Charmless semileptonic B decays and $|V_{ub}|$ at BaBar

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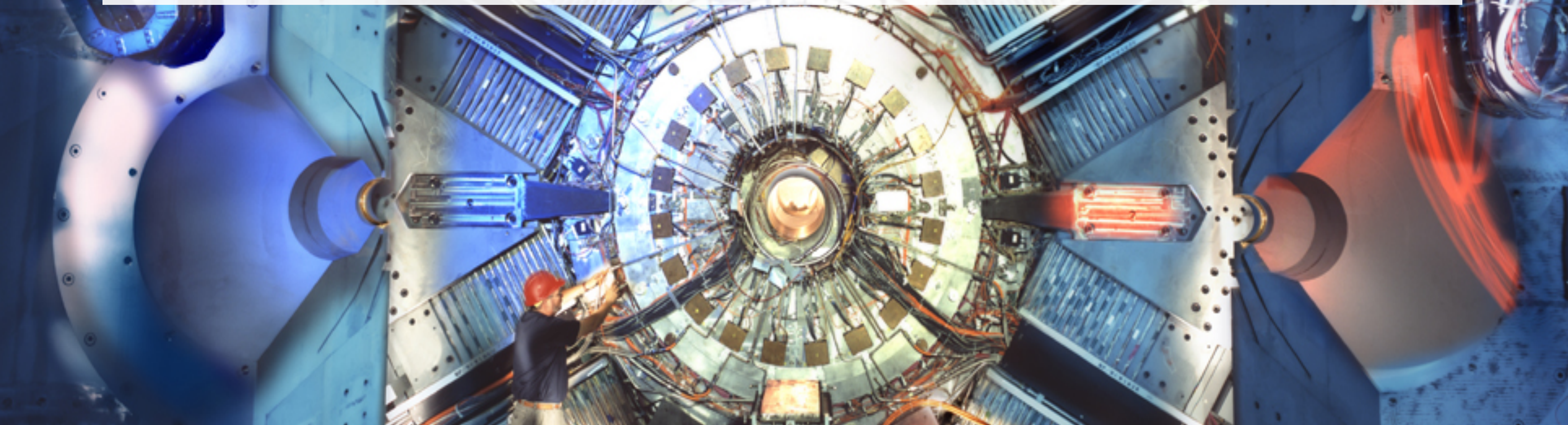
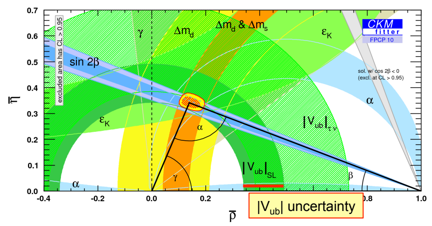
SLAC & Stanford University

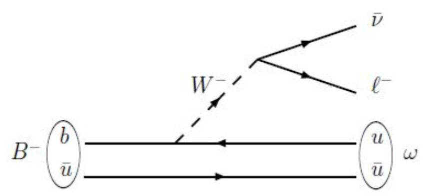


26 April 2011
UC Davis High Energy Seminar

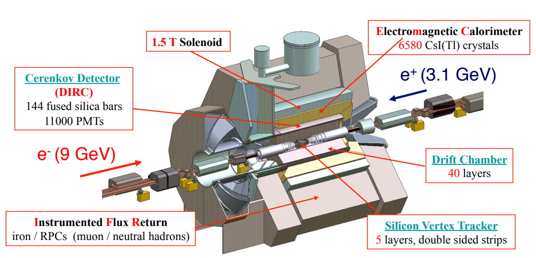
Outline



- CKM Matrix and V_{ub}



- Charmless semileptonic decay rates



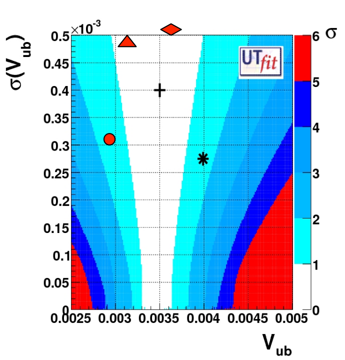
- BaBar experiment

combined fit to 4 channels

- $B\rightarrow(\pi/\rho)l\nu$ decays PRD 83, 032007 (2011)

first measurement of q^2 spectrum

- $B\rightarrow\omega l\nu$ decays (combinatoric-ω background from data)



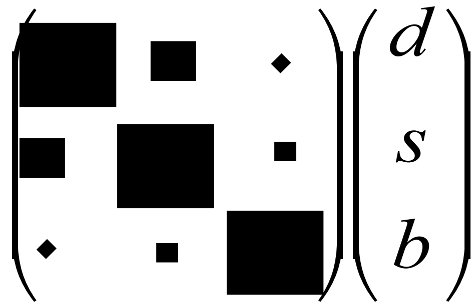
- Measurement of $|V_{ub}|$

new fit reduces $|V_{ub}|$ theory error

CKM matrix and V_{ub}

weak eigen-states	CKM matrix	mass eigen-states

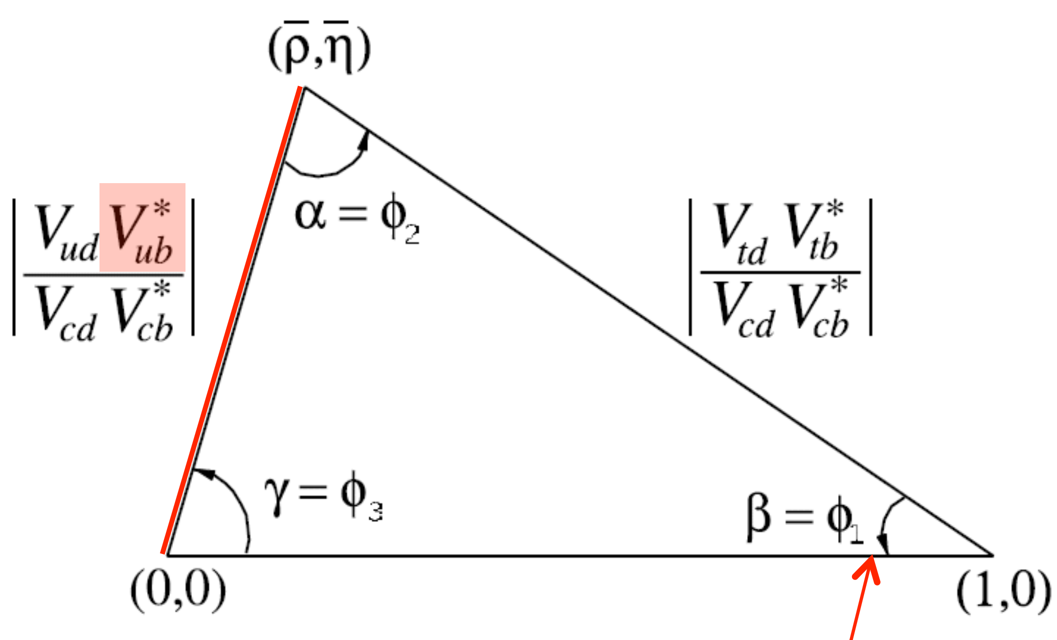
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} =$$



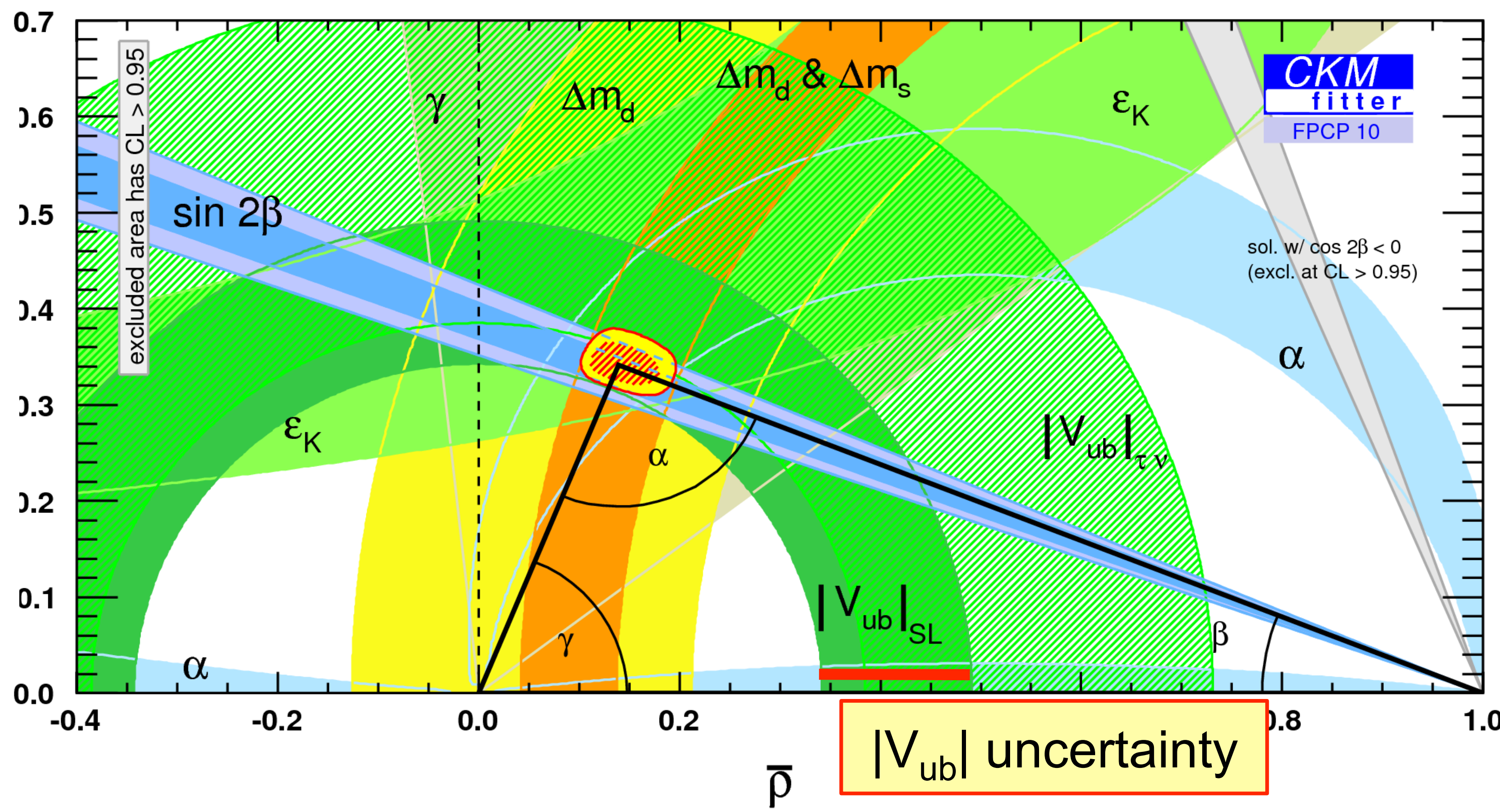
b→cW⁻ is Cabibbo-favored over b→uW⁻

$$V_{CKM}^{T*} V_{CKM} = 1 \Rightarrow$$
$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

unitarity implies a closed triangle



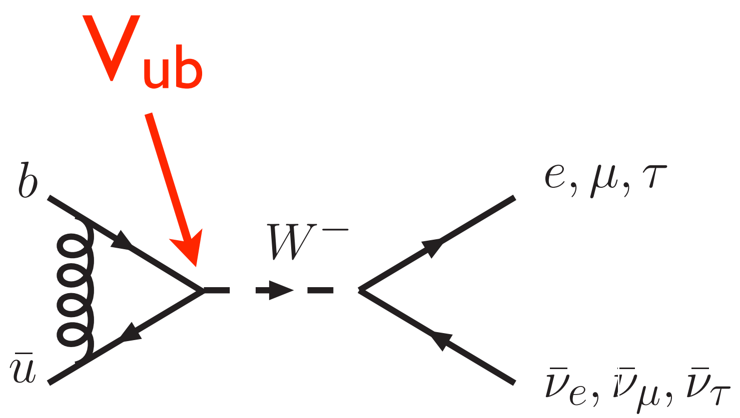
β known within 1° from B→J/ψK_S



$|V_{ub}|$ uncertainty

$b \to uW^-$ amplitude α V_{ub}

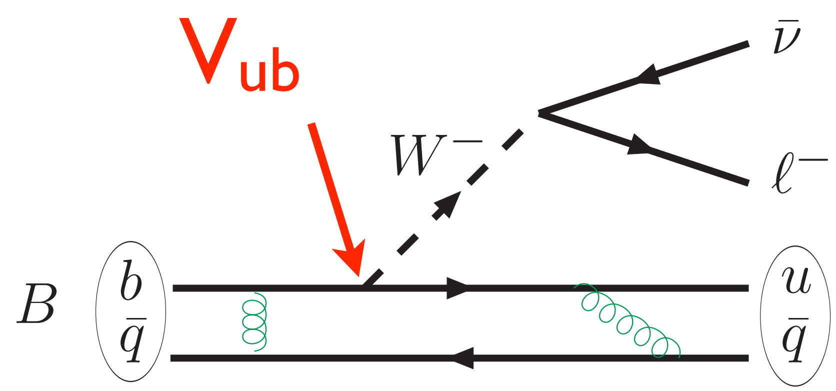
weak doublet: $\begin{pmatrix} u \\ d' \end{pmatrix} = \begin{pmatrix} u \\ V_{ud}d + V_{us}s + V_{ub}b \end{pmatrix}$



Leptonic

Helicity-suppressed

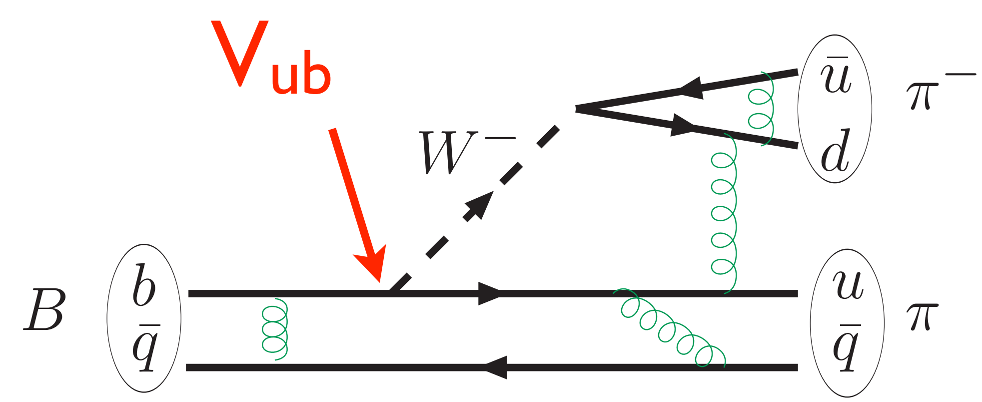
$\mathcal{B}(B^+ \to \tau^+ \nu) = 18(1 \pm 0.28) \times 10^{-5}$



Semileptonic

Leptonic and hadronic currents factorize

$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu) = 7.7(1 \pm 0.16) \times 10^{-5}$



Hadronic

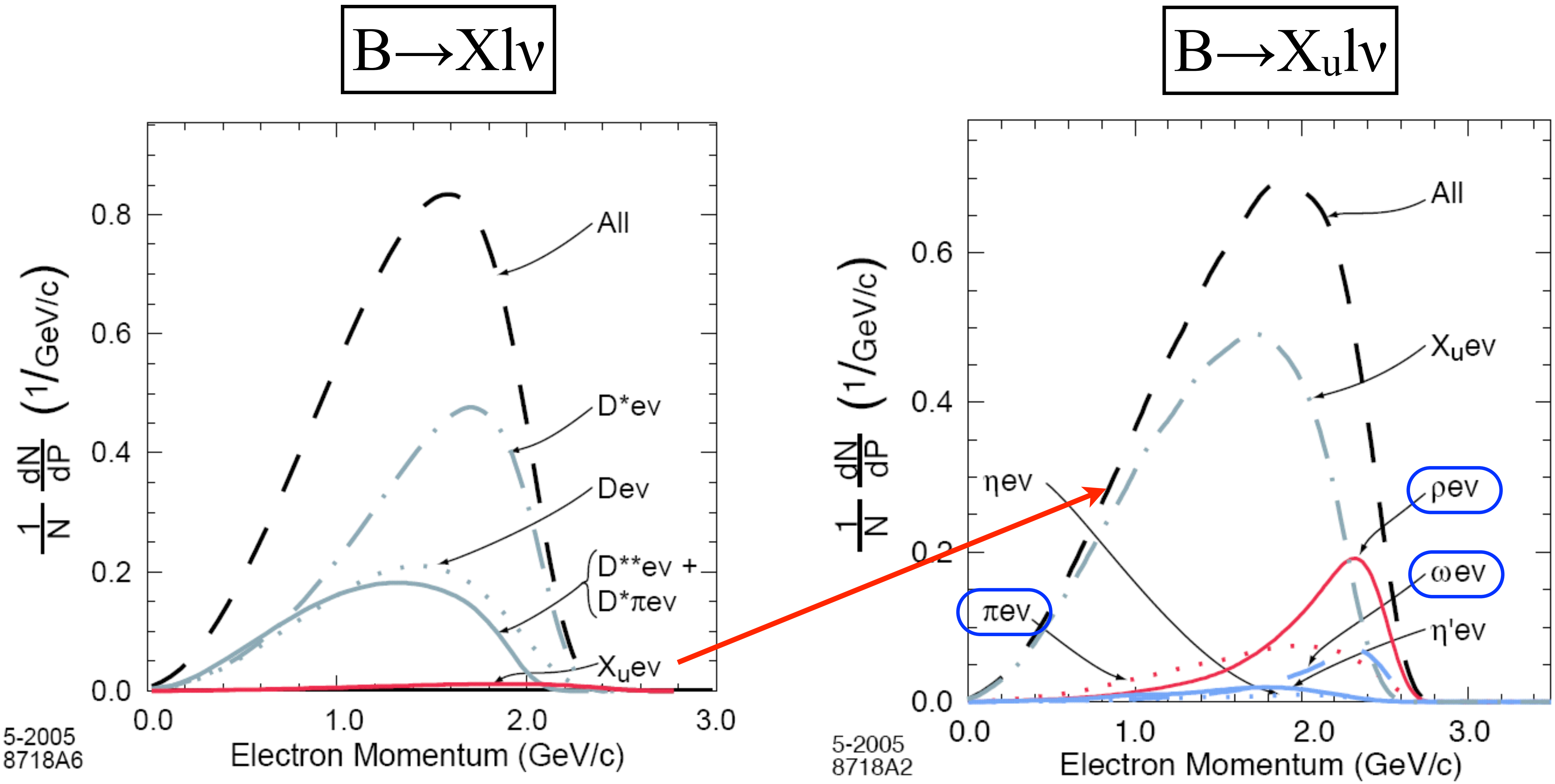
Complex QCD interactions

$\mathcal{B}(B^+ \to \pi^+ \pi^0) = 0.57(1 \pm 0.09) \times 10^{-5}$

experimentally difficult

theoretically difficult

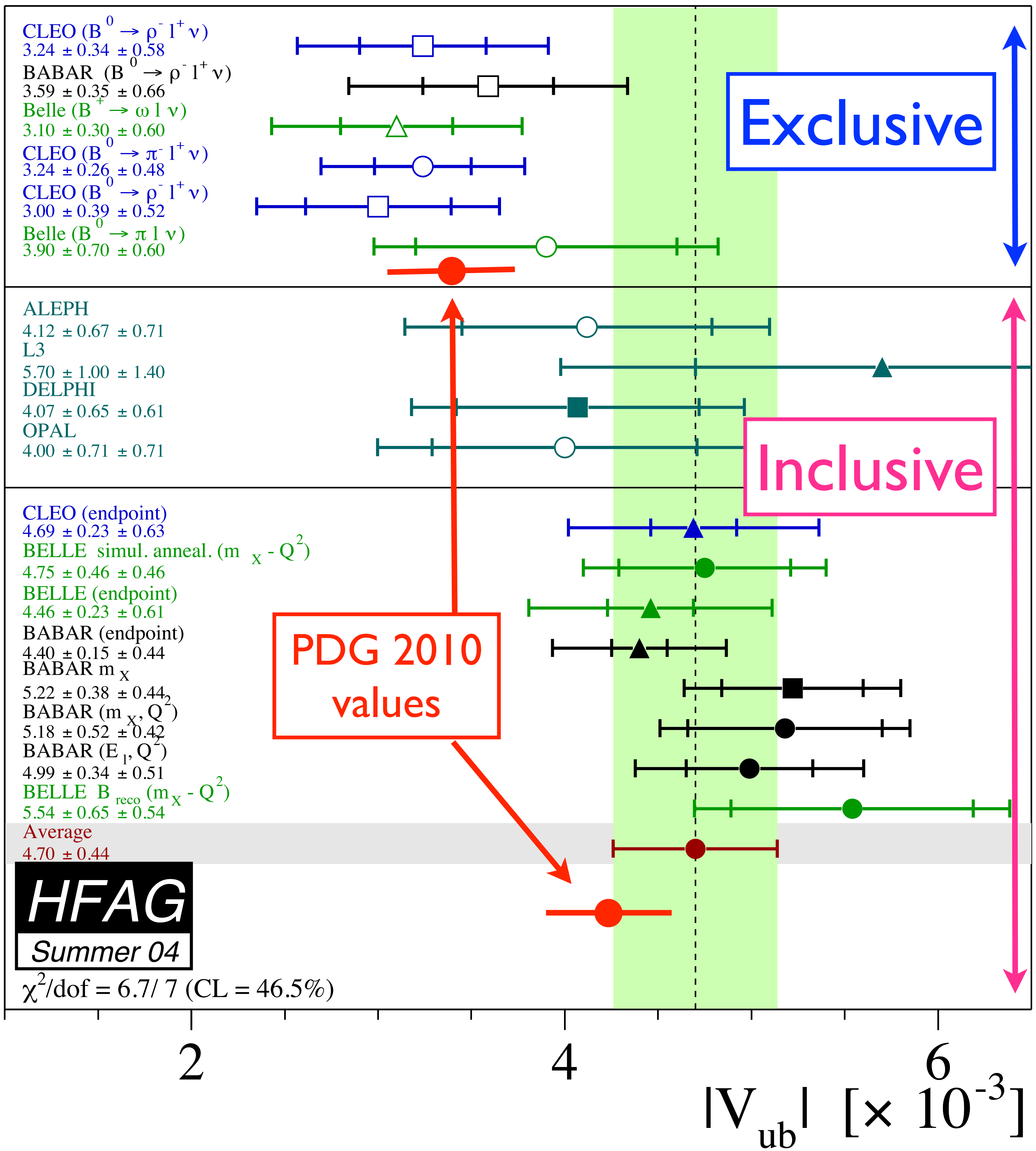
Semileptonic p_l spectra

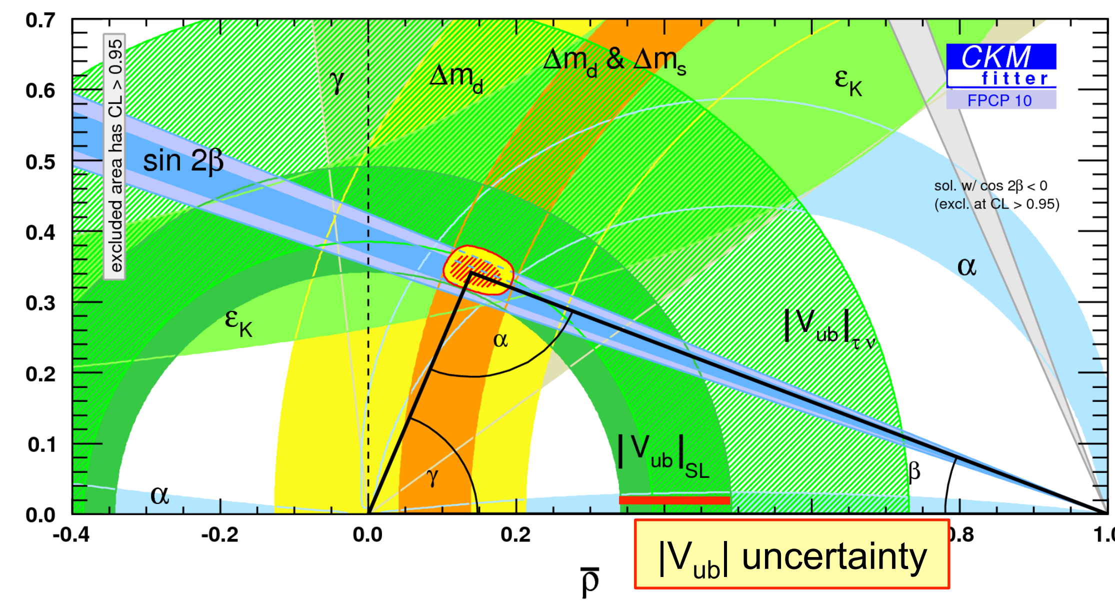


Phys. Rev. D73:012006, 2006

Challenge	Inclusive $\|V_{ub}\|$: reconstruct lep. only	Exclusive $\|V_{ub}\|$: reconstruct lep. & X_u
experimental	model large $B \to X_c l \nu$ background	better bkgd rejection; lower rates
theoretical	calculate partial decay rate in a region where background is suppressed	calculate hadronic current

Inclusive vs. exclusive $|V_{ub}|$



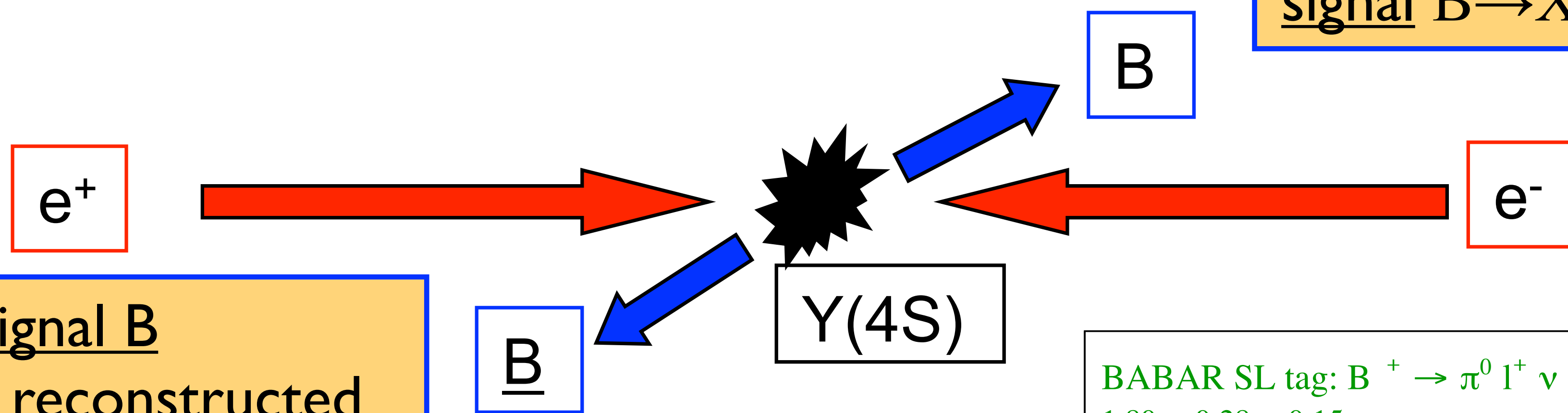


"The difference between the values for $|V_{ub}|$ obtained from inclusive and exclusive decays has persisted for many years, despite significant improvements in both theory and experiment for both methods. How to reconcile these results remains an intriguing puzzle."

