Measurement of the charged pion polarisability at COMPASS

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on behalf of the COMPASS collaboration

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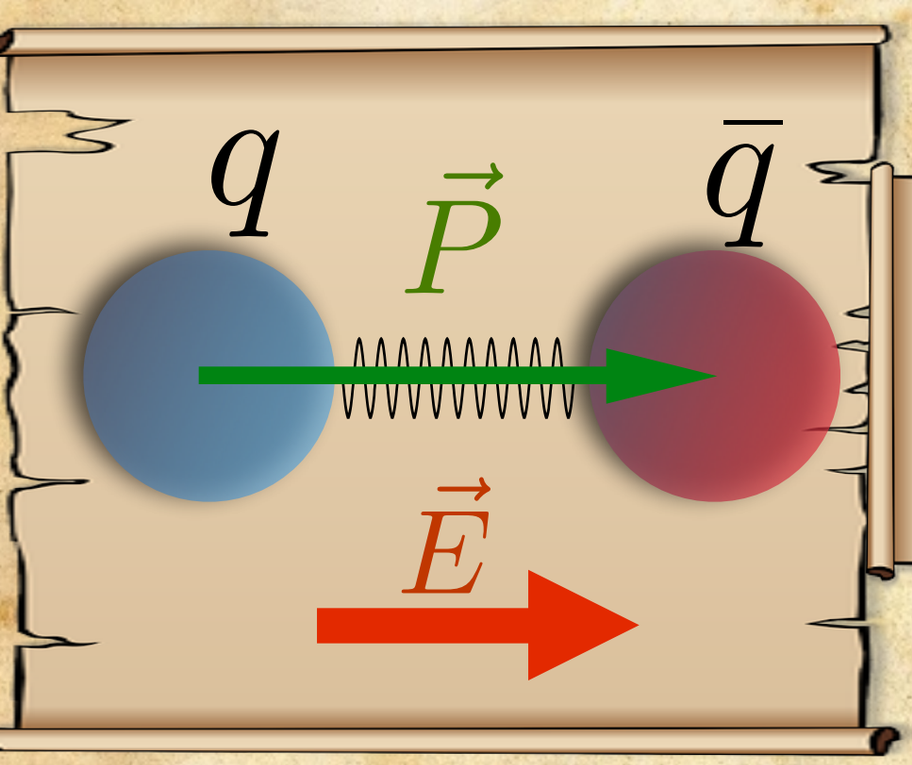
Polarizabilities of hadrons



$$\vec{P} = \alpha_X \vec{E}$$

$$\vec{\mu} = \beta_X \vec{H}$$

The electric and magnetic polarizabilities of a hadron are the quantities characterizing the rigidity of QCD system

$$H = \ldots - (\alpha_X E^2 + \beta_X H^2)/2$$

Compton amplitude:

$$A(\gamma X \to \gamma X) = \ldots$$

$$\ldots + \alpha_\pi \omega_1 \omega_2 \, \hat{e}_1 \cdot \hat{e}_2 +$$

$$+ \beta_\pi \omega_1 \omega_2 (\hat{e}_1 \times \hat{q}_1)(\hat{e}_2 \times \hat{q}_2)$$

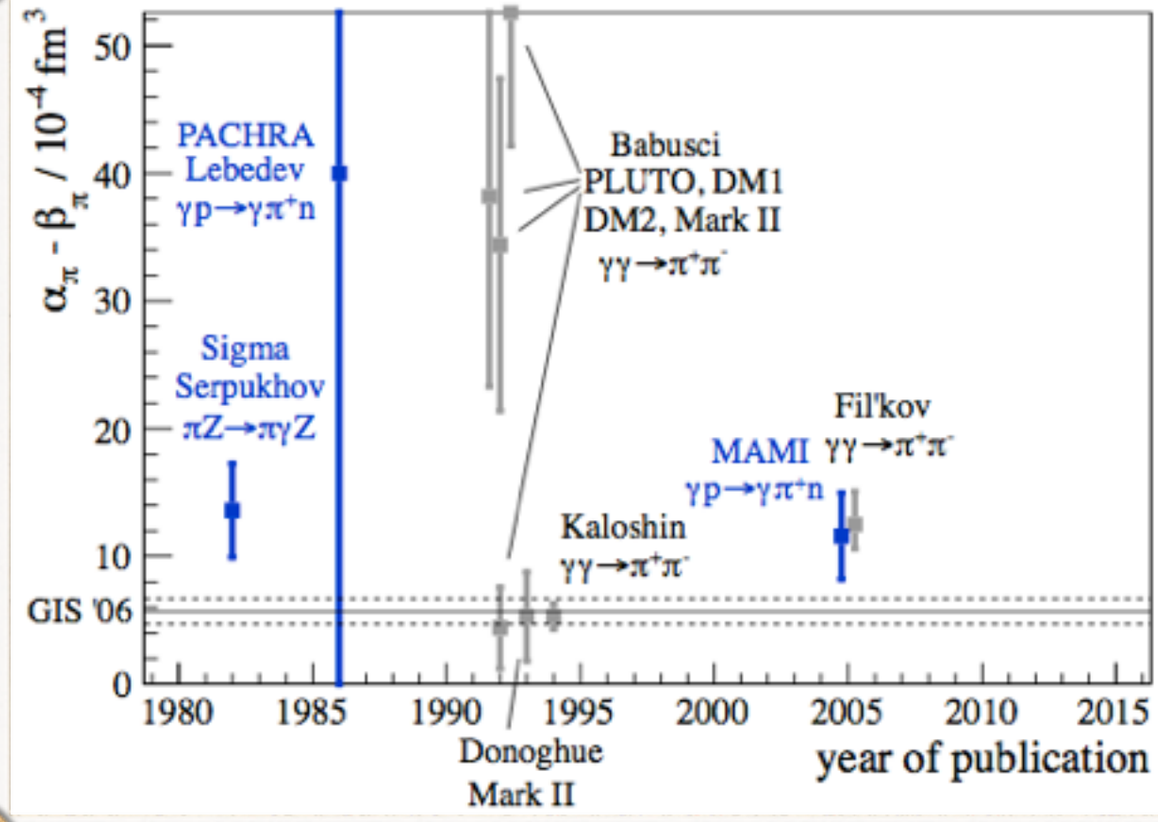
PDG data:

	a_X, 10^{-4} fm^3	β_X, 10^{-4} fm^3
p	12.0±0.6	1.9∓0.6
n	12.5±1.7	2.7∓1.8

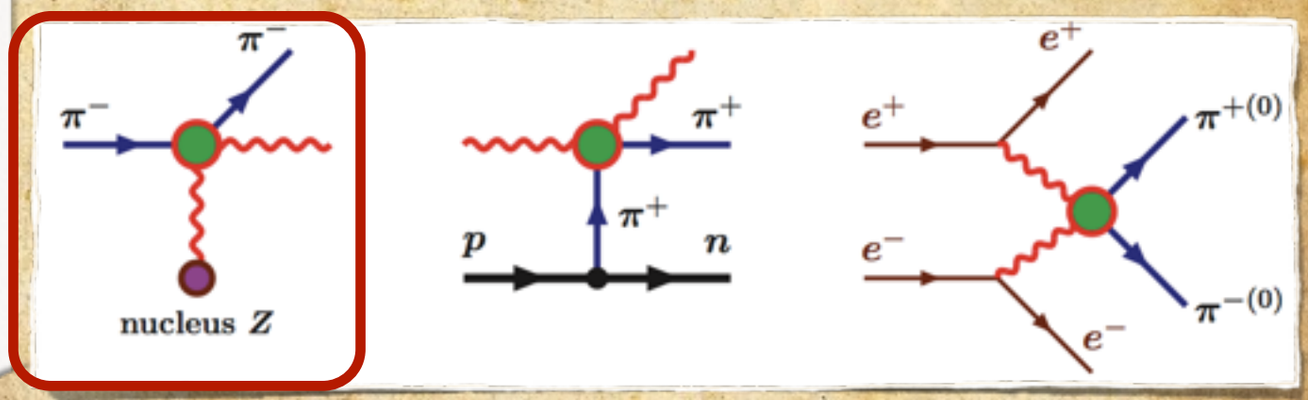
π, K ?

