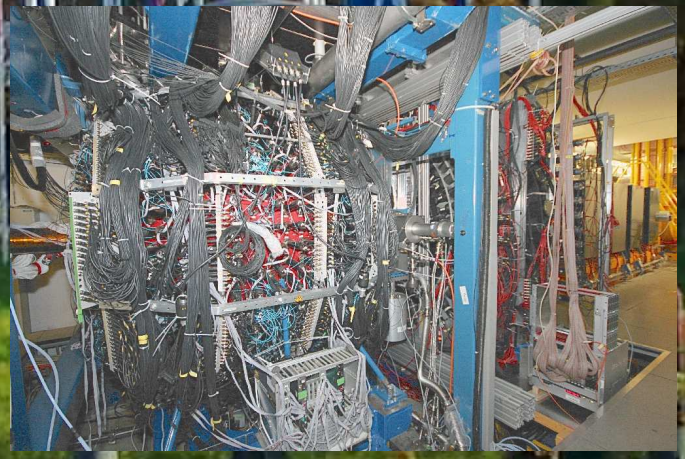
The WASA Collaboration
- past, present, future -



WASA at GSI/FAIR

GSI, Nov 27, 2017

Magnus Wolke

UPPSALA UNIVERSITET

The WASA Collaboration
- past, present, future -

The past:

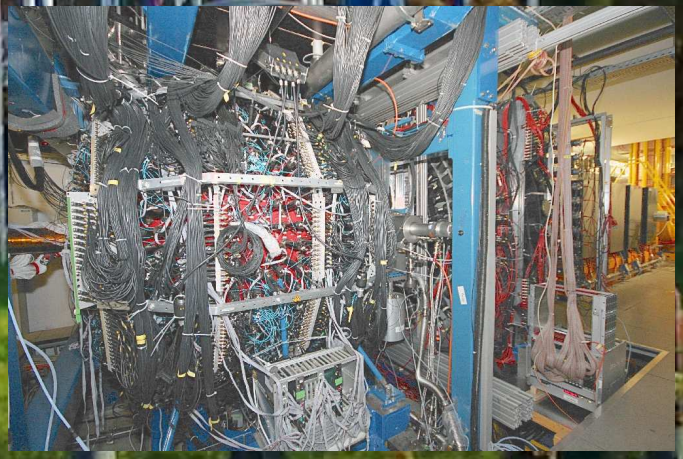
from the LoI to CELSIUS, from CELSIUS to COSY

The present:

analysis of WASA-at-COSY data

The future:

WASA at GSI/FAIR



Magnus Wolke

UPPSALA UNIVERSITET

Wide Angle Shower Apparatus

a little bit of history

A Cyclotron hall
B CELSIUS hall
C Crypt
D Marble hall
E Blue hall
F Gamma cave
G Biomedical area
H Control room,cyclotron
I Control room,CELSIUS
J Counting room,CELSIUS experiments
K Ion source building

Wide Angle Shower Apparatus
a little bit of history

from: Hans Calen,
TSL symposium, Nov 2015

Mar 1984 Letter of intent for a research program on elementary particle physics experiments at CELSIUS

Oct 1987 Wide Angle Shower Apparatus Proposal for a detector at CELSIUS from the WASA collaboration

Jun 1992 - Apr 1998 WASA/PROMICE experiments

η meson production in proton-nucleon collisions

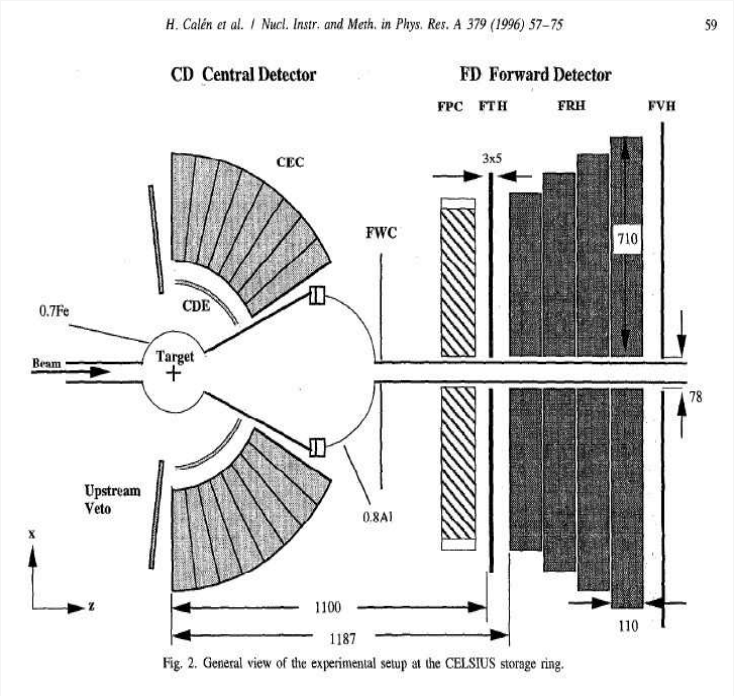
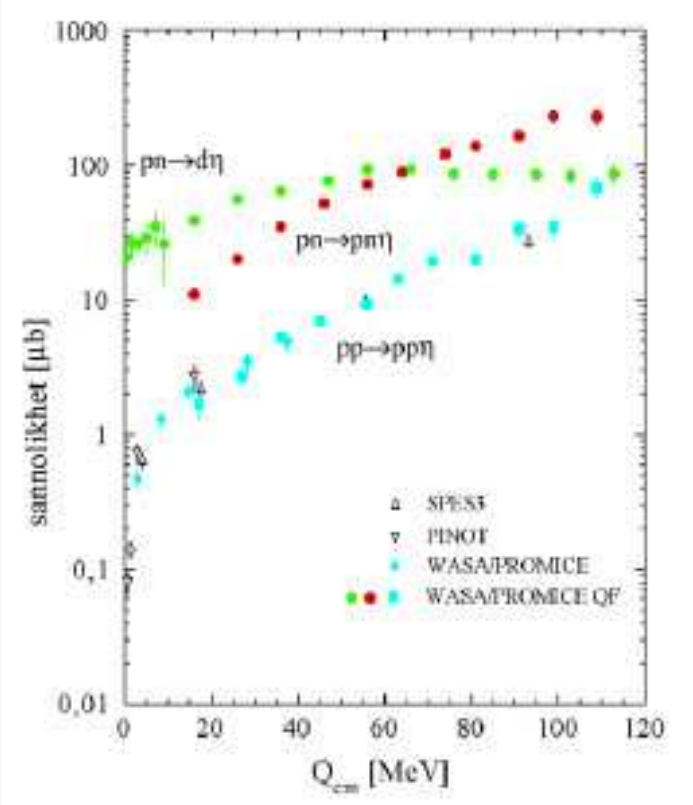


Fig. 2. General view of the experimental setup at the CELSIUS storage ring.



Wide Angle Shower Apparatus
a little bit of history

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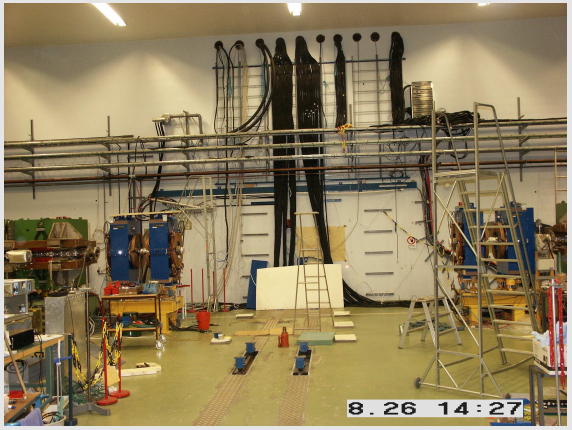
1998	CELSIUS/WASA commissioning proposal
Jun 1999 - Jun 2005	CELSIUS/WASA experiments
Oct 2004	WASA-at-COSY proposal
Jun 2005 - Aug 2006	Move of WASA from  to 
Apr 2007 - Jun 2014	WASA-at-COSY experiments

WASA to COSY

Picture Gallery

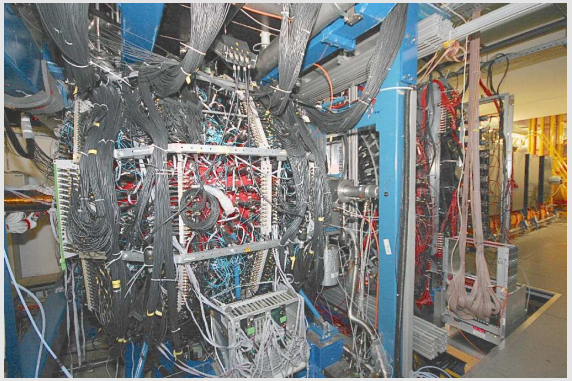
CELSIUS, June 2005

CELSIUS, Aug 29, 2005

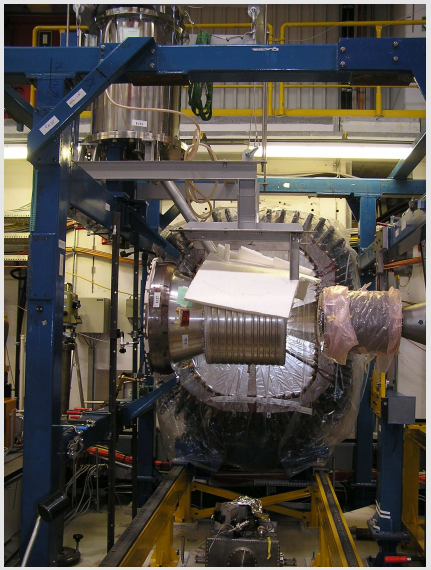


CELSIUS, October 2005

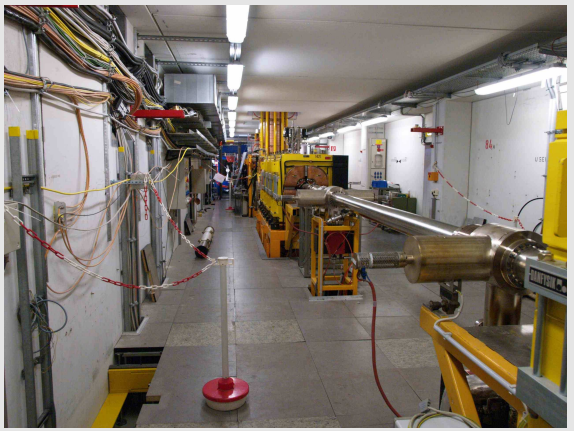
COSY, October 2005



COSY, Aug 8, 2006



COSY, Jun 12, 2006



COSY, March 2006

COSY, October 2005

Wide Angle Shower Apparatus
a little bit of history

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TSL symposium, Nov 2015

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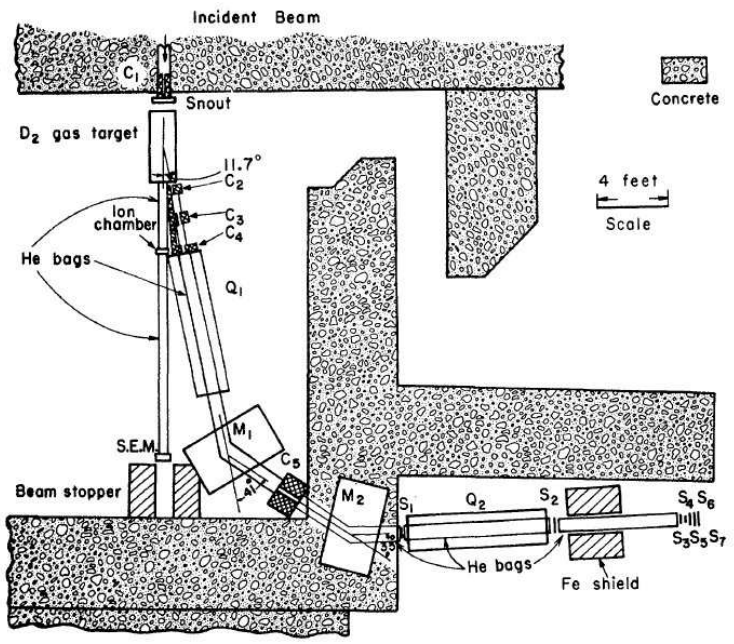
Apr 2007 - Jun 2014	WASA-at-COSY experiments