-Kowalewski and Mannel, "Determination of V_{cb} and V_{ub}," PDG 2010

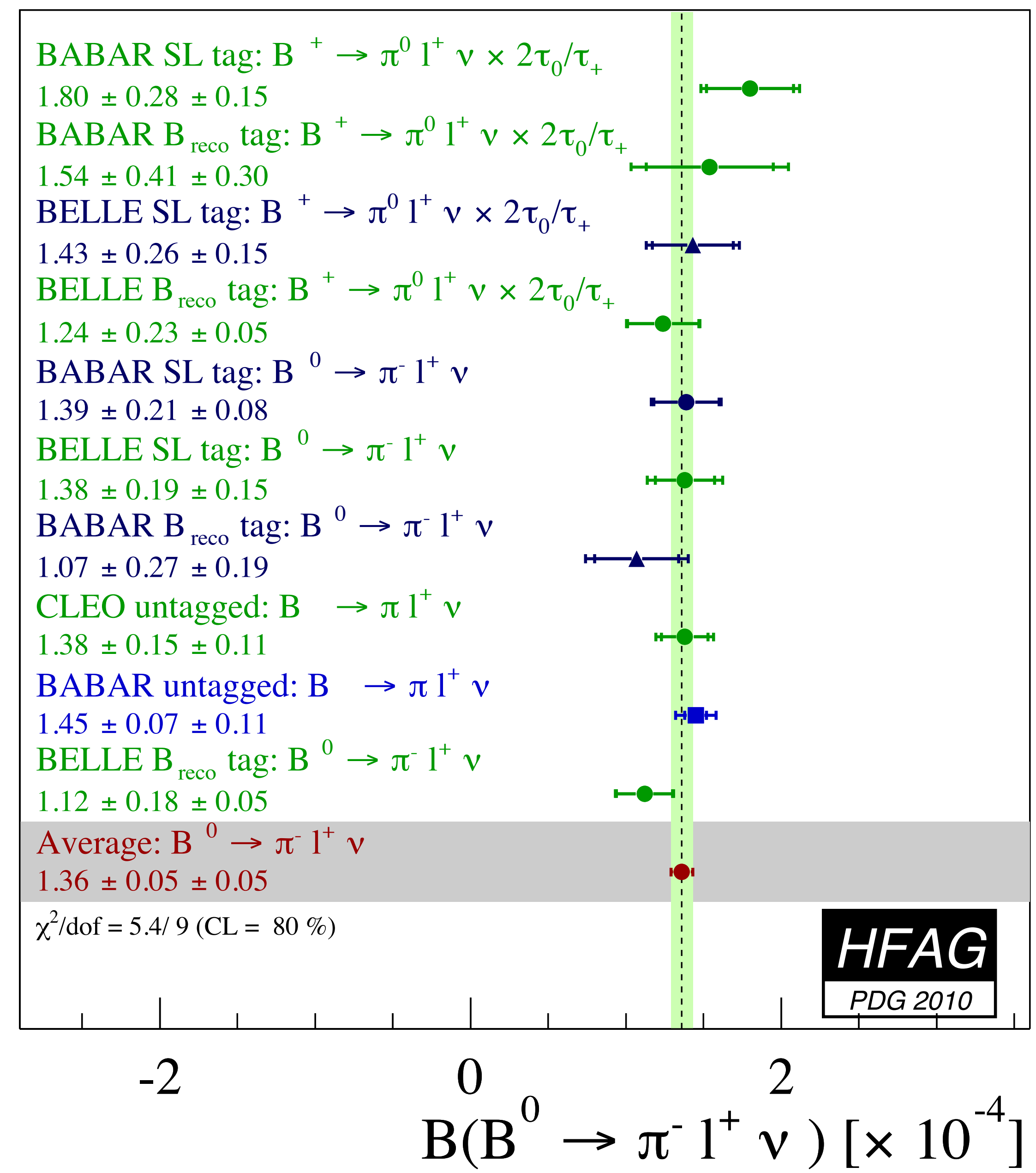
Exclusive $|V_{ub}|$: tagged vs. untagged

signal $B \to X_u l \nu$ is reconstructed



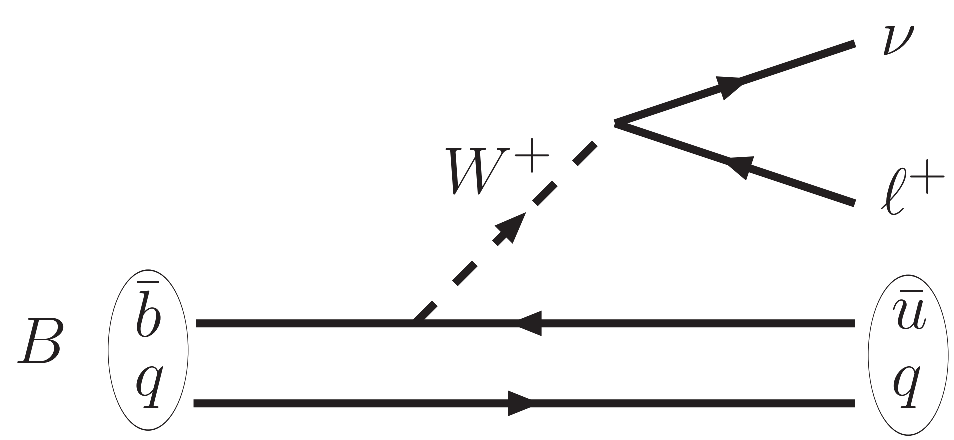
non-signal B

- untagged: not reconstructed
- tagged: reconstructed as
  - $B \to X l \nu$ (ε = 1-3%)
  - $B \to$ hadrons (ε = 0.3-0.5%)



good agreement between tagged and untagged BF's

Semileptonic B decay rate



π, ρ, ω

vector: ρ, ω

$$\frac{d\Gamma}{dq^2} = |V_{ub}|^2 \frac{G_F^2 |\vec{p}_\rho| q^2 m_B^2}{96\pi^3} \times (|H_0|^2 + |H_+|^2 + |H_-|^2)$$

$$H_i(q^2) = f(A_1, A_2, V, q^2, |\vec{p}_\rho|)$$

pseudo-scalar: π

$$\frac{d\Gamma}{dq^2} = |V_{ub}|^2 \frac{G_F^2 |\vec{p}_\pi|^3}{24\pi^3} |f_+(q^2)|^2$$

Measure $d\Gamma/dq^2$

Need theory to calculate form factors f_+ or A_1, A_2, V

QCD calculation of form factors

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(q^2_{min}, q^2_{max})}{\tau_+ \,\Delta\zeta(q^2_{min}, q^2_{max})}}$$

$$\Gamma = |V_{ub}|^2 \Delta\zeta$$

$$\Delta\zeta(q^2_{\rm min}, q^2_{\rm max}) = \frac{G_F^2}{24\pi^3}\int_{q^2_{\rm min}}^{q^2_{\rm max}} |\vec{p}_\pi|^3 |f_+(q^2)|^2 dq^2$$

$$\Delta\zeta(q^2_{\rm min}, q^2_{\rm max}) = \frac{G_F^2 m_B^2}{96\pi^3}\int_{q^2_{\rm min}}^{q^2_{\rm max}} |\vec{p}_\rho| q^2 (|H_0|^2 + |H_+|^2 + |H_-|^2) dq^2$$

Lattice QCD

HPQCD: PRD 73, 074502 (2006)
FNAL: PRD 79, 054507 (2009)

- unquenched calculations available
- none yet for vector semileptonic decays
- accurate at high q^2

Light cone sum rules

Ball/Zwicky: PRD 71, 014015 (2005)

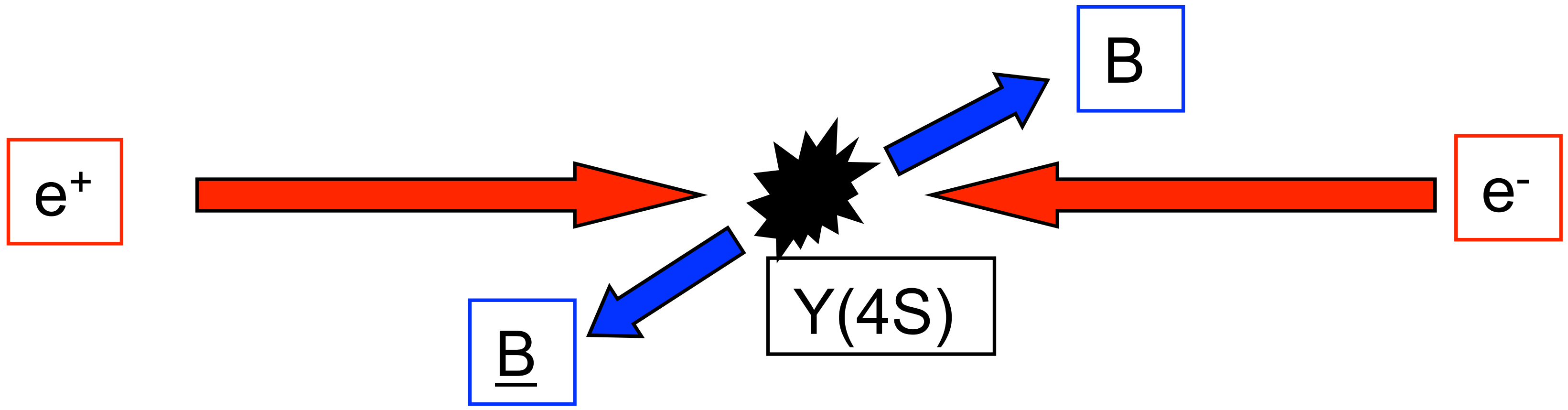
- use QCD sum rules with twist expansions
- accurate at low q^2

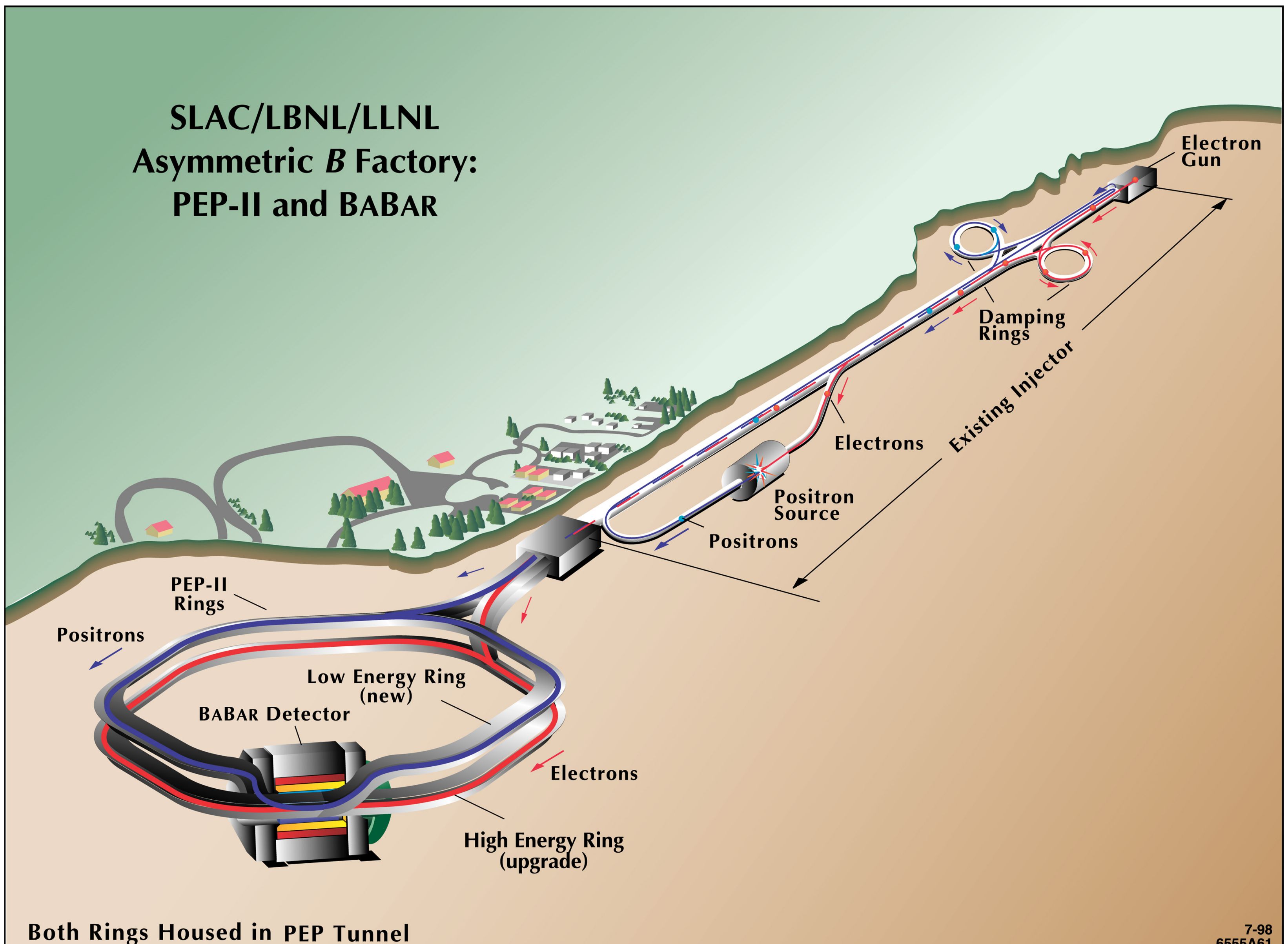
Quark model calculations

ISGW2: PRD 52, 2783 (1995)

- postulates forms for meson wave functions
- normalized at q^2_{max}

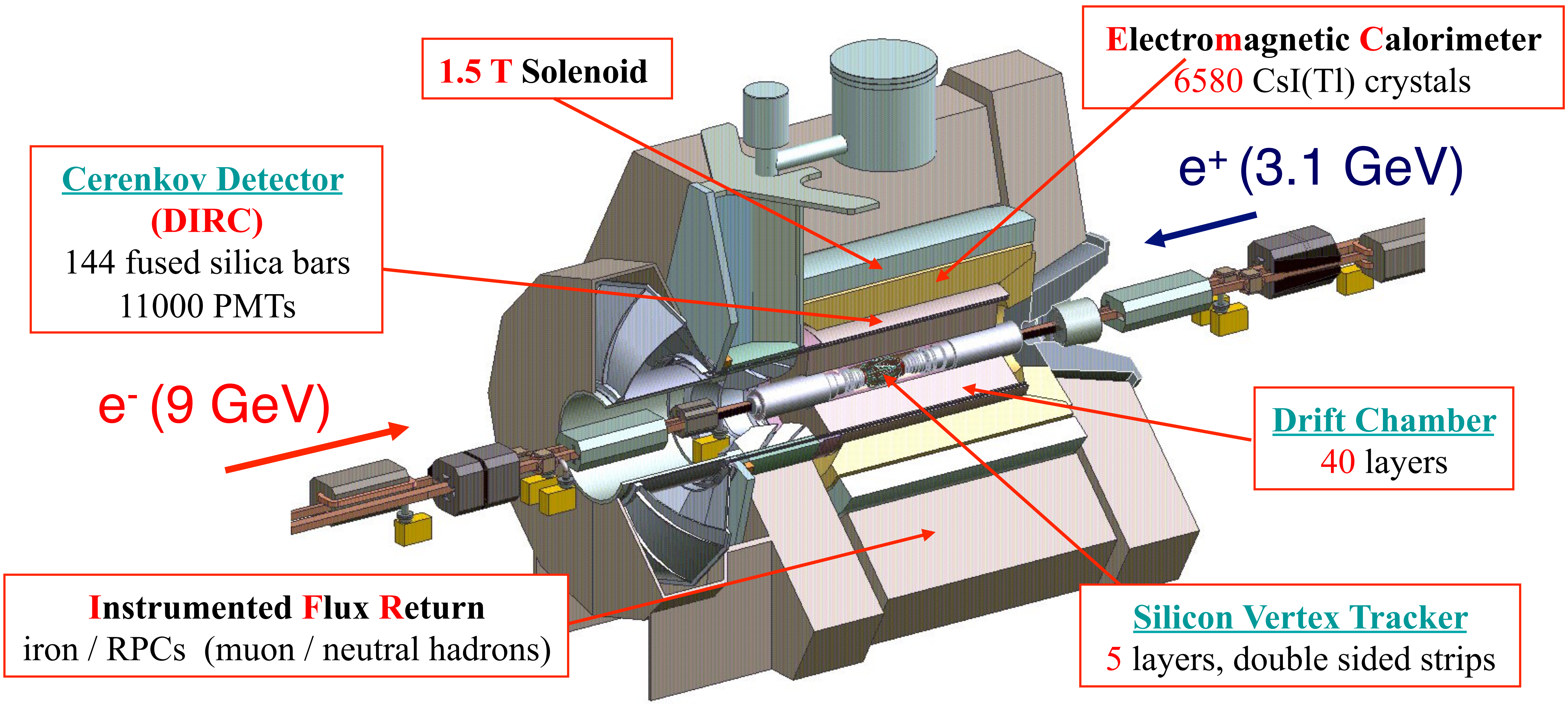
PEP-II e^+e^- Collider





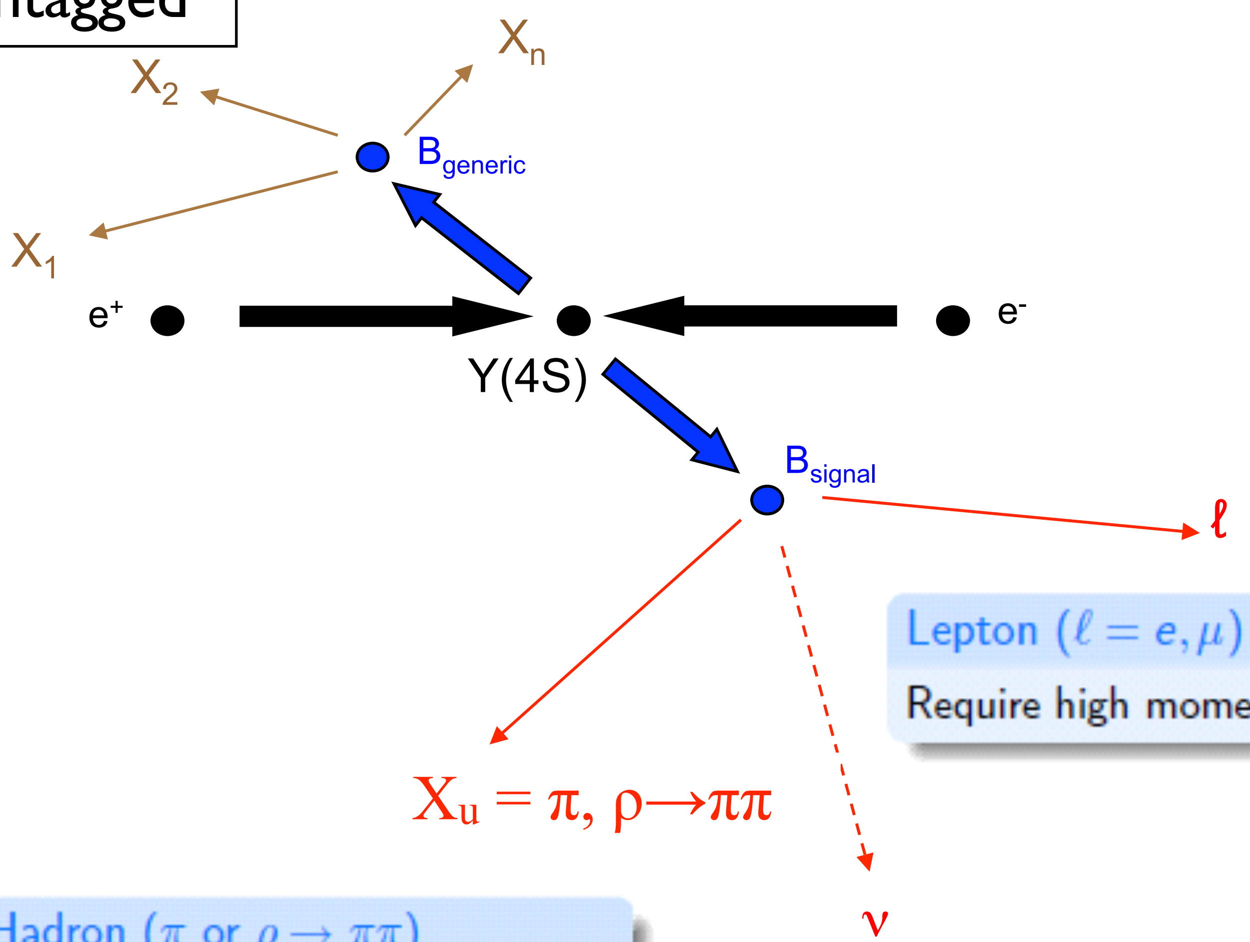
- c.m. energy: 10.58 GeV = $m\Upsilon(4S)$
- Lorentz boost ($\beta\gamma$ =0.56) reduces hermeticity
- 413 fb^{-1} collected on-resonance: 454 million BB events in Runs 1-6
- 41 fb^{-1} collected off-resonance

BaBar detector



$B \to (\pi/\rho) l \nu$ selection

untagged



Lepton ($\ell = e, \mu$)

Require high momentum.

