PANDA collaboration meeting

October 27, 2020

GPD Measurements with PANDA Based on Lepton-Pair Production in Hard Exclusive Proton Antiproton Colissions

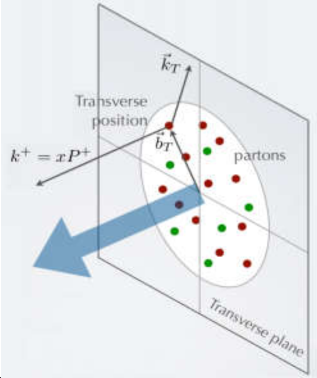
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Stefan Diehl

Justus Liebig University Giessen

University of Connecticut

Physics Motivation



Wigner function

$\int d^2 k_T$ $\int d^2 b_T$

Generalised Parton Distributions (GPDs)

space like GPDs: DV e⁻ scattering

➔ DVCS, DVMP, …

➔ hard exclusive processes

time like GPDs (GDAs): annihilation

$$p\bar{p} \rightarrow \gamma M$$

$\int dx$

Form Factors

eg: G_E, G_M

$$\bar{p}p \rightarrow e^+ e^-$$

$$\bar{p}p \rightarrow \mu^+ \mu^-$$

Transverse Momentum Distributions (TMDs)

➔ SIDIS (electr. scat.)

➔ Drell-Yan (anihilation)

$$p\bar{p} \rightarrow e^+ e^- X$$

$$p\bar{p} \rightarrow \mu^+ \mu^- X$$

Physics Motivation

Up to now: The measurement of GDAs (time like GPDs) was studied

$$p\bar{p} \rightarrow \gamma M$$

➔ Unique for annihilation experiments

Proposed study: Measure space like GPDs with PANDA as they are currently studied in hard exclusive electroproduction experiments

➔ Well developed theoretical framework

Physics content: spatial structure of the nucleon, pressure distributions, shear forces, …

Experimental method: Lepton-pair production in hard exclusive hadronic collisions

$$A\,B \rightarrow A\,B\,l^{+}\,l^{-}$$

➔ Exclusive analogue of the Drell-Yan process

Theoretical Description

Lepton-pair production in hard exclusive hadron-hadron collisions

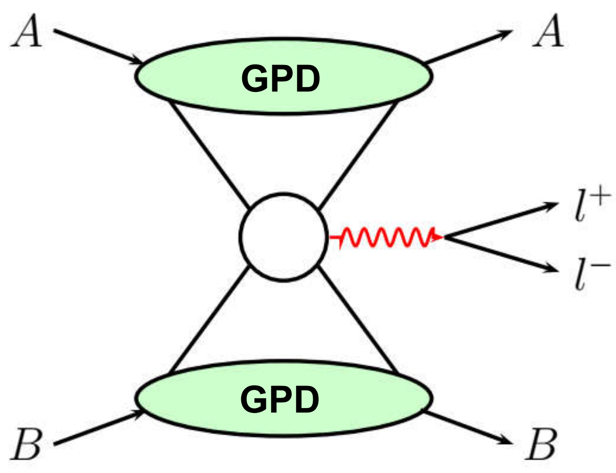
S.V. Goloskokov [§1], P. Kroll [†2] and O. Teryaev [§‡3]

§: *Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Moscow region, Russia*
†: *Fachbereich Physik, Universität Wuppertal, D-42097 Wuppertal, Germany*
‡ : *Veksler and Baldin Laboratory of High Energy Physics, Dubna 141980, Moscow region, Russia*

arXiv:2008.13594v1 [hep-ph] 31 Aug 2020

➔ Theoretical description based on the handbag approach

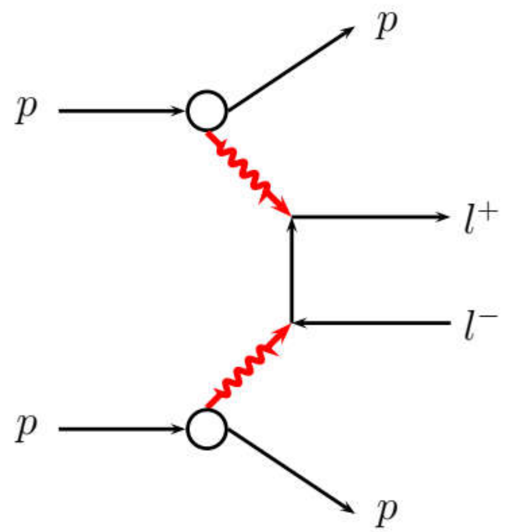
Theoretical Description



Double handbag for exclusive lepton-pair production in hadron-dadron collisions

twist-2 vector GPDs H, E

axial GPDs $\tilde{H}$, $\tilde{E}$



electromanetic lepton pair poduction

➔ Only relevant for -t < 0.2 – 0.3

PANDA kinematic regime: DH description dominated by helicity non-flip vertices A → A and B → B

➔ Controlled by the GPD H

Theoretical Description

For proton and antiproton $$H_{\text{eff}} = H - \frac{\xi_i^2}{1-\xi_i^2} E$$

Experience from electroproduction:

Contributions from the other GPDs like $\widetilde{H}$, E or from transversity GPDs are expected to be small

➔ H ~ H_{eff}

$$\frac{d\sigma(p\overline{p} \to p\overline{p}\, l^+ l^-)}{dt_1 dt_2 dQ^2} = \frac{1}{3(4\pi)^5} \frac{\alpha_{\text{em}}}{s^2 Q^2} \int \frac{ds_1 ds_2}{\sqrt{-\Delta_4}} |\mathcal{M}|^2$$

$$\mathcal{M}^{AB} \sim \sum_{a=u,d,s} \sum_{b,c} H_A^b(x_1,\xi_1,t_1) H_B^c(x_2,\xi_2,t_2)\, \mathcal{H}_0^{bc}(x_1,\xi_1,x_2,\xi_2)$$

For antiprotons it is assumed:

$$H_{\overline{p}}^{\overline{a}}(x_2,\xi_2,t_2) = H^a(x_2,\xi_2,t_2) \qquad H_{\overline{p}}^{g}(x_2,\xi_2,t_2) = H^g(x_2,\xi_2,t_2)$$

Theoretical Description

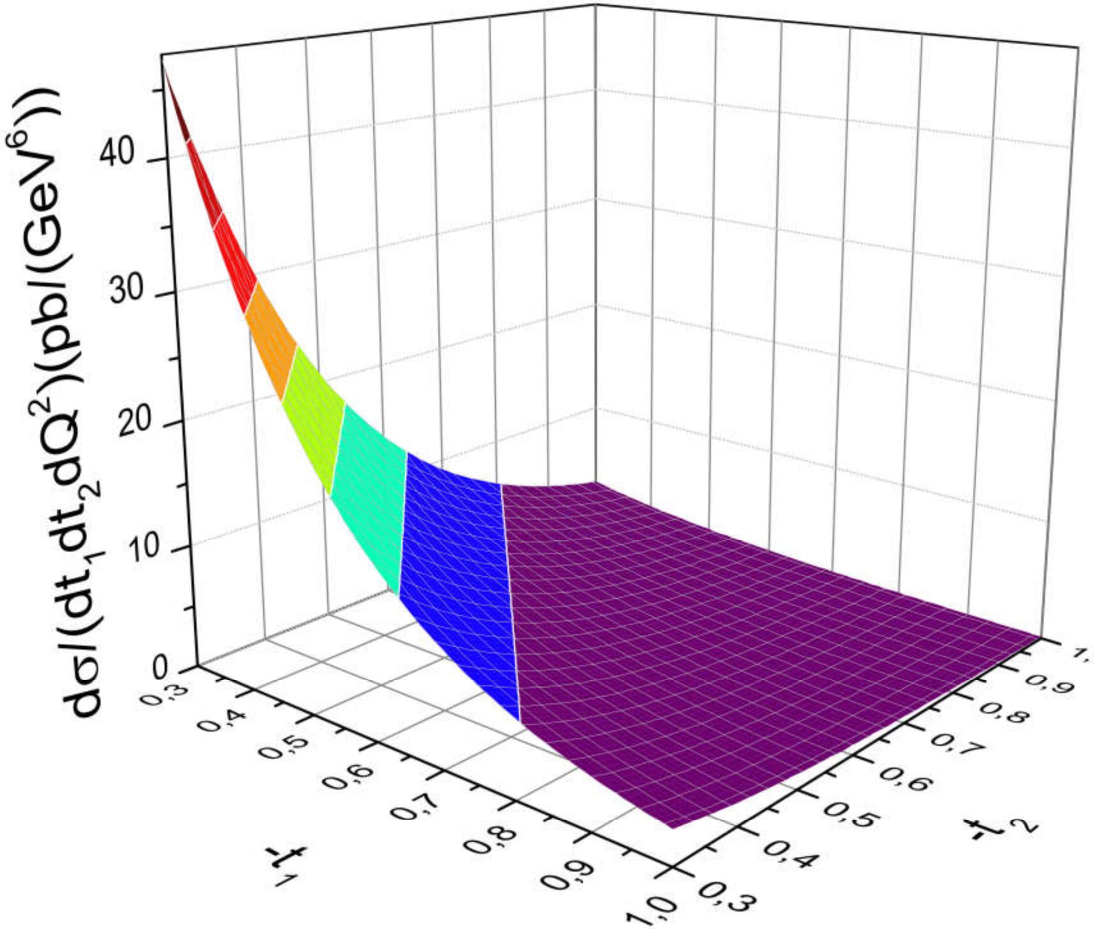
$$t_1 = (p_{target} - p'_p)^2$$

$$t_2 = (p_{beam} - p'_{\bar{p}})^2$$

$$Q^2 = p^2_{\gamma^*} = (p_{e^+} + p_{e^-})^2$$

factorisation for:

$$t_i / Q^2 << 1$$



The $p\bar{p} \rightarrow p\bar{p}\, l^+ l^-$ cross section in $pb/\ \mathrm{GeV}^6$ versus t_1 and t_2 (in GeV^2) at a typical FAIR kinematics: $s = 30\ \mathrm{GeV}^2$, $Q^2 = 3\ \mathrm{GeV}^2$

Feasability Studies

$$t_1 = (p_{target} - p'_p)^2 \qquad t_2 = (p_{beam} - p'_{\bar{p}})^2$$

$$t_i / Q^2 \ll 1$$

Q² on the hadronic scale

protons: low to medium momentum, medium angles

antiprotons: high momentum, small angles

➔ First PANDAroot simulations with a phase space event generator

$$p\bar{p} \rightarrow p\bar{p}\gamma^* \rightarrow \begin{cases} p\bar{p}e^+e^- \\ p\bar{p}\mu^+\mu^- \end{cases}$$

