New JEDI : status and perspectives
(New Judicious Experiments for Dark Sectors Investigations)

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GANIL (France): Beyhan Bastin, François de Oliveira, Marek Lewitowicz, Jean-Eric Ducret, Olivier Sorlin, Dieter Ackerman, Christelle Stodel, Abdelouahad Chbihi, Jean-Charles Thomas, Gilles De France, Marek Ploszajczak ; **IJCLab (France): Jürgen Kiener, Alain Coc**, Isabelle Deloncle, Charles-Olivier Bacri, Clarisse Hamadache, Adrien Laviron, Jérôme Bourçois, Vincent Tatischeff, Fairouz Hammache, Nicolas de Séréville and Brigitte Roussière ; **IAP (France): Cyril Pitrou ; IP2I (France):** B. Rebeiro and Y. Demande ; **Minnesota University (USA): Maxim Pospelov ; NPI (Czech Republic): Jaromir Mrazek**, Guiseppe D'Agata, Anastasia Cassisa, Eva Simeckova and Vaclav Burjan ; **ULB (Belgium): Pierre Descouvemont ; INFN LNS (Italy): Livio Lamia**, Marco La Cognata, Gianluca Pizzone, Alessia Di Pietro, Aurora Turmina, Guiseppe Rapisarda, Giovanni Luca Guardo and Dominico Santonocino; **iThemba LABS (South Africa) : Lindsay Donaldson**, Philip Adsley, Pete Jones and Kgashane Malatji.

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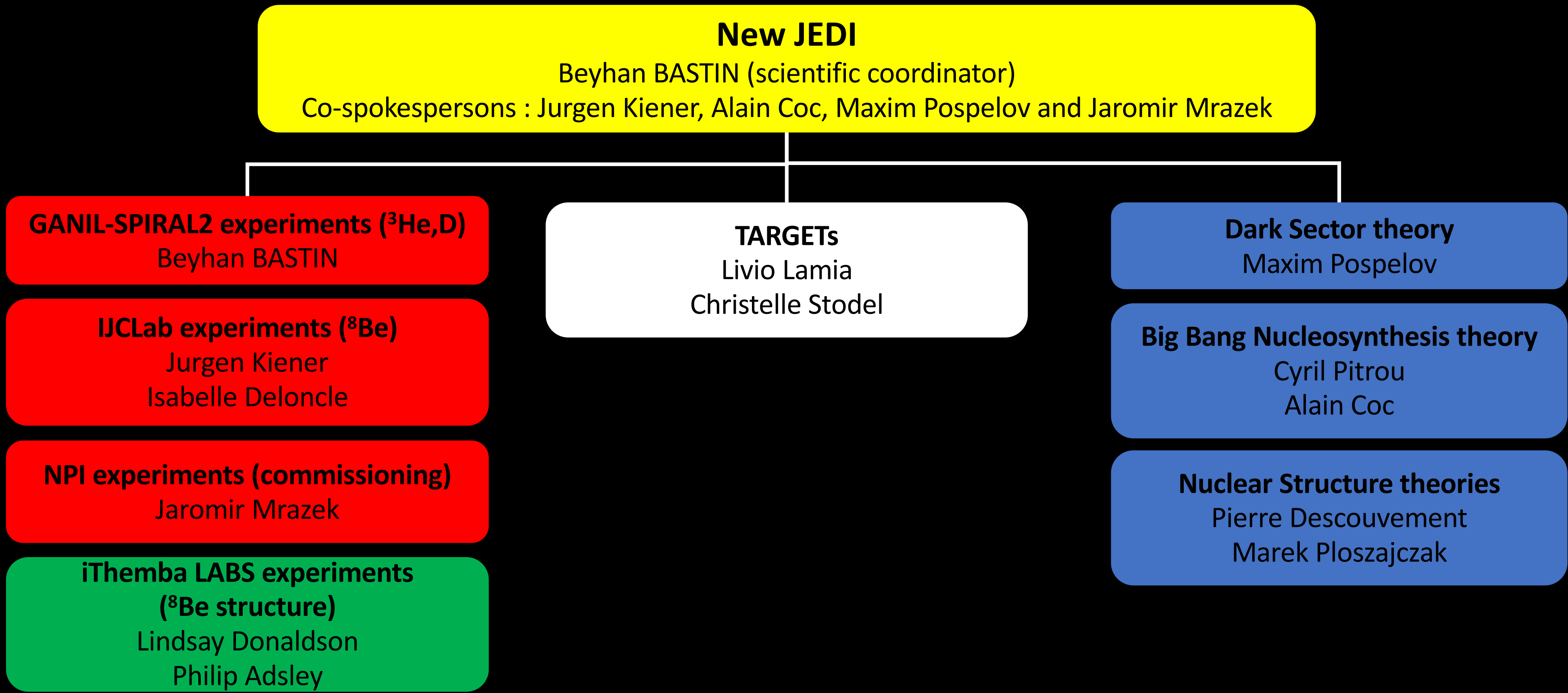

NEW JEDI

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New JEDI
Beyhan BASTIN (scientific coordinator)
Co-spokespersons : Jurgen Kiener, Alain Coc, Maxim Pospelov and Jaromir Mrazek

GANIL-SPIRAL2 experiments (^{3}He,D)
Beyhan BASTIN

IJCLab experiments (^{8}Be)
Jurgen Kiener
Isabelle Deloncle

NPI experiments (commissioning)
Jaromir Mrazek

iThemba LABS experiments (^{8}Be structure)
Lindsay Donaldson
Philip Adsley

TARGETs
Livio Lamia
Christelle Stodel

See talk of Jurgen Kiener
Study of ^{8}Be anomaly
@ ANDROMEDE

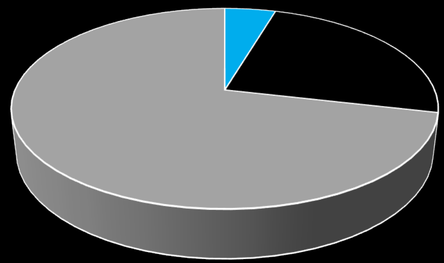
Dark Sector theory
Maxim Pospelov

Big Bang Nucleosynthesis theory
Cyril Pitrou
Alain Coc

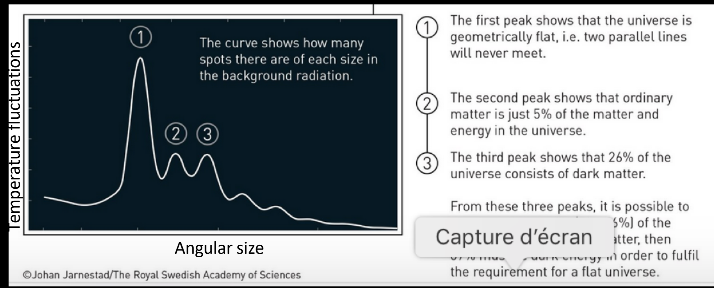
Nuclear Structure theories
Pierre Descouvement
Marek Ploszajczak

Universe composition?

Universe

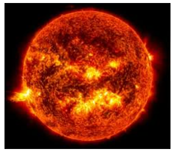


Jim Peebles (Nobel Price 2019)
Anisotropies in the temperature of the CMB



Ordinary matter (5%)

- 4% Hydrogen and Helium.
- < 1% stars

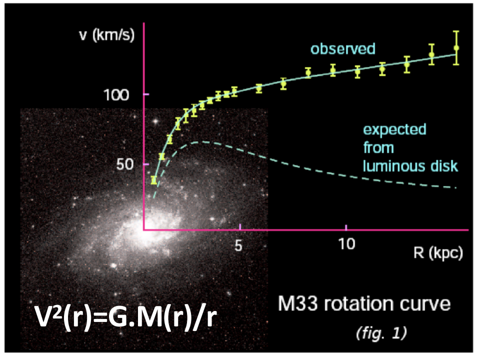


- < 1% others (heavy elements, neutrinos…)

Dark matter (26%)

(ex. d'indices)

- Rotational speed of galaxies



- Gravitationnal lenses

Dark energy (69%)

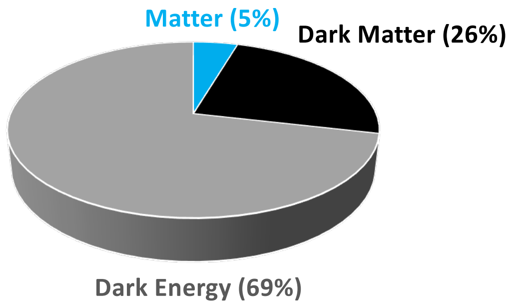
(ex. of hints)

