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SNIa Cosmology using Host Photo-z and non-SNIa contamination in the LSST

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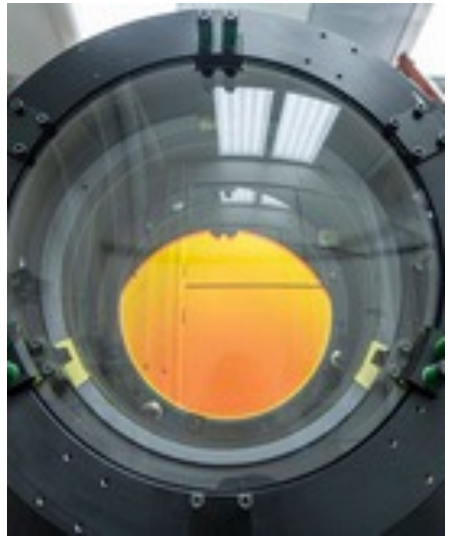

VERA C. RUBIN OBSERVATORY

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LSST DESC Dark Energy Science Collaboration

The LSST (Vera C. Rubin Observatory) Family

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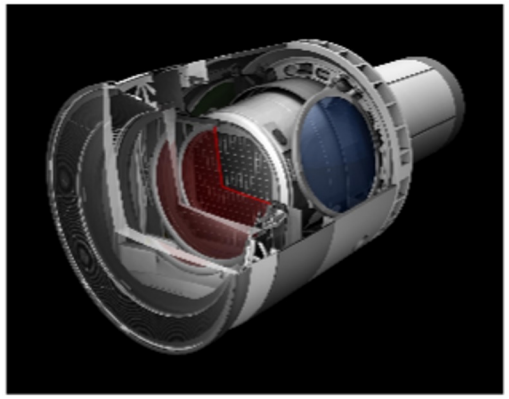
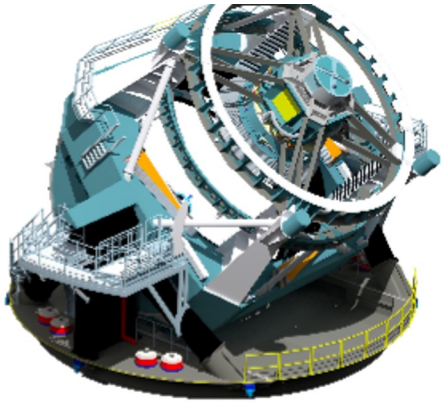
8.4m Mirror

+

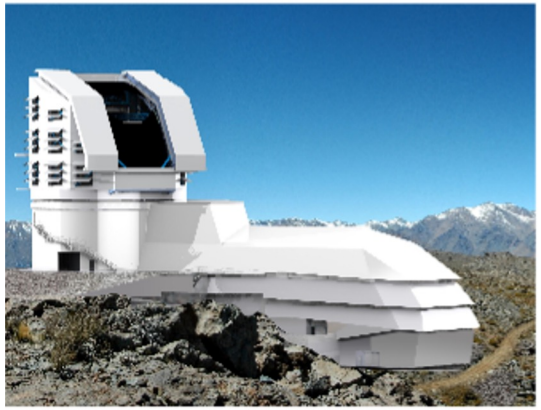


3.2Gpixel Camera

+



35 ton Telescope



10 floor Building

+

Petascale Computing Facility

+

Large International Community

LSST DESC
Dark Energy Science Collaboration

The LSST Science Collaborations comprise a federation of scientists self-organized to exploit the LSST data

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hysical Surveys
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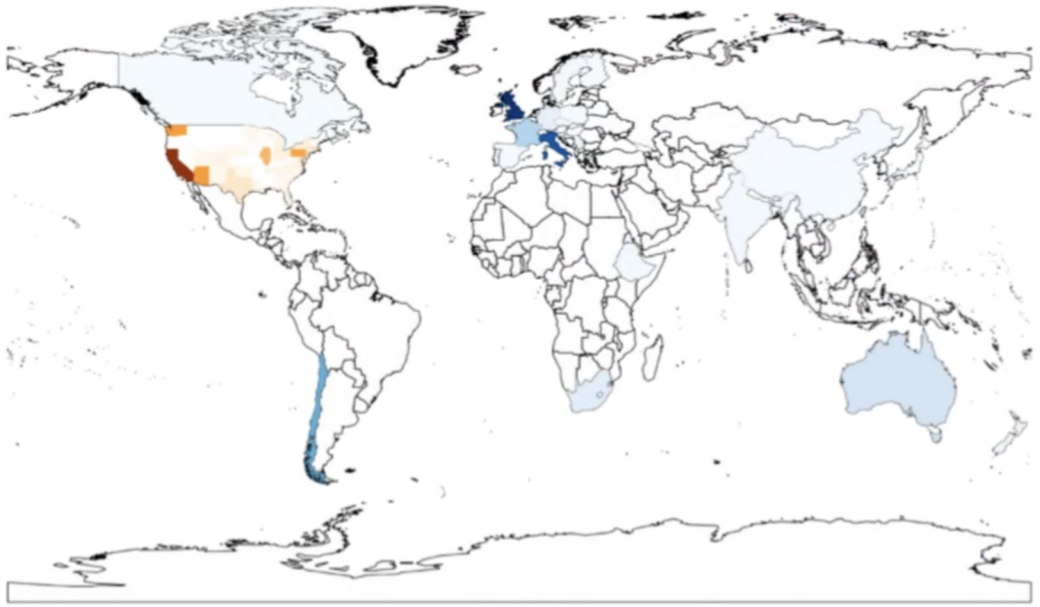
AGN ISSC SLSC TVS SMWLV SSSC DESC GalaxiesSC



