

Search for the η -mesic helium by means of COSY-11 WASA-at-COSY and TOF

Paweł Moskal



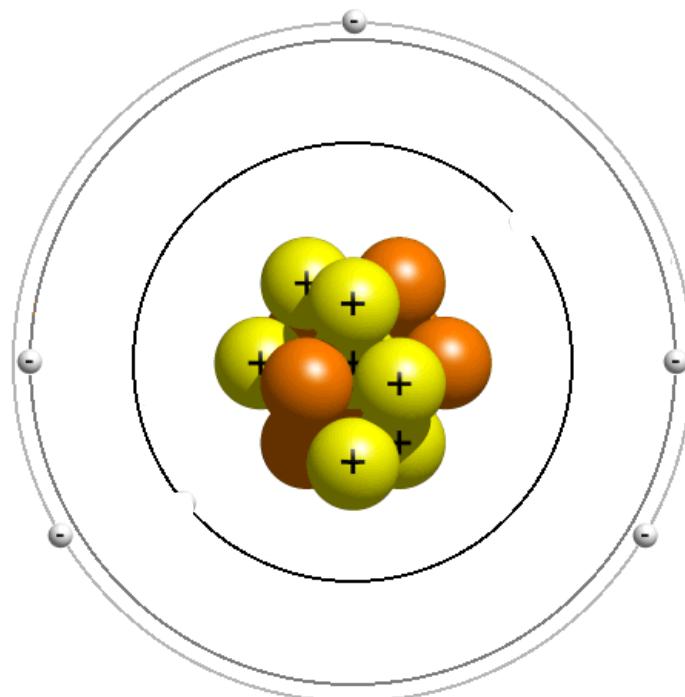
Jagiellonian University, Cracow, Poland



International Symposium on Mesic Nuclei
Kraków, 16th of June 2010

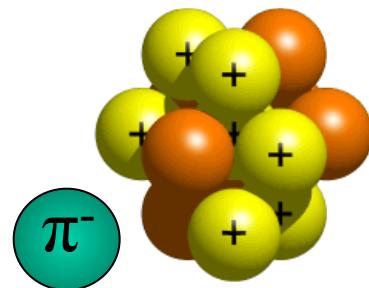
ETA-MESIC NUCLEUS

It is not an atom or mesonic atom !

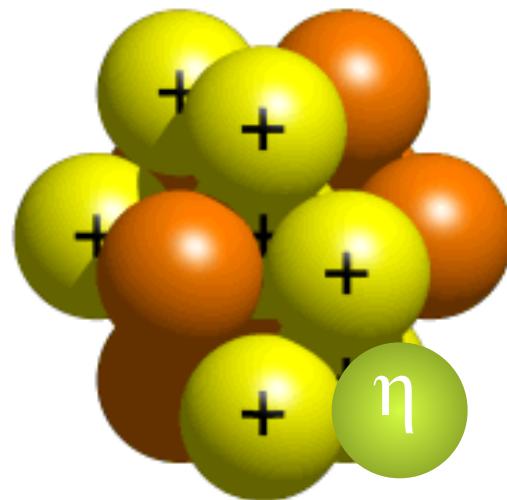


ETA-MESIC NUCLEUS

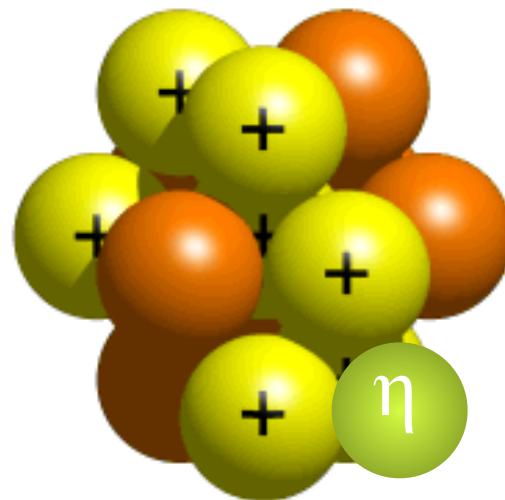
It is not an atom or mesonic atom !



ETA-MESIC NUCLEUS: eta meson bound with nucleus via STRONG INTERACTION

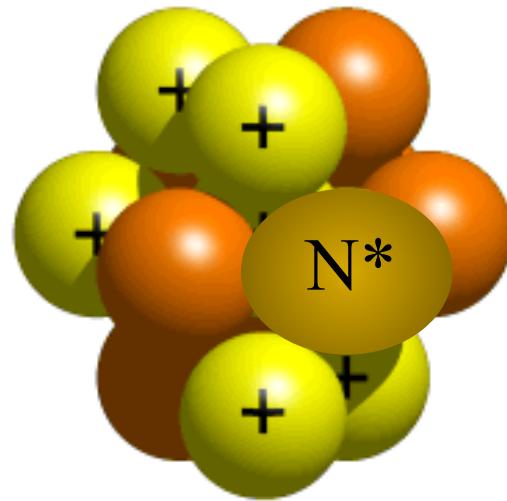


ETA-MESIC NUCLEUS: eta meson bound with nucleus via STRONG INTERACTION



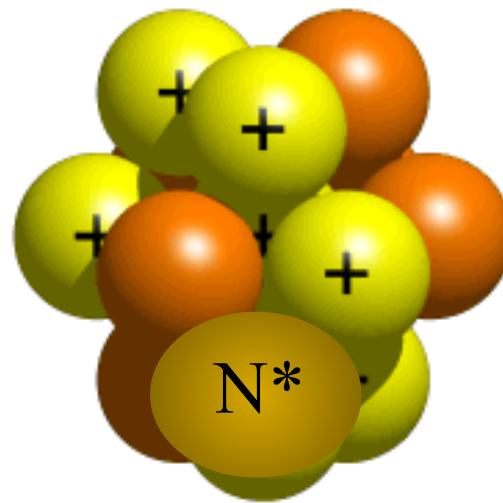
ETA-MESIC NUCLEUS:

eta meson bound with nucleus via
STRONG INTERACTION

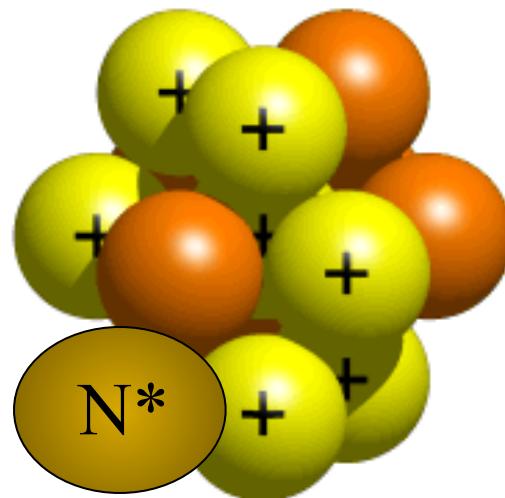


ETA-MESIC NUCLEUS:

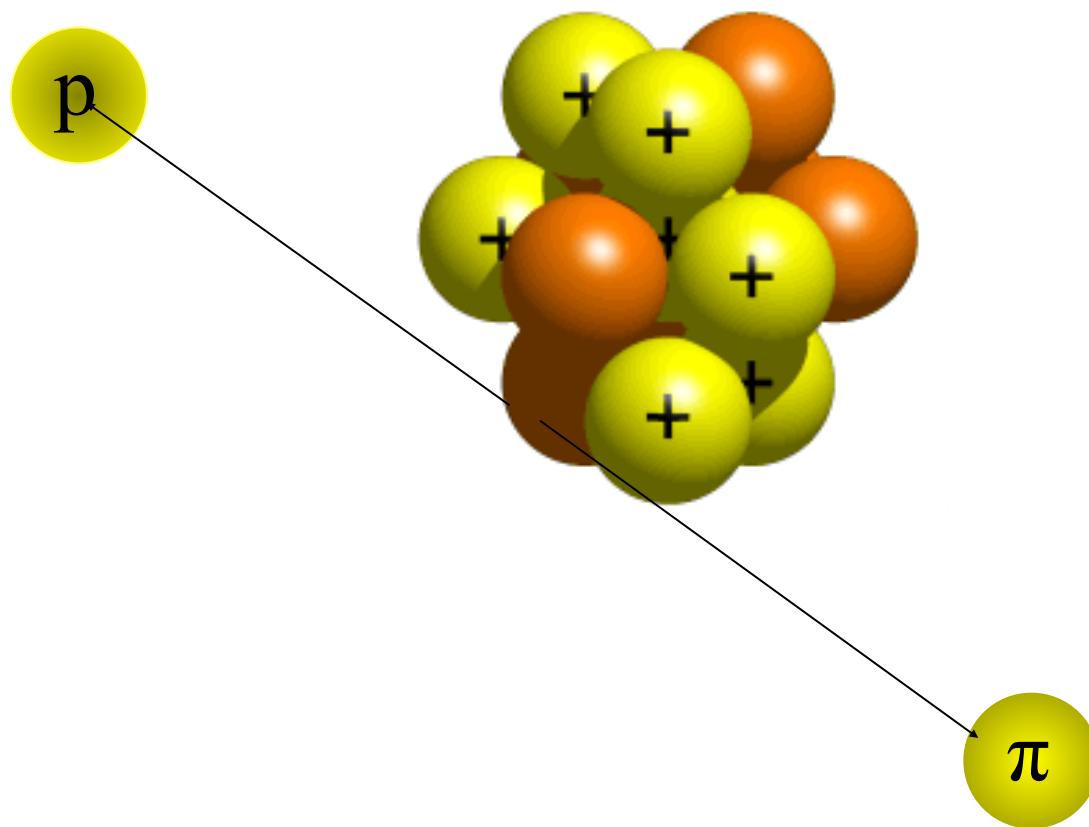
eta meson bound with nucleus via
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ETA-MESIC NUCLEUS: eta meson bound with nucleus via STRONG INTERACTION



ETA-MESIC NUCLEUS: eta meson bound with nucleus via STRONG INTERACTION



Possibility for the study of η -N interaction.

**Study of properties of N*(1535) resonance
in nuclear matter.**

Some information about η meson structure

Possibility for the study of η -N interaction.

Study of properties of N*(1535) resonance in nuclear matter.

Some information about η meson structure

| | m (MeV) | m^* (MeV) | R_{ea} (fm) |
|----------------|-----------|-------------|---------------|
| η_8 | 547.75 | 500.0 | 0.43 |
| η (-10°) | 547.75 | 474.7 | 0.64 |
| η (-20°) | 547.75 | 449.3 | 0.85 |
| η_0 | 958 | 878.6 | 0.99 |
| η' (-10°) | 958 | 899.2 | 0.74 |
| η' (-20°) | 958 | 921.3 | 0.47 |

Attractive interaction between η and N

(R. Bhalerao and L. C. Liu, Phys. Lett. B54 (1985) 685)

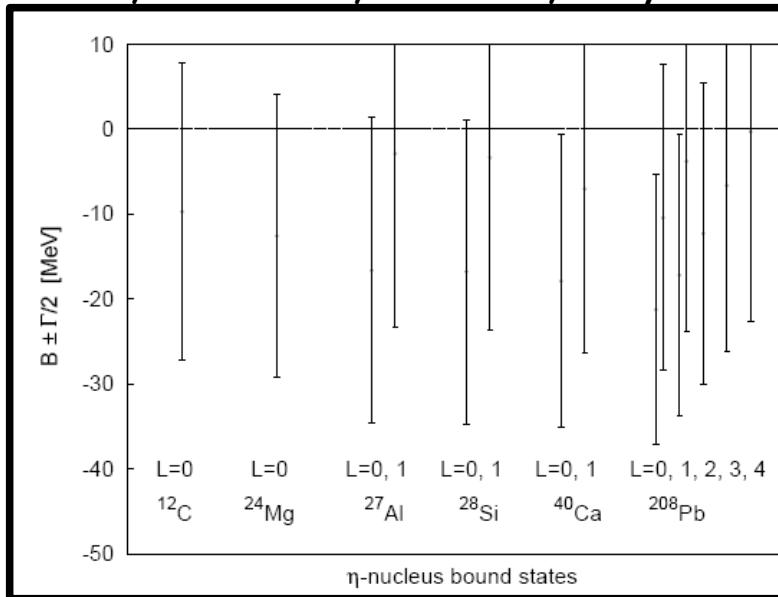


possible existence of bound states
of the η meson with nuclei for $A > 10$

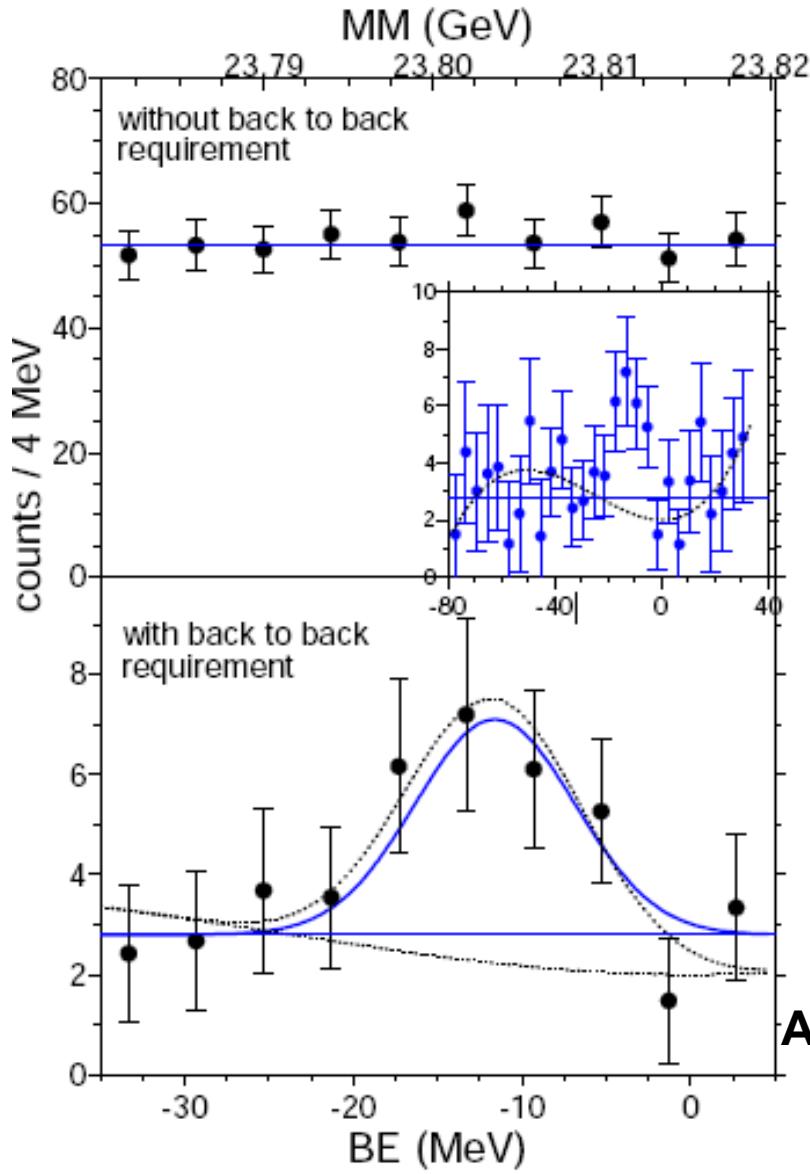
(Q. Haider and L. C. Liu, Phys. Lett. B172 (1986) 257)

Optical potential η nucleus calculated in the frame of unitarized chiral perturbative approach

(C.Garcia-Recio, T. Inoue, J.Nieves, E. Oset, Phys. Lett. B550 (2002) 47).



Search for the η -mesic nuclei in a recoil-free transfer reaction COSY-GEM Collaboration



$\eta\text{-}{}^{25}\text{Mg}$



A. Budzanowski et al., Phys. Rev. C 79 (2009)

η bound state possible with the light nuclei

$^3\text{He}-\eta$

$^3\text{H}-\eta$

$^4\text{He}-\eta$

(C. Wilkin, Phys. Rev., C47 (1993))

Supported by model calculations of:

- S. Wycech et al., Phys. Rev. **C52**(1995)544
(the multiple scattering theory)
- N. N. Scoccola and D. O. Riska, Phys. Lett. **B444**(1998)21
(the Skyrme model)

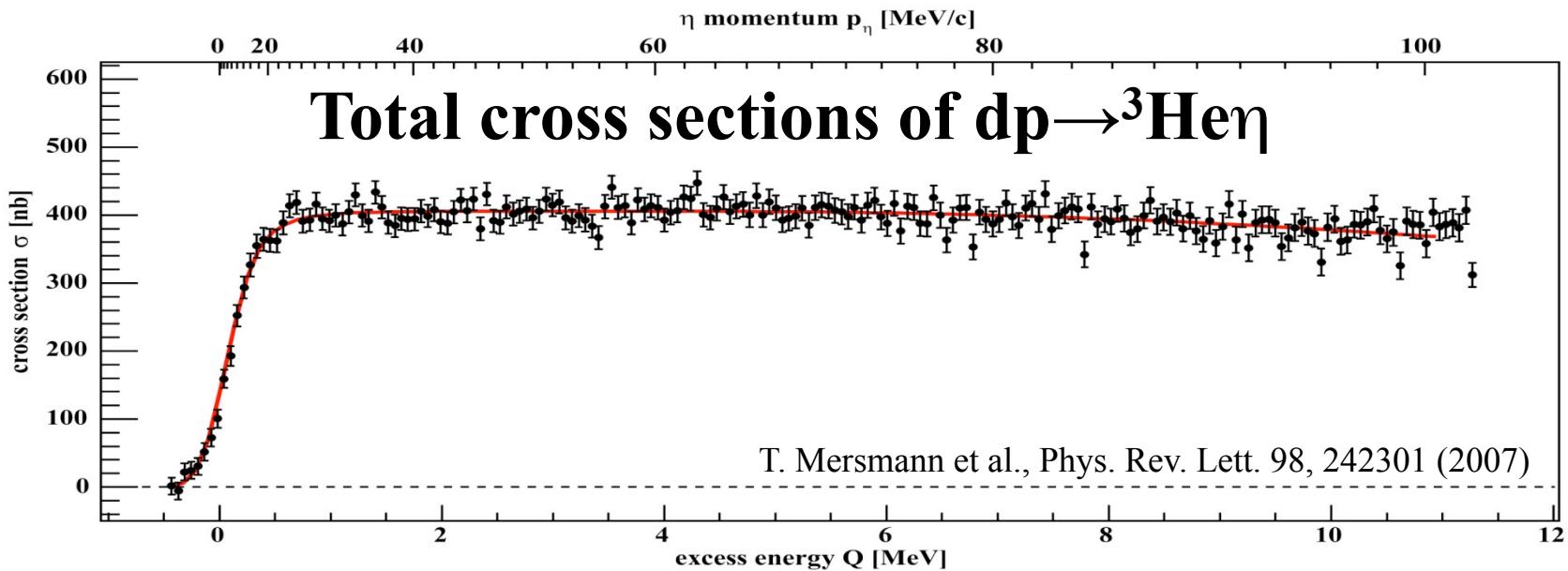
Q. Haider, L.C. Liu, Acta Phys. Pol. B Supp. 2 (2009) 121

and by observations of:

- near threshold enhancements of the amplitudes for the $dd \rightarrow ^4\text{He} \eta$ and $pd \rightarrow ^3\text{He} \eta$ reactions
(N. Willis et al., Phys. Lett. B406(1997)14)

η - ${}^3\text{He}$

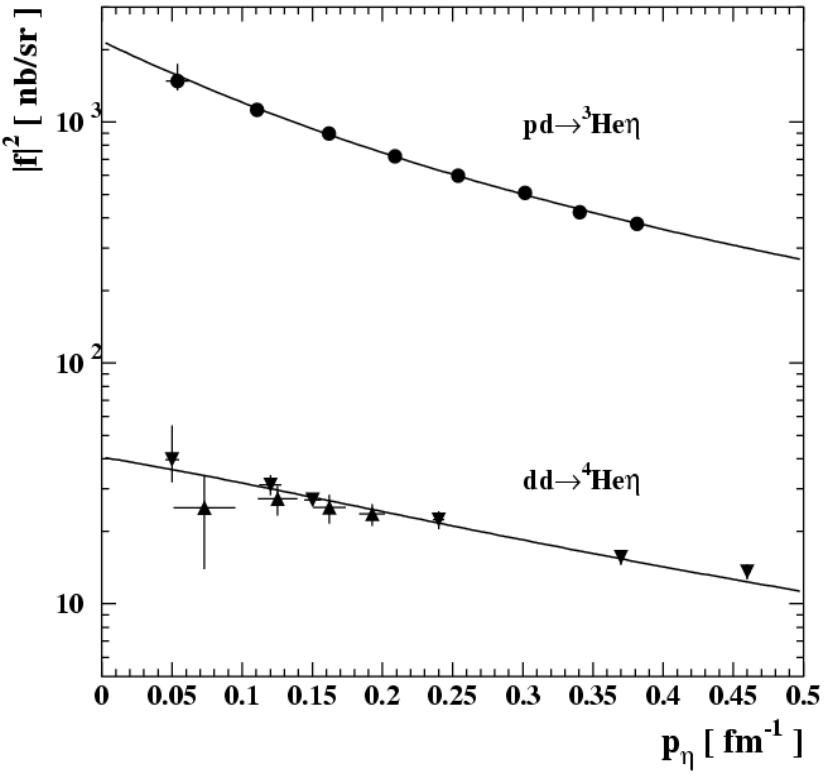
- $d\mu \rightarrow {}^3\text{He}\eta$



COSY-11: J. Smyrski et al., Phys. Lett **B 649** 258-262 (2007)

COSY-ANKE: T. Mersmann et al., Phys. Rev. Lett. **98** 242301 (2007)

η - He



SPES-2

B. Mayer et al., Phys. Rev. C 53 (1996) 2068.

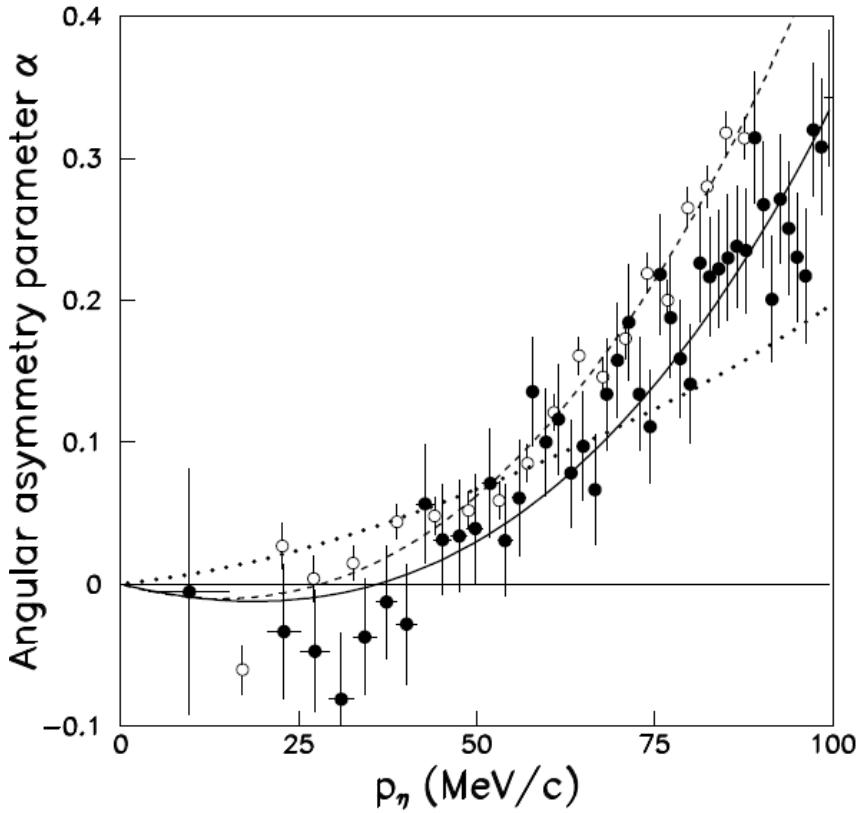
SPES-4

R. Frascaria et al., Phys. Rev. C 50 (1994) 573.

SPES-3

N. Willis et al., Phys. Lett. B 406 (1997) 14.

C. Wilkin et al., Phys. Lett. B 654 (2007) 92

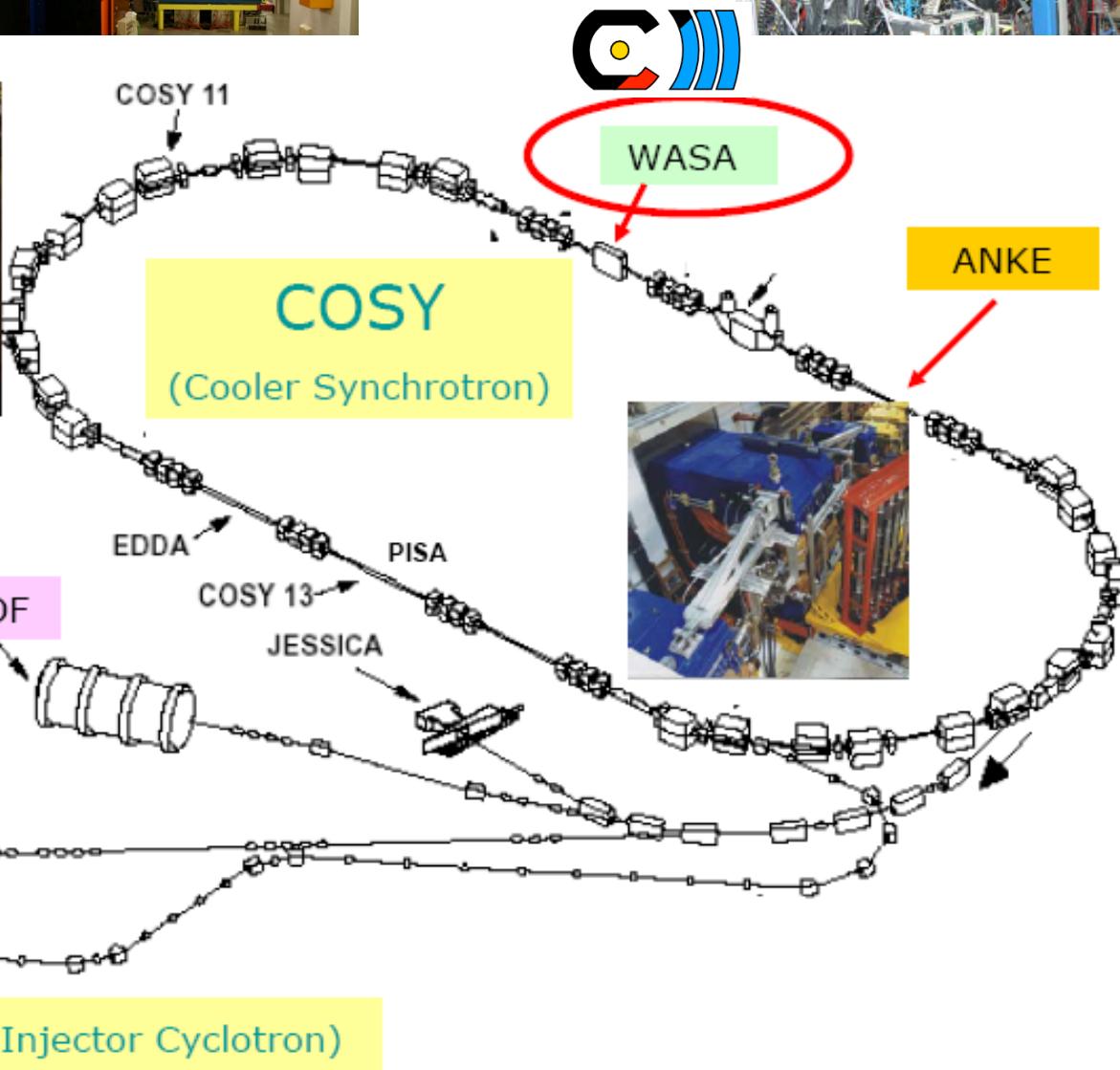
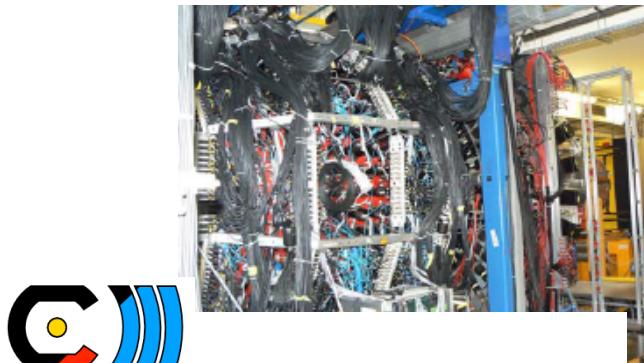
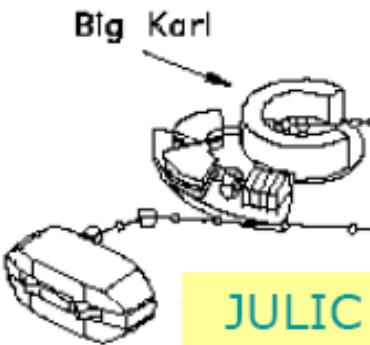


