DARK ENERGY
SURVEY

Photometric Redshifts, DES, and DESpec

Outline

- **DES photo-z calibrations: spectroscopic training set fields**

- **DES photo-z calibrations: spectroscopic follow-up**
  - **Redshift completeness**
  - **Sample variance**
    - **DESpec**
  - **Cross correlations**

DES Photo-z Training Sets (highlighted in red)

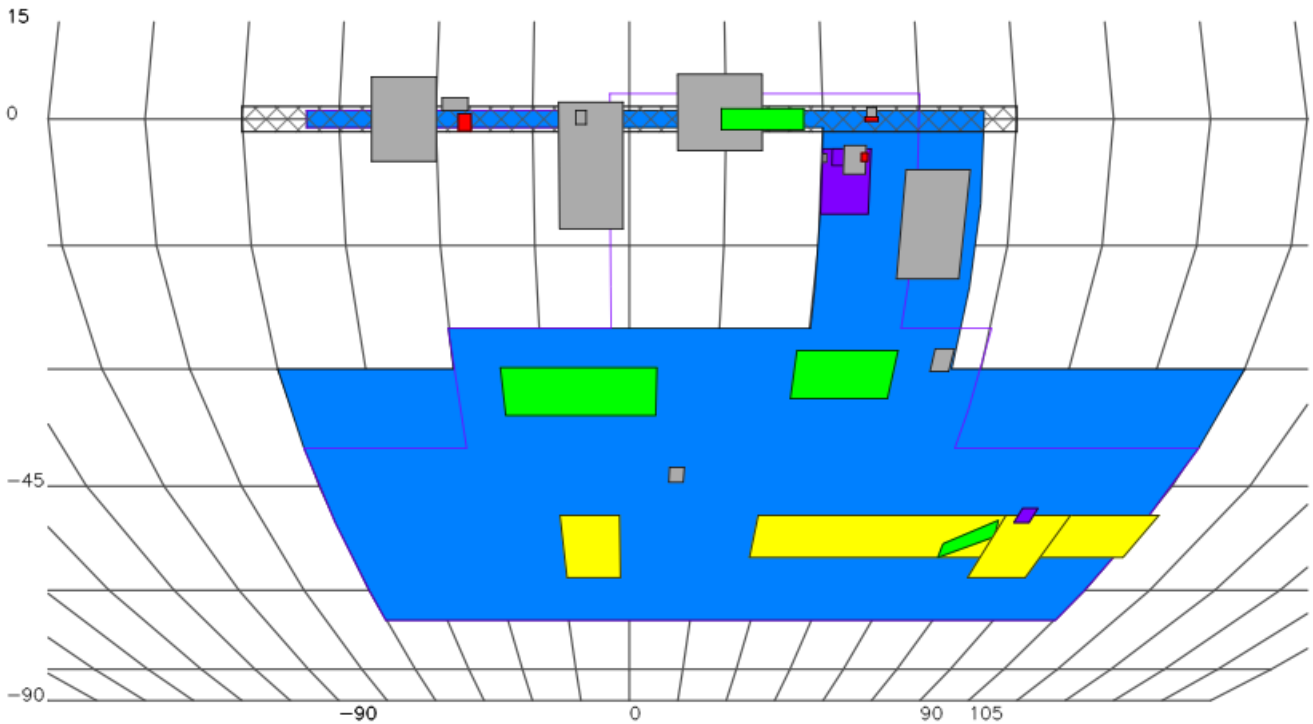
From J. Annis

Table 3. Relevant Existing Datasets

	ra (degrees)	dec (degrees)	Reason
SPT	$-60 \leq \alpha \leq 105$	$-65 \leq \delta \leq -45$	SZ
ACT	$26 \leq \alpha \leq 107$	$-55 \leq \delta \leq -49$	SZ
SPT Deep	$-13 \leq \alpha \leq +2$	$-58 \leq \delta \leq -49$	SZ+CMB polarization+Spitzer
SPT Deep	$76 \leq \alpha \leq 89$	$-58 \leq \delta \leq -49$	SZ+CMB polarization
SHELA	$14 \leq \alpha \leq 27$	$-1 \leq \delta \leq +1$	Spitzer+HETDEX
ADFS	$66 \leq \alpha \leq 75$	$-55 \leq \delta \leq -50$	Akari+Herschel
WiggleZ 1hr	$7.5 \leq \alpha \leq 20.6$	$-3.7 \leq \delta \leq +5.3$	Spectroscopy
DEEP2 2hr	37.5	0.0	Spectroscopy
PRIMUS	various	various	Spectroscopy at $i \leq 22^{nd}$
VVDS Shallow	-25	0.0	Spectroscopy at $i \leq 22^{th}$
VVDS Deep	32.5	-49.0	Spectroscopy at $i \leq 24^{th}$
Vipers W4	-27	2	Spectroscopy at $i \leq 22.5$
Vipers W1	30	5	Spectroscopy at $i \leq 22.5$
CFHTLS W1	$30 \leq \alpha \leq 37.5$	$-11.3 \leq \delta \leq -3.5$	High quality imaging
CFHTLS D1	36.5	-4.5	High quality imaging
DEEPLens F6	32.5	-4.5	High quality imaging
DEEPLens F3	80.0	-49.0	High quality imaging
SDSS Stripe82	$-60 \leq \alpha \leq 60$	$-2 \leq \delta \leq +2$	High quality imaging+spectroscopy

DES Photo-z Training Fields (in grey, with deep training fields in red)

