Development of B->D(*)taunu MC Event Generator with New Physics Effects

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Mini-workshop on D(*)taunu and related topics

New physics effect for B→D(*)$\tau\nu$ analysis

- R(D), R(D*) are changed
- Decay properties are also changed, such as
  - q^2
  - D* and tau polarization

    ← sensitive to the NP contribution

→ Need to include these effects in the **event generator**

Model-independent approach

Effective Lagrangian for $b \to c\tau\bar{\nu}$

all possible 4-fermi operators with LH neutrinos

M. Tanaka and R. Watanabe, PhysRevD87, 034028 (2013) (hep-ph/1212.1878)

$$-\mathcal{L}_{\rm eff} = 2\sqrt{2}G_F V_{cb} \sum_{l=e,\mu,\tau} \left[(\underbrace{\delta_{l\tau}}_{\text{SM}} + C^l_{V_1})\mathcal{O}^l_{V_1} + C^l_{V_2}\mathcal{O}^l_{V_2} + C^l_{S_1}\mathcal{O}^l_{S_1} + C^l_{S_2}\mathcal{O}^l_{S_2} + C^l_T\mathcal{O}^l_T \right]$$

$\mathcal{O}^l_{V_1} = \bar{c}_L\gamma^\mu b_L\,\bar{\tau}_L\gamma_\mu\nu_{Ll}\,,$	V−A	SM-like
$\mathcal{O}^l_{V_2} = \bar{c}_R\gamma^\mu b_R\,\bar{\tau}_L\gamma_\mu\nu_{Ll}\,,$	V+A	RH current
$\mathcal{O}^l_{S_1} = \bar{c}_L b_R\,\bar{\tau}_R\nu_{Ll}\,,$	S+P	charged Higgs (II)
$\mathcal{O}^l_{S_2} = \bar{c}_R b_L\,\bar{\tau}_R\nu_{Ll}\,,$	S−P	charged Higgs
$\mathcal{O}^l_T = \bar{c}_R\sigma^{\mu\nu} b_L\,\bar{\tau}_R\sigma_{\mu\nu}\nu_{Ll}$	Tensor	GUT?

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C_{V1}, C_{V2}, C_{S1}, C_{S2}, C_T denotes Wilson coefficients

– Ex) 2HDM Type2: $C_{S1} = -\frac{m_b m_\tau}{m_{H^+}^2}\tan^2\beta$ $\quad C_{S_2} = -\frac{m_c m_\tau}{m_{H^+}^2}$ $\quad C_{V_1} = C_{V_2} = C_T = 0$

→ Implement this model-independent calculation as the **<u>EvtGen decay model</u>**

How to implement $B \to D(*)\tau\nu$ EvtGen model

- PhysRevD.87.034028 gives helicity dependent amplitudes

The helicity amplitude of $\bar{B} \to M\tau\bar{\nu}$ $(M = D, D^*)$ is written as

$$\mathcal{M}_l^{\lambda_\tau,\lambda_M} = \delta_{l\tau}\,\mathcal{M}_{\rm SM}^{\lambda_\tau,\lambda_M} + \mathcal{M}_{V_1,l}^{\lambda_\tau,\lambda_M} + \mathcal{M}_{V_2,l}^{\lambda_\tau,\lambda_M} + \mathcal{M}_{S_1,l}^{\lambda_\tau,\lambda_M} + \mathcal{M}_{S_2,l}^{\lambda_\tau,\lambda_M} + \mathcal{M}_{T,l}^{\lambda_\tau,\lambda_M}\,,$$

The helicity amplitude is a function of
Wilson coefficients C_{V1}, C_{V2}, C_{S1}, C_{S2}, C_T

(details are written in the appendix of the paper)

$\lambda\tau$: **helicity** of the tau **in the (l+nu) rest frame**
λ_M: meson (D, D*) **helicity in the B rest frame**

w: velocity transfer $w = p_B \cdot p_M/(m_B m_M)$ → $q^2=(m_B^2+m_D^2-2m_Bm_D{*}w)$
$\cos\theta_\tau$: angle between momenta of τ and the meson in the (l+nu) rest frame

- M. Tanaka and R. Watanabe kindly provided their Mathematica codes of the helicity amplitude
- Well structured as a function library

→ ported to C++ class → EvtGen decay model

Implementation by EvtGen Model codes

Spin dependent complex amplitude is calculated

$$A = \sum_{\lambda_{D^*}\lambda_\tau} A^{B\to D^*\tau\nu}_{\lambda_{D^*}\lambda_\tau} \times A^{D^*\to D\pi}_{\lambda_{D^*}} \times A^{\tau\to\pi\nu}_{\lambda_\tau},$$

<u>BSTD model</u>
class EvtBSemiTauonic;
(we are developing)

<u>VSS model (vector to 2 scalars)</u>
class EvtVSS;
(Already exist in EvtGen)

<u>TAUSCALARNU model</u>
class EvtTauScalarnu;
(Already exist in EvtGen)

λ_{D^*},$\lambda\tau$: **<u>spin state</u>** at D^*,τ rest frame

In each decay() function,

1. Randomly generate the kinematics of daughter particles based on the phase space
2. Calculate decay amplitudes for each spin state
3. Set amplitude (<u>as complex variables</u>)
   by function vertex(mother_spinstate, daughter_spinstate1,…)

Calculation of the probability values and the spin density matrices are taken cared by EvtGen core

EvtGen Spin states and Helicity states

Need to translate between

- EvtGen Spin states in each rest frame
- Helicity states of BSTD model
  - $\lambda\tau$: helicity of the tau **in the (l+nu) rest frame**
  - λ_M: meson (D, D*) helicity **in the B rest frame**

- Prepared the rotation matrix in the boosted frame

EvtSpinDensity **EvtBSemiTauonicAmplitude::RotateToHelicityBasisInBoostedFrame**(const EvtParticle* p, EvtVector4R p4boost)

  - Utilize EvtDiracSpinor class of EvtGen
  - Copied and added the boost to “EvtSpinDensity EvtDiracParticle::rotateToHelicityBasis()” in EvtDiracParticle

  - Prepared by me. It seems still has a bug? (explained later)

Decay.dec Parameters

```
# Br children Model_Name parameters...
Decay MyB0
0.5 D*- tau+ nu_tau    BSTD    rhoA12 R11 R21 aR3 m_b m_c MagCV1 ArgCV1 MagCV2 ArgCV2 MagCS1 ArgCS1 MagCS2 ArgCS2 MagCT ArgCT;
0.5 D-  tau+ nu_tau    BSTD    rho12 aS1 m_b m_c  MagCV1 ArgCV1 MagCV2 ArgCV2 MagCS1 ArgCS1 MagCS2 ArgCS2 MagCT ArgCT;

#0.5 D*- tau+ nu_tau    BSTD_2HDMTYPE2  rhoA12 R11 R21 aR3 m_b m_c tanBeta/m_H+;
#0.5 D-  tau+ nu_tau    BSTD_2HDMTYPE2  rho12 aS1 m_b m_c tanBeta/m_H+;
Enddecay
```

rhoA12, R11, R21 : HQET Form Factor parameters from B->D(*)lnu data

m_b, m_c : quark masses at m_b scale

MagCXX, ArgCXX : Wilson coefficients for New Physics contributions

Each Wilson coefficient is calculated by CXX = MagCXX * exp(ArgCXX * i)

All CXX = 0 → SM

aR3, aS1 : Parameters related to the systematic errors for O(1/m_q) correction in the scalar form factors

PRD87,034028 uses 1 +/- 1 for these values to take into account the theoretical error.

Check of the BSTD Model

- Compare helicity dependent amplitude calculation
  - Original theory calculation and C++ functions used for the BSTD Model
    - the fraction of the longitudinally polarized D*
    - the tau polarization

$$P_{D^*} = \frac{\Gamma(D_L^*)}{\Gamma(D_L^*) + \Gamma(D_T^*)},$$

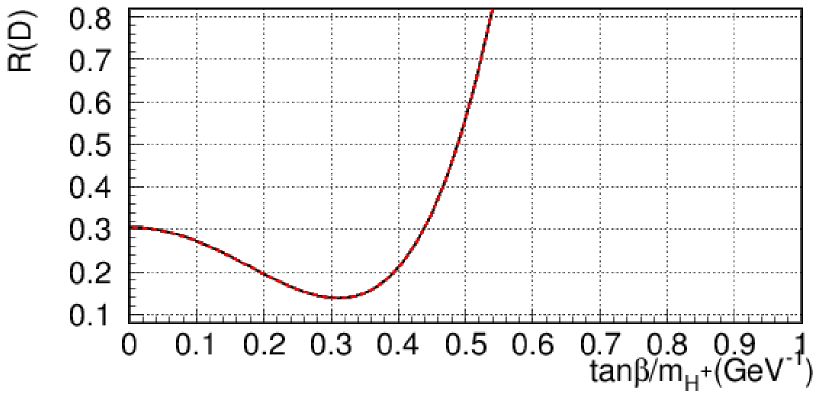
$$P_\tau(D) = \frac{\Gamma^+(D) - \Gamma^-(D)}{\Gamma^+(D) + \Gamma^-(D)},$$

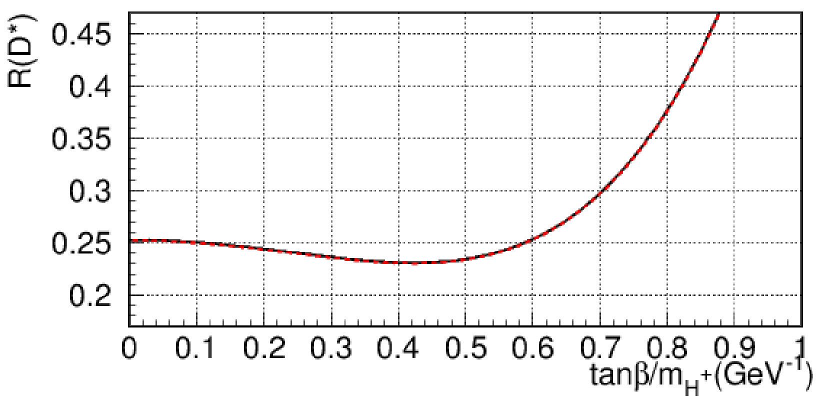
- Compare distributions generated by EvtGen to the calculation
  - Velocity transfer w $w = p_B \cdot p_M / (m_B m_M)$ (→ $q^2=(m_B^2+m_D^2-2m_Bm_D*w)$)
  - $\cos\theta_\tau$ angle between momenta of τ and the meson in the (l+nu) rest frame

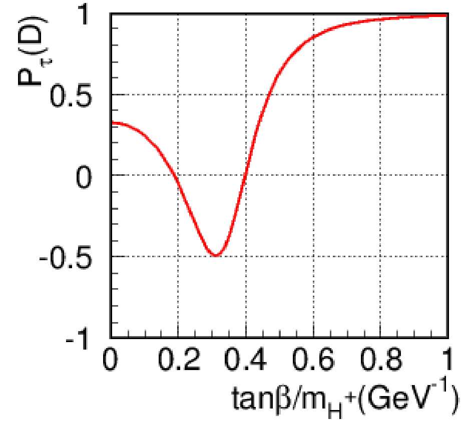
- Check the D* and tau polarization in decays generated by EvtGen
  - Check helicity angle distribution of $D^*\rightarrow D\pi$ and $\tau\rightarrow\pi\nu$ decays in the generated $B\rightarrow D(*)\tau\nu$