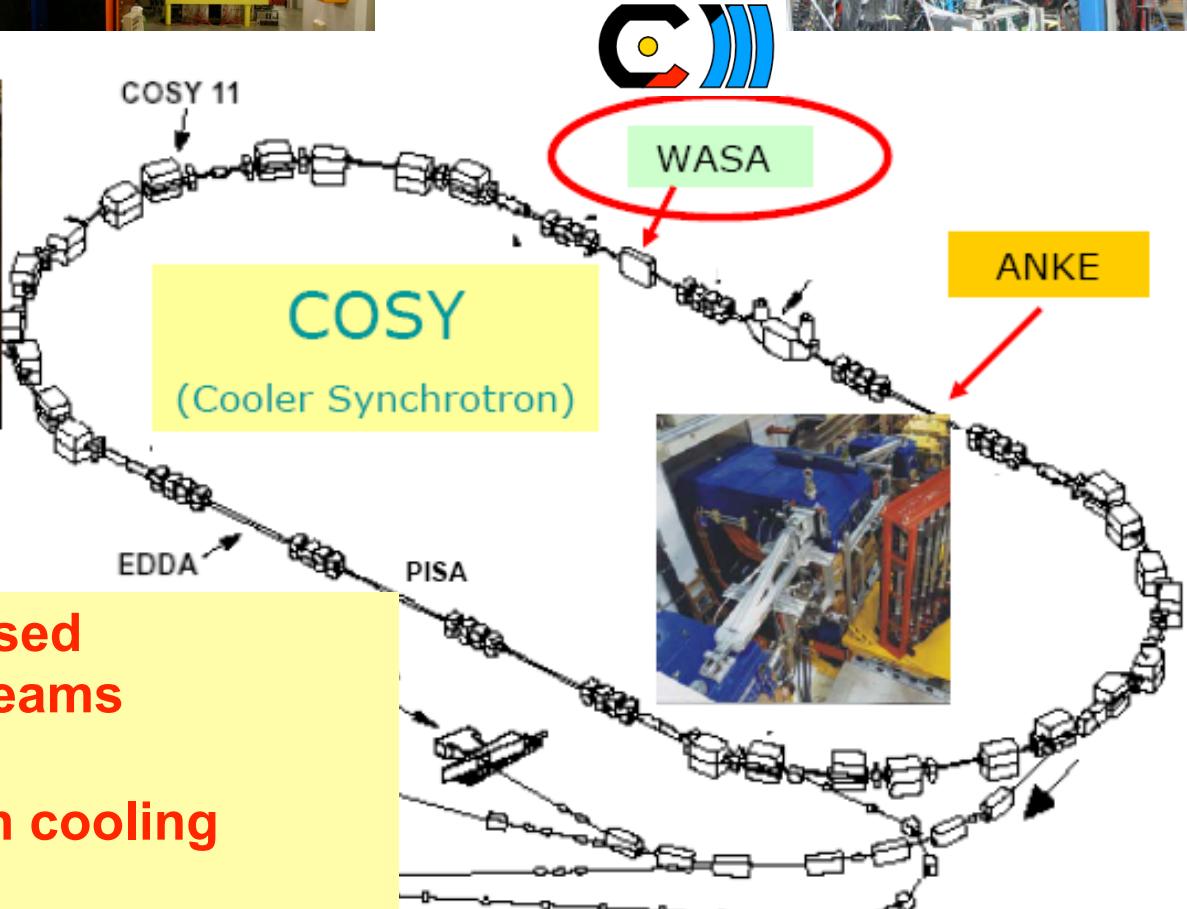
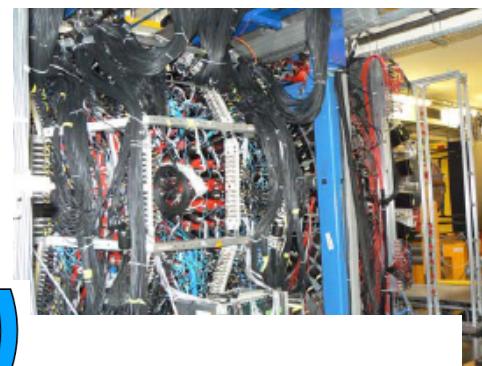
COSY-ANKE:

T. Mersmann et al., Phys. Rev. Lett. 98 242301 (2007)

COSY-11:

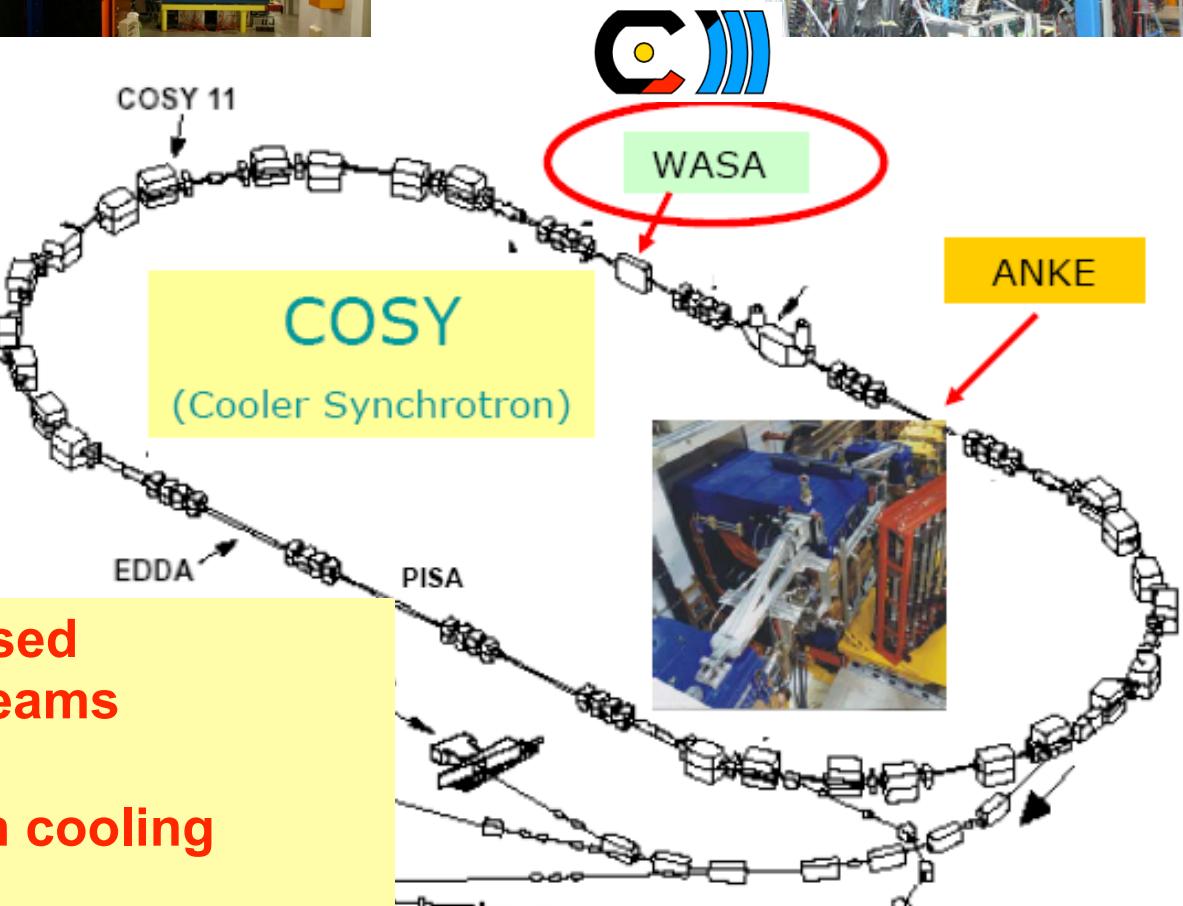
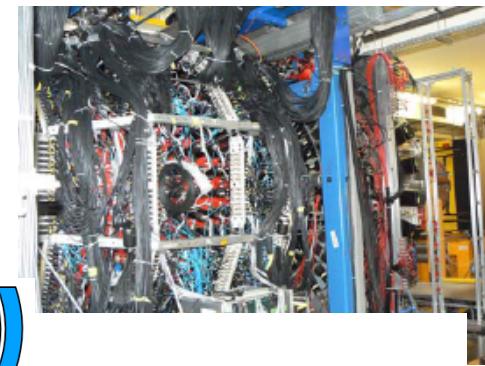
J. Smyrski et al., Phys. Lett. B 649 258-262 (2007)





- polarised and unpolarised proton and deuteron beams
- stochastic and electron cooling
- momentum range: 600 – 3700 MeV/c
- meson production up to $\phi(1020)$

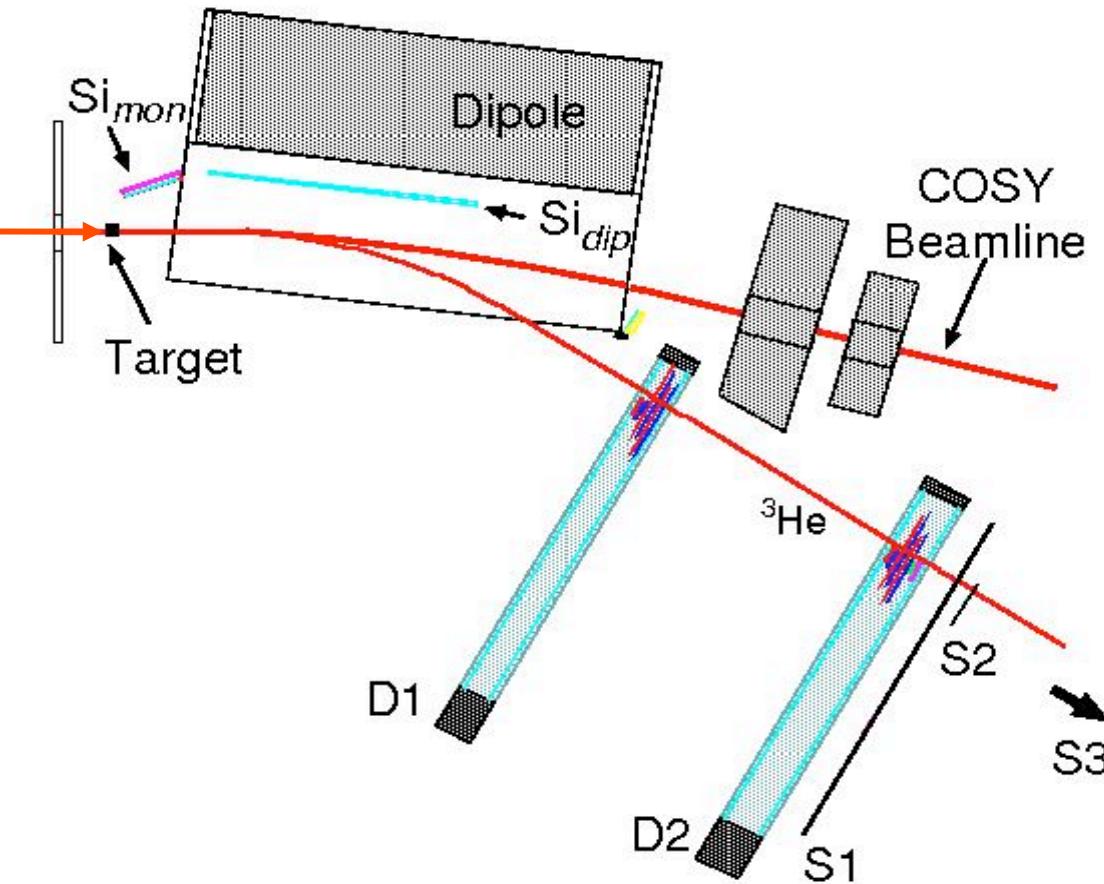
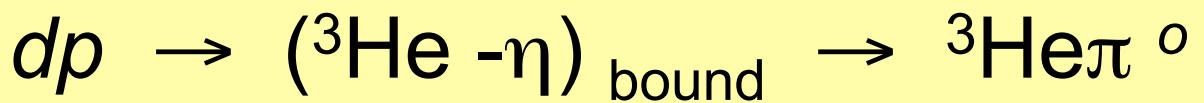
Detectors at COSY



- polarised and unpolarised proton and deuteron beams
- stochastic and electron cooling
- momentum range: 600 – 3700 MeV/c
- meson production up to $\phi(1020)$



COSY-11 detection system



T1: $dp \rightarrow ^3\text{He}X, X = \pi^0, \eta$

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

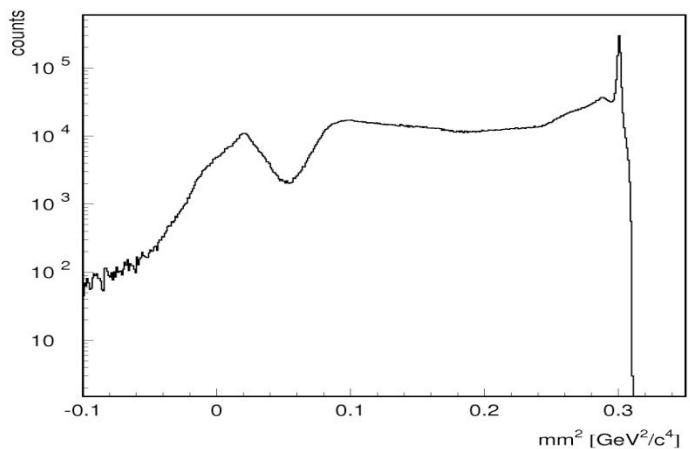
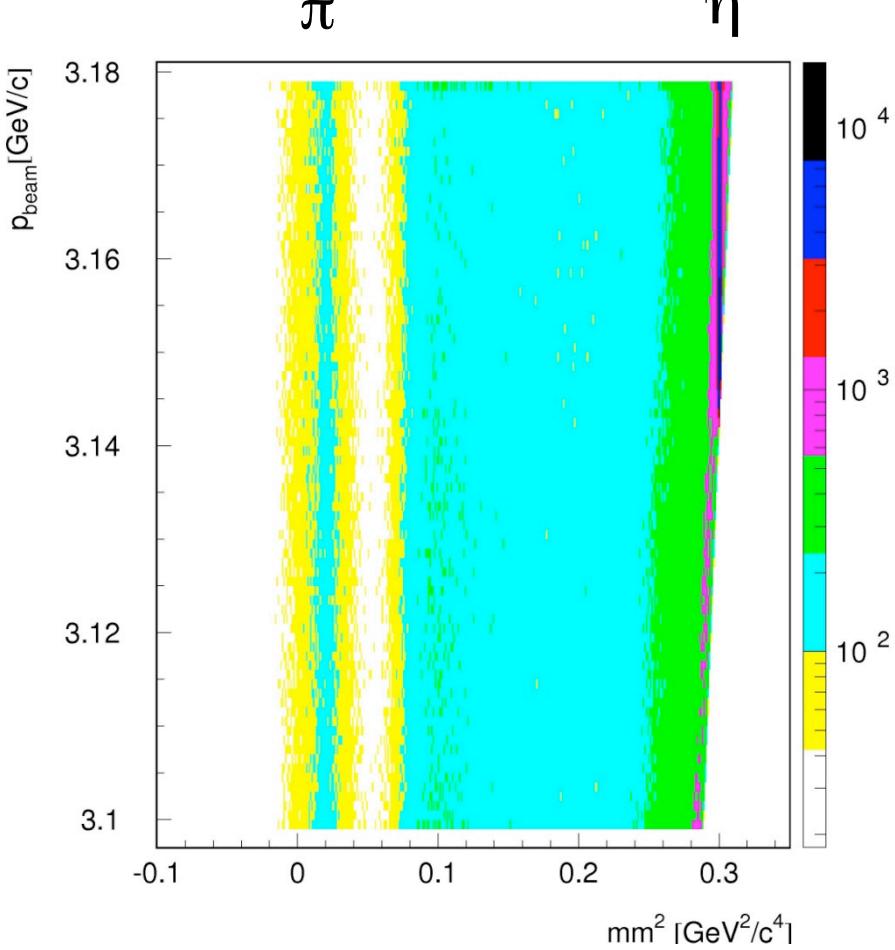
T3: $dp \rightarrow dp\eta$

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

T5: $dp \rightarrow dp\pi^0$

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

T7: $dp \rightarrow dp\gamma$

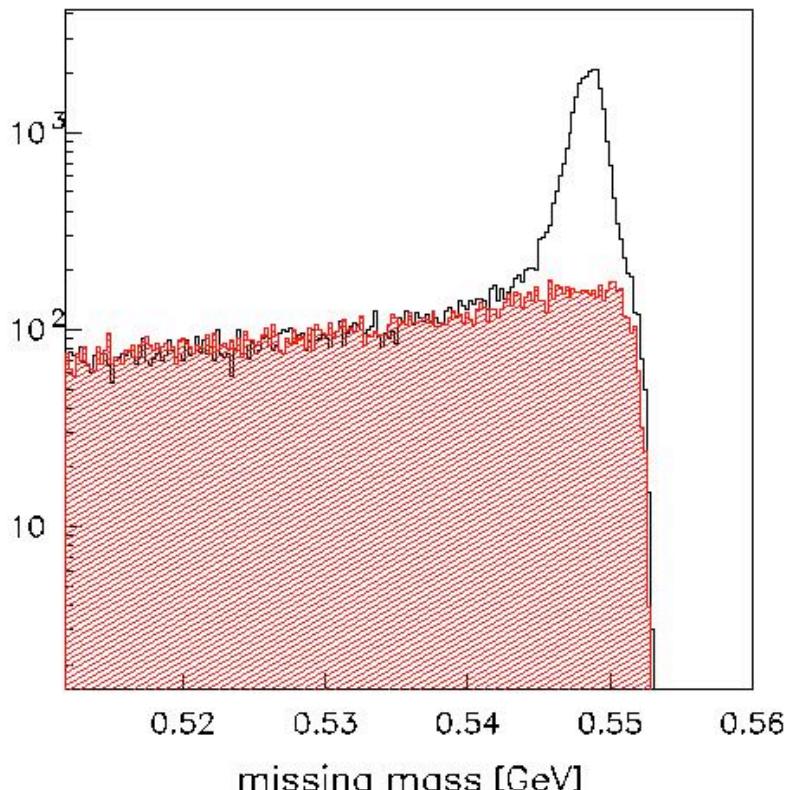


COSY-11

Missing mass

$$dp \rightarrow {}^3\text{He} X$$

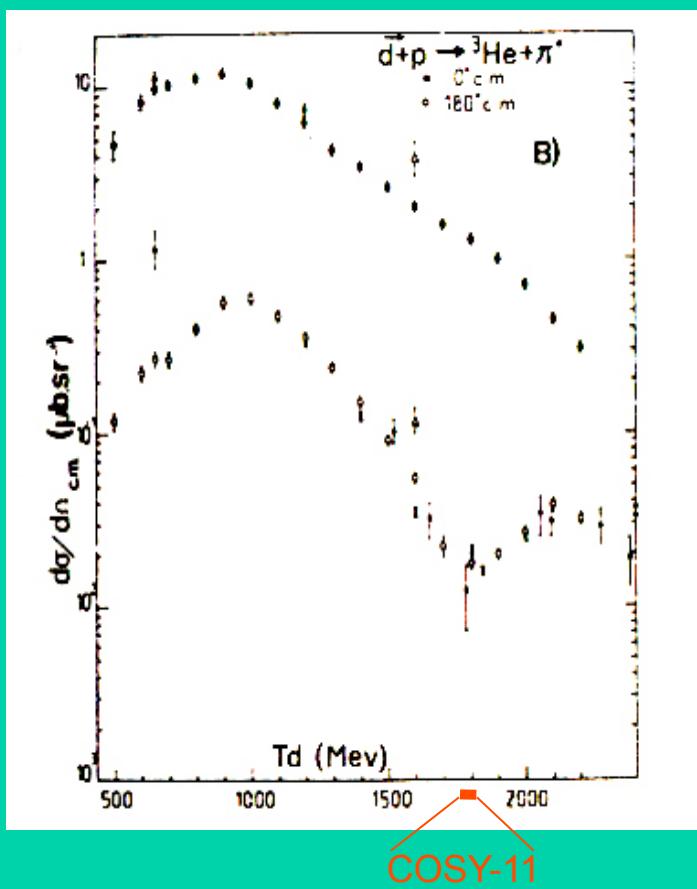
$3.166 \text{ GeV/c} < p_{beam} < 3.170 \text{ GeV/c}$
 $Q \sim 6.5 \text{ MeV}$



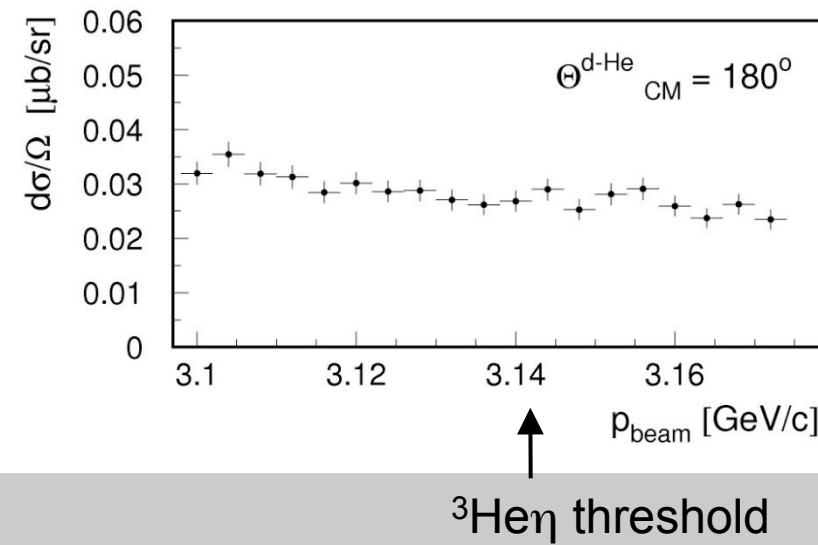
Background: $3.134 < p_{beam} < 3.138 \text{ GeV/c}$

$d\bar{p} \rightarrow {}^3\text{He}\pi^0$

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



COSY-11



$$\sigma(d\bar{p} \rightarrow ({}^3\text{He} - \eta)_{\text{bound}} \rightarrow {}^3\text{He}\pi^0) < 0.07 \mu\text{b}$$

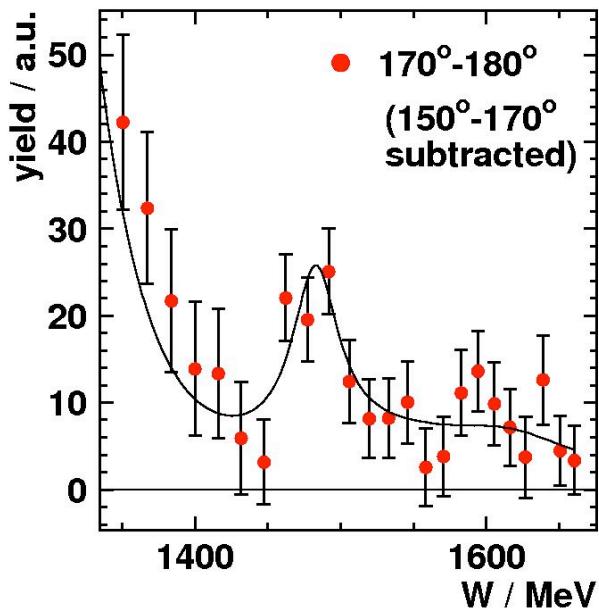
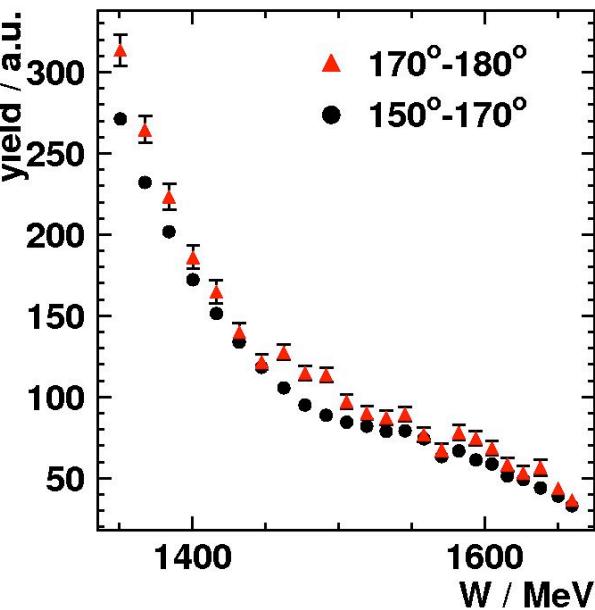
$$\sigma(d\bar{p} \rightarrow ({}^3\text{He} - \eta)_{\text{bound}} \rightarrow \text{ppp}\pi^-) < 0.27 \mu\text{b}$$

J. Smyrska et al., Acta Phys. Pol. Supp. B2 (2009) 133
J. Smyrska et al., Nucl. Phys. A790 (2007) 438

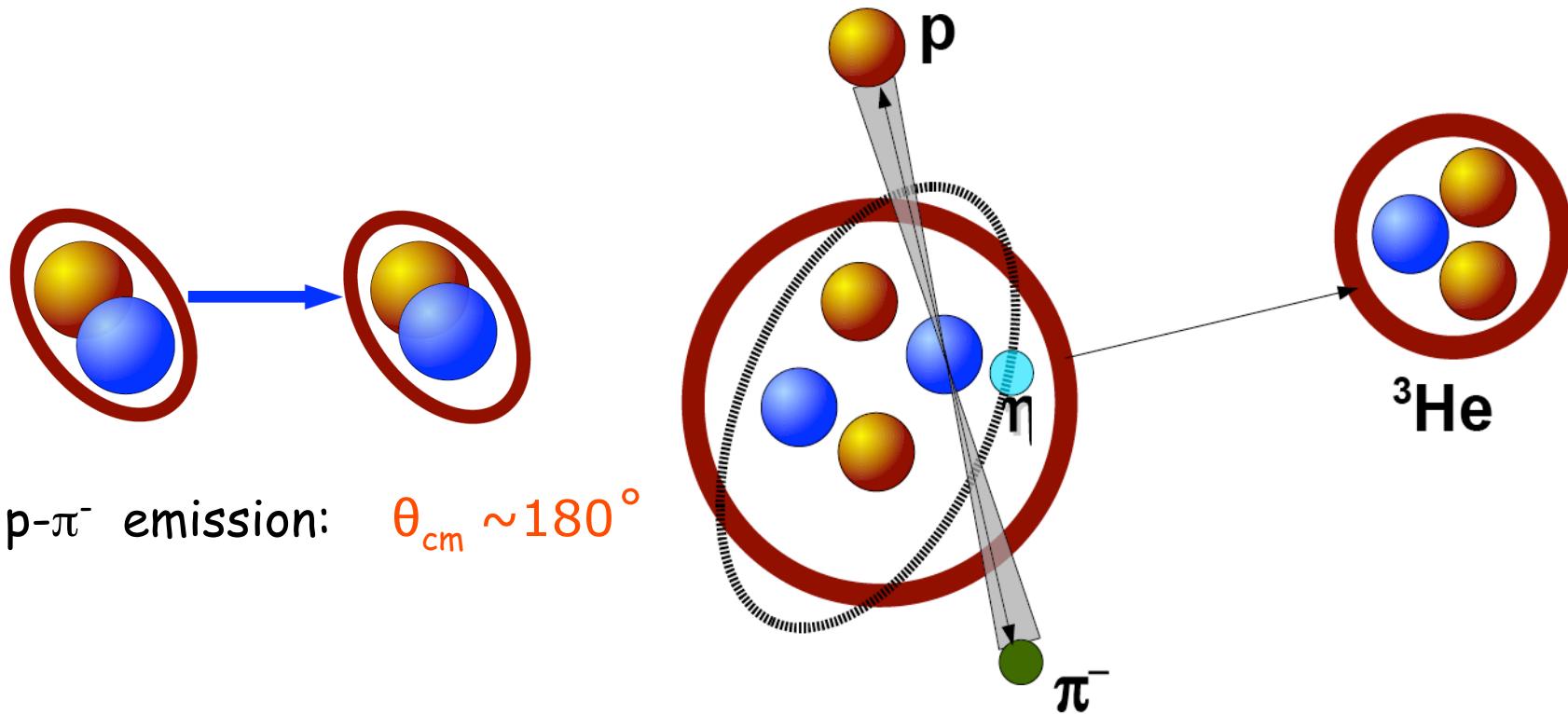
γ $^3\text{He} \rightarrow p\pi^0 X$

TAPS at MAMI

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



signal: $\sigma \approx 0.8 \mu\text{b}$

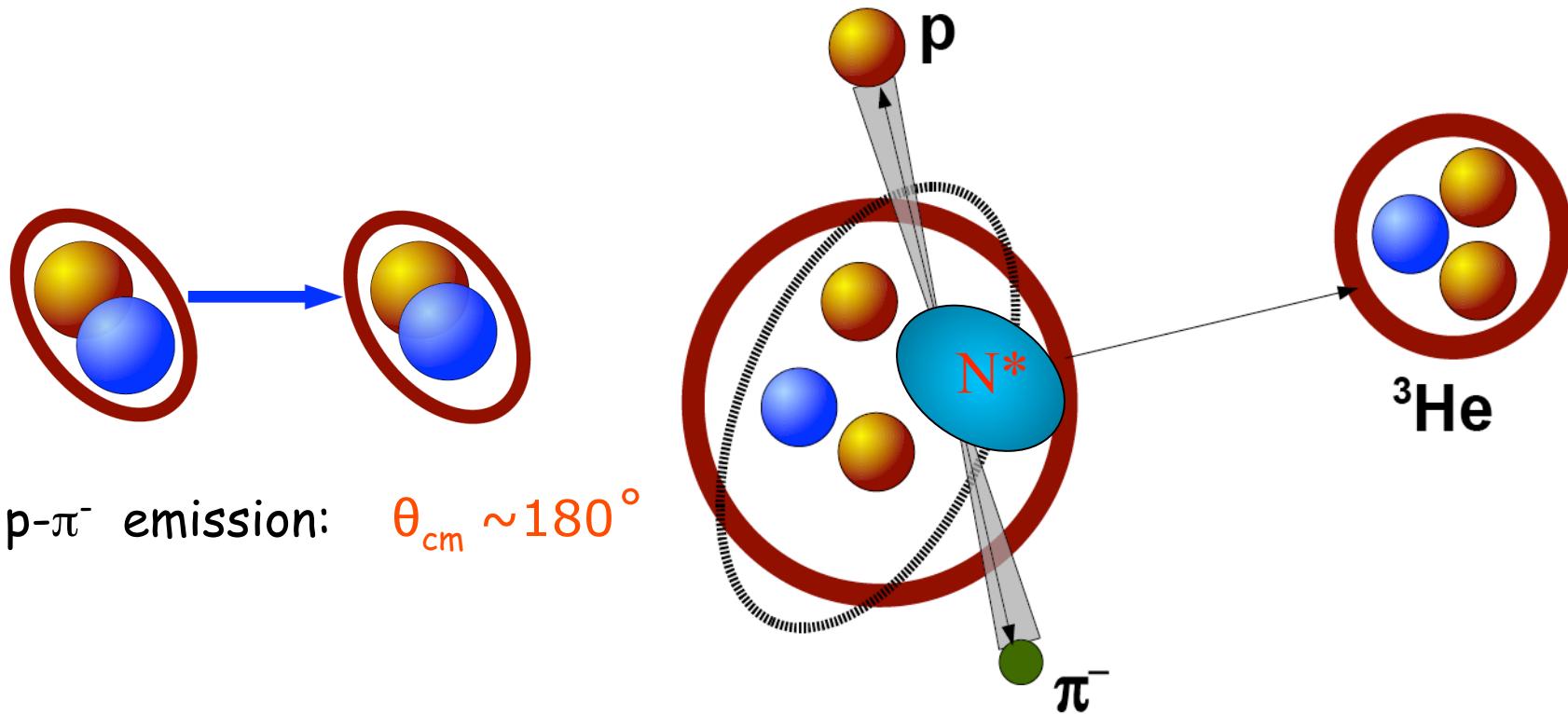


Measurement of the excitation function



search for a resonance structure with center below the eta threshold

arXiv:0909.3879

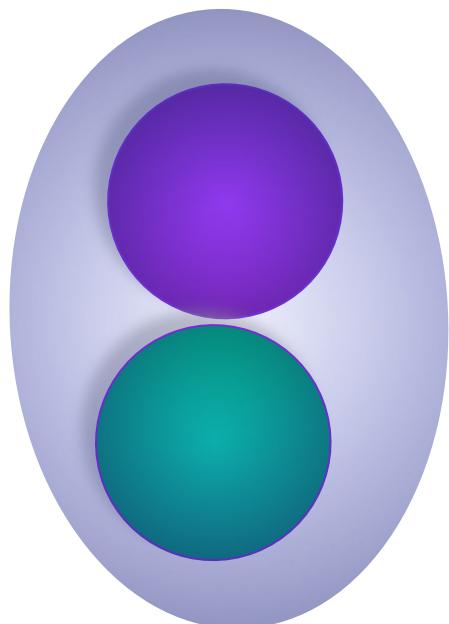
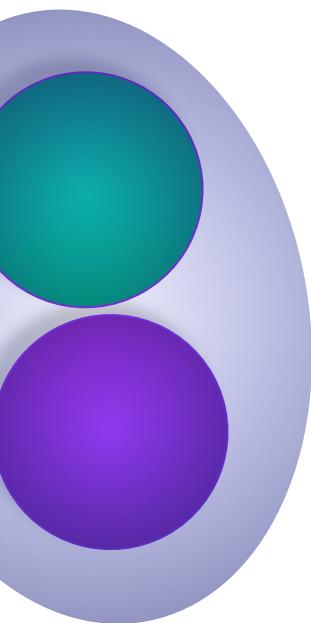


