

Feasibility studies for the
measurement of the time-like
electromagnetic form factors of the
proton with

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

Primary Studies

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Outline

- Motivation
- Primary Studies
- Summary and Outlook

Motivation

***Measurement of the time-like em form factors of the proton
with***

$$\bar{p}p \rightarrow l^+ l^- \quad l = e, \mu, \tau$$

- ***Each channel contains all necessary information of the structure of the nucleon***
- ***So far a lot of studies are under going for $\bar{p}p \rightarrow e^+ e^-$***
- ***Electrons are better distinguishable from strong pionic background than muons***
- ***Muonic channel : Good opportunity to crosscheck the results from electronic channel***

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

Primary Studies

- **Comparison of the Integrated Cross Section (including lepton rest mass)¹ with cross section² neglecting the rest mass of the electron for**

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

- **Comparison of the Integrated Cross Sections derived by 1) and 2) for**

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

- How does the polar production angle of the produced lepton depend on the particles energy in lab frame?
- **Studies of the kinematical aspects:**

Event Generator (ROOT Class „TGenPhaseSpace“) with constant cross section

Development of a first Event Generator following the realistic cross section derived by J. Van de Wiele

1) *Cross section derived by J. Van de Wiele (June 2011)*

2) *Cross section derived by A. Zichichi, S.M. Berman, N. Cabibbo, R. Gatto (1962)*

Differential and Integrated Cross Section in *CMS*

$$\bar{p}p \rightarrow l^+ l^- \quad l = e, \mu, \tau$$

$$\hbar = c = 1$$

$$\frac{d\sigma}{d \cos \theta_{CM \text{ vdw}}} (s, \theta) = \frac{\alpha^2 \pi}{2 \cdot s} \cdot \frac{p_{l^-}}{\bar{p}} \cdot |G_M|^2 \left[\frac{4M_p^2}{s} (1 - \beta^2 \cos^2 \theta_{CM}) \cdot R^2 + \left(1 + \frac{4m_l^2}{s} + \beta^2 \cos^2 \theta_{CM} \right) \right]$$

*J. Van de Wiele
(June 2011)*

$$R = \frac{|G_E|}{|G_M|}$$

$$\sigma_{vdW}(s) = \int_0^{2\pi} d\varphi \int_0^\pi d\theta \cdot \sin \theta \cdot \frac{d\sigma}{d\Omega_{vdW}} (s, \theta)$$