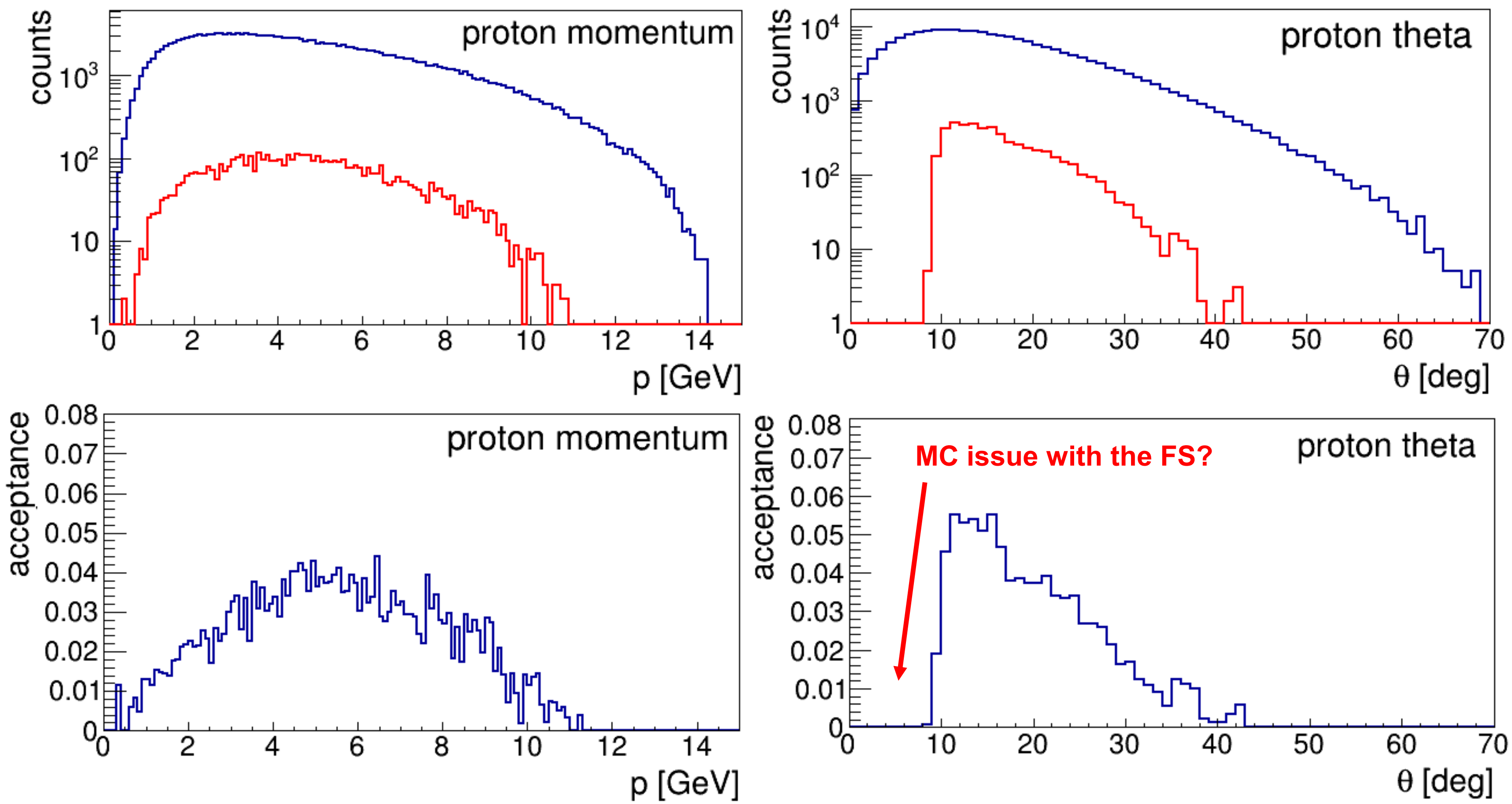
beam momentum: 2.5 GeV/c (s = 6.8 GeV²), 5 GeV/c (s = 10.3 GeV²), 15 GeV/c (s = 30 GeV²)

topology 1: All final state particles detected

➔ Event selection via a 4C kinematic fit and exclusivity cuts

$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

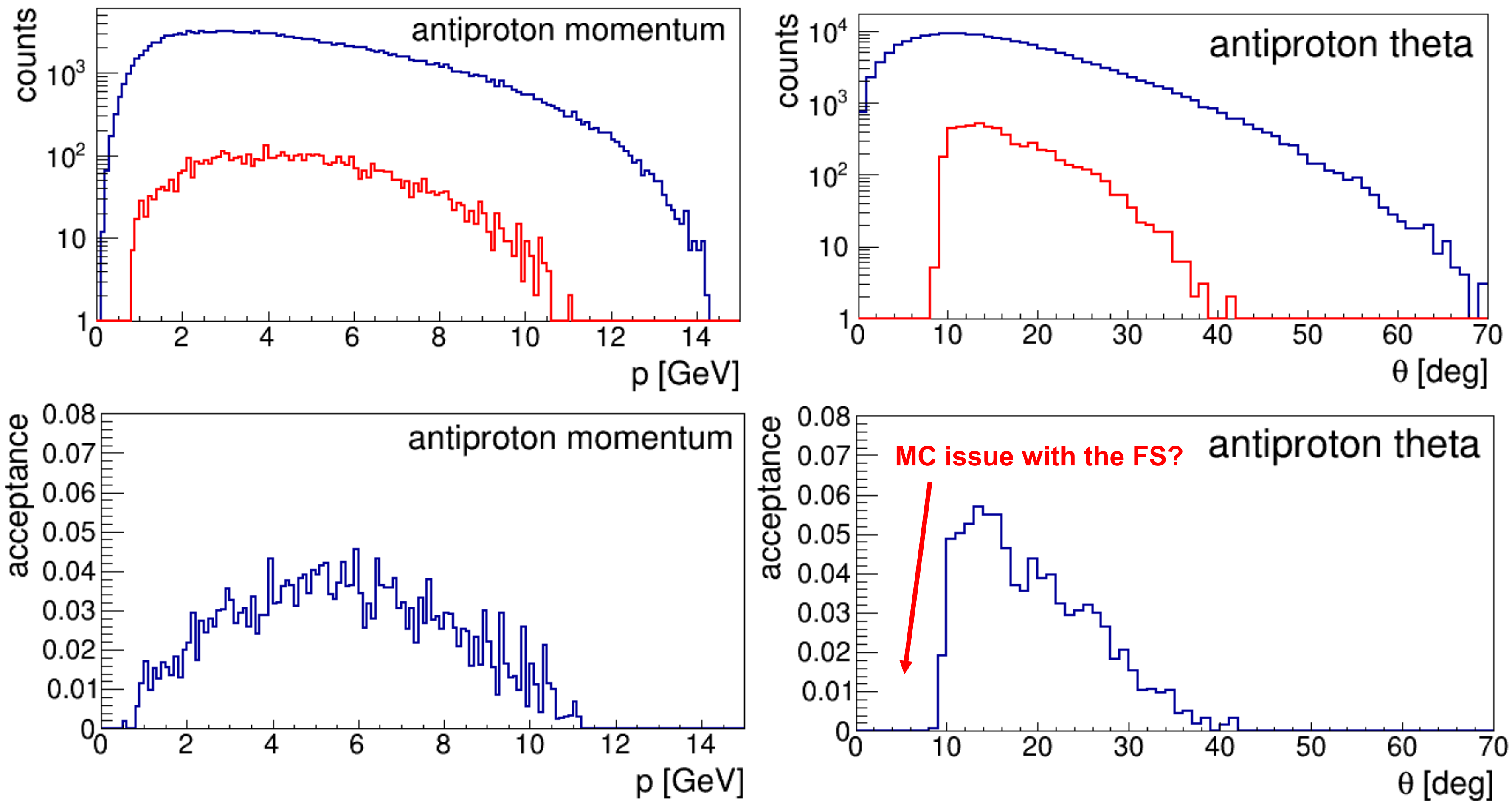
proton: generated / reconstructed



➔ Acceptance after all exclusivity cuts

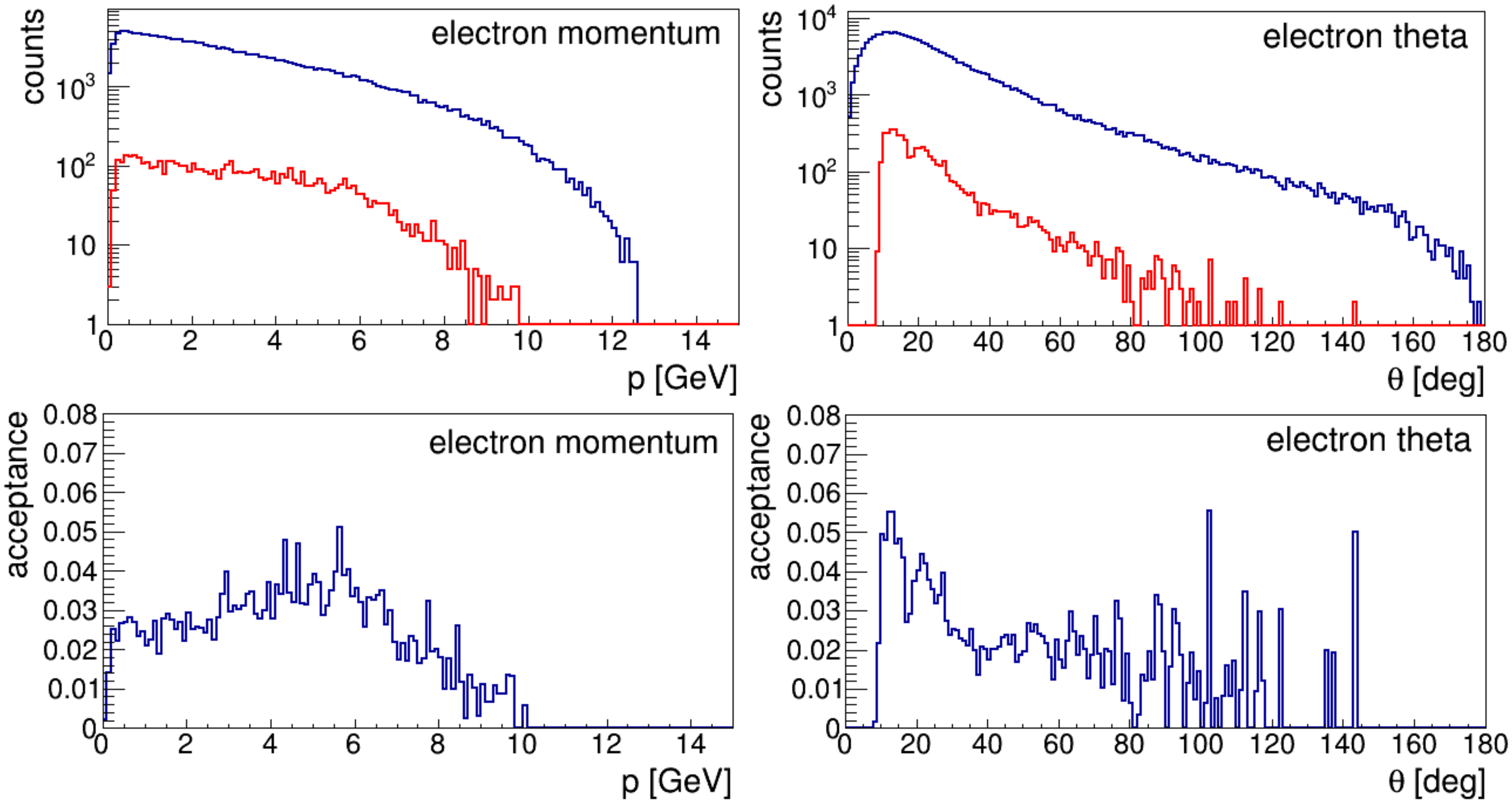
$p\bar{p} \rightarrow p\bar{p}e^+e^-$ @ 15 GeV/c

