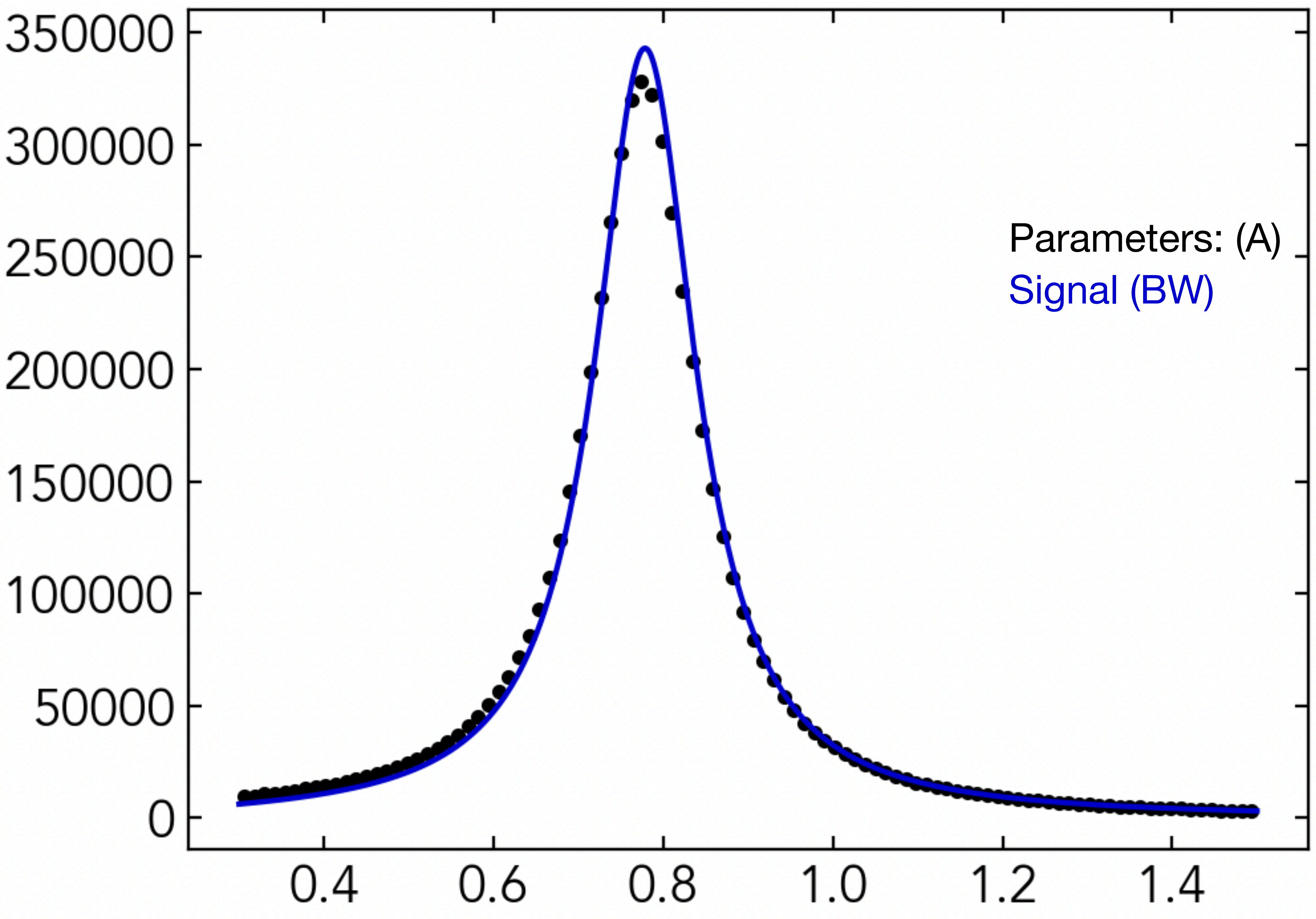

GCF Generator

- It turns out that the generator is using the regular Breit Wigner function.

```
do
  mMeson = myRand->BreitWigner(mMesonMean,gammaMeson);
while
  ((mMeson < mM_min) or (mMeson > mM_max));
do
  mBaryon = myRand->BreitWigner(mBaryonMean,gammaBaryon);
while
  ((mBaryon < mB_min) or (mBaryon > mB_max));
```

