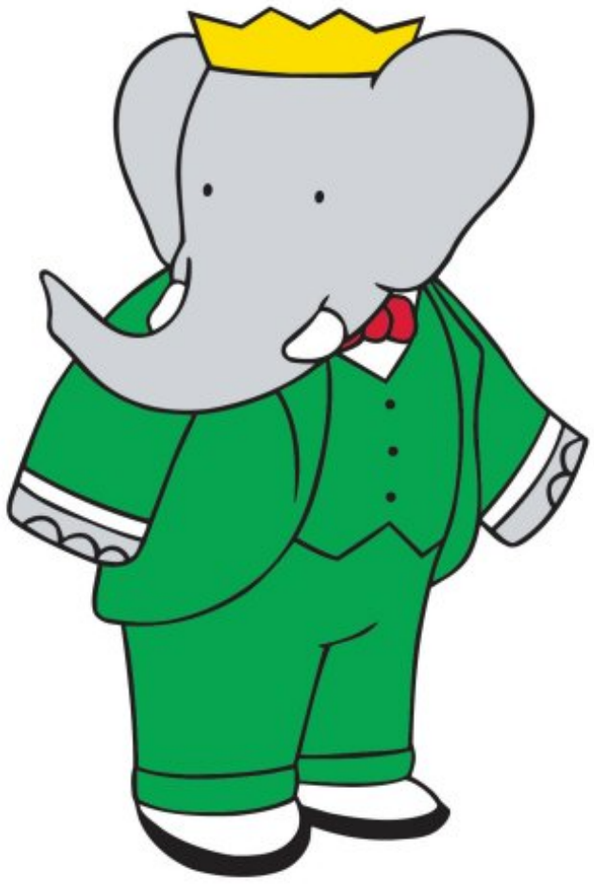
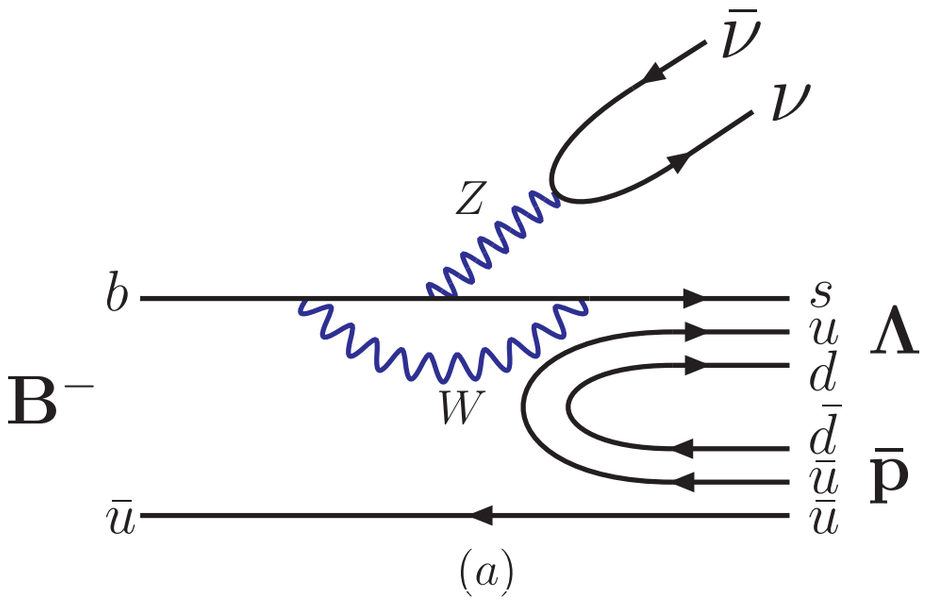
Search for $B^- \to \Lambda \bar{p} \nu \bar{\nu}$ at BABAR

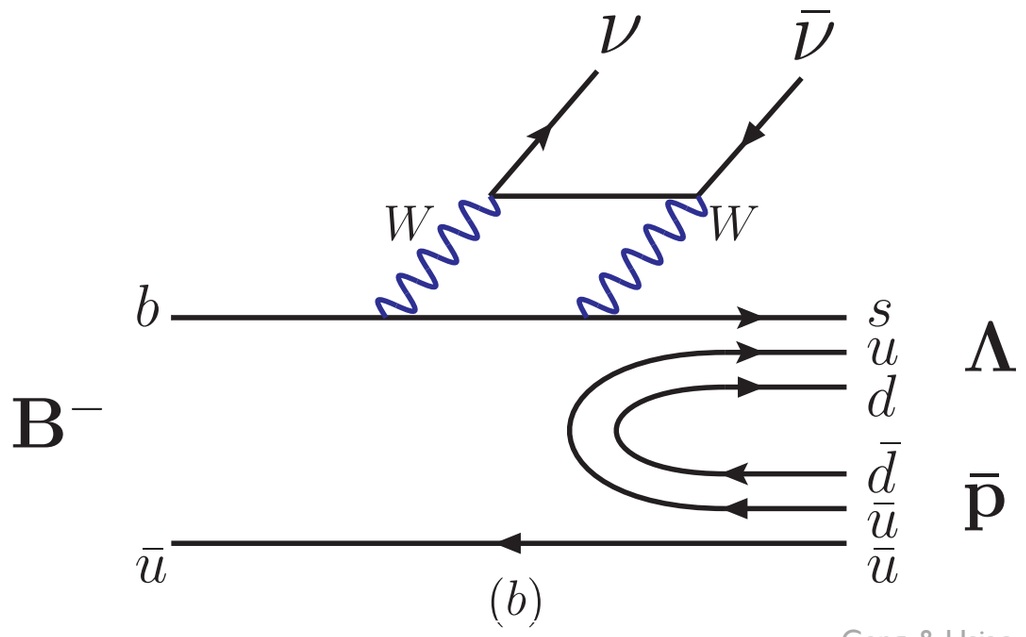


Robert Seddon (McGill University)
on behalf of the
BABAR Collaboration

Lake Louise Winter Institute
24 February 2018

$B^- \to \Lambda \bar{p} \nu \bar{\nu}$ - details and motivation





Geng, & Hsiao

C.Q. Geng, Y.K. Hsiao.
Phys. Rev. D 85 (2012) 094019

Predict $\mathcal{B}(B^- \to \Lambda \bar{p} \nu \bar{\nu})$ = (7.9 ± 1.9) x 10^{-7}

- Rare decay (suppressed by the standard model)
- New physics potentially hiding in loops - will affect branching fraction
- Amenable to further study: angular asymmetries, T-odd observables *etc.*

