PANDA collaboration meeting

May 31, 2022

Update on: PID and Background Studies for GPD Measurements with Antiproton Scattering

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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

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

➔ 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]

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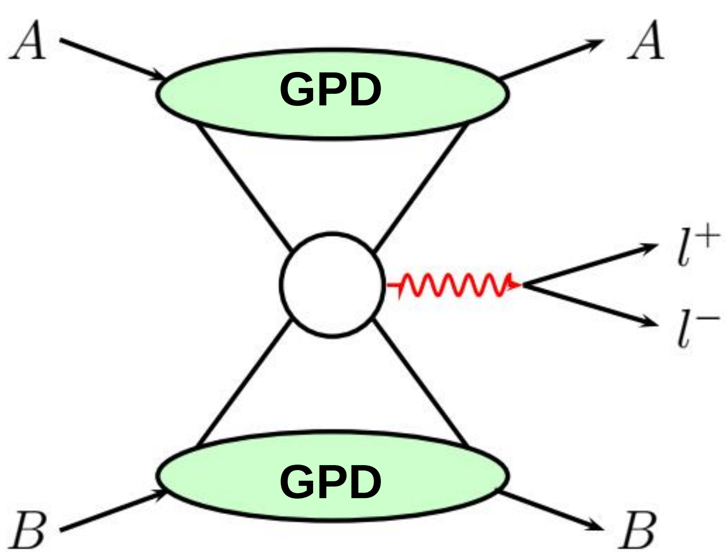
‡ : *Veksler and Baldin Laboratory of High Energy Physics, Dubna 141980, Moscow region, Russia*

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



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

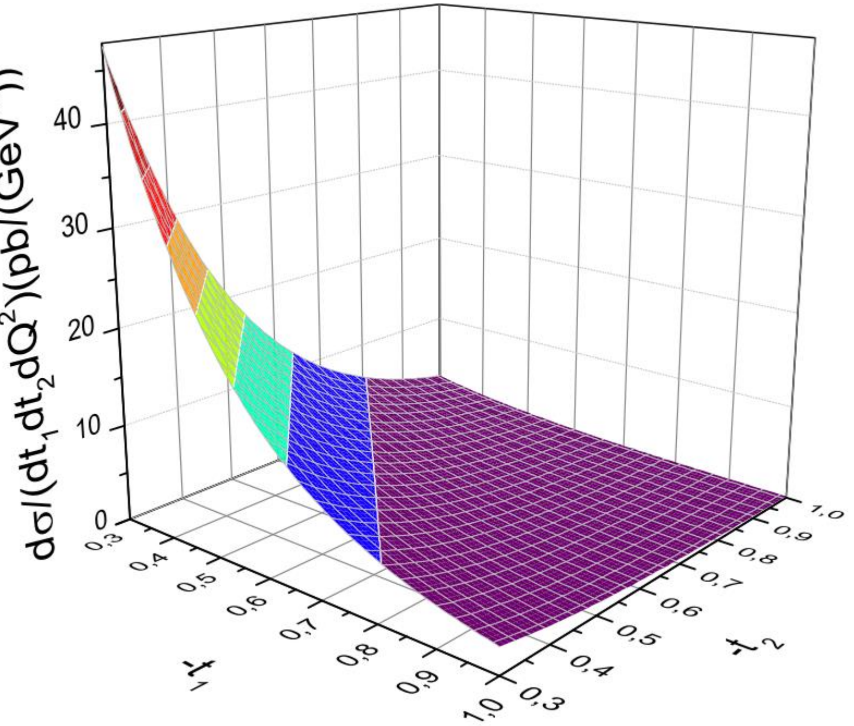
Observables

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

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

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

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



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

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

Feasability Studies

➔ PANDAroot simulations with a phase space event generator

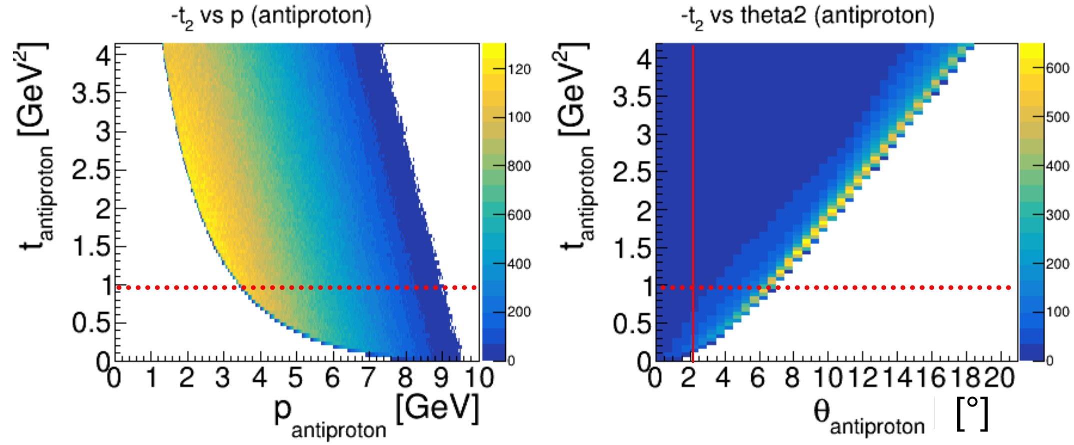
2 final states have been studied: $p\bar{p} \rightarrow p\bar{p}\gamma^* \rightarrow \begin{cases} p\bar{p}e^+e^- \\ p\bar{p}\mu^+\mu^- \end{cases}$

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 Q^2

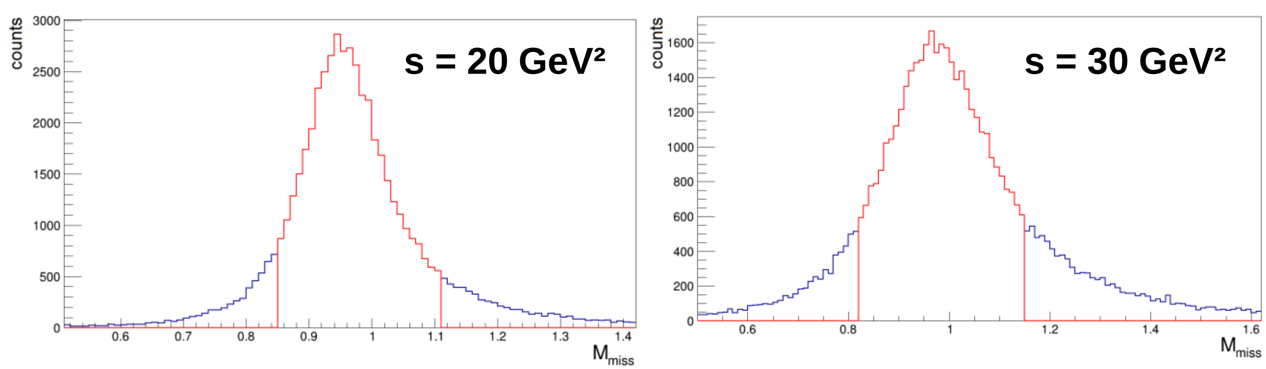
Generated Hadron Distributions vs -t

s = 20 GeV²



➔ Detection of the antiproton is not required

➔ Reconstruction via the missing antiproton mass



➔ Results after Bremsstrahlungscorrection

Expected Background and PID Refinements

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!

