$Br(B \to D^* 3\pi)$ @BABAR
The $B \to D^{**} \ell \nu$ bgd @ Belle II
CPV in $B \to D^{**} \tau \nu$ @ Belle II/LHCb

Abi Soffer

Tel Aviv University

Mini-workshop on $B \to D^{(*)} \tau \nu$ and related topics

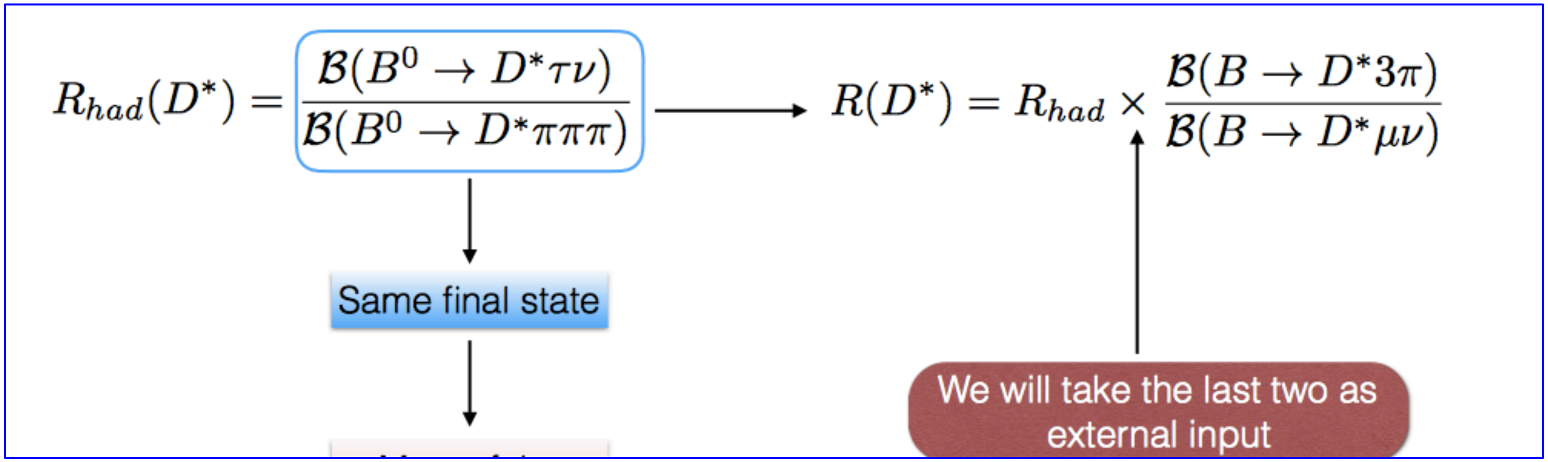
Nagoya University, 27-28 March 2017

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

PRD(RC) 94, 091101 (2016)

Connection to $B^0 \to D^{*-}\tau^+\nu$

From Benedetto's talk:



- $Br(B^0 \to D^{*-}\pi^+\pi^+\pi^-)$:
  - 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)

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

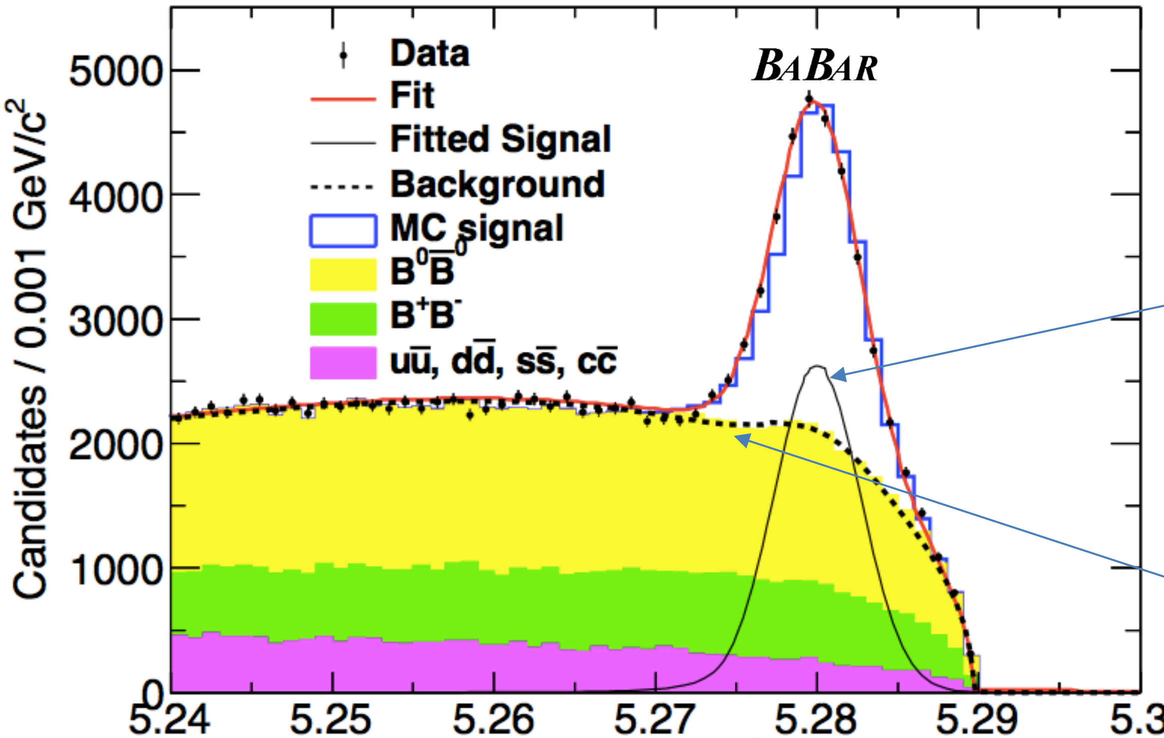
- Use only $D^{*-} \to \overline{D}{}^0\pi^-$
  $\overline{D}{}^0 \to K^+\pi^-$
- Continuum suppression NN: →
  - 69% background rejection
  - 80% signal retention
- $|\Delta E| < 90$ MeV
  - $\sim 4\sigma$

- the cosine of the angle between the B^0 candidate's thrust axis [12] and the beam axis;
- the sphericity [13] of the B^0 candidate;
- the thrust of the ROE;
- the sum over the ROE of p, where p is the magnitude of a particle's momentum;
- the sum over the ROE of $\frac{1}{2}(3\cos^2\theta - 1)p$, where θ is the polar angle of a particle's momentum;
- the cosine of the angle between the thrust axis of the B^0 candidate and the thrust axis of the ROE;
- the cosine of the angle between the sphericity axis of the B^0 candidate and the thrust axis of the ROE;
- the ratio of the second-order to zeroth-order Fox-Wolfram moment using all reconstructed particles [14];
- the cosine of the angle between the thrust axis calculated using all reconstructed particles and the beam axis.