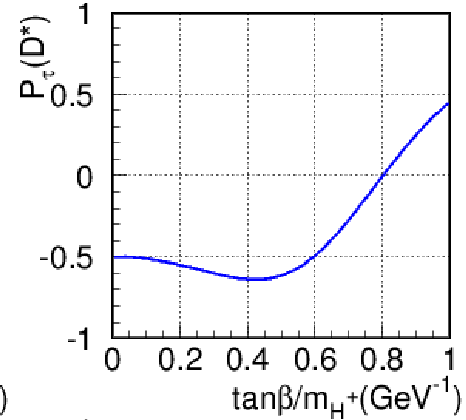
→ Compare to calculated values of PD* and Pτ

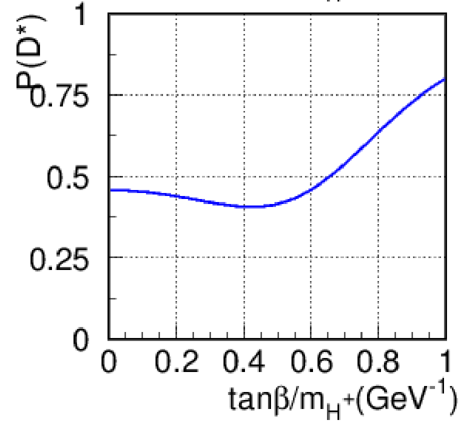
R and polarizations for 2HDM Type2 Check of helicity amplitude functions









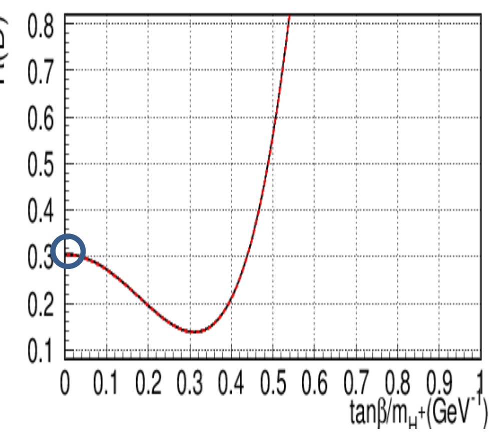


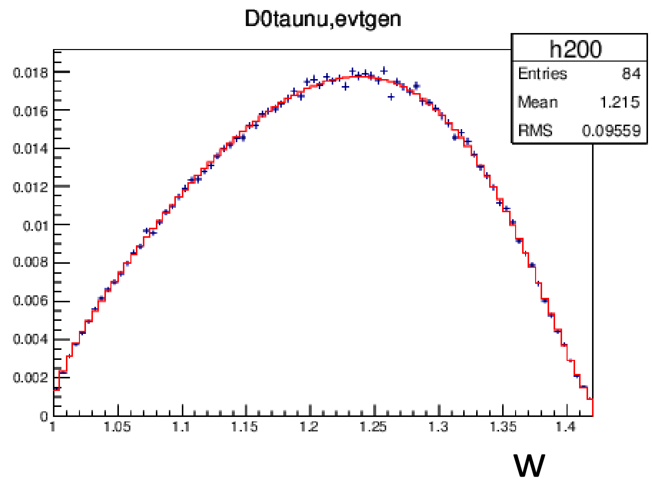
- Have been cross checked with the Tanaka-san’s calculation

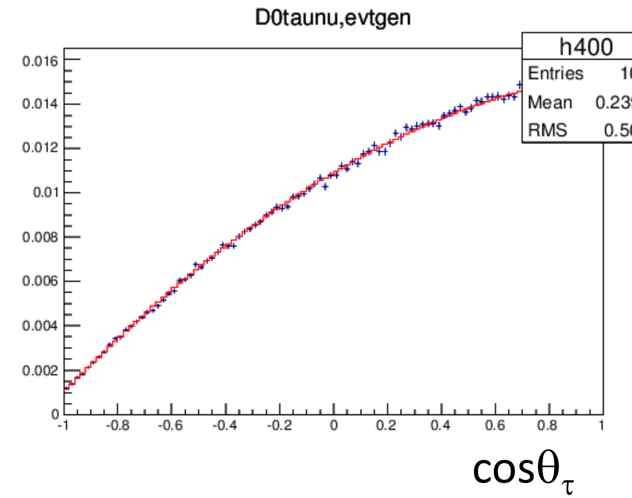
B+→Dtaunu, SM

Data points:
EvtGen events

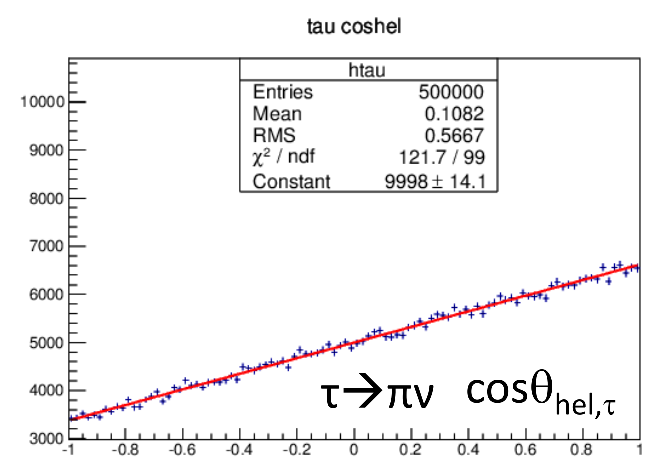
Red line:
Model Calculation





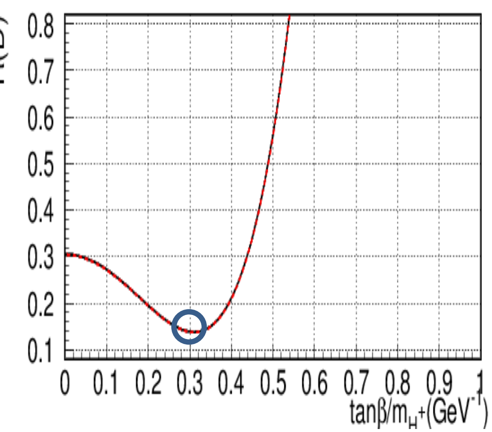


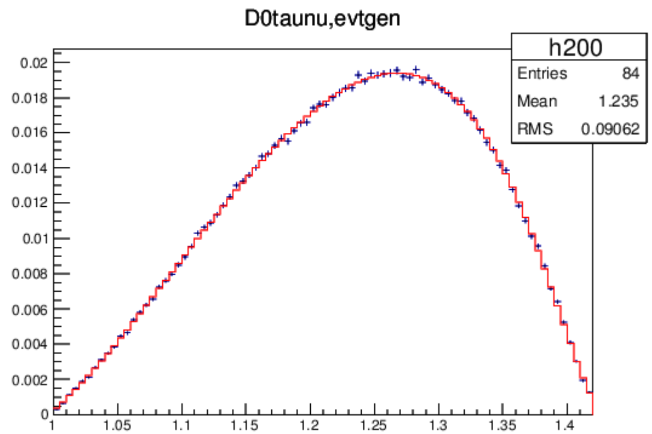
Calculated RGamD=0.305911



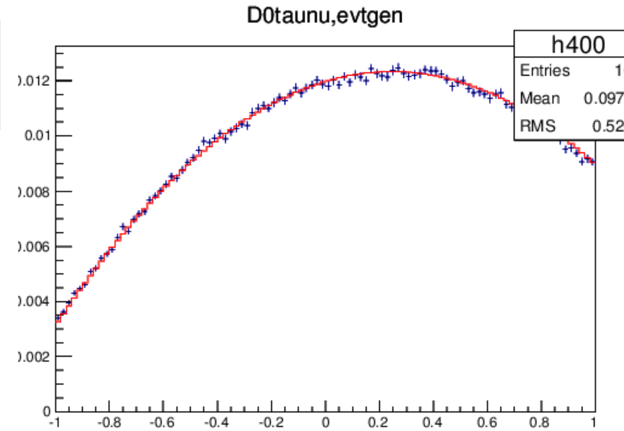
Calculated PtauD=0.324912

B+->Dtaunu, tan(beta)/mH=0.30



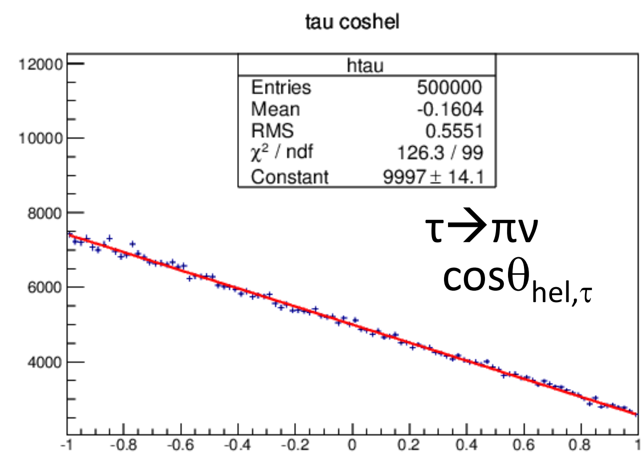


w



$\cos\theta_\tau$

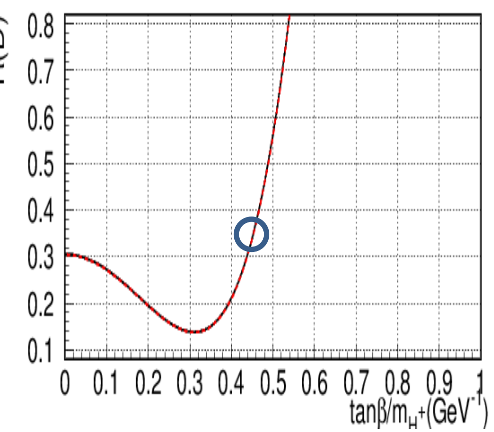
Calculated RGamD=0.139066

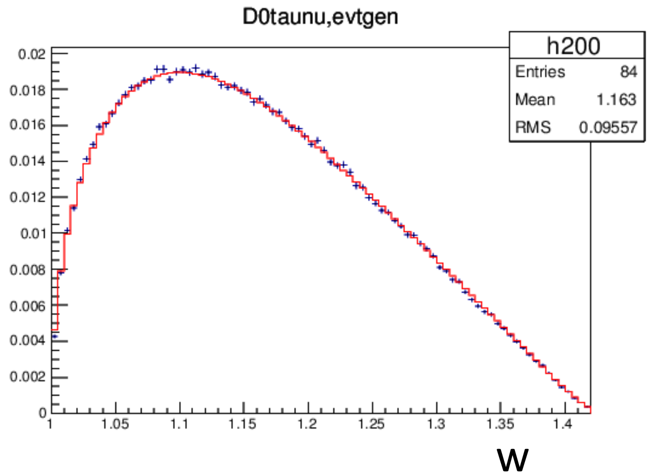


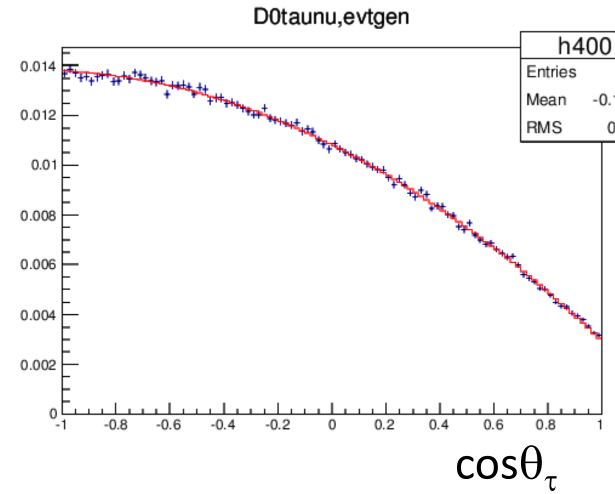
$\tau \rightarrow \pi\nu$
$\cos\theta_{hel,\tau}$

