SPhN
(Nuclear Science Division)

Update on intra-nuclear cascade models

[Mostly on the new eta production in INCLXX]

Jean-Christophe David

Plan

- A few words about Binary Cascade and Bertini Cascade
- $\eta(\omega)$ in INCL++

Binary Cascade

From Gunter Folger

For Binary Cascade and Binary Light Ion Cascade,

there has **been no development in the last year**.

From Dennis Wright

Updates and Plans for Bertini Cascade

- For 10.3
  - complete extension of kaon interactions from ~5 to ~15 GeV
    - required the addition of 8- and 9-body final state partial cross sections, and inclusion of data up to 32 GeV to get correct behavior
    - reactions enabled: K+, K-, K0, K0bar on p, n
  - no longer do filtering of low energy gamma-nuclear final states by default: too time-consuming
- For 10.4
  - re-tune gamma-nuclear with larger data set
  - re-examine giant dipole physics
  - examine de-excitation code for possible bug: may be the cause of observed over-production of low energy neutrons

Plan (2)

- A few words about Binary Cascade and Bertini Cascade
- $\eta(\omega)$ in INCL++
  - Introduction
  - Motivations
  - Inputs:
    - σ_R (production, scattering, absorption)
    - features of the reaction products (particles, E, θ)
    - in-medium Potential
    - Decay
  - Results

Introduction

INCL++ (INCLXX)

- a reaction code in Geant4
- INC (~10 MeV → 10-15 GeV)
- followed by a de-excitation code

- until 2010-2011 → 2-3 GeV
- Then, with Multipion channels → 10-15 GeV

- However other particles are produced
  - η, ω, … 2016
  - K, Y 2017

  ⟶ Minor roles, but New Physics

Motivations

Why η, ω?

- a necessary step toward K, Y
- what's the role in π production? (decay product)
- source of dileptons (= clean information of nuclear matter)
- to study rare decays violating a conservation law

Inputs

- Inputs:
  - **σ_R (production, scattering, absorption)**
  - features of the reaction products (particles, E, θ)
  - in-medium Potential
  - Decay

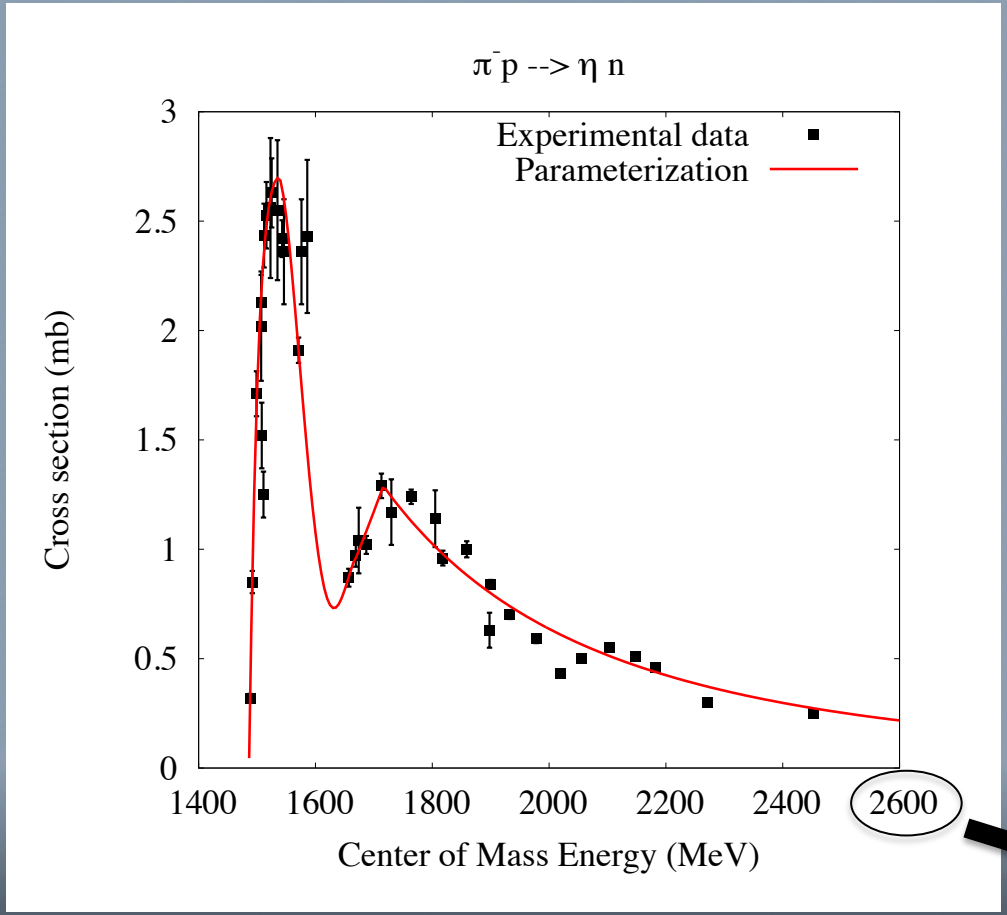
Inputs

$\pi N \rightarrow \eta N$

$NN \rightarrow \eta + X$

Inputs

$\pi N \rightarrow \eta N$

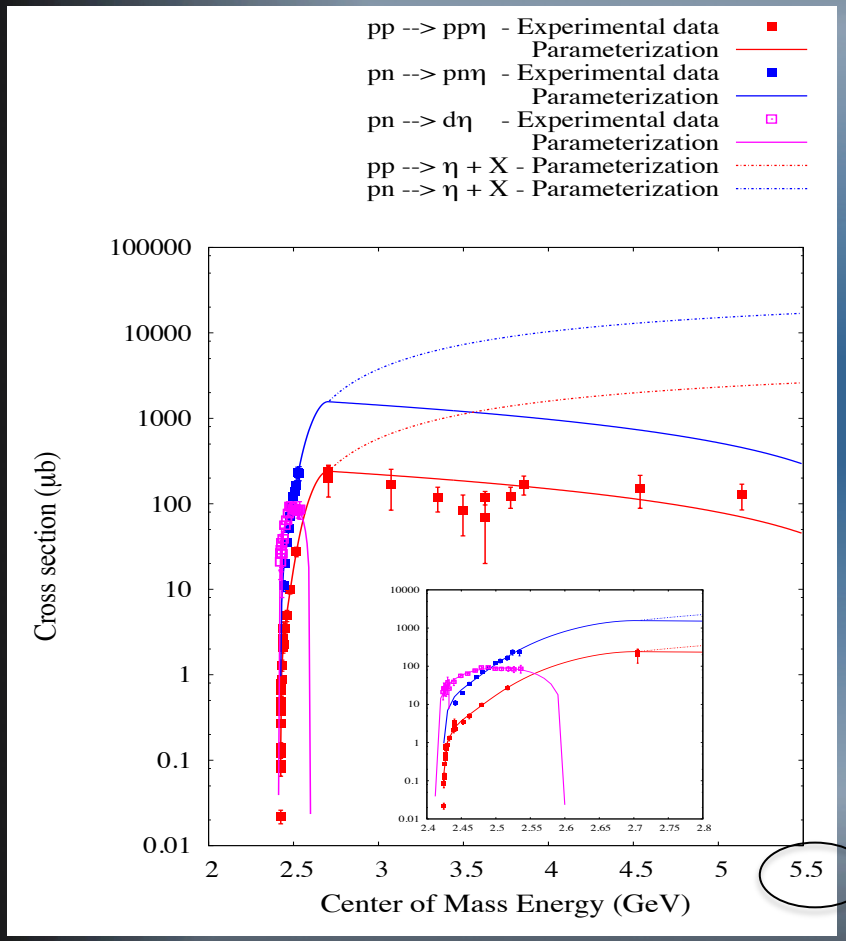


$T_\pi \approx 3$ GeV

Fit on exp. data

Inputs

NN → η + X



exclusive (NN→ NNη): Fit on exp.data

inclusive (NN→ η + X): parameterization from Sibirtsev - Z. Phys. A 358, 357 (1997).

