



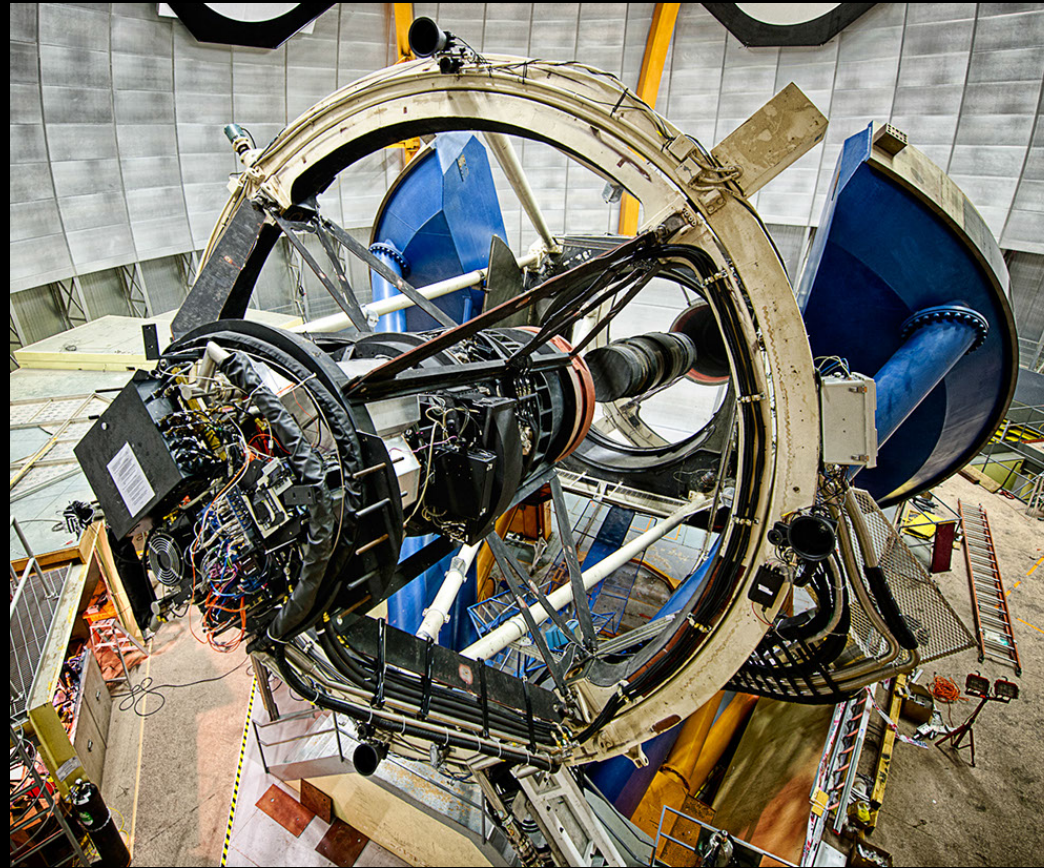
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Photometric Redshift Calibration of the Dark Energy Survey

Huan Lin, Fermilab

The Dark Energy Survey

- Survey project using 4 complementary techniques:
 - I. Cluster Counts
 - II. Weak Lensing
 - III. Large-scale Structure
 - IV. Supernovae
- Two multiband imaging surveys:
 - 5000 deg² *grizY* to 24th mag
 - 30 deg² time-domain *griz* (SNe)
- New 3 deg² FOV, 570 Megapixel camera on the Blanco 4m
 - Survey 2013-2018 (525 nights)
 - Premiere facility instrument for astronomy community



DECam on the Blanco 4m at CTIO



DES photometric redshifts

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- **DES will rely on photometric redshifts (photo-z's), i.e., redshifts determined from photometric imaging data, in primarily the 5 DES filters grizY (plus u band and near-IR JHK as available)**
- **Photo-z's are needed for both the 5000 deg² DES main survey area, as well as the deeper 30 deg² DES supernova (SN) survey area**
- **Well understood photo-z's and photo-z errors are vital for deriving accurate cosmology constraints from the different DES dark energy probes**
- **Large and deep samples of galaxies with spectroscopic redshifts, combined with DES photometry, are used to train and calibrate DES photo-z measurements**



DES Science Verification (SV) spectroscopic redshift training set fields

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- ugrizY imaging was obtained during DES Science Verification (SV; Nov 2012 – Feb 2013) on 4 fields with deep spectroscopic redshift training set data
- **VVDS Deep 02hr** (in DES supernova X3 deep field)
 - VVDS Deep redshift sample to $I_{AB} < 24$
- **CDFS** (in DES supernova C3 deep field)
 - VVDS Deep redshift sample to $I_{AB} < 24$
 - ACES redshift sample to $i < \approx 23$
 - OzDES Deep redshift sample to $i < 21$
- **VVDS Wide 14hr**
 - VVDS Wide redshift sample to $I_{AB} < 22.5$
- **COSMOS** (courtesy of DECam community program, PI A. Dey)
 - zCOSMOS Bright redshift sample to $I_{AB} < 22.5$
 - VVDS Wide 10hr redshift sample to $I_{AB} < 22.5$
- Plus additional bright redshift samples in above fields from **SDSS-I/II, SDSS-III/BOSS, and 2dFGRS**