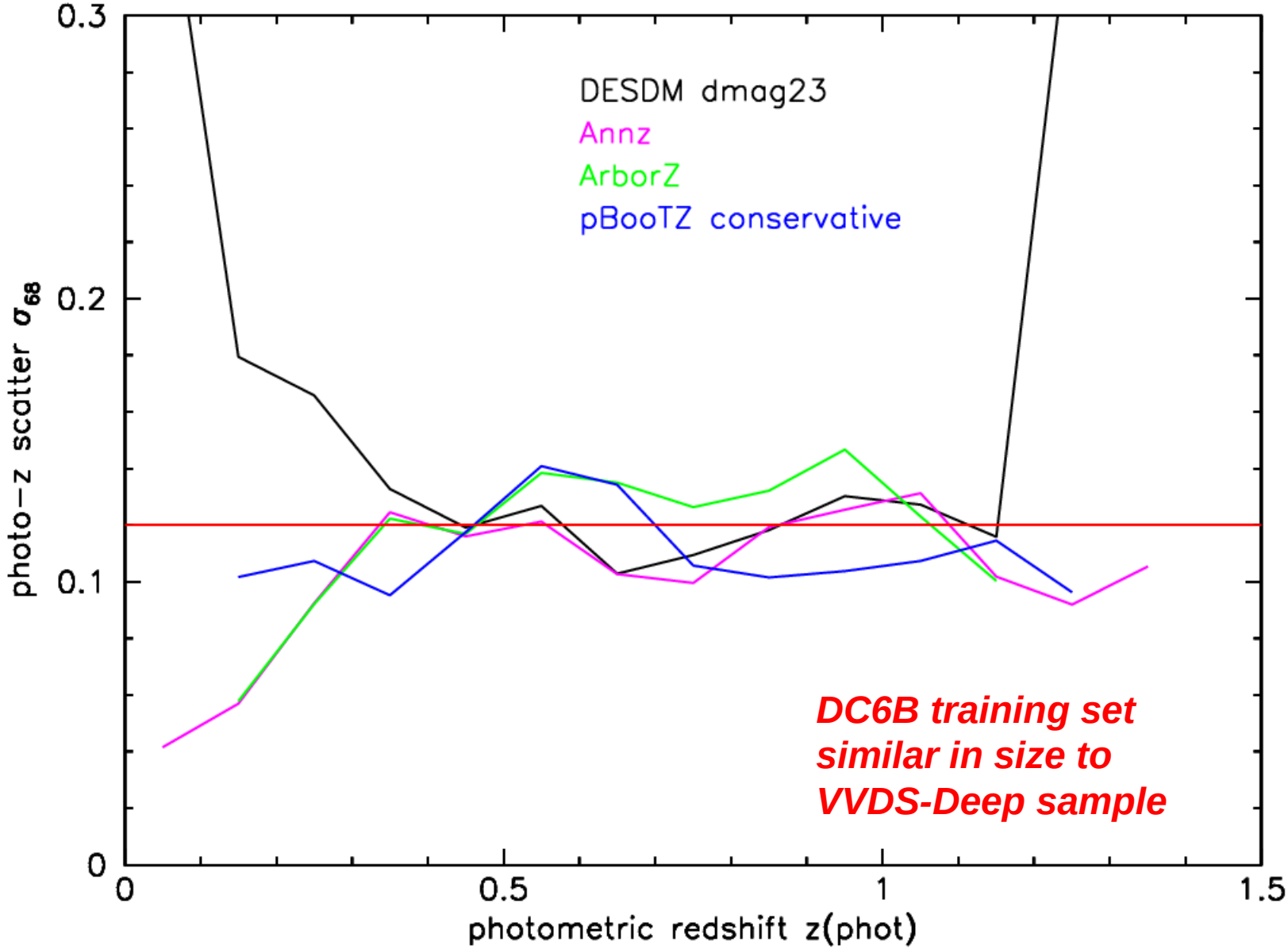
DARK ENERGY SURVEY



From J. Annis

Figure 2. The DES survey footprint along with other relevent South Galactic Cap surveys. The purple line outlines a modified 5-year DES footprint under consideration. The names of fields are given in the text and in Table 3. Grey and red areas are spectroscopic surveys. SDSS Stripe 82 is indicated by a grey cross-hatched region. Purple regions are deep intermediate-scale imaging surveys. Green areas are infrared surveys; note that the VHS covers the whole map at $\delta < 0$ and will go deeper in the DES footprint. Yellow areas are SZ surveys.

DES DC6 Photo-z Challenge: comparison of photo-z scatter



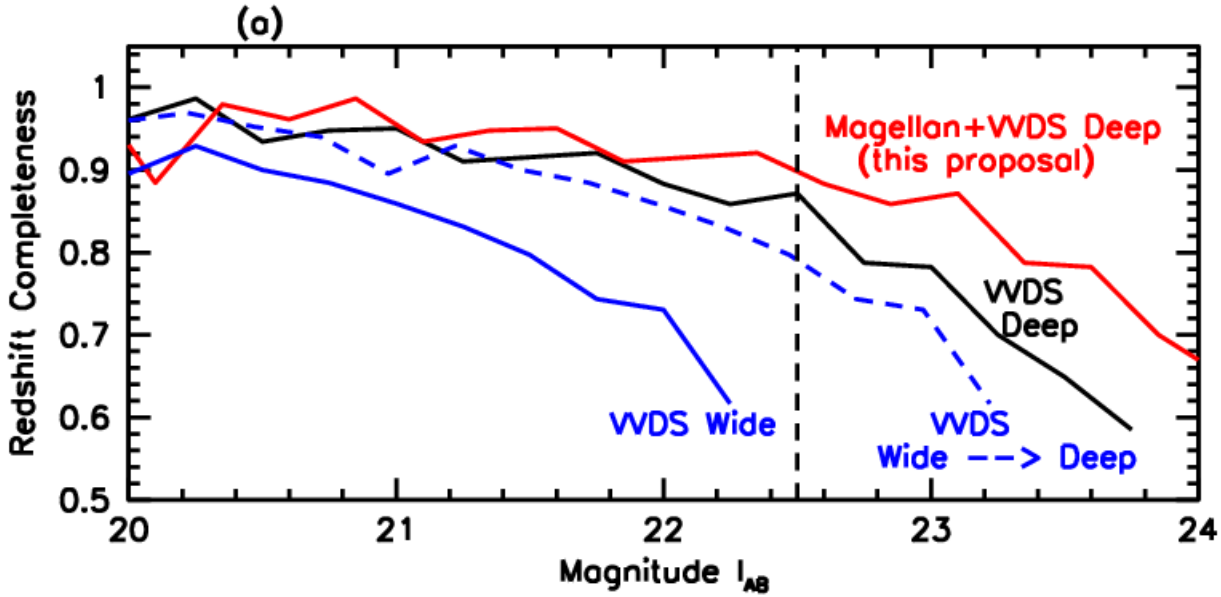
DC6B training set similar in size to VVDS-Deep sample

