Recent results from the *BABAR* experiment

Steven Robertson
steven.robertson@ualberta.ca

On behalf of the *BABAR* Collaboration

Moriond Electroweak
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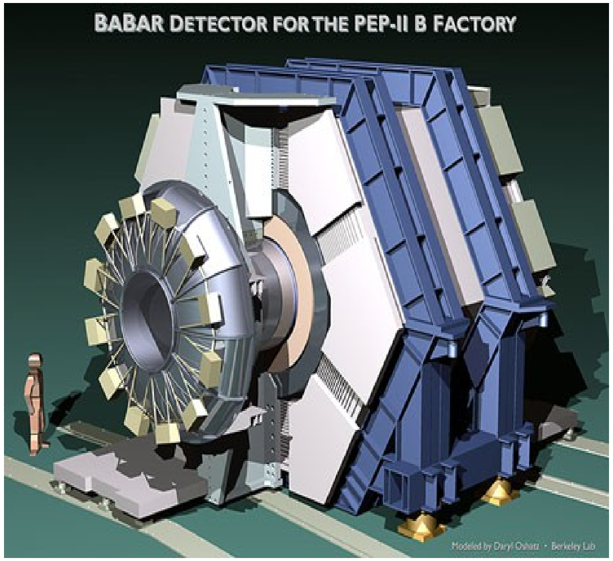
INSTITUTE OF PARTICLE PHYSICS

UNIVERSITY OF ALBERTA

Outline

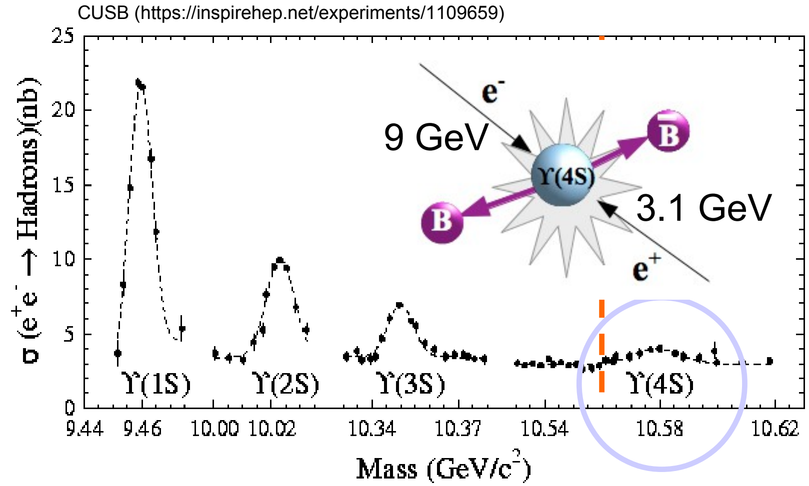


- *BABAR* overview
- Exclusive $B \rightarrow Dl\nu$ form factor measurement
  - **Phys. Rev. D 110 (2024) 3, 032018**
- *B* baryogenesis searches:
  - $B^+ \rightarrow p + \psi_D$ Phys. Rev. Lett. 131 (2023) 20, 201801
  - $B^0 \rightarrow \Lambda + \psi_D$ Phys. Rev. D 107 (2023) 9, 092001
  - $\mathbf{B^+ \rightarrow \Lambda_c^+ + \psi_D}$ **Phys. Rev. D 111 (2025) 3, L031101**

BABAR experiment

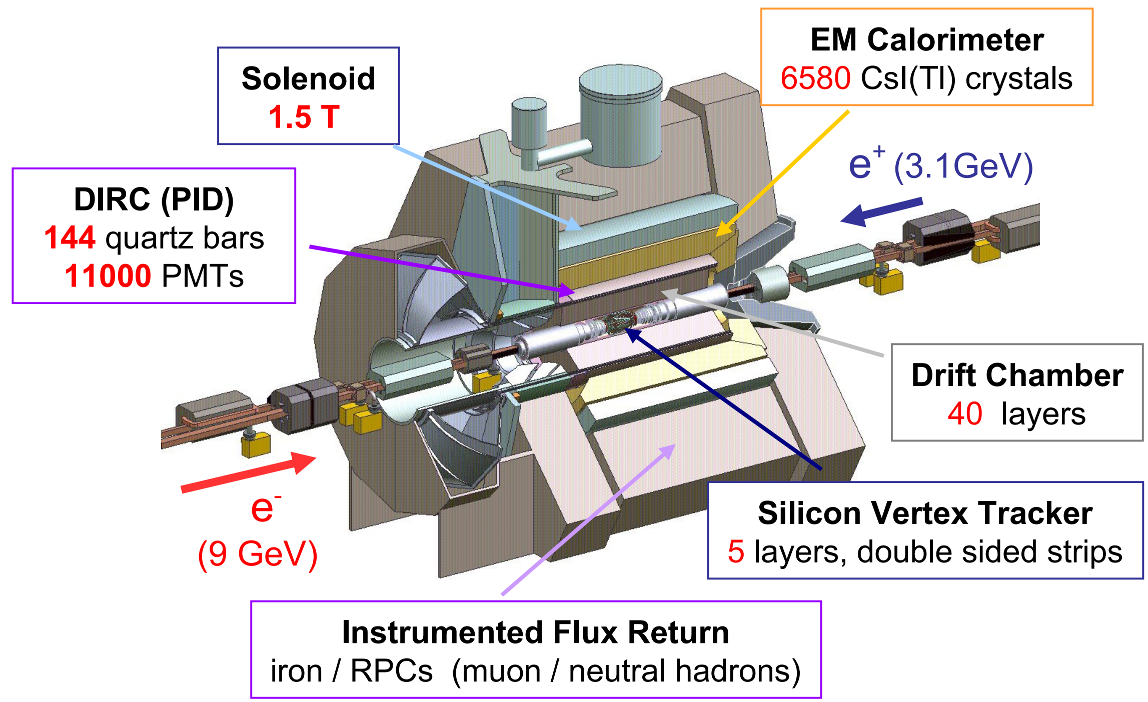
Asymmetric B Factory experiment at the SLAC National Accelerator Laboratory

- *BABAR* collected data from 1999 until 2008
- **432 fb^{-1} $\Upsilon(4S)$ "on peak"** (~470 x 10^6 $B\bar{B}$ pairs)
- 53 fb^{-1} non-resonant "off peak"
- Smaller samples at the $\Upsilon(2S)$ and $\Upsilon(3S)$ energies



Detector optimized for tracking and B vertex reconstruction, K - π particle identification, precision calorimetry, and μ ID

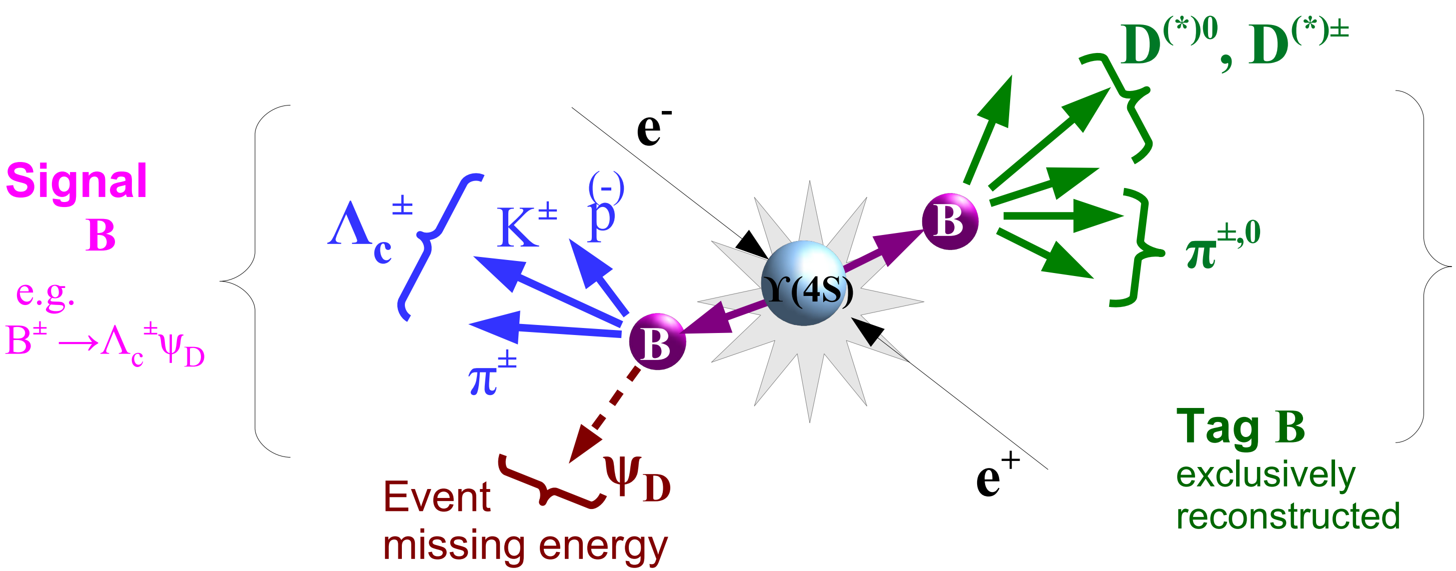
- **Clean** environment with large solid-angle detector coverage and good missing energy reconstruction
- **Inclusive trigger** (N_{tracks}>3) as well as dedicated low-multiplicity triggers

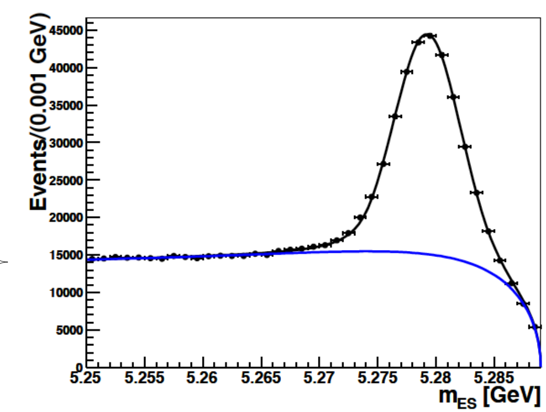


Methodology

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

- Instead, exclusively reconstruct one of the B meson decays ("**Tag B**") in one of several thousand possible hadronic decay modes, then look for the **signal** decay in whatever is left over:





$$\Delta E = E^*_{\rm tag} - \sqrt{s}/2,$$

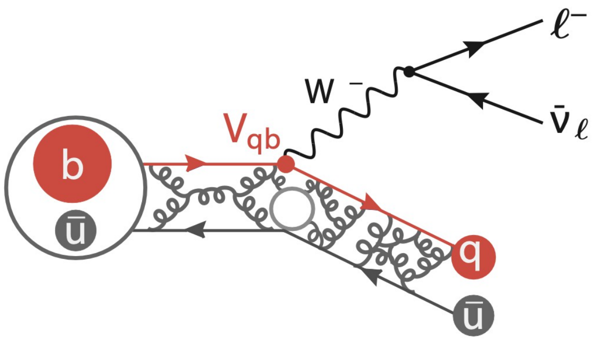
$$m_{\rm ES} = \sqrt{s/4 - |\vec{p}^{\,*}_{\rm tag}|^2}$$

- Advantage: improves knowledge of signal kinematics and missing energy, and strongly suppresses combinatorial backgrounds
- Disadvantage: low reconstruction efficiency (~0.1%)

$\mathbf{B \to D}\boldsymbol{l v}$ introduction

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

- Provide experimentally clean and high-statistics measurements of CKM matrix elements V_{ub} and V_{cb}



Inclusive measurements:

$$B \to X_u l v\ ,\ \ B \to X_c l v$$

$$\mathcal{B} = |V_{qb}|^2 \left[\Gamma(b \to q\,\ell\,\bar{\nu}_\ell) + 1/m_{c,b} + \alpha_s + \ldots\right]$$

Heavy Quark Expansion

Exclusive measurements:

$$B \to D^* l v,\ \ B \to D l v,\ \ B \to \pi l v \ \text{ etc.}$$

$$\mathcal{B} \propto |V_{qb}|^2 f^2$$

Form factors

$$\langle D|\bar{c}\gamma_\mu b|\bar{B}\rangle_V = f_+(q^2)\left((p_B+p_D)_\mu - \frac{(p_B+p_D)\cdot q}{q^2}q_\mu\right) + f_0(q^2)\frac{(p_B+p_D)\cdot q}{q^2}q_\mu$$

