Rare decays at Belle

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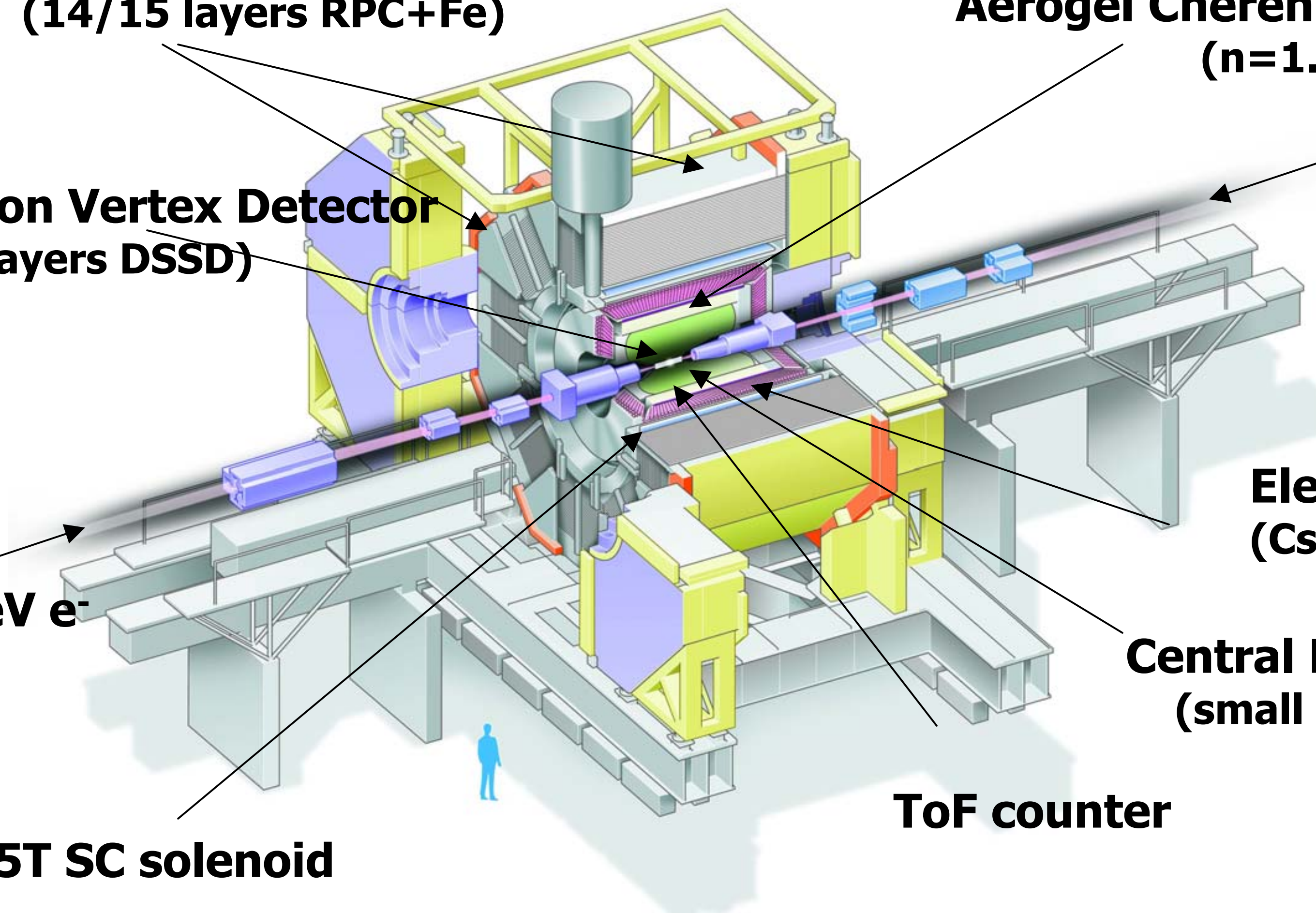
Belle @ KEK-B in Tsukuba

Belle spectrometer at KEK-B



Accumulated data sample >600 M BB-pairs

Contents

FCNC b→s decays

- b→sγ : CP violation
- Measurement of A_{fb} vs q^2 in B → $K^* l^+ l^-$ decays

Decays with >1 neutrino

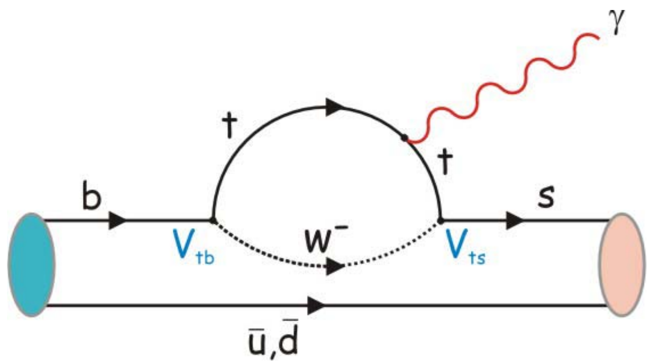
- Purely leptonic decay: $B^- \to \tau^- \nu_\tau$
- $B \to K^{(*)} \nu \nu$

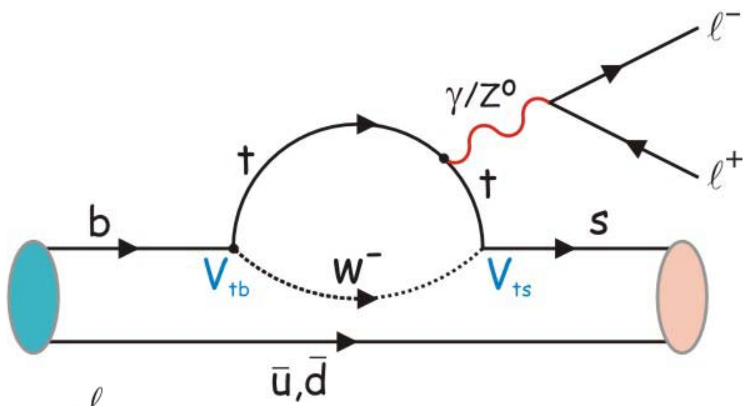
Upgrade plans

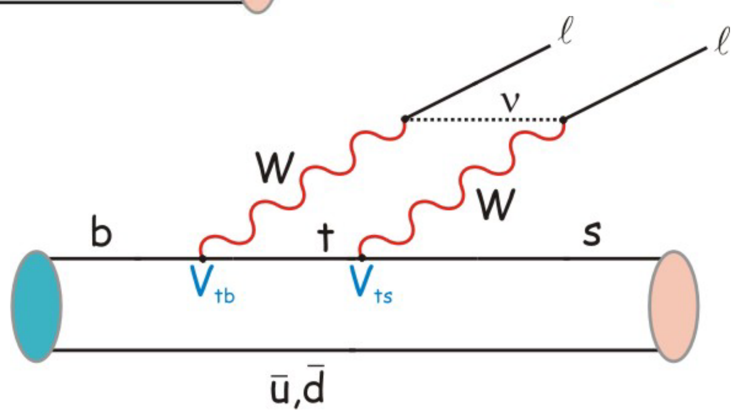
- PID in the forward region

Why FCNC decays?

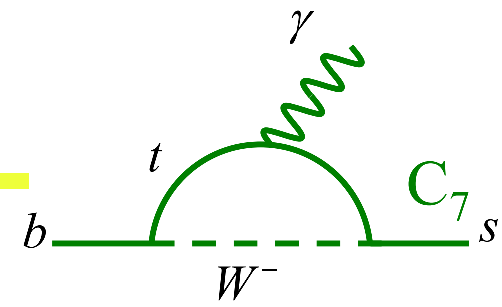
Flavour changing neutral current (FCNC) processes (like b→s, b→d) are fobidden at the tree level in the Standard Model. Proceed only at low rate via higher-order loop diagrams. Ideal place to search for new physics.





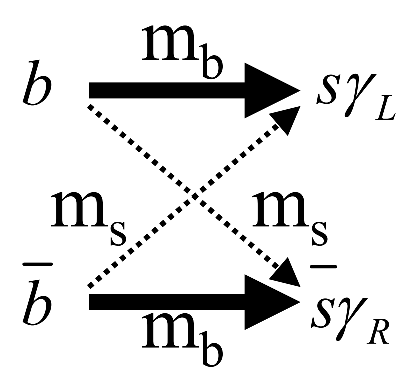


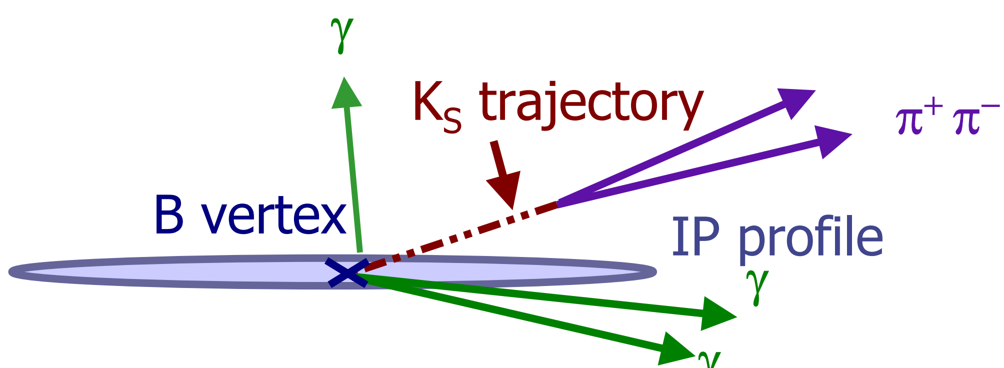
$B \to X_s\gamma$ CP Asymmetry



- Sensitive to NP – right handed currents
- Theoretically clean.
- Standard Model "~Zero".
  - γ is polarized, and the final state is almost flavor specific.
  - Helicity flip of γ suppressed by $\sim m_s/m_b \to S \sim 0.02$
  - QCD corrections → S remains small

  (Grinstein, Pirjol, PRD 73 014013; Matsumori, Sanda, PRD 73 014013)





$\sigma_x = 100\mu m, \sigma_y = 5\mu m, \sigma_z = 3mm,$

- Time dependent CPV requires vertex reconstruction with $K_S \to \pi^+\pi^-$

Vertex recon. eff. at Belle
51% (SVD2), 40% (SVD1)

$B^0 \rightarrow K_S\pi^0\gamma$ time dependent CPV

Atwood, Gershon, Hazumi, Soni, PRD71, 076003 (2005)

$M(K_S\pi^0) < 1.8\text{GeV}/c^2$

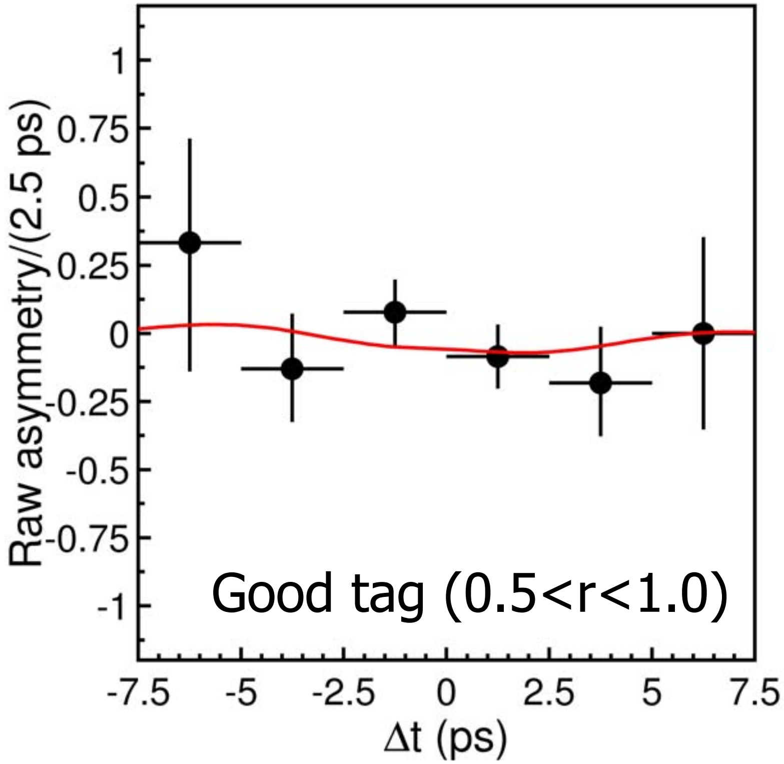
– NP effect is independent of the resonance structure.

Belle: data sample 535MBB

- Three $M(K_S\pi^0)$ regions(MR1:0.8-1.0GeV/c2, MR2:1.3-1.55, MR3: rest with $M<1.8\text{GeV}/c^2$)
- 112.5+-12.0, 28.7+-7.1, 35.2+-10.0 events in MR1,2,3.

All events:

$S= -0.10 \pm 0.31 \pm 0.07$
$A= -0.20 \pm 0.20 \pm 0.06$



$B^0 \to K_S \pi^0 \gamma$ time dependent CPV

Results:

Belle (275M BB) hep-ex/0507059

$S(B \to K^*\gamma, K^* \to K_S\pi^0) = -0.01 \pm 0.52 \pm 0.11$

$S(B \to K_S\pi^0\gamma) = 0.08 \pm 0.41 \pm 0.10$

BaBar (232M BB) PRD 71 (2005) 0501103

$S(B \to K^*\gamma, K^* \to K_S\pi^0) = -0.21 \pm 0.40 \pm 0.05$

Belle (535M BB) hep-ex/0600818

$S(B \to K^*\gamma, K^* \to K_S\pi^0) = -0.32 +0.36 -0.33 \pm 0.05$

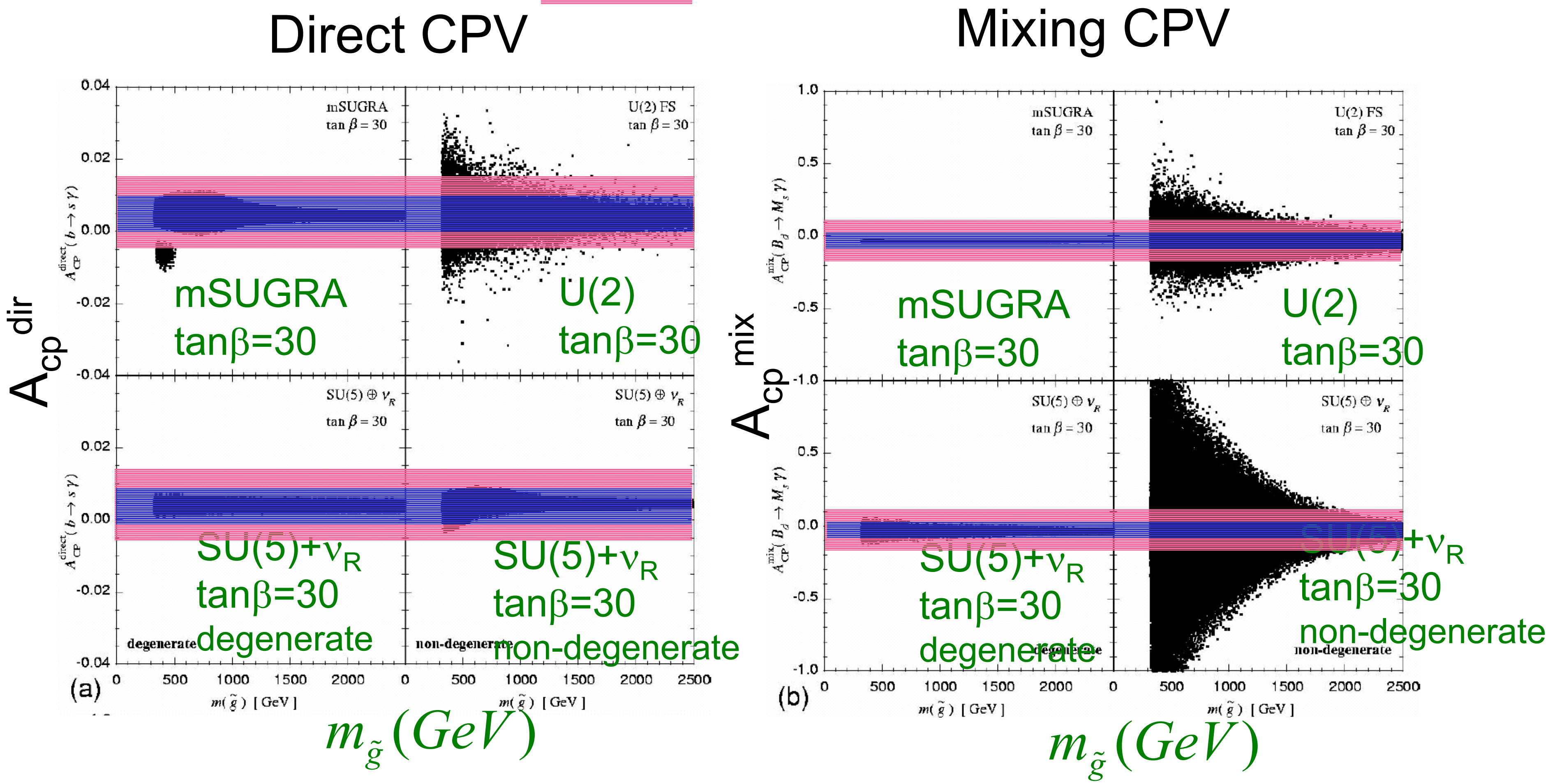
$S(B \to K_S\pi^0\gamma) = -0.10 \pm 0.31 \pm 0.07$

Prospects:	$5 ab^{-1}$	$50 ab^{-1}$
$A_{cp}^{mix}(B \to K^*\gamma, K^* \to K_S\pi^0)$	0.14	0.04
$A_{cp}^{dir}(B \to X_s\gamma)$	0.011	0.005

Add more modes: $B \to K_S\phi\gamma$ (with angular analysis), higher K resonances, $B \to K_S\eta\gamma$ (recent observation by BaBar),...

