PANDA collaboration meeting

October 26, 2021

PID and 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

➔ 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

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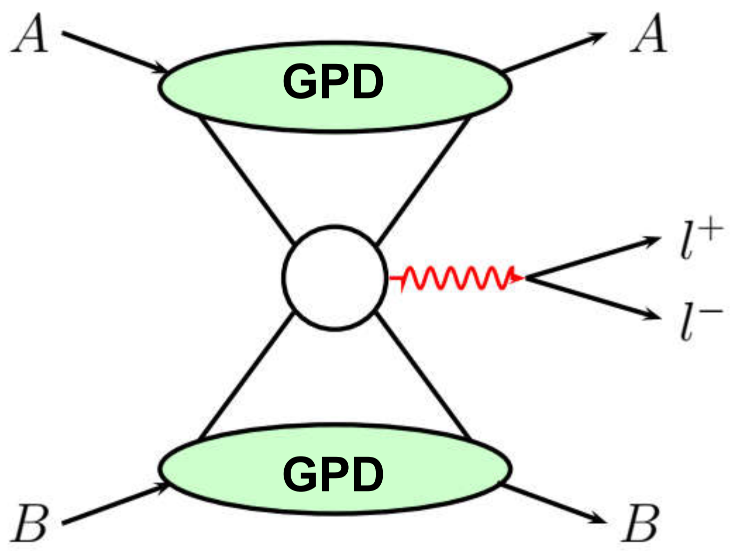
arXiv:2008.13594v1 [hep-ph] 31 Aug 2020



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

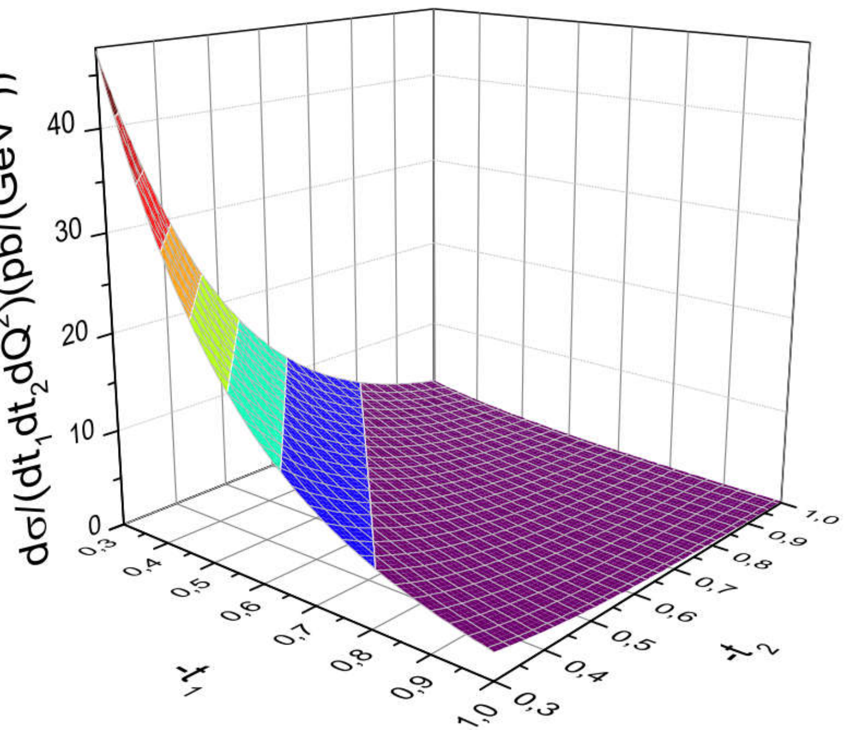
Observables

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

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

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

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



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

versions: PANDAroot: v12.0.0 (oct19) FAIRroot: v18.6.1_fs_nov20

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

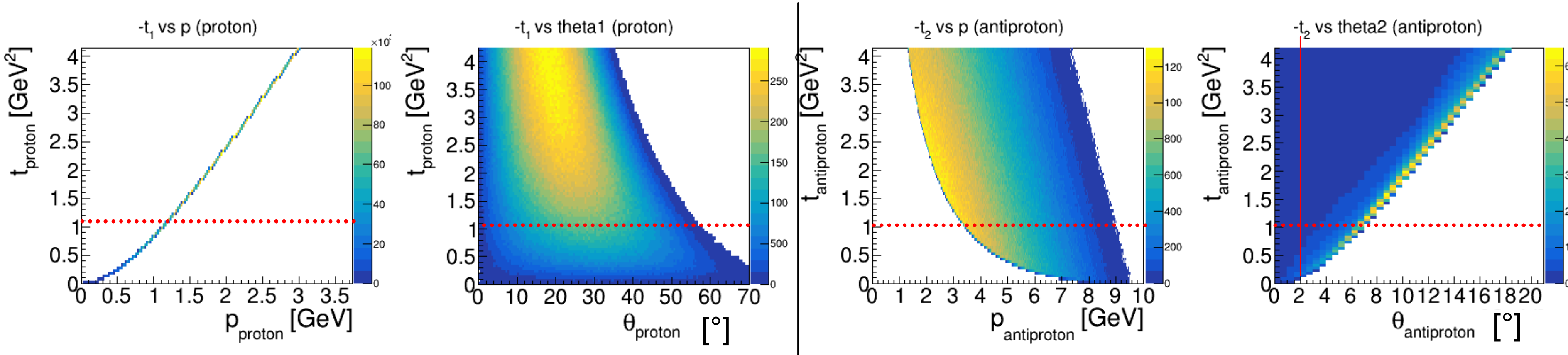
3 beam momenta have been studied:	s = 10 GeV²	(p ~ 4.3 GeV/c)	20M events
	s = 20 GeV²	(p ~ 9.7 GeV/c)	20M events
	s = 30 GeV²	(p ~ 15 GeV/c)	30M events

➔ Smaller beam momenta can not provide sufficiently high Q²

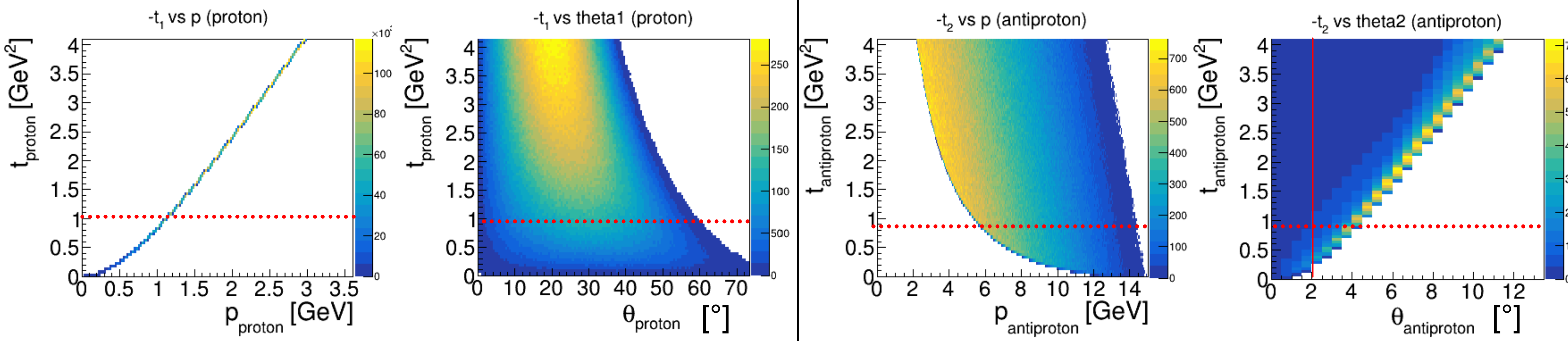
➔ Optimal study for s = 20 – 30 GeV² (see talk at the last collab. meeting)

Generated Hadron Distributions vs -t

s = 20 GeV²



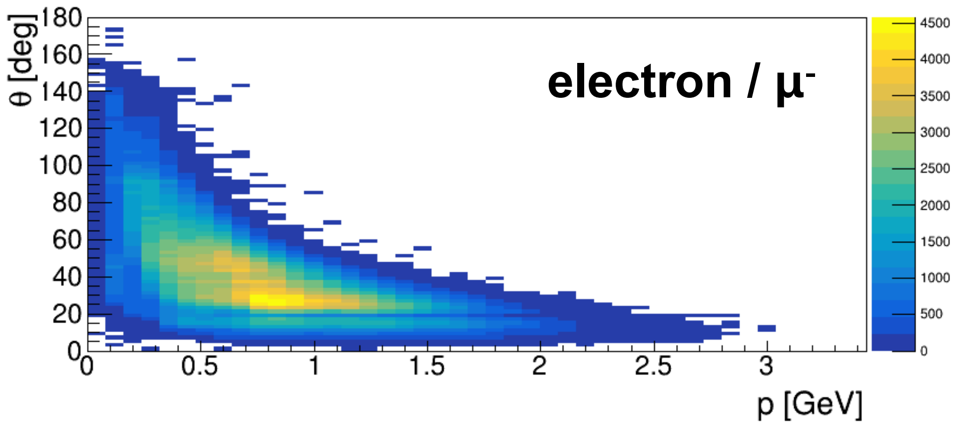
s = 30 GeV²

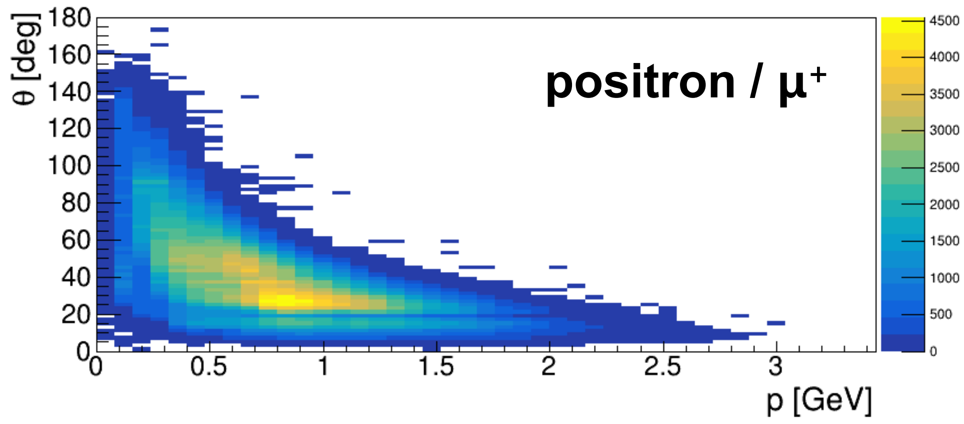


➔ Possible preselection by a s dep. cut on p for protons and θ for antiprotons

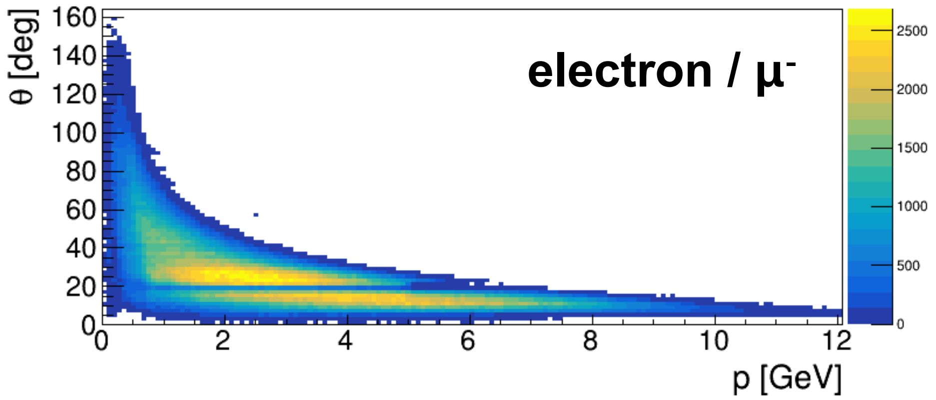
Generated Lepton Distributions

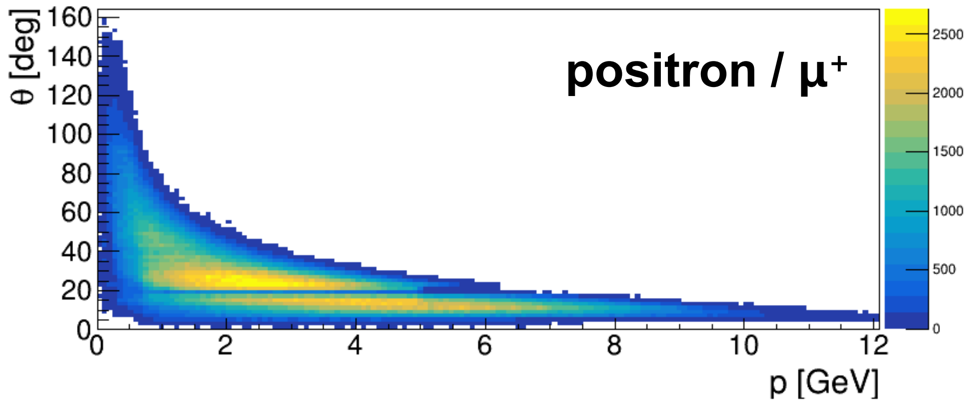
s = 10 GeV²





s = 30 GeV²





2 Topologies

Topology 1: All final state particles detected

+ Event selection via a 4C kinematic fit (prob > 0.03)

- Especially at high beam momenta the detection of antiprotons is critical

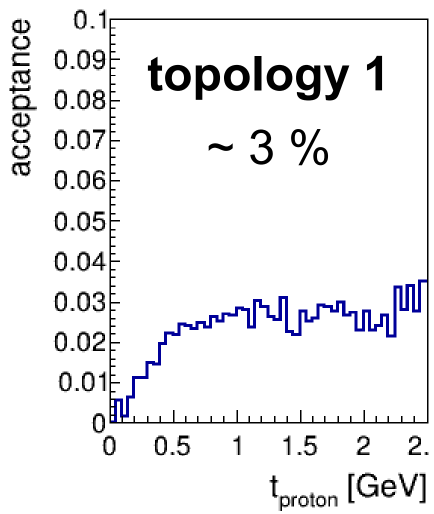
- Low acceptance due to the detection of antiprotons

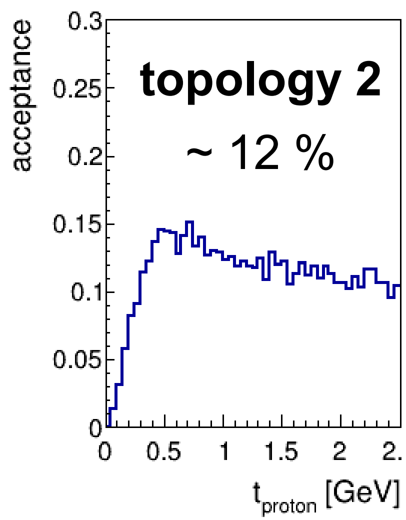
Topology 2: Detection of the antiproton is not required

➔ Reconstruction via the missing antiproton mass

Comparison of the acceptance with the standard PID cuts (see talk at the last meeting):