➔ Inital background studies focus on s = 20 GeV²

➔ 1.012 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

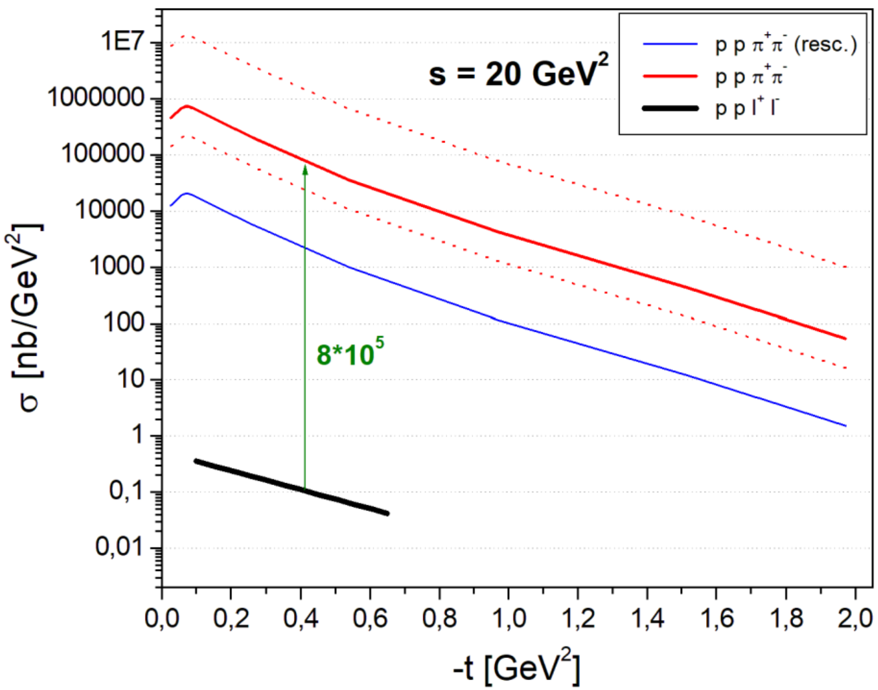
www.elsevier.com/locate/physletb

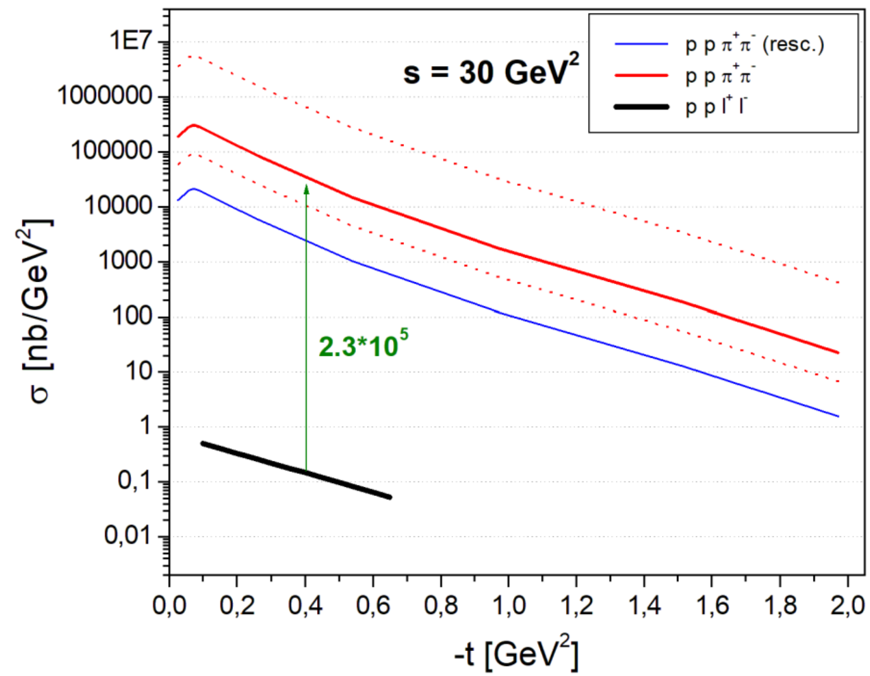
ELSEVIER

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 (Updated)





➔ Lowest background at 30 GeV²

➔ Signal cross sections have been inetgrated over the second t_i and over the full Q^2 (assumed $1/Q^2$ dep.)

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

PID Refinenements and Background Suppression

Protons: 2 configurations were investigated for protons:

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

loose: $P_C > 0.99$

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

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

Electron / Positron PID (refinements)

➔ Cuts are applied sequentially

electrons:

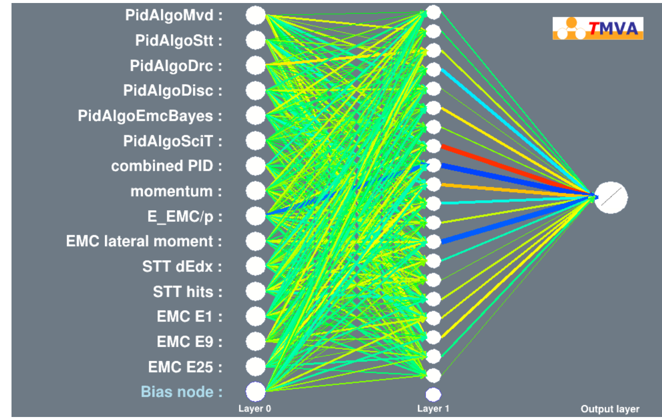
	signal eff.	BG eff.	S / BG
PID_C > 0.99	47,7	2,4750	20
PID_S > 0.19	32,5	0,5044	66
sampfrac E/p	28,6	0,1341	219
STT dE/dx	21,4	0,0477	460
EMC E1	17,6	0,0255	707
EMC lateral	15,3	0,0121	**1293**

positrons:

	signal eff.	BG eff.	S / BG
PID_C > 0.99	50,3	2,8021	18
PID_S > 0.19	36,3	0,8441	43
sampfrac E/p	30,5	0,3906	78
STT dE/dx	22,0	0,0692	319
EMC E1	18,5	0,0393	471
EMC lateral	15,8	0,0179	**883**