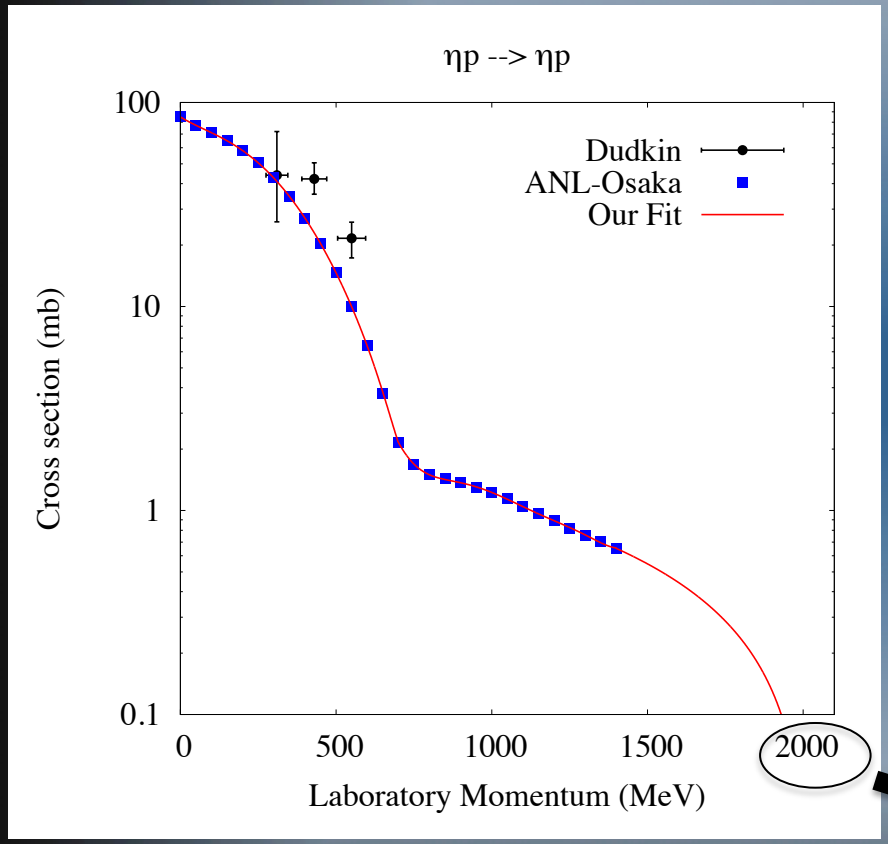
case of pn!!!

- . Exclusive
  - At low E pn = 6.5 pp
  - At high E hyp. : same factor
- . Inclusive
  - Same hypothesis…
- . pn → dη considered as pn → pnη

$T_p \approx 14$ GeV

Inputs

$\eta N \rightarrow \eta N$



Fit of ANL-Osaka model result

Courtesy of H. Kamano

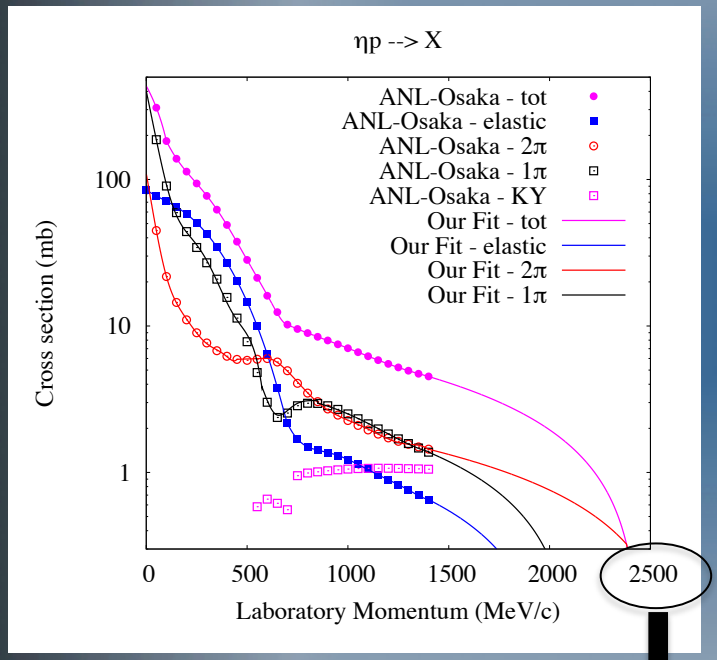
ANL-Osaka model - PRC 88, 035209 (2013)

a Dynamical Coupled-Channel model based on Lagrangians

$T_\eta \approx 1.5$ GeV

Inputs

$\eta N \rightarrow X$



$T_\eta \approx 2$ GeV

Fit of ANL-Osaka model results

Courtesy of H. Kamano

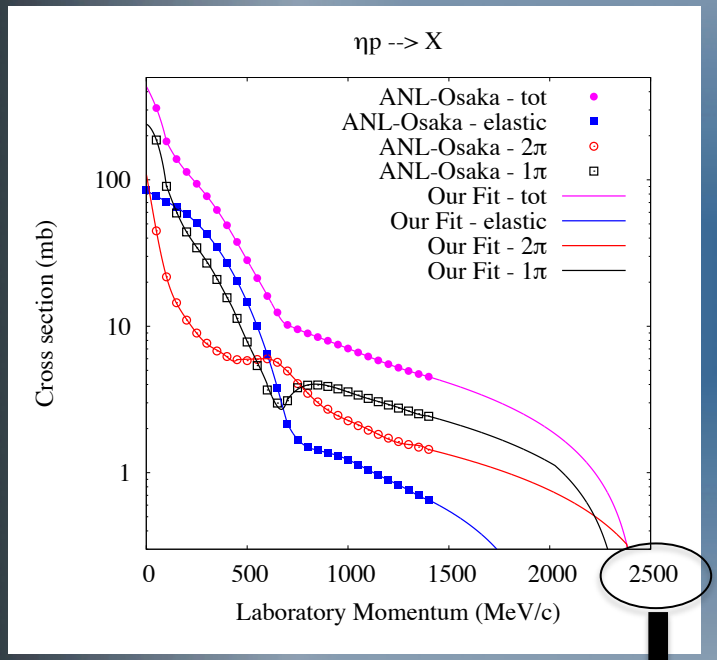
- $\eta N \rightarrow \eta N$ (elastic)
- $\eta N \rightarrow \pi N$
- $\eta N \rightarrow \pi\pi N$

- $\eta N \rightarrow KY$ (Y=Λ or Σ)

  up to now no KY in INCL++, so used later

Inputs

$\eta N \rightarrow X$



$T_\eta \approx 2$ GeV

Fit of ANL-Osaka model result

Courtesy of H. Kamano

- $\eta N \rightarrow \eta N$ (elastic)
- $\eta N \rightarrow \pi N$
- $\eta N \rightarrow \pi\pi N$

BUT THE RESULTS WILL BE SHOWN WITH

πN = Tot – elastic – $\pi\pi N$

Inputs

- Inputs:
  - σ_R (production, scattering, absorption)
  - **features of the reaction products (particles, E, θ)**
  - in-medium Potential
  - Decay

Inputs

Final products
p - θ

A+B → C+D

- Type of C and D → Obvious or via Clebsch-Gordan
- E → given by the center-of-mass energy and masses
- θ →
  - No information: Isotropy or Phase-Space
  - Information: Fit on exp.data or Model results

A+B → C+D+…

- Type of C,D,… → Clebsch-Gordan or model
- E, θ → Phase-Space

Inputs

Final products
p - θ

η

πN → ηN	Fit data
NN → η + X	Phase space
ηN → ηN	Fit Model
ηN → πN	Fit Model
ηN → ππN	Phase space

Inputs

Final products
p - θ

η

πN → ηN	Fit data
NN → η + X	Phase space
ηN → ηN	Fit Model
ηN → πN	Fit Model
ηN → ππN	Phase space

Fit on exp.

