Study of baryonic resonances in π^-+C reaction at 0.69 GeV/c

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PhD work supervised by

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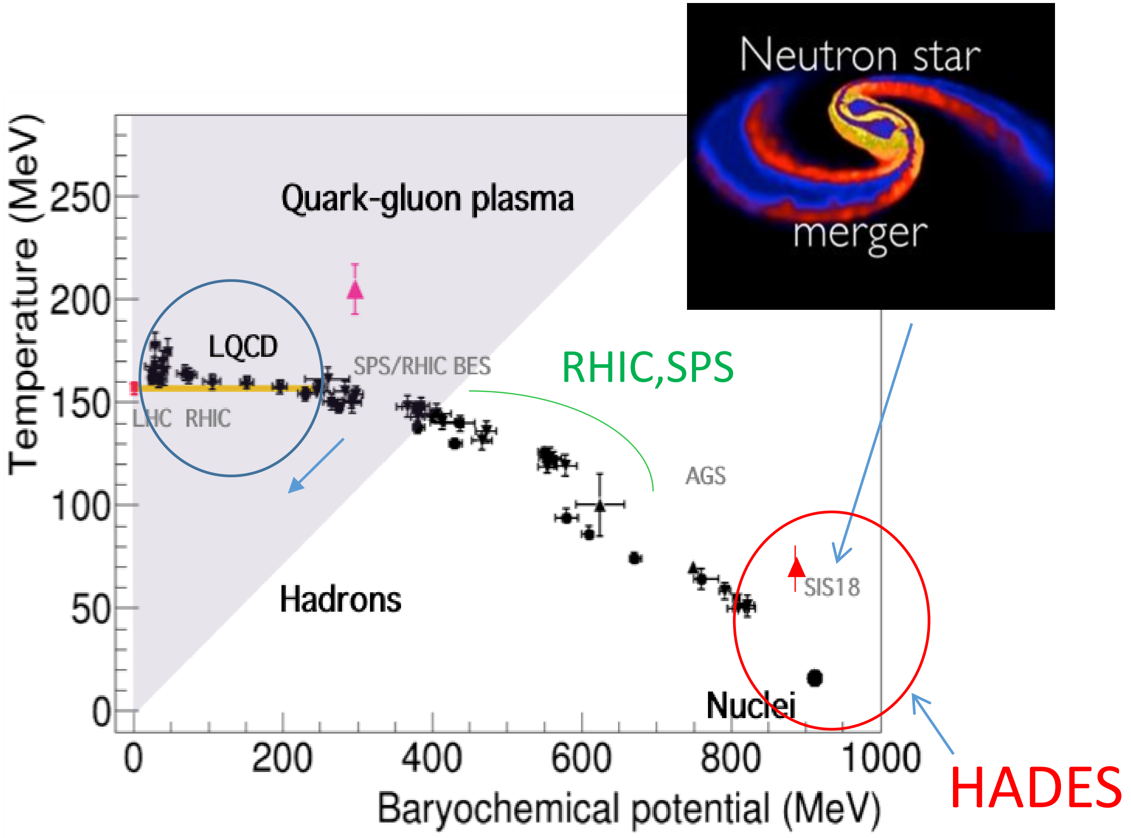
- Introduction

- Study of the quasi-elastic channel (QE) $\pi^{-}\mathrm{C} \rightarrow \mathrm{p}\pi^{-} + X'$
  - Comparison to INCL (Intranuclear Cascade model) and PLUTO (event generator for hadronic channels) .
  - Investigate sensitivity of data to short range correlations (SRC).

- Study of inelastic exclusive channels
  - $\pi^{-}\mathrm{C} \rightarrow \mathrm{p}\,\pi^{-}\pi^{-}$
  - $\pi^{-}\mathrm{C} \rightarrow \mathrm{p}\,\pi^{-}\pi^{+}$

QCD phase diagram studies (compl. to LHC, SPS, RHIC,…)



T. Galatyuk, NPA-D-18-00411 (2018) QM18

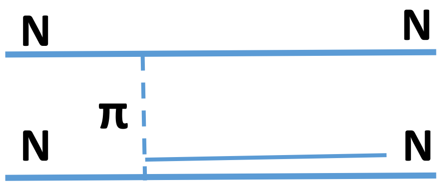
HADES objectives :
Study hadronic matter at moderate temperature and high baryonic density.

A+A: 1-3A GeV
$\sqrt{s_{NN}}$=2-2.4 GeV

- ❑ Microscopic structure of baryon dominated matter
Role of baryonic resonances (excited states of nucleons), hyperons

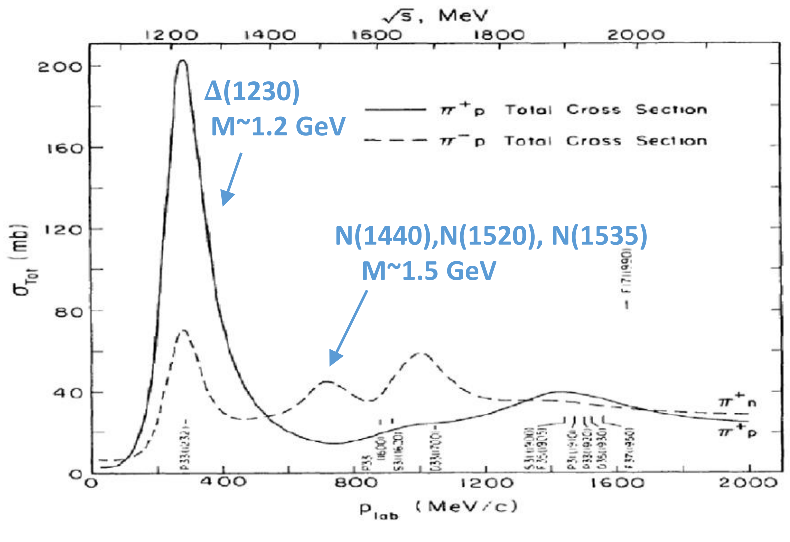
$\boldsymbol{\Delta(1232)}$
$\boldsymbol{N^*(1440)}$
$\boldsymbol{N^*(1520)}$
$\boldsymbol{N^*(1535)}$
Etc …

The Heavy Ion context

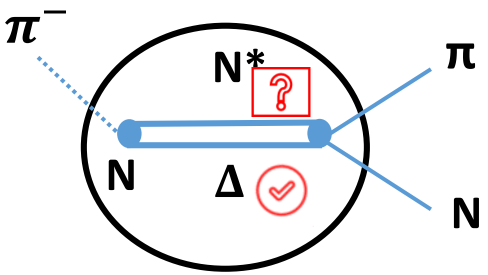


In heavy-ion collisions at a few AGeV, pion dynamics crucial to describe the evolution of the collision :

- ✓ real pions copiously produced
- ✓ NN interaction driven by pion exchange

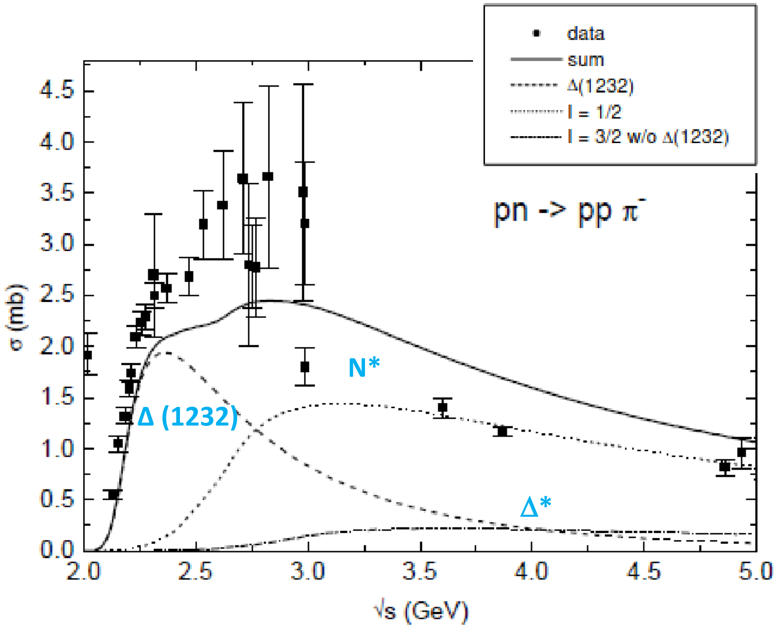


D. R. Marlow et al., Phys. Rev. C30, 1662 (1984), Pion cattering From C and Ca at 800-MeV/c.



$\pi^- N \to \pi^- N$ quasi-elastic process affected by rescattering.

$\Delta N \to NN$ absorption process is important.



S. Teis et al. Pion production in heavy ion collisions at sis energies. Z. Phys.,A356 :421, 1997.

Δ (1232) region (p_π =250 MeV/c) well-known

For p+A or A+A at $\sqrt{s_{NN}}$ > 2.6 GeV, information on higher lying resonances needed .
N(1520) region p_π ~ 700 MeV/c has not been explored.

$\pi^- + C$ in the 2^{nd} resonance region

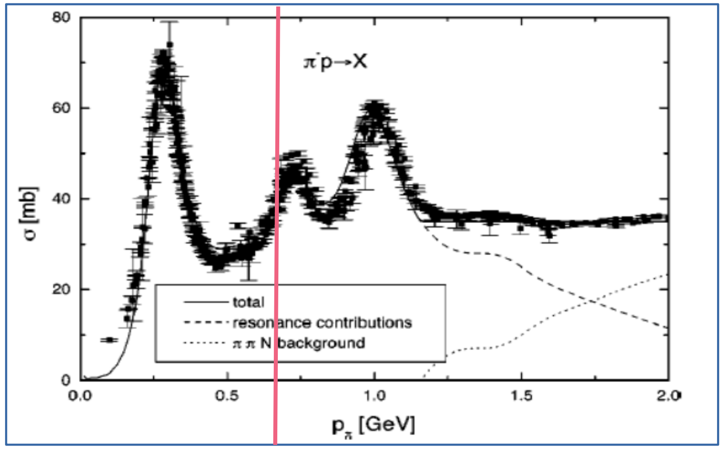
Investigate different hadronic exit channels in $\pi^- + {}^{12}C$ reaction for 2^{nd} resonance region :

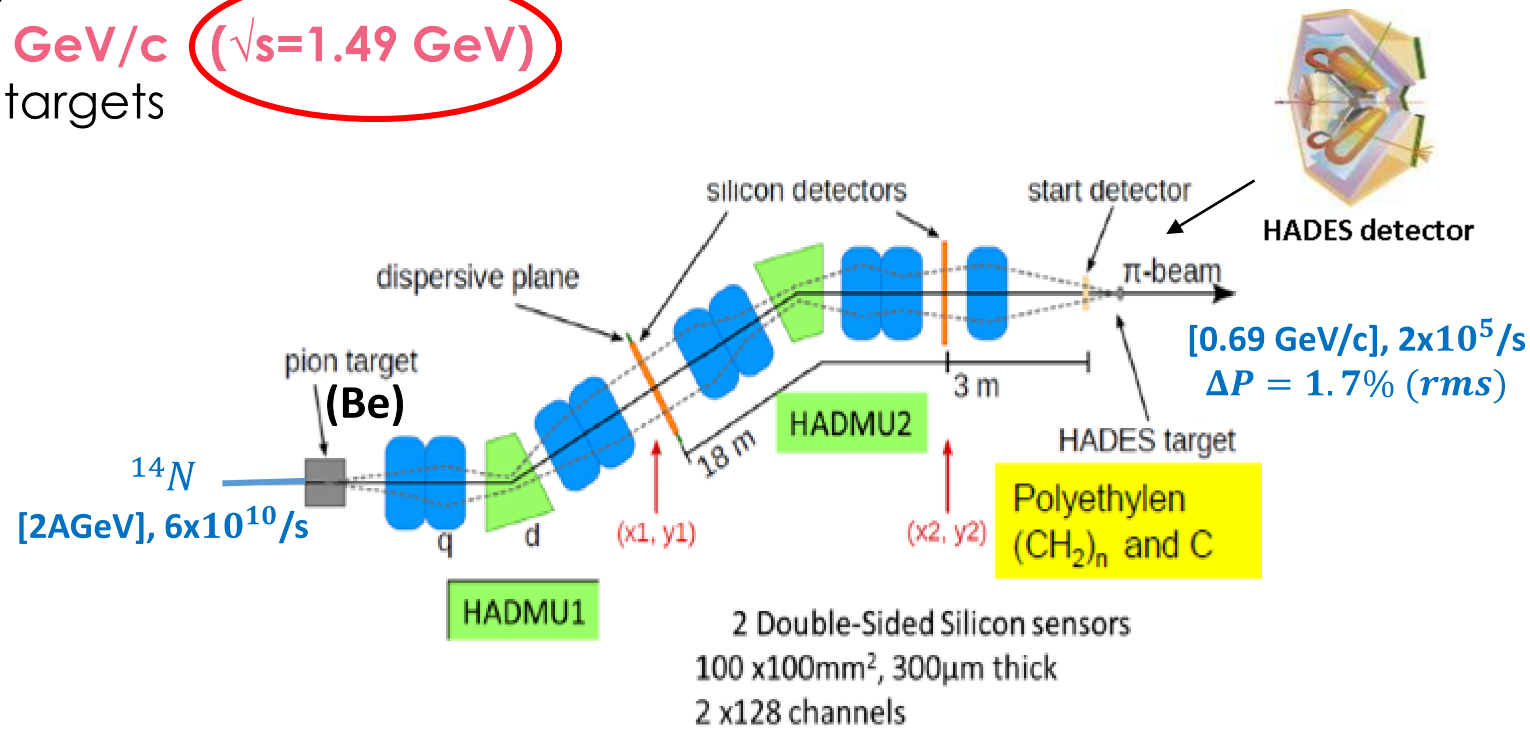
Provide very new data to an unexplored region .

- Important to test INCL++ cascade code used as a hadronic model in geant4 (binary collision, only $\Delta(1232)$ included)
- Important to test transport models used for the description of heavy ion collisions (includes all baryonic resonances) SMASH, RQMD…
- We also use PLUTO event generator to easily test phase space effects.
- Complementary to e+e- production channel already studied by HADES.

Pion beam experiment @ GSI

- **August 2014 commissioning experiment**
- Total ~15 days of measurements
- **Main run: momentum p_π = 0.690 GeV/c (√s=1.49 GeV)**
- Polyethylene (CH_2) and carbon targets
- Secondary pion beam





- **Data on carbon mainly used for subtraction of π^-+C interactions in CH2 target to study π^-+p reaction.**

  HADES collab., Phys.Rev. C102 (2020) no.2, 024001

- **Large statistics for hadronic channels (π^+, π^- ,p) on carbon target to be used for dedicated analysis .**

HADES

High Acceptance
DiElectron Spectrometer
(GSI, Darmstadt)

- **Acceptance: Azimuthal angles 85% (6 sectors)**
  polar angles: 18° - 85°
- **Detected particles: $e^{\pm}$, p, $\pi^{\pm}$, $K^{\pm}$**
- **Tracking: MDC**
- **p, $\pi^{\pm}$, $K^{\pm}$ identification TOF-Tracking**

Experiments (2004-2019)

Hadronic matter studies :

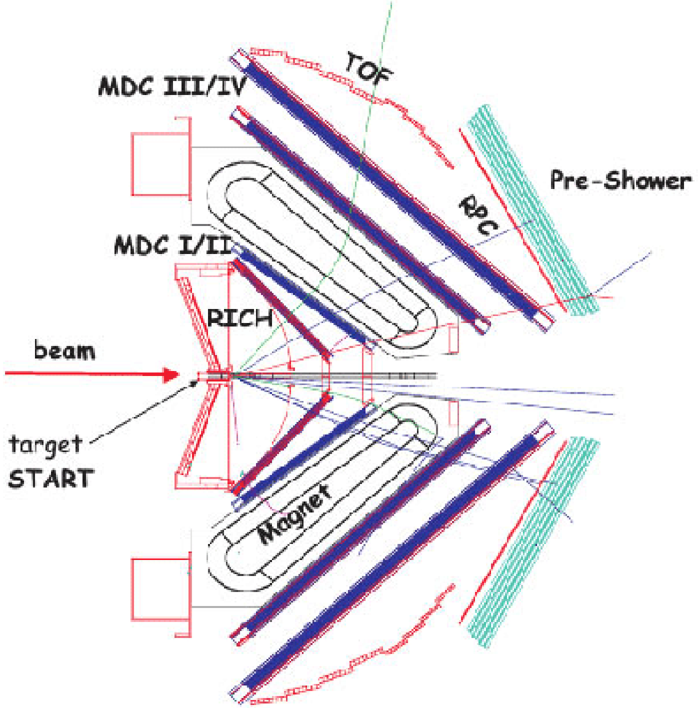
C+C 1 & 2 AGeV,
Ar+ KCl 1.75 AGeV
Au+Au 1.25 AGeV
Ag+Ag 1.65 AGeV

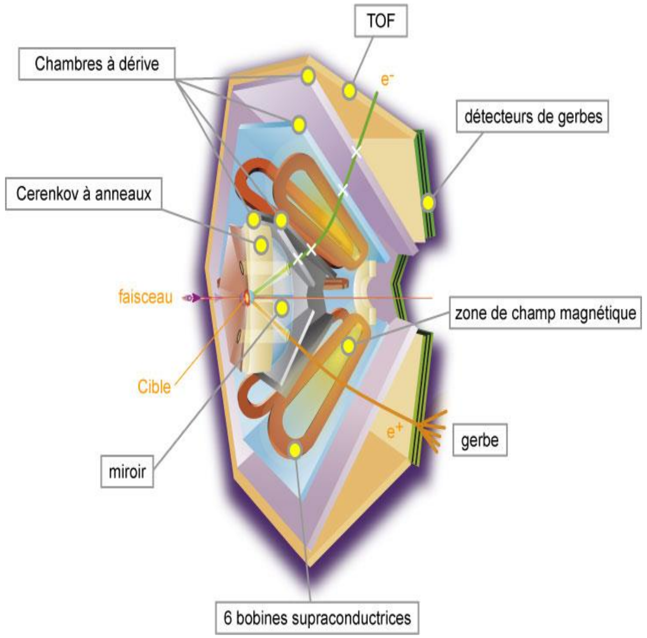
Cold matter :

p+Nb 3.5 GeV,
π^-+C/W 1.7 GeV/c

Elementary reactions :

p+ p 1.25, 2.2 , 3.5 GeV,
d+p 1.25 GeV/nucléon
π^-+CH_2/C 0.7 GeV/c





Data Analysis

DST (Data Summary Tape): Calibration-> included tracks and physics observables, P, ToF, dE/dx...