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

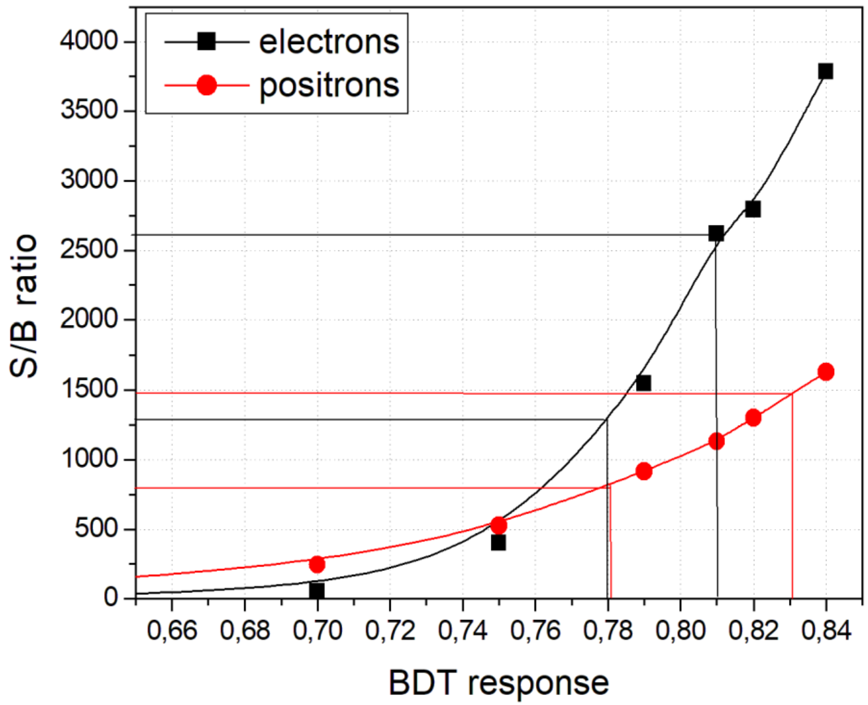
TMVA training,testing and evaluation

TMVA weight file

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

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

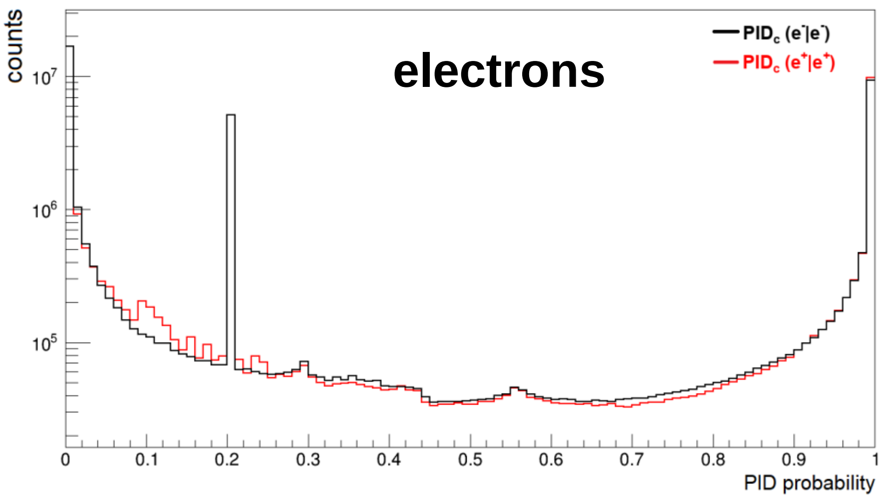
Electron / Positron PID (TMVA analysis)

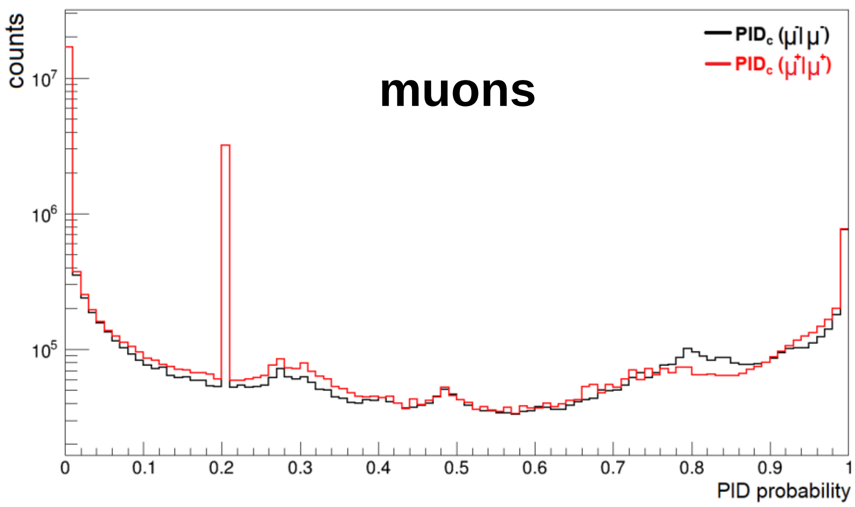


	BDT ele / pos	signal eff	S/B ele / pos
very loose	> 0.70 / 0.70	~ 26 %	53 / 244
loose	> 0.75 / 0.75	~ 19 - 20 %	400 / 526
standard	> 0.78 / 0.78	~ 15 - 16 %	1100 / 850
very tight	> 0.81 / 0.83	~ 6.7 %	2620 / 1630

μ^- / μ^+ PID (classical PID)

combined PID probability





Applied cuts: $P_C > 0.99$ && $P_S > 0.19$

signal eff = 31% (μ-) / 15% (μ+)

S/B = 14 (μ-) / 18 (μ+)

<u>compare electrons:</u> S/B = 66 (e-) / 43 (e+)

μ^- / μ^+ PID (TMVA analysis)

➔ Include also the variables of the muon system

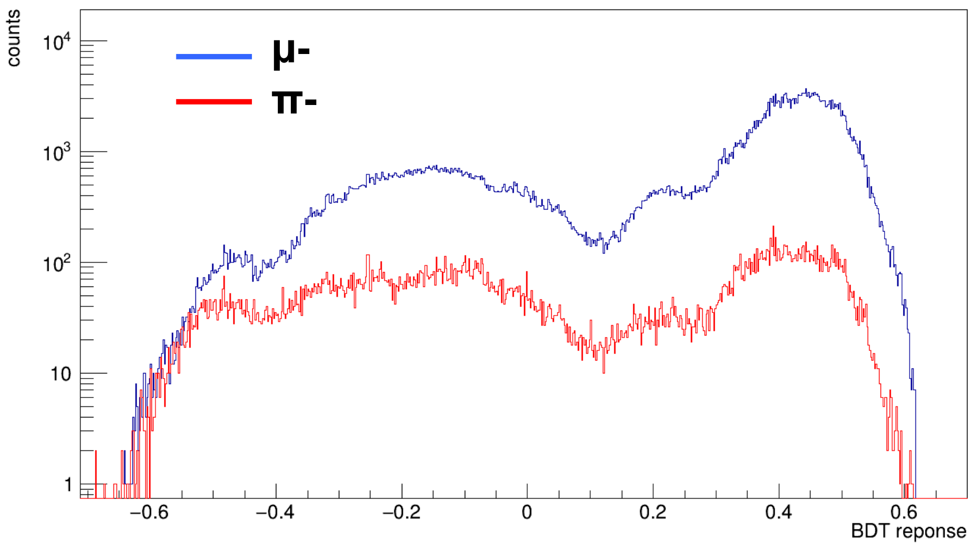
➔ Following the $\mu^+\mu^-$ form factor analysis note

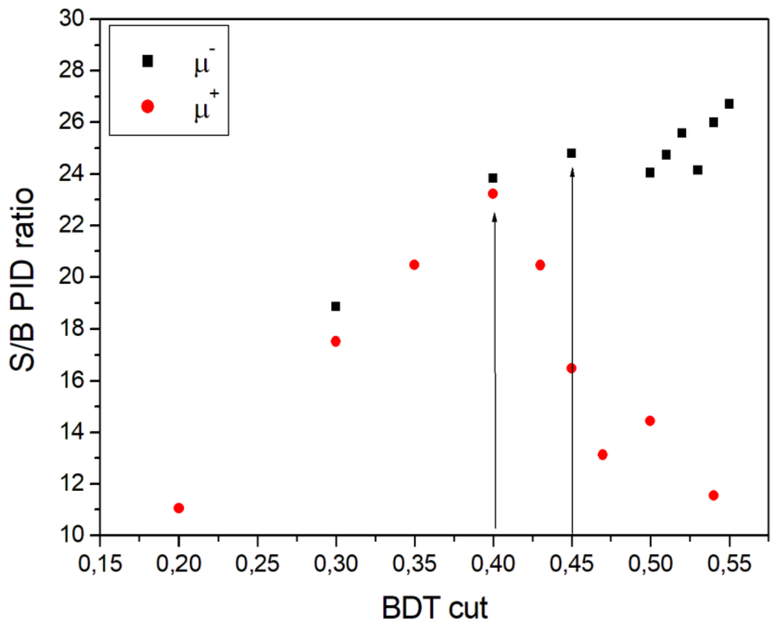
- **Path length inside iron absorber of the MS**. The length of the reconstructed trajectories is calculated inside the absorber and detections layers based on the spatial hit information, denoted as "iron thickness".
- **Number of fired layers** in the MS.
- **Initial momentum at MS layer zero**: p_{MS}.
- **Normalized path length of the tracklet** inside the MS to p_{MS}.
- **Identification probability** for being a muon based on MS observables: $P(\mu)$.

