Universität Heidelberg

Carl Zeiss Stiftung

TAU PROPERTIES IN B DECAYS FROM FINAL-STATE KINEMATICS

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based on work with Rodrigo Alonso and Jorge Martin Camalich

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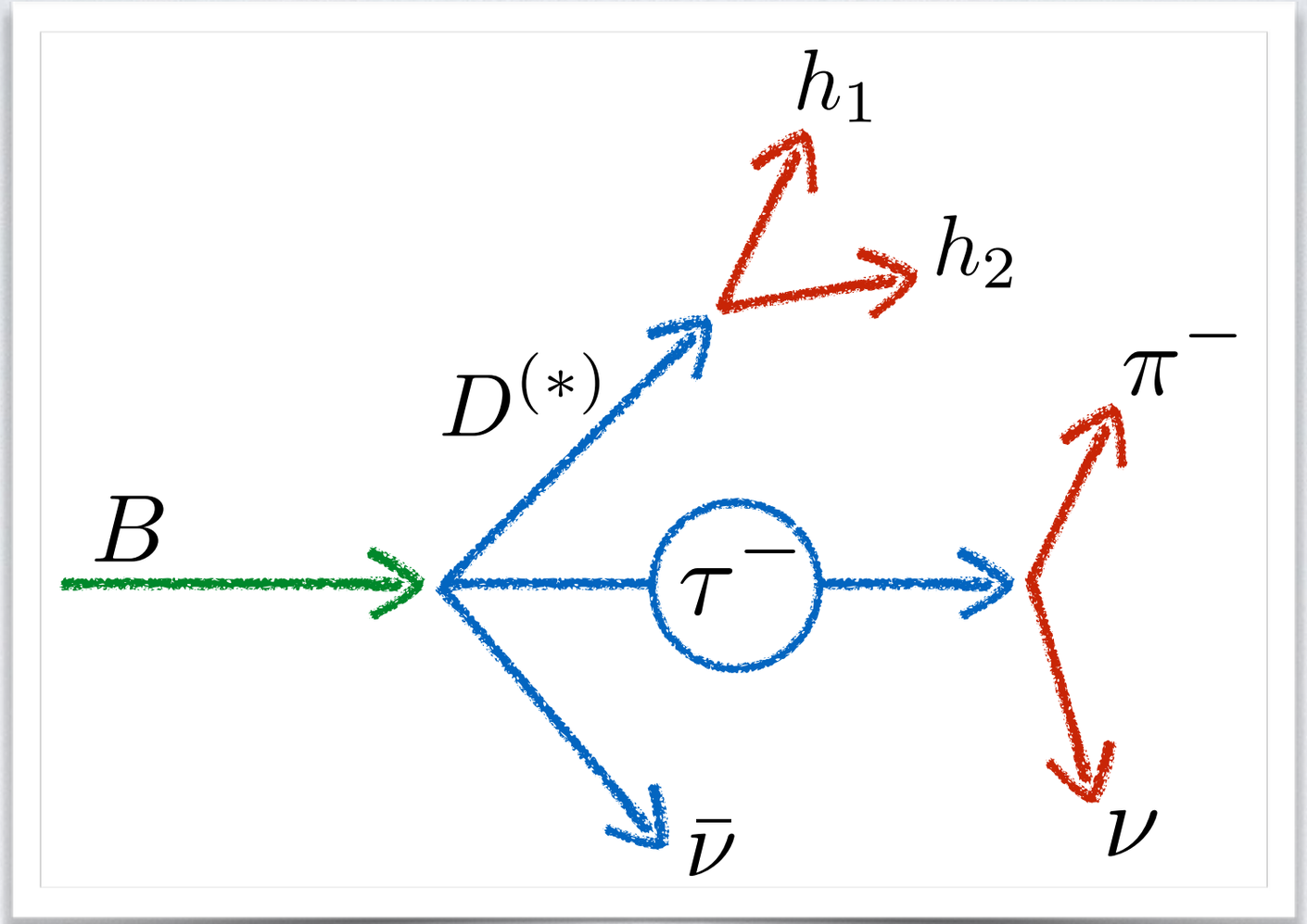
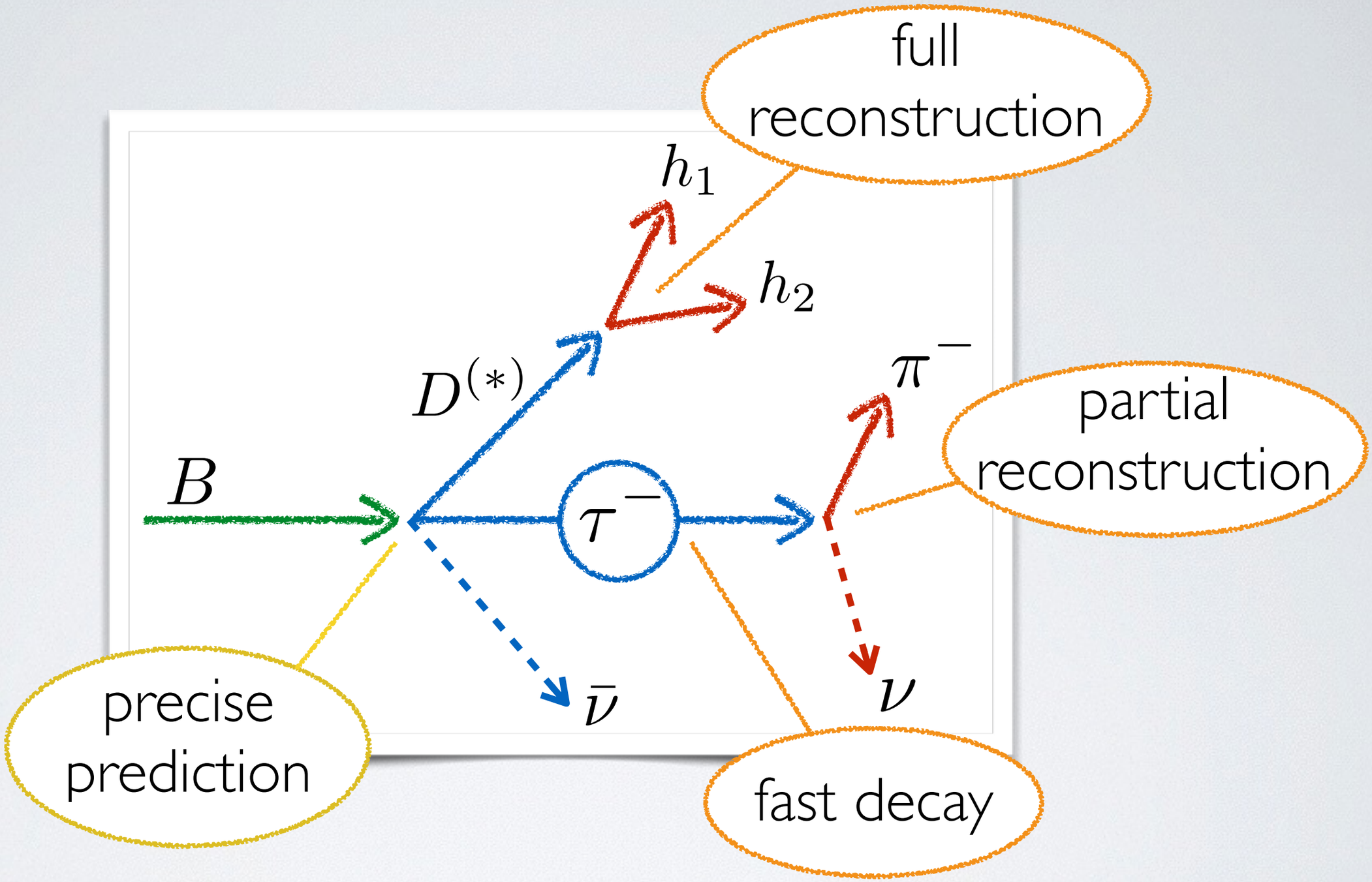
SEMI-LEPTONIC B DECAYS WITH TAUS