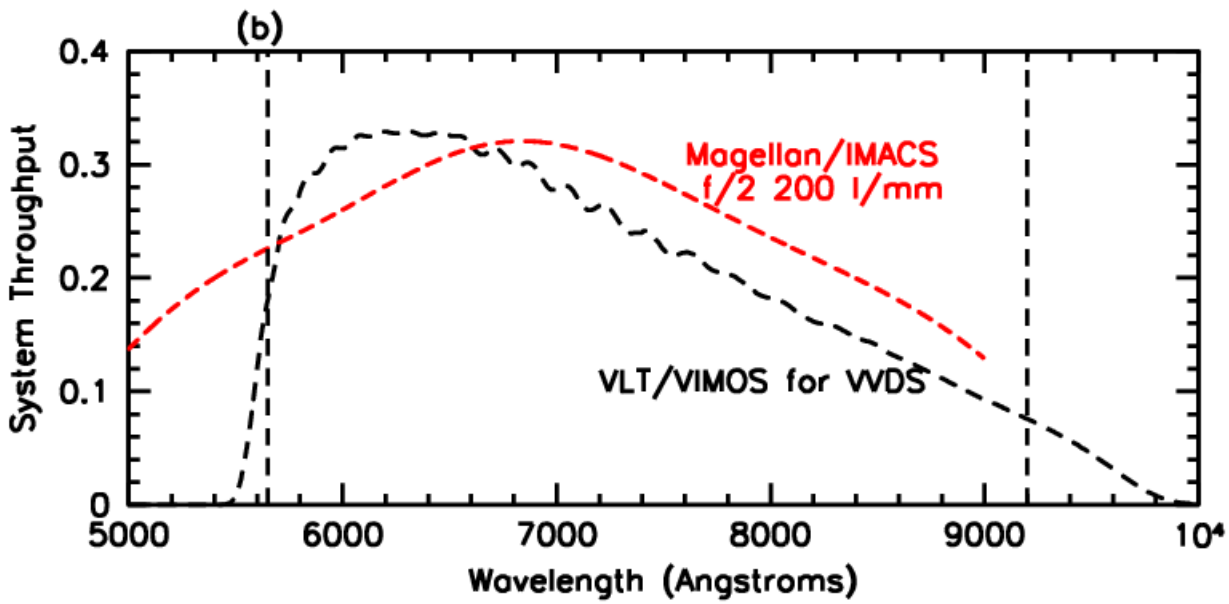
Photo-z spectroscopic follow-up: redshift completeness

DARK ENERGY SURVEY

- **Spectroscopic training samples are not complete to DES photometric limit i = 24**
  - **Even I_{AB} < 24 VVDS-Deep sample suffers from incompleteness as functions of magnitude, color, and redshift**
  - **Proposal for 2012B Magellan/IMACS time to improve completeness of VVDS-Deep 02 hr field training set by effective tripling of integration time**
  - **Also investigating completeness vs. redshift using spectroscopic simulations *(see Carlos Cunha talk)***

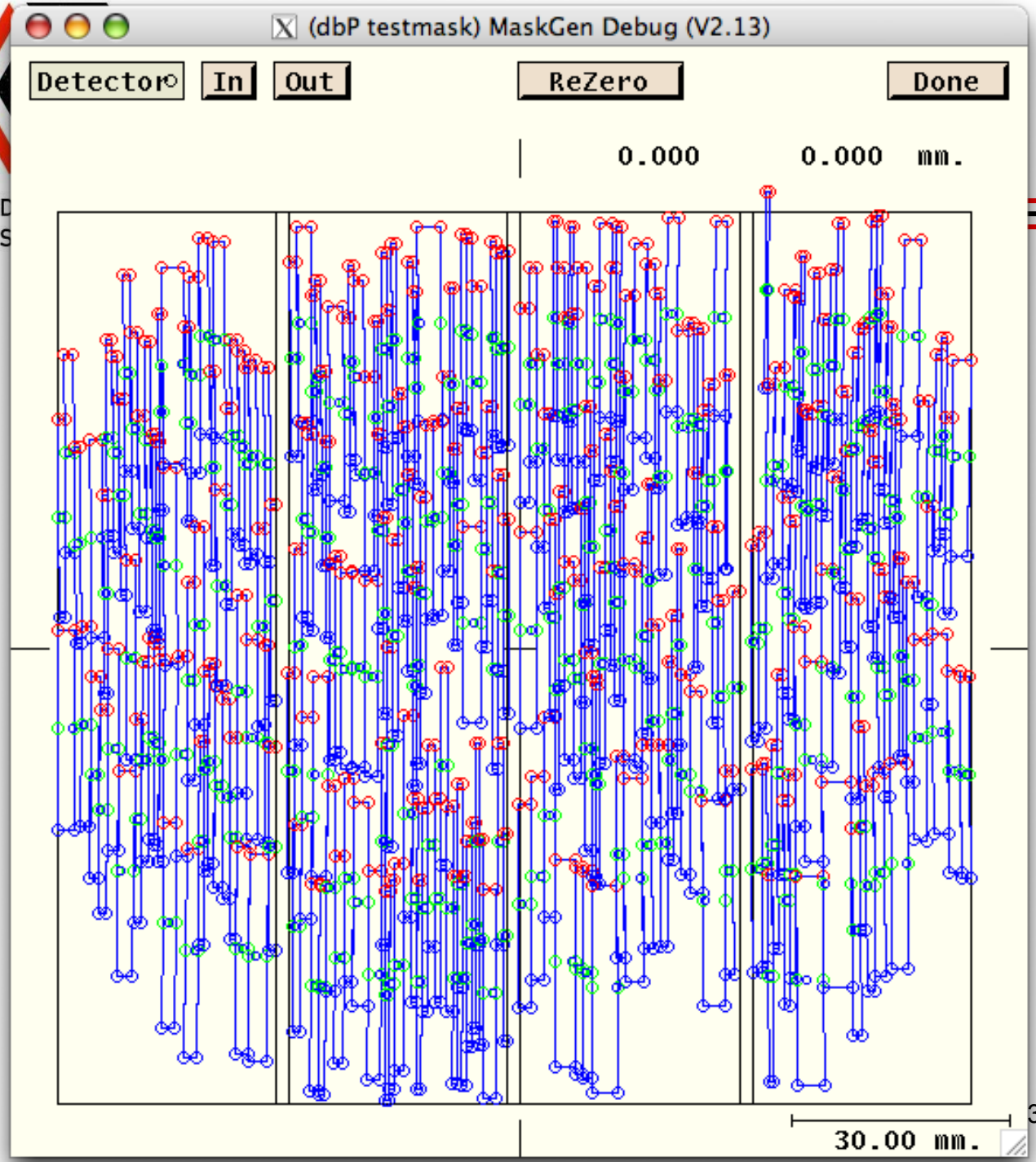
Magellan/IMACS photo-z completeness pilot program (Frieman, Lin, Kessler, & Helsby)