Backgrounds

- In events with at least one signal candidate, there are
  - 1.57 candidates/event in signal
  - 1.34 candidates/event in background
- Peaking background:
  - Misreconstructed signal
  - $B \to D^{*-}(+\pi' s, \text{other than } \pi^+\pi^-\pi^+)$
- Combinatorial background:
  - Other $B\bar{B}$
  - Continuum

Signal extraction



$m_{ES} = \sqrt{\frac{s}{4} - p_B^2}$ (GeV/c^2)

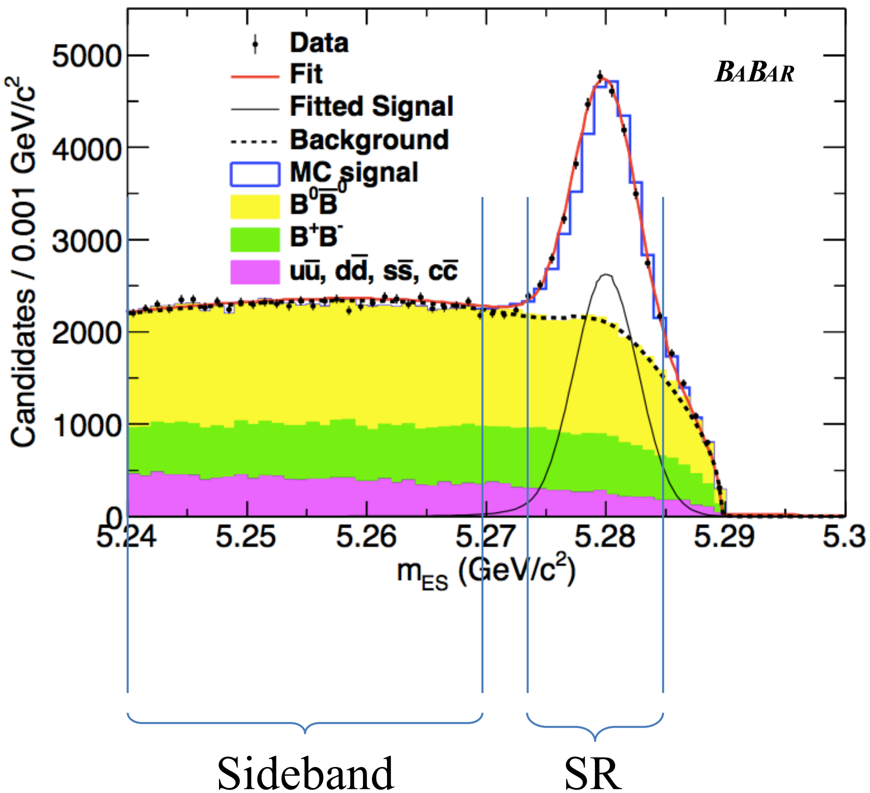
Correctly reconstructed
$B^0 \to D^{*-}3\pi$
fit to a Crystal ball function:
17800 ± 300 events

ARGUS function
+ peaking background

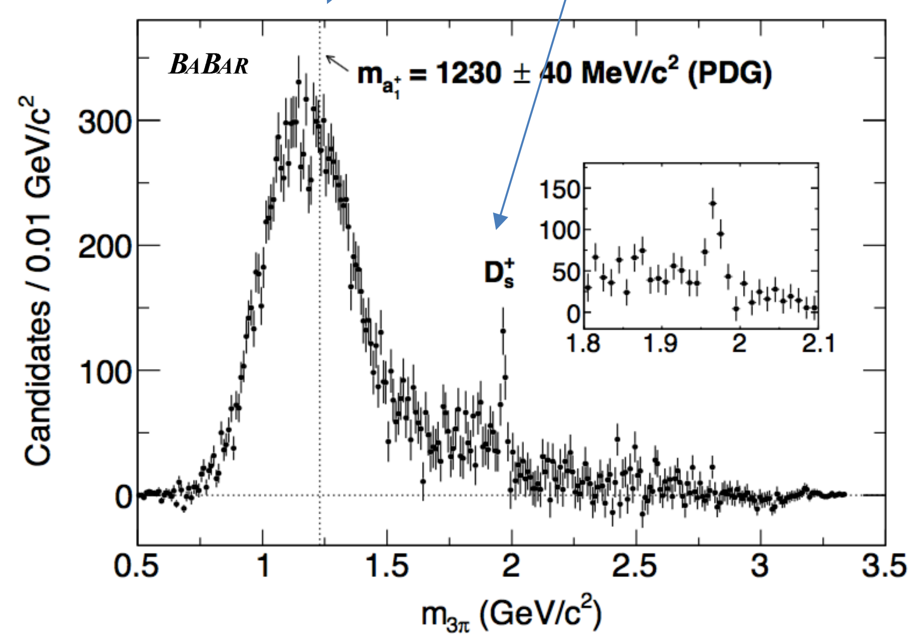
Peaking background
shape and yield come from MC

Mass difference between signal MC and data leads to
a negligible systematic uncertainty

What is the 3π?



- Sideband-subtracted $m_{3\pi}$ spectrum dominated by a_1^+, some D_s^+ (subtracted)



Systematic uncertainties and result

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

Fit algorithm and peaking backgrounds → Vary fixed fit parameters

$\pi^+\pi^-\pi^+$ invariant-mass modeling → Reweight MC $m(3\pi)$ to match data

Sideband subtraction → Different m(3π) distribution of bgd. in SR and sideband

Obtain:

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

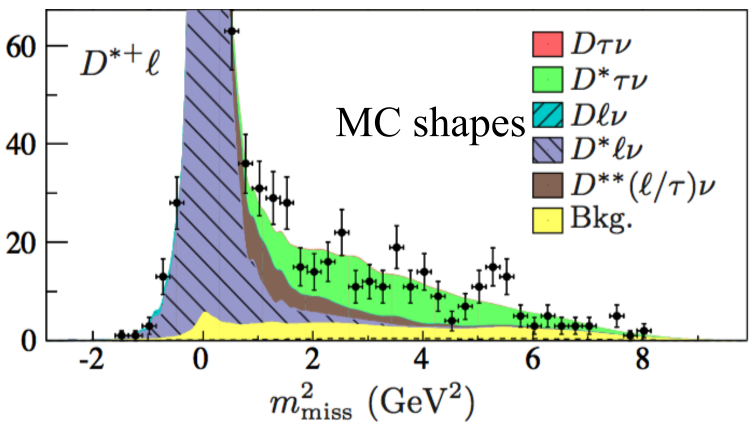
Compare to LHCb result: $(7.27 \pm 0.11 \pm 0.36 \pm 0.34)\times 10^{-3}$

