Study of the $\Sigma^+\pi^-$ Invariant Mass spectrum with the KLOE detector by AMADEUS
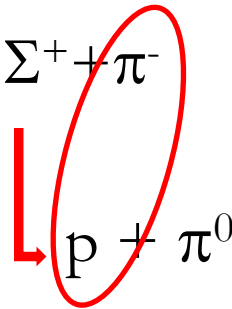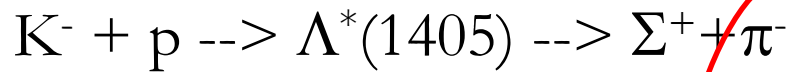
A. Scordo

"Advanced studies in the low-energy QCD in the strangeness sector and possible implications in astrophysics"
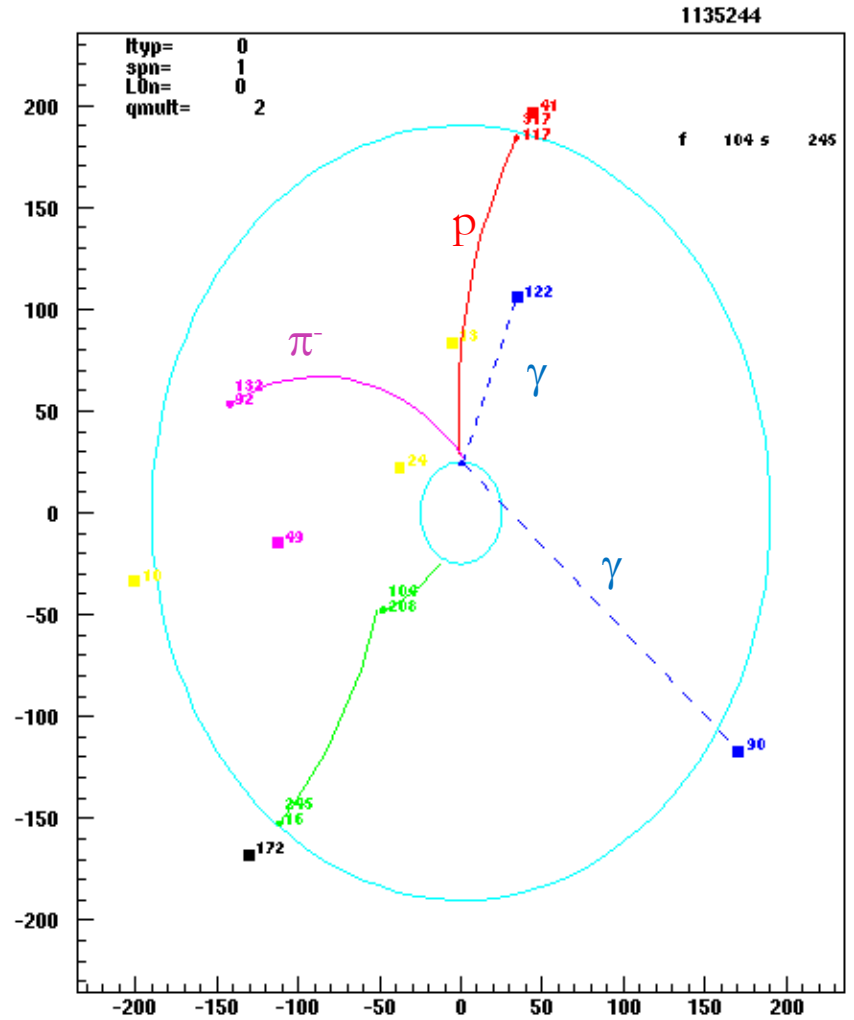
19-21 June 2013, Laboratori Nazionali di Frascati INFN

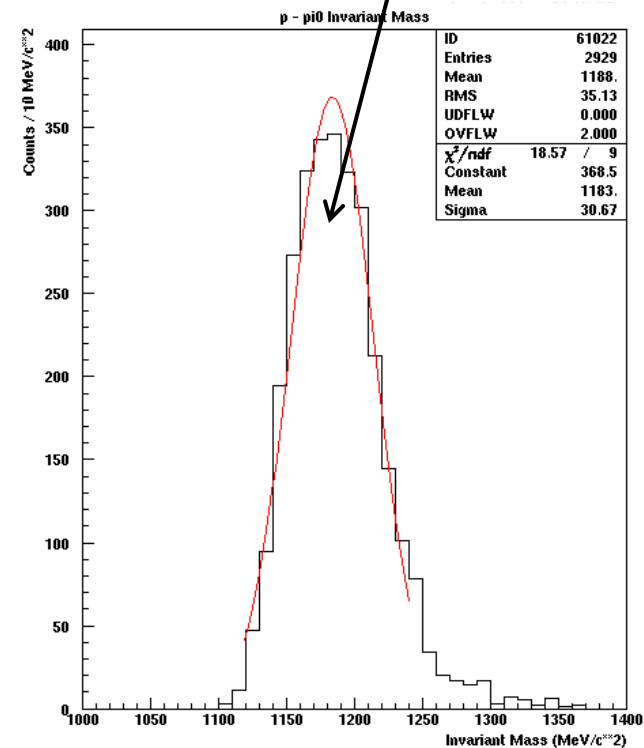# Studied channel

- What are we looking for:

$$K^- + p \longrightarrow \Lambda^*(1405) \longrightarrow \Sigma^+ + \pi^-$$
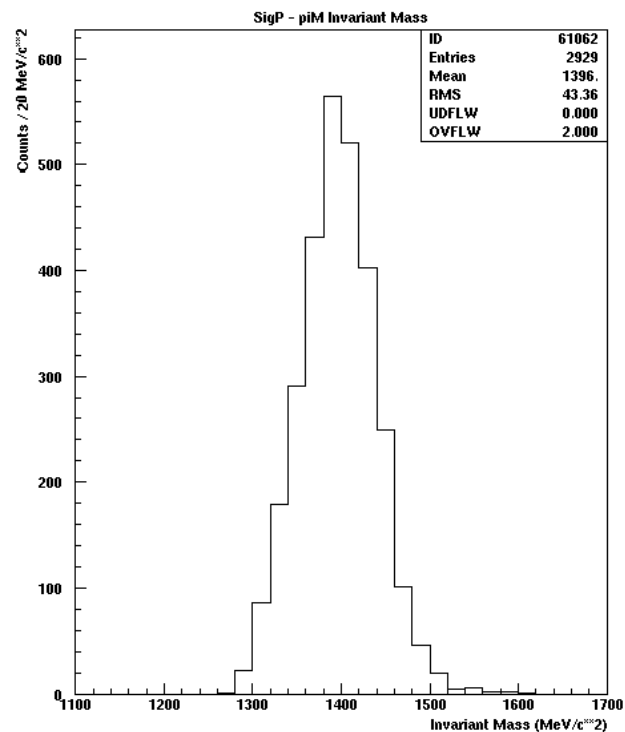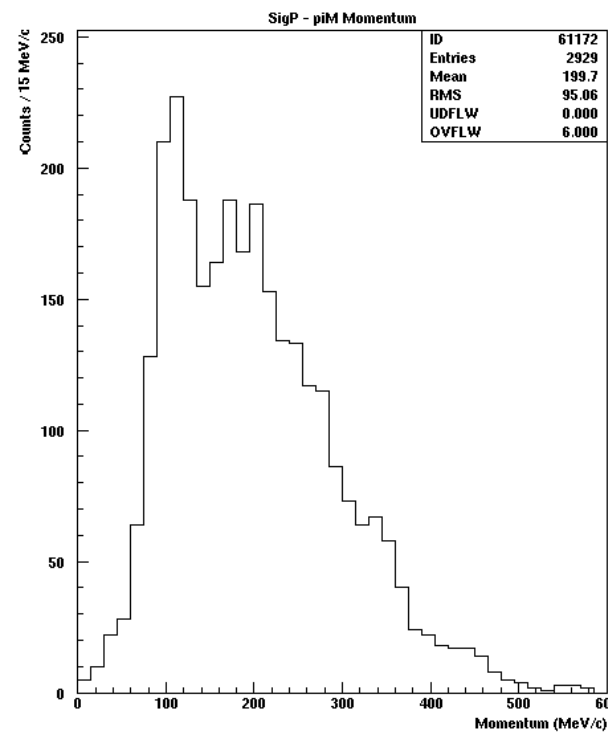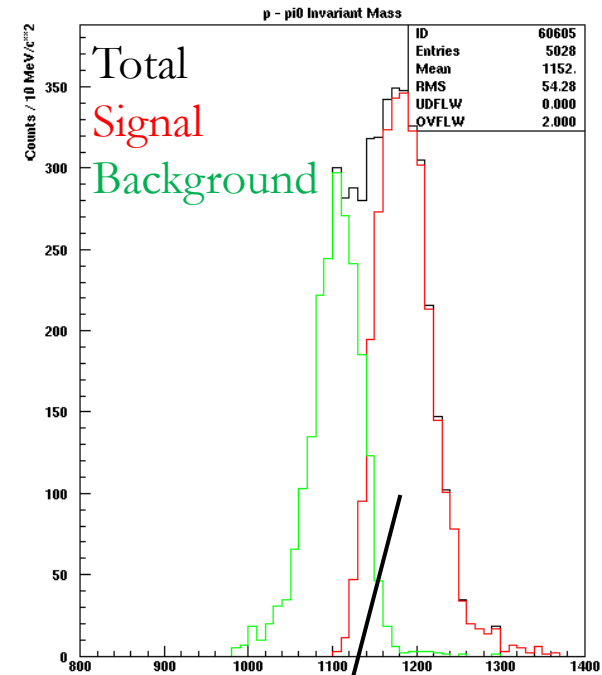$$\hookrightarrow p + \pi^0$$

Since the Σ^+ almost immediately decays, p and π^- are associated to the same vertex

Previous results

- Standard KLOE vertices and variables
- Signal / Background separation
- Internal Conversion Hypothesys
- Final $\Sigma^+\pi^-$ spectra with 2929 events in DC Wall
- 2 momentum components as in $\Sigma^0\pi^0$

What's new

A new (more accurate) analysis has been performed, leading to

1. Improved statistics and hadronic background rejection
2. Confirmation of internal conversion hypothesis
3. Deeper comprehension of the involved processes (in-flight, at-rest, resonant, non-resonant, ecc…)
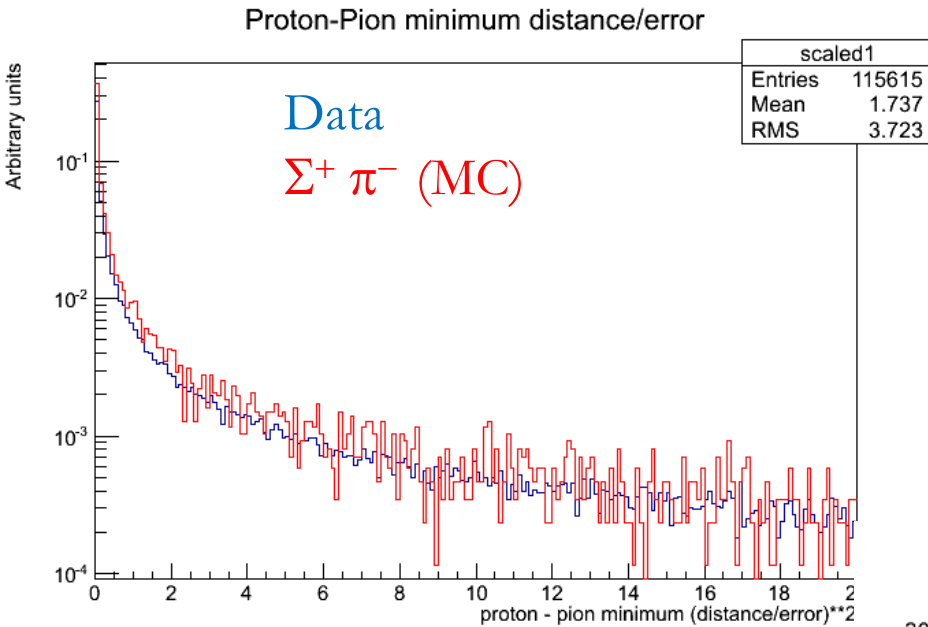4. Carbon Target 2012 data preliminary analysis

In this talk the analysis procedure and the major improvements are presented; for further details wait for I. Tucakovic's talk !!!!

