Search for the ^{3}He-η bound state at COSY-11

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Reactions: $dp \rightarrow {}^3He\ \eta$

$\rightarrow {}^3He\ \pi^o$

$\rightarrow ppp\pi^-$

Study of the η - ^{3}He interaction

Unique possibility for study of η-N interaction
and the properties of $S_{11}(1535)$ In nuclear matter

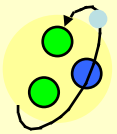
above ^{3}He-η threshold

- $dp \rightarrow {}^3\mathrm{He}\,\eta$

below ^{3}He-η threshold

- $dp \rightarrow {}^3\mathrm{He}\,\eta \rightarrow {}^3\mathrm{He}\,\pi^o$
  $\rightarrow pp\,p\pi$
  $\rightarrow \ldots$

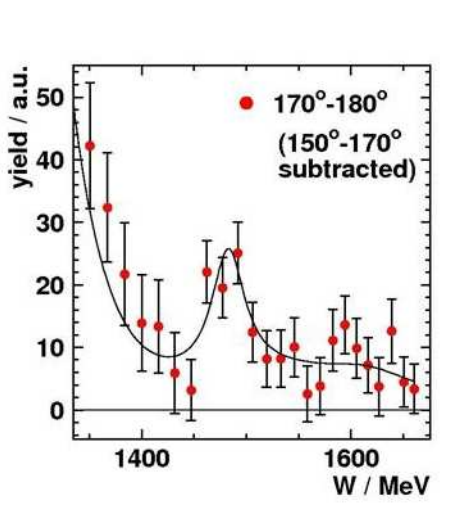
bound state



^{3}He-η interaction below threshold

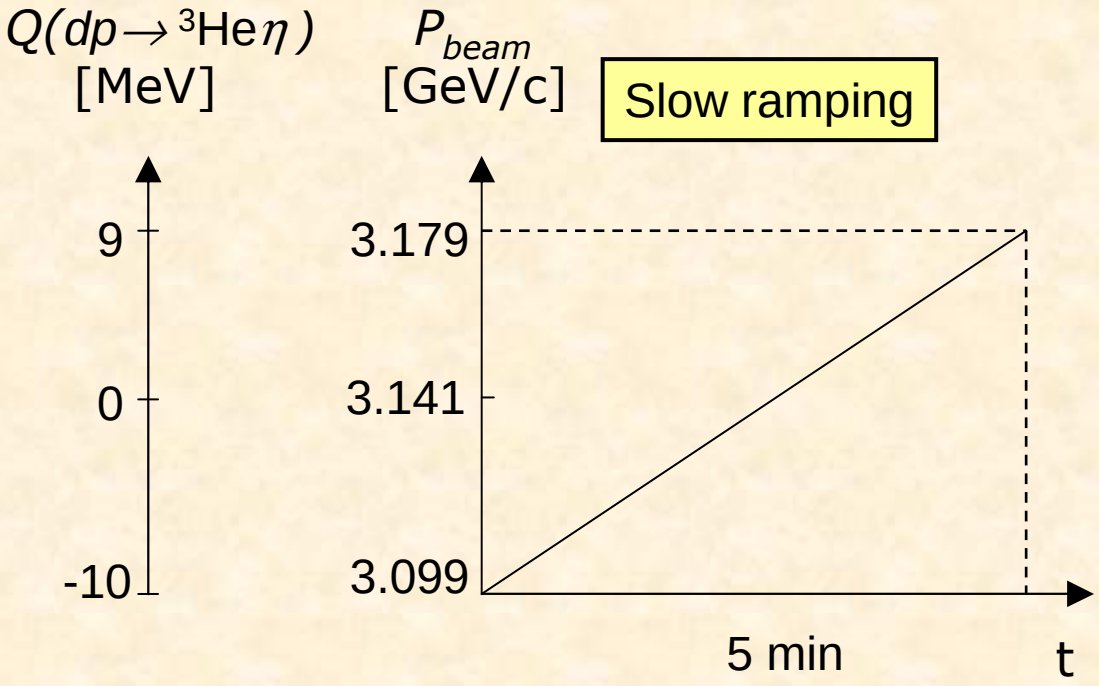
γ 3He $\rightarrow$ $p\pi^0$ X data from MAMI

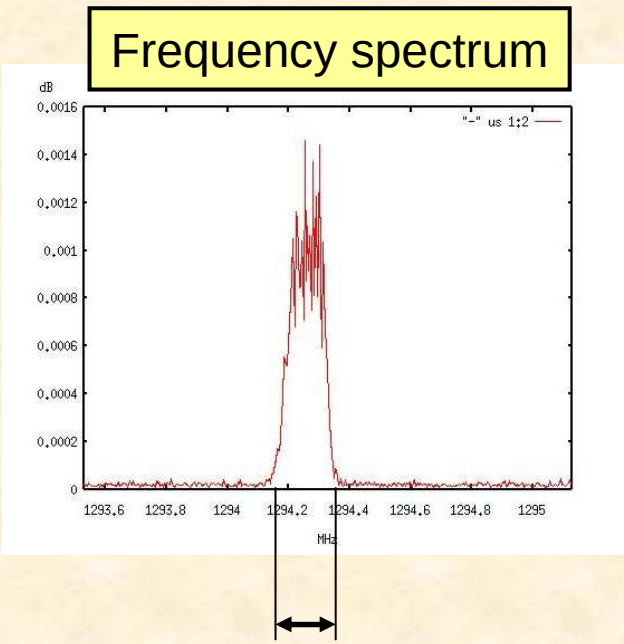
(M. Pfeiffer et al., Phys. Rev. Lett. **92**(2004)252001)



Binding energy:(-4.4 $\pm$ 4.2) MeV
Width: 25.6 $\pm$ 6.1 MeV

Internal COSY beam: ~ 3×10^{10} deuterons





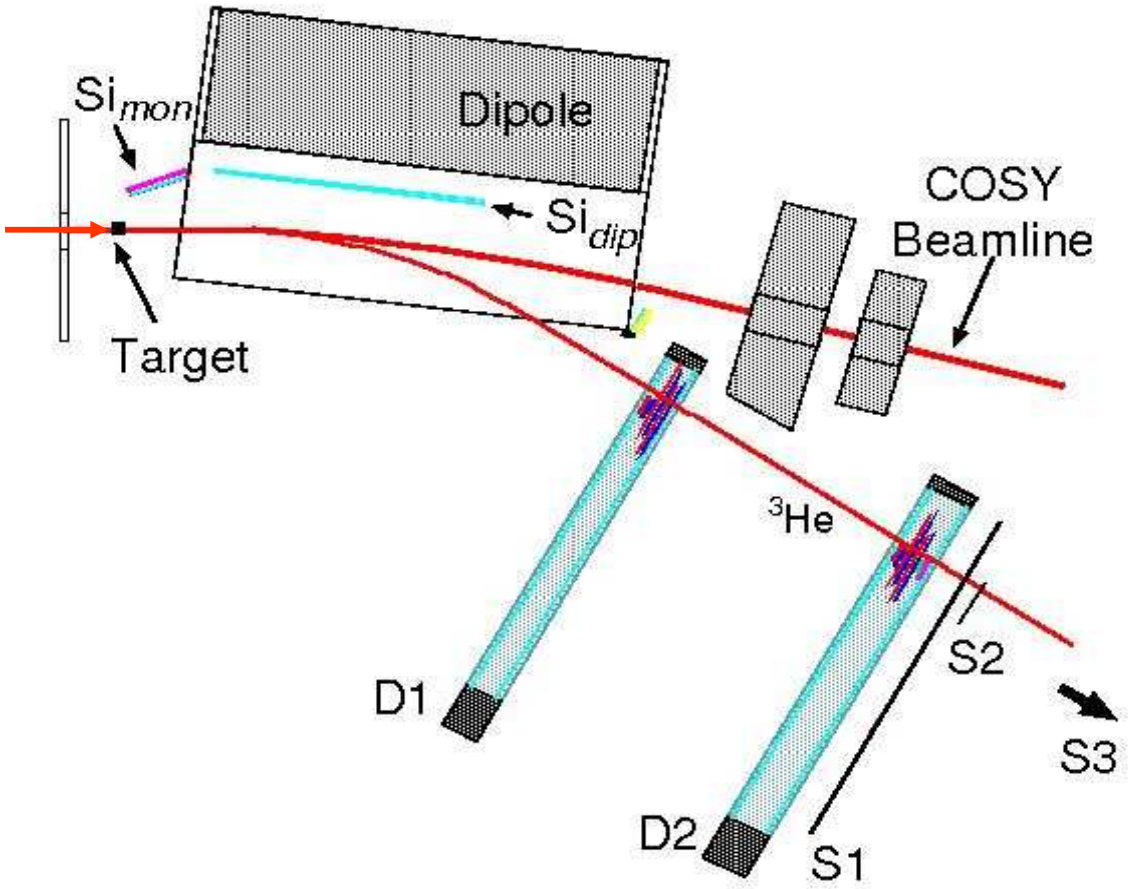
$\Delta f = 0.2$ MHz

$\Downarrow$

$\Delta p = 1.7$ MeV/c

$\Delta Q = 0.4$ MeV

COSY-11 detection system



T1: $dp \rightarrow {}^3\mathrm{He}X$, $X = \pi^o, \eta$

T2: $dp \rightarrow {}^3\mathrm{H}\pi^+$,

T3: $dp \rightarrow dp\,\eta$

T4: $dp \rightarrow dp$, $pp \rightarrow pp$ (QFS)