Effectively triple original 4.5 hour integration time of VVDS class = 1, 50% secure redshifts

Demonstrate an increase in completeness of VVDS-Deep sample



300 targets on single IMACS mask

5650-9200 Å, very similar to original VVDS spectral coverage

Poor observing conditions in October 2011, have re-submitted proposal in April for 2012B

Photo-z spectroscopic follow-up: "sample variance"

DARK ENERGY SURVEY

- "Sample variance" issue described by Cunha et al. (2012)
  - Large scale structure fluctuations cause uncertainties in training set spectroscopic redshift distributions (in a given photo-z bin): P(zspec | zphot)
  - Important systematic error in weak lensing tomography analysis: causes bias in measured dark energy equation of state parameter *w* and can dominate over statistical error
  - A few deep training set fields are not enough, may require substantial follow-up on 8-10m class telescopes, i.e., > 100 spectrograph fields, to mitigate
  - Begin to address in AAT/AAOmega 2012B program, which plans to obtain DES supernova host and other galaxy redshifts to i ~ 23, spread over 30 deg^2 area of DES supernova fields
  - Plan future proposal for large program on VLT/VIMOS and other telescopes
    - Detailed strategy to be worked out, with simulations, plus synergy with completeness follow-up and cross correlations

Bias in *w* due to photo-z's

DARK ENERGY SURVEY

Ratio of bias in w (from photo-z's) to statistical error in w

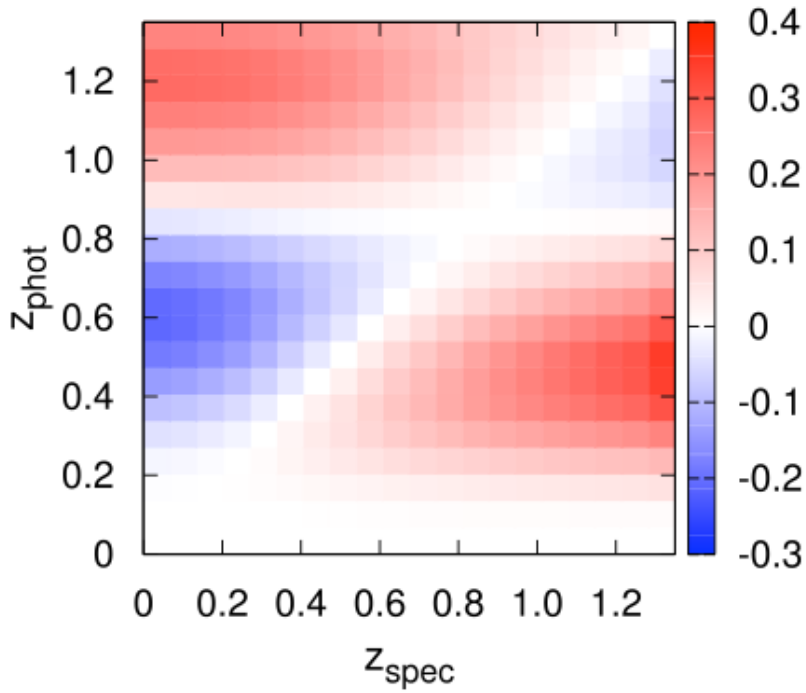


Figure 5. Bias/error ratio in the dark energy equation of state, $\delta w/\sigma(w)$, for a fixed contamination of 0.01 as a function of position in $z_p - z_s$ space.

From Cunha et al. (2012)