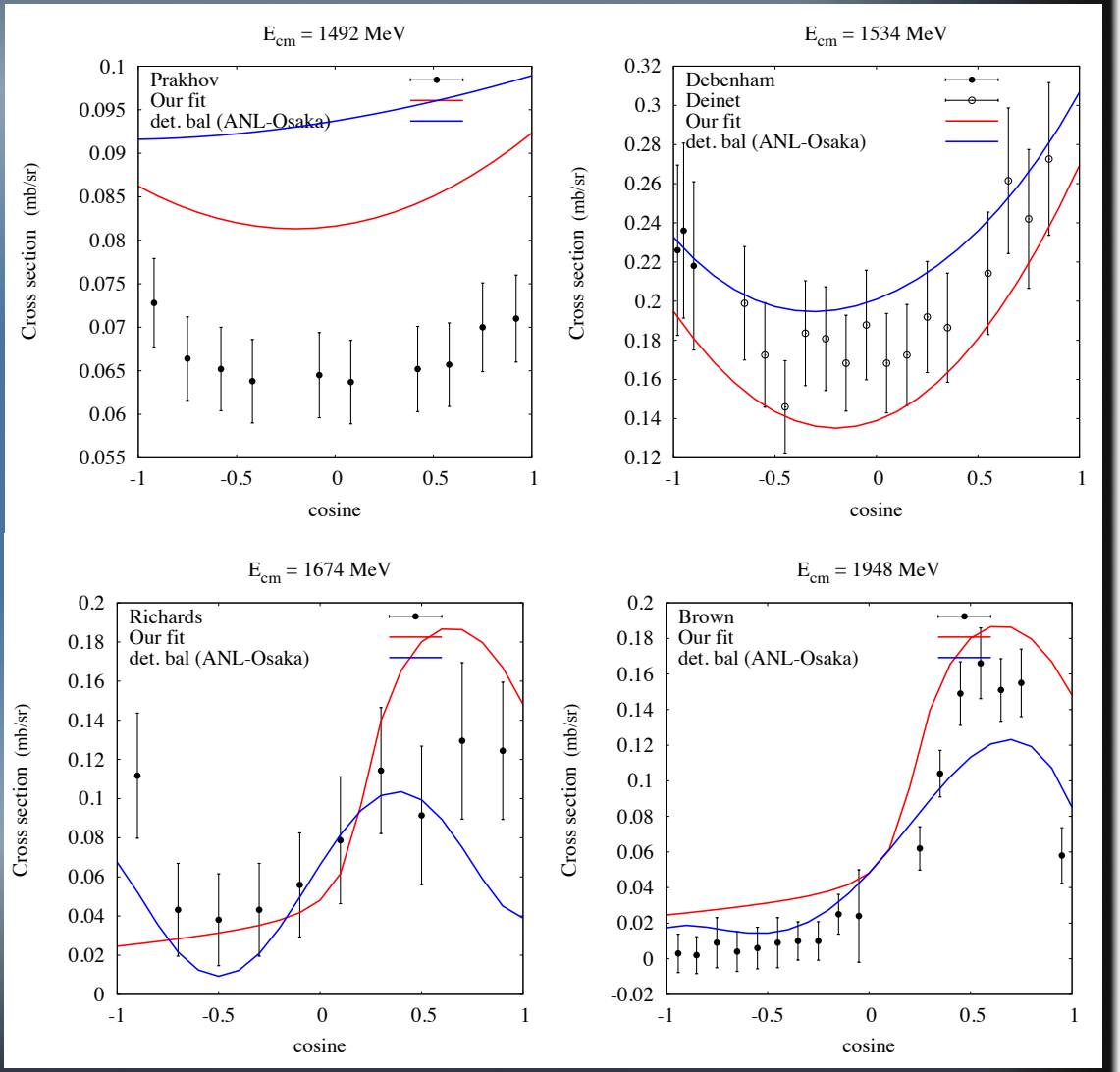
Inputs

Final products
p - θ

$\pi N \rightarrow \eta N$

Reminder:
Only the shape is important!