Credit: FBianco (Colors represent SC member count)

Dark Energy Science Collaboration

Prepare for data, **advise** Rubin personnel, **engage & train** the scientific community, **fundraise**, develop **inclusion** practices, provide **software** development

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DESC: Exploring the Dark Universe

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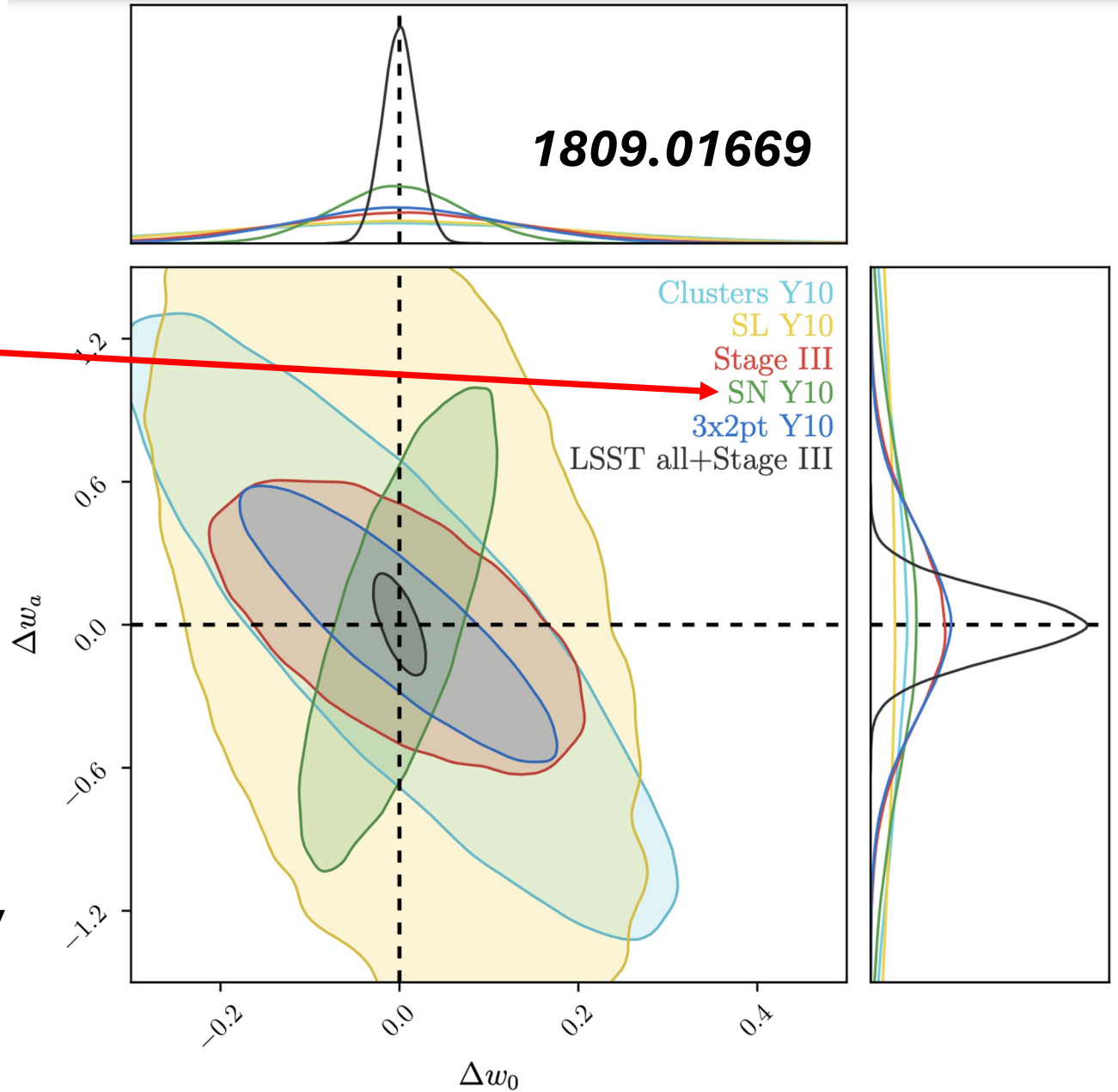
DESC will use 5 cosmological probes:

Galaxy clusters,
Large scale structure,
Supernovae Ia,
Strong lensing,
Weak lensing

Constrain dark energy using the power of these probes individually and combined

Not only precise (**10xStage II FoM**), but accurate cosmology i.e.
systematics < statistical



Road to SNIa cosmology :
Using photometric ID and redshifts (z)

Classification	Redshift	Survey/Project
Spectroscopic	Spec Only (SN or Host)	Two decades of results **Nobel prize 2011** SNLS [Astier'06], ESSENCE [Woodvasey'07], SDSS-II [Kessler'09], PS1 [Rest'14, Scolnic'14], JLA [Betoule'14], Pantheon [Scolnic'18], DES-3yr [DES collab'19]
Photometric	Spec Only (SN or Host)	PS1 [Jones'18] DES-SN5YR [DES collab'24] [2401.02945]
Spectroscopic	Spec or Photo(Host Only)	DES-5yr + redMaGiC [Chen'22] LSST DESC Sims [Mitra'23] [2210.07560]
Photometric	Spec or Photo(Host Only)	**Current Analysis**

Jargons

- PLaSTiCC : Photometric LSST Astronomical Time-Series Classification Challenge

  Produced ~ 3 million light curves of different transients.