Expectations and results for a_π, β_π

Model	Parameter	10^{-4} fm^3
χPT (2-loops)	$a_\pi - \beta_\pi$	5.7±1.0
	$a_\pi + \beta_\pi$	0.16



Data	Reaction	Paramater	$[10^{-4} fm^3]$
Serpukhov ($\alpha_\pi + \beta_\pi = 0$)	$\pi Z \to \pi Z \gamma$	α_π	6.8±1.4±1.2
Serpukhov ($\alpha_\pi + \beta_\pi \neq 0$)		$\alpha_\pi + \beta_\pi$	1.4±3.1±2.8
		β_π	$-7.1 \pm 2.8 \pm 1.8$
Lebedev	$\gamma N \to \gamma N \pi$	α_π	20±12
Mami A2	$\gamma p \to \gamma \pi^+ n$	$\alpha_\pi - \beta_\pi$	11.6±1.5±3.0±0.5
PLUTO	$\gamma\gamma \to \pi^+\pi^-$	α_π	19.1±4.8± 5.7
DM1	$\gamma\gamma \to \pi^+\pi^-$	α_π	17.2±4.6
DM2	$\gamma\gamma \to \pi^+\pi^-$	α_π	26.3±7.4
Mark II	$\gamma\gamma \to \pi^+\pi^-$	α_π	2.2±1.6
Combined fit: MARK II, VENUS, ALEPH, TPC/2γ, CELLO, BELLE (L. Fil'kov, V. Kashevarov)	$\gamma\gamma \to \pi^+\pi^-$	$\alpha_\pi - \beta_\pi$	$13.0^{+2.6}_{-1.9}$
		$\alpha_\pi + \beta_\pi$	$0.18^{+0.11}_{-0.02}$
Combined fit: MARK II, Crystal Ball (A. Kaloshin, V. Serebryakov)	$\gamma\gamma \to \pi^+\pi^-$	$\alpha_\pi - \beta_\pi$	5.25 ± 0.95



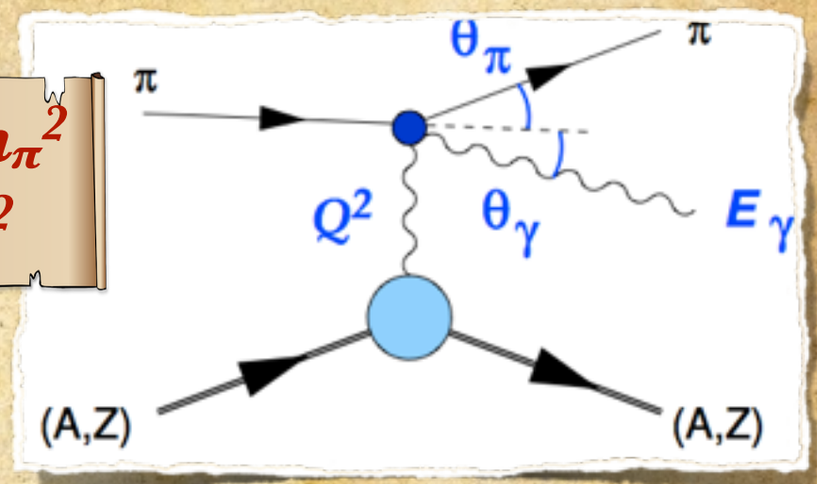
At the moment experimental uncertainty for pion polarizabilities is too high. New experiments are needed!

Pion polarizabilities and cross section

$$\frac{d\sigma}{ds\,dt\,dQ^2} = \frac{Z^2\,\alpha}{\pi(s-m_\pi^2)}\cdot F_{\text{eff}}^2(Q^2)\cdot\frac{Q^2-Q^2_{\min}}{Q^4}\cdot\frac{d\sigma_{\pi\gamma}}{dt}$$

$$Q_{\min} = (s-m_\pi^2)/2E_{\text{beam}}$$

$Q^2 \ll m_\pi^2$
$\sigma \sim Z^2$



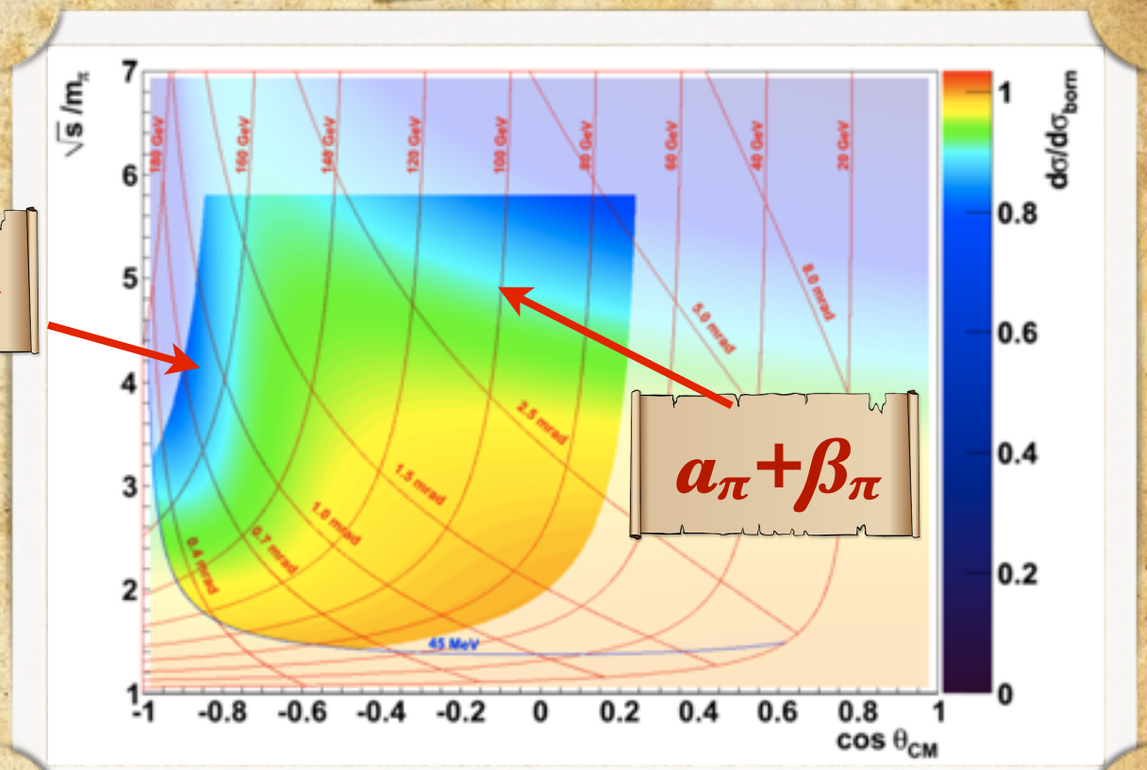
Compton cross section:

$$\frac{d\sigma_{\pi\gamma}}{d\Omega_{cm}} = \frac{\alpha^2(s^2z_+^2+m_\pi^4z_-^2)}{s(sz_+ + m_\pi^2 z_-)^2} - \frac{\alpha\, m_\pi^3\,(s-m_\pi^2)^2}{4s^2(sz_+ + m_\pi^2 z_-)}\cdot\mathcal{P}$$

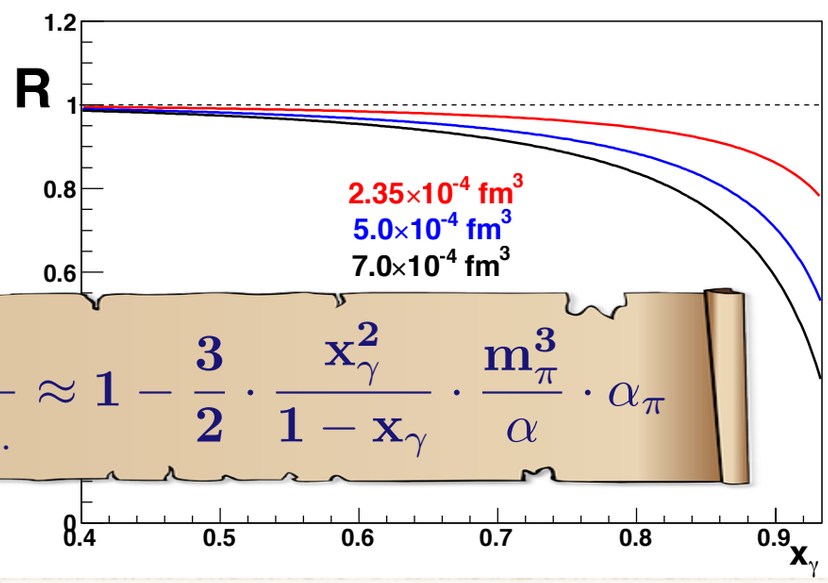
$$z_\pm = 1 \pm \cos\theta_{cm}$$

$$\mathcal{P} = z_-^2(\alpha_\pi-\beta_\pi) + \frac{s^2}{m_\pi^4}z_+^2(\alpha_\pi+\beta_\pi)$$