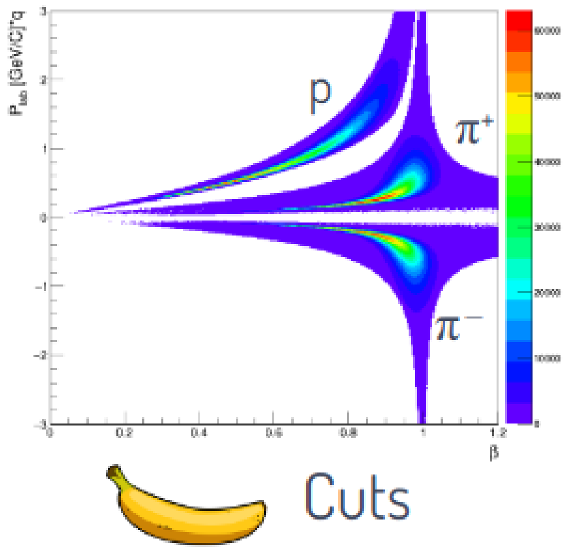
↓

PAT (PostDST Analysis Tool): Particle Identification + channel selection: ex: $1\pi^{+}$ $1\pi^{-}$ and 1 proton at least.

↓

FAT (Final Analysis Tool): File of events with all physical variables (invariant masses, angular distributions...)

Velocity Vs Momentum



Data normalisation (counts -> mb/unit) : $F_{Norm} = 2 \times \frac{\sigma_{el}}{N_{el}} \times F_{C/CH2}$

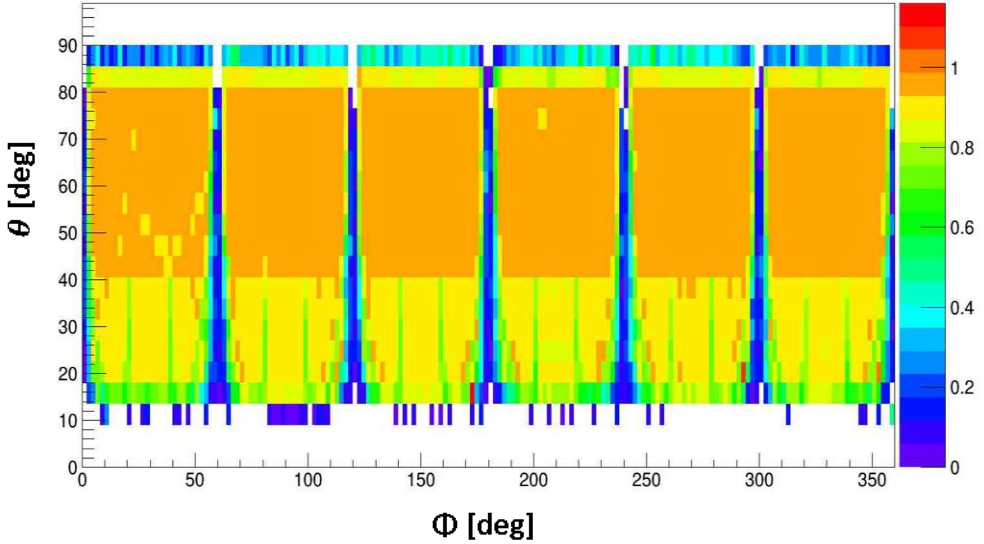
Based on π^{-}+ p elastic scattering in CH2 target and C/CH2 normalisation

Filtering of simulated events

Geant

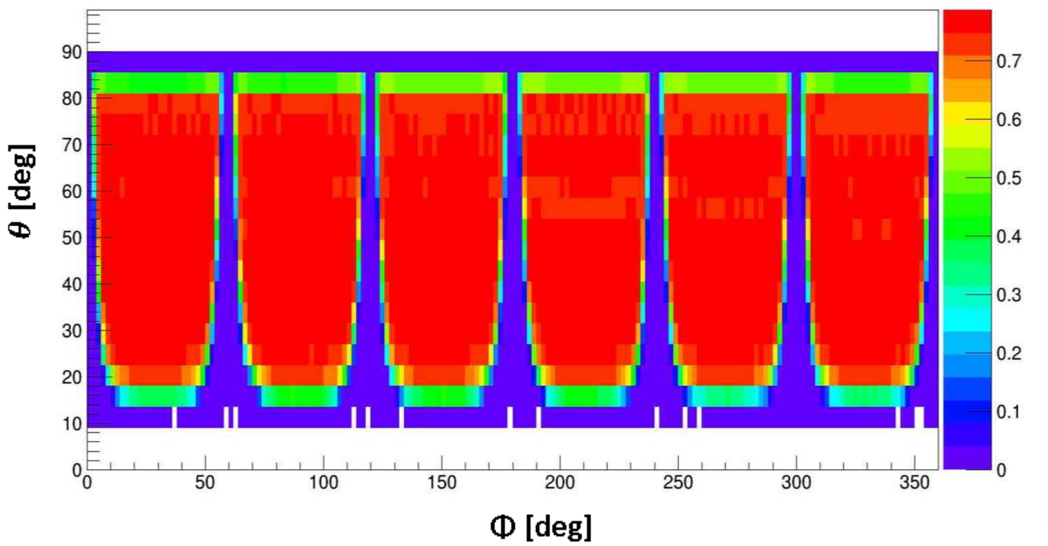
Efficiency matrices

π^- efficiency - projection yz



Acceptance matrices

Proton acceptance - projection yz



$$c_{acc}(p, \theta, \phi) = N_{acc}(p, \theta, \phi)/N_{4pi}(p, \theta, \phi)$$

$$c_{eff}(p, \theta, \phi) = N_{recons}(p, \theta, \phi)/N_{acc}(p, \theta, \phi)$$

+ smearing function of (p, θ, ϕ) to take into account the resolution

HADES

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  - Investigate sensitivity of data to short range correlations (SRC).

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  - $\pi^{-}\mathrm{C} \rightarrow \mathrm{p}\,\pi^{-}\pi^{+}$

Benchmark of models

Participant-spectator model : PLUTO

- ^{12}C = participant off-shell proton + spectator on-shell 11B
- π- interact with an off-shell proton moving with momentum distribution in agreement with $(e, e'p)$ (1)
- Further interaction of particles not taken into account
- Only elastic channels included (by choice).

IntraNuclear Cascade model : INCL

- ^{12}C= (on-shell nucleons) nucleon Fermi gas
- π- + p (moving and on-shell) → π- + p + X
- Further interaction of particles taken into account, depending on cross section

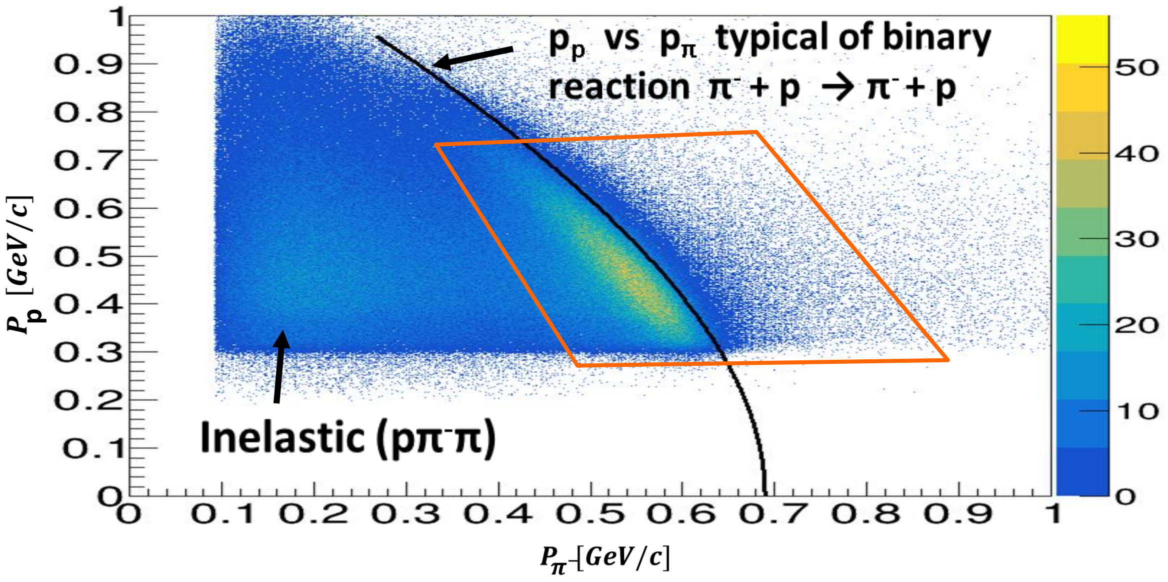
  Nuclear mean field is acting on products.
- inelastic channels are also included

Pluto is a Monte Carlo simulation framework developed by the HADES collaboration for heavy ion and hadronic-physics reactions.
INCL is used in toolkits for the simulation of the passage of particles through matter (Geant).

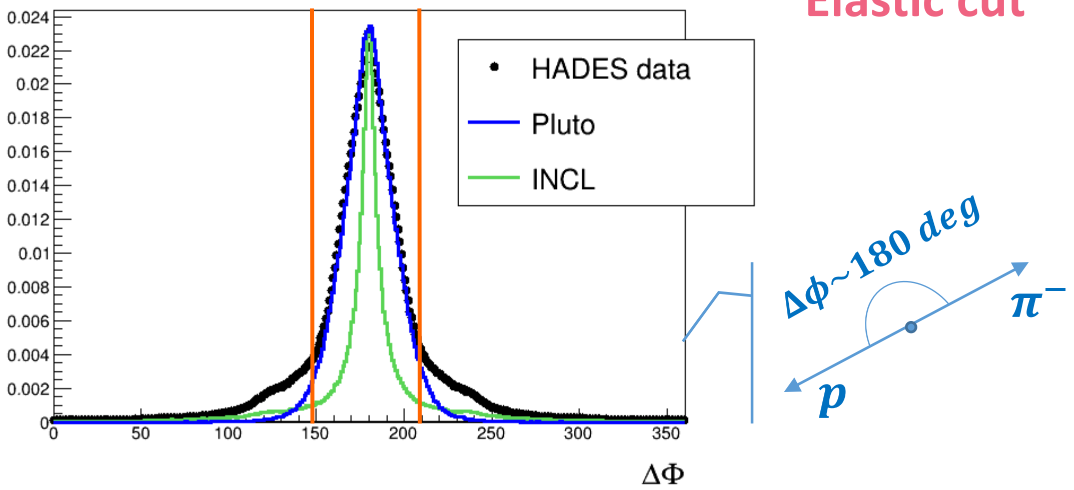
(1) K. Nakamura et al.,Nuclear Physics A, Volume 268, Issue 3, 21 September 1976, Pages 381-407

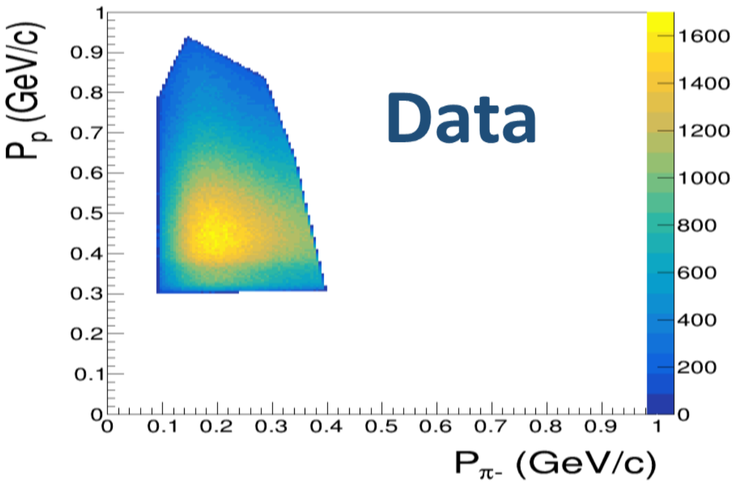
Quasi–elastic (QE) and inelastic cuts

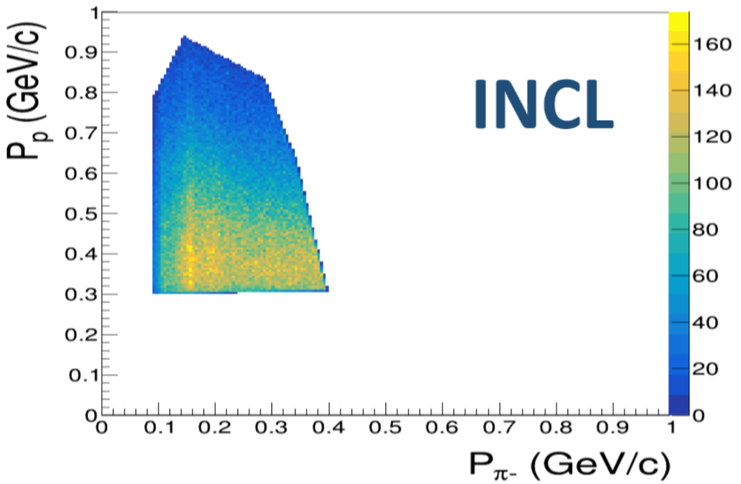
QE similar to $\pi^- + p \rightarrow \pi^- + p$ but still different



