Status and prospects for the Belle II experiment

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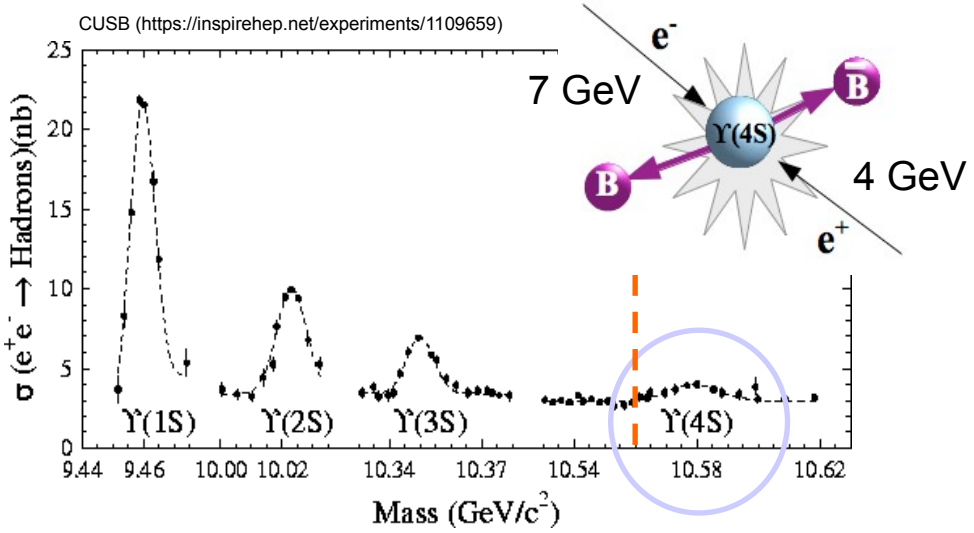


Outline

- Belle II and B factory physics
- $R(D)$ and $R(D^*)$ with Belle II
  - $R(D)$ and $R(D^*)$ with semileptonic B_{tag} reconstruction
    PRD 112.032010 (2025) Run 1 (365 fb^{-1})
  - $R(D)$ and $R(D^*)$ with hadronic B_{tag} reconstruction
    Preliminary arXiv:2609.21947 (submitted to PRL)
  - $R(D^*)$ and $P_\tau(D^*)$ with hadronic τ decays
    Preliminary (ICHEP 2026)
- Run plans and luminosity prospects
- Upgrades and Chiral Belle

Additional Belle II physics results will be presented by Peter Krizan

Asymmetric B Factories



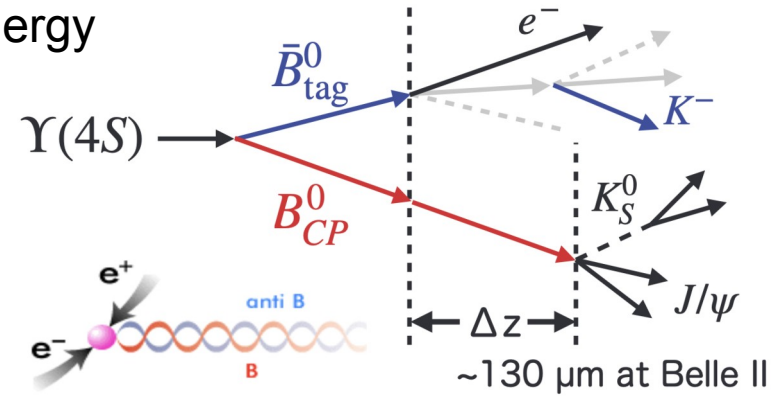
Very extensive program of non-B physics as well:

- Tau and charm precision measurements and rare decay searches
- Quarkonium and "exotic states"
- Light Higgs, Z', ALPs, dark sector etc.

Process	σ (nb)
$b\bar{b}$	1.1
$c\bar{c}$	1.3
Light quark $q\bar{q}$	2.1
$\tau^+\tau^-$	0.9
e^+e^-	~40

- B Factories produce quantum entangled $B\bar{B}$ meson pairs at the $\Upsilon(4S)$ centre of mass energy (10.58GeV)

Beam energy asymmetry results in B mesons which are longitudinally boosted in the lab frame:

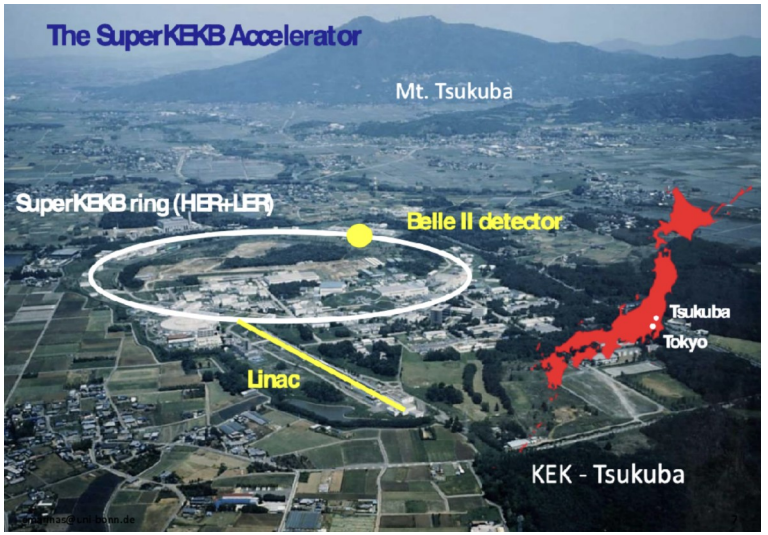


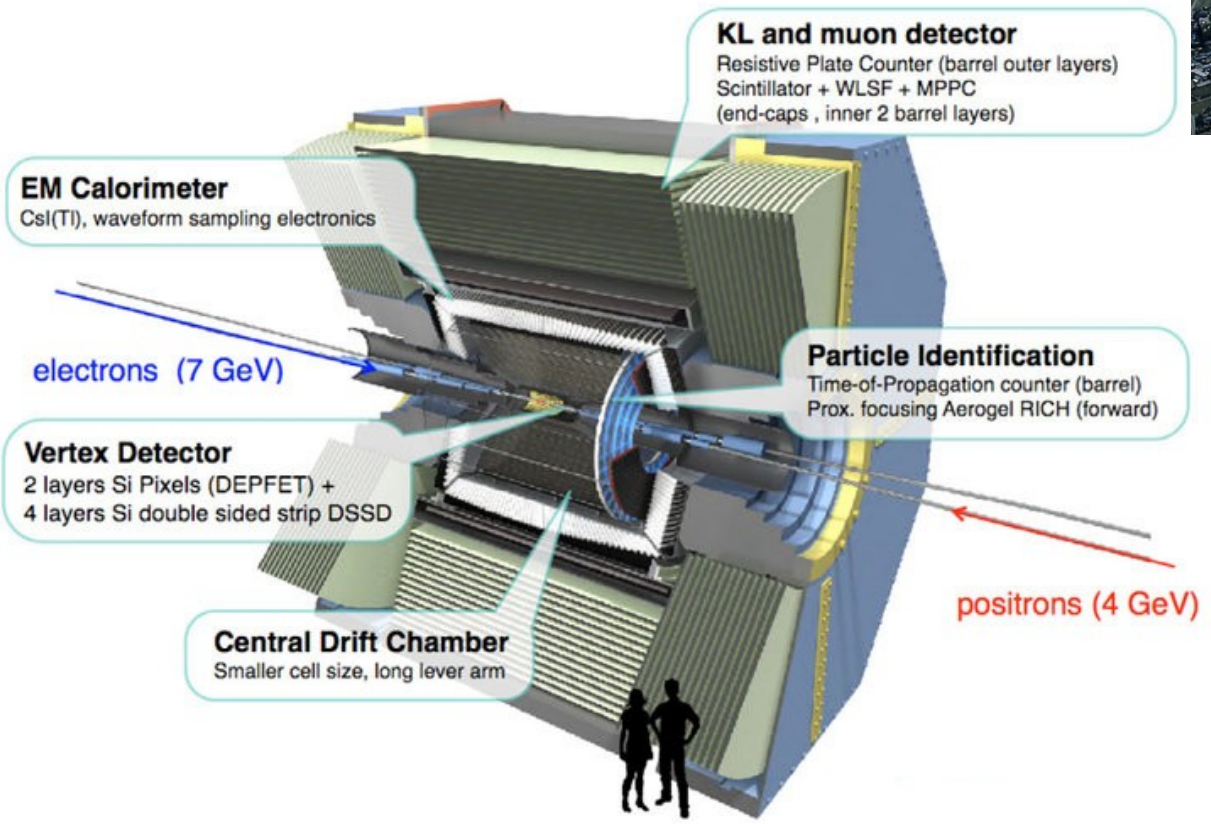
$\sigma(\Delta t) \simeq 500\,ps$ (dominated by tag vertex)

The Belle II Experiment

Belle II is a B factory experiment at the SuperKEKB e^+e^- asymmetric-energy collider

- Collaboration of ~1200 physicists from 28 countries
- Target data sample of 30 - 50 ab^{-1} i.e. > 30x data set of previous experiments **O(100 billion) B mesons**





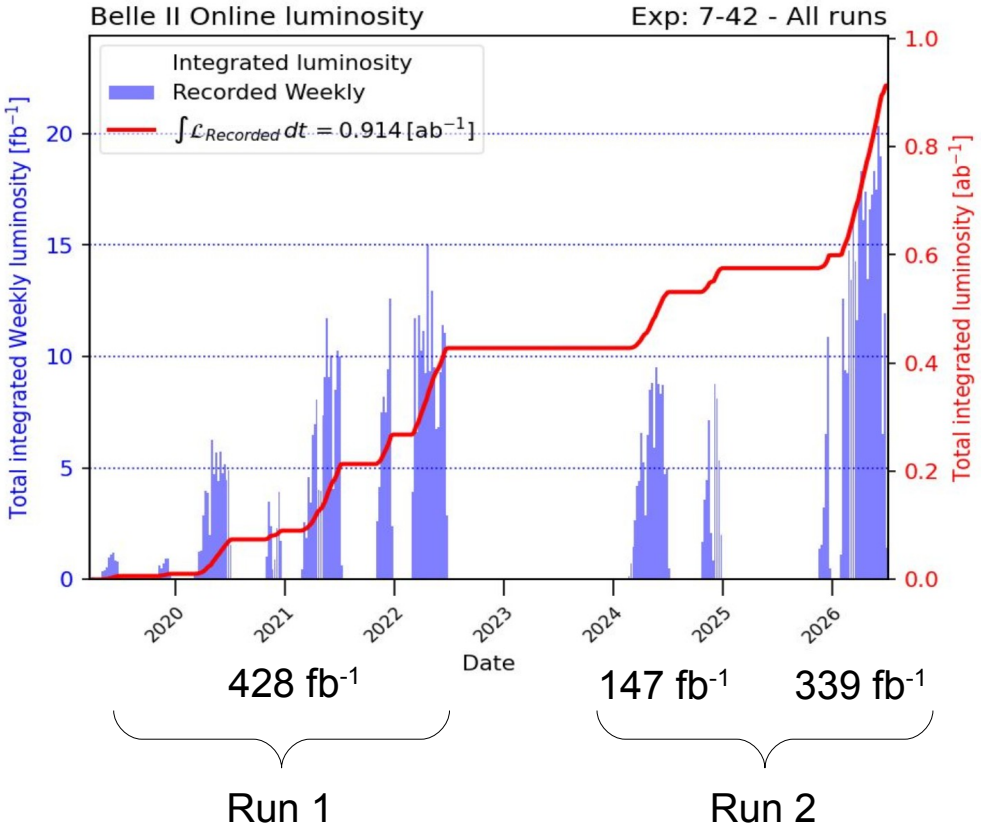
Optimized for tracking and B vertex reconstruction, K - π particle identification, and precision calorimetry

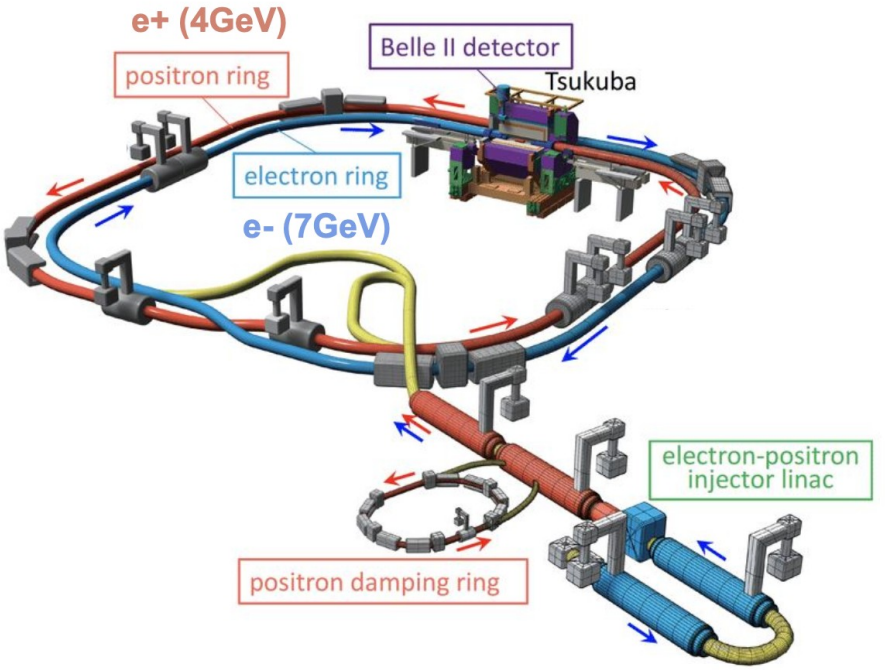
- **Low multiplicity** environment with large solid-angle detector coverage and good missing energy reconstruction
- **Inclusive trigger** (N_{tracks}>3) as well as dedicated low-multiplicity triggers

SuperKEKB

Asymmetric B factory e^+e^- collider with design instantaneous luminosity of 5 x 10^{35} $cm^{-2}s^{-1}$

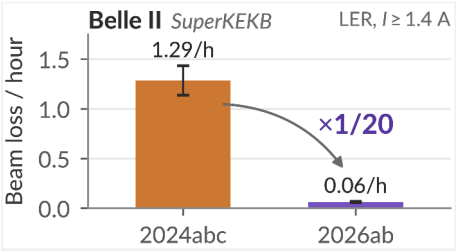
- Instantaneous luminosity record of 5.32 x 10^{34} $cm^{-2}s^{-1}$ (June 30, 2026)



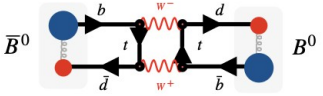


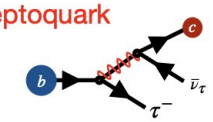
Has successfully delivered 914 fb^{-1} of integrated luminosity to Belle II since 2019

- Operational performance significantly improved in 2026 due to reduction of beam loss events:



Belle II physics program





Testing quark mixing

CKM α from $B \to \pi\pi$

$|V_{ub}|$, $|V_{cb}|$ and UT angles

Time-dependent CP asymmetries

Do leptons follow the same rules?