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*DECam focal
plane shown
by g,r,i color
composite,
coadded
image of DES
supernova X3
deep field
taken during
science
verification*

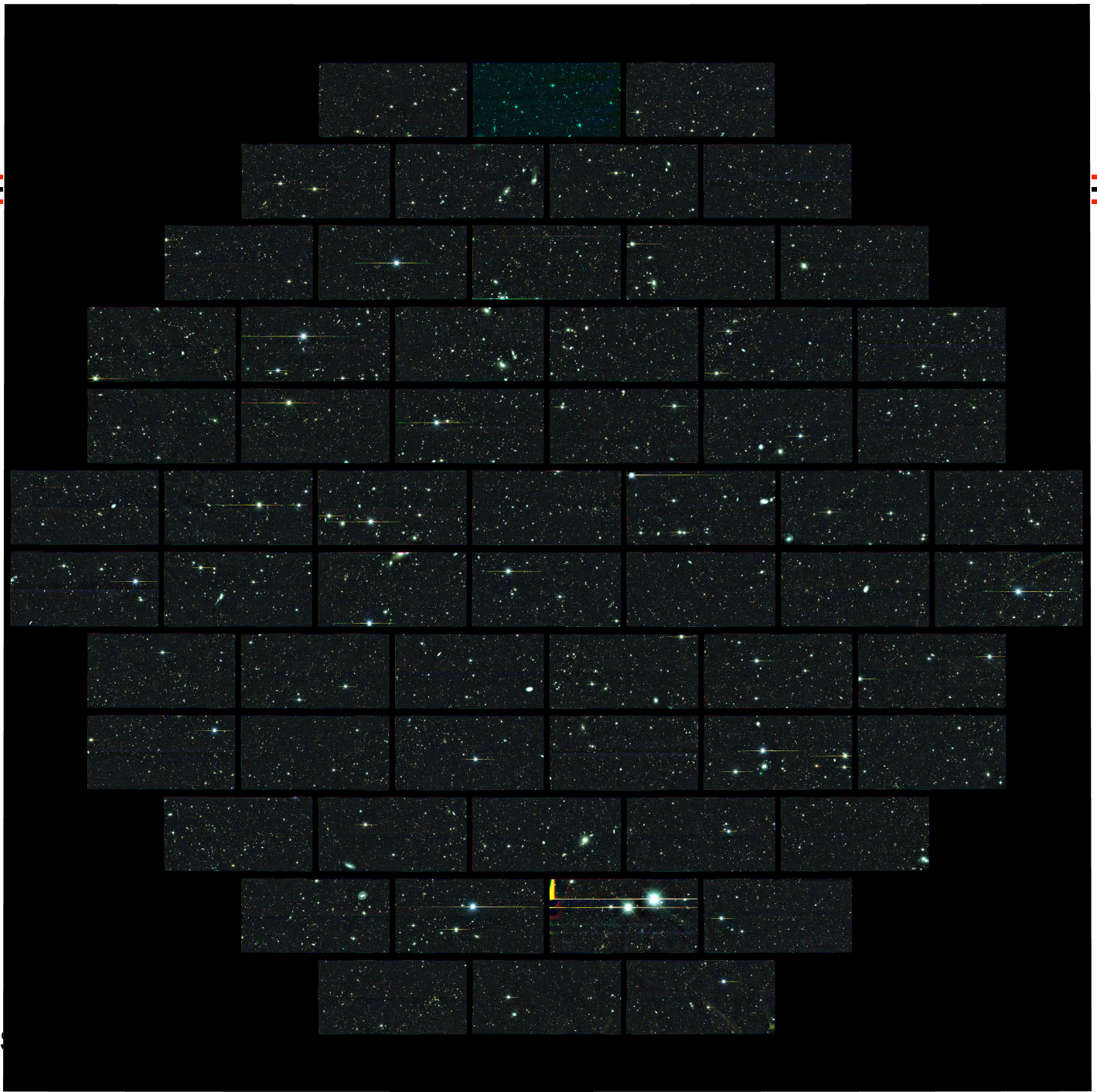




Photo-z comparison tests on DES SV data: Standardized redshift samples

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- **Goal to compare, test, and optimize photo-z codes used in the DES Photo-z Working Group**
- **“Standardized” training and validation galaxy redshift data sets assembled for use by all codes**
 - **“Main”**: DES main survey depth photometry
 - **5859 (training set) + 6381 (validation set) high-confidence redshifts**
 - **“Deep”**: typically 3x exposure of single supernova deep field visit
 - **7249 (training set) + 8358 (validation set) high-confidence redshifts**
- **Standardized set of DECam system throughput curves also assembled for use**



