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Flavour Physics at B-factories and Hadron Colliders

Part 13: Super B-factories

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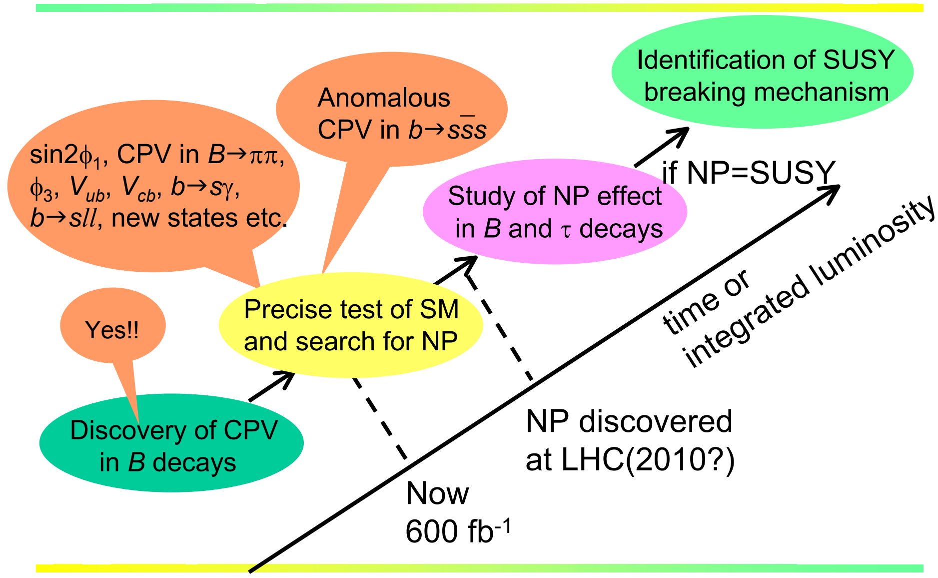
Contents

- Super B-factory motivation
- Plans at KEK
- New particle idetification device

Why? - Roadmap of B Physics



Fundamental Questions in Flavor Physics

Are there New Physics Phases and New sources of CP Violation Beyond the SM ?

Experiments: b→s CPV, compare CPV angles from tree and loops

Are there new operators with quarks enhanced by New Physics ?

Experiments: $A_{FB}(B \to K^* l\, l)$, B→K π rates and asymmetries

Are there right-handed currents ?

Experiments: b→s γ CPV, B→V V triple-product asymmetries

Are there new flavor changing neutral currents ?

Experiments: b→s ν ν bar, D-Dbar mixing+CPV+rare, τ →μ γ

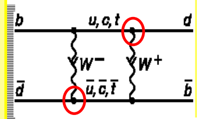
These questions can only be answered at a Super B Factory.

Super B Factory Motivation

- Physics beyond the Standard Model (SM) must exist.
  - **finite m_ν**
  - **gravity**

- If the LHC finds New Physics at the TeV scale,
  - **its flavor structure must be examined experimentally. A super B factory is the best tool for this purpose.**

<u>cf. Physics of top quark</u>
First estimate of mass: BB mixing → ARGUS
Direct production, Mass, width etc. → CDF/D0
Off-diagonal couplings, phase → BaBar/Belle



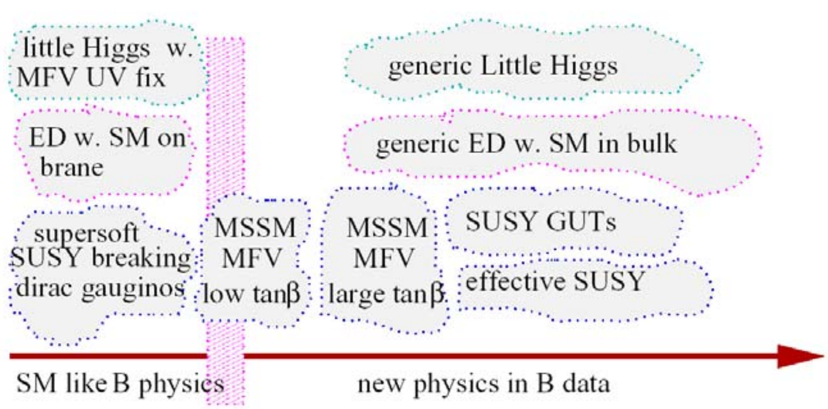
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- If the LHC finds nothing but a SM-like Higgs,
  - **searching for deviations from the SM in flavor physics will be one of the best ways to find new physics.**