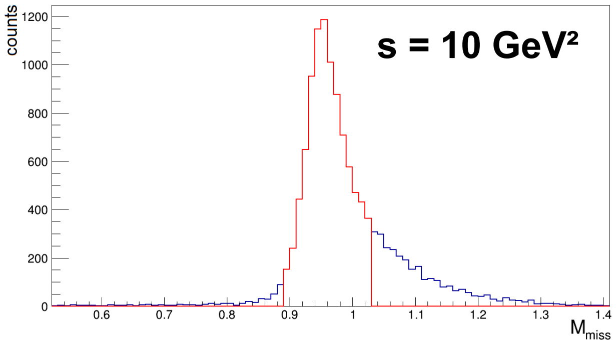
$Q^2 > 1$ GeV²
$t_2 < 0.7$ GeV²

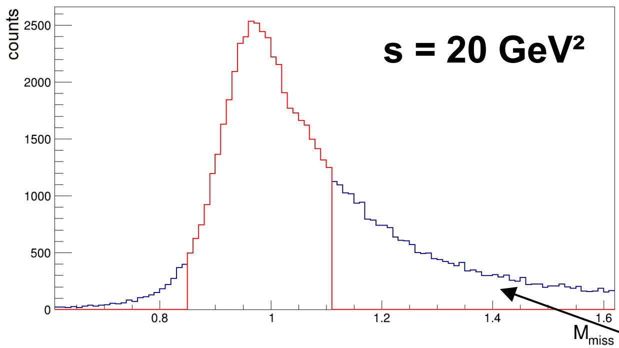


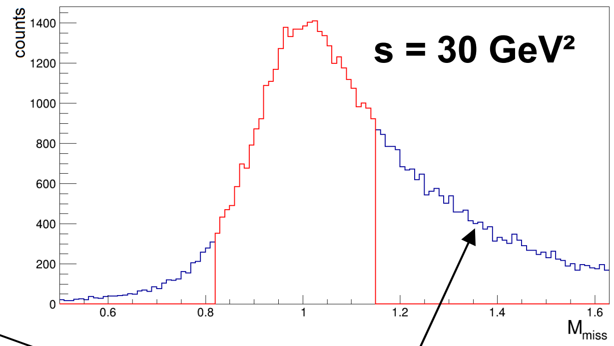


Missing Antiproton Mass of pe^-e^+X (topology 2)

Result with raw e^- and e^+ reconstruction:

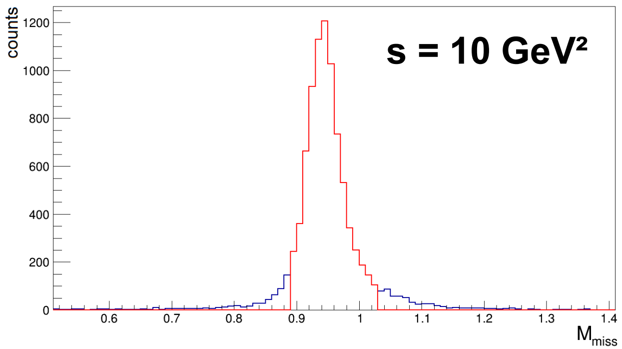


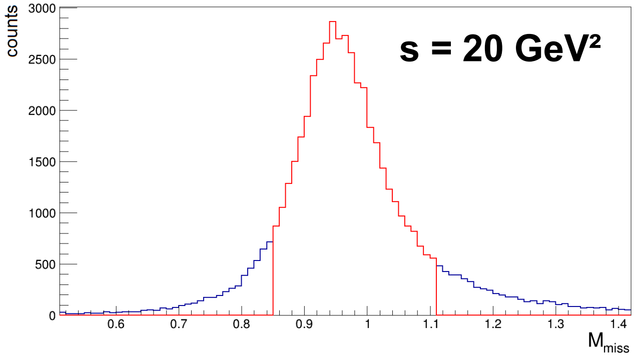


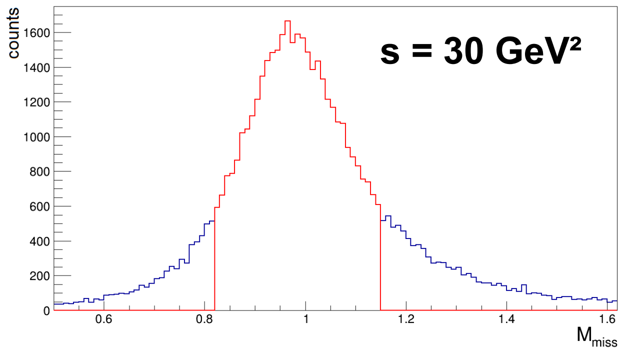


radiative tail

Result with implemented Bremsstrahlung correction:







→ Significantly reduced tail → Better separation from potential background

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 PID studies will focus on s = 20 GeV²

➔ 430 M two pion background events have been simulated

Cross section estimates for the main background channel:

Physics Letters B 680 (2009) 459–465

Contents lists available at ScienceDirect

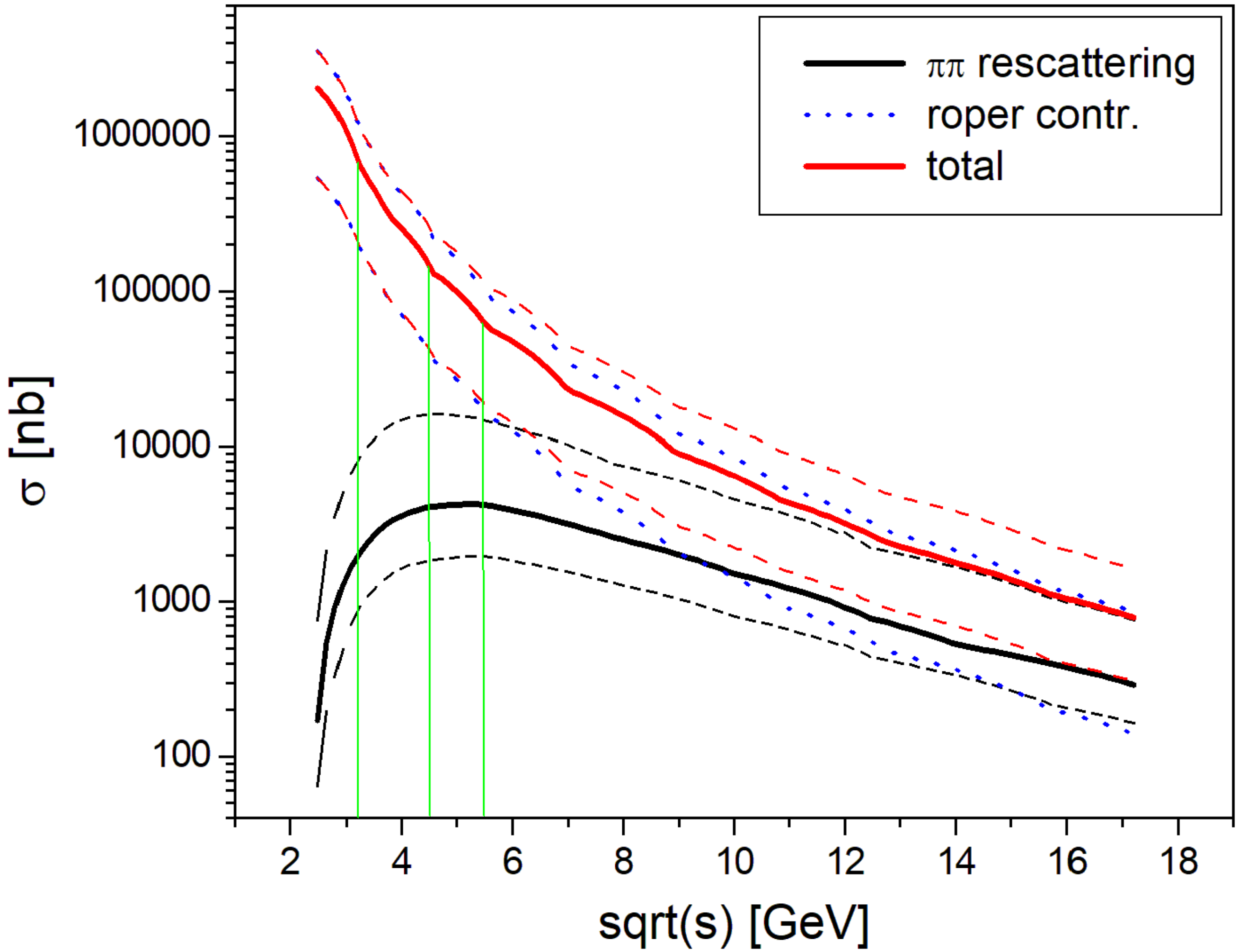
Physics Letters B

www.elsevier.com/locate/physletb

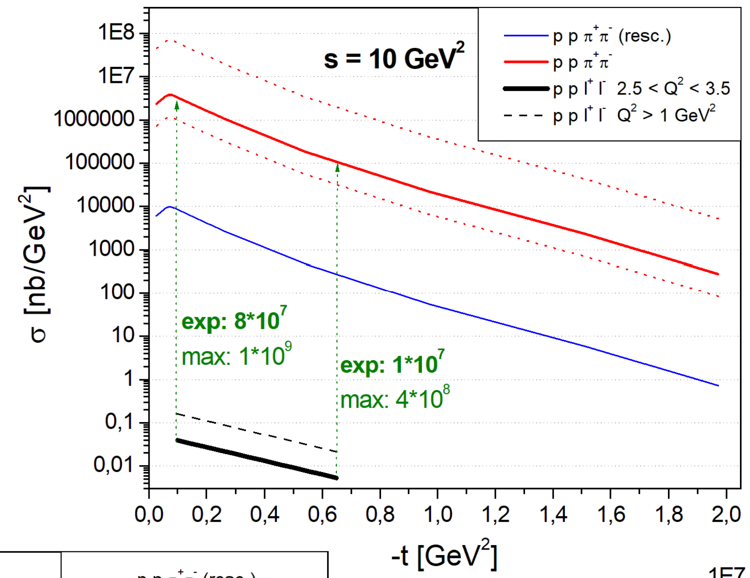
Low-energy pion–pion scattering in the $pp \rightarrow pp\pi^{+}\pi^{-}$ and $p\bar{p} \rightarrow p\bar{p}\pi^{+}\pi^{-}$ reactions

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

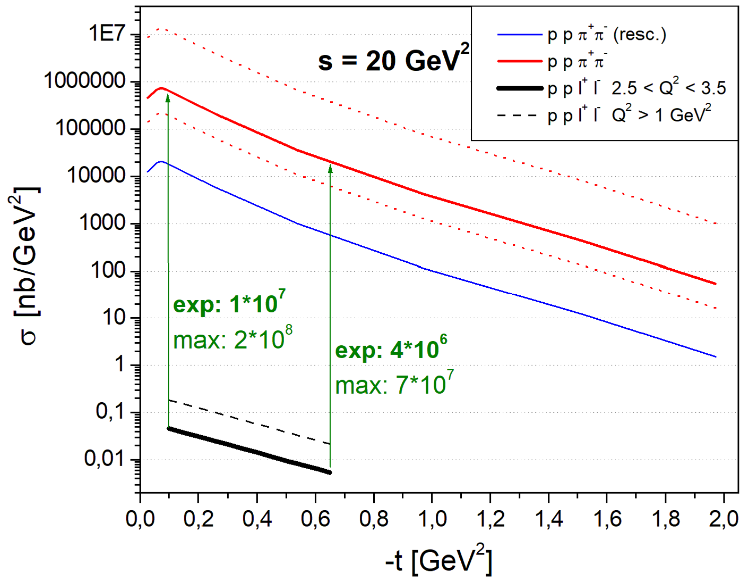
Background Studies

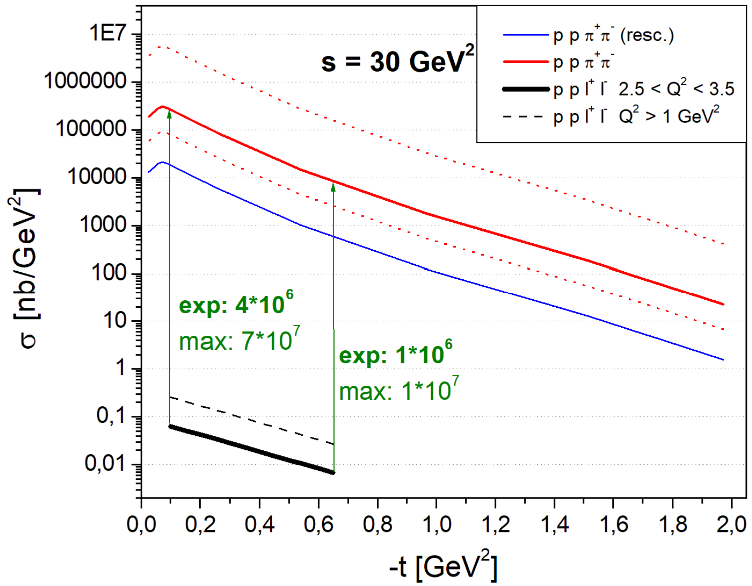


Background Studies



- ➔ Roper contribution causes strong back-ground at 10 GeV²
- ➔ Lowest background at 30 GeV²
- ➔ Q² > 1 integration increases signal by x4





PID Refinenements and Background Suppression

➔ A suppression of the two pion background by $10^6 - 10^8$ 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
(similar to the $p\bar{p} \rightarrow e^+ e^-$ form factor study)

b) A TMVA analysis including the PID and detector variables

Available PID algorithms:

PID from tracking detectors: PidAlgoMvd PidAlgoStt

PID from cherenkov detectors: PidAlgoDrc PidAlgoDisc

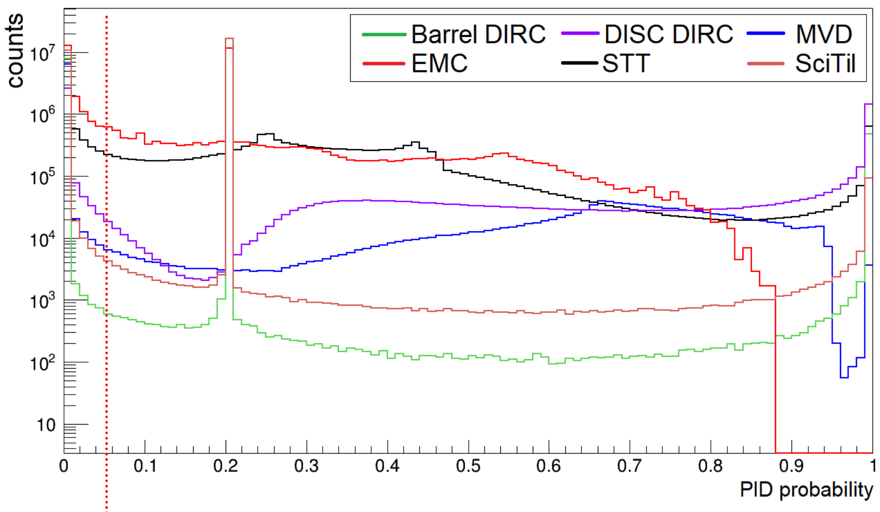
PID from calorimeter and TOF: PidAlgoEMCBayes PidAlgoSciT

