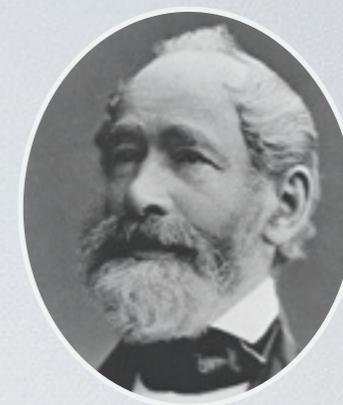




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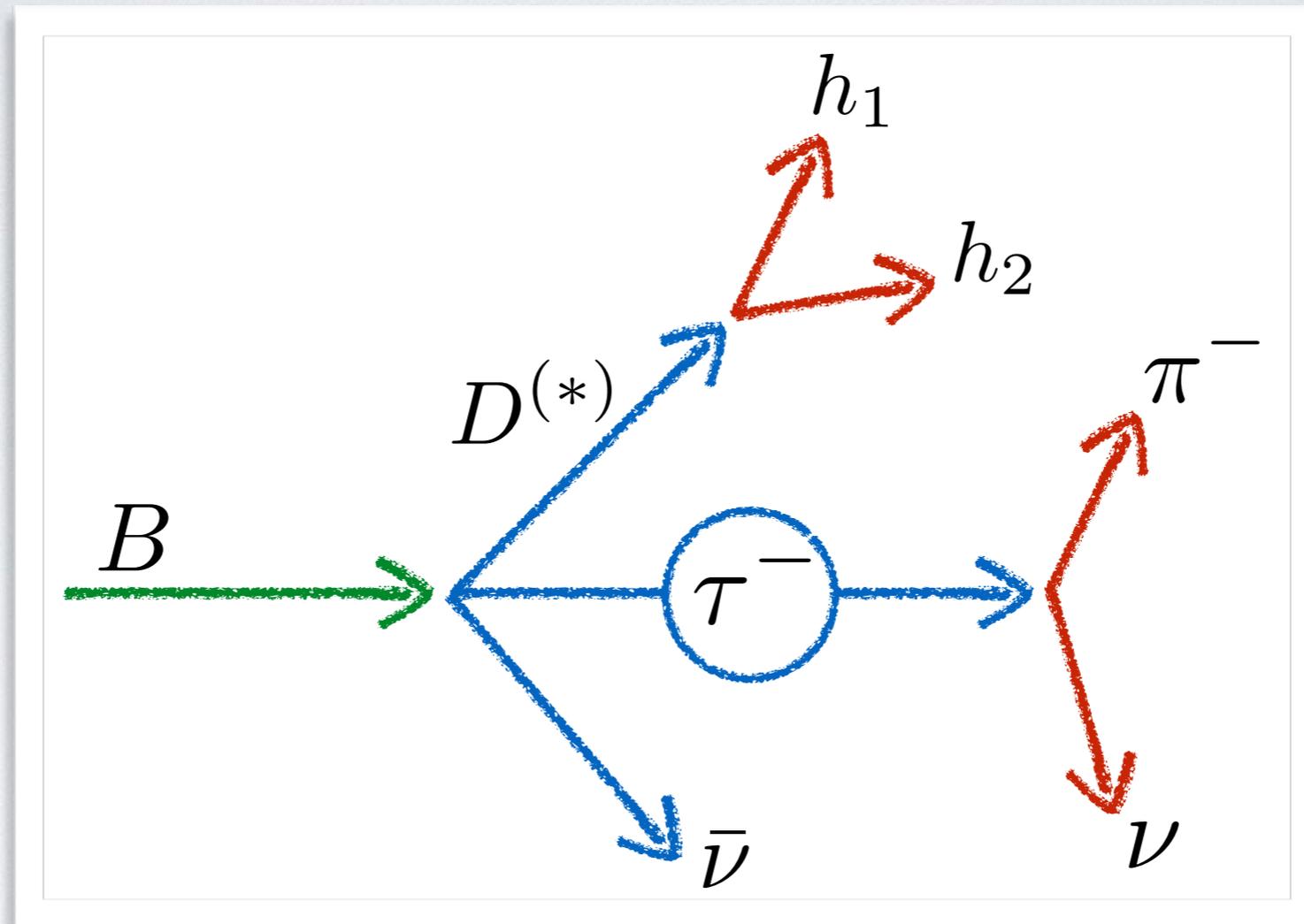
# TAU PROPERTIES IN B DECAYS FROM FINAL-STATE KINEMATICS