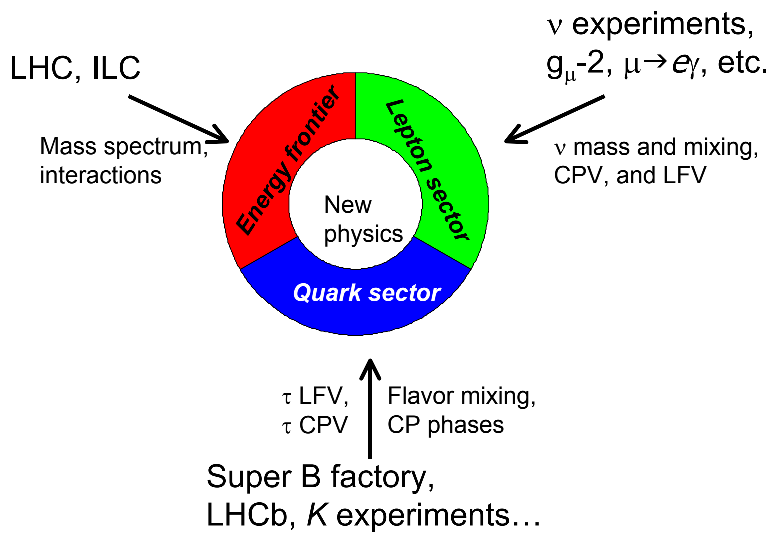
New physics effects in B physics

Different New Physics scenarios
and their effects in *B* decays.

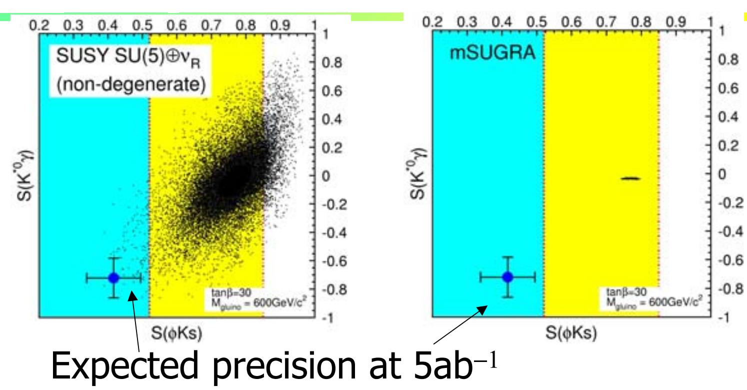
G.Hiller



A Broad Unbiased Approach to New Physics



CPV in b → s and diagnosis of new physics

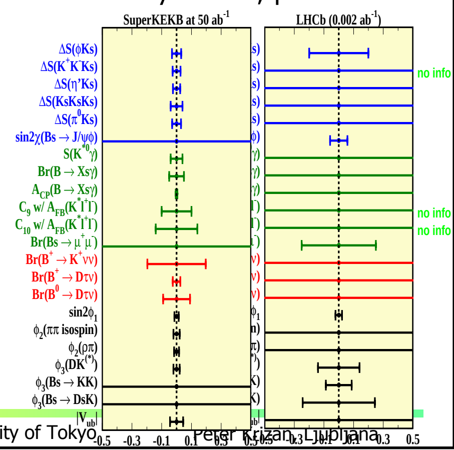


Many other examples of using correlations to distinguish new physics scenarios have been examined.

T.Goto, Y.Okada, Y.Shimizu,T.Shindou, M.Tanaka (2002, 2004) + SuperKEKB LoI

Super-B and LHCb: complementary

- Clean environment → measurements that no other experiment can perform. Examples: CPV in ***B*** → ϕ***K⁰***, ***B*** → η'***K⁰*** for new phases, ***B*** → ***K****S*$\pi^0\gamma$ for right-handed currents.
- "*B*-meson beam" technique → access to new decay modes; proof $B \rightarrow \tau\nu$
  Example: discover $B \rightarrow K\nu\nu$.
- Measure new types of asymmetries
  Example: forward-backward asymmetry in ***b*** → ***s***$\mu\mu$, ***see***
- Rich, broad physics program including *B*, τ and charm physics
  Examples: searches for $\tau \rightarrow \mu\gamma$ and *D*-*D* mixing with unprecedented sensitivity.