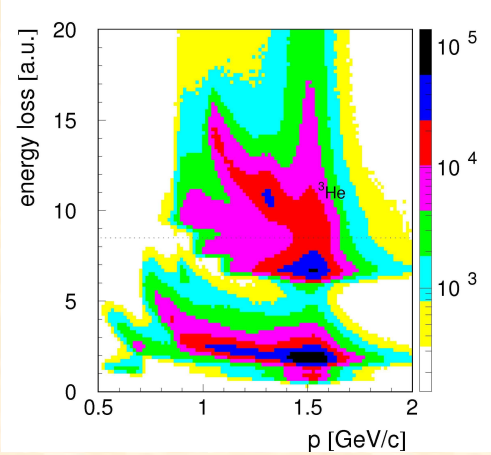
T5: $dp \rightarrow dp\pi^o$

T6: $dp \rightarrow ppp\pi^-$

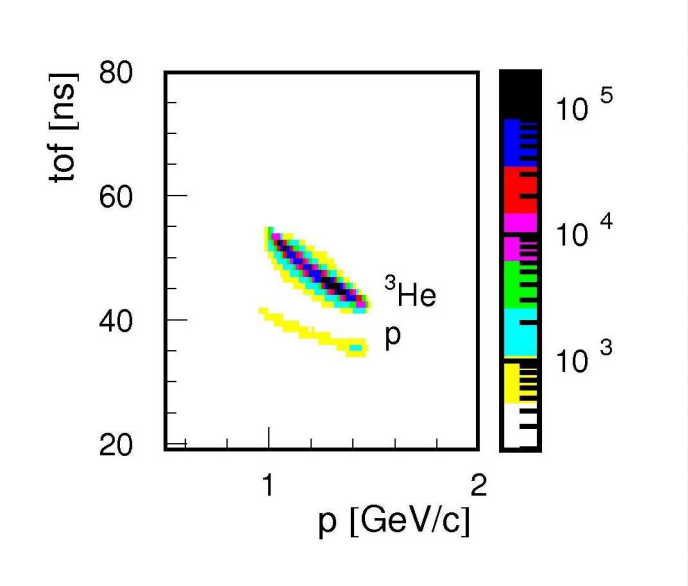
T7: $dp \rightarrow dp\gamma$

^{3}He identification

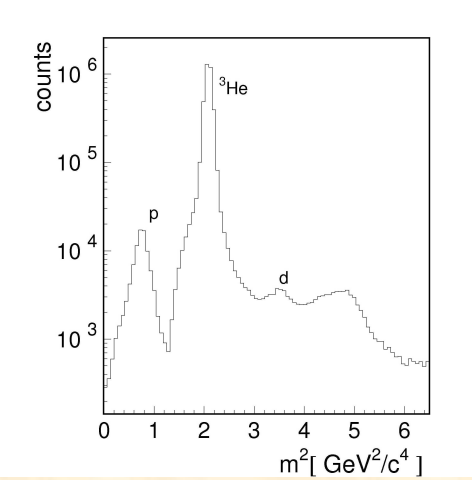
ΔE - p



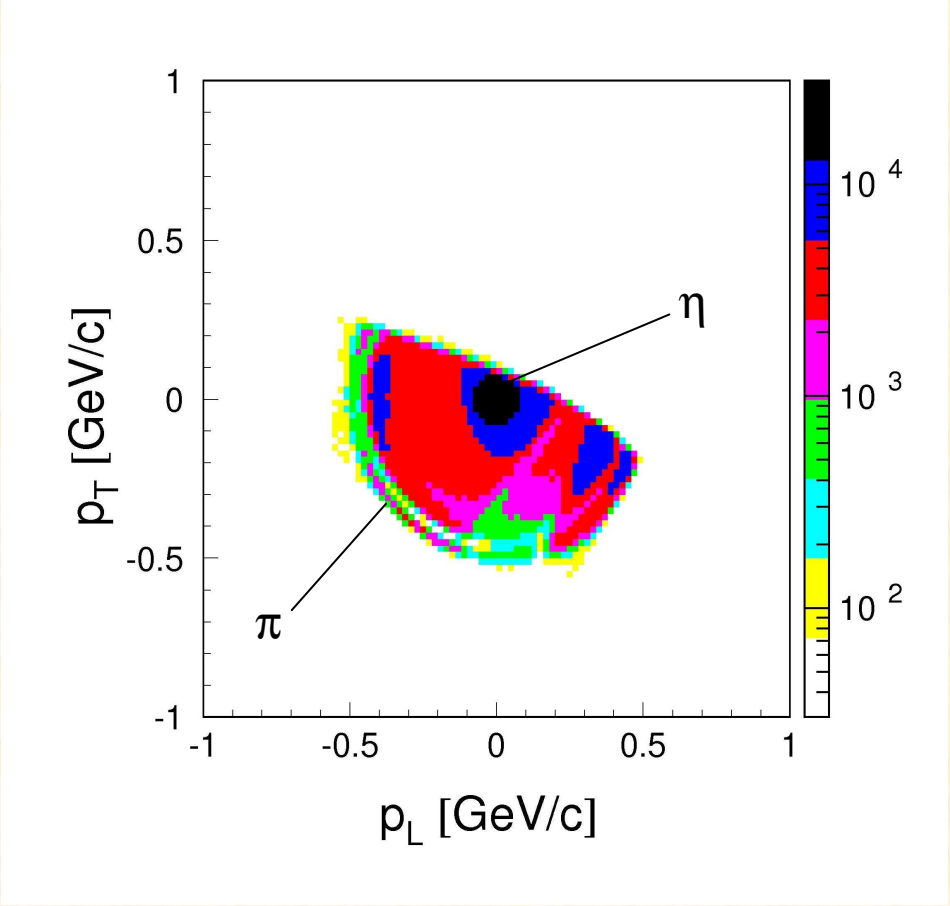
TOF - p



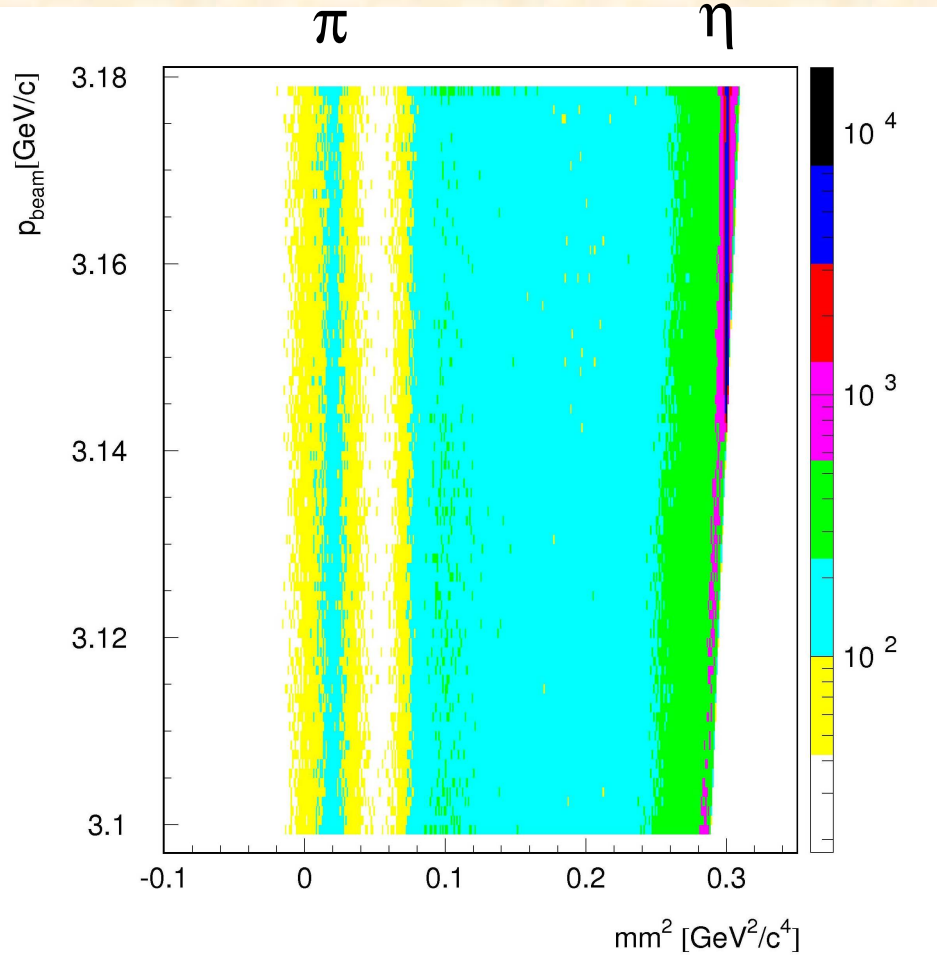
m^2 / q^2

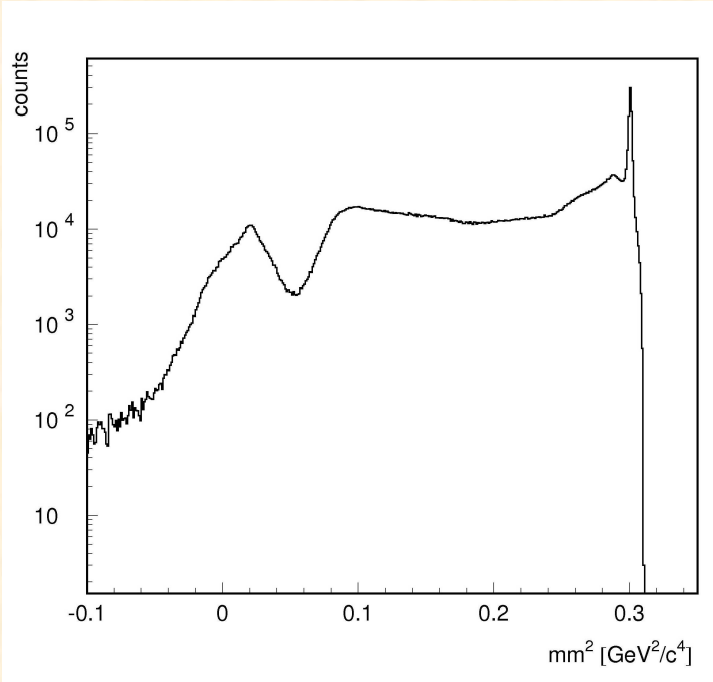


^{3}He c.m. momentum distribution

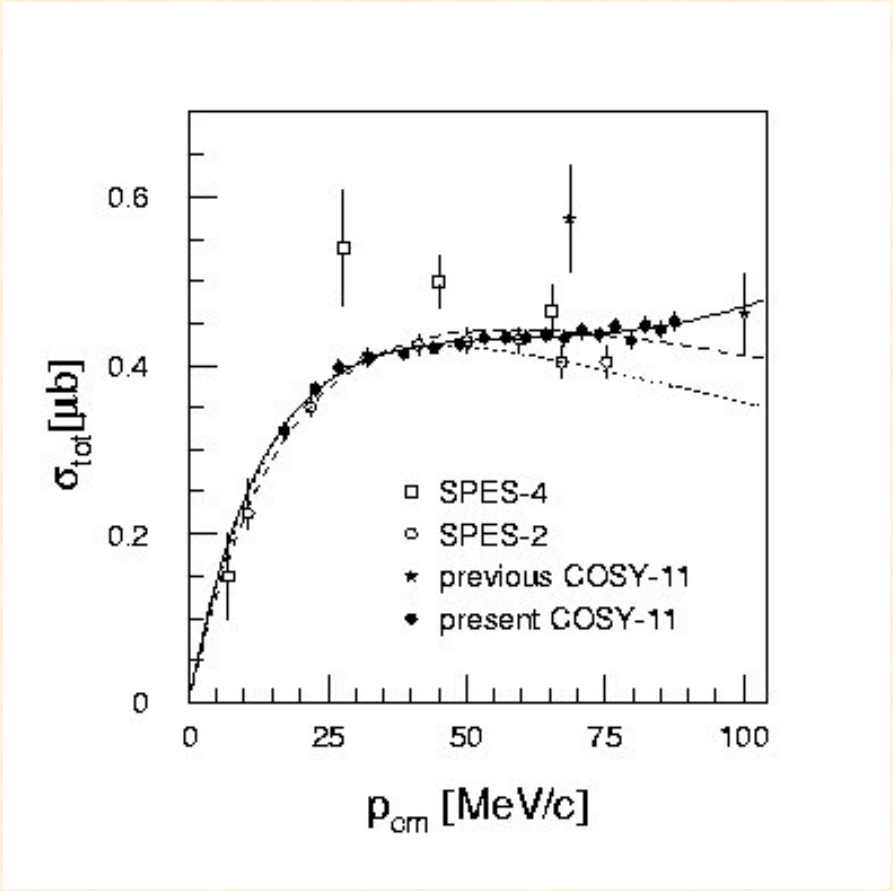


Missing mass