$R(D^{(*)})$; τ **polarization**

Forbidden τ decays; $B \to \ell\nu$

τ **lifetime, mass and LFU**

CKM and CP violation
24 papers

Leptons and universality
17 papers

Dark sectors
11 papers

Rare B decays
13 papers

Belle II

Strong interactions
22 papers

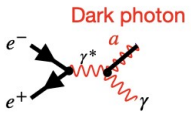
Charm physics
18 papers

Searching for hidden particles

Visible and invisible dark photons

Displaced decays

Axion-like particles

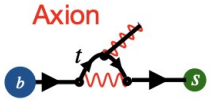


New physics in rare processes

$B \to K^{(*)}\nu\bar{\nu}$

Radiative and dilepton decays

Angular observables and LFU



Understanding hadronic dynamics

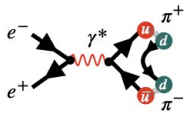
Hadronic B decays; QCD inputs

Exotic hadrons and spectroscopy

Hadronic contributions to $g-2$

Tetraquarks: compact or molecule nature?





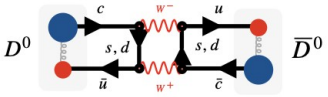
Hadronic contributions to $(g\text{-}2)_\mu$

Mixing and symmetry in charm

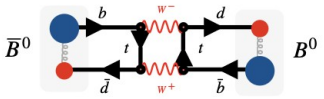
D^0 mixing and CP violation

Rare and invisible charm decays

Leptonic decays and decay constants



Belle II physics program

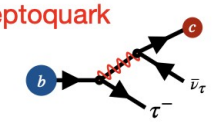


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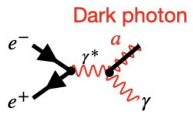
Belle II

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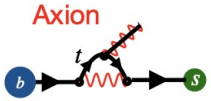


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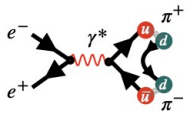
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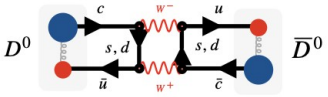
Hadronic contributions to $(g\text{-}2)_\mu$

Mixing and symmetry in charm

D^0 mixing and CP violation

Rare and invisible charm decays

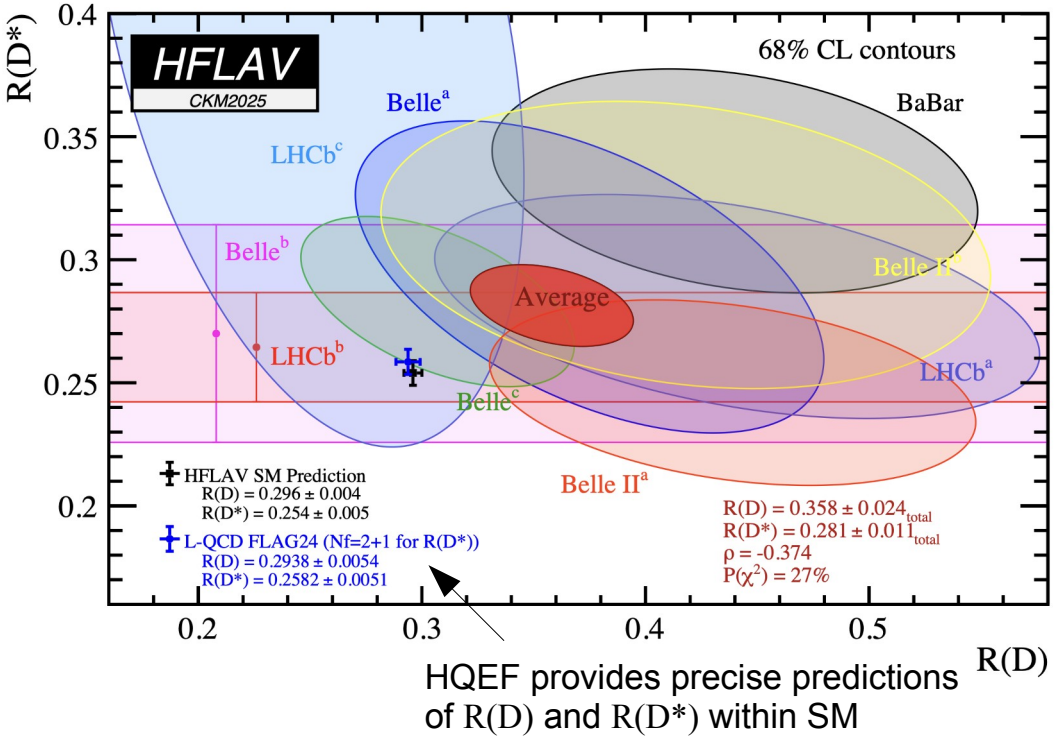
Leptonic decays and decay constants



R(D) and R(D*)

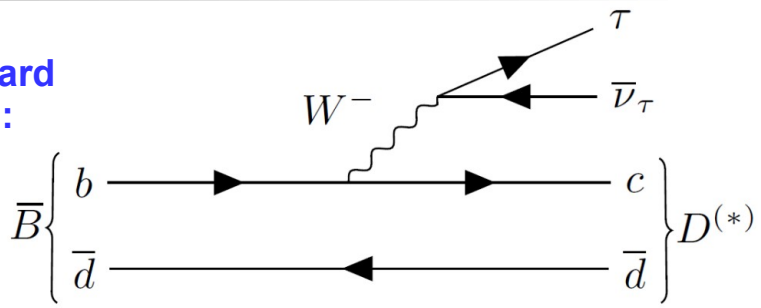
Semileptonic B decays occur via tree-level processes mediated by weak interaction

- Lepton flavour universality (LFU) tests provide theoretically clean SM probes in semileptonic decays
- Long-standing "anomaly" in LFU related to 3rd generation leptons

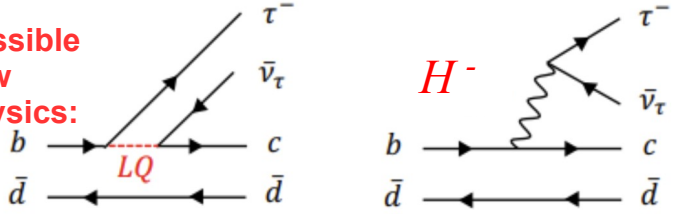


HQEF provides precise predictions of R(D) and R(D*) within SM

Standard Model:



Possible new physics:



Test LFU in ratio of $b \to c l \nu$ decays to 3rd generation τ relative to light 1st and 2nd generation e and μ

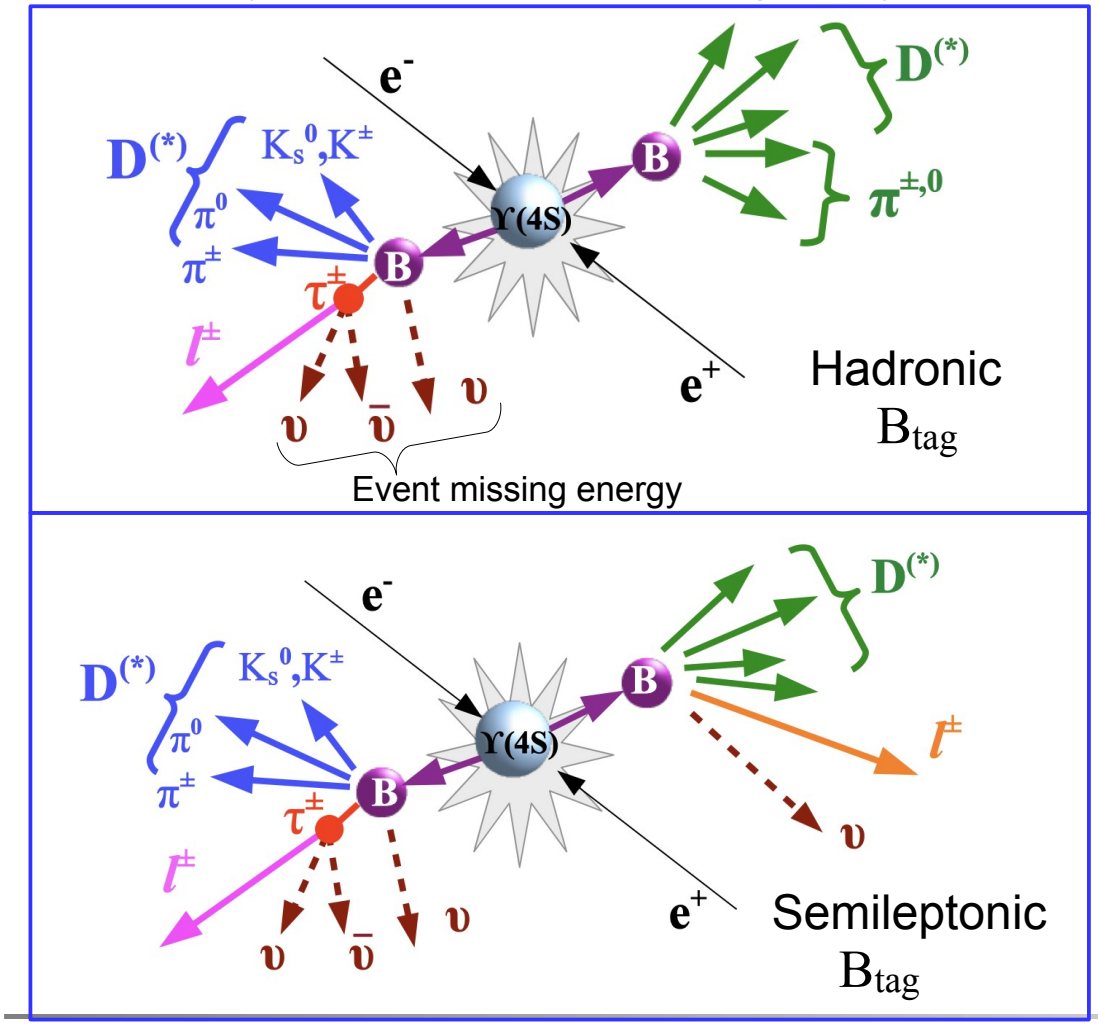
$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)} \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)} l^- \bar{\nu}_l)} \quad (l = e, \mu)$$

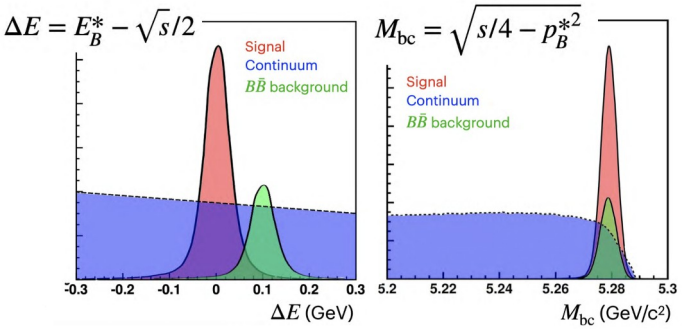
- Ratio of decay modes permits cancellation of uncertainties in absolute branching fraction measurements

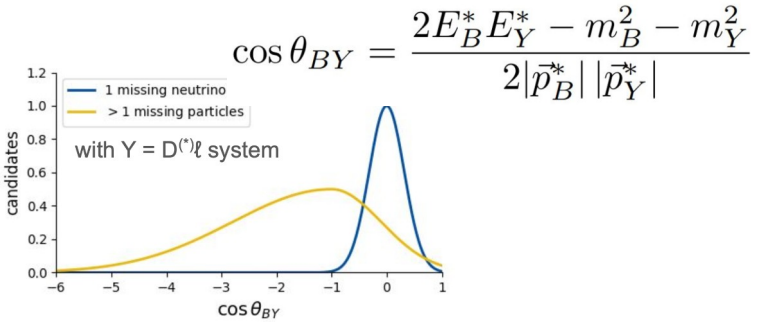
B_{tag} reconstruction

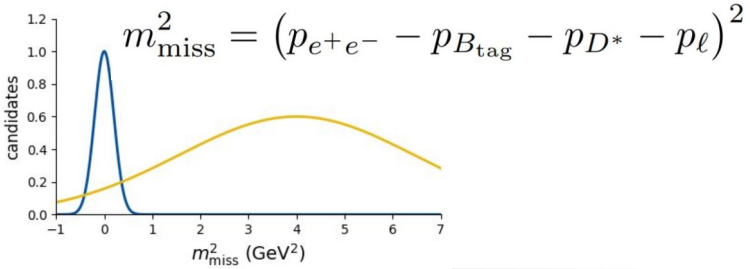
B meson decays with **missing energy** have limited kinematic information available to uniquely identify the signal decay

- Exclusively reconstruct one B meson decays ("**Btag**") in one of many possible hadronic or semileptonic decay modes, then look for the "**Bsig**" decay in whatever is left over:





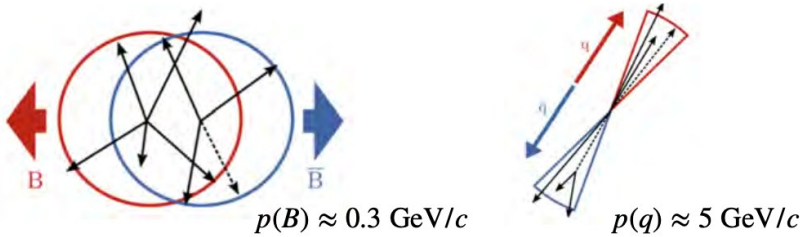




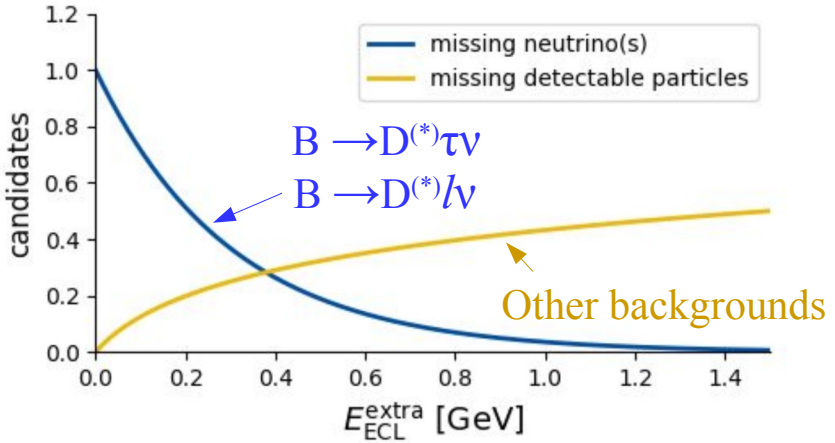
Full event Interpretation (FEI)