Comparison with LHCb

Observable	Belle 2003 (0.14ab^{-1})	SuperKEKB (5 ab^{-1})	SuperKEKB (50 ab^{-1})	LHCb (0.002ab^{-1})
$\Delta S_{\phi K^0_S}$	0.51	0.079	0.031	0.2 [390]
$\Delta S_{K^+K^-K^0_S}$	$^{+0.32}_{-0.26}$	0.056	0.026	
$\Delta S_{\eta' K^0_S}$	0.27	0.049	0.024	×
$\Delta S_{K^0_S K^0_S K^0_S}$	NA	0.14	0.04	×
$\Delta S_{\pi^0 K^0_S}$	NA	0.10	0.03	×
$\sin 2\chi\ (B_s \rightarrow J/\psi\phi)$	×	×	×	0.058
$S_{K^{*0}\gamma}$	NA	0.14	0.04	×
$\mathcal{B}(B \rightarrow X_s\gamma)$	26% (5.8 fb^{-1})	5%	5%	×
$A_{CP}(B \rightarrow X_s\gamma)$	0.064	0.011	5×10^{-3}	×
C_9 from $\overline{A}_{FB}(B \rightarrow K^*\ell^+\ell^-)$	NA	32%	10%	
C_{10} from $\overline{A}_{FB}(B \rightarrow K^*\ell^+\ell^-)$	NA	44%	14%	
$\mathcal{B}(B_s \rightarrow \mu^+\mu^-)$	×	×	×	4σ (3 years) [392]
$\mathcal{B}(B^+ \rightarrow K^+\nu\nu)$	NA		5.1σ	×
$\mathcal{B}(B^+ \rightarrow D\tau\nu)$	NA	12.7σ	40.3σ	×
$\mathcal{B}(B^0 \rightarrow D\tau\nu)$	NA	3.5σ	11.0σ	×
$\sin 2\phi_1$	0.06	0.019	0.014	0.022
ϕ_2 ($\pi\pi$ isospin)	NA	3.9°	1.2°	×
ϕ_2 ($\rho\pi$)	NA	2.9°	0.9°	×
ϕ_3 ($DK^{(*)}$)	20°	4°	1.2°	8°
ϕ_3 ($B_s \rightarrow KK$)	×	×	×	5°
ϕ_3 ($B_s \rightarrow D_sK$)	×	×	×	14°
$\lvert V_{ub}\rvert$ (inclusive)	16%	5.8%	4.4%	×
$\mathcal{B}(\tau \rightarrow \mu\gamma)$	$< 3.1 \times 10^{-7}$	$< 1.8 \times 10^{-8}$		
$\mathcal{B}(\tau \rightarrow \mu(e)\eta)$	$< 3.4(6.9) \times 10^{-7}$	$< 5 \times 10^{-9}$		
$\mathcal{B}(\tau \rightarrow \ell\ell\ell)$	$< 1.4\text{-}3.1 \times 10^{-7}$	$< 5 \times 10^{-9}$		

SuperKEKB LoI
hep-ex/0406071

SuperKEKB Parameters

Stored current:
1.27/1.7 A (KEKB)
→ 4.1/9.4 A (SuperKEKB)

Beam–beam parameter:
0.057 (KEKB)
→ 0.17 (SuperKEKB)

Lorentz factor

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Classical electron radius   Beam size ratio

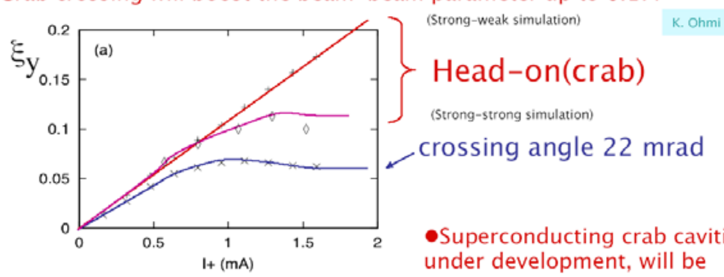
Geometrical reduction factors due to crossing angle and hour-glass effect

Luminosity:
0.15×10^{35} cm^{-2}s^{-1} (KEKB)
3.5×10^{35} cm^{-2}s^{-1} (SuperKEKB)

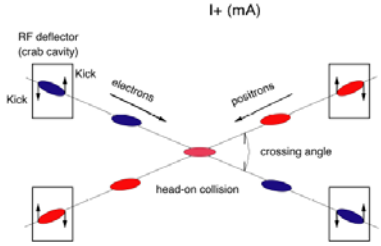
Vertical β at the IP:
5.2/6.5 mm (KEKB)
→ 3.0/3.0 mm (SuperKEKB)

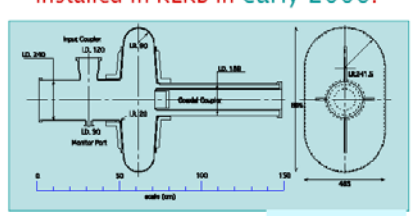
Crab Cavity

- Crab crossing will boost the beam–beam parameter up to 0.17!



- Superconducting crab cavities are under development, will be installed in KEKB in early 2006.





K. Hosoyama, et al

SuperKEKB Design

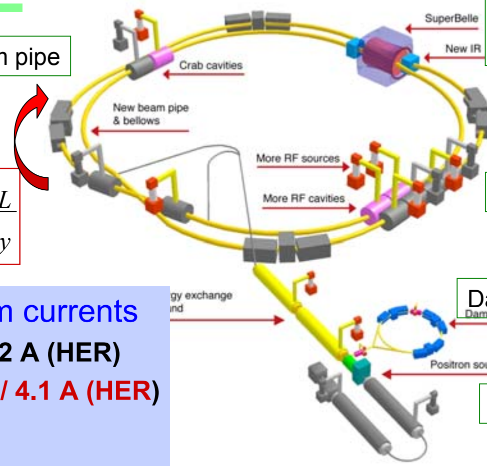
Interaction Region
Crab crossing
θ=30mrad.
βy*=3mm
New QCS

New Beam pipe

8GeV (e+, 4.1A)

3.5GeV (e-, 9.6A)

$$L \approx \frac{\gamma_\pm}{2er_e} \frac{I_\pm \xi_{\pm y}}{\beta_y^*} \frac{R_L}{R_y}$$



More RF power

Damping ring

Linac upgrade

Increase beam currents
- 1.6 A (LER) / 1.2 A (HER)
  → 9.6 A (LER) / 4.1 A (HER)