Elastic cut

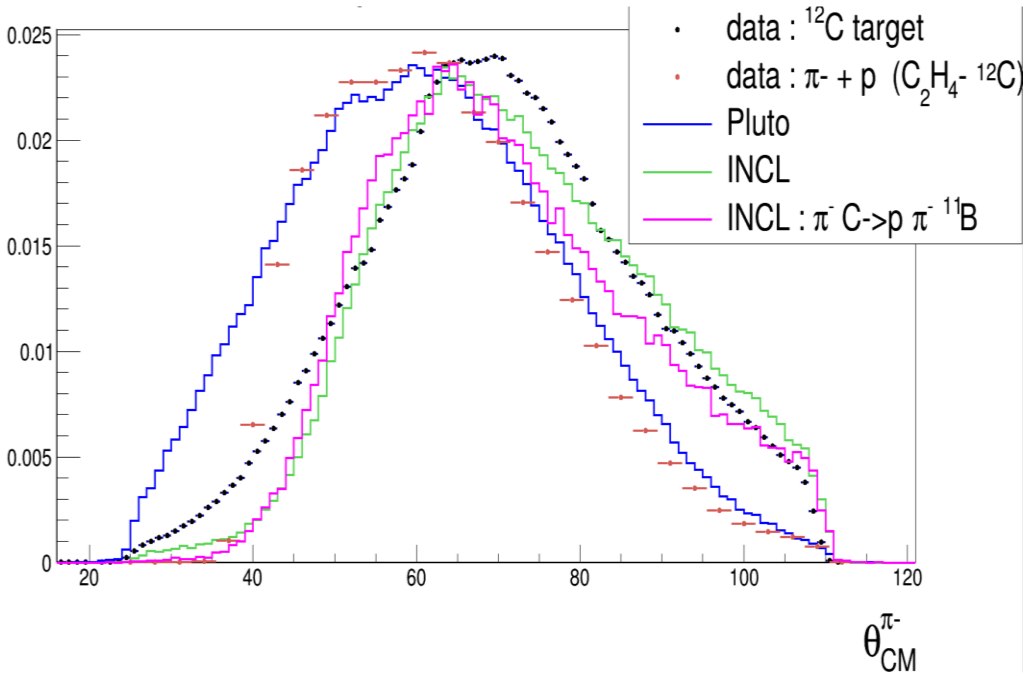






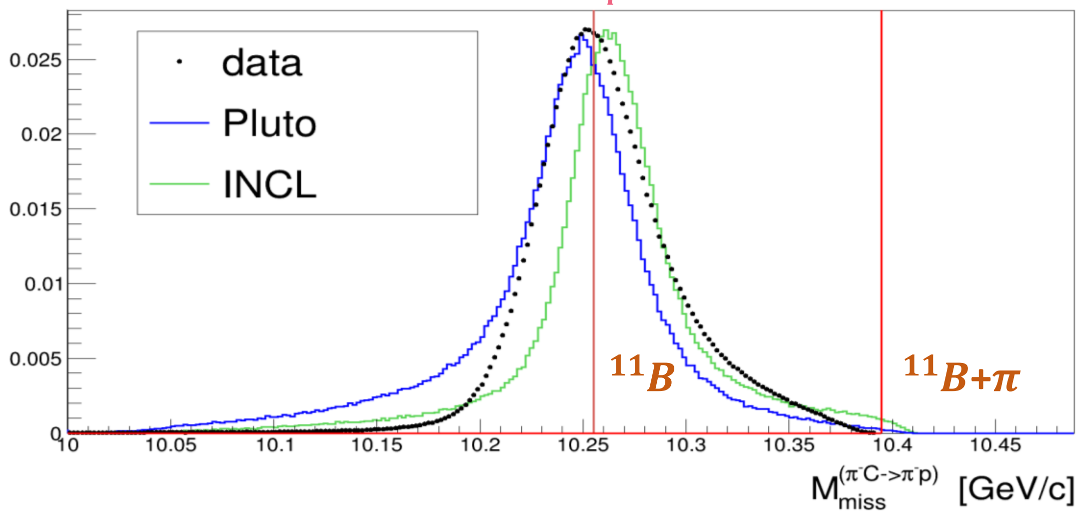
Inelastic cut

Angular distributions



Missing mass

$$M^2_{miss} = M^2_{(P_{\pi^-}+P_p-P_{\pi^-}{}^{inc}-P_C{}^i)}$$



Pluto: effective momentum distribution, no rescattering

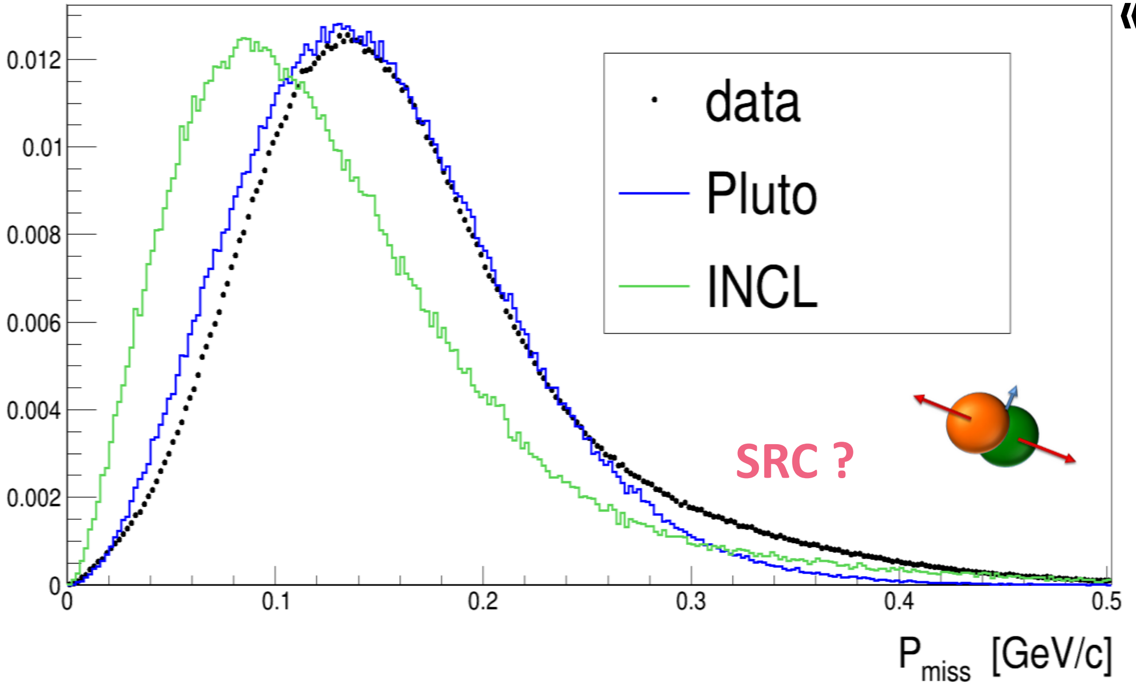
π- +'p'+ ^{11}B → π- + p + ^{11}B

INCL: Fermi gas + rescattering

- **Angular distribution is different from π^-+ p.**
- **INCL describes rather well the pion angular distribution**
- **PLUTO doesn't fit well the pion angular distribution ?**
- **Mmiss is close to ^{11}B mass.**

Fermi momentum

$$\overrightarrow{P_{miss}} = \overrightarrow{P^i_\pi} - \overrightarrow{P^f_\pi} - \overrightarrow{P^f_p}$$



« pure quasi-elastic » :

π- + p scattering on an off-shell participant (p, $\overrightarrow{P^i_p}$)

$$\overrightarrow{P^i_\pi} + \overrightarrow{P^i_p} = \overrightarrow{P^f_p} + \overrightarrow{P^i_\pi}$$
$$\overrightarrow{P_{miss}} = \overrightarrow{\Delta P} = -\overrightarrow{P^i_p}$$

SRC : short range correlations
Nucleon pairs that are close together in the nucleus high relative and low c.m. momentum, compared to the Fermi momentum (kF)

Pluto : effective spectral function: describes the missing momentum quite well.
INCL : Fermi gas distribution + rescattering : proton momentum underestimated
Data : Large tail for high proton momentum in Carbon. SRC or rescattering effects?

Reaction mecanisms for $\pi^- + {}^{12}C \rightarrow \pi^- + p + X'$

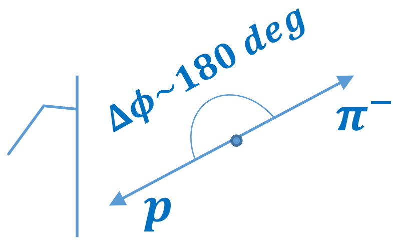
$\pi^- p \rightarrow \pi^- p$
Or ch.ex.
$\pi^- p \rightarrow \pi^0 n \rightarrow \pi^- p$?

- $N_{collisions} = 1$ ($N_\pi = 1$) — Pure quasi-elastic
- $N_{collisions} > 1$
  - $N_\pi = 1$ — Quasi-elastic + rescattering (NN)
  - $N_\pi > 1$ — Quasi-elastic+ inelastic (pion production)

$\pi^- p \rightarrow \pi\, \pi\, N$

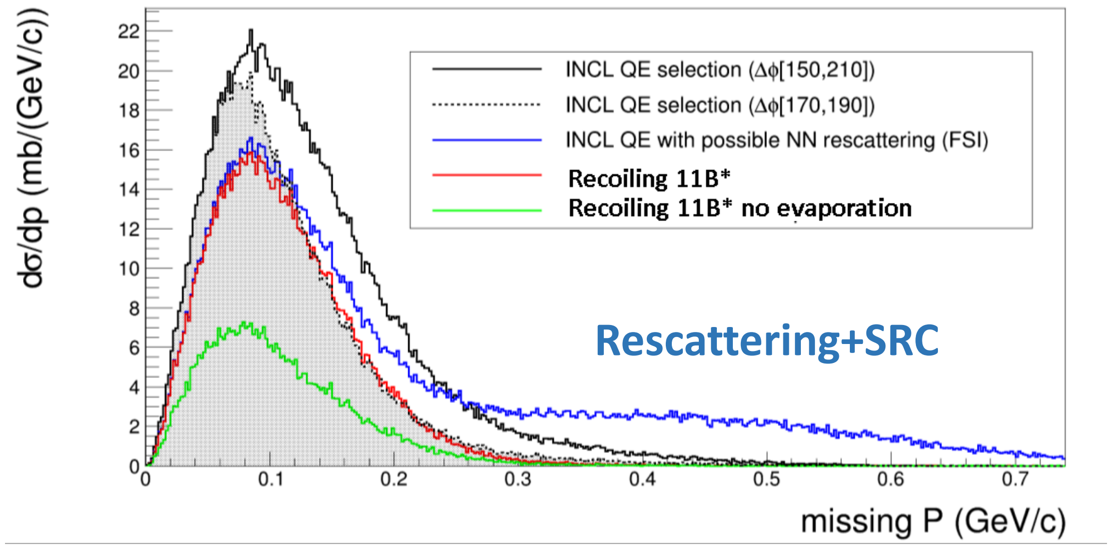
- $N_{collisions} = 1$ — $N_\pi > 1$ — Inelastic
- $N_{collisions} > 1$
  - $N_\pi = 1$ — Inelastic + pion absorption
  - $N_\pi > 1$ — Inelastic + rescattering

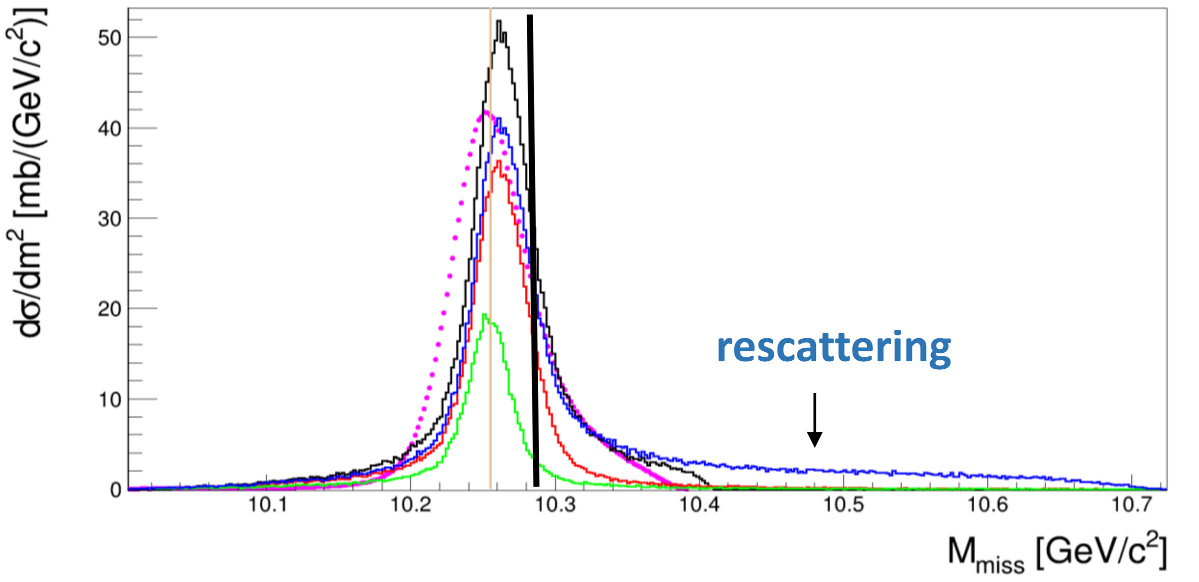
SRC preliminary study:



Adjusting cuts to reduce rescattering effects :

- **Restrict $\Delta\varphi$ (coplanarity condition of p and π^-)**
- **Cut high missing mass values (=high excitation energies)**





QE cross section

- **Acceptance correction :**

For each spectrum :

$$\frac{1}{F^{4\pi}_{corr\ (i)}} = \frac{Bin\ Content_i^{(Acc)}}{Bin\ Content_i^{(4\pi)}}$$

$$\sigma^{Data}_{C,QE}(4\pi) = 5.93 \pm 0.39\ \text{mb}$$

(preliminary)

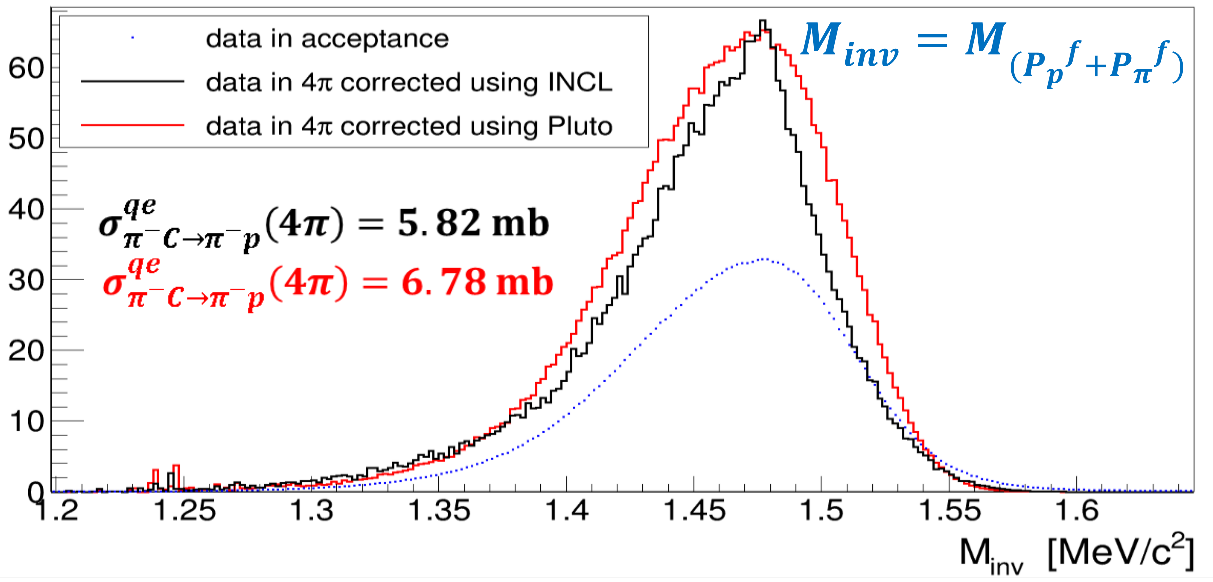
$$\sigma^{INCL}_{C,QE}(4\pi) = 6.14\ \text{mb}$$

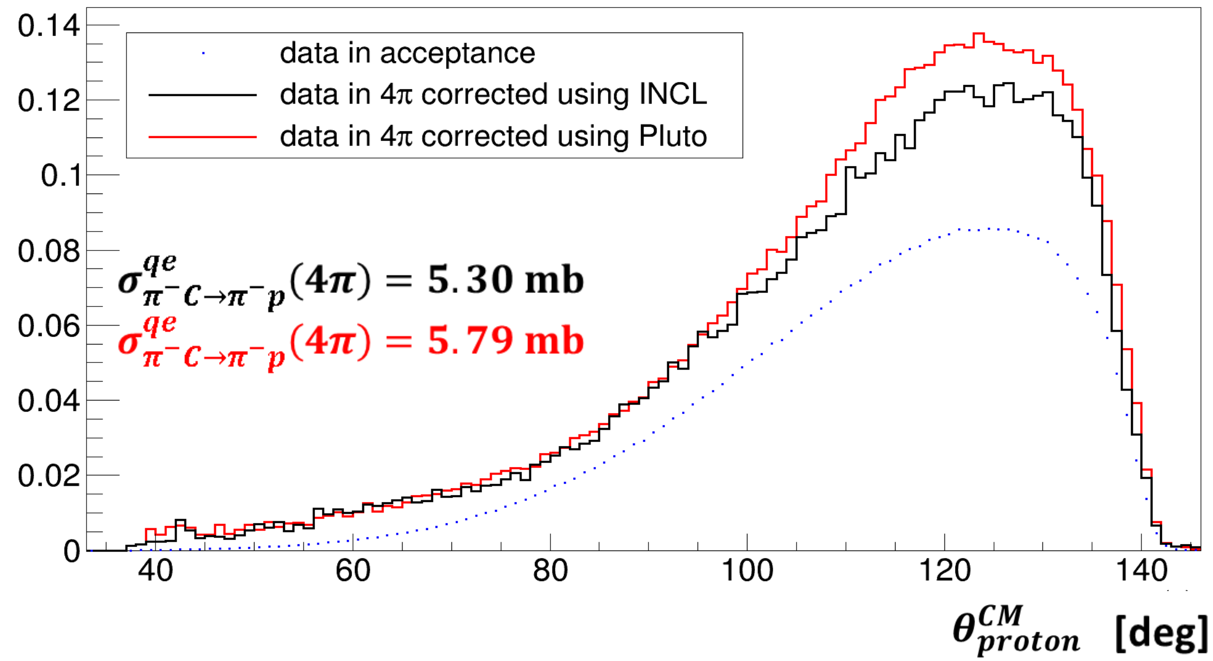
$\sigma_{C,QE} = \sigma_{H,el}\, Z_{eff}^{2/3}$

