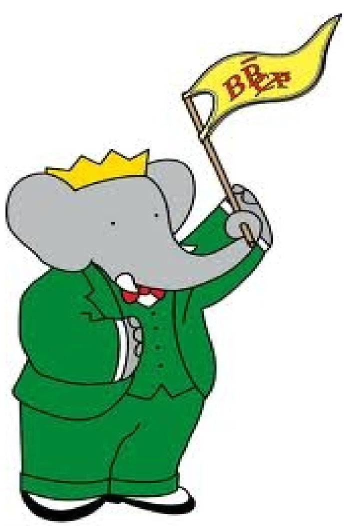
DESY Seminar

Hamburg & Zeuthen · 13 & 14 November 2012

Recent BABAR Results

Semileptonic/Leptonic B Decays: Impact on New Physics



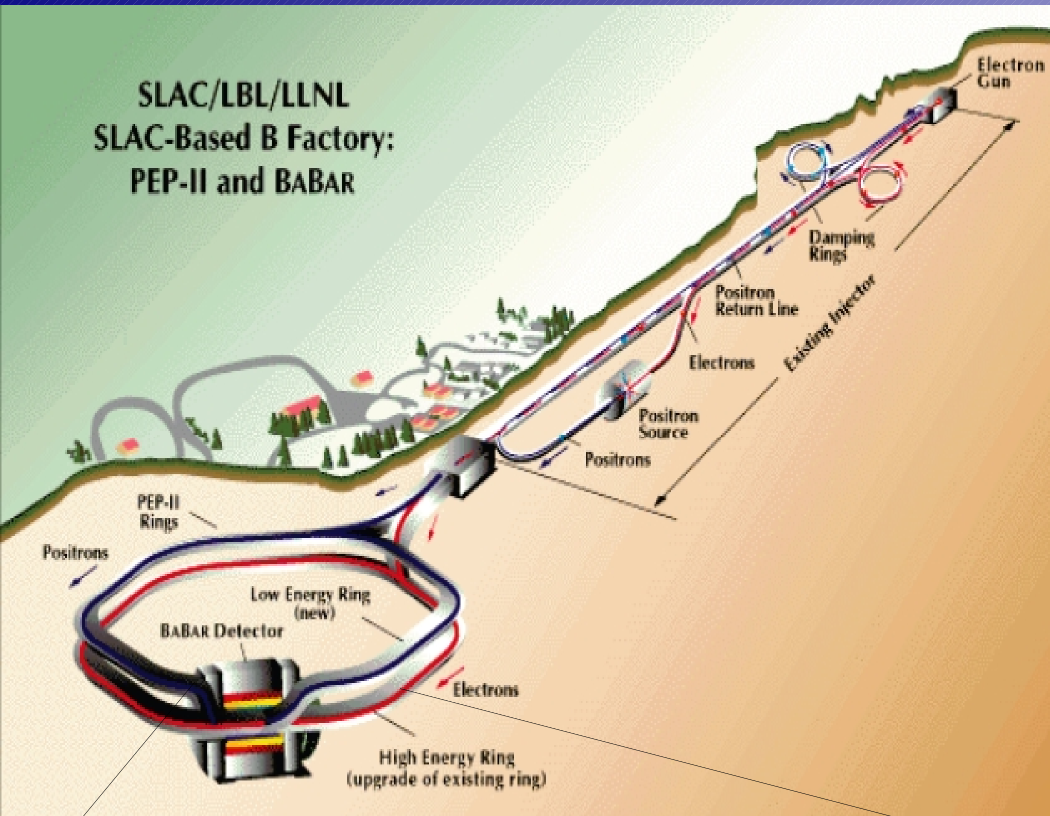
Marcello Rotondo

I.N.F.N. Padova

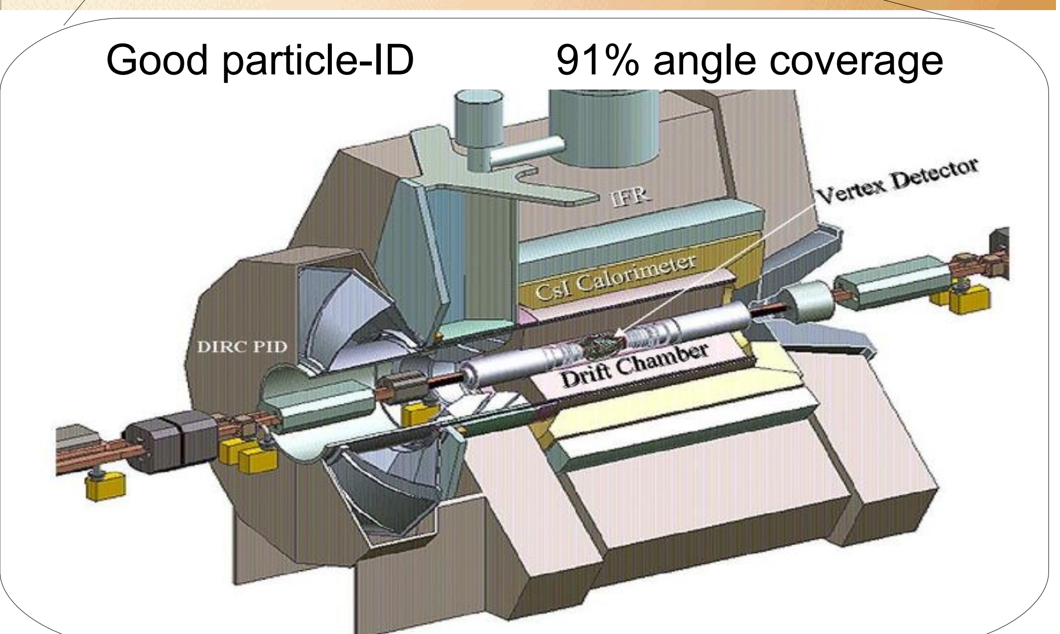
Outline

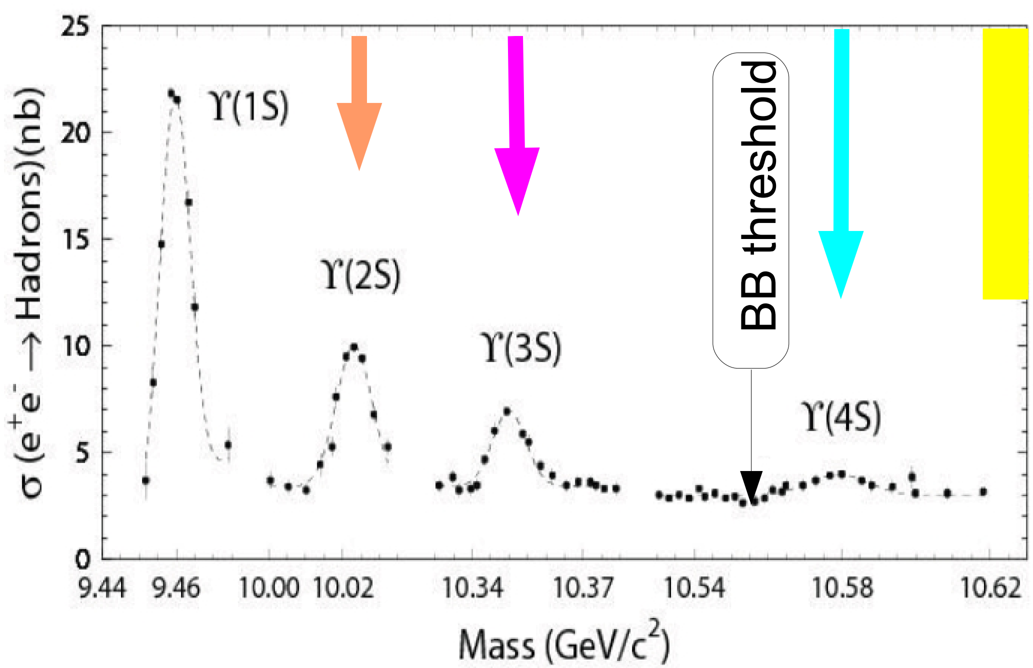
- BaBar dataset
- Quark Mixing Matrix and Unitarity Triangle
- Semileptonic Decays
  - Recent $|V_{ub}|$ measurement
  - Results on $B \to D^{(*)} \tau \nu_\tau$
- Results on leptonic $B \to \tau \nu_\tau$ decay
- Implications for the widely discussed 2HDM
- Summary

PEP-II storage rings and BaBar experiment



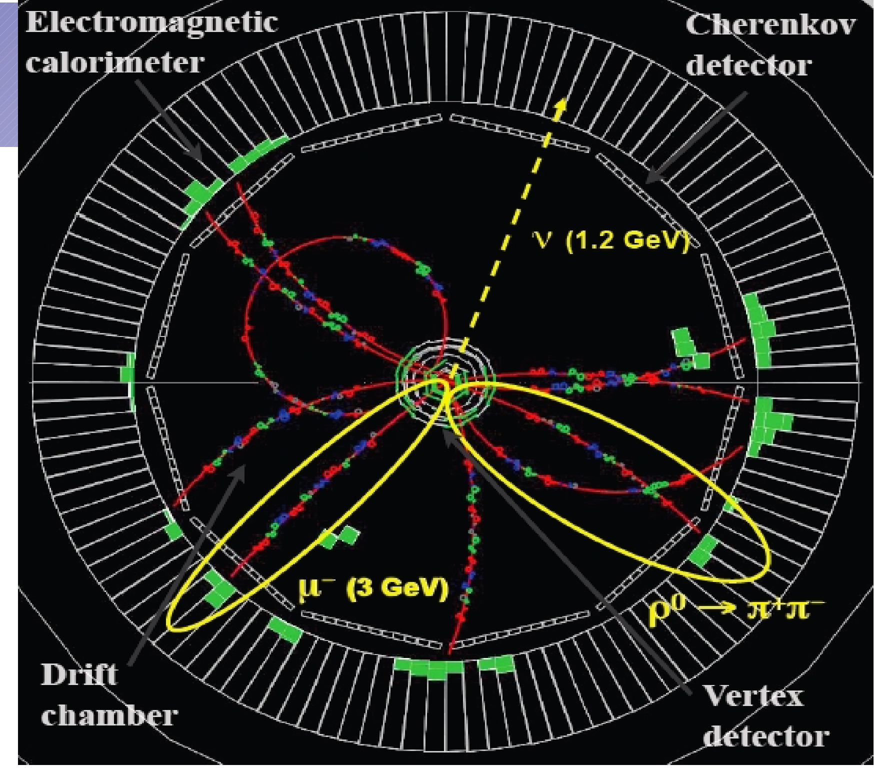
- Operation 1999-2008
- Linear accelerator injects in PEP-II
  - Asymmetric beams
    - 9.0 GeV electrons
    - 3.1 GeV positrons
  - CM energy of the ϒ(4S) = 10.58 GeV most of the time
    - Collected data at the ϒ(2S-3S) and above the ϒ(5S)

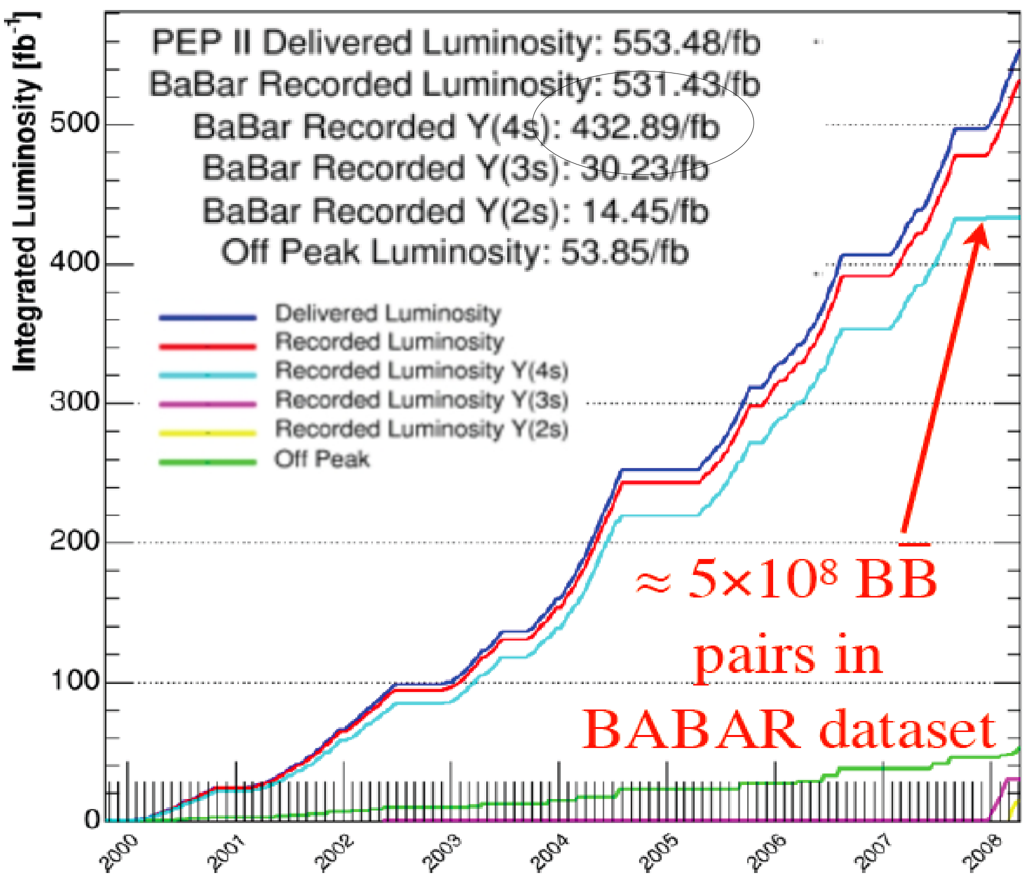




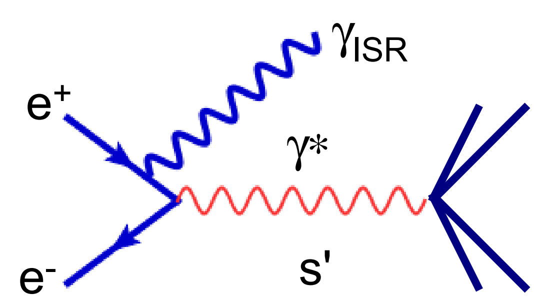
May 1999 · Apr 2008

- At Υ(4S) center of mass energy, large production of B meson from Υ decays
  - $\sigma_{10.58GeV}(e^+e^- \to bb) = 1.06nb$
  - LHC: $\sigma_{7TeV}(pp \to bb) \sim 200 \cdot 10^3 nb$



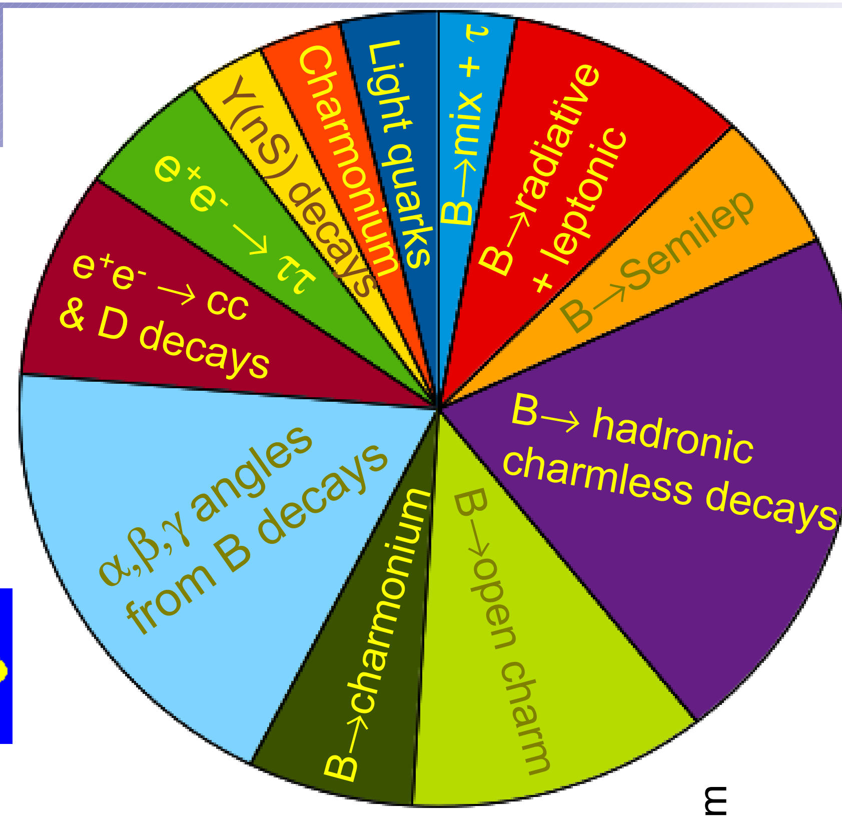


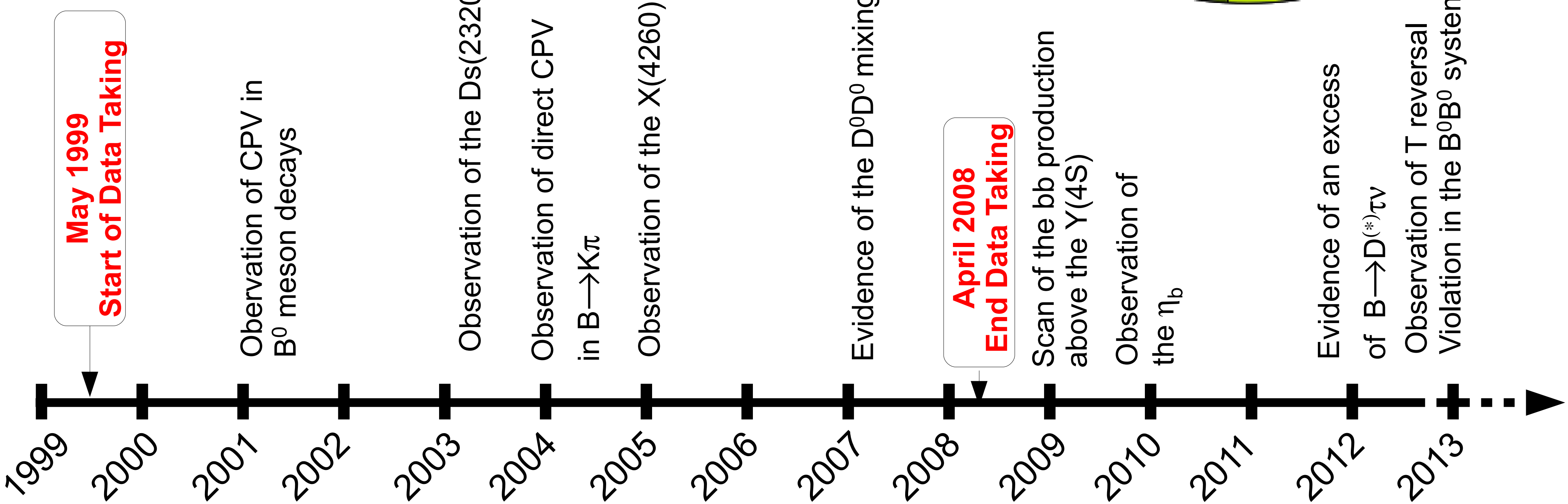
- PEPII/BaBar: Charm / Tau factory!
  - $\sigma(cc)=1.30nb$
  - $\sigma(\tau\tau)=0.91nb$
- Study light quark and cc production using ISR and $\gamma\gamma$ events



Broad physics program

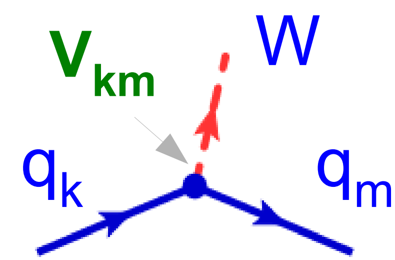
- BaBar still producing a lot of results
  - 500 published papers in total
  - 13 published + 14 submitted since Jan/2012
  - Diverse Physics
  - Strong competition with Belle





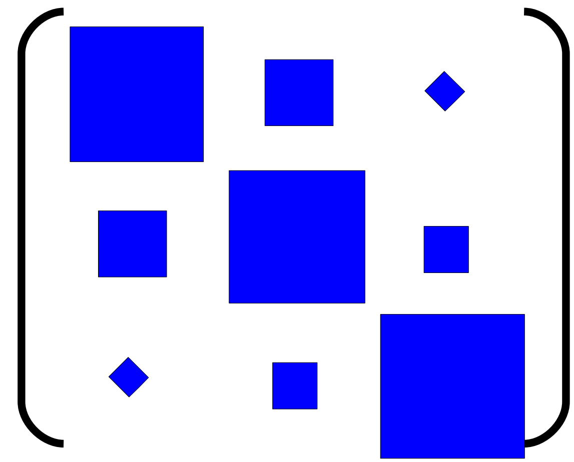
CKM Matrix Introduction

- The Standard Model quark flavor sector requires the knowledge of the quark masses and of the strength of the charge-current gauge interactions (**C**abibbo **K**obayashi **M**askawa matrix)



Weak eigenstates — V_{CKM} — Mass eigenstates

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



$$\begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Experimental evidence of a strongly hierarchical structure
- $V^{\dagger}_{CKM} \cdot V_{CKM} = \mathbf{1} \Rightarrow$ 4 independent parameters
  - 3 real + 1 complex phase (CPV)
  - A, λ~0.22, $|\rho+i\eta|=O(1)$

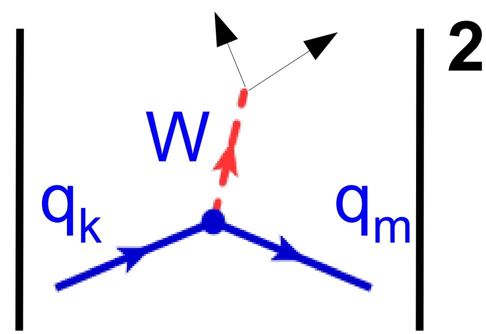
The Wolfenstein parameterization

$$V_{CKM} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CKM Matrix

- CKM cannot be predicted in the SM
- Most SM extensions contain new CP-violating phases and new quark-flavor changing interactions

V_{ud} $\pi \to \ell\nu$ β-decay	V_{us} $K \to \pi\ell\nu$ $K \to \ell\nu$	V_{ub} $b \to u\ell\nu$ $B \to \pi\ell\nu$
V_{cd} $D \to \pi\ell\nu$ $\nu+d \to c+\ell$	V_{cs} $D \to K\ell\nu$ $D_s \to \ell\nu$	V_{cb} $b \to c\ell\nu$ $B \to D\ell\nu$
V_{td} $\langle B_d \vert \overline{B}_d \rangle$ $b \to d\gamma$	V_{ts} $\langle B_s \vert \overline{B}_s \rangle$ $b \to s\gamma$	V_{tb} $t \to b\ell\nu$



$$\sim |V_{km}|^2$$

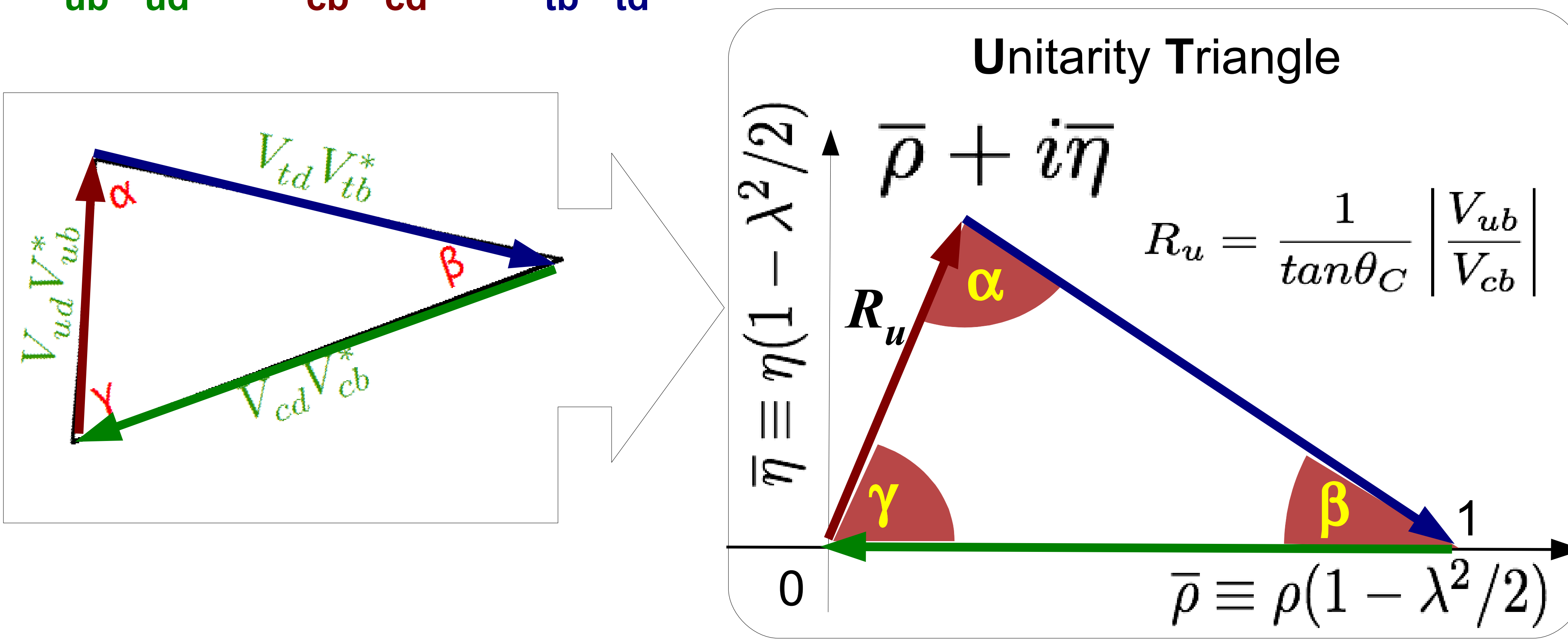
The CKM matrix extracted from tree-level processes