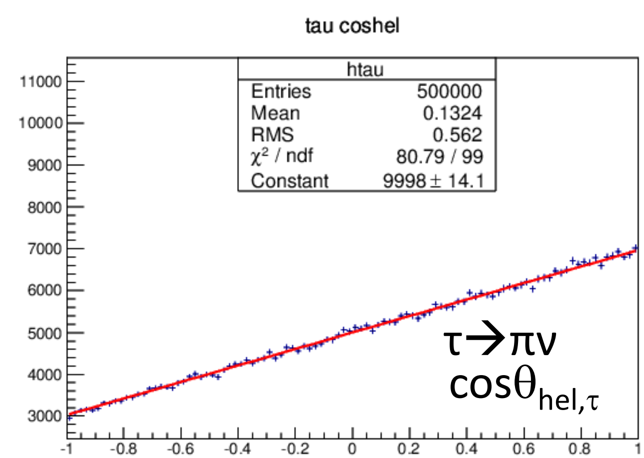
Calculated PtauD=-0.485022

B+->Dtaunu, tan(beta)/mH=0.45



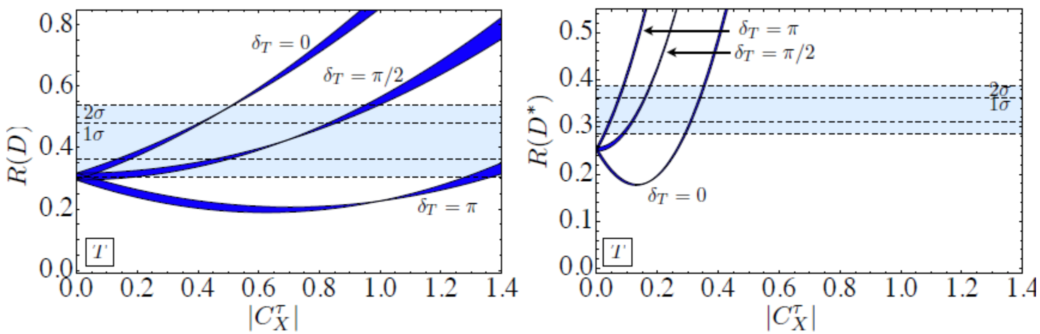




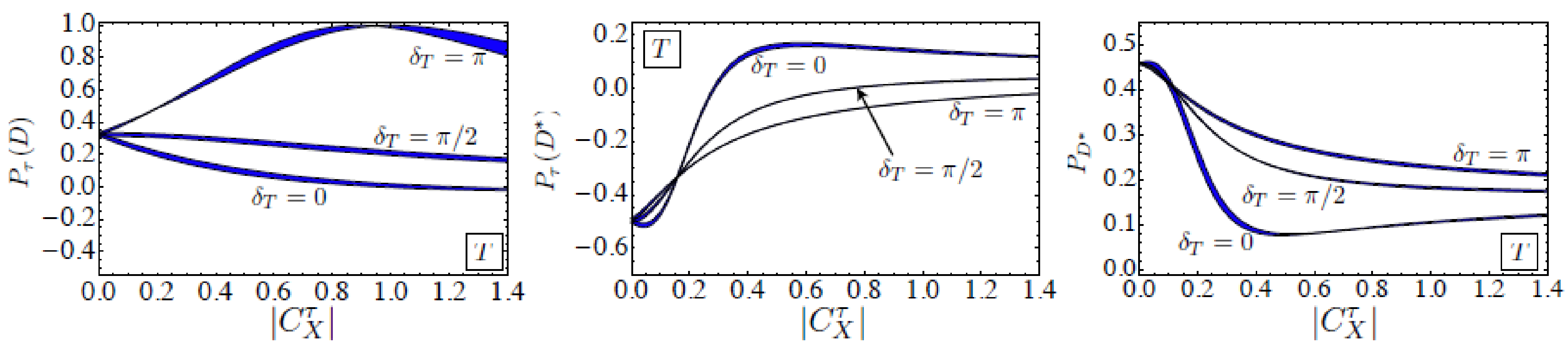


SM + T case:
Original Theory Calculation

Set others (CS1,CS2, CV1, CV2) to be 0

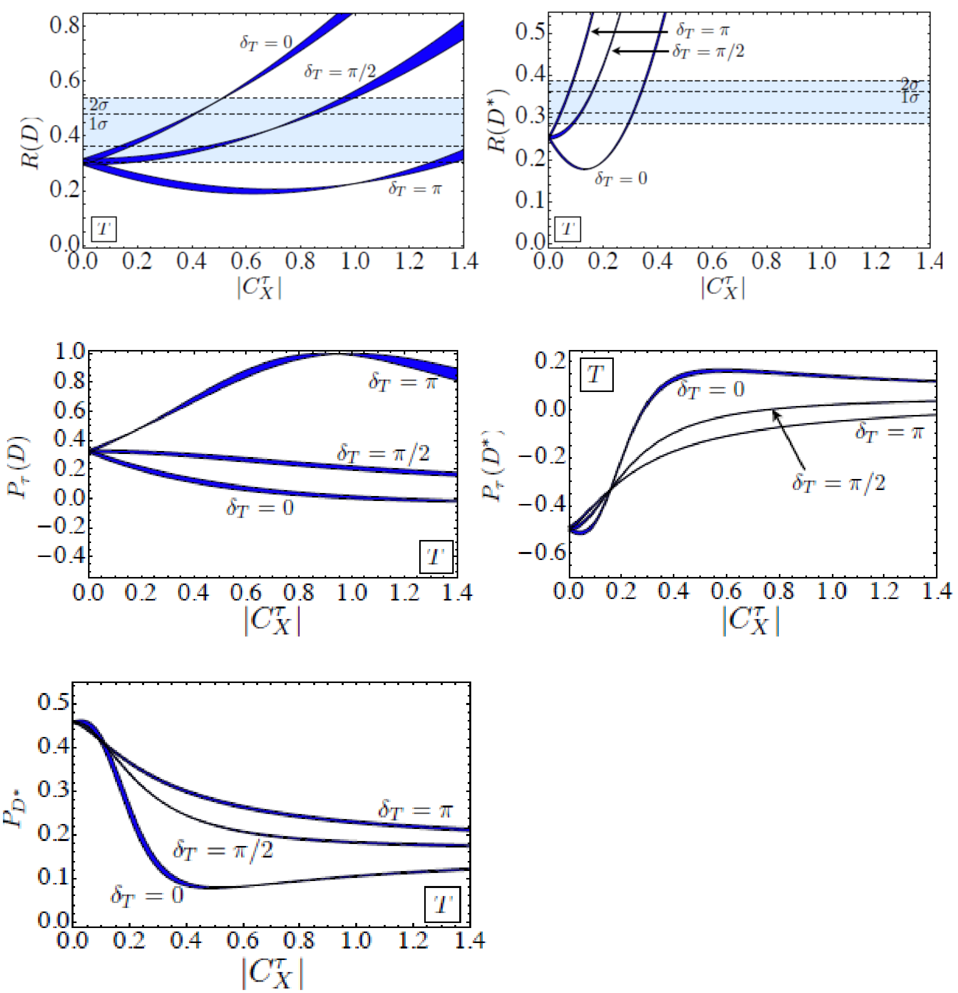


Plots from
M. Tanaka and R. Watanabe,
PhysRevD87, 034028 (2013)

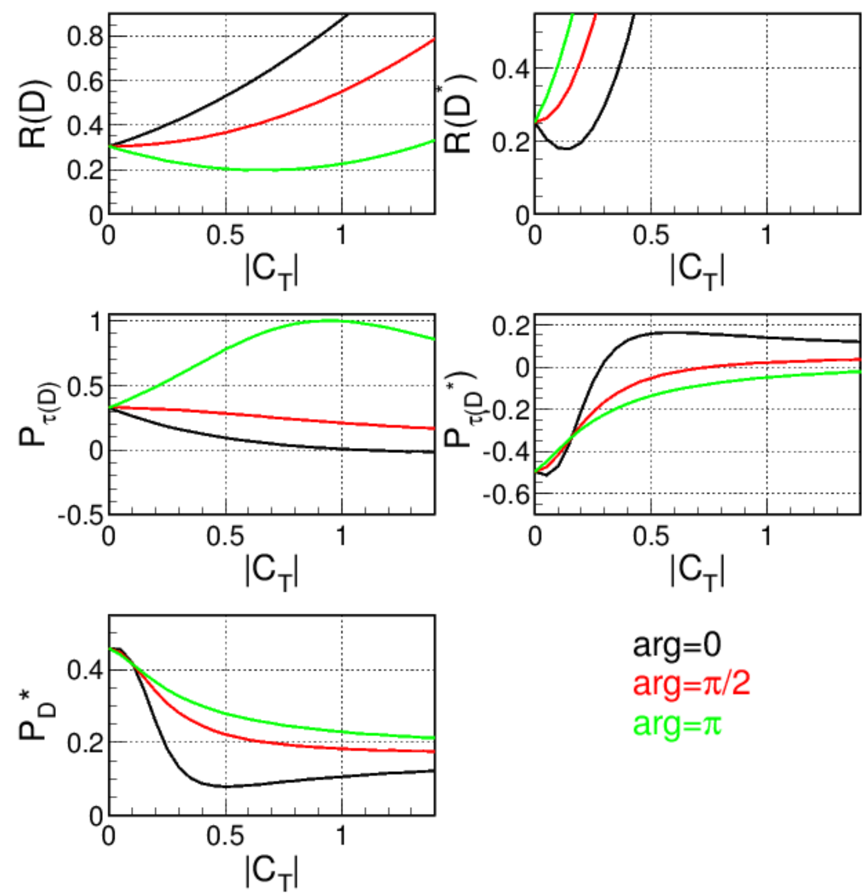


Cross check of R, P of SM + T case

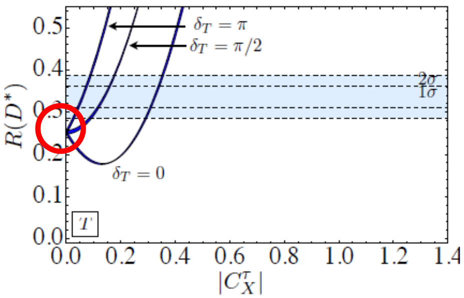
Plots from PhysRevD87, 034028 (2013)