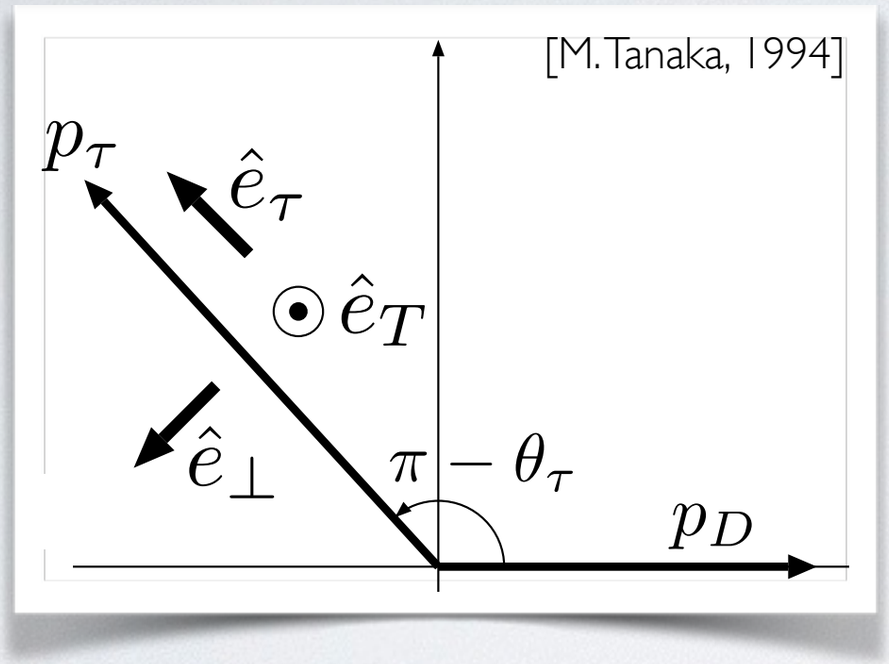
SEMI-LEPTONIC B DECAYS WITH TAUS

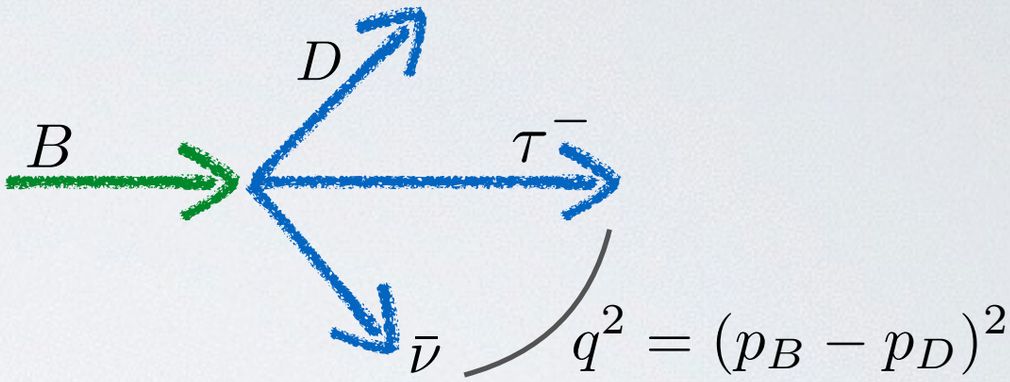


Probe tau **production** properties through **decay** kinematics.