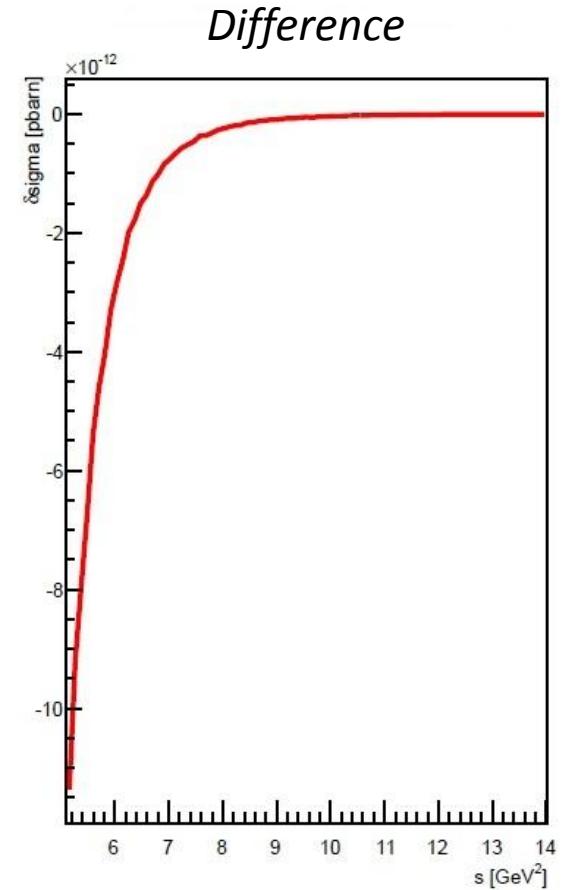
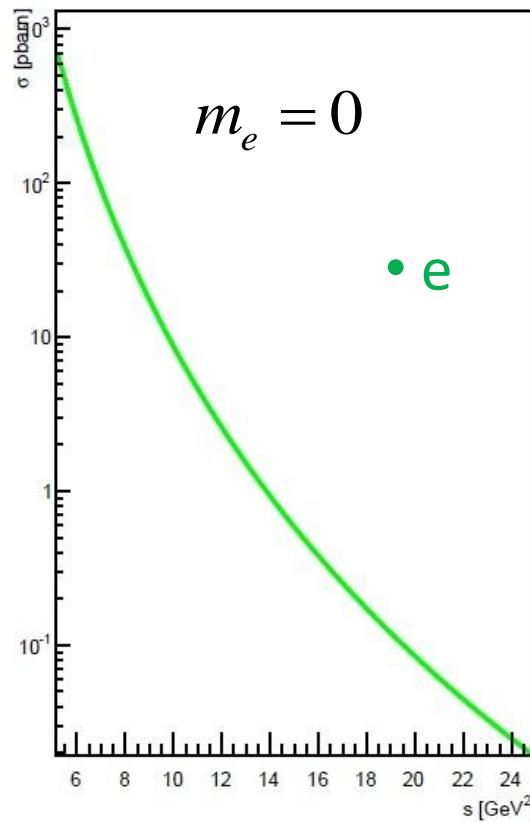
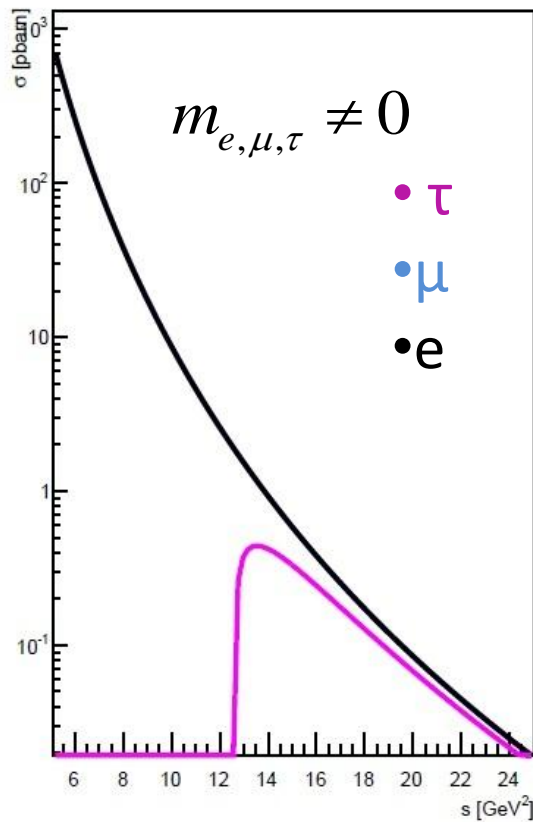
$$|G_M| = 22.5 \cdot \left(1 + \frac{s}{0.71} \right)^{-2} \cdot \left(1 + \frac{s}{3.6} \right)^{-1} \quad \text{in } \left(\frac{\text{GeV}}{c} \right)^2$$

$$\sigma_{vdW}(s) = \frac{\alpha^2 \pi}{s} \cdot \frac{p_{l^-}}{\bar{p}} \cdot |G_M|^2 \left[\frac{4M_p^2}{s} \left(1 - \frac{1}{3} \beta^2 \right) \cdot R^2 + \left(1 + \frac{4m_l^2}{s} + \frac{1}{3} \beta^2 \right) \right]$$

Comparison of the Integrated Cross Section neglecting/including electron rest mass

