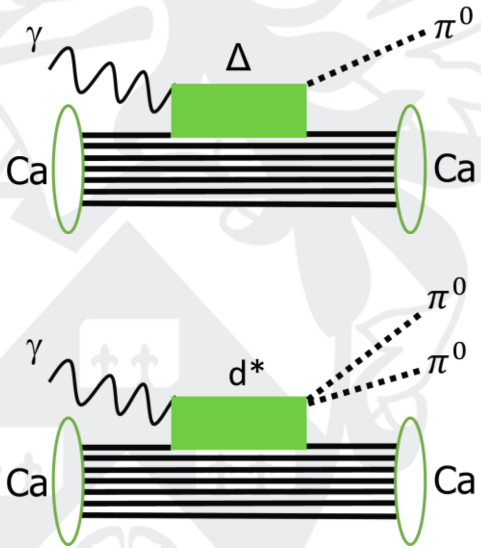
Exploring neutron stars EoS with coherent π^0 and $\pi^0\pi^0$ photoproduction at A2@MAMI

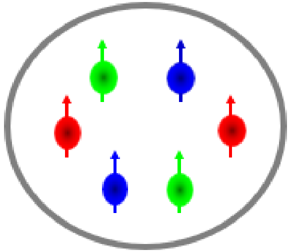
Mihai Mocanu
The University of York

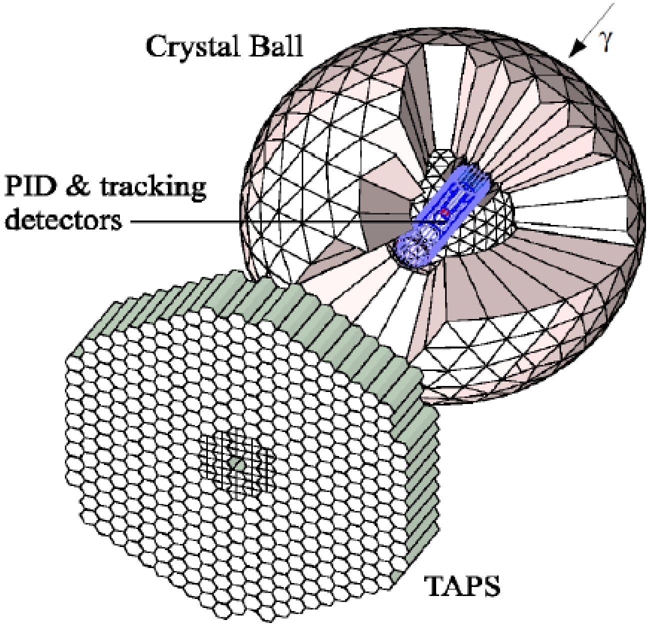
16th October 2023 – MENU2023 – Mainz, Germany

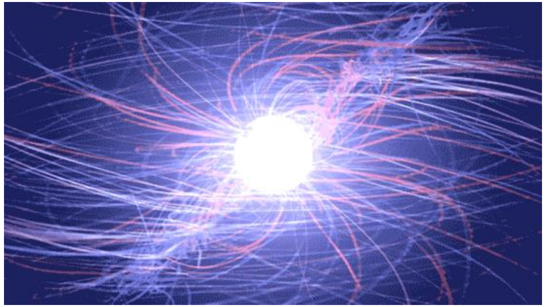
Introduction



Hexaquark







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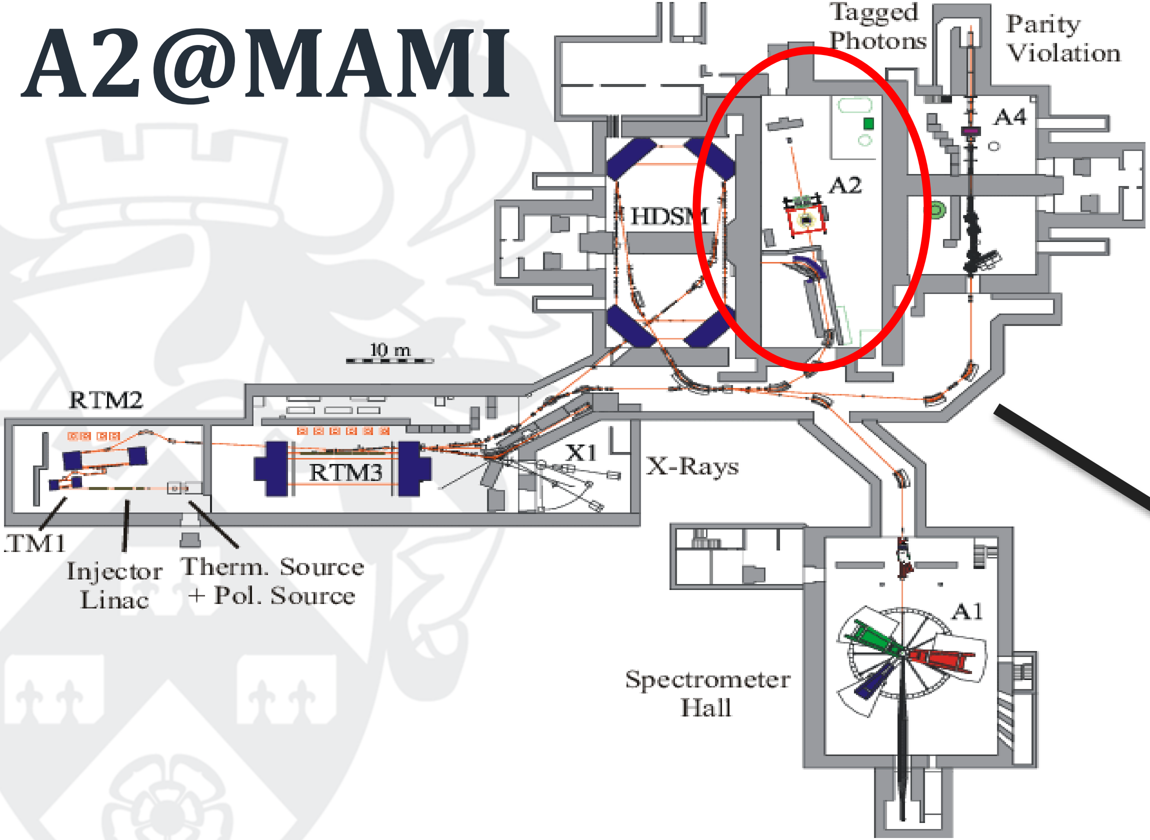