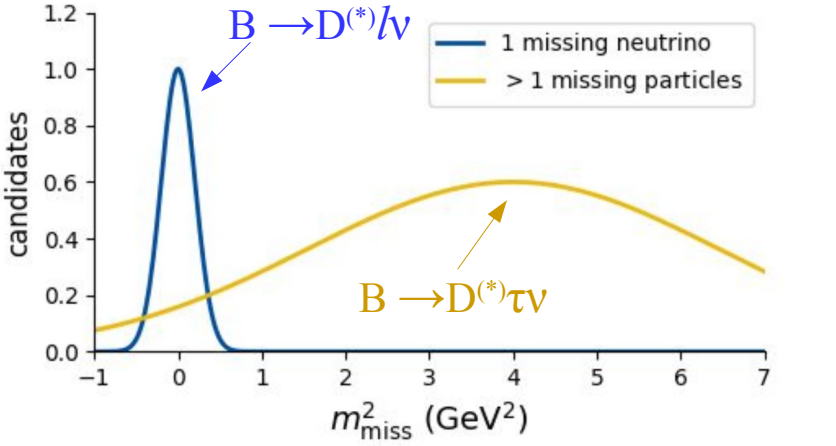
FEI provides B_{tag} and signal candidate(s) via hierarchical full reconstruction of $\Upsilon(4S)\to B\bar{B}$ event from detector charged track and neutral clusters

- Reconstruct signal B from $D^{(*)}$ and τ daughter candidates (e, μ, π, ρ depending on analysis)
- Any additional detector activity after B_{tag} and signal candidate reconstruction, $\mathbf{E_{ECL}}$, indicates possible background
- $\mathbf{m^2_{miss}}$ (and $\cos(\theta_{BY})$) can be used to distinguish $B \to D^{(*)}\tau\nu$ from background $B \to D^{(*)}l\nu$



"Event shape" variables used to suppress continuum $q\bar{q}$ combinatorial backgrounds





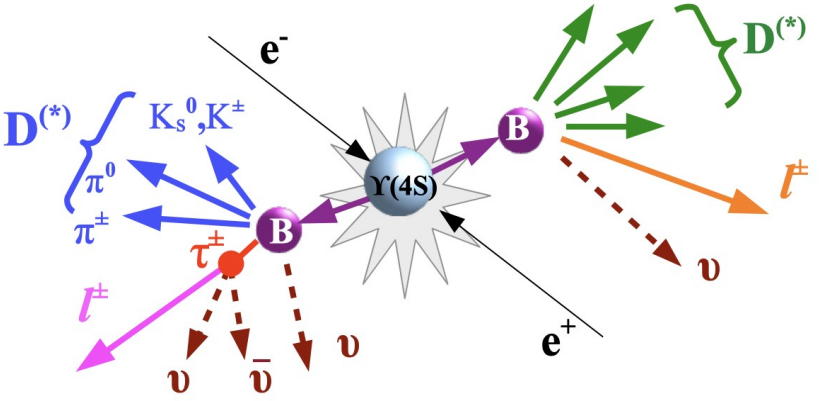
- **Advantage**: improves knowledge of signal kinematics and missing energy, and strongly suppresses combinatorial backgrounds
- **Disadvantage**: low reconstruction efficiency

R(D$^{(*)+}$) with SL tags

Phys. Rev. D 112.032010 (2025)
Run 1 (365 fb^{-1})

Signal mode $\bar{B}^0 \to D^{(*)+}\tau^-\bar{\nu}$ with leptonically decaying τ (branching fraction ~35.2%)

- B_{tag} + $D^{(*)+}$ + l (= e, μ) + missing energy



Normalization mode $\bar{B}^0 \to D^{(*)+}l^-\bar{\nu}$ (= e, μ)

- Identical topology, but different kinematics

Four signal categories:

D^+e^- $D^+\mu^-$ $D^{*+}e^-$ $D^{*+}\mu^-$

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \to D^{(*)}l^-\bar{\nu}_l)} \quad (l = e, \mu)$$

with:

$D^+ \to K^-\pi^+\pi^+$
$\to K_S^0\pi^+\pi^0$
$\to K_S^0\pi^+\pi^-\pi^+$
$\to K_S^0\pi^+$
$\to K^-K^+\pi^+$
$\to K_S^0K^+$

$D^0 \to K^-\pi^+\pi^0$
$\to K^-\pi^+\pi^-\pi^+$
$\to K_S^0K^+K^-$
$\to K^-K^+$
$\to K^-\pi^+$
$\to K_S^0\pi^+\pi^-$
$\to \pi^+\pi^-$

$D^{*+} \to D^0\pi^+$

Principal challenge is understanding of "gap modes" and backgrounds from $B \to D^{**}l\nu$

- kinematically similar to signal due to missing energy from unreconstructed particle

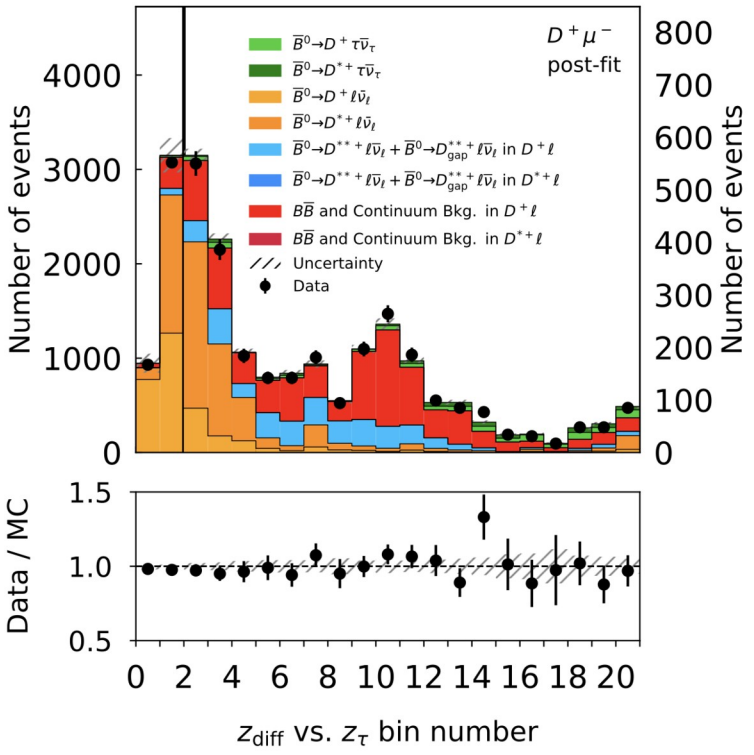
BDT trained to distinguish three event classes based on scores Z_τ, Z_l and Z_{bkg}

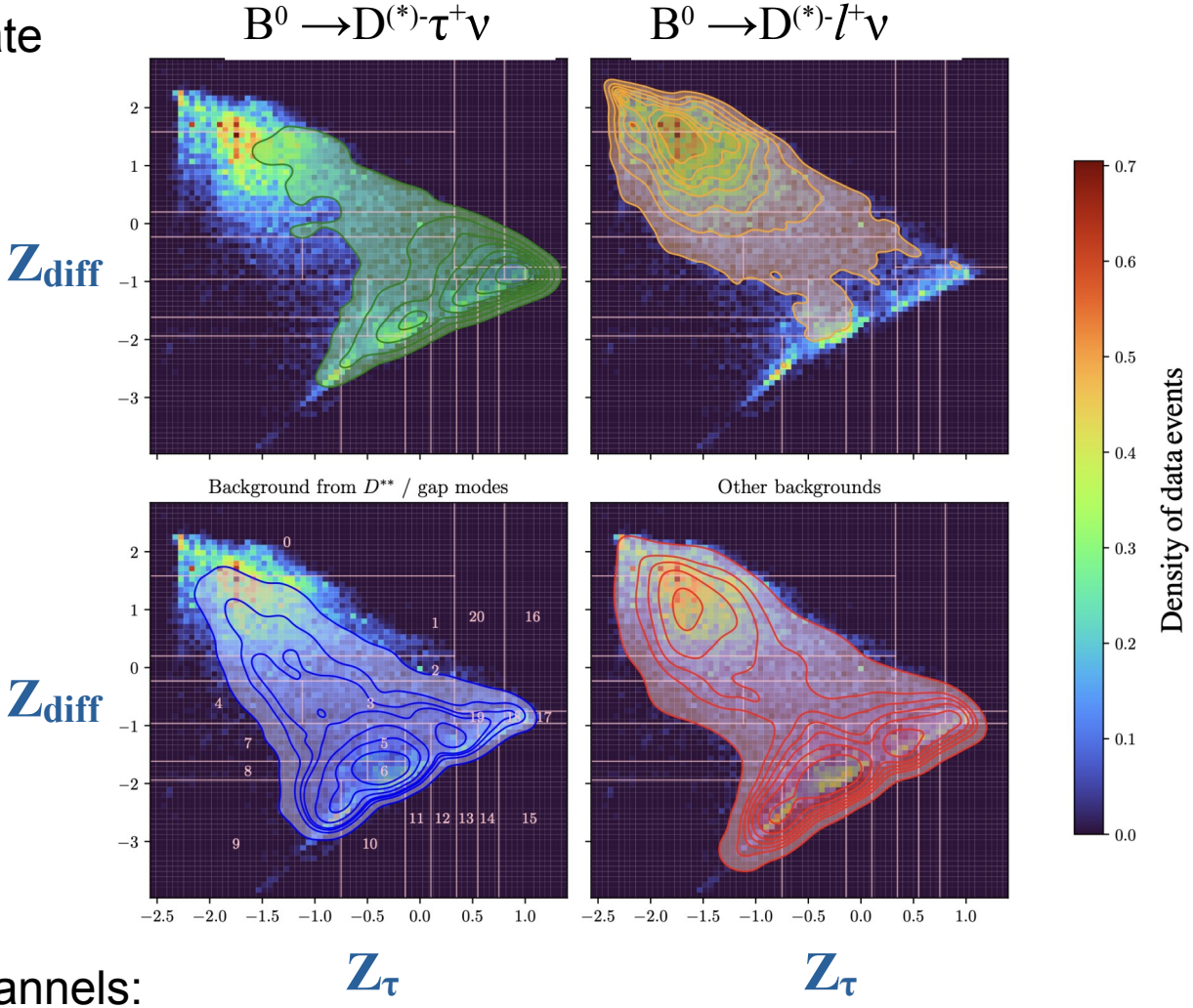
- 5 inputs, dominant contribution from $\cos(\theta_{BY})$

R(D$^{(*)+}$) with SL tags

Phys. Rev. D 112.032010 (2025)
Run 1 (365 fb^{-1})

Signal and normalization yields obtained form 2D binned template fit of Z_τ and $Z_{diff} = Z_l - Z_{bkg}$





Simultaneous fit of four signal channels:

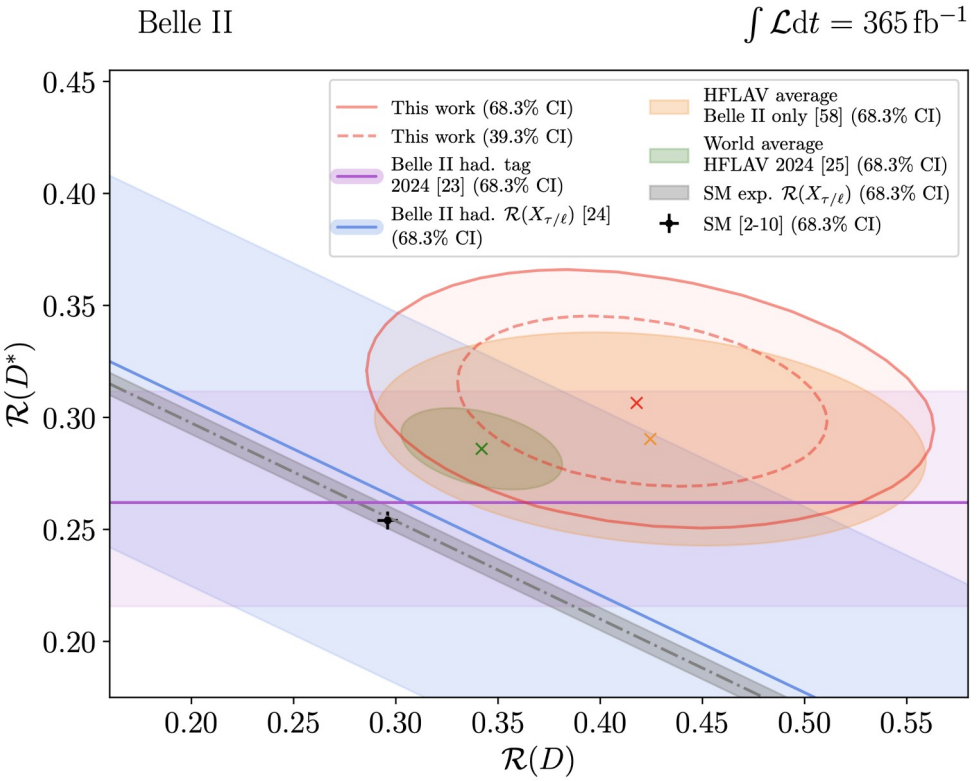
- (D^+e^-, $D^+\mu^-$, $D^{*+}e^-$, $D^{*+}\mu^-$) each for signal ($B \to D^{(*)}\tau\nu$) and normalization ($B \to D^{(*)}l\nu$) modes

