Physics & Detectors for Super-KEKB

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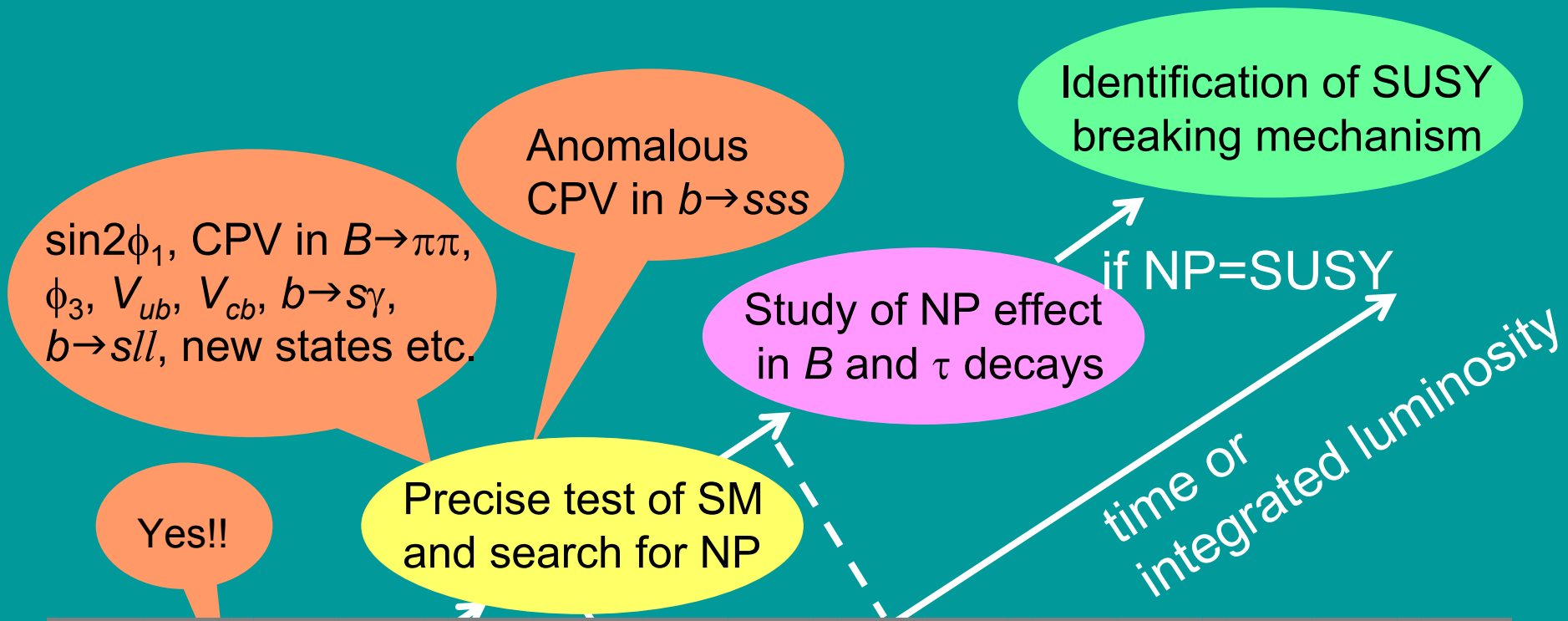
Nagoya University