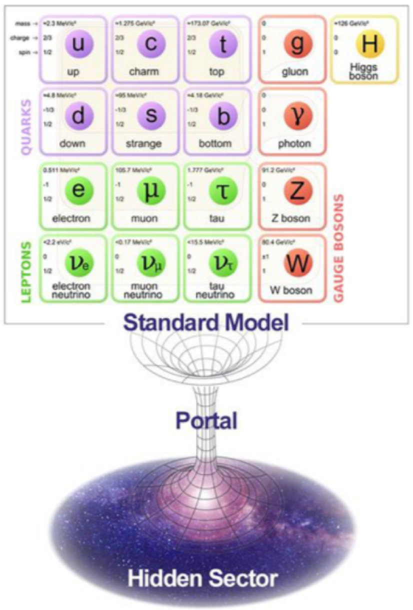
- Type 1A Supernovae

- CMB (anisotropy)

Probing New Dark Boson via Nuclear Physics Experiments

Universe composition

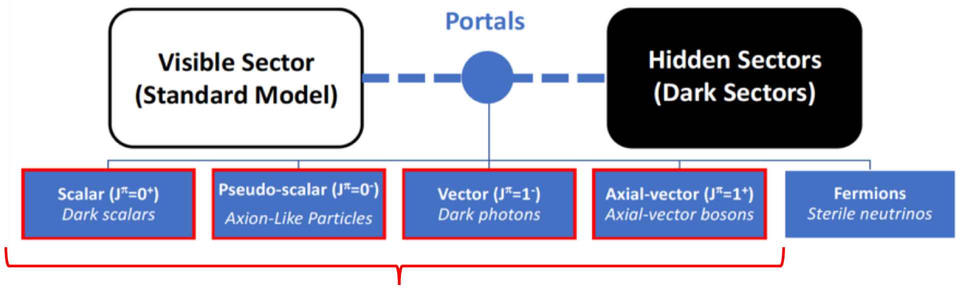




The Standard Model (SM) of particle physics fails to describe hidden sectors of our universe.

Dark Sectors (DS) = hypothetical sets of relatively light particles with interaction orders of magnitude lower than the electromagnetic interactions. DS are composed of one or more particles, that couple to SM through portals.

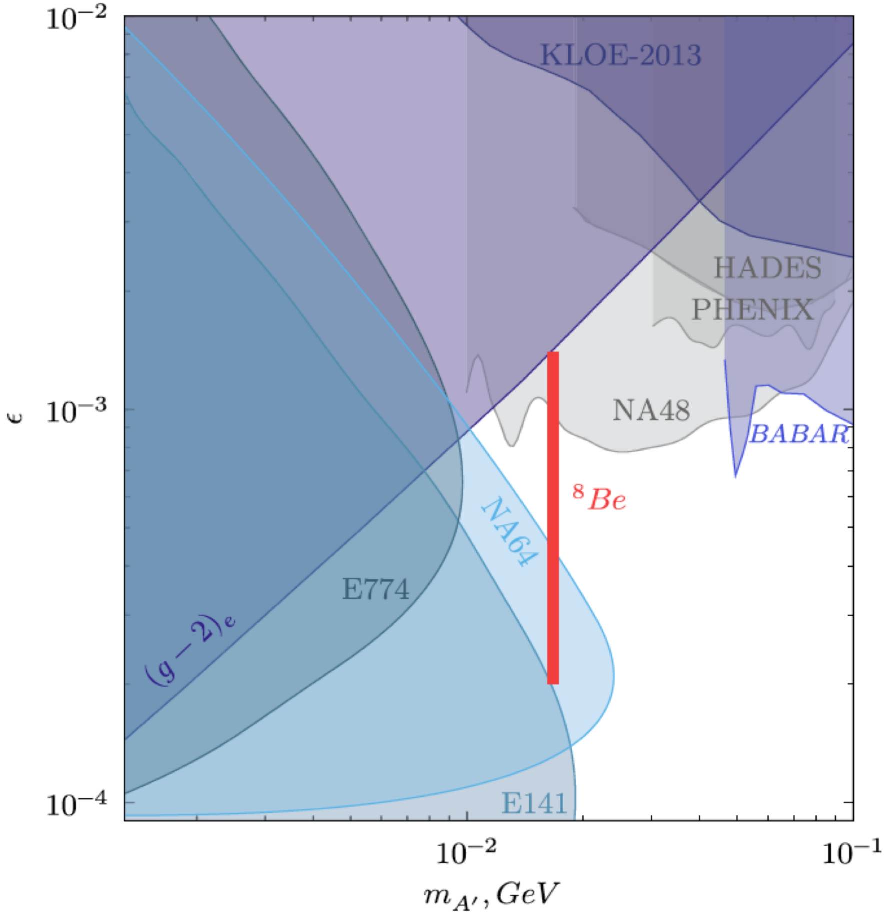
Introduced by [1] C. Boehm *et al.*, NPB 683 (04) 219. M. Pospelov *et al.* PLB 662 (08) 53. [3] N. Arkani-Hame *et al.* PRD 79 (09) 015014
...but poorly tested.



Portals that might be studied though nuclear physics experiments

=> This leads to the fundamental question of the existence of a fifth force of nature.

Focus on dark photons



- The main constraint on $m_{A'}$ comes from the ^{8}Be Anomaly [Kra16]:

  $$\mathbf{m_{A'} = m_X = 16.70 \pm 0.35\ (stat) \pm 0.5\ (syst)\ MeV/c^2}$$

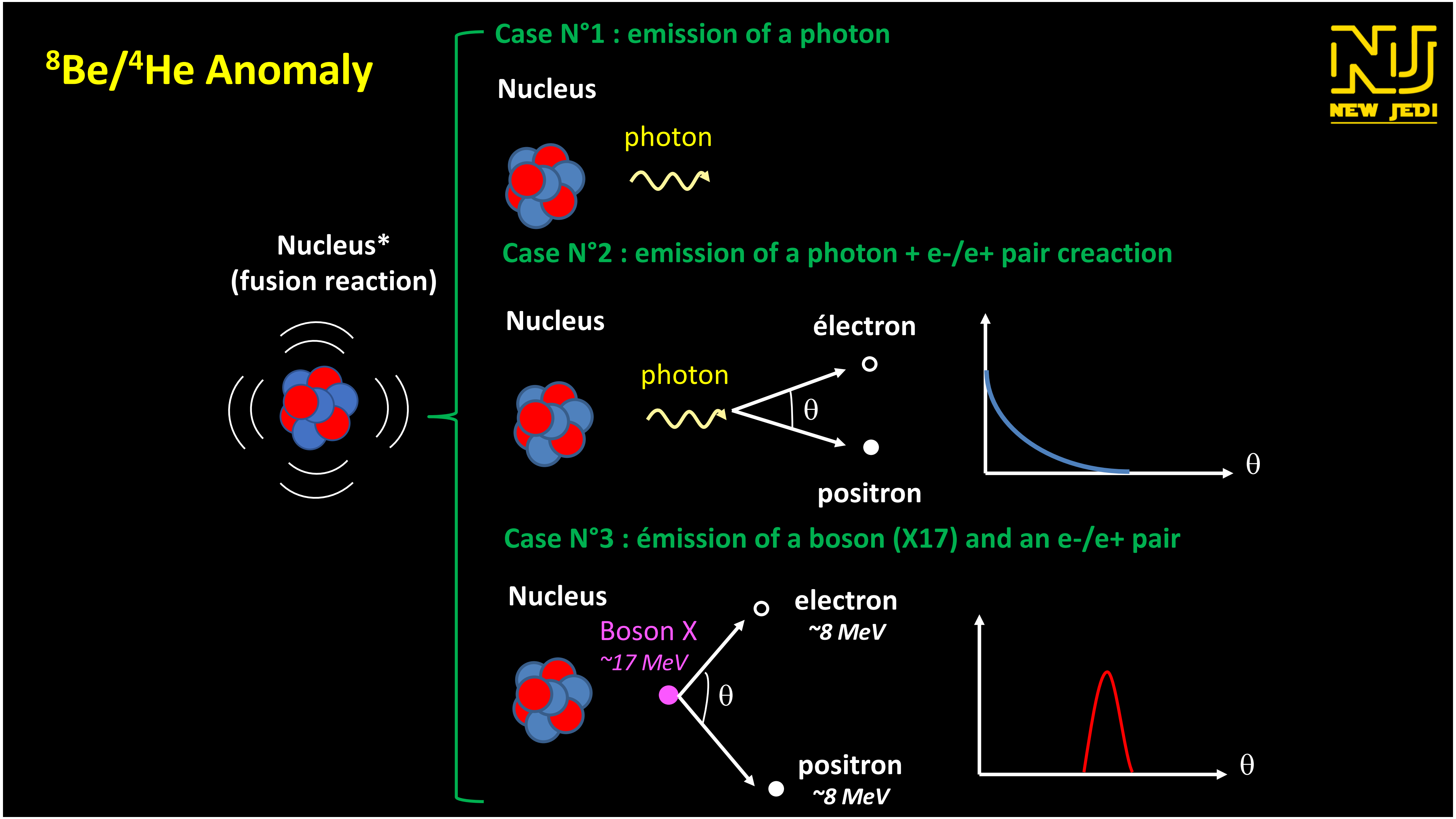
  Note : from this experiment, $|\varepsilon_e| \gtrsim \mathbf{1.3 \times 10^{-5}}$