✓ $\sigma_{H,el}$ ~ 19.0 mb $\pm 1.0\ mb$

→ Z_{eff} = 0.175 $\pm$ 0.03

Z_{eff} << 6





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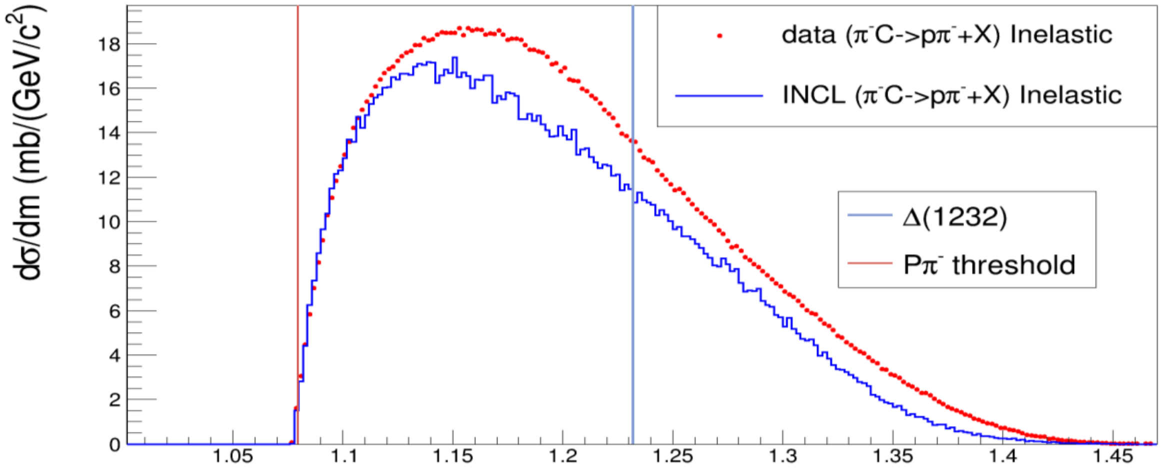
Inelastic yields

- **No clear presence of $\Delta(1232)$:**

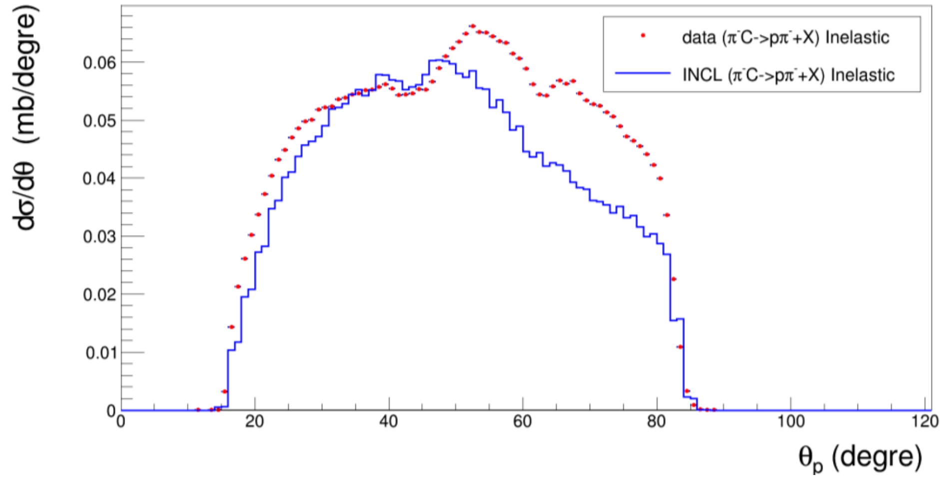


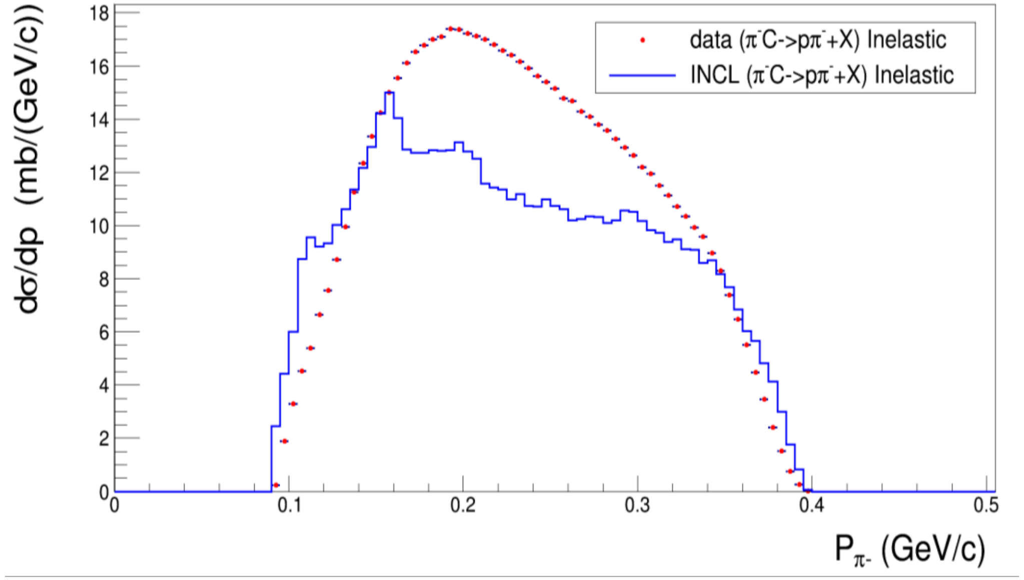
$$M_{inv} = M_{(P_p{}^f + P_\pi{}^f)} \;[\mathrm{GeV}/c^2]$$

$$N^* \rightarrow \Delta^0\pi^0 \;,\; \Delta^0 \rightarrow p\pi^- \;\; (+\,possible\ rescattering)$$
$$\Delta^+\pi^- \;,\; \Delta^+ \rightarrow \mathrm{p}\pi^0$$

- **INCL underestimates inelastic channels by 20%.**

→ Better investigation of the different processes, looking at exclusive channels $p\pi^-\pi^-$ and $p\pi^-\pi^+$





$\pi^- C \rightarrow p\pi^-\pi^- + X'$:

- $\pi^- + n \rightarrow p + \pi^- + \pi^- + {}^{11}C$ primary collision

- $\pi^- + n \rightarrow p + \pi^- + \pi^- + {}^{11}C$
  - ↳ $\pi^- + p \rightarrow \pi^- + p + {}^{10}B$
- $\pi^- + p \rightarrow \pi^- + p + {}^{11}B$
  - ↳ $\pi^- + n \rightarrow p + \pi^- + \pi^- + {}^{10}B$
- $\pi^- + n \rightarrow \pi^- + n + {}^{11}C$
  - ↳ $\pi^- + n \rightarrow p + \pi^- + \pi^- + {}^{10}C$

π^- N→ $\pi^-\pi^-$N
followed or preceeded by a quasi-elastic
π^-N → π^-N step

- $\pi^- + p \rightarrow \pi^- + p + {}^{11}B$
  - ↳ $p + n \rightarrow p + p + \pi^- + {}^{10}B$
- $\pi^- + n \rightarrow \pi^- + n + {}^{11}C$
  - ↳ $n + p \rightarrow p + p + \pi^- + {}^{10}B$
- $\pi^- + n \rightarrow \pi^- + n + {}^{11}C$
  - ↳ $n + n \rightarrow p + n + \pi^- + {}^{10}C$

quasi – free
$\pi^- N \rightarrow \pi^- + N$
followed by
$NN \rightarrow NN\pi^-$

would imply the 1^{st} π to be emitted backwards → not detected

$\pi^- C \rightarrow p\pi^-\pi^+ + X'$:

- $\pi^- + p \rightarrow \pi^- + p + \pi^- + \pi^+ + {}^{11}B$

primary collision (but with a very small cross section)

- $\pi^- + p \rightarrow \pi^- + p + {}^{11}B$
  ↳ $\pi^- + p \rightarrow n + \pi^+ + \pi^- + {}^{10}Be$

- $\pi^- + p \rightarrow \pi^- + \pi^+ + n + {}^{11}B$
  ↳ $\pi^- + p \rightarrow \pi^- + p + {}^{10}Be$

- $\pi^- + p \rightarrow \pi^0 + n + {}^{11}B$
  ↳ $\pi^0 + p \rightarrow p + \pi^+ + \pi^- + {}^{10}Be$

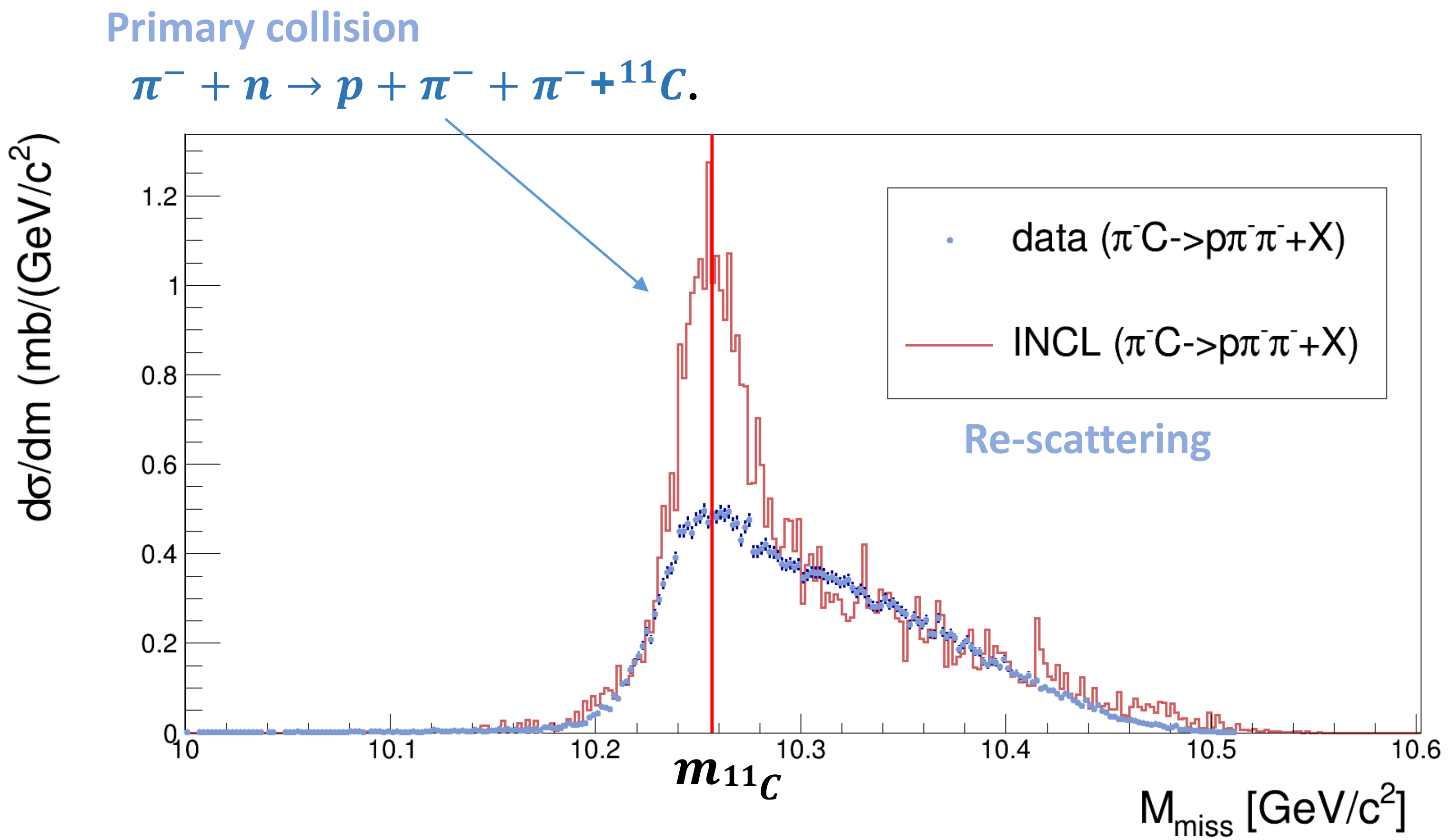
$quasi - free$
$\pi^- N \rightarrow \pi \ + N$
followed or preceeded by
$\pi \ N \rightarrow N\pi^-\pi^+$

- $\pi^- + p \rightarrow \pi^- + p + {}^{11}B$
  ↳ $p + p \rightarrow n + p + \pi^+ + {}^{10}Be$

$quasi - free$
$\pi^- N \rightarrow \pi^- + N$
$followed\ by$
$NN \rightarrow NN\pi^+$

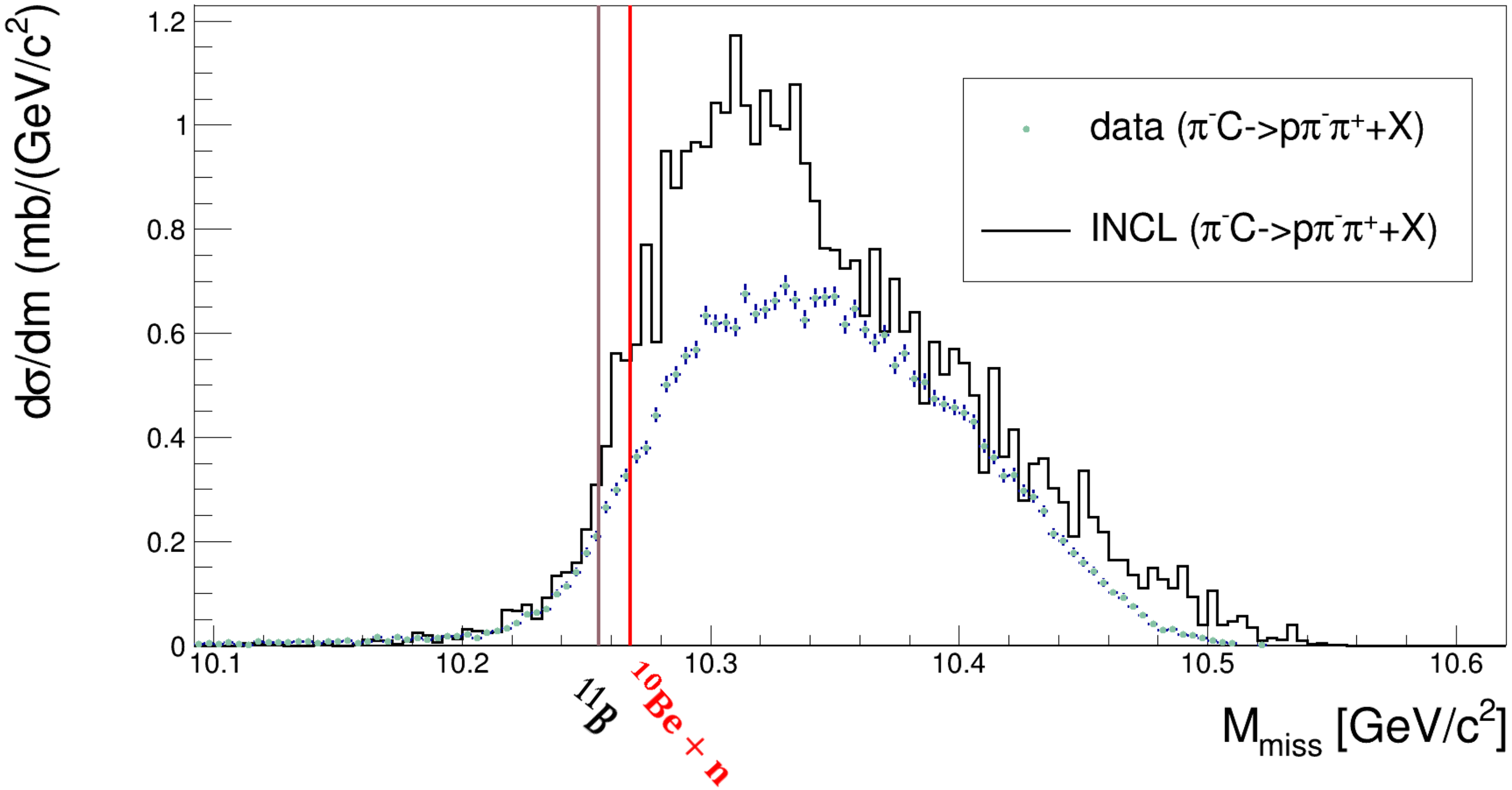
would imply the 1^{st} π to be emitted backwards → not detected

$p\pi^-\pi^-$ channel (absolute normalisation) :



- **much smaller contribution from primary collision than predicted by INCL**
- **broad distribution for higher missing mass values -> remnant is more excited due to rescattering : of pion and/or nucleon.**

$p\pi^-\pi^+$ channel (absolute normalisation) :



- $p\pi^-\pi^-$ yield overestimated by INCL

- Different from $p\pi^-\pi^-$ channel, no production from a primary reaction

→ allows a selective study of rescattering processes

Conclusion :

✓ Study of different channels in π^{-}C reaction @ 0.69 GeV/c: Quasi-elastic $(\pi^{-}C \rightarrow p\pi^{-} + X')$, rescattering and 2 pion production : $\pi^{-}C \rightarrow p\pi^{-}\pi^{+} + X'$, $\pi^{-}C \rightarrow p\pi^{-}\pi^{+} + X'$.

✓ Detailed comparison with models, starting with INCL : Discussions with experts on-going to adjust some parameters.

Quasi-elastic:

- INCL describes rather well the yields of elastic and inelastic channels but doesn't describe perfectly the kinematics and excitation energies distributions.
- Extraction for the quasi-elastic cross section in 4π : $\sigma^{\mathrm{Data}}_{\pi^{-}C\rightarrow\pi^{-}p}(4\pi) = 5.93 \pm 0.39\ \mathrm{mb}$ (preliminary). systematic errors to be checked (acceptance corrections using other models).

Multipion events: allow for a detailed test of multi-pion production mechanisms and rescattering.

Outlook :

- ➢ Investigations of rescattering/Short Range Correlations effects in the QE process.
- ➢ On-going studies with transport models (including baryonic resonances) SMASH, RQMD.
- ➢ Other channels to be studied (ppX,…) → π absorption channels .

Thank you for you attention !