$a_\pi - \beta_\pi$



Simplest case: $a_\pi = -\beta_\pi$



$$R = \frac{\sigma}{\sigma_{\text{p.l.}}} \approx 1 - \frac{3}{2}\cdot\frac{x_\gamma^2}{1-x_\gamma}\cdot\frac{m_\pi^3}{\alpha}\cdot\alpha_\pi$$

x_γ - *relative energy of emitted photon in Lab system*

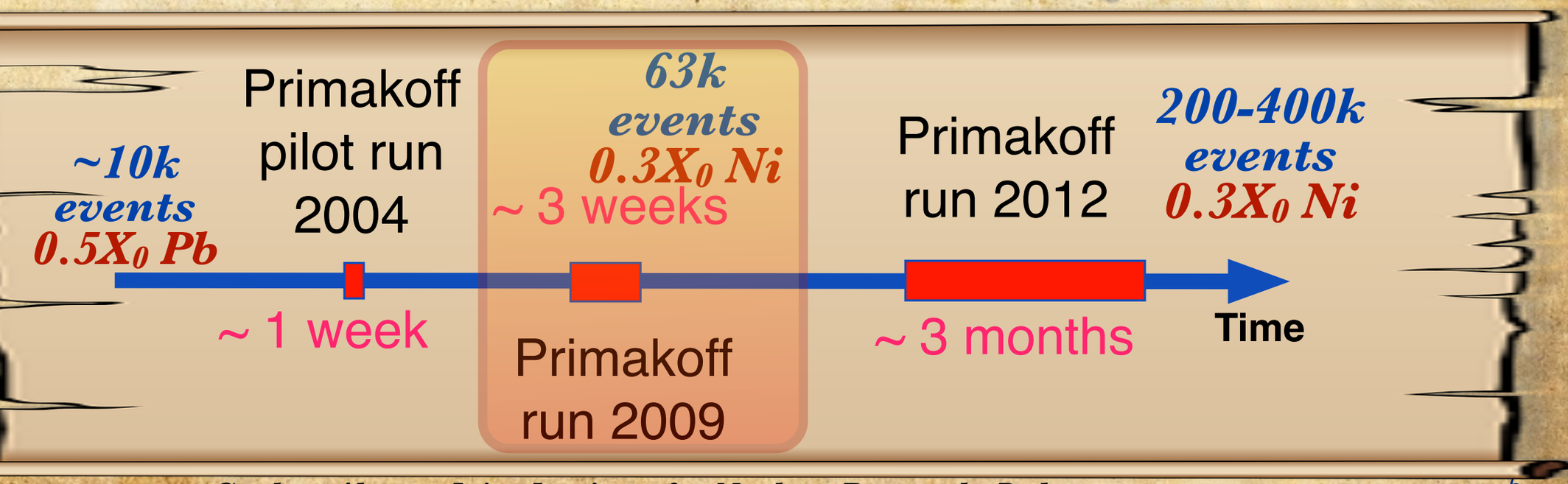
The COMPASS experiment

COMPASS (COmmon Muon Proton Apparatus for Structure and Spectroscopy) is the fixed target experiment on the secondary beam of Super Proton Synchrotron at CERN

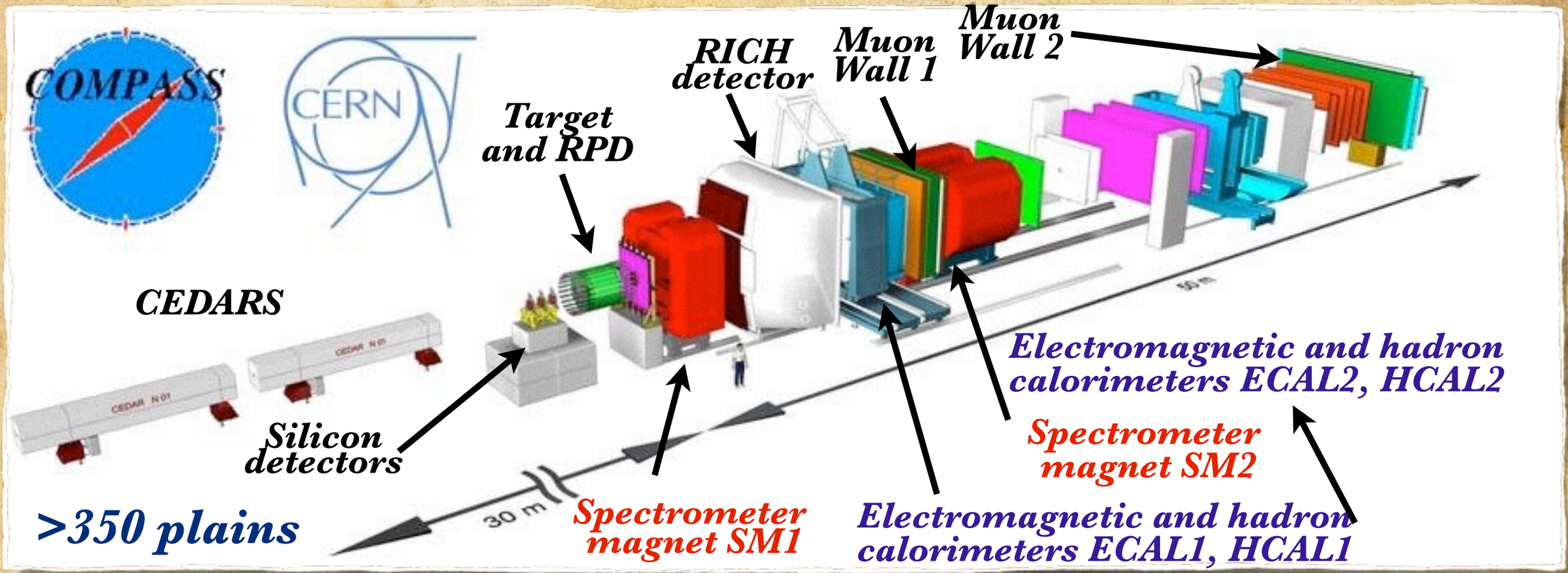
The purpose of this experiment is the study of hadron structure and hadron spectroscopy with high intensity muon and hadron beams.

1996 - Proposal
2002-2015 - Physical data taking

13 countries,
24 institutions,
~220 physicists



The COMPASS setup

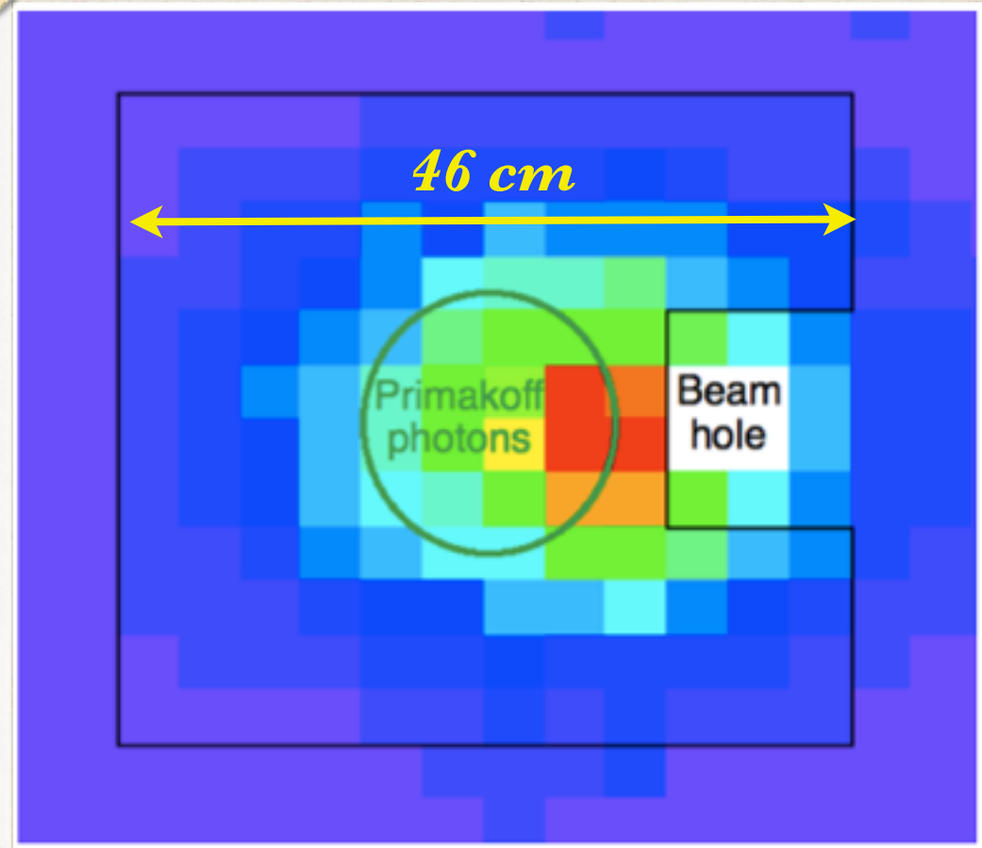


- CEDAR detectors for beam particle identification
- Precise silicon detectors to measure small scattering angles
- Magnetic spectrometer for pion momentum measurement
- Electromagnetic calorimeter with good energy and spacial resolution for photon detection
- Muon identification system
- Possibility to use pion and muon beams of the same momentum

