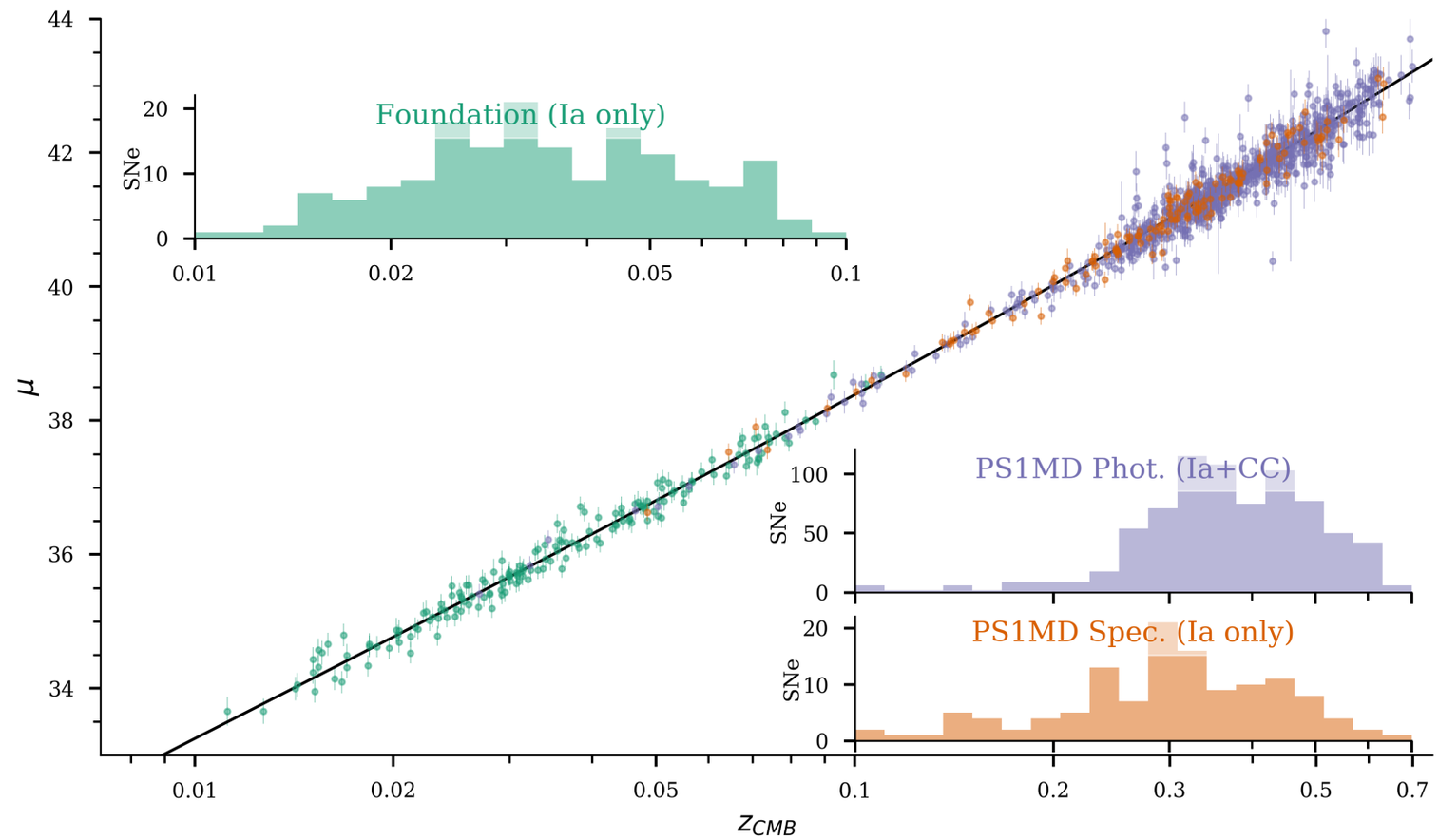


Recent Progress and Remaining Challenges in Type Ia Supernova Analyses with Photometrically Classified Data

David Jones
Moore Fellow, UC Santa Cruz

Recent Photometric Analyses from Our Group

2017

Measuring the Properties of Dark Energy with Photometrically Classified Pan-STARRS Supernovae. I. Systematic Uncertainty from Core-collapse Supernova Contamination

D. O. Jones[1], D. M. Scolnic[2,10], A. G. Riess[1,3], R. Kessler[2], A. Rest[3], R. P. Kirshner[4,5], E. Berger[4], C. A. Ortega[1], R. J. Foley[6], R. Chornock[7], P. J. Challis[4], W. S. Burgett[8], K. C. Chambers[8], P. W. Draper[9], H. Flewelling[8], M. E. Huber[8], N. Kaiser[8], R.-P. Kudritzki[8], N. Metcalfe[9], R. J. Wainscoat[8], and C. Waters[8]

2018

Measuring Dark Energy Properties with Photometrically Classified Pan-STARRS Supernovae. II. Cosmological Parameters

D. O. Jones[1], D. M. Scolnic[2,13], A. G. Riess[3,4], A. Rest[3,4], R. P. Kirshner[5,6], E. Berger[5], R. Kessler[2], Y.-C. Pan[1], R. J. Foley[1], R. Chornock[7], C. A. Ortega[3], P. J. Challis[5], W. S. Burgett[8], K. C. Chambers[8], P. W. Draper[9], H. Flewelling[8], M. E. Huber[8], N. Kaiser[8], R.-P. Kudritzki[8], N. Metcalfe[9], J. Tonry[8], R. J. Wainscoat[8], C. Waters[8], E. E. E. Gall[10,11], R. Kotak[10,12], M. McCrum[10], S. J. Smartt[10], and K. W. Smith[10]

2019

The Foundation Supernova Survey: Measuring Cosmological Parameters with Supernovae from a Single Telescope

D. O. Jones[1], D. M. Scolnic[2,14], R. J. Foley[1], A. Rest[3,4], R. Kessler[2], P. M. Challis[5], K. C. Chambers[6], D. A. Coulter[1], K. G. Dettman[7], M. M. Foley[5], M. E. Huber[6], S. W. Jha[7], E. Johnson[4], C. D. Kilpatrick[1], R. P. Kirshner[5,8], J. Manuel[9], G. Narayan[3], Y.-C. Pan[10,11,15], A. G. Riess[3,4], A. S. B. Schultz[6], M. R. Siebert[1], E. Berger[5], R. Chornock[12], H. Flewelling[6], E. A. Magnier[6], S. J. Smartt[13], K. W. Smith[13], R. J. Wainscoat[6], C. Waters[6], and M. Willman[6]

all PS1 data used for these measurements (including ~1200 light curves) are available through our STScI-hosted website (https://archive.stsci.edu/prepds/ps1cosmo/) and the Open Supernova Catalog

