Building a Photometric Hubble Diagram from DES-SN Data

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SN Classification Workshop
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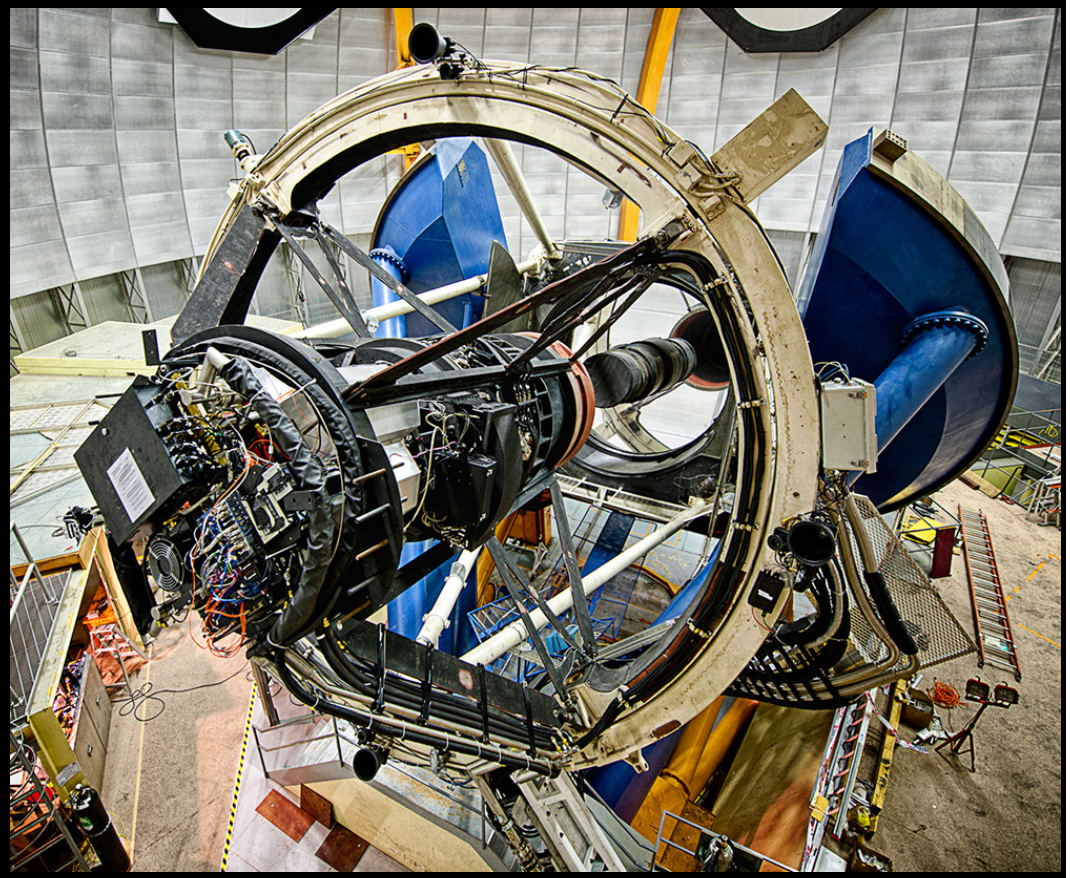
The Dark Energy Survey

- Survey project using 4 complementary techniques:
  I. Cluster Counts
  II. Weak Lensing
  III. Large-scale Structure
  IV. Supernovae
- Two multiband imaging surveys:
  5000 deg^2 *grizY* to 24th mag
  30 deg^2 repeat *griz* (SNe)
- New 3 deg^2 FOV camera on the Blanco 4m telescope
  Survey 2013-2018 (525 nights)
  Facility instrument for astronomy community (DES 30% time)
- Largest optical etendue (FoV x mirror-area)

DECam on the Blanco



www.darkenergysurvey.org
www.darkenergydetectives.org

DES-SN Overview

- Visit each field once per week in griz
- 8 “shallow” fields (24 deg^2), depth ≈ 23.5
- 2 “deep” fields (6 deg^2), depth ≈ 24.5
- Finished three `5-month’ seasons

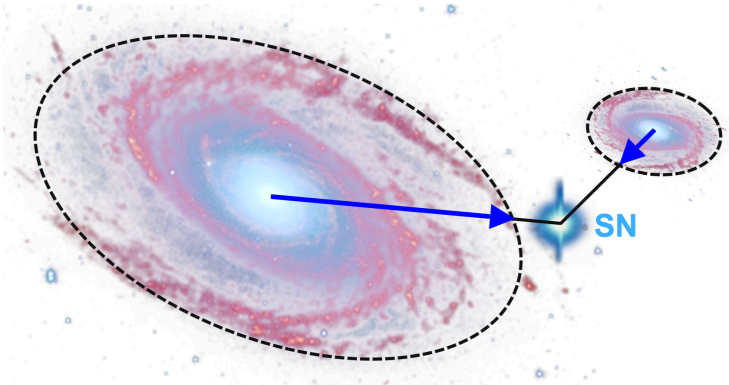
Source of Photometry (Y1+Y2+Y3)

- **Forced Photometry** (PSF-fitted fluxes) from "Difference-Imaging Pipeline" used to discover transients
- Subtracted images from A.Becker's **hotPants**
- Calibration tweaked few percent based on overlap of PS1 supercal (Scolnic et al 2015)
- More refined photometry (Scene-Modeling) in progress, but not ready yet.

Source of Redshifts

- Host Galaxy Spectroscopic redshifts, mostly from OzDES using AAT (Yuan 2015)

- Matching algorithm (D_{LR}) from Gupta et al, 2016 (arXiv:1604.06138)



Simulations

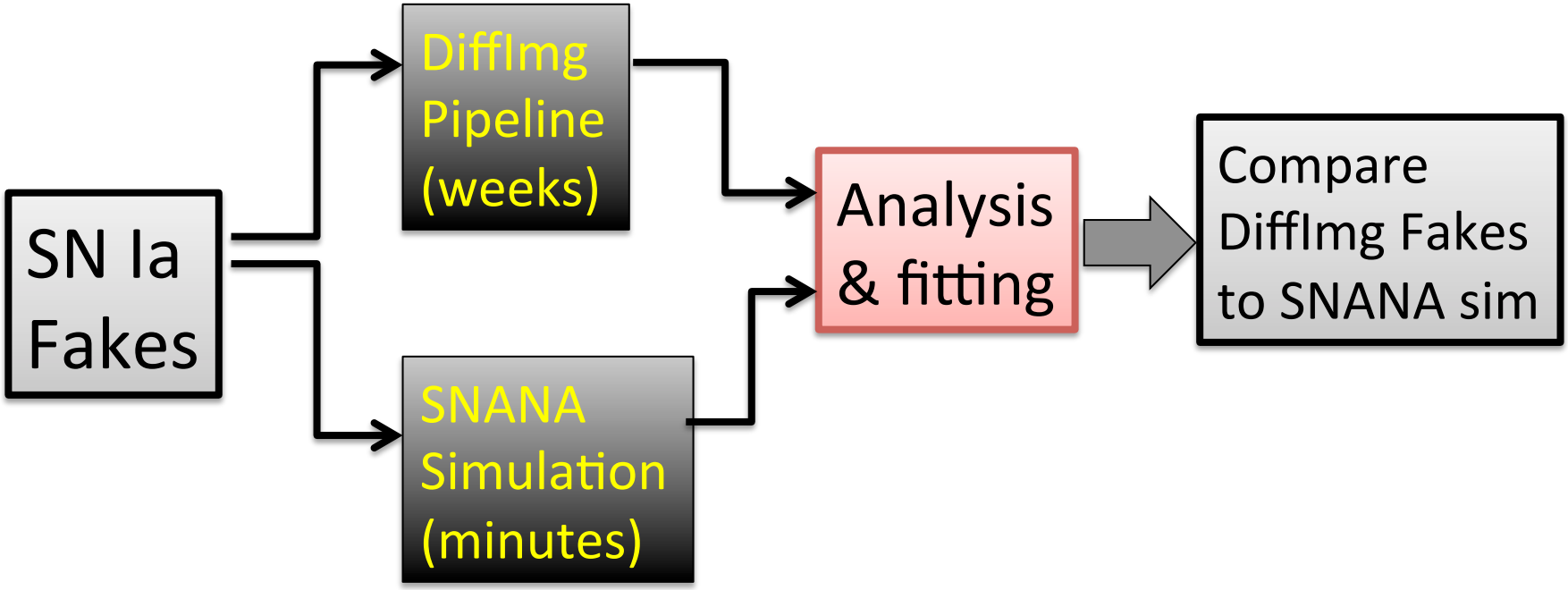
- Classification and HD Fitting make extensive use of SNANA simulations.
- Simulate SNIa with SALT2 model (α_{SIM}=0.14, β_{SIM}=3.20; c,x1 population from SK16) and intrinsic scatter models that include chromatic variations.
- Simulate CC based on 42 templates (from photometric challenge, 2010).