Susanne Westhoff

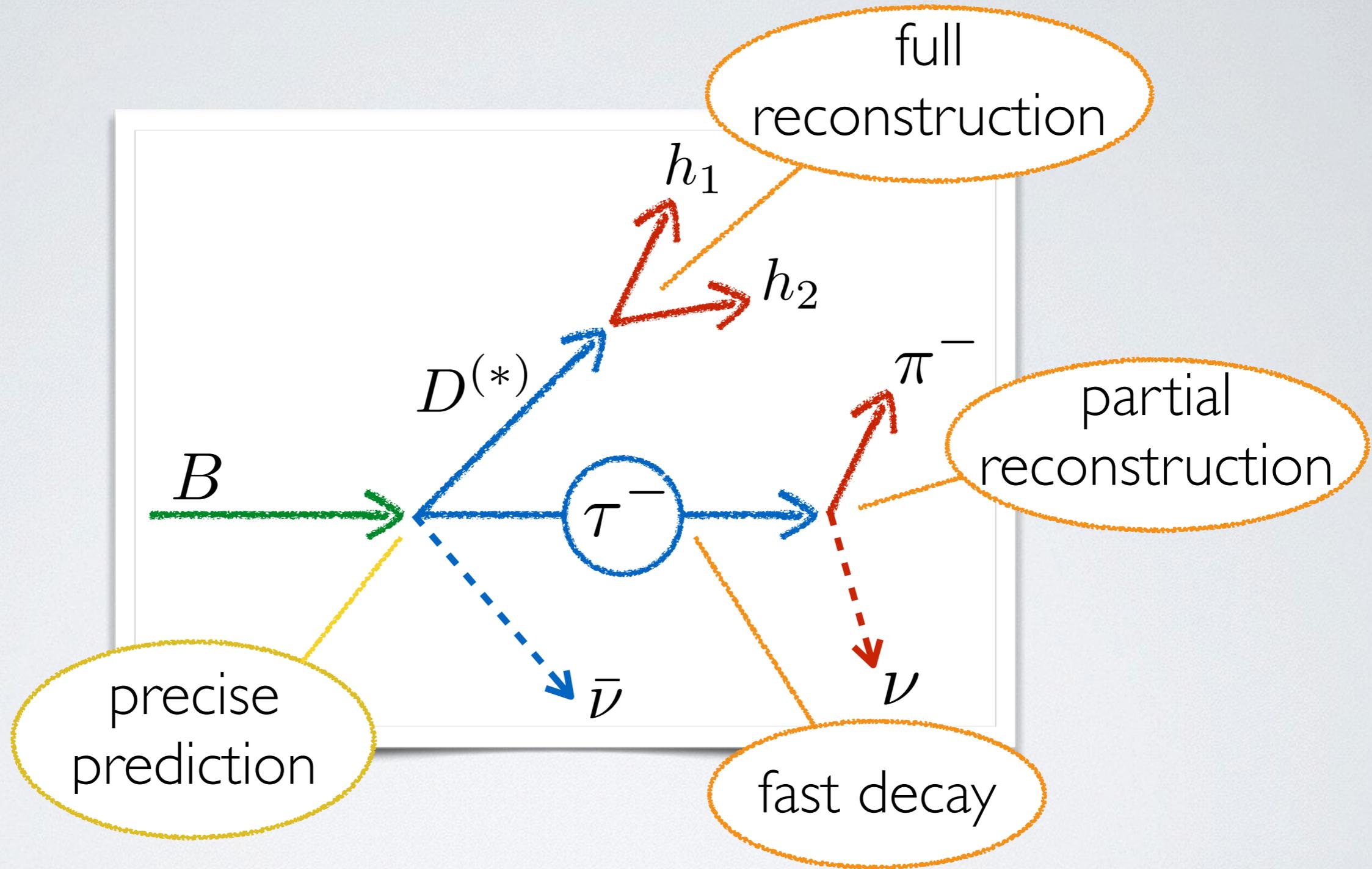
based on work with Rodrigo Alonso and Jorge Martin Camalich