The Next Decade of (Photometrically Classified) Supernova Cosmology

DARK ENERGY SURVEY

~2,500 cosmologically useful SNe Ia

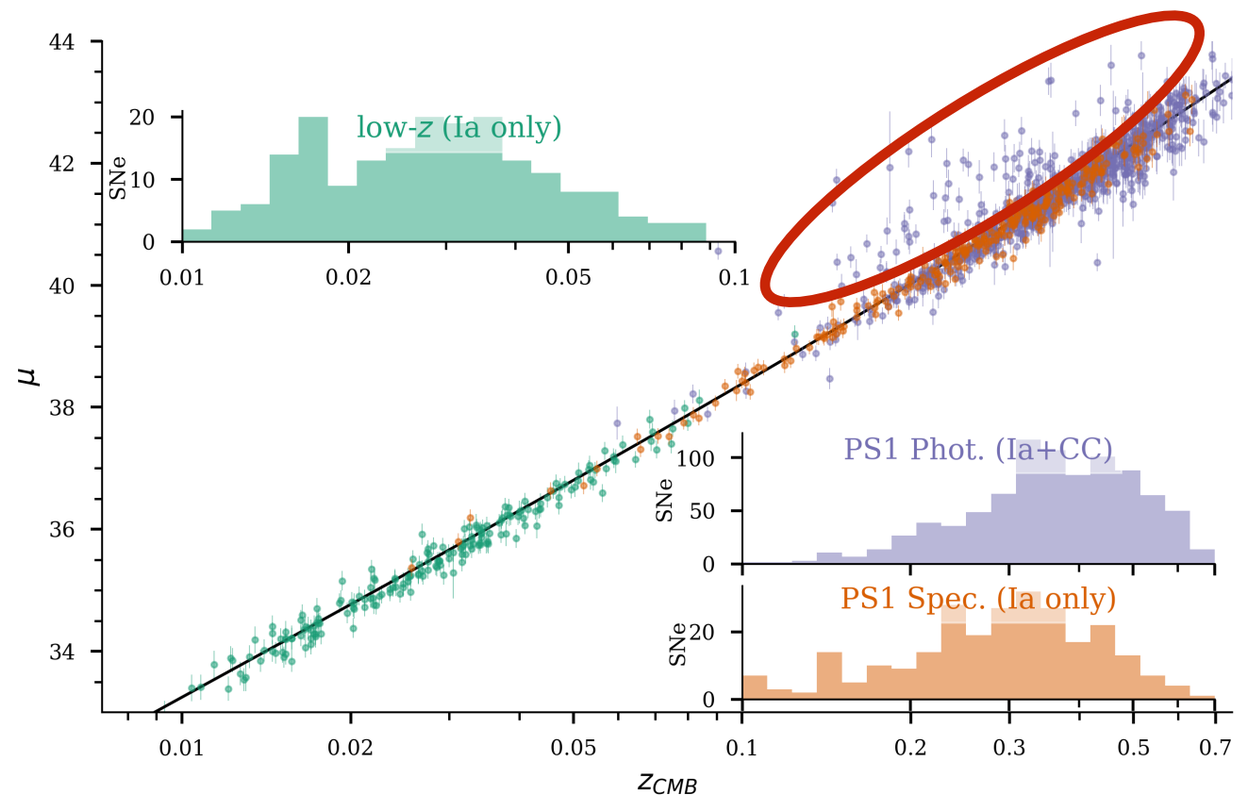
~100,000 cosmologically useful SNe Ia

~20,000 cosmologically useful SNe Ia

DES projection: Bernstein+11
WFIRST projection: Hounsell+17

Measuring *w* with Photometrically Classified Data

- Change in *w* of 5% corresponds to a difference of 0.02 mag from 0 < z < 0.5
- Assume contaminating CC SNe are 1 mag fainter than SNe Ia. Then, 5% error in w = 2% contamination at high *z*.
- We need to be able to accurately simulate our sample (big uncertainties remain) and marginalize over the contamination (going well)

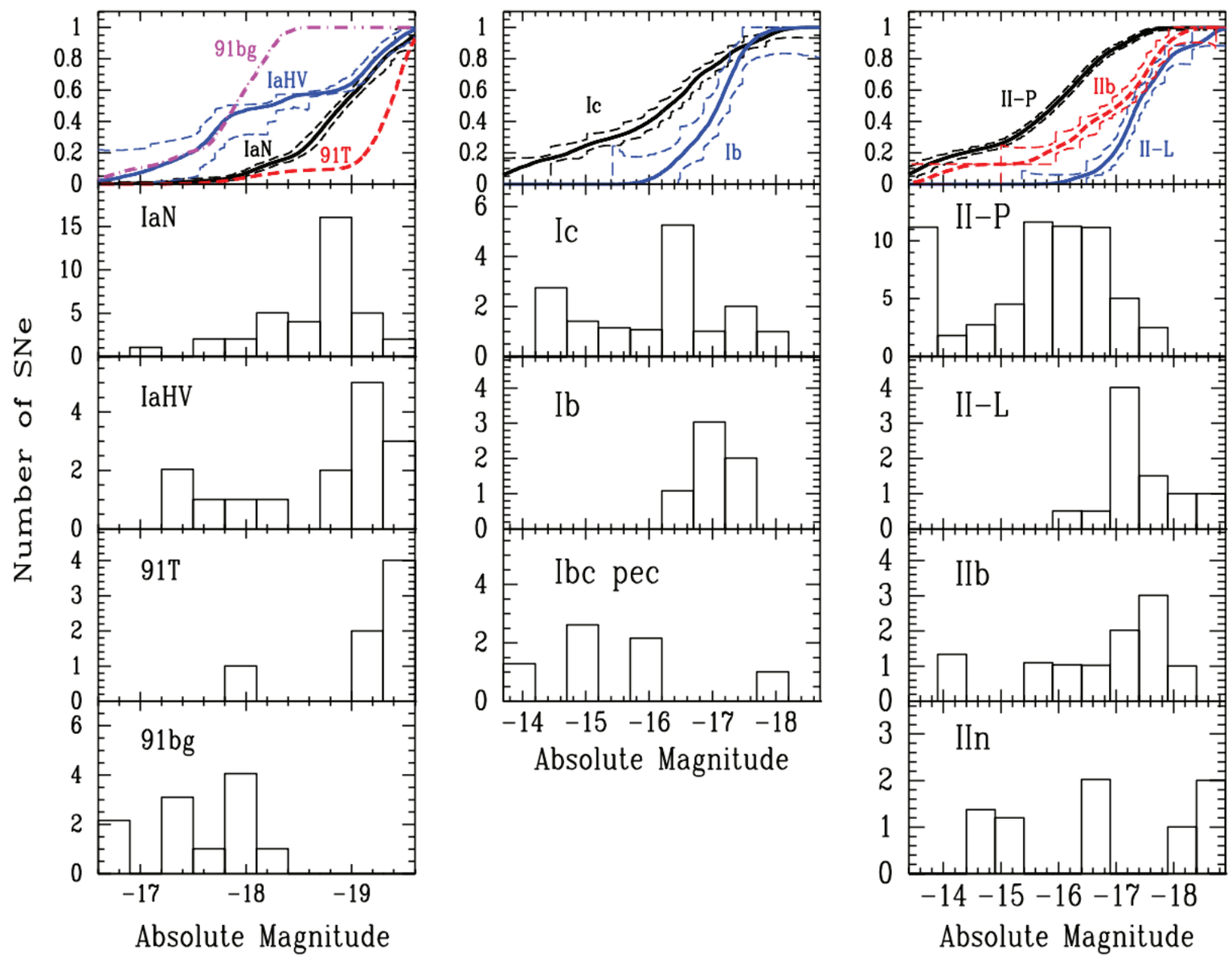


Jones+18

Building the (CC SN) Simulations

- Templates
  - Ia: SALT2 model (maybe an issue for bias corr. but not likely for classification)
  - CC SN from observations (see tomorrow's talks)
- Luminosity Functions
  - simulations typically assume these distributions are ~Gaussian
  - even if they didn't assume this, hard to draw accurate samples from stats-limited distributions

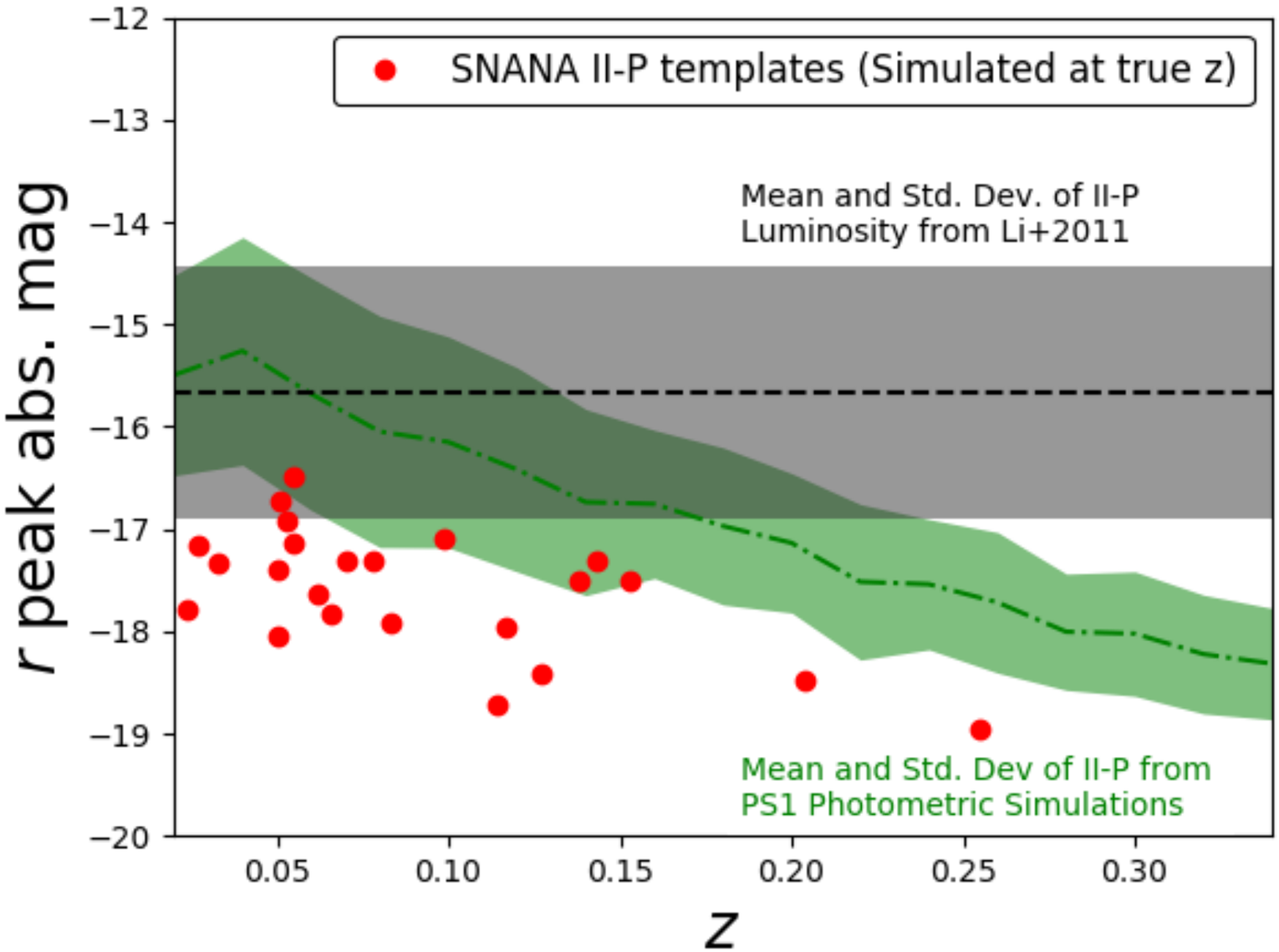
(from targeted search!)