PID from muon detector (for muons): PidAlgoMdtHardCuts

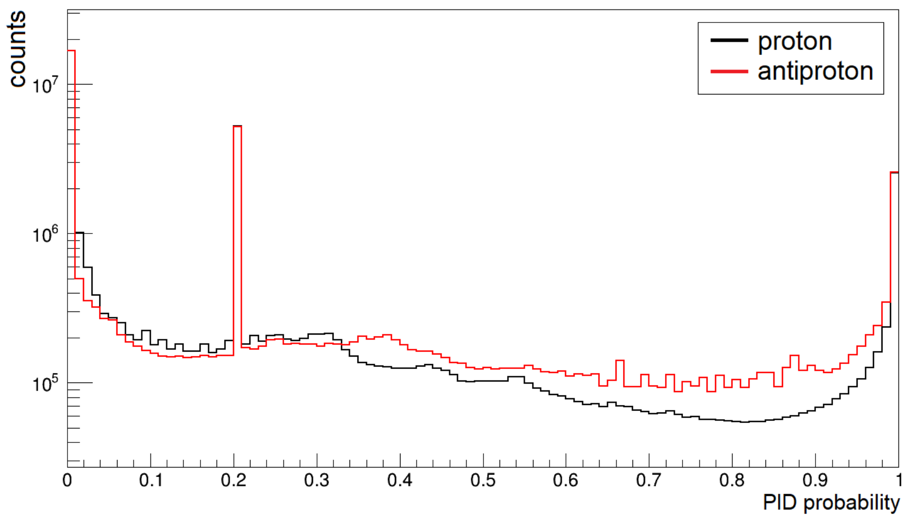
Proton / Antiproton PID

- ➔ The proton mass is well separated from electrons, pions and kaons
- ➔ Exclusivity cuts will filter most of the wrongly identified protons
- ➔ A loose PID is sufficient for protons

proton PID probability of the subsystems



Total PID probability

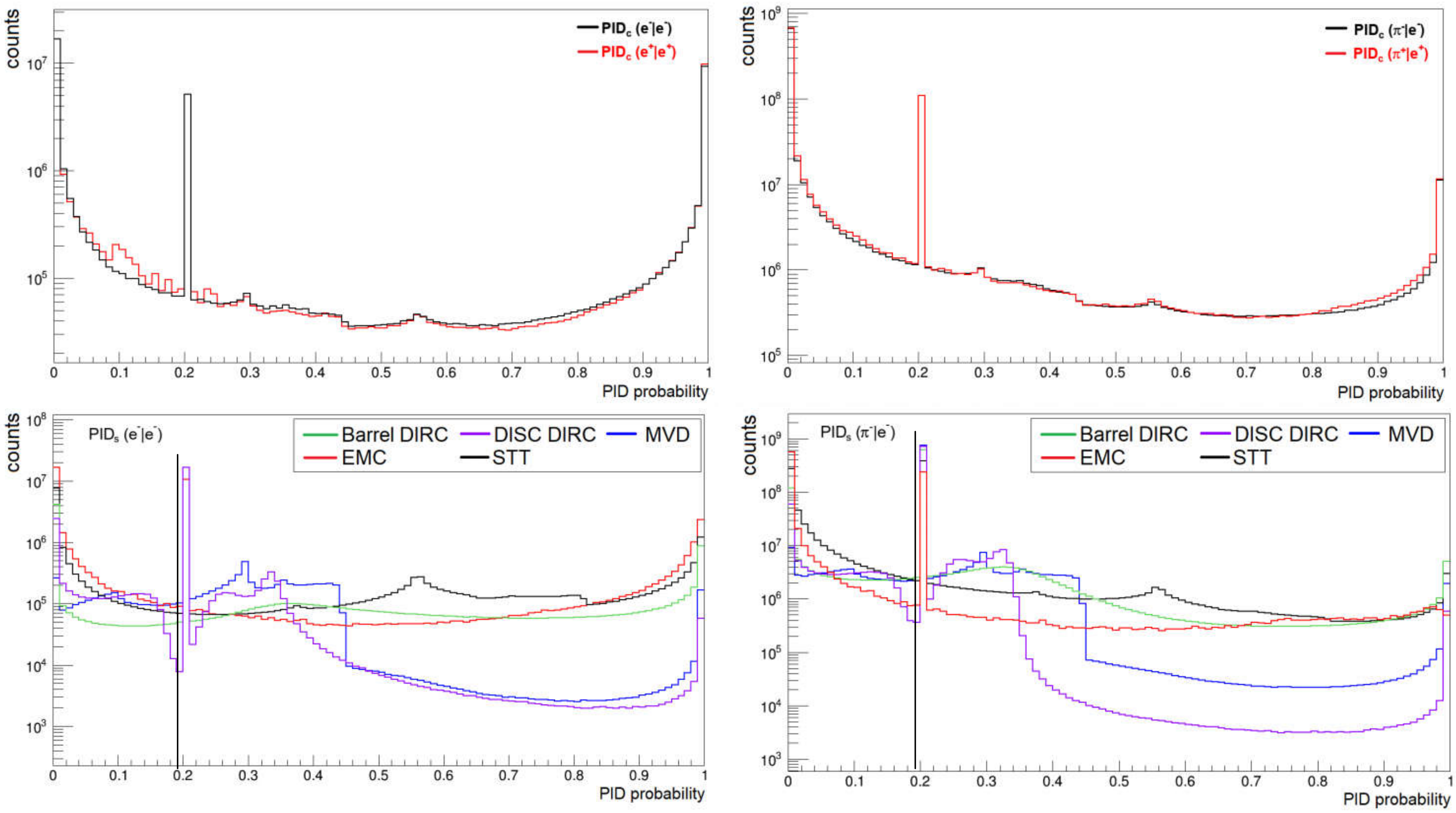


<u>2 configurations were investigated for protons</u>:

tight: $P_C > 0.99$ && $P_S > 0.05$ (eff=0.17)

loose: $P_C > 0.99$ (eff = 0.32)

Electron / Positron PID (classical PID)

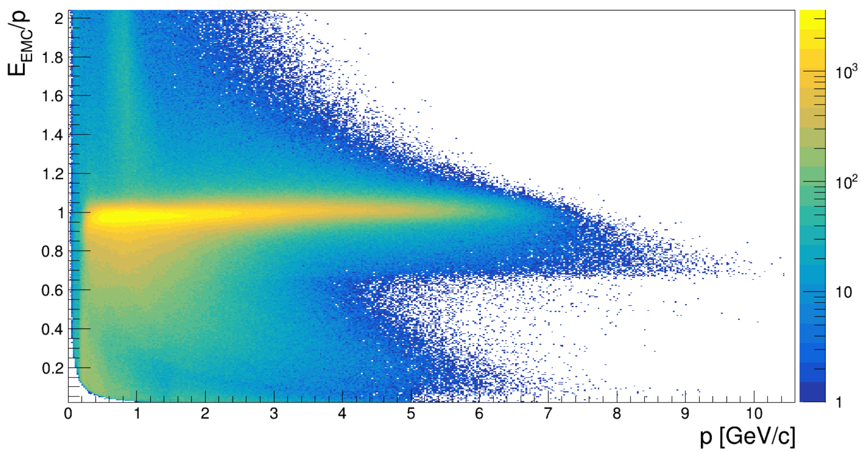


Applied cuts: $P_C > 0.99$ && $P_S > 0.19$ (eff = 33% / 36% S/B = 66 / 43)

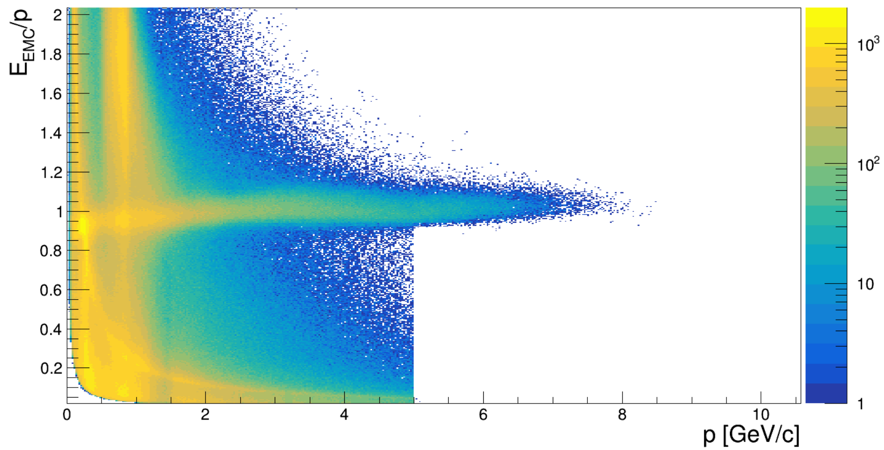
Electron / Positron PID (refinements)

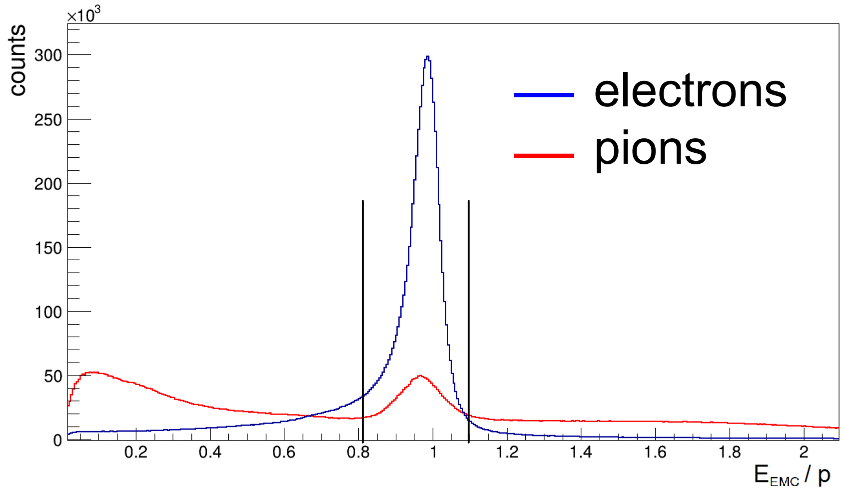
i. Calorimeter sampling fraction E/p

electron sample



pion sample





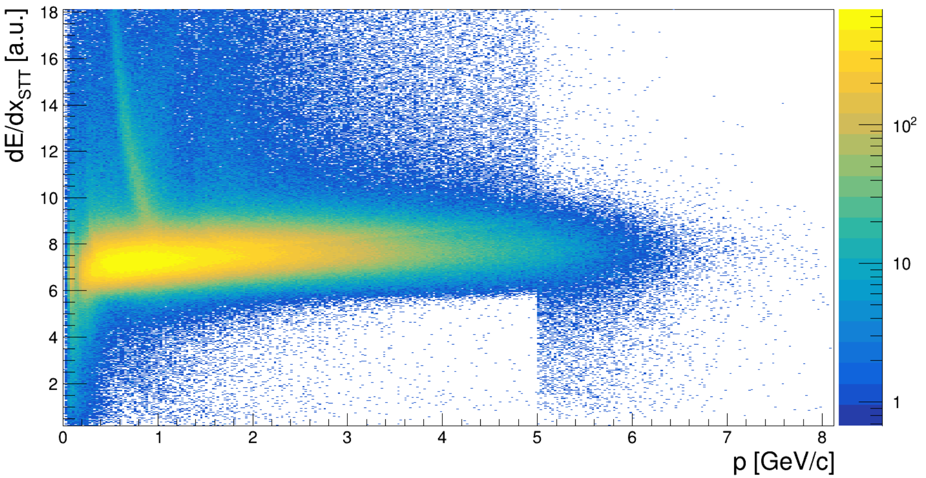
E/p > 0.8

\+ momentum dependent 3 sigma band cut

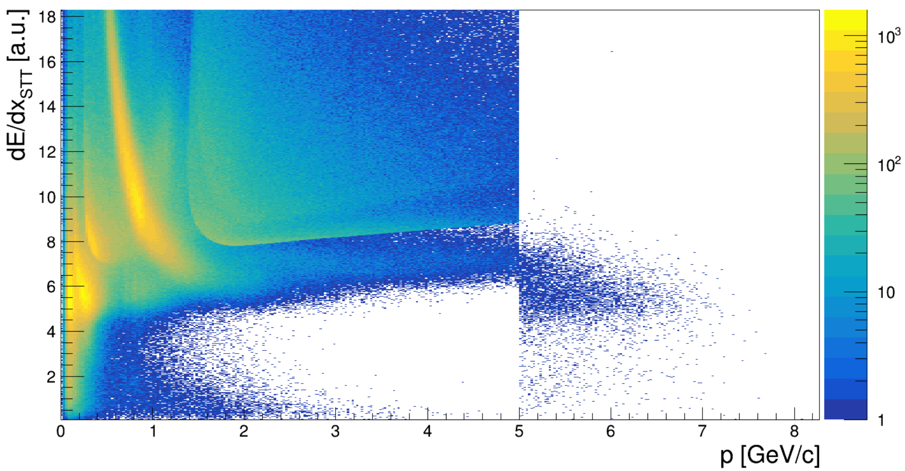
Electron / Positron PID (refinements)

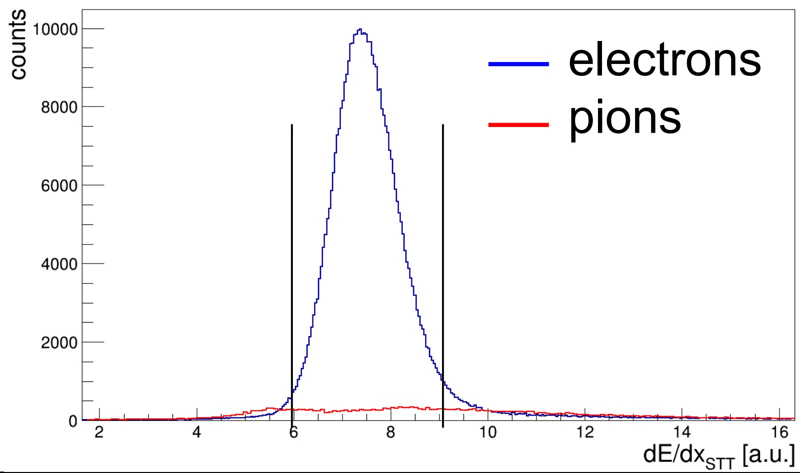
ii. Energy los per path length dE/dx in the STT

electron sample



pion sample

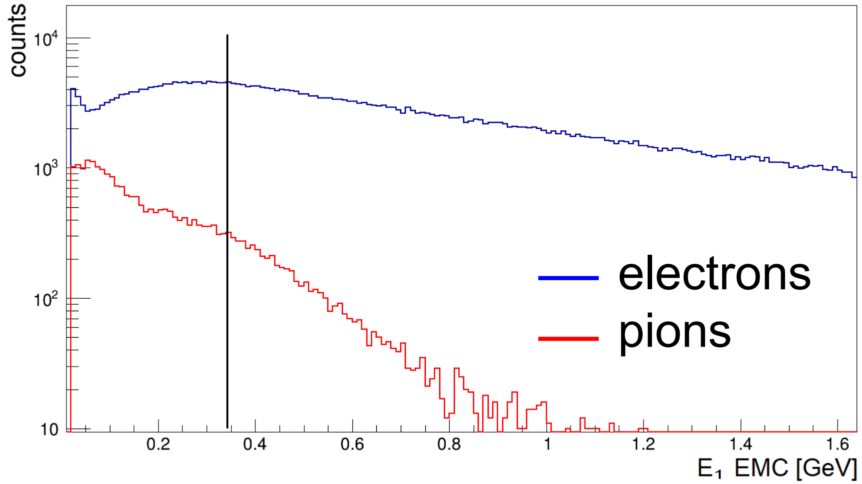




momentum dependent
3 sigma band cut

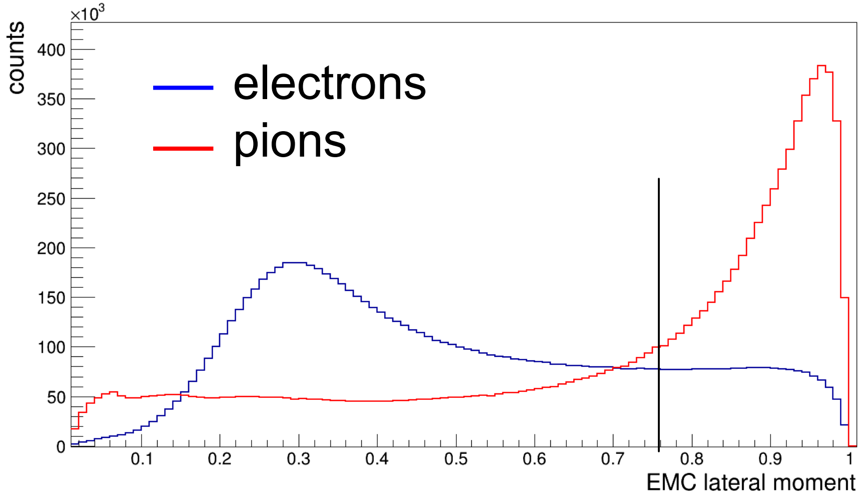
Electron / Positron PID (refinements)