antiproton: — generated — reconstructed



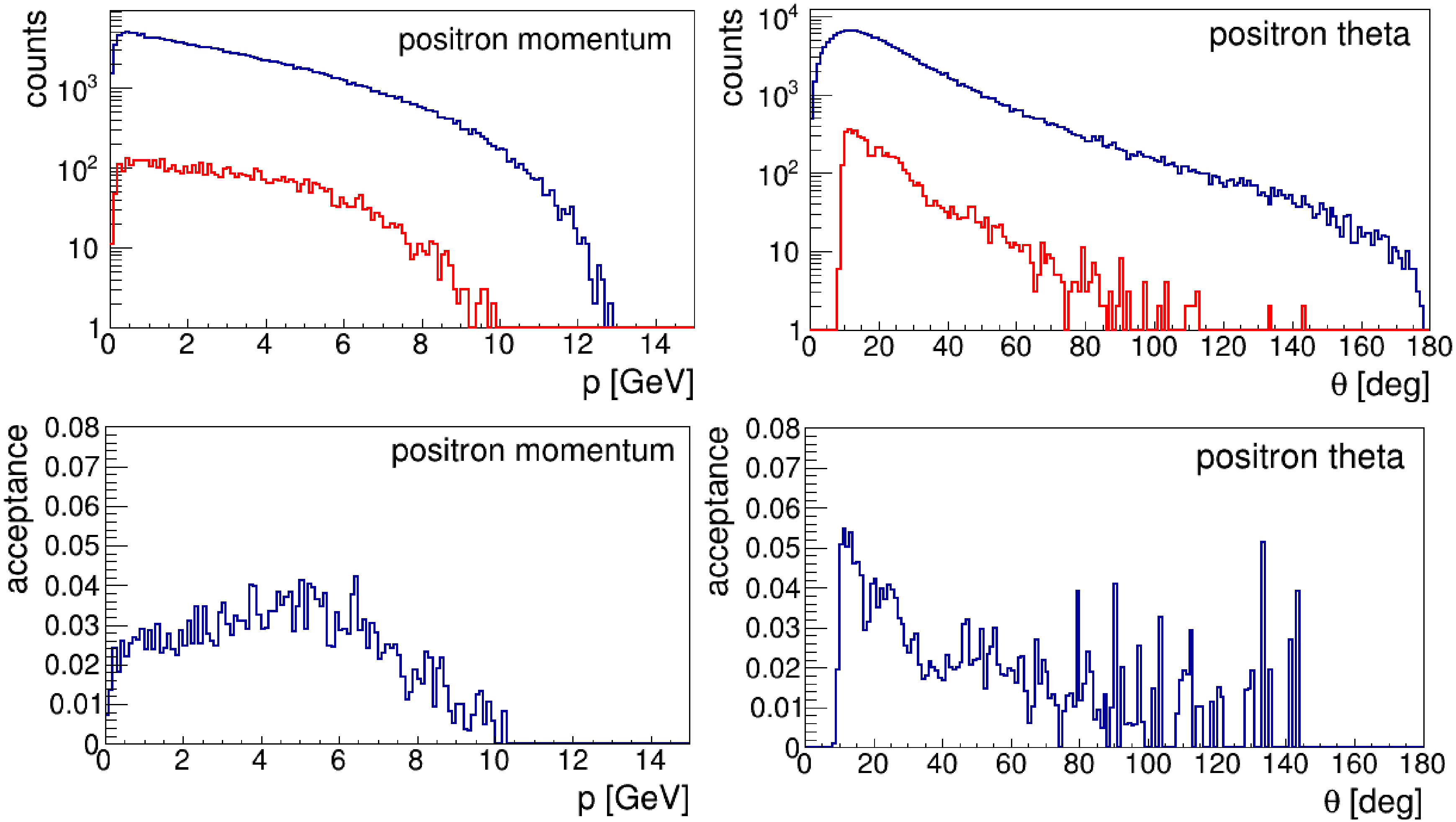
$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

electron: generated reconstructed



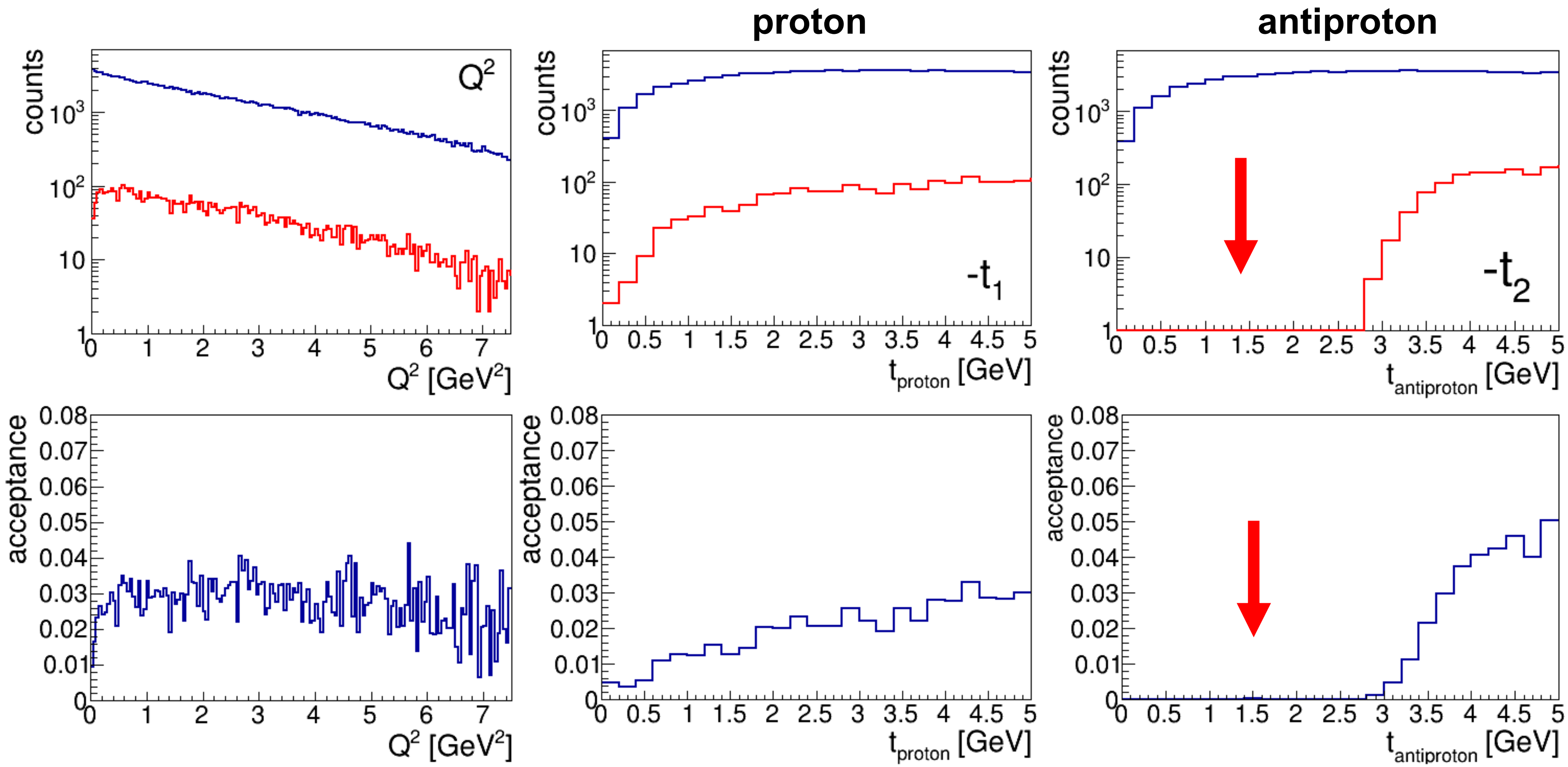
$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

positron: generated (blue) reconstructed (red)



$p\bar{p} \rightarrow p\bar{p}e^+e^-$ @ 15 GeV/c

Kinematics: generated (blue) reconstructed (red)

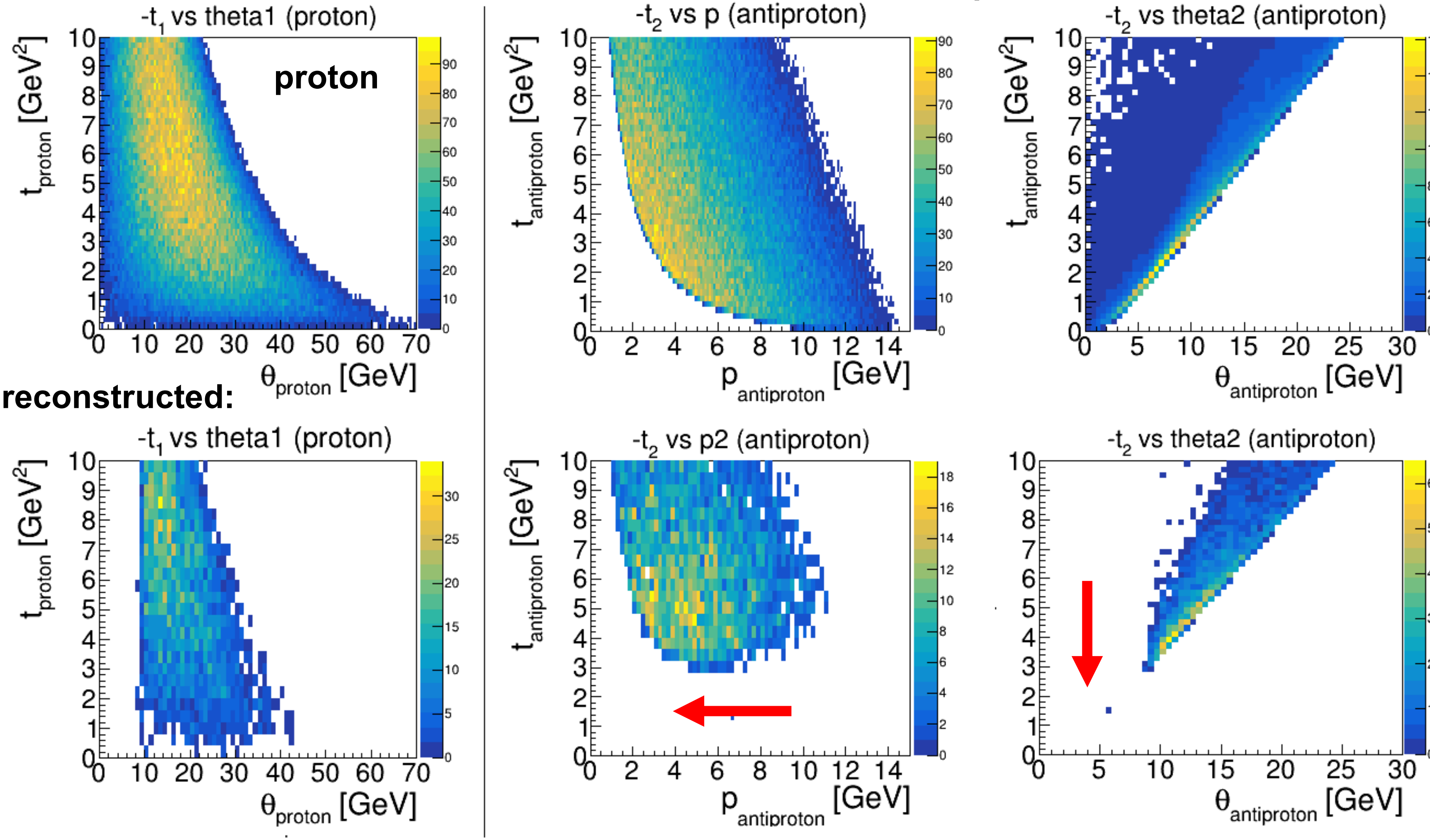


$p\bar{p} \rightarrow p\bar{p}e^+e^-$ @ 15 GeV/c

generated:

antiproton

reconstructed:

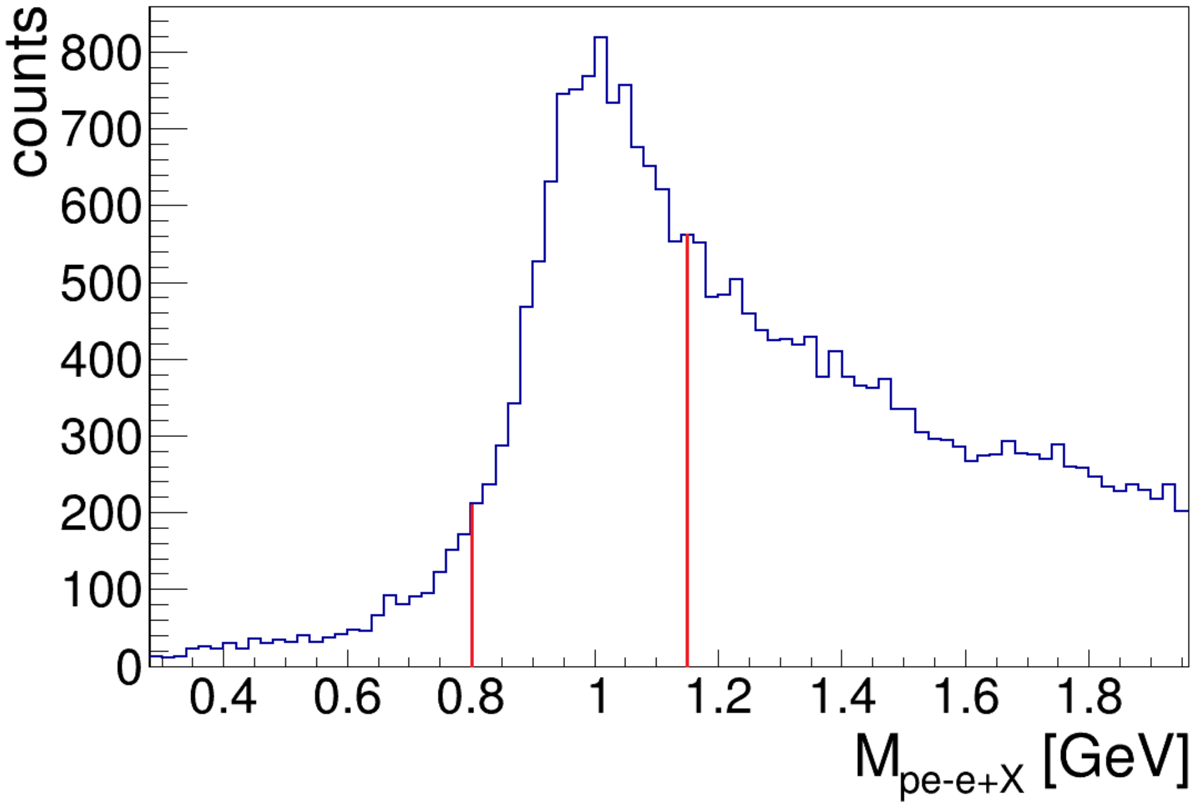


$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

Topology 2: Detection of the antiproton is not required

➔ Reconstruction via the missing antiproton mass

➔ A tight PID for the detected particles is needed to reduce the background

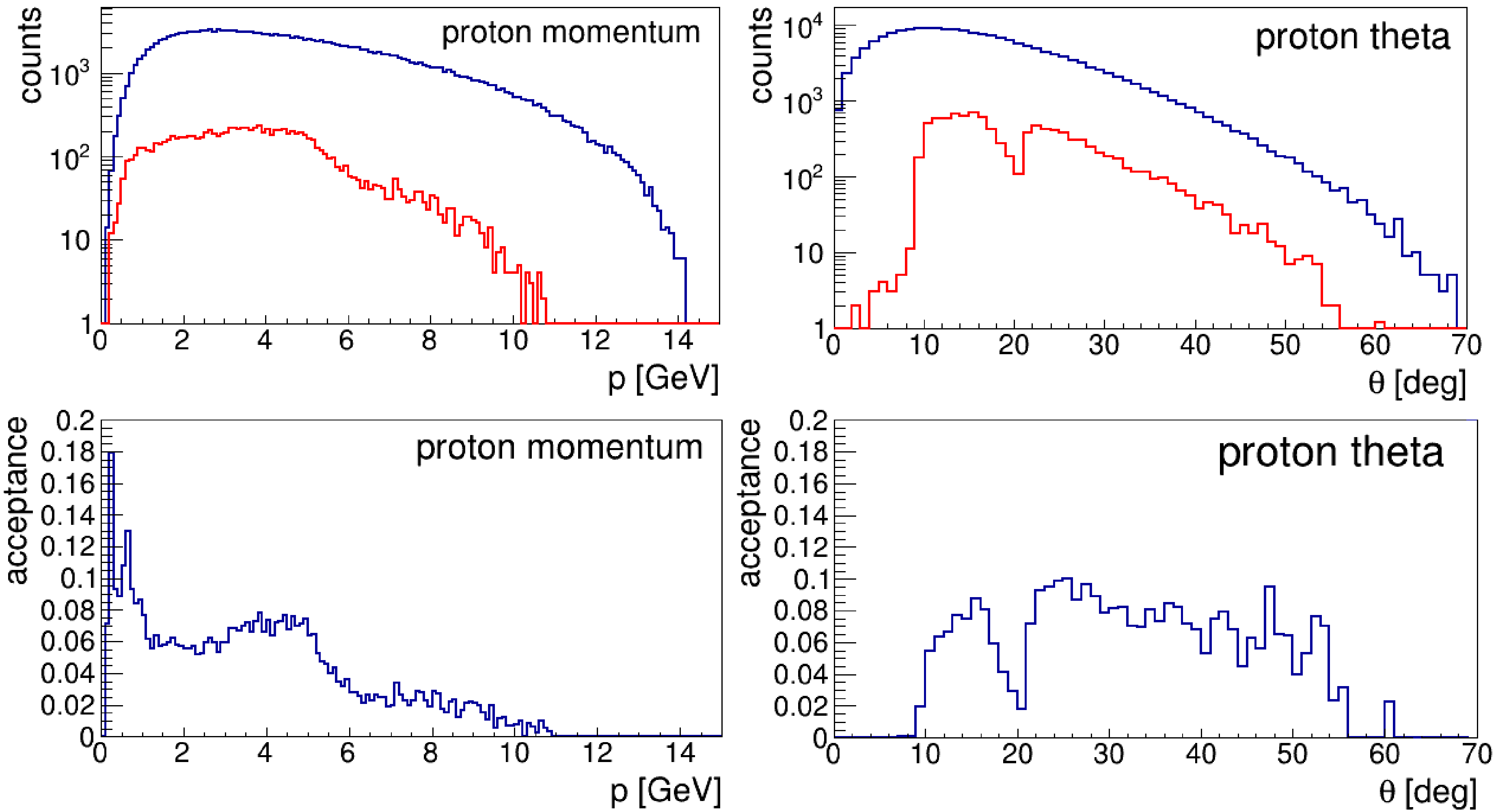


More detailed studies on PID and background will be done

$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

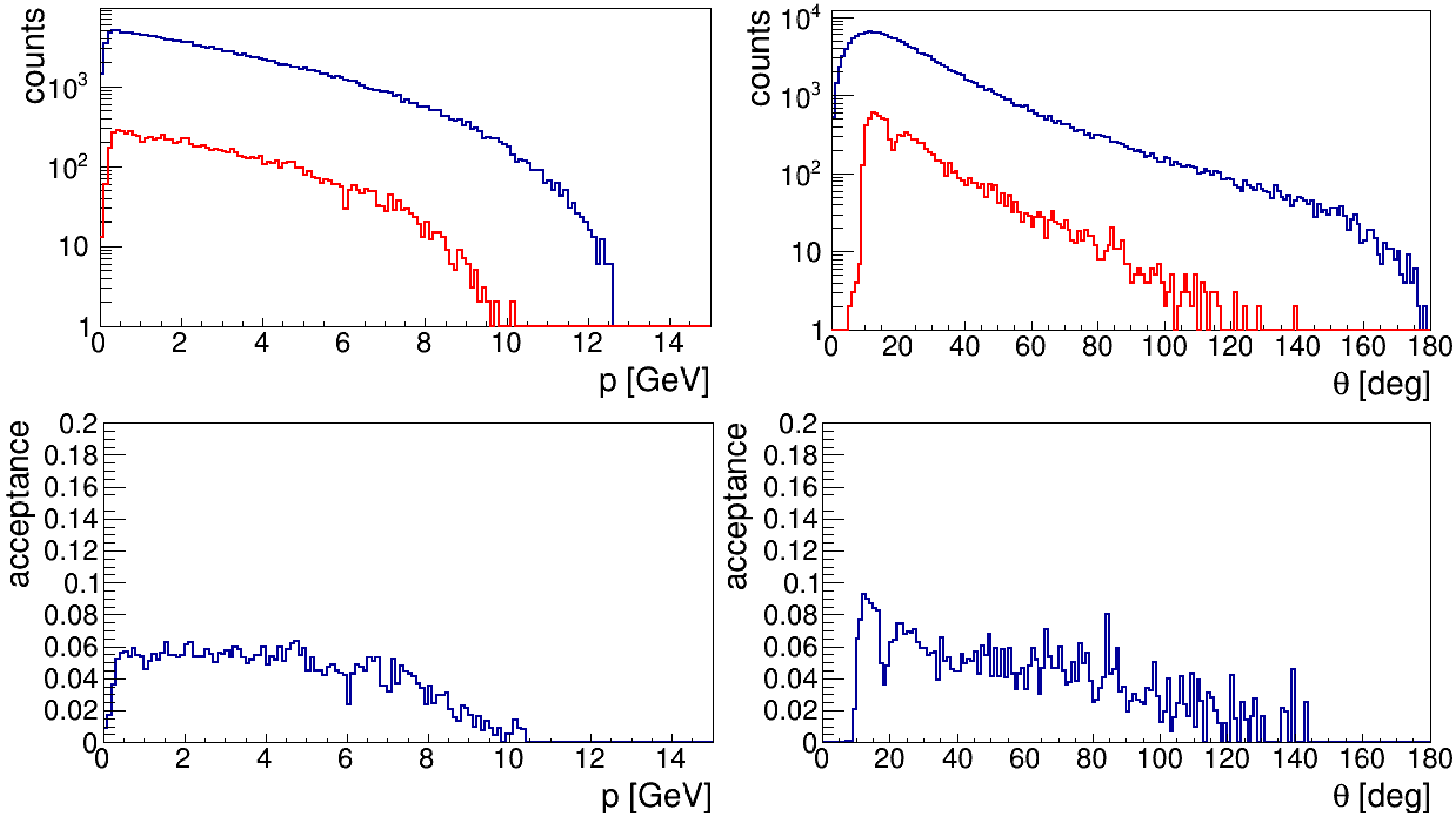
topology 2

proton: generated (blue) reconstructed (red)