Unitarity Triangle

$1-\lambda^2/2$	λ	$A\lambda^3(\rho-i\eta)$
$-\lambda$	$1-\lambda^2/2$	$A\lambda^2$
$A\lambda^3(1-\rho-i\eta)$	$-A\lambda^2$	1

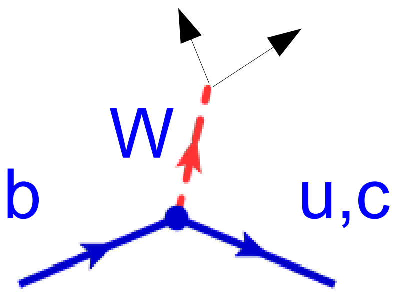
- $V^{\dagger}_{CKM} \bullet V_{CKM} = \mathbf{1}$ ⇨ 9 conditions on the CKM parameters (6 triangular relations):
  - 3rd x 1st is of great phenomenological interest
  - all sizes of the same order in λ: CP violation is "visible"

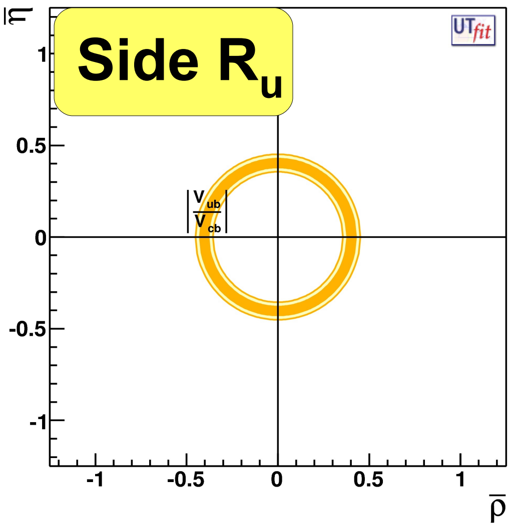
$$V^*_{ub}V_{ud} + V^*_{cb}V_{cd} + V^*_{tb}V_{td} = 0$$

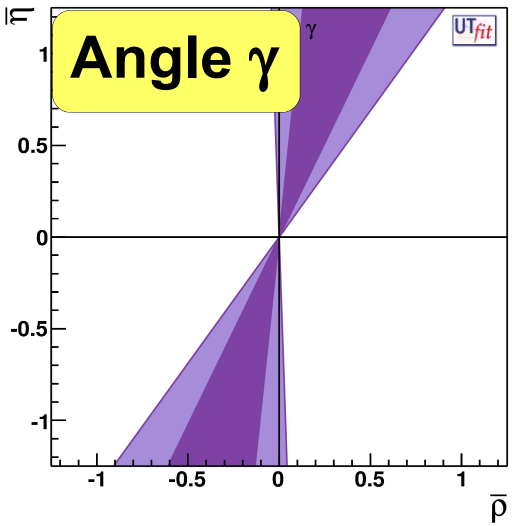


UT Constraints

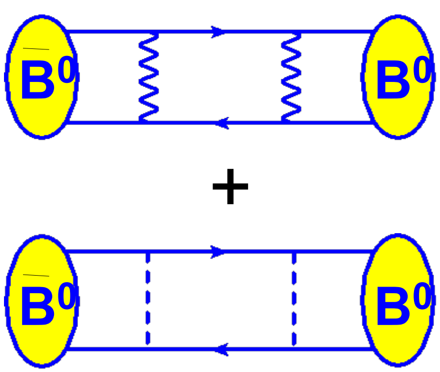
From tree-level processes
("free" of New Physics)
more will come later

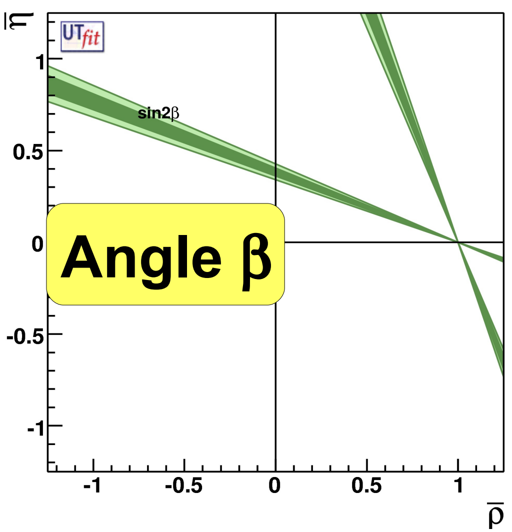


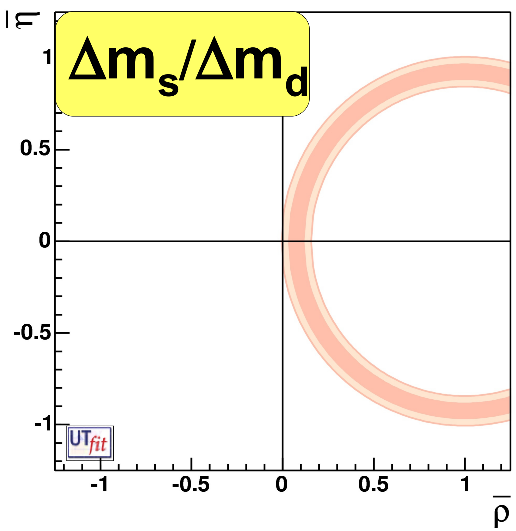




From loop mediated processes
particularly sensitive to New Physics





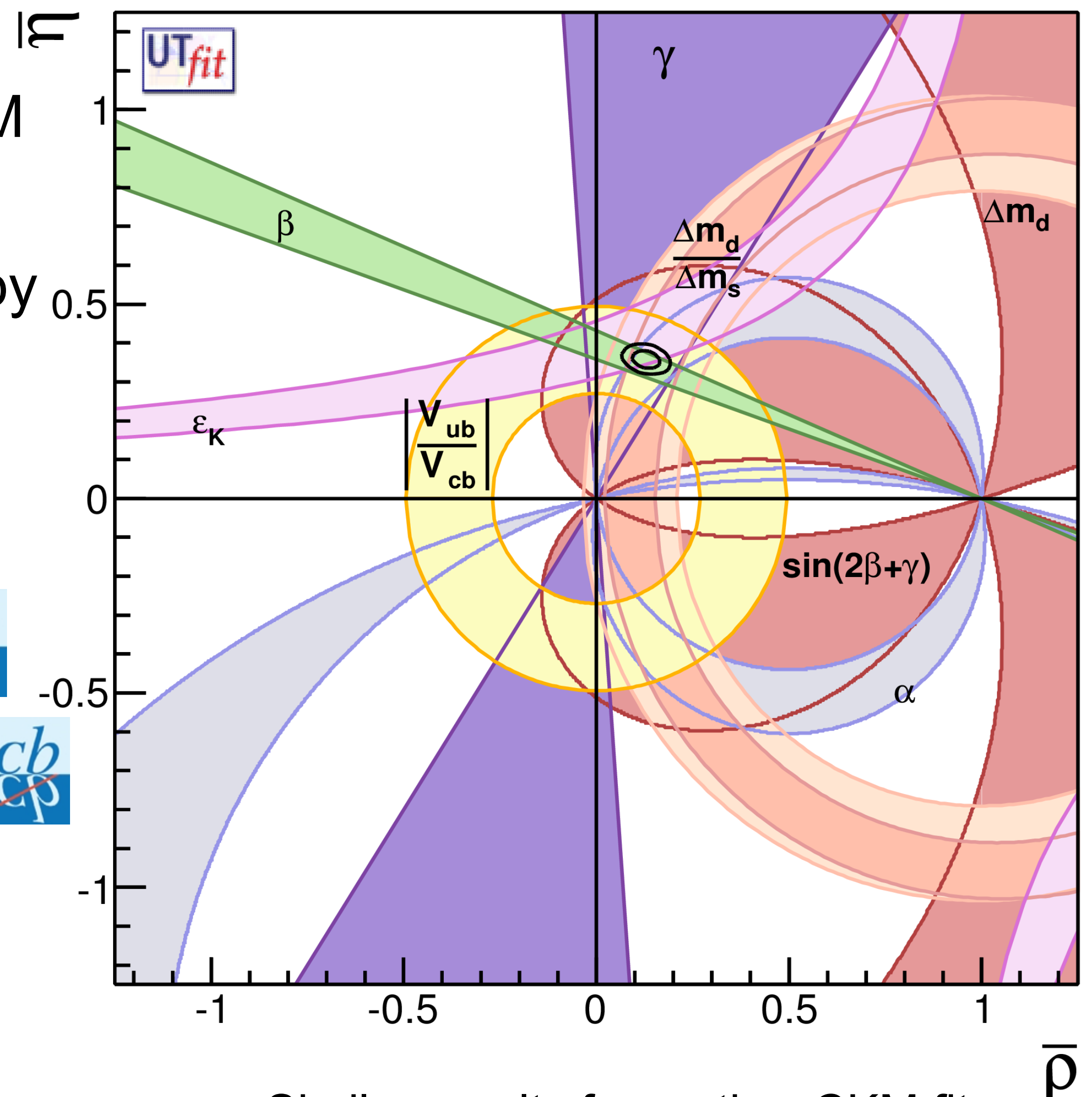


- Redundant constraints on UT and test of CKM unitarity ⟶ powerful test of the SM

UT Status (Summer 2012)

- Redundant and consistent determinations of various CKM elements

- Remarkable success of the CKM picture
- Other observables (dominated by loops) in good agreement with expectation:
  - $B \rightarrow X_s \gamma$
  - $B \rightarrow K^* \mu\mu$
  - B_s mixing phases
  - $B_s \rightarrow \mu\mu$
  - Many others...



Similar results from other CKM fits

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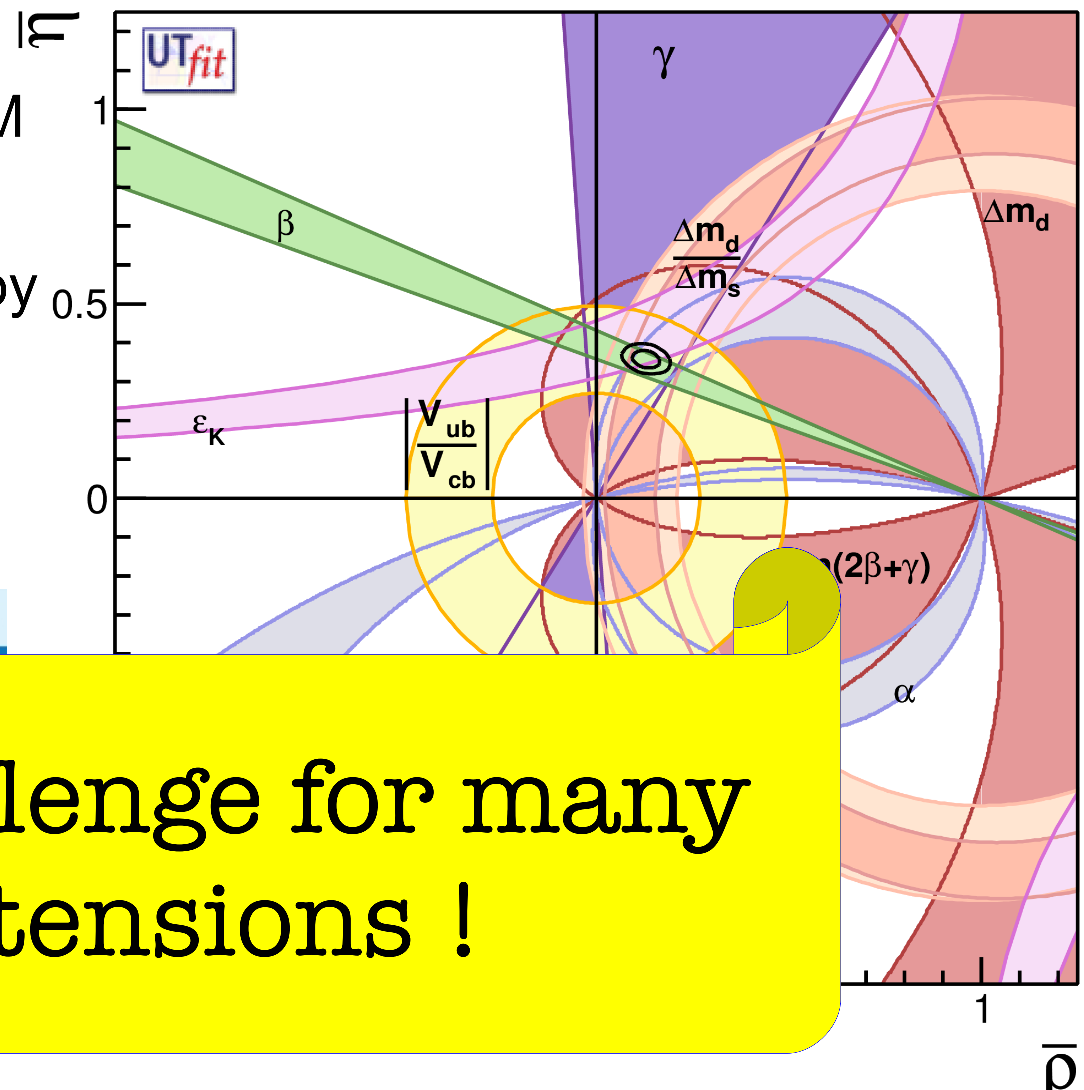


A great challenge for many SM extensions !

Similar results from other CKM fits

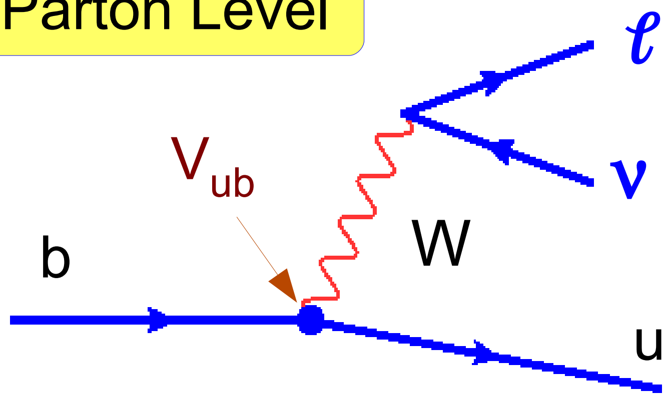
$|V_{ub}|$

Phys. Rev. D 86, 092004 (2012)

Phys.Rev.Lett. 109 101802 (2012)

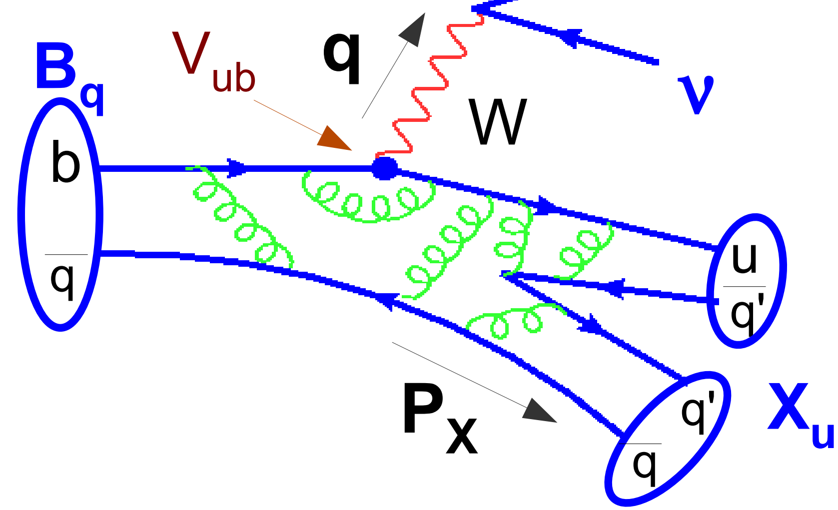
Semileptonic Decays

Parton Level



Understand
The QCD

Hadron Level



- Inclusive decays $B \to X_u \ell \nu$:
  - QCD corrections to parton level decay rate
  - Operator Product Expansion predicts the total rate Γ_u

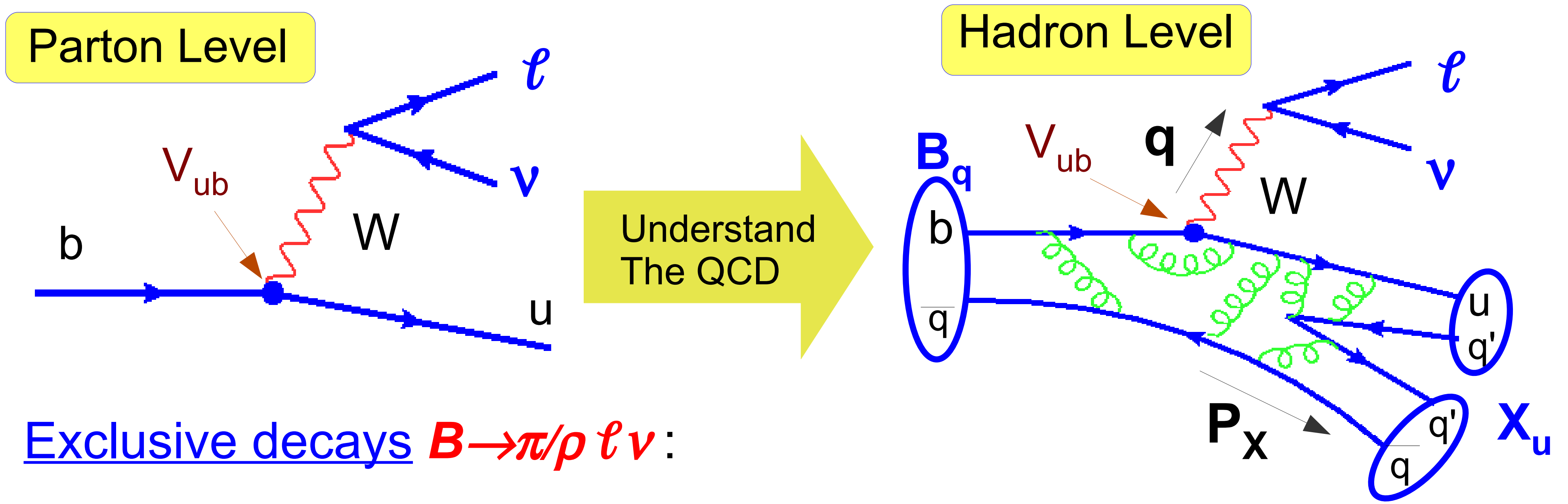
$$\Gamma_u = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3}\left[1 - \mathcal{O}\left(\frac{\alpha_s}{\pi}\right) - \mathcal{O}\left(\frac{\Lambda_{QCD}^2}{m_b^2}\right) + \cdots\right]$$

Dominant uncertainty from m_b^5

Perturbative terms known to $\mathcal{O}(\alpha_s^2)$

Non-perturb. terms suppressed by $1/m_b^2$

Semileptonic Decays



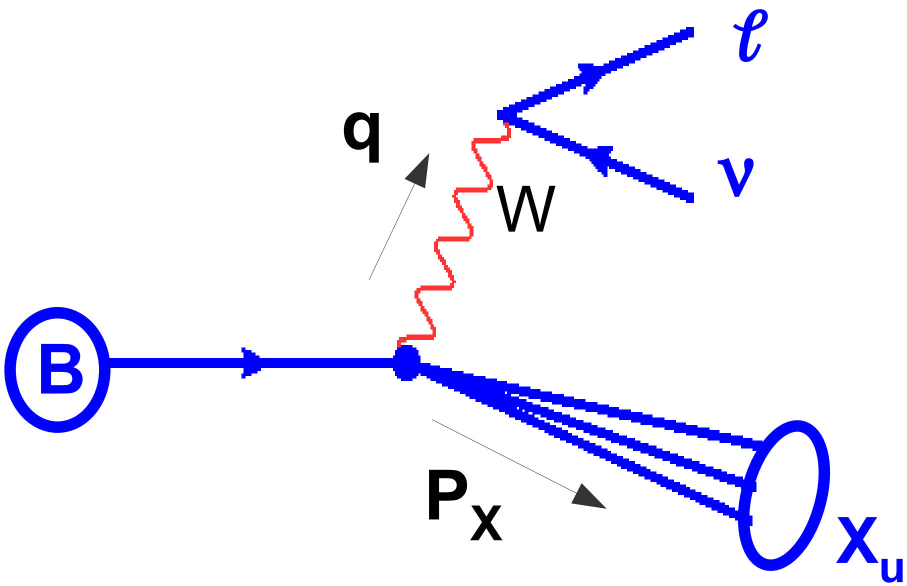
- Exclusive decays $B \to \pi/\rho\, \ell\, \nu$:
  - QCD correction parameterized in the Form Factors
  - Lattice-QCD, LCSR

$$\frac{d\Gamma(B^0 \to \pi^- \ell^+ \nu)}{dq^2} = \frac{G_F^2}{192\pi^3 m_B^3}\left[(m_B^2 + m_\pi^2 - q^2)^2 - 4m_B^2 m_\pi^2\right]^{3/2} |\mathrm{V_{ub}}|^2 |\mathrm{f_+(q^2)}|^2$$

In the $m_\ell \sim 0$ only f+ contributes

$|V_{ub}|$ from inclusive decays

$$\frac{\Gamma(b \to c\ell\nu)}{\Gamma(b \to u\ell\nu)} \approx 50$$



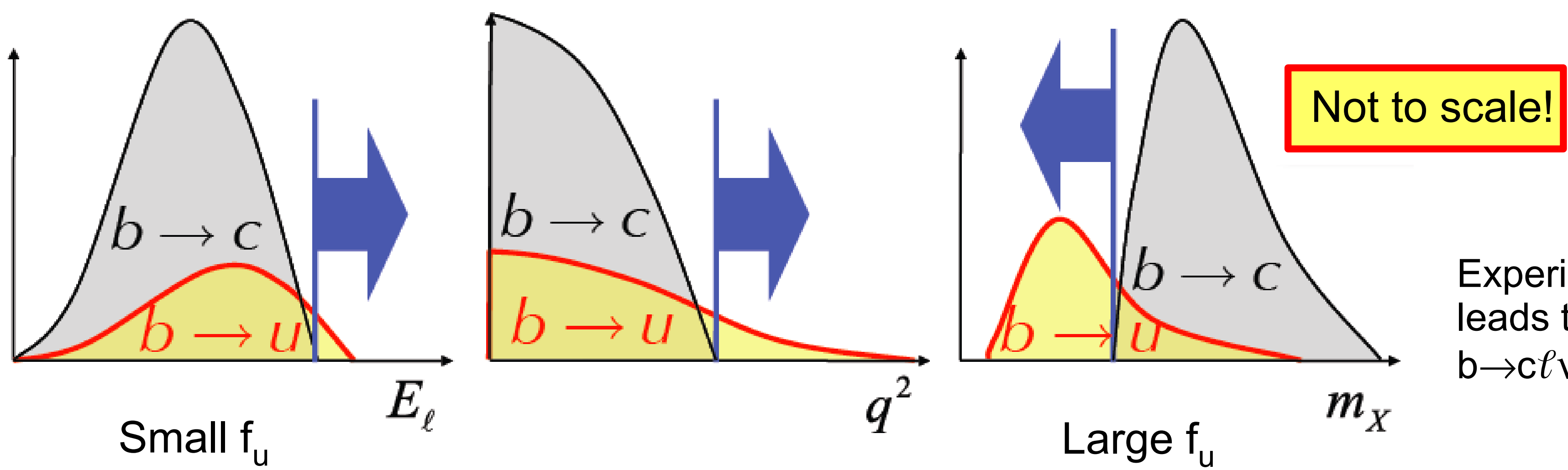
- Large background from $B \to X_c \ell \nu$
- Kinematics to extract the signal: $m_u << m_c$
  - Cut limited region of phase space (f_u)
  - From partial BF $\to$ $|V_{ub}|$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\overline{B} \to X_u \ell \bar{\nu})}{\tau_B \, \Delta\Gamma_{\text{theory}}}}$$

E_ℓ = lepton energy

Q^2 = $(P_B - P_X)^2 = (P_\ell - P_\nu)^2$

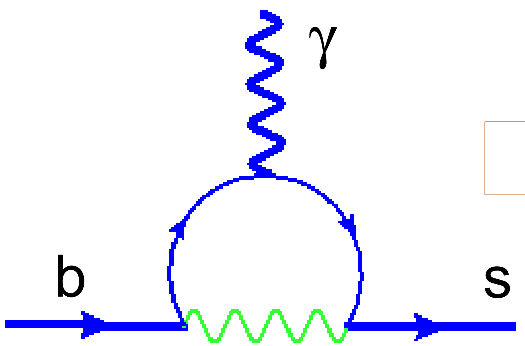
M_X = X_u hadronic mass

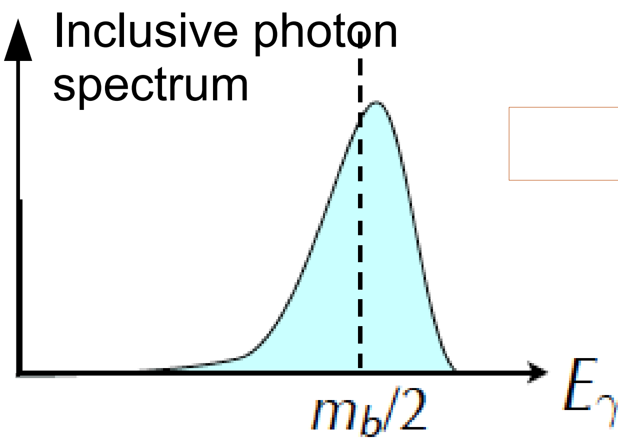


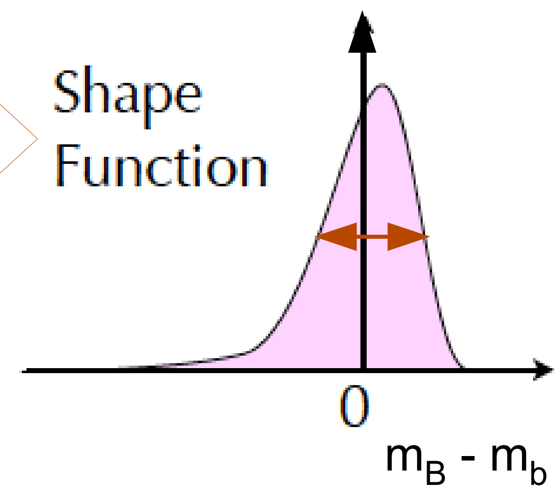
Experimental resolution leads to irreducible $b \to c \ell \nu$ contamination

