

Probe combination in *Euclid*

► Isaac Tutusaus (ICE-CSIC/IEEC/IRAP)
tutusaus@ice.csic.es

Outline

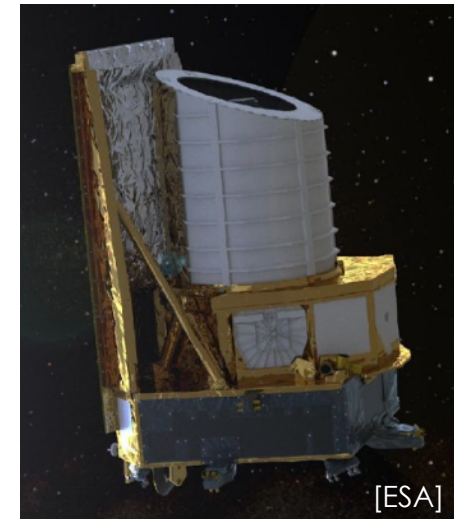
- ▶ Introduction
- ▶ *Euclid* core science
- ▶ *Euclid* since launch
- ▶ Probe combination in *Euclid*
- ▶ Conclusions

Introduction

▶ In the coming years **observational cosmology** will reap the benefits from the **investment in large projects** to better understand the Universe

▶ *Euclid*:

- Largest European project
- Exquisite measurements to shed new light on the dark components
- Different probes are considered

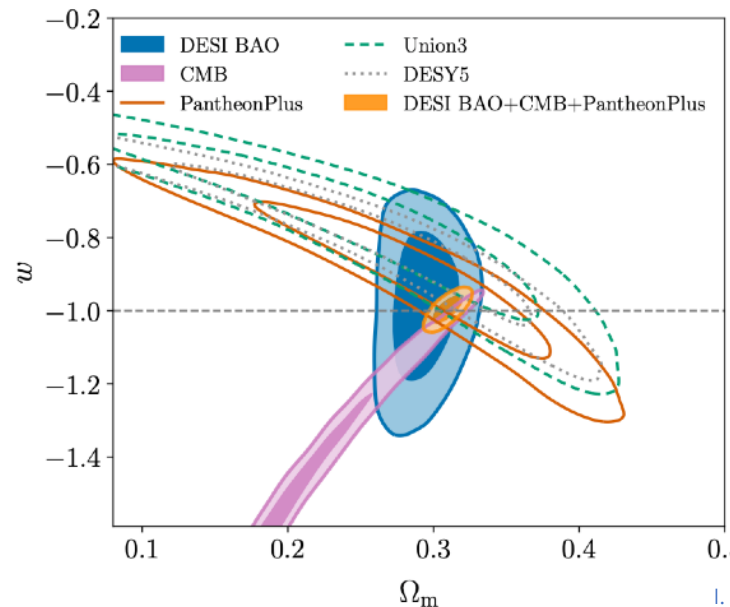


Introduction

► **Combining** different **probes** is one of the most powerful ways to **constrain** a cosmological model:

- sensitive to different aspects of how **gravity** acts in the cosmos
- different **degeneracies** and **systematic** effects

► Example:



[DESI Collaboration:
Adame et al. 2025]

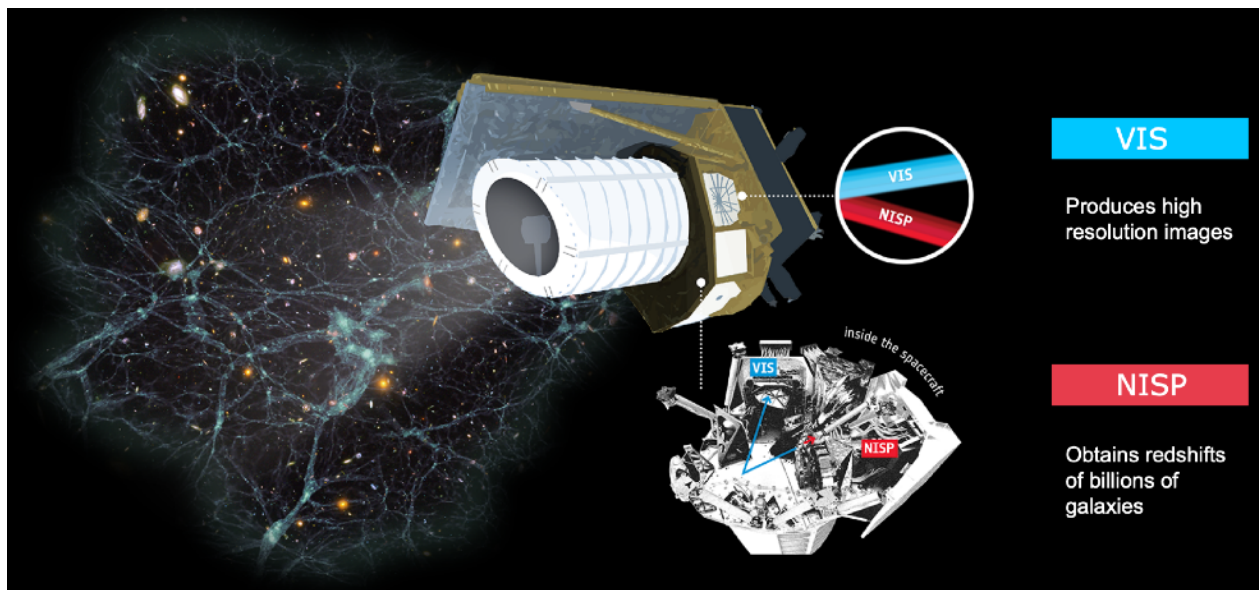
Introduction

► Euclid:

- **Survey** started on Feb 14th, 2024 — 1st stage-IV weak lensing survey **in operations**

► It contains 2 instruments onboard:

- Visible instrument (VIS) — **imaging**
- Near Infrared Spectrometer and Photometer (NISP) — **imaging** and **spectroscopy**

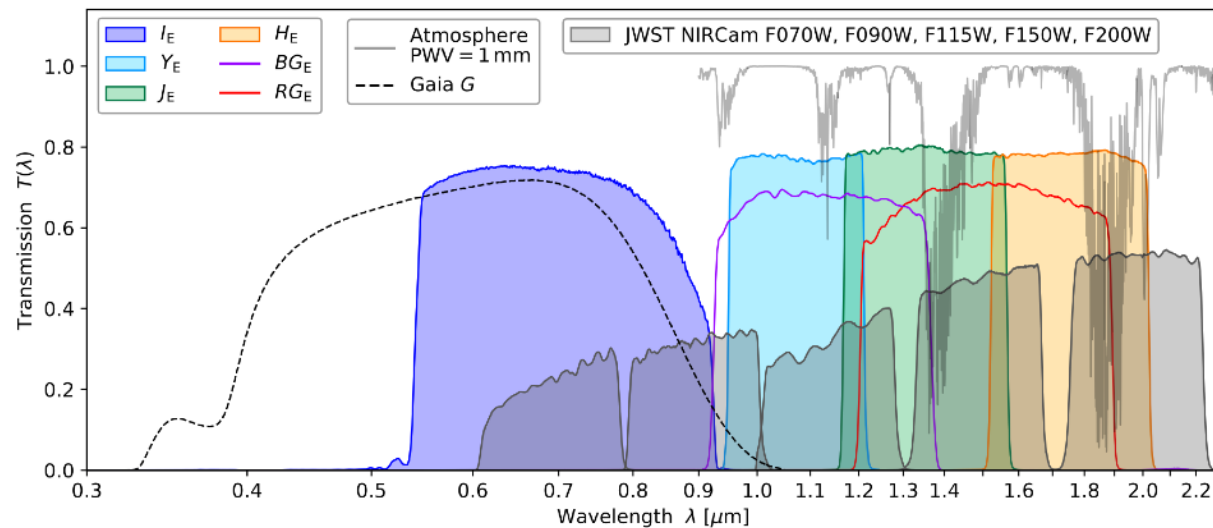


[ESA/ATG]

Introduction

► *Euclid* alone cannot provide measurements in different optical bands:

- Necessary to combine with **ground-based data** for photometric redshifts



[Euclid Collaboration: Mellier et al. 2024]

► **Combination of probes** (and data) is a **key ingredient** in *Euclid*'s analysis

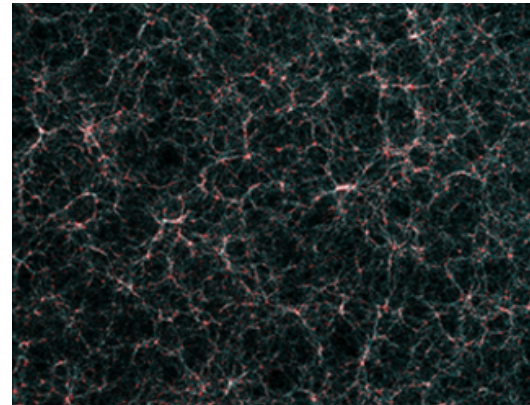
Euclid core science

- ▶ **Galaxy surveys** — powerful **source** of cosmological information
- ▶ Sensitive to **expansion** and large-scale **structure** — **dark matter** and **dark energy**