+ Calorimeter and STT variables as for electrons

μ^- / μ^+ PID

BDT response for μ- and π-





	BDT μ- / μ+	signal eff	S/B μ- / μ+
cut on PID variables		30% / 15 %	14 / 18
optimal TMVA setting	> 0.45 / > 0.4	10.6% / 9.8 %	25 / 23

no additional improvement possible

μ^- / μ^+ PID

Why is it not possible to improve the particle ID with a TMVA analysis?

a) MS Module 1: MS Barrel

b) MS Module 2: MS Forward Endcap plus Muon Filter

c) MS Module -1: Hybrid Tracking (Combining Endcap plus Barrel for common track reconstruction)

MS Module	Iron threshold	p_{min}	p_{max}
1	40 cm	0.2 GeV/c	0.8 GeV/c
-1	60 cm	0.4 GeV/c	1.1 GeV/c
2	60 cm	0.4 GeV/c	1.1 GeV/c

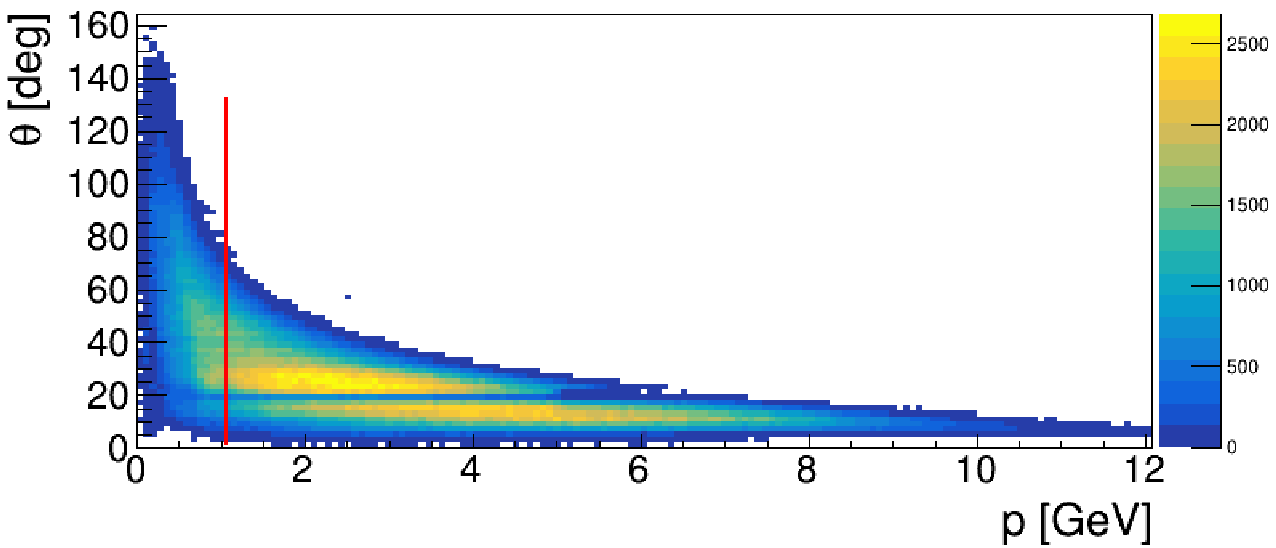
Form factor studies:

Antiprotons up to 3.3 GeV/c

This study: 10 – 15 GeV/c

expected muon distribution:

s = 30 GeV²



Expected S/B ratio for the μ- μ+ sample

➔ The PID studies so far were made for all electrons and pions of the sample

Now: - Select exclusive events with a cut on the missing antiproton mass
- Select the events of interest with a cut on Q^2, t_1 and t_2

➔ The expected S/B ratio is weighted with the expected cross section ratio of $8*10^5$

	classical PID				optimized TMVA cuts		
	signal acc.	**backgr. acc.**	**expected S/B**		**signal acc.**	**backgr. acc.**	**expected S/B**
$Q^2 > 1$ GeV²	0,0095	0,00011	1,23 E-05		0,016	2,17 E-05	0,00010
$Q^2 > 1$ GeV² $-t < 1$ GeV²	0,012	0,00012	1,40 E-05		0,015	1,23 E-05	0,00017
$Q^2 > 1$ GeV² $-t < 0.7$ GeV²	0,011	0,00013	1,17 E-05		0,013	7,91 E-06	0,00024

➔ Muon PID is not sufficient to controll the background

➔ Muons are mainly above the threshold of the muon detector

➔ **The study will focus on electrons in a first step!**

Effect of the improved PID on the final $e^- e^+$ sample

➔ The PID studies so far were made for all electrons and pions of the sample

Now: - Select exclusive events with a cut on the missing antiproton mass
- Select the events of interest with a cut on Q^2, t_1 and t_2

➔ The expected S/B ratio is weighted with the expected cross section ratio of $8*10^5$

	classical PID refinements				standard TMVA cuts		
	signal acc.	**backgr. acc.**	**expected S/B**		**signal acc.**	**backgr. acc.**	**expected S/B**
$Q^2 > 1$ GeV²	0,035	$< 1.5*10^{-9}$	> 29		0,018	$< 1.5*10^{-9}$	> 15.3
$Q^2 > 1$ GeV² $-t_{1,2} < 1$ GeV²	0,0036	$< 4.1*10^{-9}$	> 1.1		0,0021	$< 4.1*10^{-9}$	> 0.66

loose TMVA cuts

2-3 times larger wrong PID rate than classical cuts

	signal acc.	**backgr. acc.**	**expected S/B**
$Q^2 > 1$ GeV²	0,039	$1.67*10^{-9}$	~ 29
$Q^2 > 1$ GeV² $-t < 1$ GeV²	0,0044	$< 4.1*10^{-9}$	> 1.4

➔ 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!

Effect of the improved PID on the final $e^- e^+$ sample

➔ 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

loose TMVA cuts

2-3 times larger wrong PID rate than classical cuts

classical PID refinements

	signal acc.	backgr. acc.	expected S/B		signal acc.	backgr. acc.	expected S/B
$Q^2 > 1$ GeV²	0,096	~ $1.66 \cdot 10^{-9}$	~ 71		0,086	~ $3.3 \cdot 10^{-9}$	~ 32.2
$Q^2 > 1$ GeV² $-t_{1,2} < 1$ GeV²	0,0098	< $4.1 \cdot 10^{-9}$	> 3.04		0,008	< $4.1 \cdot 10^{-9}$	> 2.5

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	0,16	$1.5 \cdot 10^{-8}$	13.3
$Q^2 > 1$ GeV² $-t < 1$ GeV²	0,016	~ $4.5 \cdot 10^{-9}$	> 4.5