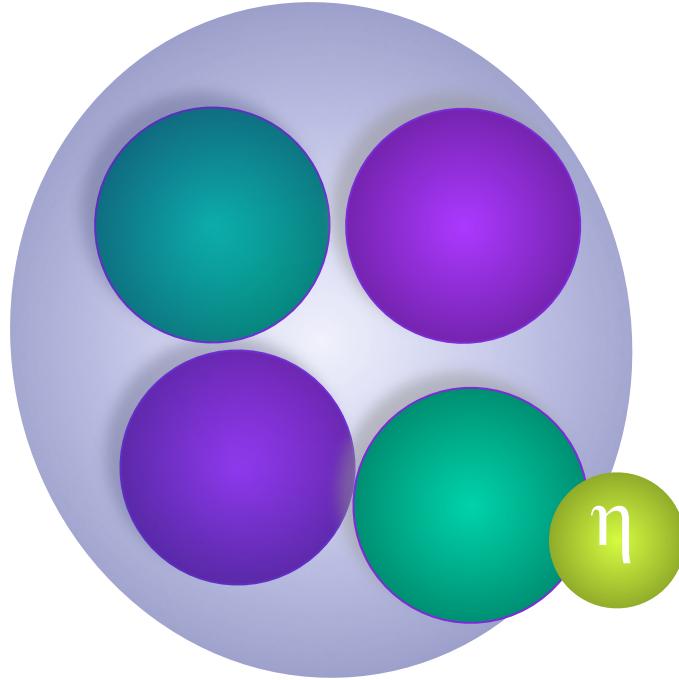
Measurement of the excitation function

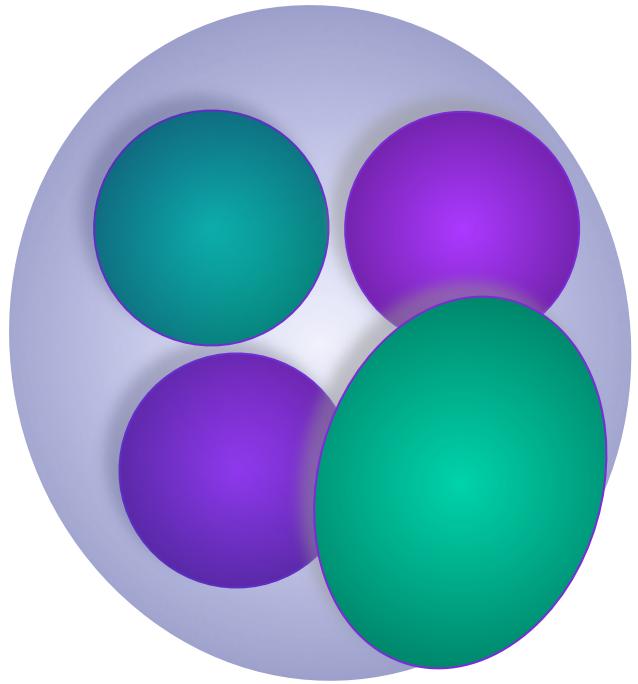


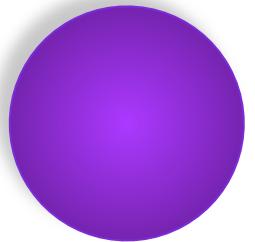
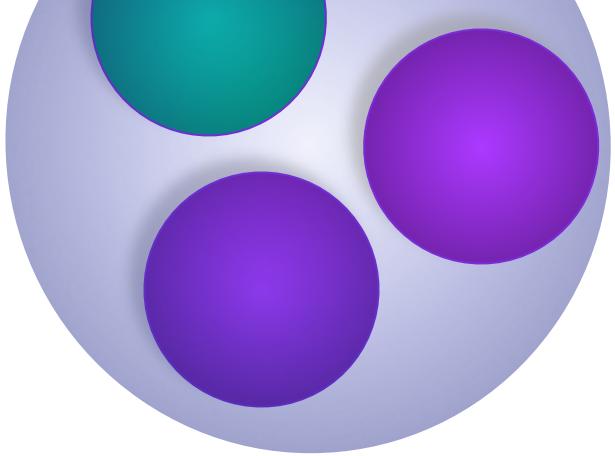
search for a resonance structure with center below the eta threshold

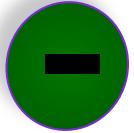
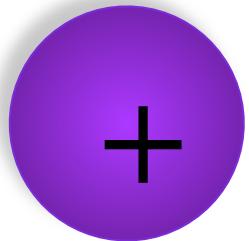
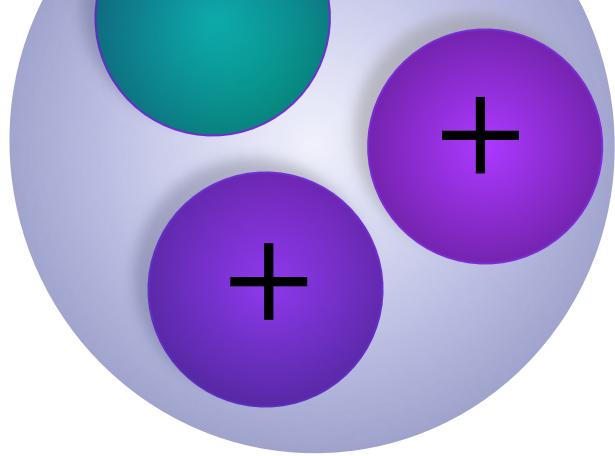
arXiv:0909.3879

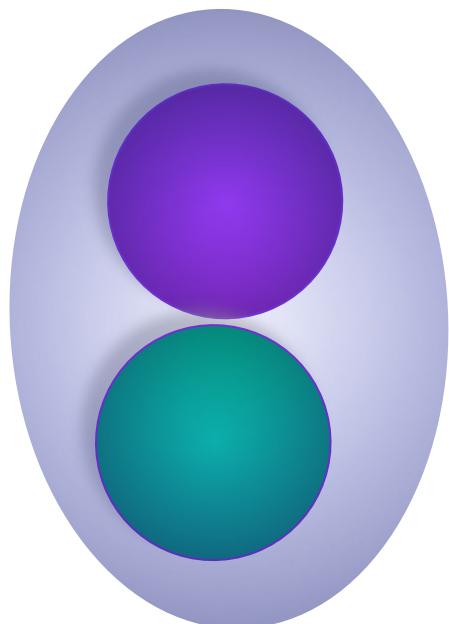
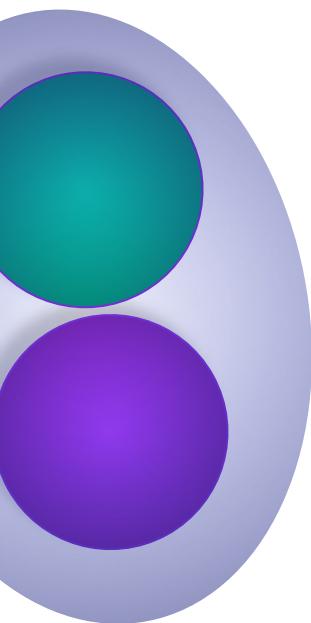


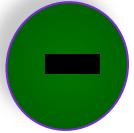
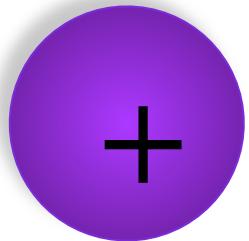
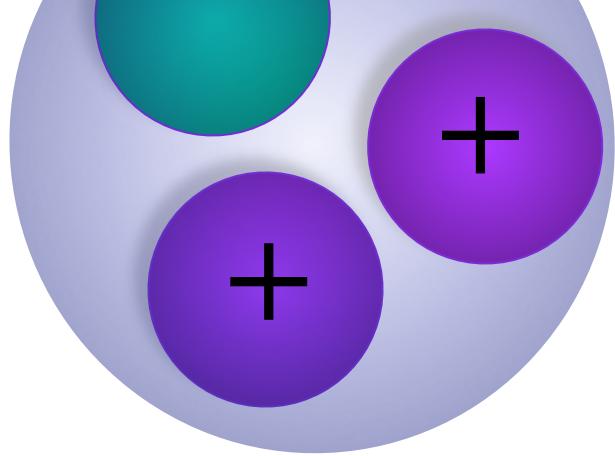


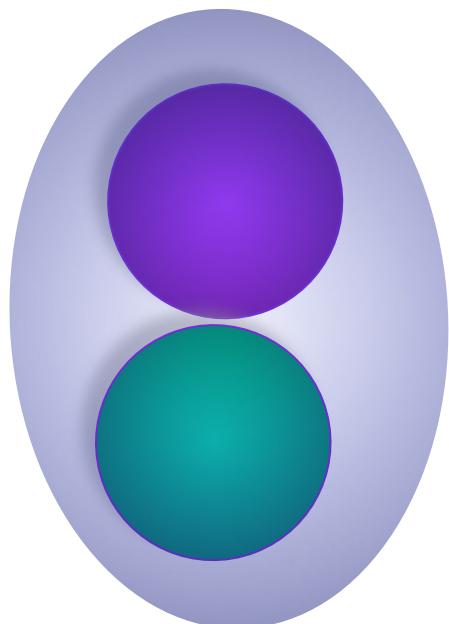
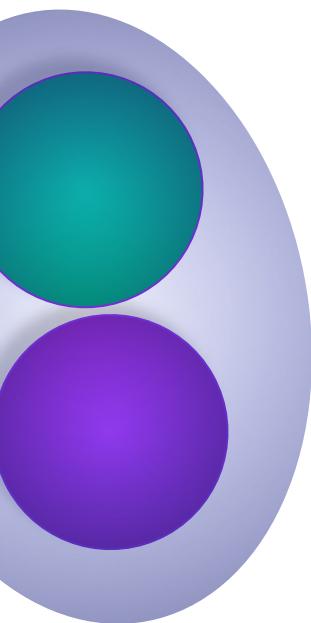


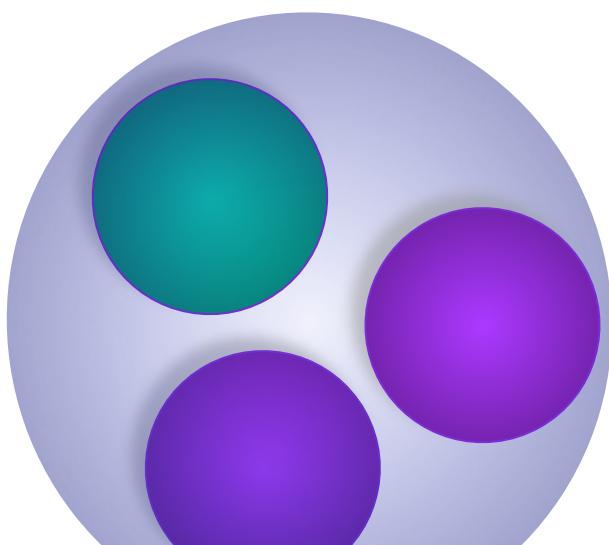
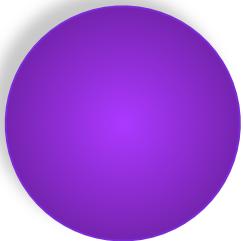
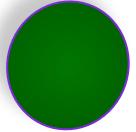




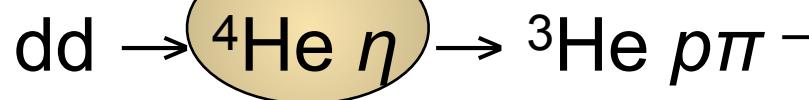




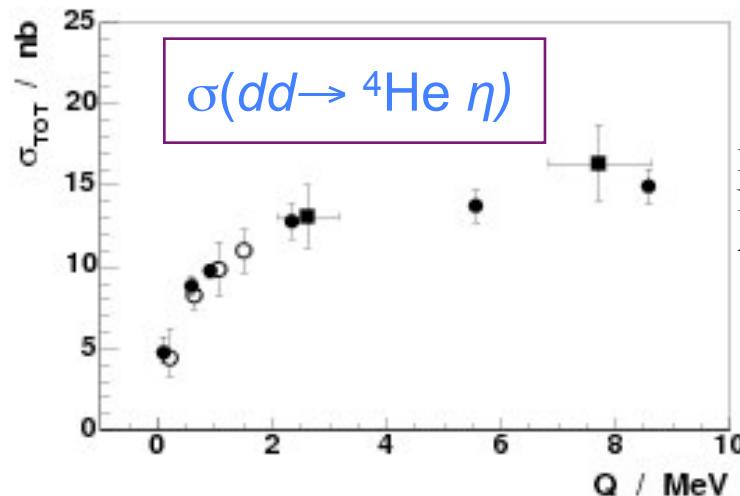




Cross section estimate



$\sigma \sim 15 \text{ nb}$



R. Frascaria et al., Phys. Rev. C 50 (1994) 573.
 N. Willis et al., Phys. Lett. B 406 (1997) 14.
 A. Wrońska et al., Acta. Phys. Pol. 56 (2006) 279

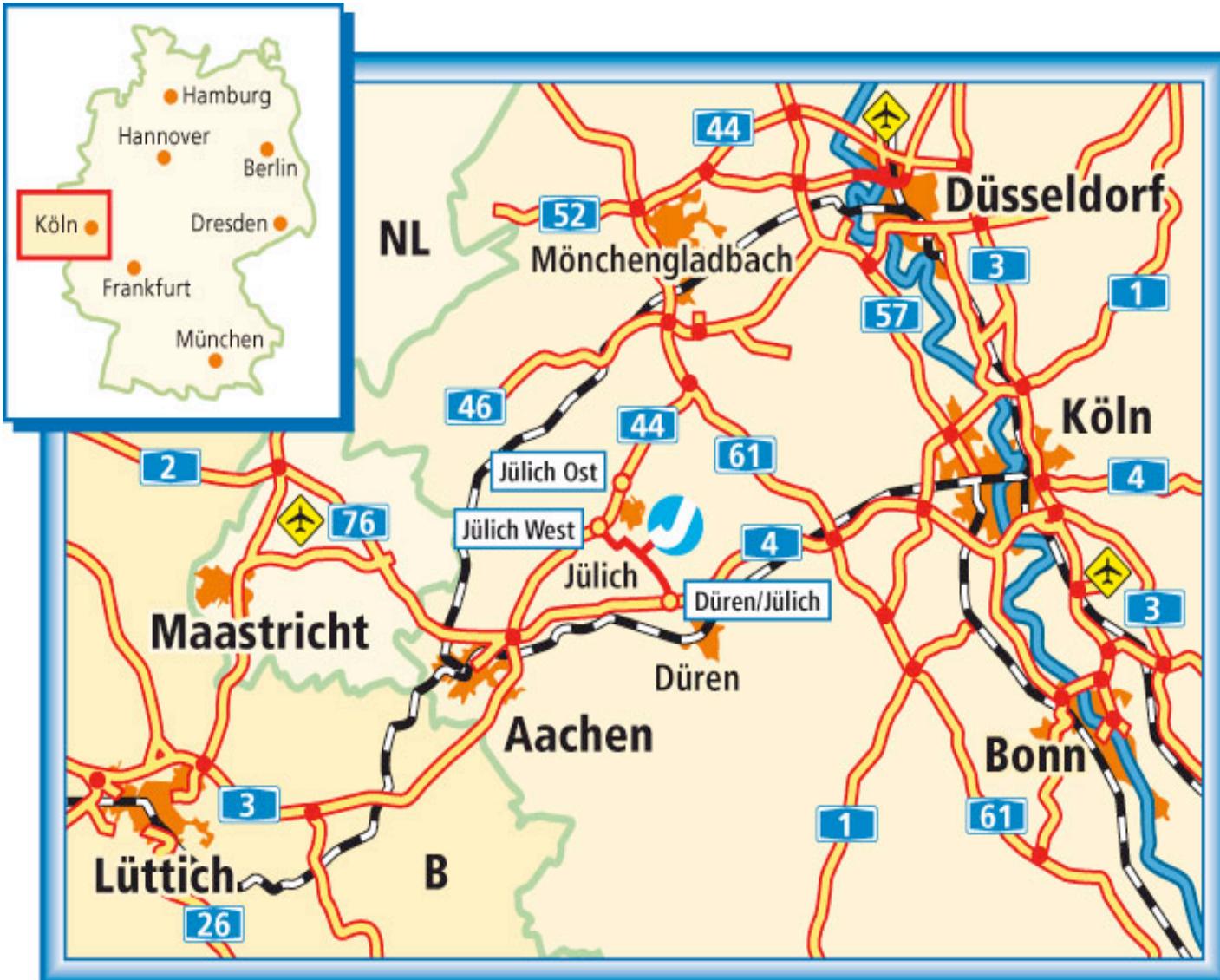
- Probability of decay $({}^4\text{He } \eta)_{\text{bound}} \rightarrow {}^3\text{He } p\pi^-$

$$\sim \frac{1}{4} \times \frac{1}{2} = \frac{1}{8}$$

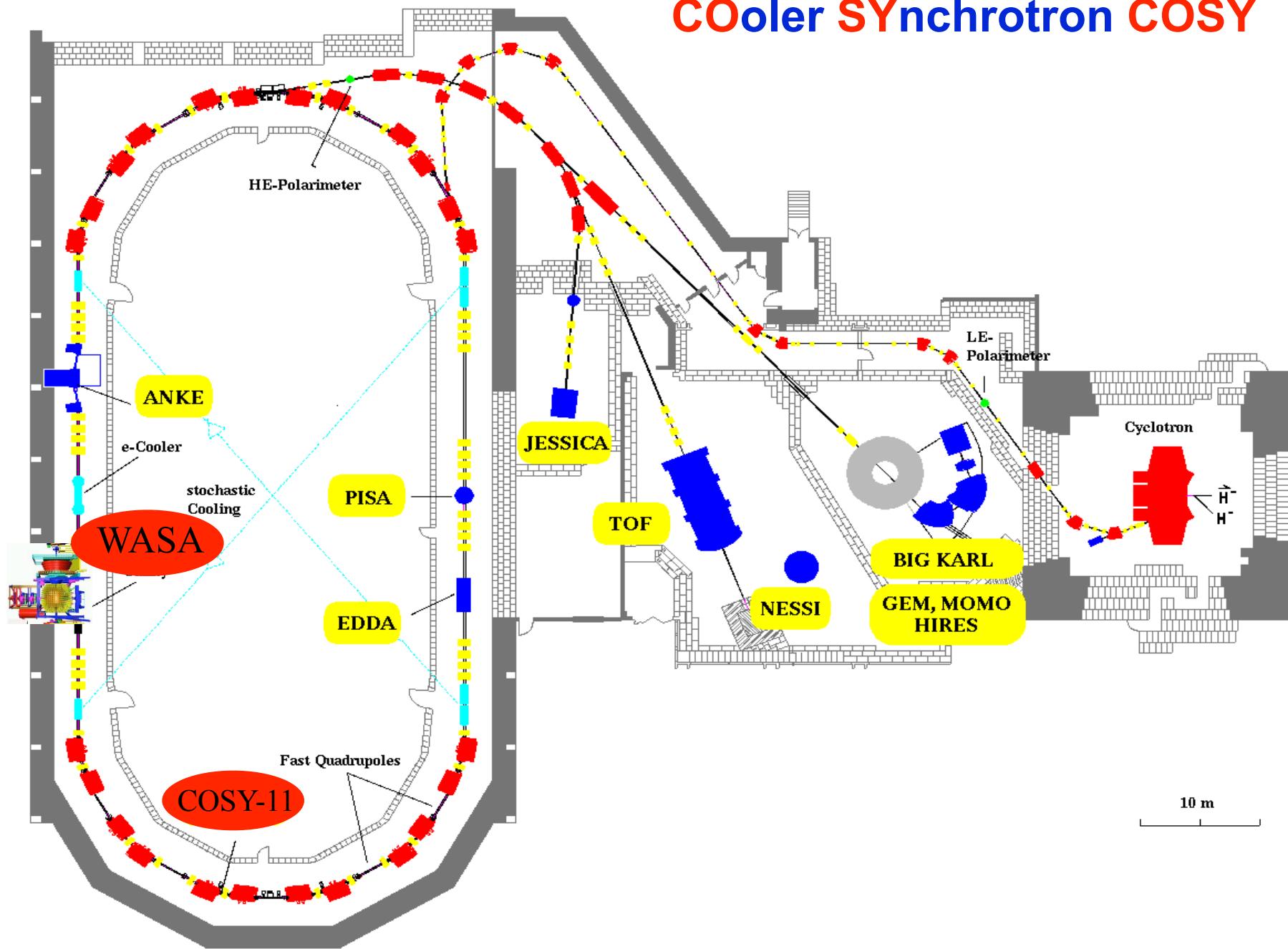
$\eta n \rightarrow p\pi^-$
one of four possible absorption channels

Probability that spectator nucleons (ppn) form ${}^3\text{He}$
By analogy to ${}^4\text{He } \Lambda \rightarrow {}^3\text{He } p\pi^-$

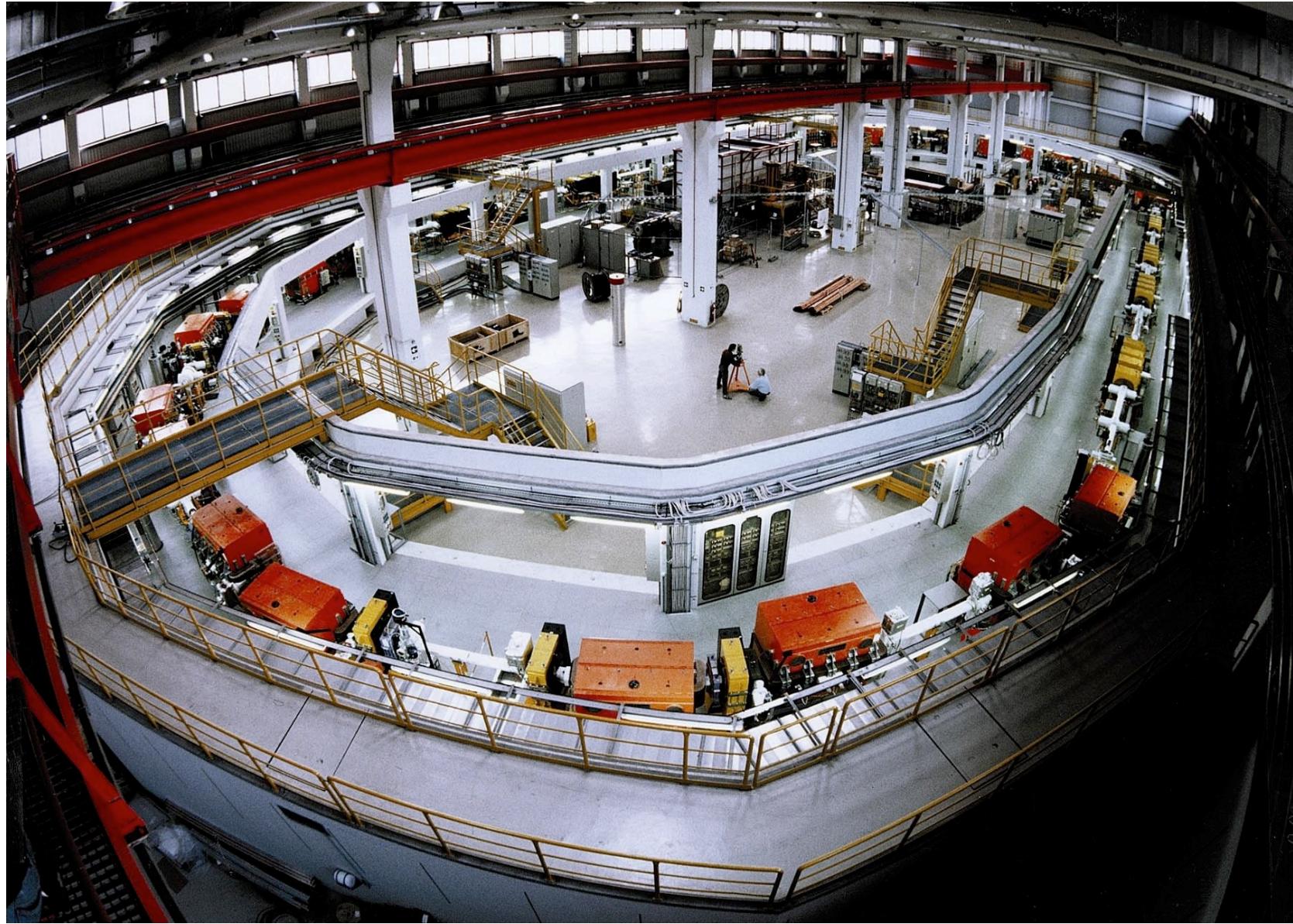
$$\sigma(dd \rightarrow ({}^4\text{He } \eta)_{\text{bound}} \rightarrow {}^3\text{He } p\pi^-) = 2 \text{ nb}$$