$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c topology 2

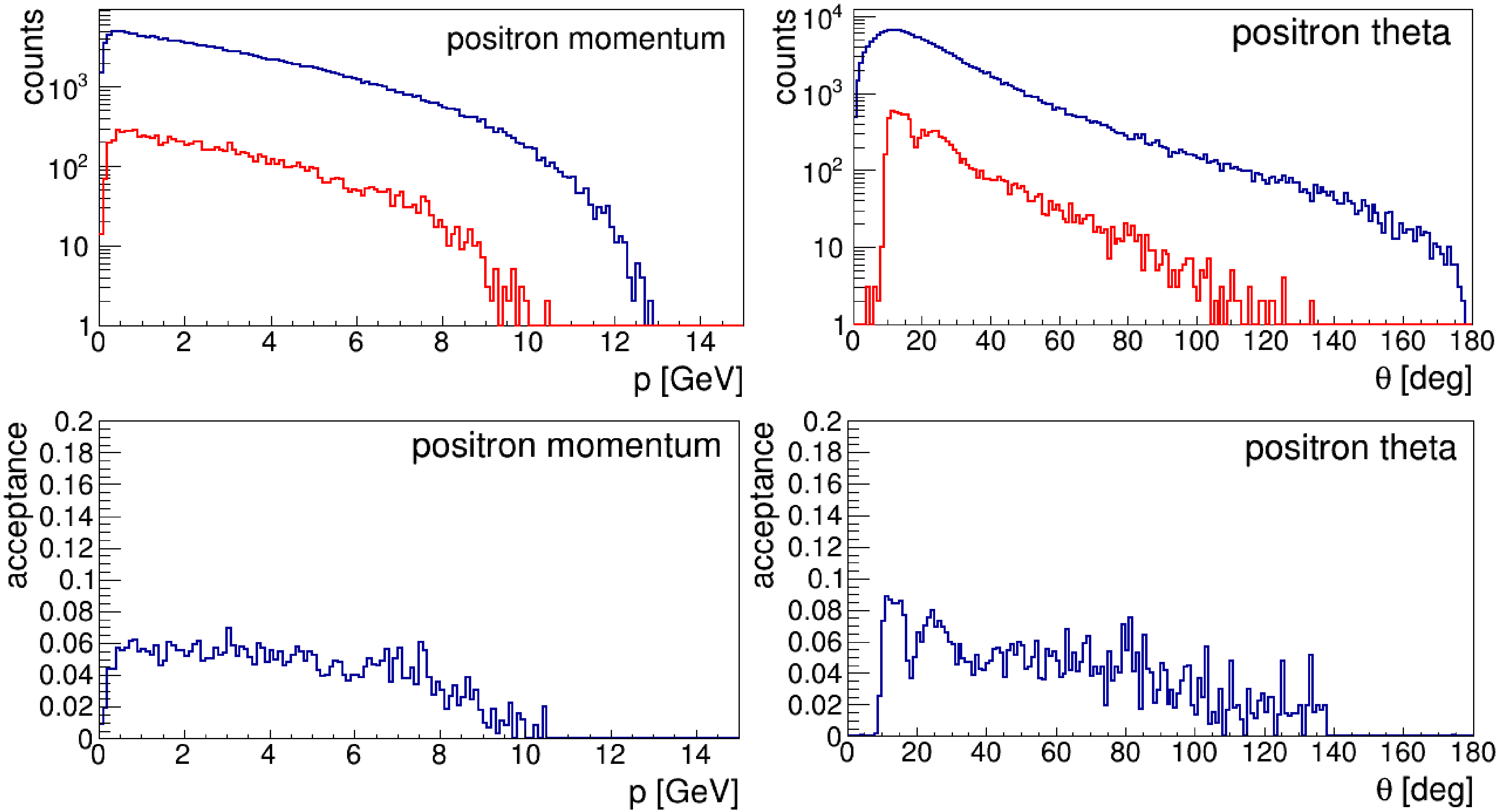
electron: generated reconstructed



$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

topology 2

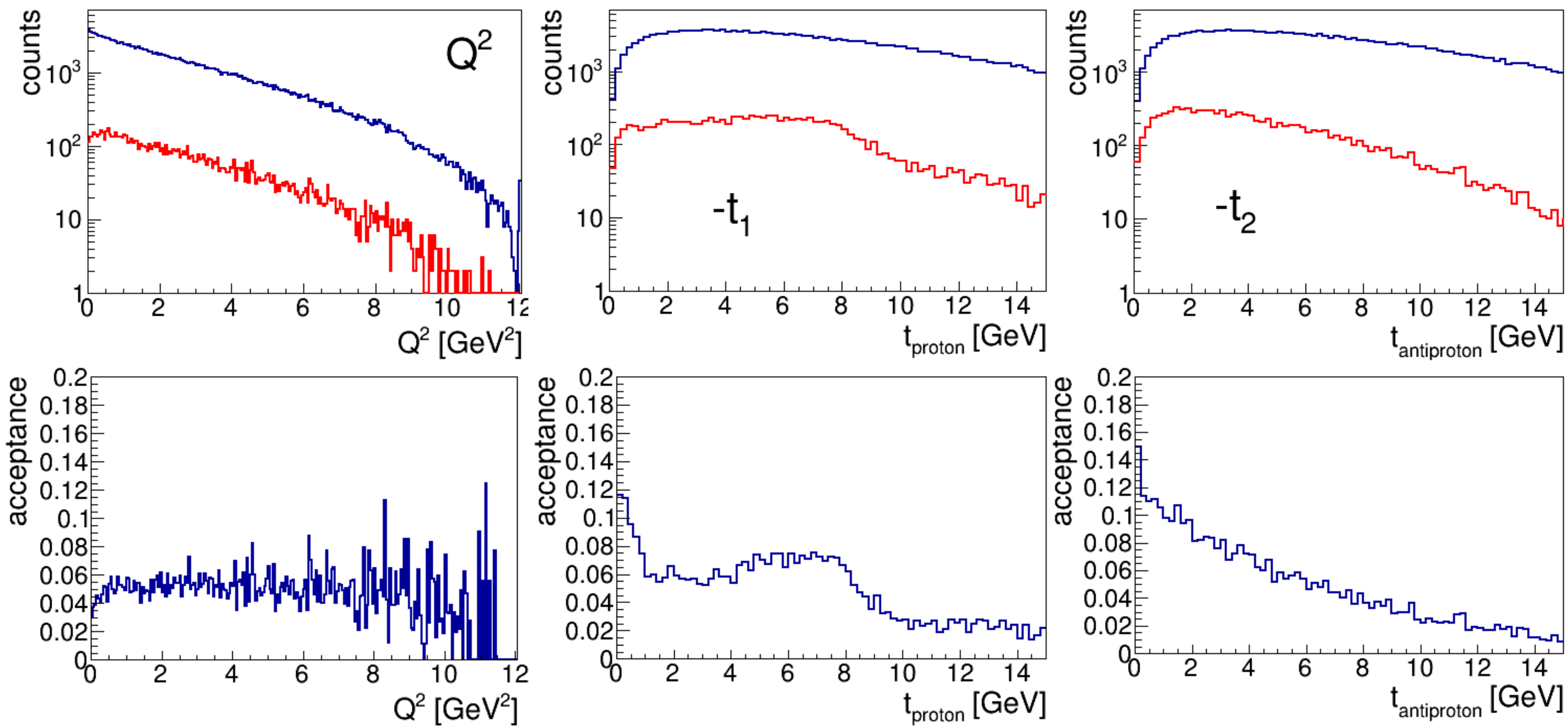
positron: generated reconstructed



$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

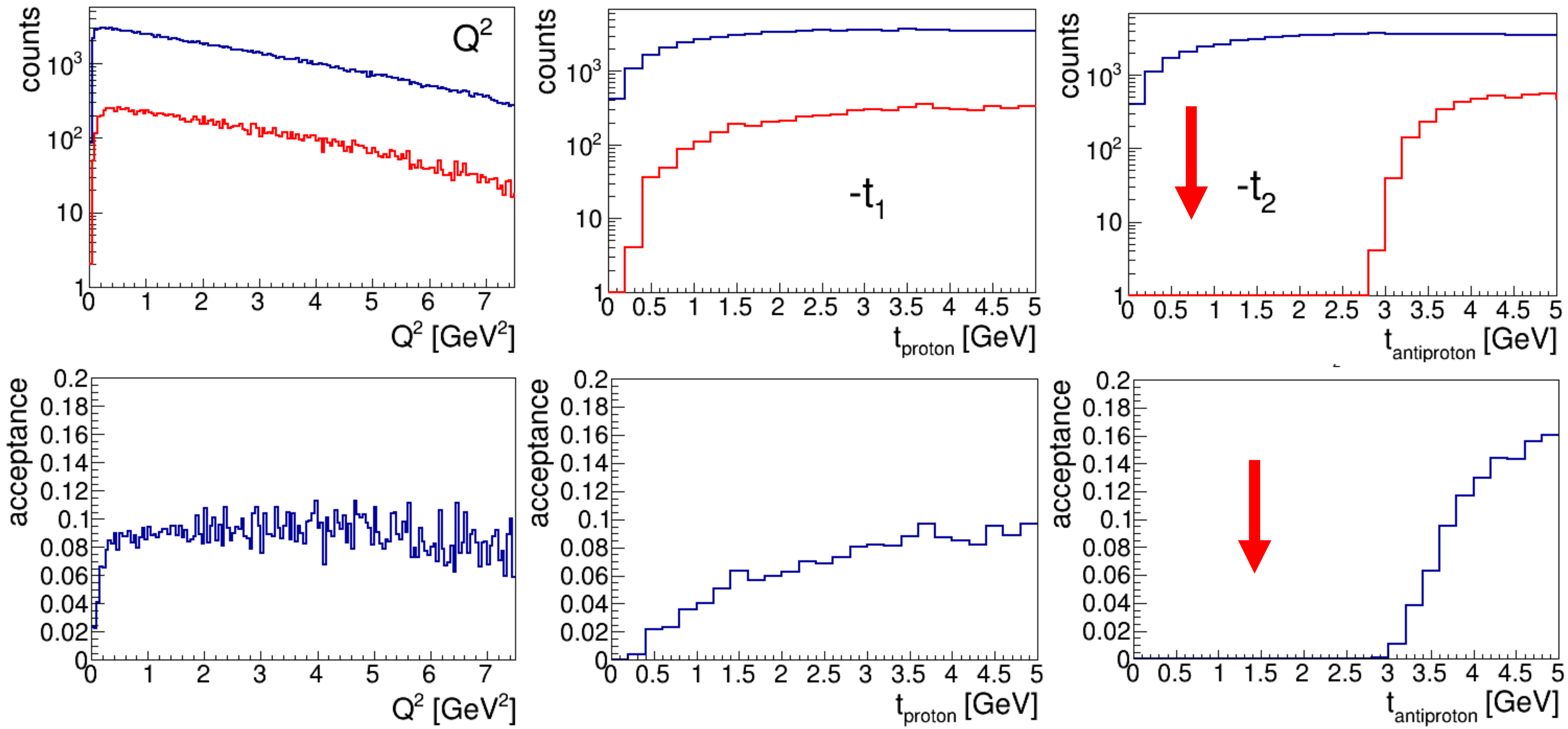
topology 2

Kinematics: generated reconstructed



$p\bar{p} \rightarrow p\bar{p}\mu^{+}\mu^{-}$ @ 15 GeV/c

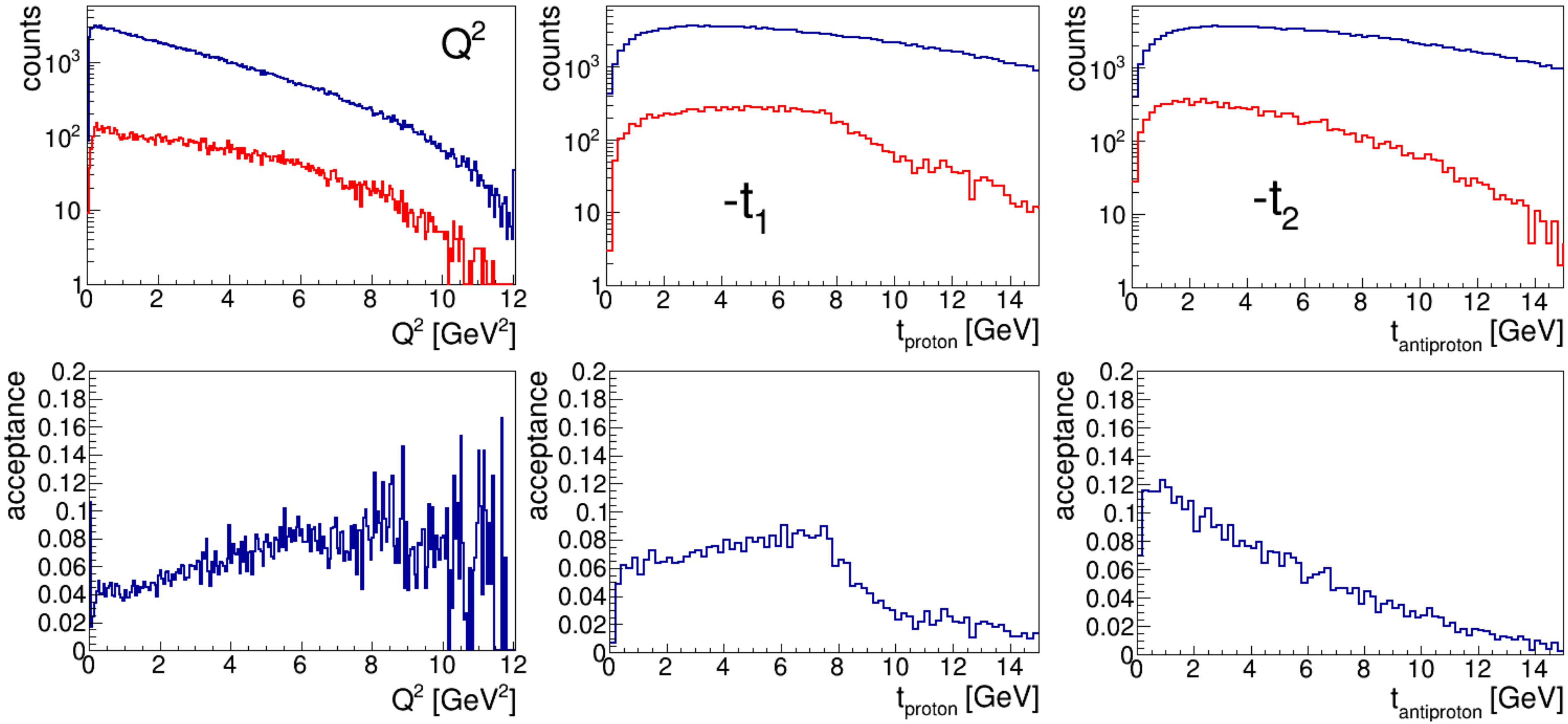
topology 1



