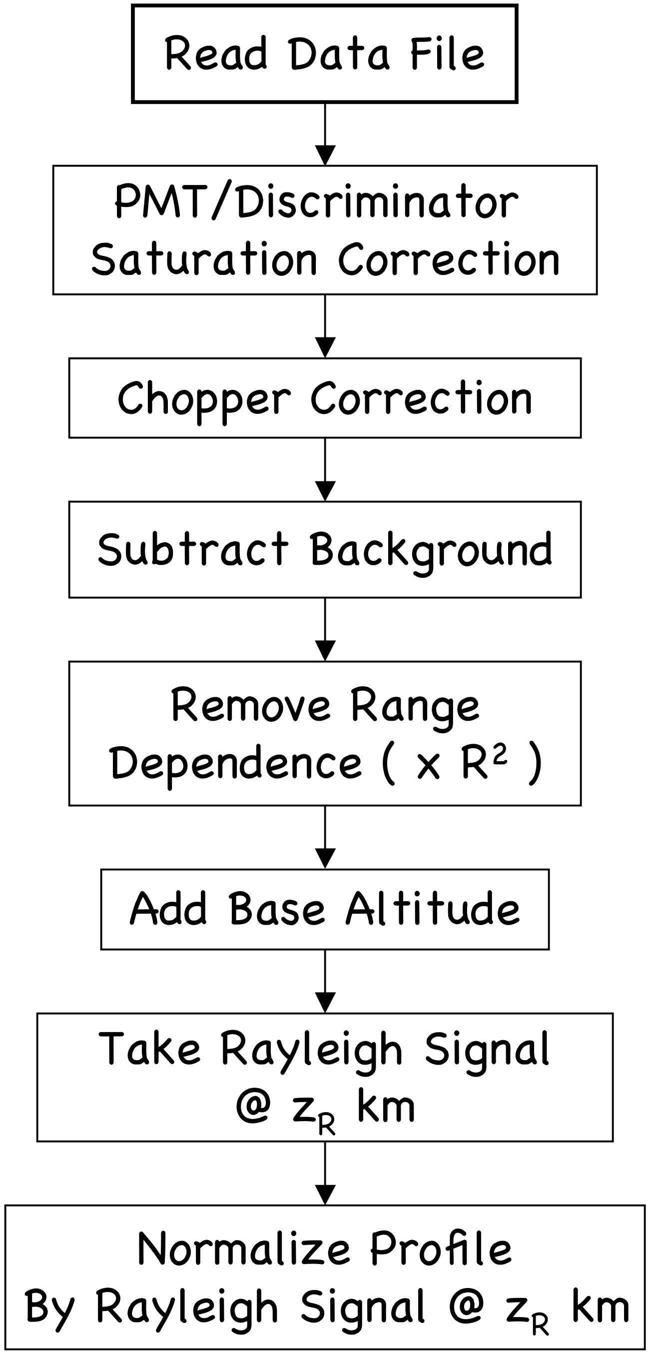
Lecture 14. Lidar Data Inversion and Sensitivity Analysis

- Data inversion process
- Nonlinearity of PMT and discriminator
- More considerations for Na Doppler lidar
- Definition of sensitivity
- Summary
- Office demonstration