ABC — first observation

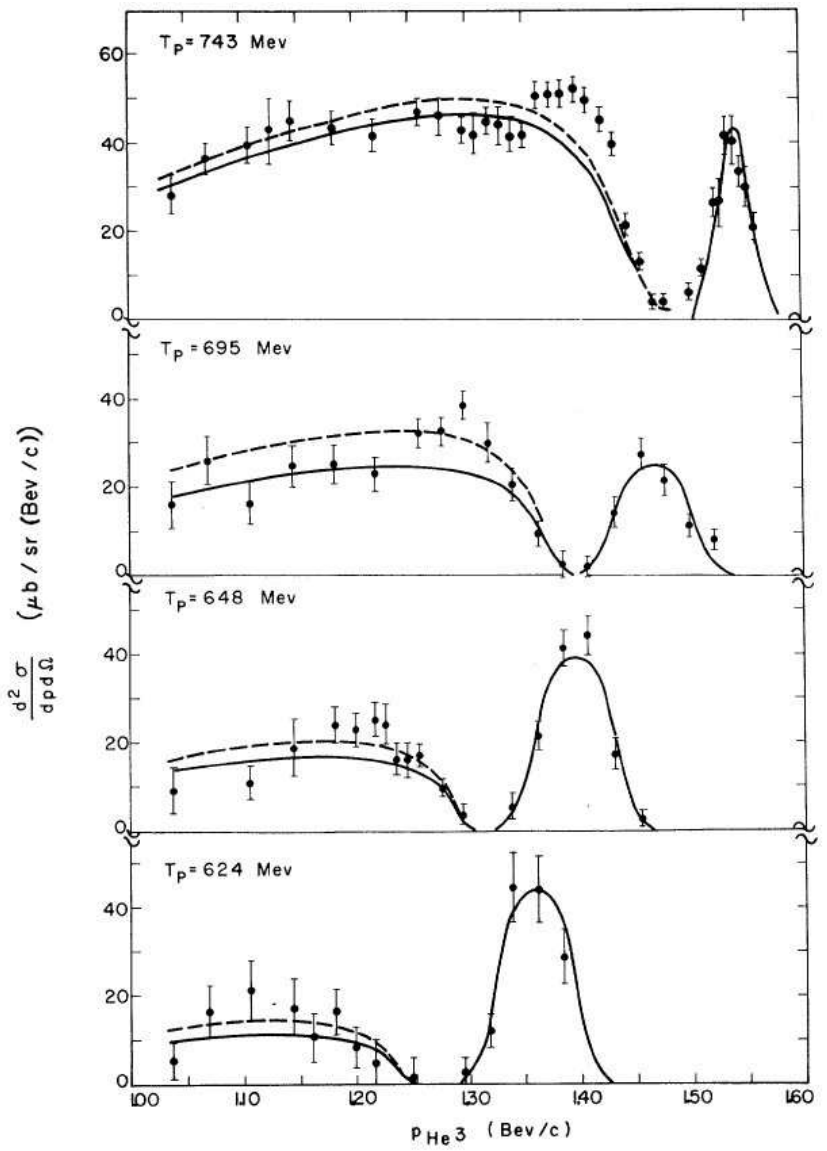
(Abashian, Booth, Crowe)

A. Abashian, N. E. Booth, K. M. Crowe,
Phys. Rev. Lett. 5 (1960) 258

Lawrence Radiation Laboratory
184 inch cyclotron (p), d_2 gas target



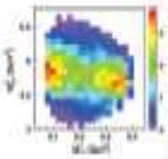
$pd \rightarrow {}^3He X$, $\theta_{He} = 11.5°$



at the time of PRL 5 (1960):

"The data are inconsistent with the relativistically invariant phase space assumed. [...] Plausible explanations [...] are the existence of a new neutral particle or a resonant π–π system."

Discovery of $d^*(2380)$



Dalitz plot of the d-π^0 versus the π^0-π^0 invariant mass squared for the $pd \to d\pi^0\pi^0 +$ (spectator proton) interaction, from an experiment by the WASA at COSY Collaboration. The experimental results point to the existence of a new, unconventional $I=0$, $J^P=3^+$ resonance in the two-baryon system. [P. Adlarson et al., Phys. Rev. Lett. 106, 242302 (2011)]

PHYSICAL REVIEW LETTERS

Contents

Articles published – 17 June 2011

VOLUME 106, NUMBER 24 17 June 2011

Frankfurter Allgemeine
ZEITUNG FÜR DEUTSCHLAND

Frankfurter Allgemeine Zeitung, Frankfurt vom 29.06.2011
Seite: N1
Auflage: 383676

Top

Neuer Exot im Teilchenzoo?

Am Beschleuniger des Forschungszentrums Jülich hat man Hinweise auf ein neues exotisches Teilchen aus sechs Quarks gefunden. Die Entdeckung könnte ein altes Rätsel lösen.

Von Robert Gast

Schon wieder ein neues Teilchen? Es ist noch keine zwei Monate her, da sorgte die Nachricht vom amerikanischen Forschungszentrum Fermilab in

Teilchenbeschleunigern. Bei entsprechend hohen Kollisionsenergien können dem Standardmodell der Teilchenphysik zufolge theoretisch auch Partikeln kreiert werden, die aus vier, fünf oder aus sechs Quarks bestehen. Bisher konnten jedoch keine derartigen exotischen Quarkzuständen experimentell nachgewiesen werden, auch wenn es in den vergangenen Jahren immer wieder Hinweise auf die Existenz von Tetra- und Pentaquarks gab. Der exotische Quarkzustand, der am ringförmigen Teilchenbeschleuniger Cosy jetzt möglicherweise gesichtet wurde, soll sogar aus sechs Quarks bestehen.

Die Wissenschaftler haben bei ihrem Experiment Protonen in dem 184 Meter umfassenden Ringbeschleuniger Cosy nahezu auf Lichtgeschwindigkeit beschleunigt und mit Neutronen kollidieren lassen. Dabei verschmolzen die beiden Stoßpartner, die jeweils aus drei Quarks beste-

Forscher müssen aber noch zeigen, dass die Resonanz auch bei elastischen Kollisionen auftritt, also dann, wenn das Proton und das Neutron, die kollidieren, nicht zu einem Deuteron fusionieren. Das ausstehende Experiment wollen die Forscher demnächst angehen. Mit belastbaren Ergebnissen rechnen sie in zwei Jahren.

Als recht unwahrscheinlich gilt unter Experten derweil, dass die Resonanz auf eine statistische Schwankung oder einen Messfehler zurückzuführen ist, wie das bei dem vermeintlichen Teilchenfund im April am Tevatron höchstwahrscheinlich der Fall gewesen war. „Das Experiment hat Hand und Fuß", sagt Ahmed Ali vom Deutschen Elektronensynchrotron Desy in Hamburg über die Arbeit seiner Kollegen, an der er nicht beteiligt war.

Unabhängig davon, ob sich die Resonanz als neues Teilchen entpuppt oder

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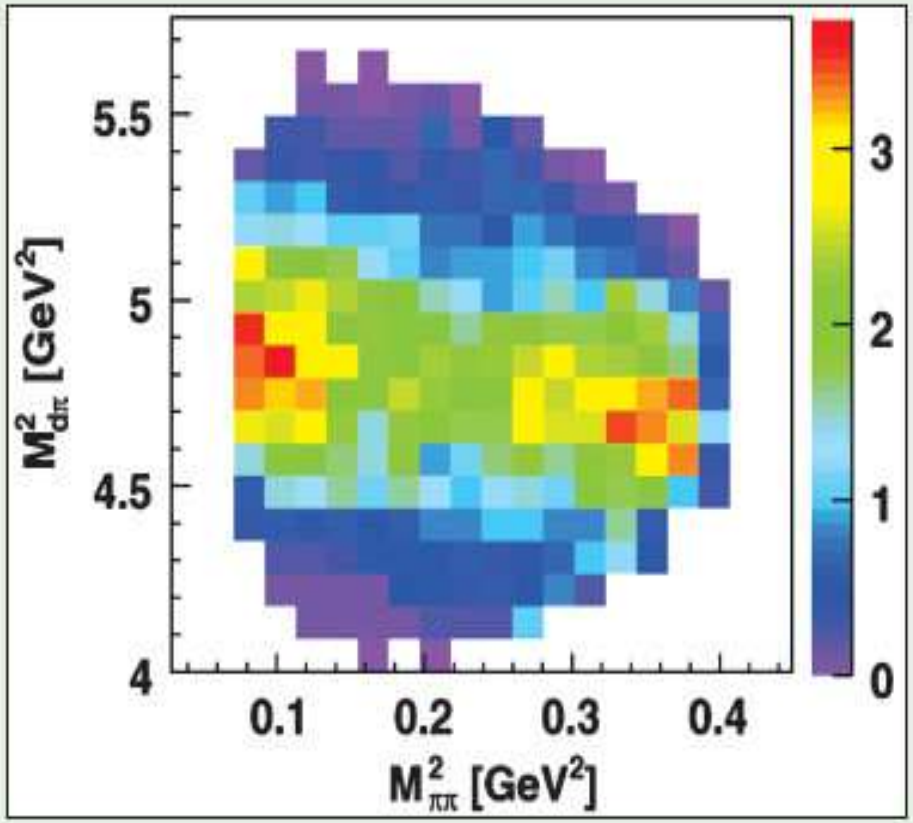
PHYSICAL REVIEW LETTERS

Articles published week ending 17 JUNE 2011

PRL 106 (24) 240401–249901, 17 June 2011 (240 total pages)



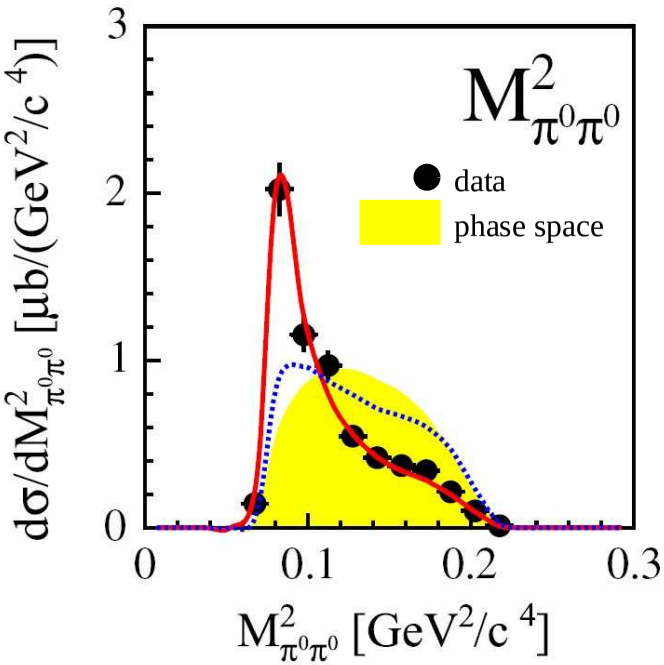
Why was it discovered by WASA-at-COSY and not by CELSIUS/WASA?

The ABC Gallery

CELSIUS/WASA measurements

$pn \rightarrow d\pi^0\pi^0$

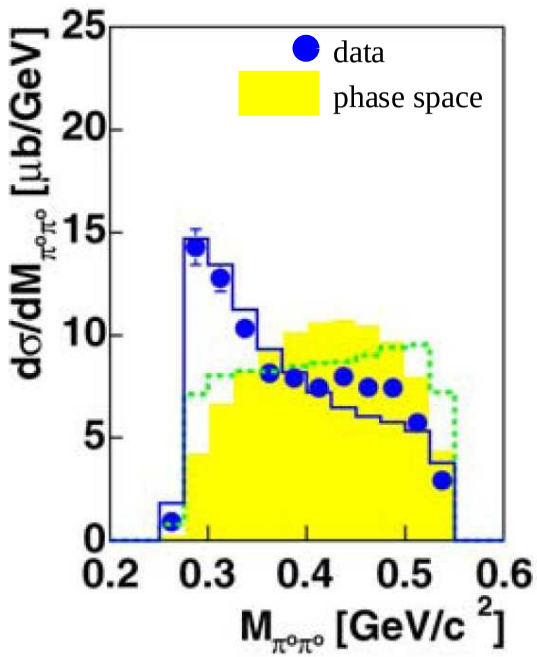
1.0 GeV



PRL 102 (2009) 052301

$pd \rightarrow {}^3He\pi^0\pi^0$

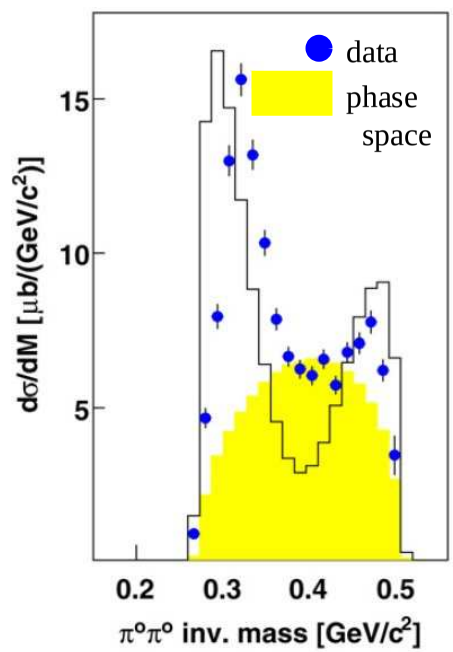
0.9 GeV



PLB 637 (2006) 223

$dd \rightarrow {}^4He\pi^0\pi^0$

1.0 GeV



NPA 825 (2009) 71

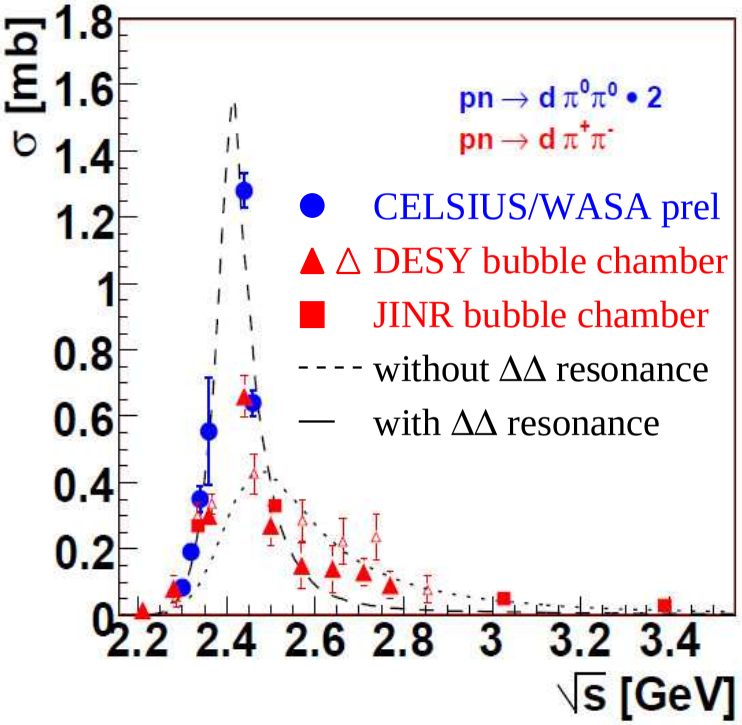
WASA-at-COSY

new exclusive measurements
over the full ΔΔ region

Discovery of $d^*(2380)$

CELSIUS/WASA preliminary results

from: M.Bashkanov, H.Clement,
COSY proposal 183 (2007)