Inclusive decays: Shape Function

- Cut in limited region of phase space is theoretically challenge:
  - OPE breaks down: $\Delta\Gamma_u$ depends on $\mathcal{O}(1/m_b)$ non-perturbative effects!
  - Increase dependence on b-quark mass
  - Need the **shape function**:
    - In principle directly from experimental data with $B \to X_s\gamma$



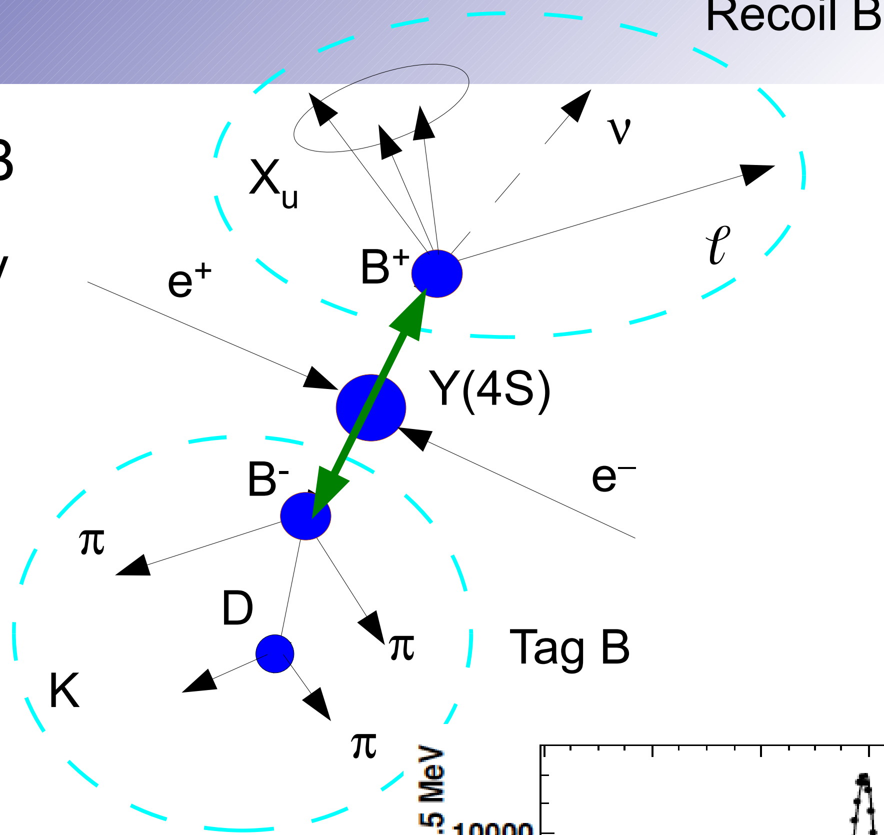




In practice: the SF is determined indirectly from fitting many kinematical variables related to $B \to X_s\gamma$ and $B \to X_c\ell\nu$ or only to $B \to X_c\ell\nu$ with m_c constrained

Events Reconstruction

- Two B in the Y decay: $e^+e^- \to Y(4S) \to BB$
    - Fully reconstruct one B in hadronic decay modes (with a D or a D*)
    - The rest comes from the other B (B^{recoil})
- Tag efficiency ~ 0.2-0.4%
- Recoil momentum is know from P_{tag}

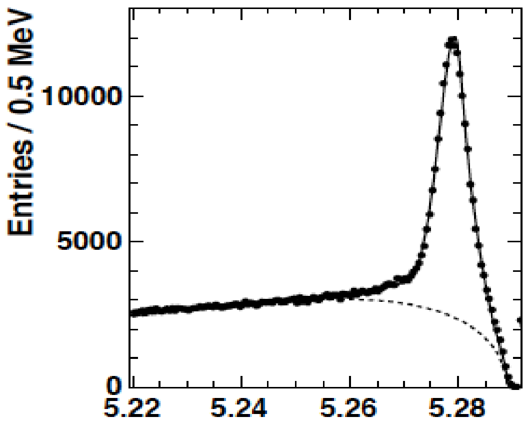


$$\vec{p}_{B^{recoil}} = -\vec{p}_{B^{tag}}$$

$$p_\nu = p_{B^{recoil}} - p_X - p_\ell \qquad (p_\nu{}^2 = m^2{}_{miss})$$

$$p_X = \sum_i p_i^{track} + \sum_i p_i^{clust.}$$

$$q^2 = (p_{B^{recoil}} - p_X)^2$$

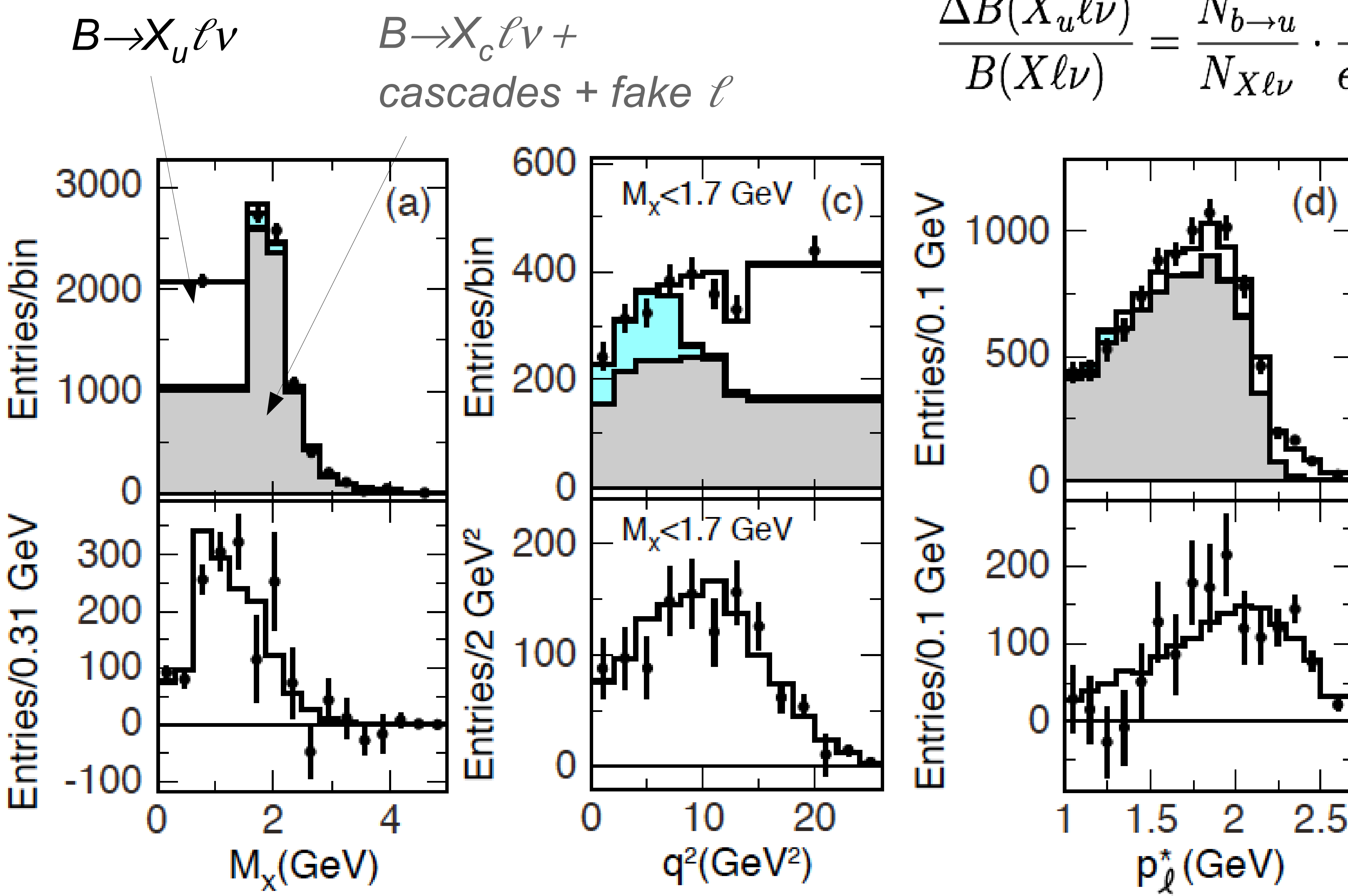


Recoil kinematics boosted in the B^{recoil}

ΔB in the B rest frame

Fit results in limited regions of phase space

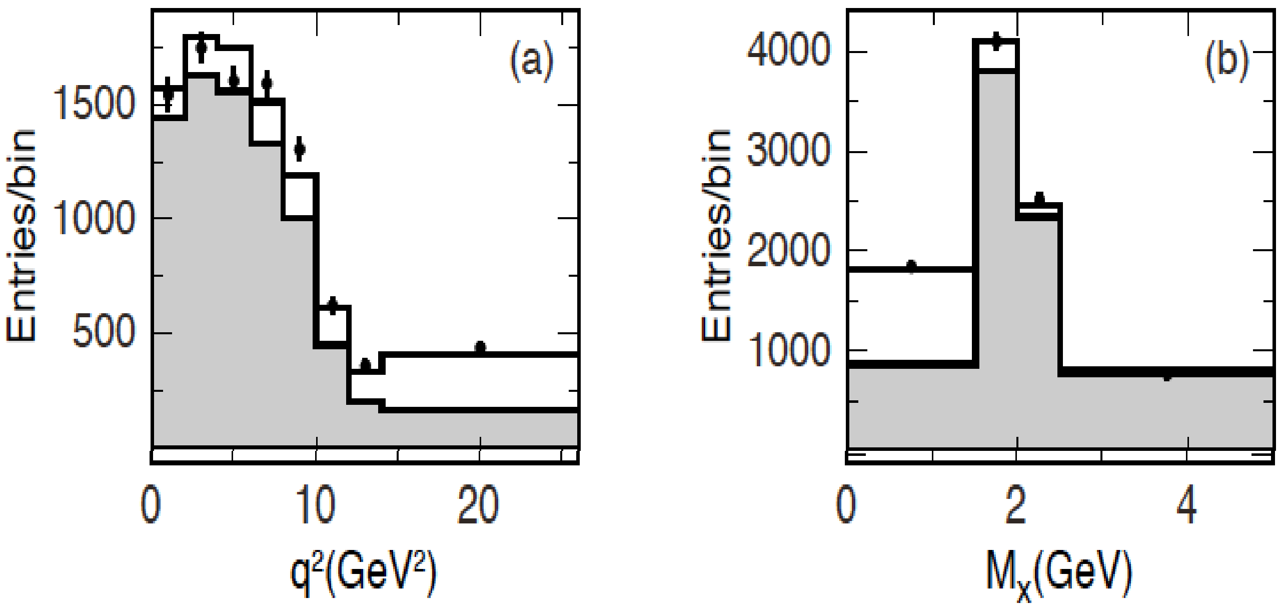
$$\frac{\Delta B(X_u \ell \nu)}{B(X \ell \nu)} = \frac{N_{b \to u}}{N_{X \ell \nu}} \cdot \frac{F}{\epsilon_{sel}}$$



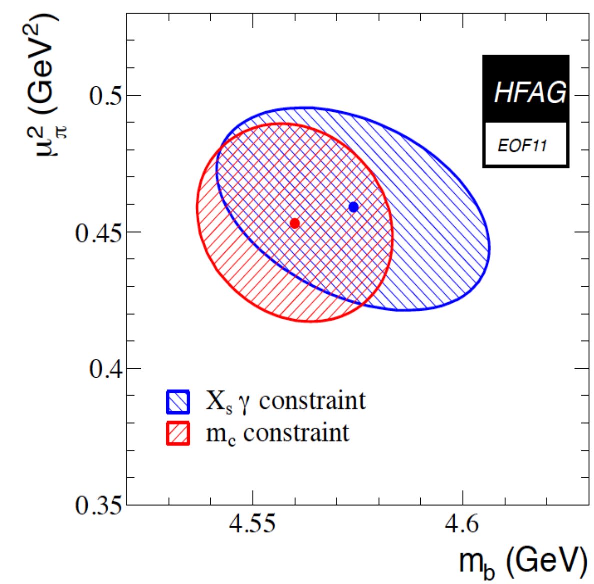
Best Measurements ($\sigma_{exp} \oplus \sigma_{theory}$)

- Fit the (M_x,q^2) distribution in the region defined by p_{lepton} > 1GeV: 89% of Phase Space

Signal events:
1441±102



Inputs from HFAG2011



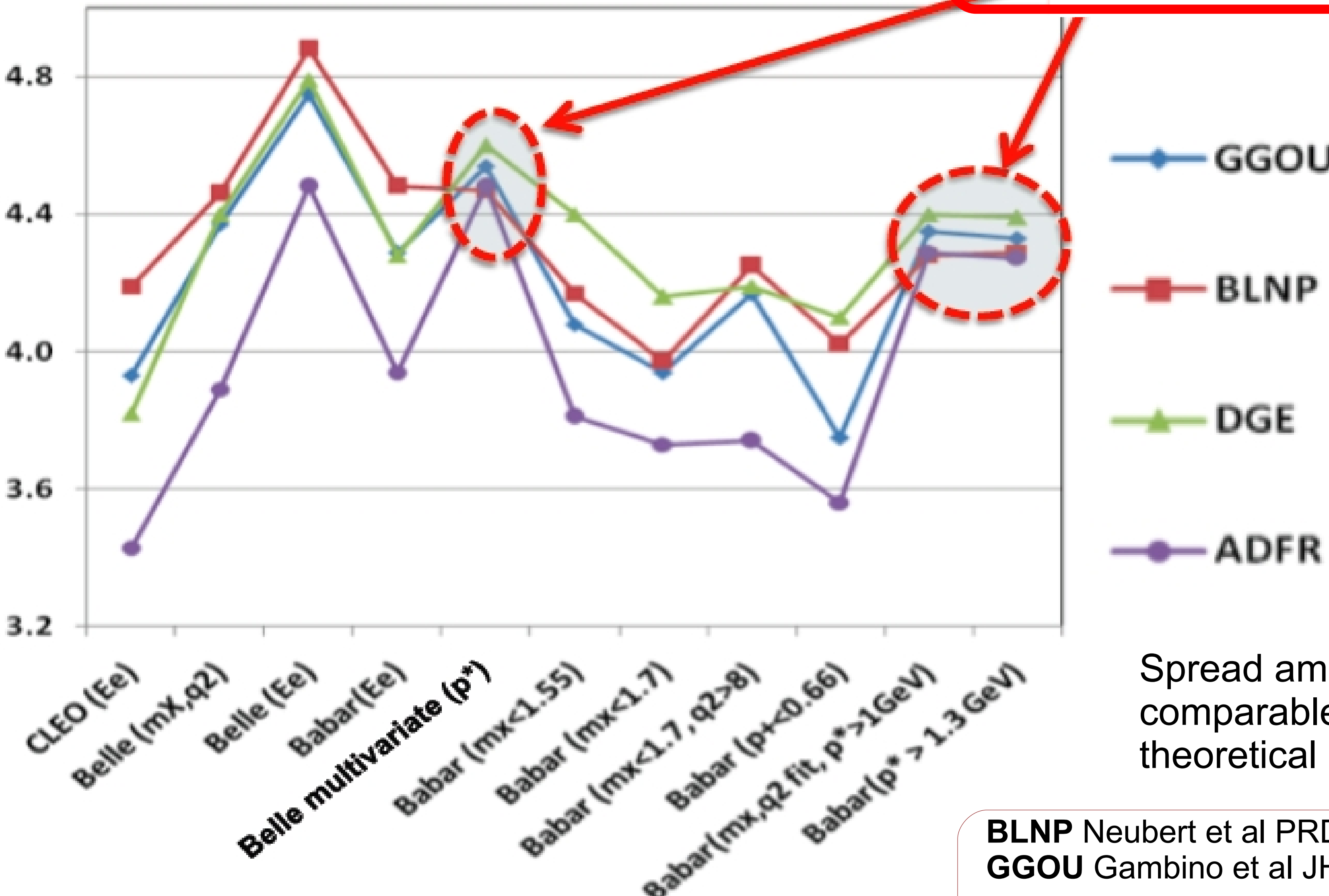
Measurement	BLNP $\lvert V_{ub}\rvert$ $[10^{-3}]$	GGOU $\lvert V_{ub}\rvert$ $[10^{-3}]$	DGE $\lvert V_{ub}\rvert$ $[10^{-3}]$
(m_X, q^2); $p_\ell^{B*} > 1.0$ GeV	$4.28 \pm 0.23^{+0.18}_{-0.20}$	$4.35 \pm 0.24^{+0.09}_{-0.10}$	$4.40 \pm 0.24^{+0.12}_{-0.13}$
$p_\ell^{B*} > 1.0$ GeV	$4.30 \pm 0.28^{+0.18}_{-0.20}$	$4.36 \pm 0.30^{+0.09}_{-0.10}$	$4.42 \pm 0.30^{+0.13}_{-0.13}$
Belle [Phys.Rev.Lett.104:021801]	$4.47 \pm 0.27^{+0.19}_{-0.21}$	$4.54 \pm 0.27^{+0.10}_{-0.11}$	$4.60 \pm 0.27^{+0.11}_{-0.13}$

Largest systematics: signal model

Comparison of the available calculations

C. Bozzi @ HQL12

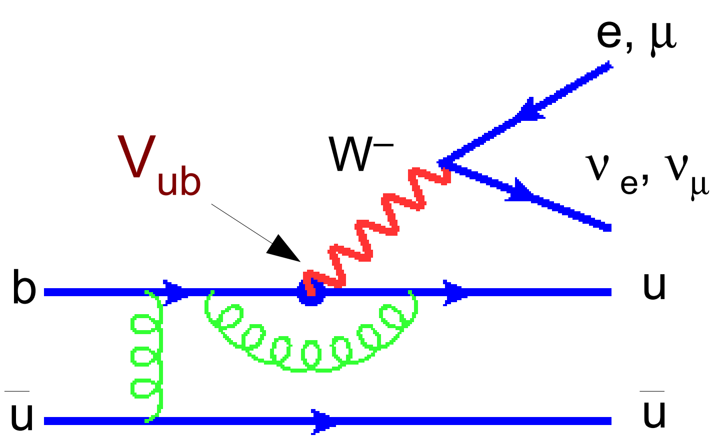
Most inclusive measurements



Spread among calculations comparable with quoted theoretical error

BLNP Neubert et al PRD72, 073006 (2005)
GGOU Gambino et al JHEP0710, 058 (2007)
DGE Gardi et al JHEP0601, 097 (2006)
ADFR Aglietti et al EPJC 59, 831 (2009)

Exclusive B→π/ρ ℓν

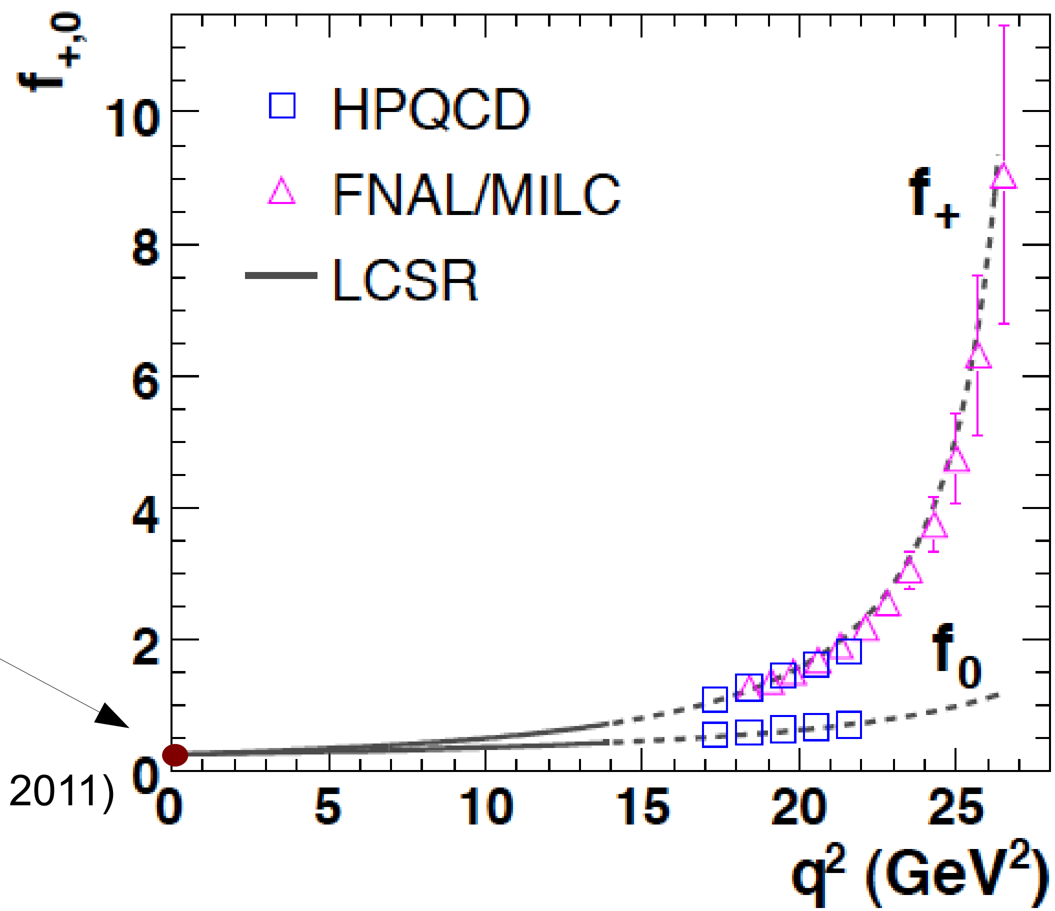


$$\frac{d\Gamma(B\to\pi\ell\nu)}{dq^2}=\frac{G_F^2|V_{ub}|^2}{24\pi^3}p_\pi^3|f_+(q^2)|^2$$

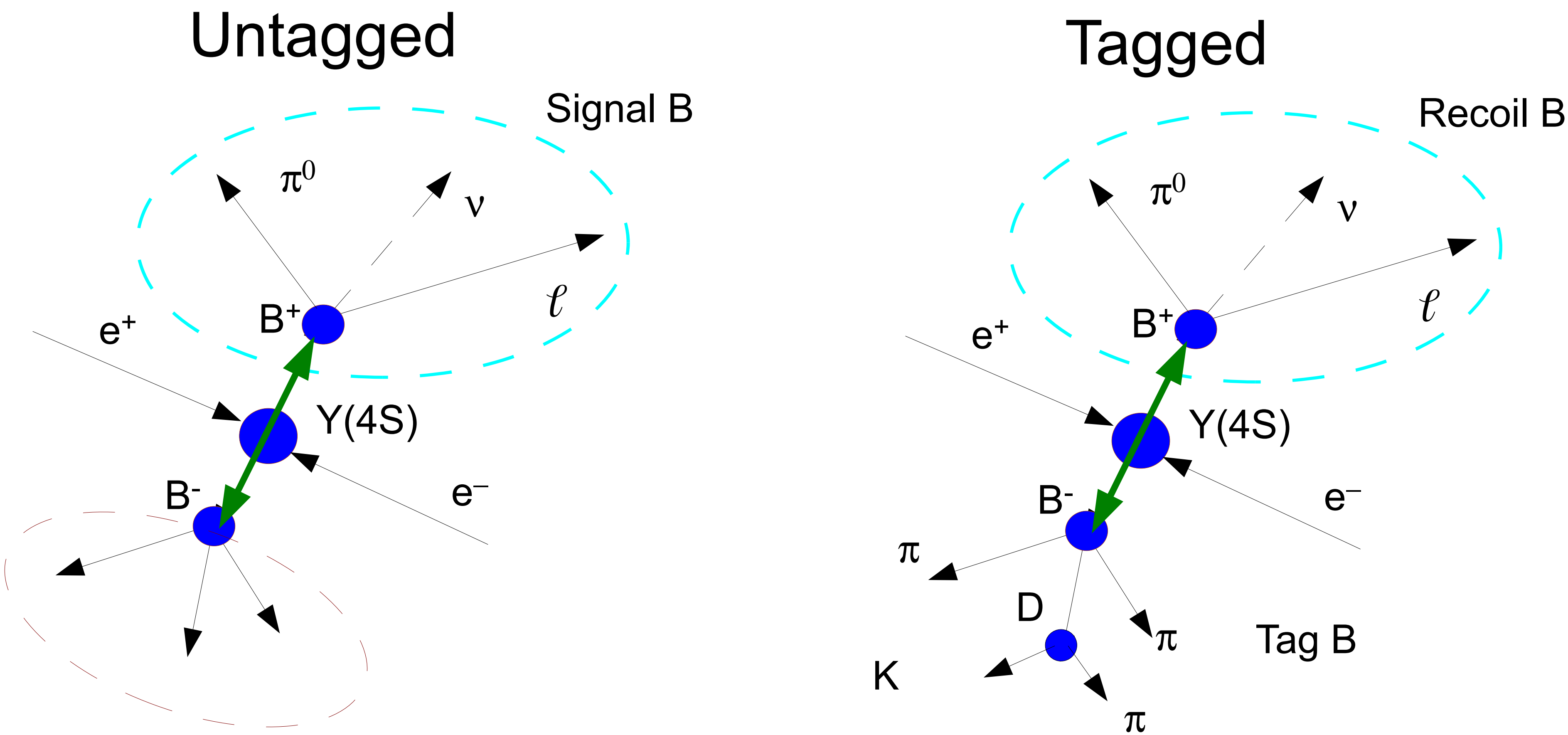
(the ρ and other mesons are difficult on lattice because these are unstable and have a large Γ/m)