Pheno 2017 — May 8-10, 2017 — University of Pittsburgh

# SEMI-LEPTONIC B DECAYS WITH TAUS



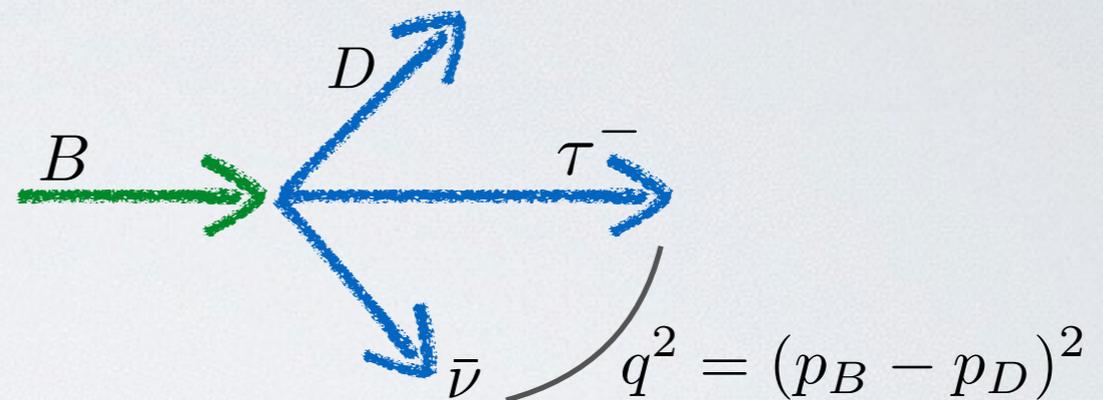
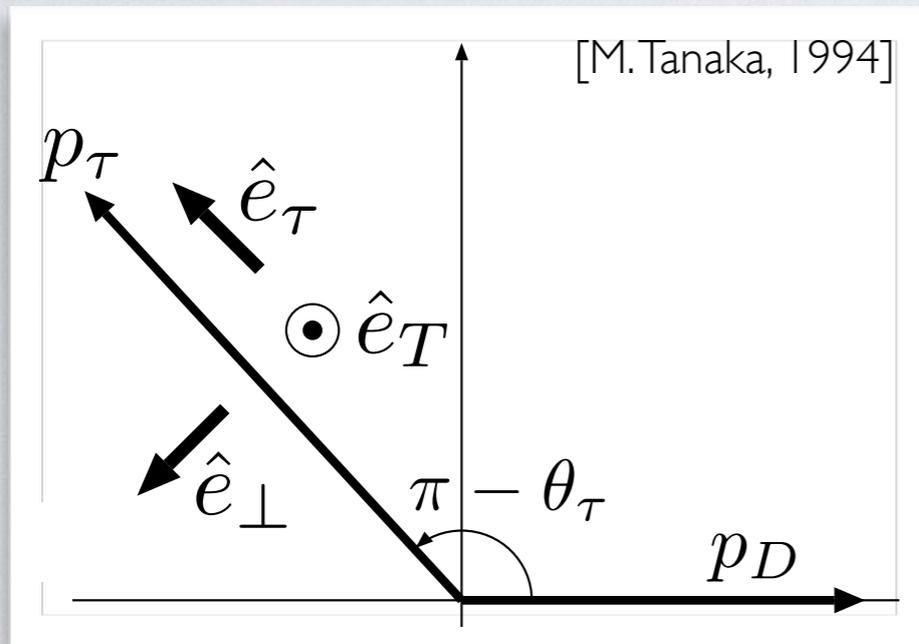
# SEMI-LEPTONIC B DECAYS WITH TAUS



Probe tau **production** properties through **decay** kinematics.

# TAU PRODUCTION PROPERTIES

in  $q$  rest frame



Tau polarizations:  $dP_i = \frac{d\Gamma_i}{d\Gamma}$

$$d\Gamma(\hat{s}) = \frac{1}{2} \left[ d\Gamma + (d\Gamma_L \hat{e}_\tau + d\Gamma_\perp \hat{e}_\perp + d\Gamma_T \hat{e}_T) \cdot \hat{s} \right]$$

Tau forward-backward asymmetry:

$$\Gamma A_\tau = \int_0^1 d \cos \theta_\tau \frac{d\Gamma}{d \cos \theta_\tau} - \int_{-1}^0 d \cos \theta_\tau \frac{d\Gamma}{d \cos \theta_\tau}$$

# TAU PROPERTIES FROM FINAL-STATE KINEMATICS

Idea:

Obtain information on tau production *directly* from kinematics of *visible* particles in final state.

[Kiers, Soni, 1997] [Nierste, Trine, SW, 2008]

## Recent development:

Tau polarizations and asymmetry:

[Alonso, Martin Camalich, SW, 2017] [Ivanov, Koerner, Tran, 2017]

[Tanaka, Watanabe, 2010] [Sakaki, Tanaka, 2013]

$$B \rightarrow D^{(*)} \nu [\tau \rightarrow (\ell \nu, \pi, \rho) \nu]$$

CP violation: [Hagiwara, Nojiri, Sakaki, 2014, MC]

$$B \rightarrow D \nu [\tau \rightarrow 3\pi \nu]$$

Background for  $B \rightarrow (D, \pi) \mu \nu$ :

$$B \rightarrow (D, \pi) \nu [\tau \rightarrow \mu \nu \nu]$$

[Bordone, Isidori, van Dyk, 2016, MC]

Searches for new physics:

[Alonso, Kobach, Martin Camalich, 2016]

$$B \rightarrow D^{(*)} \nu [\tau \rightarrow \ell \nu \nu]$$

[Ligeti, Papucci, Robinson, 2016, MC]