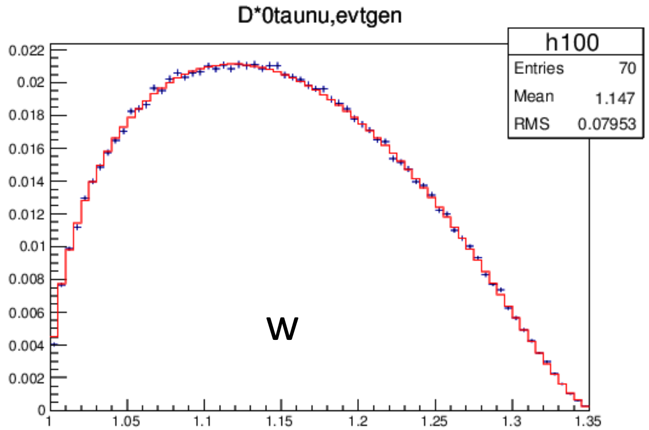


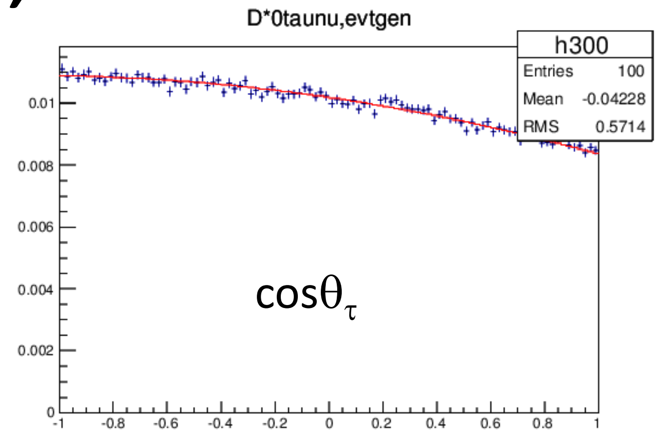
Plots by C++ helicty amplitude functions used in the BSTD model

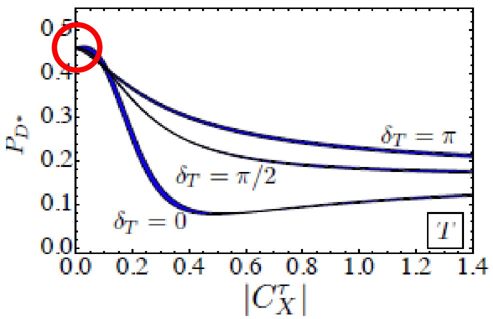


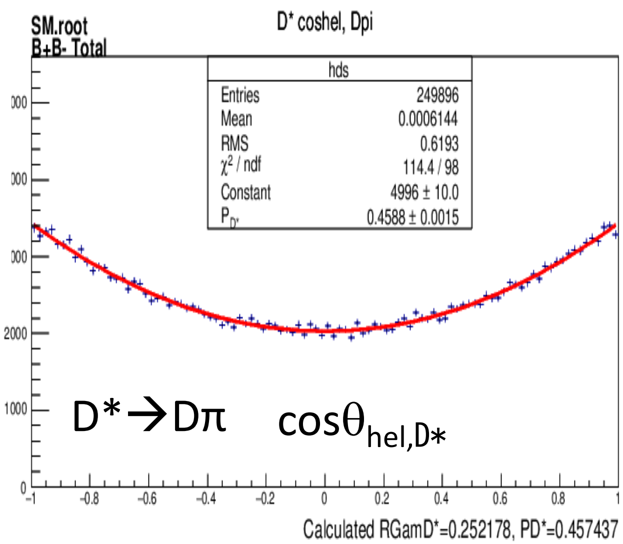
B+→D*taunu, SM

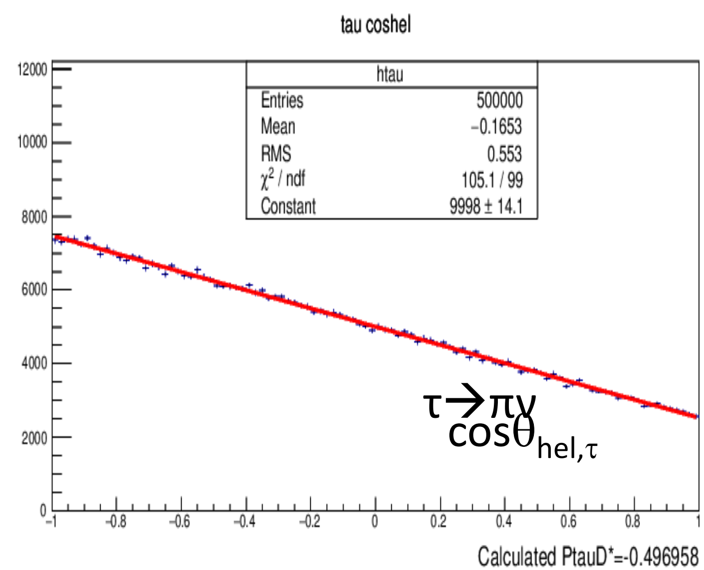

$R(D^*)$
$|C_X^\tau|$
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
2σ
1σ
T

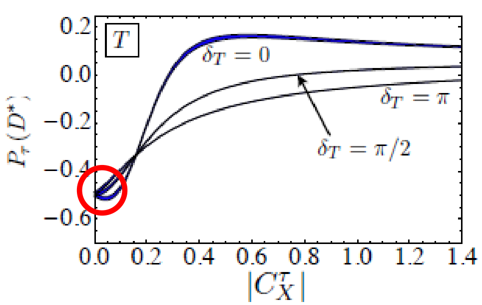

D*0taunu,evtgen
h100
Entries 70
Mean 1.147
RMS 0.07953
w


D*0taunu,evtgen
h300
Entries 100
Mean -0.04228
RMS 0.5714
$\cos\theta_\tau$

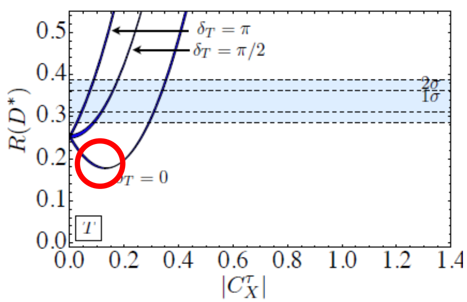

P_{D^*}
$|C_X^\tau|$
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
T


SM.root
B+B- Total
D* coshel, Dpi
hds
Entries 249896
Mean 0.0006144
RMS 0.6193
χ^2 / ndf 114.4 / 98
Constant 4996 ± 10.0
P_{D^*} 0.4588 ± 0.0015
D*→Dπ
$\cos\theta_{hel,D*}$
Calculated RGamD*=0.252178, PD*=0.457437

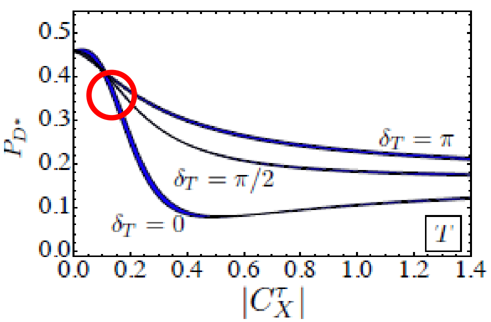

tau coshel
htau
Entries 500000
Mean −0.1653
RMS 0.553
χ^2 / ndf 105.1 / 99
Constant 9998 ± 14.1
τ→πν
$\cos\theta_{hel,\tau}$
Calculated PtauD*=-0.496958


$P_\tau(D^*)$
$|C_X^\tau|$
$\delta_T = 0$
$\delta_T = \pi$
$\delta_T = \pi/2$
T

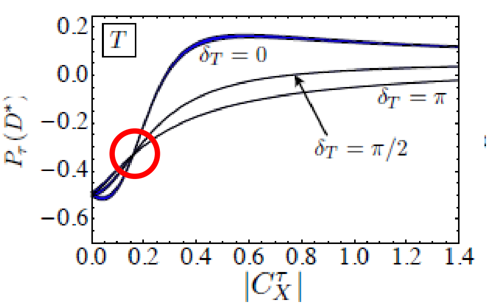
SM + 0.15 T



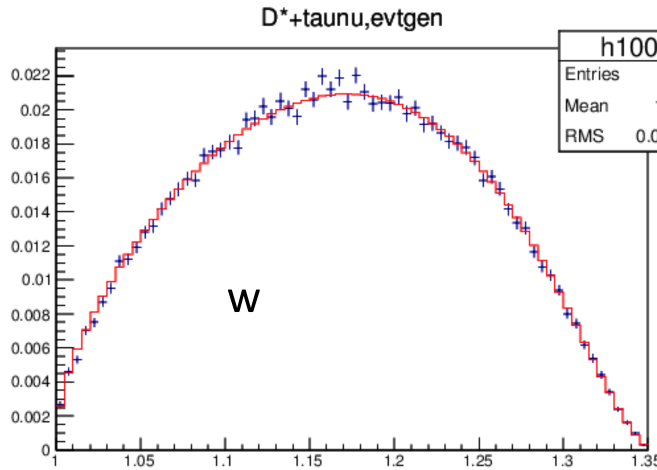
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
2σ
1σ
$R(D^*)$
$|C_X^\tau|$
T



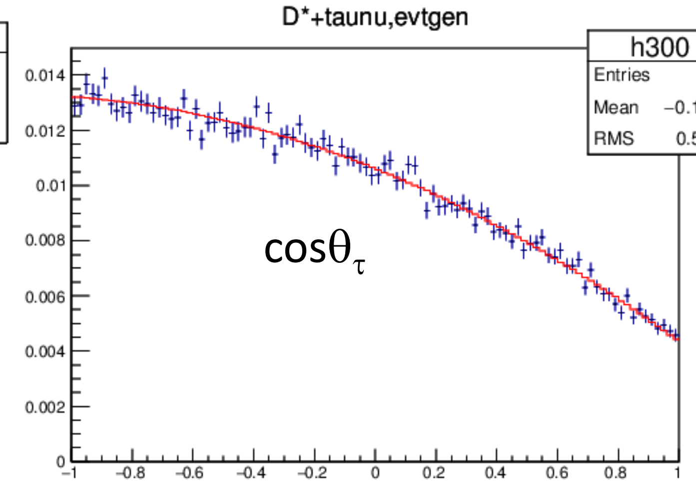
P_{D^*}
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
T
$|C_X^\tau|$



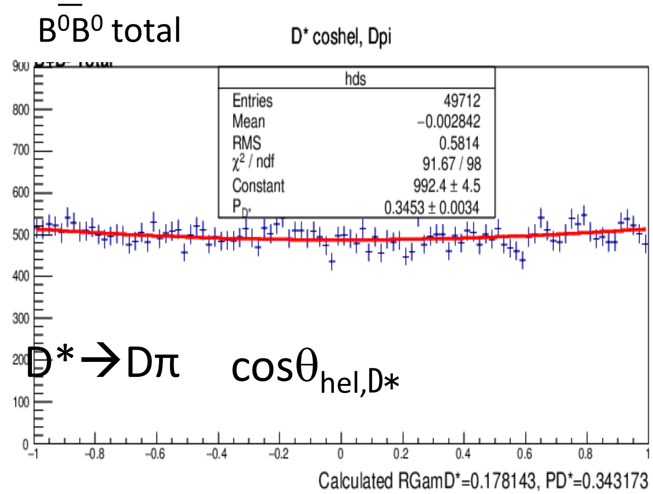
T
$\delta_T = 0$
$\delta_T = \pi$
$\delta_T = \pi/2$
$P_\tau(D^*)$
$|C_X^\tau|$