R(D$^{(*)+}$) with SL tags

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Systematic Uncertainty	$\Delta\mathcal{R}(D^+)$	$\Delta\mathcal{R}(D^{*+})$
Additive		
MC sample size	0.033 (7.9%)	$^{+0.011(3.4\%)}_{-0.012(3.9\%)}$
Gap $\mathcal{B}$	$^{+0.014(3.4\%)}_{-0.038(9.1\%)}$	0.001 (0.1%)
LID efficiency (μ)	$^{+0.025(6.1\%)}_{-0.016(3.9\%)}$	0.001 (0.1%)
Fake rates (e)	$^{+0.016(3.7\%)}_{-0.008(2.0\%)}$	^{0}.002 (0.7%)
$\pi^{\pm}$ from $D^* \to D\pi$	0.003 (0.7%)	0.001 (0.1%)
Continuum fraction	$^{+0.003(0.7\%)}_{-0.002(0.4\%)}$	0.001 (0.2%)
Gap FFs	$^{+0.003(0.6\%)}_{-0.001(0.3\%)}$	0.001 (0.1%)
$\mathcal{B}(\overline{B} \to D^{**}\ell\bar{\nu}_\ell)$	0.002 (0.5%)	0.001 (0.1%)
$\overline{B} \to D^{**}\ell\bar{\nu}_\ell$ FFs	0.001 (0.3%)	0.001 (0.2%)
BDT modeling	0.001 (0.3%)	0.001 (0.2%)
$\overline{B} \to D^{(*)}\ell\bar{\nu}_\ell$ / $\tau\bar{\nu}_\tau$ FFs	0.001(0.1%)	0.001(0.3%)
LID efficiency (e)	0.001 (0.1%)	0.001 (0.3%)
Fake rates (μ)	0.001 (0.1%)	0.001 (0.1%)
Total Additive Uncertainty	$^{+0.047(11.3\%)}_{-0.054(12.9\%)}$	$^{+0.011(3.6\%)}_{-0.012(4.0\%)}$
Total Syst. Uncertainty	$^{+0.049(11.6\%)}_{-0.056(13.4\%)}$	$^{+0.016(5.2\%)}_{-0.018(5.8\%)}$
Total Stat. Uncertainty	$^{+0.075(17.9\%)}_{-0.073(17.5\%)}$	$^{+0.035(11.4\%)}_{-0.033(10.8\%)}$
Total Uncertainty	$^{+0.089(21.4\%)}_{-0.092(22.0\%)}$	$^{+0.038(12.6\%)}_{-0.037(12.2\%)}$

$$\mathcal{R}(D^+) = 0.418^{+0.075}_{-0.073}\ (\text{stat})^{+0.049}_{-0.056}\ (\text{syst})$$
$$\mathcal{R}(D^{*+}) = 0.306^{+0.035}_{-0.033}\ (\text{stat})^{+0.016}_{-0.018}\ (\text{syst})$$



- Results are statistically limited, with major systematics arising from modelling of D** and “gap” modes

R(D(*)) with Hadronic tags

Simultaneous determination of $R(D)$ and $R(D^*)$ using hadronic B_{tag} reconstruction and leptonic τ decays

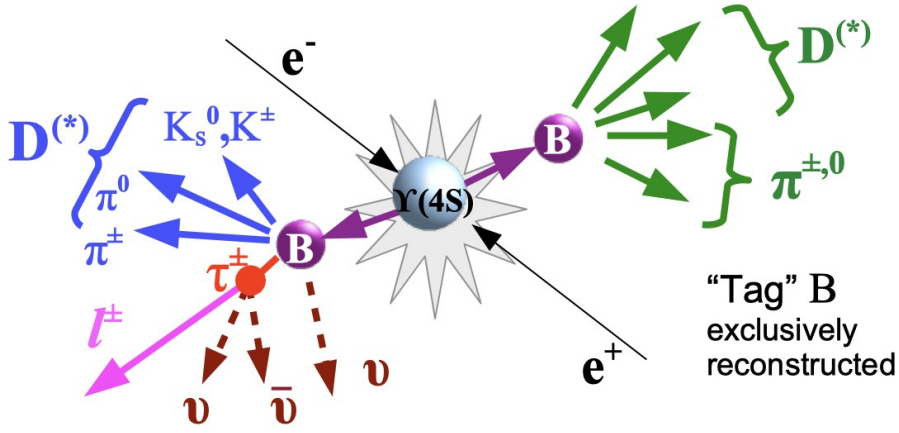
Preliminary arXiv:2609.21947
submitted to PRL
Run 1 (365 fb^{-1})

- Supersedes previous Belle II measurement of $R(D^*)$ using 189 fb^{-1} (Phys.Rev.D.110.072020)
- Signal efficiency increased by reconstruction of 13 D meson decay modes:

$D^0 \to K^- \pi^+$
$\to K_s^0 \pi^0$
$\to K^+ K^-$
$\to K_s^0 \pi^+ \pi^-$
$\to K^- \pi^+ \pi^0$
$\to K^- \pi^+ \pi^- \pi^+$
$\to K_s^0 \pi^+ \pi^- \pi^0$
~36%

$D^{*+} \to D^0 \pi^+$
$\to D^+ \pi^0$
$D^{*0} \to D^0 \pi^0$
$\to D^0 \gamma$

$D^+ \to K_s^0 \pi^+$
$\to K^- \pi^+ \pi^+$
$\to K^- K^+ \pi^+$
$\to K_s^0 \pi^+ \pi^0$
$\to K^- \pi^+ \pi^+ \pi^0$
$\to K_s^0 K^+$
~29%

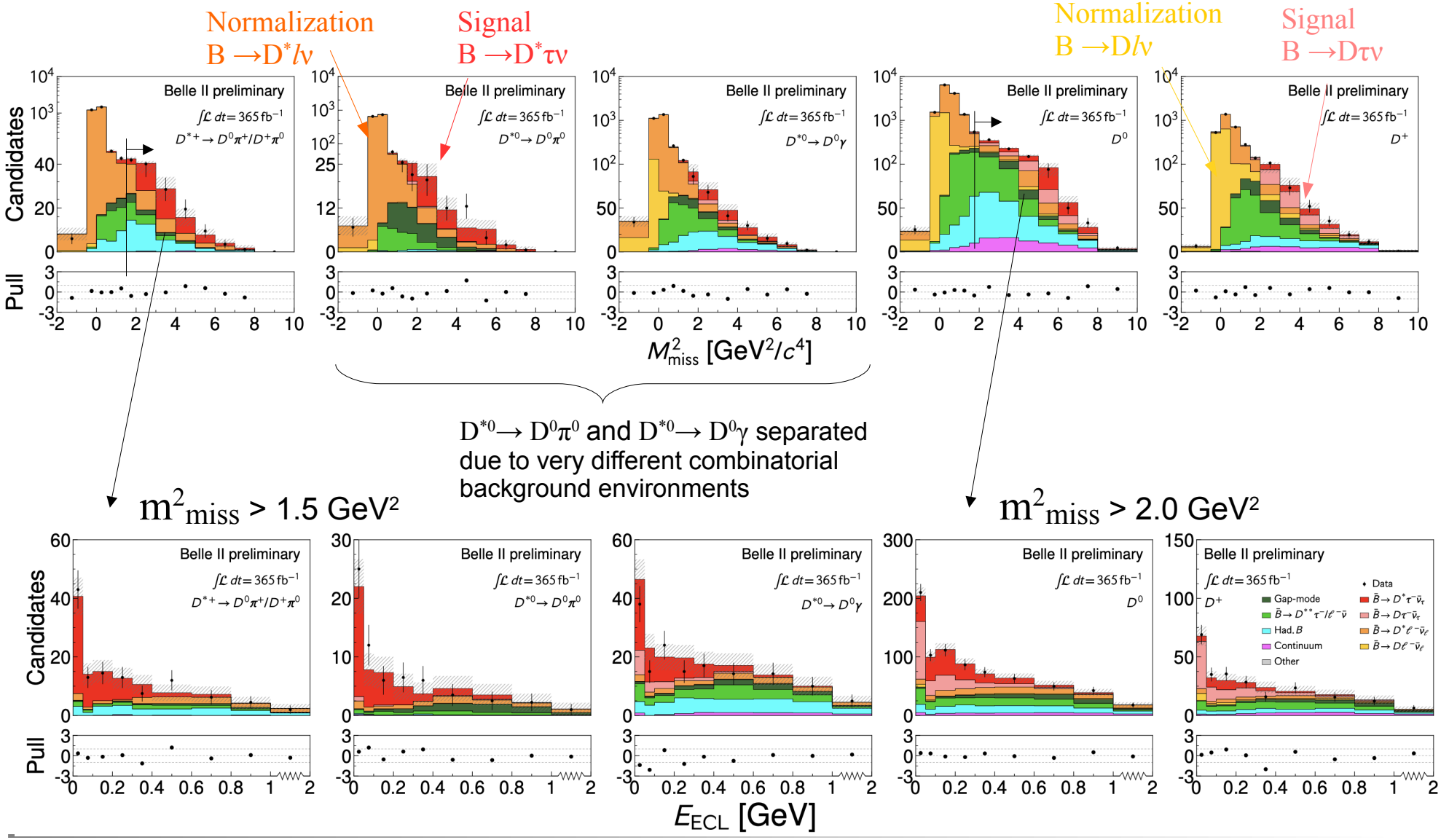


Leptonic τ decay modes

- Reconstruct (charged or neutral) hadronic B_{tag}
- Reconstruct D and D^* mesons from π, K, K_s^0, π^0
- Select signal candidate $D^{(*)}$ and lepton (e,μ)
  - Overall signal efficiencies typically ~(few x 10^{-5})
- Require that no additional charged tracks are present in the event

R(D(*)) with Hadronic tags

Extract signal via 2D Binned extended maximum-likelihood fit to m^2_{miss} and E_{ECL}



R(D$^{(*)}$) with Hadronic tags

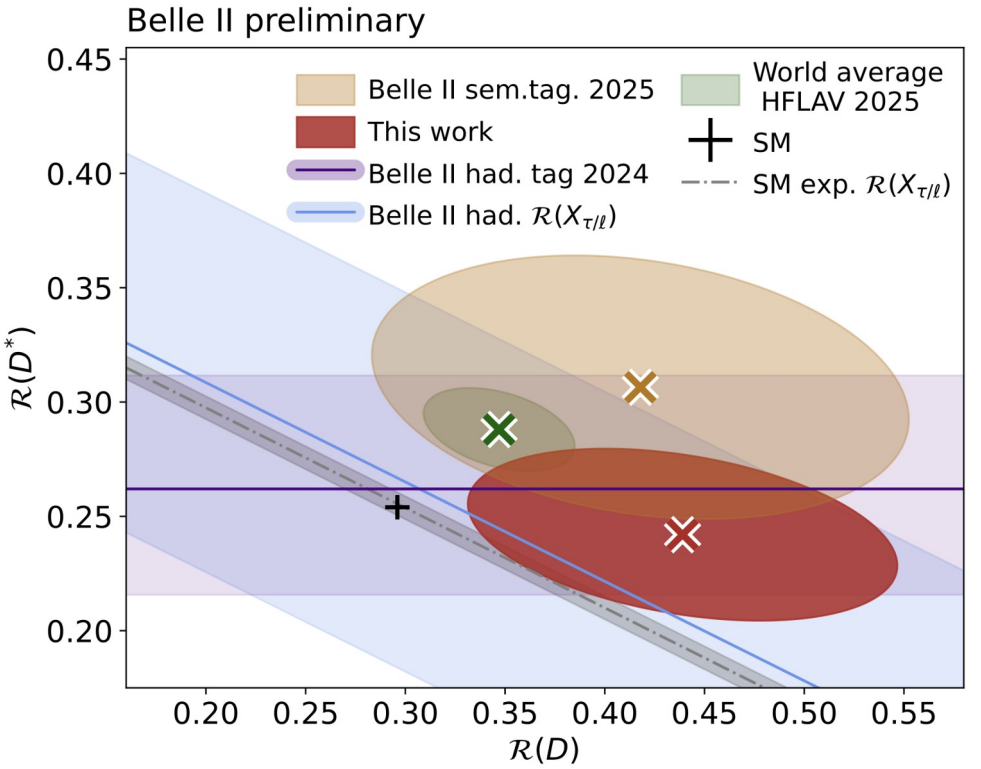
Preliminary arXiv:2609.21947
submitted to PRL
Run 1 (365 fb^{-1})

- Signal modelling and background expectations validated in various control samples and signal sideband regions

Source	$R(D^*)$	$R(D)$	ρ
Simulation sample size	4.8%	8.4%	−0.44
Gap-mode branching fractions	2.7%	3.1%	0.00
$\bar{B} \to D^{**}\tau^-/(\ell^-)\bar{\nu}$ branching fractions	0.3%	1.3%	0.25
Hadronic B decay branching fractions	1.6%	1.5%	−0.26
Form factors	0.5%	0.9%	−0.70
Misreconstructed $D^{(*)}$ candidates	0.5%	1.2%	0.00
Continuum background	2.4%	2.1%	0.93
Fit biases	0.3%	1.2%	0.00
Low-momentum π^0 and γ efficiencies	2.2%	2.4%	0.99
B-tagging efficiency	0.9%	2.5%	−1.00
Other efficiency corrections	0.7%	1.4%	0.92
M^2_{miss} resolution	0.5%	0.8%	0.48
Total systematic uncertainty	6.7%	10.3%	−0.20
Statistical uncertainty	7.9%	12.5%	−0.40

$$R(D) = 0.439 \pm 0.055(\text{stat}) \pm 0.046(\text{syst})$$

$$R(D^*) = 0.242 \pm 0.019(\text{stat}) \pm 0.016(\text{syst})$$



Most precise hadronic tagging result to date:

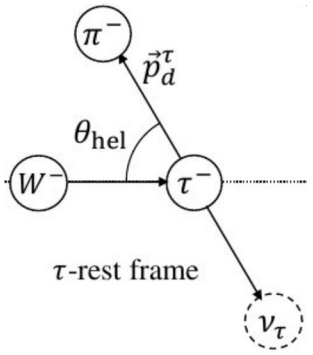
- R(D) consistent with SM prediction
- R(D*) consistent with SM at 2σ level

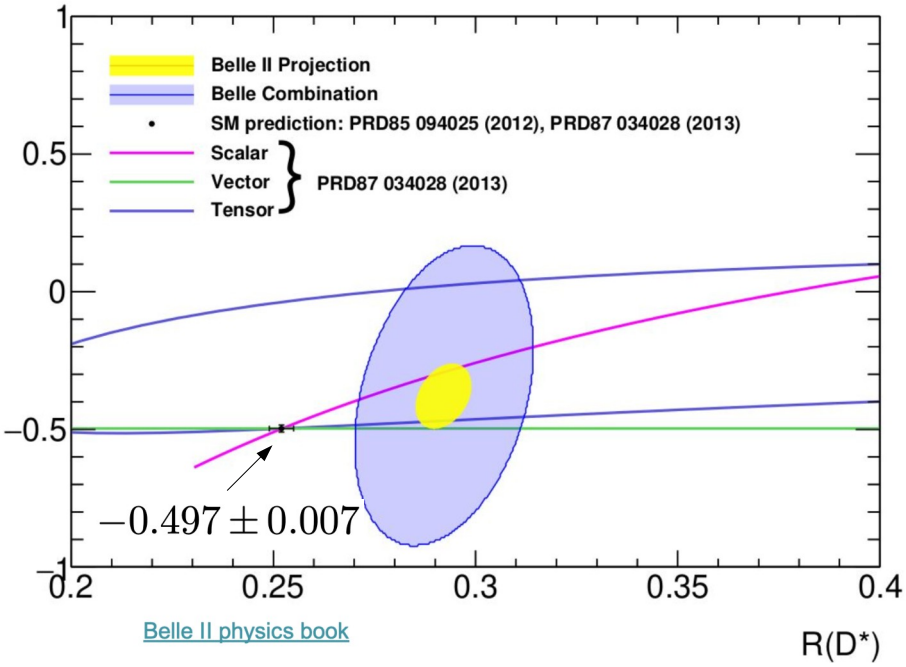
R(D*) and $P_\tau(D^*)$ with $\tau \to (\pi/\rho)\upsilon$

