PANDA collaboration meeting

GSI, October 11, 2022

Background Studies for GPD Measurements with Antiproton Scattering

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

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Introduction

Antiproton Scattering: Measure space like GPDs with PANDA as they are currently studied i.e. in hard exclusive electroproduction experiments @ JLAB

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

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

$$p\bar{p} \rightarrow p\bar{p}\, l^+ l^-$$

➔ 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]

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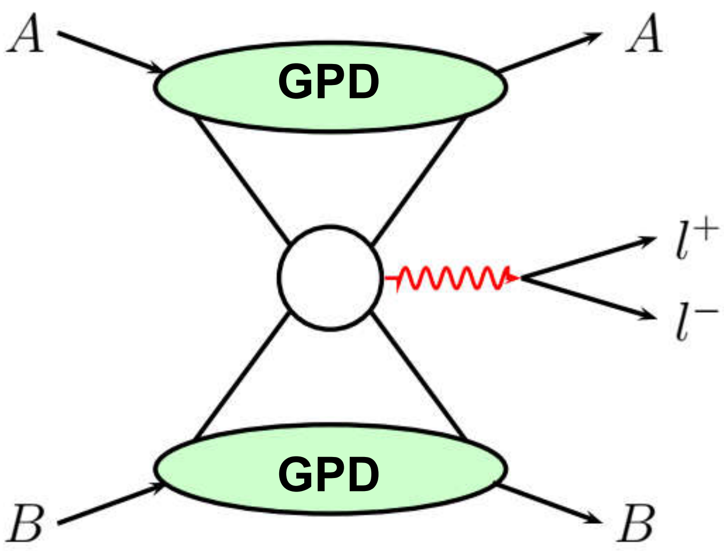
†: *Fachbereich Physik, Universität Wuppertal, D-42097 Wuppertal, Germany*
‡ : *Veksler and Baldin Laboratory of High Energy Physics, Dubna 141980, Moscow region, Russia*

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



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

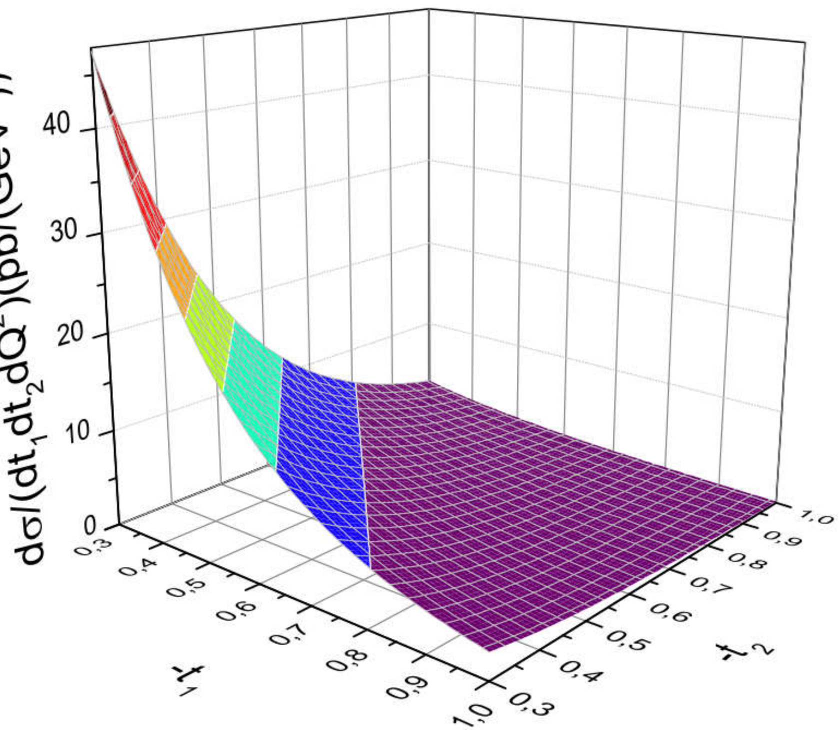
Observables

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

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

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

factorisation for: $t_i / Q^2 << 1$



The $p\bar{p} \to p\bar{p}\, l^+ l^-$ cross section in $pb/\ \text{GeV}^6$ versus t_1 and t_2

$s = 30\ \text{GeV}^2$, $Q^2 = 3\ \text{GeV}^2$

Feasability Studies

➔ PANDAroot simulations with a phase space event generator

2 final states have been studied: $p\bar{p} \rightarrow p\bar{p}\gamma^* \rightarrow \begin{cases} p\bar{p}e^+e^- \\ p\bar{p}\mu^+\mu^- \end{cases}$

➔ It was found, that only the e^+e^- final state is feasible since the high muon momenta are mostly outside the PID range of the PANDA muon system
(see my talk at the May CM)

2 beam momenta have been studied:

s = **20 GeV²** (p ~ 9.7 GeV/c)

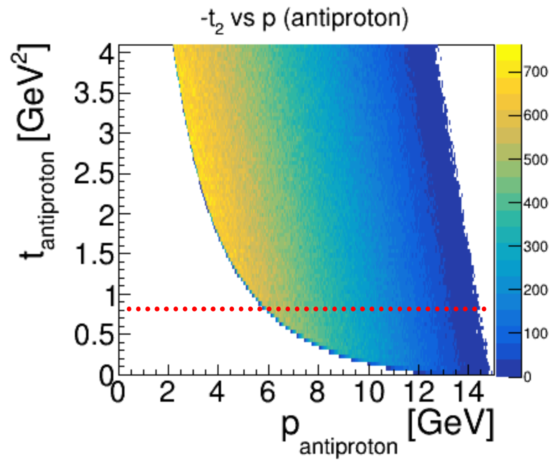
s = **30 GeV²** (p ~ 15 GeV/c)

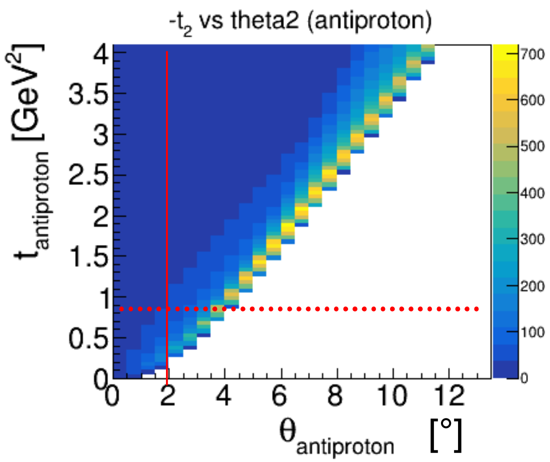
➔ Smaller beam momenta can not provide sufficiently high Q²

➔ Feasibility for s = 20 GeV² has been shown at the last CM

Generated Antiproton Distributions vs -t

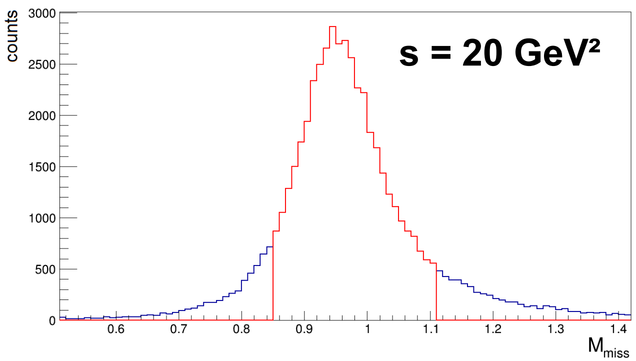
s = 30 GeV²

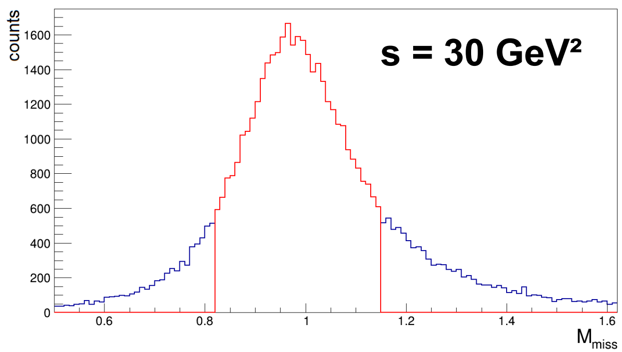




➔ Detection of the antiproton is not required

➔ Reconstruction via the missing antiproton mass





➔ Results after Bremsstrahlungscorrection

Expected Background

Main background channel: $p\bar{p} \rightarrow p\bar{p}\pi^+\pi^-$

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

A good lepton PID is essential!

