Studies of $B \to D^{*}3\pi$ and $B \to K\tau\tau$ at BABAR

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Tel Aviv University

On behalf of the BABAR Collaboration

Lake Louise Winter Institute 2017

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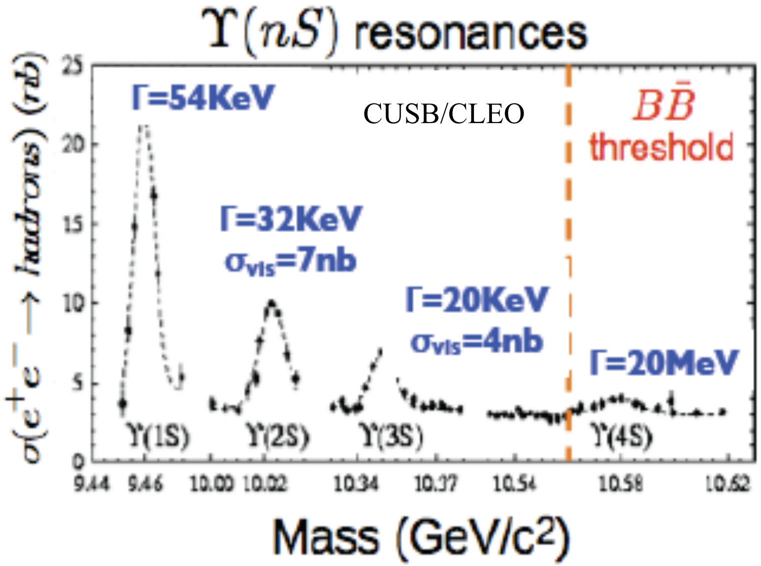
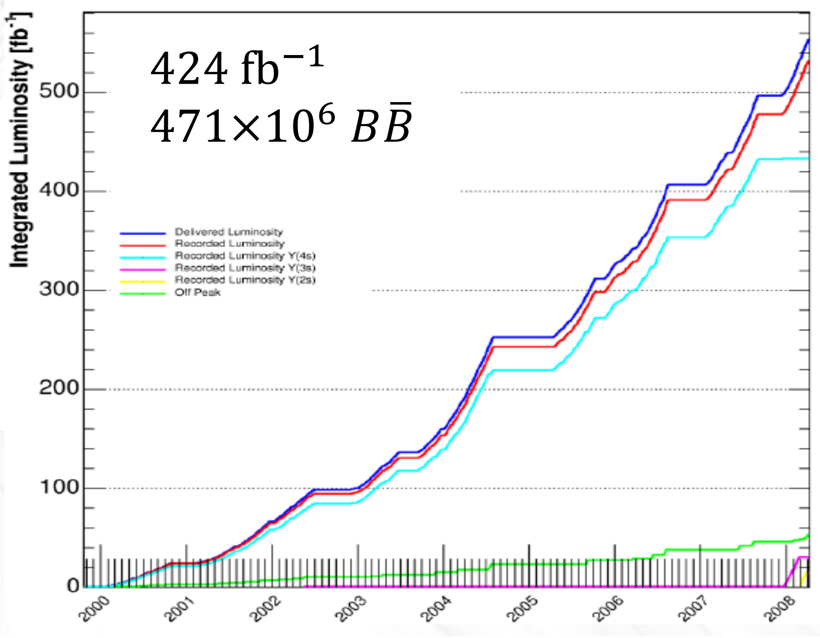
Outline