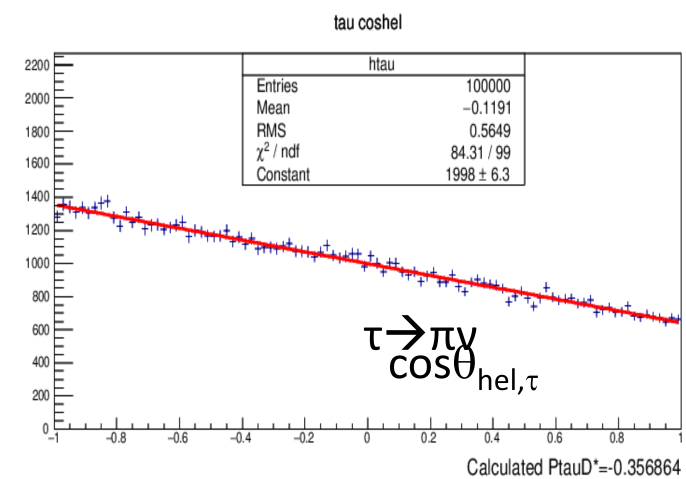
D*+taunu,evtgen
h100
Entries 70
Mean 1.166
RMS 0.07944
w



D*+taunu,evtgen
h300
Entries
Mean
RMS
$\cos\theta_\tau$

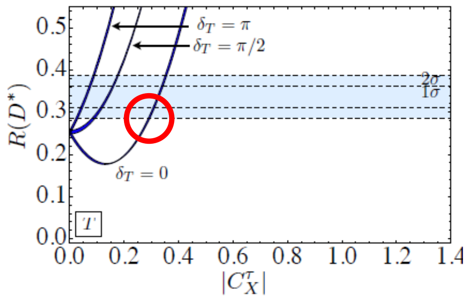


$B^0\bar{B}^0$ total
D* coshel, Dpi
hds
Entries 49712
Mean −0.002842
RMS 0.5814
χ^2 / ndf 91.67 / 98
Constant 992.4 ± 4.5
P_{D^*} 0.3453 ± 0.0034
$D^* \to D\pi$
$\cos\theta_{hel,D*}$
Calculated RGamD*=0.178143, PD*=0.343173

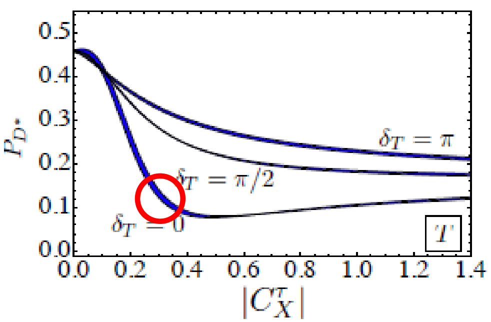


tau coshel
htau
Entries 100000
Mean −0.1191
RMS 0.5649
χ^2 / ndf 84.31 / 99
Constant 1998 ± 6.3
$\tau \to \pi\nu$
$\cos\theta_{hel,\tau}$
Calculated PtauD*=-0.356864

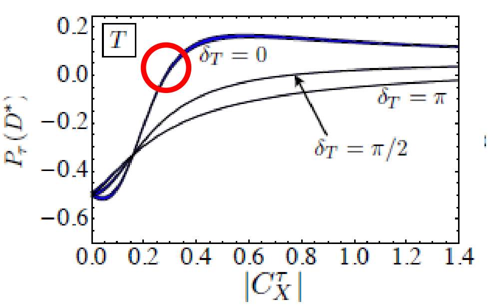
SM + 0.3 T



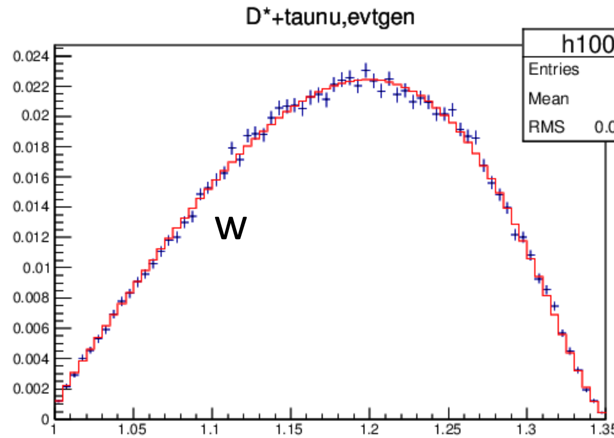
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
2σ
1σ
$R(D^*)$
T
$|C_X^\tau|$



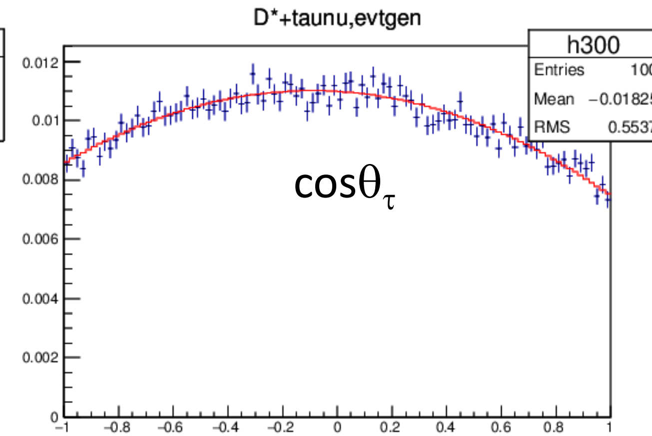
P_{D^*}
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
T
$|C_X^\tau|$



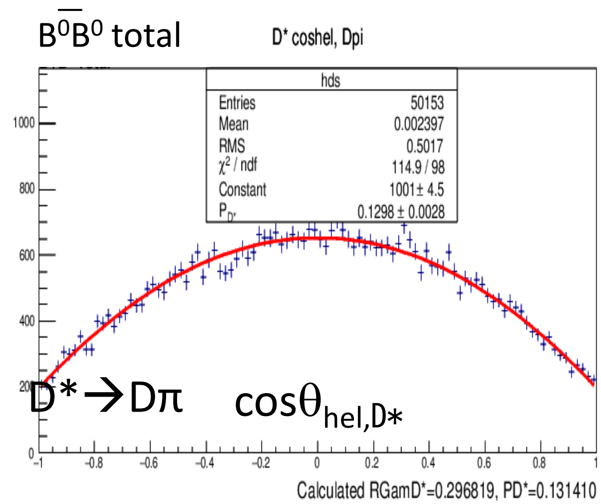
T
$\delta_T = 0$
$\delta_T = \pi$
$\delta_T = \pi/2$
$P_\tau(D^*)$
$|C_X^\tau|$



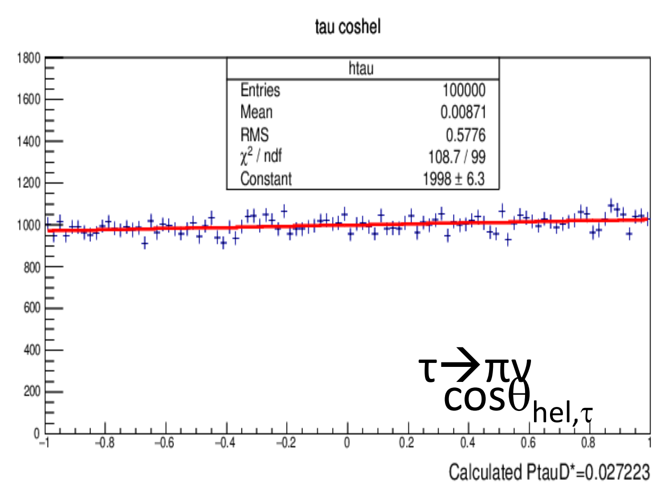
D*+taunu,evtgen
h100
Entries 70
Mean 1.181
RMS 0.07665
w



D*+taunu,evtgen
h300
Entries 100
Mean −0.01825
RMS 0.5537
cosθ$_\tau$

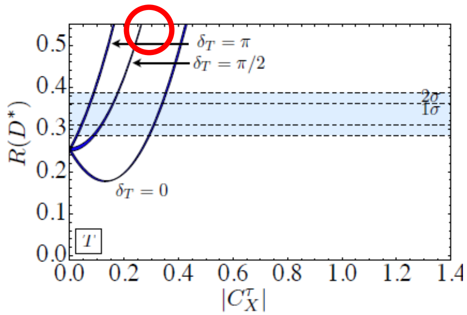


$B^0\bar{B}^0$ total
D* coshel, Dpi
hds
Entries 50153
Mean 0.002397
RMS 0.5017
χ^2 / ndf 114.9 / 98
Constant 1001 ± 4.5
P_{D^*} 0.1298 ± 0.0028
D*→Dπ
cosθ$_{hel,D*}$
Calculated RGamD*=0.296819, PD*=0.131410

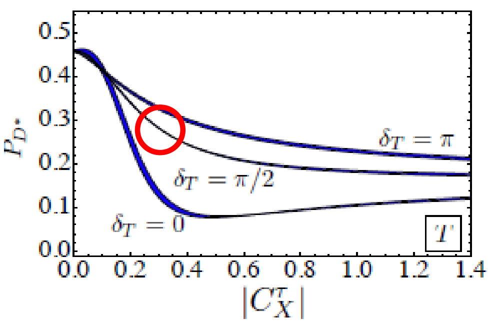


tau coshel
htau
Entries 100000
Mean 0.00871
RMS 0.5776
χ^2 / ndf 108.7 / 99
Constant 1998 ± 6.3
τ→πν
cosθ$_{hel,\tau}$
Calculated PtauD*=0.027223

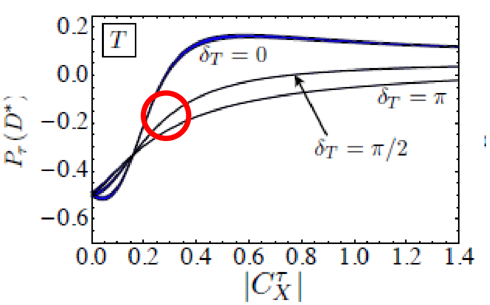
SM + 0.3 $e^{i\pi/2}$ T



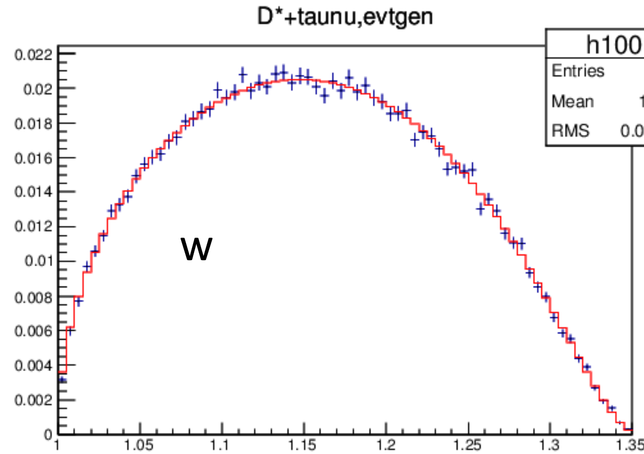
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
2σ
1σ
$R(D^*)$
$|C_X^\tau|$
T