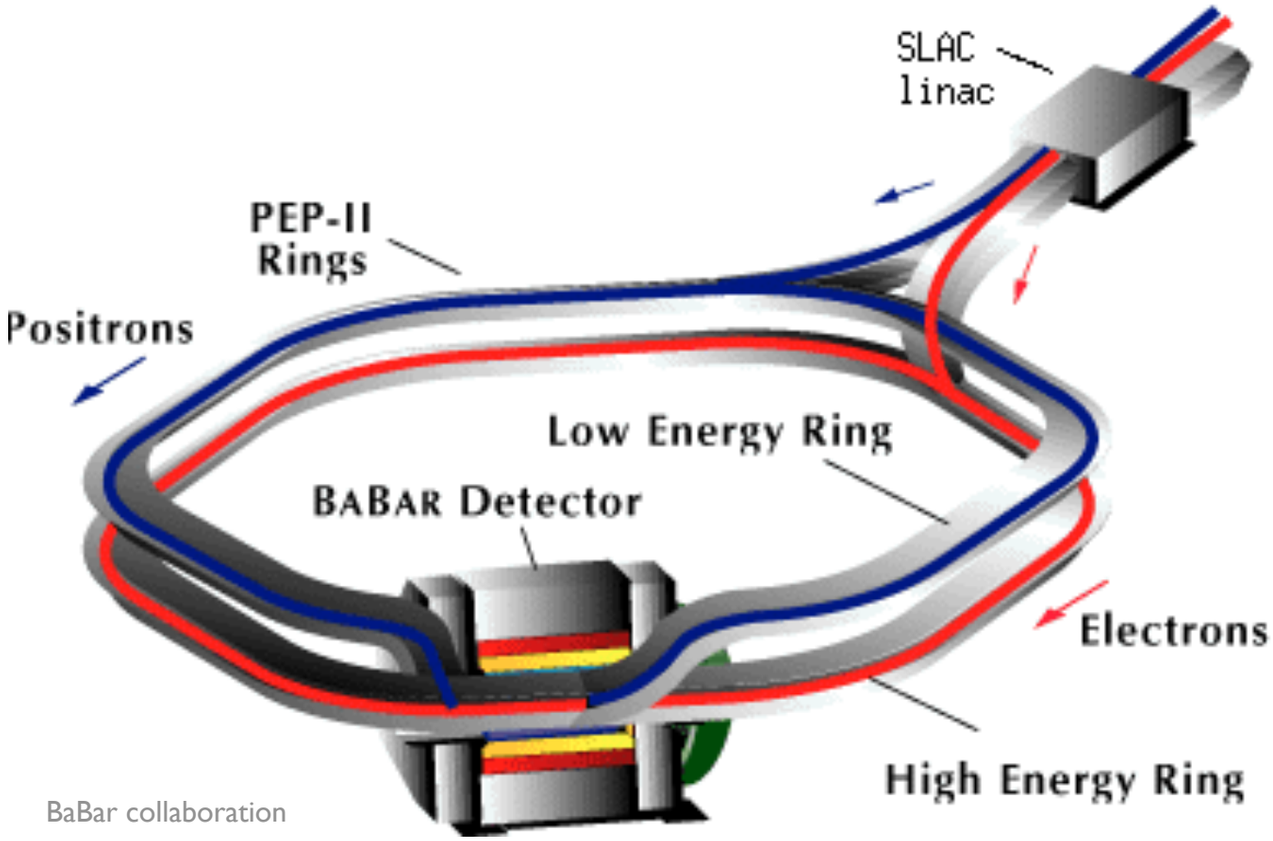
$B^- \to K^- \nu \bar{\nu}$

- Predicted: (4.5 ± 0.7) x 10^{-6} (J. High Energy Phys. 2009, 022)
- Measured:

BABAR (hadronic): <3.7 x 10^{-5} (Phys. Rev. D 87 (2013) 112005)
BABAR (semi-leptonic): <1.3 x 10^{-5} (Phys. Rev. D 82 (2010) 112002)
Belle (hadronic): <5.5 x 10^{-5} (Phys. Rev. D 87 (2013) 11110)

The BABAR experiment - PEP-II collider

PEP-II: Located at the SLAC National Accelerator Laboratory, California. Provides electrons and positrons for collision inside BABAR detector.



BaBar collaboration

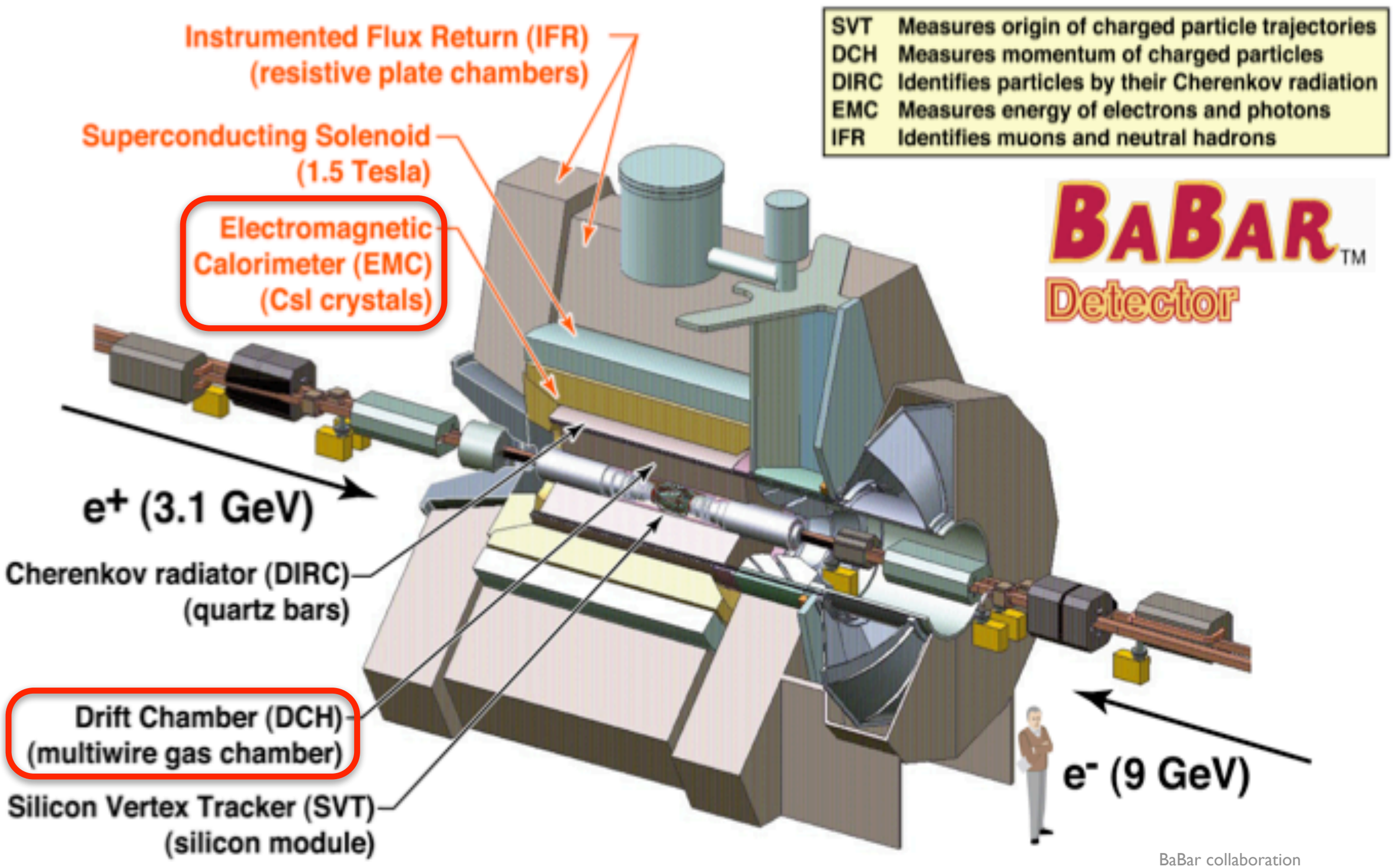
- High energy ring - 9.0 GeV electrons
- Low energy ring - 3.1 GeV positrons