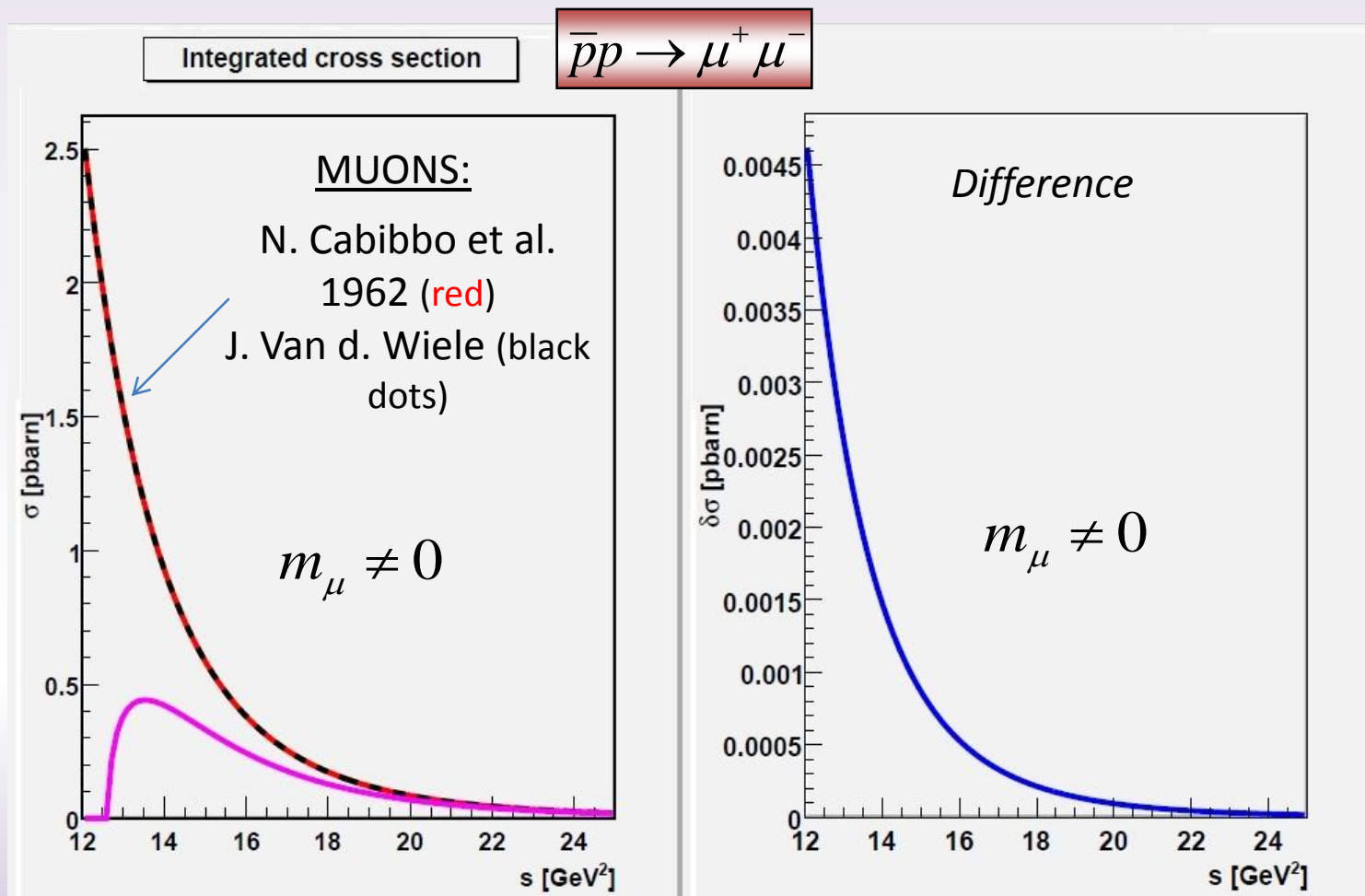
$$R = 1$$

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



Comparison of the Integrated Cross Section formulas (N. Cabibbo et al. vs. J. Van de Wiele)