November 11, 2005

Super-B meeting at Frascati

Grand Scenario of B Physics



Search for New Origin of Flavor Mixing & CP Violation

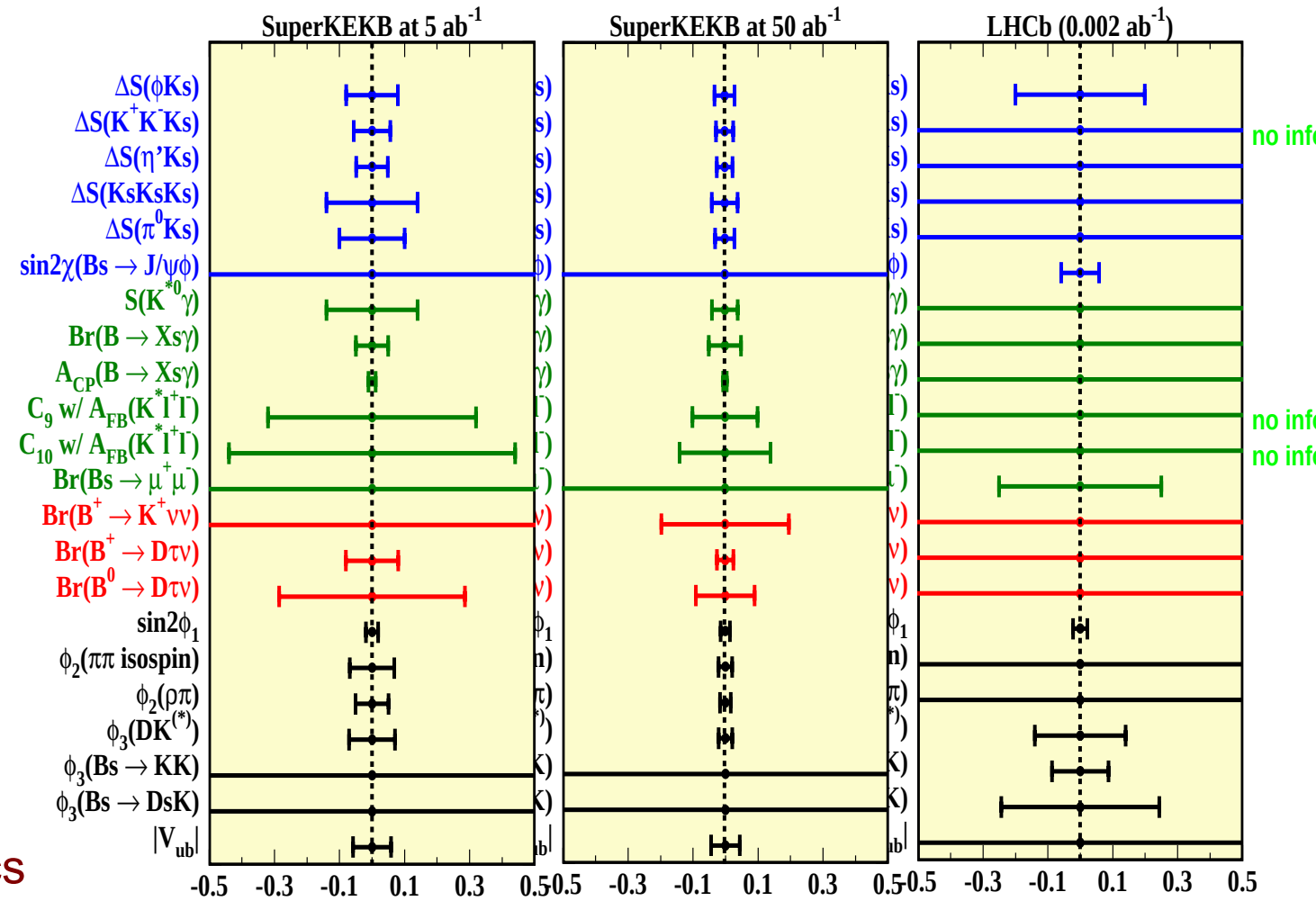
Elucidation of New Physics Scenario

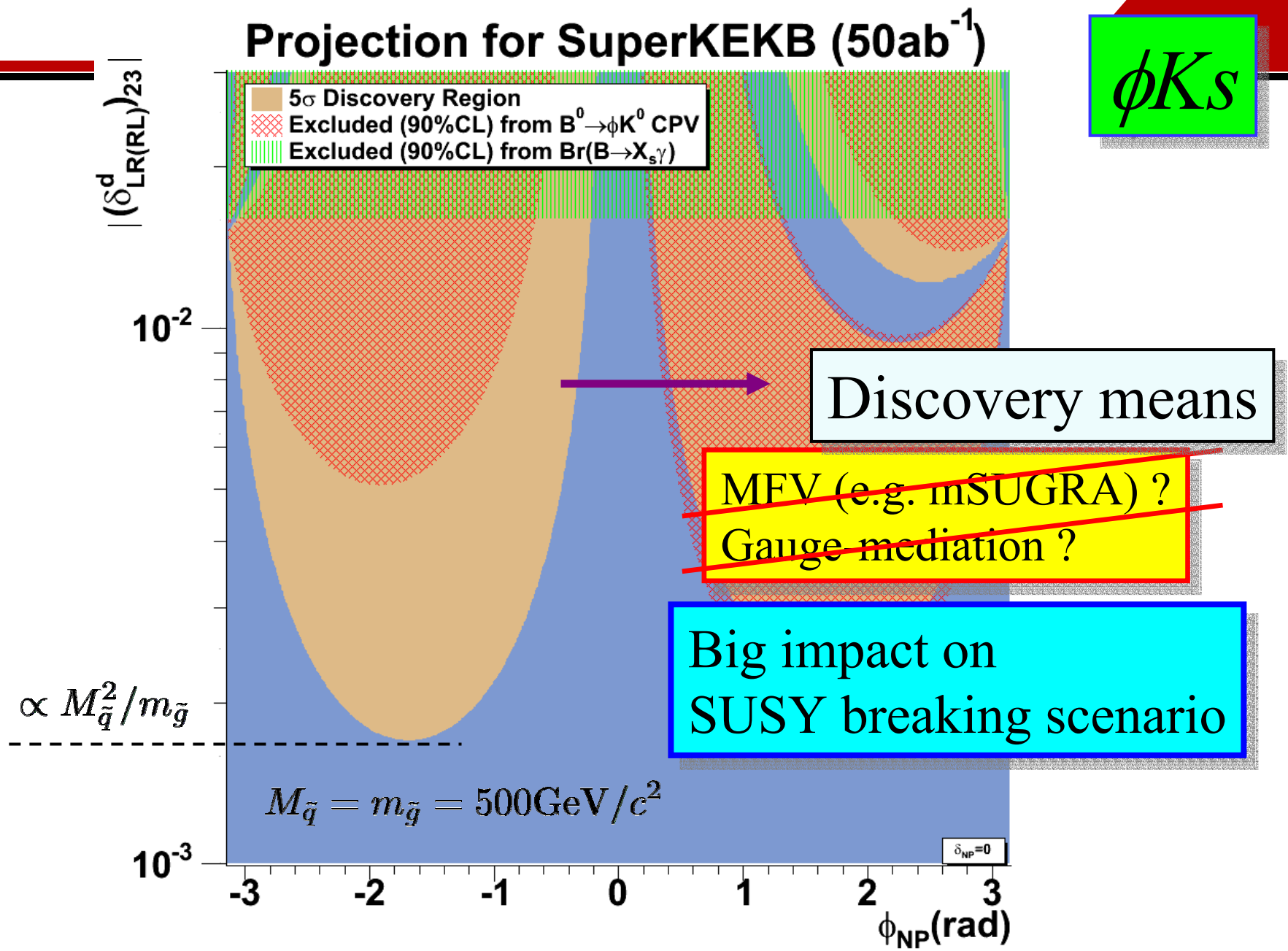
Physics Reach at Super-KEKB

		SuperKEKB (5 ab^{-1})	(50 ab^{-1})
CPV ($b \to s$)	$S(\phi K_S)$	0.079	0.031
	$S(K^+K^-K_S)$	0.056	0.026
	$S(\eta' K_S)$	0.049	0.024
	$S(K_S K_S K_S)$	0.14	0.04
	$S(\pi^0 K_S)$	0.10	0.03
	$\sin 2\beta(B \to J/\psi K^0)$	×	×
FCNC	$S(K^{*0}\gamma)$	0.14	0.04
	$A_{CP}(b \to s\gamma)$	5%	5%
	$\mathrm{Br}(B \to X_s\gamma)$	0.011	5×10^{-3}
	$A_{FB}(B \to K^{*}\ell^+\ell^-)$ zero-crossing	32%	10%
	C_9 w/ $A_{FB}(B \to K^{*}\ell^+\ell^-)$	44%	14%
	C_{10} w/ $A_{FB}(B \to K^{*}\ell^+\ell^-)$	×	×
w/ ν	$\mathrm{Br}(B \to \mu\nu)$		5.1σ
	$\mathrm{Br}(B \to \tau\nu)$	8%	2.5%
	$\mathrm{Br}(B \to D\tau\nu)$	3.5σ	9%
CKM	$\lvert V_{ub}\rvert$	0.019	0.014
	$\phi_2(\pi\pi$ isospin)	3.9°	1.2°
	$\phi_2(\rho\pi)$	2.9°	0.9°
	$\phi_3(DK^{(*)})$	4°	1.2°
	$\phi_3(B_s \to KK)$	×	×
	$\phi_3(B_s \to D_s K)$	×	×
	$\lvert V_{ub}\rvert$	5.8%	4.4%

and rich τ physics

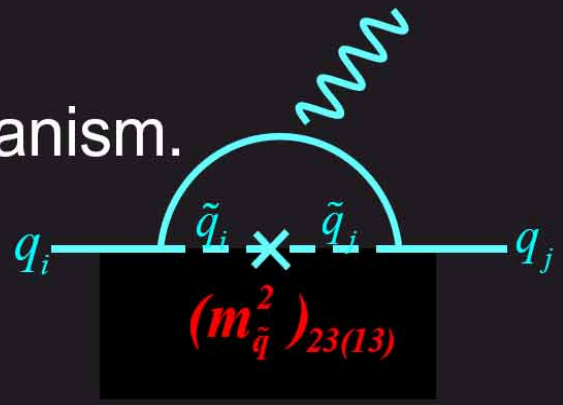
SuperKEKB 5ab^{-1} 50ab^{-1} LHCb 2fb^{-1}




Projection for SuperKEKB (50ab-1)
φKs
5σ Discovery Region
Excluded (90%CL) from B0→φK0 CPV
Excluded (90%CL) from Br(B→Xsγ)
$|(\delta^d_{LR(RL)})_{23}|$
10-2
10-3
$\propto M^2_{\tilde{q}}/m_{\tilde{g}}$
$M_{\tilde{q}} = m_{\tilde{g}} = 500\mathrm{GeV}/c^2$
δNP=0
-3
-2
-1
0
1
2
3
φNP(rad)
Discovery means
MFV (e.g. mSUGRA) ?
Gauge mediation ?
Big impact on
SUSY breaking scenario

In Case of SUSY…

- The squark/slepton mass matrix
  - Sensitive to SUSY breaking mechanism.



$$\left(m^2_{\tilde{q}}\right)_{ij} = \begin{pmatrix} m^2_{11} & m^2_{12} & m^2_{13} \\ m^2_{21} & m^2_{22} & m^2_{23} \\ m^2_{31} & m^2_{32} & m^2_{33} \end{pmatrix}$$

Off-diagonal terms
Flavor Physics
Luminosity frontier

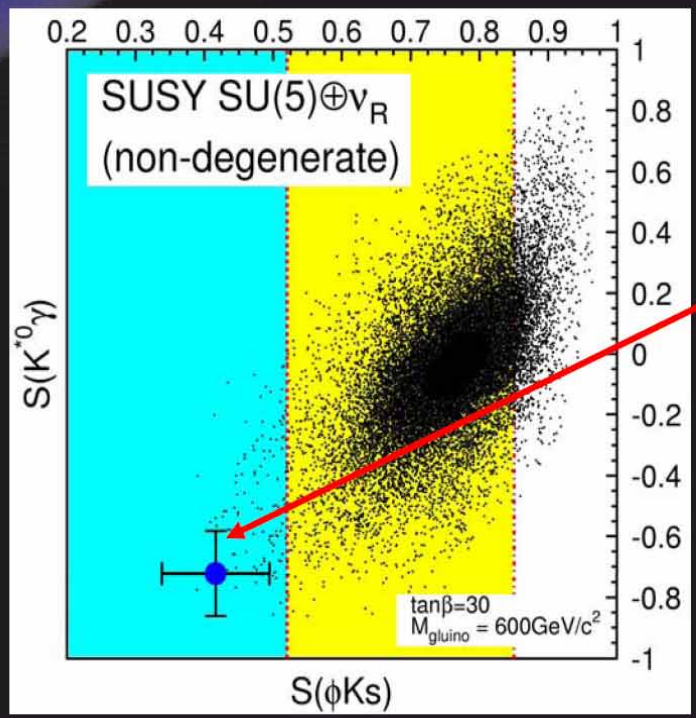
Diagonal terms:
LHC/ILC
Energy frontier

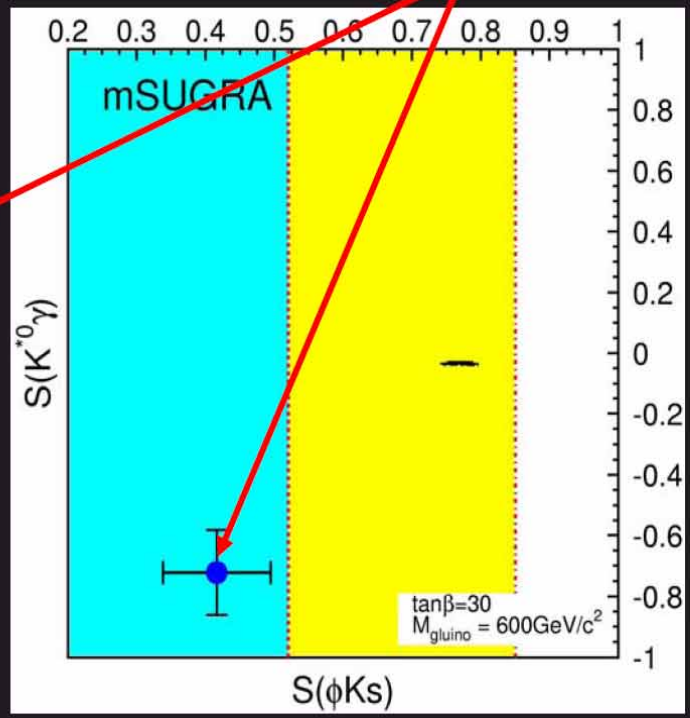
B and τ are in the 3rd generation ("hub" quark & lepton)
➡ probe for both 3→2, 3→1 transitions.

CPV in b→s and SUSY Scenario

- Different SUSY breaking scenario can be distinguished in $A_{cp}^{mix}(\phi Ks)$ - $A_{cp}^{mix}(K^{*0}\gamma)$ correlation.

Expected precision at $5ab^{-1}$



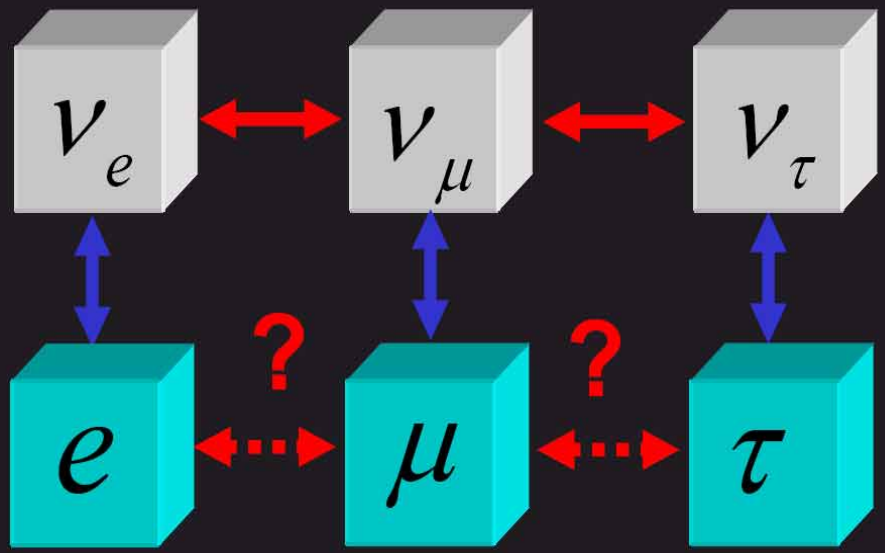


Correlation of other ovservables are also useful.