+ dark matter
- dark energy



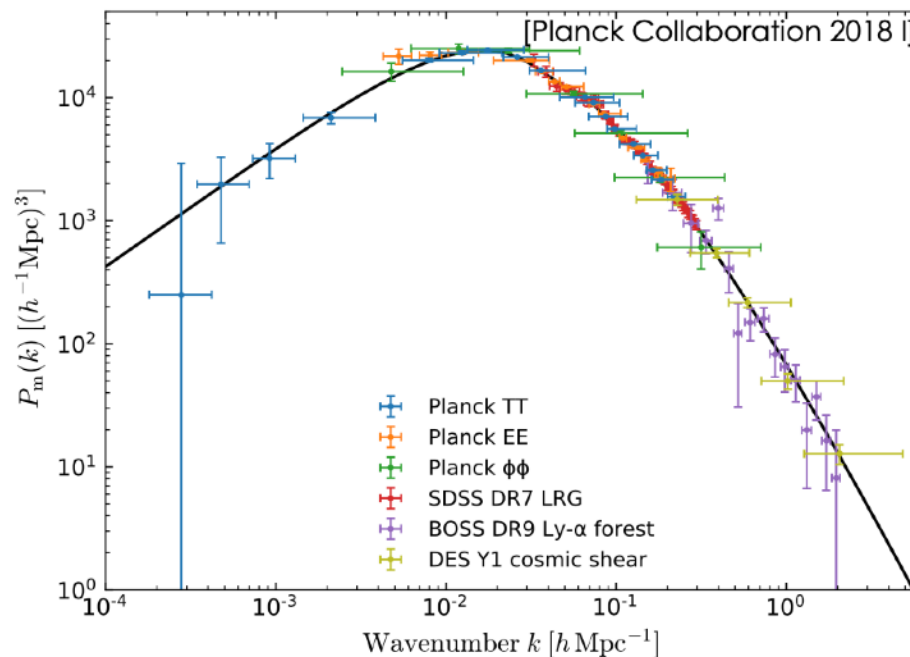
+ structure



[Carretero, Tallada, Serrano, Euclid Consortium]

Euclid core science

- ▶ **Galaxy surveys** — powerful **source** of cosmological information
- ▶ Main **summary statistic**: matter/galaxy power spectrum



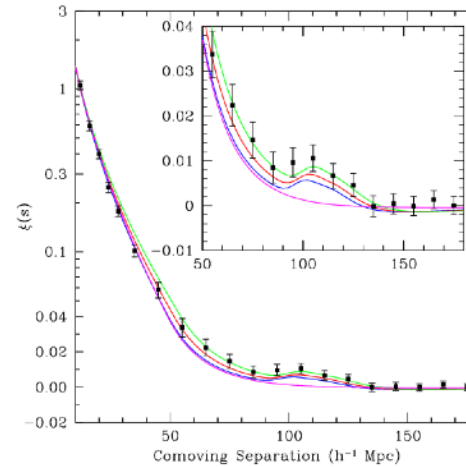
- ▶ New scales probed by galaxy surveys

Euclid core science

▶ (Spectroscopic) **galaxy clustering** (GC)

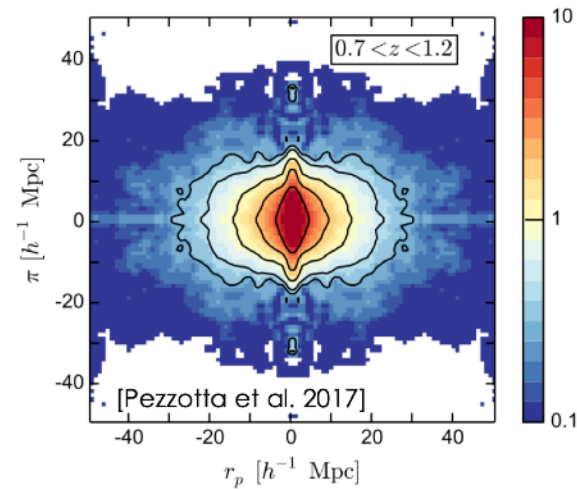
▶ Baryon acoustic oscillations:

- Provide a **cosmic ruler**
- Sensitive to the **expansion** history and the angular-diameter **distance**



▶ Redshift-space distortions:

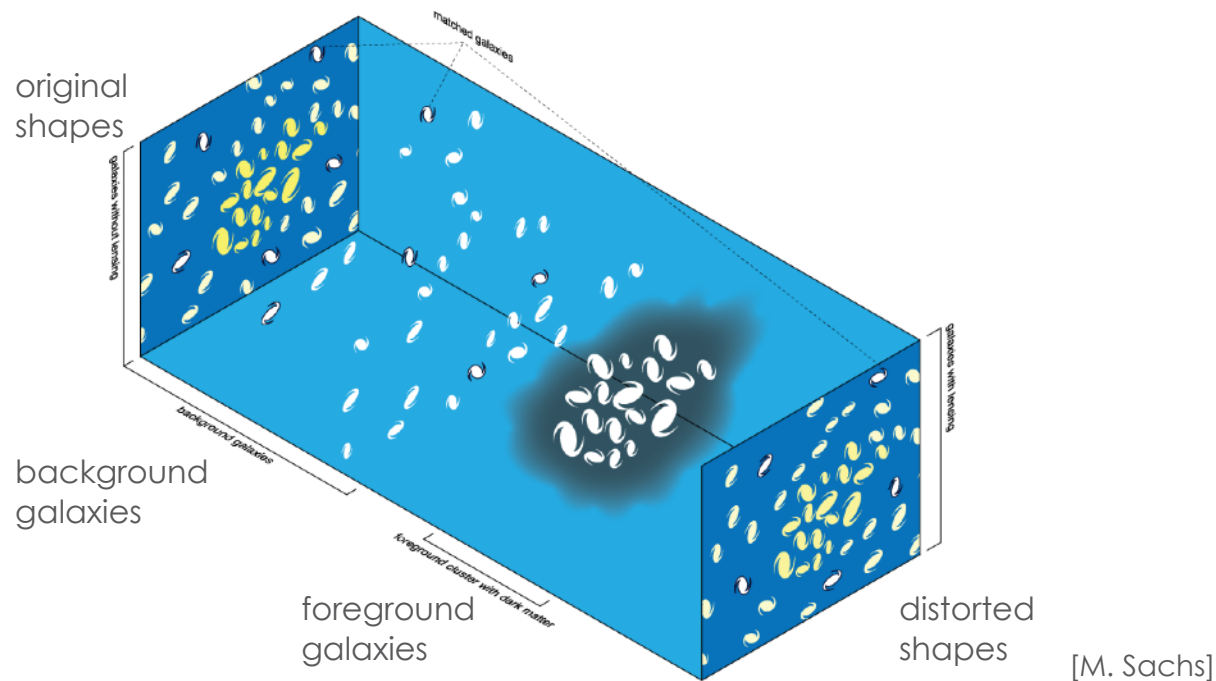
- Sensitive to the **growth rate** of structures
- Tests of **modified gravity**



Euclid core science

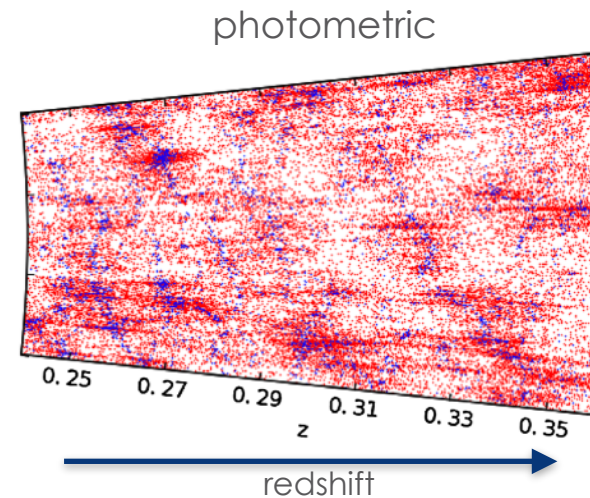
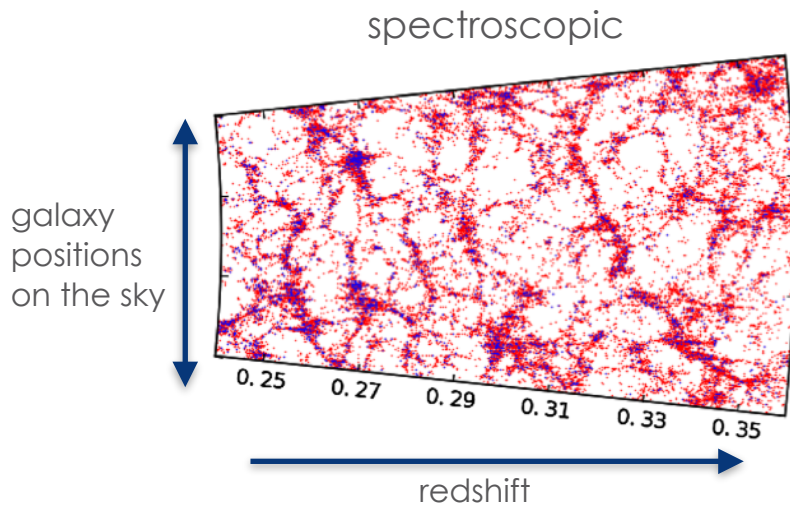
► (Photometric) **weak lensing** (WL):

- information about **mass distribution** imprinted on galaxy images
- sensitive to **matter density**, initial conditions, and **growth of structures**



► Photometric galaxy clustering:

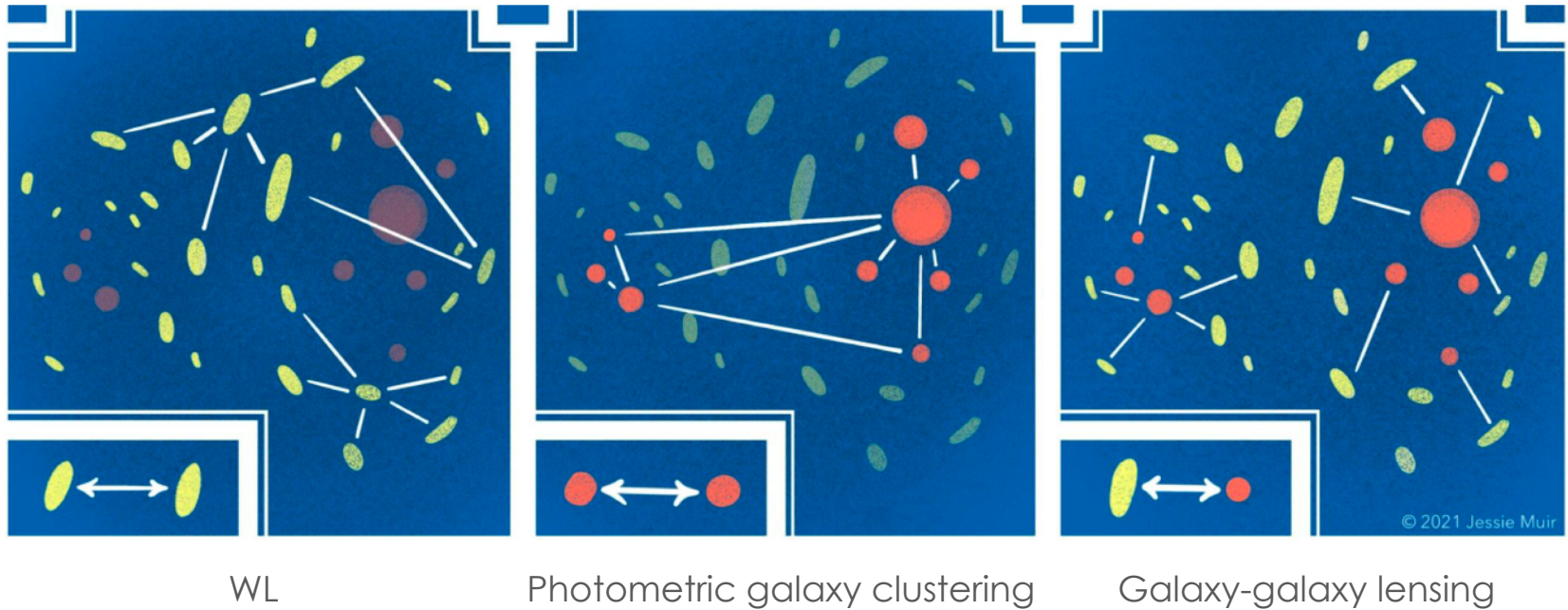
- loss of radial information
- higher number density & different systematic uncertainties
- **source** of cosmological information



[Stothert et al. 2018]

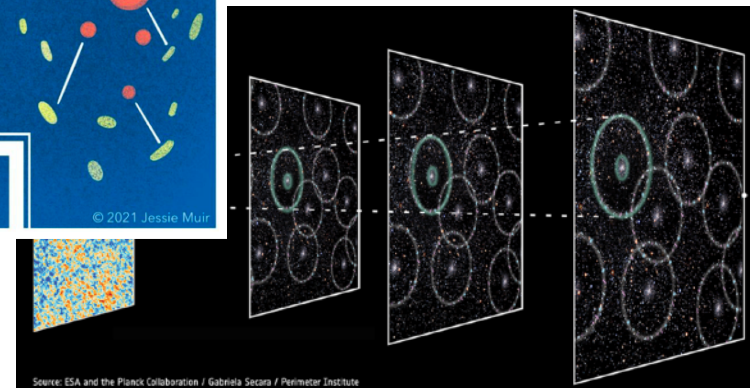
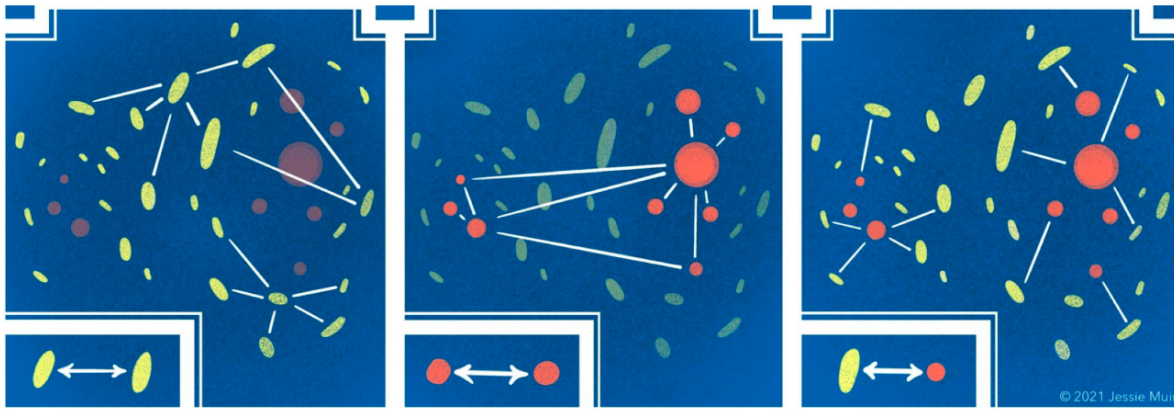
Euclid core science

► Combined **3x2pt** analysis from **photometric** data:



Euclid core science

- ▶ *Euclid* has been designed to perform both a **photometric** and a **spectroscopic** survey
- ▶ **Baseline** analysis: 3x2pt from the photometric data + spectroscopic galaxy clustering (probably negligible cross-covariance)



► **Cross-covariance** between spectroscopic galaxy clustering and 3x2pt:

- **High-redshift** spectroscopic sample vs **low-redshift** weak lensing kernel
- **Different modes** probed by spectroscopic vs photometric probes (Taylor & Markovic 2022)
- Currently estimating the **cross-covariance for Euclid DR1**

► Next step: Cross-correlations as an additional data vector?

Euclid since launch

► **Launch** 1st of July 2023:

- Cape Canaveral, Florida, USA with a Space X Falcon 9
- Destination: 2nd Lagrange point



[Space X; ESA]

Euclid since launch

► Early Release Observations:

- 24h of observations to allocated targets
- 10 images (new low-mass dwarf galaxies, very distant galaxies,...)



[ESA/Euclid/Euclid Consortium/NASA, image processing by J.-C. Cuillandre (CEA Paris-Saclay), G. Anselmi]

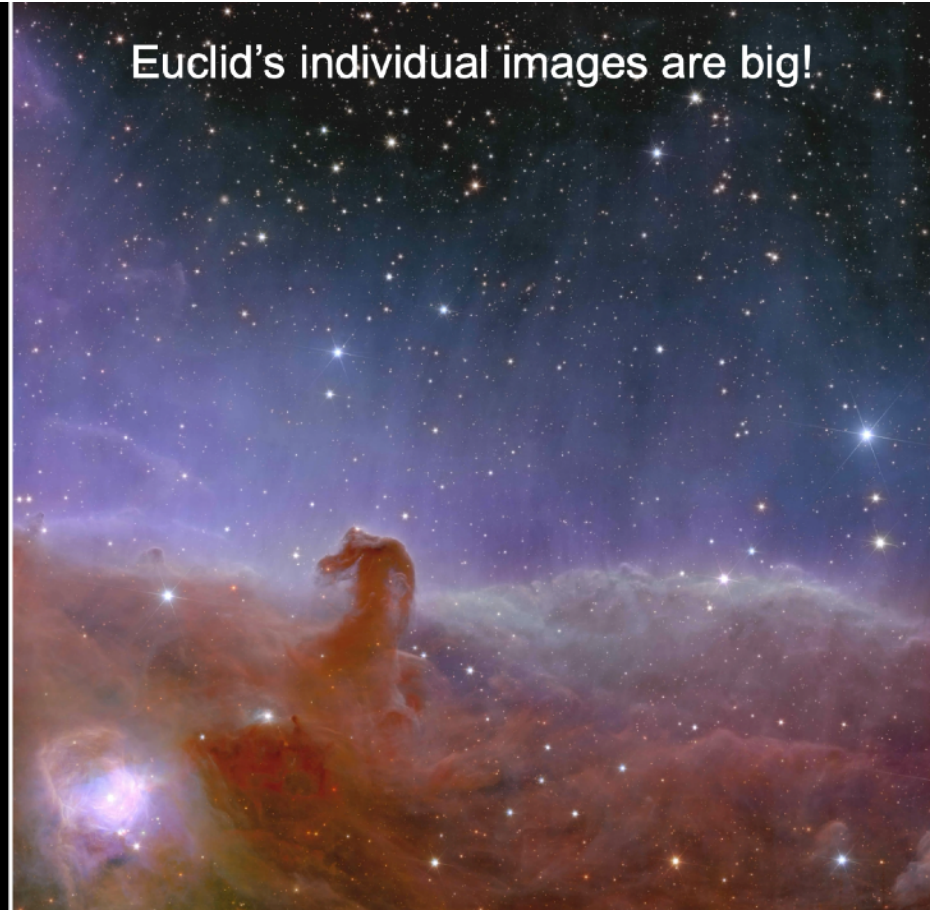
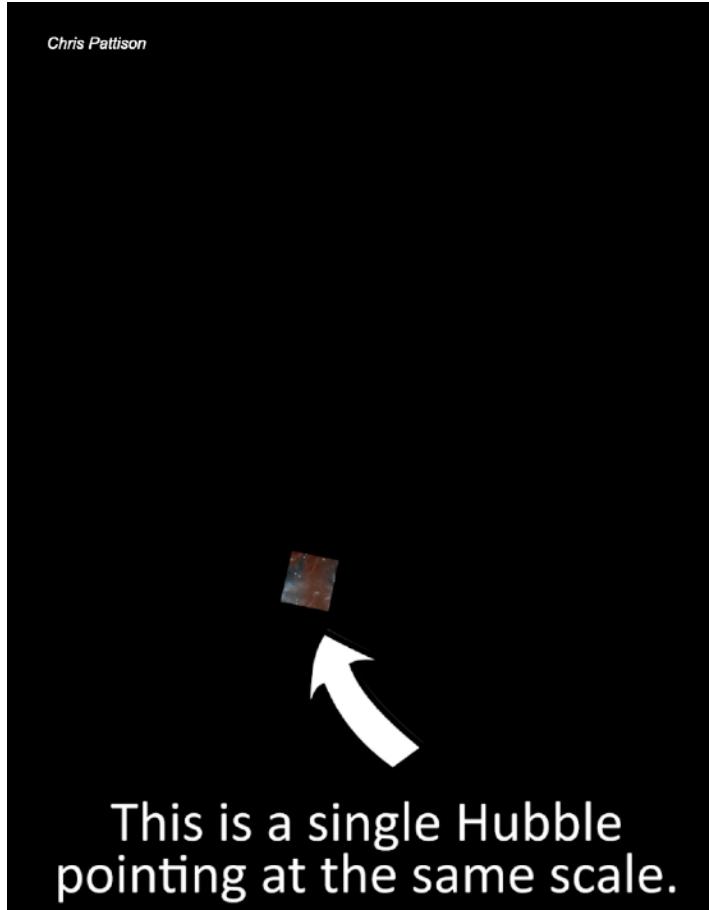
I. Tutusaus

