Dissipative effect, $\mathcal{A}_{\ell\ell}$, and $\Delta\Gamma(B^0)$

Dissipative effects,

Mixing induced CP violation ($\mathcal{A}_{\ell\ell}$),

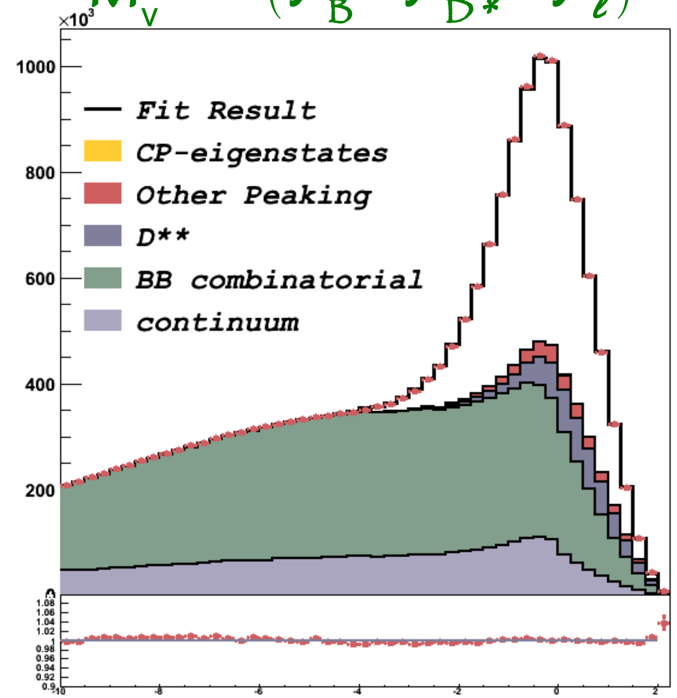
$$\Delta\Gamma(B^0) = \Gamma(B_H) - \Gamma(B_L)$$

with partial reconstruction of

$$B^0 \to D^{*-} \ell \nu_\ell$$

Perspectives

$$M_\nu^2 = (\mathcal{P}_B - \mathcal{P}_{D*} - \mathcal{P}_\ell)^2$$



Outline

- Theoretical motivations
- Data sets
- Fit method
- Progress report
- Status & perspectives

Theoretical motivation

- Consider $B\bar{B}$ as an Open Quantum System:
  - i.e. , interacting with an environment
- Weak coupling (gravitational interaction) :
  - dynamics well known
  - standard time evolution equations modified by interaction with environment
  - dissipation effects described by 6 new parameters, each of the scale of about

$$\frac{M_B^2}{M_{Planck}} \simeq 10^{-18} GeV \quad \left(\simeq 10^{-6} \Gamma_B \right)$$

  - test in fact simplified model with just one dissipative parameter

Benatti, Floreanini, Romano
"Irreversibility and dissipation in neutral B-meson decays"
Nuclear Physics B 602 (2001) 541–571

Single Tag Decay Rate

- Time evolution of untagged $B^0 \rightarrow \ell \nu X$

lepton charge

$$N(\tau) = N_0 e^{-|\tau|}\left[1 + \frac{q_\ell \xi}{1+\xi}(\cos\omega\tau + \sin\omega\tau) + \mathcal{D}(1+|\tau|) + \delta^2\left(-\tau + \frac{\tau^2}{2}\right)\right]$$

- where :
  - $\tau = \Gamma\Delta t$
  - $\xi = (|p|^2 - |q|^2) \,/\, (|p|^2 + |q|^2)$
  - $\delta = \Delta\Gamma / 2\Gamma$
  - $\omega = \Gamma\,\Delta m_d$
  - $\mathcal{D}$: adimensional dissipative parameter

more details in S.Marcantoni's thesis :
" Dissipative effects in neutral B meson decays"
Universita' Trieste AA 2013 2014

- Similar relations apply to tagged events
- Test feasibility on *BABAR* data (415 fb^{-1})

Data set

- 5×10^6 signal events from $B^0 \to D^{*-}\ell^+\nu$ decays with partial $D^{*-} \to \pi^-_s D^0$, which does not need reconstruction of the D^0.
- Well established, high efficient selection of B^0 states, used for world class BABAR measurements:

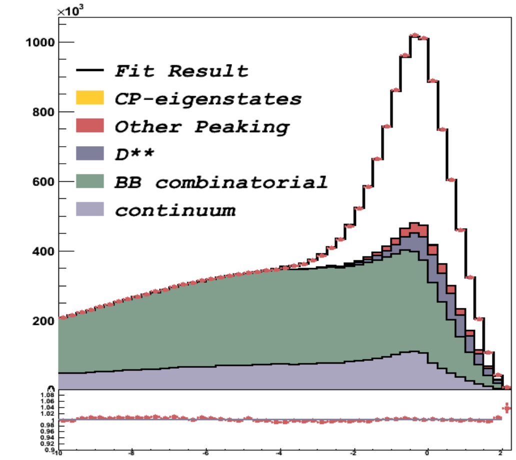
$$\Gamma^{-1} = 1.504 \pm 0.013^{+0.018}_{-0.013}\ ps$$
$$\Delta m_d = 0.511 \pm 0.007 \pm 0.007\ ps^{-1}$$

lepton tag, PRD 012004 73 (2006), 81 fb^{-1}

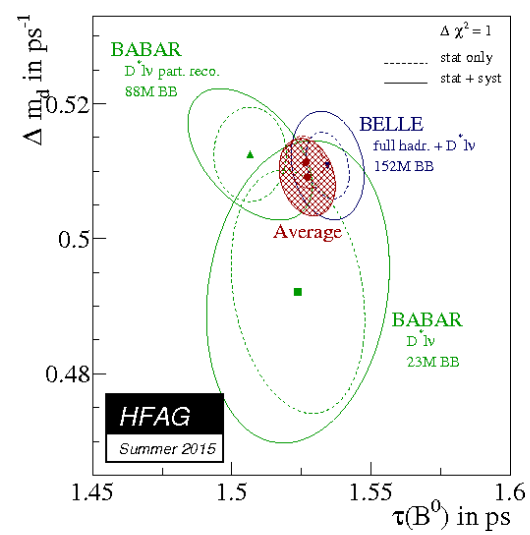
$$\delta_{CP} = \left(0.29 \pm 0.84^{+1.88}_{-0.61}\right) \times 10^{-3}$$