  CC Rate, Ibc/II ratio, and LF from Li 2011.

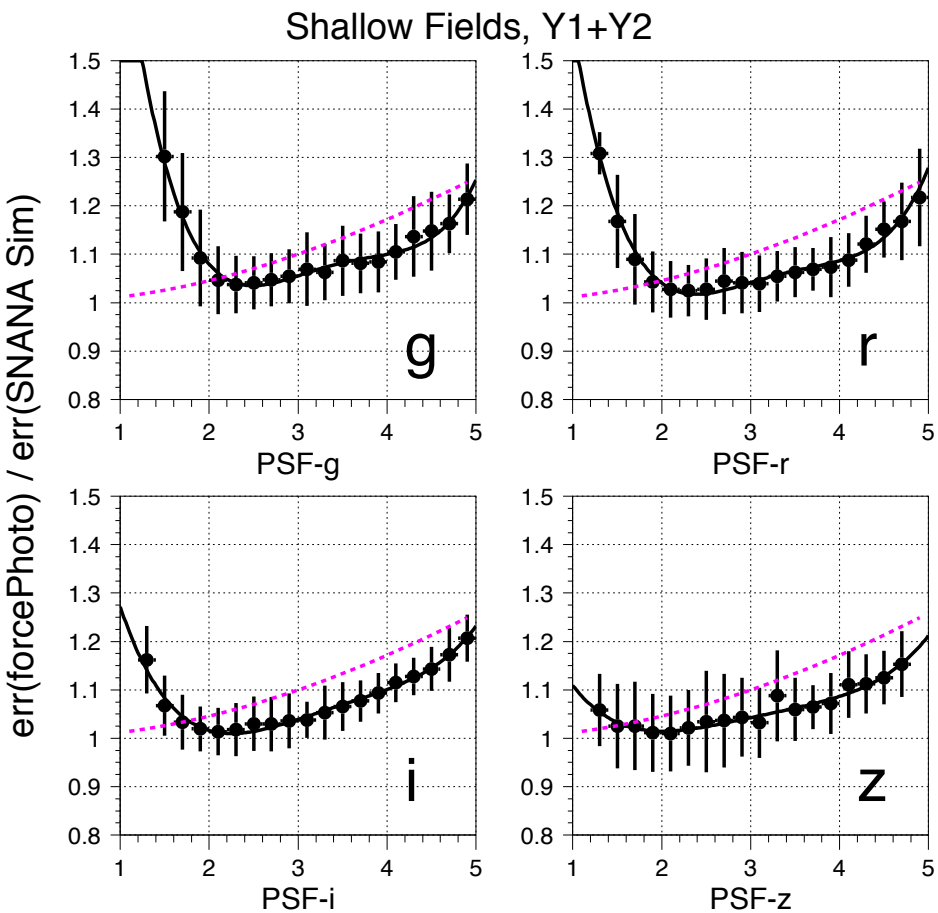
Pre-Analysis Preparation: Analyze Fake SNIa Overlaid on Images

- **Are photometry errors correct ?**
  → Yes, after correcting for surface brightness
  (see Figs 9-10 in arXiv:1507.05137)
- **Does fast SNANA sim reproduce fake SNe ?**
  → yes, after scaling simulated error vs. PSF
  (see Sim-validation slides to follow)

Sim-Validation: Overview



Empirical Flux-Error Adjustment for SNANA sim



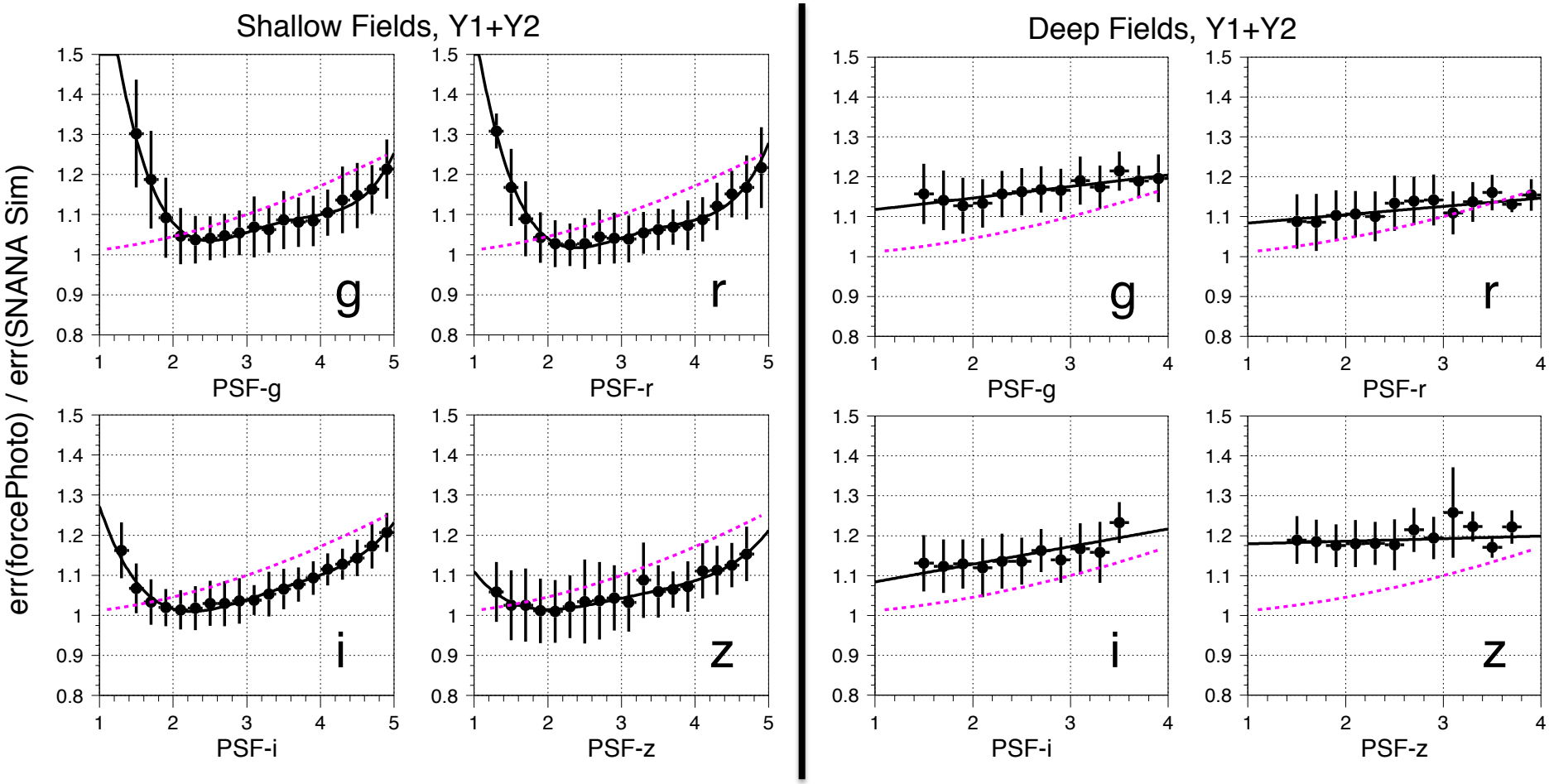
Scale simulated flux-errors by black curves at left.