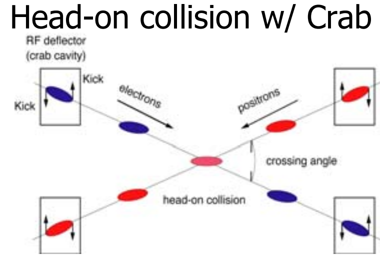
Smaller β_y^*
- 6 mm→3 mm

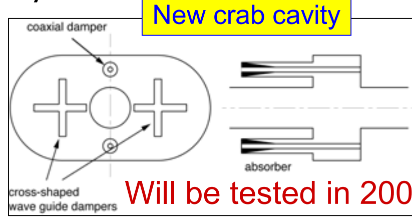
Increase ξ_y
- 0.05→0.28(W-S)

$L=3.5\times10^{35}cm^{-2}s^{-1}$

Super-KEKB (cont'd)

- Head-on collision w/ Crab cavity

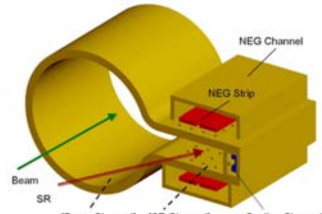




New crab cavity

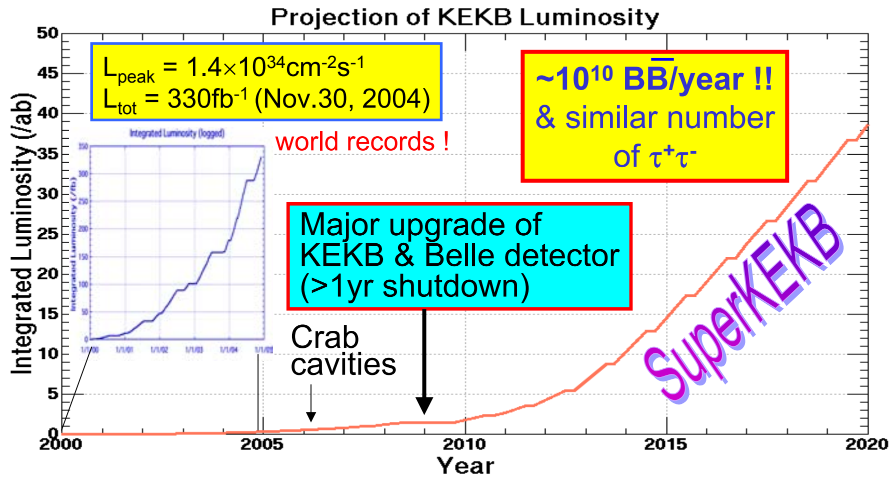
Will be tested in 2006.

- Ante-chamber /solenoid for reduction of electron clouds



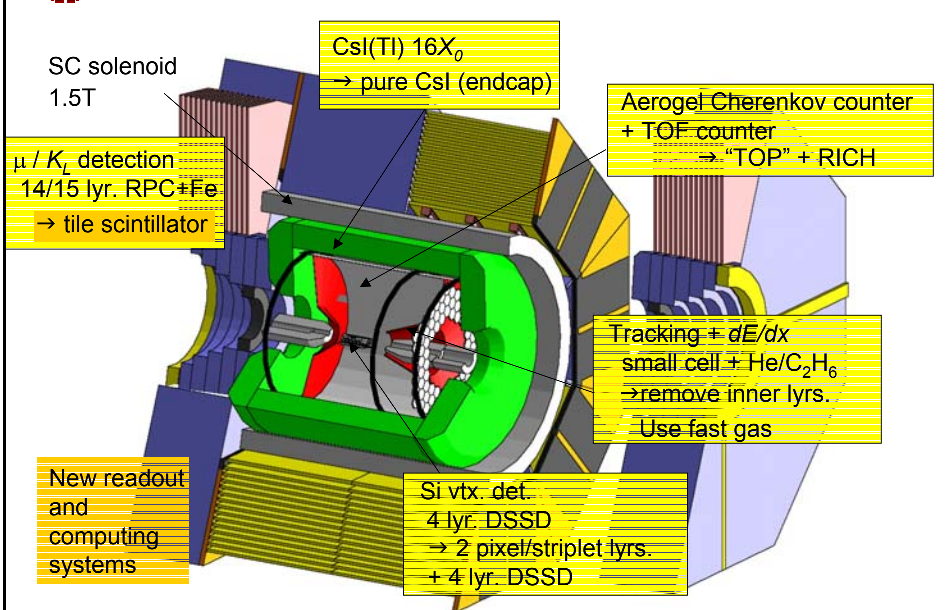
Ante-chamber
with solenoid field

KEKB Upgrade Scenario



L_{peak} ($cm^{-2}s^{-1}$)	1.4×10^{34}	5×10^{34}	5×10^{35}
L_{int}	330 fb^{-1}	~1 ab^{-1}	~10 ab^{-1}