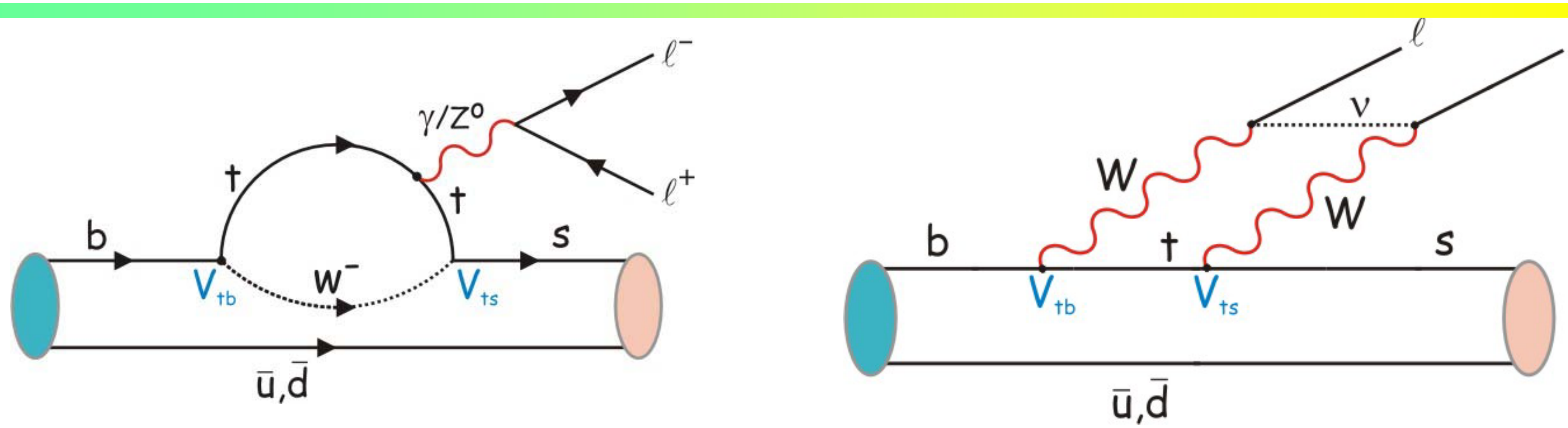
$A_{cp}(B \rightarrow X_s\gamma)$ vs SUSY models

5ab^{-1} 50ab^{-1}



T. Goto, Y.Okada, Y.Shimizu,T.Shindou, M.Tanaka
hep-ph/0306093, also in SuperKEKB LoI

$B \to K^* l^+ l^-$



Important for further searches for the physics beyond SM

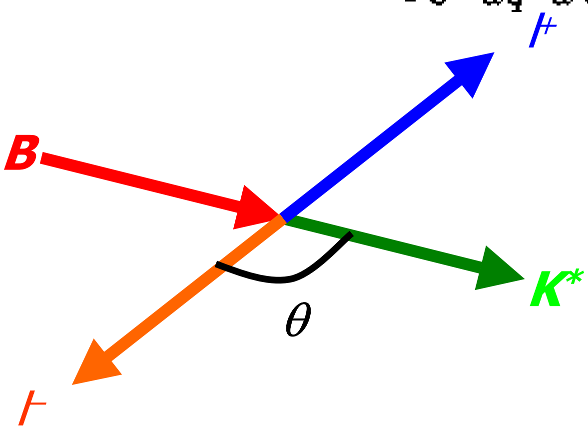
$$\frac{d\Gamma\left(b \to s\ell^+\ell^-\right)}{d\hat{s}} = \left(\frac{\alpha_{em}}{4\pi}\right)^2 \frac{G_F^2 m_b^5 \left|V_{ts}^* V_{tb}\right|^2}{48\pi^3} \left(1-\hat{s}\right)^2$$

$$\times\left[\left(1+2\hat{s}\right)\left(\left|C_9^{\text{eff}}\right|^2+\left|C_{10}^{\text{eff}}\right|^2\right)+4\left(1+\frac{2}{\hat{s}}\right)\left|C_7^{\text{eff}}\right|^2+12\,\text{Re}\left(C_7^{\text{eff}} C_9^{\text{eff}*}\right)\right]$$

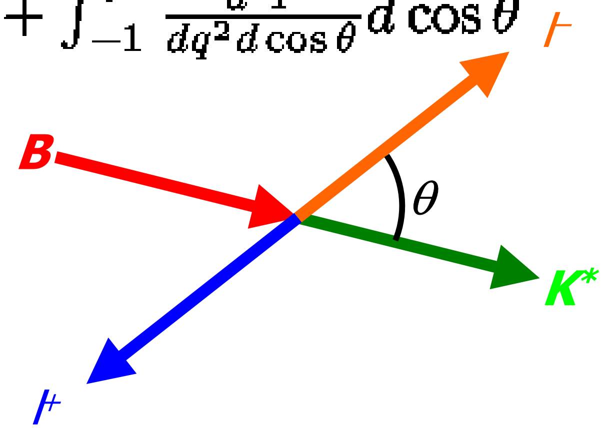
C_i: Wilson coefficients

Particularly sensitive:
forward-backward asymmetry in $K^* \, l^+l$

$$A_{\rm FB}(q^2) = \frac{\int_0^1 \frac{d^2\Gamma}{dq^2\, d\cos\theta} d\cos\theta - \int_{-1}^0 \frac{d^2\Gamma}{dq^2\, d\cos\theta} d\cos\theta}{\int_0^1 \frac{d^2\Gamma}{dq^2\, d\cos\theta} d\cos\theta + \int_{-1}^0 \frac{d^2\Gamma}{dq^2\, d\cos\theta} d\cos\theta}.$$



Backward event



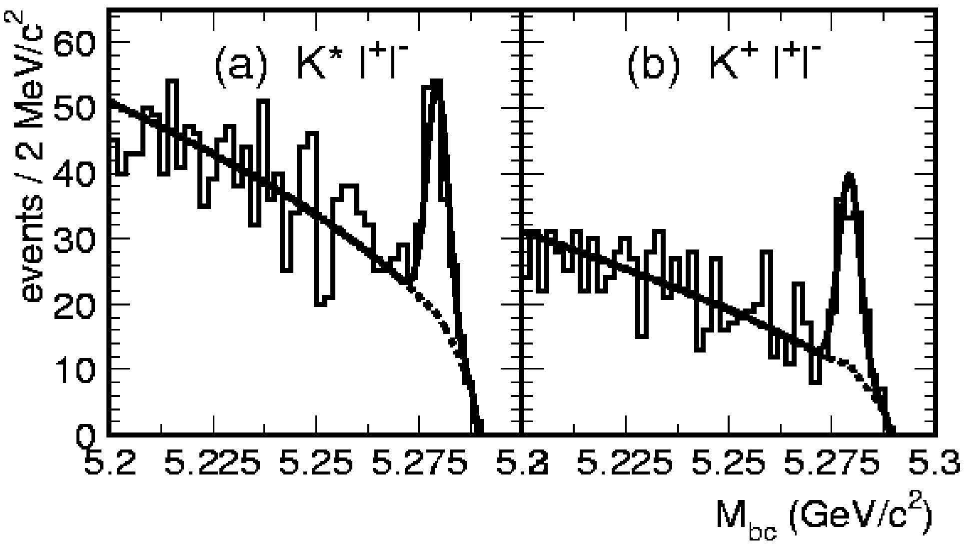
Forward event

[γ* and Z* contributions in B→K* l l interfere and give rise to forward-backward asymmetries c.f. $e^+e^- \rightarrow \mu^+ \mu^-$]

$$A_{FB}(K^* l^+ l^-) \propto C_{10}\xi(q^2)\left[\mathrm{Re}\left(C_9\right)F_1 + \frac{1}{q^2}C_7 F_2\right]$$

Sample used for $A_{FB}(B \to K^* ll)(q^2)$

PRL 96, 251801 (2006)



$$
\begin{aligned}
&P(q^2, \cos\theta; A_9/A_7, A_{10}/A_7) \\
&= f_{\rm sig}\epsilon_{\rm sig}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,\cos\theta)/N_{\rm sig} \\
&+ f_{\rm cfcf}\epsilon_{\rm cfcf}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,\cos\theta)/N_{\rm cfcf} \\
&+ f_{\rm ifcf}\epsilon_{\rm ifcf}(q^2,\cos\theta)\frac{d^2\Gamma}{dq^2 d\cos\theta}(q^2,-\cos\theta)/N_{\rm ifcf} \\
&+ f_{X_s\ell\ell}\mathcal{P}_{X_s\ell\ell}(q^2,\cos\theta) \\
&+ f_{\rm dilep}\Big\{(1-f_{K^*\ell h})\mathcal{P}_{\rm dilep}(q^2,\cos\theta) \\
&\quad +f_{K^*\ell h}\mathcal{P}_{K^*\ell h}(q^2,\cos\theta)\Big\} \\
&+ f_{K^*hh}\mathcal{P}_{K^*hh}(q^2,\cos\theta) + f_\psi\mathcal{P}_\psi(q^2,\cos\theta), \qquad (
\end{aligned}
$$

Sample for $B \to K^*\, l\, l$:
113±13 events

Treat q^2, $\cos(\theta)$ dependence of bkgs.

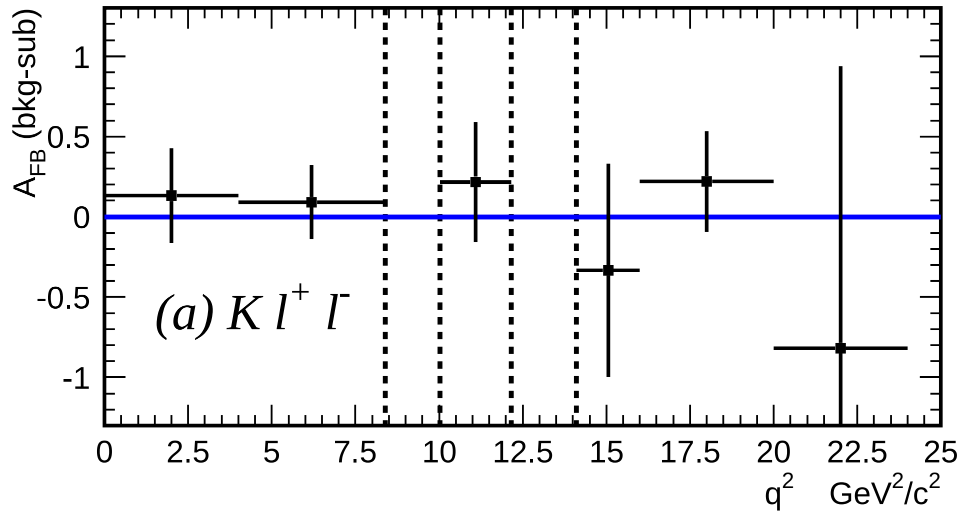
Unbinned fit to the variables q^2 (di-lepton invariant mass) and $\cos(\theta)$ for the $B \to K^*\, l\, l$ data.

Fit parameters A_9/A_7 and A_{10}/A_7 (A_i = leading term in C_i)

Control sample B→Kll

B→K l l control sample:
96±12 events

Consistent with 0

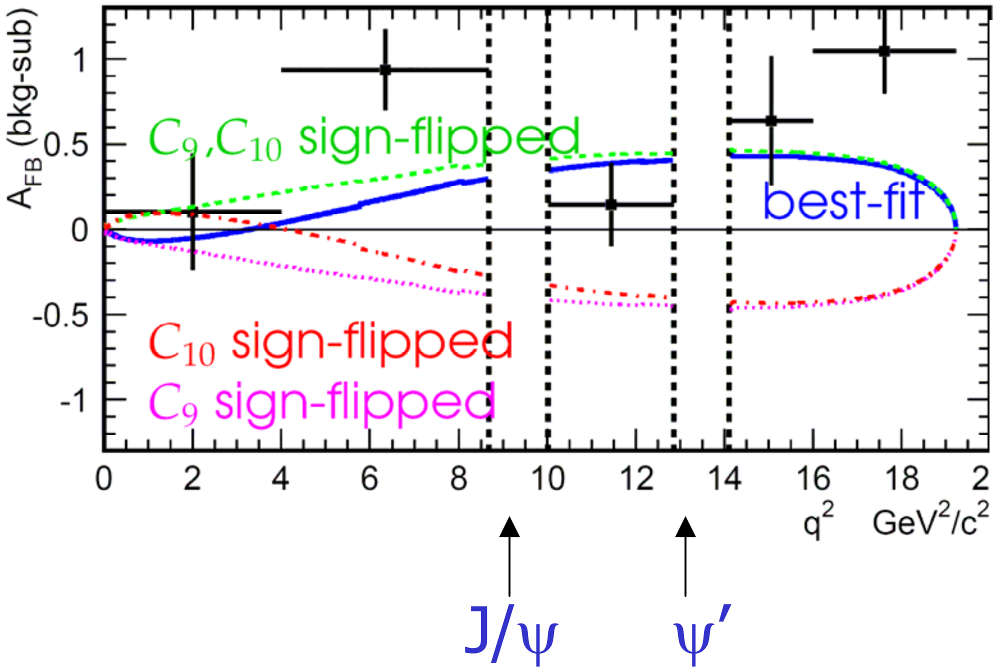


Integrated asymmetry:

$$A_{FB}(B \to K^+ l^- l^+) =$$
$$0.10 \pm 0.14 \pm 0.01$$

Constraints on Wilson coefficients from $A_{FB}(B \to K^* l l)(q^2)$

Projections of the full fit to q^2, $\cos(\theta)$



Integrated FB asymmetry

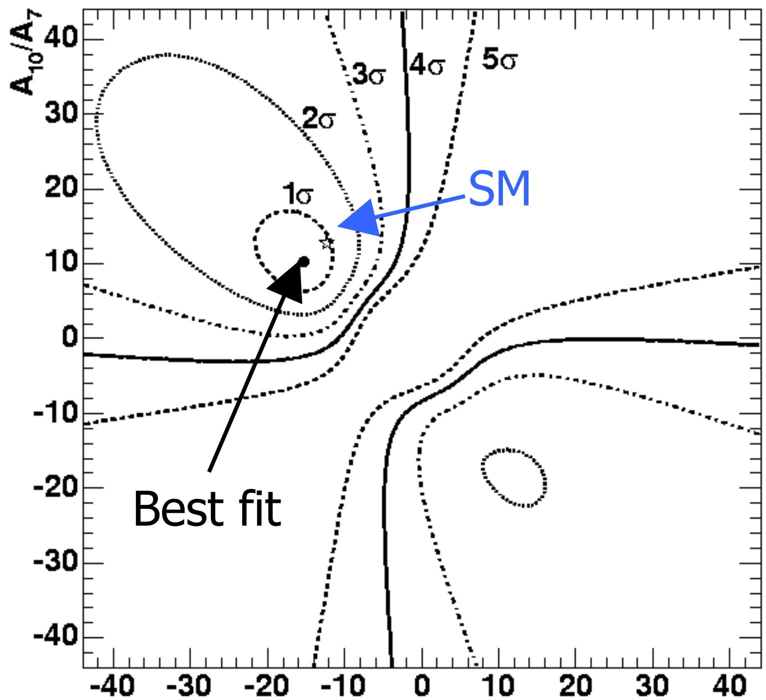
$$A_{FB}(B \to K^* l^- l^+) = 0.50 \pm 0.12 \pm 0.02; (3.4\sigma)$$

BaBar: A_{FB} >0.55 (@ 95% CL)

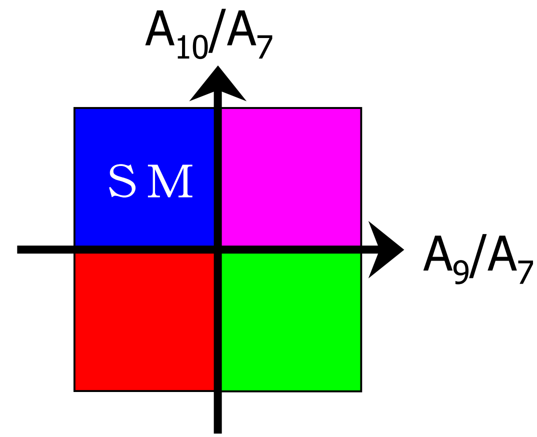
Observed integrated A_{FB} rules out some radical New Physics Models with incorrect signs/magnitudes of C_9 and C_{10} (red and pink curves)

Results of the unbinned fit to q^2 and cos(θ) distributions for ratios of Wilson coefficients

A_{10}/A_7



A_9/A_7



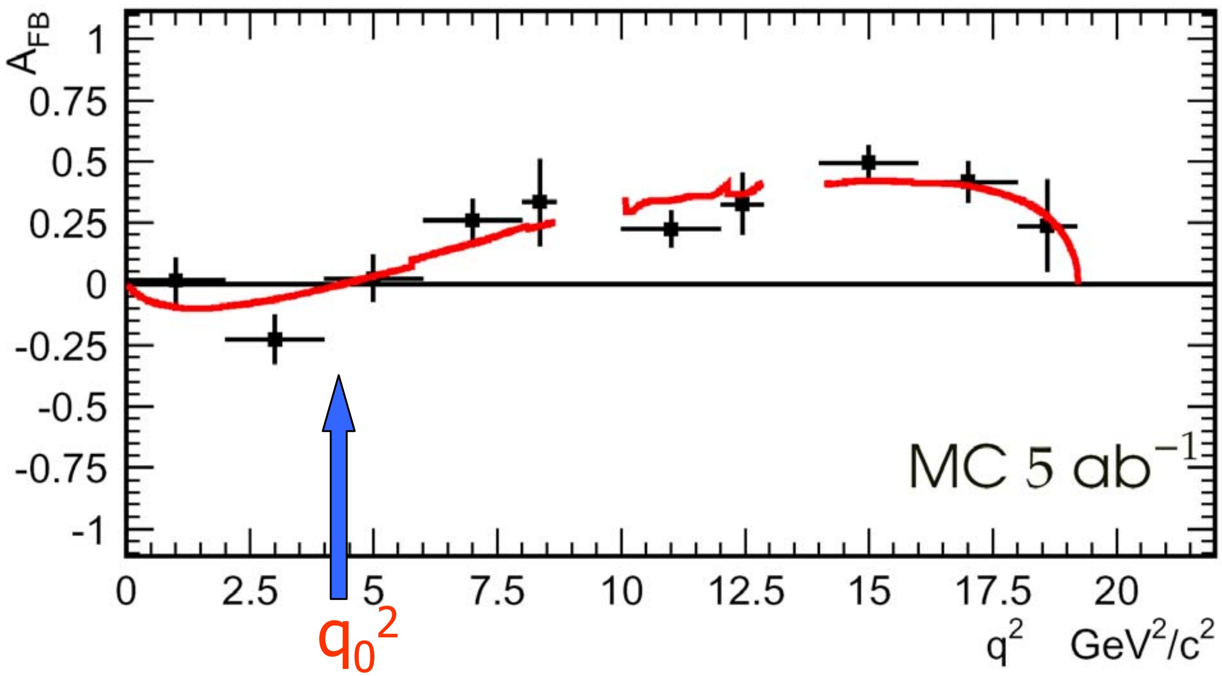
$|A_7|$ constrained from b→s γ to be close to SM

	negative A_7	positive A_7
A_9/A_7	$-15.3^{+3.4}_{-4.8} \pm 1.1$	$-16.3^{+3.7}_{-5.7} \pm 1.4$
A_{10}/A_7	$10.3^{+5.2}_{-3.5} \pm 1.8$	$11.1^{+6.0}_{-3.9} \pm 2.4$

$$-1401 < A_9 A_{10}/A_7^2 < -26.4.$$

at 95% C.L.