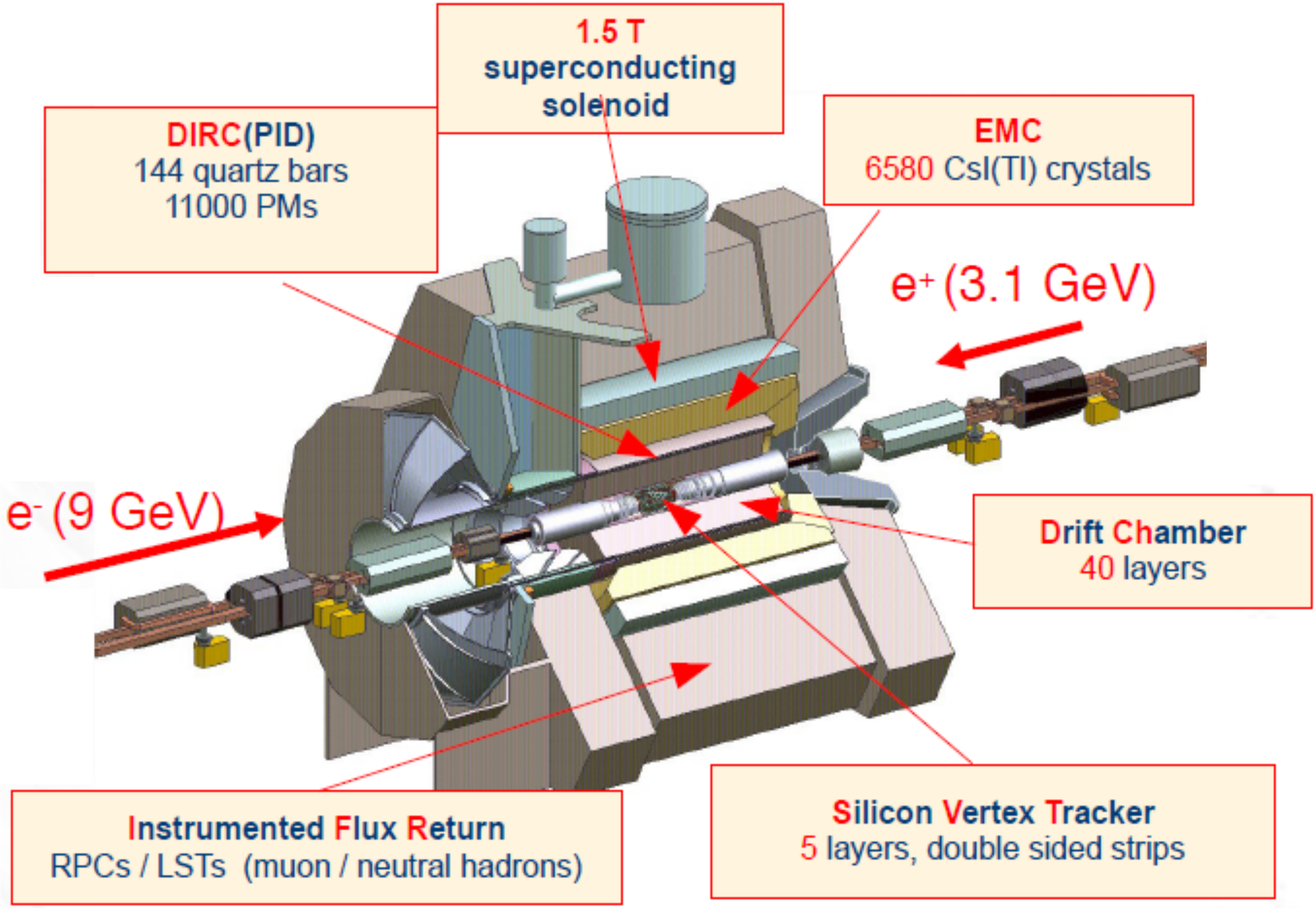
- The BABAR experiment
- Measurement of $\mathrm{Br}(B^0 \to D^{*-}\pi^+\pi^-\pi^+)$
- Search for $B^+ \to K^+\tau^+\tau^-$