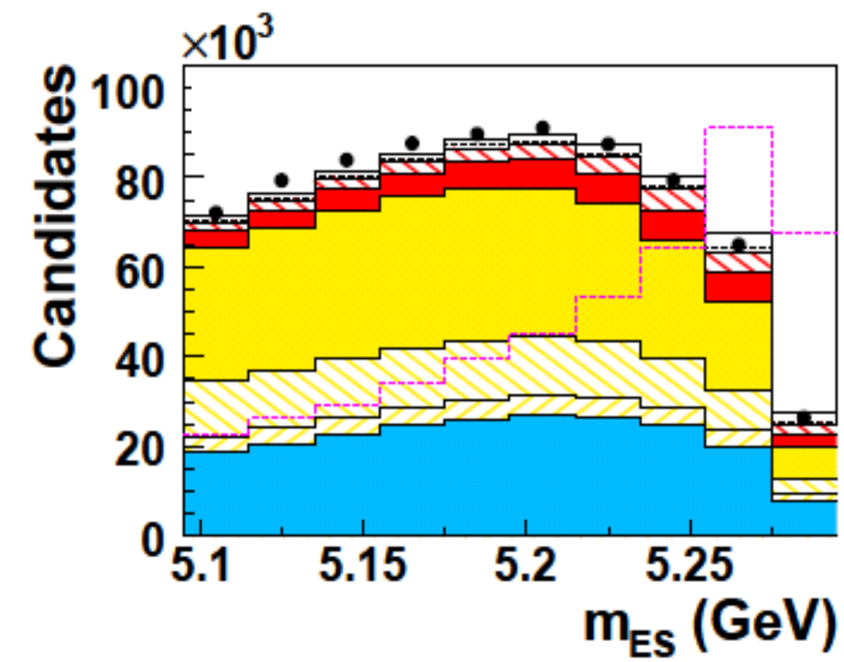
Hadron (π or $\rho \to \pi\pi$)

$|m_{\pi\pi} - m_\rho^{PDG}| \leq 1$ full width

Neutrino

Reconstructed from missing 4-momentum of event:

$(E_\nu, \vec{p}_\nu) = (E_{miss}, \vec{p}_{miss}) = (E_{e^+e^-}, \vec{p}_{e^+e^-}) - (\sum_i E_i, \sum_i \vec{p}_i)$



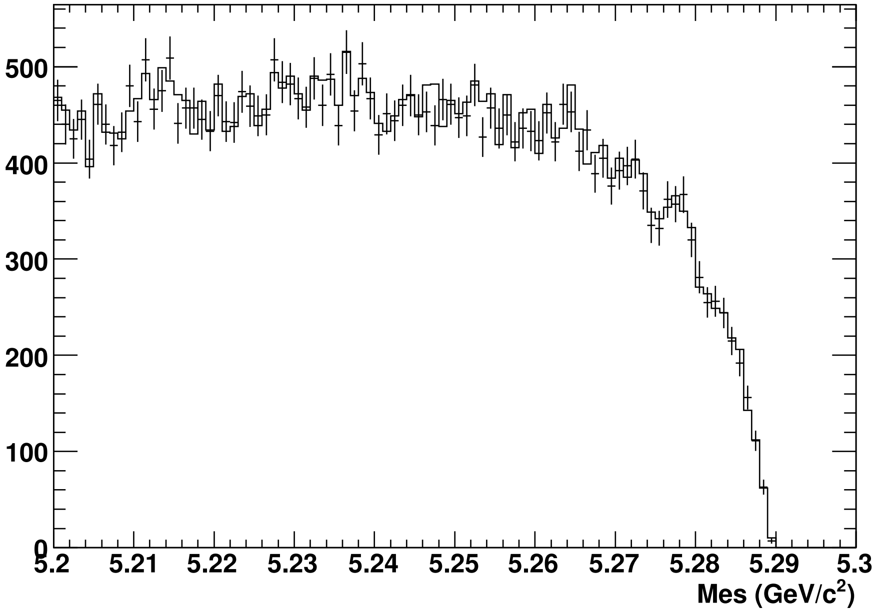
$B^0 \to \pi^- l^+ \nu$ after preselection; neural nets further enhance signal

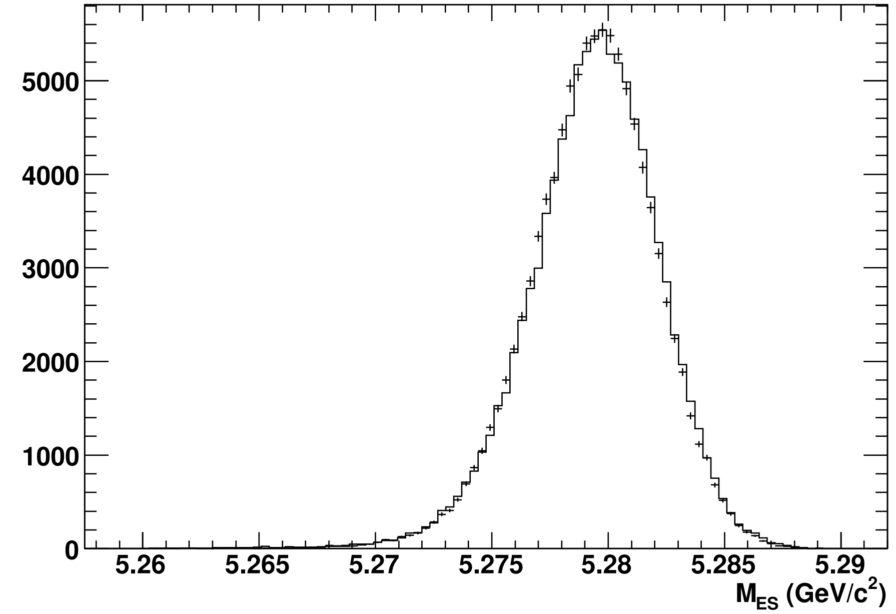
Sample components	
Signal	small relative to bkgd
$B \to X_u l \nu$	similar to signal
other $B\bar{B}$	dominant background
$e^+e^- \to q\bar{q}$ $(q = u,d,s,c)$	off-resonance data used to correct fit variable shapes

Signal selection variables

background

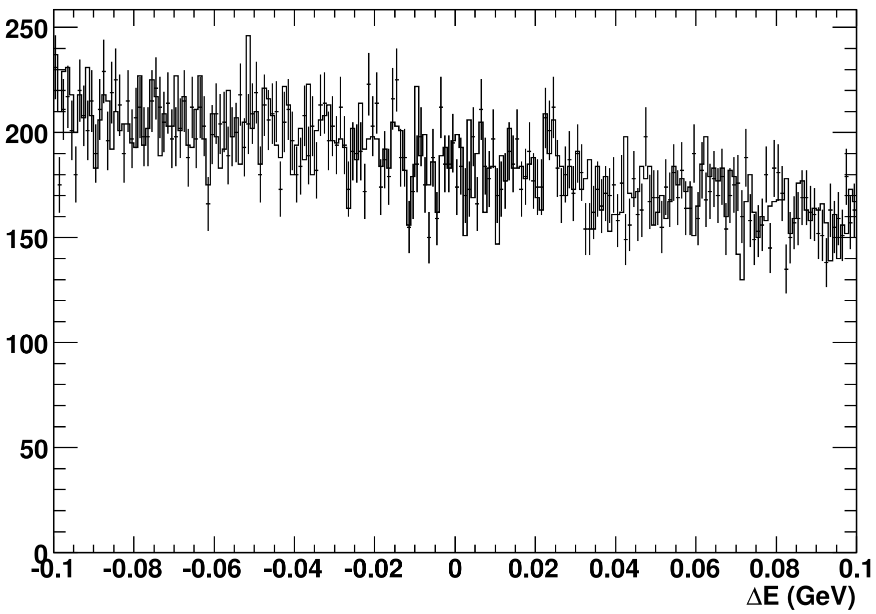
signal

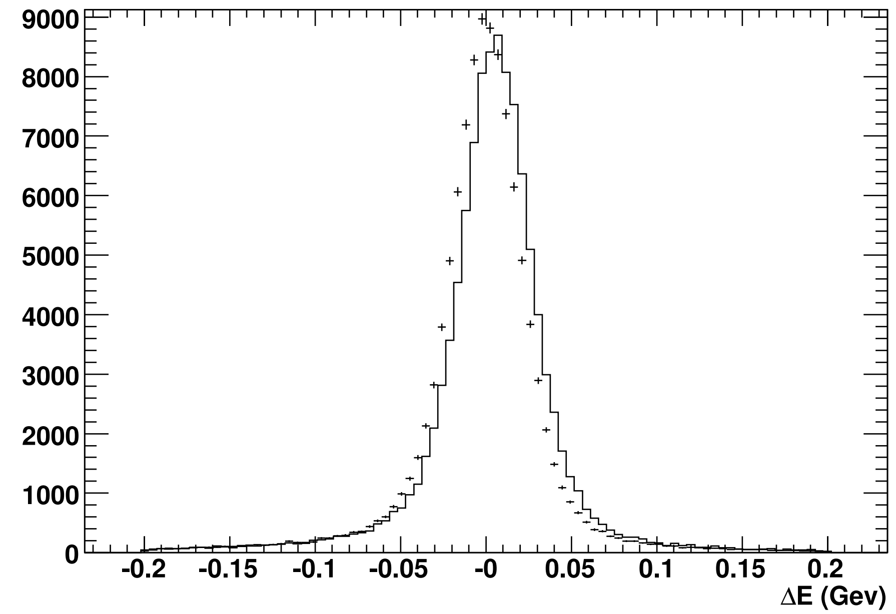




$$m_{\rm ES} = \sqrt{\frac{(s/2 + \vec{p}_B \cdot \vec{p}_{e^+e^-})^2}{E^2_{e^+e^-}} - p_B^2}$$

signal peaks at
$m_{ES} = m_B = 5.28$ GeV/c^2





$$\Delta E = \frac{P_B \cdot P_{e^+e^-} - s/2}{\sqrt{s}}$$

signal peaks at $\Delta E = 0$

plots from $B^0 \rightarrow K^0 K^0$bar BaBar analysis

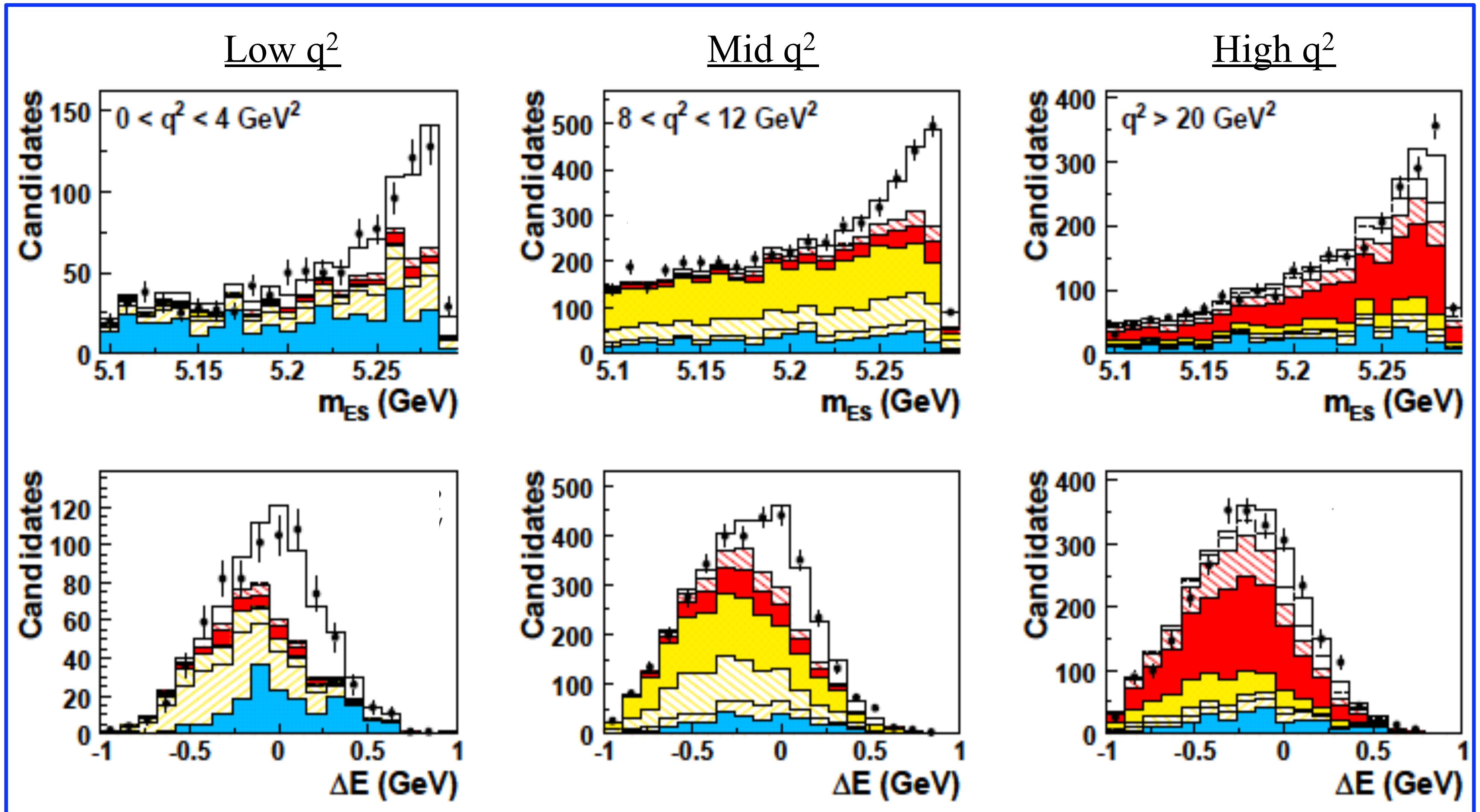
m_{ES} and ΔE test consistency of reconstructed B with a true B

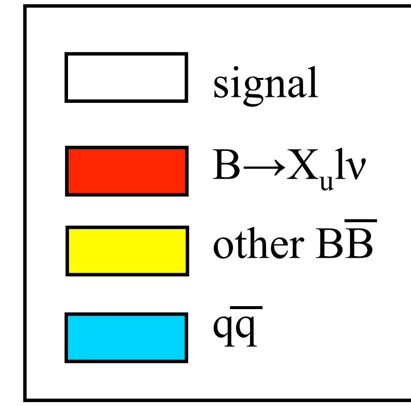
$B \to \pi l \nu$ branching fraction

binned ML fit in $m_{\rm ES}$, ΔE, and q^2 for $B \to (\pi^\pm/\pi^0/\rho^\pm/\rho^0)\ell\nu$ simultaneously, with isospin constraint

$B^0 \to \pi^- \ell^+ \nu$ in 6 q^2 bins

Backgrounds vary with q^2.





$$m_{\rm ES} = \sqrt{\frac{(s/2 + \vec{p}_B \cdot \vec{p}_{e^+e^-})^2}{E^2_{e^+e^-}} - p_B^2}$$

signal peaks at $m_{ES} = m_B = 5.28$ GeV/c^2

$$\Delta E = \frac{P_B \cdot P_{e^+e^-} - s/2}{\sqrt{s}}$$

signal peaks at $\Delta E = 0$

Single mode yields →

4-mode yield used to find BF →

$B^0 \to \pi^- \ell^+ \nu$	7181 ± 279
$B^+ \to \pi^0 \ell^+ \nu$	3446 ± 208
$B \to \pi \ell \nu$	10604 ± 376

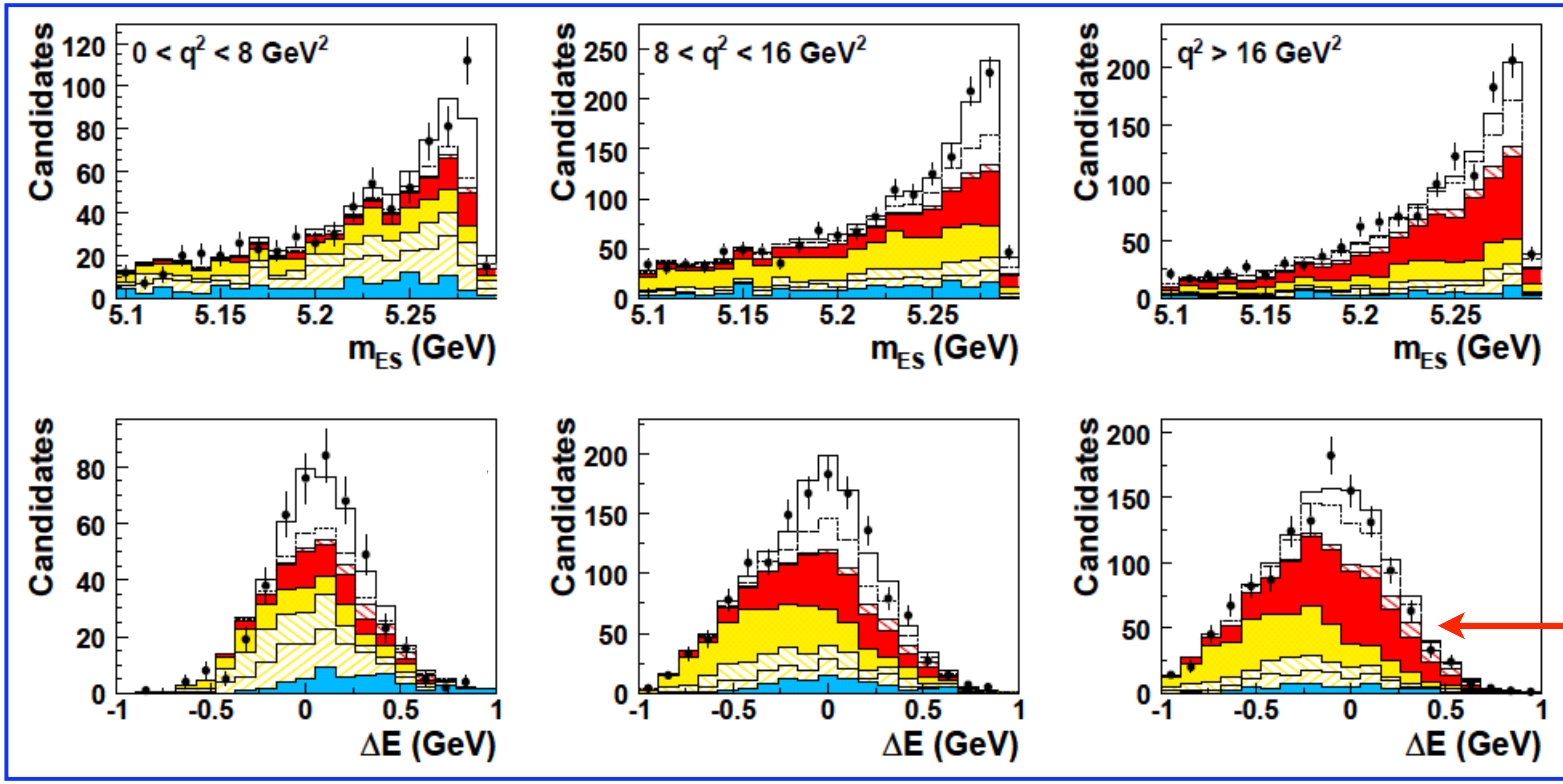
$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.41 \pm 0.05_{stat} \pm 0.07_{syst}) \times 10^{-4}$$

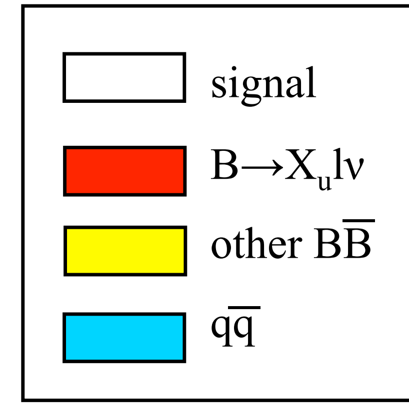
$\sigma_{stat} = 3.5\%$; $\sigma_{syst} = 5.0\%$; $\sigma_{tot} = 6.1\%$

B→ρlν branching fraction

binned ML fit in $m_{\rm ES}$, ΔE, and q^2 for $B \to (\pi^\pm/\pi^0/\rho^\pm/\rho^0)\ell\nu$ simultaneously, with isospin constraint

$B^0 \to \rho^-\ell^+\nu$ in 3 q^2 bins





Large B→X_ulν background is highly correlated with signal and must be fixed in the fit.

$B^0 \to \rho^-\ell^+\nu$	1577 ± 130
$B^+ \to \rho^0\ell^+\nu$	1970 ± 154
$B \to \rho\ell\nu$	3332 ± 286

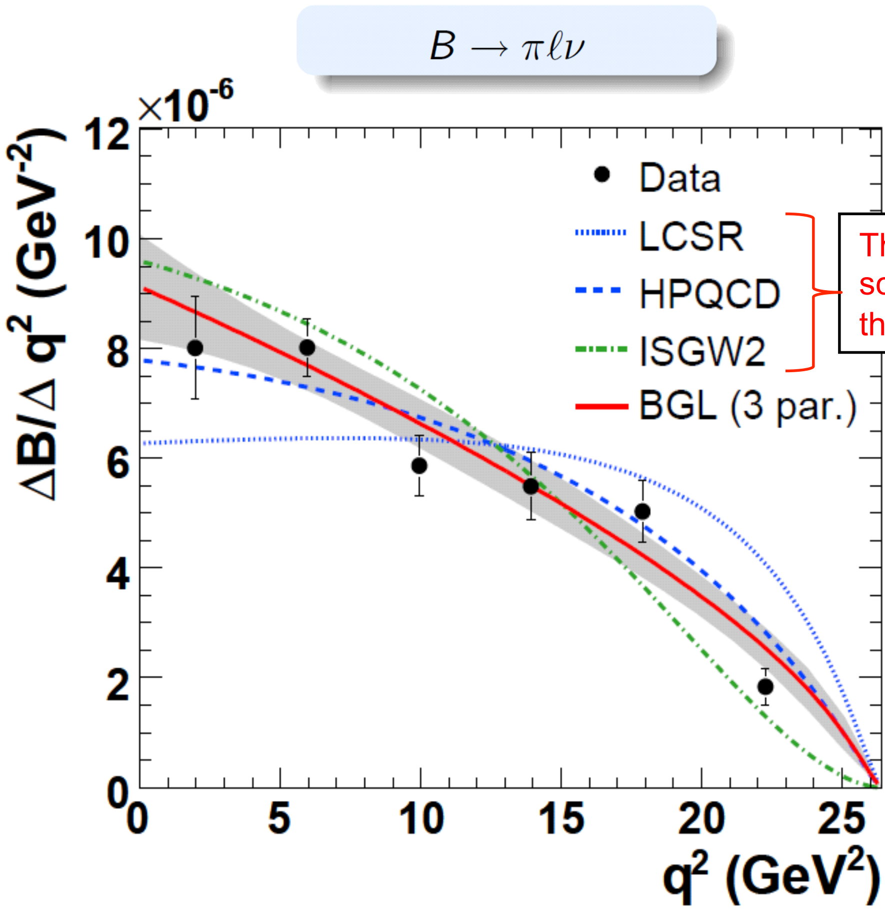
Smaller yield than B→πlν

$$\mathcal{B}(B^0 \to \rho^-\ell^+\nu) = (1.75 \pm 0.15_{stat} \pm 0.27_{syst}) \times 10^{-4}$$

$\sigma_{\rm stat}$ = 8.6%; $\sigma_{\rm syst}$ = 16%; $\sigma_{\rm tot}$ = 18%

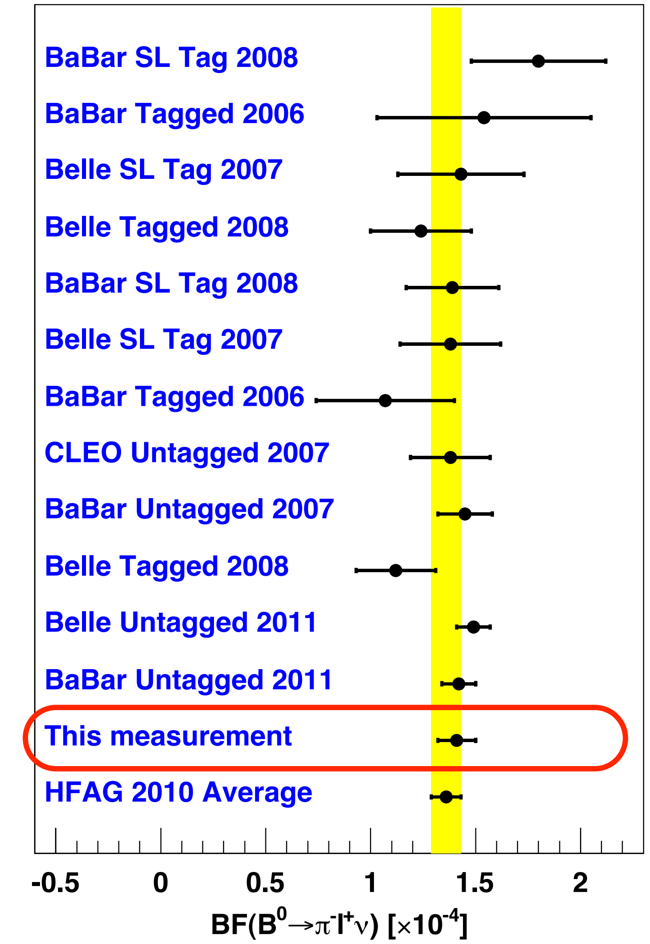
Systematic errors	$B \to \pi\ell\nu$	$B \to \rho\ell\nu$
detector effects	3.2%	4.9%
K_L simulation	3.0%	7.5%
$B \to (\pi/\rho)\ell\nu$ FF	2.2%	9.4%
$B \to X_u\ell\nu$ bkgd.	0.9%	12.9%
$B \to X_c\ell\nu$ bkgd.	1.0%	1.5%
$q\bar{q}$ bkgd.	2.0%	4.0%
other effects	1.5%	2.5%
Total	5.0%	15.7%