New PDG average will be useful for the LHCb $R(D^*)$ measurement

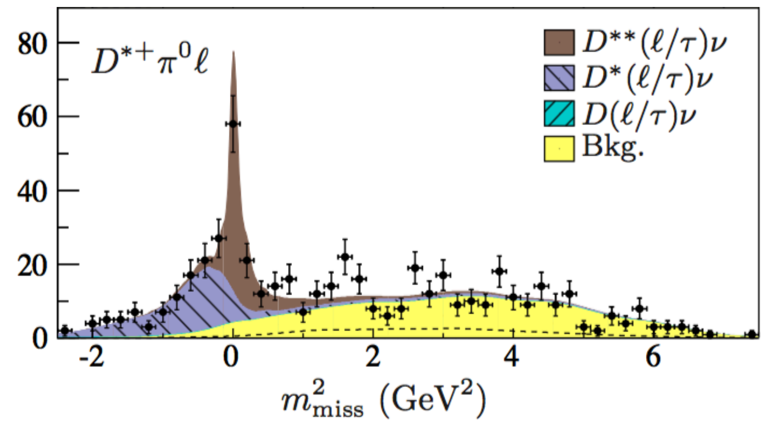
Addressing the $\bar{B} \to D^{**}\ell\bar{\nu}$ bgd.

Impact of $\bar{B} \to D^{**}\ell\bar{\nu}$

E.g., in the BABAR analysis: Simultaneous fit:



Vera's talk



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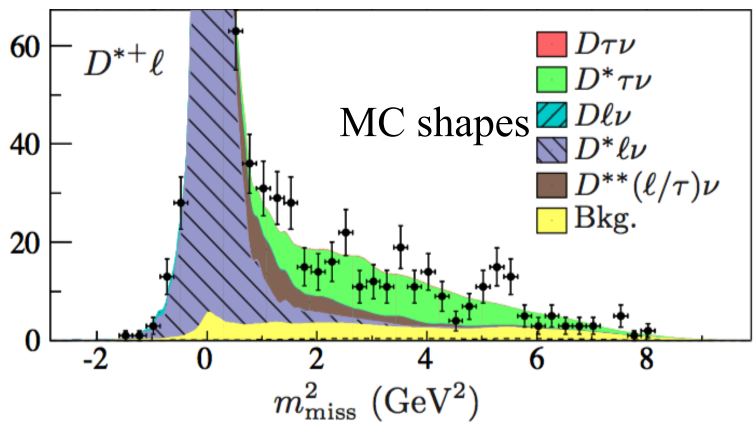

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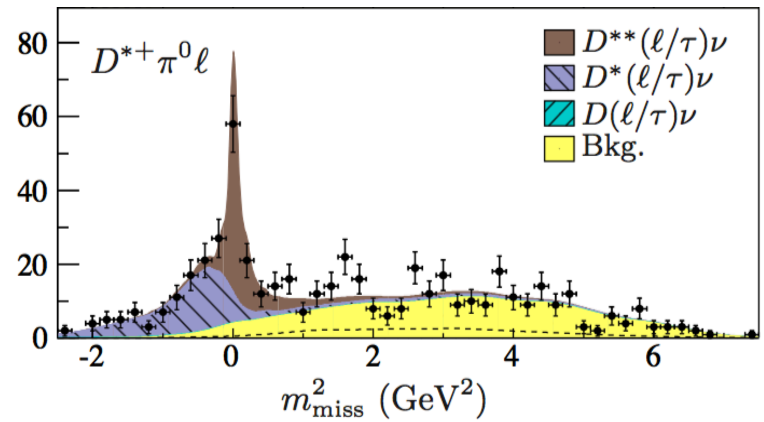


→ D** systematic uncert. (%)	$R(D)$	$R(D^*)$
• Relative efficiencies	5.0	2.0
• $Br(D^{**} \to D^{(*)}\pi^0/\pi^\pm)$	0.7	0.5
• $Br(D^{**} \to D^{(*)}\pi\pi)$	2.1	2.6
• $Br(\bar{B} \to D^{**}\ell\bar{\nu})$	0.8	0.3
• $Br(\bar{B} \to D^{**}\tau\bar{\nu})$	1.8	1.7

~ 2% estimated for most Belle analyses
See Phill's and Shigeki's talks

- Additional resonances?
- Non-resonant component?
- Is $\bar{B} \to D^{**}\ell\bar{\nu}$ the reason for the excess?
- At Belle II, 2% will be a large error

What we know about D^{**} states

State	~Width (MeV)	J^P	Seen/allowed decays
$D_0^*(2400)$	270	0^+	$D\pi, D\eta$
$D_1(2420)$	27	1^+	$D^*\pi, D\pi\pi, D^*\pi\pi$
$D_1'(2430)$	380	1^+	$D^*\pi, D^*\eta, D^{(*)}\pi\pi$
$D_2^*(2460)$	50	2^+	$D^{(*)}\pi, D^{(*)}\pi\pi, D^{(*)}\eta$
$D(2550)$	130	0^-	$D^*\pi$
$D(2600)$	90	$?^?$	$D^{(*)}\pi$
$D^*(2640)$	< 15	$?^?$	$D^*\pi\pi$
$D(2750)$	65	$?^?$	$D^{(*)}\pi$

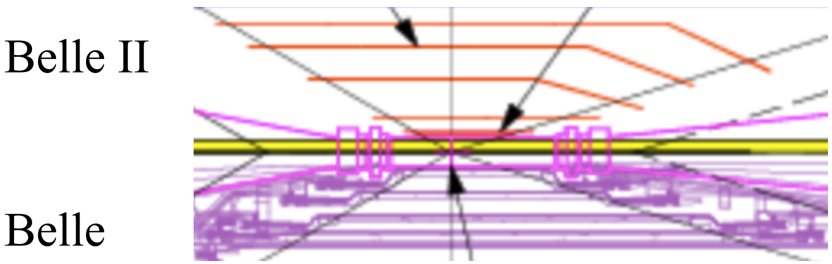
- $\bar{B} \to D^{**}\ell\bar{\nu}$ decays observed only for the lightest states
- Theory is only a weak guide here…

Need a model-independent handle on $\bar{B} \to D^{**}\ell\bar{\nu}$ background in $\bar{B} \to D^{(*)}\tau\bar{\nu}$

