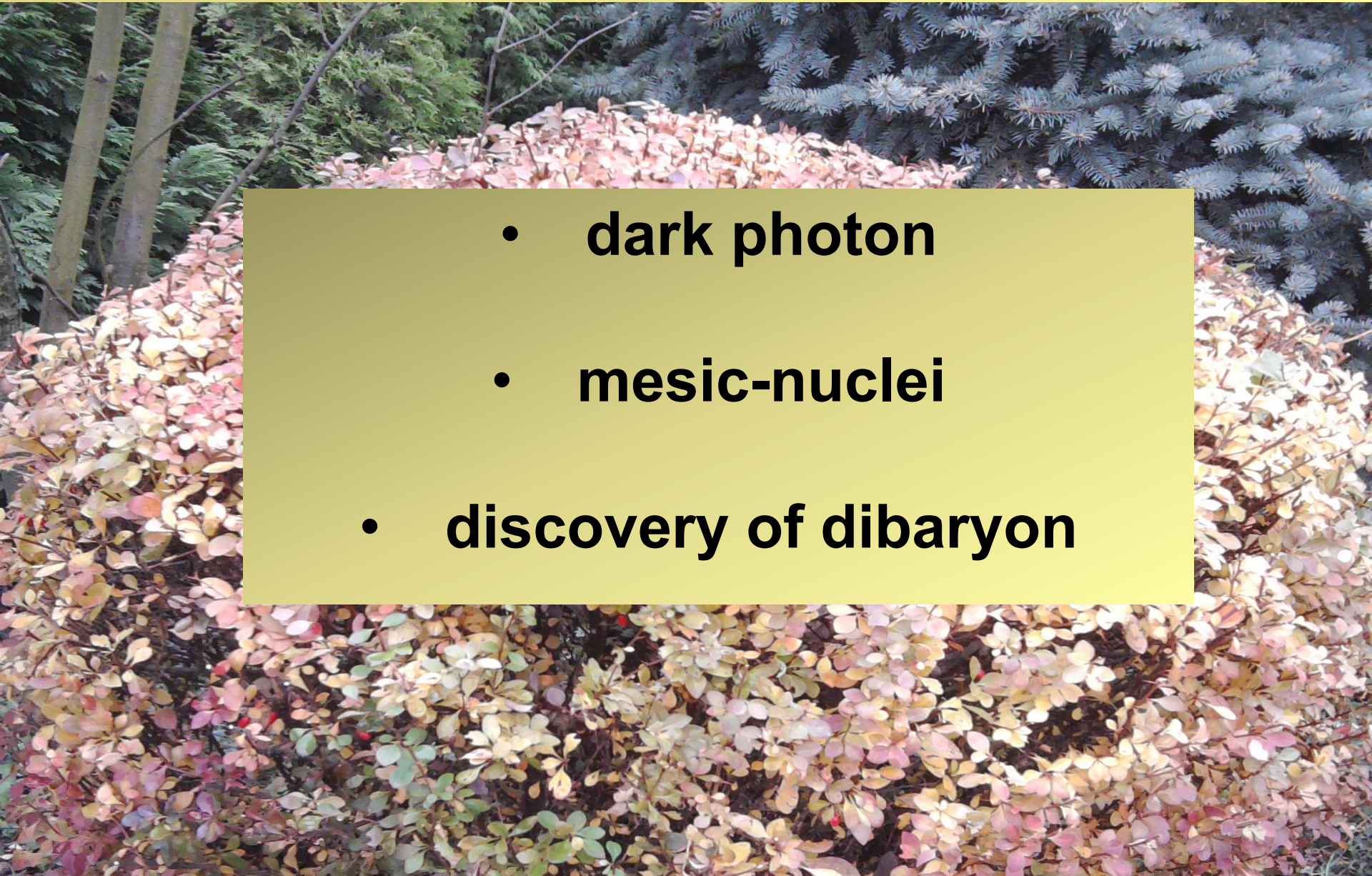
# Search for dark photon and for exotic hadronic matter

Paweł Moskal
Jagiellonian University, Cracow,Poland

**55 Cracow School of Theoretical Physics**
**Zakopane, June 27, 2015**

# Search for dark photon and for exotic hadronic matter



- dark photon
- mesic-nuclei
- discovery of dibaryon

CHANDRA
SATELLITE

chandra.harvard.edu

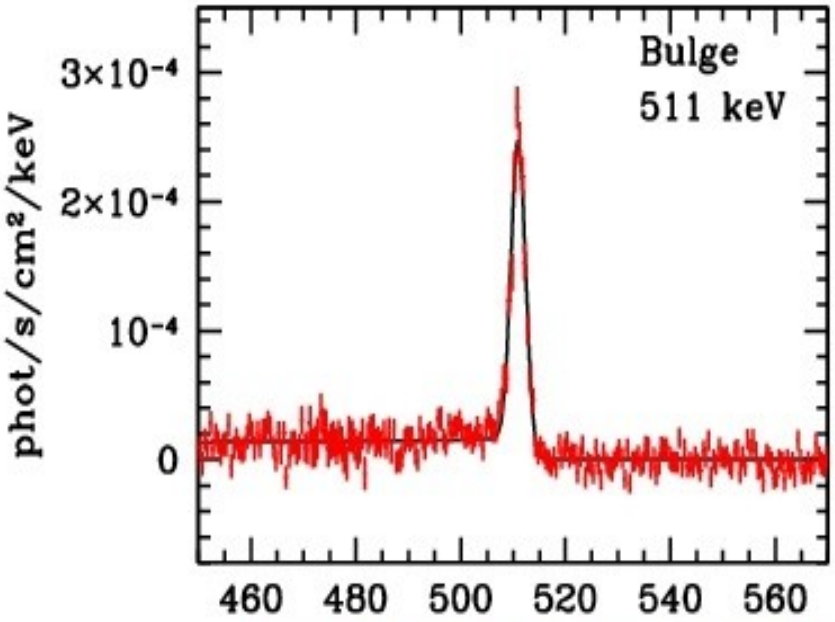
0.5 Mpc

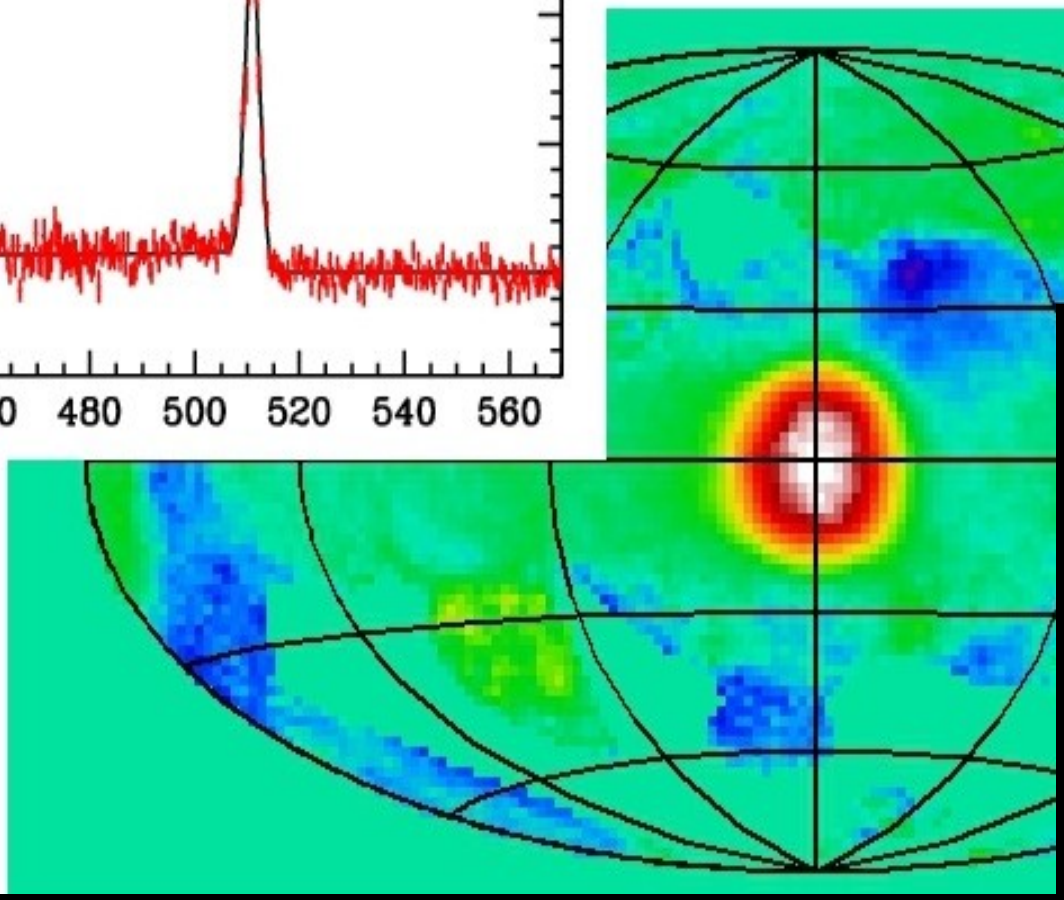
**Princess Elisabeth of Bohemia writes on 10.vi.1643:**

„…I don't see how the idea that you used to have about weight can guide us to the idea we need in order to judge **how the (nonextended and immaterial) soul can move the body"**

**Descartes writes on 28.vi.1643:**

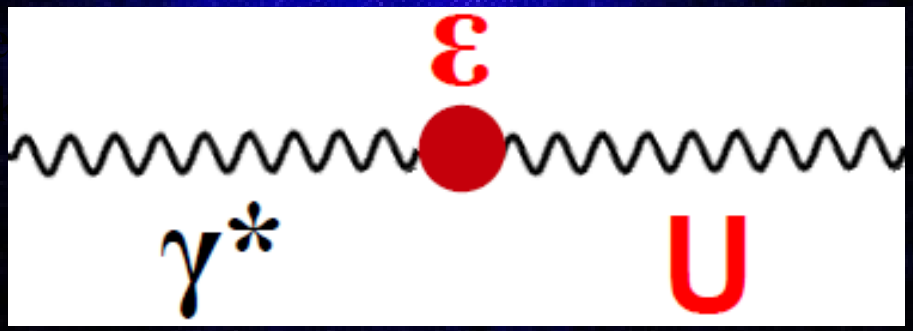
„…I ought to have made clear that although one may wish to think of the soul as material (…), that wouldn't stop one from realizing that the soul is separable from the body. I think that those cover everything that you asked me to do in your letter."