Comparison of BF(B→π/ρlν) with theory

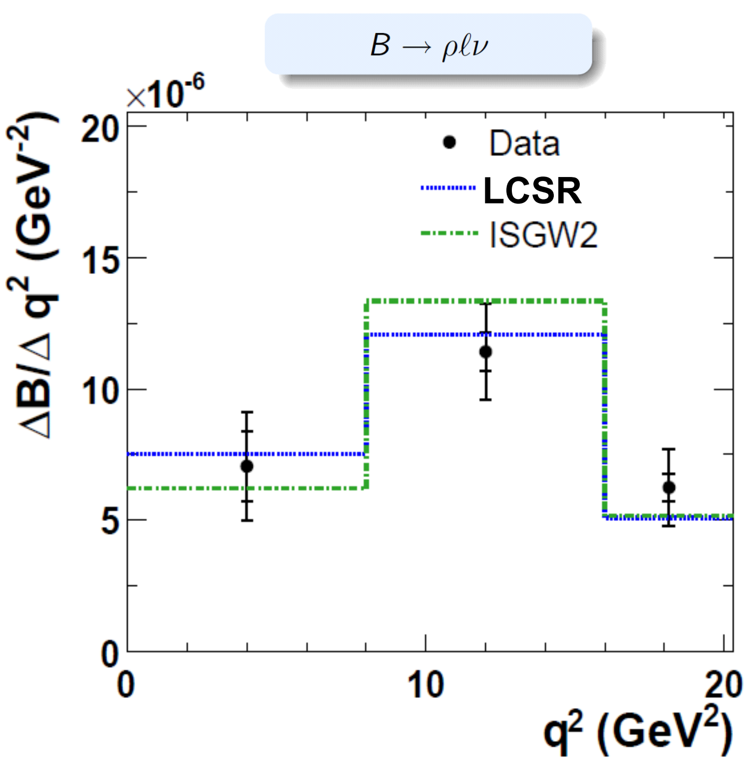


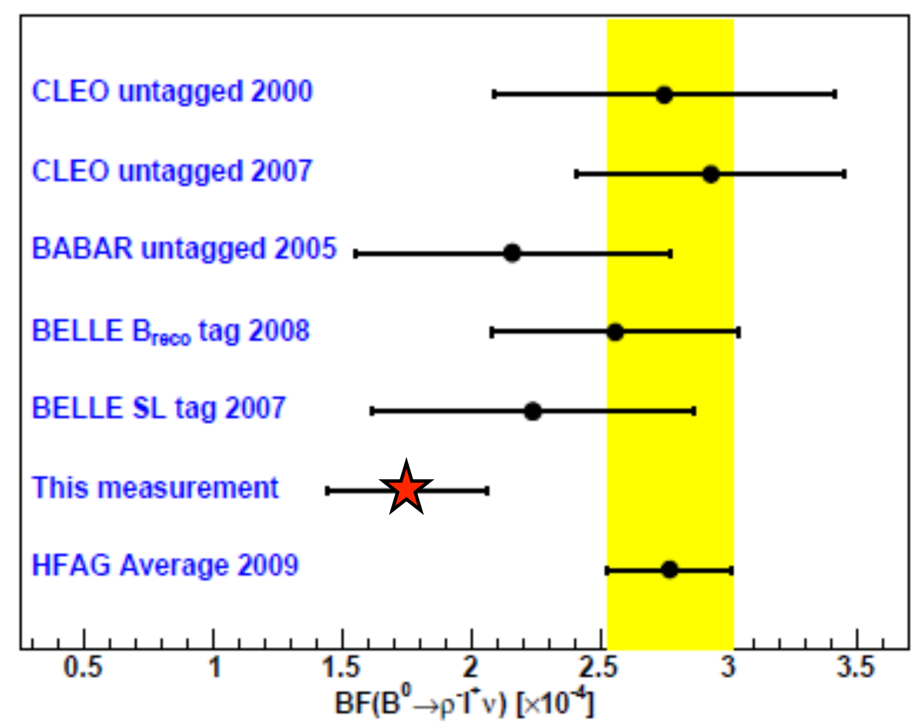
Theory curves scaled to area of the data.

BGL: PRL **74**, 4608 (1995)



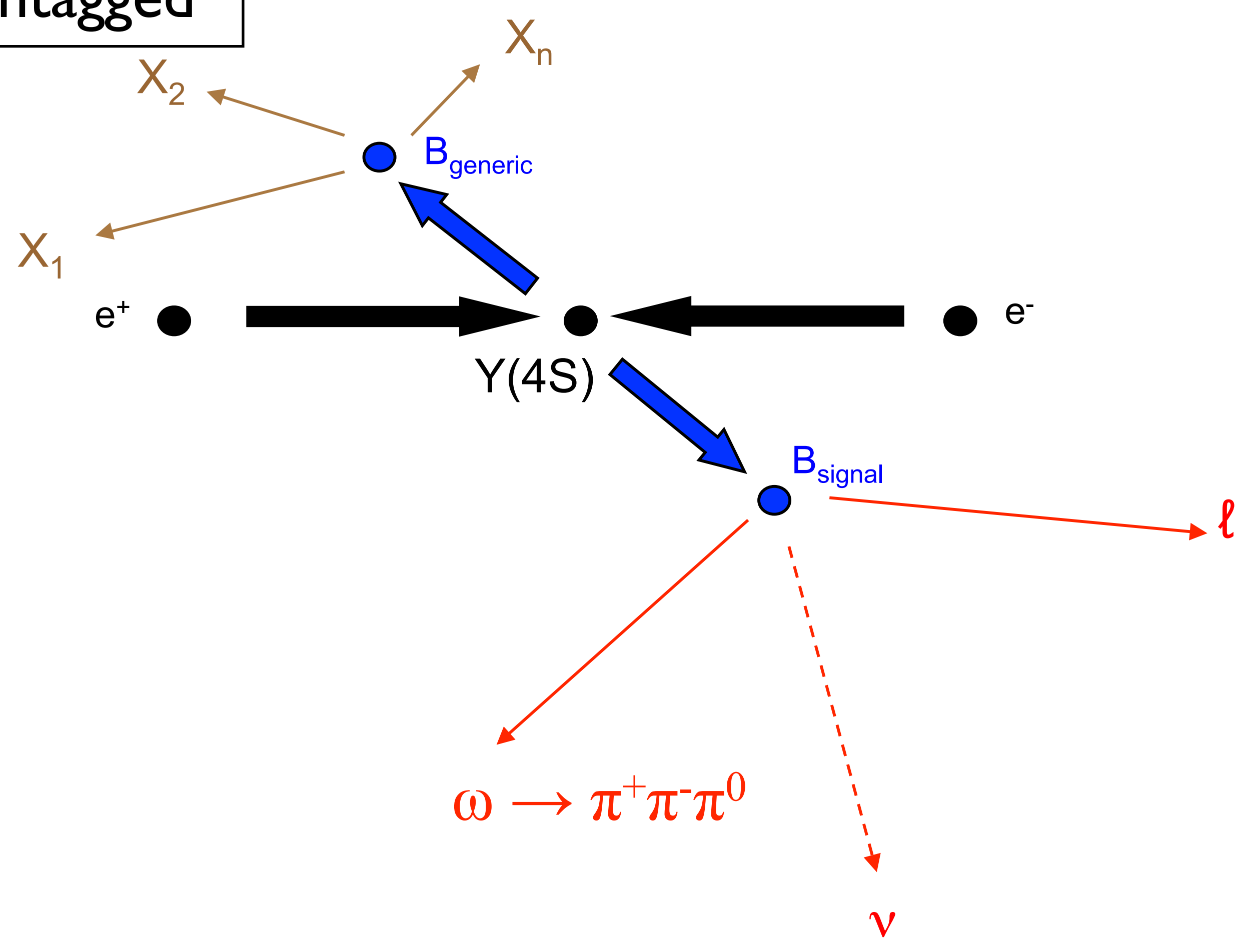
most precise measurement of BF(B→π/ρlν)





$B \to \omega l \nu$ selection

untagged



Preselection cuts

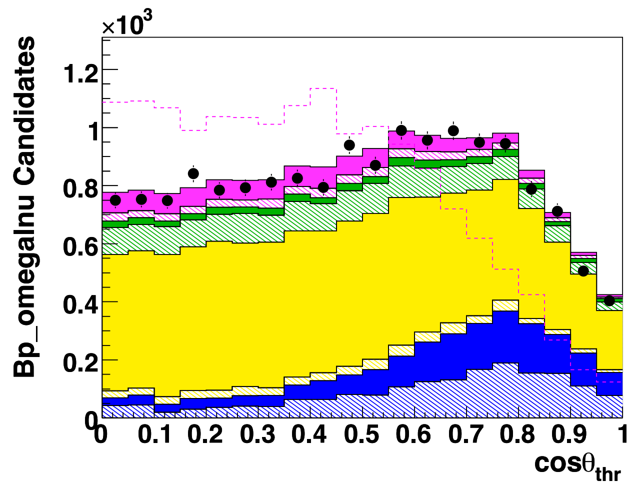
EcsCutSetR22_Training_V0; Cut (Sequential) [%]	True-ω signal
Candidate [weighted events]	18438.5
$R_2 < 0.5$	100.0
$nTrk > 3$	99.8
$Q_{tot} <= 1$	89.1
$\|p_z\|^{tot}/E^{tot} < 0.7$ (e^- only)	99.0
Lepton fiducial cut: $0.4090 < \theta < 2.3720$	98.9
$\|m_{\ell X} - m_{J/\Psi}\| > 25$ MeV	98.8
ℓ $p_l^* > 1.6$ GeV	75.6
All GoodTracksLoose	80.1
Hadron: Kaon veto	99.4
Hadron: Lepton veto	98.8
ω $\omega \to \pi^+\pi^-\pi^0$ Selection (BAD 1891)	47.3
$D^*\ell\nu$ veto	95.6
P($\omega\ell\nu$ vertex) > 0.001	90.0
$0.760 < m(\pi^+\pi^-\pi^0) < 0.806$ GeV	86.4
$p_h^* > 1.3 \|\| p_l^* > 2.0 \|\| p_l^* + p_h^* \geq 2.65$	99.5
Dalitz amp. > 0; $p_{\pi^0}^* > 0$ GeV	99.4
$-1.2 < \cos\theta_{BY} < 1.1$	95.4
$L_2 < 3.0$	98.9
ν $p_{\rm miss} > 0.5; 0.3 < \theta_{\rm miss} < 2.2$	80.6
$\|m^2_{\rm miss}/(2 * E_{\rm miss})\| < 2.5$	99.7
$q^2_{corr} > 0GeV$	100.0
$-0.95 < \Delta E < 0.95$ GeV; $5.095 < M_{es} < 5.295$ GeV	69.1
$-0.15 < \Delta E \leq 0.25$ GeV; $M_{es} > 5.255$ GeV	27.8
Overall efficiency	2.6

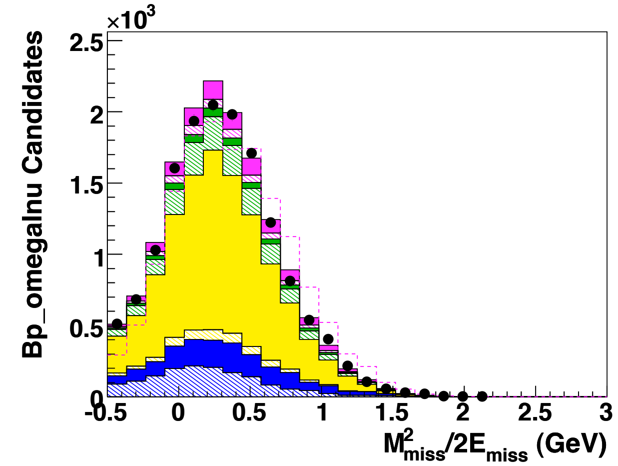
Efficiency	true-ω signal	comb.-ω signal	$B \to X_c l \nu$	cc
skim	52.4%	52.4%	12.6%	1.6%
presel.	9.3%	0.18%	0.015%	0.012%
NN	49%	20%	7.2%	9.3%
Total (est.)	2.4×10^{-2}	1.9×10^{-4}	1.4×10^{-6}	1.8×10^{-7}

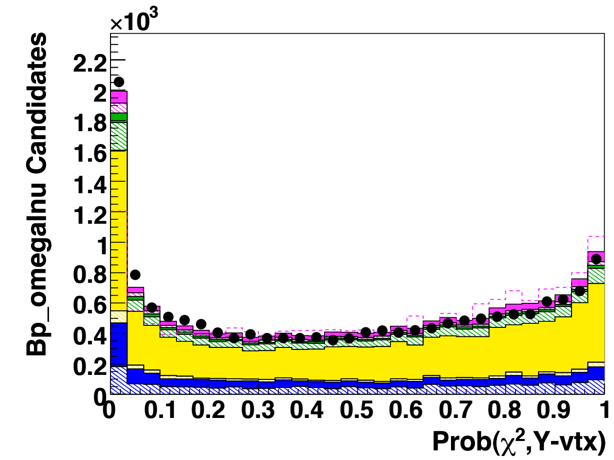
Neural net selection

Input variables

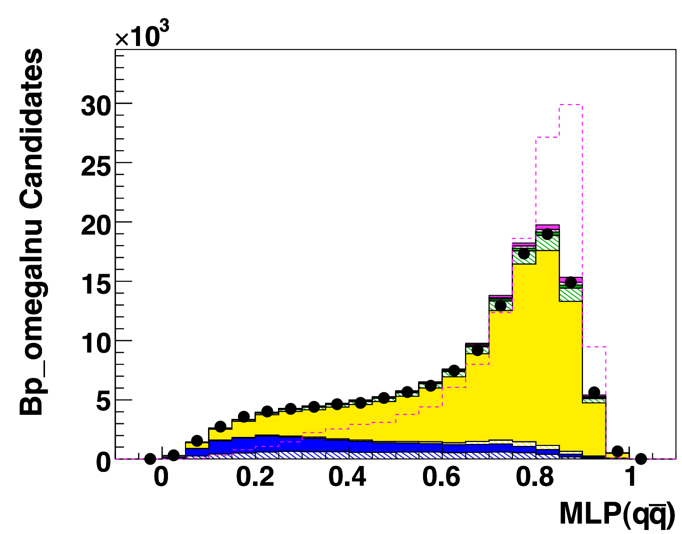
- Event shape
  - L2
  - R2
  - **cosθ$_{thrust}$**
- neutrino quality
  - θ$_{miss}$
  - **m$_{miss}^2$/2E$_{miss}$**
  - cosθ$_{BY}$
- other
  - cosθ$_{Wl}$
  - **Prob(Y$_{vtx}$)**
  - ω Dalitz amplitude

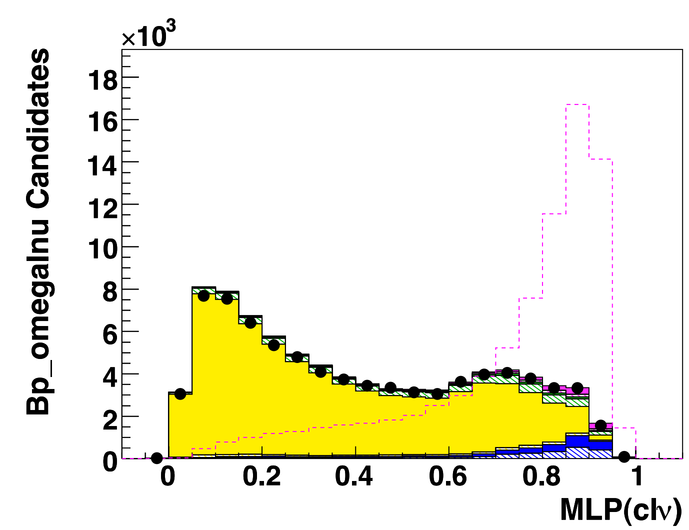






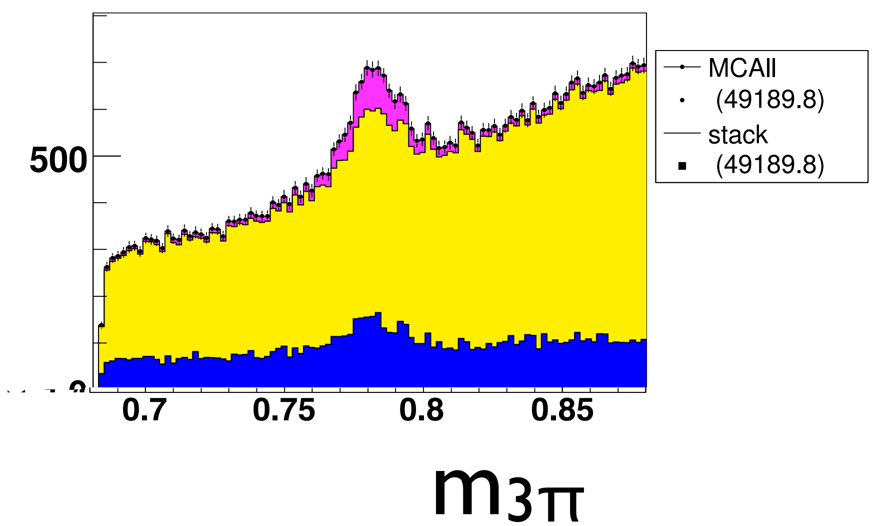
good data/MC agreement of NN input variables and output discriminants





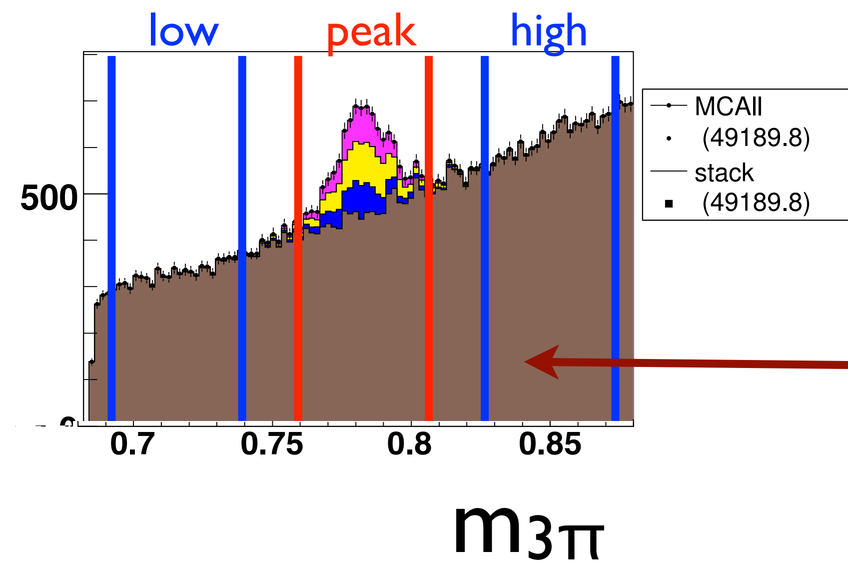
Classification

Traditional



- MCAll (50042.9)
- Sig (2057.9)
- BB (38479.8)
- qq (9505.2)

Sideband



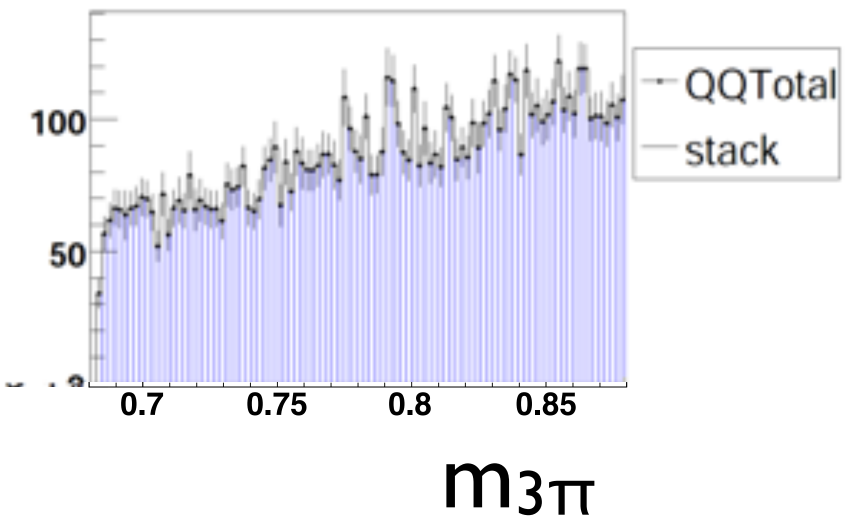
- MCAll (50042.9)
- Sig (1029.4)
- BB (1230.2)
- qq (823.4)
- MCComb (46959.9)

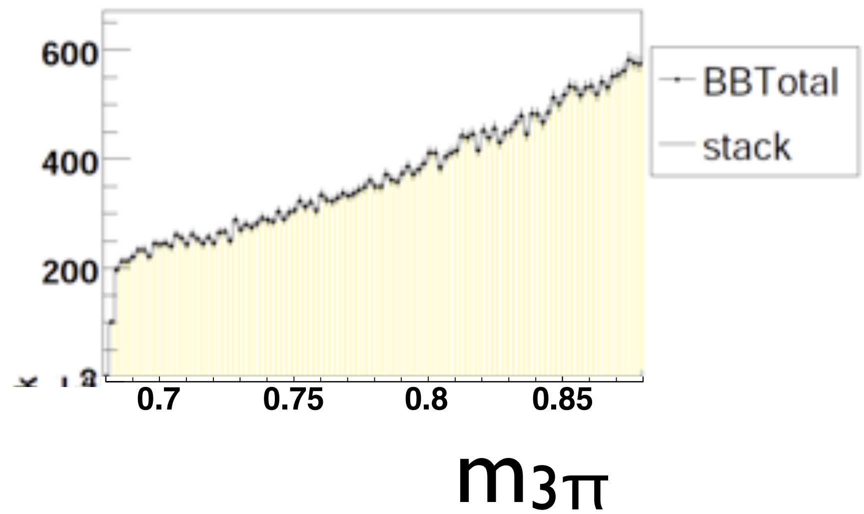
combinatoric-ω signal and background: one or more daughter π does not come from a true ω

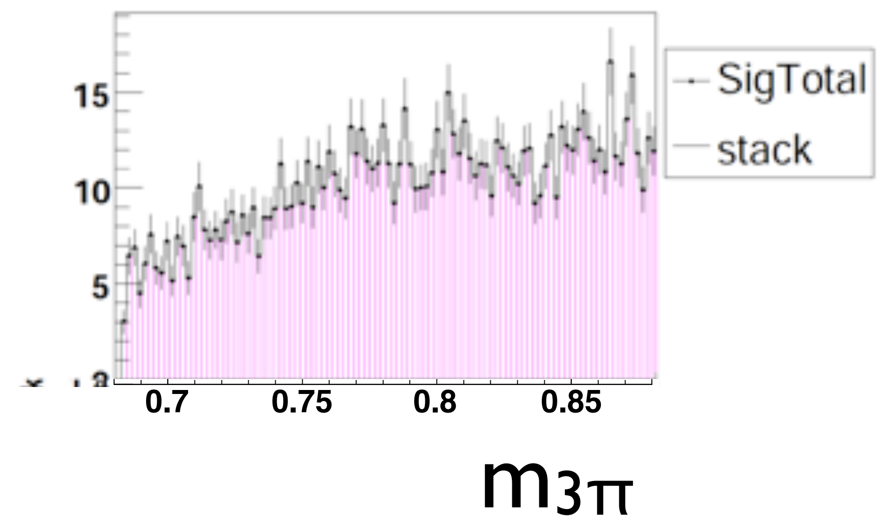
true-ω background

- >80% of background in $m_{3\pi}$ peak is combinatoric-ω
- model it with data from the sidebands

