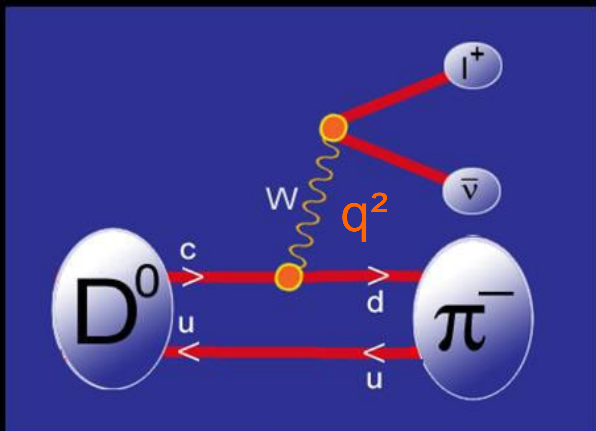
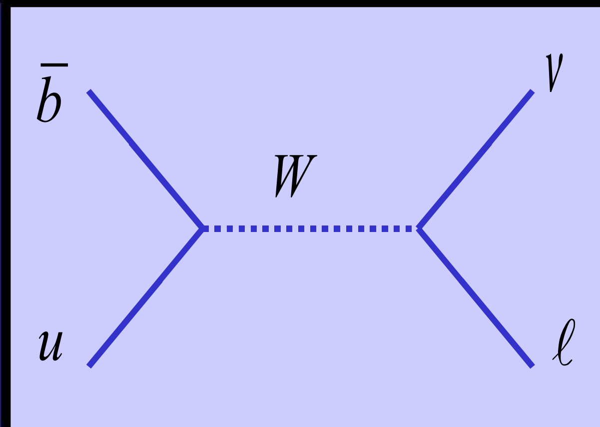
Semileptonic D^0 decays & $B^{\pm} \rightarrow \tau\nu$ at Belle

4th International Workshop on CKM Unitarity Triangle
2006 Nagoya





Laurenz Widhalm
HEPHY Vienna
Belle Collaboration

Belle in a nutshell

- located at KEK / Japan
- KEKB Collider

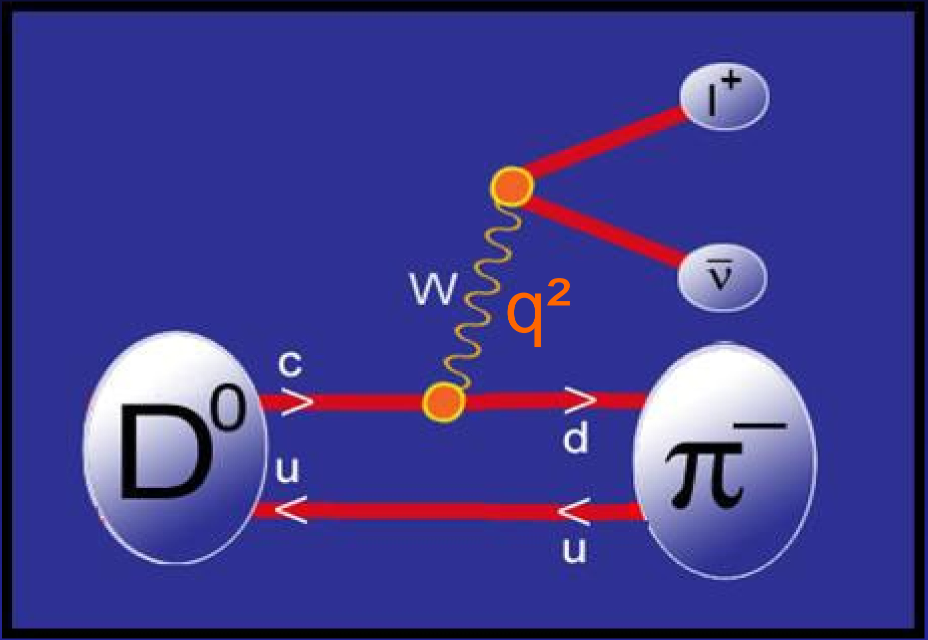
e^- 8GeV → ← e^+ 3.5GeV
$\beta\gamma = 0.425$

- B-Factory at ϒ(4s) resonance
- peak luminosity 16.270 1/nb/s
- integrated luminosity 700 1/fb

(as of Dec 2006; only part of it used in presented analyses)

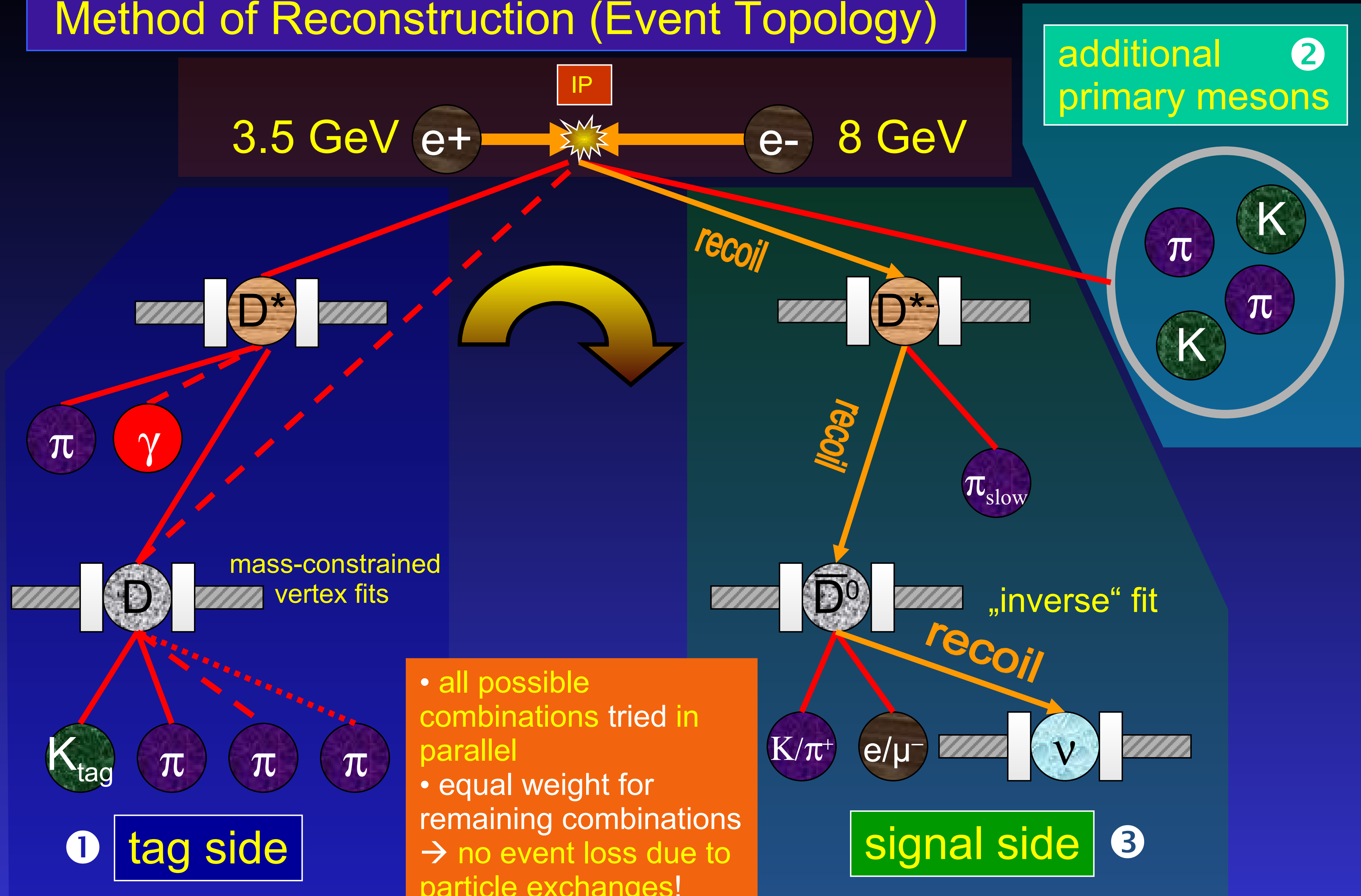
semileptonic D^0 decays

Why are semileptonic decays interesting?



- single form factor $f_D(q^2)$
- calcuable in LQCD, but
- needs checking from data
- D-System ideal for experimental input
- results can be applied in B-physics
  (extraction of CKM parameters)

Method of Reconstruction (Event Topology)



- all possible combinations tried in parallel
- equal weight for remaining combinations

→ no event loss due to particle exchanges!

D^0 Signal and Background*

* from decays without a D^0 , or combinatorial background

cuts

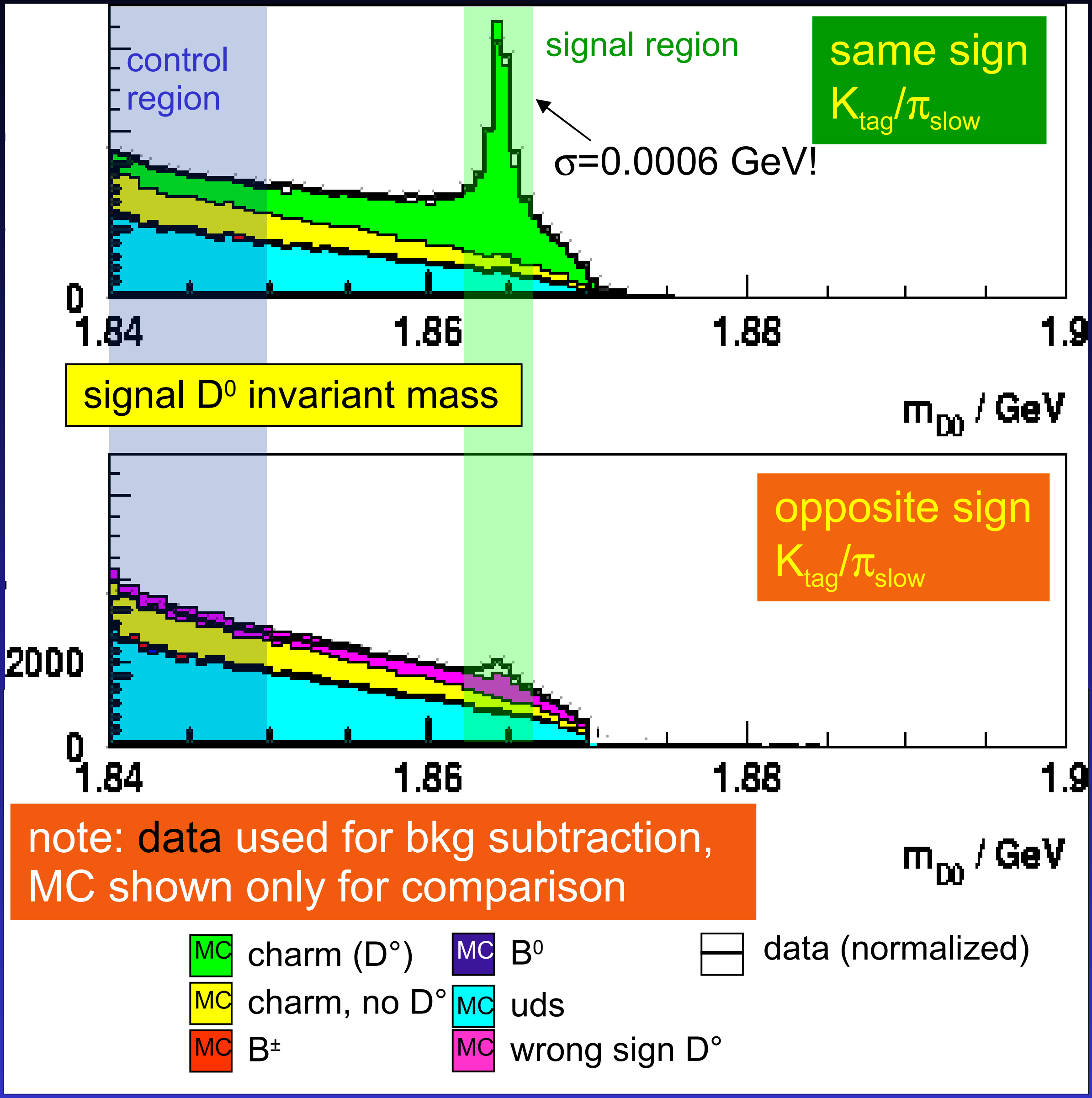
- all mass-constr. fits CL >0.1%

(released on D^0 fit for righthand plot)