  $$\Gamma(X \to e^+e^-) = \varepsilon_e^2 \alpha \frac{m_X^2 + 2m_e^2}{3\, m_X} \sqrt{1 - 4m_e^2/m_X^2}$$

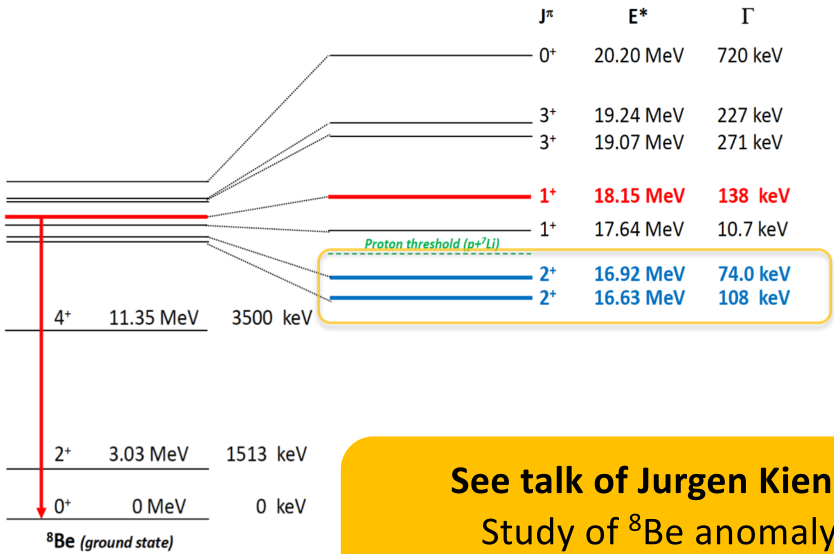
- **The limits on the figure are from [Fen16][Fen17]** :
- $|\varepsilon_e| < \mathbf{1.4 \times 10^{-3}}$ $(\mathbf{3\sigma})$ anomalous magnetic moment of the electron
- $|\varepsilon_e| > \mathbf{2 \times 10^{-4}}$ from the E141 SLAC experiment (search for dark photons bremsstrahlung)

- Recently NA64 : $\mathbf{1.3 \times 10^{-4}} \lesssim \varepsilon_e \lesssim \mathbf{4.2 \times 10^{-4}}$

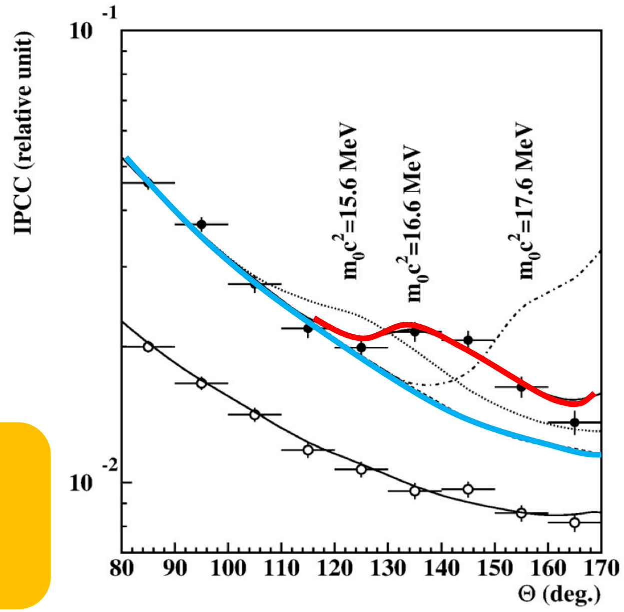
  (bremsstrahlung reaction $e^- + Z \to e^- + Z + X$)


8Be/4He Anomaly
Nucleus*
(fusion reaction)
Case N°1 : emission of a photon
Nucleus
photon
Case N°2 : emission of a photon + e-/e+ pair creaction
Nucleus
photon
électron
θ
positron
θ
Case N°3 : émission of a boson (X17) and an e-/e+ pair
Nucleus
Boson X
~17 MeV
electron
~8 MeV
θ
positron
~8 MeV
θ
NEW JEDI

The ^{8}Be anomaly: experimental results and interpretations



See talk of Jurgen Kiener
Study of ^{8}Be anomaly
@ ANDROMEDE



Depending on its spin-parity, the observed 17 MeV boson can be:

- vector if $J^{\pi}=1^{-}$ [Fen17],
- pseudo-vector if $J^{\pi}=1^{+}$ [Koz17],
- pseudo-scalar if $J^{\pi}=0^{-}$ [Ell16],

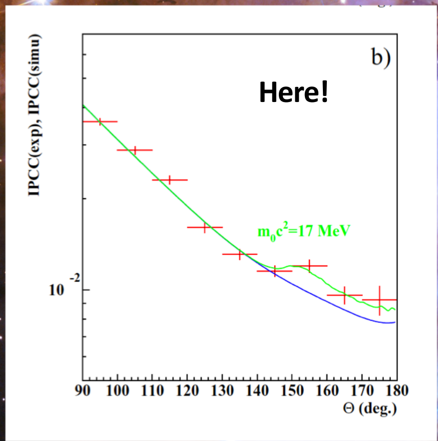
Note: The X boson cannot be scalar ($J^{\pi}=0^{+}$) due to spin-parity conservation.

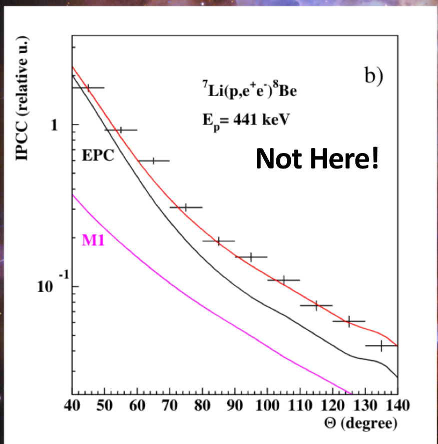
From this experiment, the following branching ratios were also extracted (assuming Br(X⟶e-e+)=1):

1) **Proton decay**: Br(p + ^{7}Li) ≈ 100%
2) **γ- decay**: Br(^{8}Be + γ) ≈ 1.5 x 10^{-5}
3) **Internal pair creation**: Br(^{8}Be + e-e+) ≈ 5.5 x 10^{-8}
4) **Ejection of a new particle**: Br(^{8}Be + X) ≈ 5.5 x 10^{-10}.