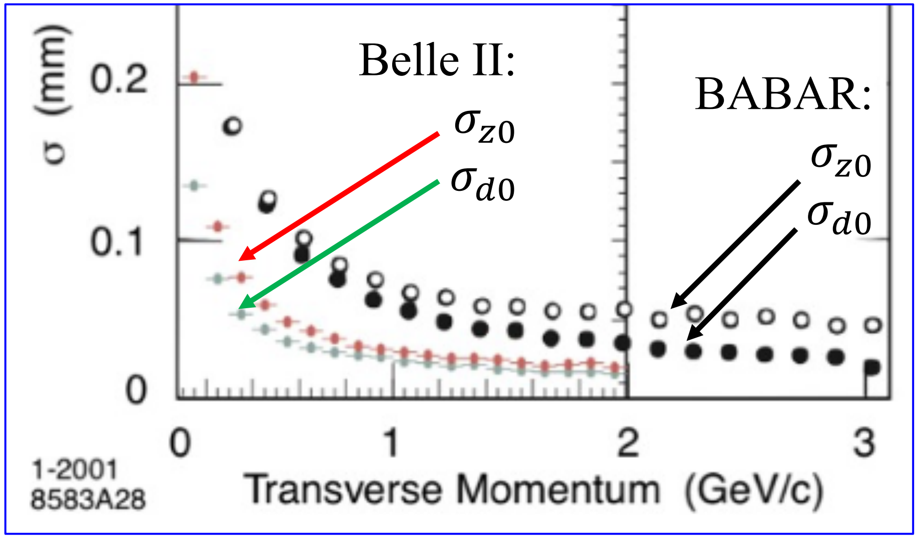
Vertexing the τ at Belle II

- Average τ flies 50 μm << @ LHCb
- But the spatial resolution > @ BABAR/Belle

Guglielmo's talk



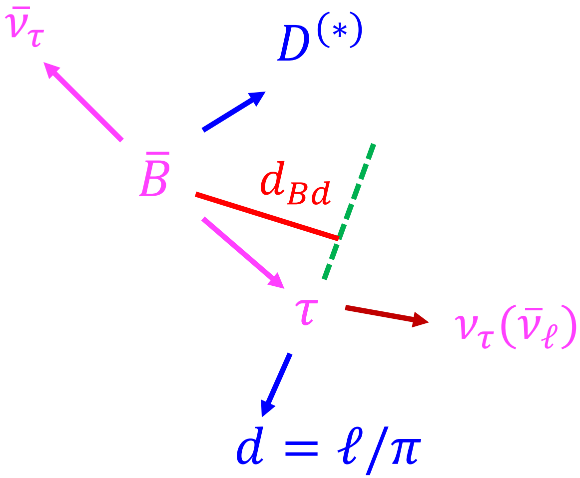
Phill's talk



- Tiny beamspot:
  - $\sigma_x = 6\ \mu m$, $\sigma_y = 0.06\ \mu m$, $\sigma_z = 150\ \mu m$