➔ Background studies for s = 20 GeV² and s = 30 GeV² have been perfomed.

➔ > 1 B two pion background events ($t_{1,2}$ < 1.5 GeV²) have been simulated.

Cross section estimates for the main background channel:

Physics Letters B 680 (2009) 459–465

Contents lists available at ScienceDirect

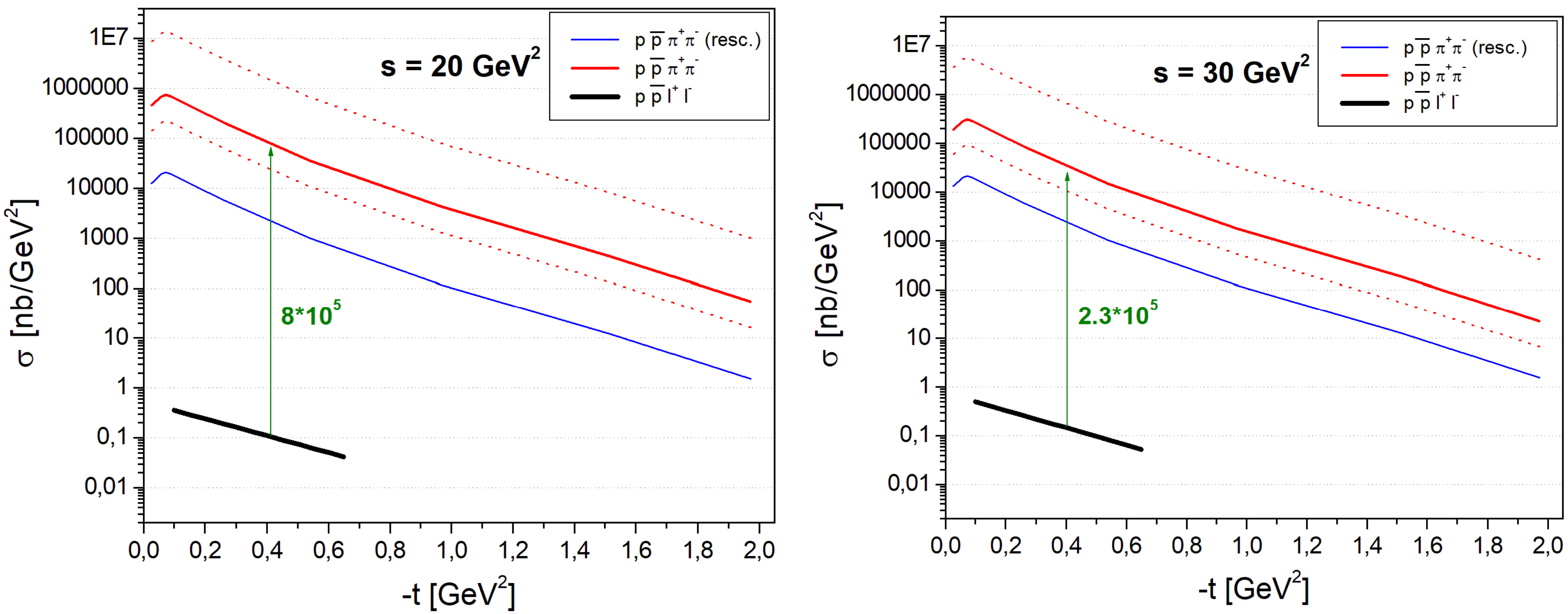
Physics Letters B

www.elsevier.com/locate/physletb

Low-energy pion–pion scattering in the $pp \rightarrow pp\pi^+\pi^-$ and $p\bar{p} \rightarrow p\bar{p}\pi^+\pi^-$ reactions

P. Lebiedowicz [a], A. Szczurek [a,b,*], R. Kamiński [a]

Background Cross Section



Signal cross sections have been inetgrated over the second t_i and over the full Q² (assumed 1/Q² dep.)

➔ Lowest background at 30 GeV²

PID Refinenements and Background Suppression

➔ A suppression of the two pion background by 10^5 – 10^6 is needed

➔ PID refinements are needed to reach this!

Two PID versions have been investigated:

a) Cuts on the PID variables and additional detector variables

b) A TMVA analysis including the PID and detector variables

Classsical PID Refinenements

Protons: 2 configurations were investigated

tight: $P_C > 0.99$ && $P_S > 0.05$

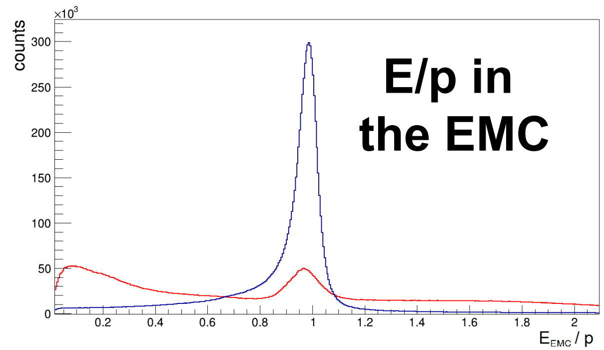
loose: $P_C > 0.99$

Electrons: $P_C > 0.99$ && $P_S > 0.19$

blue: electrons red: pions

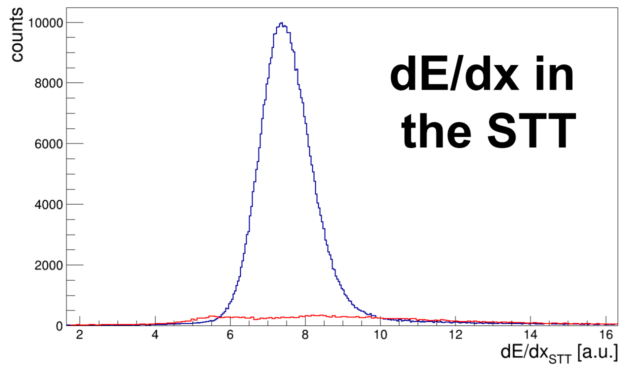
i. Calorimeter sampling fraction E/p

E/p > 0.8 + momentum dependent 3 sigma band cut



ii. Energy los per path length dE/dx in the STT

momentum dependent 3 sigma band cut



iii. EMC E_1 $E_1 > 0.35$ GeV

iv. EMC lateral moment EMC lateral < 0.75

Effect of the Classical PID Refinements

electron (- pion):