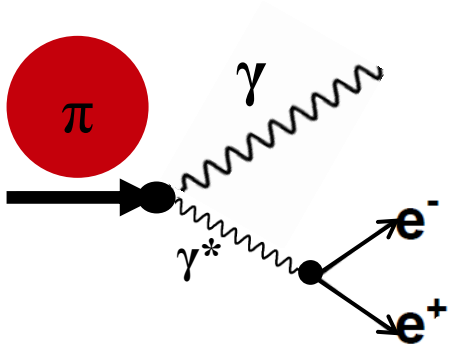
# INTEGRAL SATELLITE

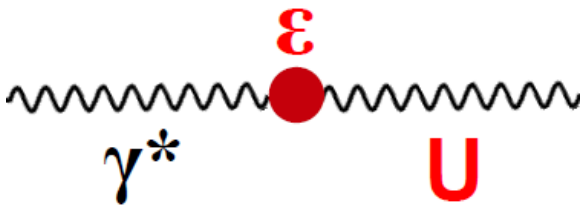
CHANDRA
SATELLITE

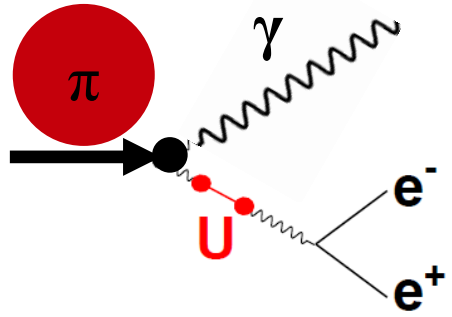


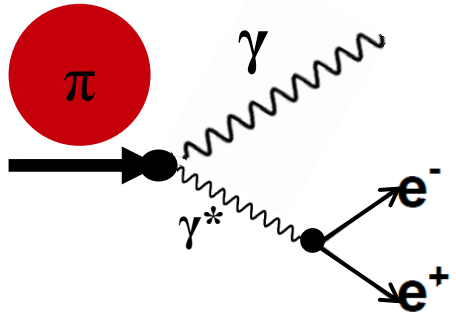

chandra.harvard.edu

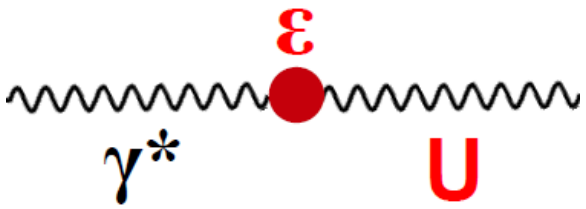
0.5 Mpc

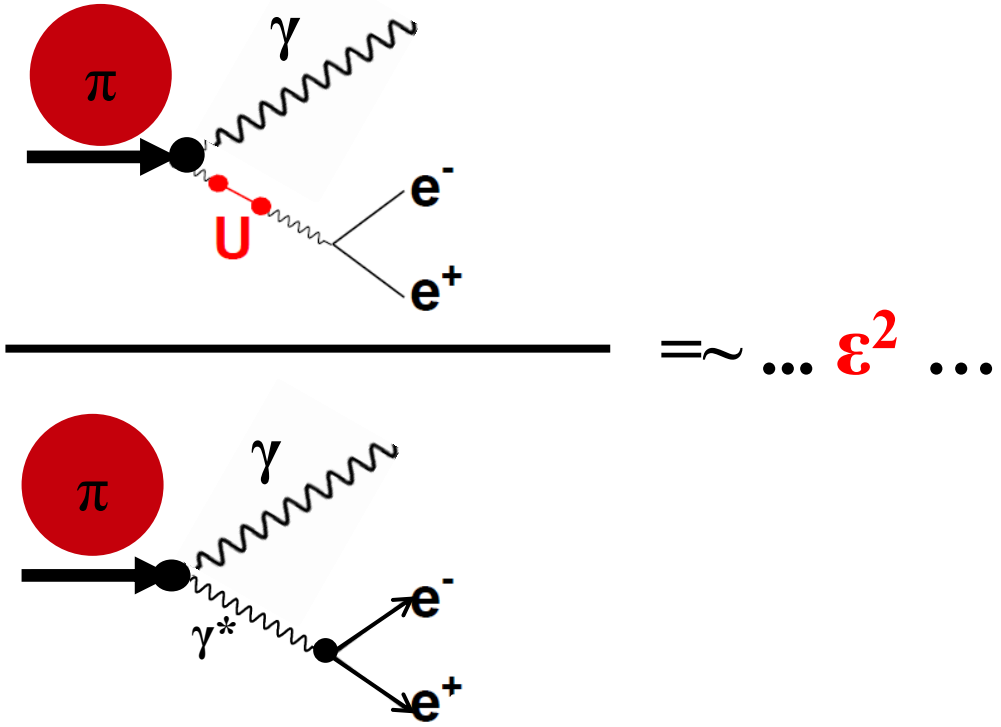

π
γ
γ*
e-
e+


ε
γ*
U


π
γ
U
e-
e+


π
γ
γ*
e-
e+


ε
γ*
U

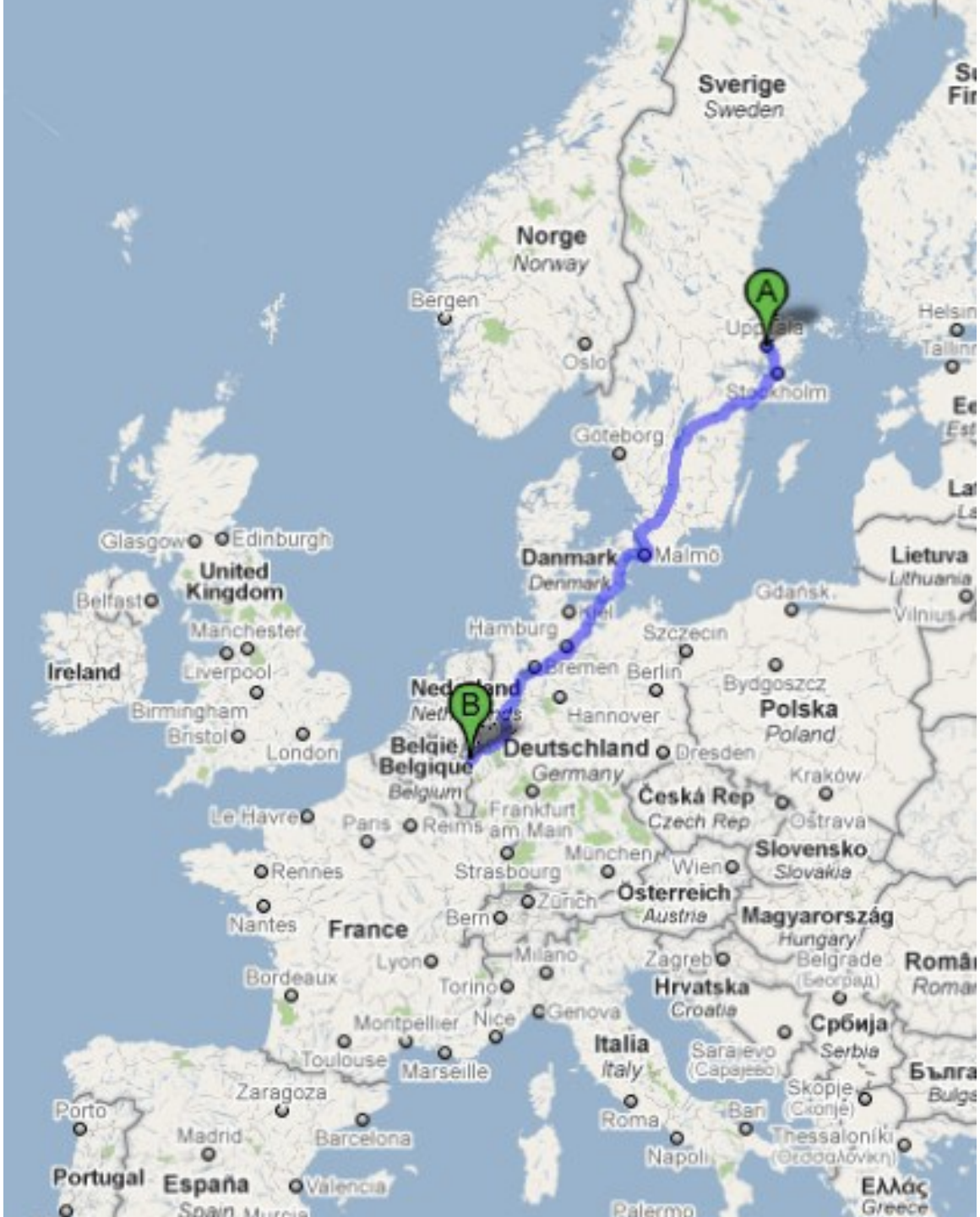

π
γ
e-
U
e+
=~ … ε2 …
π
γ
e-
γ*
e+

# WASA-at-COSY

# $10^9\ \eta$ and $10^{11}\ \pi^0$ mesons on discs

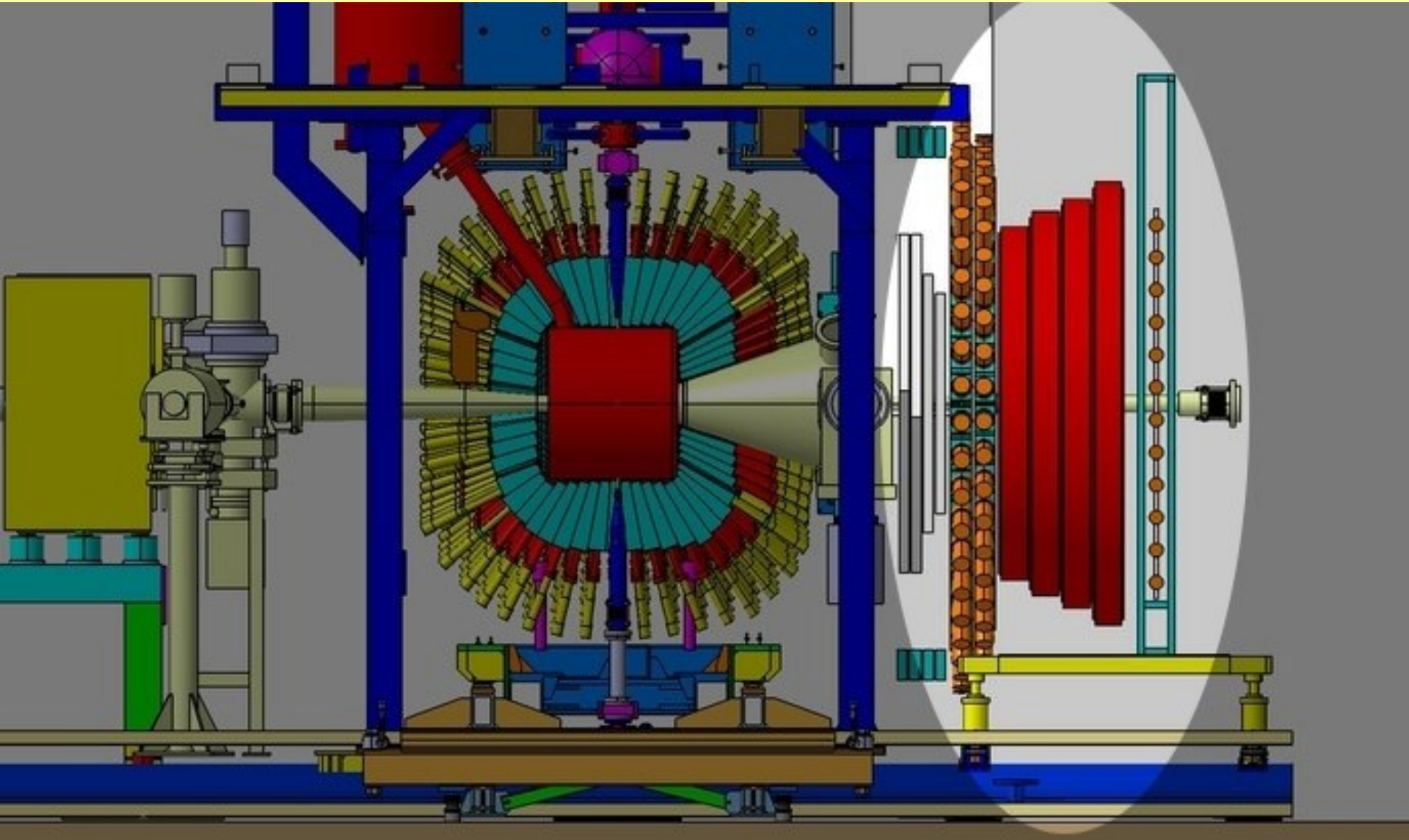
WASA

A WARSHIP built for the war with Poland
which sank in 1628 in the middle of Stockholm harbour
after sailing barely 1300 meters


A
B
Sverige
Sweden
Norge
Norway
Bergen
Oslo
Göteborg
Stockholm
Uppsala
Helsinki
Tallinn
Glasgow
Edinburgh
United Kingdom
Belfast
Ireland
Manchester
Liverpool
Birmingham
Bristol
London
Danmark
Denmark
Malmö
Lietuva
Lithuania
Gdańsk
Vilnius
Hamburg
Kiel
Szczecin
Bremen
Berlin
Bydgoszcz
Polska
Poland
Nederland
Netherlands
Hannover
België
Belgique
Belgium
Deutschland
Germany
Dresden
Kraków
Česká Rep
Czech Rep
Ostrava
Le Havre
Paris
Reims
Frankfurt am Main
München
Wien
Slovensko
Slovakia
Rennes
Strasbourg
Österreich
Austria
Zürich
Nantes
France
Bern
Magyarország
Hungary
Lyon
Milano
Zagreb
Belgrade
Bordeaux
Torino
Hrvatska
Croatia
Montpellier
Nice
Genova
Србија
Serbia
Toulouse
Marseille
Italia
Italy
Sarajevo
Zaragoza
Skopje
Porto
Roma
Bari
Madrid
Barcelona
Napoli
Thessaloníki
Portugal
España
Valencia
Ελλάς
Greece
Palermo

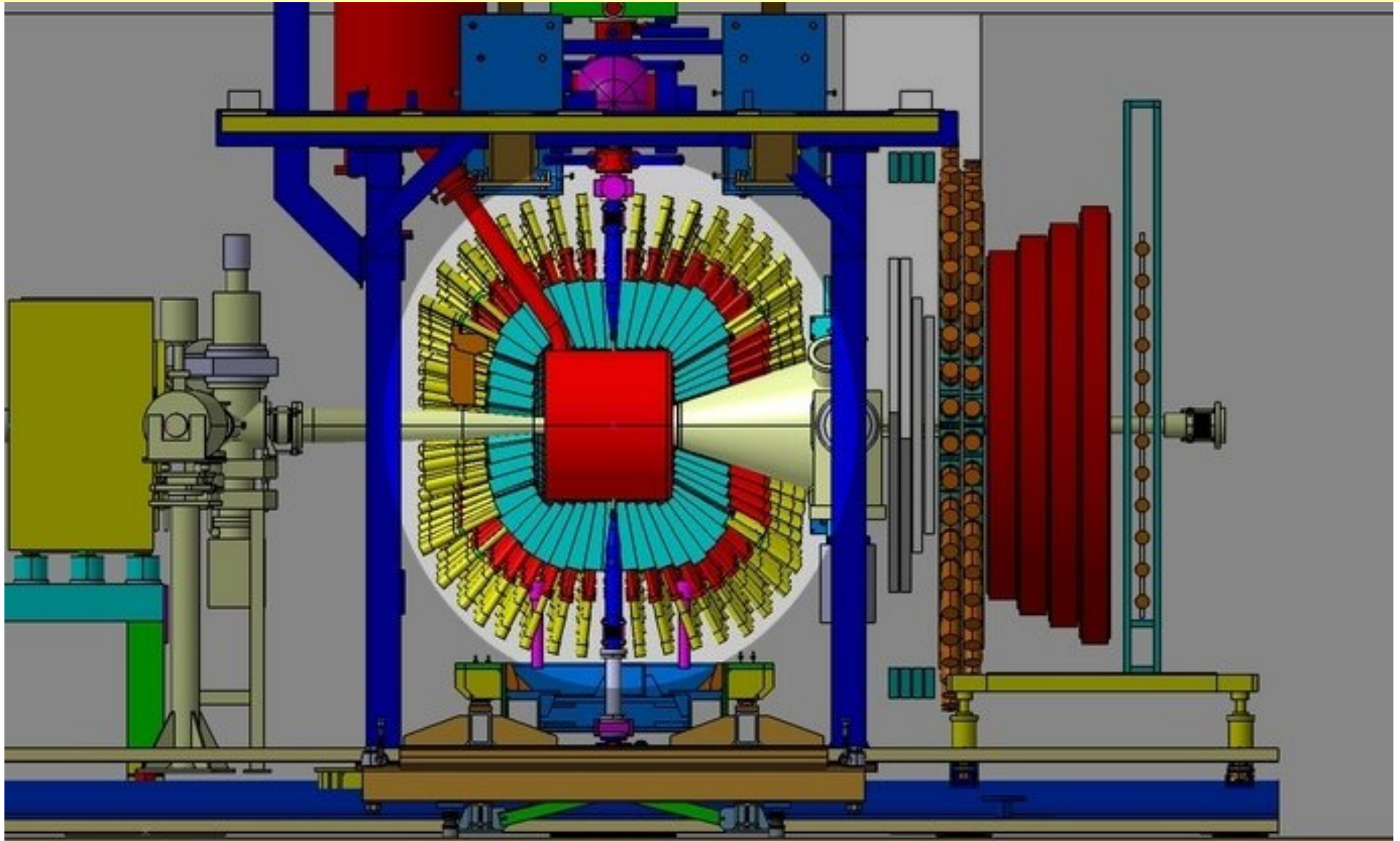
# WASA-at-COSY

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



# WASA-at-COSY

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



# WASA-at-COSY

## $pp \rightarrow pp\,\eta$ $\qquad$ $pd \rightarrow {}^3He\,\eta$

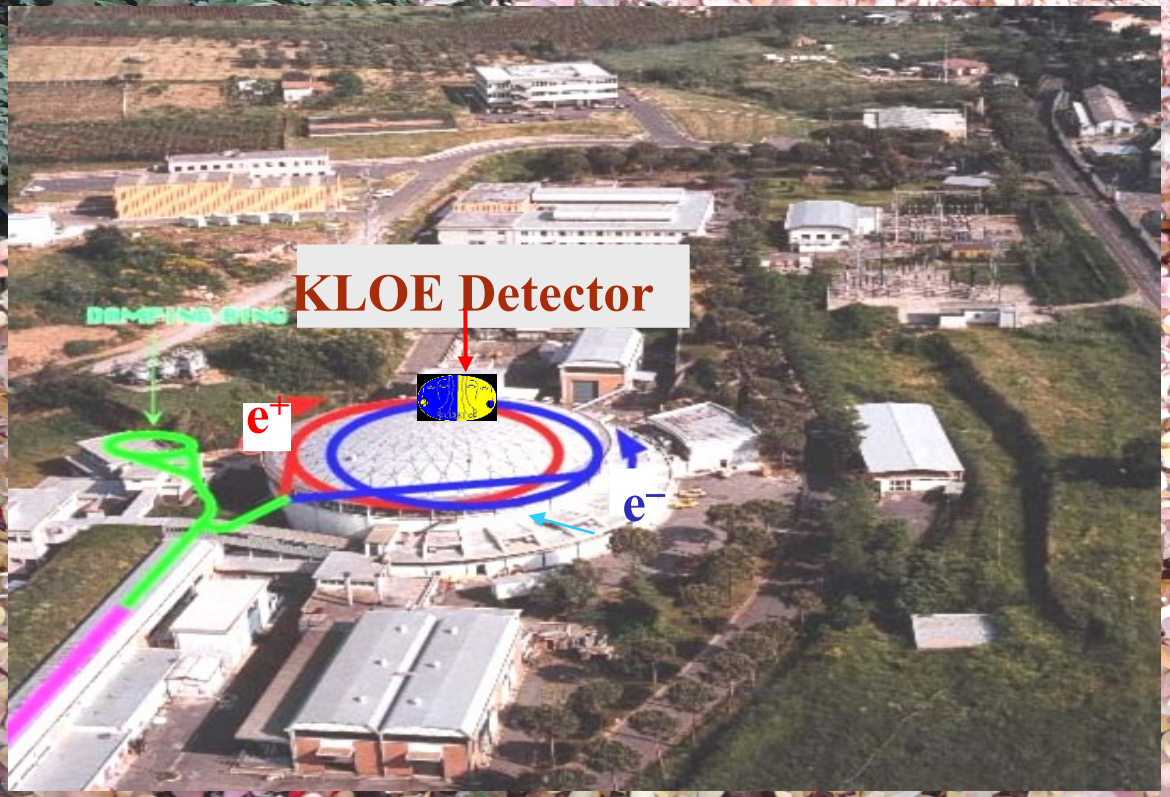
E. Czerwiński, P.M. et al., Phys. Rev. Lett. 113 (2014) 062004

E. Czerwiński, P.M. et al., Phys. Rev. Lett. 105 (2010) 122001

R. Czyżykiewicz, P.M. et al., Phys. Rev. Lett. 98 (2007) 122003

P.M. et al., Phys. Rev. Lett. 80 (1998) 3202

# DAΦNE $e^+e^-$ collider Frascati (Rome)

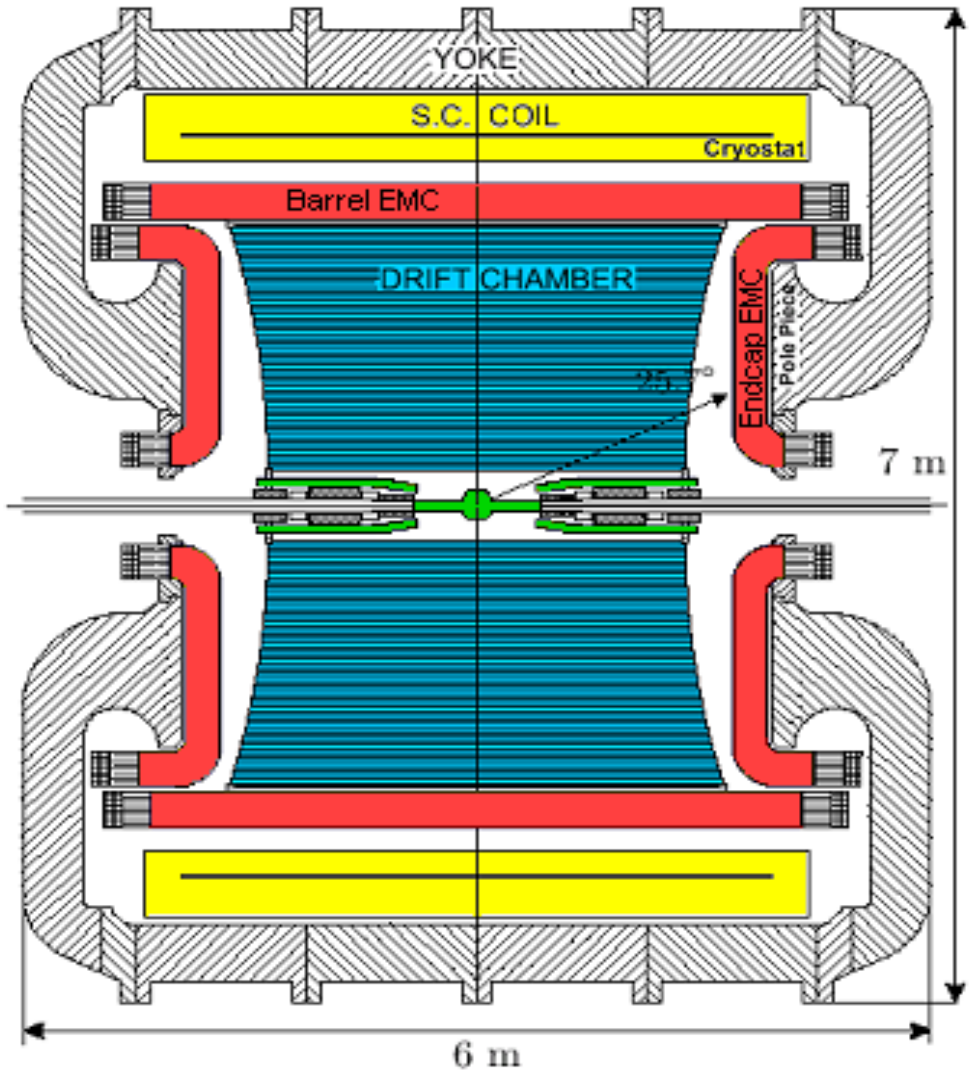



- $e^+e^- \rightarrow \phi \quad \sqrt{s} \sim m_\phi = 1019.4$ MeV

| *BR's for selected $\phi$ decays* | |
|---|---|
| $K^+K^-$ | 49.1% |
| $K_SK_L$ | 34.1% |
| $\rho\pi + \pi^+\pi^-\pi^0$ | 15.5% |
| $\eta\,\gamma$ | 1.3 % |
| $\eta'\,\gamma$ | 0.006% |