  Aim : Public Photometric Classification

  Based on light curve input data

- ELaSTiCC : Extended LSST Astronomical Time-Series Classification Challenge

  In addition to PLaSTiCC, add host galaxy correlations, updated transient models

  Instead of point estimate photo-z → full photo-z Prob. Density function. **MORE REALISTIC**

  Produce ~ 5 million detected events

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Recap: Photo-z Analysis on LSST-DDF Sims based on PLaSTiCC

Mitra et. al. [2210.07560]

- **SN Ia Only**
- Spectroscopic redshift using 4MOST forecast
- Host Photo-z based on Graham 2018
- Using SNANA

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Simulation and Analysis : Overview

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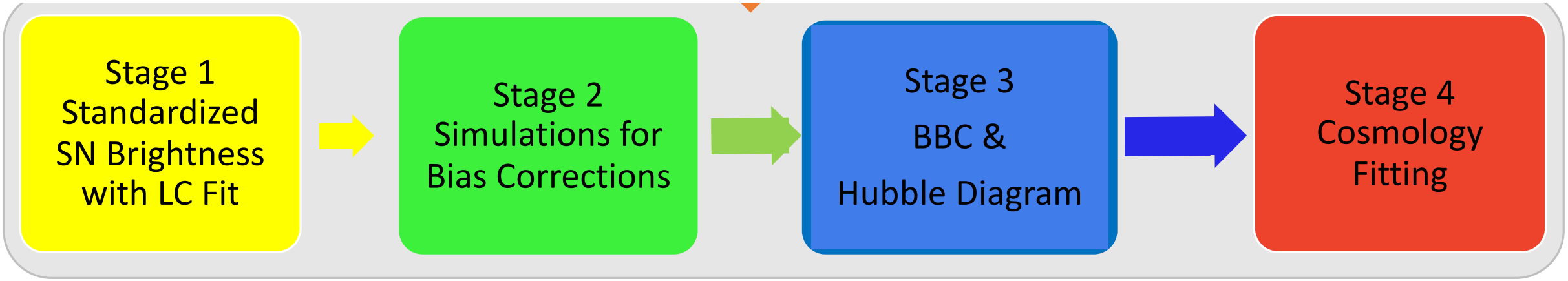
- Simulation : PLaSTiCC SNe Ia + low-z (WFD-DC2)
  - If no zspec, redshift is determined from ZPHOT and ZPHOTERR
- Light Curve (LC) Fit stage :
  - 5 Parameter Photo-z Fit with Host Redshift (Specz or Photoz) as a Gaussian Prior.
- Correct Hubble Diagram for selection bias and contamination
- Create STAT + SYST Covariance Matrix
- Cosmology Fit (SNIa + CMB Prior)



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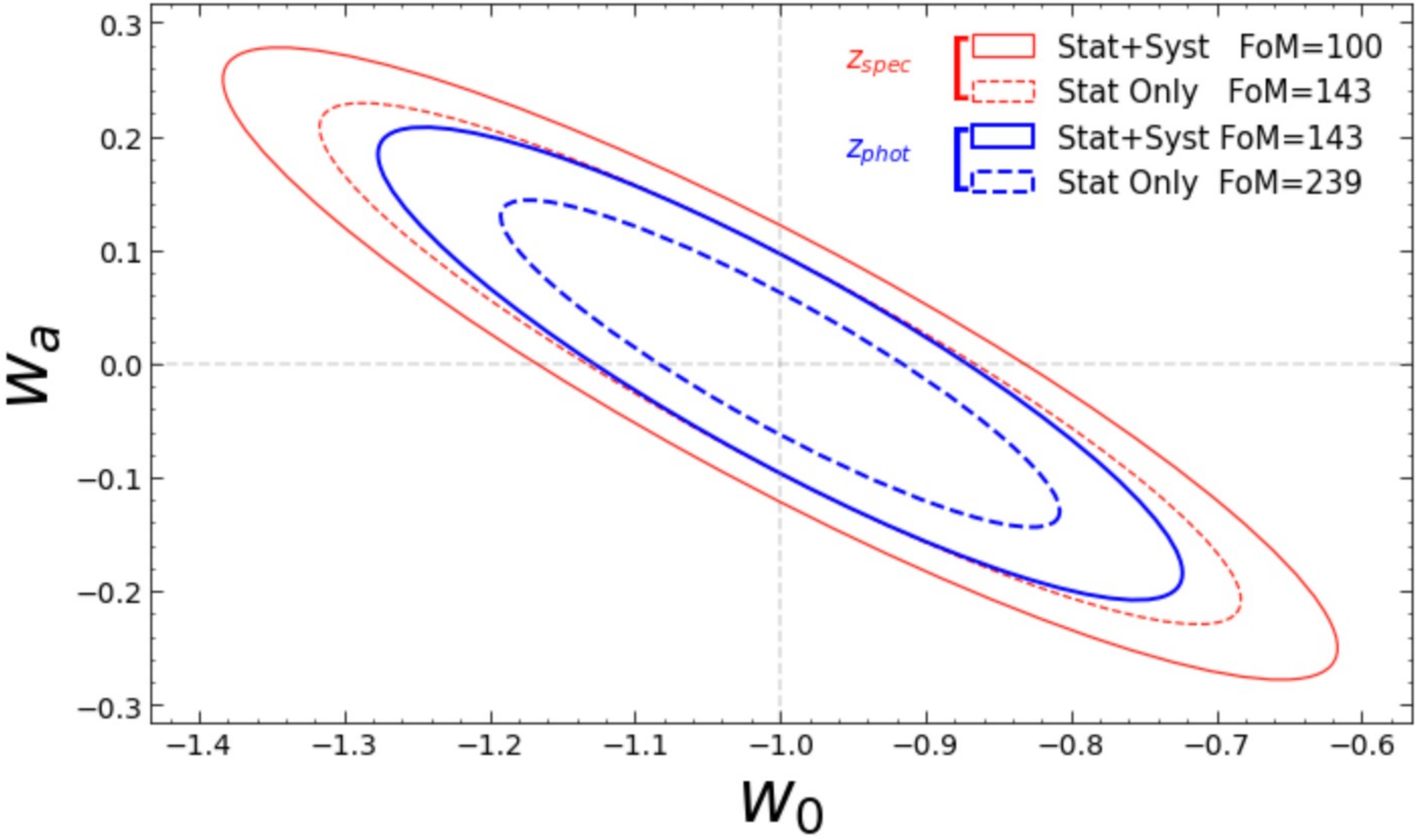