$A_{cp}^{dir}(X_s\gamma)$, $A_{FB}(X_s ll)$, $Br(\tau\rightarrow\mu\gamma)$, CKM

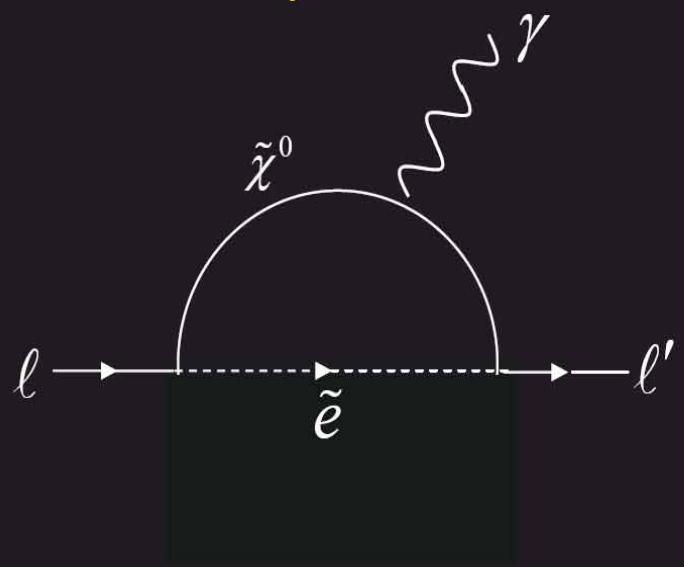
Lepton Flavor Violation

- Quarks have flavor mixing.
- Neutrino mixing has been found.
- What about charged leptons ?



(Original figure by Dr. Kuno / Osaka Univ.)

$\ell \to \ell' \gamma$ in SUSY

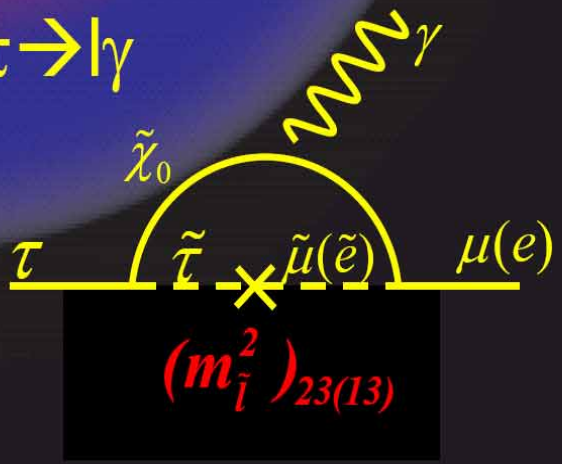


LFV Search at Super-B

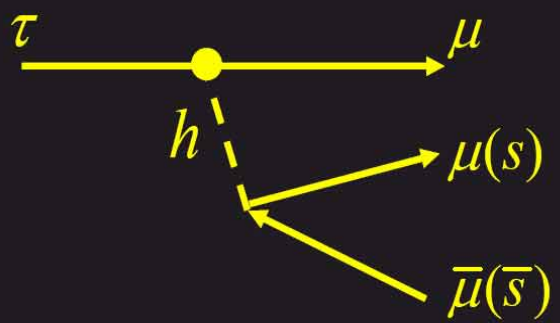
LFV in neutrino sector ⇒LFV in charged leptons ?

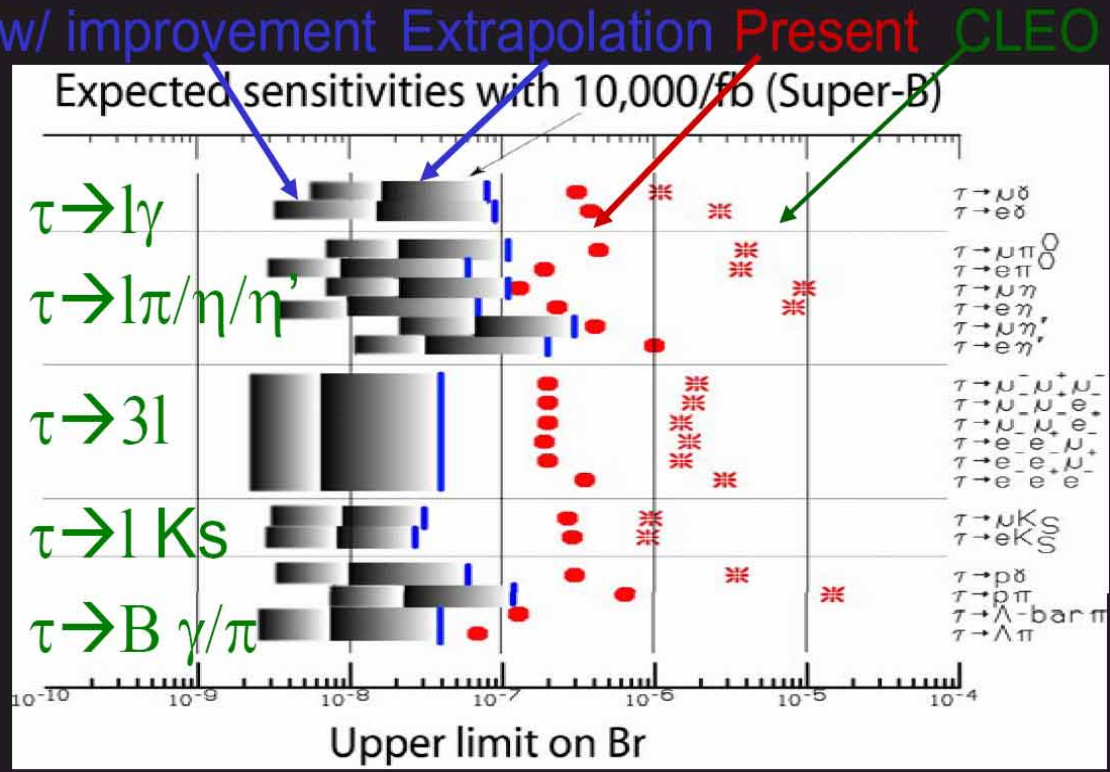
Search for "SM Zero"

$\tau \rightarrow l\gamma$



$\tau \rightarrow 3l$, $l\eta$





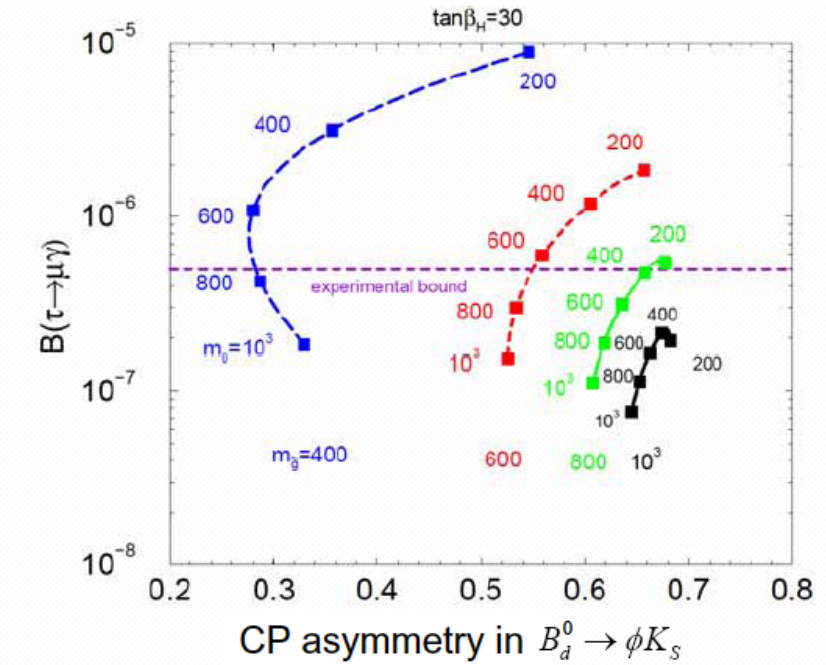
Search region enters into $O(10^{-8} \rightarrow 10^{-9})$

Interplay between B and τ

b-s penguin v.s. $\tau \to \mu\gamma$

GUT relation: $(m^2_{\tilde{d}_R})_{23} \approx (m^2_{\tilde{l}_L})_{23}\ e^{i(\varphi_1-\varphi_2)}$

Thus, b-s penguin processes and $\tau \to \mu\gamma$ are correlated in the SUSY GUTs.



$m_{\nu_\tau} = 5\times10^{-2}\,eV,$

$U_{\mu 3} = 1/\sqrt{2},$

$M_{N_\tau} = 5\times10^{14}\,GeV,$

$\tan\beta = 30$

This is non-trivial test for the SUSY GUTs.

J.Hisano @ Tau04 Workshop, Nara, Nov, 2004.

J.Hisano, Y.Shimizu PLB565(2003)183.

Comment

τ decay is an important physics program at luminosity frontier !