➔ Releasing the proton cut increases the acceptance by a factor > 2

➔ S/B ratio improves slightly

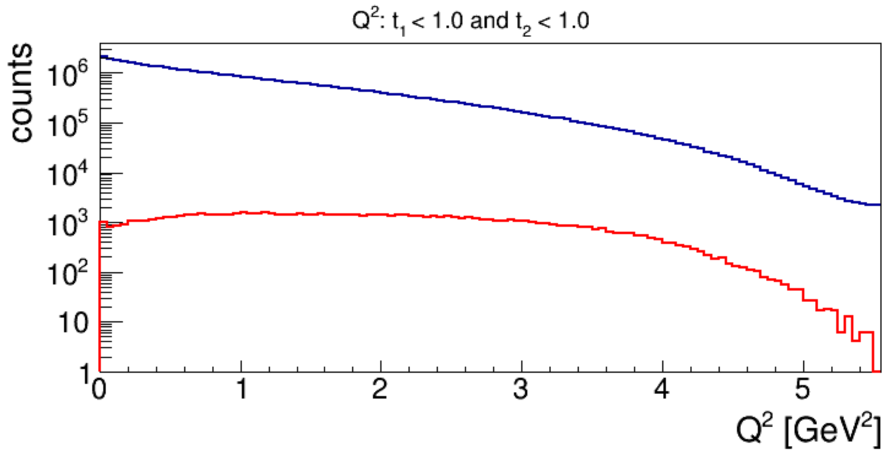
➔ A cut on $PID_C > 0.99$ only is sufficient for protons

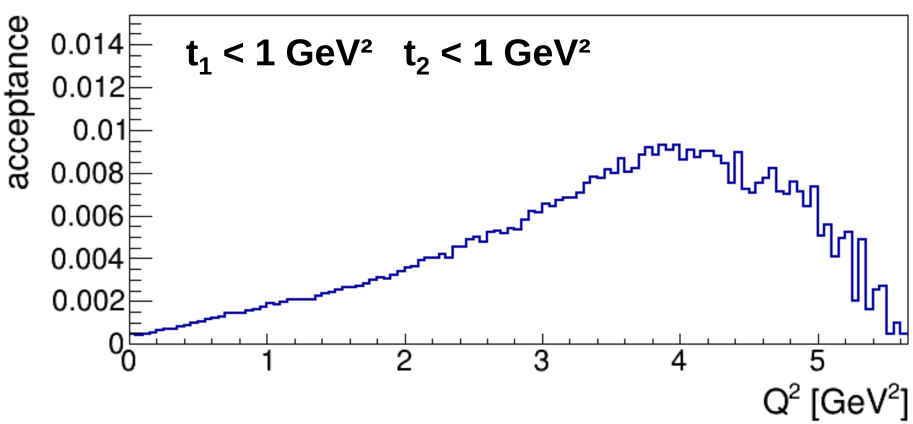
Effect of the PID cuts on the Q^2 acceptance