Alternatively, use **hadronic** τ decay modes in $B \to D^*\tau\nu$ to measure $R(D^*)$ and τ polarization

- 2-body hadronic τ decays can be used to measure the $P_\tau(D^*)$ via the helicity angle θ^τ_{hel}

Decay angle (in τ rest frame) relative to τ flight direction





Belle II physics book

- Probes the Lorentz structure of potential new physics contributions

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

Decay rate of $B \to D^*\tau\nu$ with τ in + or – helicity state

$$\frac{1}{\Gamma}\frac{d\Gamma}{d(\cos\theta^\tau_{hel})} = \frac{1}{2}\left[1 + \alpha P_\tau(D^*)\cos\theta^\tau_{hel}\right]$$

Previous Belle measurement of $P_\tau(D^*)$
S. Hirose et al. (Belle Collaboration), Phys. Rev. D 97, 012004 (2018)

- Hadronic decays of τ in $B \to D^*\tau\nu$ have higher intrinsic backgrounds, but also large branching fractions (~36.3% for π and ρ modes combined)
- (Mostly) statistically independent from other two Belle II $R(D^*)$ measurements

R(D*) and $P_\tau(D^*)$ with $\tau \to (\pi/\rho)\upsilon$

Preliminary (ICHEP)
Run 1 (365 fb^{-1})

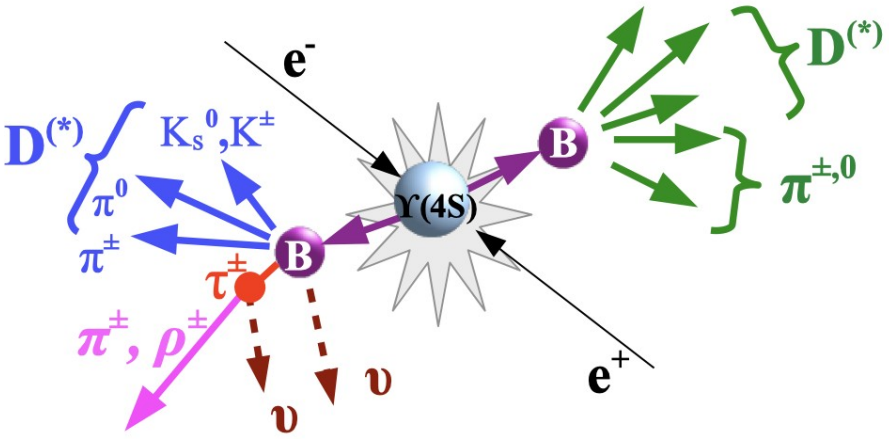
Hadronic FEI for B_{tag} reconstruction

- Signal $B \to D^* \tau \nu$ with $\tau \to \pi/\rho\, \nu$ $(\rho \to \pi\pi^0)$
- Normalization modes $B \to D^* l \nu$ $(l = e, \mu)$

$D^0 \to K^- \pi^+$
$\to K_s^0 \pi^0$
$\to K^- \pi^+ \pi^0$
$\to K_s^0 \pi^+ \pi^-$
$\to K_s^0 K^+ K^-$
$\to K^- \pi^+ \pi^- \pi^+$

$D^{*+} \to D^0 \pi^+$
$D^{*0} \to D^0 \pi^0$

Dedicated reconstruction for "slow" π^+ and π^0 for increased efficiency



Signal final state is all hadrons (+ missing energy)

Distinct backgrounds arising from:

- prompt hadronic decays with missing particles ($B \to D^* n H_u$)
- double charm ($B \to D^* H_c H_u$)

Continuum backgrounds ($q\bar{q}$) suppressed based on event shapes ($\cos\theta_T$)

Background MC reweighed to account for EvtGen issue reported in SciPostPhys.20.6.161

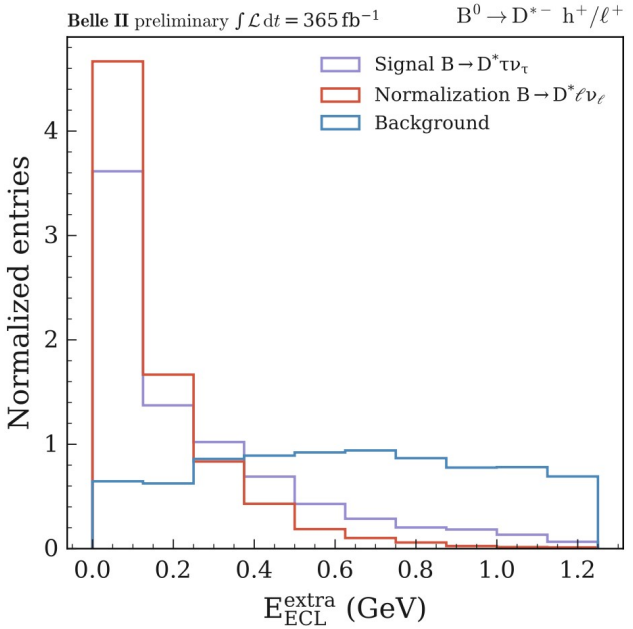
- Resulting shift well within systematics (~10%) for this analysis

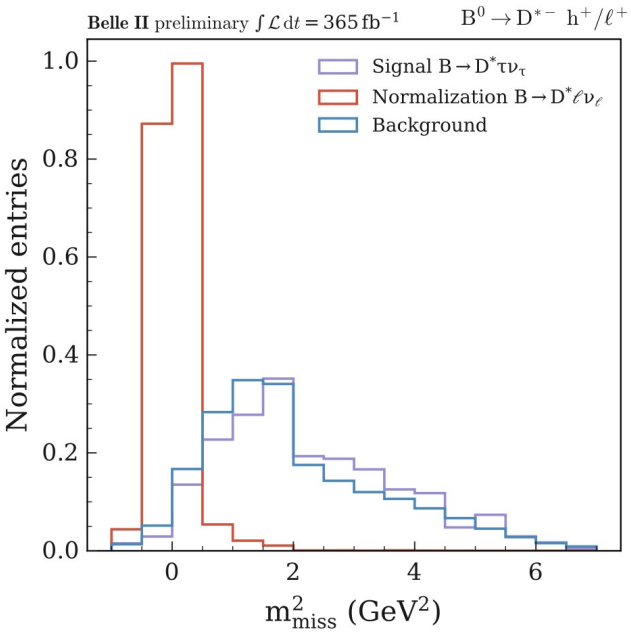
R(D*) and $P_\tau(D^*)$ with $\tau \to (\pi/\rho)\upsilon$

Preliminary (ICHEP)
Run 1 (365 fb^{-1})

Require:

- No additional charged particles
- $E_{ECL} < 1.25GeV$
- $B \to D^*\tau\nu$ signal region: $-1 < m^2_{miss} < 7\ GeV^2$
- Normalization modes: $B \to D^* l\nu$ $(= e, \mu)$ $-1 < m^2_{miss} < 2\ GeV^2$





Signal and normalization yield obtained from simultaneous 3D binned template fit in E_{ECL}, m^2_{miss} and $\cos\theta_{hel}$

$$\nu_{D^*\tau_{\theta\pm}} = f\left(\nu_{D^*\mu}, R(D^*), P_\tau(D^*), R_{e/\mu}(D^*), f_{+0}, \frac{\epsilon_{D^*\tau_{\theta\pm}}}{\epsilon_{\bar{D}^{*0}\mu+}}\right)$$

Parameters of interest

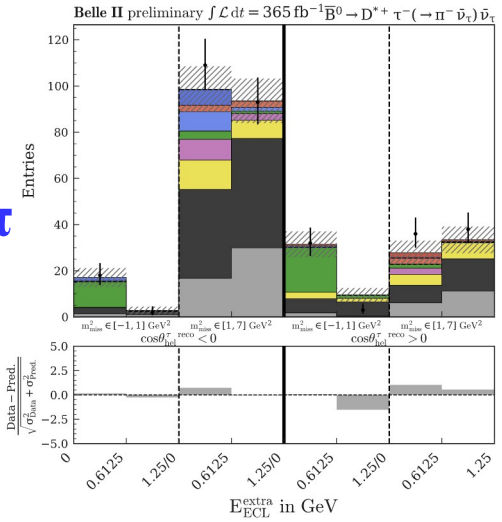
Ratios of experimental efficiencies

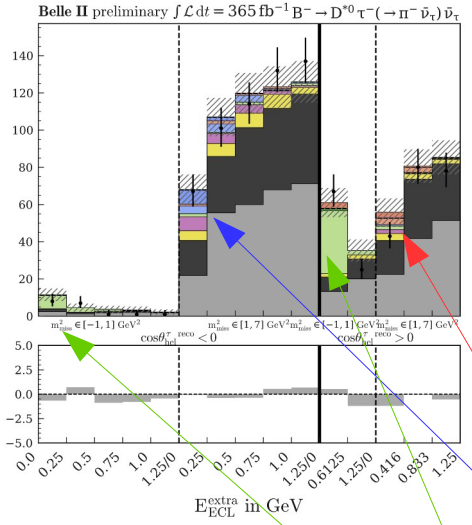
R(D*) and $P_\tau(D^*)$ with $\tau \to (\pi/\rho)\upsilon$

Preliminary (ICHEP)
Run 1 (365 fb^{-1})

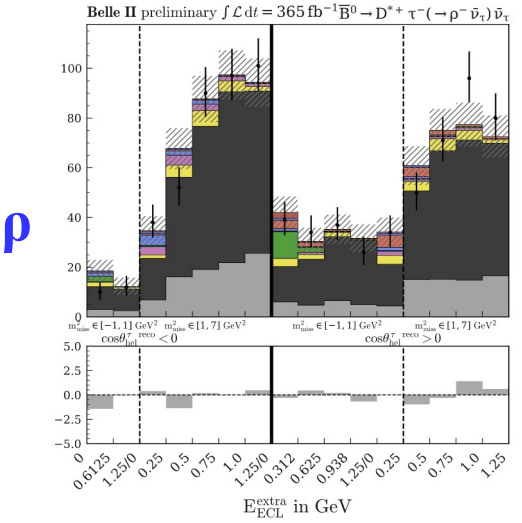
B^0 B^+

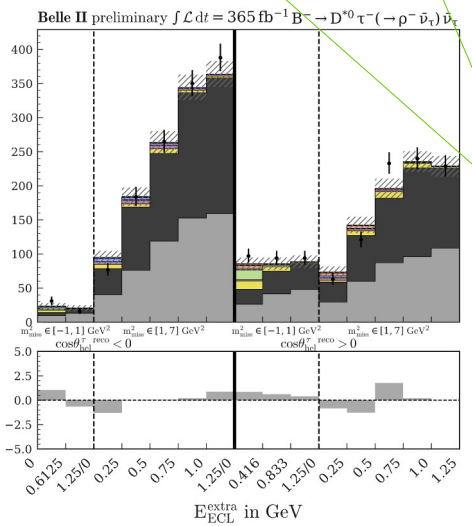
π





ρ





	- helicity	+ helicity
$-1<m^2_{\text{miss}}<1$	$1<m^2_{\text{miss}}<7$	...
E_{ECL} bins	...	...

- $B^0 \to D^{*-}\tau^+(\pi^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} > 0)$
- $B^0 \to D^{*-}\tau^+(\pi^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} < 0)$
- $B^0 \to D^{*-}\tau^+(\rho^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} > 0)$
- $B^0 \to D^{*-}\tau^+(\rho^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} < 0)$
- $B^+ \to \overline{D}^{*0}\tau^+(\pi^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} > 0)$
- $B^+ \to \overline{D}^{*0}\tau^+(\pi^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} < 0)$
- $B^+ \to \overline{D}^{*0}\tau^+(\rho^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} > 0)$
- $B^+ \to \overline{D}^{*0}\tau^+(\rho^+\nu_\tau)\nu_\tau$ $(\cos\theta^{\tau\,\text{gen}}_{\text{hel}} < 0)$
- $B^0 \to D^{*-}\ell^+\nu_\ell$
- $B^+ \to \bar{D}^{*0}\ell^+\nu_\ell$
- $B \to D^*\tau\nu_\tau$ (cross.)
- $B \to D^{**}\ell\nu_\ell$
- $B\bar{B}$
- $q\bar{q}$
- Model stat. unc.
- Data

Lepton misidentified as pion

Signal, but crossfeed from other τ decay modes (μ, $\pi\pi^0\pi^0$)