Purple-dash curve is prediction based on floating background in PSF fit.

forcePhoto-error excess at small-PSF is not understood.

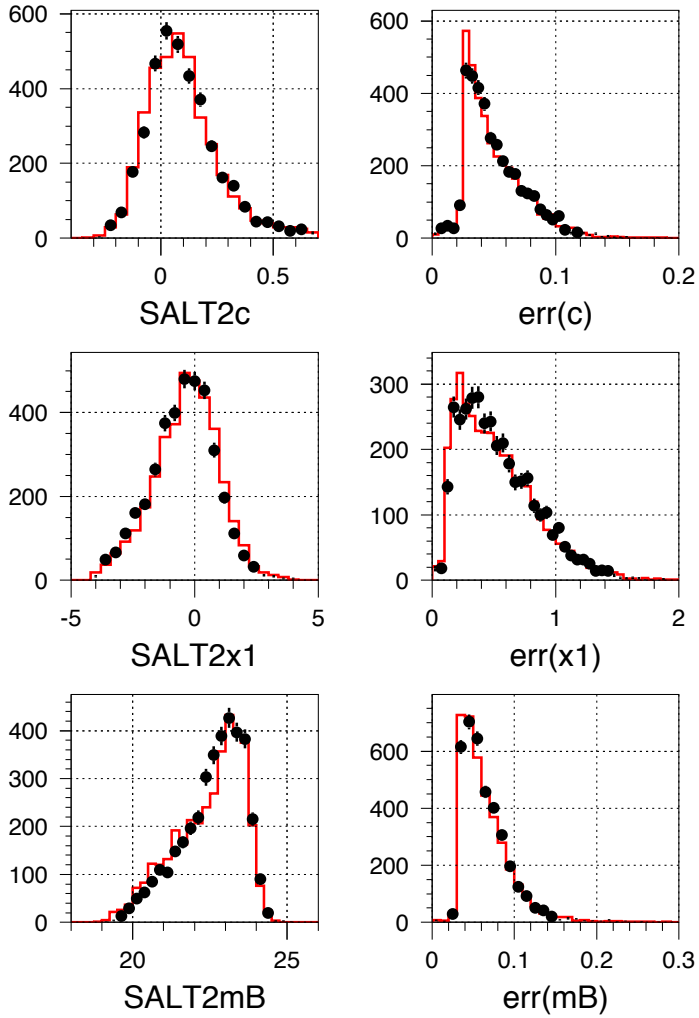
PSF units: sigma, pixels [= 1.6 × PSF(fwhm,arcsec)]

Empirical Flux-Error Adjustment for SNANA sim

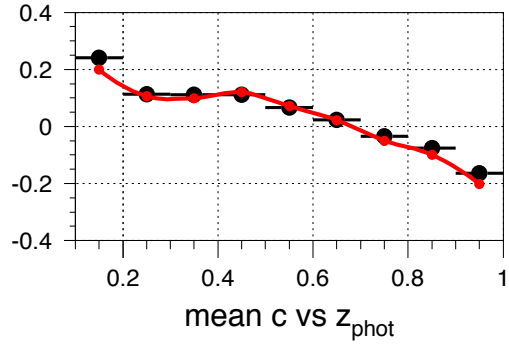


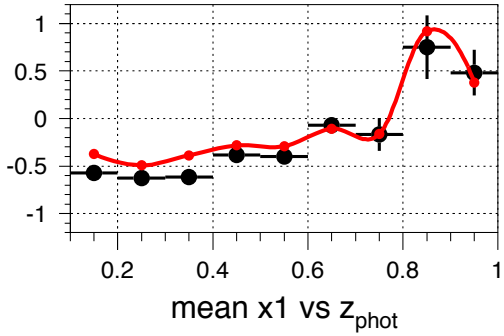
PSF units: sigma, pixels [= 1.6 × PSF(fwhm,arcsec)]

Fake/Sim Overlays of Fitted Params



- Fake SN → DiffImg
- SNANA sim



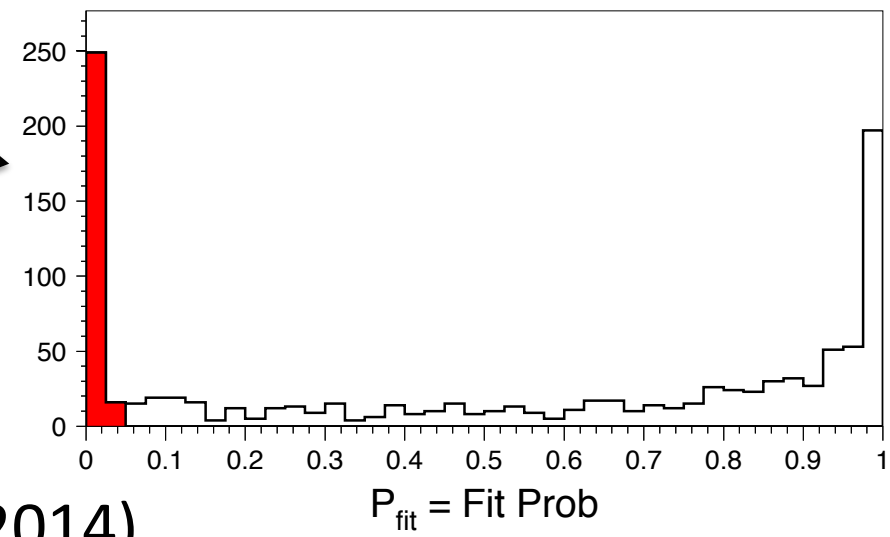


- Done with pre-analysis of fake SN
- Now start real analysis on data

Everything here is Extremely PRELIMINARY !!!

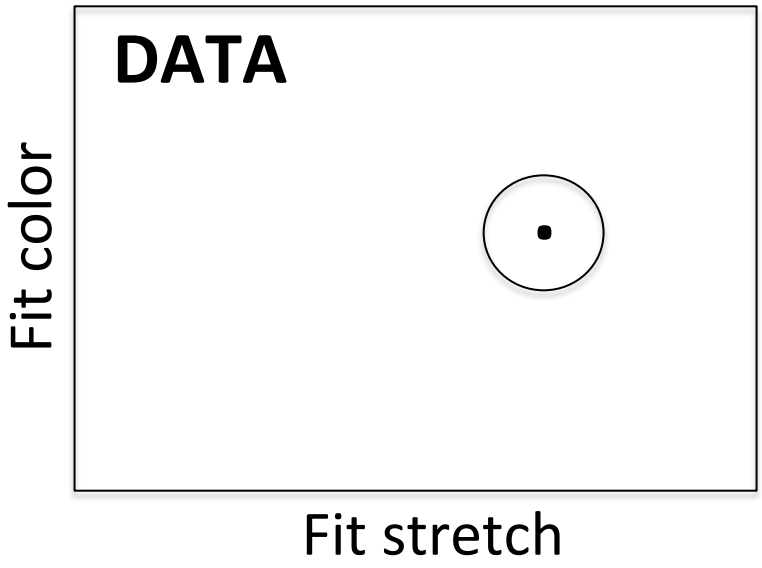
Photometric Selection

- **Box cuts:**
  * 3 bands with obs having SNR>5
  * at least one epoch with Trest < -2
  * at least one epoch with Trest > +10
  * |x1| < 4
  * FitProb > 0.05
    (from SALT2 LC fit)