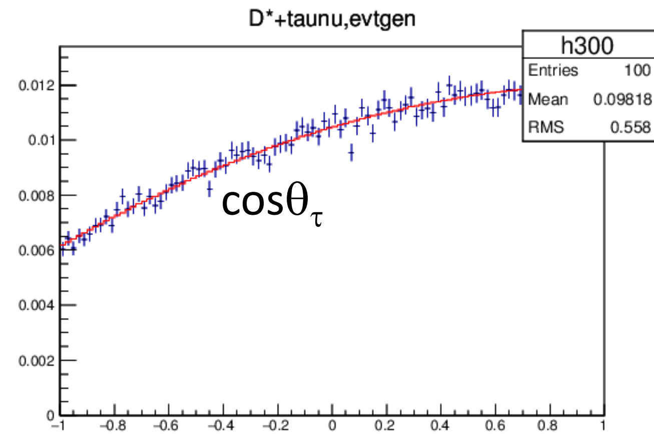
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
P_{D^*}
$|C_X^\tau|$
T



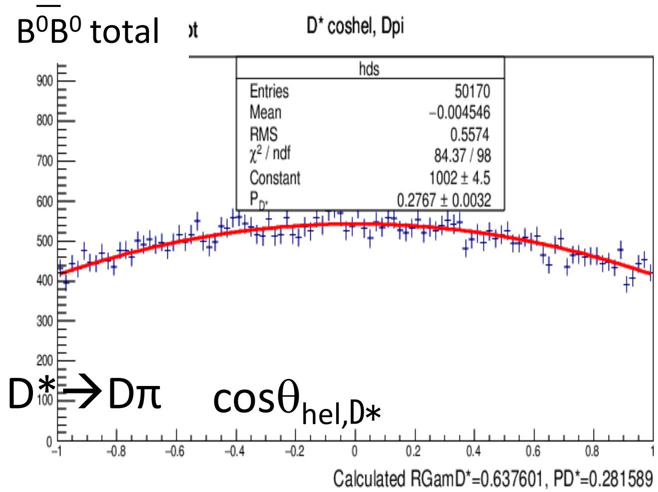
$\delta_T = 0$
$\delta_T = \pi$
$\delta_T = \pi/2$
$P_\tau(D^*)$
$|C_X^\tau|$
T



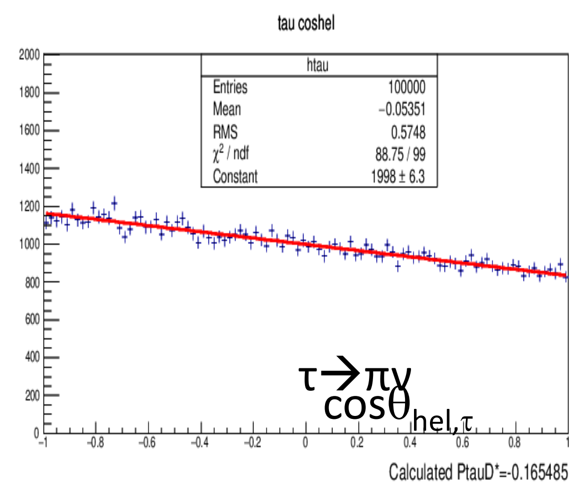
D*+taunu,evtgen
h100
Entries 70
Mean 1.157
RMS 0.08018
w



D*+taunu,evtgen
h300
Entries 100
Mean 0.09818
RMS 0.558
$\cos\theta_\tau$

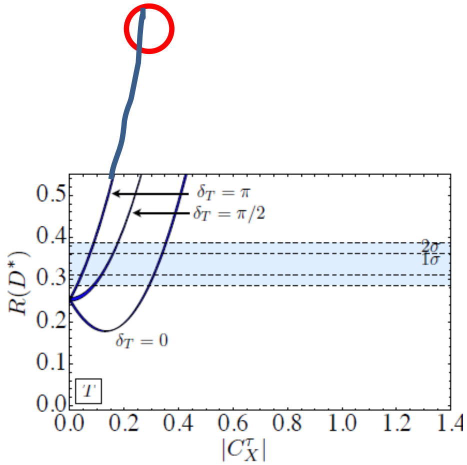


$B^0\bar{B}^0$ total
D* coshel, Dpi
hds
Entries 50170
Mean −0.004546
RMS 0.5574
χ^2 / ndf 84.37 / 98
Constant 1002 ± 4.5
P_{D^*} 0.2767 ± 0.0032
$D^* \to D\pi$
$\cos\theta_{hel,D*}$
Calculated RGamD*=0.637601, PD*=0.281589

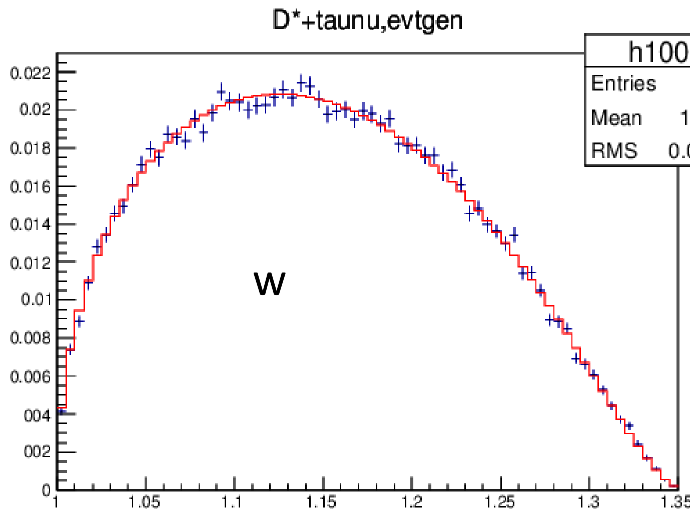


tau coshel
htau
Entries 100000
Mean −0.05351
RMS 0.5748
χ^2 / ndf 88.75 / 99
Constant 1998 ± 6.3
$\tau \to \pi\nu$
$\cos\theta_{hel,\tau}$
Calculated PtauD*=-0.165485

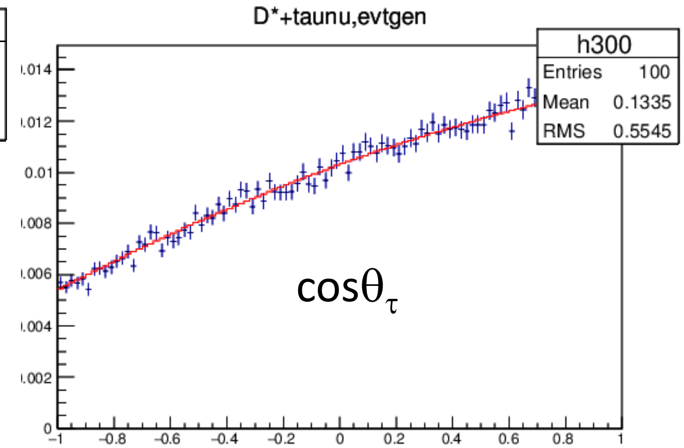
SM + 0.3 $e^{i\pi}$ T



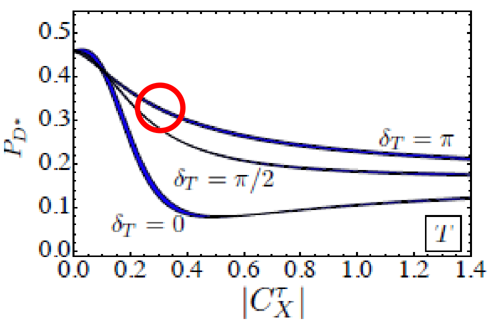
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
2σ
1σ
$R(D^*)$
$|C_X^\tau|$
T



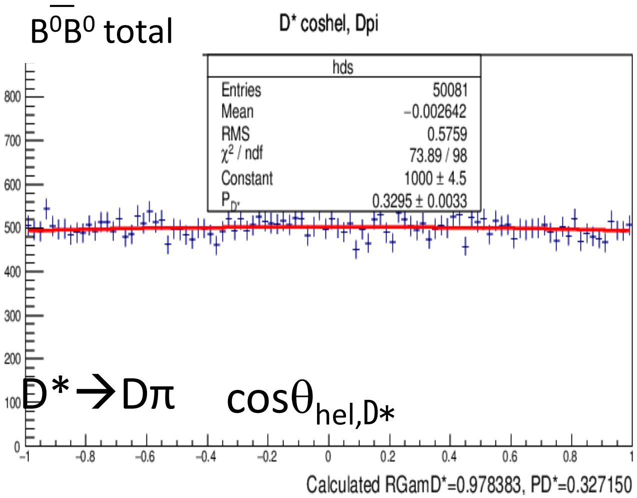
D*+taunu,evtgen
h100
Entries 70
Mean 1.149
RMS 0.0798
w



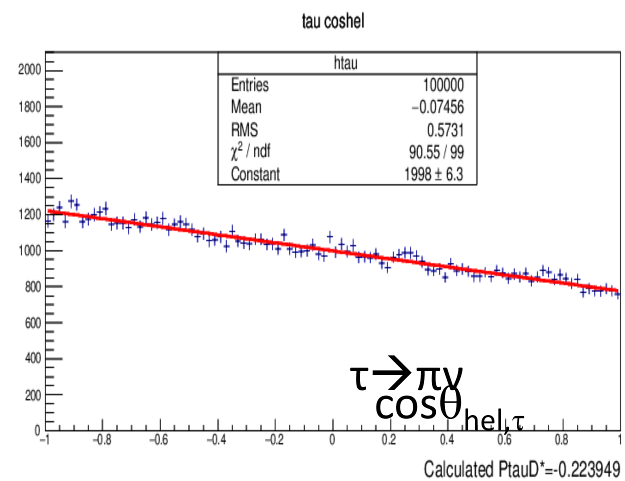
D*+taunu,evtgen
h300
Entries 100
Mean 0.1335
RMS 0.5545
$\cos\theta_\tau$



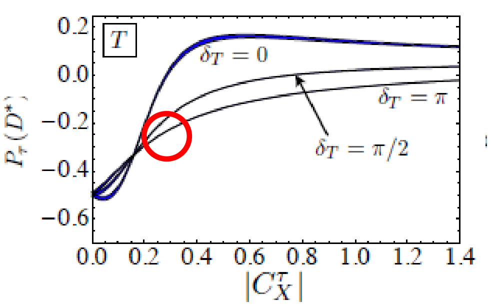
P_{D^*}
$\delta_T = \pi$
$\delta_T = \pi/2$
$\delta_T = 0$
$|C_X^\tau|$
T



$B^0\overline{B}^0$ total
D* coshel, Dpi
hds
Entries 50081
Mean −0.002642
RMS 0.5759
χ^2 / ndf 73.89 / 98
Constant 1000 ± 4.5
P_{D^*} 0.3295 ± 0.0033
D*→Dπ
$\cos\theta_{hel,D*}$
Calculated RGamD*=0.978383, PD*=0.327150



tau coshel
htau
Entries 100000
Mean −0.07456
RMS 0.5731
χ^2 / ndf 90.55 / 99
Constant 1998 ± 6.3
τ→πν
$\cos\theta_{hel,\tau}$
Calculated PtauD*=-0.223949



$P_\tau(D^*)$
$\delta_T = 0$
$\delta_T = \pi$
$\delta_T = \pi/2$
$|C_X^\tau|$
T

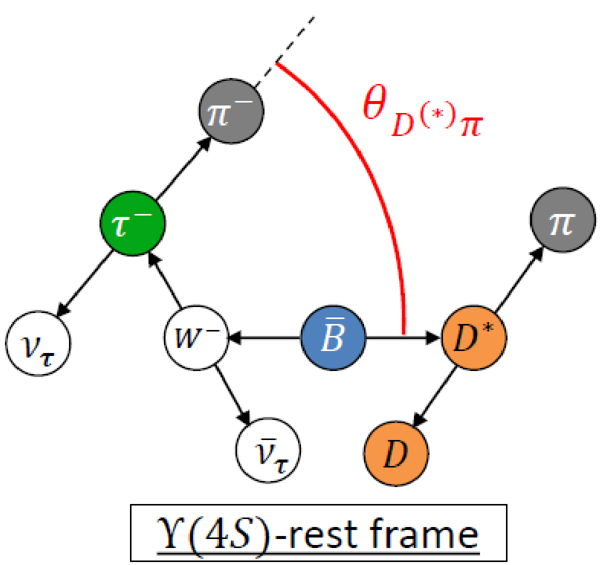
So far It looks good, but..