$q = p_B - p_D$ is the 4-momentum of the recoiling lv system.

$$w = \frac{m_B^2 + m_D^2 - q^2}{2 m_B m_D}$$

is the recoil parameter characterizing the boost of the D meson in the B meson rest frame, and

$$k = m_D\sqrt{w^2 - 1}$$

- In massless lepton limit, the differential decay rate depends only on the vector form factor:

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}q^2 \mathrm{d}\cos\theta_\ell} = \frac{G_F^2 |V_{cb}|^2 \eta_{\mathrm{EW}}^2}{32\pi^3} k^3 |f_+(q^2)|^2 \sin^2\theta_\ell$$

Alternatively expressed in terms of:

$$\mathcal{G}(w)^2 = \frac{4r}{(1+r)^2} f_+(w)^2$$

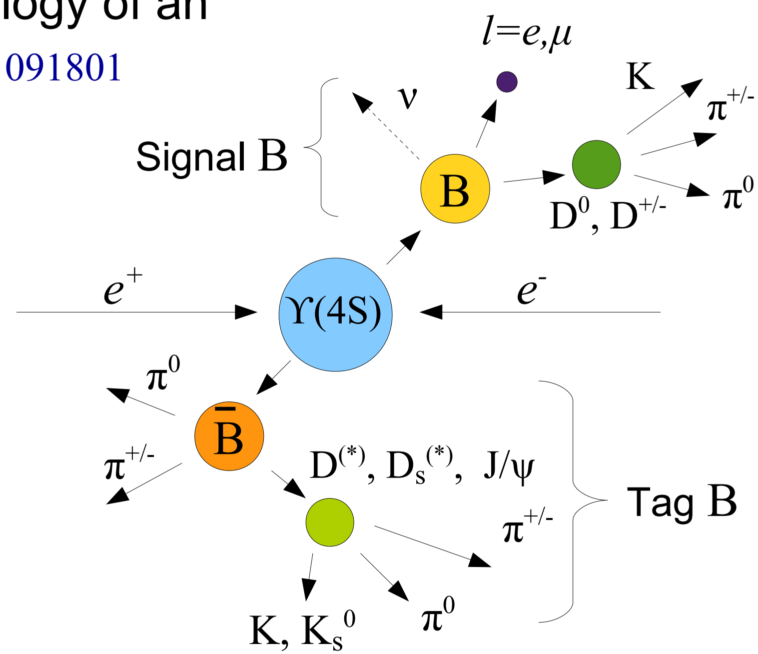
with

$$r = m_D/m_B$$

$B \to Dl\nu$

New *BABAR* $B \to Dl\nu$ measurement follows methodology of an earlier paper on $B \to D^{*}l\nu$: Phys. Rev. Lett. 123 (2019) 9, 091801

- Utilizes full *BABAR* $\Upsilon(4S)$ data set of 426 fb^{-1} , equivalent to ~471 million $B\bar{B}$ events
- Exclusively reconstruct the accompanying "tag" B meson in $\Upsilon(4S)$ event in one of many hadronic decay modes



The remaining detector activity defines the signal B candidate:

- Identified lepton is combined with a reconstructed D meson
- E_{extra} variable sums energies of anything not used for either signal or tag B reconstruction

Reconstruct signal $B \to Dl\nu$ in e and μ modes:

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

10 signal modes in total (e, μ)

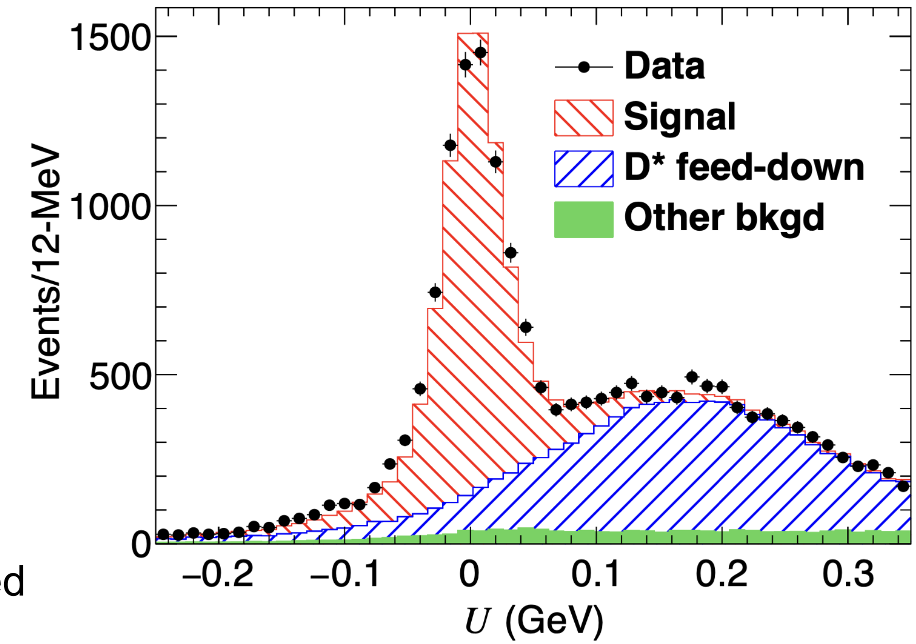
Candidate selection

Missing energy 4-vector computed from overall event kinematics:

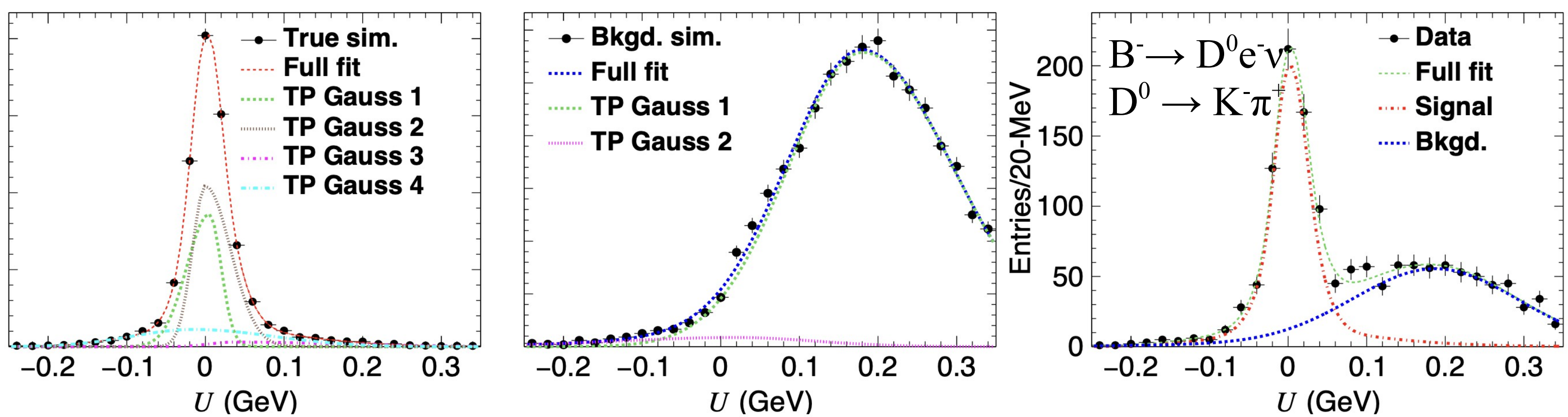
$$p_\nu \equiv p_{\text{miss}} = p_{e^+e^-} - p_{\text{tag}} - p_D - p_\ell$$

$$U = E^{**}_{\text{miss}} - |\vec{p}^{\,**}_{\text{miss}}|$$

Computed in B rest frame



- Background differs in each signal mode, and varies with q^2 and $\cos\theta_l$ of signal lepton
- Signal and background parameters determined from fits in q^2 and $\cos\theta_l$ bins to simulation:

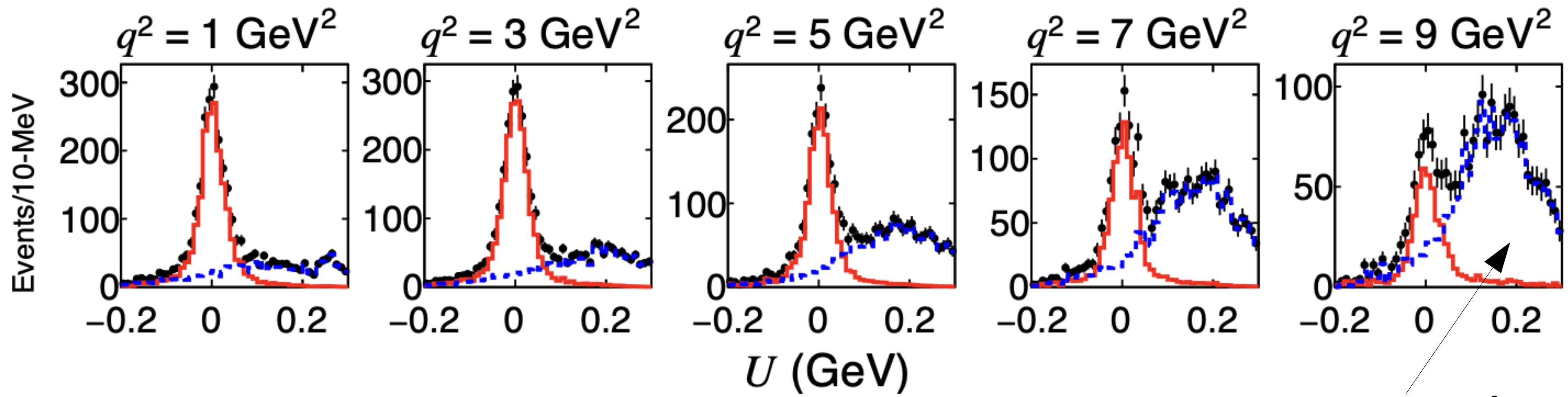


- Retain events in region $|U| \leq 50$ MeV

Local fit results

Signal events identified using unbinned "local" fits to data to determine signal probability event weight Q_i

- Approximately 5500 signal events are retained for amplitude analysis:

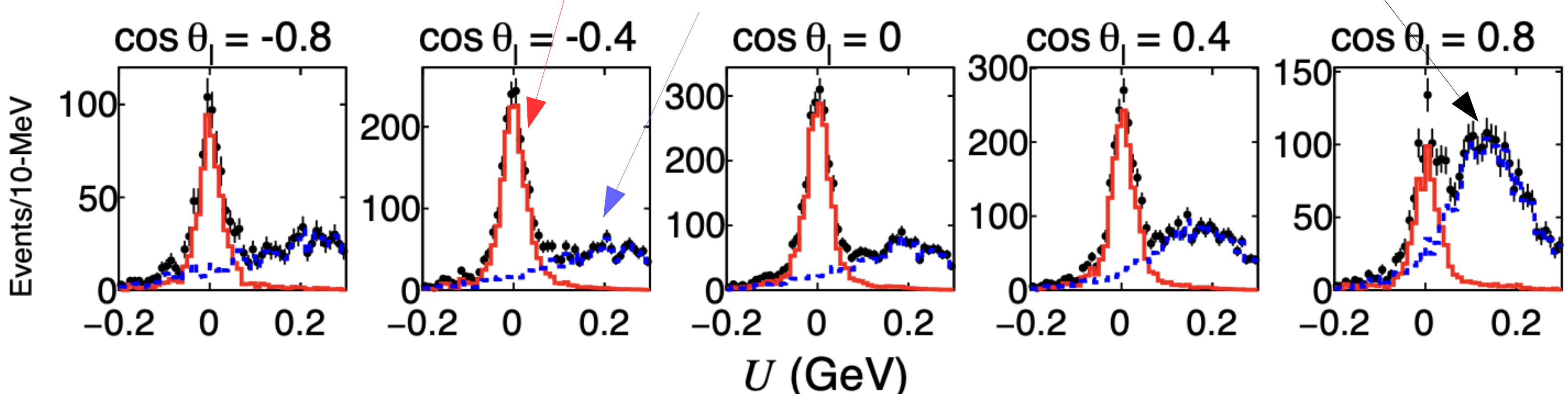


lepton helicity distribution follows expected $\sin^2\theta_l$ distribution:

Q_i event weights

$(1-Q_i)$ event weights

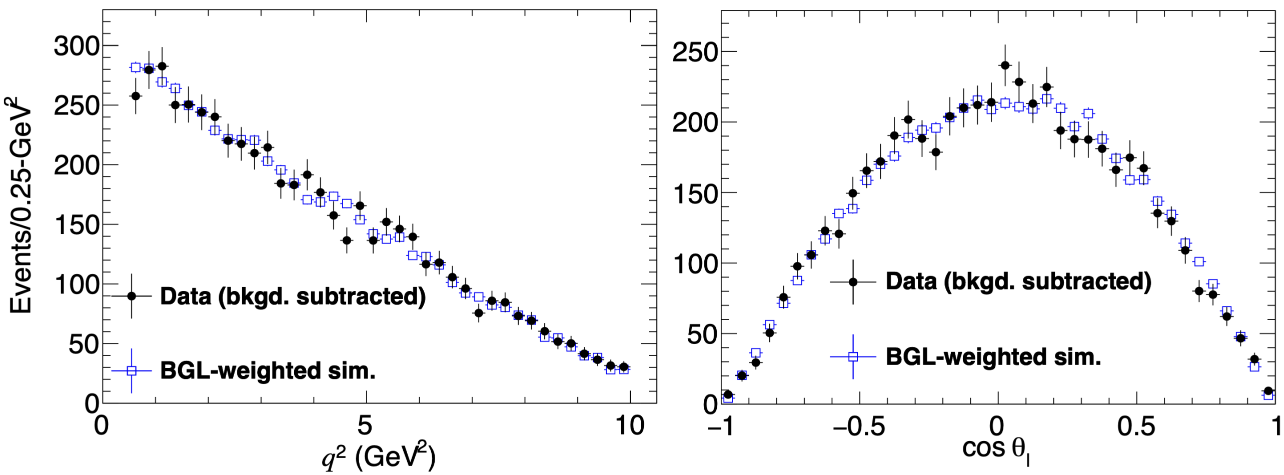
large background at high q^2 and $\cos\theta_l$ from D^* feed-down



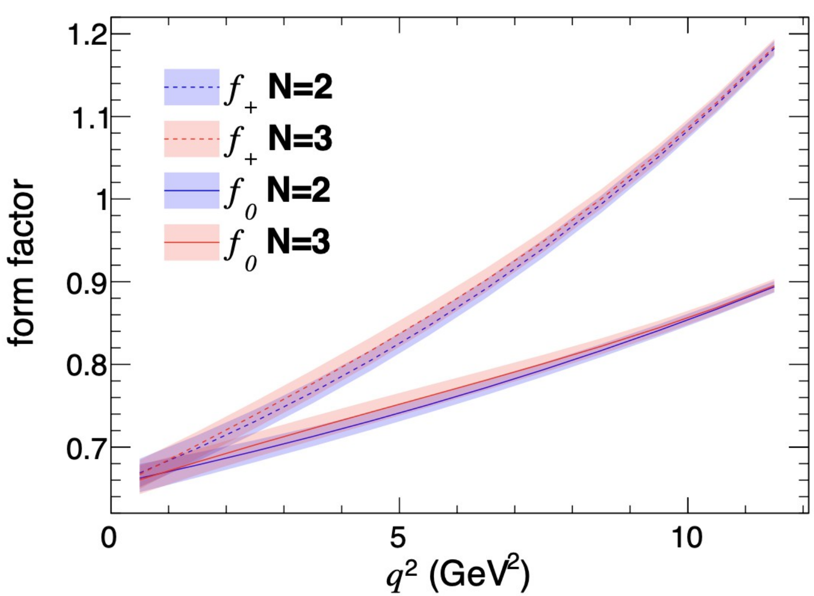
Form factor results

Form factor results obtained for BGL and CLN models:

BGL $N=2$	value
$\|V_{cb}\| \times 10^3$	41.09 ± 1.16
$a_0^{f_+} \times 10$	0.126 ± 0.001
$a_1^{f_+}$	-0.096 ± 0.003
$a_2^{f_+}$	0.352 ± 0.053
$a_1^{f_0}$	-0.059 ± 0.003
$a_2^{f_0}$	0.155 ± 0.049



CLN	value
$\|V_{cb}\| \times 10^3$	40.90 ± 1.14
$\mathcal{G}(1)$	1.056 ± 0.008
ρ_D^2	1.155 ± 0.023



Fits with different background configurations obtain consistent parameters

- No significant difference between BGL with N=2 or N=3; no improvement in fit from including cubic terms:

Phys. Rev. D 110(2024) 3, 032018

B Baryogenesis

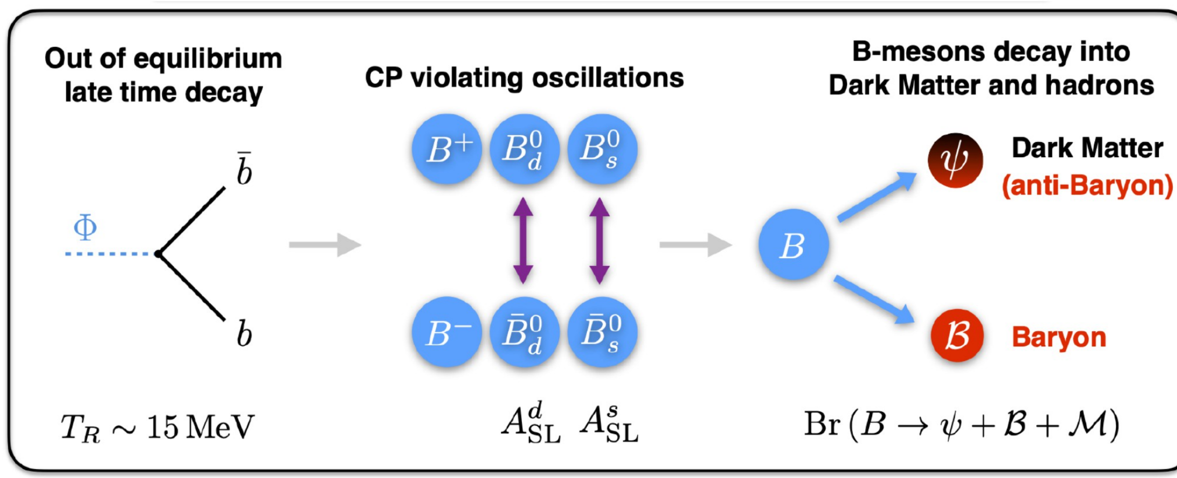
Model provides a possible mechanism to explain dark matter abundance and baryon asymmetry of the universe (BAU):

- **Baryon number conservation includes both visible and dark sector**
- Postulates the existence of a light dark-sector anti-baryon (ψ_D) and a TeV-scale color-triplet bosonic mediator (**Y**)
- Matter – antimatter asymmetry arises from CP violation in B^0 - $\bar{B}^0$ oscillations
- BAU results from B meson decays into a baryon and a dark sector anti-baryon ψ_D (+ mesons)

G. Elor, M. Escudero and A. E. Nelson, Phys. Rev. D 99, 035031 (2019).

G. Alonso-Alvarez, G. Elorand, and M. Escudero, Phys.Rev. D 104, 035028 (2021).

See talk tonight!



Visible and dark sectors have equal but opposite baryon number asymmetries, but total baryon number is conserved

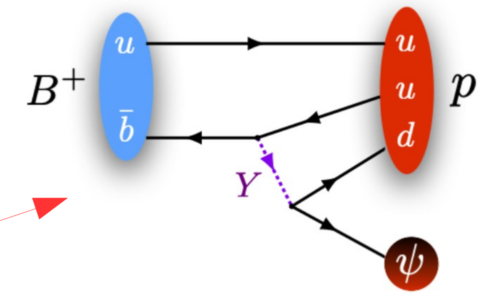
- Experimentally testable predictions of $\mathbf{B} \rightarrow \psi_D + \mathcal{B}$ (+ additional light mesons)

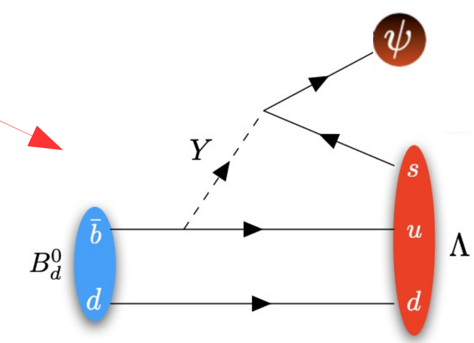
Decay modes

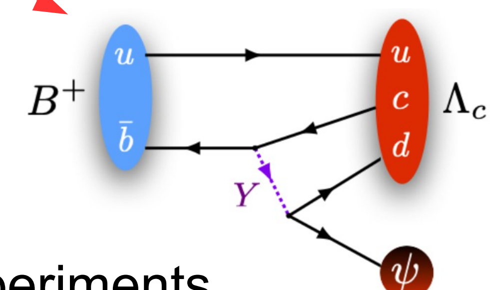
Baryon asymmetry is produced by B^0 decays, but the same operators produce analogous charged B^+ decays as well:

Y couples b to u, and d to ψ_D

Operator and Decay	Initial State	Final State	ΔM (MeV)
$\mathcal{O}_{ud} = \psi\, b\, u\, d$; $\bar{b} \to \psi\, u\, d$	B_d	$\psi + n\,(udd)$	4340.1
	B_s	$\psi + \Lambda\,(uds)$	4251.2
	B^+	$\psi + p\,(duu)$	4341.0
	Λ_b	$\bar{\psi} + \pi^0$	5484.5
$\mathcal{O}_{us} = \psi\, b\, u\, s$; $\bar{b} \to \psi\, u\, s$	B_d	$\psi + \Lambda\,(usd)$	4164.0
	B_s	$\psi + \Xi^0\,(uss)$	4025.0
	B^+	$\psi + \Sigma^+\,(uus)$	4090.0
	Λ_b	$\bar{\psi} + K^0$	5121.9
$\mathcal{O}_{cd} = \psi\, b\, c\, d$; $\bar{b} \to \psi\, c\, d$	B_d	$\psi + \Lambda_c + \pi^-\,(cdd)$	2853.6
	B_s	$\psi + \Xi_c^0\,(cds)$	2895.0
	B^+	$\psi + \Lambda_c^+\,(dcu)$	2992.9
	Λ_b	$\bar{\psi} + \overline{D}^0$	3754.7
? $\mathcal{O}_{cs} = \psi\, b\, c\, s$; $\bar{b} \to \psi\, c\, s$	B_d	$\psi + \Xi_c^0\,(csd)$	2807.8
	B_s	$\psi + \Omega_c\,(css)$	2671.7
	B^+	$\psi + \Xi_c^+\,(csu)$	2810.4
	Λ_b	$\bar{\psi} + D^- + K^+$	3256.2







- Expect only one of these operators to dominate

- B^+ and B_d modes potentially accessible at B factory experiments

Decay modes

Baryon asymmetry is produced by B^0 decays, but the same operators produce analogous charged B^+ decays as well:

Operator and Decay	Initial State	Final State	ΔM (MeV)
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$\mathcal{O}_{cs} = \psi\, b\, c\, s$, $\bar{b} \to \psi\, c\, s$	B_d	$\psi + \Xi_c^0\,(csd)$	2807.8
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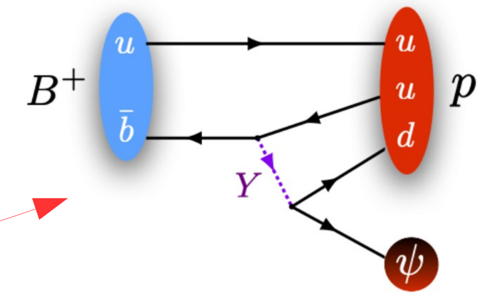
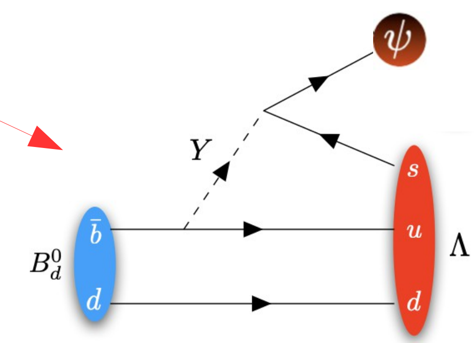
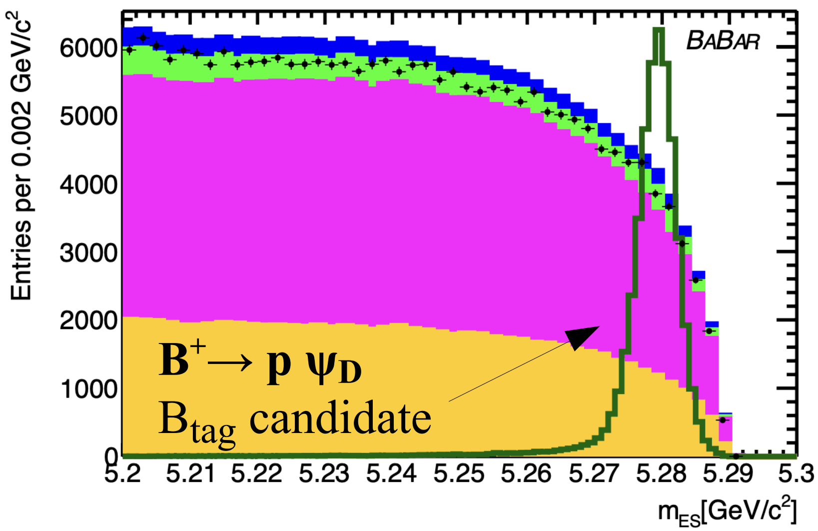