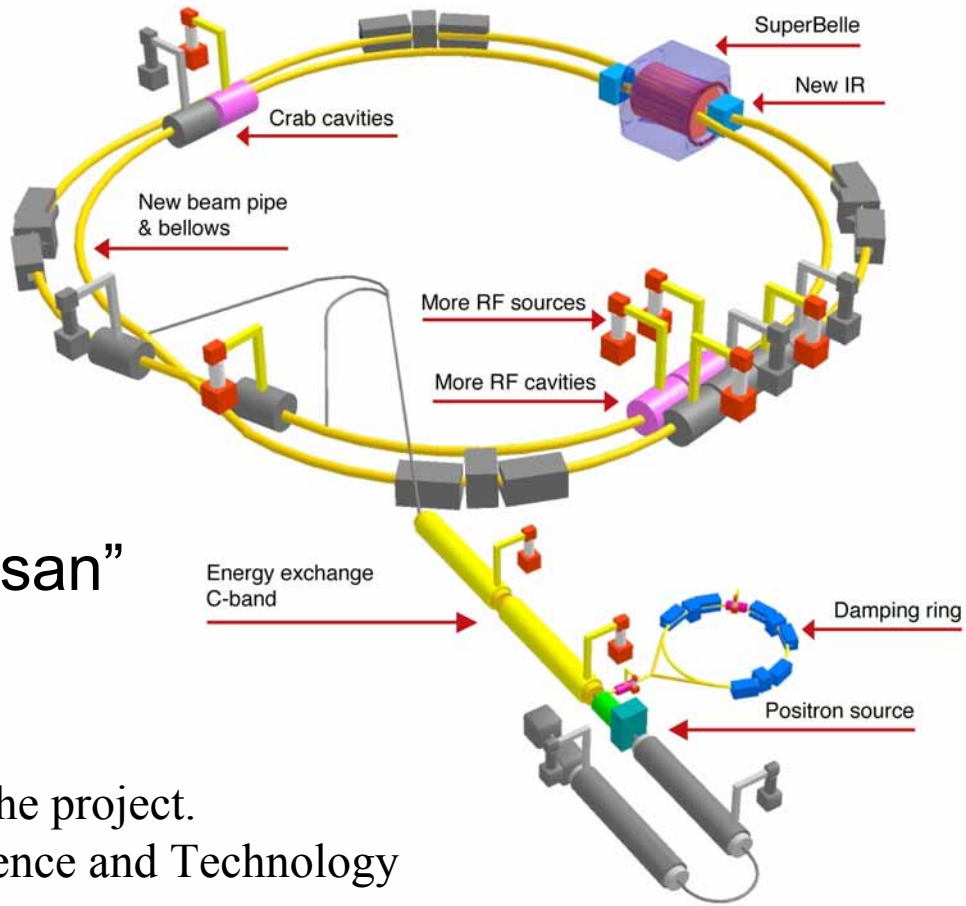
- Upper limit $O(10^{-8\sim-9})$ enough ?
- We need more studies to maximize the sensitivity at Super-B.
- LFV in τ decays would be a good application of e+e- machines w/ Lum. beyond $10^{35\sim36}$.
- If we start to see something at Super-B, it would strongly motivate us push forward the luminosity frontier.

SuperKEKB overview

- Super-high luminosity $\cong 4\times10^{35}$ cm^{-2}s^{-1}
  - 5×10^{9} $B\bar{B}$ per yr.
  - 4×10^{9} $\tau^{+}\tau^{-}$ per yr.

40 × KEKB design goal
25 × present world record from KEKB

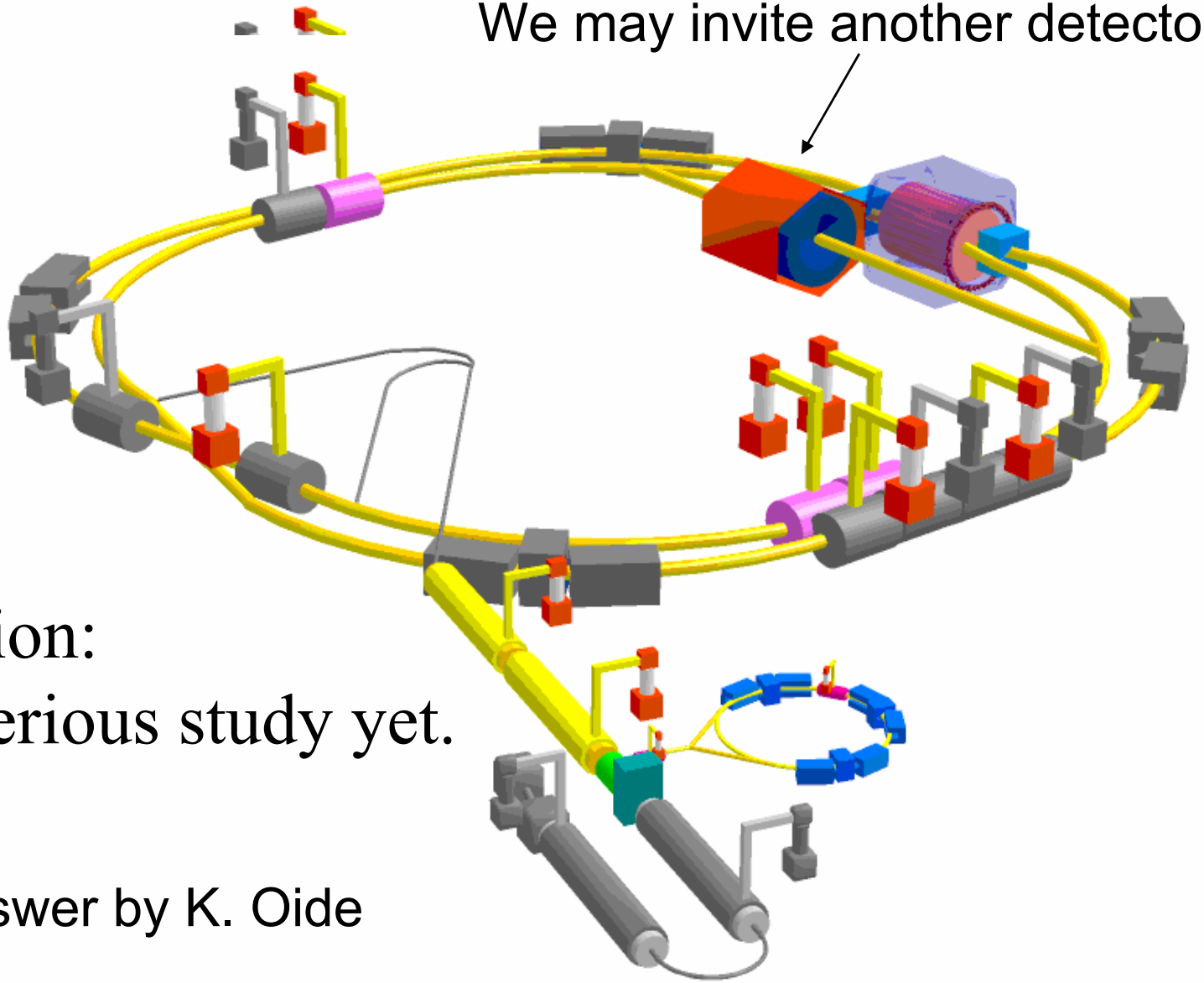
- Letter of Intent (LoI) in 2004
  - 276 authors from 61 institutions
  - available at http://belle.kek.jp/superb/loi
  - "Physics at Super B Factory" hep-ex/0406071



- Official budget request* ("gaisan" request) sent from KEK to MEXT** in Aug. 2005

*This does not mean the official approval of the project.
**Ministry of Education, Culture, Sports, Science and Technology

Second detector ?



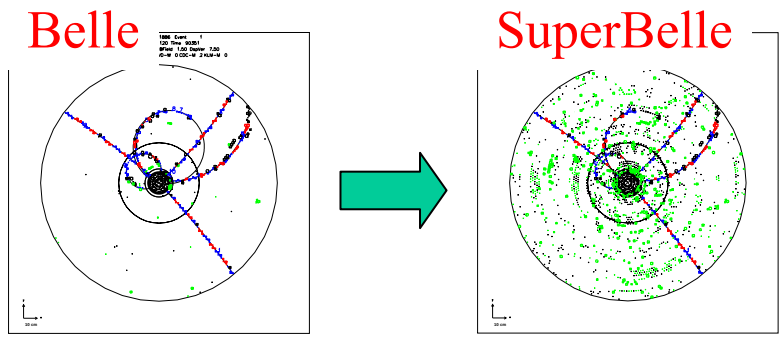
Caution:
No serious study yet.

Answer by K. Oide

HL6 workshop, 2004

Feature of Super-Belle Exp.

- Cleaner than hadron machines even after the upgrade
  - Many off-timing hits, but typical track eff. 91% → 89%

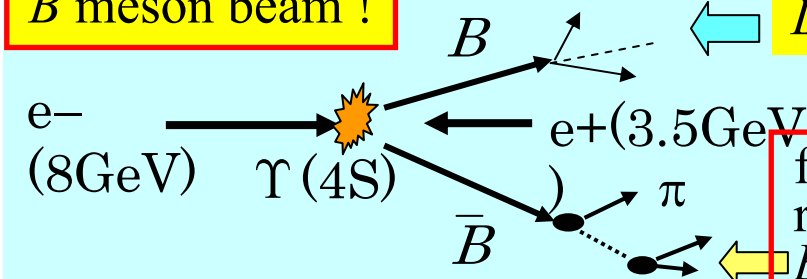


- *B* decays with neutrinos
  $B \to \underline{D\tau\nu}, \underline{\tau\nu}, \underline{u\,l\nu}$ etc.

Charged Higgs

Vub

B meson beam !



$D\tau\nu$ etc.

full (0.1~0.3%) reconstruction
$B \to D\pi$ etc.

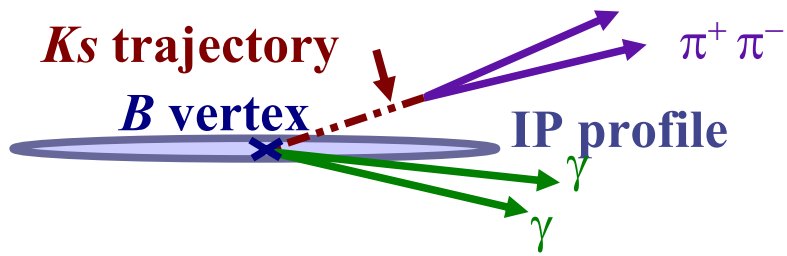
- *B* decays with γ, π^0

direct *CPV*

$\phi_2(\alpha)$ isospin analysis

$B \to Xs\gamma$, $\pi^0\pi^0$ etc.