COoler SYnchrotron COSY



COoler SYnchrotron COSY

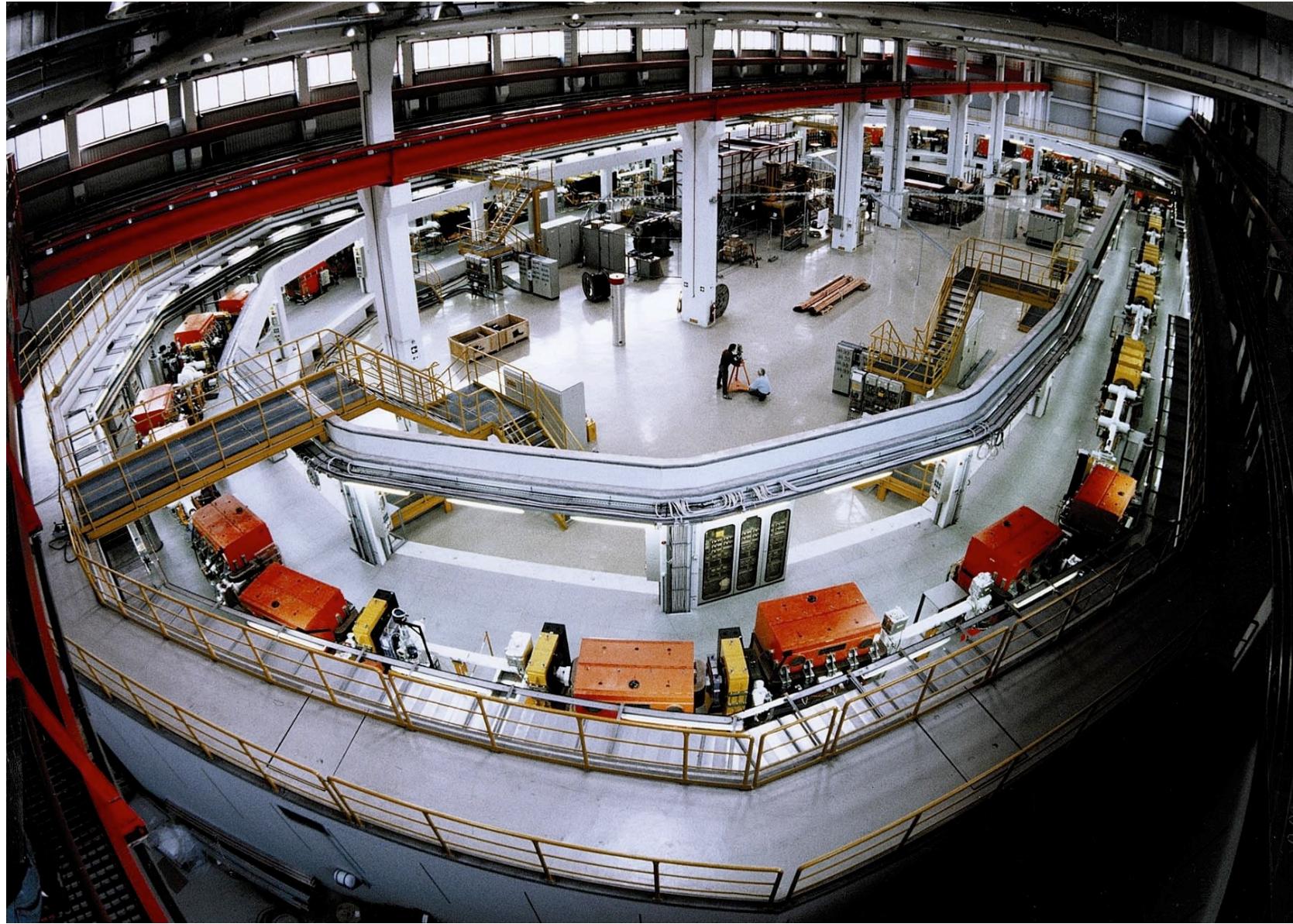


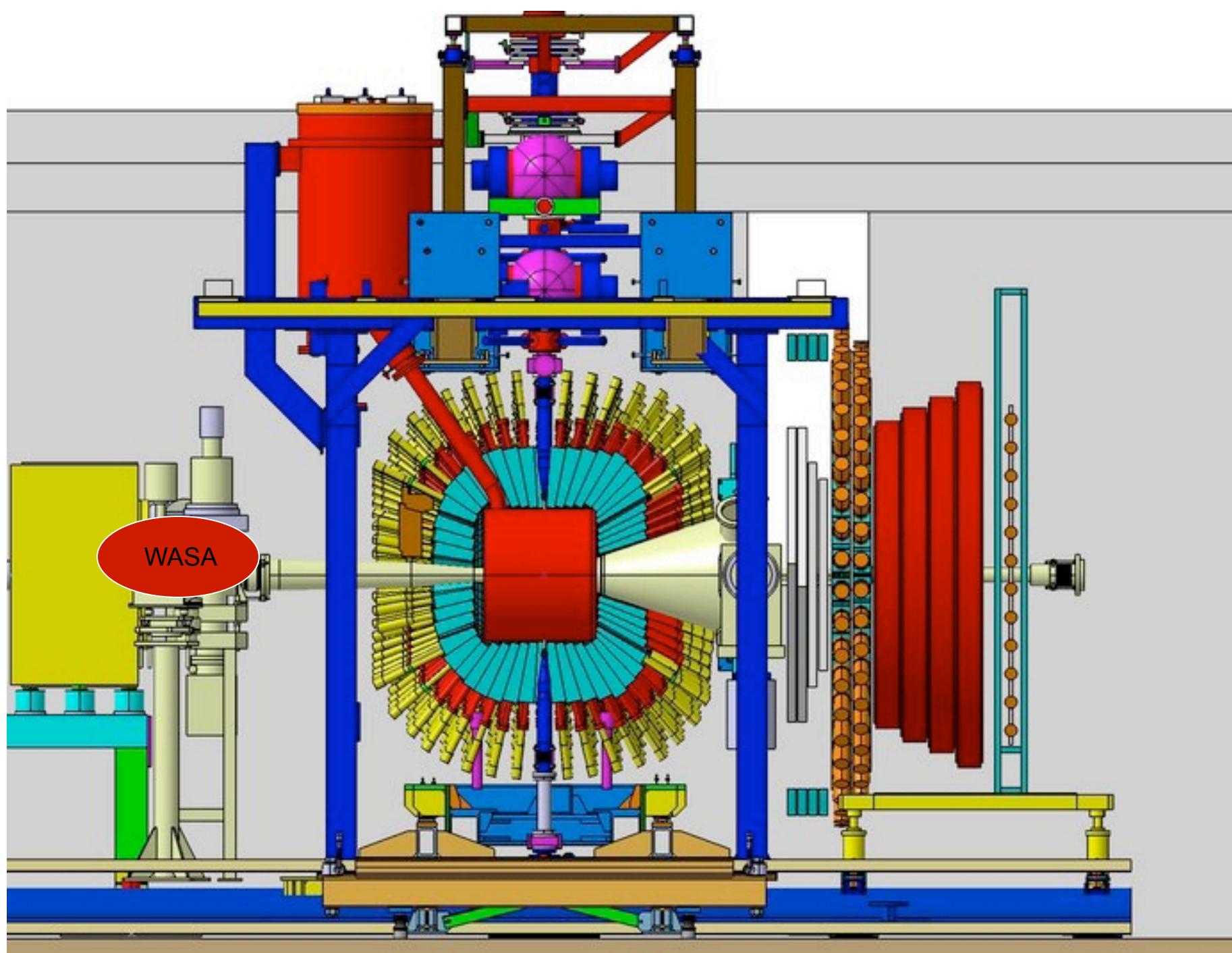
COoler SYnchrotron COSY

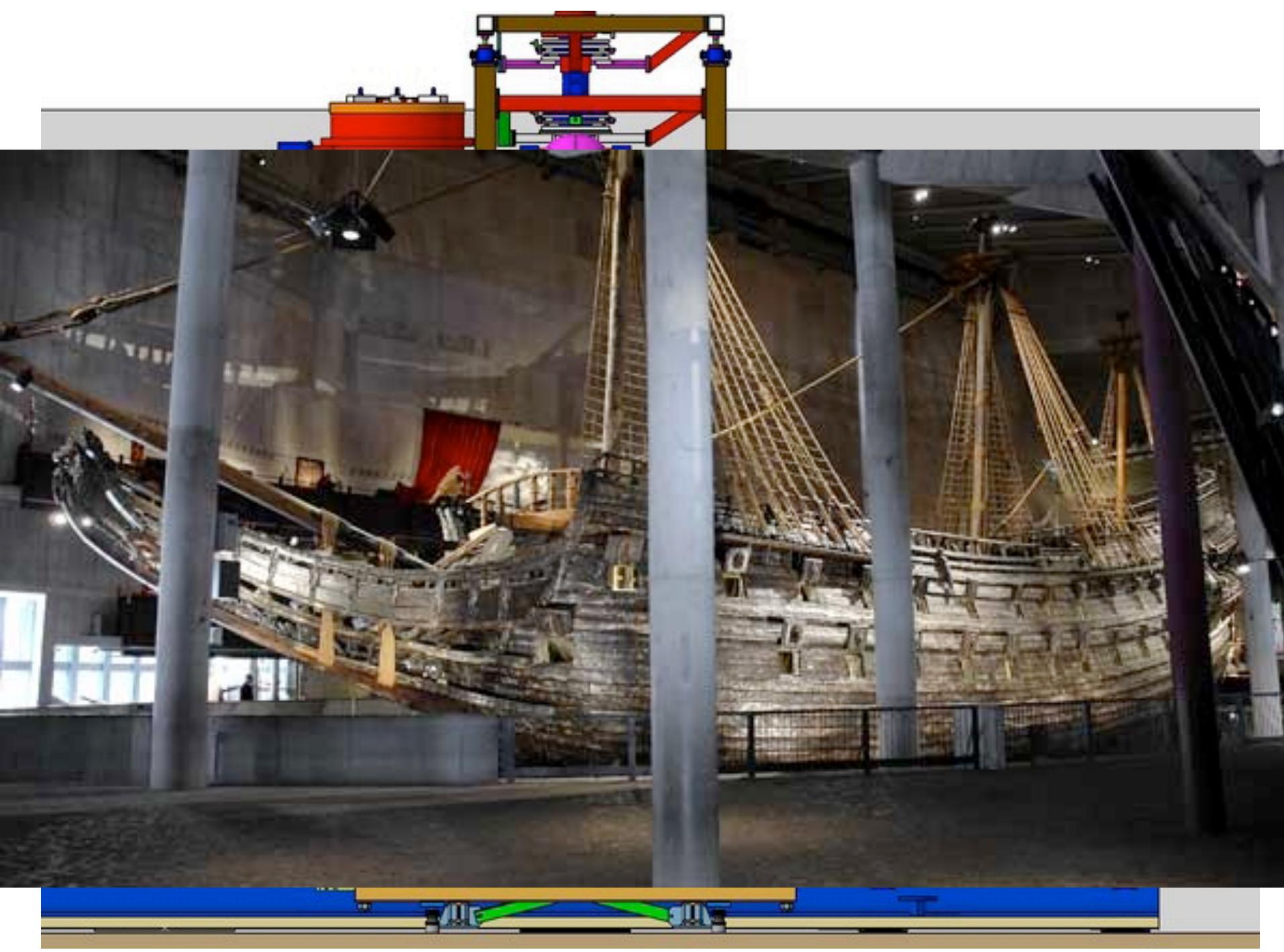
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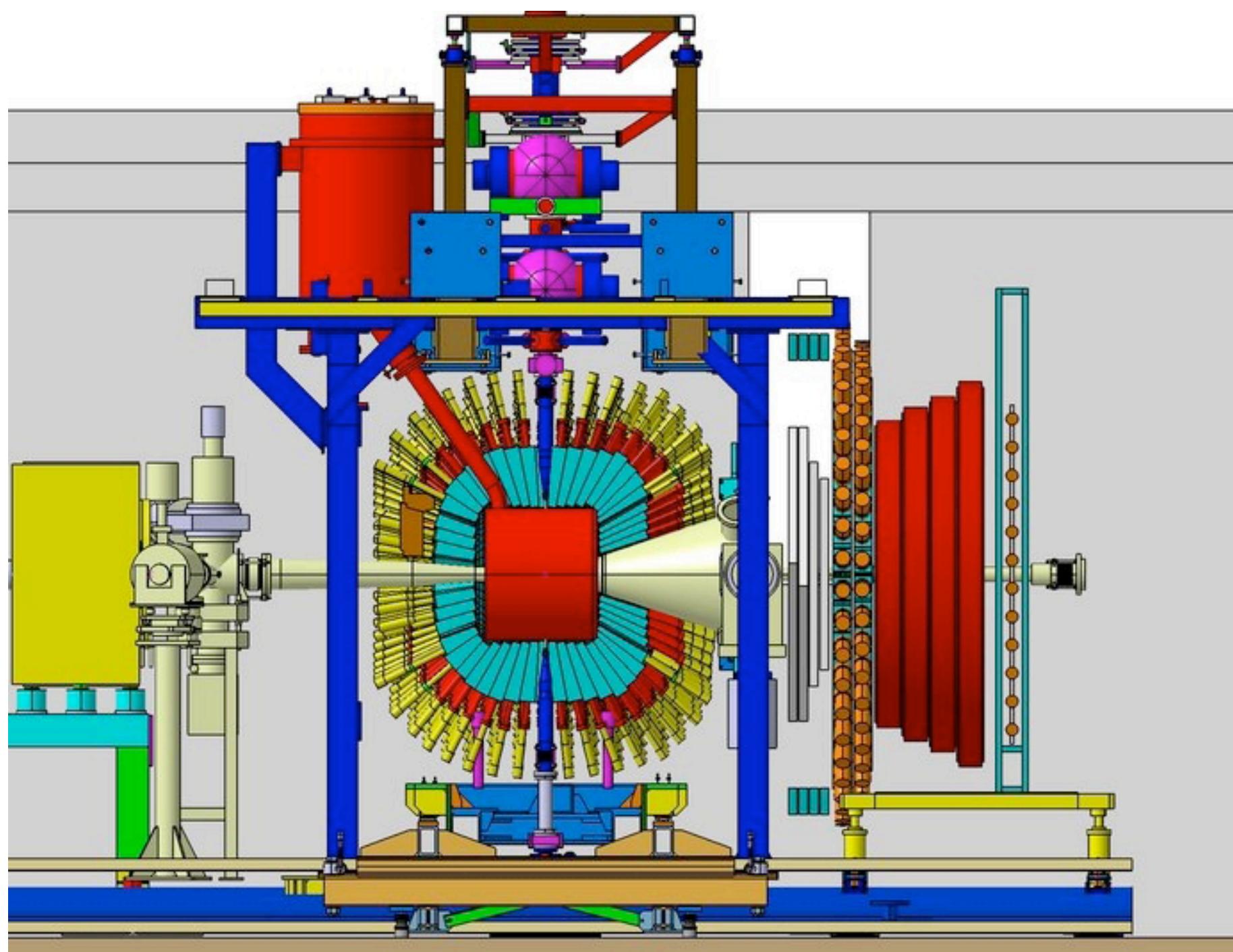


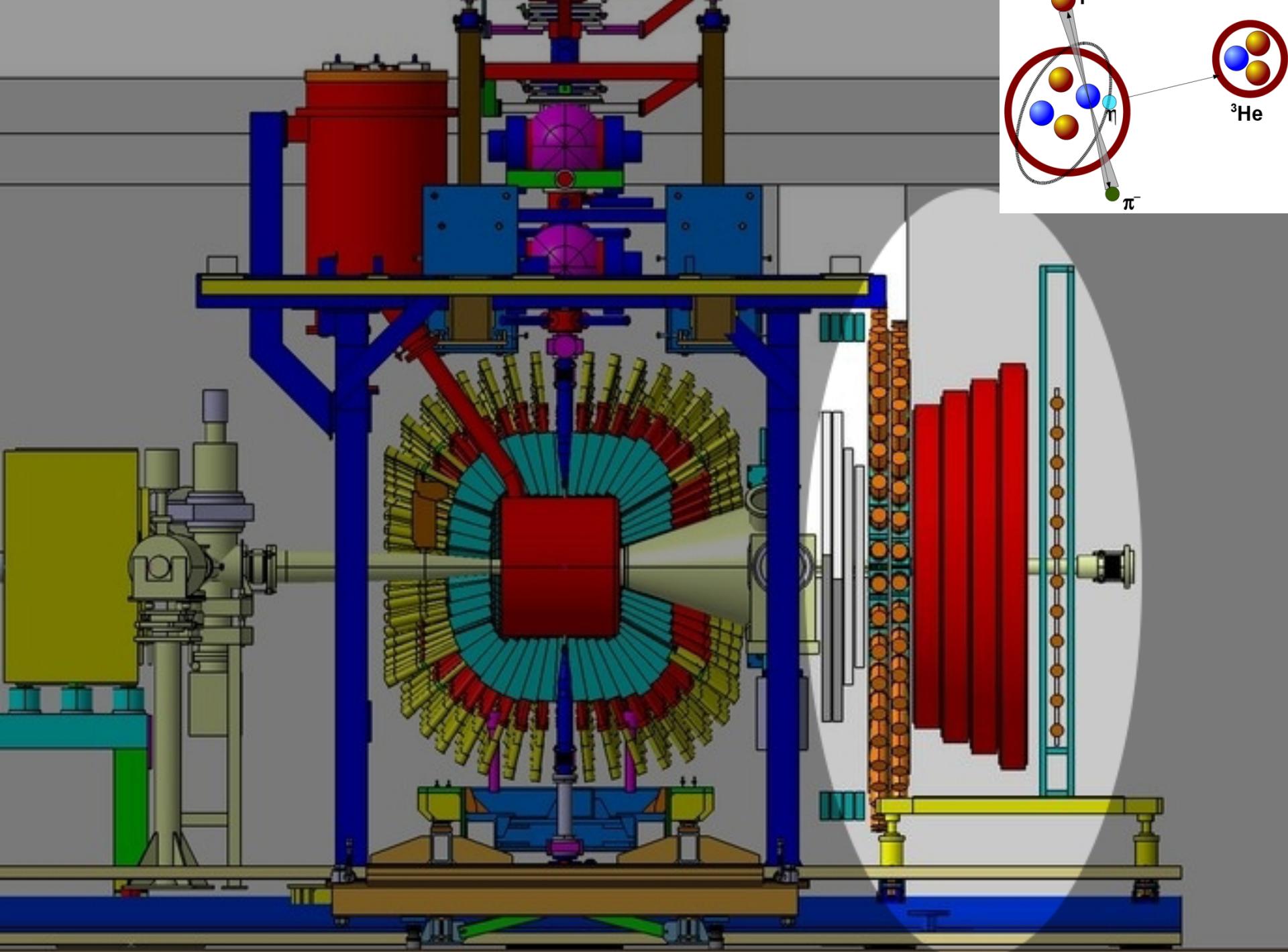
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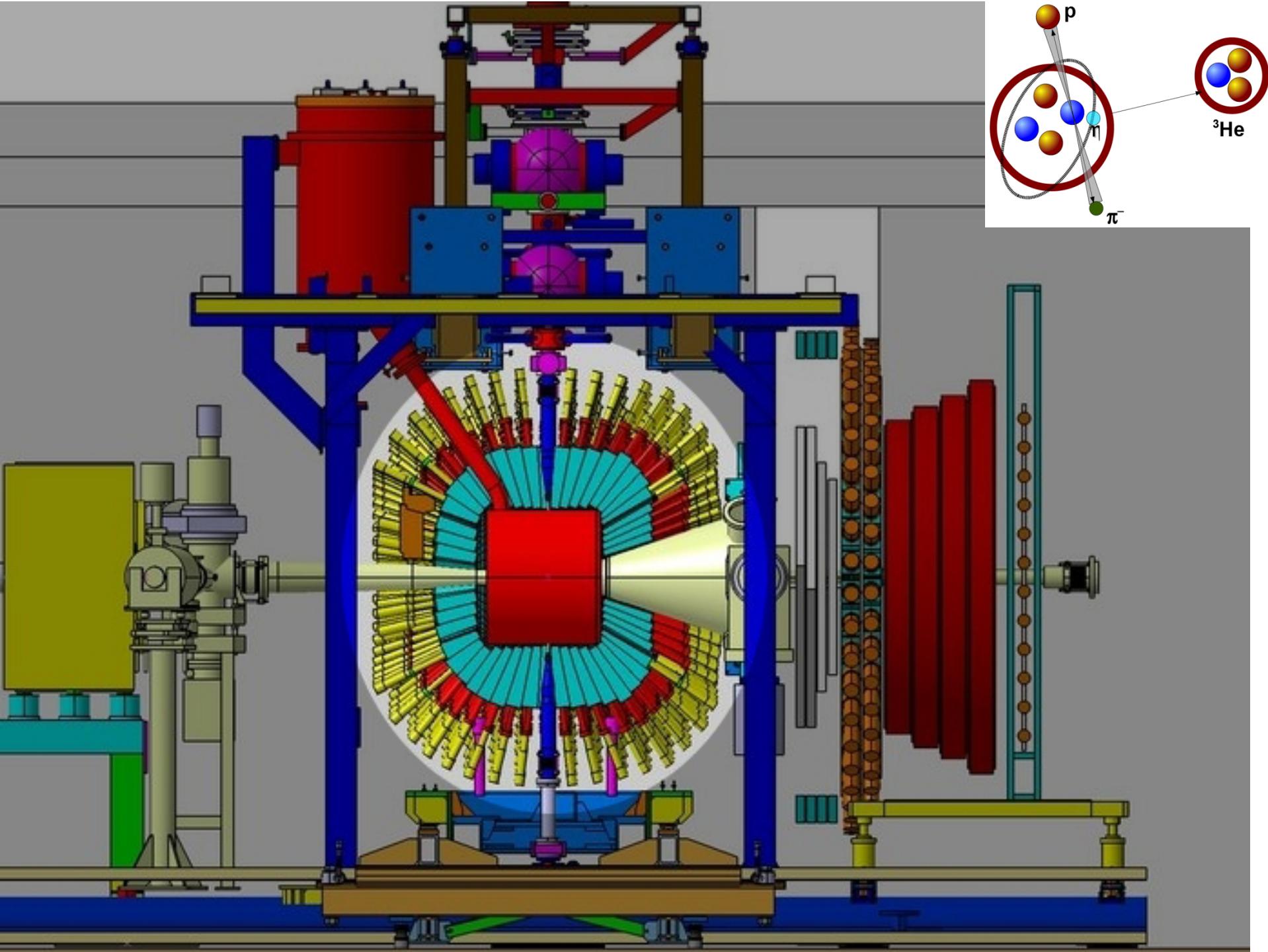






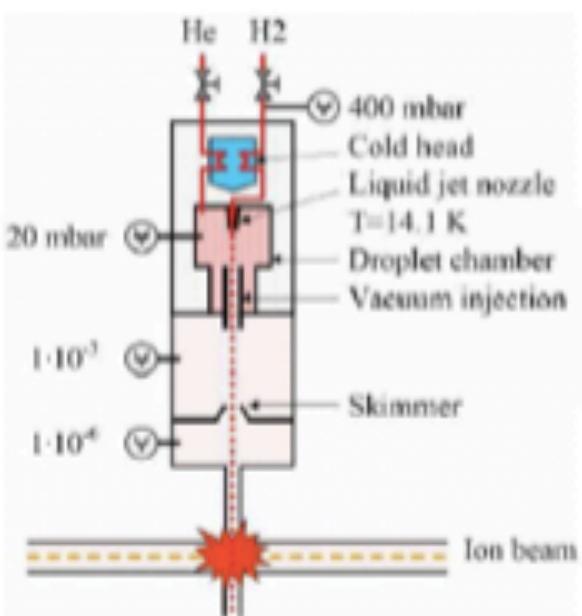






WASA at COSY — Pellet Target Operation

The Pellet Target



vacuum injection



Typical Target Values:

Pellet diameter 20 - 30 μm

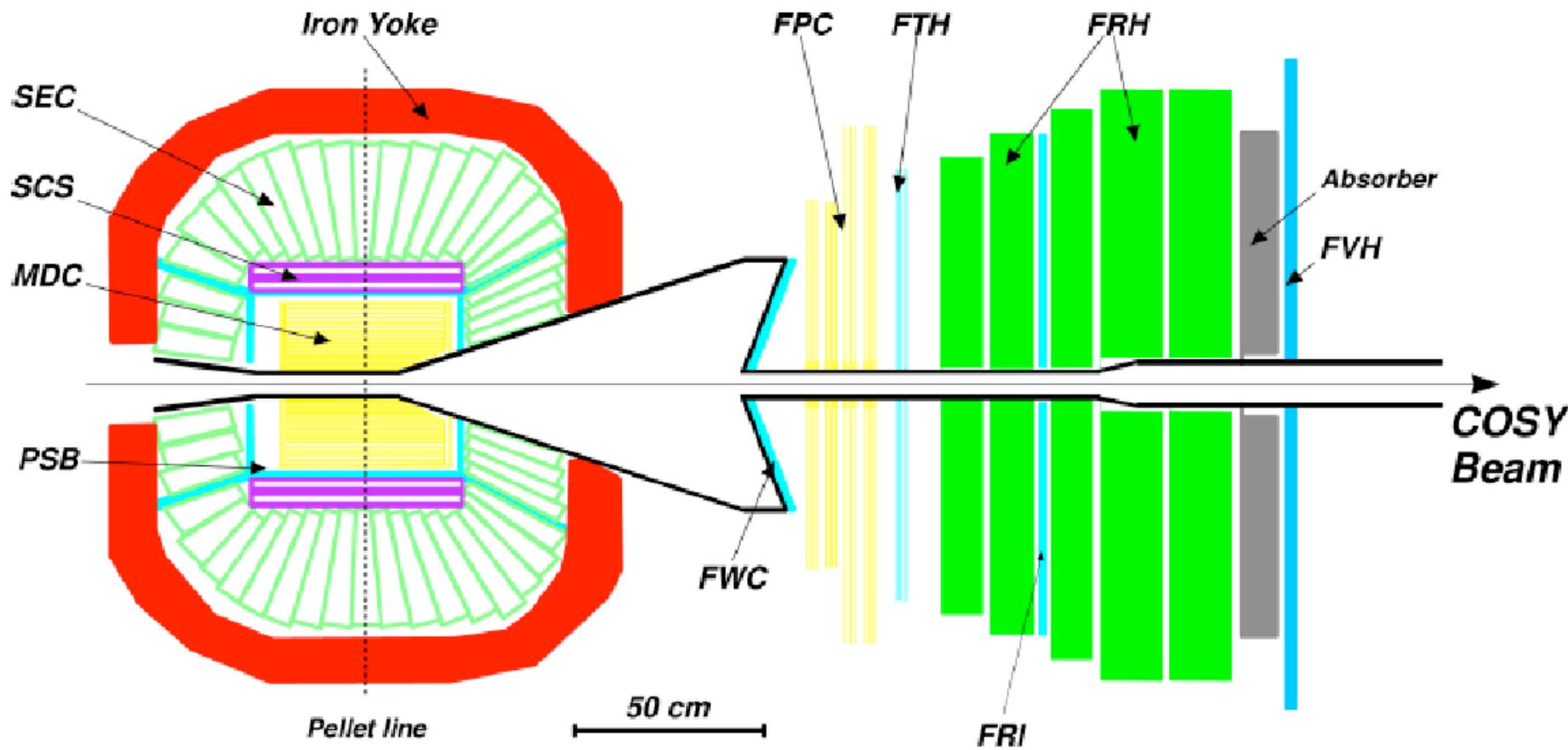
Pellet frequency 5 - 12 kHz

Pellet velocity 60 - 80 m/s

Effective thickness >10¹⁵ atoms/cm²



WASA-at-COSY

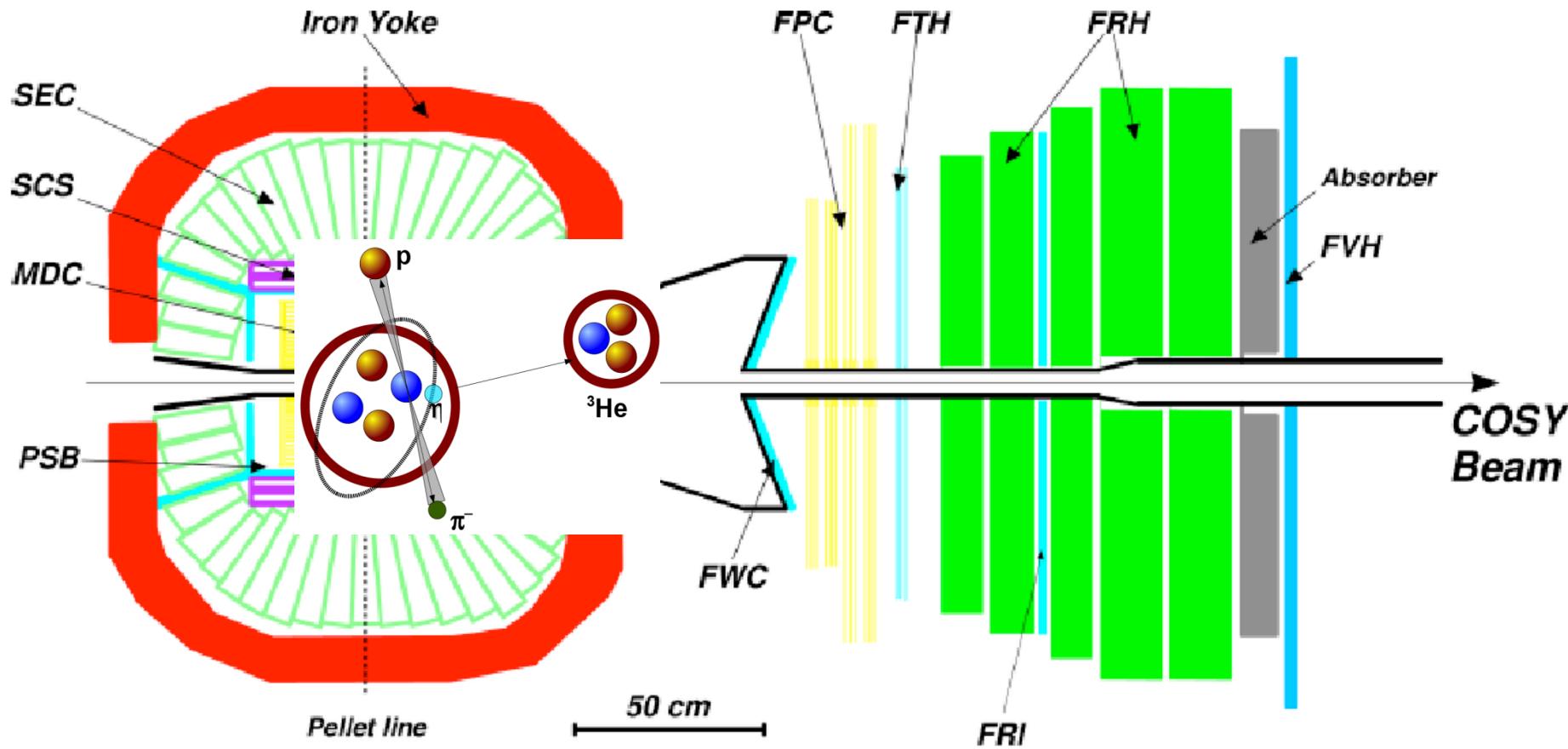


Central Detector

Forward Detector



WASA-at-COSY



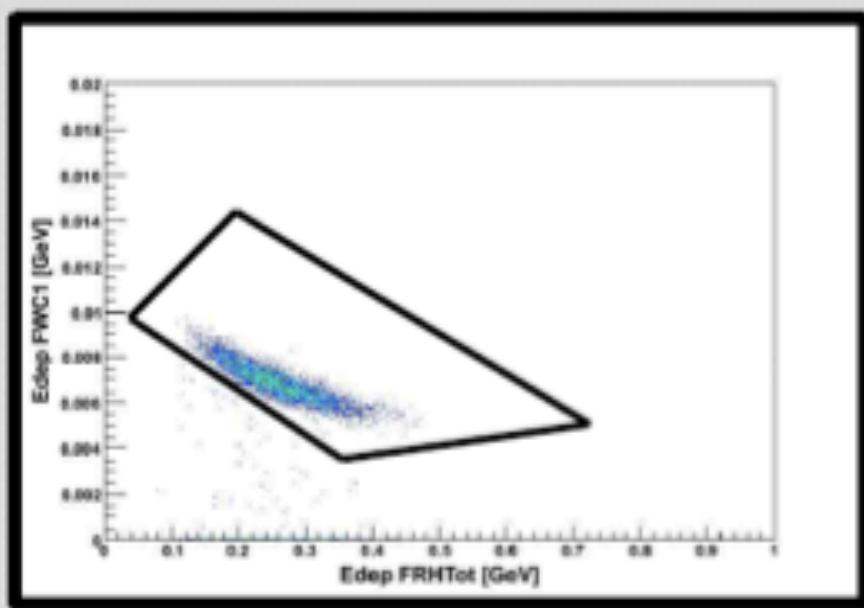
Central Detector

Forward Detector

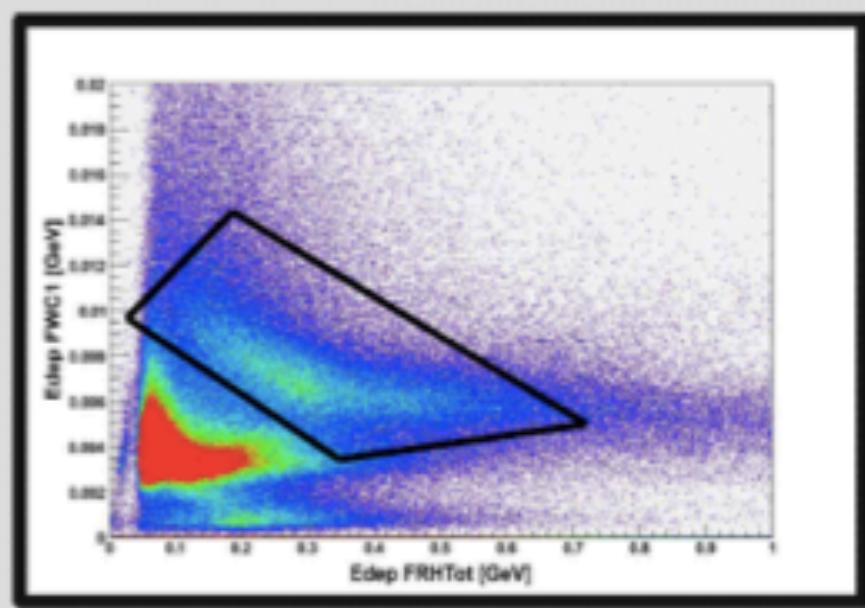
^3He identification in FD

- ^3He selection based on the ΔE - E method.

