THE UNIVERSITY OF BRITISH COLUMBIA

INSTITUTE OF PARTICLE PHYSICS

Searches for baryogenesis and dark matter at BaBar

Christopher Hearty
U. British Columbia / IPP
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On behalf of the BaBar collaboration

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Elor, Escudero, Nelson, PRD 99, 035031 (2019)
Alonso-Álvarez, Elor, Escudero, PRD 104, 035028 (2021)

Baryogenesis and dark matter from B mesons

- Matter in the universe is dominated by dark matter.
- The universe is composed of baryons, not anti-baryons.
- Perhaps these two issues are related
  ⇒ meson baryogenesis.

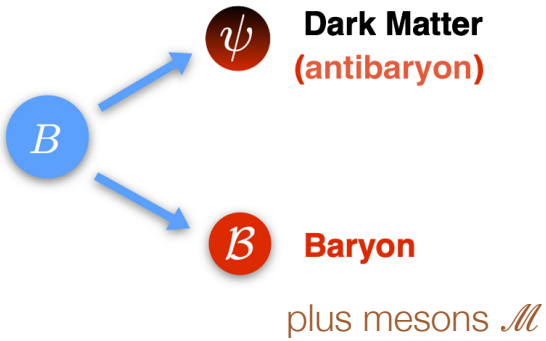
Neutral B meson baryogensis

- In this model, a heavy scalar decays to (GeV) B mesons when the universe is at (1—10's) MeV temperature.

- B mesons then decay to a dark baryon and a standard model baryon (plus mesons).

- CP violation in B^0 mixing:
  - net baryon excess in visible sector
  - net anti-baryon excess in dark sector

- But baryon number is conserved overall.