NB: ANL-Osaka model could be used also



Fit on model

Inputs

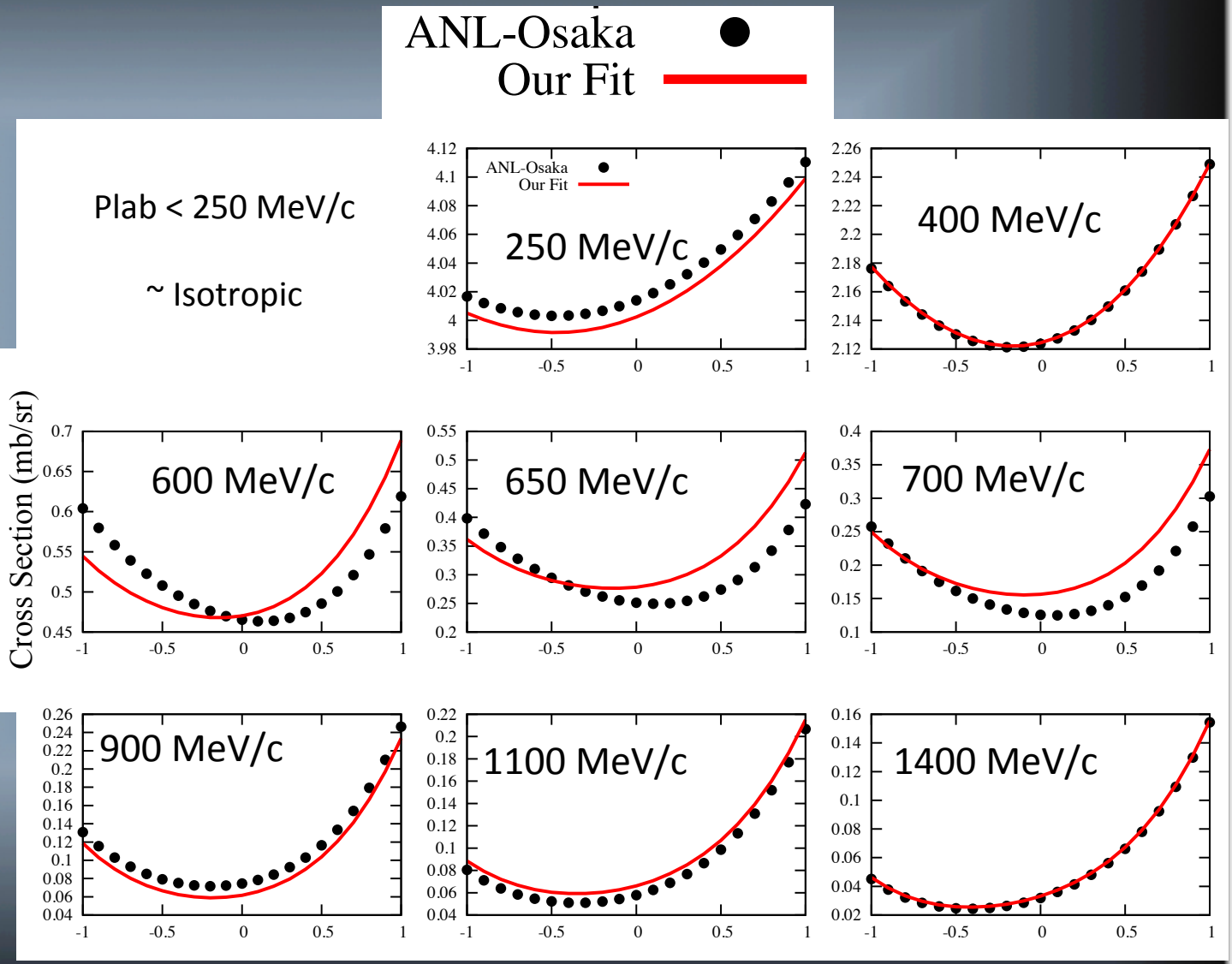
Final products
p - θ

ηN → ηN

Plab > 250 MeV/c

Fit with polynomials
(p,θ) of dσ/dΩ
from ANL-Osaka Model

Courtesy of H. Kamano



Fit on model

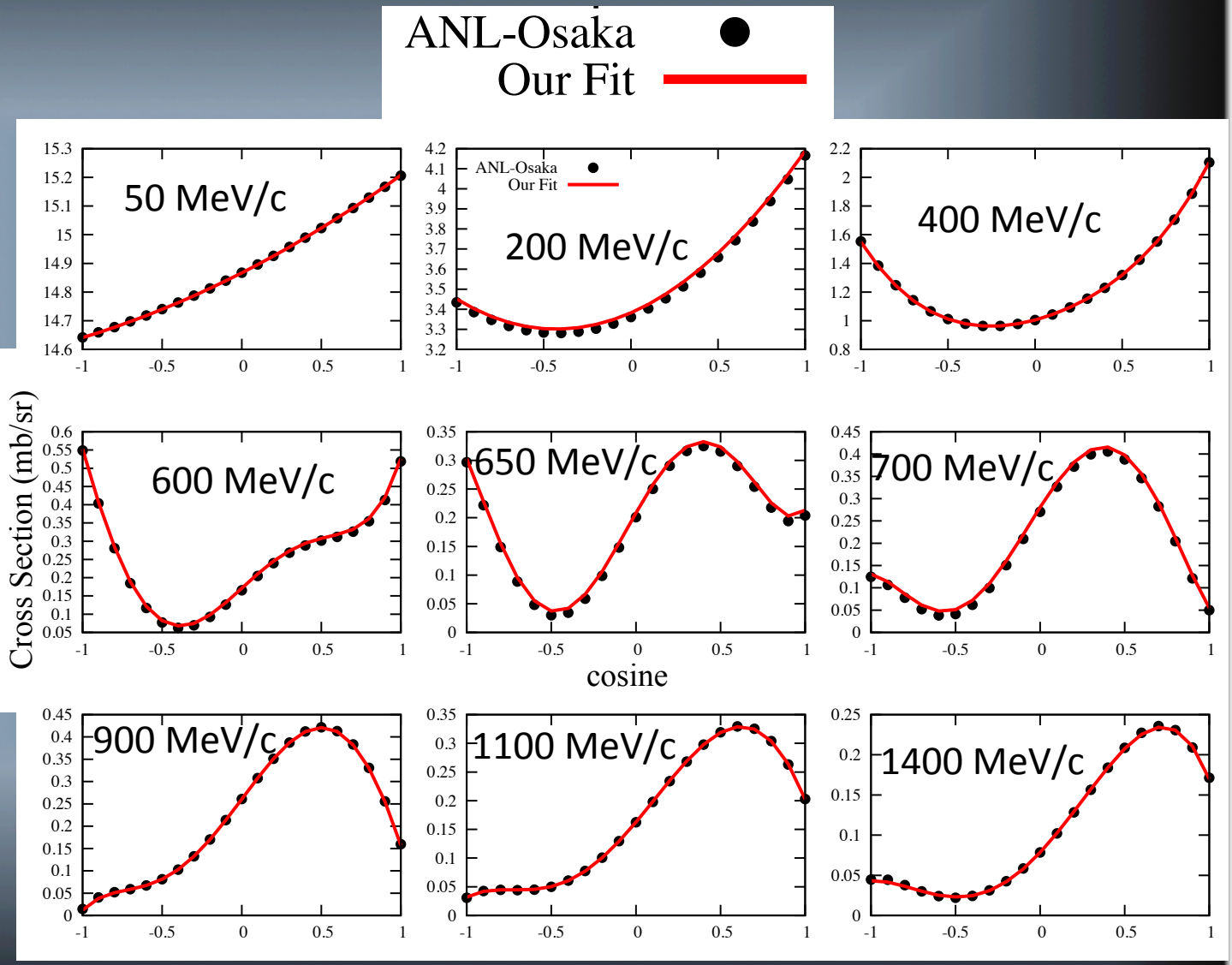
Inputs

Final products
p - θ

$\eta N \rightarrow \pi N$

Fit with polynomials
(p,θ) of dσ/dΩ
from ANL-Osaka Model

Courtesy of H. Kamano



Inputs

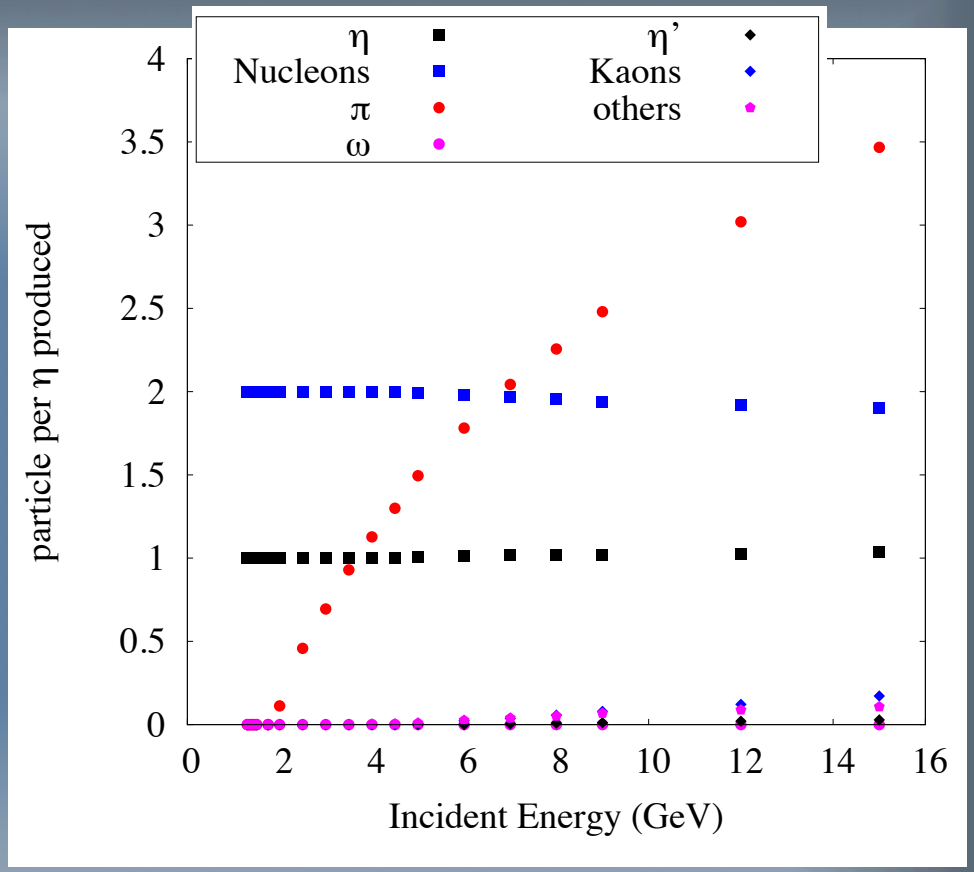
Final products
p - θ

NN → η +X

When 1 η

2 nucleons

up to 3-4 π



From Fritiof (geant4 10.1-p02)

