Decay Time Resolution Model Study for Lifetime and Mixing using $B^0 \rightarrow D^* l \nu$

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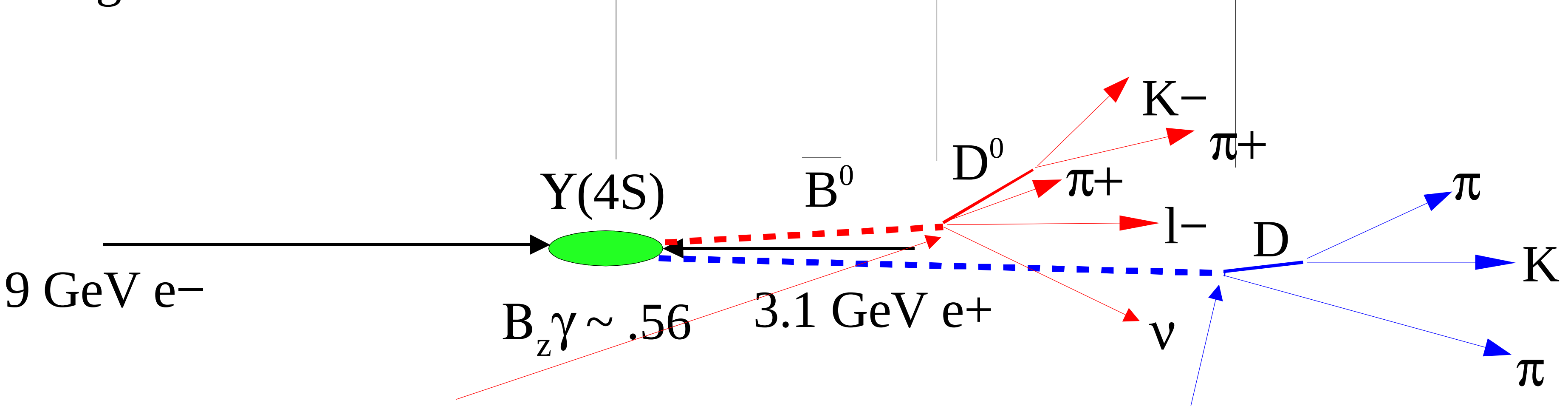
Motivation for Study

- $D^*l\nu$ lifetime and mixing measurements are systematics limited − time resolution function is one of largest systematic errors.
- Resolution (~1 ps) is of the same order as the B^0 lifetime (~1.5 ps).
- All resolution parameters measured with real data; Monte Carlo used for testing and validation.
- This study uses a large signal MC sample (>100 fb^{-1}). Our current dataset is 20.6 fb^{-1}.

Reconstruction (Reco) Side: Reconstructed $\bar{B}^0 \to D^* l \nu$. Here the reconstructed side decayed first. The flavor of the other B is the opposite of the reconstructed B at the time of decay.

Tag Side: The other B can decay as a B^0 or $\bar{B}^0$, depending on its time evolution.

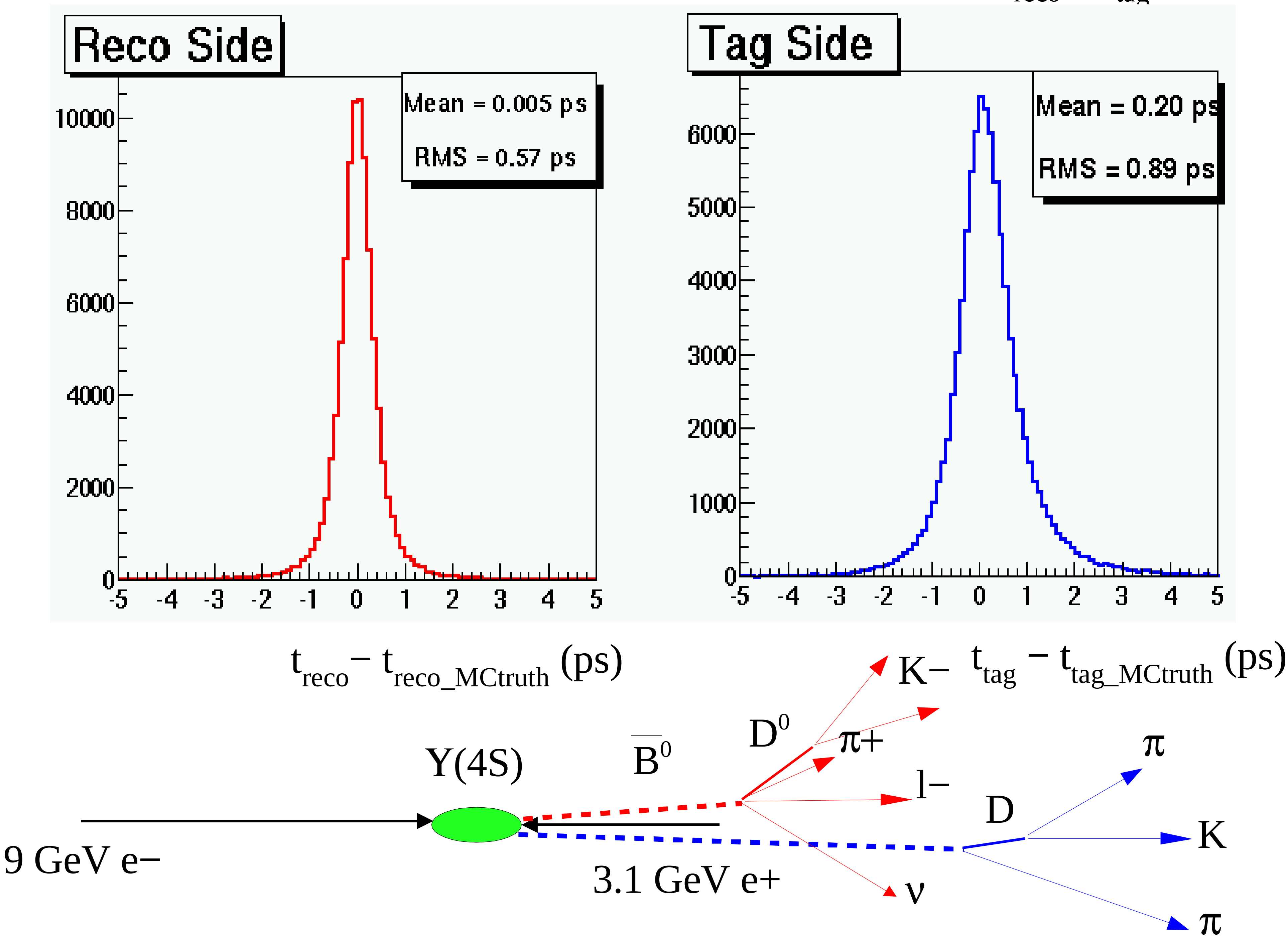
The Bs travel, to a very good approximation, along the boost axis.



Reco side: vertex found while reconstructing the $D^* l \nu$ candidate.

Tag side: vertex all remaining charged tracks, recursively remove poor χ^2 tracks until $prob(\chi^2_{vertex}) > prob(\chi^2_{min})$. Reco + Tag vertices yield Δt. Tag side fitter also calculates an error of the fit (per−event−error).

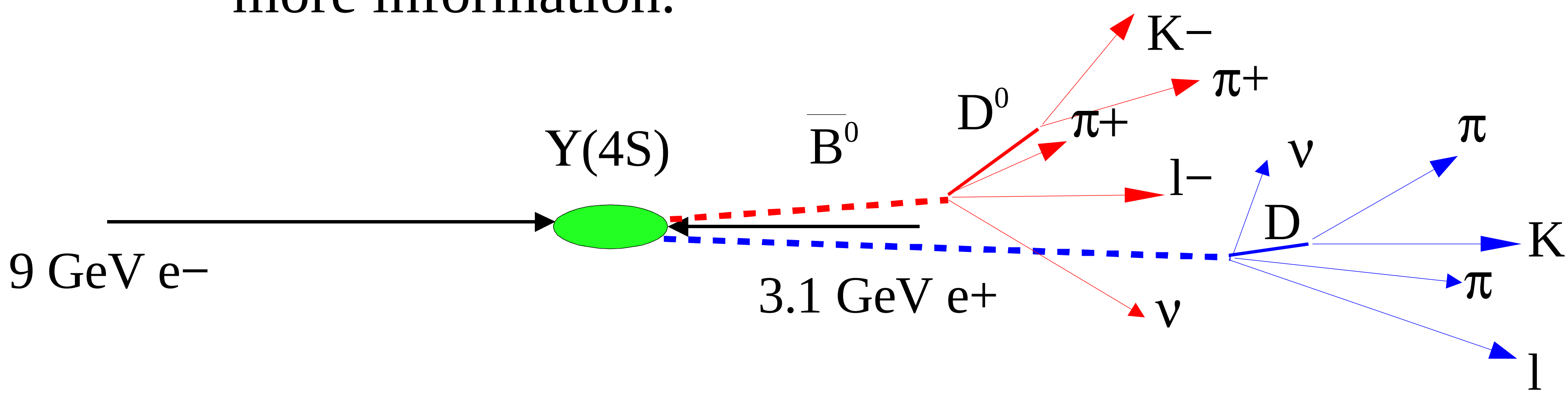
Vertex resolution is dominated by the tag side vertex. $\Delta t = t_{reco} - t_{tag}$.