Li+11

Building the Simulations

- Templates
- Luminosity Functions
- Survey Properties
- Simulations

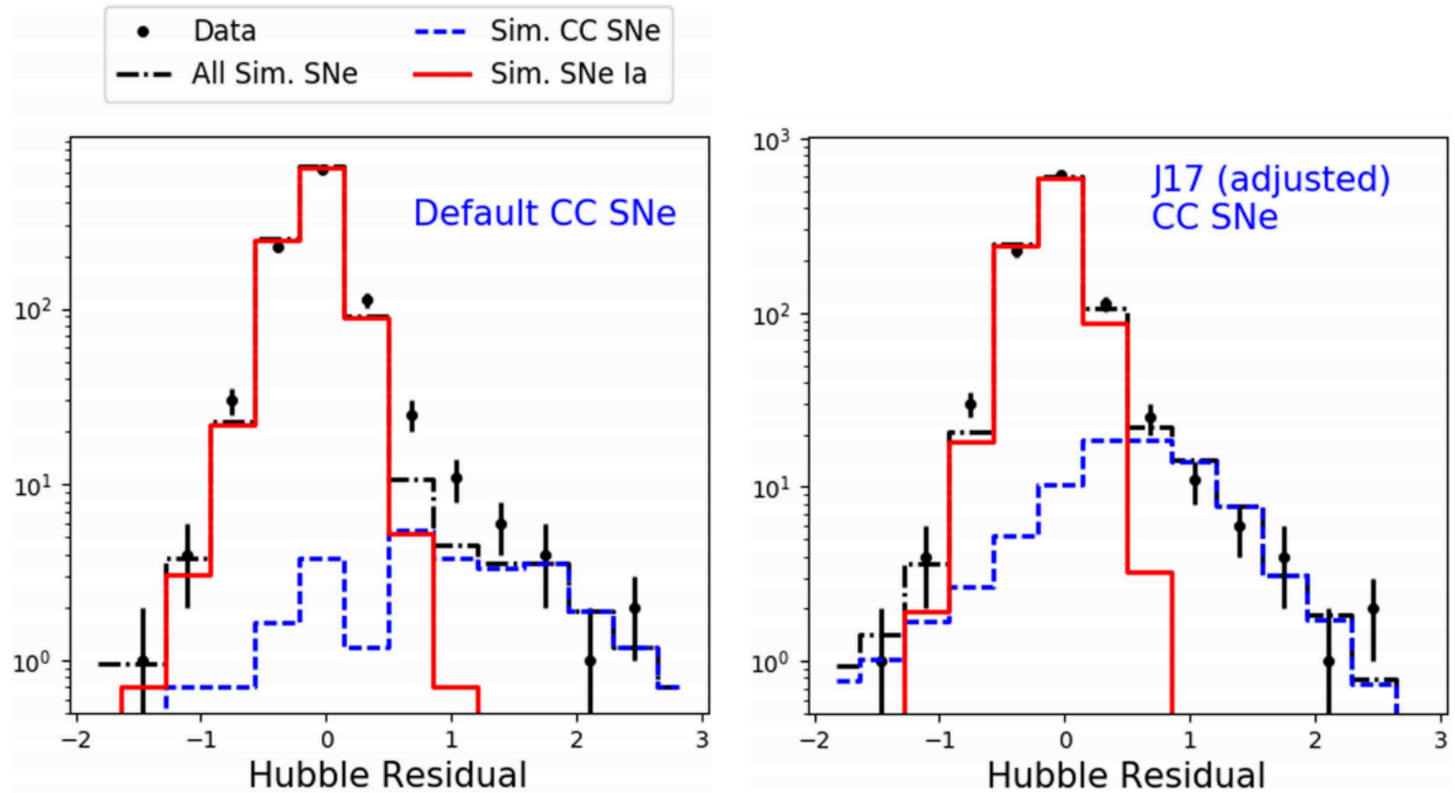


- Current CC SN templates have biased luminosities and other attributes may be biased as well
- *Much* larger template samples are now available (see PLAsTiCC and Maria's talk tomorrow, but biases inevitably still exist)