Photo-z comparison tests on DES SV data: Comparison test metrics

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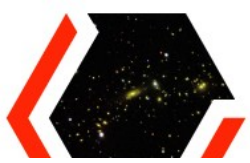
- **Comparison tests of photo-z codes based on a set of metrics, primarily the following (with DES science requirements in parentheses):**
 - **Mean bias $z(\text{phot}) - z(\text{spec})$**
 - **Scatter σ and σ_{68} (< 0.12)**
 - **2σ ($< 10\%$) and 3σ ($< 1.5\%$) outlier fractions**
 - **Bias and σ of $z(\text{phot}) - z(\text{spec})$ normalized by the photo-z error**
 - **N_{Poisson} : rms difference between photo-z and true z distributions, normalized by Poisson fluctuations**
- **Metrics applied after culling 10% of galaxies in each method with largest photo-z errors, per science requirements**
- **Metrics also weighted to account for incompleteness of redshift samples, in order to be appropriate for an $i < 24$ DES galaxy sample**



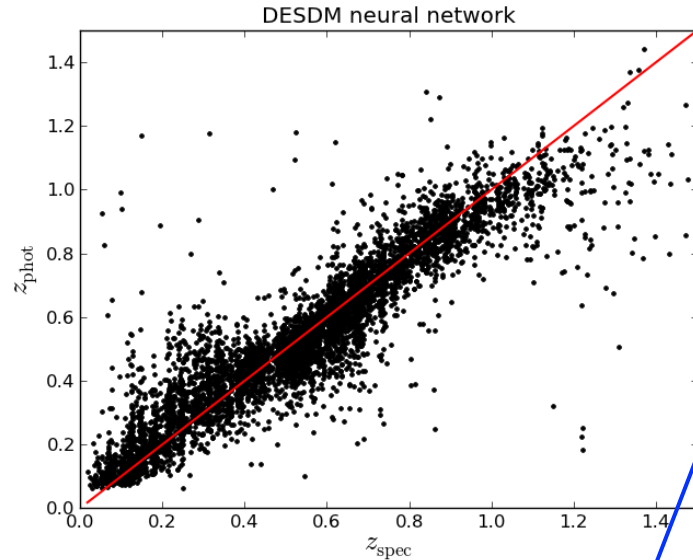
Photo-z comparison tests on DES SV data: Photo-z codes

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- **19 different entries have been submitted from within the DES Photo-z Working Group**
- **3 broad categories of methods**
 - **Training-based methods: e.g., ANNz, TPZ**
 - **Template-fitting methods: e.g., BPZ, LePhare, HyperZ, ZEBRA, EAZY**
 - **P(z) methods: e.g., LePhare P(z), ZEBRA P(z), BPZ P(z), ArborZ**
- **Comparison tests still ongoing and iterating, so following slides will just show preliminary summary results without specific methods named, except for one example method**
- **Results shown are for tests using “Main” sample, using DES main survey depth grizY photometry, though other tests (e.g., “Deep” samples and photometry) are also ongoing**



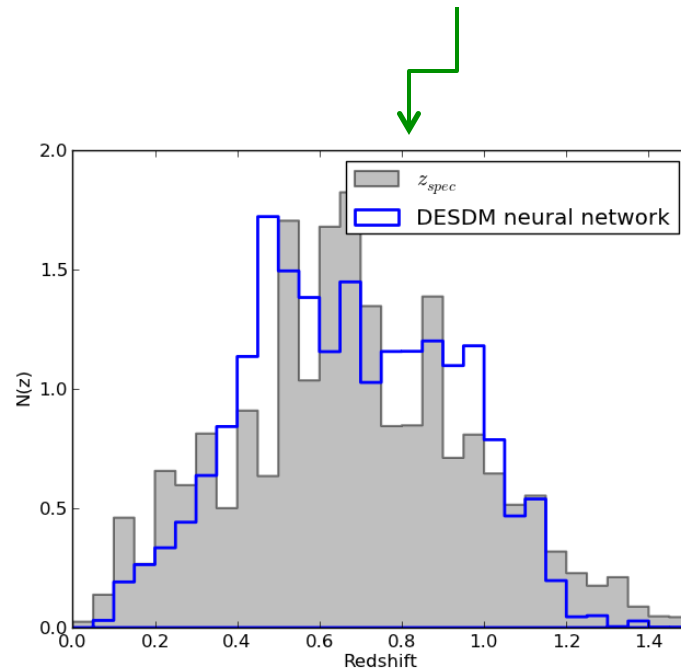
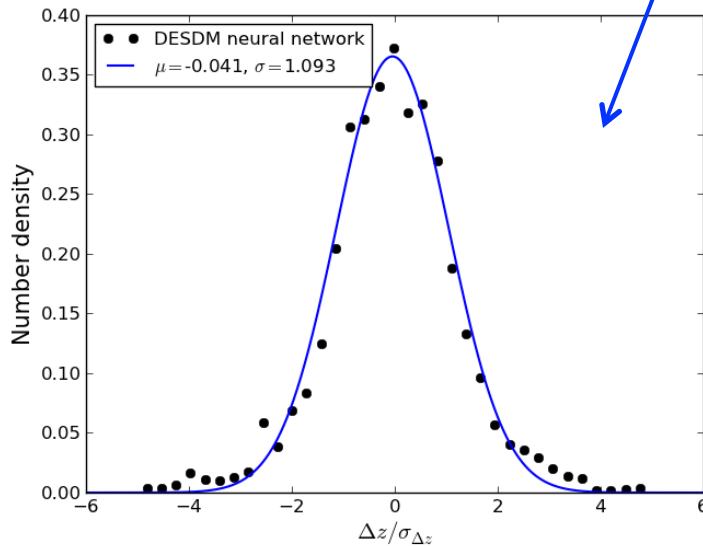
Example photo-z results, for DESDM neural network method