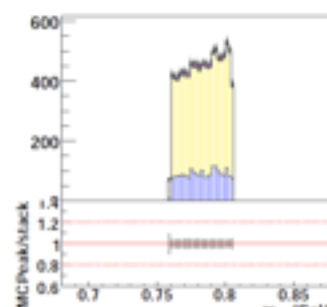
Test extrapolation from $m_{3\pi}$ sidebands to peak

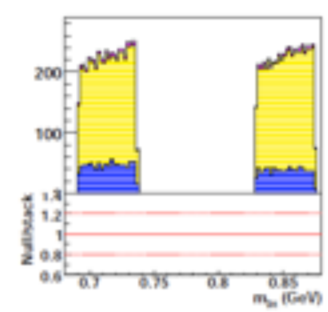






$m_{3\pi}$ distribution of combinatoric-ω differs for qq, BB, signal



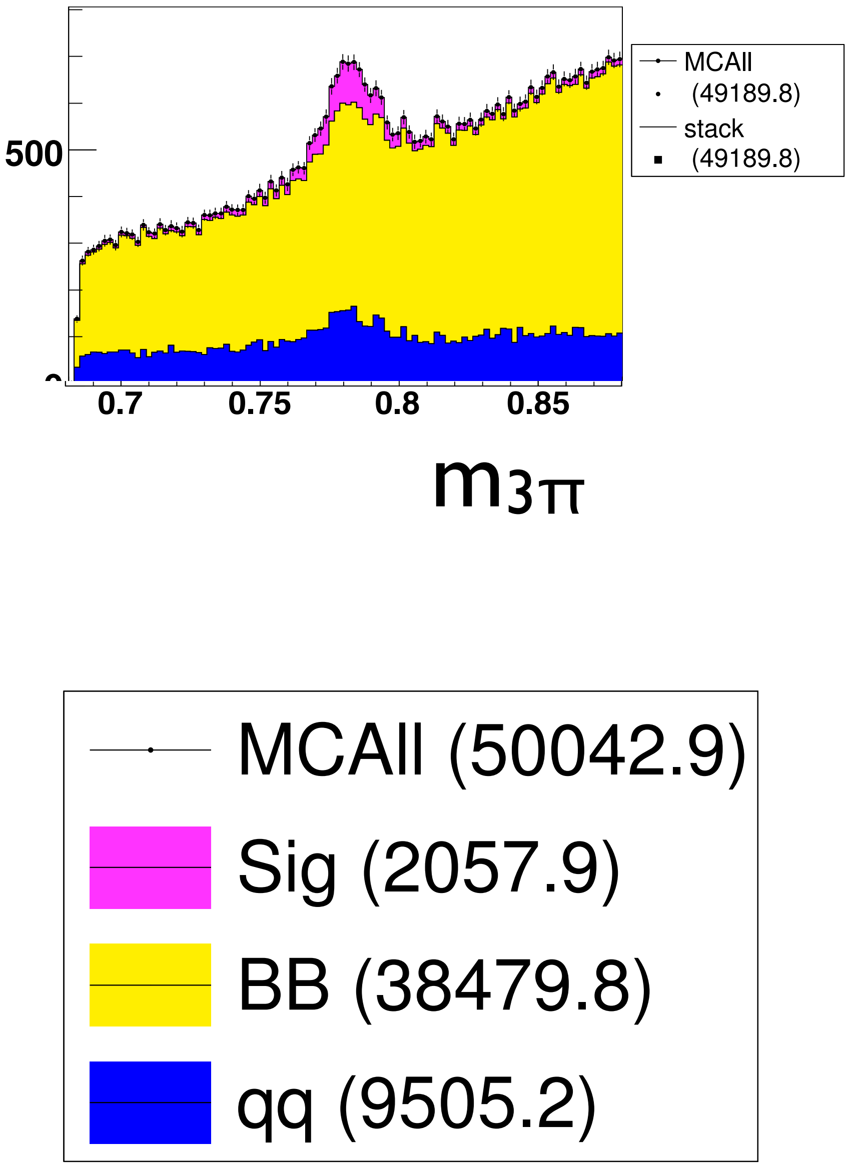


source	comb.-ω in peak	weighted sideband	peak/ sdband
qq	2081	1969	1.06
BB	8256	8277	0.997
signal	265	238	1.11
Total	10601	10484	1.01

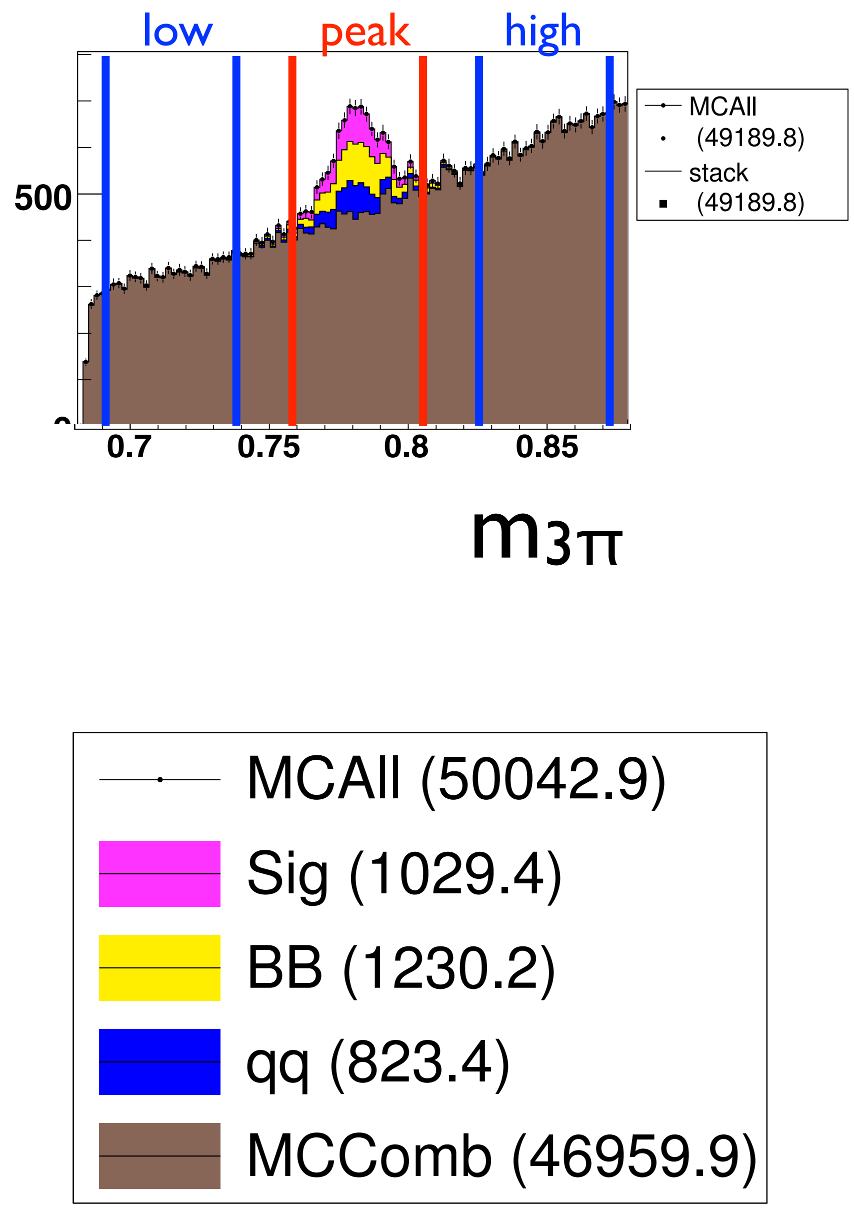
Sidebands are corrected by subtracting the comb.-ω signal before the $m_{3\pi}$ fit, then adding it afterward.

Classification

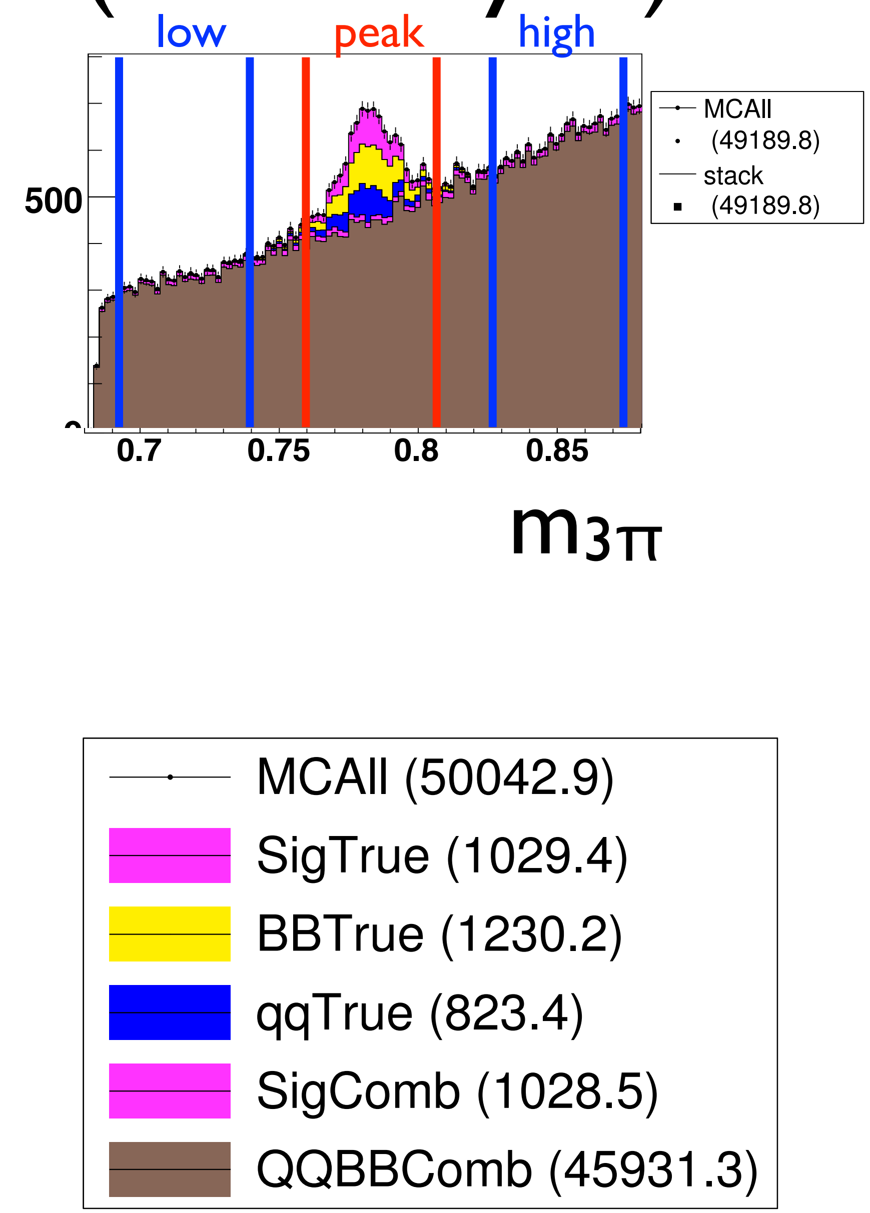
Traditional



Sideband



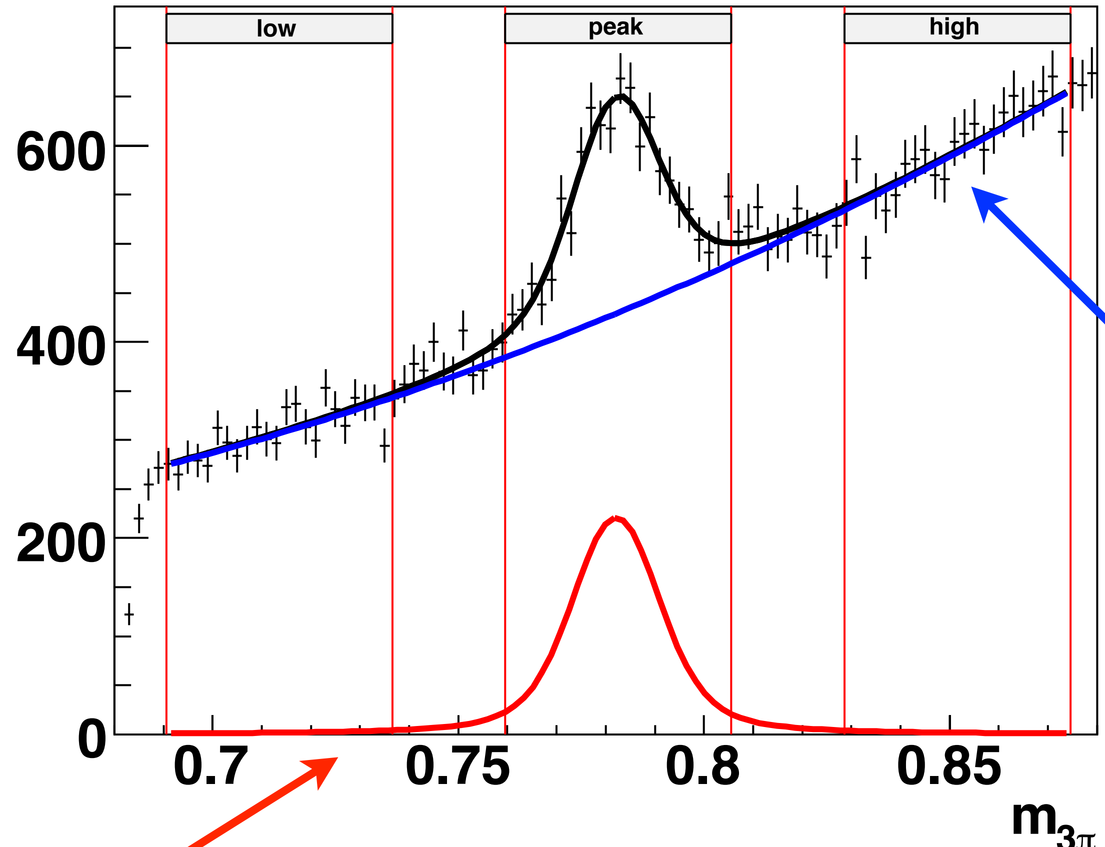
Sideband-corrected (this analysis)



>80% of background in $m_{3\pi}$ peak is combinatoric-ω

$m_{3\pi}$ fit

$m_{3\pi}$ fit performed to:
data - (comb.-ω signal)
with $f = f_{sig} + f_{bkg}$

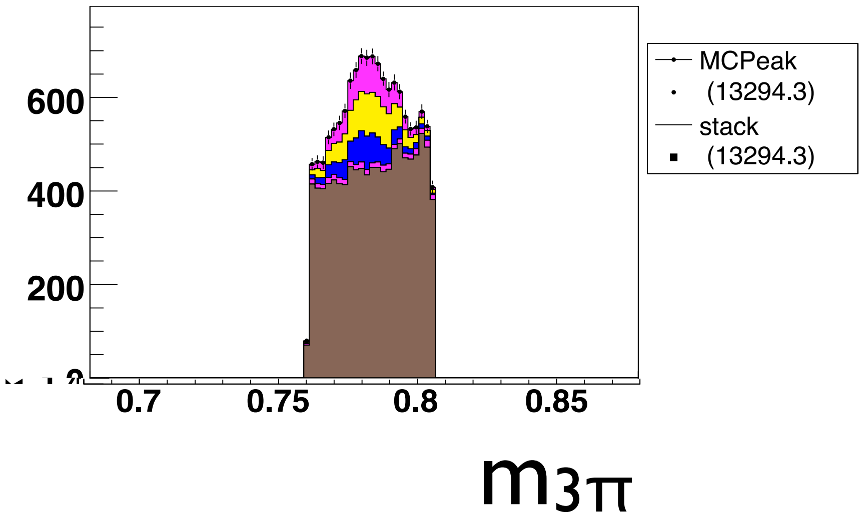


f_{bkg} = 2nd-order polynomial

f_{sig} = relativistic Breit-Wigner, convoluted with Gaussian

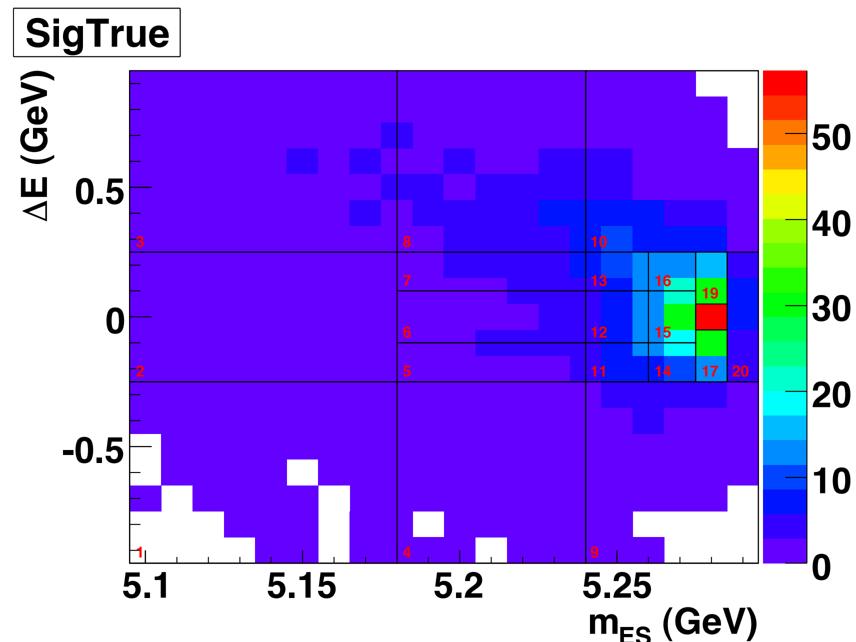
From f_{bkg}, weights are calculated to scale upper, lower sidebands to area in peak.

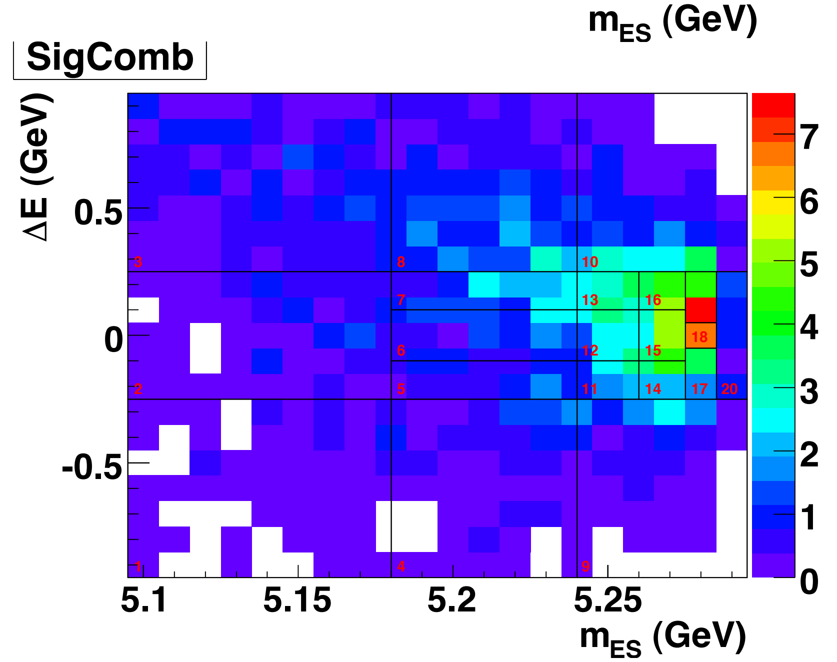
ΔE vs. m_{ES} and fit parameters

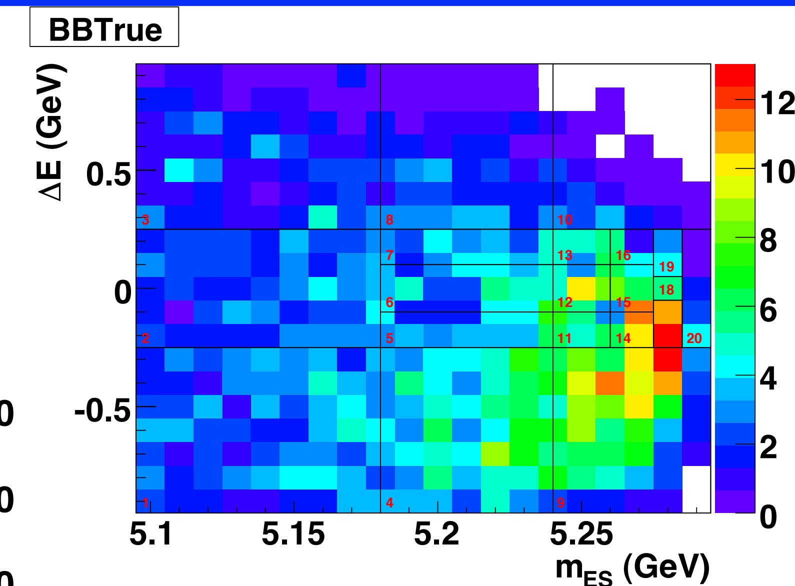


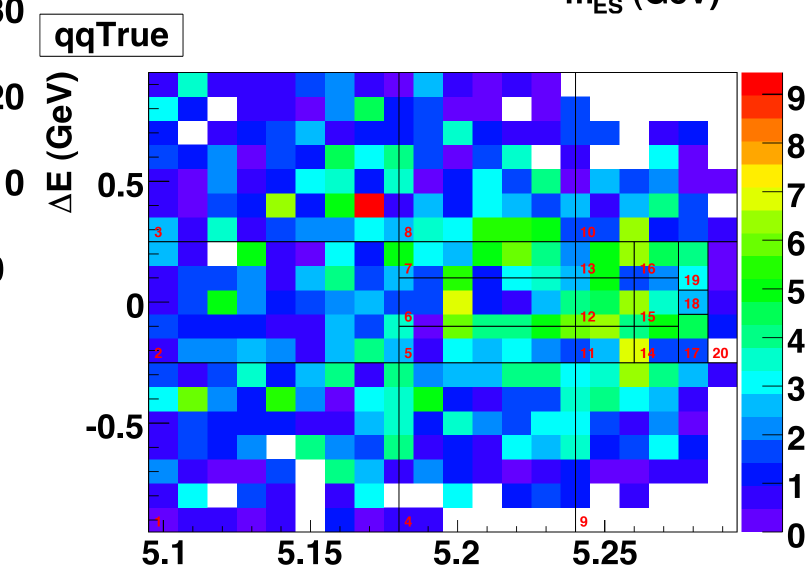
	Fit params
MCPeak (13294.3)	
SigTrue (900.2)	sig
BBTrue (1076.2)	BB
qqTrue (716.5)	qq
SigComb (264.9)	sig
QQBBComb (10336.5)	fixed

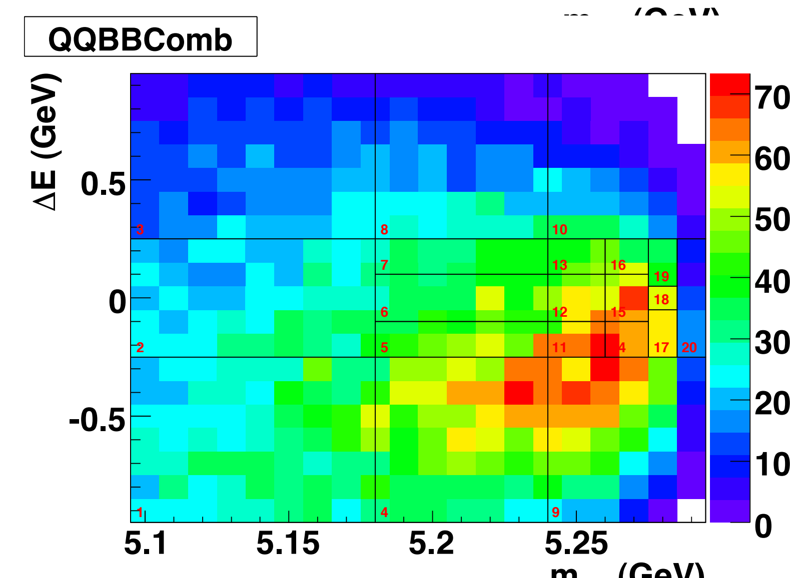
(pre-fit yields)