- **Nearest Neighbor** (Sako 2014)
  P_{Ia} > 0.5 with >1σ significance

Nearest Neighbor (NN):
3D Space of Redshift, Stretch, Color



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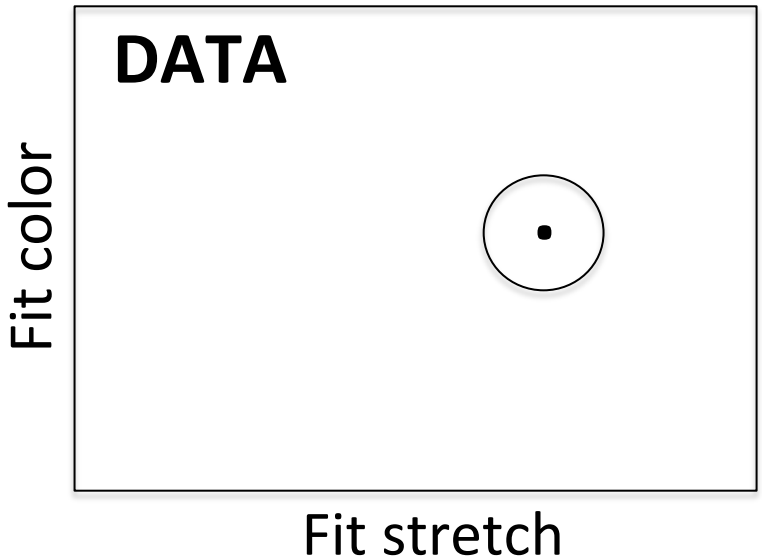
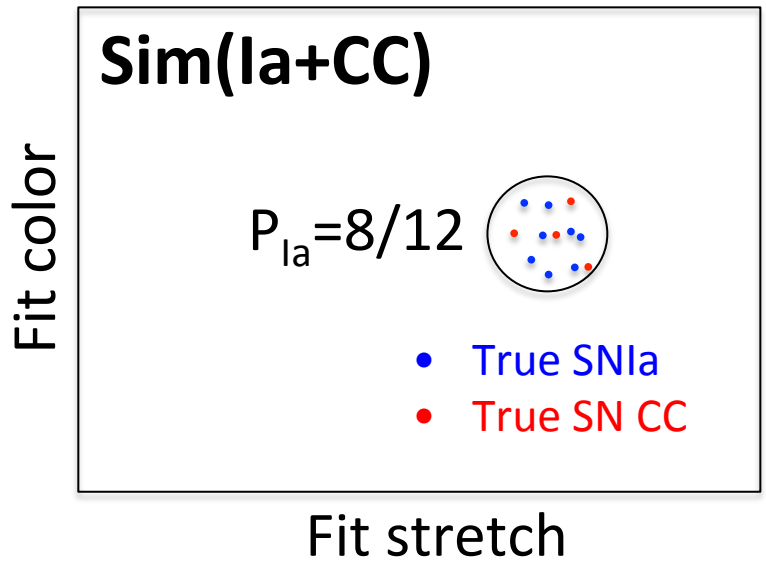




"NN Training" finds optimal radius of 3D sphere by maximizing Eff x Purity.

NN Performance on Simulation:

After box cuts:

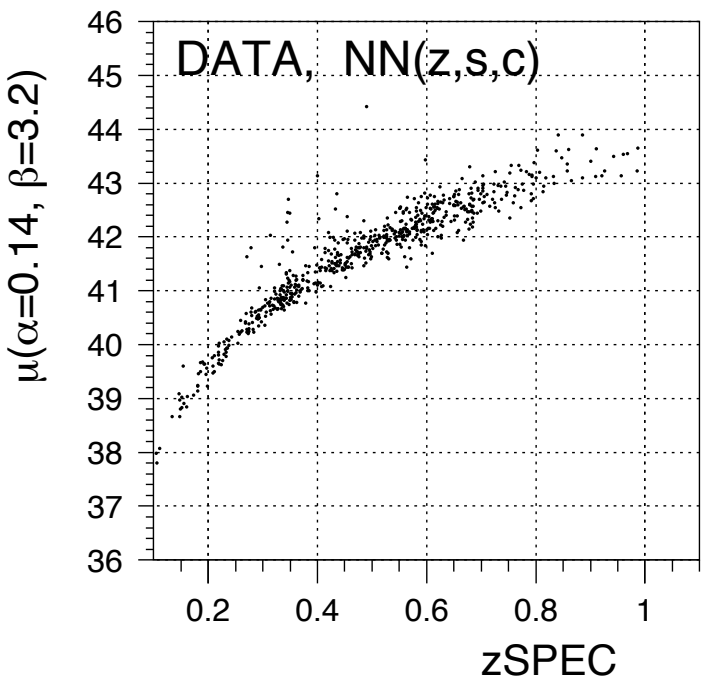
SNIa Purity ≈ 90%

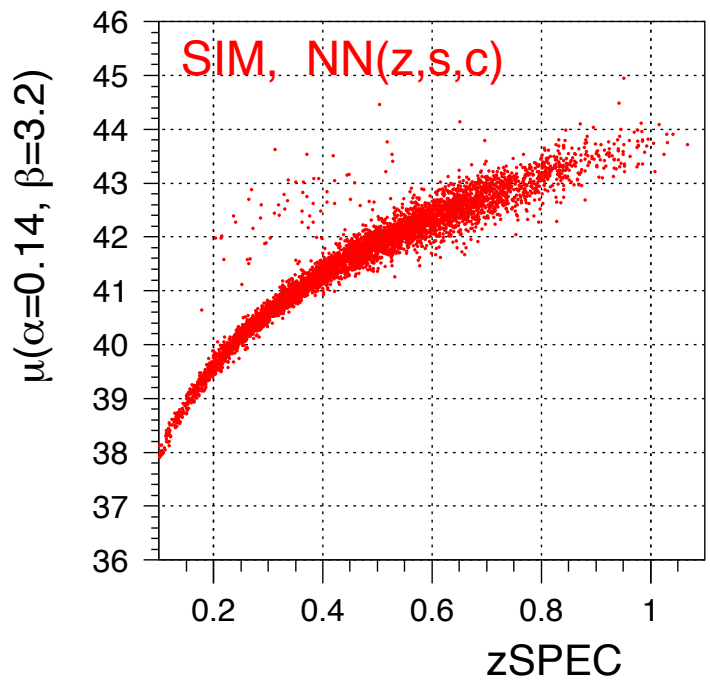
After $P_{NN,Ia} > ½$:

SNIa Purity → 98% with 2% SNIa loss

Data/Sim Comparisons

- Box cuts + $P_{NN,Ia} > ½$
- Sim zHost tuned to match DES data (Eff_{zHOST} not known yet)
- No other sim tuning (except flux-errors to match fakes)