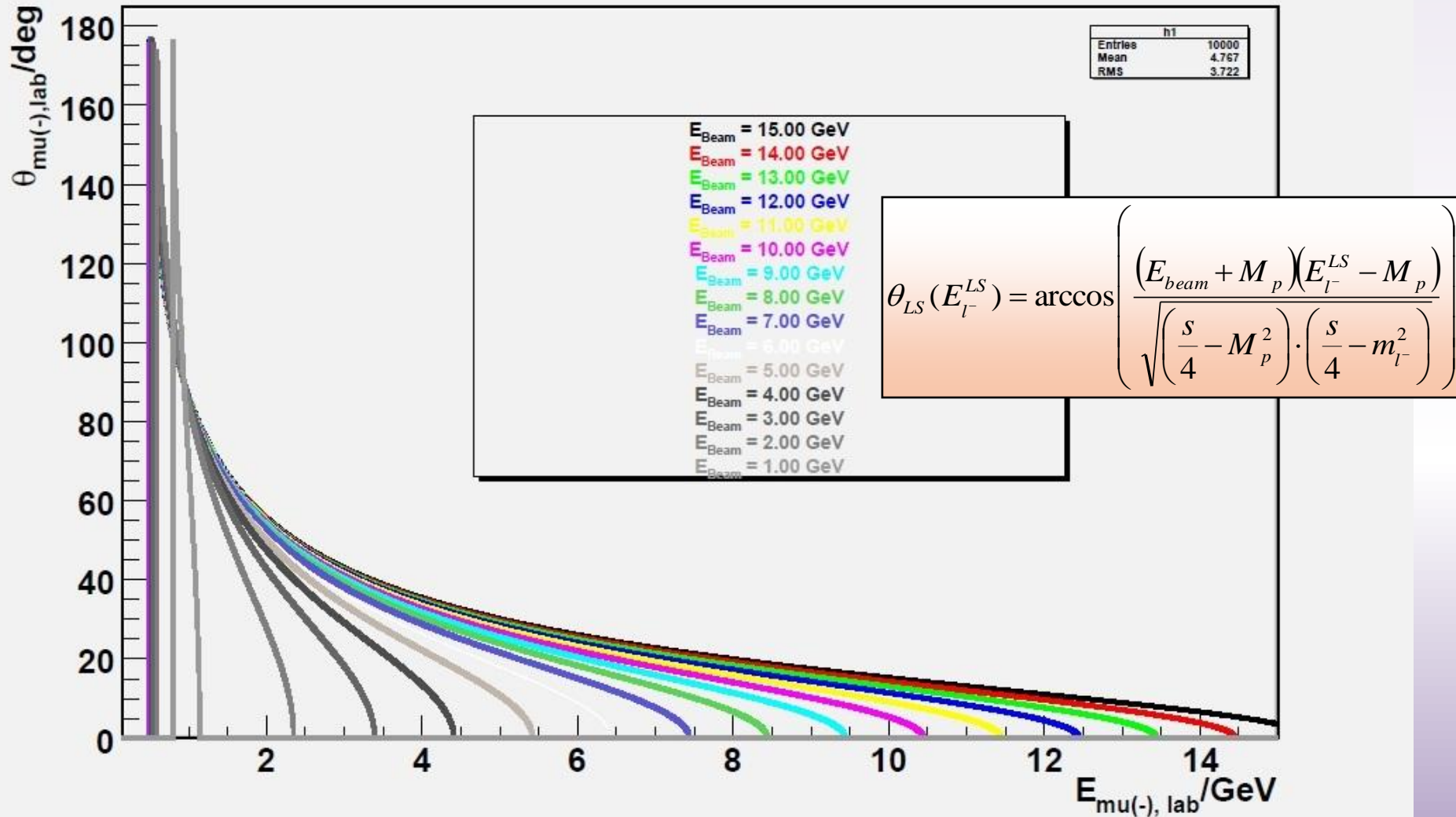
$$R = 1$$



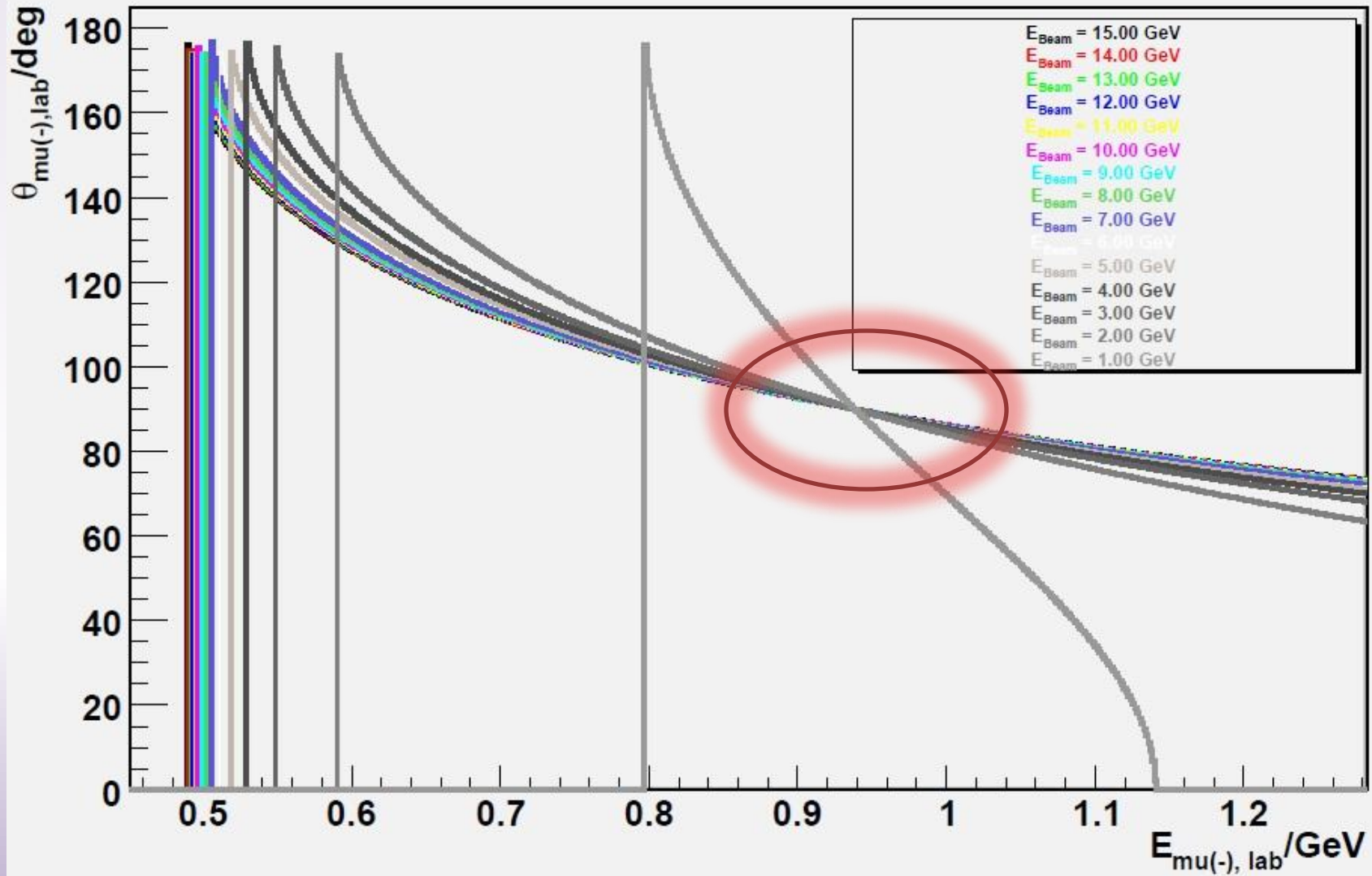
N. Cabibbo et al.: „... we give the exact expression (not neglecting the muon mass) ...“
(A. Zichichi, S.M. Berman, N. Cabibbo, R. Gatto, Nuovo Cimento **170** (1962).

Muon polar production angle

- Polar angle of the produced muon as a function of its energy in lab frame
- Parameter: Beam momentum



Polar production angle of the muon



Kinematical Studies with simple Event Generator (ROOT class „TGenPhaseSpace“)