Kaon tag PRL 112006 86 (2012), 425 fb^{-1}

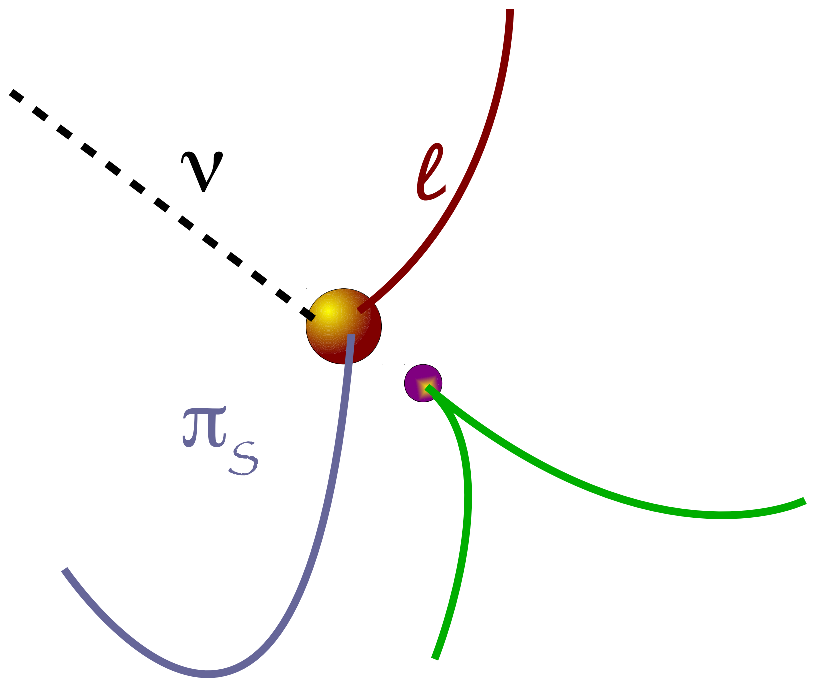
- *Main issue :*
  - Δt measurement



$$M_\nu^2 = (\mathcal{P}_B - \mathcal{P}_{D*} - \mathcal{P}_\ell)^2$$

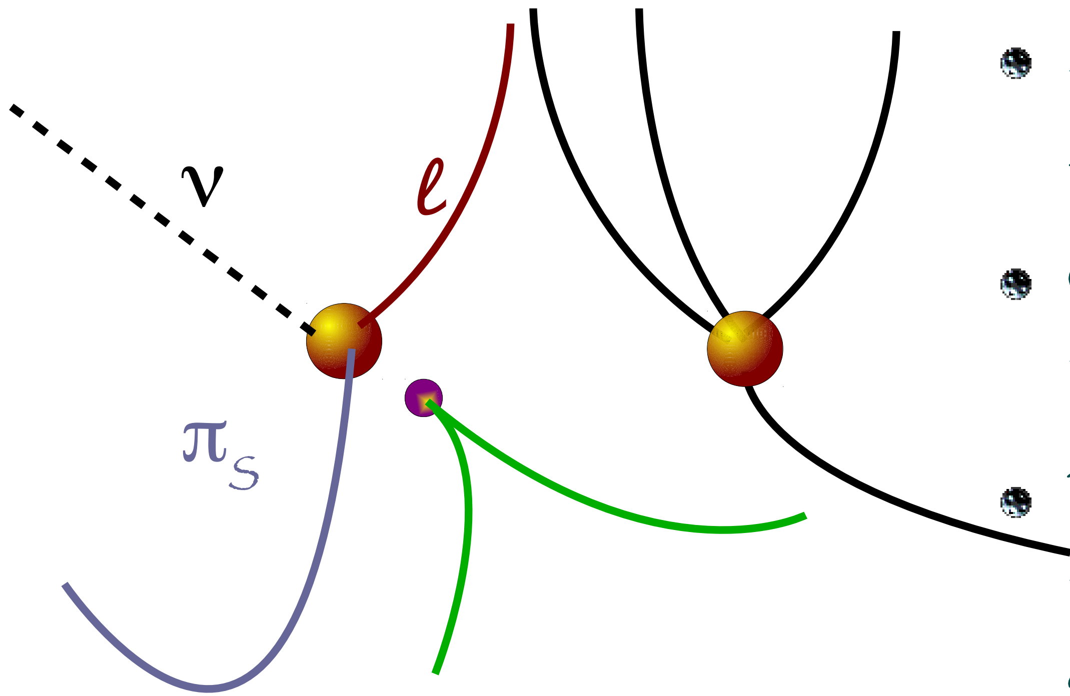


Δt with partial reco: "Decay" side



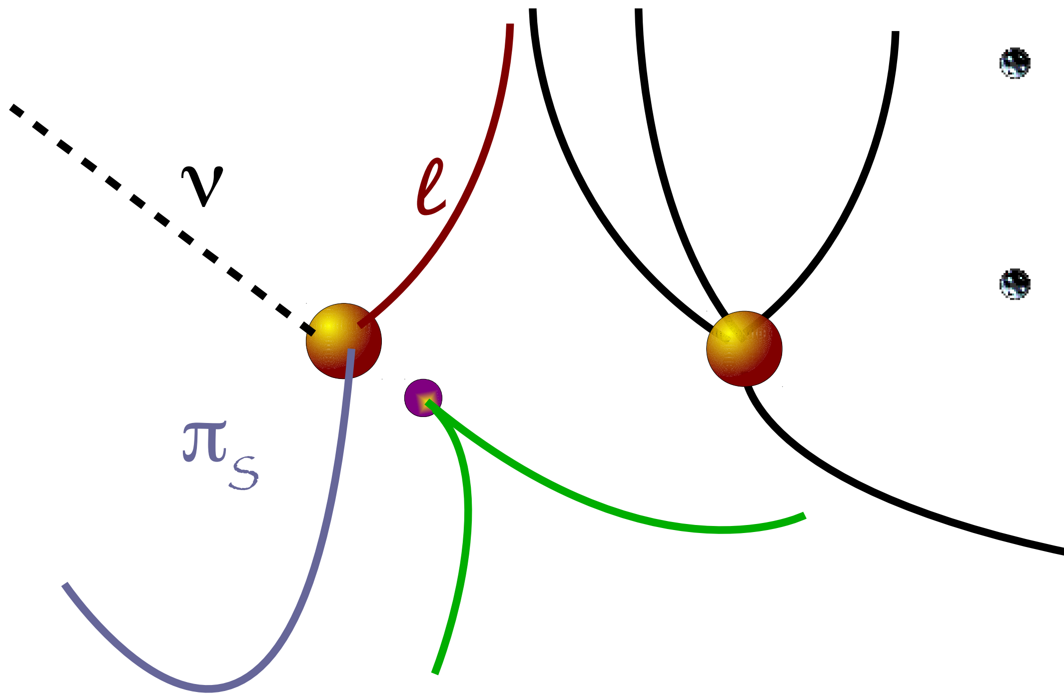
- Decay vertex from ℓ, π_s and beam spot intersection
- Tracks from unresolved D^0 (green) are not identified

Δt with partial reco: "other" side



- Decay vertex from ℓ, π_s and beam spot intersection
- Other vertex from the remaining charge tracks
- Tracks from the unresolved D^0 pull the tag vertex towards the decay vertex