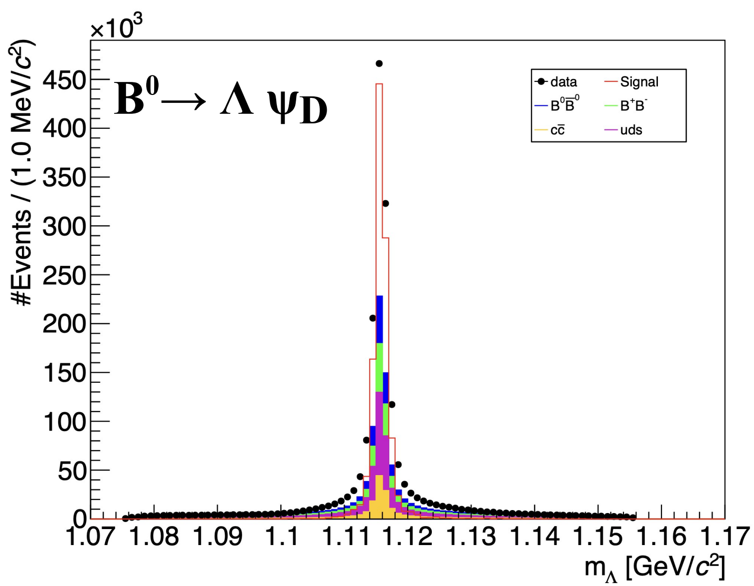
- B^+ and B_d modes potentially accessible at B factory experiments

$B^+ \rightarrow \psi_D + p$ and $B^0 \rightarrow \psi_D + \Lambda$

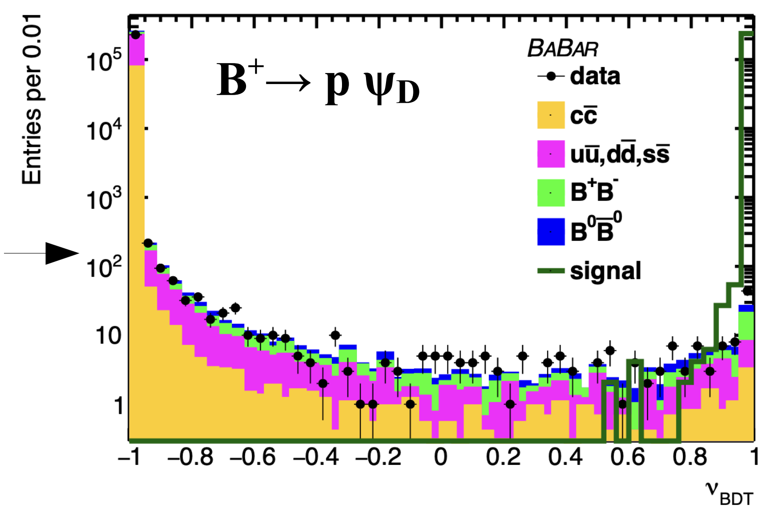


Reconstruct accompanying B meson from $\Upsilon(4S) \rightarrow B^+B^-$ and (or $B^0\bar{B}^0$) and look for signal signature in the remainder of the event:

- identified proton (and no additional tracks), or
- reconstruct $\Lambda^0 \rightarrow p\ \pi^-$, including displaced vertex significance requirement and kinematic fit



Boosted decision tree used to suppress continuum backgrounds based on event shape and kinematic variables



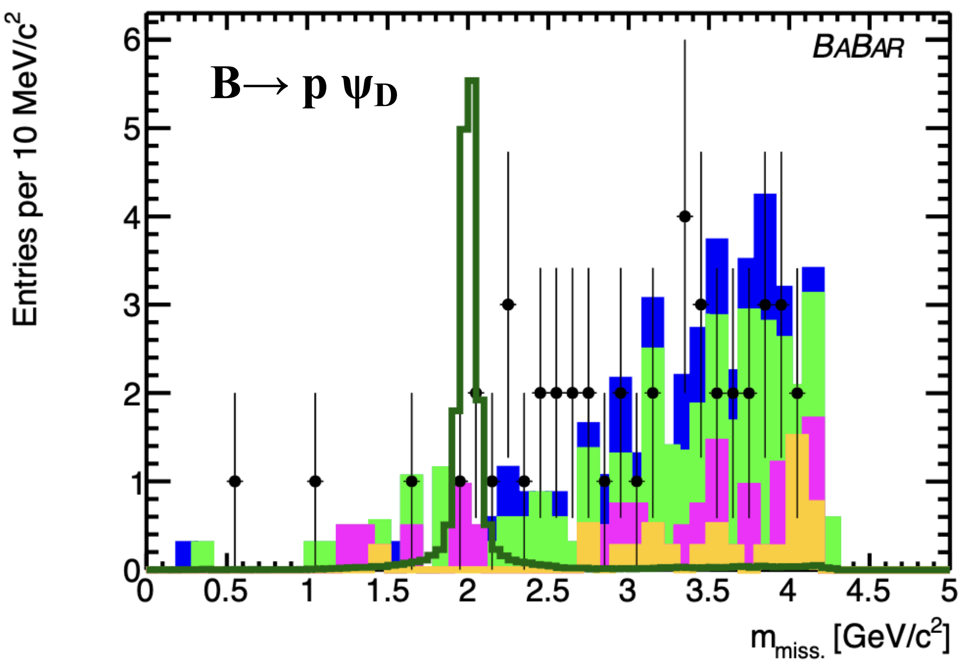
The dark sector ψ_D escapes undetected, but can be inferred from the event kinematics

Dark anti-baryon reconstruction

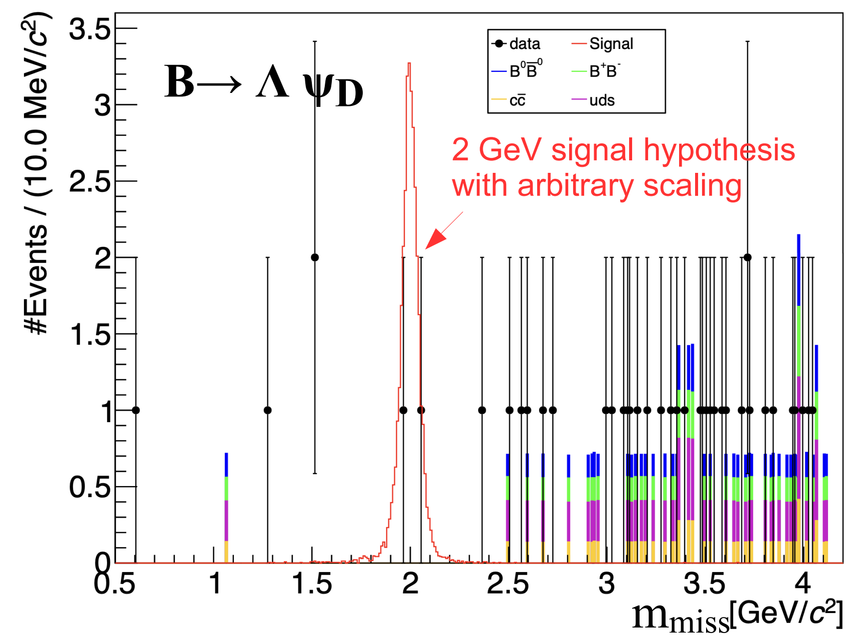
Missing energy 4-vector of "recoil" against the p or Λ yields the ψ_D invariant mass

$$m_{\text{miss}}c^2 = \sqrt{(E^*_{B_{\text{sig}}} - E^*_{\text{p}})^2 - |\vec{\text{p}}^{\,*}_{B_{\text{sig}}} - \vec{\text{p}}^{\,*}_{\text{p}}|^2 c^2}$$

- For $B \to p\,\psi_D$, m_{miss} resolution varies from ~110 MeV/c^2 (low mass) to ~11 MeV/c^2 (high mass)
- Background estimated directly from m_{miss} sideband data



46 events pass signal selection



41 events pass signal selection

Scan the recoil m_{miss} distribution in steps of $\sigma(m_{\text{miss}})$ for evidence of a narrow signal peak above a smoothly varying background

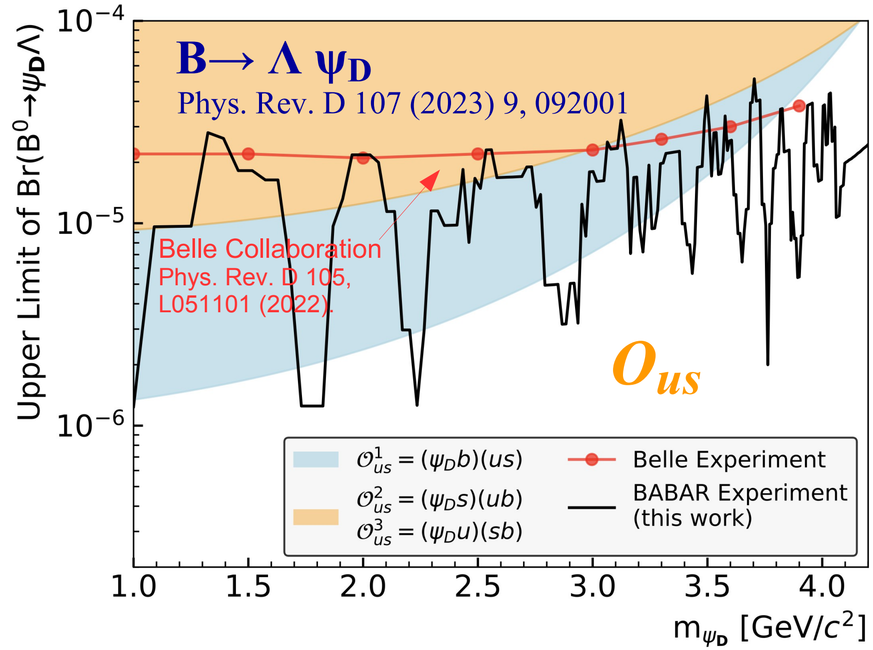
Branching fraction limits

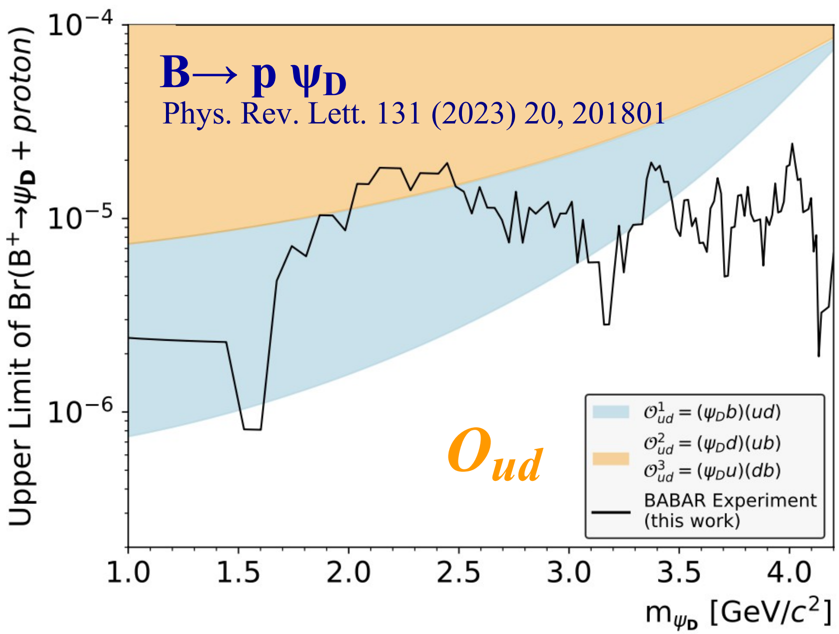
$B \to p\,\psi_D$:

- a total of 127 mass hypotheses are tested
- largest local significance @ 3.3 GeV/c^2 corresponds to ~1 σ global significance

$B \to \Lambda\,\psi_D$:

- 193 mass hypotheses are tested
- largest local significance @ 3.7 GeV/c^2 corresponds to ~0.4 σ global significance





Branching fraction 90% confidence limits obtained at level of $10^{-6} - 10^{-5}$ for both modes:

- Probes effective operators $O_{i,j} = (\psi_D b)(q_i q_j)$ with $q_i = \mathrm{u}$ and $q_j = \mathrm{d,s}$
- Results exclude a large fraction of the model parameter space

Decay modes

Baryon asymmetry is produced by B^0 decays, but the same operators produce analogous charged B^+ decays as well:

Operator and Decay	Initial State	Final State	ΔM (MeV)
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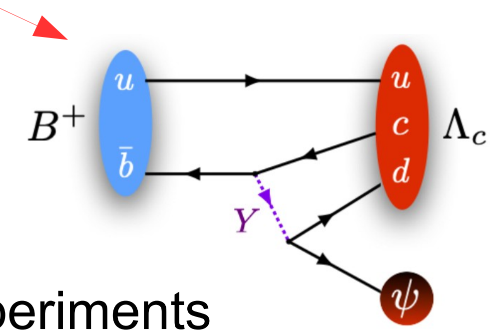
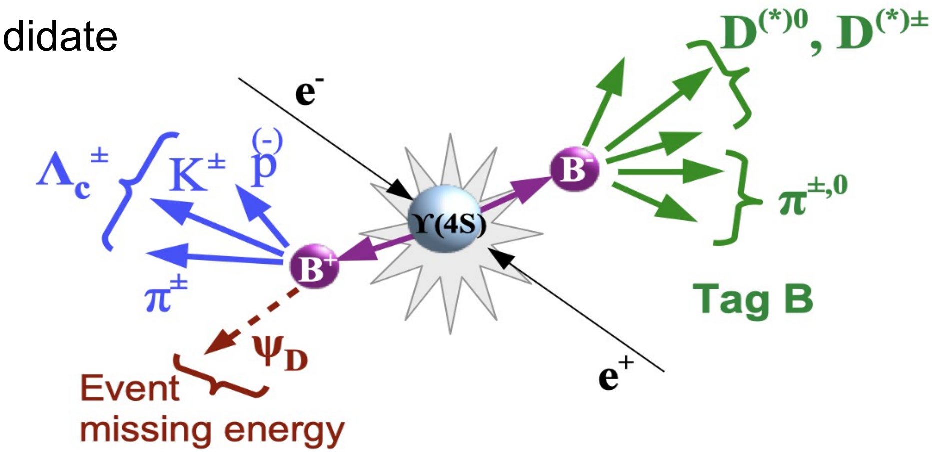


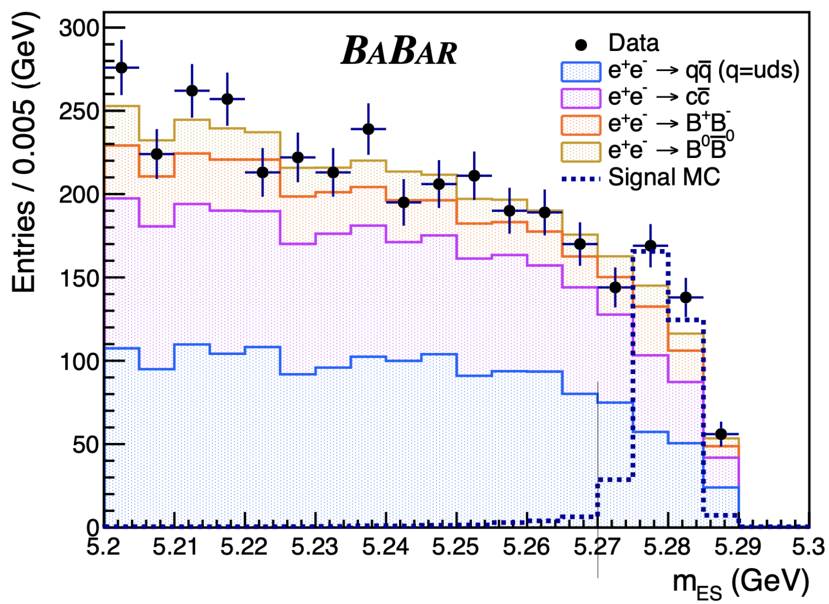
- B^+ and B_d modes potentially accessible at B factory experiments

$B^+ \rightarrow \psi_D + \Lambda_c^+$

Operator $O_{cd} = \psi bcd$ can be accessed via $B^+ \rightarrow \Lambda_c^+ \psi_D$ mode

- Hadronic tag reconstruction of B_{tag} with Λ_c^+ candidate reconstructed from remaining tracks
- Λ_c^+ reconstructed via $\Lambda_c^+ \rightarrow p K^- \pi^+$ (all charged tracks)





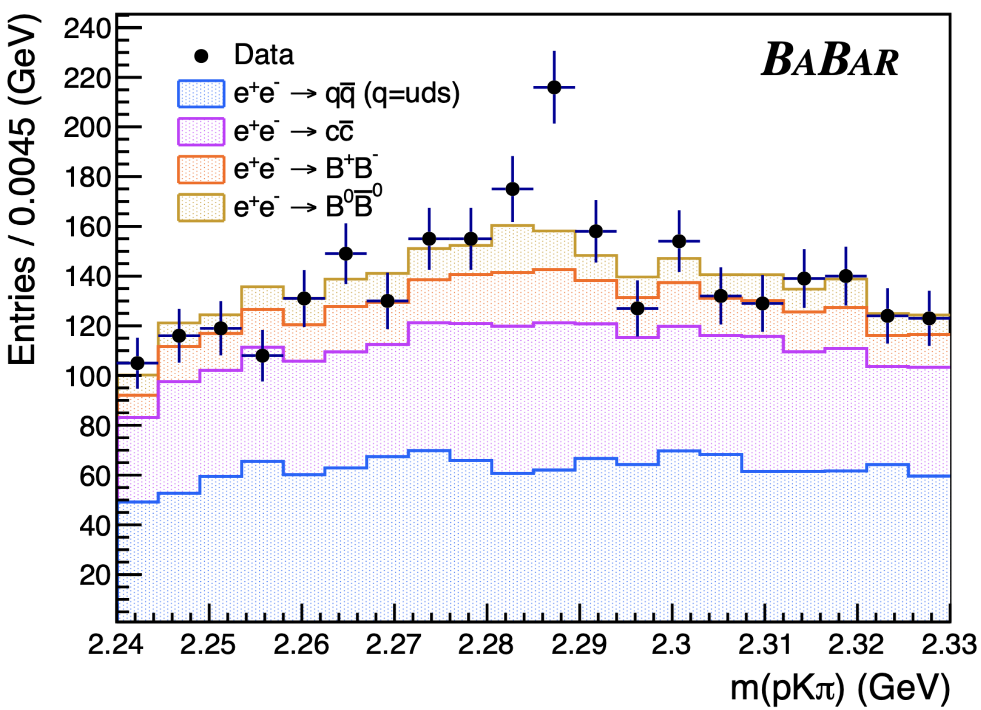
- Require exactly three high quality tracks, satisfying $\Lambda_c^+ \rightarrow p K^- \pi^+$ charge and particle ID expectations
- Backgrounds arise primarily from $q\bar{q}$ (continuum); very low background from $B \rightarrow$ baryons $+ X$;

- Analysis based on 399 fb^{-1} of data (~2 x 10^8 B^+B^- events), with an additional 32 fb^{-1} used for (unblinded) analysis optimization and subsequently discarded

Signal reconstruction

Signal Λ_c^+ reconstruction is validated using m_{ES} sideband region data

- Clear Λ_c^+ peak visible from continuum $q\bar{q}$ $(q = u,d,s,c)$ with an incorrectly reconstructed B_{tag}
- Not present in continuum MC, but enables data-driven background estimate in m_{ES} signal region, as well as check of resolution of $m(pK\pi)$ in data



Λ_c^+ candidates in m_{ES} sideband region

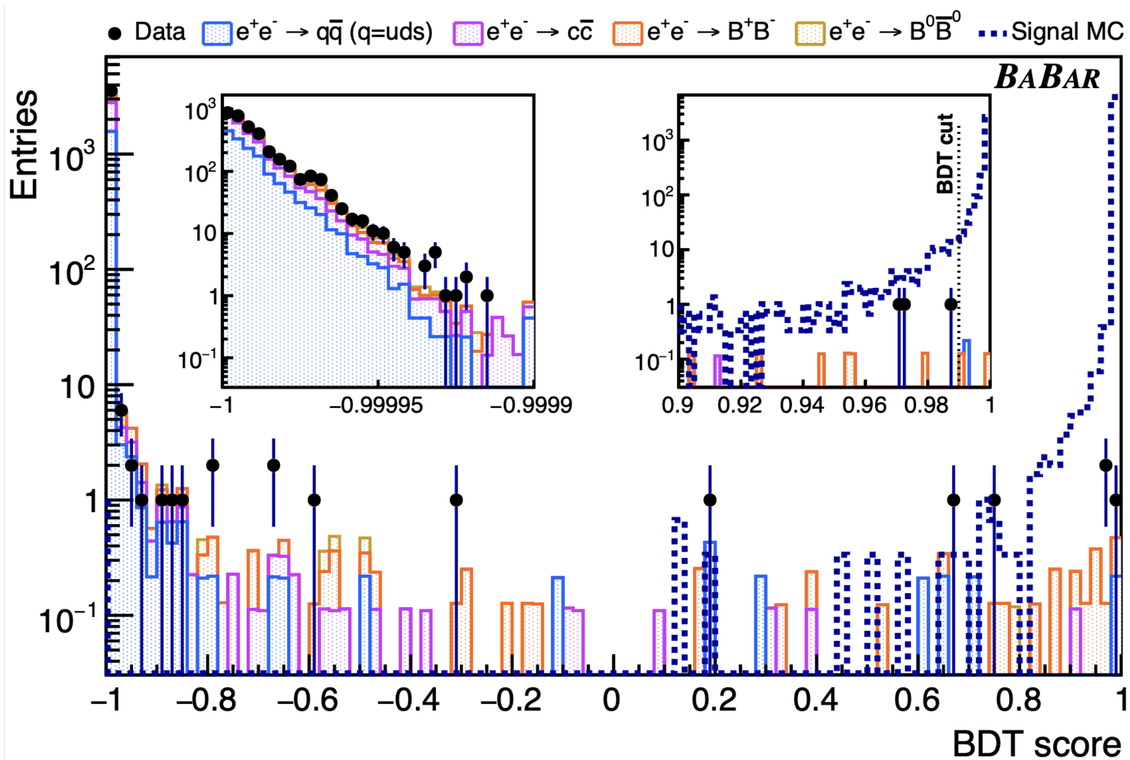
Continuum Λ_c^+ events and $B \rightarrow$ baryons$+X$ backgrounds typically have low missing energy and additional neutral particles besides the B_{tag} and Λ_c^+ candidates

- Multivariate (BDT) selector to suppress remaining backgrounds
- 14 inputs, based on overall event shape, B_{tag} properties, Λ_c^+ candidate properties, and additional detector activity in the event

Background rejection

Boosted decision tree (BDT) provides extremely high suppression of remaining backgrounds with little loss of signal efficiency

- 32 fb^{-1} data sample used for input validation and training, then discarded
- Signal samples spanning full kinematically accessible ψ_D mass range.
- Optimization performed blinded
- Require BDT score > 0.99



No events survive BDT selection (~0.4 expected background)

