Refined Simulations of Double Pion Electroproduction for CLAS22

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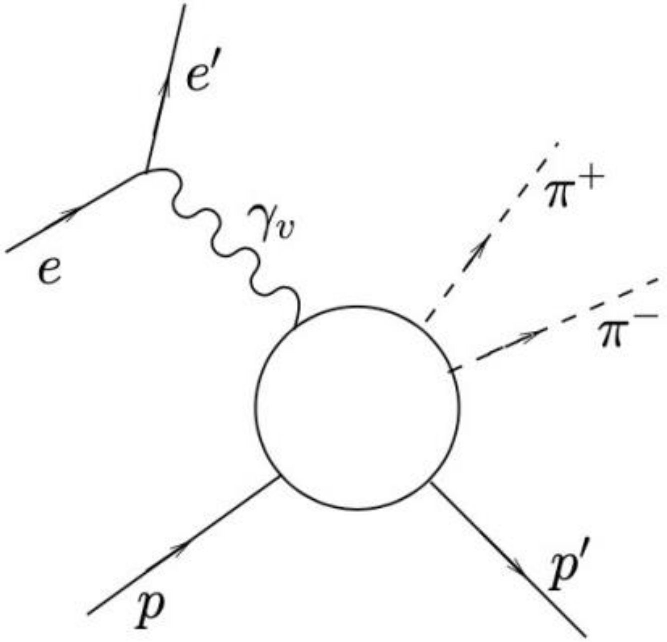
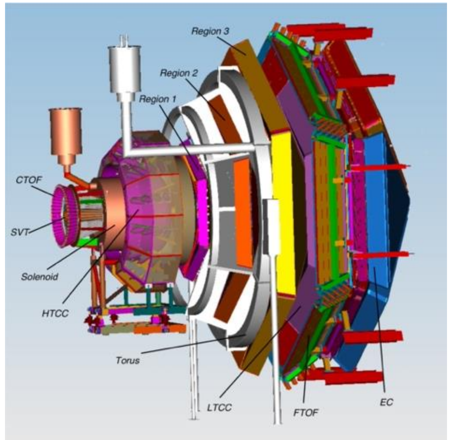
Context

$$e + p \rightarrow e' + p' + \pi^+ + \pi^-$$



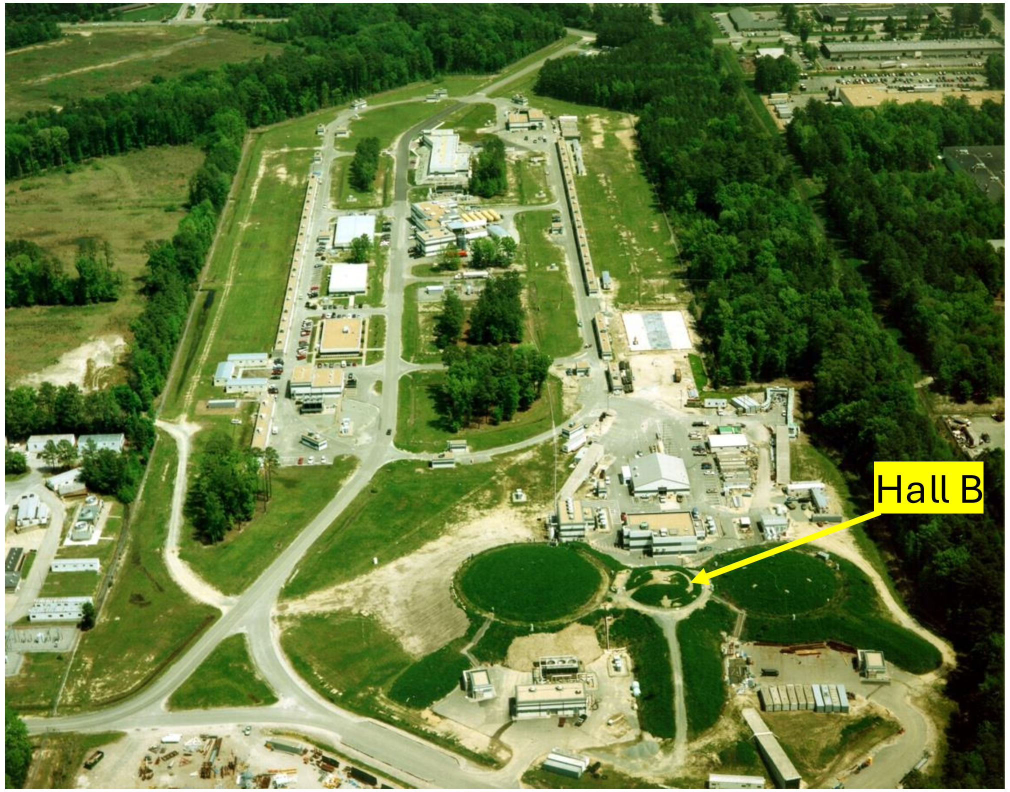
- Simulating final state used by the program to extract cross sections and resonance parameters (in the resonance region)
- Includes comparison with CLAS12 TwoPion channel
- Feasibility study to see if these measurements can be extended to CLAS22



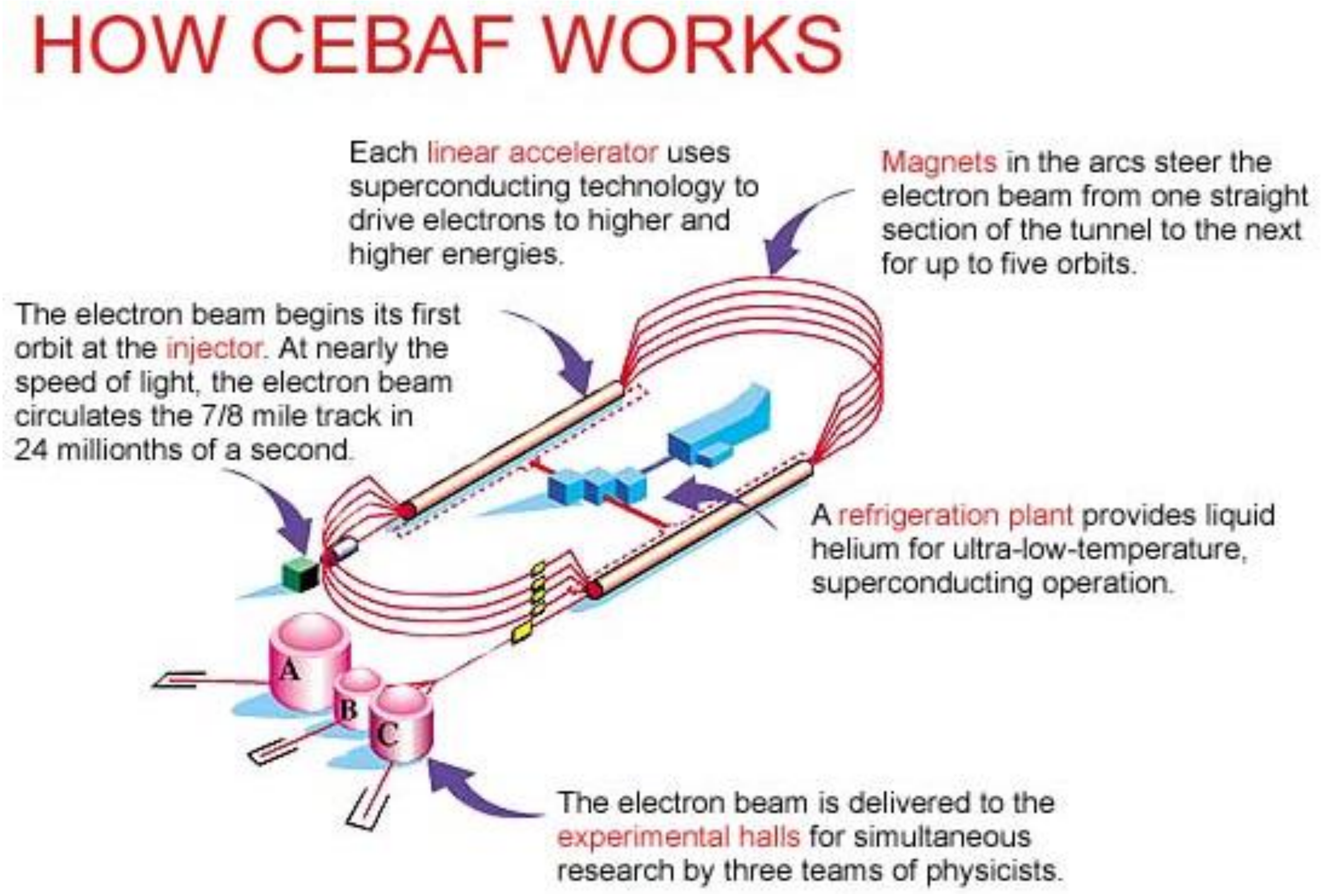
Outline

- Brief Introduction
  - Experiment: CLAS12
  - Simulation: TWOPEG
- Updated histograms
  - Acceptance
  - Momentum vs. Δt
  - Missing mass squared resolution
  - Slice normalization: W vs. MM^2, Q^2 vs. MM^2
- Feasibility
  - Integrated hadronic cross section
  - Needed integrated luminosity, needed integrated charge, and needed beam time

Continuous Electron Beam Accelerator Facility



Thomas Jefferson National Accelerator Facility (JLab)
Newport News, VA

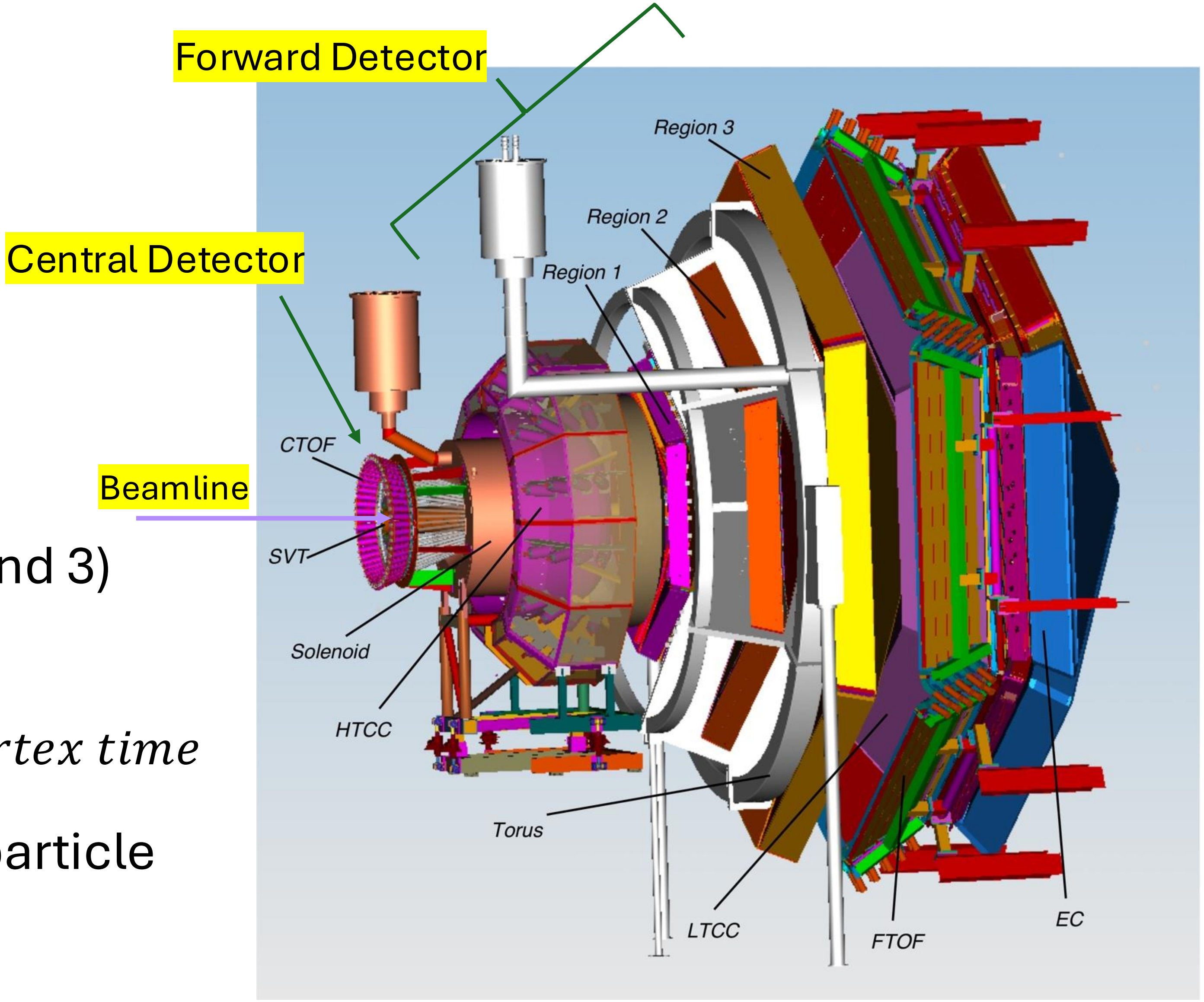


CLAS12

- **C**EBAF **L**arge **A**cceptance **S**pectrometer
  - **12** GeV
- Forward Detector
  - Drift Chambers (Regions 1, 2, and 3)
  - Forward Time-of-Flight (FTOF)

$$\Delta t = electron\ vertex\ time\ - hadron\ vertex\ time$$

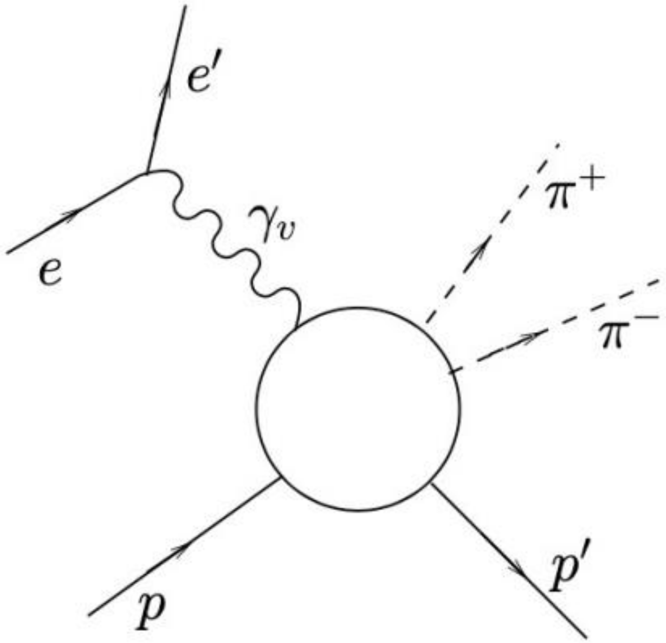
  - Vertex time: calculated time a particle interacted with the target



TWOPEG: Two-Pion Event Generator

- For $\pi^+\pi^-$ electroproduction off protons
  - Iuliia Skorodumina
- Available on GitHub
- Weighted event generation
- Each event is weighted by cross section
  - Cross sections include physics of double pion electroproduction in each W-Q^2 bin
- Produces LUND files
- LUND format limited to precision 6

$$e + p \to e' + p' + \pi^+ + \pi^-$$

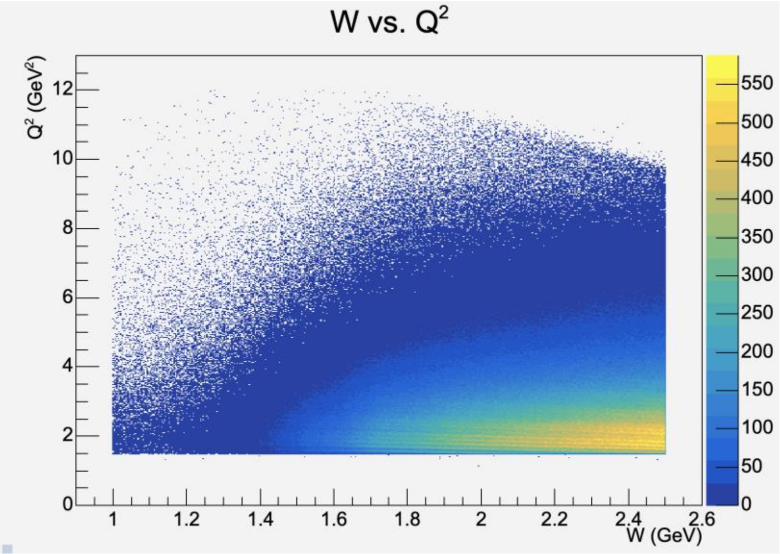


$$W = \sqrt{(p_\mu + q_\mu)(p^\mu + q^\mu)} = \sqrt{(p'_\mu + \pi^+_\mu + \pi^-_\mu)(p'^\mu + \pi^{+\mu} + \pi^{-\mu})}$$

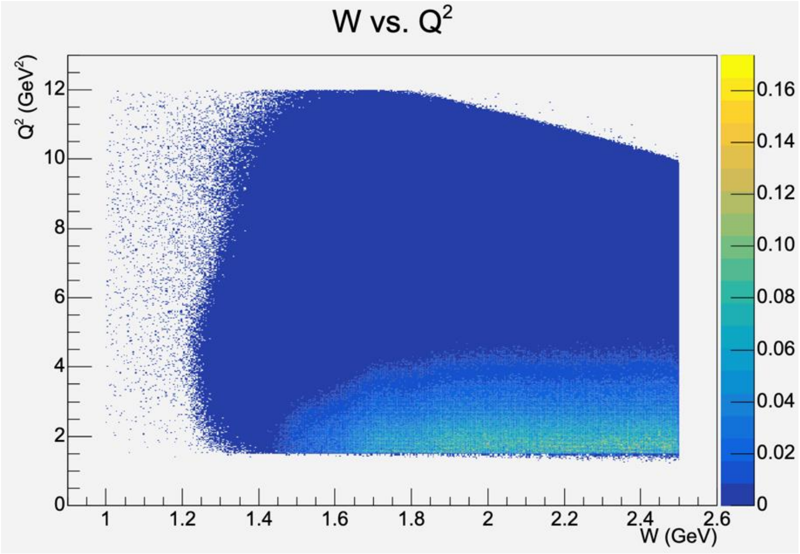
$$Q^2 = -q_\mu q^\mu, \quad q^\mu = e^\mu - e'^\mu$$

Invariant mass vs. four-momentum transfer squared (W vs. Q^2)

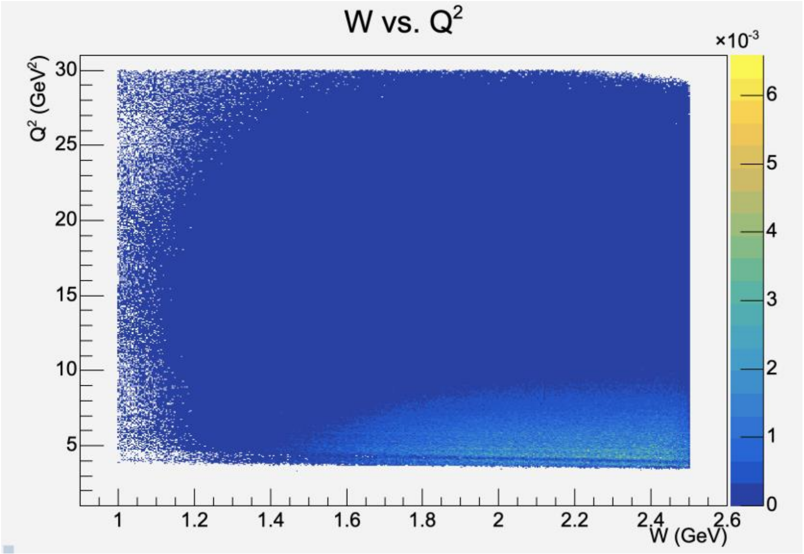
10.6 GeV experiment
Fall 2018, inbending, pass 2, golden runs