Tagged Photons
Parity Violation
A4
A2
HDSM
10 m
RTM2
RTM3
X1
X-Rays
RTM1
Injector Linac
Therm. Source + Pol. Source
A1
Spectrometer Hall

Denmark
Baltic Sea
North Sea
Canal
Kiel
Hamburg
Schwerin
Bremen
Elbe R.
Havel R.
Poland
Netherlands
Ems R.
Mittelland
Hannover
Canal
Potsdam
Berlin
Spree R.
Magdeburg
Rhine R.
Essen
Weser R.
Elbe R.
Düsseldorf
Cologne (Köln)
Bonn
Leipzig
Weimar
Dresden
Germany
Frankfurt
Main R.
Mainz
Czech Republic
Vltava R.
Luxembourg
Saarbrücken
Stuttgart
Danube R.
Isar R.
Inn R.
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Lech R.
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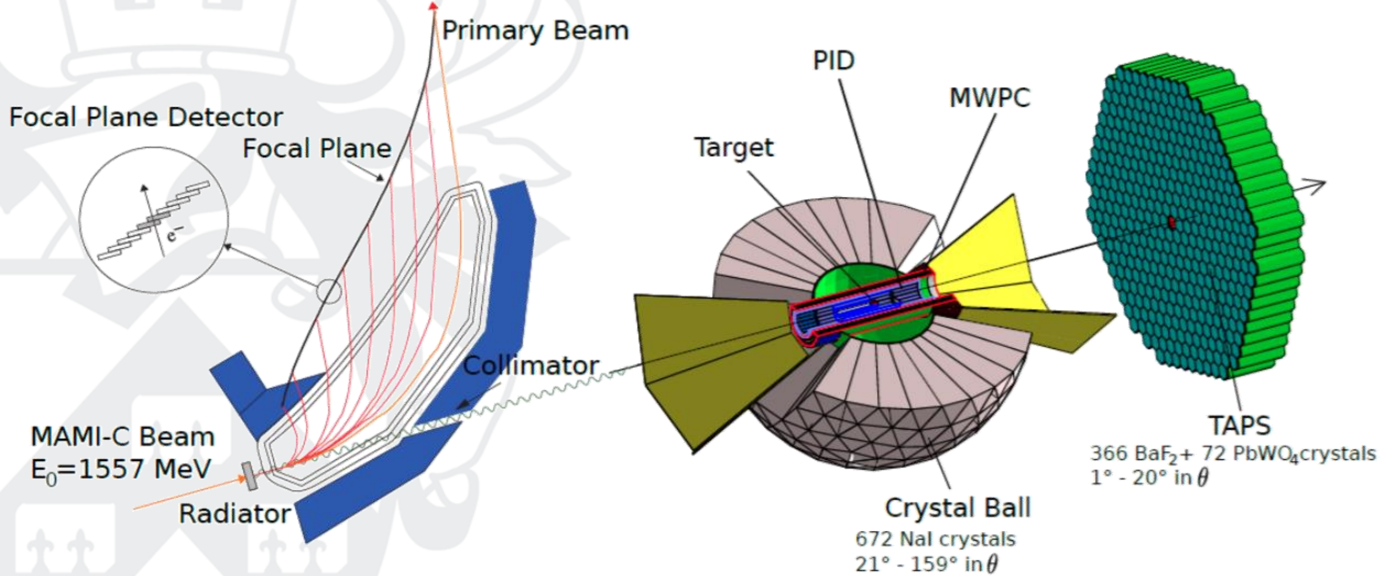
Glasgow photon tagging spectrometer



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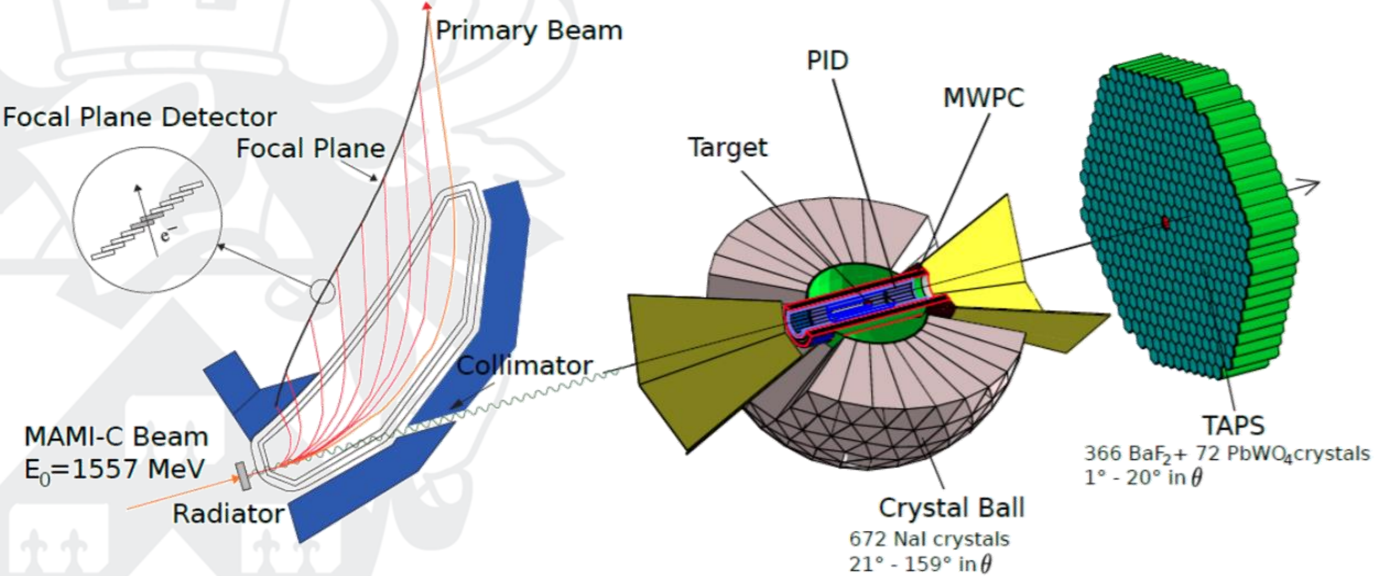
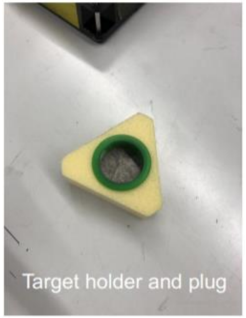
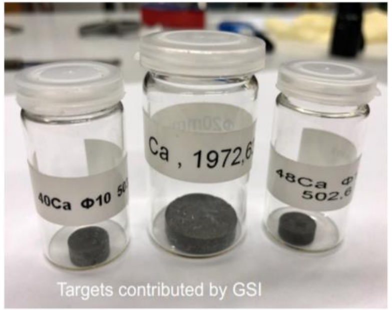
Glasgow photon tagging spectrometer





