Pileup Construction and Systematic Estimation

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Muon g-2 Experiment and How We Get ω_a
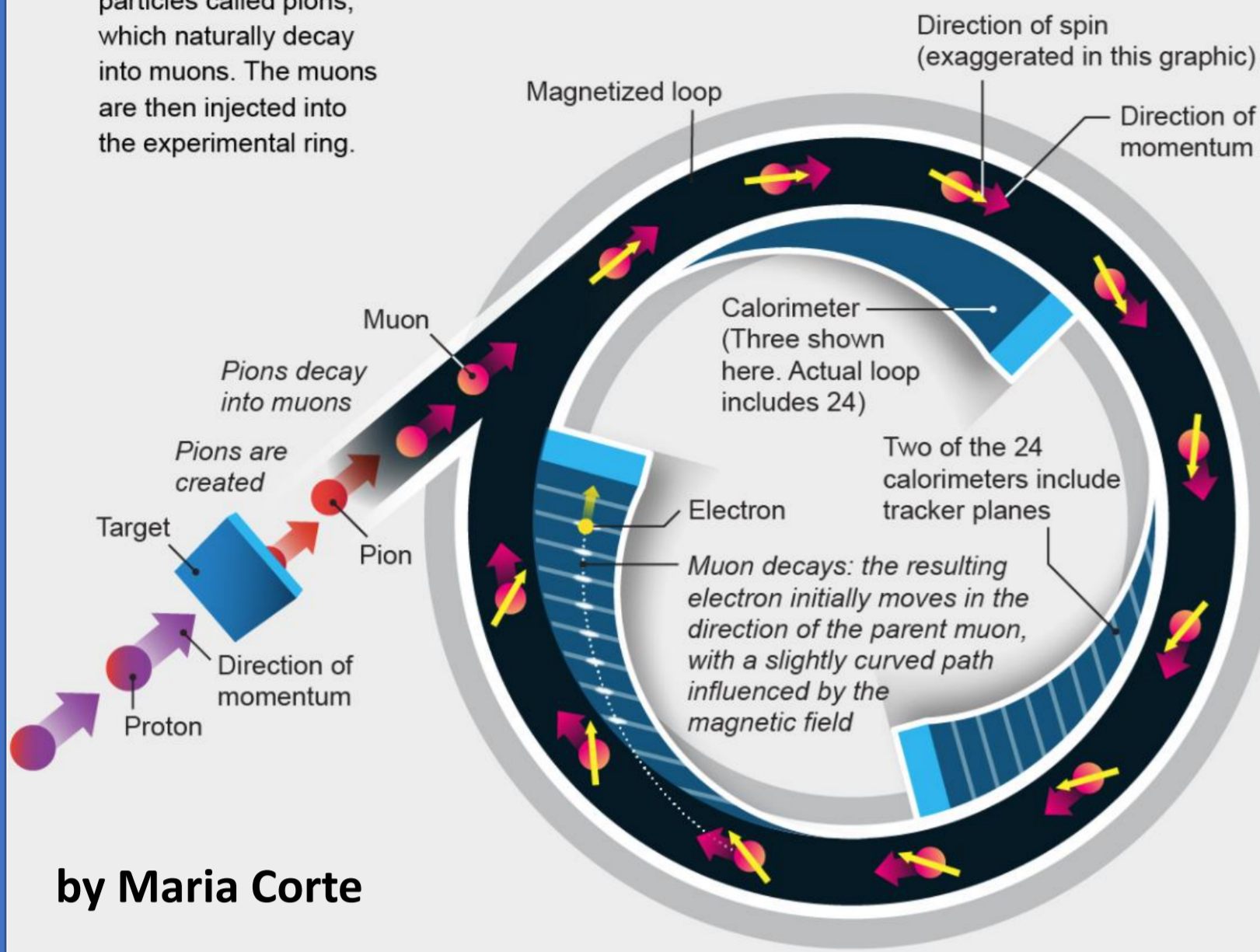
by Maria Corte

- The muon magnetic anomaly of a_μ measured by
$$a_\mu = \frac{g_e}{2}(\frac{\omega_a}{\widetilde{\omega_P}})(\frac{m_p}{m_e})(\frac{\mu_p}{\mu_e})$$