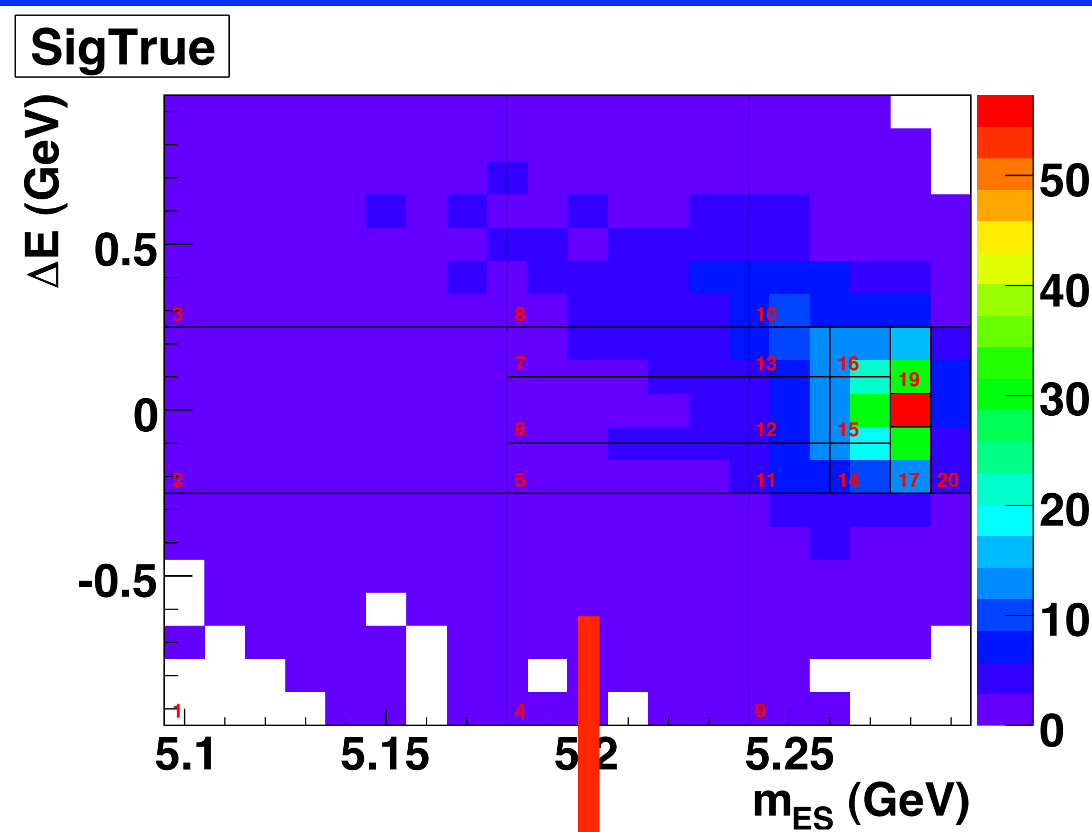




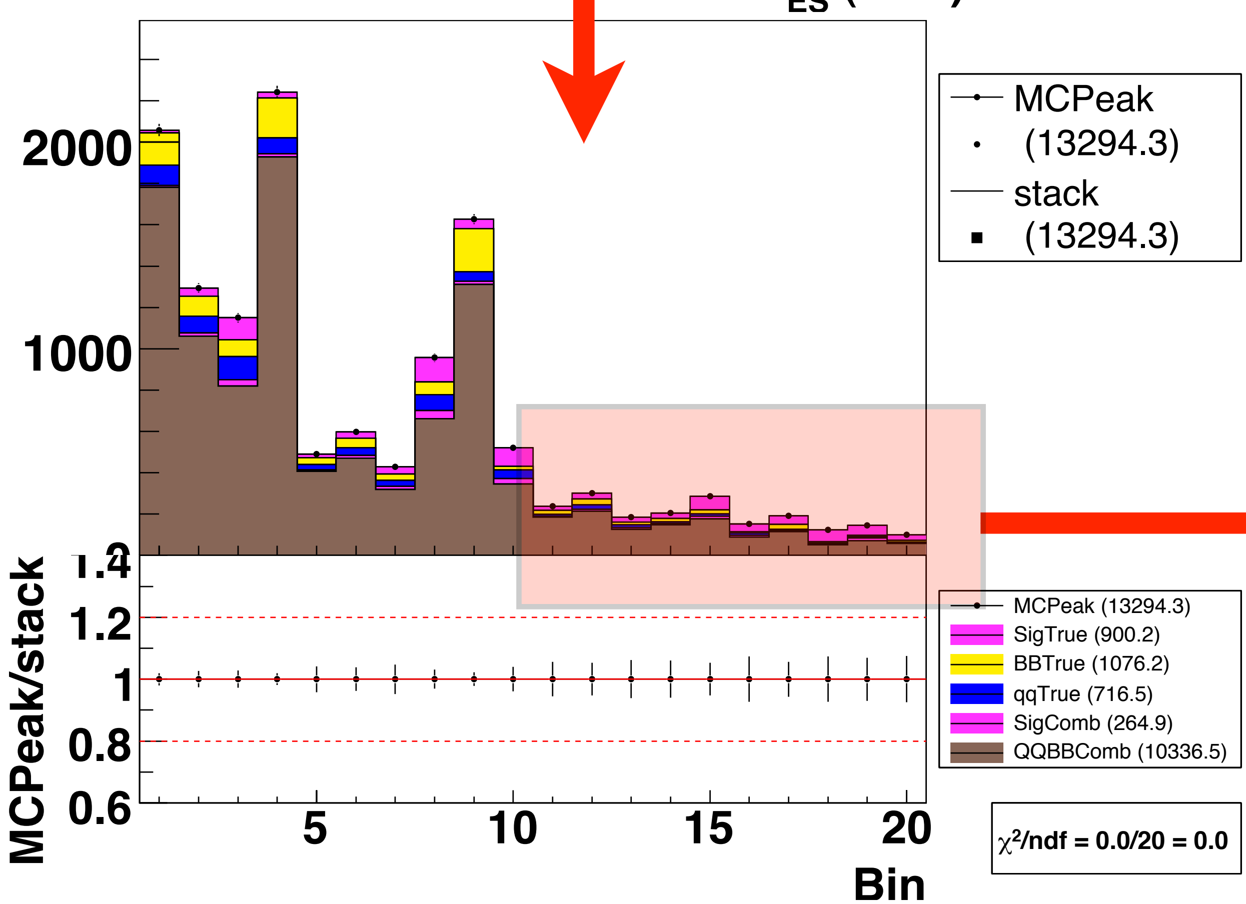


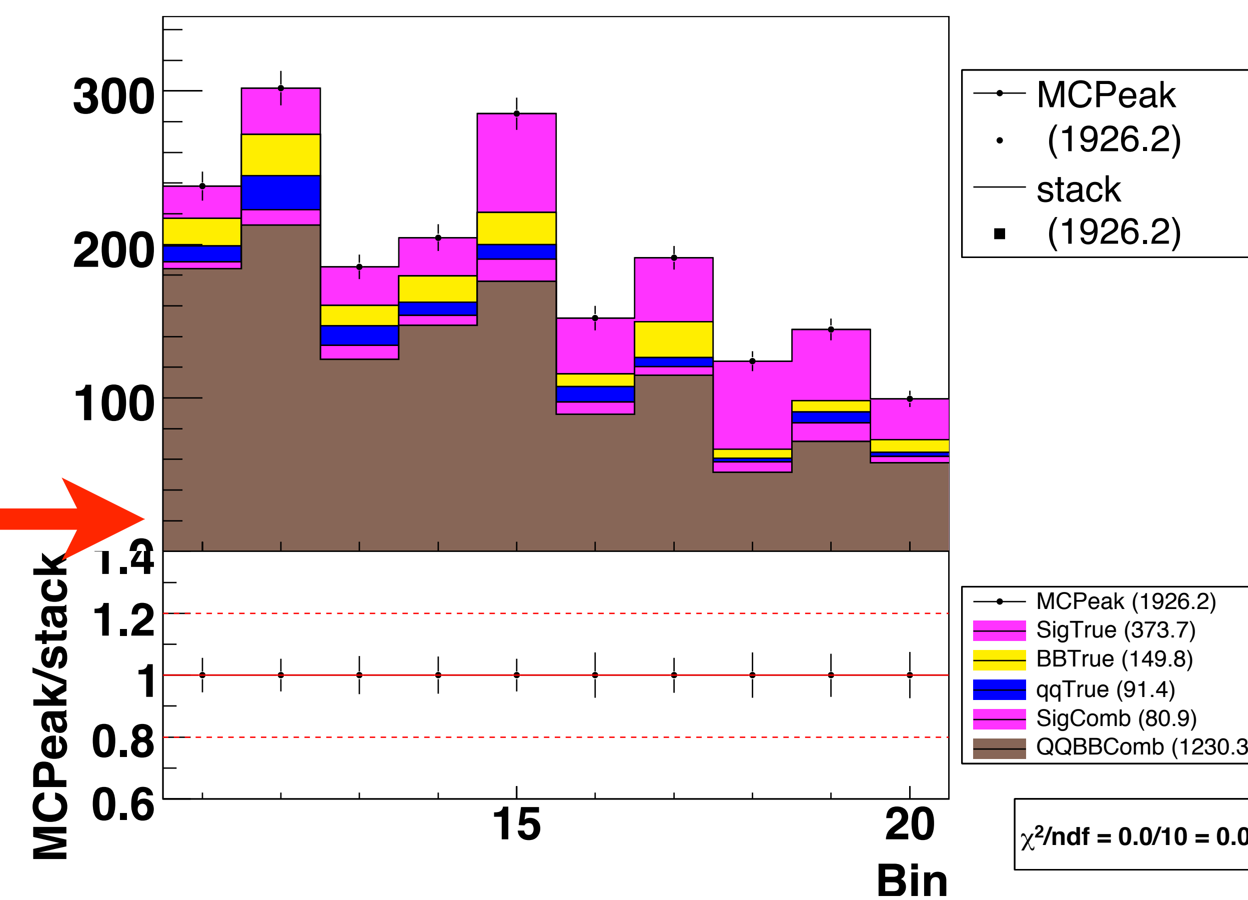


ΔE vs. m_{ES} binning

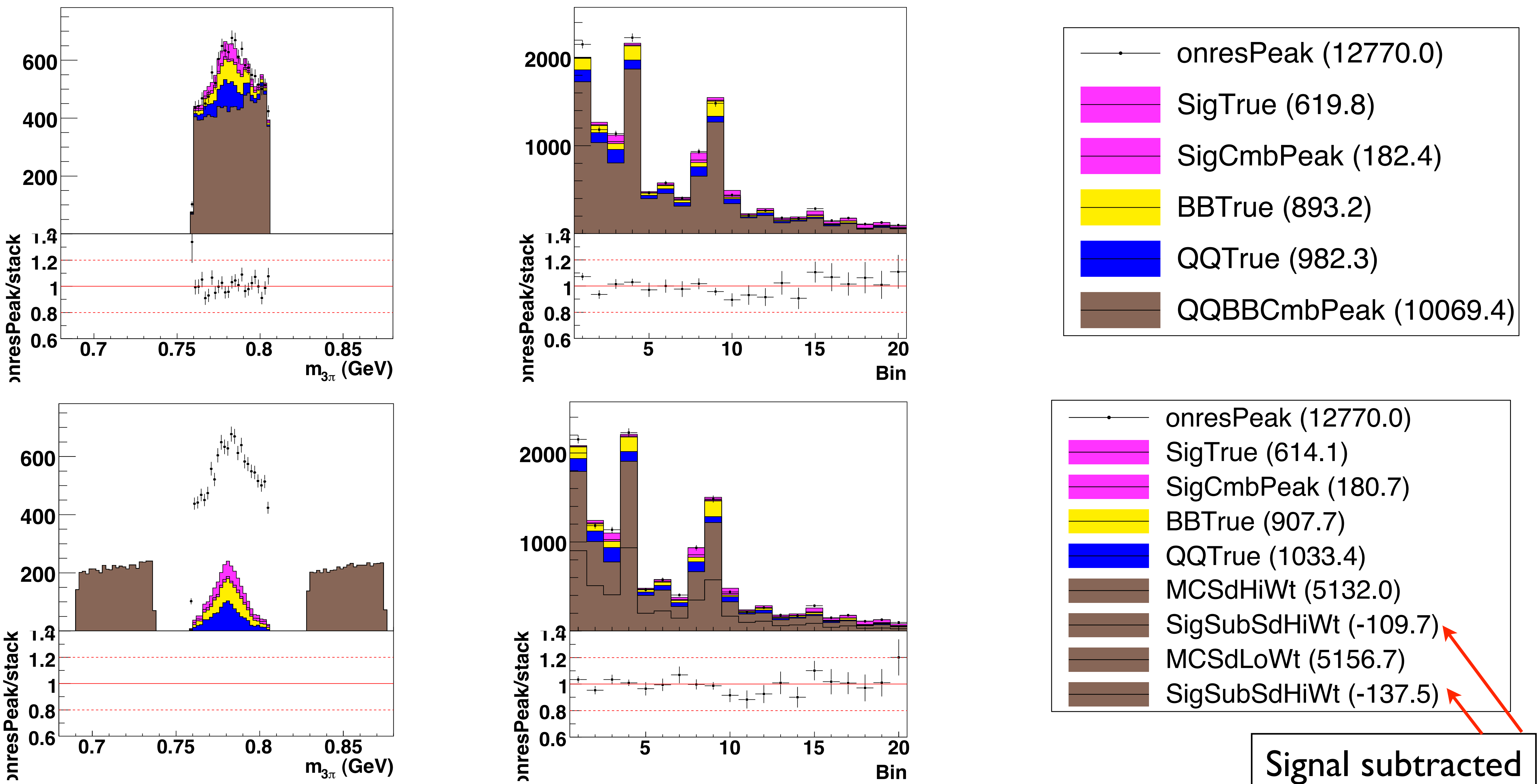


ΔE-m_{ES} plane divided into 20 bins, with smaller bins where the signal changes more.





Test $m_{3\pi}$ sidebands-to-peak extrapolation

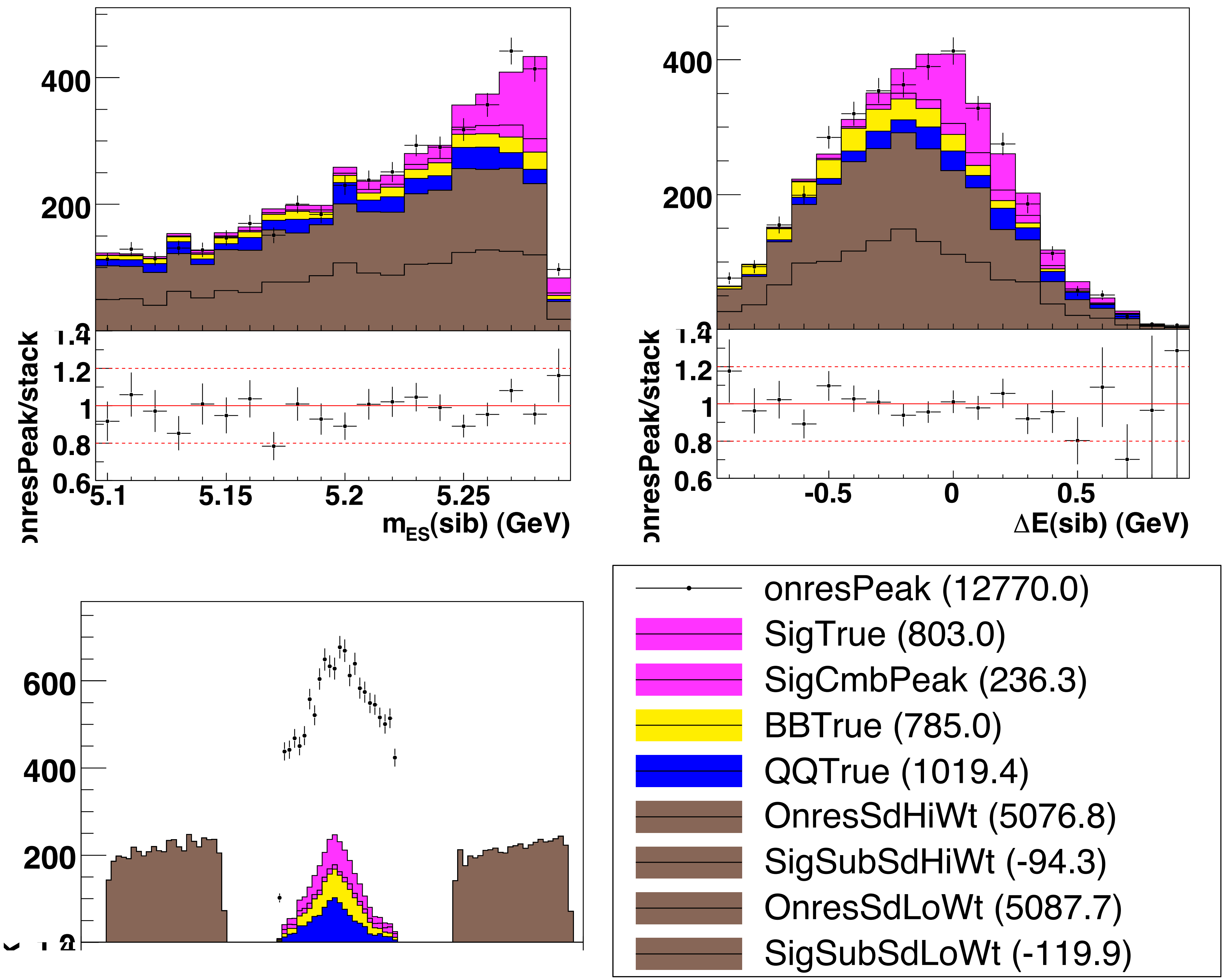


Signal subtracted from sidebands

signal yield (combinatoric-ω bkgd from $m_{3\pi}$ peak) : 802 ± 125
signal yield (combinatoric-ω bkgd from $m_{3\pi}$ sidebands): 795 ± 121

Signal yield changes <1% using MC from $m_{3\pi}$ sidebands instead of from $m_{3\pi}$ peak.

Fit results: all-q^2

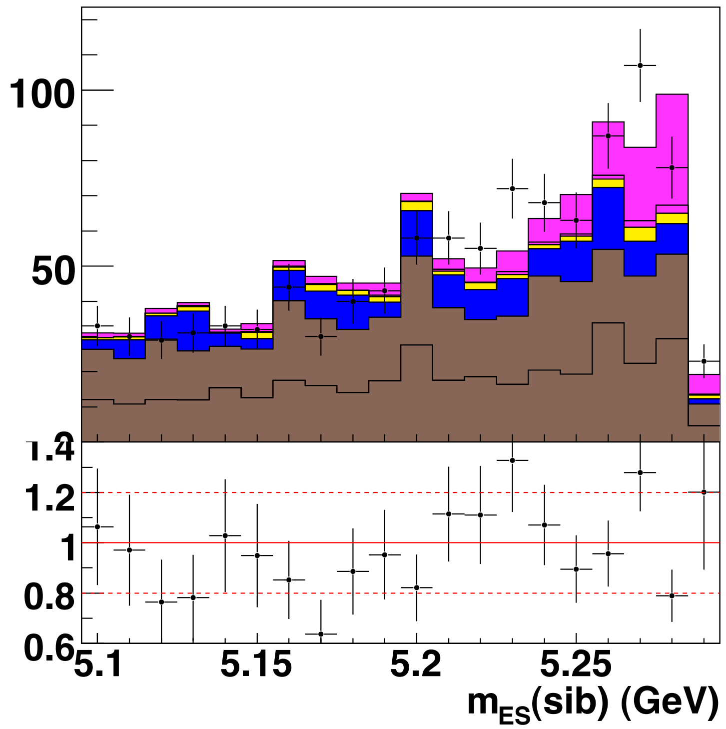


signal yield: 1029

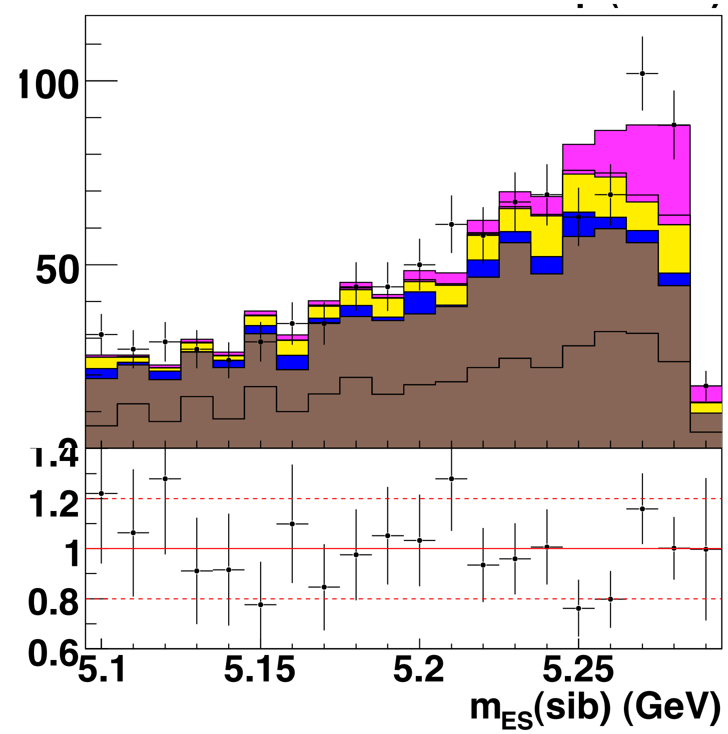
σ_{stat} = 13%;
σ_{syst} = 10%;
σ_{tot} = 16%

$BF(B^+ \to \omega l^+ \nu) = (1.25 \pm 0.16 \pm 0.13) \times 10^{-4}$

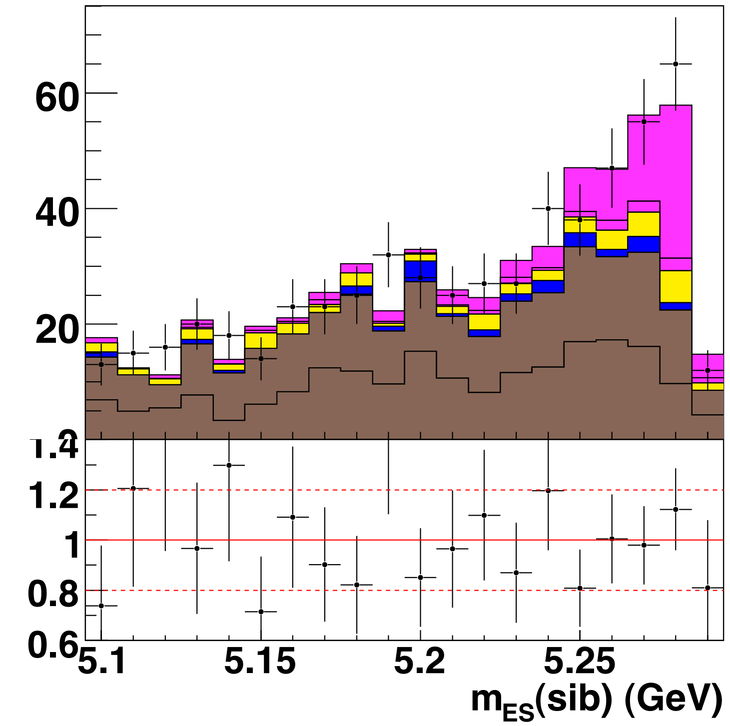
Fit results: 5 q^2 bins



0<q^2<4 GeV^2
signal yield = 263 ± 75

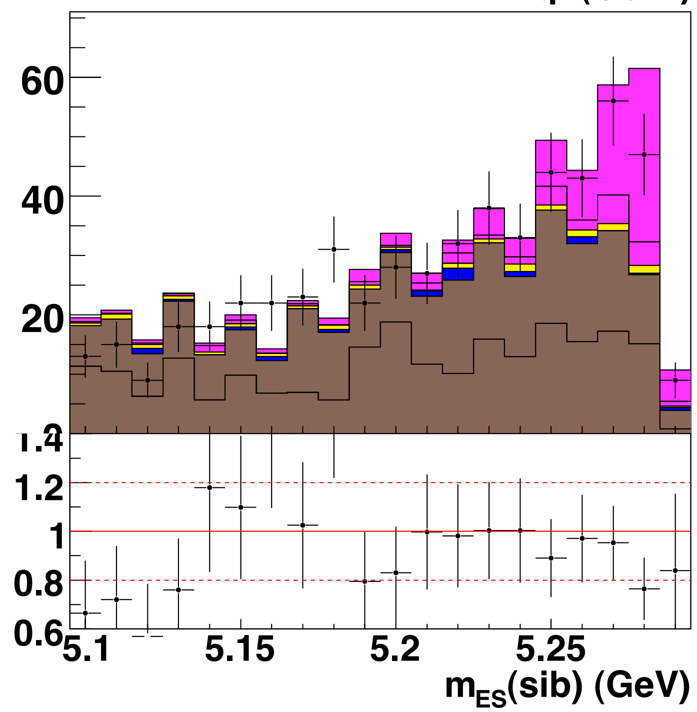


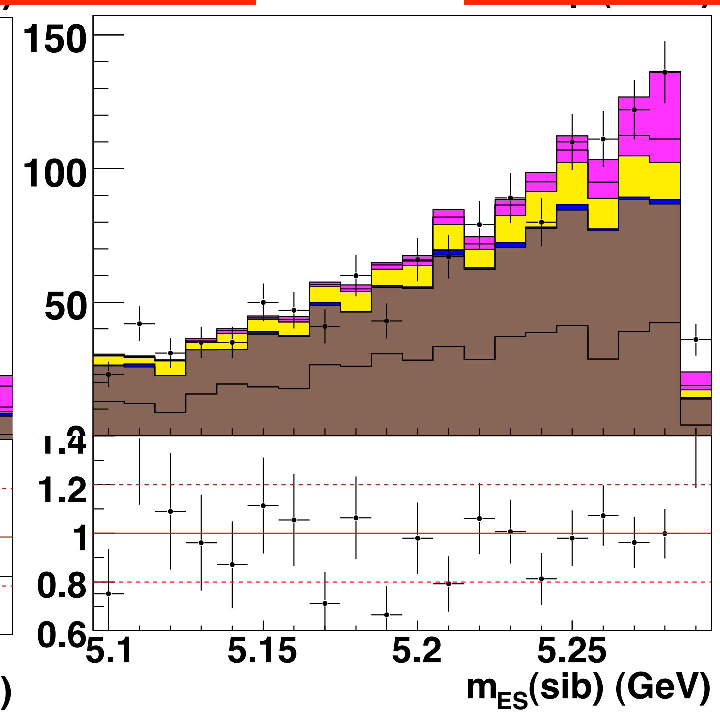
4<q^2<8 GeV^2
signal yield = 197 ± 55



8<q^2<10 GeV^2
signal yield = 178 ± 40

10<q^2<12 GeV^2
signal yield = 219 ± 38





12<q^2<22 GeV^2
signal yield = 236 ± 61

sizable signal yield in each q^2 bin

Systematics

	Source	Variation	Uncertainty (%)
event reconstruction	track efficiency	kill tracks	4.7
	photon efficiency	kill photons	4.3
	K_L prod./interaction	rate of K_L prod. & reco'd. energy	4.4
	lepton ID	lepton selector efficiency	1.4
signal	signal form factors	$A_1(q^2)$, $A_2(q^2)$, $V(q^2)$	4.1
	BF($\omega \to \pi\pi\pi$)	error from PDG	0.8
true-ω bkgd.	qq ΔE-m_{ES} shapes	reweight with data ctrl. sample	0.7
	BB ΔE-m_{ES} shapes	reweight with data ctrl. sample	1.1
comb.-ω sig.	$m_{3\pi}$ shape of comb. sig.	remove signal sdband subtraction	2.3
comb.-ω bkgd.	scale ($m_{3\pi}$ statistical)	sideband weights	1.0
	scale ($m_{3\pi}$ ansatz)	linear bkgd. fcn. (not quadratic)	3.2
$N(B^+B^-)$	BB counting	± 1.1%	1.1
	$f_{\pm}/f_{00}$	± 1.2%	1.2
Total systematic			**10.5**
Total statistical			**12.6**
Total error			**16.5**