Spec-z + Photo-z Better FoM ~40% improvement

$$\text{FoM} \equiv \frac{1}{\sigma(w_o)\times\sigma(w_a)}$$

--DETF Report; Albrecht et al 2006

Fig. VI, Page 9, M23

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Conclusions

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- Adding SN + host Photo-z significantly improves average distance measurements for $z > 0.6$.
- FoM $w0 - wa$ improves by $\sim 50\%$ (includes systematics)
- Hubble diagram that extends 0.3 further in redshift

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Current Analysis:
Including Photometric Contamination , Host Mis-association and improved photo-z model

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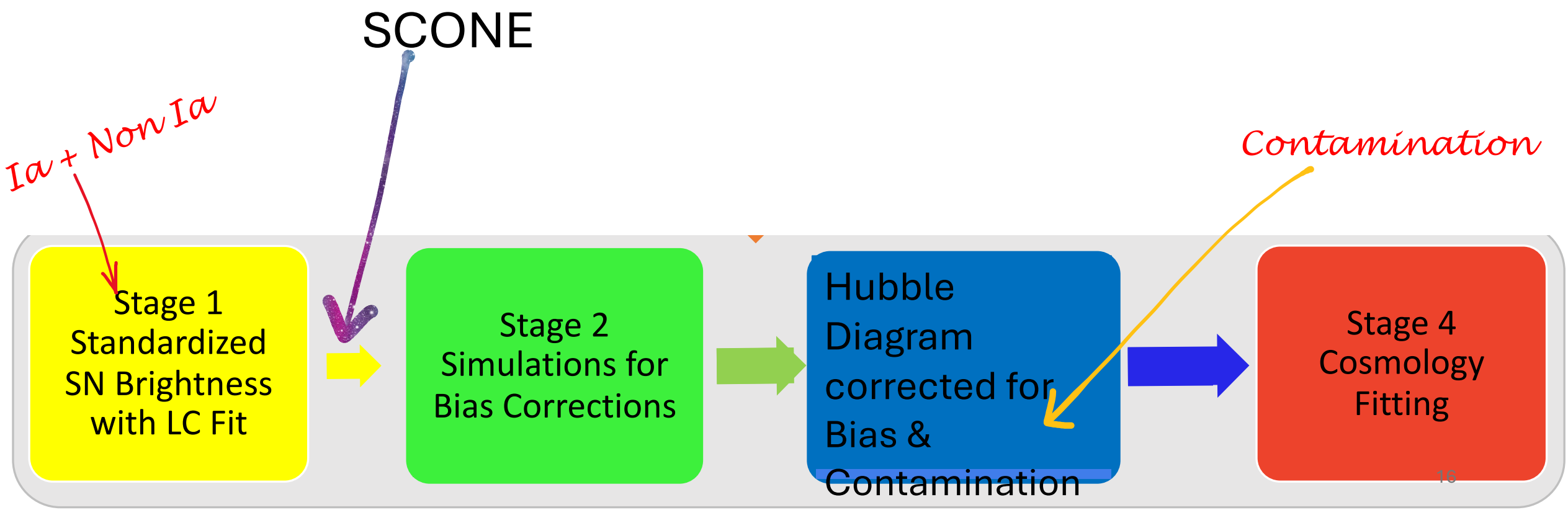
Motivation : **Photometric Classification**

- Large number of SNe for which spectroscopic confirmation is not possible, and more so for the LSST!
- Due to recent advancements in photometric classifiers, it is shown that the contamination from other types of SNe in the analyses is not debilitating, and not even the largest systematic uncertainty
- Moller et.al. [2402.18690] Showed that instead of taking only spec-z classified candidates, if we use a photometric classification framework instead, we can optimize the spectroscopic follow up routine and access a lot more data. They show a 700 additional DES-SN without spec-z could be used, not present in DES-SN5YR cosmology analysis.
- Rebecca Chen is working on the real data on a similar analysis in DES.