- Four steps to get ω_a:
  - **Convert raw data to (E,T) pairs.**
    Reconstruct the data from the calorimeters.
  - **Apply an analysis method.**
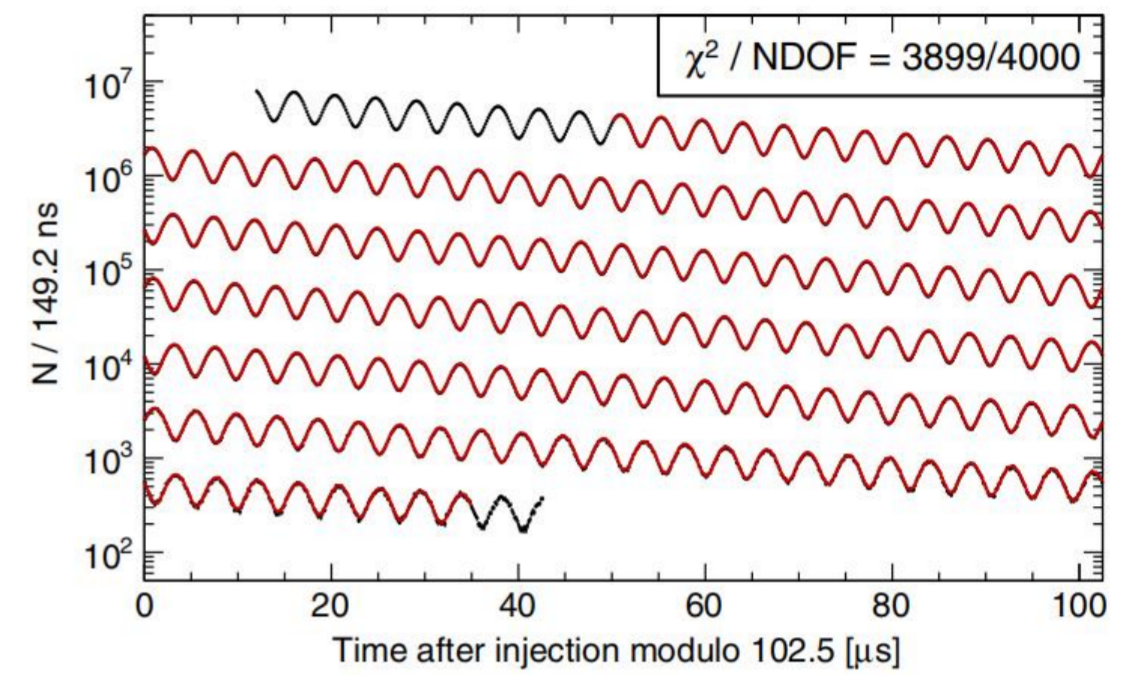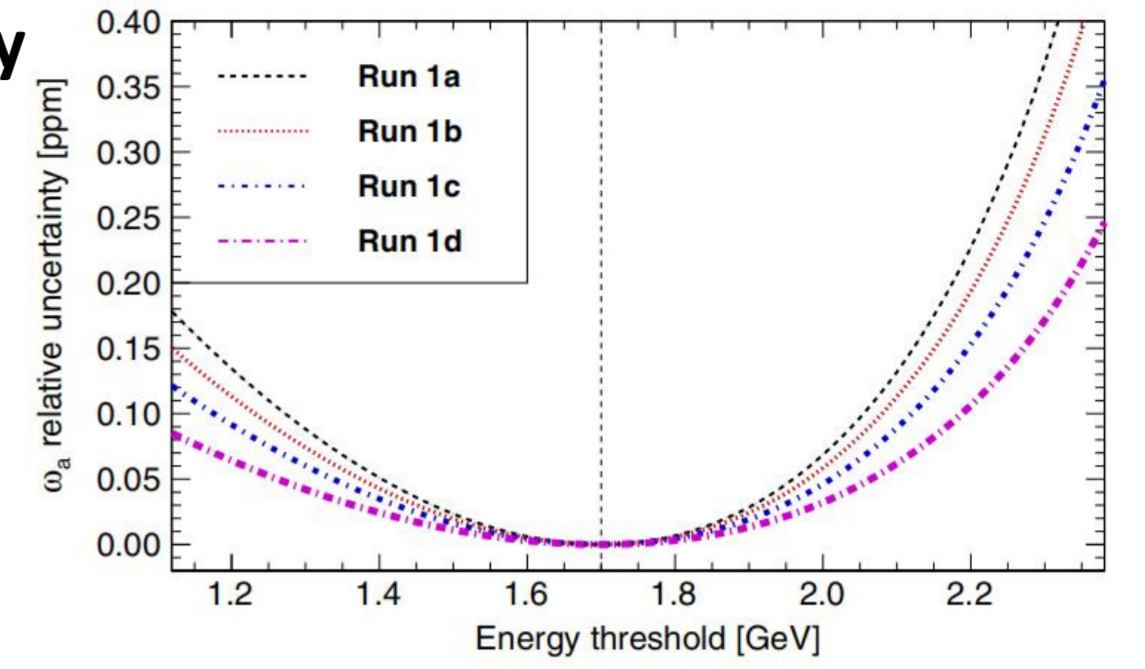   e.g. T method: choose energy > 1700MeV.