Inputs

Final products
p - θ

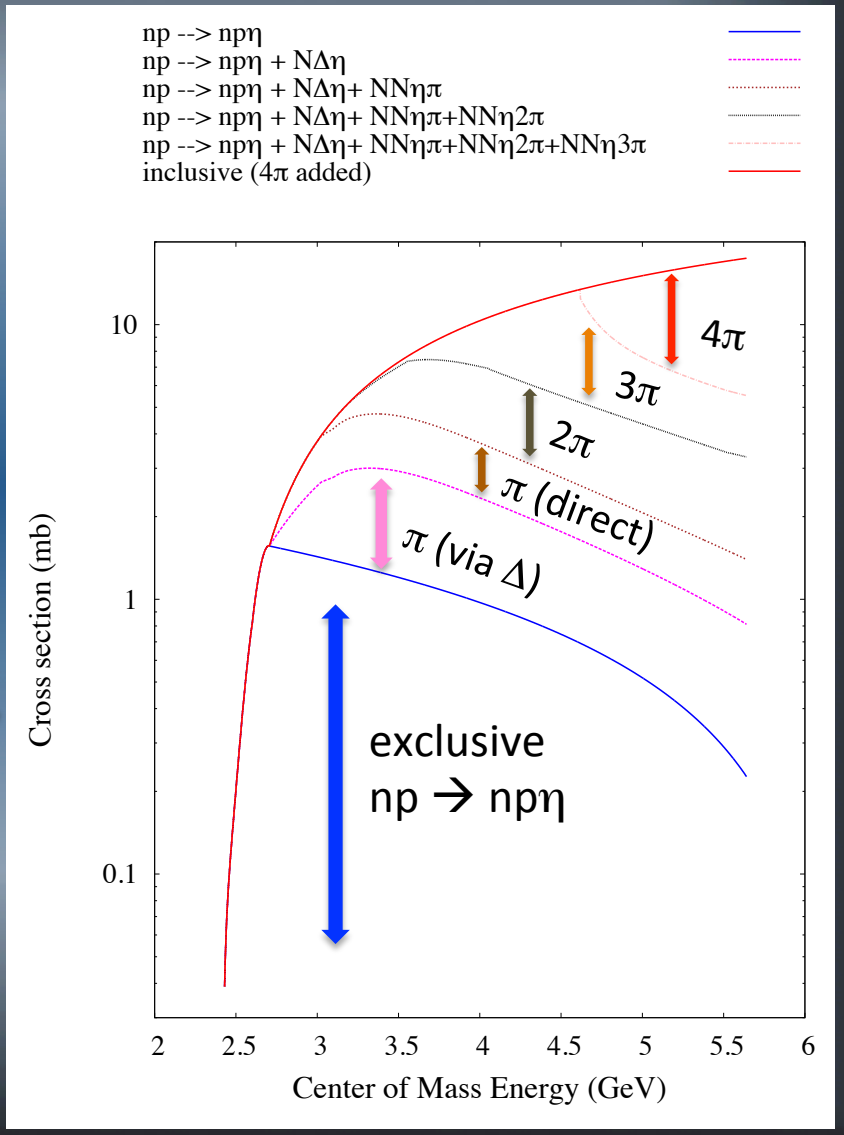
NN → η +X

When 1 η

2 nucleons
up to 3-4

So multipion applied

NN → NNη + xπ
(from NN → NN + xπ)



Inputs

- Inputs:
  - σ_R (production, scattering, absorption)
  - features of the reaction products (particles, E, θ)
  - **in-medium Potential**
  - Decay

Inputs

η

Few information

3 values tested

- $V = 1.5\ V_{\pi 0}$
- $V = V_{\pi 0}$
- **V = 0**

Inputs

- Inputs:
  - σ_R (production, scattering, absorption)
  - features of the reaction products (particles, E, θ)
  - in-medium Potential
  - **Decay**

Inputs

η

- 2γ 39.72 %
- $3\pi^0$ 32.93 %
- $\pi^+\pi^-\pi^0$ 23.10 %
- $\pi^+\pi^-\gamma$ 4.25 %

→ η decays only after being emitted

→ Decay can be switched off (option using a time threshold)

Results

η production

- **π^+(680 MeV/c) + X** (Ye. S. Golubeva et al, NPA 562 (1993) 389)
  - $\sigma_{\eta\_production}$ with several targets
  - T_η spectrum (X = ^{12}C)
- **p(1 GeV) + X** (Ye. S. Golubeva et al, NPA 562 (1993) 389)
  - $\sigma_{\eta\_production}$ with several targets
  - T_η spectrum (X = ^{11}B)
- **p(3.5 GeV) + Nb** (G. Agakishiev et al., PRC 88, 024904 (2013))
  - transverse momentum distribution