- Collide at CoM energy 10.58 GeV - mass of the $\Upsilon(4S)$ resonance ($b\bar{b}$ quark-antiquark pair)

- $\Upsilon(4S)$ decays 96% to $B\bar{B}$ (B^+B^- or $B^0\bar{B}^0$) - "B factory".

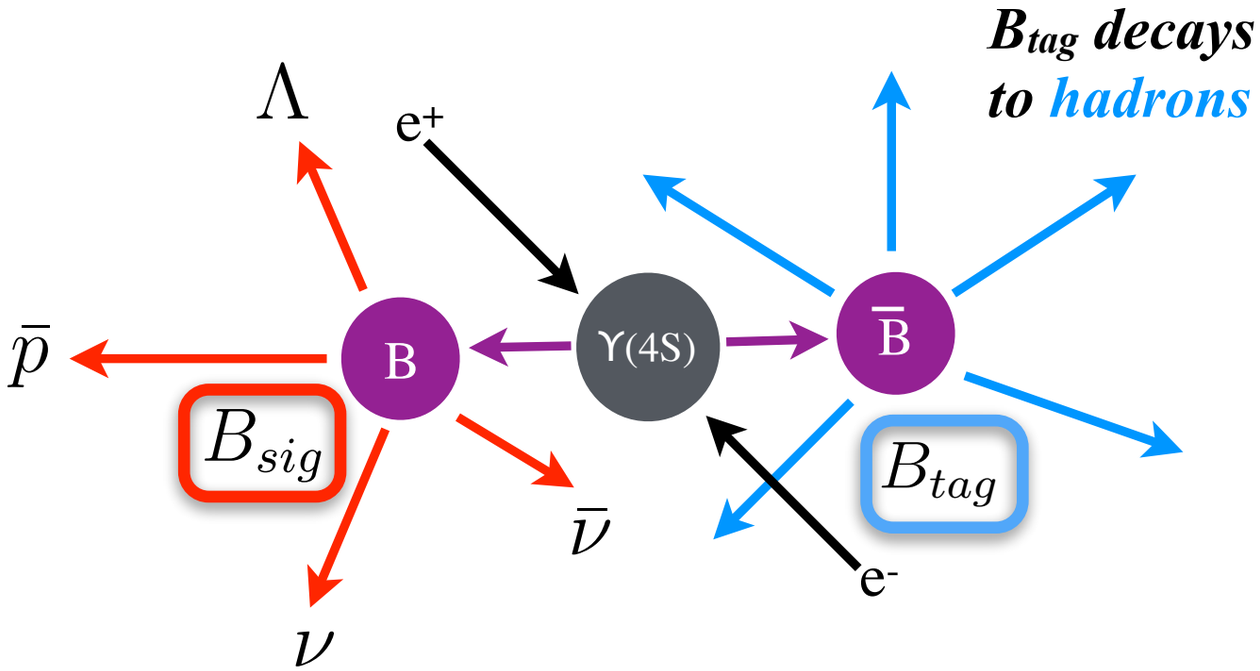
- BABAR collected data from 1999 to 2008
- Produced 471 million $B\bar{B}$ pairs
- 429 fb^{-1} integrated luminosity at $\Upsilon(4S)$ resonance

The BABAR experiment - detector



BaBar collaboration

Analysis method - hadronic B_{tag} reconstruction



B_{tag}

Exclusively reconstruct from known hadronic decays.

Require:

- one B_{tag}
- mass consistent with B meson
- charge is opposite that of B_{sig} daughters

B_{sig}

Everything else in the event, including missing energy, that isn't assigned to the B_{tag} is assumed to come from the B_{sig}