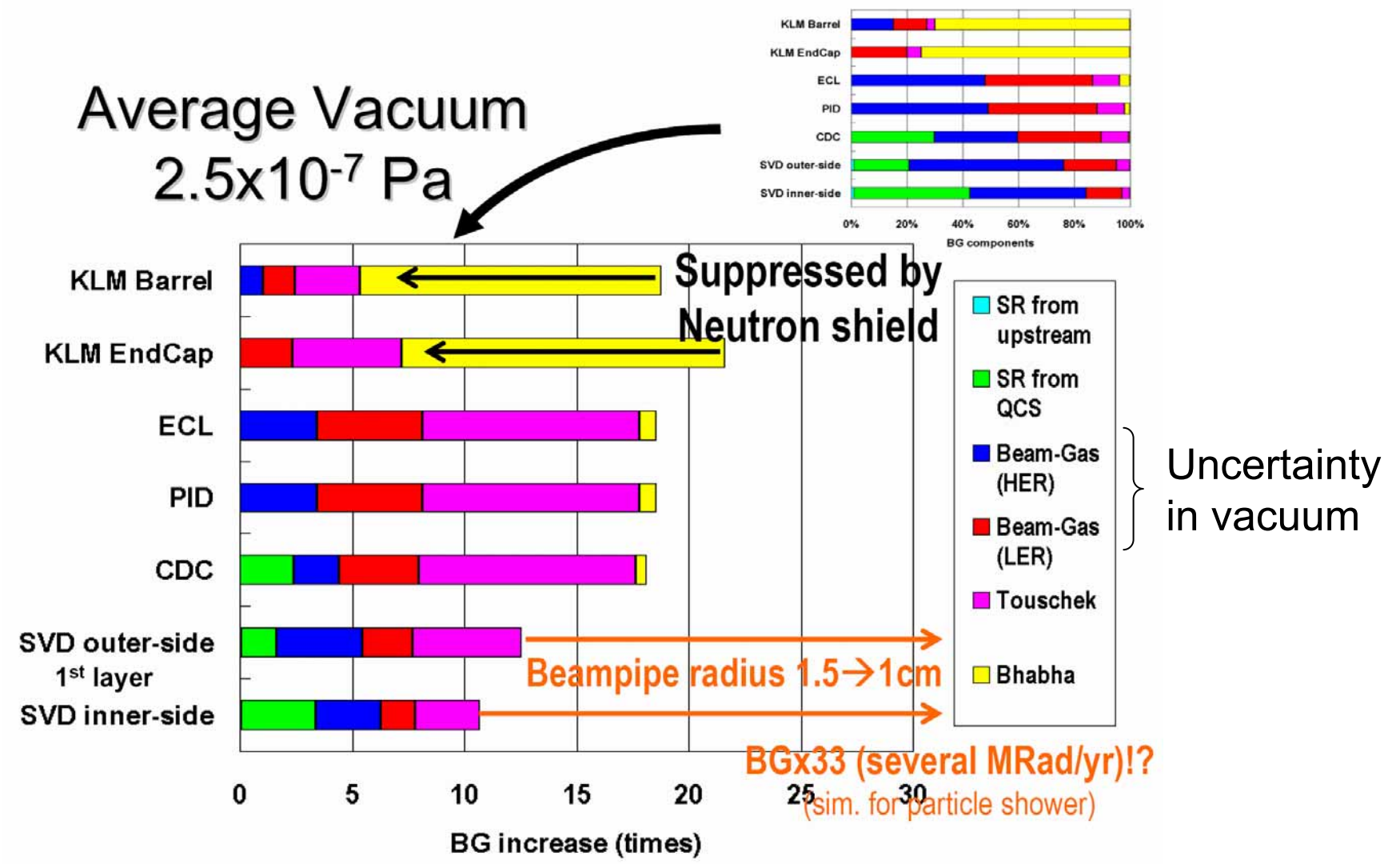
- *B* vertex reconstruction with *Ks* only !
  $B \to Ks\pi^0$, $Ks\pi^0\gamma$ etc.



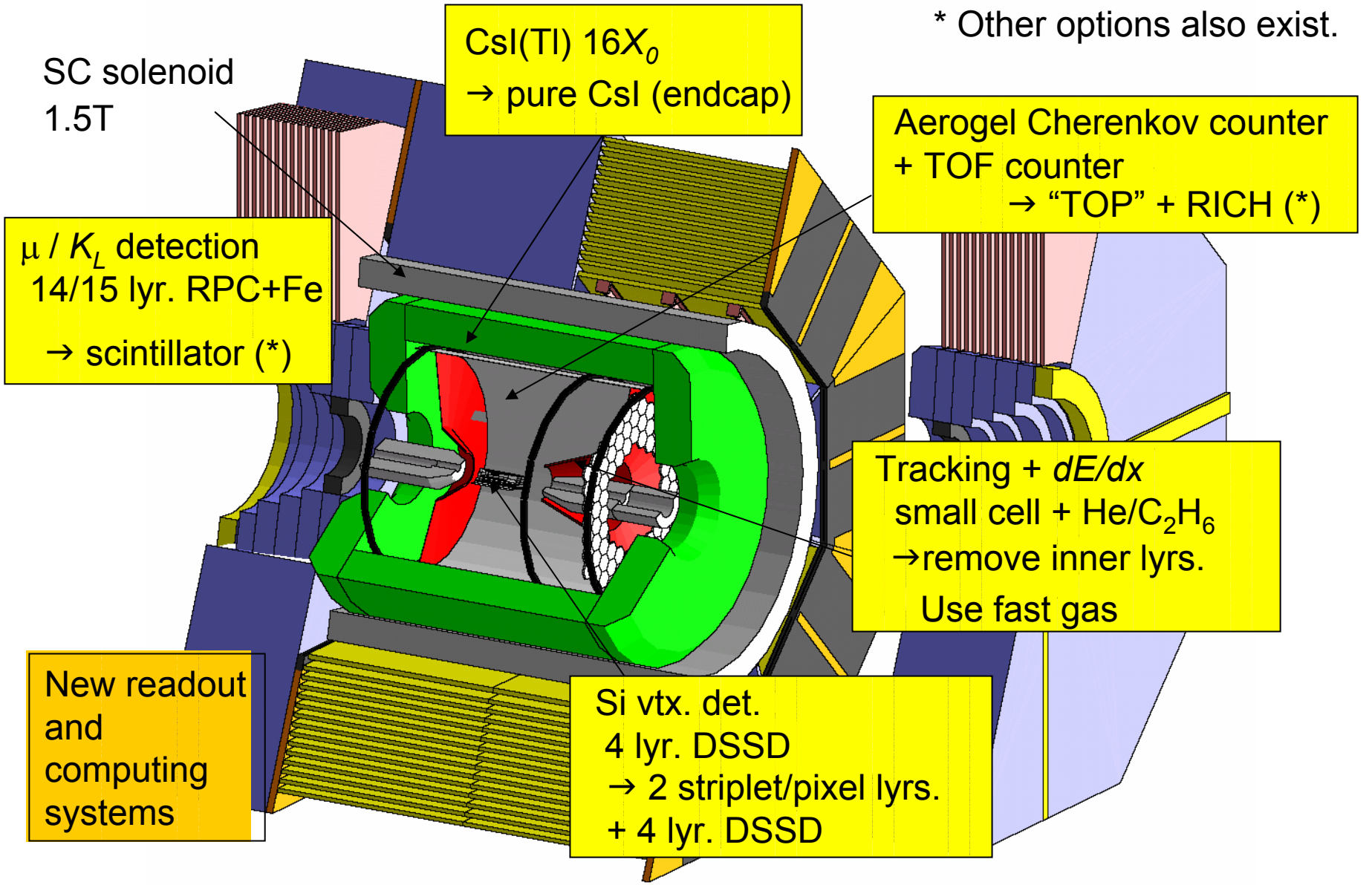
Detector Challenge

- Higher background
  - radiation damage and occupancy in the near beam detector (SVD/CDC)
  - fake hits and pile-up noise in ECL
  - neutron background in KLM?
- Higher event rate
  - higher rate trigger, DAQ and computing
- Require special features
  - Good K/π, low π μ identification $\leftarrow$ s$\mu\mu$ recon. eff.
  - Hermeticity $\leftarrow$ ν “reconstruction”
  - Full reconstruction