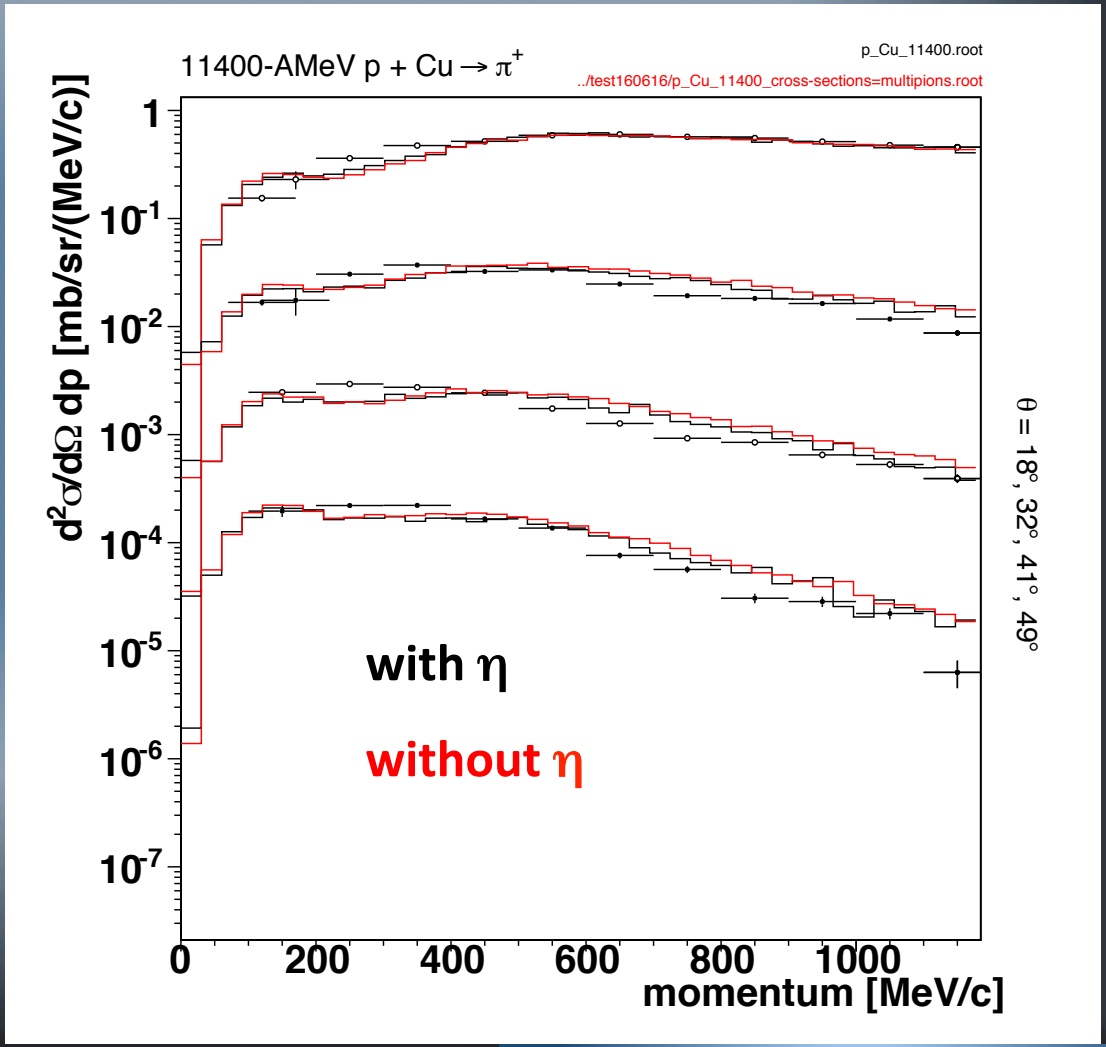
Threshold and Subthreshold Reactions

Results

π production

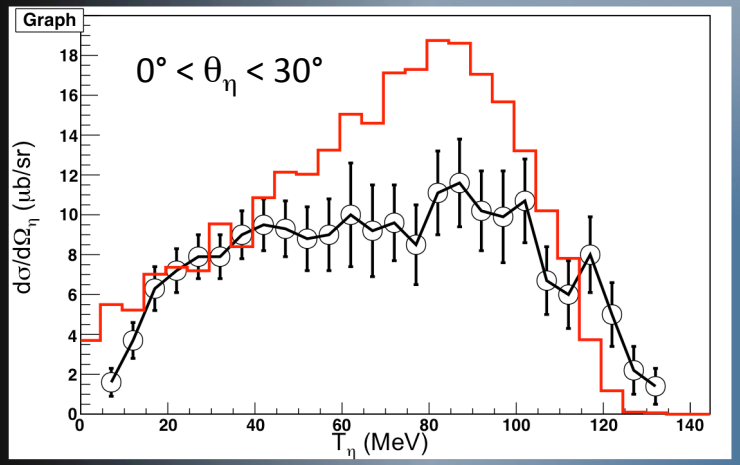
HARP experiment

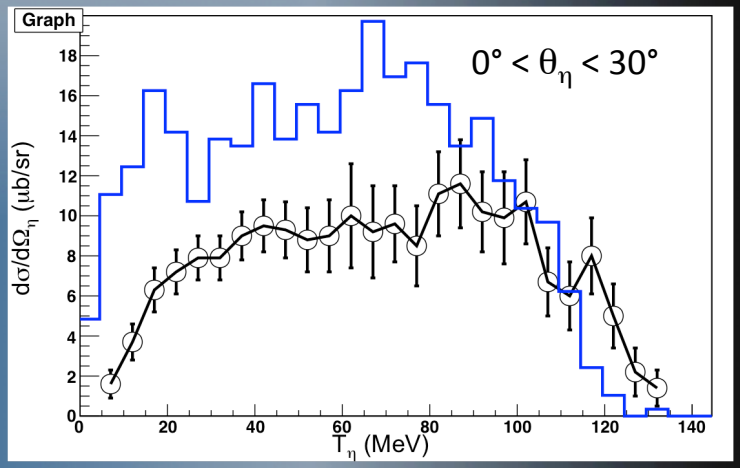
η: no effect on π production



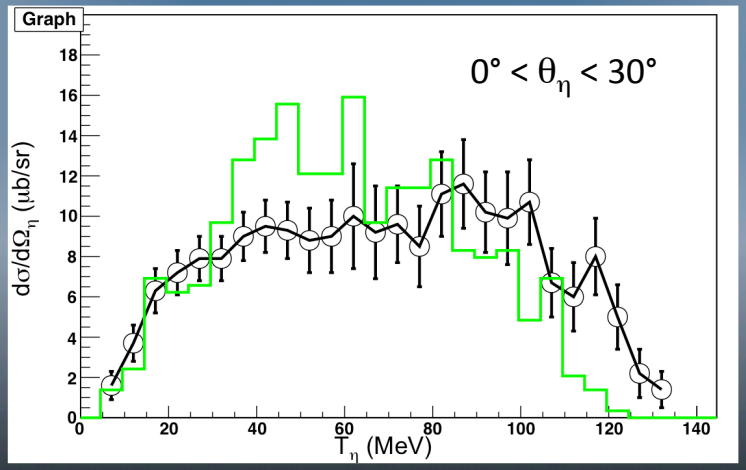
Results

π^+(680 MeV/c) + ^{12}C
(η Spectrum)





V_η ~ 50 MeV
V_η ~ 33 MeV
V_η = 0 MeV



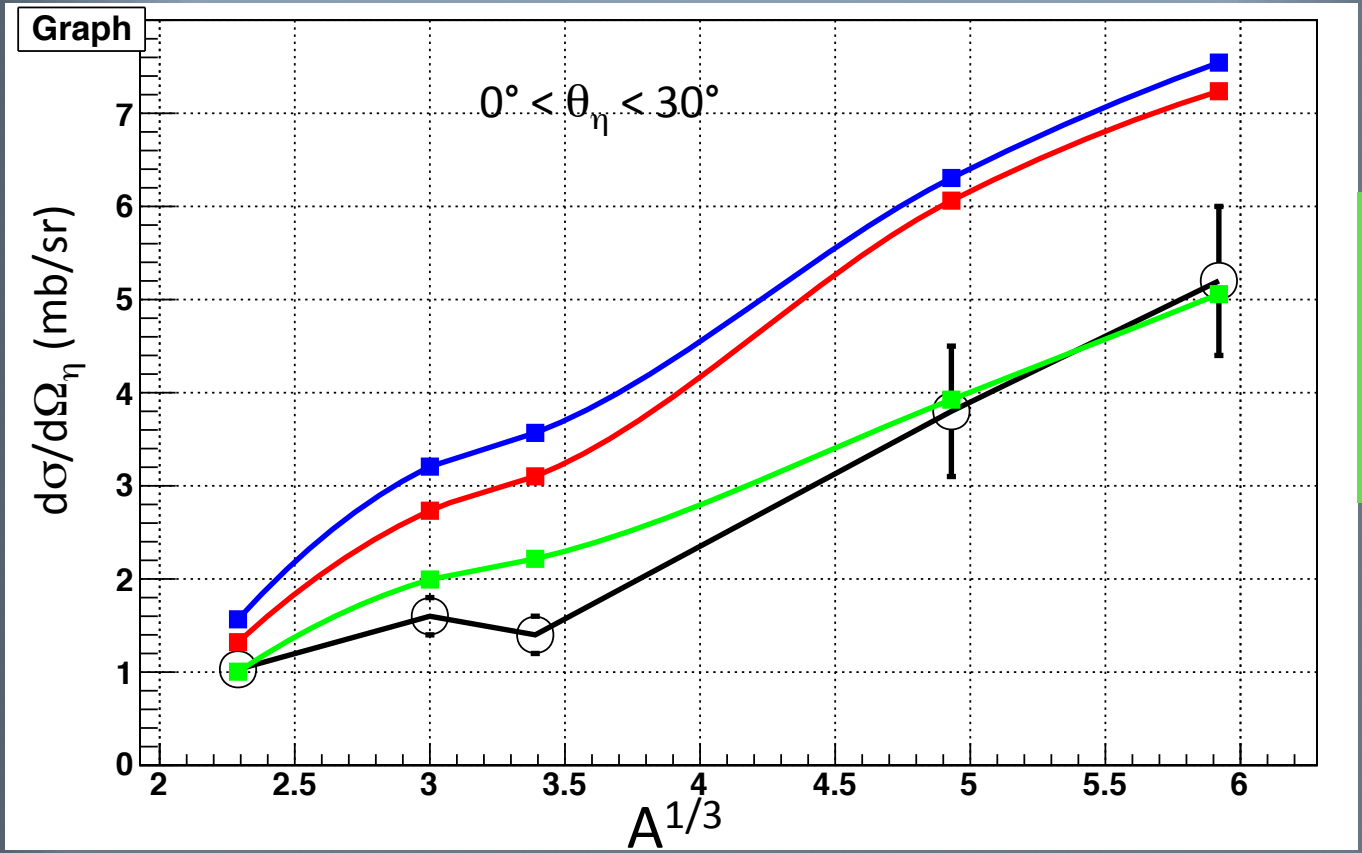
Better Results with V=0!