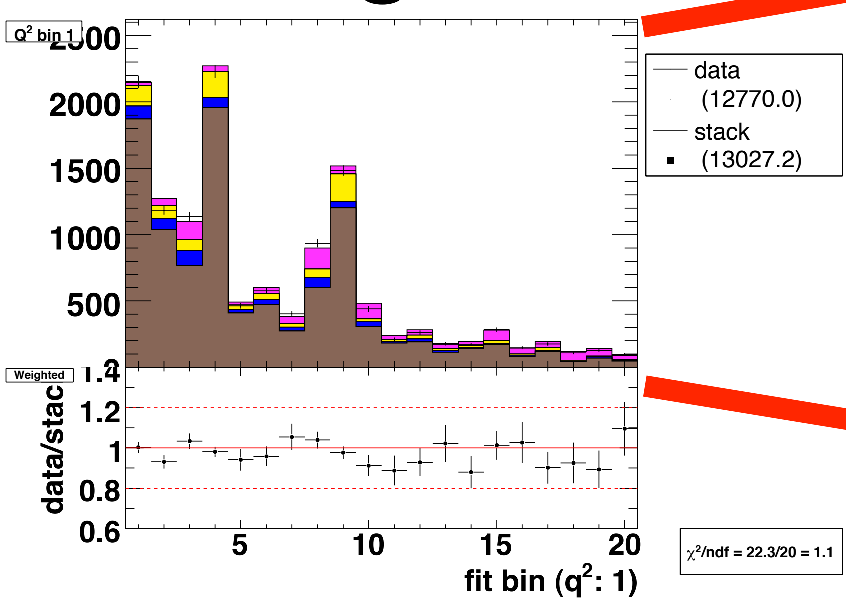
evt reco is largest

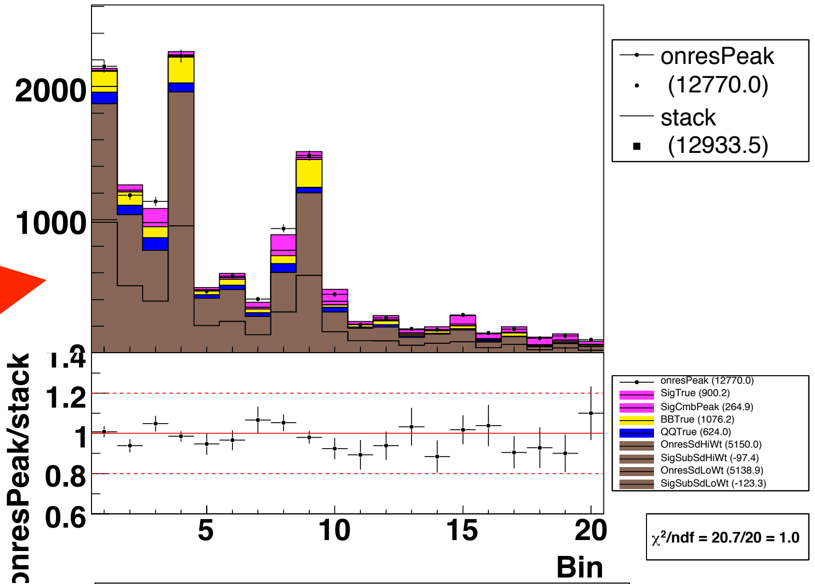
statistical and systematic uncertainties are comparable