Backup

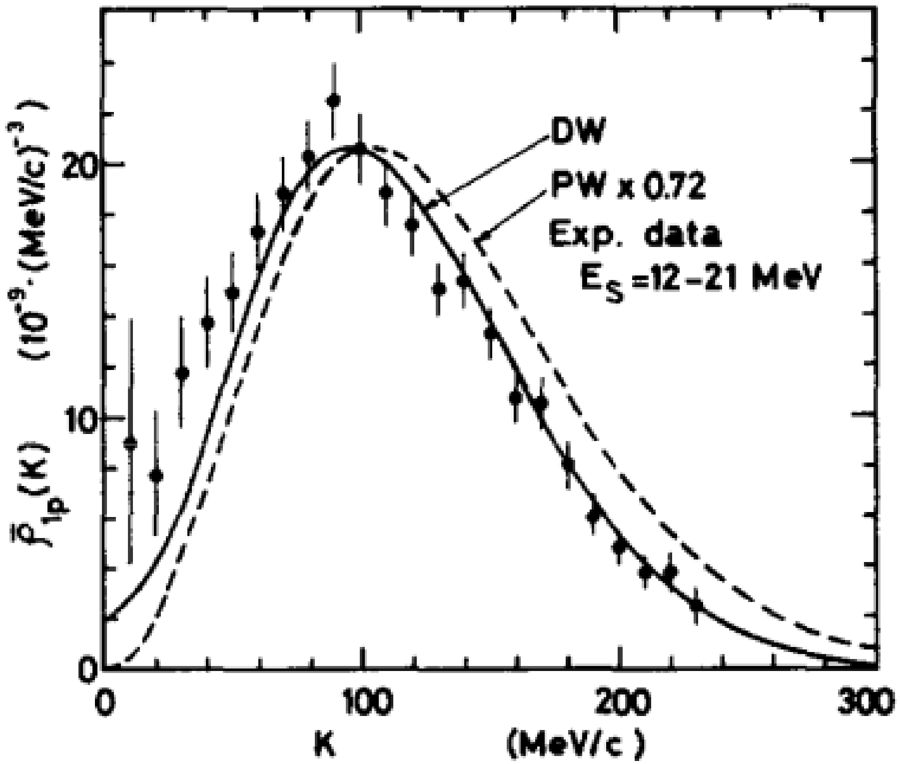


Fig. 10a. Distorted (DW) and undistorted (PW) momentum distributions for the $1p_{3/2}$ proton state of ^{12}C, calculated from the bound-state potential given by Elton and Swift [12]). Data points are arbitrarily normalized.

K. Nakamura et al.,Nuclear Physics A, Volume 268, Issue 3, 21 September 1976, Pages 381-407

NORMALISATION counts → mb/unit

Data : $F_{Norm} = 2 \times \frac{\sigma_{el}}{N_{el}} \times F_{C/CH2}.$

- **Normalisation for pi-+p cross section CH2 target (all statistics):** $\frac{\sigma_{el}}{N_{el}} = 1.107\text{x}10^{-7}$
  - σ_{el} - known cross-section of elastic scattering in full solid angle.
  - N_{el} - number of elastic scattering events in full solid angle
  - N_R - number of collisions of the reaction of interest.
- **relative normalisation C (all stat.)/CH2 (all stat.) =** $F_{C/CH2}$ **= 1./0.2178.**

INCL : $$F_{Norm} = \frac{\sigma_{reaction}}{\text{Number of shots}}$$

- $\sigma_{reaction}$ = 1462.32 mb.
- Number of shots = 100 000 000.

Local E (J.C David)

- Particles move in straight lines
- Momentum of the particles does not change
- For a given momentum (p), a particle can move in sphere of radius Rmax(p)

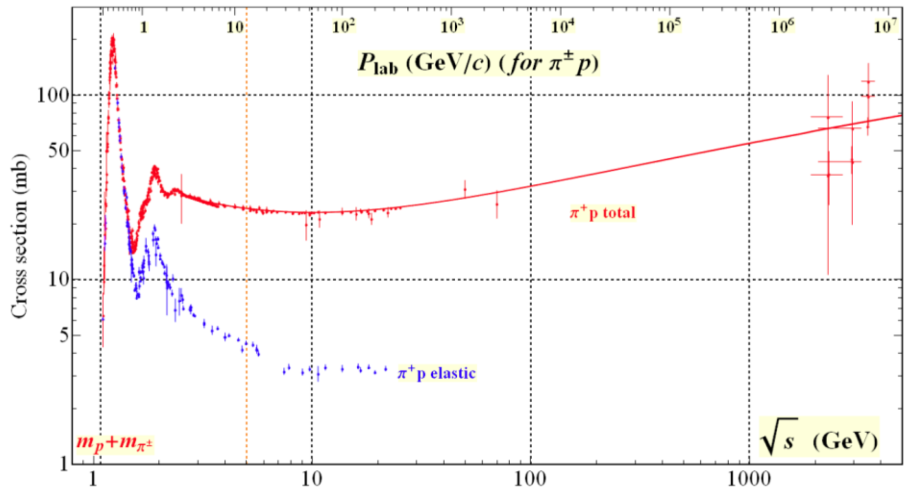
And this works well!

However, at low energy, interaction cross sections vary rapidly with « p »
→ The right momentum is needed
→ INCL momentum must be corrected
→ A local energy must be calculated (to get the right cross sections)

How?
→ At a position « r », the minimum momentum to reach it is p_min such as r=Rmax(p_min)
→ Then, at this position, the minimum energy required to reach it is $E\_min=(p\_min^2 + m^2)^{1/2} – m$
→ And, at this position, a particle of momentum p_min should have no more kinetic energy, but a potential energy instead
→ This potential energy is E_min
→ And this potential must be substracted to the energy of your particle (probably higher than E_min)

Local energy = E_min

Local E (J.C David)



HADES: 0.680 MeV/c

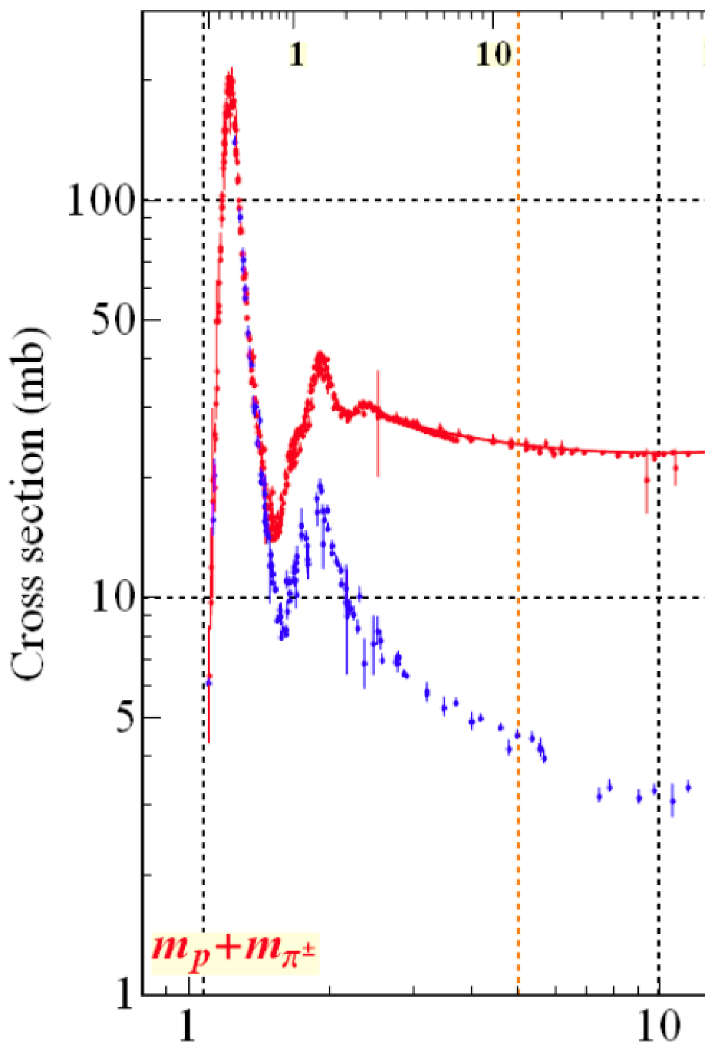
If we consider a proton of p=250 MeV/c

→ E_{CM}=1.61 GeV (without local energy)

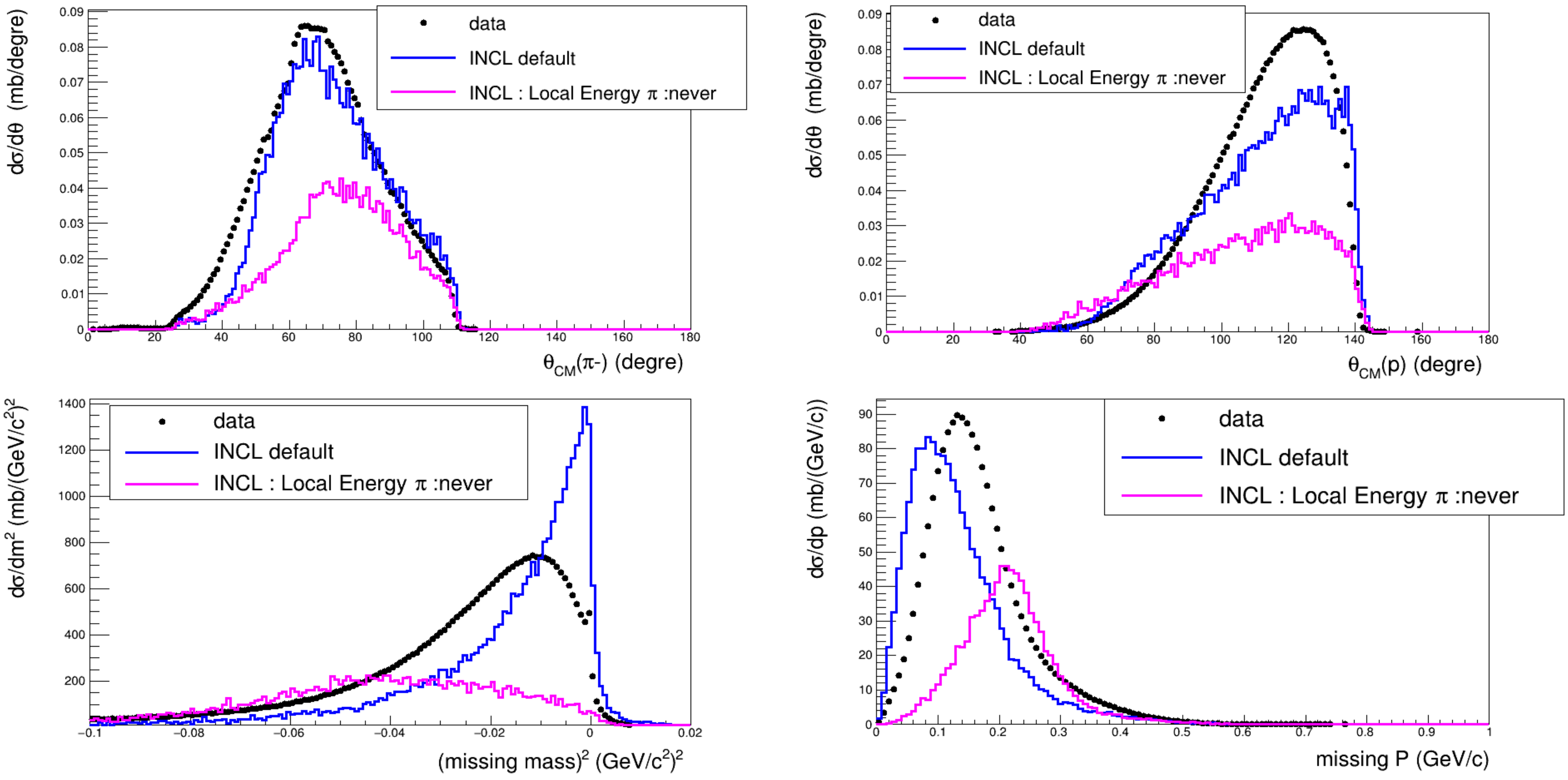
→ E_{CM}=1.48 GeV (with local energy)

To be checked, but

The proportion of elastic increases with local energy…



Local E test INCL



Quasi-free $\pi^- p \rightarrow \pi^- p$ followed by $NN \rightarrow NN\pi^-$ kinematics :

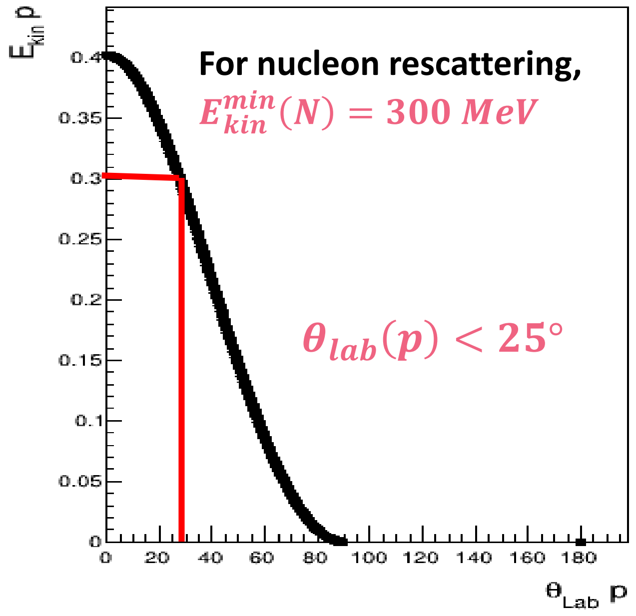
(I.Ciepal)

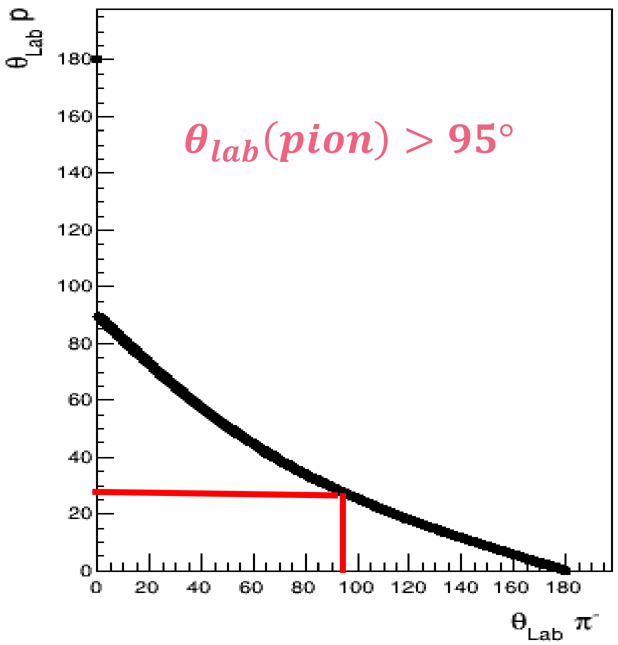
Minimum nucleon energy for $NN \rightarrow NN\pi^-$ > 300 MeV

θ_{lab} π^- > 95°

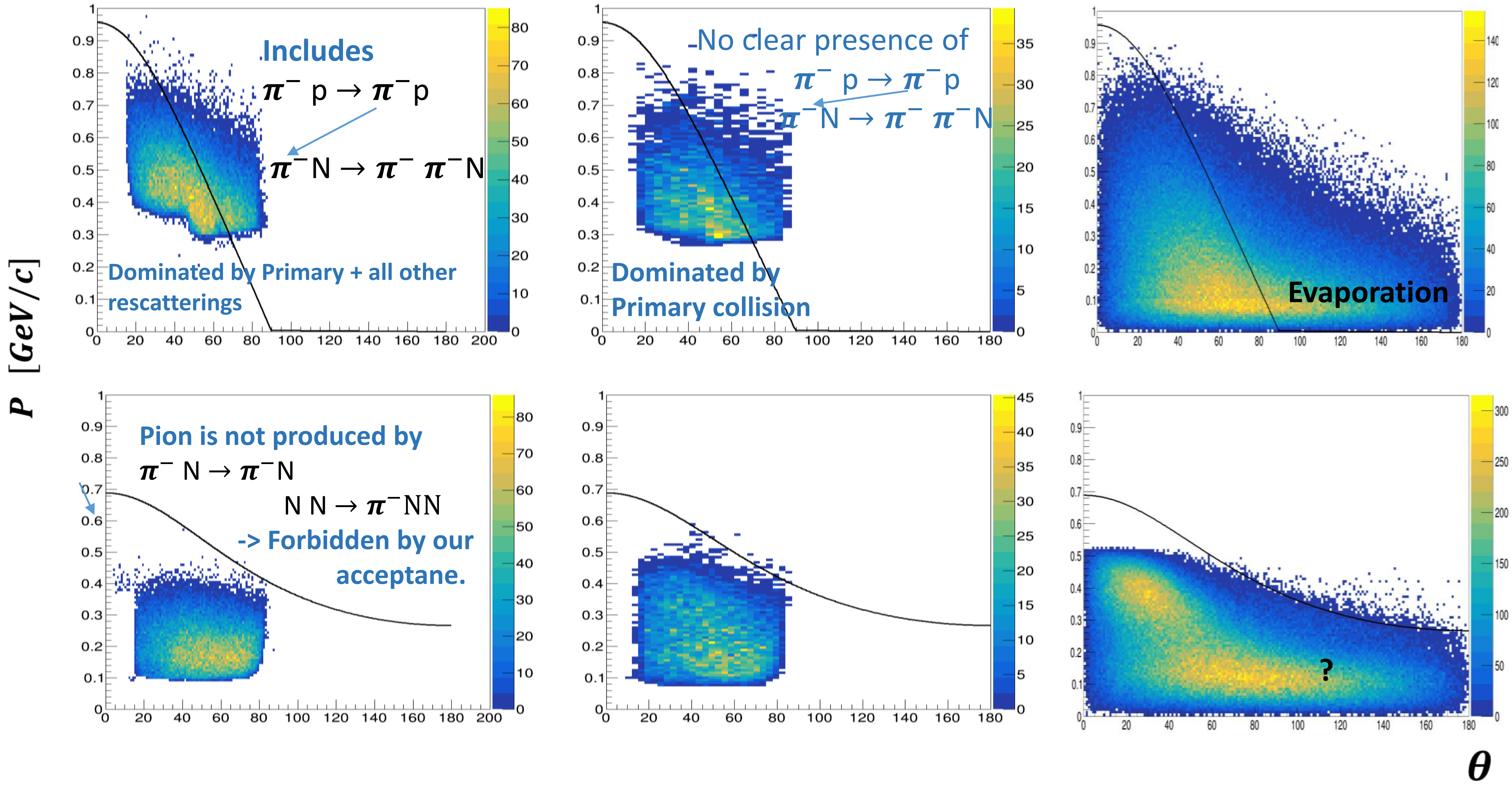
Pion not detected

Most events expected from $\pi^- N \rightarrow \pi^- \pi^- N$ (with or without rescattering).