New analysis

In the new analysis, the good event selection is done, for each event, via the following steps:

1. Search for the best 4 $p\,\pi^-$ couples in terms of distance at PCA
2. Search, for each selected couple, of 2 γ in time from the PCA and selecting the 4 best π^0 in terms of χ^2_t and χ^2_m
3. For each of the 16 possible $p\,\pi^0$ couples, the χ^2_m on the Σ^+ mass is calculated
4. The final triplet is chosen via the minimization of the 3 χ^2
5. $\Lambda(1116)$ are rejected using the $p\,\pi^-$ CM momentum
6. Signal and background separation
7. Study of the background
8. Internal conversion hypothesis

1) p π⁻ vertex reconstruction

Proton-Pion minimum distance/error

Data

$\Sigma^+ \pi^-$ (MC)

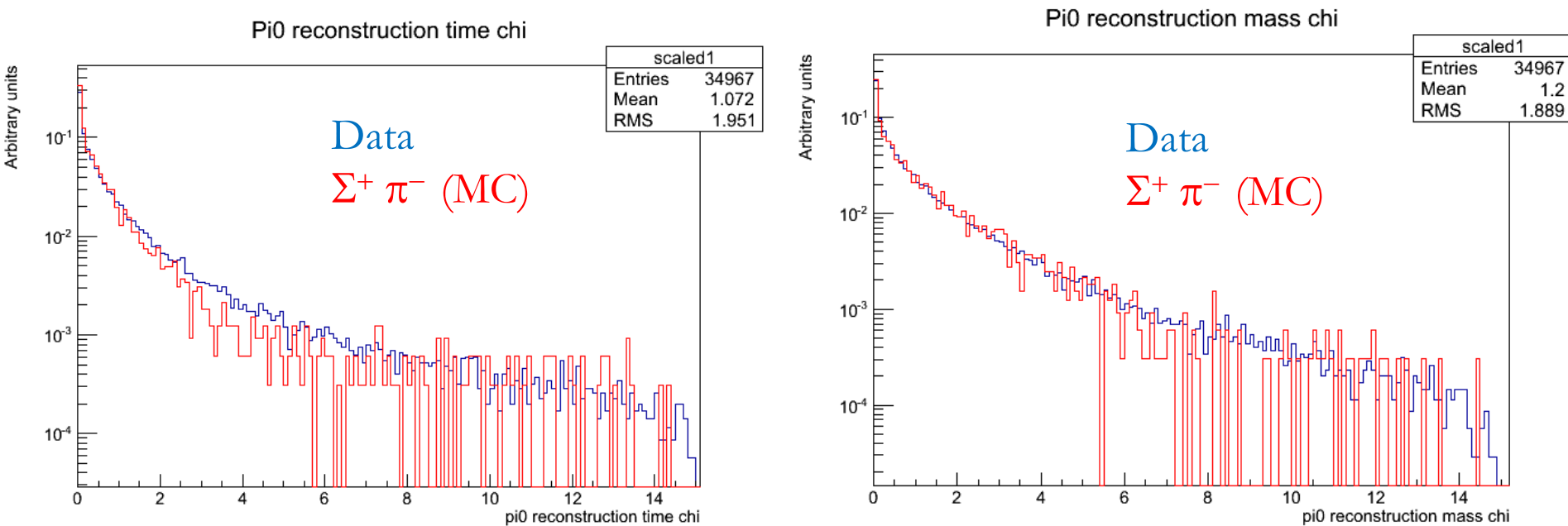| scaled1	
Entries	115615
Mean	1.737
RMS	3.723

proton - pion minimum (distance/error)**2

For each event, the best 4 p-π⁻ couples are selected using a procedure searching for the point of minimum distance between the tracks (PCA).

A cut value is chosen via an estimation of the S/B value in the XY vertex position plot.

Vertex radial position

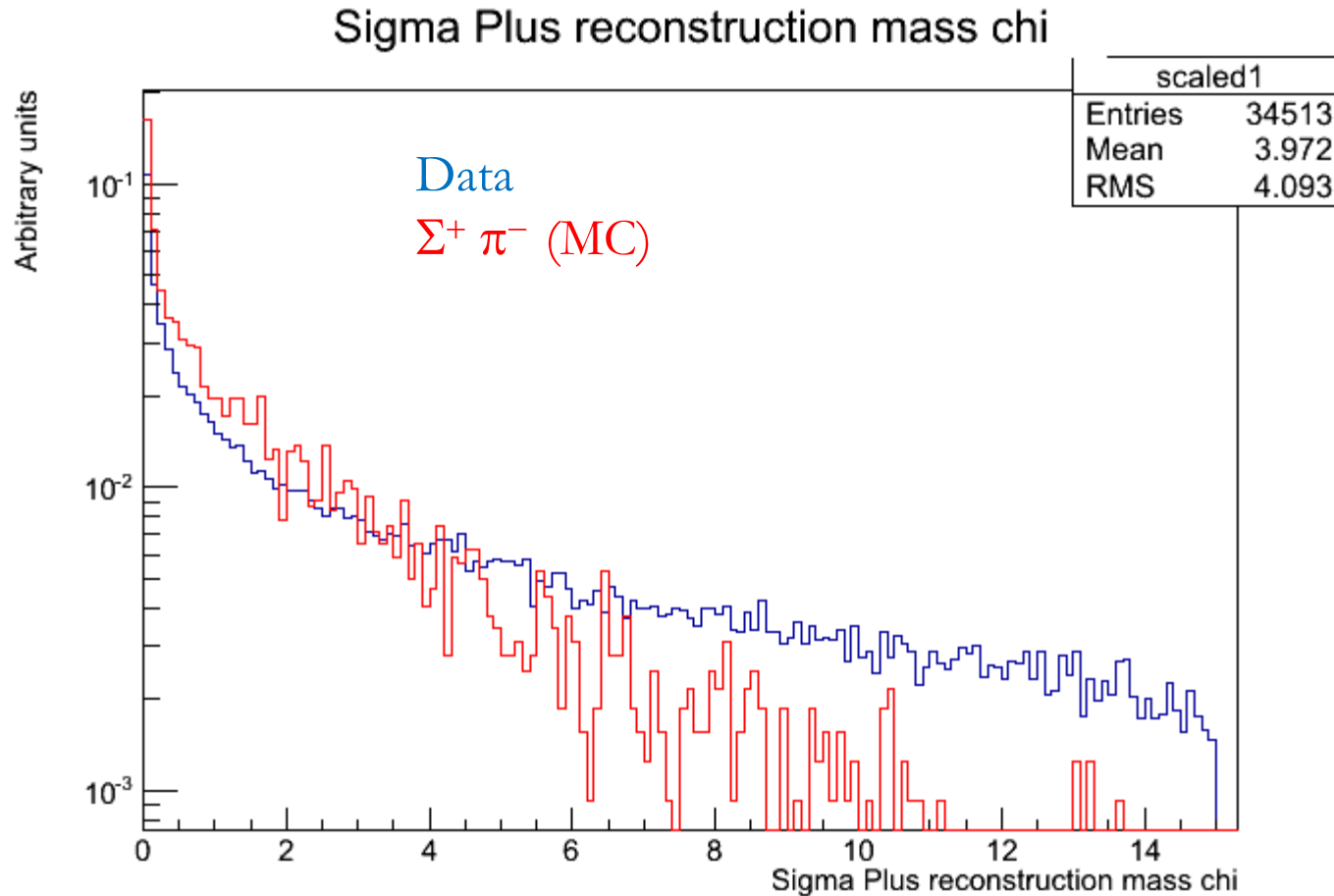| rho	
Entries	58755
Mean	19.06
RMS	7.825
χ² / ndf	849.2 / 56
p0	1048 ± 17.3
p1	9.692 ± 0.021
p2	1.429 ± 0.024
p3	2794 ± 27.6
p4	25.14 ± 0.01
p5	1.262 ± 0.011
p6	257.8 ± 3.3
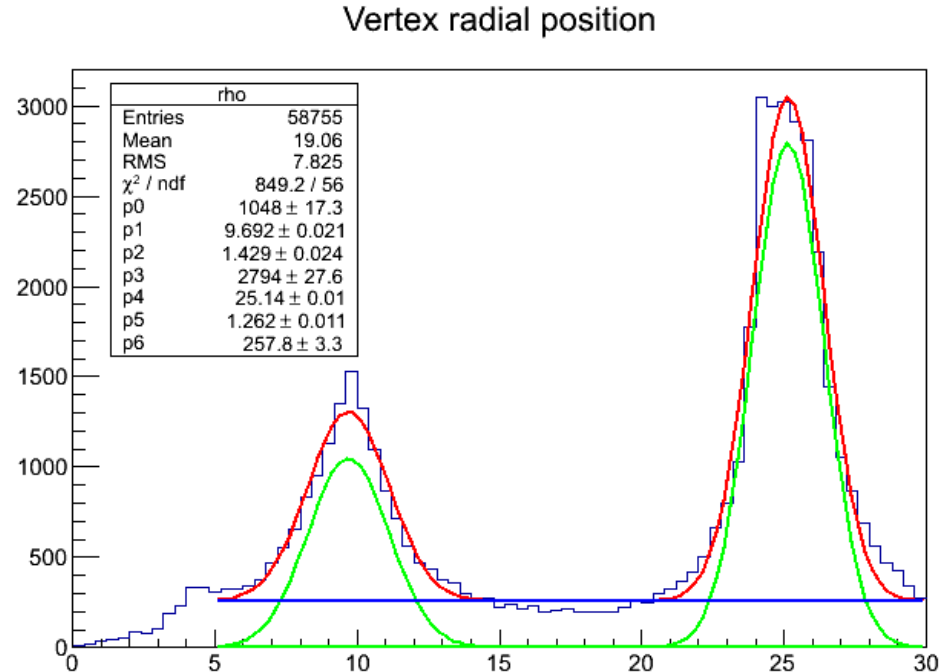
2) π^0 reconstruction

For each p π^- couple, the best 4 π^0 are searched looking for 2 photons in time from the PCA and minimizing a mass χ^2.

3) Σ^+ reconstruction

Sigma Plus reconstruction mass chi

Data

$\Sigma^+ \pi^-$ (MC)

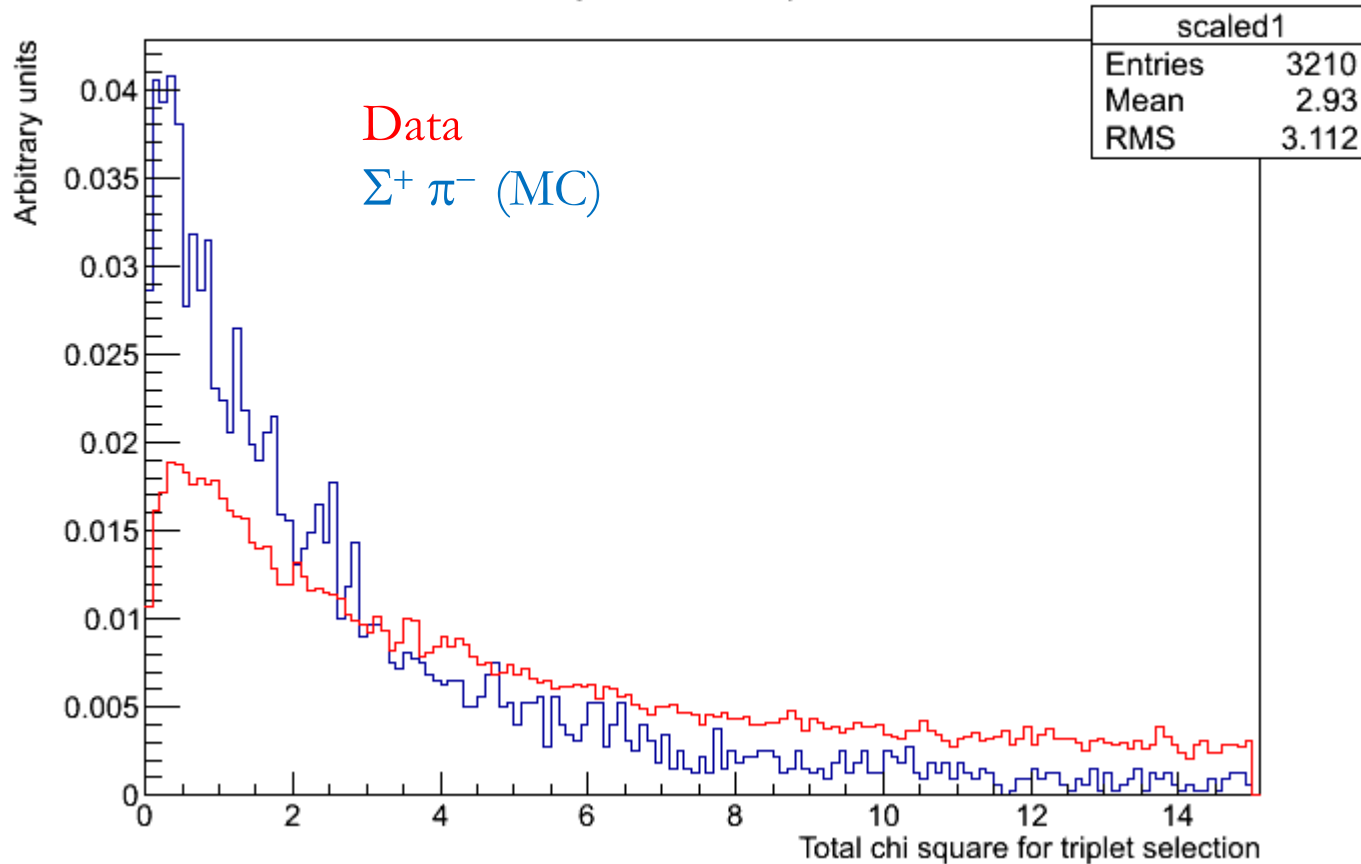| scaled1	
Entries	34513
Mean	3.972
RMS	4.093