Jones+17

Current Simulations Don't Look Like Data

matching data requires **large** adjustments to the LFs



Jones+17, Vincenzi+19

Current Simulations Don't Look Like Data

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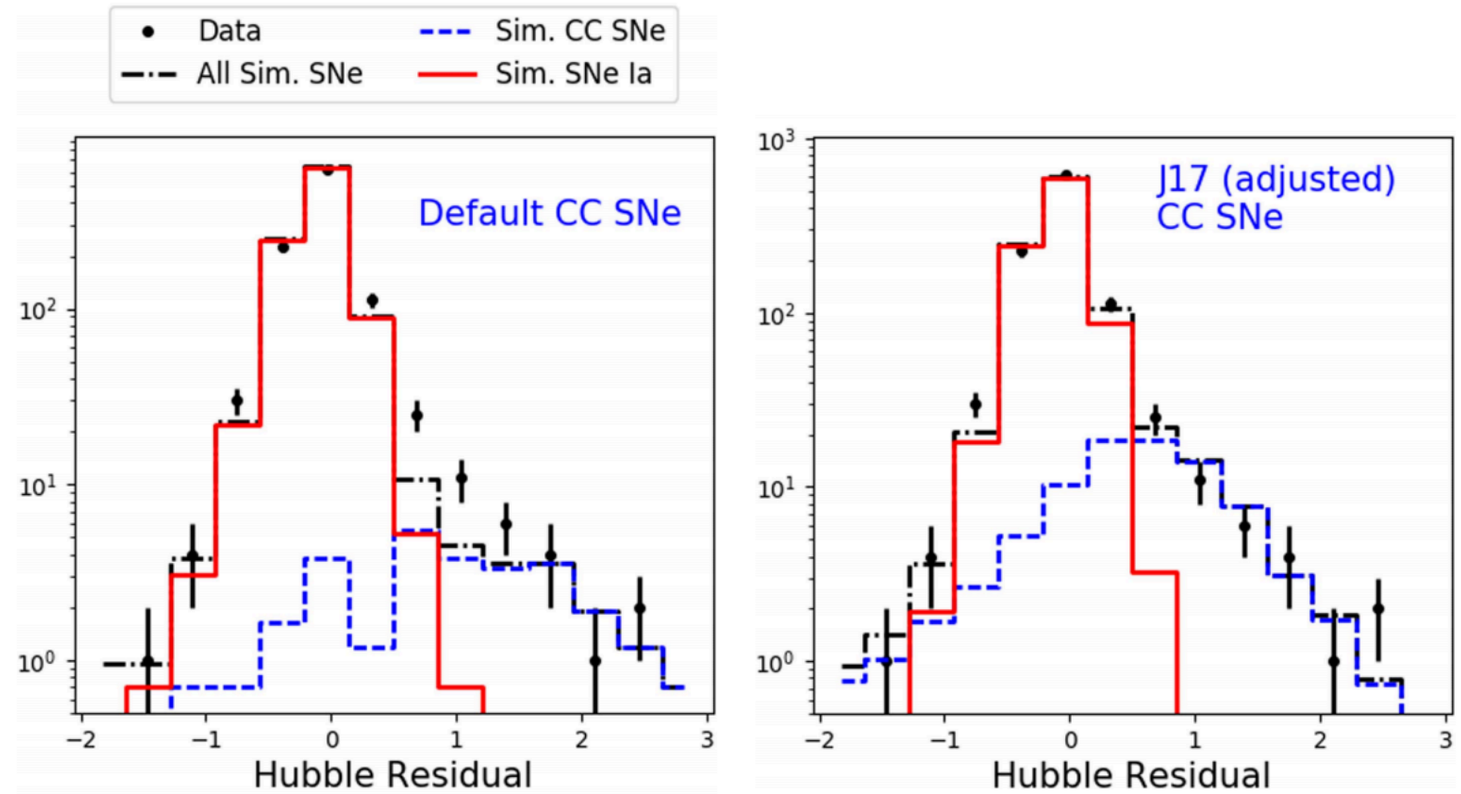
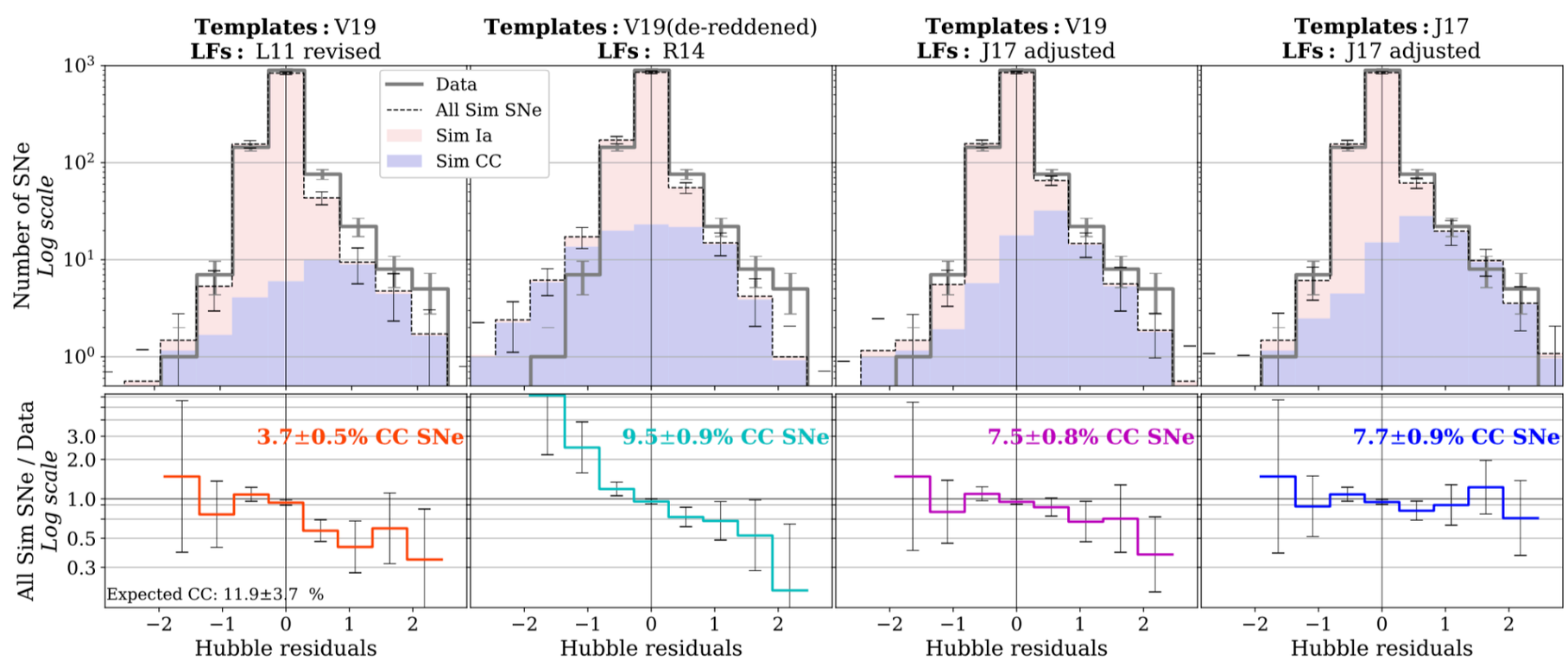




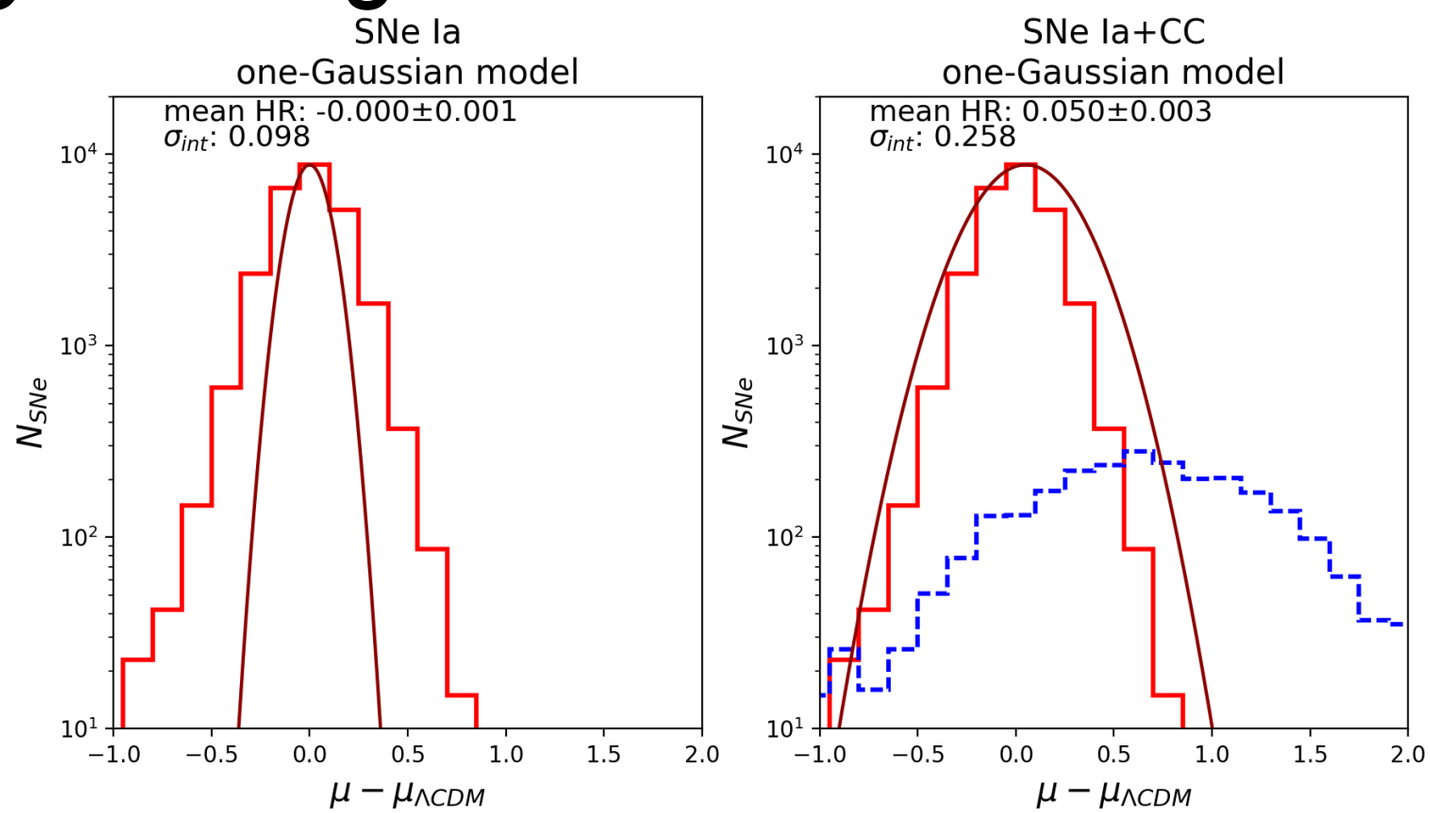
Jones+17, Vincenzi+19

Training on Real Data?