Photometric Classifier [2106.04370]

- Simulation : ELaSTiCC SNe Ia + low-z (WFD-DC2)
  - If no zspec, redshift is determined from photo-z PDF
  - More realistic cadence
- Light Curve (LC) Fit stage :
  - 5 Parameter Photo-z Fit with Host Redshift (Specz or Photoz) as a Gaussian Prior.
- SCONE : NN Photo-z Classifier for selecting SNe Ia
- Correct Hubble Diagram for selection bias and contamination
- Create STAT + SYST Covariance Matrix
- Cosmology Fit (SNIa + CMB Prior)

Photometric Classifier [2106.04370]



Samples

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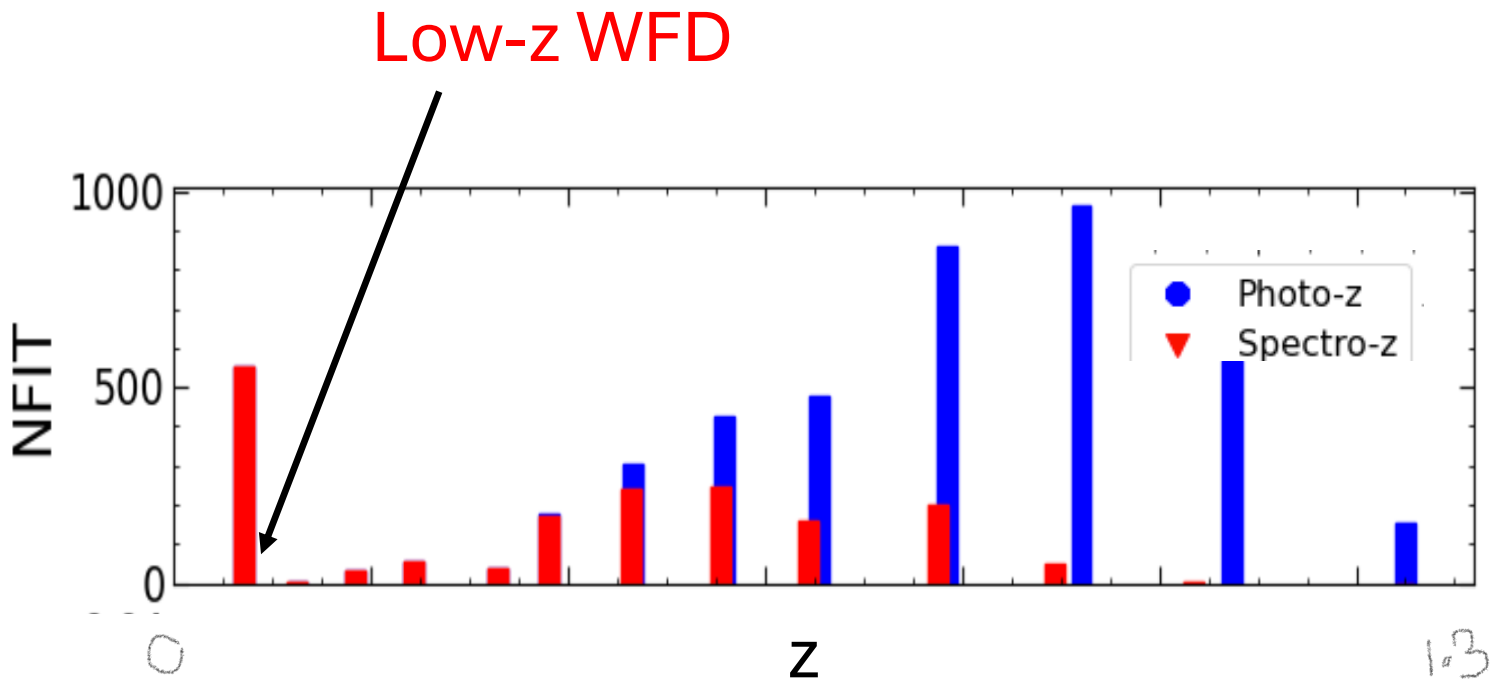
- Final sample contains a mix of Spectroscopic(red) candidates at low-z and Photometric (blue) candidates at high-z.
- Both Redshift binned and unbinned Hubble Diagram → Cosmology Fit



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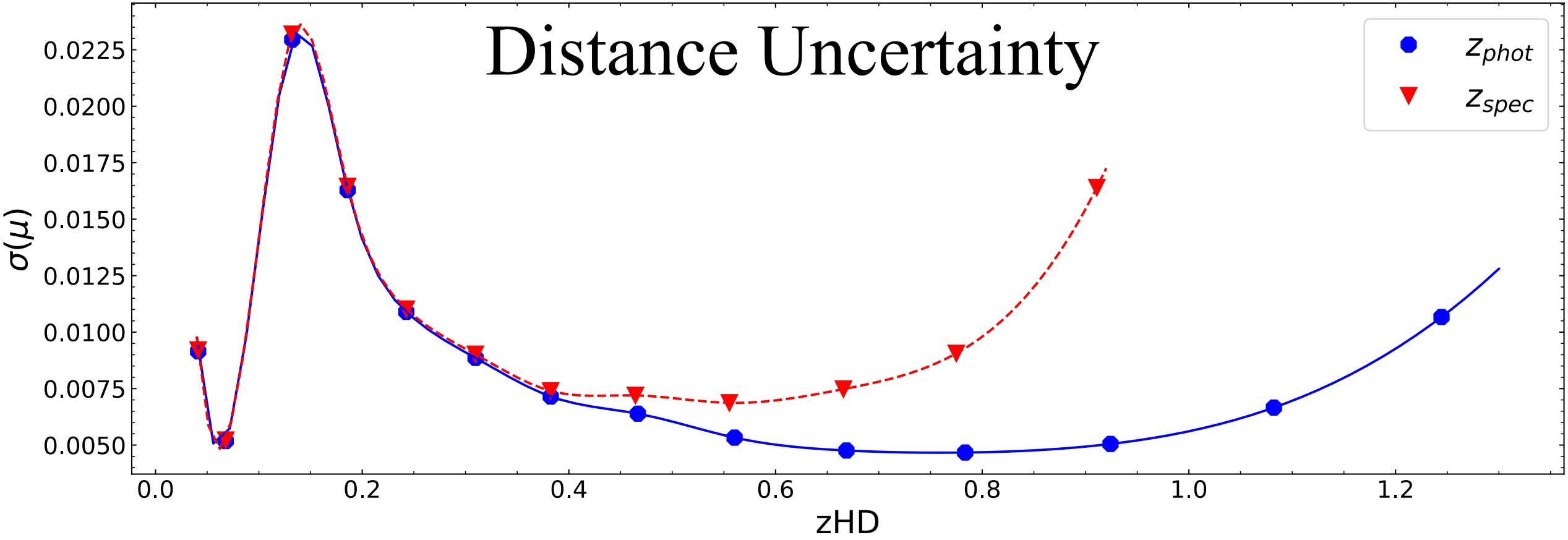
Systematics for Covariance Matrix