- Exclusive $|V_{ub}|$ from **B→π ℓν**
  - One FF (for massless leptons)
- L-QCD (HPQCD, FNAL)
  - Unquenched calculations
- Light Cone Sum Rules
  - Reliable at low q^2

$f_{+,0}(0)=0.28 \pm 0.03$
(Khodjamirian et al (KMOW) 2011)



Techniques employed at the BFactories



Purity →

$\int \mathcal{L}dt \approx 100 fb^{-1}$

$\int \mathcal{L}dt \approx 1 ab^{-1}$

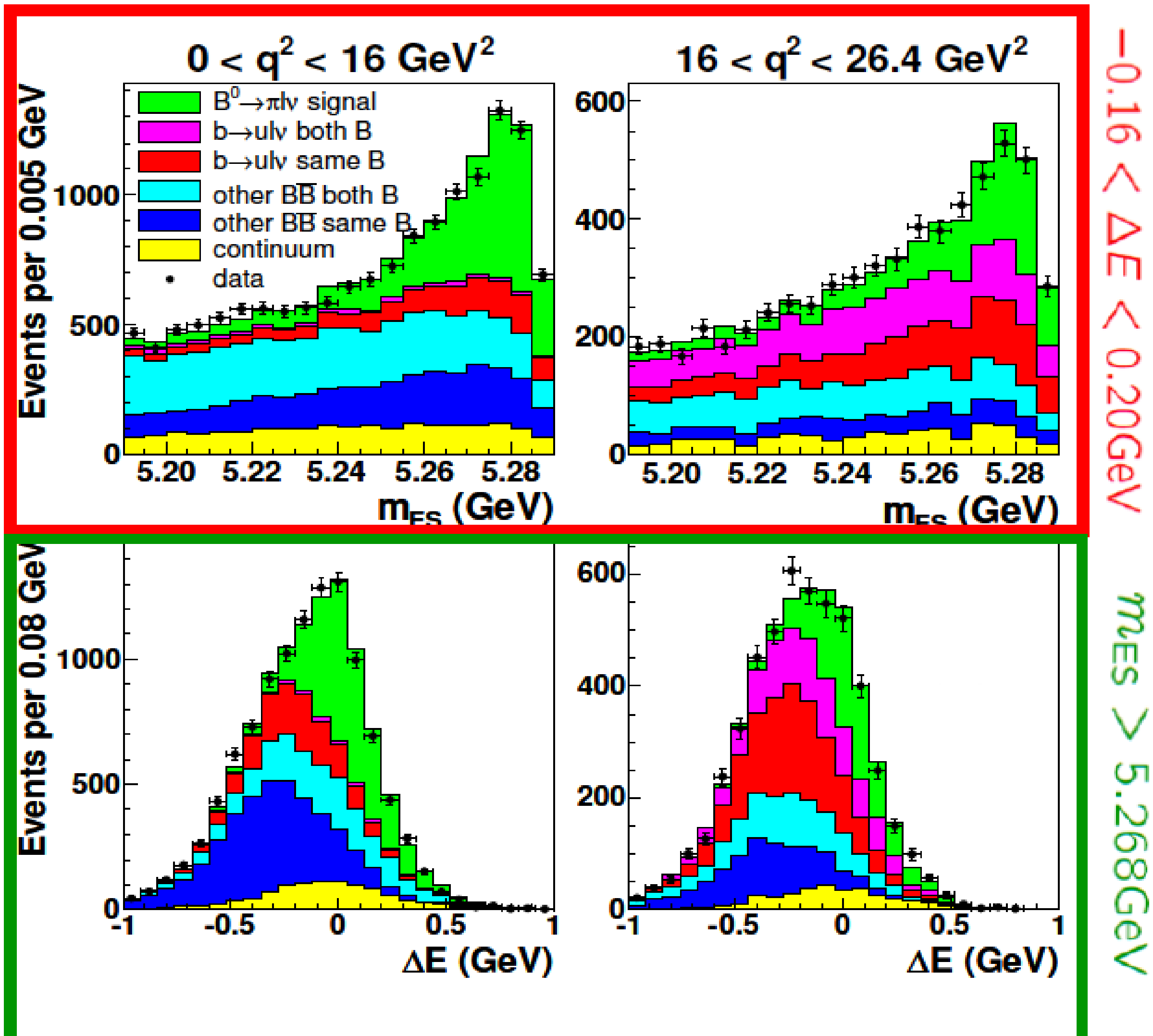
← Efficiency

Exclusive $B \to \pi \ell \nu$

- Identity only π+e/μ
- Neutrino from the rest of the event
  - (B momentum magnitude is know)

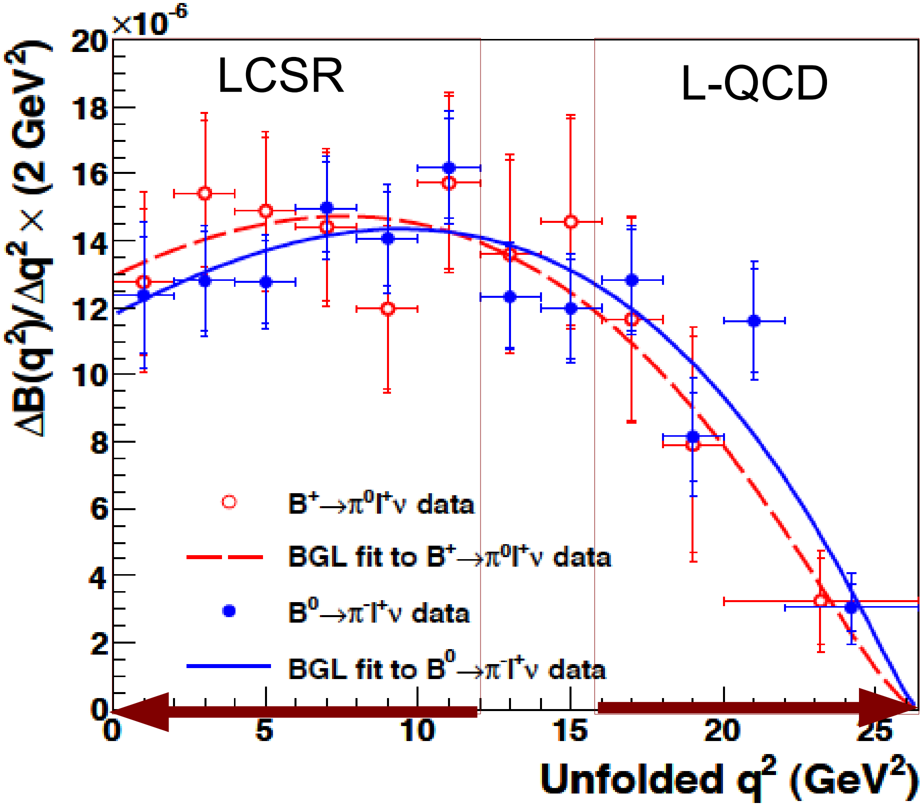
$$m_{ES} = \sqrt{E^{*2}_{beam} - \mathbf{p}^{*2}_{\pi\ell\nu}}$$

$$\Delta E = E^{*}_{\pi\ell\nu} - E^{*}_{beam}$$

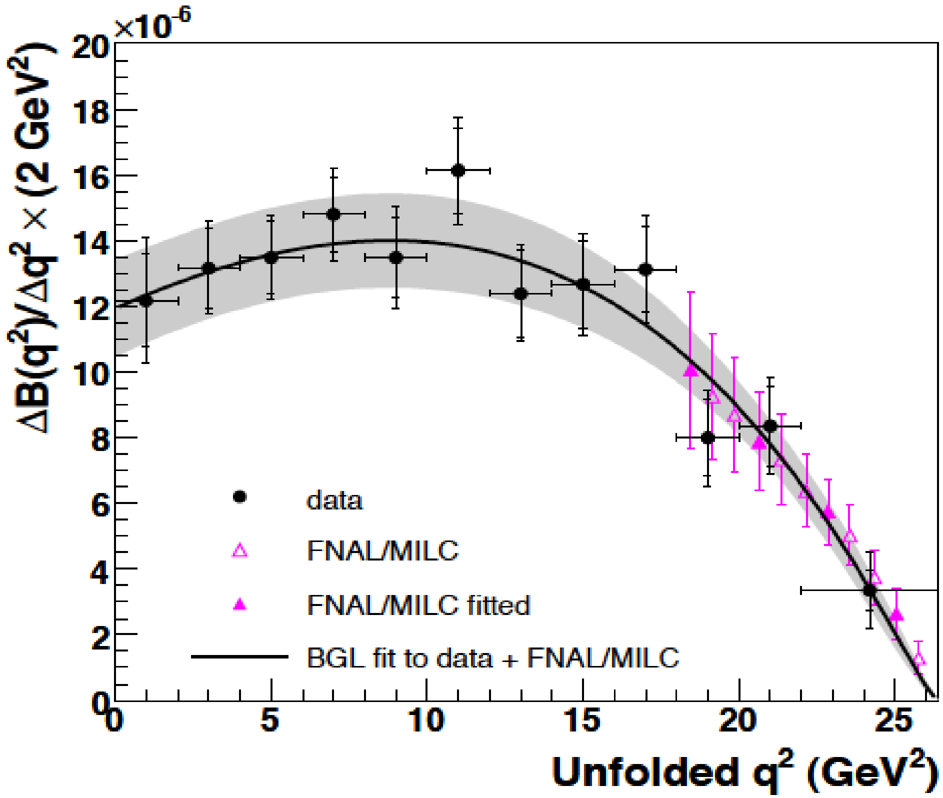


- 12K signal $B \to (\pi^{+} + \pi^{0})\, \ell \nu$
  - S/N~0.1
- Same technique used also to extract the BF and the FF shape of other resonances
  - $B \to \eta\, \ell \nu$
  - $B \to \eta' \ell \nu$
  - $B \to \omega\, \ell \nu$

$|V_{ub}|$ from exclusive decays



Simultaneous fit to data and L-QCD calculations



FF Parameterization: Boyd-Grinstein-Lebed

$$f_+(q^2) = \frac{1}{\mathcal{P}(q^2)\phi(q^2, q_0^2)} \sum_{k=0}^{k_{max}} a_k(q_0^2)[z(q^2, q_0^2)]^k$$

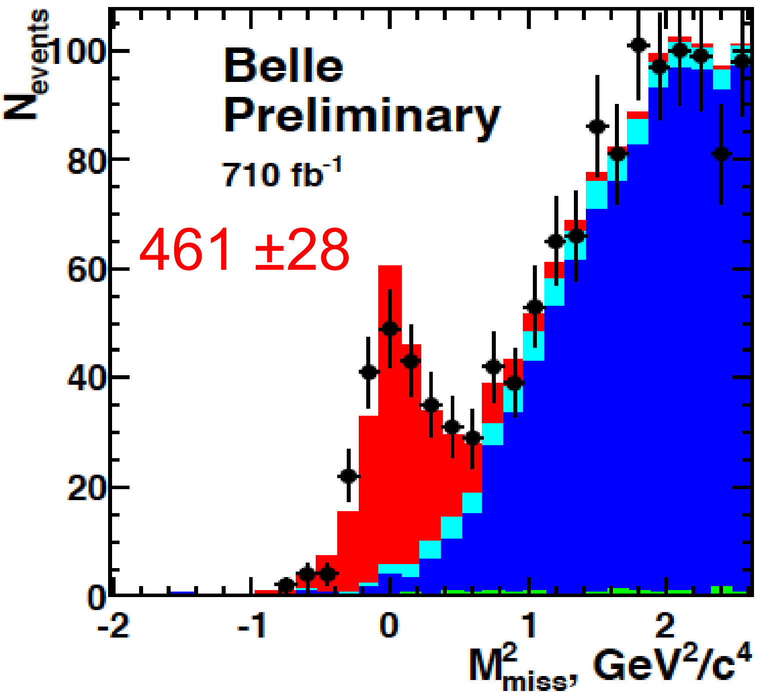
$$z(q^2, q_0^2) = \frac{\sqrt{m_+^2 - q^2} - \sqrt{m_+^2 - q_0^2}}{\sqrt{m_+^2 - q^2} + \sqrt{m_+^2 - q_0^2}}$$

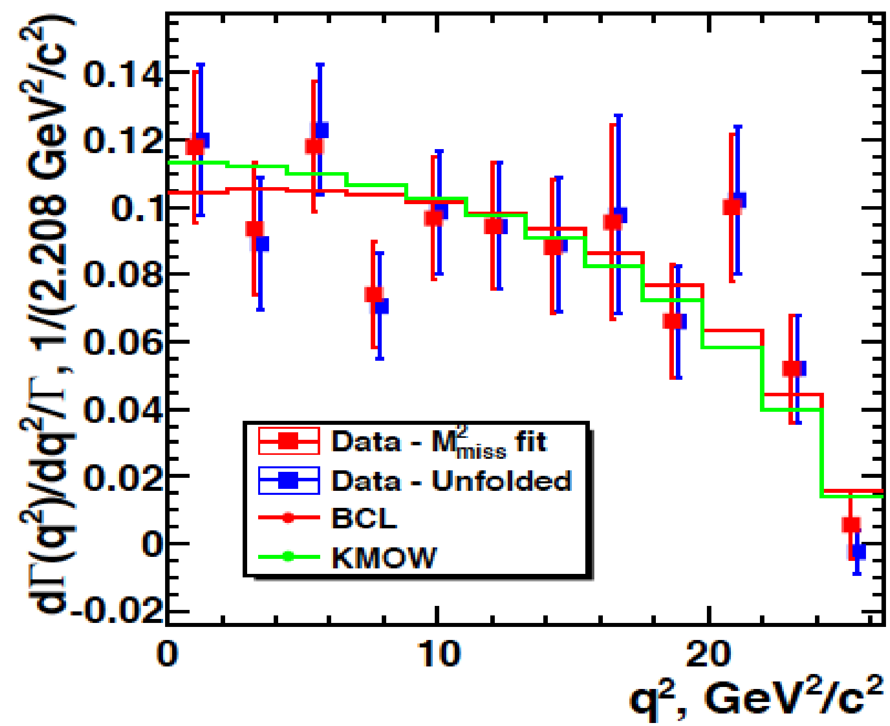
q^2 / GeV^2	$\lvert V_{ub} \rvert \times 10^3$
FNAL > 16	$3.47 \pm 0.13^{+0.60}_{-0.39}$
KMOW < 12	$3.46 \pm 0.10^{+0.37}_{-0.32}$
0	$3.34 \pm 0.11^{+0.29}_{-0.26}$

New BELLE analysis: hadronic tag

- Use the hadronic B tag with 710 fb^{-1}
  - New algorithm: tag selection based on NeuroBayes NN (NIM A654 (2011))

$$B^+ \to \pi^0 \ell \nu$$



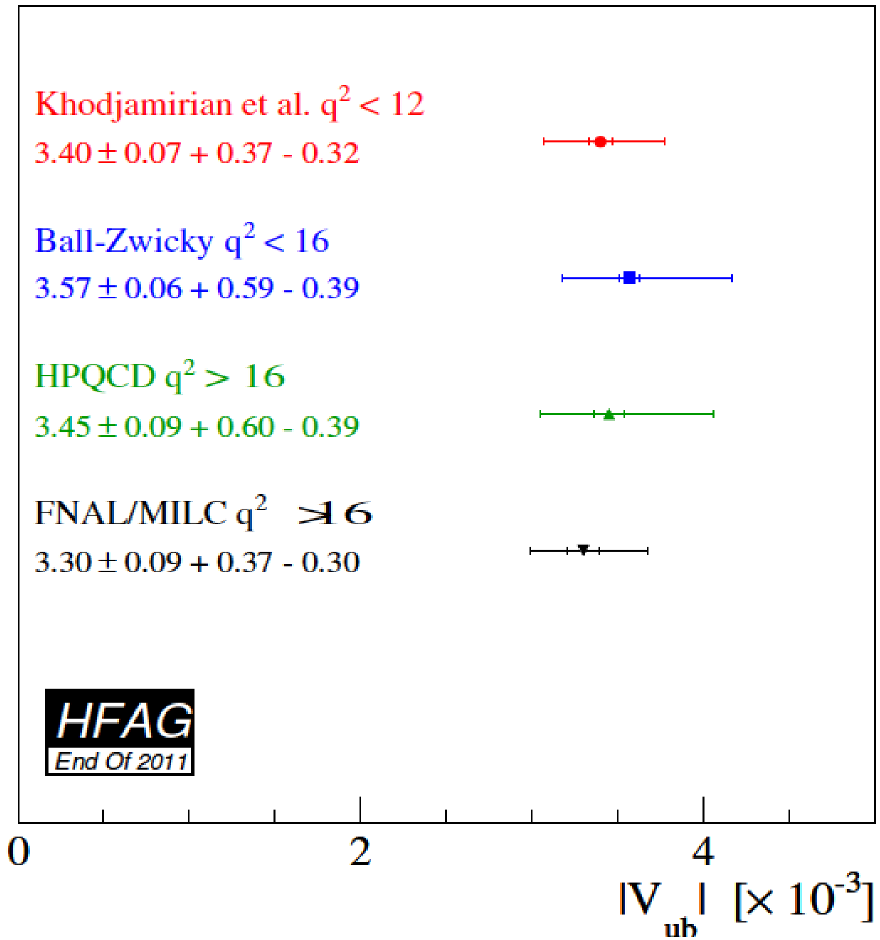


KMOW[1]	<12	$3.38 \pm 0.14 \pm 0.09^{+0.37}_{-0.31}$
Ball/Zwicky[2]	<16	$3.57 \pm 0.13 \pm 0.09^{+0.47}_{-0.47}$
FNAL[3]	>16	$3.69 \pm 0.22 \pm 0.09^{+0.39}_{-0.35}$
HPQCD[4]	>16	$3.86 \pm 0.23 \pm 0.10^{+0.53}_{-0.53}$

@SuperBFactories will become the ultimate technique for excl $|V_{ub}|$

World average

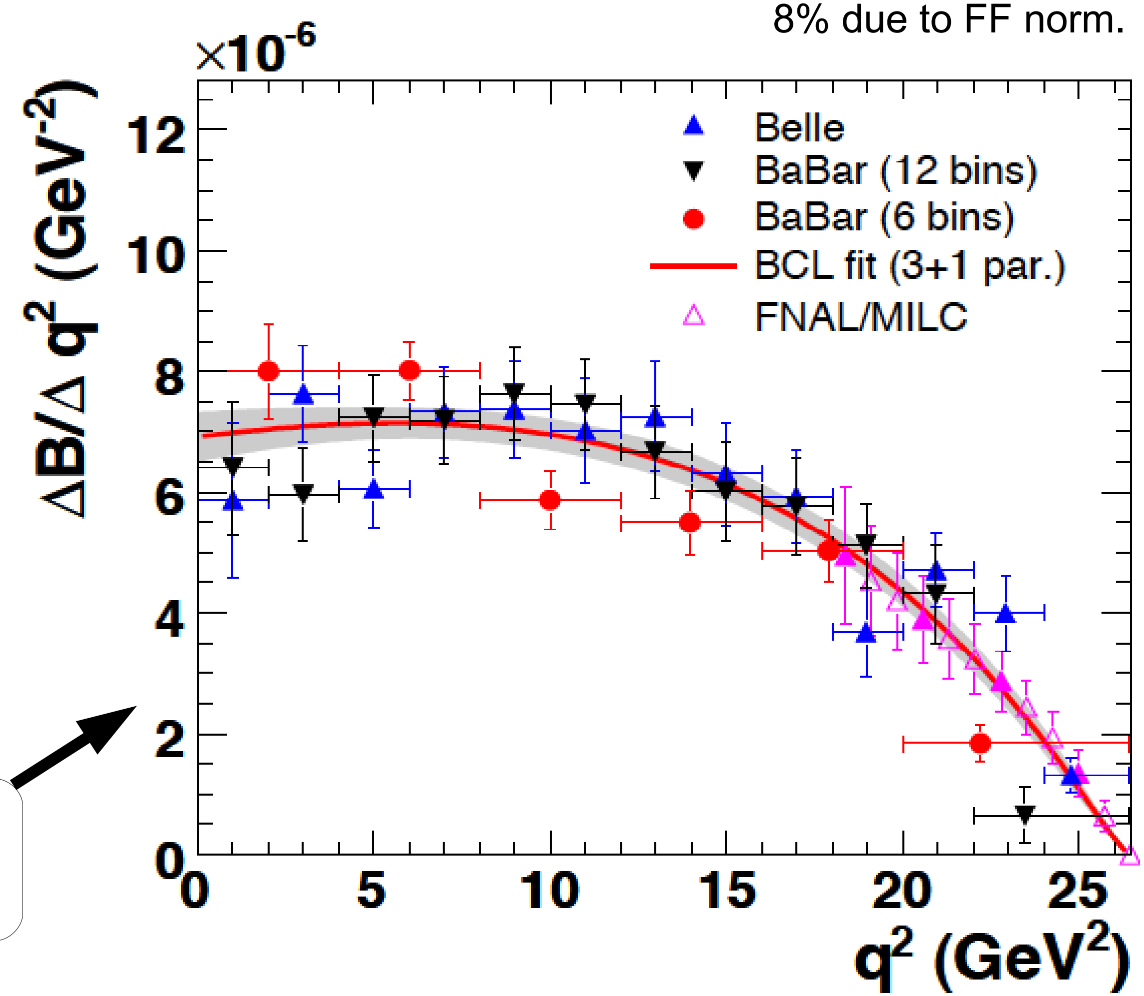
World average



$$|V_{ub}| = (3.23 \pm 0.30) \times 10^{-3}$$

$$\chi^2/DOF = 58.9/31$$

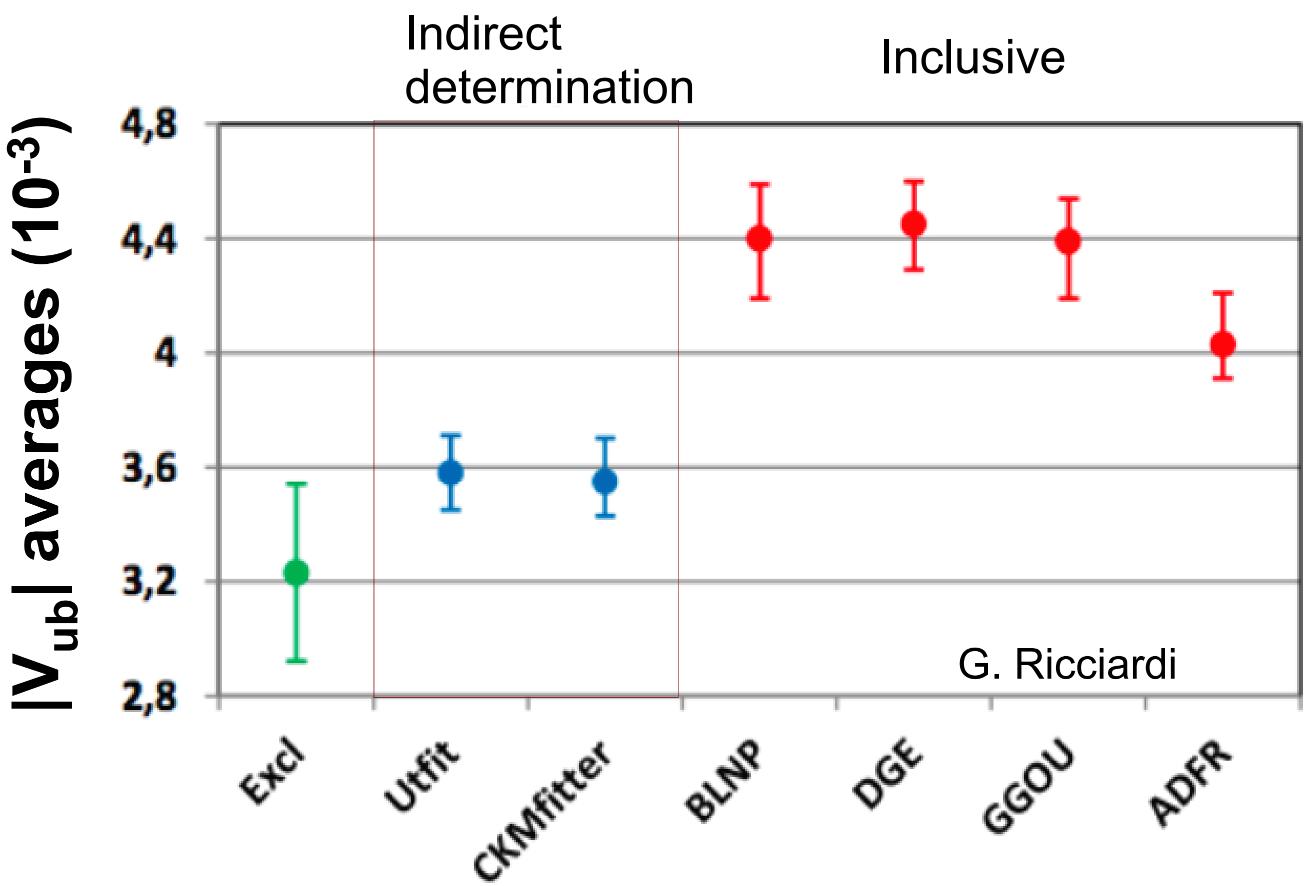
8% due to FF norm.