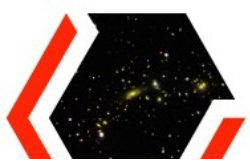
←
Top left: Photo-z vs. spectro-z

Bottom left: Photo-z – spectro-z, normalized by photo-z errors, and Gaussian fit

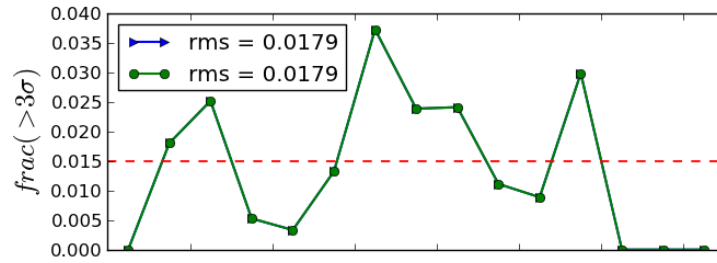
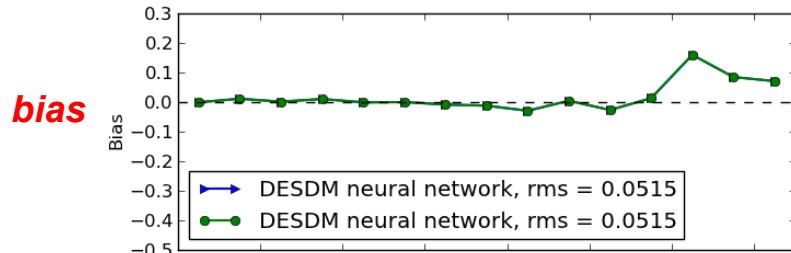
Bottom right: Photo-z redshift distribution compared to true redshift distribution



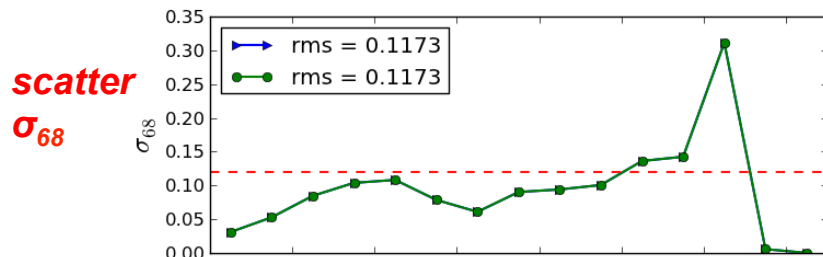
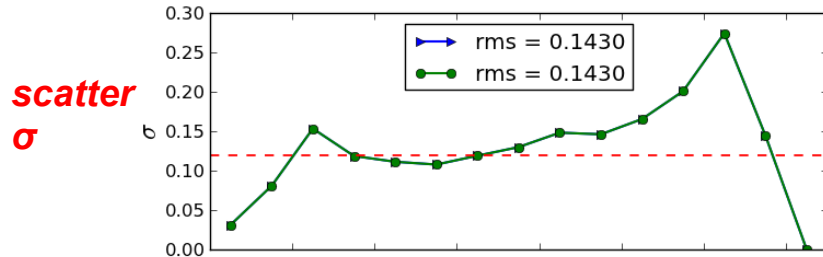
**Plots generated
using Python code
of M. Carrasco**