Next Step

- switch to phase-space correction relativistic Breit-Wigner function

$$\frac{dN}{dM_{2\pi}} \propto \frac{\Gamma_\rho M_\rho M_{2\pi}}{(M_\rho^2 - M_{2\pi}^2)^2 + M_\rho^2 \Gamma_\rho^2}, \ \Gamma_\rho = (q/q_0)^3 \cdot \Gamma_0 \cdot M_\rho / M_{2\pi}$$

Previous GlueX Result

3.1 Generator

We use the gen_amp generator included in the halld_sim framework to simulate the process $\gamma p \to p\pi^+\pi^-$. We assume an exponential 4-momentum transfer distribution e^{bt} with the slope parameter $b = 6\,(\mathrm{GeV}/c)^{-2}$. Since the GlueX experiment accepts only exclusive events with $|t|$ above a minimal 4-momentum transfer of $0.1\,(\mathrm{GeV}/c)^2$, we simulated only events with $-t > 0.05\,(\mathrm{GeV}/c)^2$ for efficiency purposes. This simplified model does not reproduce the experimentally observed t-distribution exactly (cf. Fig. 7a), but serves as a good approximation when binning finely in t.

We restricted the MC sample to the analyzed range in $\pi^+\pi^-$ invariant mass between 0.6 and $0.88\,\mathrm{GeV}/c^2$. We modeled the shape of the invariant mass using a relativistic Breit-Wigner function [21] with the orbital angular momentum barrier factor F [22] according to $L = 1$:

$$BW(m) = \frac{\sqrt{m_0\Gamma_0}}{m^2 - m_0^2 - i\Gamma(m,L)} \tag{2}$$

$$\Gamma(m,L) = \Gamma_0 \frac{q}{m}\frac{m_0}{q_0}\left[\frac{F(q,L)}{F(q_0,L)}\right]^2 \tag{3}$$

where q signifies the breakup momentum. The reconstructed mass distribution reproduces the experimentally measured one with the parameters $m_0 = 0.757\,\mathrm{GeV}/c^2$ and $\Gamma_0 = 0.146\,\mathrm{GeV}/c^2$ (cf. Figure 7b). The apparent shift of the resonance mass by about $18\,\mathrm{MeV}/c^2$ compared to the PDG value [18] will be discussed in Appendix E.

GlueX Analysis Note:
Spin-Density Matrix Elements for $\rho(770)$ Meson Photoproduction

Alexander Austregesilo[1], Naomi S. Jarvis[2] and Curtis A. Meyer[2]

[1]TJNAF
[2]CMU

March 30, 2023

The mass shift is from interference

- We need to consider the interference from non-resonant $\pi\pi$
- Have been observed in ALICE, CMS, STAR, etc.
- Several parameterizations of the shape exist
- Soding Model

$$\frac{\mathrm{d}N_{\pi^+\pi^-}}{\mathrm{d}M_{\pi^+\pi^-}} = \left| A \frac{\sqrt{M_{\pi^+\pi^-} M_{\rho(770)} \Gamma_{\rho(770)}}}{M^2_{\pi^+\pi^-} - M^2_{\rho(770)^0} + iM_{\rho(770)^0}\Gamma_{\rho(770)}} + B + Ce^{i\phi_\omega} \frac{\sqrt{M_{\pi^+\pi^-} M_{\omega(783)} \Gamma_{\omega(783)\to\pi\pi}}}{M^2_{\pi^+\pi^-} - M^2_{\omega(783)} + iM_{\omega(783)^0}\Gamma_{\omega(783)}} \right|^2$$

$$\Gamma_{\rho(770)} = \Gamma_0 \frac{M_{\rho(770)^0}}{M_{\pi^+\pi^-}} \left[\frac{M^2_{\pi^+\pi^-} - 4m^2_{\pi^\pm}}{M^2_{\rho(770)^0} - 4m^2_{\pi^\pm}} \right]^{\frac{3}{2}},$$

$$\Gamma_{\omega(783)} = \Gamma_0 \frac{M_{\omega(783)}}{M_{\pi^+\pi^-}} \left[\frac{M^2_{\pi^+\pi^-} - 9m^2_{\pi^\pm}}{M^2_{\omega(783)} - 9m^2_{\pi^\pm}} \right]^{\frac{3}{2}},$$