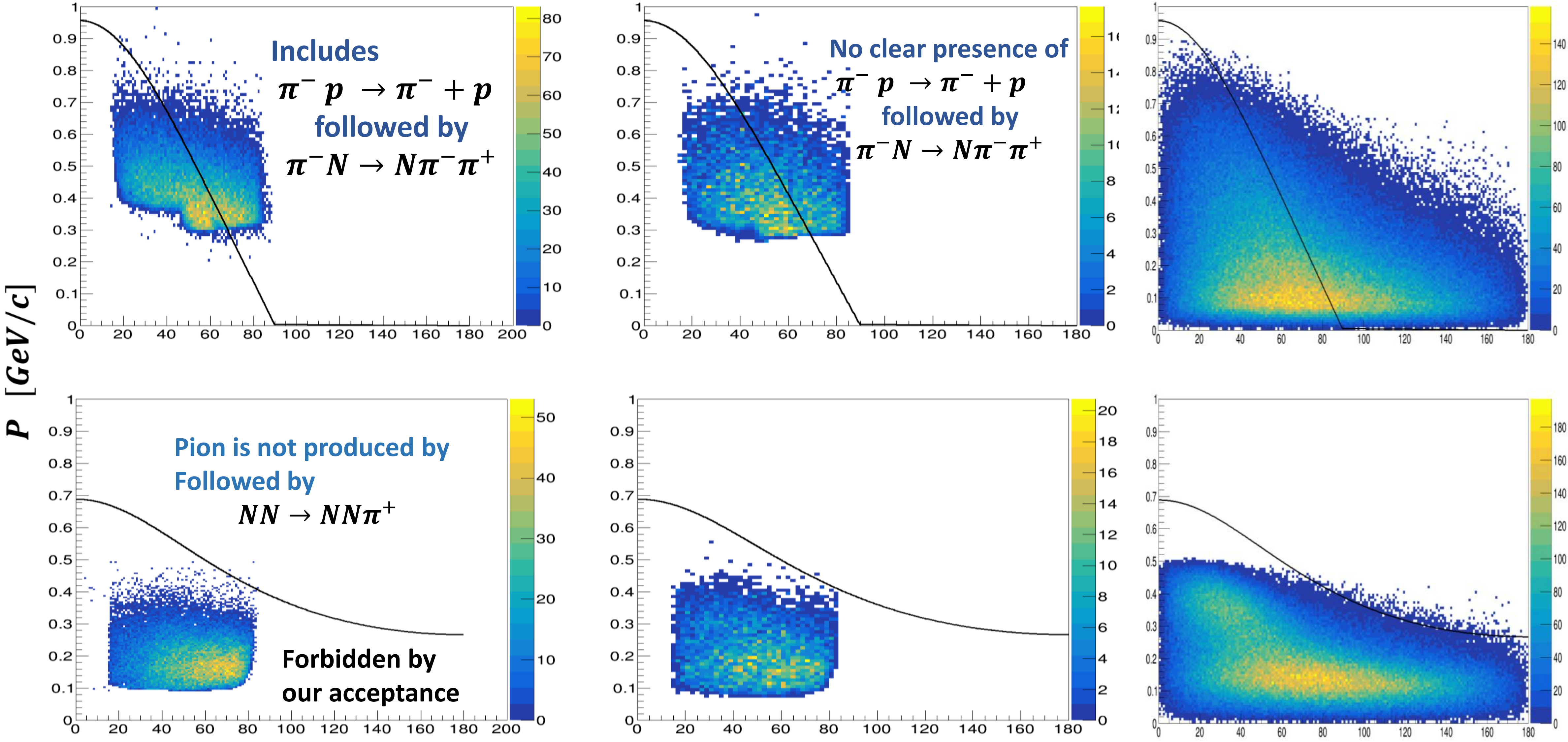




$p\pi^-\pi^-$ channel kinematics : data & INCL



$p\pi^-\pi^+$ channel kinematics : data & INCL



Evidence for free elastic scattering

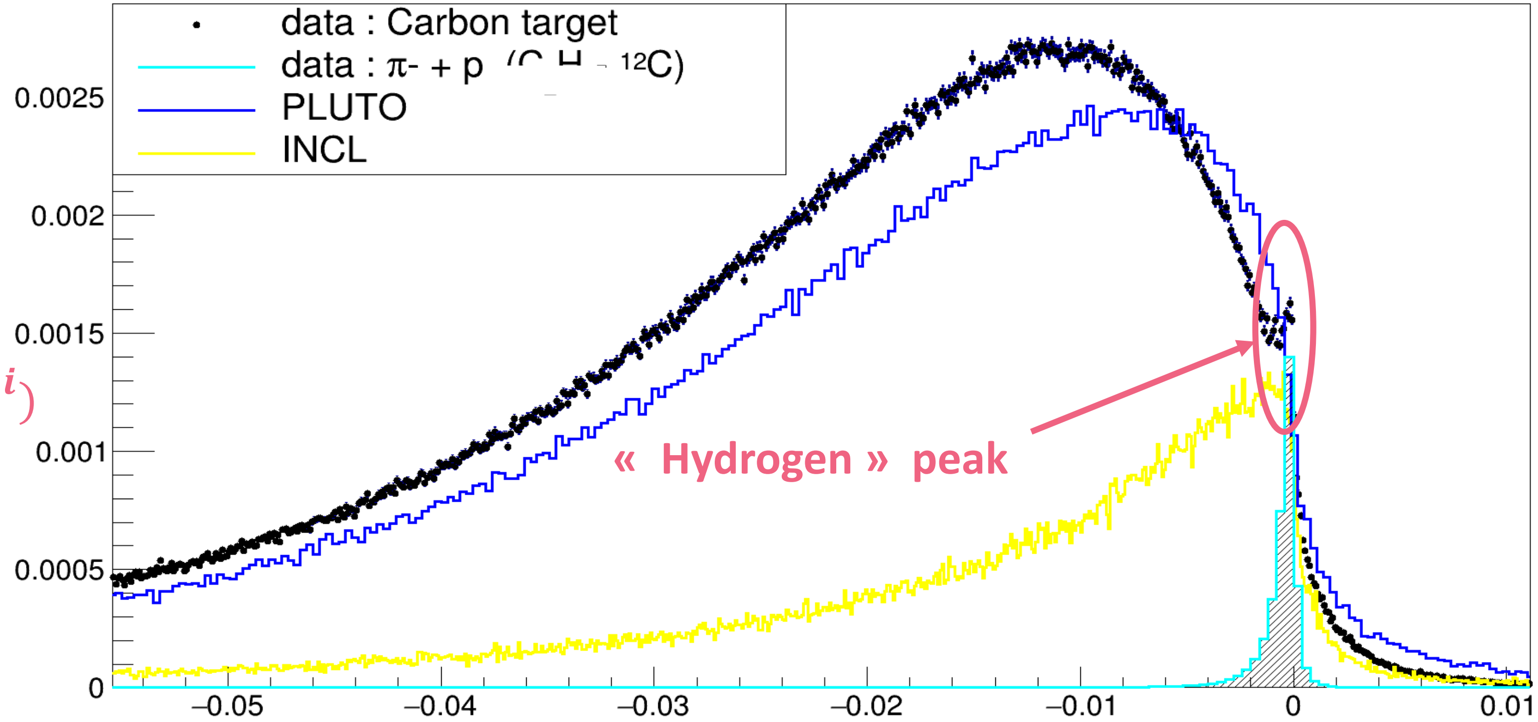
Data (on proton target) :

- Narrow peak expected due to energy and momentum conservations.

Data (on Carbon target) :

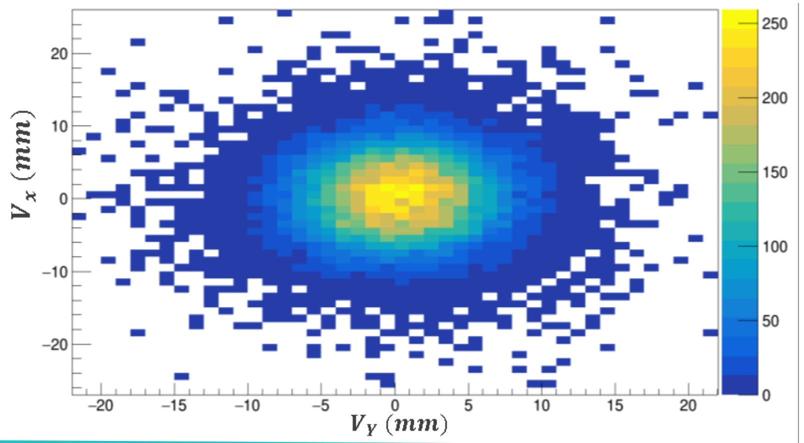
- Broader distribution due to Fermi momentum + rescattering.
- Effect partially described by the simulations. Pluto describes much better Mmiss.
- Intriguing small peak similar to free elastic → interactions with hydrogen in C target !

$$M^2_{miss} = M^2_{(P_{\pi^-}+P_p-P_{\pi^-}{}^{inc}-P_p{}^{i})}$$

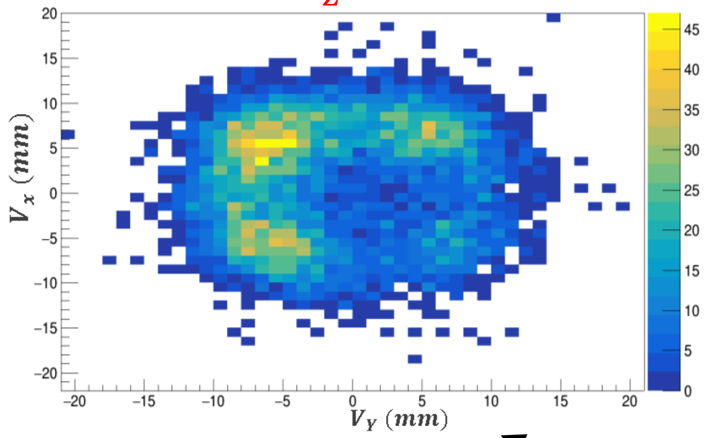


Vertex study for hydrogen-like events :

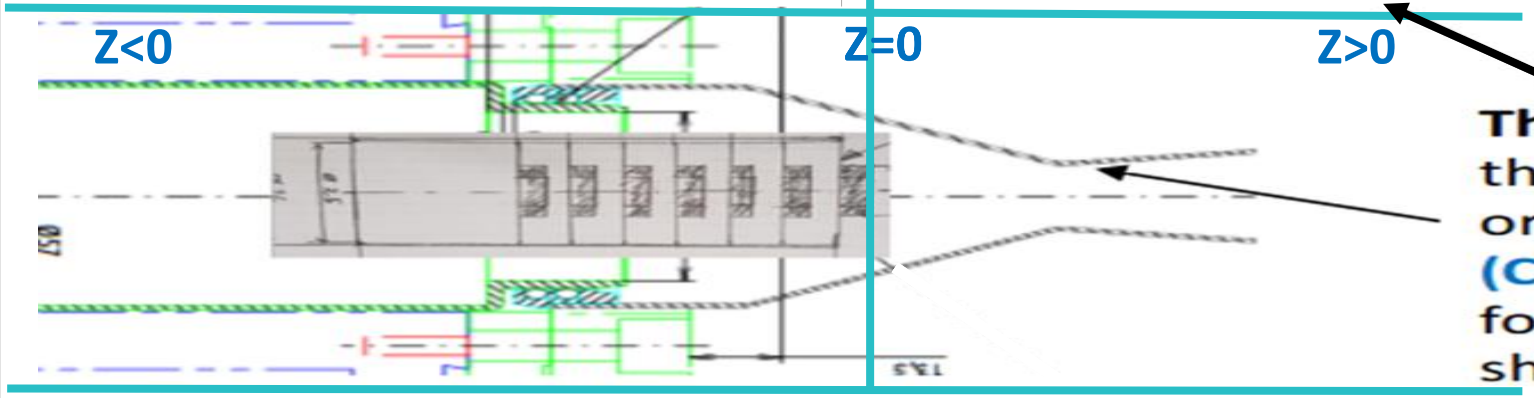
$-60 \le V_Z \le -10$



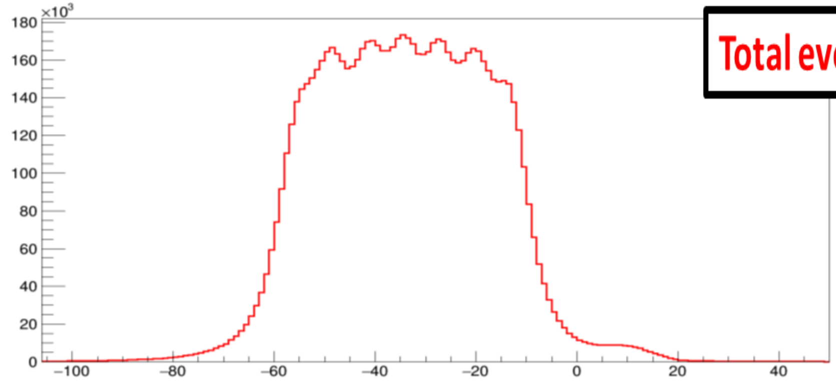
$V_Z > 0$

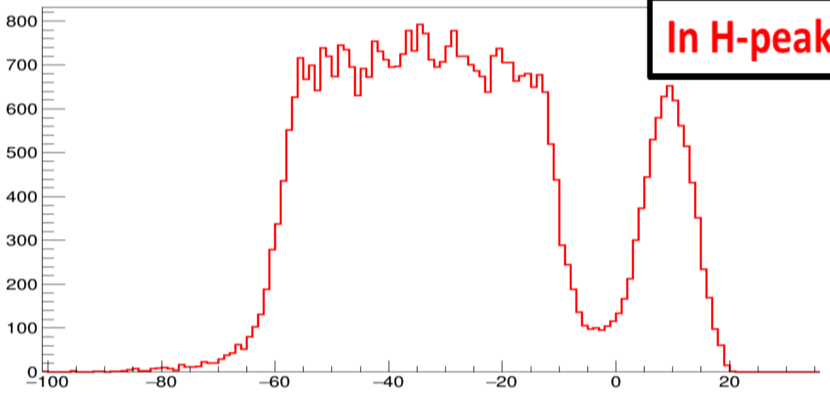


Events with Z>0 due to interaction of π^- with RICH tube.