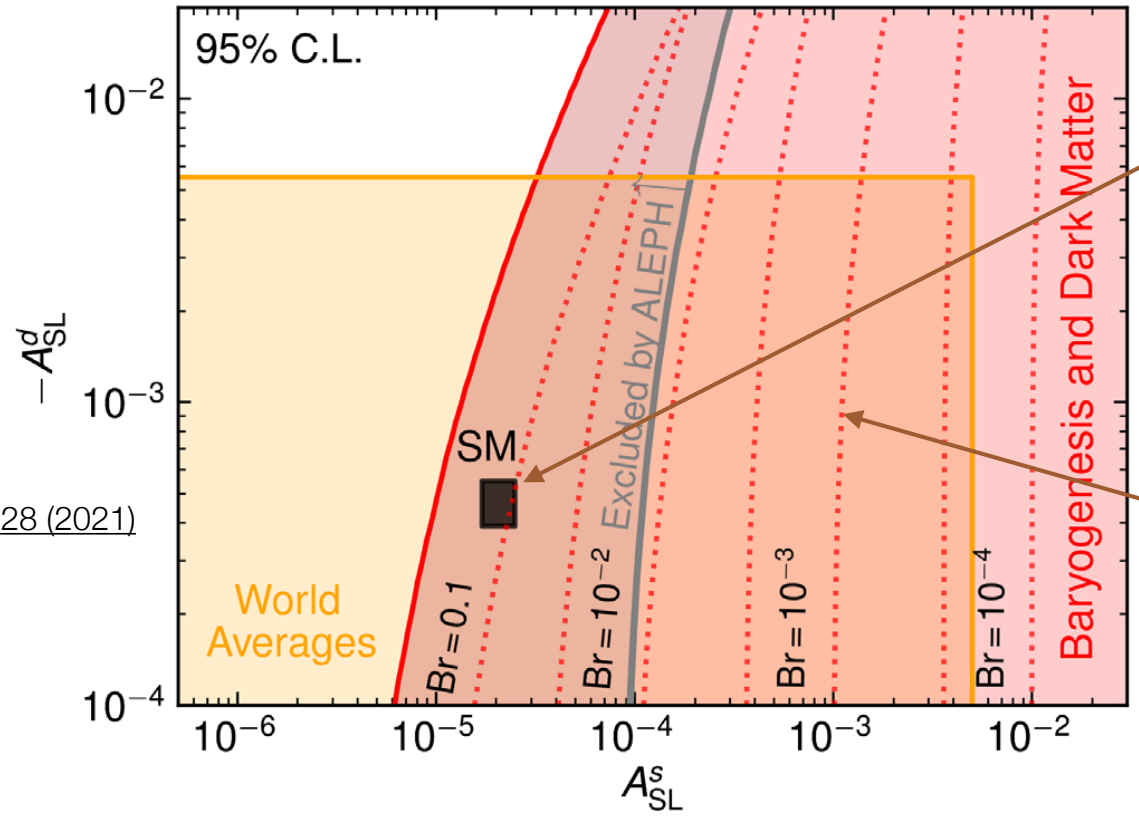


Reproducing the observed baryon number asymmetry

- Asymmetry depends on branching fraction to dark baryons, and on level of CP violation in neutral B mixing.

- Use the asymmetry in semileptonic $B^0_{d/s}$ decays A^q_{SL}:
  - e.g., $B^0 \to D^- \mu^+ \nu_\mu$, single amplitude (in SM), tree level, so CP violation is entirely from B^0 mixing.
  - could be additional CP violation in the dark sector.

- Need $A^{s,d}_{SL} \times B_r(B^0 \to \psi_D \mathscr{B}\mathscr{M}) > 10^{-6}$.



PRD 104, 035028 (2021)

for SM predicted CPV, would need 10% branching fraction to dark baryons

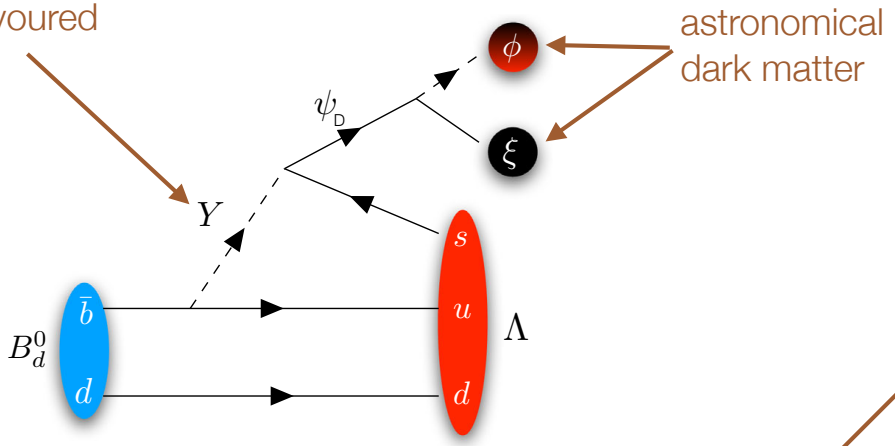
10^{-3} asymmetry and 10^{-3} BF also works

- The mass of the dark baryon ψ_D must be large enough that the proton can't decay, and small enough to be produced in B decay.

- It must decay rapidly to other dark sector particles, so that it doesn't decay to protons (and wash out asymmetry).

Decay of B mesons to dark baryons

- Decay is mediated by a heavy (TeV) flavoured scalar Y. Four different variants.



Various operators (Y) are possible

Operator	Initial state	Final state	ΔM [MeV]
ψbus	B_d	$\psi + \Lambda(usd)$	4163.95
	B_s	$\psi + \Xi^0(uss)$	4025.03
	B^+	$\psi + \Sigma^+(uus)$	4089.95
	Λ_b	$\bar{\psi} + K^0$	5121.9
ψbud	B_d	$\psi + n(udd)$	4340.07
	B_s	$\psi + \Lambda(uds)$	4251.21
	B^+	$\psi + p(duu)$	4341.05
	Λ_b	$\bar{\psi} + \pi^0$	5484.5
ψbcs	B_d	$\psi + \Xi_c^0(csd)$	2807.76
	B_s	$\psi + \Omega_c(css)$	2671.69
	B^+	$\psi + \Xi_c^+(csu)$	2810.36
	Λ_b	$\bar{\psi} + D^- + K^+$	3256.2
ψbcd	B_d	$\psi + \Lambda_c + \pi^-(cdd)$	2853.60
	B_s	$\psi + \Xi_c^0(cds)$	2895.02
	B^+	$\psi + \Lambda_c(dcu)$	2992.86
	Λ_b	$\bar{\psi} + \bar{D}^0$	3754.7