For each possible p-π^0 couple, the invariant mass is reconstructed and a mass χ^2 is calculated

4) Final triplets

Total chi square for triplet selection

| scaled1	
Entries	3210
Mean	2.93
RMS	3.112

Data

$\Sigma^+ \pi^-$ (MC)

For each event, the final (p π^- π^0) triplet is selected minimizing the quantity:

$$\chi^2 = \sqrt{(\chi_t^2(\pi^0))^2 + (\chi_m^2(\pi^0))^2 + (\chi_m^2(\Sigma^+))^2}$$

5) Excluding Λ1116

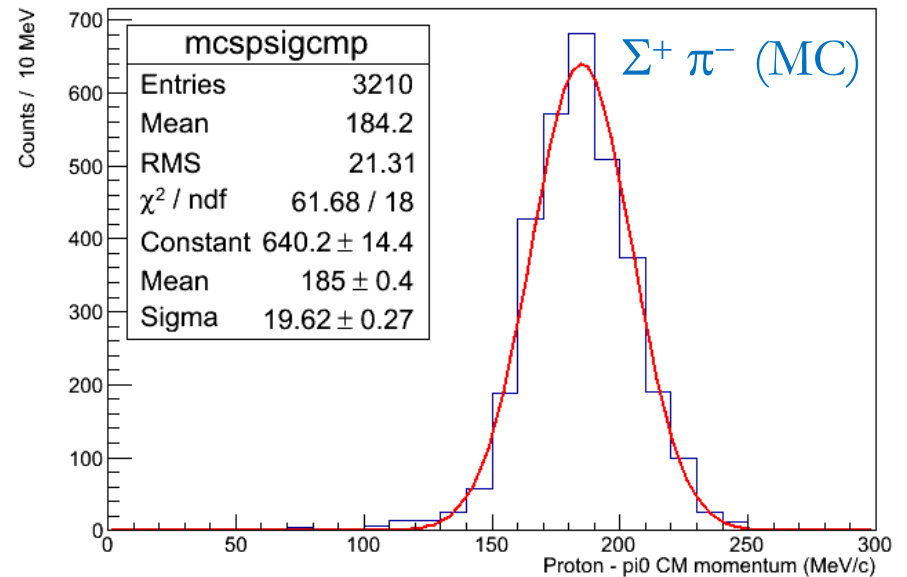| Interaction	First Output particles	Daughters particles	B. R.	Situation
$K^- p$	$\Lambda \pi^0$	$p \pi^- \pi^0$	64 %	Cut on Λ vertices
		$n \pi^0 \pi^0$	36 %	No $p\pi^-$ vertex
$K^- p$	$\Sigma^+ \pi^-$	$p \pi^0 \pi^-$	52 %	SIGNAL
		$n \pi^+ \pi^-$	48 %	No $p\pi^-$ vertex
$K^- p$	$\Sigma^0 \pi^0$	$\Lambda(p\pi^-) \gamma \pi^0$	64 %	Cut on Λ vertices
		$\Lambda(n\pi^0) \gamma \pi^0$	36 %	No $p\pi^-$ vertex
$K^- p$	$\Sigma^- \pi^+$	$n \pi^- \pi^+$	100 %	No $p\pi^-$ vertex
$K^- p$	Λ	$p \pi^-$	64 %	No $p\pi^0$ vertex
		$n \pi^0$	36 %	No $p\pi^-$ vertex
$K^- p$	Σ^0	$\Lambda(p\pi^-) \gamma$	64 %	No π^0
		$\Lambda(n\pi^0) \gamma$	36 %	No $p\pi^-$ vertex
$K^- n$	$\Lambda \pi^-$	$p \pi^- \pi^-$	64 %	No π^0
		$n \pi^0 \pi^-$	36 %	No $p\pi^-$ vertex
$K^- n$	$\Sigma^0 \pi^-$	$\Lambda(p\pi^-) \gamma \pi^-$	64 %	No π^0
		$\Lambda(n\pi^0) \gamma \pi^-$	36 %	No $p\pi^-$ vertex
$K^- n$	$\Sigma^- \pi^0$	$n \pi^- \pi^0$	100 %	No $p\pi^-$ vertex
$K^- n$	Σ^-	$n \pi^-$	100 %	No $p\pi^-$ vertex
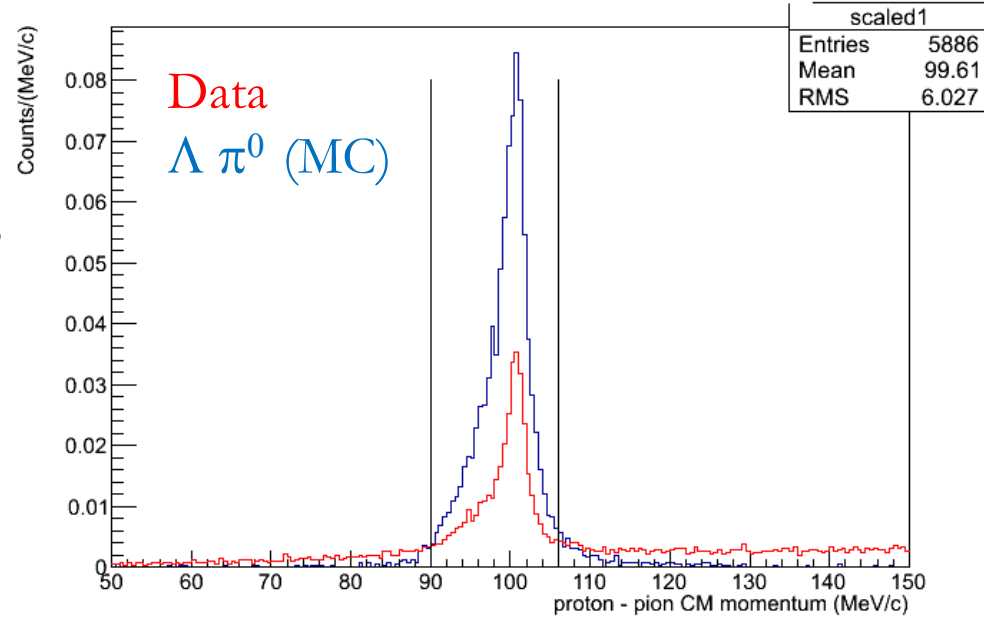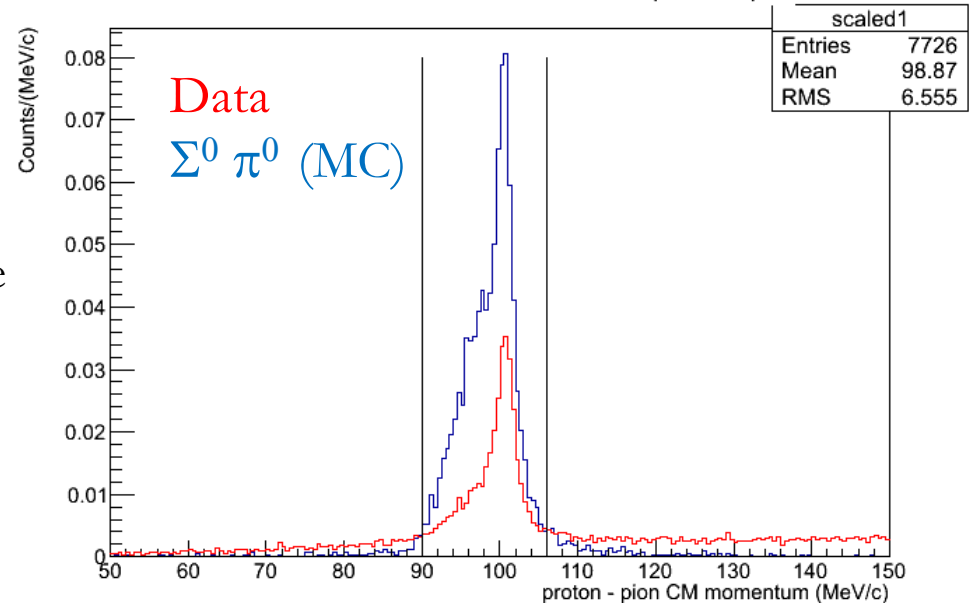
Principal hadronic background sources can be rejected setting a cut on the p-π⁻ CM momentum; the cut value is obtained from MC simulations.