(7) L'anomalie dans le spectre de désexcitation du ^{8}Be: résultats expérimentaux interprétations

decay of the 17.6 MeV transition (M1)

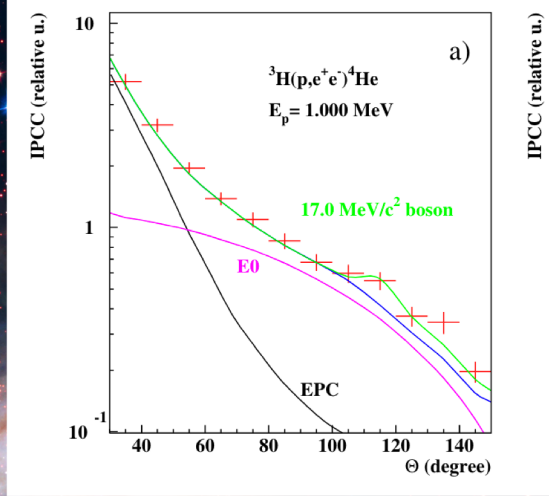


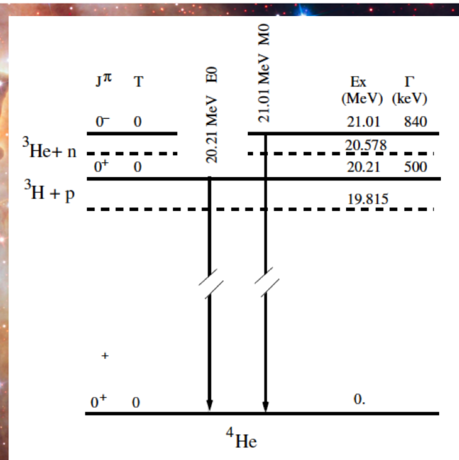


Web of Conferences 142, 01019 (2017)

Acta Physica Polonica B 50 (2019) 675

decay of the 21.01 MeV transition (M0)

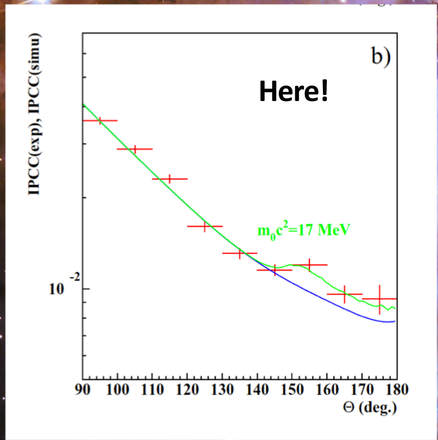


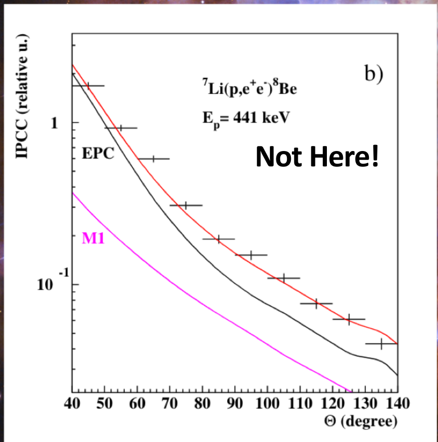


A.J. Krasznahorkay et al., Acta Physica Polonica B 50 (2019) 675

(7) L'anomalie dans le spectre de désexcitation du ^{8}Be: résultats expérimentaux interprétations

decay of the 17.6 MeV transition (M1)

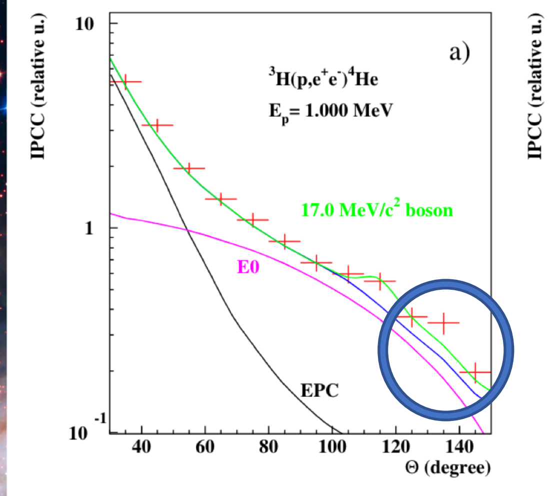


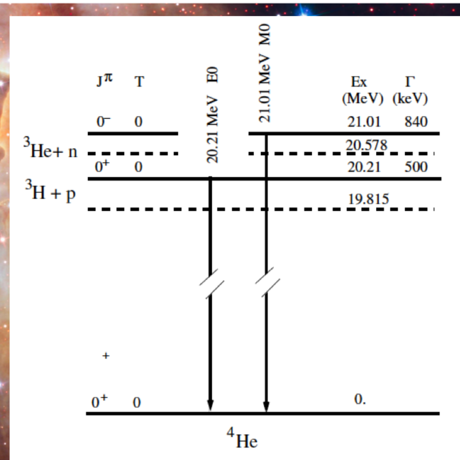


EPJ Web of Conferences 142, 01019 (2017)

Acta Physica Polonica B 50 (2019) 675

decay of the 21.01 MeV transition (M0)





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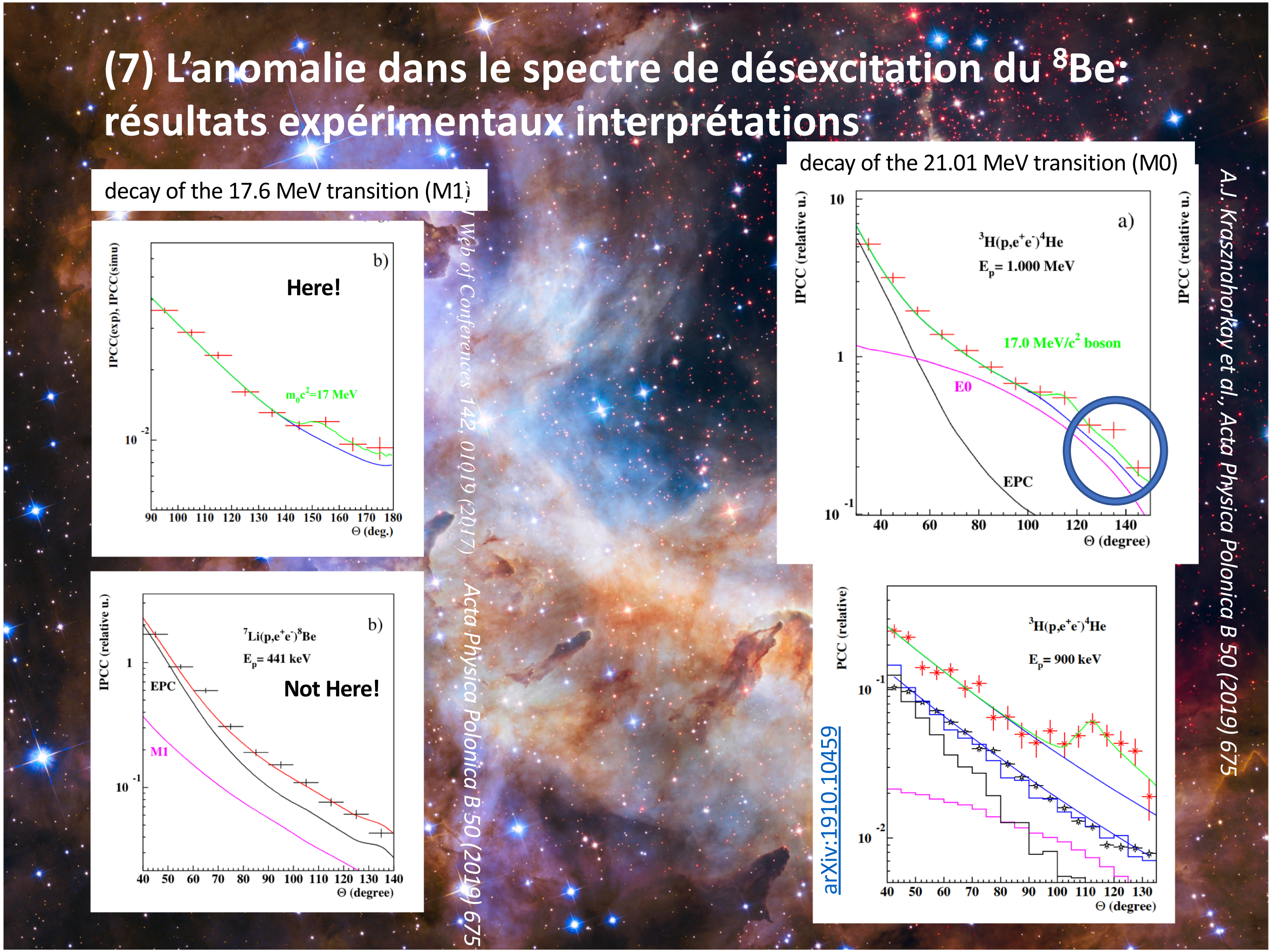