10.6 GeV simulation
TWOPEG event generator, pass 2



22.0 GeV simulation
TWOPEG event generator, pass 2

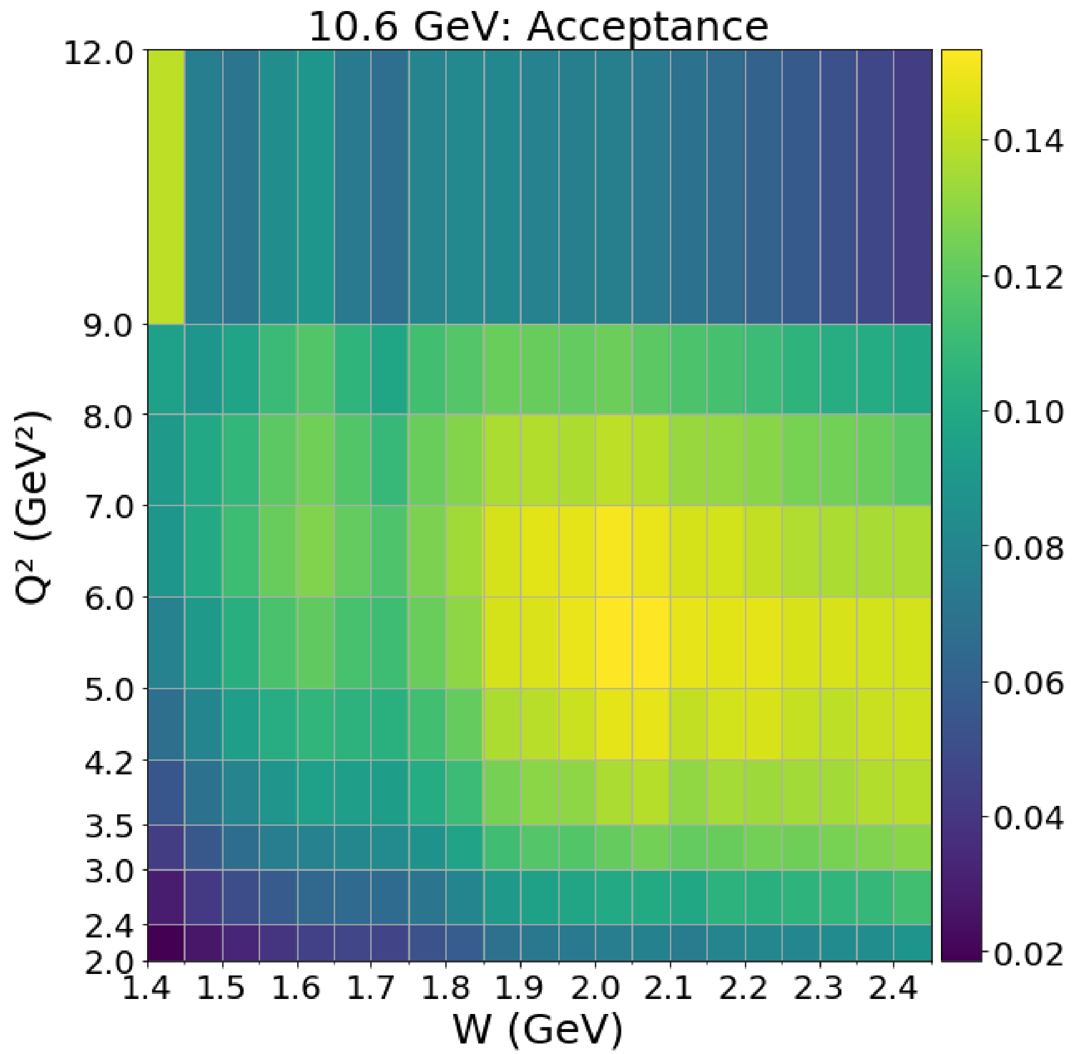


- Goal for 22 GeV: increase four momentum transfer (Q^2)

$$W = \sqrt{(p_\mu + q_\mu)(p^\mu + q^\mu)} = \sqrt{(p'_\mu + \pi^+_\mu + \pi^-_\mu)(p'^\mu + \pi^{+\mu} + \pi^{-\mu})}$$

$$Q^2 = -q_\mu q^\mu, \quad q^\mu = e^\mu - e'^\mu$$

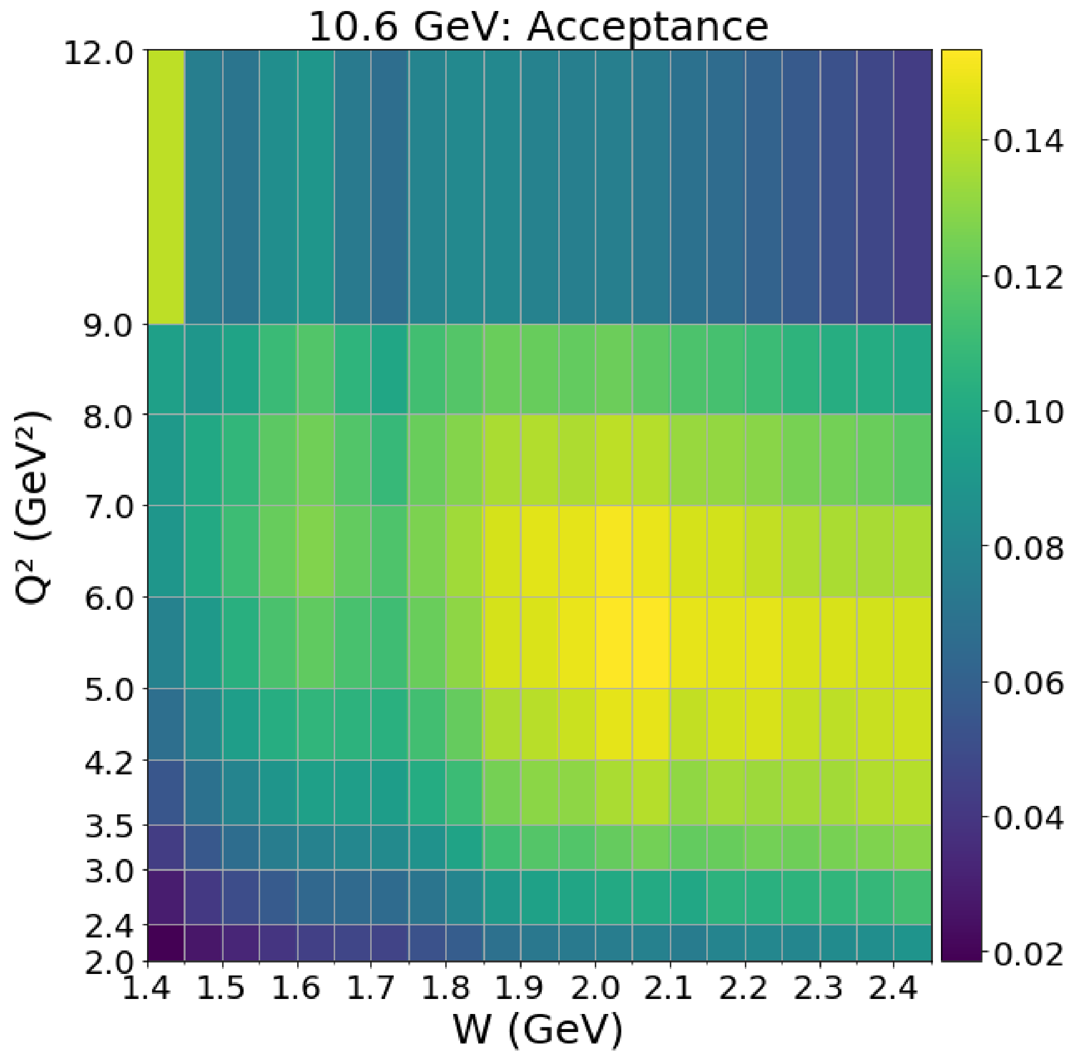
Acceptance



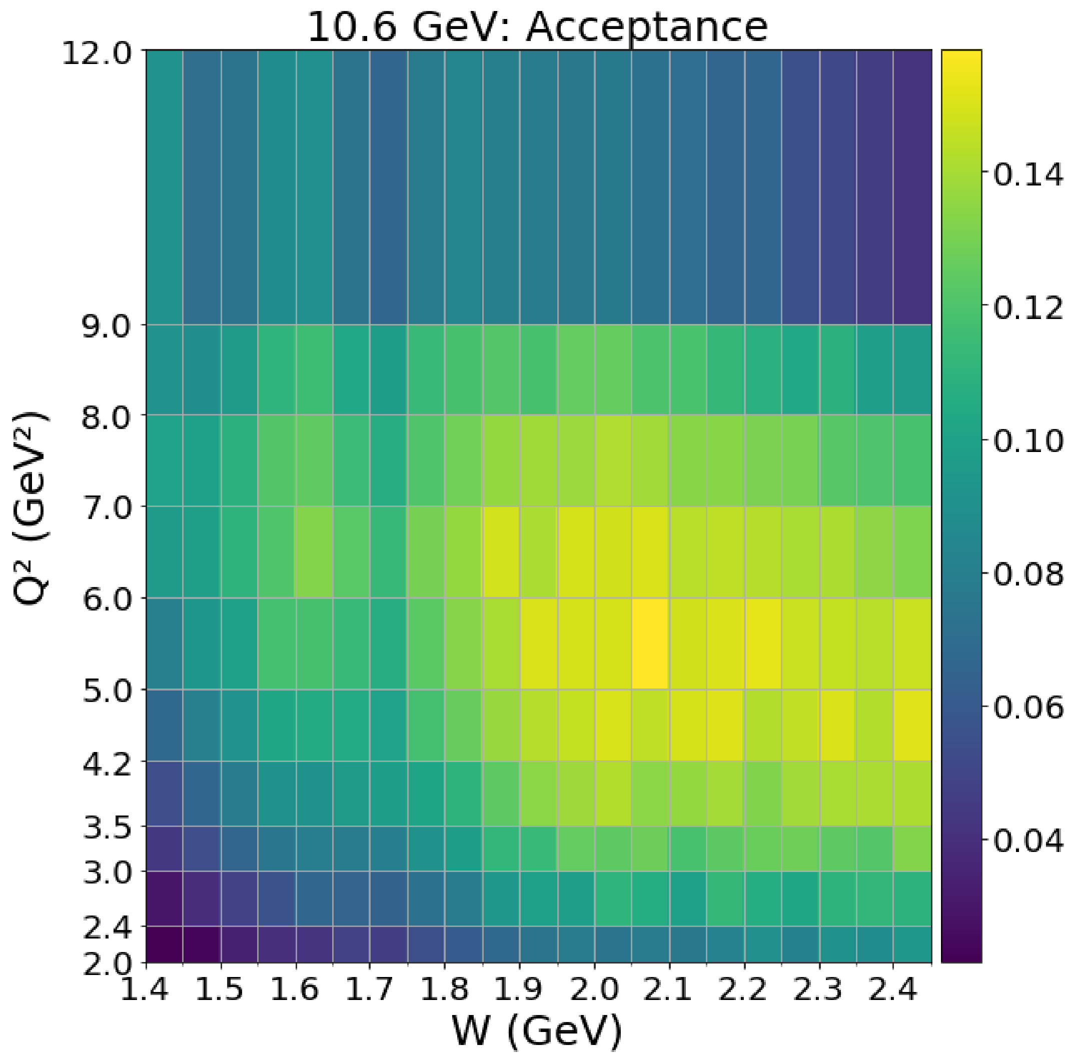
$$\text{Acceptance} = \frac{\sum \text{weights}_{\text{reconstructed}}}{\sum \text{weights}_{\text{generated}}}$$

- Weights are cross sections averaged in each bin
- Artificially large acceptance (yellow bin, low W, high Q^2)
- Limited number of significant figures
- Weights assigned zero due to lack of precision

Acceptance

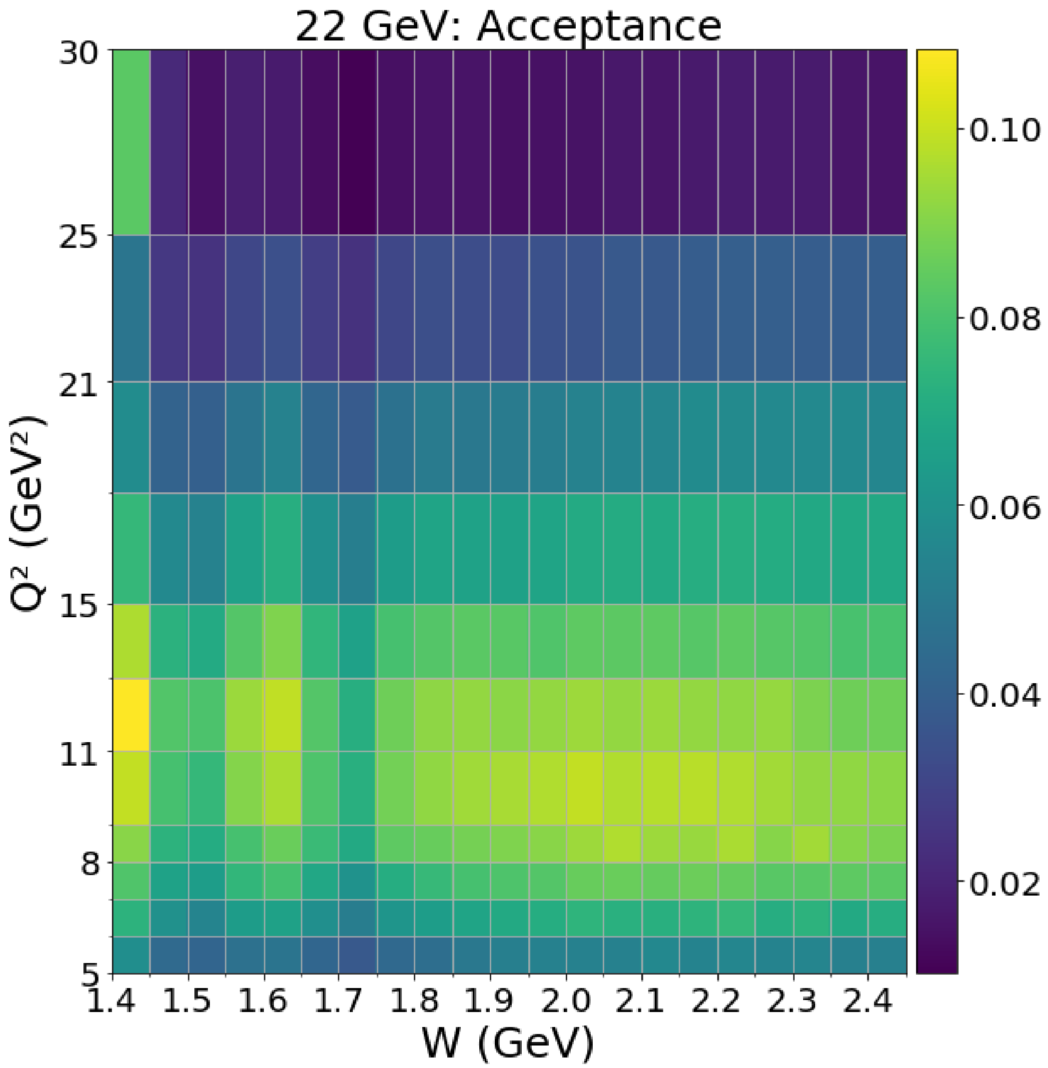


10.6 GeV: Acceptance
Q² (GeV²)
W (GeV)
12.0
9.0
8.0
7.0
6.0
5.0
4.2
3.5
3.0
2.4
2.0
1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4
0.14
0.12
0.10
0.08
0.06
0.04
0.02



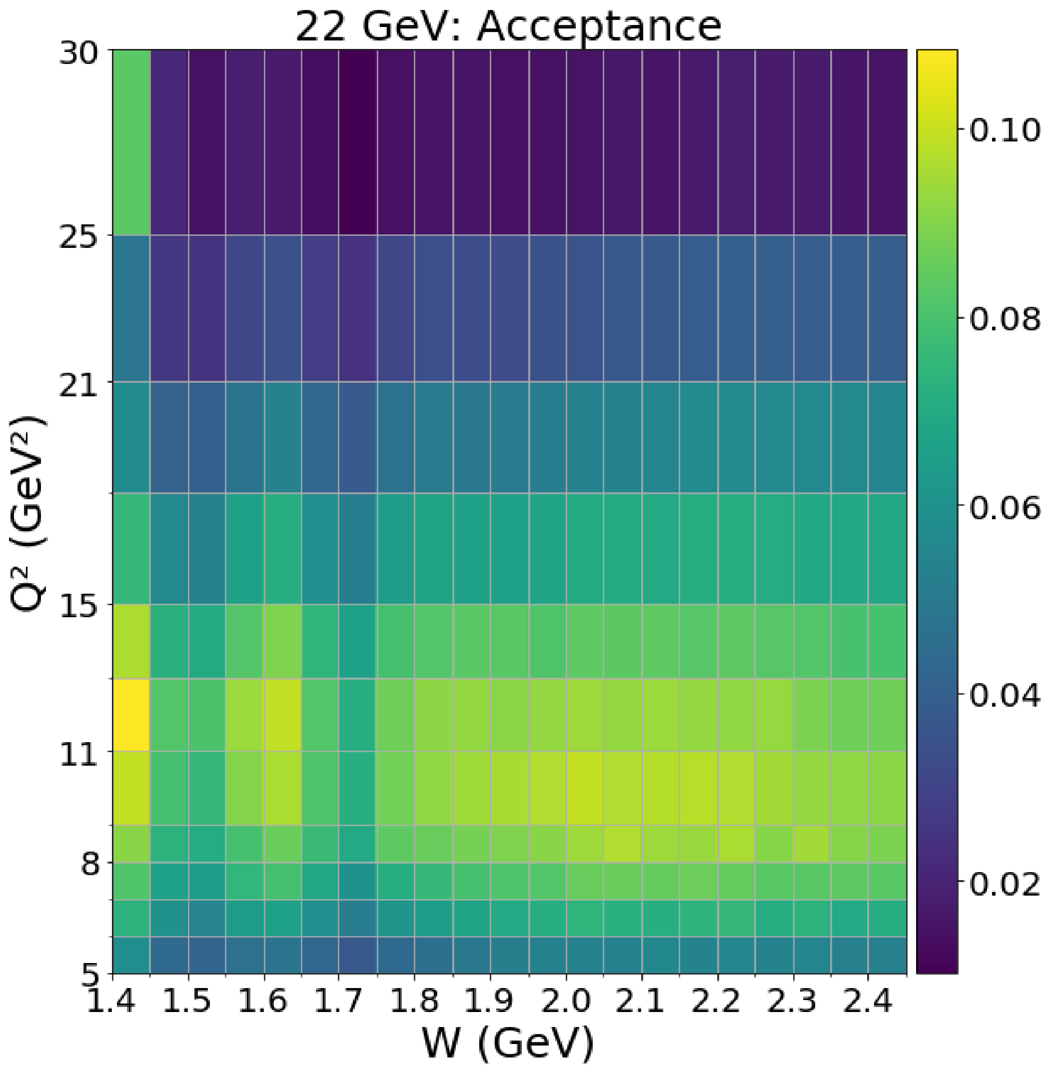
10.6 GeV: Acceptance
Q² (GeV²)
W (GeV)
12.0
9.0
8.0
7.0
6.0
5.0
4.2
3.5
3.0
2.4
2.0
1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4
0.14
0.12
0.10
0.08
0.06
0.04