➔ Cuts are applied sequentially

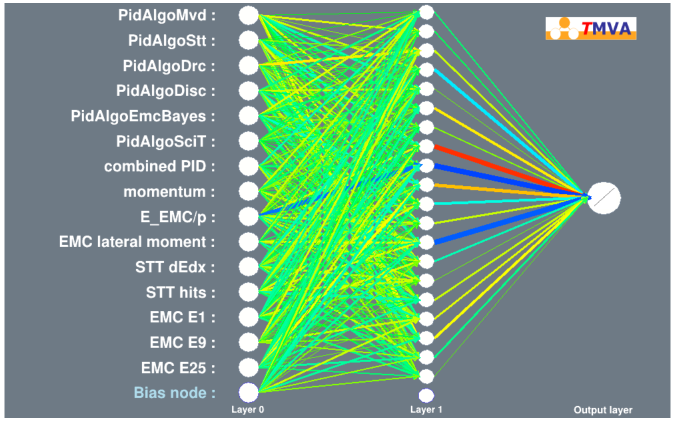
	s = 20 GeV²		s = 30 GeV²	
	signal eff. [%]	**S / BG**	**signal eff. [%]**	**S / BG**
PID_C > 0.99	47,7	20	46,3	31
PID_S > 0.19	32,5	66	34,9	65
sampfrac E/p	28,6	219	25,4	198
STT dE/dx	21,4	460	16,6	456
EMC E1	17,6	707	14,5	811
EMC lateral	15,3	**1293**	13,2	**1053**

positron (- pion):

	s = 20 GeV²		s = 30 GeV²	
	signal eff.	**S / BG**	**signal eff.**	**S / BG**
PID_C > 0.99	50,3	18	52,9	8
PID_S > 0.19	36,3	43	37,8	34
sampfrac E/p	30,5	78	26,8	111
STT dE/dx	22,0	319	17,5	253
EMC E1	18,5	471	15,5	383
EMC lateral	15,8	**883**	13,9	**548**

Electron / Positron PID (TMVA analysis)

➔ Use machine learning to exploit correlations between the PID and detector variables



signal sample
$\bar{p}\,p \rightarrow \bar{p}\,p\,e^-\,e^+$
$(x_1, x_2, x_3, \ldots)$

background sample
$\bar{p}\,p \rightarrow \bar{p}\,p\,\pi^-\,\pi^+$
$(x_1, x_2, x_3, \ldots)$

unknown data sample

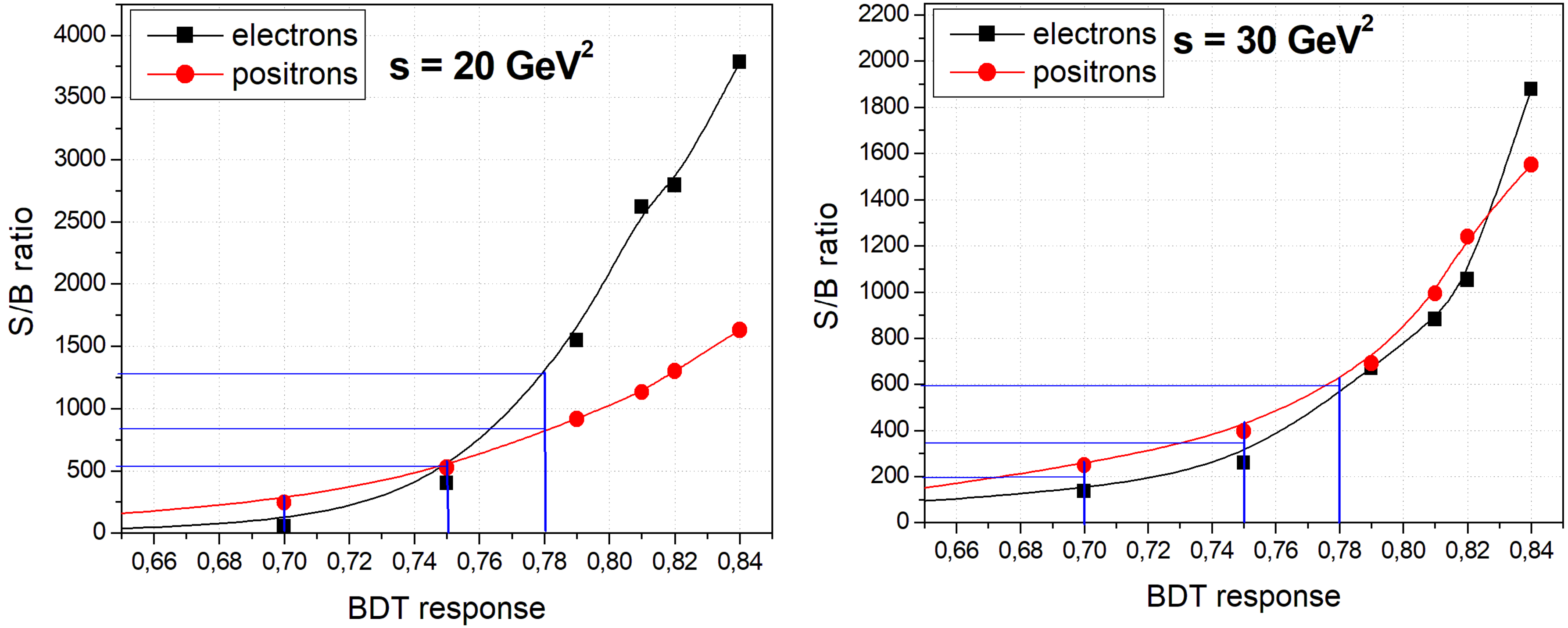
TMVA training, testing and evaluation

TMVA weight file

Analysis of unknown data sample with a cut on the TMVA response

➔ Best results obtained with a boosted decision tree (BDT)

Electron / Positron PID (TMVA analysis)



		s = 20 GeV²		s = 30 GeV²	
	BDT ele, pos	signal eff	S/B ele/pos	signal eff	S/B ele/pos
very loose	> 0.70	~ 26 %	115 / 270	~ 32 %	136 / 249
loose	> 0.75	~ 19 - 20 %	540 / 540	~ 23 %	259 / 396
standard	> 0.78	~ 11 - 16 %	1280 / 820	~ 16 %	560 / 620

S/B ratio for exclusive events @ s = 30 GeV²

- **Select exclusive events** with a cut on the missing antiproton mass
- **Select the events of interest** with a cut on Q², t_1 and t_2

➔ The expected S/B ratio is weighted with the expected cross section ratio ($2.3 \cdot 10^5$)

	classical PID refinements			standard TMVA cuts		
	signal acc.	**backgr. acc.**	**expected S/B**	**signal acc.**	**backgr. acc.**	**expected S/B**
Q² > 1 GeV² **$-t_{1,2}$ < 1 GeV²**	0,0030	< $3.6*10^{-9}$	> 3.7	0,0047	$4.0*10^{-9}$	**~ 5.2**
Q² > 1 GeV² **$-t_{1,2}$ < 0.7 GeV²**	0,0026	< $1.1*10^{-8}$	> 1.0	0,0042	< $1.1*10^{-8}$	> 1.6
Q² > 3 GeV² **$-t_{1,2}$ < 1.0 GeV²**	0,0045	< $1.0*10^{-8}$	> 2.0	0,0060	< $1.0*10^{-8}$	> 2.6

loose TMVA cuts

2-3 times larger wrong PID rate than classical cuts

	signal acc.	**backgr. acc.**	**expected S/B**
Q² > 1 GeV² -t < 1.0 GeV²	0,0078	$7.9*10^{-9}$	**~ 4.3**
Q² > 1 GeV² -t < 0.7 GeV	0,0071	< $1.1*10^{-8}$	> 2.8
Q² > 3 GeV² -t < 1.0 GeV	0,0093	< $1.0*10^{-8}$	> 4.1

➔ If „>“ is stated, the given background acceptances and S/B ratios are only limits, no single event of the generated BG sample (1 B events) was reconstructed!