6)Signal and Background identification

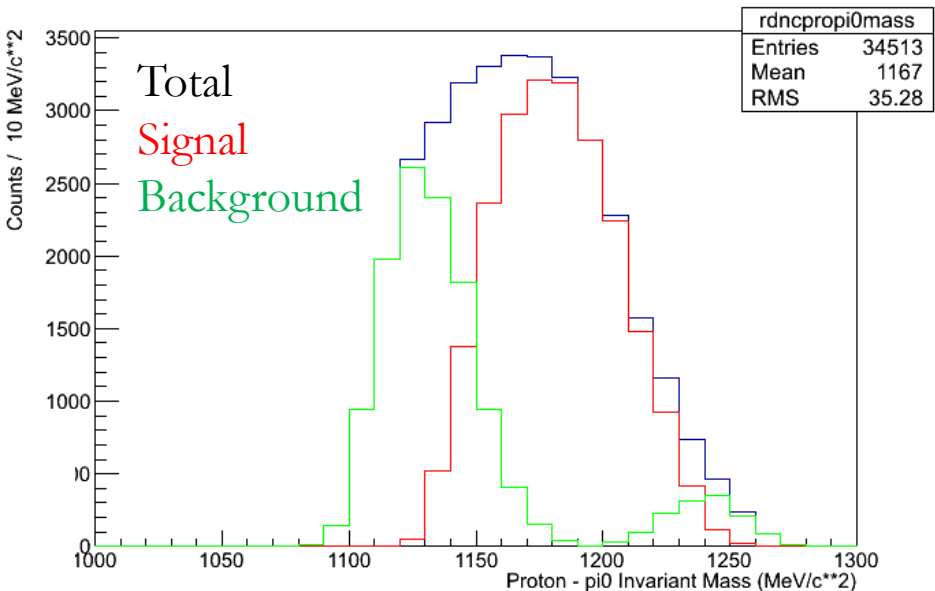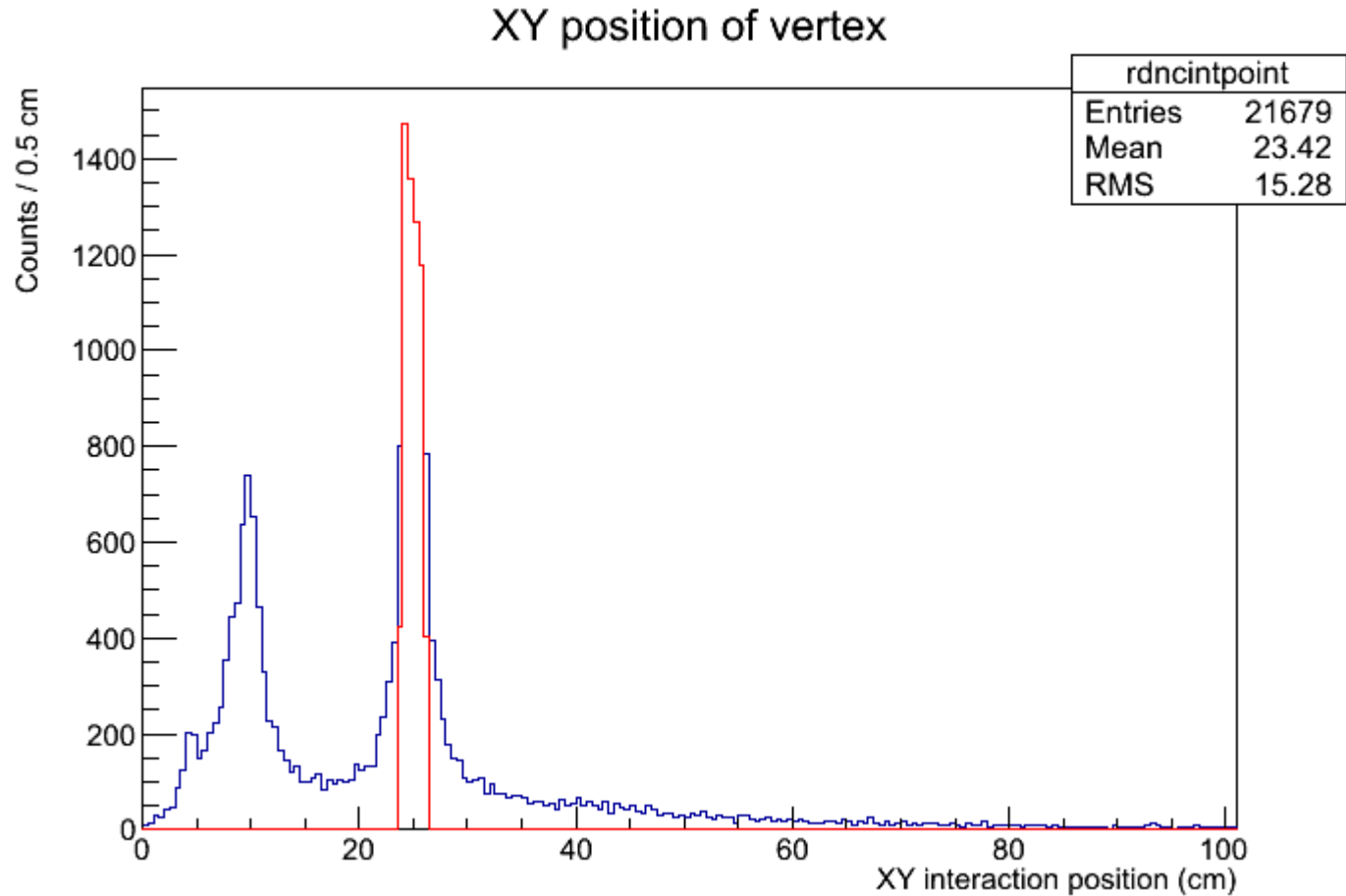proton-pi0 CM momentum

Data
$\Sigma^+ \pi^-$ (MC)

scaled1	
Entries	3210
Mean	184.2
RMS	21.31

proton-pi0 CM momentum

$\Sigma^+ \pi^-$ (MC)

mcspsigcmp	
Entries	3210
Mean	184.2
RMS	21.31
χ^2 / ndf	61.68 / 18
Constant	640.2 ± 14.4
Mean	185 ± 0.4
Sigma	19.62 ± 0.27

Proton-Pion Invariant Mass

Total
Signal
Background

rdncpropi0mass	
Entries	34513
Mean	1167
RMS	35.28
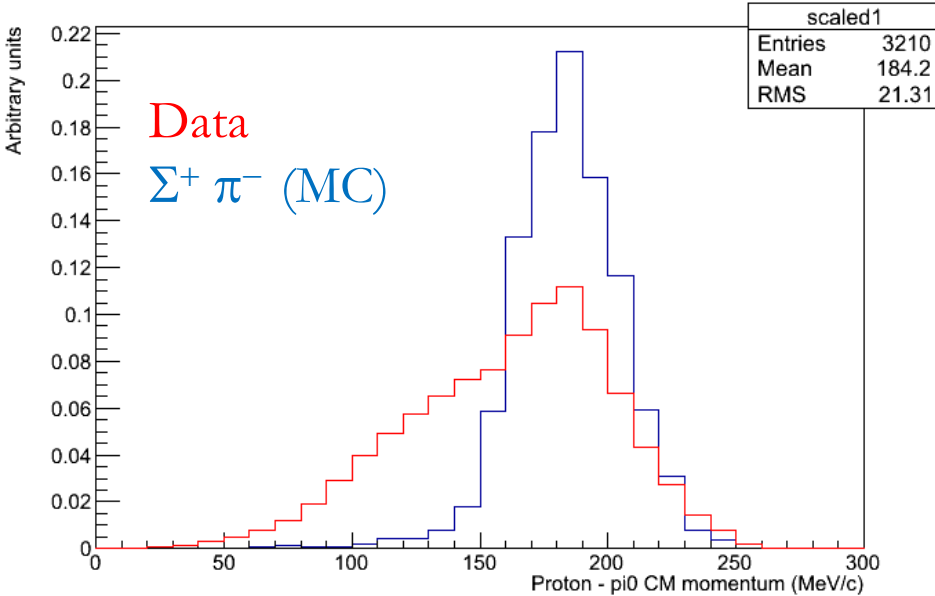
Signal and background components can be separated from the p-π^0 CM momentum.

In case of a real Σ^+, this momentum should be peaked at the nominal PDG value (189 MeV/c)
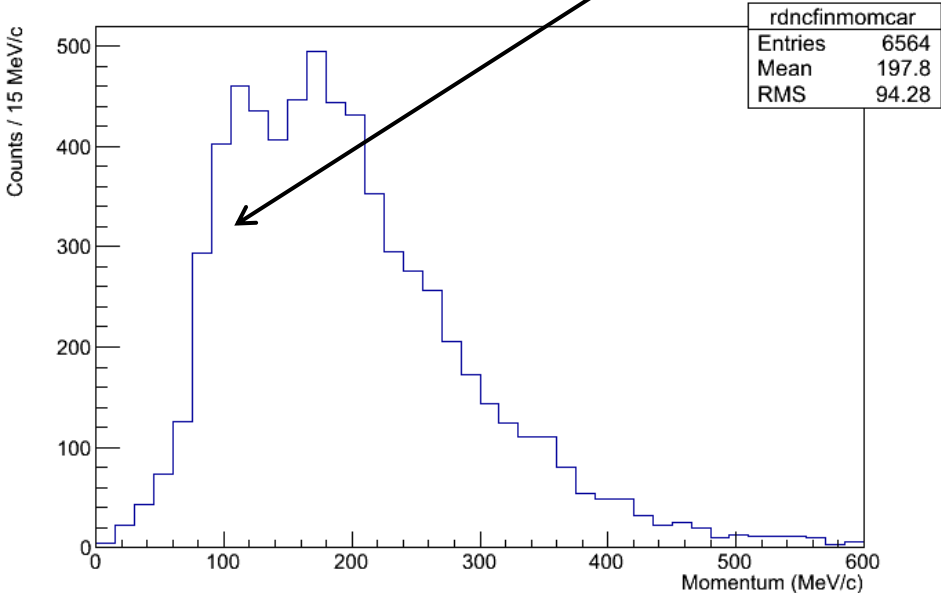
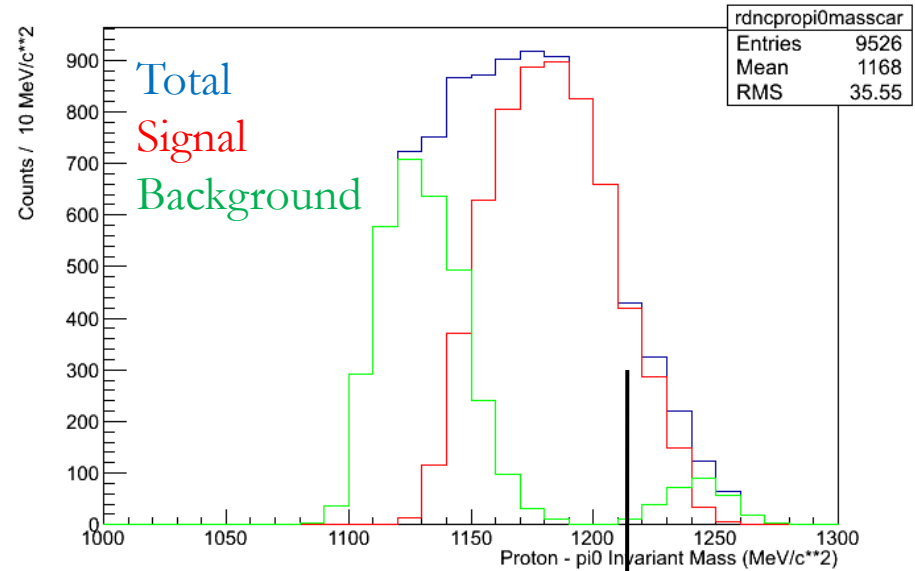# $\Sigma^+ \pi^-$ in DC Wall

New results: 6099 events in DC wall

- Statistics is improved of a factor 2 (and we can even go further…)

- Double structure in momentum spectrum is confirmed, but…

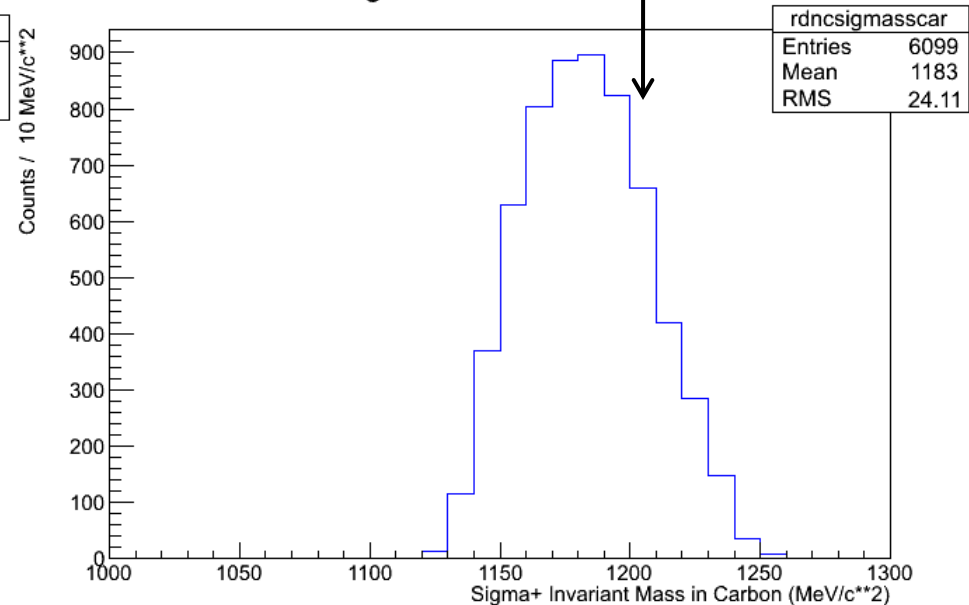NOW WE KNOW WHAT IT IS: Hydrogen! (see I. Tucakovic's talk)