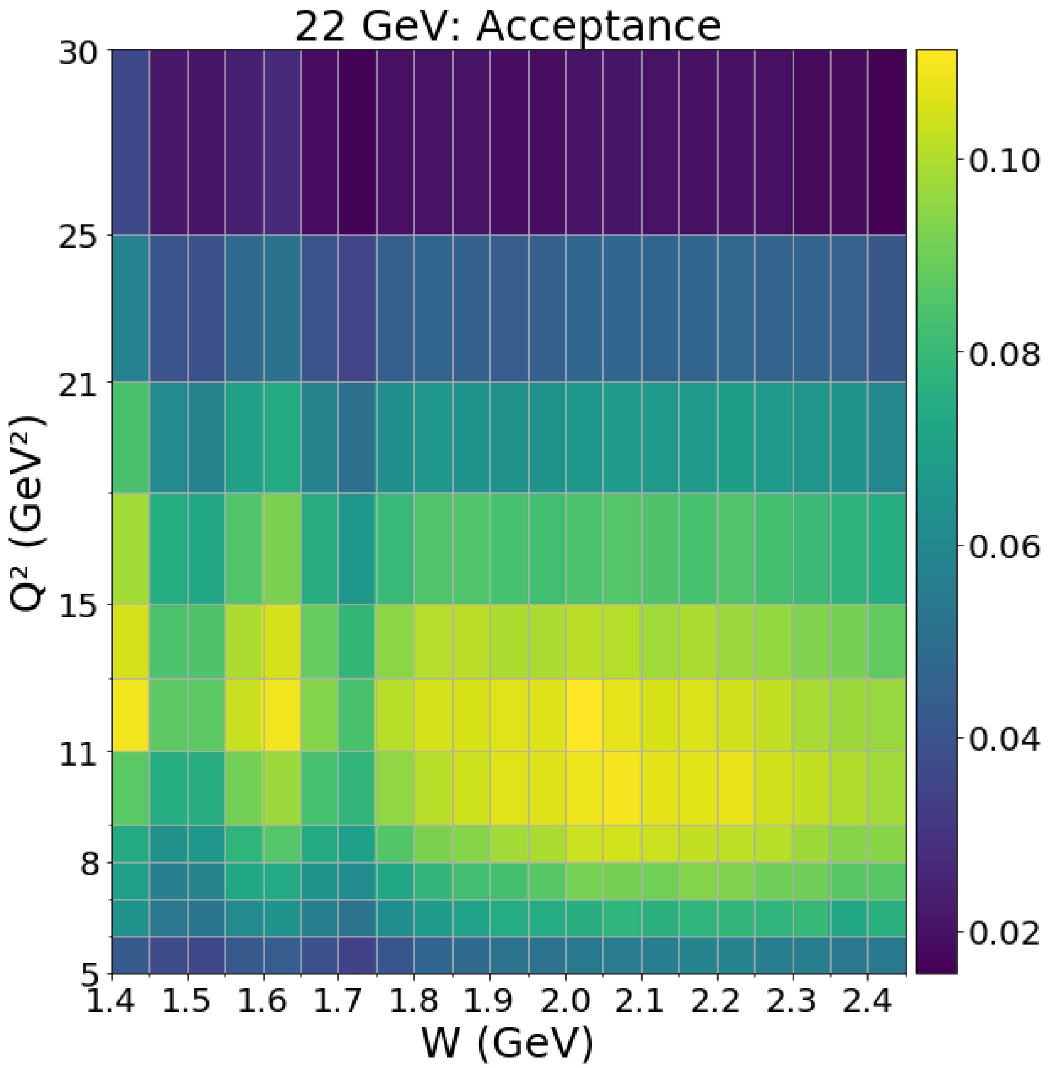
Acceptance



- Similar problem seen in 22 GeV simulation
- Low W, high Q^2 range known for weights equal to zero
- Zeros due to lack of precision
- Increase precision, decrease artificially high acceptance

Acceptance


22 GeV: Acceptance
30
25
21
15
11
8
5
Q² (GeV²)
1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4
W (GeV)
0.10
0.08
0.06
0.04
0.02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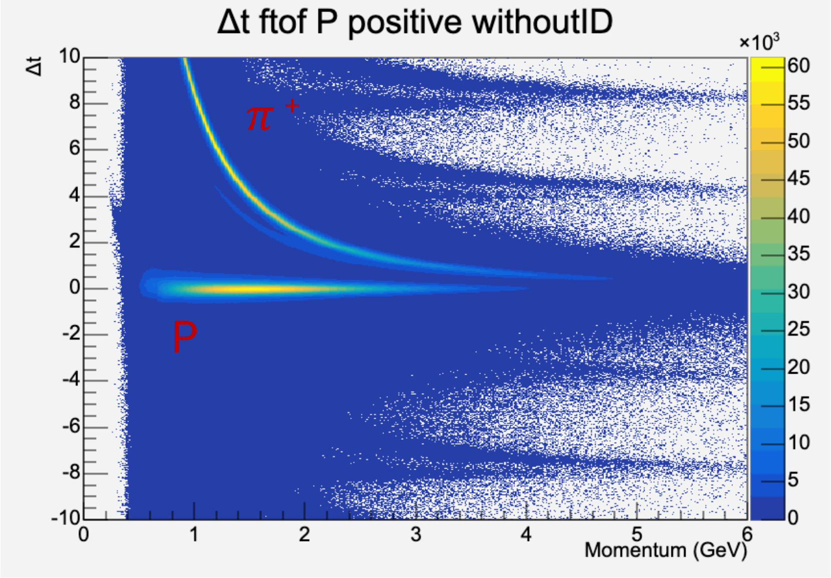
W (GeV)
0.10
0.08
0.06
0.04
0.02

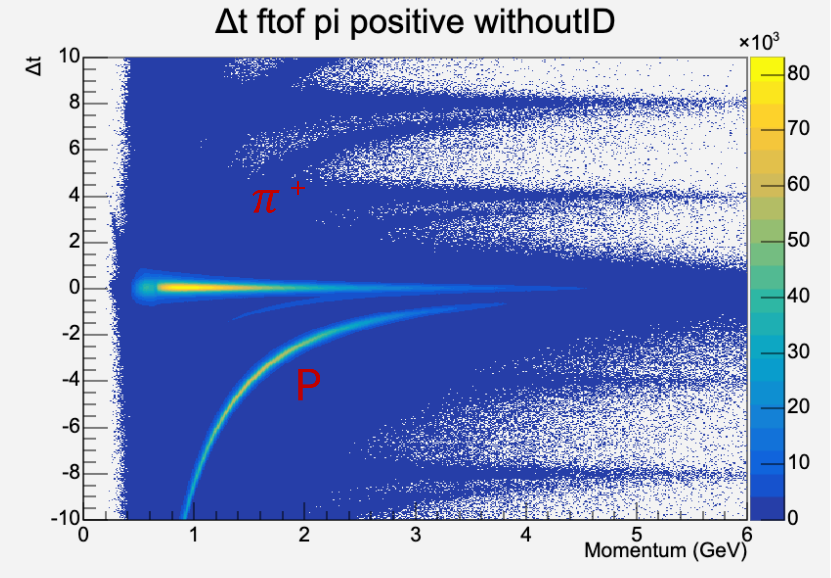
Momentum vs. Δt, forward detector, without PID

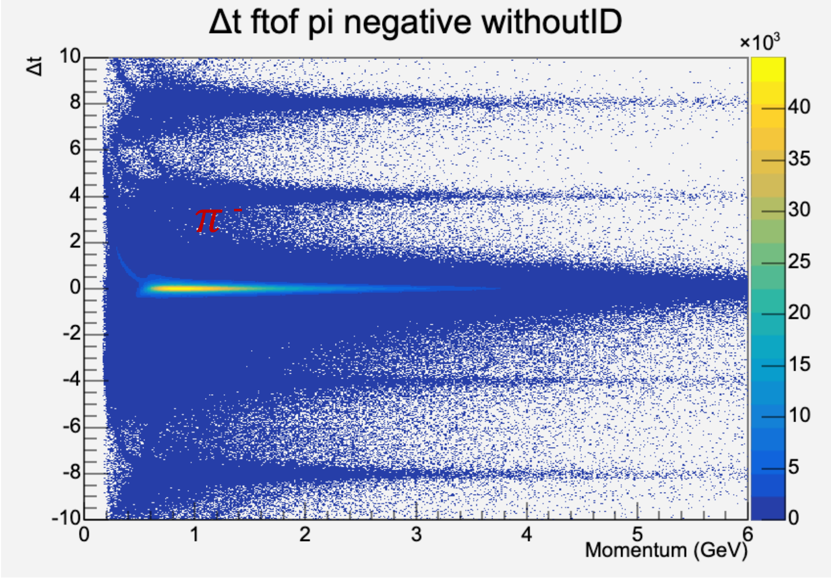
$$\Delta t = electron\ vertex\ time\ - hadron\ vertex\ time$$

10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs







Momentum vs. Δt, forward detector, without PID

10.6 GeV experiment

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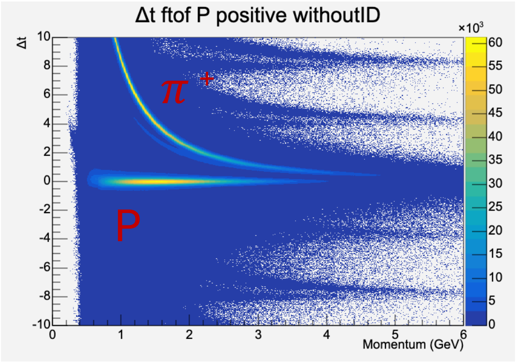

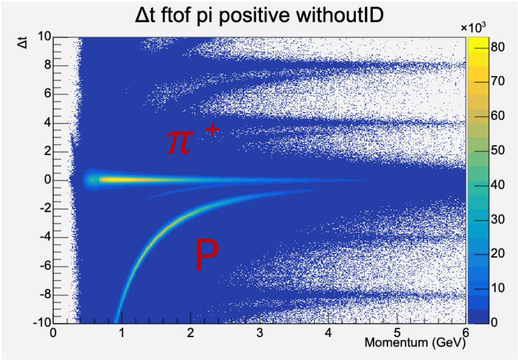

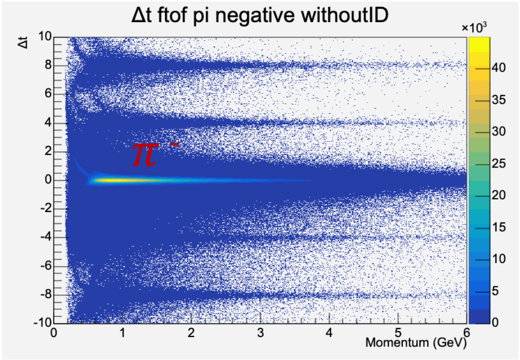

Momentum vs. Δt, forward detector, without PID

10.6 GeV experiment

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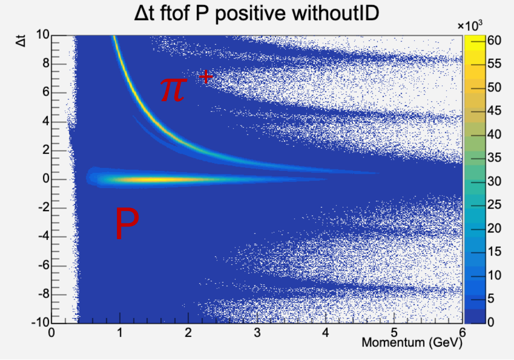
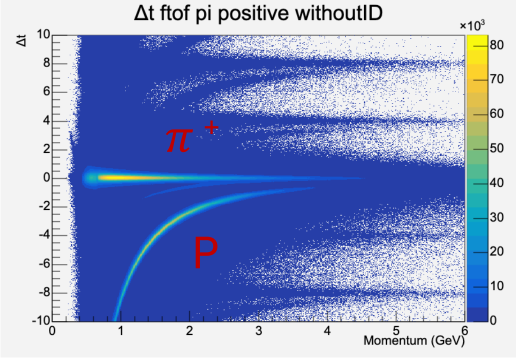
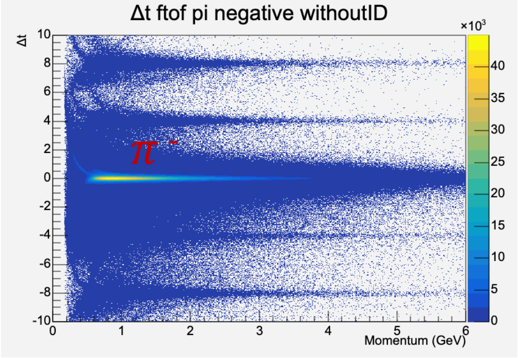
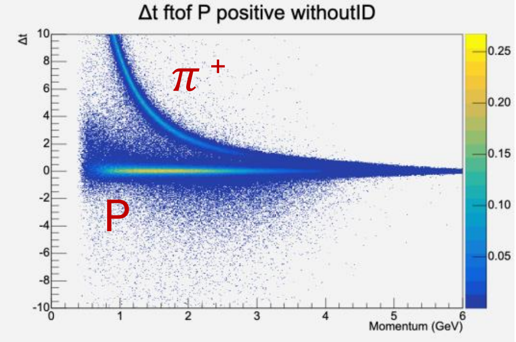


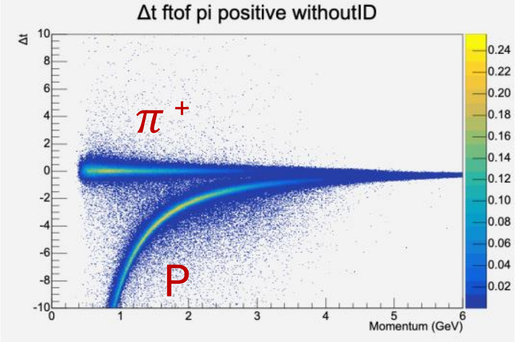


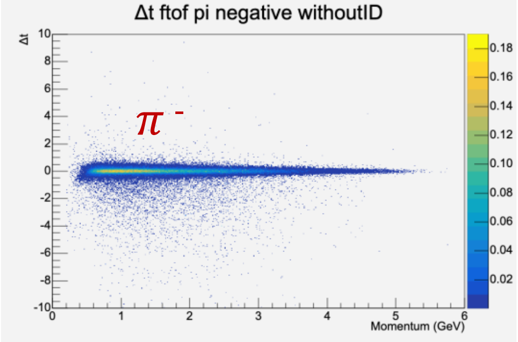


10.6 GeV simulation

TWOPEG event generator, pass 2

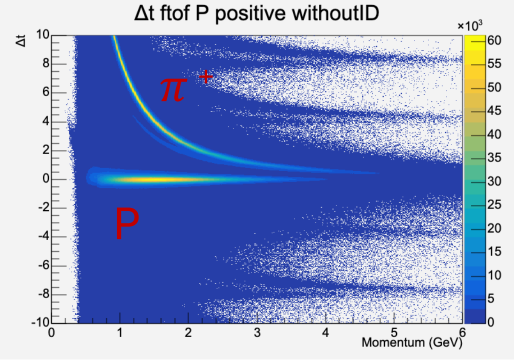


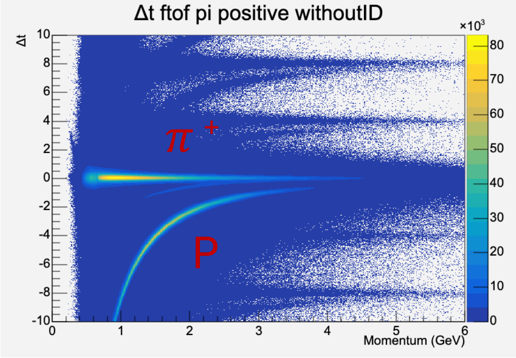


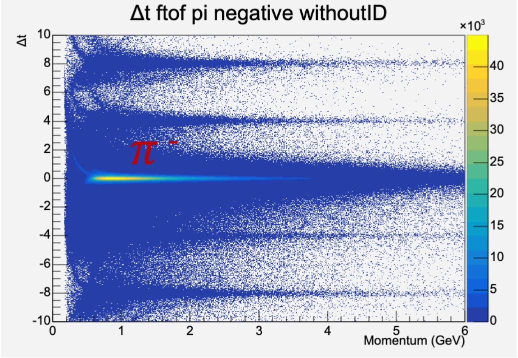


Momentum vs. Δt, forward detector, without PID

10.6 GeV experiment
Fall 2018, inbending, pass 2, golden runs







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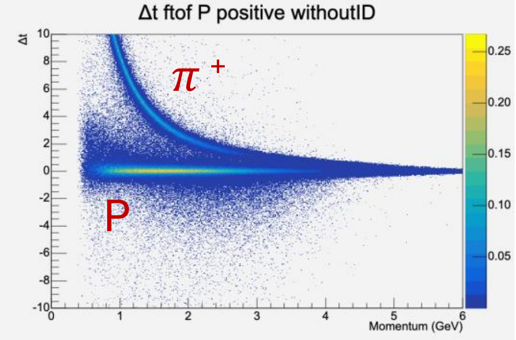
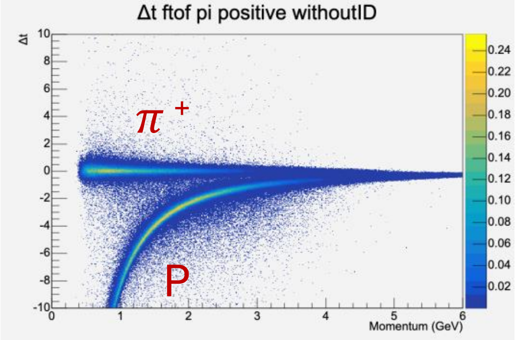
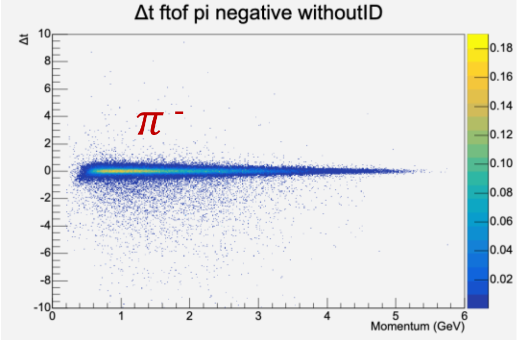
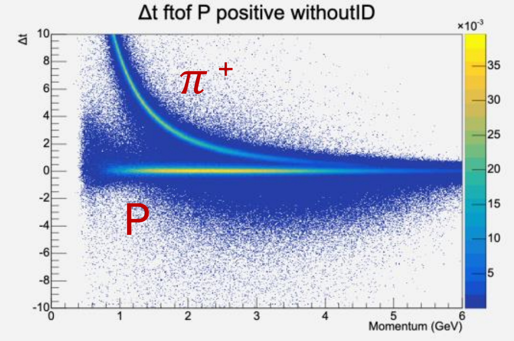
TWOPEG event generator, pass 2