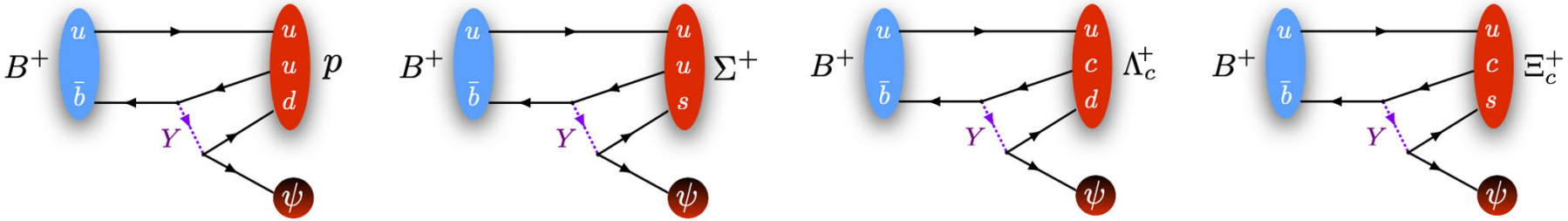
BaBar searches

not yet

Y induces $b \to u$ with s

PRD 99, 035031 (2019)

- The baryon asymmetry is produced by B^0 decay, but the same mechanism produces charged B decays.