Does not include the new BaBar untagged and Belle tagged results

Inclusive · Exclusive difference

- Long - standing puzzle
  - Despite progresses from B-factories+Theory, the inclusive-exclusive discrepancy still present: Δ @ 2.5-3.0σ



Inclusive · Exclusive difference

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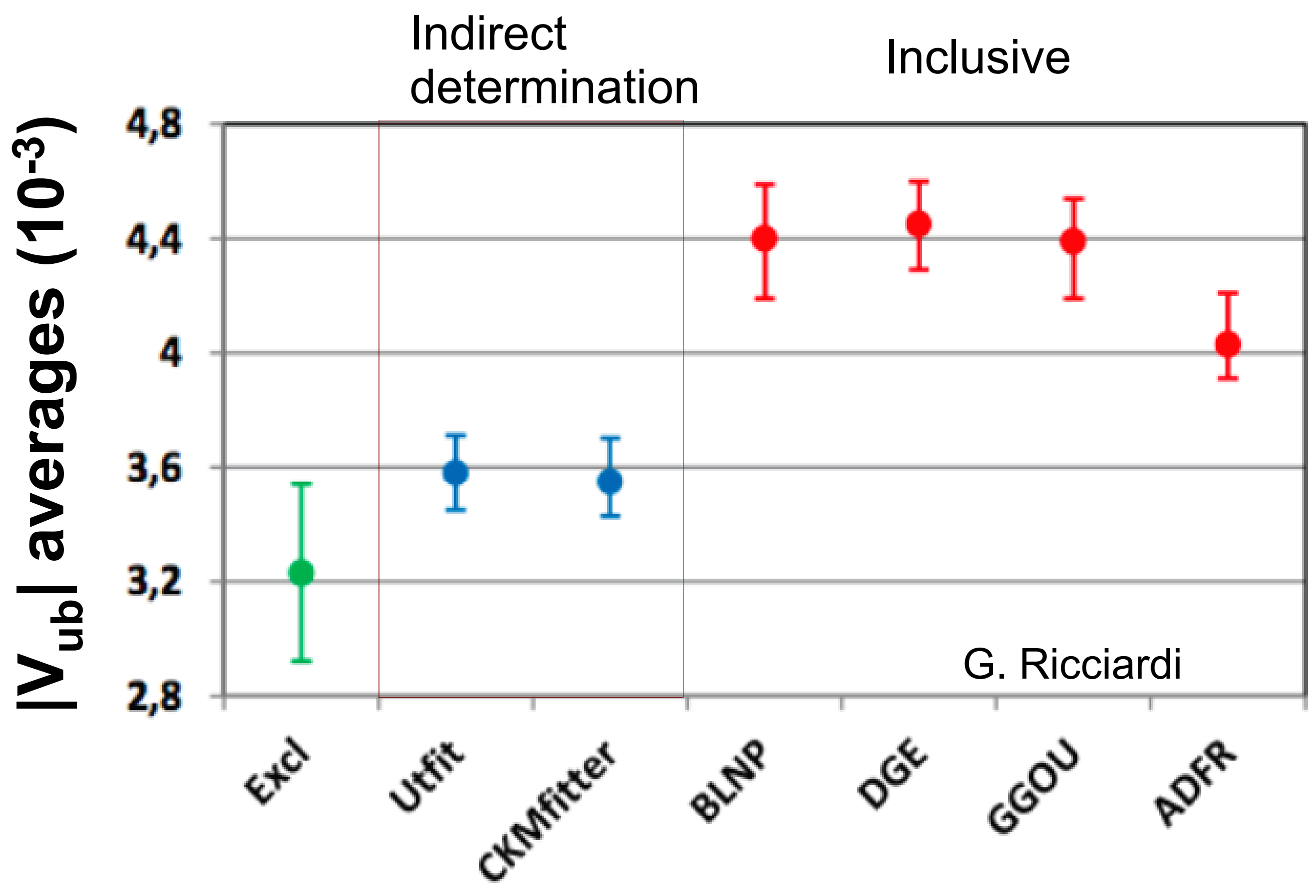


Are we underestimating our uncertainties?

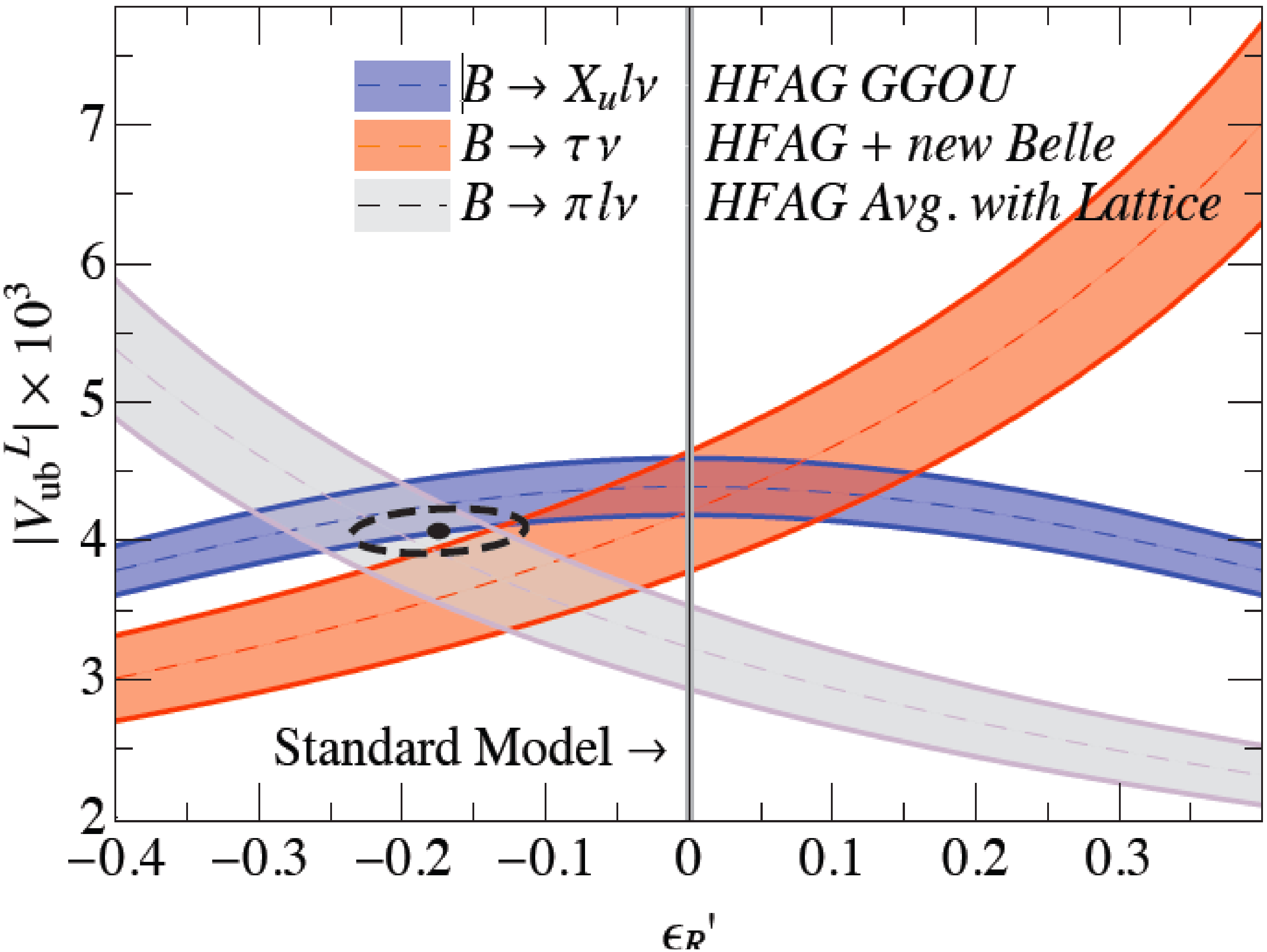
Experiment ???
Theory ???

With $B_s \to K\ell\nu$?

. . . if New Physics, what kind ?

Left Right model

New physics observable via right-handed currents? $|V_{ub}| = |V_{ub}^L| \, f(\epsilon'_R = \epsilon_R \Re \frac{V_{ub}^R}{V_{ub}^L})$



$f(\epsilon'_R)$:
$B \to \pi \ell \bar{\nu}_\ell$: $1 + \epsilon'_R$
$B \to \tau \bar{\nu}_\tau$: $1 - \epsilon'_R$
$B \to X_u \ell \bar{\nu}_\ell$: $1 + \epsilon'^2_R$

Proposed by
[hep-ph/0505166]
[arXiv:0907.2461]
[arXiv:1007.1993]

Private Fit

Dashed: All
Input: see Backup

$\|V_{ub}^L\|$	ϵ'_R	Tension wrt SM	χ^2/ndf
4.07 ± 0.16	-0.17 ± 0.06	2.8σ	$2.8/1$

$$B \rightarrow D^{(*)} \tau \nu_{\tau}$$

Evidence for an excess over the SM prediction

Phys.Rev.Lett. 109 101802 (2012)

Heavy leptons: introduction

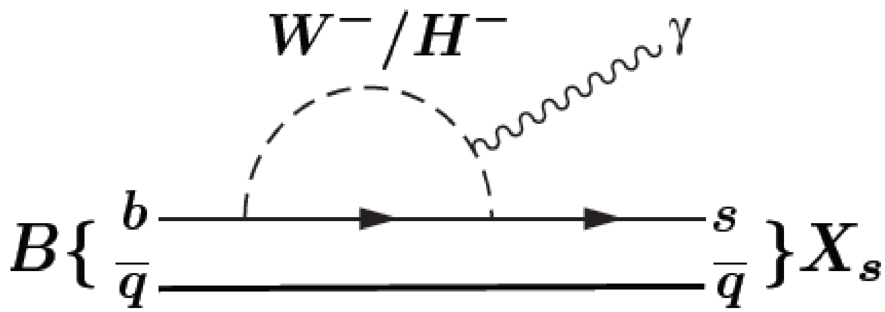
- Charged Higgs required in multiple New Physics scenarios
  - Coupling is proportional to the fermion mass: $H^- - \ell$ coupling $\propto m_\ell$

MSSM

A^0 H^+

H^0 H^-

Loop

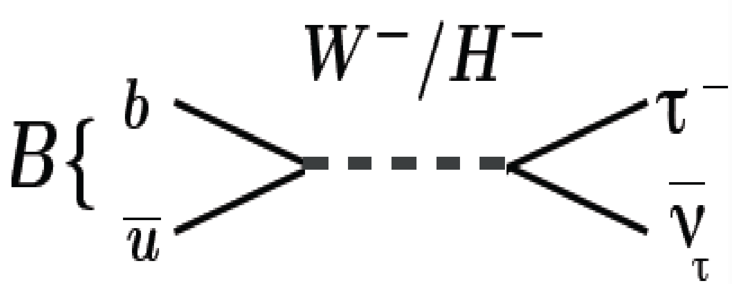


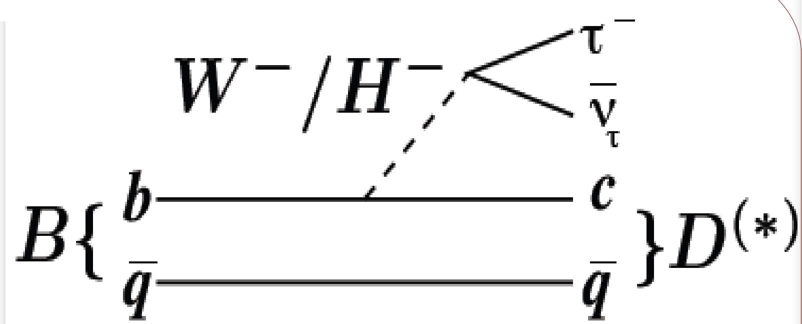
@ BFactories

Tree Level

$t \rightarrow bH^+$

$gb \rightarrow tH^-$



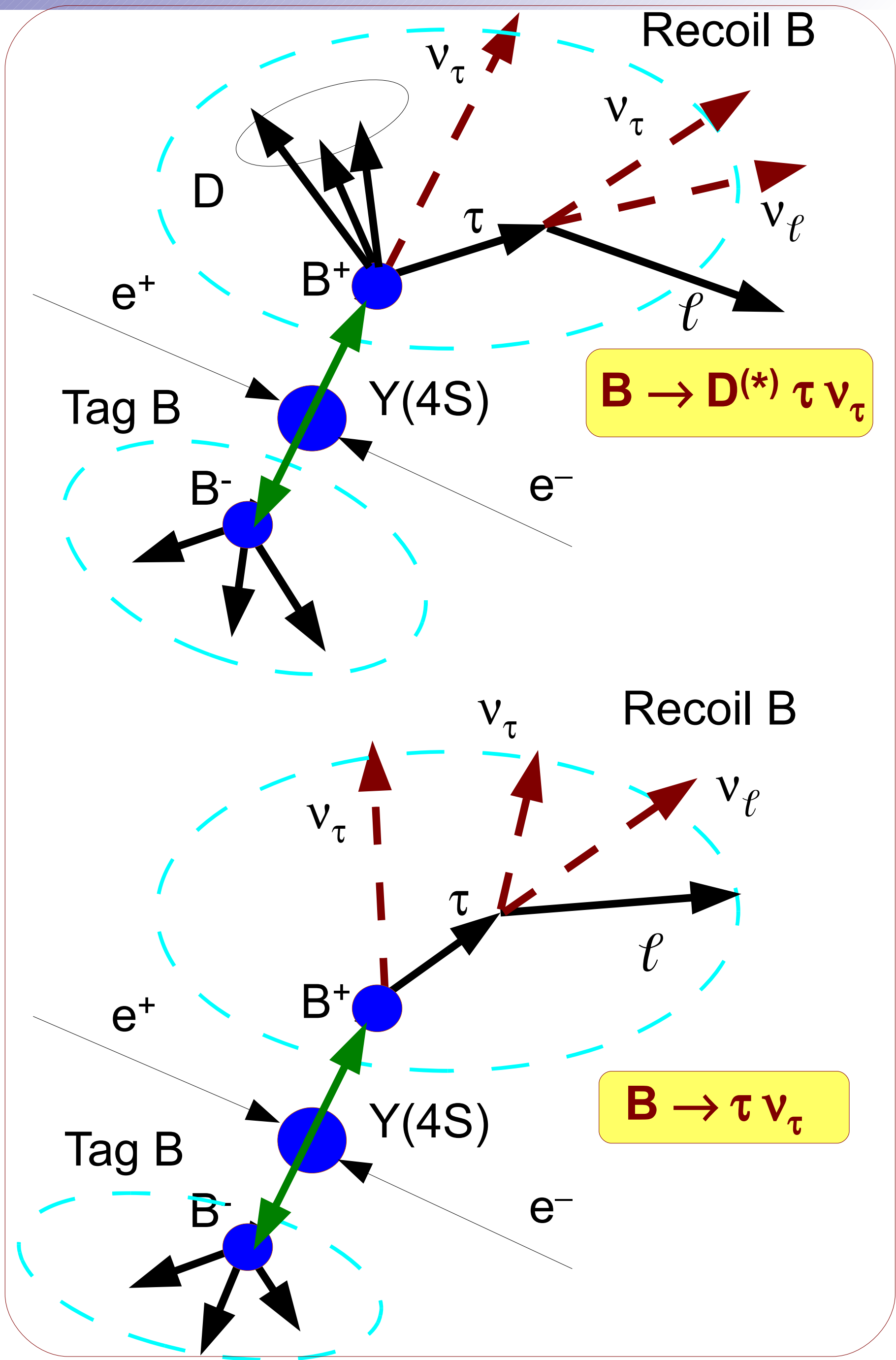


@ BFactories

Introduction to the event reconstruction

Weak signal signature

- Decay with missing momentum
  - Many neutrinos in the final state
- Lack of kinematics constraints in the final state



Use the hadronic B sample: reconstruct one B and look at the rest of the event

- Expected only tracks from signal
- No additional tracks
- Little activity in the Calorimeter

$B \to D^{(*)} \tau \nu_\tau$: measurement

- We measure directly the *R*(D) and *R*(D*) ratios

$$\mathcal{R}(D) = \frac{\Gamma(B \to D\tau\nu_\tau)}{\Gamma(B \to D\ell\nu_\ell)_{\ell = e, \mu}}$$

$$\mathcal{R}(D^*) = \frac{\Gamma(B \to D^*\tau\nu_\tau)}{\Gamma(B \to D^*\ell\nu_\ell)}_{\ell = e, \mu}$$

Signal

Normalization

$$\mathcal{R}(D^{(*)}) = \frac{N_{sig}}{N_{norm}} \times \frac{\epsilon_{norm}}{\epsilon_{sig}}$$

Several experimental and theoretical uncertainties cancel in ratio
- D reconstruction / Particle ID /tracking eff.
- $|V_{cb}|$ & FFs (partially)

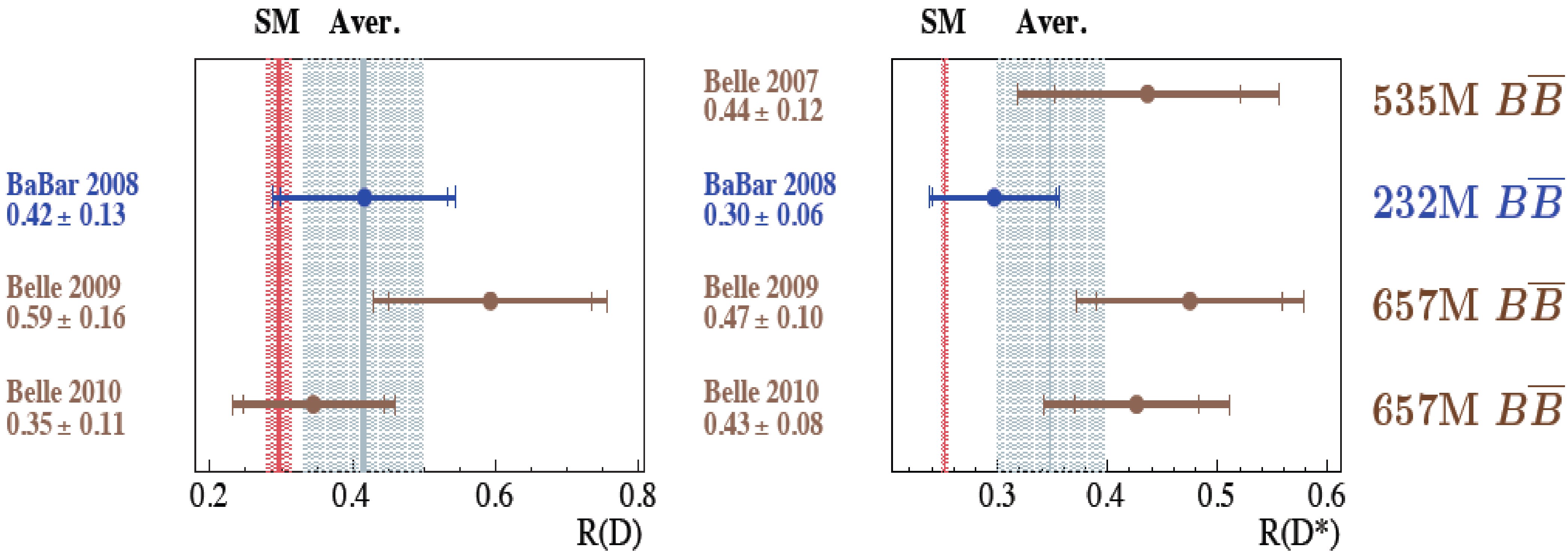
Very precise SM prediction

R(D) = 0.297 ± 0.017 and R(D*) = 0.252 ± 0.003

σ = 5.7% σ = 1.2%

Existing measurements

Previous measurements exceed SM by 1-2 σ



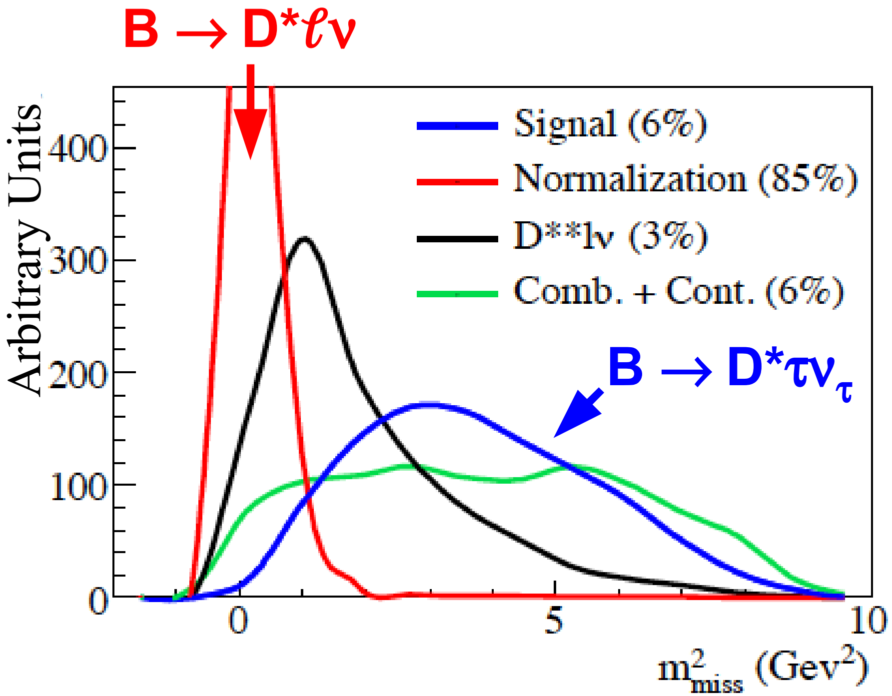
Update BaBar 2008 with 2x data and 2x efficiency
- improved tag B and better muon ID

$B \to D^{(*)} \tau \nu_\tau$: Yields Extraction

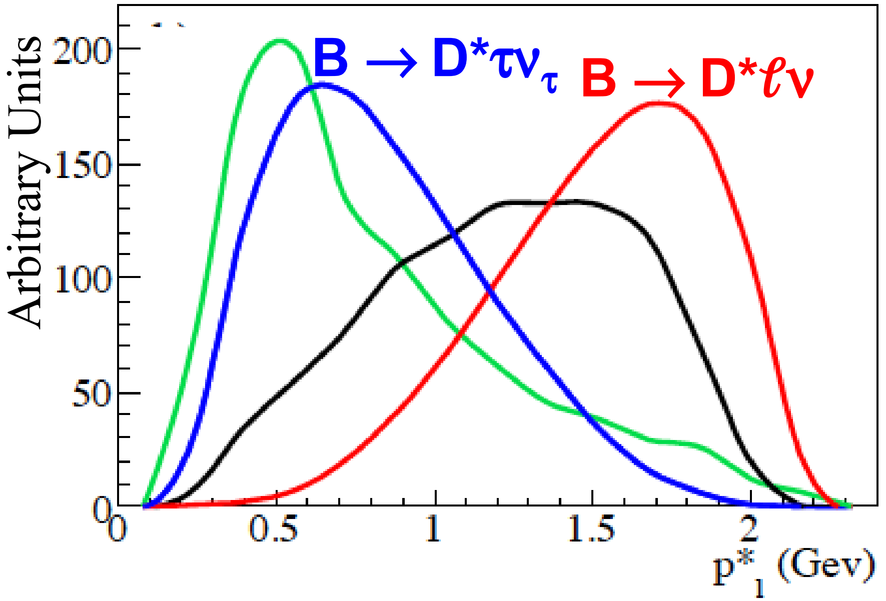
- Simultaneous un-binned M.L. Fit
  - 4 signal samples $D^0\ell$, $D^{*0}\ell$, $D^+\ell$, $D^{*+}\ell$
  - 4 $D^{(*)}\pi^0\ell\nu$ Control samples
  - 2 dimensional distributions:

$$m_{miss}^2 = (p_{e+e-} - p_{tag} - p_{D(*)} - p_\ell)^2$$

p^*_ℓ in the B_{sig} rest-frame



- PDFs from MC: approximated using KEYS function
- Fitted Yields
  - 4 $D^{(*)}\tau\nu$ + 4 $D^{(*)}\ell\nu$ + 4 $D^{**}\ell\nu$