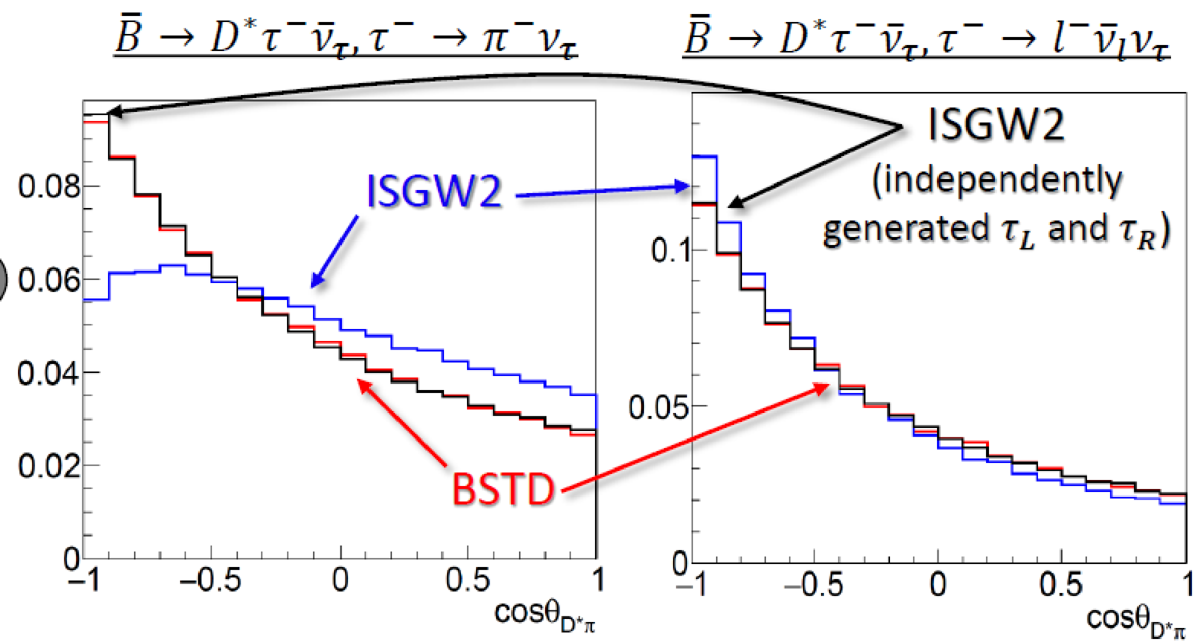
- C++ Helicity amplitude functions are compared with the original theory calculation → identical results
- Polarization of D* and tau checked by the helicity angle distribution generated by EvtGen → seems good

- Developed BSTD model is installed in the Belle and Belle II library
  - Being checked in Belle group analyses
  - Several bugs found and fixed
  - Remaining problem: no or wrong interference between +/- tau helicities

■ Discrepancy between BSTD and ISGW2

- K. Adamczyk and M. Rozanska (Krakow) reported that one angular distribution is different between BSTD and ISGW2
  - ISGW2 is the original decay model in EvtGen
- Difference is significant in the $\tau^- \to \pi^- \nu_\tau$ mode





No interference between two τ helicities in BSTD

(This problem also happens in $\bar{B} \to D\tau^- \bar{\nu}_\tau$)

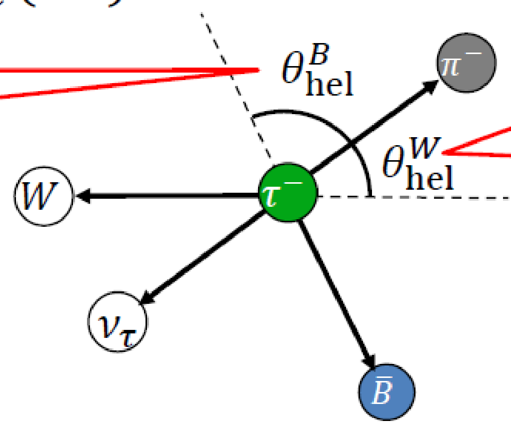
S. Hirose, K. Adamczyk, M. Rozanska

$P_\tau(D^*)$ in B-rest frame

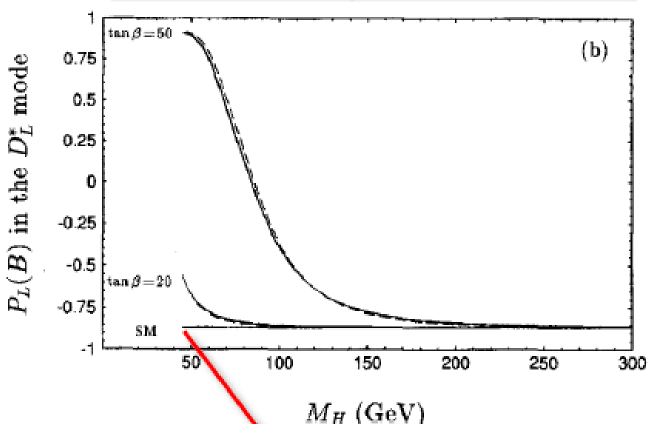
- Cross-check suggested by M. Tanaka (author of PRD 87, 034028): calculate $P_\tau(D^*)$ in B-rest frame

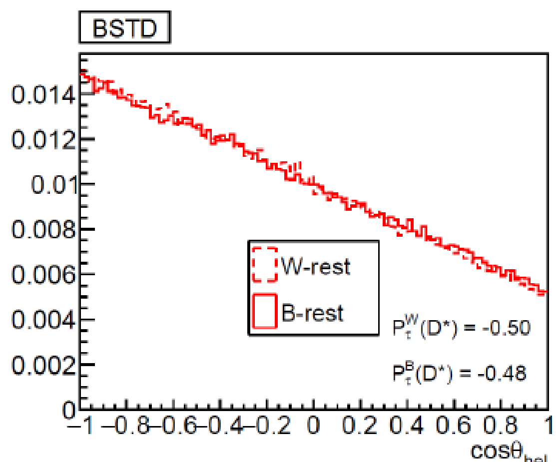
$P_\tau(D^*)$ can be also defined in B-rest frame

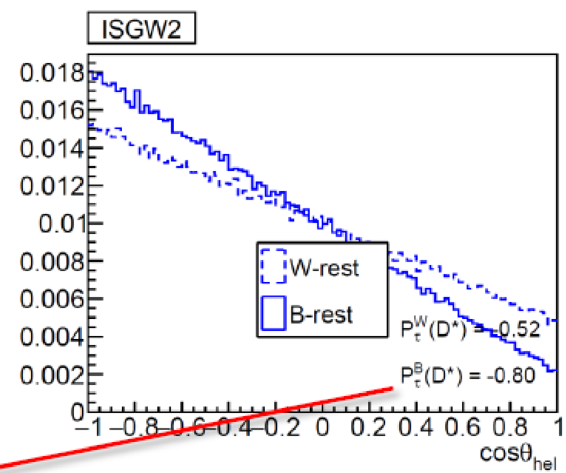
Usually we discuss $P_\tau(D^*)$ in W-rest frame



M. Tanaka, Z. Phys. C 67, 321 (1995)







Polarization in ISGW2 is correct → Obviously there is a problem in BSTD

S. Hirose

+/- tau helicity interference problem

- It should be OK up to the helicity amplitude calculation
- Suspicious part is the conversion between helicity amplitudes to the spin amplitudes

$\lambda\tau$: **helicity** of the tau **in the (l+nu) rest frame**
λ_M: meson (D, D*) **helicity in the B rest frame**

Conversion function made by me

λ_{D*},$\lambda\tau$: **spin state** at D*,τ rest frame

- Still working to fix the problem

Summary

- Developing the EvtGen model of B→D(*)taunu including New Physics effects
  - Based on M. Tanaka and R. Watanabe PRD87, 034028 (2013)
  - Including Vector, Scalar, Tensor NP contributions, controlled by complex Wilson Coefficients
- Debugging on-going in Belle/Belle II library
- Interference problem remains → working on the fix
- When it gets fixed, will release to public to be a model in the official EvtGen

Particle Spin in EvtGen Decay

[http://evtgen.warwick.ac.uk/static/docs/EvtGenGuide.pdf]

1. Generate B decay

Decay Amplitude $A = \sum_{\lambda_{D^*}\lambda_\tau} A^{B\to D^*\tau\nu}_{\lambda_{D^*}\lambda_\tau} \times A^{D^*\to D\pi}_{\lambda_{D^*}} \times A^{\tau\to\pi\nu}_{\lambda_\tau}$,

λ is the spin state of D* and τ

(Re)generate B decay kinematics randomly based on the phase space and

$$P_B = \sum_{\lambda_{D^*}\lambda_\tau} |A^{B\to D^*\tau\nu}_{\lambda_{D^*}\lambda_\tau}|^2.$$

take the event passes the accept-reject algorithm for P_B

2. D* spin density matrix → D* decay

Calculate the spin density matrix for D* after summing over τ spins

$$\rho^{D^*}_{\lambda_{D^*}\lambda'_{D^*}} = \sum_{\lambda_\tau} A^{B\to D^*\tau\nu}_{\lambda_{D^*}\lambda_\tau}[A^{B\to D^*\tau\nu}_{\lambda'_{D^*}\lambda_\tau}]^*,$$

The decay probability of D* is given by

$$P_{D^*} = \frac{1}{\mathrm{Tr}\,\rho^{D^*}} \sum_{\lambda_{D^*}\lambda'_{D^*}} \rho^{D^*}_{\lambda_{D^*}\lambda'_{D^*}} A^{D^*\to D\pi}_{\lambda_{D^*}}[A^{D^*\to D\pi}_{\lambda'_{D^*}}]^*,$$