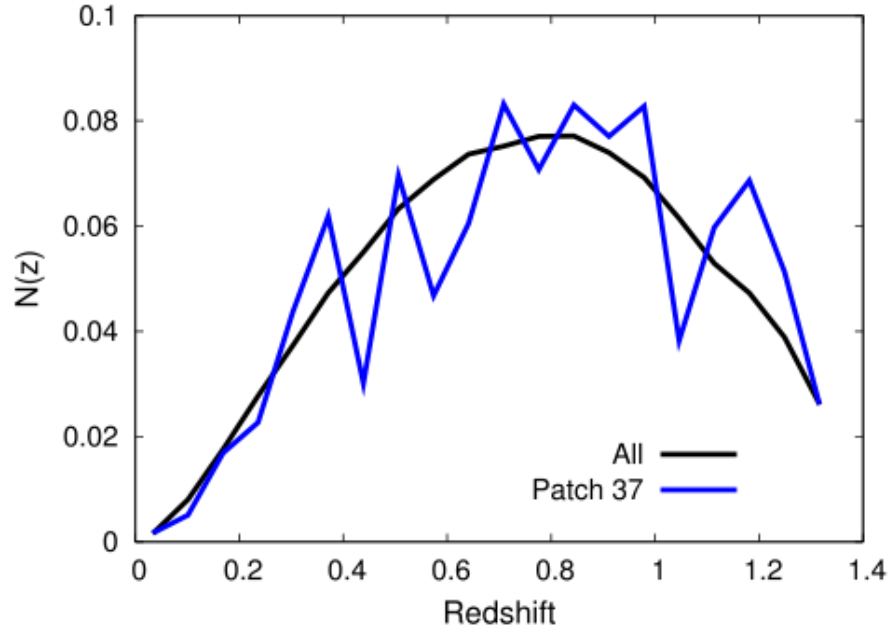
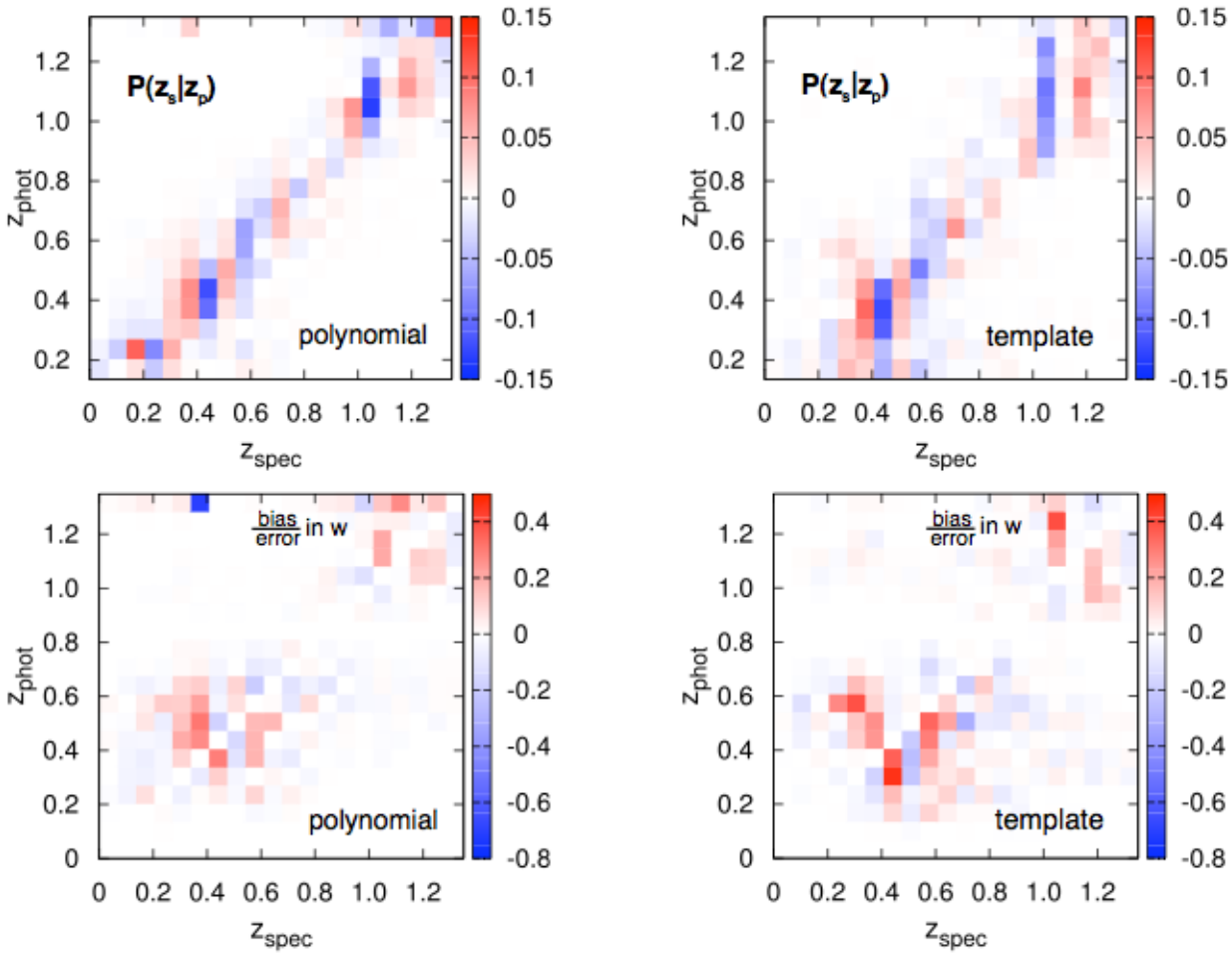


Figure 6. spectroscopic redshift distribution of the whole survey (i.e. the photometric sample), $N(z_s)^{\rm phot}$, in black, and of Patch 37, $N(z_s)^{\rm p37}$, shown in blue.

Bias in *w* due to photo-z's (cont'd)

DARK ENERGY SURVEY

From Cunha et al. (2012)



Difference in P(zs|zp) between training and full samples

Resulting bias-to-error ratio in w

Figure 7. Biases in Patch 37. The top-row panels shows the difference of $P(z_s|z_p)$ for the photometric and calibration samples for the polynomial (top left panel) and template (top right panel) method. The bottom-row panels show the corresponding contribution to bias/error ratio in the dark energy equation of state w due to photometric redshift errors in each z_s, z_p bin. The fractional biases in w shown in the bottom row panels are equal to the product of the photometric redshifts errors (shown in the top row panels) and the sensitivity to a fixed photometric redshift (shown in Fig. 5).