Monte Carlo

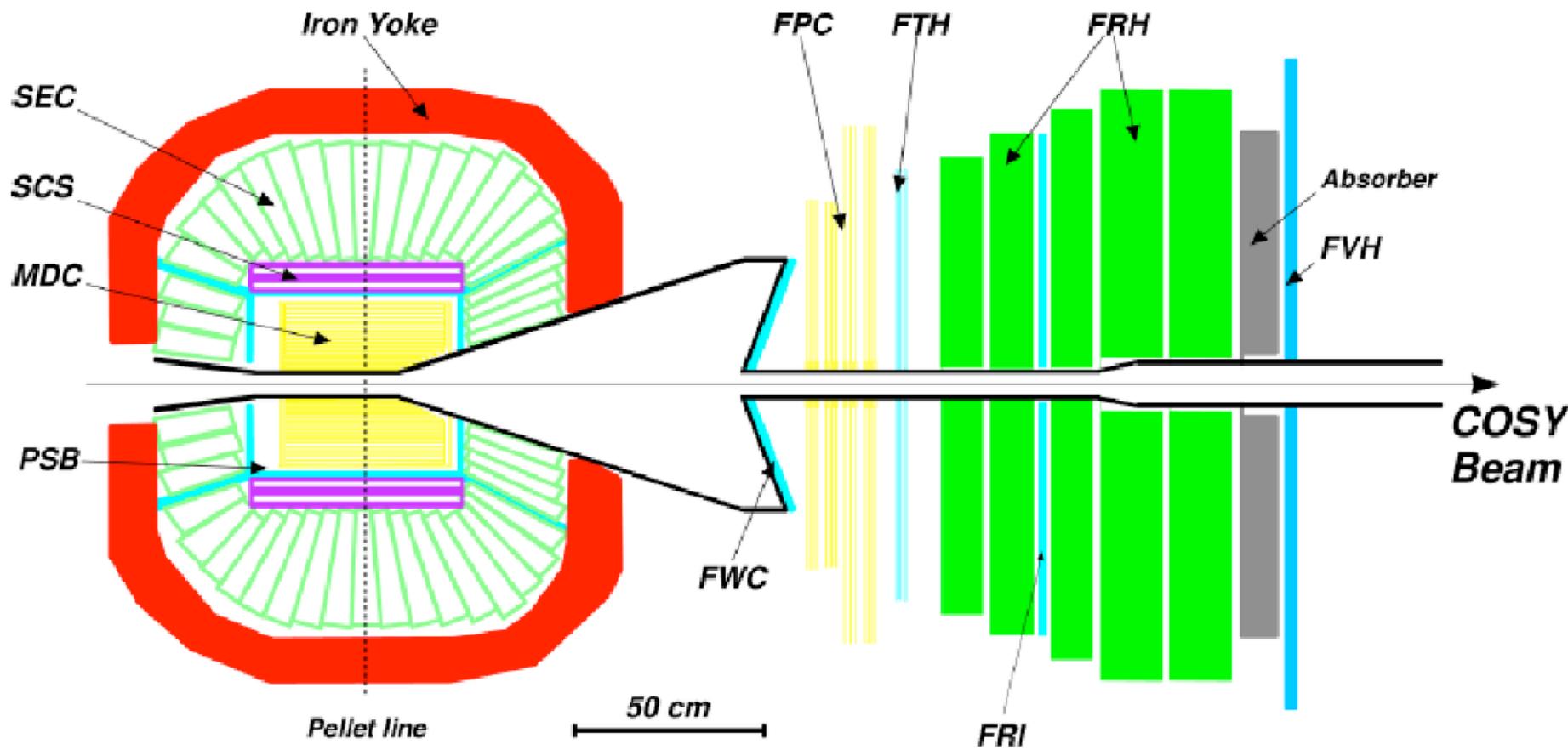


Data





WASA-at-COSY

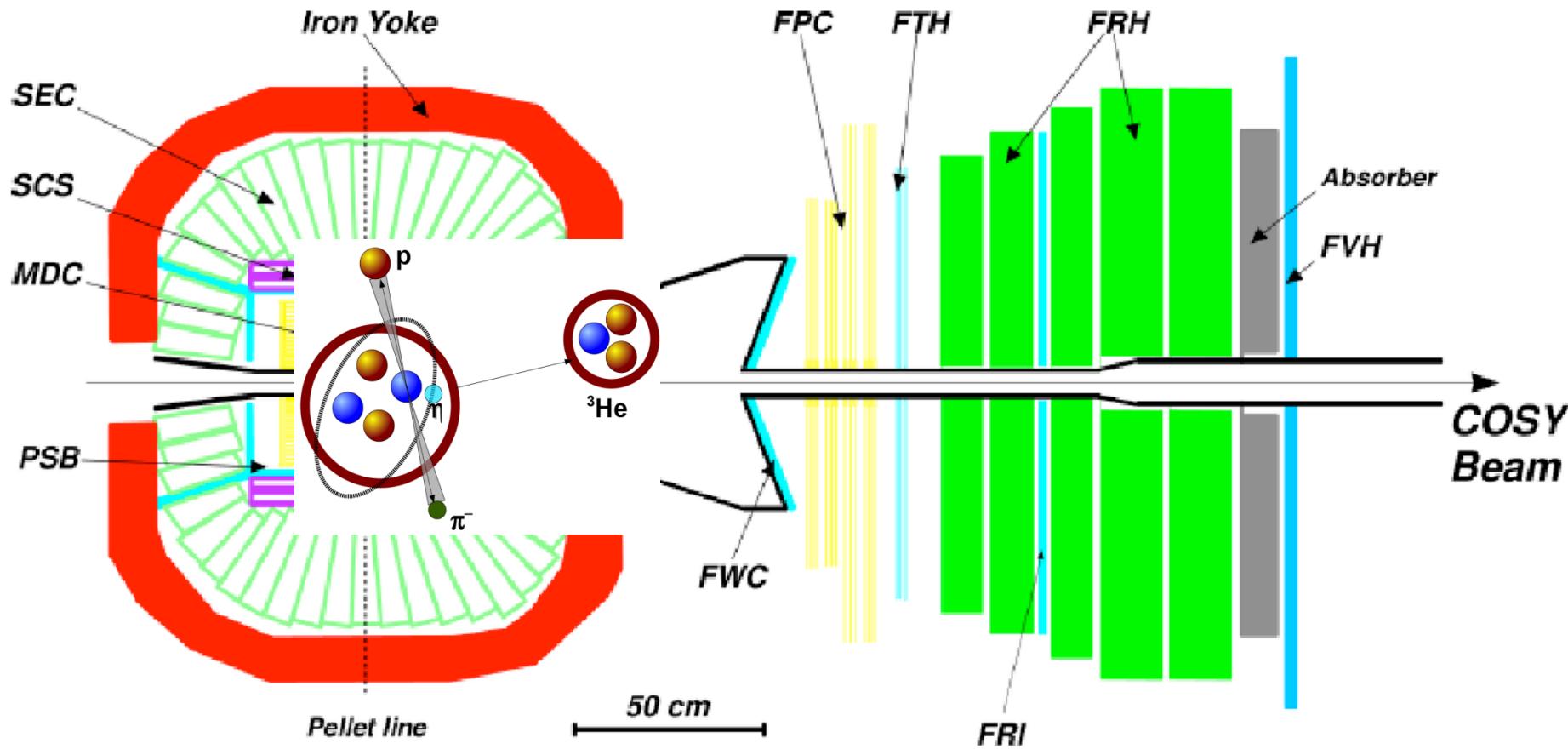


Central Detector

Forward Detector



WASA-at-COSY

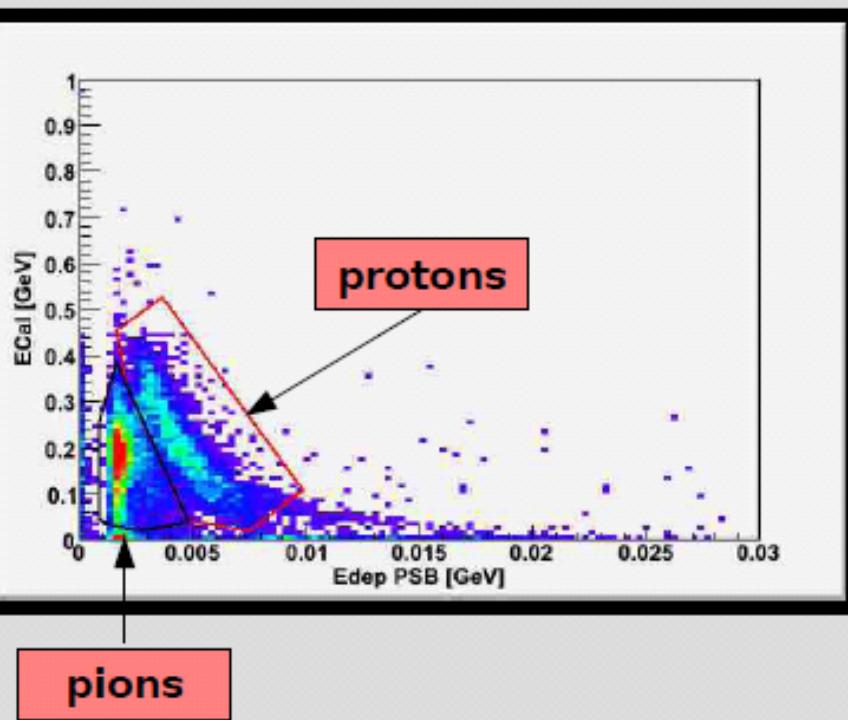


Central Detector

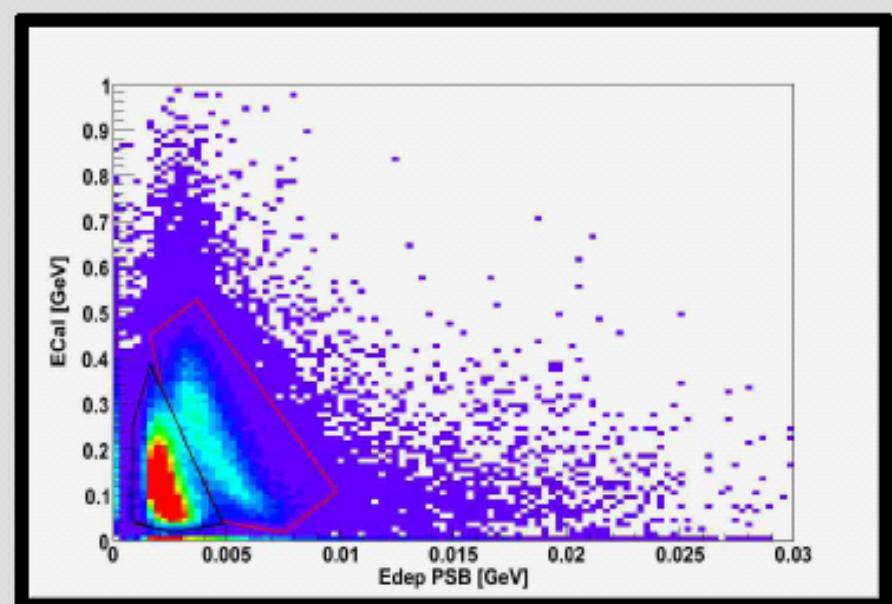
Forward Detector

p/π identification in CD

Monte Carlo

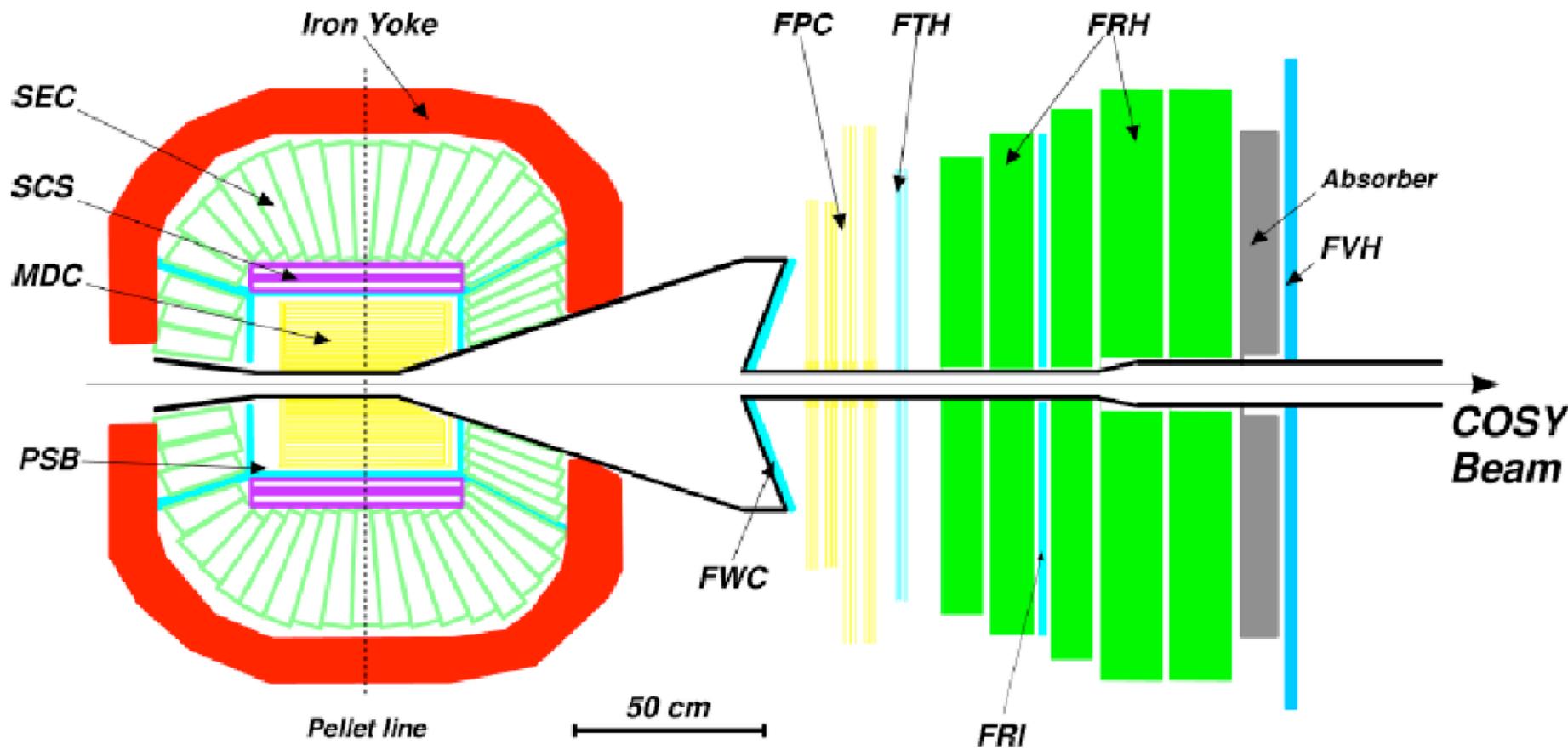


Data





WASA-at-COSY

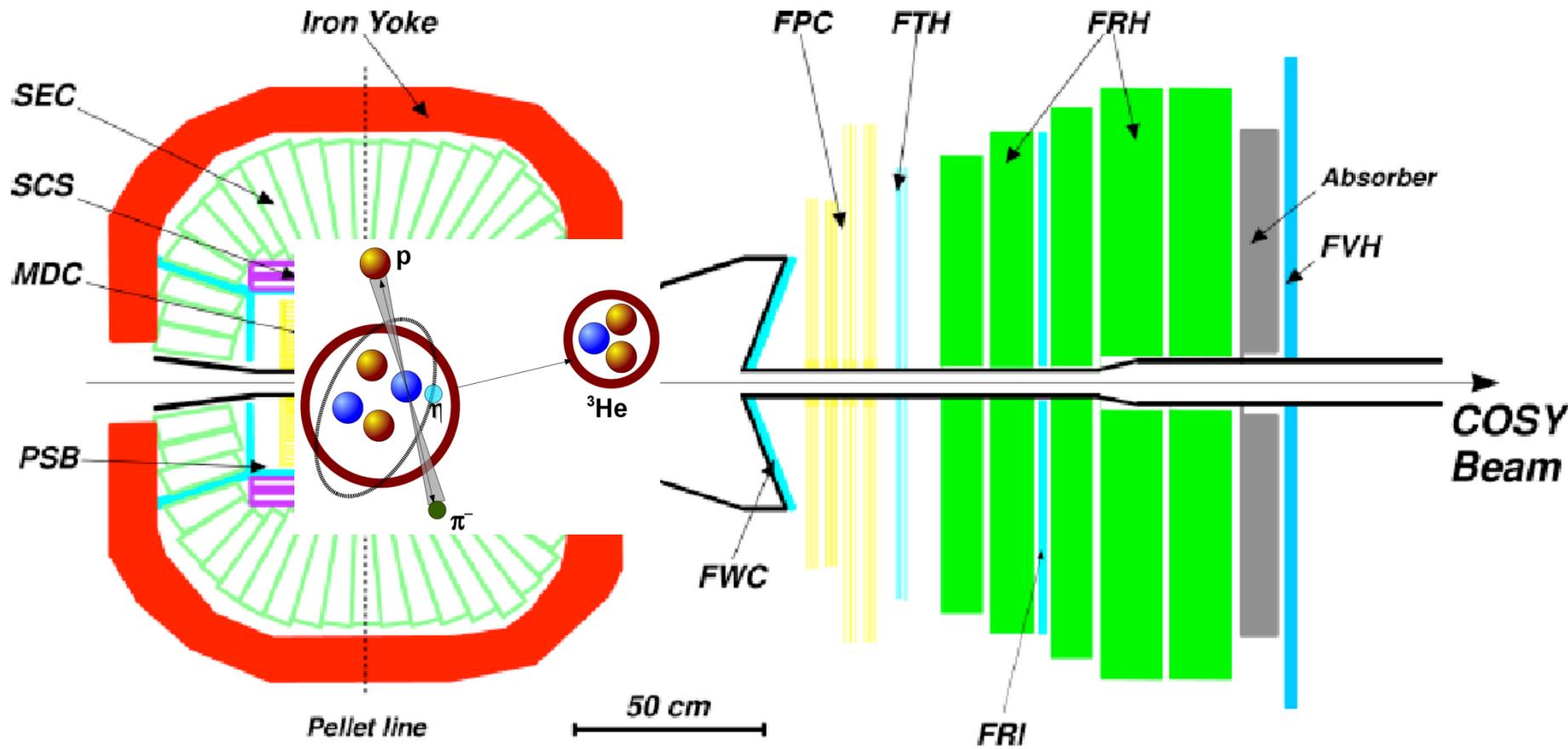


Central Detector

Forward Detector

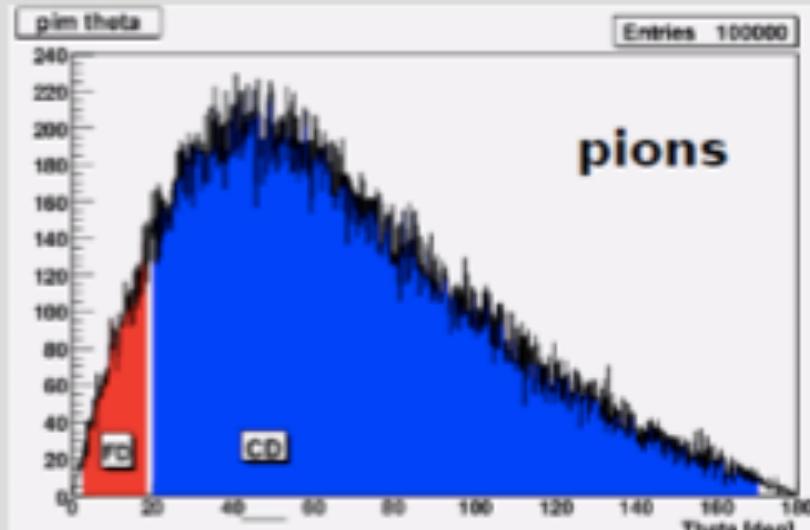
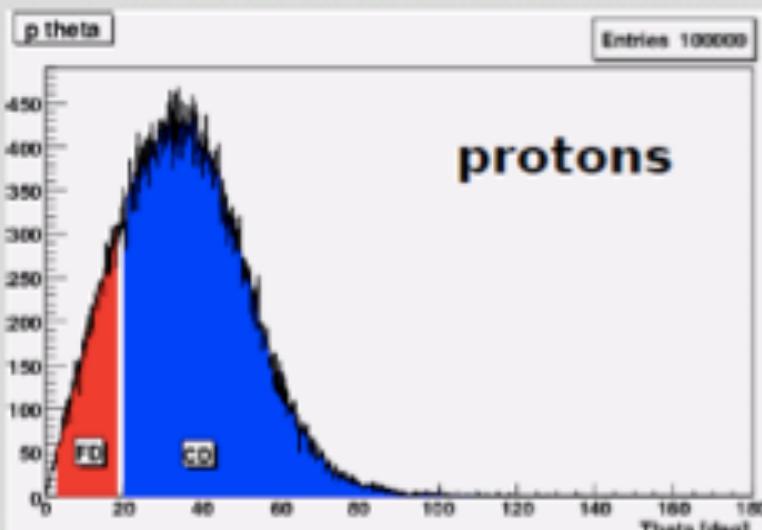
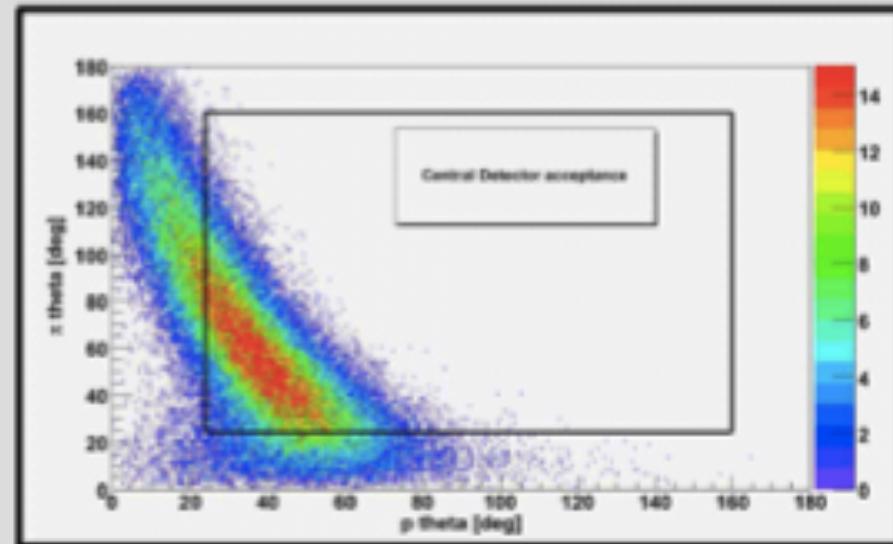
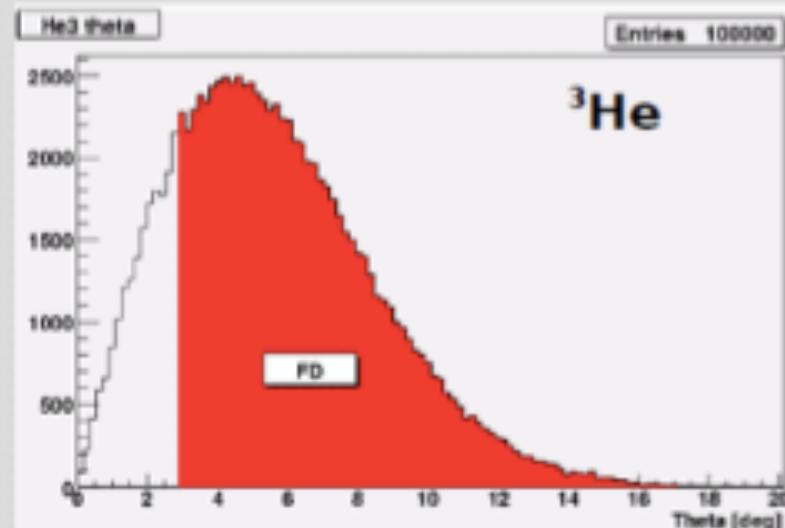
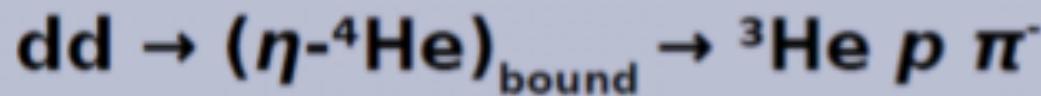


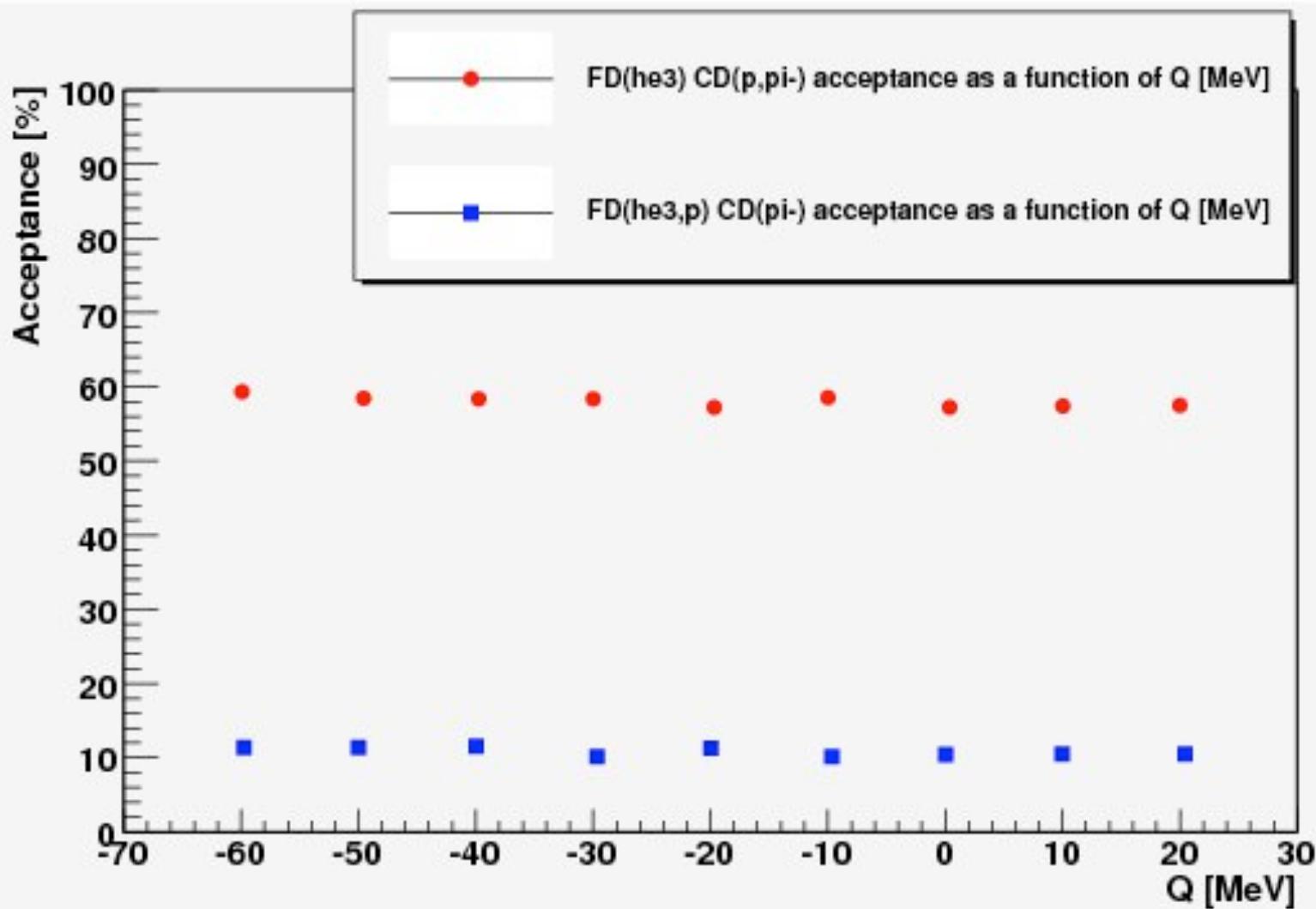
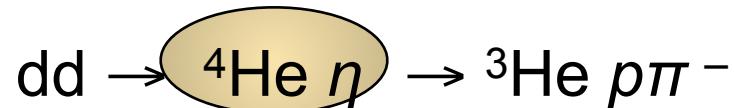
WASA-at-COSY

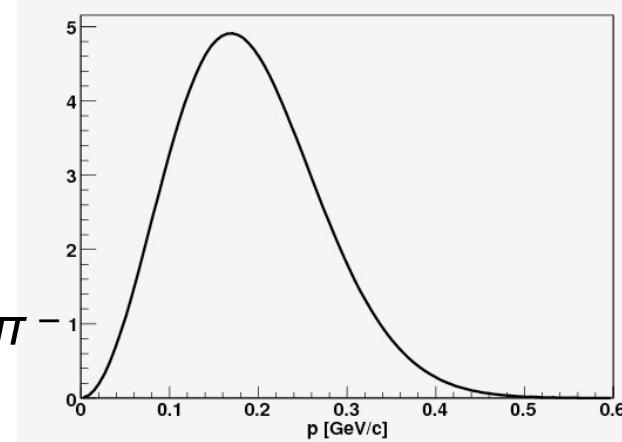
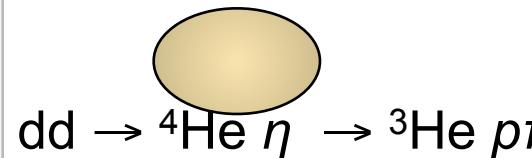
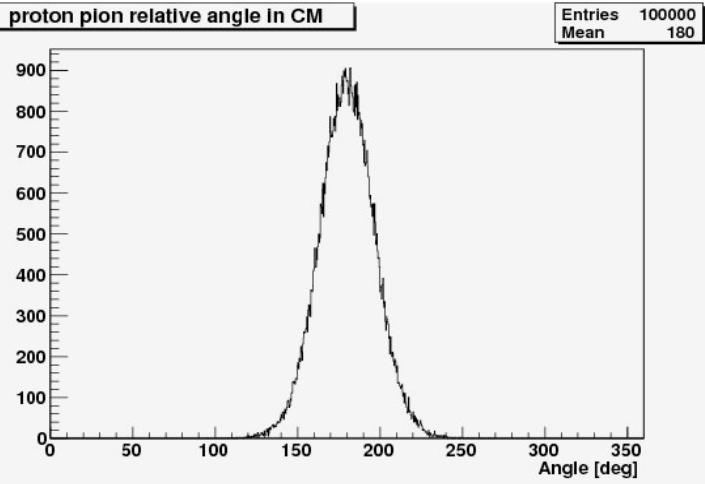


Central Detector

Forward Detector

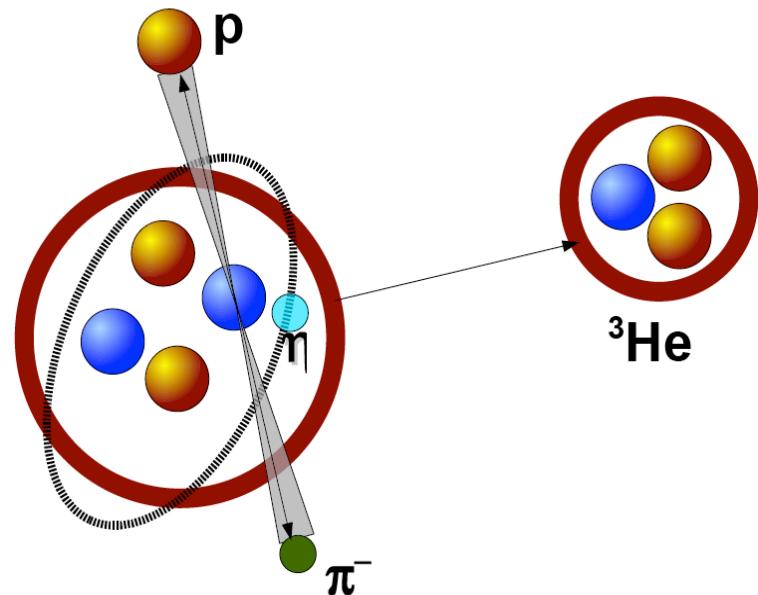
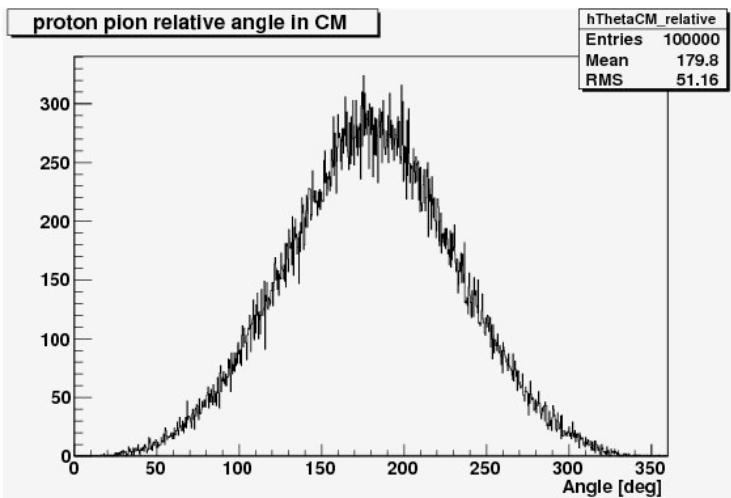




