Search for Exotic Matter at COSY

Paweł Moskal

Jagiellonian University, Cracow, Poland

Zakopane, 12th of February 2009

ETA-MESIC HELIUM ???

GLUONIC MATTER IN ETA-PRIME ???

KAON-ANTIKAON MOLECULES ???

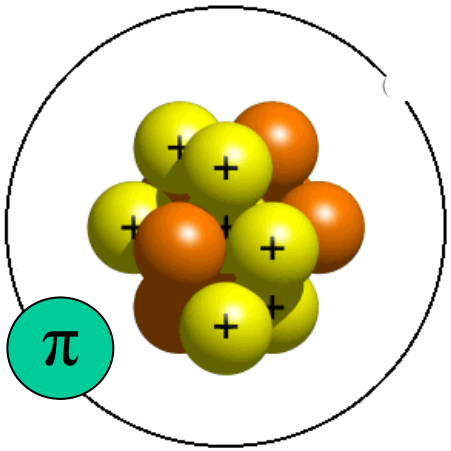
COSY

WASA-at-COSY

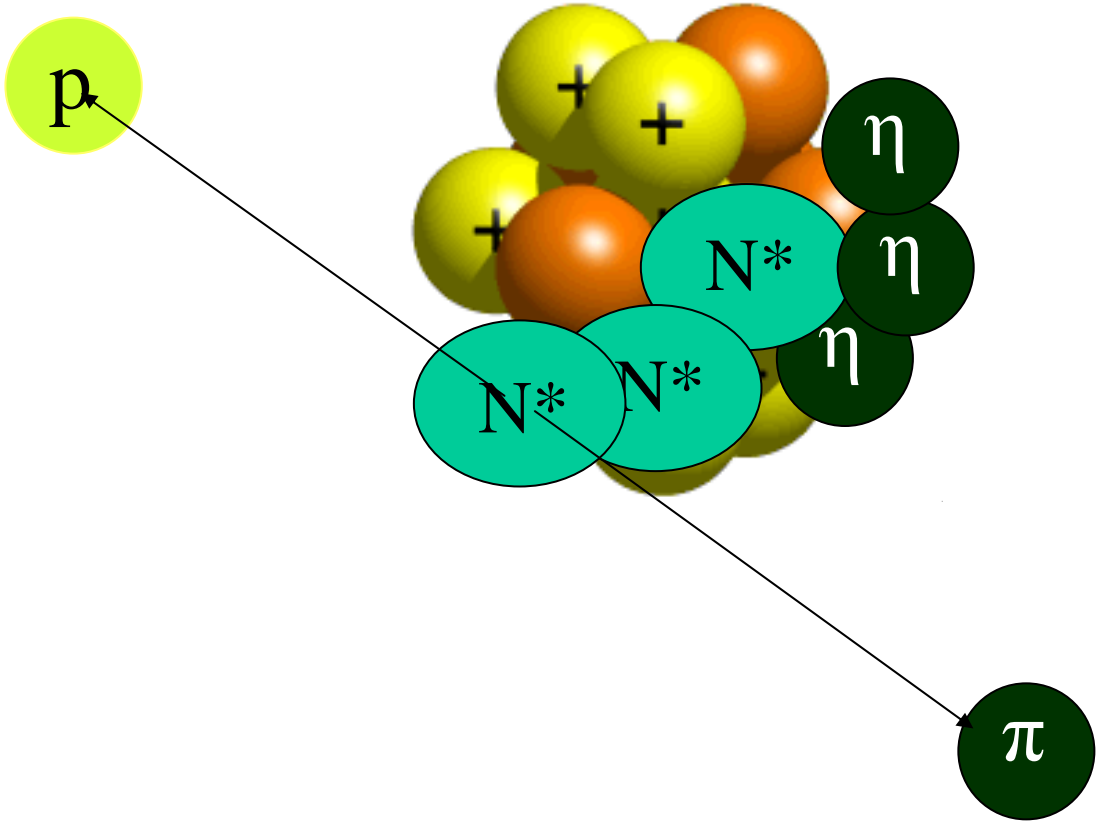
COSY-11

ETA-MESIC NUCLEUS

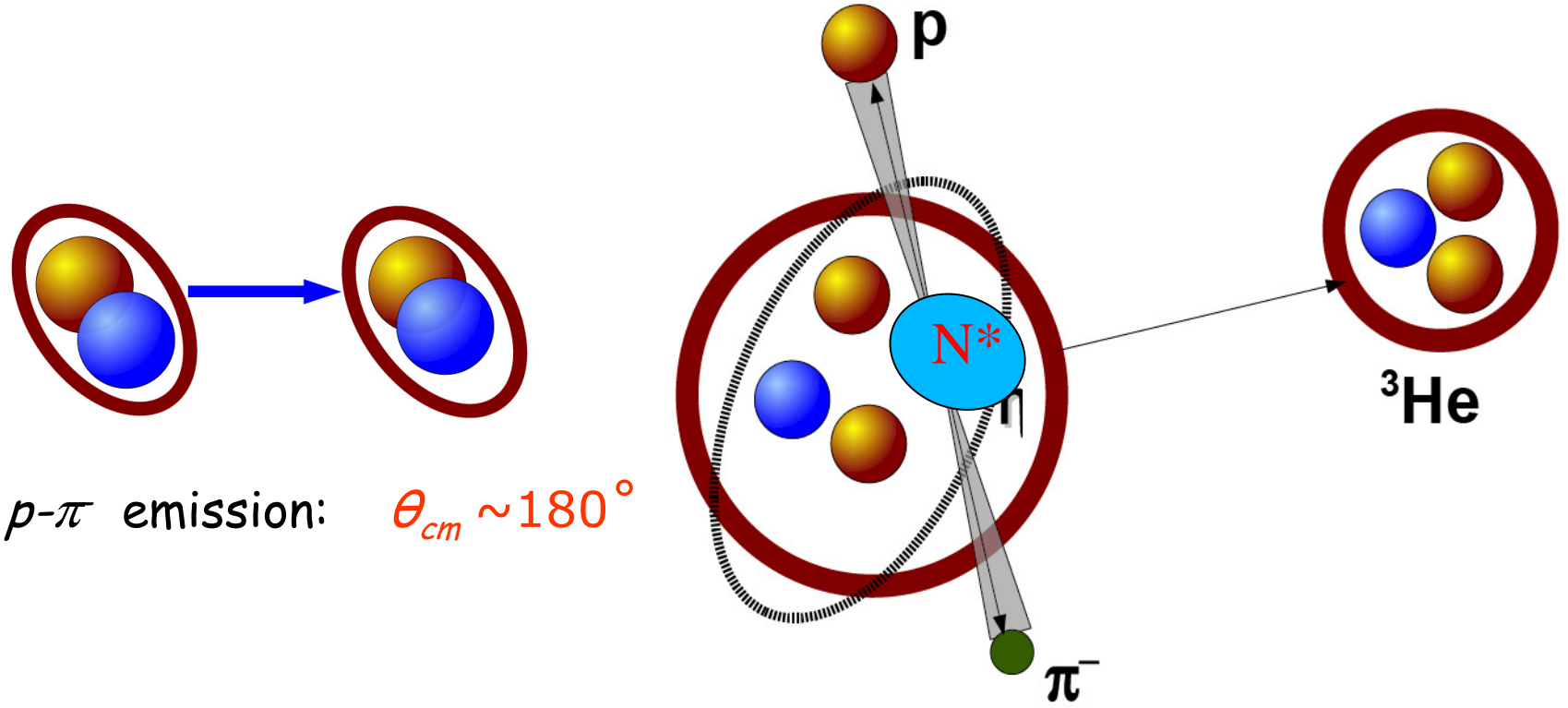
It is not an atom or mesonic atom



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



$$d+d \rightarrow (^4He\text{-}\eta)_{bound} \rightarrow X + p + \pi^-$$



p-π emission: $\theta_{cm} \sim 180^\circ$

Measurement of the excitation function

$d+d \rightarrow (^4He\text{-}\eta)_{bound} \rightarrow p + \pi^- + {}^3He$

search for a resonance structure with center below the eta threshold

T. Inoue, E. Oset, Nucl. Phys. A 710 (2002) 354.

Unique 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)	Rea (fm)
η_8	547.75	0.43
η (-10°)	547.75	0.64
η (-20°)	547.75	0.85
η_0	958	0.99
η' (-10°)	958	0.74
η' (-20°)	958	0.47

S. D. Bass, A. W. Thomas, Phys. Lett. B 634 (2006) 368.

Attractive interaction between η and N

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

⬇

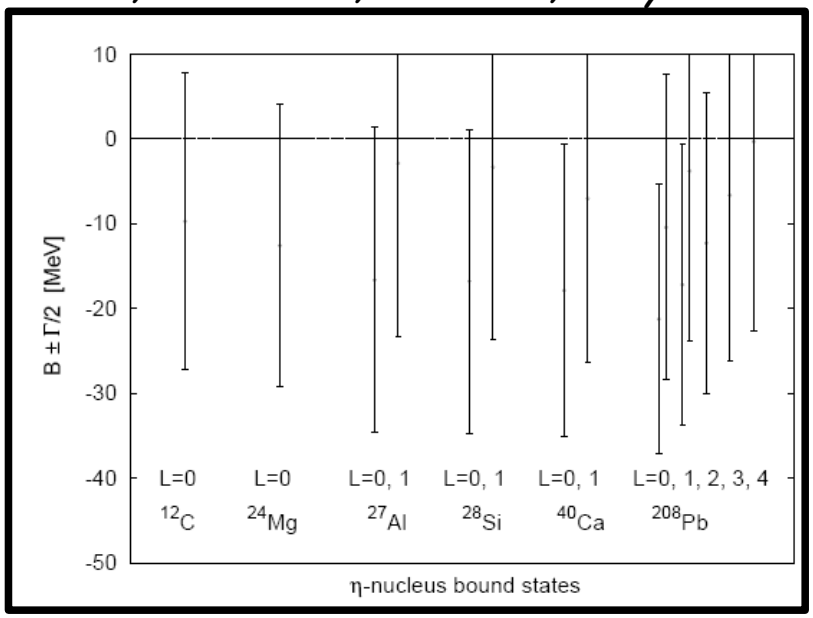
possible existence of bound states
of the η meson with nuclei for A>10

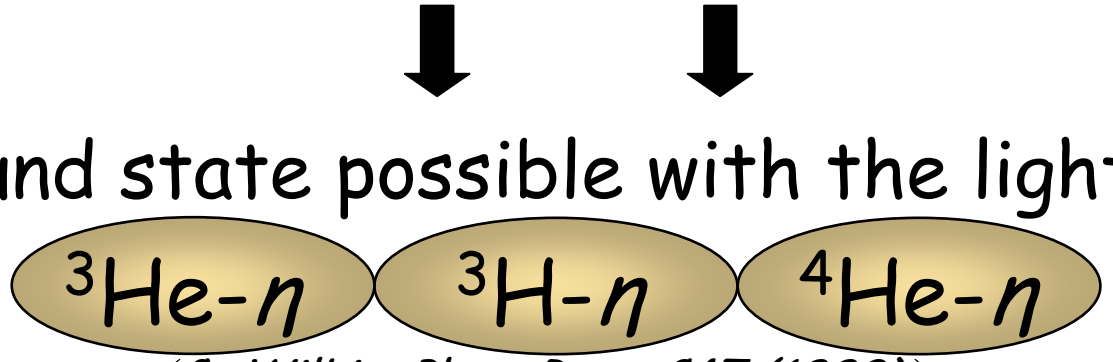
(*Q. Haider and L. C. Liu, Phys. Lett. B172 (1986) 257*)

⬇

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).





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)

and by observations of:

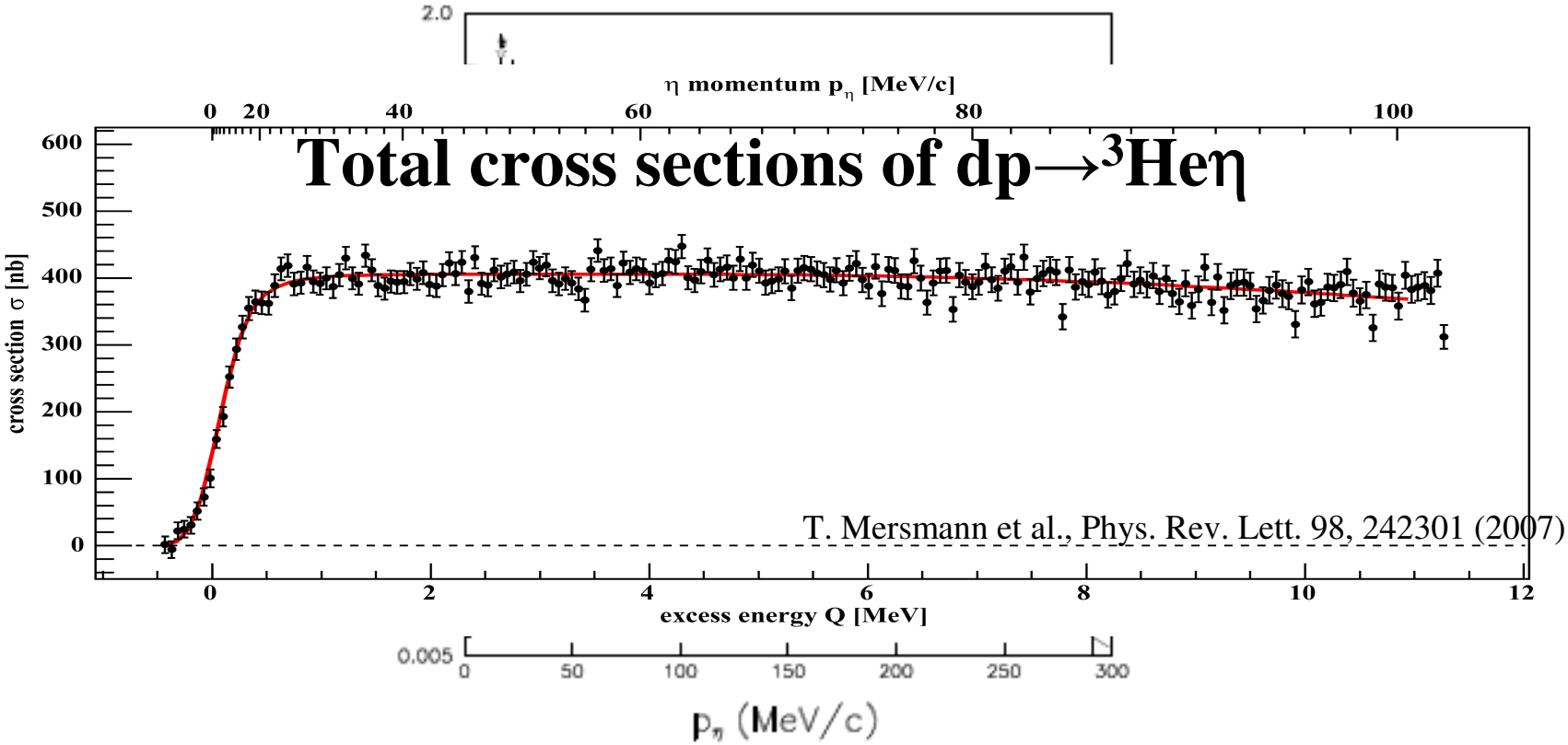
- near threshold enhancements of the amplitudes for the

$dd \rightarrow {}^4\mathrm{He}\ \eta$ and $pd \rightarrow {}^3\mathrm{He}\ \eta$ reactions

(N. Willis et al.., Phys. Lett. B406(1997)14)

η - ^{3}He

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



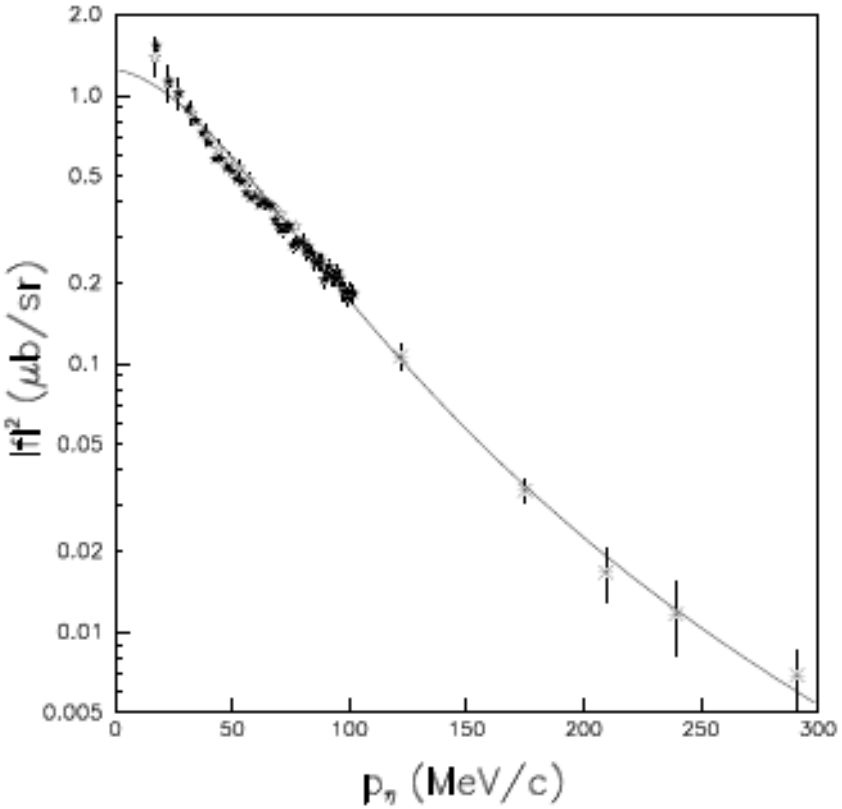
ANKE: T. Mersmann et al., Phys. Rev. Lett. **98** 242301 (2007)