- A couple warnings
  - If we can't produce realistic simulations, the community might not believe our classifications are actually working
  - If your training set has a different luminosity distribution than the classification set, other attributes could be biased:
    - fraction of different subtypes
    - properties of each subtype (host galaxy dust, LC shape, epoch of first detection)
  - If the training set has different noise properties or cadence, feature extraction could be biased?
- Our team's approach is training on simulations that look as much as possible like the data, with systematic uncertainties computed by varying the training sample in realistic ways

Marginalizing over CC SNe with BEAMS

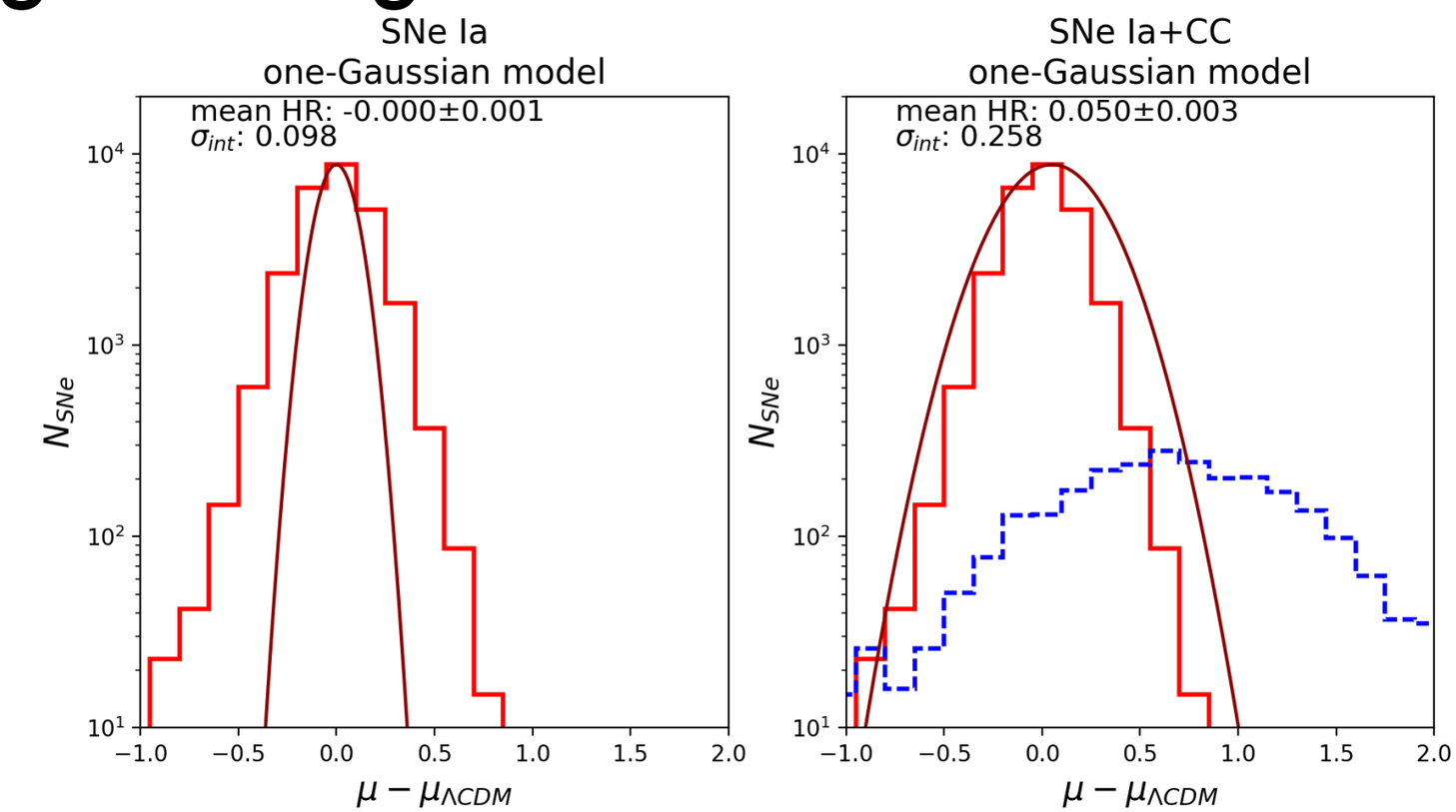