<u>Advantages:</u>

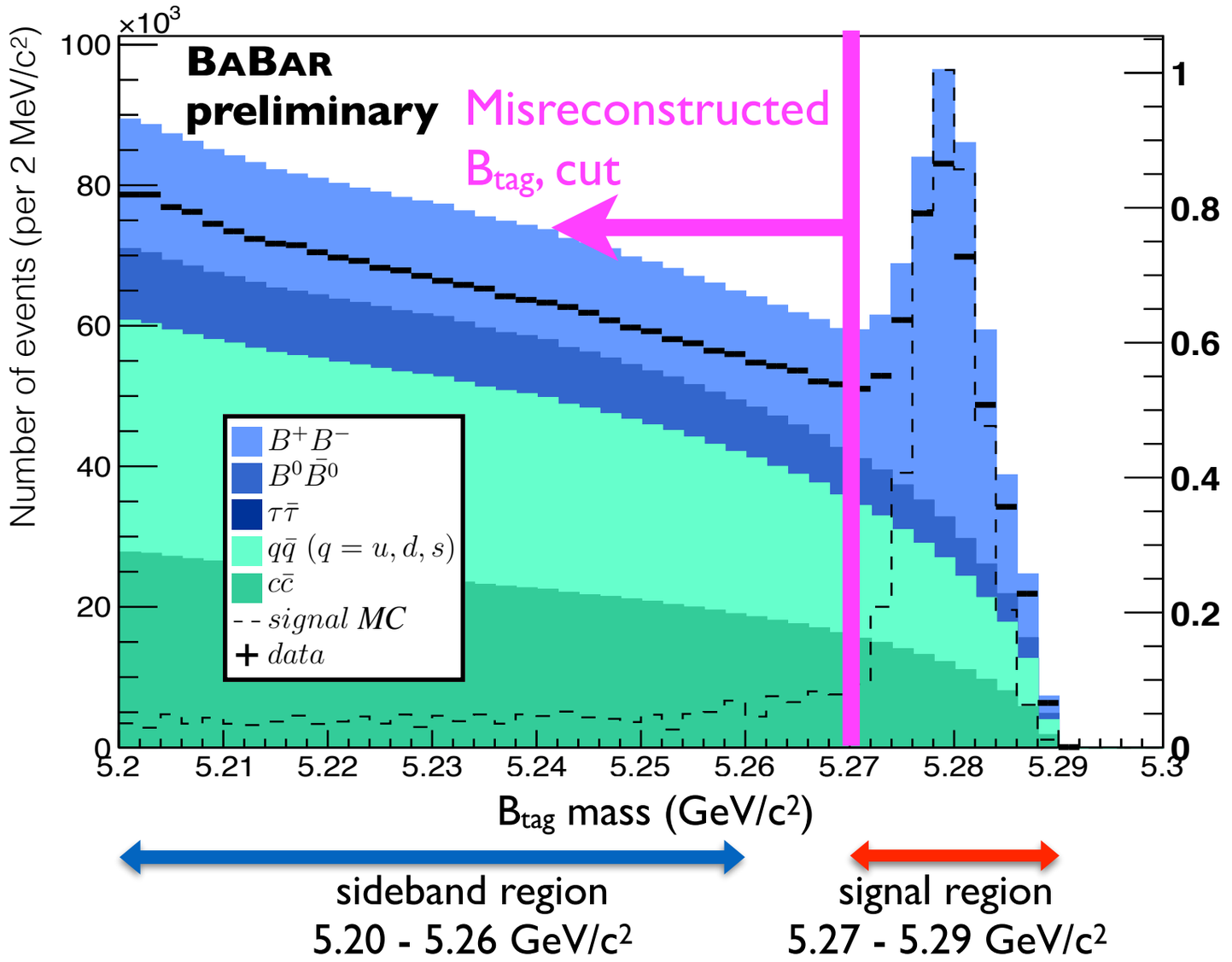
- Completely separates B_{tag} from B_{sig}
- Fully determines kinematics of B_{sig}
- Missing energy and all other particles assigned to B_{sig}
- Eliminates background

<u>Disadvantages:</u>

- Low efficiency

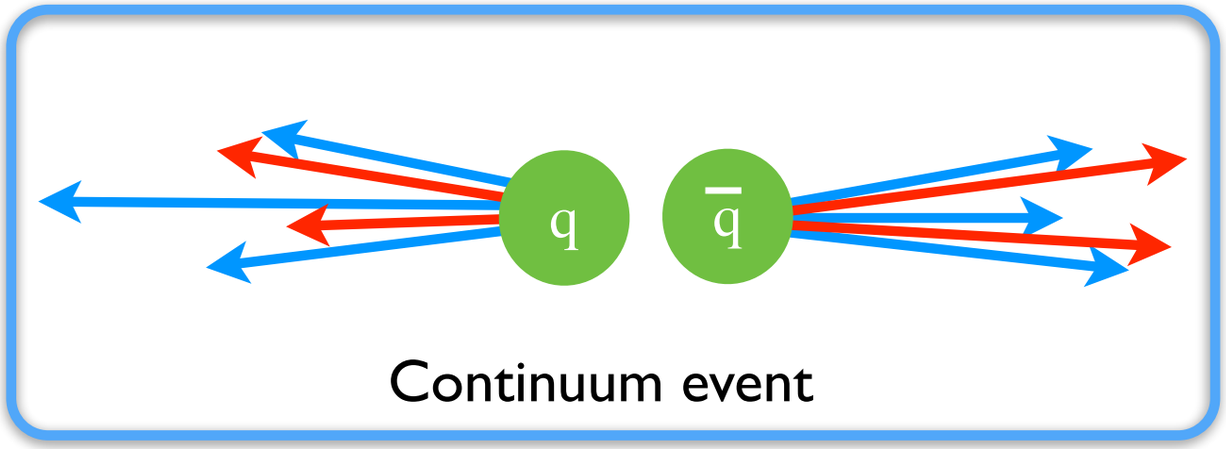
Analysis method - Monte Carlo simulation

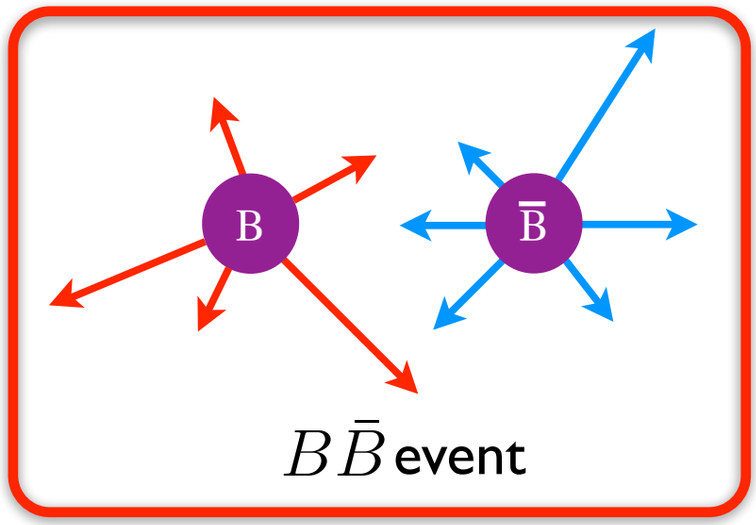
- Use Monte Carlo data and detector simulation to perform analysis.
- Signal Monte Carlo weighted to match theoretically-predicted phase space constraints.



- Discrepancy between data and MC due to incorrectly-simulated branching fractions, reconstruction efficiencies.
- Correct for by determining combinatorial yield from data in sideband region, and correct B^+B^- MC peaking yield by comparing with data in signal region with little/no signal sensitivity.