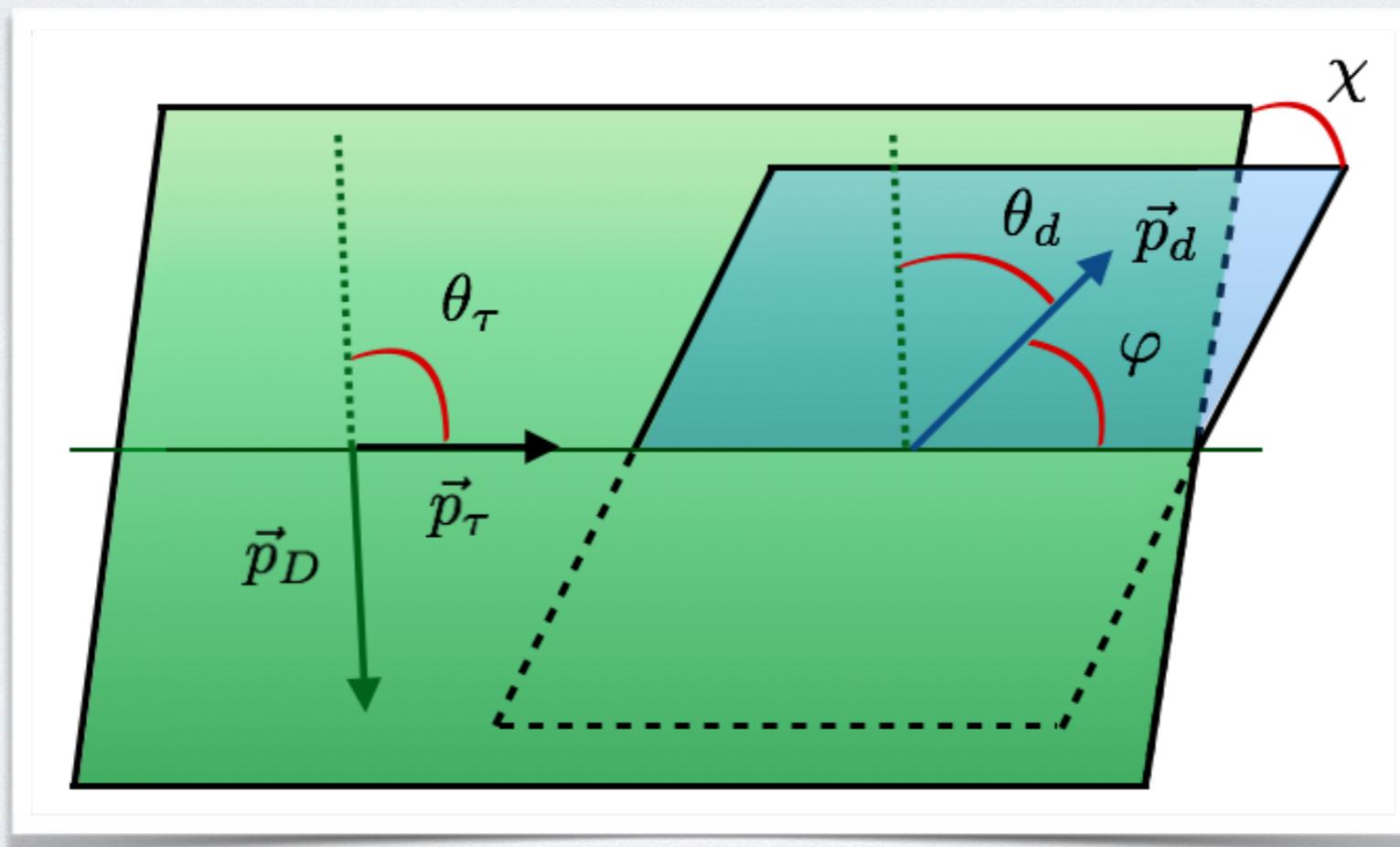
$$B \rightarrow [D^{(*)} \rightarrow D(\pi, \gamma)] \nu [\tau \rightarrow (\ell \nu, \pi) \nu]$$

# DIFFERENTIAL DECAY DISTRIBUTIONS

Full decay chain  $B \rightarrow D\nu[\tau \rightarrow d\nu(\nu)]$ :

$$\frac{d^3\Gamma_d}{dq^2 ds_d d\cos\theta_d} \sim I_0(q^2, s_d) + I_1(q^2, s_d)\cos\theta_d + I_2(q^2, s_d)\cos^2\theta_d$$

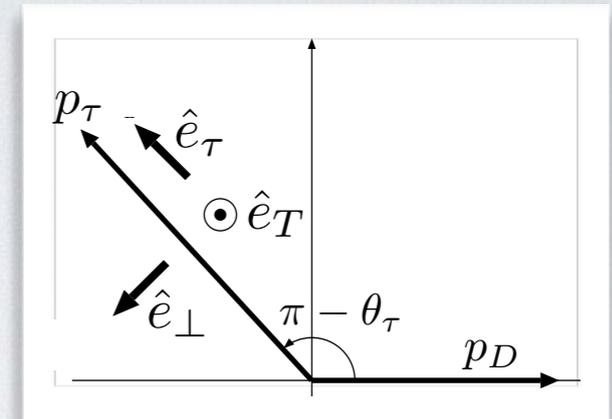
→ visible final state described by  $q^2, s_d = E_d/\sqrt{q^2}, \cos\theta_d$