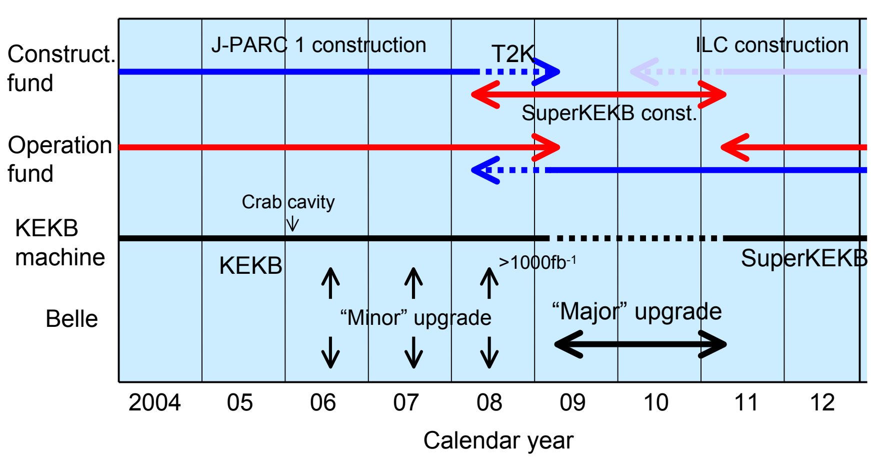
Belle Upgrade



Baseline Design of SuperBelle

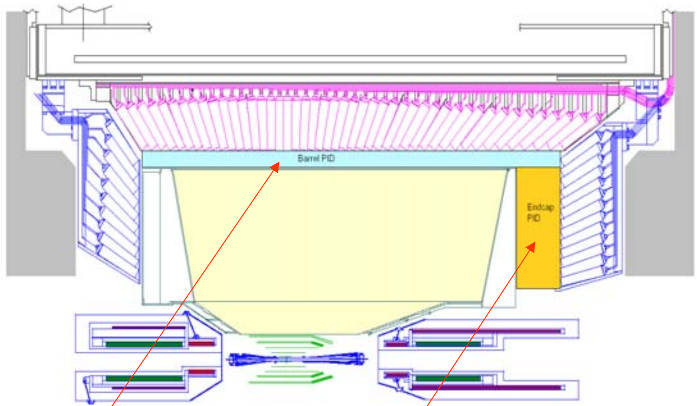
- Vertexing detector: “striplet” + APV25 or pixel
- Central drift chamber: small cell + faster gas
- PID device: TOP(B) + Aerogel RICH(E)
- EM calorimeter: Pure CsI + tetrode (E)
- Scintillator K_L and μ detector (KLM) <– no RPCs
- Pipelined DAQ
- Much bigger computing system

Proposed Schedule



June 5-8, 2006 Course at University of Tokyo Peter Križan, Ljubljana

Belle upgrade – side view

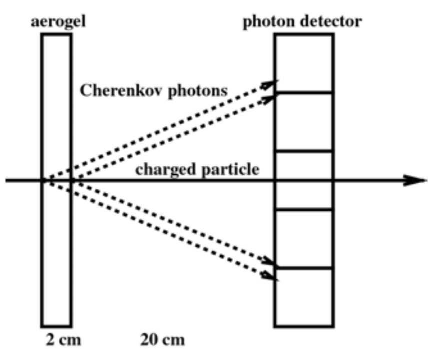


Two new particle ID devices, both RICHes:

Barrel: Time-Of-Propagation (TOP) or focusing DIRC

Endcap: proximity focusing RICH

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

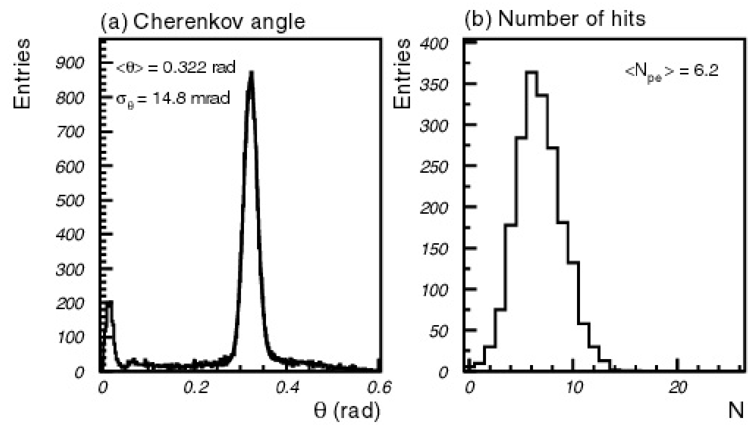
$d\theta_c$(meas.) = σ_0 ~ 13 mrad
With 20mm thick aerogel and 6mm PMT pad size

→ 6σ separation with N_{pe}~10

Beam test: Cherenkov angle resolution and number of photons

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation

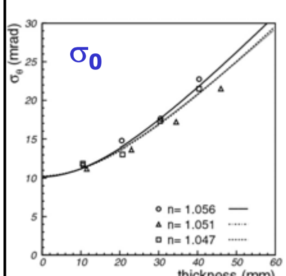


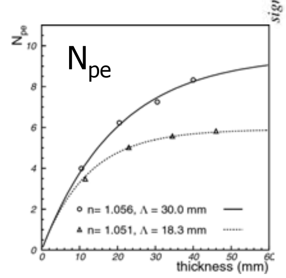
-> Number of photons has to be increased.