Analysis method - continuum suppression

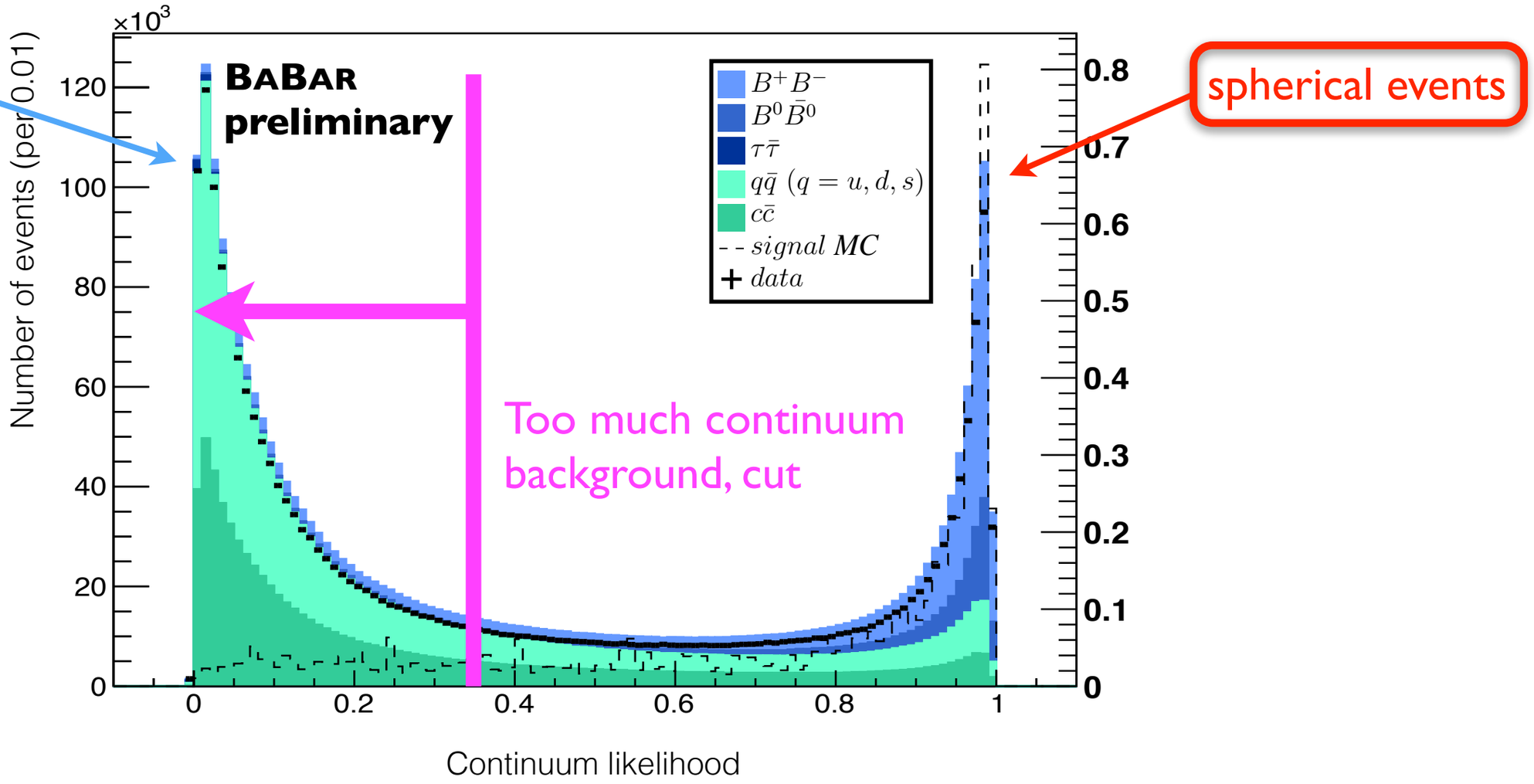




Use a multivariate likelihood to measure the shape of the event:

jet-like events

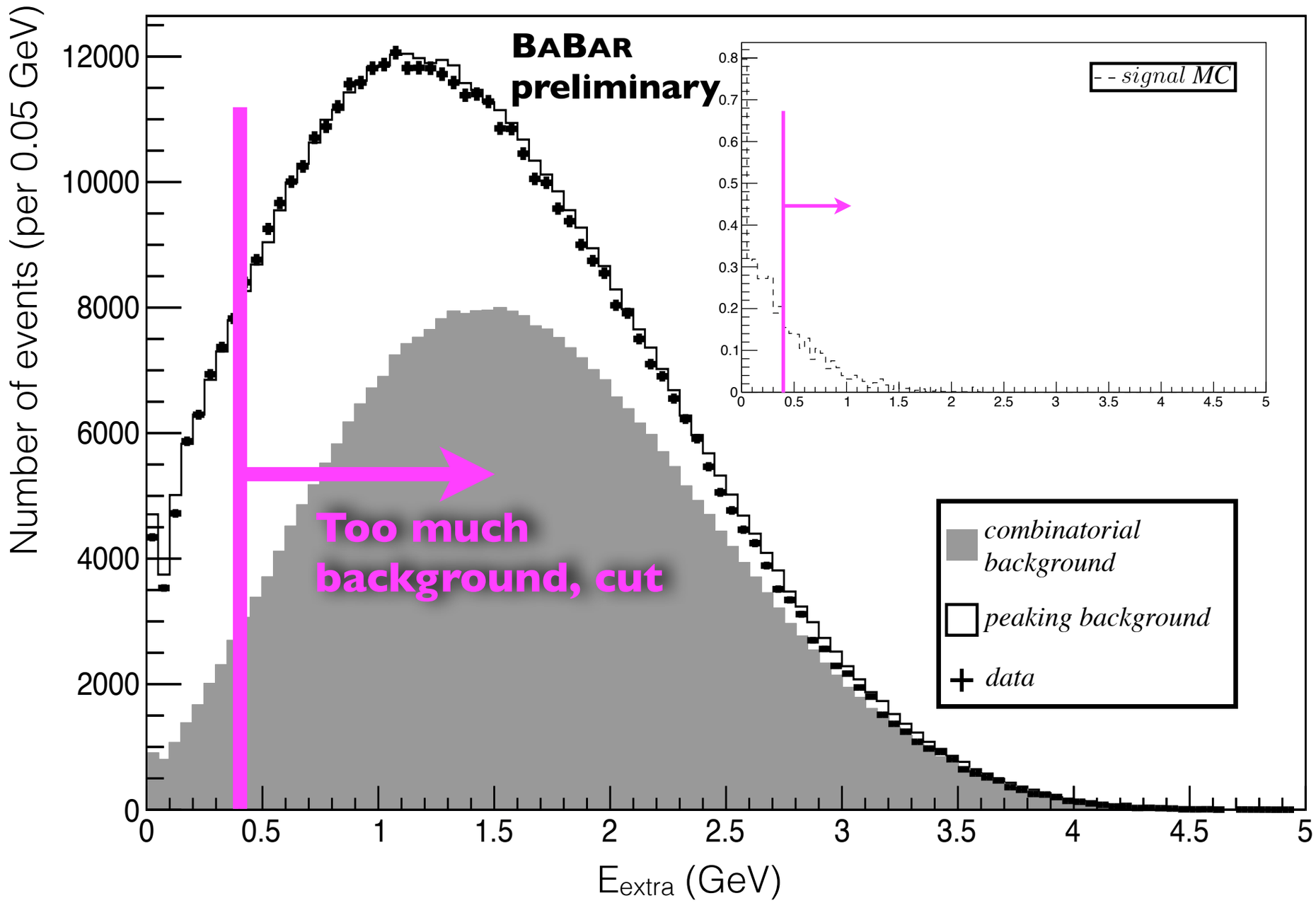
spherical events



Analysis method - extra energy

Extra energy - in theory represents energy deposits from neutral particles, in reality can be:

- showers from decay products,
- mis-assignment of B-meson daughters,
- real neutral particles.