(7) L'anomalie dans le spectre de désexcitation du ^{8}Be:
résultats expérimentaux interprétations
decay of the 17.6 MeV transition (M1)
Here!
b)
m_0c^2=17 MeV
IPCC(exp), IPCC(simu)
10^{-2}
90 100 110 120 130 140 150 160 170 180
Θ (deg.)
Web of Conferences 142, 01019 (2017)
^{7}Li(p,e$^+$e$^-$)^{8}Be
E_p= 441 keV
Not Here!
EPC
M1
IPCC (relative u.)
1
10^{-1}
40 50 60 70 80 90 100 110 120 130 140
Θ (degree)
Acta Physica Polonica B 50 (2019) 675
decay of the 21.01 MeV transition (M0)
a)
^{3}H(p,e$^+$e$^-$)^{4}He
E_p= 1.000 MeV
17.0 MeV/c^2 boson
E0
EPC
IPCC (relative u.)
10
1
10^{-1}
40 60 80 100 120 140
Θ (degree)
^{3}H(p,e$^+$e$^-$)^{4}He
E_p= 900 keV
PCC (relative)
10^{-1}
10^{-2}
40 50 60 70 80 90 100 110 120 130
Θ (degree)
arXiv:1910.10459
A.J. Krasznahorkay et al., Acta Physica Polonica B 50 (2019) 675

(7) L'anomalie dans le spectre de désexcitation du ^{8}Be: résultats expérimentaux interprétations

TABLE III. Nuclear excited states N_*, their spin-parity $J_*^{P_*}$, and the possibilities for X (scalar, pseudoscalar, vector, axial vector) allowed by angular momentum and parity conservation, along with the operators that mediate the decay and references to the equation numbers where these operators are defined. The operator subscripts label the operator's dimension and the partial wave of the decay, and the superscript labels the X spin. For example, $\mathcal{O}_{4P}^{(0)}$ is a dimension-4 operator that mediates a P-wave decay to a spin-0 X boson.

N_*	$J_*^{P_*}$	Scalar X	Pseudoscalar X	Vector X	Axial Vector X
^{8}Be(18.15)	1^+	—	$\mathcal{O}_{4P}^{(0)}$ (27)	$\mathcal{O}_{5P}^{(1)}$ (37)	$\mathcal{O}_{3S}^{(1)}$ (29), $\mathcal{O}_{5D}^{(1)}$ (34)
^{12}C(17.23)	1^-	$\mathcal{O}_{4P}^{(0)}$ (27)	—	$\mathcal{O}_{3S}^{(1)}$ (29), $\mathcal{O}_{5D}^{(1)}$ (34)	$\mathcal{O}_{5P}^{(1)}$ (37)
^{4}He(21.01)	0^-	—	$\mathcal{O}_{3S}^{(0)}$ (39)	—	$\mathcal{O}_{4P}^{(1)}$ (40)
^{4}He(20.21)	0^+	$\mathcal{O}_{3S}^{(0)}$ (39)	—	$\mathcal{O}_{4P}^{(1)}$ (40)	—

Can we check experimentally the existence of this possible 5th force of nature?

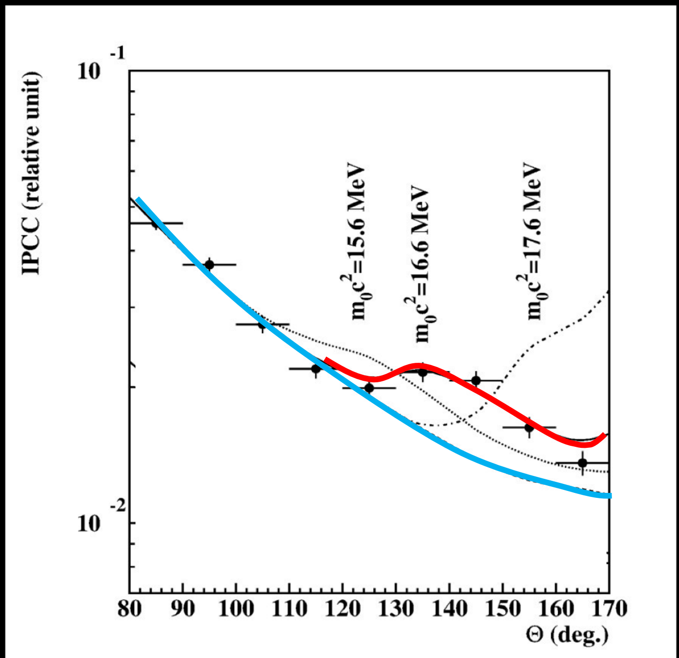
Many experiments give just exclusion zones (interaction amplitude probability, boson mass…,

AND a Nuclear Physics experiment

Observation of Anomalous Internal Pair Creation in ^{8}Be: A Possible Indication of a Light, Neutral Boson

A. J. Krasznahorkay, M. Csatlós, L. Csige, Z. Gácsi, J. Gulyás, M. Hunyadi, I. Kuti, B. M. Nyakó, L. Stuhl, J. Timár, T. G. Tornyi, Zs. Vajta, T. J. Ketel, and A. Krasznahorkay

Phys. Rev. Lett. **116**, 042501 – Published 26 January 2016



Is the X17 a dark boson ?
No so clear…

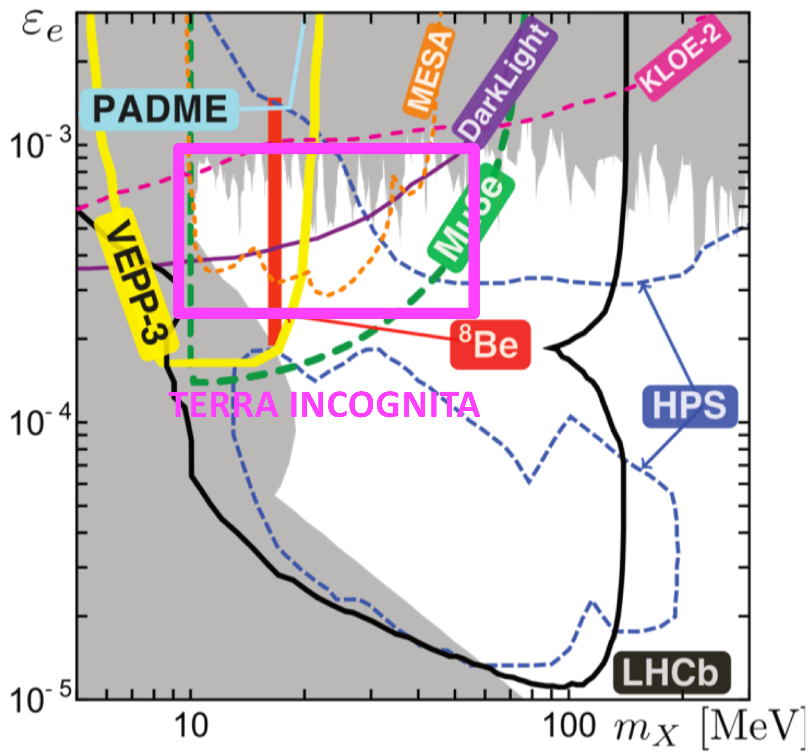
- **Not really compatible with the NA48 experiment (CERN)**

$$\pi^0 \longrightarrow X\,\gamma$$

- **Is it a real experimental signature of a boson?**

- **Artefact linked to an experimental error or a subtle nuclear physics effect in ^{8}Be (very complexe nucleus)?**