$A_{FB}(B \rightarrow K^* l^+ l^-)[q^2]$ at Super B Factory



Precision with $5ab^{-1}$

δC_9 ~ 11%

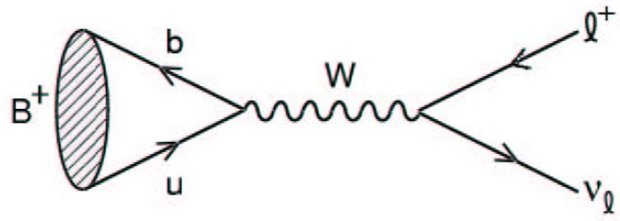
δC_{10} ~14%

$\delta q_0^2/q_0^2$ ~11%

- A_{FB} zero-crossing q_0^2 will be determined with 5% error with $50ab^{-1}$

Purely leptonic decay B→τ ν

- Challenge: B decay with at least two neutrinos
- Proceed via W annihilation in the SM.



- Branching fraction

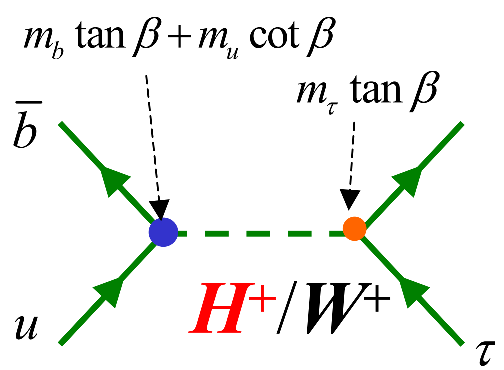
$$\mathcal{B}(B^- \to \ell^- \bar{\nu}) = \frac{G_F^2 m_B m_\ell^2}{8\pi}\left(1 - \frac{m_\ell^2}{m_B^2}\right)^2 f_B^2 |V_{ub}|^2 \tau_B$$

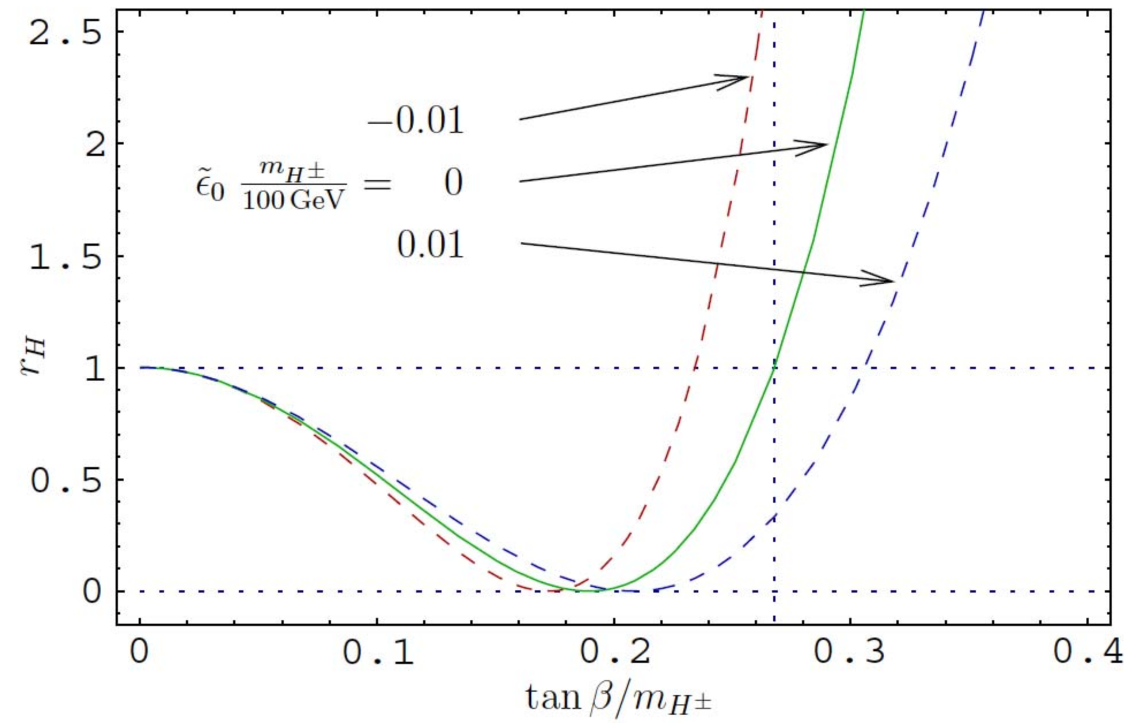
- Provide information of $f_B|V_{ub}|$
  - $|V_{ub}|$ from $B \to X_u l \nu$ → f_B ⇔ cf) Lattice
  - $Br(B \to \tau\nu)/\Delta m_d$ → $|V_{ub}| / |V_{td}|$

- Expected branching fraction

$|V_{ub}| = (4.39 \pm 0.33)\times10^{-3}$ (HFAG)
$f_B = (216 \pm 22)$ MeV (lattice)
} $BF(B \to \tau \nu_\tau) = (1.59 \pm 0.40)\times10^{-4}$

Charged Higgs contribution to B→τ ν





$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H,$$

$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

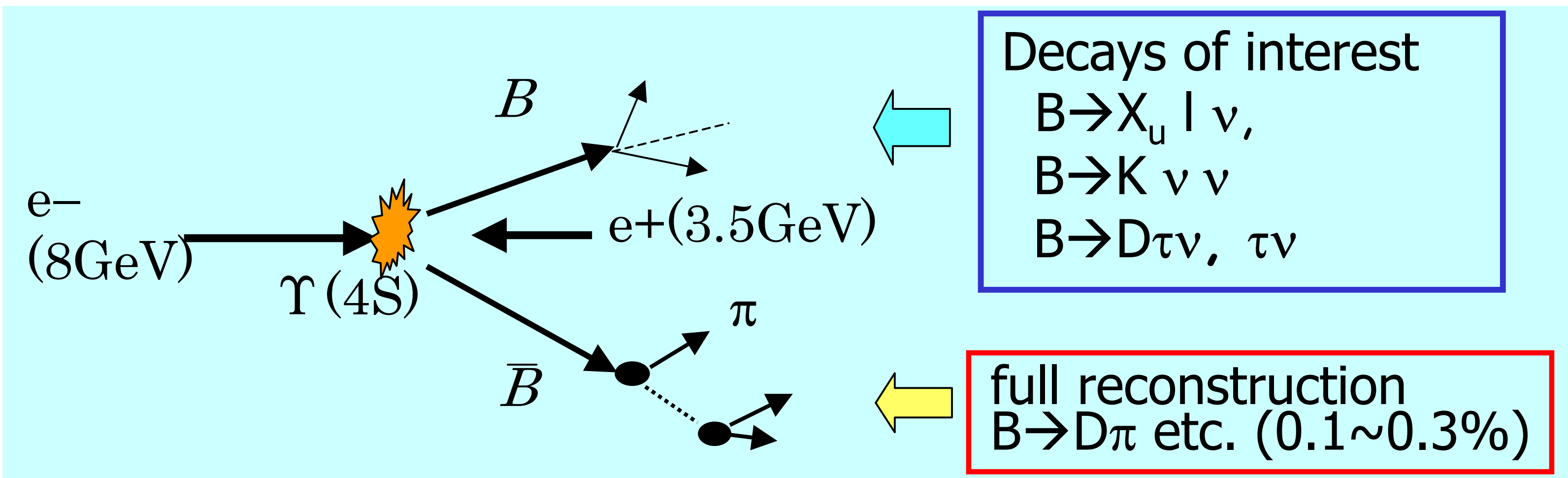
$\tilde{\varepsilon}_0$ = SUSY corrections to b Yukawa coupling

Br(SM) ~ 1.59 x 10^{-4}

Phys. Rev. D **48**, 2342 (1993)

Full Reconstruction Method

- Fully reconstruct one of the B's to
  - Tag B flavor/charge
  - Determine B momentum
  - Exclude decay products of one B from further analysis



Offline B meson beam!

Powerful tool for B decays with neutrinos

Fully reconstructed sample

Belle (447M $B\bar{B}$) → 4.12×10^5 $B^0\bar{B}^0$

+ 6.80×10^5 B^+B^-

Fully reconstructed sample

Clean environment but small sample: $\varepsilon_{reco} \approx 3\cdot10^{-3}$

Exclusive method: 180 decay channels

Reconstructed channels:

$B^0 \to D^{(*)-}\pi^+ / D^{(*)-}\rho^+ / D^{(*)-}a_1^+ / D^{(*)-} D_s^{(*)+}$

$B^+ \to D^{(*)0}\pi^+ / D^{(*)0}\rho^+ / D^{(*)0}a_1^+ / D^{(*)0} D_s^{(*)+}$

$D^{*0} \to D^0\pi^0$

$D^* \to D^0\pi / D\pi^0$

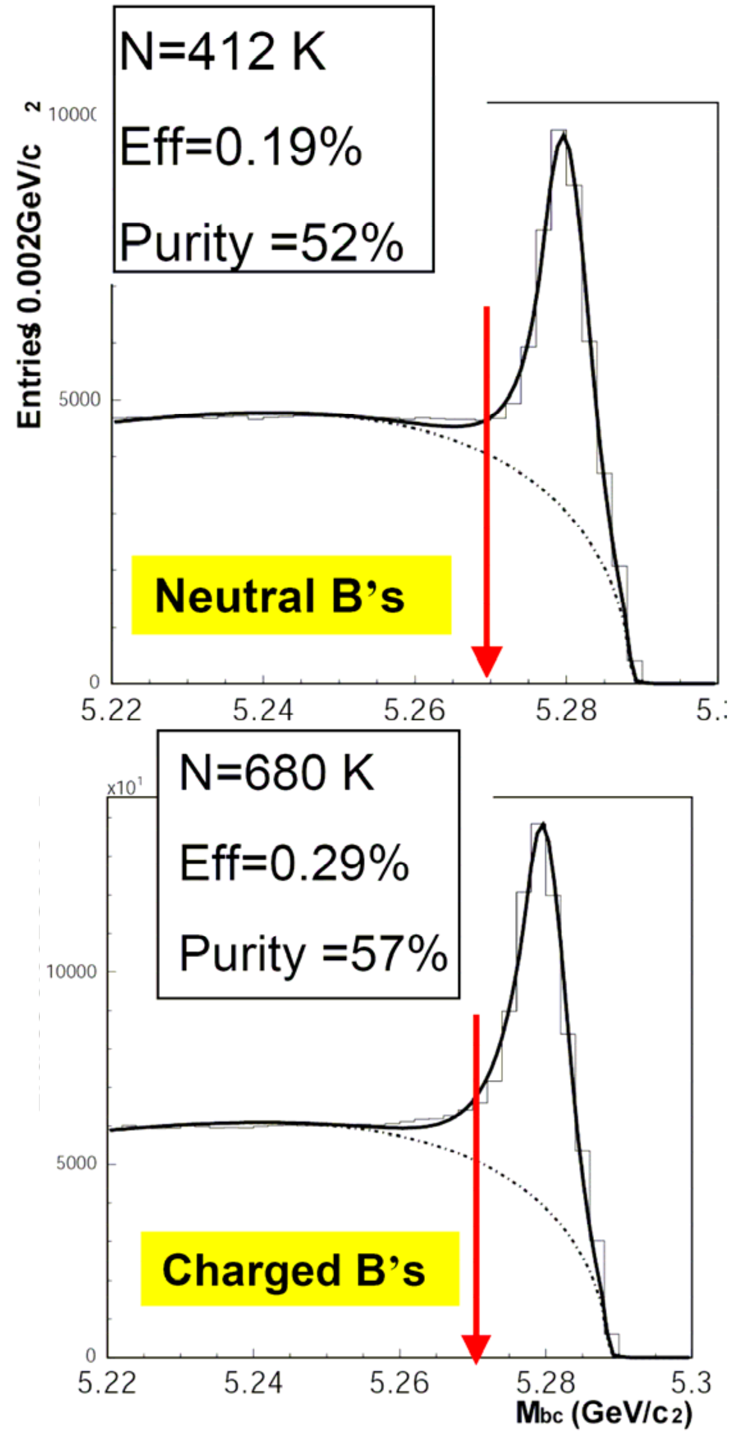
$D_s^* \to D_s\gamma$

$D^0 \to K\pi / K\pi\pi^0 / K\pi\pi\pi / K_s\pi^0 / K_s\pi\pi / K_s\pi\pi\pi^0 / KK$

$D \to K\pi\pi / K\pi\pi\pi^0 / K_s\pi / K_s\pi\pi^0 / K_s\pi\pi\pi / KK\pi$

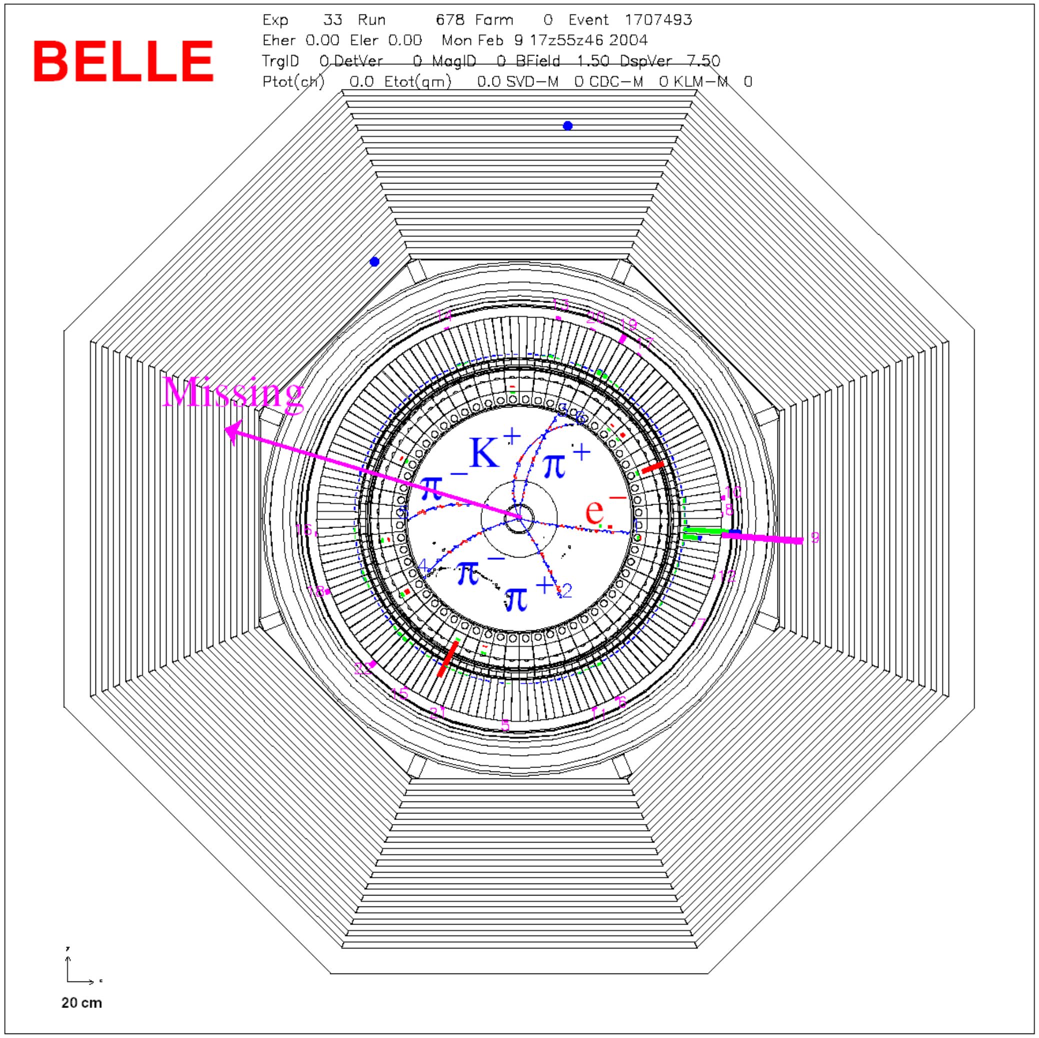
$D_s \to K_sK\pi / KK\pi$

→ SLAC seminar by Ilija Bizjak, Nov 2005



Event candidate $B^- \rightarrow \tau^- \nu_\tau$

$$B^+ \rightarrow D^0 \pi^+$$
$$(\rightarrow K\pi^-\pi^+\pi^-)$$
$$B^- \rightarrow \tau(\rightarrow e\nu\bar{\nu})\nu$$



B→τ ν

τ decay modes

$$\tau^- \to \mu^- \nu \bar{\nu}, e^- \nu \bar{\nu}$$

$$\tau^- \to \pi^- \nu, \pi^- \pi^0 \nu, \pi^- \pi^+ \pi^- \nu$$

- Cover 81% of τ decays
- Efficiency 15.8%

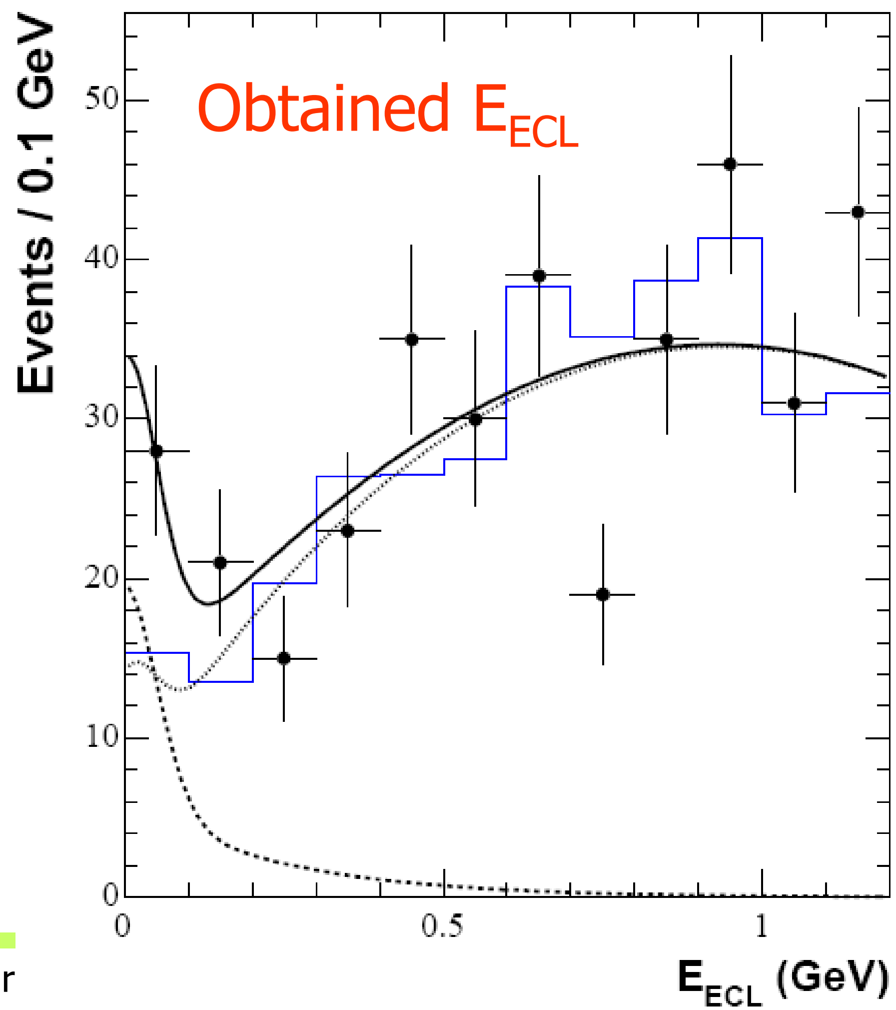
Event selection

- Main discriminant: extra neutral ECL energy

Fit to $E_{residual}$ → $17.2^{+5.3}_{-4.7}$ signal events.