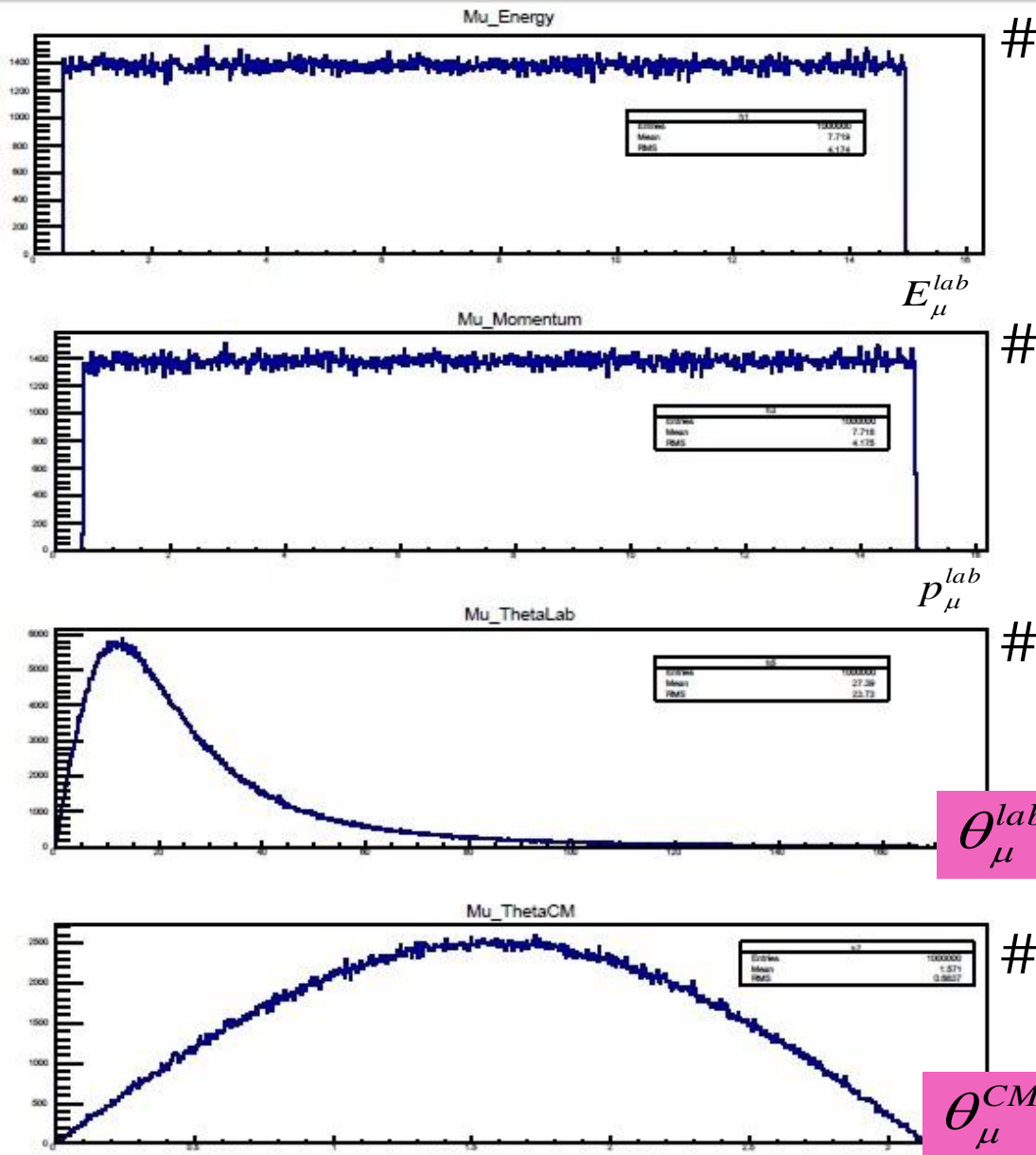
10^6 events

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

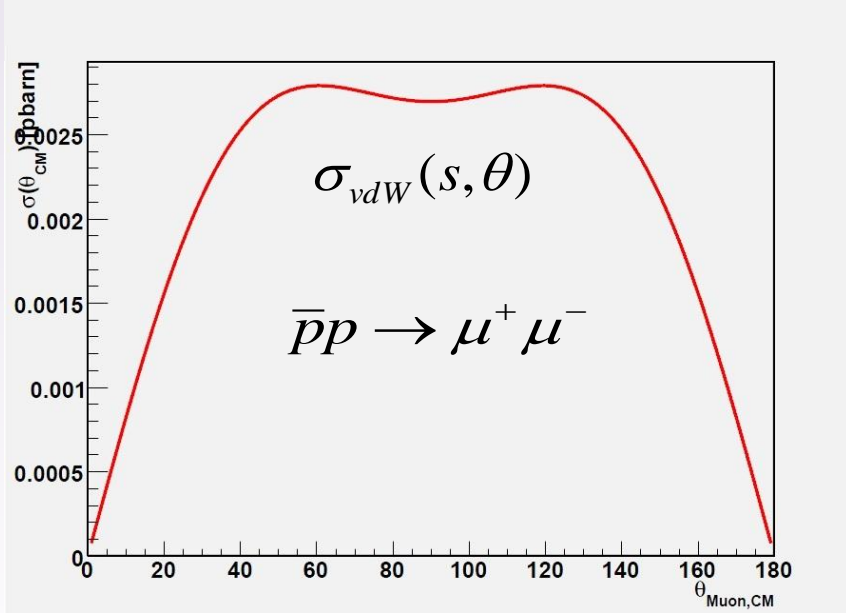
$$p_{\bar{p}} = 14.5 \text{ GeV}$$

ROOT Event Generator
using the class
„TGenPhaseSpace“:

Generation of two-body
events
with constant Cross
Section