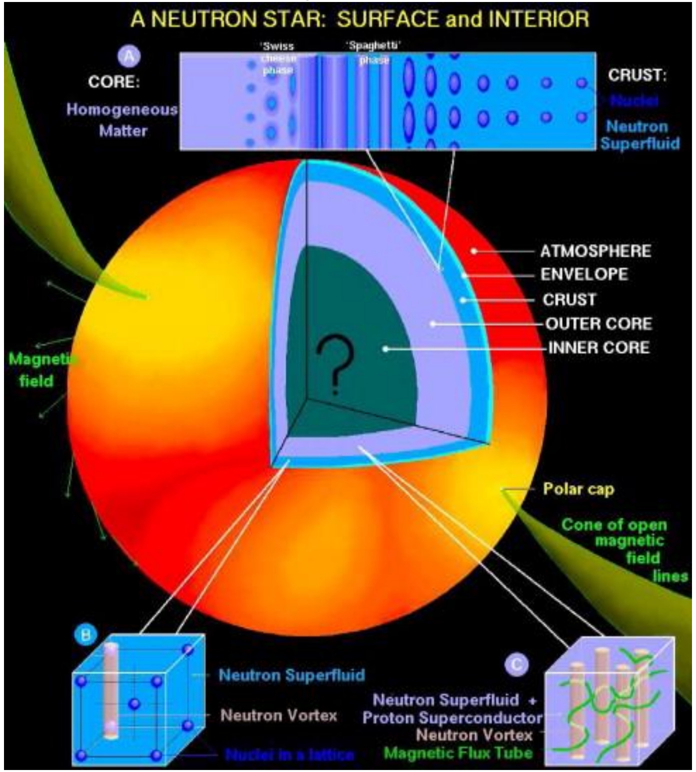


- Experiment beam time: November 2018 & February 2019

Target	Diameter (mm)	Mass (mg)	Mass Number	Natural Abundance (%)	Half-life (years)	Beamtime (hours)
^{40}Ca	10	503.2	40	96.94	> 3.0 x 10^{21}	120
^{48}Ca	10	502.6	48	0.187	> 5.8 x 10^{22}	180
^{112}Sn	20	3800	112	-	-	54

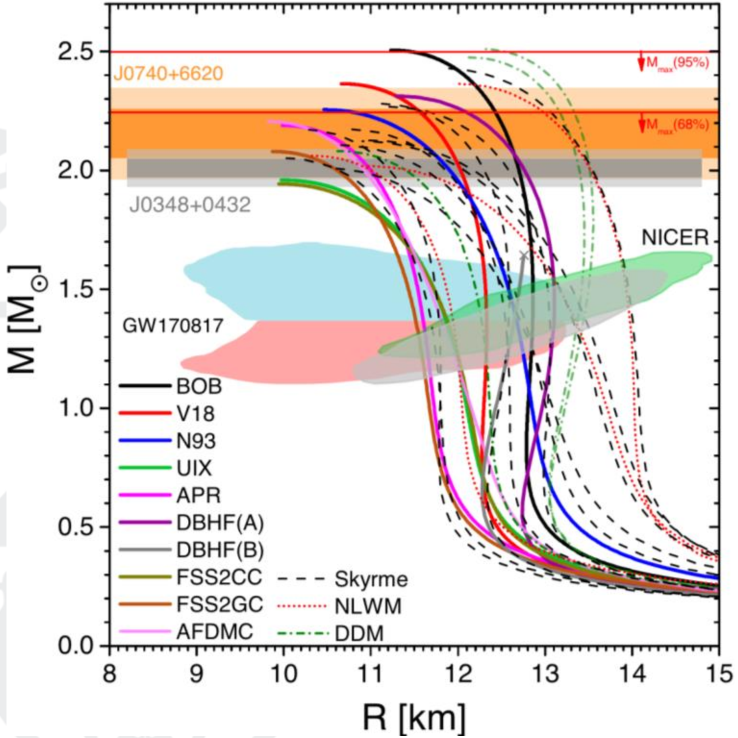
Neutron Stars

- Remains of super-massive-star supernova
- Compact object (~10km radius)
- Heavy (1-2 M_{Sun})
- Central densities up to 5 nuclear matter saturation density
- Fast rotating
- Extreme magnetic fields
- Very cold (for nuclear scales)