Analysis method - particle ID & distance of closest approach

Charge/PID requirements:

- Require three charged tracks consistent with signal decay
- Identify (anti)protons, remaining charged track must be the pion

Proton PID ~95% efficiency, <1% mis-ID rate.

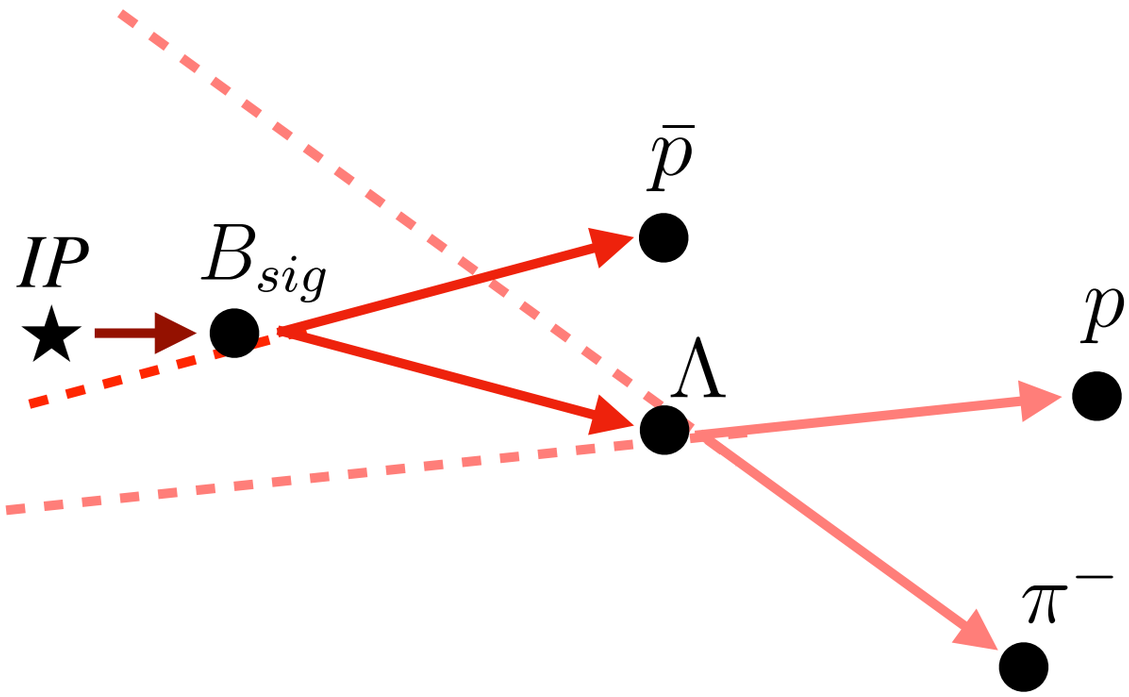
$$B^- \to \Lambda \bar{p} \nu \bar{\nu}$$
$$\hookrightarrow p\pi^-$$

(63.9 ± 0.5)%

DOCA requirements:
DOCA = extrapolated **D**istance **O**f **C**losest **A**pproach to interaction point (IP).

Expect:
- Lowest DOCA - proton from B
- Middle DOCA - proton from lambda
- Highest DOCA - pion

Decreases signal efficiency by ~10% but decreases background by ~24%.

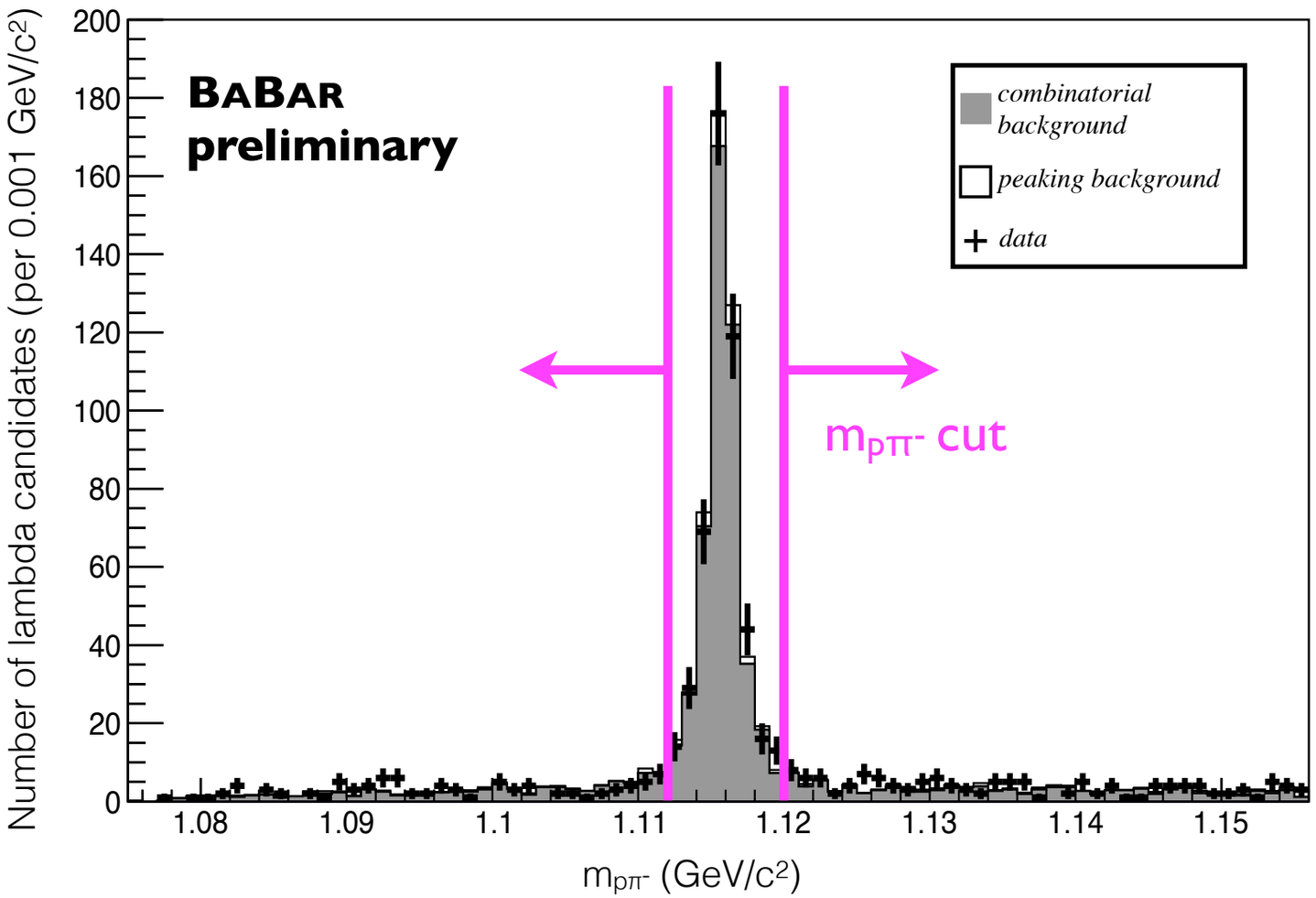


Analysis method - Λ reconstruction

• Reconstruct Λ candidates using kinematic fit based on Λ decay vertex and event-wise beamspot constraint and B_{sig} flight length.