Trigger

TRIGGER = (BC & ECAL2)
!SW !BK1 !BK2

Trigger name	ECAL2 threshold, GeV	Scale factor	Rate, kHz
Primakoff 1	~40	2	~20
Primakoff 2	~60	1	



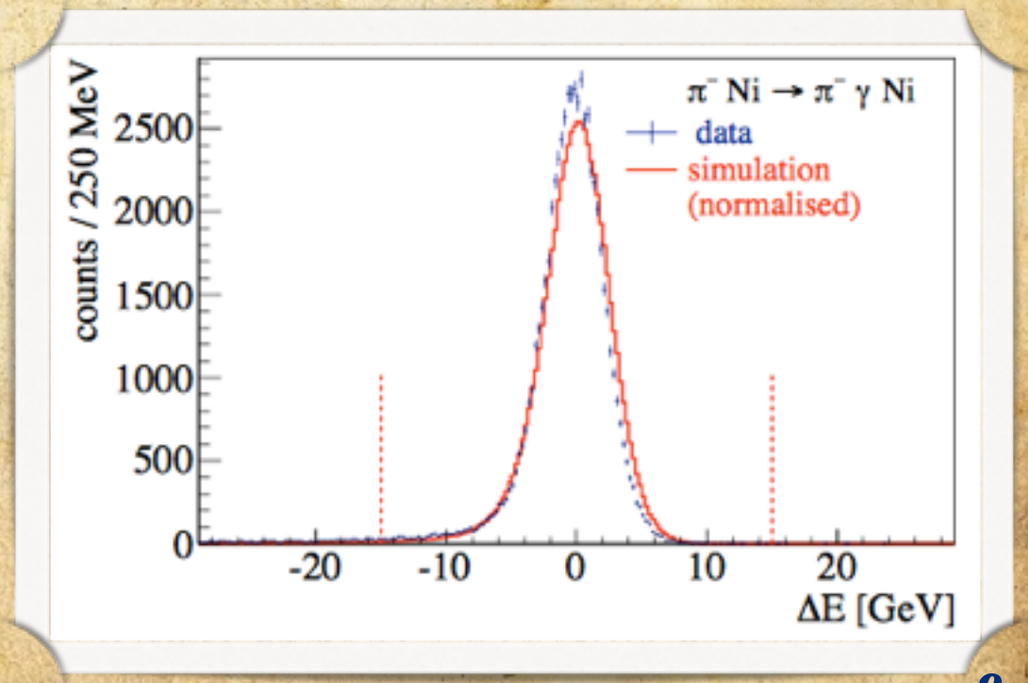
Event selection

- *Primakoff1, Primakoff2 triggers*
- *1 vertex with 1 outgoing negative track*
- *No other tracks*
- *Beam track is parallel to the nominal beam axis*
- *Scattered track is not muon*
- *No activity in RPD*
- *Exactly 1 neutral cluster in ECAL2 (E>2 GeV)*
- *Beam particle is pion (CEDAR)*
- *Exclusivity cut on the level ±15 GeV to reject events with missed particles in the final state*
- *Parallel analysis of three channels*