J.M. Lattimer /New Astronomy Reviews 54 (2010) 101–109

Neutron Stars & EOS



L. BŁASZKIEWICZ et al.; Acta Geophysica vol. 64, no. 1, Feb. 2016, pp. 293-315

I. Vidaña, M. Bashkanov, D.P. Watts, A. Pastore; Phys.Lett. B781 (2018) 112-116

K. Olofsson; Degree Project (2022); https://shorturl.at/fhi68 (Accessed: 09/11/22)

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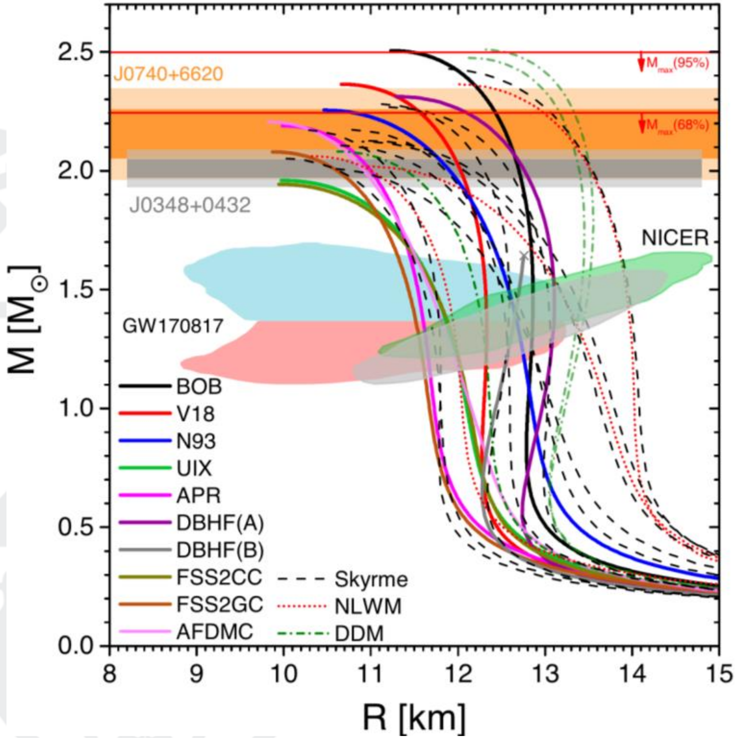

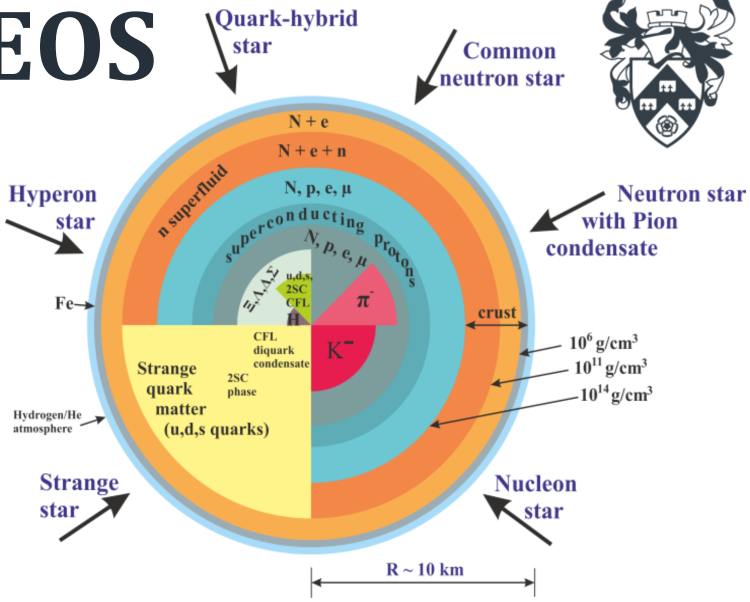

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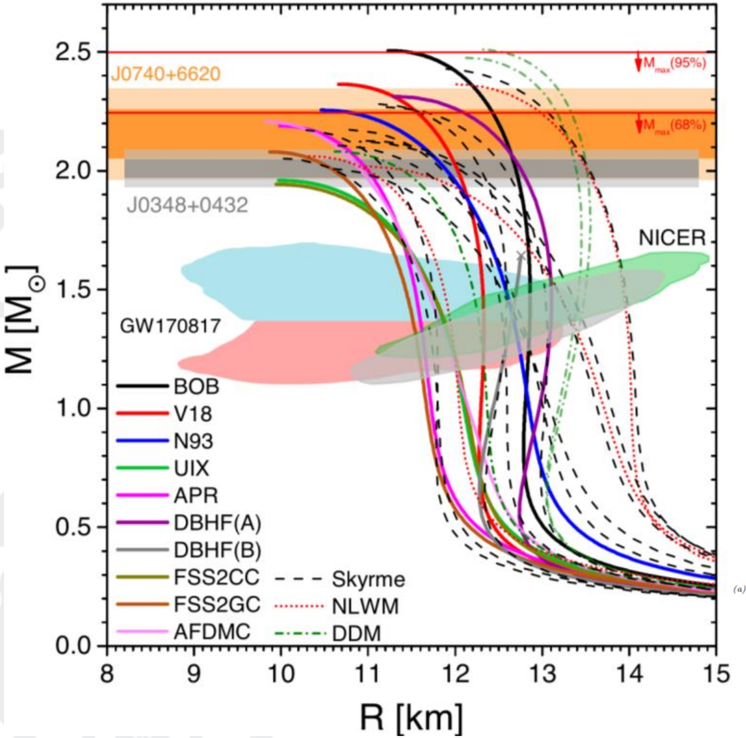
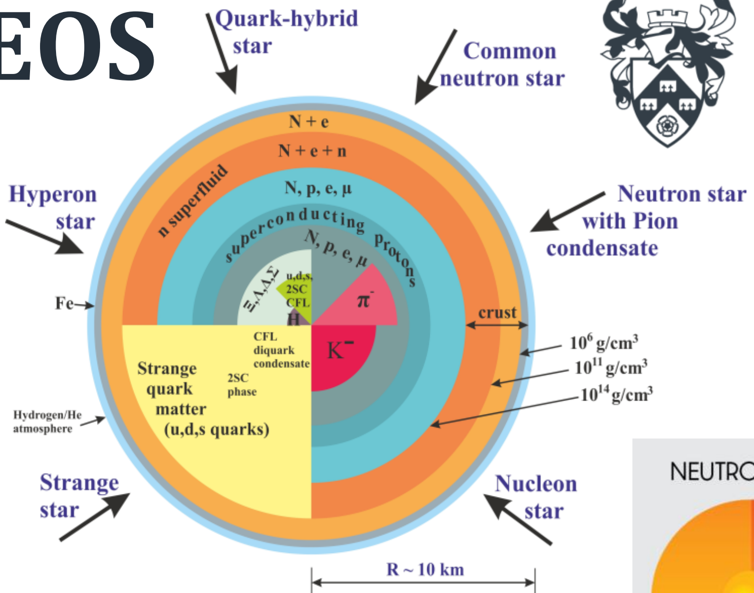