29th October 2025

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Euclid since launch

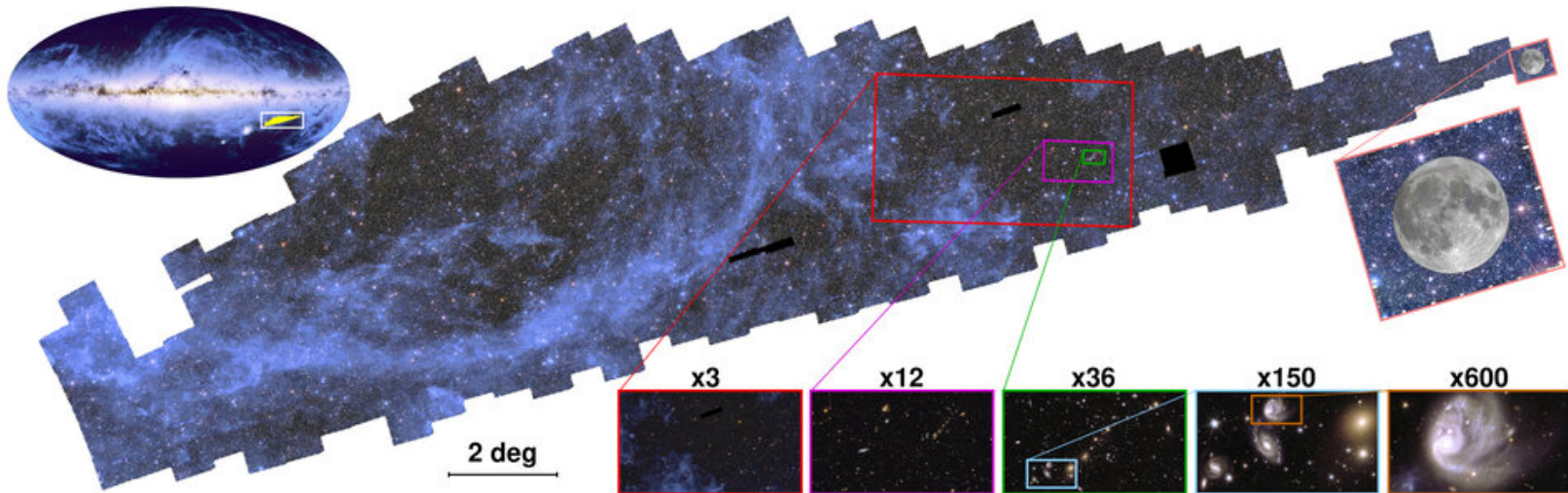
► Early Release Observations:



Euclid since launch

► 1% of the wide survey:

- 260 observations taken in 2 weeks
- 132 sq deg, 100M sources, 14M galaxies for cosmology



[ESA/Euclid/Euclid Consortium/NASA, CEA Paris-Saclay, image processing by J.-C. Cuillandre, E. Bertin, G. Anselmi; ESA/Gaia/DPAC; ESA/Planck Collaboration]

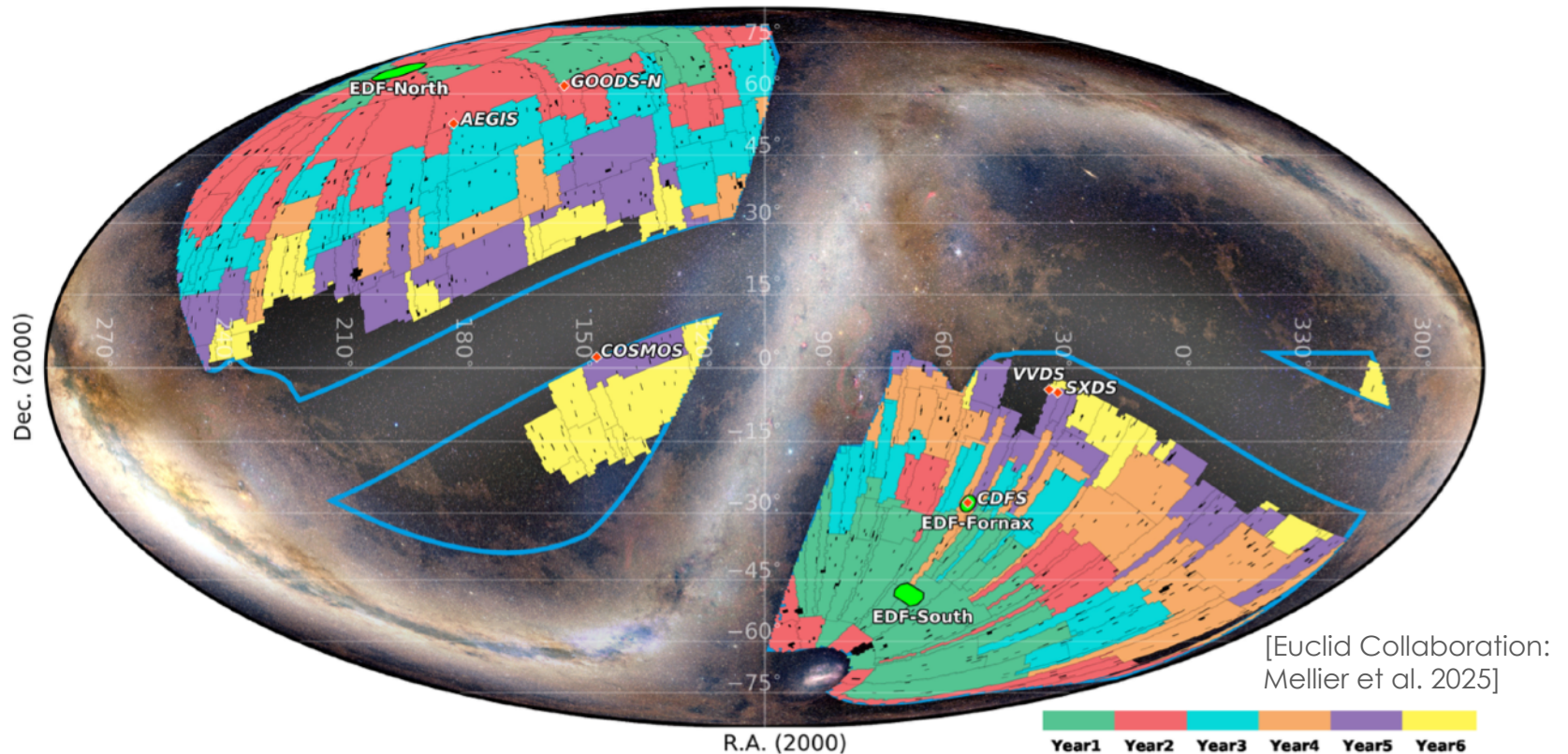
Euclid since launch

► Quick data release 1 (Q1):

- Public release of the data (and first batch of papers) in March 2025
- 63 sq deg
- 27 science papers + 7 data/technical papers (more in fall 2025)
- Non-cosmological science for the moment: Milky Way, galaxy morphology, galaxy evolution, proto-clusters, transient objects,...