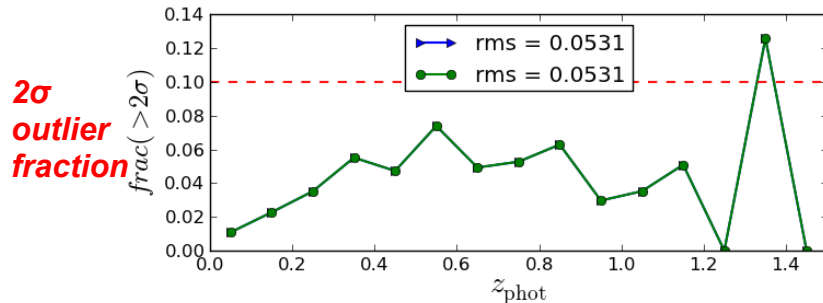
Example photo-z statistics, for DESDM neural network method



**3σ
outlier
fraction**



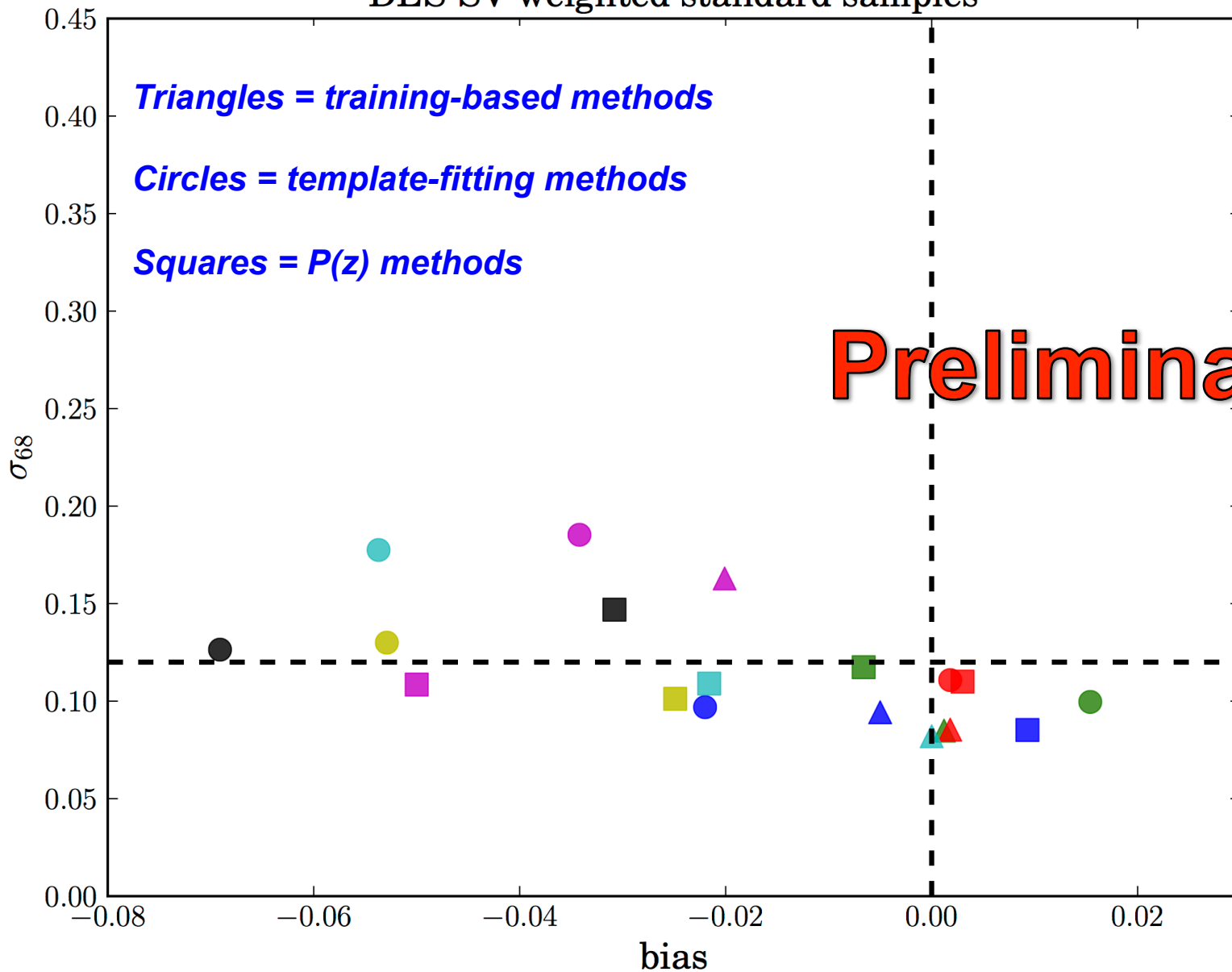
**All statistics plotted vs. photo-z, in
bins of redshift width = 0.1**