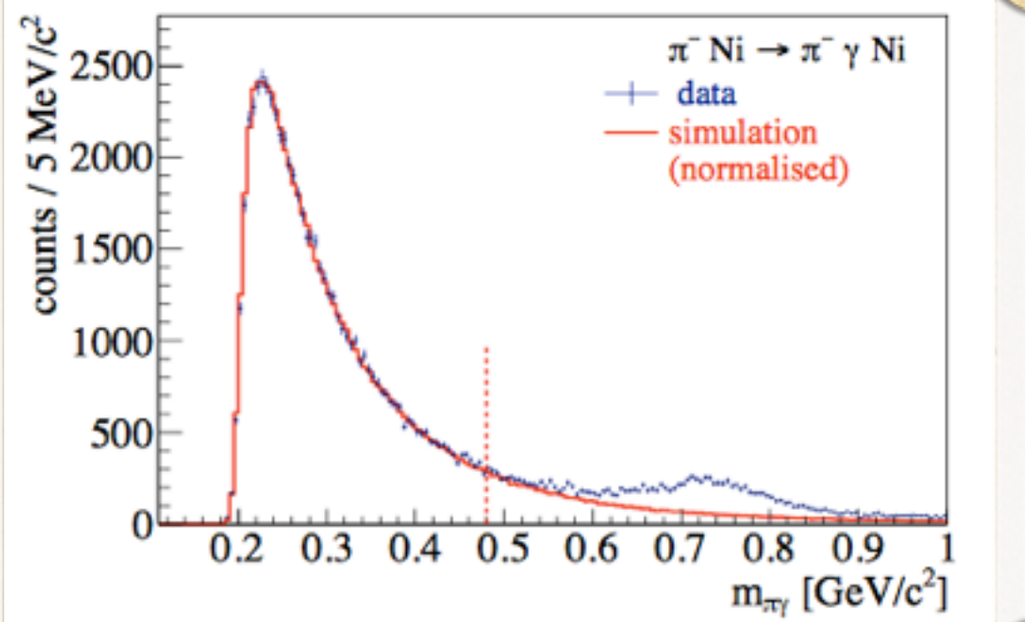
$\pi^- Ni \to \pi^- Ni\ \gamma$

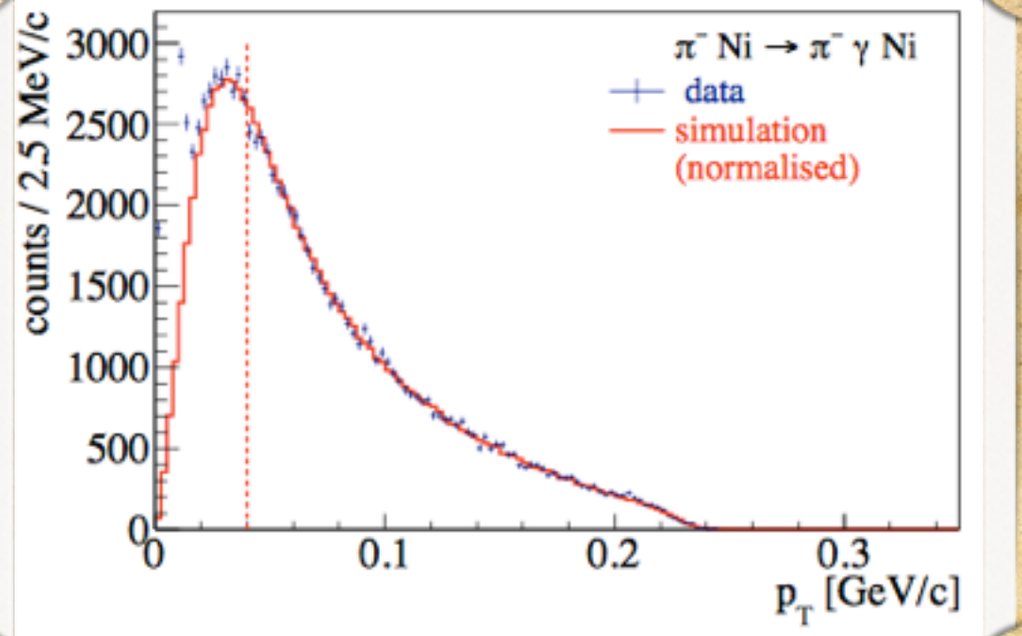
$\mu^- Ni \to \mu^- Ni\ \gamma$

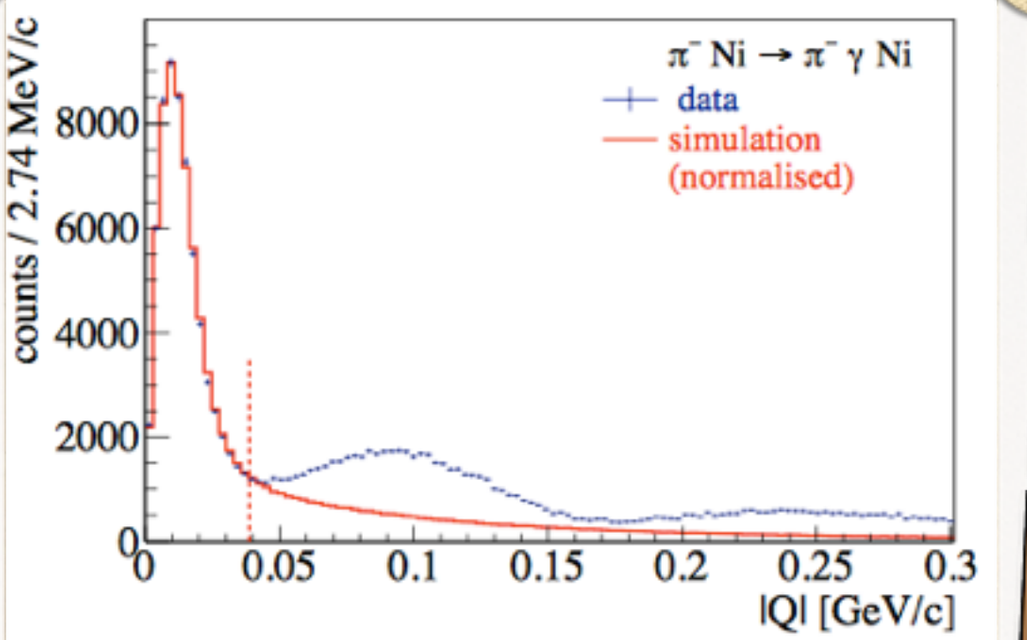
$\pi^- Ni \to \pi^- Ni\ \pi^0 \to \pi^- Ni\ \gamma\gamma$



Kinematic cuts





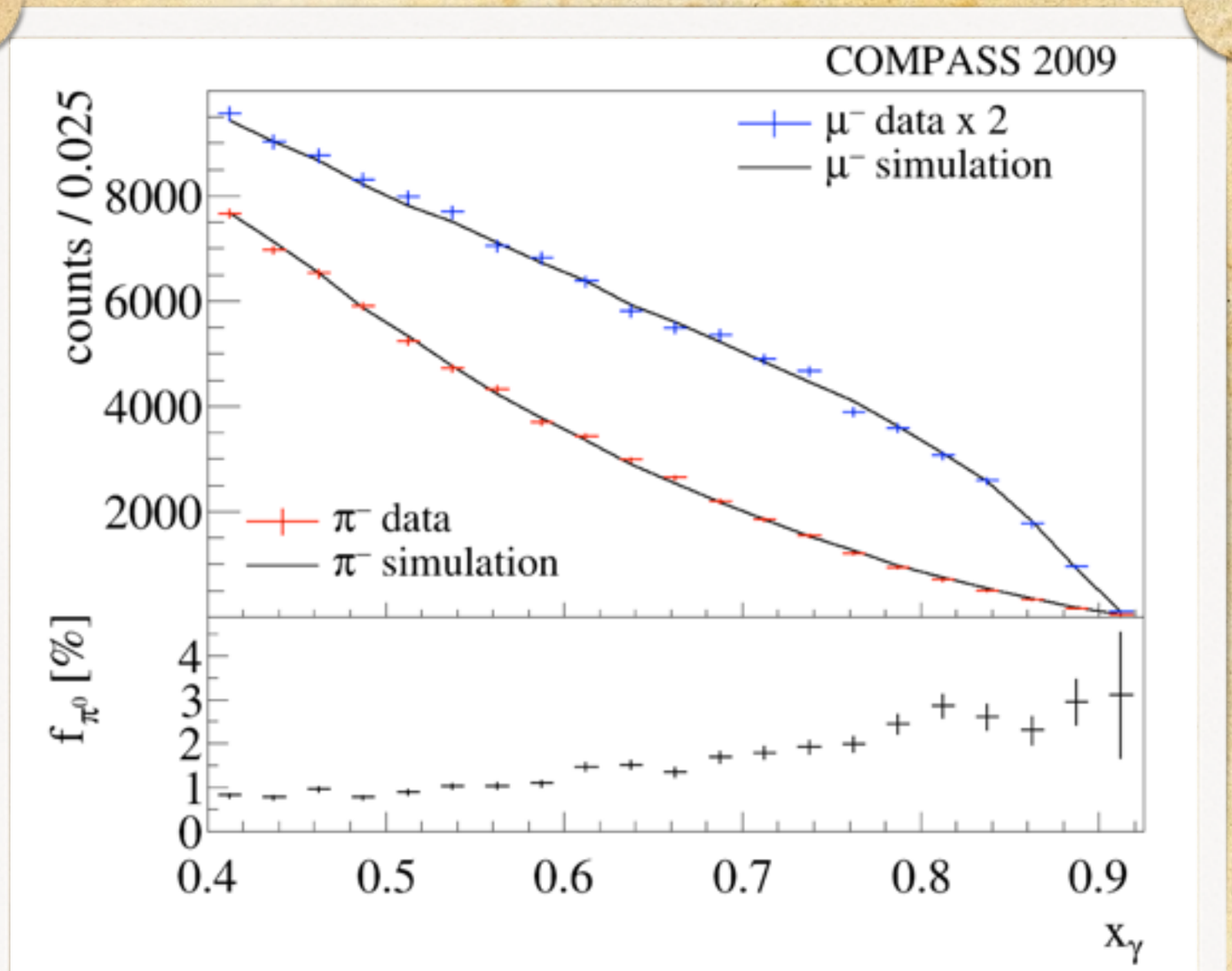


p_T-cut to reject low p_T region related with multiple scattering in the material

$M_{\pi\gamma} < 3.5\ m_\pi$ to suppress ρ-meson production and decay to $\pi\pi^0$

$Q^2 < 1.5\times10^{-3}$ (GeV/c)^2 to reject πγ state production via strong interaction

The measured x_γ distributions



Main background:

$\pi^- Ni \rightarrow \pi^- Ni\, \pi^0 \rightarrow \pi^- Ni\, \gamma\gamma$

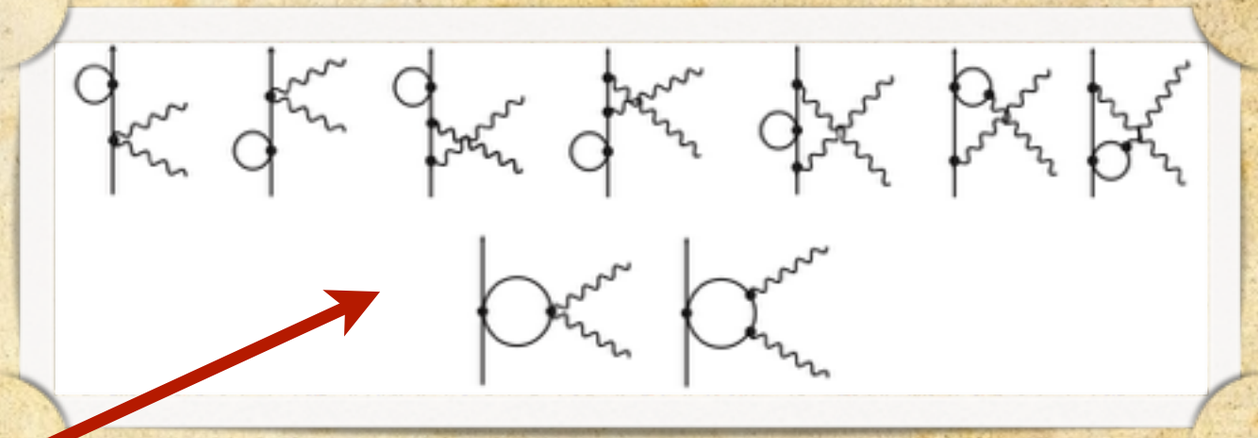
1 γ lost

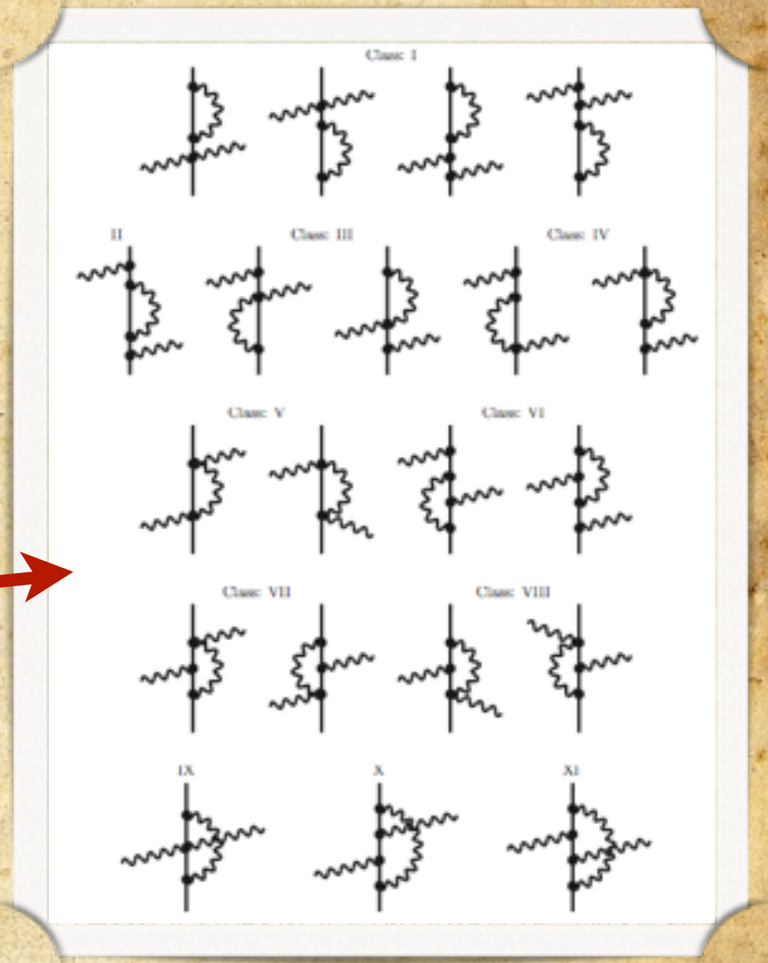
single cluster in ECAL2

Kaon decay $K^- \rightarrow \pi^- \pi^0$ out of the target was the reference process

Fraction of mis-reconstructed $\pi^- \pi^0$ events in $\pi^- \gamma$ sample from kaon decay was used to estimate contribution f_{π^0} of π^0 background

Corrections





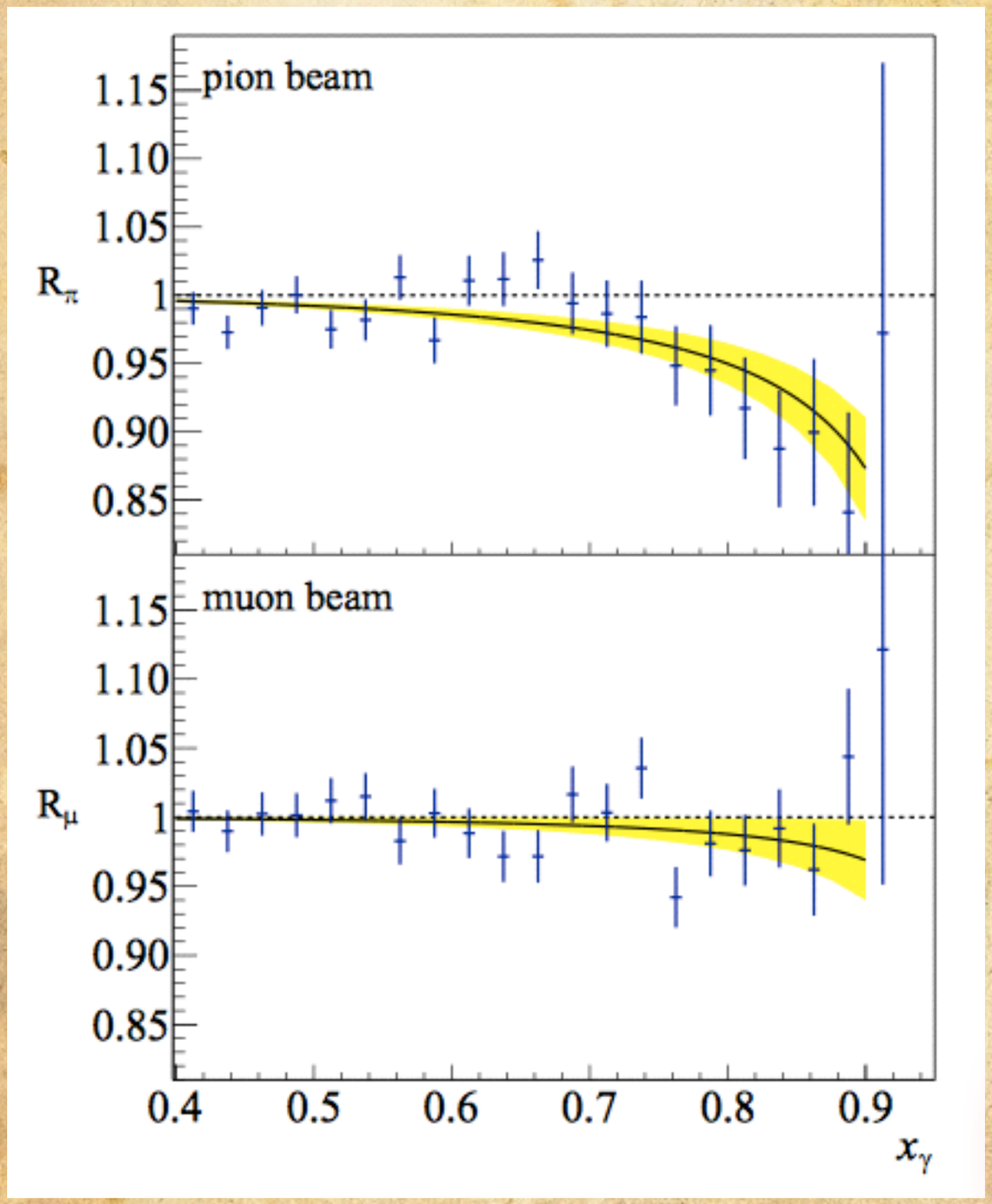
applied

- ***pion rescattering***
- ***radiative corrections (Compton vertex)***
- ***form factor of the Ni nucleus***

put to systematics

- ***High Z effects (Zα=0.2)***
- ***Nuclear charge screening by atomic electrons***

The COMPASS result



COMPASS 2009

Source of uncertainty	Estimated magnitude $[10^{-4}\,\mathrm{fm}^3]$
Determination of tracking detector efficiency	0.5
Treatment of radiative corrections	0.3
Subtraction of π^0 background	0.2
Strong interaction background	0.2
Pion-electron elastic scattering	0.2
Contribution of muons in the beam	0.05
Quadratic sum	0.7

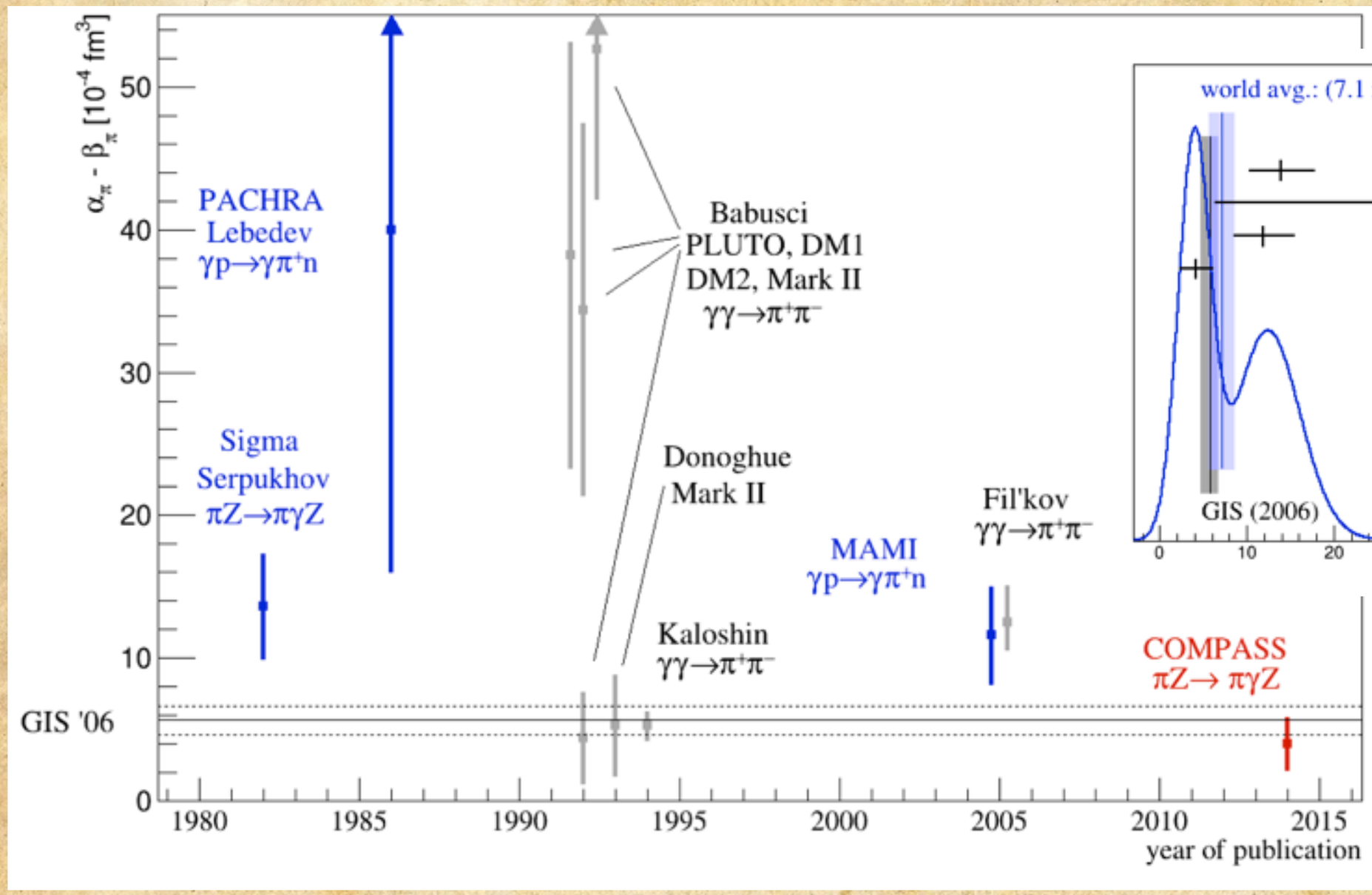
Under assumption $a_\pi = -\beta_\pi$:

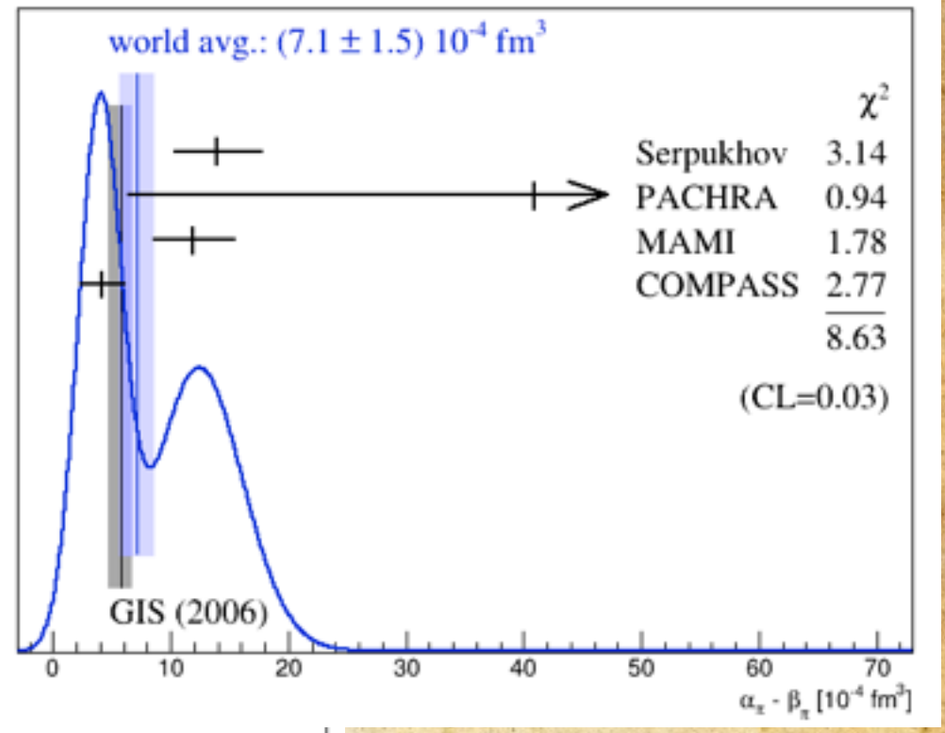
$$a_\pi = (2.0 \pm 0.6_{stat} \pm 0.7_{syst}) \times 10^{-4}\ fm^3$$

Phys. Rev. Lett. 114 (2015) 06002

Protvino: $a_\pi = -\beta_\pi = (6.8 \pm 1.4_{stat} \pm 1.2_{syst}) \times 10^{-4}\ fm^3$, χPT: $a_\pi \approx 2.8 \times 10^{-4}\ fm^3$

Pion polarizabilities and COMPASS





COMPASS

2009

COMPASS preliminary result for pion polarizability is the most precise among dedicated measurements

Summary

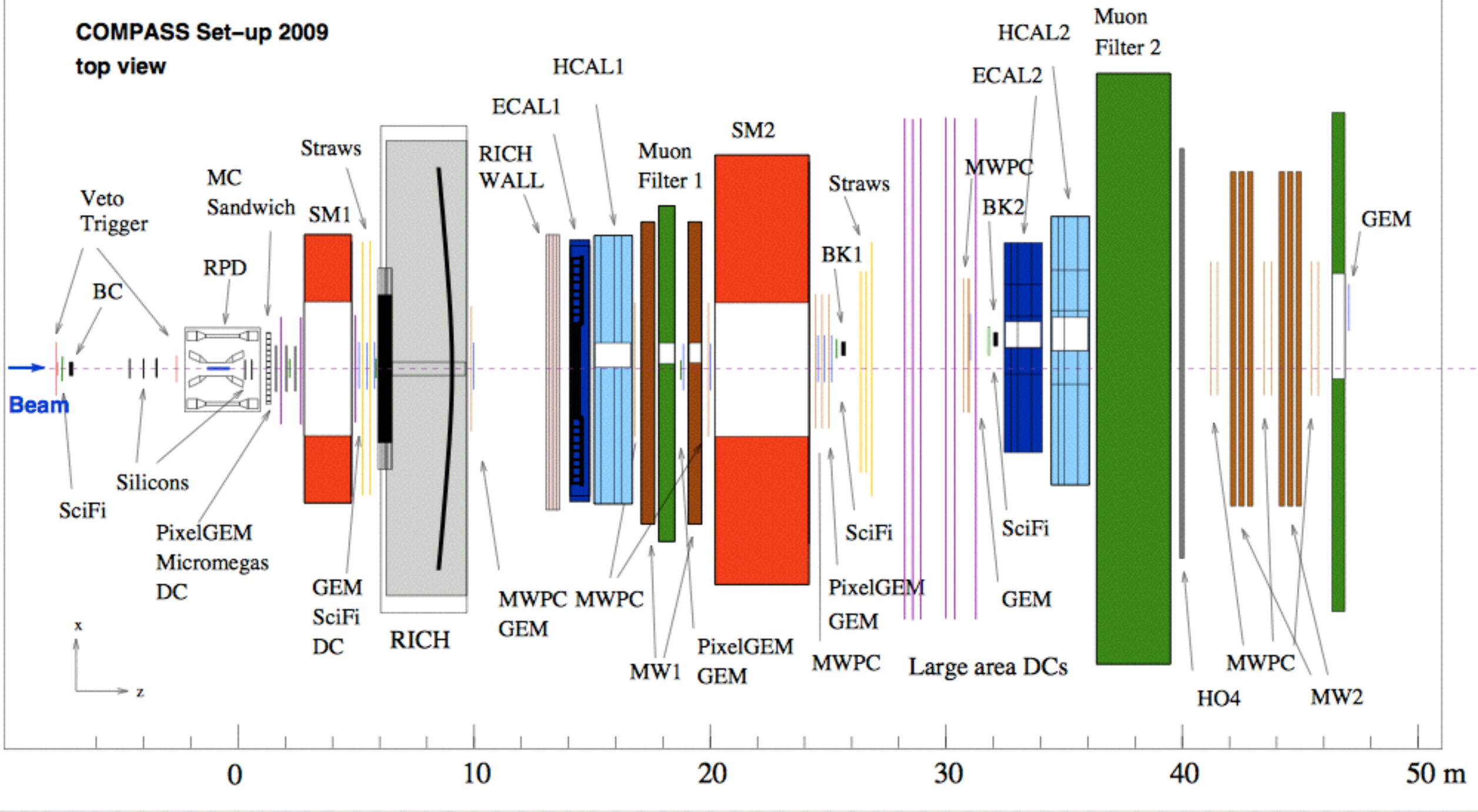
- The COMPASS experiment performed the most precise dedicated measurement of pion polarizability a_π under assumption $a_\pi+\beta_\pi=0$ basing on the data of 2009 year.
- The result is:

$$a_\pi=(2.0\pm0.6_{stat}\pm0.7_{syst})\times10^{-4}\ fm^3$$

published in PRL 114 (2015) 06002

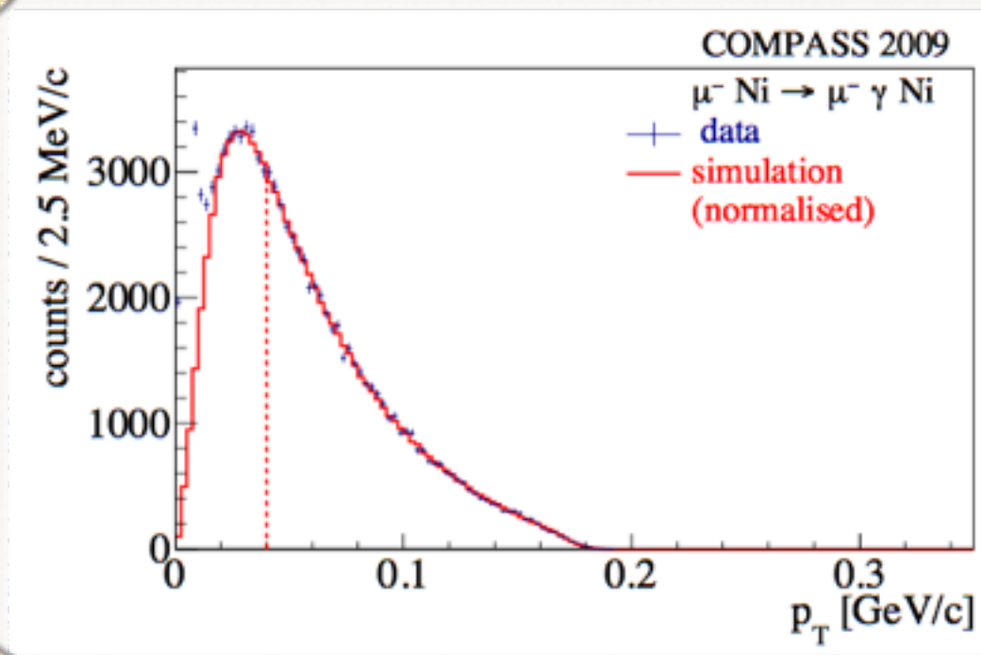
- COMPASS Primakoff data of 2012 still are under analysis and new results for pion (and kaon) polarizabilities are expected

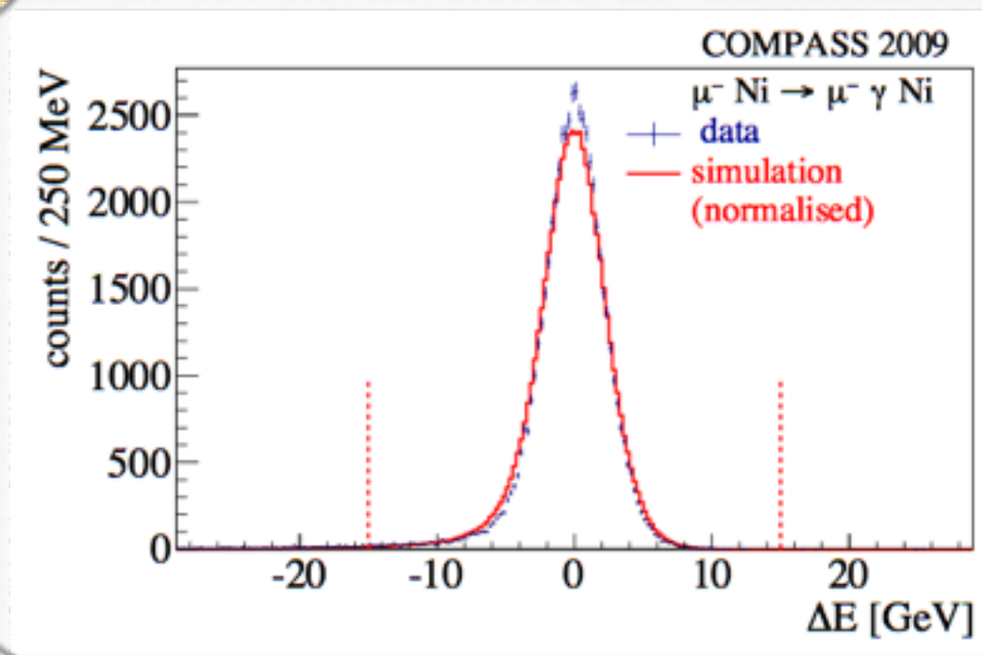
Backup slides

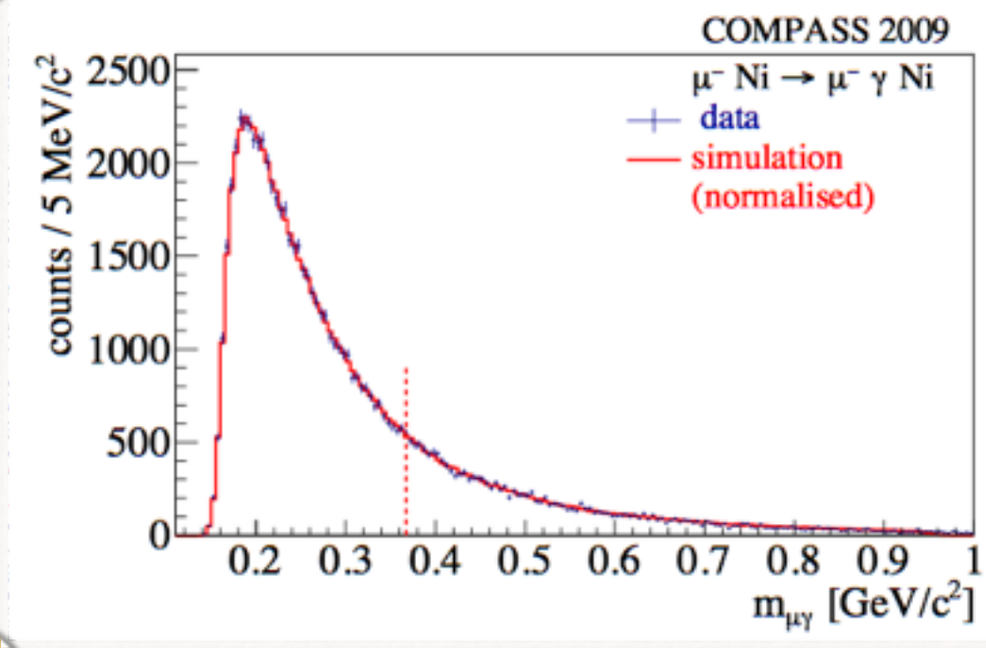


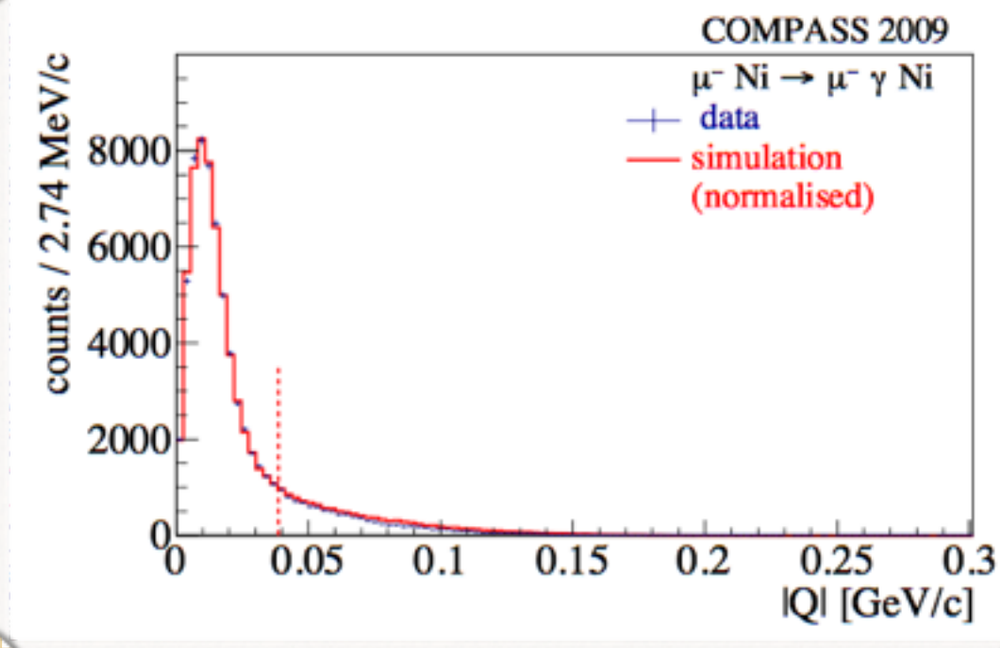
Muon data

The same selection + muon beam momentum measurement









Backup slides