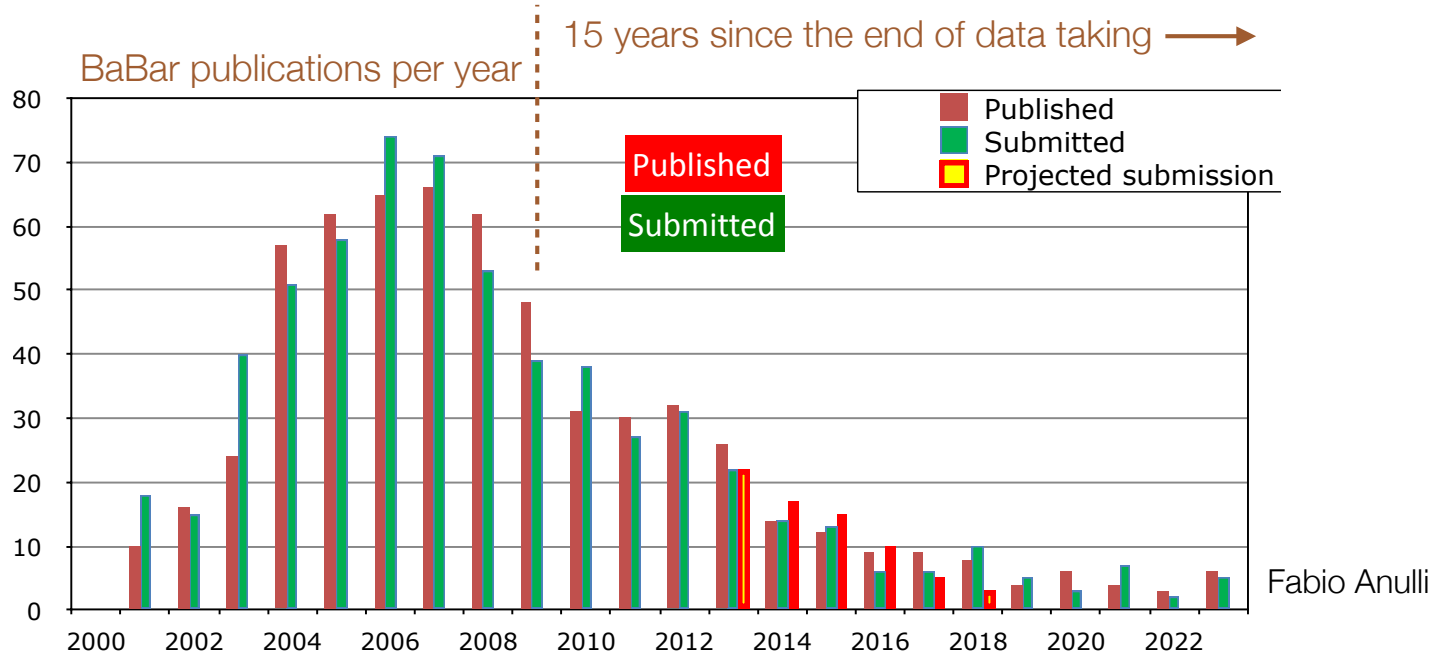


PRD 104, 035028 (2021)

BaBar: searches for baryogenesis and dark matter

- BaBar operated at the PEP-II e^+e^- collider at SLAC from 1999–2009.

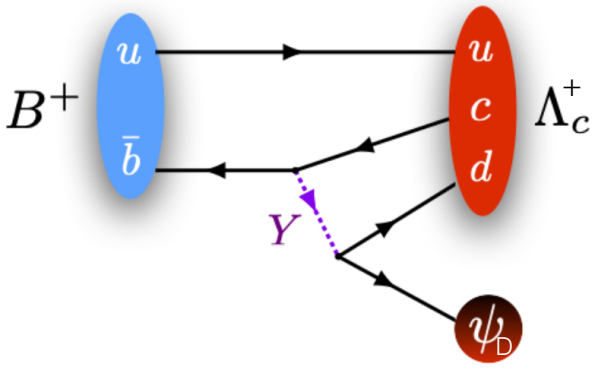
- 431 fb^{-1} at the Y(4S), plus Y(3S) and Y(2S), plus continuum.



Fabio Anulli

Search for $B^+ \to \Lambda_c^+ \psi_D$

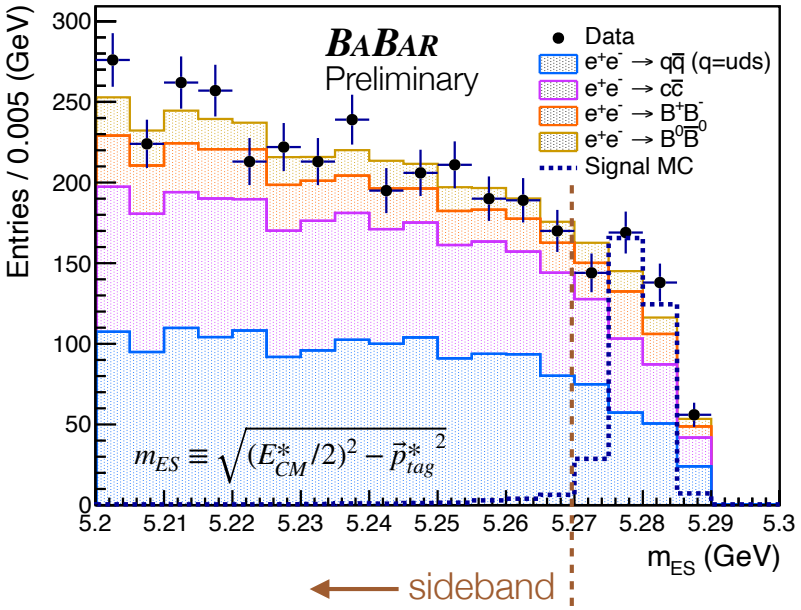
- Signature is a B^+ decaying to a Λ_c^+ and nothing else. Recoil mass = $m(\psi_D)$.