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:

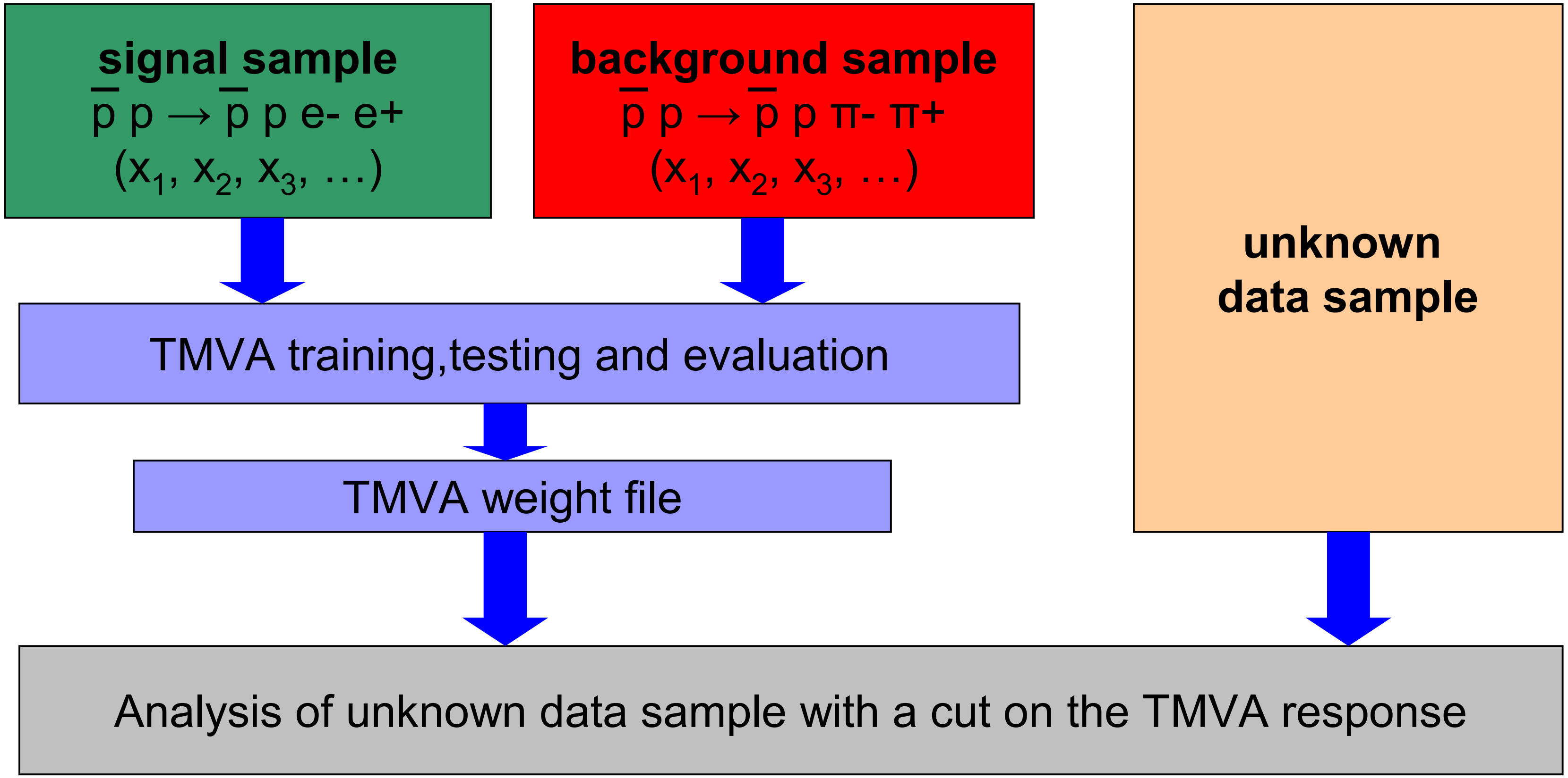
	signal eff.	**BG eff.**	**S / BG**
PID_C > 0.99	47,7	2,4750	20
PID_S > 0.19	32,5	0,5044	66
sampfrac E/p	28,6	0,1341	219
STT dE/dx	21,4	0,0477	460
EMC E1	17,6	0,0255	707
EMC lateral	15,3	0,0121	**1293**

positrons:

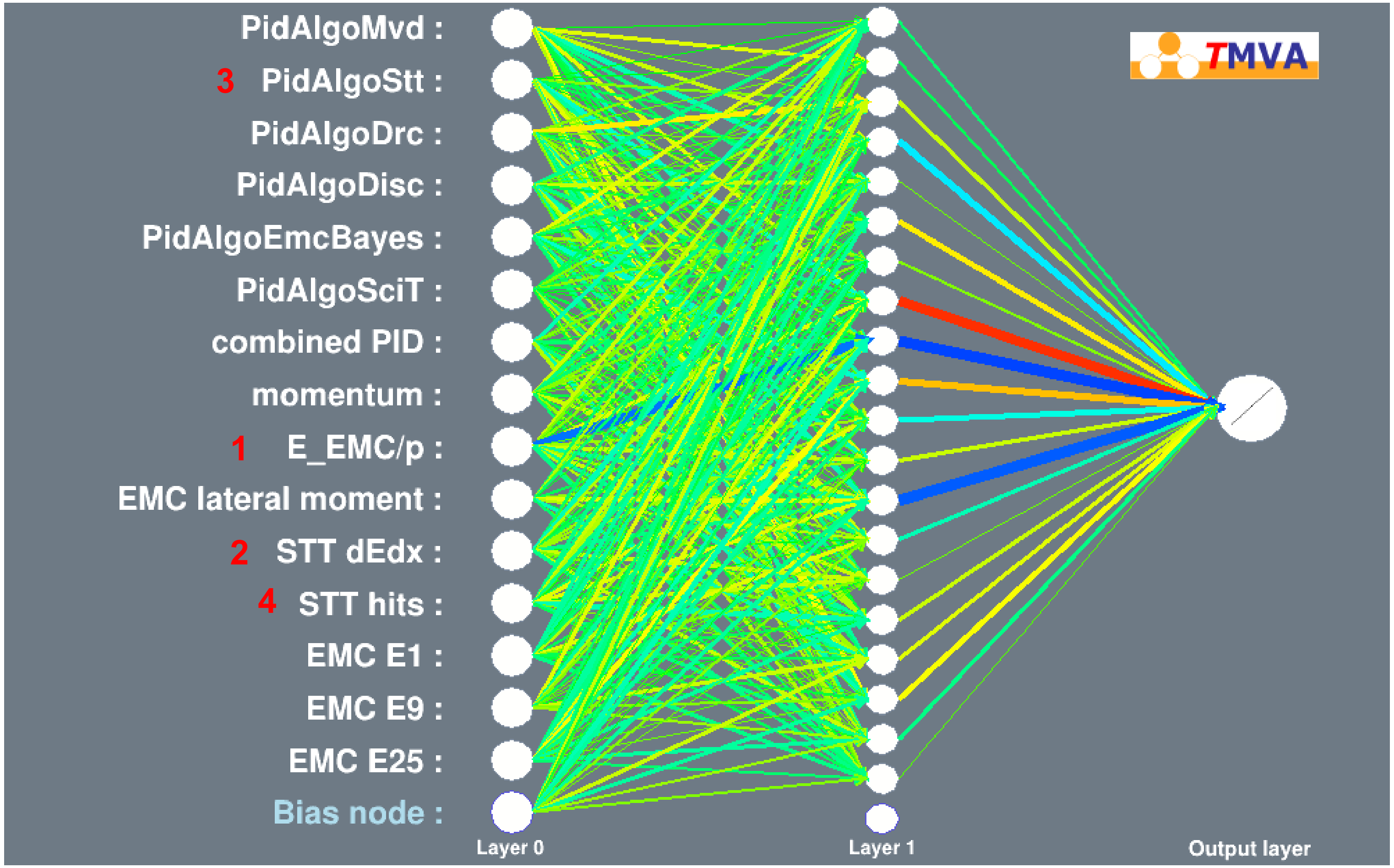
	signal eff.	**BG eff.**	**S / BG**
PID_C > 0.99	50,3	2,8021	18
PID_S > 0.19	36,3	0,8441	43
sampfrac E/p	30,5	0,3906	78
STT dE/dx	22,0	0,0692	319
EMC E1	18,5	0,0393	471
EMC lateral	15,8	0,0179	**883**

Electron / Positron PID (TMVA analysis)

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

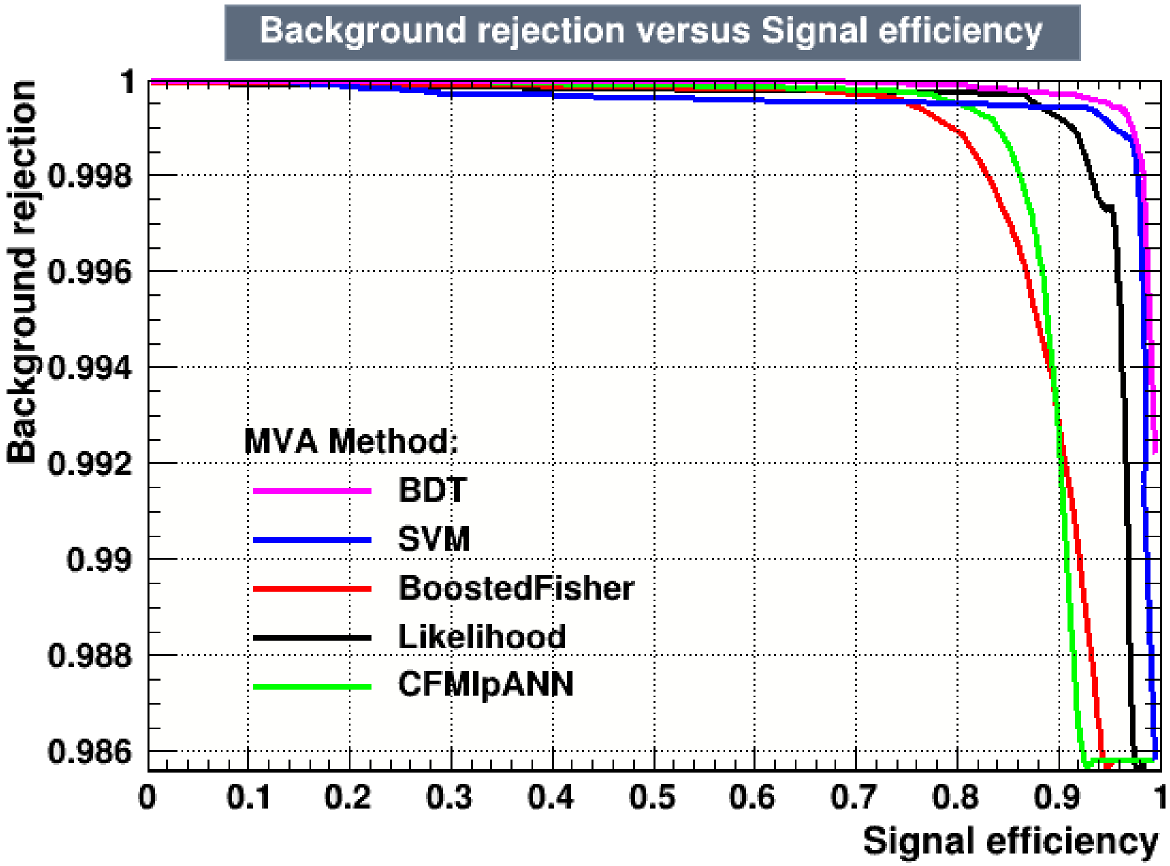


Electron / Positron PID (TMVA analysis)



Electron / Positron PID (TMVA analysis)

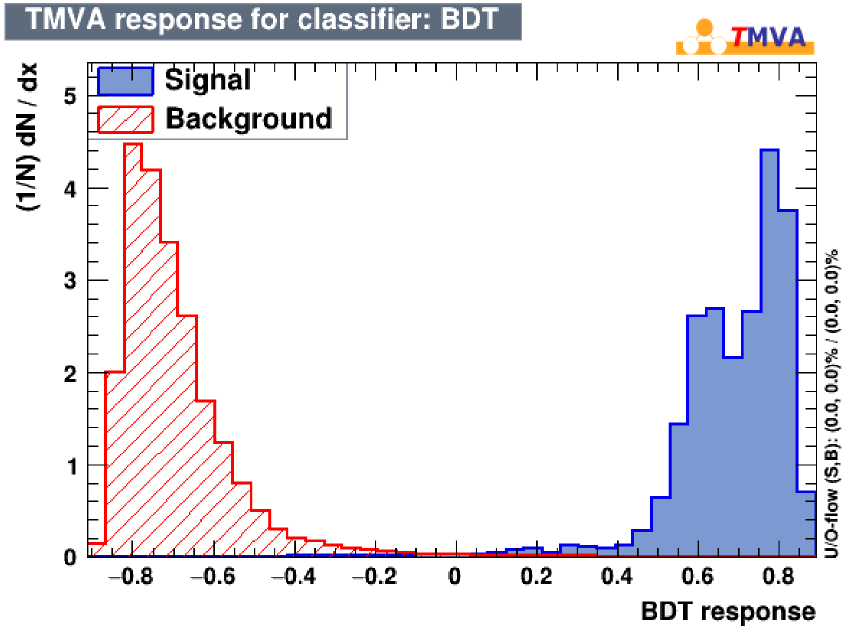
➔ **Different methods have been investigated**: Boosted decision tree (BDT), Support Vector Maschine (SVM), Boosted Fisher Discriminants, Likelyhood based naive Bayes estimator, artificial neural network (CFMlpANN)



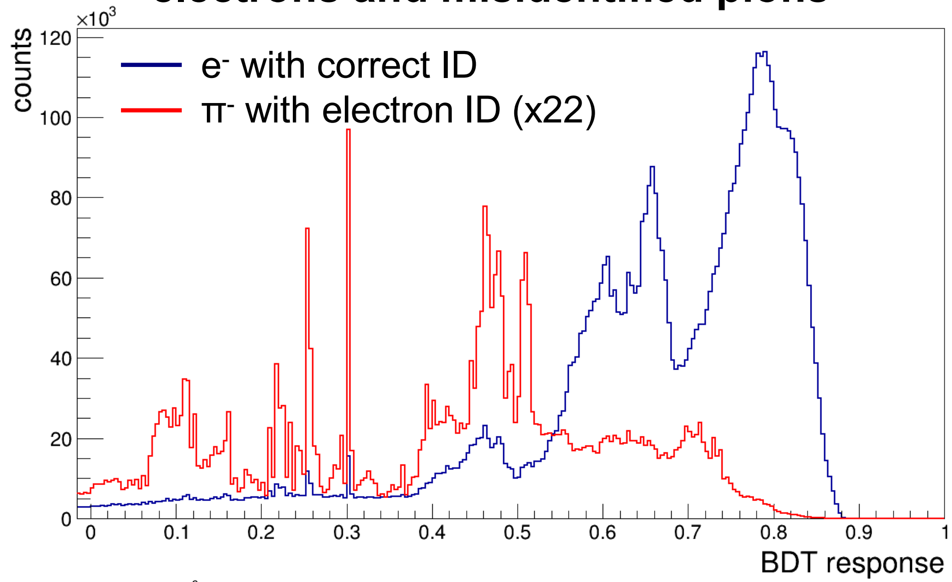
➔ A boosted decision tree (BDT) provides the best ratio of back-ground rejection and signal efficiency