# KLOE

## K LOng Experiment



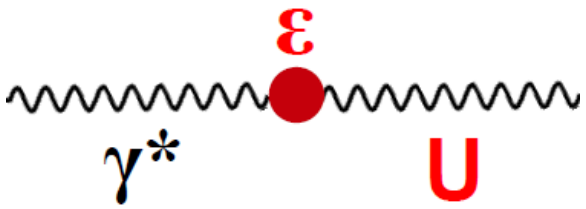
# WASA-at-COSY

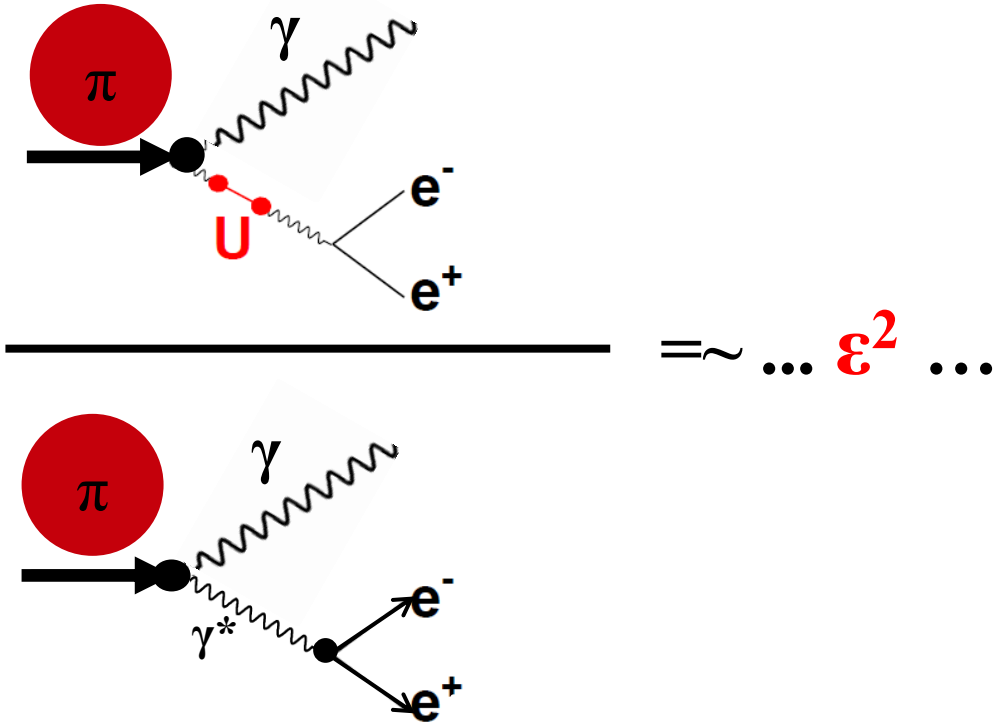
## $10^9\ \eta$ and $10^{11}\ \pi^0$

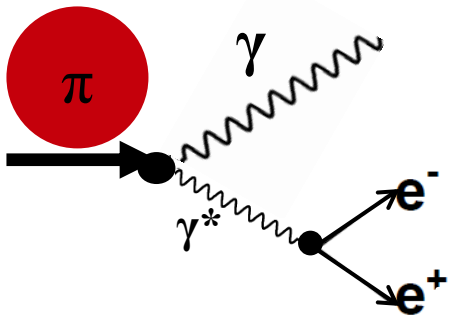
# KLOE

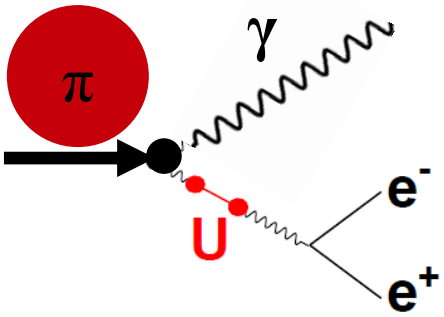
## completed data taking with 2.5 $fb^{-1}$

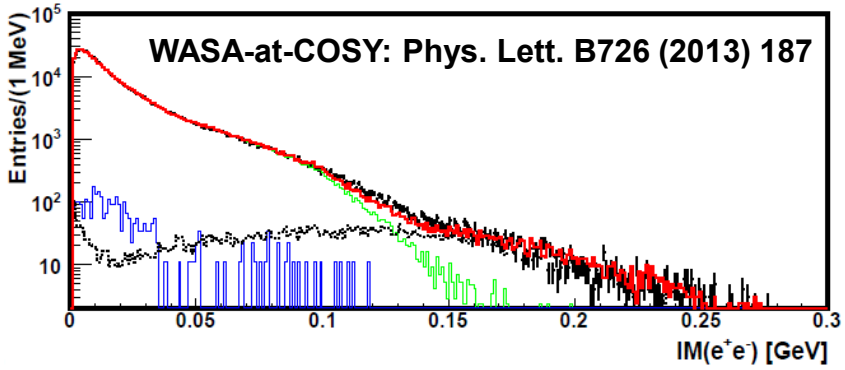
## $\sim 8 \cdot 10^9\ \phi$ , $\sim 10^8\ \eta$ , $\sim 5 \cdot 10^5\ \eta'$

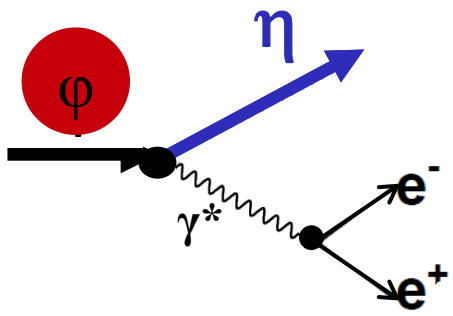

ε
γ*
U

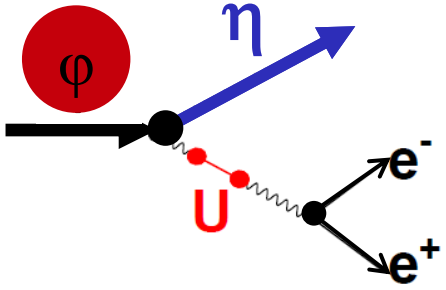

π
γ
e-
U
e+
=~ … ε2 …
π
γ
e-
γ*
e+

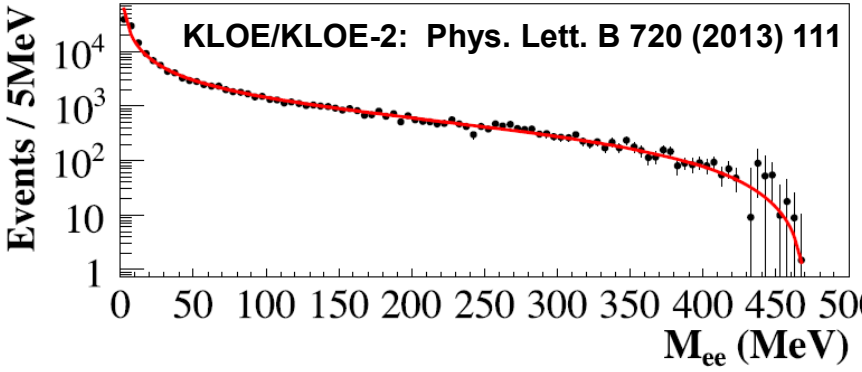

π
γ
γ*
e-
e+

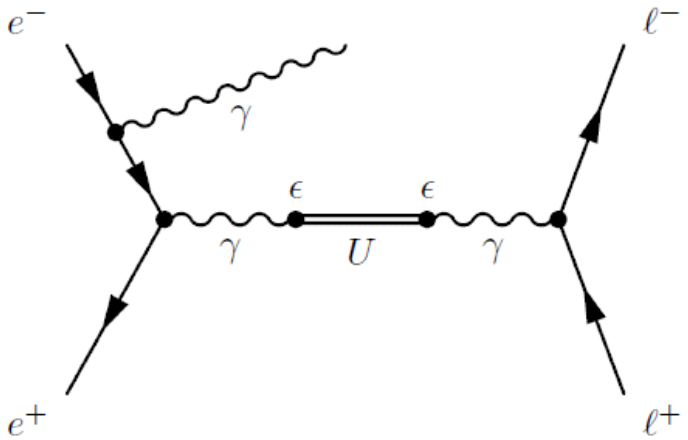

π
γ
U
e-
e+

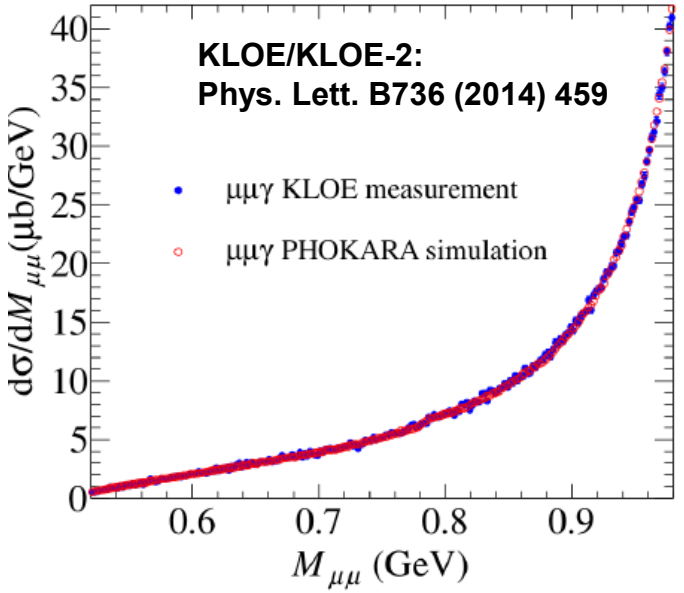

WASA-at-COSY: Phys. Lett. B726 (2013) 187
Entries/(1 MeV)
IM(e+e-) [GeV]

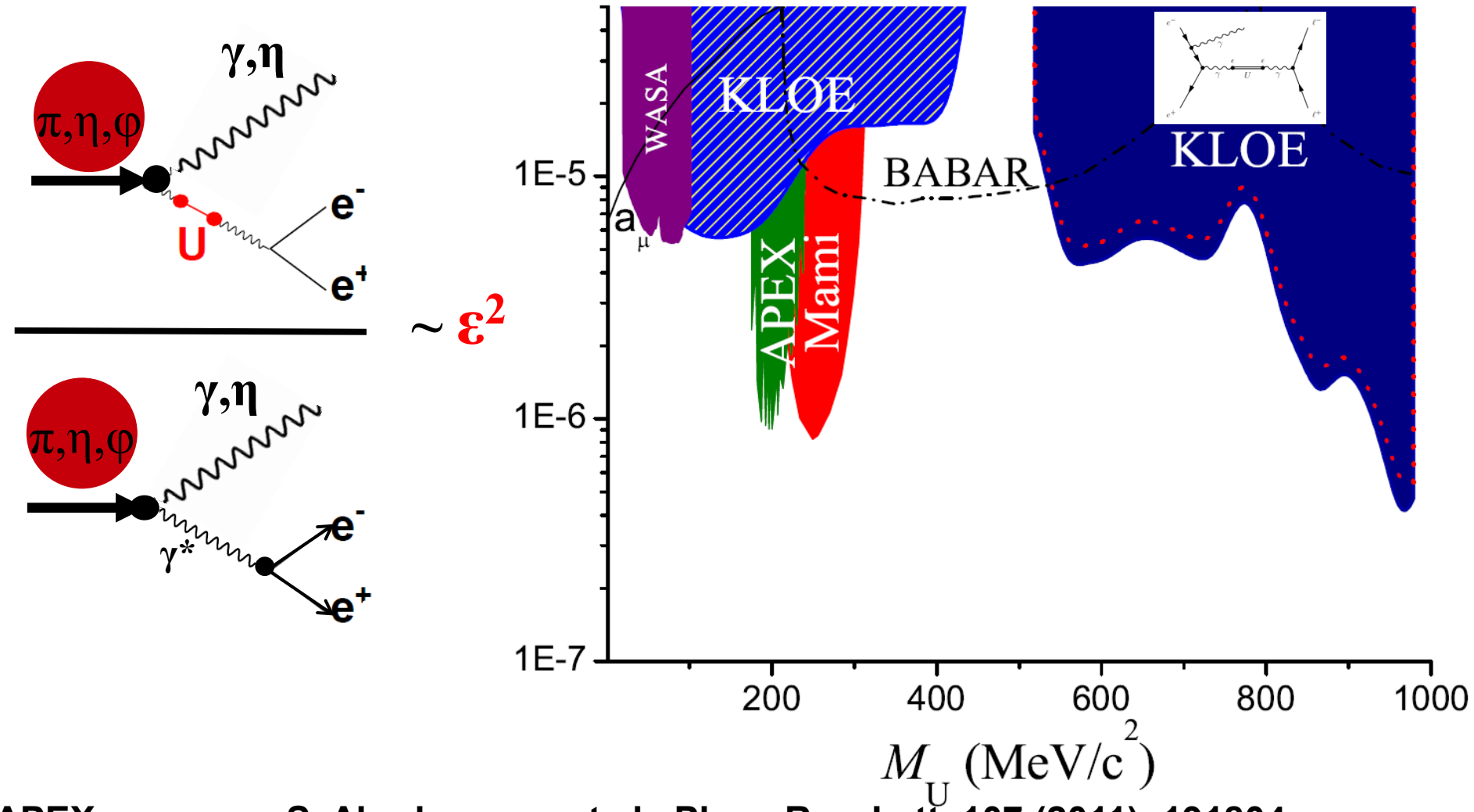

φ
η
γ*
e-
e+


φ
η
U
e-
e+


KLOE/KLOE-2: Phys. Lett. B 720 (2013) 111
Events / 5MeV
Mee (MeV)

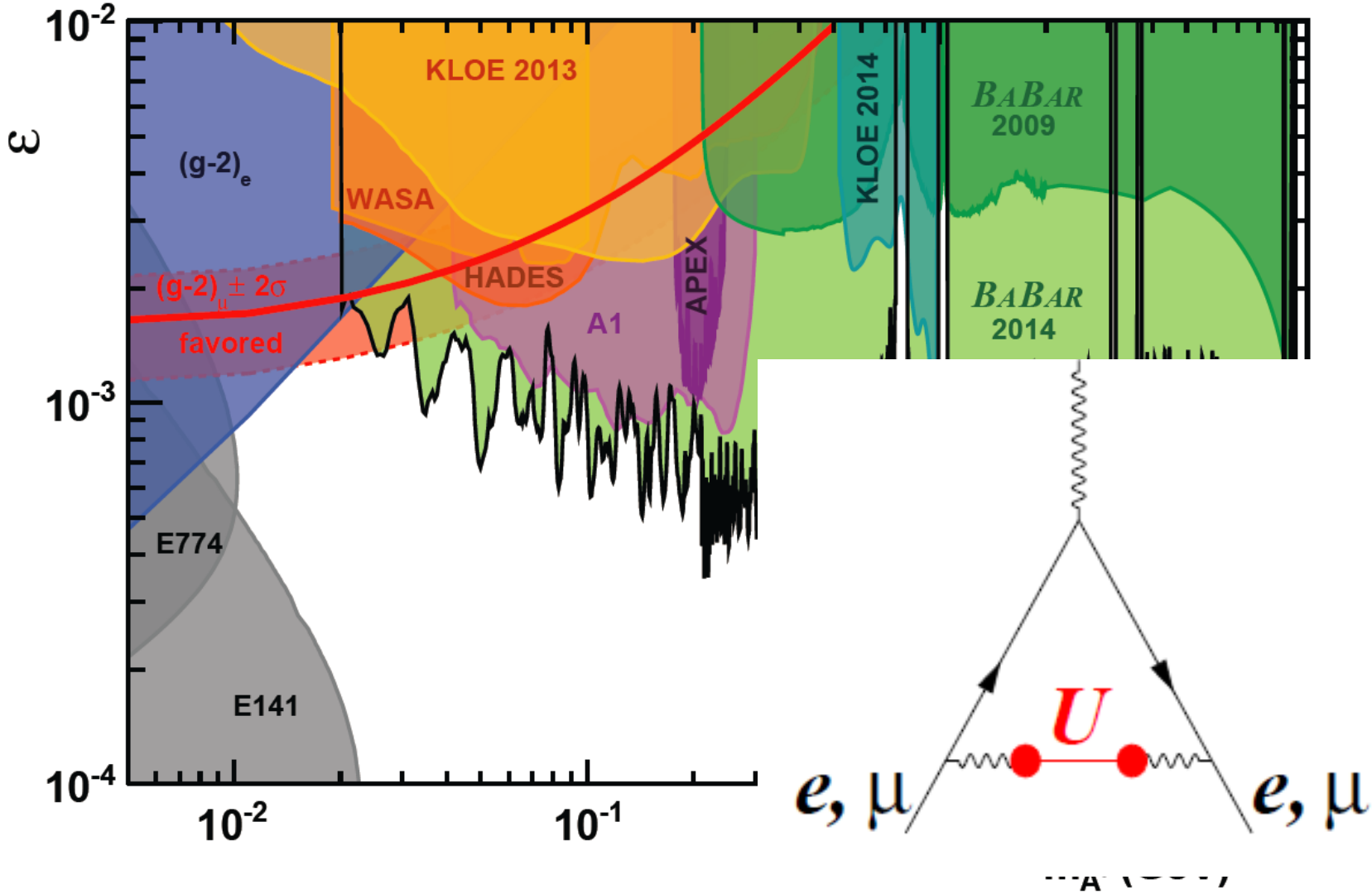

e−
ℓ−
γ
ϵ
ϵ
γ
U
γ
e+
ℓ+


KLOE/KLOE-2:
Phys. Lett. B736 (2014) 459
μμγ KLOE measurement
μμγ PHOKARA simulation
dσ/dMμμ(μb/GeV)
Mμμ (GeV)