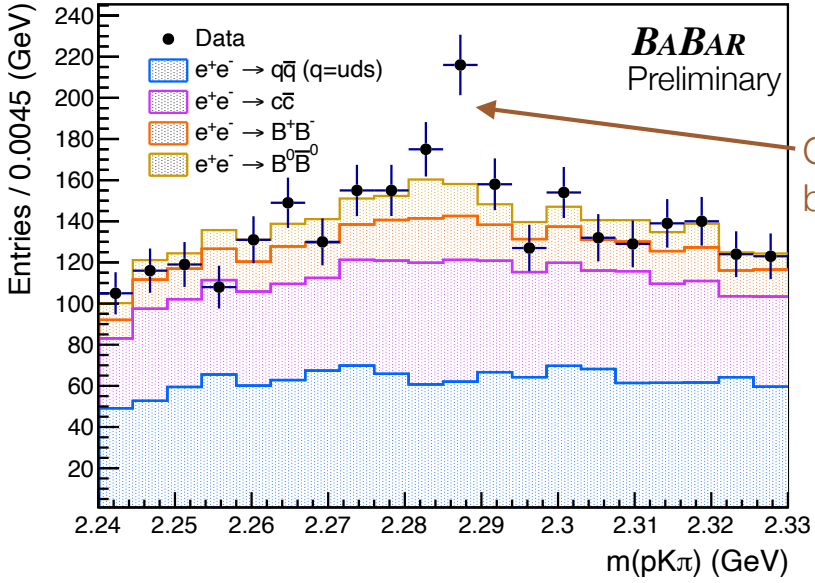
- Branching fraction for $\Lambda_c^+ \psi_D$ is 10—100% of $\Lambda_c^+ \psi_D X$, depending on mass.

- Recall that $\Upsilon(4S) \to B\bar{B}$. Fully reconstruct the other B in the event, using J/ψ or charm meson plus other particles.
  - $\mathcal{O}(0.1)\,\%$ reconstruction efficiency.
  - event must have zero net charge.

energy-substituted mass of tag B for events with exactly 3 other good tracks

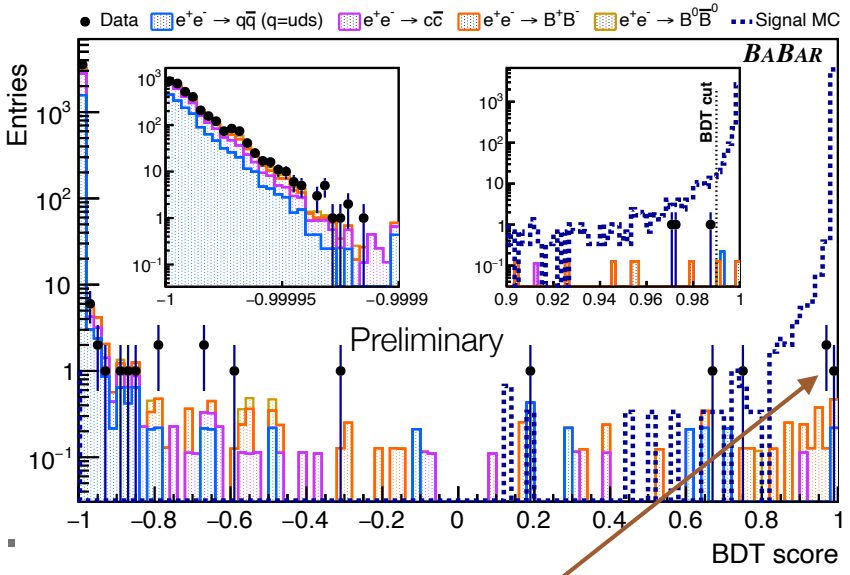


3-track mass in sideband (continuum)