➔ Higher acceptance than for $p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$

$p\bar{p} \rightarrow p\bar{p}\mu^+\mu^-$ @ 15 GeV/c

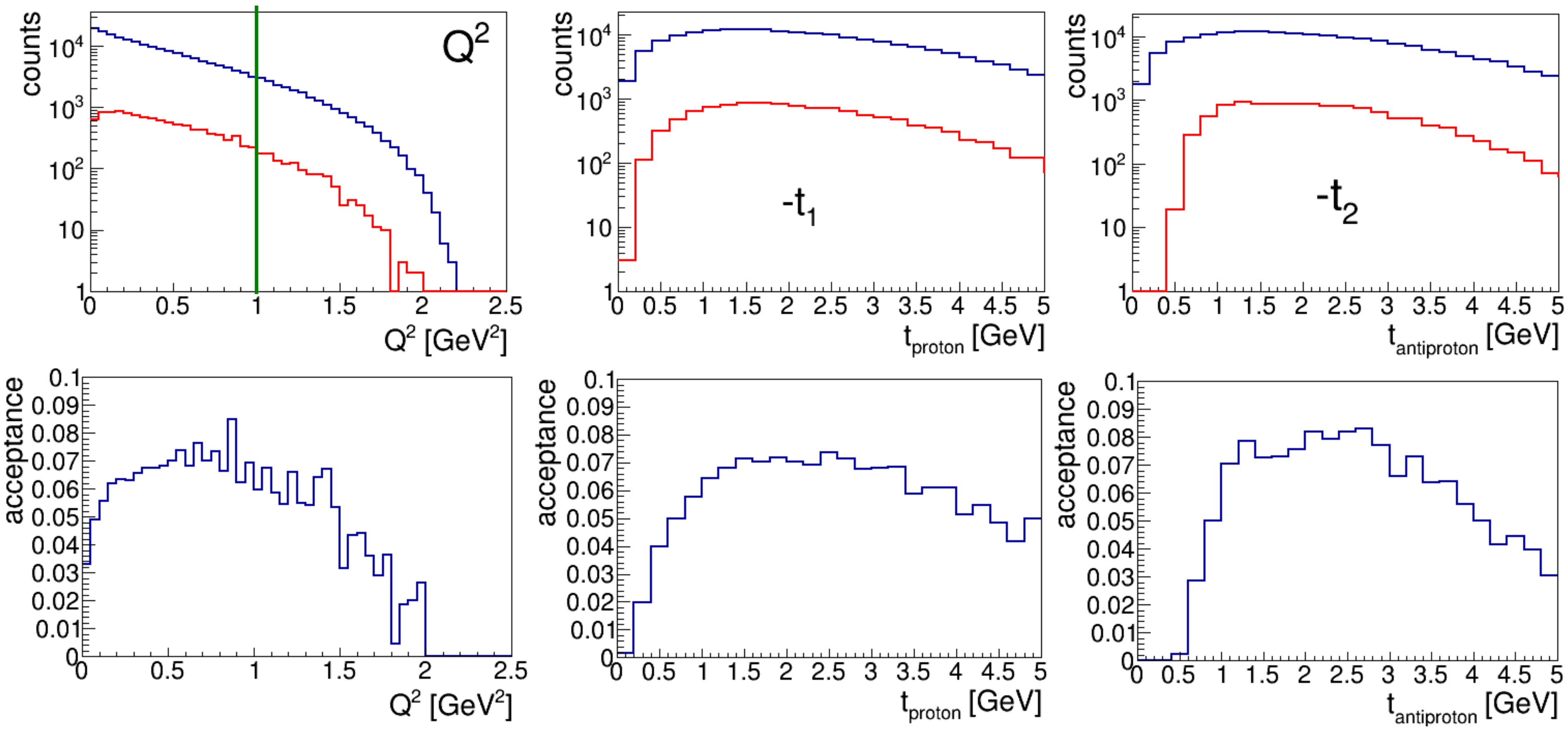
topology 2 (missing antiproton)



➔ Higher acceptance than for $p\bar{p} \rightarrow p\bar{p}e^+e^-$

$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 5 GeV/c

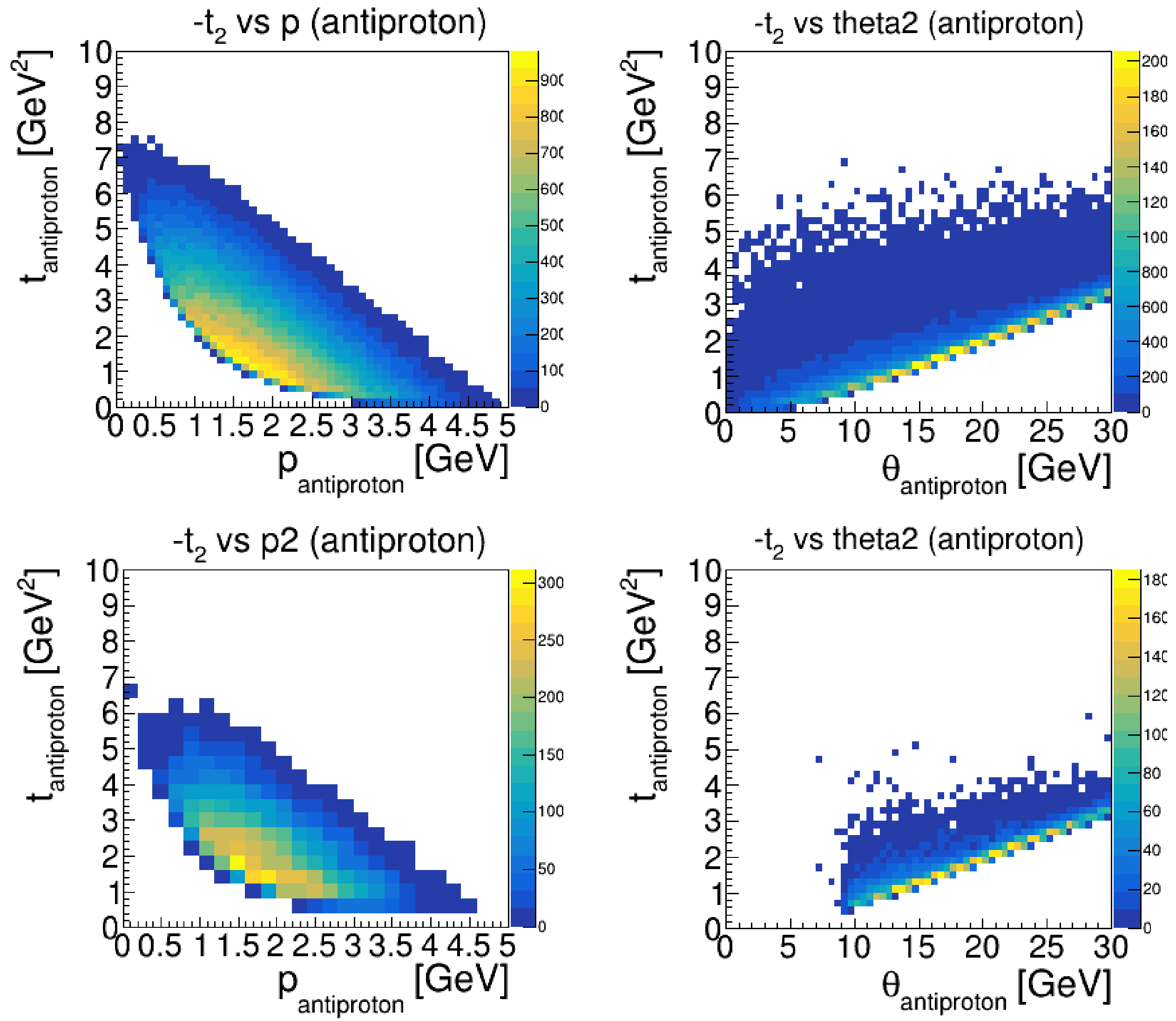
topology 1



➔ Acceptance level increase by a factor ~ 2-3 compared to 15 GeV/c

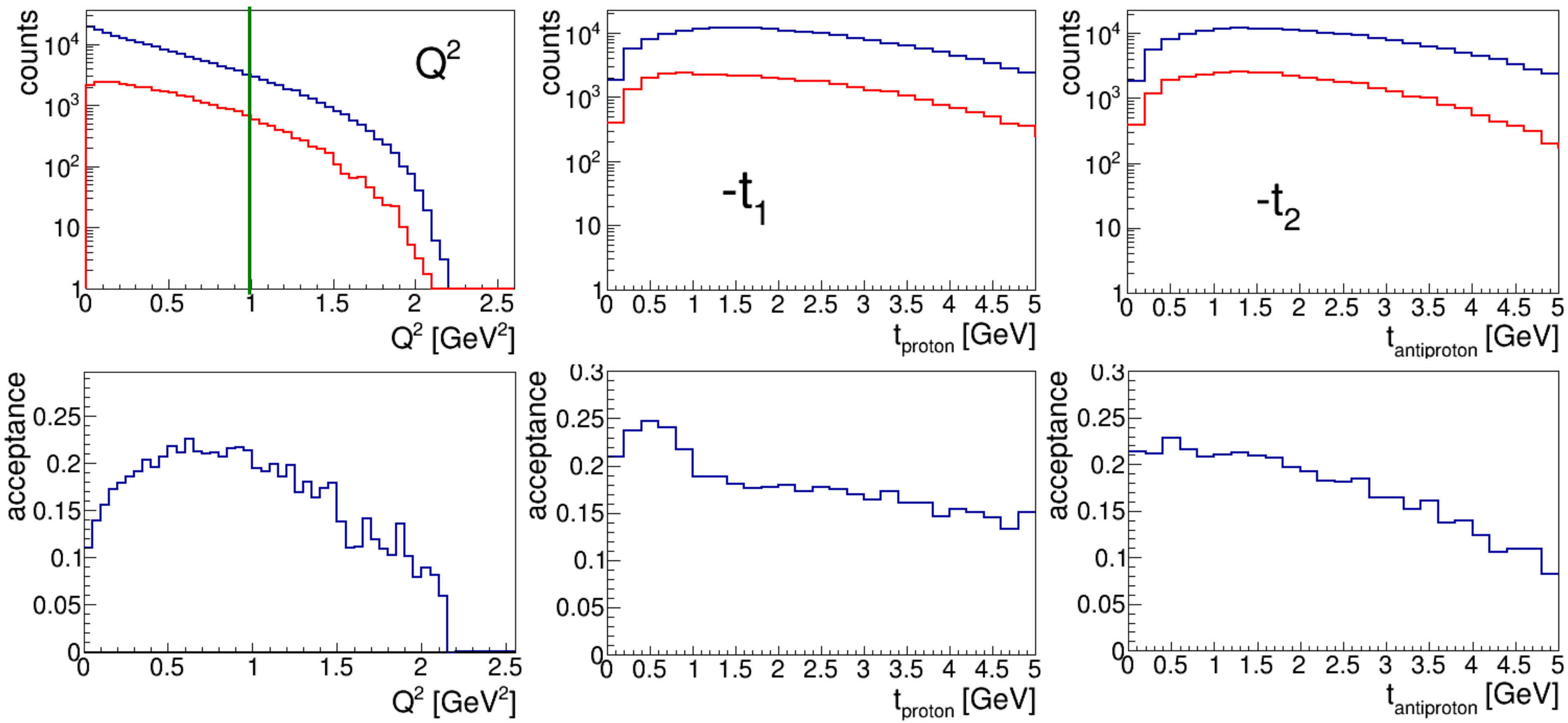
$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 5 GeV/c