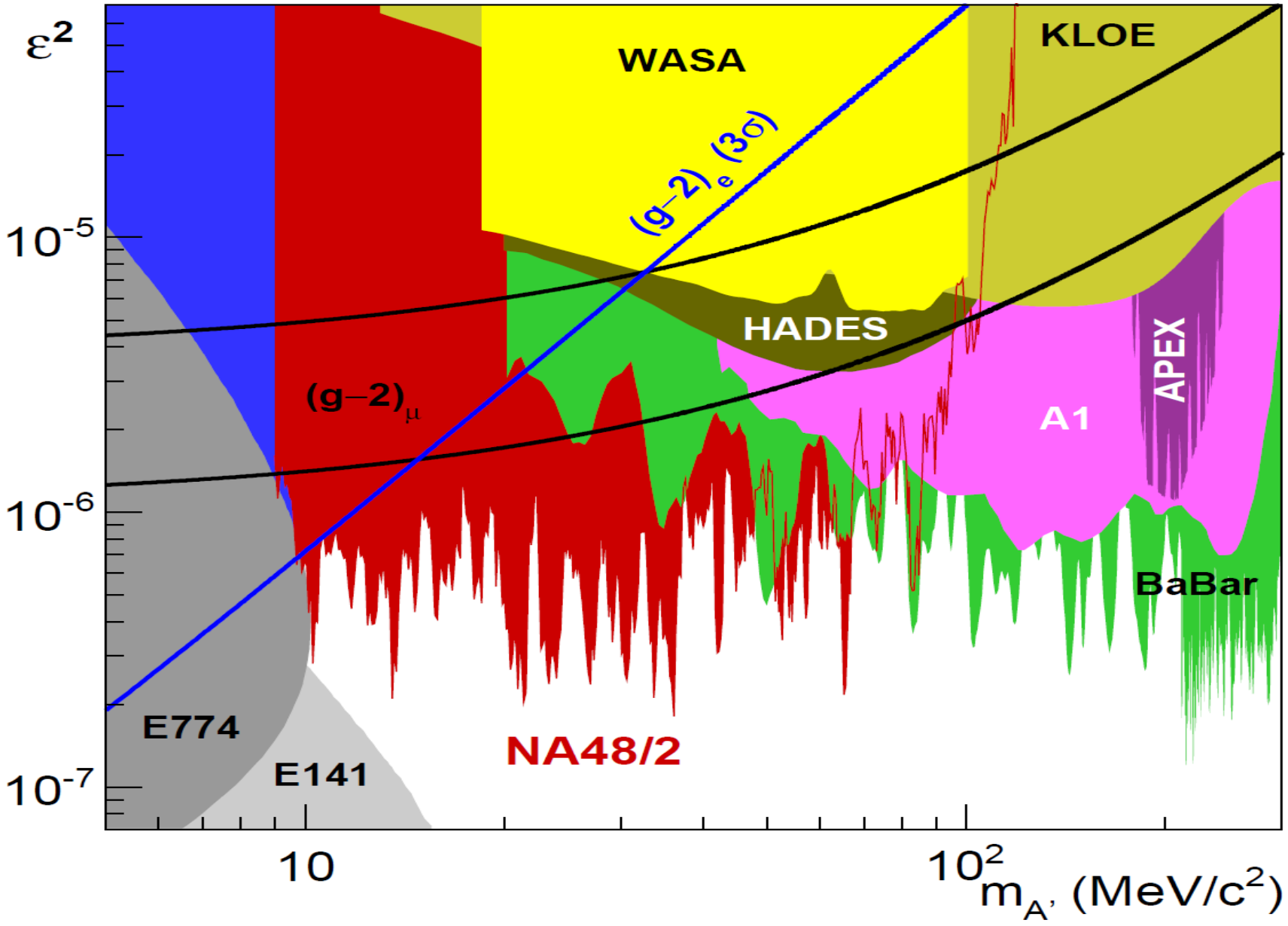




**APEX:** S. Abrahamyan et al., Phys. Rev. Lett. 107 (2011) 191804
**BABAR:** B. Aubert et al., Phys. Rev. Lett. 103 (2009) 081803
**KLOE/KLOE-2:** F. Archilli et al., Phys. Lett. B 720 (2013) 111
**KLOE/KLOE-2:** D. Babusci et al., Phys.Lett B 706 (2012) 251
**MAMI:** M. Merkel et al., Phys. Rev. Lett. 106 (2011) 251802
**WASA-at-COSY:** P. Adlarson et al., Phys. Lett. B 726 (2013) 187
**KLOE/KLOE-2:** D. Babusci et al., Phys.Lett. B736 (2014) 459-464

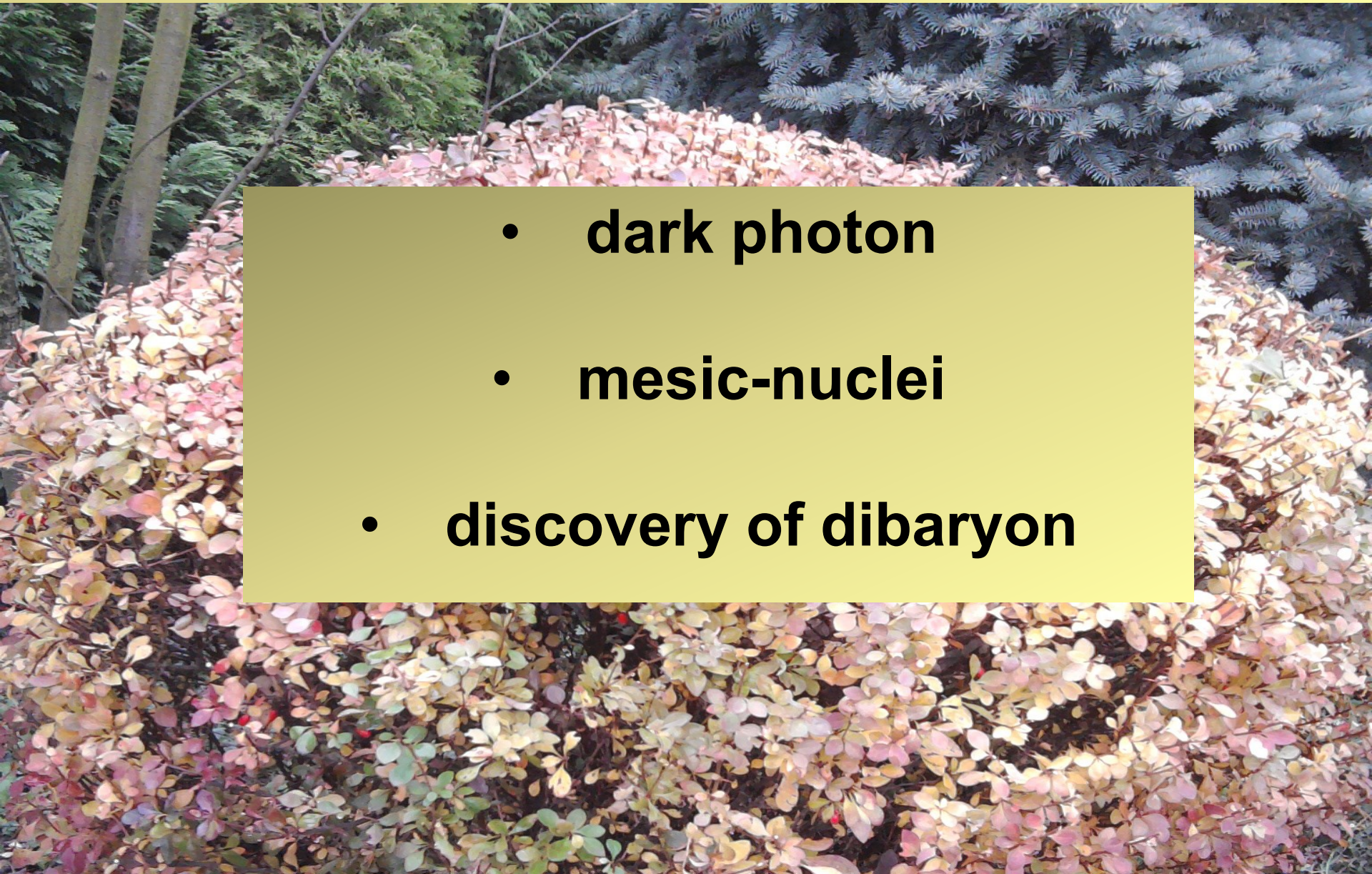



BABAR: J.P. Lees et al., Phys.Rev.Lett. 113 (2014) 20, 201801
HADES: G. Agakishiev et al., Phys.Lett. B731 (2014) 265-271

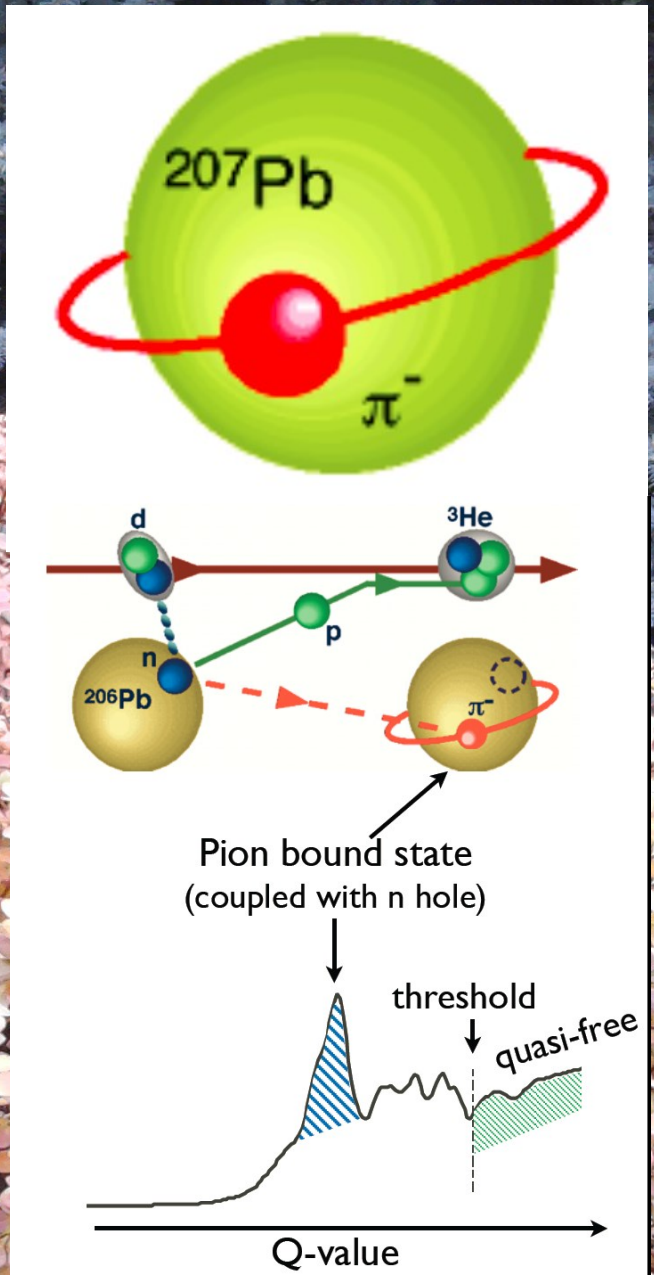



NA48/NA62: J. R. Batley et al. Phys. Lett. B746 (2015) 178

# Search for dark photon and for exotic hadronic matter



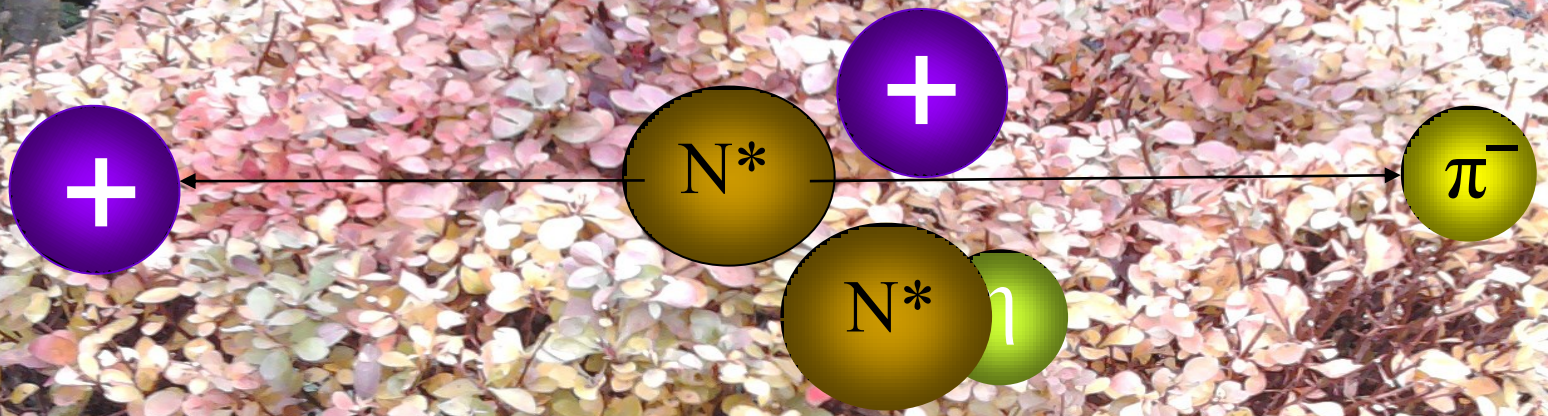
- dark photon
- mesic-nuclei
- discovery of dibaryon




**Kenta Itahashi, RIKEN**
**From talk at Symposium in Cracow 2013**

# THE ETA-MESIC NUCLEUS

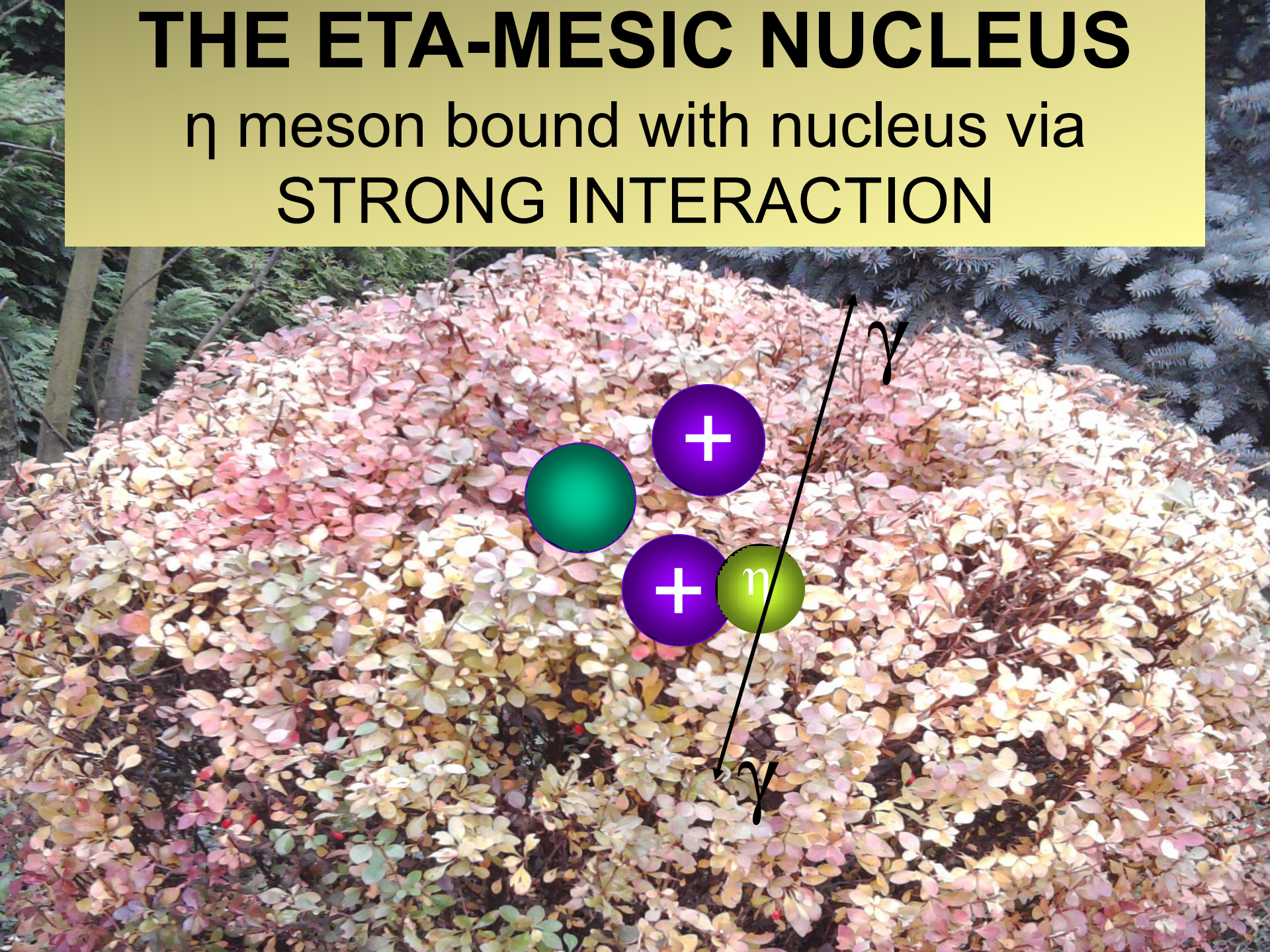
η meson bound with nucleus via STRONG INTERACTION