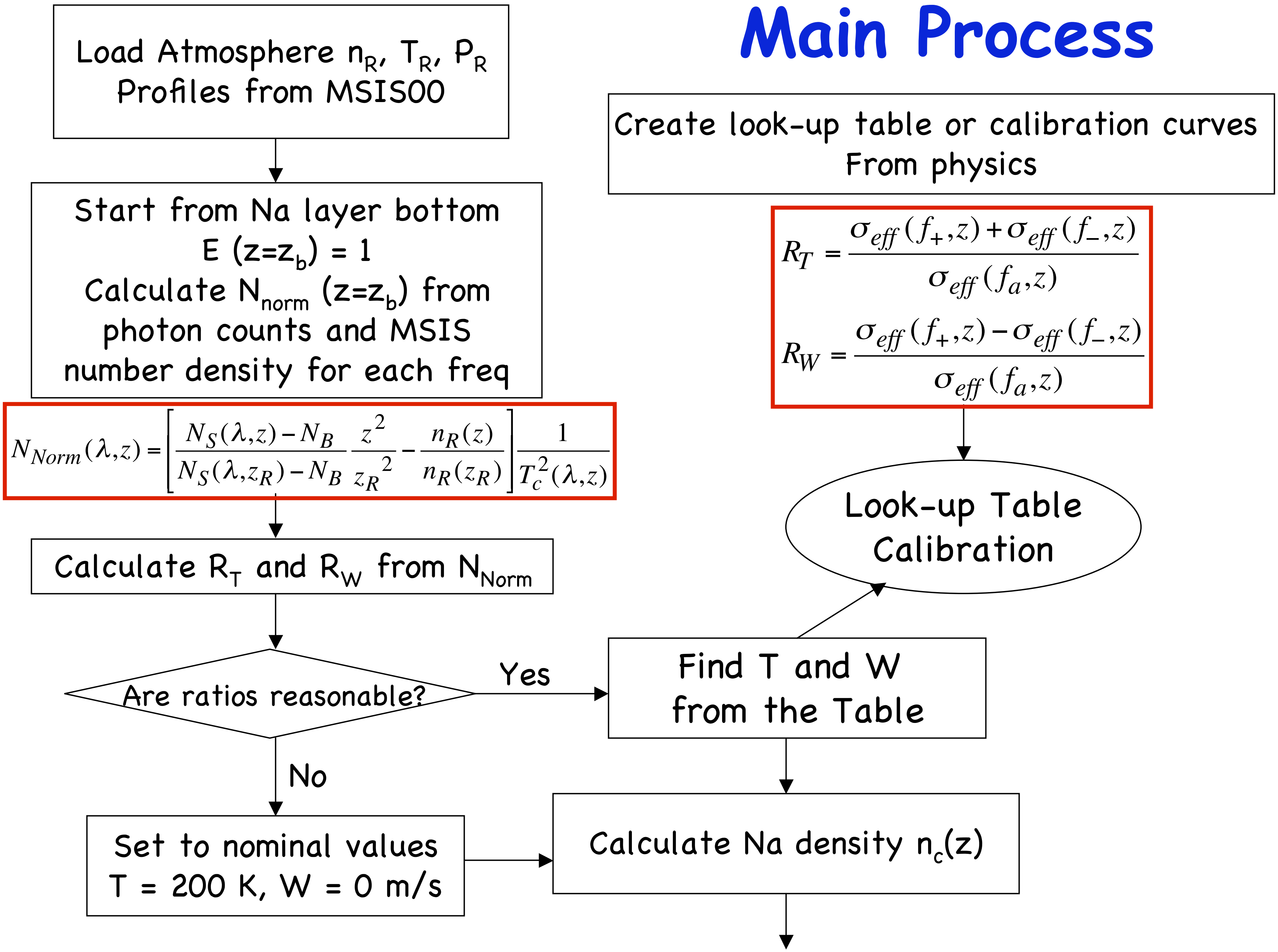


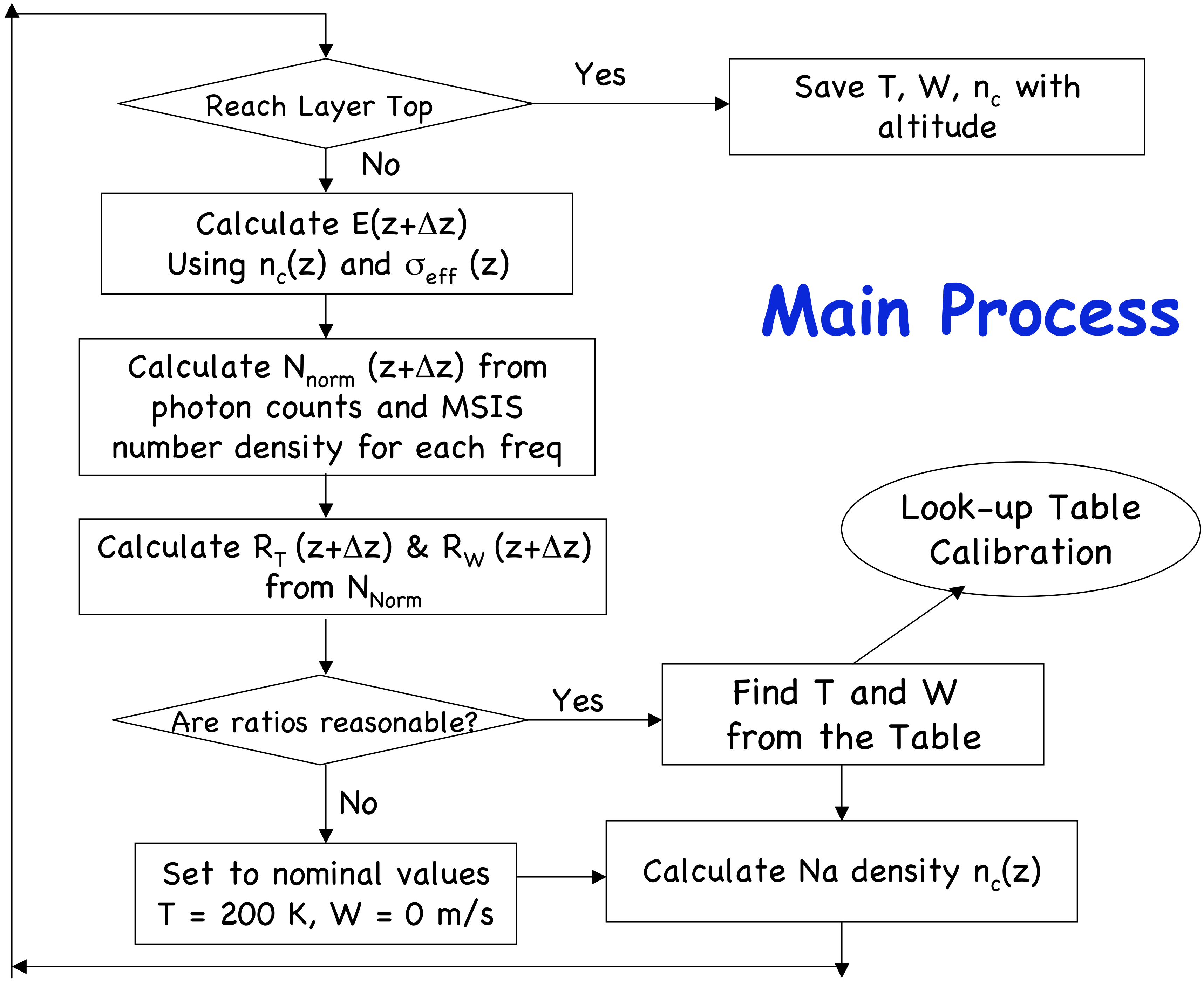
Preprocess Procedure for Na Doppler Lidar

- Read data: for each set, and calculate T, W, and n for each set
- PMT/Discriminator saturation correction
- Chopper correction
- Background estimate and subtraction
- Range-dependence removal (not altitude)
- Base altitude adjustment
- Take Rayleigh signal @ z_R (Rayleigh fit or Rayleigh sum)
- Rayleigh normalization

$$N_N(\lambda,z) = \frac{N_S(\lambda,z) - N_B}{N_S(\lambda,z_R) - N_B}\,\frac{z^2}{z_R^{\,2}}$$

Main Process




Main Process
Reach Layer Top
Yes
Save T, W, n_c with altitude
No
Calculate $E(z+\Delta z)$ Using $n_c(z)$ and $\sigma_{eff}(z)$
Calculate $N_{norm}(z+\Delta z)$ from photon counts and MSIS number density for each freq
Calculate $R_T(z+\Delta z)$ & $R_W(z+\Delta z)$ from N_{Norm}
Look-up Table Calibration
Are ratios reasonable?
Yes
Find T and W from the Table
No
Set to nominal values T = 200 K, W = 0 m/s
Calculate Na density $n_c(z)$

Nonlinearity of PMT + Discriminator

For small input photon flux, PMT output photon counts are proportional to the input photon counts:

$$\lambda_{oP} = \lambda_S = \lambda_i \eta_{QE}$$

When the input photon flux is considerably large, the output photon counts are no longer linear with input photons. Nonlinearity of PMT occurs:

$$\lambda_{oP} = \lambda_S e^{-\lambda_S \tau_p}$$

A discriminator is used to judge real photon signals and also has a saturation effect, i.e., its output photon counts are smaller than input photon counts when input count rate is large:

$$\lambda_o = \frac{\lambda_{iD}}{1 + \lambda_{iD} \tau_d}$$

Nonlinearity of PMT + Discriminator

Since PMT output is the input of discriminator

$$\lambda_{iD} = \lambda_{oP}$$

we obtain

$$\lambda_o = \frac{\lambda_S e^{-\lambda_S \tau_p}}{1 + \lambda_S \tau_d e^{-\lambda_S \tau_p}} = \frac{\lambda_S e^{-\lambda_S \tau_p}}{1 + \lambda_S \tau_d e^{-\lambda_S \tau_p}}$$