σ_{TOT} $(dp \rightarrow {}^3\mathrm{He}\,\eta)$



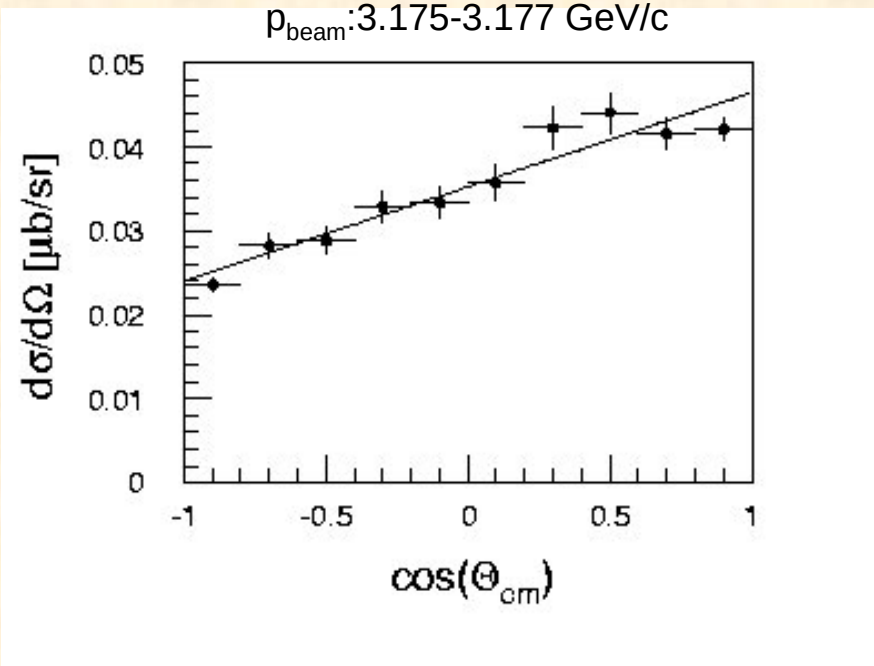
$$T^0 \sim \frac{1}{1 - i p_{cm} a}$$

$$T^1 \sim p_{cm}$$

Fitted: $|T^0|$, $|T^1|$, a

$|a|$=4.3±0.5 fm, χ^2/nfree=0.4

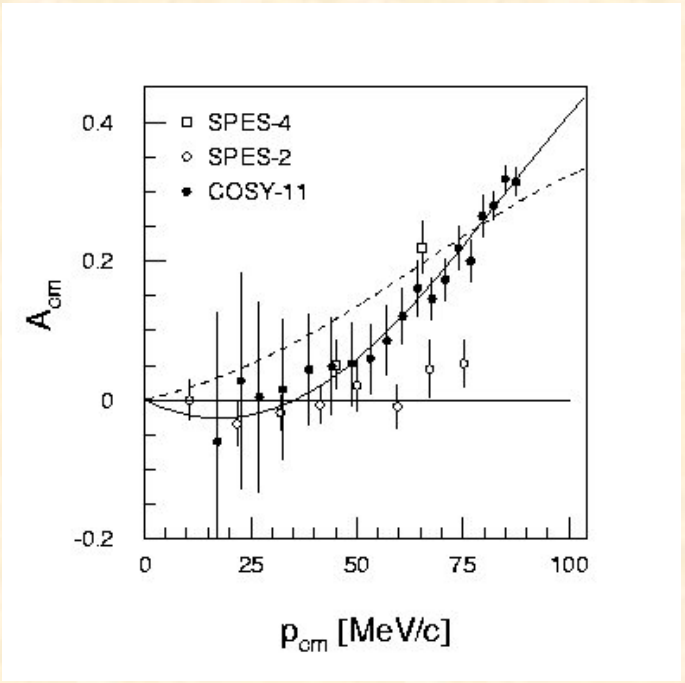
Angular distributions



$$d\sigma/d\Omega_{cm} = \sigma_{tot}/4\pi\,[1 + A_{cm}\cos(\theta_{cm})]$$

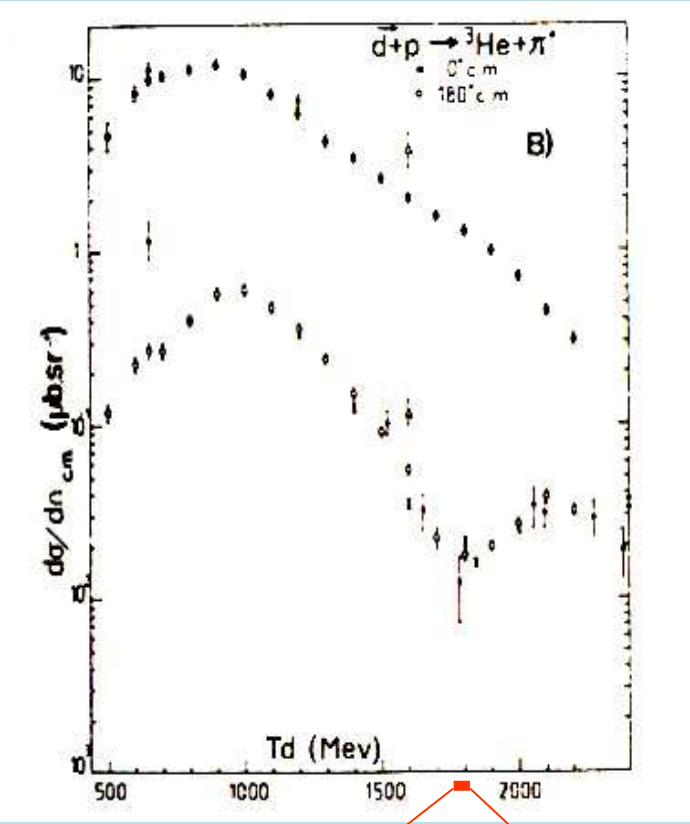
Forward-backward asymmetries

$$A_{cm} \sim \frac{2\,\mathrm{Re}(T^0 T^{1*})}{\left|T^0\right|^2 + \left|T^1\right|^2}$$