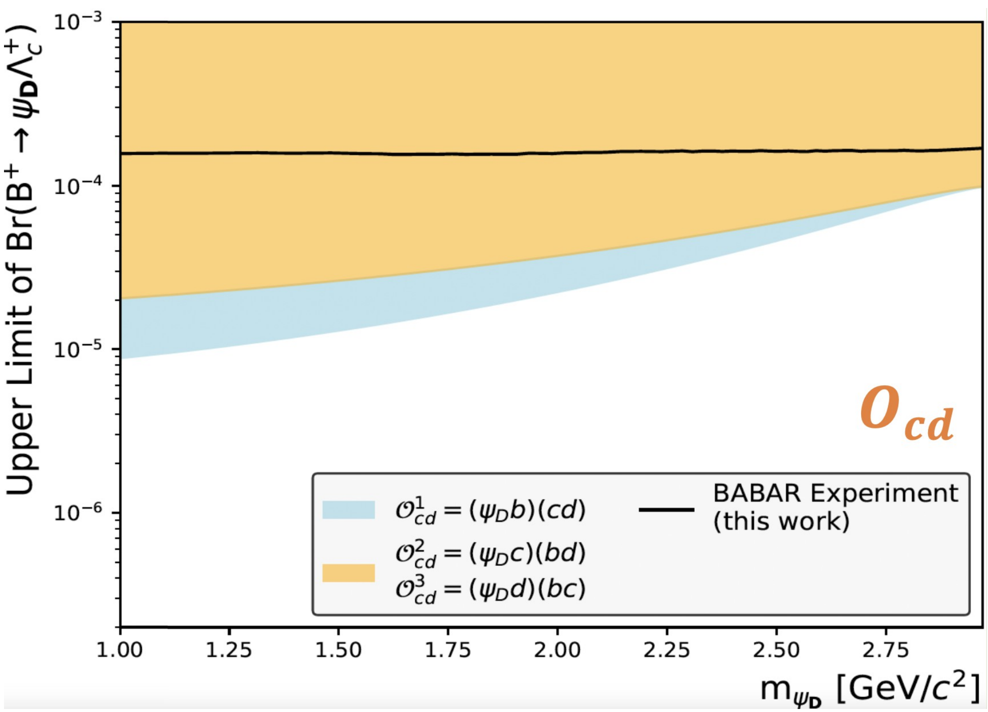
- Three events close to signal region were examined and found to be consistent with $q\bar{q}$ continuum production of Λ_c^+

Results

Phys. Rev. D 111 (2025) 3, L031101

Signal significance determined as a function of ψ_D mass by scanning across $m(\psi_D)$ in steps of $\sigma(m(\psi_D))$

- 4-vector of ψ_D obtained from inferred B_{sig} kinematics in range
  $0.94 < m(\psi_D) < 2.99$ GeV/c^2
- $m(\psi_D)$ resolution varies from 60 – 20 MeV/c^2 as a function of mass



Branching fraction limit @ 90% CL
$B(B^+ \to \Lambda_c^+ \psi_D) < (1.6 - 1.7) \times 10^{-4}$
over kinematically accessible mass range

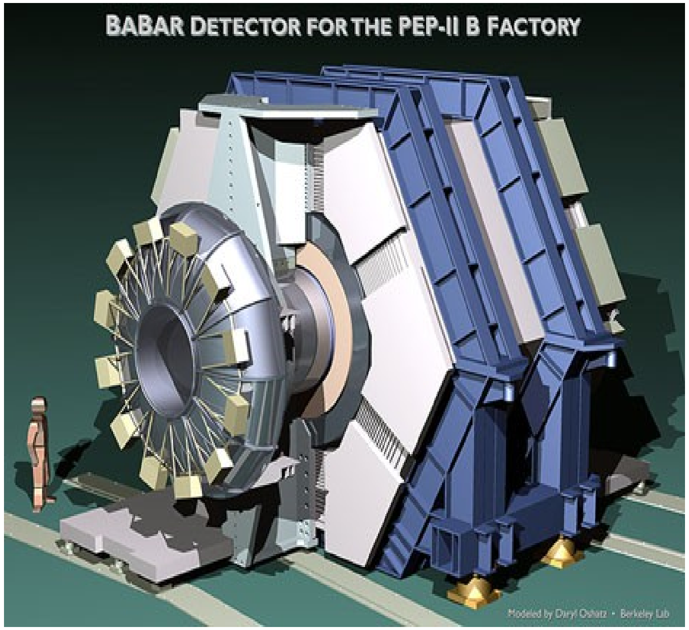
Exclusive $B^+ \to \Lambda_c^+ \psi_D$ branching fraction expected to range from 10% - 100% of inclusive $B(B^+ \to \Lambda_c^+ \psi_D X)$, depending on mass

- Substantial new constraint on model parameter space for O_{cd} operator

Conclusion

Clean B factory environment is extremely well suited to studies of B decays with missing energy

- New measurement of form factors in $B \rightarrow D l \nu$ Phys. Rev. D 110 (2024) 3, 032018
- New results for $B^+ \rightarrow \Lambda_c^+ \psi_D$ search constrain B-baryogenesis operator $O_{cd} = \psi bcd$, further restricting the model space from two 2023 *BABAR* papers probing operators $O_{ud} = \psi bud$ and $O_{us} = \psi bus$



$B^+ \rightarrow p + \psi_D$ Phys. Rev. Lett. 131 (2023) 20, 201801

$B^0 \rightarrow \Lambda + \psi_D$ Phys. Rev. D 107 (2023) 9, 092001

$B^+ \rightarrow \Lambda_c^+ + \psi_D$ Phys. Rev. D 111 (2025) 3, L031101

Unique *BABAR* data set remains productive more than 15 years after the end of data taking!

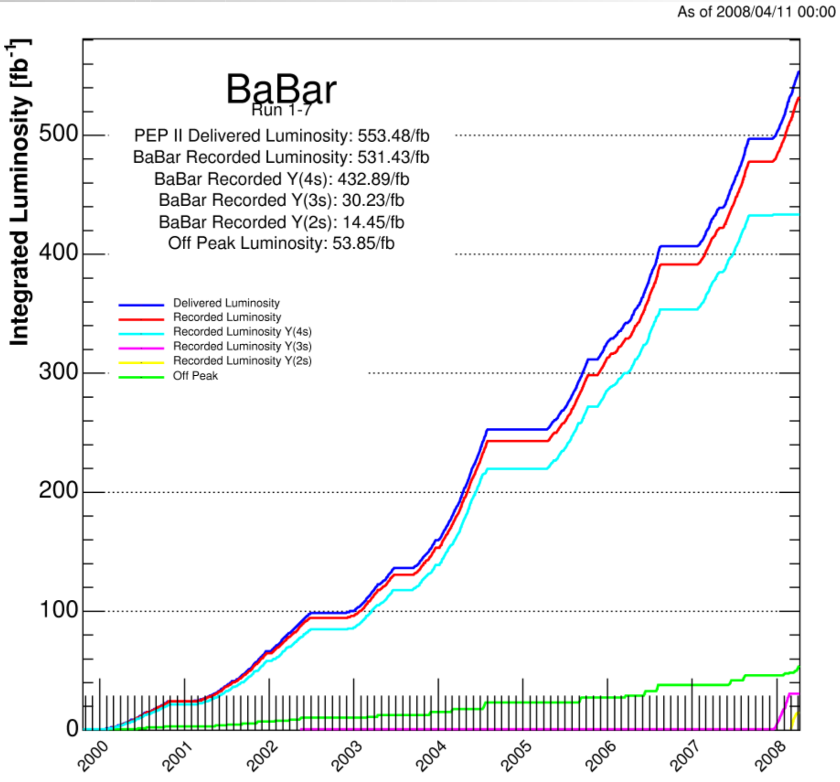
Extra Material

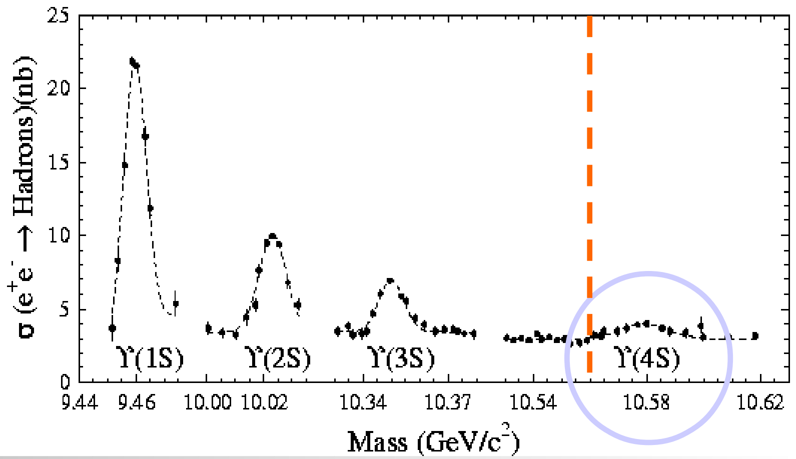
BABAR data sets

BABAR collected data from 1999-2008

- 432 fb^{-1} $\Upsilon(4S)$ "onpeak"
  (~470 x 10^6 BB pairs)
- 53 fb^{-1} non-resonant "offpeak"
  - collected ~40MeV below $\Upsilon(4S)$ peak
- Samples of "narrow Υ" events collected during last few months of running:
  - 122 x 10^6 $\Upsilon(3S)$ decays
  - 99 x 10^6 $\Upsilon(2S)$ decays

Process	Cross section (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





$B \to Dl\nu$ signal yields

Signal events identified using unbinned "local" fits to data to determine signal event weights

- fit 50 "nearest" events in phase space to obtain a signal quality factor

$$g_{ij}^2 = \sum_{k=1}^{n} \left[\frac{\phi_k^i - \phi_k^j}{r_k} \right]^2$$

with n=2: $\Phi_i = q^2$, $\cos\theta_l$

r_k is the range of q^2 and $\cos\theta_l$

$$Q_i = \frac{\mathcal{S}_i(U_i)}{\mathcal{S}_i(U_i) + \mathcal{B}_i(U_i)}$$

- total yields are obtained by summing the event weights

$$\mathcal{Y} = \sum_i Q_i$$

- fit configurations are varied to consider systematics

Approximately 5500 signal events are retained for amplitude analysis

ℓ^-	D	decay mode	mode	N_{sig}	N_{bkgd}
e^-	D^0	$K^-\pi^+$	0	539	63
		$K^-\pi^+\pi^0$	1	813	196
		$K^-\pi^+\pi^-\pi^+$	2	550	82
e^-	D^+	$K^-\pi^+\pi^+$	3	721	41
		$K^-\pi^+\pi^+\pi^0$	4	204	120
μ^-	D^0	$K^-\pi^+$	5	433	64
		$K^-\pi^+\pi^0$	6	798	221
		$K^-\pi^+\pi^-\pi^+$	7	608	84
μ^-	D^+	$K^-\pi^+\pi^+$	8	665	55
		$K^-\pi^+\pi^+\pi^0$	9	233	134
			Total	5563	1061

Form factor results

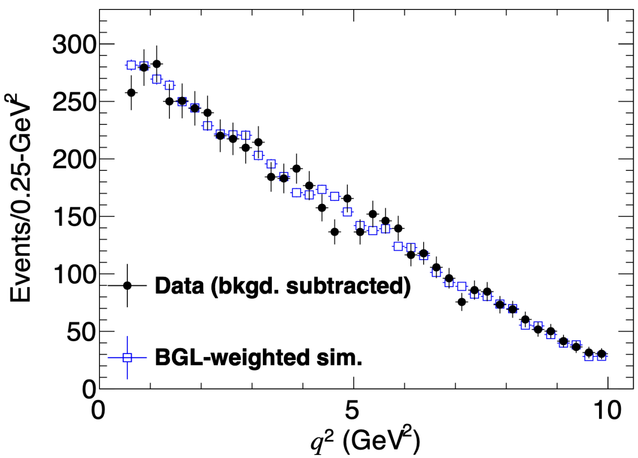
BGL parametrization:

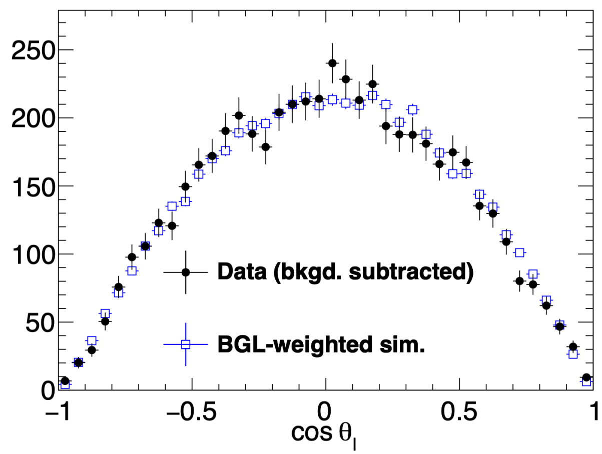
- Expansion variable: $z(w) = (\sqrt{w+1} - \sqrt{2})/(\sqrt{w+1} + \sqrt{2})$

$$f_i(z) = \frac{1}{P_i(z)\phi_i(z)} \sum_{n=0}^{N} a_n^i z^n, \quad i \in \{+, 0\} \quad N = 2, 3$$

a^i_n free parameters
$Pi(z)$ Blaschke factors
$\Phi_i(z)$ non-perturbative functions