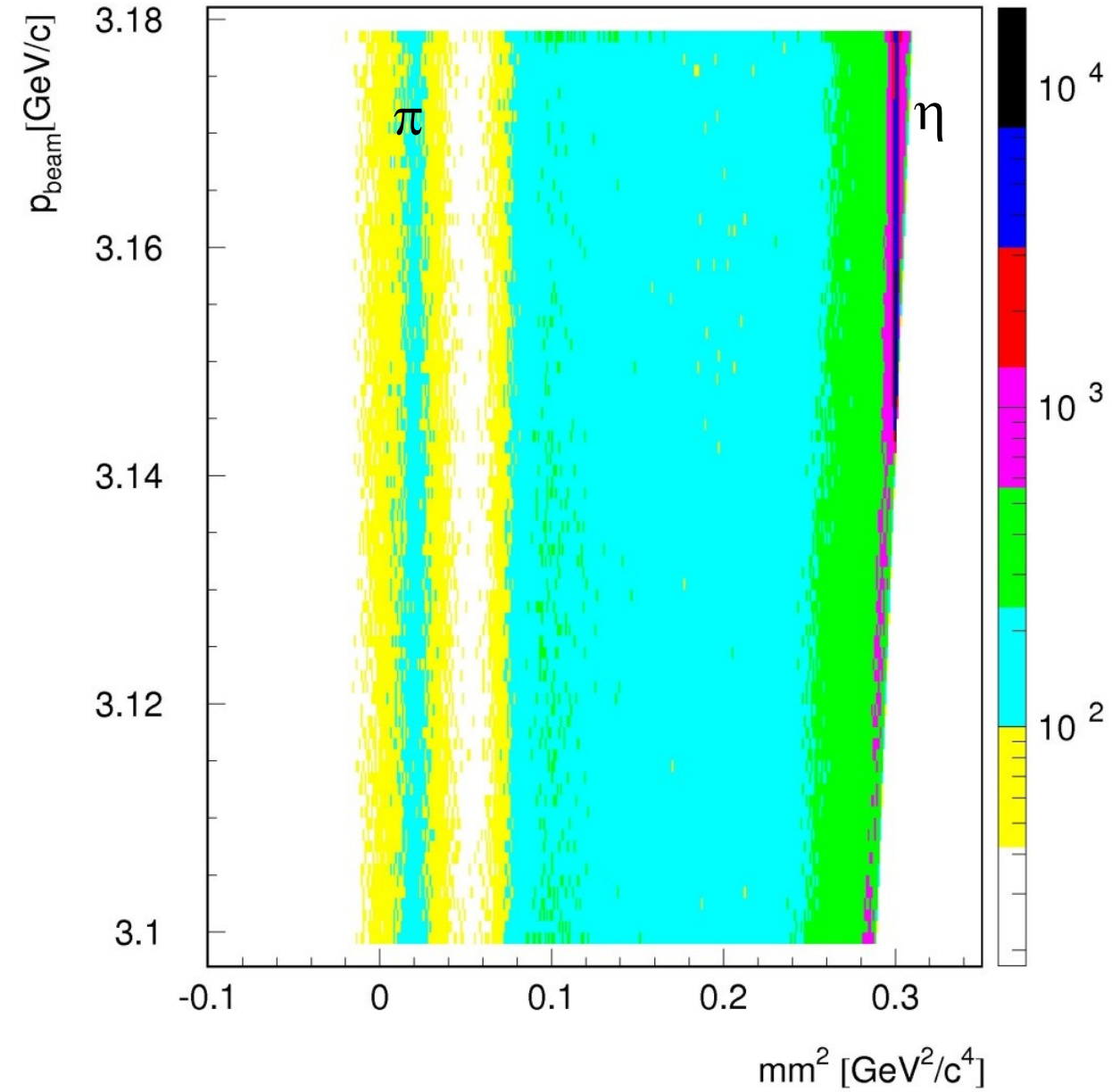

COSY, J-PARC, MAMI, GSI, LPI/JINR

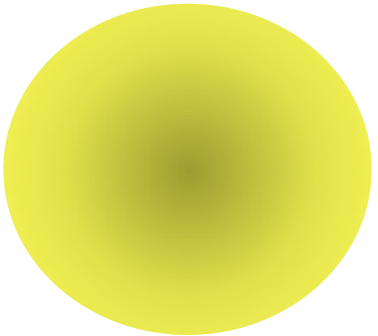
# THE ETA-MESIC NUCLEUS

η meson bound with nucleus via STRONG INTERACTION

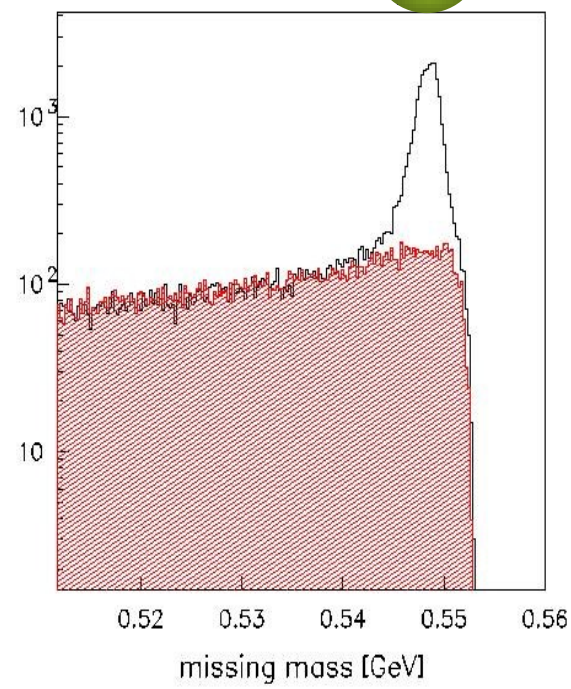


# pd → $^3$He X


3.18
3.16
3.14
3.12
3.1
$p_{beam}$[GeV/c]
π
η
$10^4$
$10^3$
$10^2$
-0.1
0
0.1
0.2
0.3
$mm^2$ [GeV$^2$/c$^4$]



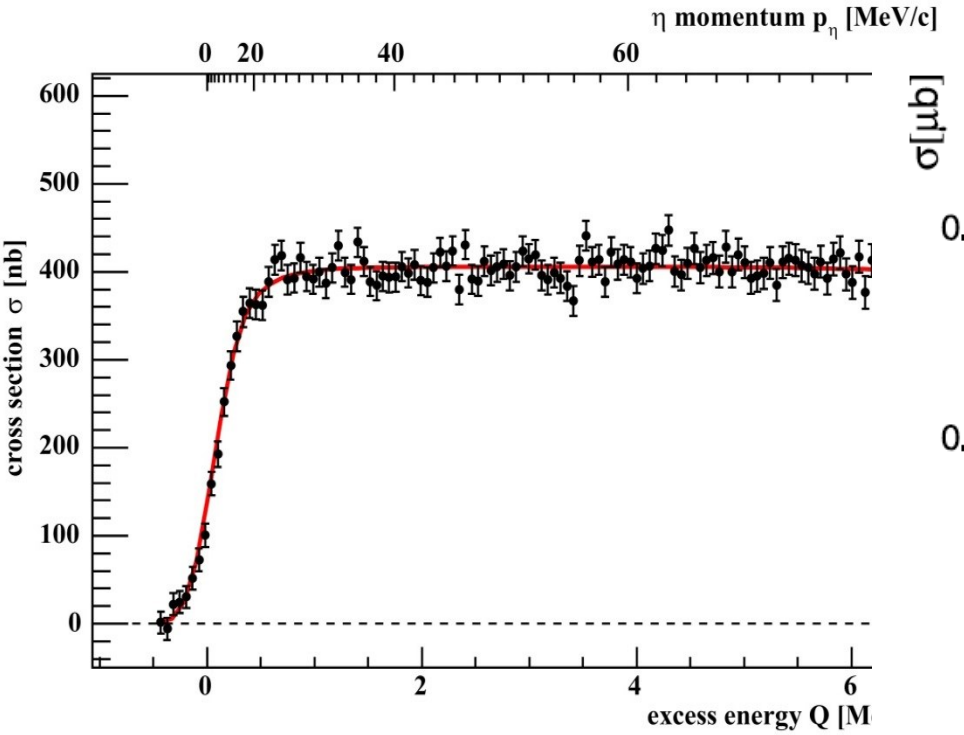

η

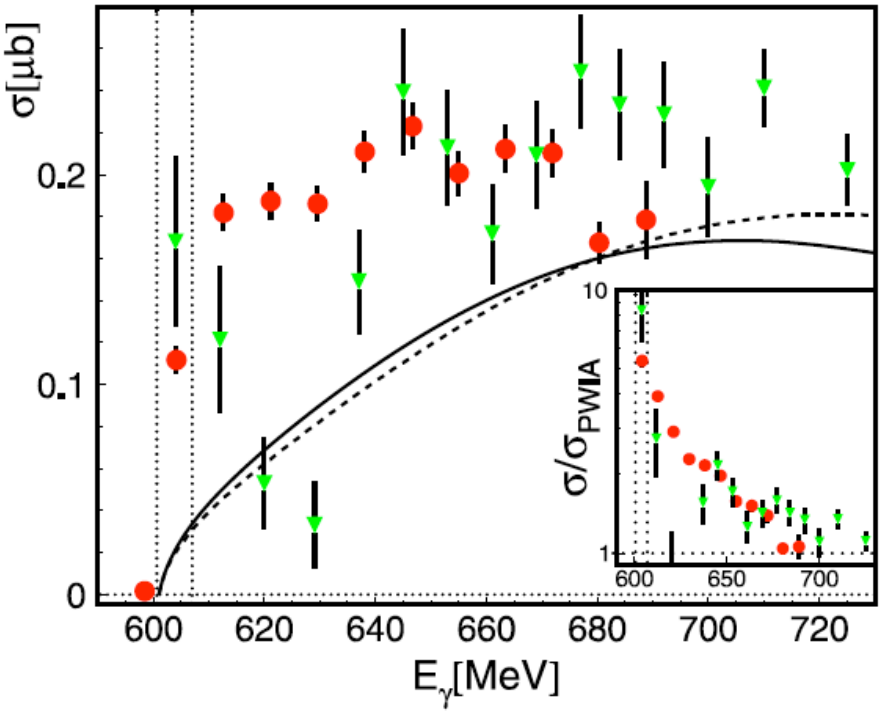

$10^3$
$10^2$
10
0.52
0.53
0.54
0.55
0.56
missing mass [GeV]

# $\eta$ - $^3$He

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

## COSY




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

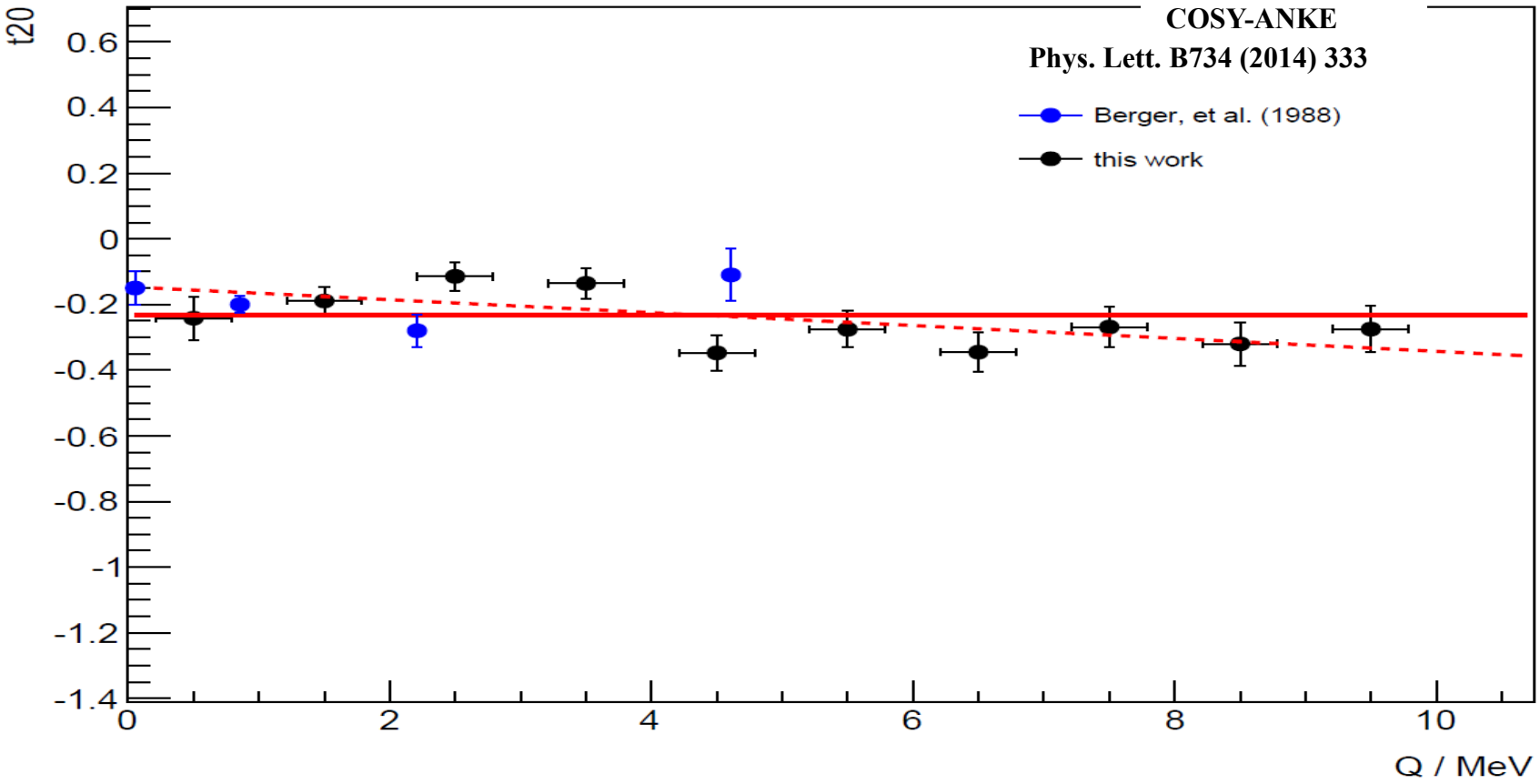
**COSY-11**: J. Smyrski et al., Phys. Lett **B 649** 258-262 (2007)

**MAMI**:

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

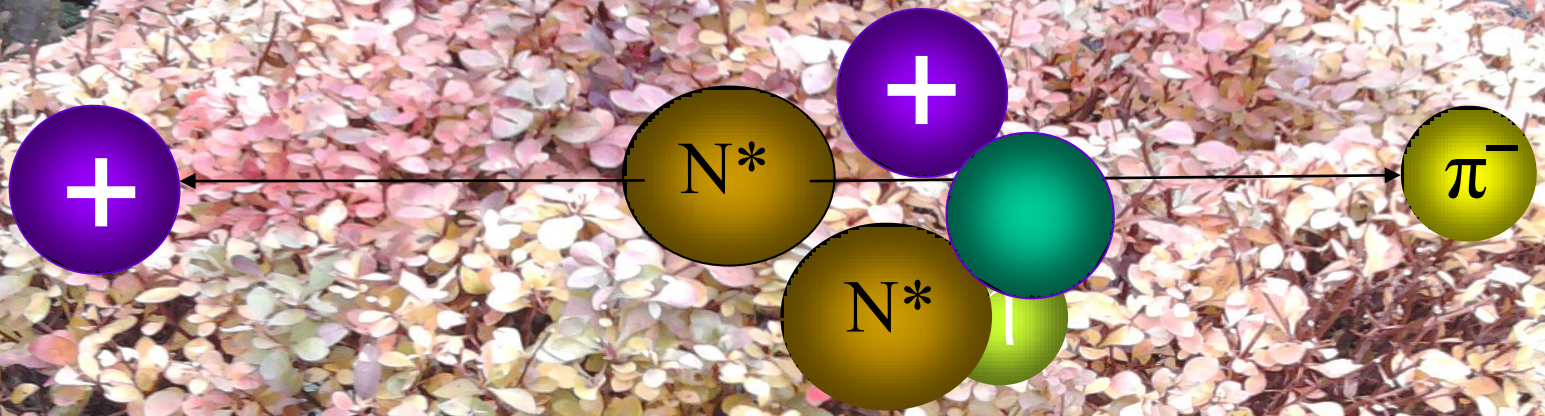
F. Pheron et al., Phys. Lett. **B709** 21 (2012)

# $\eta$ - $^3$He


t20
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
0
2
4
6
8
10
Q / MeV
COSY-ANKE
Phys. Lett. B734 (2014) 333
Berger, et al. (1988)
this work