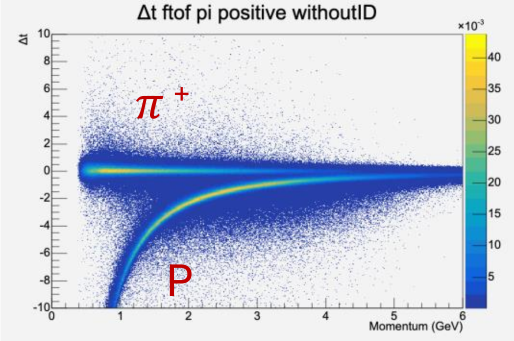


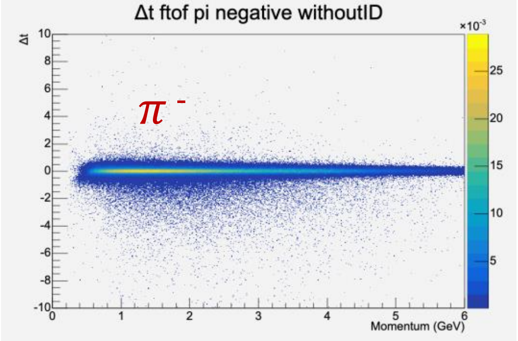




22.0 GeV simulation
TWOPEG event generator, pass 2

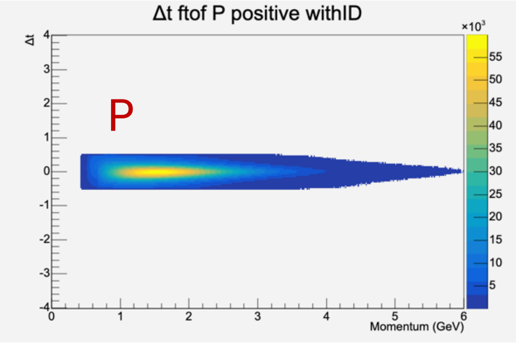


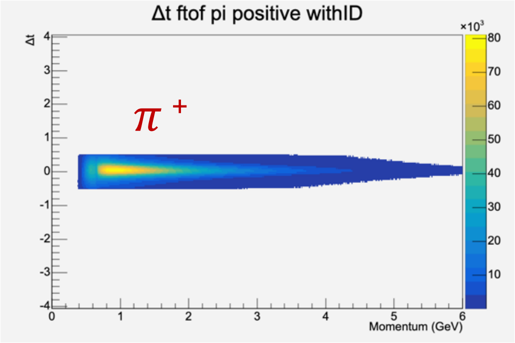


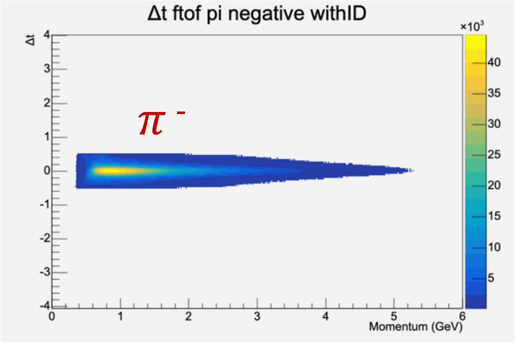


Momentum vs. Δt, forward detector, with PID

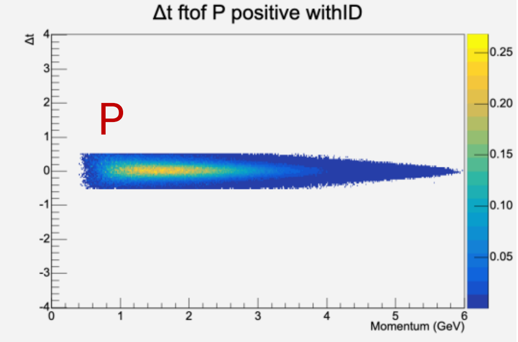
10.6 GeV experiment
Fall 2018, inbending, pass 2, golden runs

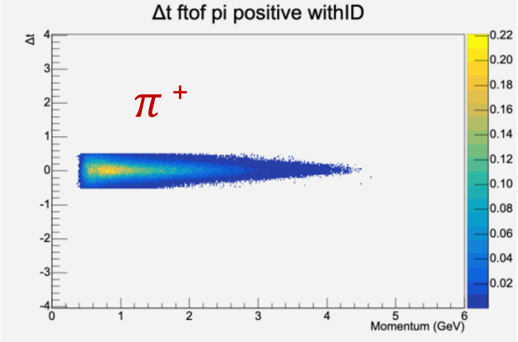


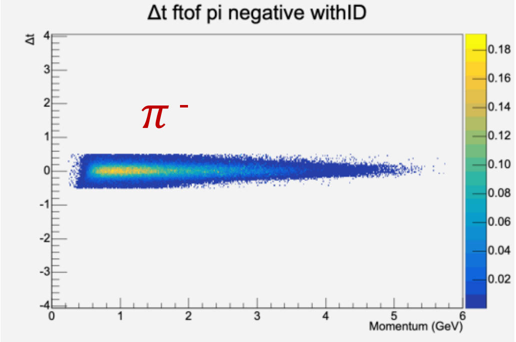




10.6 GeV simulation
TWOPEG event generator, pass 2







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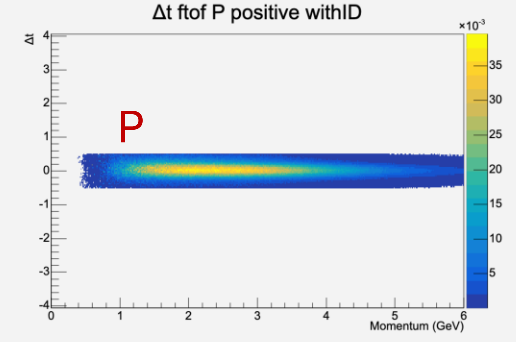
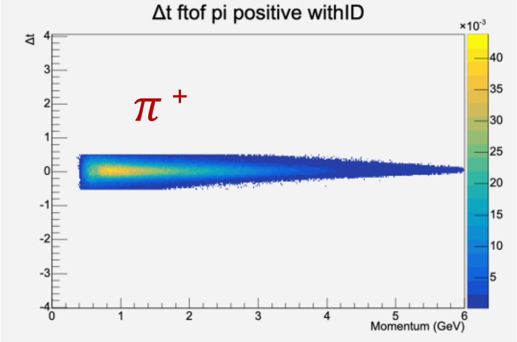
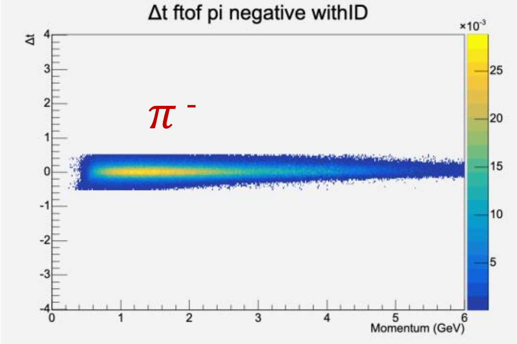


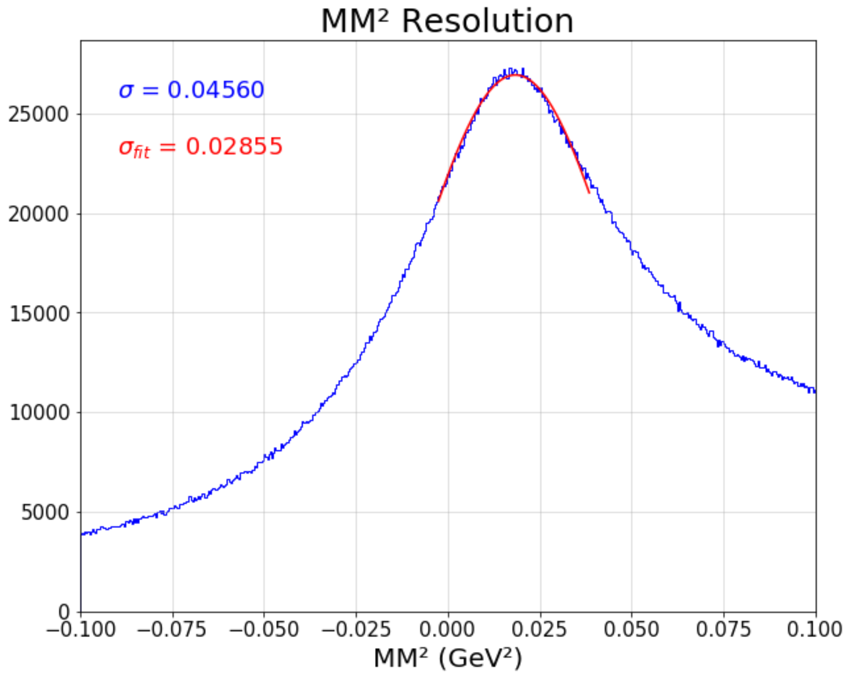




Missing Mass Squared Resolution, mPim

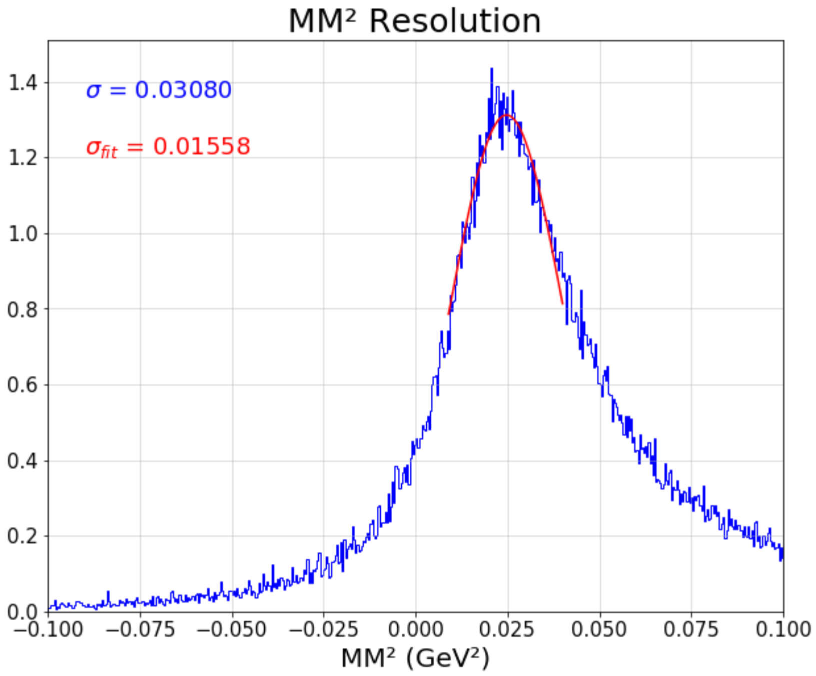
10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs



10.6 GeV simulation

TWOPEG event generator, pass 2



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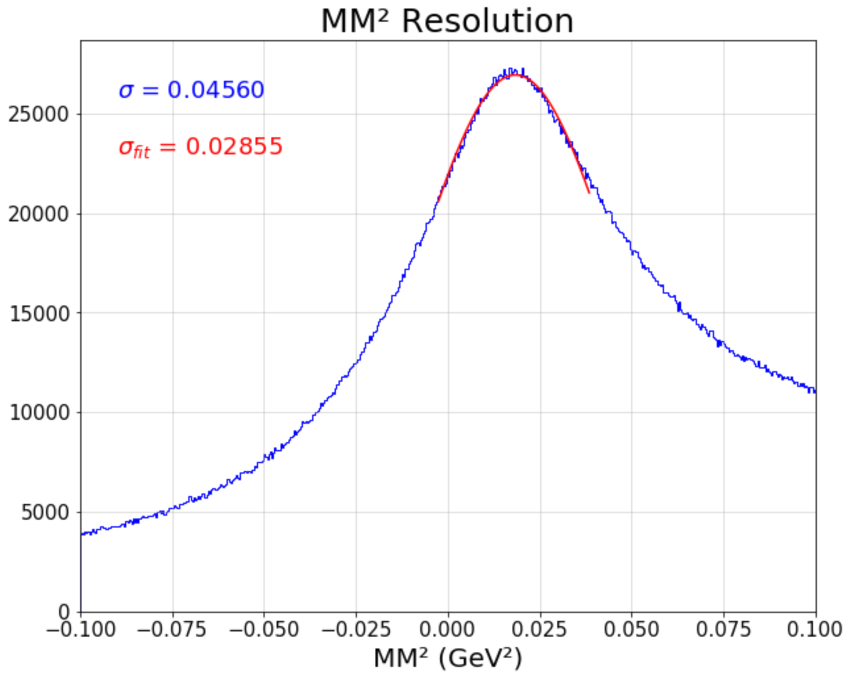

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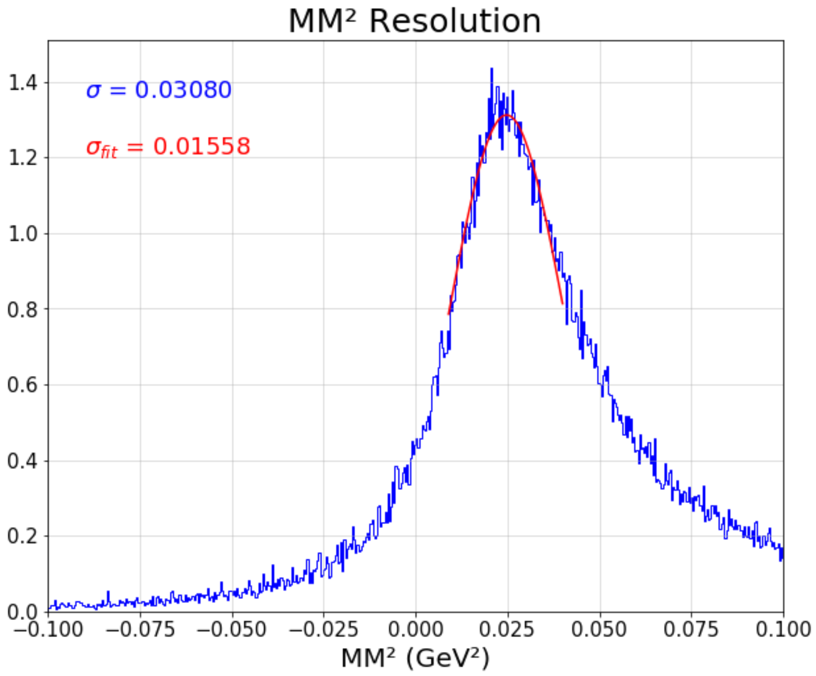
TWOPEG event generator, pass 2



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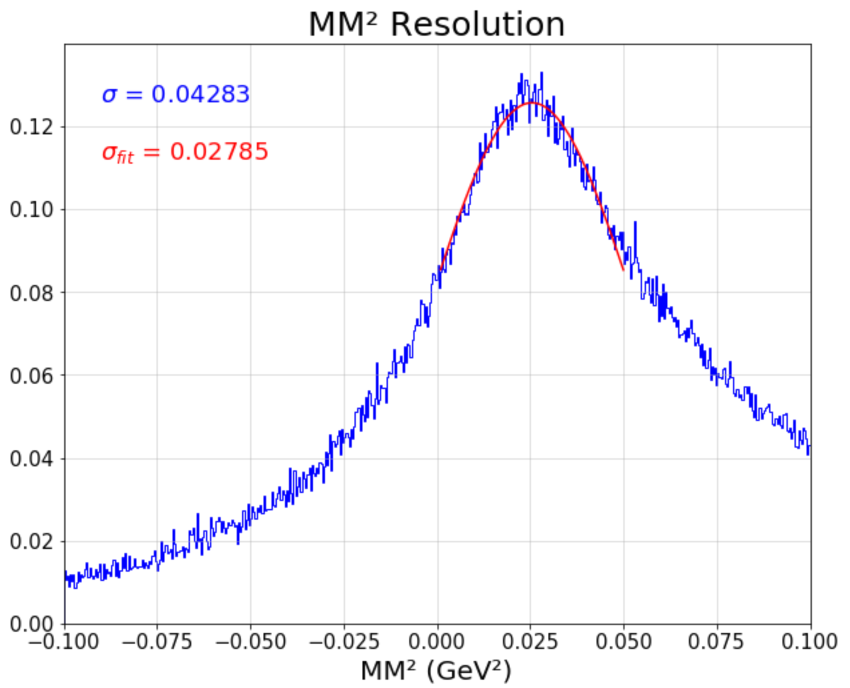
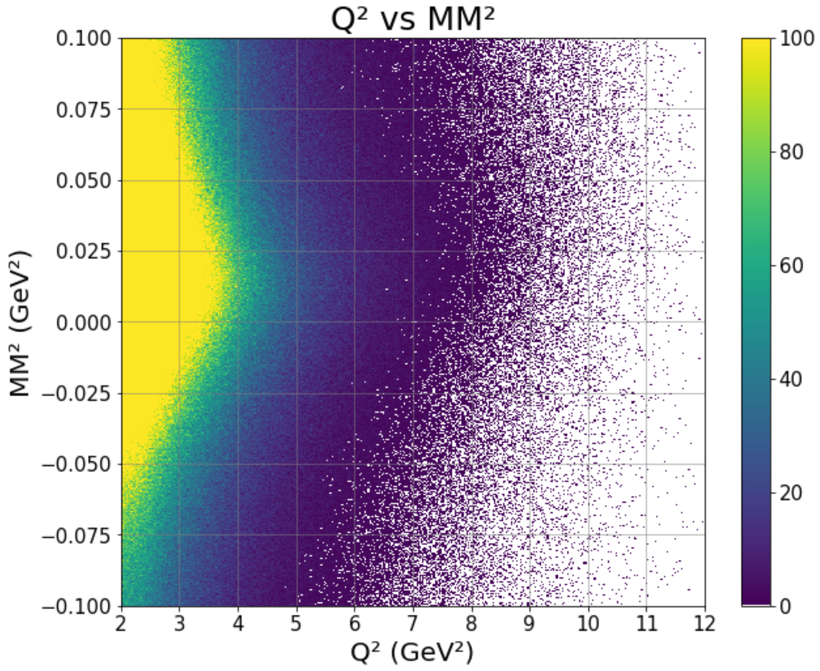


Q^2 vs. MM^2 for mPim

10.6 GeV experiment
Fall 2018, inbending, pass 2, golden runs



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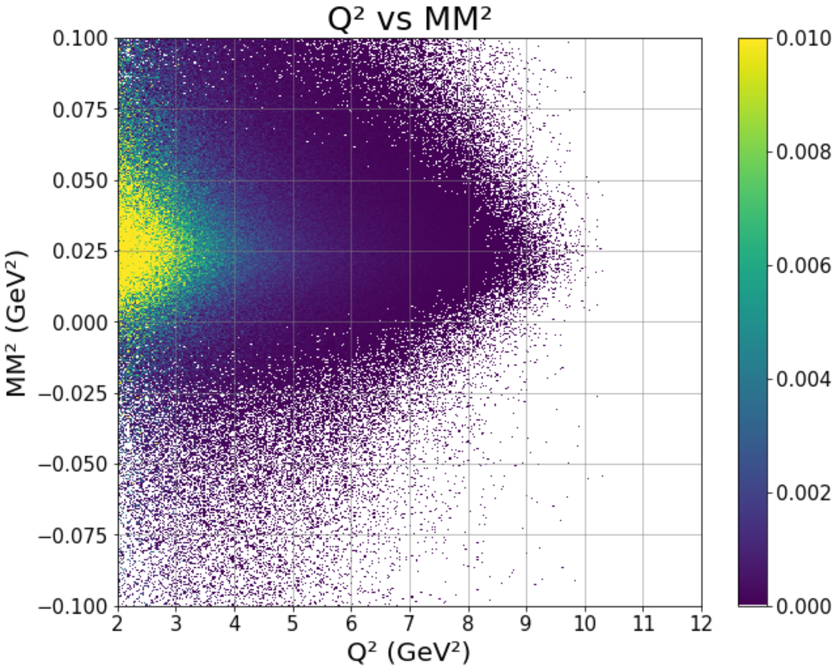
TWOPEG event generator, pass 2