An independante measurement is needed…



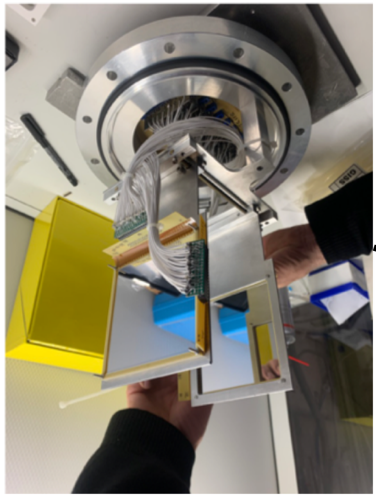
Experiment			2018	2019	2020	2021	2022	2023	2024
LHCb	[8]	Charm meson decay $D^*(2007)^0 \to D^0 A'$, $A' \to e^-e^+$							
Mu3e	[8]	Muon decay channel $\mu^+ \to e^+ \nu_e \overline{\nu_\mu}$ ($A' \to e^- e^+$)							
VEPP-3	[8]	$e^-e^+ \to A' \gamma$	proposed						
KLOE-2	[8]	$e^-e^+ \to \gamma (X \to e^-e^+)$							
MESA	[8]	e- beam on gaseous target, to produce A'				commissioning			
Darklight	[8]	e- scattering of H gas target, to produce A'							
HPS	[8]	e- beam on W to study $A' \to e^-e^+$ and $A' \to \mu^-\mu^+$							
PADME	[8]	e+ beam on diamond target $e^-e^+ \to X\gamma$							
NA64		$eZ \to eZ + X17$							
NSL	[Bro17]	^{8}Be (A' →e-e+)	Proposal (Funding Requested)						
8BeP	[Lan17]	^{8}Be (A' →e-e+)	Proposal (Funding Requested)						
New JEDI		^{8}Be/^{3}He/d... (A' →e-e+)	First experiment : September 2021						
Montréal Uni.		^{8}Be (A' →e-e+)	Proposal						
NSCL	[Mit20]	^{8}Be (A' →e-e+)	First experiment : June 2021						
IUAP CTU	[Hug20]	^{8}Be and ^{4}He (A' →e-e+)	Proposal (Funding Requested)						
INFN Roma	[Gus21]	^{8}Be and ^{4}He(A' →e-e+)	Proposal (Funding Requested)/1rst exp. : end 2021						
Zürick (MAG2)		^{8}Be							

Figure: *(left) projected sensitivities of future experiments on the kinetic mixing parameter ϵ_e and a possible dark photon mass m_X, taken from [Fen17]. Current experimental constraints (grey) and constraint from 8Be (red), established from [Kra16][Fen16][Fen17], are also reminded. In pink the Terra Incognita area that the New JEDI BiRTh project can investigate (Right) details concerning these experiments: foreseen reaction and timeline (see [Fen17] for references about these projects). In addition, new emerging NP experimental programs are indicated within the red frame, including New JEDI [Bro17][Lan17][Hug20][Mit20][Gus21].*

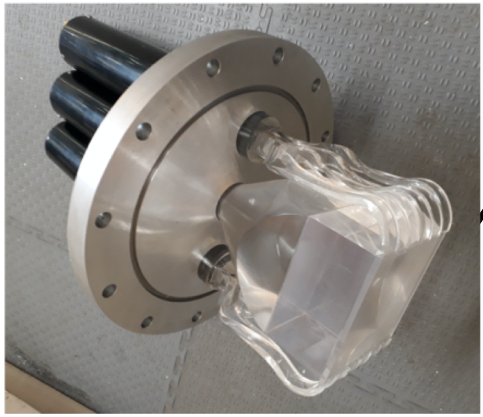
New JEDI : setup and current status

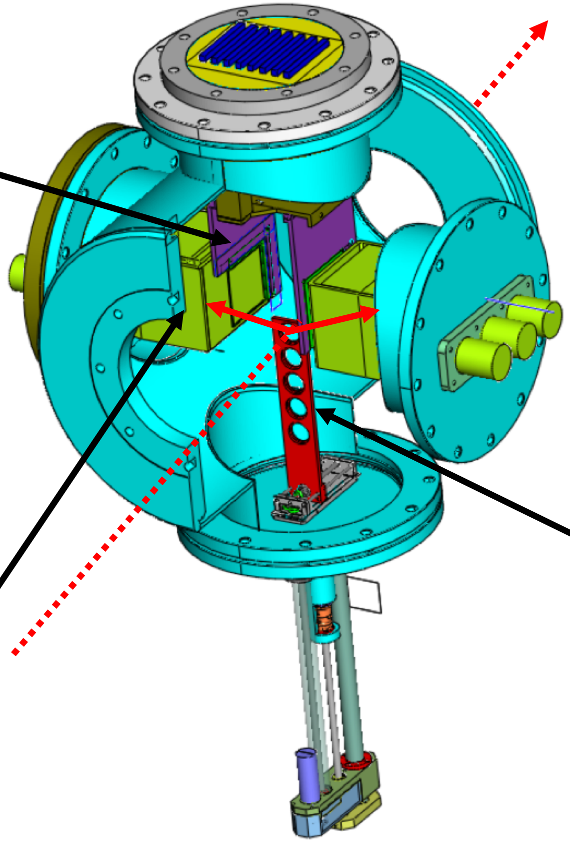
Based on results from test runs carried out in 2018 and 2019 @ ARAMIS-SCALP (IJCLAB) + GEANT3 simulations