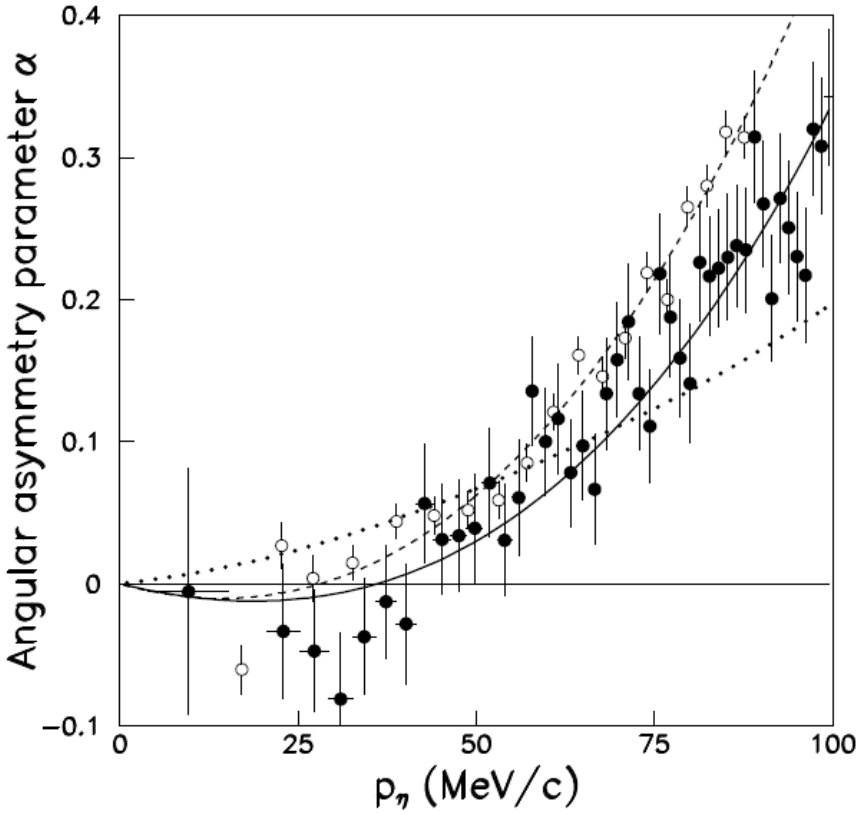
COSY-11: J. Smyrski et al., Phys. Lett **B 649** 258-262 (2007)

η - ^{3}He

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

C.Wilkin et al., Phys. Lett. B654 (2007) 92





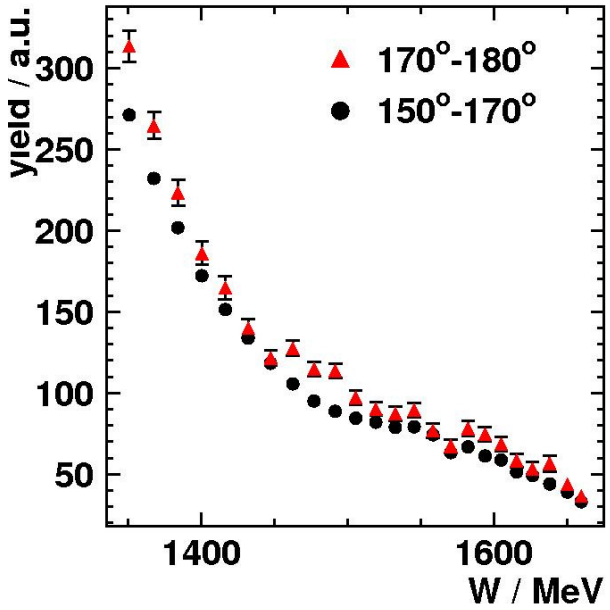
ANKE: T. Mersmann et al., Phys. Rev. Lett. **98** 242301 (2007)

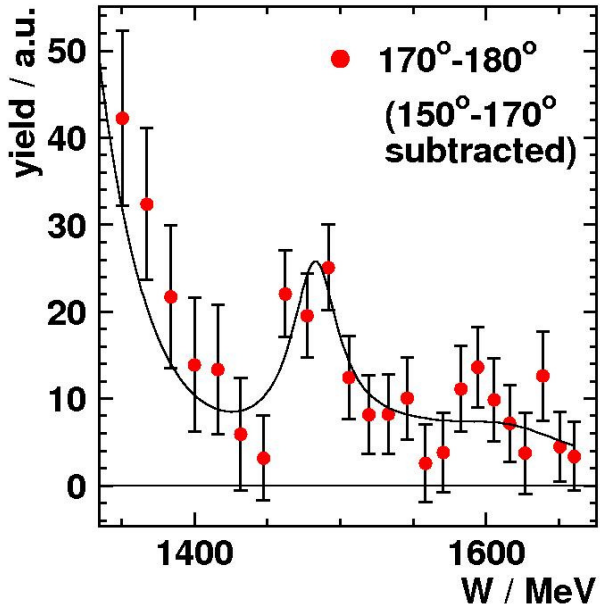
COSY-11: J. Smyrski et al., Phys. Lett **B 649** 258-262 (2007)

γ 3He $\rightarrow p\pi^0$ X

TAPS at MAMI

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

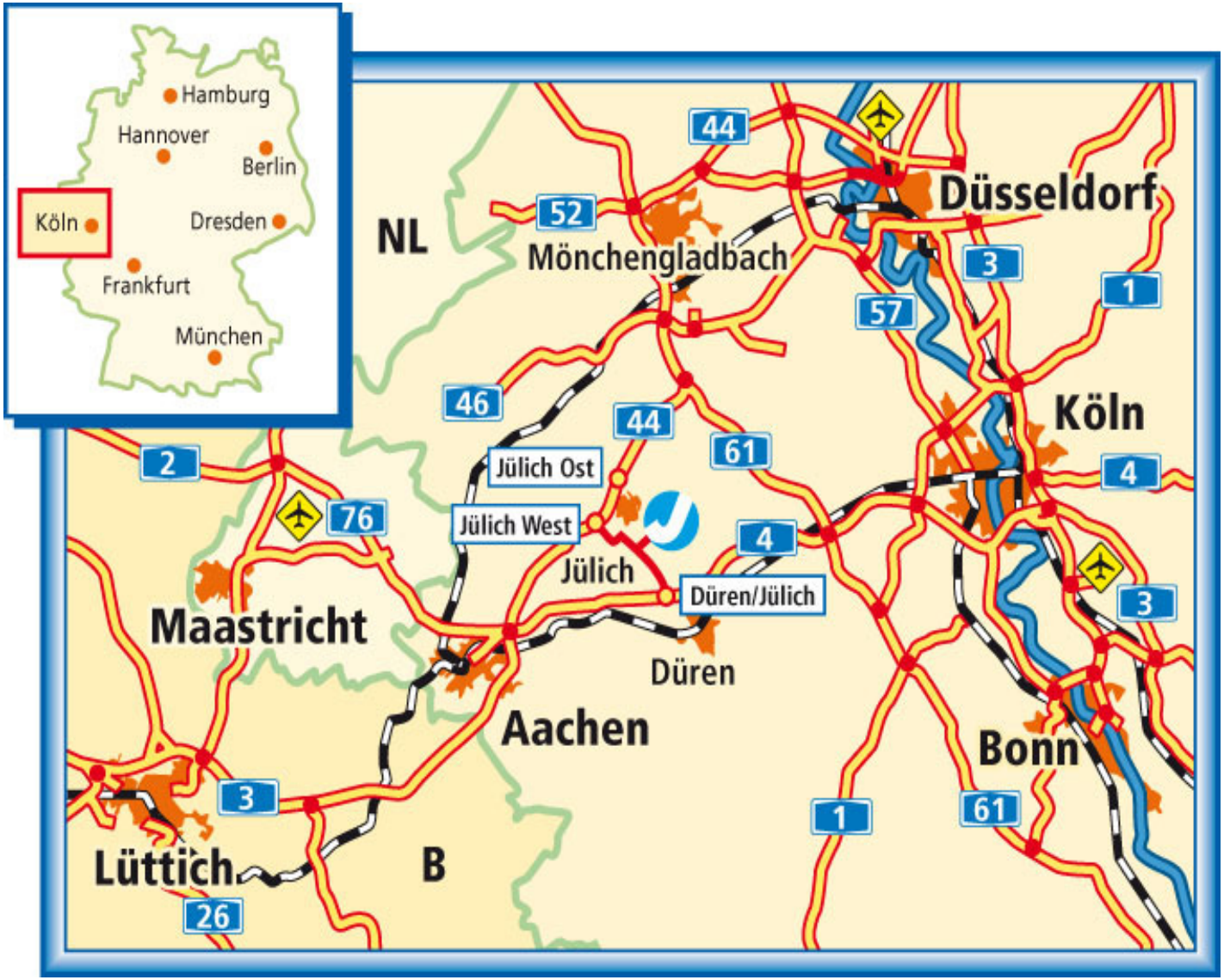


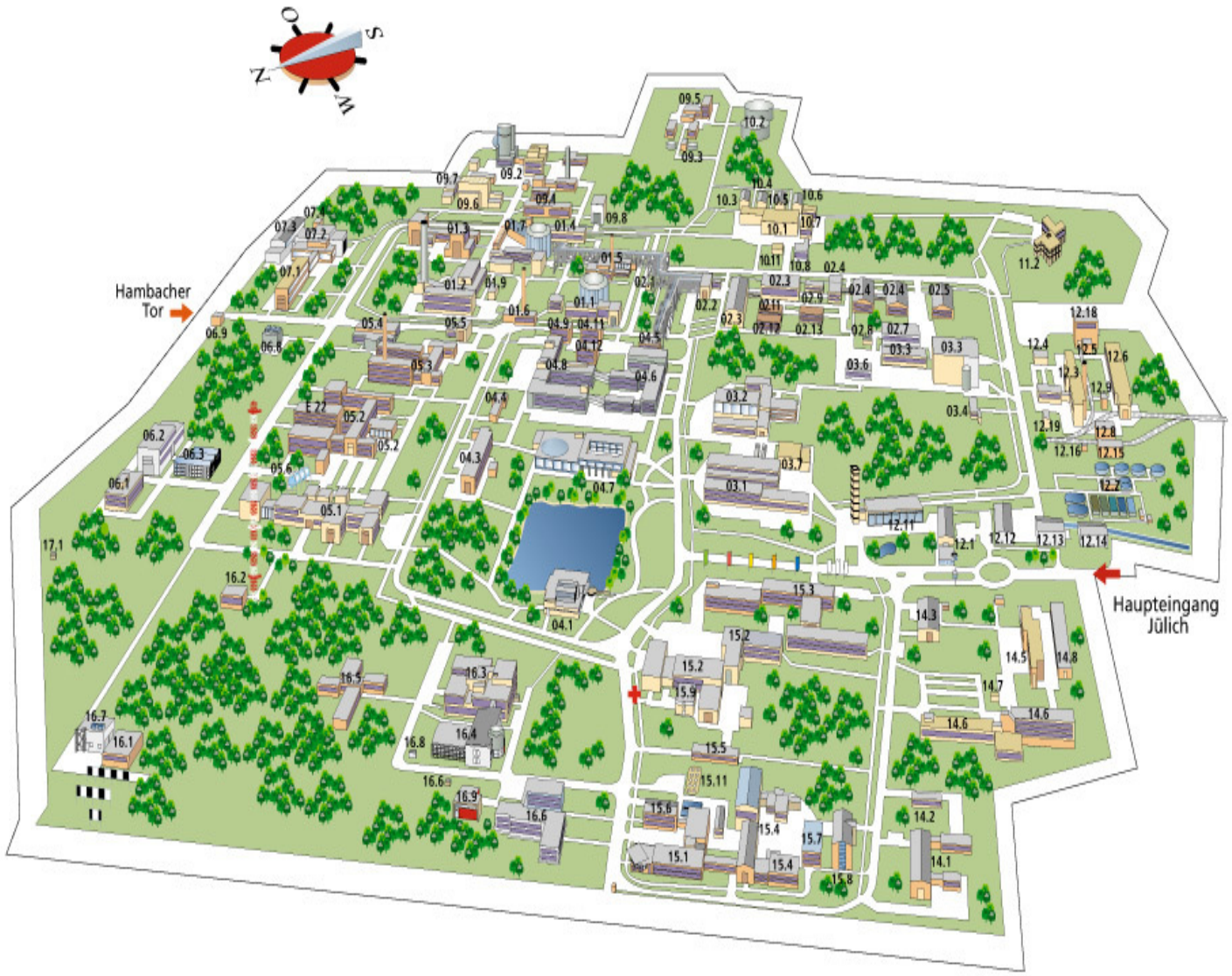


Binding energy:(-4.4 ± 4.2) MeV
Width: 25.6 ± 6.1 MeV

signal: σ ≈ 0.8 μb (3σ above background)

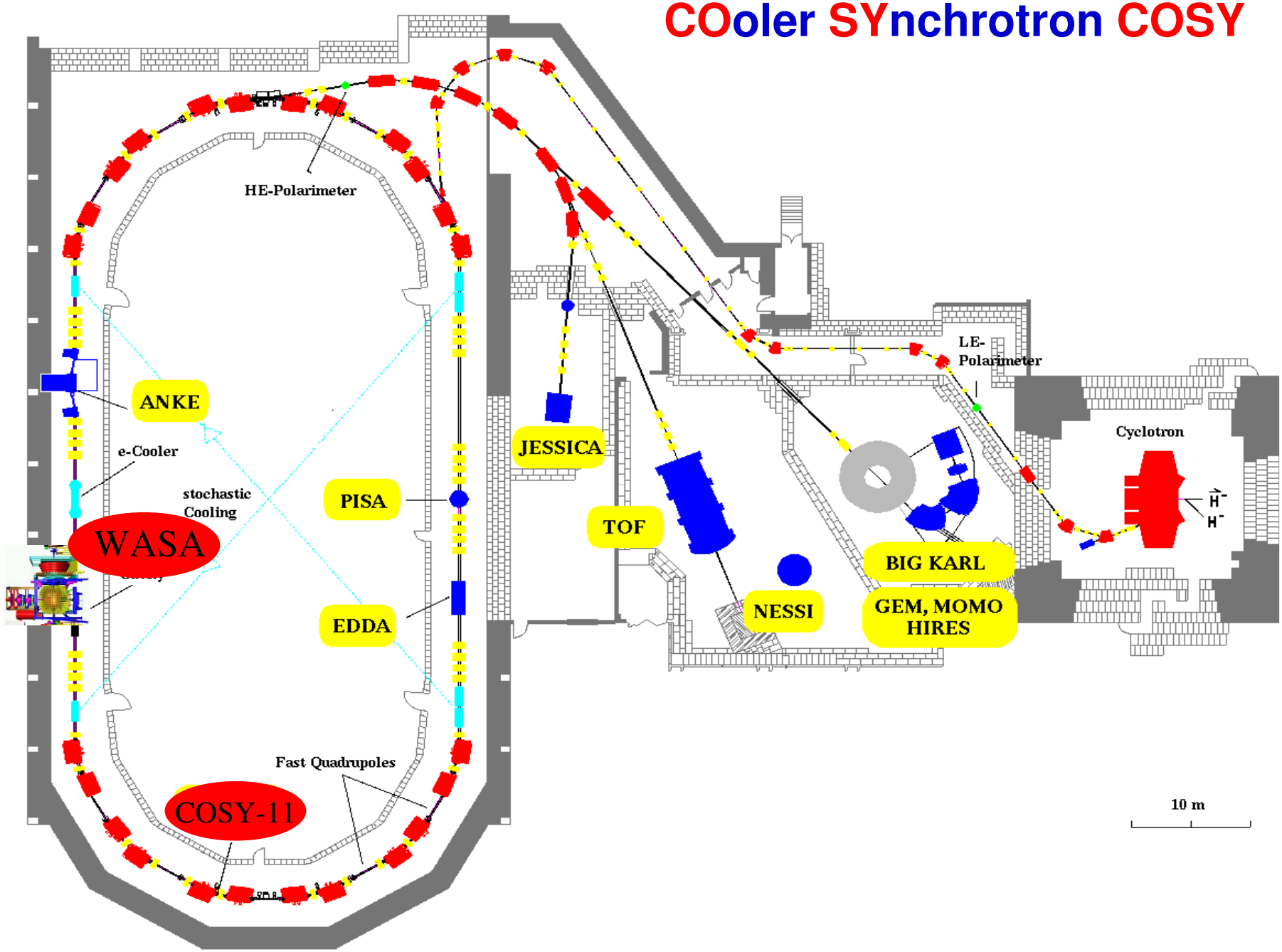
background 3 μb


Hamburg
Hannover
Berlin
Köln
Dresden
Frankfurt
München
NL
Mönchengladbach
Düsseldorf
Köln
Bonn
Jülich Ost
Jülich West
Jülich
Düren/Jülich
Düren
Maastricht
Aachen
Lüttich
B
44
52
46
44
61
57
3
1
4
2
76
4
3
1
61
26