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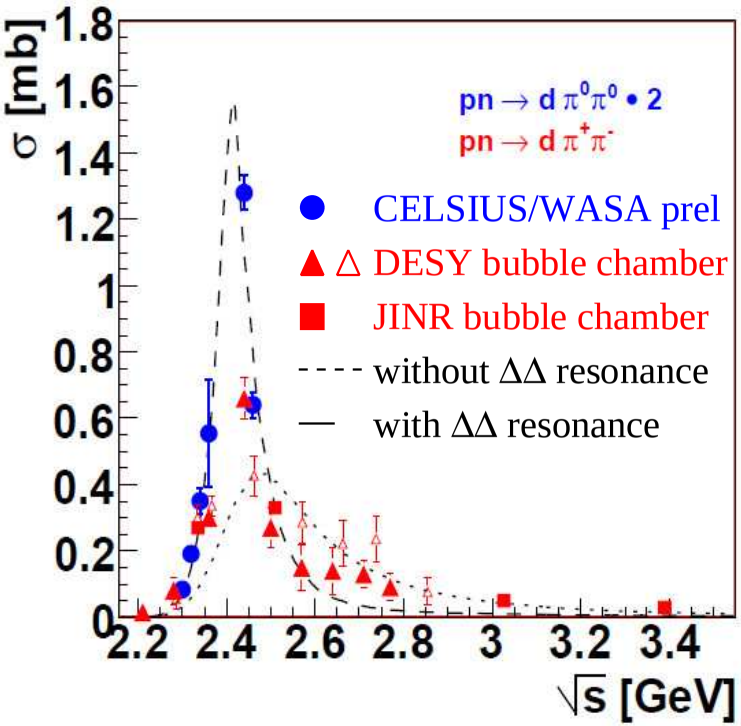
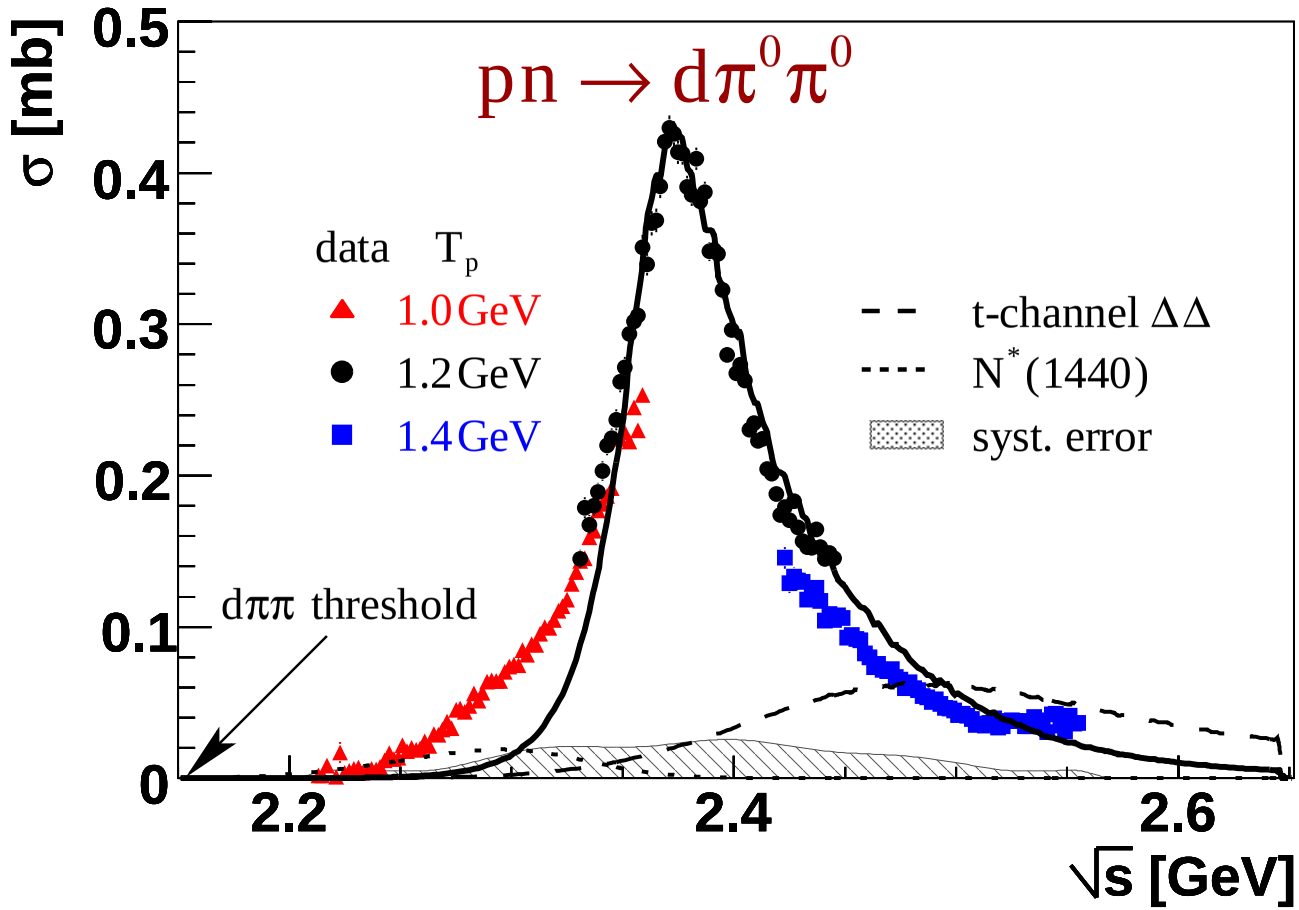


WASA-at-COSY results
P. Adlarson et al.,
PRL 106 (2011) 242302

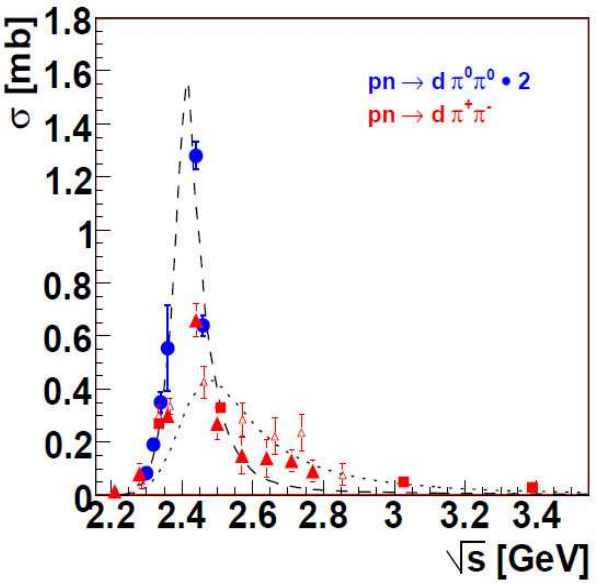


- Lorentzian shaped energy distribution
- 4 times narrower compared with ΔΔ, peak 80 MeV below $2m_\Delta$

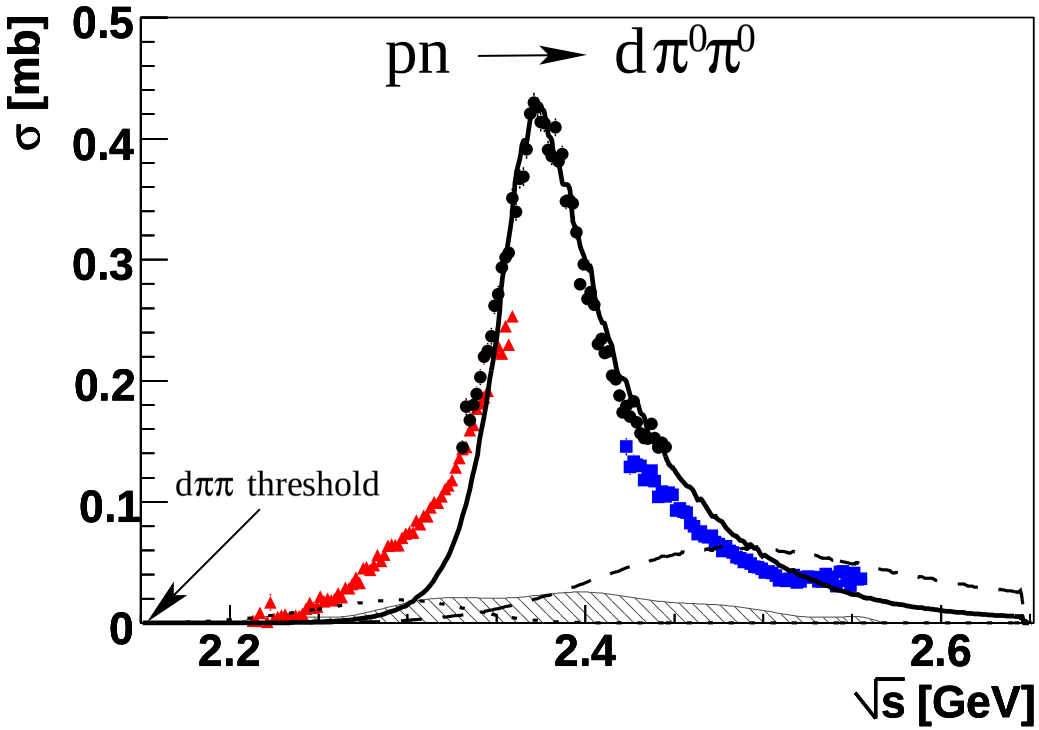
2 orders of magnitude larger statistics
compared to CELSIUS/WASA! ... But how?

From CELSIUS to COSY: the $d^*(2380)$ example

CELSIUS/WASA preliminary results



WASA-at-COSY results



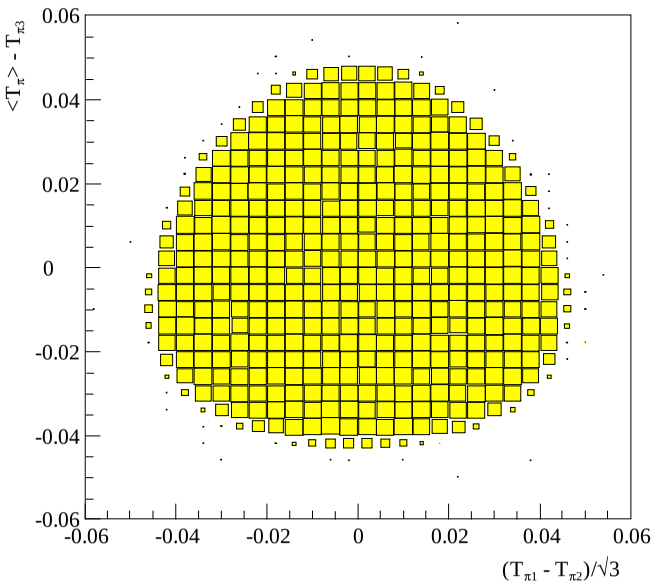
2 orders of magnitude larger statistics compared to CELSIUS/WASA by...