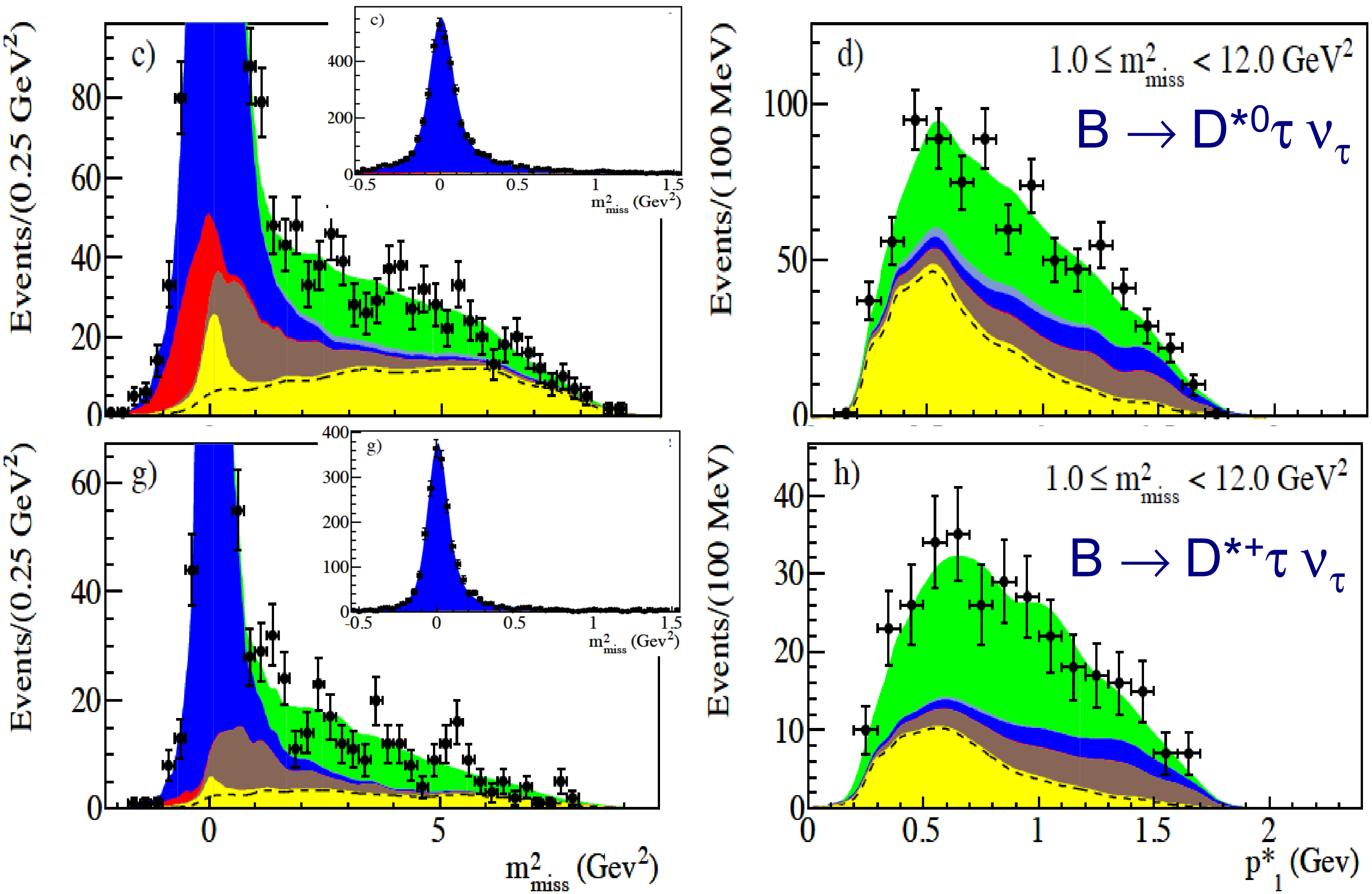


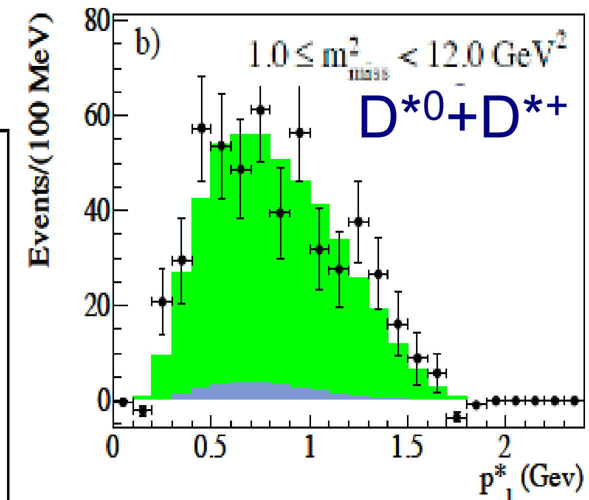
Results of Fit $B \to D^* \tau \nu_\tau$

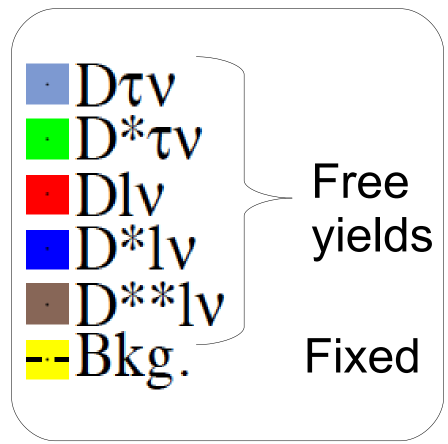
Isospin Constrained

	$D^{*0}\tau\nu$	$D^{*+}\tau\nu$	$D^{*}\tau\nu$
N_{sig}	639 ± 62	245 ± 27	888 ± 63
Significance (σ)	11.3	11.6	16.4
$R(D^*)$	0.322 ± 0.032	0.355 ± 0.039	0.332 ± 0.024

Statistical errors only





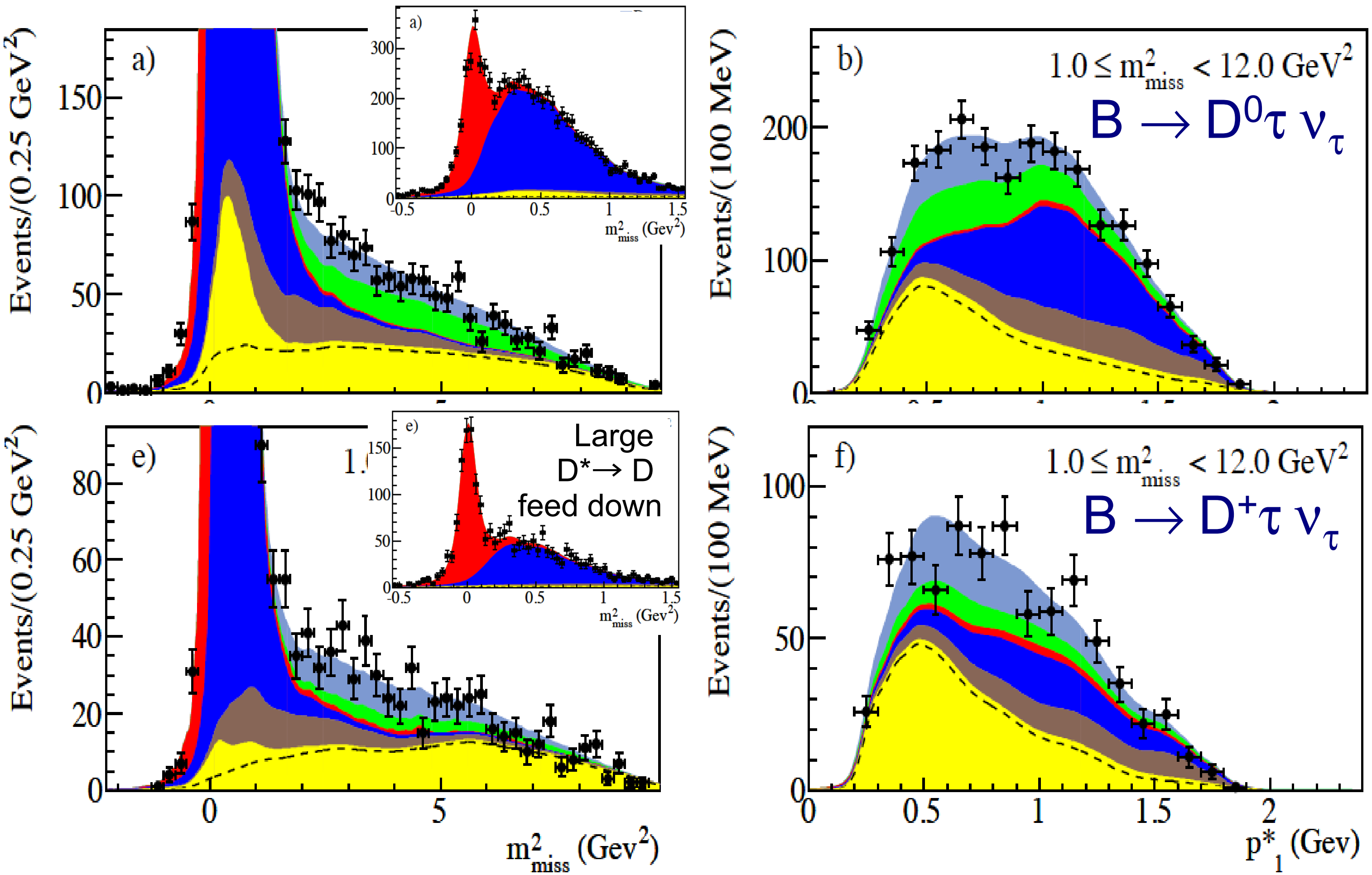


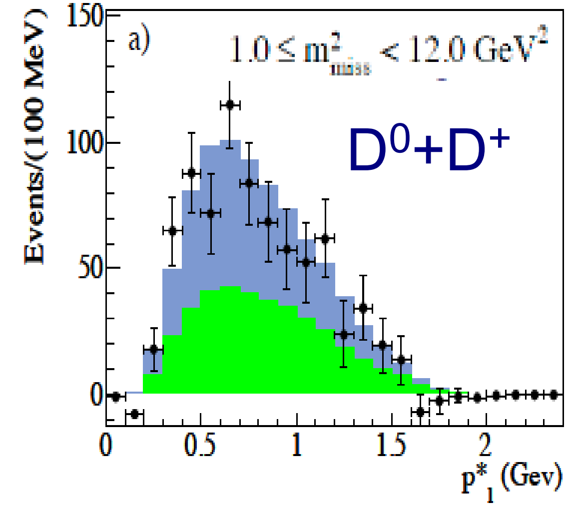
Results of Fit $B \to D \tau \nu_\tau$

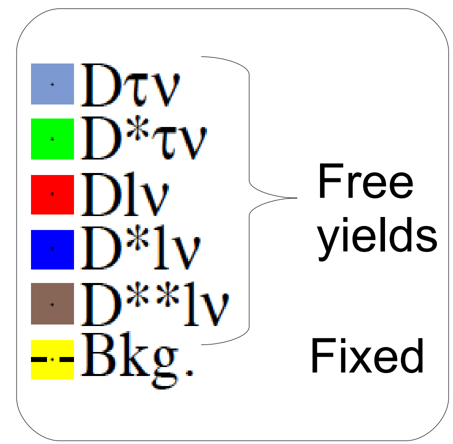
Isospin Constrained

	$D^0\tau\nu$	$D^+\tau\nu$	$D\tau\nu$
N_{sig}	314 ± 60	177 ± 31	489 ± 63
Significance (σ)	5.5	6.1	8.4
$R(D)$	0.429 ± 0.082	0.469 ± 0.084	0.440 ± 0.058

Statistical errors only







Results and Systematics Uncertainties

Decay	N_{sig}	N_{norm}	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	$\Sigma_{tot}(\sigma)$
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

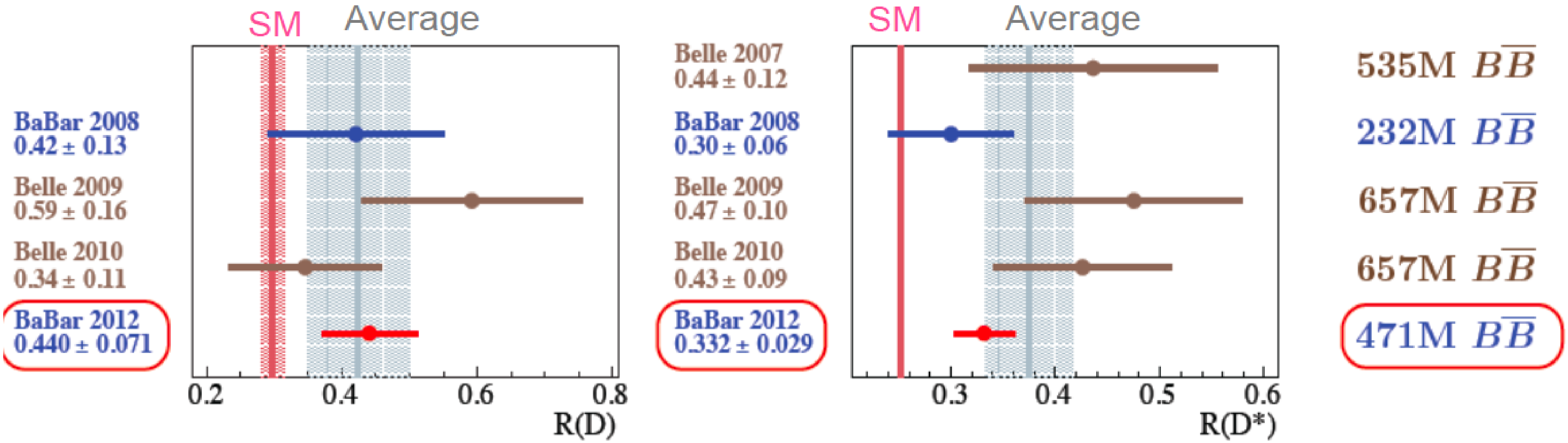
	R(D)	R(D*)	ρ_{corr}
D** τ/l ν	5.8	3.7	0.62
MC statistics	5.0	2.5	-0.48
Continuum and BB bkg	4.9	2.7	-0.30
$\varepsilon_{sig}/\varepsilon_{norm}$	2.6	1.6	0.22
Syst. Uncertainty	9.5	5.3	0.05
Stat. Uncertainty	13.1	7.1	-0.45
Total Uncertainty	16.2	9.0	-0.27

Uncertainties due to FFs, PID, tracks, photons and soft pion reconstruction cancel in the ratio: contribution ~1%

SM Predictions of R(D) and R(D*)

- The new measurements are fully compatible with earlier results

Average does not include this measurement

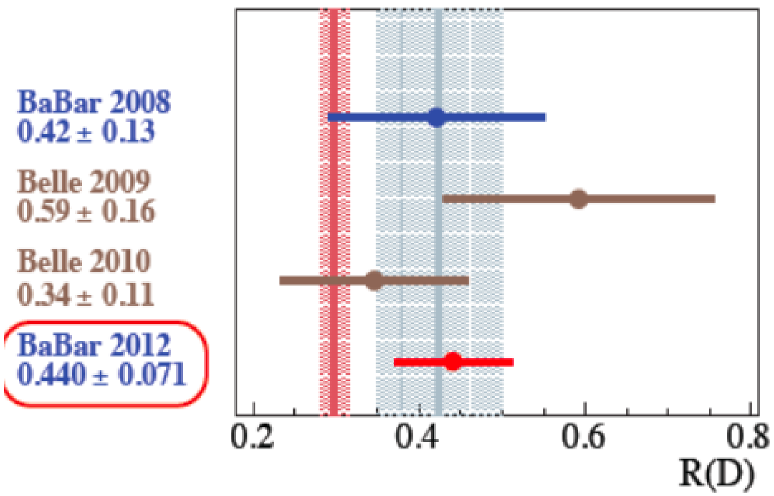


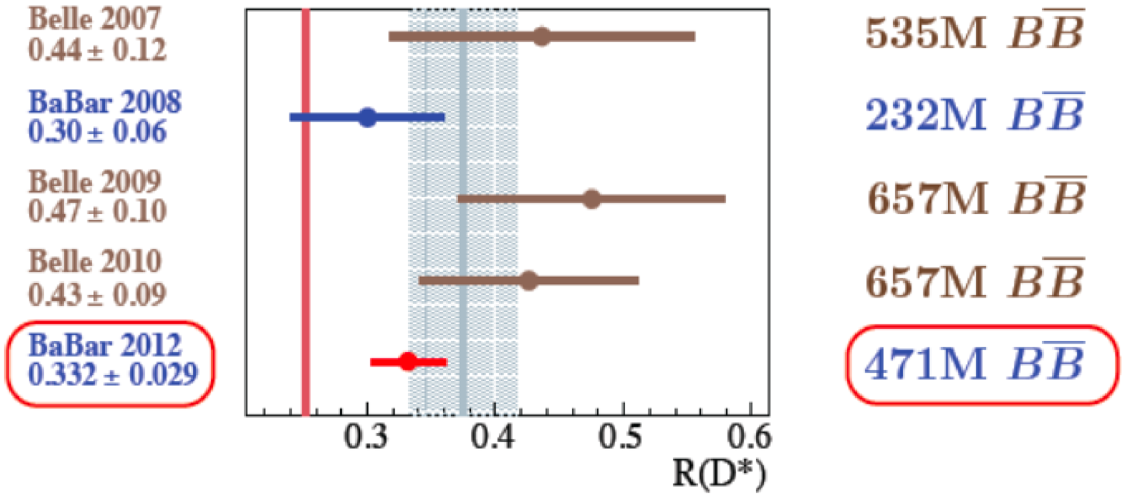
SM Predictions of R(D) and R(D*)

[*] Kaminik Mescia 2008
Fajfer et al 2012

- The new measurements are fully compatible with earlier results

Average does not include this measurement



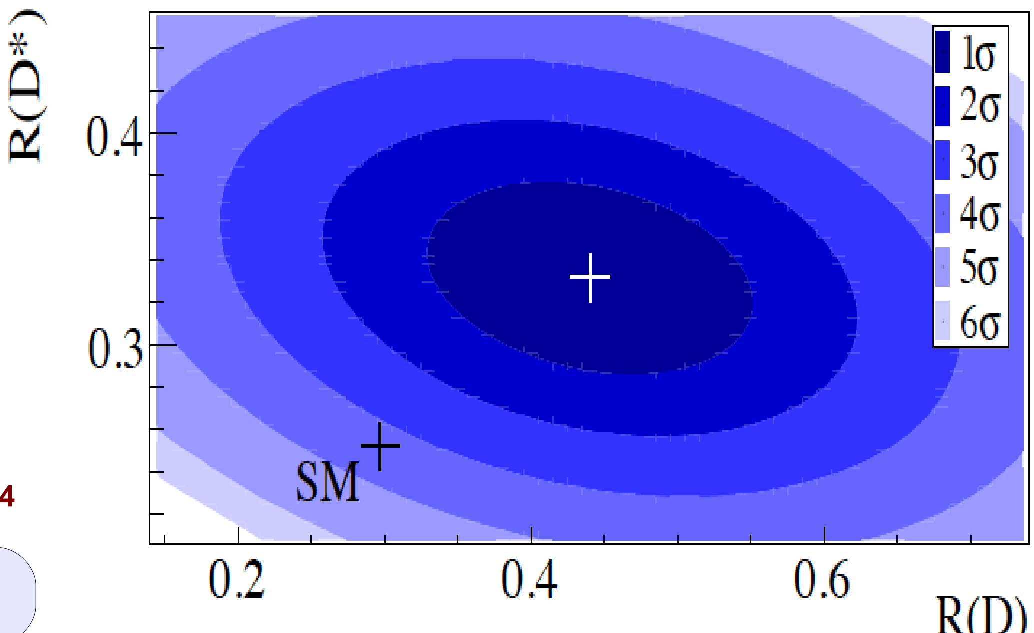


- And above the SM prediction!

	R(D)	R(D*)
BaBar	0.440 ± 0.071	0.332 ± 0.029
SM [*]	0.293 ± 0.017	0.252 ± 0.003
Δ	2.0σ	2.7σ

The combination of the two measurements (-0.27 Correlation) yields χ^2/NDF=14.6/2 –> **Prob=6.9 x 10^{-4}**

SM prediction is excluded at 3.4σ



2HDM calculation

Differential decay rate in the SM

B → D* FFs

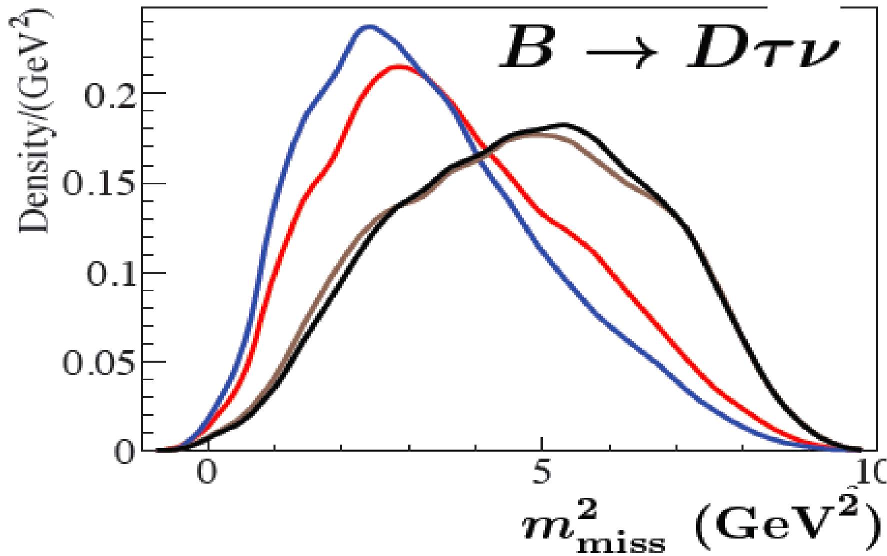
$$\frac{d\Gamma(\overline{B} \to D^* \ell^- \overline{\nu}_\ell)}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |p| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[\left(|H_{++}|^2 + |H_{--}|^2 + |H_{00}|^2\right) \left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2} |H_{0t}|^2 \right]$$

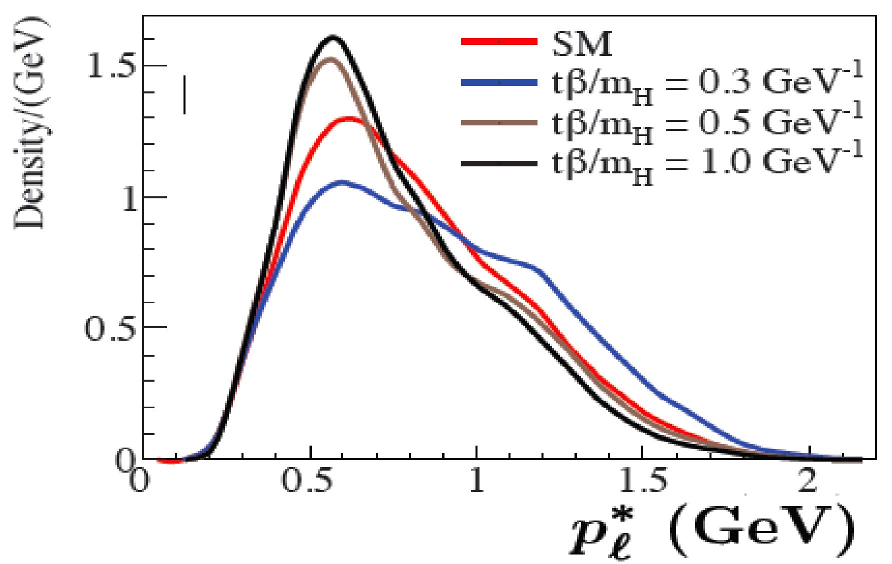
A charged Higgs (**Type II 2HDM**) of spin 0 coupling with the τ will affect H_{0t}

$$H_{0t}^{2HDM} \approx H_{0t}^{SM} \times \left(1 - \frac{\tan^2\beta}{m_{H+}^2} \frac{q^2}{1 \mp m_c/m_b}\right)$$

– for $B \to D\tau\nu_\tau$

+ for $B \to D^*\tau\nu_\tau$

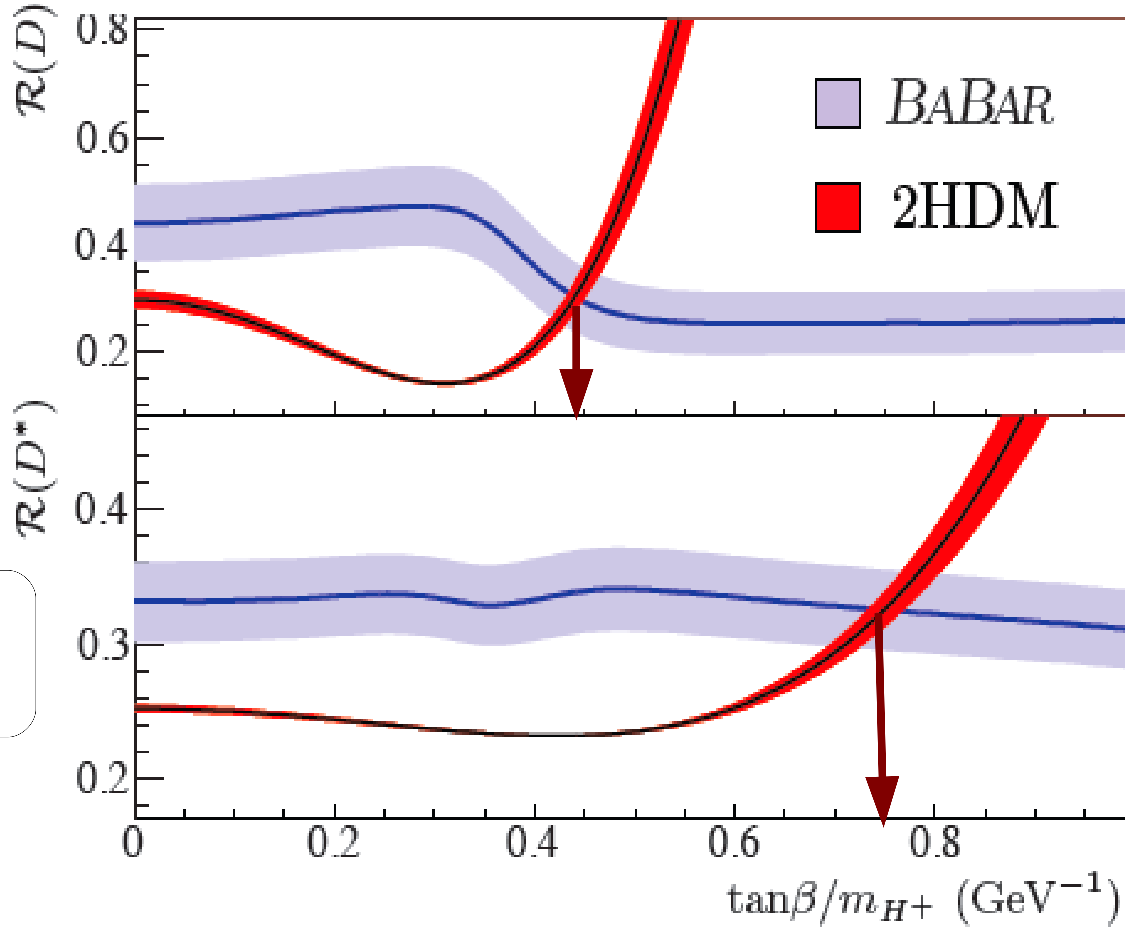




Effects both the signal efficiency and the signal yields (m^2_{miss}-p^*_ℓ shapes): simulated reweighting the MC signal events

Can we explain the excess events?

Scan the full 2HDM parameter space



$$\mathcal{R}(D) \Longrightarrow \tan\beta/m_H = 0.44 \pm 0.02$$
$$\mathcal{R}(D^*) \Longrightarrow \tan\beta/m_H = 0.75 \pm 0.04$$

- The combination of R(D) and R(D*) excludes the Type II 2HDM in the full tanβ-m_H parameter space (with m_H>10 GeV) with a probability >99.8%

  - Low m_H range (m_H<~300 GeV) already excluded by $B \to X_s\gamma$ data!