# OBSERVABLES OF TAU PROPERTIES

$P_L$  : from **energy distribution** of visible tau decay particle  $d$

$$\frac{d^2\Gamma_d}{dq^2 ds_d} = \mathcal{B}_d \frac{d\Gamma}{dq^2} \left[ f_0^d + f_L^d(s_d) P_L(q^2) \right]$$



$P_\perp$  : from **angular asymmetry of  $d$**  in  $D$  direction

$$\begin{aligned} \frac{dA_d}{ds_d} &= \left( \mathcal{B}_d \frac{d\Gamma}{dq^2} \right)^{-1} \left[ \int_0^1 d \cos \theta_d d^3\Gamma_d - \int_{-1}^0 d \cos \theta_d d^3\Gamma_d \right] \\ &= f_A^d(s_d) A_\tau(q^2) + f_\perp^d(s_d) P_\perp(q^2) \end{aligned}$$

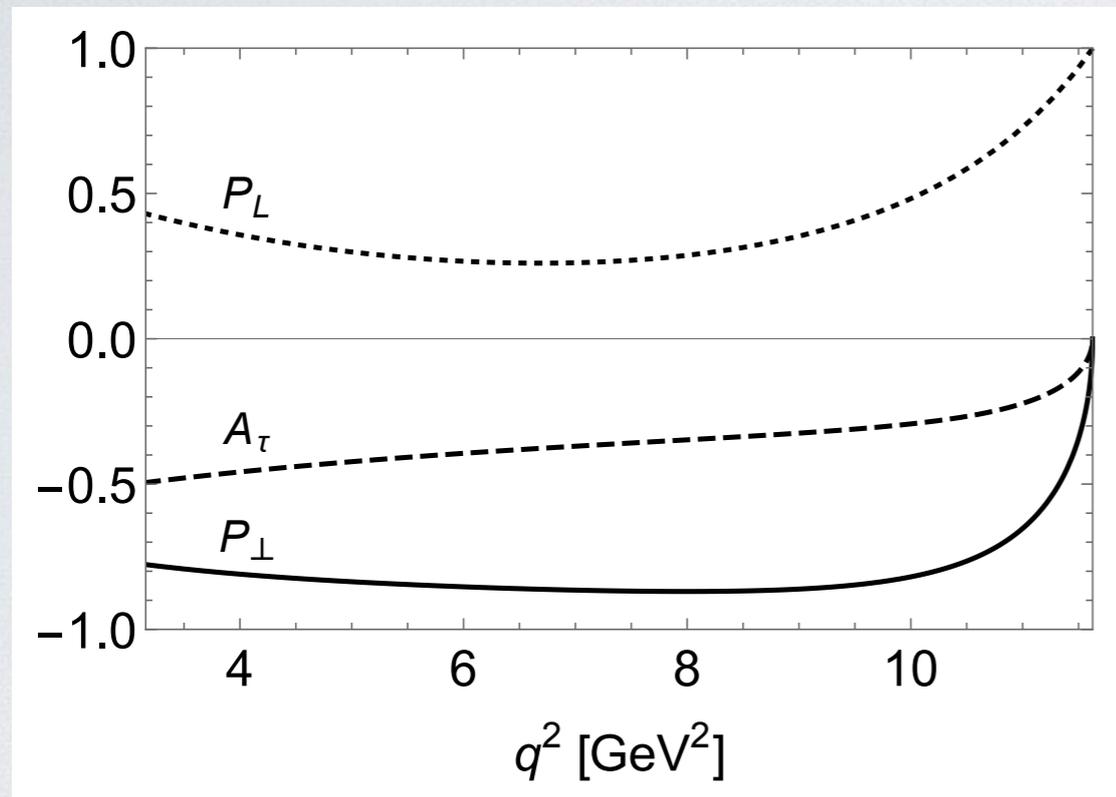
complementary to tau forward-backward asymmetry!

$P_T$  : requires additional information perpendicular to  $d$ - $D$  plane  
(tau tracks? three-prong decay?)