Beam Background

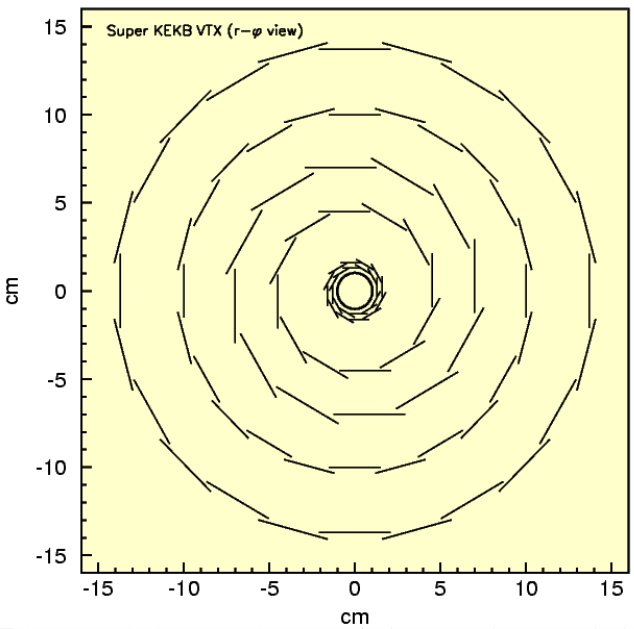


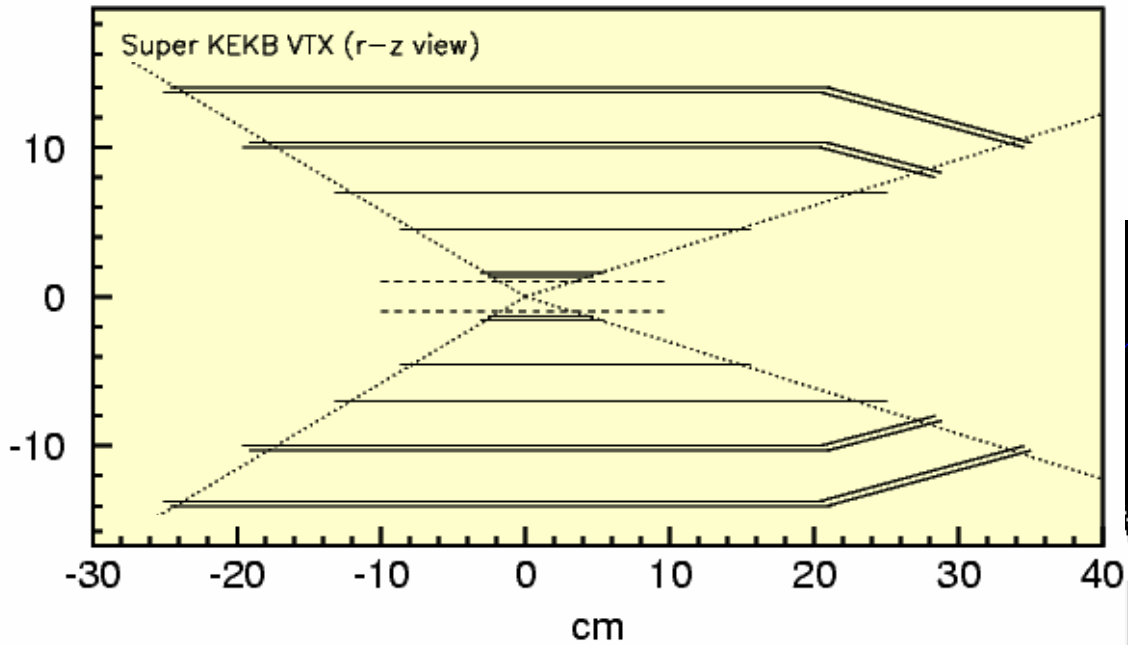
Super-Belle


* Other options also exist.
SC solenoid
1.5T
CsI(Tl) 16X_0
→ pure CsI (endcap)
Aerogel Cherenkov counter
+ TOF counter
→ "TOP" + RICH (*)
μ / K_L detection
14/15 lyr. RPC+Fe
→ scintillator (*)
Tracking + *dE/dx*
small cell + He/C_2H_6
→remove inner lyrs.
Use fast gas
New readout
and
computing
systems
Si vtx. det.
4 lyr. DSSD
→ 2 striplet/pixel lyrs.
+ 4 lyr. DSSD

Vertex detector for SuperKEKB

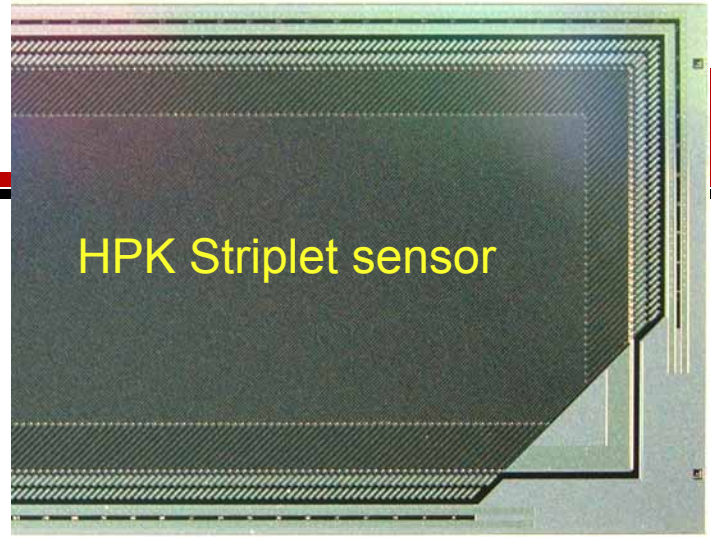
- Six layers from 1.3 to 14 cm radius.
  - Number of readout channels: ~4x SVD2.0





- The baseline is to use APV25 and striplet DSSD.
  - Continous Acquisition Pixel (CAP) as an alternative solution
- Keep the hit occupancy <10% at x20 BKG.
  - 1/10 reduction by shaping time, 1/5 reduction by short strips.

R&D on Striplet + APV25



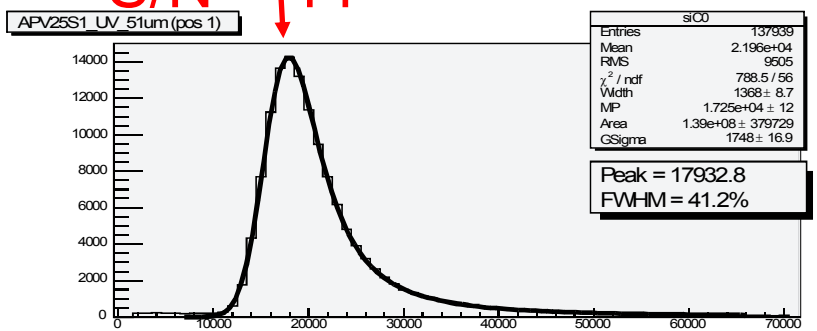
Beam test at CERN

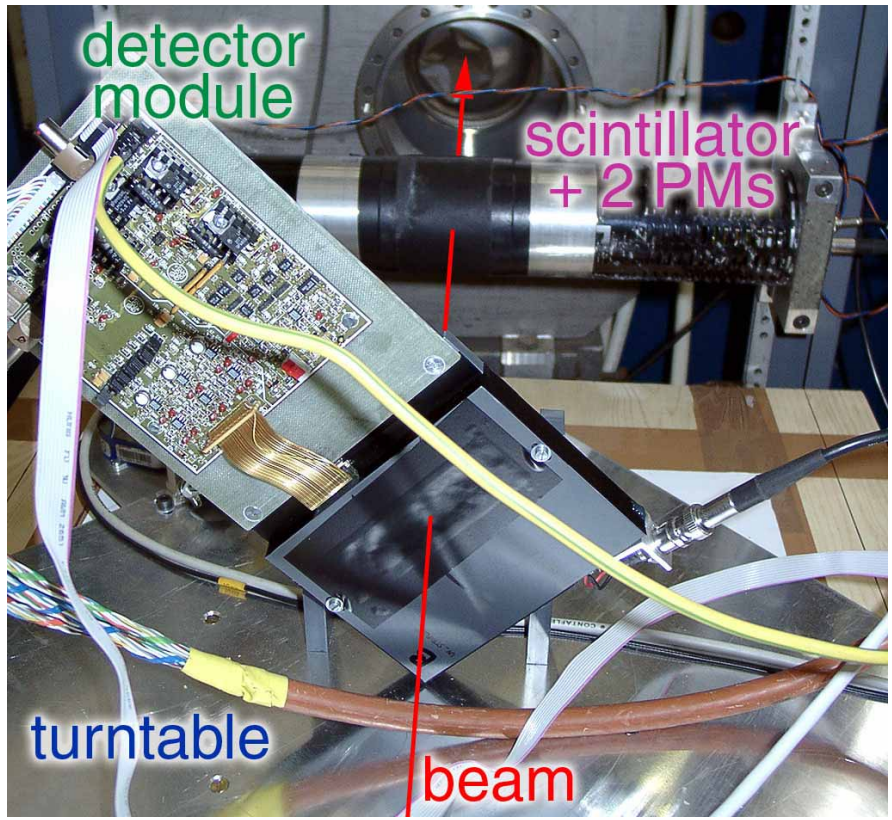
- 5 GeV/c π^- beam
- APV25 readout on n-side, no p-side readout
- 51/102 μm readout pitch
- 40/60/80 MHz system clock