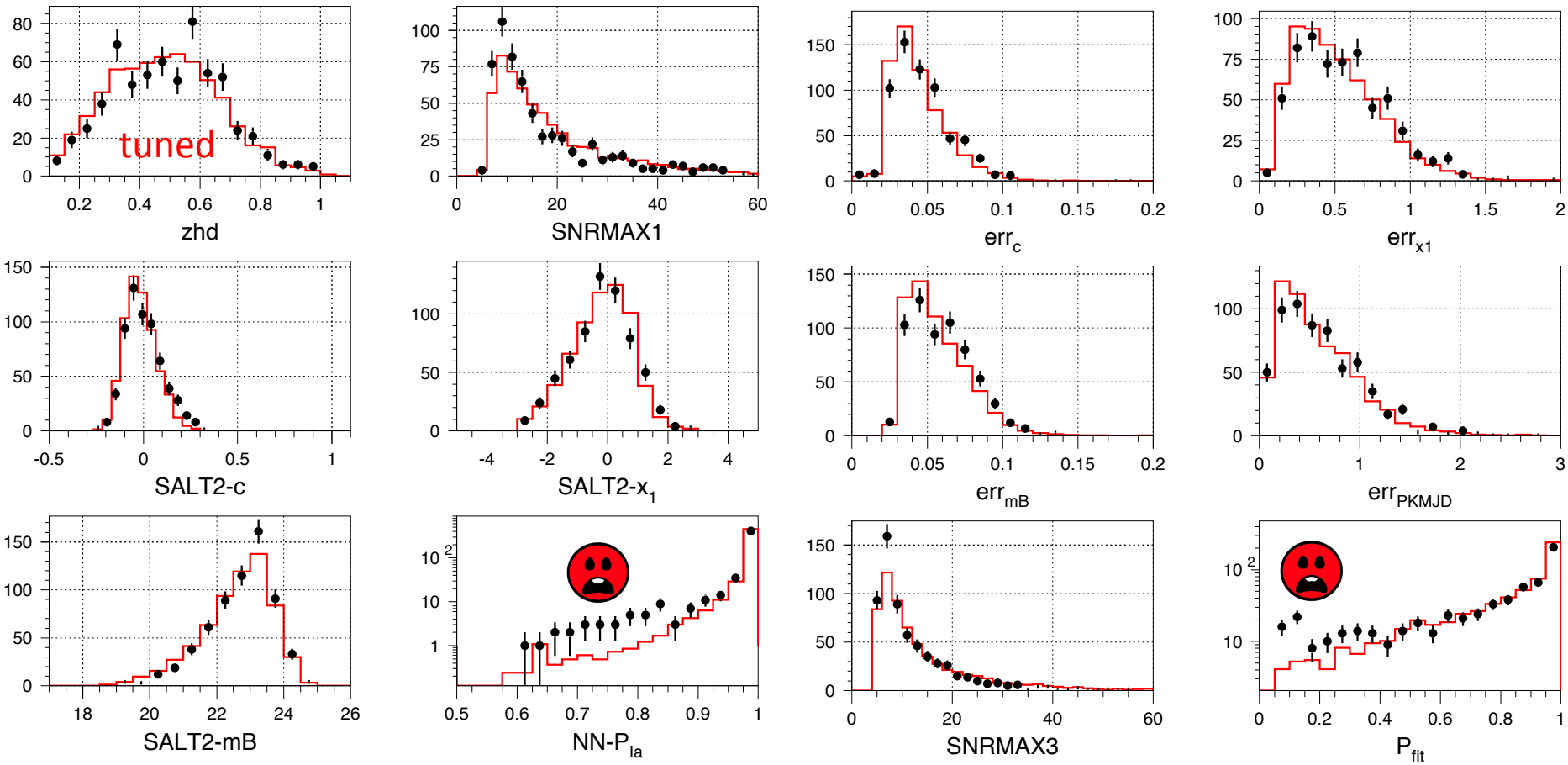




Data/Sim Comparisons

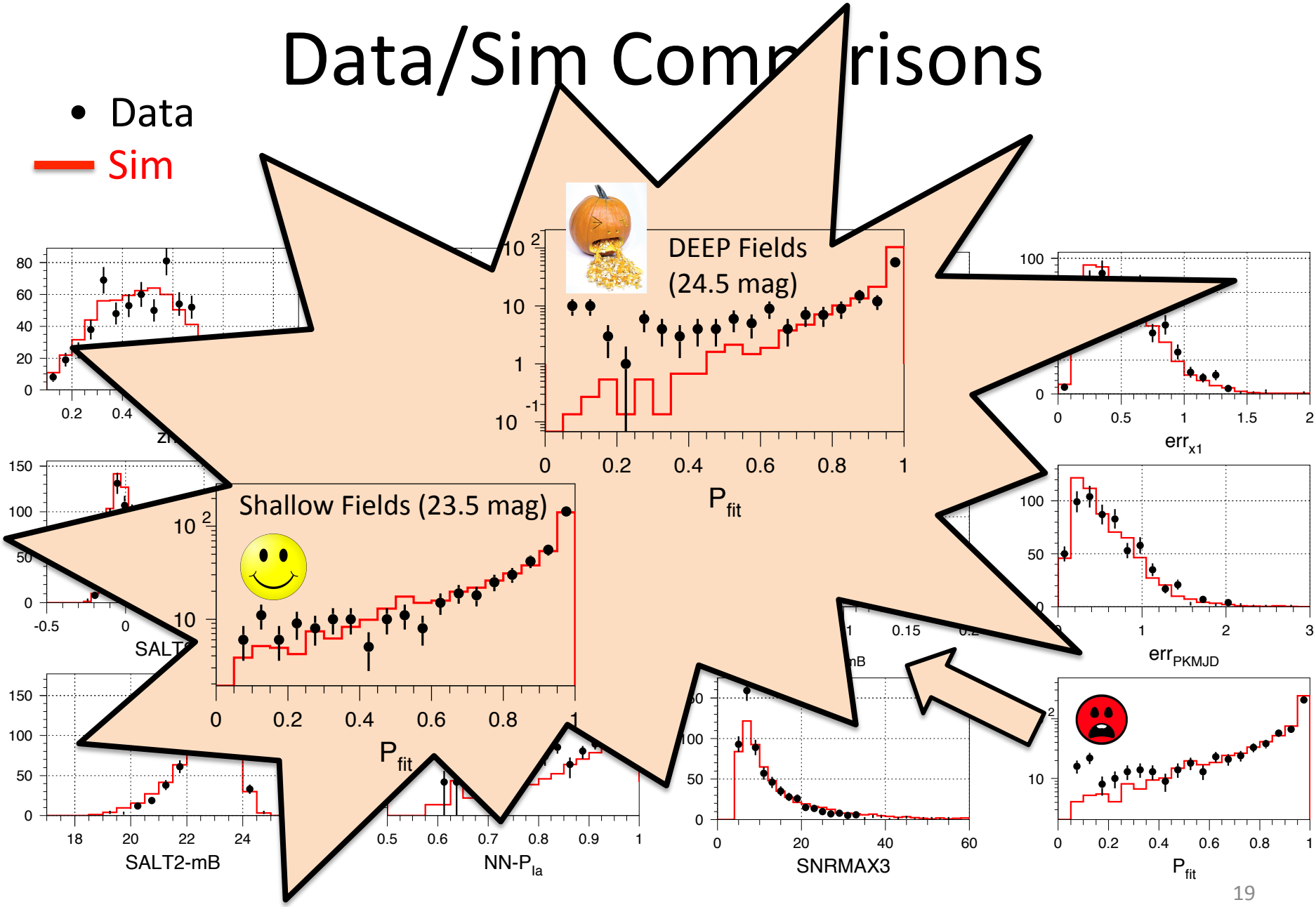
- Data

Sim



Data/Sim Comparisons

- Data
- Sim



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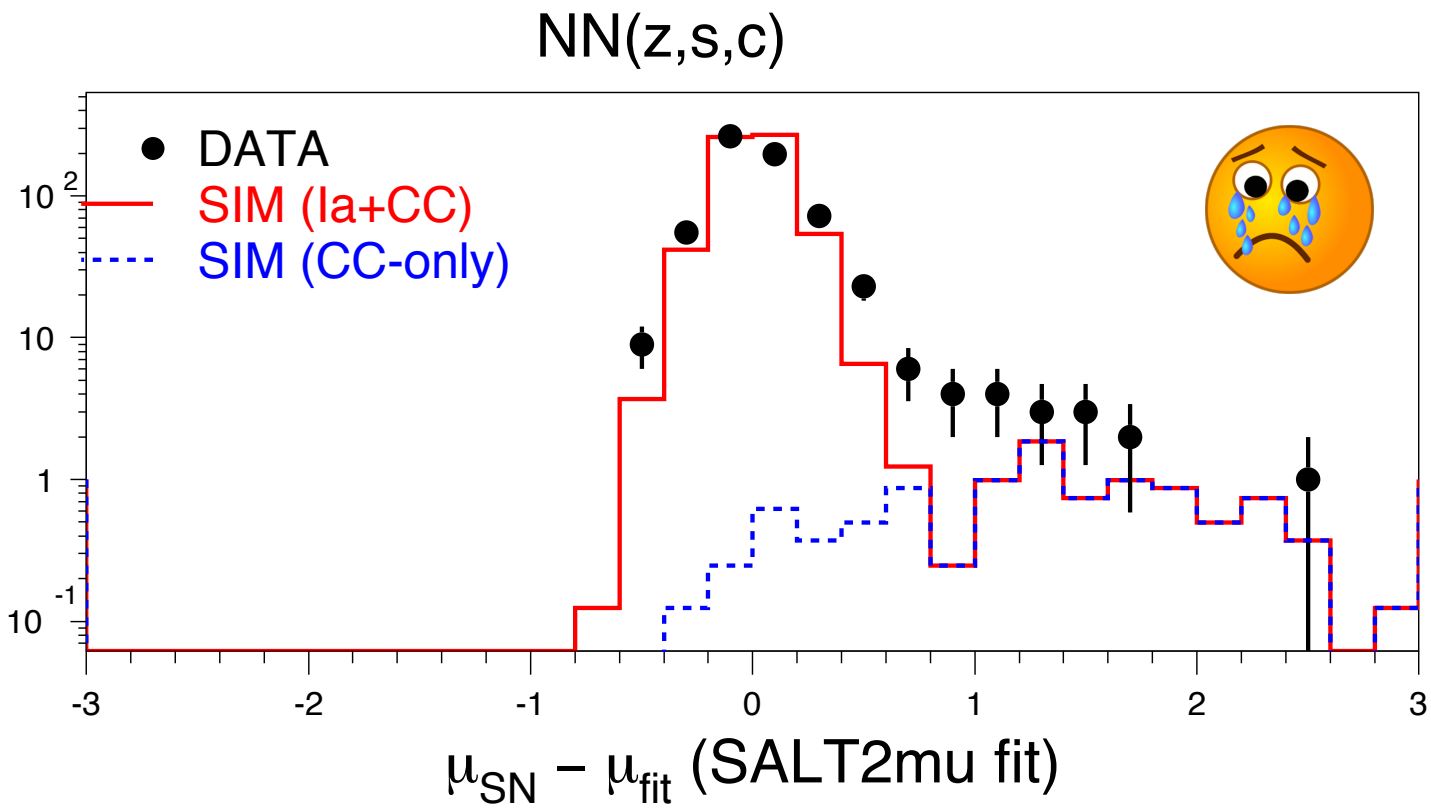