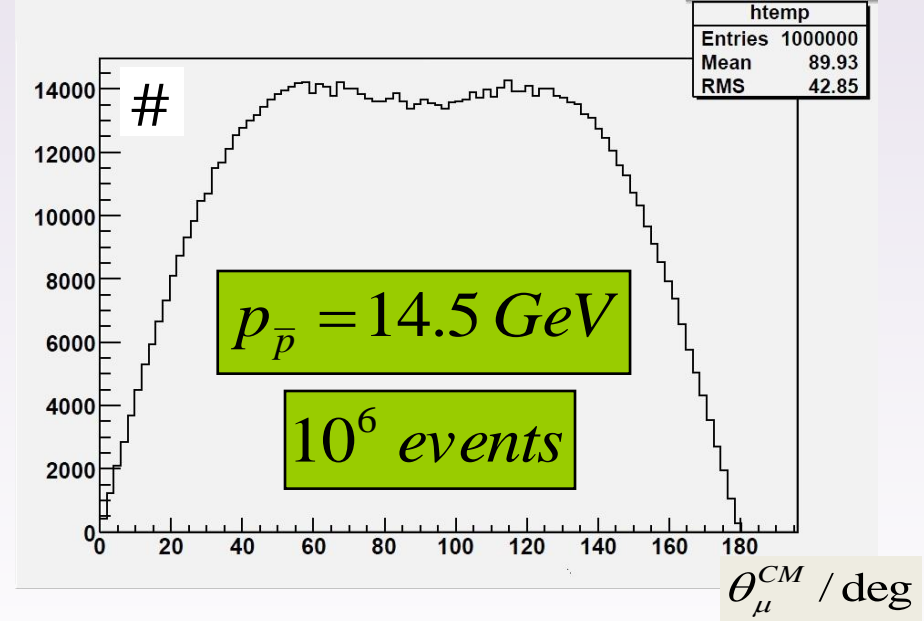


First Study for an Event Generator for muon production



$$\sigma_{vdW}(s, \theta) = \int_0^{2\pi} d\varphi \int_0^{\theta} d\theta' \cdot \sin \theta' \cdot \frac{d\sigma}{d\Omega_{vdW}}(s, \theta')$$

Finding the primitive of the Differential Cross Section regarding the polar angle