TAU PRODUCTION PROPERTIES

in q rest frame





Tau polarizations:

$$d\Gamma(\hat{s}) = d\Gamma\left[1 + \tfrac{1}{2}(dP_L \hat{e}_\tau + dP_\perp \hat{e}_\perp + dP_T \hat{e}_T) \cdot \hat{s}\right]$$

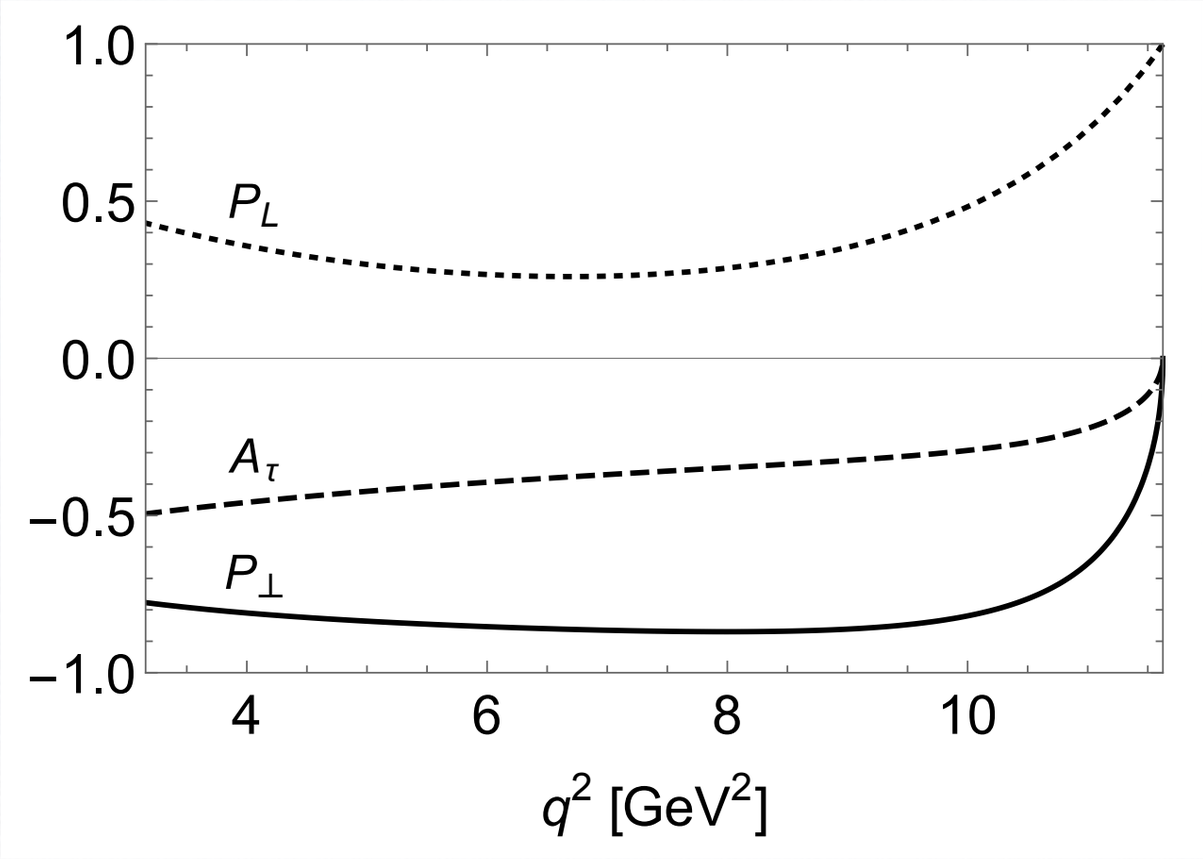
Tau forward-backward asymmetry:

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

TAU PRODUCTION PROPERTIES

Predictions in standard model:

$B \to D\tau\nu$



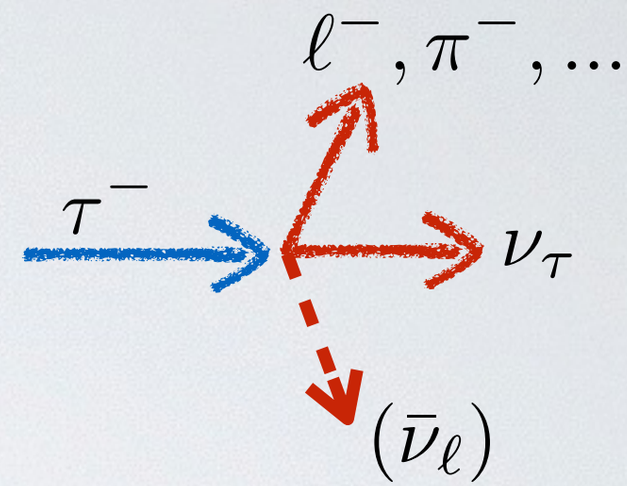
Integrated over q^2: [Alonso, Camalich, SW, 2017]

$$P_L = 0.34(3), \quad P_\perp = -0.839(7), \quad A_\tau = -0.359(3)$$

TAU DECAYS

Short lifetime due to large mass:

$$\tau_\tau \approx \frac{1}{5}\tau_\mu \left(\frac{m_\mu}{m_\tau}\right)^5 = 3.3 \times 10^{-13} s$$



Tau decay branching ratios:

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

[J. M. Camalich, CKM 2016]

Experimental information on tau decays: [A. Pich, 2014 and refs.]