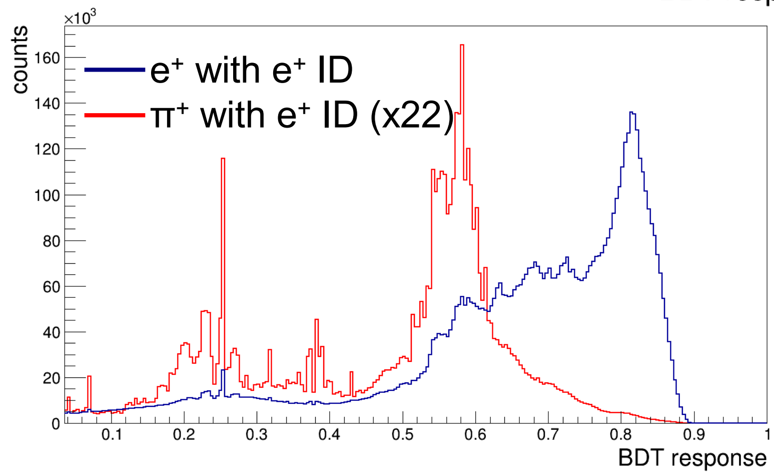
Electron / Positron PID (TMVA analysis)

BDT response for the training sample

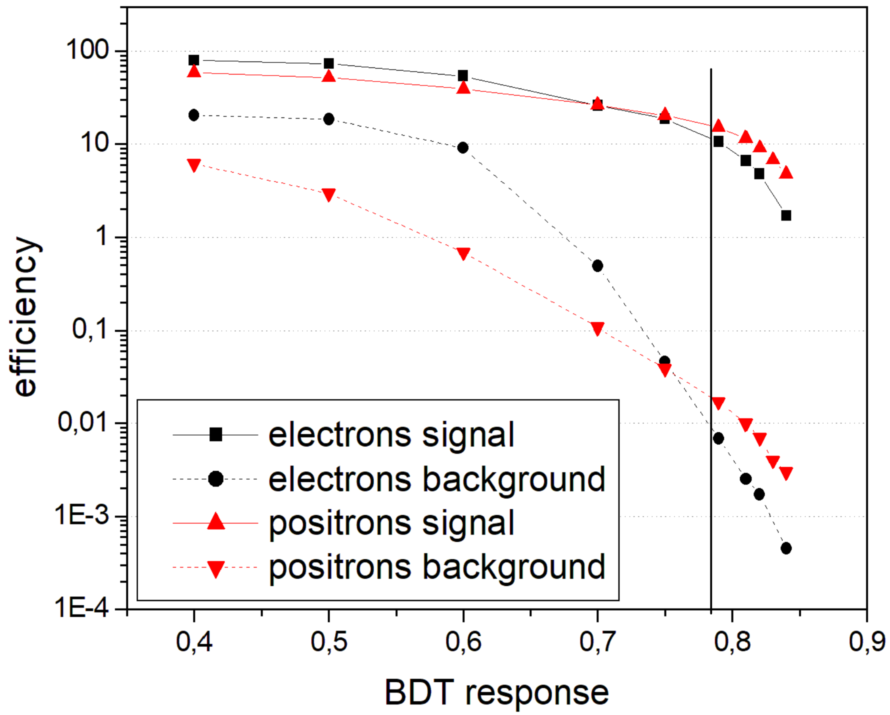


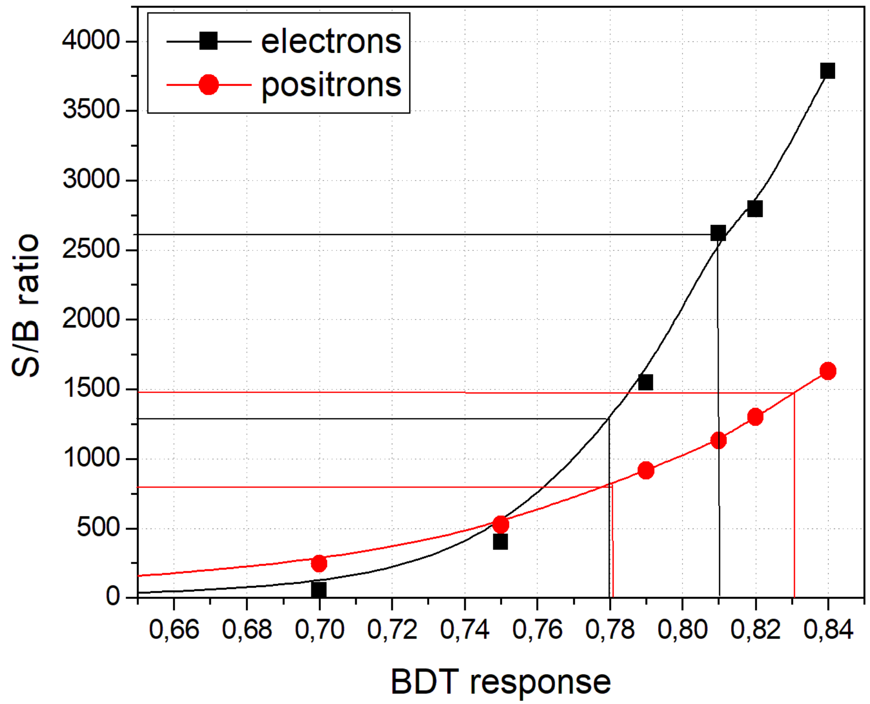
BDT response for correctly identified electrons and misidentified pions





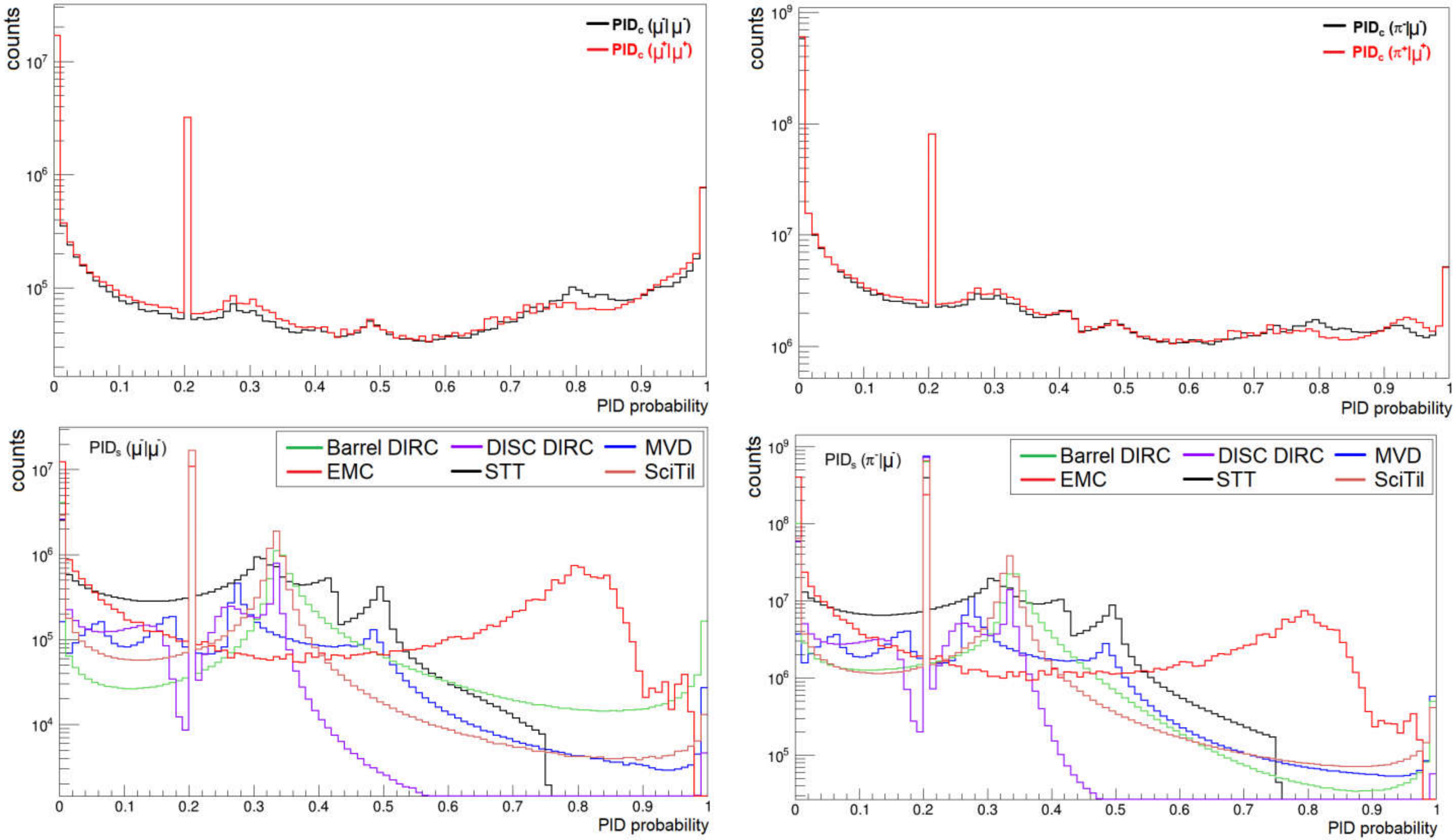
Electron / Positron PID (TMVA analysis)





	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)



Applied cuts: $P_C > 0.99$ && $P_S > 0.19$ eff = 31% / 15% S/B = 14 / 18

μ^- / μ^+ PID (TMVA analysis)

➔ Include also the variables of the muon system

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

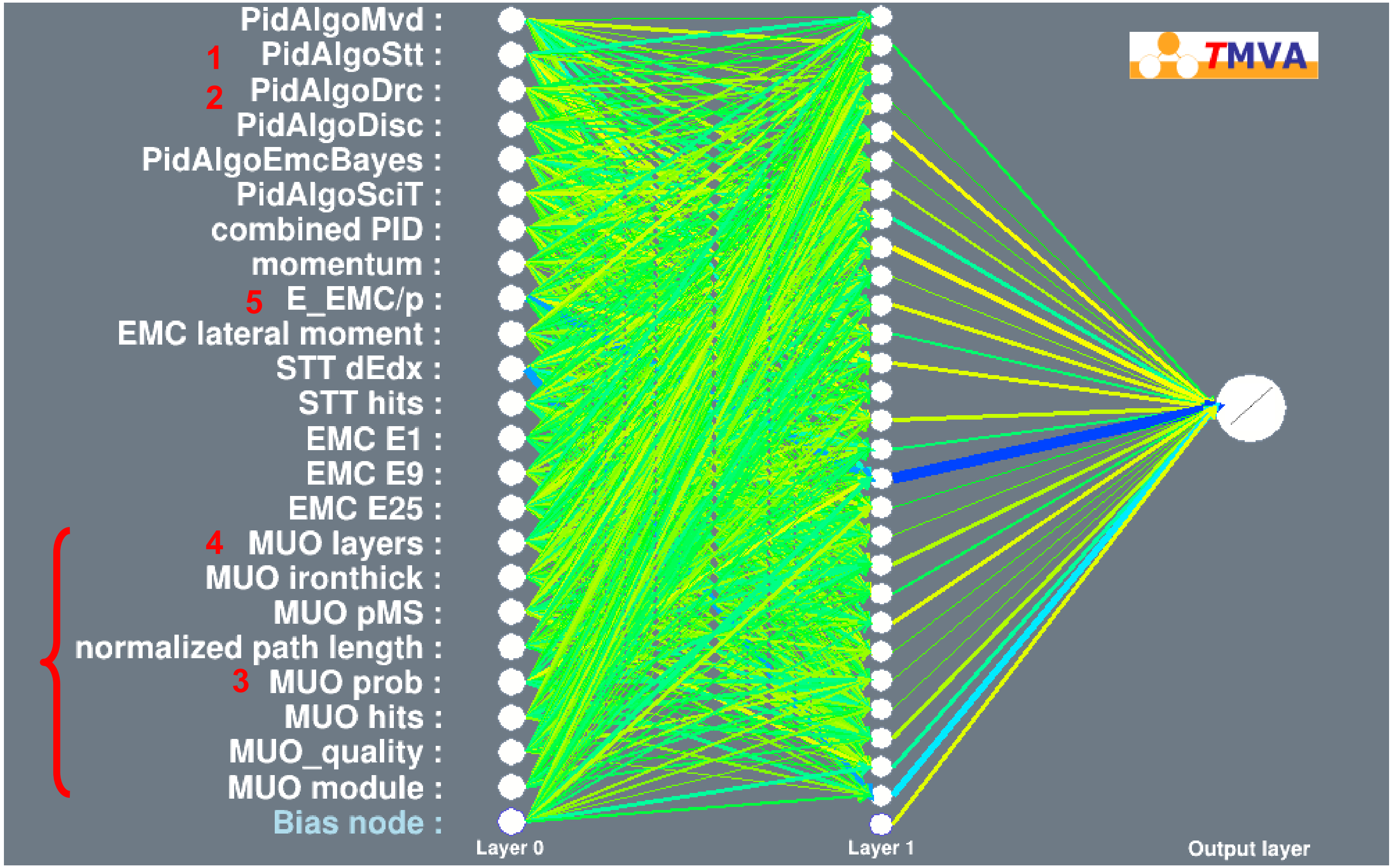
- **Path length inside iron absorber of the MS**. The length of the reconstructed trajectories is calculated inside the absorber and detections layers based on the spatial hit information, denoted as "iron thickness".
- **Number of fired layers** in the MS.
- **Initial momentum at MS layer zero**: p_{MS}.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