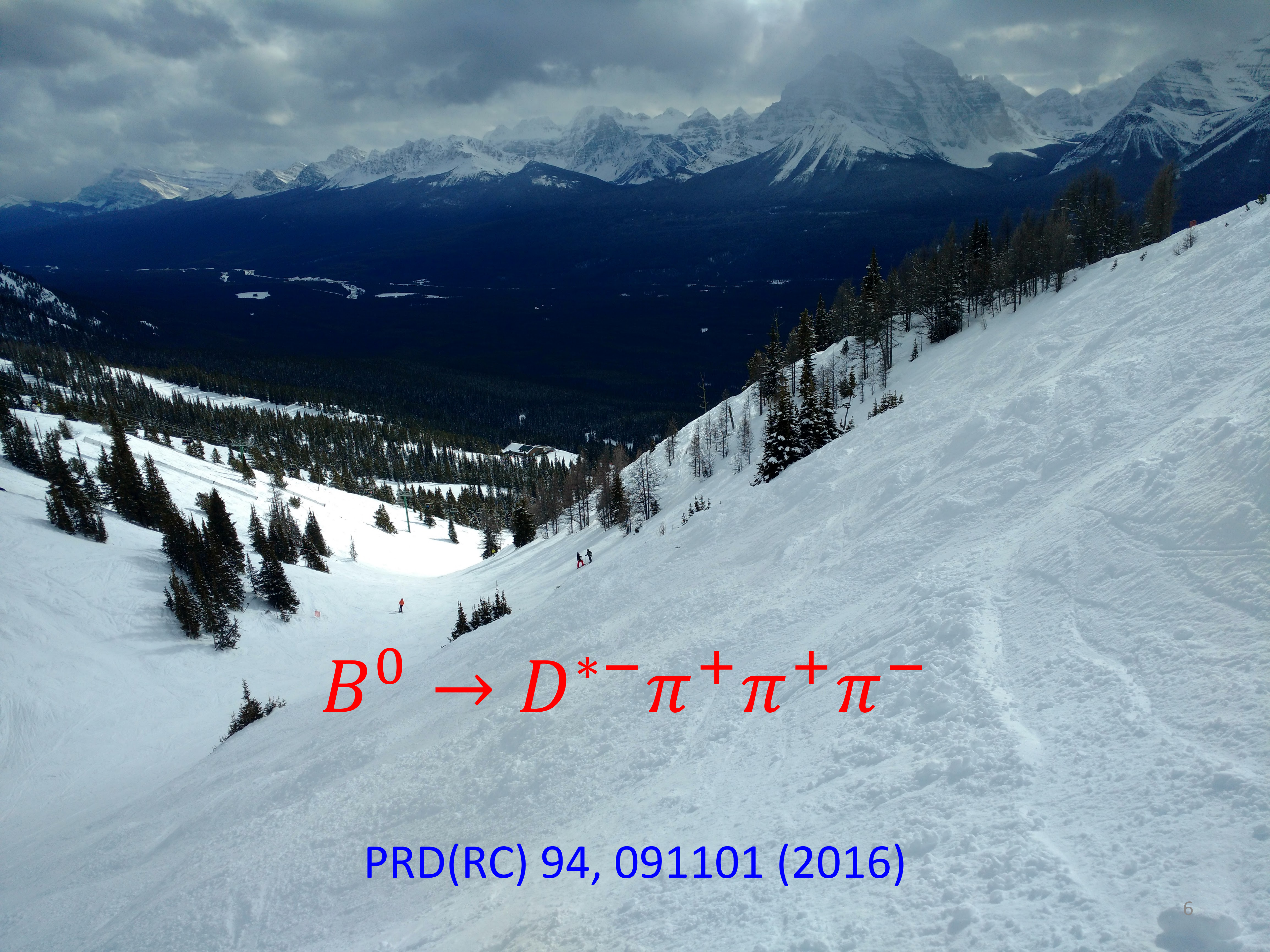
BABAR: energy and dataset





The BABAR Detector



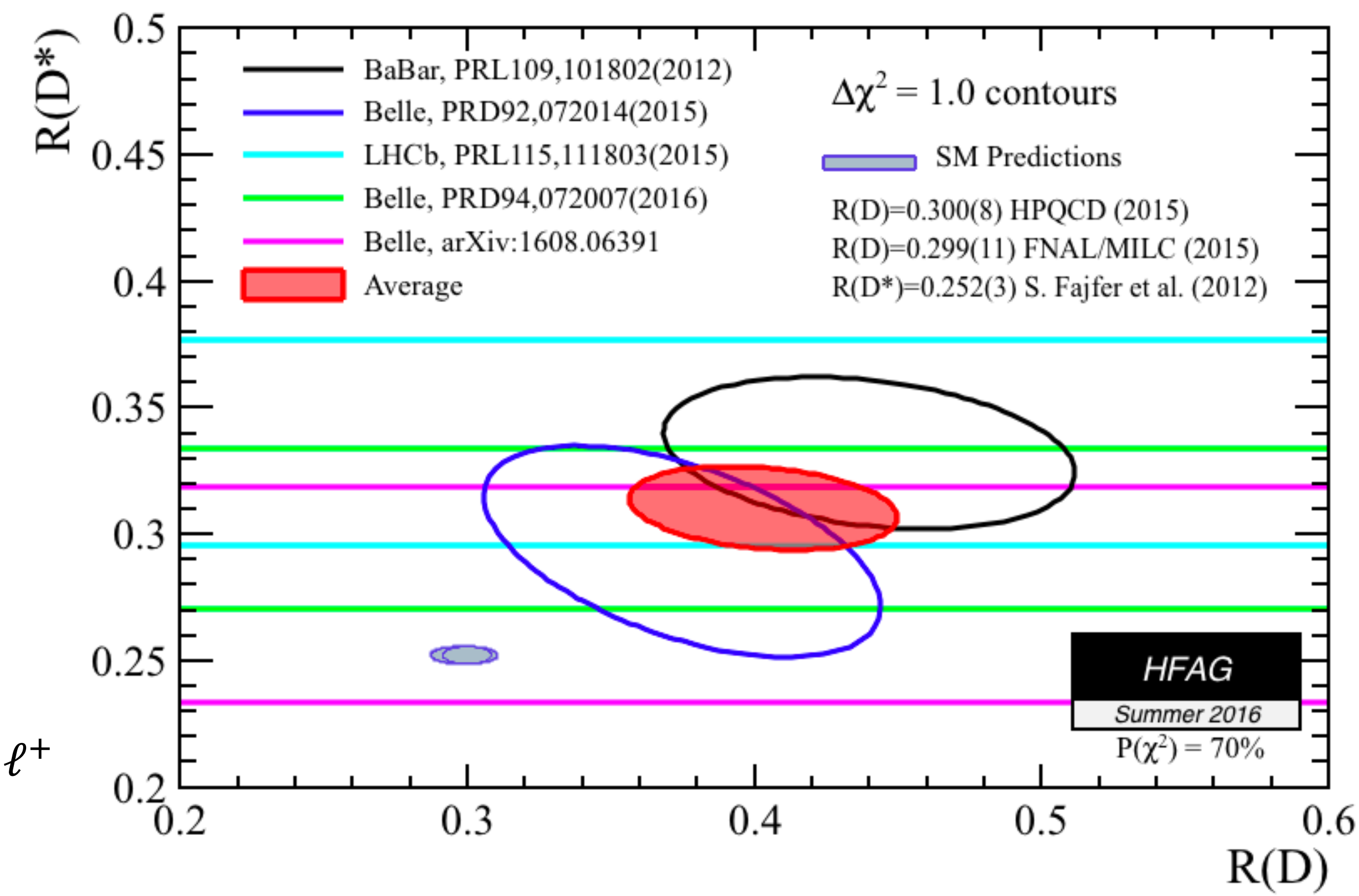


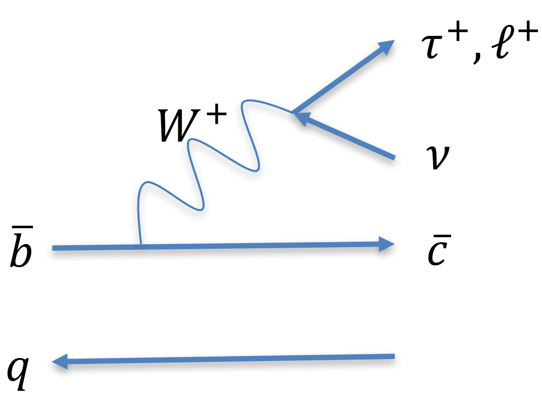
$$B^0 \to D^{*-}\pi^+\pi^+\pi^-$$

PRD(RC) 94, 091101 (2016)

Motivation: 3.9 σ discrepancy in $B \to \overline{D}^{(*)}\tau^+\nu$

$$R(D^*) \equiv \frac{Br(B \to \overline{D}^*\tau^+\nu)}{Br(B \to \overline{D}^*\ell^+\nu)}$$





$$R(D) \equiv \frac{Br(B \to \overline{D}\tau^+\nu)}{Br(B \to \overline{D}\ell^+\nu)}$$

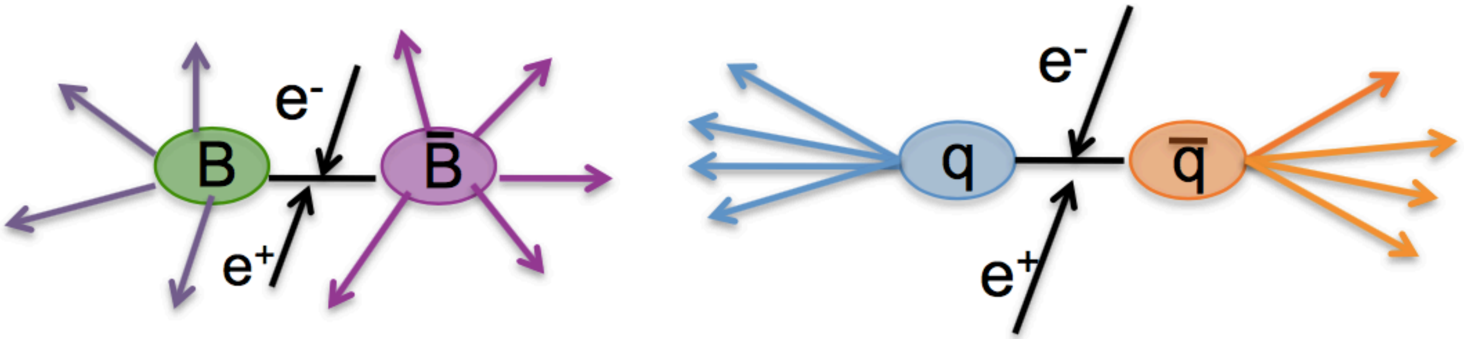
Connection to $B^0 \to D^{*-}3\pi$

- LHCb measured $R(D^*)$ with $B^0 \to D^{*-}\tau^+\nu$
  $\tau^+ \to \mu^+\nu_\mu\bar{\nu}_\tau$
  - Simultaneously measure the normalization $Br(B^0 \to D^{*-}\mu^+\nu)$
- LHCb can also use $\tau^+ \to \pi^+\pi^+\pi^-\bar{\nu}_\tau$
  - Competitive sensitivity
  - Natural normalization decay: $B^0 \to D^{*-}\pi^+\pi^+\pi^-$
  - $Br(B^0 \to D^{*-}\pi^+\pi^+\pi^-)$:
    - PDG: $(7.0 \pm 0.8)\times 10^{-3}$
    - LHCb: $(7.27 \pm 0.11 \pm 0.36 \pm 0.34)\times 10^{-3}$ Phys. Rev. D 87, 092001 (2013)
      (last uncertainty: $Br(B^0 \to D^{*+}\pi^-)$ normalization)