Proton-Pion Invariant Mass in carbon

Total
Signal
Background

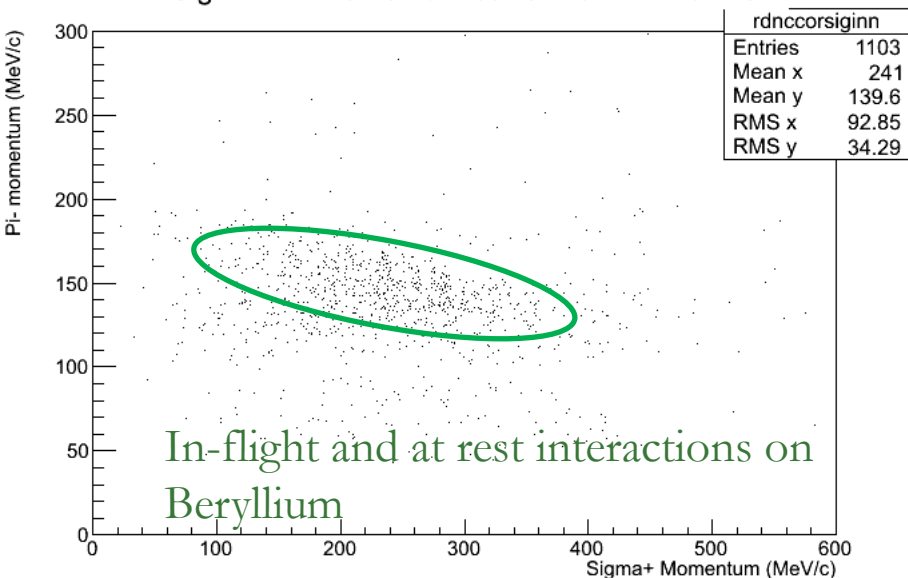| rdncpropi0masscar	
Entries	9526
Mean	1168
RMS	35.55

Proton - pi0 Invariant Mass (MeV/c**2)

SigP - PiM momentum in carbon

rdncfinmomcar	
Entries	6564
Mean	197.8
RMS	94.28

Momentum (MeV/c)

Sigma+ Invariant Mass

rdncsigmasscar	
Entries	6099
Mean	1183
RMS	24.11

Sigma+ Invariant Mass in Carbon (MeV/c**2)

$\Sigma^+ \pi^-$ momentum correlations

SigP - PiM momentum correlation in inner Be

rdnccorsiginn	
Entries	1103
Mean x	241
Mean y	139.6
RMS x	92.85
RMS y	34.29

In-flight and at rest interactions on Beryllium

SigP - PiM momentum correlation in beam sphere
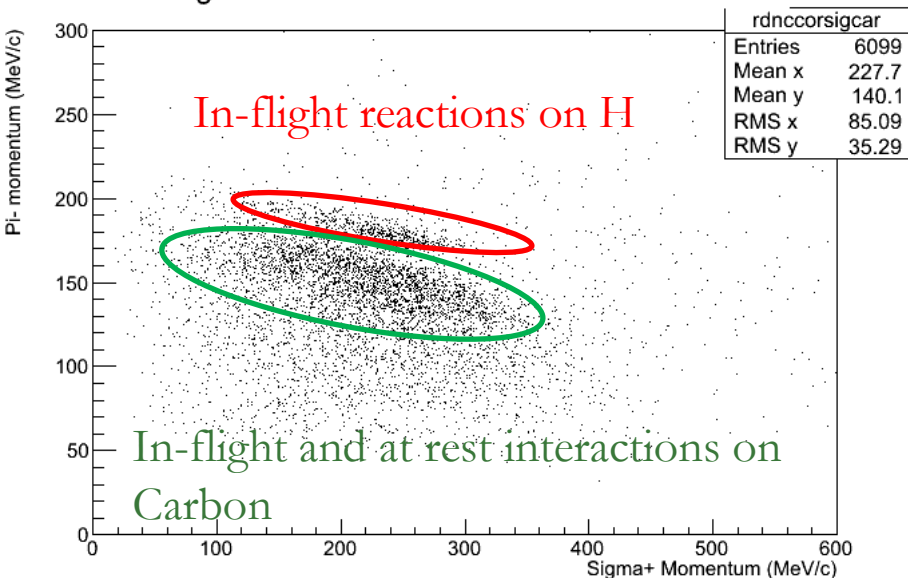
rdnccorsigsph	
Entries	5411
Mean x	236.5
Mean y	139.4
RMS x	91.52
RMS y	31.98

In-flight and at rest interactions on Aluminum and Beryllium

SigP - PiM momentum correlation in carbon

rdnccorsigcar	
Entries	6099
Mean x	227.7
Mean y	140.1
RMS x	85.09
RMS y	35.29

In-flight reactions on H

In-flight and at rest interactions on Carbon

SigP - PiM momentum correlation in DC gas
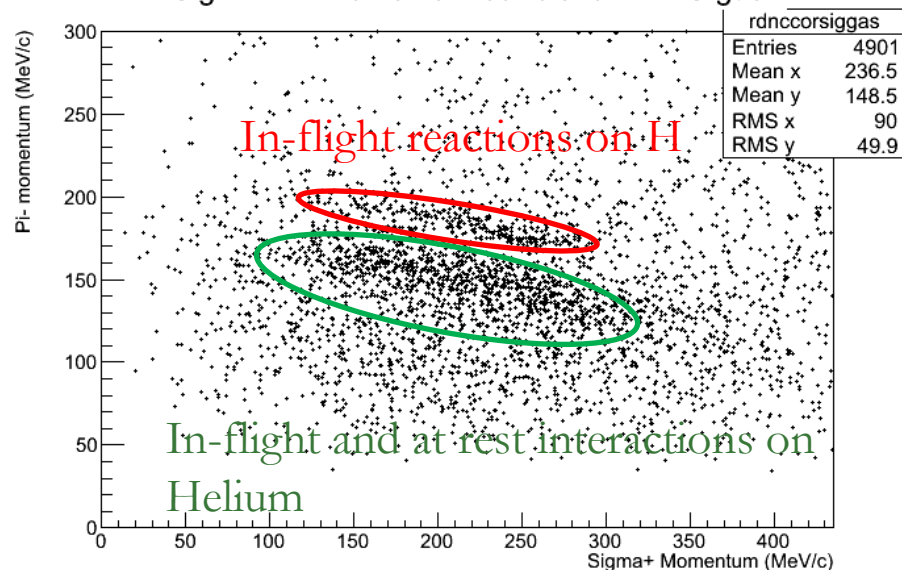
rdnccorsiggas	
Entries	4901
Mean x	236.5
Mean y	148.5
RMS x	90
RMS y	49.9

In-flight reactions on H
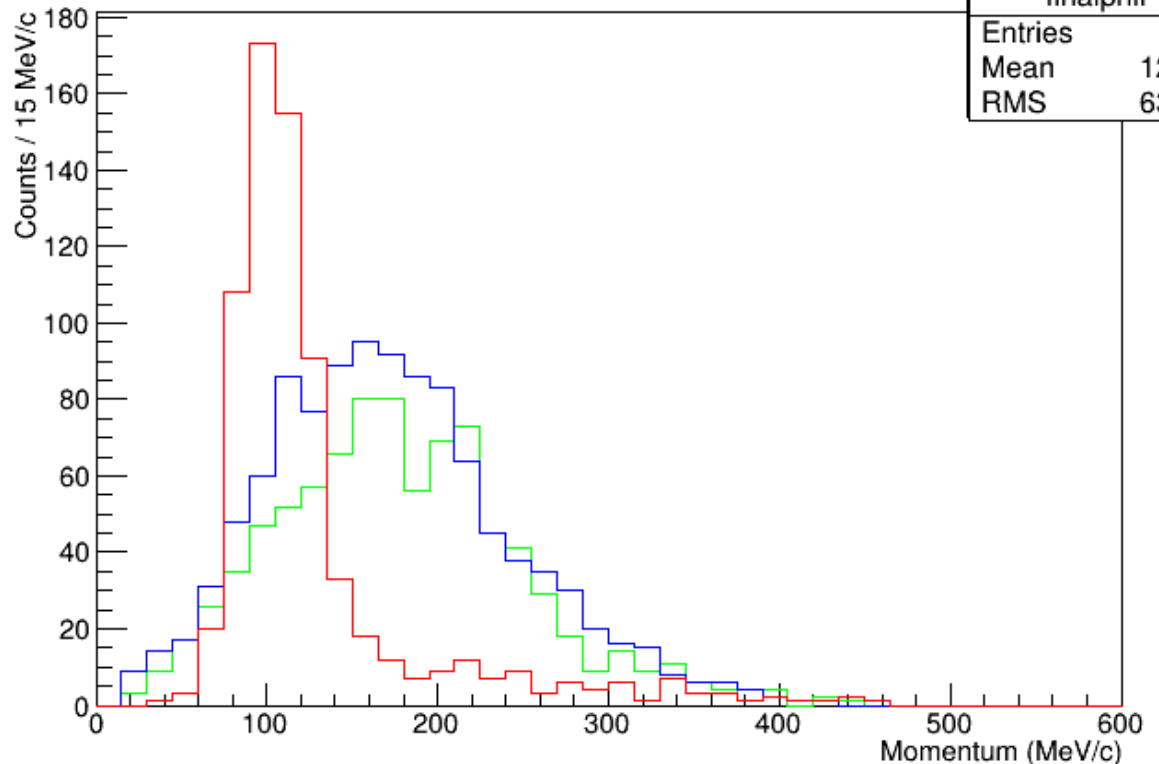
In-flight and at rest interactions on Helium

$\Sigma^+ \pi^-$ momentum correlations in DC wall
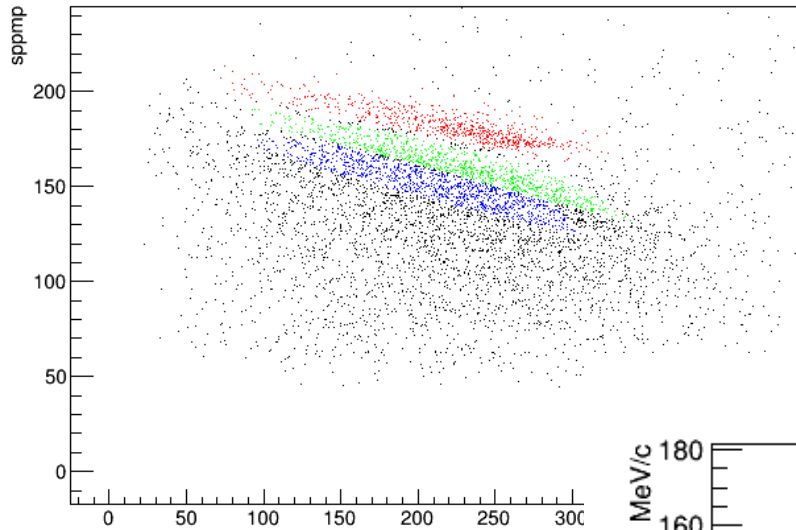
In-flight reactions on H
In-flight reactions on C
At-rest reactions on C
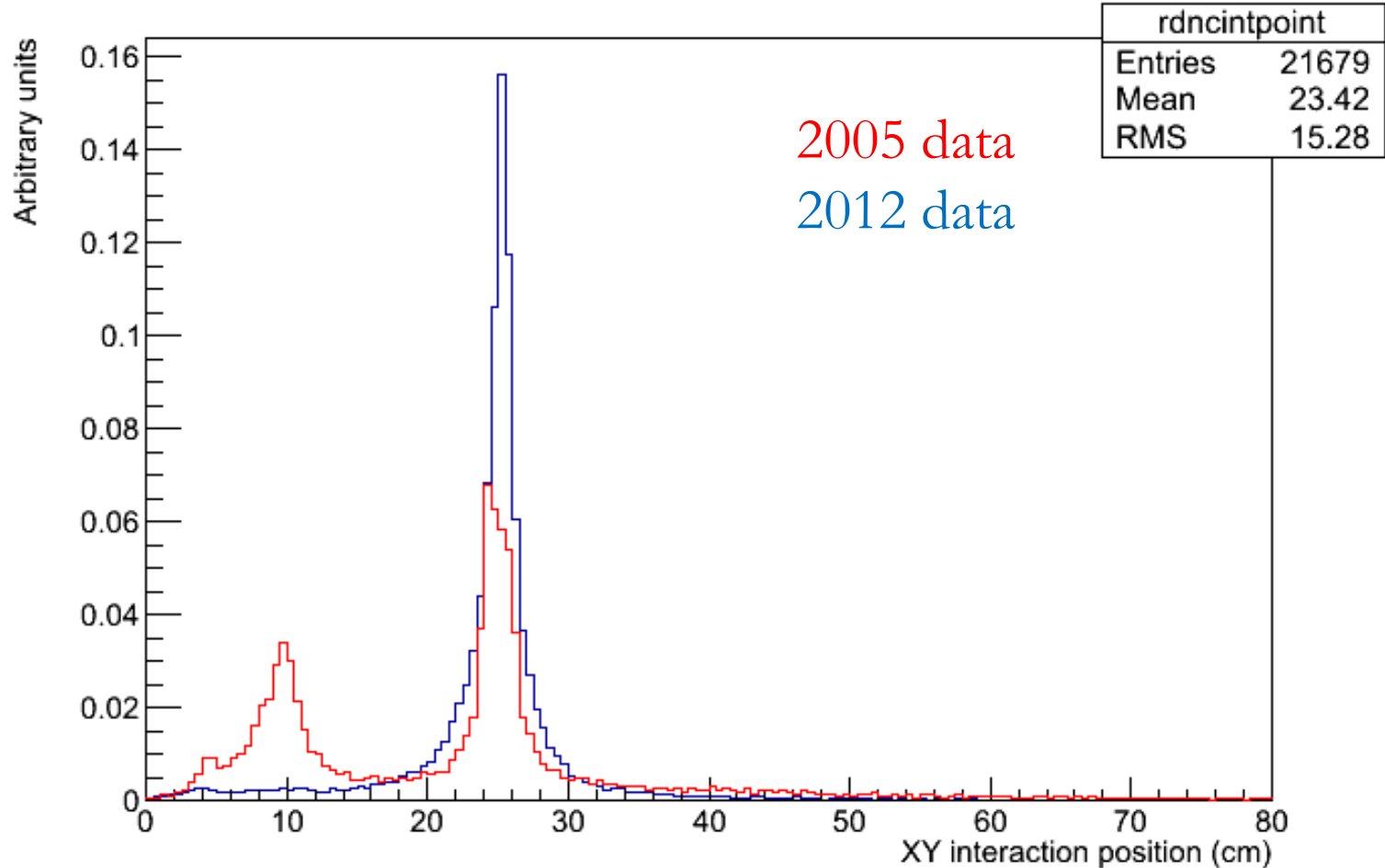
Sig+ pi- momentum