S/B ratio for exclusive events @ s = 30 GeV²

➔ So far protons were selected with a cut on $PID_S > 0.05$ and $PID_C > 0.99$

➔ Now only $PID_C > 0.99$ is used

classical PID refinements | **loose TMVA cuts** (2-3 times larger wrong PID rate than classical cuts)

	signal acc.	backgr. acc.	expected S/B	signal acc.	backgr. acc.	expected S/B
$Q^2 > 1$ GeV², $-t_{1,2} < 1$ GeV²	0,0071	$< 3.6 \cdot 10^{-9}$	> 8.7	0,017	$1.58 \cdot 10^{-8}$	**~ 4.8**
$Q^2 > 1$ GeV², $-t_{1,2} < 0.7$ GeV²	0,0033	$< 1.1 \cdot 10^{-8}$	> 1.3	0,0092	$< 1.1 \cdot 10^{-8}$	> 3.6
$Q^2 > 3$ GeV², $-t_{1,2} < 1.0$ GeV²	0,0096	$< 1.0 \cdot 10^{-8}$	> 4.2	0.021	$< 1.0 \cdot 10^{-8}$	> 9.1

very loose TMVA cuts

3.5 times larger wrong PID rate than classical cuts

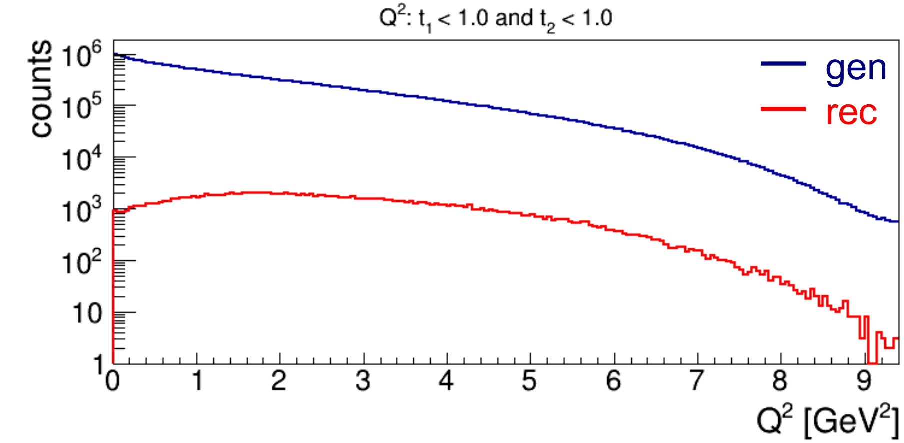
	signal acc.	backgr. acc.	expected S/B
$Q^2 > 1$ GeV² $-t < 1.0$ GeV²	0,026	$6.7 \cdot 10^{-8}$	**~ 1.7**
$Q^2 > 1$ GeV² $-t < 0.7$ GeV	0,014	$2.5 \cdot 10^{-8}$	**~ 2.5**
$Q^2 > 3$ GeV² $-t < 1.0$ GeV	0,031	$3.3 \cdot 10^{-8}$	**~ 4.0**

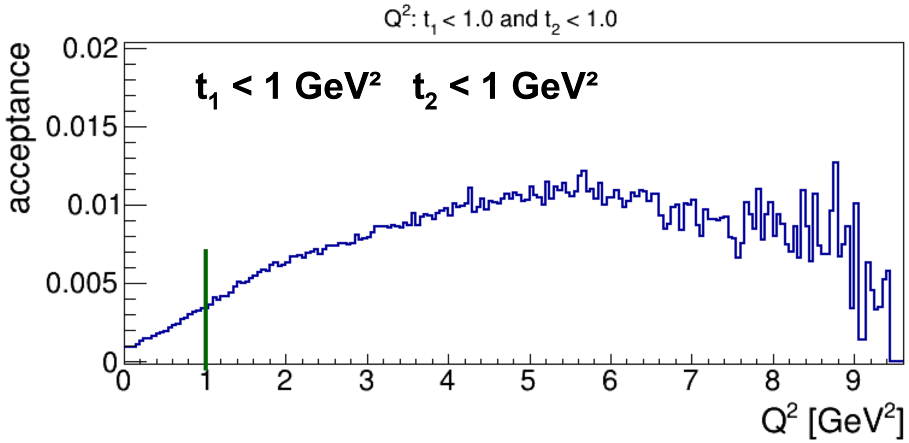
➔ Releasing the proton cut increases the acceptance by a factor > 3