Clear Λ_c^+ in data but not MC

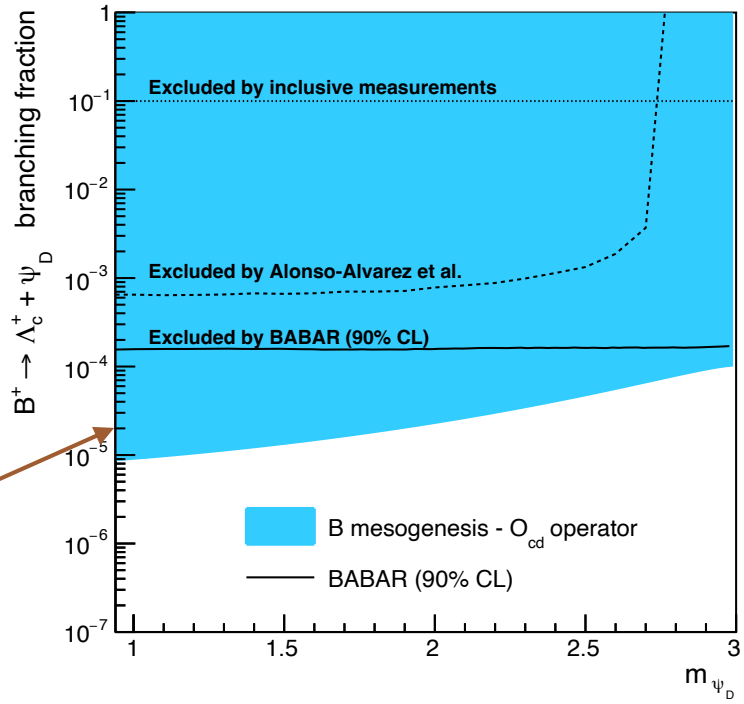
- Boosted decision tree using event shape and kinematics reduces expected background to <1 event. None observed.
- Overall signal efficiency ~6×10^{-5}.



3 events close to signal region

- Resulting limit: $\mathcal{B}(B^+ \to \Lambda_c^+ \psi_D) < (1.6 - 1.7) \times 10^{-4}$ for $0.94 < m_{\psi_D} < 2.99$ GeV/c^2.

- Strongly constrains parameter space that would explain the observed baryon asymmetry.