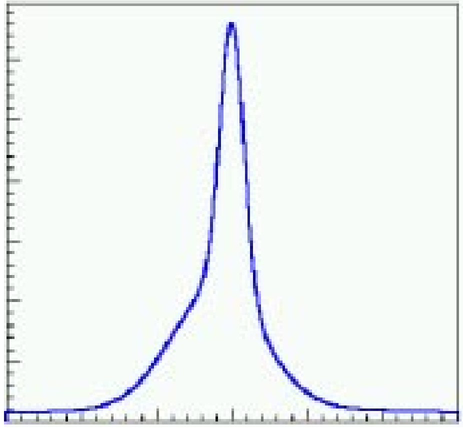
Tagging

The flavor of the B_{tag} is determined by using the correlations between the B_{tag} decay products and its flavor. Four tagging categories are used:

- Lepton: high momentum lepton probably b−>clν
- Kaon: most probable decay chain b−>c−>s.
- Net1, Net2: Single neural network used to exploit more information.



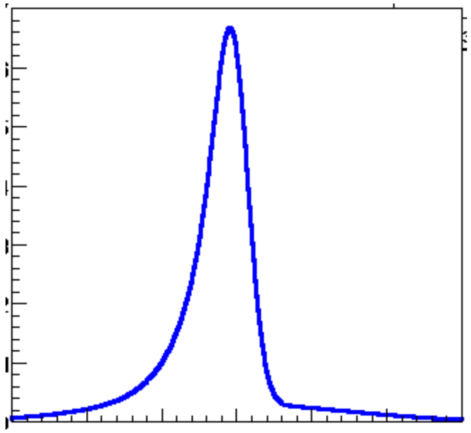
Resolution Models



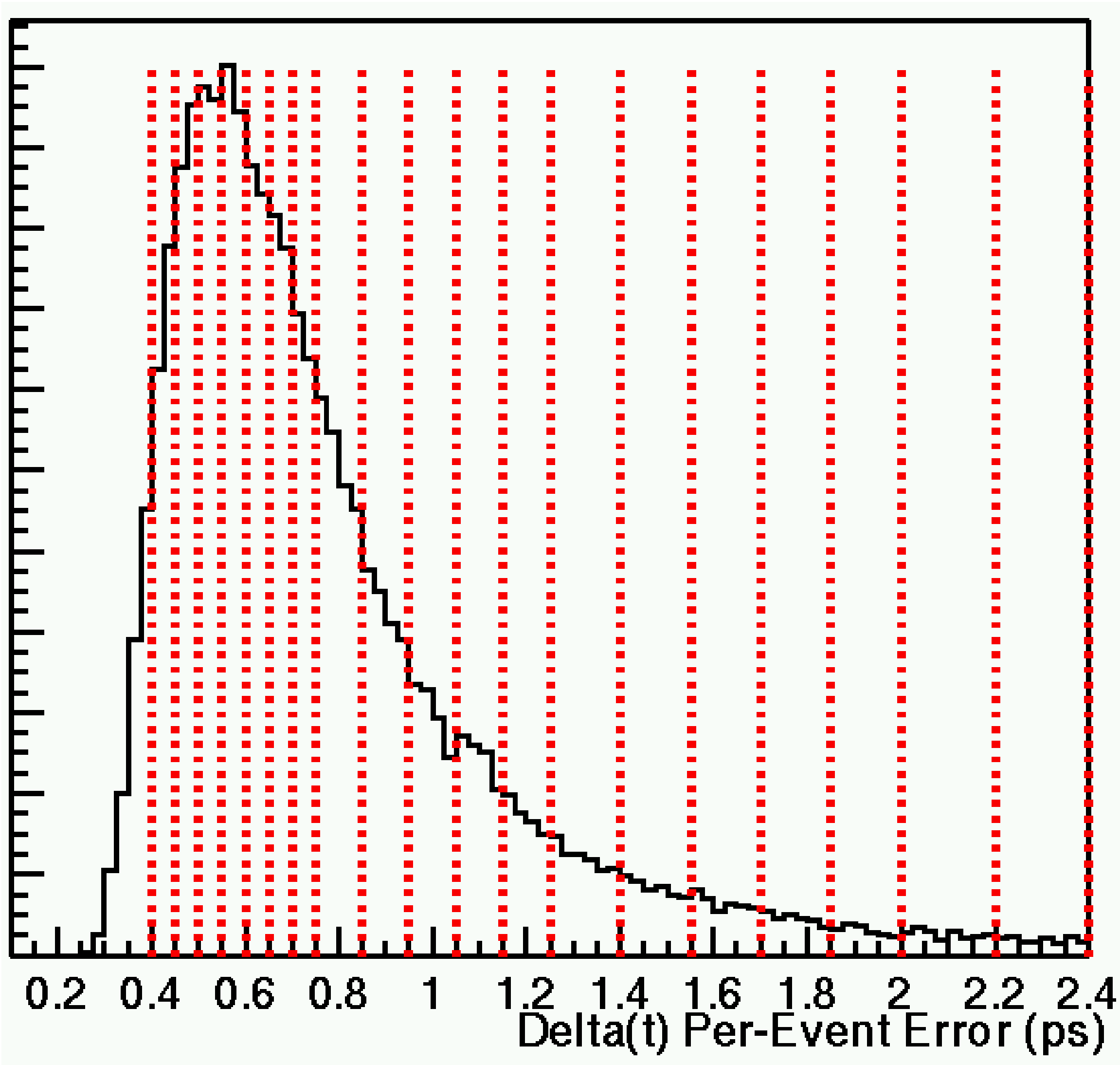
- G+G+G – two gaussians for core region, one for outliers. (8 parameters – 3 bias, 3 width, 2 fractions)

Plots are exagerated to show underlying structure

- GExp – $G\otimes(\delta+e^{-|\rho|})+G$. One gaussian with zero bias is convoluted with a delta function and one sided lifetime. Outliers modeled by single gaussian. (6 parameters – core width, core lifetime, core fraction, outlier width, bias and fraction)



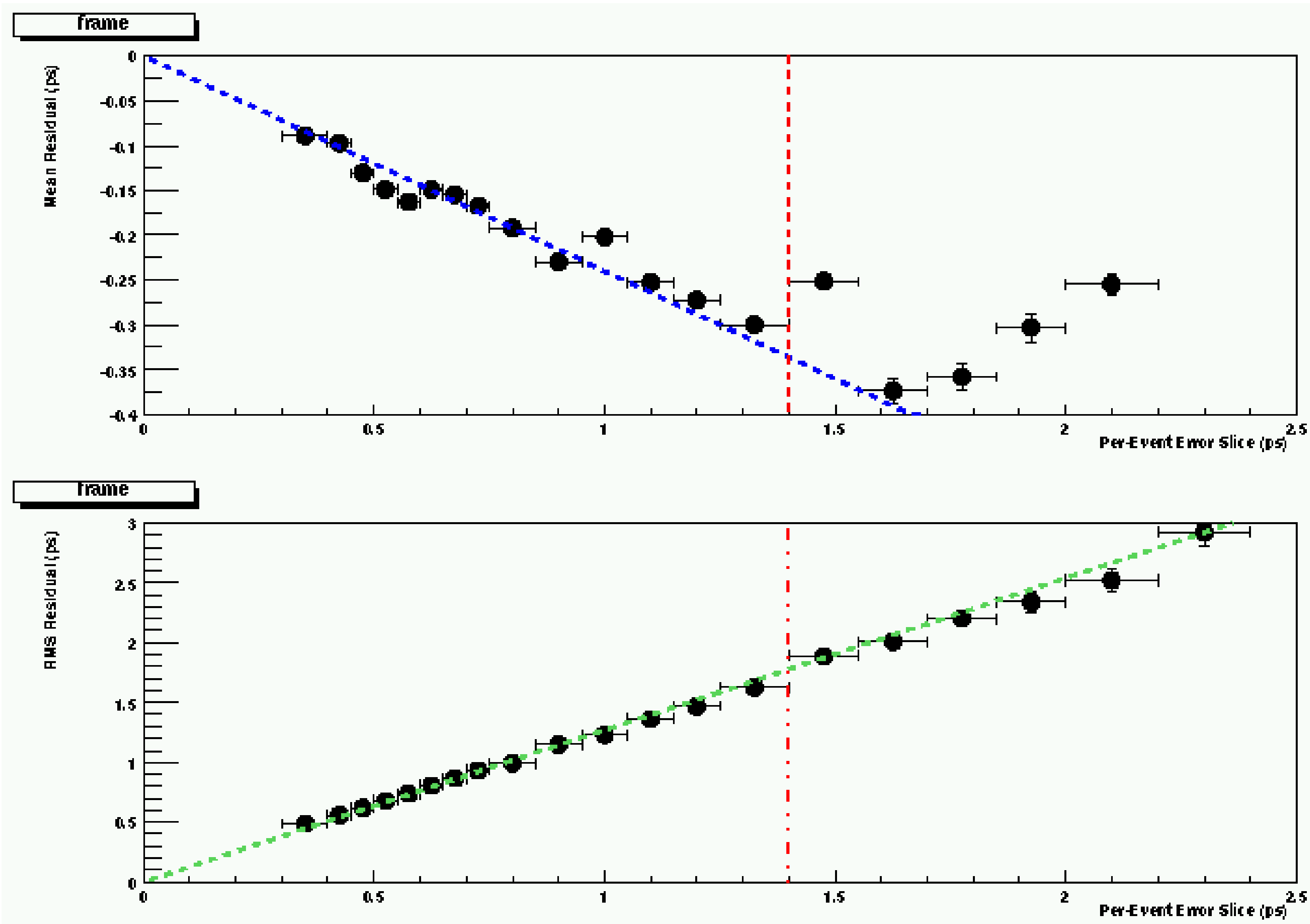
- The relationship between per−event−errors and fit parameters was investigated by dividing the sample into small per−event−error slices. The Δt residual distribution for each slice was fit with the resolution models.