➔ S/B ratio stays comparable / improves slightly

Q^2 acceptance @ s = 30 GeV²

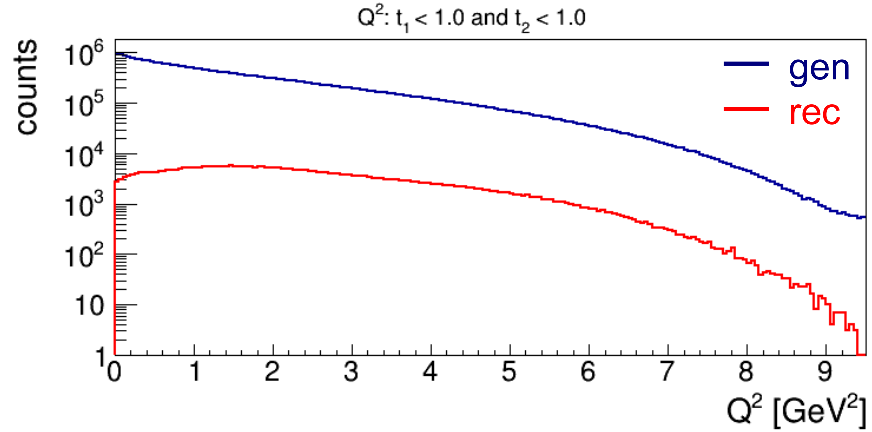
classical PID refinements

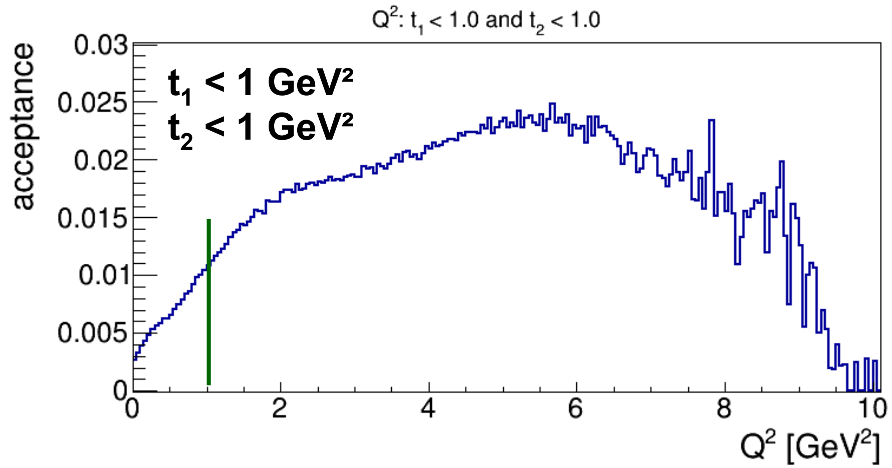




acc = 0.5 – 1.1 %

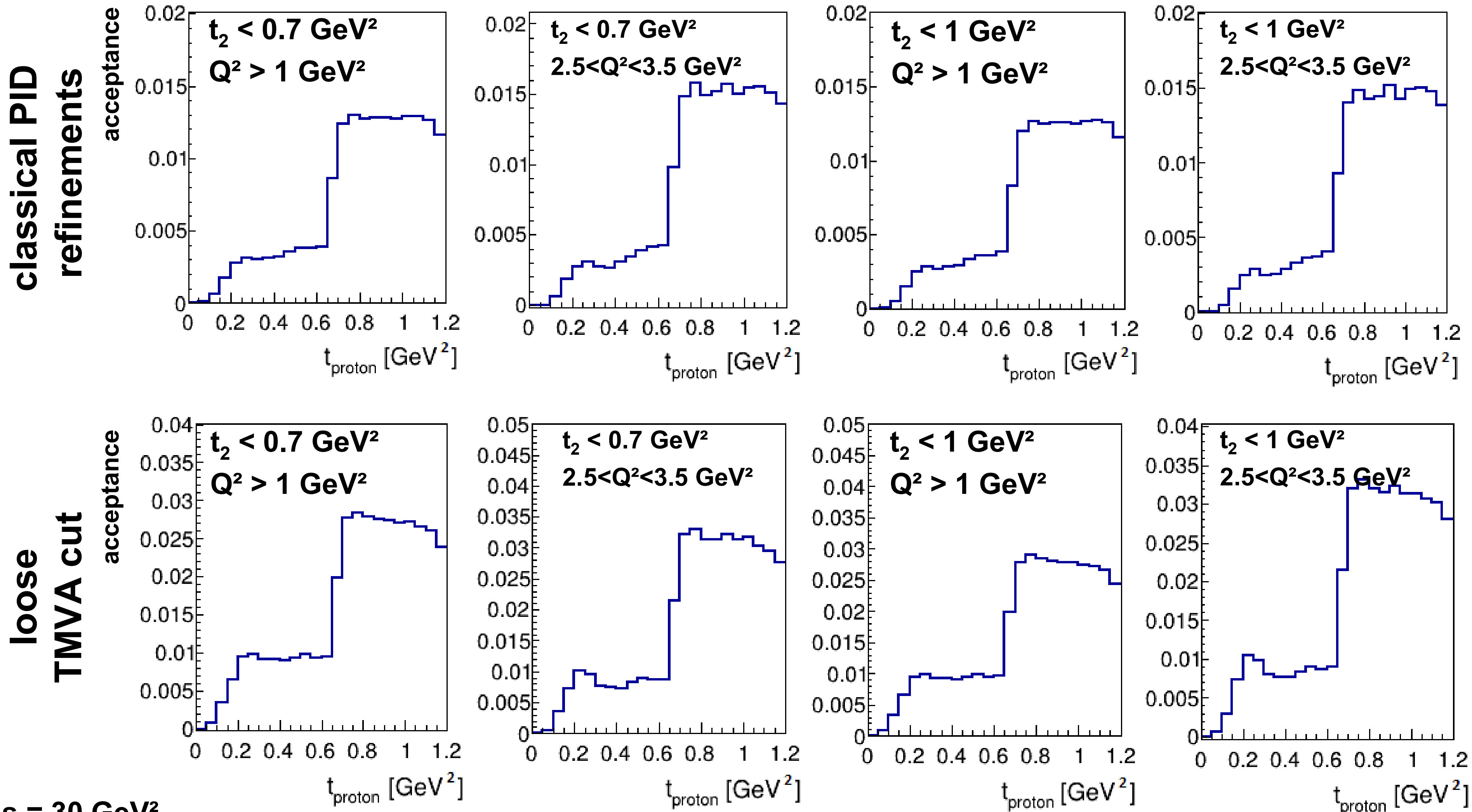
loose TMVA cut





acc = 1.5 – 2.5 %

t_1 (proton) acceptance @ s = 30 GeV²

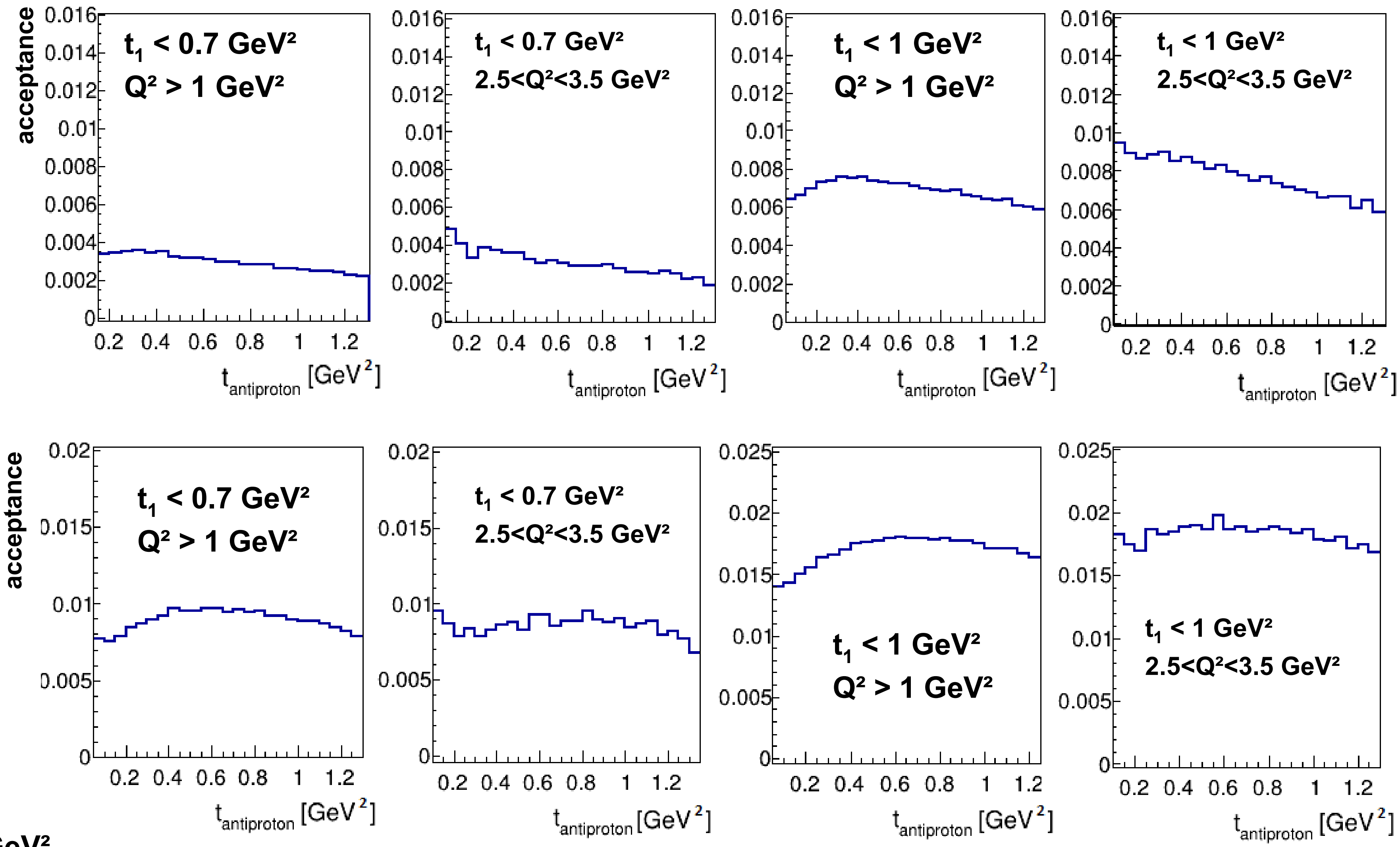


s = 30 GeV²

t_2 (antiproton) acceptance @ s = 30 GeV²

classical PID refinements

loose TMVA cut



s = 30 GeV²

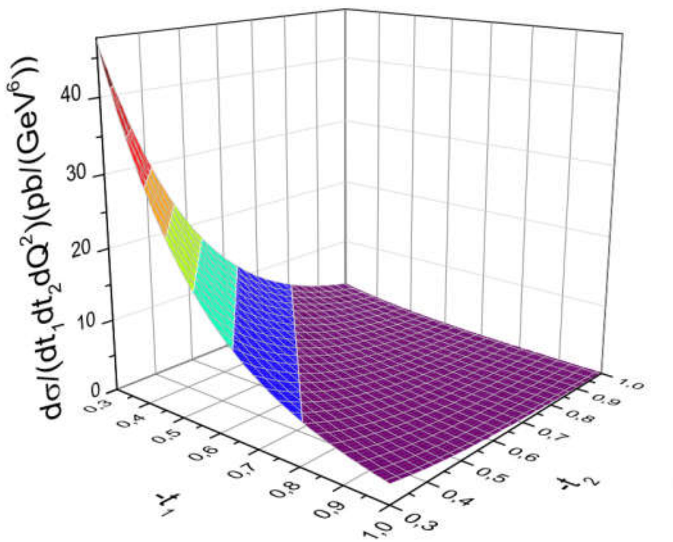
Count rates and cross section uncertainties

- **Differential cross section available for s = 20 GeV² and 30 GeV² @ Q² = 3 GeV²**

$$\frac{d\sigma(pp \to pp\, l^+ l^-)}{dt_1 dt_2 dQ^2} \sim \frac{\alpha_{em}}{s^2 Q^2}$$