BGL $N=2$	value
$\lvert V_{cb}\rvert \times 10^3$	41.09 ± 1.16
$a_0^{f+} \times 10$	0.126 ± 0.001
a_1^{f+}	-0.096 ± 0.003
a_2^{f+}	0.352 ± 0.053
$a_1^{f_0}$	-0.059 ± 0.003
$a_2^{f_0}$	0.155 ± 0.049





External inputs:

$$\mathbb{L}_{\text{total}}(\vec{x}) = -2\ln\mathcal{L}(\vec{x})|_{BABAR} + \chi^2(\vec{x})|_{\text{Belle}} + \chi^2(\vec{x})|_{\text{FNAL/MILC}}$$

R. Glattauer et al. (Belle Collaboration), Phys. Rev. D 93, 032006 (2016), arXiv:1510.03657 [hep-ex].

J. A. Bailey et al. (FNAL/MILC Collaboration), Phys. Rev. D 92, 034506 (2015), arXiv:1503.07237 [hep-lat].

CLN form based on HQET and takes into account QCD dispersion relations

- Only two parameters, normalization and slope:

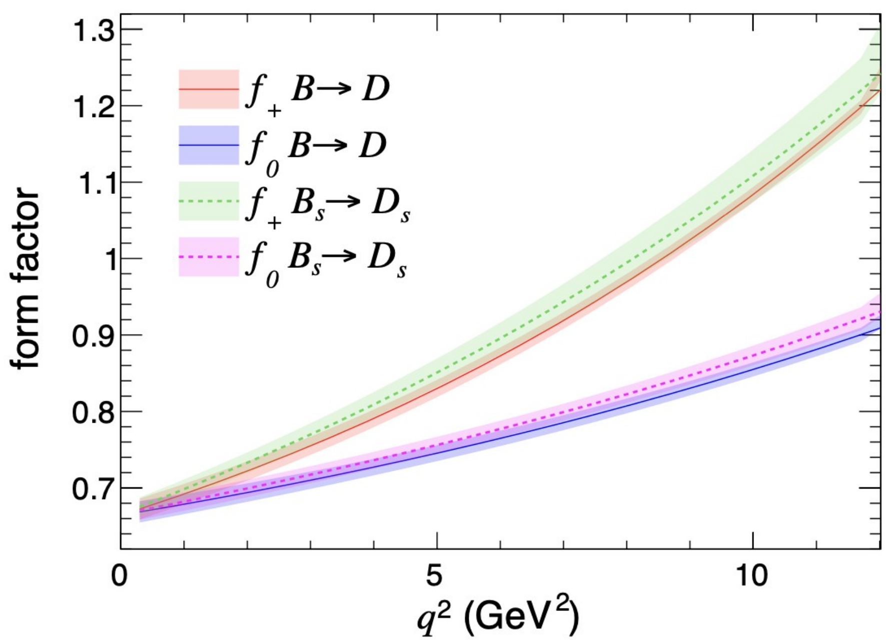
$$\mathcal{G}(w) = \mathcal{G}(1)(1 - 8\rho_D^2 z(w) + (51\rho_D^2 - 10)z(w)^2 - (252\rho_D^2 - 84)z(w)^3)$$

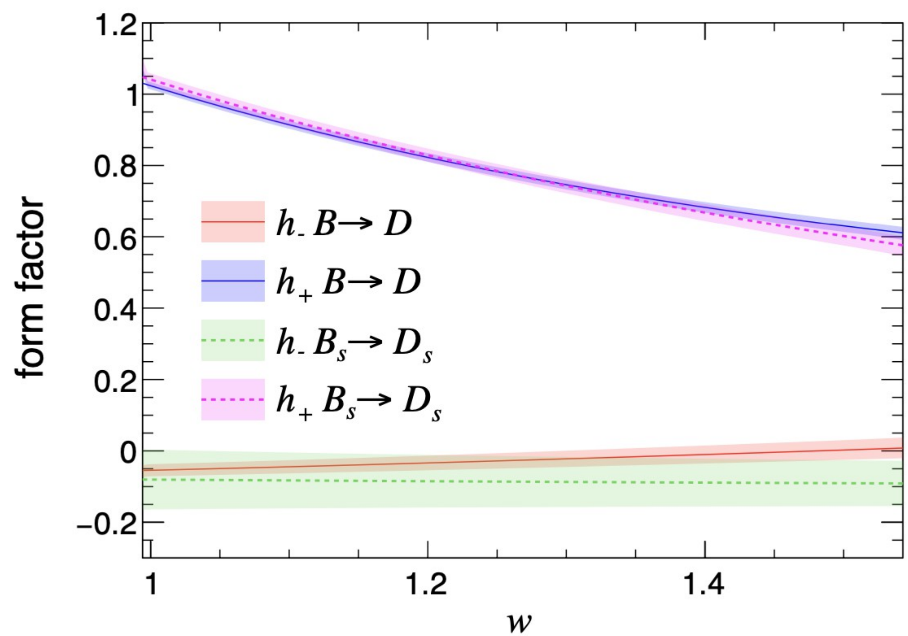
CLN	value
$\lvert V_{cb}\rvert \times 10^3$	40.90 ± 1.14
$\mathcal{G}(1)$	1.056 ± 0.008
ρ_D^2	1.155 ± 0.023

Form factor results

Fairly good consistency seen between $B \to D$ form factor measurements and $B_s \to D_s$ heavy-HISQ lattice calculations by HPQCD collaboration PRD 101, 074513 (2020)

- Expected if SU(3) is respected

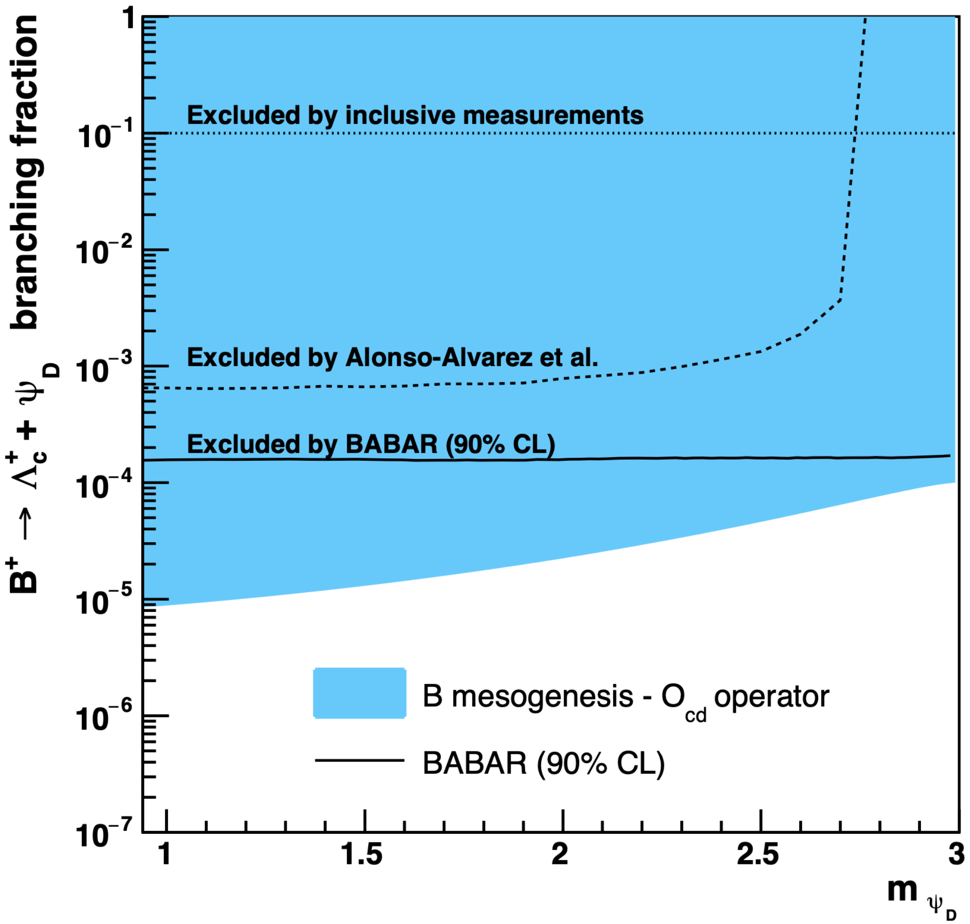




$$f_+(q^2) = \frac{1}{2\sqrt{r}}\left((1+r)h_+(w) - (1-r)h_-(w)\right)$$

$$f_0(q^2) = \sqrt{r}\left(\frac{w+1}{1+r}h_+(w) - \frac{w-1}{1-r}h_-(w)\right)$$