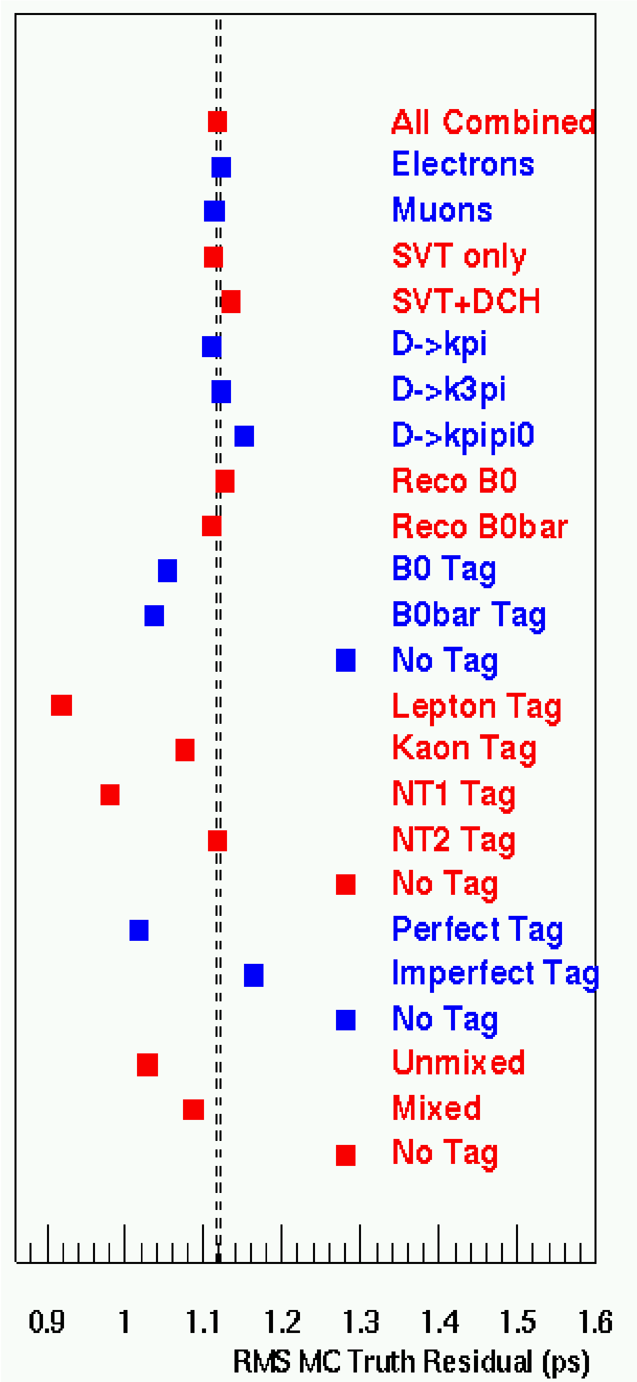
These plots show how the residual distribution mean and RMS scale with the calculated per−event−errors. All models have at least one variable that deviates from linearity above a per−event−error of 1.4 ps.

Sample Mean

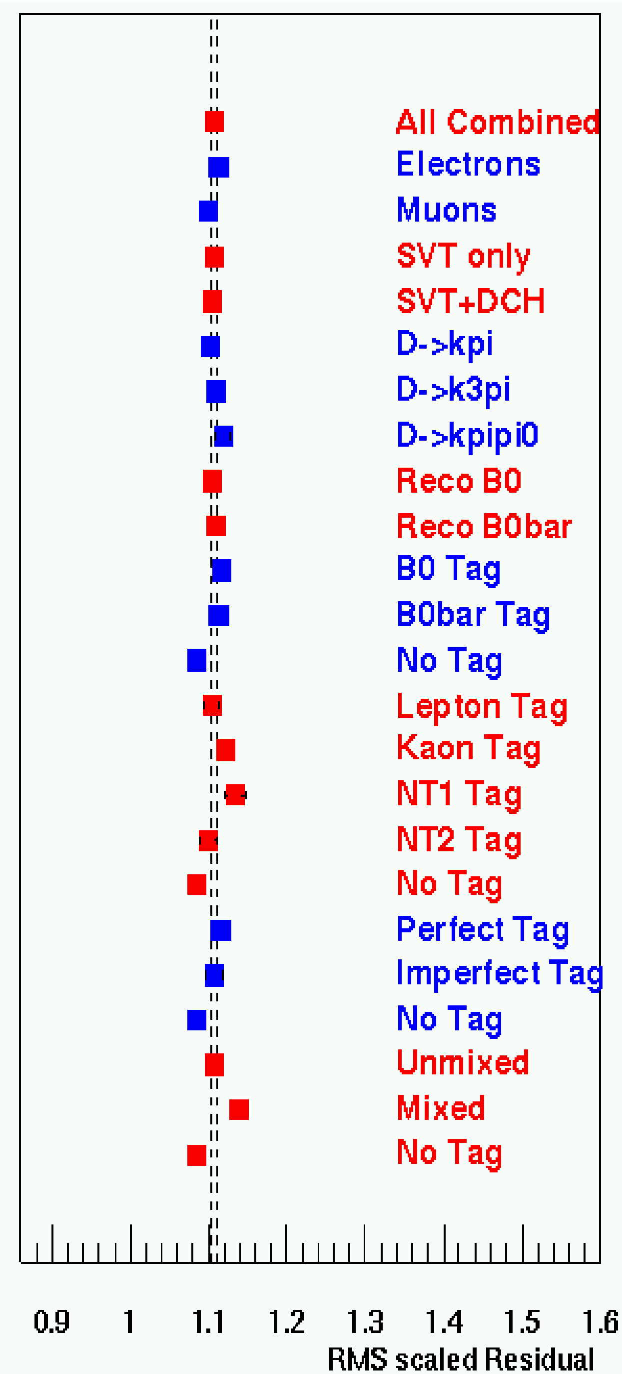
Sample RMS



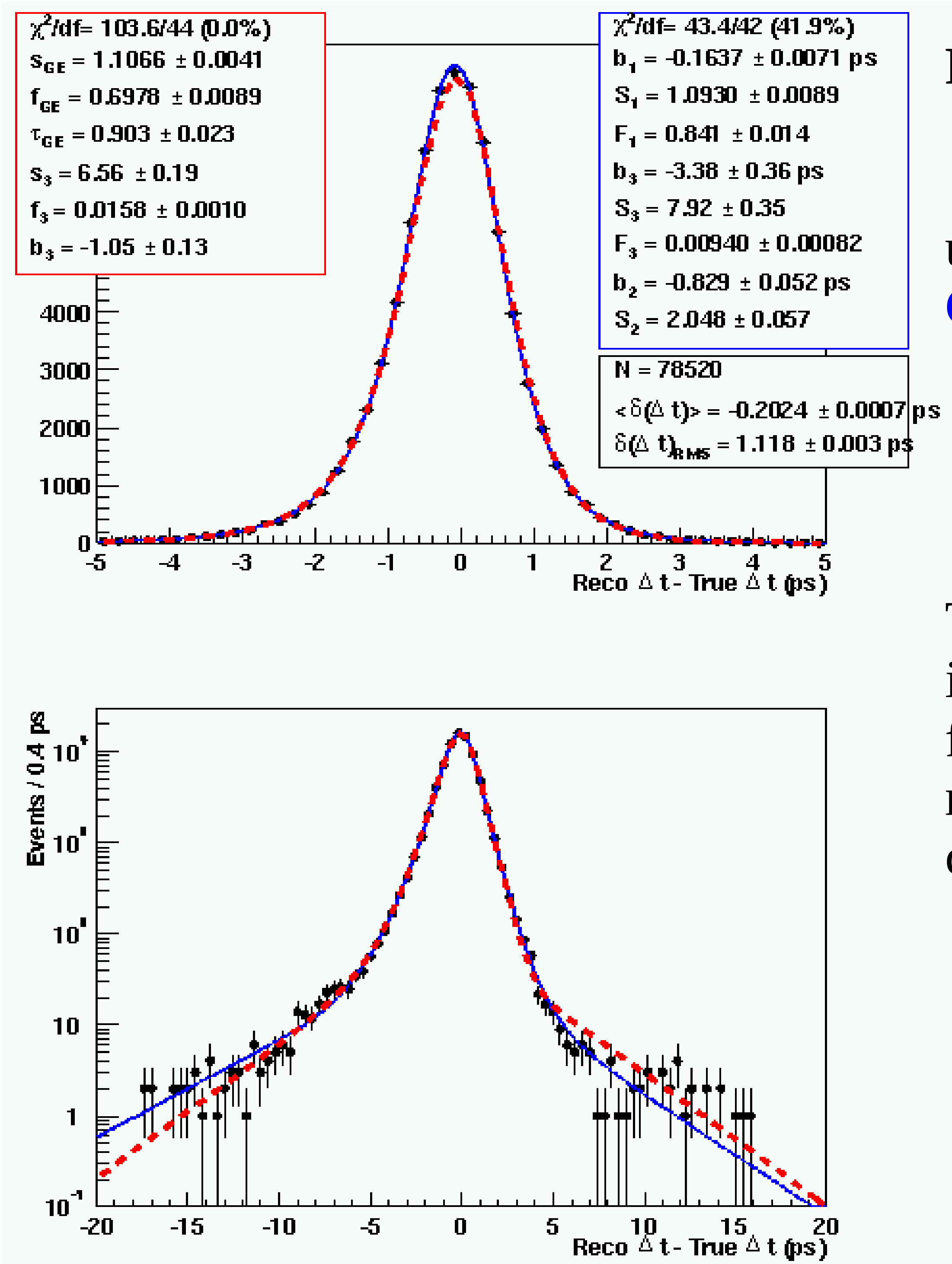
RMS from data by category



RMS scaled by per−event−error



This shows how well the per−event−error accounts for variations in residual due to different tagging categories, if the tag was correct or incorrect, if the event was tagged at all, etc...