    - BABAR knows the # of B mesons produced, can measure $Br(B^0 \to D^{*-}\pi^+\pi^+\pi^-)$ more precisely

$B^0 \to D^{*-}\pi^+\pi^-\pi^+$ reconstruction

- $D^{*-} \to \bar{D}^0\pi^-$
  $\bar{D}^0 \to K^+\pi^-$
- 9 event-shape variables to suppress "continuum" $e^+e^- \to q\bar{q}$:

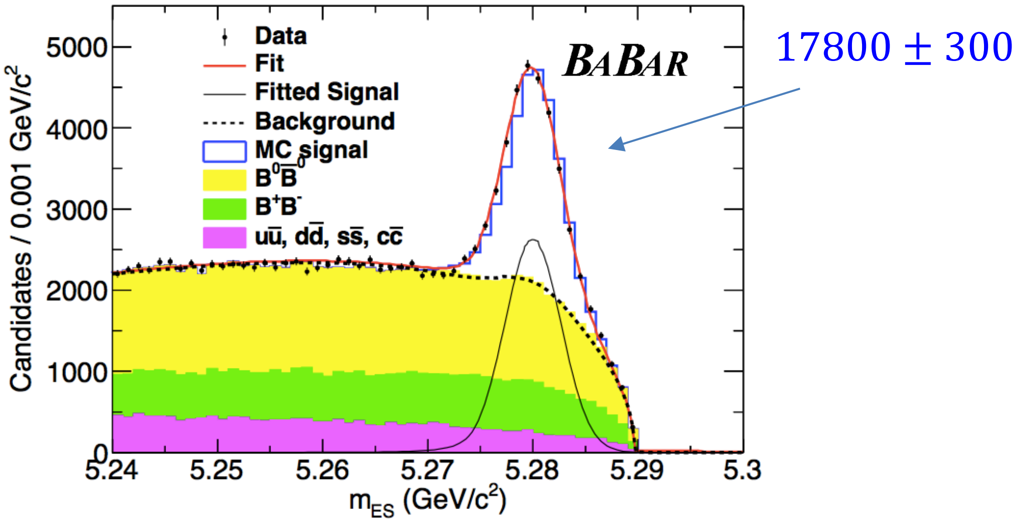


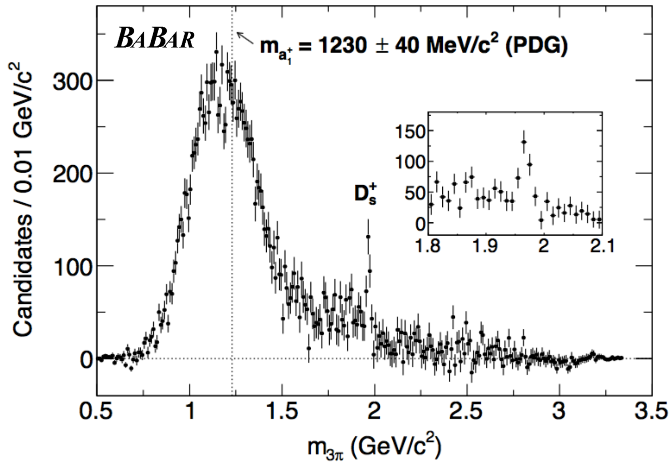
- $|\Delta E| \equiv \left| E_B - \frac{\sqrt{s}}{2} \right| < 90$ MeV

in center-of-mass (CM) frame

$B^0 \to D^{*-}\pi^+\pi^-\pi^+$ results

- Plot $m_{ES} \equiv \sqrt{\frac{s}{4} - p_B^2}$
- Fit, floating:
  - Signal yield & parameters
  - Non-peaking background yield & parameters
- Peaking background from MC:
  - Misreconstructed signal
  - Other $B \to D^*X$ decays
- Sideband-subtracted $m_{3\pi}$ spectrum dominated by a_1^+, some D_s^+ (subtracted)