Some interesting following papers

- SM prediction is sensitive to the f_0 FF
  - Becirevic, Kosnik, Tayduganov, (1206.4977) proposal, using lattice data
  - MILC collaboration: 1206.4992, first SM lattice calculation unquenched (difference with SM reduced to 3.2 σ)
- 2HDM type II (alone) cannot accommodate the results on $B \to \tau \nu_\tau$ and $B \to D^{(*)} \tau \nu_\tau$
- New models have been studied so far
  - Crivellin et al 1206.2634: possibile explanation with Type III 2HDM
  - Fajfer et al. 1206.1872: 2HDM with leptoquarks

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- New Belle measurements with improved B_{tag} (NeuroBayes®) welcome!
- Confirmation? If yes, look for other observables:
  - q^2 distribution, τ polarization using $\tau \rightarrow \pi\nu_\tau$, D* polarization from D* decay angular analysis => Rich physics for future SuperB factories and... perhaps also for LHCb now!!!

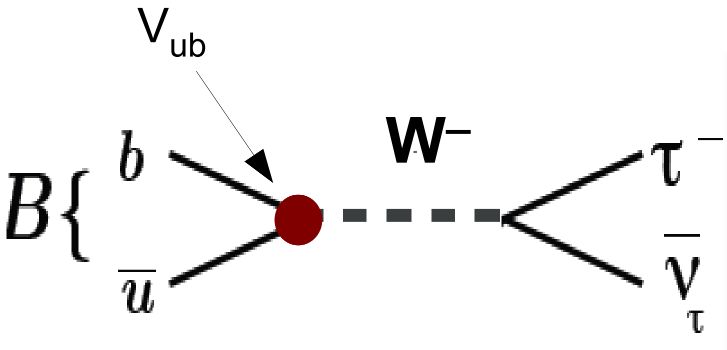
$B \rightarrow \tau \nu_\tau$

arXiv:1207.0698

Analysis of B → $\tau\,\nu_\tau$

Theoretically very clean

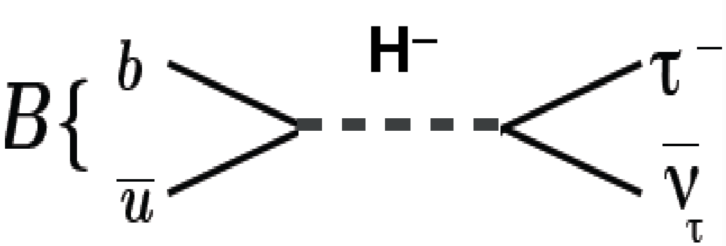
$$\mathcal{B}(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$



Allow $|V_{ub}|$ extraction from f_B & BF

Experimentally difficult:
- helicity suppression
- BF(τ)~10^{-4} (and BF(μ)~10^{-7} out of reach of current Bfactories
- only the Branching Fraction is accessible)

Power probe of physics beyond the SM



$$\mathcal{B}_{2HDM}(B \to \tau\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B \times \left(1 - m_B^2 \frac{\tan^2\beta}{m_H^2}\right)^2$$

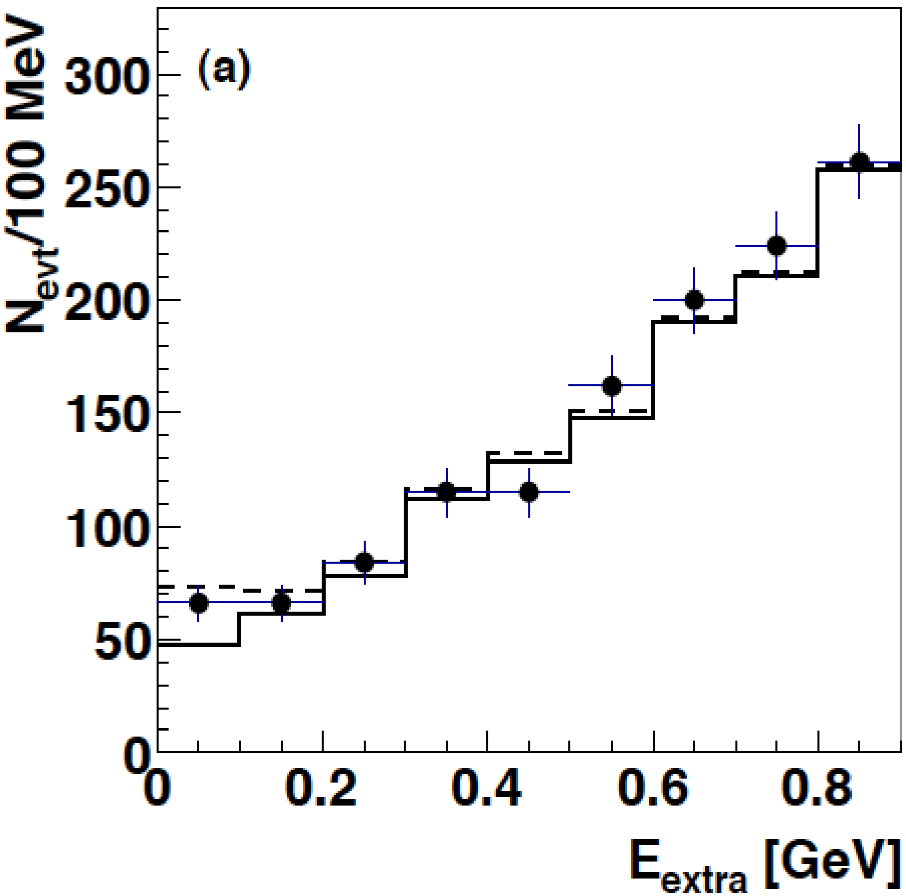
B(τν) In the SM

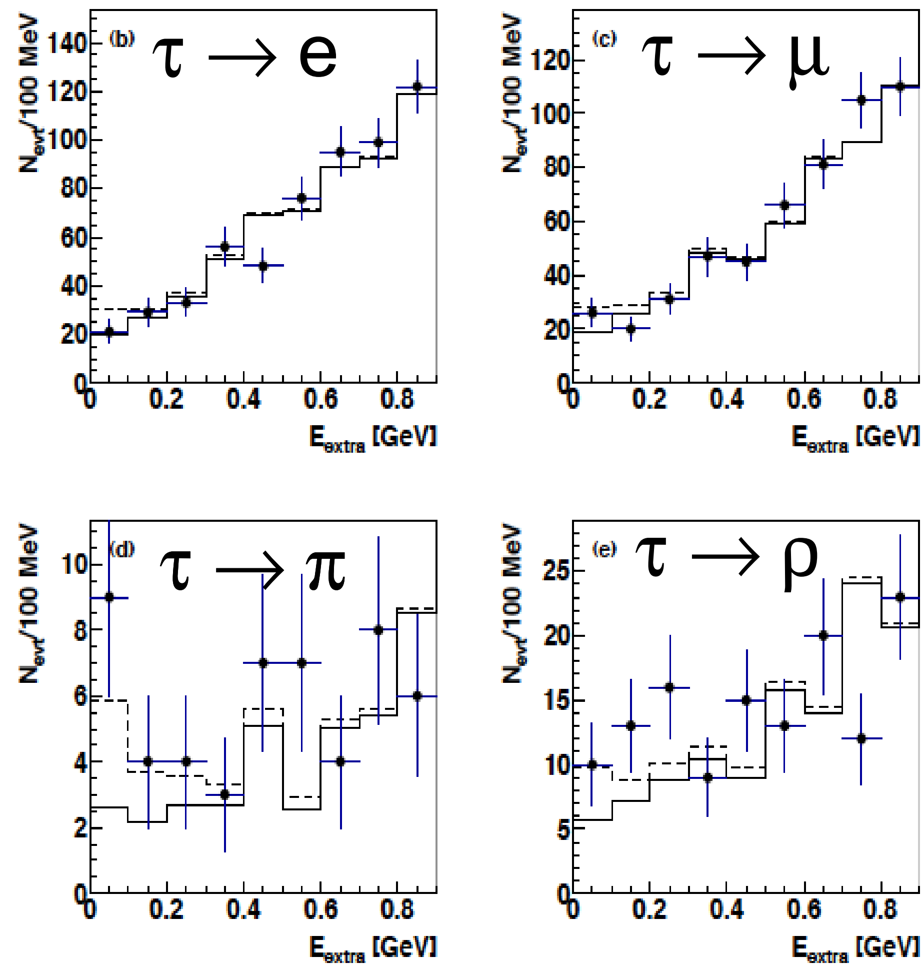
In the Type-II 2HDM

Results: $B \to \tau \nu_\tau$

- Fit to residual energy in the EMC simultaneously in 4 τ decay modes

$$E_{\mathrm{Extra}} = \sum_{\mathrm{unused}\ \gamma} E_\gamma$$





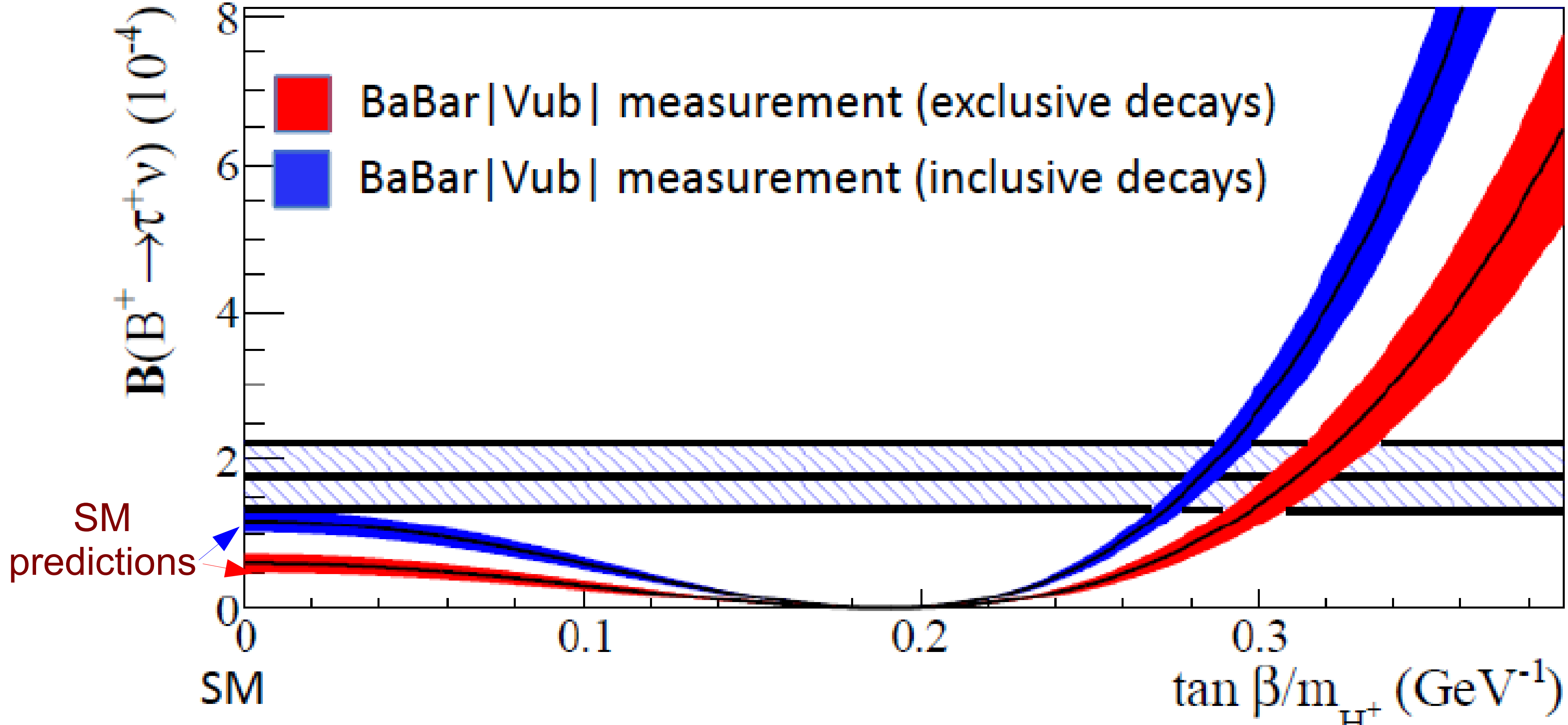
$$\mathcal{B}(B^+ \to \tau^+ \nu) = (1.83^{+0.53}_{-0.49}(\mathrm{stat.}) \pm 0.24(\mathrm{syst.})) \times 10^{-4}$$

Significance 3.8σ

Comparison with 2HDM-II

$$\mathcal{B}_{2HDM}(B \to \tau\nu) = \frac{G_F^2 m_B m_\tau^2}{8\pi}\left(1 - \frac{m_\tau^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B \times \left(1 - m_B^2 \frac{\tan^2\beta}{m_H^2}\right)^2$$

Uncertainty in SM prediction is dominated by $|V_{ub}|$

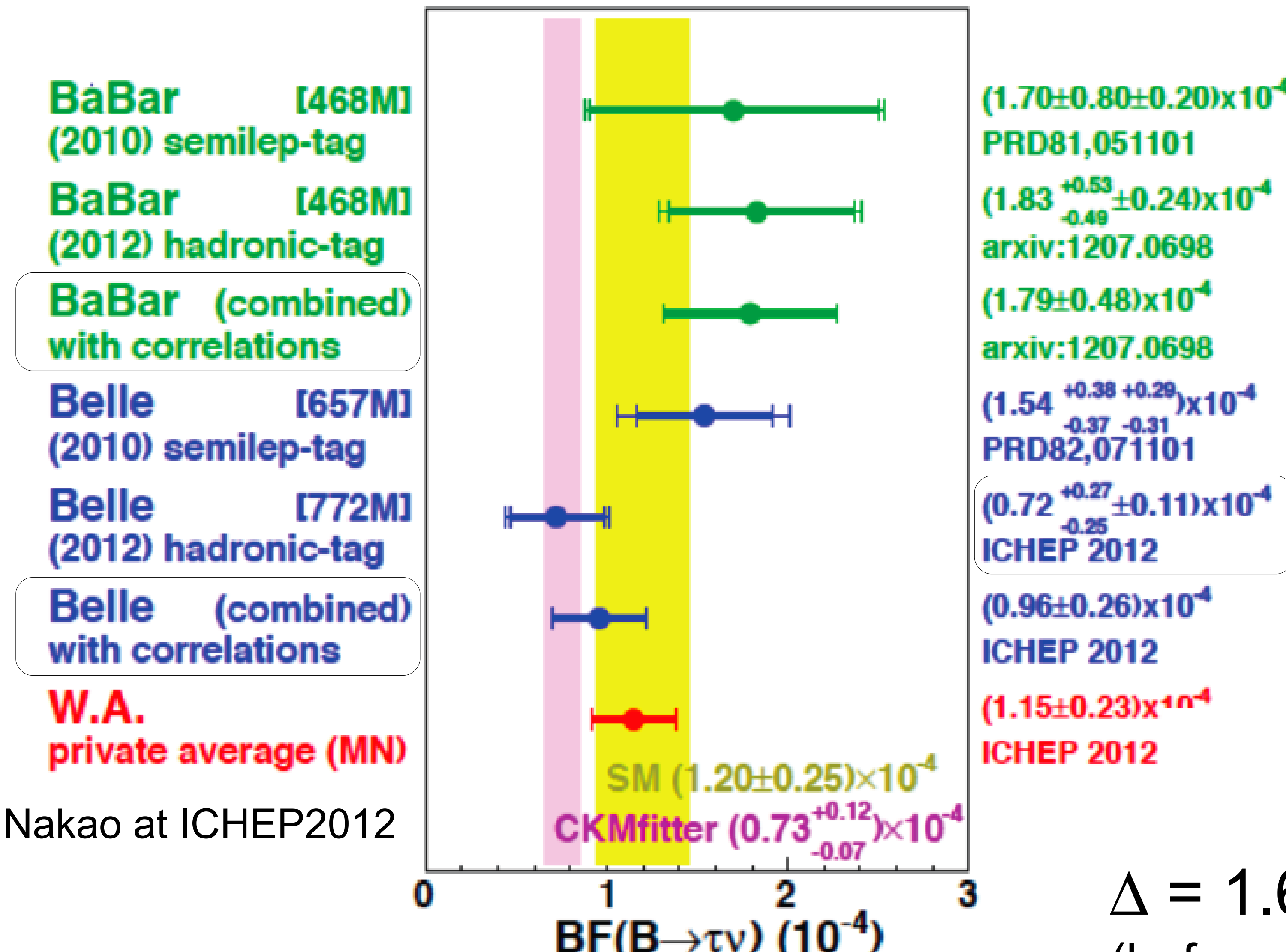


$|V_{ub}|_{incl} = (4.33 \pm 0.28) \cdot 10^{-3}$

$|V_{ub}|_{excl} = (3.13 \pm 0.30) \cdot 10^{-3}$

$f_B = (189 \pm 4)$ MeV (HPQCD arXiv:1202.4914)

Experimental Results on $B \to \tau \nu_\tau$



Nakao at ICHEP2012

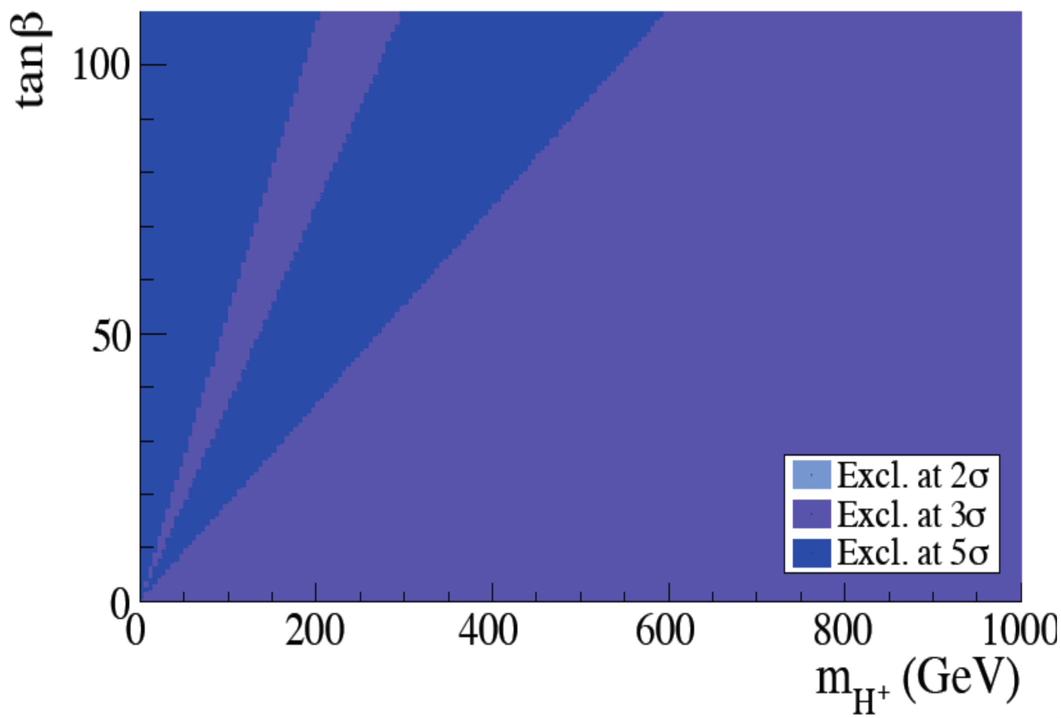
New Hadronic B Tag

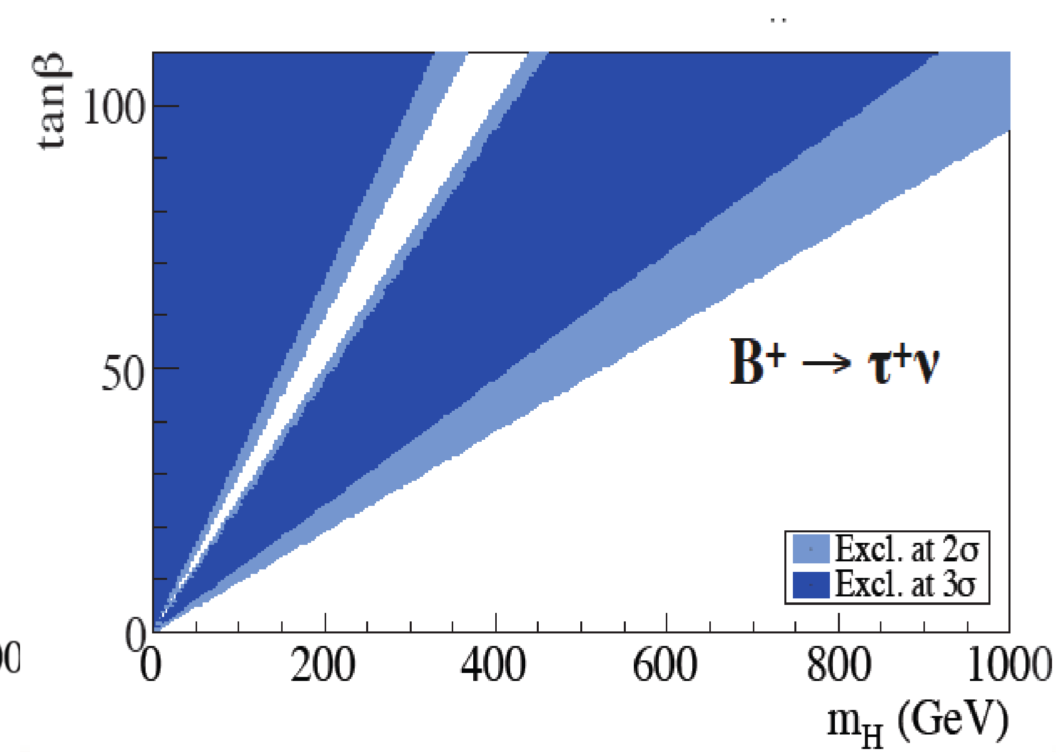
$\Delta = 1.6\sigma$

(before ICHEP was 2.7s)

Exclusion region for 2HDM-II

Using both D · D* results: Type II 2HDM excluded at 99.8% (3.1s)