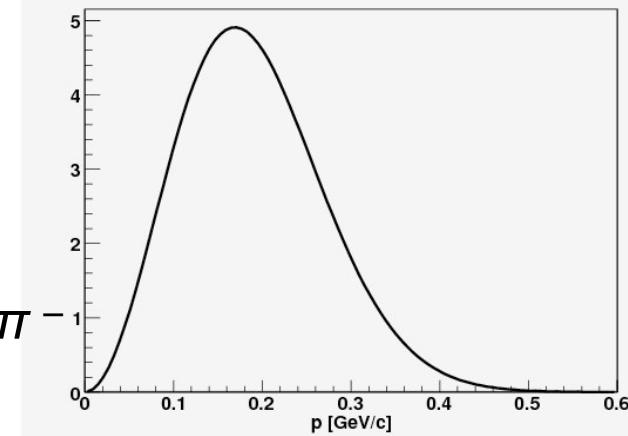
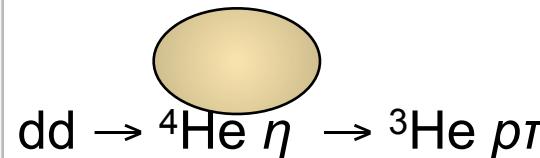
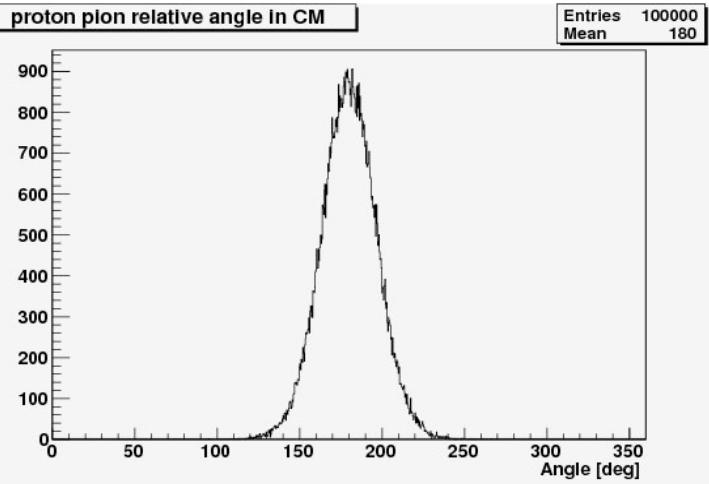


V. Hejny, PhD

A. Nogga, ...

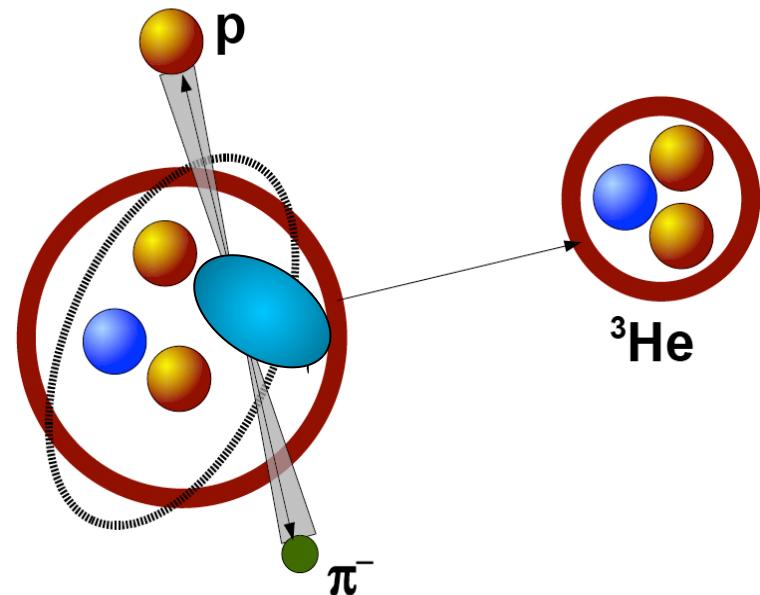
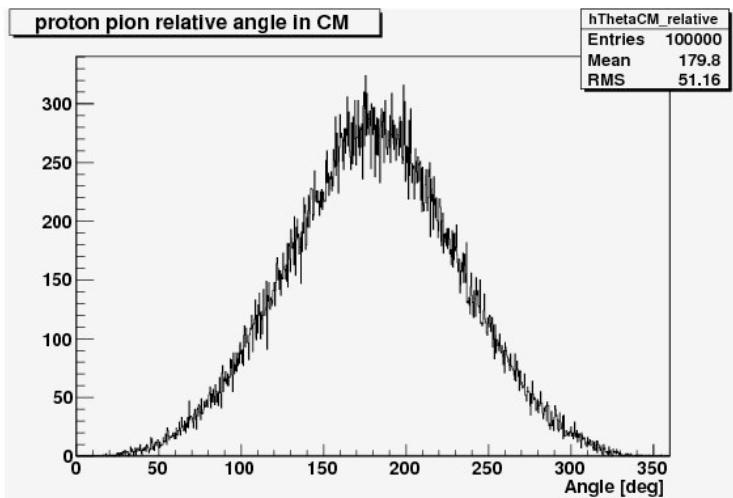


analysis and simulations:
WOJCIECH KRZEMIĘŃ

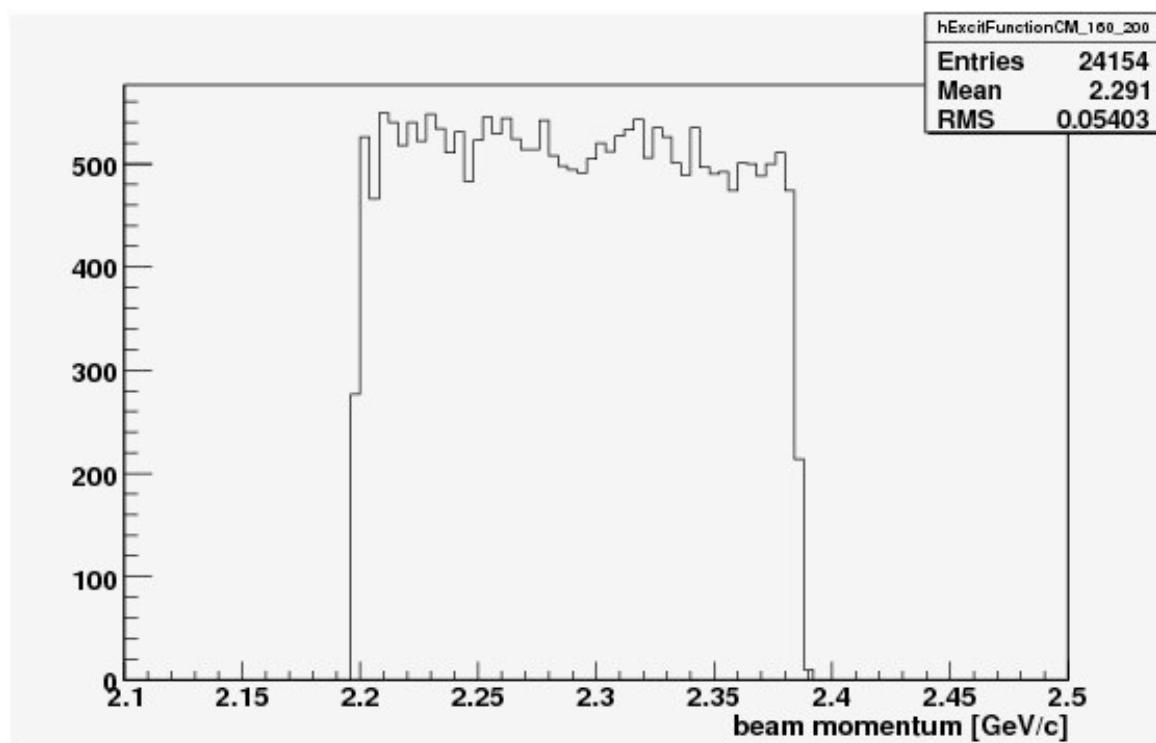
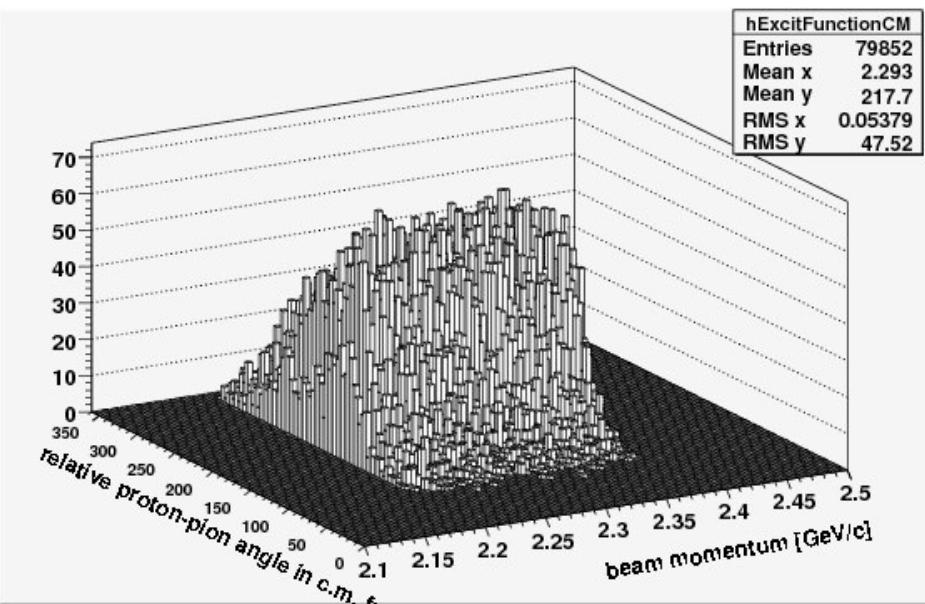


V. Hejny, PhD

A. Nogga, ...

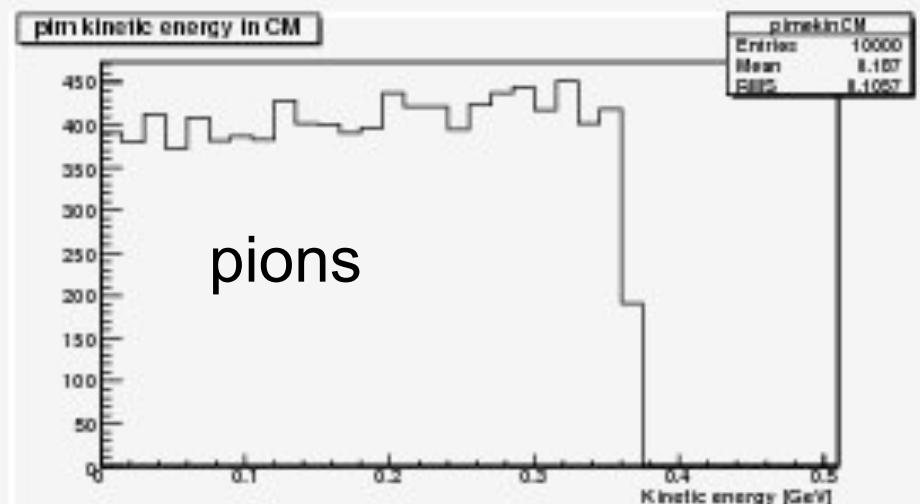
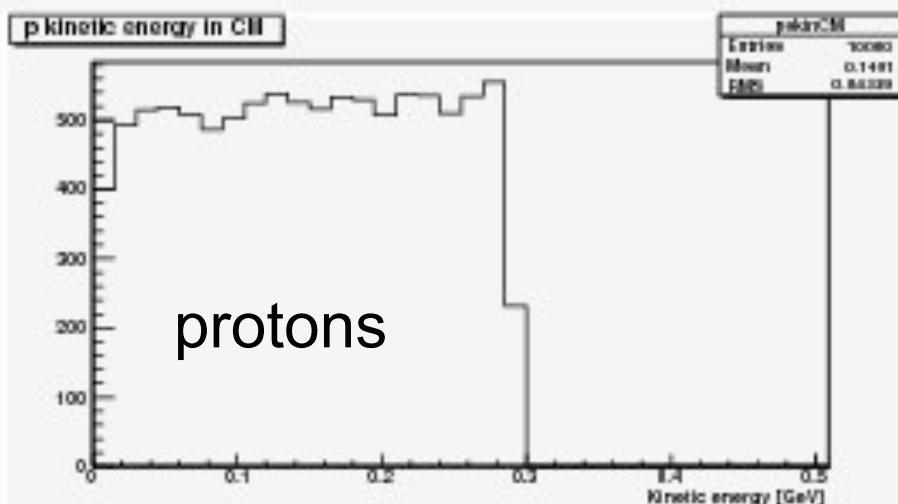
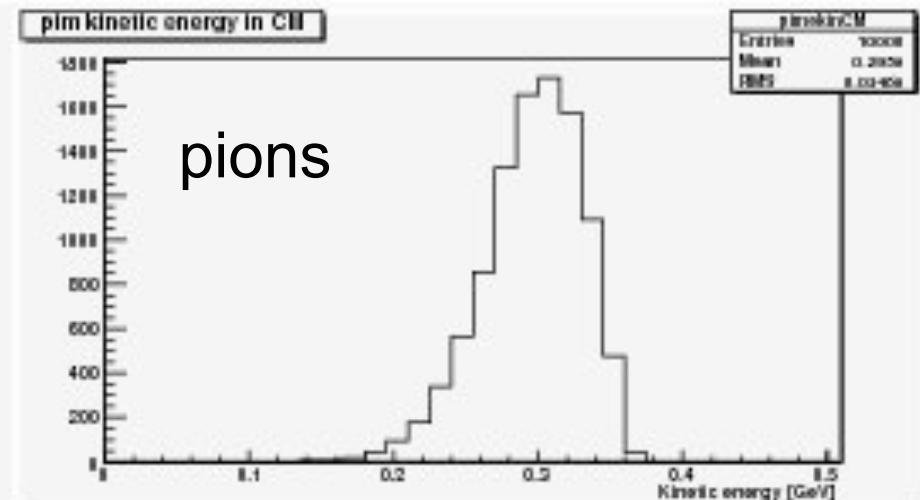
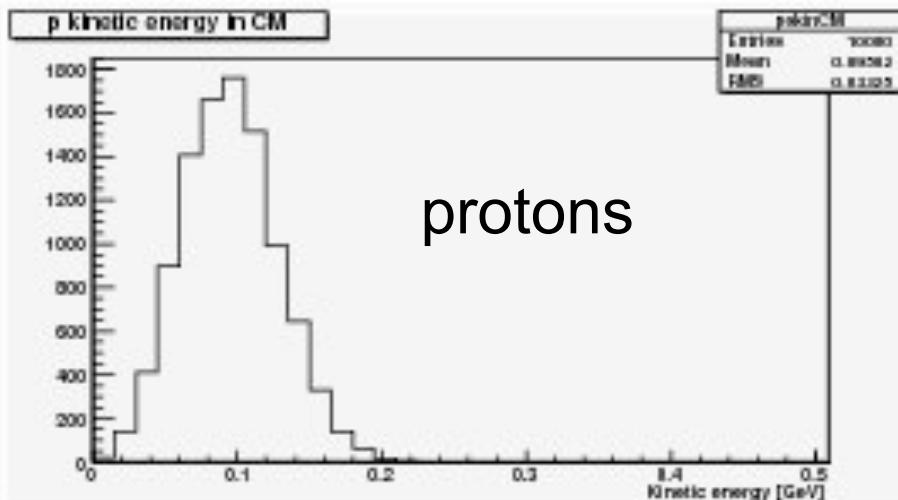


analysis and simulations:
WOJCIECH KRZEMIĘŃ





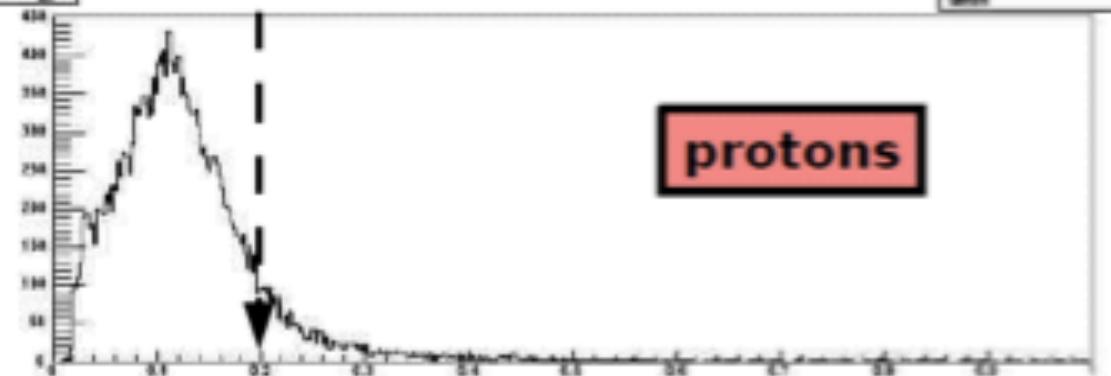
Further background reduction possibilities



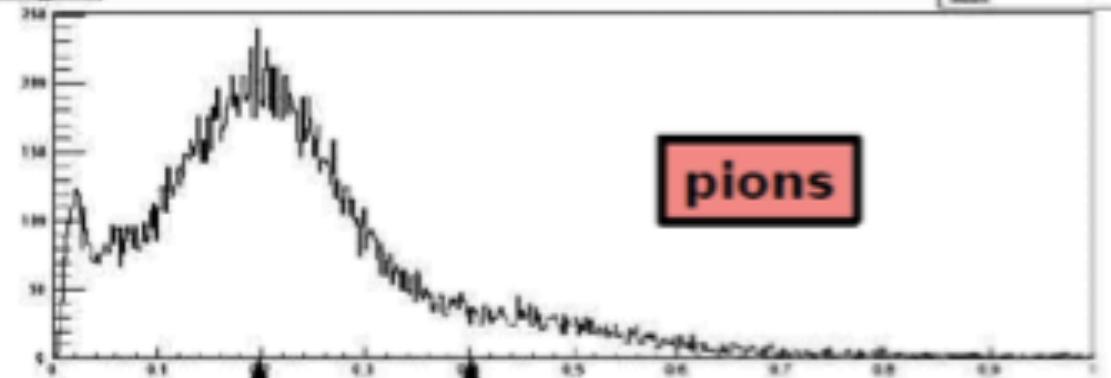
Cut on p/π^- Ekin distribution in CM

Data

nEkin/CM_p



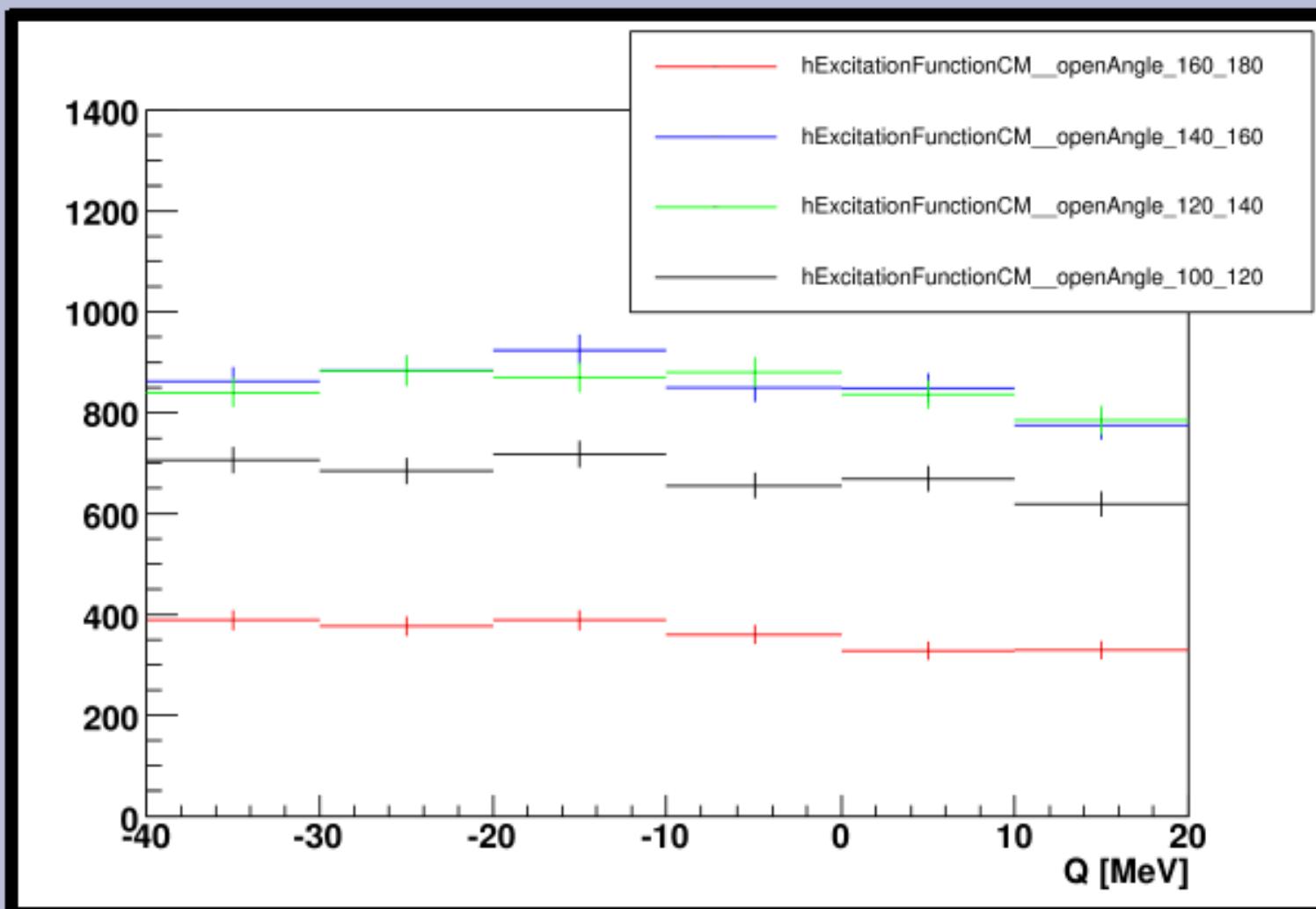
nEkin/CM_pi



| | MC | data |
|--------------|----|------|
| cut on p | 1% | 25% |
| cut on π | 8% | 45% |

Excitation functions (after Ekin cut)

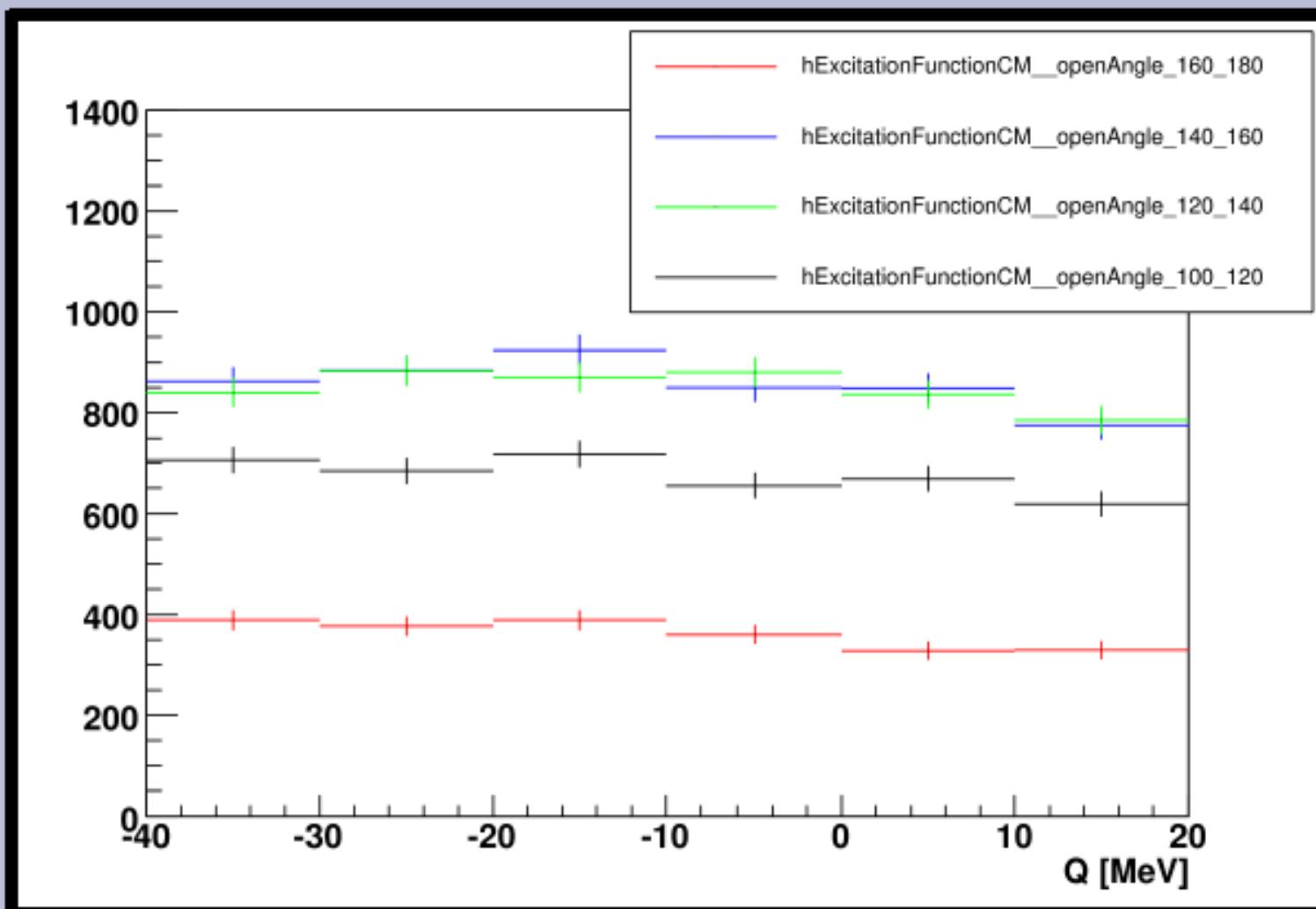
Opening angle



Excitation functions (after Ekin cut)

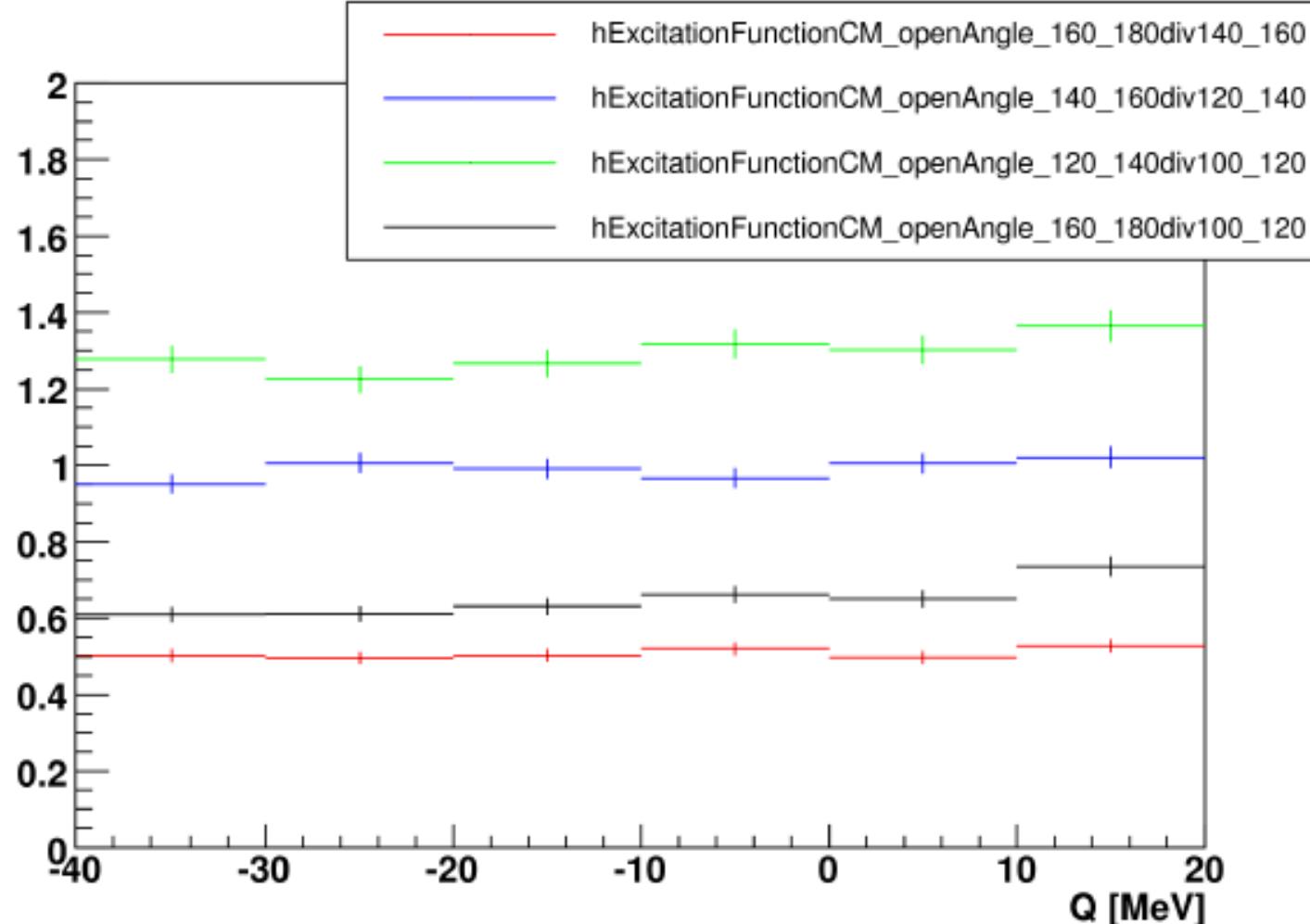
Upper limit 20 nb
PRELIMINARY

Opening angle



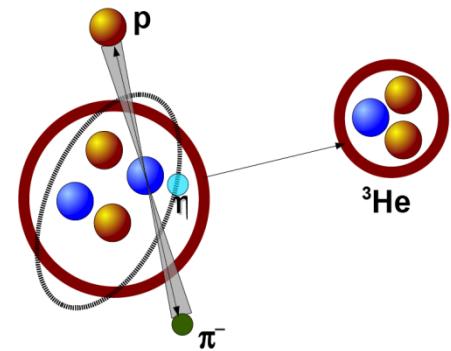
Excitation functions (before Ekin cut)