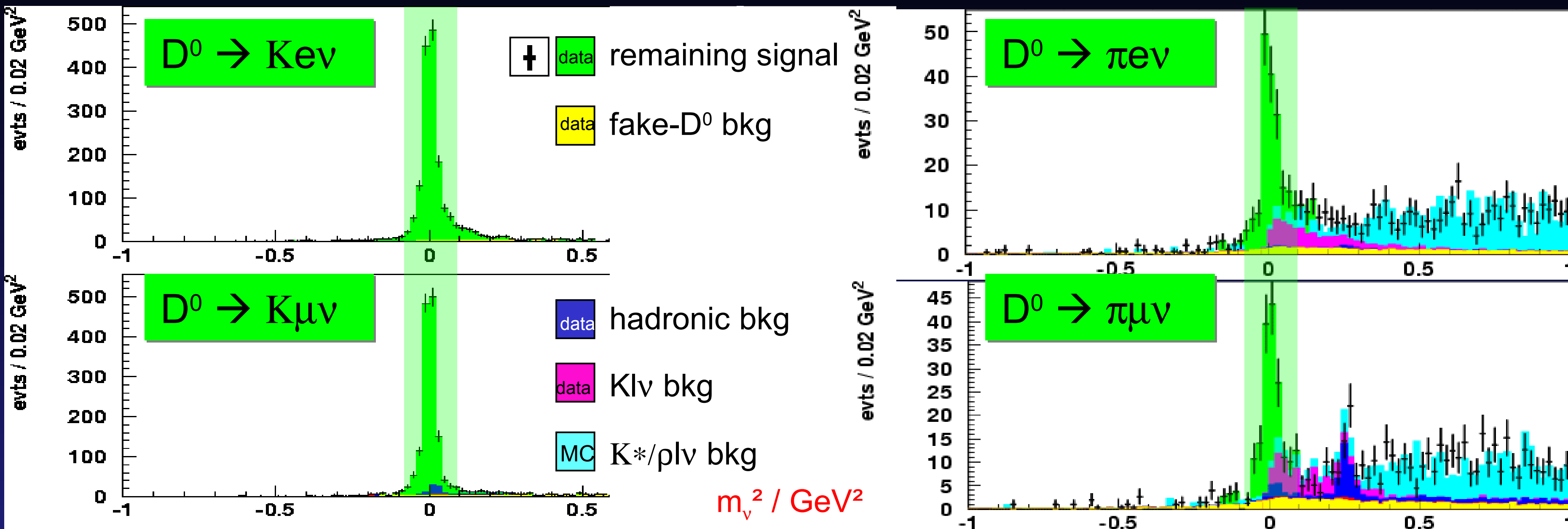
- same charge K_{tag}/π_{slow}

282/fb (~40% of Dec '06 total) of BELLE data used

result	yield
after cuts	95250
background	38789
signal	56461
	$\pm 309_{stat}$
charge correlation	$\pm 776_{syst}$
signal subtraction	$\pm 233_{syst}$
stats bkg sample	$\pm 194_{syst}$



Summary of Signal / Background Decomposition



Results (282 fb-1 of BELLE data)	Keν	Kμν	πeν	πμν
signal events	1318 $\pm 37_{stat} \pm 7_{syst}$	1249 $\pm 37_{stat} \pm 25_{syst}$	126 $\pm 12_{stat} \pm 3_{syst}$	106 $\pm 12_{stat} \pm 6_{syst}$
fake D^0 bkg	12.6 ± 2.2	12.2 ± 4.8	12.3 ± 2.2	12.5 ± 4.5
semileptonic bkg*	6.7 ± 2.6	10.0 ± 2.5	11.7 ± 1.2	12.6 ± 1.9
hadronic bkg**	11.9 ± 5.6	62.1 ± 23.9	1.8 ± 0.7	9.7 ± 3.7

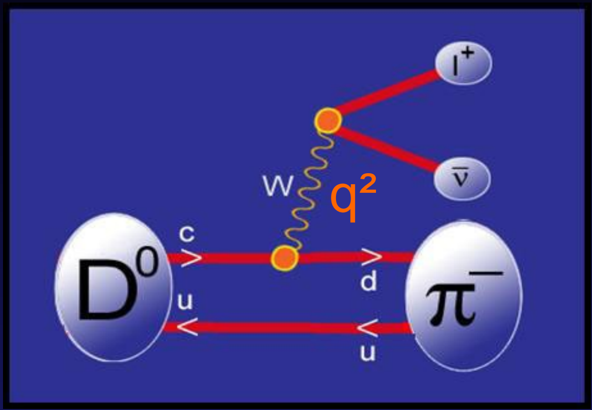
* error dominated by MC stats ** error dominated by fit errors & bias special bkg sample

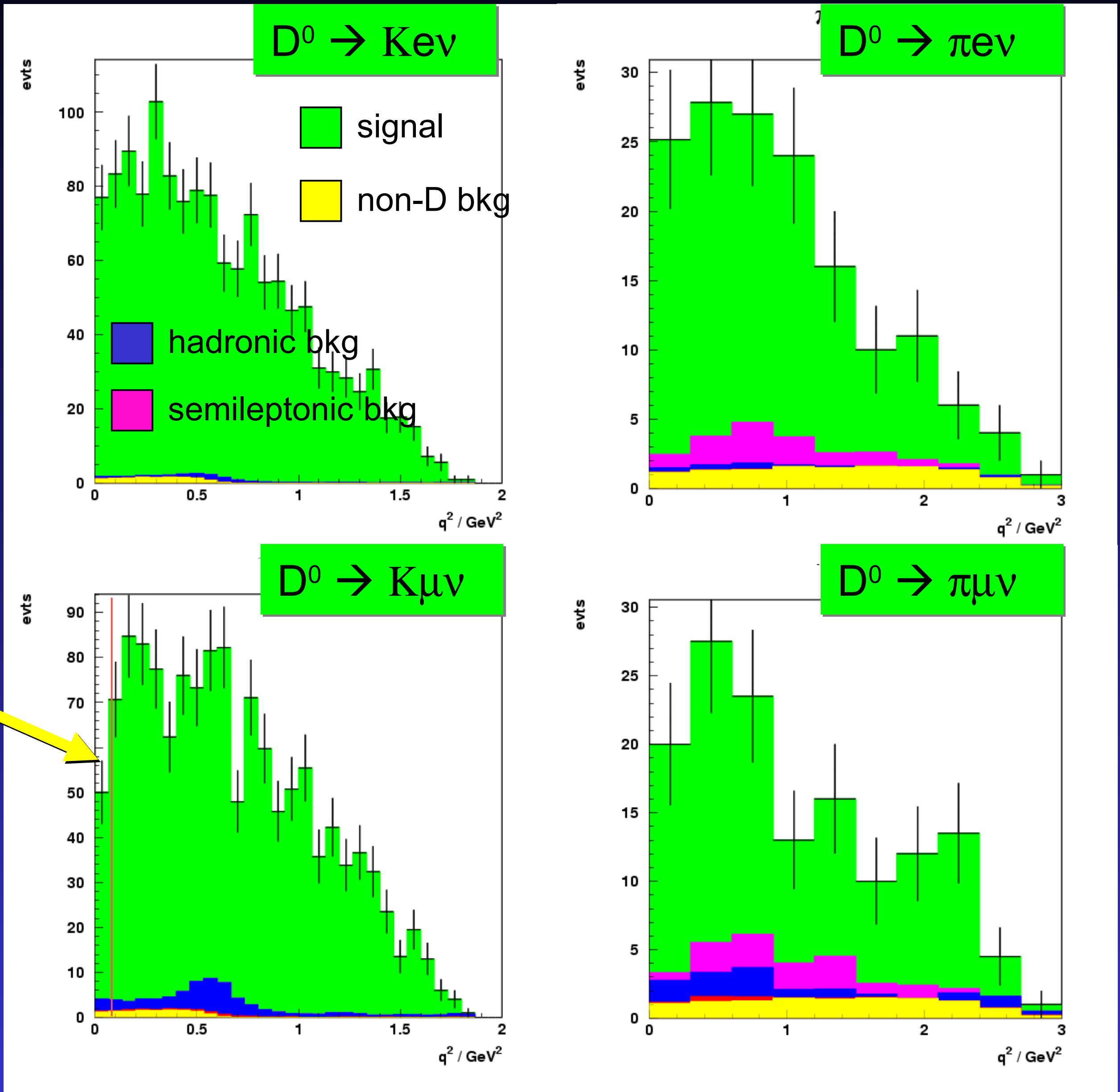
Absolute Branching Ratios

- ratio to total number of recoil D^0 tags
- efficiency correction
- corrected for bias due to differences data/MC (1.9%±3.9%)

BRs (%)	this analysis	PDG (2006)
$K^- e^+ \nu$	$3.45 \pm 0.10_{stat} \pm 0.19_{syst}$	3.51 ± 0.11
$K^- \mu^+ \nu$	$3.45 \pm 0.10_{stat} \pm 0.21_{syst}$	3.19 ± 0.16
$\pi^- e^+ \nu$	$0.279 \pm 0.027_{stat} \pm 0.016_{syst}$	0.281 ± 0.019
$\pi^- \mu^+ \nu$	$0.231 \pm 0.026_{stat} \pm 0.019_{syst}$	0.24 ± 0.04

Form Factors – q² distribution





$\sigma(q^2) = 0.0145\ \mathrm{GeV}^2/c^2$
(width of red line)
→ no unfolding necessary!

background shapes from data

Form Factors – Comparison with Models

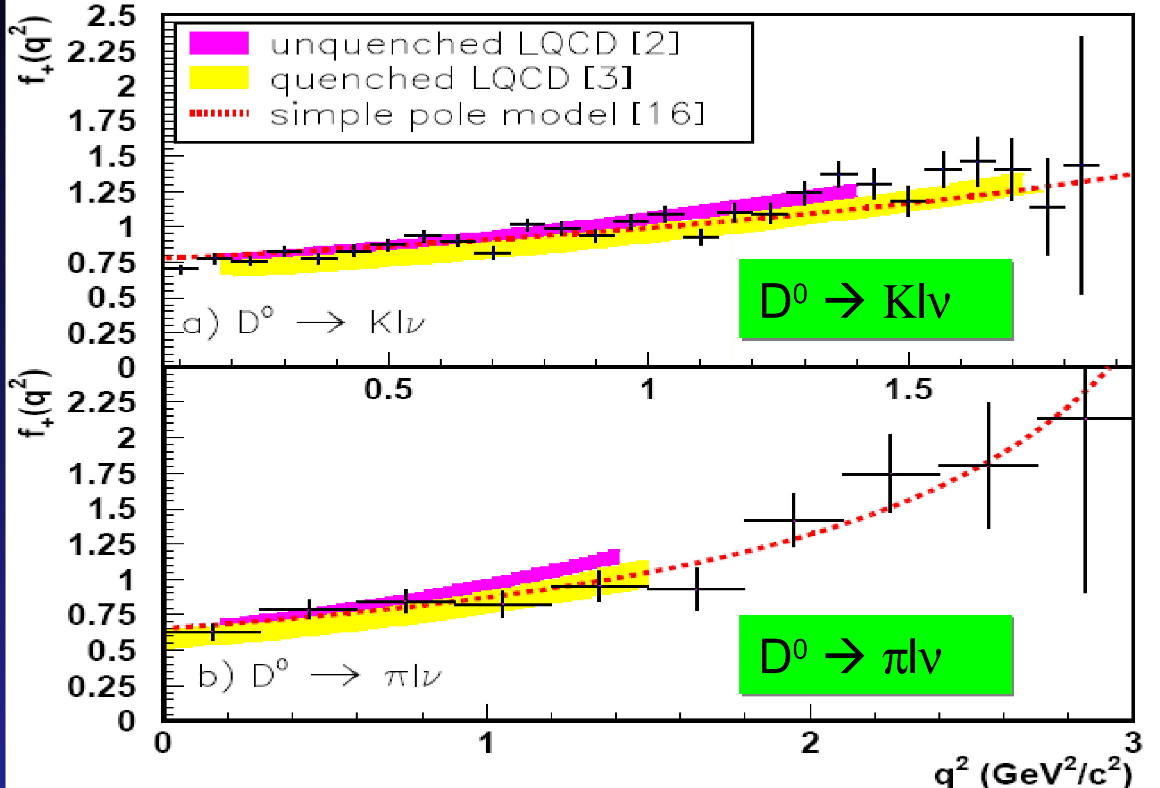
fit results

simple pole

	pole mass (GeV)
Klν	$1.82 \pm 0.04_{stat} \pm 0.03_{syst}$
πlν	$1.97 \pm 0.08_{stat} \pm 0.04_{syst}$

modified pole
(poles fixed at theo. values)