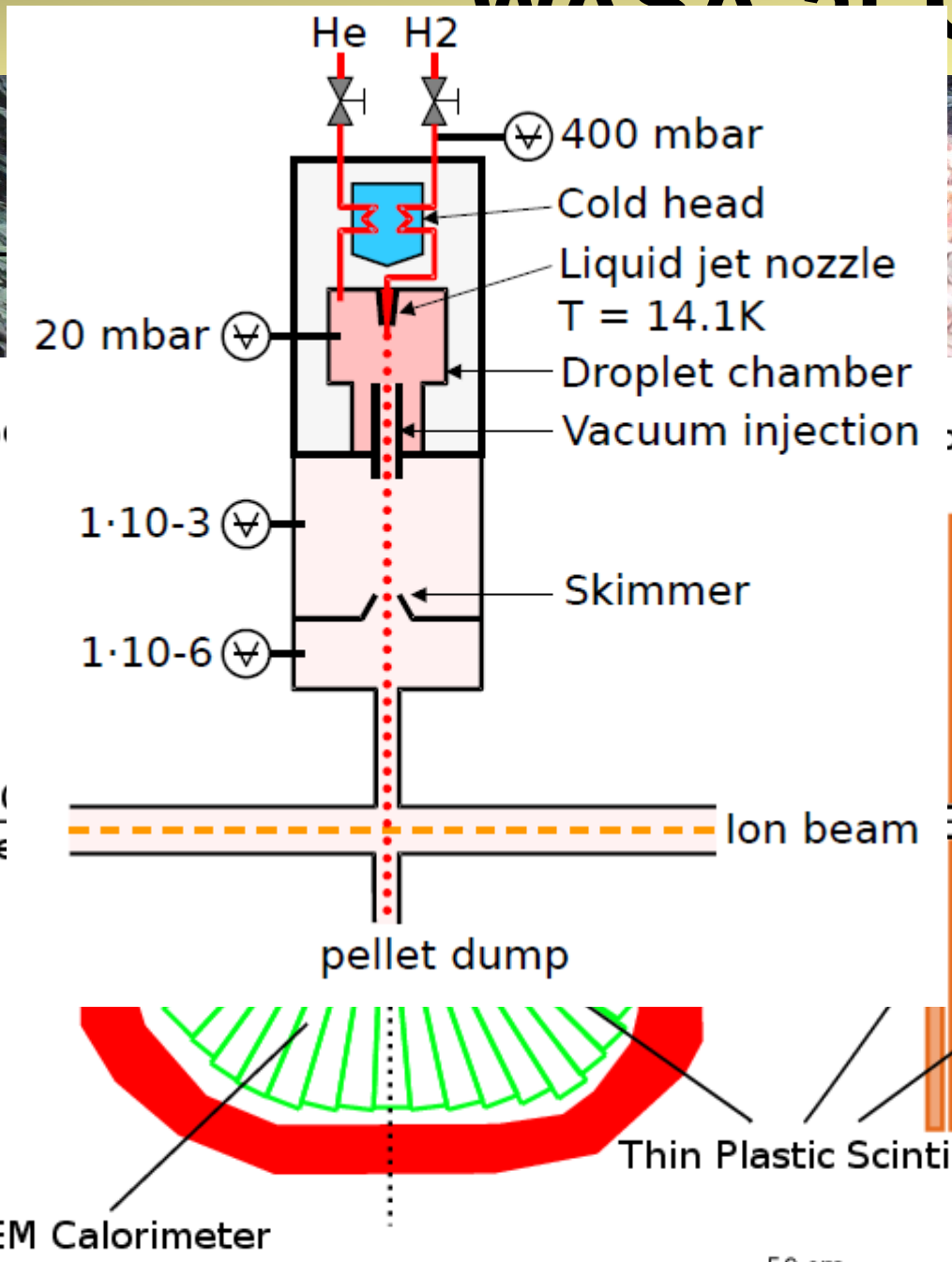
# THE ETA-MESIC NUCLEUS

η meson bound with nucleus via STRONG INTERACTION



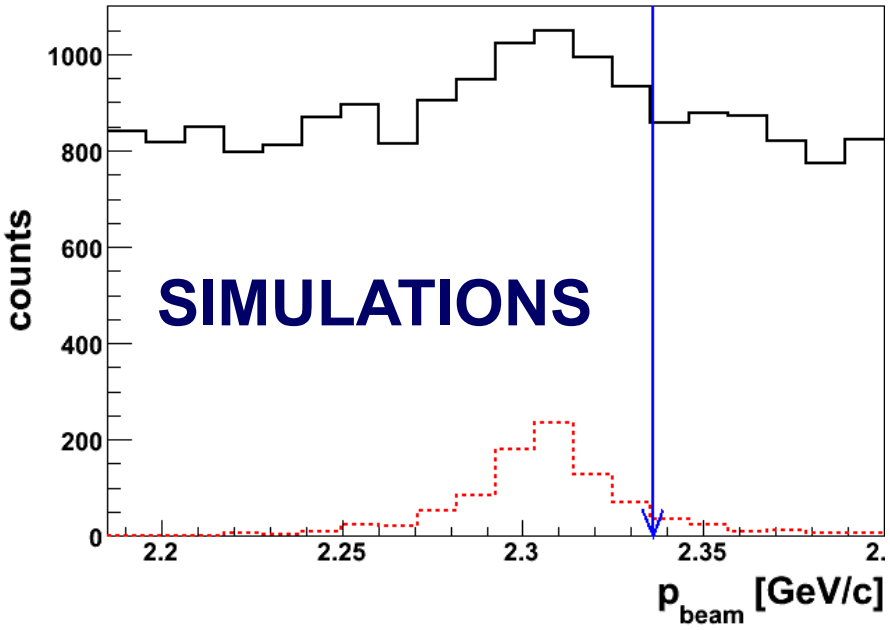

COSY, J-PARC, MAMI, GSI, LPI/JINR

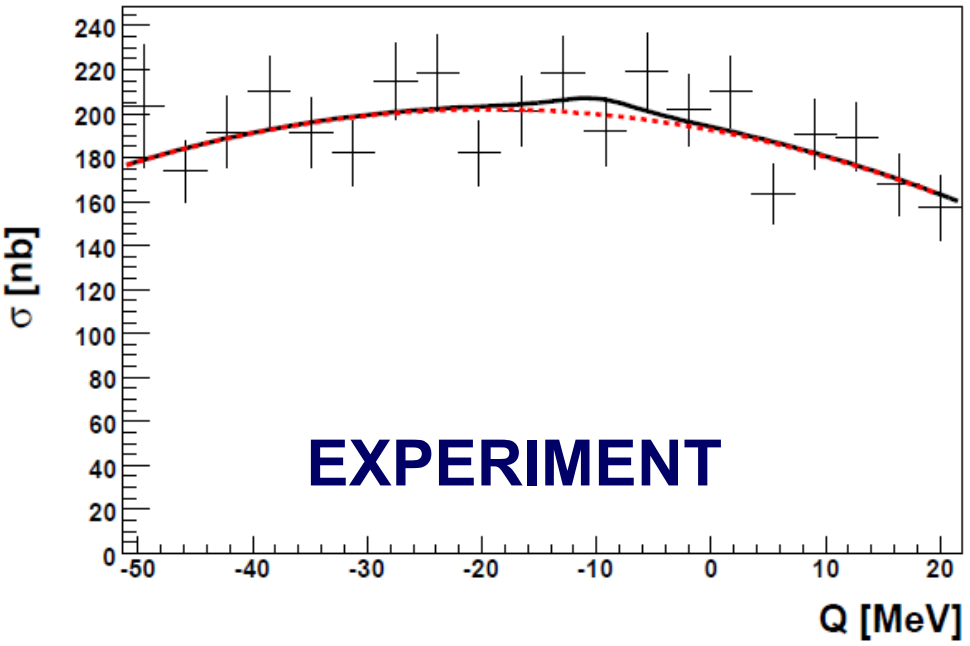
# WASA at COSY


He
H2
400 mbar
Cold head
Liquid jet nozzle
T = 14.1K
20 mbar
Droplet chamber
Vacuum injection
1·10-3
Skimmer
1·10-6
Ion beam
pellet dump
EM Calorimeter
Thin Plastic Scintillat ors
TOF Detector
Range Hodoscope
50 cm

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

$$d+d \rightarrow {}^3He + p + \pi^-$$

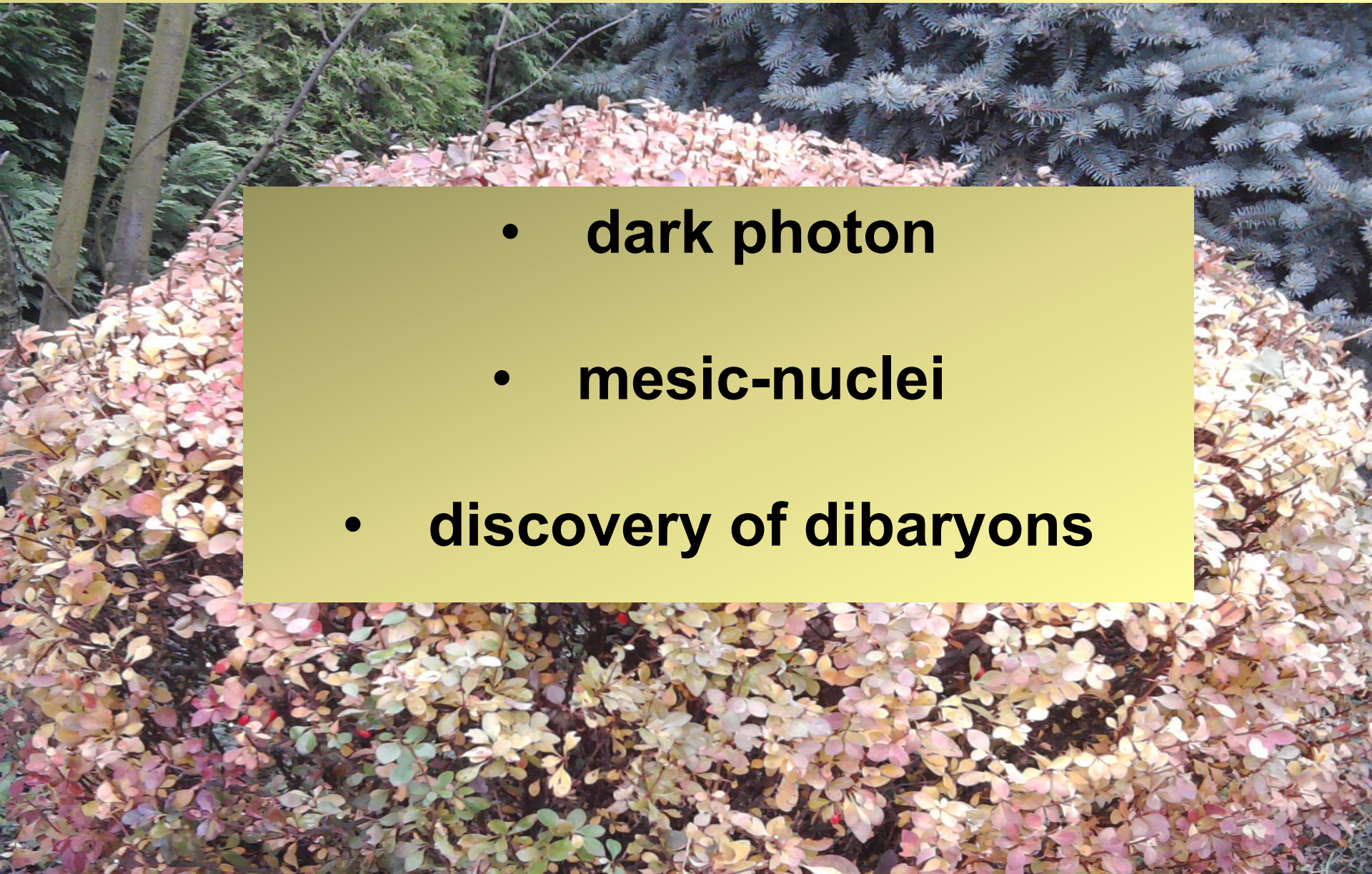



**Upper limit of about 25 nb**

**WASA-at-COSY: Phys. Rev. C87(2013) 035204**

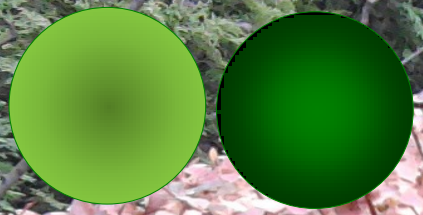
# Search for dark photon and for exotic hadronic matter



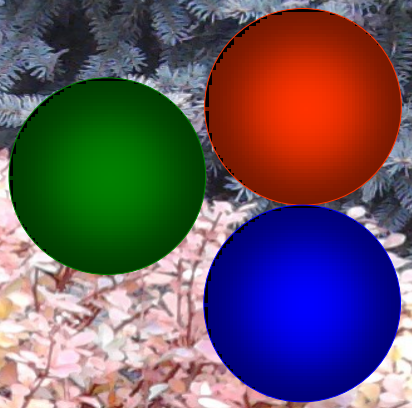
- dark photon
- mesic-nuclei
- discovery of dibaryons

# MATTER

Meson



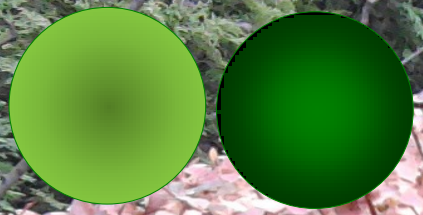
Baryon



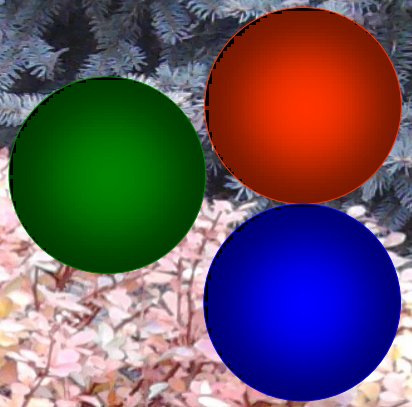
1947 Powell in Cracow
1950 Powell <-- Nobel Prize
~1960 Quark Model