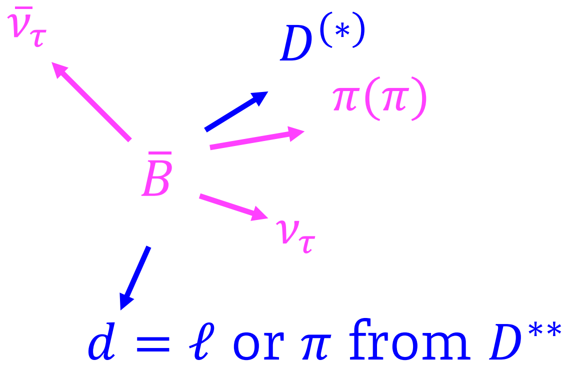
Vertexing the τ at Belle II

Signal

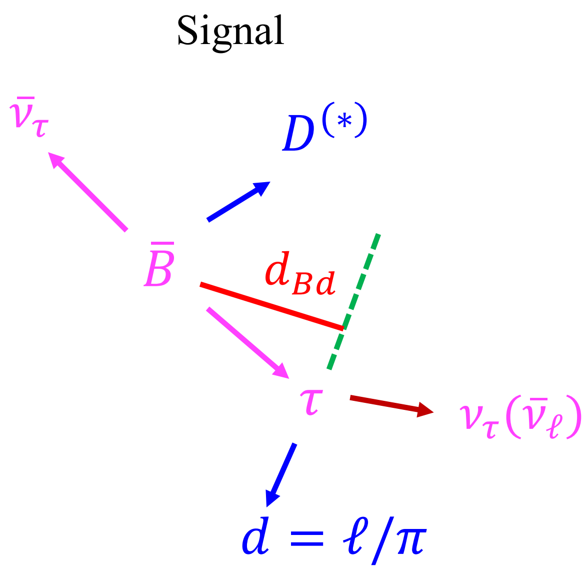


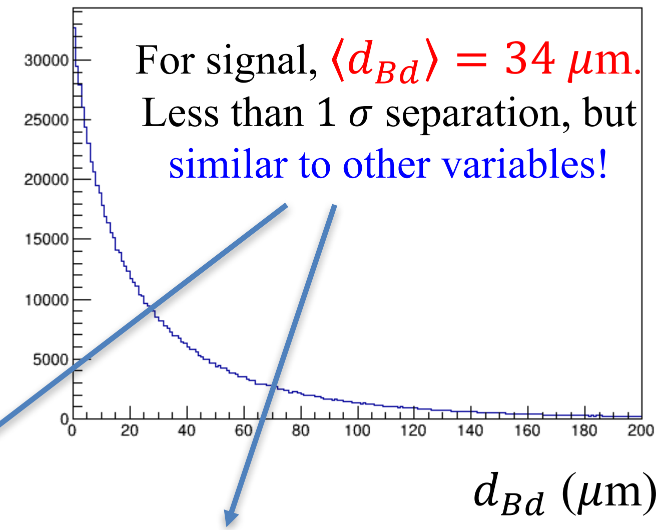
For 3π, just use vertex

$\bar{B} \to D^{**}\ell\bar{\nu}$

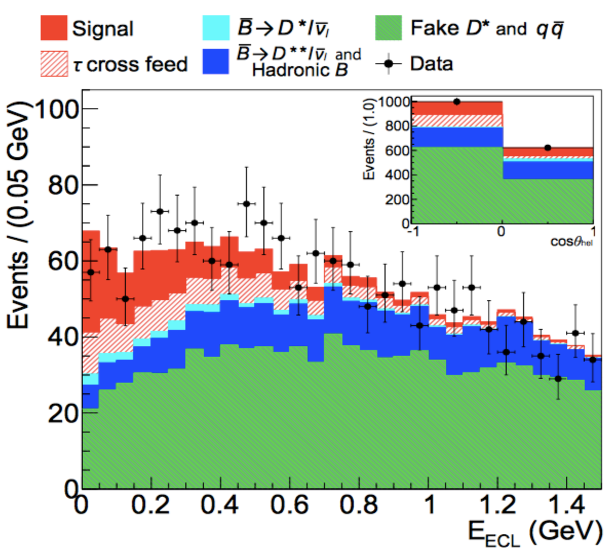


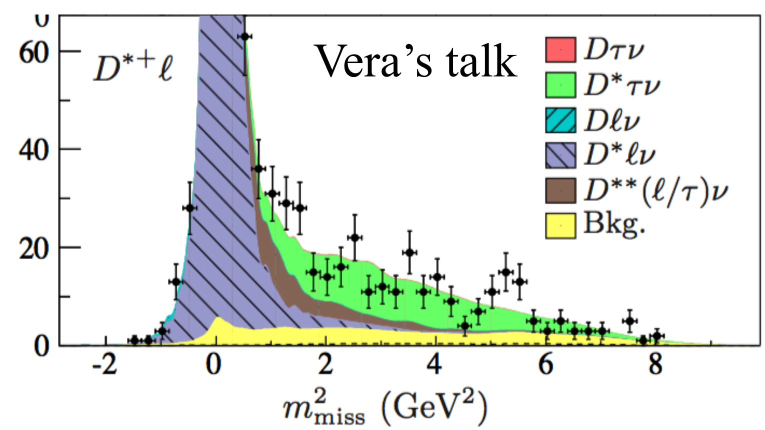
Vertexing the τ at Belle II





Shigeki's talk

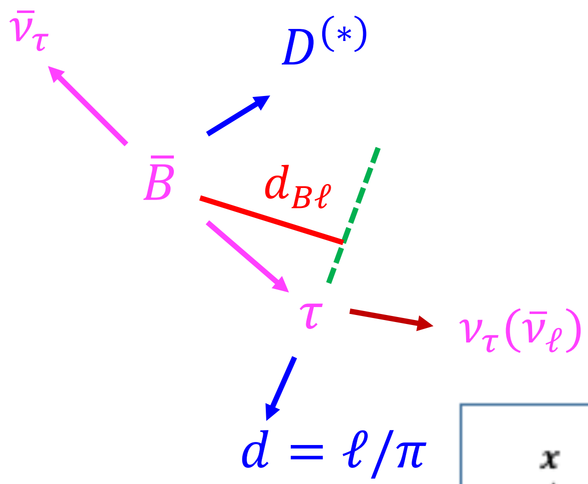




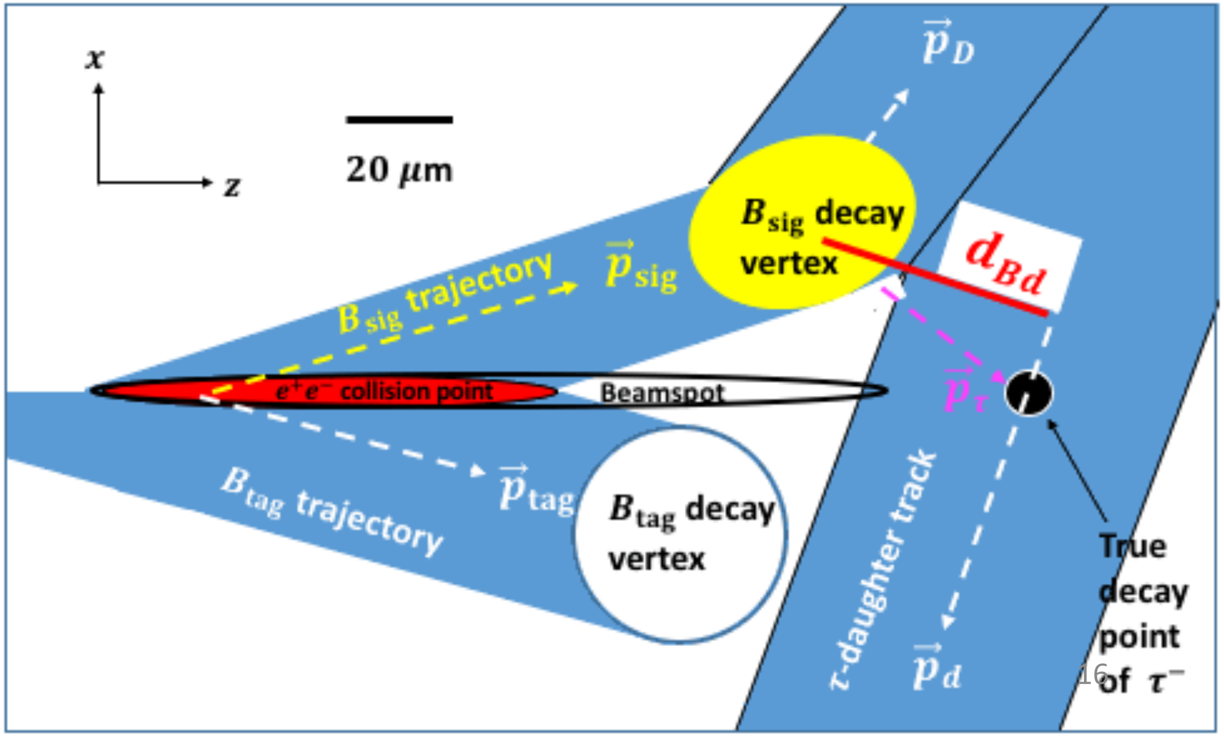
d_{Bd}: new info, background-model independent,
resolution from $\bar{B} \to D^{(*)}\ell\bar{\nu}$

Measuring d_{Bd}

Signal



Hadronic tagging,
Drawn to approximate scale



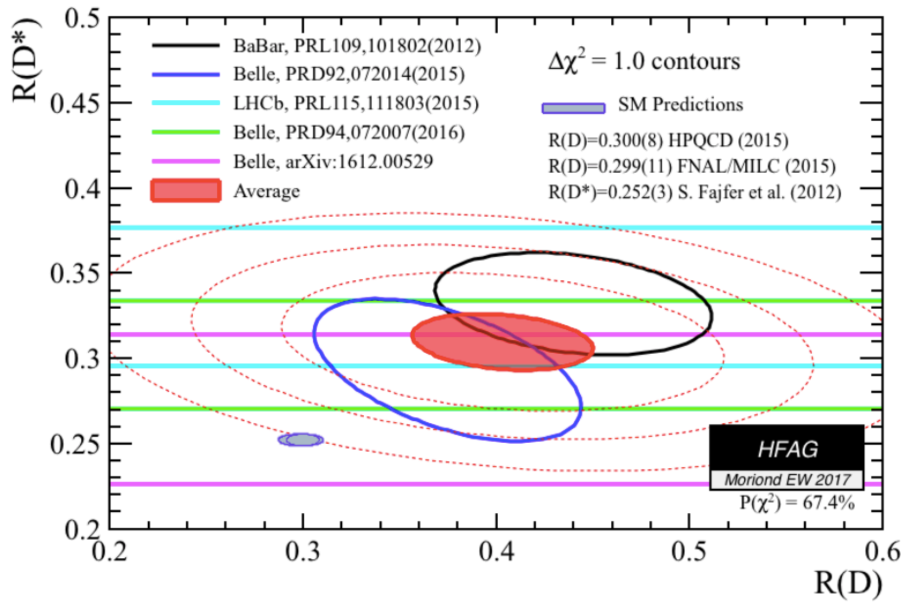
For leptonic & inclusive tagging, d_{Bd} = 3D distance between the τ daughter and the D tracks