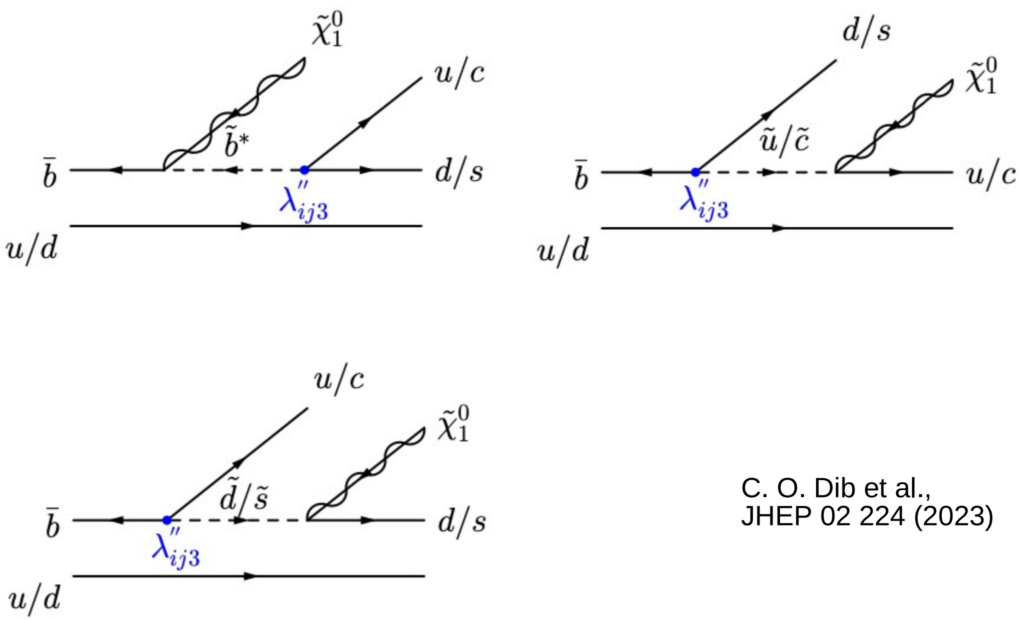
$B^+ \rightarrow \psi_D + \Lambda_c^+$



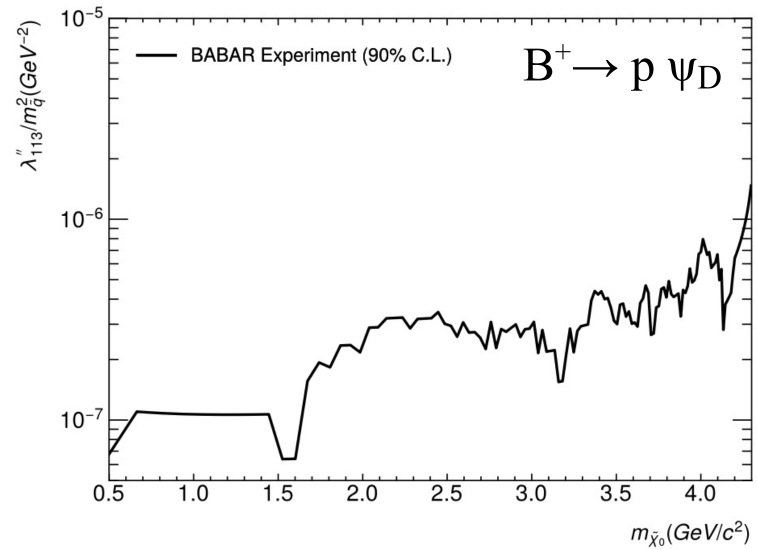
RPV SUSY interpretation

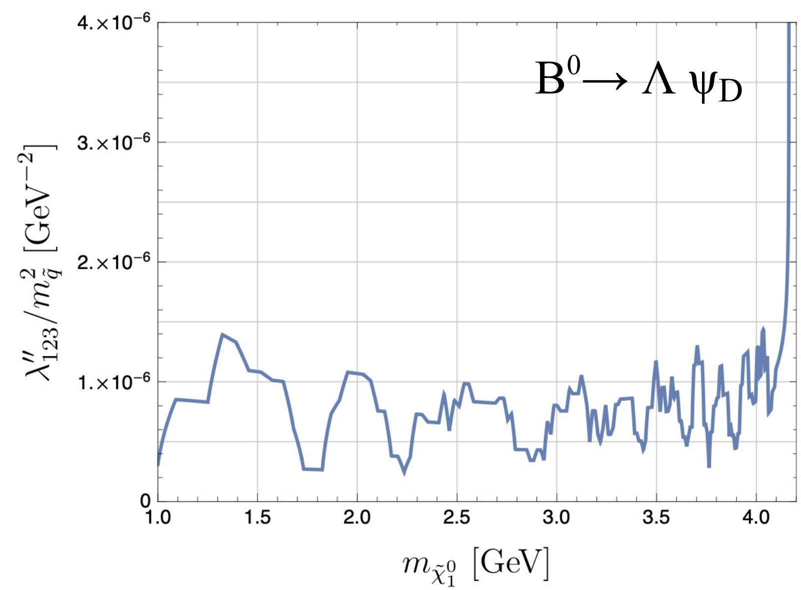
$B \to \mathcal{B}$ + (missing energy) signature can also be generically interpreted in other new physics models

- e.g. missing neutralino in $B \to \mathcal{B} + \chi^0$ in RPV SUSY model



C. O. Dib et al.,
JHEP 02 224 (2023)

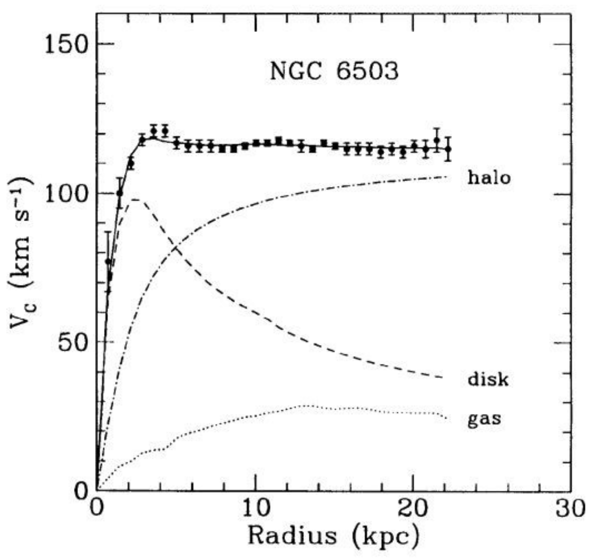




- limits on RPV coupling λ''_{113} and λ''_{123}

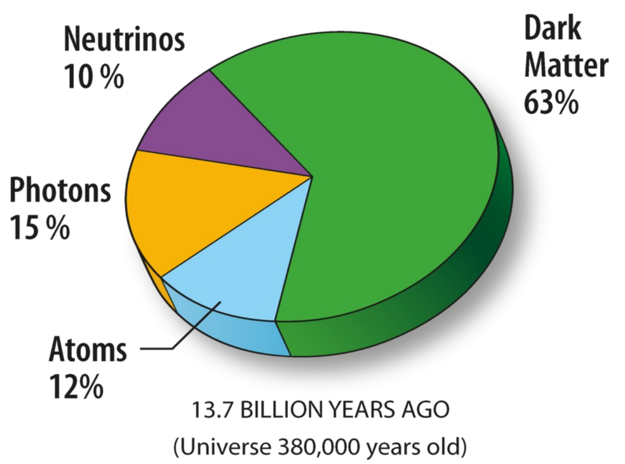
Dark matter and the BAU

The particle physics Standard Model has no explanation for two of the biggest problems in cosmology



Baryon Asymmetry of the Universe (BAU)

- Sakharov conditions: **Sakharov, A D, JETP 5 (1967) 24**
  - Baryon number violation
  - C and CP violation
  - Deviation from thermal equilibrium

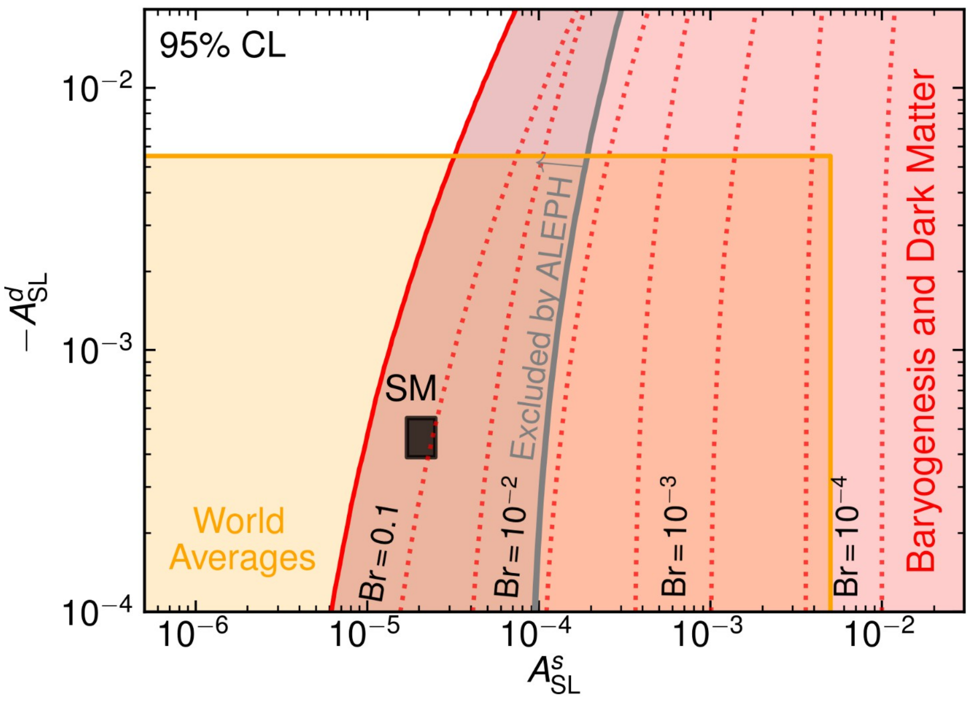


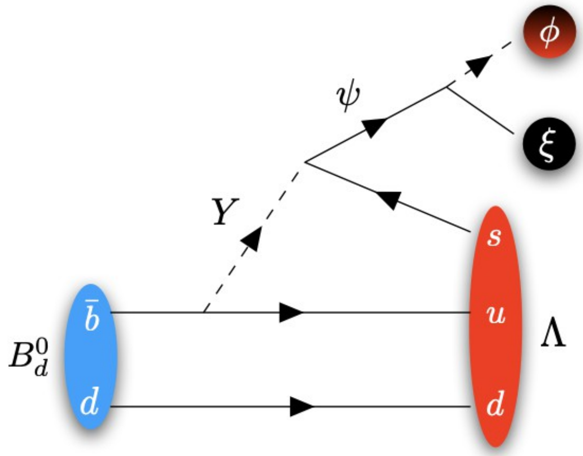
Nature of dark matter:

- Astronomical evidence for dark matter is overwhelming, all measurements to date are gravitational in nature
- The majority of the matter in the universe has an unknown composition

Dark matter and the BAU

- Baryon number asymmetry depends on the level of CP violation in B mixing, and on the branching fraction to dark baryons
- Dark baryon mass must be large enough to protect against proton decay but small enough to permit production from B meson decays





$$Y_{\mathcal{B}} \simeq 8.7 \times 10^{-11} \frac{\text{Br}(B \to \psi\, \mathcal{B}\, \mathcal{M})}{10^{-3}} \sum_q \alpha_q \frac{A^q_{\text{SL}}}{10^{-3}}$$

- Dark baryon must decay rapidly into other dark sector particles (i.e. astronomical dark matter), to avoid decay to SM particles

Dark sector and BSM @

$B^+ \to \Lambda_c^+ \psi_D$	Phys. Rev. D 111 (2025) 3, L031101
$B^+ \to p\, \psi_D$	Phys. Rev. Lett. 131, 201801 (2023)
$B^0 \to \Lambda\, \psi_D$	Phys. Rev. D 107, 092001 (2023)

Extensive *BABAR* program of searches for physics beyond the Standard Model, and dark sector in particular

Darkonium
Phys. Rev. Lett. 128 021802 (2022)

Axion-like particles
Phys. Rev. Lett. 128, 131802 (2022).

Dark Leptophilic scalar
Phys. Rev. Lett. 125,181801 (2020).

Six quark dark matter
Phys. Rev. Lett. 122, 072002 (2019).

Dark photon
Phys. Rev. Lett. 113, 201801 (2014);
Phys. Rev. Lett. 119, 131804 (2017).

Muonic dark force
Phys. Rev. D 94, 011102 (2016).

Dark Higgs bosons
Phys. Rev. Lett. 108, 211801 (2012)

Search for heavy neutral leptons in τ decays
Phys. Rev. D 107, 5, 052009 (2023)

Search for LFV in $\Upsilon(3S) \to e\, \mu$
Phys. Rev. Lett. 128, 091804 (2022)

Lepton universality in $\Upsilon(3S)$ decays
Phys. Rev. Lett .125, 241801 (2020)

Rare and forbidden D decays
Phys. Rev. Lett. 124, 071802 (2020)

Search for LFV in $D^0 \to X^0 e^+ \mu^-$
Phys. Rev. D 101, 112003 (2020)

Dark sectors

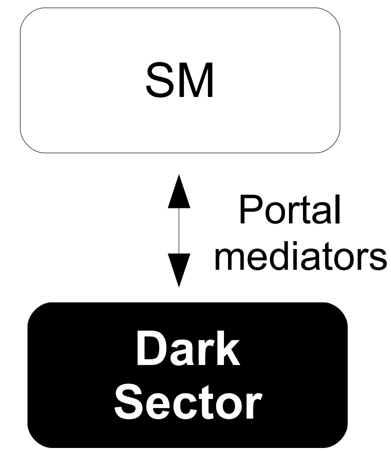
Dark matter may carry charges for non-SM gauge interactions, possibly acquiring mass via dark sector Higgs etc.

- Effective Field Theory (EFT) provides a number of "portals" to access this dark sector:

$$\mathcal{L} = \sum_{n=k+l-4} \frac{c_n}{\Lambda^n} \mathcal{O}_k^{(\mathrm{SM})} \mathcal{O}_l^{(\mathrm{med})} = \mathcal{L}_{\mathrm{portals}} + \mathcal{O}\left(\frac{1}{\Lambda}\right)$$

$$= -\frac{\epsilon}{2} B^{\mu\nu} A'_{\mu\nu} - H^\dagger H (AS + \lambda S^2) - Y_N^{ij} \bar{L}_i H N_j + \mathcal{O}\left(\frac{1}{\Lambda}\right)$$

Vector portal — Higgs portal — Neutrino portal



Dark sector can be probed via mixing of the portal mediators with SM particles

At *BABAR*:

- Production of on-shell dark bosons via $e^+e^- \to \gamma Z'$ "**radiative**" and $e^+e^- \to f\, f\, Z'$ "**-strahlung**" processes
- Light dark sector particles can be produced in **decay**s of B and D mesons

Some *BABAR* dark sector results:

Dark Leptophilic scalar:	Phys. Rev. Lett. 125,181801 (2020)
Six quark dark matter:	Phys. Rev. Lett. 122, 072002 (2019)
Dark photon:	Phys. Rev. Lett. 119, 131804 (2017); Phys. Rev. Lett. 113, 201801 (2014)
Muonic dark force:	Phys. Rev. D 94, 011102 (2016)
Dark Higgs bosons:	Phys. Rev. Lett. 108, 211801 (2012)