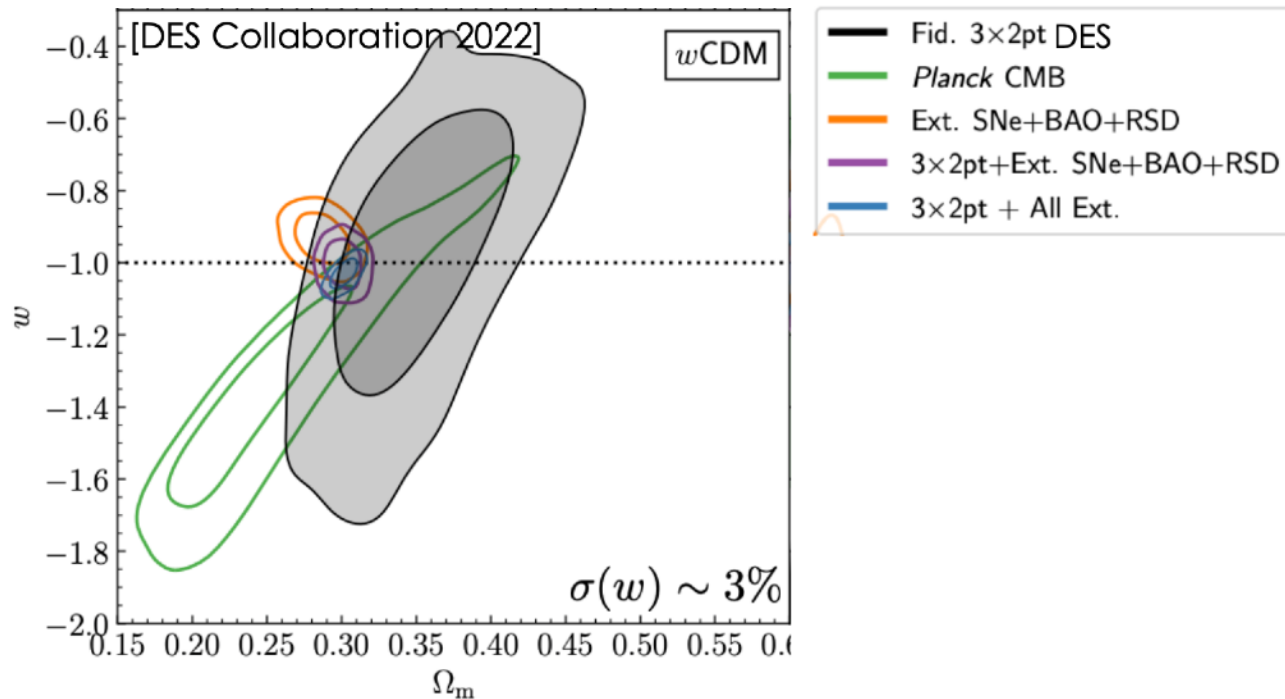
Probe combination in *Euclid*

► *Euclid* will cover about **14 000 sq. deg.** of extragalactic sky in **6 years**



Probe combination in *Euclid*

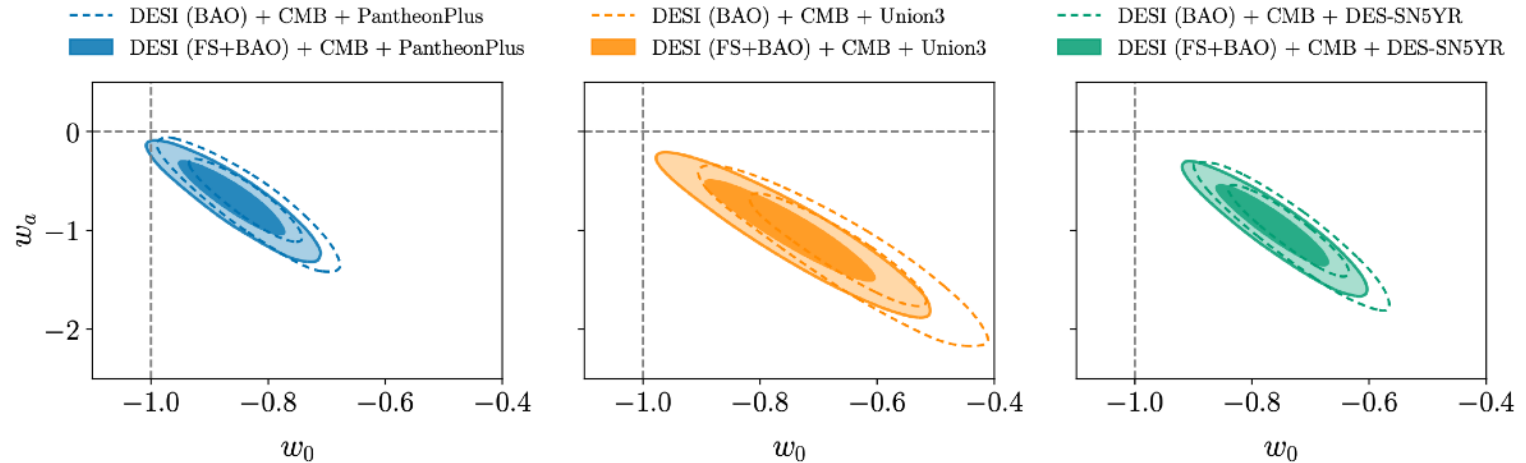
- All probes with **stage-III** galaxy surveys:



- **~3% constraint** on the dark energy equation of state parameter (constant)

Probe combination in *Euclid*

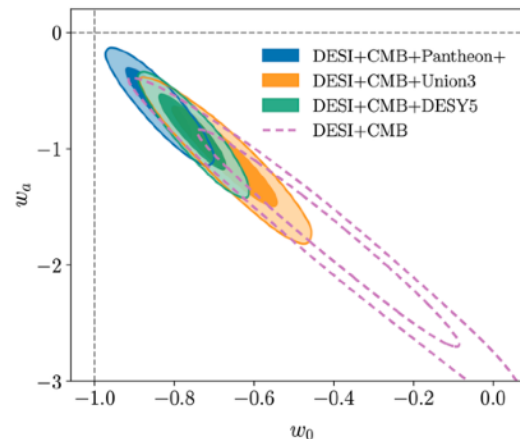
► First spectroscopic **stage-IV** data: Dark Energy Spectroscopic Instrument DR1



► **~6%** constraint on w_0 and **~0.3** uncertainty on w_a

[DESI Collaboration 2025a]

► Improved with DR2

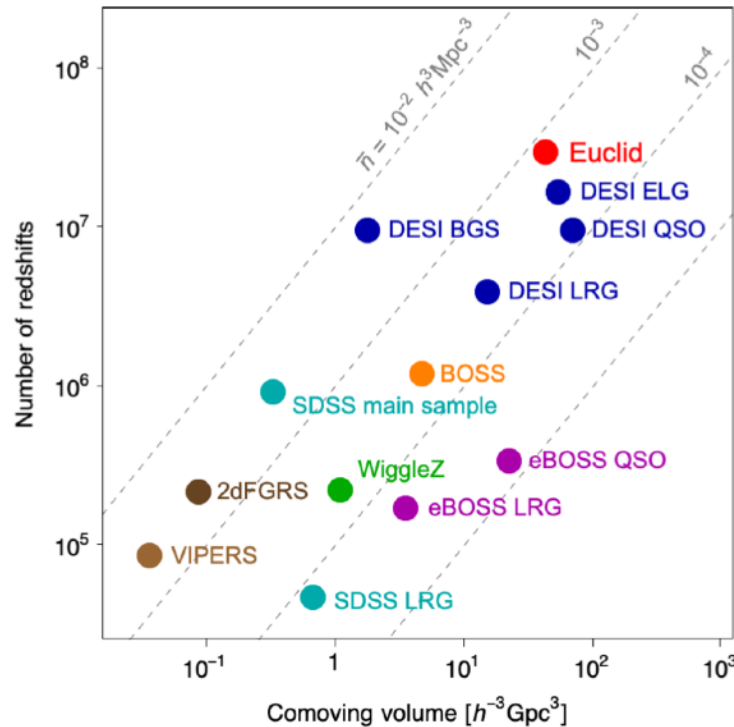


[DESI Collaboration 2025b]

Probe combination in *Euclid*

► Spectroscopic galaxy clustering:

- More than 10^7 spectroscopically-detected galaxies at high redshift (0.9-1.8)

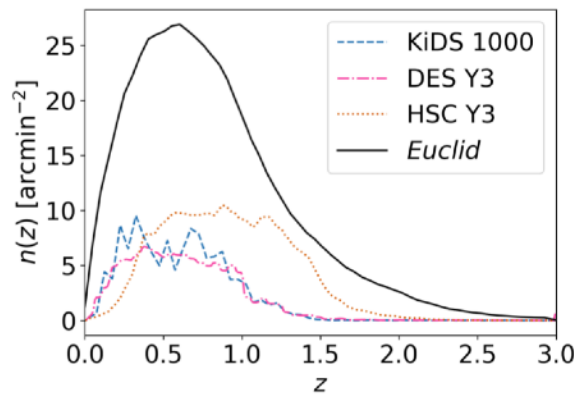


[Euclid Collaboration:
Mellier et al. 2025]