  - **Do corrections.**
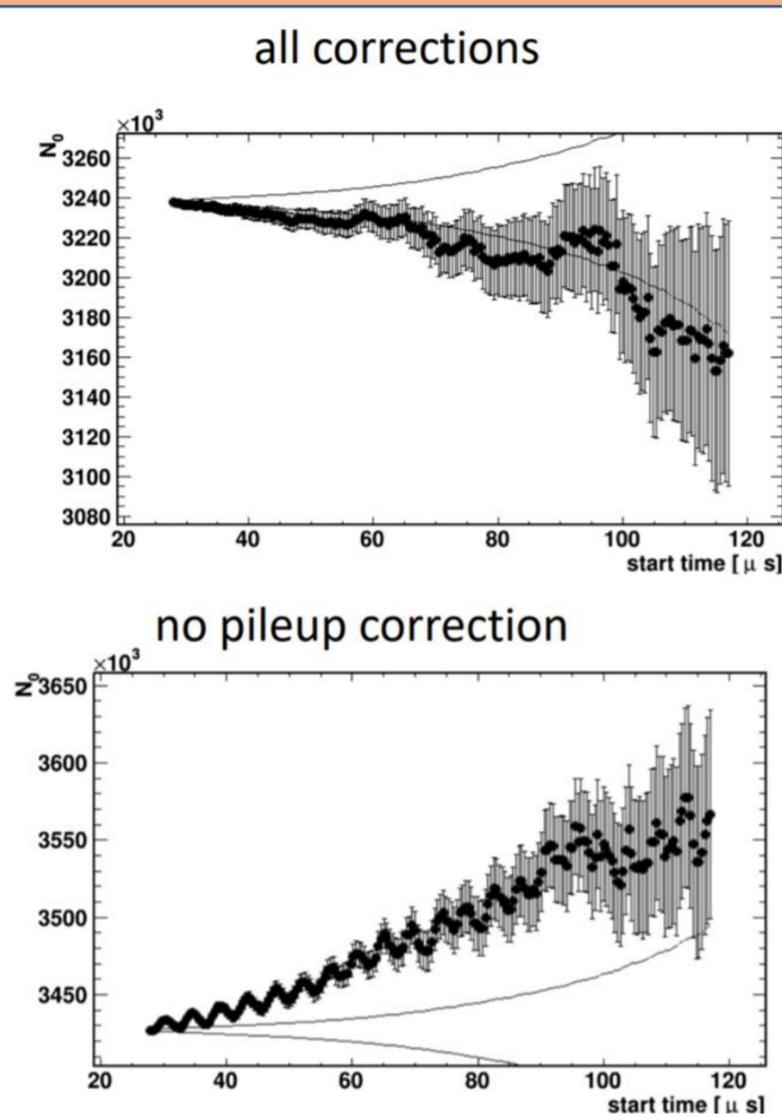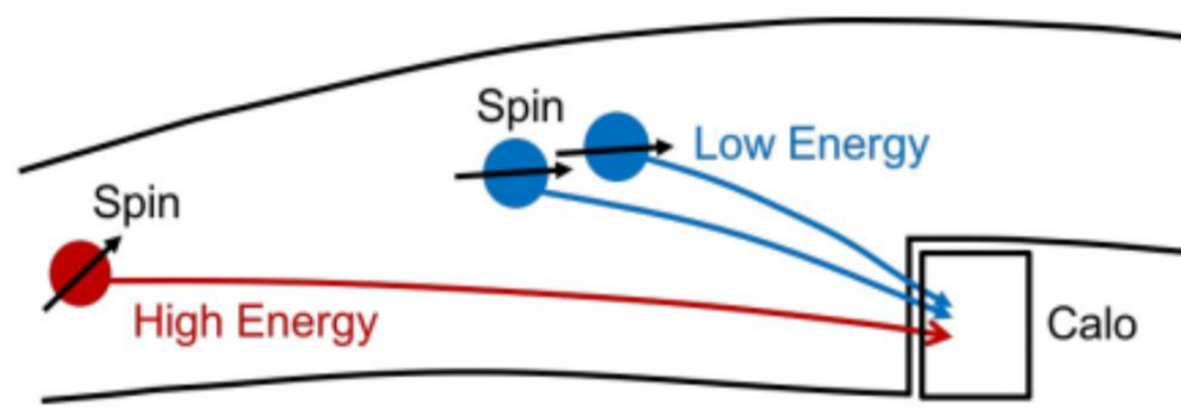   Pileup Correction, etc..
  - **Fit the time wiggle plot.**
    Basic five parameter model:
    $$N = N_0 e^{\frac{-t}{\tau}}[1 + A\cos(\omega_a t - \varphi)]$$