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

s = 20 GeV²

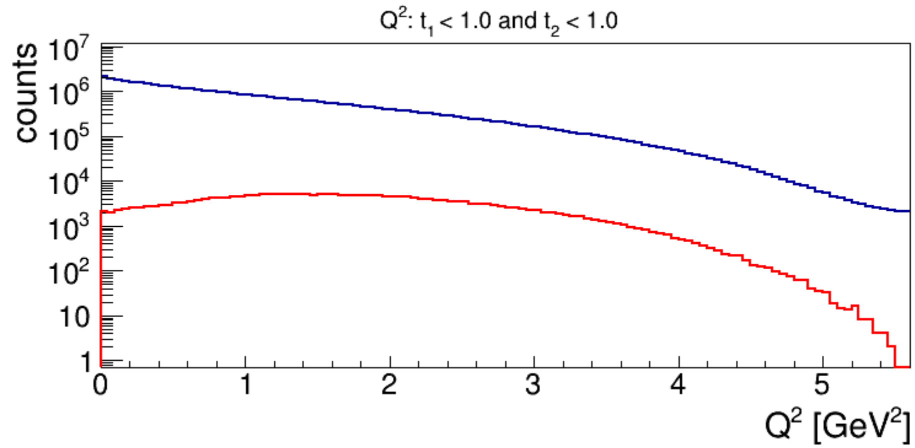
classical PID refinements

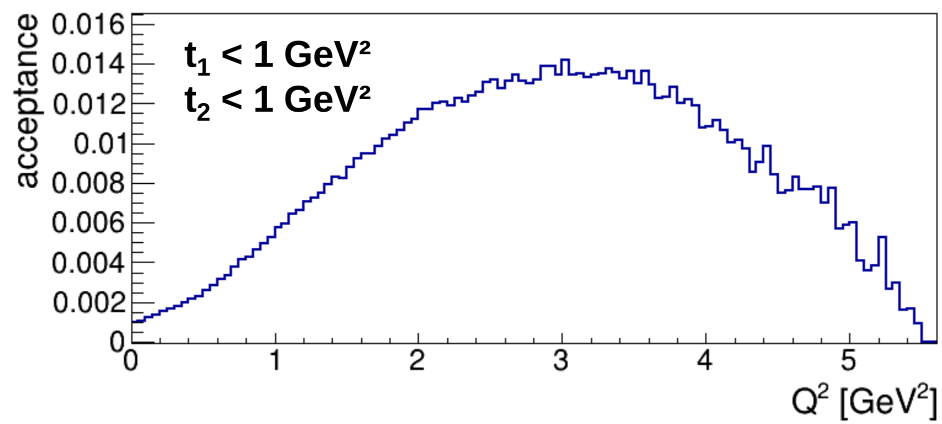




acc = 0.2 – 1.0 %

very loose TMVA cut



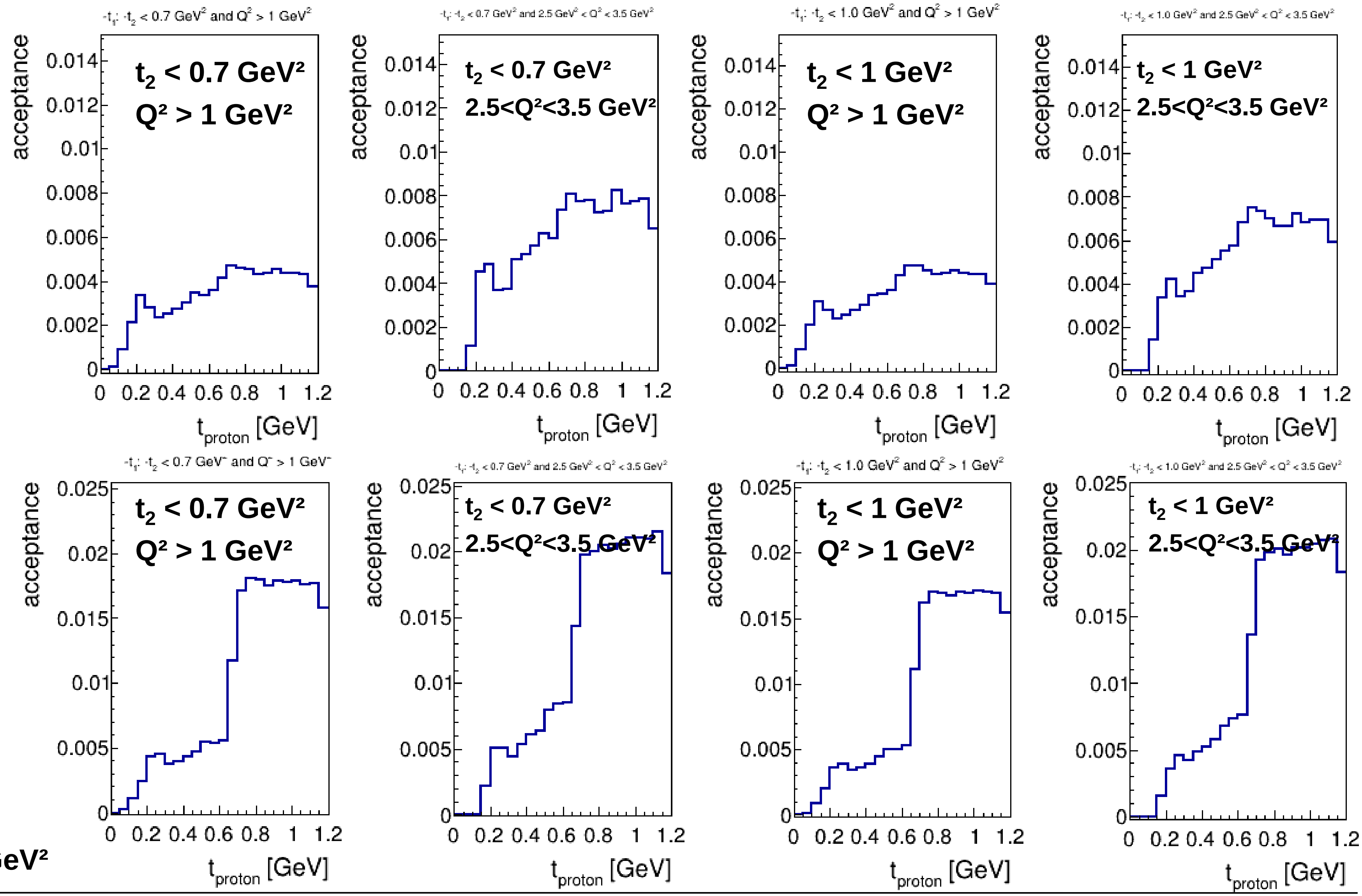


acc = 0.6 – 1.4 %

Effect of the PID cuts on the t_1 acceptance

classical PID refinements

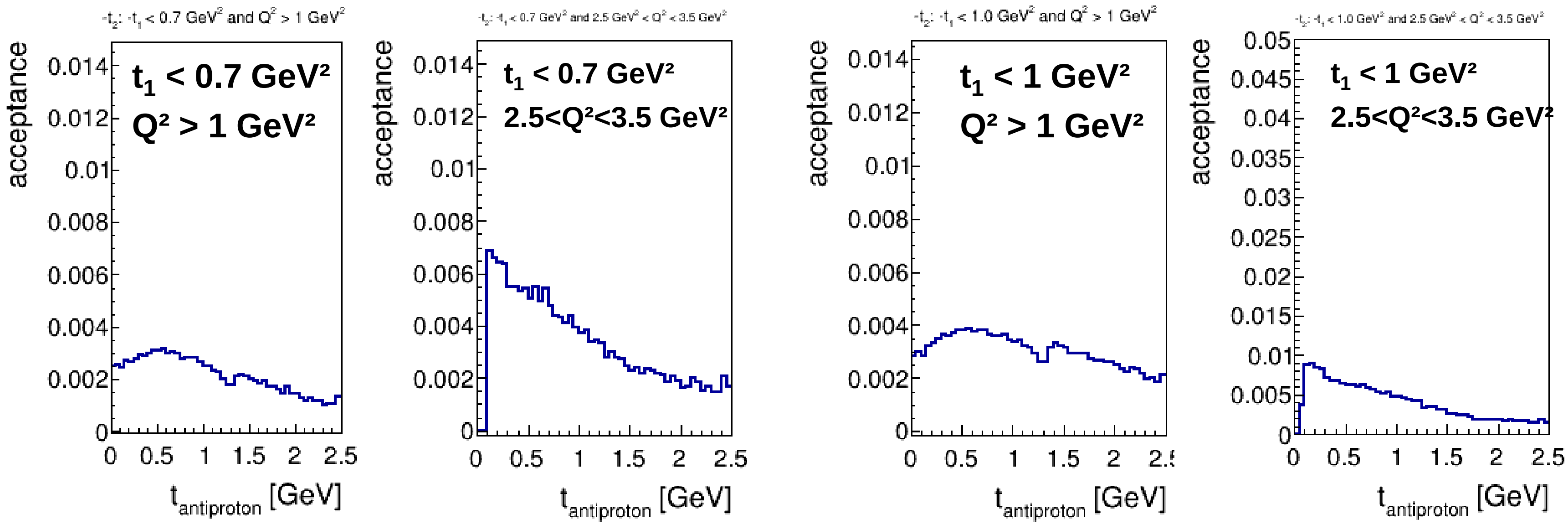
very loose TMVA cut



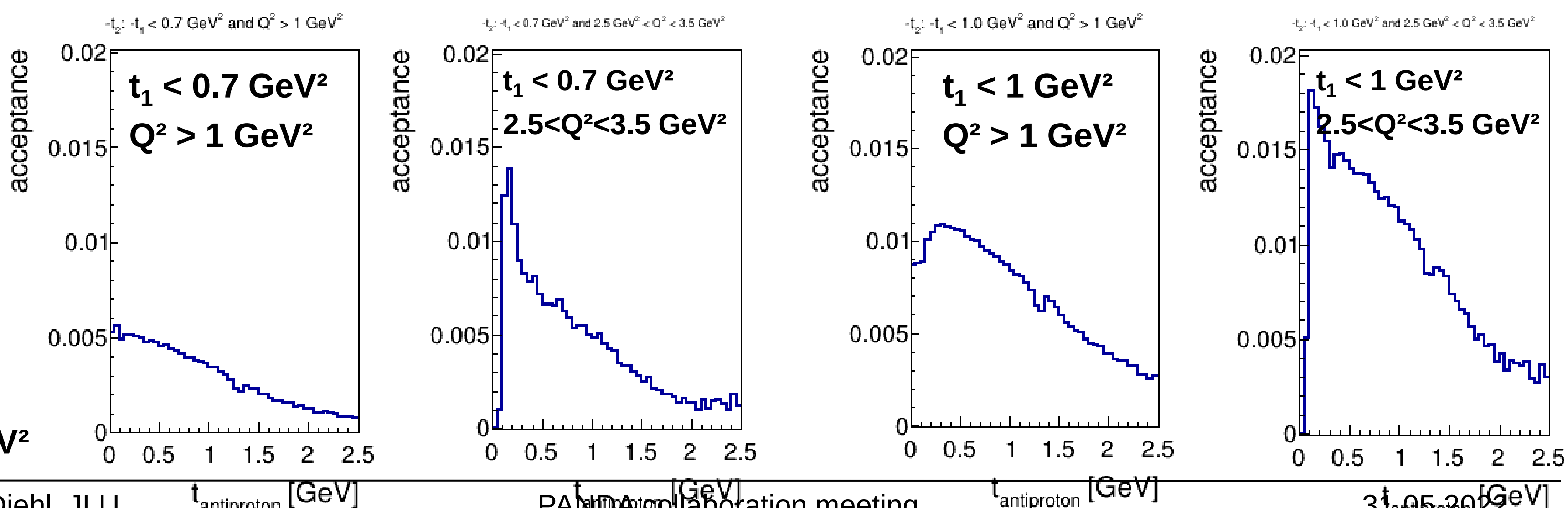
s = 20 GeV²

Effect of the PID cuts on the t_2 acceptance

classical PID refinements



very loose TMVA cut

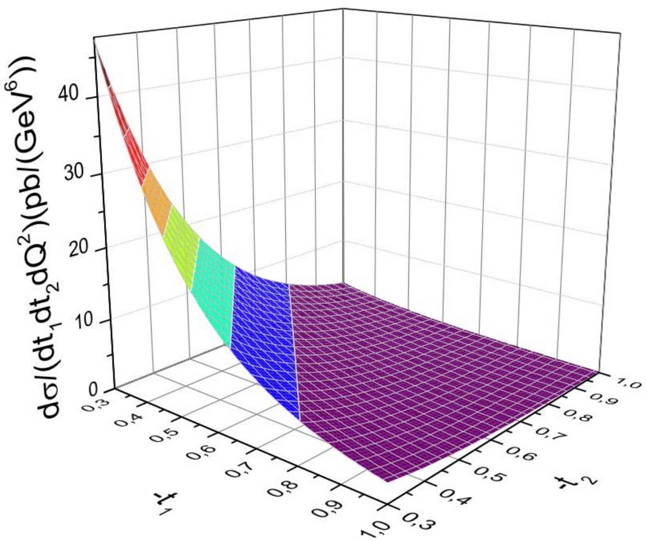


s = 20 GeV²

Effect of the PID on the count rates and uncertainties

- **Differential cross section available for s = 10 GeV², 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 $1/Q^2$