Peter Grünberg, Nobel Prize 2007

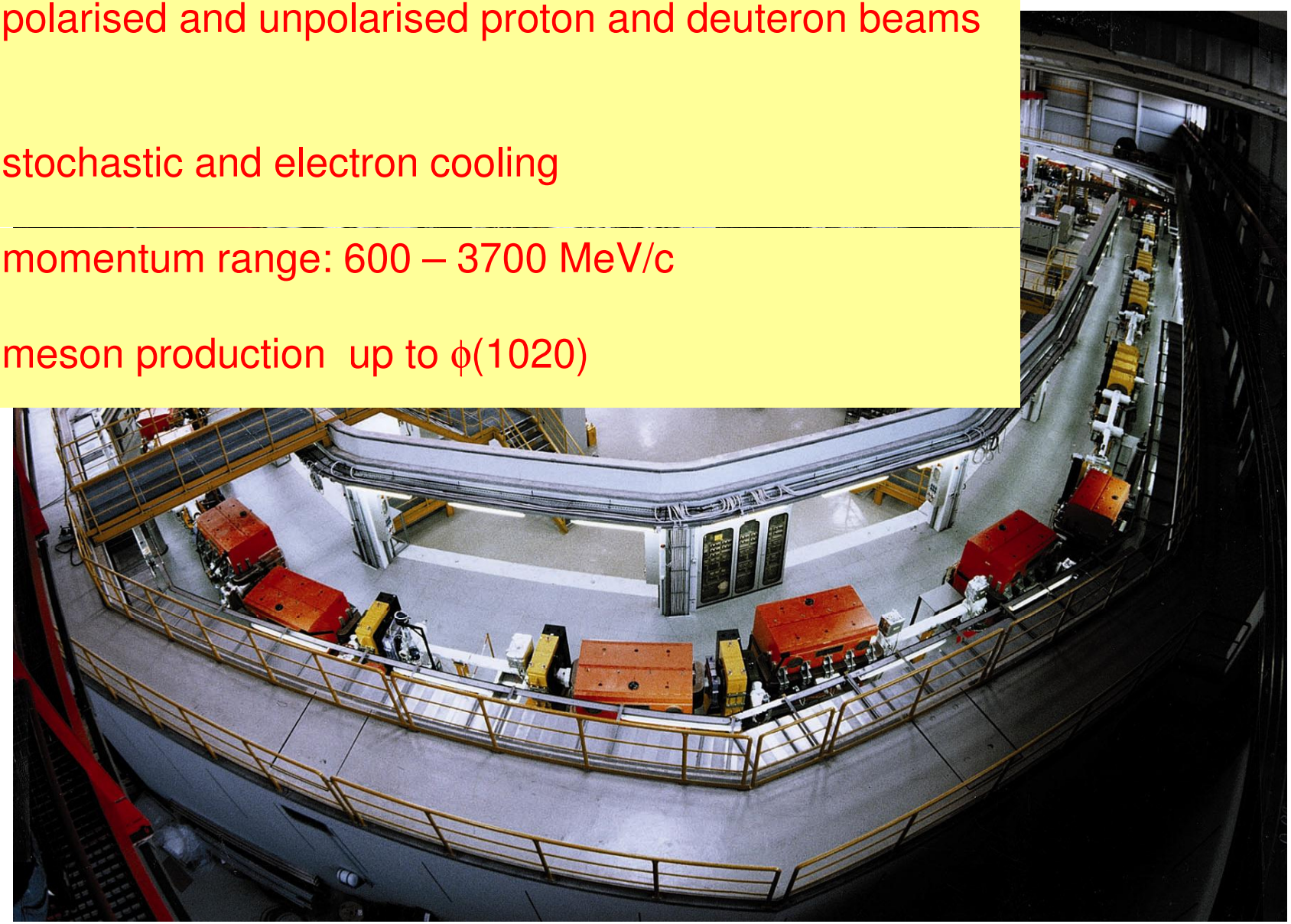
COoler SYnchrotron COSY

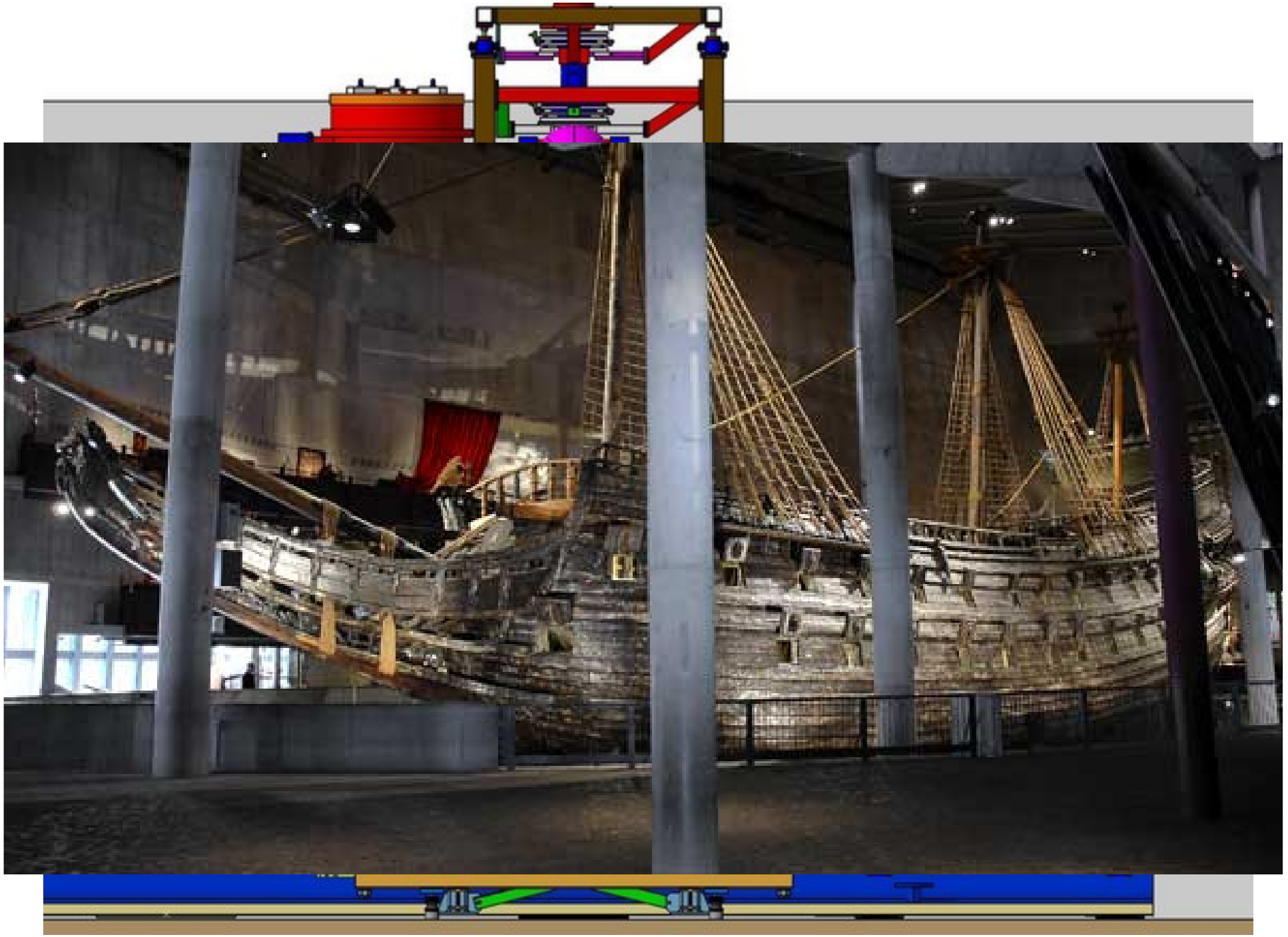


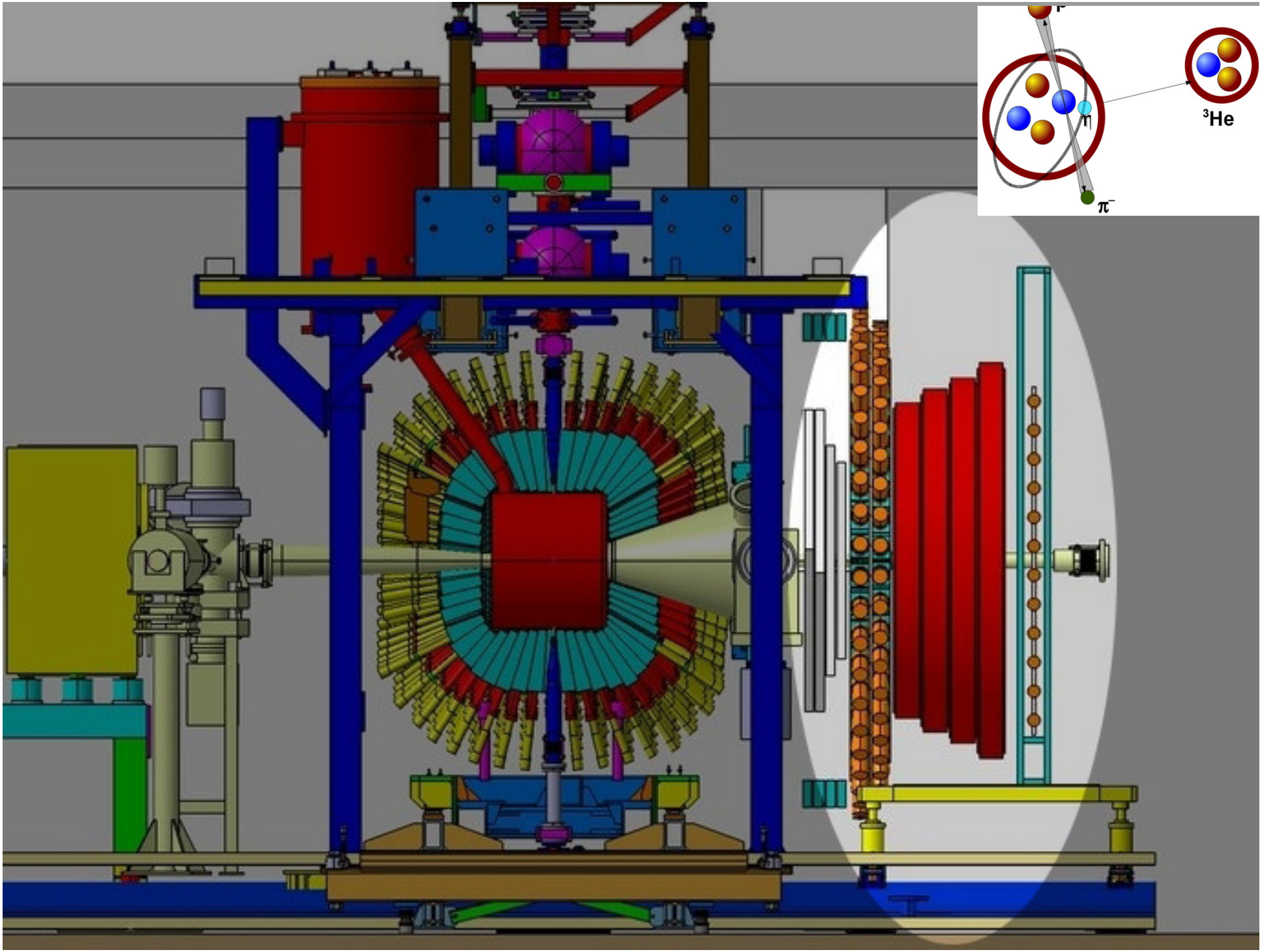
COoler SYnchrotron COSY

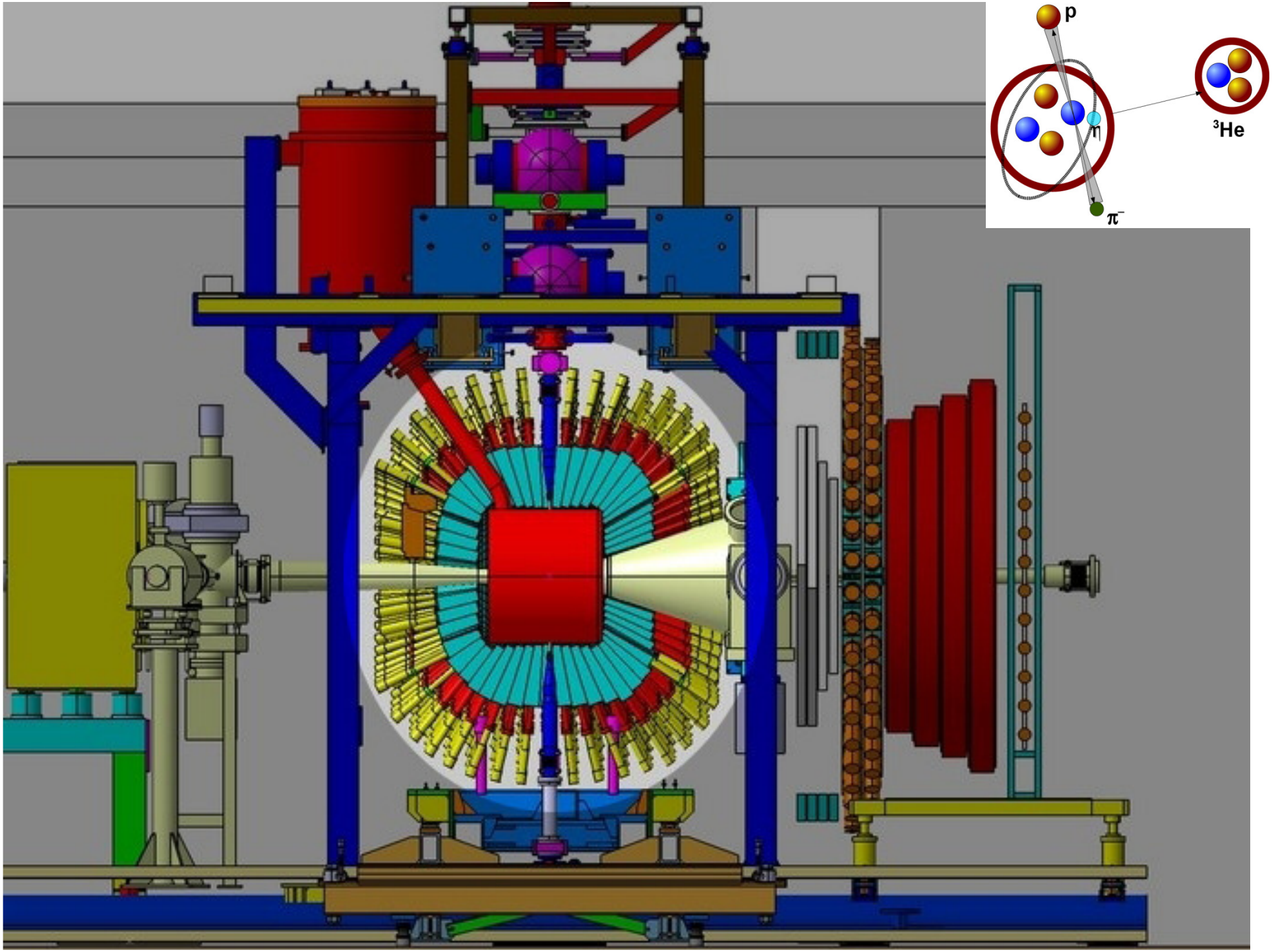
- polarised and unpolarised proton and deuteron beams
- stochastic and electron cooling

- momentum range: 600 – 3700 MeV/c
- meson production up to $\phi(1020)$



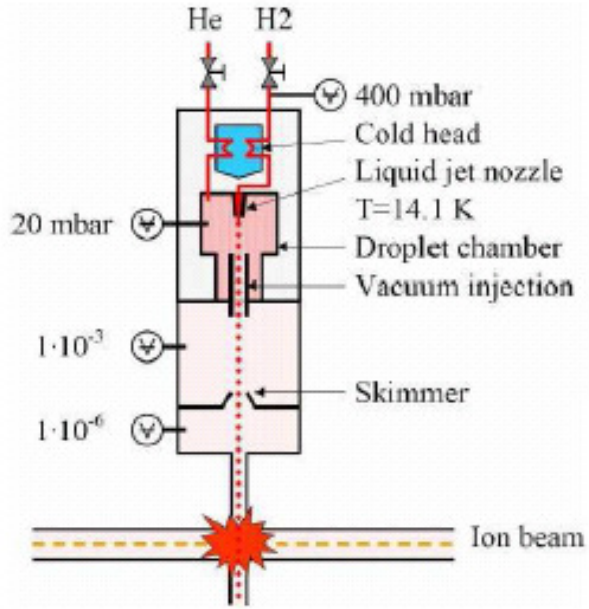



η
^{3}He
π^-

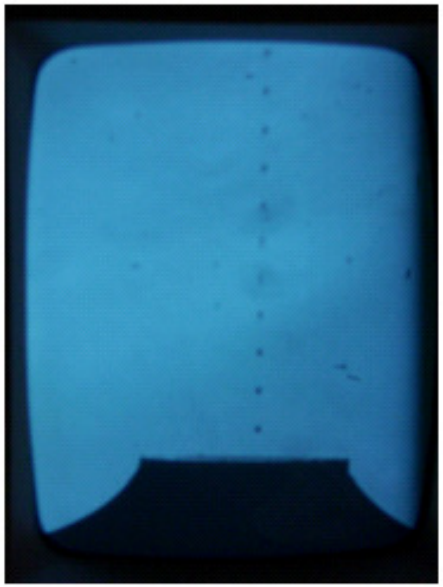

p
η
^{3}He
π⁻

WASA at COSY — Pellet Target Operation

The Pellet Target

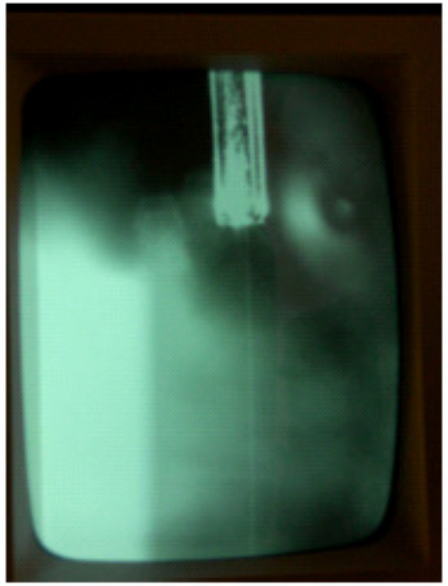


vacuum injection



droplet formation chamber

exit vacuum injection



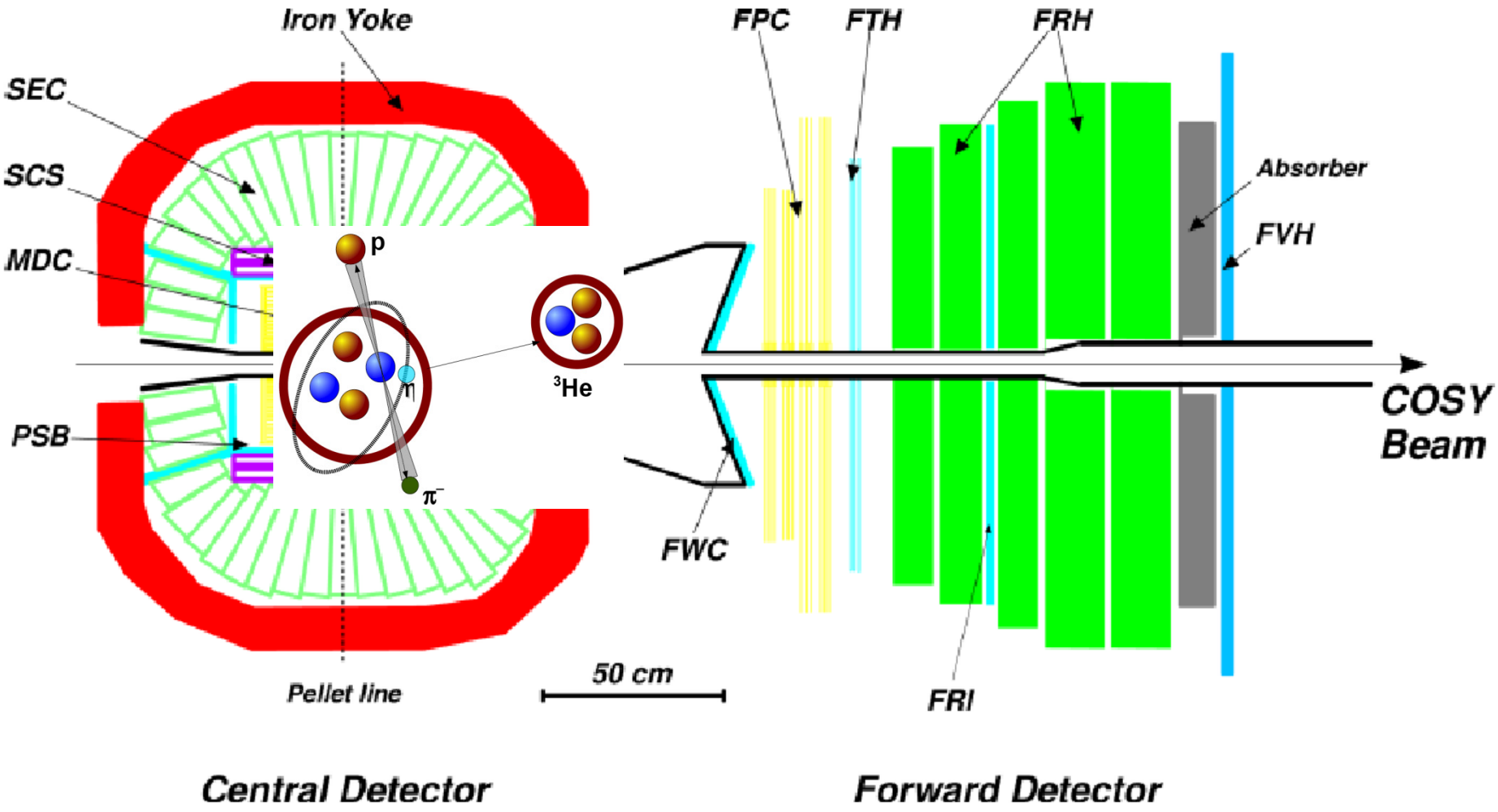
skimmer

Typical Target Values:

llet diameter	20 - 30 µm
llet frequency	5 - 12 kHz
llet velocity	60 - 80 m/s
fective thickness	$>10^{15}$ atoms/cm^2