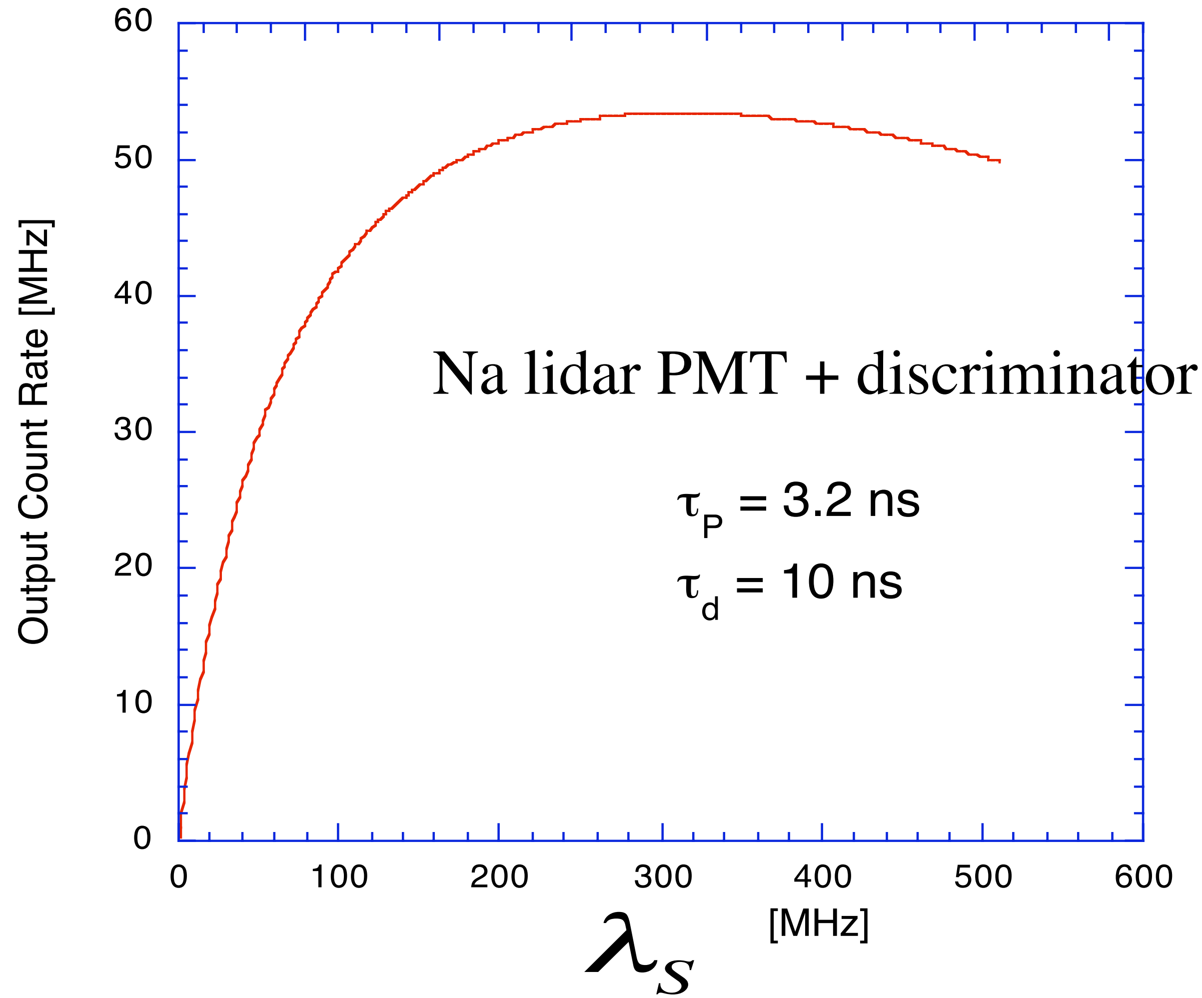
where

$\lambda_S = \lambda_i \eta_{QE}$ η_{QE} is the quantum efficiency of cathode

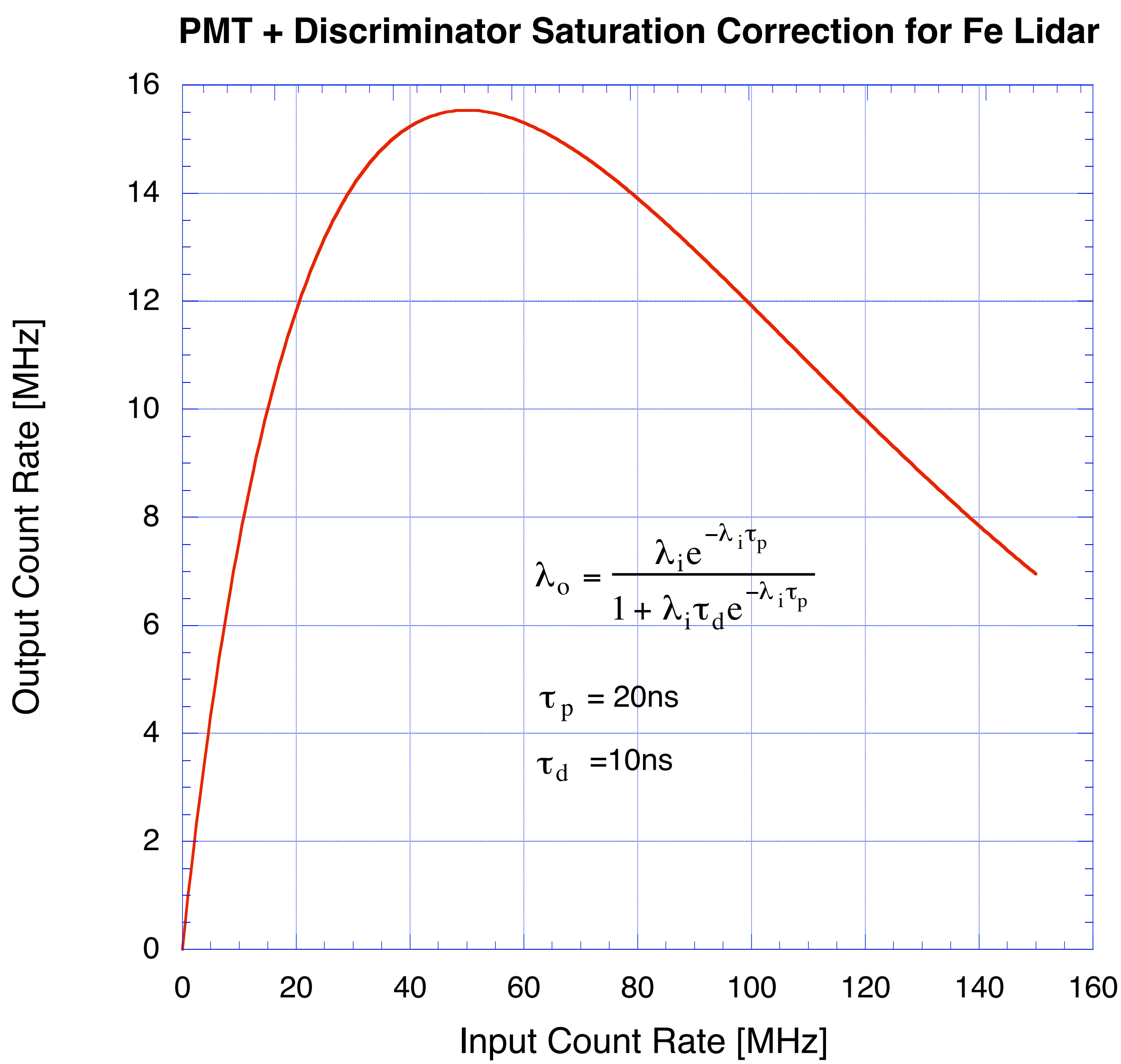
Maximum output count rate is reached when $\lambda_S = 1/\tau_p$

$$\lambda_{o\,\max} = \frac{1}{\tau_p e + \tau_d} \quad \Rightarrow \quad \tau_p = \frac{\frac{1}{\lambda_{o\,\max}} - \tau_d}{e}$$

Nonlinearity of PMT + Discriminator



Nonlinearity of PMT + Discriminator



More Considerations

- PDA frequency offset: usually nonzero, so must be taken into account. For AR1102 data, the freq offset is 10.27MHz.

Actual laser freq = CW laser freq + PDA freq offset

- Binning, smoothing, or temporal integration in order to improve the signal-to-noise ratio (SNR).