finalphif	
Entries	699
Mean	127.6
RMS	63.15

See I. Tucakovic's talk for further details

$\Sigma^+ \pi^-$ in Carbon Target

XY position of vertex

2005 data

2012 data

rdncintpoint	
Entries	21679
Mean	23.42
RMS	15.28

Arbitrary units

XY interaction position (cm)

$\Sigma^+ \pi^-$ in Carbon Target

SigP - PiM momentum correlation in carbon

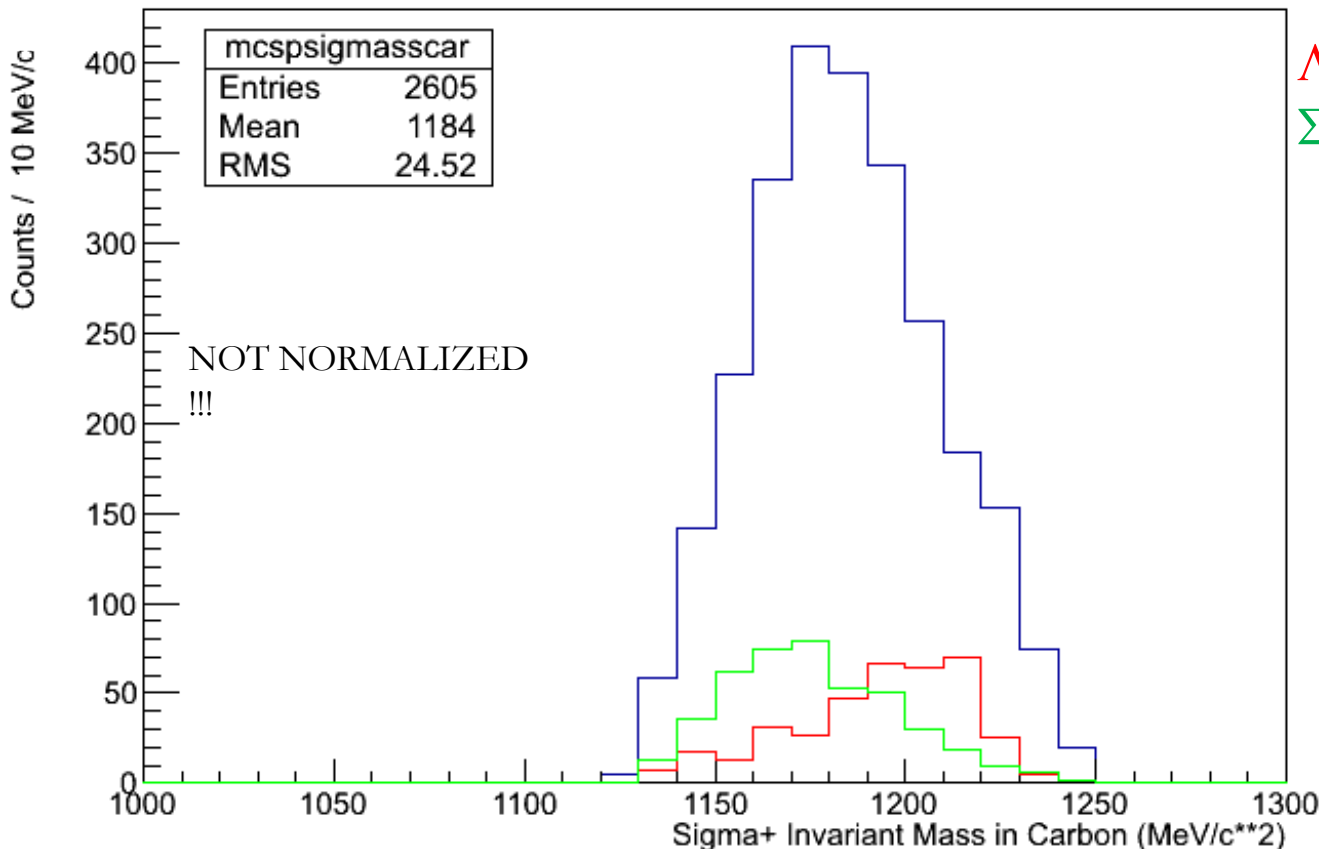| rdctcorsigcar	
Entries	26423
Mean x	237.6
Mean y	128.9
RMS x	108.8
RMS y	39.64

No in-flight component
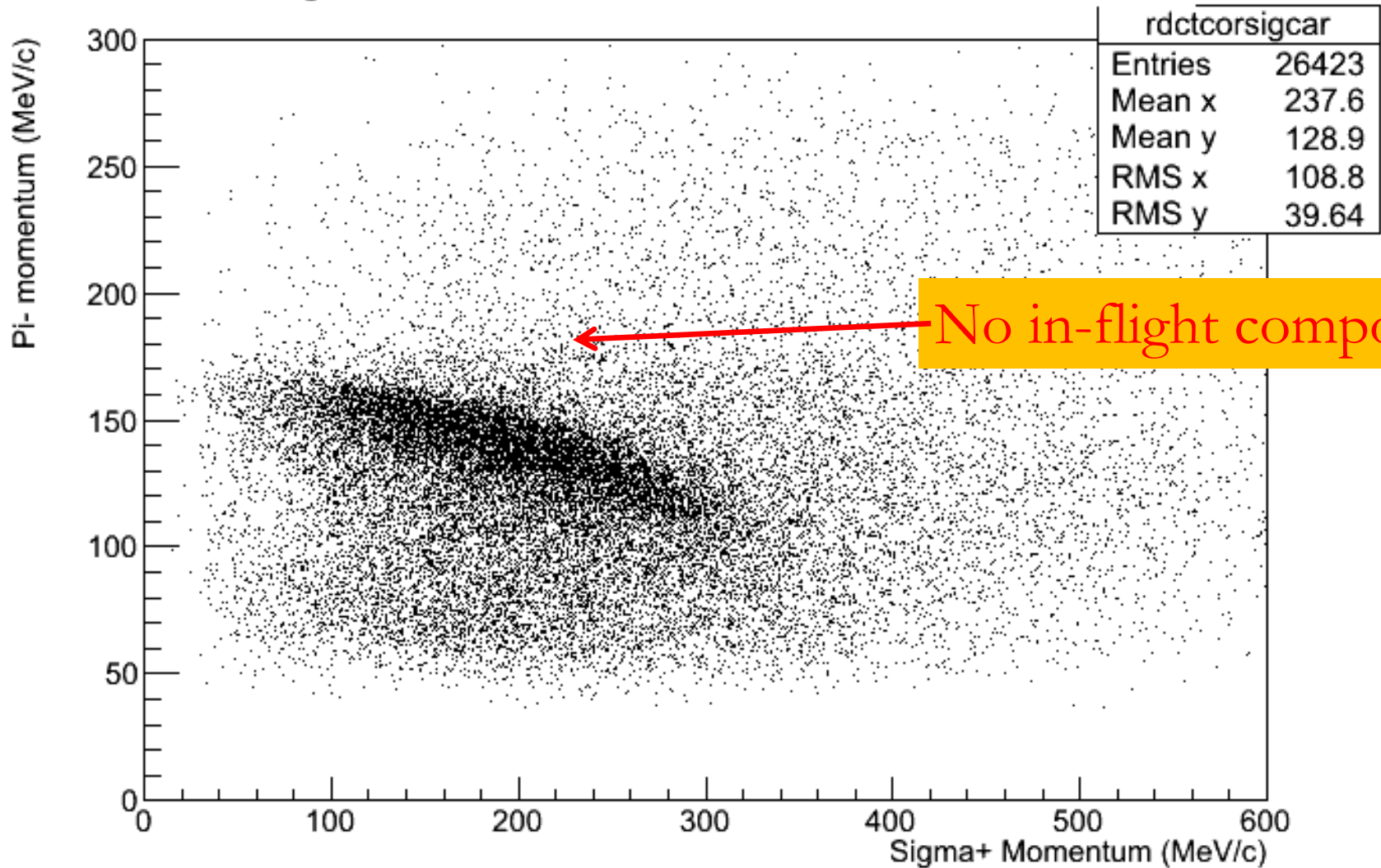
7) Hadronic background evaluation

Comparing MC simulation in the DC entrance wall, an estimation of the two hadronic background components can be obtained

Sigma+ Invariant Mass

NOT NORMALIZED !!!
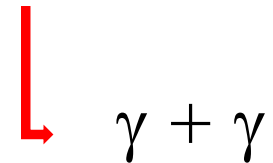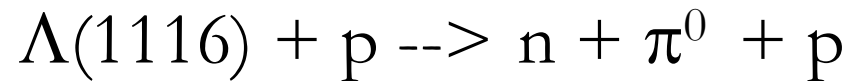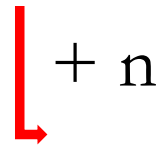
$\Lambda\pi^0 / \Sigma^+\pi^- = 0.84 \pm 0.02 \%$
$\Sigma^0\pi^0 / \Sigma^+\pi^- = 5.4 \pm 0.1 \%$

The new analysis provides a bigger hadronic background rejection!
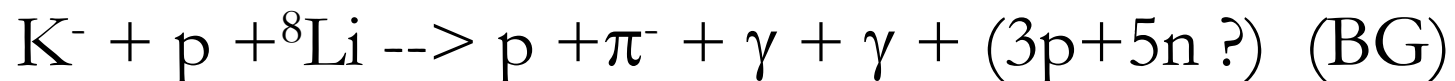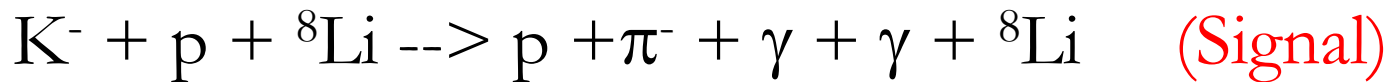
The internal conversion component is still present and confirmed!