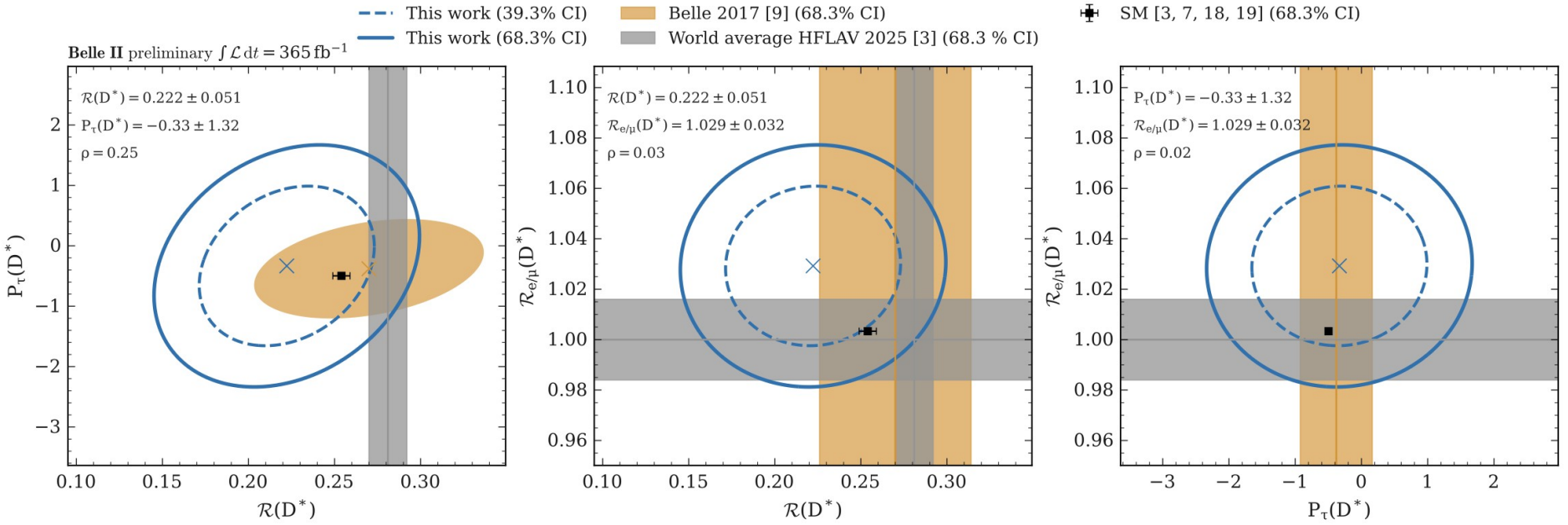
Data driven hadronic backgrounds estimates obtained from simultaneously fitted control regions, and data/MC validation studies

R(D*) and $P_\tau(D^*)$ with $\tau \to (\pi/\rho)\upsilon$

Preliminary (ICHEP)
Run 1 (365 fb^{-1})

First Belle II measurement of τ polarization in $B \to D^*\tau\nu$

- Also "incidental" measurement of $R_{e/\mu}(D^*)$ ratio of normalization modes $B \to D^* e\nu$ and $B \to D^* \mu\nu$



$$R(D^*) = 0.222 \pm 0.041\ (\text{stat}) \pm 0.030\ (\text{syst})$$
$$P_\tau(D^*) = -0.33 \pm 1.15\ (\text{stat}) \pm 0.65\ (\text{syst})$$
$$R_{e/\mu}(D^*) = 1.029 \pm 0.029\ (\text{stat}) \pm 0.014\ (\text{syst})$$

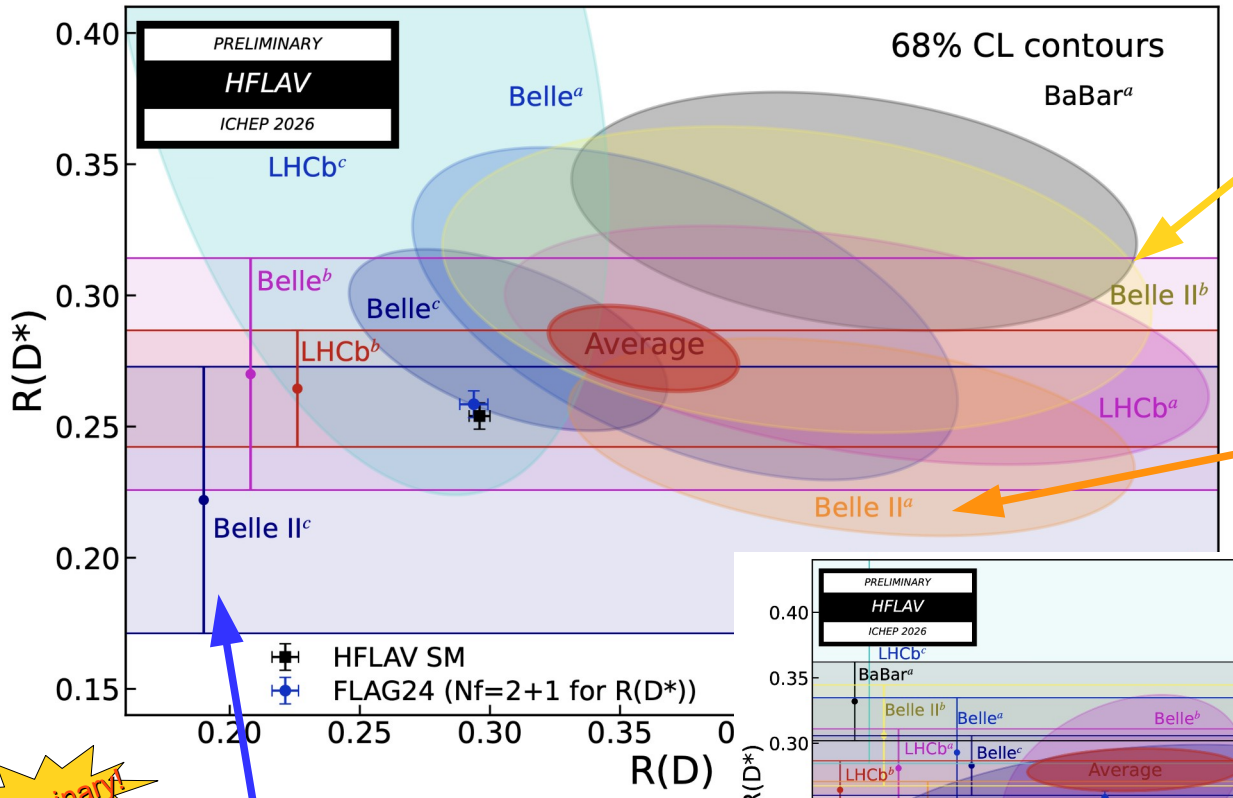
Correlation matrix:

	$R(D^*)$	$P_\tau(D^*)$	$R_{e/\mu}(D^*)$
$R(D^*)$	1	0.25	0.03
$P_\tau(D^*)$		1	0.02
$R_{e/\mu}(D^*)$			1

- Consistent with previous Belle measurement, but with only half the integrated luminosity

R(D(*)) summary

All three recent Belle II measurements yield consistent results, compatible with the SM expectations and world average:



Semileptonic B_{tag} ($\tau \to e,\mu$)

$$\mathcal{R}(D^+) = 0.418^{+0.075}_{-0.073}\ (\text{stat})^{+0.049}_{-0.056}\ (\text{syst})$$
$$\mathcal{R}(D^{*+}) = 0.306^{+0.035}_{-0.033}\ (\text{stat})^{+0.016}_{-0.018}\ (\text{syst})$$

Hadronic B_{tag} ($\tau \to e,\mu$)

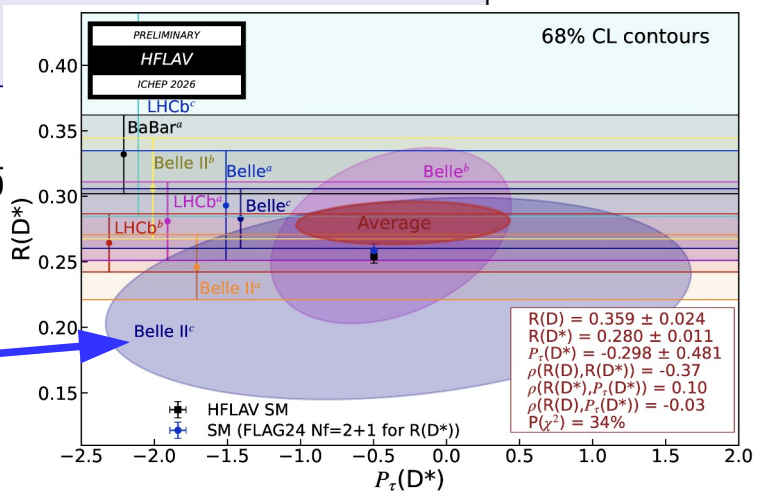
$$R(D) = 0.439 \pm 0.055(\text{stat}) \pm 0.046(\text{syst})$$
$$R(D^*) = 0.242 \pm 0.019(\text{stat}) \pm 0.016(\text{syst})$$

Preliminary!

Preliminary!

$$R(D^*) = 0.222 \pm 0.041\ (\text{stat}) \pm 0.030\ (\text{syst})$$
$$P_\tau(D^*) = -0.33 \pm 1.15\ (\text{stat}) \pm 0.65\ (\text{syst})$$
$$R_{e/\mu}(D^*) = 1.029 \pm 0.029\ (\text{stat}) \pm 0.014\ (\text{syst})$$

Hadronic B_{tag} ($\tau \to \pi,\rho$)



- Statistically limited measurements, all based on Run 1 data set (365 fb^{-1})

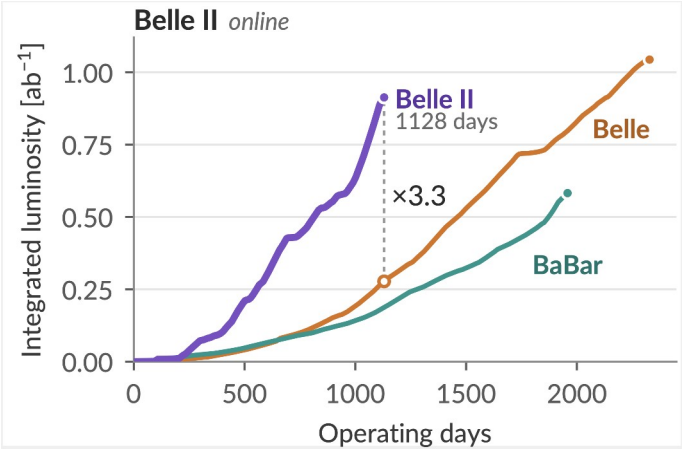
Future plans: operations

Current Belle II data set is comparable to integrated luminosity of previous generation of B Factory experiments (BABAR and Belle): O(1ab^{-1})

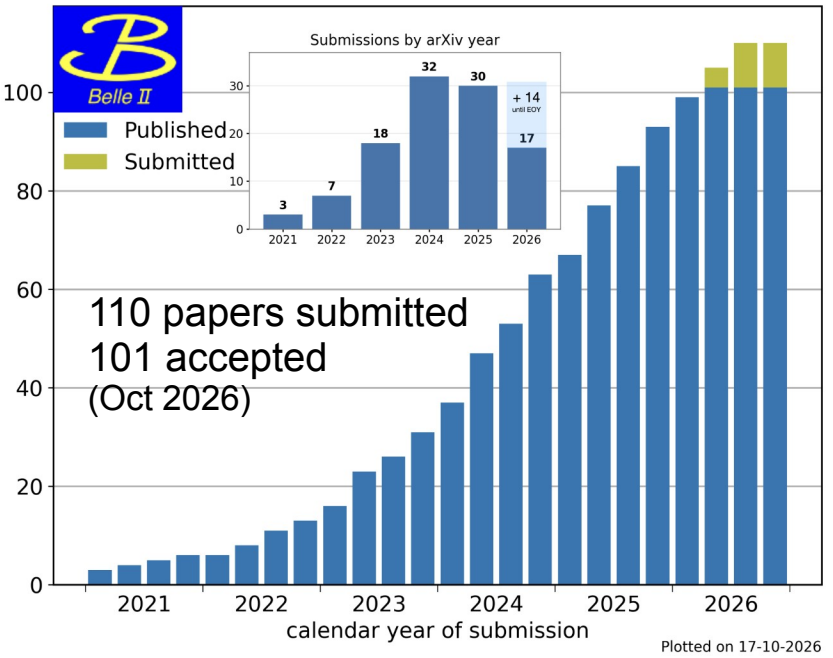
- **Run 1 (365 fb^{-1}) physics results based on ~1% of ultimate target data sample**

2027 run plan calls for doubling of integrated luminosity on timescale of summer 2028

- Conditions similar to 2026 run; (5-7) x 10^{35} cm^{-2}s^{-1} with focus on stable running



- **Goal of integrating 5 – 10 ab^{-1} by 2032 (LS2)**

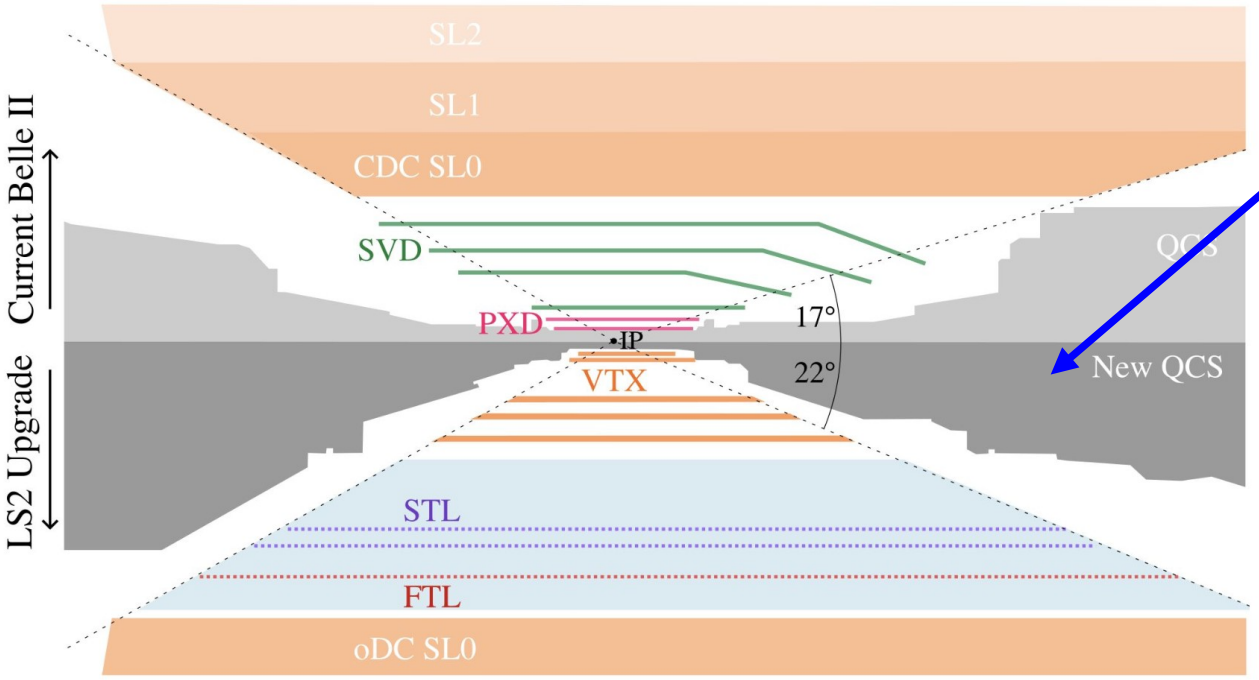


Long Shutdown 2 (LS2) scheduled for 2032, lasting for 2 years

- Substantial accelerator and detector upgrades to handle extremely high luminosity running conditions
- Target of **30 – 50 ab^{-1}** by 2040