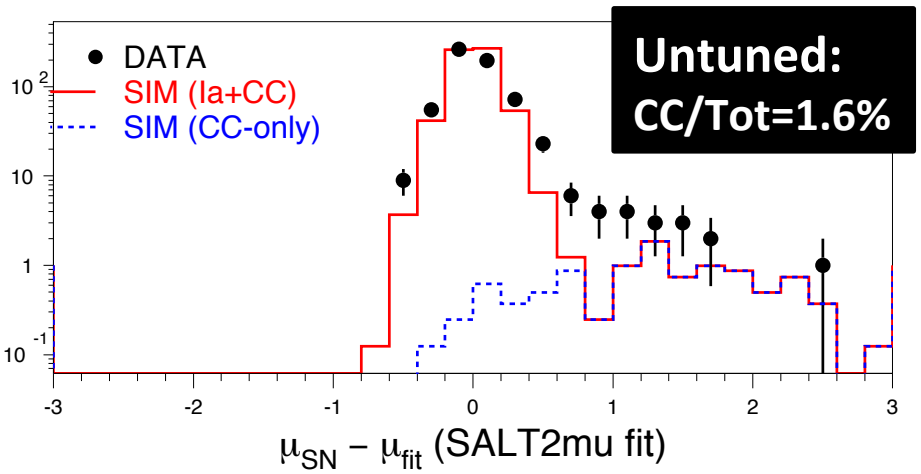
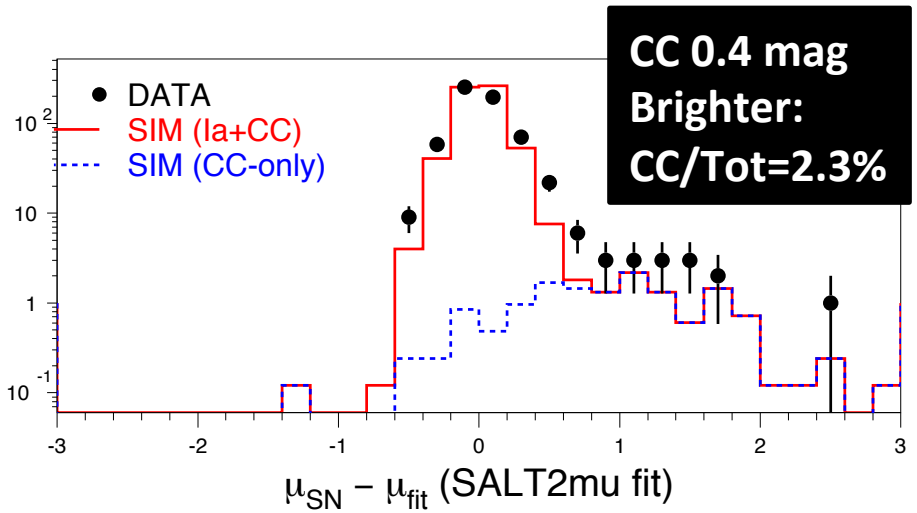


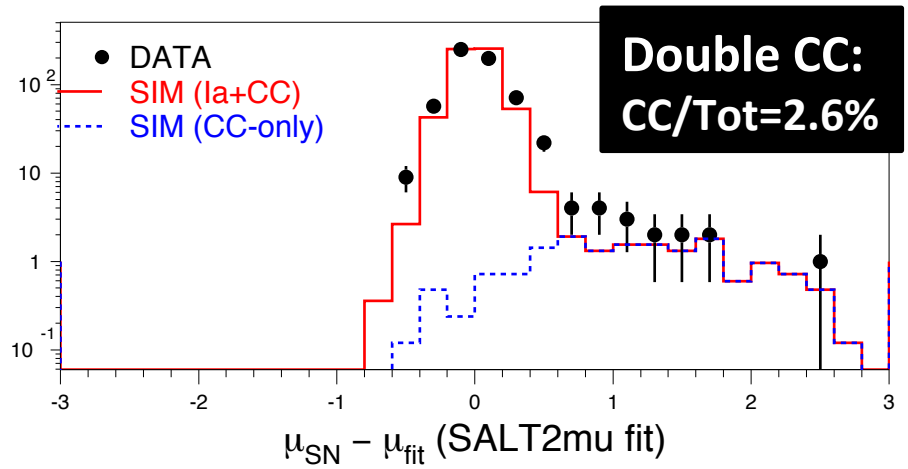
Sim CC/Tot = 1.6% .

Data contamination is clearly few times more.