# EXTRACTING TAU PROPERTIES

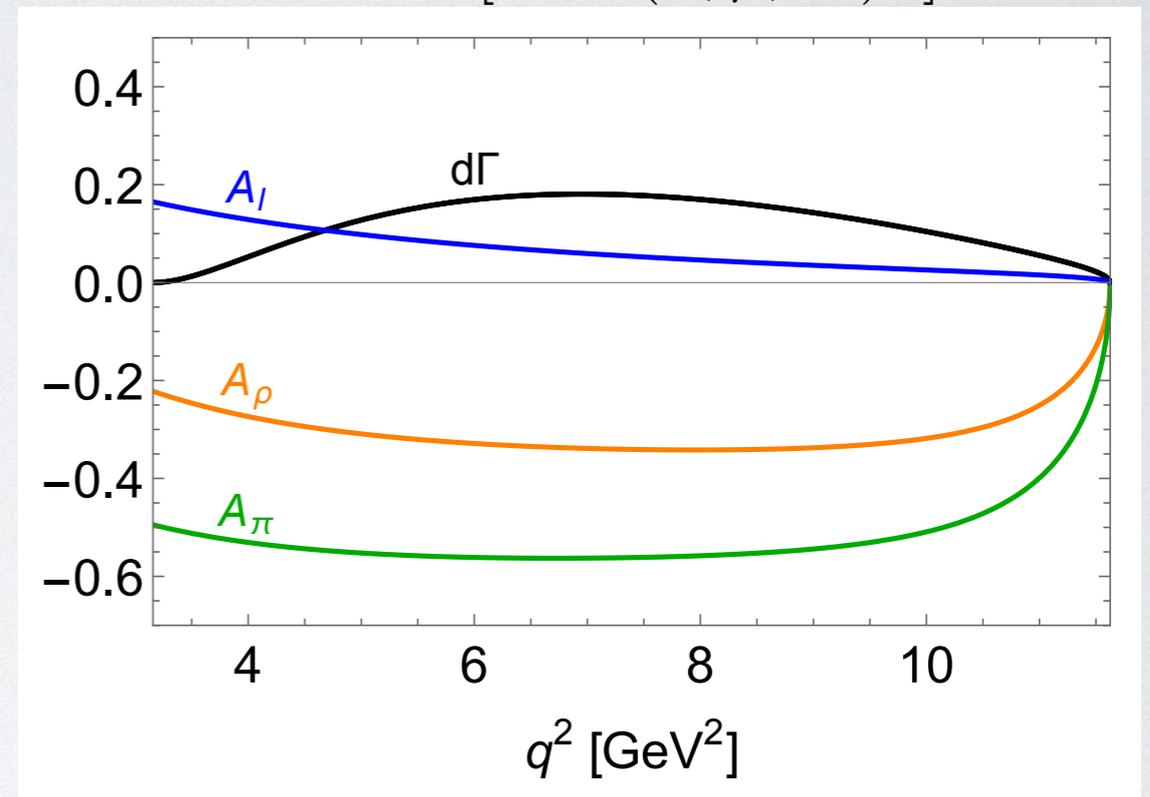
Production:

$$B \rightarrow D\tau\nu$$



Observable:

$$B \rightarrow D\nu[\tau \rightarrow (\pi, \rho, \ell\nu)\nu]$$



[Alonso, Martin Camalich, SW, 2017]

Tau decays:

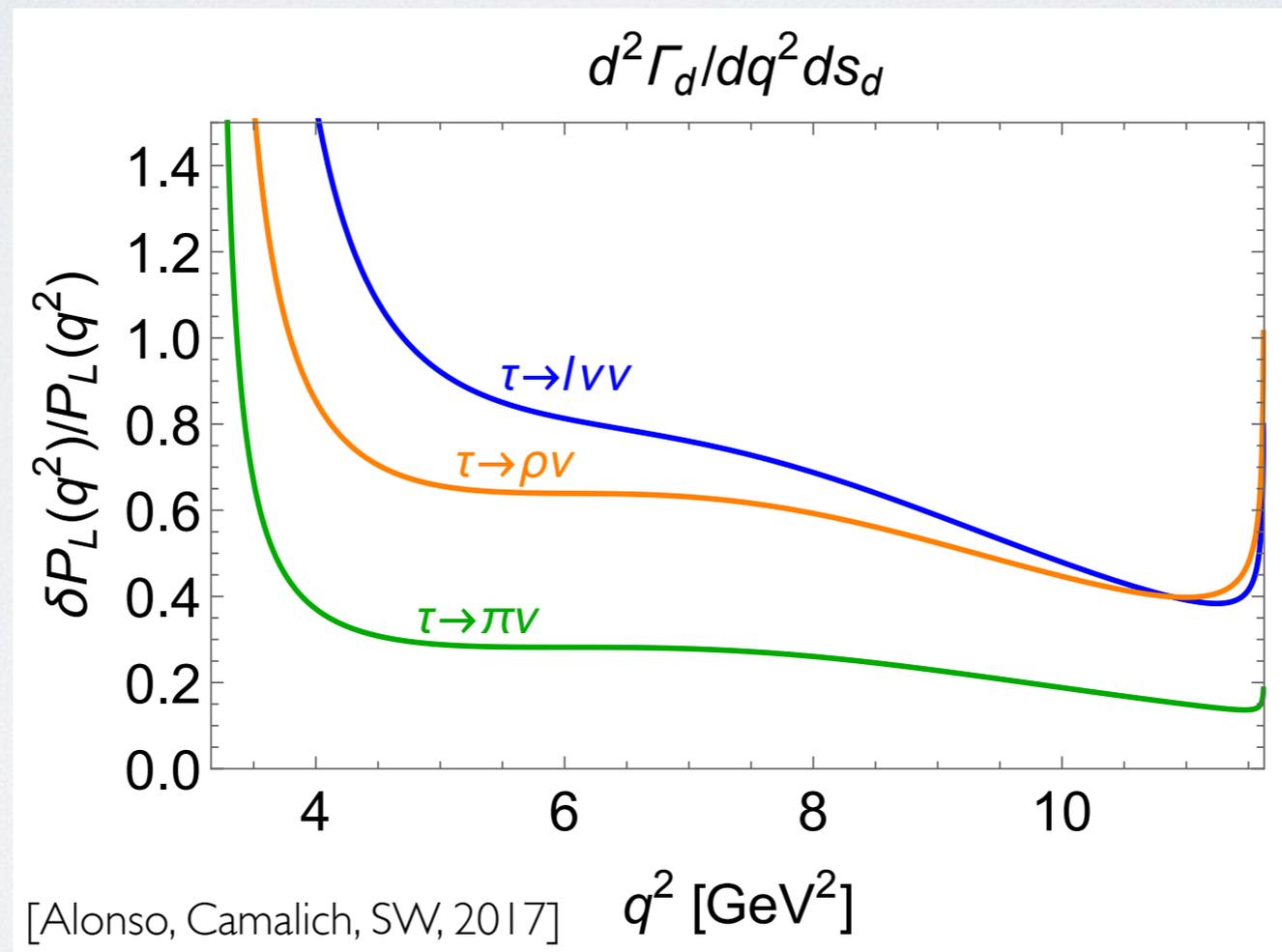
Channel	$\tau \rightarrow \mu\nu\nu$	$\tau \rightarrow e\nu\nu$	$\tau \rightarrow \pi\nu$	$\tau \rightarrow \rho\nu$	$\tau \rightarrow 3\pi\nu$	TOTAL
$\mathcal{B}$	17.4%	17.8%	10.82%	25%	9%	$\sim 80\%$

[Martin Camalich, CKM 2016]

# LONGITUDINAL POLARIZATION AT BELLE II

Statistical uncertainty with  $N(q^2)$  events per  $q^2$  (bin):

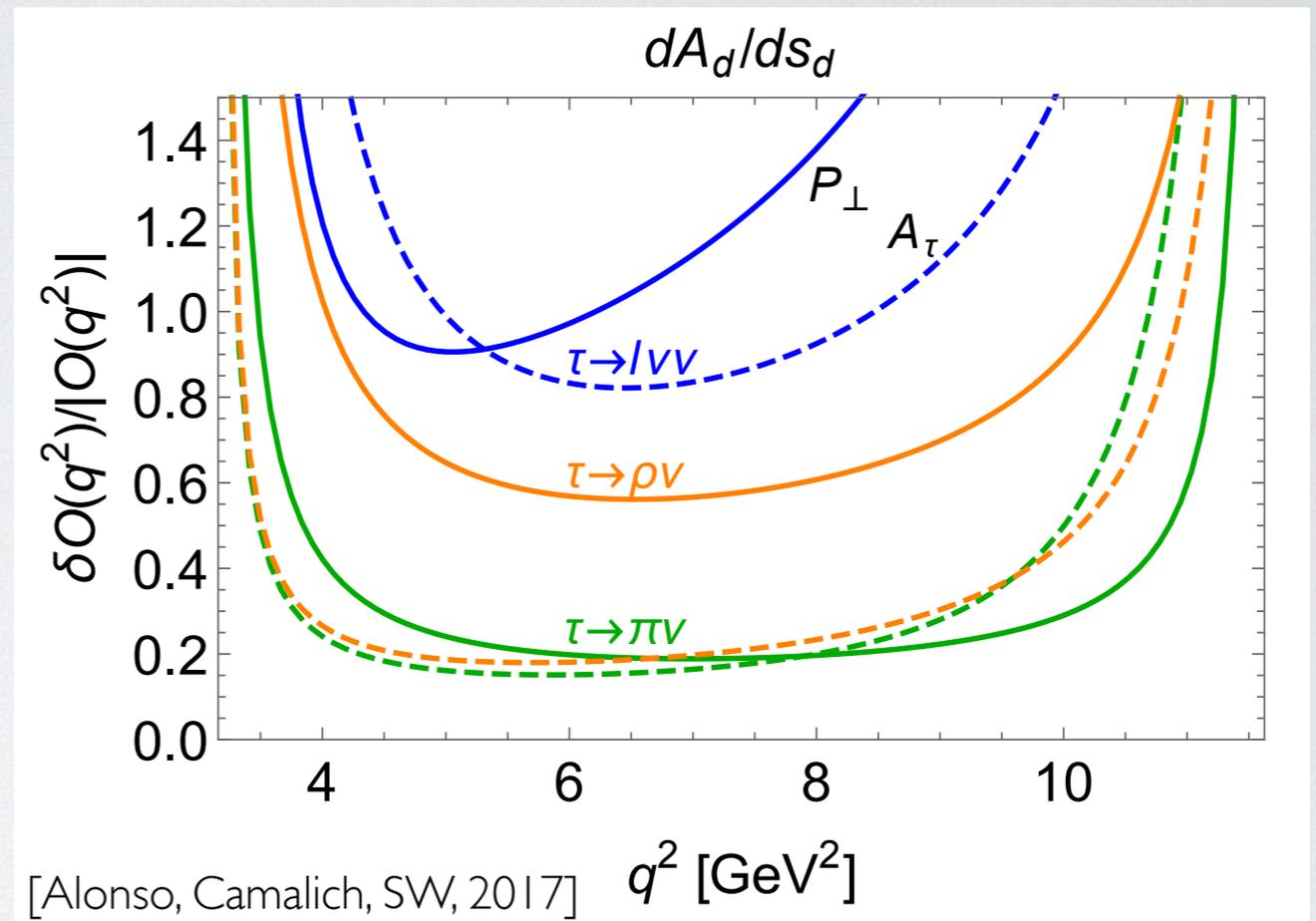
$$\delta P_L(q^2) = \frac{1}{\sqrt{N(q^2)S_L(q^2)}} \quad \text{with} \quad S_L^2(q^2) = \int ds_d \frac{f_L^d(s_d)^2}{f_0^d + f_L^d(s_d)P_L(q^2)}$$