# MATTER

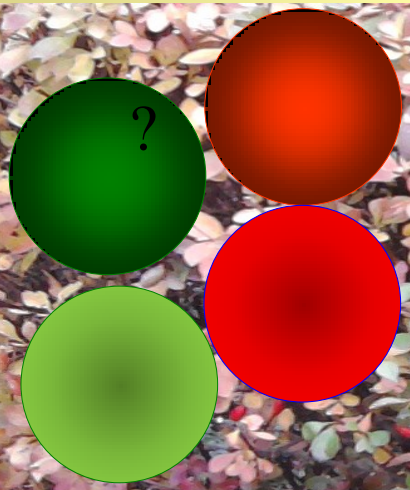
Meson



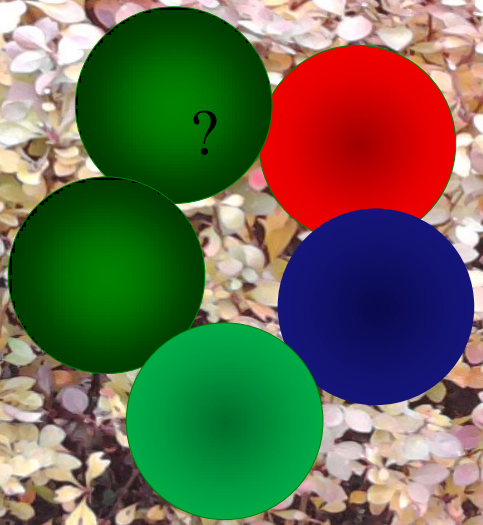
Baryon



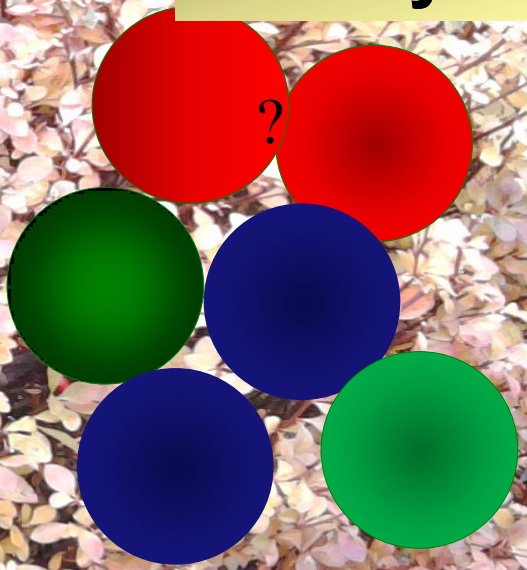
Tetraquark



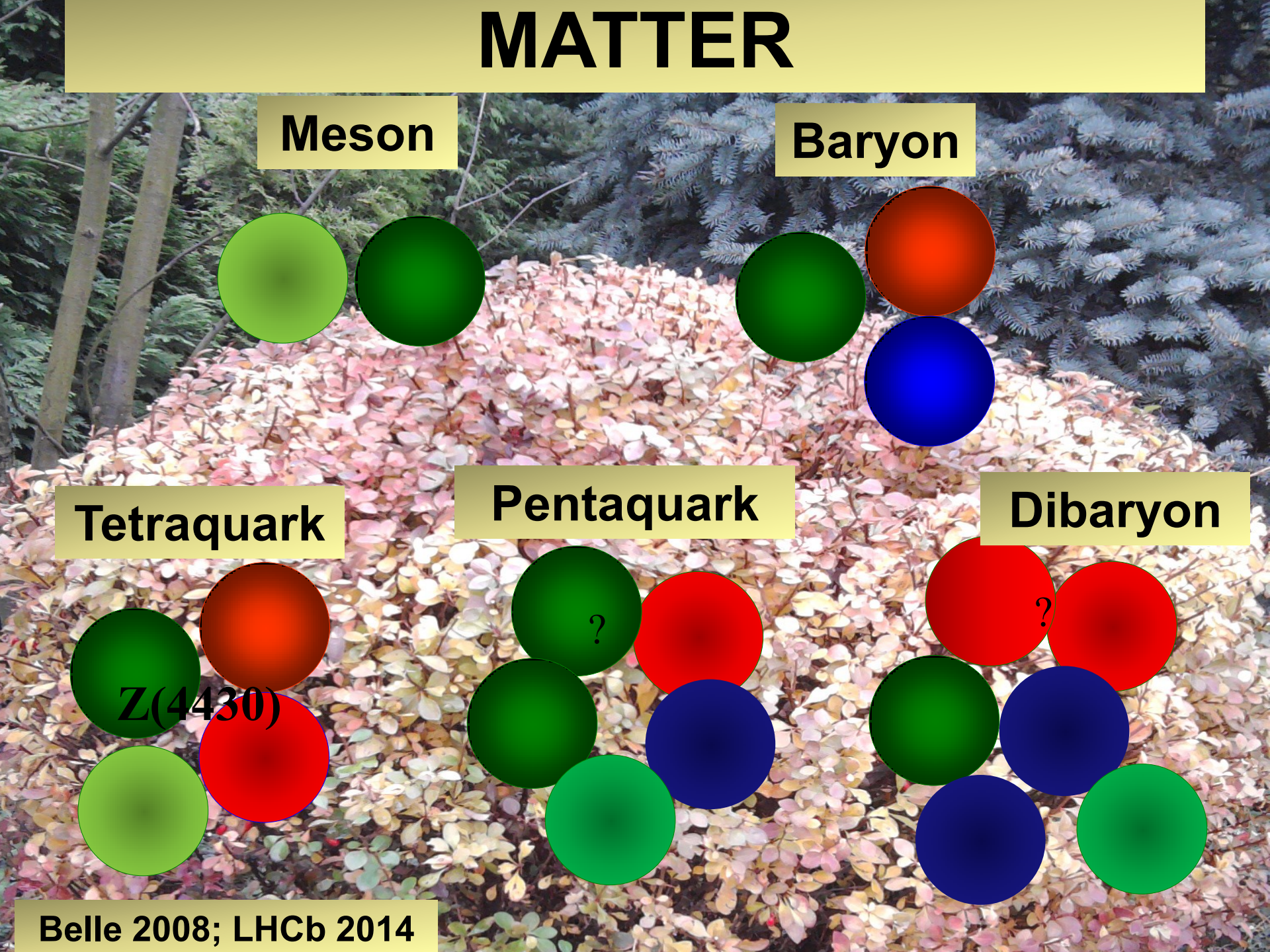

Pentaquark




Dibaryon

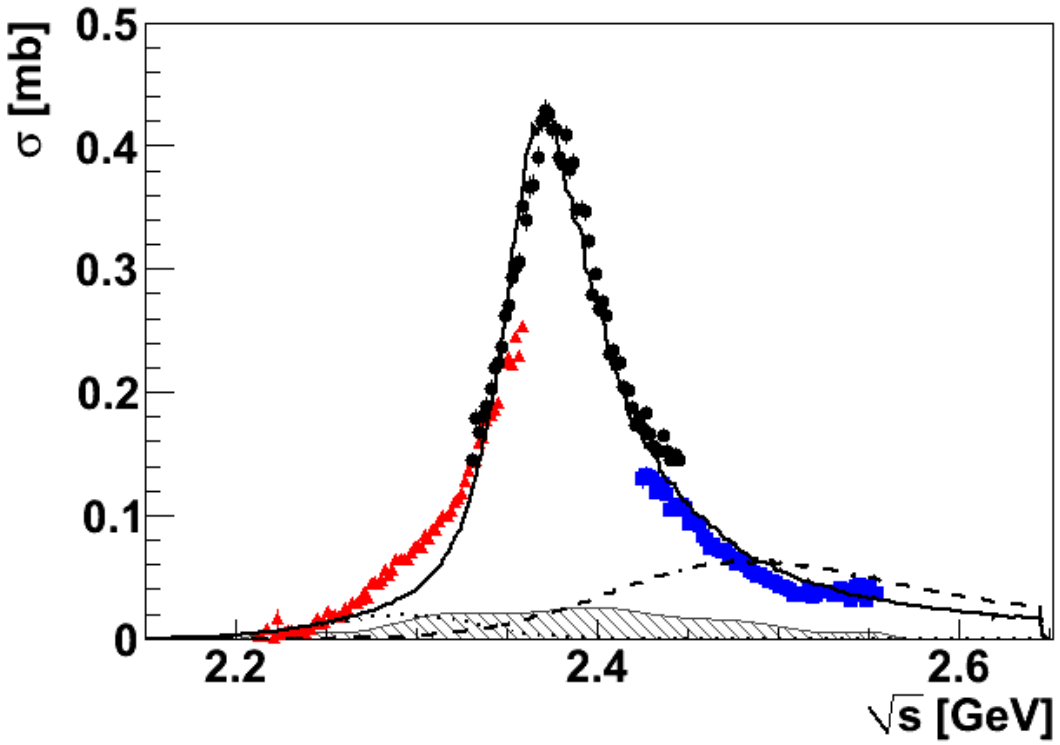


# MATTER


Meson
Baryon
Tetraquark
Z(4430)
Pentaquark
?
Dibaryon
?
Belle 2008; LHCb 2014

# Double pionic fusion - a new resonance?

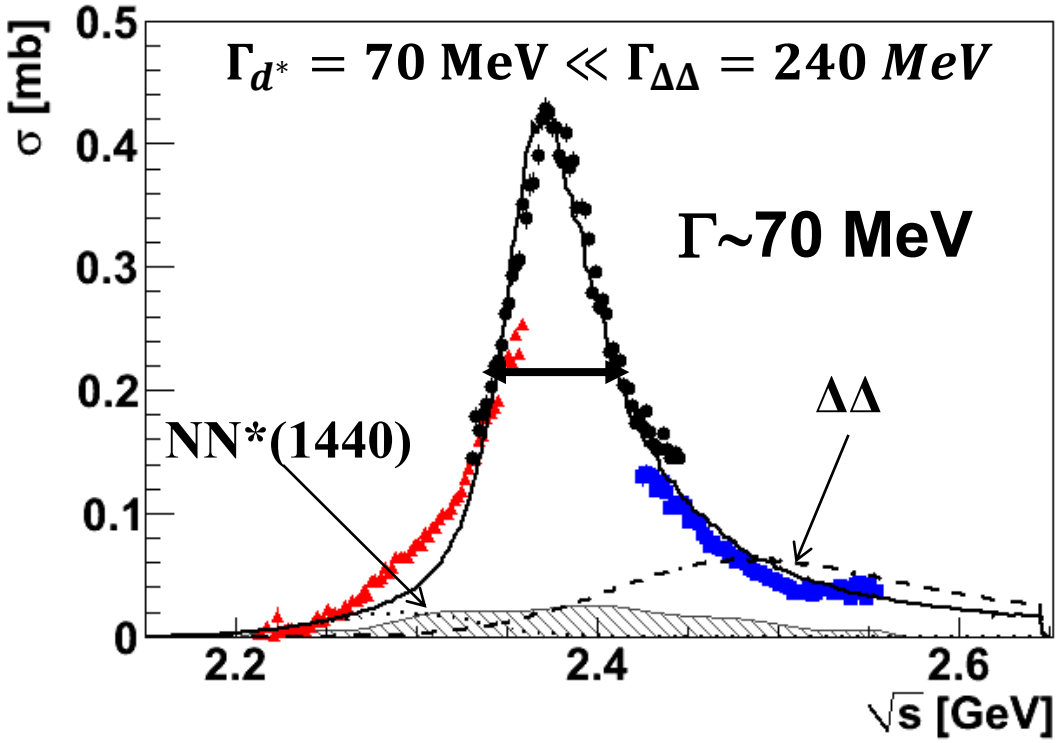
## Cross section for $pn \rightarrow d\pi^0\pi^0$




WASA-at-COSY: Phys. Rev. Lett. 106 (2011) 242302

# Double pionic fusion - a new resonance

## Cross section for $pn \rightarrow d\pi^0\pi^0$



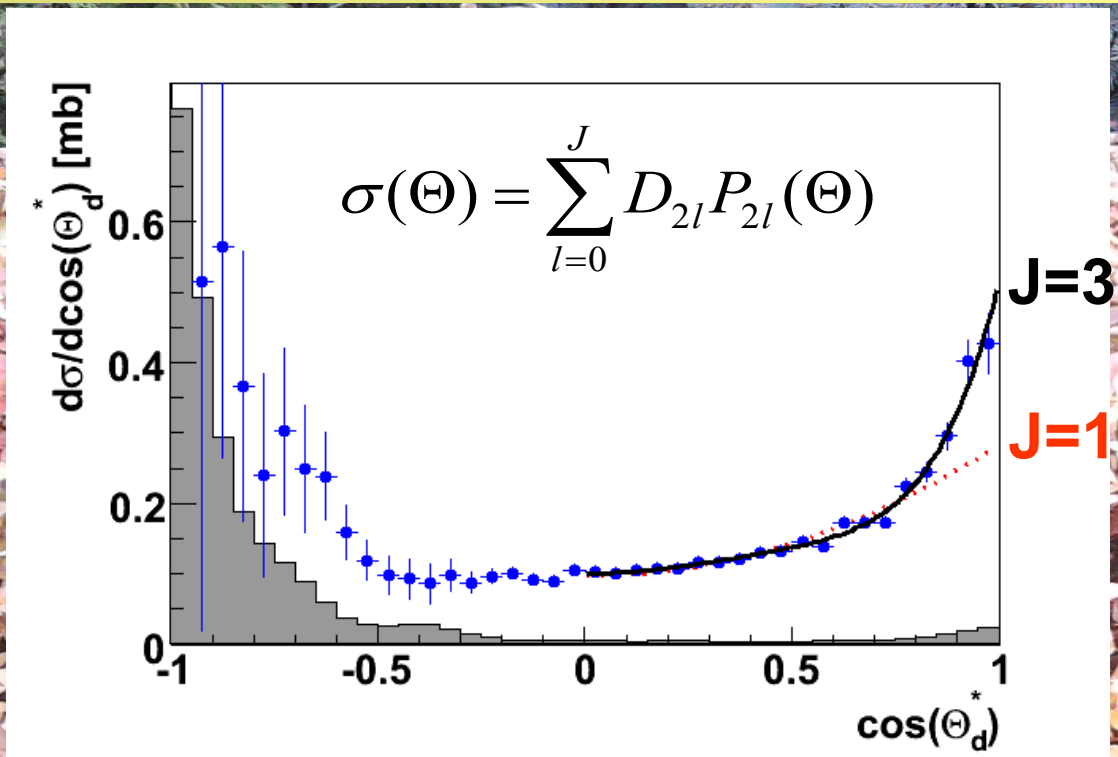

WASA-at-COSY: Phys. Rev. Lett. 106 (2011) 242302

$pn \rightarrow \Delta\Delta \rightarrow d\pi^0\pi^0$ ; $pn \rightarrow NN^* \rightarrow d\pi^0\pi^0$

$pn \rightarrow$ **dibaryon** $\rightarrow \Delta\Delta \rightarrow d\pi^0\pi^0$

# Double pionic fusion - a new resonance?

## Cross section for $pn \rightarrow d\pi^0\pi^0$



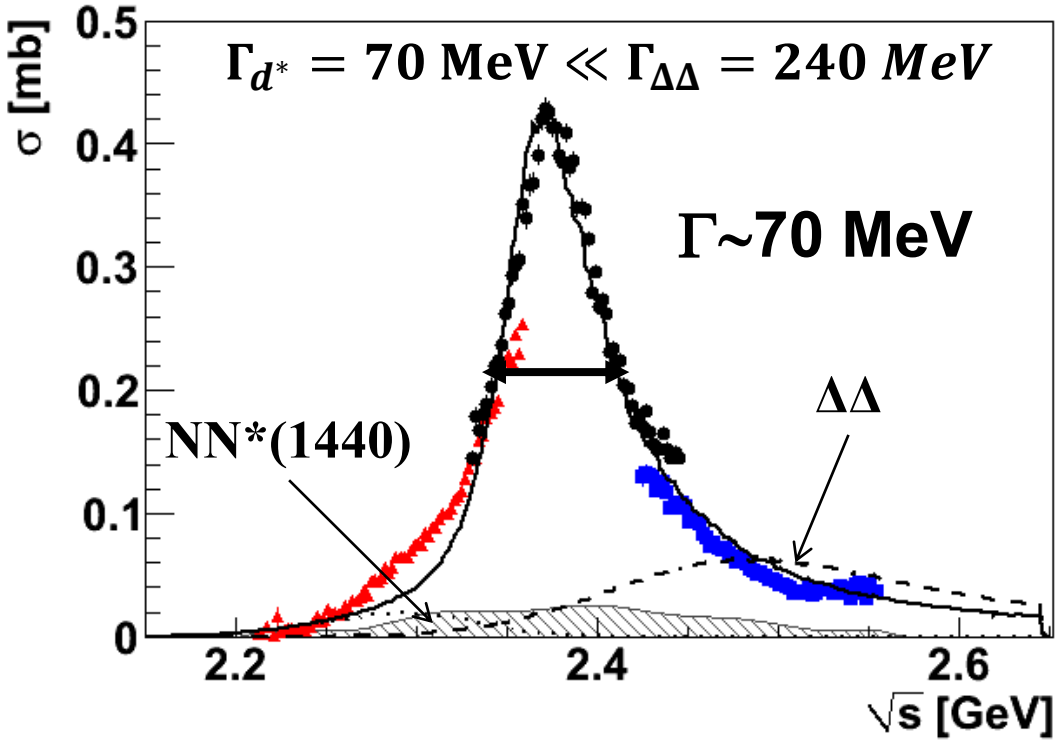

WASA-at-COSY: Phys. Rev. Lett. 106 (2011) 242302

**$I = 0;\ J^P = 3^+$**

F. J. Dyson, N.-H. Xuong, Phys. Rev. Lett. **13**, 815 (1964).

# Double pionic fusion - a new resonance

## Cross section for $pn \rightarrow d\pi^0\pi^0$




WASA-at-COSY: Phys. Rev. Lett. 106 (2011) 242302

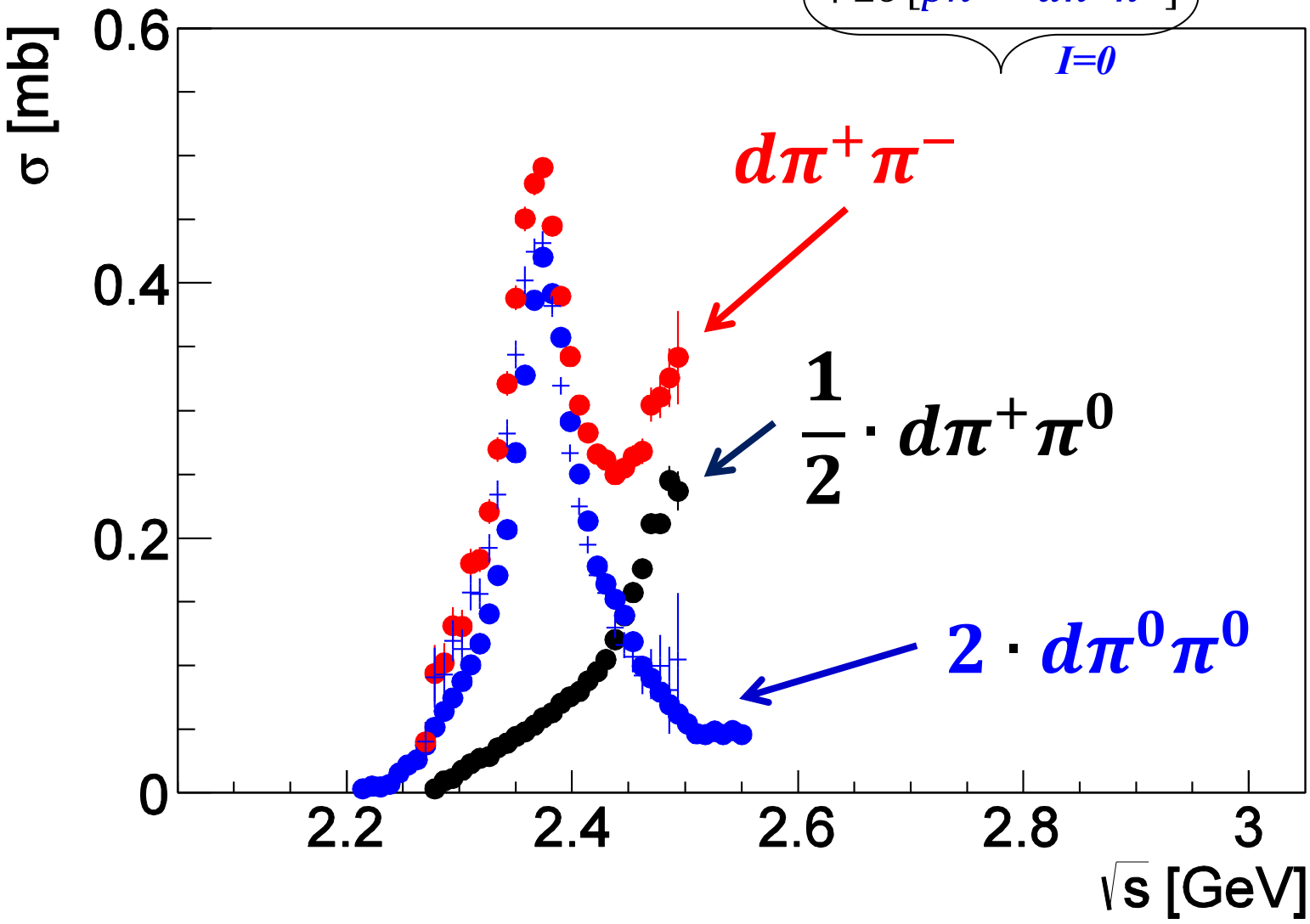
**$I = 0;\ J^P = 3^+$**

F. J. Dyson, N.-H. Xuong, Phys. Rev. Lett. **13**, 815 (1964).

# The decay modes of the dibaryon

| Channel | Publications |
|---|---|
| **d $\pi^0\pi^0$** | **P. Adlarson et. al Phys. Rev. Lett. 106 (2011) 242302**<br>P. Adlarson et. al Phys. Lett. B721 (2013) 229-236 |
| **d $\pi^+\pi^-$**<br>**d $\pi^+\pi^0$** | P. Adlarson et. al Phys. Lett. B721 (2013) 229-236 |
| **pp$\pi^0\pi^-$** | P. Adlarson et. al Phys. Rev. C 88 (2013) 055208 |
| **np$\pi^0\pi^0$** | P. Adlarson et al., Phys. Lett. B743 (2015) 325-332 |
| **np** | **P. Adlarson et al. Phys. Rev. Lett. 112 (2014) 202301**<br>P. Adlarson et al. Phys. Rev. C**90** (2014) 035204 |
| **$^3$He $\pi\pi$** | P. Adlarson et al., Phys. Rev. C91 (2015) 015201 |
| **$^4$He $\pi\pi$** | P. Adlarson et. al. Phys. Rev. C86 (2012) 032201 |
| | .... |

$$\sigma[pn \to d\pi^+\pi^-] = \underbrace{\frac{1}{2}\sigma[pp \to d\pi^+\pi^0]}_{I=1} + \underbrace{2\sigma[pn \to d\pi^0\pi^0]}_{I=0}$$