Require:

- At least one Λ candidate per event
- Λ candidates must have two charged daughters
- Reconstructed Λ mass 1.112 < m < 1.120 GeV/c^2 (PDG mass 1.116 GeV/c^2)
- If >1 Λ candidate, choose candidate with best decay length significance

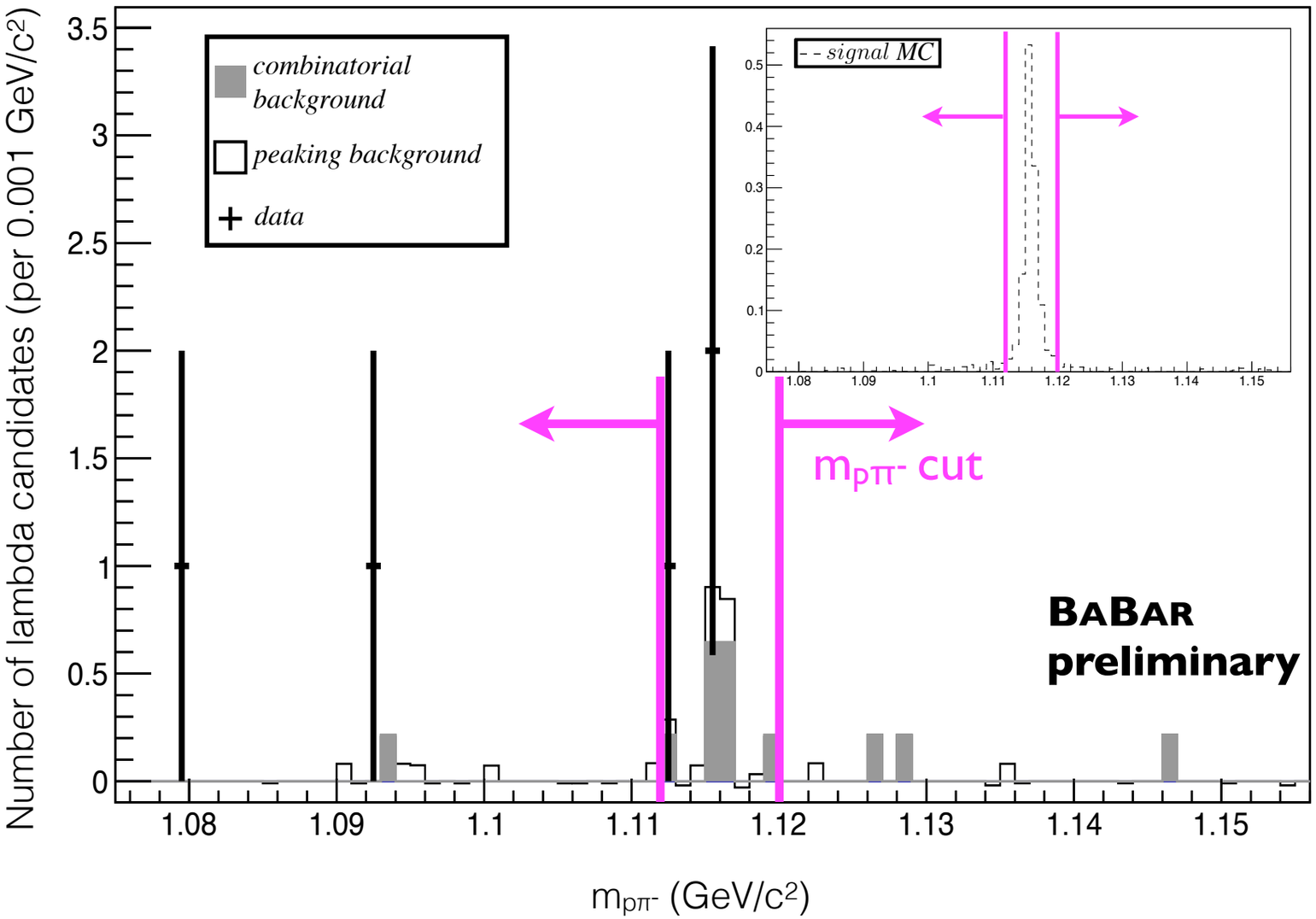


Final results

BABAR preliminary

- Data in signal region: 3 events
- Final background estimate: 2.3 ± 0.7(stat.) ± 0.6(sys.)
- Final signal efficiency: (3.42 ± 0.08(stat.) ± 0.80(sys.)) x 10^{-4}

- Branching fraction calculations: central value: (0.4 ± 1.1(stat.) ± 0.6(sys.)) x 10^{-5}
  upper limit at 90% confidence level: 3.0 x 10^{-5}
  (compare theory: (7.9 ± 1.9) x 10^{-7})



Conclusion

- Search for $B^- \to \Lambda\bar{p}\nu\bar{\nu}$ decay at BaBar.

- Rare decay - good probe to test for new physics.

- This analysis: first ever measurement of $B^- \to \Lambda\bar{p}\nu\bar{\nu}$. Results:
  BF central value: (0.4 ± 1.1(stat.) ± 0.6(sys.)) x 10^{-5}
  BF upper limit at 90% confidence level: 3.0 x 10^{-5}
  (Compare theory: (7.9 ± 1.9) x 10^{-7})

- No observation of signal or New Physics.