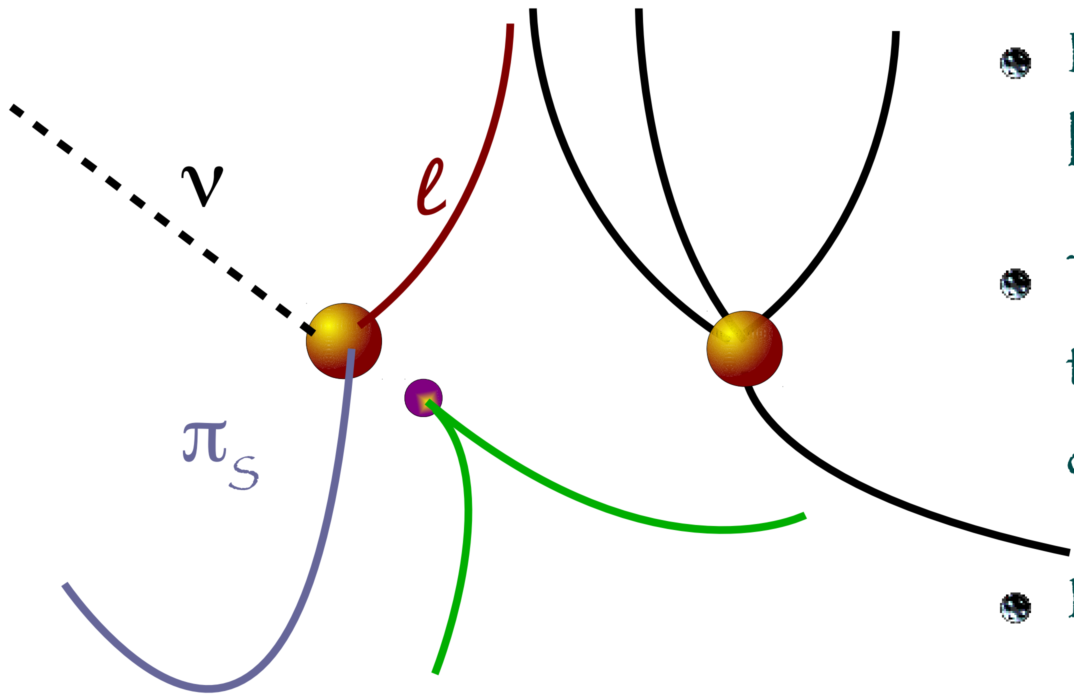
Δt with partial reco: BIAS



- Decay vertex from ℓ, π_s and beam spot intersection
- Tracks from unresolved D^0 pull the tag vertex towards the decay vertex

Bias: $\Delta t_{meas} < \Delta t_{true}$

Δt with partial reco: remedy



- Decay vertex from ℓ, π_s and beam spot intersection
- Tracks from unresolved D^0 pull the tag vertex towards the decay vertex
- Bias : $\Delta t_{meas} < \Delta t_{true}$
- "Cone cut" : remove tracks near to the π_s
  - bias only reduced
  - efficiency loss, resolution worsened
- Use just one track (ℓ, K)
  - good only for tagged analysis
  - spoils Δt resolution