$\tau \to \ell\nu\nu$: Michel parameters probe charged current at % level

$$\tau \to \pi\nu : \; R_{\tau/\pi} = \frac{\Gamma(\tau^- \to \nu_\tau \pi^-)}{\Gamma(\pi^- \to \mu^- \bar{\nu}_\mu)}$$

probes tau-mu universality at sub-% level

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

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

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

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

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

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

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

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

Searches for new physics:

[Alonso, Kobach, Camalich, 2016]

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

[Ligeti, Papucci, Robinson, 2016, MC]

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

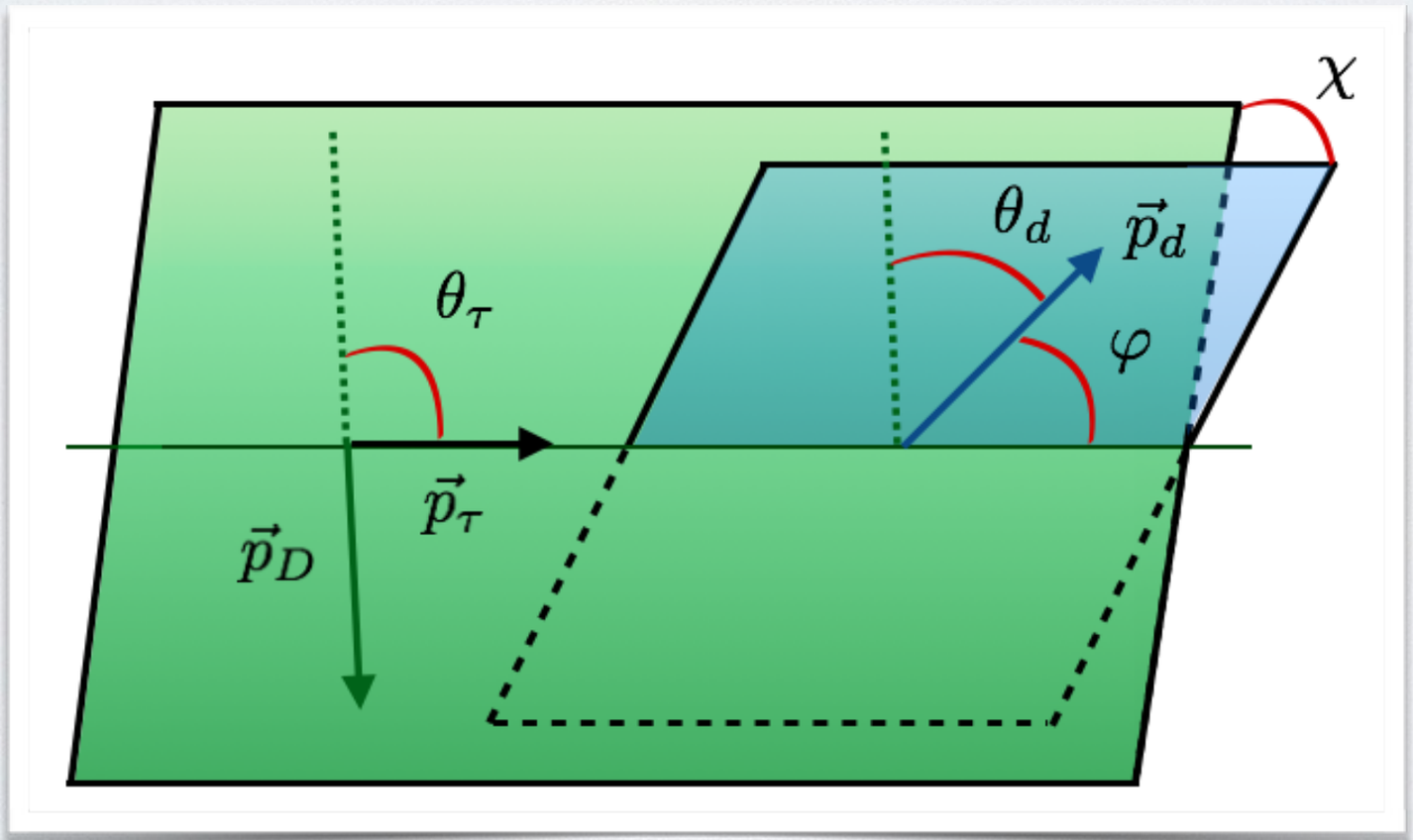
DIFFERENTIAL DECAY DISTRIBUTIONS

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

Integration over phase-space of invisible neutrinos yields

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

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

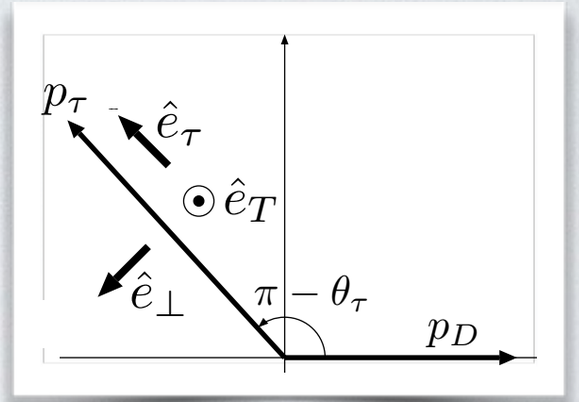


[Alonso, Kobach, Camalich, 2016]
[Alonso, Camalich, SW, 2017]