strategic investments to remove bottlenecks:

complete redesign of DAQ system

improved pellet target reliability

First WASA-at-COSY Run April 2007: $\eta \to 3\pi^0$ Dalitz Plot

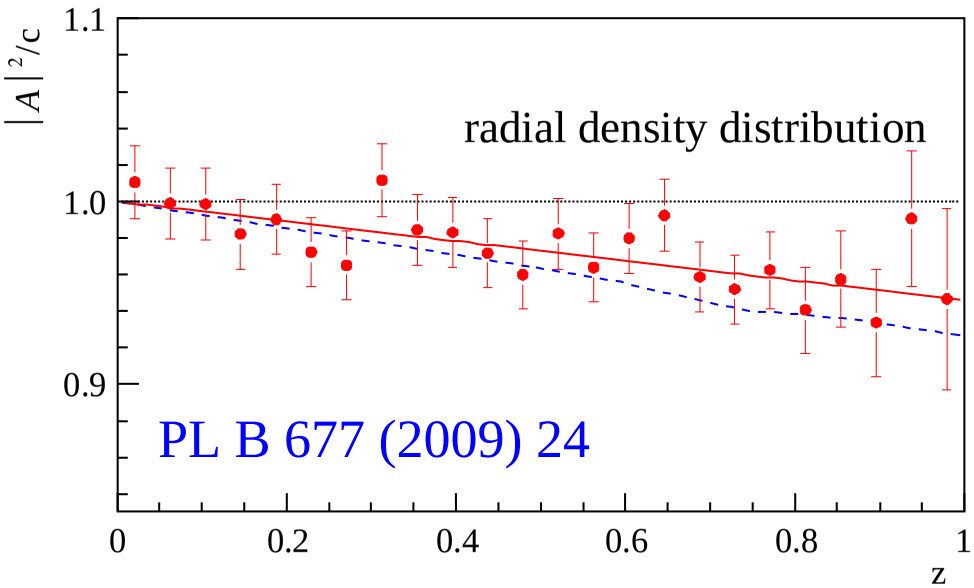


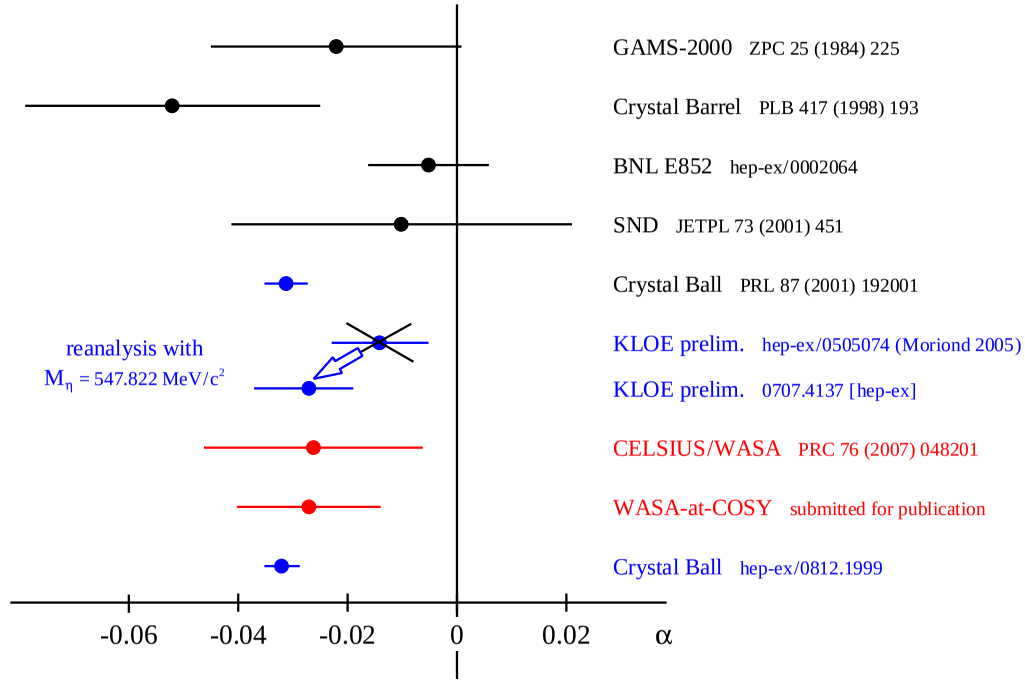
$$\overline{\Gamma} \propto |A(z)|^2 = c_0(1+2\alpha z) \qquad z = (\rho/\rho_{max})^2 = 6\sum_{i=1}^{3}\left(\frac{E_i - m_\pi/3}{m_\eta - m_\pi}\right)^2$$

First step to compare dynamics
with ChPT prediction: slope parameter α

four days of data taking $\to$ 120000 events

combined CELSIUS/WASA statistics $\to$ 75000 events





note: historic slide covers only results until end of 2008!

WASA - at CELSIUS and at COSY

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Physics Letters B 637 (2006) 223–228
PHYSICS LETTERS B
www.elsevier.com/locate/physletb

Exclusive measurements of $pd \to {}^3\mathrm{He}\,\pi\pi$: The ABC effect revisited

M. Bashkanov [a], D. Bogoslawsky [b], H. Calén [c], F. Cappellaro [d], H. Clement [a,*], L. Demiroers [e], C. Ekström [c], K. Fransson [c], J. Greiff [c], L. Gustafsson [d], B. Höistad [d], G. Ivanov [b], M. Jacewicz [d], E. Jiganov [b], T. Johansson [d], O. Khakimova [a], M.M. Kaskulov [a], S. Keleta [d], I. Koch [d], F. Kren [a], S. Kullander [d], A. Kupść [c], A. Kuznetsov [b], P. Marciniewski [c], R. Meier [a], B. Morosov [b], W. Oelert [f], C. Pauly [e], Y. Petukho [b], A. Povtorejko [b], R.Z.M.Y. Ruber [c], W. Scobel [e], T. Skorodko [a], B. Shwartz [g], V. Sopov [h], J. Stepaniak [i], V. Tchernyshev [h], P. Thörngren-Engblom [d], V. Tikhomirov [b], A. Turowiecki [j], G.J. Wagner [a], M. Wolke [d], A. Yamamoto [k], J. Zabierowski [i], J. Zlomanczuk [d]

[a] Physikalisches Institut der Universität Tübingen, D-72076 Tübingen, Germany
[b] Joint Institute for Nuclear Research, Dubna, Russia
[c] The Svedberg Laboratory, Uppsala, Sweden
[d] Uppsala University, Uppsala, Sweden
[e] Hamburg University, Hamburg, Germany
[f] Forschungszentrum Jülich, Germany
[g] Budker Institute of Nuclear Physics, Novosibirsk, Russia
[h] Institute of Theoretical and Experimental Physics, Moscow, Russia
[i] Soltan Institute of Nuclear Studies, Warsaw and Lodz, Poland
[j] Institute of Experimental Physics, Warsaw, Poland
[k] High Energy Accelerator Research Organization, Tsukuba, Japan

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Available online 5 May 2006
Editor: V. Metag

first CELSIUS/WASA publication

Physics Letters B 677 (2009) 24–28
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Physics Letters B
www.elsevier.com/locate/physletb

Measurement of the $\eta \to 3\pi^0$ Dalitz plot distribution with the WASA detector at COSY

WASA-at-COSY Collaboration

C. Adolph [a], M. Angelstein [b,c], M. Bashkanov [d], U. Bechstedt [b,c], S. Belostotski [e], M. Berlowski [f], H. Bhatt [g], J. Bisplinghoff [b], A. Bondar [i], B. Borasoy [h], M. Büscher [b,c], H. Calén [j], K. Chandwani [g], H. Clement [d], E. Czerwiński [b,c,k], R. Czyżykiewicz [k], G. D'Orsaneo [b,c], D. Duniec [l,3], C. Ekström [j], R. Engels [b,c], W. Erven [m,c], W. Eyrich [n], P. Fedorets [o], O. Felden [b,c], K. Fransson [j], D. Gil [k], F. Goldenbaum [b,c], K. Grigoryev [b,c,o], A. Heczko [k], C. Hanhart [b,c], V. Hejny [b,c], F. Hinterberger [p], M. Hodana [b,c,k], B. Höistad [j], A. Izotov [e], M. Jacewicz [j,2], M. Janusz [b,c,k], B.R. Jany [b,c,k], L. Jarczyk [k], T. Johansson [j], B. Kamys [k], G. Kemmerling [m,c], L. Keshelashvili [b,c,3], O. Khakimova [d], A. Khoukaz [q], K. Kilian [b,c], N. Kimura [q], S. Kistryn [k], J. Klaja [b,c,k], P. Klaja [b,c,k], H. Kleines [m,c], B. Klos [r], A. Kowalczyk [b,c,k], F. Kren [d], W. Krzemień [b,c,k], P. Kulessa [s], S. Kullander [j], A. Kupść [j], A. Kuzmin [t], V. Kyryanchuk [b,c,d], J. Majewski [b,c,k], H. Machner [b,c,l], A. Magiera [k], R. Maier [b,c], P. Marciniewski [j], W. Migdał [k], U.-G. Meißner [b,c,h,u], M. Mikirtychiants [b,c,e], O. Miklukho [e], N. Milke [p,5], M. Mittag [b,c], P. Moskal [b,c,k], B.K. Nandi [g], A. Nawrot [f], R. Nißler [b], M.A. Odoyo [b,c], W. Oelert [b,c], H. Ohm [b,c], N. Paul [b,c], C. Pauly [b,c], Y. Petukhov [v], N. Piskunov [v], P. Pluciński [j], P. Podkopał [b,c,k], A. Povtoreyko [v], D. Prasuhn [b,c], A. Pricking [d,h], K. Pysz [s], J. Rachowski [w], T. Rausmann [p], C.F. Redmer [b,c], J. Ritman [b,c], A. Roy [g], R.J.M.Y. Ruber [j], Z. Rudy [k], R. Salmin [b,c,v], S. Schadmand [b,c], A. Schmidt [a], H. Schneider [b,c], W. Schroeder [a,6], W. Scobel [x], T. Sefzick [b,c], V. Serdyuk [b,c,y], N. Shah [g], M. Siemaszko [r], R. Siudak [b,c,k,s], T. Skorodko [d], T. Smoliński [b,c,k], J. Smyrski [k], V. Sopov [z], D. Spölgen [b,c], J. Stepaniak [f], G. Sterzenbach [b,c], H. Ströher [b,c], A. Szczurek [k], A. Teufel [a], T. Tolba [b,c], A. Trzciński [e], K. Ulbrich [b], R. Varma [g], P. Vlasov [b,c,e], W. Weglorz [b,c,r], A. Winnemöller [p], A. Wirzba [b,c], M. Wolke [b,c], A. Wrońska [k], P. Wüstner [m,c], H. Xu [aa], A. Yamamoto [q], H. Yamaoka [q], X. Yuan [b,c,aa], L. Yurev [b,c,y], J. Zabierowski [w], C. Zheng [b,c,aa], M.J. Zieliński [b,c,k], W. Zipper [r], J. Złomańczuk [j], K. Zwoll [m,c], I. Zychor [ab]

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$\eta \to 3\pi^0$
Dalitz plot

ABSTRACT
In the first production run of the WASA experiment at COSY, the eta decay into three neutral pions was measured in proton–proton interactions at a proton beam kinetic energy of 1.4 GeV. The Dalitz plot of the three pions was studied using 1.2×10^7 fully reconstructed events, and the quadratic slope parameter α was determined to be $-0.027 \pm 0.008(\mathrm{stat}) \pm 0.005(\mathrm{syst})$. The result is consistent with previous measurements and further corroborates the importance of pion–pion final state interactions.

first WASA at COSY publication

significant increase in user community and collaboration size

WASA-at-COSY Collaboration (2014)

147 members
27 institutions

Sofia

Spokesperson: M. Wolke (Uppsala)
Deputy: P. Moskal (Cracow)

Lanzhou

Physics Coordinator:
A. Kupsc (Uppsala)

Bochum

Bonn

Erlangen

Technical Coordinators:
H. Calen (Uppsala)
F. Goldenbaum (Jülich)

Jülich

Münster

Tübingen

IT Coordinator: V. Hejny (Jülich)

Uppsala

Mumbai

Indore

KEK

Cracow

Katowice

Warsaw

Lodz, Warsaw

Dubna

Moscow

Novosibirsk

The WASA Collaboration
- past, present, future -

The past:

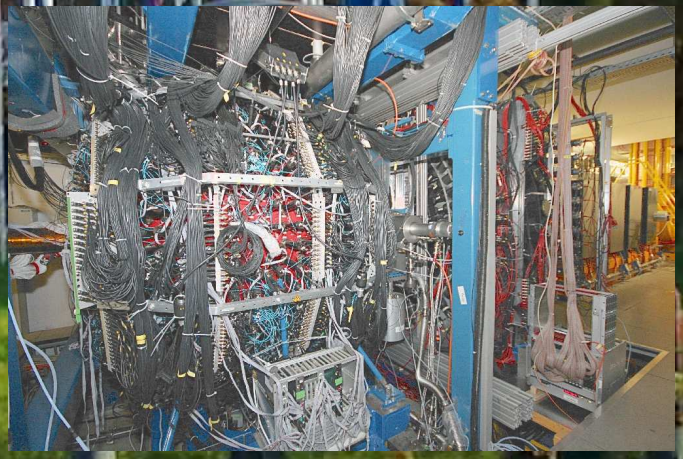
from the LoI to CELSIUS, from CELSIUS to COSY

The present:

analysis of WASA-at-COSY data

The future:

WASA at GSI/FAIR



Magnus Wolke

UPPSALA UNIVERSITET

What is special about the η meson?