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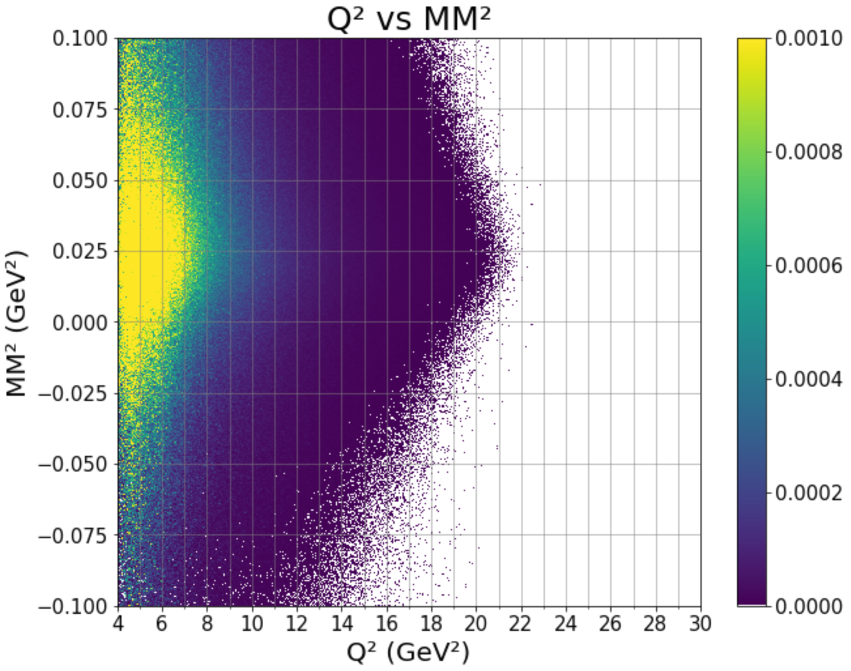
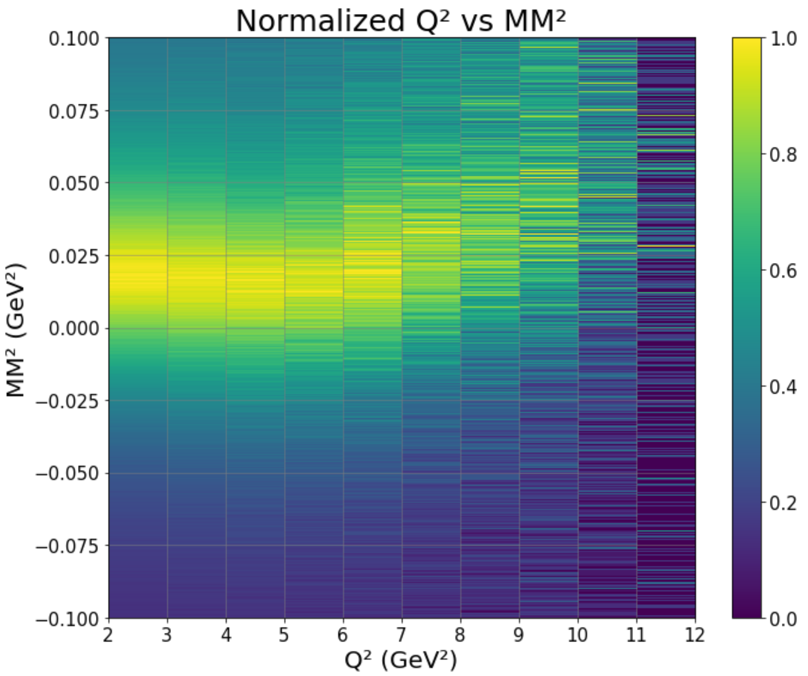


Normalized Q^2 vs. MM^2 for mPim

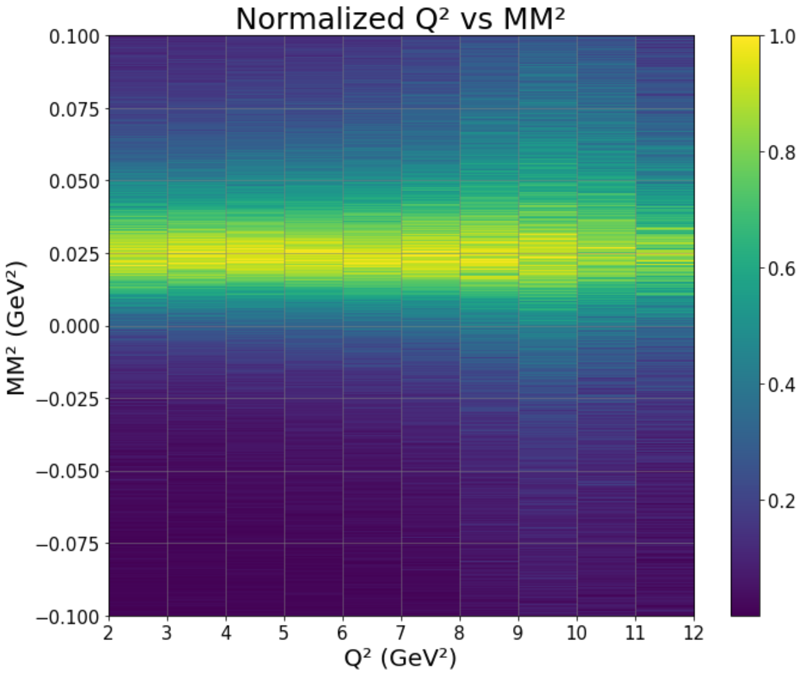
10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs