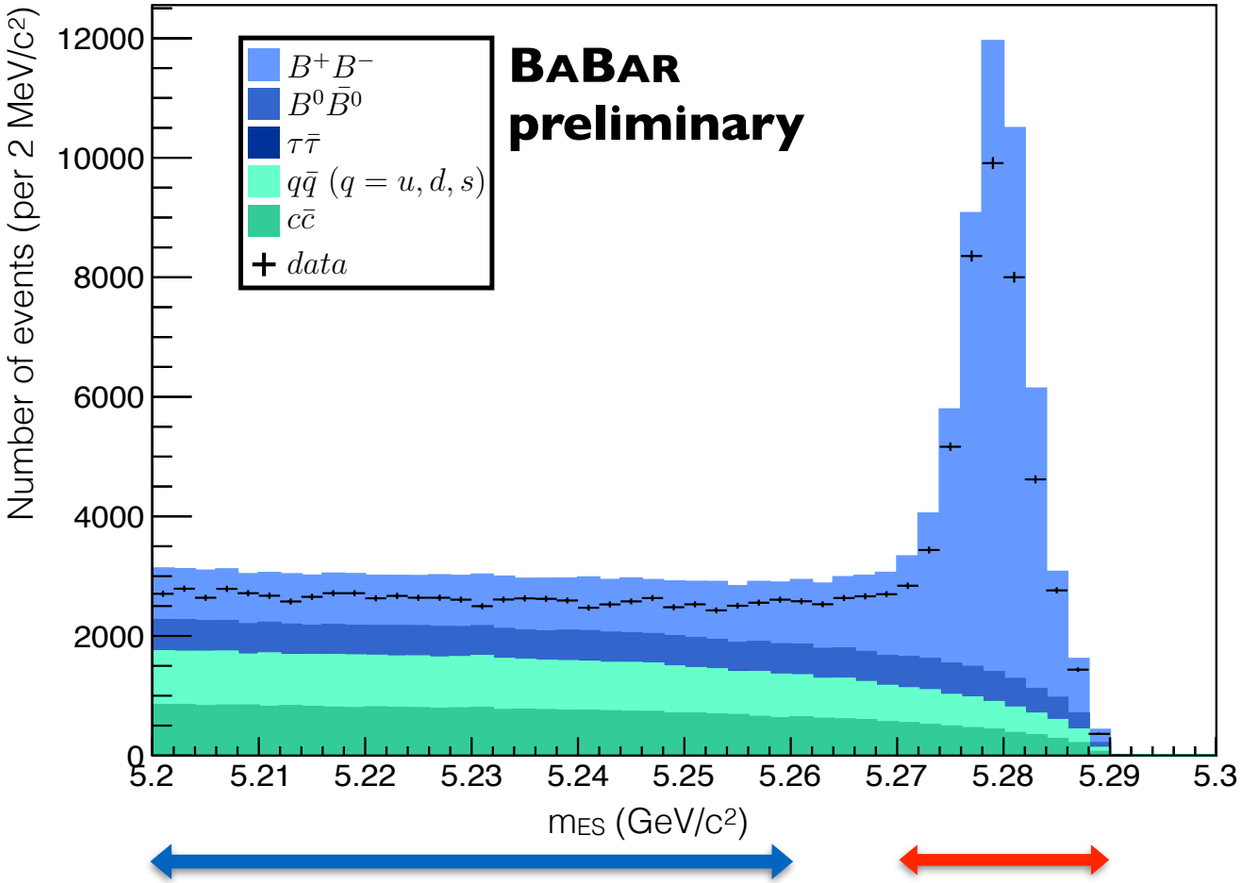
Backup slides

Analysis method - MC/data agreement

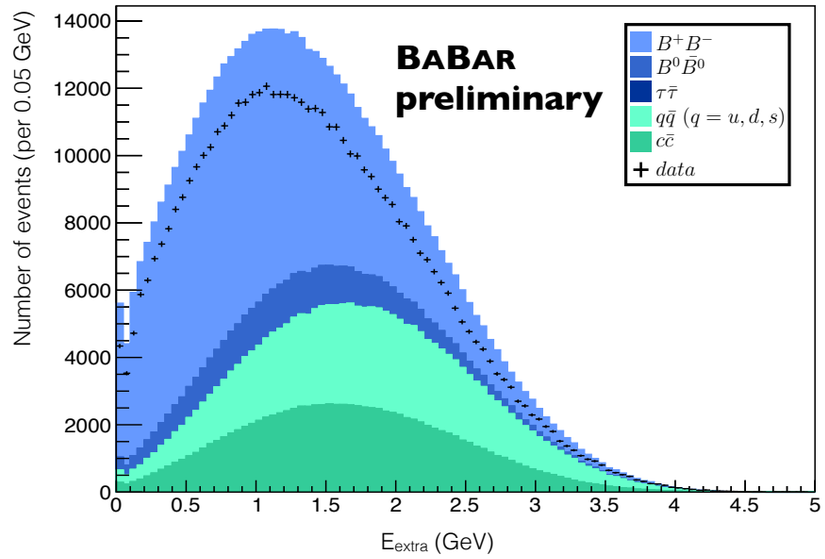
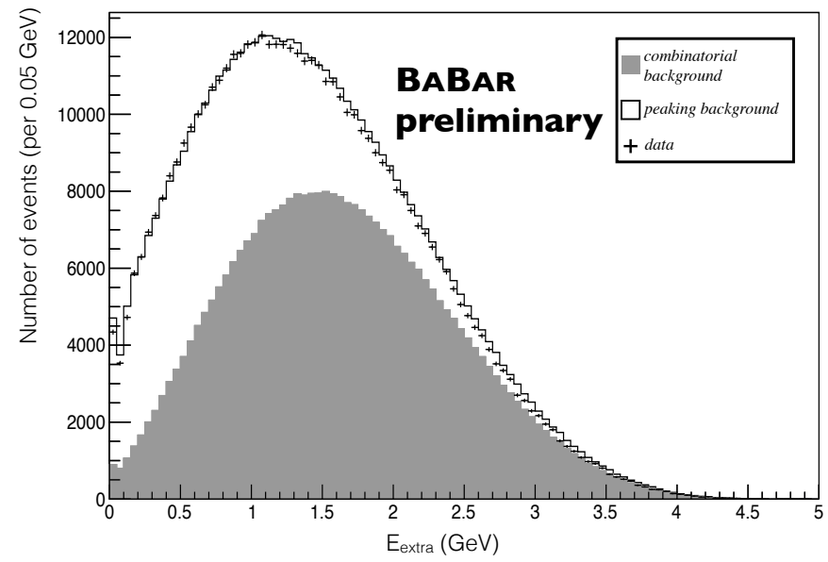
Data and background MC do not agree due to incorrectly simulated branching fractions and reconstruction efficiencies. Correct for by:

- extrapolating data in m_{ES} sideband region into m_{ES} signal region → combinatorial background in m_{ES} signal region, and
- scale up B^+B^- MC to account for any remaining discrepancy using straightforward multiplicative factor to normalise to peaking data → peaking background in m_{ES} signal region. Apply same correction to signal MC.

RBm_{ES} at intermediate stage of signal selection



sideband region
5.20 - 5.26 GeV/c²

signal region
5.27 - 5.29 GeV/c²

Result when applied to E_{extra}