Opening angle (divided)



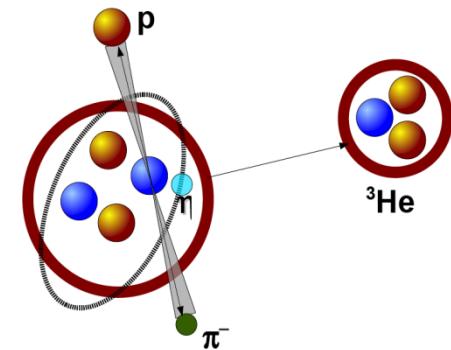
At present

WASA-at-COSY 20 nb vs. 2 nb



At present

WASA-at-COSY 20 nb vs. 2 nb



PERSPECTIVES with WASA-at-COSY

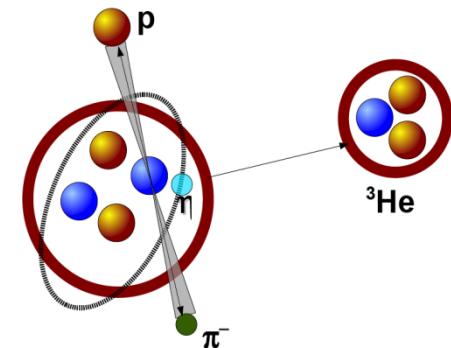
2 weeks beam-time scheduled for 2010

Only main trigger not prescaled: 5 x luminosity

16 hours → 14 days : 20 x luminosity

At present

WASA-at-COSY 20 nb vs. 2 nb



PERSPECTIVES with WASA-at-COSY

2 weeks beam-time scheduled for 2010

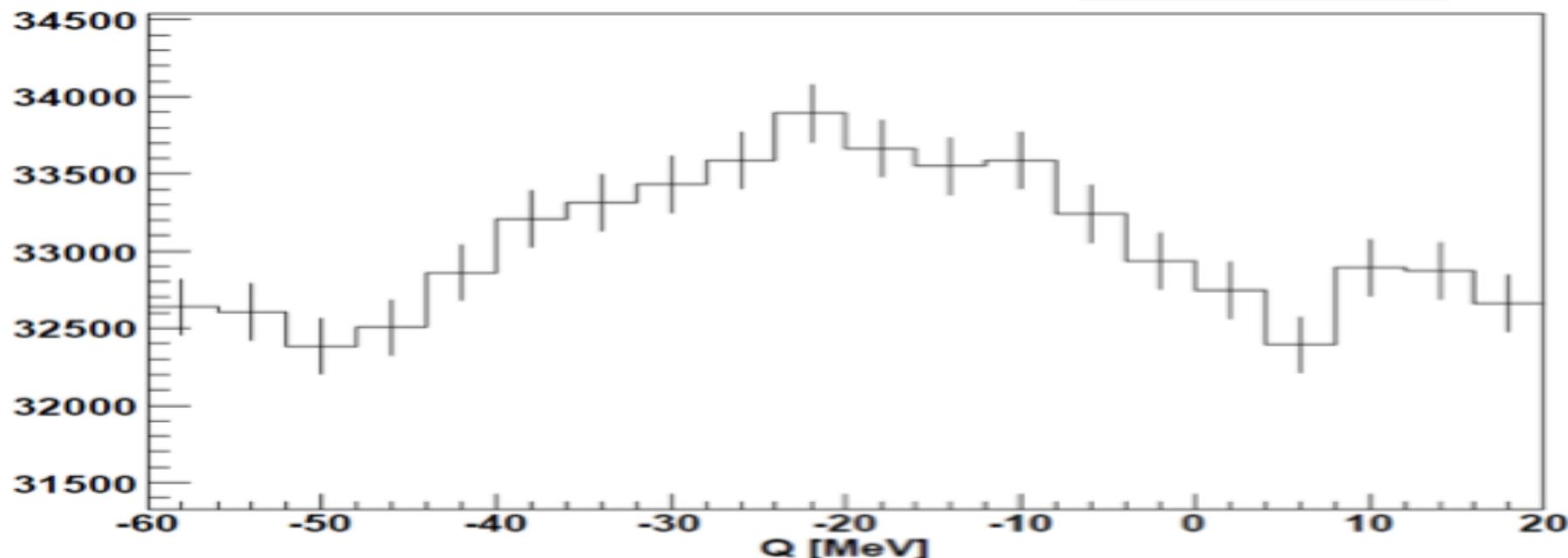
Only main trigger not prescaled: 5 x luminosity

16 hours \rightarrow 14 days : 20 x luminosity

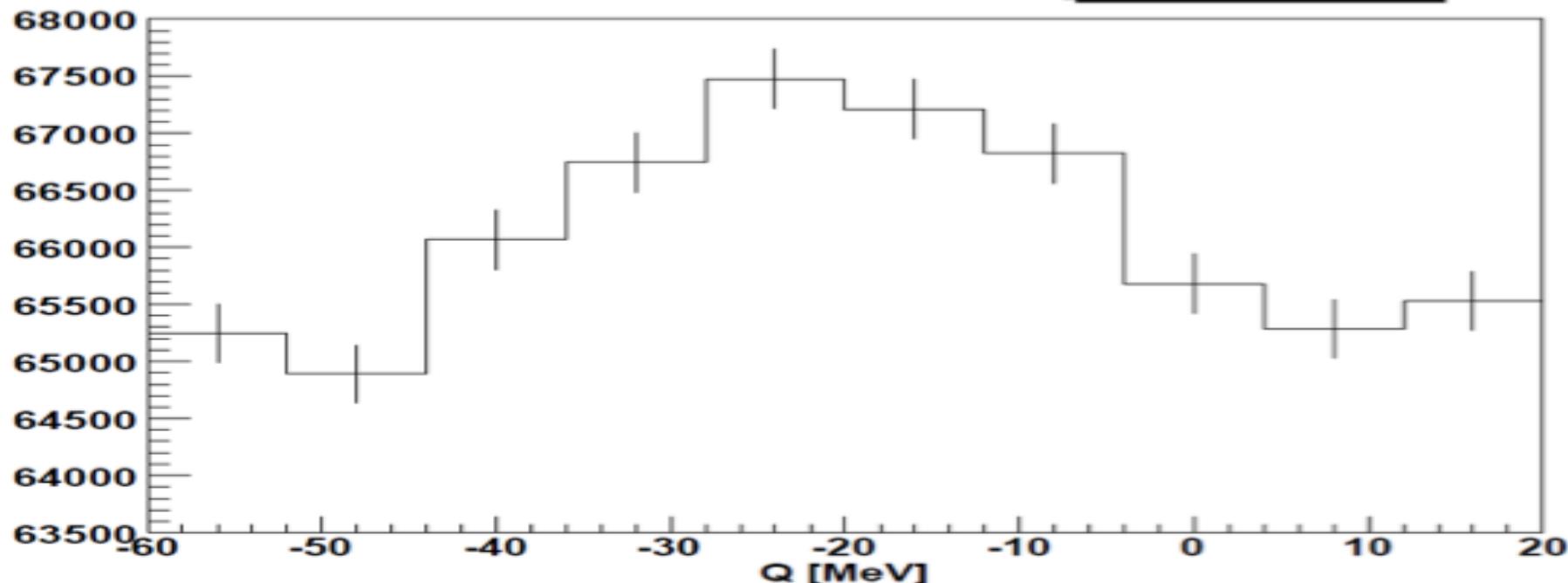
Expectation: ~2 nb vs. 2 nb

**UNIQUE OPPORTUNITY TO DETECT ALL EJECTILES
EXCLUSIVE MEASUREMENT**

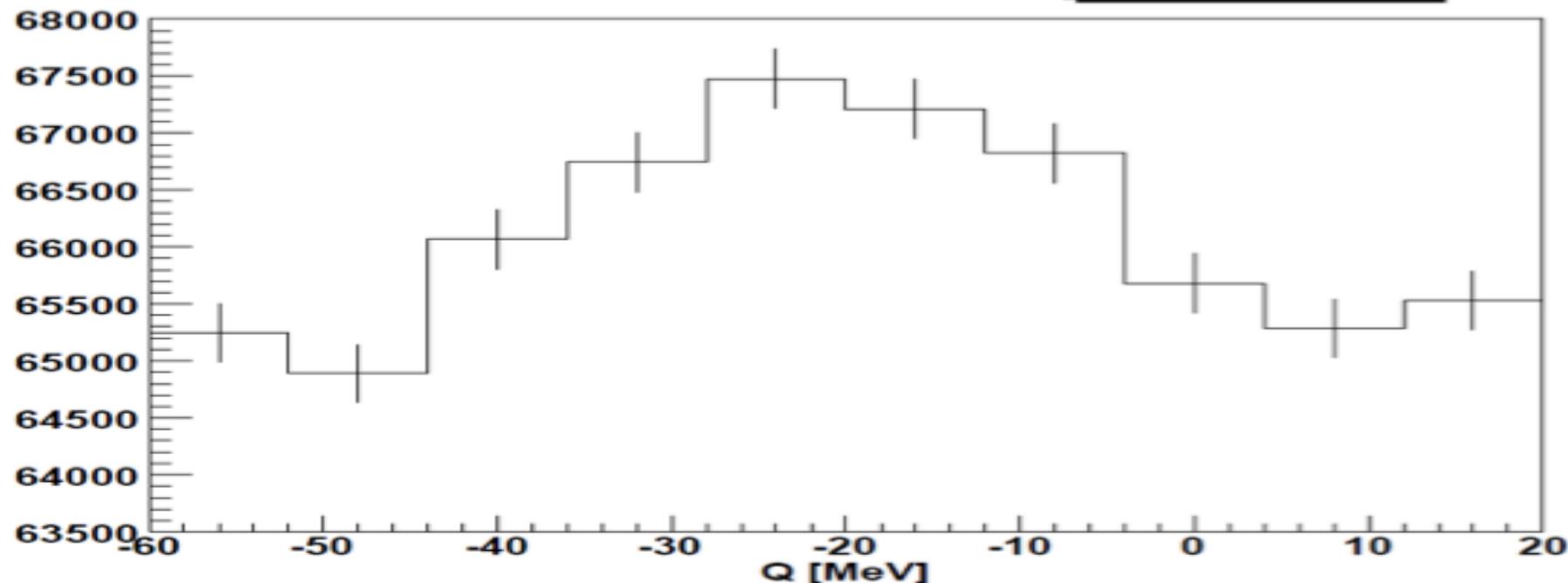
10 nb



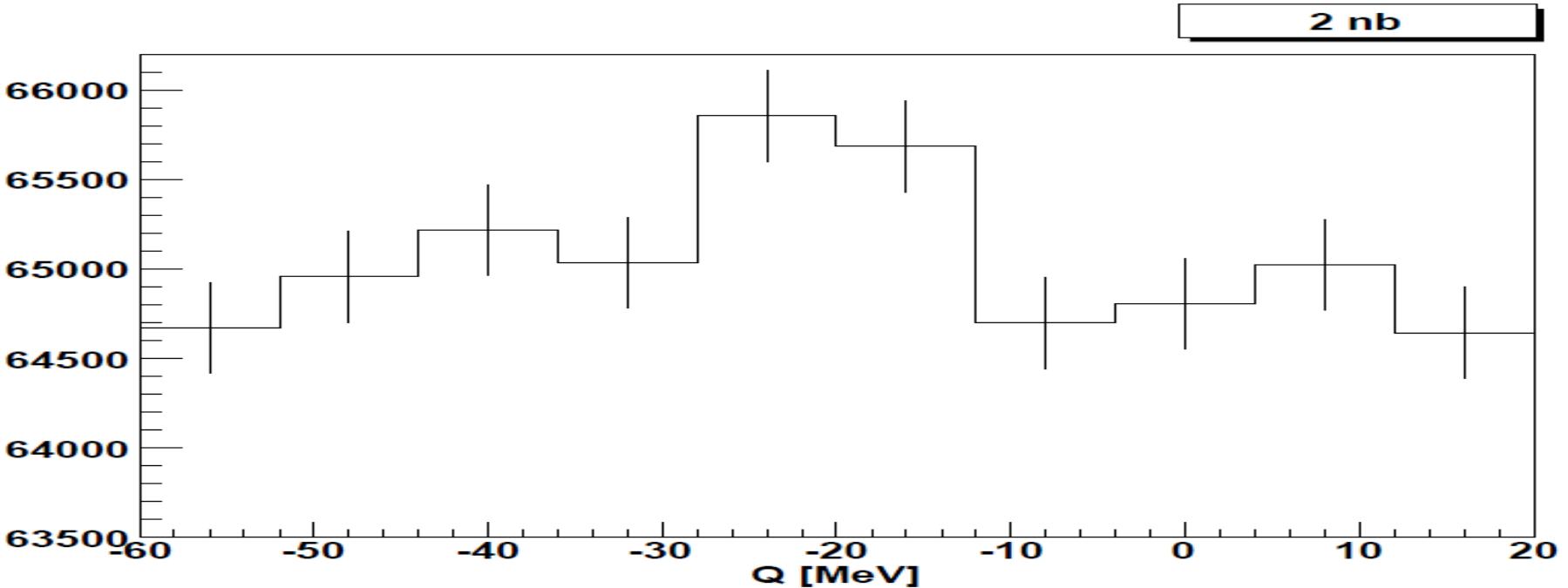
10 nb

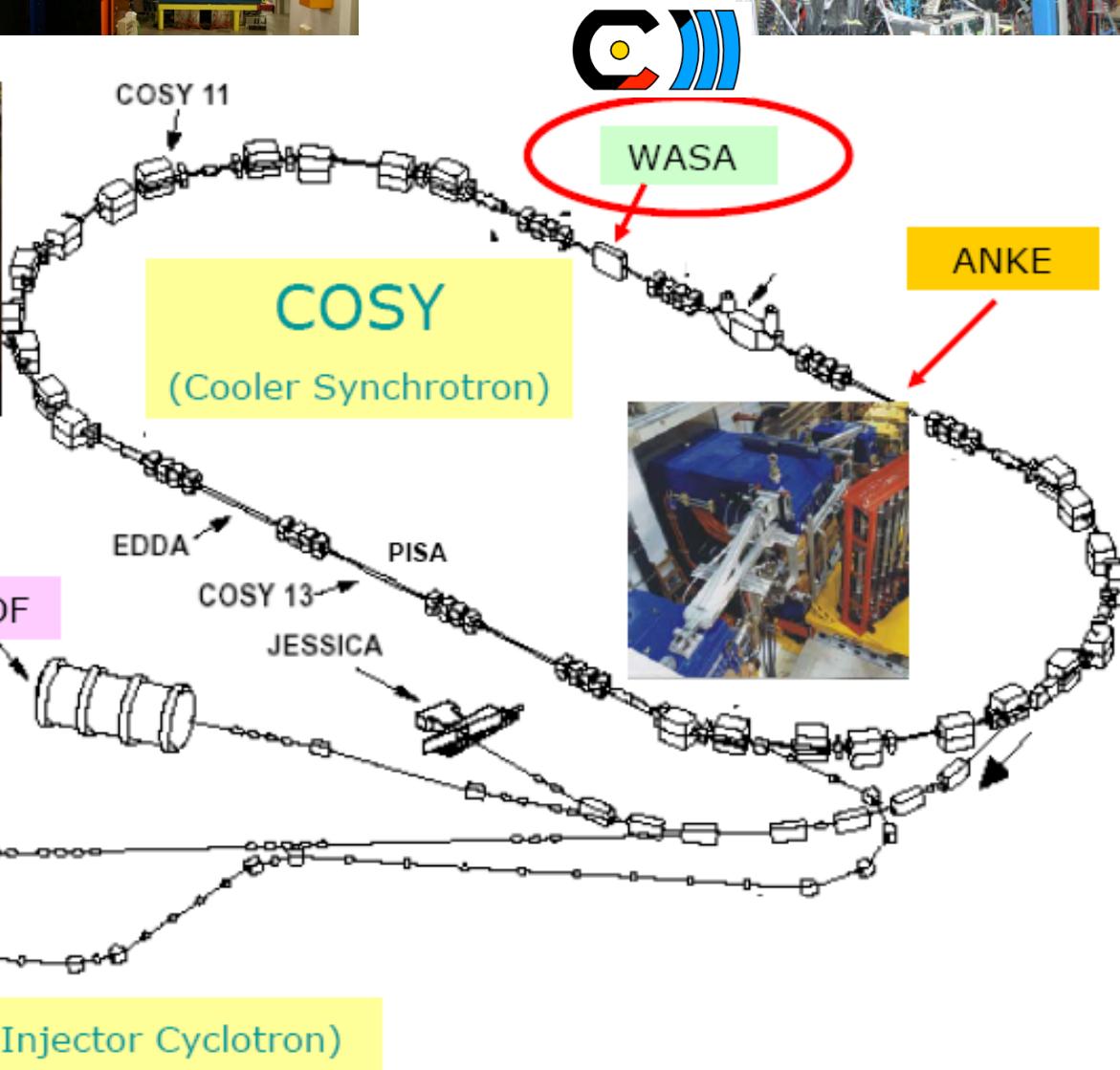
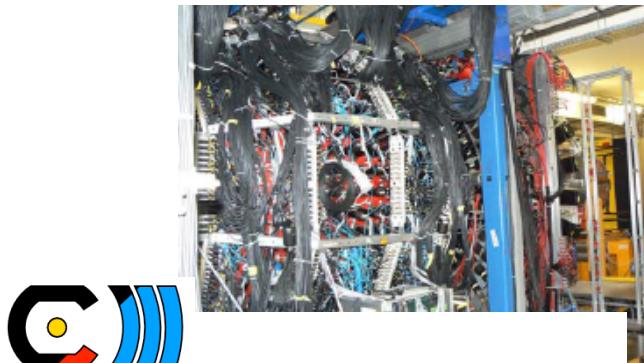
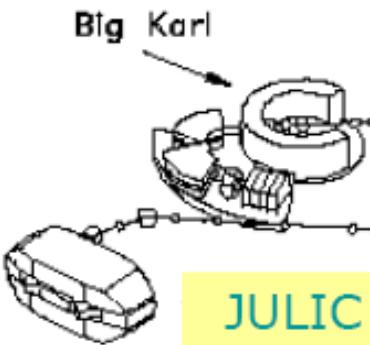


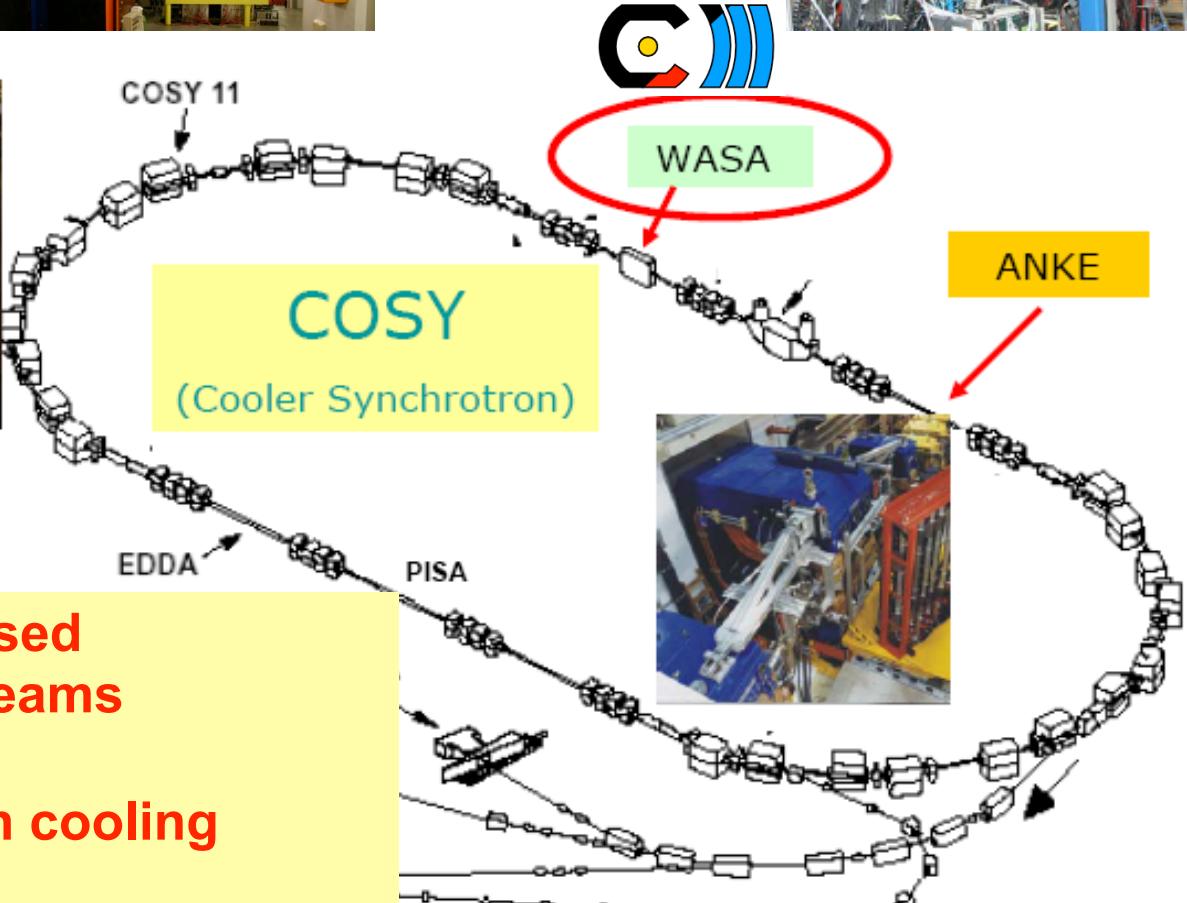
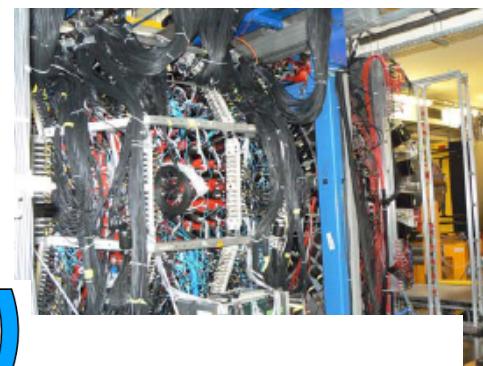
10 nb



2 nb

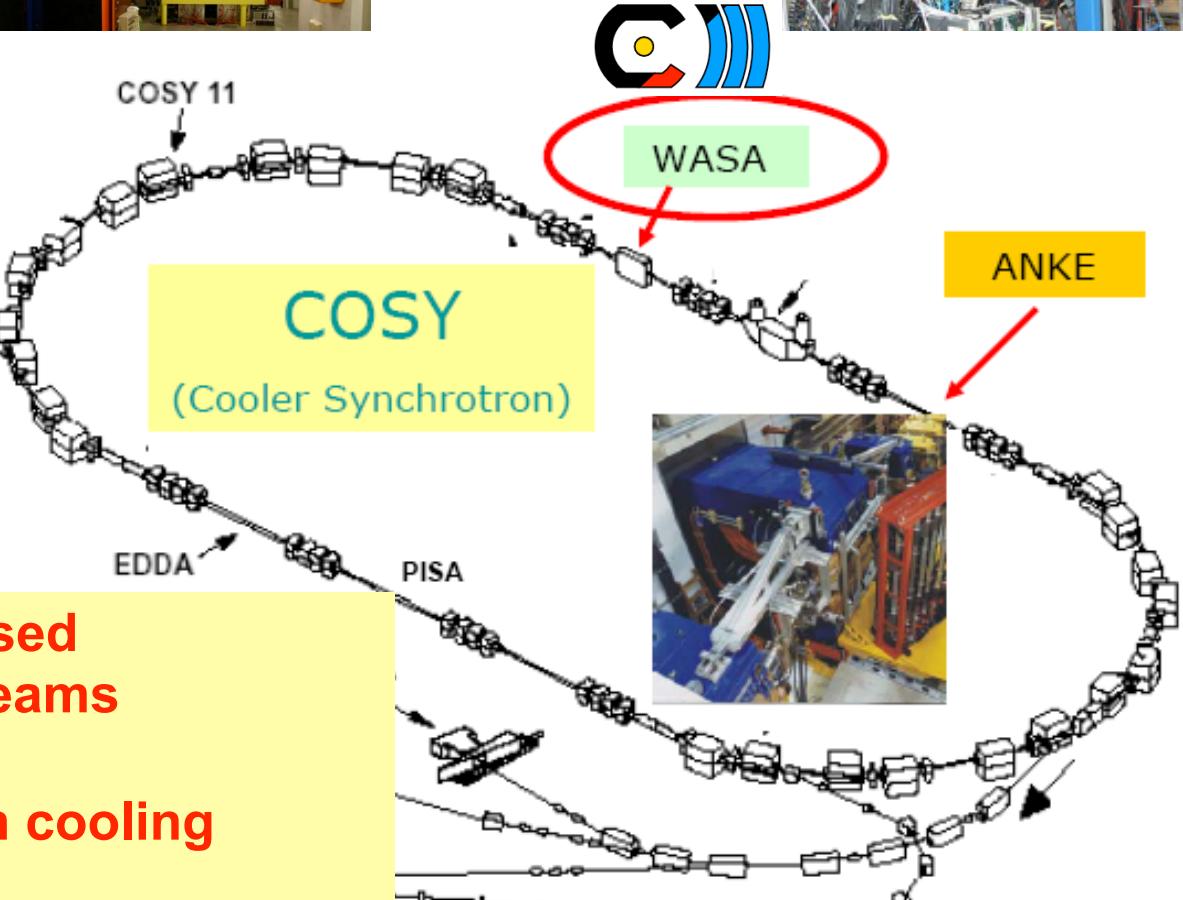
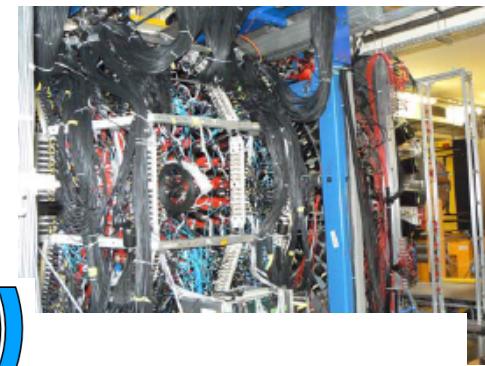




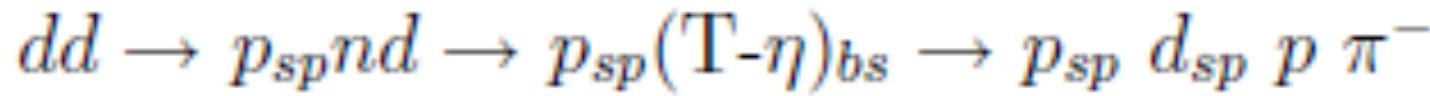
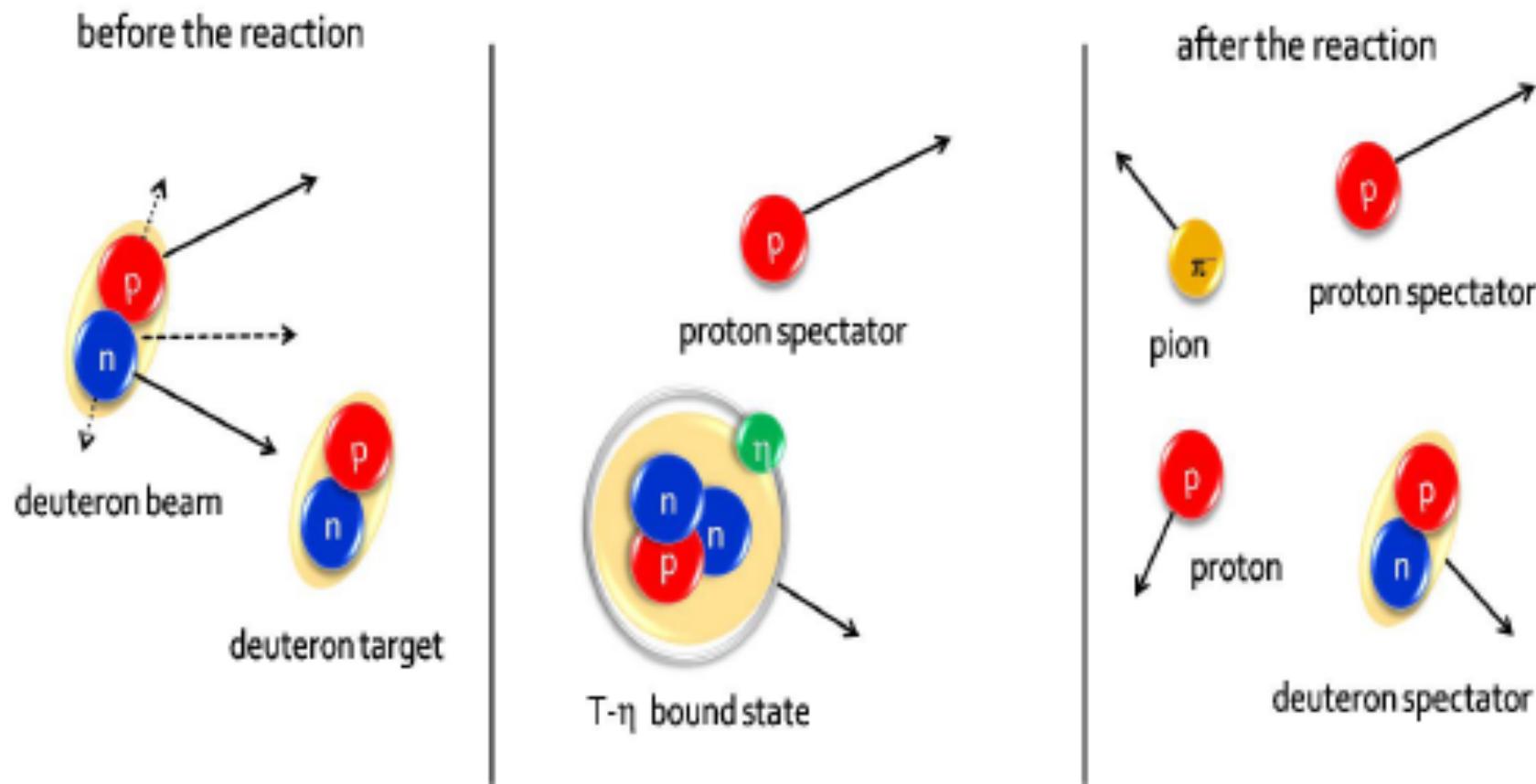


- polarised and unpolarised proton and deuteron beams
- stochastic and electron cooling
- momentum range: 600 – 3700 MeV/c
- meson production up to $\phi(1020)$