Geant 4
21st Collaboration Meeting
12-16 September 2016
Ferrara, Italy

Update on intra-nuclear cascade models

Results

π^+(680 MeV/c) + X
(η Production)



Good Results with V=0

Whatever the target

V_η ~ 50 MeV
V_η ~ 33 MeV
V_η = 0 MeV

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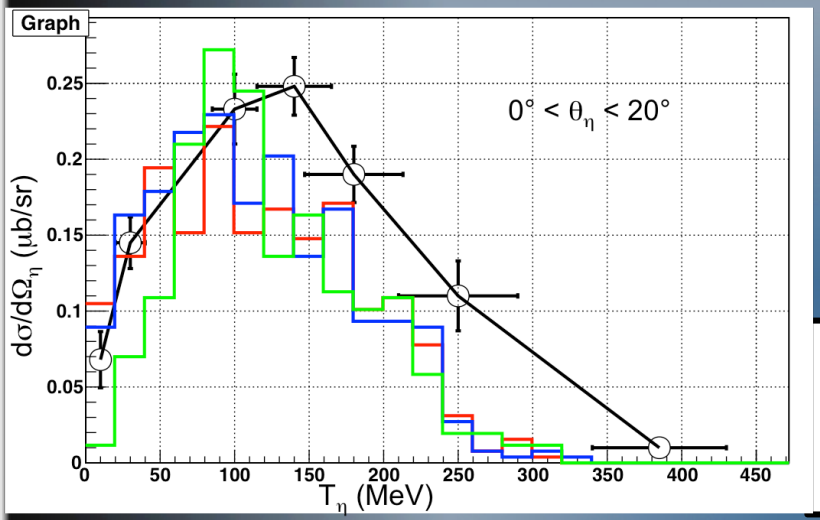
Update on intra-nuclear cascade models

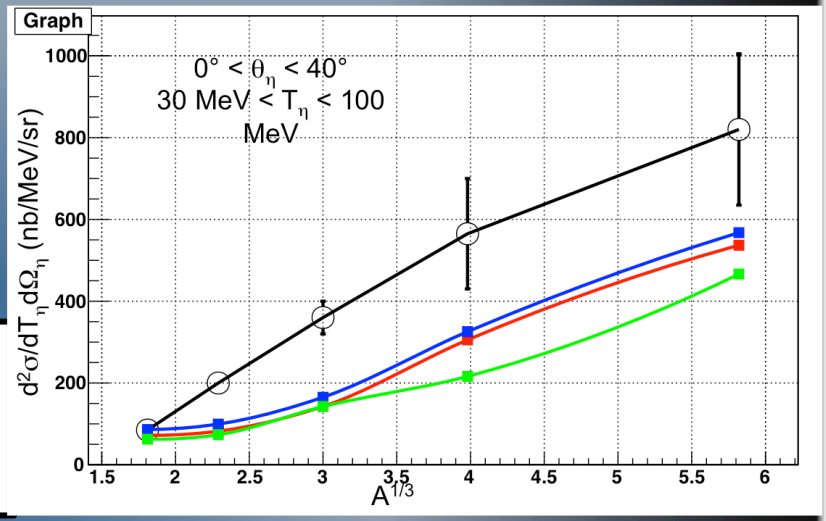
Results

p(1 GeV) + ^{11}B



V_η ~ 50 MeV
V_η ~ 33 MeV
V_η = 0 MeV

p(1 GeV) + X



V=0, not better not worse…

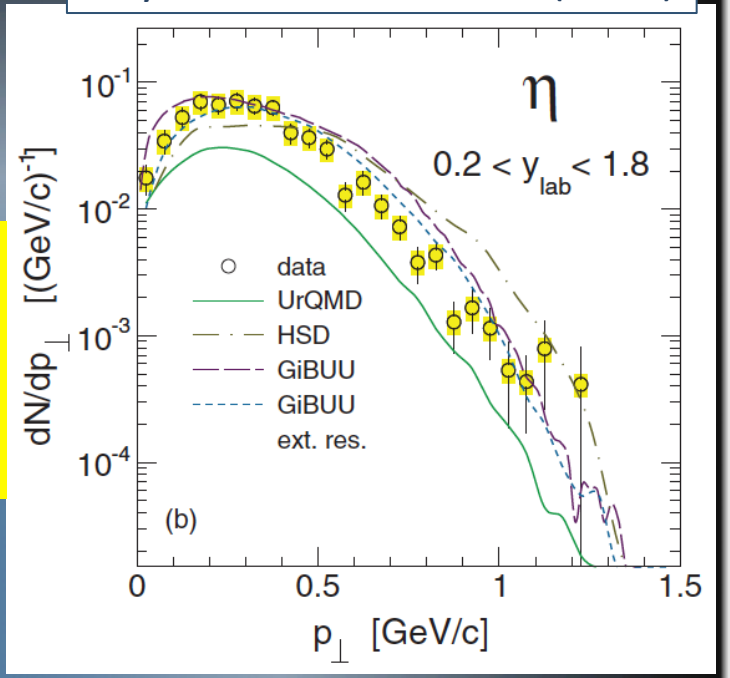
BUT subthreshold reaction → more tricky (momentum distribution of the Ns…)

Results

Phys.Rev. C 88, 024904 (2013)

p(3.5 GeV) + Nb

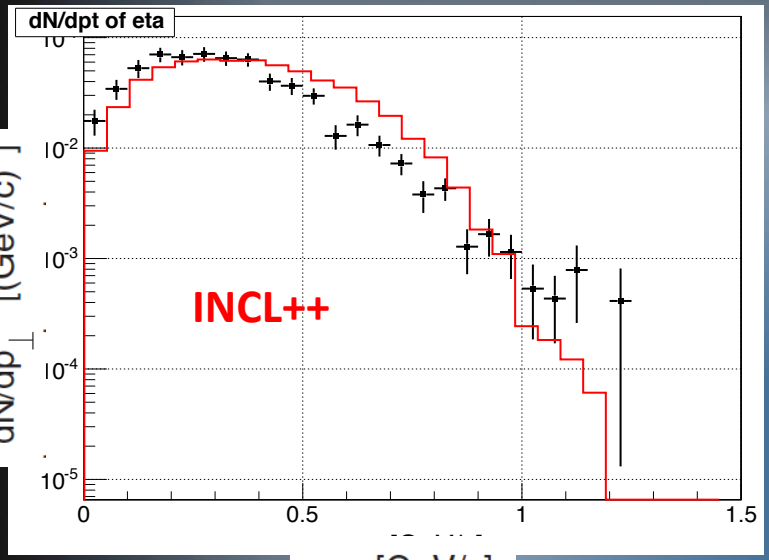
data:
HADES
collaboration



Thanks to
R. Holzmann and B. Ramstein
(exp. data)