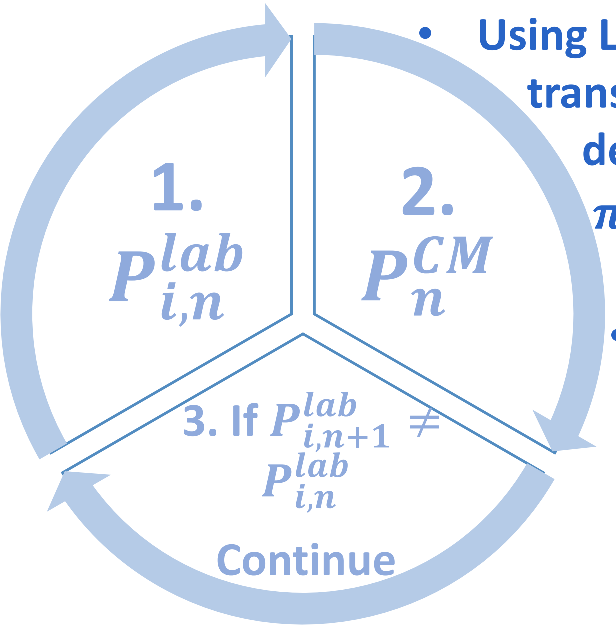
This pattern confirms that the second group of reactions originate from the **RICH tube (C fiber material)** and are folded with the Start detector shape (trigger effect)





Interest for pion momentum calibration :

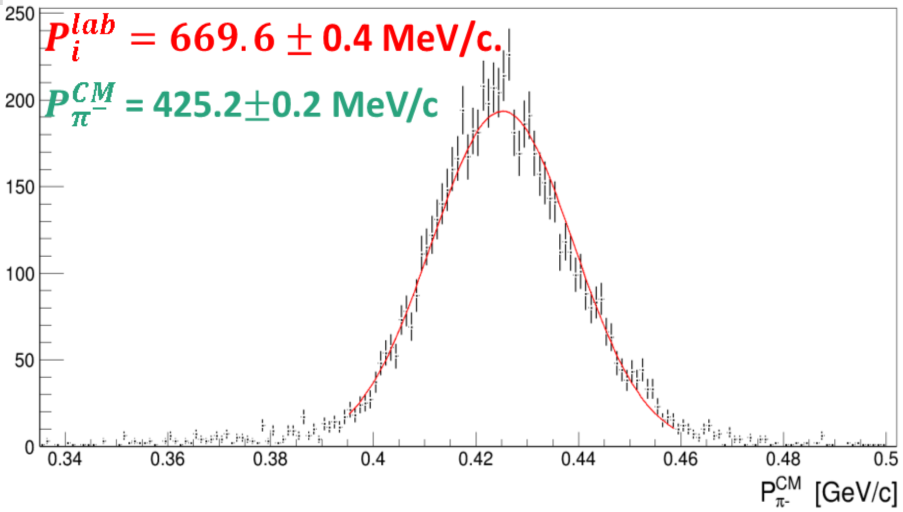
Iterative method :



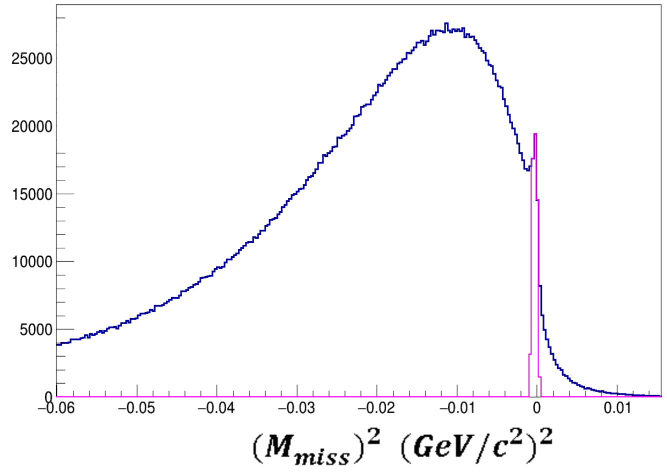
- Using Lorentz transformation, β_{CM} is determined from initial π^- at $P_{i,n}^{lab}$ and proton.
- $P_{\pi^-,n}^{CM}$ deduced from gaus Fit.

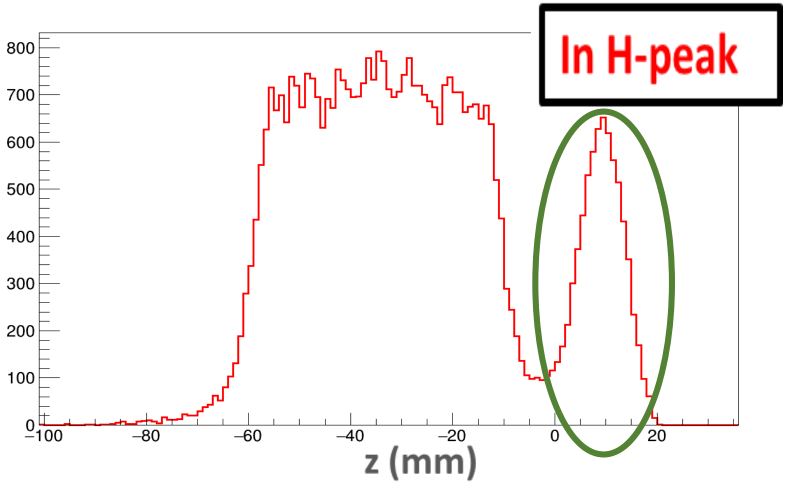
$$P_{i,n+1}^{lab} = \frac{\sqrt{s} \times P_n^{CM}}{m_{proton}}$$

$\sqrt{s}$ is calculated from measured π^- and proton.



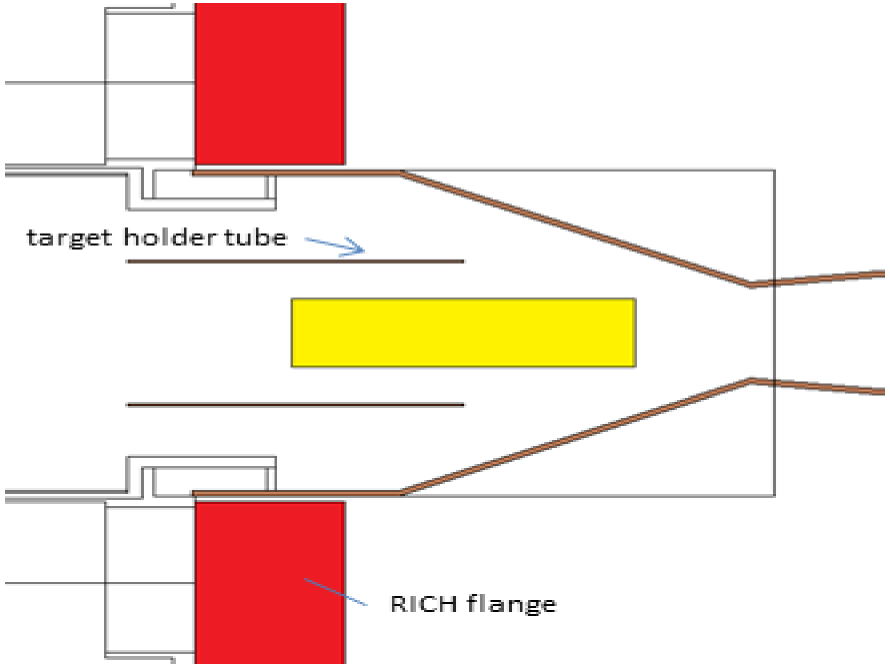
Selection of free elastic scattering events :
π^-+p → π^-+p





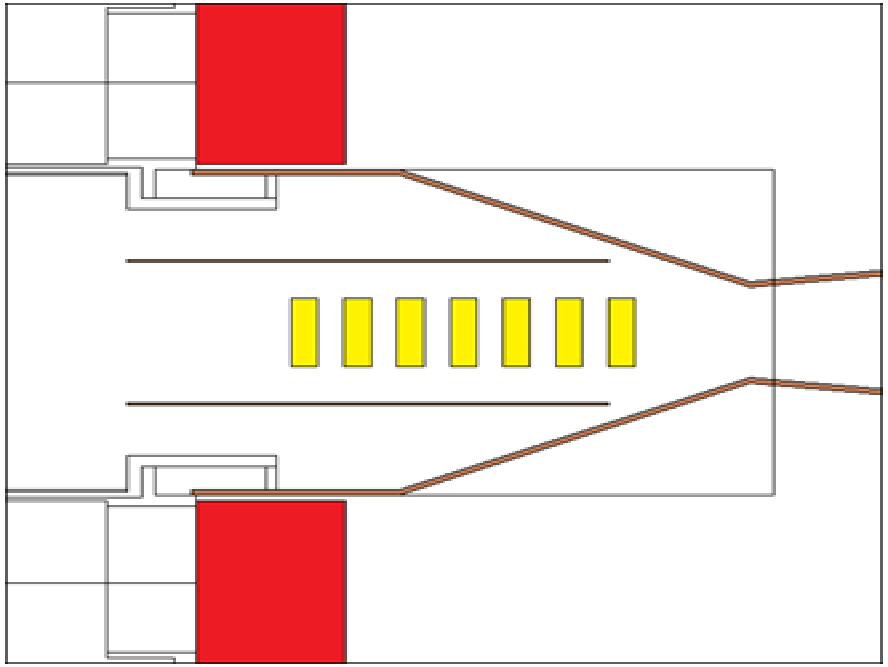
Incident pion momentum calibrated for the CH2 target using π^-+p → π^-+p elastic scattering

Targets for pion beam time AUG14



Polyethylen target

Diameter:	12 mm
Length:	46 mm
Lab position of center:	-32.7 mm

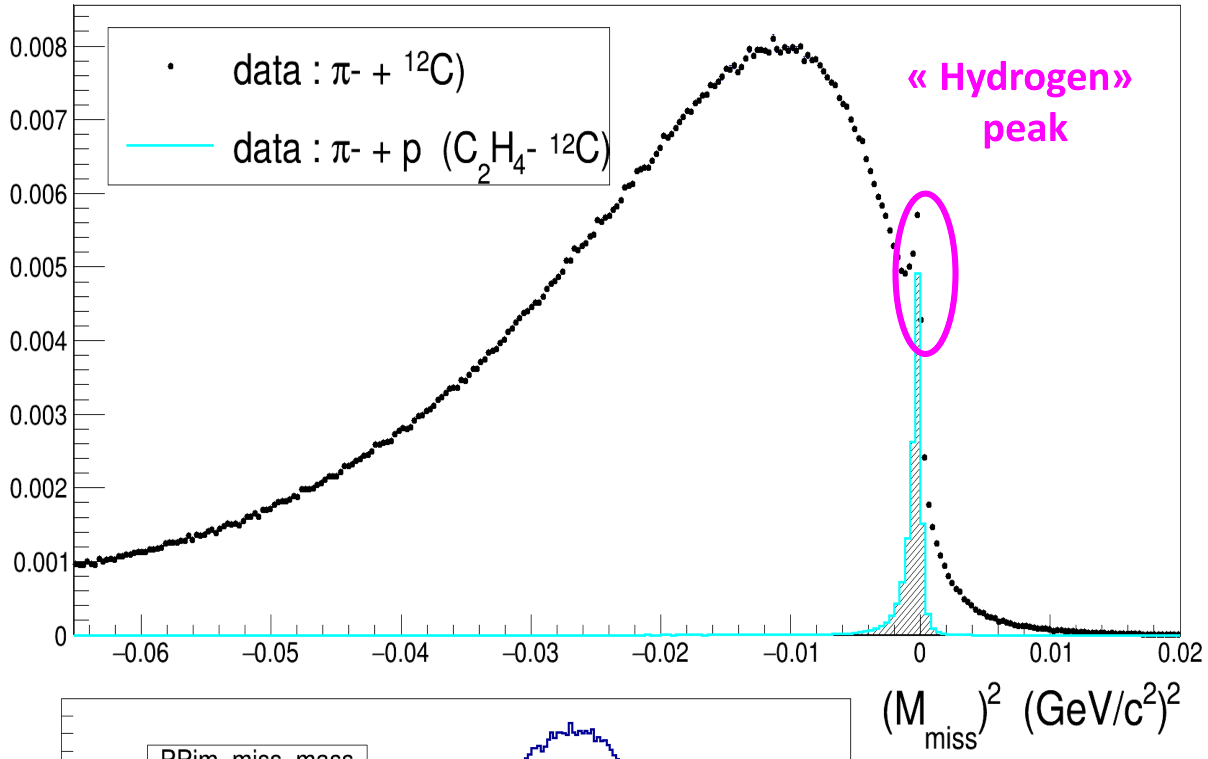


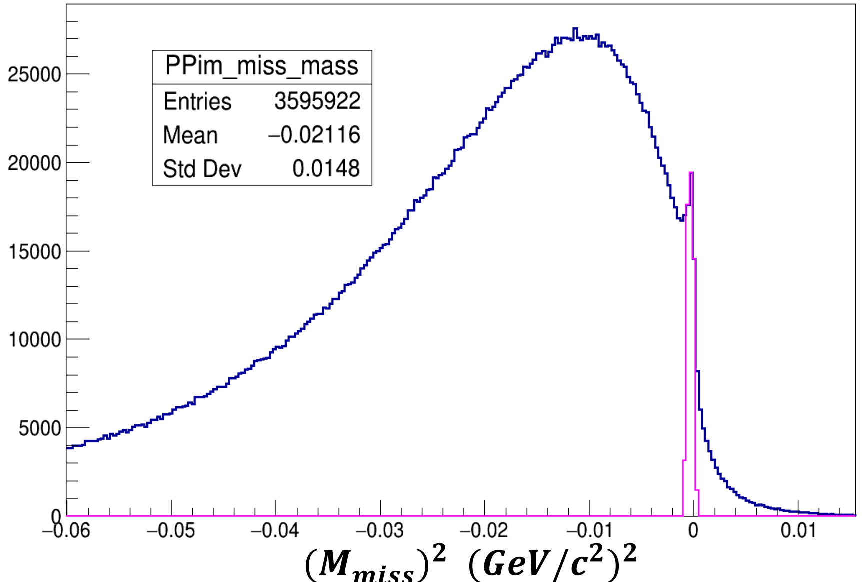
Carbon target

Number of segments:	7
Diameter of segments:	12 mm
Thickness of segments:	3.6 mm
Distance between segment centers:	7.1 mm
Total length:	46.2 mm
Lab position of center:	-32.6 mm

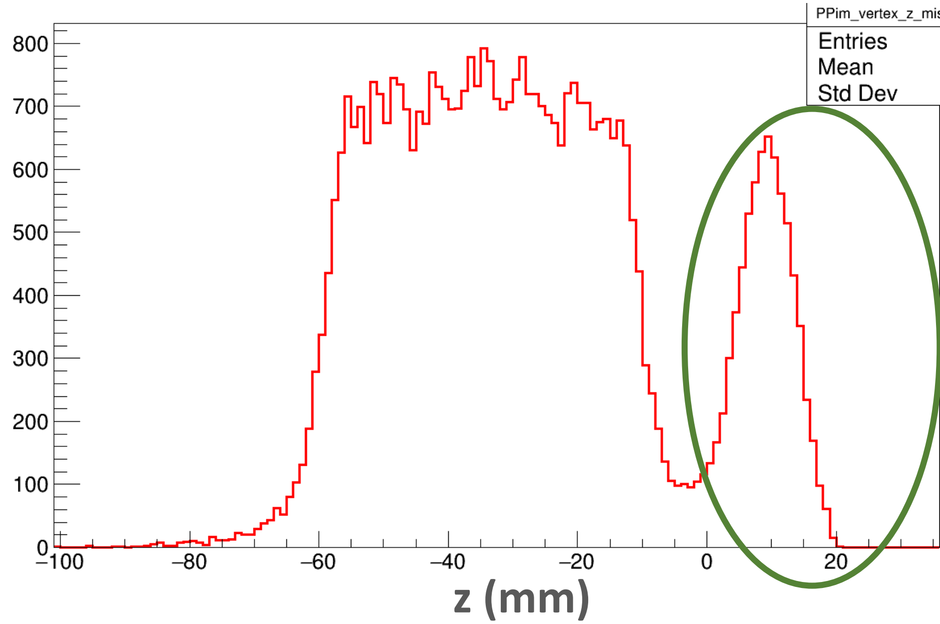
Target holder:
carbon-fibre tube with outer diameter of 26mm and wall thickness of 0.5 mm

$(M_{miss})^2$ for quasi–elastic : $\pi^- + {}^{12}C \rightarrow \pi^- + p + X$





Z position of the Vertex in the H-like peak



Selection for Quasi-free events :