Future plans: detector

High luminosity running requires significant detector and interaction region upgrades:

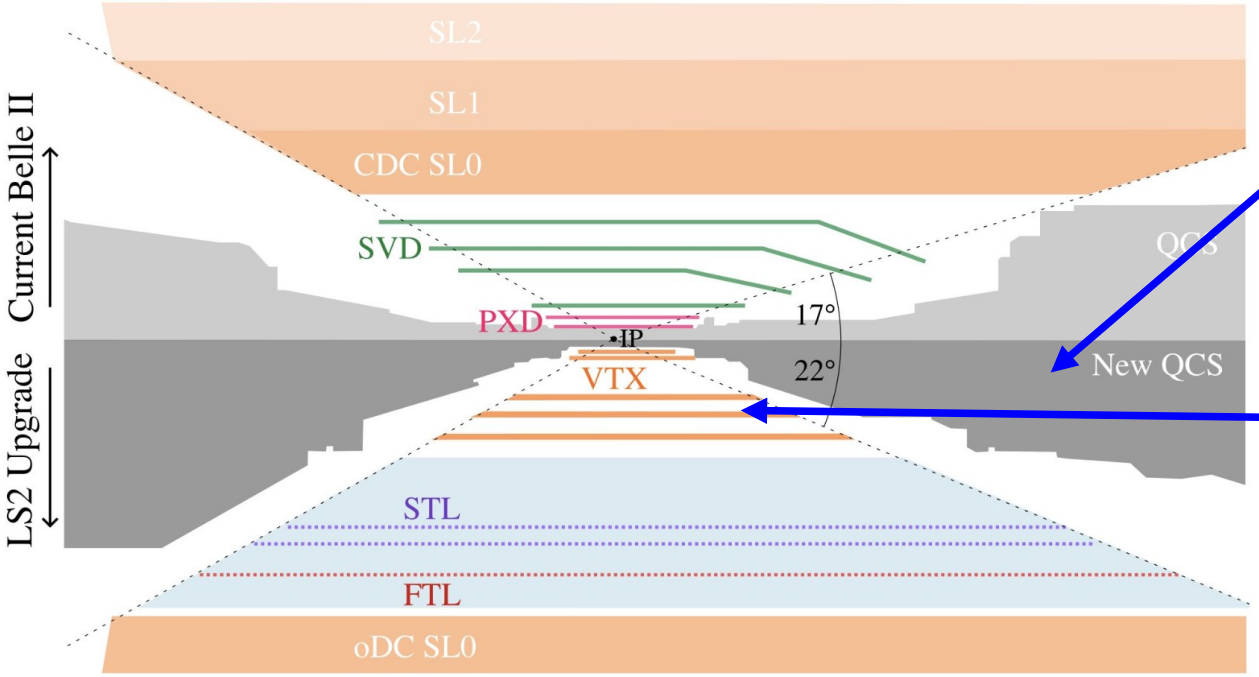


New QCS magnets

- Impacts detector acceptance in forward direction

Future plans: detector

High luminosity running requires significant detector and interaction region upgrades:

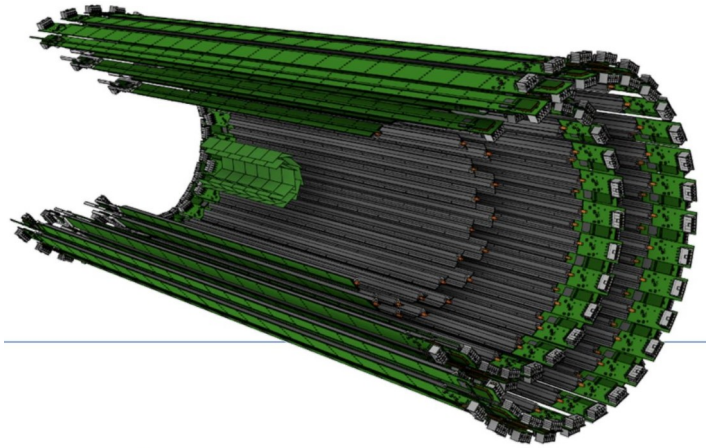


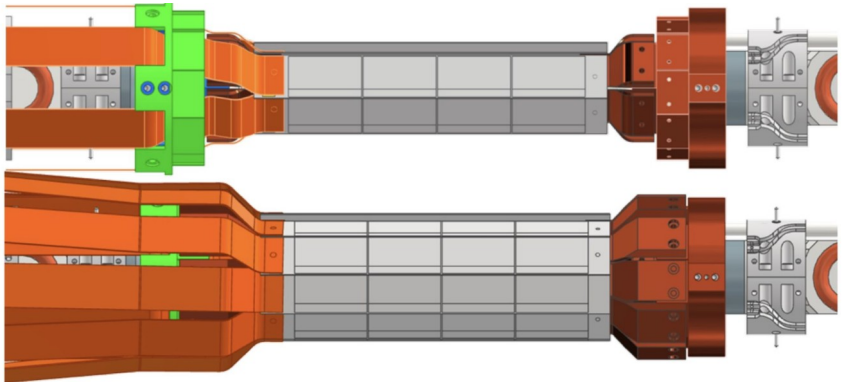
New QCS magnets

- Impacts detector acceptance in forward direction

All-silicon VTX detector

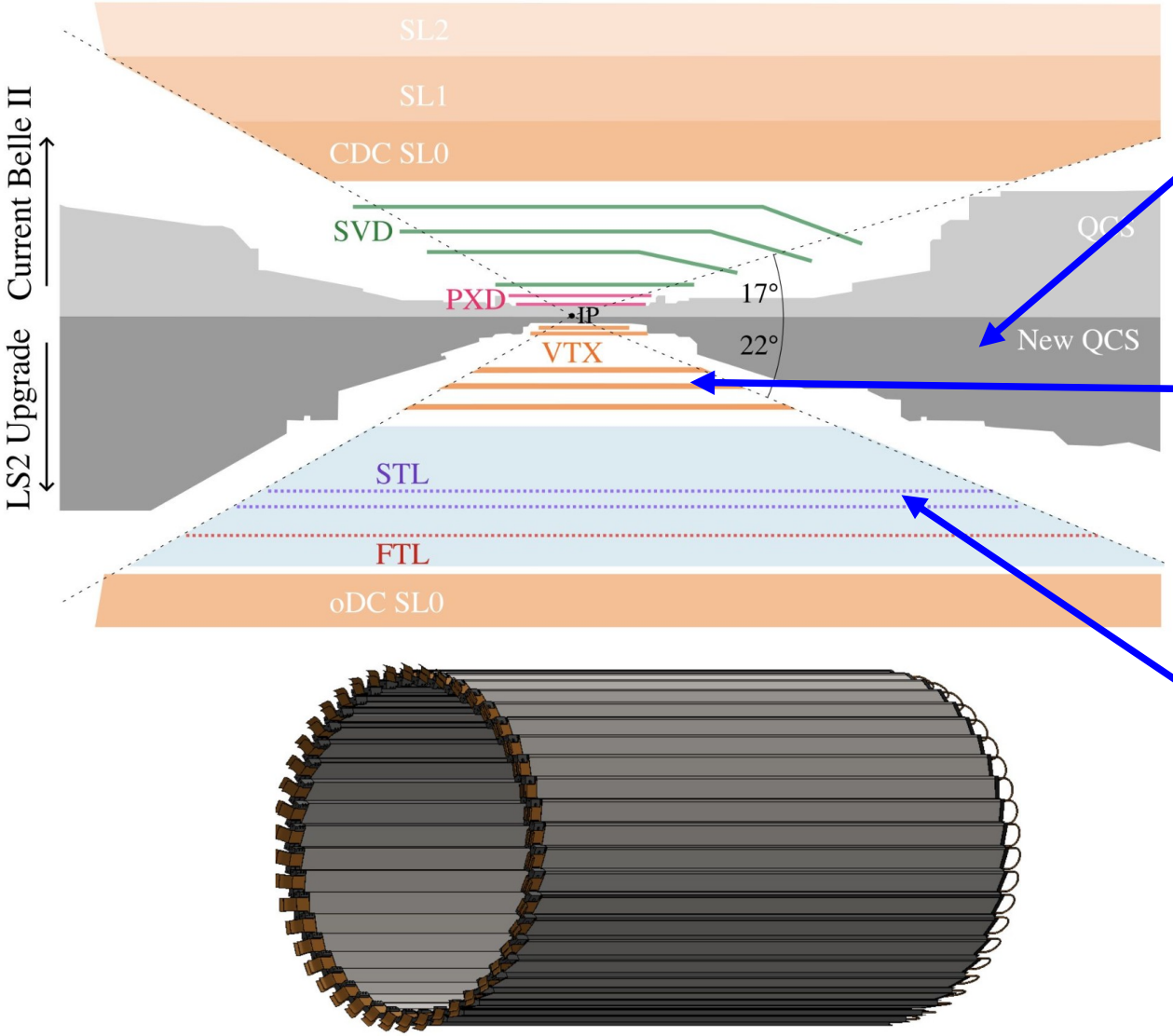
- 5 layers DMAPS (depleted monolithic active pixels)
- Very low material budget (0.2-0.8% rad length per layer)
- Excellent time and space granularity (33μm pitch)
- Significant improvements in low-pT tracking and vertexing





Future plans: detector

High luminosity running requires significant detector and interaction region upgrades:



New QCS magnets

- Impacts detector acceptance in forward direction

All-silicon VTX detector

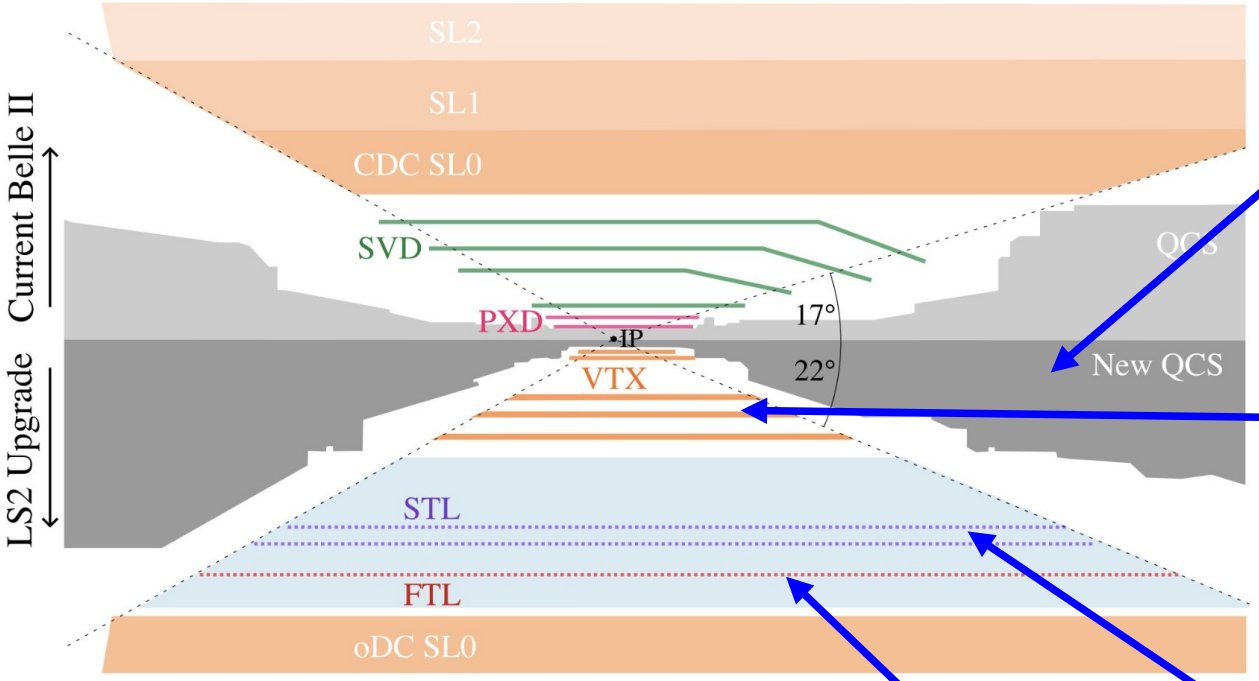
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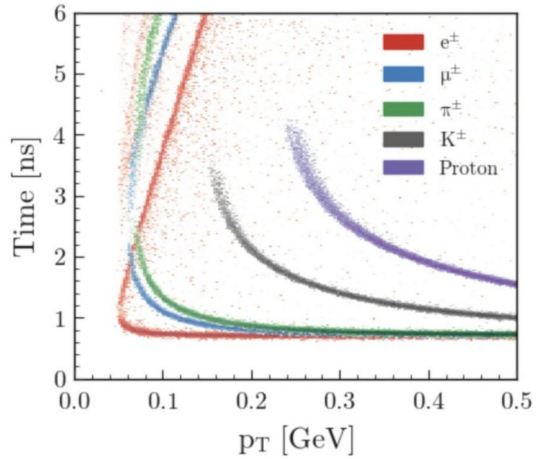
Silicon transition layer (STL)

- 2 double layers of CMOS strips(150μm pitch) based on ATLAS ITk design
- Provide additional tracking points in region between VTX and new oDC

Future plans: detector

High luminosity running requires significant detector and interaction region upgrades:





New QCS magnets

- Impacts detector acceptance in forward direction

All-silicon VTX detector

- 5 layers DMAPS (depleted monolithic active pixels)
- Very low material budget (0.2-0.8% rad length per layer)
- Excellent time and space granularity (33μm pitch)
- Significant improvements in low-pT tracking and vertexing

Fast timing layer (FTL)