Results

Phys.Rev. C 88, 024904 (2013)



p(3.5 GeV) + Nb

data:
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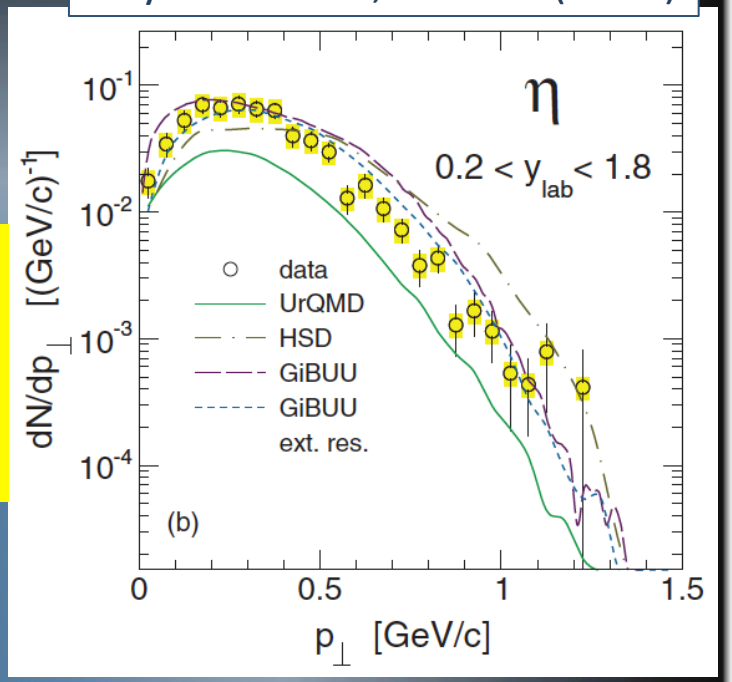
collaboration



Pretty good result
compared to
experiment and other models

Conclusions

- η is in INCL++ and gives good results
- A first implementation in Geant4 works
- Some (minor) changes until the *official* version
- ω is almost in INCL++ and soon in Geant4
  (unfortunately no data to test it)
- See you next year for the strangeness (PhD - Jason Hirtz)

Thank you!

Grazie!

backup

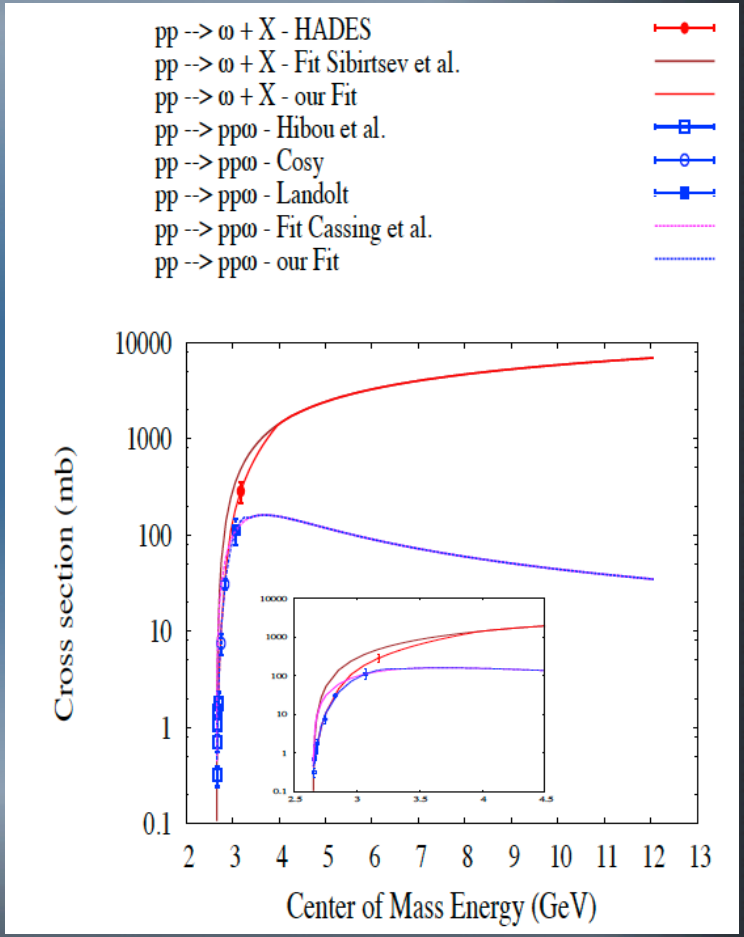
Inputs

exclusive (NN→ NNη):
parameterization from Cassing - NPA 604, 455-465 (1996) modified (low energies)

inclusive (NN→ η + X):
parameterization from Sibirtsev modified (recent datum from HADES - A. Rustamov *et al.*, AIP Conference Proceedings, 1257, 736 (2010))

case of pn
factor 3

NN → ω + X



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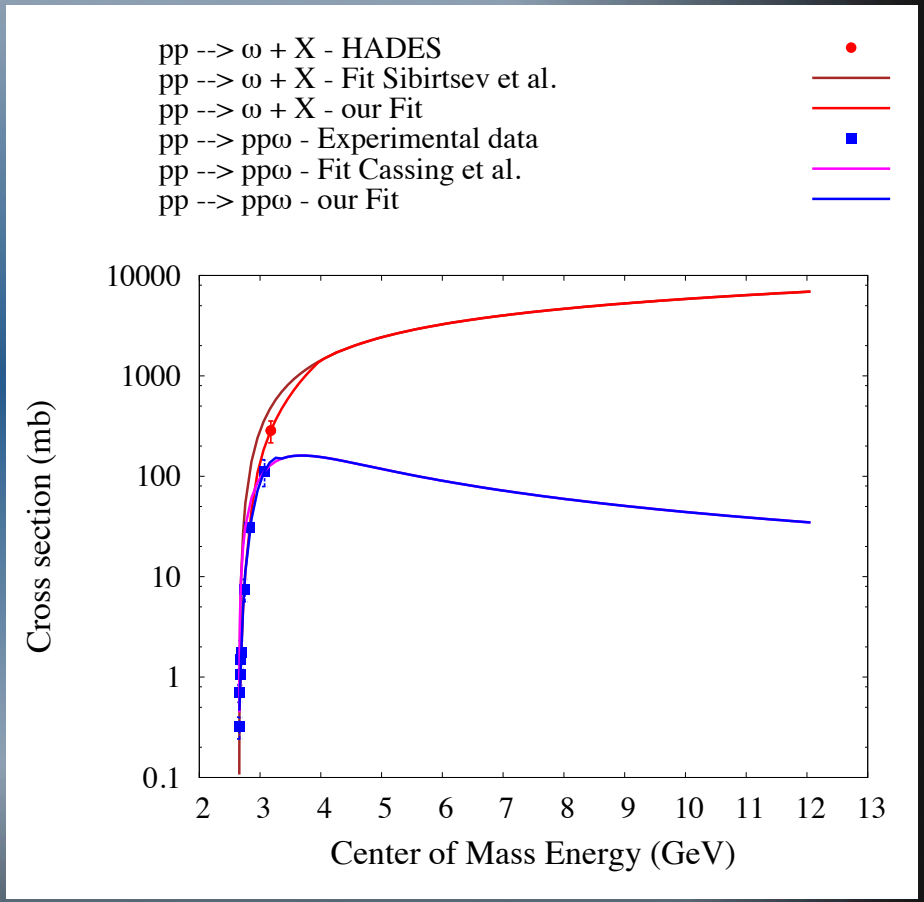

Inputs

ωN → ωN

$$\sigma(\omega N \rightarrow \omega N) = 5.4 + 10.^{-0.6\, p_{Lab}}$$

Lykasov - EPJ A 6, 71 (1999)

Inputs

$\omega N \rightarrow \pi N$ detailed balance

$\omega N \rightarrow \pi\pi N$ $\pi\pi N$ = Inelastic – πN

$$\sigma_{\omega N}^{inelastic} = 20. + 4./p_{Lab}$$

Lykasov - EPJ A 6, 71 (1999)

Inputs

η		ω	
• 2γ	39.72 %	• $\pi^+\pi^-\pi^0$	90.09 %
• $3\pi^0$	32.93 %	• $\pi^0\gamma$	8.36 %
• $\pi^+\pi^-\pi^0$	23.10 %	• $\pi^+\pi^-$	1.55 %
• $\pi^+\pi^-\gamma$	4.25 %		

→ 2 particles: Isotropy --- 3 particles: Phase-Space

→ η decays only after being emitted

→ Decay can be switched off (option using a time threshold)