**Plots generated
using Python code
of M. Carrasco**

Photo-z scatter σ_{68} vs. mean bias

DES-SV weighted standard samples



*C. Sánchez &
M. Carrasco
for the DES
Photo-z
Working
Group*

3 σ vs. 2 σ outlier fractions

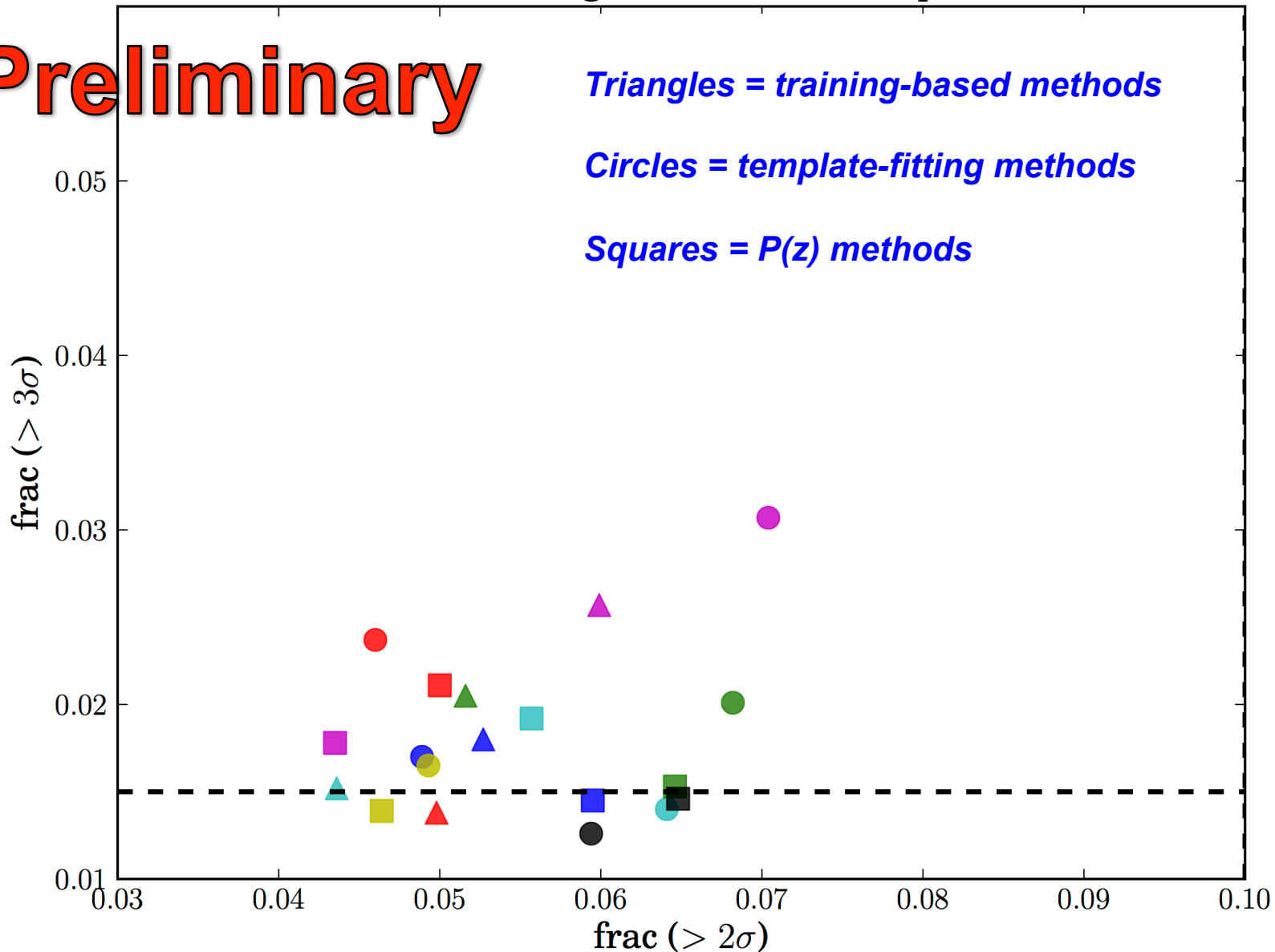