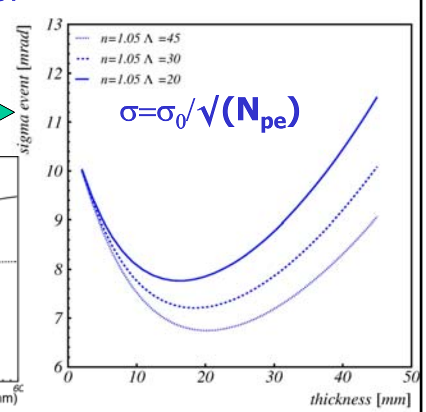
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}



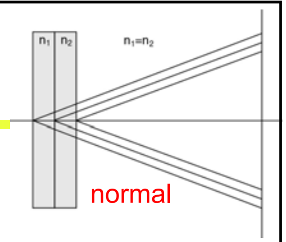




Minimize the error per track: $\sigma=\sigma_0/\sqrt{N_{pe}}$

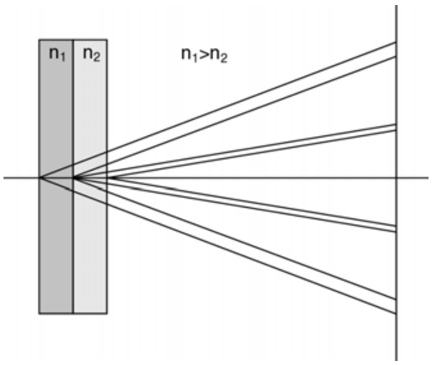
Optimum is close to 2 cm

Radiator with multiple refractive indices

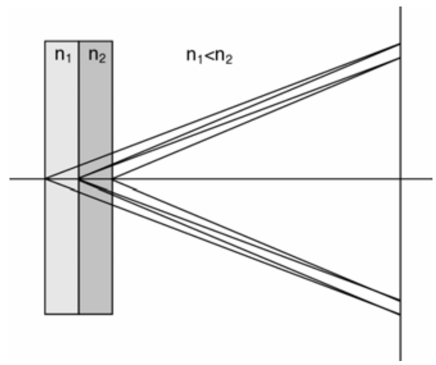


How to increase the number of photons without degrading the resolution?

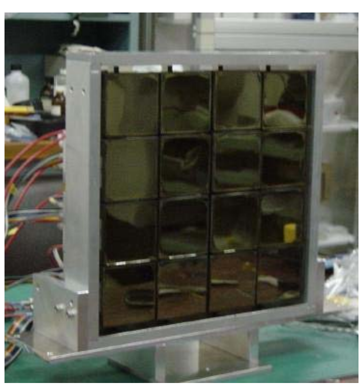
- measure two separate rings
"defocusing" configuration



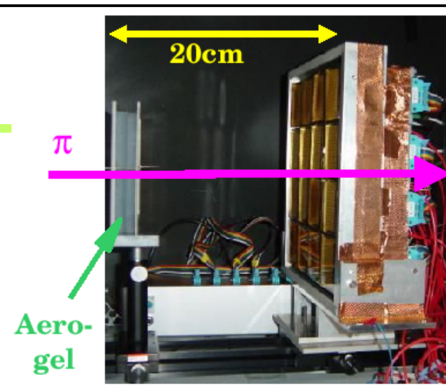
- measure overlaping rings
"focusing" configuration