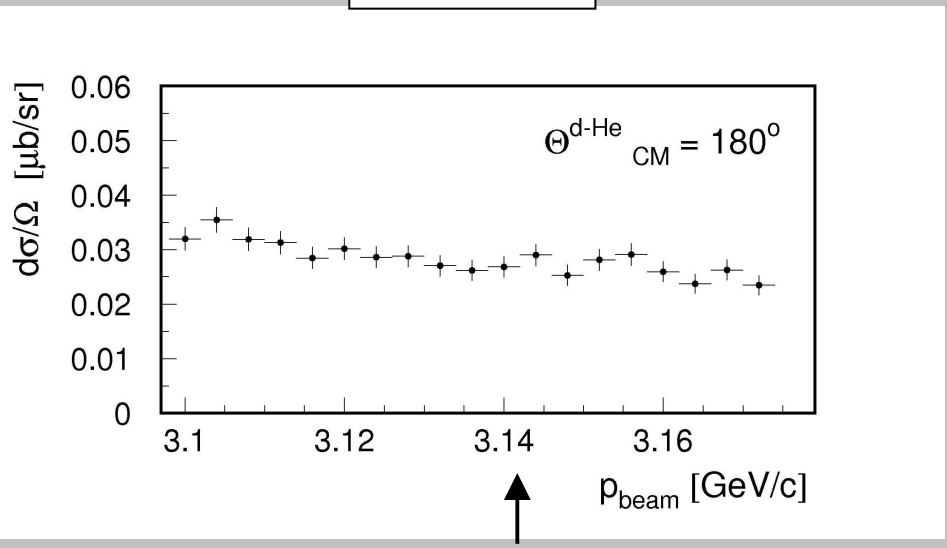


$dp \rightarrow {}^3\mathrm{He}\pi^o$

Fig. from C. Kerboul et al., PL B181(1986)28



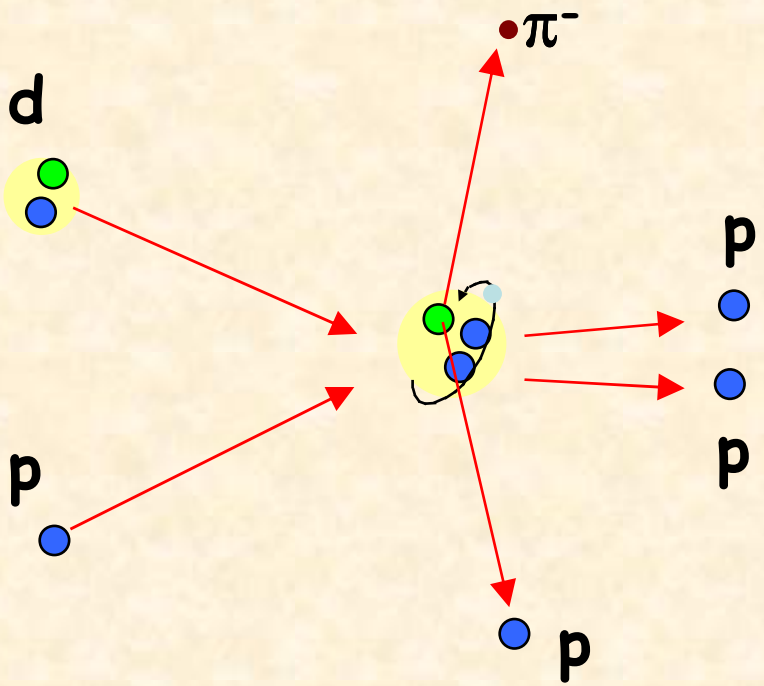
COSY-11



$^3\mathrm{He}\eta$ threshold

$\sigma(dp \rightarrow (^3\mathrm{He}\text{-}\eta)_{\text{bound}} \rightarrow {}^3\mathrm{He}\pi^o) < 0.07\ \mu\mathrm{b}$

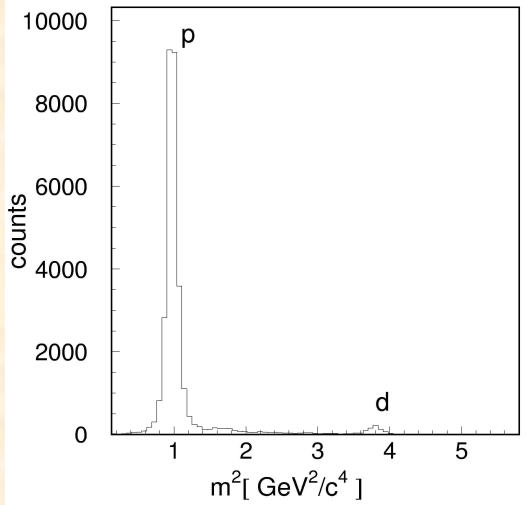
Preliminary results for $dp \rightarrow ppp\pi^-$



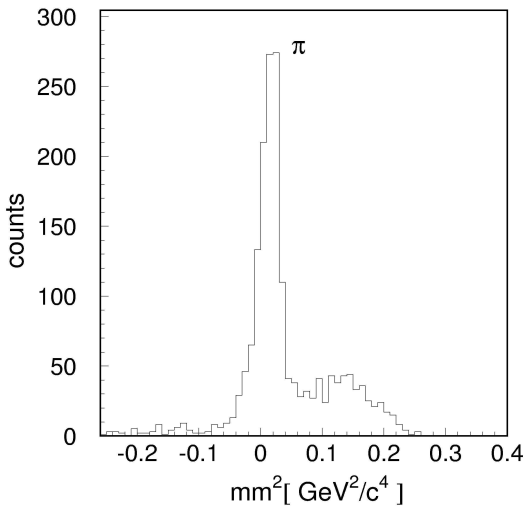
- p-π back-to-back emission: $\theta_{cm} \sim 180^\circ$
- proton spectators : $p_{cm} \sim 100$ MeV/c,

Particle identification

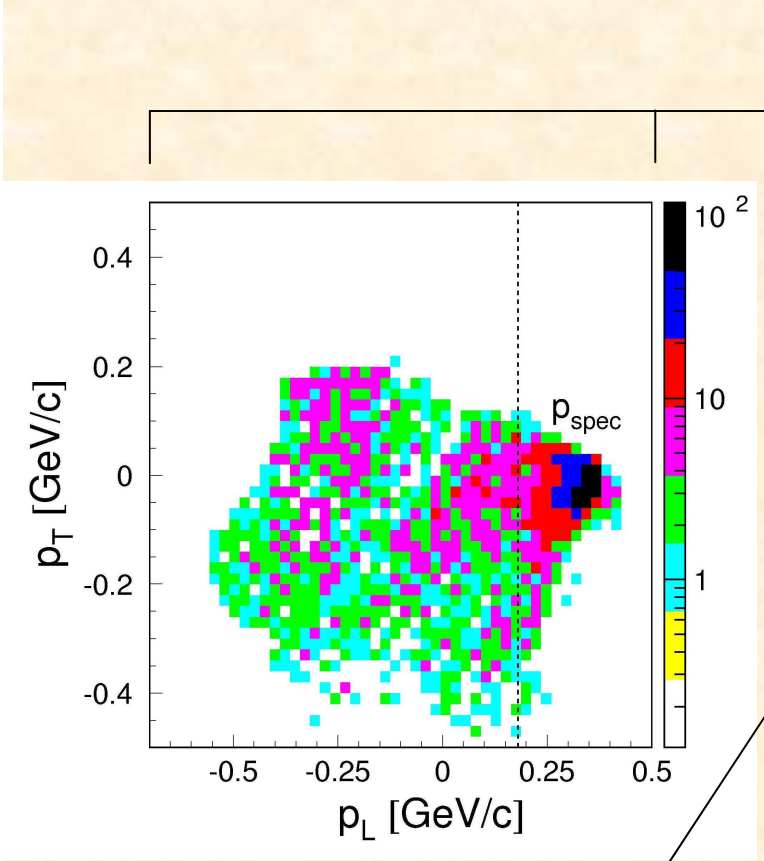
invariant mass

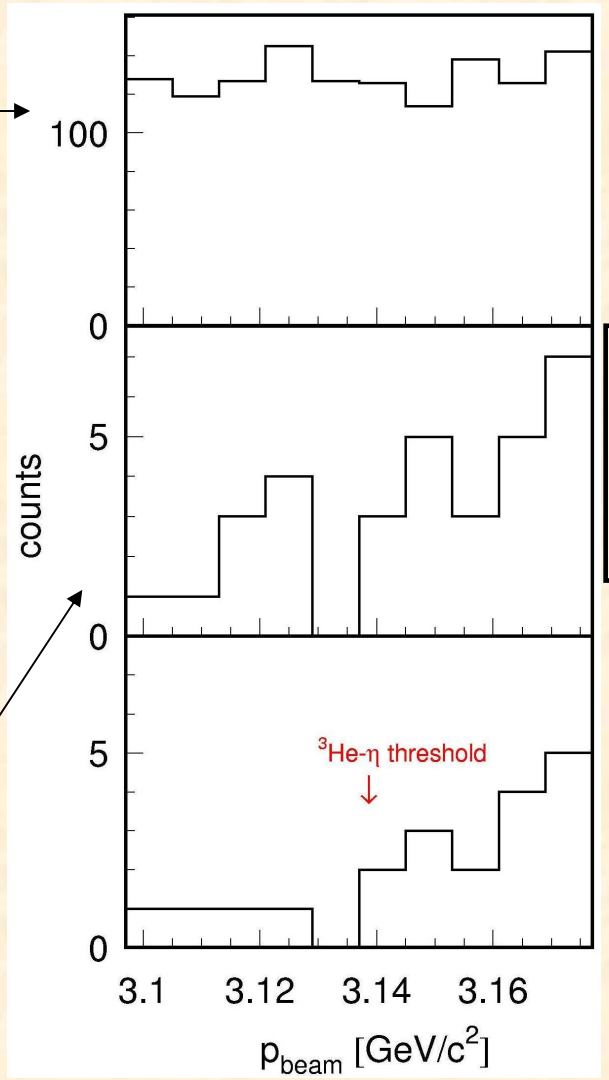


missing mass



Counting rate near threshold



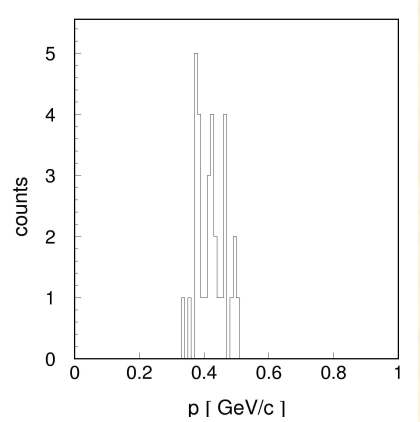


Difference between counts below and above 3He-η threshold (2.5 σ effect)