What is a Pileup Event?

- One event that actually is consist of two or more events.
- Caused by calo response relaxation time or reconstruction process.
- Affect the energy spectrum shape and the phase of precession.

Pileup Systematic Uncertainty on ω_a

- Pileup systematics are evaluated in many ways,
- E.g. for pileup amplitude, we calculate its value = sensitivity slope * minimum χ^2 distance = $Slope_{R\ vs.\ multiplier} * 1/\sqrt{(a_{\chi^2} * Ndf)}$
  (Here a_{χ^2} the coefficient of quadratic term for χ^2 vs. multiplier fitting and Ndf the degree of freedom for ω_a fitting)

- The total pileup systematic ranges from about 30 to 40 ppb across the 4 sub-datasets of Run1 and the largest term is from pileup time model.
- Run2 & Run3 pileup systematic study is on going, preliminary results below :

Systematics[ppb]	Pileup Amplitude	Pileup Time Model	Pileup Energy Model	Unseen Pileup
Run1	5.1	16.6	2.7	2.7
Run2	< 5	~ 5	< 2	2.5

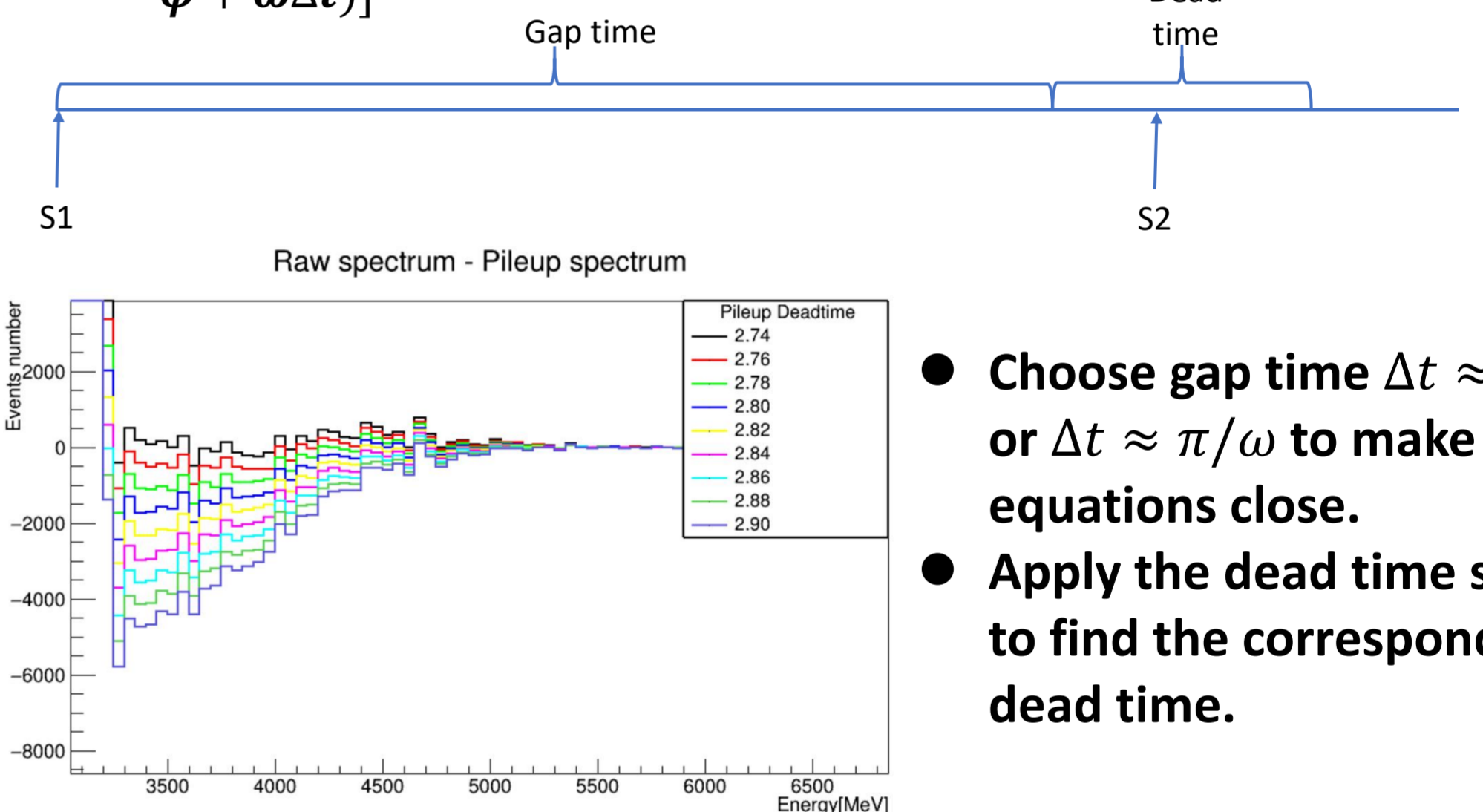## Pileup Correction : Shadow Method

- **Build the pileup spectrums from data.**
- **Take double pileup for instance.**
  - The probability of two e^+ hit the same calo at same time:
    $$D(t)_{pileup} \propto N(t)^2 \propto \left[e^{\frac{t}{-\tau}}\right]^2 [1 - A\cos(\omega t + \varphi)]^2$$
  - The probability of finding a pileup event using shadow method:
    $$\rho(t) \cdot \rho(t + \Delta t) \propto \left[e^{\frac{t}{-\tau}}\right][1 - A\cos(\omega t + \varphi)]\left[e^{\frac{t+\Delta t}{-\tau}}\right][1 - A\cos(\omega t + \varphi + \omega\Delta t)]$$
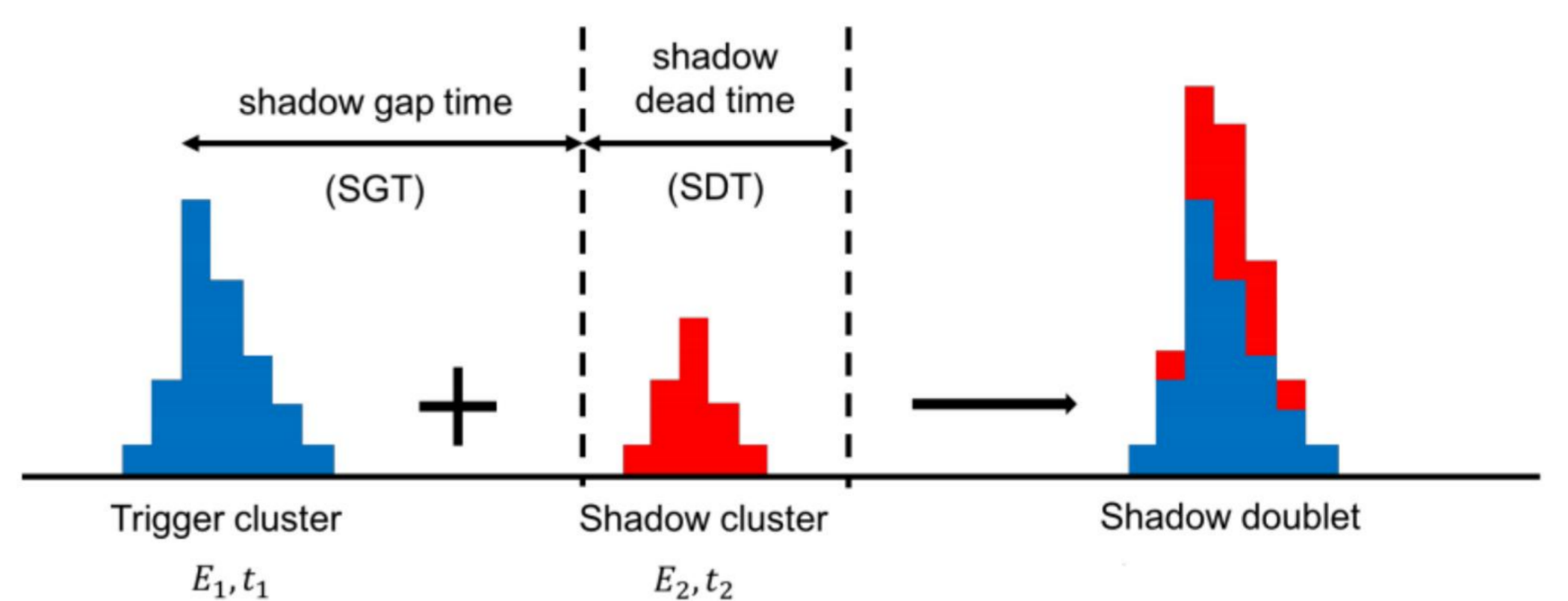
Gap time