topology 1



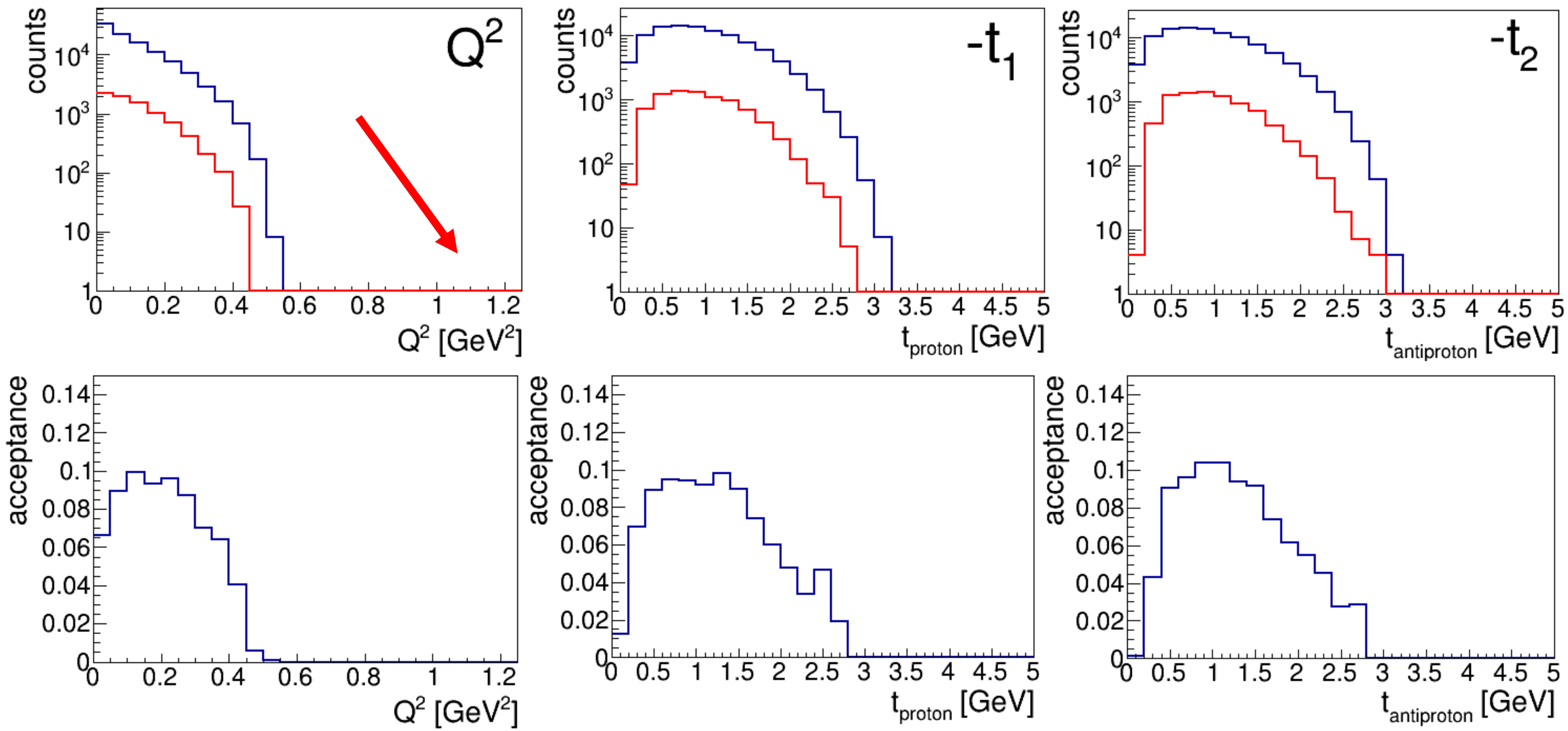
$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 5 GeV/c

topology 2 (missing antiproton)



$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 2.5 GeV/c

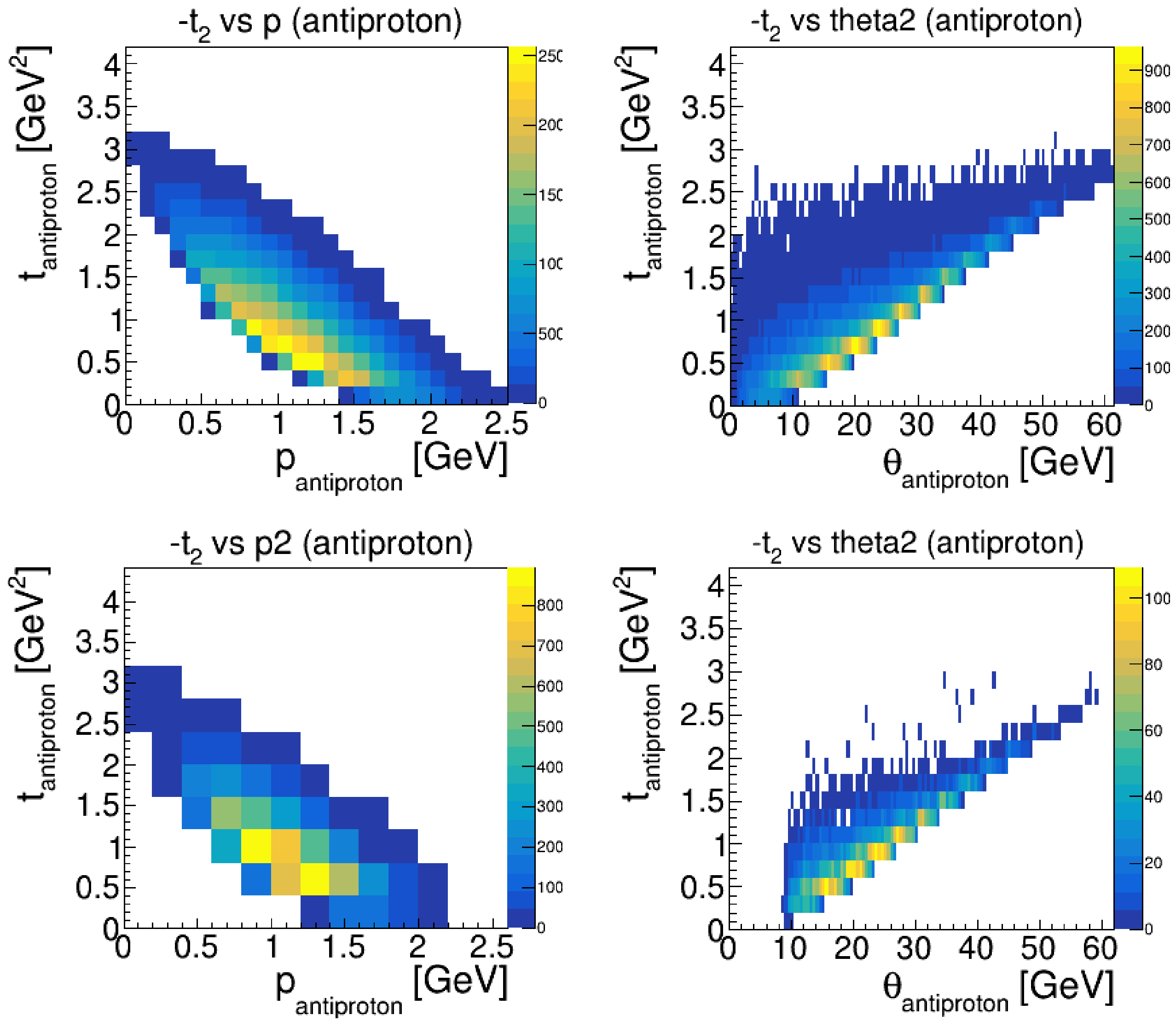
topology 1



➔ Acceptance increases compared to 5 GeV/c

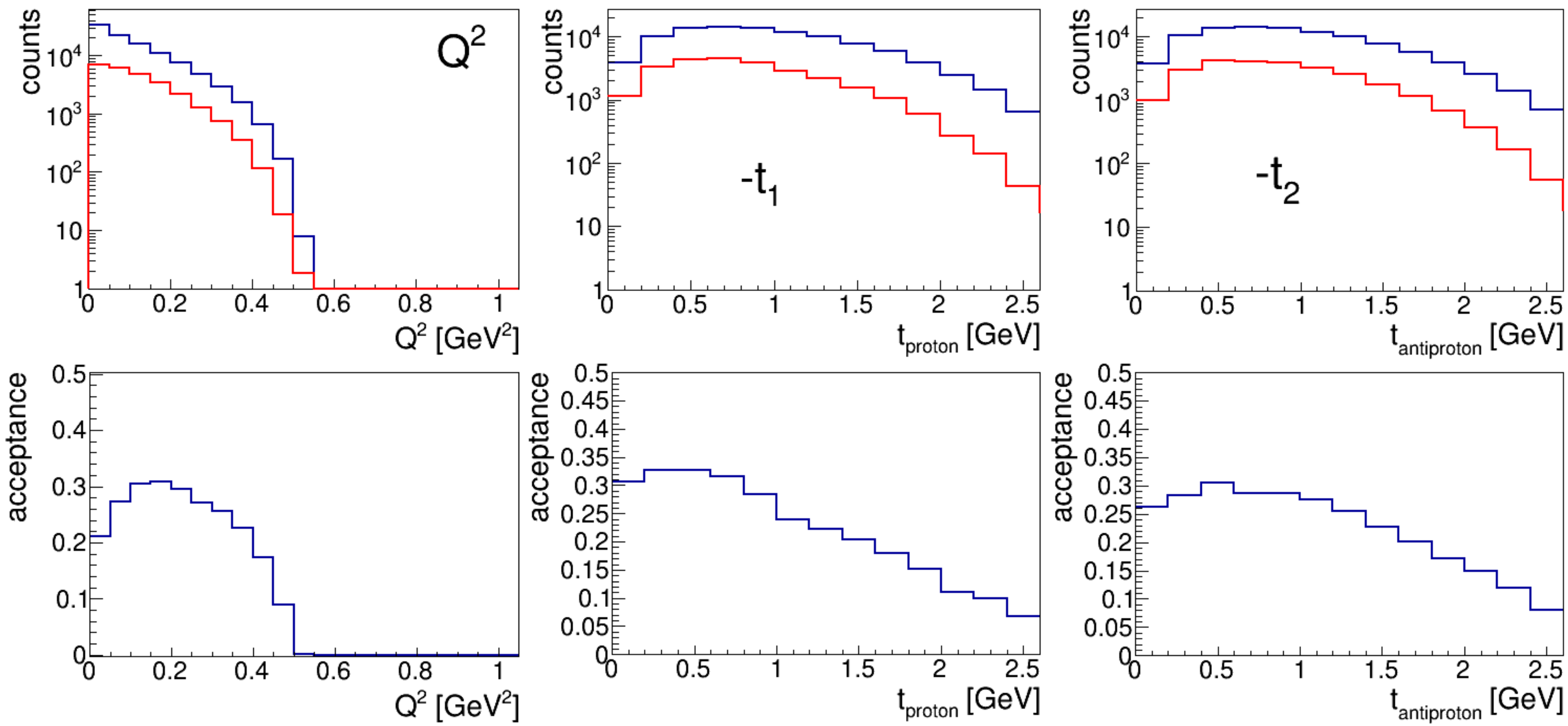
$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 2.5 GeV/c