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

$$\frac{dA_d}{ds_d} = \left(\mathcal{B}_d \frac{d\Gamma}{dq^2}\right)^{-1}\left[\int_0^1 d\cos\theta_d\, d^3\Gamma_d - \int_{-1}^0 d\cos\theta_d\, d^3\Gamma_d\right]$$

$$= f_A^d(s_d) A_\tau(q^2) + f_\perp^d(s_d) P_\perp(q^2)$$

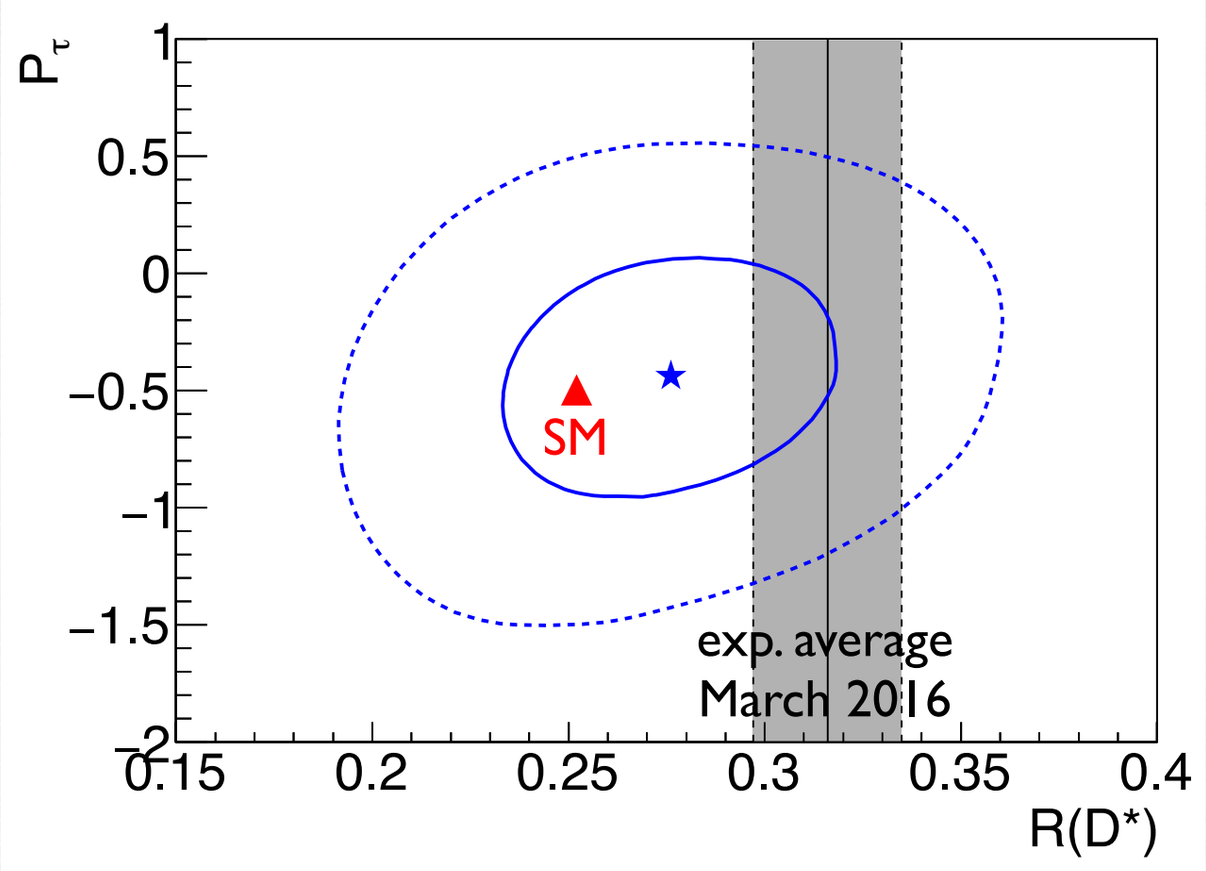
complementary to tau forward-backward asymmetry!

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

TAU POLARIZATION MEASUREMENT

Based on hadronic decay modes $\tau \to \pi\nu,\ \tau \to \rho\nu$:

$B \to D^*\tau\nu$



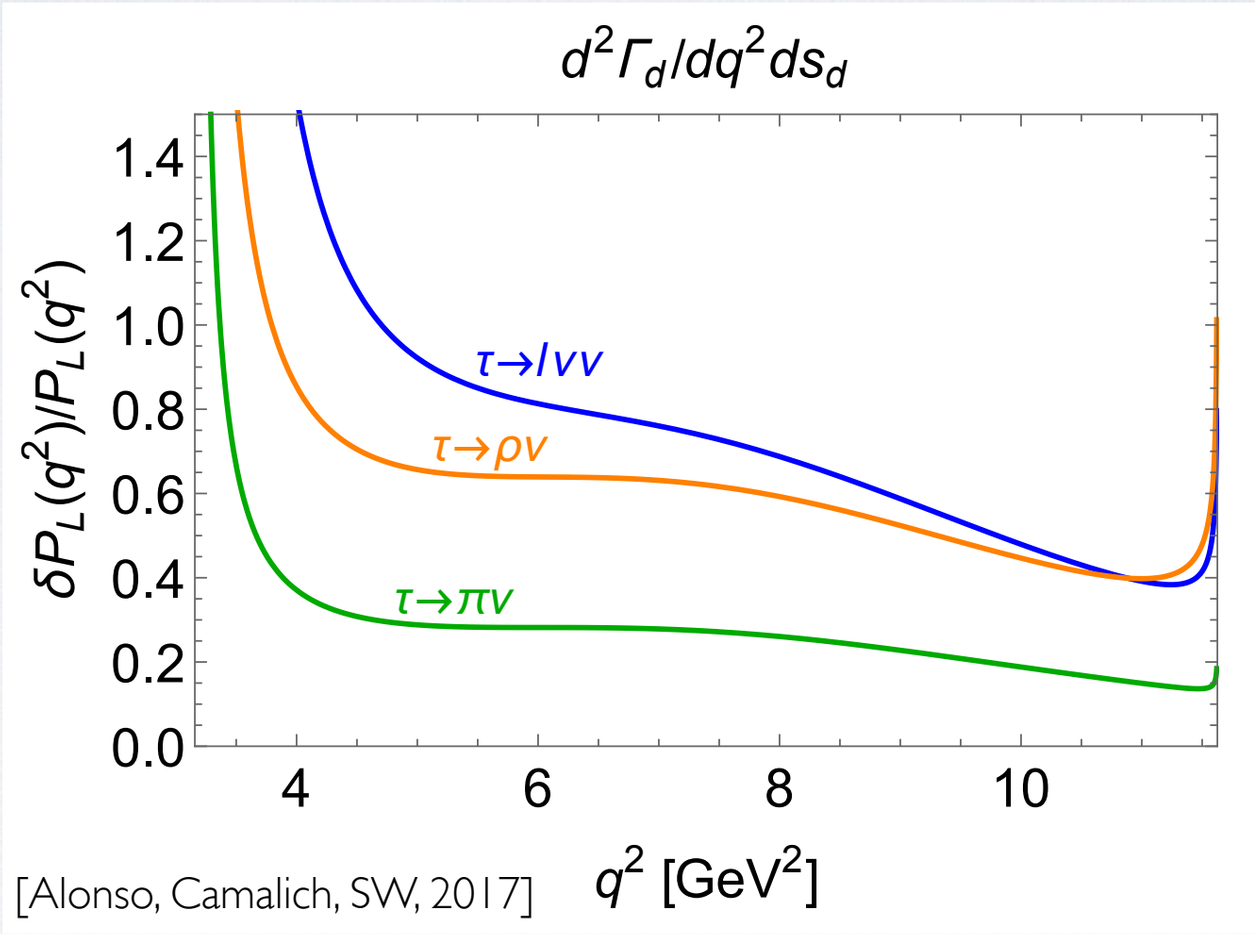
[BELLE collaboration, 2016]

$$P_\tau = P_L = -0.44 \pm 0.47(\text{stat.})^{+0.20}_{-0.17}(\text{syst.})$$

EXPECTED SENSITIVITY AT BELLE II

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

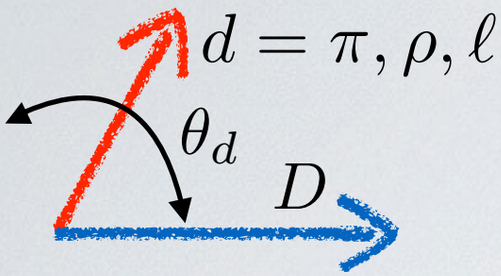
$$\delta P_L(q^2) = \frac{1}{\sqrt{N(q^2)}S_L(q^2)} \quad \text{with} \quad S_L^2(q^2) = \int ds_d \frac{f_L^d(s_d)^2}{f_0^d + f_L^d(s_d)P_L(q^2)}$$



[Alonso, Camalich, SW, 2017]