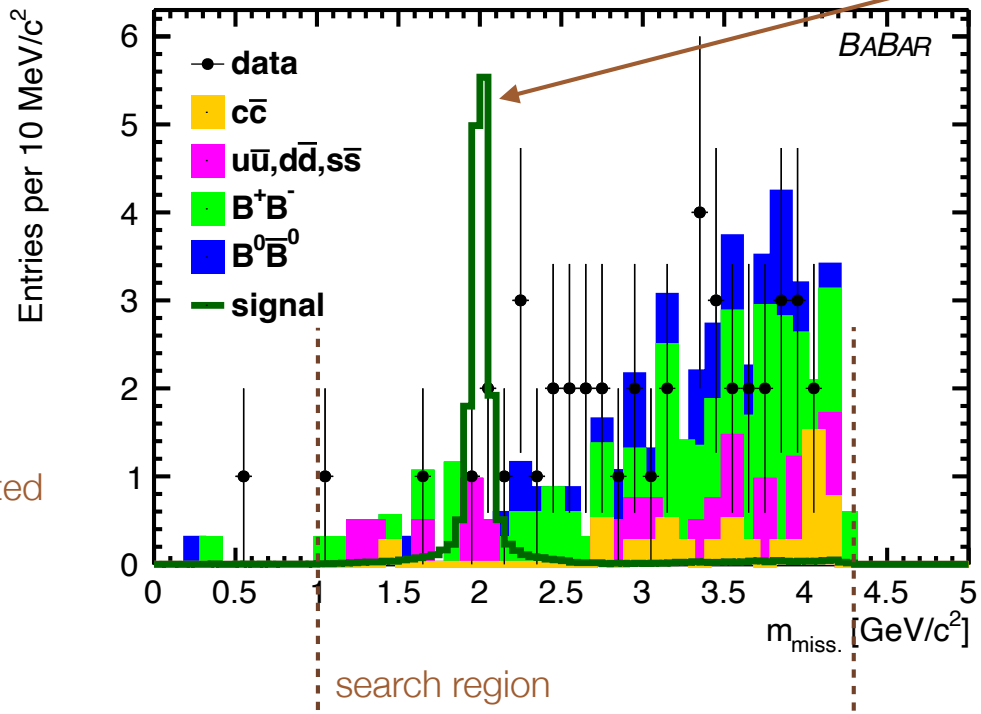


Result uses 399 fb^{-1} of data
= 2×10^8 B$^+$B$^-$ events ;
32 fb^{-1} used to optimize the analysis (not blinded) then discarded

This is a limit on the 2-body decay; slide 5 is for inclusive B→ ψ_DX

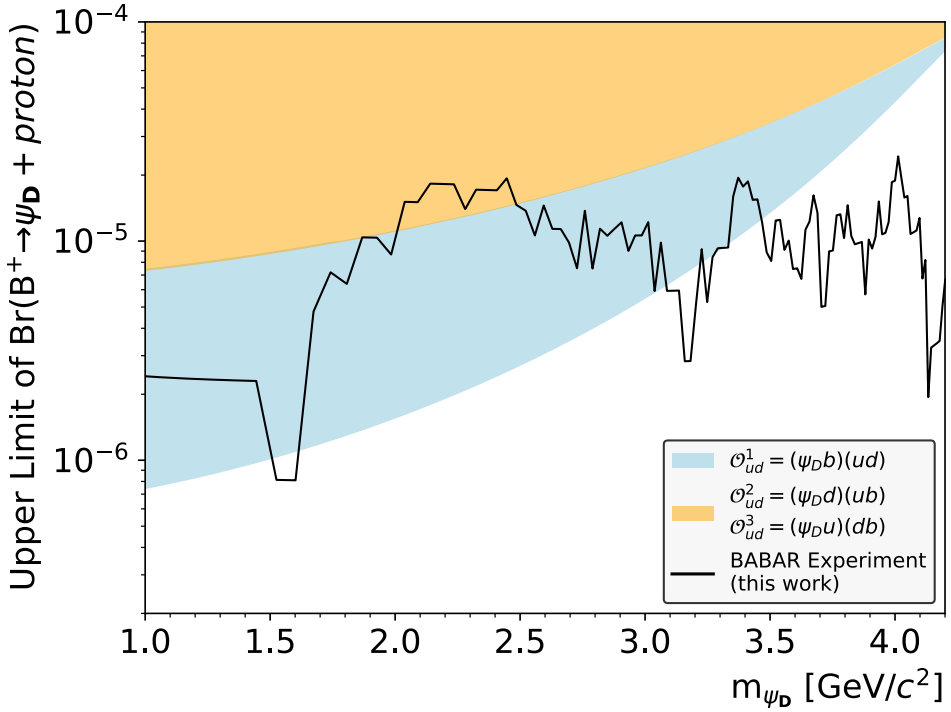
Search for $B^+ \to p\psi_D$

- Search for the proton final state is similar, except exactly 1 track is required, which must be identified as a proton.
- Signal efficiency (6—15)×10^{-4}.



46 events observed, consistent with 48 expected from simulation

- Strong constraints on relevant parameter space.



Summary

- Neutral B meson baryogenesis looks to explain both dark matter abundance and the apparent baryon number asymmetry. Predicts striking signatures in B decays.

- BaBar has searched for three final states, corresponding to three of the four possible operators, strongly constraining the relevant parameter space.
  - see reference above for the third one, $\Lambda\psi_D$.

- Variants on this model (e.g. *mesogenesis with a morphing mediator*, 2408.12647) allow for smaller branching fraction ⇒ Belle II.