→3.5σ significance including systematics

Submitted to PRL, hep-ex/0604018



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Consistency Check with $B \rightarrow D^* l \nu$

- Extra neutral energy E_{ECL} validation with double-tagged sample (control sample):
  - B_{tag} is fully reconstructed
  - B_{sig} is a semileptonic decay

$B^+ \rightarrow D^{(*)0} X^+$ (full reconstruction)

$B^- \rightarrow D^{*0} l^- \nu$

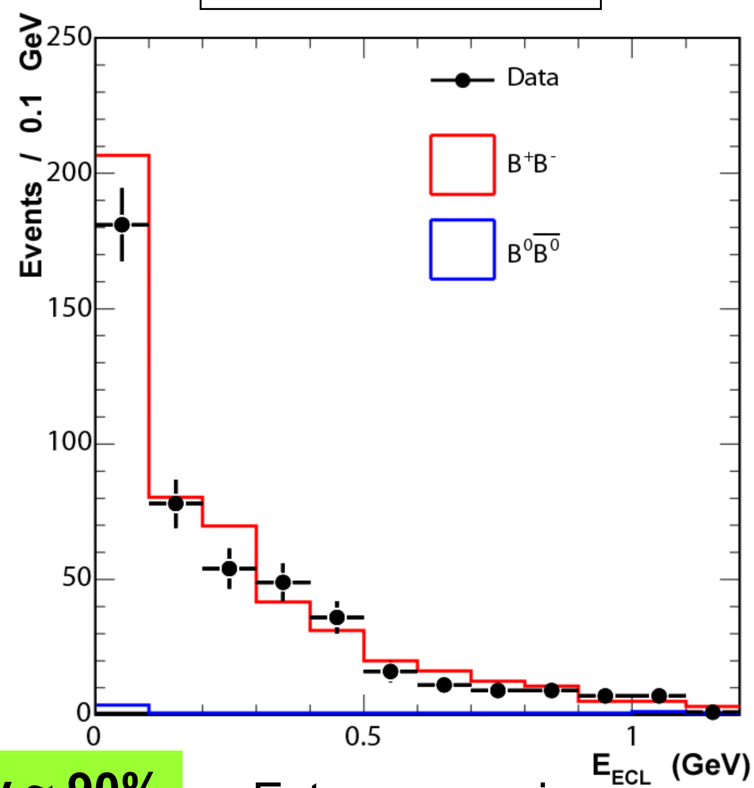
$\quad \hookrightarrow D^0 \pi^0$

$\quad\quad \hookrightarrow K^- \pi^+$

$\quad\quad\quad K^- \pi^+ \pi^- \pi^+$

B^+B^-	494 ± 18
B^0B^0	7.9 ± 2.2
Total	502 ± 18
Data	458

Calibration data



Purity ~ 90%

Extra energy in the calorimeter

B→τν yields broken down by τ decay mode

	N_{obs}	N_s	N_b	Σ
$\mu^- \bar{\nu}_\mu \nu_\tau$	13	$5.6^{+3.1}_{-2.8}$	$8.8^{+0.1}_{-0.1}$	2.7σ
$e^- \bar{\nu}_e \nu_\tau$	12	$4.1^{+3.3}_{-2.6}$	$9.0^{+0.1}_{-0.1}$	1.8σ
$\pi^- \nu_\tau$	9	$3.8^{+2.7}_{-2.1}$	$3.9^{+0.1}_{-0.1}$	2.4σ
$\pi^- \pi^0 \nu_\tau$	11	$5.4^{+3.9}_{-3.3}$	$5.4^{+0.6}_{-0.6}$	1.7σ
$\pi^- \pi^+ \pi^- \nu_\tau$	9	$3.0^{+3.5}_{-2.5}$	$4.8^{+0.4}_{-0.4}$	1.1σ
Combined	54	$17.2^{+5.3}_{-4.7}$	$32.0^{+0.7}_{-0.7}$	4.6σ

(stat sign. only)

For all modes, the background is fitted with a 2^{nd} order polynomial plus a small Gaussian peaking component.

MC studies: small peaking bkg in the $\tau \to \pi\pi^0\nu$ and $\tau \to \pi\pi\pi^0\nu$ modes.

$B \rightarrow \tau \nu_\tau$

$$\mathrm{BF}(B^+ \rightarrow \tau^+ \nu_\tau) = (1.79^{+0.56+0.46}_{-0.49-0.51}) \times 10^{-4}$$

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

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

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

$$f_B = 229^{+36+34}_{-31-37}\, MeV$$

15% 15% = 13%(exp.) + 8%(V_{ub})

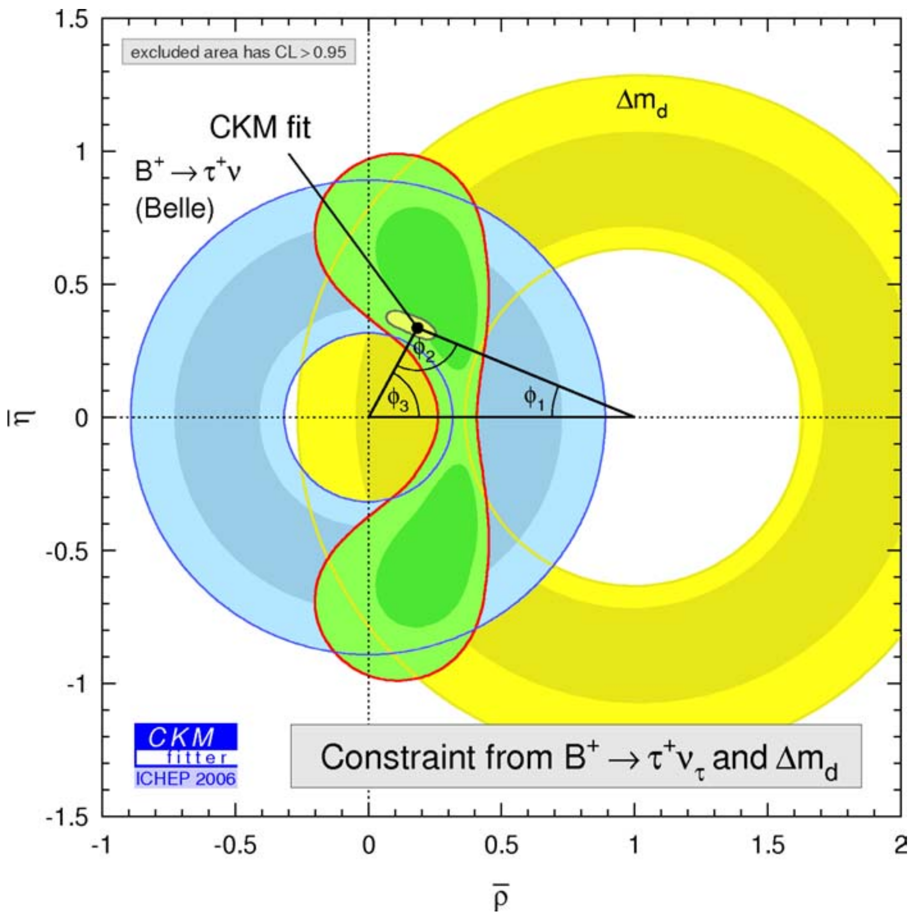
First measurement of f_B!

f_B = (216 ± 22) MeV (an unquenched lattice calc.)

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

Impact of $B^- \rightarrow \tau^- \nu_\tau$

•Use BF($B \rightarrow \tau \nu_\tau$) with $\Delta m_d \rightarrow$ constraint in the (ρ,η) plane



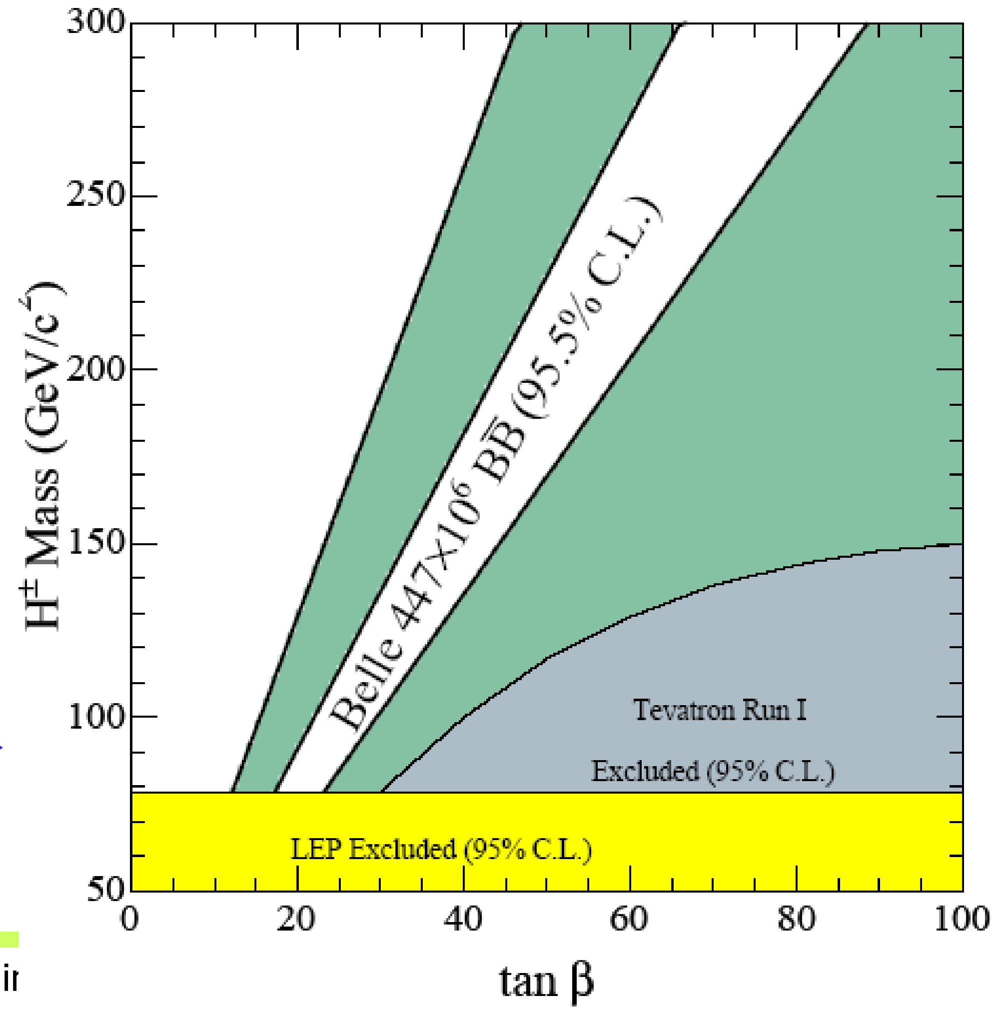
Charged Higgs limits from $B^- \to \tau^- \nu_\tau$

If the theoretical prediction is taken for $\mathbf{f_B}$
→ limit on charged Higgs mass vs. tanβ

$$r_H = \frac{BF(B \to \tau\nu)}{BF(B \to \tau\nu)_{SM}}$$

$$= \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

r_H=1.13±0.51 →



$B \to \tau\ \nu$ prospects

- Expected precision at Super-B
  - 13% at 5 ab^{-1}
  - 7% at 50 ab^{-1}

- Search with $D^{(*)}\ l\ \nu$ tag will help.
  - → BaBar 232M BB PRD 73 (2006) 057101
  - Tag eff ~ 1.75×10^{-3}
  - Signal selection eff. ~31%
  - Similar S/N to Belle (full recon. sample)

⇨ $Br(B \to \tau\nu) < 2.8 \times 10^{-4}\,(90\%CL)$

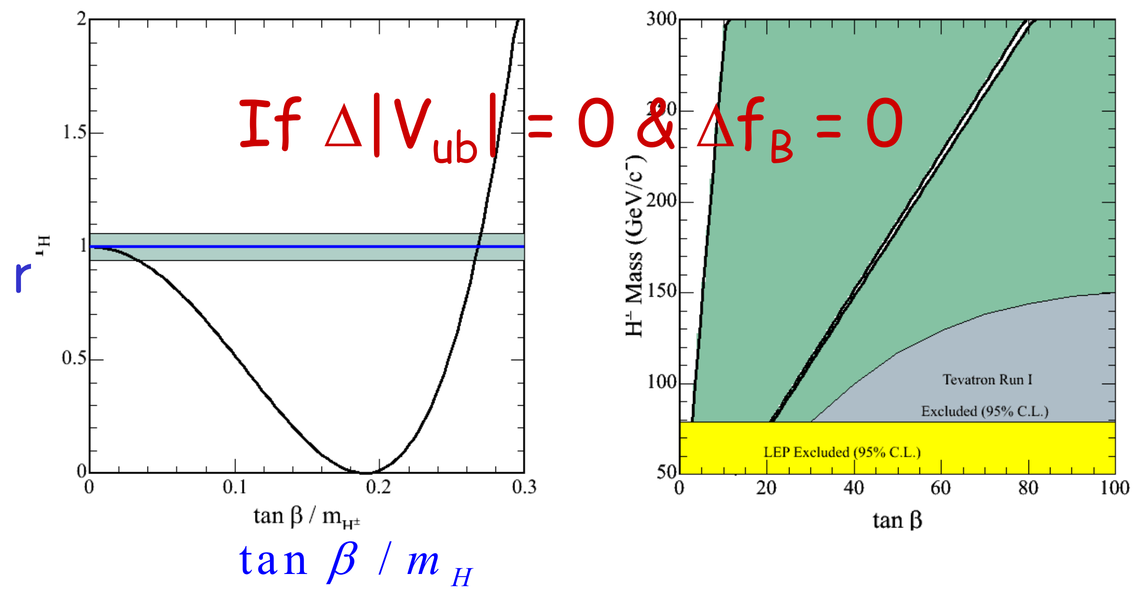
Future Prospects: $B \rightarrow \tau\nu$

95.5%C.L. exclusion boundaries

(for $BF_{obs} = BF_{SM}$)

$50ab^{-1}$

If $\Delta|V_{ub}| = 0$ & $\Delta f_B = 0$



$B \to K^{(*)}\nu\nu$

$B \to K^{(*)}\nu\nu$ is a particularly interesting and challenging mode (with $B \to \tau\nu$ as a small background), theoretically clean

Experimental signature: $B \to K$ + nothing

The "nothing" can also be light dark matter with mass of order 1 GeV. Direct dark-matter searches cannot see the M<10 GeV region.

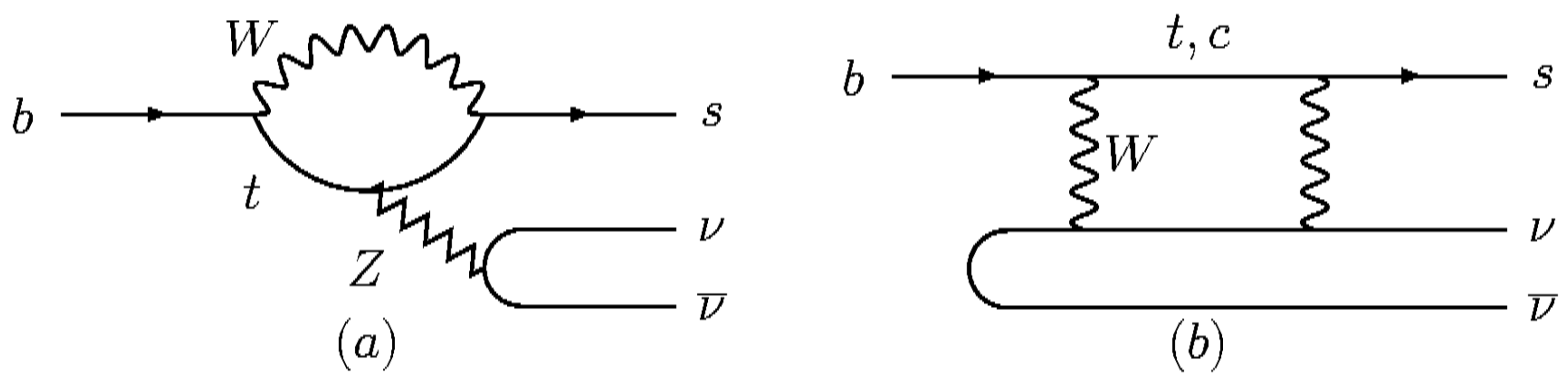
SM prediction for $B^+ \to K^+\nu\nu$: $(3.8^{+1.2}_{-0.6}) \times 10^{-6}$

$B \to \tau\nu$ analysis is a proof that such a one prong decay can be studied at a B factory

Present limits:

- BaBar (89M BB): $BF(B^+ \to K^+\nu\nu) < 52 \times 10^{-6}$ PRL 94 (2005)101801
- Belle (277M BB): $BF(B^+ \to K^+\nu\nu) < 36 \times 10^{-6}$ hep-ex/0507034

Motivation for B→K$^*\nu\nu$ (b→s with 2 ν's)



SM: BF(B→K$^*\nu\nu$) ~1.3 x 10^{-5} (Buchalla, Hiller, Isidori)

PRD 63, 014015

BSM: New particles in the loop

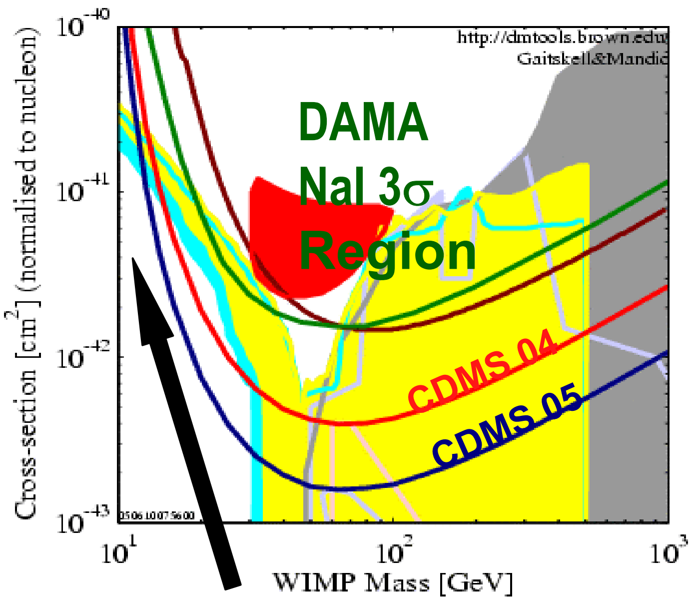
Other weakly coupled particles: light dark matter