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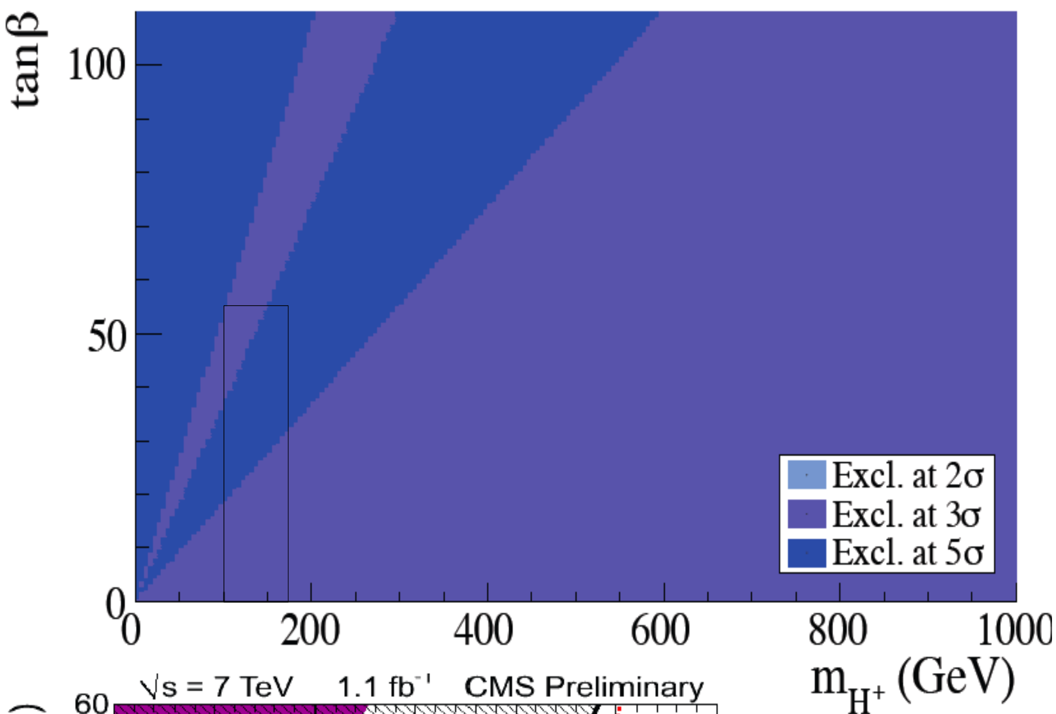
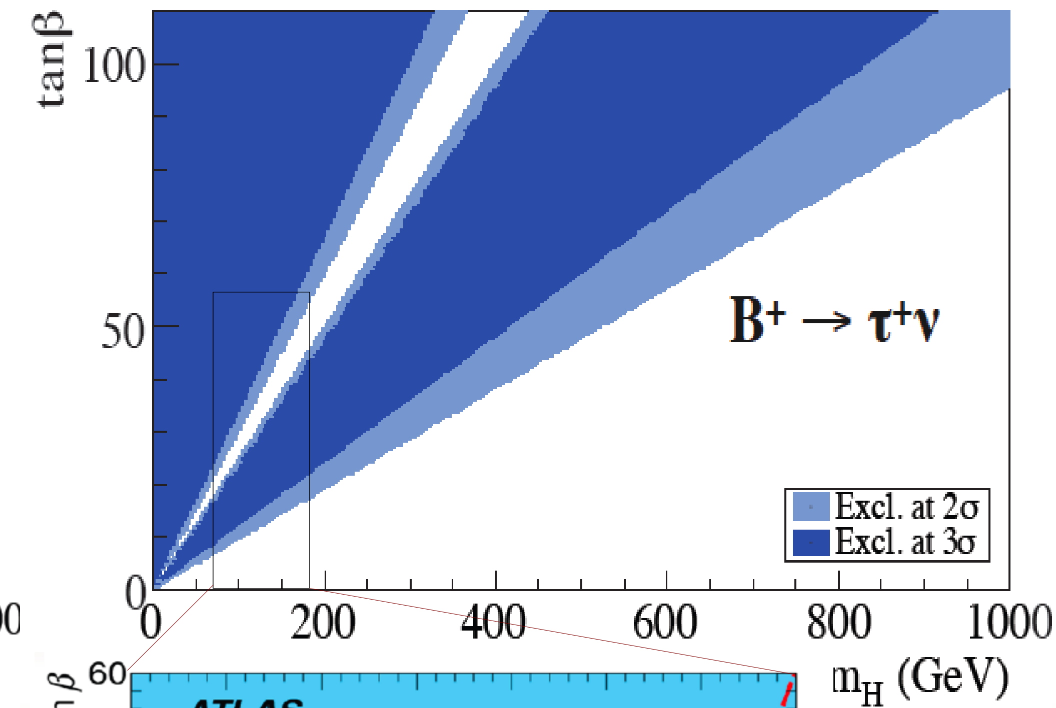
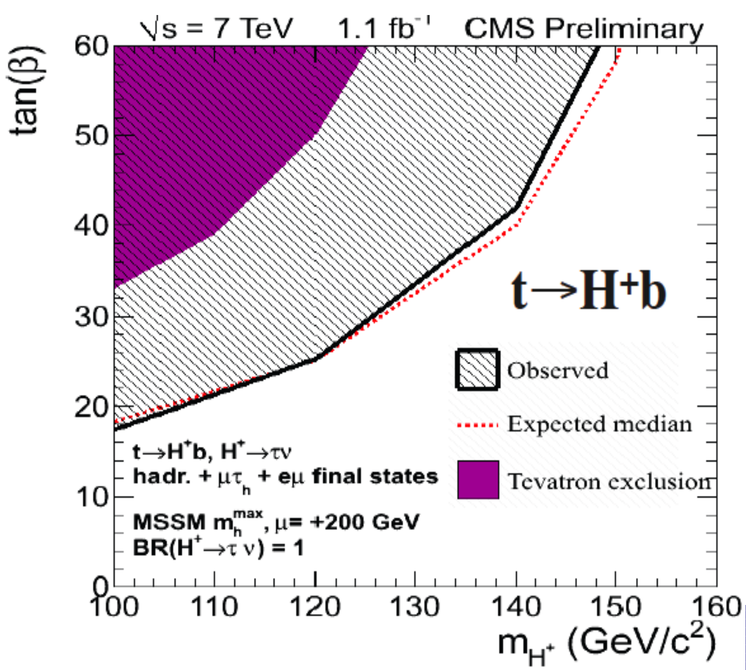
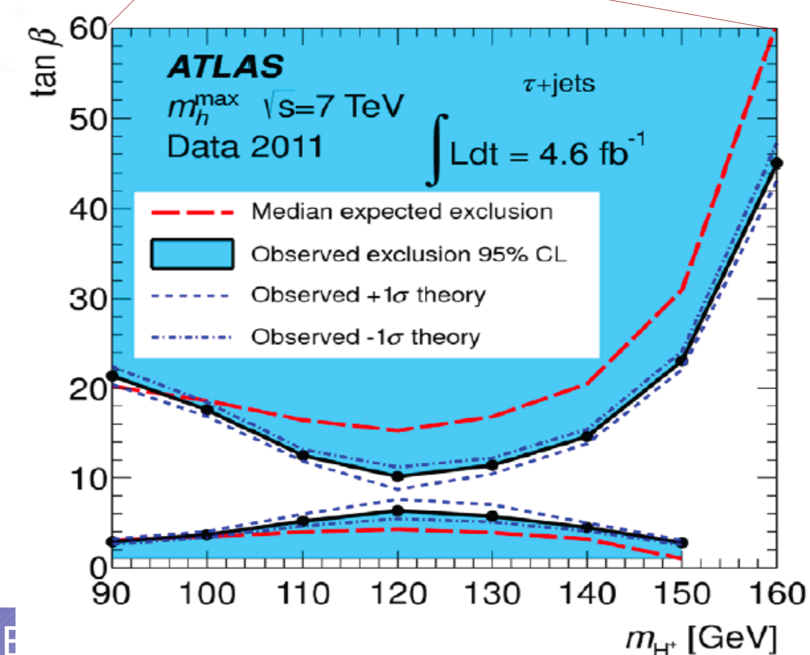






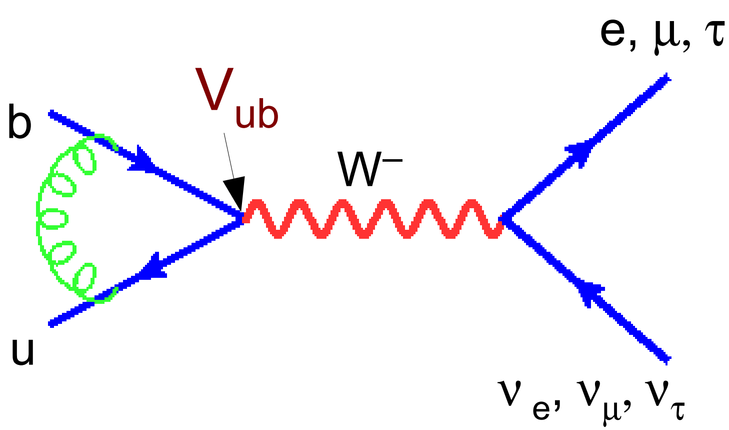


Summary

- New (legacy) BaBar results on $|V_{ub}|$
  - Puzzle about the Inclusive-Exclusive difference and bad compatibility with indirect extractions
  - Will stay with us for long
- $B \to D^{(*)} \tau \nu_\tau$: not in agreement with SM prediction
  - Wait for a confirmation from Belle (LHCb ?)
- $B \to \tau \nu_\tau$: reached the B-factory limits
  - Status is cloudy
  - But will be explored with high precision at SupeB-Factorys.

BACK UP

Leptonic Decays

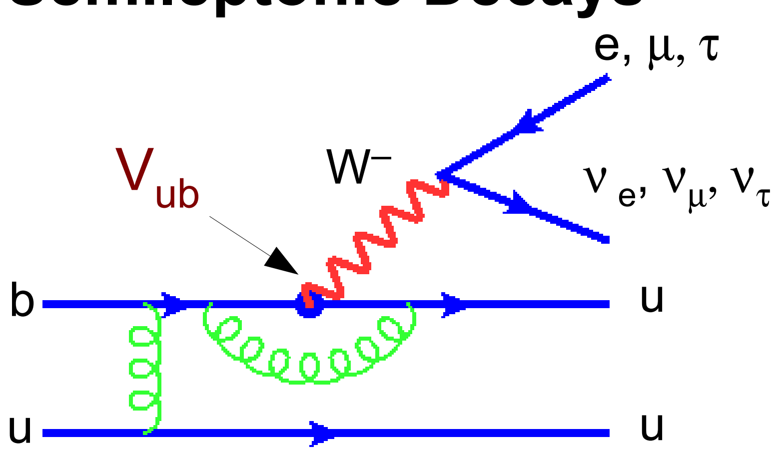


B meson decay constant

$$\mathcal{M}(B \to \ell^- \overline{\nu}) = i\frac{G_F}{\sqrt{2}} \cdot V_{ub} \cdot f_B \cdot L^\mu q_\mu$$

Clean, but helicity suppressed

Semileptonic Decays



Leptonic and hadronic currents factorize

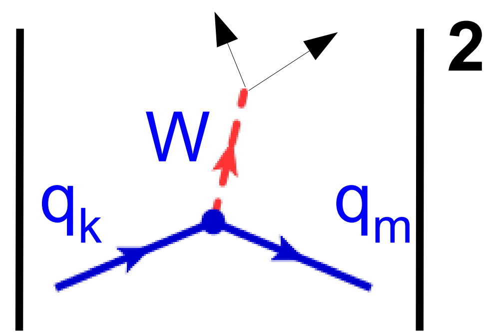
$$\mathcal{M}(B \to \pi \ell^- \overline{\nu}) = -i\frac{G_F}{\sqrt{2}} \cdot V_{ub} \cdot L^\mu H_\mu$$

$B \to \pi$ hadronic current

CKM Matrix measurements

- CKM cannot be predicted in the SM
- Most SM extensions contain new CP-violating phases and new quark-flavor changing interactions

V_{ud} $\pi \to \ell\nu$ β-decay	V_{us} $K \to \pi\ell\nu$ $K \to \ell\nu$	V_{ub} $b \to u\ell\nu$ $B \to \pi\ell\nu$
V_{cd} $D \to \pi\ell\nu$ $\nu+d \to c+\ell$	V_{cs} $D \to K\ell\nu$ $D_s \to \ell\nu$	V_{cb} $b \to c\ell\nu$ $B \to D\ell\nu$
V_{td} $\langle B_d \vert \overline{B}_d \rangle$ $b \to d\gamma$	V_{ts} $\langle B_s \vert \overline{B}_s \rangle$ $b \to s\gamma$	V_{tb} $t \to b\ell\nu$



$$\sim |V_{km}|^2$$

The CKM matrix extracted from tree-level processes

CKM Matrix measurements

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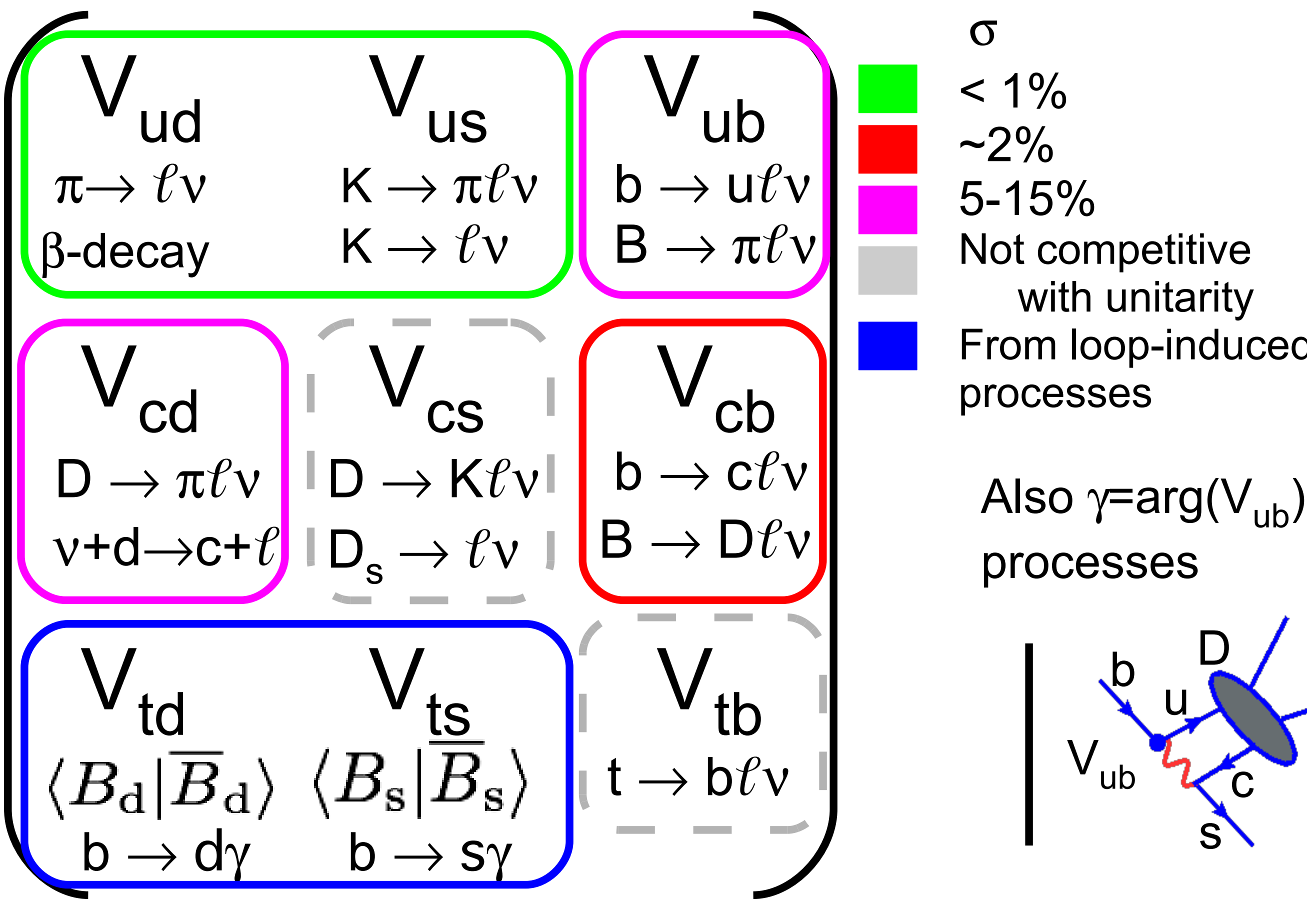
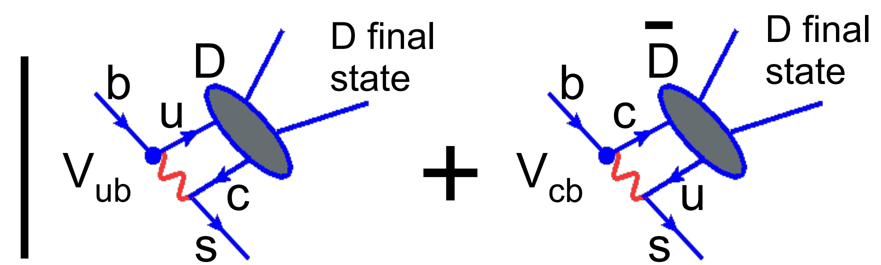


Semileptonic and leptonic decays play a crucial role

Two matrix elements from B SL decays: 1 side and the normalization of the UT

Also γ=arg(V_{ub}) can be obtained by tree-level processes



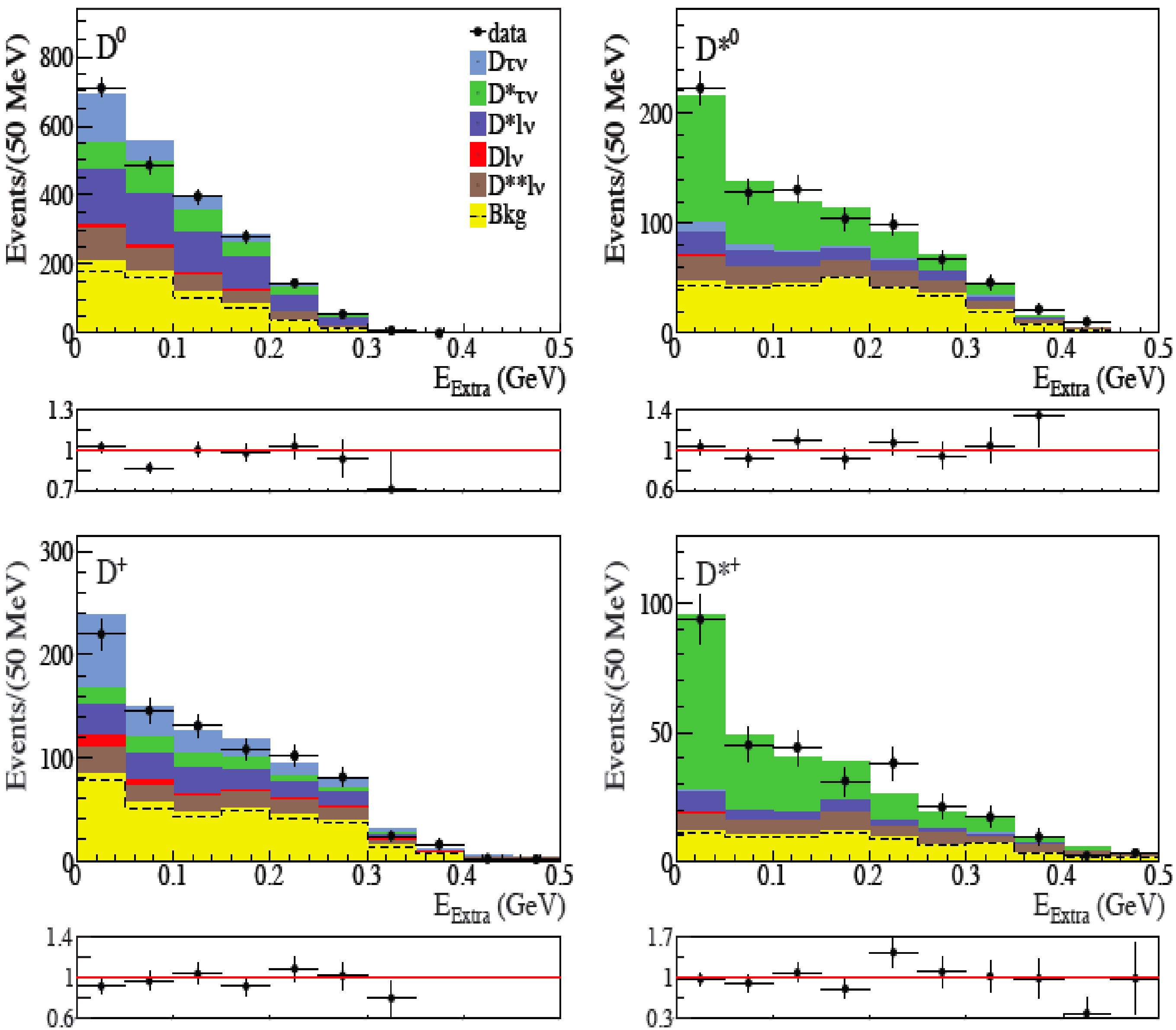
Only V_{td}, V_{ts} cannot be accessed by tree-level processes

(From G.Isidori)

Event Reconstruction: Details

- B_{tag} reconstructed in $B \to D^{(*)}X$, $B \to D_s^{(*)}X$, $B \to J/\psi X$ ($X=\pi,K$ modes with $n_X<6$) and selected using
  - beam energy substituted mass $$m_{ES} = \sqrt{(E^*_{beam})^2 - (\mathbf{p}^*_{tag})^2}$$
  - the energy difference $$\Delta E = E^*_{tag} - E^*_{beam}$$
- Signal side $D^{(*)}$ in D^0, D^{*0}, D^+, D^{*+} and require an identified lepton
- No additional charged particles
- Kinematic selection: $q^2 = (p_B - p_{D^{(*)}})^2 = q^2 > 4$ GeV^2
- Boosted Decision Tree (BDT)
  - Reduce combinatorial and D** backgrounds
- Because the $B \to D^{**}(\ell,\tau)\nu$ have large uncertainties
  - We fit simultaneously also a sample of 4 $D^{(*)}\pi^0\ell\nu$
    - same selection as signal but added π^0: captures $D^{**} \to D^{(*)}\pi^0$
- Three control samples to validate and correct the simulation:
  - $E_{extra}>0.5$ GeV, $q^2<4$ GeV, $m_{ES}<5.26$ GeV
  - + off-peak data to correct lepton spectrum of simulated continuum events

Energy extra in the EMC



$$E_{\mathrm{Extra}} = \sum_{\mathrm{unused}\ \gamma} E_\gamma$$

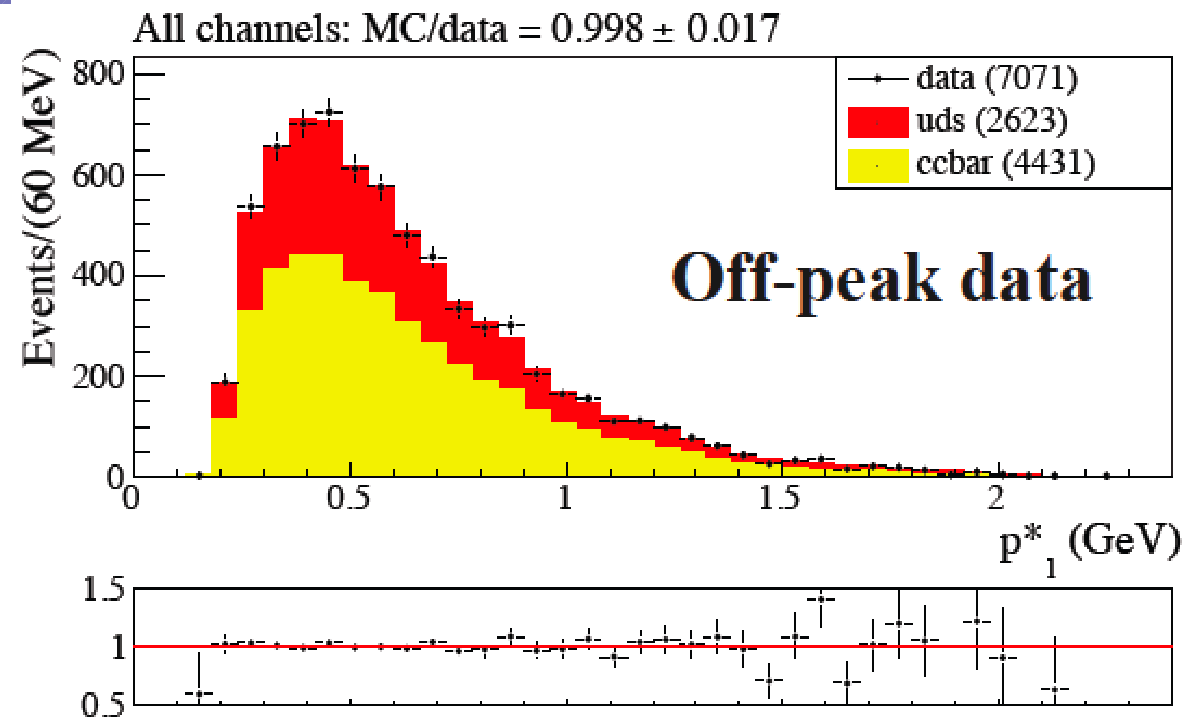
E_{Extra} distribution after the Fit

m^2_{miss} > 1.5 GeV2

Background estimation

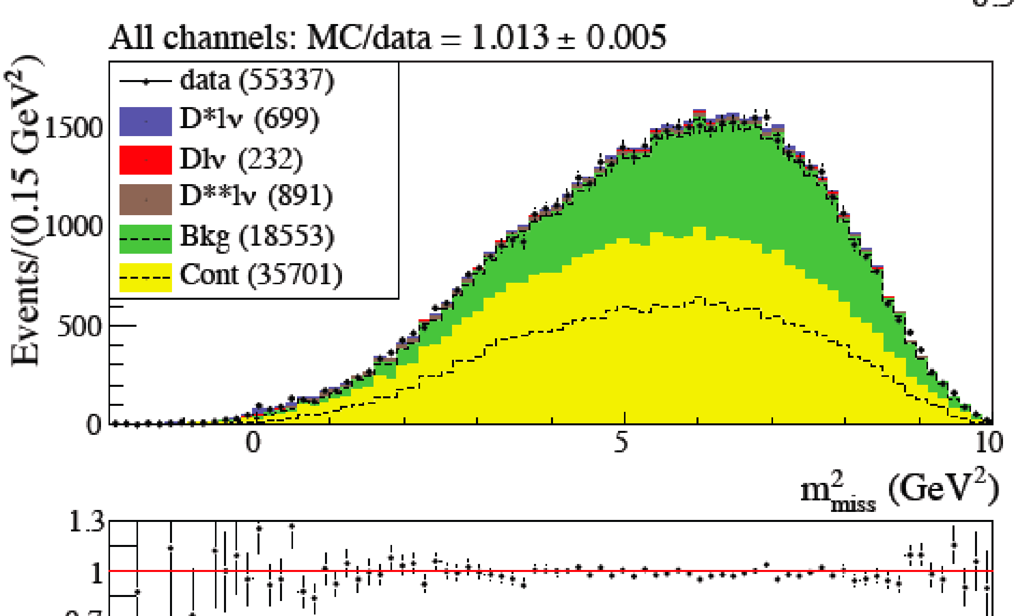
Continnum:

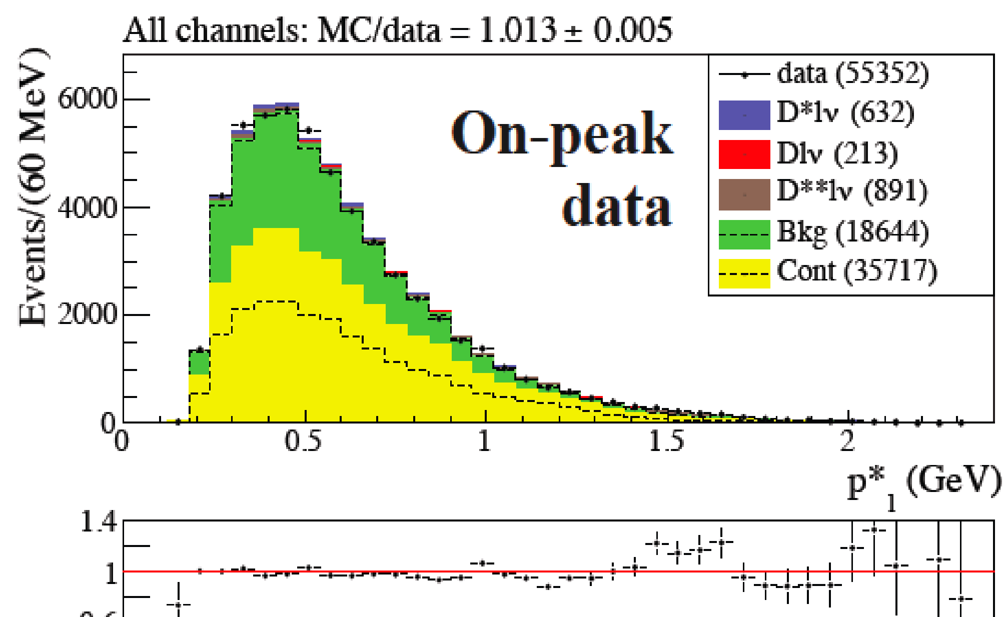
- Using off-peak data
- Special runs taken below the Y(4S) peak



BB background:

- Estimated in events with large E_{extra}





Two Higgs Doublet Model