Fitting for Resolution Parameters:

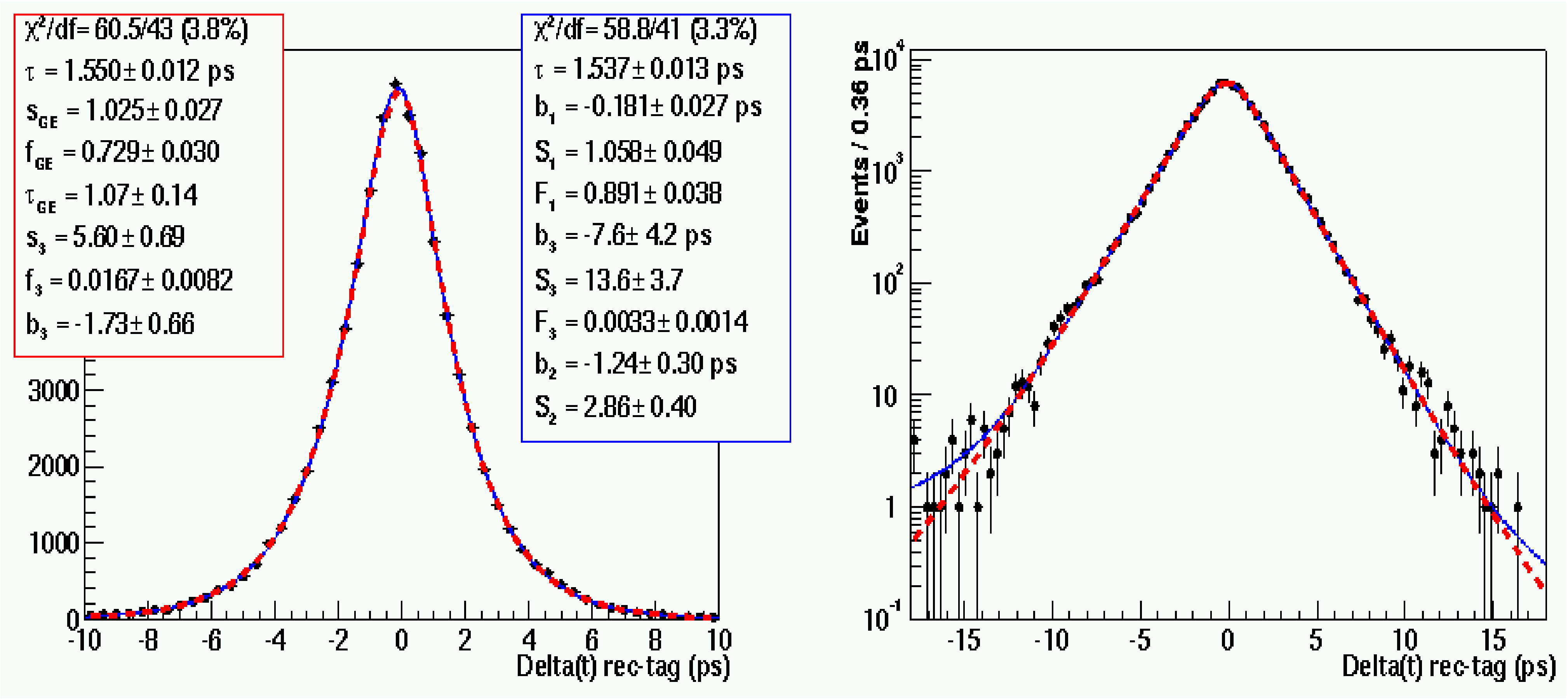
A fit for resolution parameters using MC truth for Gexp (red) and G+G+G (blue) models.

χ^2/dof G+G+G = 43.4/42
χ^2/dof Gexp = 103.6/44

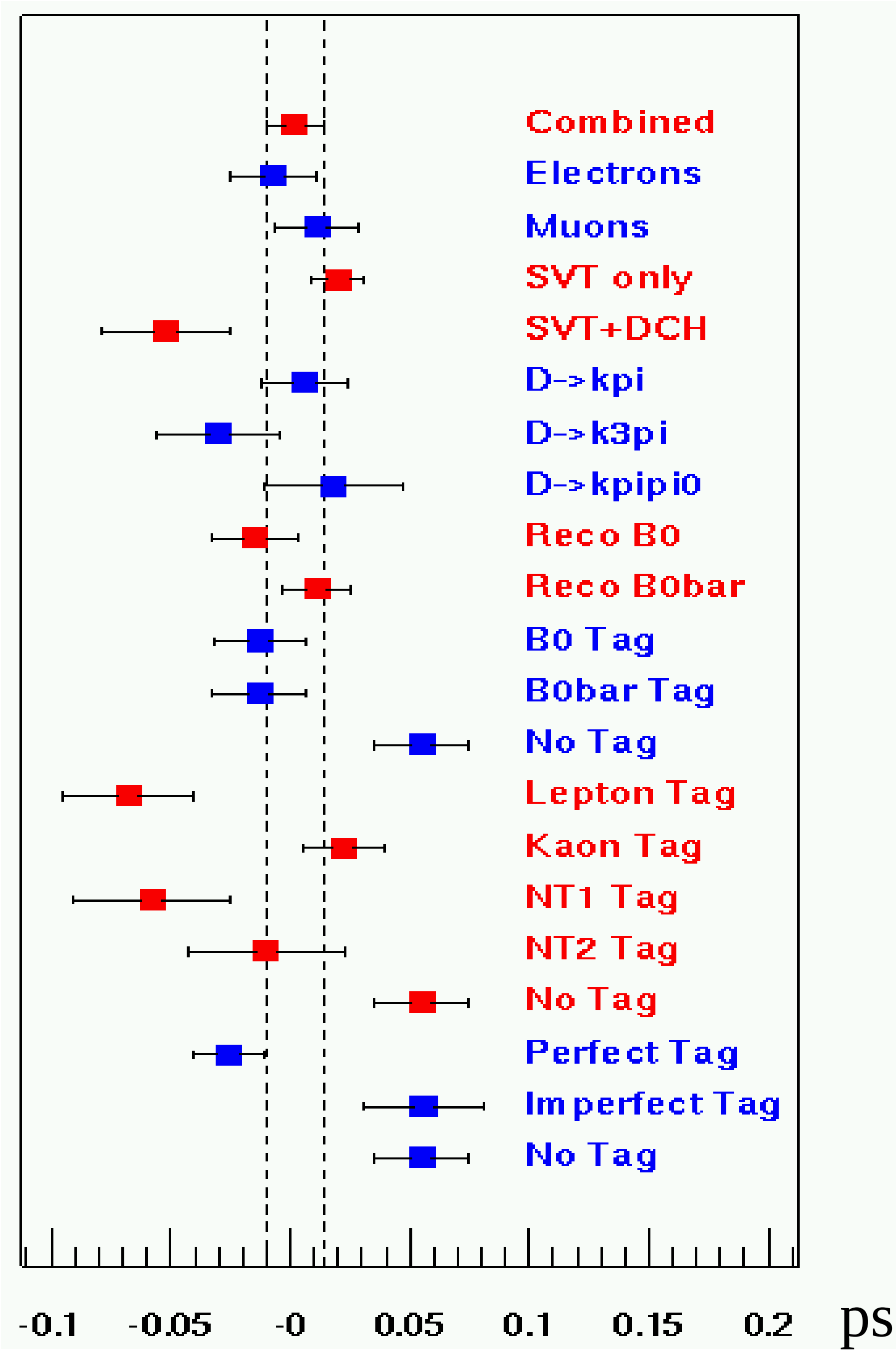
The most important feature to investigate is whether the resolution function introduces a bias in our measurements, the next step is to check this on lifetime measurements.

Fitting for Lifetimes

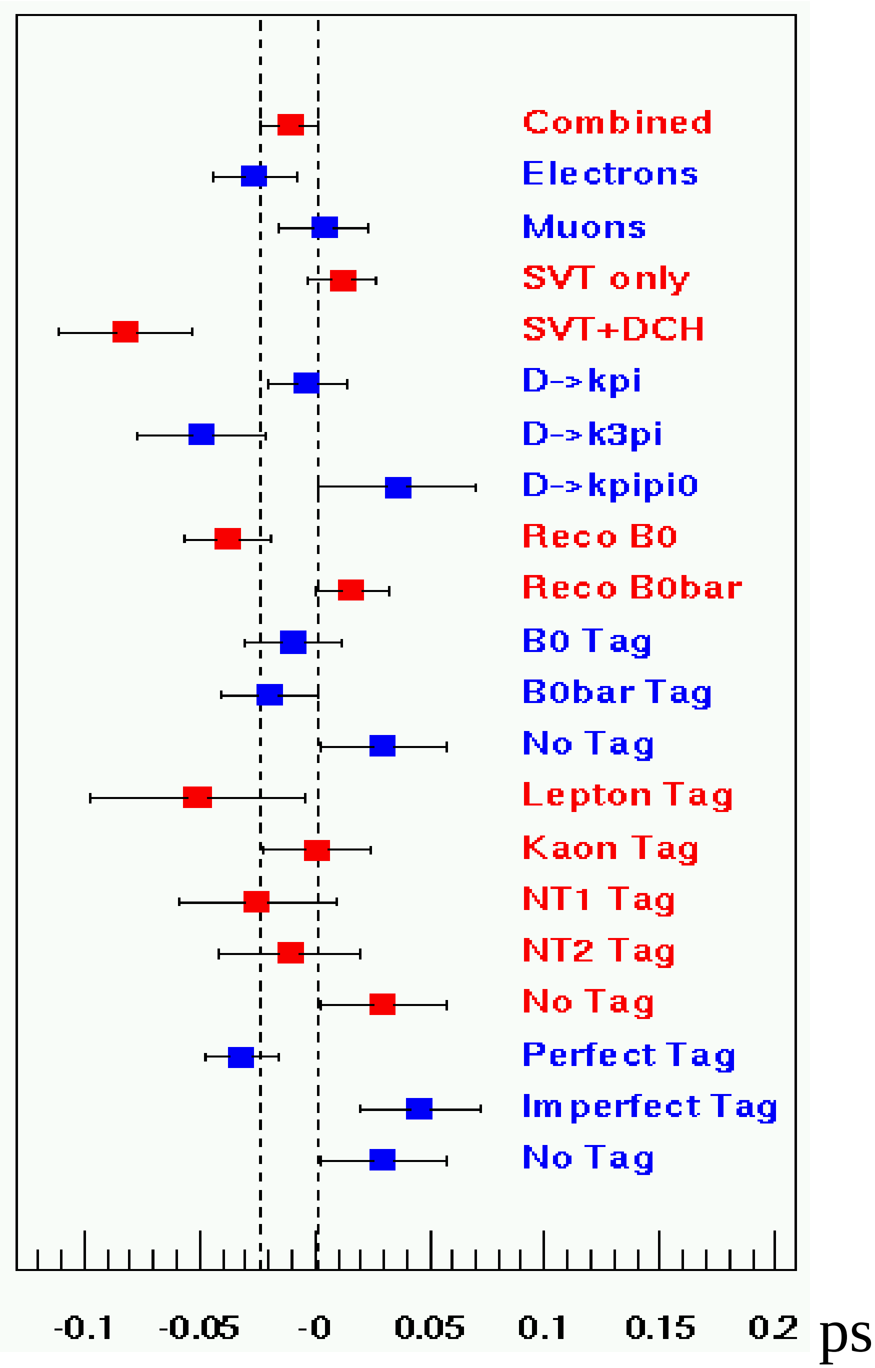
- The B0 lifetime is determined with all resolution parameters allowed to float.
- Results compared to generator value of 1.548 ps.