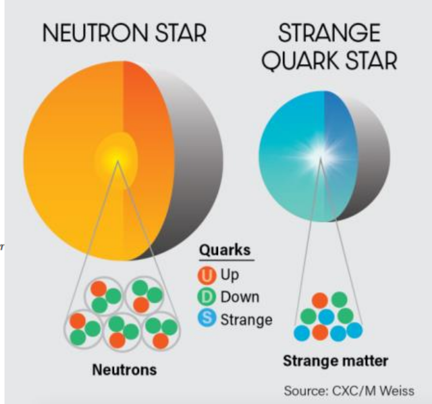


Merger of two neutron stars: predictions from the two-families scenario

Alessandro Drago[(a)] and Giuseppe Pagliara[(a)]

[(a)] *Dip. di Fisica e Scienze della Terra dell'Università di Ferrara and INFN Sez. di Ferrara, Via Saragat 1, I-44100 Ferr*

If only one family of "neutron stars" exists, their maximum mass must be equal or larger than $2M_\odot$ and then only in less than about 18% of cases the outcome of the merger of two neutron stars is a direct collapse to a black hole, since the newly formed system can avoid the collapse at least until differential rotation is present. In the so-called two-families scenario, stars made of hadrons are stable only up to about $1.5-1.6M_\odot$, while the most massive compact stars are entirely made of strange quark matter. We show that in this scenario the outcome of the merger of two neutron stars is a prompt collapse in at least 34% of the cases. It will therefore be easy to discriminate between the two scenarios once the gravitational waves emitted at the moment of the merger are detected.



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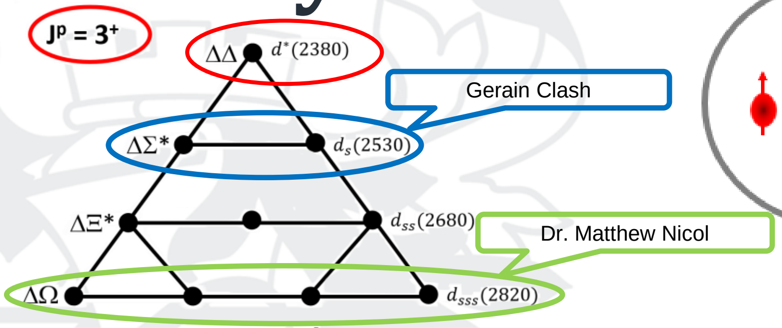
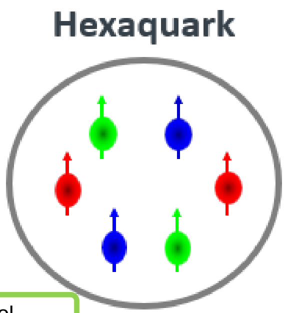
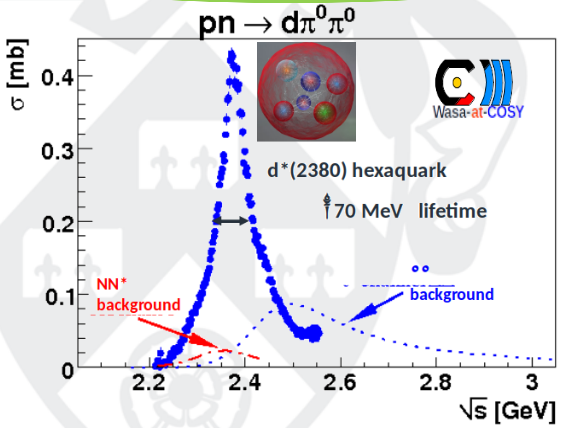
Dibaryons

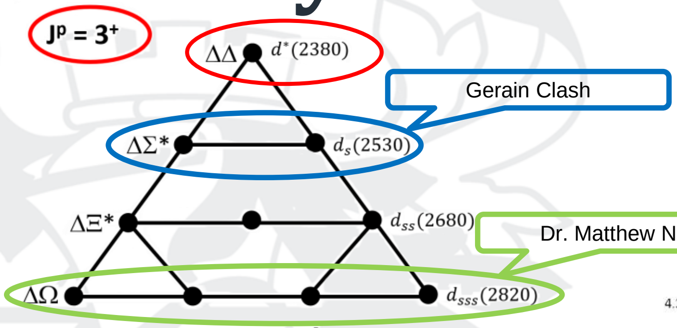






[1] I. Vidaña, M. Bashkanov, D.P. Watts, A. Pastore; Phys.Lett. B781 (2018) 112-116
[2] P. Adlarson et. al Phys. Rev. Lett. 106:242302, 2011