Δt : a new hope

- Three sets of tracks
  - ℓ,π_s (from $B \to \nu\, \ell^+ D^{*-} \to \pi_s D^0$) "Reco" vertex
  - $D^0 \to X$ "D" vertex
  - other $B \to X'$ "Tag" vertex
- In each event consider all possible combination of tracks (except ℓ,π_s) in two sets :
  - "D" side / Tag side
- Choose the combination maximizing a likelihood $\mathcal{L}$ based on several variables (N_{tag}, N_D, E_{tag}, E_D, χ^2_{Tag}, χ^2_D, $\cos(\Theta)$, ΔE ...)
- $\mathcal{L}$ tuned on simulated data

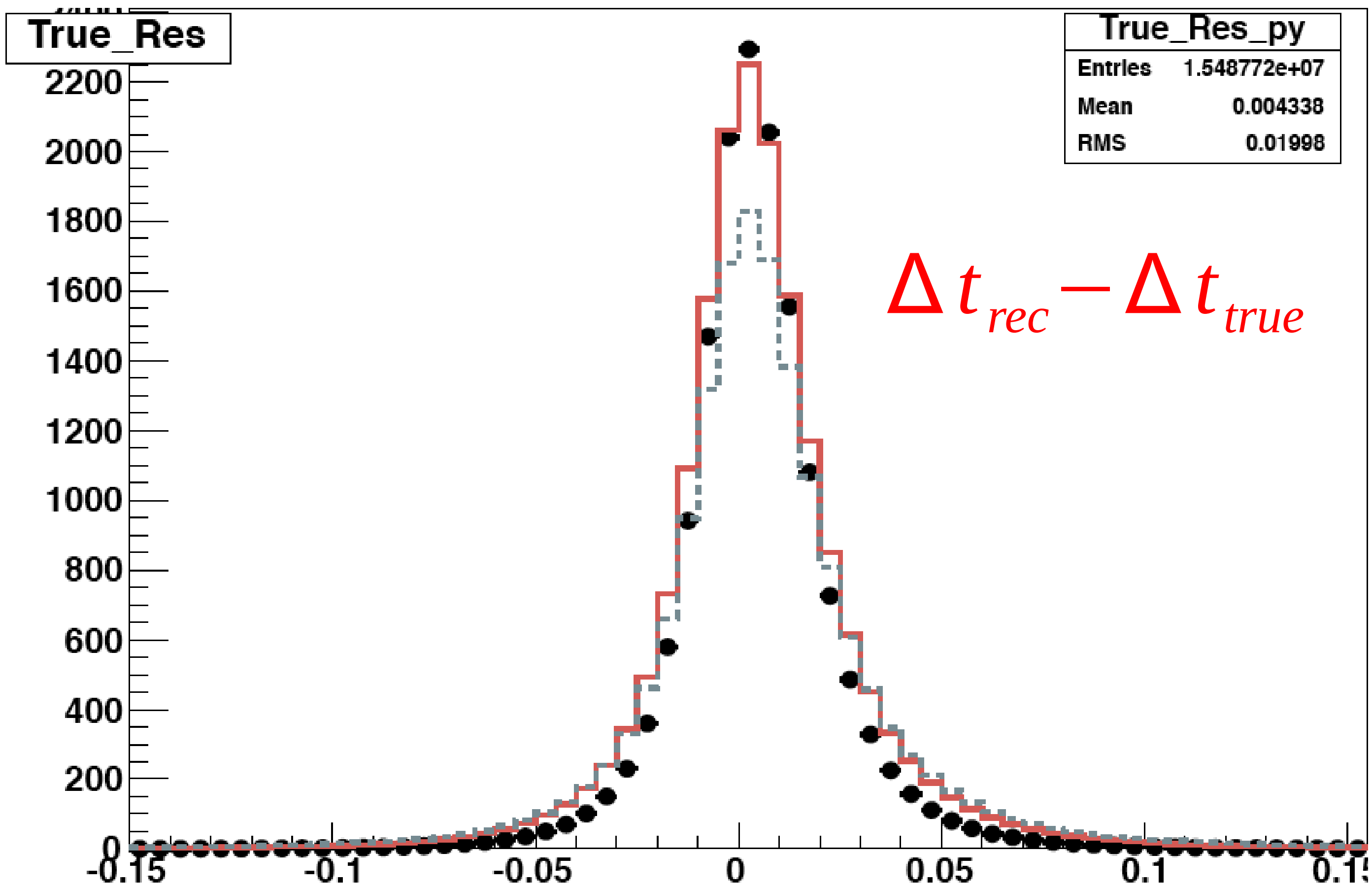
New Δt reconstruction

- Three coordinates are reconstructed
  - Z_R : B^0 decay position, from ℓ,π_s and beam spot constraint ("Reco")
  - Z_{Tag} : other B decay point, from the tracks assigned to the other B
  - Z_D : obtained from the remaing tracks, representing the D^0 decay point
- Define
  - $DZ = Z_R - Z_{TAG}$ -> evolution of the entangled BB wave function
  - $dZ = Z_R - Z_D$ -> D lifetime projected along beam axis
- Proper time difference is computed in the "boost approximation" :

$$\Delta t \simeq \Delta Z / (c\beta\gamma) = (Z_R - Z_{Tag}) / (\beta\gamma ct)$$

Result

- Resolution (red line) is almost as good as that with fully reconstructed events (dots with error bars) !
- Grey dashed line : result with a cone cut



Resolution Effects

- First test on *BABAR* signal simulation, fit for $\Delta\Gamma$, $\mathfrak{D}_1$:

$$\Delta\Gamma = \left(1.2^{+0.7}_{-3.1}\right)\times 10^{-2}$$

$$\mathfrak{D} = -\left(1.98 \pm 1.27\right)\times 10^{-3}$$

- Test resolution effect : smear pseudo-data per event resolution by 10%

$$\Delta\Gamma = \left(-0.0014^{+0.85}_{-0.85}\right)\times 10^{-2}$$

$$\mathfrak{D} = -\left(3.78 \pm 0.86\right)\times 10^{-3}$$

- Conclusion:
  - Resolution effects have sizable impact on both central values and errors, possibly leading to claim (fake) 4σ discovery !
  - Actual resolution should be determined with o(%) precision

Perspectives

- The measurement is potentially very <u>sensitive</u> and <u>interesting</u>
  - Dissipative effects have never been tested in BB entangled system
  - Strong opportunity to improve the knowledge of other fundamental parameters (δ, $\Delta\Gamma$, Γ^0 , Δm_d ...) just using *BABAR* data
  - ... using a brand new approach for vertex reconstruction
- ... however ...