signal ≈ 18 ke

noise = 411 e

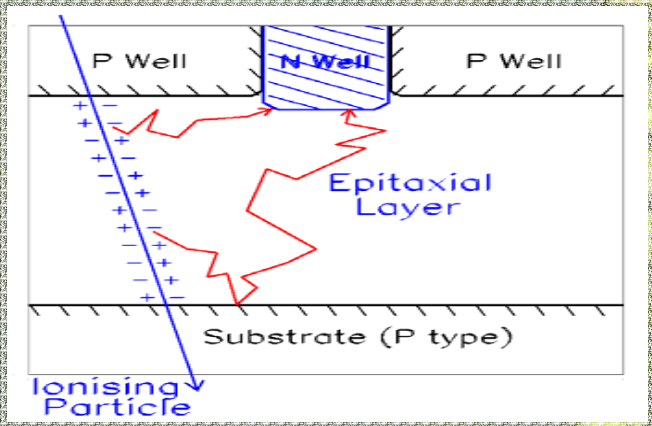
S/N = 44

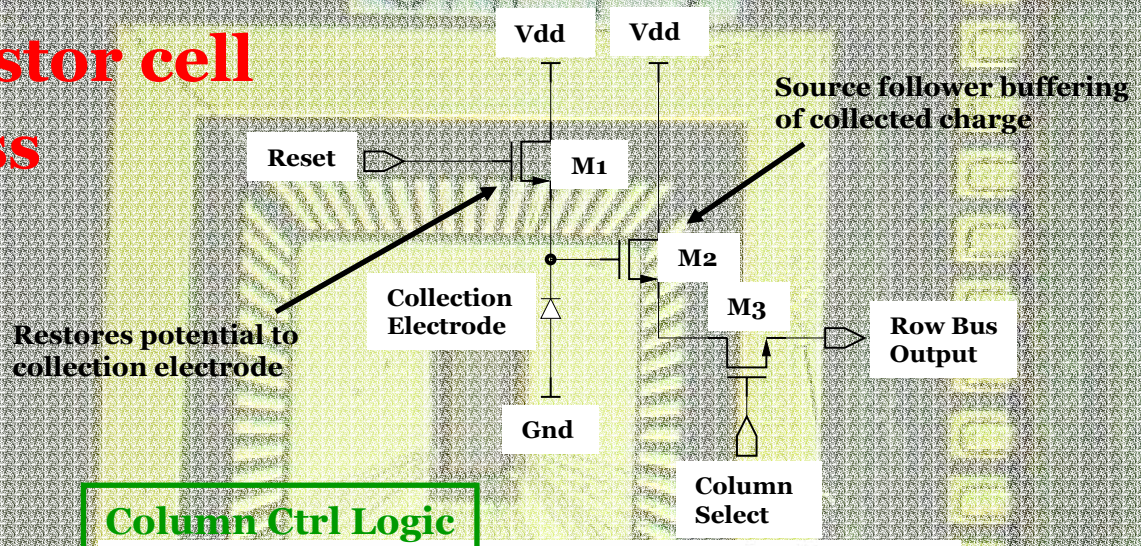




Cont. Acq. Pixels (CAP) 1 Prototype

CAP1: simple 3-transistor cell
TSMC 0.35μm Process

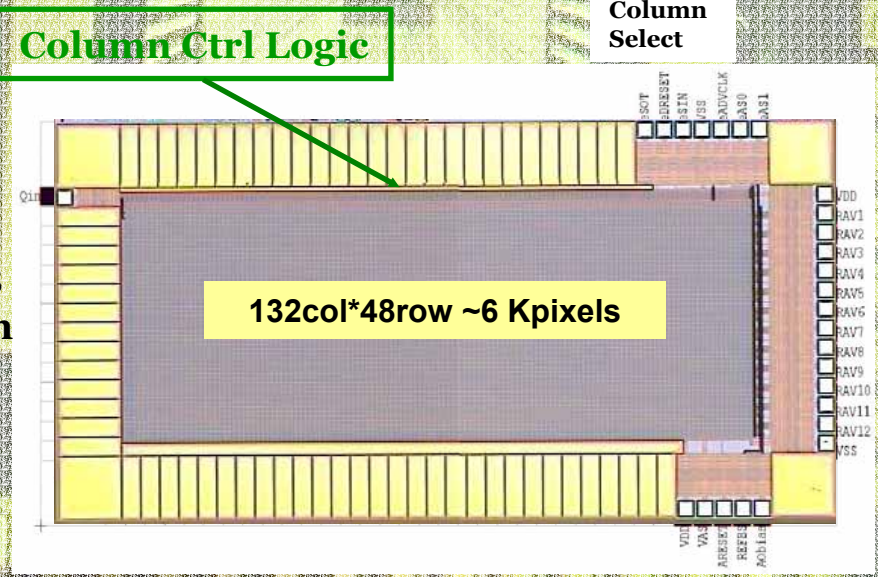




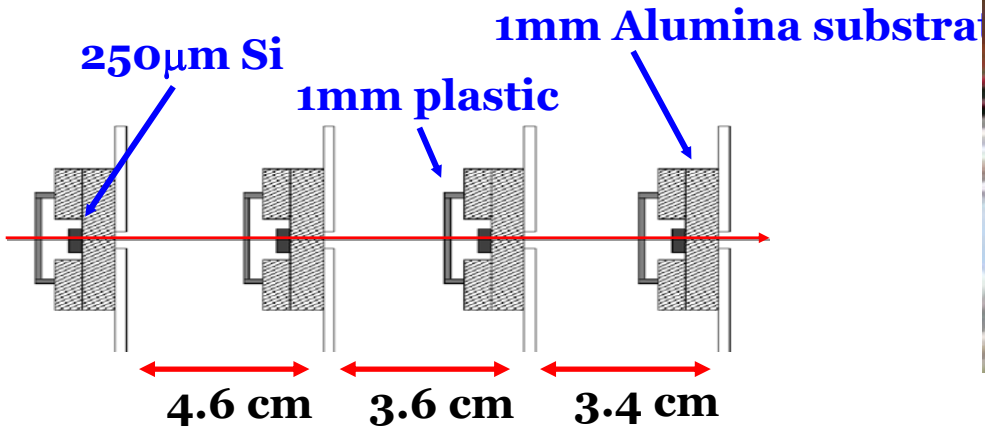
Pixel size:

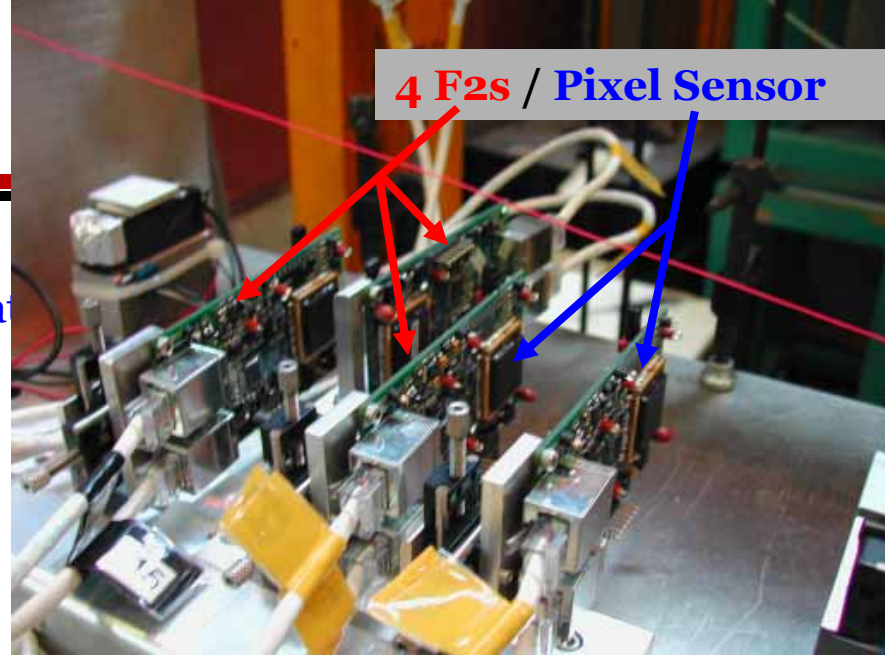
22.5 μm x 22.5 μm

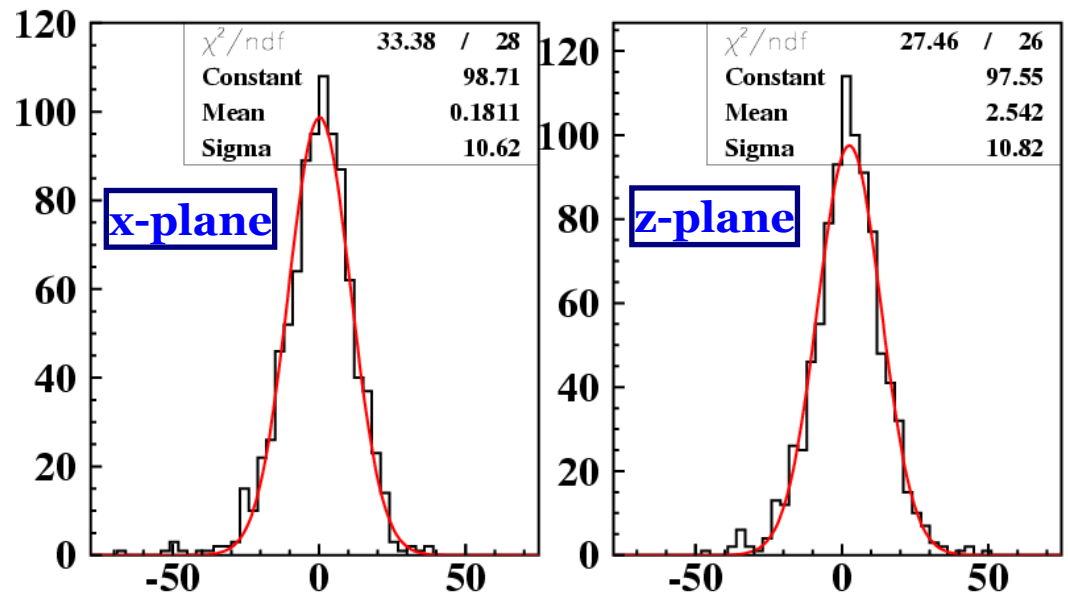
CAPs sample tested: all detectors (>15) function.