Motivation for B→K*νν - 2

The experimental signature is B→K + Nothing

The “nothing” can also be *light dark matter* (mass of order (1 GeV))

C. Bird et al
PRL 93 201803



Direct dark-matter searches cannot see M<10 GeV region

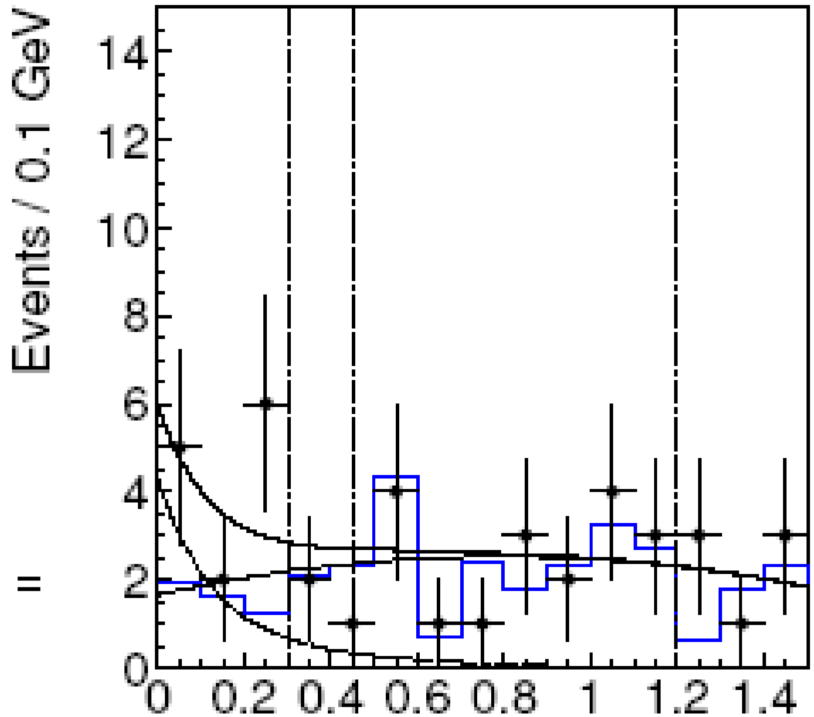
Search for B→K*νν

535 x 10^6 B Bbar pairs

BELLE-CONF-0627

Sideband = 19

MC expectation = 18.7±3.3



Extra Calorimeter Energy (GeV)

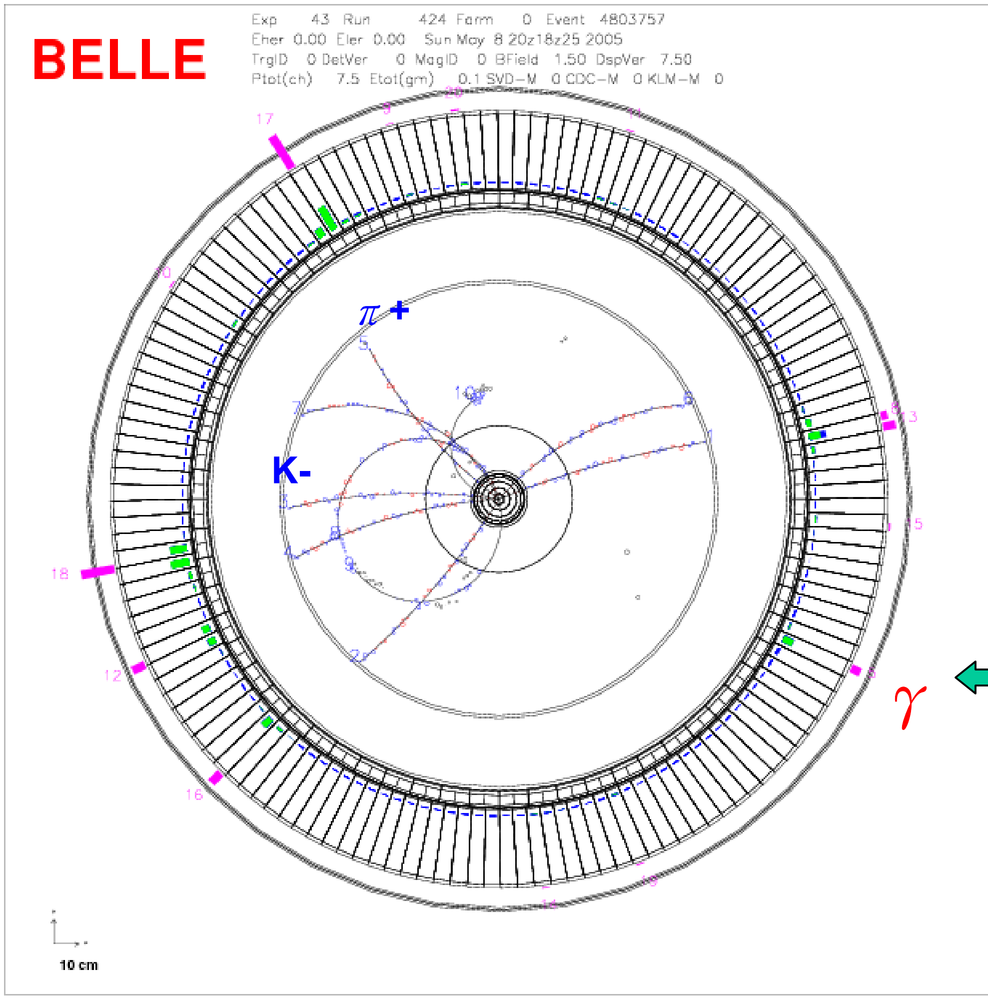
$$Yield = 4.7^{+3.1}_{-2.6}$$

(1.7σ stat. significance)

SM (Buchalla, Hiller, Isidori) 1.3 x 10^{-5}

$$B(B^0 \to K^{*0}\nu\nu) < 3.4\times10^{-4}$$ (at 90% C.L)

Event display for a B→K$^*\nu\nu$ candidate due to an identified background (B→K$^*\gamma$)



Tag Side

B → D$^+$ a$_1^-$

D$^+$ → K$^-$ $\pi^+\pi^+$

a$_1^-$ → $\rho^0\ \pi^-$, ρ^0 → $\pi^+\pi^-$

Missing mass ~ 0

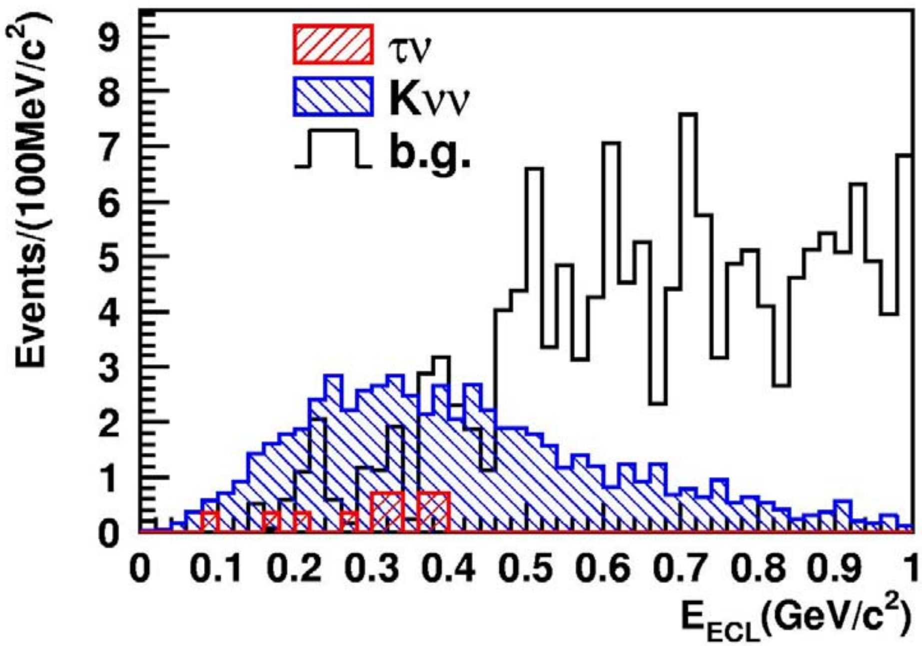
(Hard photon is lost in the barrel-endcap calorimeter gap)

MC: Expected bkg from this source ~0.3 evts.

$B^- \rightarrow K^- \nu\nu$ prospects

MC extrapolation to 50 ab^{-1}

5σ Observation of $B^\pm \rightarrow K^\pm \nu\nu$



Extra EM calorimeter energy

SM prediction:
G.Buchalla, G.Hiller, G.Isidori
(PRD 63 014015)

Fig. from SuperKEKB LoI

Summary

- Radiative, electroweak and tauonic B decays are of great importance to probe new physics.

- We are starting to measure B→ $\tau\nu$, $K\nu\nu$, $D\tau\nu$, $A_{FB}(K^*ll)$, $A_{CP}(K\pi^0\gamma)$ etc. at the current B factories.

  →Hot topics in the coming years !

- For precise measurements, we need a Super-B factory!

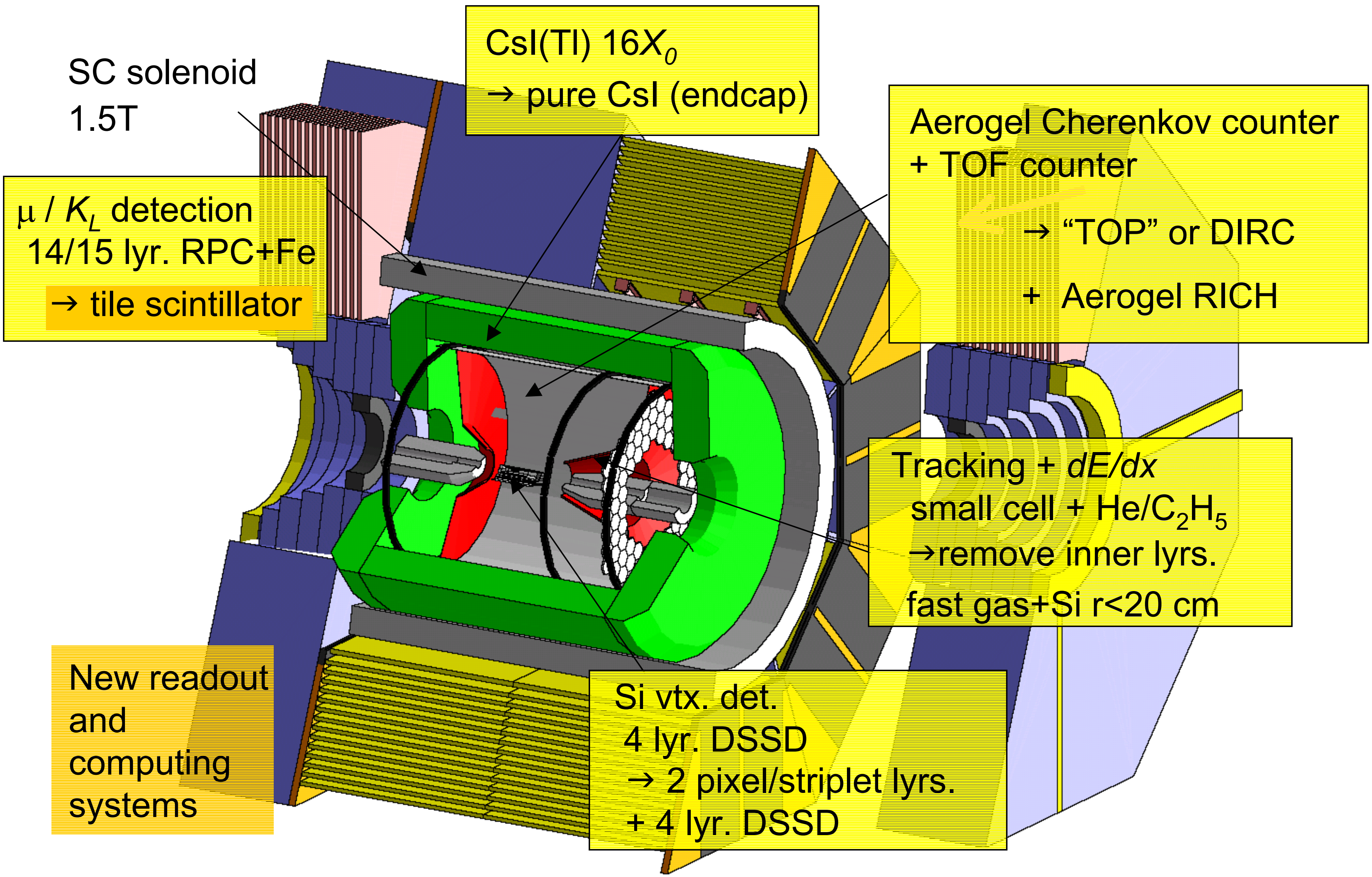
→Observe $K^{(*)}\nu\nu$, zero crossing in A_{FB}, $D^{(*)}\tau\nu$

→ Expected precision ($5ab^{-1}$→$50ab^{-1}$);

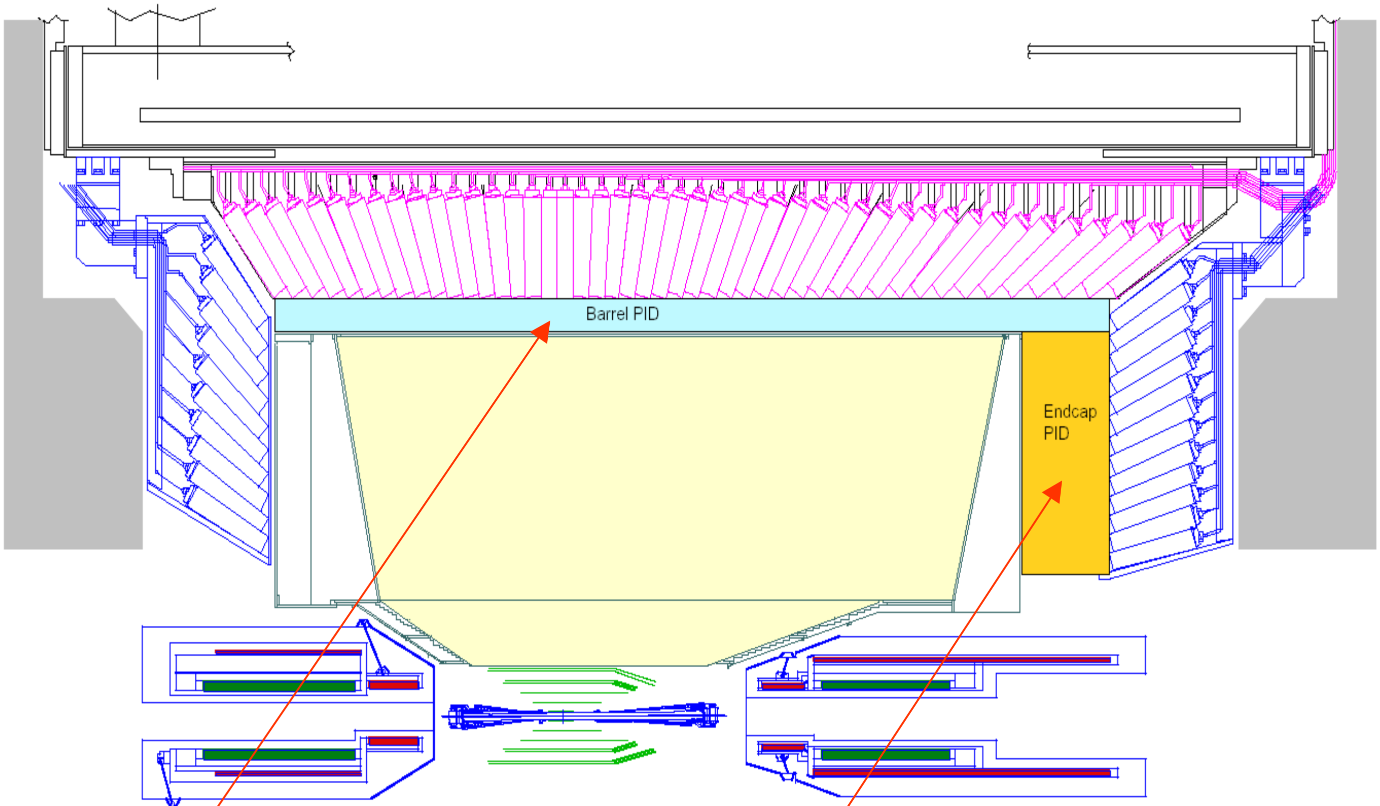
  - $Br(\tau\nu)$: 13%→7%
  - $Br(D^{(*)}\tau\nu)$: 7.9%→2.5%
  - q_0^2 of $A_{FB}(K^*ll)$: 11%→5%
  - $A_{CP}(K\pi^0\gamma)$ tCPV: 0.14→0.04

→ Substaintial upgrade of the detector is mandatory

Belle Upgrade for Super-B



Belle upgrade – side view

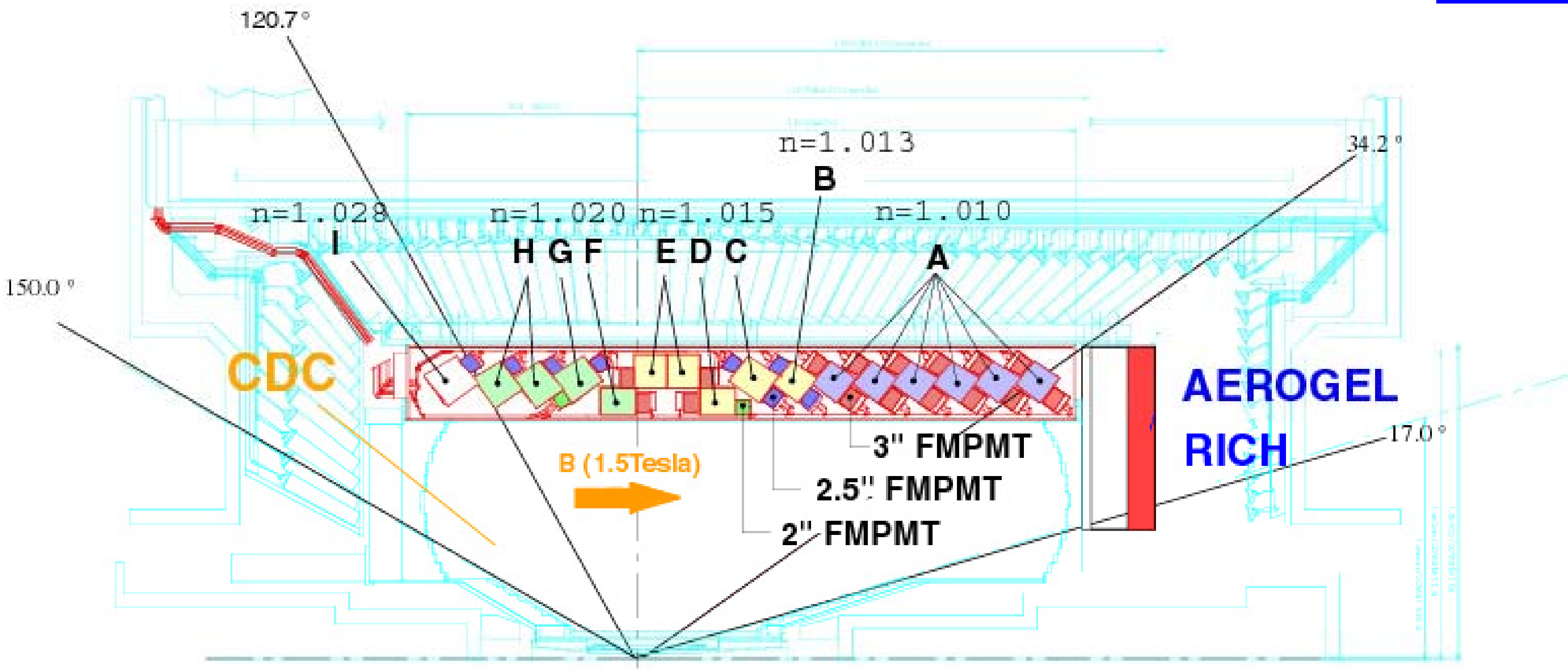


Two new particle ID devices, both RICHes:

Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

PID upgrade in the endcap



improve K/π separation in the forward (high mom.) region for few-body decays of B mesons

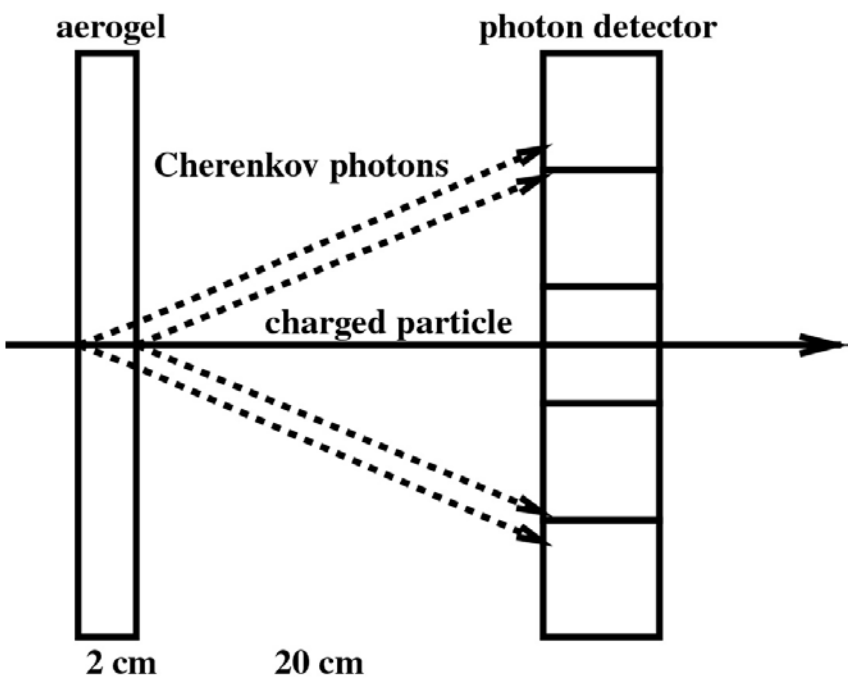
good K/π separation for b -> dγ , b -> sγ

improve purity in fully reconstructed B decays

low momentum (<1GeV/c) e/μ/π separation (B ->Kll)

keep high the efficiency for tagging kaons

Proximity focusing RICH in the forward region



K/π separation at 4 GeV/c
$\theta_c(\pi)$ ~ 308 mrad (n = 1.05)
$\theta_c(\pi) - \theta_c(K)$ ~ 23 mrad

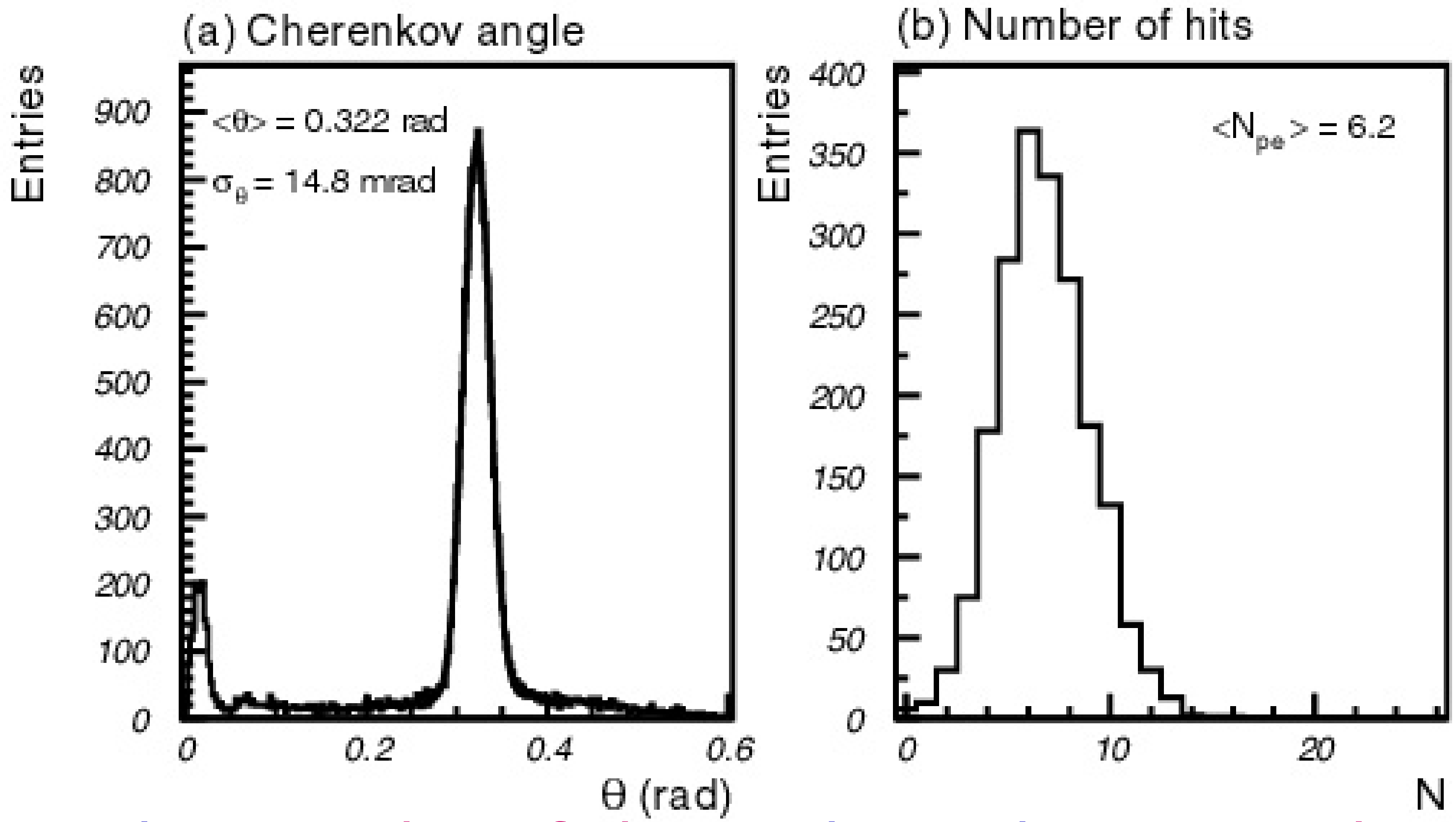
$d\theta_c$(meas.) = σ_0 ~ 13 mrad
With 20mm thick aerogel and 6mm PMT pad size

→ 6σ separation with N_{pe}~10

Beam test: Cherenkov angle resolution and number of photons

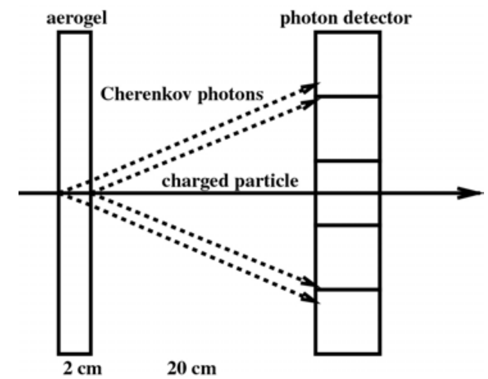
Beam test results with 2cm thick aerogel tiles:
excellent, >4σ K/π separation

NIM A521(2004)367



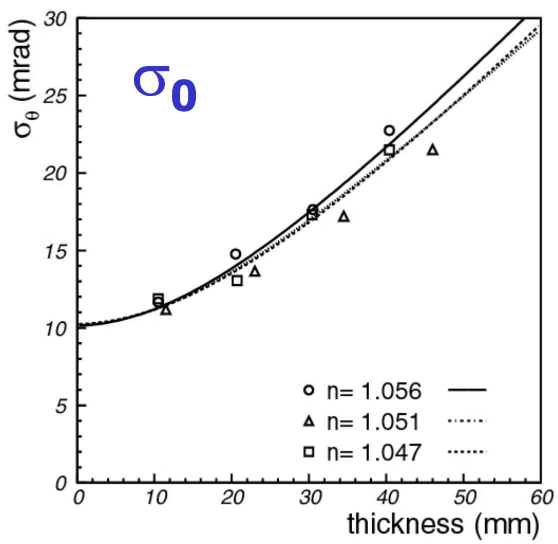
but: Number of photons has to be increased. →

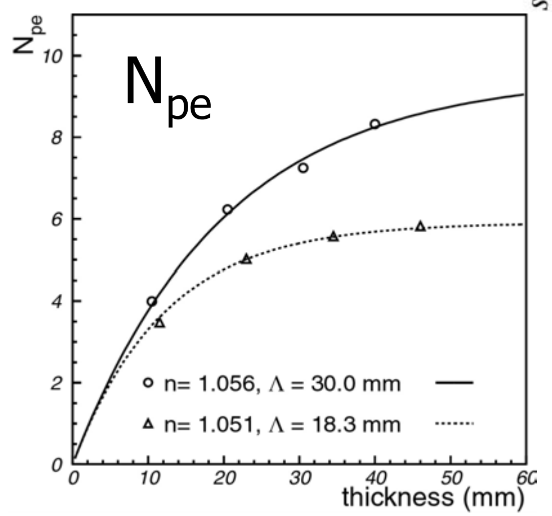
How to increase the number of photons?

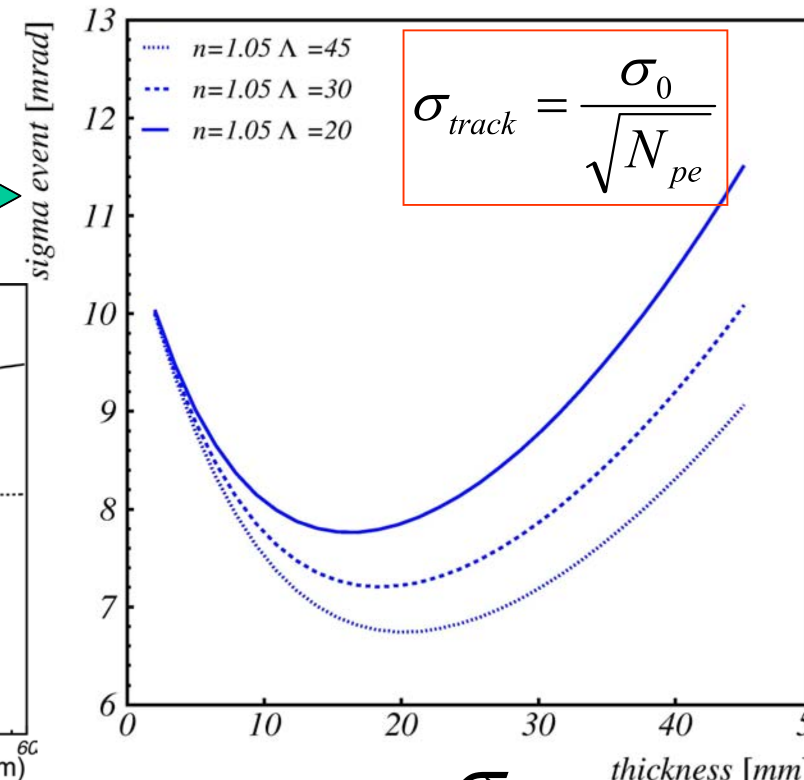


What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}







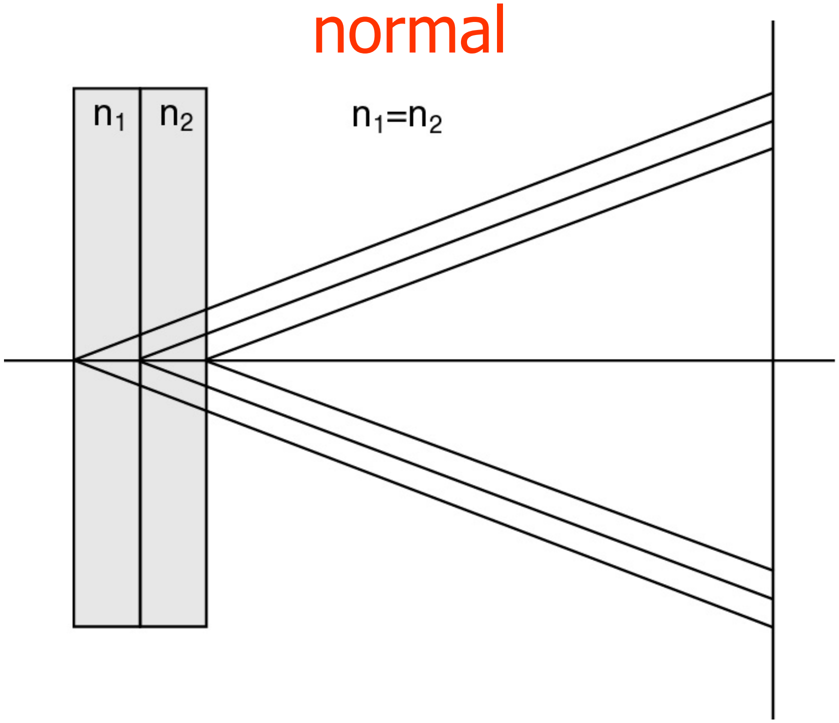
Minimize the error per track: $\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$

Optimum is close to 2 cm

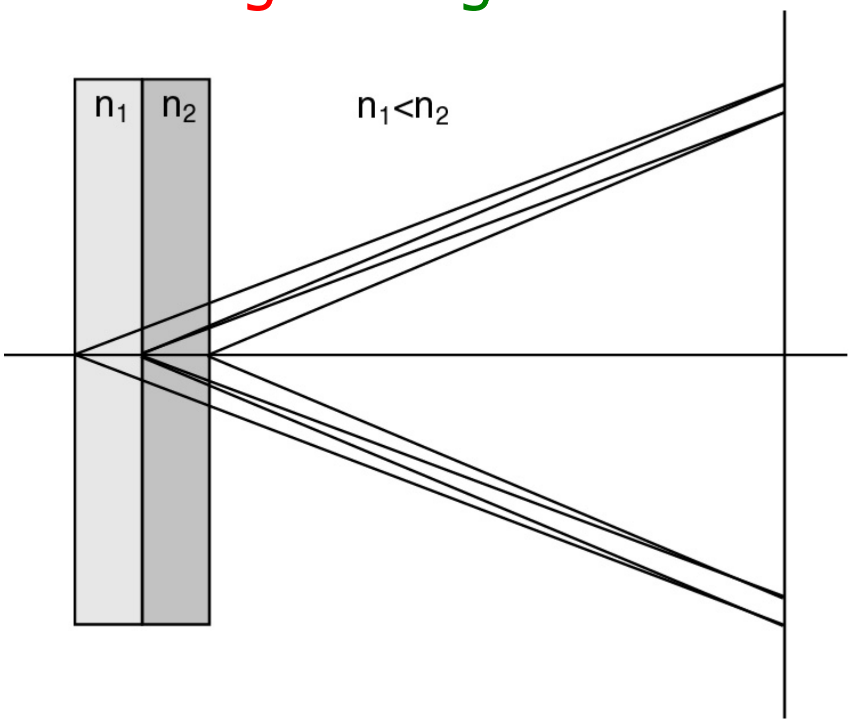
Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

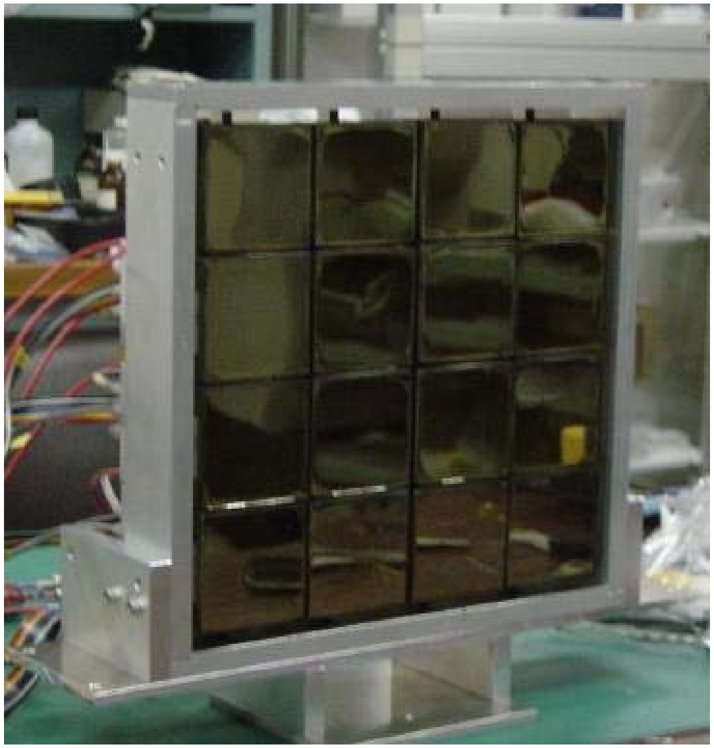
normal



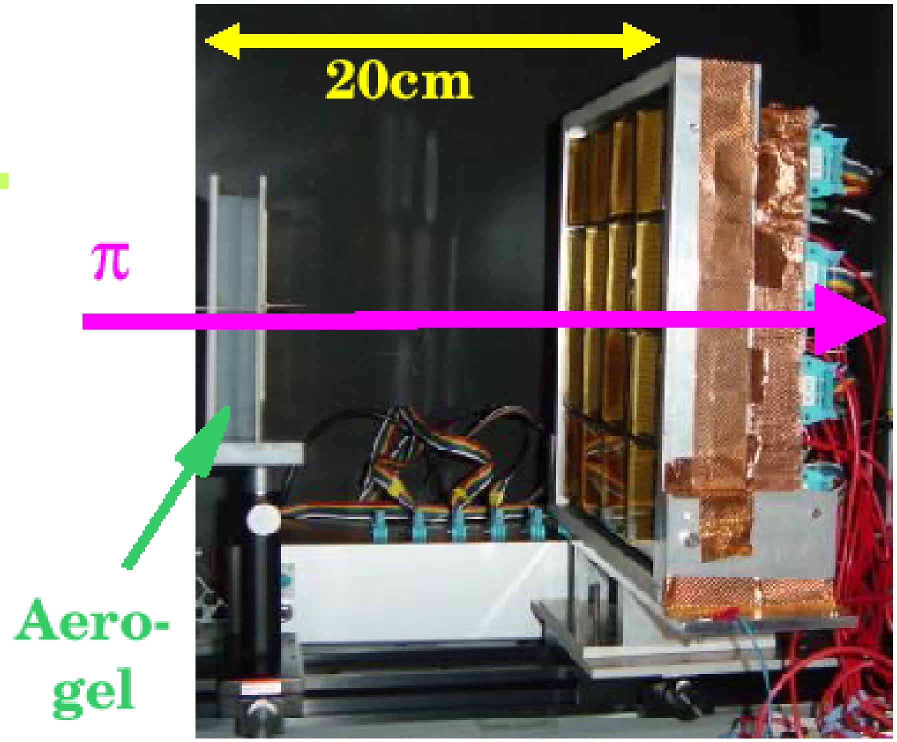
measure overlaping rings
→"focusing" configuration