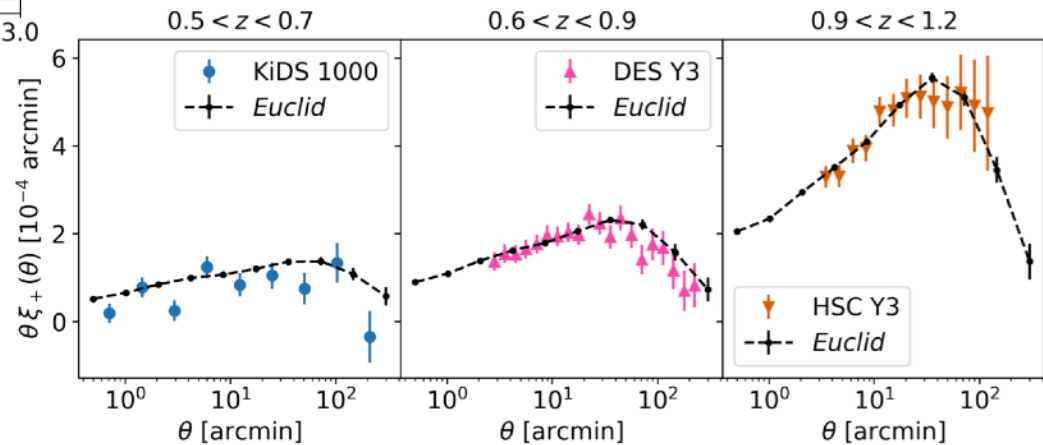
Probe combination in *Euclid*

► Weak lensing:

- More than a billion shapes of galaxies up to high redshift



[Euclid Collaboration:
Mellier et al. 2025]



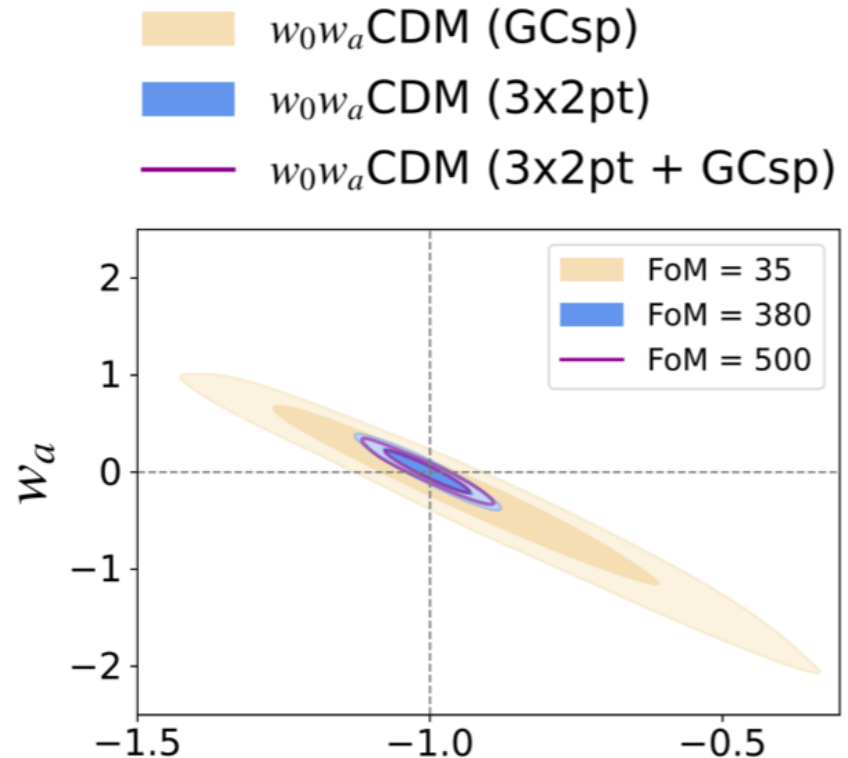
Probe combination in *Euclid*

► Very **precise** constraints on the nature of **dark energy**

- Dark energy equation of state parameter:

$$w(z) = w_0 + w_a \frac{z}{1+z}$$

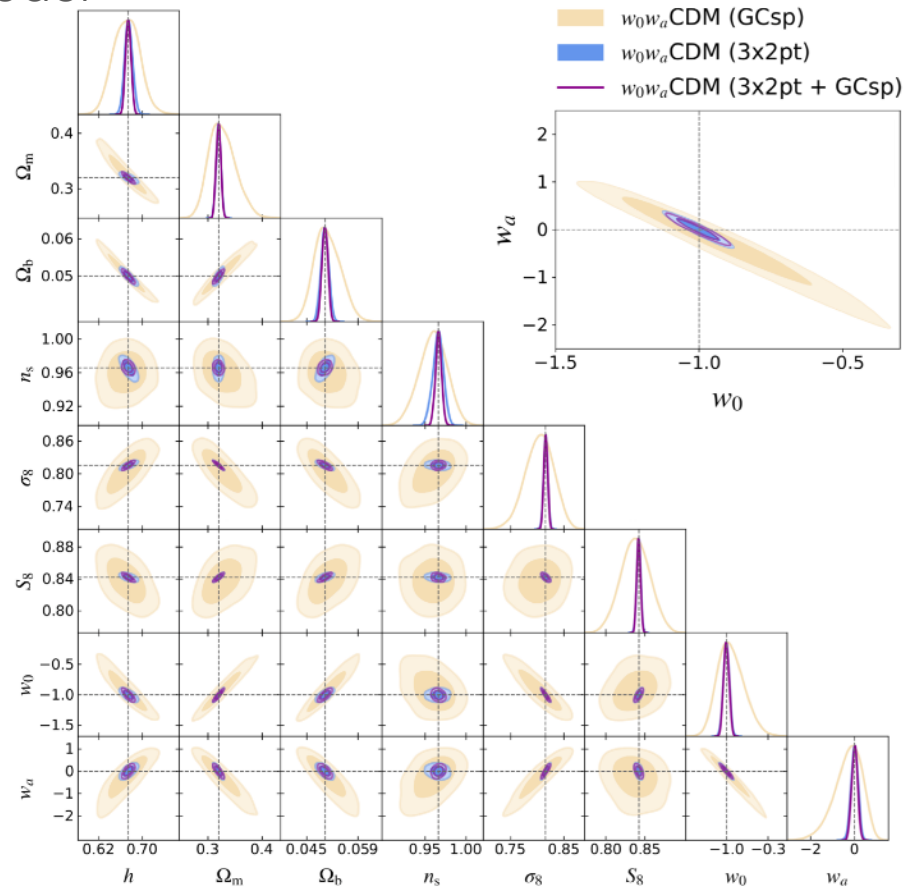
- **x2 more precise** than **combined** current constraints with *Euclid* main probes **alone**



w_0 [Euclid Collaboration: Mellier et al. 2025]

Probe combination in *Euclid*

- Also very precise constraints on the other parameters of the standard model



[Euclid Collaboration:
Mellier et al. 2025]

29th October 2025

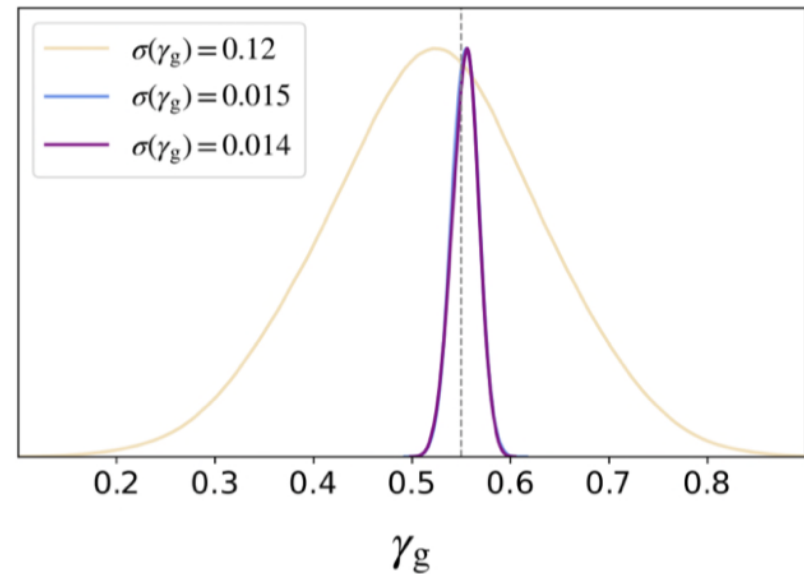
Probe combination in *Euclid*

► *Euclid* will allow us to constrain modified gravity

- Linear growth rate of matter perturbations:

$$f_g(z) \equiv \frac{d \ln g_+(z)}{d \ln a} \simeq [\Omega_m(z)]^{\gamma_g}$$

■ $\Lambda\text{CDM} + \gamma_g$ (GCsp)
■ $\Lambda\text{CDM} + \gamma_g$ (3x2pt)
— $\Lambda\text{CDM} + \gamma_g$ (3x2pt + GCsp)