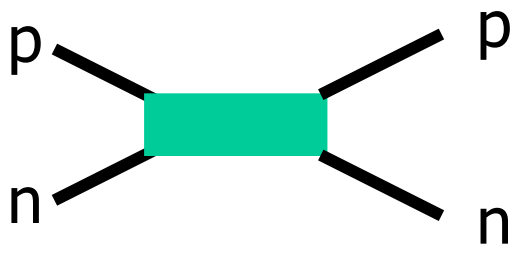



**WASA-at-COSY: Phys. Lett. B721 (2013) 229**

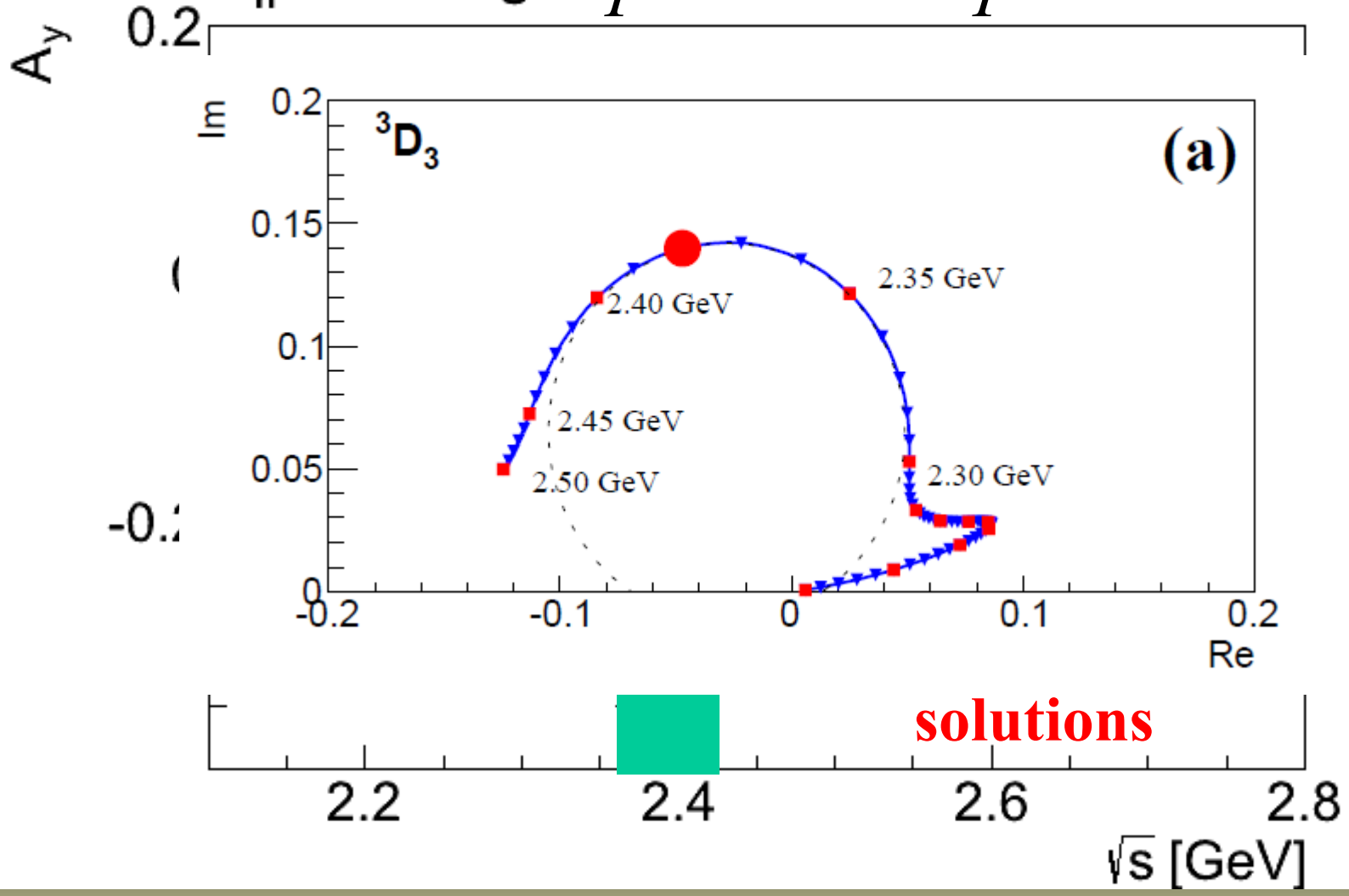
# The decay modes of the dibaryon

| Channel | Publications |
|---|---|
| **d $\pi^0\pi^0$** | **P. Adlarson et. al Phys. Rev. Lett. 106 (2011) 242302**<br>P. Adlarson et. al Phys. Lett. B721 (2013) 229-236 |
| **d $\pi^+\pi^-$**<br>**d $\pi^+\pi^0$** | P. Adlarson et. al Phys. Lett. B721 (2013) 229-236 |
| **pp$\pi^0\pi^-$** | P. Adlarson et. al Phys. Rev. C 88 (2013) 055208 |
| **np$\pi^0\pi^0$** | P. Adlarson et al., Phys. Lett. B743 (2015) 325-332 |
| **np** | **P. Adlarson et al. Phys. Rev. Lett. 112 (2014) 202301**<br>P. Adlarson et al. Phys. Rev. C**90** (2014) 035204 |
| **$^3$He $\pi\pi$** | P. Adlarson et al., Phys. Rev. C91 (2015) 015201 |
| **$^4$He $\pi\pi$** | P. Adlarson et. al. Phys. Rev. C86 (2012) 032201 |
| | .... |

# $A_y$ energy dependence at 83°

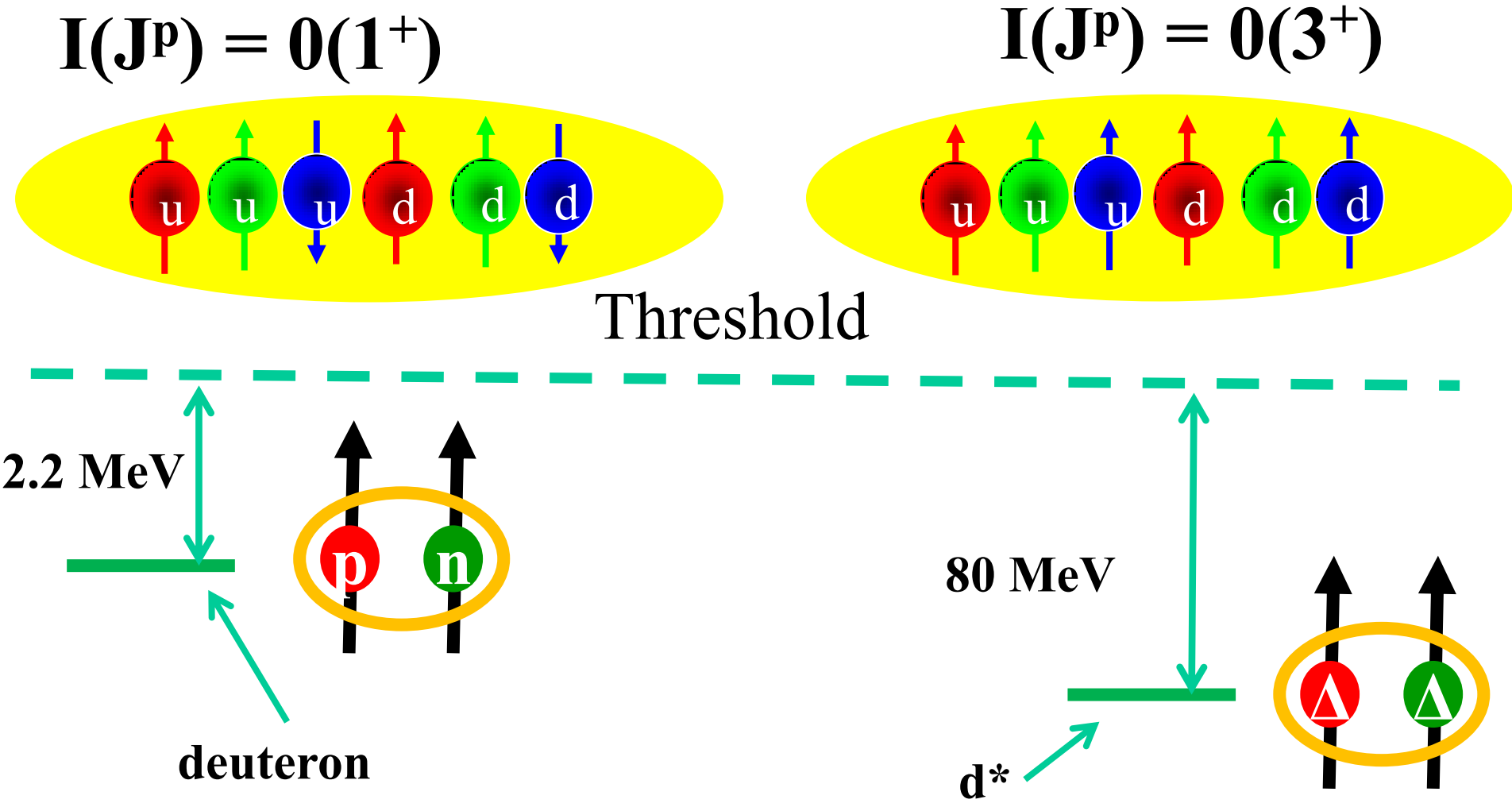



$\Theta_n^{cm} = 83$ deg $\quad \vec{n}p \rightarrow d^* \rightarrow pn$




**WASA-at-COSY: Phys. Rev. Lett. 112 (2014) 202301**

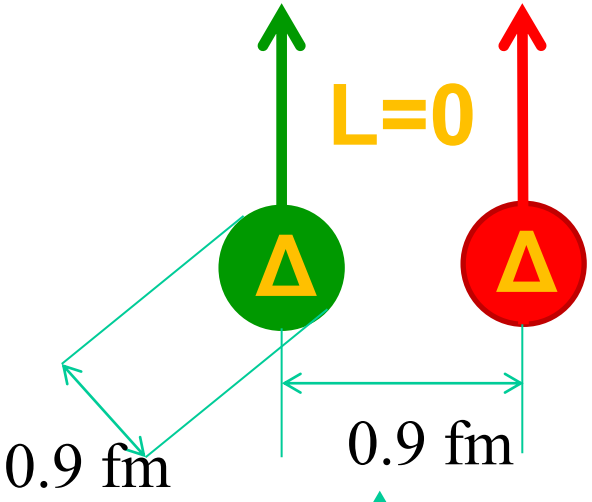
# Deuteron to Deltaron

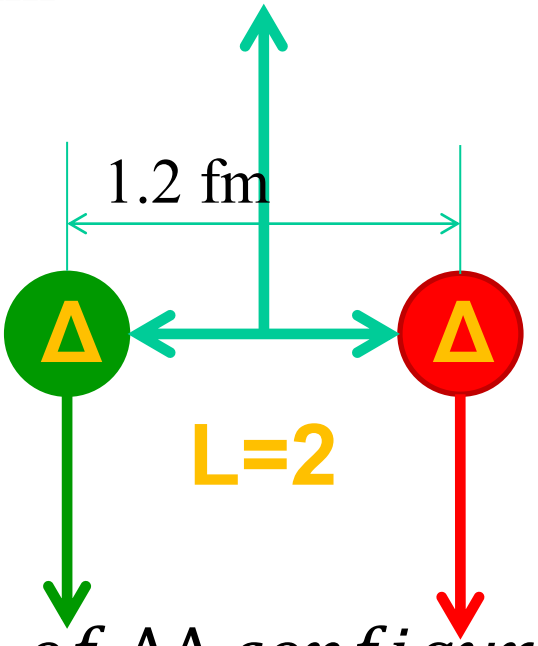




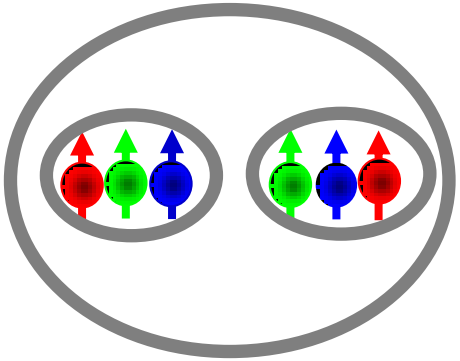

M. Bashkanov, Jagiellonian Symposium, 2015

# Deltaron vs Hexaquark

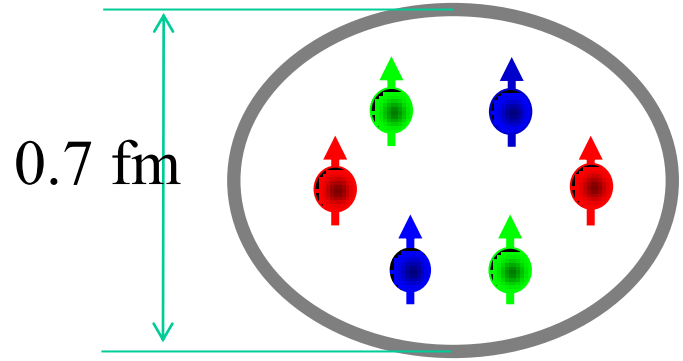


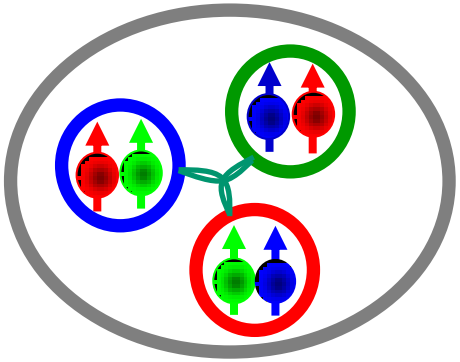

$\approx 5\%\ of\ \Delta\Delta\ configuration$



≈ 33%




≈ 66%



?

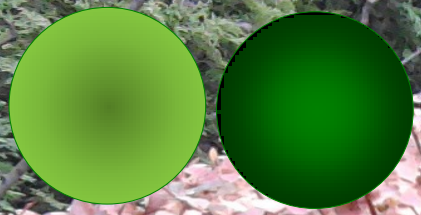
F. Huang et al, arXiv:1408.0458



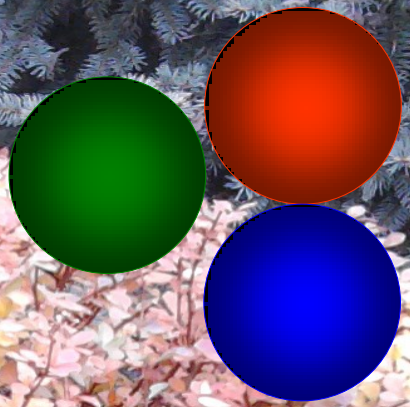
M. Bashkanov, Jagiellonian Symposium, 2015

# MATTER

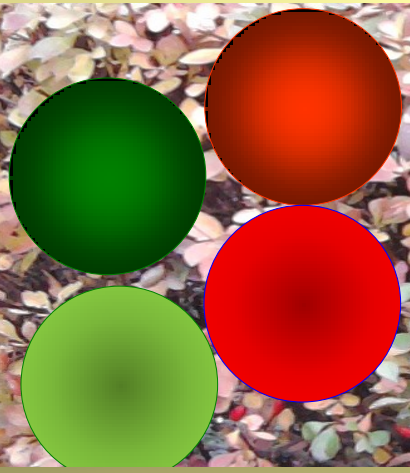
Meson

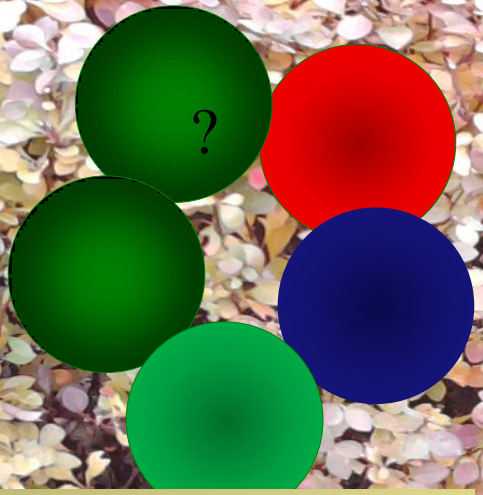


Baryon



Tetraquark



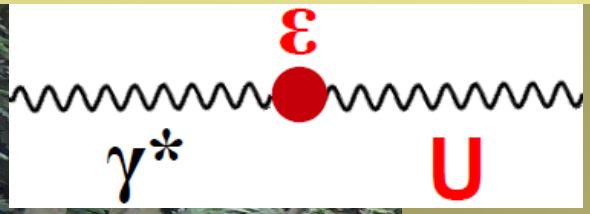



Dibaryon

Belle 2008: Phys. Rev. Lett. 100 (2008) 142001
LHCb 2014: Phys. Rev. Lett. 112 (2014) 222002

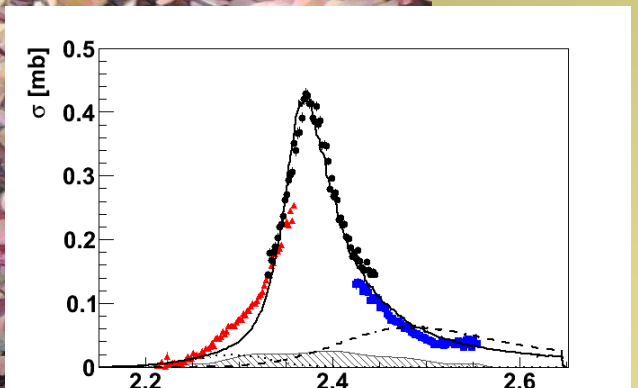
WASA-at-COSY
Phys. Rev. Lett.
112 (2014) 202311

# Search for dark photon and for exotic hadronic matter




- dark photon


- mesic-nuclei




discovery of dibaryons


THANK YOU
FOR YOUR ATTENTION