Calibration Systematics

Redshift Systematics

Row	Label	Decription	Value
1	StatOnly	no systematic shifts	—
2	MWEBV	shift $E(B-V)$	5%
3	CAL_HST	HST calibration offset	$0.007 \times \lambda$
4	CAL_ZP	LSST zero point shift	5 mmag
5	CAL_WAVE	LSST Filter shift	5 Å
6	zSPEC	shift $z_{\rm spec}$ redshifts	5×10^{-5}
7	zPHOT	shift $z_{\rm phot}$ redshifts	0.01
8	zPHOTERR	scale host $z_{\rm phot}$ uncertainty	1.2
9	Stat+Syst	all systematics	—

Tab. III, Page 7, M23



$z < 0.6$ ⇒The distance precision is similar for **spec-z** and **spec-z + photo-z**

$z > 0.6$ ⇒ spec-z + photo-z cases have significantly smaller uncertainties.

Results : ELaSTiCC

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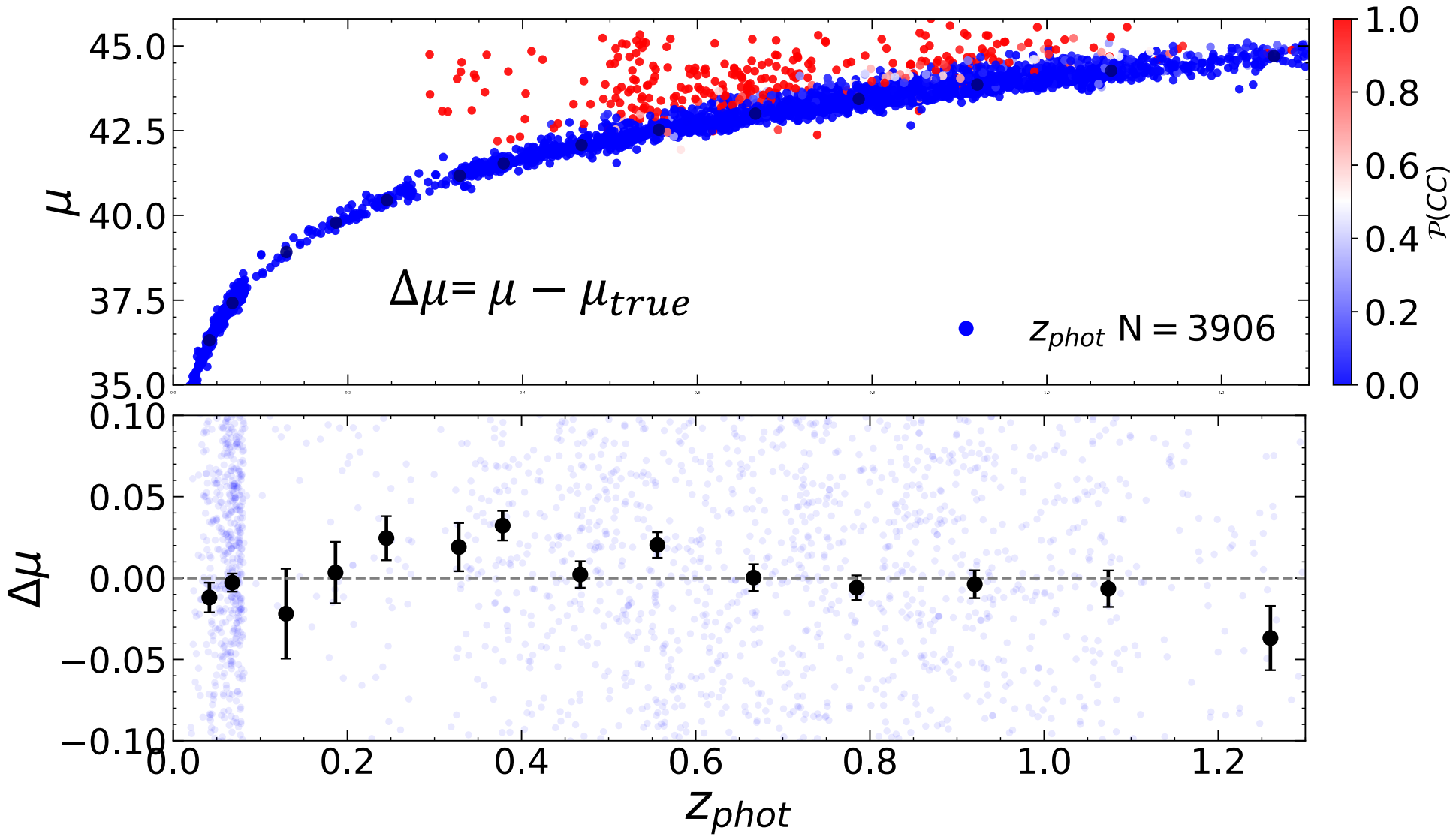