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

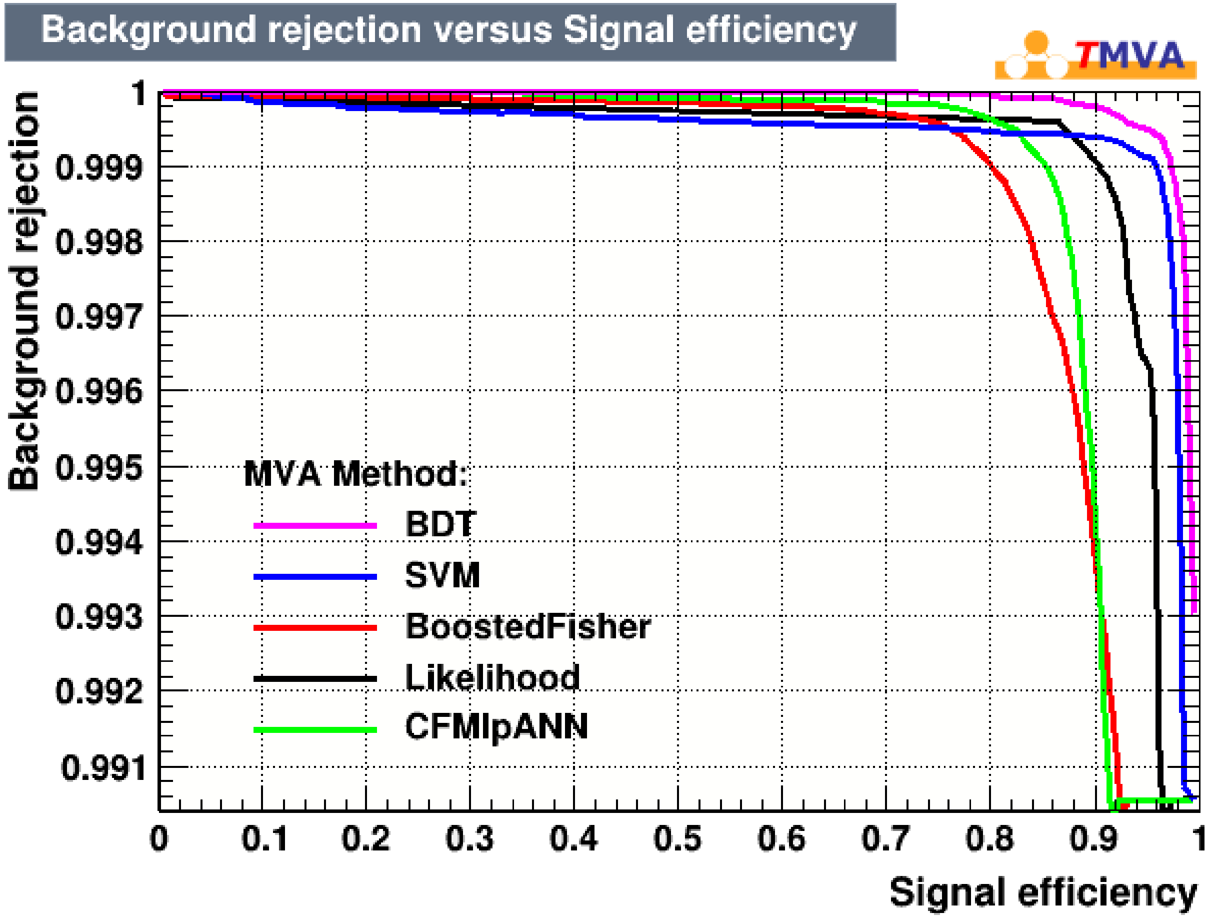
1. $(p_{MS} < p_{min}) \rightarrow P(\mu) = 0.0$
2. $(p_{MS} > p_{min})$ **and** (iron thickness > iron threshold) $\rightarrow P(\mu) = 1.0$
3. $(p_{MS} > p_{max})$ **but** (iron thickness < iron threshold) $\rightarrow P(\mu) = 0.0$
4. $(p_{min} < p_{MS} < p_{max})$ and (iron thickness > iron threshold $\cdot$ $(\frac{p_{MS}-p_{min}}{p_{max}-p_{min}})$) $\rightarrow$ $P(\mu) = 1.0$
5. $(p_{min} < p_{MS} < p_{max})$ but (iron thickness < iron threshold $\cdot$ $(\frac{p_{MS}-p_{min}}{p_{max}-p_{min}})$) $\rightarrow$ $P(\mu) = 0.0$

μ^- / μ^+ PID (TMVA analysis)

➔ Include also the variables of the muon system



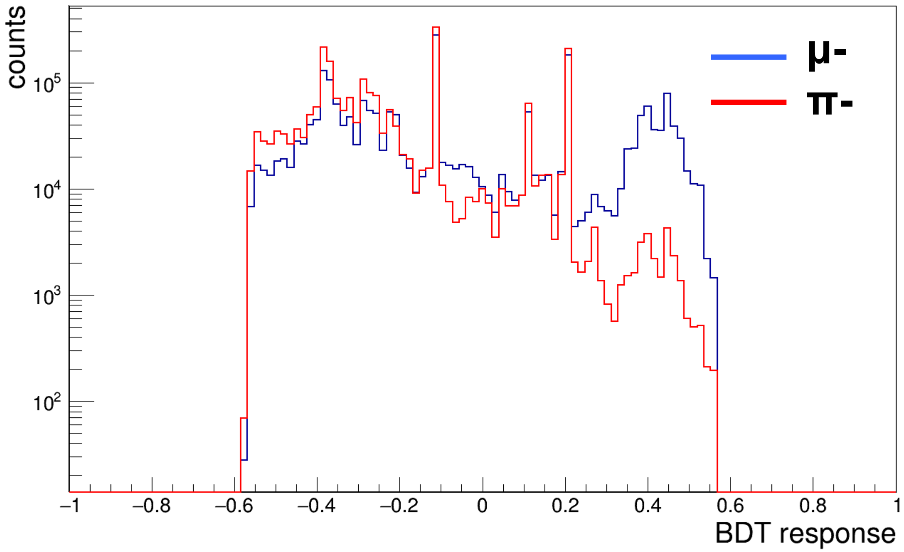
μ^- / μ^+ PID



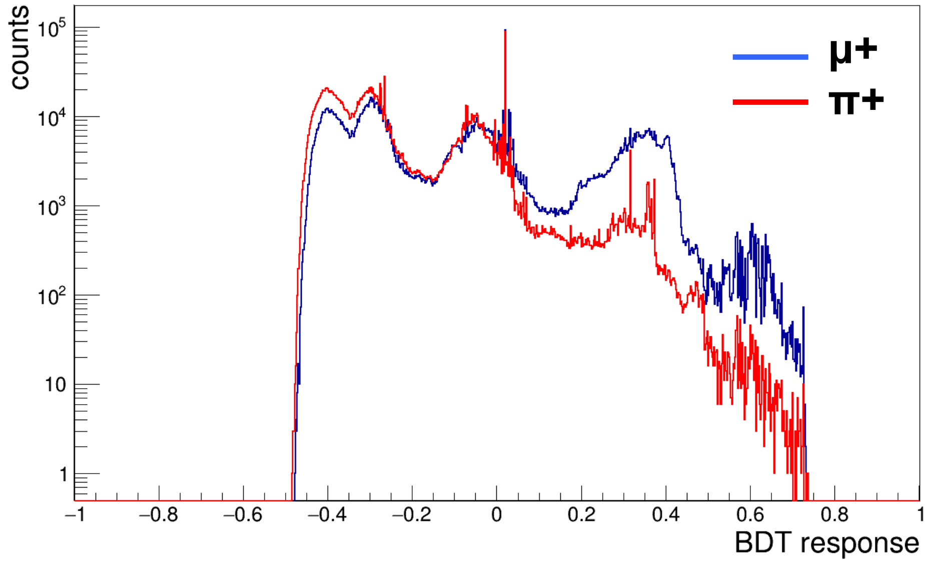
➔ Also for muons a boosted decision tree (BDT) provides the best results

μ^- / μ^+ PID

BDT response for μ- and π-



BDT response for μ+ and π+



	BDT μ- / μ+	**signal eff**	**S/B μ- / μ+**
very loose	> 0.0 / 0.0	~ 42 - 43 %	15 / 12
loose	> 0.1 / 0.1	~ 41 - 42 %	16 / 14
standard	> 0.2 / 0.2	~ 37 - 38 %	19 / 18
very tight	> 0.2 / 0.37	37% / 10%	19 / 28
cut on PID variables		30% / 15 %	14 / 18

no additional improvement for μ^- for BDT > 0.2

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 $7 \cdot 10^6$

	classical PID refinements				standard TMVA cuts		
	signal acc.	**backgr. acc.**	**expected S/B**		**signal acc.**	**backgr. acc.**	**expected S/B**
Q² > 1 GeV²	0,0036	< 3,44 E-09	> 0,15		0,0027	< 3,44 E-09	> 0,11
Q² > 1 GeV² -t < 1 GeV²	0,0039	< 2,71 E-07	> 0,0021		0,0034	< 2,71 E-07	> 0,0018
Q² > 1 GeV² -t < 0.7 GeV²	0,0033	< 8,90 E-07	> 0,00052		0,0028	< 8,90 E-07	> 0,00045
Q² > 1-3 GeV² -t < 1 GeV²	0,0034	< 3,12 E-07	> 0,0016		0,0031	< 3,12 E-07	> 0,0014
Q² > 3 GeV² -t < 1 GeV²	0,0072	< 2,08 E-06	> 0,00050		0,0052	< 2,08 E-06	> 0,00036

➔ The given background acceptances and S/B ratios are only limits, since in all cases no single background event was accepted from 261.339.500 generated $\pi^+ \pi^-$ events with $Q^2 > 1$ GeV²

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

	very tight TMVA cuts			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	0,00052	< 3,44 E-09	> 0,021	0,00463	~ 3,83 E-09	~ 0,17
$Q^2 > 1$ GeV², $-t < 1$ GeV²	0,00068	< 2,71 E-07	> 0,00036	0,00554	< 2,71 E-07	> 0,0029
$Q^2 > 1$ GeV², $-t < 0.7$ GeV²	0,00051	< 8,90 E-07	> 8,2 E-05	0,00458	< 8,90 E-07	> 0,00074
$Q^2 > 1\text{-}3$ GeV², $-t < 1$ GeV²	0,00065	< 3,12 E-07	> 0,00030	0,00519	< 3,12 E-07	> 0,0024
$Q^2 > 3$ GeV², $-t < 1$ GeV²	0,00089	< 2,08 E-06	> 6,1 E-05	0,00807	< 2,08 E-06	> 0,00056

Very tight TMVA cuts:
- → Signal efficiency is reduced by a factor 4-5
- → As expected also now no single background event is accepted

Loose TMVA cuts:
- → Signal efficiency increases by a factor 2-3
- → A single background event out of 260 M is detected for the $Q^2 > 1$ case
- → For this case the background is expected to be 6 x larger than the signal

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
$Q^2 > 1\ GeV^2$	0,00693	~ 3,83 E-09	~ 0,26		0,00544	< 3,44 E-09	> 0,23
$Q^2 > 1\ GeV^2$ $-t < 1\ GeV^2$	0,01138	< 2,71 E-07	> 0,0060		0,00817	< 2,71 E-07	> 0,0043
$Q^2 > 1\ GeV^2$ $-t < 0.7\ GeV^2$	0,00594	< 8,90 E-07	> 0,00095		0,00433	< 8,90 E-07	> 0,00069
$Q^2 > 1\text{-}3\ GeV^2$ $-t < 1\ GeV^2$	0,01137	< 3,12 E-07	> 0,0052		0,00791	< 3,12 E-07	> 0,0036
$Q^2 > 3\ GeV^2$ $-t < 1\ GeV^2$	0,01144	< 2,08 E-06	> 0,00079		0,01005	< 2,08 E-06	> 0,00069

➔ Signal efficiency doubles and background does not change (within the available statistics)

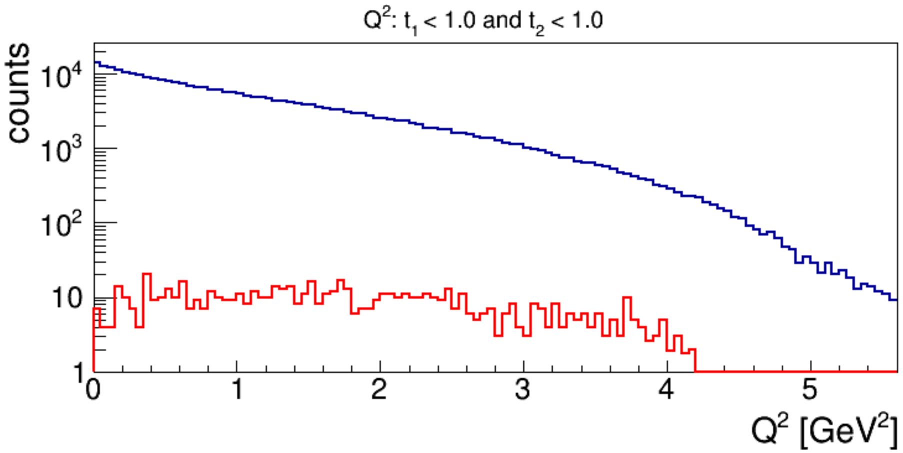
➔ A cut on $PID_C > 0.99$ only for protons seems to be sufficient

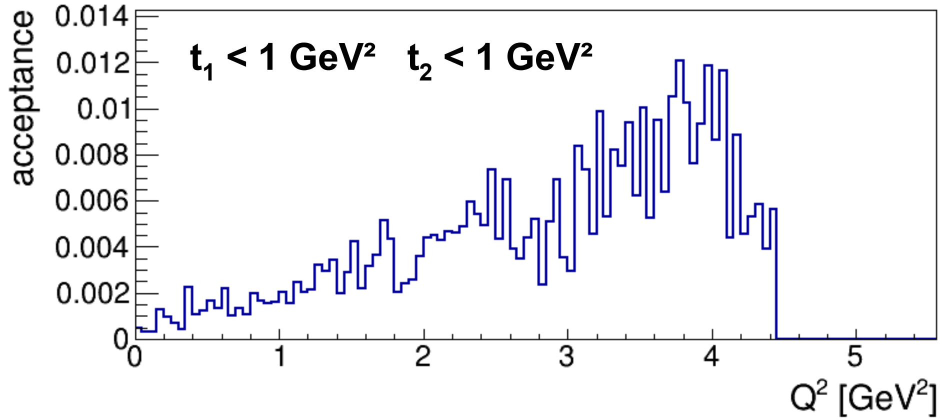
Effect of the PID cuts on the Q^2 acceptance