When all else Fails, Tune the CC Sim

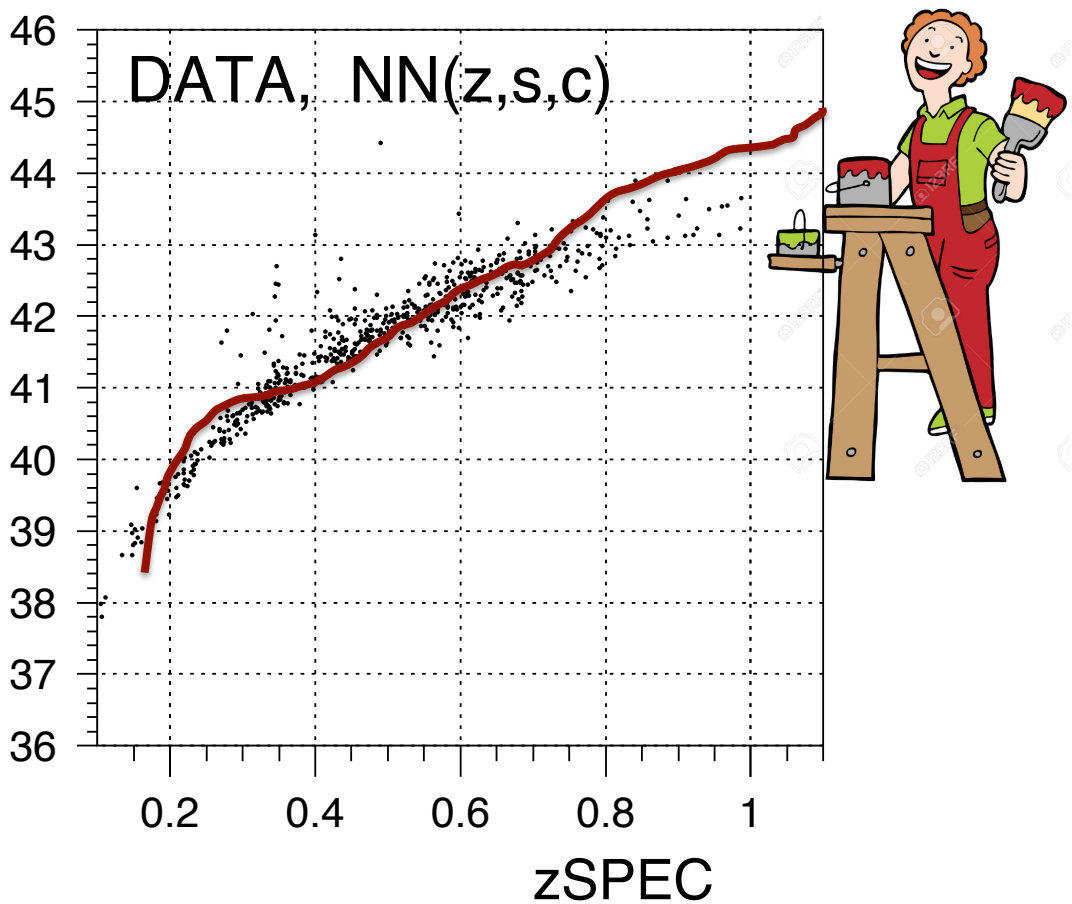






Can tune CC to match μ-resid tail, but cannot fix shoulder problem. See Jones talk for tests with 91bg, Iax . . . .

Fitting the Hubble Diagram:
Correcting for Biases and CC Contamination



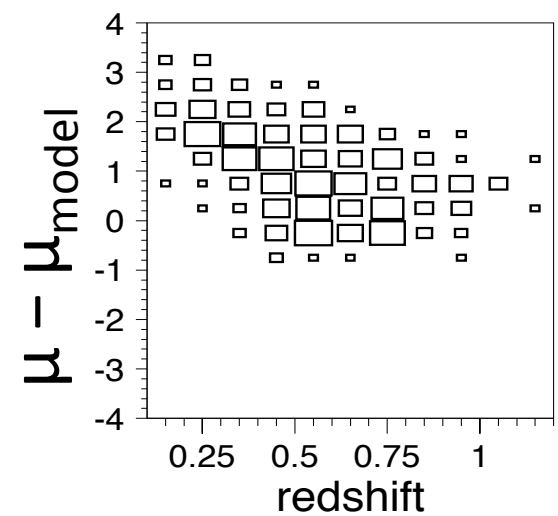
Average
Bias
Corrected
Distances

Fitting the Hubble Diagram:
Framework

$$\mathcal{L}_i \equiv \left[\frac{P^i_{\mathrm{NN,Ia}}}{P^i_{\mathrm{tot}}} D_{\mathrm{Ia}}(z_i, \mu_i)\right] + \left[\frac{{S_{\mathrm{CC}}}^i (1 - P^i_{\mathrm{NN,Ia}})}{P^i_{\mathrm{tot}}} D_{\mathrm{CC}}(z_i, \mu_i)\right]$$

From Hlozek 2011
L = L(Ia) + L(CC)

$$P_{\mathrm{tot}} = P_{\mathrm{NN,Ia}} + S_{\mathrm{CC}}(1 - P_{\mathrm{NN,Ia}}) \ ,$$
$$D_{\mathrm{Ia}} = \exp[-\chi^2_{\mathrm{Ia}}/2]/(2\pi\sigma^2_\mu)^{1/2} \ ,$$
$$D_{\mathrm{CC}} = \text{map from simulation.}$$



Fitting the Hubble Diagram:
Framework

$$\mathcal{L}_i \equiv \left[\frac{P^i_{\mathrm{NN,Ia}}}{P^i_{\mathrm{tot}}} D_{\mathrm{Ia}}(z_i, \mu_i)\right] + \left[\frac{{S_{\mathrm{CC}}}^i (1 - P^i_{\mathrm{NN,Ia}})}{P^i_{\mathrm{tot}}} D_{\mathrm{CC}}(z_i, \mu_i)\right]$$

From Hlozek 2011
L = L(Ia) + L(CC)

Fix cosmology params (w, Ω_M) and fit for
μ-offset in redshift bins (along with α,β):
"SALTmu" program in SNANA, Marriner 2011.

Can then fit mu-offset vs. redshift with any cosmo program

Fitting the Hubble Diagram:

Correcting for Biases and CC Contamination

$$\mu = m_B + \alpha x_1 - \beta c - M_0$$

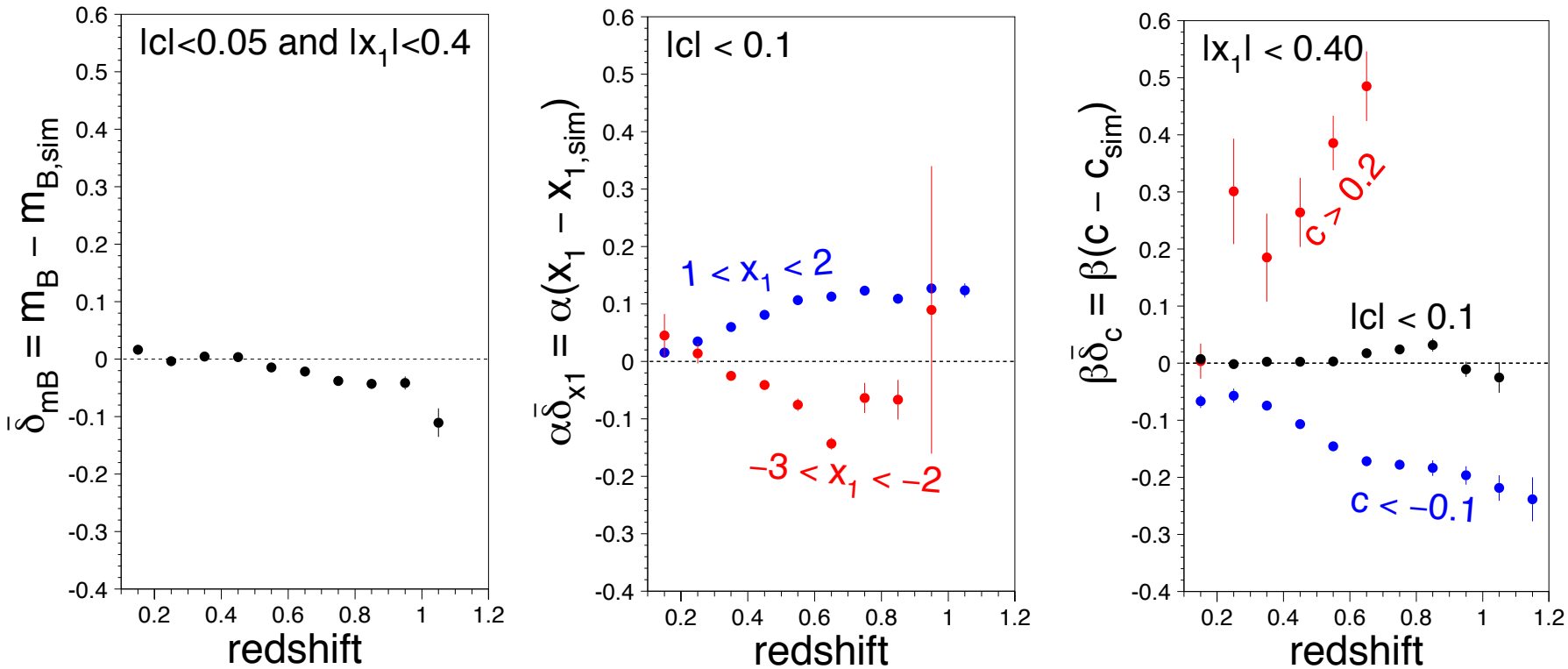
$$\mu^\star = m_B^\star + \alpha x_1^\star - \beta c^\star - M_0 \qquad ($$

$$= (m_B - \bar{\delta}_{m_B}) + \alpha(x_1 - \bar{\delta}_{x_1}) - \beta(c - \bar{\delta}_c) - M_0$$