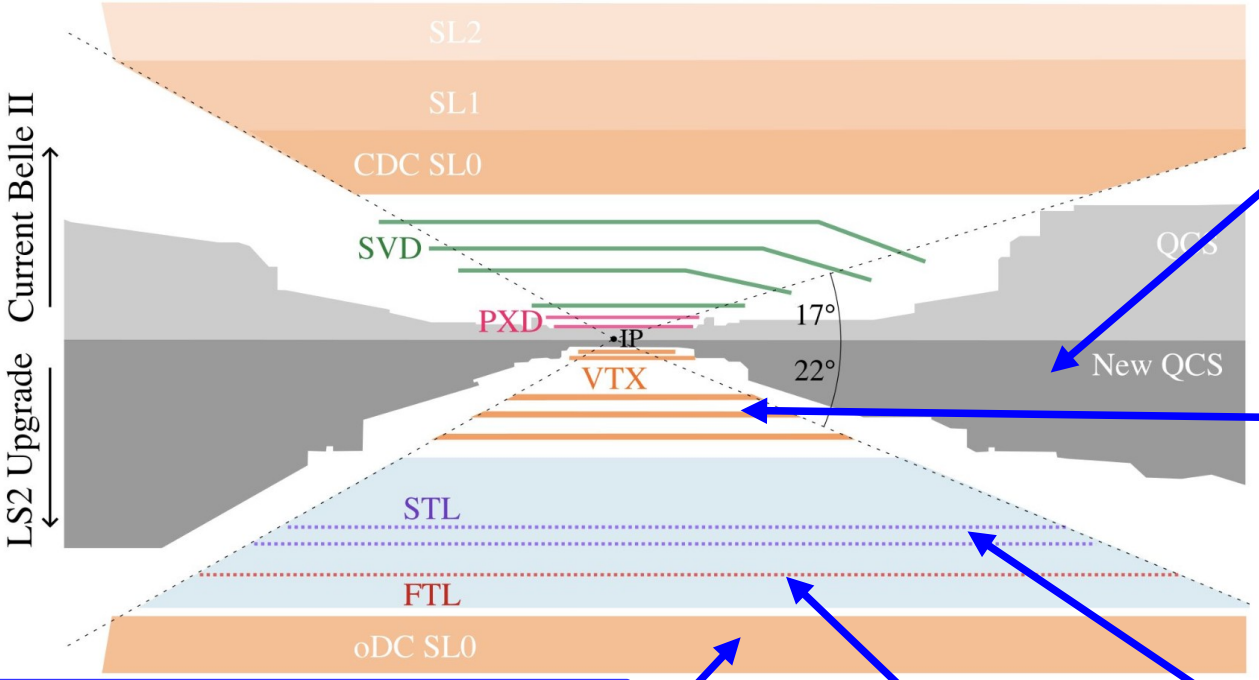
- Single layer of strip AC-LGADs with timing resolution better than 50ps
- Time-of-flight based PID and event T_0
- Low pT electron ID and μ-π discrimination. Kaon ID (all pT)

Silicon transition layer (STL)

- 2 double layers of CMOS strips(150μm pitch) based on ATLAS ITk design
- Provide additional tracking points in region between VTX and new oDC

Future plans: detector

High luminosity running requires significant detector and interaction region upgrades:



New QCS magnets

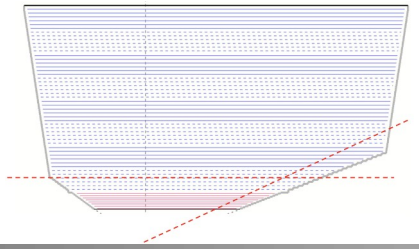
- Impacts detector acceptance in forward direction

All-silicon VTX detector

- 5 layers DMAPS (depleted monolithic active pixels)
- very low material budget (0.2-0.8% rad length per layer)
- Excellent time and space granularity (33μm pitch)
- significant improvements in low-pT tracking and vertexing

Outer Drift Chamber (oDC)

- Small-cell drift chamber with increased inner radius to accommodate high background rates



Fast timing layer (FTL)

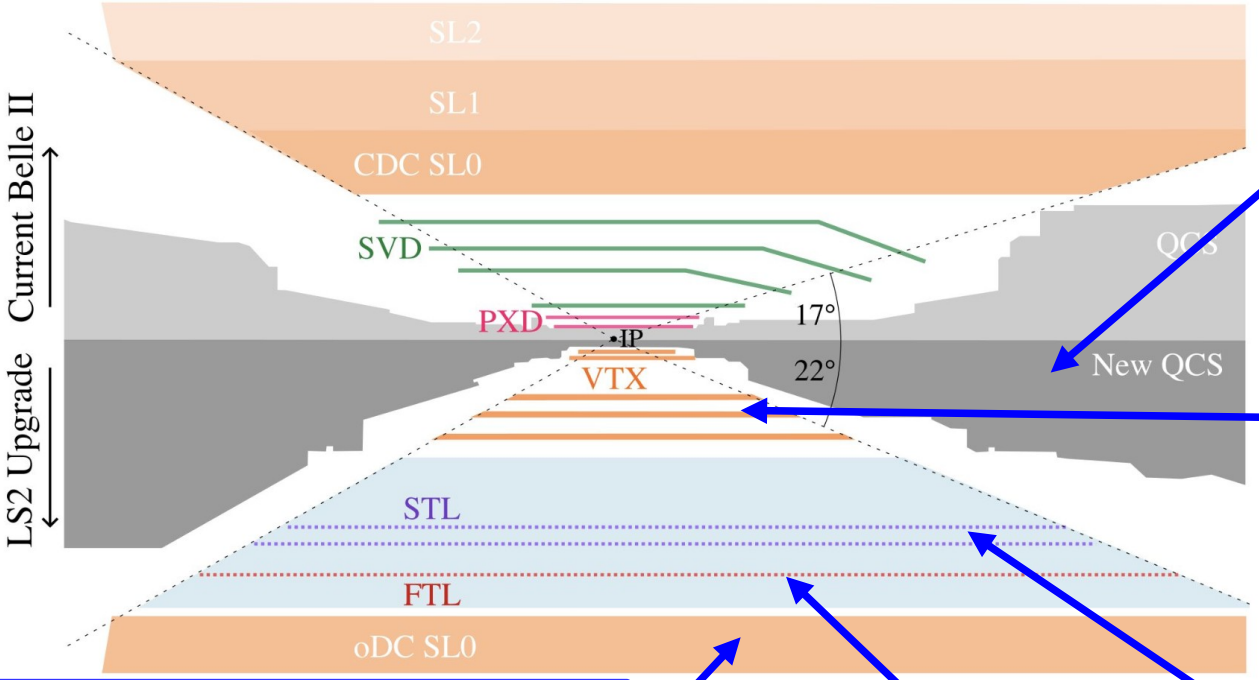
- Single layer of strip AC-LGADs with timing resolution better than 50ps
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Silicon transition layer (STL)

- 2 double layers of CMOS strips(150μm pitch) based on ATLAS ITk design
- Provide additional tracking points in region between VTX and new oDC

Future plans: detector

High luminosity running requires significant detector and interaction region upgrades:



New QCS magnets

- Impacts detector acceptance in forward direction

All-silicon VTX detector

- 5 layers DMAPS (depleted monolithic active pixels)
- very low material budget (0.2-0.8% rad length per layer)
- Excellent time and space granularity (33μm pitch)
- significant improvements in low-pT tracking and vertexing

Outer Drift Chamber (oDC)

- Small-cell drift chamber with increased inner radius to accommodate high background rates

Outer detectors (ARICH, TOP, ECL, KLM)

- More modest upgrades to accommodate increased rates

Fast timing layer (FTL)

- Single layer of strip AC-LGADs with timing resolution better than 50ps
- Time-of-flight based PID and event T_0
- Low pT electron ID and μ-π discrimination. Kaon ID (all pT)

Silicon transition layer (STL)

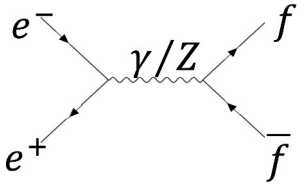
- 2 double layers of CMOS strips(150μm pitch) based on ATLAS ITk design
- Provide additional tracking points in region between VTX and new oDC

Beam polarization?

Longitudinally polarized electron beam would enable measurement of A^f_{LR} at √10.6 GeV via left-right asymmetries

- results from γ-Z interference
- source of tension in the overall EW fit due to ~3σ discrepancy in LEP and SLD measurements for b and c quarks

$$A^f_{LR}(\mathrm{SM}) = \frac{\sigma^f_{\mathbf{L}} - \sigma^f_{\mathbf{R}}}{\sigma^f_{\mathbf{L}} + \sigma^f_{\mathbf{R}}} = \frac{sG_F}{\sqrt{2}\pi\alpha Q_f} g^e_A g^f_V$$

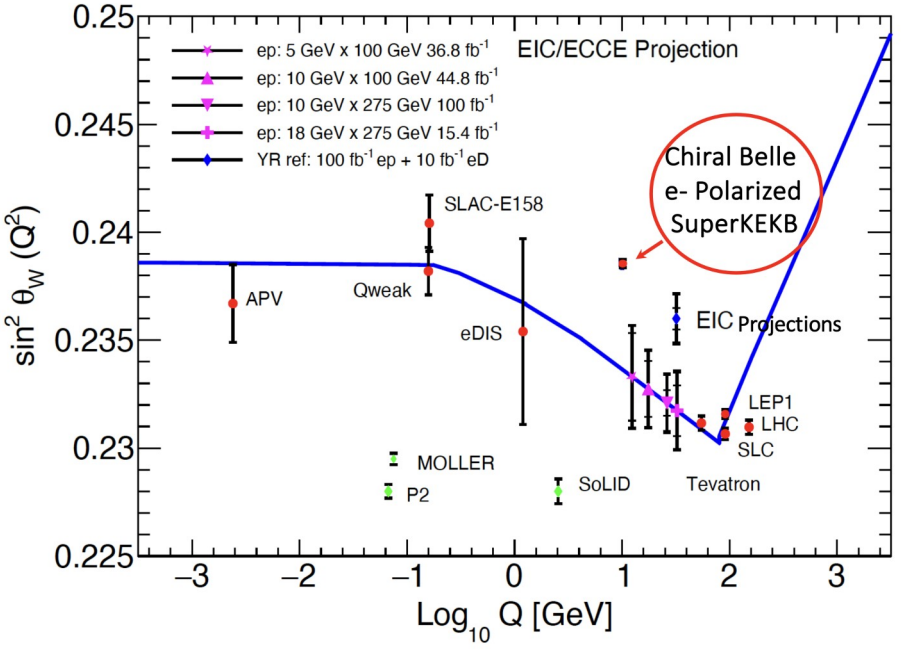


$$g^f_V = T^f_3 - 2Q_f \sin^2\theta_W$$

$$g^e_A = T^e_3 = -\tfrac{1}{2}$$

$$A^f_{LR}(\mathrm{measured}) = \frac{N^f_{\mathbf{L}} - N^f_{\mathbf{R}}}{N^f_{\mathbf{L}} + N^f_{\mathbf{R}}} \langle Pol \rangle$$

Asymmetry between measured rates when longitudinal beam polarization is left or right handed



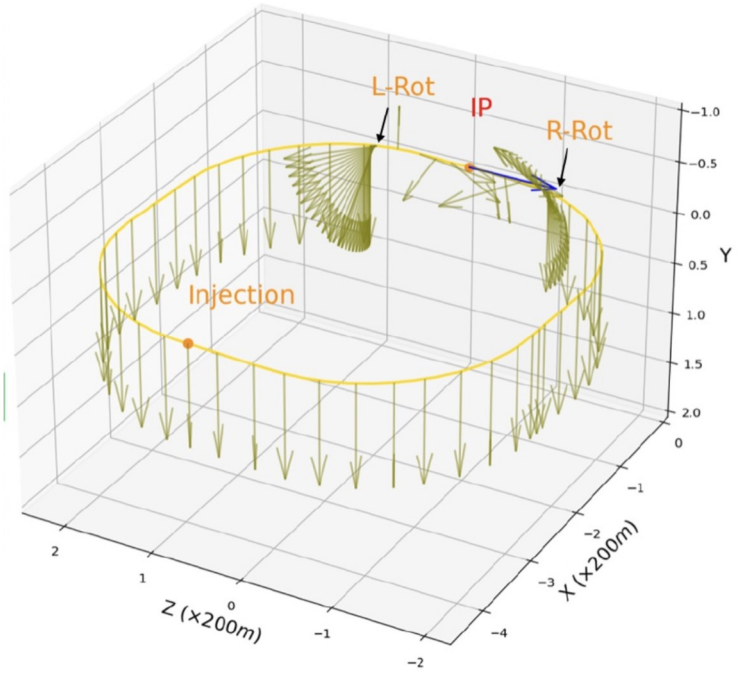
"Chiral Belle II" could provide world-leading measurement of neutral current vector coupling g^f_V for various fermions f

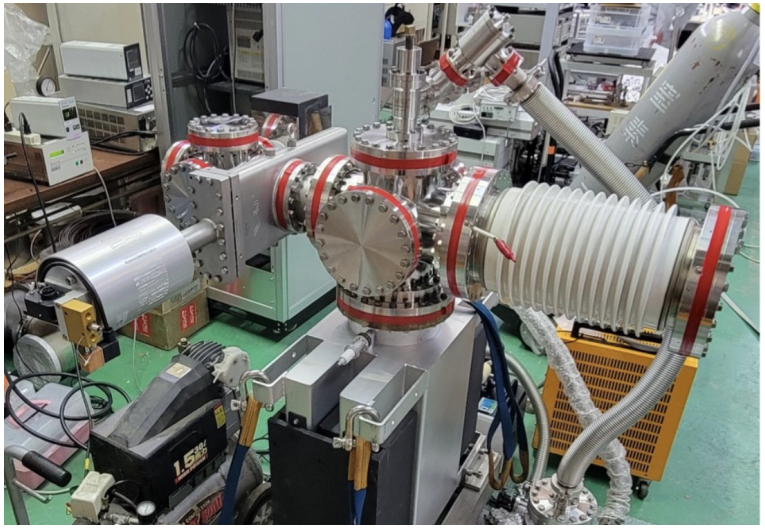
- Weak Mixing Angle $\sin^2\theta_W$ measured independently for five fermion types: c, b, e, μ, τ
- ~40 ab^{-1} would provide comparable sensitivity to current Z-pole measurements, but at √10.6 GeV
- Other potential measurements include $(g\text{-}2)_\tau$ and τ Michel parameters

Beam polarization?

Chiral Belle:

- Can achieve 70% transverse beam polarization with an 80% polarized source
- **Polarized electron beam source**: GaAs photocathode illuminated with polarized laser
- **Compact spin rotator** to produce longitudinal polarization at IP: replace two existing dipole magnets with superconducting solenoid-dipole combined function magnets
- Monitor real-time (transverse) polarization with to better than 1% with **Compton polarimeter**





- Flip laser polarization to invert beam polarization
- "Normal" unpolarized SuperKEKb can be recovered simply by turning off spin rotators (i.e. no changes to lattice/optics)

► Aim to complete R&D phase by 2029, with installation during LS2 (or subsequent summer shutdown)

A. Beaubien (UVic)
M. Yoshida (KEK)

Closing remarks

High quality Belle II data set is now fully competitive with BABAR and Belle

- Run 1 results based on 365 fb^{-1} but over 900 fb^{-1} has already been recorded
- Focus on luminosity integration over next few years with 5-10 ab^{-1} anticipated by LS2 (2032)
- Excellent prospects for high luminosity running post-LS2, possibly with polarized electron beam, with 30-50 ab^{-1} target



Thank you for your attention!