➔ Scaling is expected to follow 1/Q²

➔ Fix a Q² bin: 2.5 GeV² < Q² < 3.5 GeV²

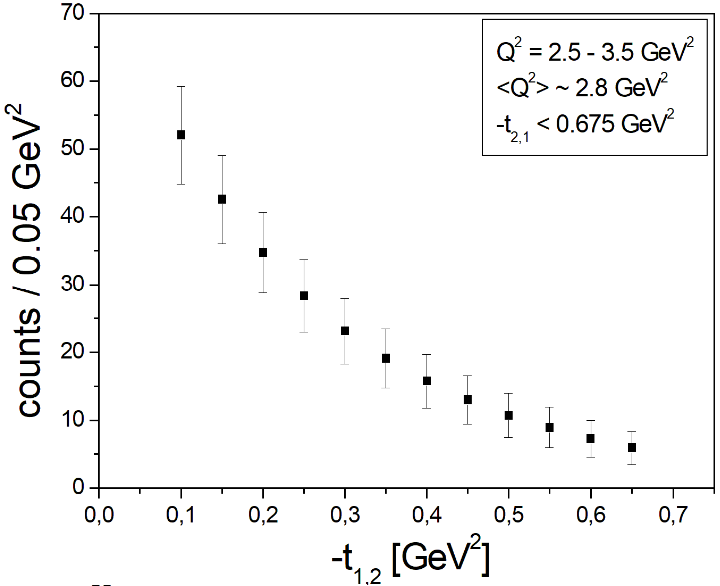


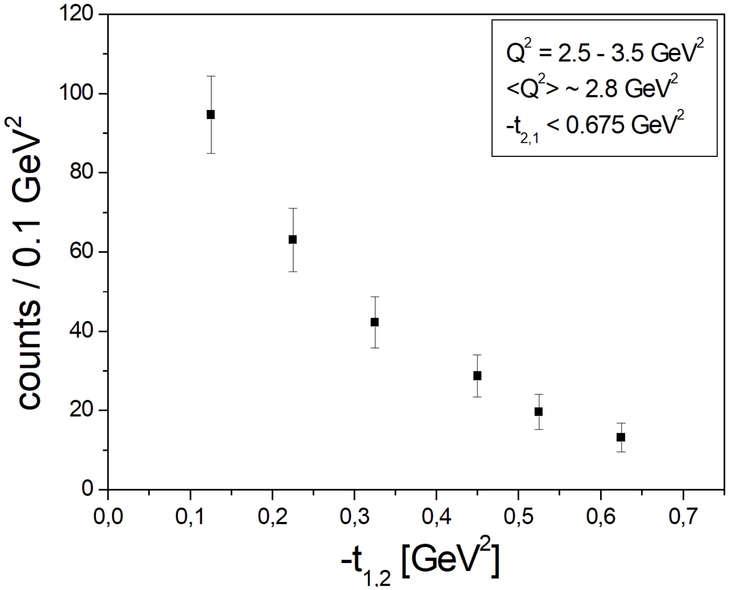
- Acceptance based on MC simulations

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

- L = 10 fb^{-1} → 2.5 years at the design luminosity

Rate cross section estimate for s = 30 GeV²

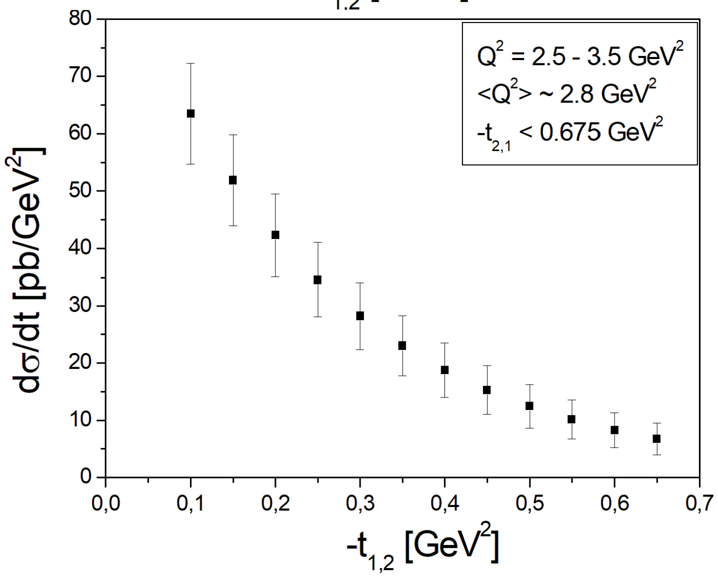


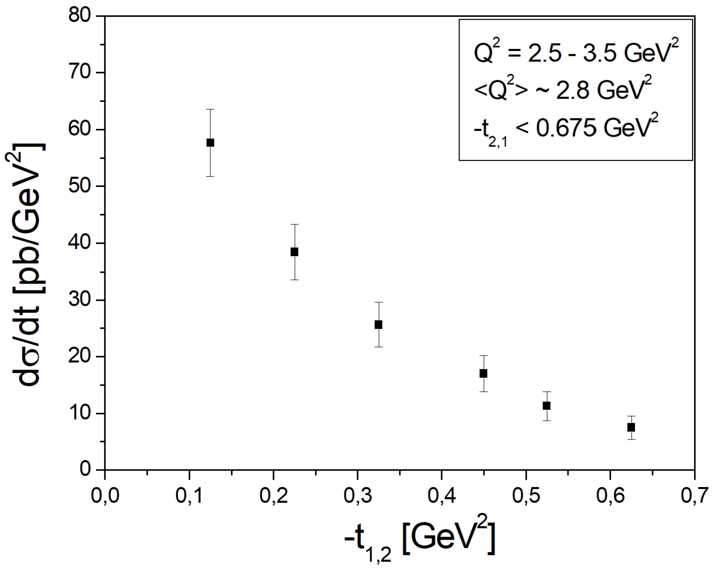


L = 2 fb^{-1}

Q^2 > 1 GeV²

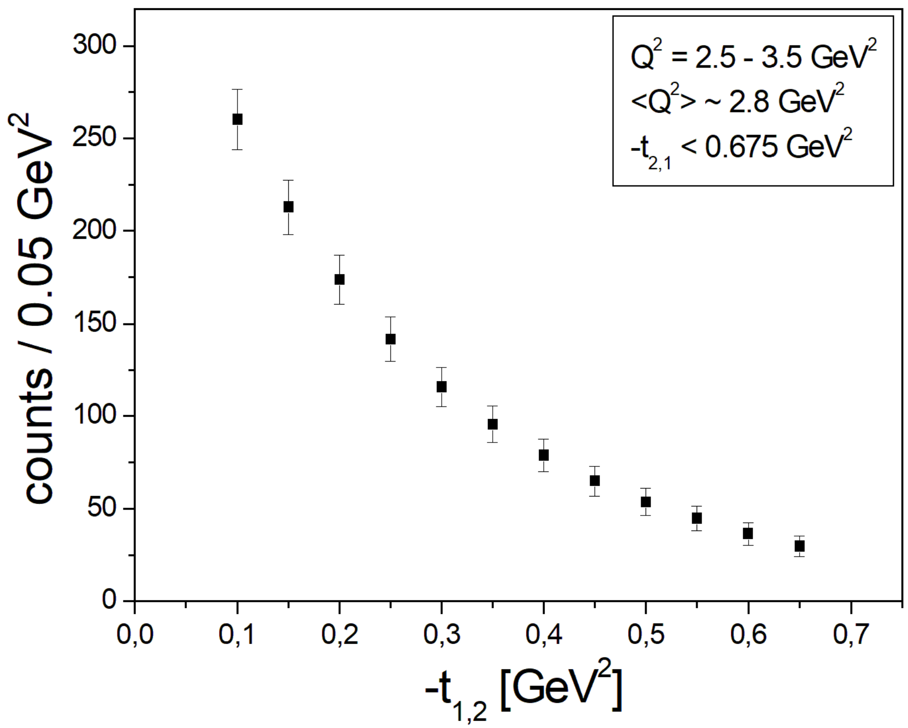
~ counts * 4

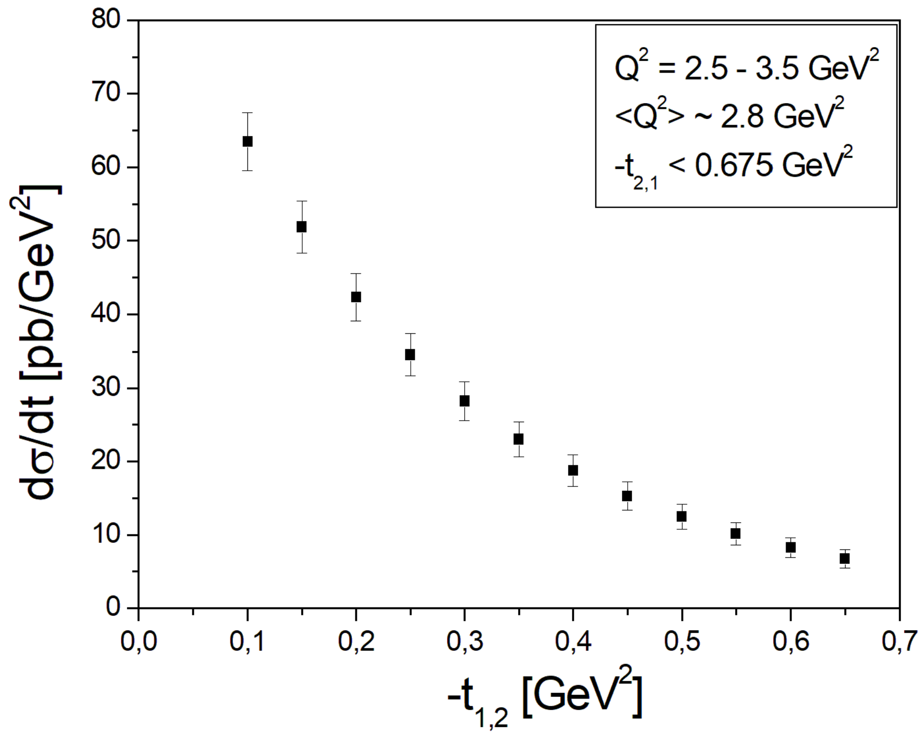




Rate estimate for s = 30 GeV²