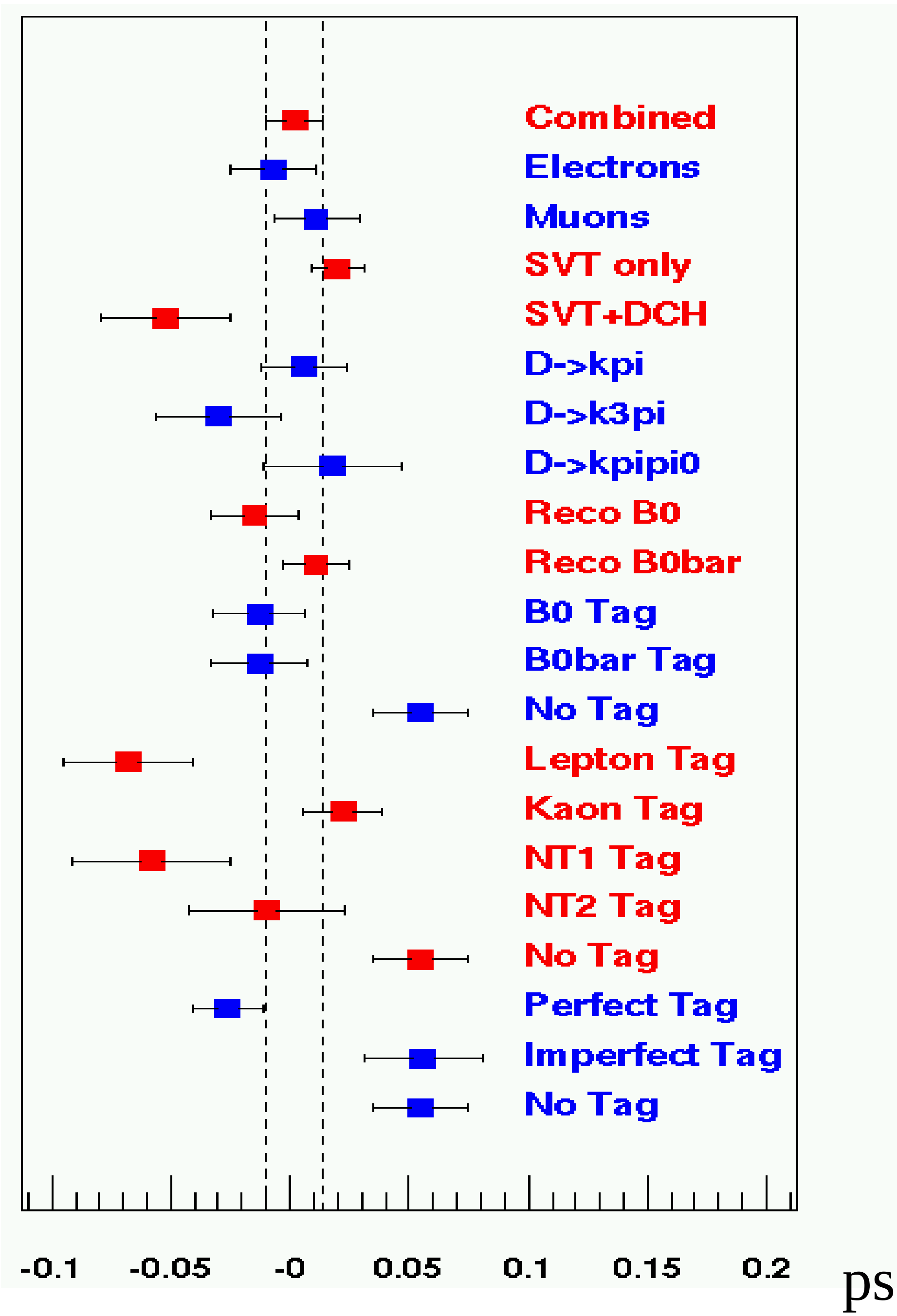
Gexp $\tau_{fit}-\tau_{true}$ = (0.002±0.012) ps



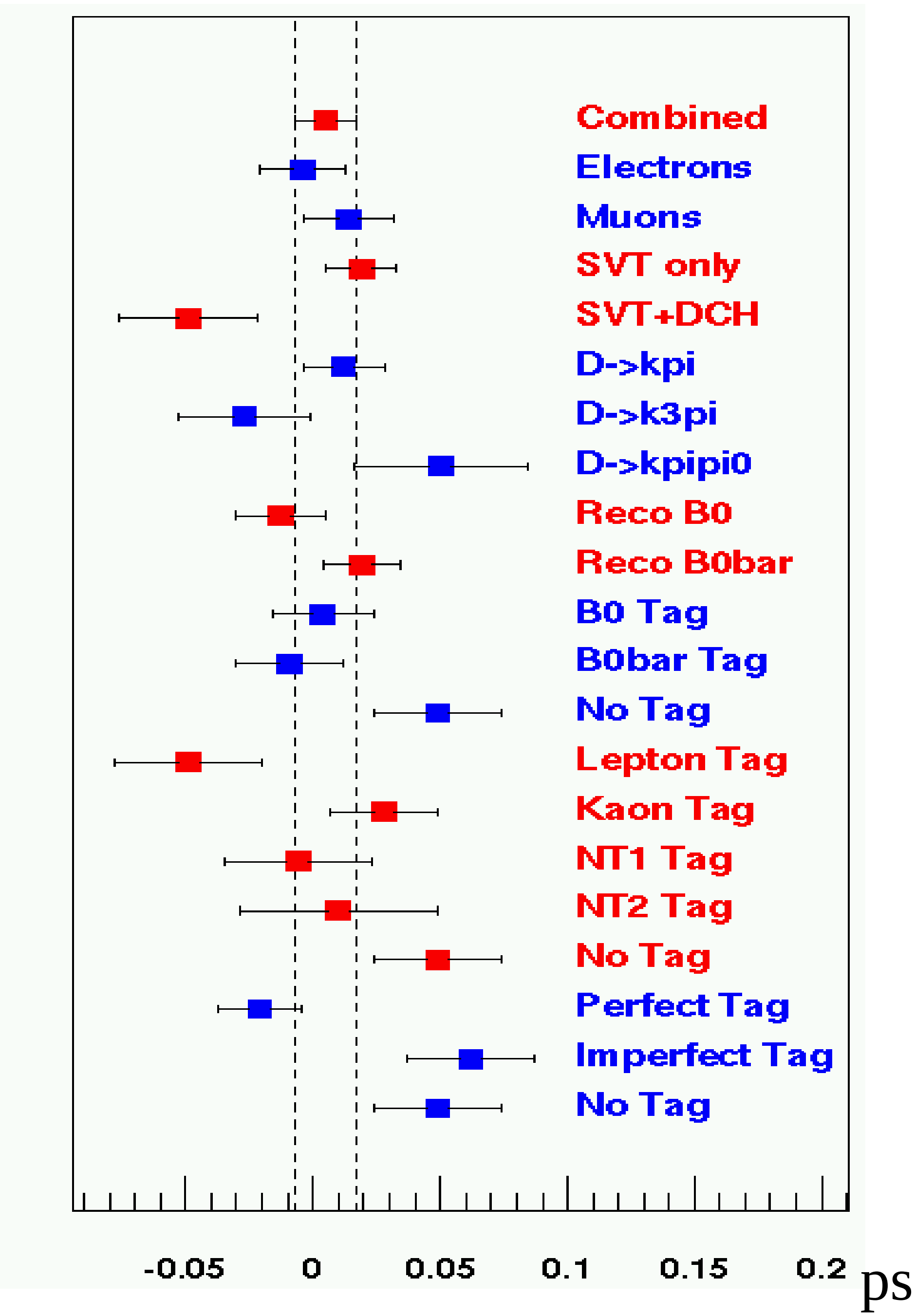
G+G+G $\tau_{fit}-\tau_{true}$ = (−0.011±0.013) ps