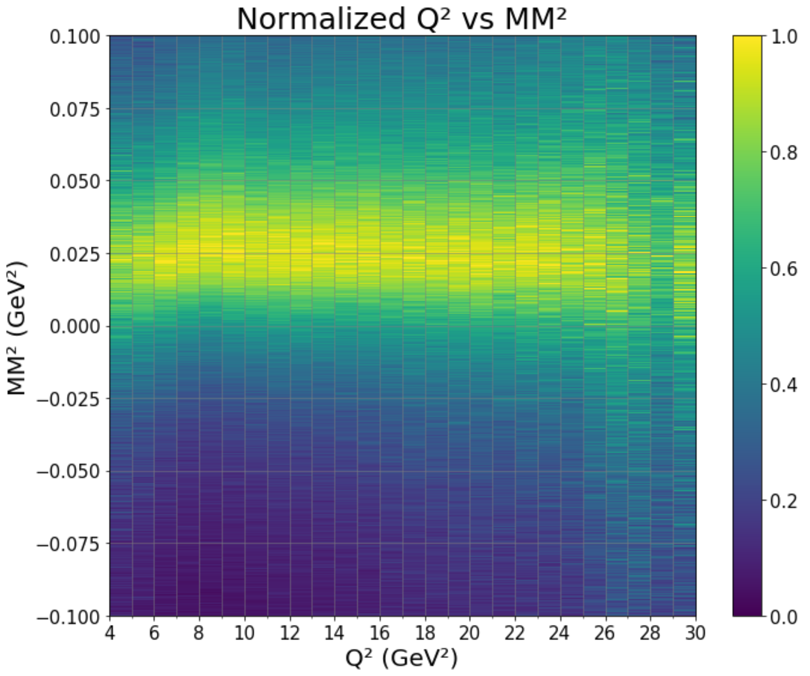
10.6 GeV simulation

TWOPEG event generator, pass 2



22.0 GeV simulation

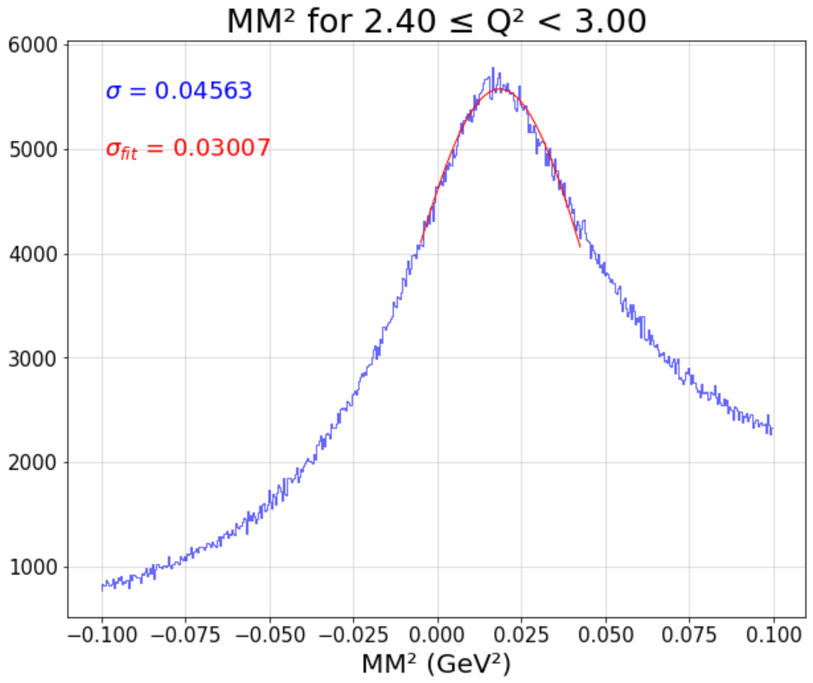
TWOPEG event generator, pass 2

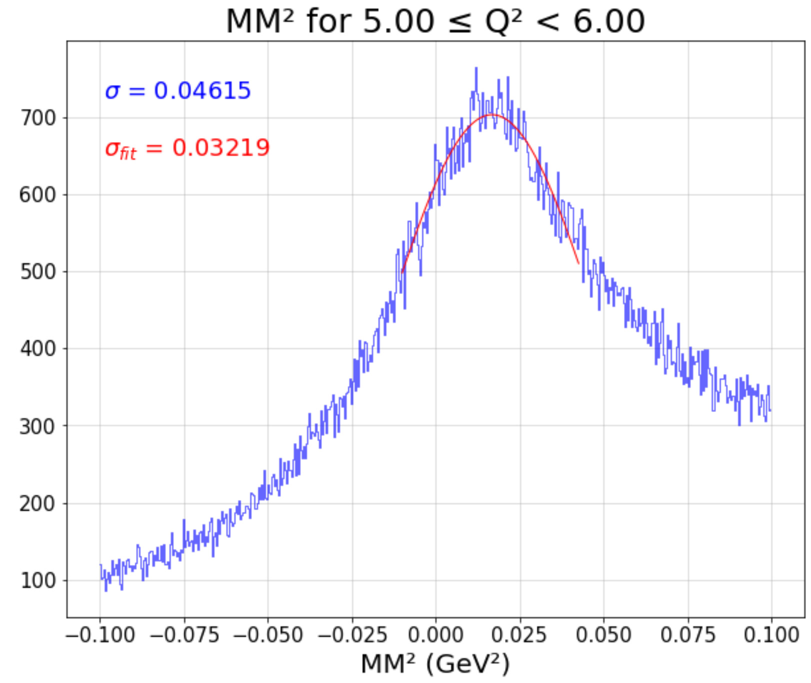


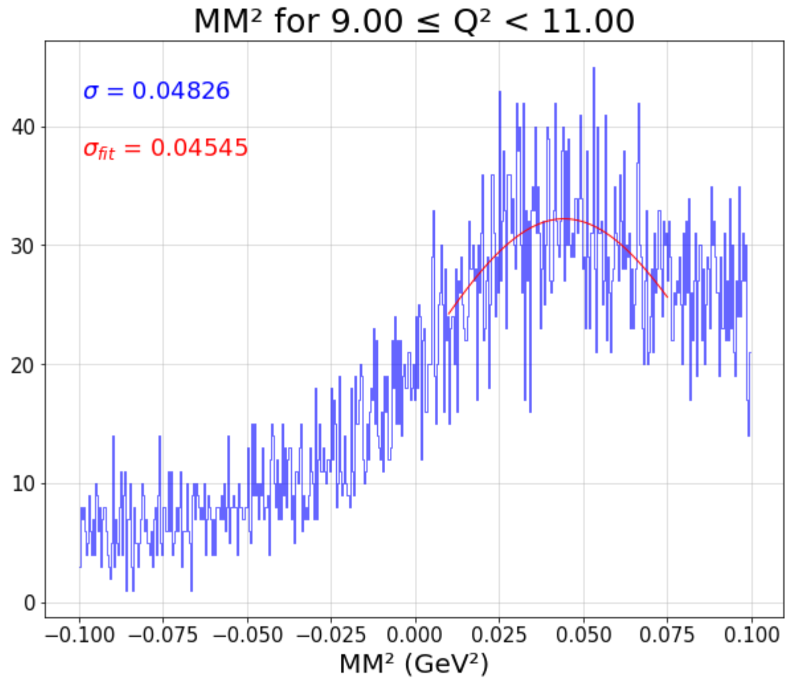
MM^2 for mPim

10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs



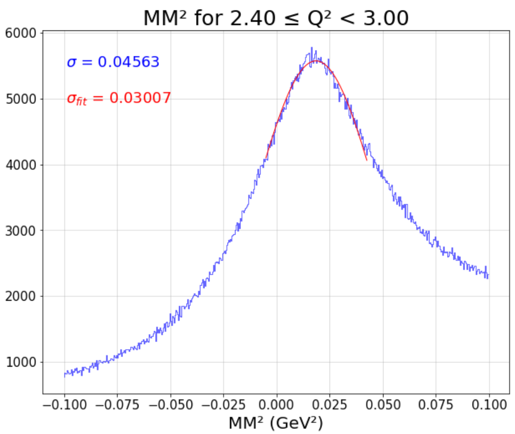


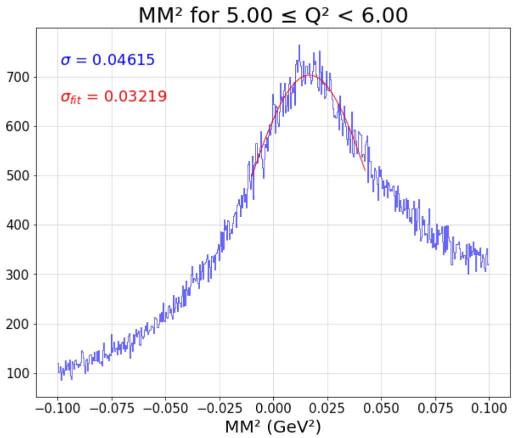


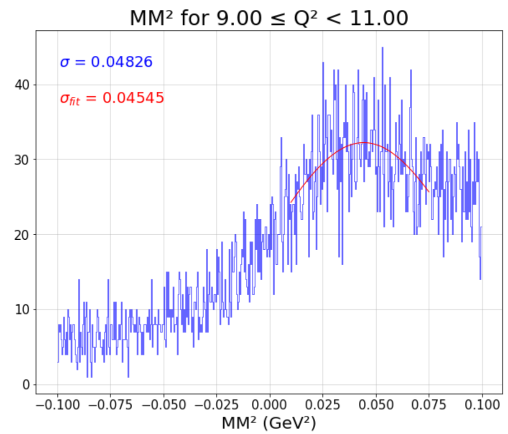
MM² for mPim

10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs



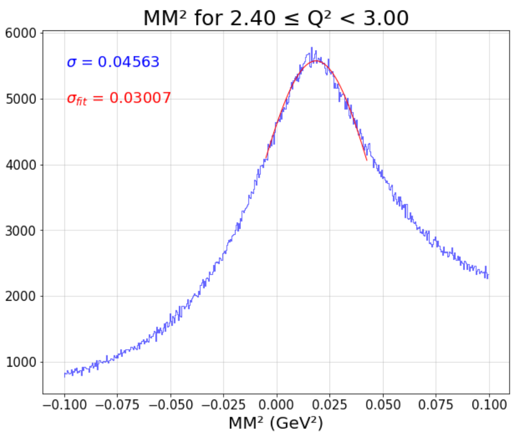


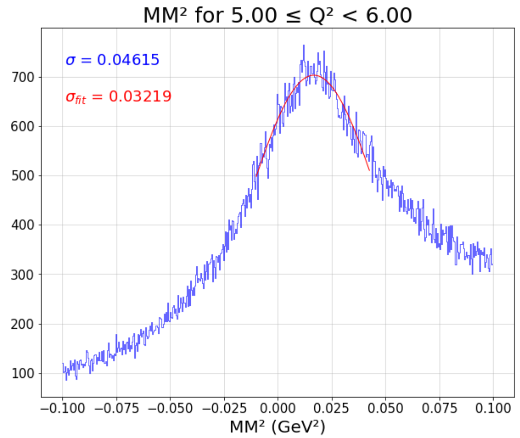


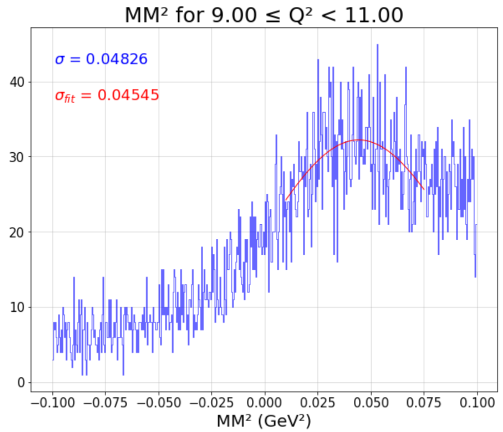
MM^2 for mPim

10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs

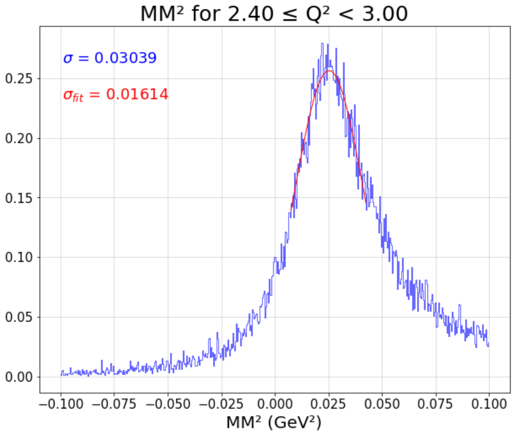


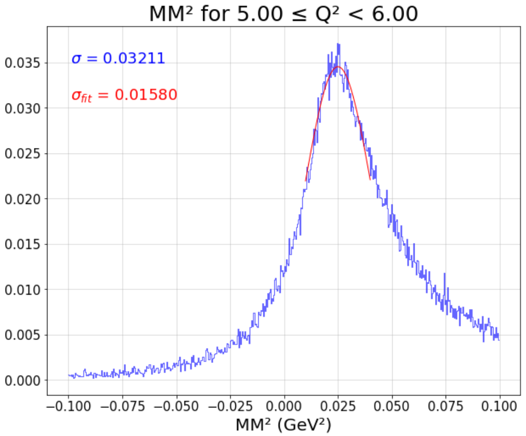


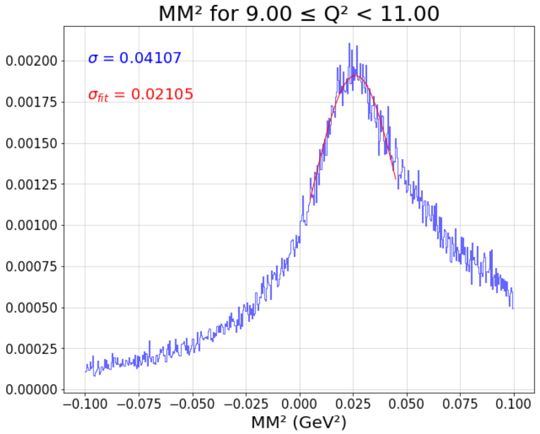


10.6 GeV simulation

TWOPEG event generator, pass 2







MM^2 for mPim

10.6 GeV experiment

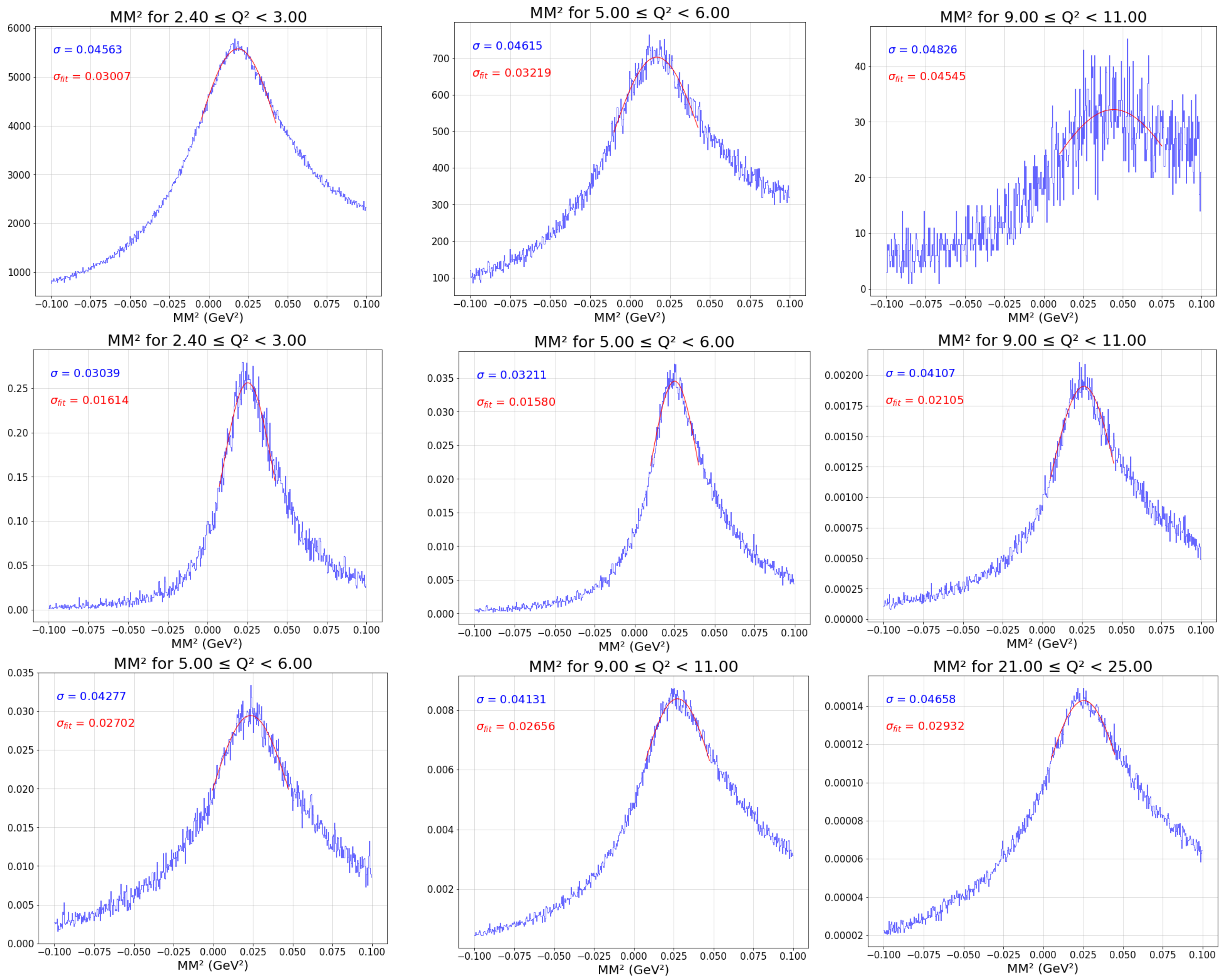
Fall 2018, inbending, pass 2, golden runs

10.6 GeV simulation

TWOPEG event generator, pass 2

22.0 GeV simulation

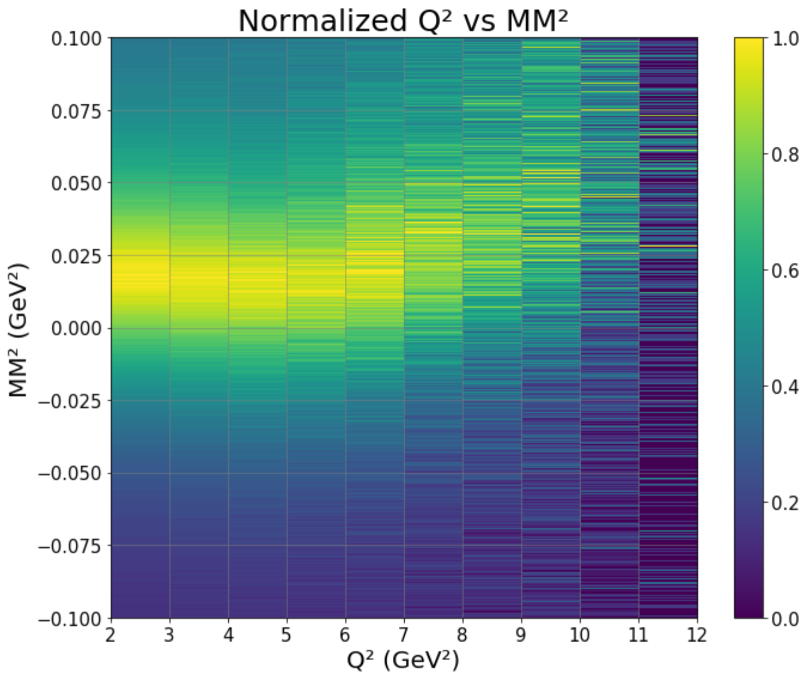
TWOPEG event generator, pass 2



Normalized Q^2 vs. MM^2 for mPim

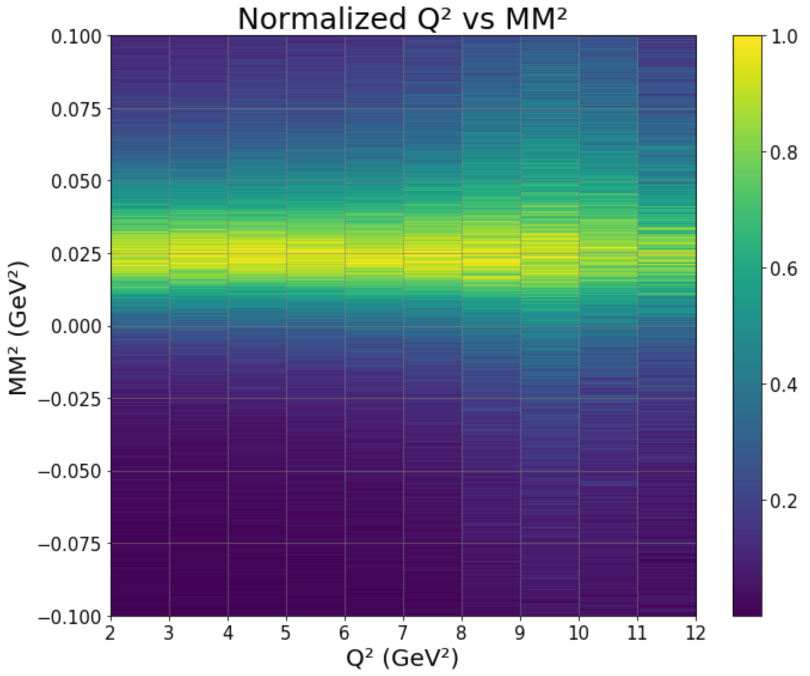
10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs



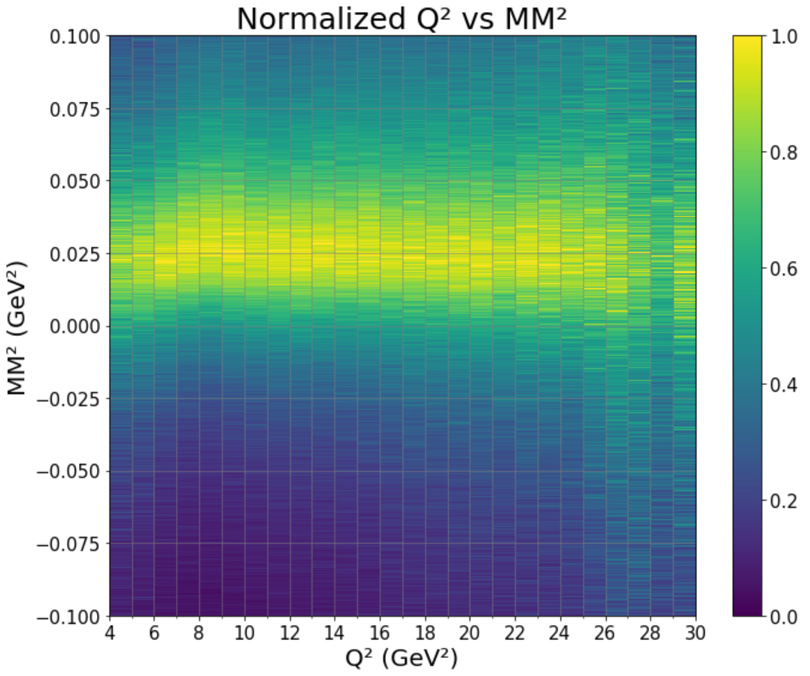
10.6 GeV simulation

TWOPEG event generator, pass 2



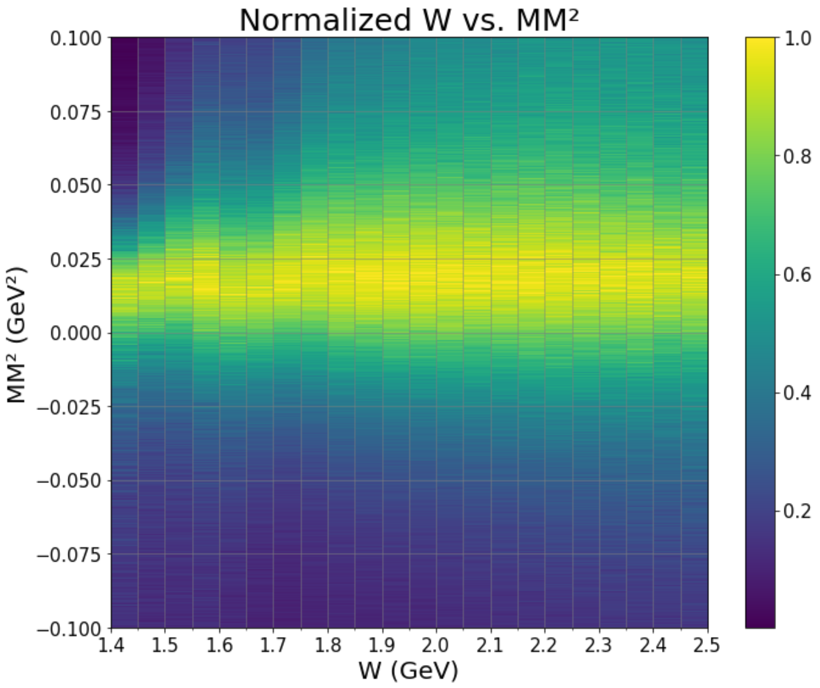
22.0 GeV simulation

TWOPEG event generator, pass 2

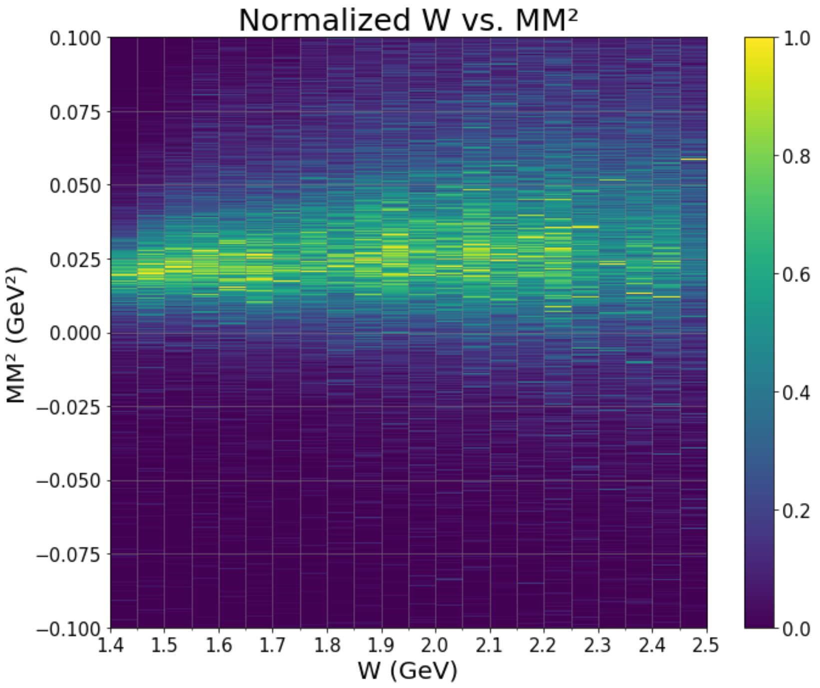


Normalized W vs. MM^2 for mPim

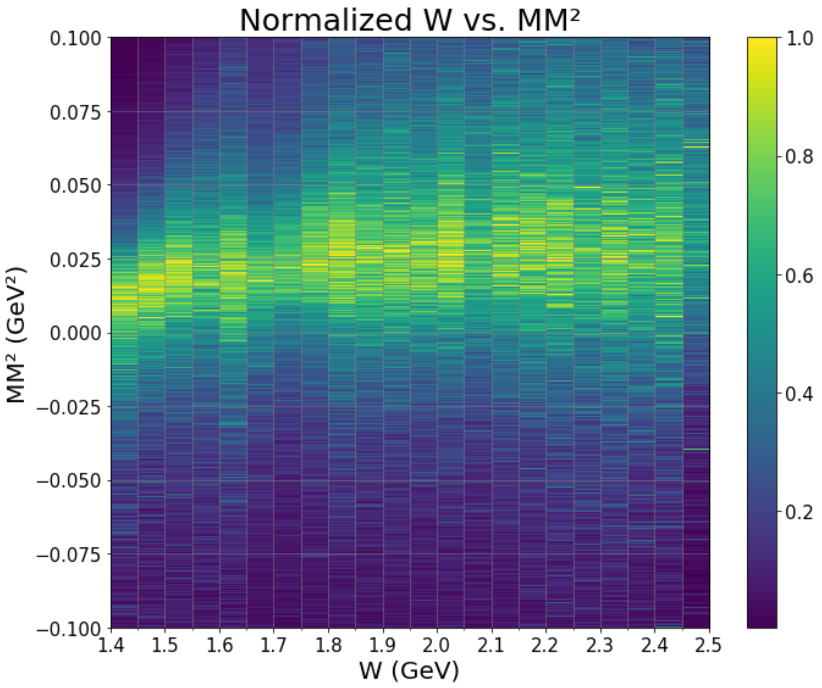
10.6 GeV experiment
Fall 2018, inbending, pass 2, golden runs



10.6 GeV simulation
TWOPEG event generator, pass 2



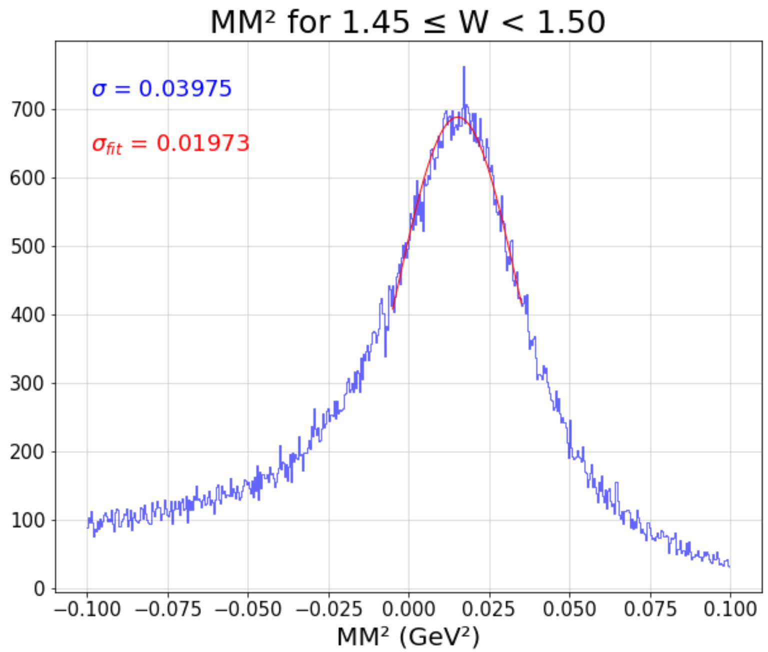
22.0 GeV simulation
TWOPEG event generator, pass 2