- heaviest of octet Goldstone bosons ⇒ many open decay channels

- mass and all interactions vanish in the chiral limit
  ⇒ basis for effective field theory approach (ChPT)

- eigenstate of P, C, CP, and G, $I^G(J^{PC}) = 0^+(0^{-+})$
  ⇒ first order strong and electromagnetic decays forbidden
  ⇒ laboratory to study (non-)conservation of these discrete symmetries

Tests of C symmetry in rare η decays

η decays into neutrals with an odd number of photons

- simplest case: $\eta \to 3\gamma$

  $\eta \to \gamma + (\gamma\gamma)_{J=0}$ forbidden for real γ ($0 \to 0$ transition)

  $\eta \to \gamma + (\gamma\gamma)_{J=1}$ forbidden by Bose symmetry

  $\Rightarrow$ each $(\gamma\gamma)$ pair hase to have at least J=2

$BR(\eta \to 3\gamma) \leq 1.6 \times 10^{-5}$

KLOE PLB 591 (04) 49

- $\eta \to \pi^0\gamma$ $0 \to 0$ transition

$BR(\eta \to \pi^0\gamma) \leq 9 \times 10^{-5}$

Crystal Ball PRC 72 (05) 035212

- $\eta \to \pi^0\pi^0\gamma$, $\eta \to 3\pi^0\gamma$, ...

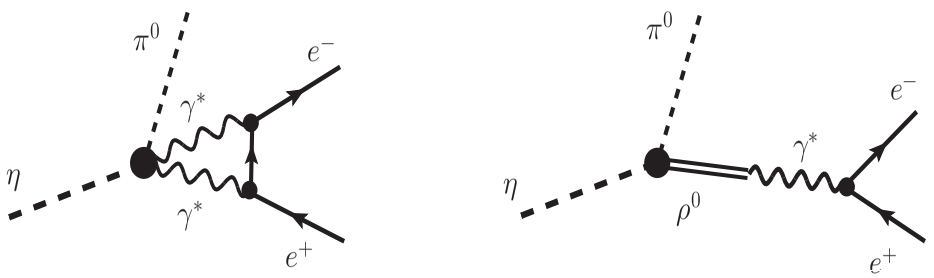
η decays into neutrals with an odd number of l^+l^-

- $\eta \to \pi^0 e^+ e^-$

Tests of C symmetry in rare η decays

η decays into neutrals with an odd number of l^+l^-

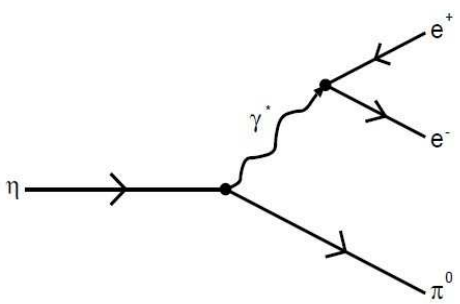
Standard Model C conserving contribution:



$$\mathrm{BR}(\eta \to \pi^0 e^+ e^-) \approx 1.1 \times 10^{-8}$$

T.P.Cheng, PR 162 (67) 1734

C invariance violating process:



experiment:

$$\mathrm{BR}(\eta \to \pi^0 e^+ e^-) \leq 4.5 \times 10^{-5}$$

M.R.Jane et al., PLB 59 (75) 99

PDG:

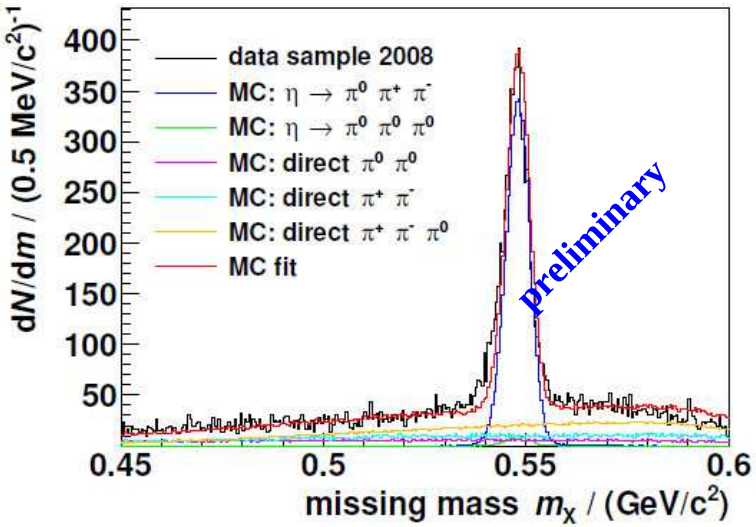
$$\mathrm{BR}(\eta \to \pi^0 e^+ e^-) \leq 4.0 \times 10^{-5}$$

$\eta \to \pi^0 e^+ e^-$ with WASA-at-COSY

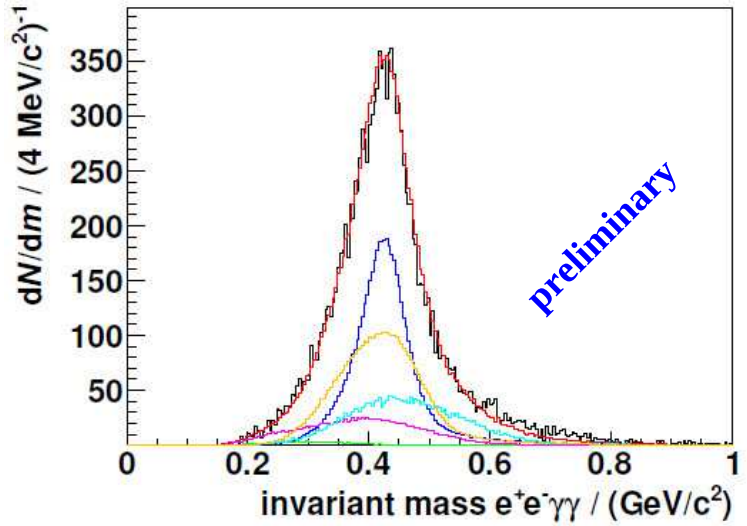
F.S.Bergmann, PhD thesis,
WWU Münster (2017)

$pd \to {}^3He\,X$, after preselection

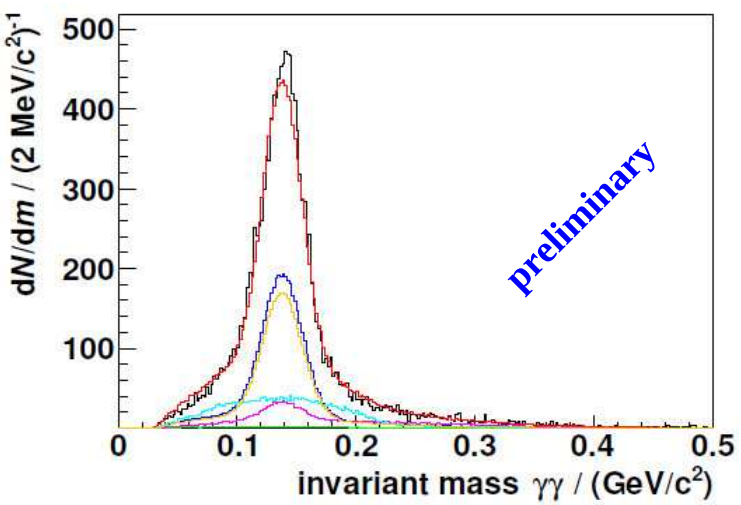
missing mass m_X



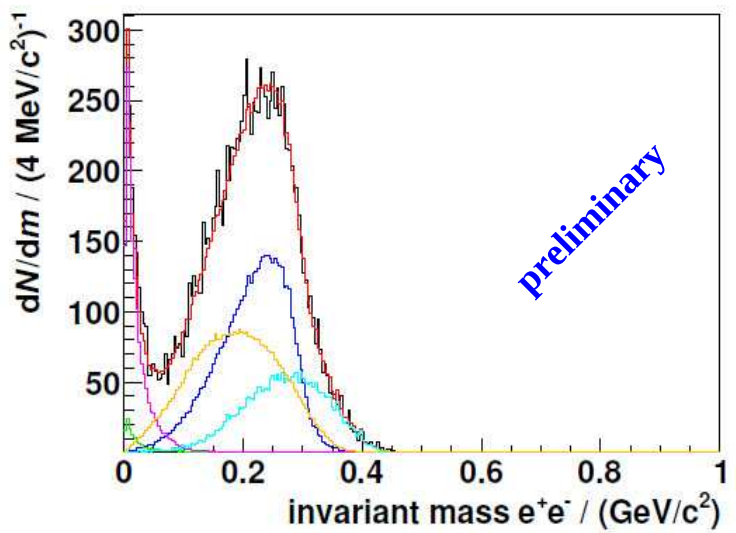
invariant mass ($e^+e^-\gamma\gamma$)



invariant mass ($\gamma\gamma$)



invariant mass (e^+e^-)



remaining background: $\eta \to \pi^+\pi^-\pi^0$, direct $\pi^+\pi^-\pi^0$, $\pi\pi$

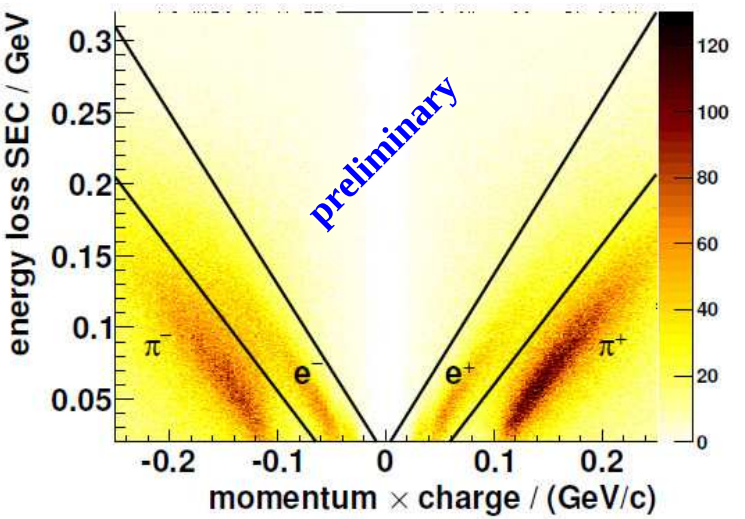
$\eta \to \pi^0 e^+ e^-$ with WASA-at-COSY

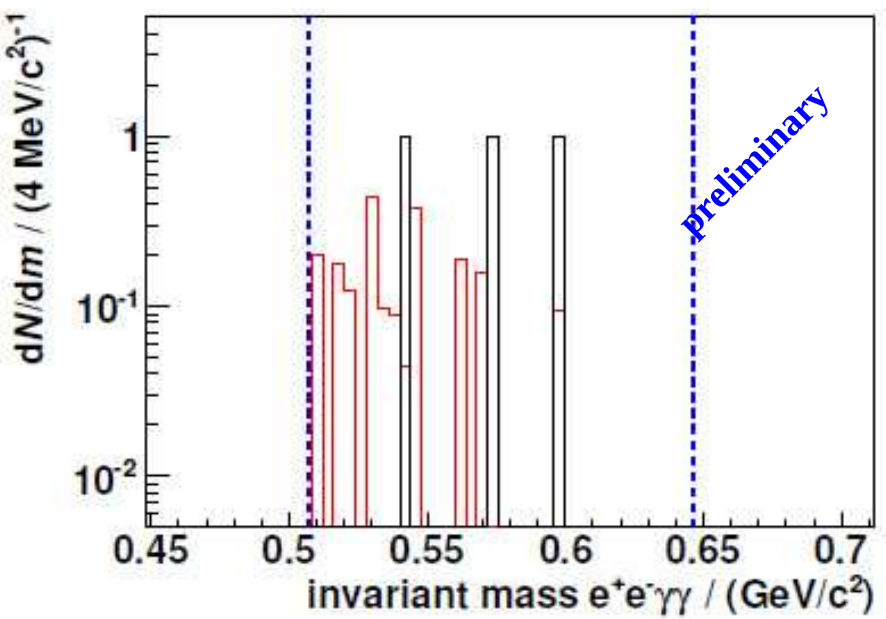
F.S.Bergmann, PhD thesis,
WWU Münster (2017)

$pd \to {}^3He X$, signal selection

signal selection cuts

- missing mass m_X
- invariant mass ($\gamma\gamma$)
- χ^2 $e^+e^-\gamma\gamma$ kinematic fit
- invariant mass ($e^+e^-\gamma\gamma$)
- invariant mass (e^+e^-)
- e^+e^- identification





- 3 events left after selection criteria
- 2 events expected ($pd \to {}^3He\pi^+\pi^-\pi^0$)

preliminary result:

$BR(\eta \to \pi^0 e^+ e^-) < 7.5\ (9.5) \times 10^{-6}$

for VMD (phase space) decay of signal channel

factor 6 (5) below present upper limit

publication drafted

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The future:

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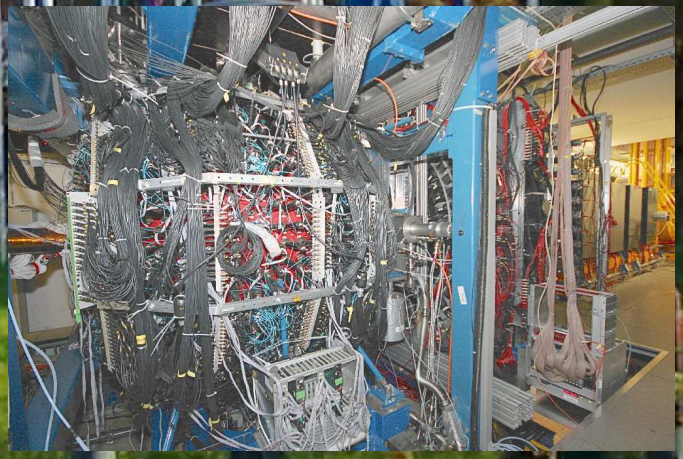

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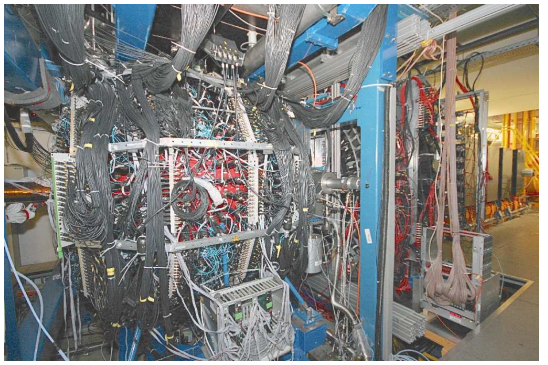
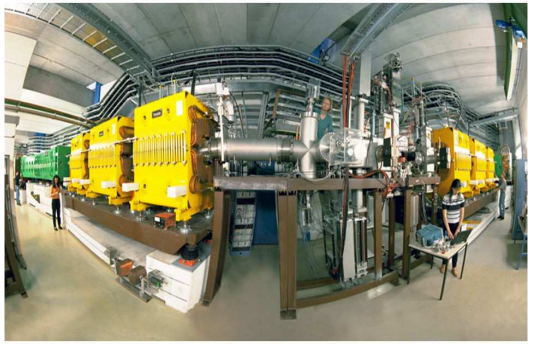
WASA at GSI/FAIR



With the end of the experimental programme at COSY it has been the wish of the owners that the detector shall be used for excellent physics in future

WASA FD in use at COSY

WASA CD to GSI/FAIR: unique opportunity



Key ingredients:

- strong physics case
- investment against bottlenecks
- user community, manpower
- infrastructure

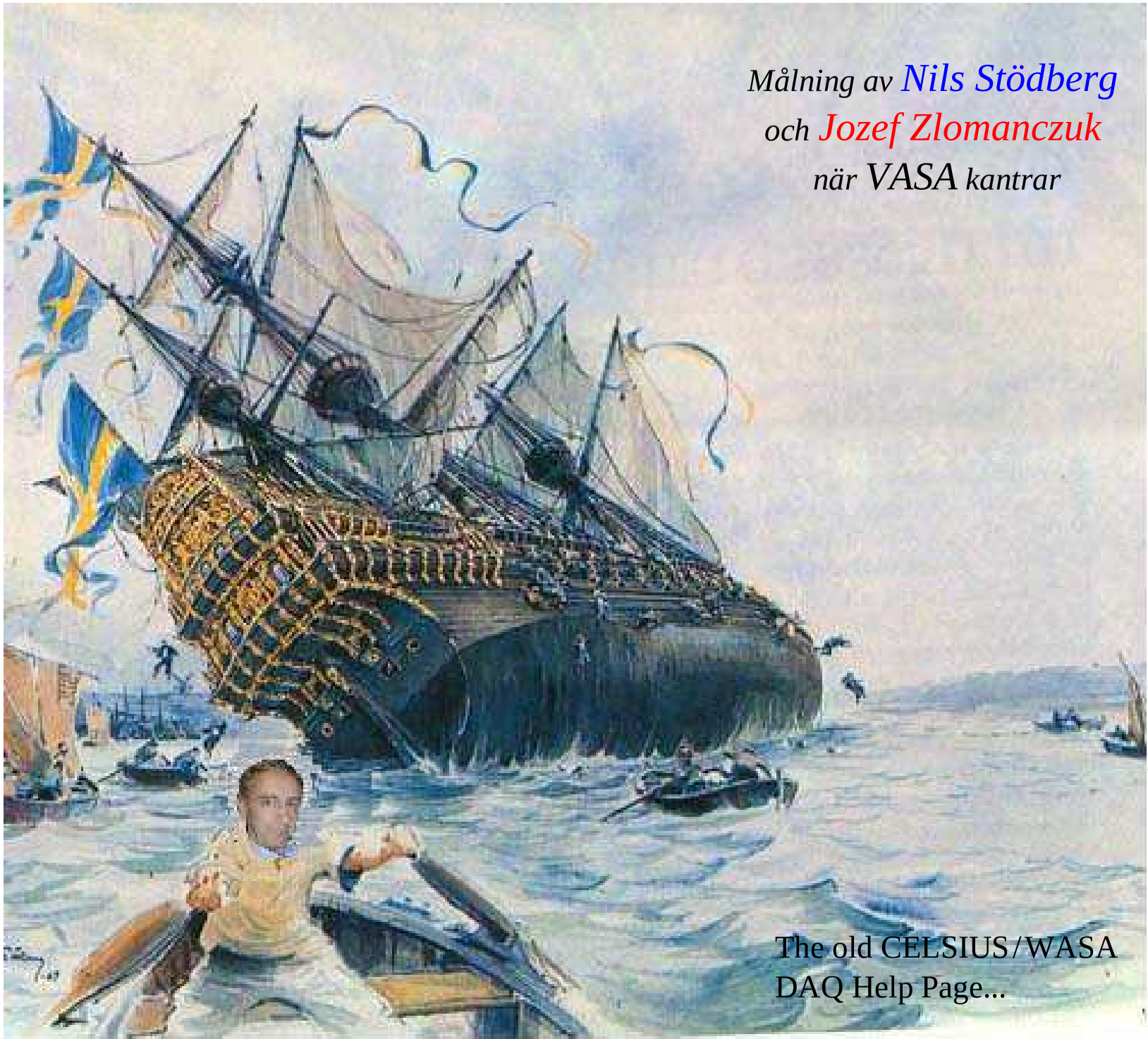
⇒ This workshop is the place to take important steps in these directions

Even if some people may be tempted to think so,

The WASA experiment

has (**almost**) nothing to do with

what you see on the picture!

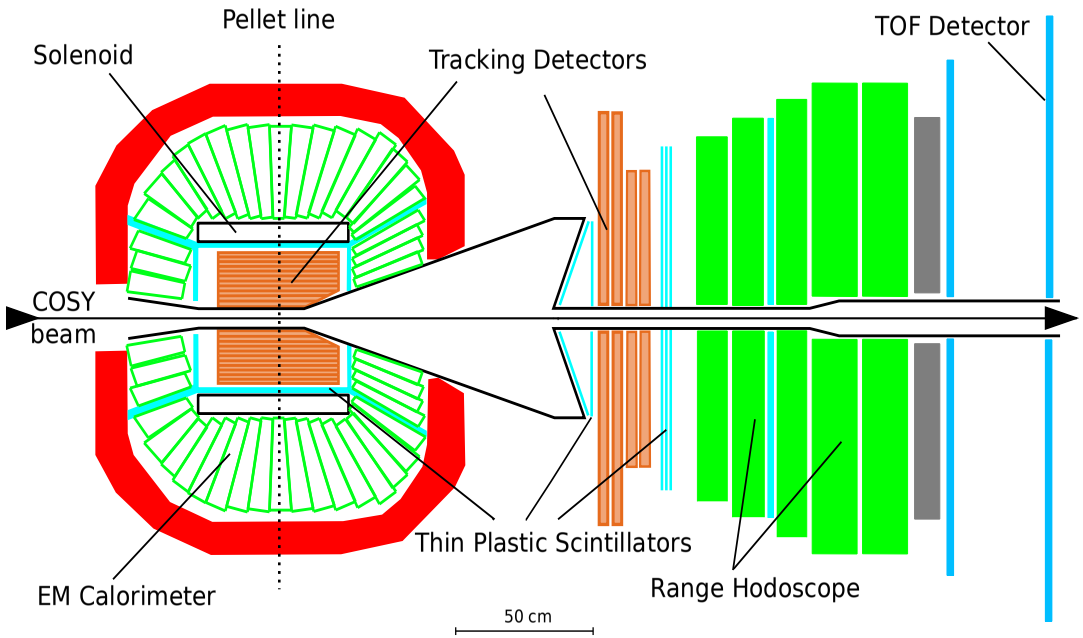


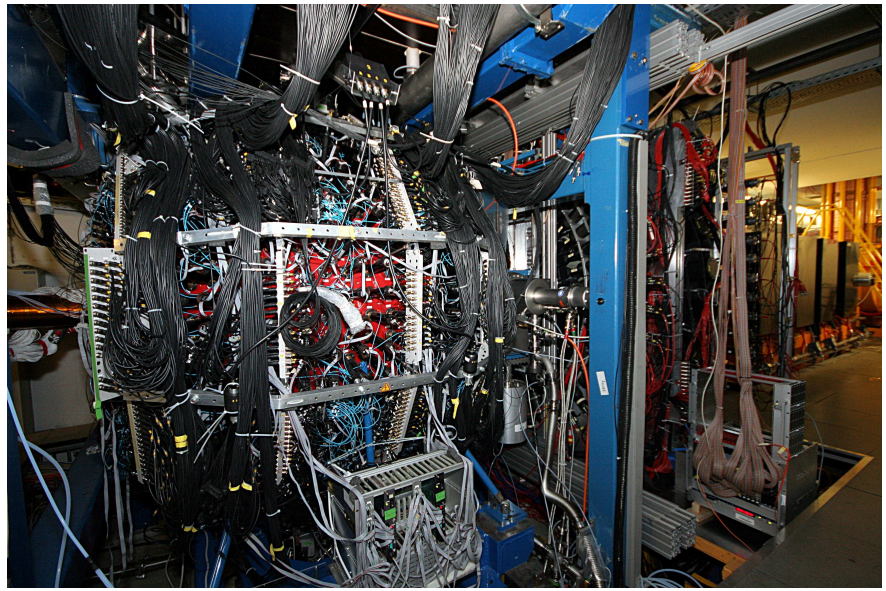
The WASA Facility

an internal 4π detector

H.-H. Adam et al. (proposal), nucl-ex/0411038

~~www2.fz-juelich.de/ikp/wasa~~





Central Detector

...light meson decay products

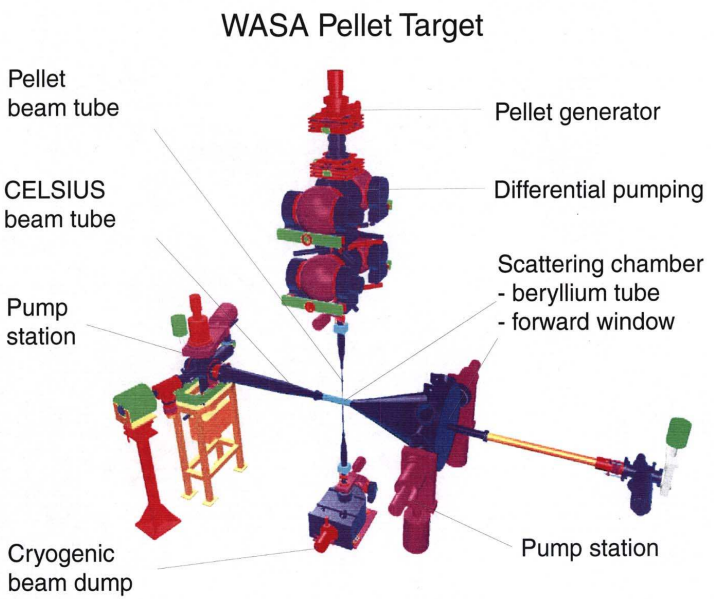
- Superconducting Solenoid
- Plastic Scintillator Barrel
- Straw Chamber
- Scintillator Electromagnetic Calorimeter