L = 10 fb^{-1}

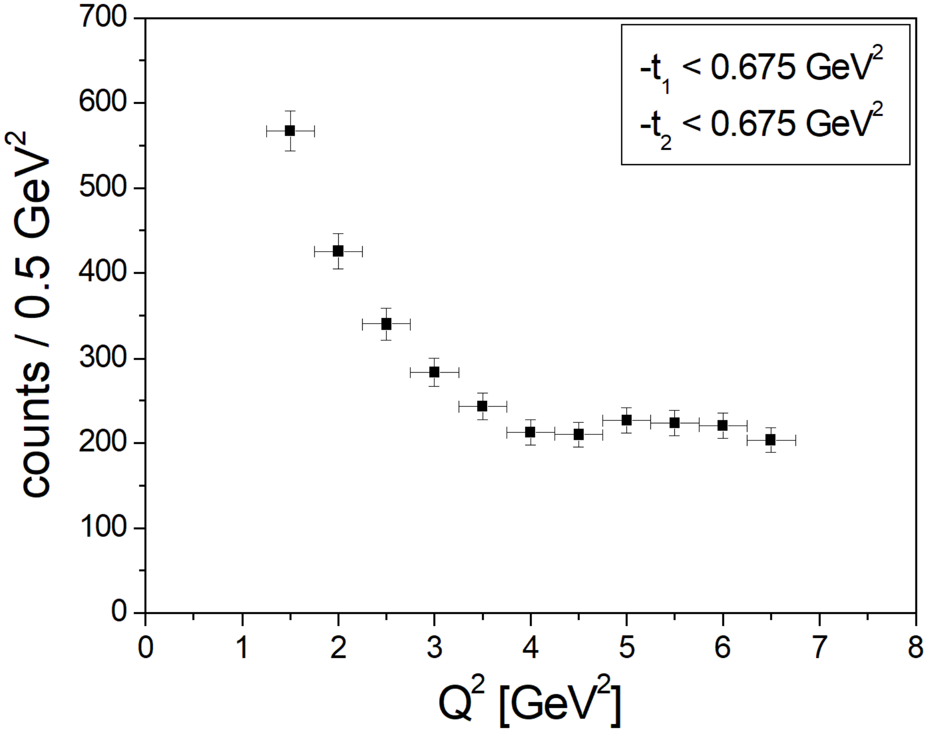


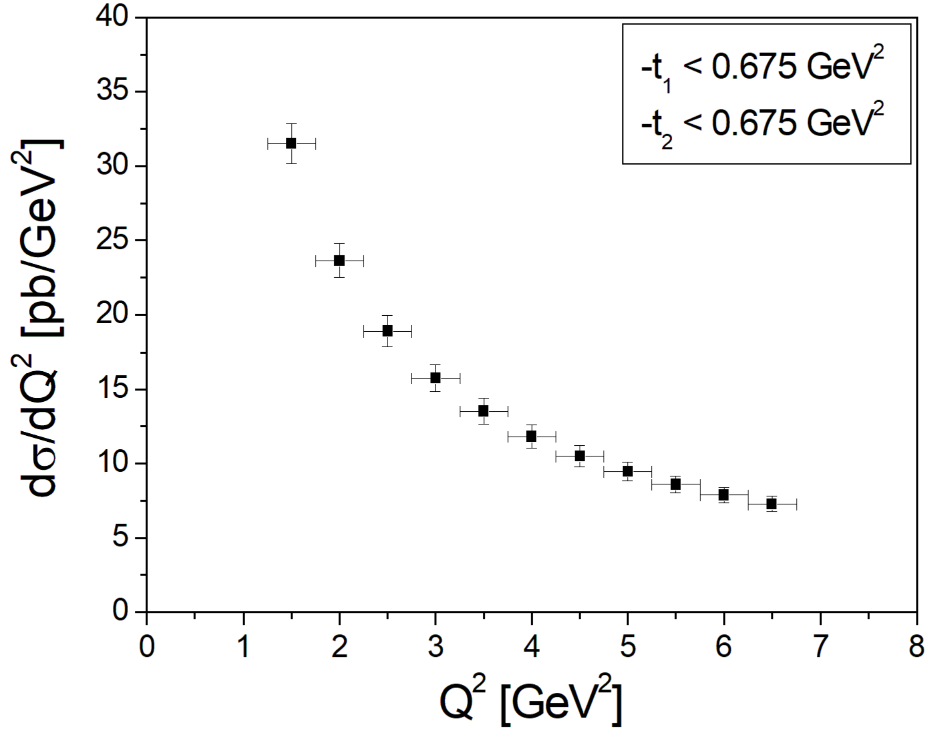


➔ With 10 fb^{-1} precise measurements will become possible

Q^2 dependence at s = 30 GeV²

L = 2 fb^{-1}





➔ The Q^2 dependence for s = 30 GeV² can be measured up to 7 GeV²

➔ For s = 20 GeV² a measurement is only possibel up to 4.5 GeV²

Summary and Outlook

- Center of mass energies squared between s = 20 GeV² and 30 GeV² provide suitable kinematics to measure the reaction with PANDA
- For e^- / e^+ a good pion suppression can be achieved even with a relatively loose TMVA cut