Gexp $\tau_{fit} - \tau_{true} = (0.002 \pm 0.012)$ ps



G+G $\tau_{fit} - \tau_{true} = (0.005 \pm 0.012)$ ps

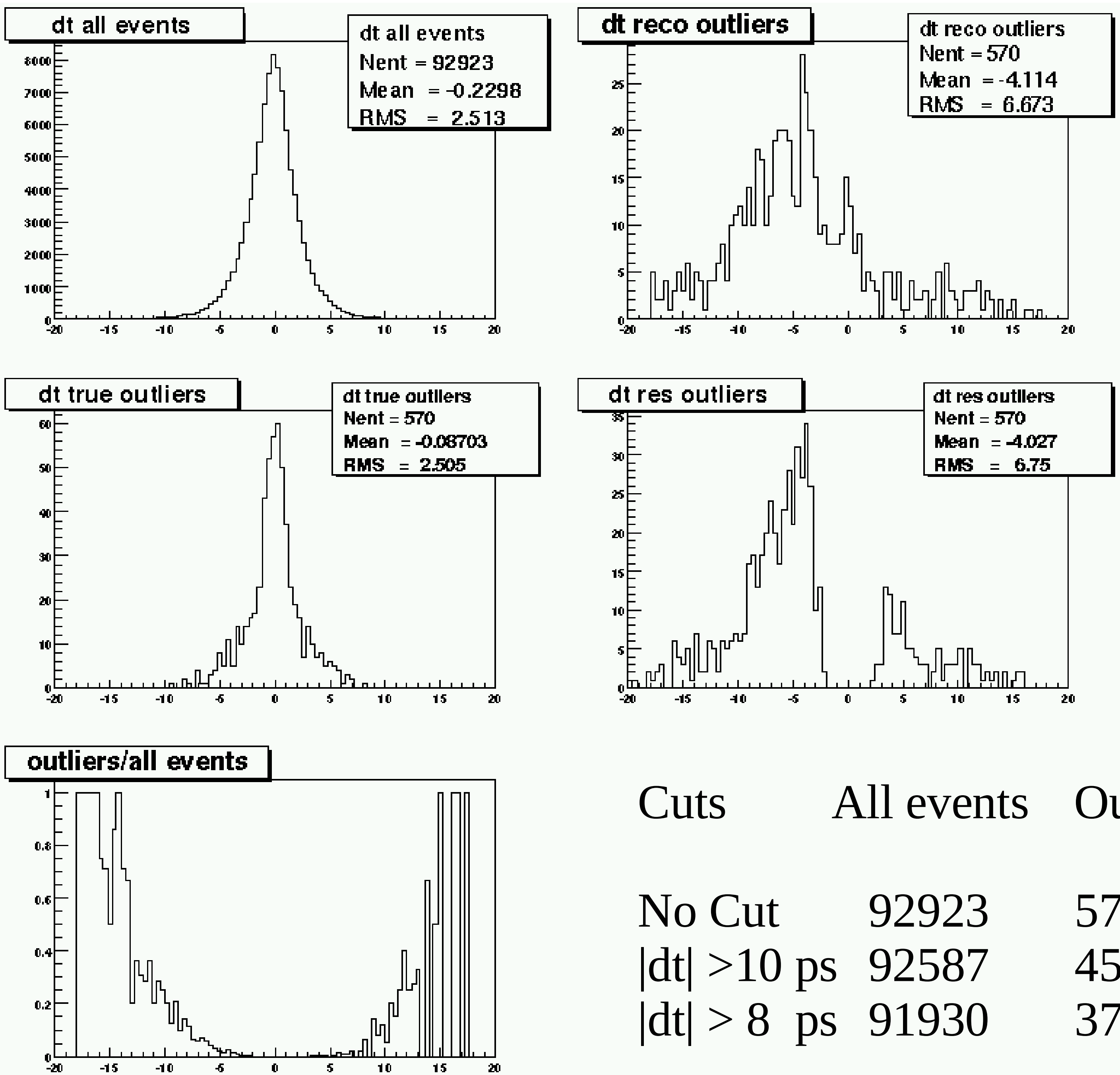


Progress on current problems

There are a number of interesting problems under examination right now:

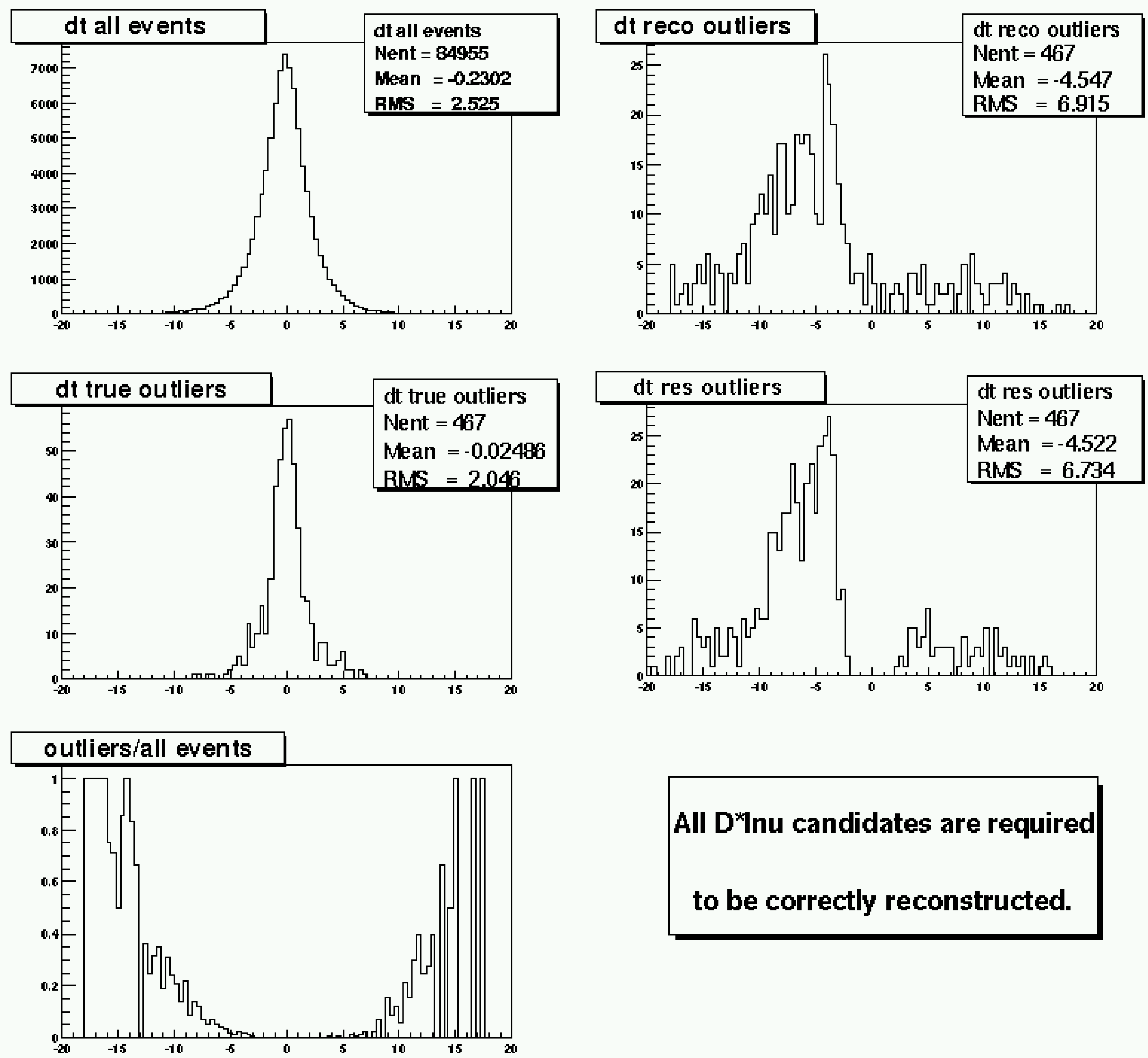
- Why does width scale factor seem to have non−zero intercept?
- Why does bias ~ scale with per−event−error?
- How can outliers be reduced? (also, what are they?)

- Things we have to work with:
  - Δt, Δt error, tracks used on tag side, tag category