DARK ENERG
SURVEY

Bias in w

6 deg^2		LSS		Random		
Technique	$\overline{\delta w/\sigma(w)}$	σ_{68}	$\Delta\chi^2_{\rm med}$	$\overline{\delta w/\sigma(w)}$	σ_{68}	$\Delta\chi^2_{\rm med}$
Template	0.04	2.56	3.14	0.04	0.44	0.14
Polynomial	-0.07	1.53	2.04	-0.04	0.39	0.12
$p(z)_w$	0.05	2.33	2.56	0.07	0.31	0.10
1 deg^2						
Template	-0.04	3.75	7.36	0.01	0.92	0.75
Polynomial	-0.19	2.96	4.74	0.00	0.93	0.64
$p(z)_w$	-0.01	3.99	9.05	0.029	0.78	0.50
1/4 deg^2						
Template	0.03	4.61	16.4	-0.15	1.9	2.9
Polynomial	-0.11	3.99	10.3	-0.17	1.7	2.2
$p(z)_w$	0.07	5.88	32.3	-0.10	2.0	3.0

Table 2. Mean fractional bias in w (i.e. mean of $\delta w/\sigma(w)$) and σ_{68} (i.e. width of the $|\delta w|/\sigma(w)$ distribution) for the different techniques, assuming patches of area 6, 1, 1/4 deg^2 for training and calibration or a random subsample with the same number of galaxies. The $\Delta\chi^2_{\rm med}$ column indicates the median value (among all patches) of $\Delta\chi^2_{\rm tot}$ of the fit over all cosmological parameters; see Eq. (20).

From Cunha et al. (2012)

Sample variance (LSS) causes bias-to-error ratio in w to be > 1 for typical small training set patches

Sample variance requirements from Cunha et al. (2012)

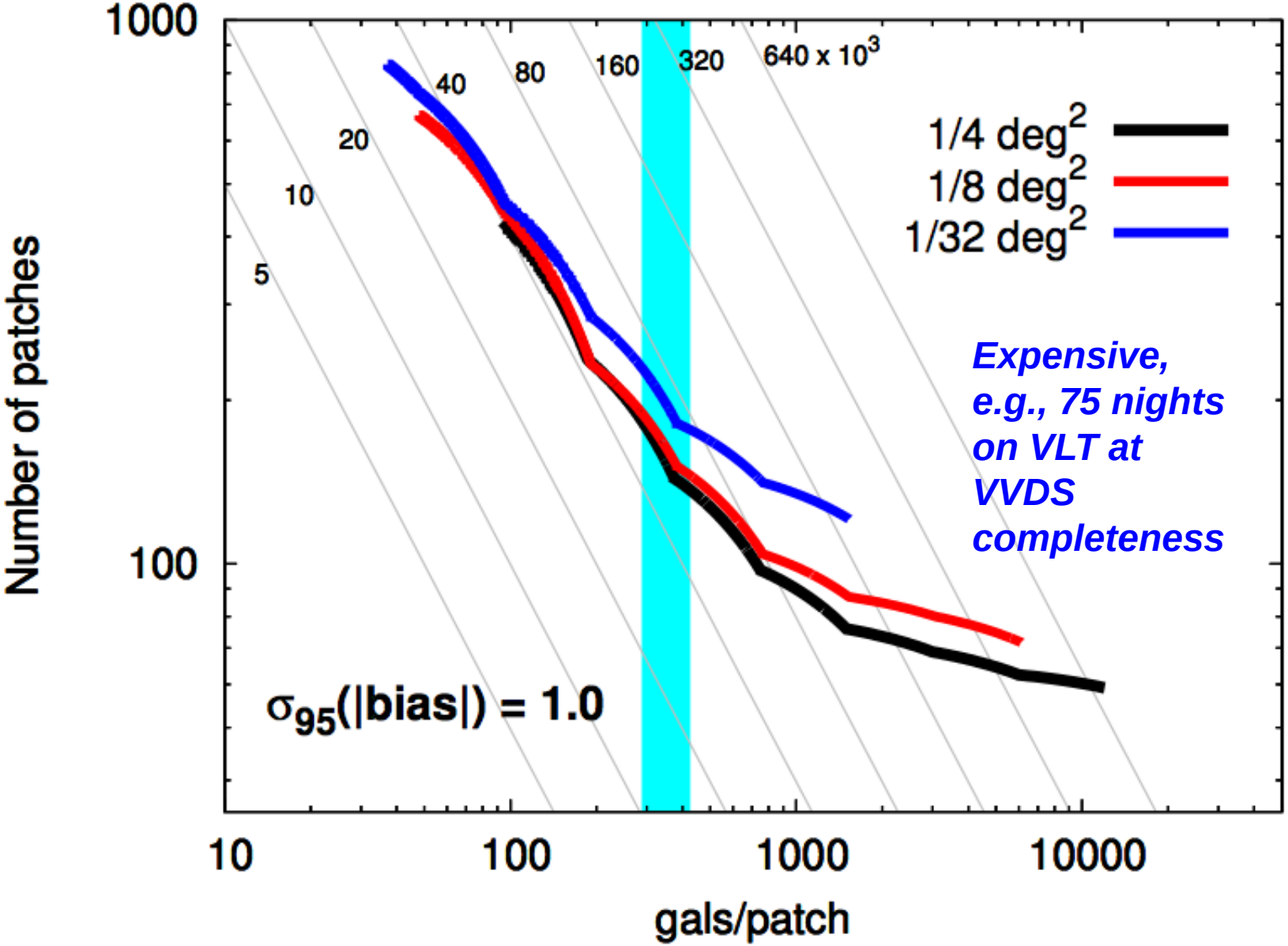
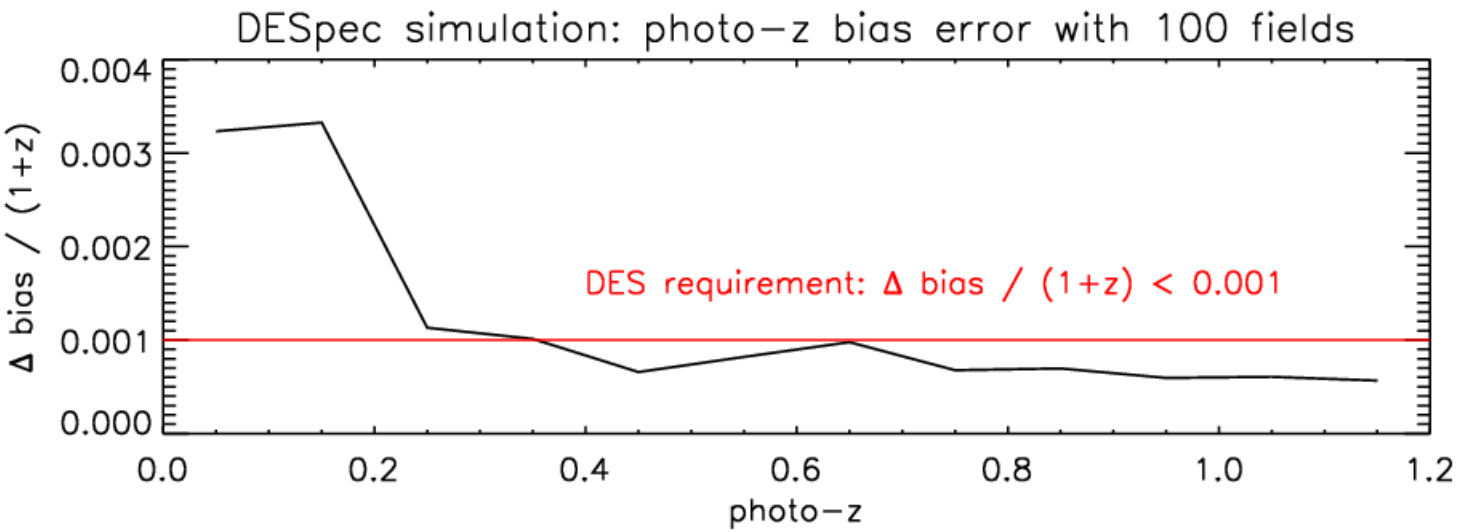
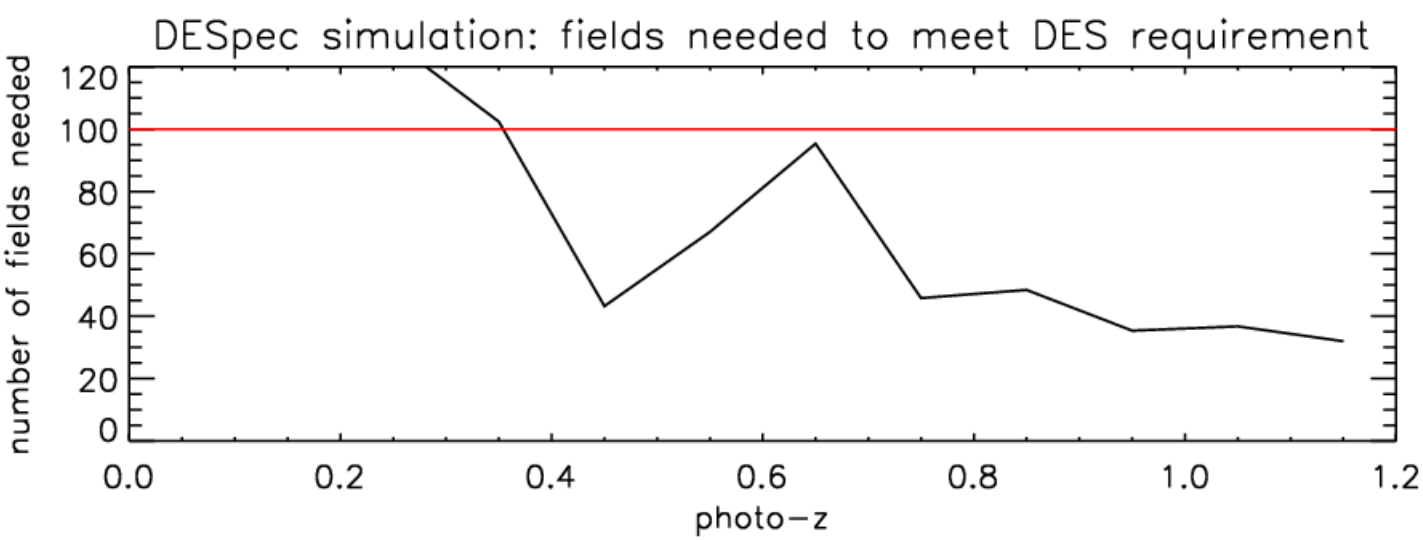