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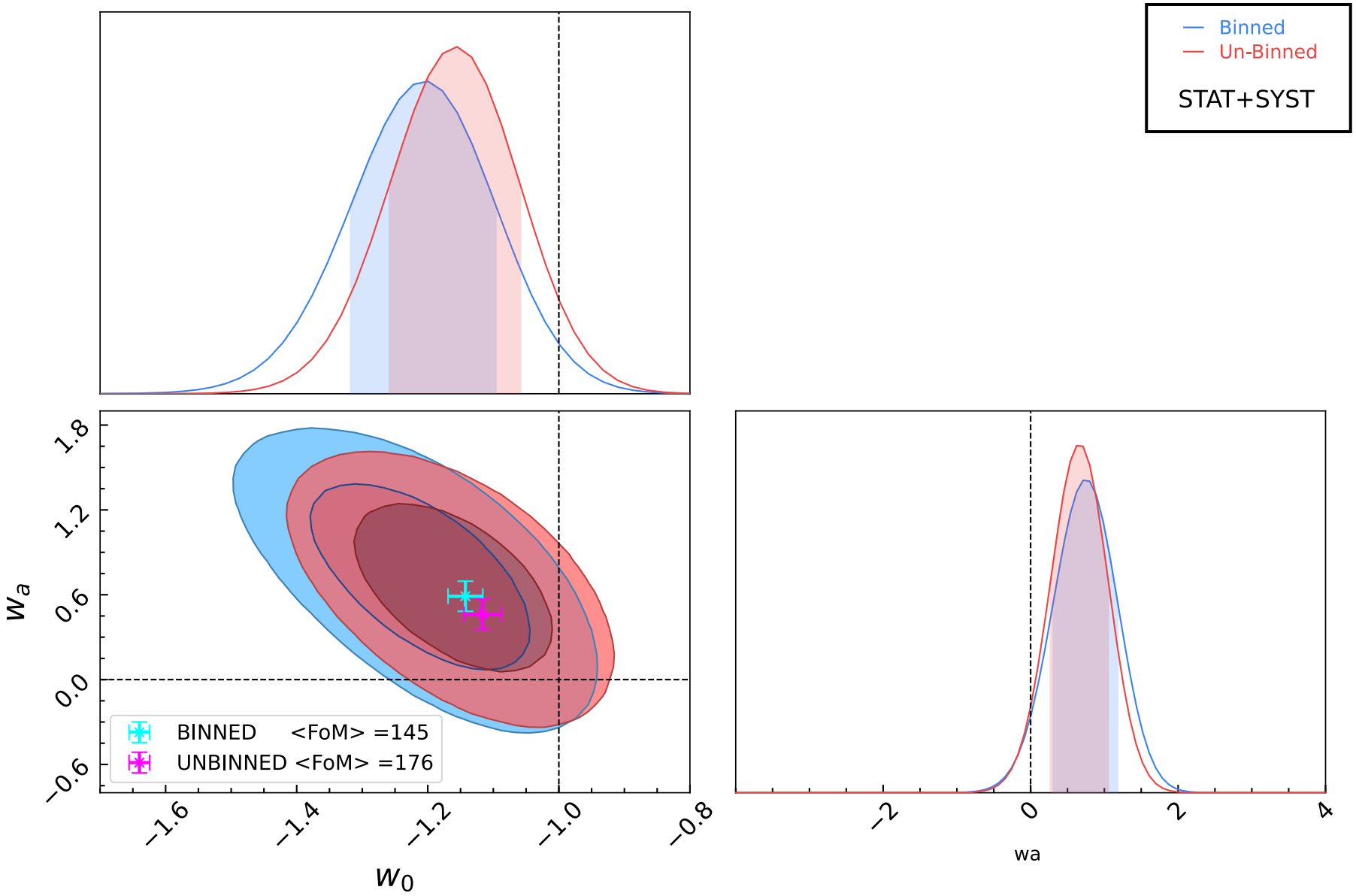
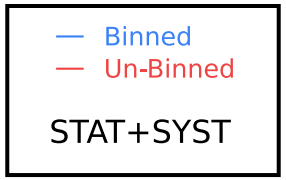
Results



Binned
Un-Binned
STAT+SYST
BINNED <FoM> =145
UNBINNED <FoM> =176
w_a
w_0
wa
1.8
1.2
0.6
0.0
−0.6
−1.6
−1.4
−1.2
−1.0
−0.8
−2
0
2
4