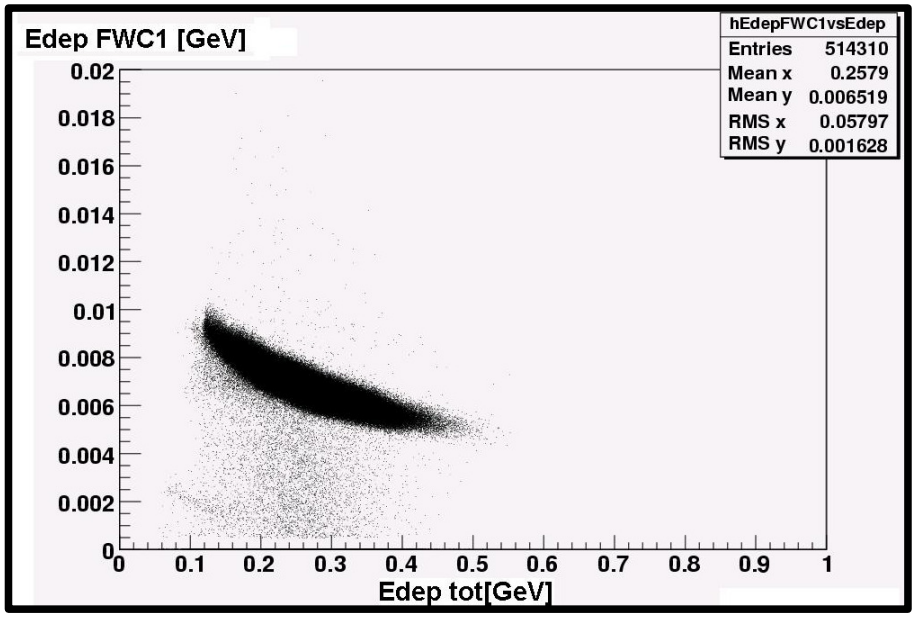
WASA-at-COSY

$d+d \rightarrow (^4He\text{-}\eta)_{bound} \rightarrow p + \pi^- + {}^3He$



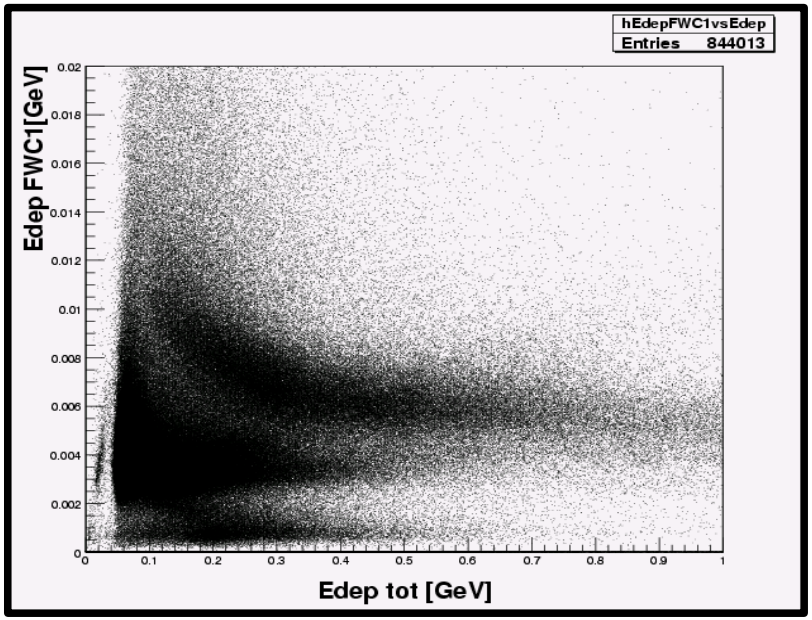
Helium in FD

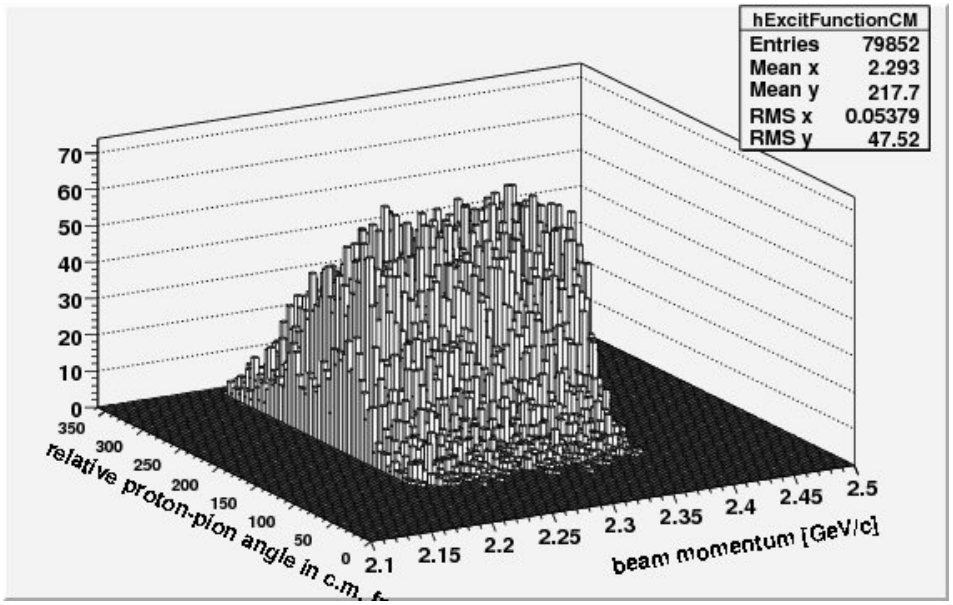
Monte Carlo

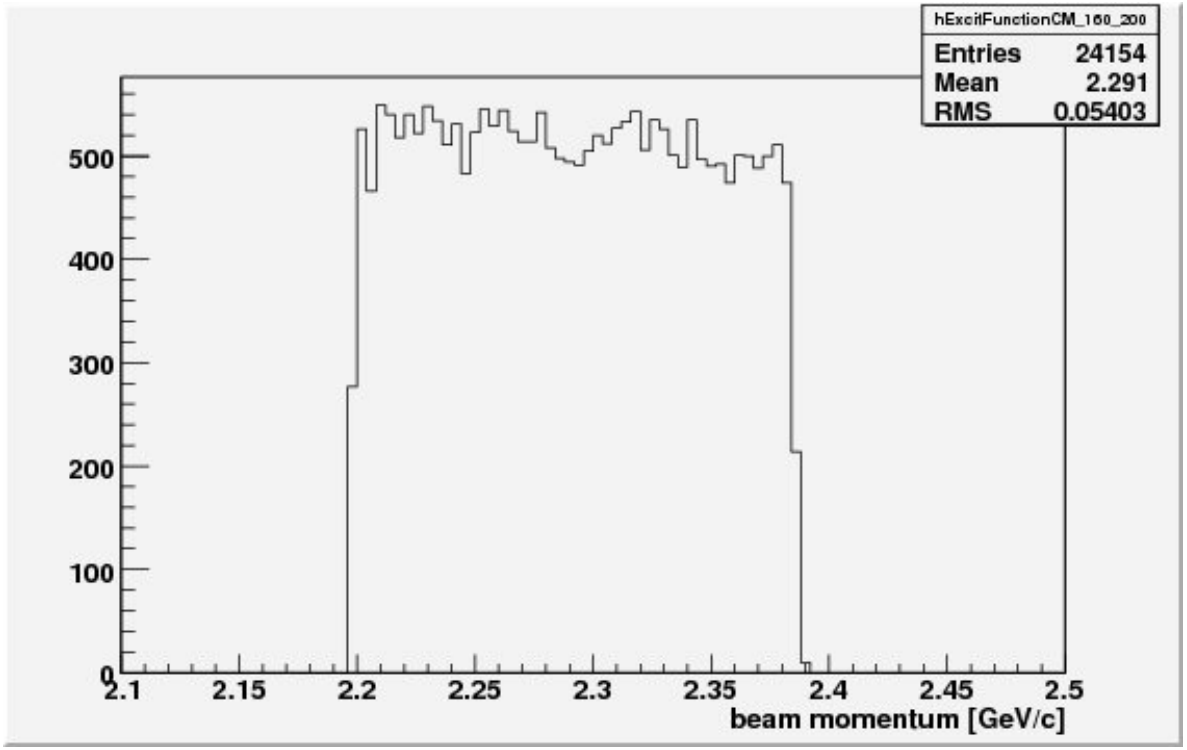


only helium

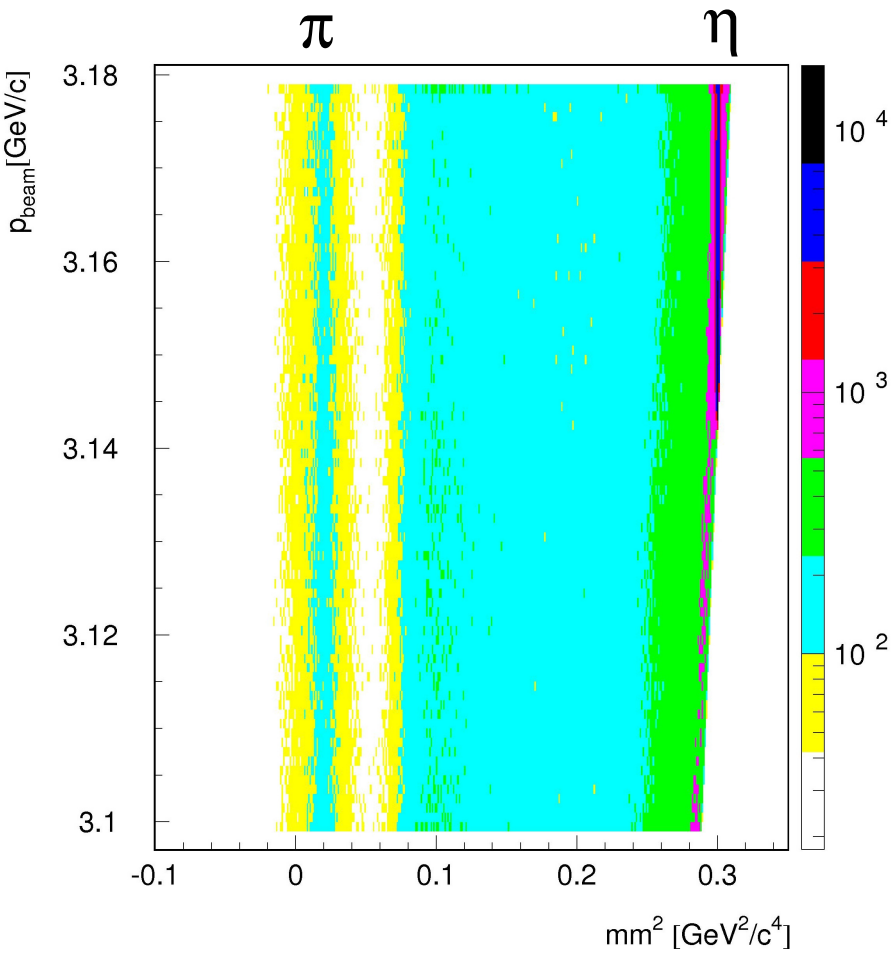
Data

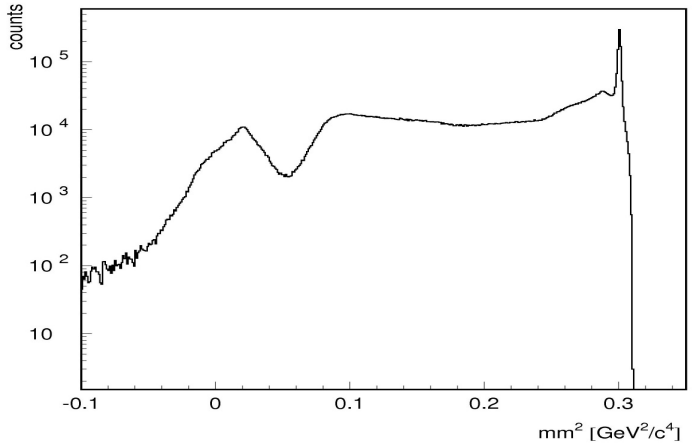



hExcitFunctionCM
Entries 79852
Mean x 2.293
Mean y 217.7
RMS x 0.05379
RMS y 47.52
70
60
50
40
30
20
10
0
350
300
250
200
150
100
50
0
relative proton-pion angle in c.m. f
2.1
2.15
2.2
2.25
2.3
2.35
2.4
2.45
2.5
beam momentum [GeV/c]

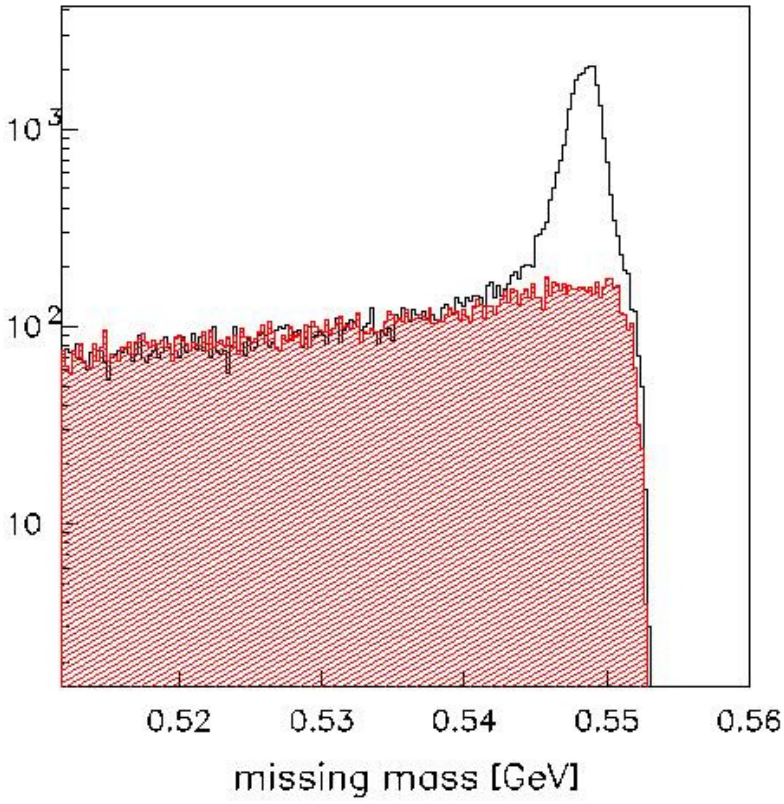

hExcitFunctionCM_160_200
Entries 24154
Mean 2.291
RMS 0.05403
500
400
300
200
100
0
2.1
2.15
2.2
2.25
2.3
2.35
2.4
2.45
2.5
beam momentum [GeV/c]

Missing mass COSY-11





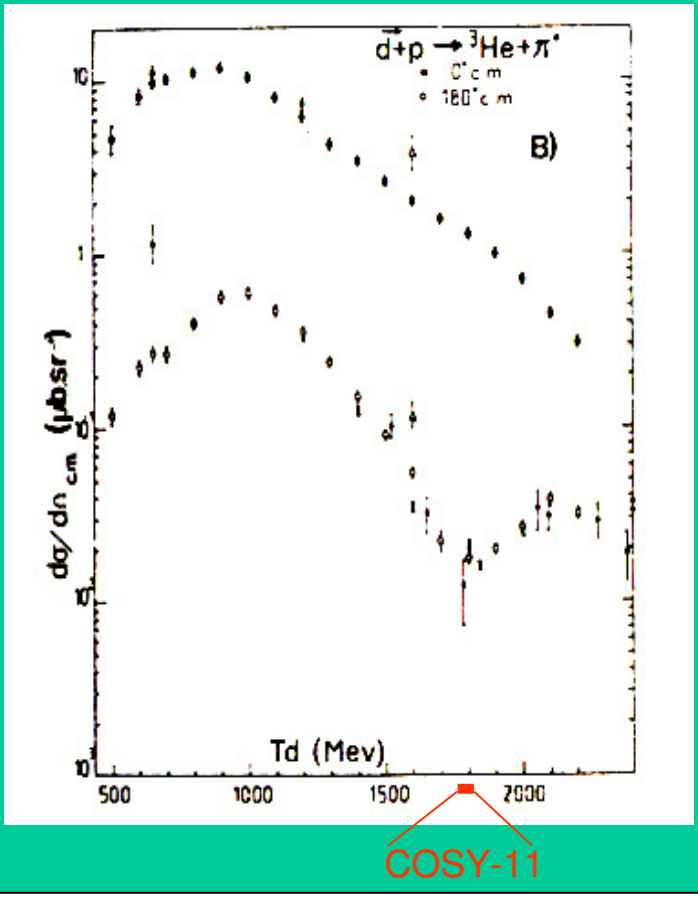
3.166 GeV/c < p_{beam} < 3.170 GeV/c
Q ~ 6.5 MeV