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

s = 20 GeV²

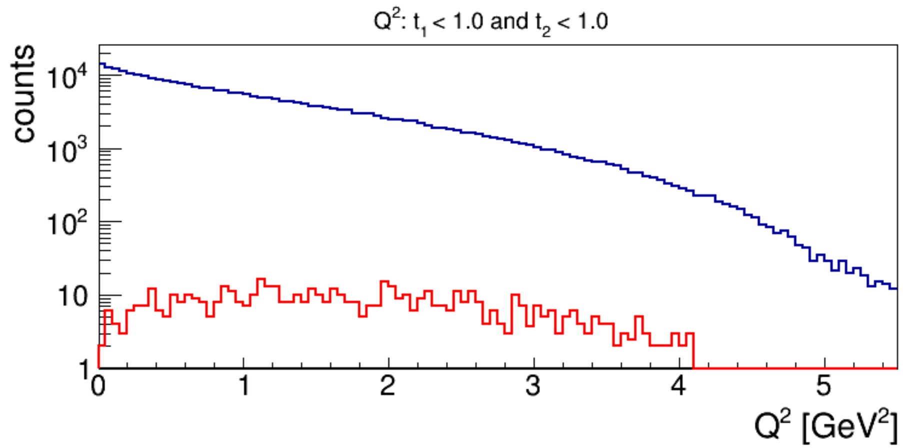
classical PID refinements

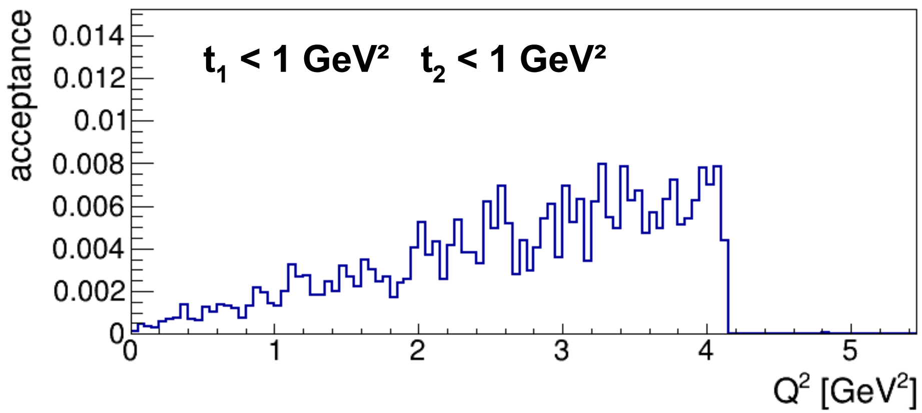




acc = 0.2 – 1.0 %

standard TMVA cut



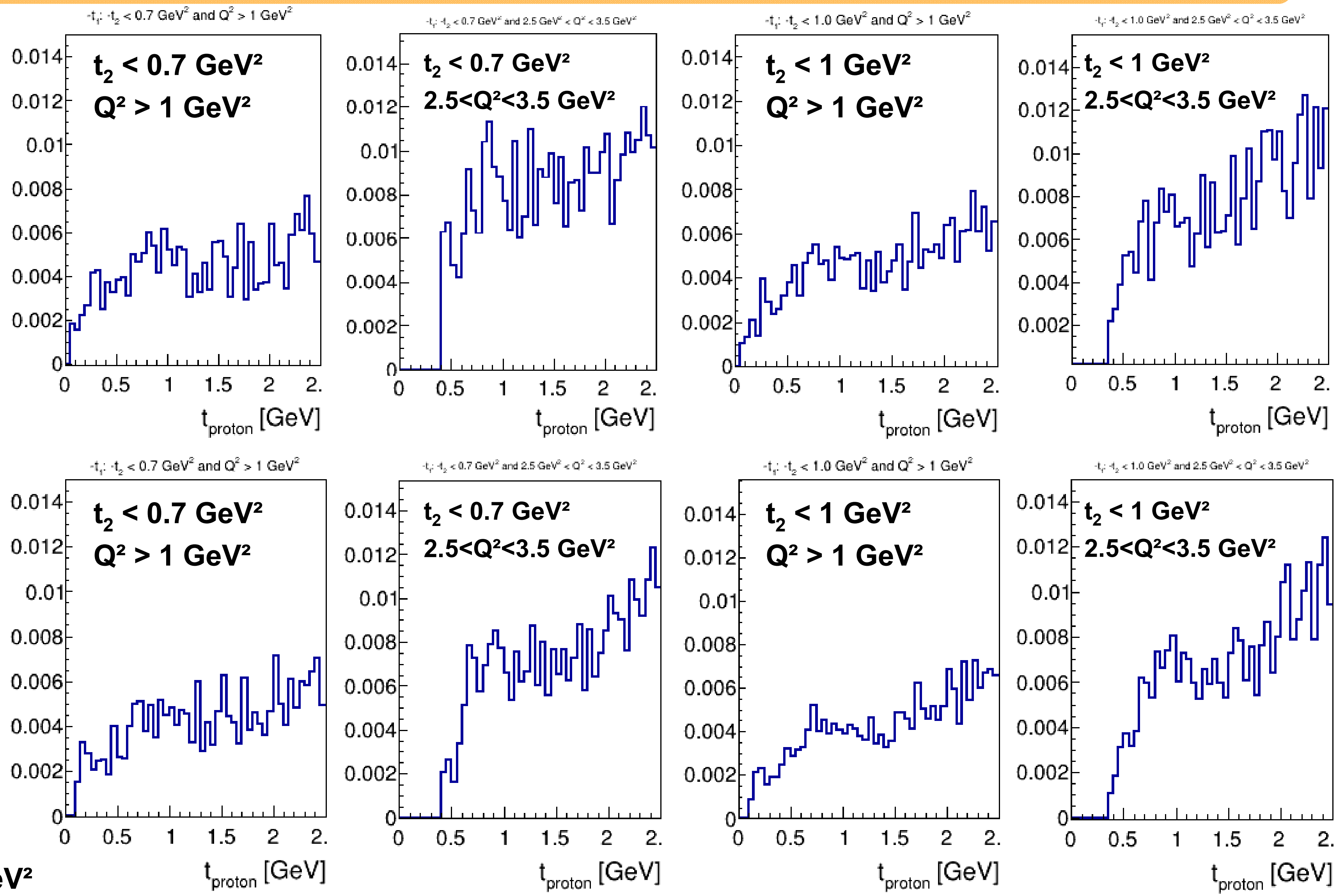


acc = 0.2 – 0.60 %

Effect of the PID cuts on the t_1 acceptance

classical PID refinements

standard TMVA cut

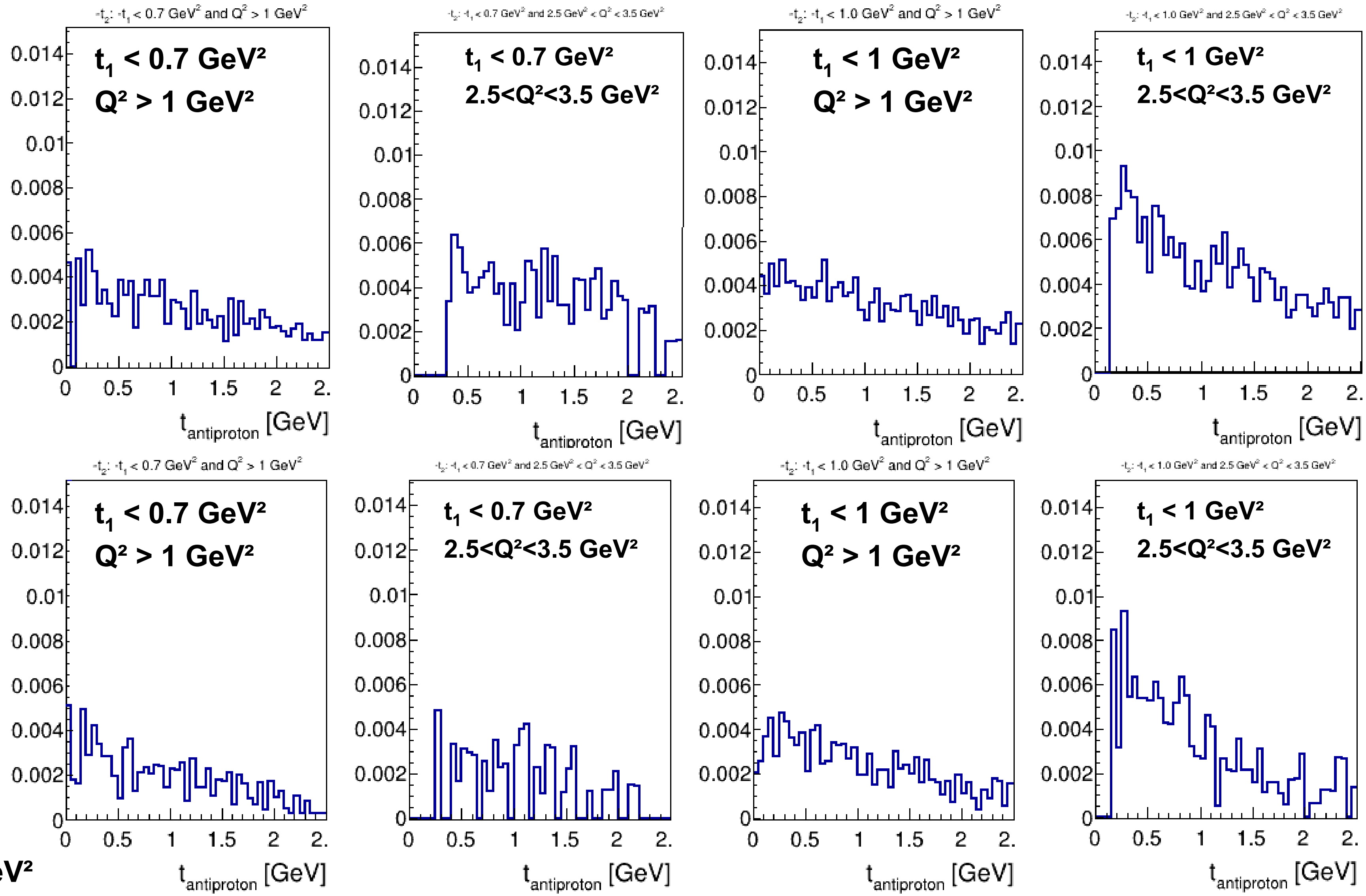


s = 20 GeV²

Effect of the PID cuts on the t_2 acceptance

classical PID refinements

standard TMVA cut



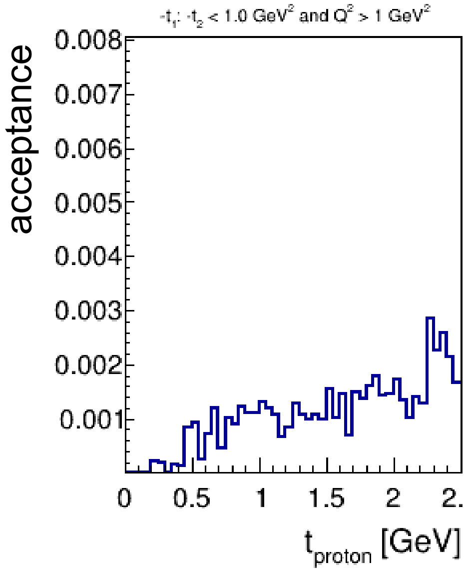
s = 20 GeV²

Effect of a very tight TMVA PID on the acceptance

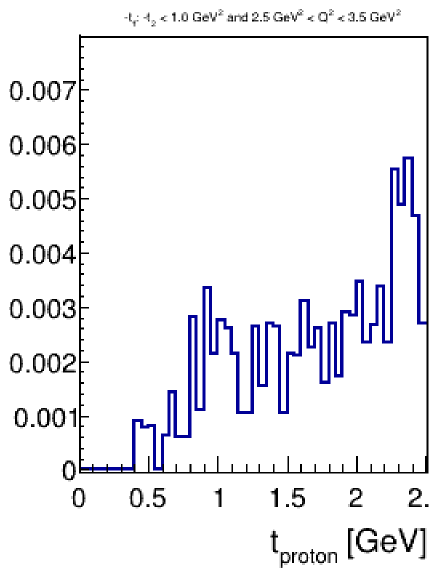
$s = 20$ GeV²

proton

$t_1 < 1$ GeV²
$Q^2 > 1$ GeV²

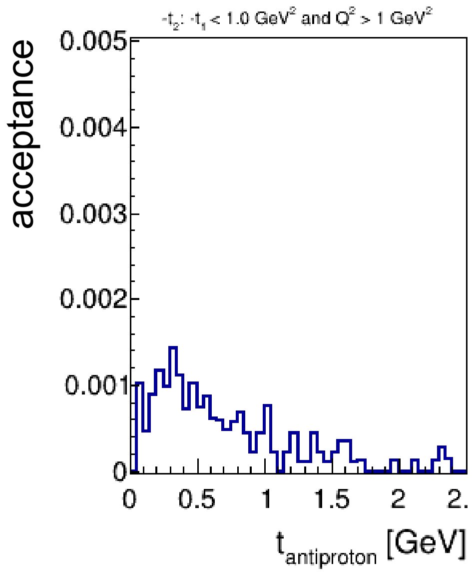


$t_1 < 1$ GeV²
$2.5 < Q^2 < 3.5$ GeV²

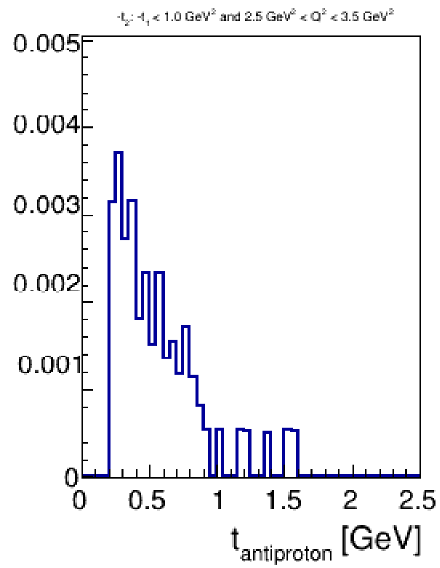


antiproton

$t_1 < 1$ GeV²
$Q^2 > 1$ GeV²



$t_1 < 1$ GeV²
$2.5 < Q^2 < 3.5$ GeV²



Very tight cut (probably not necessary): Acceptance in the order of 0.1 – 0.3 %

Effect of the improved PID on the final μ- μ+ sample

➔ The expected S/B ratio is weighted with the expected cross section ratio of $7*10^6$

	classical PID				standard 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	0,00010	2,17 E-05
$Q^2 > 1$ GeV² $-t < 1$ GeV²	0,012	0,00012	1,40 E-05		0,015	0,00017	1,23 E-05
$Q^2 > 1$ GeV² $-t < 0.7$ GeV²	0,011	0,00013	1,17 E-05		0,013	0,00024	7,91 E-06
$Q^2 > 1$-3 GeV² $-t < 1$ GeV²	0,011	0,00012	1,29 E-05		0,011	0,00018	9,00 E-06
$Q^2 > 3$ GeV² $-t < 1$ GeV²	0,022	0,00015	2,11 E-05		0,038	0,00015	3,59 E-05

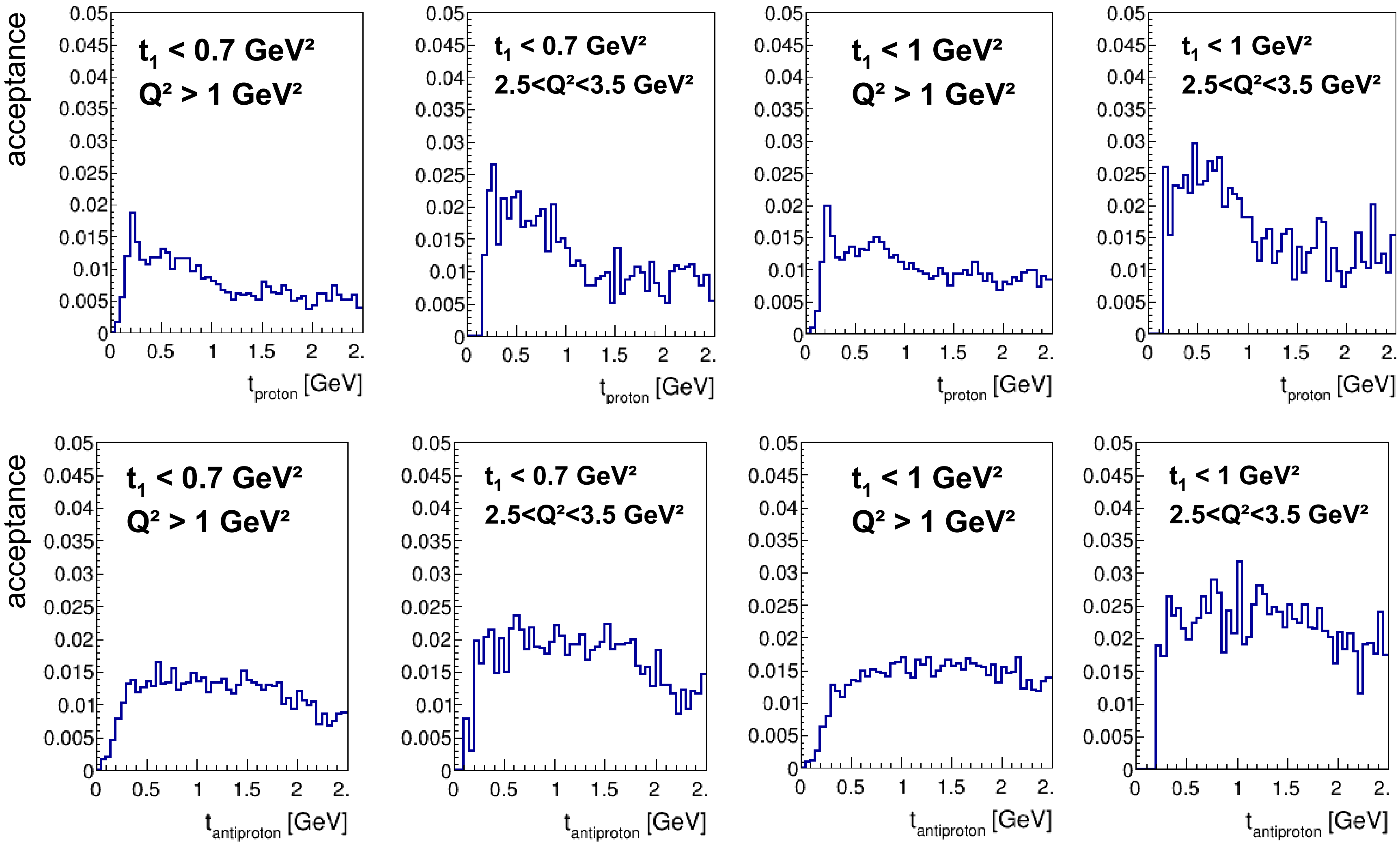
➔ Muon PID is not sufficient to controll the background