Dead time

S1

S2

- Choose gap time $\Delta t \approx 0$ or $\Delta t \approx \pi/\omega$ to make the equations close.
- Apply the dead time scan to find the corresponding dead time.

- The energy and time for the pileup doublet:
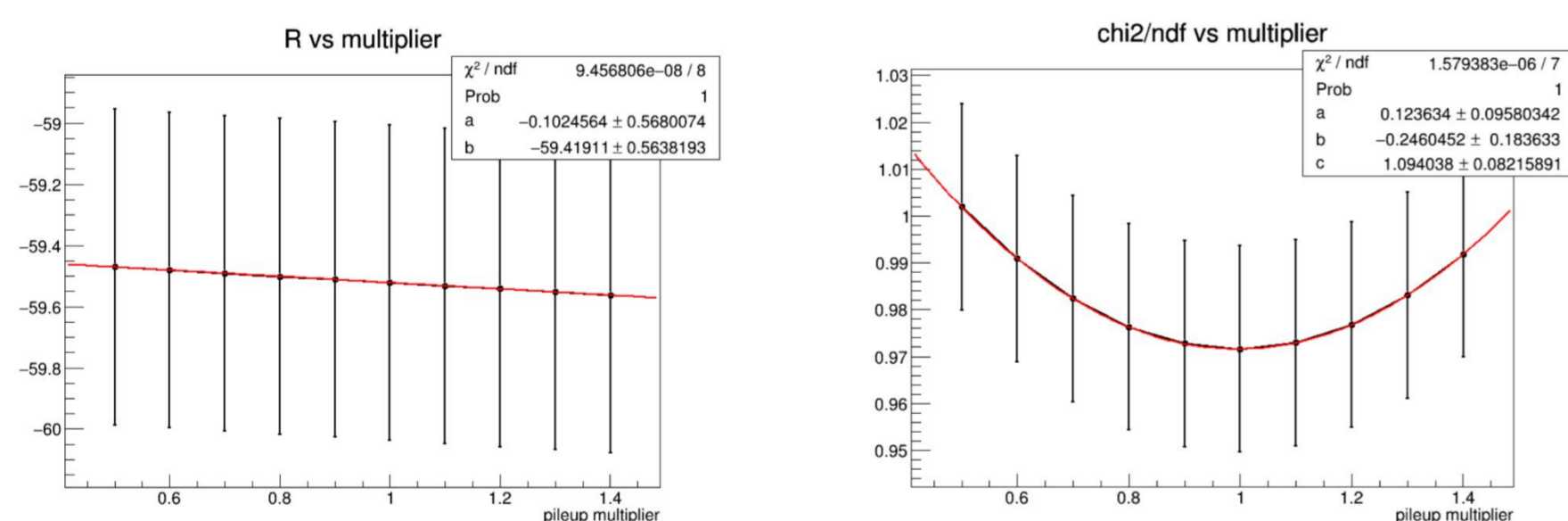 $$E_{doublet} = E_1 + E_2 \quad , \quad T_{pileup} = \frac{t_1 \cdot E_1 + (t_2 - T_{gap}) \cdot E_2}{E_1 + E_2}$$
- The pileup spectrum is built by adding the doublet and removing the individual e^+ contribution:
  $$P(E,t) = D(E,t) - S_1(E,t) - S_2(E,t)$$

shadow gap time (SGT)

shadow dead time (SDT)

Trigger cluster E_1, t_1

Shadow cluster E_2, t_2

Shadow doublet

Conclusion and Outlook

- Run2/3 pileup uncertainty for ω_a analysis is expected to be 18 ppb, reduced by 50% compared with Run1.
- Other methods for pileup correction : PDF method and Empirical method(dealing with pileup events at the waveform level).
- The bump in energy spectrum at 4000-5000 MeV after pileup correction indicates there might be residual contamination in the default shadow method.
- Significant improvement when applying re-clustering algorithm to shadow method. Will try Empirical method in future analysis for further comparison.