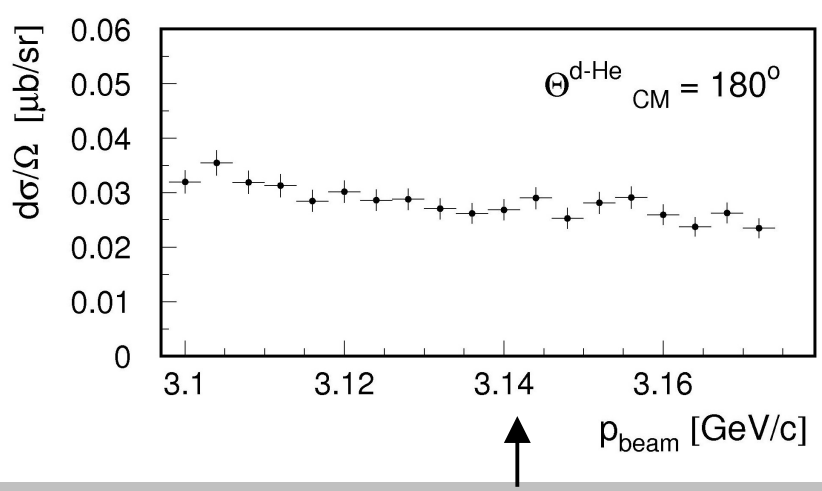
Background: 3.134 < p_{beam} < 3.138 GeV/c

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

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



COSY-11



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

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

To what extent the eta-prime meson is build out of gluons?

$$\eta' = \alpha \left| u\bar{u} + d\bar{d} + s\bar{s} \right\rangle + \beta \left| \text{gluons} \right\rangle$$

$\eta' \to 2\pi$ (P); $\eta' \to 3\pi$ (G); $\eta' \to \pi^0(2\pi, 3\pi\ldots)\gamma$ (C);

First order strong and electromagnetic decays are also forbidden for eta-prime and additionally:

meson	calculated mass	empirical mass
π	140	138
K	484	496
η	559	549
η′	349	958
ρ	780	776
ω	780	783
K^*	896	892
φ	1032	1020

$$m_{qq} = m_{q_1} + m_{q_2} + A \frac{\vec{S}_1 \vec{S}_2}{m_{q_1} m_{q_2}}$$

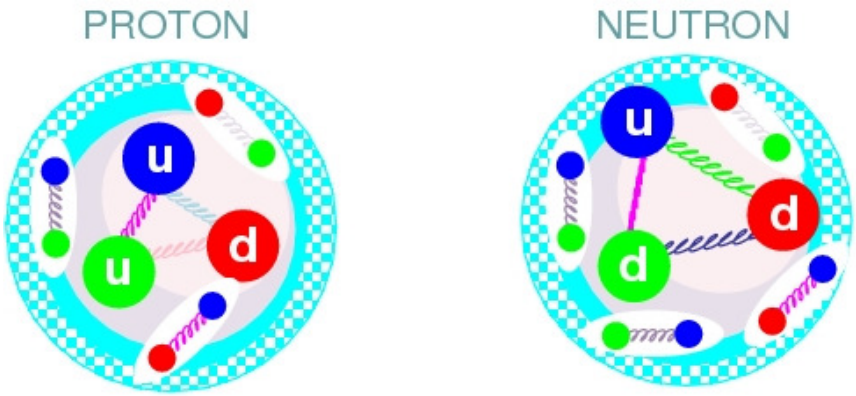
A , m_u , m_d , m_s

* $B^+ \to K^+ \eta'$ $= (6.5 \pm 1.7) \cdot 10^{-5}$

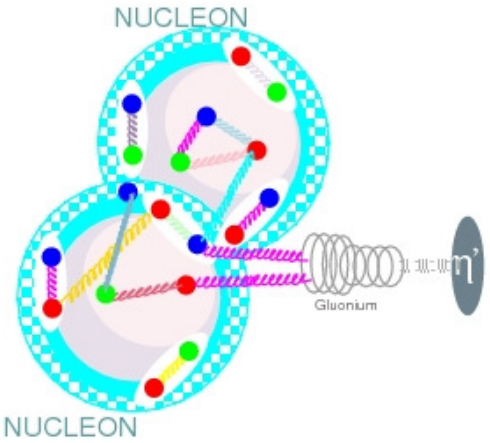
* $B^+ \to K^+ \eta$ $< 1.4 \cdot 10^{-5}$

$$\frac{\Gamma(D_s^+ \to \eta' \rho^+)}{\Gamma(D_s \to \eta' e^+ \nu)} = 12.0 \pm 4.3$$

$$\frac{\Gamma(D_s^+ \to \eta \rho^+)}{\Gamma(D_s \to \eta e^+ \nu)} = 4.4 \pm 1.2$$



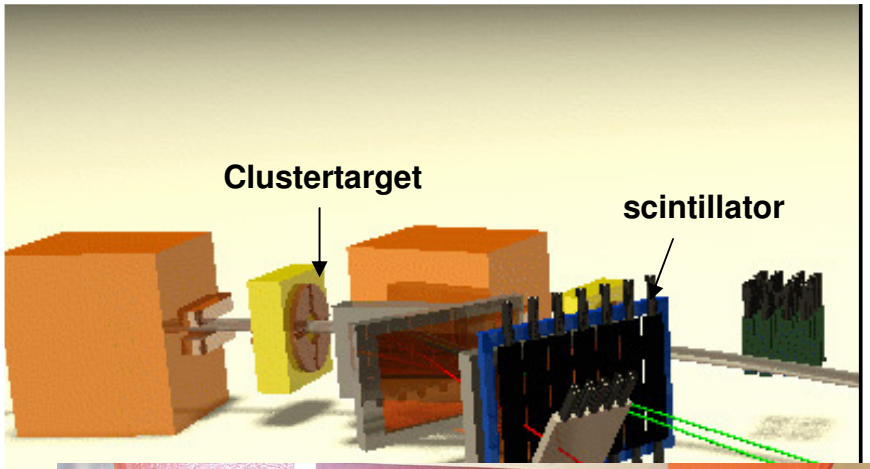
$$\eta' = \alpha \left| u\bar{u} + d\bar{d} + s\bar{s} \right\rangle + \beta \left| \text{gluons} \right\rangle$$

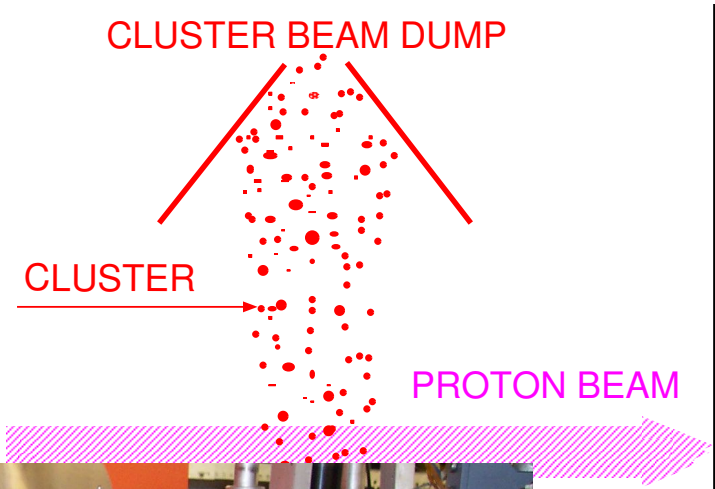


$$R \equiv \frac{p\,n \dashrightarrow p\,n\eta'}{p\,p \dashrightarrow p\,p\eta'} = ?$$

$R = 1$ only gluons

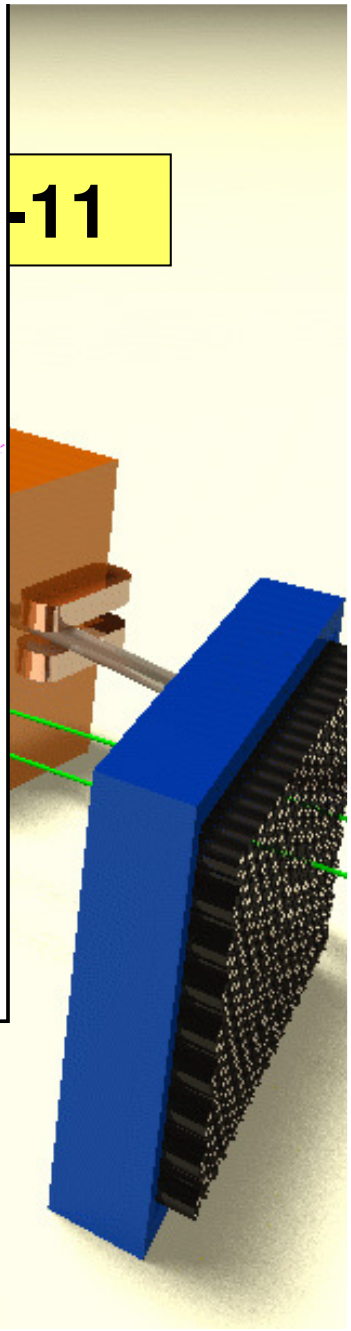
$R \approx 6$ only quarks

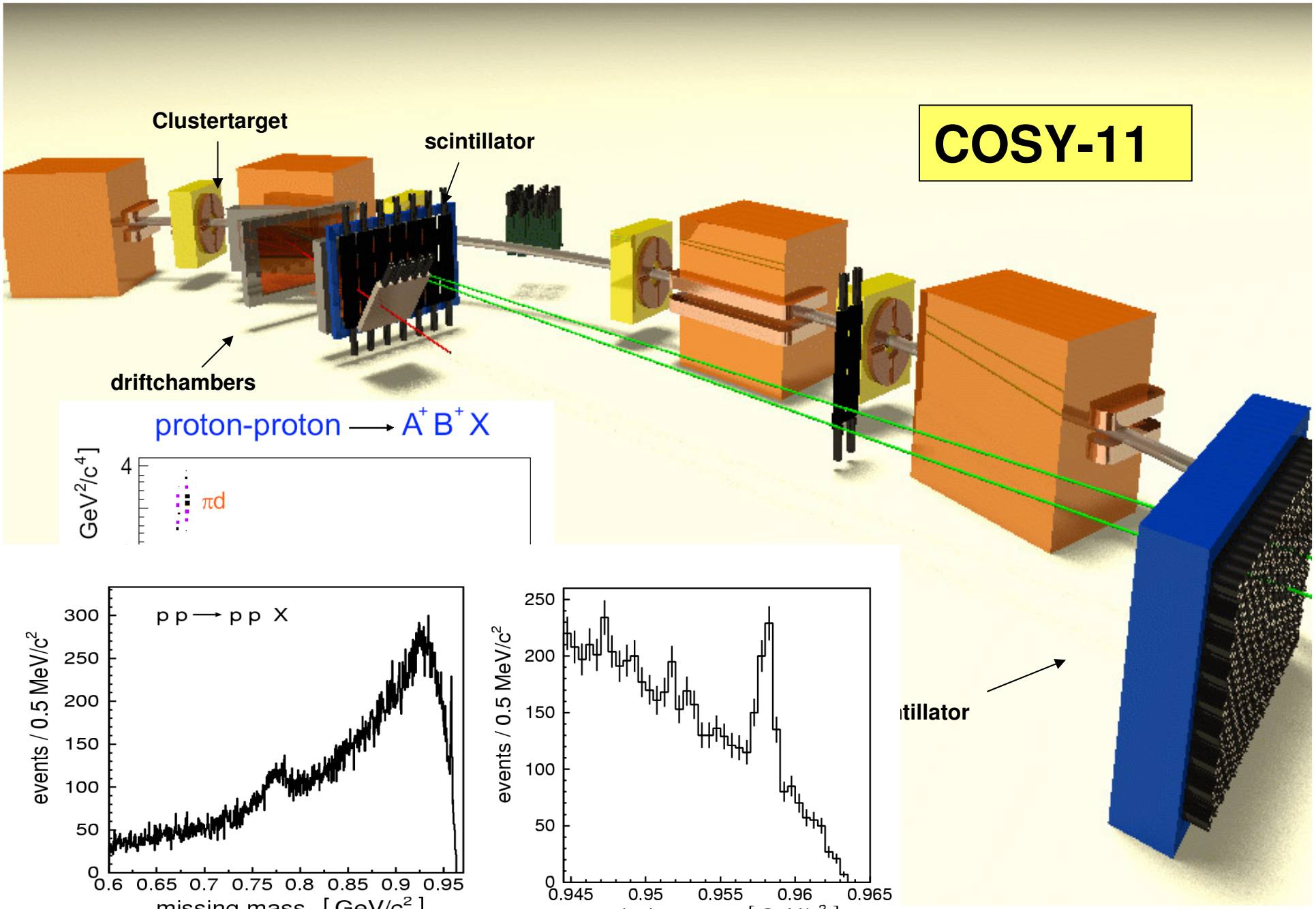

Clustertarget
scintillator

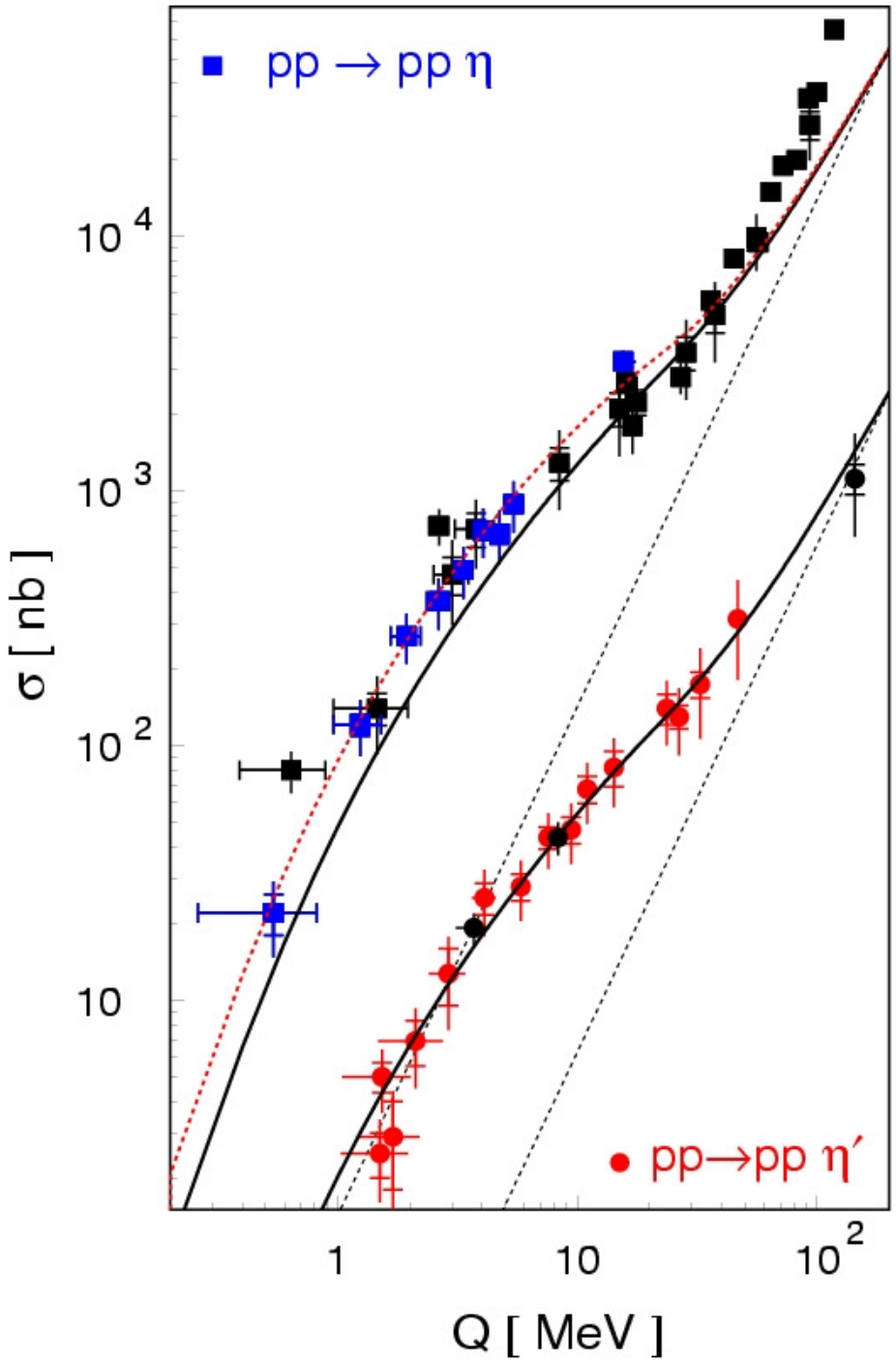

CLUSTER BEAM DUMP
CLUSTER
PROTON BEAM

-11

ϕ16µm




COSY-11
Clustertarget
scintillator
driftchambers
proton-proton → A⁺ B⁺ X
GeV²/c⁴]
4
πd
p p → p p X
events / 0.5 MeV/c²
missing mass [GeV/c²]
tillator



$$\sigma = \frac{1}{F}\int dV_{ps}\,|M|^2$$

$$|M|^2 \sim |M_0|^2\,|M_{FSI}|^2$$

$$|M_{FSI}|^2 \sim |M_{pp}|^2\,|M_{p1\eta}|^2\,|M_{p2\eta}|^2$$

dynamics → $|M_0|^2$

interaction → σ (Q)

CELSIUS

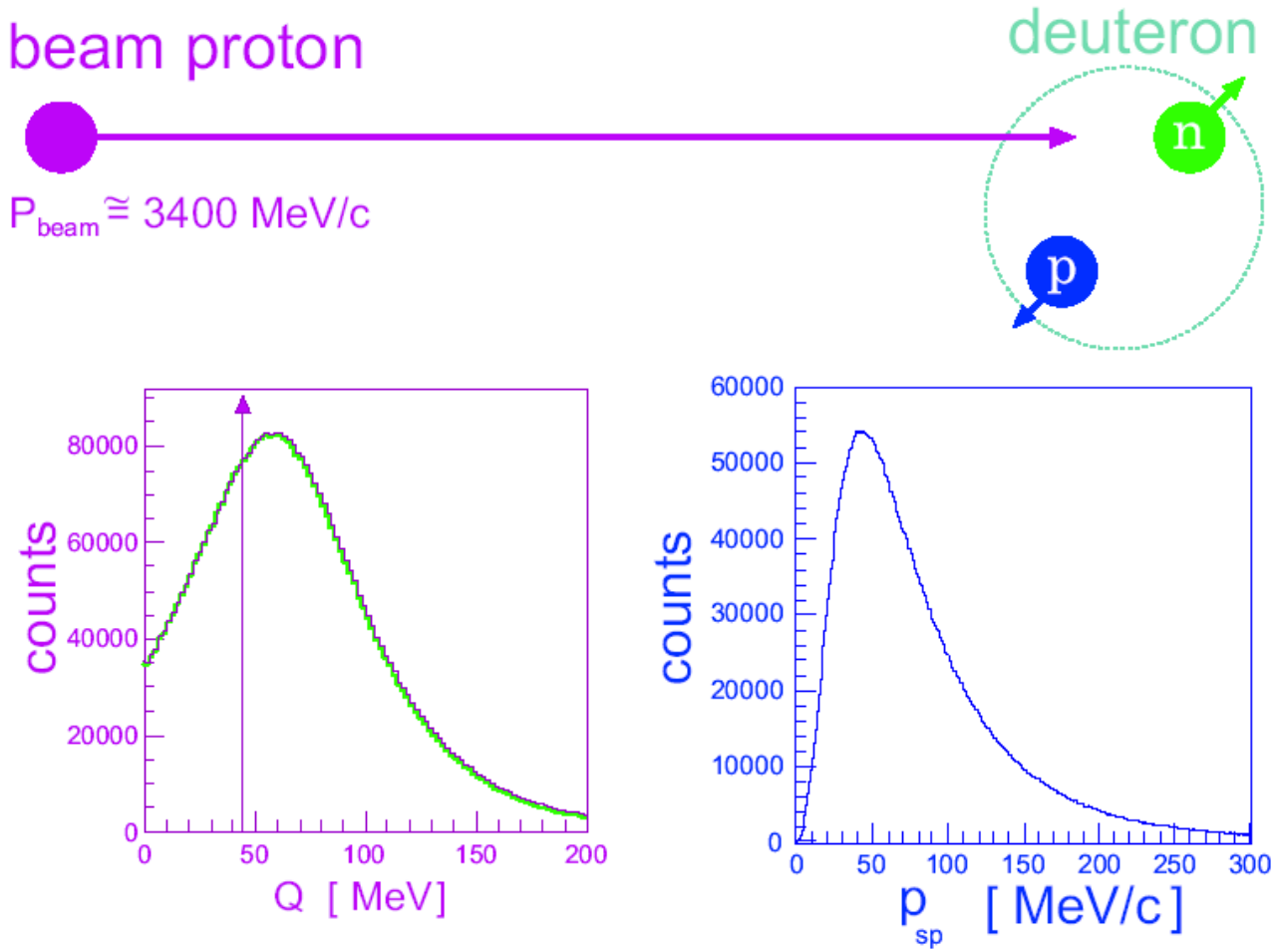
WASA/CELSIUS: H. Calen et al., Phys. Lett. **B 366** (1996) 39.
WASA/CELSIUS: H. Calen et al., Phys. Rev. Lett. **79** (1997) 2642.