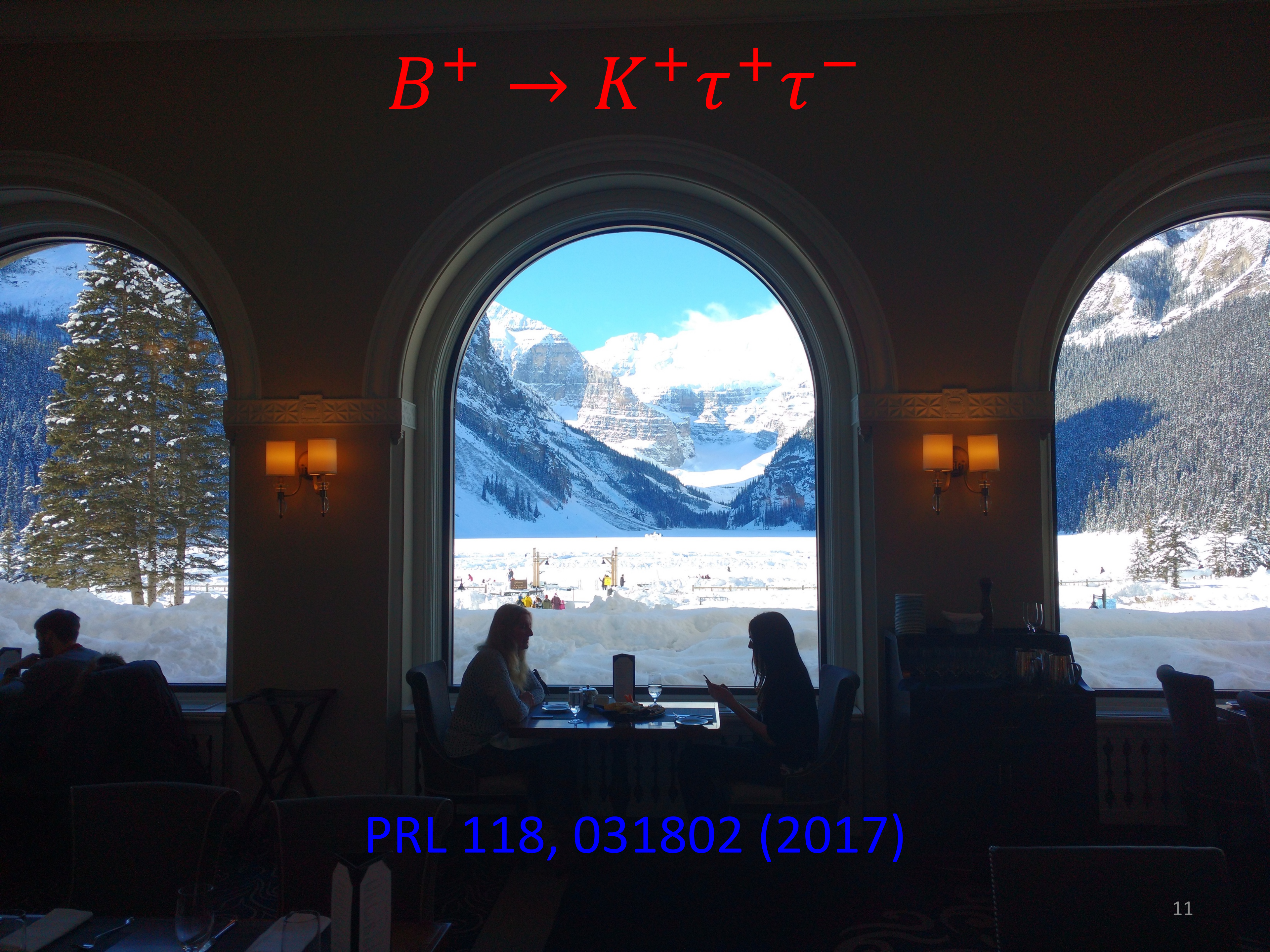




$$Br(B^0 \to D^{*-}\pi^+\pi^-\pi^+) = (7.26 \pm 0.11 \pm 0.31) \times 10^{-3}$$

Dominant systematics: fit, track finding, 3π spectrum

$B^+ \to K^+ \tau^+ \tau^-$

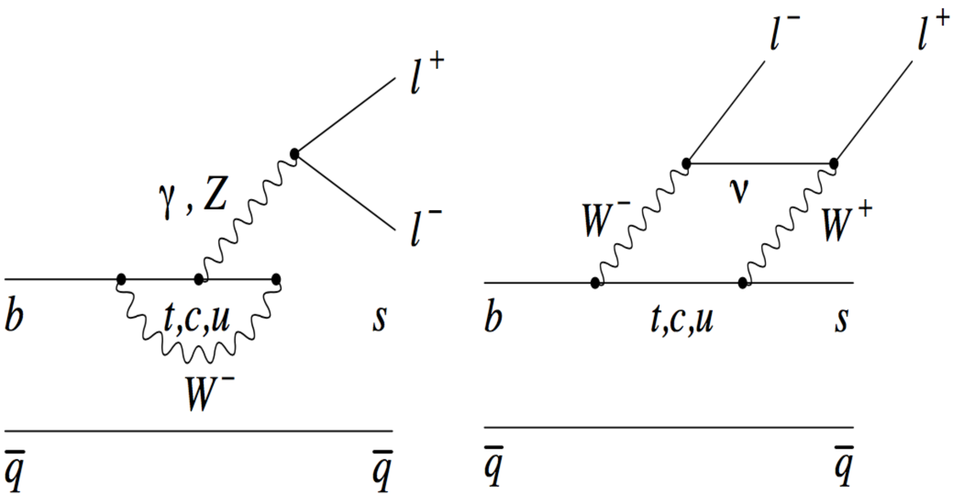


PRL 118, 031802 (2017)