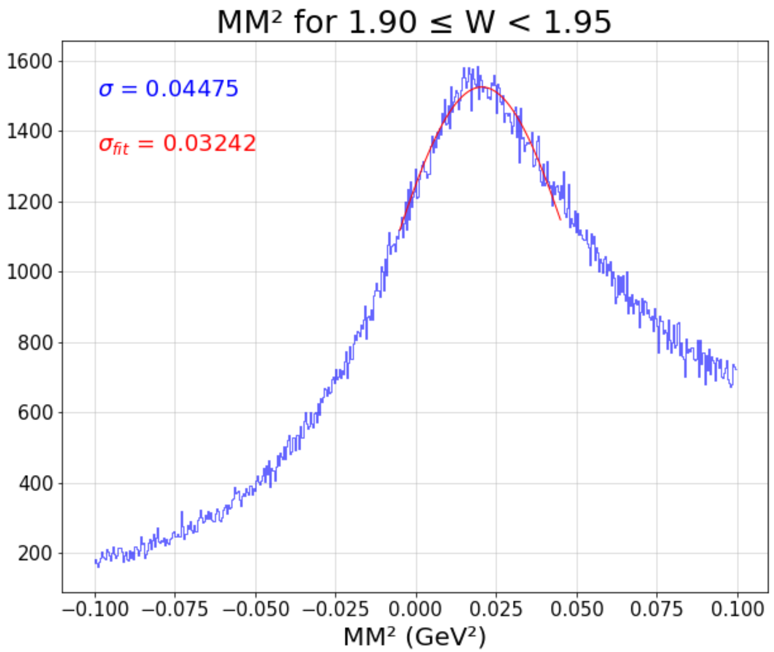


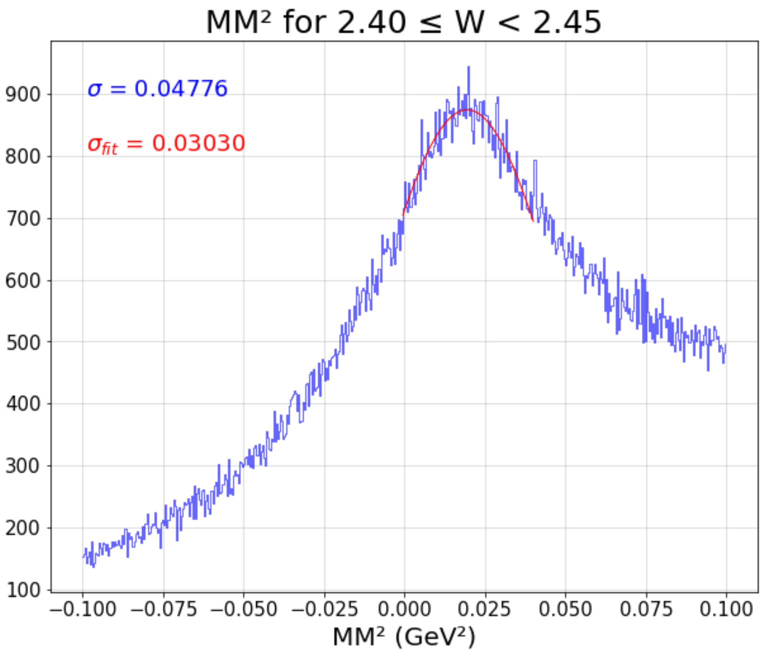
MM^2 for mPim

10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs



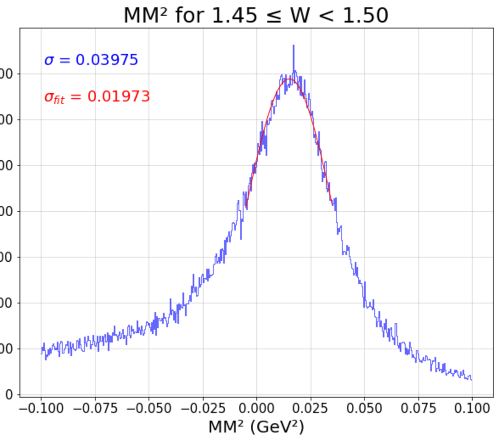


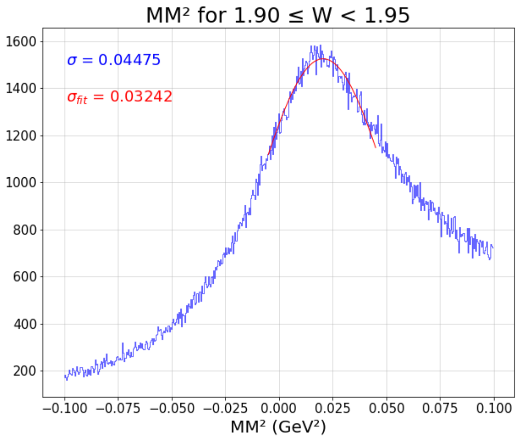


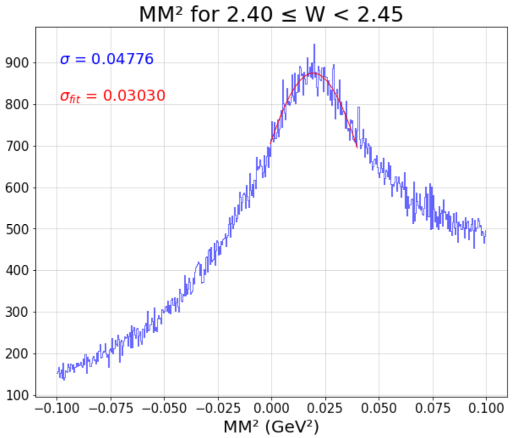
MM^2 for mPim

10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs



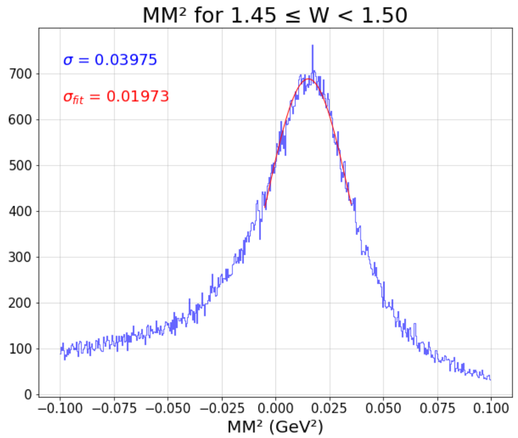


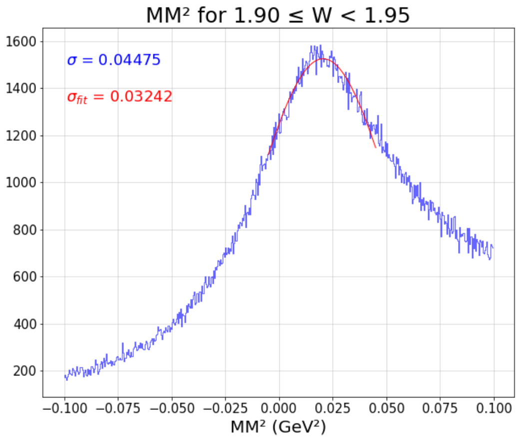


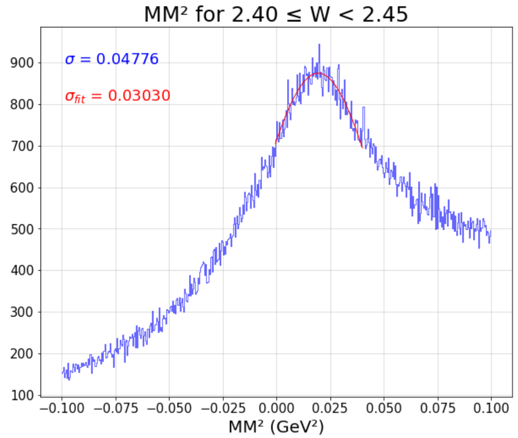
MM^2 for mPim

10.6 GeV experiment

Fall 2018, inbending, pass 2, golden runs

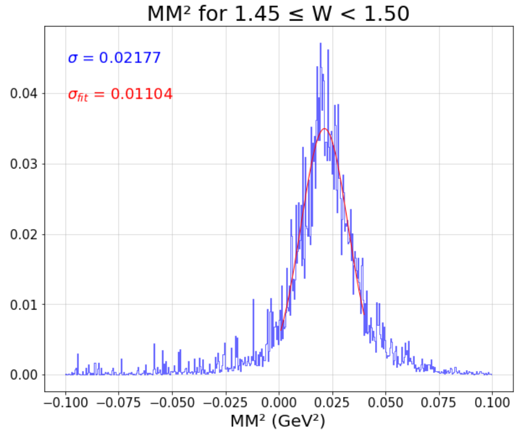


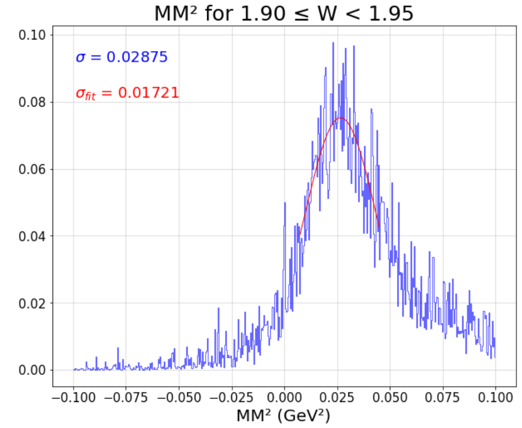


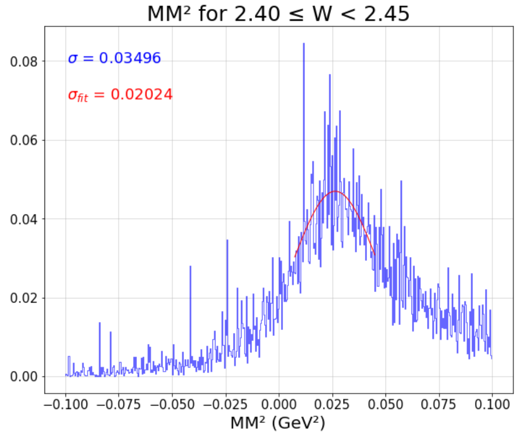


10.6 GeV simulation

TWOPEG event generator, pass 2







MM^2 for mPim

10.6 GeV experiment
Fall 2018, inbending, pass 2, golden runs

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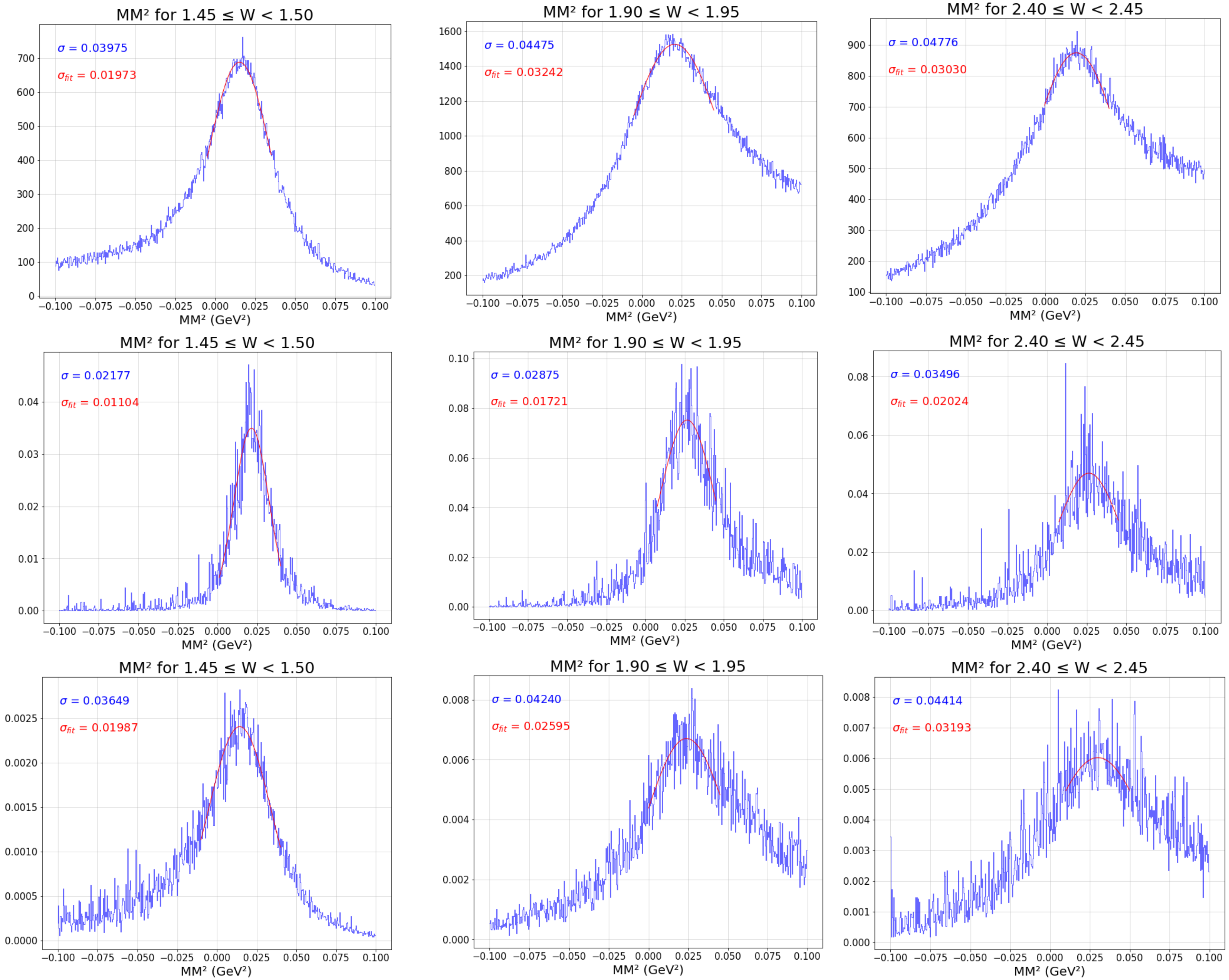
TWOPEG event generator, pass 2

22.0 GeV simulation
TWOPEG event generator, pass 2

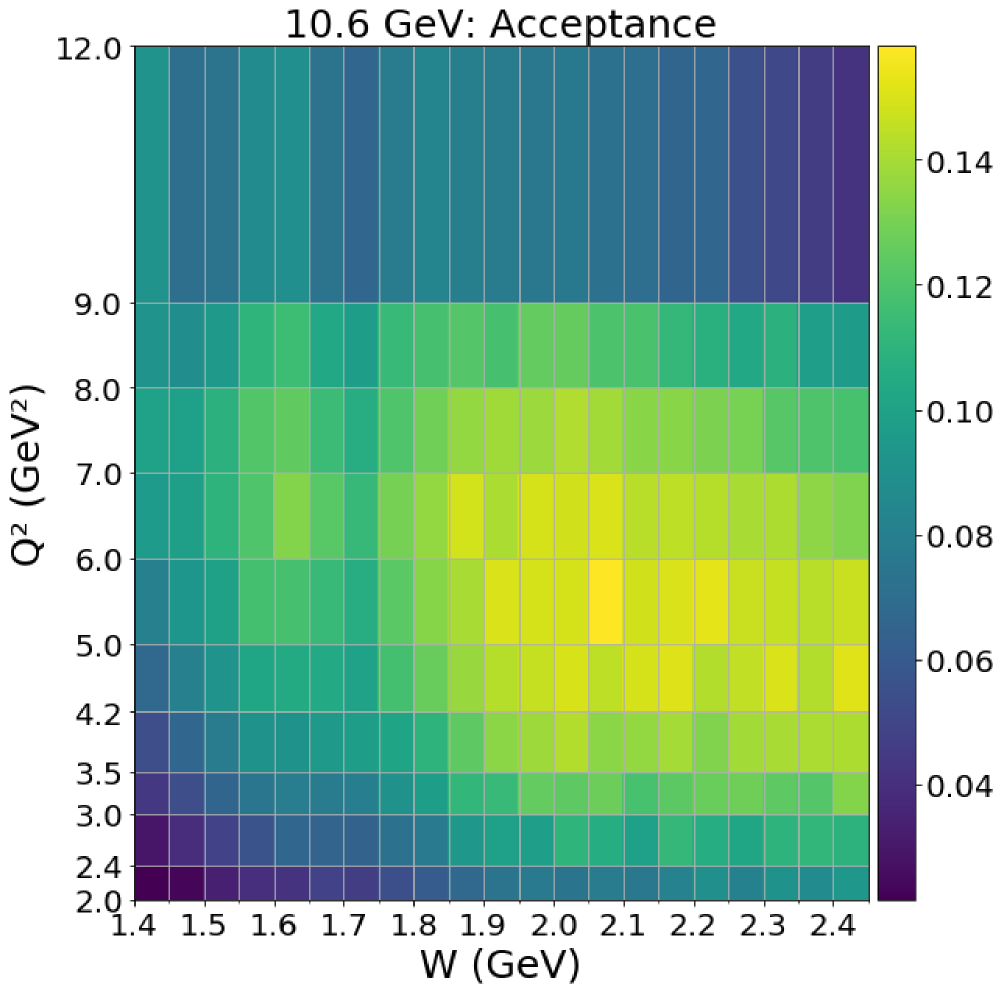


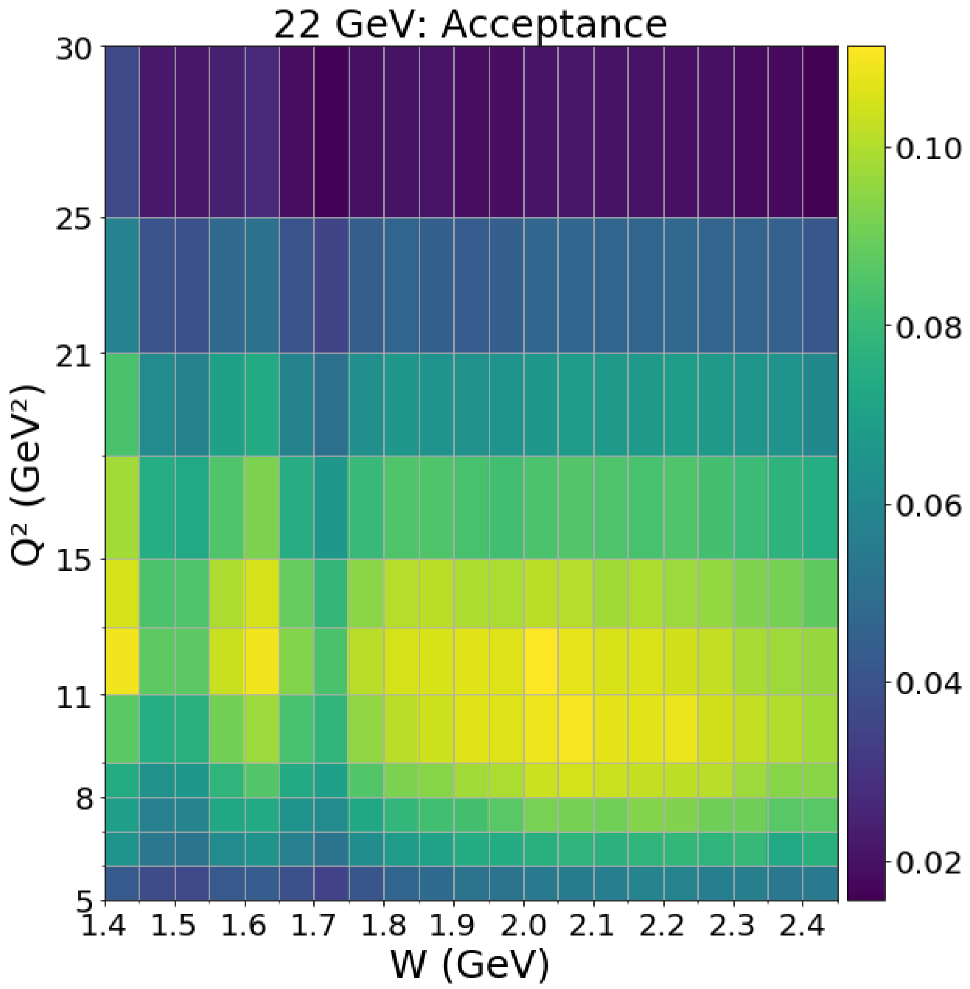
Feasibility

- Integrated hadronic cross section
- Needed integrated luminosity
- Needed integrated charge
- Needed beam time, in years

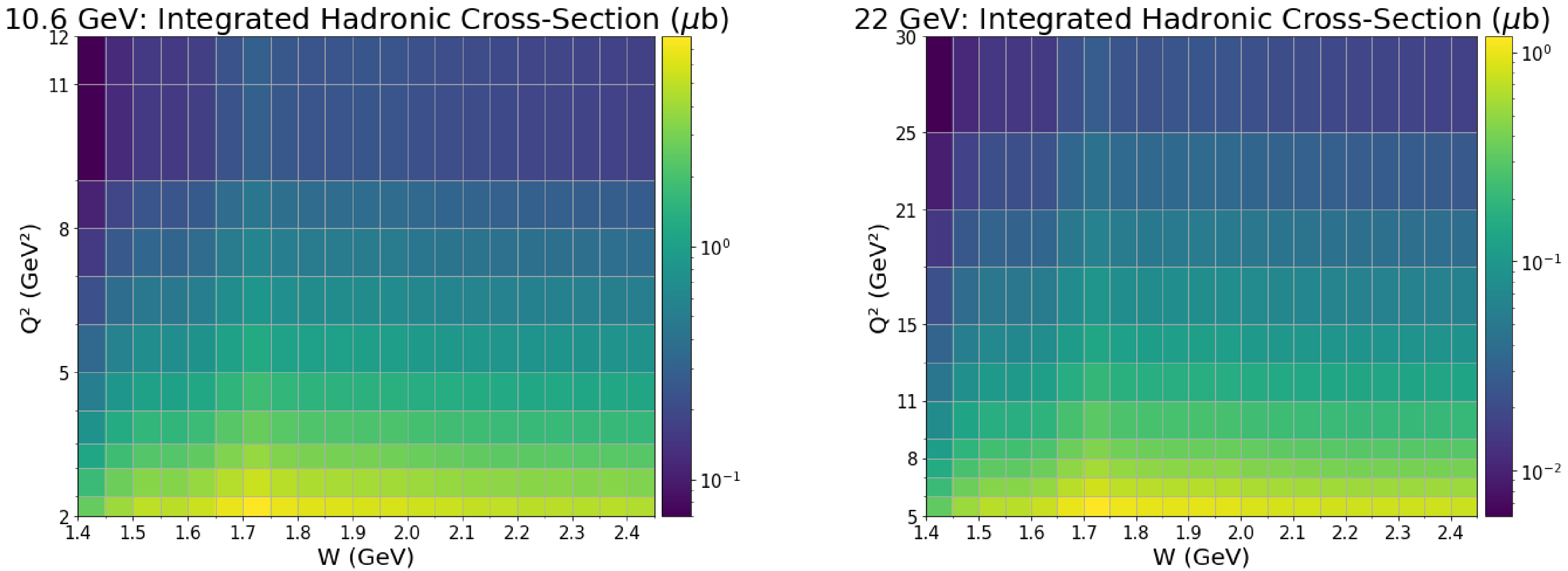
Acceptance

$$\text{Acceptance} = \frac{\sum \text{weights}_{\text{reconstructed}}}{\sum \text{weights}_{\text{generated}}}$$