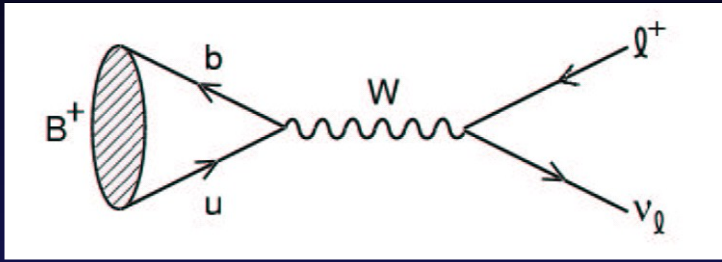
	$f_+(0)$
Klν	$0.695 \pm 0.007_{stat} \pm 0.022_{syst}$
πlν	$0.624 \pm 0.020_{stat} \pm 0.030_{syst}$
	α
Klν	$0.52 \pm 0.08_{stat} \pm 0.06_{syst}$
πlν	$0.10 \pm 0.21_{stat} \pm 0.10_{syst}$



[2] C. Aubin *et al.*, (Fermilab Lattice Collaboration, MILC Collaboration a
ration), Phys. Rev. Lett. **94**, 011601 (2005).
[3] A. Abada, D. Becirevic, P. Boucaud, J. P. Leroy, V. Lubicz and F. M
619, 565 (2001).
[16] G. Amoros, S. Noguera, J. Portoles, Eur. Phys. J. **C27**, 243 (2003).

$$\frac{f_+^\pi(0)^2|V_{cd}|^2}{f_+^K(0)^2|V_{cs}|^2} = 0.042 \pm 0.003_{stat} \pm 0.003_{syst}$$

$B^{\pm} \to \tau\nu$ decays



- Proceed via W annihilation in the SM.
- SM Branching fraction

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

$Br(\tau\nu)=1.6\times10^{-4}$

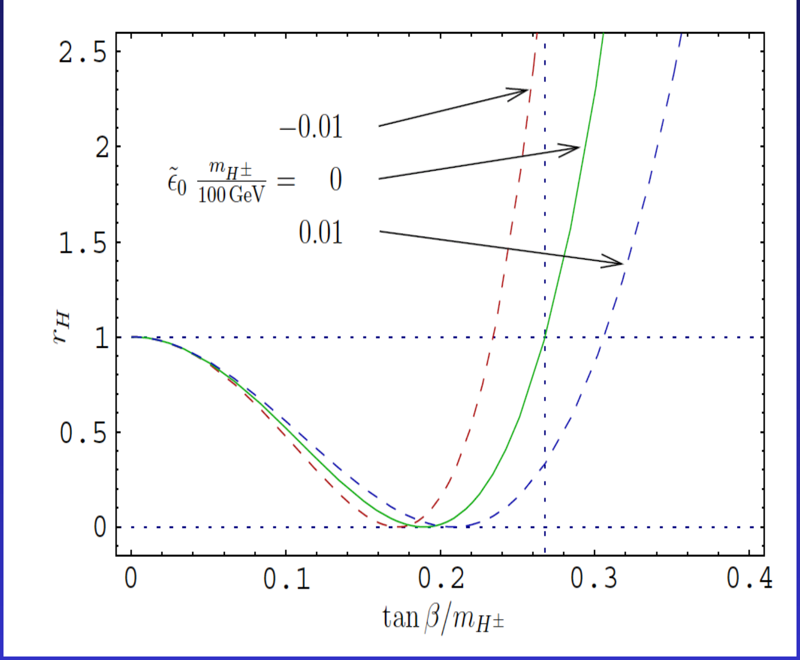
$Br(\mu\nu)=7.1\times10^{-7}$

$Br(e\nu)=1.7\times10^{-11}$

➡ Provide $f_B|V_{ub}|$

- In two Higgs doublets model, charged Higgs exchange interferes with the helicity suppressed W-exchange.

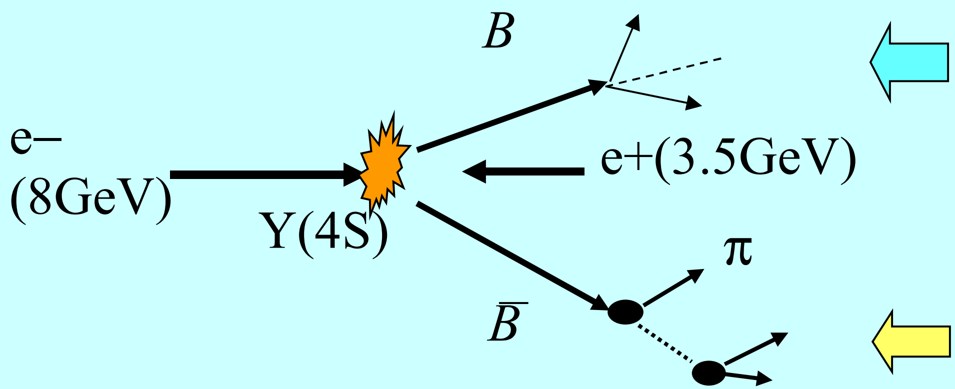
$$Br = Br_{SM} \times r_H,\quad r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan\beta^2\right)^2$$



- If μν is also measured, lepton universality can be tested.
  → SUSY correction etc.

Full Reconstruction Method

- Fully reconstruct one of the B's to tag
  - B production
  - B flavor/charge
  - B momentum



Decays of interests:
B→τν

full (0.1~0.3%) reconstruction
B→*Dπ* etc.

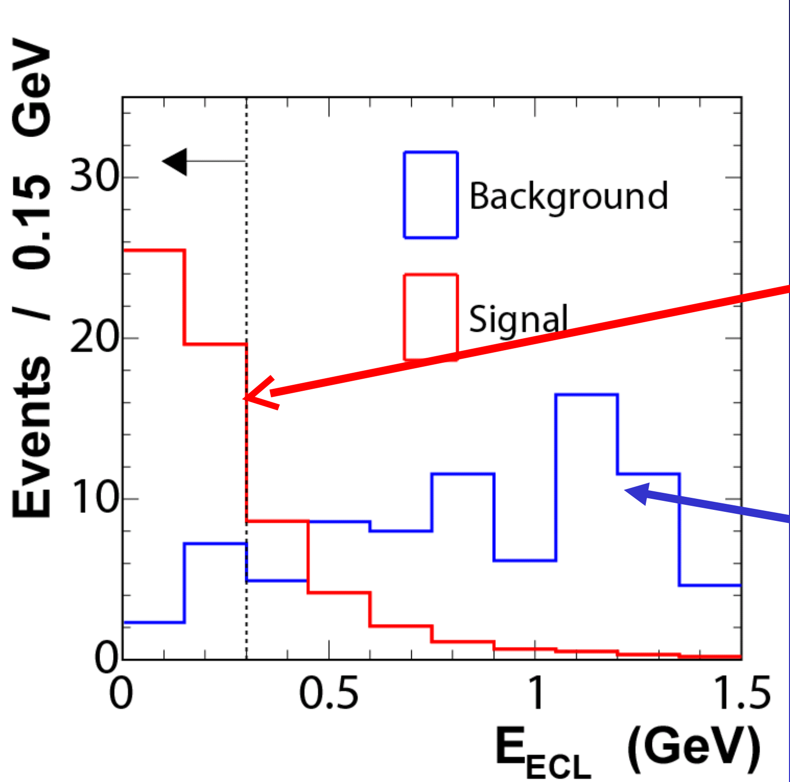
Single B meson beam in offline !

Powerful tools for B decays w/ neutrinos

B→τν event selection

- Extra neutral energy in calorimeter E_{ECL}
  - Most powerful variable for separating signal and background
  - Total calorimeter energy from the neutral clusters which are not associated with the tag B

$$E_{ECL} = E_{tot} - E_{rec.\ B} \quad (-E_{\pi^0} \text{ for } \pi^-\pi^0\nu)$$



Minimum energy threshold

- Barrel : 50 MeV
- For(Back)ward endcap : 100(150) MeV

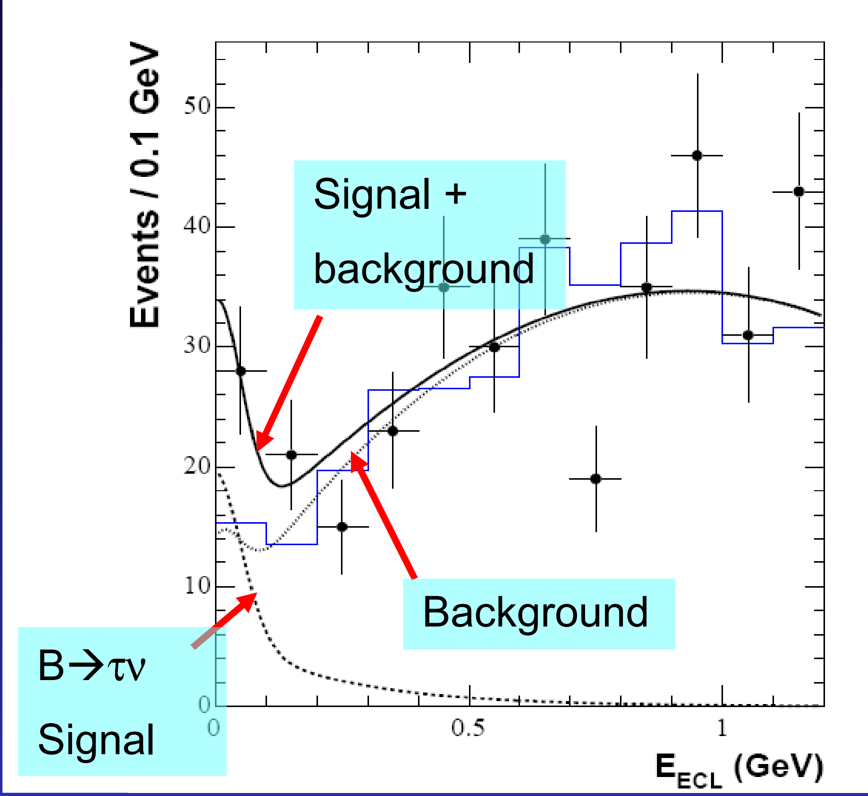
Zero or small value of E_{ECL} arising only from beam background

Higher E_{ECL} due to additional neutral clusters

MC includes overlay of random trigger data to reproduce beam backgrounds.

The first evidence of B→τν

- The final results are deduced by unbinned likelihood fit to the obtained E_{ECL} distributions.



	N_{obs}	N_s	N_b	$\varepsilon^{sel}(\%)$	$\mathcal{B}(10^{-4})$	Σ
$\mu^-\bar{\nu}_\mu\nu_\tau$	13	$5.6^{+3.1}_{-2.8}$	$8.8^{+1.1}_{-1.1}$	3.64 ± 0.02	$2.57^{+1.38}_{-1.27}$	2.2σ
$e^-\bar{\nu}_e\nu_\tau$	12	$4.1^{+3.3}_{-2.6}$	$9.0^{+1.1}_{-1.1}$	4.57 ± 0.03	$1.50^{+1.20}_{-0.95}$	1.4σ
$\pi^-\nu_\tau$	9	$3.8^{+2.7}_{-2.1}$	$3.9^{+0.8}_{-0.8}$	4.87 ± 0.03	$1.30^{+0.89}_{-0.70}$	2.0σ
$\pi^-\pi^0\nu_\tau$	11	$5.4^{+3.9}_{-3.3}$	$5.4^{+1.6}_{-1.6}$	1.97 ± 0.02	$4.54^{+3.26}_{-2.74}$	1.5σ
$\pi^-\pi^+\pi^-\nu_\tau$	9	$3.0^{+3.5}_{-2.5}$	$4.8^{+1.4}_{-1.4}$	0.77 ± 0.02	$6.42^{+7.58}_{-5.42}$	1.0σ

Σ : Statistical Significance

Observe $17.2^{+5.3}_{-4.7}$ events in the signal region.