➔ Fix a Q^2 bin: 2.5 GeV² < Q^2 < 3.5 GeV²

- Set the bin size in -t:
  i. e. $\Delta t_1 = \Delta t_2$ = 0.05 GeV² or 0.1 GeV²

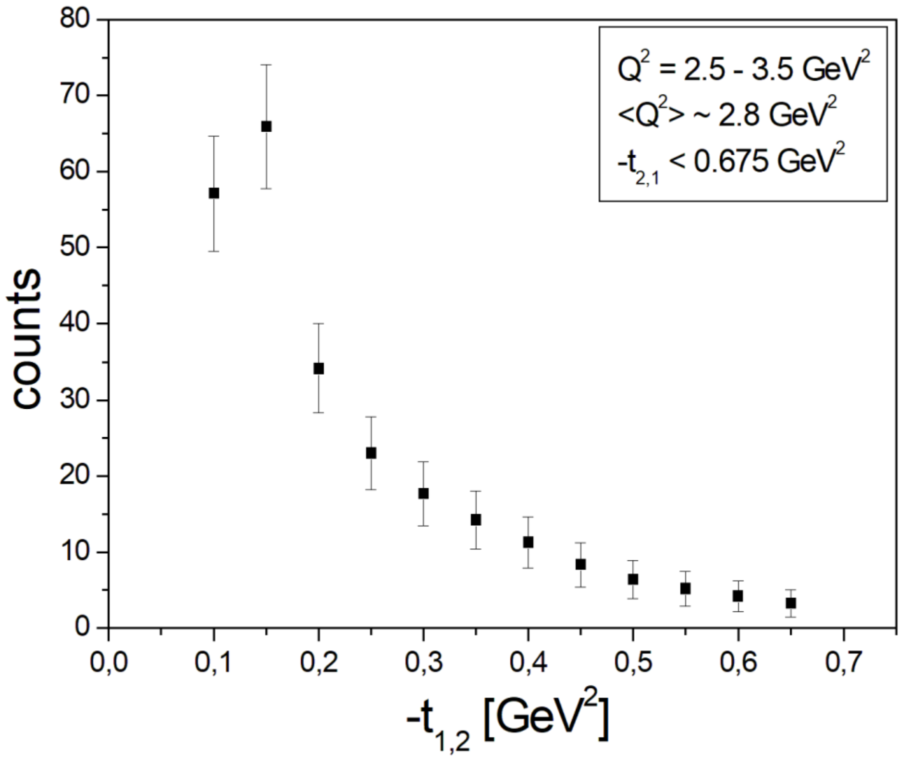
- L = 2 fb^{-1} → 1/2 year at the design luminosity
- L = 10 fb-1 → 2.5 years at the design luminosity