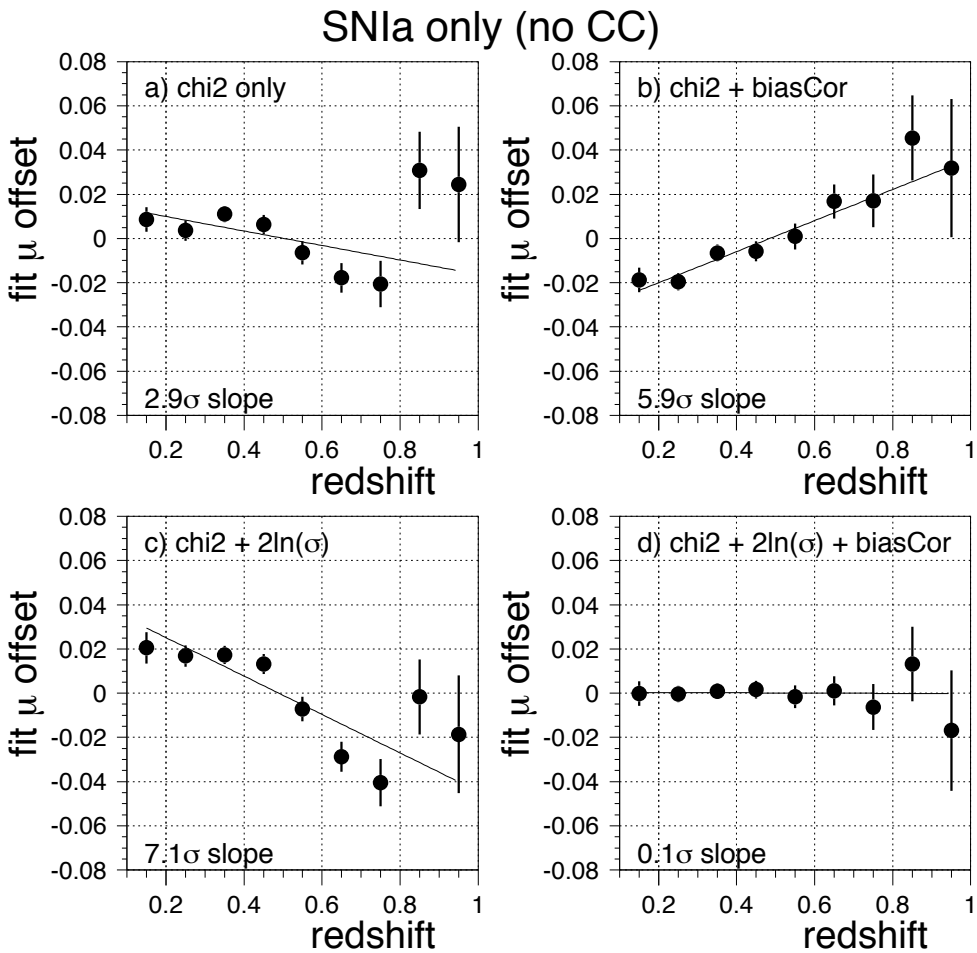
Avg bias corrections from simulation using color & stretch populations from SK16: Corrections binned in 3D map of { z, x_1, c }

Fitting the Hubble Diagram:

Correcting for Biases and CC Contamination



Fitting the Hubble Diagram:
Correcting for Biases : **Sim SNIa only**



Unbiased results require both ln(σ) term + biasCor (leaving out either is bad):

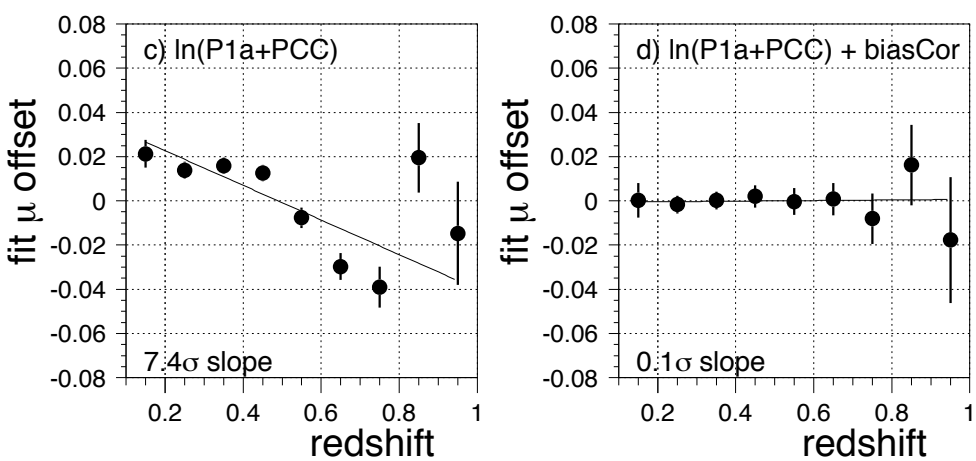
$\alpha_{fit}/\alpha_{SIM} = 0.977(16)$

$\beta_{fit}/\beta_{SIM} = 1.000(8)$

Fitting the Hubble Diagram:

Correcting for Biases and CC Contamination

Fit Ia + double-CC Sim



Unbiased results
Require biasCor:

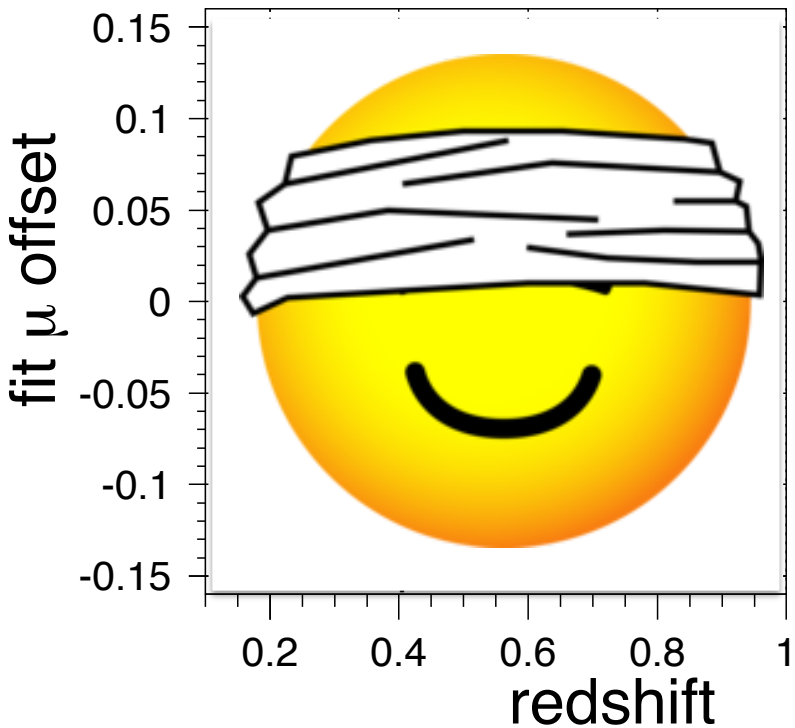
$\alpha_{fit}/\alpha_{SIM} = 0.986(20)$

$\beta_{fit}/\beta_{SIM} = 0.999(10)$

$S_{CC} = 0.82(10)$

Fitting the Hubble Diagram:

Correcting for Biases and CC Contamination



DES Data:

Blind Analysis

For data, SALT2mu program adds crazy μ-offset in each redshift bin … unless explicitly asked to unblind.
Fitted α, β, σ_{int} are shown to compare with spec samples.

Final Caveat:
Bias Correction is Similar to NN Cut

- **NN cut** removes events where sim CC are majority in local {z,x1,c} region
- **Bias Correction** removes events where there are no sim-Ia in local {z,x1,c} bin (since correction cannot be made)

Requirement after box cuts	True CC/Tot ratio for sim with double CC
None	0.11
Bias Correction (no NN)	0.039
NN (no bias correction)	0.026
NN + Bias correction	0.024

Conclusions

- Overall data/sim agreement is good.
- Fake SN → photometry pipeline is important for tuning & validating SNANA simulation.
- Simulated Hubble Residuals underestimate high-side (faint) shoulder:
  Wrong LF ? Wrong rate ? Missing templates?
- New HD fitting method to simultaneously account for biases and CC contamination.