Significance decreased to 3.5 σ after including systematics

Signal shape : Gauss + exponential

Background shape : second-order polynomial
+ Gauss (peaking component)

Results (Br & f_B Extraction)

- Measured branching fraction:

$$Br(B \to \tau\nu) = \left(1.79\,^{+0.56}_{-0.49}\,^{+0.46}_{-0.51}\right) \times 10^{-4}$$

- Product of B meson decay constant f_B and CKM matrix element $|V_{ub}|$

$$f_B |V_{ub}| = \left(10.1\,^{+1.6}_{-1.4}\,^{+1.3}_{-1.4}\right) \times 10^{-4}\,\mathrm{GeV}$$

- Using $|V_{ub}| = (4.39 \pm 0.33) \times 10^{-3}$ from HFAG

$$f_B = 0.229\,^{+0.036}_{-0.031}\,^{+0.034}_{-0.037}\ \mathrm{GeV}$$

15% 16% = 14%(exp.) + 8%(V_{ub})

$f_B = 216 \pm 22$ MeV

[HPQCD, Phys. Rev. Lett. 95, 212001 (2005)]

Constraints on Charged Higgs

$$Br_{exp} = (1.79\ ^{+0.56}_{-0.49}\ ^{+0.46}_{-0.51}) \times 10^{-4}$$

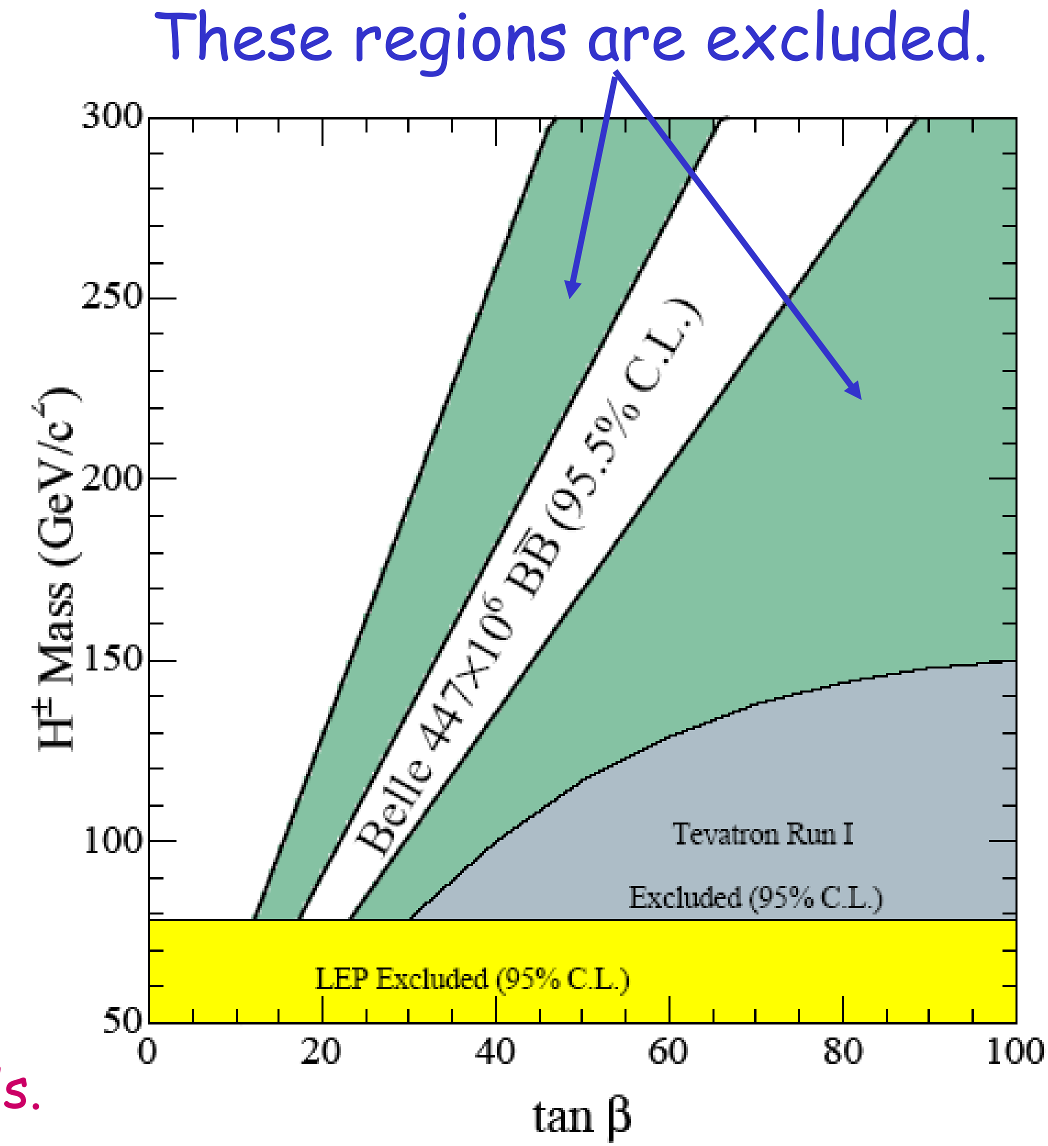
$$Br_{SM} = (1.59 \pm 0.40) \times 10^{-4}$$

f_B from HPQCD

$|V_{ub}|$ from HFAG

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2 = \frac{Br_{exp}}{Br_{SM}} = 1.13 \pm 0.53$$

Much stronger constraint than those from energy frontier exp's.



Future Prospect for B→τν

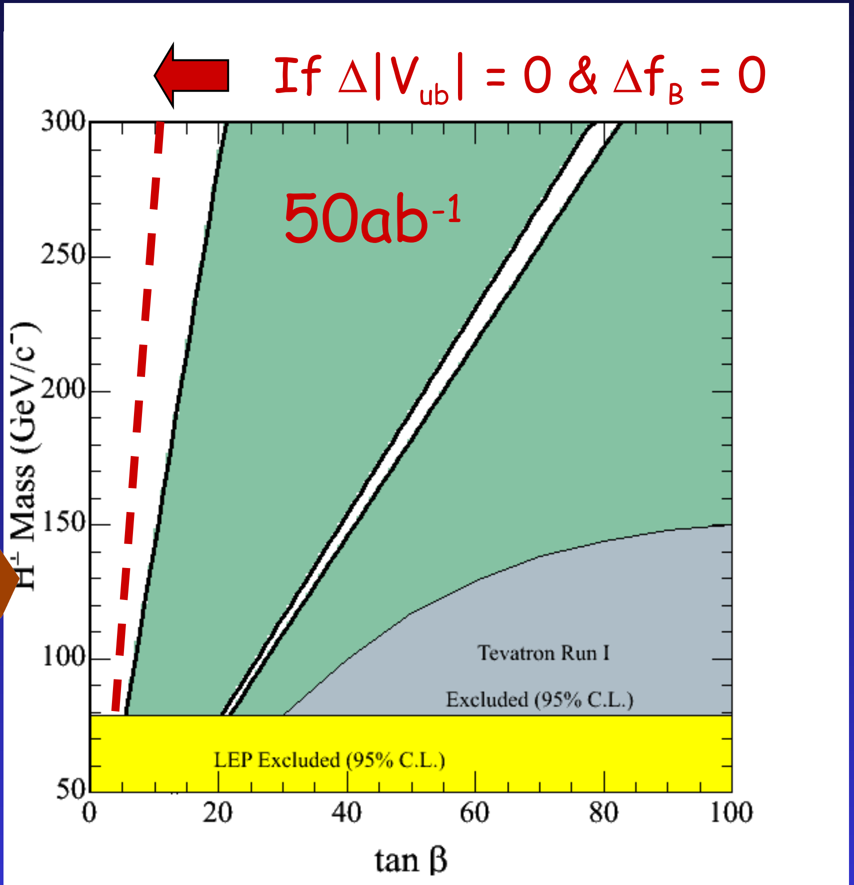
- Br(B→τ ν) measurement:

  More luminosity help to reduce both stat. and syst. errors.
  - Some of the syst. errors limited by statistics of the control sample.
- $|V_{ub}|$ measurement: < 5% in future is a realistic goal.
- f_B from theory: ~10% now → 5% ?

  assumption: Δf_B(LQCD) = 5%

Lum.	$\Delta B(B\to\tau\nu)_{exp}$	$\Delta\|V_{ub}\|$
414 fb^{-1}	36%	7.5%
5 ab^{-1}	10%	5.8%
50 ab^{-1}	3%	4.4%

Preliminary



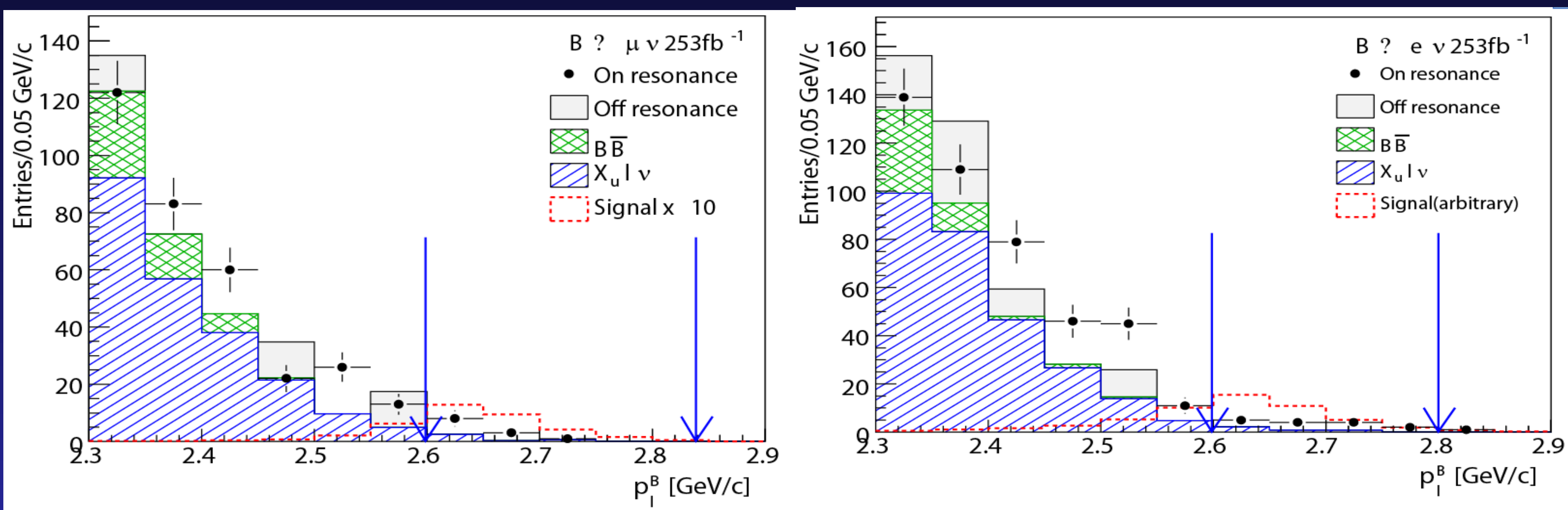
$Br(B\to\tau\nu)/\Delta m_{Bd}$ to cancel f_B ?

G.Isidori&P.Paradisi, hep-ph/0605012

B→μν, eν

- Belle @ 253fb^{-1}

with “inclusive ” reconstruction of the companion B.



$Br(B \to e\nu) < 9.8 \times 10^{-7}$

$Br(B \to \mu\nu) < 1.7 \times 10^{-6}$

@90%C.L.

SM: $Br(\tau\nu)=1.6\times10^{-4}$

$Br(\mu\nu)=7.1\times10^{-7}$

$Br(e\nu)=1.7\times10^{-11}$

Submitted to Phys.Lett. B hep-ex/0611045

Summary & Conclusion

semileptonic D^0 decays

Phys.Rev.Lett.97:061804,2006 hep-ex/0604049

- studied in events of type $e^+e^- \rightarrow \bar{D}^{(*)}D^{*c}X$ ($X=n\pi/K$)
- new full-reconstruction-recoil method 56k D^0 in 282 fb^{-1} of BELLE data
- high q^2 resolution (no unfolding), absolute multi-bin measurement of $f_+(q^2)$
- better accuracy than previous experiments
- good agreement with theoretical predictions, previous experiments and recent CLEOc results

$B^\pm \rightarrow \tau\nu$ decays

To appear in Phys.Rev.Lett. hep-ex/0604018

- studied in events of type $e^+e^- \rightarrow B^+B^-$ (449M B-pairs in 414 fb^{-1} of BELLE data)
- one B fully-reconstructed,
- powerfull extra-neutral-energy variable to select signal
- first evidence for $B \rightarrow \tau\nu$
- upper limits for $B \rightarrow \mu\nu$ and $B \rightarrow e\nu$

Laurenz.Widhalm@oeaw.ac.at

hephy Institut für Hochenergiephysik der Österreichischen Akademie der Wissenschaften