A 1D example with simulated data

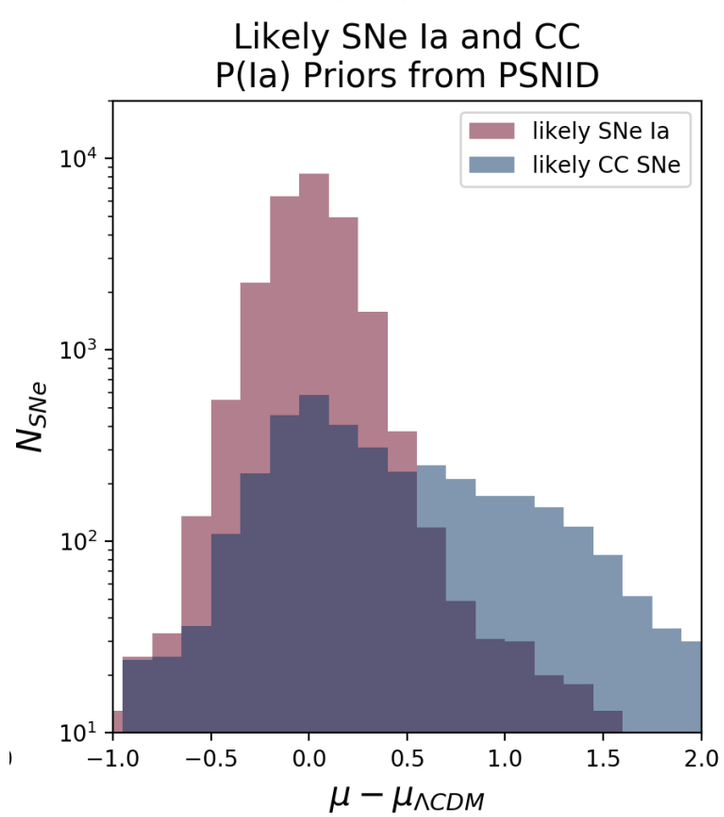


Mean HR is biased by 0.05 mag and dispersion is off by a factor of 2.5

Marginalizing over CC SNe with BEAMS

A 1D example with simulated data



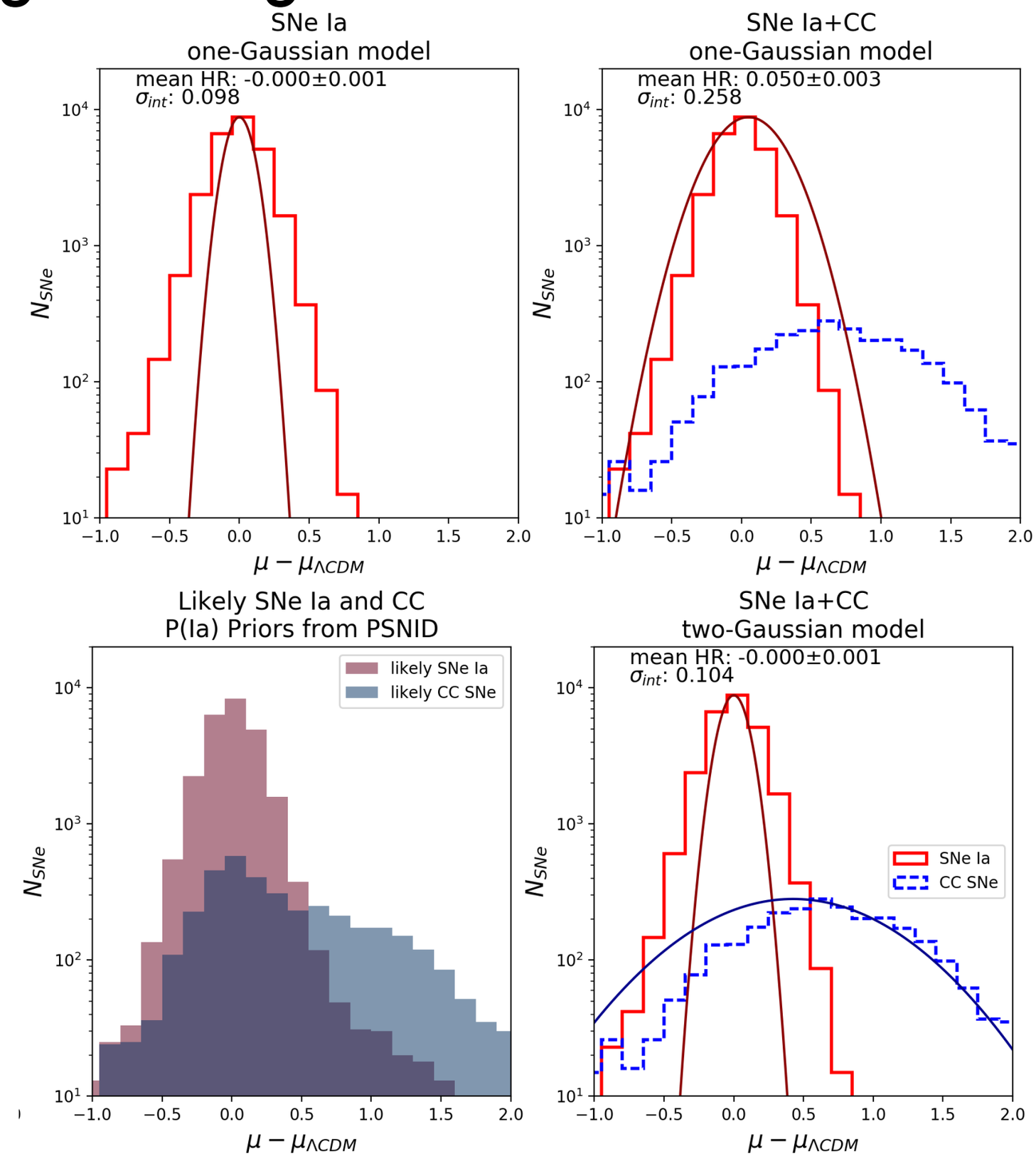


Priors distributions are not a perfect match to the (simulated) data

PSNID: Sako+2011, 2014

Marginalizing over CC SNe with BEAMS

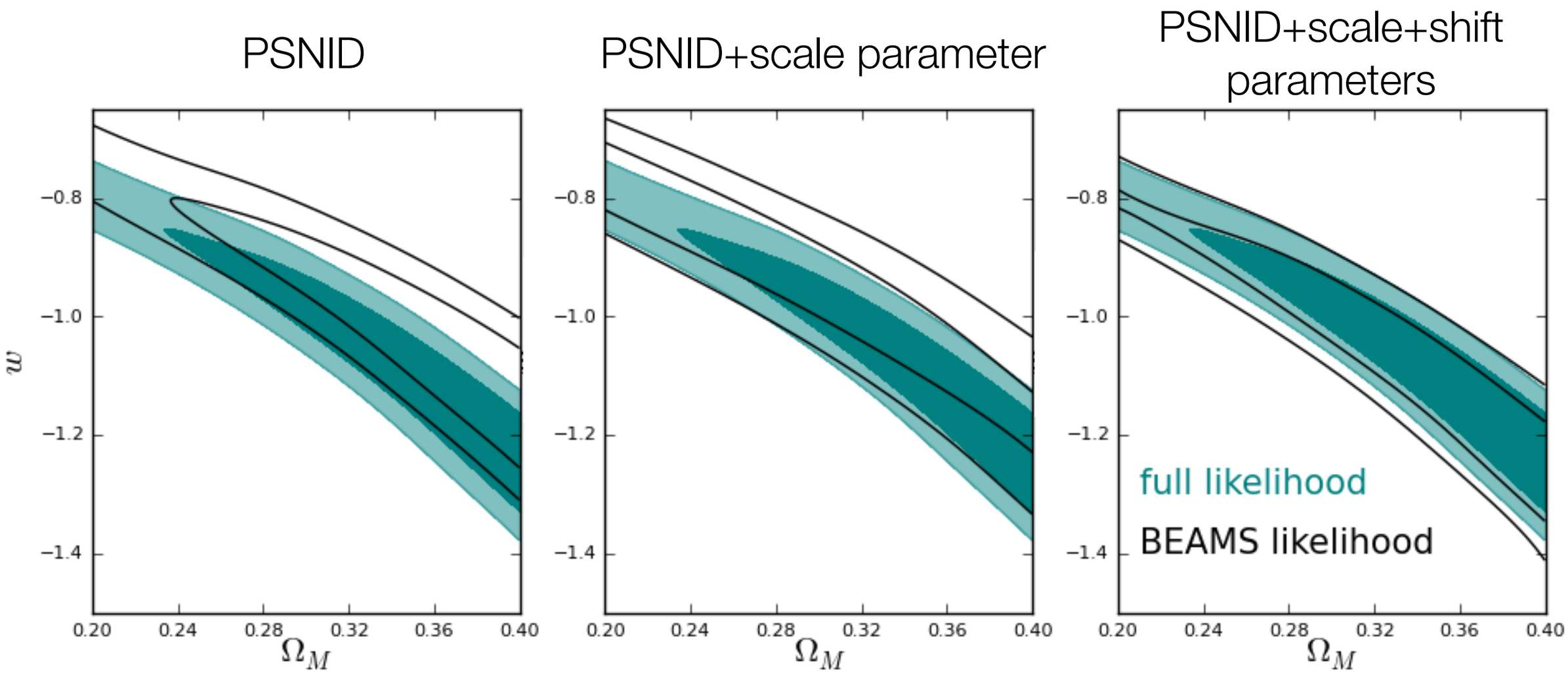
A 1D example with simulated data



Mean HR is exactly right and dispersion changes by only 6%

Marginalizing over CC SNe with BEAMS

we can also allow BEAMS to try and take care of uncertain probabilities



$$\tilde{P}(\mathrm{Ia}) = \frac{A \times (P(\mathrm{Ia}) + S)}{1 - (P(\mathrm{Ia}) + S) + A \times (P(\mathrm{Ia}) + S)}$$