  ➔ Feasibility has been shown for s = 20 GeV² and 30 GeV²
- Further studies to fine tune the PID and event selection are in progress
- A release note for the e^-e^+ topology will be prepared

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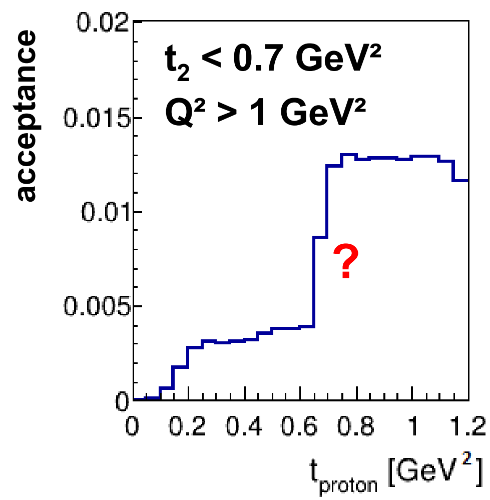
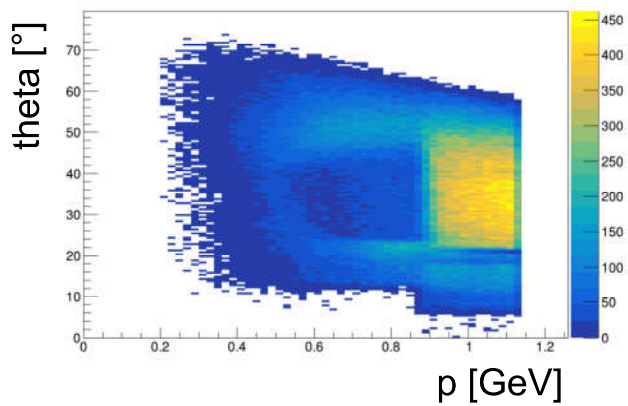
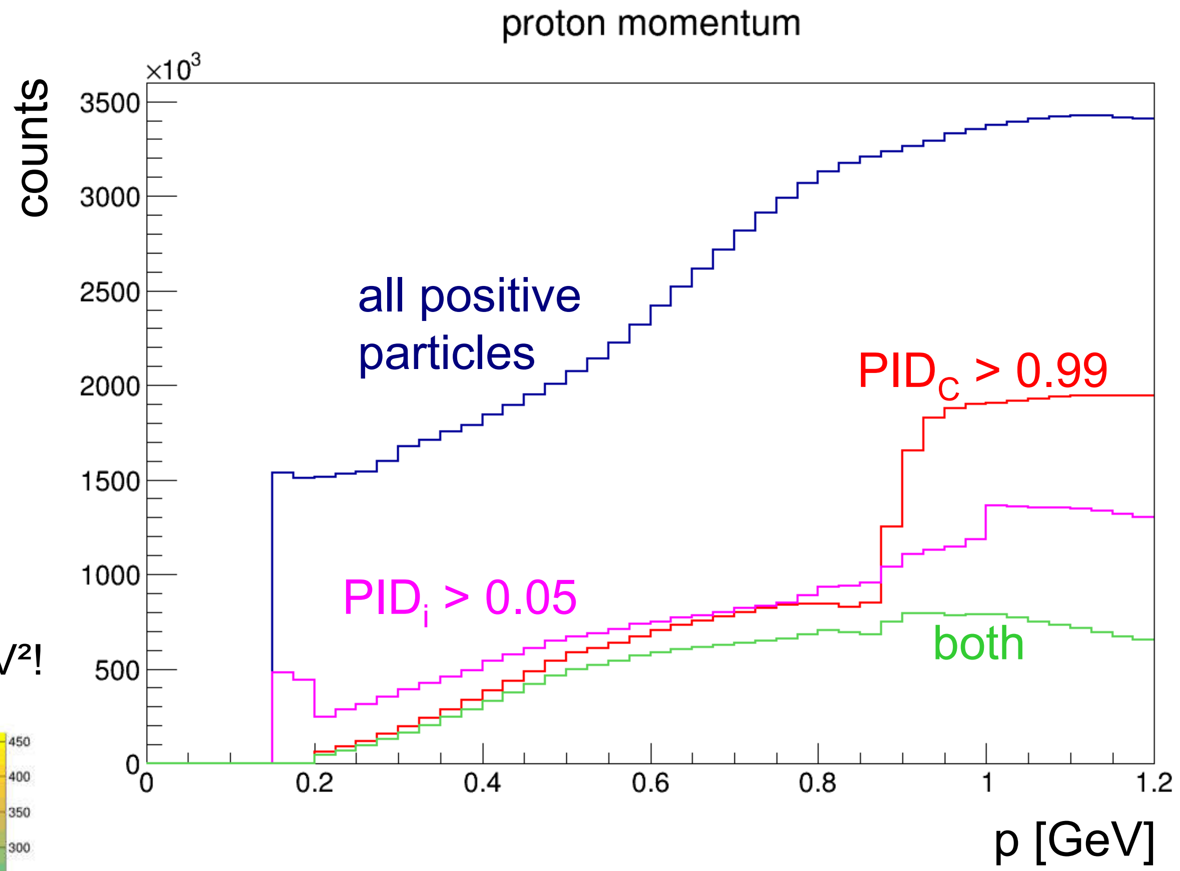
Where is the step in t_{proton} coming from?



➔ We are mostly interested in t < 0.7 GeV²!





➔ PID_C is less strict after a threshold of 0.9 GeV.

➔ A cut on PID_i removes this events again.

→ Study showed tha this cut is not needed.