Spares

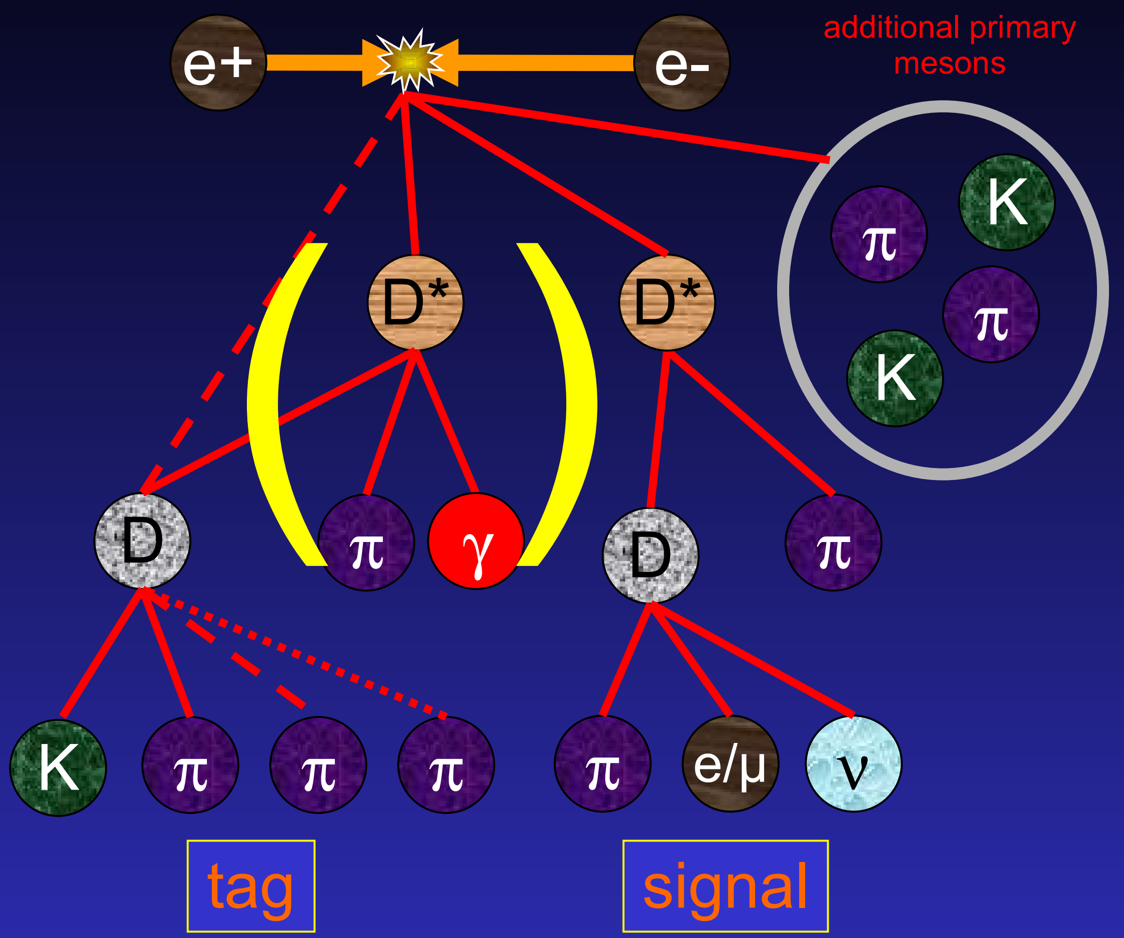
Method of Reconstruction (Event Topology)

tag side:

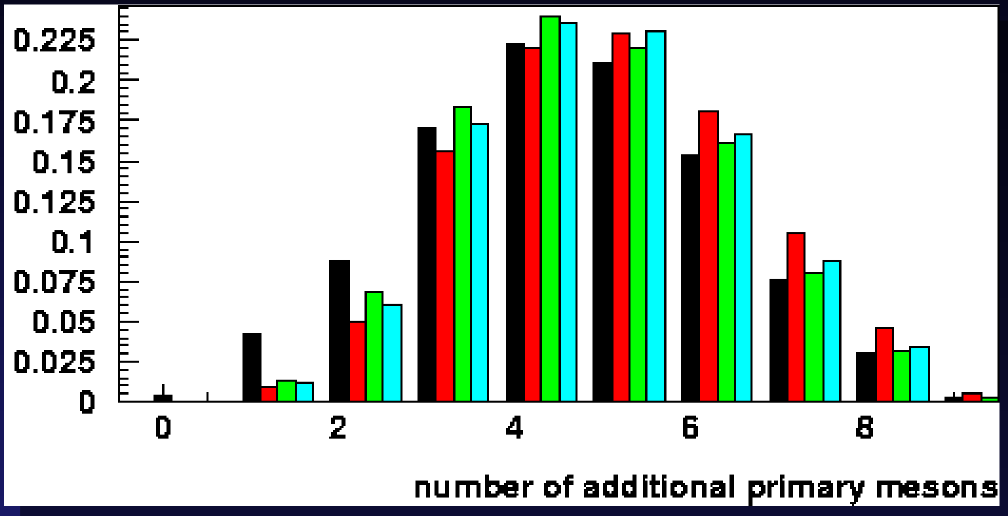
- reconstruction & fit of $D^{0,\pm}$ → Kπ, K2π, K3π
- reconstruction & fit of $D^{*0,\pm}$ → Dπ, Dγ
- use either D or D* as primary meson

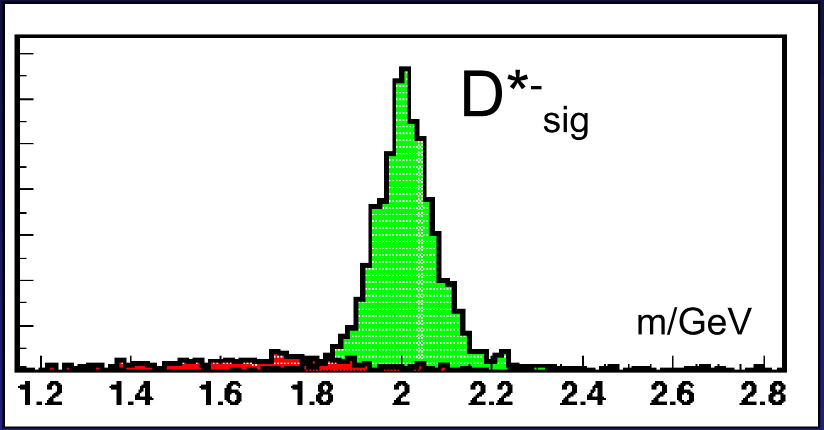
signal side:

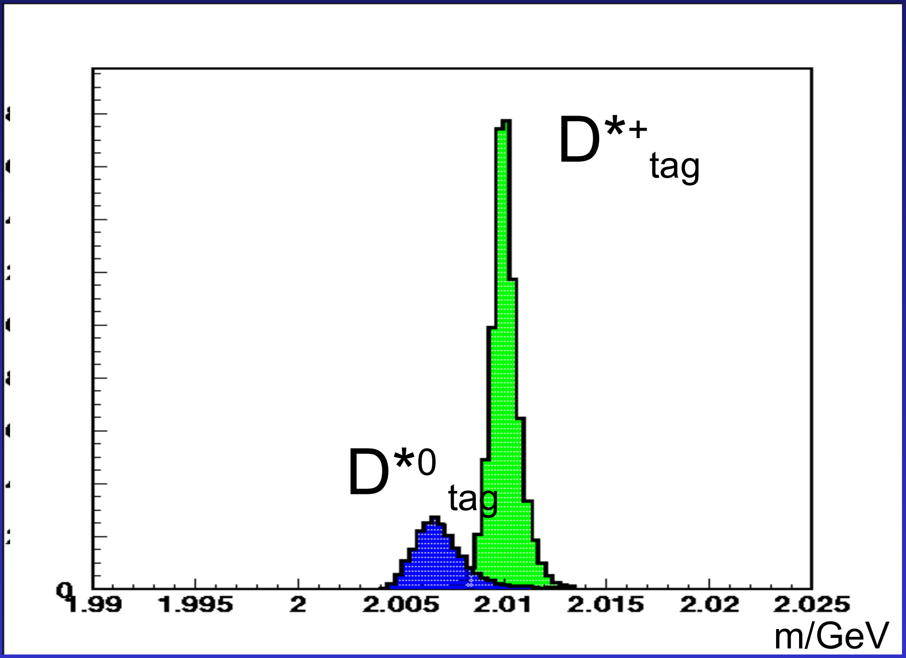
- reconstruction & fit of *inclusive* $D^{*0,\pm}$ via recoil from e+e- → $D^{(*)}$ D*nπ /K
- reconstruction & fit of *inclusive* D^0 via recoil from D* → Dπ
- reconstruction & fit of *neutrino* via recoil from D → mπν

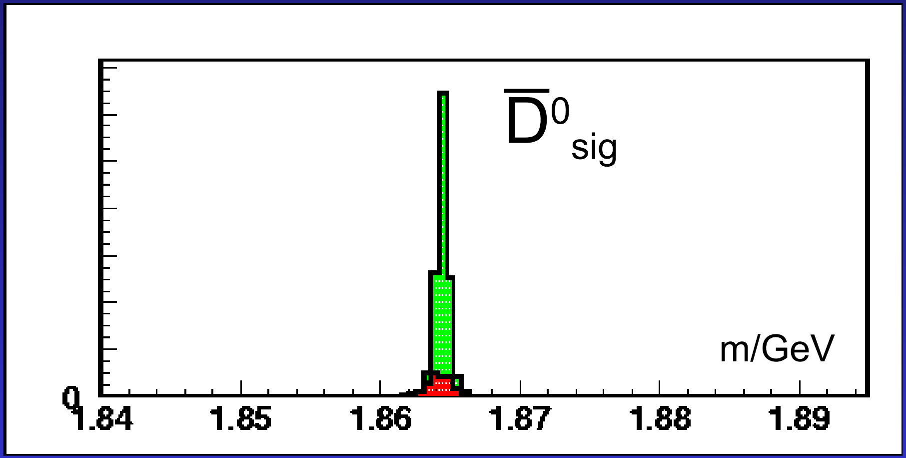


Method of Reconstruction (Event Topology)









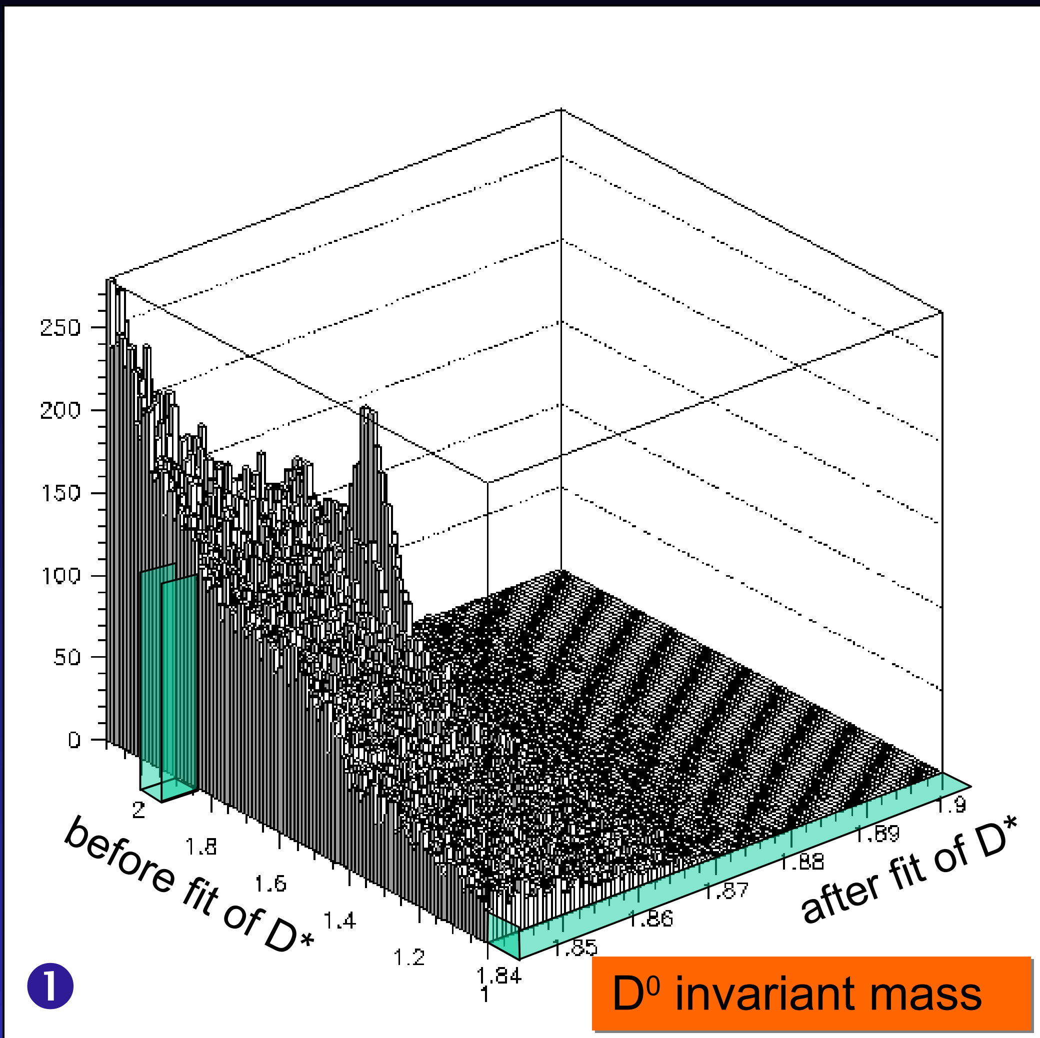
List of Cuts (D^0 selection)