Dibaryons



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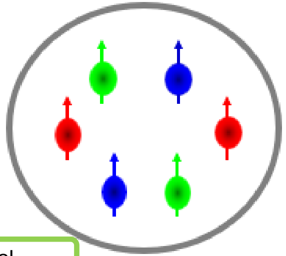
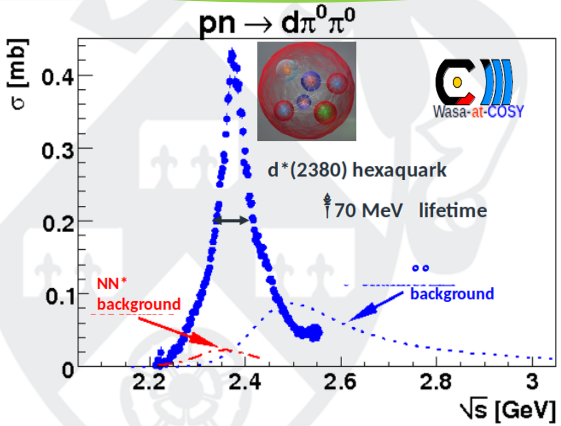
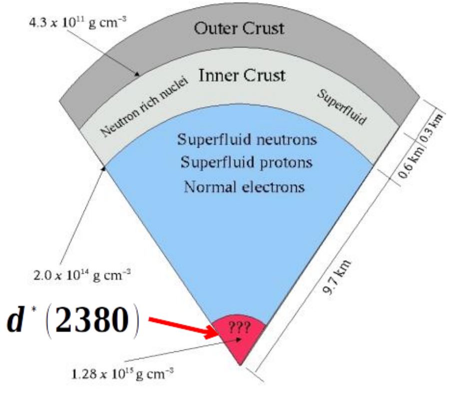
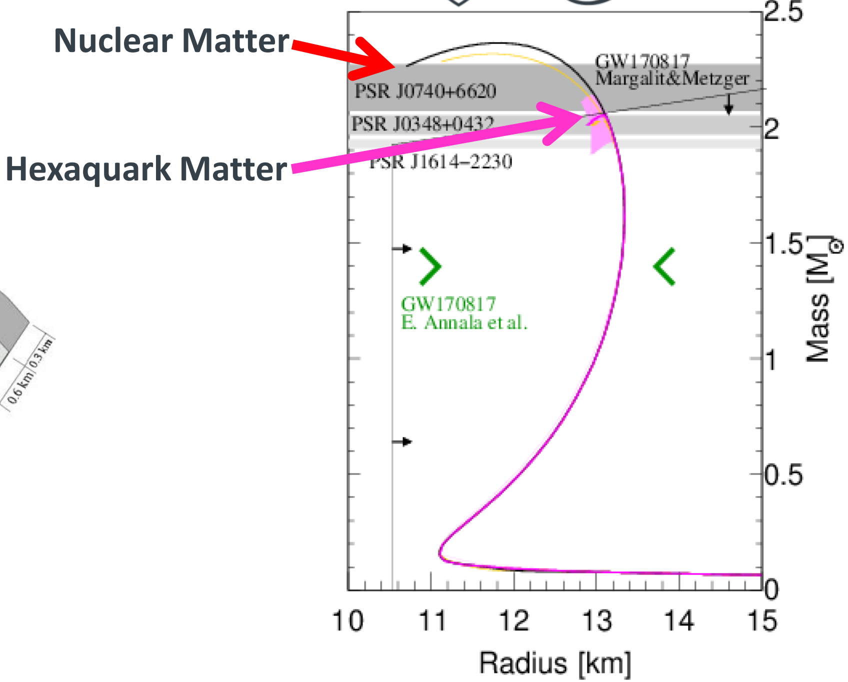






Neutron Star Pizza



[1] I. Vidaña, M. Bashkanov, D.P. Watts, A. Pastore; Phys.Lett. B781 (2018) 112-116

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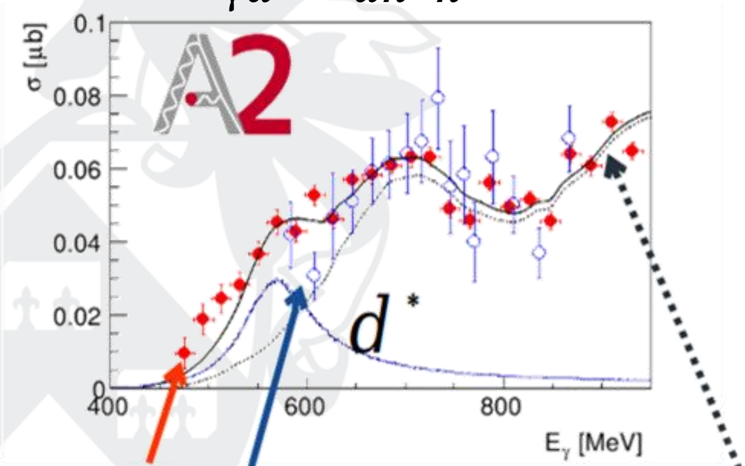
d*(2380) Observation