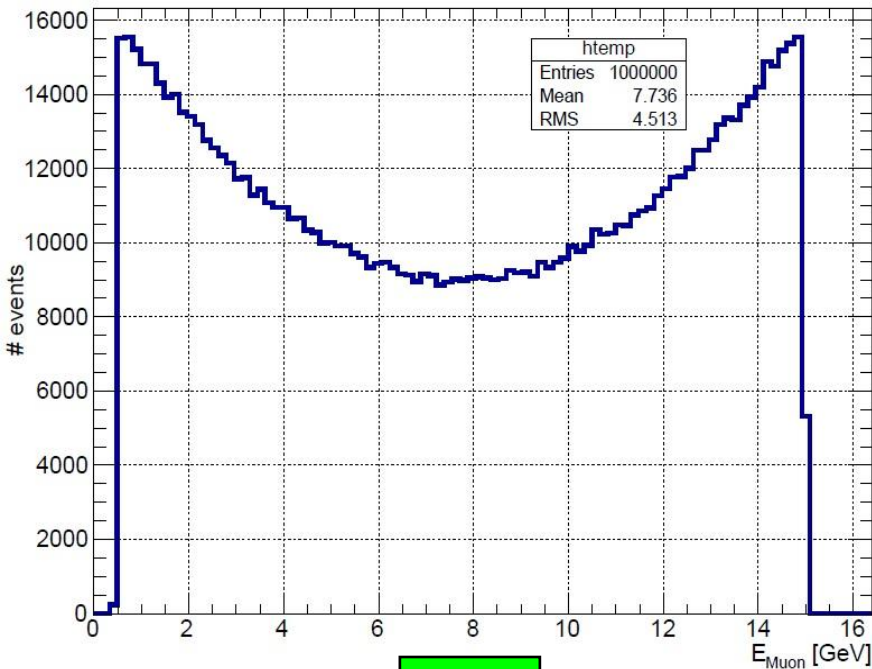


Distribution of the polar production angle of the muon in CM-System

Event Generator follows the **realistic cross section** of lepton production.

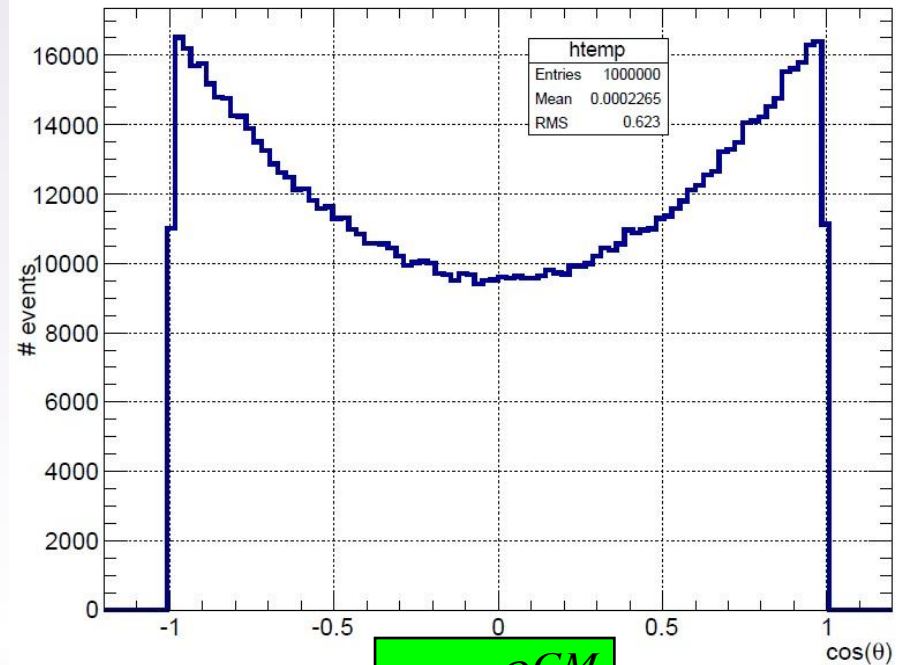
All physical quantities of interest can be derived from the angular distribution.

Distributions of angle and muon energy of the produced muons for 10^6 events



E_{μ}^{lab}

#



$\cos \theta_{\mu}^{CM}$

#

$$p_{\bar{p}} = 14.5 \text{ GeV}$$

The same distributions can be received for the anti-particle $\mu(+)$.

Summary and Outlook

- **Cross sections for the annihilation reaction**

$$\bar{p}p \rightarrow l^+l^- \quad l = e, \mu$$

show good agreement in case of electrons and muons especially in case of high energies.

- **Kinematical studies** of the muonic channel have been done with both constant and real cross section

- *Implementation of an **Event Generator for muons** (M. Zambrana) into PANDARoot:*

Simulation and Analysis of the processes of interest

- *Important background processes mostly caused by pion production have to be simulated*
- *Background separation possible? (Separation of pion and muon processes can be a challenge due to the similar rest masses)*
- *First simulations of pion production are under going*