$B^+ \to K^+\tau^+\tau^-$ motivation

- Flavor-changing neutral current
  → sensitive to new physics

  (FCNCs exclude NP regions inaccessible by LHC)



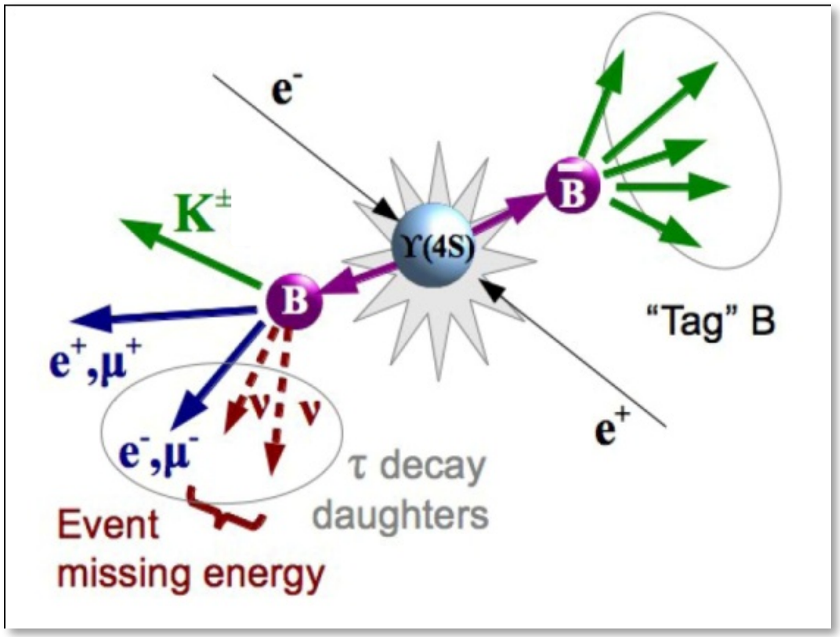
- LHCb sees weak tensions in angular distributions & decay rates of $B \to K^{(*)}\ell^+\ell^-$

- 3rd generation counterpart is interesting, especially in light of the $3.9\ \sigma$ tension in $B \to \bar{D}^{(*)}\tau^+\nu$

- SM: $\mathrm{Br}(B^+ \to K^+\tau^+\tau^-) \sim 10^{-7}$

$B^+ \to K^+\tau^+\tau^-$ reconstruction

- Multiple neutrinos – no handle on B mass or energy
- But known $e^+e^- \to B^+B^-$ initial state:



Signal-$B^+ \to K^+\ell^+\ell'^- +$ missing

Background mostly $\bar{B} \to D^{(*)}\ell^+\nu$,
$D \to \bar{K}\ell'^-\bar{\nu}$,
which has the same final-state particles

Tag-$B \to CX$

- 9 D^0 modes
- 7 D^+ modes
- 2 D_s modes
- $J/\psi \to \ell^+\ell^-$

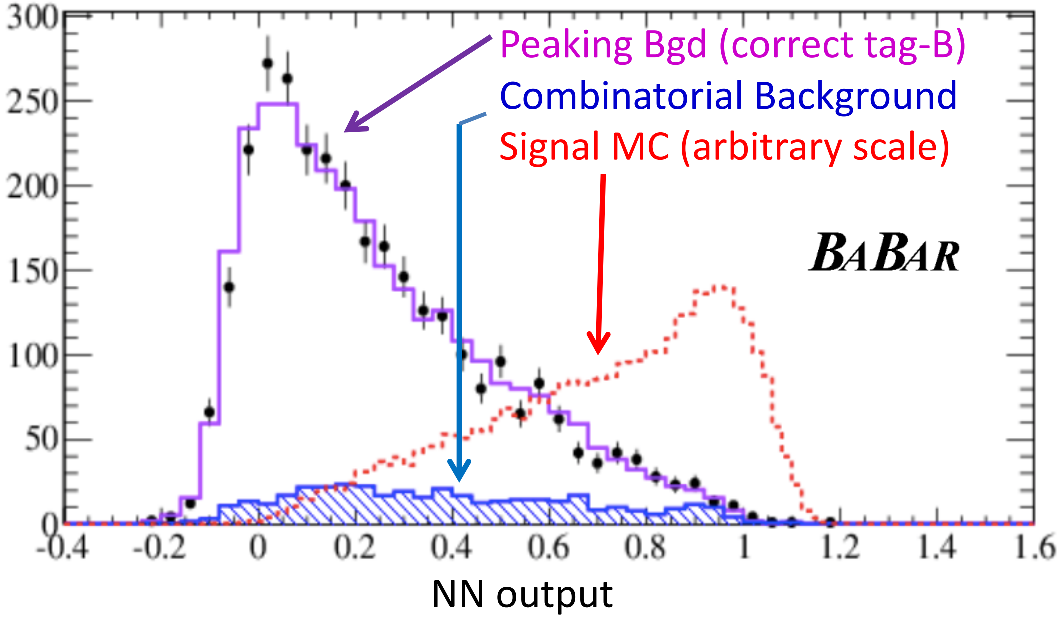
Up to 5 charged or neutral kaons and pions with total charge 0, ± 1