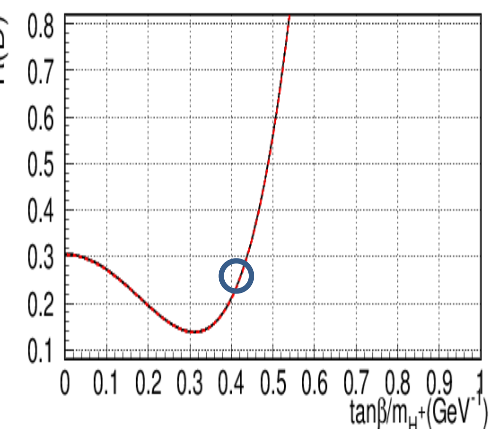
3. Tau spin density matrix → tau decay

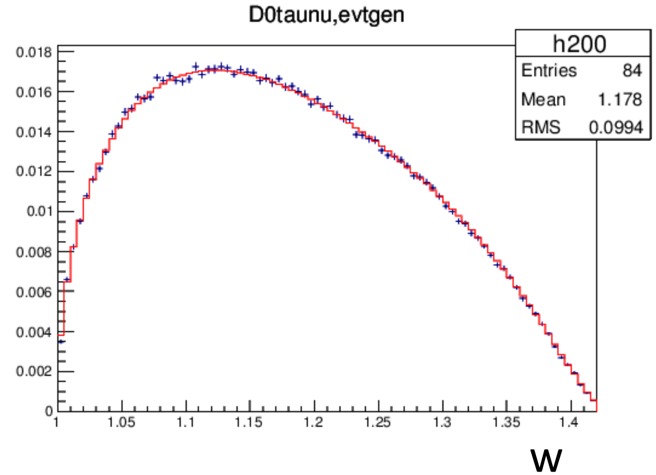
Calculate the spin density matrix for τ including kinematic correlation with D

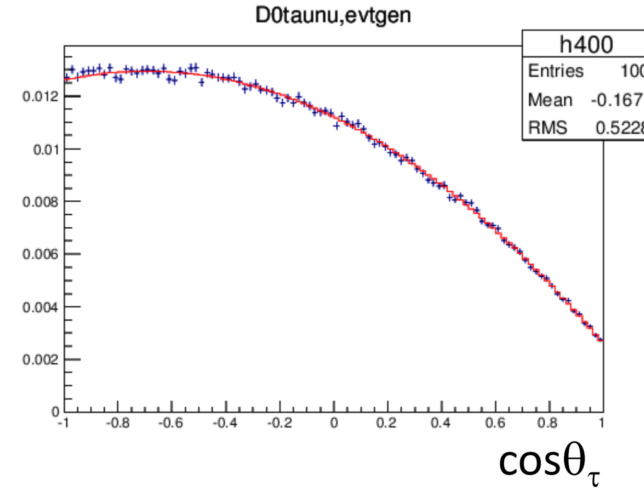
$$\tilde{\rho}^{D^*}_{\lambda_{D^*}\lambda'_{D^*}} = A^{D^*\to D\pi}_{\lambda_{D^*}}[A^{D^*\to D\pi}_{\lambda'_{D^*}}]^*,$$

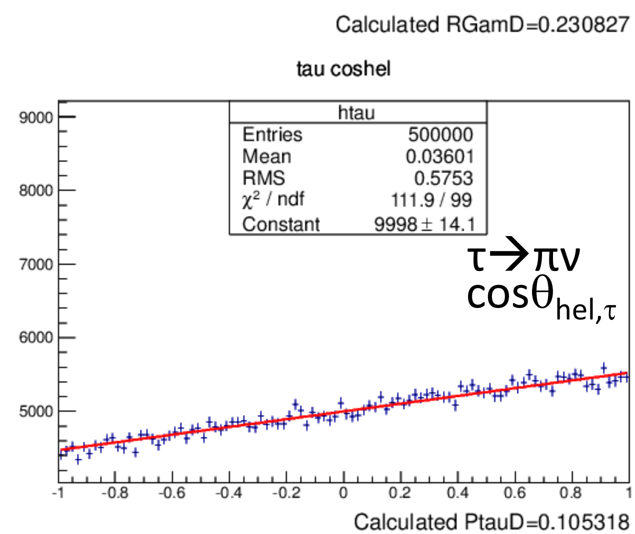
$$\rho^{\tau}_{\lambda_\tau\lambda'_\tau} = \sum_{\lambda_{D^*}\lambda'_{D^*}} \tilde{\rho}^{D^*}_{\lambda_{D^*}\lambda'_{D^*}} A^{B\to D^*\tau\nu}_{\lambda_{D^*}\lambda_\tau}[A^{B\to D^*\tau\nu}_{\lambda'_{D^*}\lambda'_\tau}]^*.$$

B+->Dtaunu, tan(beta)/mH=0.41









Example of imported C++ codes

```
// Total amplitude
EvtComplex EvtBSemiTauonicHelicityAmplitudeCalculator::helAmp(const EvtComplex& CV1, const
EvtComplex& CV2, const EvtComplex& CS1, const EvtComplex& CS2, const EvtComplex& CT$
   double mtau, int tauhel, int Dhel, double w, double costau) const
{
  // sanity check
  assert(chktauhel(tauhel) && chkDhel(Dhel));

  return //(GF/sqrt(2))*Vcb* // <-- constants which does not affect the distribution omitted
   (1.*helampSM(mtau, tauhel, Dhel, w, costau)
    + CV1 * helampV1(mtau, tauhel, Dhel, w, costau)
    + CV2 * helampV2(mtau, tauhel, Dhel, w, costau)
    + CS1 * helampS1(mtau, tauhel, Dhel, w, costau)
    + CS2 * helampS2(mtau, tauhel, Dhel, w, costau)
    + CT * helampT(mtau, tauhel, Dhel, w, costau));
}
```

```
// Helicity Amplitudes
// SM
double EvtBSemiTauonicHelicityAmplitudeCalculator::helampSM(double mtau, int tauhel, int
Dhel, double w, double costau) const
{
  double amp(0.);
  for (int whel = -1; whel <= 2; whel++) {
    amp += eta(whel) * Lep(mtau, tauhel, whel, q2(Dhel, w), costau)
        * HadV1(Dhel, whel, w);
  }
  return amp;
}
```

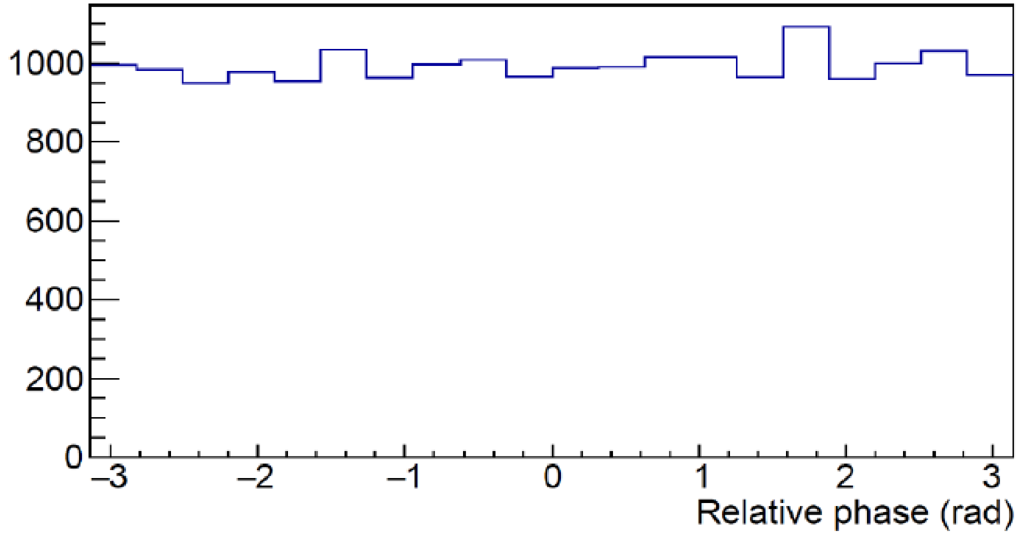
```
// Hadronic Amplitudes //
// V-A
double EvtBSemiTauonicHelicityAmplitudeCalculator::HadV1(int Dhel, int whel, double w) const
{
  // sanity check
  assert(chkDhel(Dhel) && chkwhel(whel));

  const double r0 = r(Dhel);
  if (Dhel == 2 && whel == 0) {
    return m_mB * sqrt(r0 * (w * w - 1.) / qh2(2, w)) * ((1 + r0) * hp(w) - (1 - r0) * hm(w));
  }
  if (Dhel == 2 && whel == 2) {
    return m_mB * sqrt(r0 / qh2(2, w)) * ((1 - r0) * (w + 1) * hp(w) - (1 + r0) * (w - 1) * hm(w));
  }
  if (Dhel == +1 && whel == +1) {
    return m_mB * sqrt(r0) * ((w + 1) * hA1(w) - sqrt(w * w - 1) * hV(w));
  }
  if (Dhel == -1 && whel == -1) {
    return m_mB * sqrt(r0) * ((w + 1) * hA1(w) + sqrt(w * w - 1) * hV(w));
  }
  if (Dhel == 0 && whel == 0) {
    return m_mB * sqrt(r0 / qh2(0, w)) * (w + 1) *
          (-(w - r0) * hA1(w) + (w - 1) * (r0 * hA2(w) + hA3(w)));
  }
  if (Dhel == 0 && whel == 2) {
    return m_mB * sqrt(r0 * (w * w - 1) / qh2(0, w)) * (-(w + 1) * hA1(w) + (1 - r0 * w) * hA2(w) + (w - r0) * hA3(w));
  }

  // other cases
  return 0.;

}
```

Misc. function added EvtGen model

- Parameter initialization
  - Wilson coefficients CV1, CV2, CS1, CS2, CT
  - Quark masses
  - HQET FF parameters
- Set maximum probability value properly for the input parameters
- Proper CP-transformation between B and B-bar
  - Model calculation given for B-bar
- Checked in the Belle / Belle II library

Relative Phase

- Checked relative phase between τ_L and τ_R amplitudes
  - If relative phase is 90 degrees, interference doesn't happen
- Phase difference is not always 90 degrees
  - Interference must be considered in BSTD code, but it disappears at some point...
- Interference occurs after the τ decay
  - $\tau_L \rightarrow \pi\nu$ and $\tau_R \rightarrow \pi\nu$ interferes
  - Helicity information is lost somewhere in EvtGen base functions?



```
# example decay file of BSTD model, based on M. Tanaka and R. Watanabe PRD87,034028(2013)
# author: Koji Hara (koji.hara@kek.jp)

# Wilson coefficients for New Physics contributions
# Each Wilson coefficient is calculated by
# CXX = MagCXX * exp( ArgCXX * i )
# Negative value of MagCXX is allowed.
# all CXX = 0 --> Standard Model
Define MagCV1           0
Define ArgCV1           0
Define MagCV2           0
Define ArgCV2           0
Define MagCS1           0
Define ArgCS1           0
Define MagCS2           0
Define ArgCS2           0
Define MagCT            0
Define ArgCT            0

# quark masses at the m_b scale
# taken from PRD77, 113016 (2008)
# m_b = 4.20+/-0.07 GeV/c^2
# m_c = 0.901+0.111-0.113 GeV/c^2
Define m_b      4.20
Define m_c      0.901

# HQET Form Factor parameters from B->D(*)lnu data
# taken from HFAG End Of Year 2011
# rho_1^2 = 1.186 +/- 0.036 +/- 0.041
# rho_A1^2 = 1.207 +/- 0.015 +/- 0.021
# R_1(1) = 1.403 +/- 0.033
# R_2(1) = 0.854 +/- 0.020
Define rho12    1.186
Define rhoA12   1.207
Define R11      1.403
Define R21      0.854

# Parameters related to the O(1/m_q) correction in the scalar form factors
# The authors of PRD87,034028 use 1 +/- 1 for these values to take into account the theoretical error.
Define aS1      1.0
Define aR3      1.0
```