topology 1

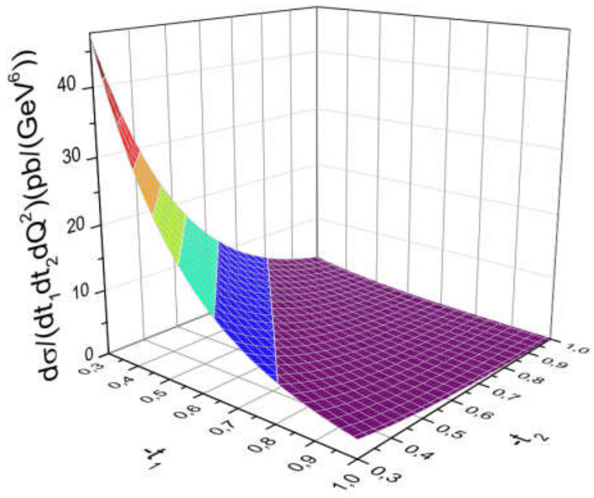


$p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 2.5 GeV/c

topology 2 (missing antiproton)



Rate estimate for $p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c



- **Cross section available for $Q^2 = 3$ GeV²**

  ➔ Set a Q^2 bin from 2.5 GeV² to 3.5 GeV²

  ➔ $\Delta Q^2 = 1$ GeV²

- Set the bins in -t as: $\Delta t_1 = \Delta t_2 = 0.15$ GeV²

- L = 2 fb^{-1} → 1/2 year at the design luminosity

- Acceptance from MC simulations

  ➔ 0.5 – 0.9 % for $t_1 < 0.65$ GeV² if all particles are detected
  ($t_2 < 0.65$ not accessible ! MC issue ???)

  ➔ 10 – 12 % for $t_1 < 0.65$ GeV² if the antiproton is not detected
  but reconstructed via the missing mass

Rate estimate for $p\bar{p} \to p\bar{p}e^+e^-$ @ 15 GeV/c

$-t_1$	$-t_2$	σ in pb	rate / 0.5a	counts / 0.5a	err	err %
0,15	0,15	3,68	7360	846	29	3,4
0,3	0,15	2	4000	440	21	4,8
0,45	0,15	1,09	2180	218	15	6,8
0,6	0,15	0,59	1180	118	11	9,2
0,15	0,3	2	4000	460	21	4,7
0,3	0,3	1,09	2180	240	15	6,5
0,45	0,3	0,59	1180	118	11	9,2
0,6	0,3	0,32	640	64	8	12,5
0,15	0,45	1,09	2180	251	16	6,3
0,3	0,45	0,59	1180	130	11	8,8
0,45	0,45	0,32	640	64	8	12,5
0,6	0,45	0,17	340	34	6	17,1
0,15	0,6	0,59	1180	136	12	8,6
0,3	0,6	0,32	640	70	8	11,9
0,45	0,6	0,17	340	34	6	17,1
0,6	0,6	0,09	180	18	4	23,6

$Q^2 = 2.5 – 3.5\ GeV^2$

rate = $\sigma \cdot L_{int}$

counts = rate · acc

➔ Antiproton not detected

➔ Reconstructed via missing mass

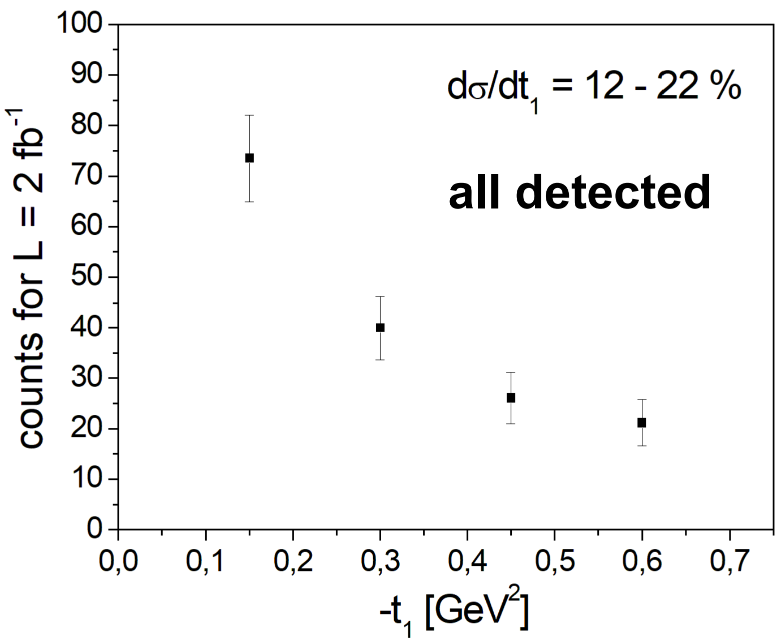
➔ Counts lower if all particles are detected

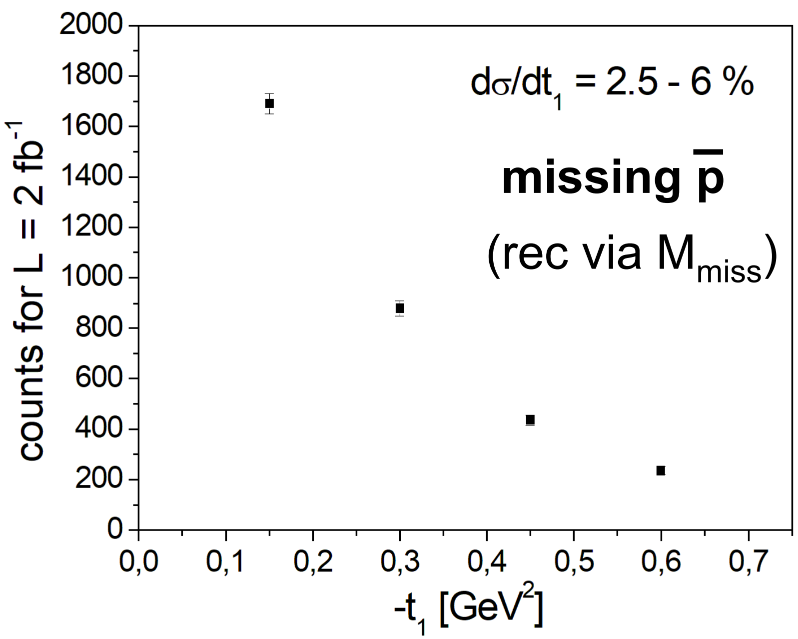
Rate estimate for $p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

$Q^2 = 2.5 – 3.5\ GeV^2$

Integrate over $-t_2 < 0.65\ GeV^2$:

			all detected		missing $\bar{p}$	
$-t_1$ [GeV²]	σ in pb	rate/0.5a	counts / 0.5a	err	counts / 0.5a	err
0,15	7,36	14720	74	8,6	1691	41,1
0,3	4,007	8014	40	6,3	880	29,7
0,45	2,17	4340	26	5,1	435	20,9
0,6	1,17	2340	21	4,6	235	15,3





Rate estimate for $p\bar{p} \rightarrow p\bar{p}e^{+}e^{-}$ @ 15 GeV/c

Additional options to increase the statistics:

→ Decrease Q^2: σ increases with $(Q^2)^2$ ➔ 4 x σ for Q^2 = 1.5 GeV^2

→ Integrate over Q^2 > 1 GeV^2 can gain a factor 8 in statistics

---

➔ Partially integrated measurements are possible during phase 1

➔ Fully differential measurements can be done in phase 2 and 3

➔ High statistics in phase 3 will also allow to differentiate the decay angle of the lepton pair

→ Study interference between DH and EM production ~ Re(M) ~ $H^q H^g$

Up to now: Only cross sections for s = 30 GeV^2 have been calculated

Studies showed: Factorisation region only covered for p > 5 GeV (s = 10 GeV^2)

➔ Cross section calculations for smaller beam momenta (s = 10 GeV^2, s = 20 GeV^2) are in progress

Summary

- Besides time like GPDs (GDAs) also classical GPDs can be measured wih PANDA
- Beam momenta between 5 GeV/c and 15 GeV/c provide suitable kinematics
- More theory calculations are in progress
- **Two topologies have been investigated**

a) All particles detected: + Clean event identification
- Reduced acceptance
- Issue with the antiproton detection in the forward spectrometer (probably due to the MC) has to be solved.

b) Missing antiproton: + Increased acceptance
+ small $-t_1$ and $-t_2$ can be accessed
- More issues with background suppression
→ Tight PID is needed

Outlook

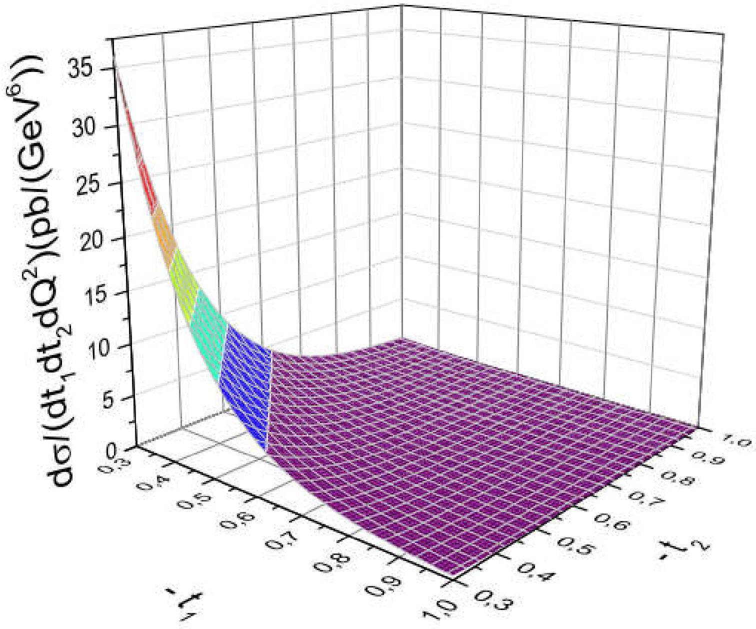
$$pp \rightarrow pp\,l^+l^-$$

- Formalism is also applicable for **proton proton colissions**

➔ Potential study for the **start phase of PANDA**

But: Cross section identical to the antiproton case

➔ High statistics needed!



The DH contribution to the $pp \rightarrow pp\,l^+l^-$ cross section (in pb/ GeV^6) versus t_1 and t_2 (in GeV^2) at $\sqrt{s} = 24$ GeV and $Q^2 = 3$ GeV^2

➔ Comparison to antiproton case can proof the universality of the GPDs

Long term perspective: Measurments with a **polarized beam / target** can be used to access more / different GPDs