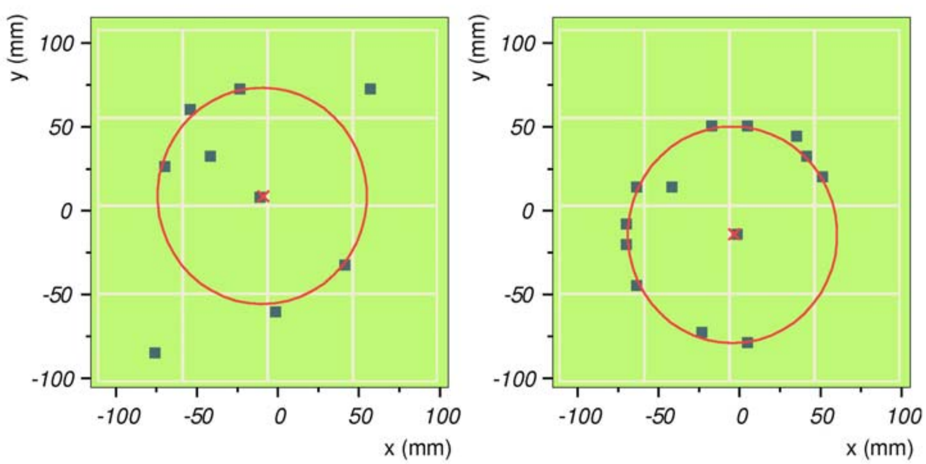
Beam tests



Photon detector: array of 16 H8500 PMTs



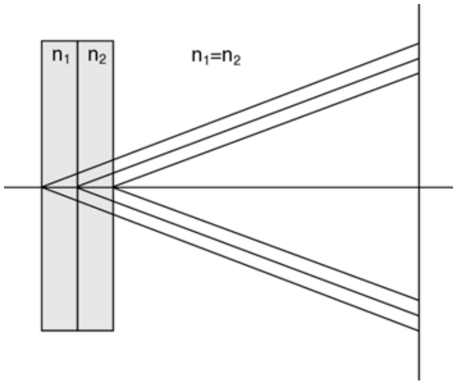
Clear rings, little background

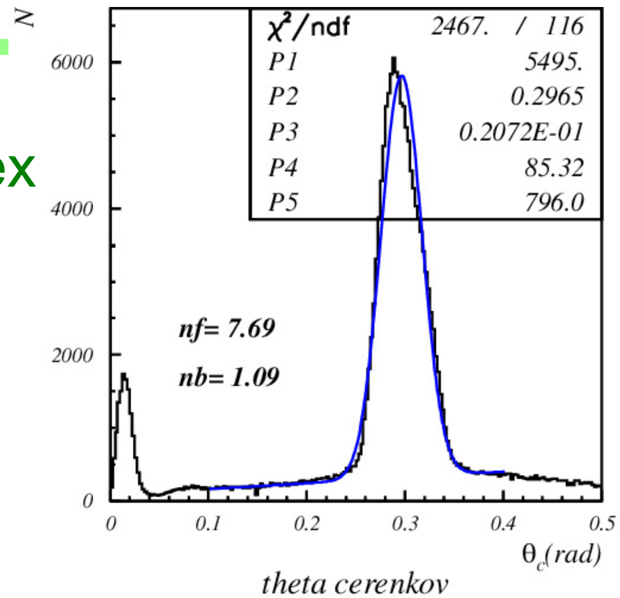


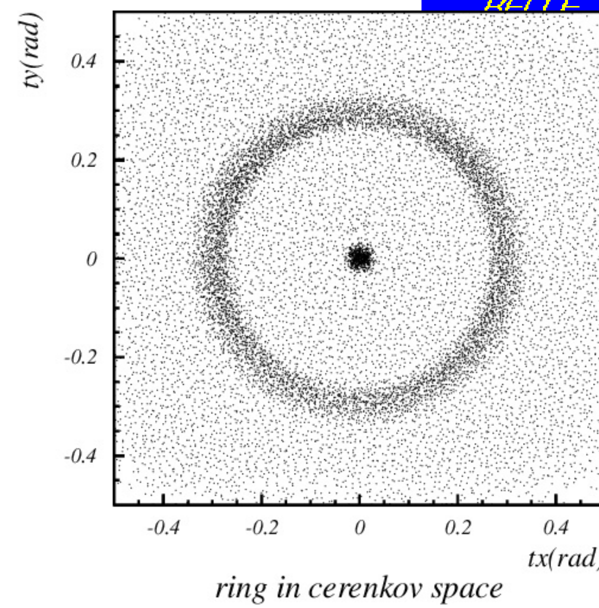
Focusing configuration

NIM A565 (2006) 457

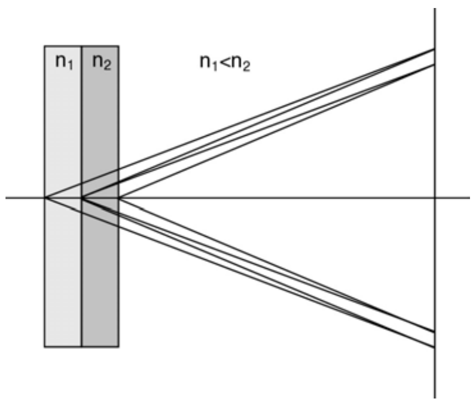
4cm aerogel single index

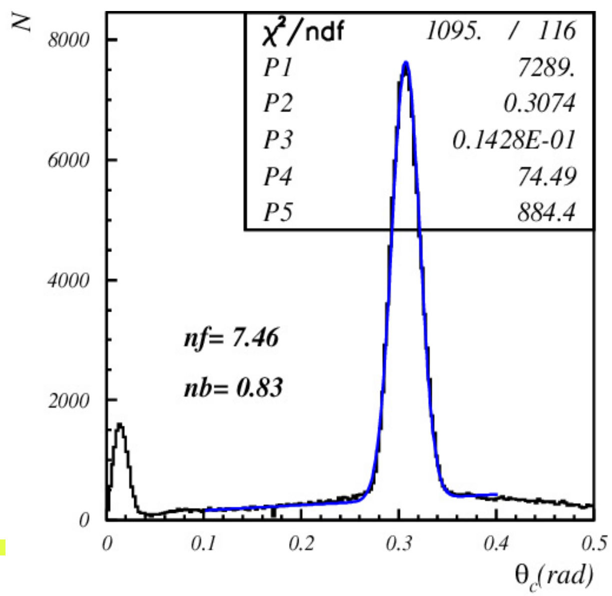


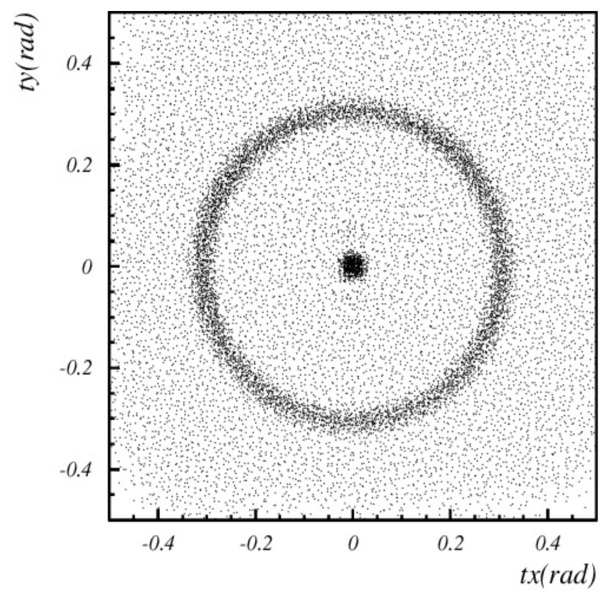




2+2cm aerogel



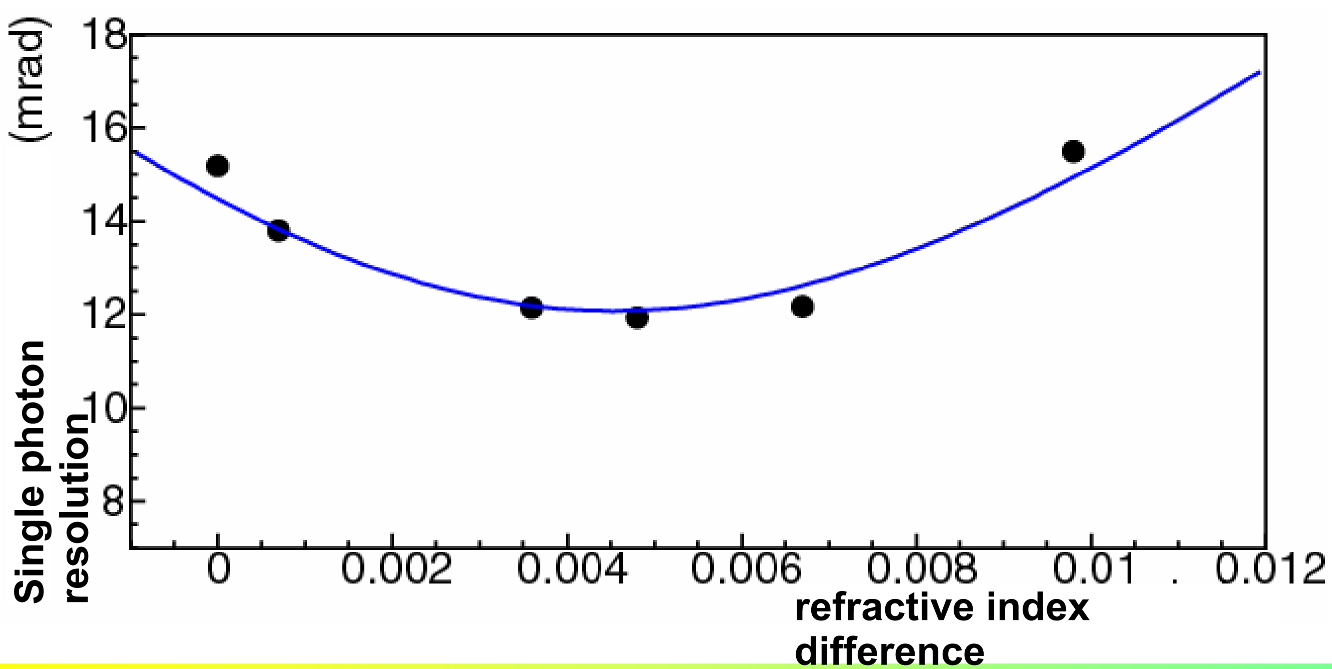




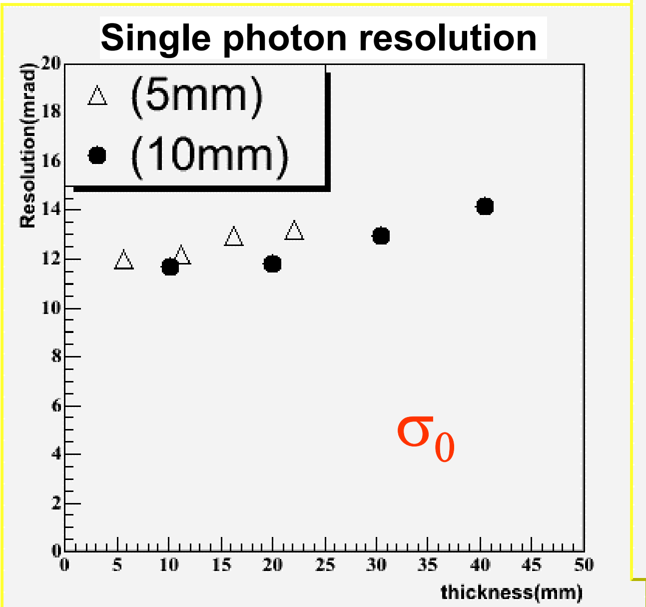
Focusing configuration – n_2-n_1 variation

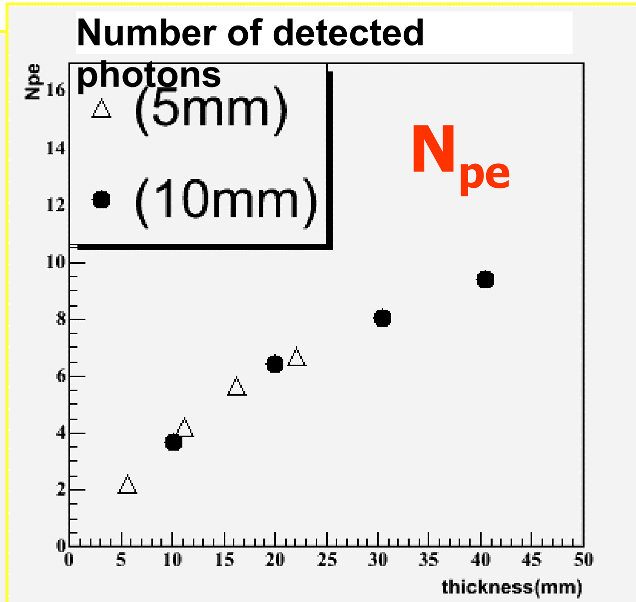
- upstream aerogel: d=11mm, n=1.045
- downstream aerogel layer: vary refractive index
- measured resolution in good agreement with prediction
- wide minimum allows some tolerance in aerogel production

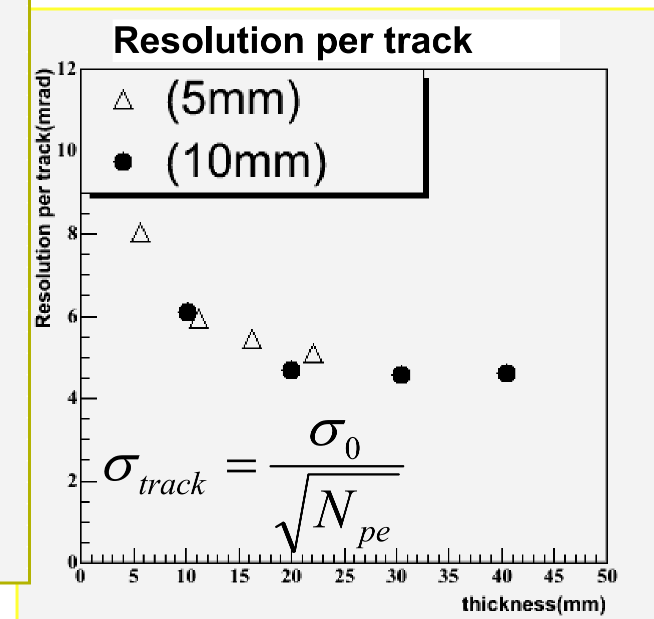
NIM A565 (2006) 457

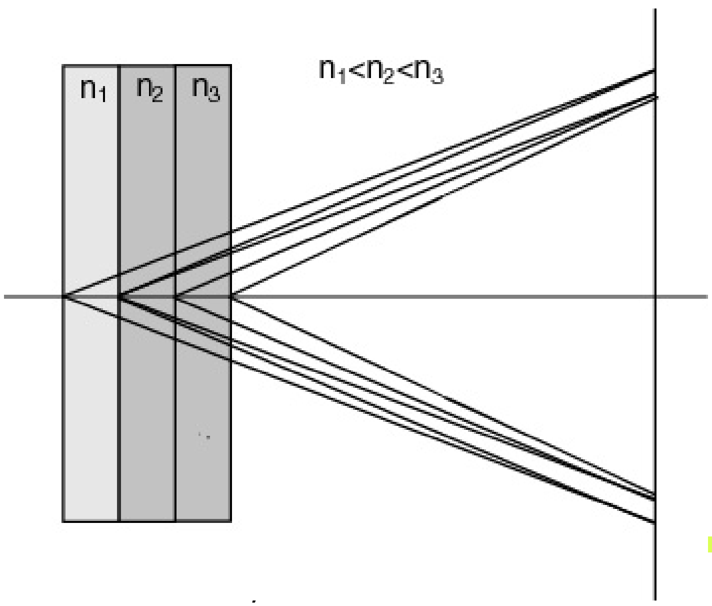


Multilayer extensions







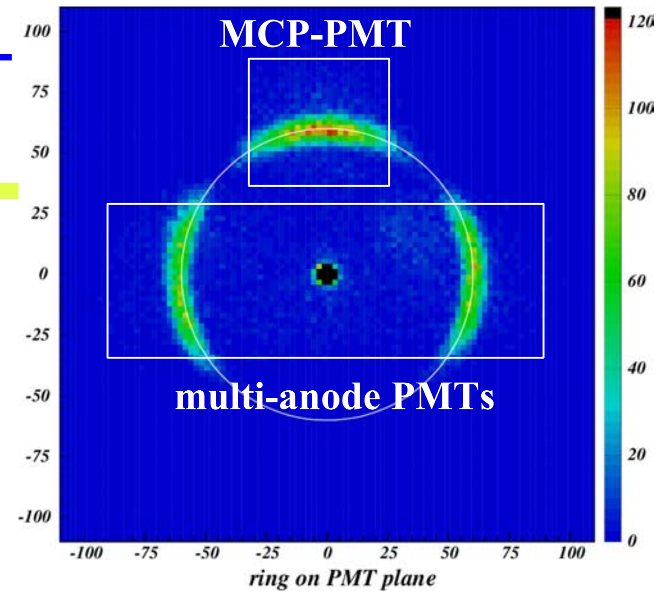


Multiple layer radiators combined from 5mm and 10mm tiles

Cherenkov angle resolution per track: around 4.3 mrad

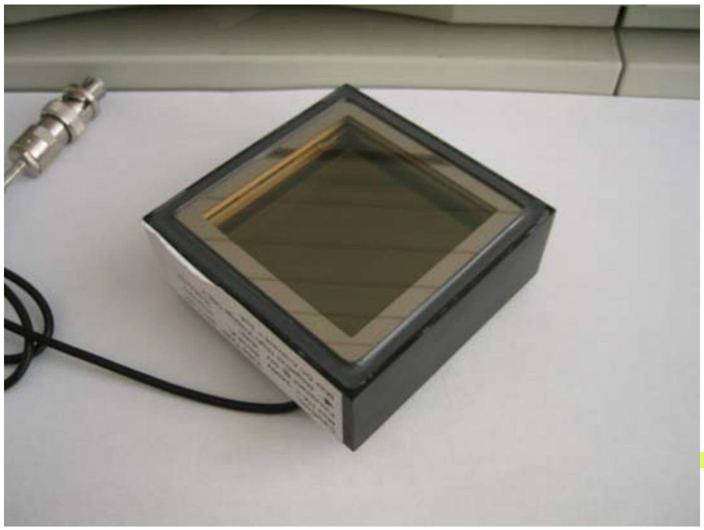
→ π/K separation at 4 GeV better than **5**σ