Photo-z bias error for DESpec simulation





Galaxies and LSS from DES v3.04 mocks (Wechsler, Busha, et al.)

p(z) photo-z's (Cunha et al. 2009)

4000 fibers per DESpec field

DARK ENEF
SURVEY

Bias in w (with $P(z_p\|z_s)$)					
6 deg^2					
Technique	Mean	σ_{68}	$\Delta\chi^2_{\rm med}$	$R(\sigma_{68})$	$R(\Delta\chi^2_{\rm med})$
Template	-0.06	0.52	0.36	0.20	0.11
Polynomial	-0.13	0.87	0.43	0.57	0.21
$p(z)_w$	-0.14	0.52	0.34	0.22	0.13
1 deg^2					
Template	-0.17	1.28	1.39	0.34	0.19
Polynomial	-0.39	1.31	1.69	0.44	0.36
$p(z)_w$	-0.29	0.98	1.14	0.25	0.13

Table 5. Mean and σ_{68} scatter of the fractional bias in w for the different techniques, assuming patches of area 6, 1, 1/4 deg^2 for training and calibration or a random subsample with the same number of galaxies. The $\Delta\chi^2_{\rm med}$ column indicates the median $\Delta\chi^2_{\rm tot}$ of the fit over all cosmological parameters. Results in this Table assume the true redshift distribution of the photometric sample was known, allowing us to use $P(z_p|z_s)$ instead of $P(z_s|z_p)$ as described in the text. The $R(\sigma_{68})$ shows the ratio of the σ_{68} used in this Table, to the corresponding value in Table 2.