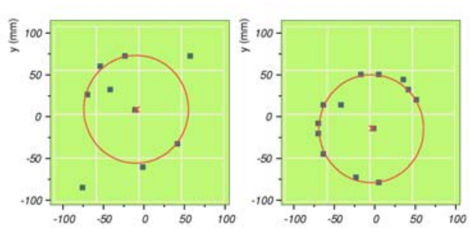
Beam tests



Photon detector: array of 16 H8500 PMTs

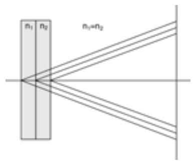


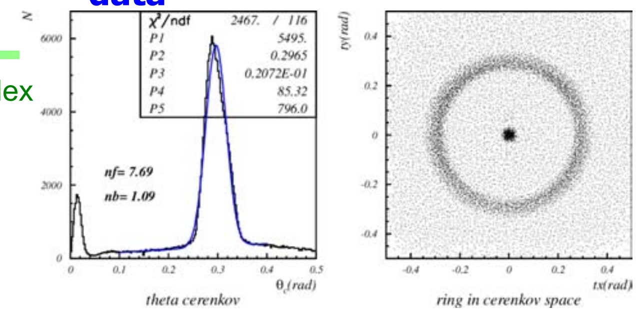
Clear rings, little background



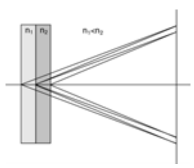
FOCUSING CONFIGURATION - data

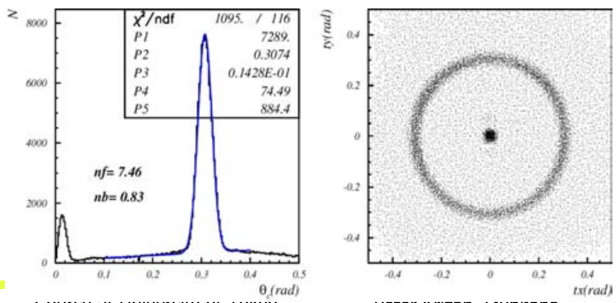
4cm aerogel single index





2+2cm aerogel





Aerogel production R&D

- Colloidal formation

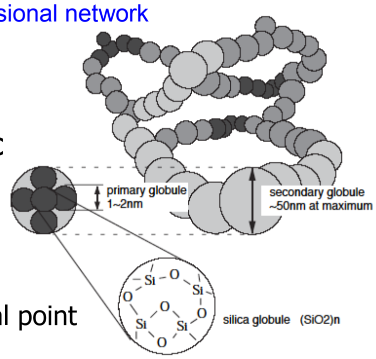
nSi(OR)$_4$ + 4nH$_2$O → nSi(OH)$_4$ + 4nH$_2$O hydrolysis

nSi(OH)$_4$ → (SiO$_2$)$_n$ + 2nH$_2$O condensation

ammonia alcohol

→ 3-dimensional network

- Treatment for hydrophobic
- Supercritical drying
  - Use CO_2 extraction
  - Safer due to low supercritical point
    - 31degree & 7.5MPa



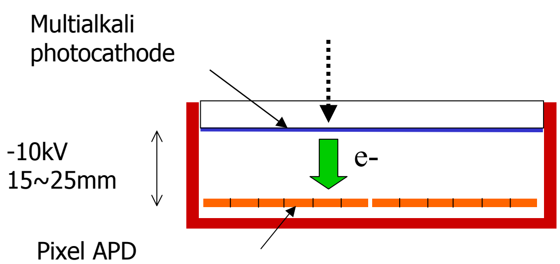
cf: methanol: 240degree & 8.1MPa

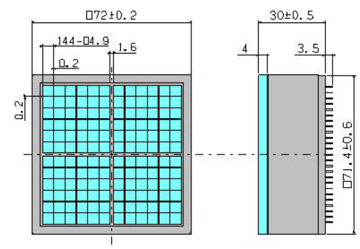
Photon detectors

Need: Operation in a high magnetic field (1.5T)
Pad size ~5-6mm

Candidates:

- MCP PMT (Burle 85011)
- large active area HAPD of the proximity focusing type





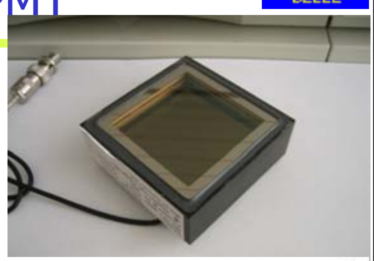
HAPD R&D project in collaboration with HPK.

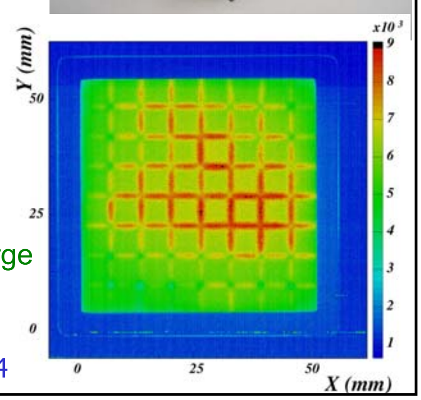
Problems: sealing the tube at the window-ceramic box interface, photocathode activation changes the properties of APD.

Photon detector R&D: Burle MCP-PMT

BURLE 85011 MCP-PMT:

- multi-anode PMT with 2 MCPs
- 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%





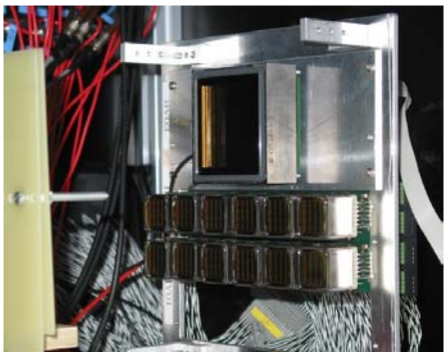
count rates - all channels: charge sharing at pad boundaries

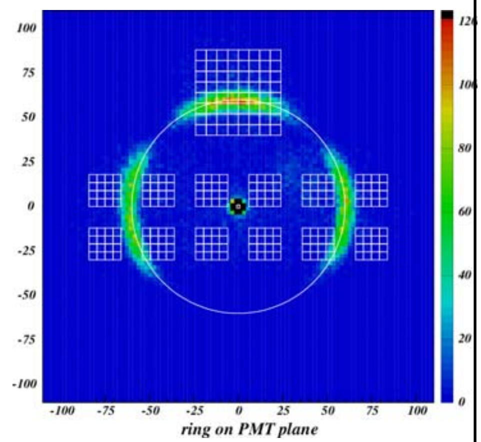
→Proc. IEEE NSS 2004

June 5-8, 2006

Burle MCP PMT beam test

- **BURLE MCP-PMT** mounted together with an array of 12(6x2) **Hamamatsu R5900-M16 PMTs** at 30mm pitch (reference counter)