➔ Even stricter TMVA cuts show no significant improvements

➔ More investigations have to be performed

Effect of the PID cuts on the -t acceptance of μ^- / μ^+

➔ **standard TMVA cut**



Effect of the PID on the count rates and uncertainties

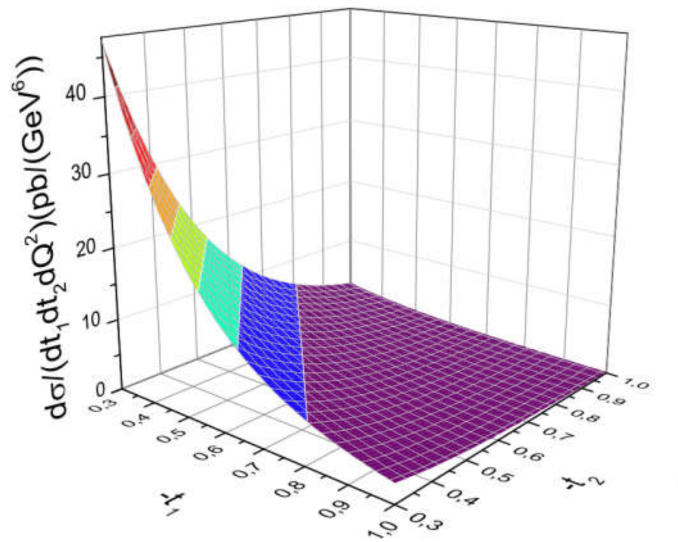
- **Differential cross section available for s = 10 GeV², 20 GeV² and 30 GeV² @ Q² = 3 GeV²**

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

➔ Scaling is expected to follow $1/Q^2$

➔ Fix a Q² bin i.e. 2.5 GeV² < Q² < 3.5 GeV²

➔ ΔQ^2 = 1 GeV²



- Set the bin size in -t:

  i. e. $\Delta t_1 = \Delta t_2$ = 0.05 GeV²

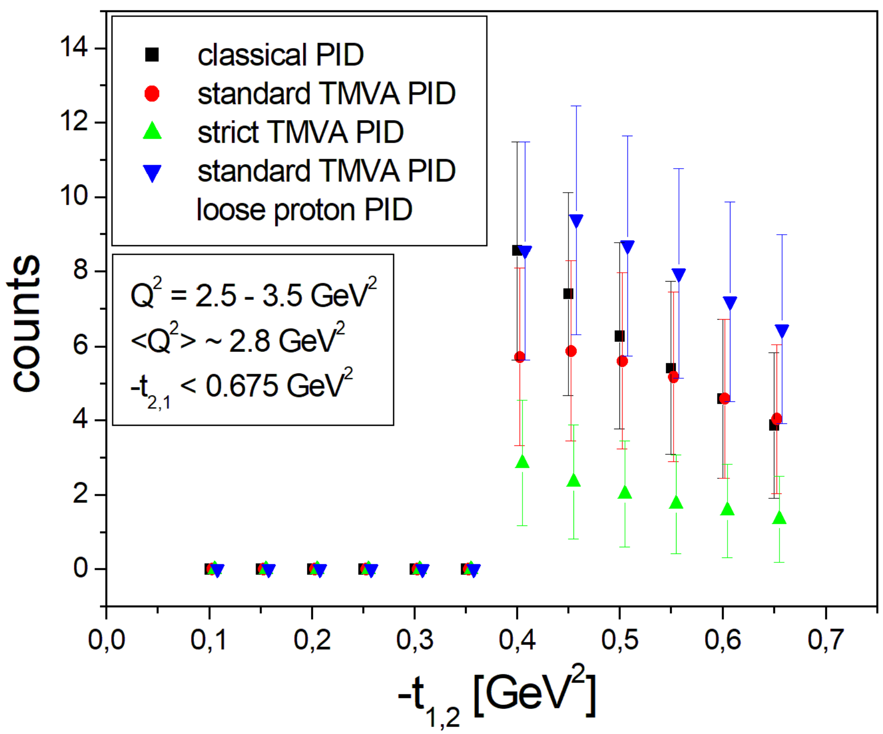
- L = 2 fb^{-1} → 1/2 year at the design luminosity

- Acceptance based on MC simulations (without a detected antiproton – topology 2)

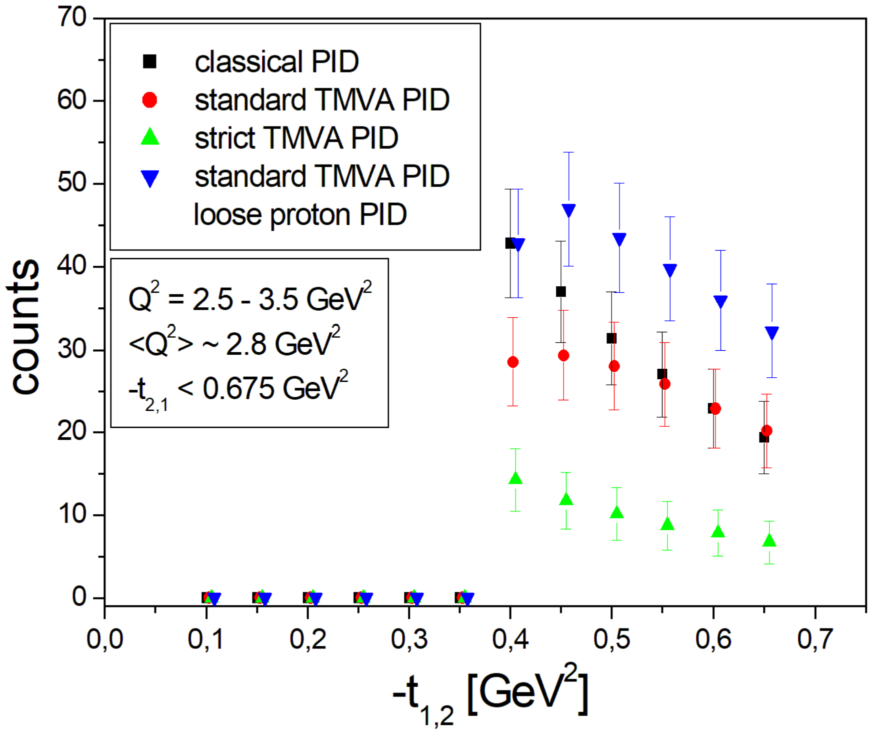
Rate estimate for s = 20 GeV²

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

L = 2 fb^{-1}



L = 10 fb^{-1}

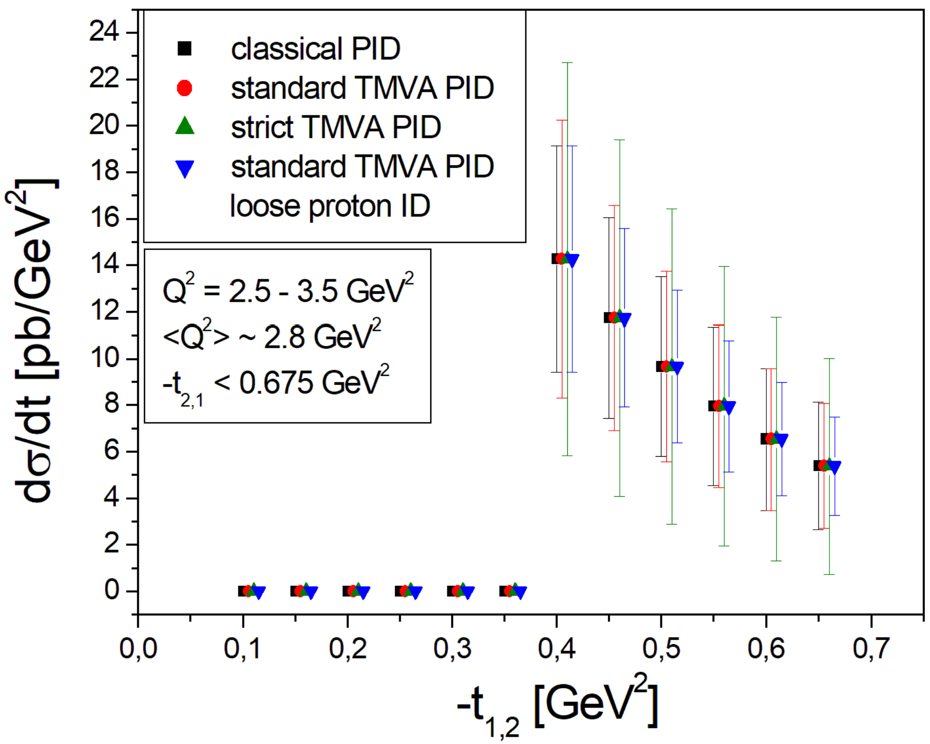


Q² > 1 GeV² ➔ ~ counts * 4

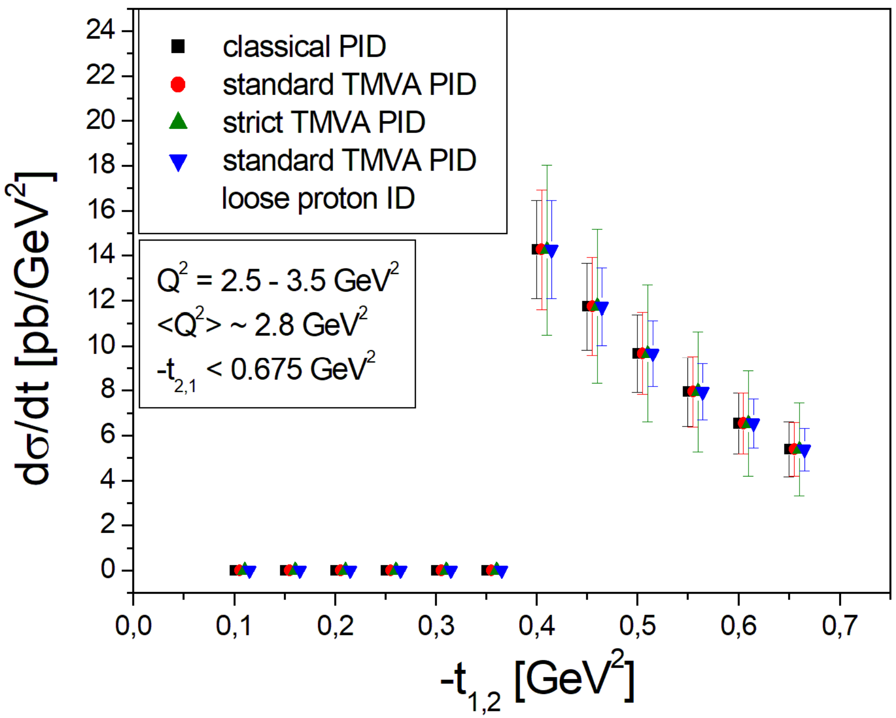
Rate estimate for s = 20 GeV²

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

L = 2 fb^{-1}

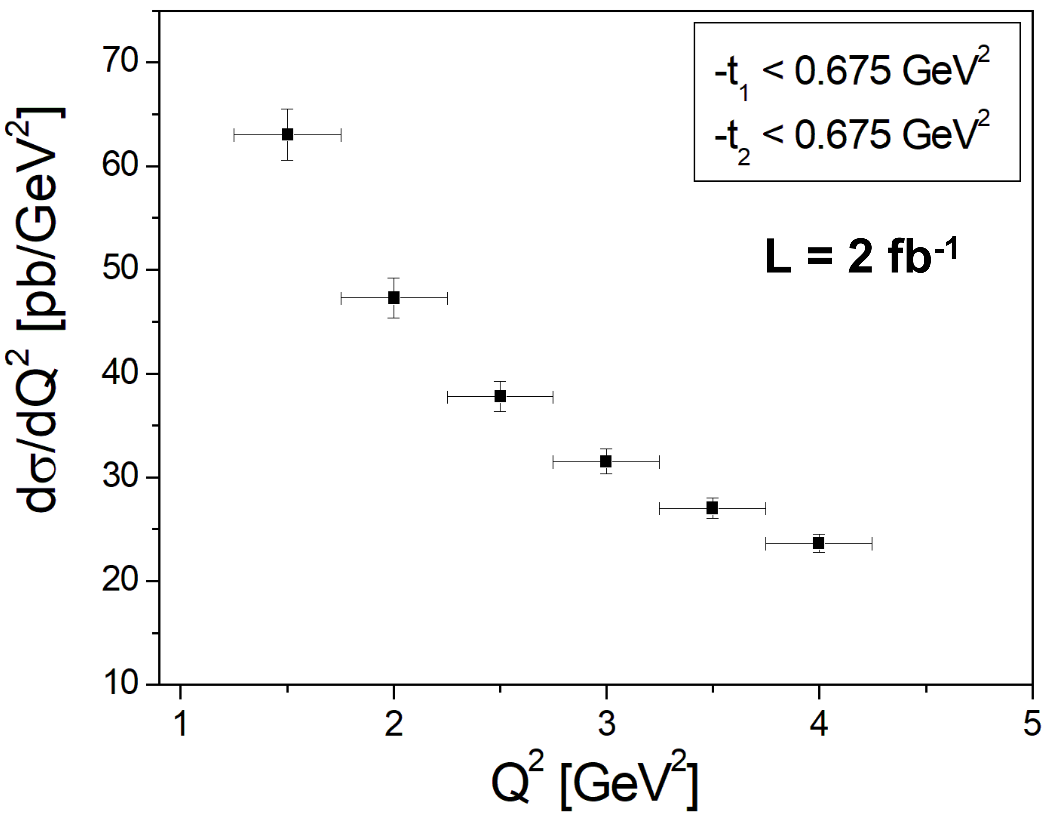


L = 10 fb^{-1}



Q^2 dependence at s = 20 GeV^2

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



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
- For μ^- / μ^+ more investigations are needed
- More MC data needs to be produced after the filters are working for the generator
- A stricter cut reduces the acceptance
  ➔ More integrated luminosity is needed for a reasonable uncertainty
- **A trade-off between background rejection and acceptance has to be found!**