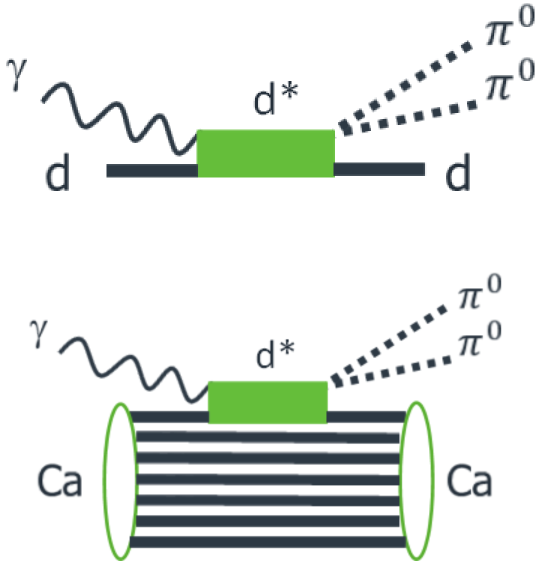
$\gamma d \rightarrow d\pi^0\pi^0$



B. Krusche, NStar 2019

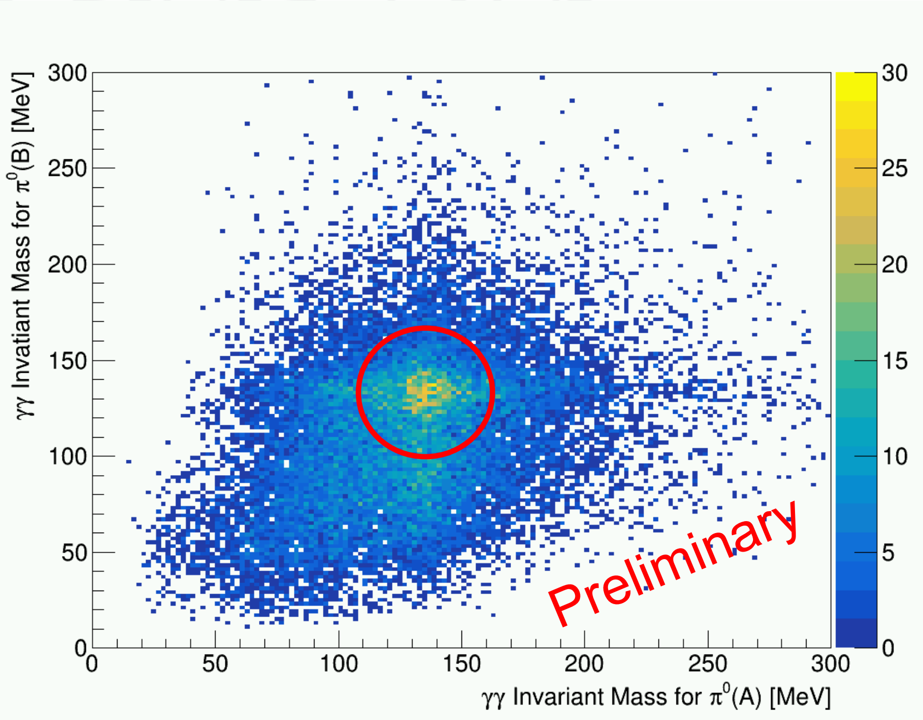
T. Ishikawa et al. Phys.Lett. B772 (2017) 398

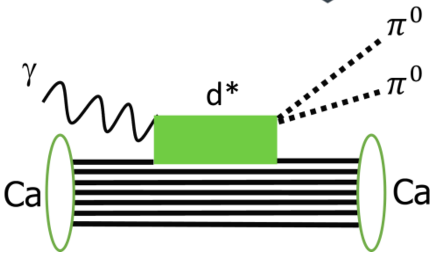
Conventional Background
M. Egorov, A. Fix,
Nucl.Phys. A933 (2015) 104-113



D.Watts, M.Bashkanov, A.Pastore; PPT: STRONG2020 - Six quarks for Muster Mark?; STRONG2020 - INFN(IT) Mar 2021

$\pi^0\pi^0$ Analysis

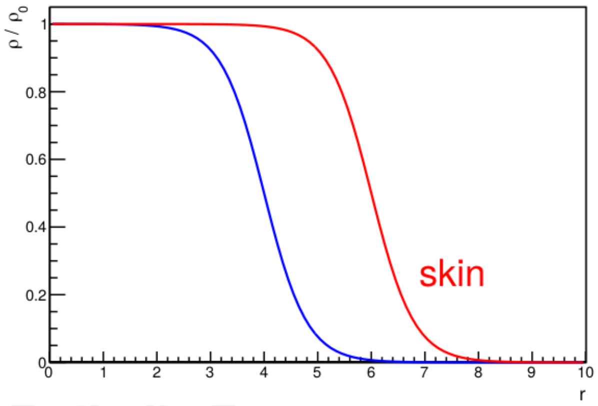




- Invariant mass of selection on the $\pi^0\pi^0$ pairs.
- The identification of the relevant pions is done via selection cuts: angle, detector, coincidence and energy.

Neutron Skin

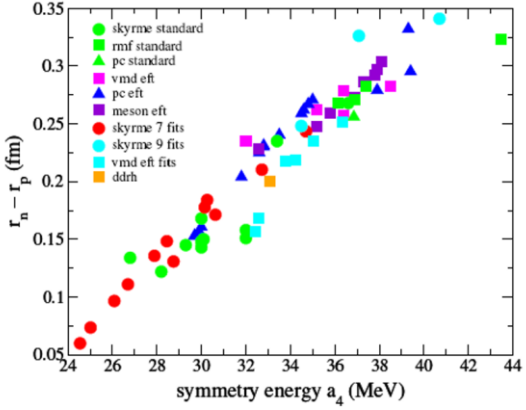
- Charge formfactor (protons) is well understood;
- Neutron skin measurement - serves as benchmark to understand the distribution of nucleons in the nucleus;
- Neutron skin is measured using coherent π^0 photoproduction;



D. Worthmueller – A2 Collaboration Meeting 2020

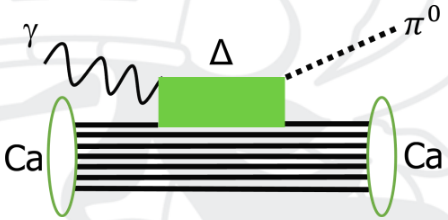
$$\Delta r_{np} = \langle r_n^2 \rangle^{1/2} - \langle r_p^2 \rangle^{1/2}$$

$$r_{np} > 0 \Rightarrow \text{neutron skin}$$

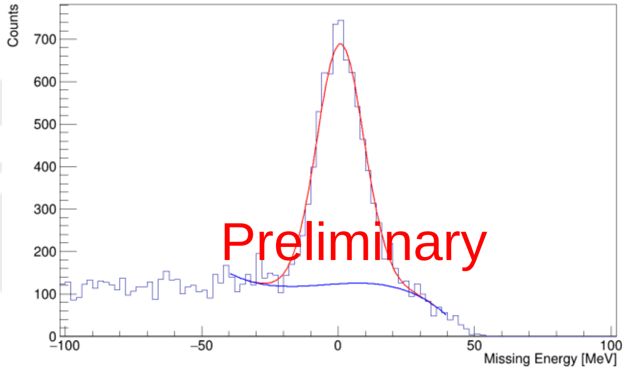


C.M. Tarbert et. al.; PRL 112, 242502 (2014)