Hundreds of modes!
Retain those with >40% purity after ΔE & m_{ES} cuts

Signal-B momentum:

$$p^\mu_{\text{sig}} = p^\mu_{e^+e^-} - p^\mu_{\text{tag}}$$

$B^+ \to K^+\tau^+\tau^-$ Selection



Use a 7-variable neural-network to separate S-B.
Optimal cuts on NN:

- > 0.70 for the ee & $\mu\mu$ modes
- > 0.75 for the $e\mu$ mode

Obtain background yield:

- Combinatorial: m_{ES} sideband
- Peaking: MC, corrected to tag-B yield in data
  validated with $B^+ \to D^0\ell^+\nu$, $D^0 \to K^-\pi^+$ control sample

$B^+ \to K^+\tau^+\tau^-$ Results

	e^+e^-	$\mu^+\mu^-$	$e^+\ \mu^-$
$N^i_{\rm bkg}$	49.4±2.4±2.9	45.8±2.4 ±3.2	59.2±2.8 ±3.5
$\epsilon^i_{\rm sig}(\times 10^{-5})$	1.1 ±0.2±0.1	1.3±0.2±0.1	2.1±0.2±0.2
$N^i_{\rm obs}$	45	39	92
Significance (σ)	-0.6	-0.9	3.7

$$\sigma = \frac{\text{observed} - \text{expected}}{\text{error}}$$

(Not interpreted as probability)

Scrutiny of the $e\mu$ events shows
- neither signal-like excess
- nor modeling problems

$$Br(B^+ \to K^+\tau^+\tau^-) = \left(1.31\ ^{+0.66}_{-0.61}\ ^{+0.35}_{-0.25}\right)\times 10^{-3}$$

$$Br(B^+ \to K^+\tau^+\tau^-) < 2.25\times 10^{-3}\ \ @\ 90\ \text{CL}$$

Thank you!

Snowshoe hike to 6 Glaciers leaves from lobby at 1:15

Backup slides

B->D*3pi systematics

Source	Uncertainty (%)
Fit algorithm and peaking backgrounds	2.4
Track-finding	2.0
$\pi^+\pi^-\pi^+$ invariant-mass modeling	1.7
D^{*-} and $\overline{D}^0$ decay branching fractions	1.3
$\Upsilon(4S) \to B^0\overline{B}^0$ decay branching fraction	1.2
K^+ identification	1.1
Signal efficiency MC statistics	0.9
Sideband subtraction	0.7
$B\overline{B}$ counting	0.6
Total	4.3

Tag-B reconstruction modes

or ± 1. The D seeds are reconstructed in the decay modes $D^+ \to K^0_S\pi^+$, $K^0_S\pi^+\pi^0$, $K^0_S\pi^+\pi^-\pi^+$, $K^-\pi^+\pi^+$, $K^-\pi^+\pi^+\pi^0$, $K^+K^-\pi^+$, $K^+K^-\pi^+\pi^0$; $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^0$, $K^-\pi^+\pi^-\pi^+$, $K^0_S\pi^+\pi^-$, $K^0_S\pi^+\pi^-\pi^0$, K^+K^-, $\pi^+\pi^-$, $\pi^+\pi^-\pi^0$, and $K^0_S\pi^0$; $D^{*+} \to D^0\pi^+$, $D^+\pi^0$; $D^{*0} \to D^0\pi^0$, $D^0\gamma$. The D_s^{*+} and J/ψ seeds are reconstructed as $D_s^{*+} \to D_s^+\gamma$; $D_s^+ \to \phi\pi^+$, $K^0_S K^+$; and $J/\psi \to e^+e^-$, $\mu^+\mu^-$, respectively. K^0_S and ϕ candidates are reconstructed via their decay to $\pi^+\pi^-$ and K^+K^-, respectively.