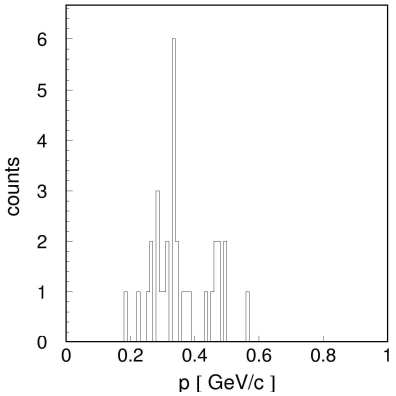
Additional requirement:
c.m. momentum of two protons smaller than 0.2 GeV/c

Momentum distributions

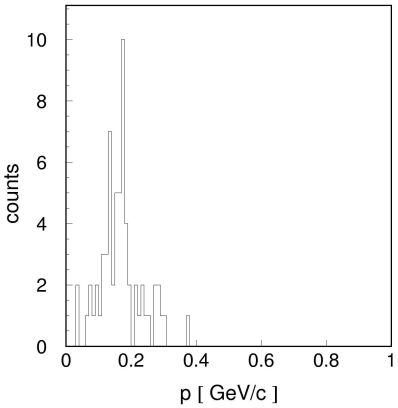
pions



„leading" protons

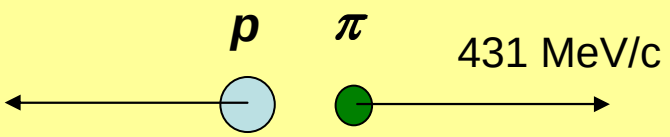


„spectator" protons

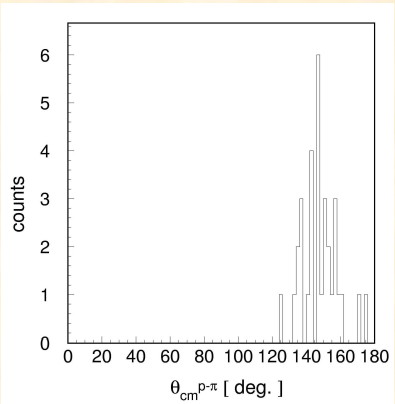


Suggested scenario:

^{3}He-η FSI leading to absorption of eta on neutron and conversion to p-π pair



Pion-proton c.m. angle



Summary

- Strong enhancement of σ_{TOT} due to S-wave ^{3}He-η FSI; $|a|=4.3 \pm 0.5$ fm

- Non-zero forward-backward asymmetries: S- and P-wave interference; indication of a pole in the ^{3}He-η S-wave scattering amplitude

- We see no signal from decay of ^{3}He-η bound state in the $dp \rightarrow {}^3\mathrm{He}\pi^0$ channel

- Observed difference between counting rate for the $dp \rightarrow ppp\pi^-$ *reaction* below and above the ^{3}He-η threshold (2.5 σ effect).
  Suggested scenario:
  ^{3}He-η FSI leading to absorption of eta on neutron and conversion to p-π- pair

Structures at the η threshold

^{3}He η

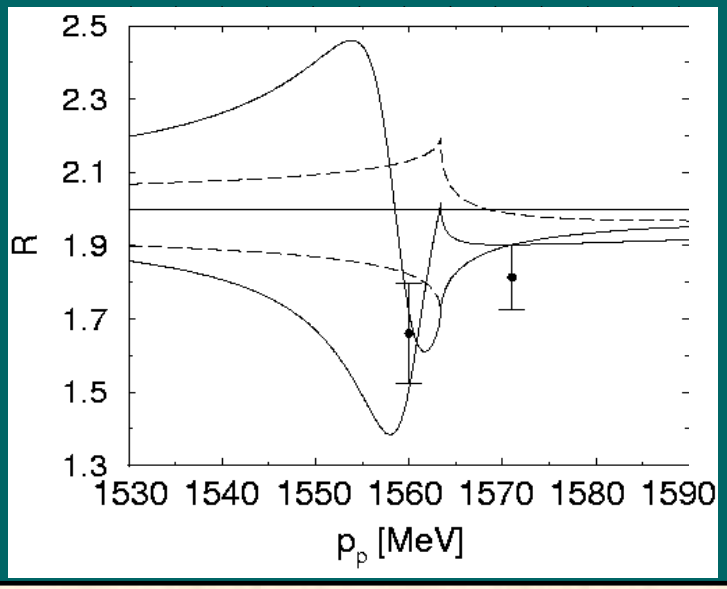
Re(a) < 0 Bound state ? **Re(a) > 0** Virtual state

π-η mixing

$$R = \frac{d\sigma/d\Omega\,(pd \to {}^3\mathrm{H}\,\pi^+)}{d\sigma/d\Omega\,(pd \to {}^3\mathrm{He}\,\pi^0)} = \frac{p_{\pi^+}}{p_{\pi^0}} \frac{|T_{\pi^+}|^2}{|T_{\tilde{\pi}^0} + \theta_m T_{\tilde{\eta}}|^2}$$

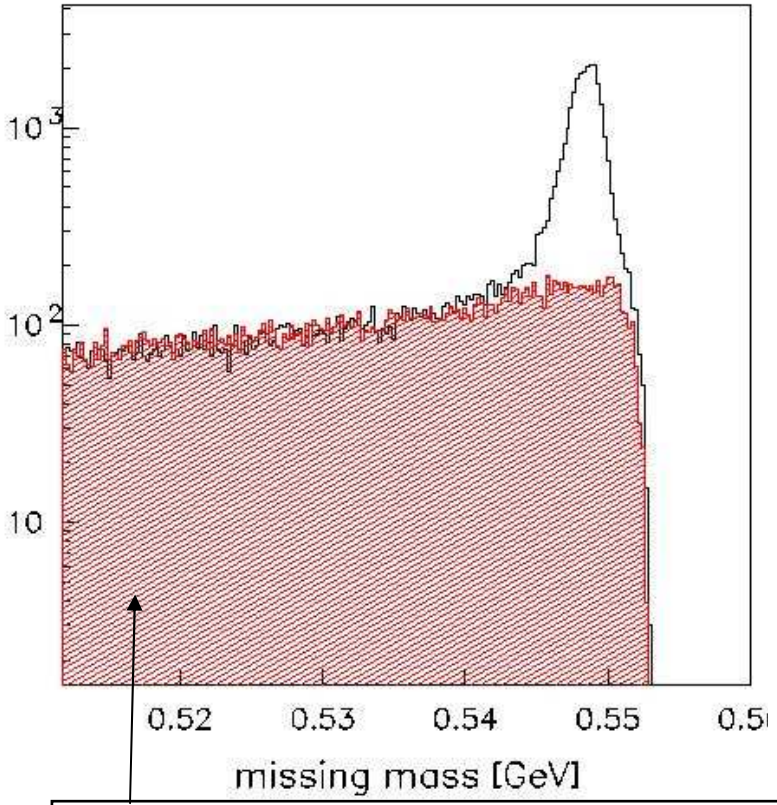
V. Baru, J. Haidenbauer, C. Hanhart and J. A. Niskanen, Phys. Rev. **C68**(2003)035203