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

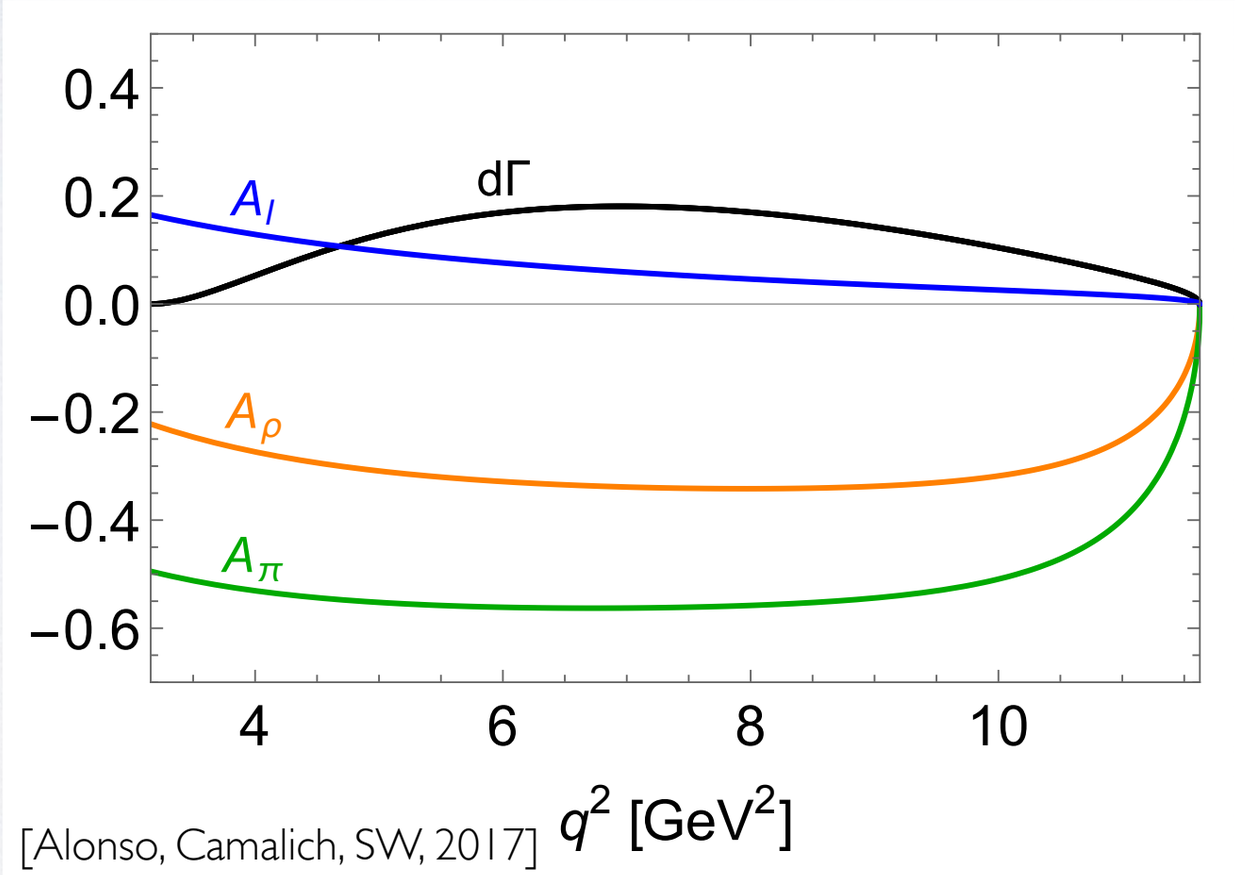
ASYMMETRY OF DECAY PARTICLE



Integrated over q^2:

$$A_\pi = -0.54, \quad A_\rho = -0.32, \quad A_\ell = +0.06$$

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



[Alonso, Camalich, SW, 2017]

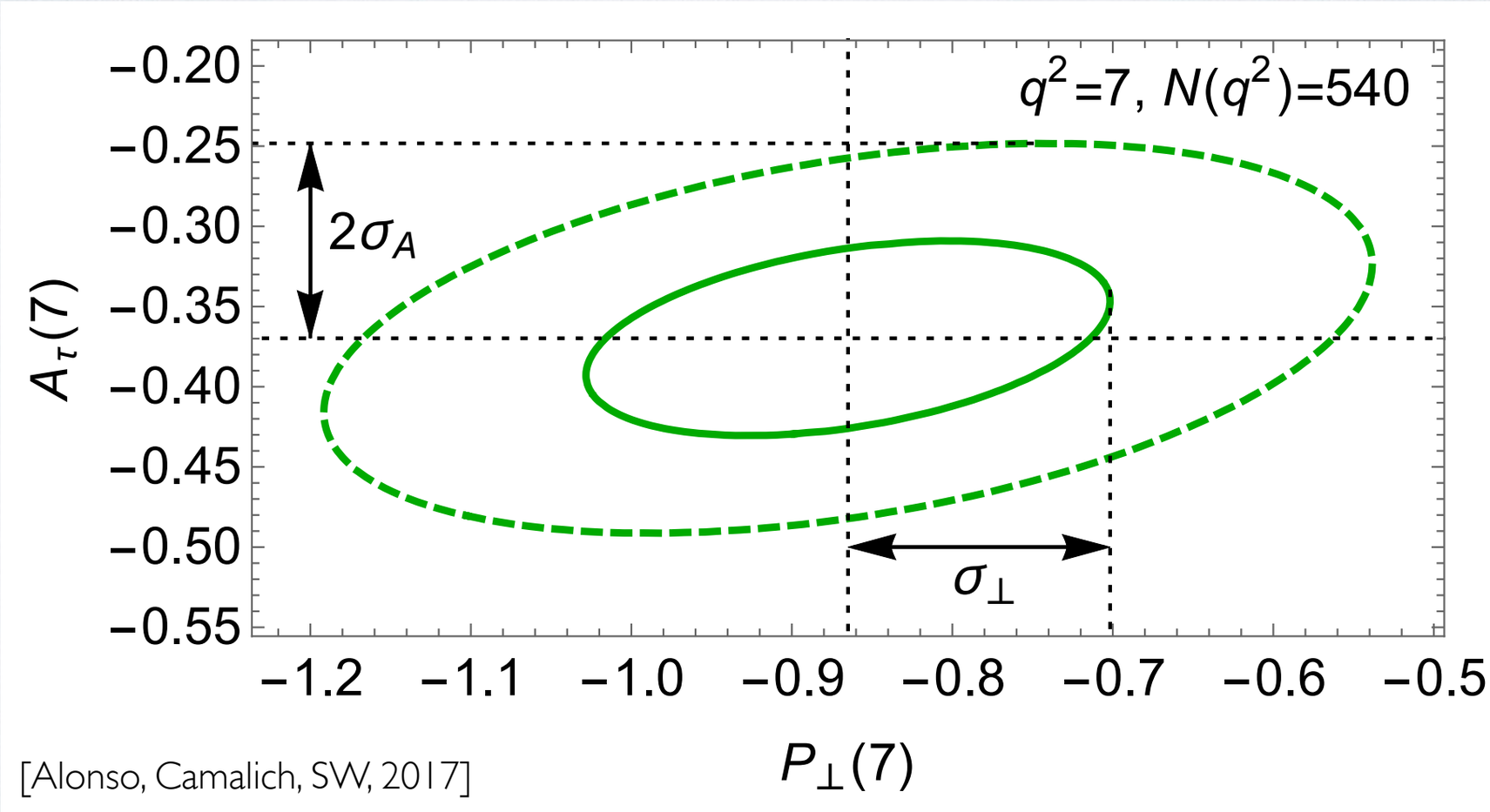
Theory prediction: best sensitivity with **hadronic** tau decays.