A: scale parameter

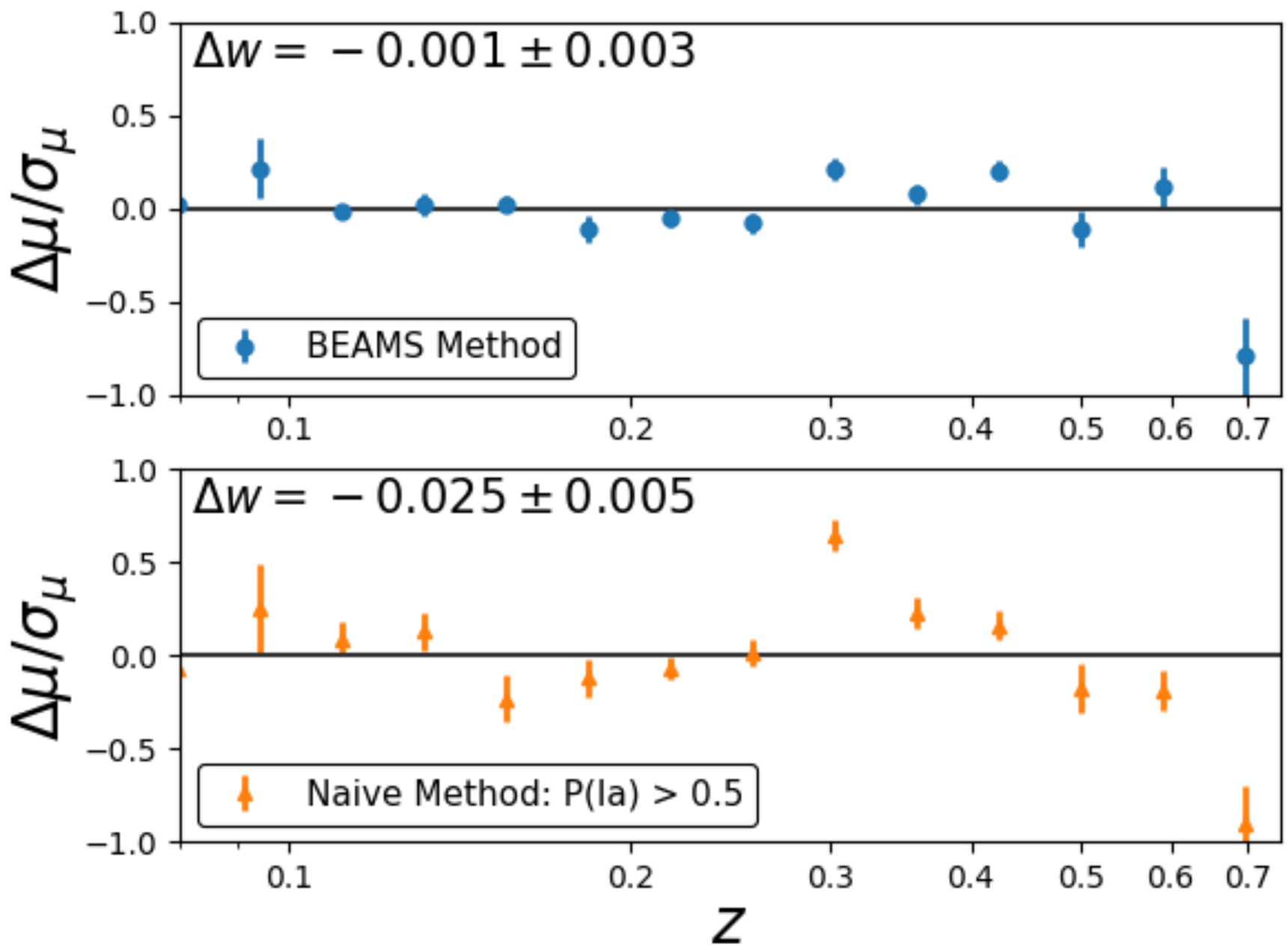
S: shift parameter

Using Simulations to Validate the Method

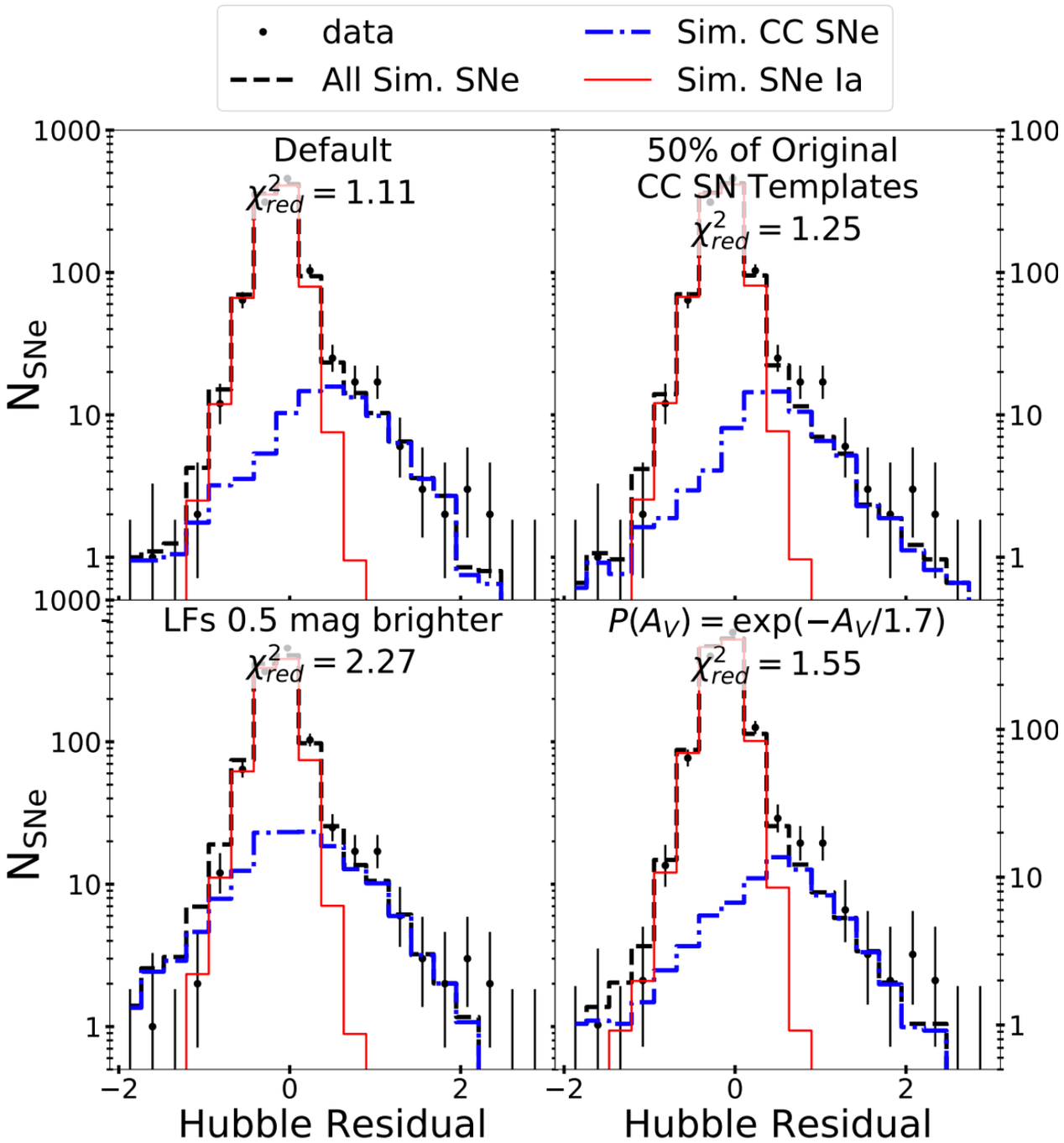
We tested BEAMS on 25 simulations of 1,250 SNe

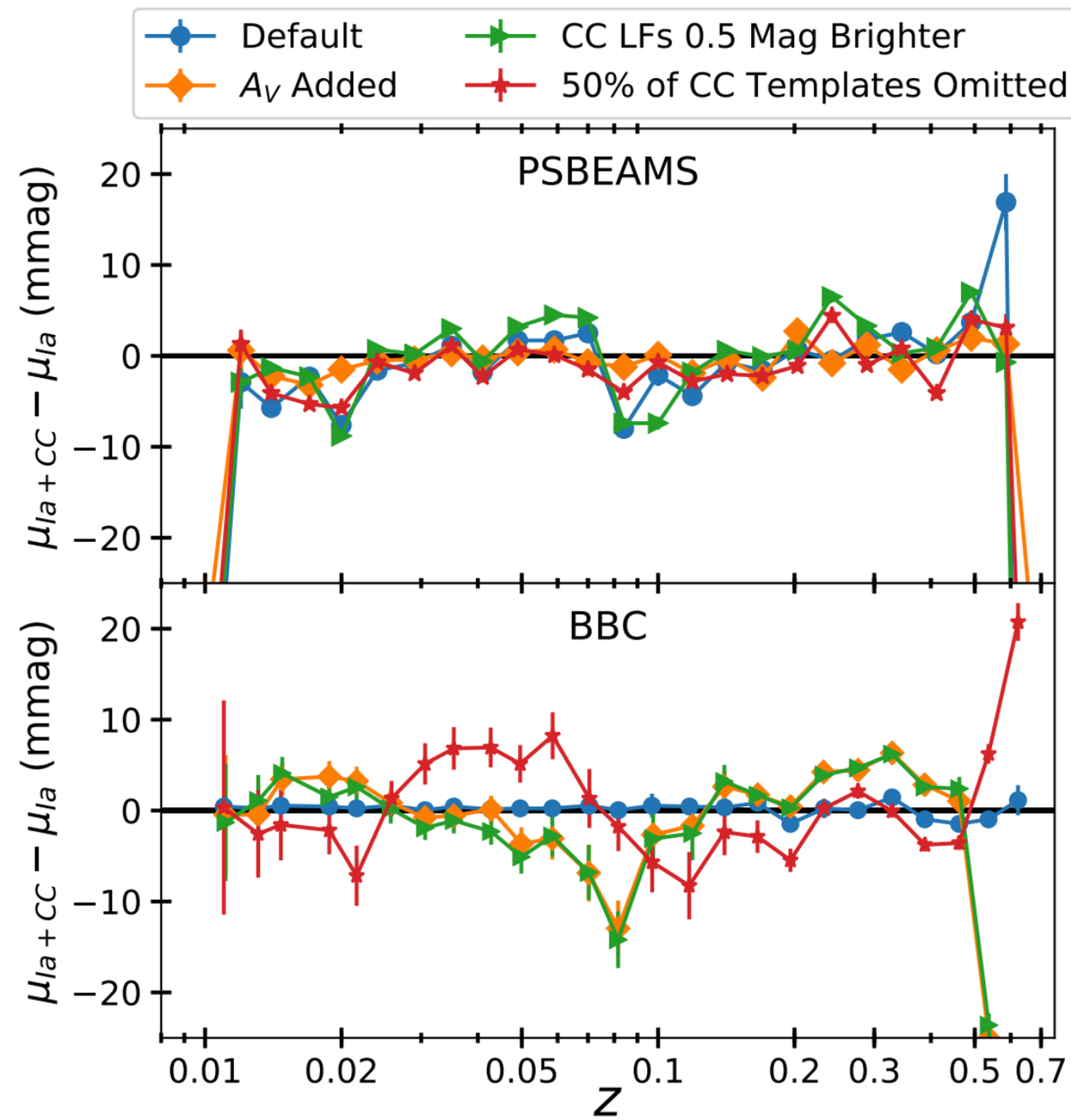
With BEAMS:

Without BEAMS: making a light curve classifier cut of P(Ia) > 0.5



Using Simulations to Validate the Method





Jones+19

Systematic Uncertainty due to Marginalizing over CC SNe

- Should include:
  - Alternative classifiers
  - Alternative simulations/training samples
  - Alternative modeling of the CC SN distribution
  - Checking for biases on global nuisance parameters
  - Incorrect redshifts (small in our analysis)

Measurements of w from Alternative Methods of Marginalizing over CC SNe

	w	Δw
Baseline	-0.920 ± 0.033	⋯
CC SN simulations	-0.924 ± 0.033	-0.004
CC SN prior	-0.938 ± 0.033	-0.018
Classification prior[a]	-0.886 ± 0.036	0.034
Nuisance parameters fixed	-0.922 ± 0.033	-0.002

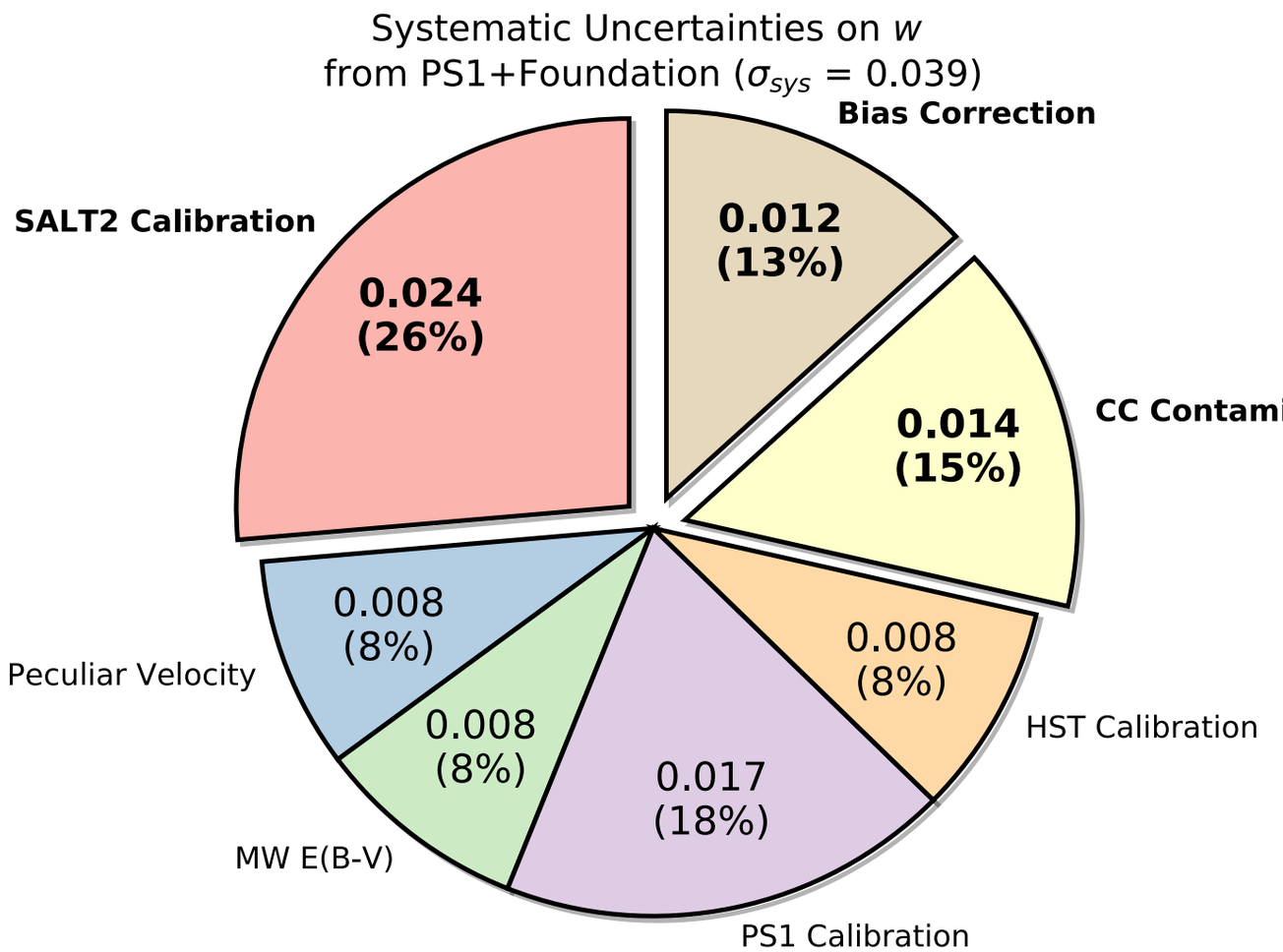
stat+sys: w = -0.938 +/- 0.053

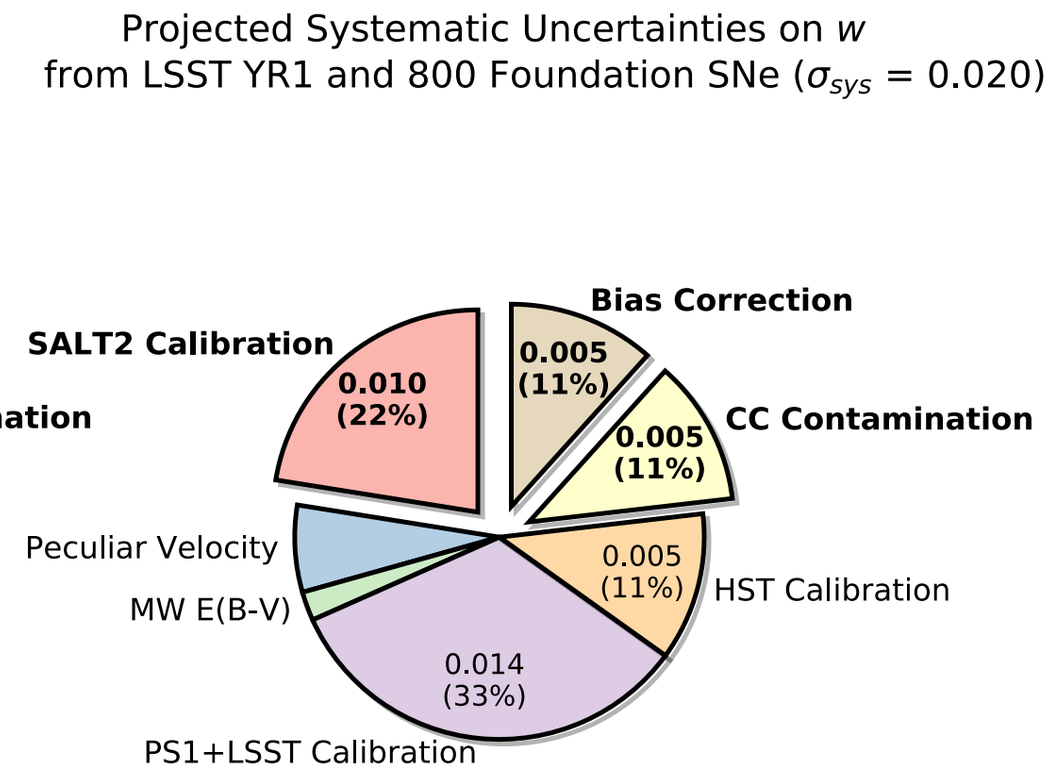
due to highest-z bins, only this large before other classification systematics!

Jones+19

Looking Ahead to DES/LSST

Projected systematic uncertainties from just one year of LSST (I fudged the CC contam. numbers for LSST assuming that things will get better!)





Left: Jones+19; Right: LSST Estimates from LSST DESC+18

Conclusions

- Still lots of uncertainty in CC SN models and luminosity functions
- We have to satisfy both ourselves and the community - nobody will believe the results unless we can produce simulations that look like our data
- We don't need perfect probabilities, but it really helps to have *unbiased* probabilities
- BEAMS works very well - current systematics on *w* from marginalizing over CC SN contamination are at the 1-1.5% level
- But, Pan-STARRS BEAMS approach relied on a spectroscopically classified low-*z* sample, and this data has less leverage if global nuisance parameters like the SN Ia dust law and dispersion (biased by CC SNe!) are evolving with cosmic time