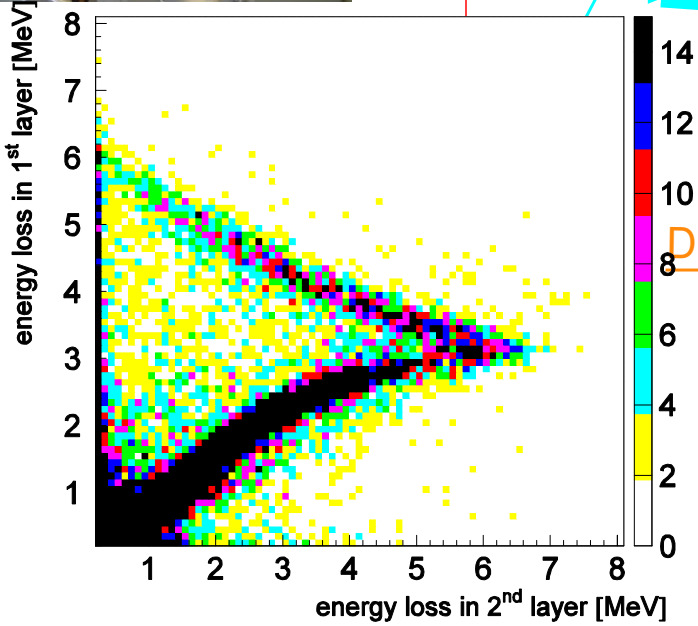
COSY

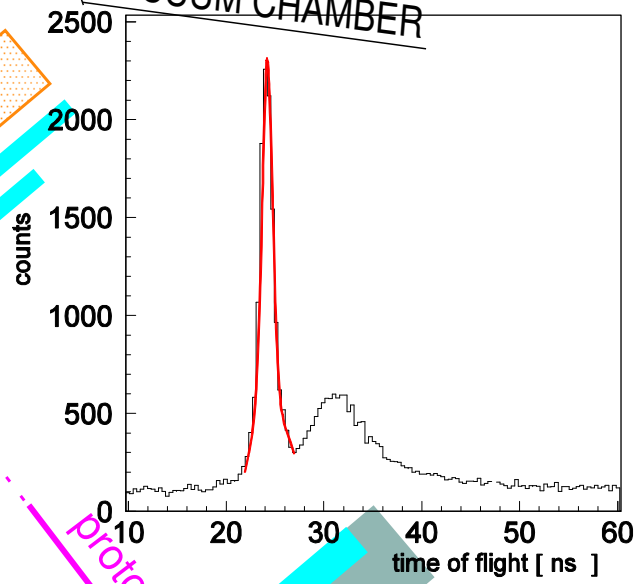
COSY-11: A. Khoukaz et al., Eur. Phys. J. **A 20** (2004) 345.
COSY-11: P. M. et al., Phys. Rev. **C 69** (2004) 025203.
COSY-11: P. M. et al., Phys. Lett. **B 482** (2000) 356.
COSY-11: P. M. et al., Phys. Lett. **B 474** (2000) 416.
COSY-11: J. Smyrski et al., Phys. Lett. **B 474** (2000) 182.
COSY-11: P. M. et al., Phys. Rev. Lett. **80** (1998) 3202.

SATURNE

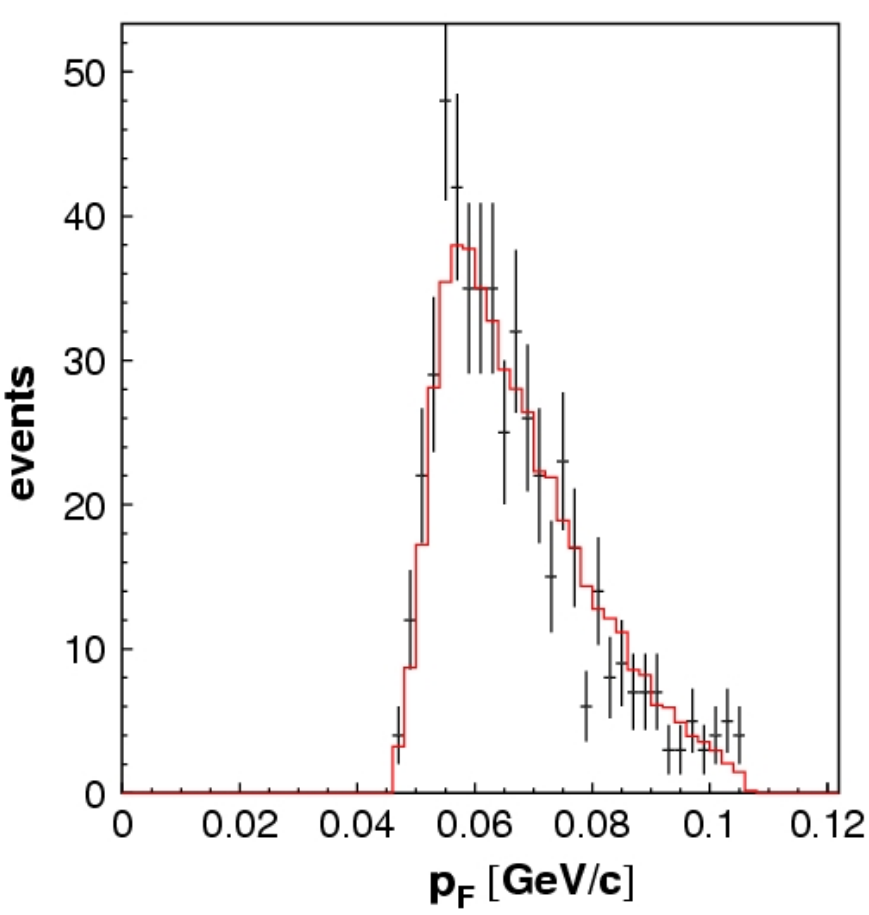
DISTO/SATURNE: F. Balestra et al., Phys. Lett. **B 491** (2000) 29.
SPES/SATURNE: F. Hibou et al., Phys Lett. **B 438** (1998) 41.
PINOT/SATURNE: E. Chiavassa et al., Phys. Lett. **B 322** (1994) 270.
SPES/SATURNE: A. M. Bergdold et al., Phys. Rev. **D 48** (1993) R2969.
SPES/SATURNE: R. Wurzinger et al., Phys. Lett. **B 374** (1996) 283.

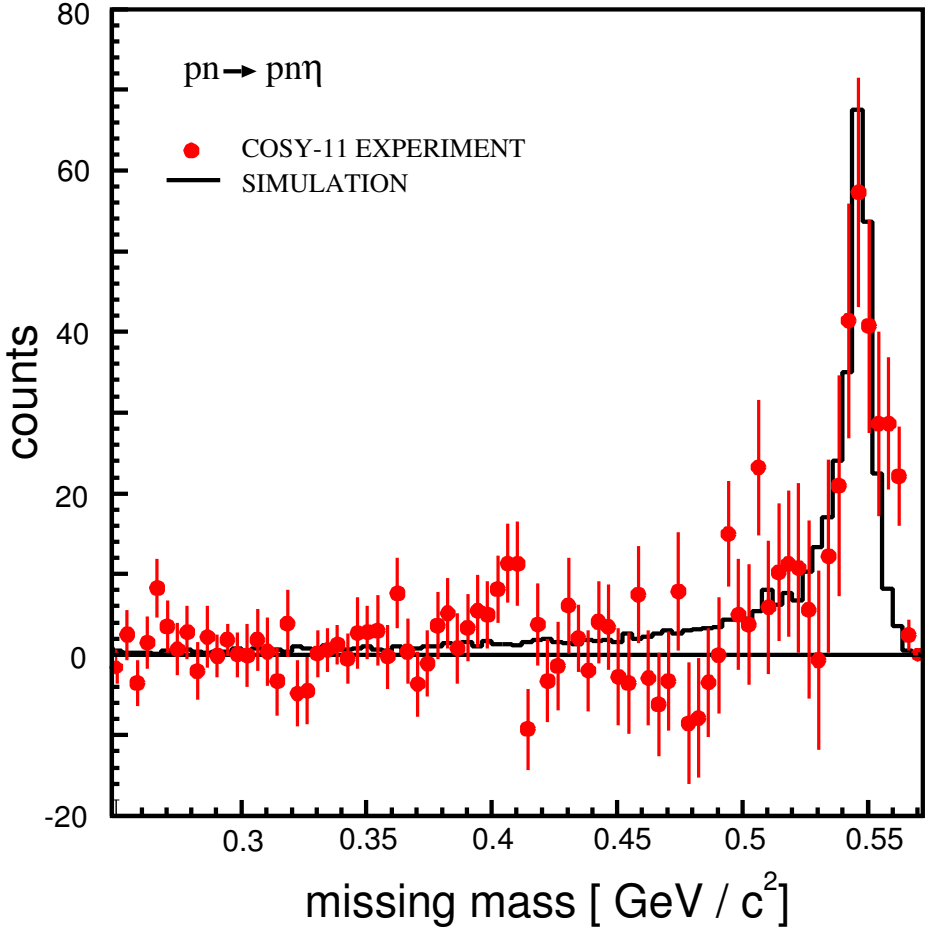

beam proton
deuteron
n
p
$P_{beam} \cong 3400$ MeV/c
counts
80000
60000
40000
20000
0
0
50
100
150
200
Q [MeV]
counts
60000
50000
40000
30000
20000
10000
0
0
50
100
150
200
250
300
p_{sp} [MeV/c]


energy loss in 1st layer [MeV]
energy loss in 2nd layer [MeV]


counts
time of flight [ns]

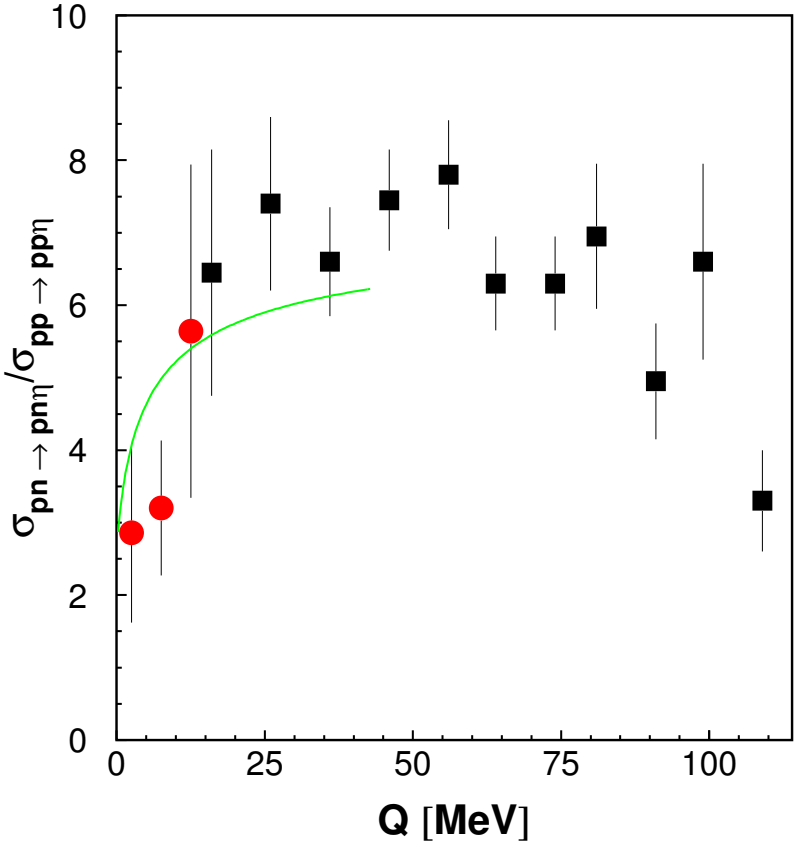
DIPOLE
S4
Si mon
Si dip
S5
B
neutron
proton
D3
D4
VACUUM CHAMBER
D1
D2
S1
S2
proton
n
p
p
n
η
p
p
sp


events
50
40
30
20
10
0
0
0.02
0.04
0.06
0.08
0.1
0.12
p_F [GeV/c]

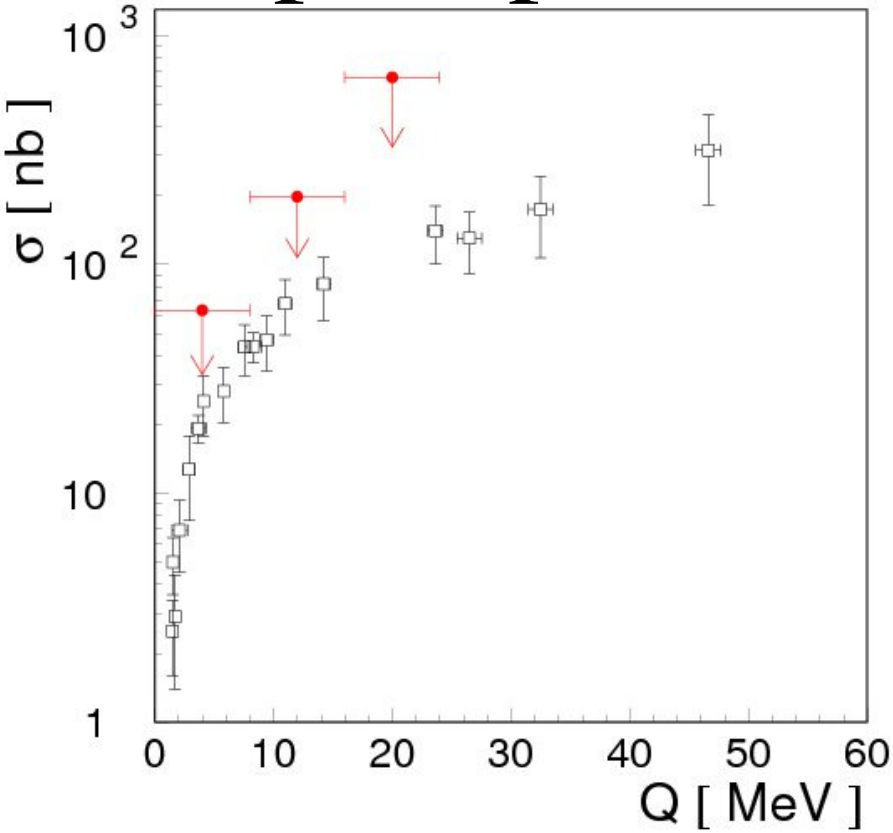

pn→ pnη
COSY-11 EXPERIMENT
SIMULATION
counts
80
60
40
20
0
-20
0.3
0.35
0.4
0.45
0.5
0.55
missing mass [GeV / c^2]

Results

pn→pnη



pn→pnη'