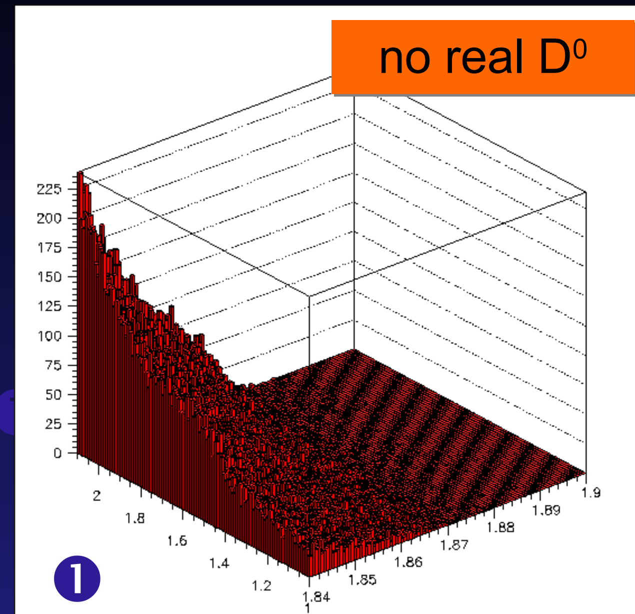
stable particle selection:
- gammas:
  - p > 40 MeV
- charged tracks (general):
  - p > 100 MeV
  - trk_fit.nhits(3) > 0
  - dr < 2 cm, dz < 4 cm
- electron:
  - p > 500 MeV
  - eid.prob(3,-1,5) > 0.9
- muon:
  - p > 500 MeV
  - prerejection != 1
  - Muon_likelihood > 0.9
- kaon / pion:
  - atc_pid (3,1,5,3,2)
  - prob*(1-prob_e-prob_mu) > 0.5
    for meson in hlnu: > 0.9

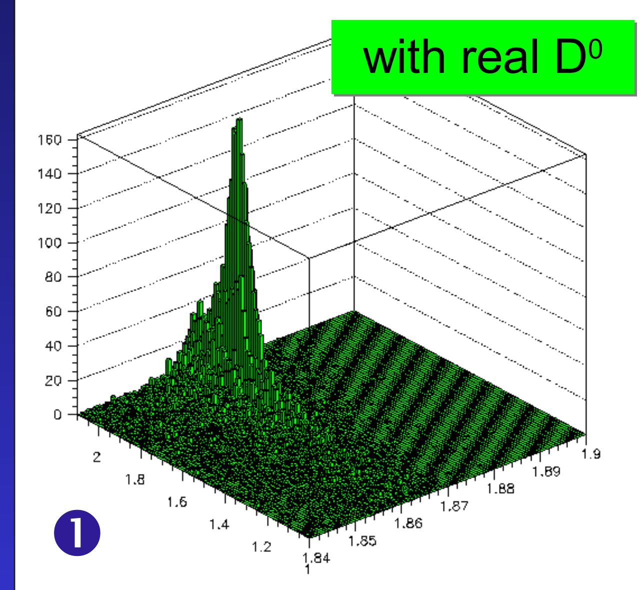
additional cuts for K/π lν
- same charge π_{slow} / lepton
- extra γ energy < 700 MeV, no excess charge
- Eν > 100 MeV

unstable particle selection:
- pi0:
  - PDG mass ± 10 MeV
  - fit CL > 0.1
- K0:
  - only via decay pi+pi-
  - PDG mass ± 25 MeV
- D_tag:
  - channels Knpi, n=1-3
  - PDG mass ± 20 MeV
- D*_tag:
  - channel Dpi, Dγ
  - PDG mass ± 5 MeV
  - mass/vertex fit CL > 0
- D*_signal:
  - via recoil from D*_tag+n pi/K, n=0-5
  - mass/vertex fit CL > 0.001
- D_signal:
  - via recoil from D*_signal → Dpi
  - mass/vertex fit CL > 0.001
- ν:
  - via recoil from D_signal → hlnu
  - $|m^2| < 0.05$ GeV²
  - mass/vertex fit CL > 0

Bias by mass-constrained Fits on Background?





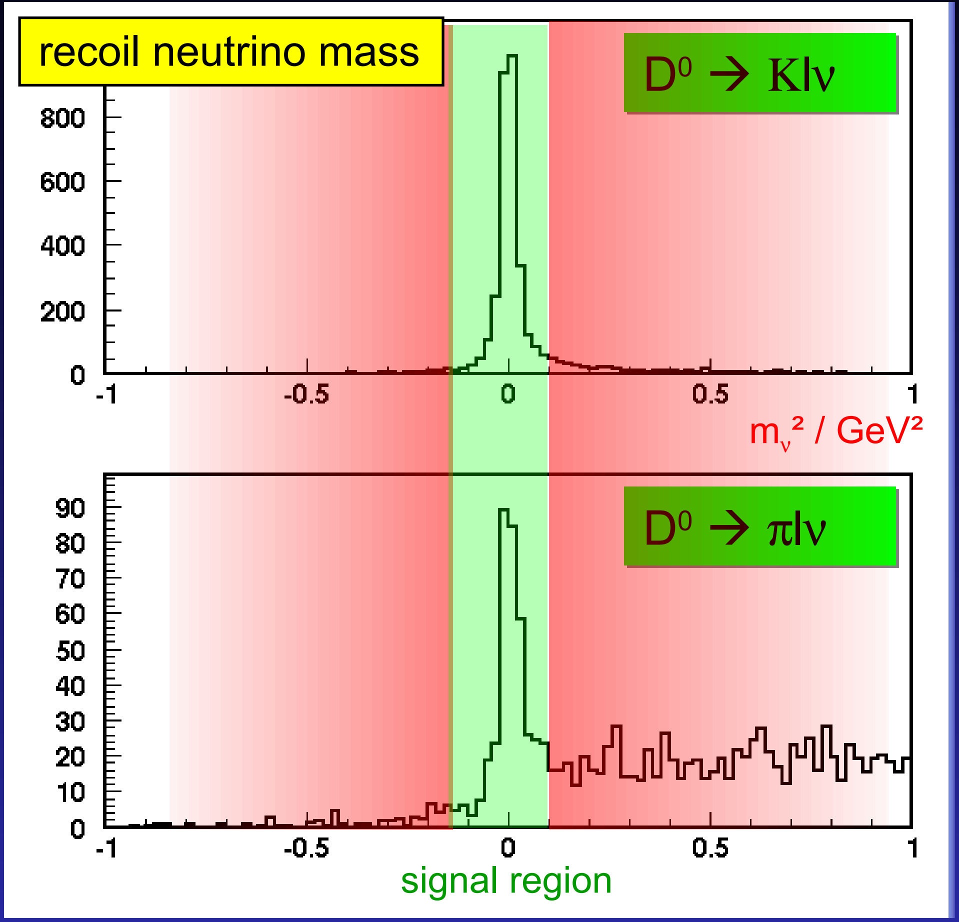


- very sharp mass peak after fit
- no bias on background

$D^0 \rightarrow K/\pi l\nu$ Signal and Background

additional cuts

- same charge π_{slow} / lepton
- extra γ energy < 700 MeV
- no excess charge
- $E\nu$ > 100 MeV



Background sources

3. fake D^0
4. other semileptonic channels
5. hadronic channels

note high resolution $\sigma(m^2_\nu)=0.016\ GeV^2$

$\overline{D}^0$ Signal and Background*

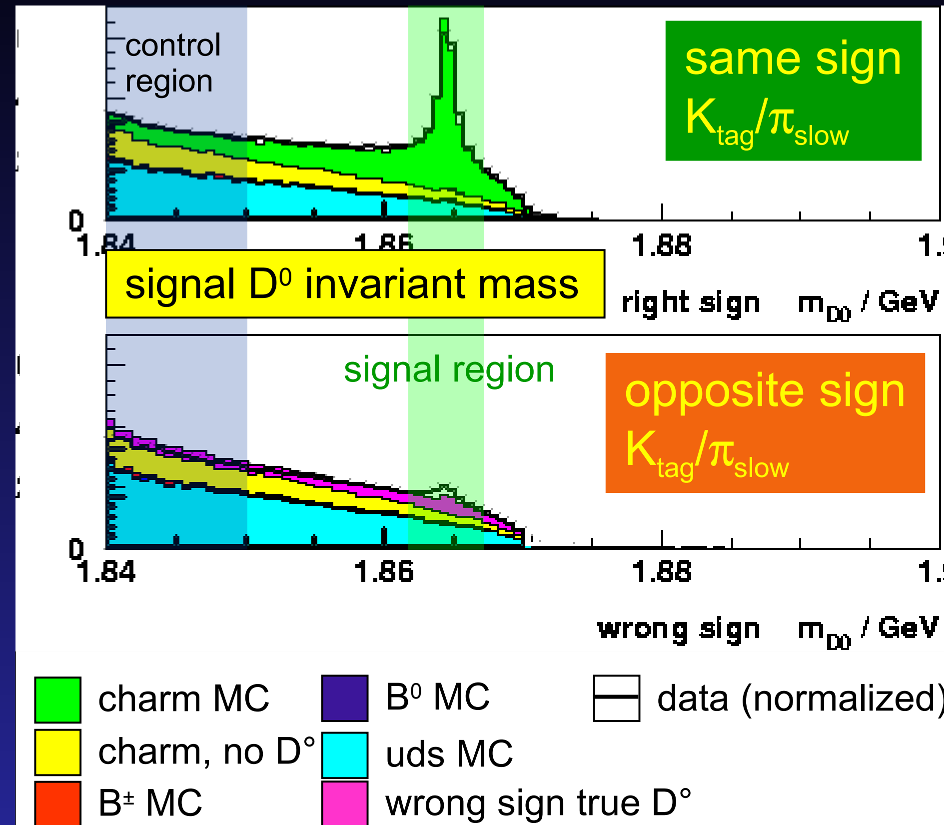
* from decays without a D^0 , or combinatorial background

cuts

- confidence level of all mass-constrained vertex fits >0.1% (released on D^0 fit for righthand plot)
- right charge correlation between slow pion and tag side kaon (right sign, RS)

procedure to measure background:

- select wrong charge correlation data (WS) to get shape of background
- correct for small WS signal component
- normalize to RS data in region 1.84-1.85 GeV



result (282 fb^{-1} of BELLE data)	yield
selected D^0 events	95250
subtracted background	38789
signal	56461 $\pm 309_{stat} \pm 830_{syst}$

systematics breakdown	events
charge correlation RS/WS	776
WS signal subtraction	233
statistics of WS sample	194

Measurement of Semileptonic Background (for πlν)*

procedure to measure background:

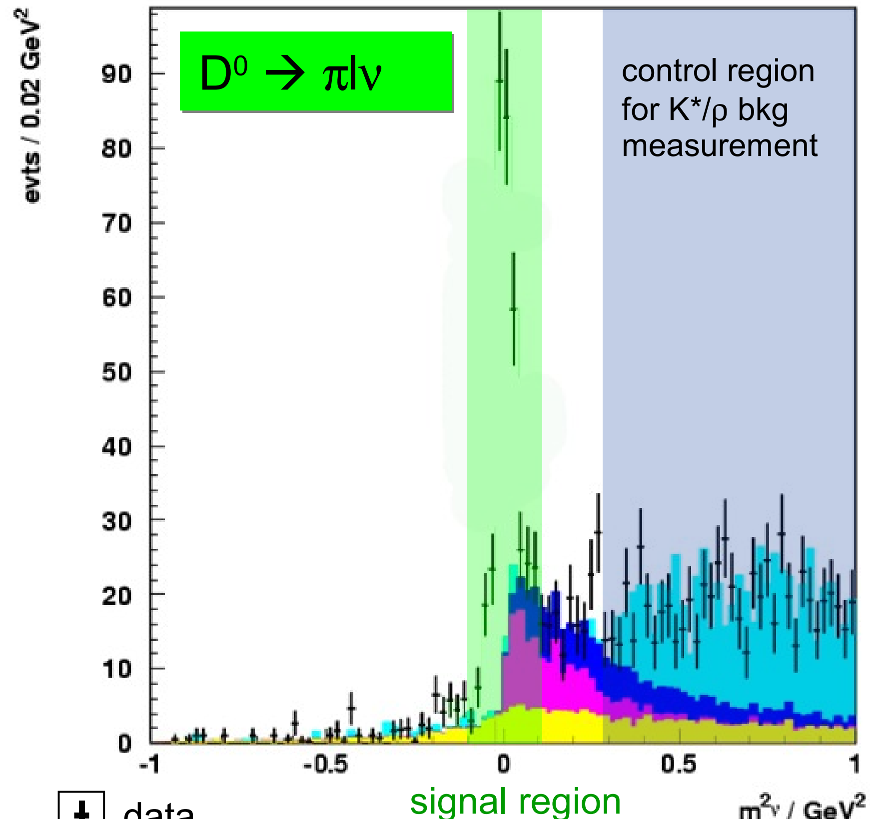
1. crosstalk from Klν:

- prepare special background sample, with K intentionally misidentified as π
- normalize to standard Klν sample
- then reweight the sample using known** efficiencies / fake rates (in p,θ)

2. background from vector mesons:

- get shapes for K*lν and ρlν from MC (simulated ratio K*/ρ from PDG)
- normalize to data in region $m^2_\nu > 0.3\ GeV^2$

recoil neutrino mass



data
non-D° bkg (measured as described previously)
measured bkg from Klν
measured bkg from K*lν
measured bkg from ρlν

* background for Klν is very small, and is handled the same way
** measured independently in data

Measurement of Hadronic Background (for $\pi\mu\nu$)*

procedure to measure background:

- prepare special background samples, with $K(\pi)$ intentionally misidentified as μ

(subtract fake D^0 background in these samples with the method described above)

- separate into same sign (SS) and opposite sign (OS) samples, with respect to the charges of the lepton and the slow pion
- semileptonic channels are highly suppressed in OS → clean sample of hadronic background
- perform a 2-parameter fit in the standard OS sample, using the shapes from the OS background samples for K and π, to measure the effective fake rates
- then apply these fake rates in the background SS sample to obtain the backgrounds in the signal sample

same sign SS

signal: $D^* \to D^0\pi^+$, $\hookrightarrow \pi^-\mu^+\nu$

$D^* \to D^0\pi^+$, $\hookrightarrow K^-\pi^+\pi^0/K^0$ → $\pi^-\mu^+\ \nu$

SS both signs OS

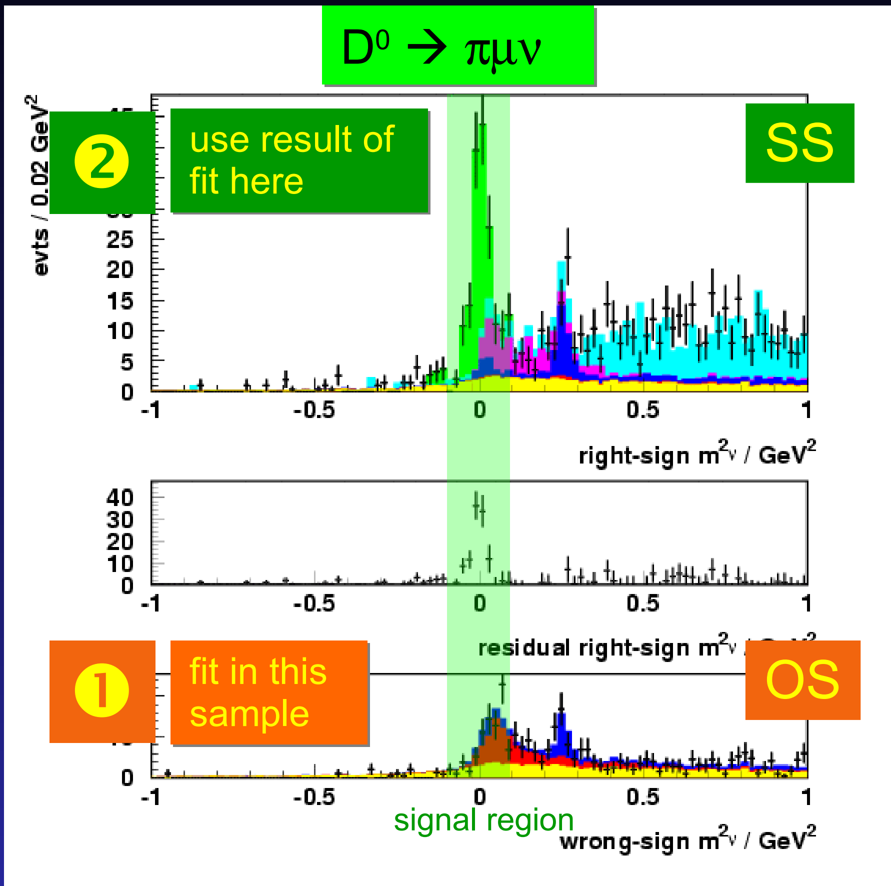
$D^* \to D^0\pi^+$, $\hookrightarrow \pi^-\pi^+\pi^0/K^0$ → $\pi^-\mu^\pm\ \nu$

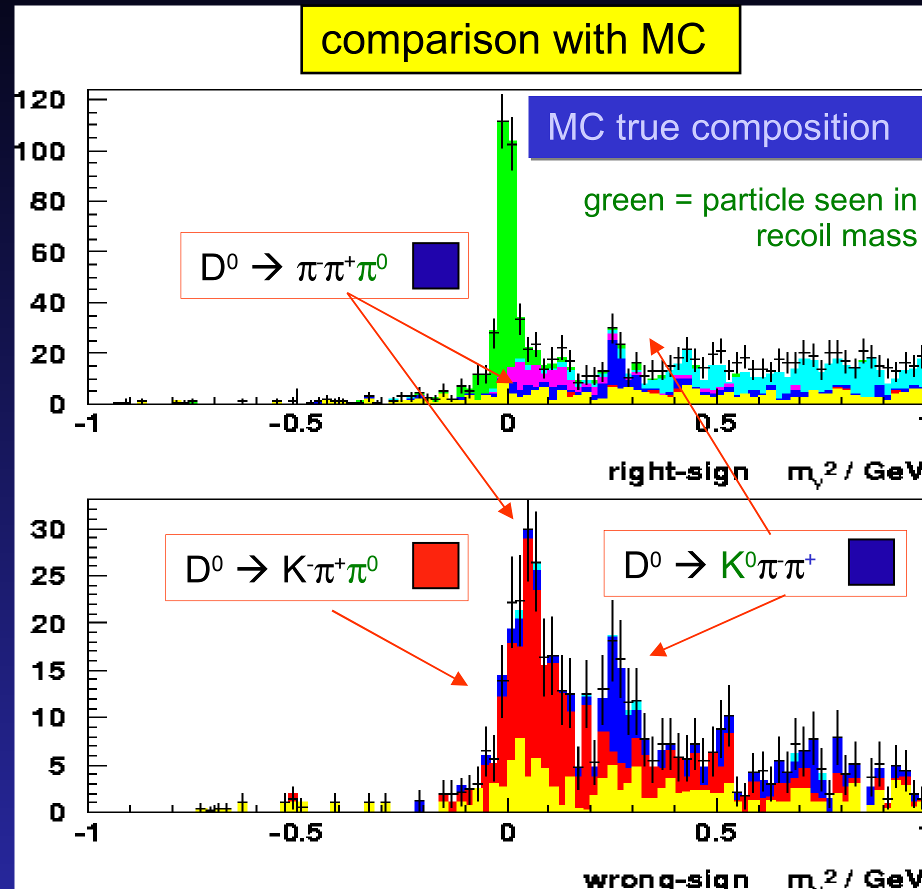
opposite sign OS

$D^* \to D^0\pi^+$, $\hookrightarrow K^-\pi^+\pi^0$ → $\pi^+\mu^-\nu$

* significant background only for this channel; other channels are handled likewise

Fit of Hadronic Background (for πμν)*

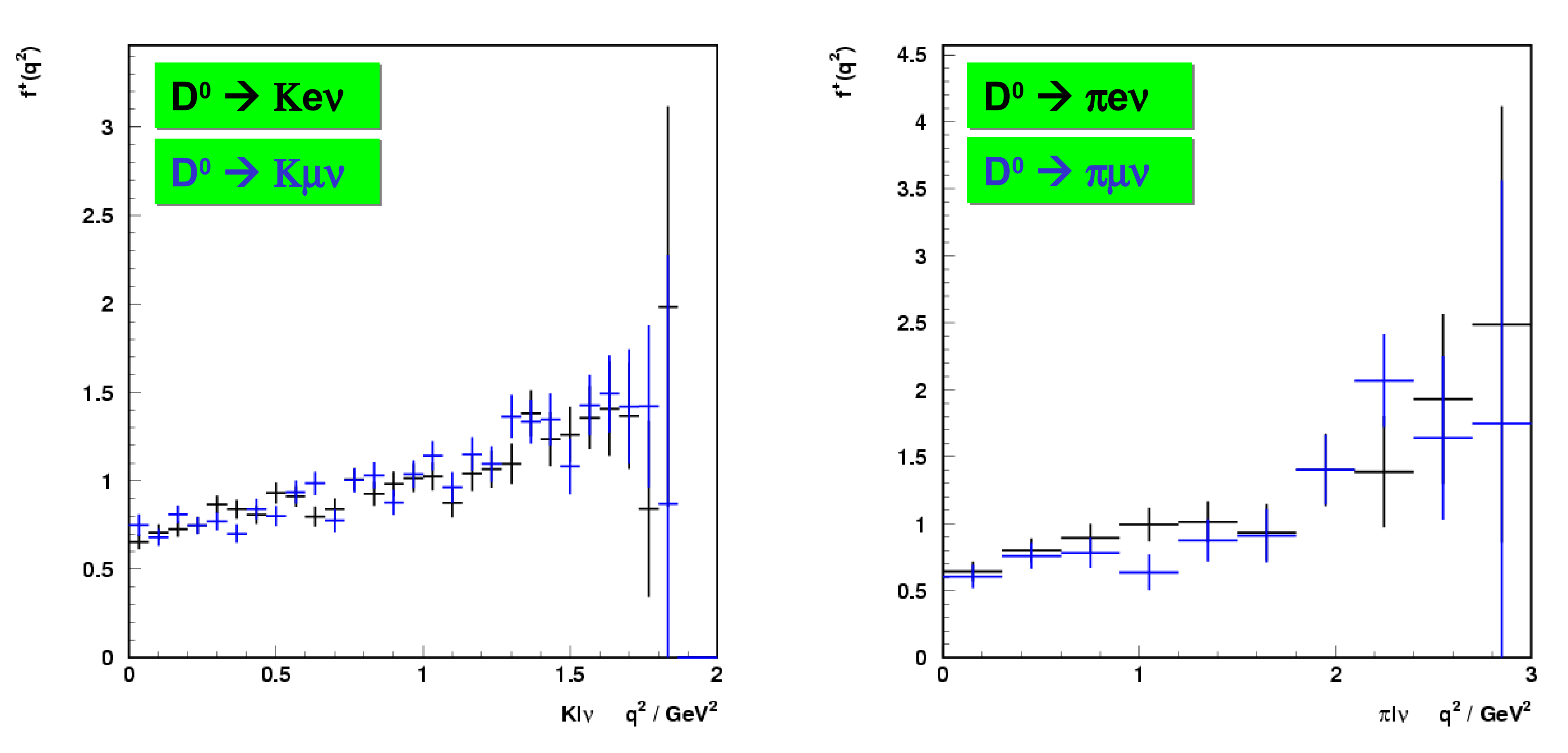




- bkg from misidentified kaons
- bkg from misidentified pions
- fake-D0 bkg
- bkg from Kμν
- bkg from K*/ρμν
- remaining events in signal region

* background for πeν and Klν are much smaller

Measured Absolute Form Factors as function of q²



- extracted by dividing q² distribution by kinematical factor
- no unfolding necessary due to very good q² resolution

Form Factors - Theory

in principle, two form factors $f^+(q^2)$ and $f^-(q^2)$

$$\frac{d\,\Gamma(D \to P\ell^+\nu_\ell)}{d\,q^2} = \frac{G_F^2\,|V_{CKM}|^2}{384\,\pi^3\,m_D^3}\,\frac{\sqrt{\lambda(q^2,m_D^2,m_P^2)}}{q^6}\,(q^2-m_\ell^2)^2\;\cdot$$
$$\Big\{|f_+(q^2)|^2\left[(2q^2+m_\ell^2)\,\lambda(q^2,m_D^2,m_P^2)\,+\,3\,m_\ell^2\,(m_D^2-m_P^2)^2\right]$$
$$+\,3\,q^2\,m_\ell^2\left[2\,Re(f_+(q^2)f_-^*(q^2))\,(m_D^2-m_P^2)\,+\,|f_-(q^2)|^2\,q^2\right]\Big\}$$