Results

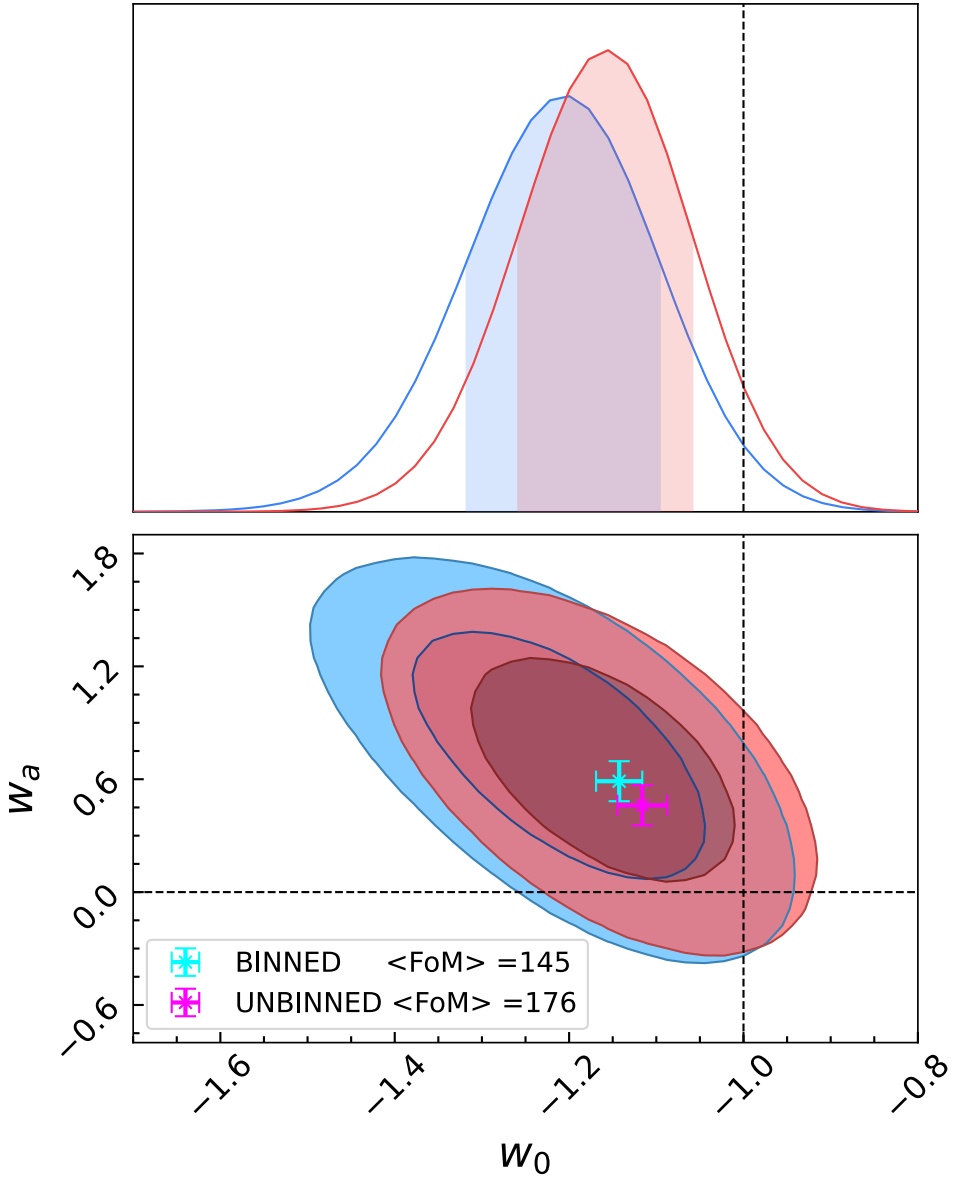


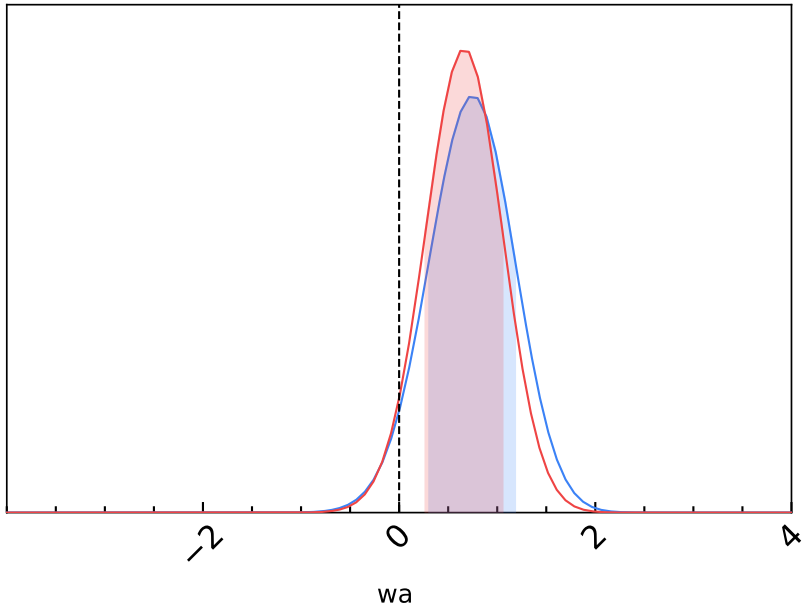
M23 :

FoM = 143

Stat + Syst, Binned

Photoz





Conclusion

- **Using Photometrically classified SNIa dataset + Photometric redshift, can be a feasible option for SNIa cosmology with the LSST.**
- A photometric SNIa dataset with Photometric redshift, can give better Dark energy FoM constraint over its spectroscopic counterpart.
- Using Unbinned Hubble diagram analysis can reduce the systematic uncertainty
- Warnings :
- This is a simulated dataset and challenges of a real data analysis still needs to be taken into account, including adequate photo-z training sets, possible photo-z outliers beyond what the sim predicts etc.

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The END

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Non-Ia Contamination: BEAMS

- Current Analysis : Generate SNIa + Non-Ia (Core Collapse) light curve dataset
- Photometric SN samples require the application of photometric classification algorithms to determine the SN types.
- **B**ayesian **E**stimation **A**pplied to **M**ultiple **S**pecies (BEAMS) : incorporates type Ia probability and marginalise over non Ia SNe, in cosmological fits.
- BEAMS was extended to include the modelling and selection effects corrections and to measure nuisance parameters independent of cosmological parameters [1610.04677]. This extended framework is called as BEAMS with Bias Correction (BBC).