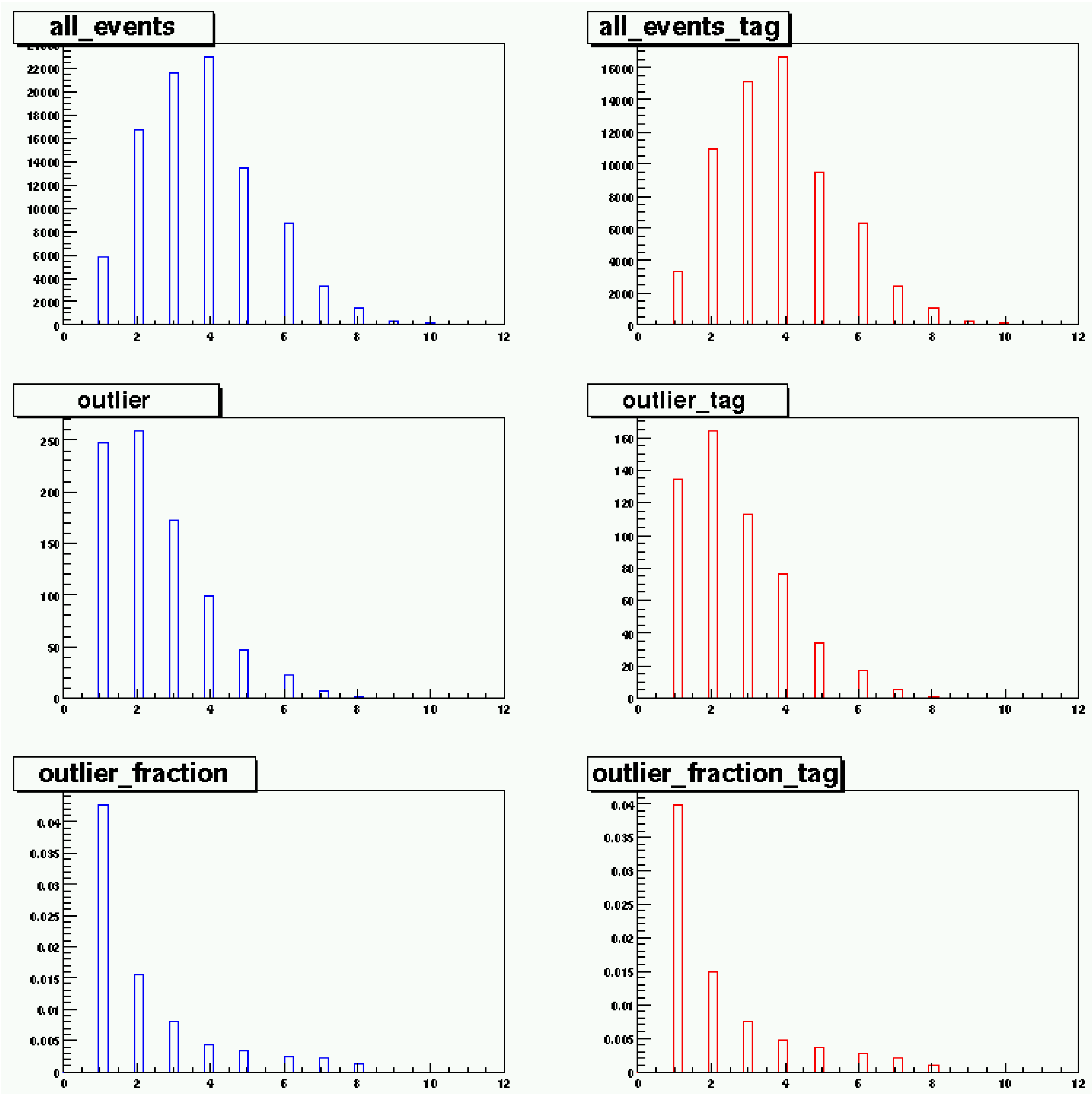


An outlier is defined as an event with |pull|>5.
The last plot shows what percentage of events in various Δt bins are outliers.

Cuts	All events	Outlier	Outlier %
No Cut	92923	570	0.61
|dt| >10 ps	92587	452	0.49
|dt| > 8 ps	91930	372	0.40



dt all events
dt all events
Nent = 84955
Mean = -0.2302
RMS = 2.525
dt reco outliers
dt reco outliers
Nent = 467
Mean = -4.547
RMS = 6.915
dt true outliers
dt true outliers
Nent = 467
Mean = -0.02486
RMS = 2.046
dt res outliers
dt res outliers
Nent = 467
Mean = -4.522
RMS = 6.734
outliers/all events
All D*lnu candidates are required
to be correctly reconstructed.

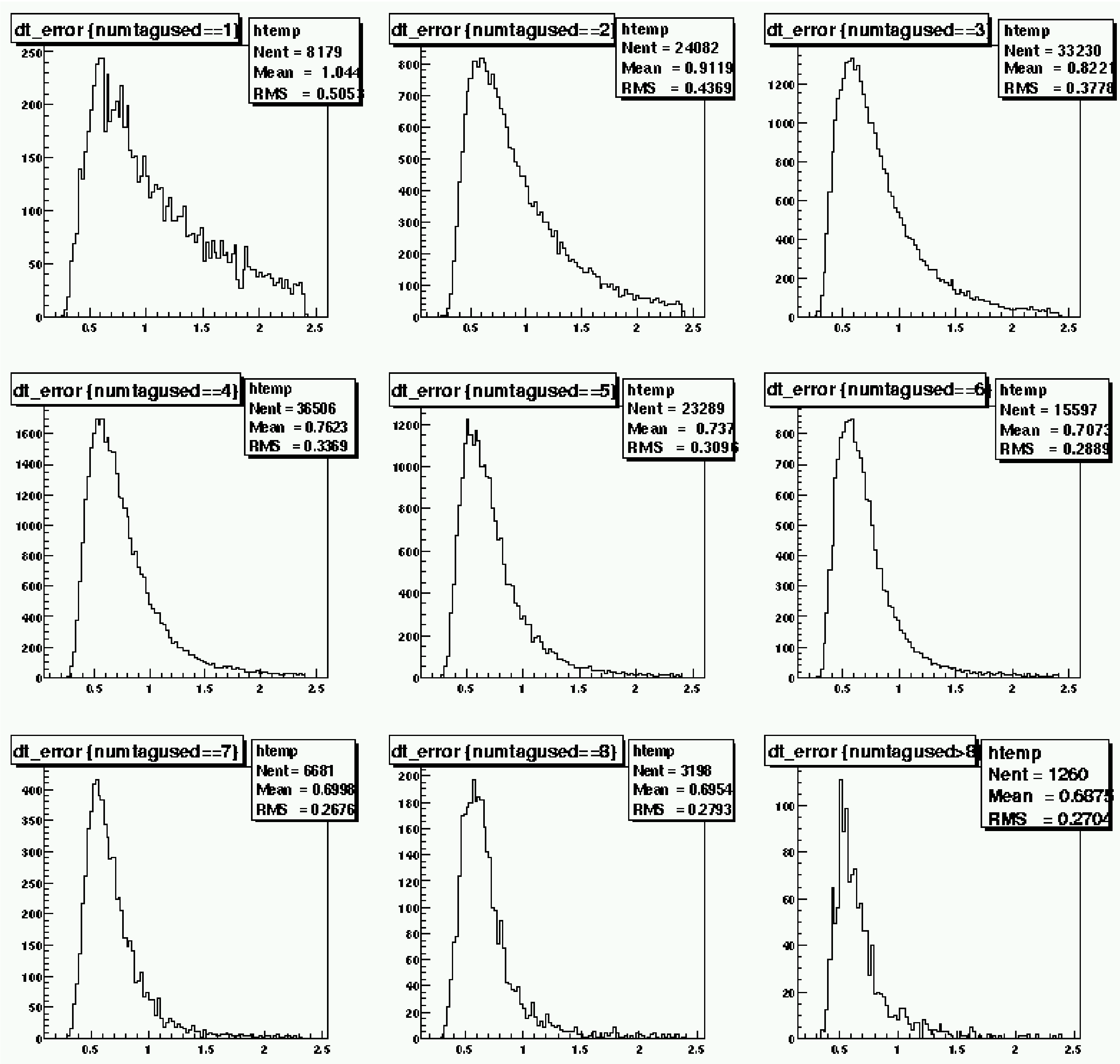


The bin with N=1 has the largest fraction of outliers (~4%).

N=2 is 1.5%
N=3 is 0.9%

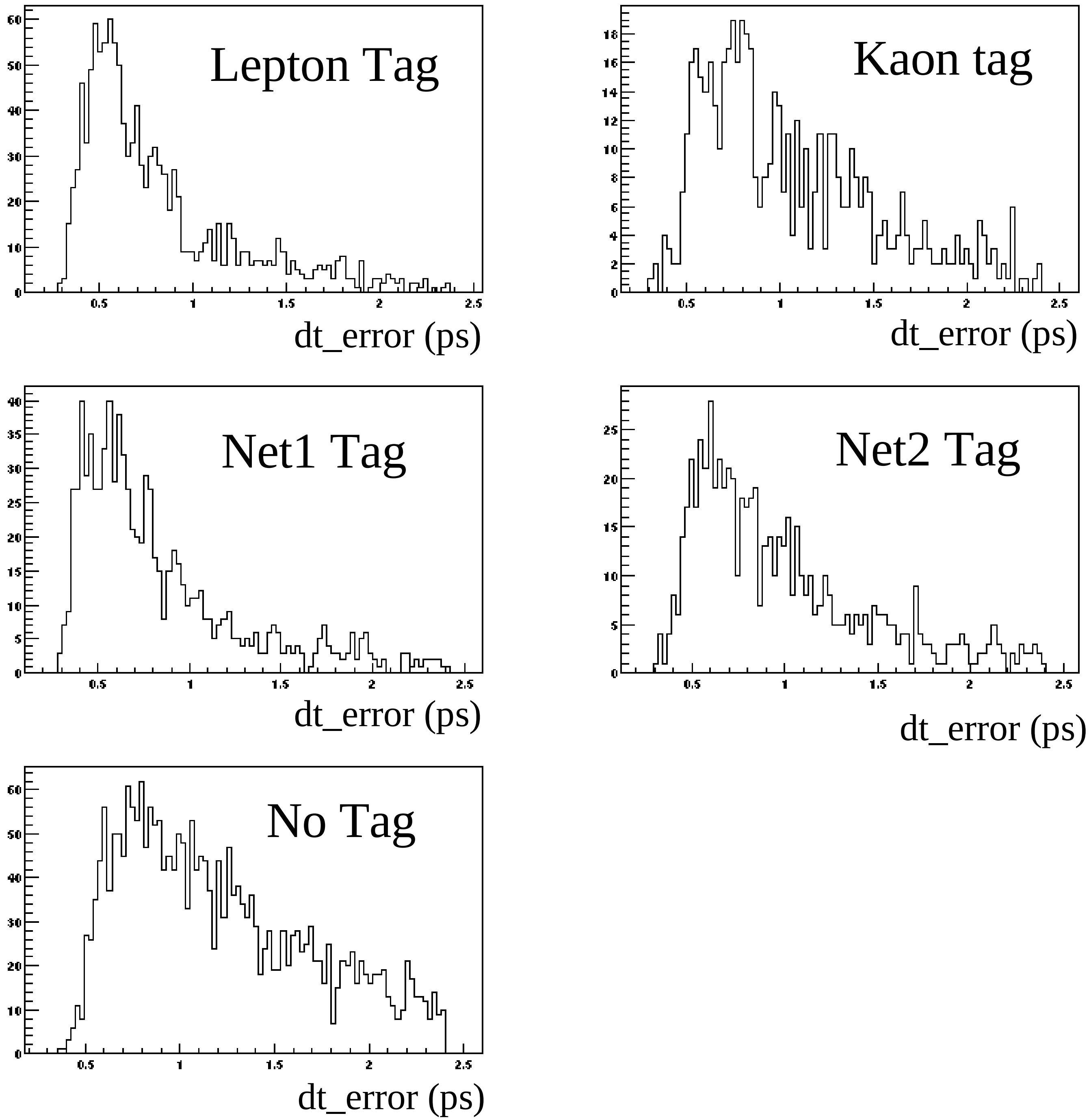
The others are all <.5%

The second column (red) shows the same sample with untagged events removed. There is no significant changes in outlier fractions.