Conclusions (in fact advertising)

- Progress is hampered by lack of people @ work
- Depending on available resources one could perform:
  - untagged measurement of ($\mathfrak{D}$, δ, $\Delta\Gamma$, Γ^0) on existing *BABAR* data
  - add tagging information (increase sensitivity, + improve on Δm_d ...)
  - perform a combined analysis of *BABAR* and Belle results
- In any case
  - pave **the way for an elegant and sophisticated high-precision measurement with Belle2 data**

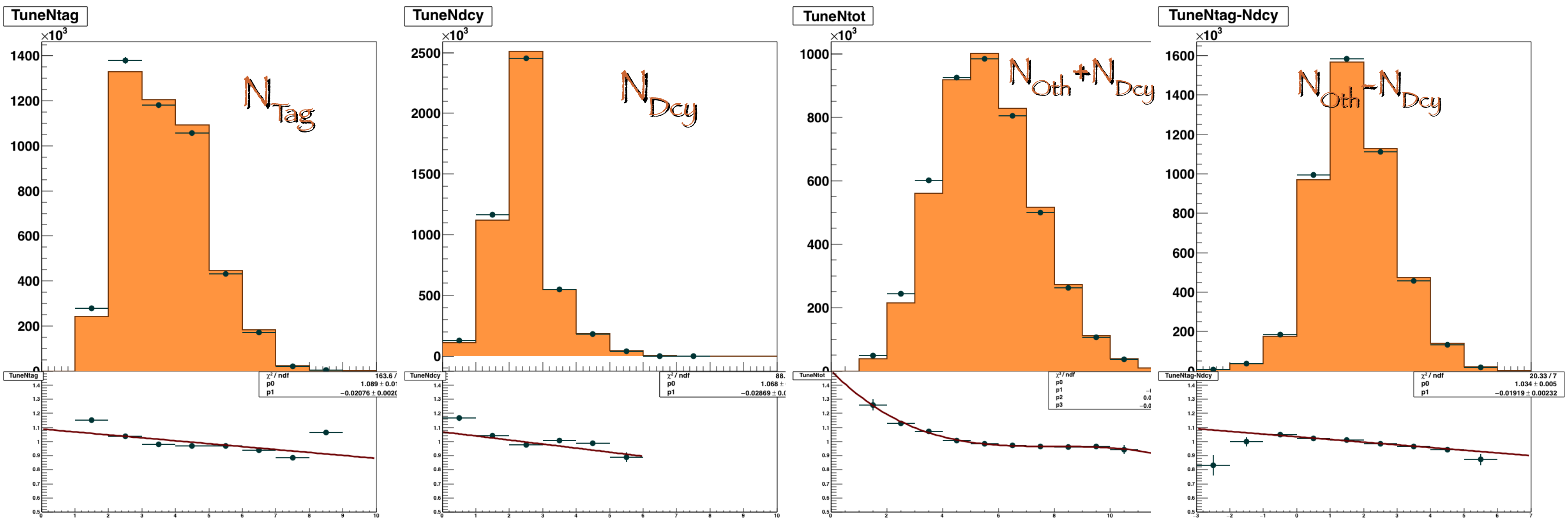
Backup

In the following : a recollection of some studies performed on Babar simulation

Resolution effects

- Need careful understanding of resolution effects
- So far investigated
  - track multiplicity in Tag & D side
  - $\sigma(\Delta t)$ distribution in Tag & D side
  - Δt distribution in D side
- Next plots :
  - points with error bars : background subtracted data
  - yellow area: MC expectation for signal (and paking background) events
  - Ratio : Data/MC