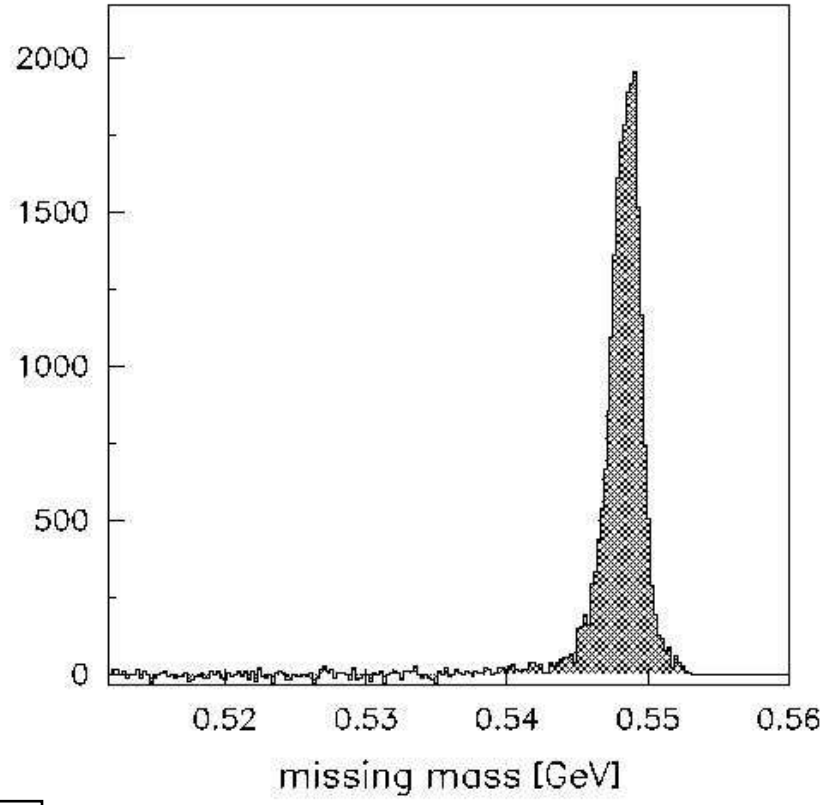
$a_R + ia_I = (\pm 3.8 + i1.6)$fm



Background subtraction

3.166 GeV/c $< p_{beam} <$ 3.170 GeV/c Q ~ 6.5 MeV

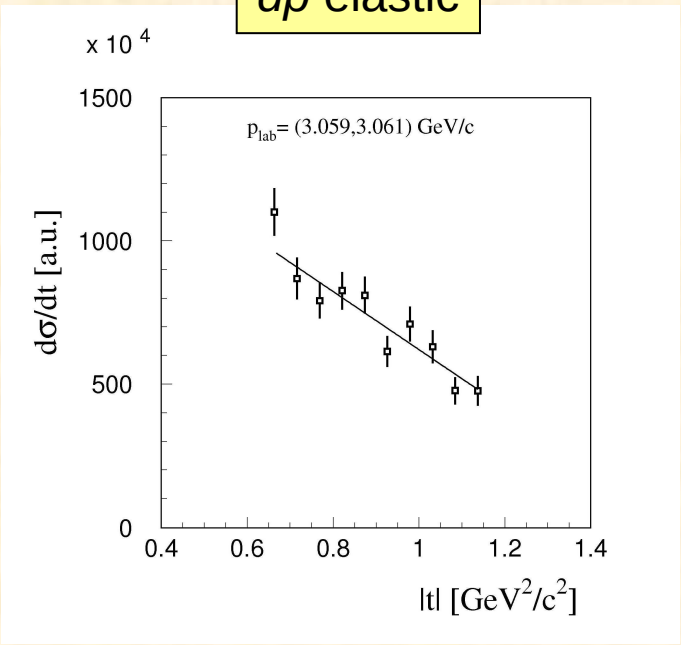




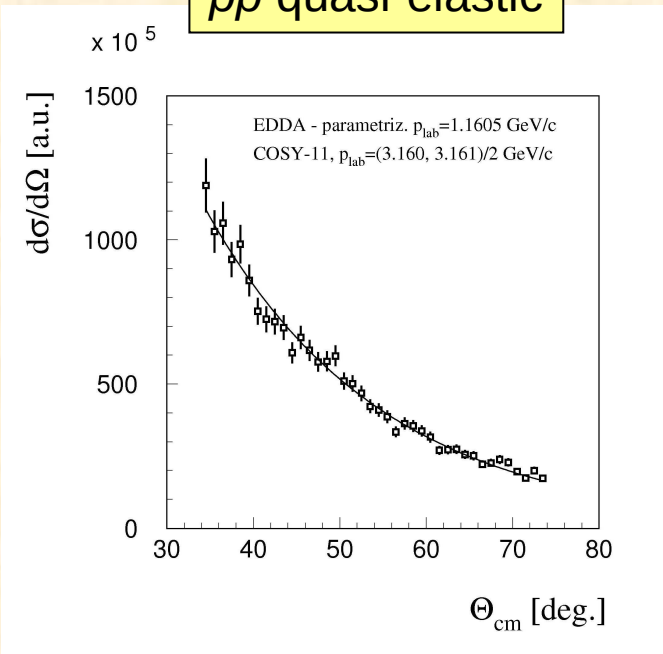
Background:
3.134 GeV/c $< p_{beam} <$ 3.138 GeV/c

Luminosity determination

dp elastic



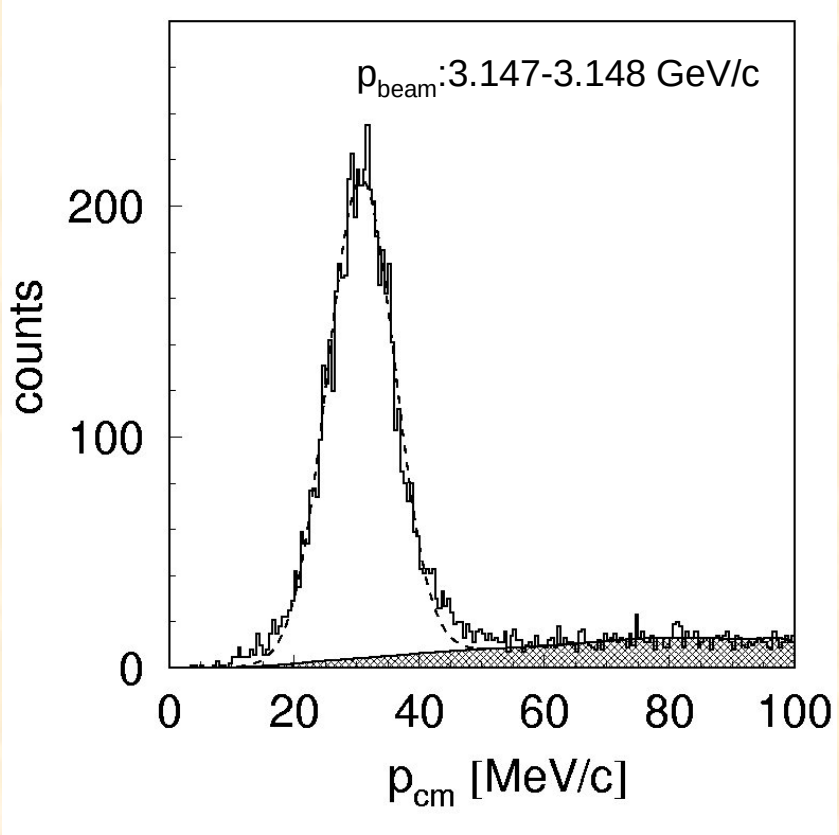
pp quasi-elastic



Absolute normalization: ±12%

Relative normalization: ±0.3%

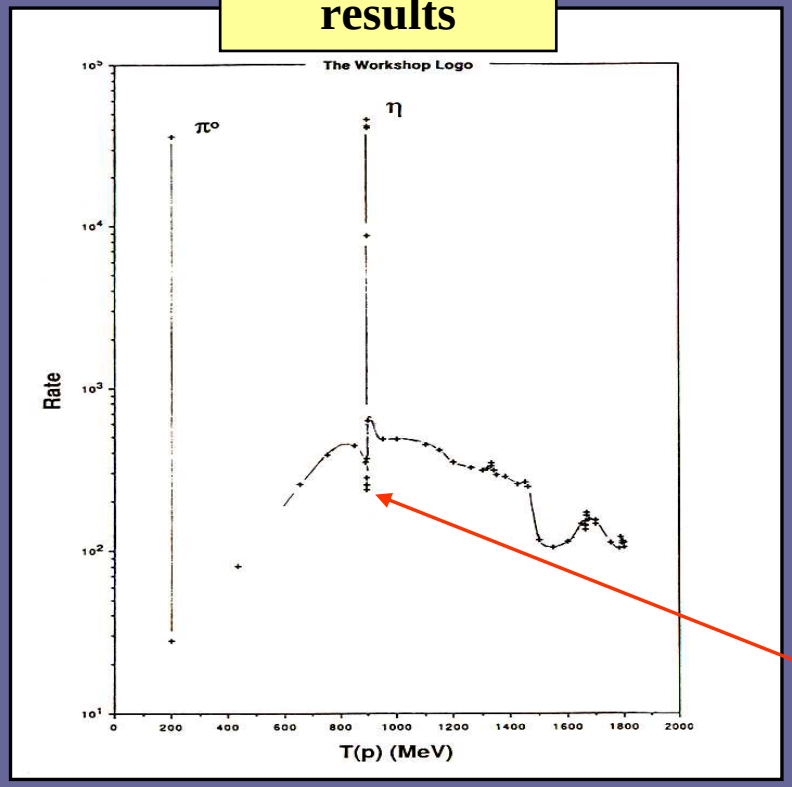
Beam momentum determination



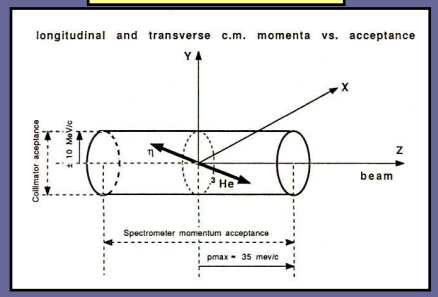
Correction: Δp_{beam} = -3.0 ± 0.2 (syst.) ± 0.8 (eta mass) MeV/c

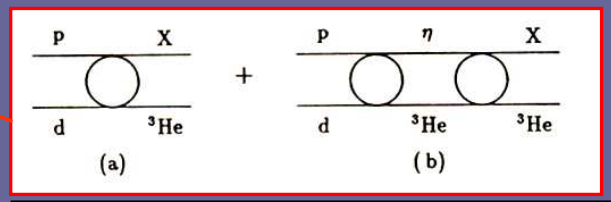
SATURNE $pd \rightarrow {}^3\mathrm{He}\,X$ threshold excitation curve