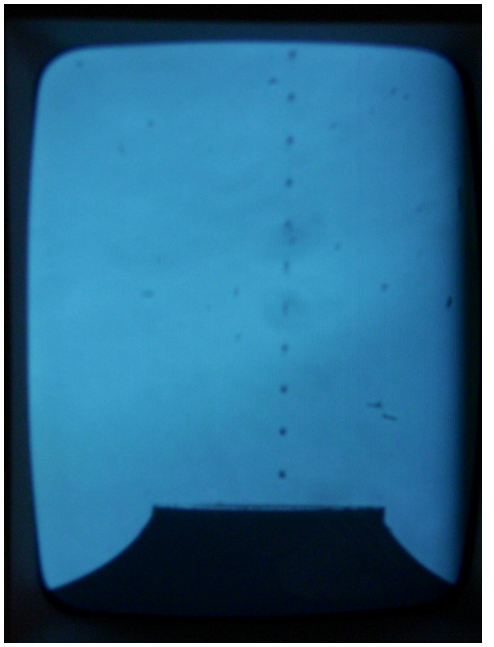
Forward Detector

...scattered projectiles and charged recoil particles

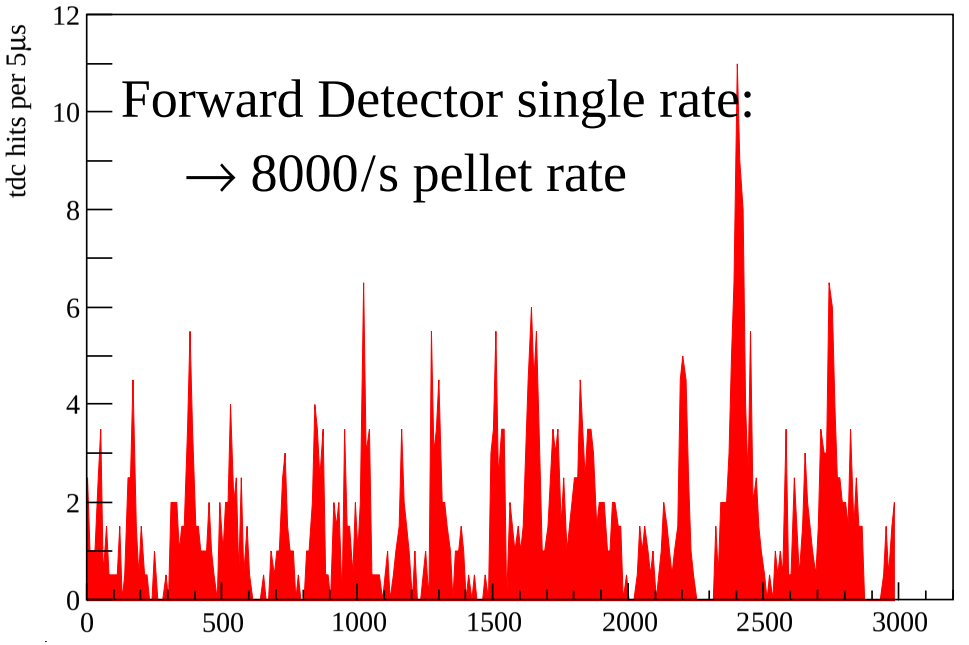
- Plastic Scintillators
- Forward Straw Tracker

Pellet Target





droplet stream
before vacuum injection

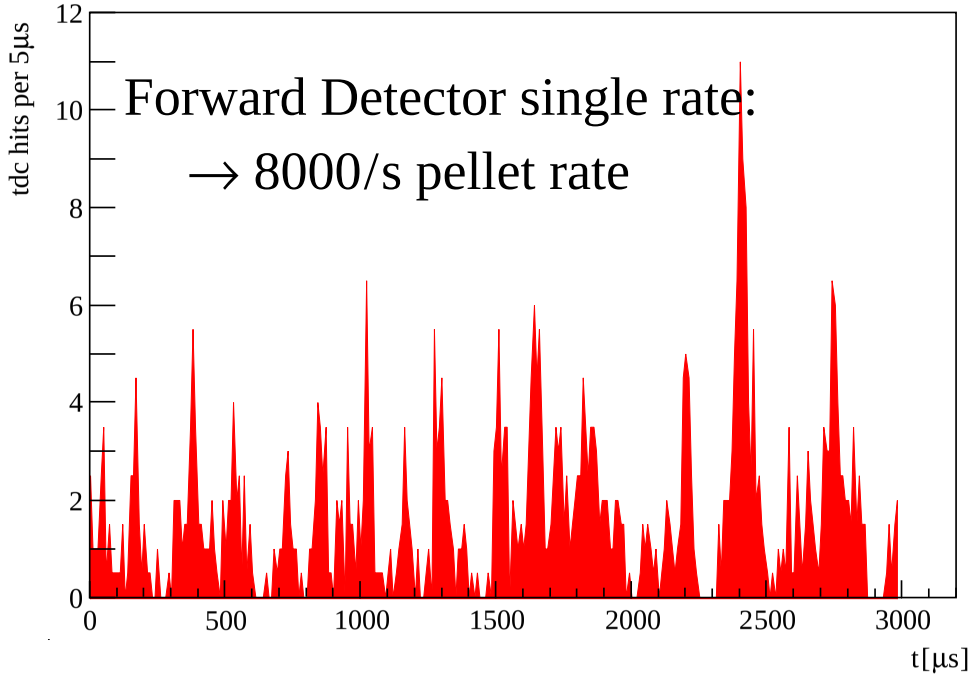


Typical Target Values:

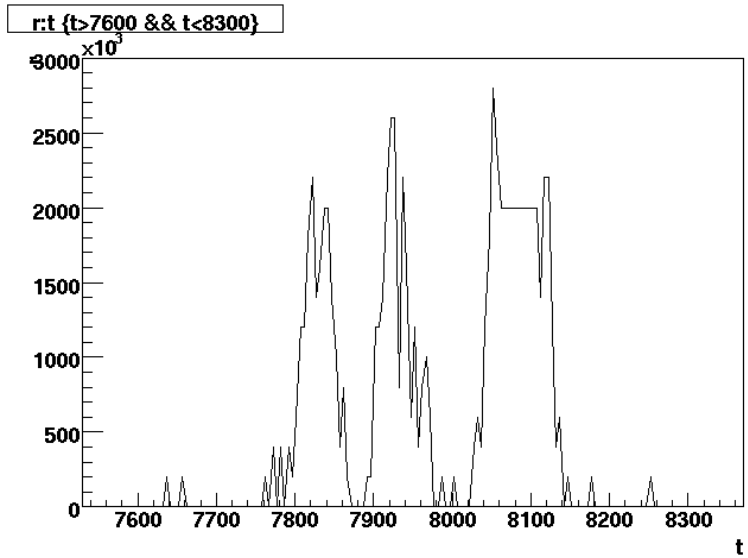
Pellet diameter	20 - 30 µm
Pellet frequency	5 - 12 kHz
Pellet velocity	60 - 80 m/s
Effective thickness	$>10^{15}$ atoms/cm^2

Goal: always one "pellet in beam"

Pellet rates



→ average time "pellet in beam"
≈ 80-100µs



Goal for target operation: always one "pellet in beam"

Higher droplet frequency

Uniform time distribution

Future developments:

Pellet Tracking

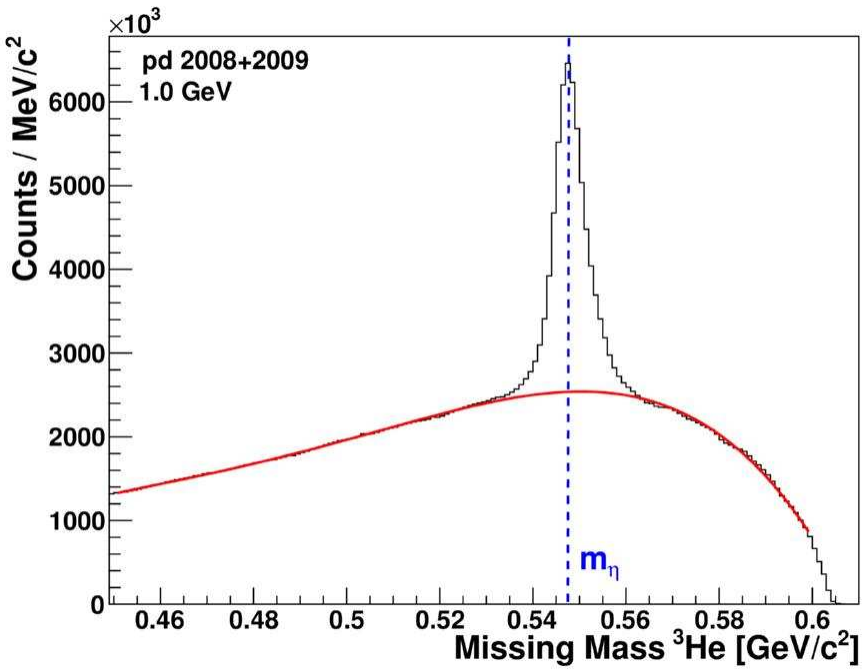
→ Improved vertex reconstruction

Time and velocity distribution

→ MC studies of pellet-beam interaction as preparation for PANDA

η tagging with WASA-at-COSY

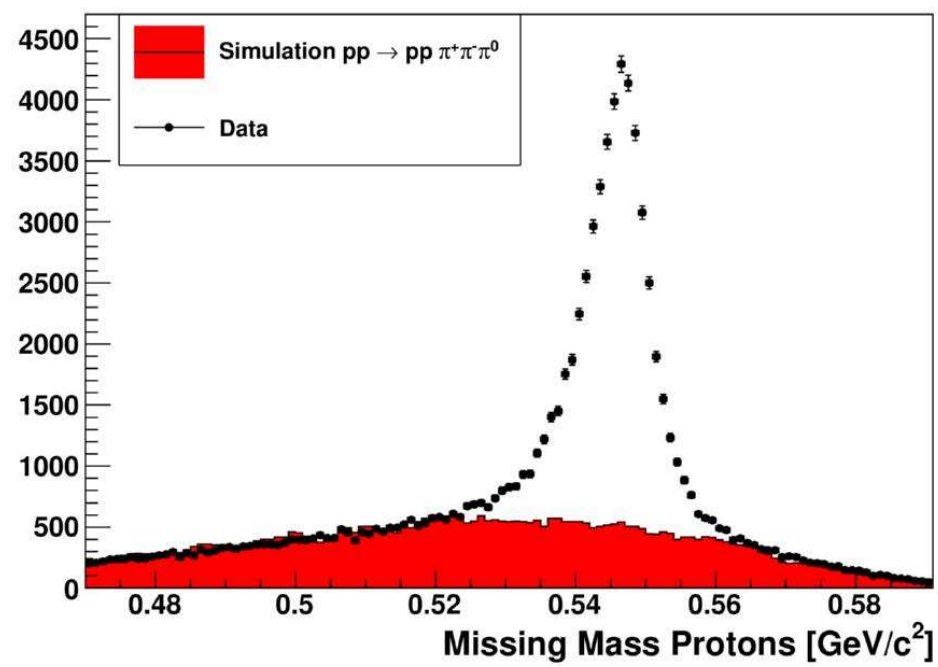
$pd \rightarrow {}^3He\eta$



- lower cross section
- unbiased trigger
- 3×10^7 η mesons tagged

⇒ precision studies for common decays

$pp \rightarrow pp\eta$

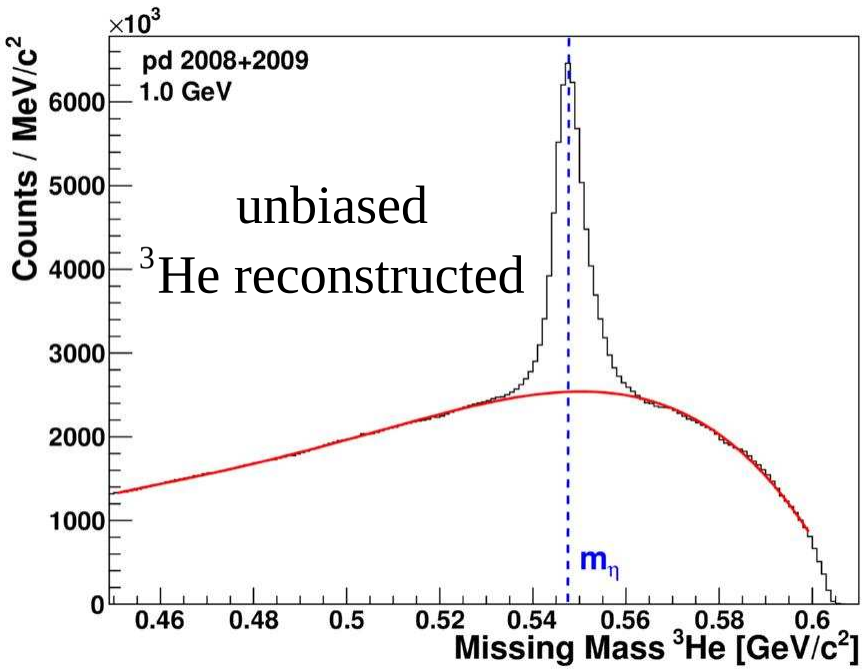


- larger cross section
- decay selective trigger required
- $\sim5\times10^8$ η mesons tagged