Looks promising, currently simulating

CP asymmetry in $\bar{B} \to D^{**}\tau\bar{\nu}$

What's needed for CPV

- At least 2 interfering amplitudes with
  - different CPV and CPC phases ("weak" and "strong" phases in SM),
  - hopefully comparable magnitudes
- In the SM $b \to c\tau\bar{\nu}$ has one amplitude
- If the excess is real and due to NP, that's the 2nd amplitude!
- Maybe it has a CPV phase
- Now need:
  - Interference
  - CPC phase difference



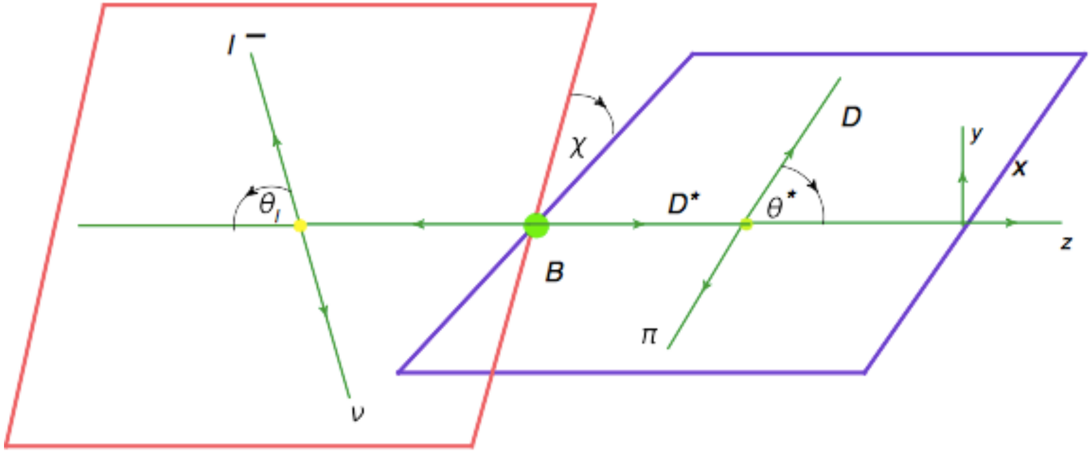
Ideas for CPV (TV) in $\bar{B} \to D^{(*)}\tau\bar{\nu}$

1302.7031 (Duraisamya & Datta)

Triple product in $\bar{B} \to D^{*}\tau\bar{\nu}$

$\hookrightarrow \pi\nu_\tau$

$\hookrightarrow D\pi$

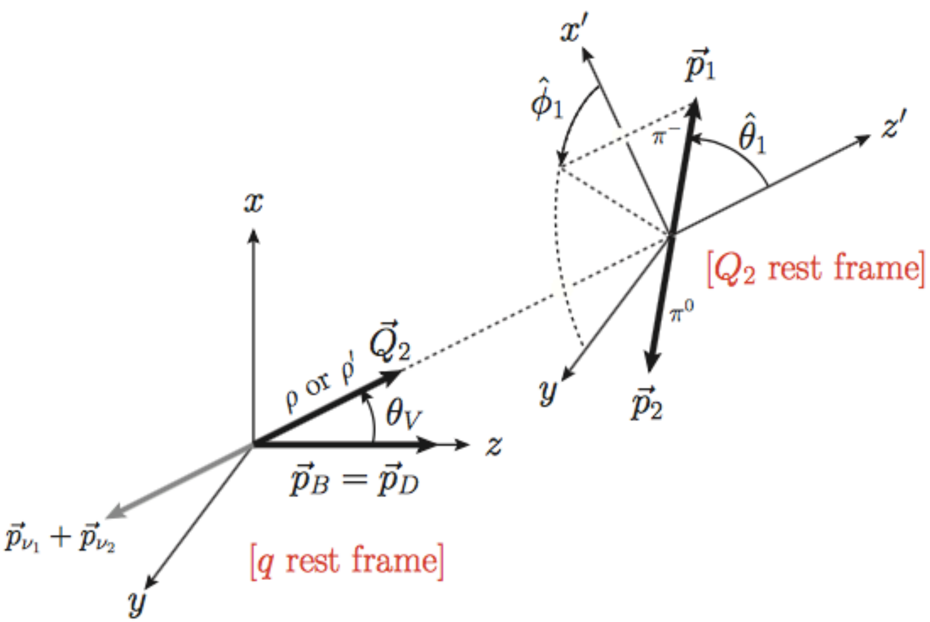


1403.5892 (Hagiwara, Nojiri, Sakaki)

$\bar{B} \to D\tau\bar{\nu}$

$\hookrightarrow \rho/a_1\nu_\tau$

$\hookrightarrow \pi's$



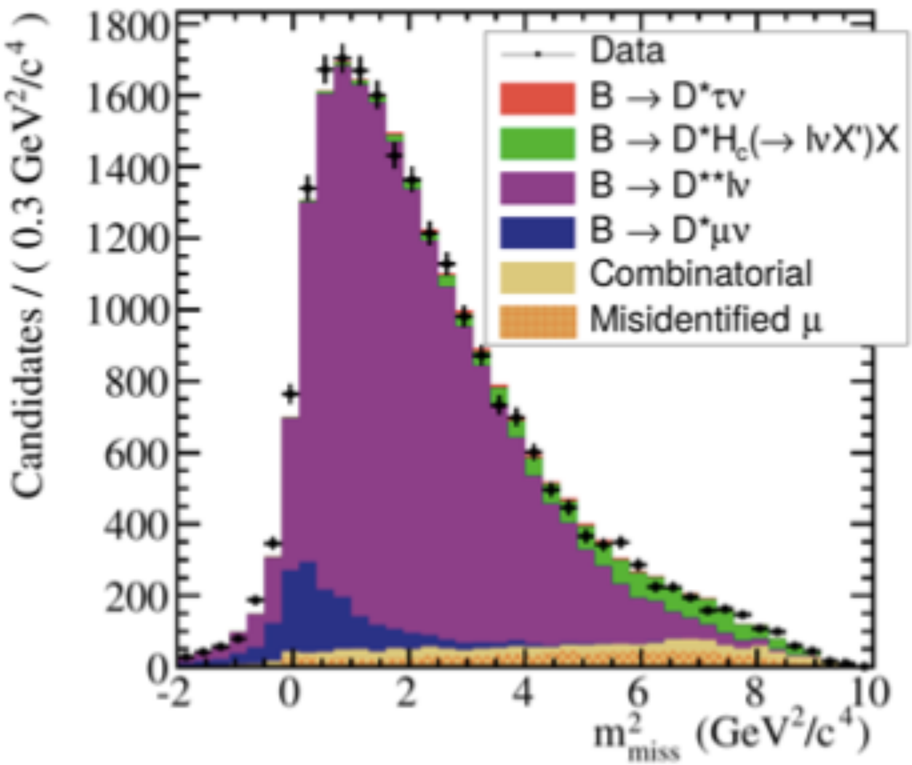
Require hadronic τ decays:

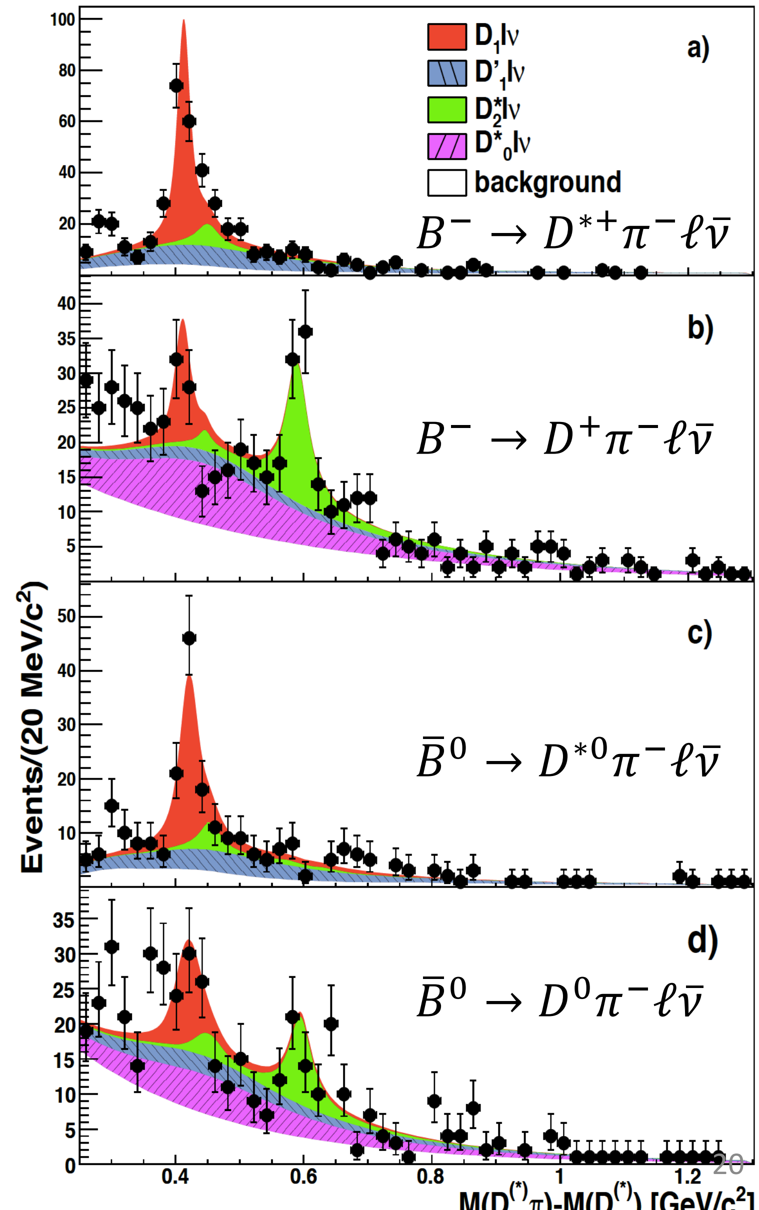
- Lose the leptonic decays
- Complicated angular analysis

Learn from $\bar{B} \to D^{**}\ell\bar{\nu}$

BABAR
0808.0528
hadronic tag

LHCb
Greg's talk





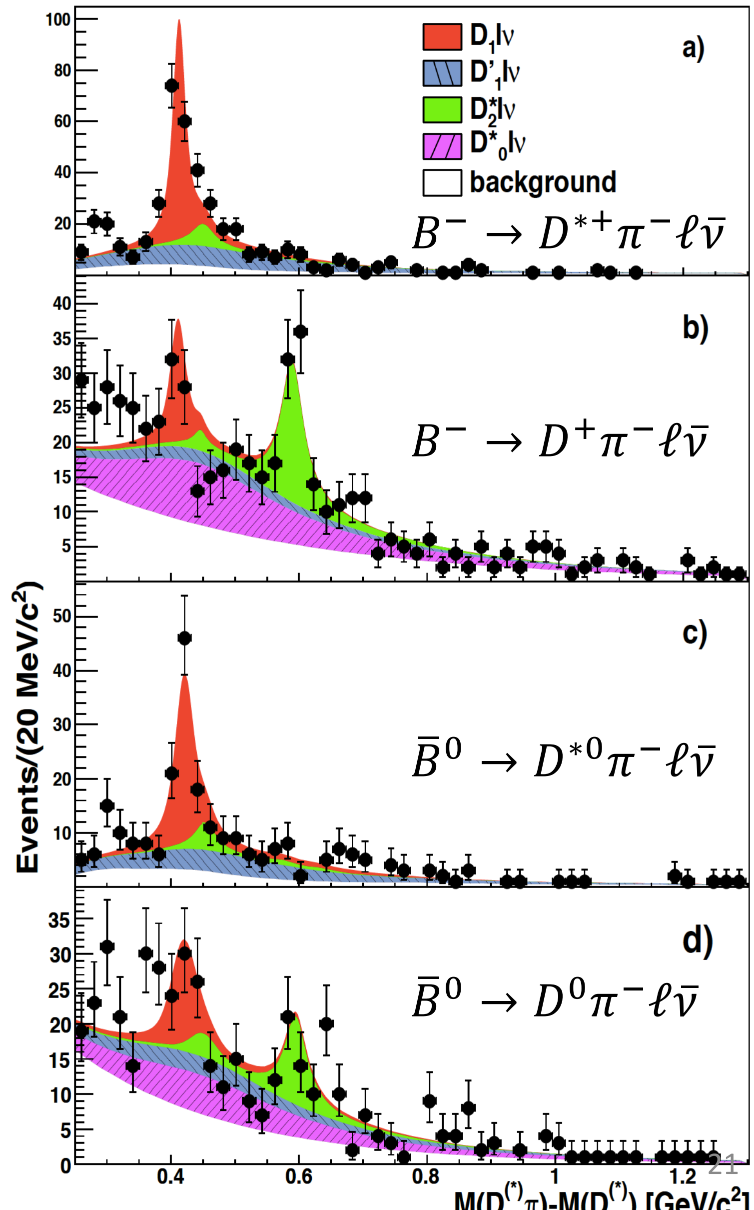
- R(D^{**}) ~ 0.06
  (1606.09300, Bernlochner, Ligeti)
  So this is like the $B^- \to D^{**}\tau\bar{\nu}$
  signal statistics @ ~8 ab^{-1}