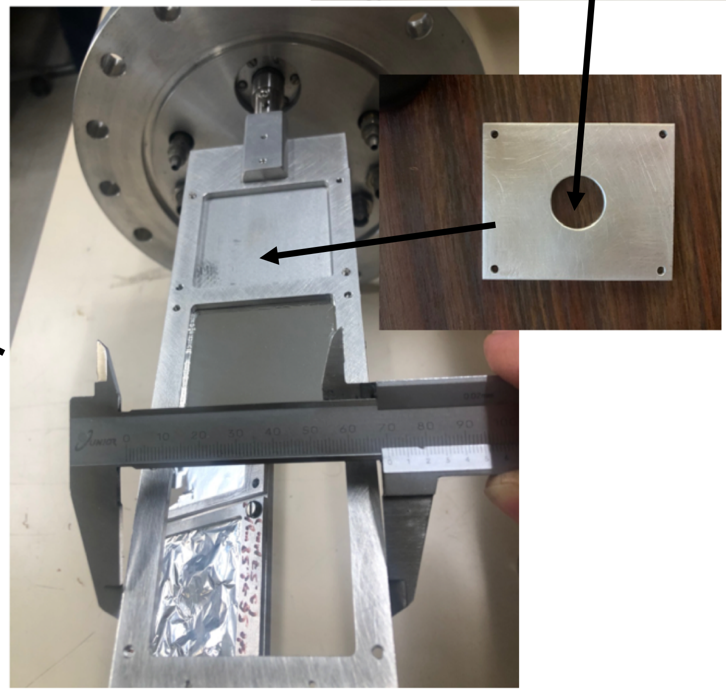
DSSSDs from Microns



Plastic detectors





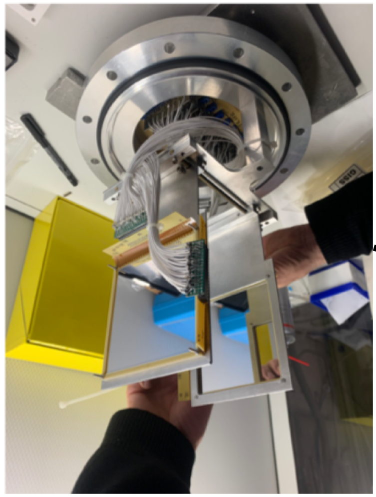


Offline characterisation using ^{207}Bi source

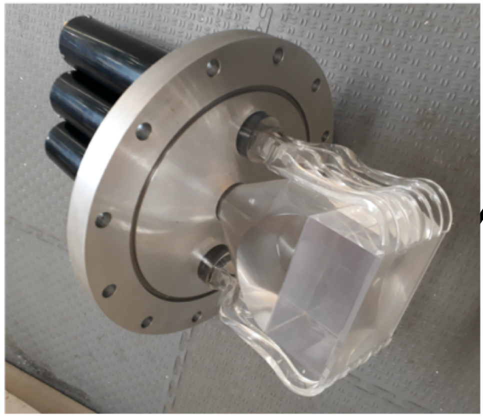
New JEDI : setup and current status

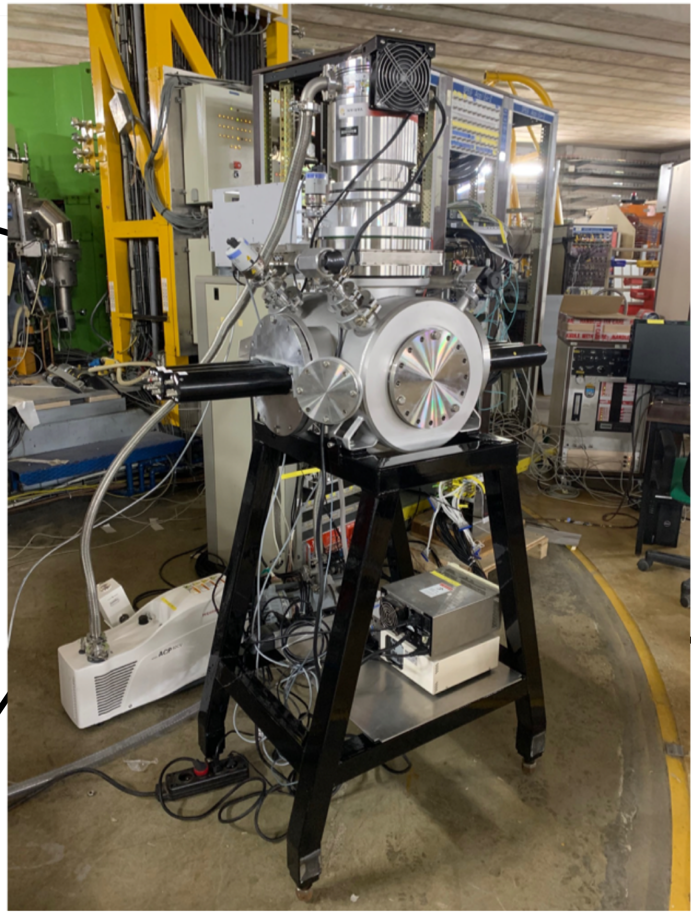
Based on results from test runs carried out in 2018 and 2019 @ ARAMIS-SCALP (IJCLAB) + GEANT3 simulations

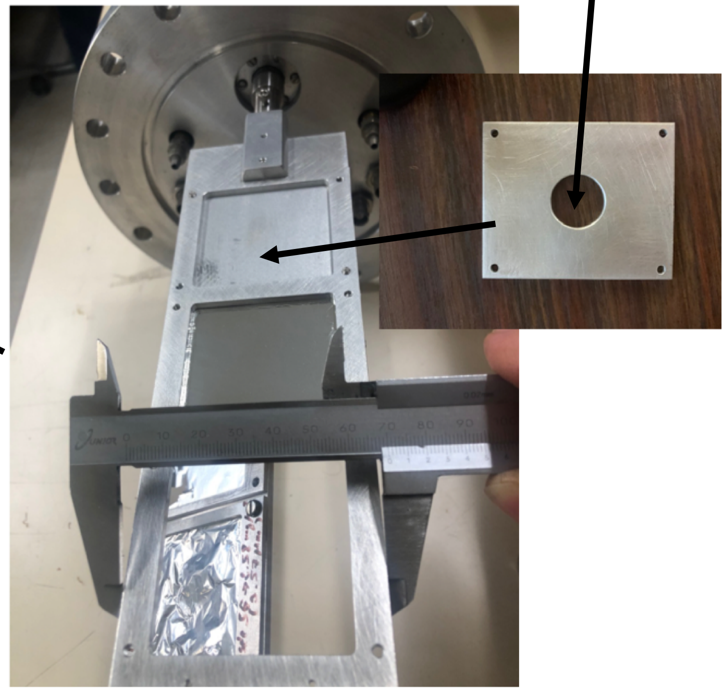
DSSSDs from Microns



Plastic detectors

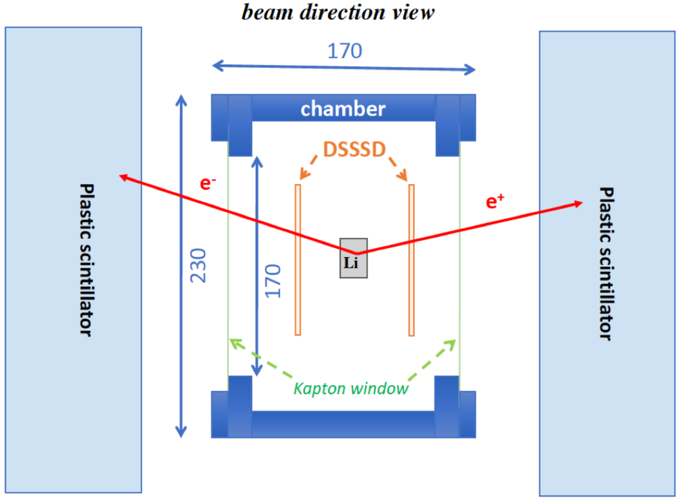






Offline characterisation using ^{207}Bi source

scheme of the new JEDI detection setup (current optimized performances for the p+^{7}Li reaction)



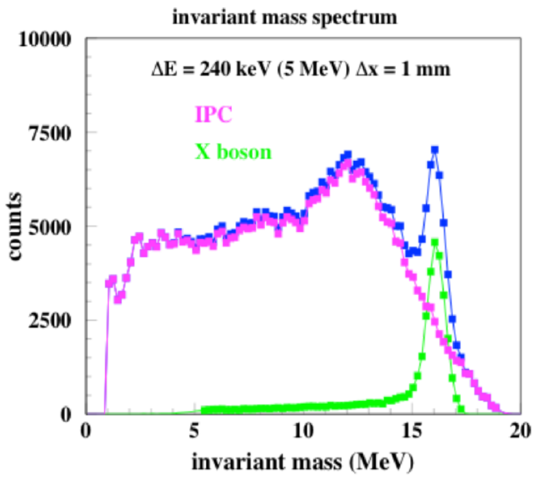
For the simulation, :

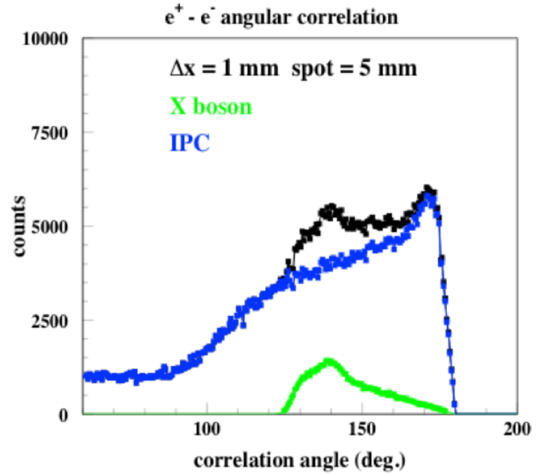
- the diameter of the **beam spot was set to 5 mm**
- spatial resolution of the DSSSD considered was **Δx=1.0 mm**
- energy resolution of the DSSSD and the plastic scintillator used were typically **ΔE=20 keV at 1 MeV** and **ΔE=240 keV at 5 MeV**

The detection efficiency from X boson e-e+ pair decay is ε_{coinc}=14.4%.

If invariant mass between 15.5 to 18.0 MeV + selection on the e-e+ symmetry energy (selection of symmetric pairs), the X signal is much more improve with respect to IPC contribution.

The detection efficiency for **X boson e-e+ pair decay is still reasonable ε_{coinc}=10.0%.**