Detectors at COSY



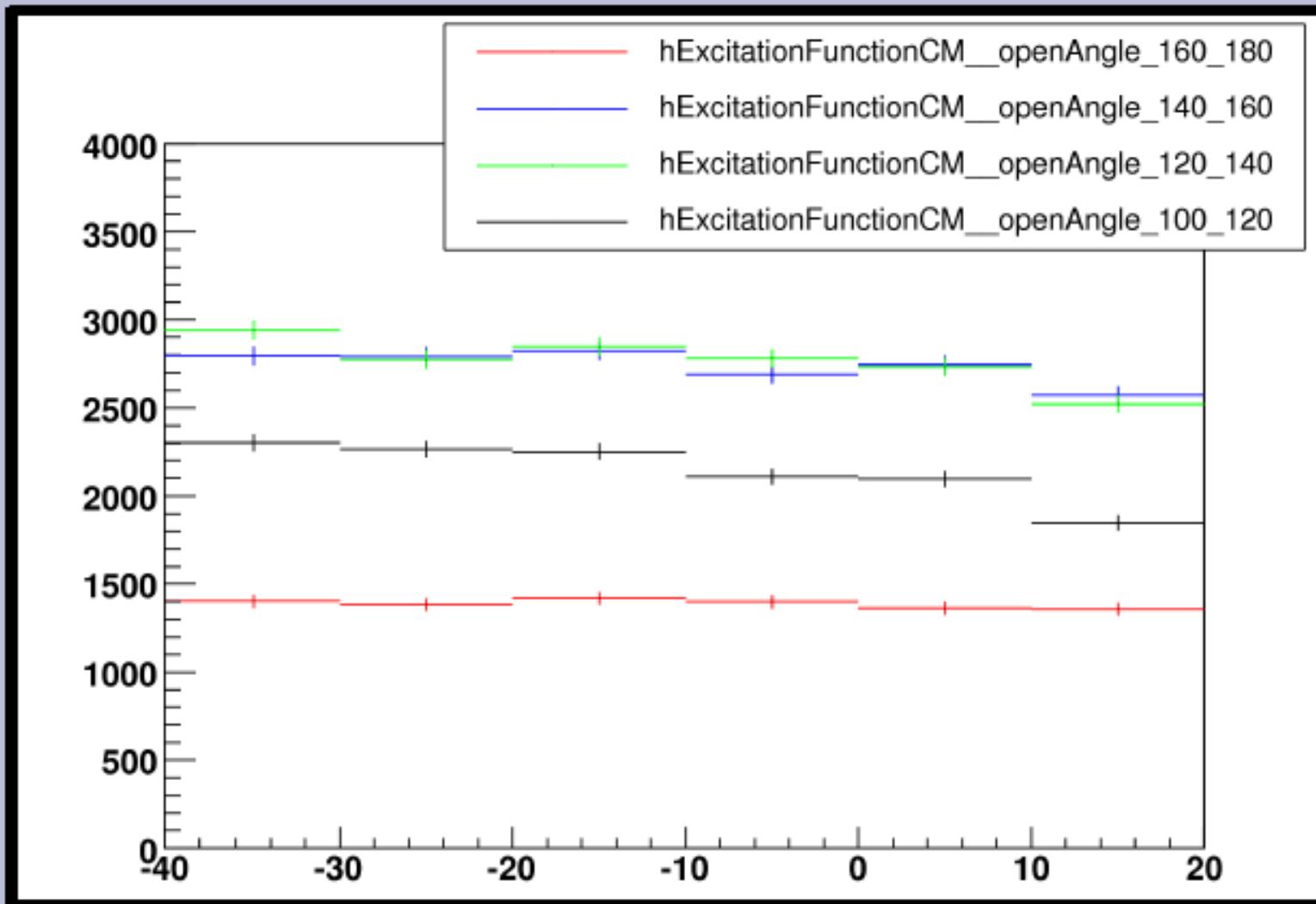
- polarised and unpolarised proton and deuteron beams
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- momentum range: 600 – 3700 MeV/c
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Thank You

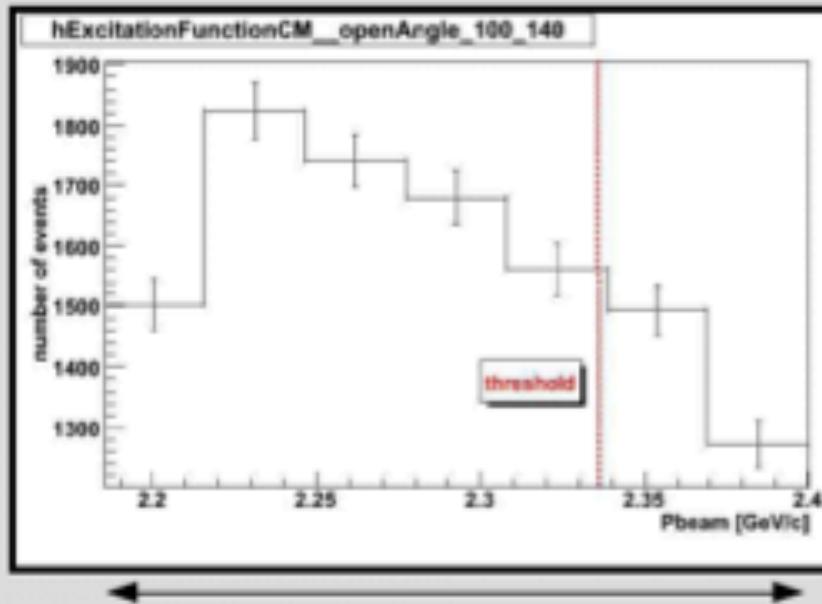
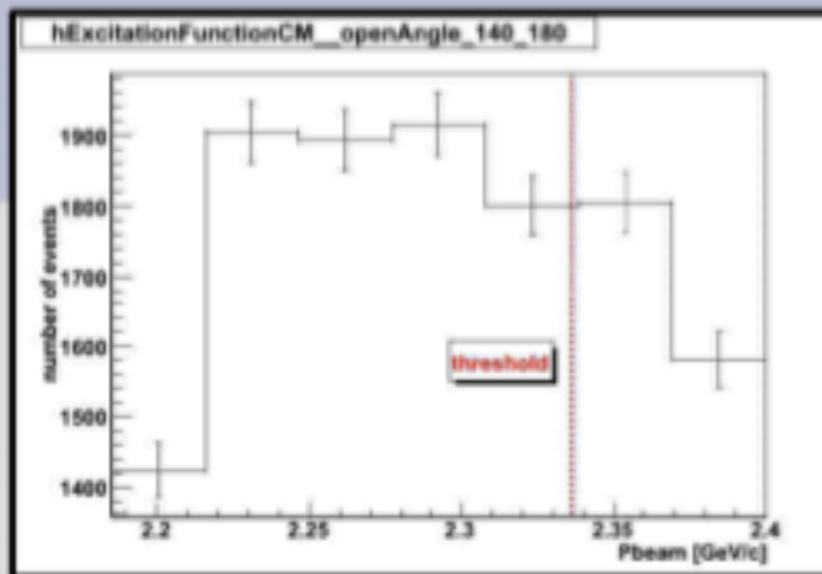
Excitation functions (before Ekin cut)

Opening angle



Excitation function example

PRELIMINARY

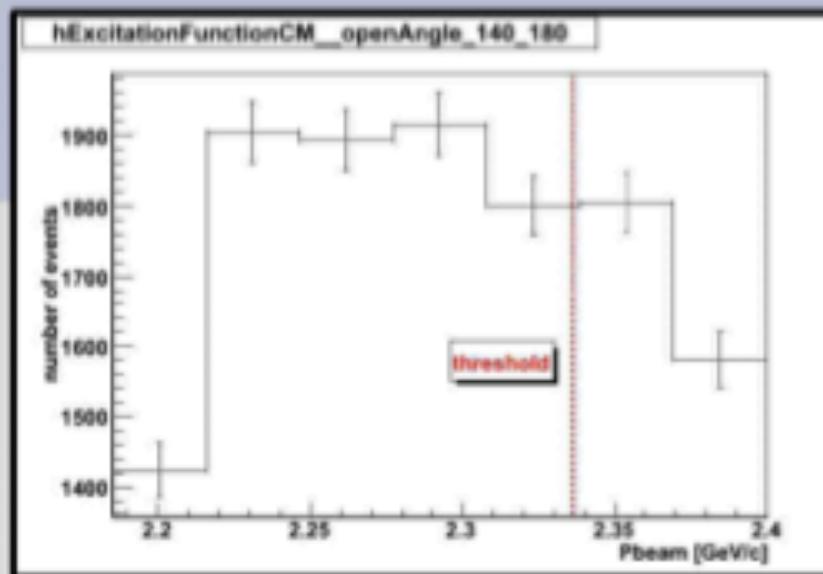


Q=-51.4 MeV

Q=22 MeV

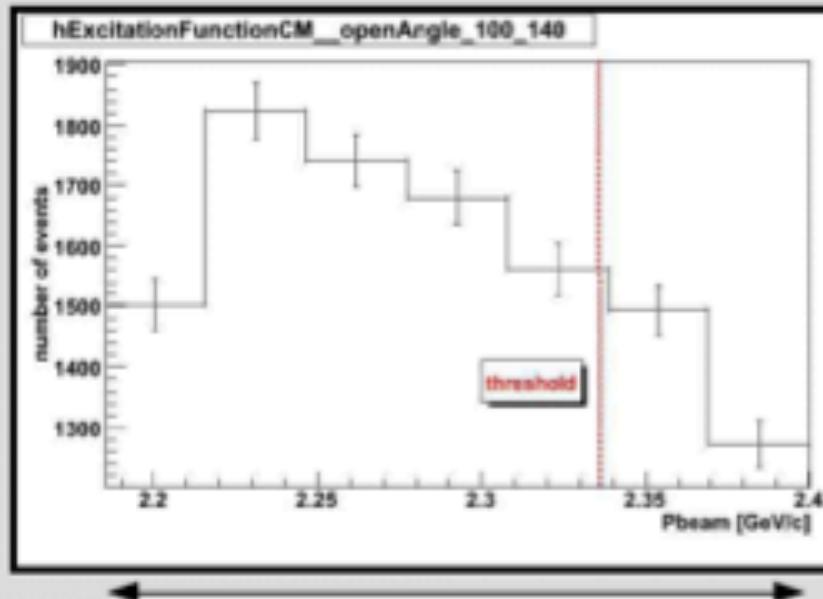
Excitation function example

PRELIMINARY



PRELIMINARY

Upper limit 20 nb
PRELIMINARY

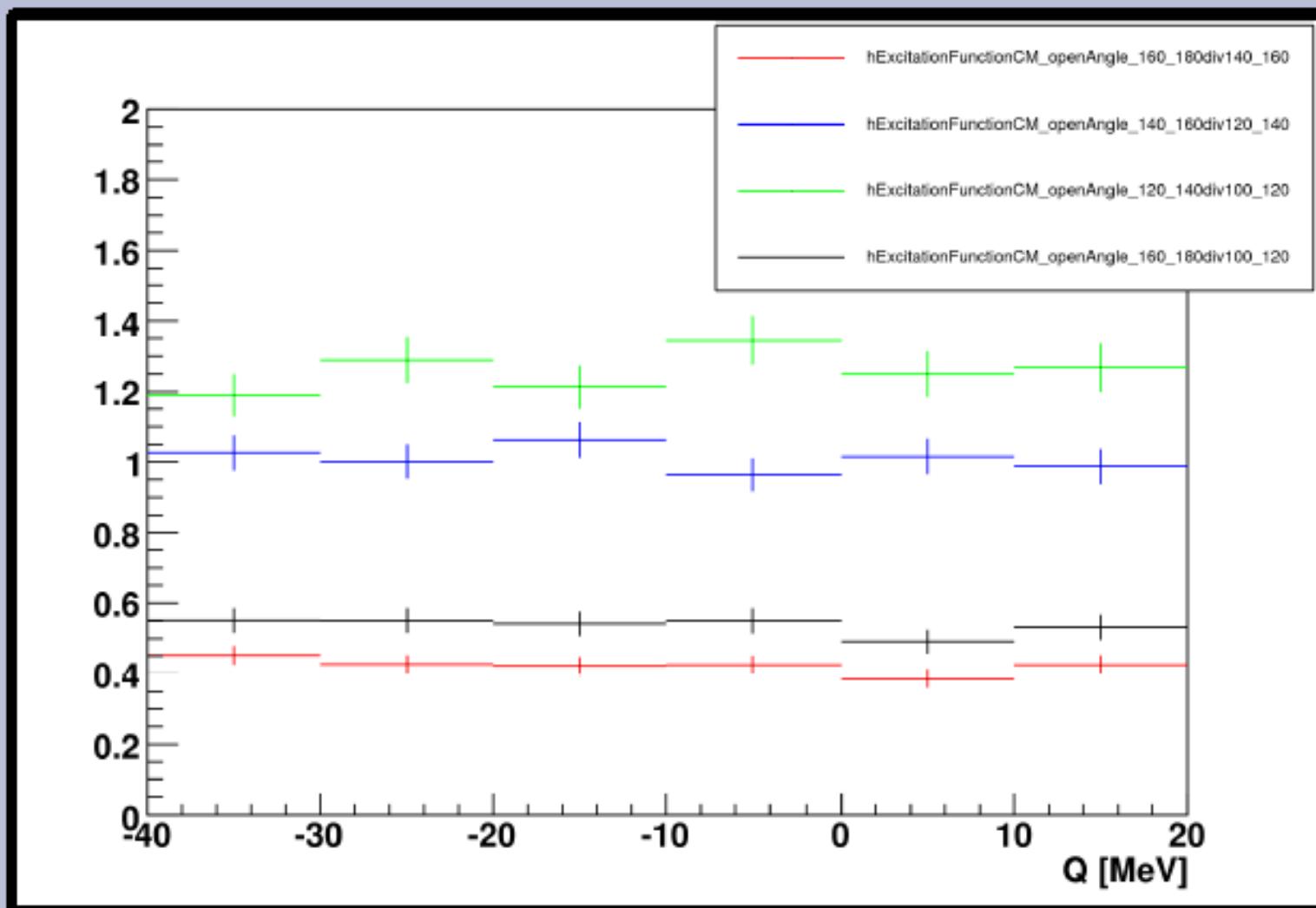


Q=-51.4 MeV

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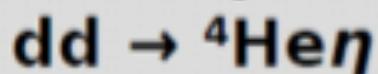
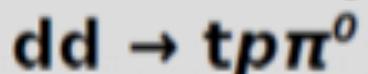
Excitation functions (after Ekin cut)

Opening angle (divided)



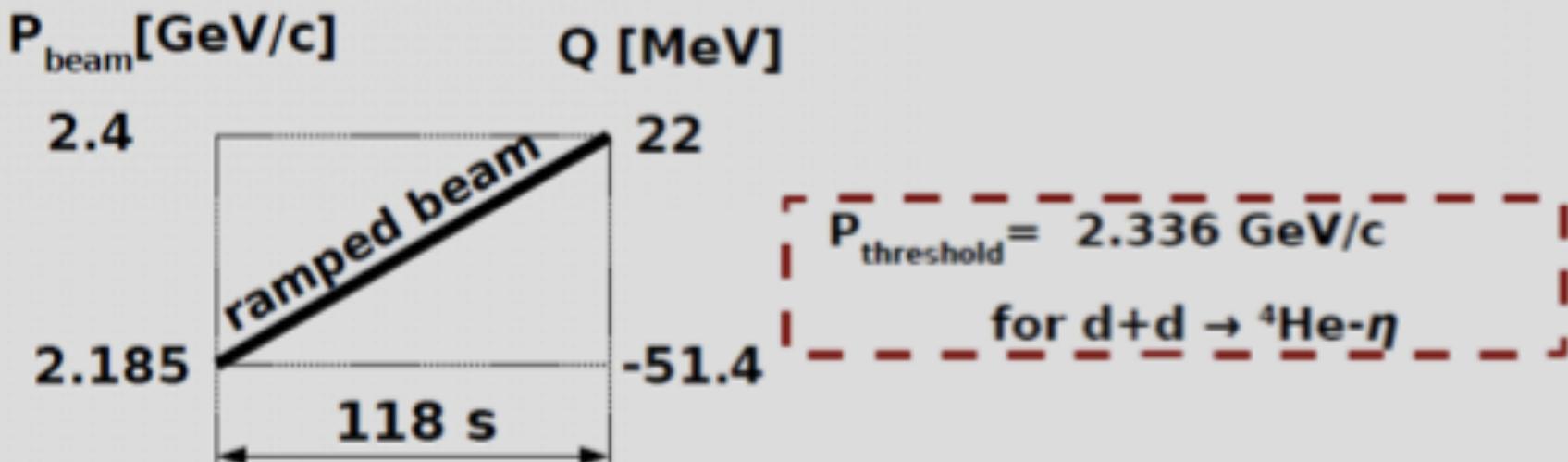
First measurement in June 2008

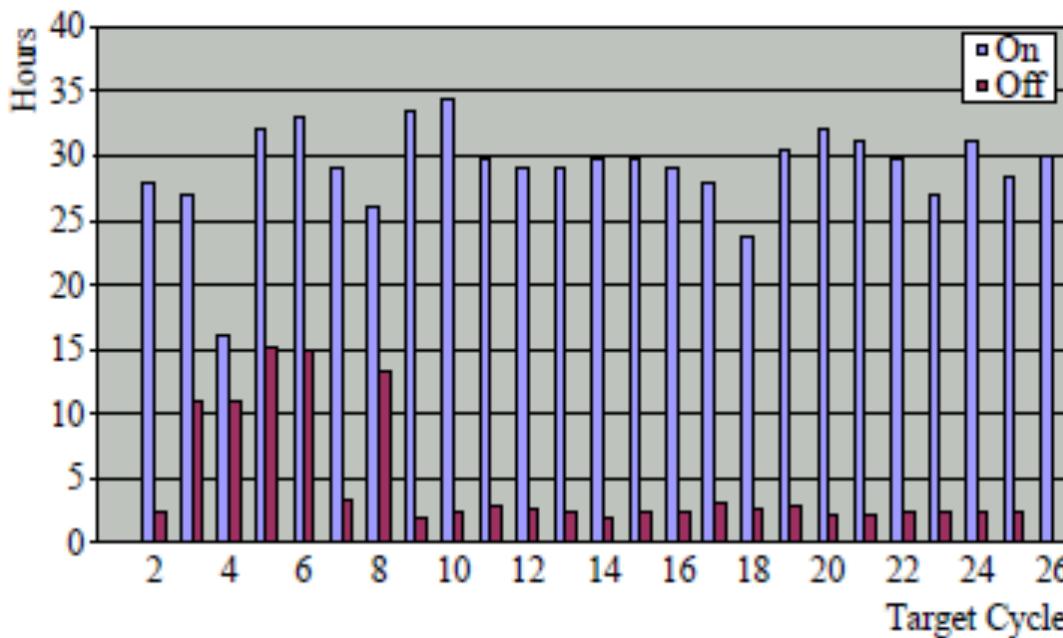
Main channels:



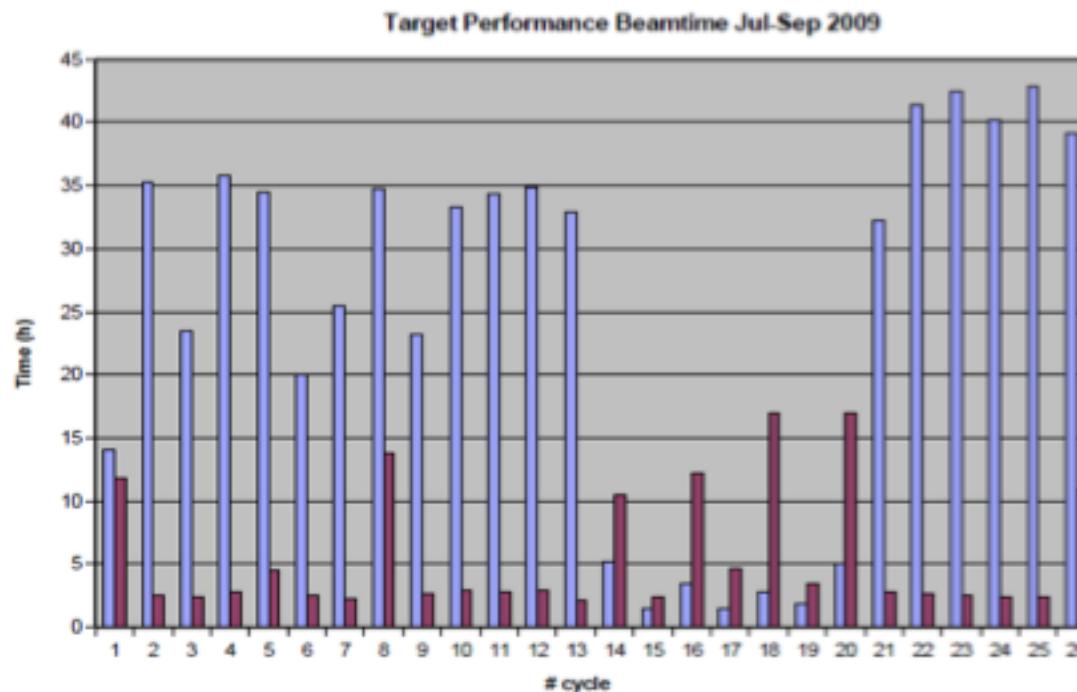
Time:

- About 1 day of data taking
- Luminosity: $\sim 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$





2008



2009

Some facts about η

- simple quantum mechanical characterization: all important quantum numbers zero:
spin, isospin, electric charge, strangeness, charm, baryon and lepton number
parity: $P |\eta\rangle = -1 |\eta\rangle$
charge conjugation: $C |\eta\rangle = +1 |\eta\rangle$
- uncomplicated quark structure:

SU(3) singlet and octet representations

$$|\eta_0\rangle = \frac{1}{\sqrt{3}} (u\bar{u} + d\bar{d} + s\bar{s})$$

$$|\eta_8\rangle = \frac{1}{\sqrt{6}} (u\bar{u} + d\bar{d} - 2s\bar{s})$$

isospin eigenstates

$$|\tilde{\pi}^0\rangle = \frac{1}{\sqrt{2}} (u\bar{u} - d\bar{d})$$

$$|\tilde{\eta}\rangle = \cos\theta_{PS} |\eta_8\rangle - \sin\theta_{PS} |\eta_0\rangle$$

$$|\tilde{\eta}'\rangle = \sin\theta_{PS} |\eta_8\rangle - \cos\theta_{PS} |\eta_0\rangle$$

octet-singlet mixing angle $\theta_{PS} = -20^\circ$ (PDG, $P \rightarrow \gamma\gamma$) ($\cos\theta_{PS} \approx 1$, $\sin\theta_{PS} \approx 1/2\sqrt{2}$)

$$|\tilde{\eta}\rangle \approx \frac{1}{\sqrt{3}} (u\bar{u} + d\bar{d} - s\bar{s})$$

Eta bound-states in nuclei

| | m (MeV) | z | m^* (MeV) | $\text{Re}a$ (fm) |
|----------------|-----------|------|-------------|-------------------|
| η_8 | 547.75 | 3.31 | 500.0 | 0.43 |
| η (-10°) | 547.75 | 3.15 | 474.7 | 0.64 |
| η (-20°) | 547.75 | 3.00 | 449.3 | 0.85 |
| η_0 | 958 | 1.46 | 878.6 | 0.99 |
| η' (-10°) | 958 | 1.62 | 899.2 | 0.74 |
| η' (-20°) | 958 | 1.76 | 921.3 | 0.47 |

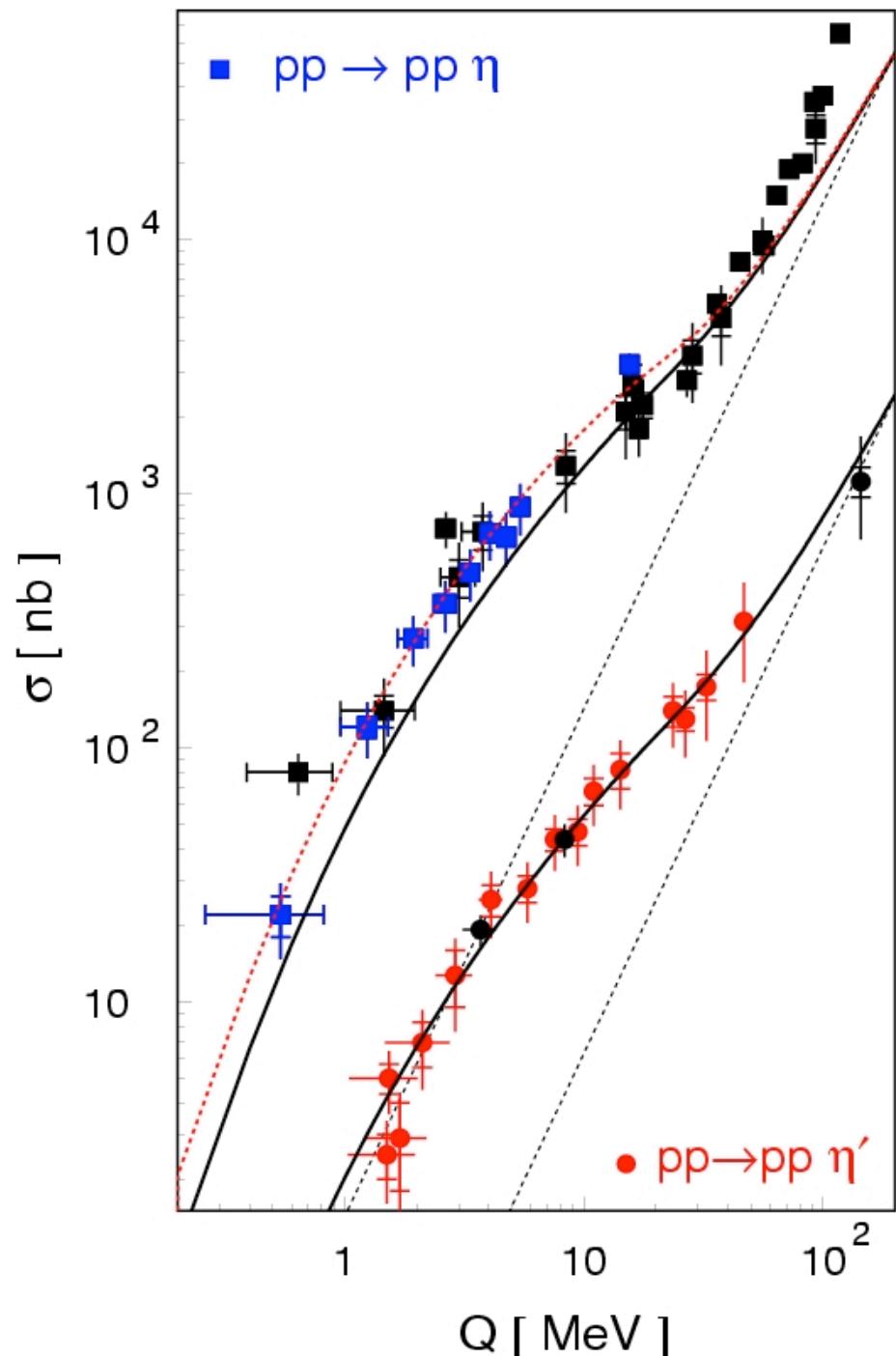
- Sigma mean field couples to light quarks and not to strange quarks
→ Flavour-singlet component is important !
The bigger the eta-eta' mixing angle, the bigger the singlet component in the eta
→ greater the attraction
→ more binding
→ bigger eta-N scattering length

SD Bass, AW Thomas, hep-ph/0507024

$$\frac{\text{BR}(\varphi \rightarrow \eta \gamma)}{\text{BR}(\varphi \rightarrow \eta' \gamma)} \sim= 200$$

$$\frac{\sigma(pp \rightarrow pp\eta)}{\sigma(pp \rightarrow pp\eta')} \sim= 30$$

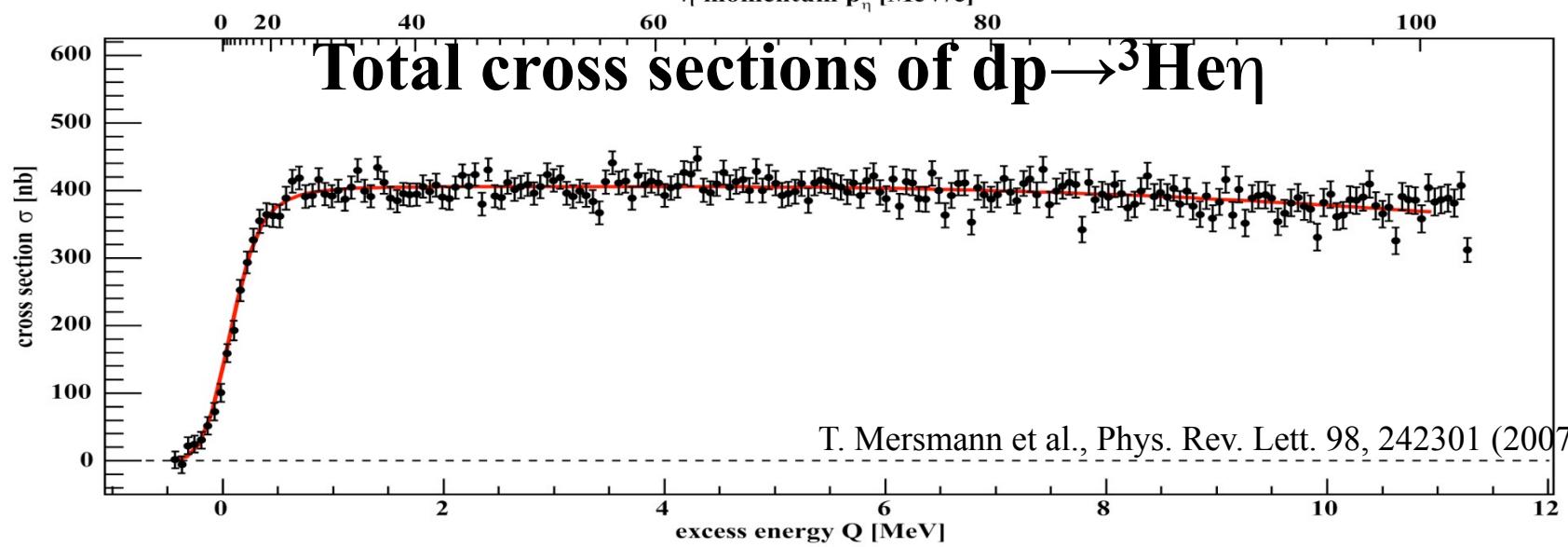
$$\frac{\sigma(pp \rightarrow pp\eta)}{\sigma(pp \rightarrow {}^3\text{He}\eta)} \sim= 20$$



$$\frac{\text{BR}(\phi \rightarrow \eta \gamma)}{\text{BR}(\phi \rightarrow \eta' \gamma)} \approx 200$$

$$\frac{\sigma(pp \rightarrow pp\eta)}{\sigma(pp \rightarrow pp\eta')} \approx 30$$

$$\frac{\sigma(pp \rightarrow pp\eta)}{\sigma(pp \rightarrow {}^3\text{He}\eta)} \approx 20$$



T. Mersmann et al., Phys. Rev. Lett. 98, 242301 (2007)