Burle MCP PMT beam test

Resolution and number of photons (clusters)

- 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**

Open questions

Operation in high magnetic field:

- the present tube with 25μm pores only works up to 0.8T, for 1.5T need ~10μm
- 10μm version with 4 channels available since June, tests done (J. Va'vra)

Number of photons per ring: too small. Possible improvements:

- bare tubes (52%->63%)
- increase active area fraction (bare tube 63%->85%)
- increase the photo-electron collection efficiency (from 60% at present up to 70%)

-> Extrapolation from the present data 4.5 ->8.5 clusters per ring

σ_ϑ: 6 mrad -> 4.5 mrad (per track)

-> >5 σ π/K separation at 4 GeV/c

Aging of MCP-PMTs ?

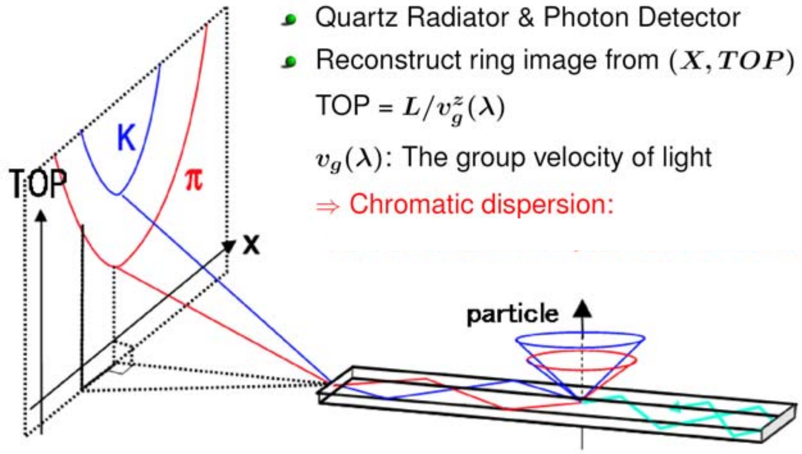
TOP counter R&D status

- Ring Imaging Cherenkov counter
with precise measurement of the Time Of Propagation (and TOF)
  - Quartz Radiator & Photon Detector
  - Reconstruct ring image from (X, TOP)

TOP = $L/v_g^z(\lambda)$

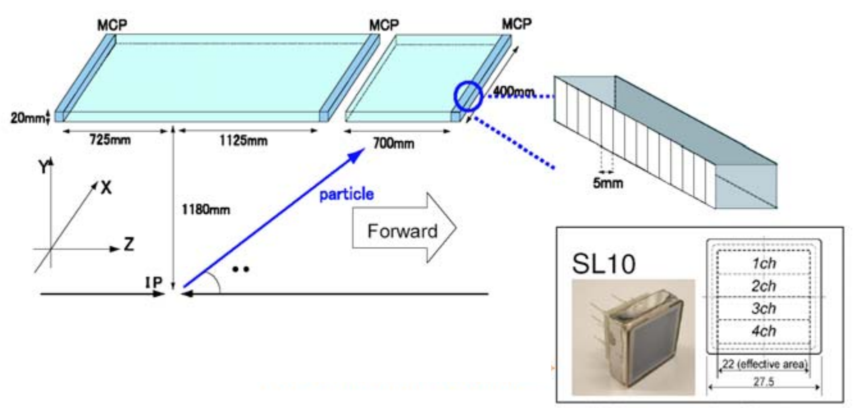
$v_g(\lambda)$: The group velocity of light

⇒ Chromatic dispersion:



TOP baseline design

- Radiator: Quartz bar of 255cm^L × 40cm^W × 2cm^T × 18 units in ϕ
segmented at $\theta = 46°$ to reduce chromatic dispersion error
- Photon detector: Multi-anode MCP-PMT at three readout planes
SL10 (R&D w/ HPK) : 5mm pitch linear array, $\sigma_{TTS} \sim 30$ ps.



Photon detectors for the TOP counter

Tests on the bench: amplification and time resolution in high magnetic field.

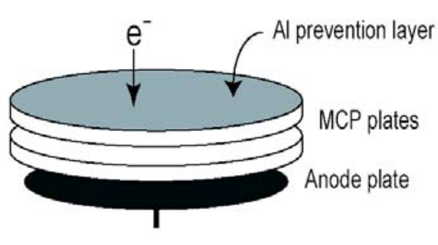
3 MCP-PMTs studied: Burle (25 μm pores), BINP (6μm pores), Hamamatsu SL10 (6 and 10μm pores)

All: good time resolution at B=0, 25μm pore tube does not work at 1.5T → NIM A528 (2004) 763

SL10: cross-talk problem solved by segmenting the electrodes at the MCP

MCP ageing

- Study tubes with and without protective Al foil (stops feedback ions to reach the photocathode, but reduces the photo-electron collection efficiency by 60%) from two producers, Hamamatsu and BINP, with bi-alkali phocathodes.



→Al foil is needed