First Check : track multiplicity

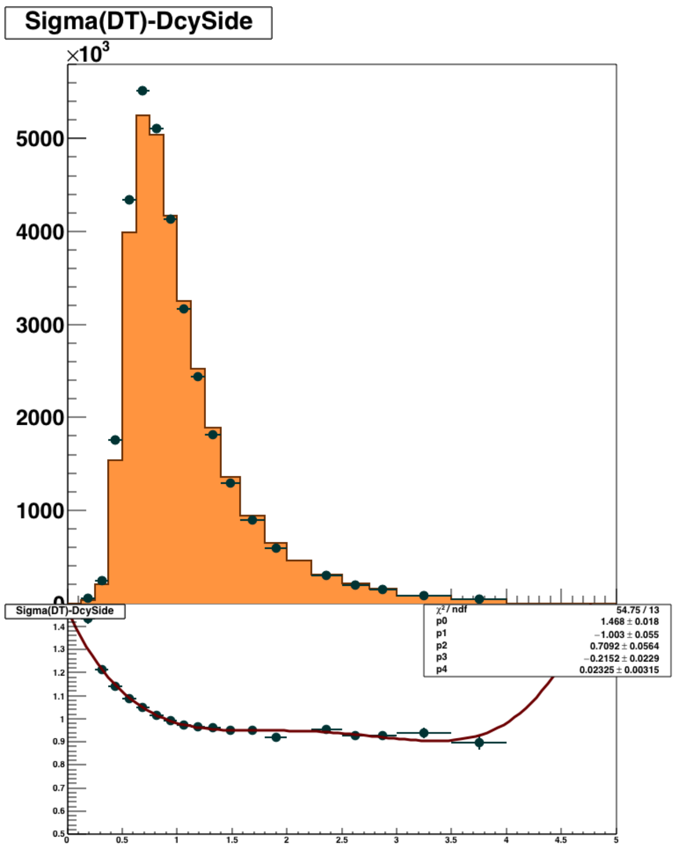


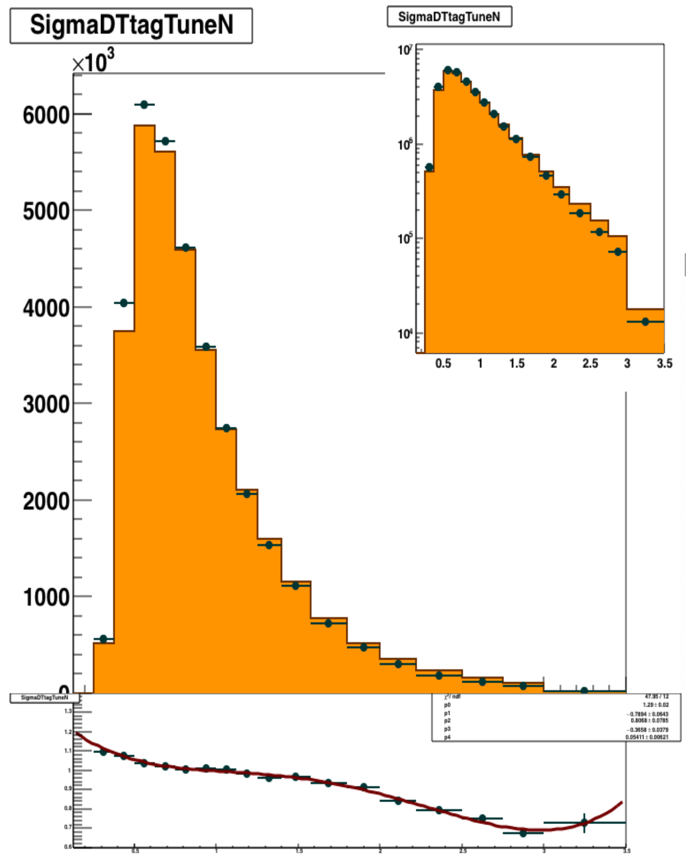
- Disagreement in the total track distribution (3rd plot) , equally shared by tag and decay side
- Tune: remove randomly MC events so that total multiplicity agrees.

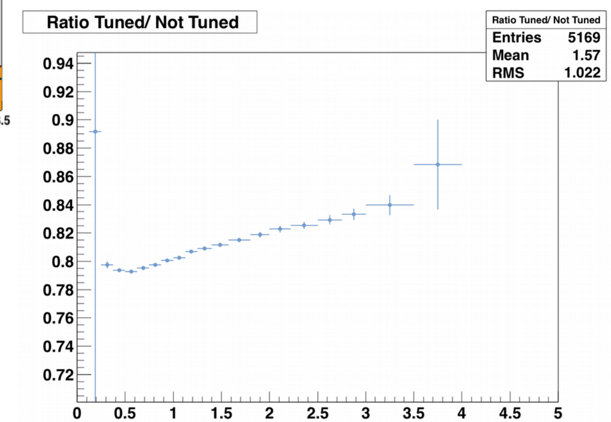
Test : $\sigma(\Delta T)$ distribution D side