PERP. POLARIZATION AND TAU ASYMMETRY

Coefficients of energy distribution of decay particle *d* :

$$\frac{dA_d}{ds_d} = f_A^d(s_d) A_\tau(q^2) + f_\perp^d(s_d) P_\perp(q^2)$$

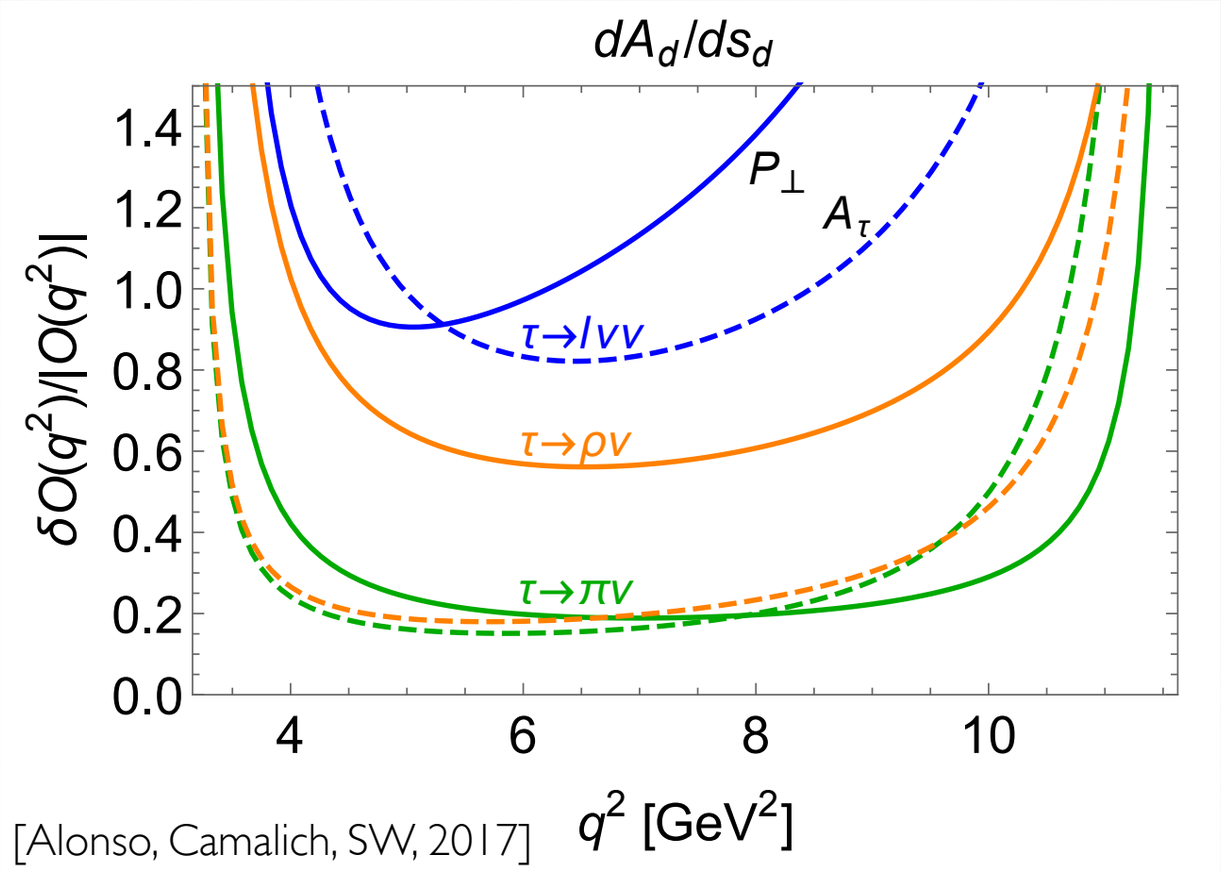
Correlation between polarization and asymmetry:



[Alonso, Camalich, SW, 2017]

EXPECTED SENSITIVITY AT BELLE II

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



[Alonso, Camalich, SW, 2017]

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

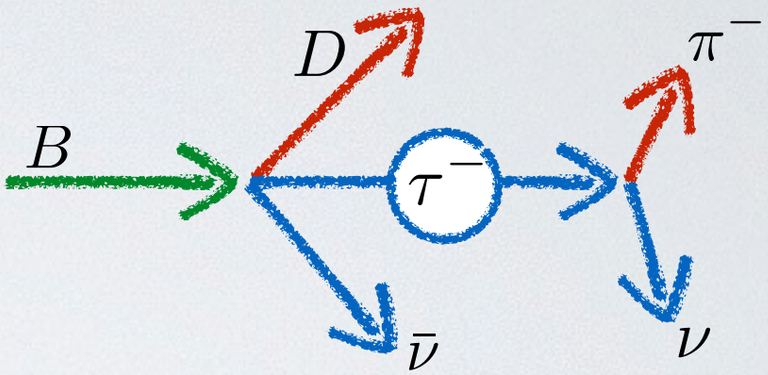
	BELLE I [total]	BELLE II [1 year]	BELLE II [total]
$\mathcal{L}$ [ab^{-1}]/N [events]	1/60	5/300	50/3000
$\delta P_L/P_L$	$\{0.21, 0.49, 0.62\}$	$\{0.10, 0.22, 0.28\}$	$\{0.03, 0.07, 0.09\}$
$\delta P_\perp/\lvert P_\perp\rvert$	$\{0.62, 1.8, 4.0\}$	$\{0.28, 0.81, 1.8\}$	$\{0.09, 0.25, 0.57\}$
$\delta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

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.