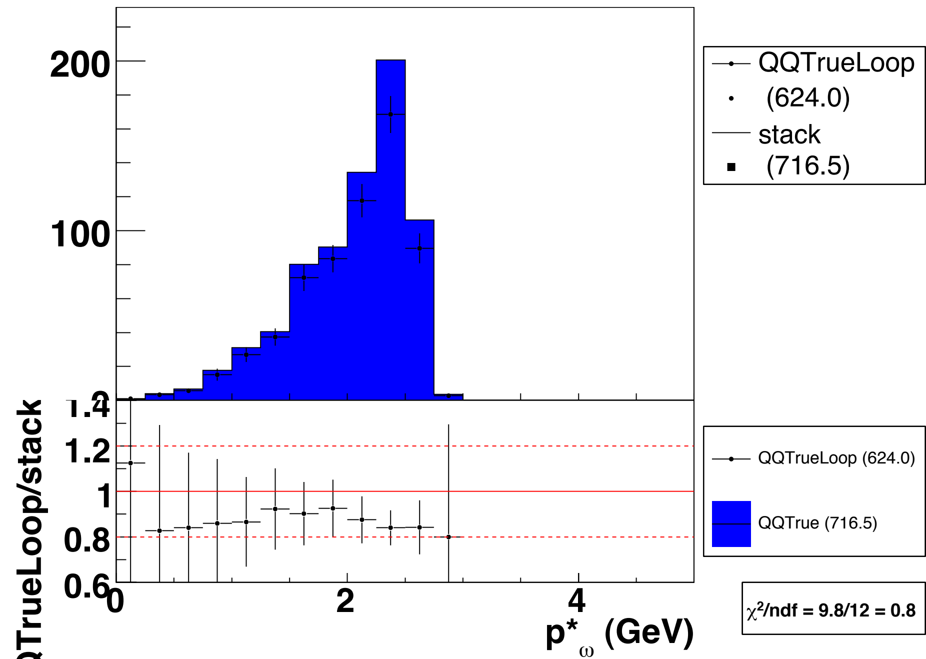
Systematics: true-ω ΔE-m_{ES} shapes

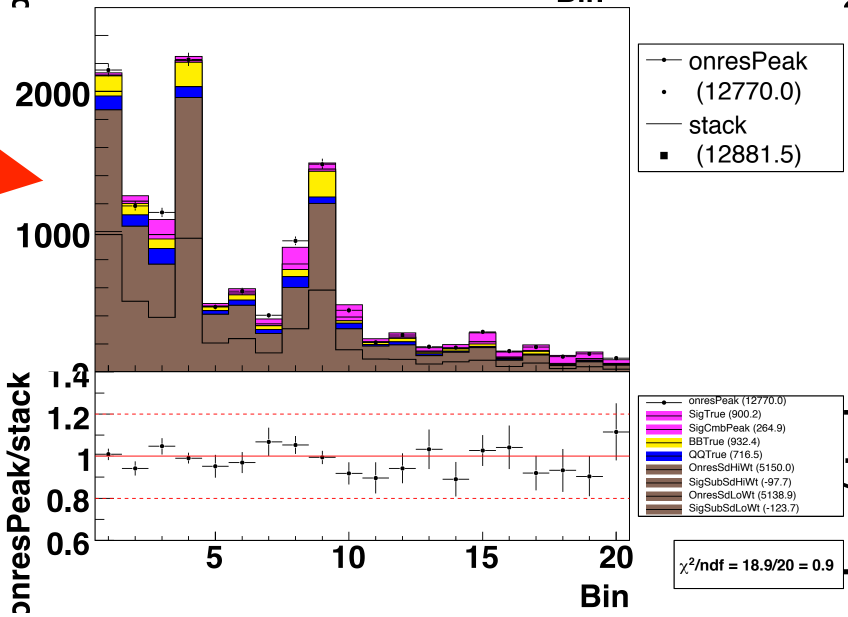
reweight with p_ω from qq:
Δsig = 0.7%

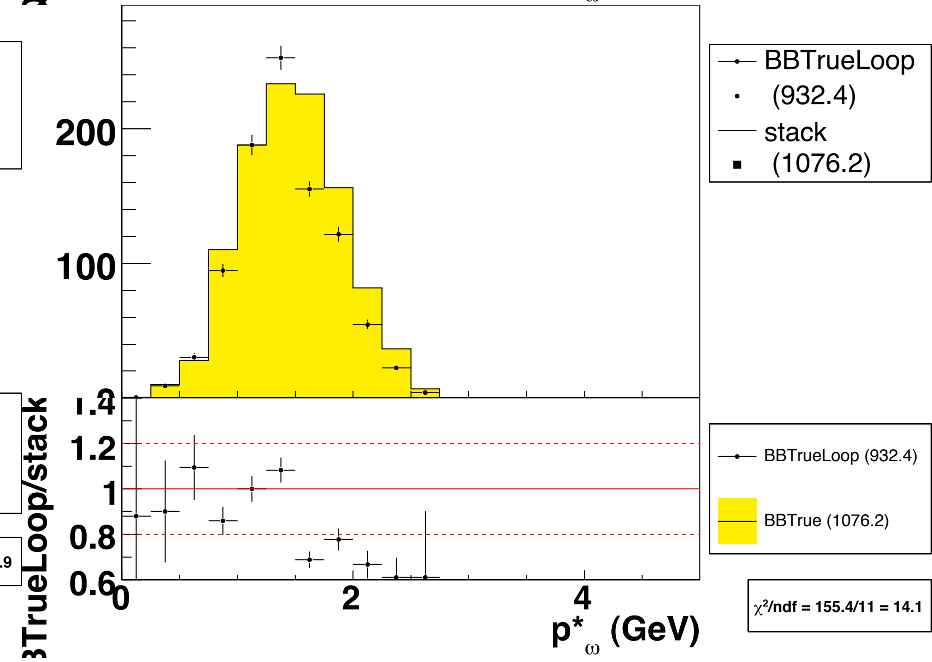
original





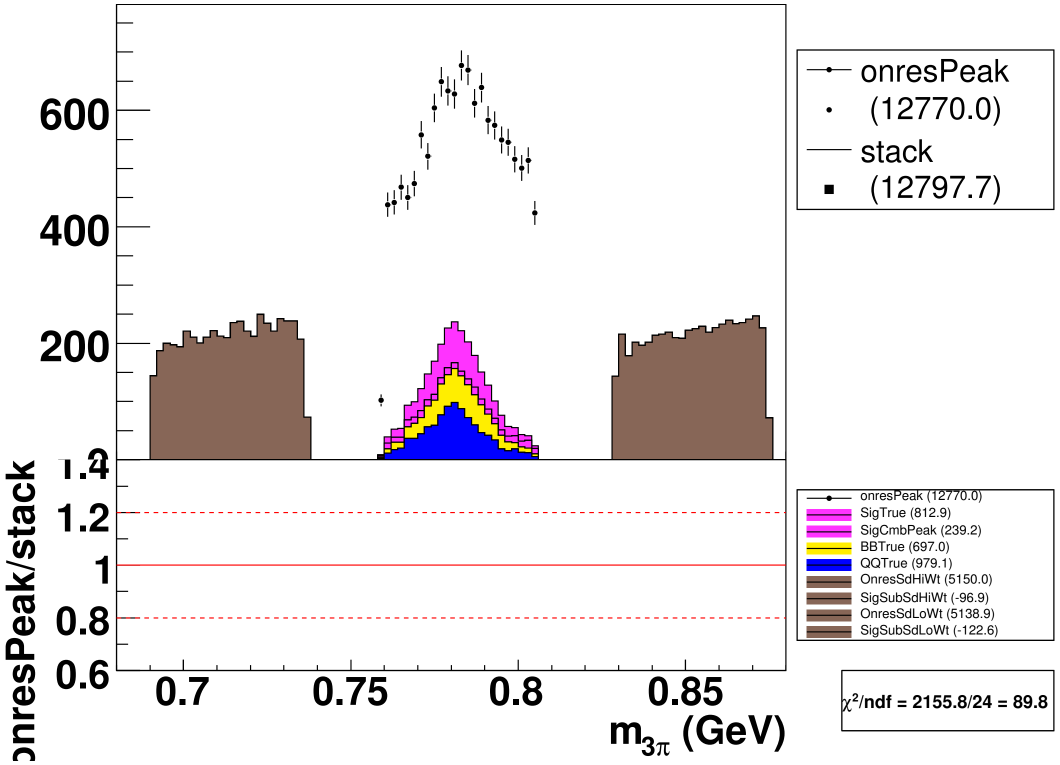


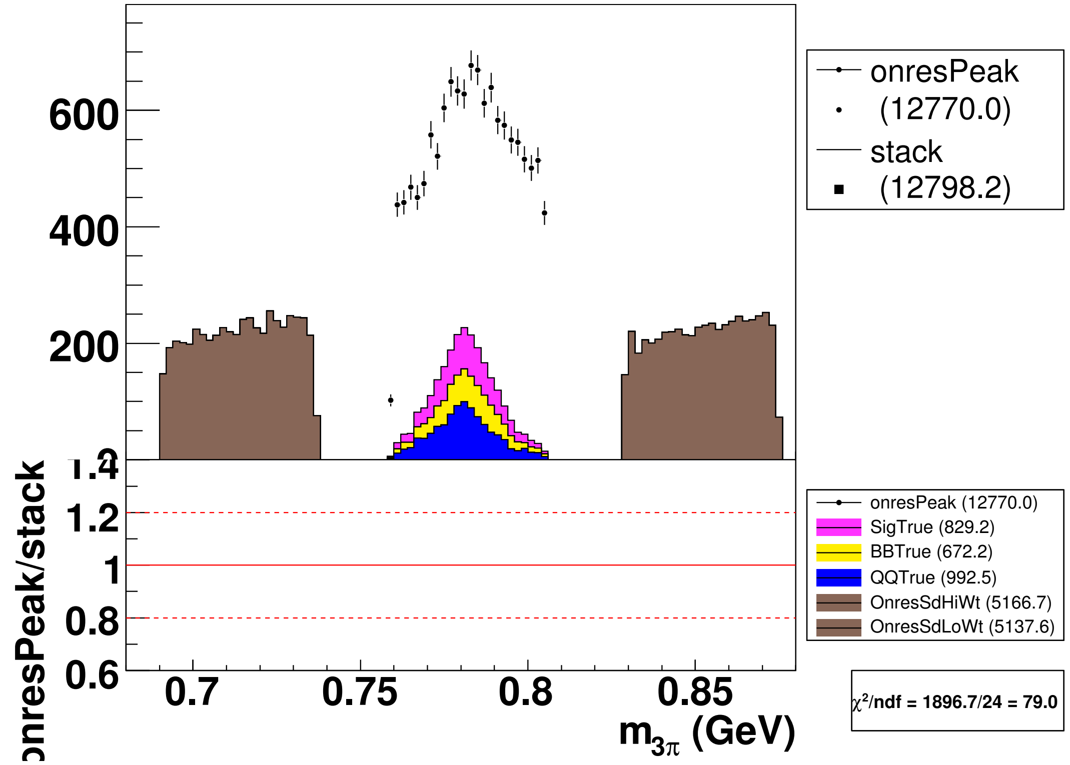


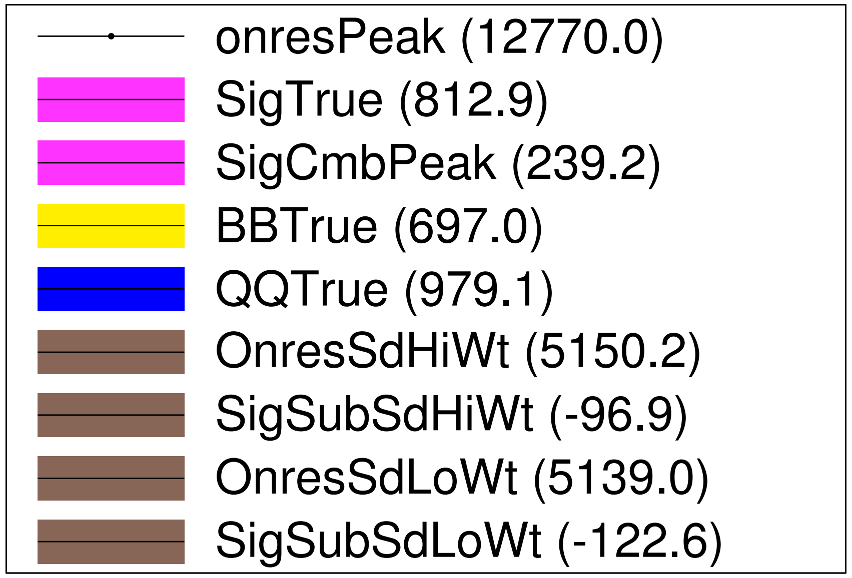


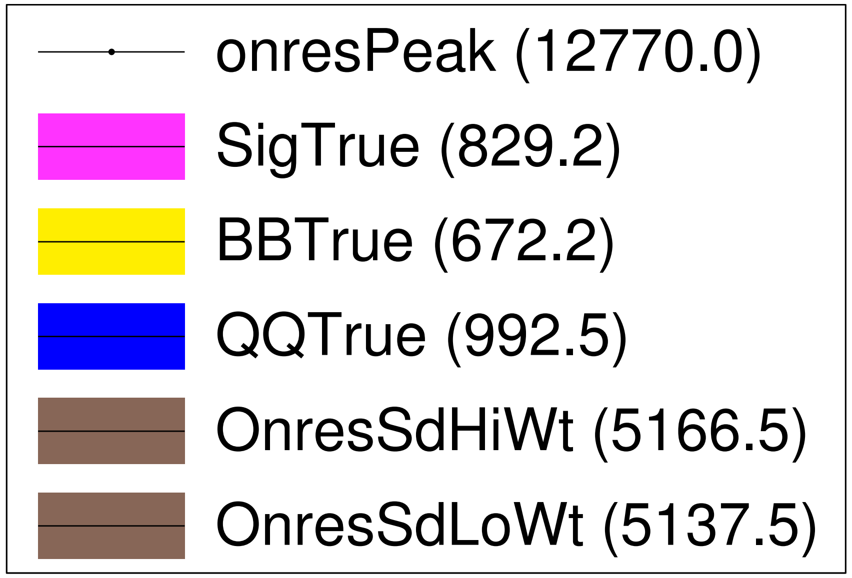
reweight with p_ω from BB:
Δsig = 1.1%

Systematics: $m_{3\pi}$ distribution of comb.-ω signal





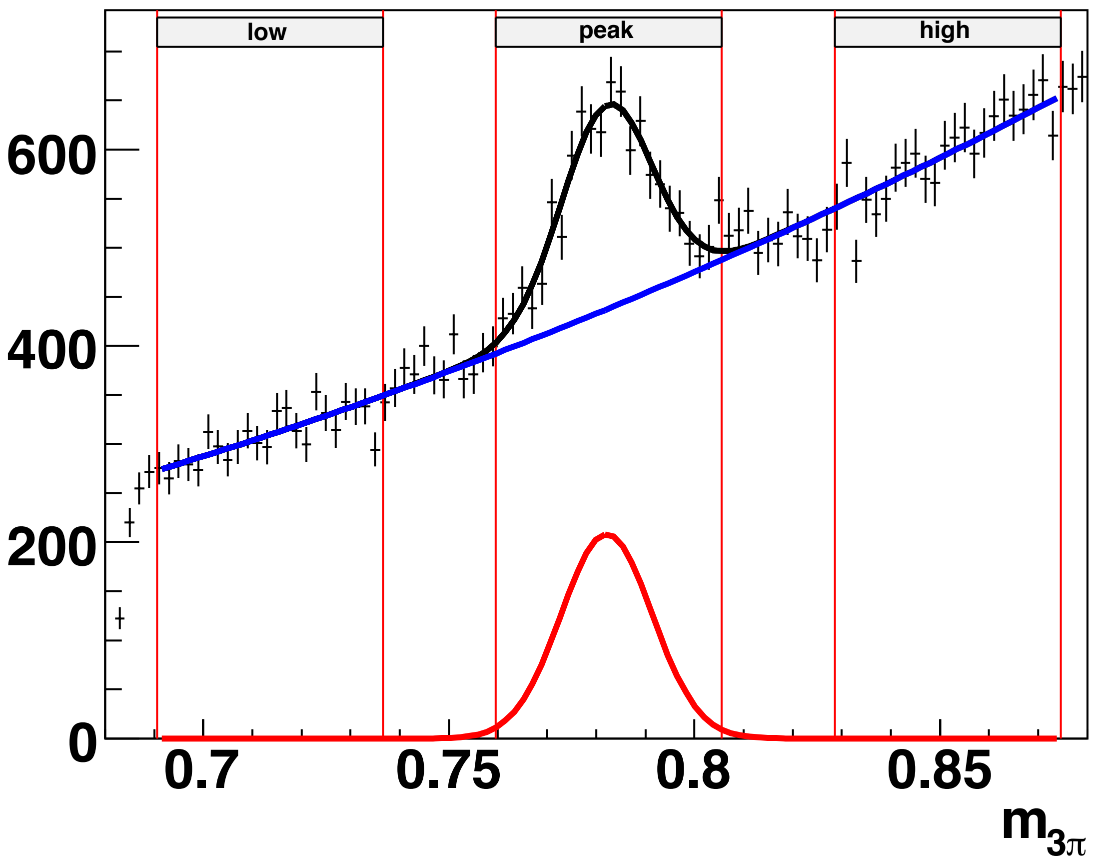


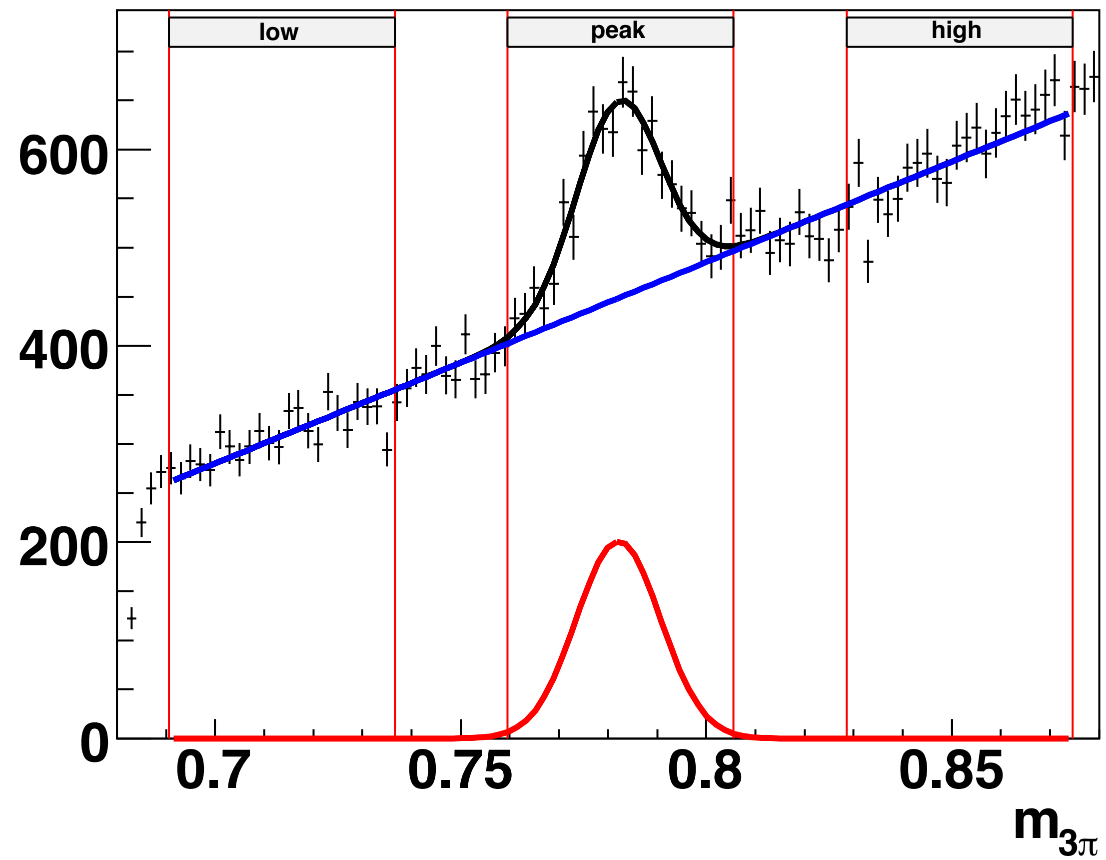


corrected sidebands:
nominal fit

no signal correction of sidebands:
Δsig = 2.3%

Systematics: scale of non-signal background



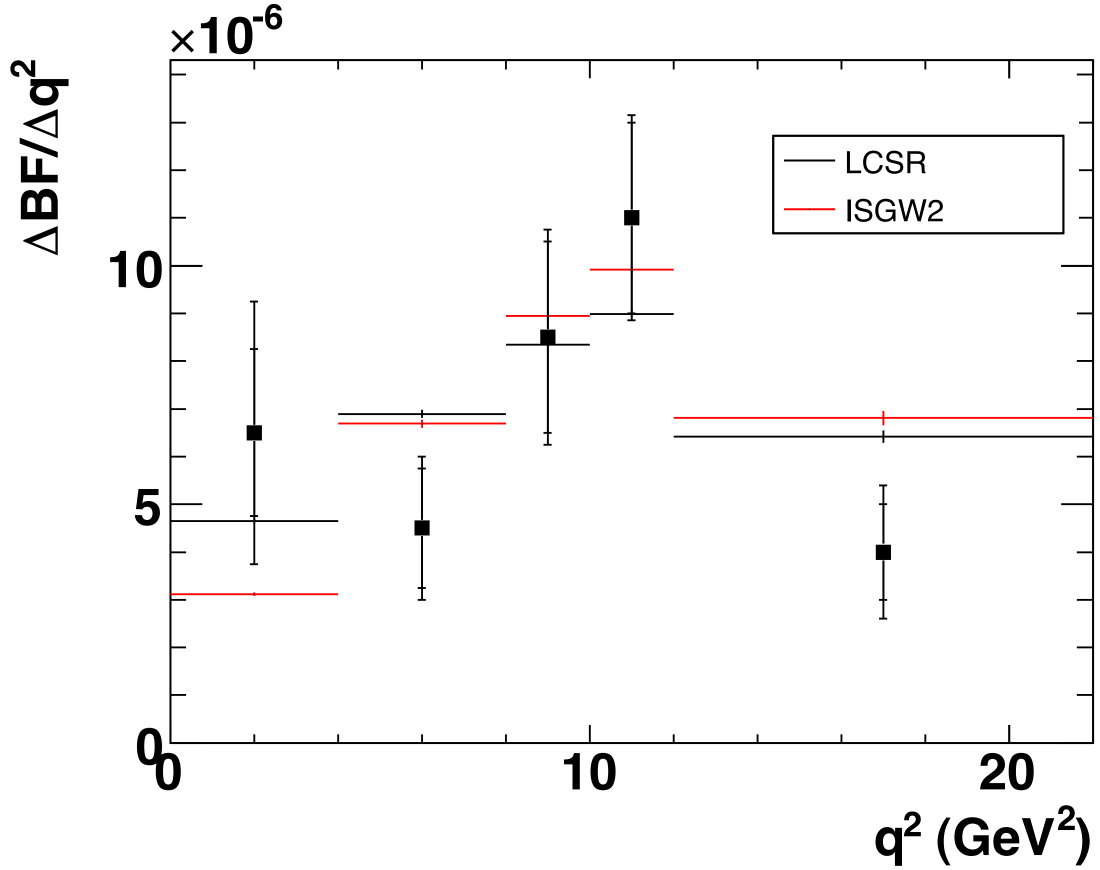


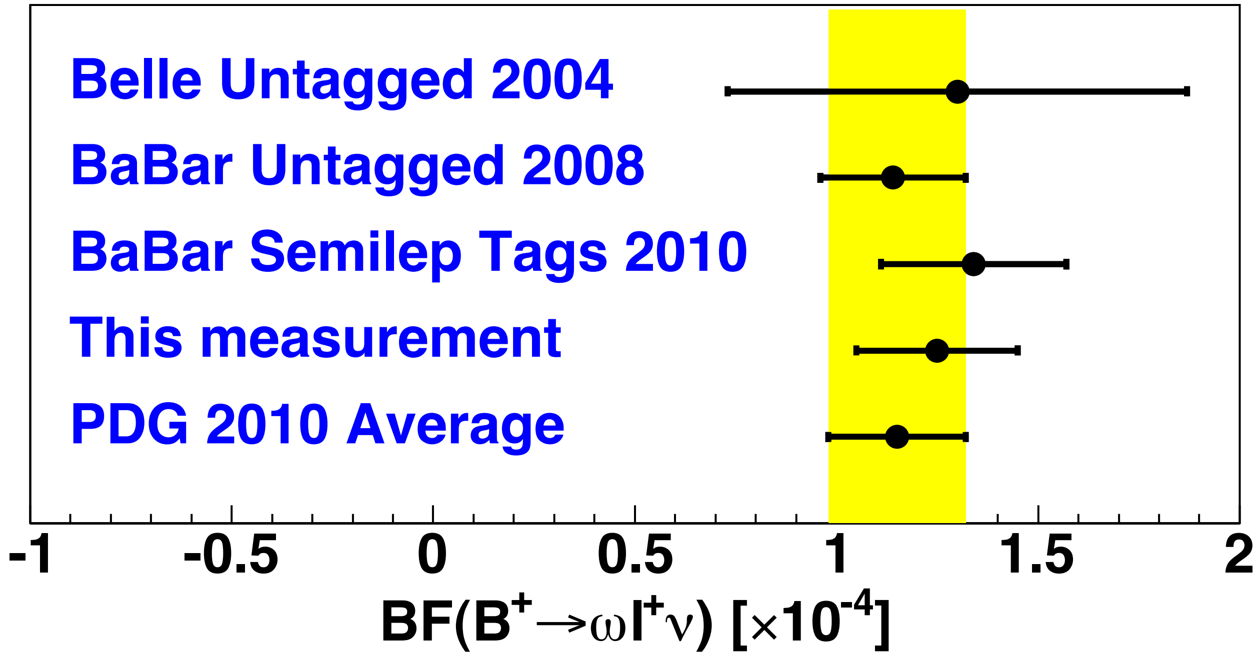
nominal fit:
f_{bkg} = quadratic poly.

f_{bkg} = linear poly.:
Δsig = 3.2%

BF in 5 q^2 bins

q^2 range (GeV^2)	$\Delta\mathcal{B}(\times 10^{-5})$
$0 < q^2 < 4$	$2.6 \pm 0.7 \pm 0.8$
$4 < q^2 < 8$	$1.8 \pm 0.5 \pm 0.3$
$8 < q^2 < 10$	$1.7 \pm 0.4 \pm 0.2$
$10 < q^2 < 12$	$2.2 \pm 0.4 \pm 0.2$
$12 < q^2 < 22$	$4.0 \pm 1.0 \pm 1.0$
$0 < q^2 < 22$	$12.5 \pm 1.6 \pm 1.3$





$|V_{ub}|$ from $B \to (\rho/\omega) l \nu$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(q^2_{min}, q^2_{max})}{\tau_+ \, \Delta\zeta(q^2_{min}, q^2_{max})}}$$

$$\Gamma = |V_{ub}|^2 \Delta\zeta$$

$$\Delta\zeta(q^2_{\rm min}, q^2_{\rm max}) = \frac{G_F^2 m_B^2}{96\pi^3} \int_{q^2_{\rm min}}^{q^2_{\rm max}} |\vec{p}_\rho| q^2 (|H_0|^2 + |H_+|^2 + |H_-|^2) dq^2$$

$B \to \rho l \nu$

LCSR: $|V_{ub}| = (2.75 \pm 0.24) \times 10^{-3}$

ISGW2: $|V_{ub}| = (2.83 \pm 0.24) \times 10^{-3}$

$B \to \omega l \nu$

LCSR: $|V_{ub}| = (2.32 \pm 0.21) \times 10^{-3}$

ISGW2: $|V_{ub}| = (2.33 \pm 0.20) \times 10^{-3}$

theory errors not available

$|V_{ub}|$ from $B\to\pi l\nu$

partial q^2 range

Solve rate equation for $|V_{ub}|$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(q^2_{min}, q^2_{max})}{\tau_0\ \Delta\zeta(q^2_{min}, q^2_{max})}}$$

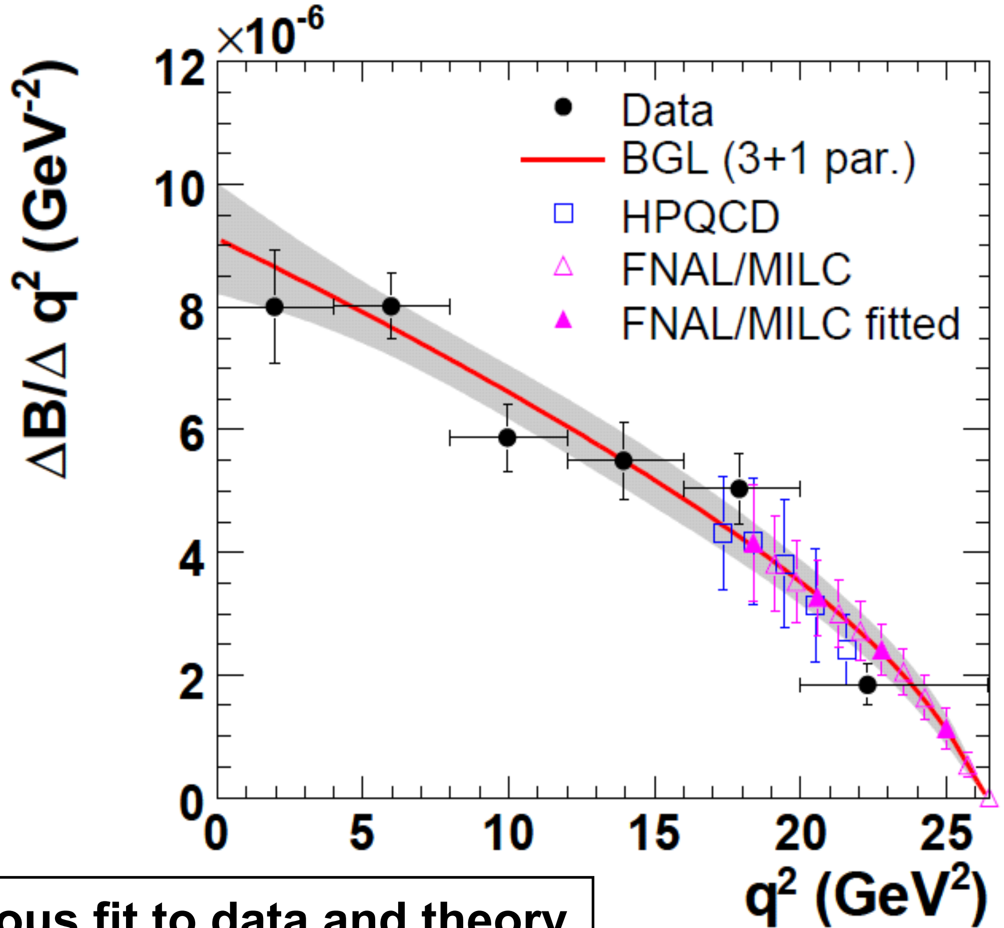
$$\Delta\zeta(q^2_{min}, q^2_{max}) = \frac{G_F^2}{24\pi^3}\int_{q^2_{min}}^{q^2_{max}} p_\pi^3 |f_+(q^2)|^2 dq^2$$

theory needed to calculate

		$\|V_{ub}\|(\times 10^{-3})$
LCSR	$(q^2 < 16\,\mathrm{GeV}^2)$	$3.63 \pm 0.12^{+0.59}_{-0.40}$
HPQCD	$(q^2 > 16\,\mathrm{GeV}^2)$	$3.21 \pm 0.17^{+0.55}_{-0.36}$

σ_{exp} = 3-5%; σ_{thy} = ~15%
Theory error dominates

full q^2 range

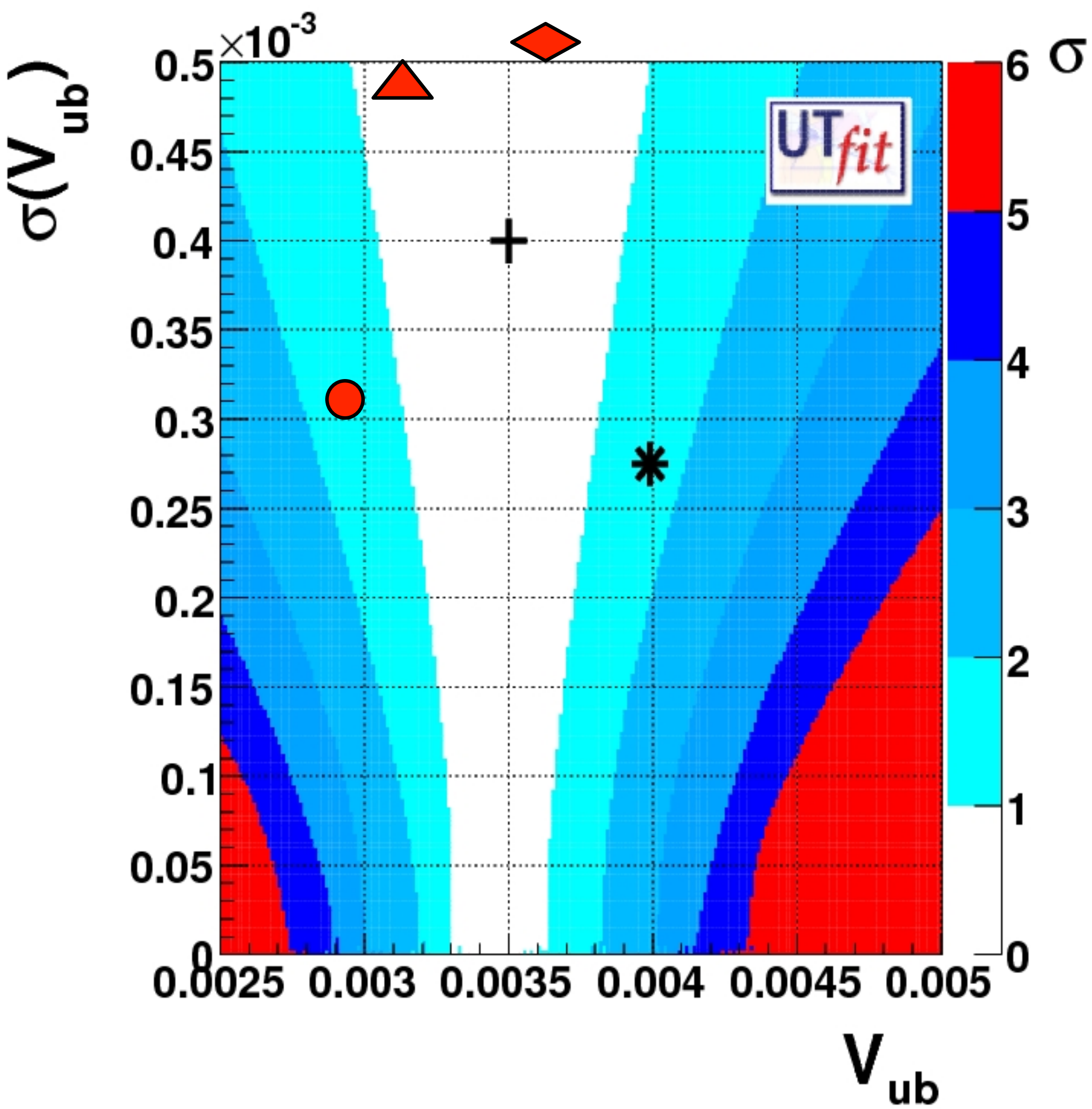


Simultaneous fit to data and theory
- 3 parameters: BGL quadratic polynomial
- 4th parameter: relative normalization between theory and data, $\alpha\ |V_{ub}|^2$
- Theory points are correlated, so not all are used in fit.

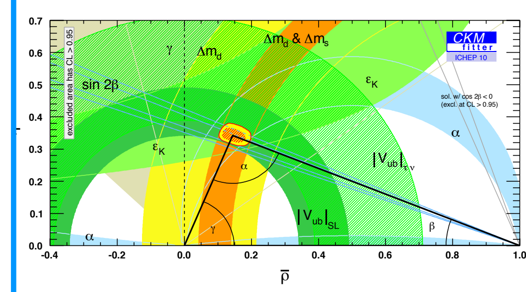
σ(data BF) = 3%
σ(data q^2 shape) = 5%
σ(theory FF norm.) = 8.5%
σ_{total} = 10.5%

$$|V_{ub}| = (2.99 \pm 0.35)\times 10^{-3} \quad \text{HPQCD (1 point)}$$
$$|V_{ub}| = (2.92 \pm 0.37)\times 10^{-3} \quad \text{FNAL/MILC (1 point)}$$
$$|V_{ub}| = (2.95 \pm 0.31)\times 10^{-3} \quad \text{FNAL/MILC (4 points)}$$

|V_{ub}| summary



significance bands drawn relative to global fit of all other unitarity triangle constraints:
|V_{ub}| = (3.48 ± 0.16) x 10^{-3}



|V_{ub}| from this $B \to \pi l \nu$ analysis

- ◆ LCSR, low q^2 = (3.63 ± 0.51) × 10^{-3}
- ▲ HPQCD, high q^2 = (3.21 ± 0.49) × 10^{-3}
- ● FNAL/MILC, full q^2 = (2.95 ± 0.31) × 10^{-3}

UT Fit values

+ exclusive average
✱ inclusive average
Δ between inclusive and exclusive is <2σ

Conclusions

improved BF's

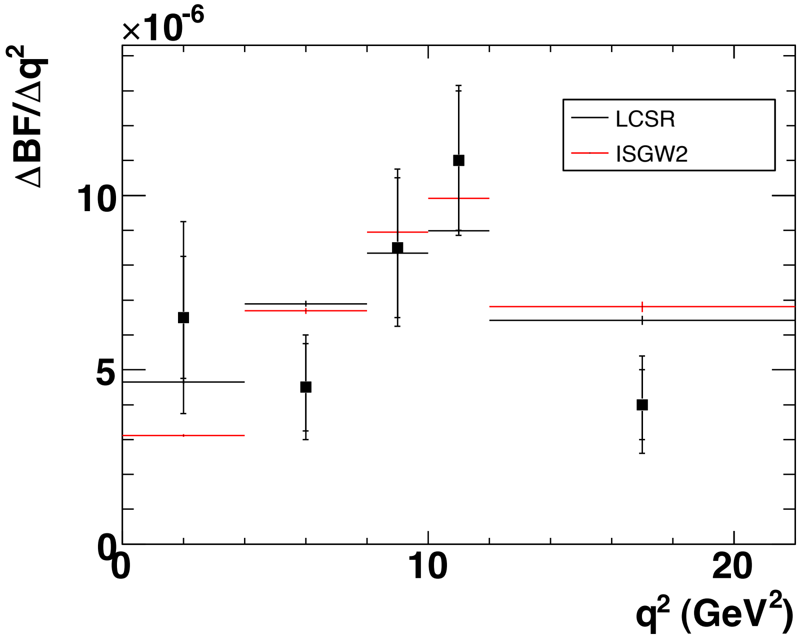
$BF(B^0 \to \pi^- l^+ \nu) = 1.41 \pm 0.05 \pm 0.07) \times 10^{-4}$

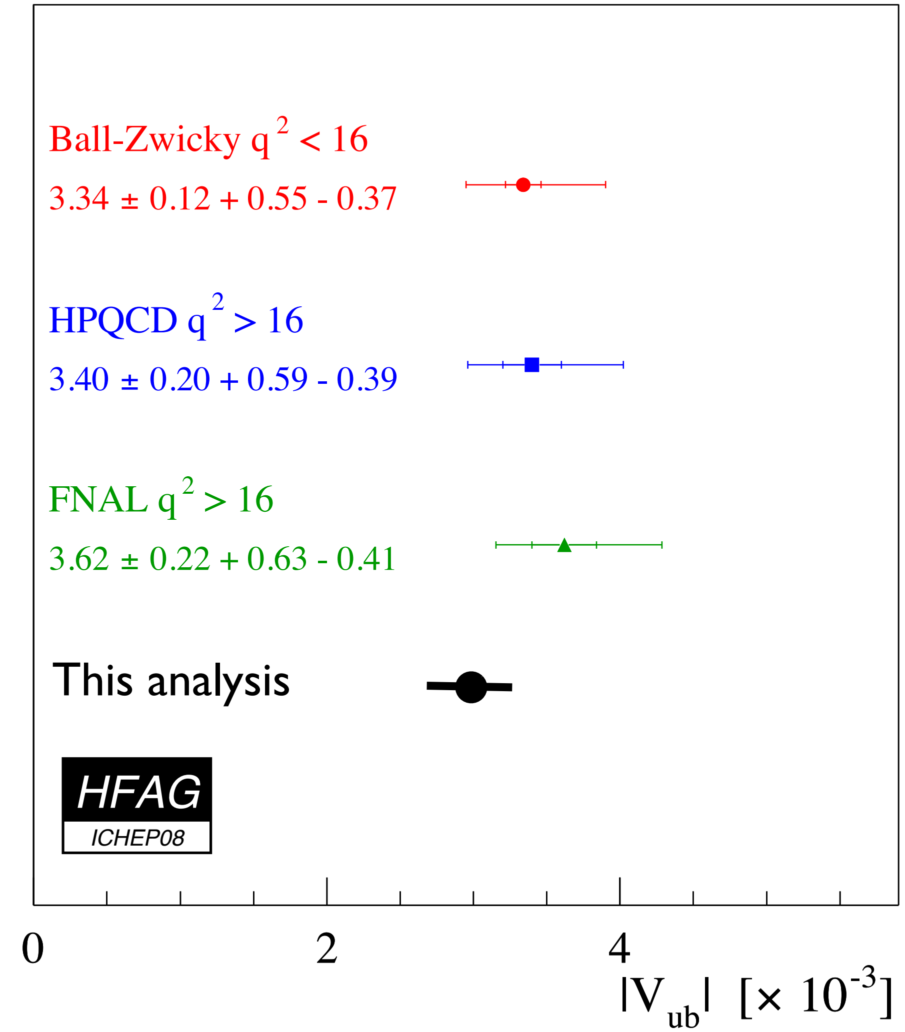
$BF(B^0 \to \rho^- l^+ \nu) = 1.75 \pm 0.15 \pm 0.27) \times 10^{-4}$

$BF(B^+ \to \omega l^+ \nu) = 1.25 \pm 0.16 \pm 0.13) \times 10^{-4}$

combined fit to theory & data reduces exclusive $|V_{ub}|$ error (but theory errors still dominate)

taking comb.-ω bkgd from data reduces MC dependence and allows q^2 spectrum measurement





Backup