not adjusted for N_{tracks}

adjusted





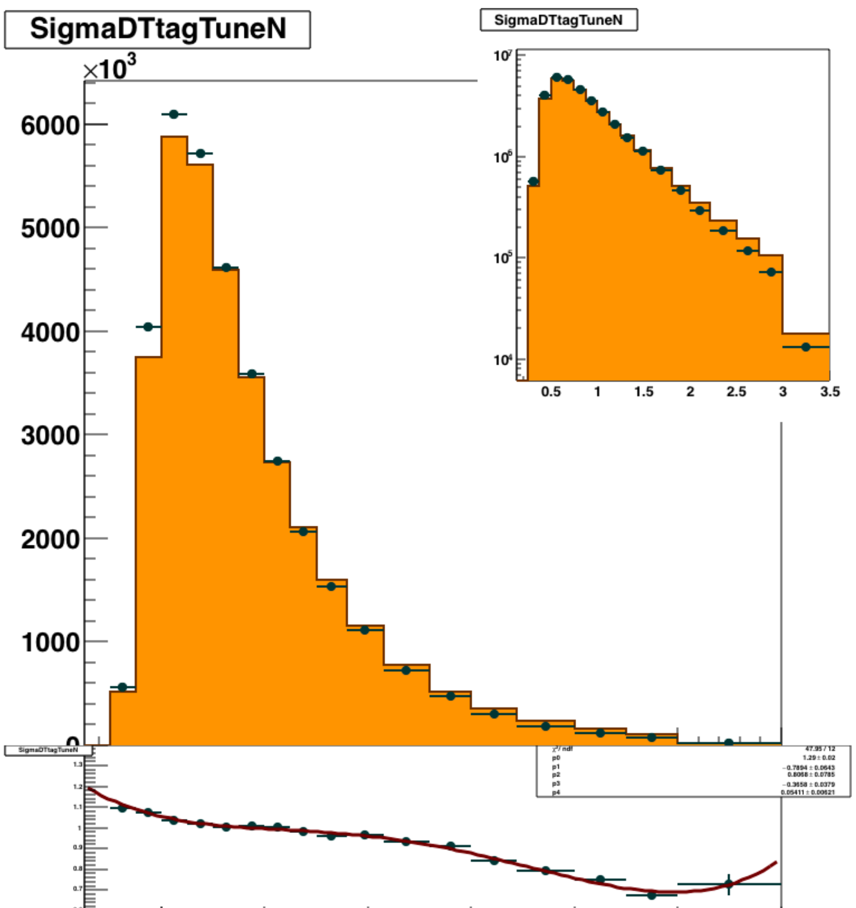


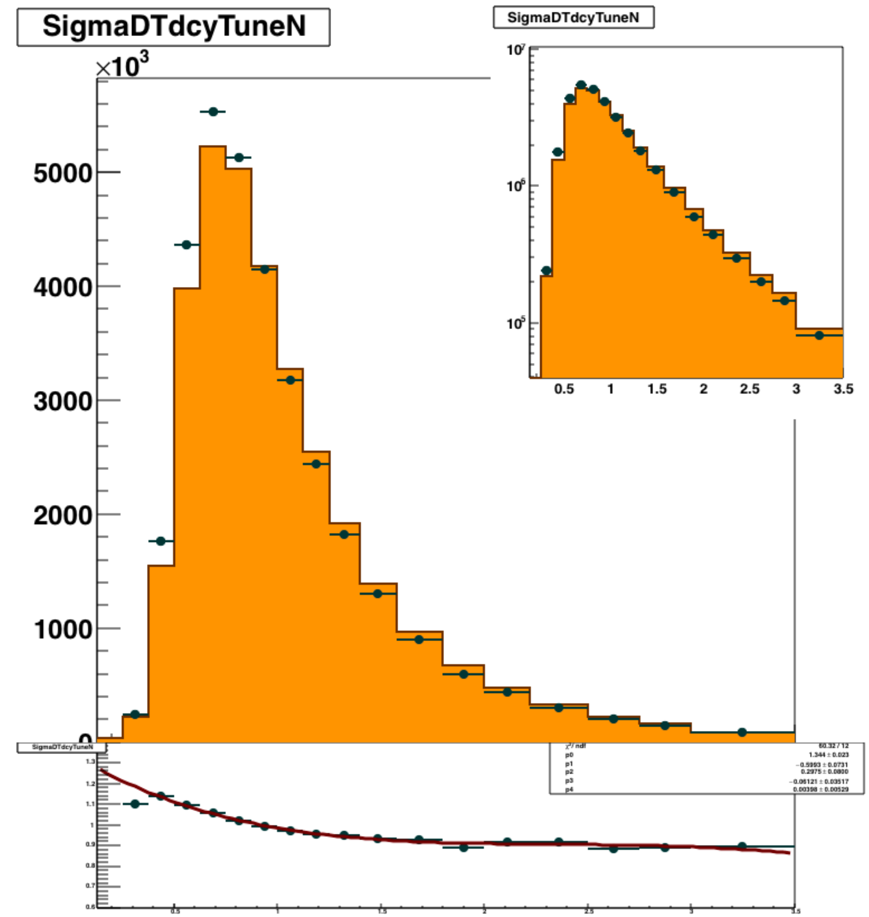
Simulation:

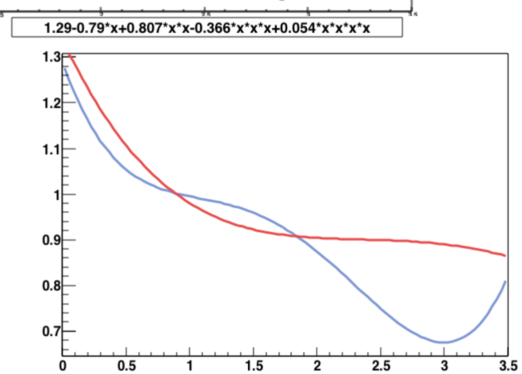
- ratio adjusted / not adjusted

Multiplicity tuning not much effective

$\sigma_{\Delta T}$, N_{track} adjusted, for Tag & D Side







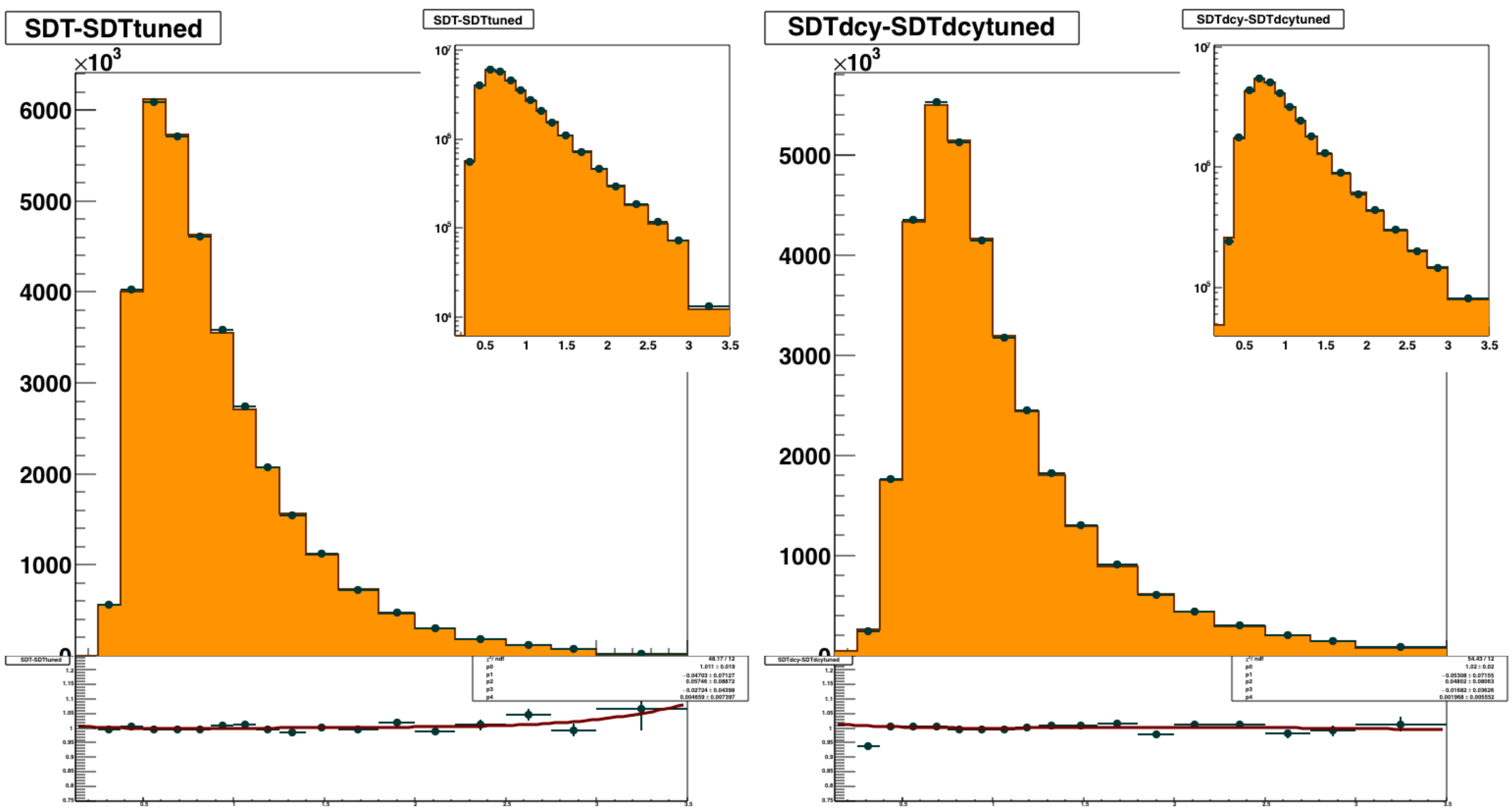
Ratio Comparison:

- Tag side
- D side

Rough agreement

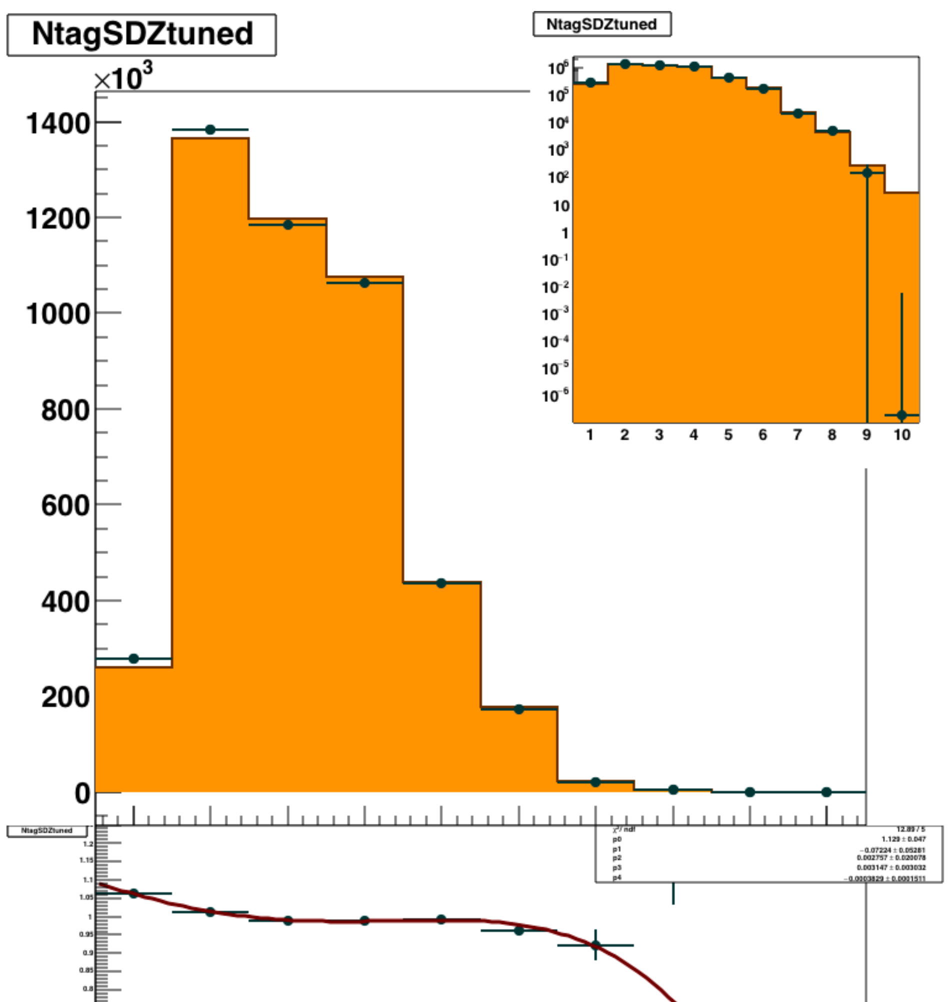
Comparison σ(Δt)

- Weight MC events to have same σ(Δt) as in data
- Use independent set of parameters for Tag and D side
- Plot σ(Δt) after tuning as a cross check.



Tag side multiplicity after $\sigma(\Delta T)$ tuning

- Cross check: compare N_{track} after $\sigma(\Delta t)$ correction



Very tiny distortion

Just remove events with

$N_{track} > 9$

•Fit Δt -D with 3 Gaussian functions

MC | Data