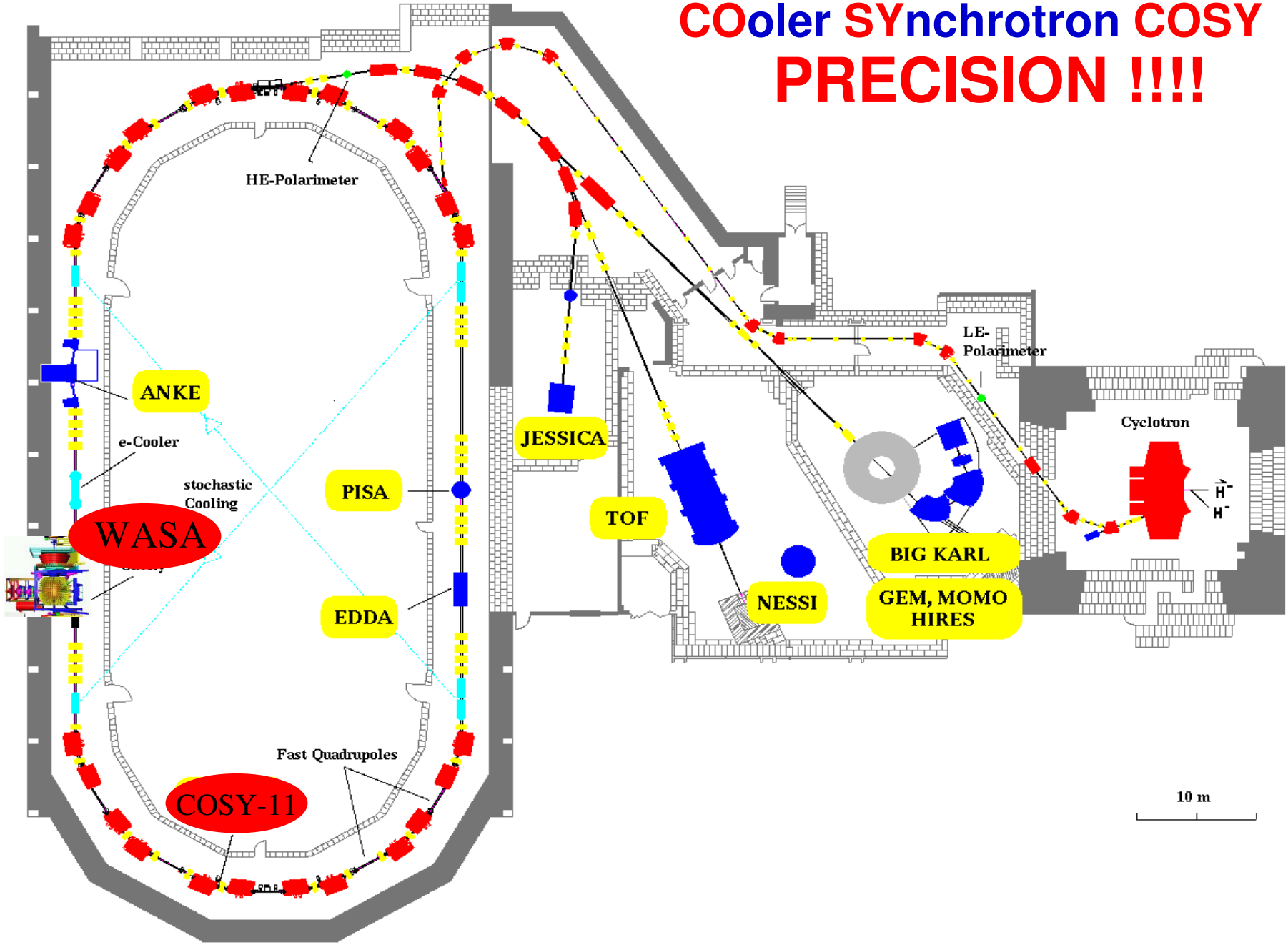


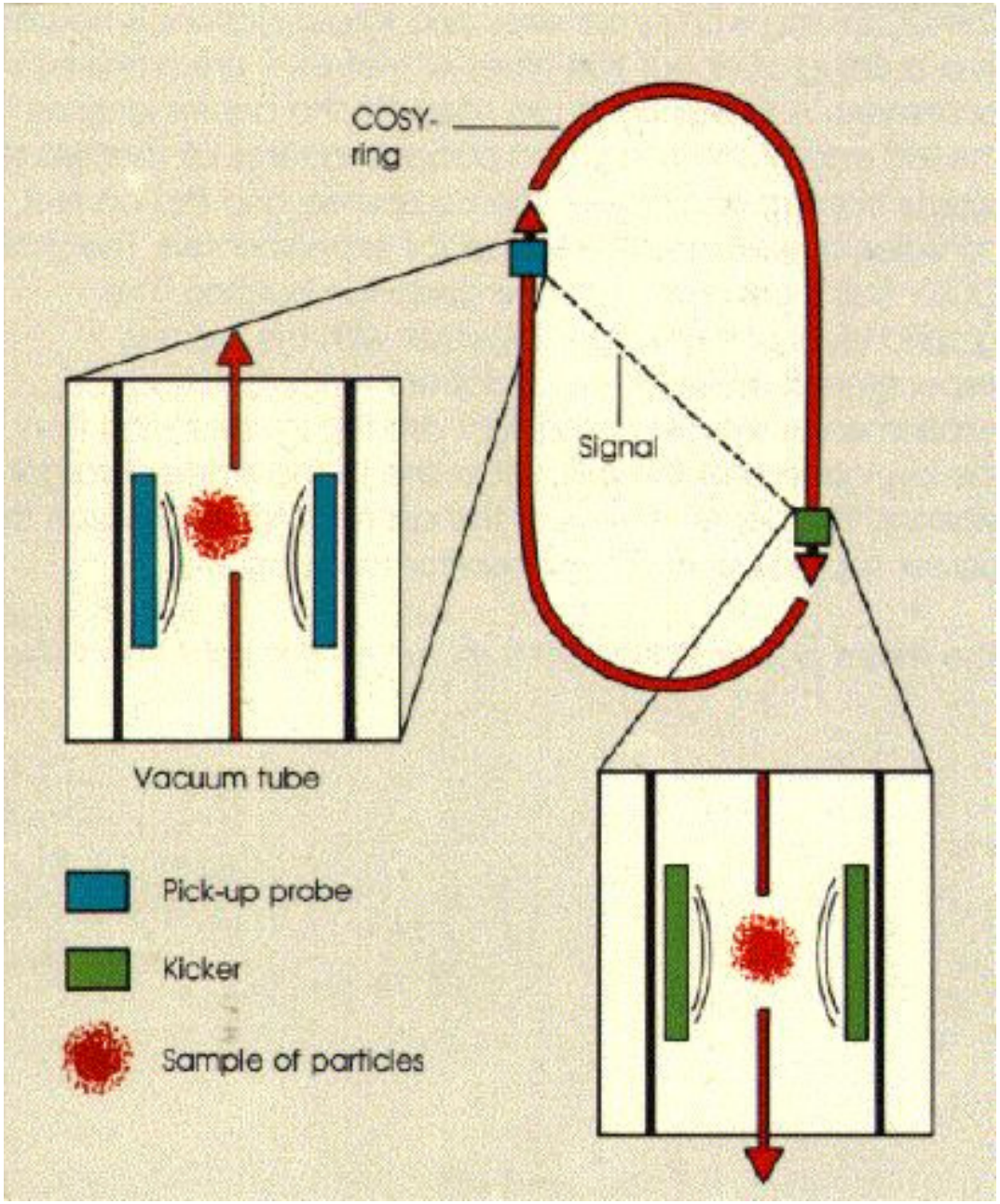
$$\frac{\sigma(pn\to pn\eta)}{\sigma(pp\to pp\eta)} = 0.5 + A\left(\frac{\sqrt{(\varepsilon_{pp})} + \sqrt{(\varepsilon_{pp}+Q)}}{\sqrt{(\varepsilon_{pn})} + \sqrt{(\varepsilon_{pn}+Q)}}\right)^2$$

G. Faeldt, C. Wilkin, Phys. Lett. B382 (1996) 209.
G. Faeldt, C. Wilkin, Phys. Rev. C56 (1997) 2067.

COoler SYnchrotron COSY

PRECISION !!!!



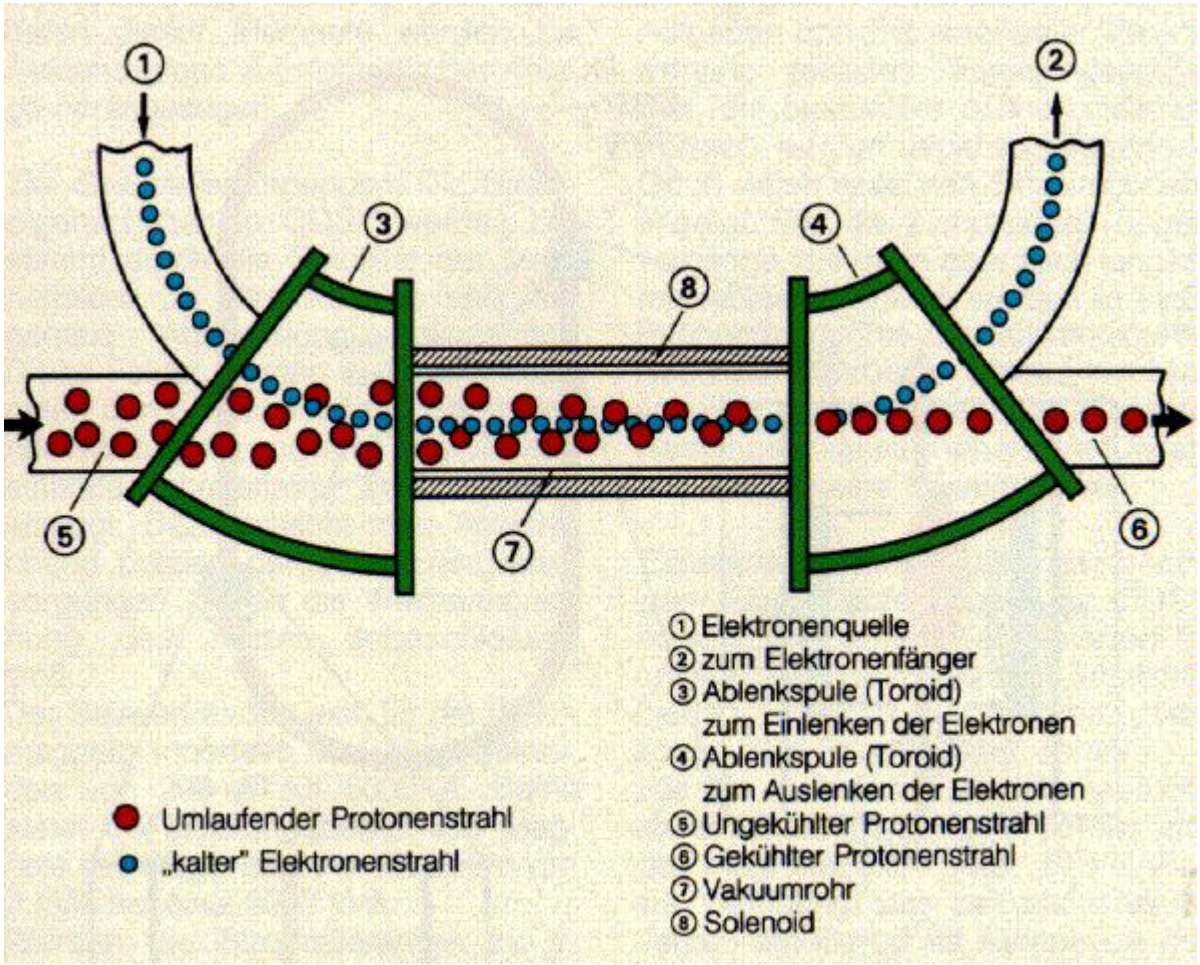


stochastic cooling

S. van der Meer

Nobel Prize 1984

electron cooling



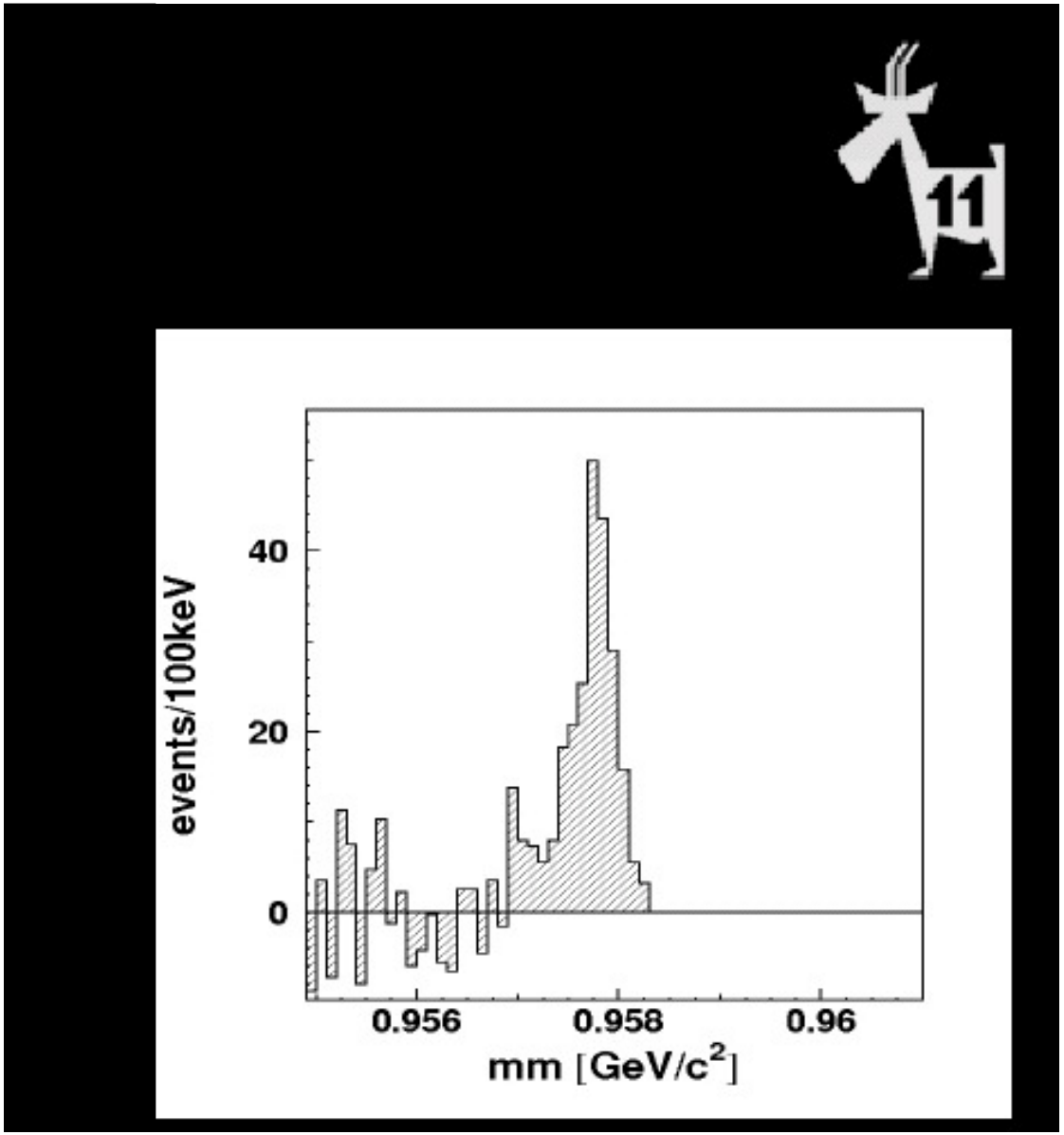
proposed by G. Budker

in 1966

first tested in 1974

in Novosibirsk

Direct measurement of the mass distribution of the eta-prime meson with a unique precision