At BELLE II with luminosity  $\mathcal{L} = 50 \text{ ab}^{-1}$  :  $N_{\text{tot}} \approx 3000$ .

# PERPENDICULAR POLARIZATION AT BELLE II

Maximum-likelihood fit of  $A_\tau$  and  $P_\perp$  to  $d$  energy distribution of  $A_d$  :



Statistical precision for  $\tau \rightarrow \{\pi\nu, \rho\nu, \ell\nu\nu\}$ :

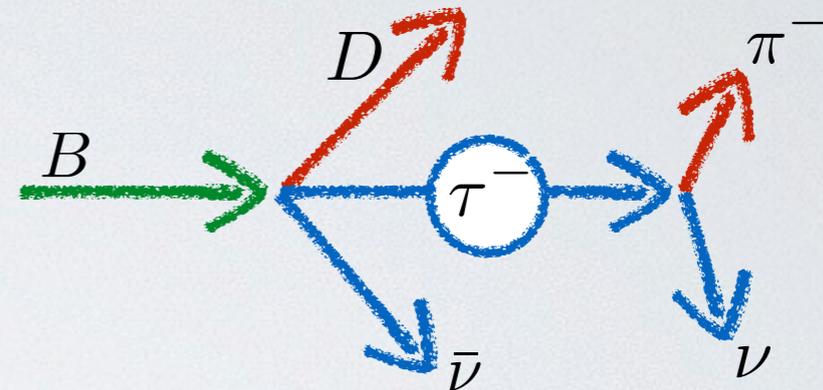
	BELLE I [total]	BELLE II [1 year]	BELLE II [total]
$\mathcal{L}$ [ab <sup>-1</sup> ]/ $N$ [events]	1/60	5/300	50/3000
$\delta P_L/P_L$	{0.21, 0.49, 0.62}	{0.10, 0.22, 0.28}	{0.03, 0.07, 0.09}
$\delta P_\perp/ P_\perp $	{0.62, 1.8, 4.0}	{0.28, 0.81, 1.8}	{0.09, 0.25, 0.57}
$\delta A_\tau/ A_\tau $	{0.74, 0.69, 2.8}	{0.33, 0.31, 1.3}	{0.11, 0.10, 0.40}

# TAKE HOME

- Tau properties in semi-leptonic B decays from final states:

- longitudinal polarization

$$P_L \leftrightarrow d\Gamma_d(E_d)$$



- perpendicular polarization and tau asymmetry

$$P_{\perp}, A_{\tau} \leftrightarrow A_d(E_d)$$

(similar strategy for  $D^*$ )

- **Hadronic** tau decays have **highest sensitivity** to tau properties.
- Good prospects for **measurements** with BELLE (II) data.
- Rich opportunities to probe **new physics** with tau interactions.