Photon detector candidate: MCP-PMT



BURLE 85011 MCP-PMT:

- multi-anode PMT with two MCP steps
- 25 μm pores
- bialkali photocathode
- gain ~ 0.6 x 10^6
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 64(8x8) anode pads
- pitch ~ 6.45mm, gap ~ 0.5mm
- active area fraction ~ 52%



- Tested in combination with multi-anode PMTs

- σ_ϑ~13 mrad (single cluster)
- number of clusters per track N ~ 4.5
- σ_ϑ~ 6 mrad (per track)
- **-> ~ 4 σ π/K separation at 4 GeV/c**

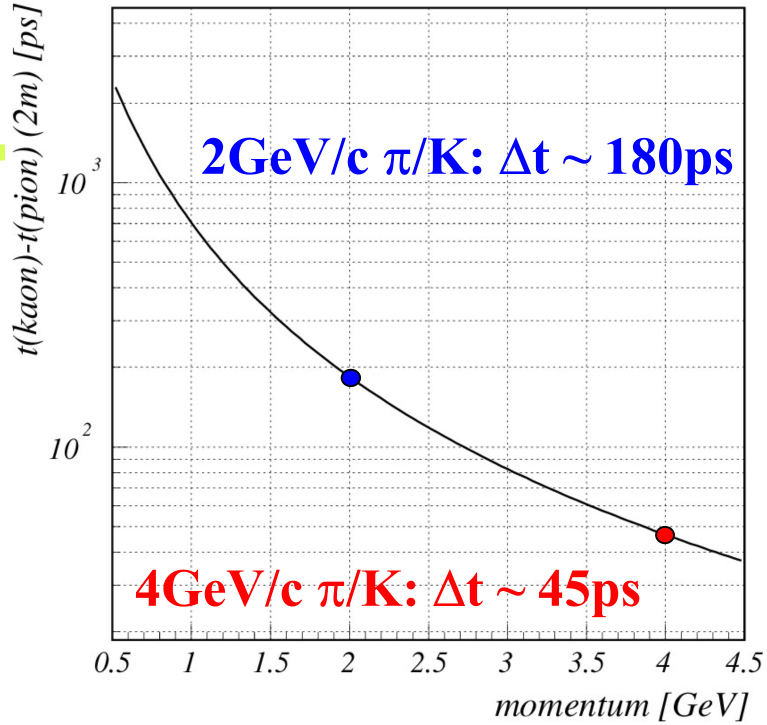
- 10 μm pores required for 1.5T
- collection eff. and active area fraction should be improved
- aging study should be carried out

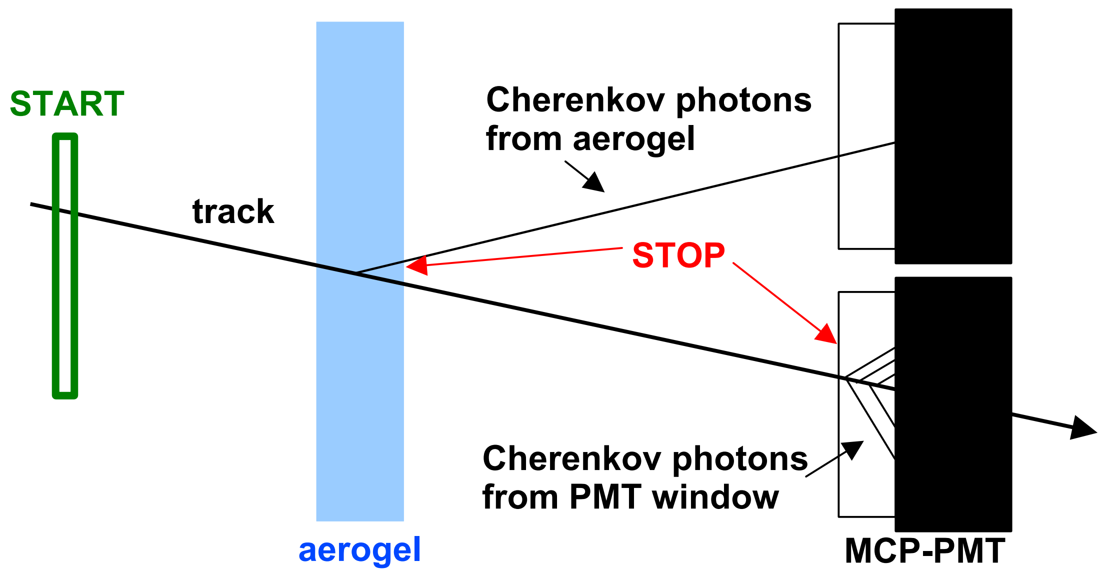
TOF capability

With the use of a fast photon detector, a proximity focusing RICH counter can be used also as a time-of-flight counter.

Cherenkov photons from two sources can be used:

- photons emitted in the aerogel radiator
- photons emitted in the PMT window



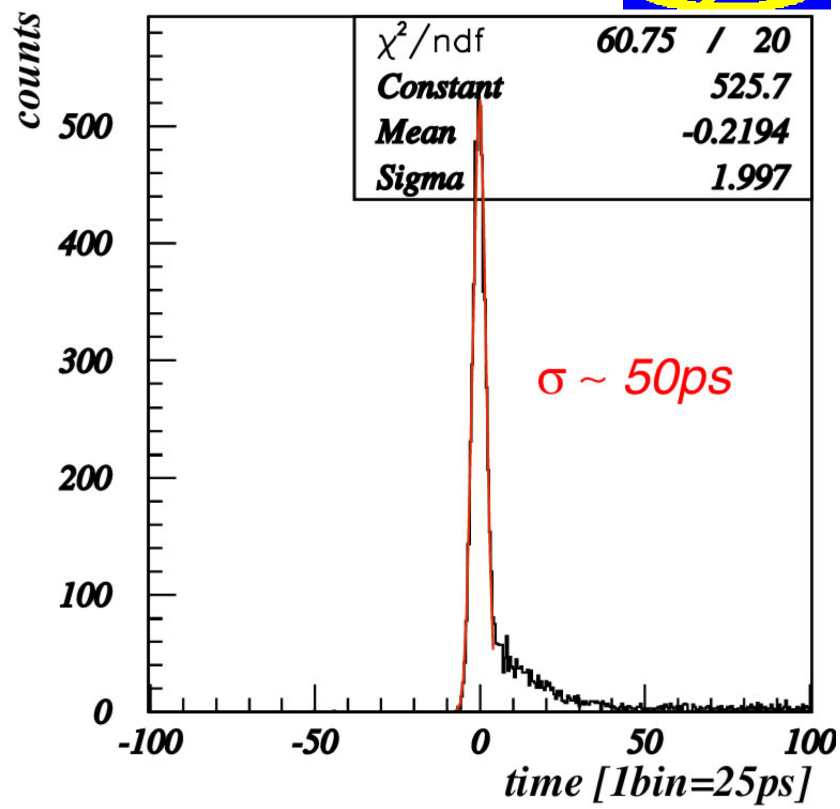


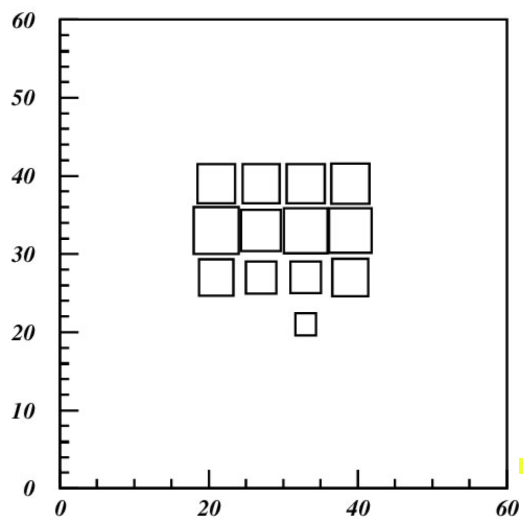
Beam tests: study timing properties of such a configuration.

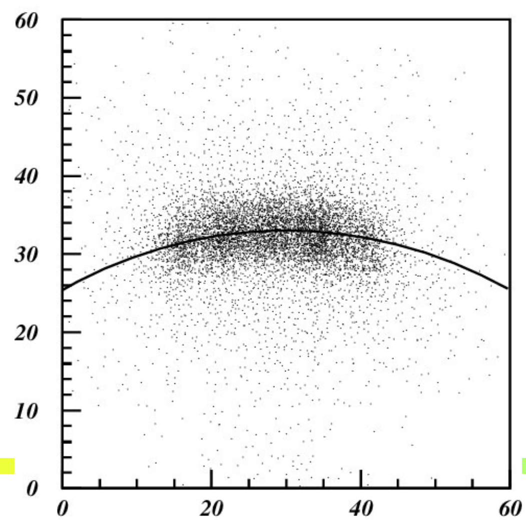
TOF capability: photons from the ring

Time resolution for Cherenkov photons from the aerogel radiator: 50ps
→agrees well with the value from the bench tests

Resolution for full ring (~10 photons) would be around 20 ps







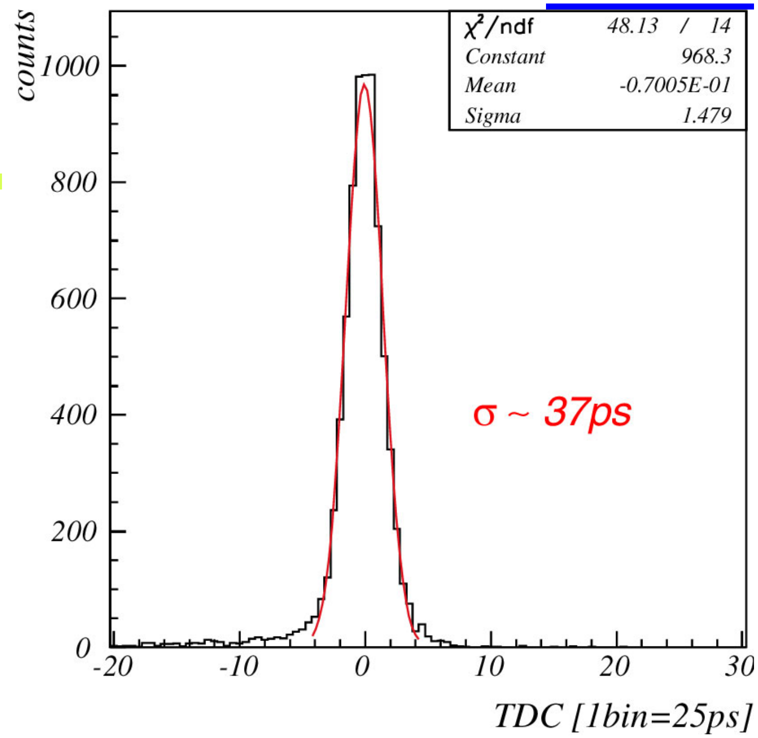
Distribution of hits on the MCP-PMT (13 channels were instrumented) - left

Corrected distribution using the tracking information - left

TOF capability: window photons

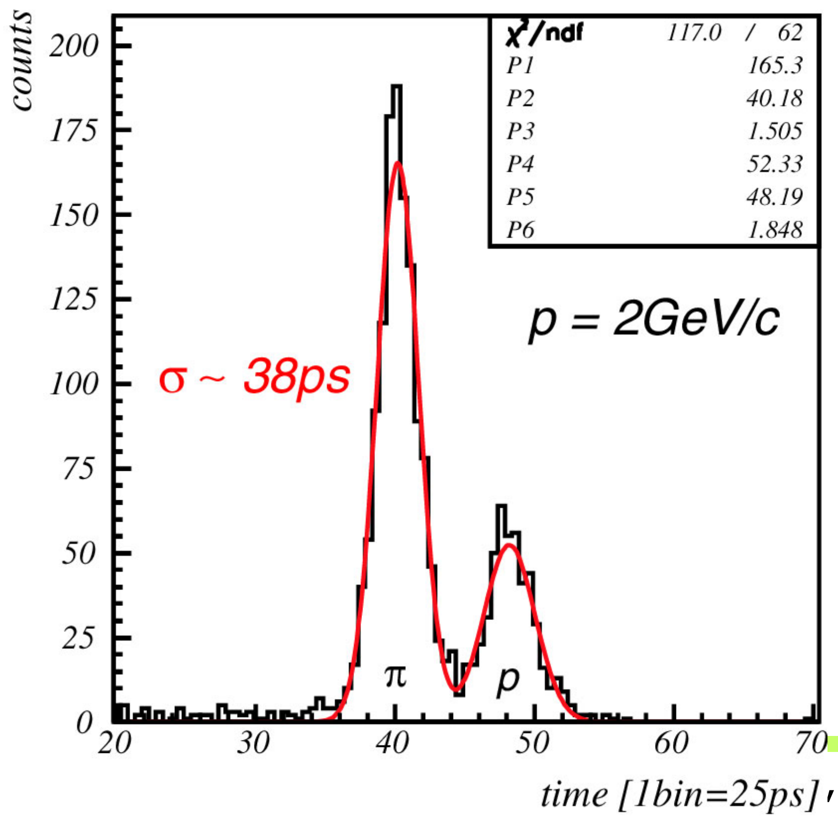
Expected number of detected Cherenkov photons emitted in the PMT window (2mm) is ~15

Expected resolution ~35 ps →

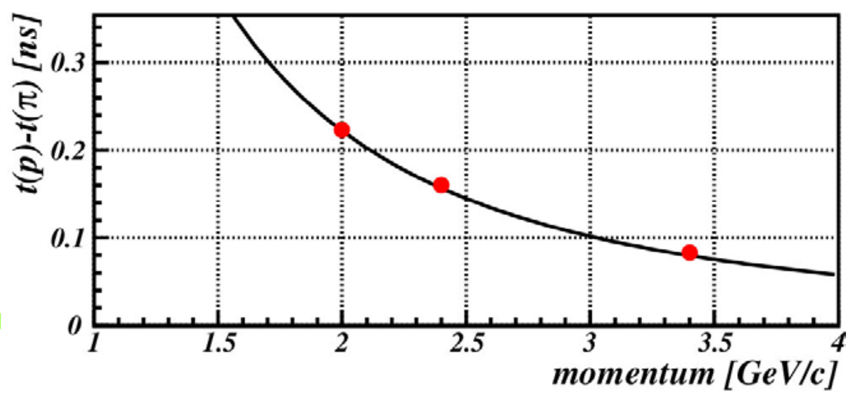


TOF test with pions and protons at 2 GeV/c

Distance between start counter and MCP-PMT is 65cm

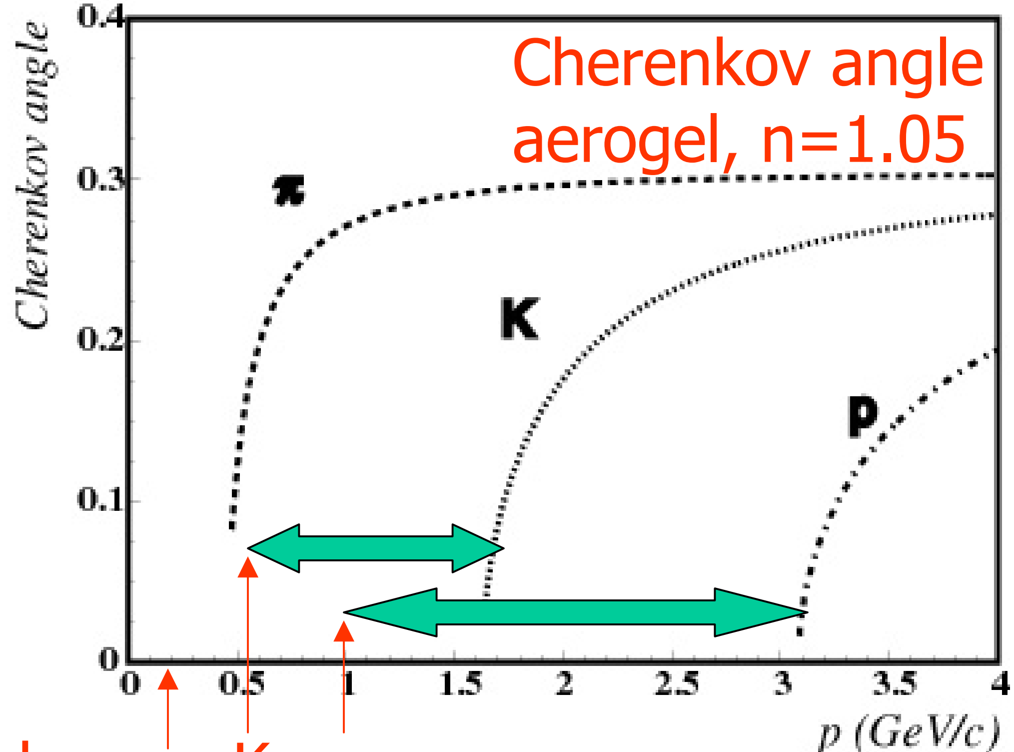


, SLAC



Time-of-flight with photons from the PMT window

Benefits: Čerenkov threshold in glass (or quartz) is much lower than in aerogel.



Aerogel: kaons (protons) have no signal below 1.6 GeV (3.1 GeV): identification in the veto mode.

Threshold in the window: π K p

Window: threshold for kaons (protons) is at ~0.5 GeV (~0.9 GeV): → positive identification possible.