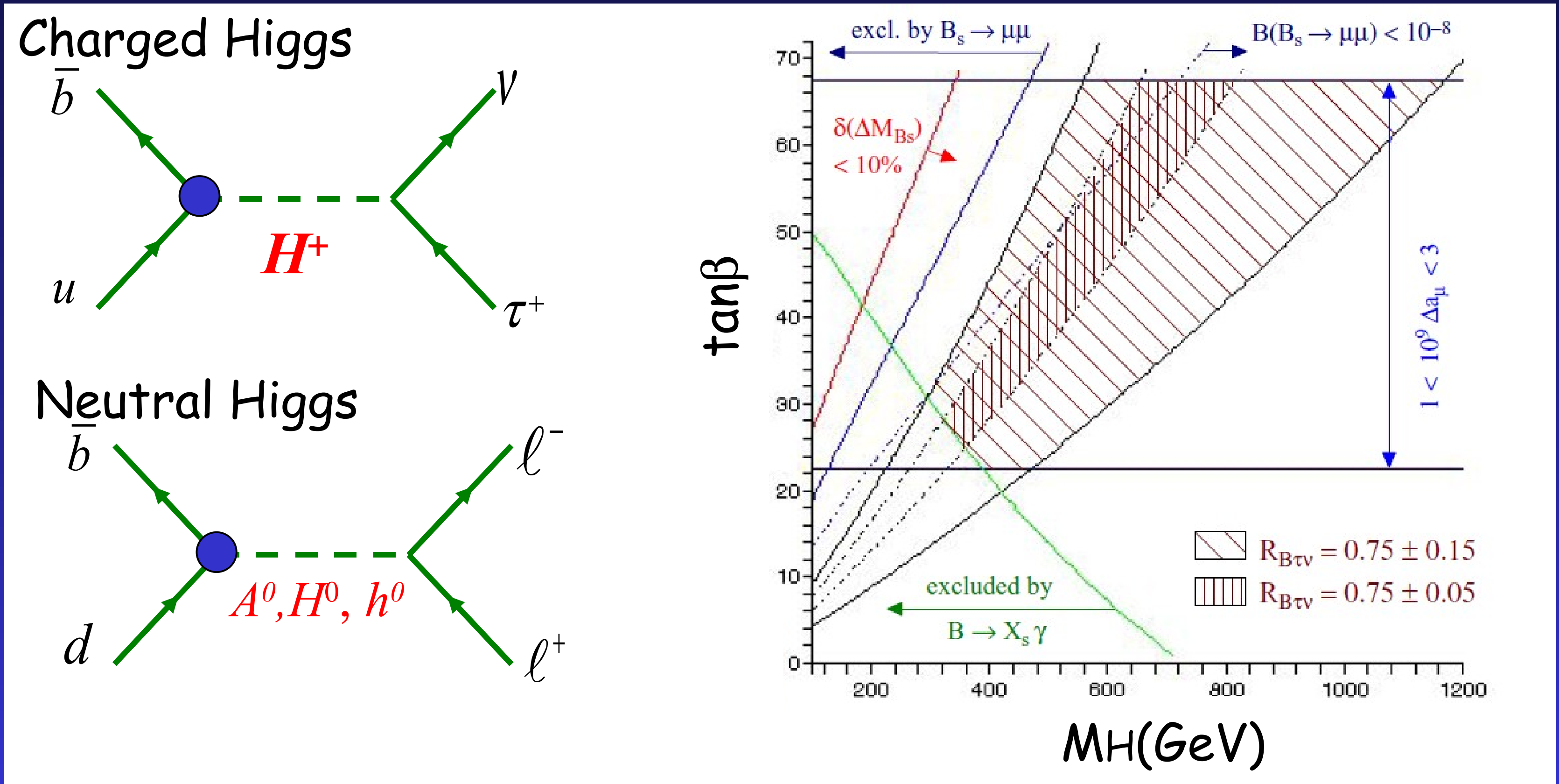
- kinematically only $f^+(q^2)$ relevant, $f^-(q^2)$ suppressed by m_l^2
- three different models that are frequently discussed in literature:

simple pole modified pole	$f_+(q^2) = \frac{\Omega}{1-q^2/m^2}$	$\Omega \equiv f_+(0)$ m......pole mass $= m\,D^*_s \approx 2.11$ GeV ($Kl\nu$) $= m\,D^* \approx 2.01$ GeV ($\pi l\nu$)
G. Armoros, S. Noguera, J. Portoles, Eur. Ph. J. C27, 243 (2003)	$f_+(q^2) = \frac{\Omega}{(1-q^2/m^2)\,(1-\alpha q^2/m^2)}$	$\alpha_{theor.} \approx 0.50$ ($Kl\nu$) ≈ 0.44 ($\pi l\nu$)
ISGW2 *N. Isgur and D. Scora, Phys. Lett. B 592 1(2004)*	$f_+(q^2) = \frac{\Omega}{(1-\alpha(q^2-q^2_{max}))^2}$	

New Physics in large tanβ

- Leptonic decays (B→lν, ll) are theoretically clean, free from hadronic uncertainty.
- In particular, they are good probes in large tanβ region, together with other measurements; Δm_{Bs}, $B_s \to \mu\mu$, $B \to X_s\gamma$ and also τ decays (τ→μη, τ→μγ).

Ex.) G.Isidori & P.Paradisi, hep-ph/0605012



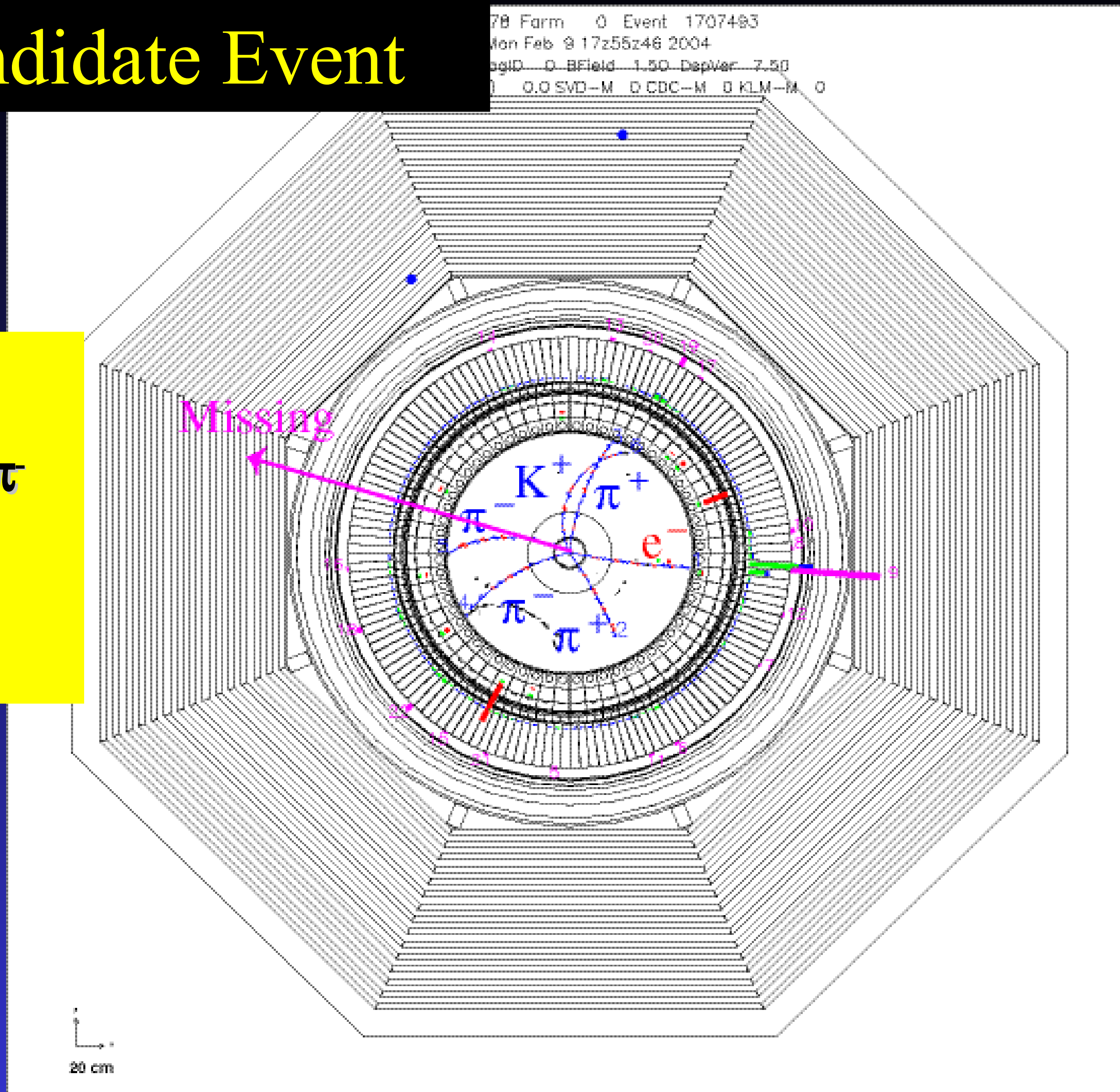
B→τν Candidate Event

$B^+ \rightarrow \overline{D}^0 \pi^+$

└→ $K^+ \pi^- \pi^+ \pi^-$

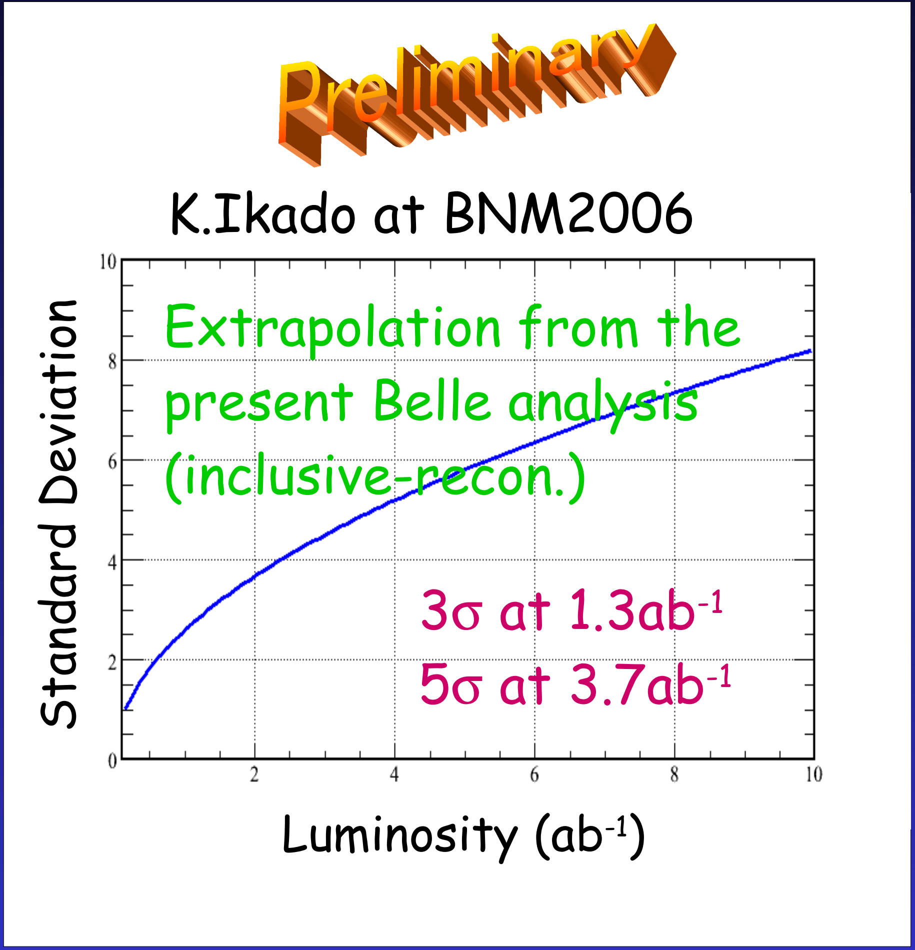
$B^- \rightarrow \tau^- \nu$

└→ $e^- \nu \nu$



Future Prospect: B→μν

- B→μν is the next milestone decay mode.
- Measurements will offer a cross check to the results obtained by B→τ ν.
  - $f_B|V_{ub}|$ determination.
  - Test the lepton universality.



- Method?
  - Inclusive-recon method has high efficiency but poor S/N.

    $\text{limit} \propto 1/\sqrt{L}$

  - Hadronic tag will provide very clean and ambiguous signals, but very low efficiency.

    $\text{limit} \propto 1/L$