- Acceptance based on MC simulations

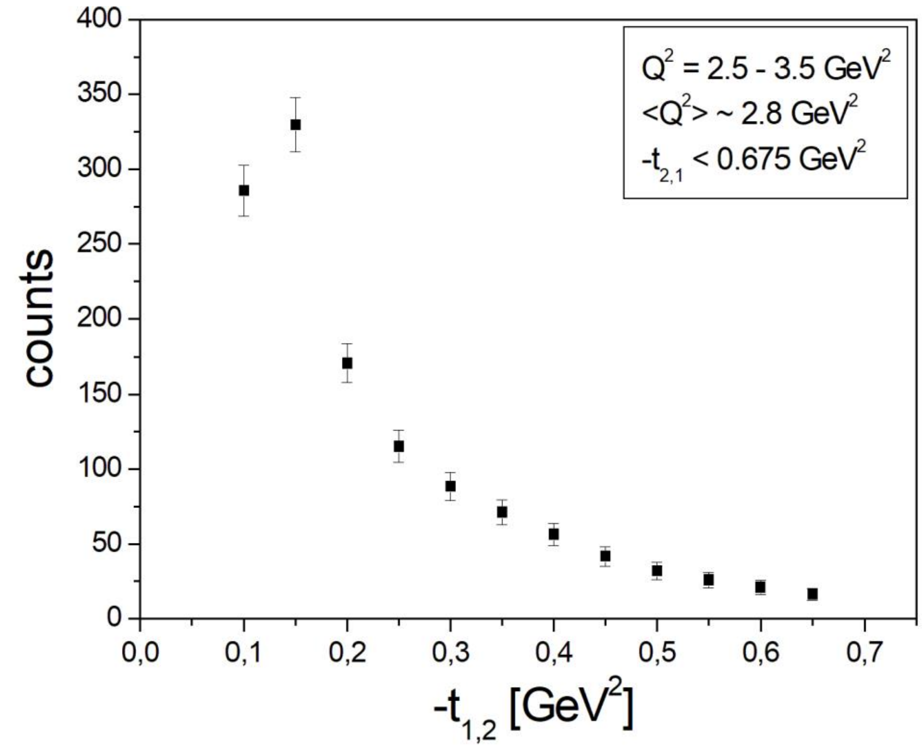
Rate estimate for s = 20 GeV²

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

L = 2 fb^{-1}



L = 10 fb^{-1}

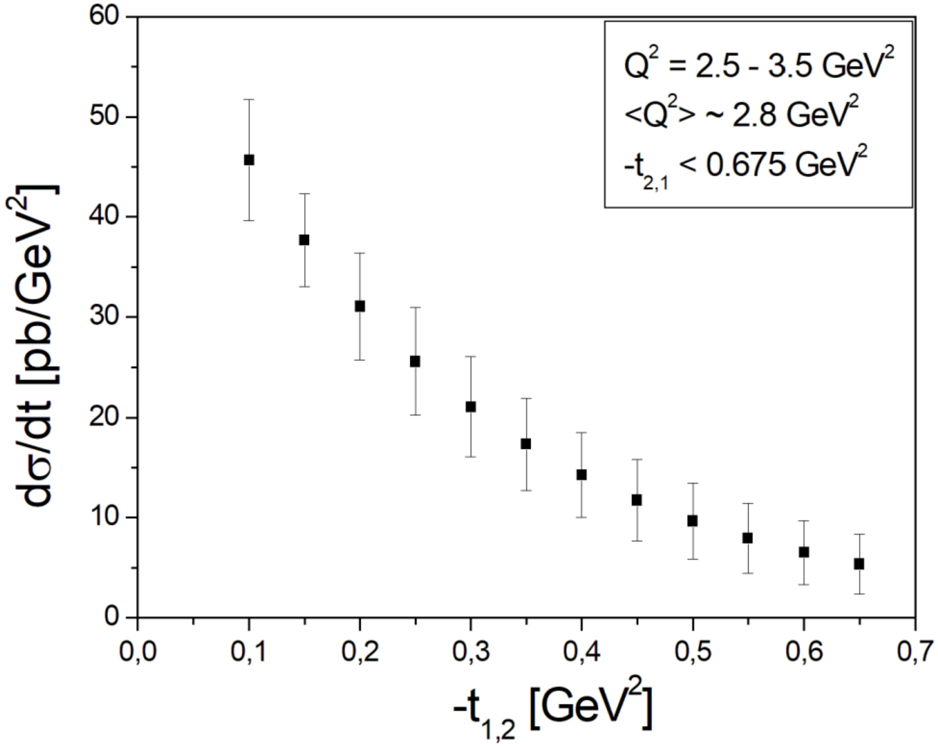


$Q^2 > 1$ GeV² ➔ ~ counts * 4

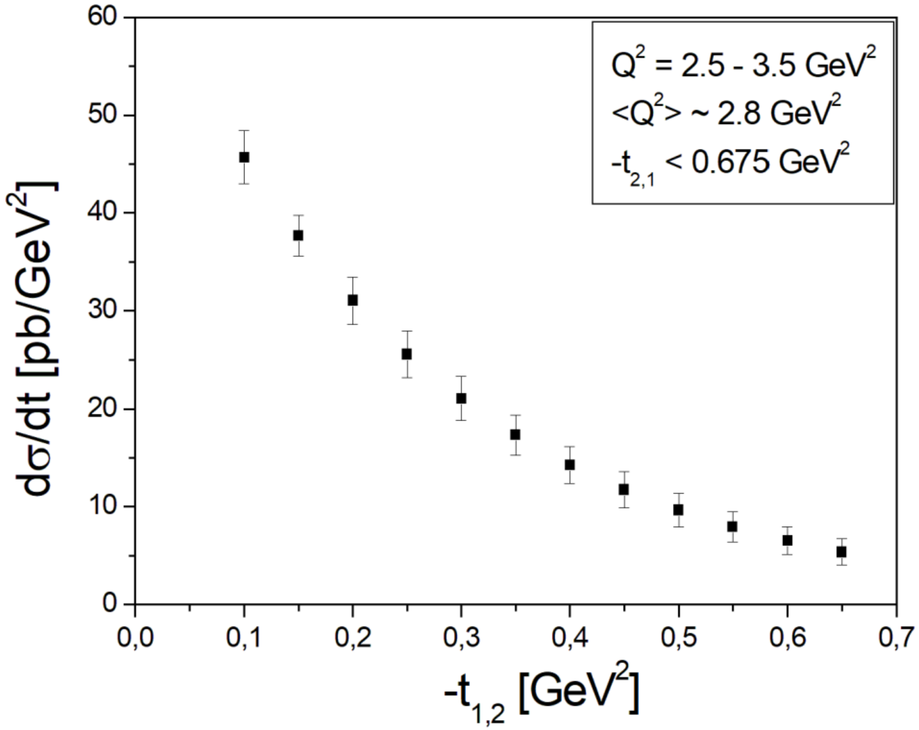
Rate estimate for s = 20 GeV²

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

L = 2 fb^{-1}

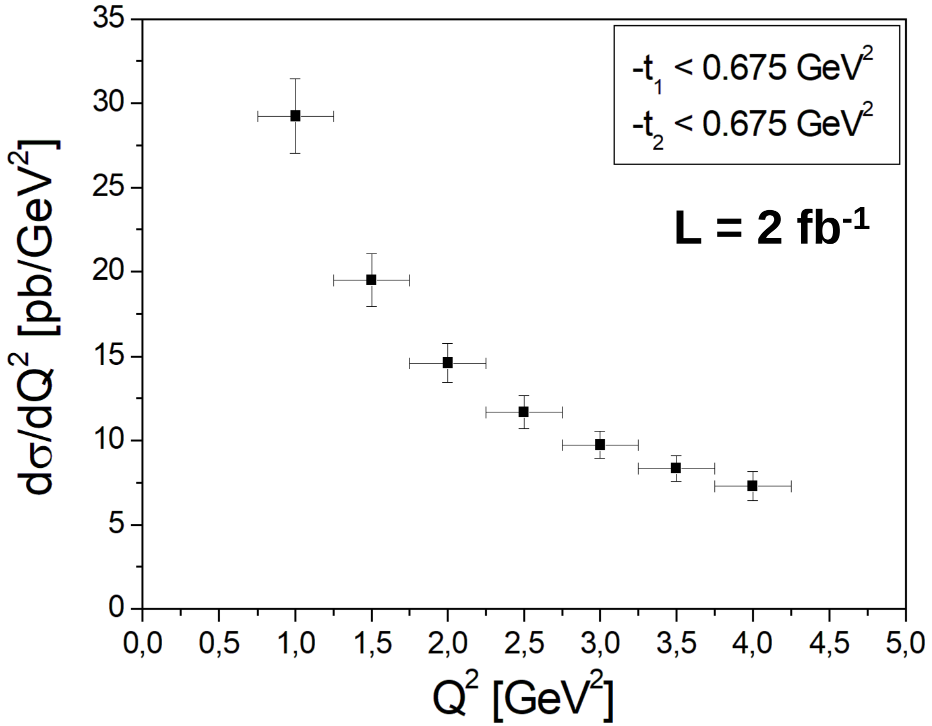


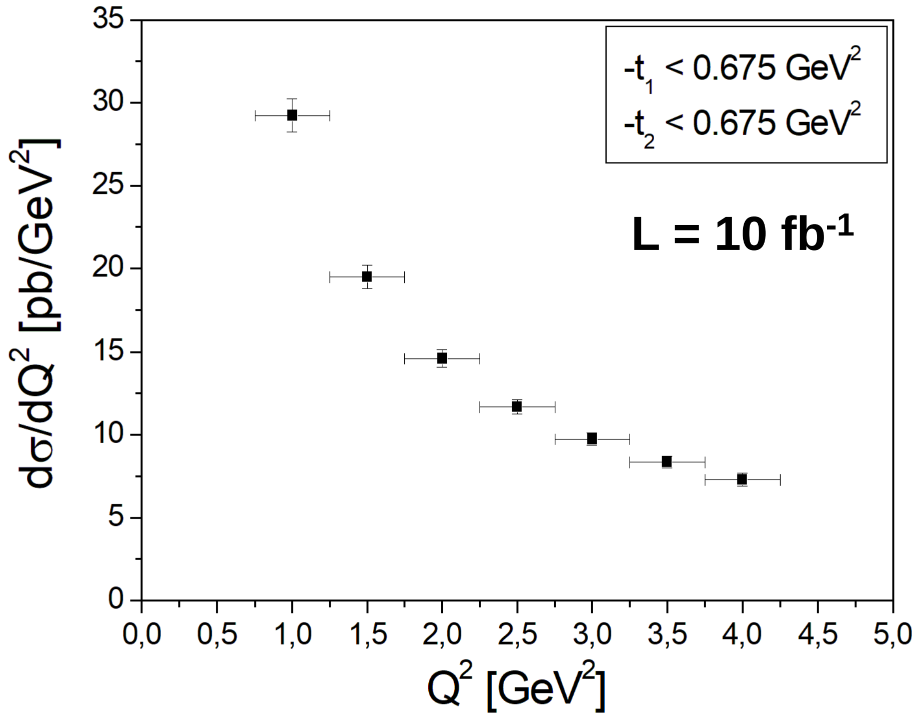
L = 10 fb^{-1}



Q² dependence at s = 20 GeV²

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





Summary and Outlook

- Center of mass energies between s = 20 GeV² and s = 30 GeV² provide suitable kinematics to measure the reaction
- PID refinements with classical cuts and a TMVA analysis have been investigated for electrons and muons
- For e^- / e^+ a good pion suppression can be achieved even with a relatively loose TMVA cut
- For μ^- / μ^+ probably the energies are to high for a reliable ID
  → e^- / e^+ topology will be used as a first stage.
- Production of a lare scale background MC sample for s = 30 GeV² (> 1 B events) was completed last week
  → Analysis is in progress
  → For electrons similar results as for s = 20 GeV² are expected