Peak at -0.000254.262 $(GeV/c^2)^2$

Selection between :

peaki = peak-0.0005 $(GeV/c^2)^2$

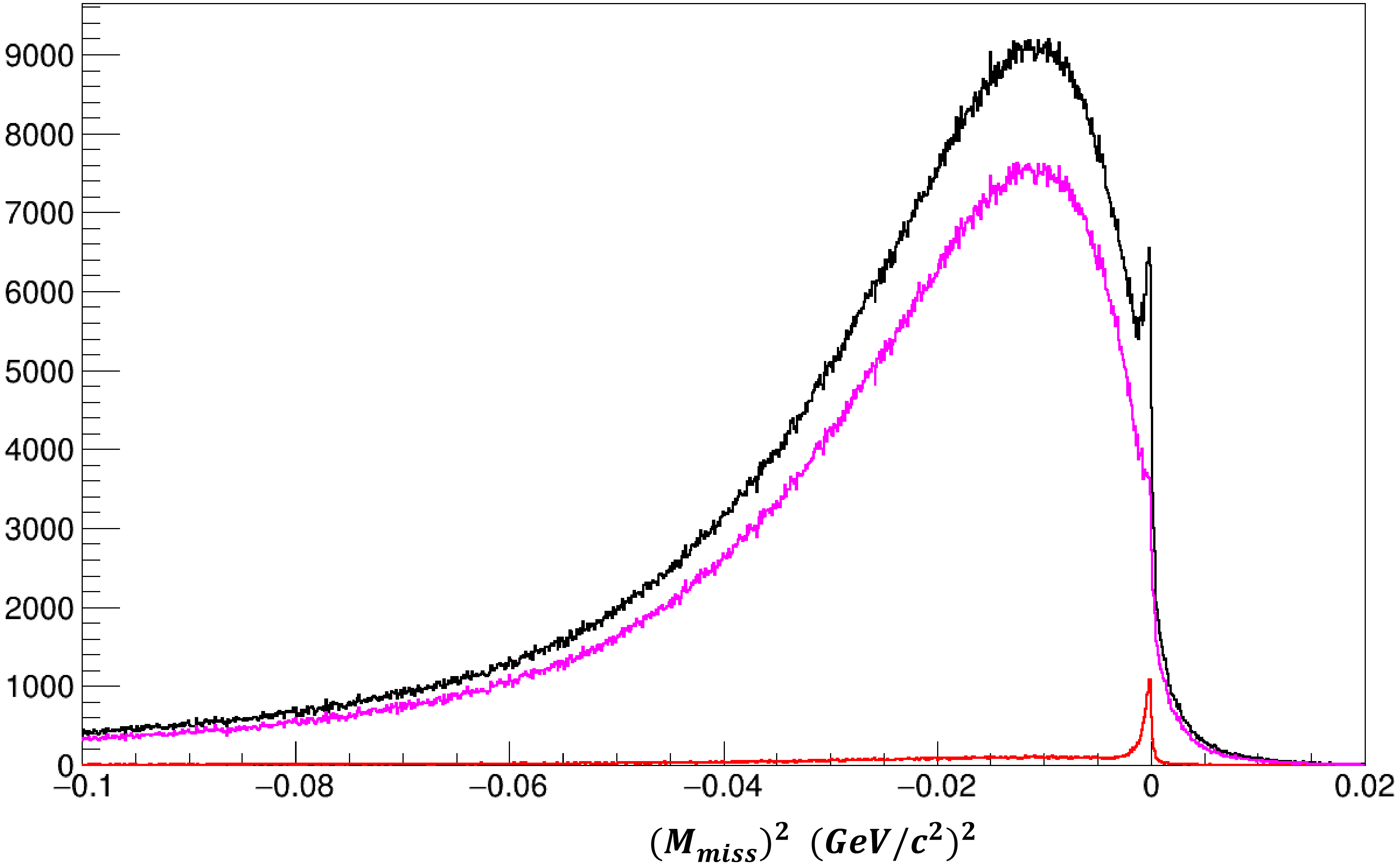
and

peakf = peak+0.0005 $(GeV/c^2)^2$

As showed in magenta

+ Vz>0

$(M_{miss})^2$ for $Z_{Vertex} < -10$ and for $Z_{Vertex} > 0$:



Total elastic

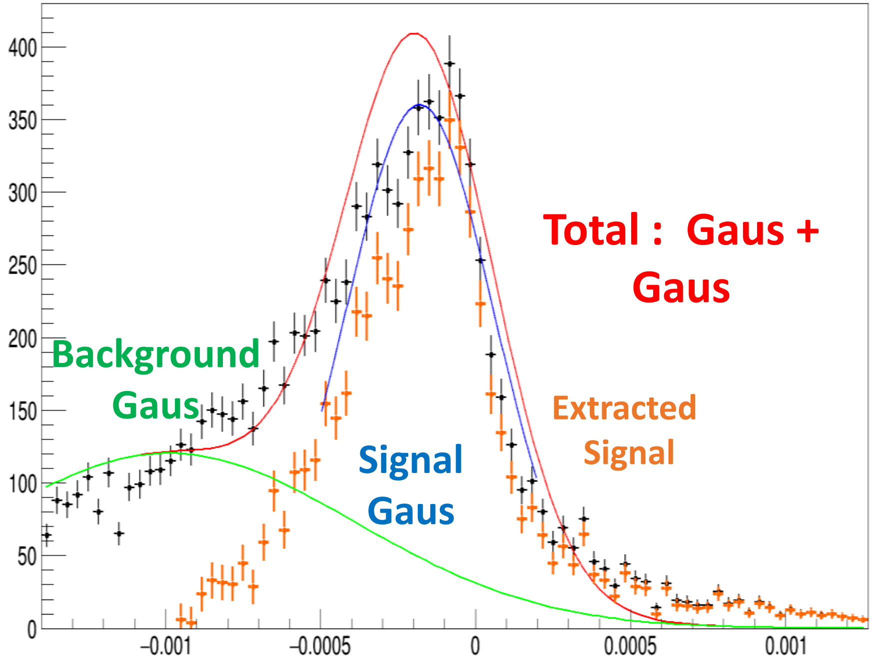
$Z_{Vertex} < -10$

$Z_{Vertex} > 0$

Hydrogen content:

Contamination in number of atoms : $\frac{N_H^{at}}{N_C^{at}} = \frac{N_{H,el}}{N_{C,qf}} \times \frac{\sigma_{C,qf}}{\sigma_{H,el}}$

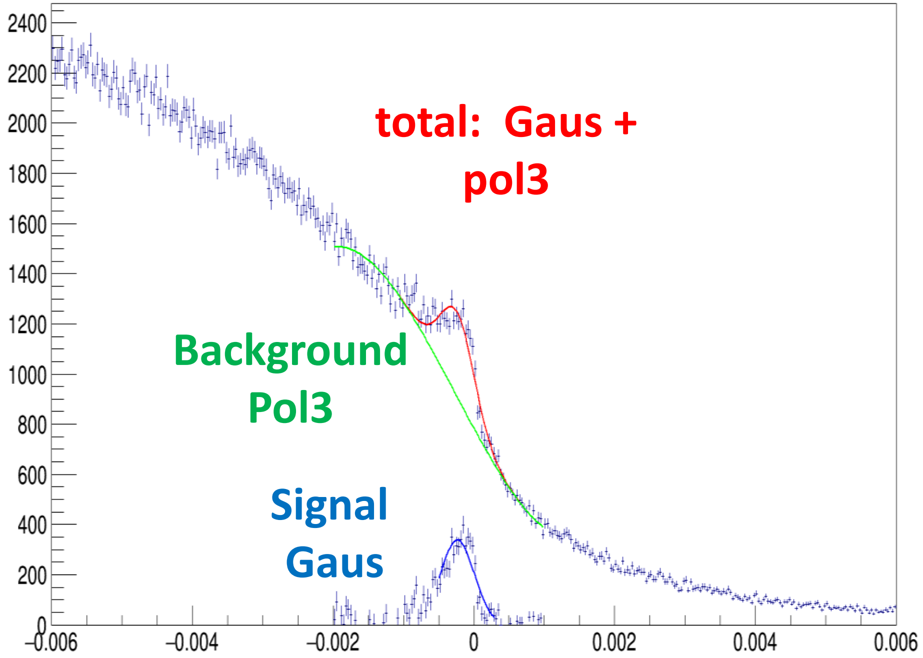
Contamination in mass : $\frac{m_H}{m_C} = \frac{N_H^{at}}{12 \times N_C^{at}}$



$0 \leq Z_{Vertex} \leq 20$ $(M_{miss})^2$ $(GeV/c^2)^2$

RICH tube (carbon fiber):

$$\frac{m_H}{m_C} = (5.5 \pm 0.5) \times 10^{-3}$$



$-60 \leq Z_{Vertex} \leq -10$ $(M_{miss})^2$ $(GeV/c^2)^2$

target region (high purity carbon):

$$\frac{m_H}{m_C} = (0.8 \pm 0.1) \times 10^{-4}$$

GSI (Gesellschaft für Schwerionen Forschung) & FAIR (Facility for Antiproton and Ion research)

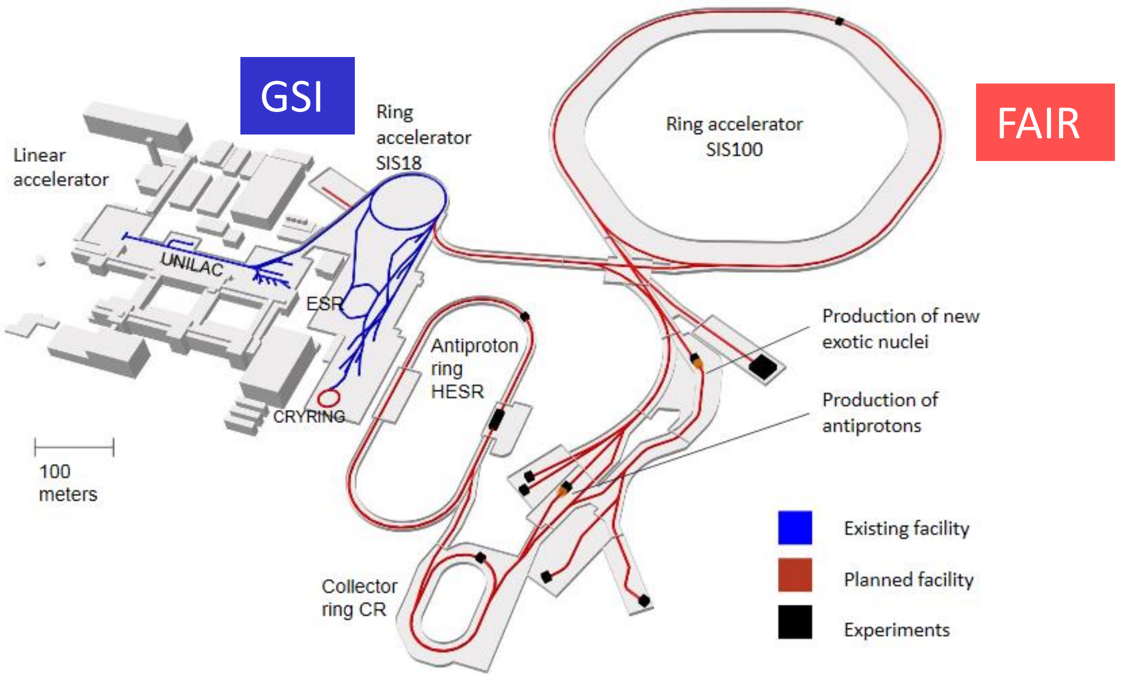
The 4 pillars of FAIR:

APPA (Atomic Physics, Plasma and Applied sciences)
NUSTAR (Nuclear Structure, Astrophysics and Reactions)
CBM (Compressed Baryonic Matter: HADES & CBM experiments)
PANDA (AntiProton Annihilation at Darmstadt)

1st experiments in 2025

Primary beams :

Au - 10^9/s - E_{max} /A = 11 GeV
C, Ca,.. - 10^9/s - E_{max} /A = 14 GeV
p - 10^{11}/s - E_{max} = 29 GeV



FAIR: construction planning

Modularized Start version (MSV): experimental program in 4 phases :

Phase 0- with instrumental devices (detectors, prototypes, etc.) of FAIR before the start of FAIR 2018

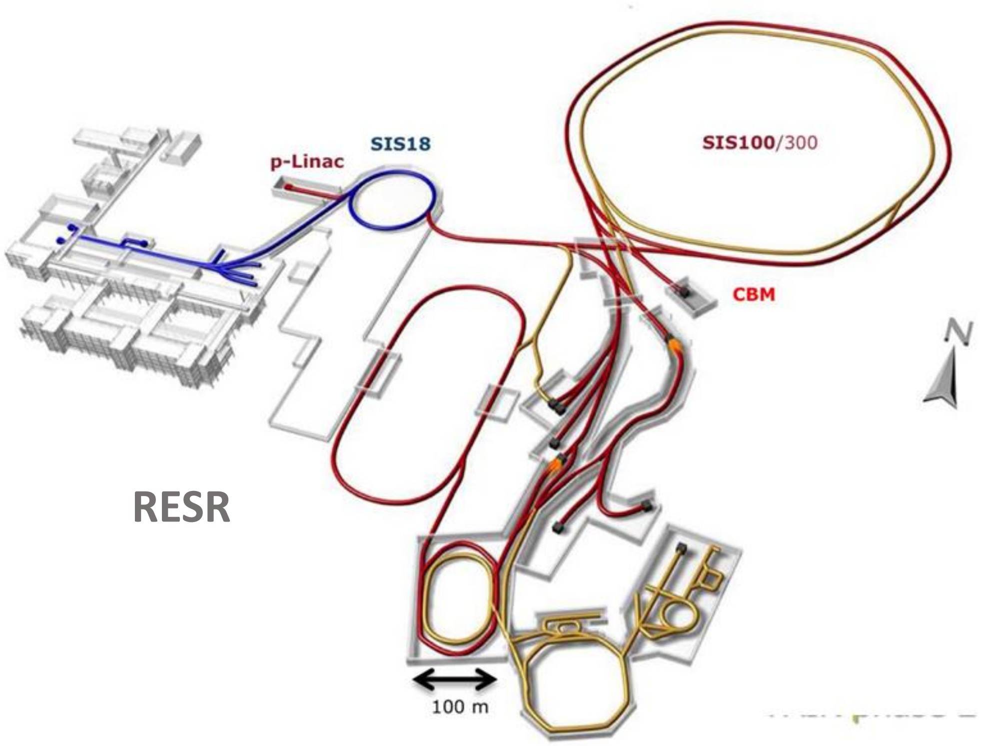
Phase 1- with SIS100 and secondary beams, first version of detectors ("day 1") 2025

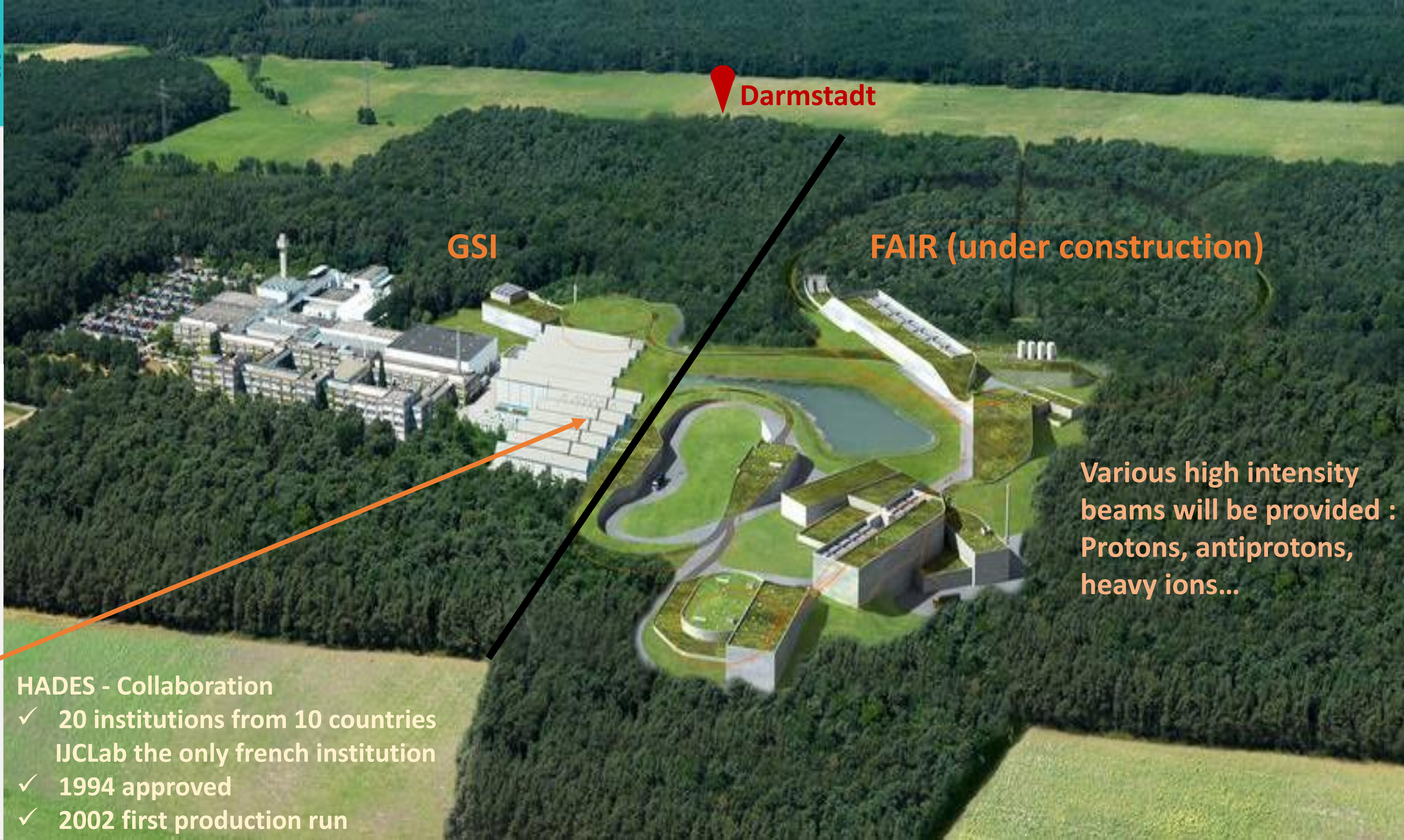
Phase 2 - complete detectors ~ 2027

Phase 3 - beyond MSV ; requires additional funding (SIS300, RESR)

Beyond MSV (planned, but not yet funded):
SIS300 At Emax: 11→35 AGeV

- **RESR pre-storage of antiprotons**
- **10^{31} cm^{-2}s^{-1} → 2 10^{32} cm^{-2}s^{-1}**





Various high intensity beams will be provided : Protons, antiprotons, heavy ions…

HADES is here !

HADES - Collaboration

- ✓ 20 institutions from 10 countries
  IJCLab the only french institution
- ✓ 1994 approved
- ✓ 2002 first production run

CBM and HADES Resource Coordinator

Jürgen Eschke