8)Example of internal conversion in ^{9}Be

- Possible explanation: Σ^+ internal conversion on neutron

$$K^- + p + {}^8Li \longrightarrow \Sigma^+ + \pi^- + (3p+5n\ ?)$$

$$\downarrow\ + n$$

$$\Lambda(1116) + p \longrightarrow n + \pi^0 + p$$

$$\downarrow\ \gamma + \gamma$$

Similar final states:

$$K^- + p + {}^8Li \longrightarrow p + \pi^- + \gamma + \gamma + {}^8Li \quad \text{(Signal)}$$

$$K^- + p + {}^8Li \longrightarrow p + \pi^- + \gamma + \gamma + (3p+5n\ ?) \quad \text{(BG)}$$
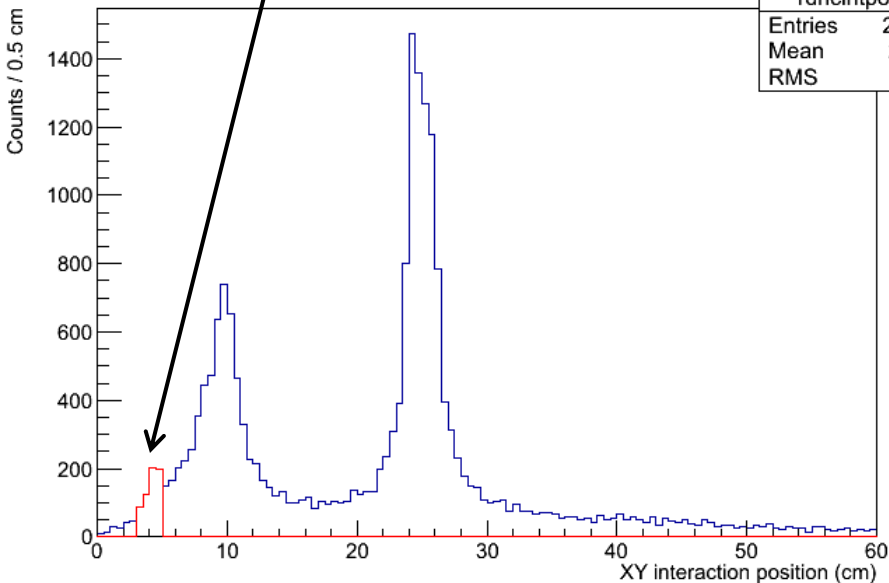
Internal conversion in ^{9}Be

Missing Mass for signal events in inner Be
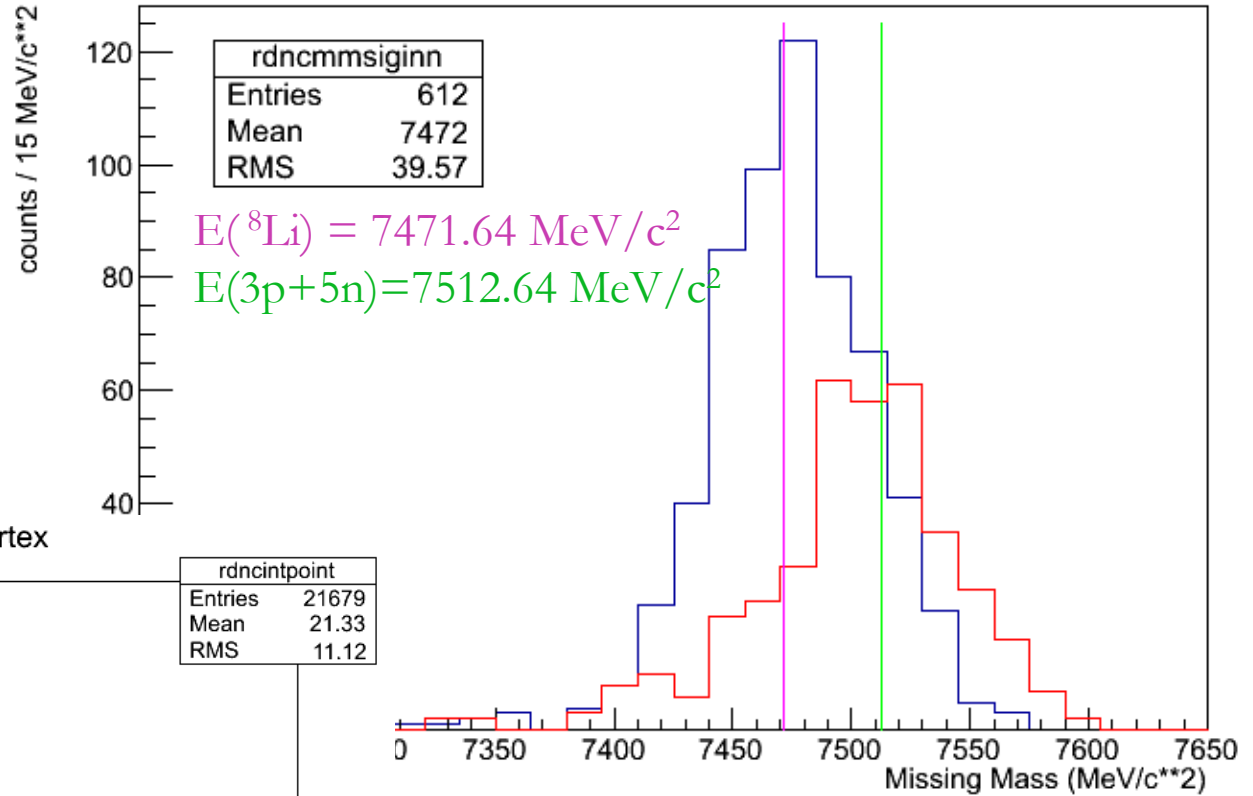
Inner Beryllium layer is ~ 99% pure Beryllium

$E(^8Li) = 7471.64$ MeV/c^2
$E(3p+5n)=7512.64$ MeV/c^2

rdncmmsiginn	
Entries	612
Mean	7472
RMS	39.57

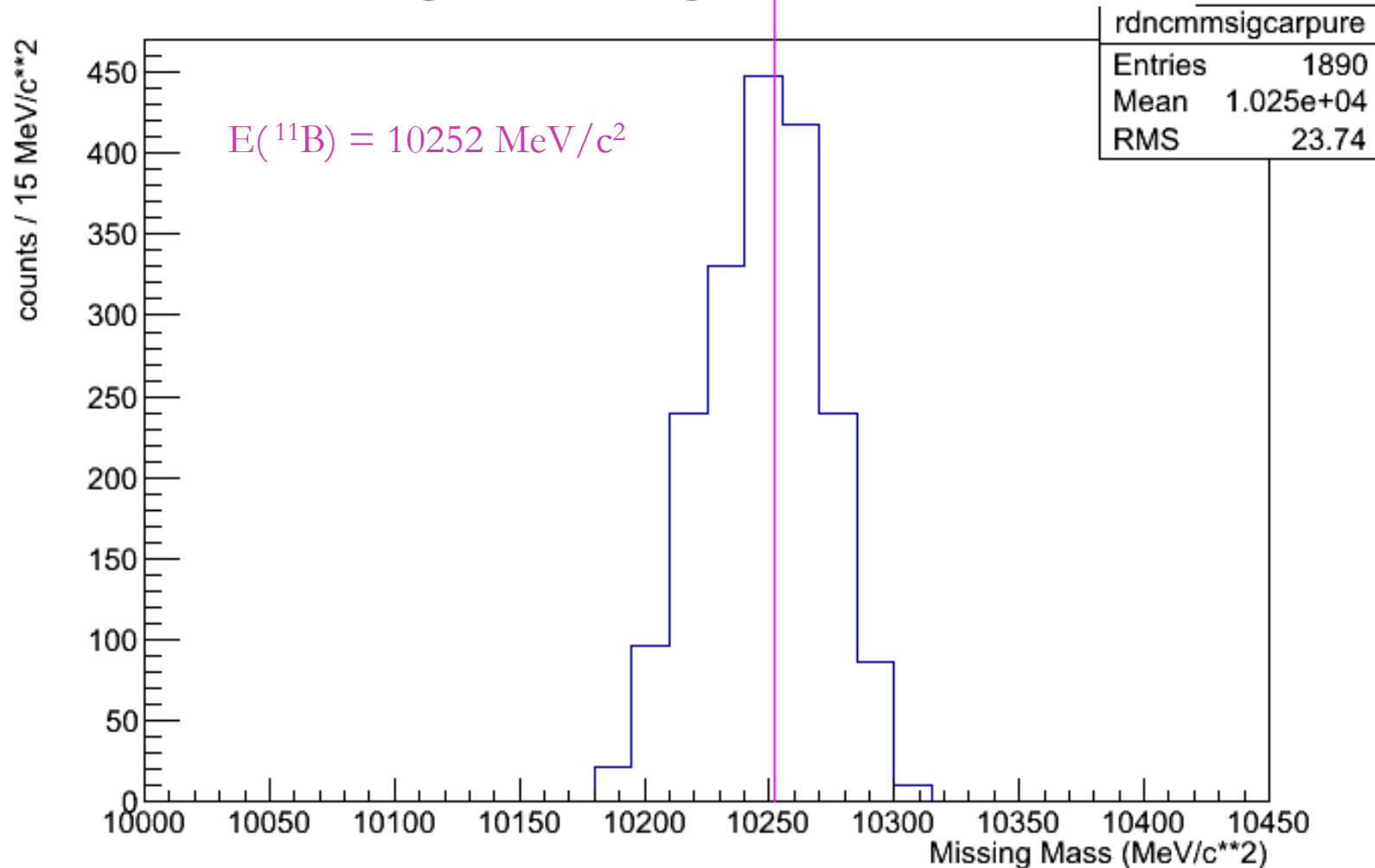| rdncintpoint	
Entries	21679
Mean	21.33
RMS	11.12

XY position of vertex

New analysis allows the investigation of this processes in the beryllium layer !!!

Internal conversion in ^{12}C
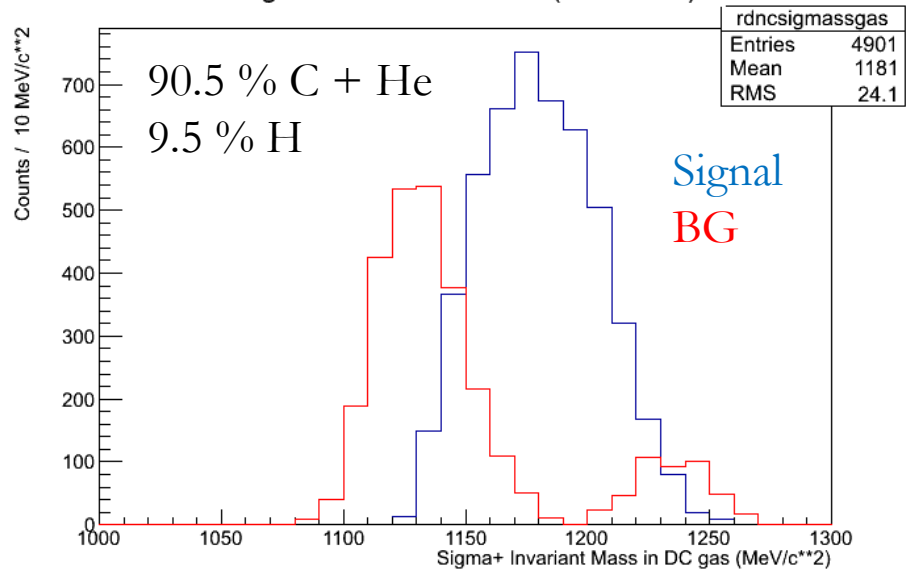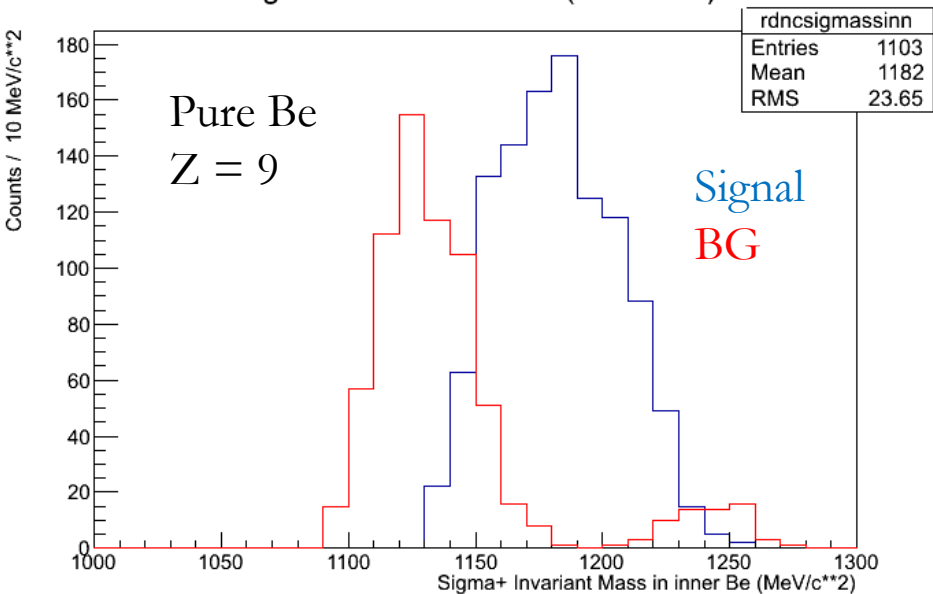