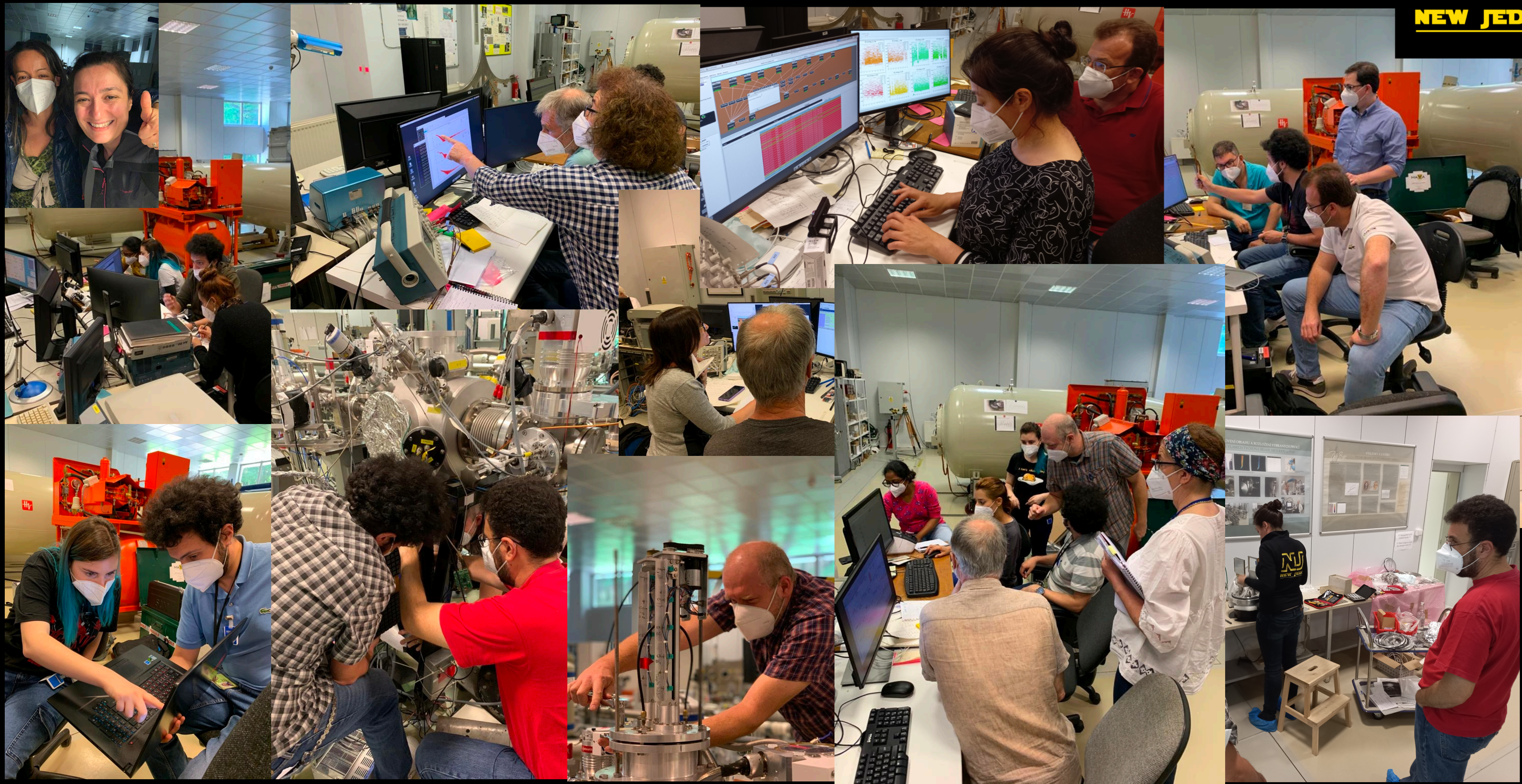




New JEDI commissioning at Rez 3MV tandetron facility (May-June 2021)

New JEDI commissioning team (France, Italy and Czech republic)

New JEDI commissioning at Rez 3MV tandetron facility (May-June 2021)

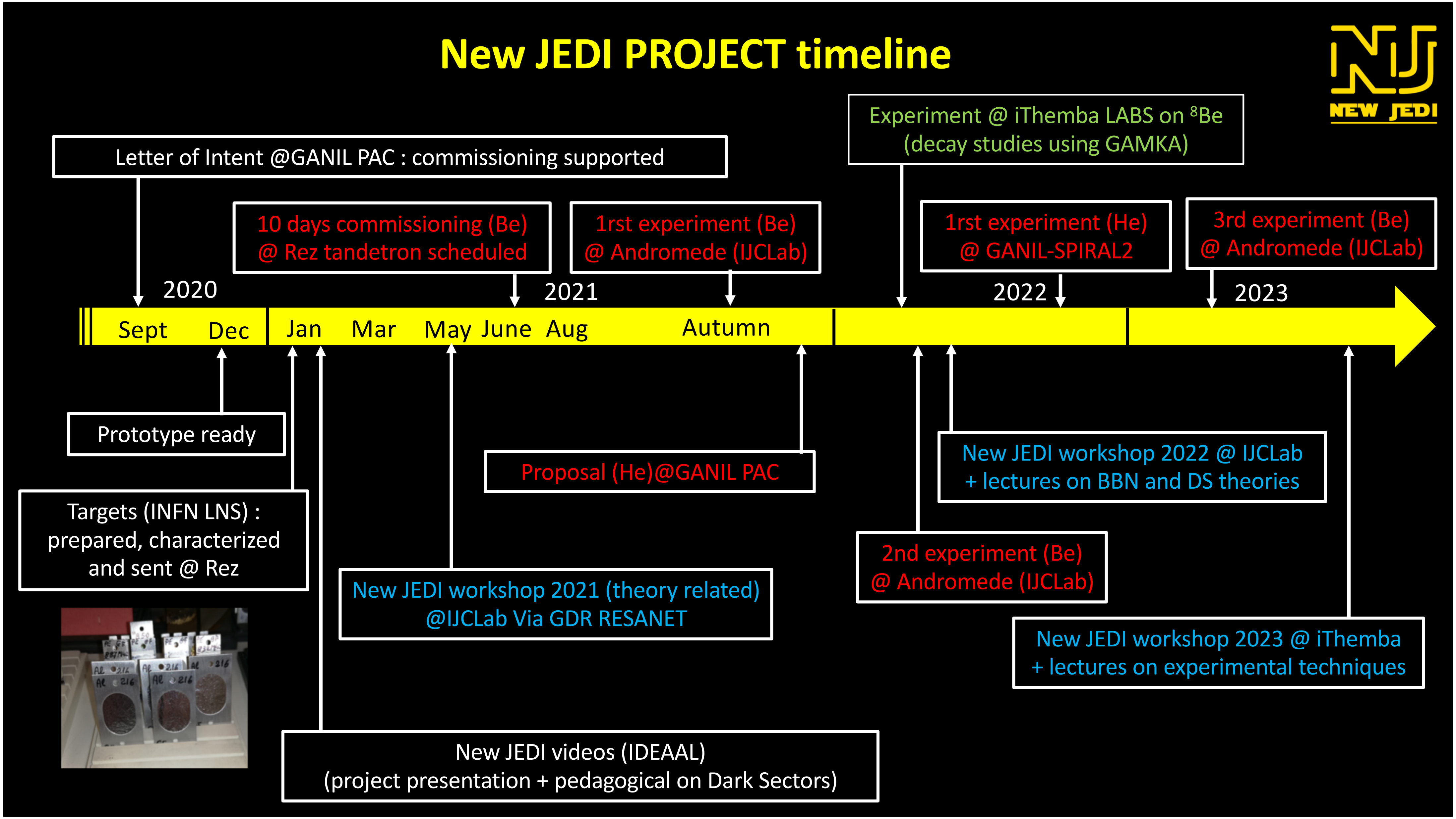


New JEDI commissioning at Rez 3MV tandetron facility (May-June 2021)

NEW JEDI

Every milisecond, **hundreds of ^{8}Be** nuclei are created but only **few per minute could be the X boson**

- **Major contribution of the $^{19}F(p,a)^{15}O$ reaction** in the DSSSDs : stopped using a thick foil in front of the detector.
- **The Lithium target emits also a lot of electrons** : stopped with front and back conductive foils to avoid charge and discharge effects)
- **Observed clearly lot of multi-scattering processes that needs to be investigated more in details (GEANT simulations)**.
- **The methods developed to measure and to check the proper coincidences between the different detectors seems to work properly.**
- **CaF and FH targets developed by the INFN-LNS laboratory (disentangle the contribution of reaction from F in the spectra) showed online very promising characteristics**.
- **The detection efficiency and observed count rates are very similar to those expected from the simulations. We estimate about a reasonable efficiency of 10% for the X boson electron-positron pair decay, if it exists.**
- We also **observed interesting geometrical effects.**


New JEDI PROJECT timeline
NEW JEDI
Letter of Intent @GANIL PAC : commissioning supported
10 days commissioning (Be)
@ Rez tandetron scheduled
1rst experiment (Be)
@ Andromede (IJCLab)
Experiment @ iThemba LABS on ^{8}Be
(decay studies using GAMKA)
1rst experiment (He)
@ GANIL-SPIRAL2
3rd experiment (Be)
@ Andromede (IJCLab)
2020
2021
2022
2023
Sept
Dec
Jan
Mar
May
June
Aug
Autumn
Prototype ready
Targets (INFN LNS) :
prepared, characterized
and sent @ Rez
Proposal (He)@GANIL PAC
New JEDI workshop 2021 (theory related)
@IJCLab Via GDR RESANET
New JEDI workshop 2022 @ IJCLab
+ lectures on BBN and DS theories
2nd experiment (Be)
@ Andromede (IJCLab)
New JEDI workshop 2023 @ iThemba
+ lectures on experimental techniques
New JEDI videos (IDEAAL)
(project presentation + pedagogical on Dark Sectors)