From Cunha et al. (2012)

Using Bayes' Theorem

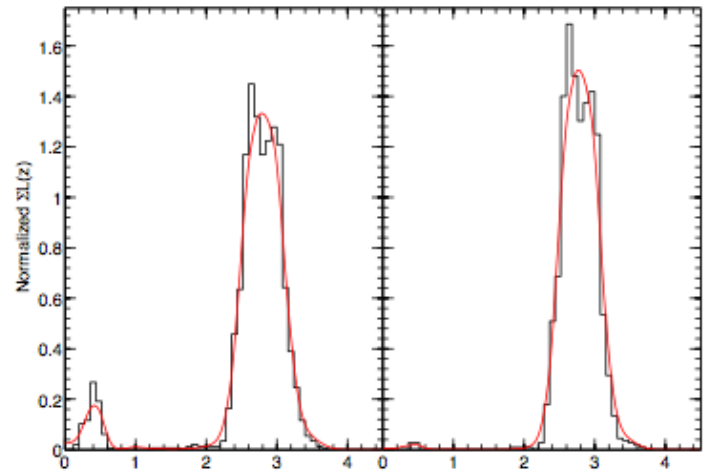
$$P(z_s^i|z_p^j) = P(z_p^j|z_s^i)\frac{N_s^i}{N_p^j}$$

Reduced sensitivity of P(zp|zs) to sample variance may enable relaxed training set follow-up requirements

Photo-z derivation of N(z)

Basic problem: How to get individual p.d.f. $P(z_s|z_p)$ (=L'(z)) from likelihood function $L(z)$)

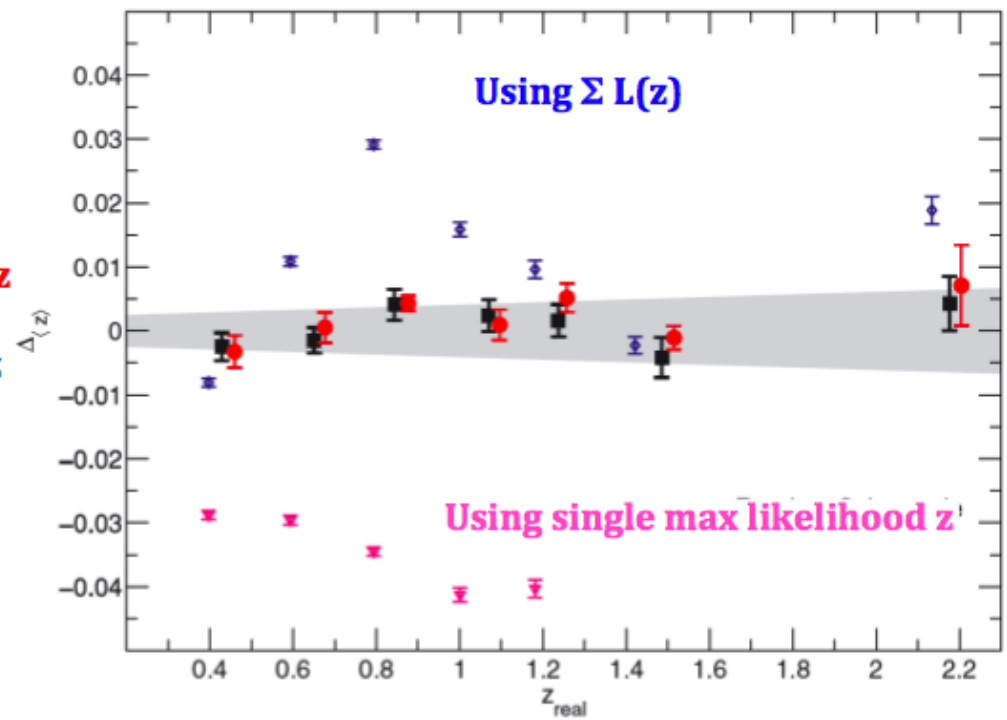
- Use z_{ML} as in bin construction ? ✗
- Use N(z) = Σ L(z) ? ✗
- Use N(z) = Σ L'(z) with modified L'(z) ? ✓



Σ L'(z) based on total of 1000 spec-z in a single field

ΣL'(z) based on total of 1000 spec-z from all 24 fields

Note: Only 1000 calibrating z_{spec} and Cosmic Variance not a problem



Slide from S. Lilly; see Bordoloi et al. (2010)

Photo-z spectroscopic follow-up: angular cross correlations

DARK ENERGY SURVEY

- **Angular cross correlations (e.g., Matthews & Newman 2010) between spectroscopic and photometric galaxy samples**
  - **Get redshift distributions of galaxies fainter than easily accessible via spectroscopy, in particular to DES limit i = 24**
  - **Advantage that bright and even incomplete spectroscopic training sets are useful**
  - **Investigating performance of this technique (Helsby et al., in prep.) using DES mock galaxy catalogs to optimize follow-up scenarios *(see Jen Helsby talk)***
  - **Combine redshift distributions from cross correlations to help with sample variance issue**
  - **Will examine both cross correlations and sample variance in submitted 2012B DES spectroscopic follow-up proposals**
    - **AAT/AAOmega proposal: i ~ 23, over 30 deg^2 area of DES supernova fields**
    - **Magellan/IMACS proposal: i < 22.5, with 6 masks spread over 9 deg^2 DES CDFS supernova field**

Conclusions

- DES will use multiple, existing spectroscopic surveys to provide training sets to calibrate photo-z's
  - VVDS-Deep provides photo-z calibrations early on for DES
- DES photo-z spectroscopic follow-up plans focused on issues of
  - Redshift completeness
  - Sample variance
  - Cross correlations
- Have submitted small-scale 2012B proposals to Magellan and AAT
- Detailed strategy for larger-scale proposals are being developed and optimized in context of photo-z, SN, and other science
- DESpec can provide training sets over large areas of sky and help mitigate sample variance/large scale structure issues for DES photo-z calibrations