Missing Mass for signal events in Carbon

rdncmmsigcarpure	
Entries	1890
Mean	1.025e+04
RMS	23.74

$E(^{11}B) = 10252 \text{ MeV/c}^2$

Internal conversion ratios

Sigma+ Invariant Mass
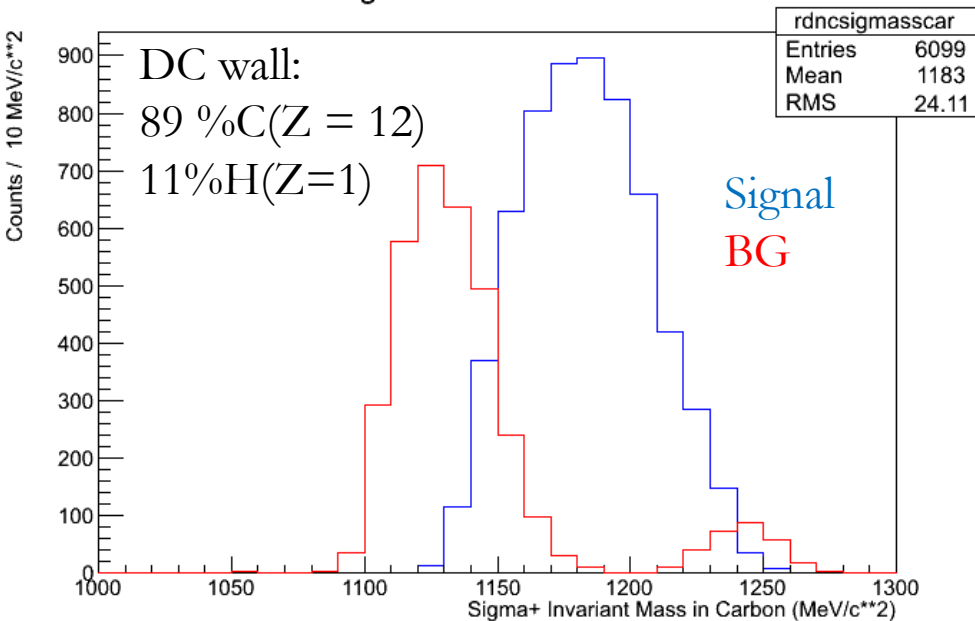
DC wall:
89 %C(Z = 12)
11%H(Z=1)

Signal
BG

rdncsigmasscar	
Entries	6099
Mean	1183
RMS	24.11

Sigma+ Invariant Mass (MeV/c**2)

90.5 % C + He
9.5 % H

Signal
BG

rdncsigmassgas	
Entries	4901
Mean	1181
RMS	24.1

Sigma+ Invariant Mass (MeV/c**2)

Pure Be
Z = 9

Signal
BG

rdncsigmassinn	
Entries	1103
Mean	1182
RMS	23.65

Sigma+ Invariant Mass (MeV/c**2)

62 % Be (Z=9)
38 % Al (Z=21)

Signal
BG

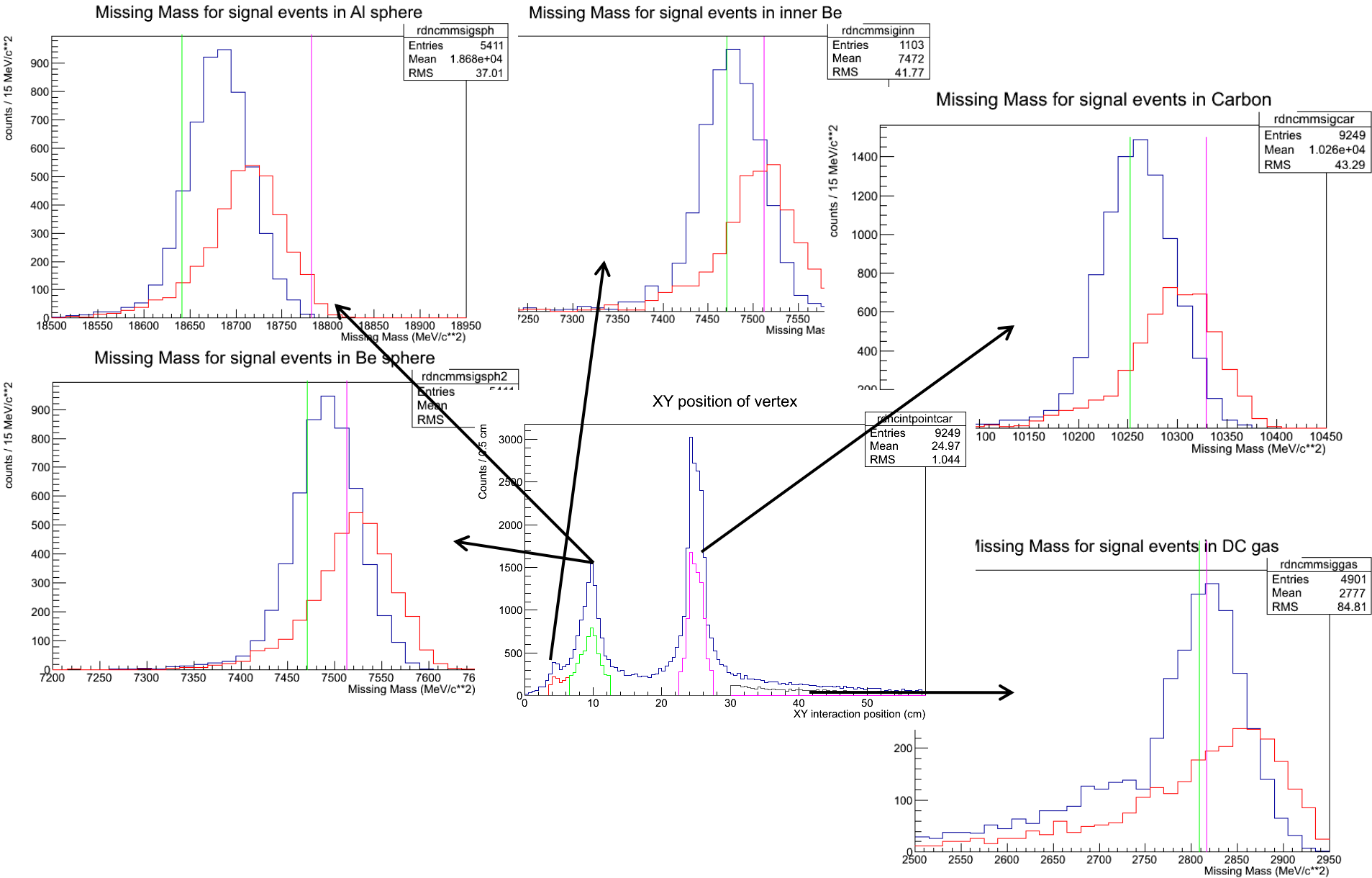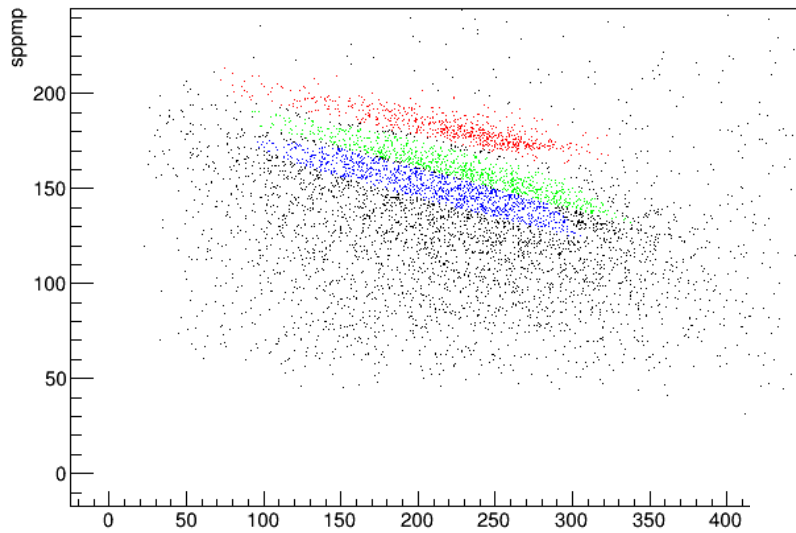| rdncsigmasssph	
Entries	5411
Mean	1182
RMS	24.4
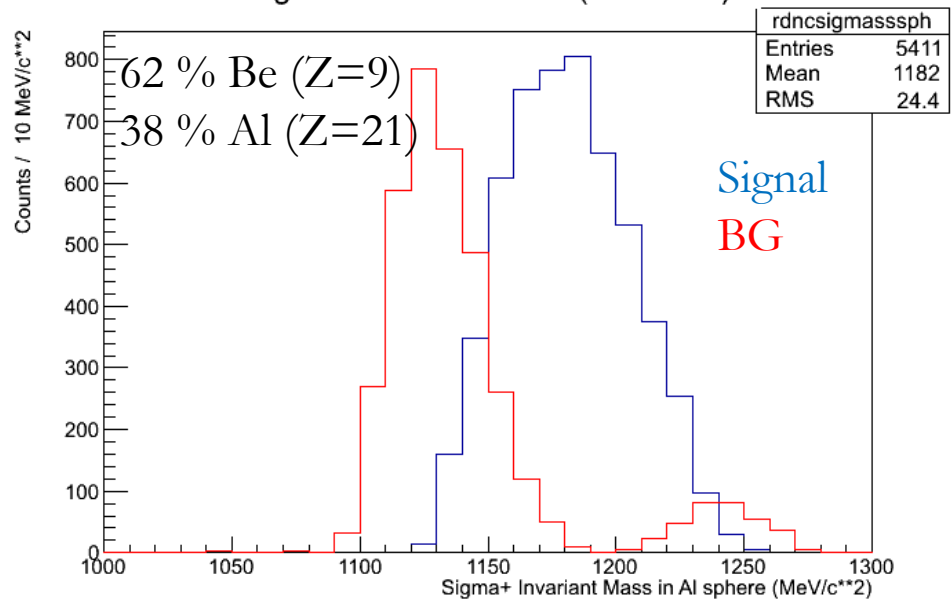
New perspectives

- Refined analysis of Carbon target data
- Possibility to separate different components
- Improve statistics (both 2005 and 2012)
- MC simulations of all possible backgrounds
- Acceptance correction
- Fit the final invariant mass and momentum including all components
- Possibility to measure the different branching ratios

Thanks for your attention

Internal conversion hypothesis: missing mass spectra

Missing Mass for signal events in Al sphere

Missing Mass for signal events in inner Be

Missing Mass for signal events in Carbon

Missing Mass for signal events in Be sphere

XY position of vertex

Missing Mass for signal events in DC gas

$\Sigma^+ \pi^-$ momentum correlations in DC wall

In-flight reactions on H
In-flight reactions on C
At-rest reactions on C

See I. Tucakivic's talk for further details