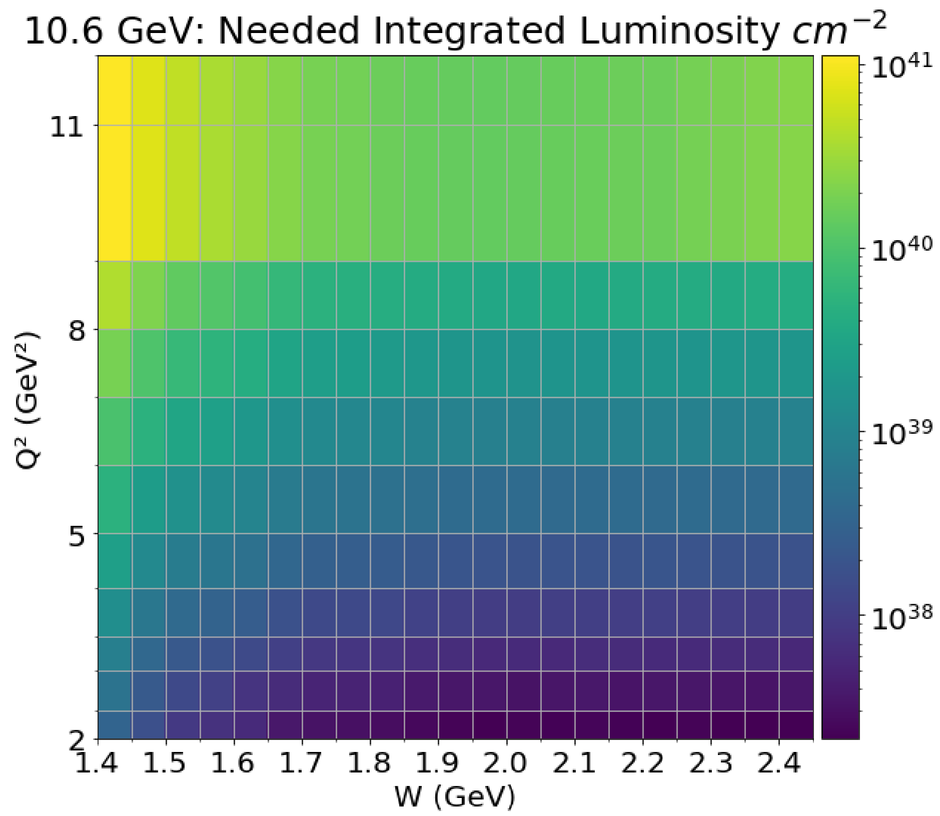


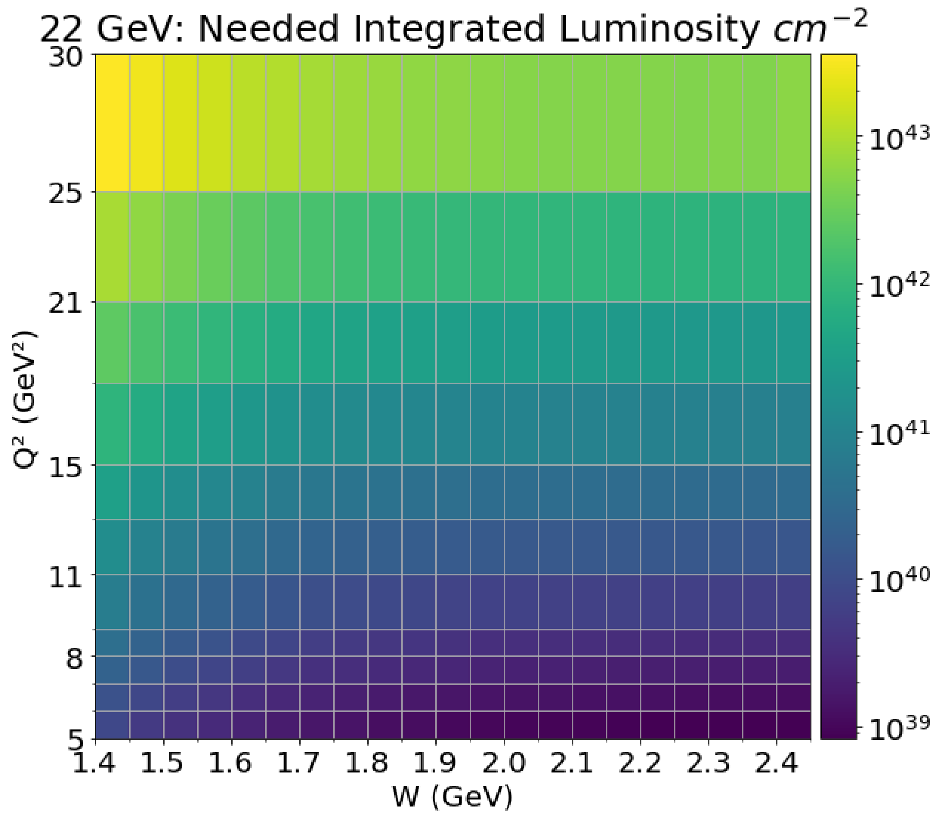
Integrated hadronic cross sections



- Total probability for double pion electroproduction
- σ_{had} = sum of gen weights / number of gen events
- Cross section calculated to be represented in microbarns
  - 1 μb = 10^{-30} cm^2

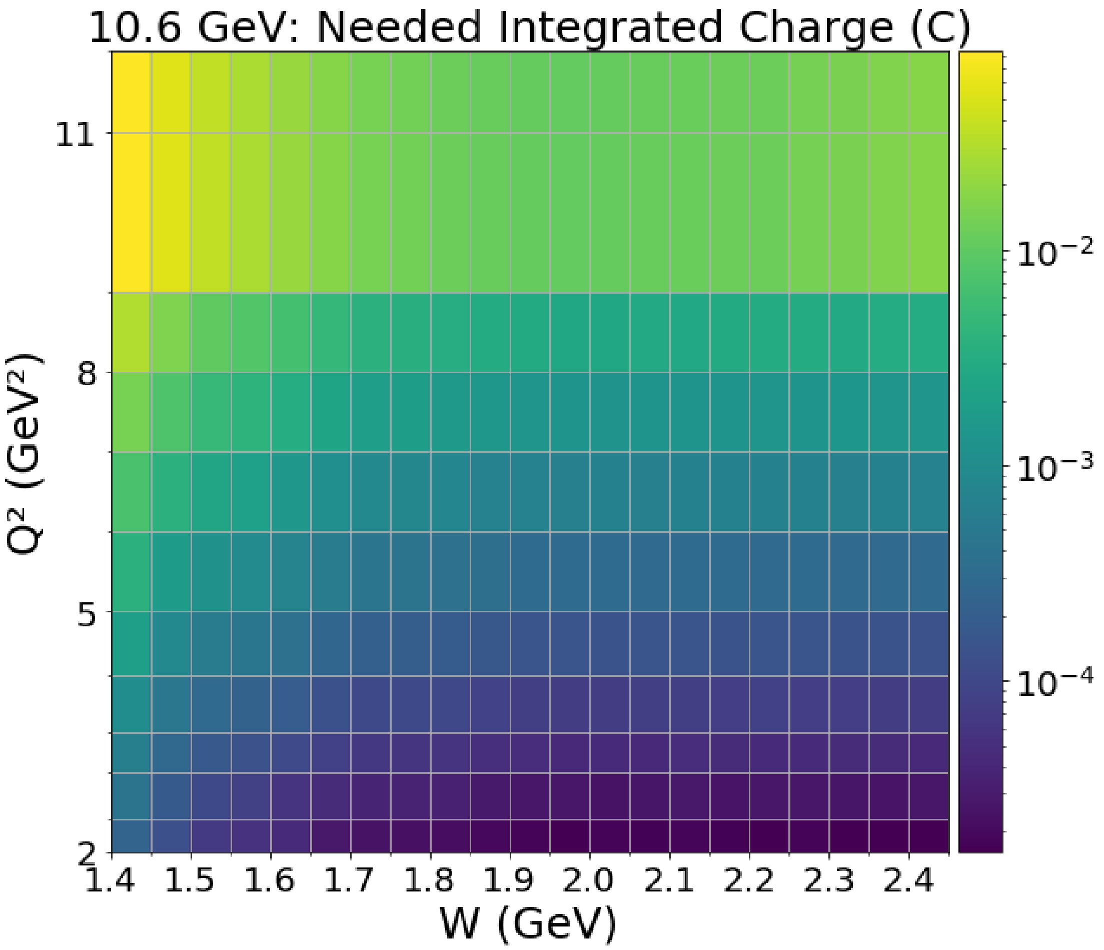
Needed luminosity

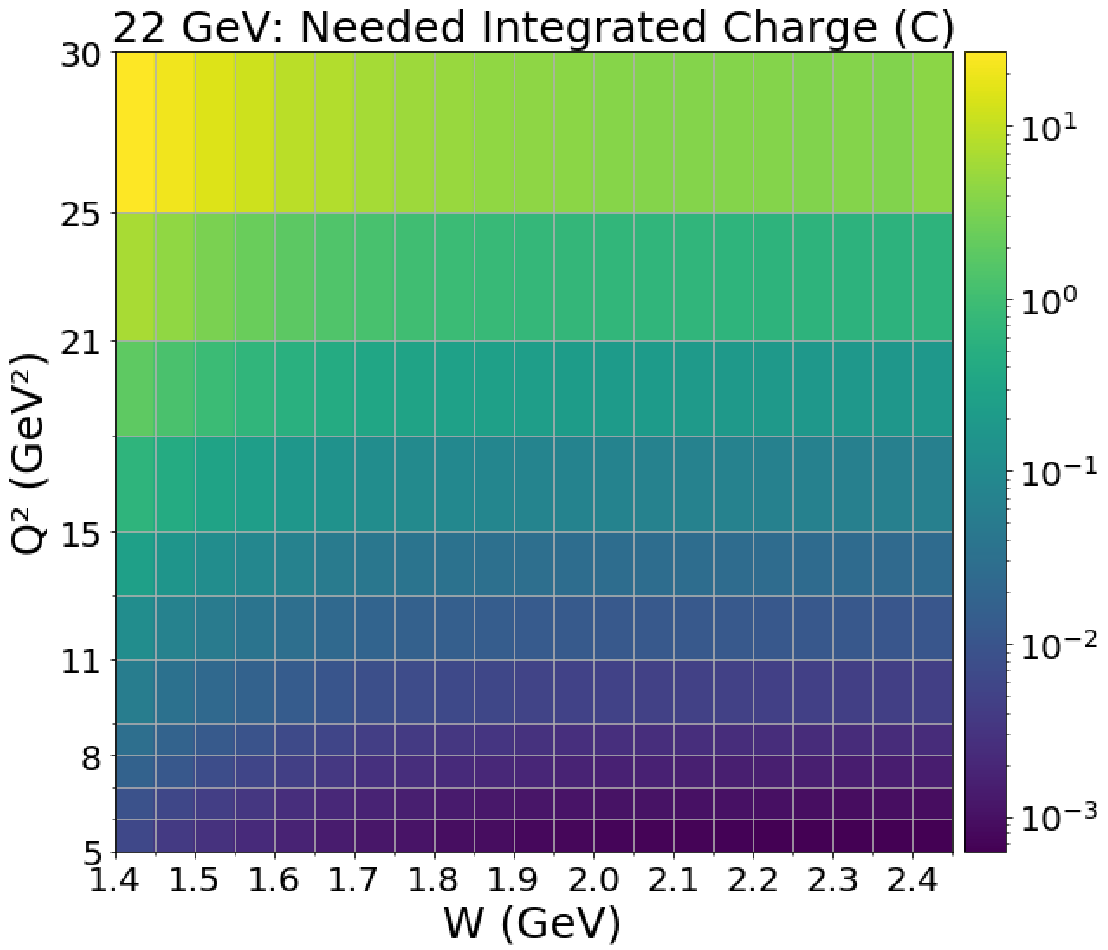




- σ_{elec} calculated similarly to σ_{had}
- Luminosity $\mathcal{L}$ determined from acceptance and σ_{elec}

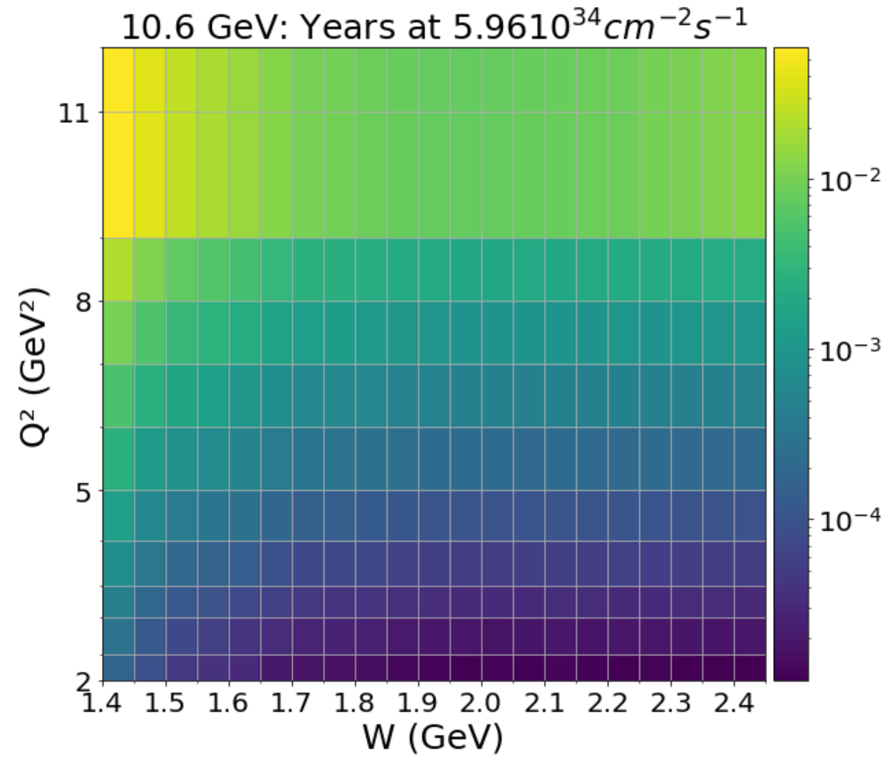
Needed integrated charge

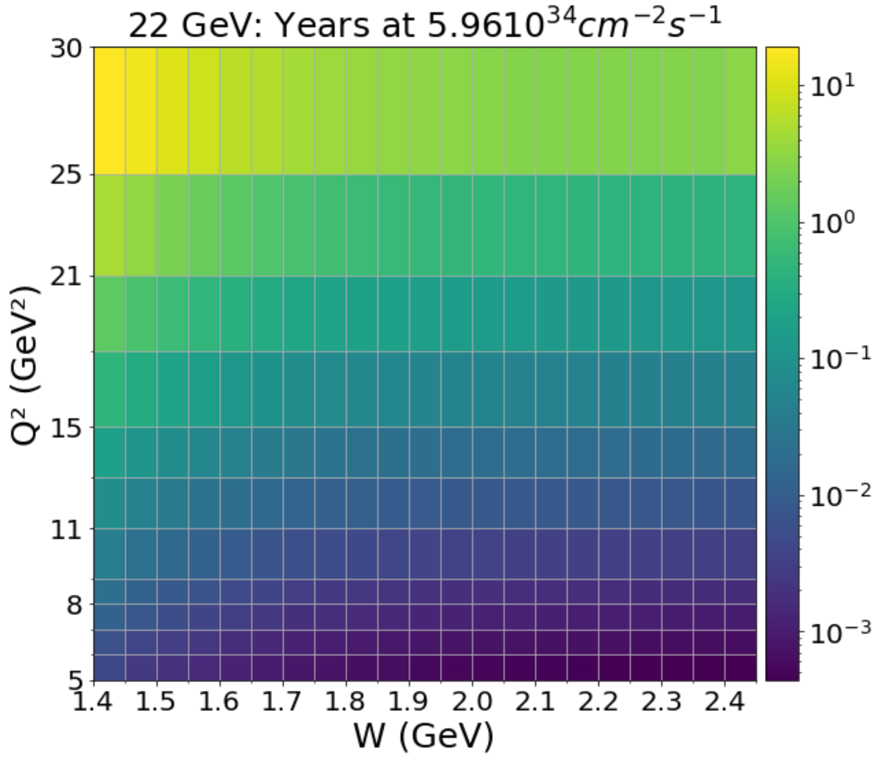




- Charge calculated from luminosity by dividing out target density

Beam time needed, in years





- Calculation for 10.6 GeV: implementing all analysis cuts [3/2], Golden Run Selection [3], PAC Days [2]
- For 22 GeV: 8 (16) years at $5.96 \cdot 10^{34}$ cm^{-2} s^{-1} **or** 11 (22) months at $5 \cdot 10^{35}$ cm^{-2} s^{-1}
  - Days (PAC Days)

Conclusion

- Acceptance calculation improved with increased precision in the TWOPEG event generator
  - Achieved a better description of the high Q^2 area
- Resolution for 10.6 GeV experiment (Fall 2018, inbending, golden runs) is comparable to resolution for 22 GeV simulation
- Needed beam time at designed luminosity is of the order of 11 months (22 PAC months)
  - Too early to say definitively how many PAC days (need more statistics)

Backup slide: Calculation of time needed

$$\text{Acceptance} = \frac{\sum \text{weights}_{\text{reconstructed}}}{\sum \text{weights}_{\text{generated}}}$$

$$\Phi = \frac{\left(\omega - \frac{Q^2}{2M_P}\right)}{137 \cdot 2\pi \cdot E_{\text{beam}} \cdot Q^2 \cdot (1-\epsilon)} \cdot \frac{W}{E_{\text{beam}} \cdot M_P}$$

$$\sigma = \frac{\sum \text{weights}_{\text{generated}}}{\text{number of generated events} \cdot \Phi} \cdot \left[\frac{1}{\left(1+\frac{Q^2}{0.7}\right)^{0.31660}}\right] \cdot \left[\left(\frac{1}{\left(1+\frac{0.65}{0.7}\right)}\right)^{-1.18085}\right]$$

Φ = flux, $1/\text{GeV}^3$
ω = energy transfer (virtual photon energy), GeV
M_P = mass of proton, GeV
E_{beam} = energy of electron beam, GeV
σ = cross section, $1\,\mu b = 10^{-30}\,\text{cm}^2$
$\sum \text{weights}_{\text{generated}}$ = sum of generated event weights, cm^2
terms in brackets [ ] = correction factors, dimensionless

$$\sigma_{\text{elec}} = \frac{\sum \text{weights}_{\text{generated}}}{\text{number of generated events}}$$

$$\int \mathcal{L}_{\text{elec}}\, dt = L_{elec} = \frac{2 \cdot 10^{33}}{\sigma_{\text{elec}} \cdot \text{Acceptance}}$$

$$Q_{\text{elec}} = \frac{L_{\text{elec}}}{1.324 \cdot 10^{42}}$$

$$T_{\text{sec}} = \frac{Q_{\text{elec}}}{45 \cdot 10^{-9}\,\text{C/s}}$$

$$T_{\text{years}} = \frac{\frac{Q_{\text{elec}}}{45 \cdot 10^{-9}}}{31,536,000\,\text{s/year}}$$