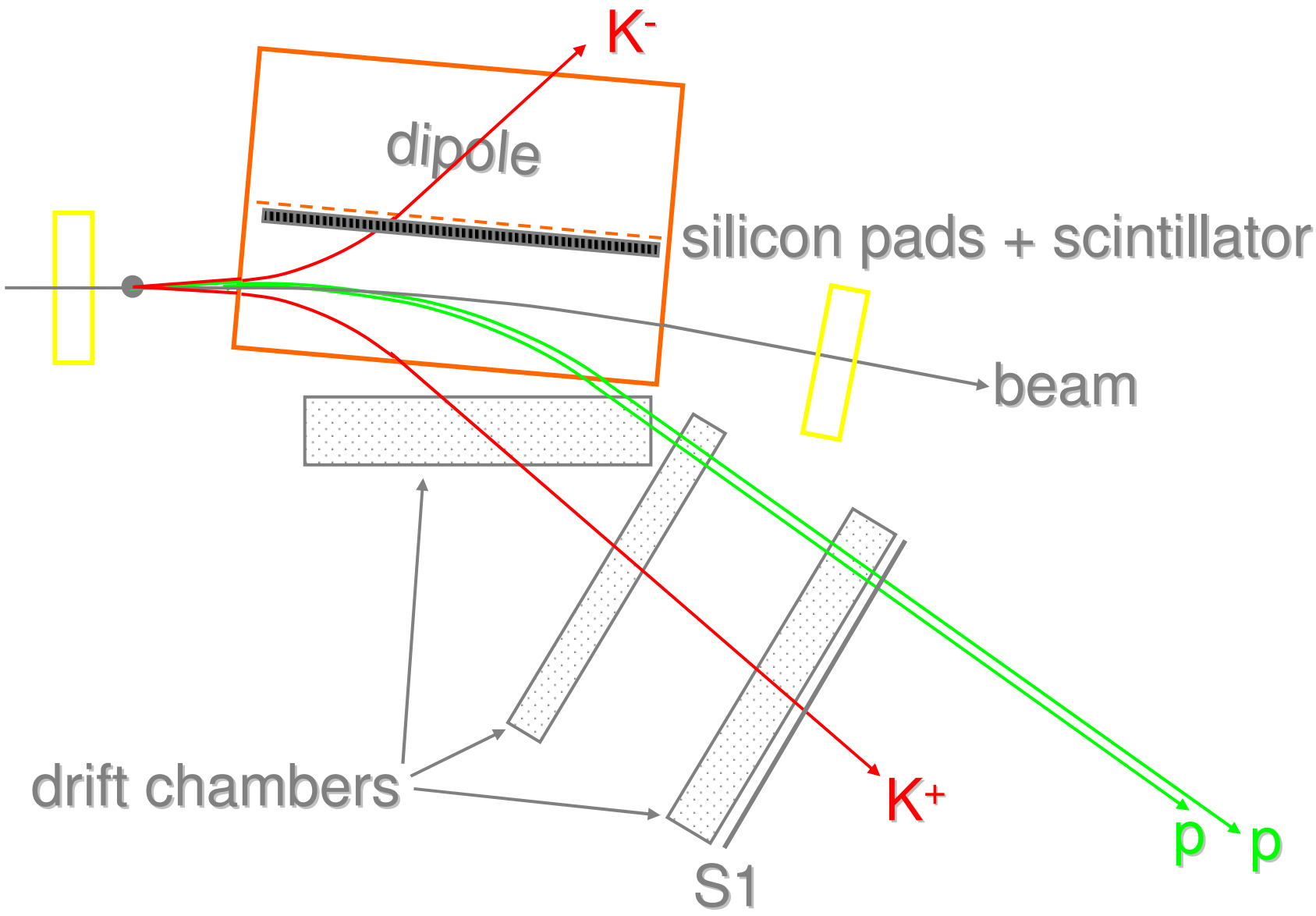


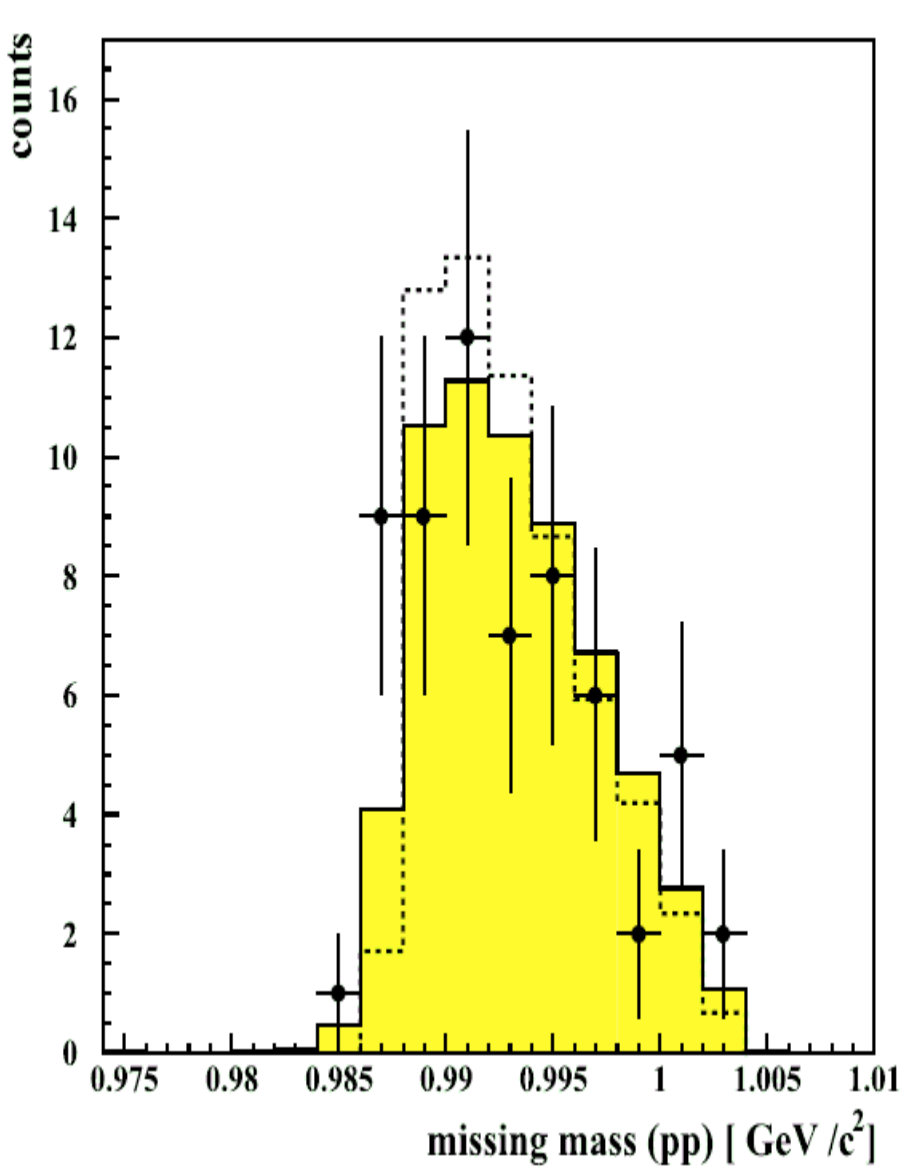
$\Gamma \sim 0.2$ MeV,

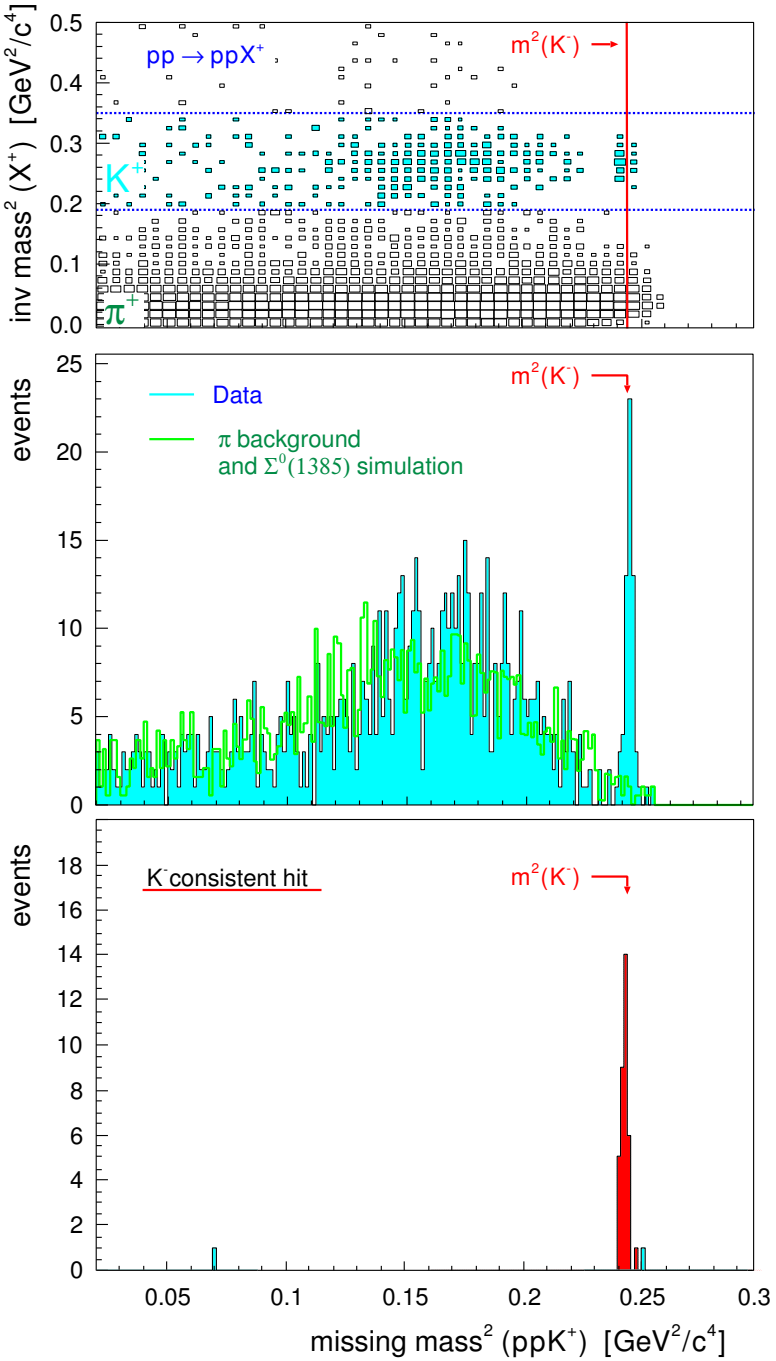
typical accuracy

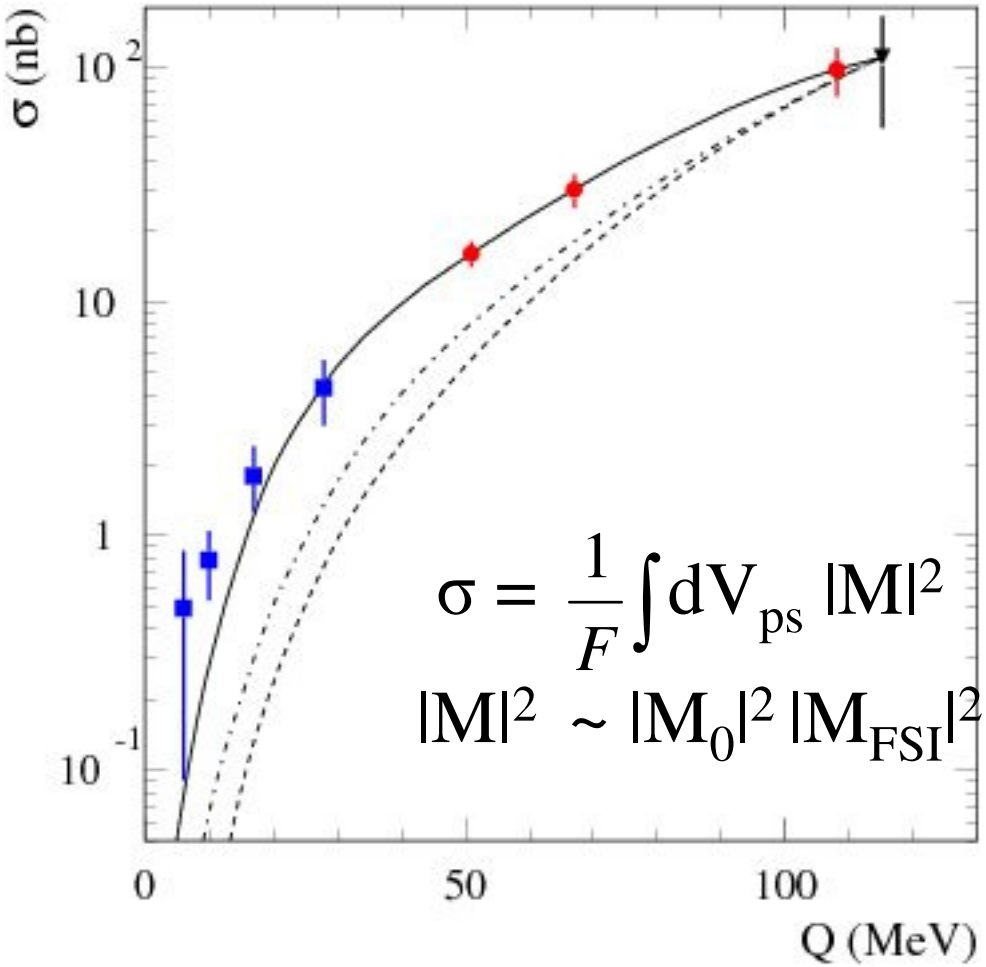
is in the order of few MeV

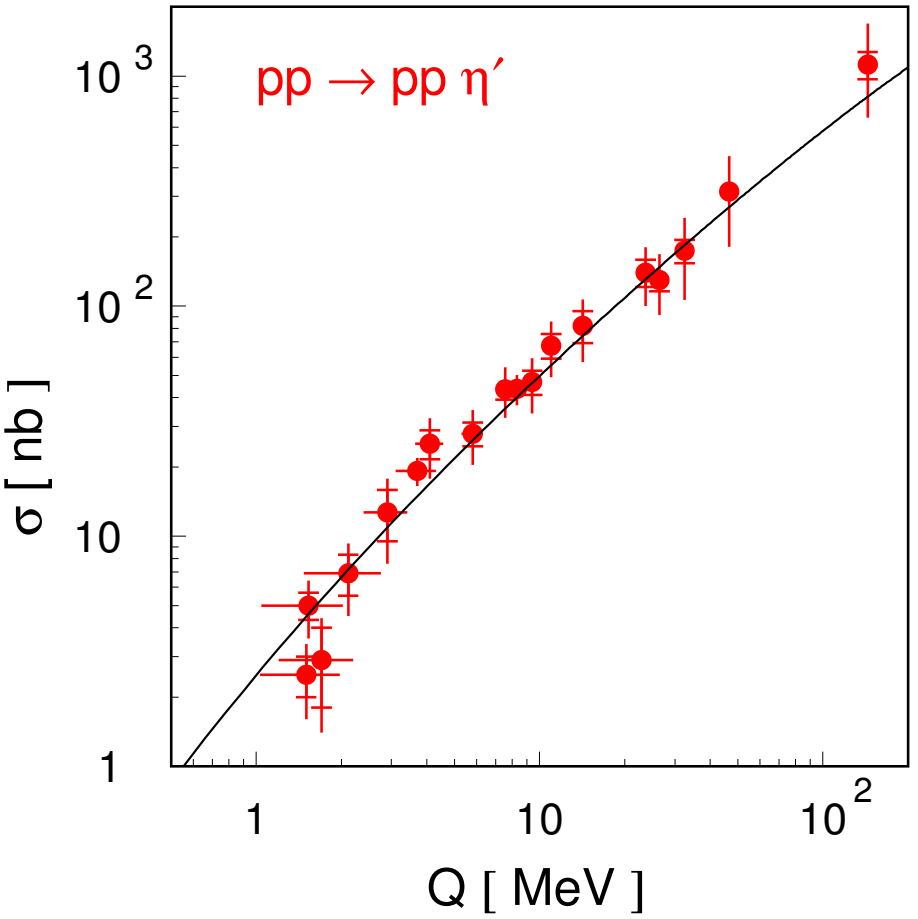
← COSY + COSY 11


K-
dipole
silicon pads + scintillator
beam
drift chambers
K+
p
p
S1


counts
missing mass (pp) [GeV /c^2]


inv mass^2 (X$^+$) [GeV^2/c^4]
pp → ppX$^+$
m^2(K$^-$)
K$^+$
π$^+$
events
Data
π background
and Σ^0(1385) simulation
K$^-$consistent hit
missing mass^2 (ppK$^+$) [GeV^2/c^4]



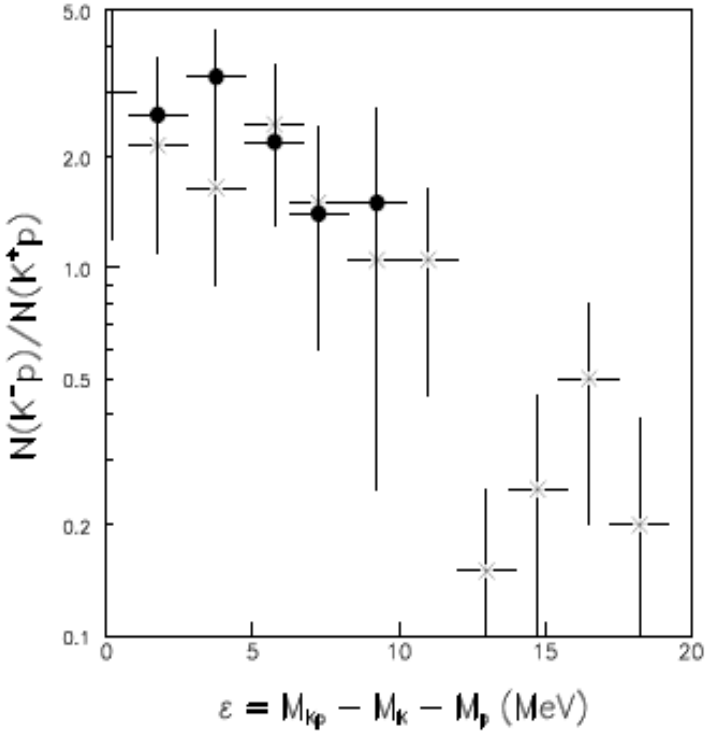


COSY-11: P. Winter et al., Phys. Lett. **B 635** (2006) 23.

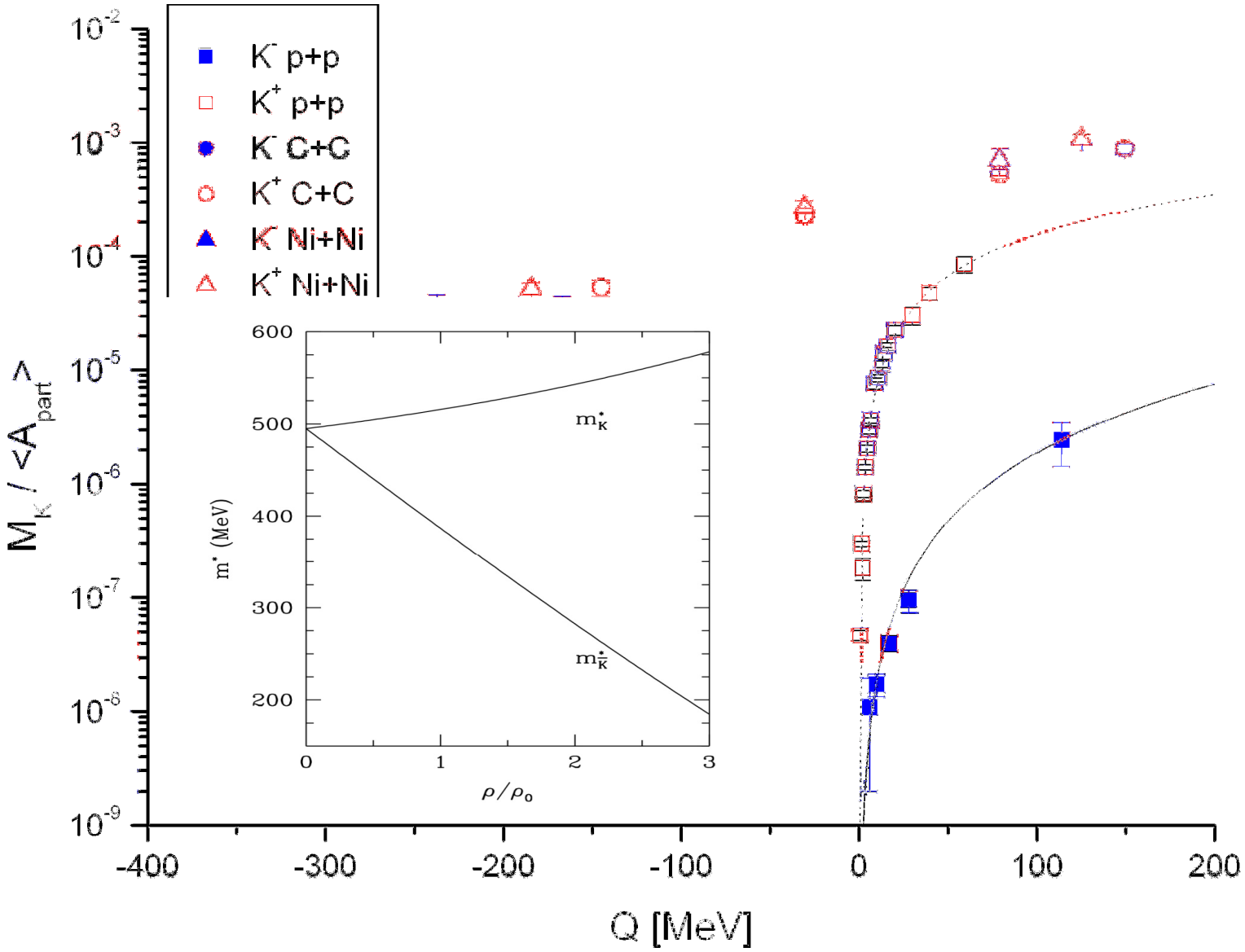
COSY-11: C. Quentmeier et al., Phys. Lett. **B 515** (2001) 276.

ANKE: Y. Maeda et al.., Phys. Rev. **C 77** (2008) 01524.

DISTO: F. Balestra et al., Phys. Rev. **C 63** (2001) 024004.



Multiplicity of kaon and anti-kaon production per participating nucleon for *C+C*, *Ni+Ni*, and proton-proton collisions



Thank You