SATURNE results



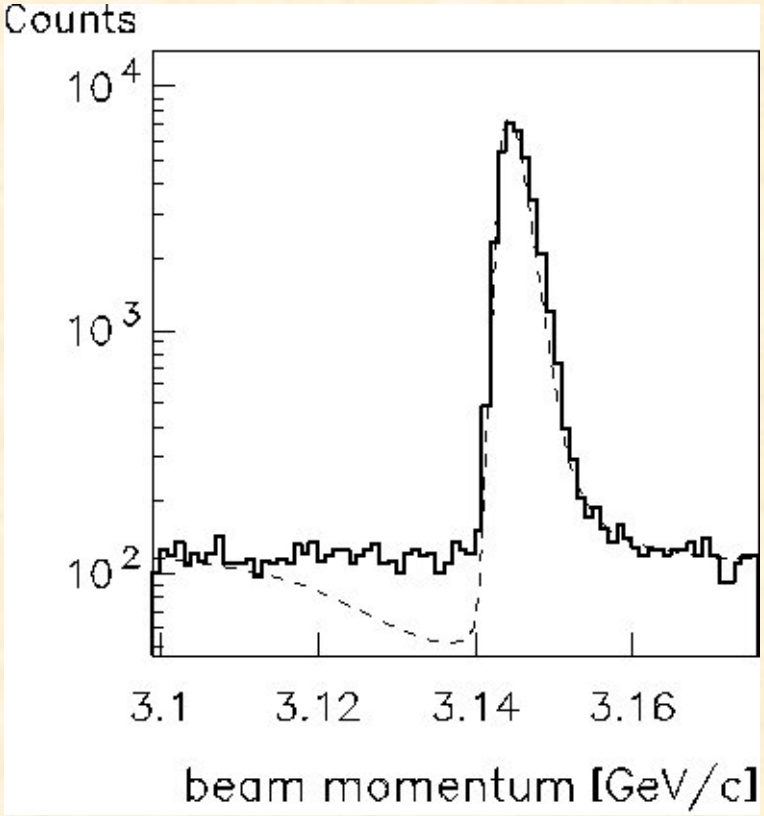
Spectrometer momentum acceptance





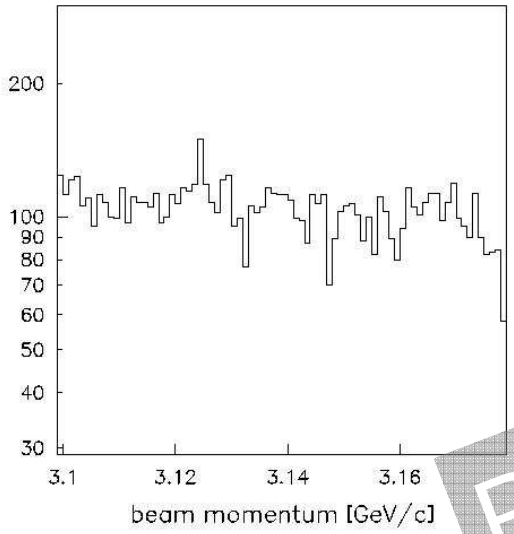
C. Wilkin, in "Production and Decay of Light Mesons", edited by P. Fleury, p.187

COSY-11 $pd \rightarrow {}^3\mathrm{He}\,X$ threshold excitation curve



Excitation curves for

***dp* elastic**
at backward angles

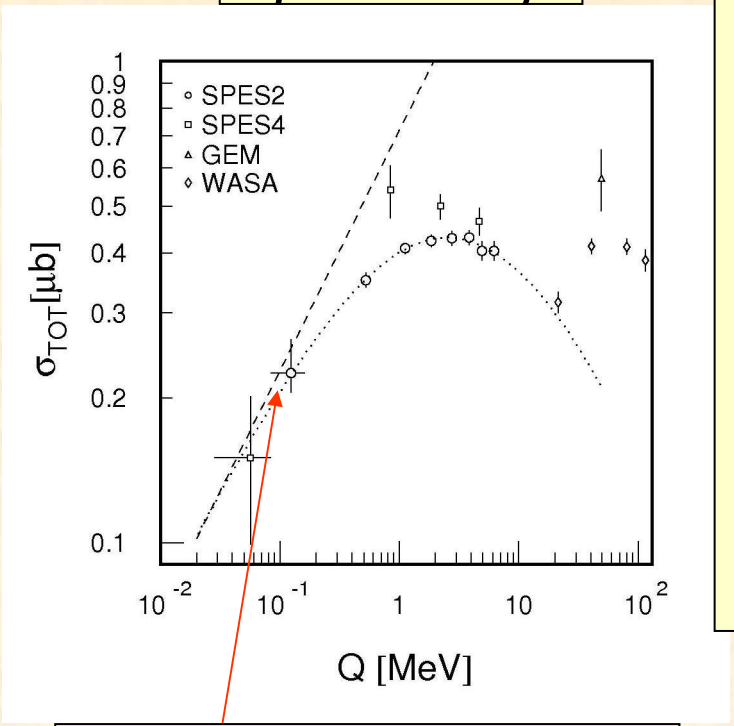


Preliminary

^{3}Heη threshold

^{3}He-η scattering length

$dp \rightarrow {}^3\mathrm{He}\,\eta$



Scattering length
$\boldsymbol{a}$=|3.8±0.6|+i(1.6±1.1) fm

questions:

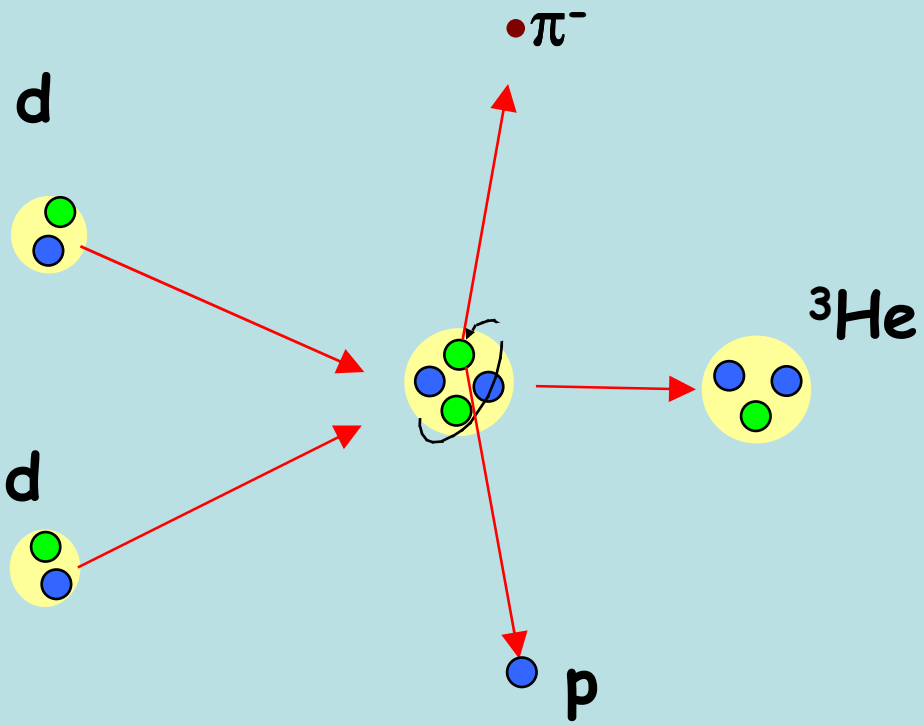
(A. Sibirtsev et al., Eur. Phys. J. **A22**(2004)495)

- inconsistencies between data sets
- contributions from higher partial waves to σ_{tot} at Q <10 MeV
- $|a_R| > a_I$ (?) (necessary condition for bounding) data very close to threshold (Q <1 MeV) needed

$$|f|^2 = \frac{|f_p|^2}{1+2a_I q+|a|^2 q^2}$$

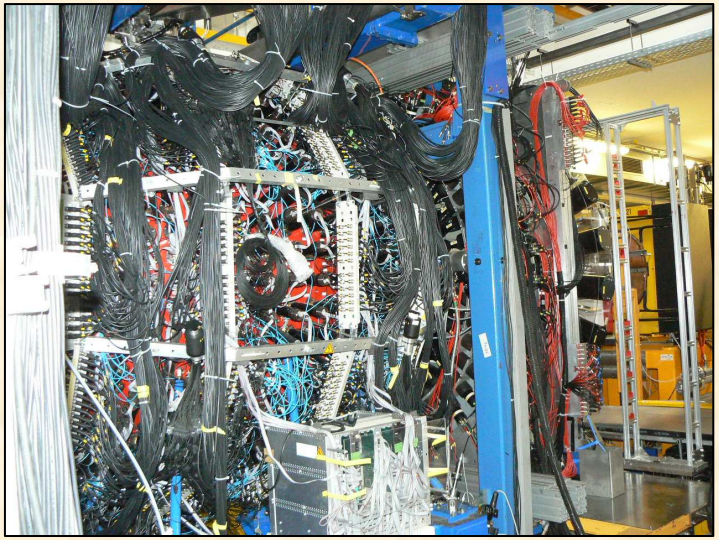
Search for the ^{4}He– η bound state in *d-d* collisions