DES-SV weighted standard samples

Preliminary

Triangles = training-based methods

Circles = template-fitting methods

Squares = P(z) methods

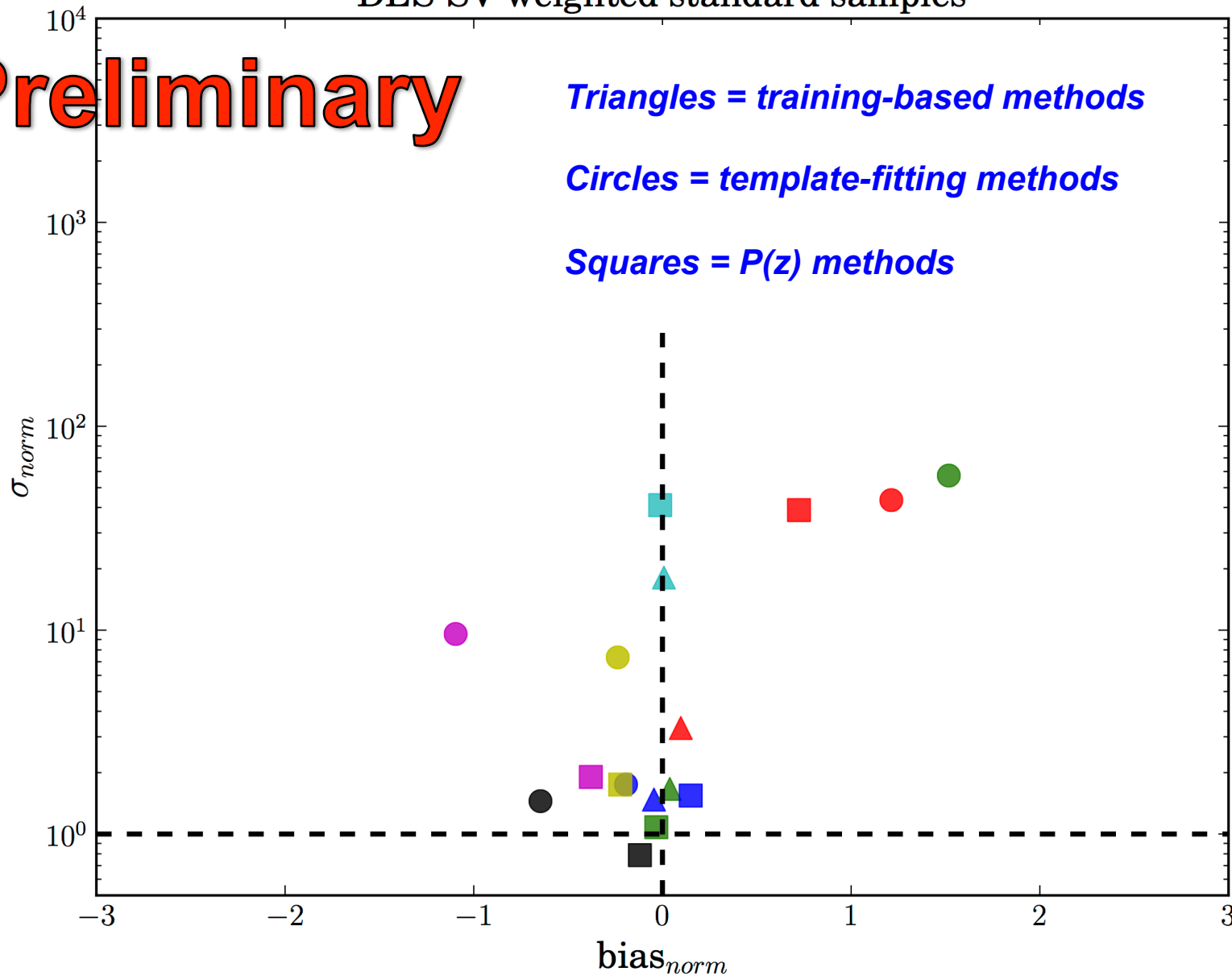


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Error-normalized σ vs. error-normalized bias