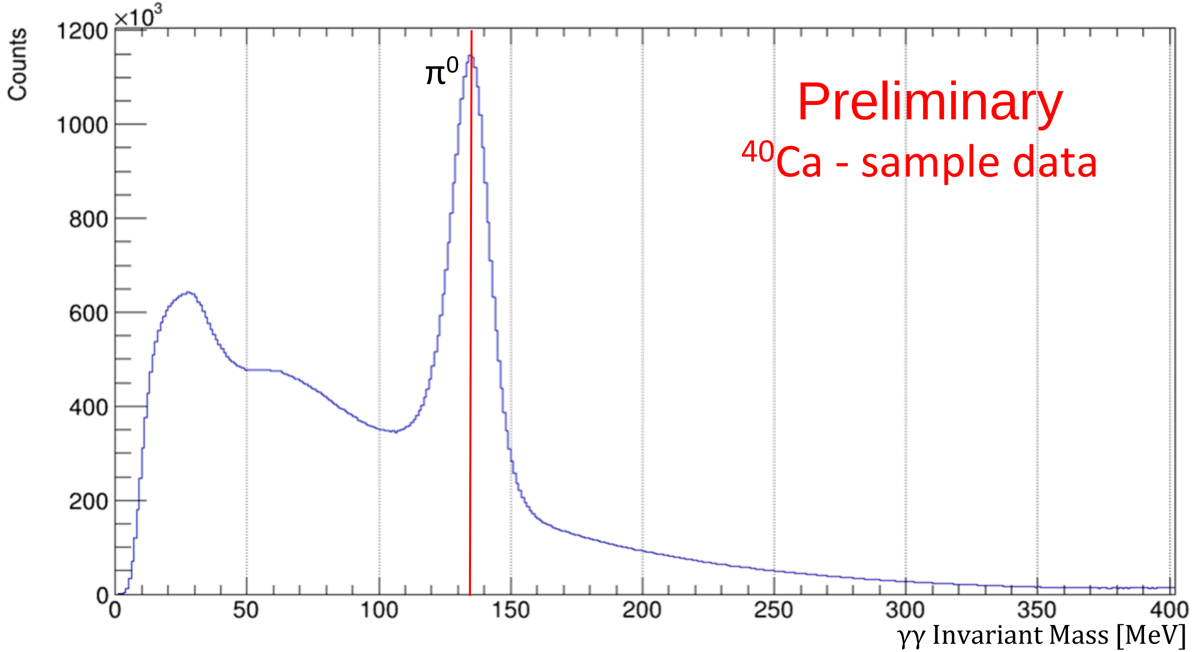
π^0 Analysis



^{40}Ca Single π^0 missing energy at E_γ =170MeV and θ ~60˚

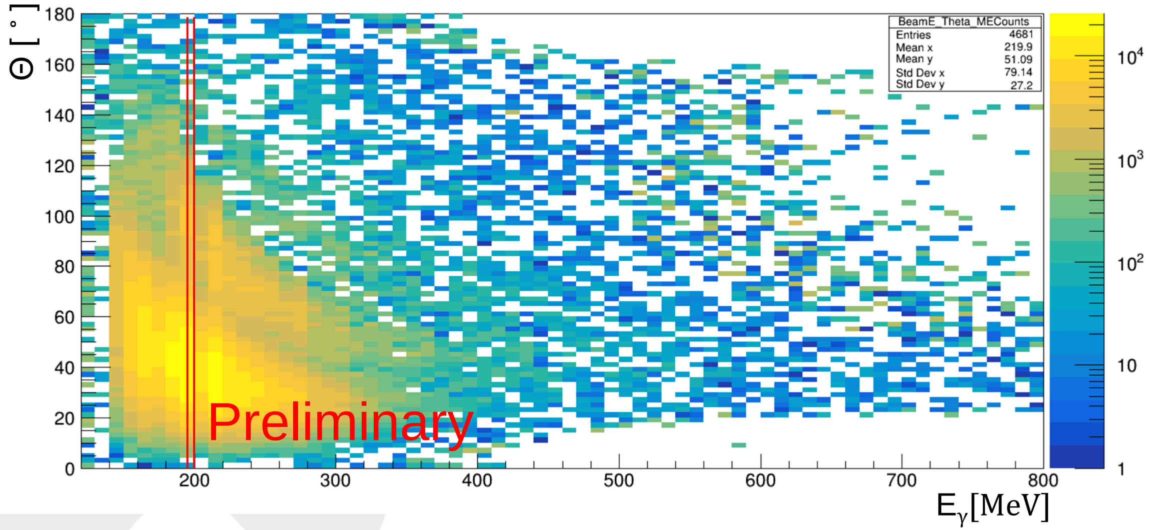


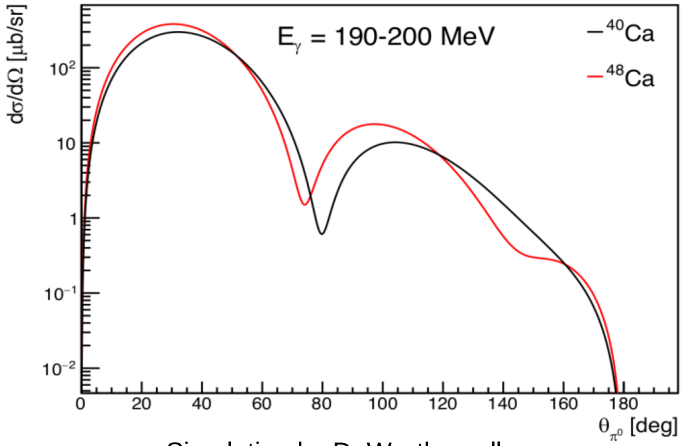
^{40}Ca Single π^0 invariant mass



π^0 Analysis

^{40}Ca Missing Energy signal region (-20MeV to 20MeV)





Simulation by D. Werthmueller

Summary

- Positive results at this stage of the analysis;
- Neutron skin <–> compressibility of nuclear matter at $1\rho_0$;
- Coherent $\pi^0\pi^0$ production -> nuclear matter at $3\rho_{0;}$
- Results will be followed by publication.

Special Mentions

Dr. Mikhail Bashkanov – Supervisor
Prof. Daniel Watts – Supervisor/Head of Hadron Group
Dr. Andreas Thomas – Head of A2 Collaboration
Dr. Stuart Fegan
Dr. Nick Zachariou

Thank you for your attention!