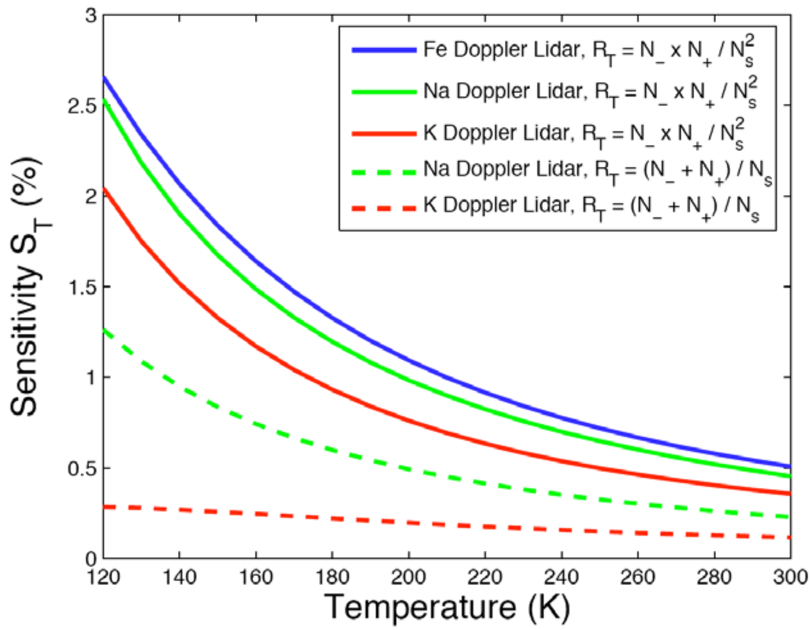
- More considerations will be shown in our office demonstration.

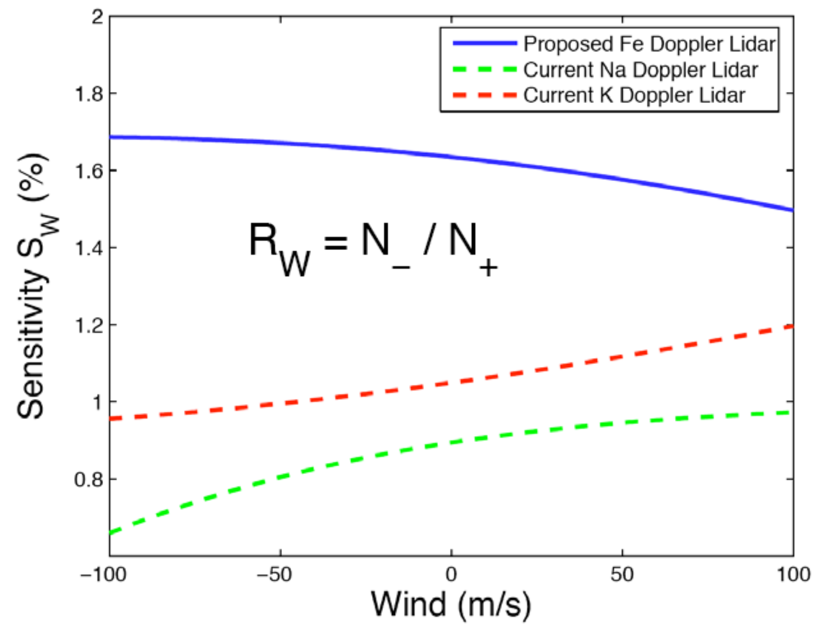
Sensitivity for T and W

- The temperature and wind sensitivities are defined as

$$S_T = \frac{\partial R_T / \partial T}{R_T} = \frac{\Delta R_T / R_T}{\Delta T}$$

$$S_W = \frac{\partial R_W / \partial W}{R_W} = \frac{\Delta R_W / R_W}{\Delta W}$$





Summary

- Lidar data inversion is to convert raw photon counts to meaningful physical parameters like temperature, wind, number density, and volume backscatter coefficient. It is a key step in the process of using lidar to study science.
- The basic procedure of data inversion originates from solutions of lidar equations, in combination with detailed considerations of hardware properties and limitations as well as detailed considerations of light propagation and interaction processes.
- The data inversion procedure consists of three main processes: (1) preprocess, (2) process of T and V_R, (3) process of n_c and β, etc.

Summary

- The preprocess is to convert the raw photon counts to corrected and normalized photon counts in consideration of hardware properties and limitations.
- The process of T and V_R is to convert the normalized photon counts to T and V_R through integration, iteration or looking-up table methods.
- The process of n_c is to convert the normalized photon counts to meaningful number density, in combination with prior acquired knowledge or model knowledge of certain atmosphere information or atomic/molecular spectroscopy.
- These processes sometimes involve considerable binning, smoothing, or temporal integration in order to improve the signal-to-noise ratio (SNR) to result in meaningful results.