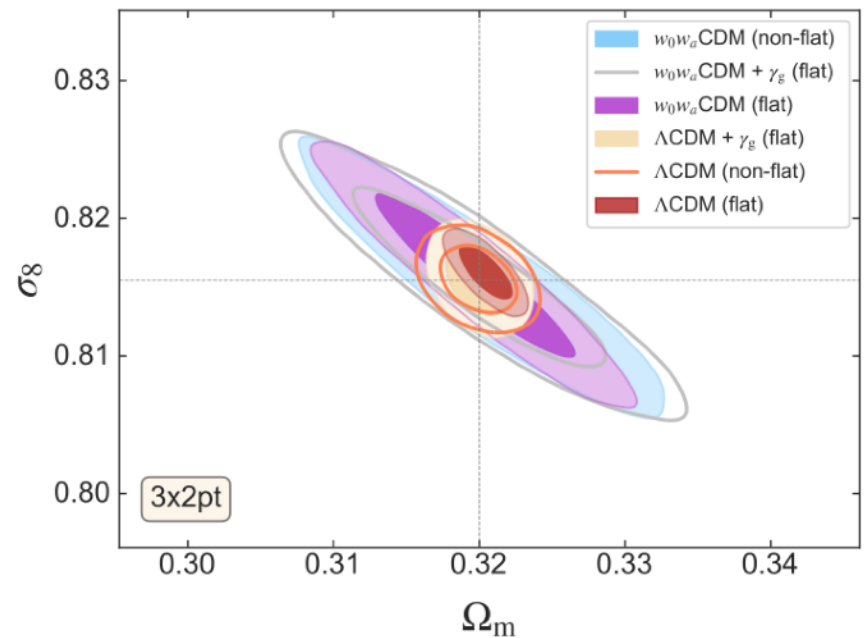
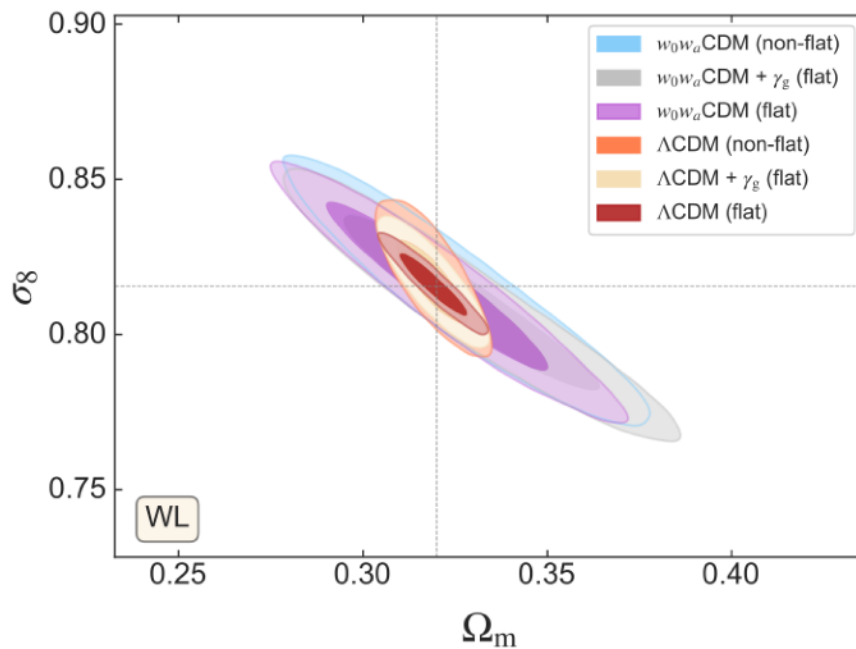


[Euclid Collaboration:
Mellier et al. 2025]

Probe combination in *Euclid*

► Using the latest DR3 specifications

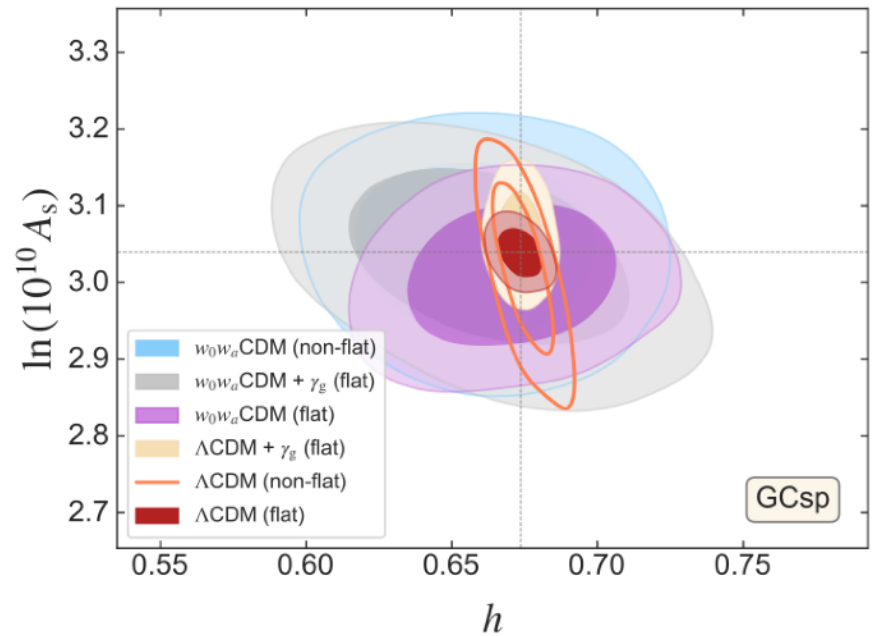
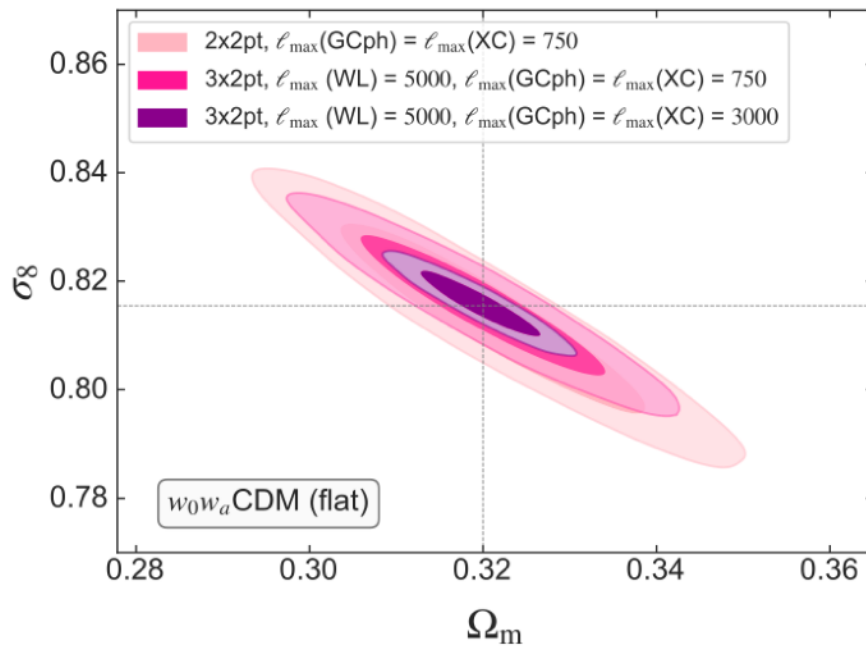
[Euclid Collaboration:
Cañas-Herrera et al. 2025]



Probe combination in *Euclid*

► Using the latest DR3 specifications

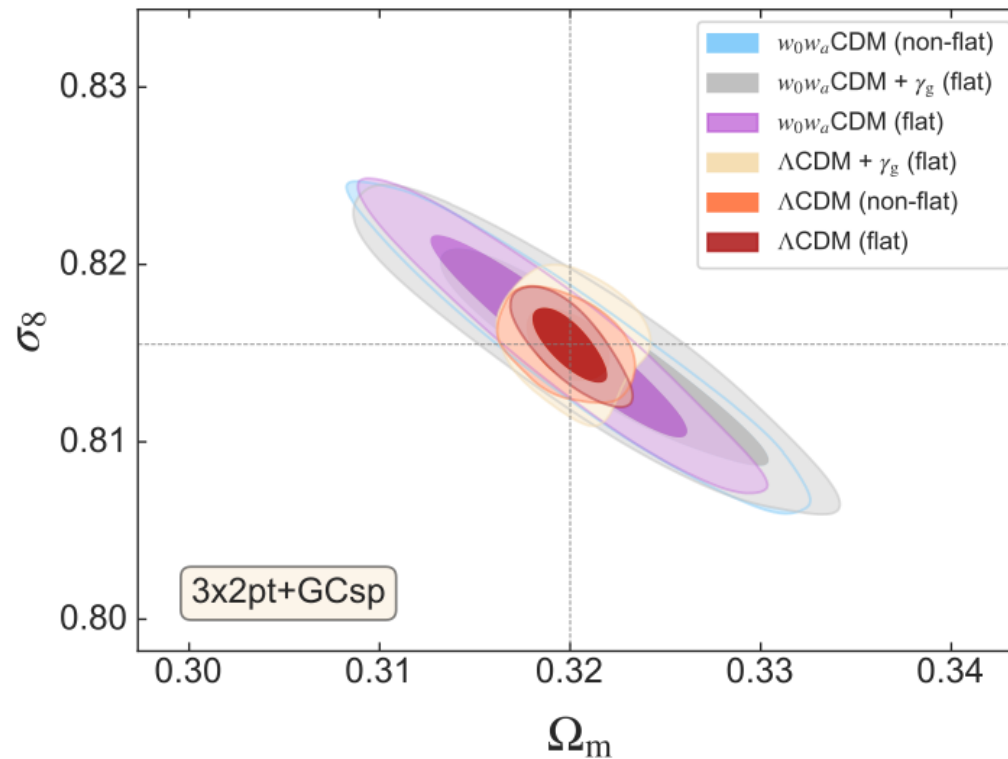
[Euclid Collaboration:
Cañas-Herrera et al. 2025]



Probe combination in *Euclid*

► Using the latest DR3 specifications

[Euclid Collaboration:
Cañas-Herrera et al. 2025]