Princilple of measurements

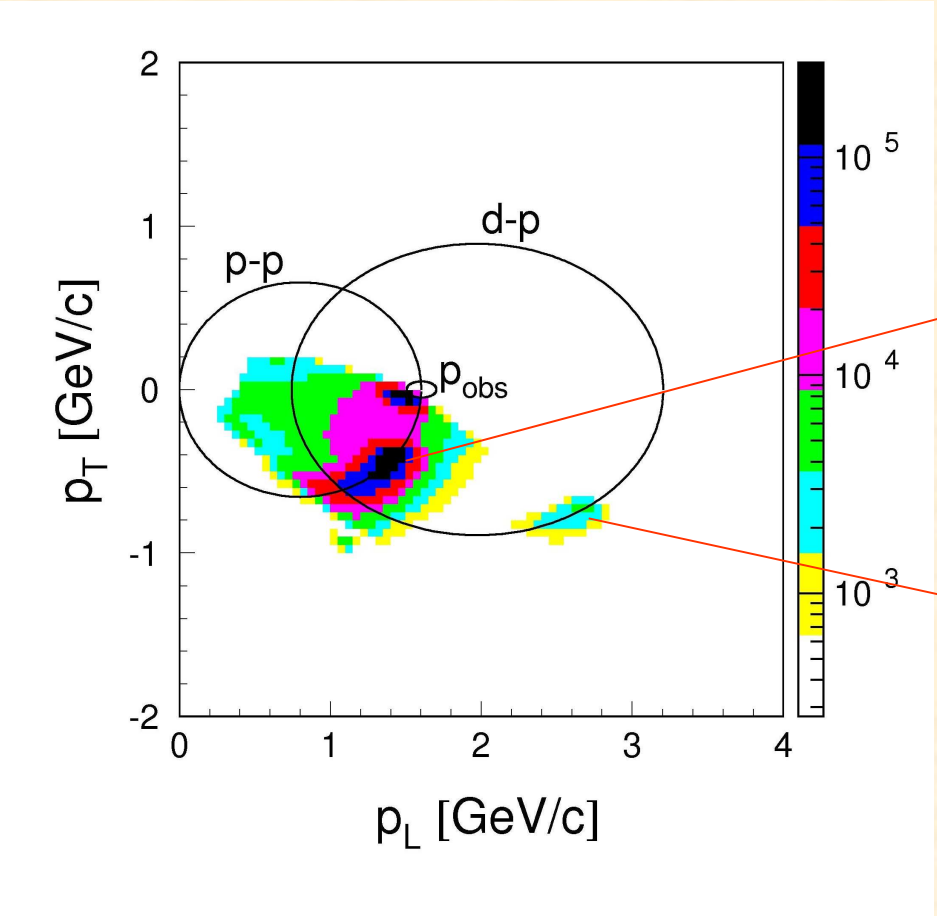


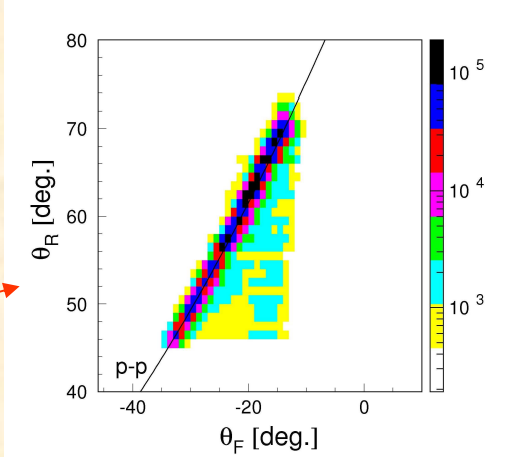
- *p*-π back-to-back emission: $\theta_{cm} \sim 180^\circ$
- ^{3}He is a spectator : $p_{cm} \sim 50$ MeV/c,
  $\theta_{lab} \sim 50/1500$ rad $= 1.9^\circ$

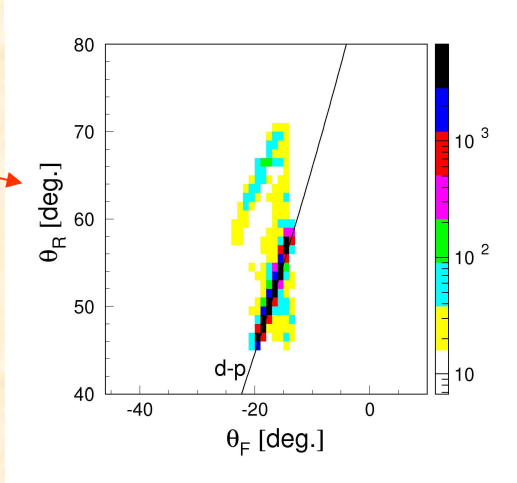
Experiment
WASA@COSY



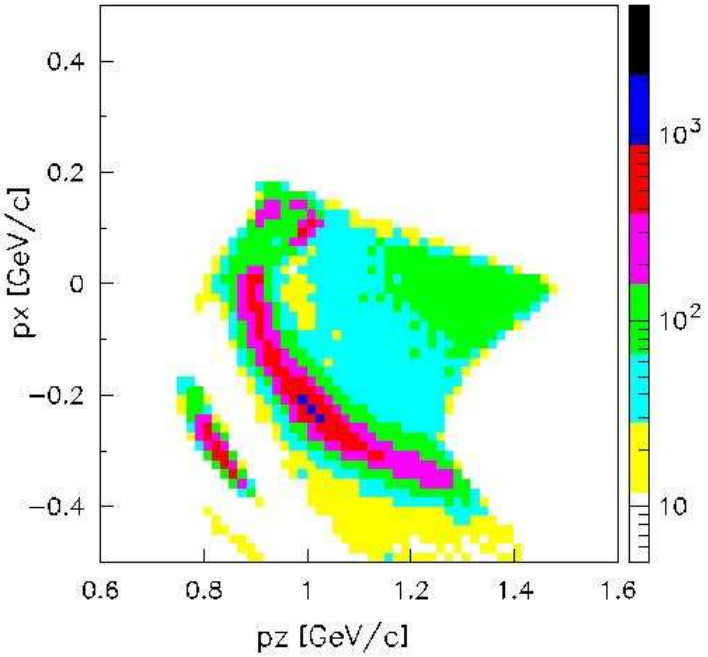
dp elastic and *pp* quasi-elastic scattering

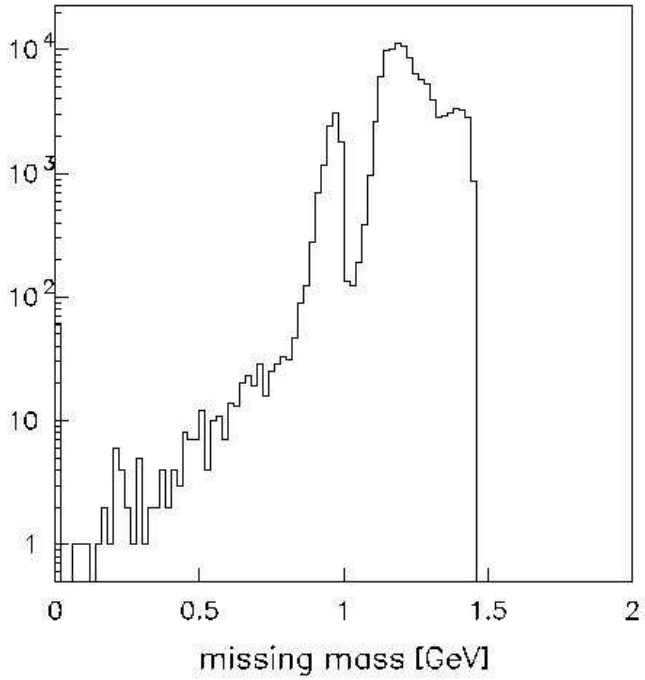




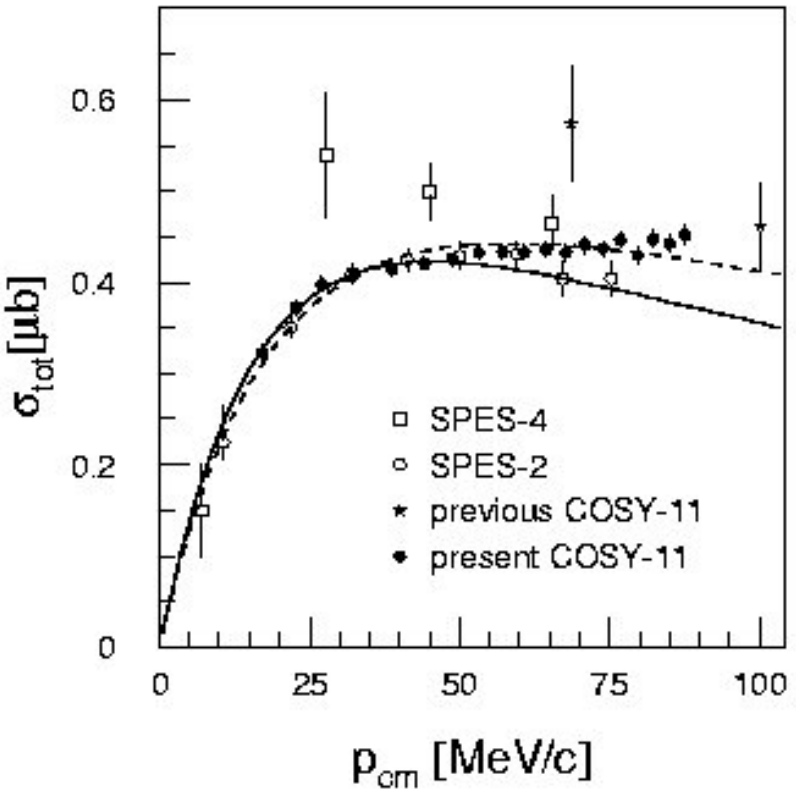


dp elastic scattering at backward cm angles





$\sigma_{TOT}\ (dp \rightarrow {}^3\mathrm{He}\,\eta)$



$$\sigma_{TOT} = \frac{p_{cm}}{p_{beam}^{cm}} \left| \frac{f}{1 - i p_{cm} a} \right|^2$$

(data below 50 MeV/c)

$|a_R|$ = 2.9±2.7 fm, a_I = 3.2±1.8 fm

$|a|$ = 4.3±0.5 fm

χ^2/nfree = 0.5

Centrifugal barrier model

- A plane wave $e^{ipz} = \sum_{l=0}^{\infty} (2l+1) i^l j_l(pr) P_l(\cos\theta)$
- For $pr = \frac{2\pi r}{\lambda} << 1$

$$j_l(pr) \approx \frac{(pr)^l}{1 \cdot 3 \cdot \ldots \cdot (2l+1)}$$

- $T^l \sim p^l$ $\quad$ $\boxed{T^{1-} \sim p}$

Transition amplitudes

- Final state ^{3}He-η

l=0,	***J=1/2***	T^{0}
l=1,	***J=1/2***	T^{1-}
l=1,	***J=3/2***	T^{1+}

- Cross section

$$\frac{d\sigma}{d\Omega} \sim \left|T^{0}\right|^2 + \left|T^{1-}\right|^2 + \left|T^{1+}\right|^2 (1+3\cos^2\theta)$$

$$+ 2\,\mathrm{Re}(2T^{0}T^{1+*} + T^{0}T^{1-*})\cos\theta + 2\,\mathrm{Re}(2T^{1+}T^{1-*})(3\cos^2\theta - 1)$$

- For

$$T^{1+} \equiv 0$$

$$\frac{d\sigma}{d\Omega} \sim \left|T^{0}\right|^2 + \left|T^{1-}\right|^2 + 2\,\mathrm{Re}(T^{0}T^{1-*})\cos\theta$$