Number of charged tracks used in tag vertex vs per−event_error

The plots are N=1, 2, ... , 8, >8.


Lepton Tag
dt_error (ps)
Kaon tag
dt_error (ps)
Net1 Tag
dt_error (ps)
Net2 Tag
dt_error (ps)
No Tag
dt_error (ps)

Conclusion

- For a high statistics sample like $D^* l \nu$, important to scale both the width and lifetime/bias.
- Per−event−error calculation working well.
- Both resolution functions give lifetime residuals consistent with zero => result insensitive to choice of resolution model.
- Several loose ends still left: scaling bias, outliers.

Outlook: With current sample we expect

- Δm = xxx ± 0.011 ± 0.018 ħ/ps 0.472 ± 0.017 ħ/ps (PDG)
- τ = xxx ± 0.016 ± xxx ps 1.548 ± 0.032 ps (PDG)

(systematic errors extrapolated from Osaka results, no semi-leptonic lifetime measurement from Osaka)

(cuts − must be correctly reconstructed, dterr<1.4)

Sample	Events	Mean $\delta\Delta t$ (ps)	RMS $\delta\Delta t$ (ps)	$\langle\sigma^2_{\Delta t}\rangle$ (ps)	$f(\|\text{pull}\| > 5)$ (%)
All Combined	78520	-0.20240 ± 0.00072	1.1179 ± 0.0028	0.749	0.866 ± 0.033
Electrons	40141	-0.2039 ± 0.0010	1.1220 ± 0.0040	0.751	0.825 ± 0.045
Muons	38379	-0.2008 ± 0.0010	1.1136 ± 0.0040	0.747	0.909 ± 0.048
SVT only	62012	-0.19770 ± 0.00079	1.1132 ± 0.0032	0.755	0.827 ± 0.036
SVT+DCH	16508	-0.2200 ± 0.0017	1.1353 ± 0.0062	0.726	1.012 ± 0.078
$D^0 \to K\pi$	44318	-0.20063 ± 0.00095	1.1094 ± 0.0037	0.740	0.885 ± 0.044
$D^0 \to K3\pi$	18229	-0.2064 ± 0.0015	1.1214 ± 0.0059	0.742	0.911 ± 0.070
$D^0 \to K\pi\pi^0$	13984	-0.2016 ± 0.0017	1.1507 ± 0.0069	0.783	0.801 ± 0.075
$D^0 \to K_s\pi\pi$	1989	-0.2110 ± 0.0047	1.038 ± 0.016	0.765	0.50 ± 0.16
Lepton Tag	11043	-0.10474 ± 0.00100	0.9182 ± 0.0062	0.670	0.589 ± 0.073
Kaon Tag	27002	-0.2316 ± 0.0014	1.0757 ± 0.0046	0.732	0.785 ± 0.054
NT1 Tag	6829	-0.1263 ± 0.0015	0.9814 ± 0.0084	0.686	0.586 ± 0.092
NT2 Tag	11257	-0.1910 ± 0.0018	1.1171 ± 0.0074	0.757	0.977 ± 0.093
No Tag	22389	-0.2443 ± 0.0016	1.2811 ± 0.0061	0.817	1.130 ± 0.071
Reco'd B^0	39768	-0.2020 ± 0.0010	1.1264 ± 0.0040	0.748	0.888 ± 0.047
Reco'd $\overline{B^0}$	38752	-0.2028 ± 0.0010	1.1092 ± 0.0040	0.750	0.844 ± 0.046
B^0 Tag	28194	-0.1920 ± 0.0011	1.0535 ± 0.0044	0.721	0.784 ± 0.053
$\overline{B^0}$ Tag	27937	-0.1794 ± 0.0011	1.0369 ± 0.0044	0.719	0.737 ± 0.051
Perfect Tag	46088	-0.17199 ± 0.00080	1.0170 ± 0.0033	0.712	0.688 ± 0.038
Imperfect Tag	10043	-0.2486 ± 0.0025	1.1644 ± 0.0082	0.754	1.10 ± 0.10
Unmixed	39989	-0.17319 ± 0.00087	1.0280 ± 0.0036	0.715	0.723 ± 0.042
Mixed	16142	-0.2167 ± 0.0017	1.0863 ± 0.0060	0.733	0.855 ± 0.072

Extra Slide

Sample	True $\Delta\tau$	G+G+G $\Delta\tau$ Only	G+G+G $\Delta\tau$+Resln	G+G $\Delta\tau$ Only	G+G $\Delta\tau$+Resln	GExp $\Delta\tau$ Only	GExp $\Delta\tau$+Resln
Combined	-0.0056 ± 0.0055	-0.0077 ± 0.0065	-0.011 ± 0.013	-0.0134 ± 0.0065	0.005 ± 0.012	-0.0105 ± 0.0065	0.002 ± 0.012
Electrons	0.0018 ± 0.0077	-0.0039 ± 0.0091	-0.026 ± 0.018	-0.0110 ± 0.0091	-0.004 ± 0.017	-0.0066 ± 0.0091	-0.007 ± 0.018
Muons	-0.0133 ± 0.0078	-0.0114 ± 0.0092	0.004 ± 0.019	-0.0154 ± 0.0092	0.014 ± 0.018	-0.0140 ± 0.0092	0.011 ± 0.018
SVT only	-0.0031 ± 0.0062	-0.0047 ± 0.0073	0.012 ± 0.015	-0.0101 ± 0.0073	0.019 ± 0.014	-0.0077 ± 0.0073	0.020 ± 0.011
SVT+DCH	-0.015 ± 0.012	-0.019 ± 0.014	-0.082 ± 0.029	-0.025 ± 0.014	-0.049 ± 0.027	-0.021 ± 0.014	-0.052 ± 0.027
$D^0 \to K\pi$	-0.0128 ± 0.0073	-0.0106 ± 0.0086	-0.003 ± 0.017	-0.0166 ± 0.0086	0.012 ± 0.016	-0.0132 ± 0.0086	0.006 ± 0.018
$D^0 \to K3\pi$	0.005 ± 0.012	-0.002 ± 0.014	-0.049 ± 0.028	-0.007 ± 0.013	-0.027 ± 0.026	-0.005 ± 0.014	-0.030 ± 0.026
$D^0 \to K\pi\pi^0$	-0.006 ± 0.013	-0.013 ± 0.015	0.036 ± 0.034	-0.018 ± 0.015	0.05 ± 0.034	-0.017 ± 0.015	0.018 ± 0.029
$D^0 \to K_s\pi\pi$	0.062 ± 0.036	0.048 ± 0.041	-0.043 ± 0.075	0.037 ± 0.041	-0.026 ± 0.075	0.044 ± 0.041	-0.032 ± 0.074
Reco'd B^0	-0.0101 ± 0.0077	-0.0098 ± 0.0091	-0.038 ± 0.019	-0.0154 ± 0.0091	-0.013 ± 0.018	-0.0126 ± 0.0091	-0.015 ± 0.018
Reco'd $\overline{B^0}$	-0.0010 ± 0.0079	-0.0057 ± 0.0092	0.016 ± 0.016	-0.0114 ± 0.0092	0.019 ± 0.015	-0.0085 ± 0.0092	0.011 ± 0.014
B^0 Tag	0.0026 ± 0.0092	-0.011 ± 0.011	-0.009 ± 0.021	-0.017 ± 0.011	0.004 ± 0.020	-0.013 ± 0.011	-0.013 ± 0.019
$\overline{B^0}$ Tag	-0.0210 ± 0.0091	-0.020 ± 0.011	-0.020 ± 0.021	-0.025 ± 0.011	-0.009 ± 0.021	-0.023 ± 0.011	-0.013 ± 0.020
Lepton Tag	-0.030 ± 0.014	-0.036 ± 0.016	-0.051 ± 0.047	-0.040 ± 0.016	-0.049 ± 0.029	-0.038 ± 0.016	-0.068 ± 0.027
Kaon Tag	0.0000 ± 0.0094	-0.004 ± 0.011	0.001 ± 0.023	-0.007 ± 0.011	0.028 ± 0.021	-0.006 ± 0.011	0.022 ± 0.017
NT1 Tag	-0.032 ± 0.018	-0.028 ± 0.021	-0.025 ± 0.034	-0.035 ± 0.021	-0.006 ± 0.029	-0.028 ± 0.021	-0.058 ± 0.033
NT2 Tag	0.004 ± 0.015	-0.017 ± 0.017	-0.011 ± 0.031	-0.023 ± 0.017	0.010 ± 0.039	-0.021 ± 0.017	-0.010 ± 0.033
No Tag	0.003 ± 0.010	0.013 ± 0.013	0.030 ± 0.027	0.006 ± 0.013	0.049 ± 0.025	0.010 ± 0.013	0.055 ± 0.020
Perfect Tag	-0.0139 ± 0.0071	-0.0181 ± 0.0082	-0.032 ± 0.016	-0.0222 ± 0.0082	-0.021 ± 0.016	-0.0202 ± 0.0082	-0.026 ± 0.015
Imperfect Tag	0.013 ± 0.016	-0.002 ± 0.018	0.046 ± 0.026	-0.009 ± 0.018	0.062 ± 0.025	-0.005 ± 0.018	0.056 ± 0.025