Interference and CPC

BABAR
0808.0528
hadronic tag

- D^{**} resonances overlap significantly
- Breit-Wigner amplitudes give CPC phases that are
  - Known
  - Vary with $m(D^*\pi)$ in a known way
  - Large: vary in $\sim[-\pi, \pi)$
  - Determined from $\bar{B} \to D^{**}\ell\nu$ sample

(resonance interference has previously been exploited to obtain CPC phases)



One more condition (*)

- For simplicity, consider just two BW resonances $B_1(m)$, $B_2(m)$:

$$A(m) = \left(A_1^{SM} + A_1^{NP}\right)B_1(m) + \left(A_2^{SM} + A_2^{NP}\right)B_2(m)$$

- Rely on interference b/w $B_1(m)$ and $B_2(m)$

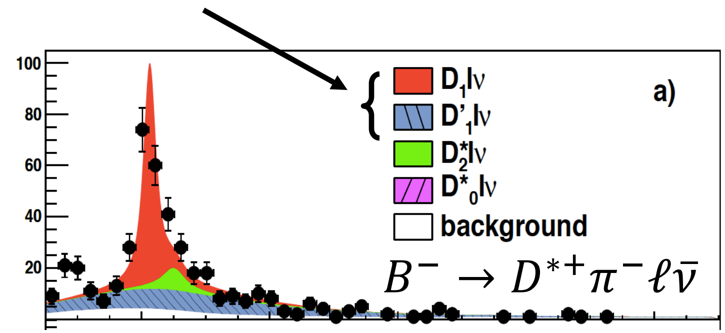
- For this to also be interference b/w A^{SM} and A^{NP}, they must contribute differently to the two resonances: $A_1^{SM}/A_2^{SM} \neq A_1^{NP}/A_2^{NP}$

What the measurement involves

- In principle, just

$$A_{CP}(m) = \frac{\Gamma(\bar{B} \to D^* \pi \tau \bar{\nu})(m) - \Gamma(B \to \bar{D}^* \pi \tau^+ \nu)(m)}{+}$$

- But then interference is only b/w the two vector resonances
  - Interf. b/w different-spin resonances integrates over angles to 0
  - Condition * relies only on the different form factors of the two vectors

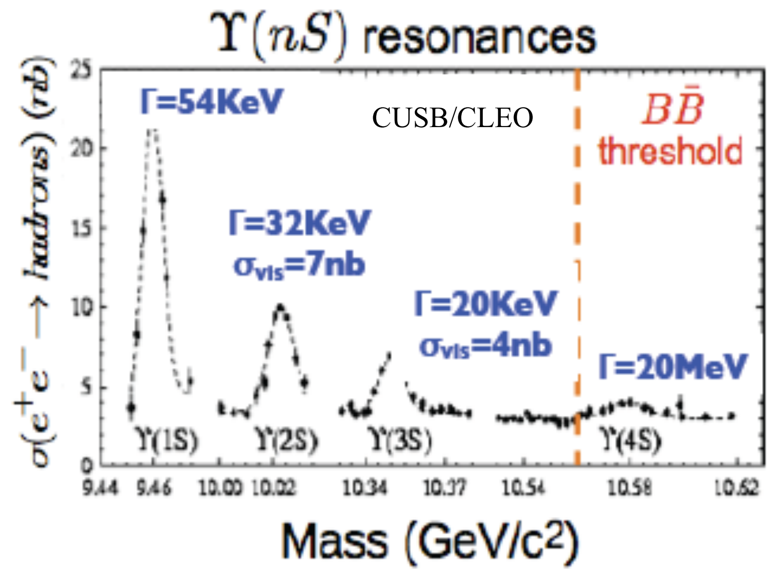


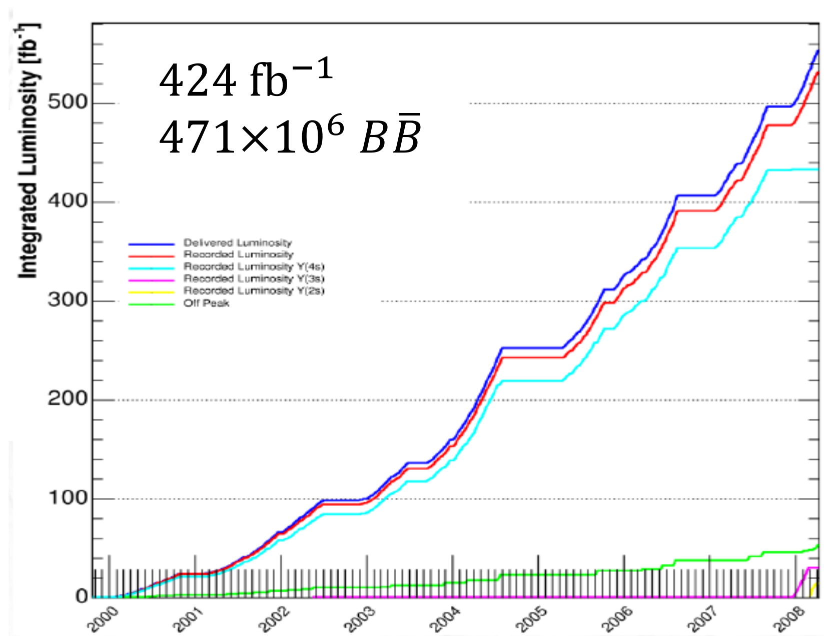
- To exploit e.g., the narrow D_2^*, must also analyze D^{**} decay angle
- For $D^{**} \to D^* \pi(\pi)$, need to include also D^* decay angle (I'm pretty sure…)
- These angles are easy to measure (unlike τ-related angles of triple products), but still complicate the analysis


Thank you

Backup slides

BABAR:
energy and dataset





The BABAR Detector