⇒ large statistics studies, rare decays

η tagging with WASA-at-COSY

$pd \rightarrow {}^3He\eta$



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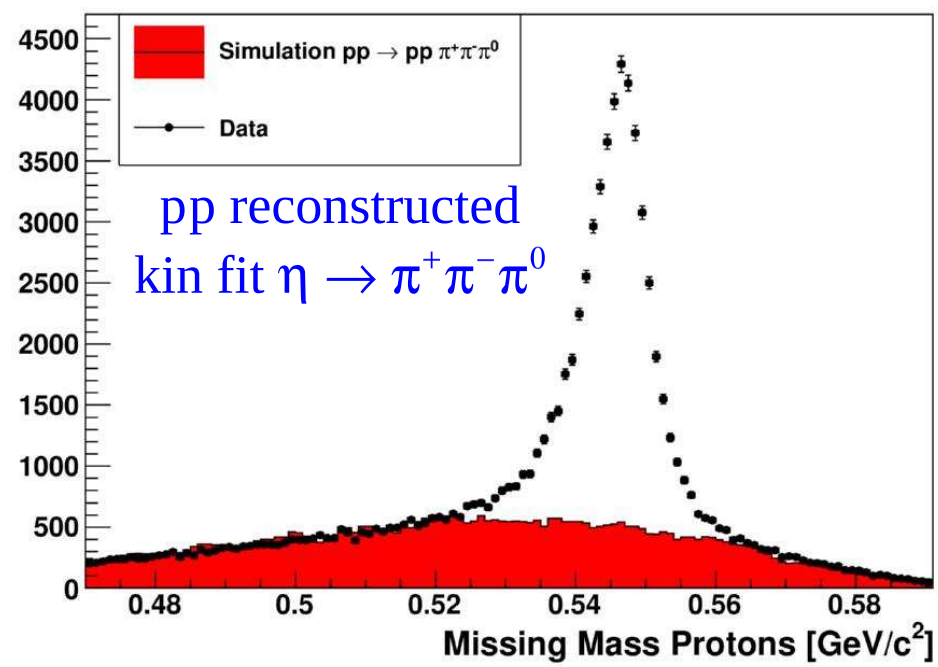

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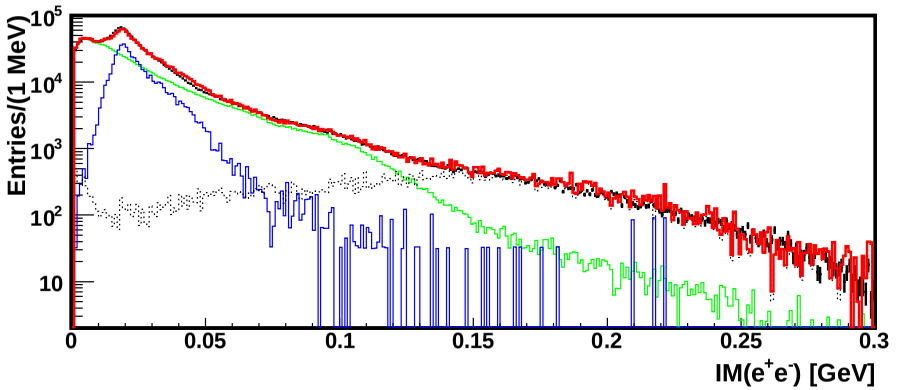
Search $\pi^0 \to \gamma U$ with WASA

P.Adlarson et al.,
PLB 726 (2013) 187



- data
- MC sum
- $\pi^0 \to e^+e^-\gamma$
- $\pi^0 \to \gamma\gamma$
- accidentals

$\Rightarrow$ considerable background from γ conversion

Search $\pi^0 \to \gamma U$ with WASA

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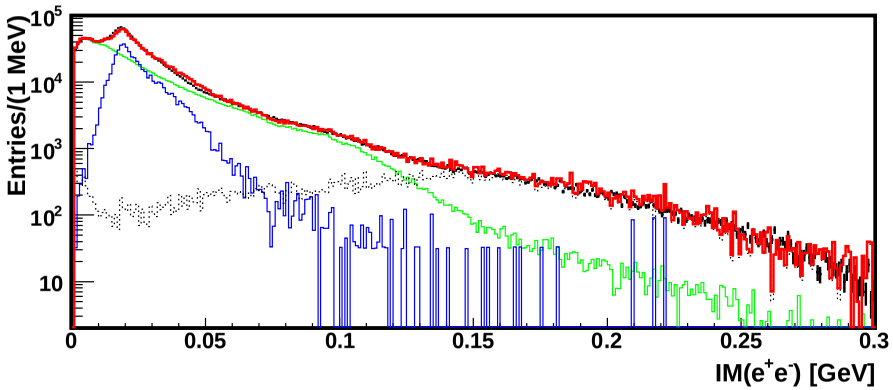

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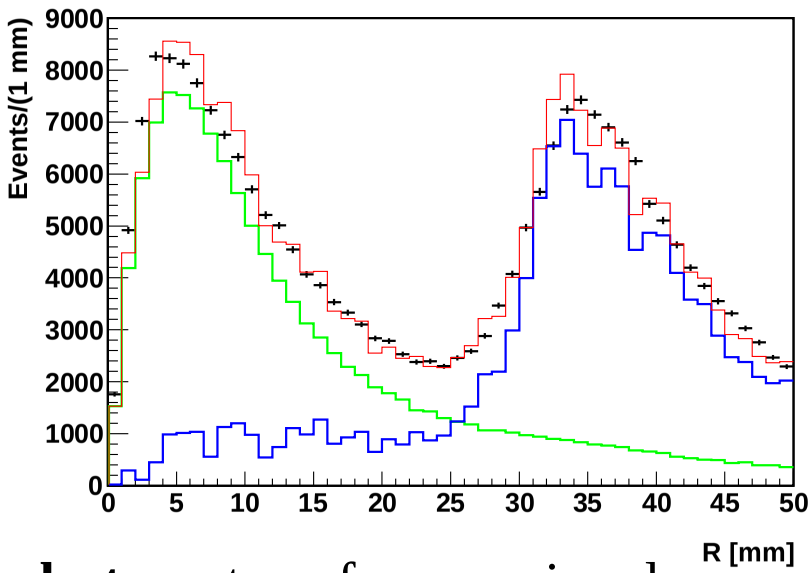

but: vertex of conversion decays is not at the target point

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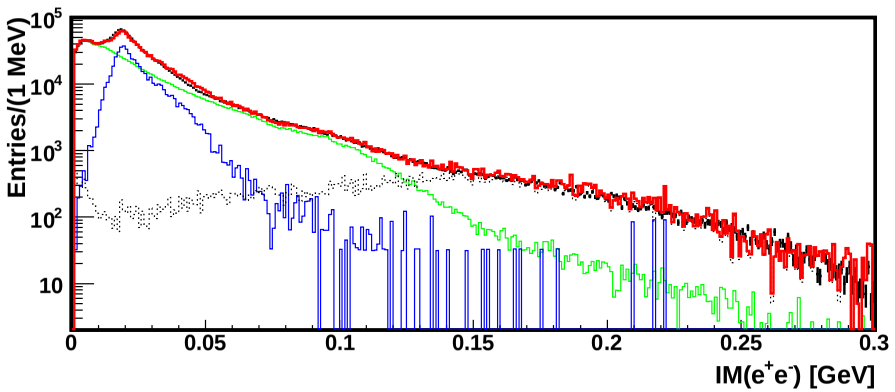

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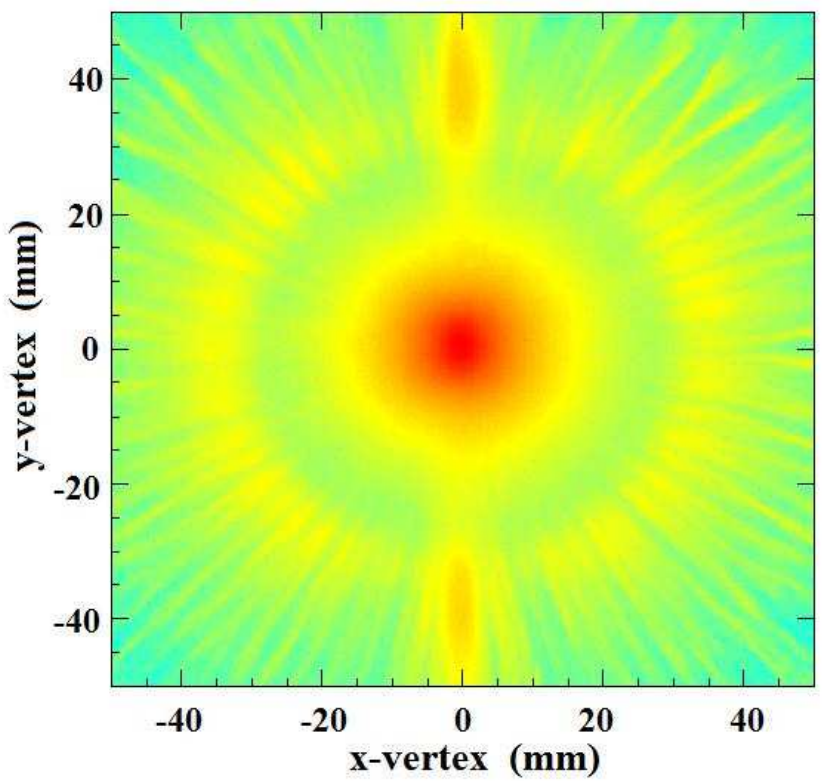
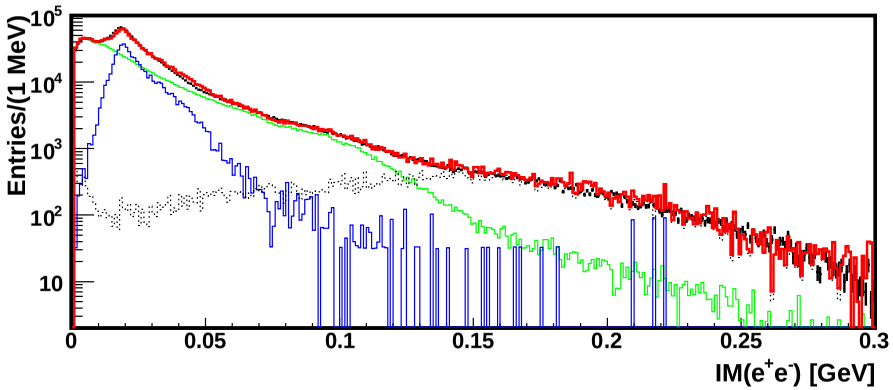


target and conversion decays
from reconstructed vertices

Search $\pi^0 \to \gamma U$ with WASA

P.Adlarson et al.,
PLB 726 (2013) 187



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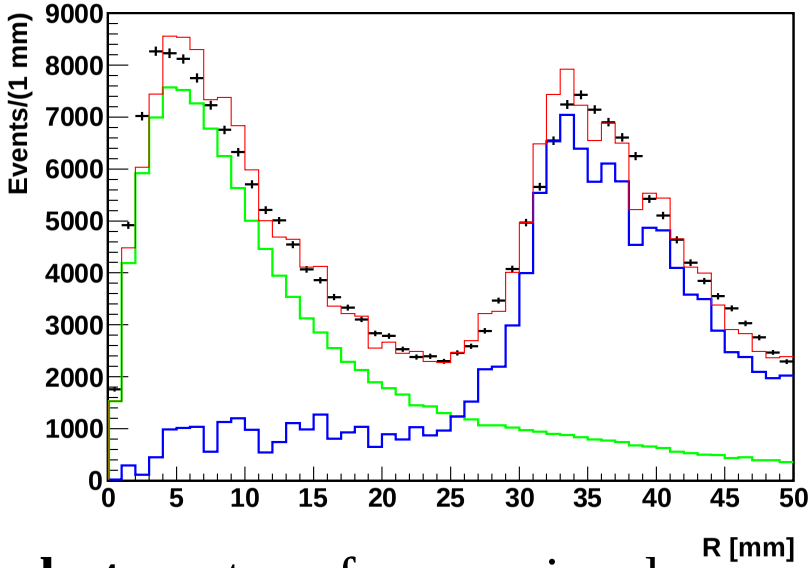

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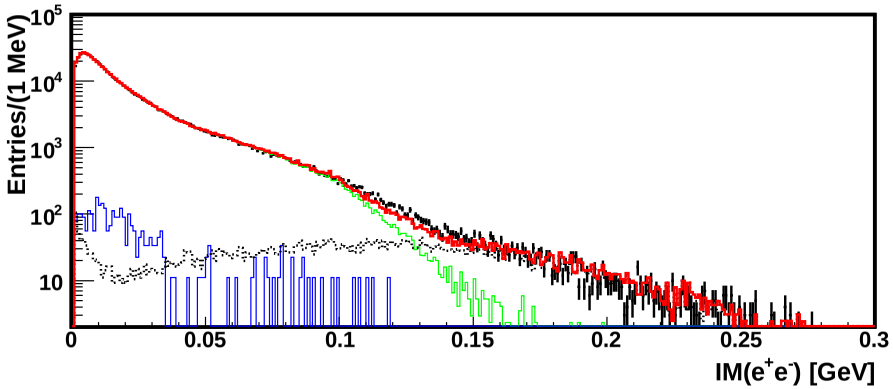

$\Rightarrow$ almost background free $\pi^0 \to e^+e^-\gamma$ events (~ 500k)

Dark photon mixing parameter ε

P.Adlarson et al.,
PLB 726 (2013) 187

$$\frac{\Gamma(\pi^0 \to \gamma U)}{\Gamma(\pi^0 \to \gamma\gamma)} = 2\varepsilon^2 |F(M_U^2)|^2 (1 - \frac{M_U^2}{M^2})^2$$

M.Reece, L.-T.Wang, JHEP 0907 (2009) 051