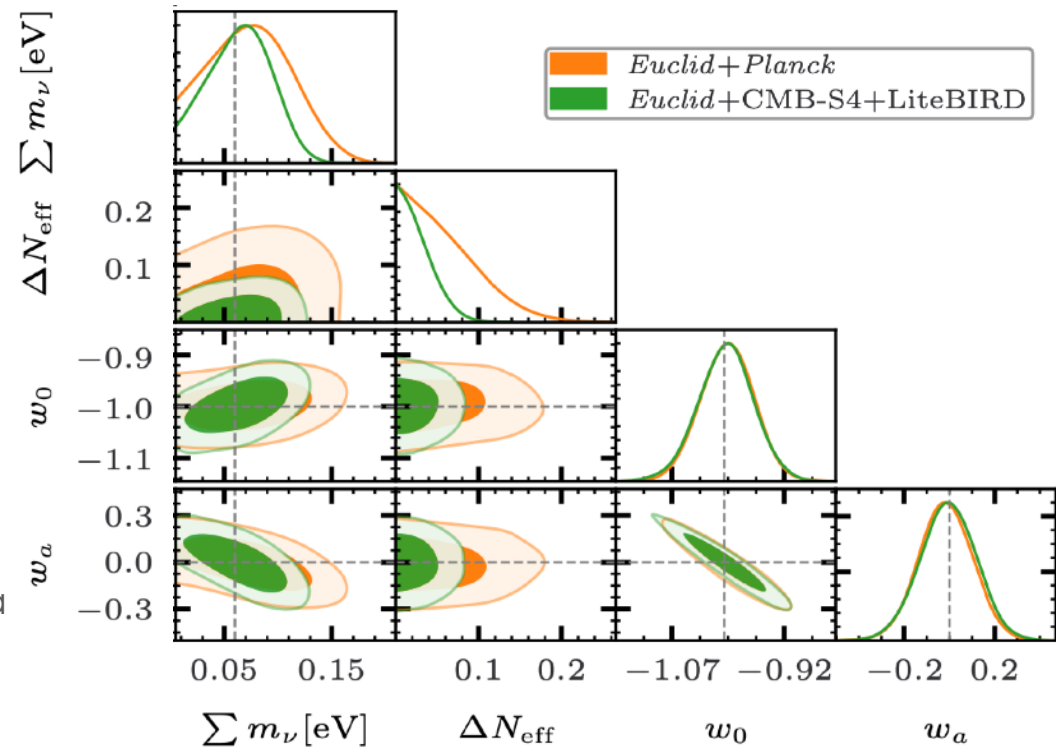


Probe combination in *Euclid*

► *Euclid* will also help us test **neutrinos** and other **particles beyond**

the standard model

- Neutrino sensitivity of
Euclid alone: 56 meV (in
LCDM)
- *Euclid* + *Planck*: 23 meV
- Evidence for a non-zero
neutrino mass at 2.6 sigma
(4 sigma with future data)



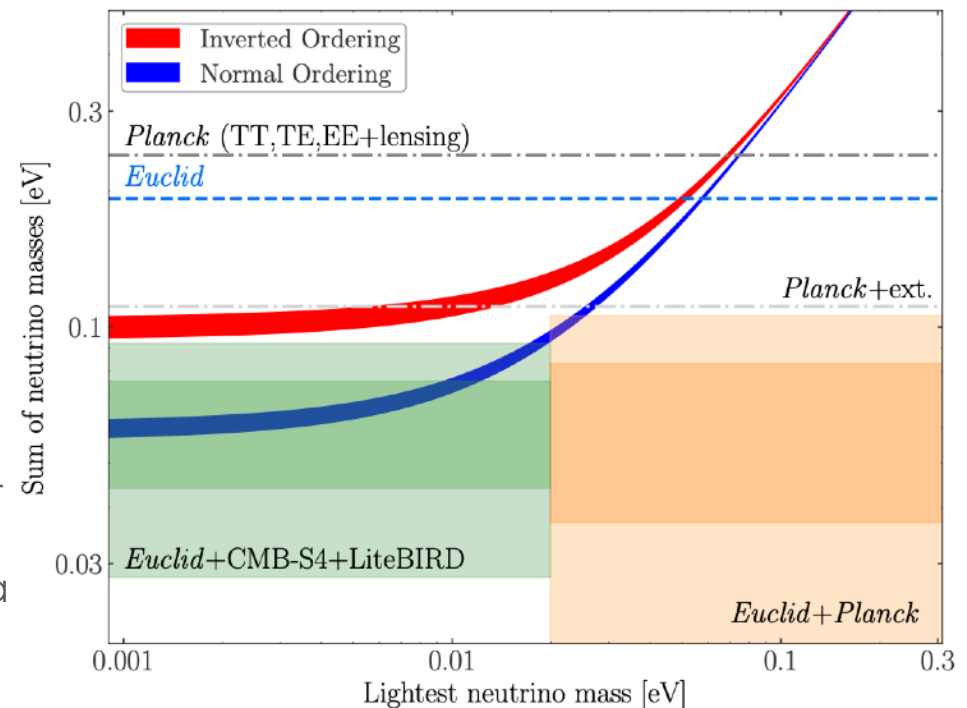
[Euclid Collaboration:
Archidiacono et al. 2025]

Probe combination in *Euclid*

► *Euclid* will also help us test **neutrinos** and other **particles beyond**

the standard model

- If the true sum of neutrino masses is 0.06 eV (normal ordering), *Euclid* + future cosmic microwave background data will rule out inverted ordering at 2.5 sigma



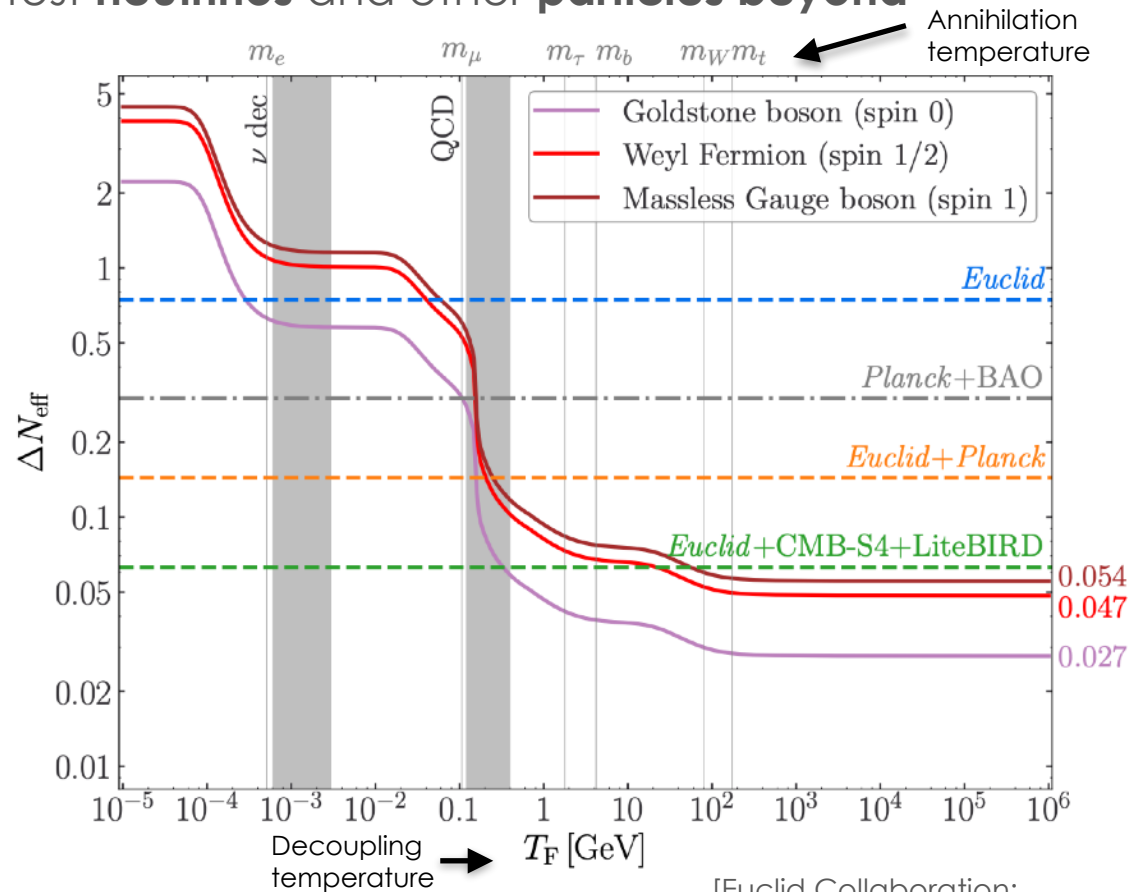
[Euclid Collaboration:
Archidiacono et al. 2025]

Probe combination in *Euclid*

► *Euclid* will also help us test **neutrinos** and other **particles beyond**

the standard model

- Adding *Euclid* improves the current limit on the presence of new light particles by more than a factor 2



[Euclid Collaboration:
Archidiacono et al. 2025]

Conclusions

- ▶ *Euclid* will provide exquisite measurements to perform **galaxy clustering** and **weak lensing** analyses
- ▶ **Probe combination** is key to get the most amount of information from the data
— spectroscopic GC and photometric 3x2pt
- ▶ **Additional cosmological probes** are also being considered (galaxy clusters, correlations with the cosmic microwave background,...)
- ▶ *Euclid* will help us shed light on the **dark sectors** of the Universe and test gravity
- ▶ A lot of non-cosmological science is planned (Milky Way, galaxy morphology, galaxy evolution, proto-clusters, transient objects,...)
- ▶ The **first data release** will be public on 21st October 2026