DES-SV weighted standard samples

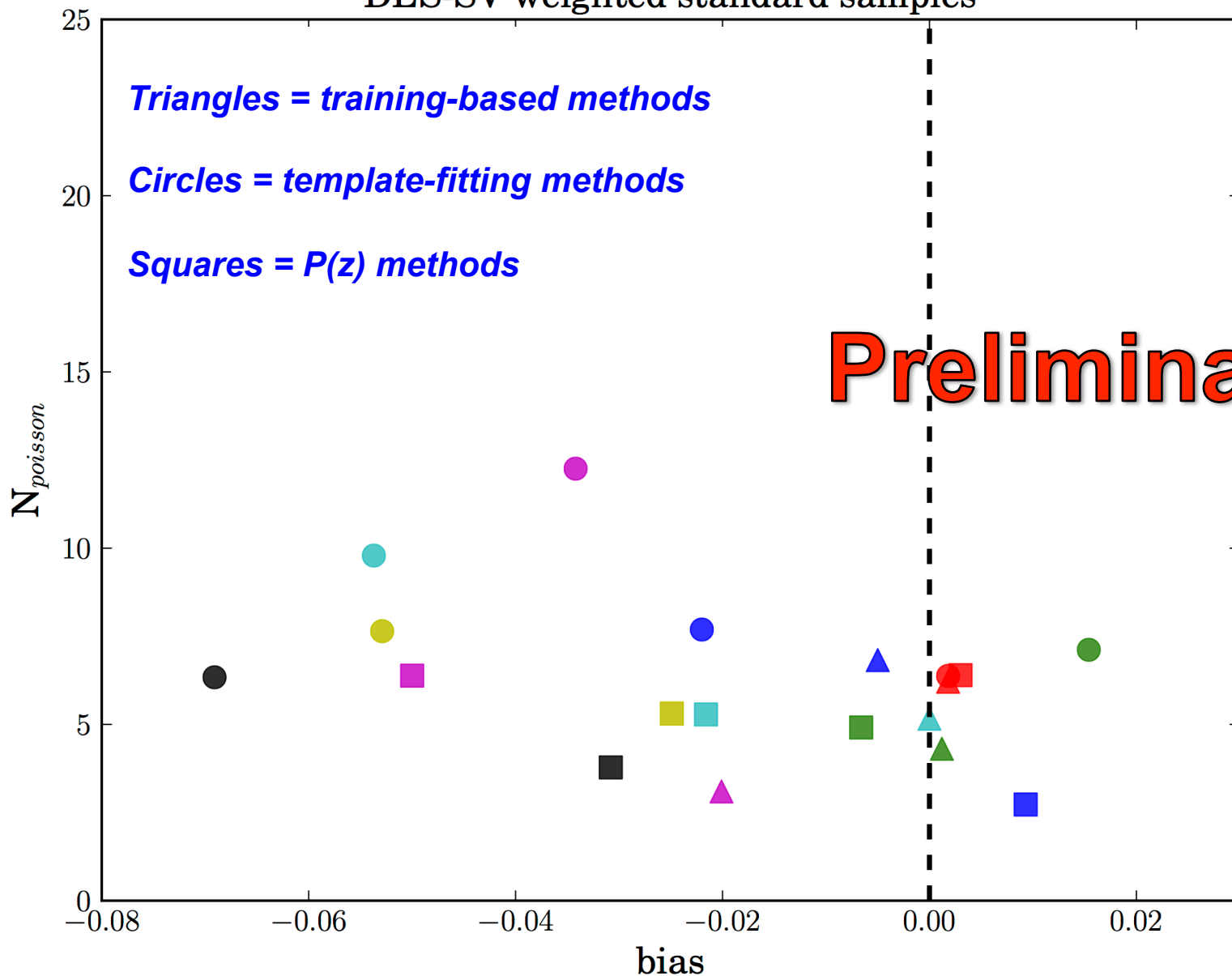
Preliminary



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M. Carrasco
for the DES
Photo-z
Working
Group*

Redshift distribution metric N_{Poisson} vs. mean bias

DES-SV weighted standard samples



*C. Sánchez &
M. Carrasco
for the DES
Photo-z
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Photo-z comparison tests on DES SV data: Summary of preliminary results

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- **Most methods meet DES photo-z scatter requirement $\sigma_{68} < 0.12$**
- **All methods meet requirement that 2σ outlier fraction $< 10\%$, and a few methods also meet 3σ outlier fraction $< 1.5\%$, though most methods are close at $< 2\%$**
- **Nearly all methods underestimate the photo-z error, with most methods within a factor < 2**
- **Performance of training-based methods show more uniformity among entries, compared to template-fitting and $P(z)$ methods**
 - **Further debugging/optimization of some methods needed**



DES photo-z calibrations: next steps

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- **Finish comparison tests of SV data, choose a few optimal methods, and compute photo-z's for full DES SV photometric data set**
- **First DES observing season begins Aug 31, and will cover larger sky areas useful for photo-z calibrations, in particular**
 - **SDSS Stripe 82: much larger area overlap with SDSS-I/II, SDSS-III/BOSS, and eBOSS, enabling cross-correlation techniques to estimate redshift distributions**
 - **Overlap with more deep samples, including VIPERS, DEEP2, CNOC2, WiggleZ**
- **Spectroscopic redshift follow-up programs also in progress or planned, including**
 - **OzDES Deep observations on AAT of 30 deg² DES SN fields, including photo-z targets: magnitude limited $i < 21$ galaxies, LRGs, and ELGs**
 - **Magellan/IMACS pilot program to improve completeness of VVDS Deep sample**
 - **ESO's recent call for public spectroscopic surveys on VLT/VIMOS**
- **Combine optical DES photometry with near-IR VHS photometry to improve photo-z's at redshifts $z \sim 1$ and above**



Conclusions

- **DECam imaging obtained during DES Science Verification (SV) period**
 - **4 fields observed with deep spectroscopic redshift training set data**
 - **Photometry for 15,000 galaxies with high-confidence redshifts for photo-z calibration and testing purposes**
- **Photo-z code comparison and testing project being carried out by DES Photo-z Working Group using this SV data set**
 - **Preliminary results show that codes can meet DES requirements on photo-z scatter and outlier fractions**
 - **Test still ongoing and codes continue to be optimized on the real SV data**
- **Upcoming first season of DES, plus ongoing and planned spectroscopic follow-up observations, will provide data to further improve DES photo-z calibrations**