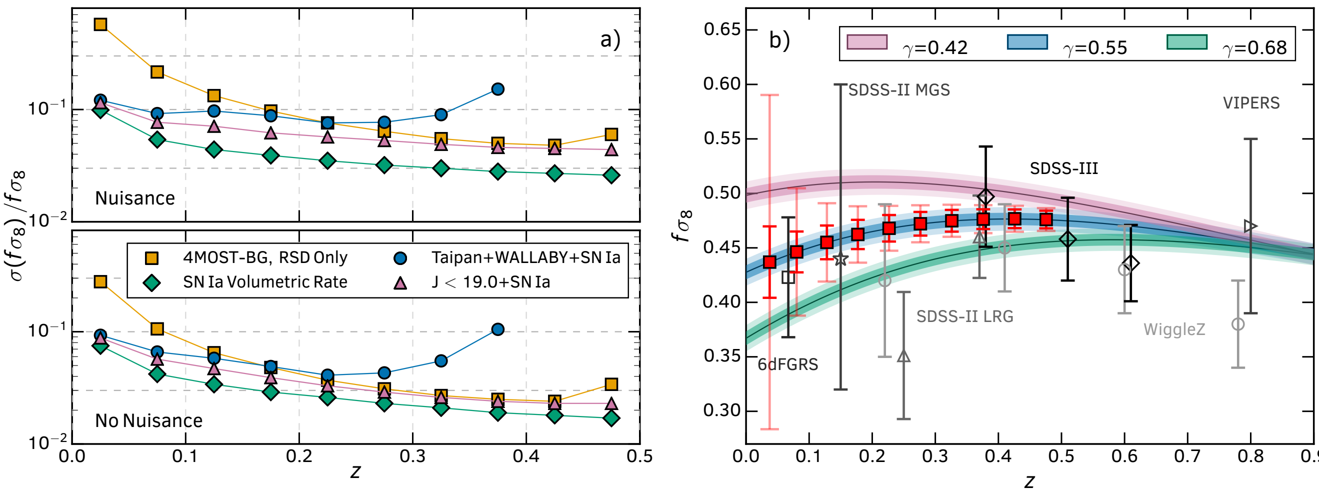

Figure 4. Forecasts for our three SNe Ia samples against the 4MOST-BG sample, assuming 5% distance errors. **a).** Fractional errors with and without nuisance parameters (top and bottom respectively). **b).** A comparison of the volumetric rate forecasts against existing measurements (Beutler et al. 2012; Howlett et al. 2015; Oka et al. 2014; Alam et al. 2016; Blake et al. 2011a,b; de la Torre et al. 2013) and predictions from Planck (Planck Collaboration et al. 2016; normalised at the redshift of recombination) with different values for γ.

redshift bin we marginalise over separate nuisance parameters, whilst the $0.0 < z < 0.5$ constraints use a single set. The fractional errors for the RSD-only 4MOST-BG sample and the SNe Ia samples are plotted in Fig. 4. The right-hand panel of this Figure then compares the volumetric rate constraints against current measurements and the predictions from different models of gravity.

We find similar constraints for the DESI-BG and 4MOST-BG surveys, reflecting their similar design and the fact that, as they only use RSD, these surveys quickly reach the cosmic variance limit at low redshift. The SNe Ia PVs allow us to break this limit as they sample the same underlying structure as the RSD measurements. This is most apparent at the lowest redshifts, where the volumetric rate predictions show a factor of ~ 2 improvement over the RSD constraints.

Without any nuisance parameters we find comparable or better growth rate constraints using the volumetric rate sample for all redshift bins, even though the total number of objects is a factor of ~ 3 less than for the DESI-BG and 4MOST-BG surveys. This comparison only grows starker as we include nuisance parameters in our forecasts.

For SNe Ia that are likely to already have host redshifts, the Taipan+WALLABY+SN Ia sample achieves better constraints than 4MOST or DESI below $z \approx 0.15$, but at higher redshifts the number of galaxies drops significantly resulting in poor constraining power. For the $J < 19.0$ sample the constraints are again comparable or better than with RSD-only for all redshift bins. This is because at low redshift the SNe Ia provide an increase in constraining power, whilst at high redshift we still obtain large numbers of galaxies and can constrain the growth rate via RSD

We do not consider forecasts beyond $z = 0.5$ as at higher redshift the SNe Ia distance errors become large and the majority of the growth rate information comes from RSD. Whilst we can see from Table 1 that at $z = 0.5$ SNe Ia still help in marginalising over the nuisance parameters, the constraining power of DESI and 4MOST improves significantly beyond this due to the large cosmological volumes they can probe with their Luminous Red Galaxy and Emission Line Galaxy samples. Combined, these can also be used to break the cosmic variance limit in the same way as a sample of SNe Ia. Hence the SNe Ia samples quickly become less competitive.

4.3. *Systematics*

In our analysis we have not included SN Ia systematics, such as flux calibration or extinction correction errors. These can be described via a systematic 'error floor' in each redshift bin or across the full SNe Ia sample (Kim & Linder 2011), which would manifest as a constant addition to the SN Ia absolute magnitude difference and a zero-point in the PVs. Whilst an issue for measurements of the bulk flow, where this zero-point acts in the same way as the bulk motion of the local universe, Howlett et al. (2017) showed that this acts as additional shot-noise in the velocity power spectrum. Hence as long as these systematics are small compared to the intrinsic SN Ia scatter, the effect of this on growth rate constraints is negligible. Alternatively, the additional shot-noise component can be marginalised over analytically and at little cost to the growth rate constraints (Johnson et al. 2014).

Another systematic arises from the incorrect assignment of SNe Ia to host galaxies, which can be mitigated if we have spectra for the SNe Ia themselves. Furthermore, measurements of the growth rate depend on the *distribution* of PVs, rather than individual measurements. On linear scales the peculiar velocities (not accounting for statistical measurement errors) are expected to be Gaussian distributed. Hence, in most cases incorrect assignment of SNe Ia to hosts would result in abnormally large PVs, which could be removed via sigma-clipping and not included in our measurements.