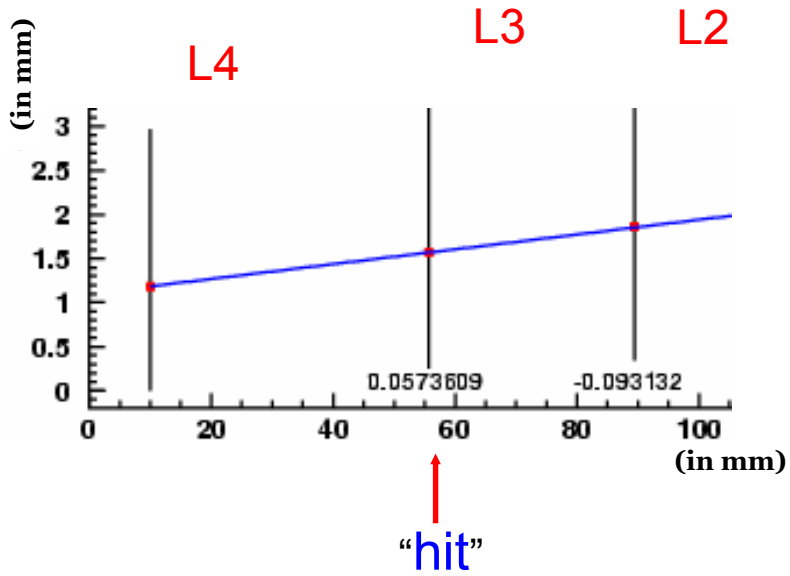


CAP: Hit resolution





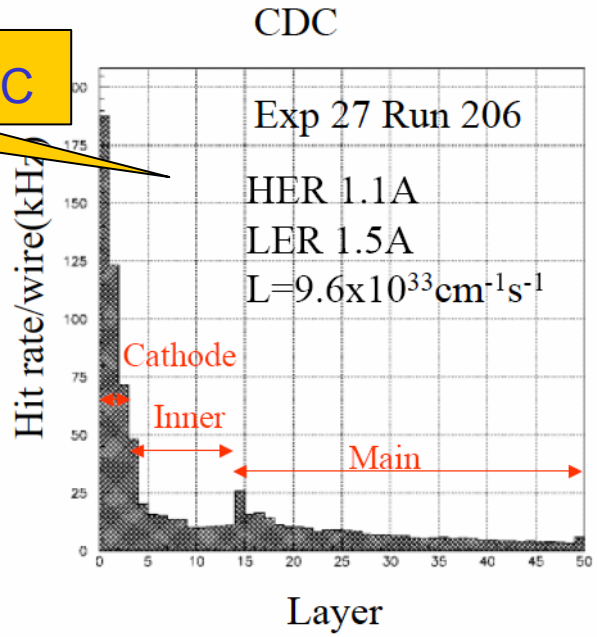




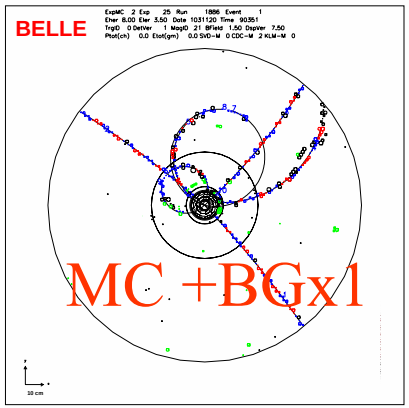
Residuals for 4GeV/c pions:
- <11μm (in both planes)

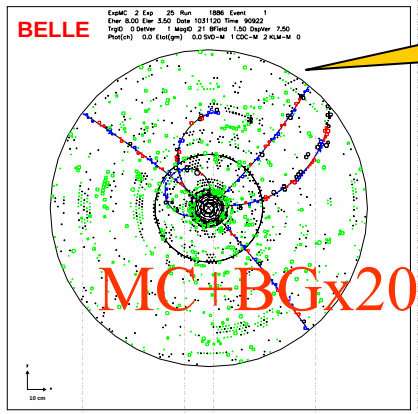
Tracking

Hit rate in the present CDC

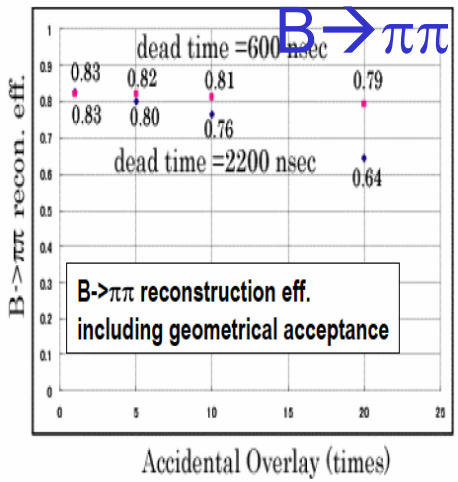


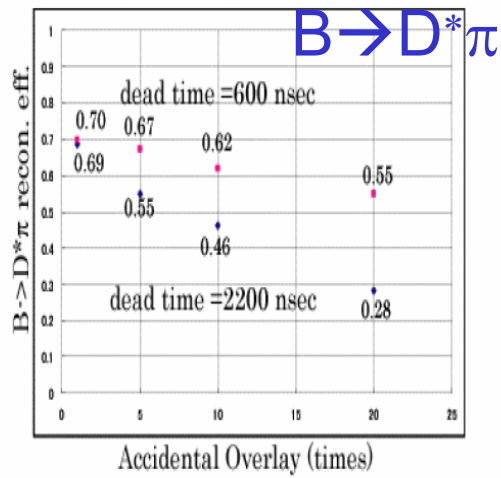
- CDC radius: r=16cm－114cm
  - Hit rate similar to the present inner part.
  - Larger diameter for better resolution.
  - Smaller cell size to reduce occupancy.
- MC study for tracking with bkg. Overlay
  - Tracking possible even with 20 more bkg.
  - Low p track should be covered by SVD.





Typical event w/ background overlaid

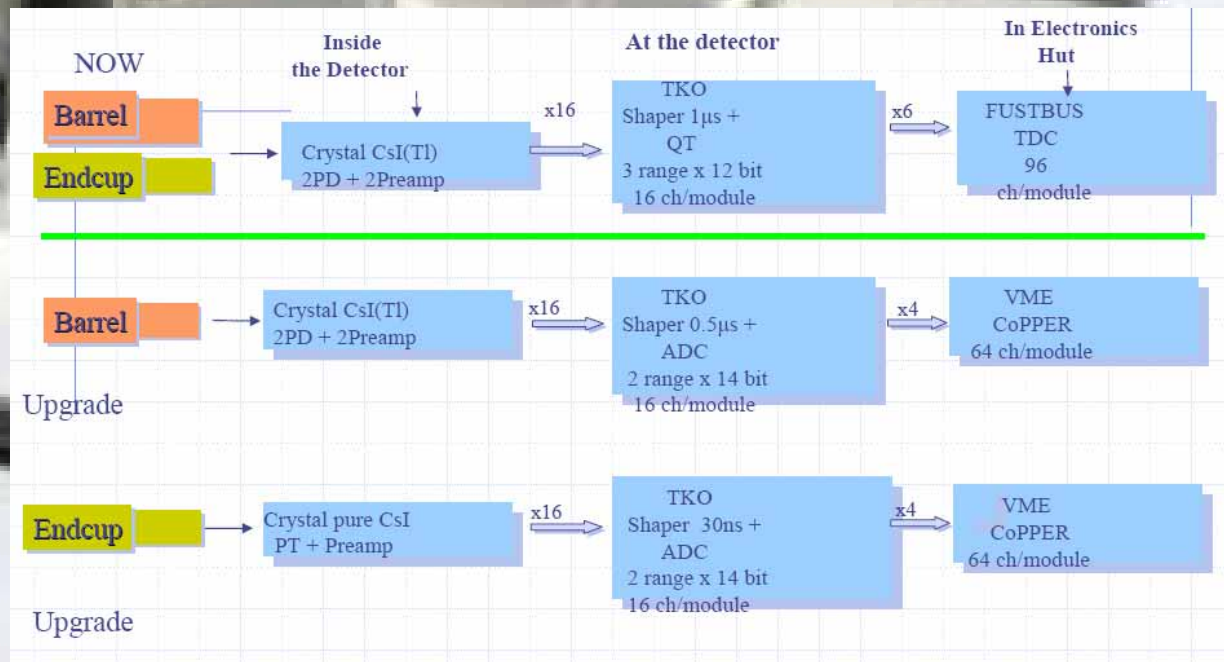




Estimated B decay recon. eff.

CsI Calorimeter

- Pure CsI + phototetrode (BINP)
  - 30ns shaping time + wave form sampling (43MHz)
  - Noise reduction factor: 33x5 = 165
  - Pile-up noise = 0.8MeV at x20 bkg.
  - ENE = 0.4-0.5 MeV
- Barrel as it is + new shaper (0.5μs) + w.f. sampling

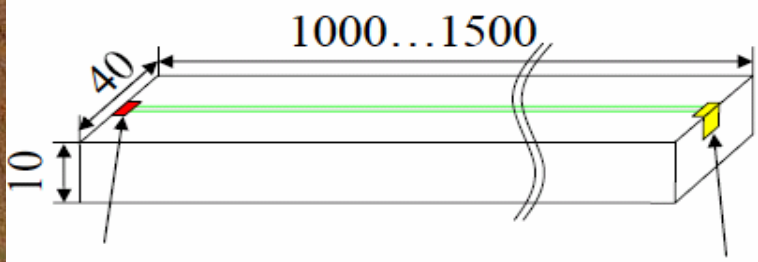


Super-Belle KLM

KLM based on scintillator counters with novel photodetectors (multipixel photodiodes in Geiger mode)

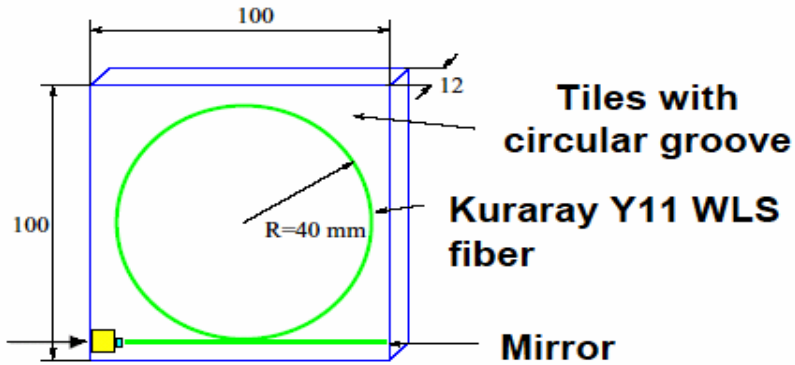
Strip option:

x and y layers of 4cm wide strips in each KLM gap



Tile option

Two layers of 10×10cm² tiles shifted by 1/2×1/2 tile size



~25k scintillator strips

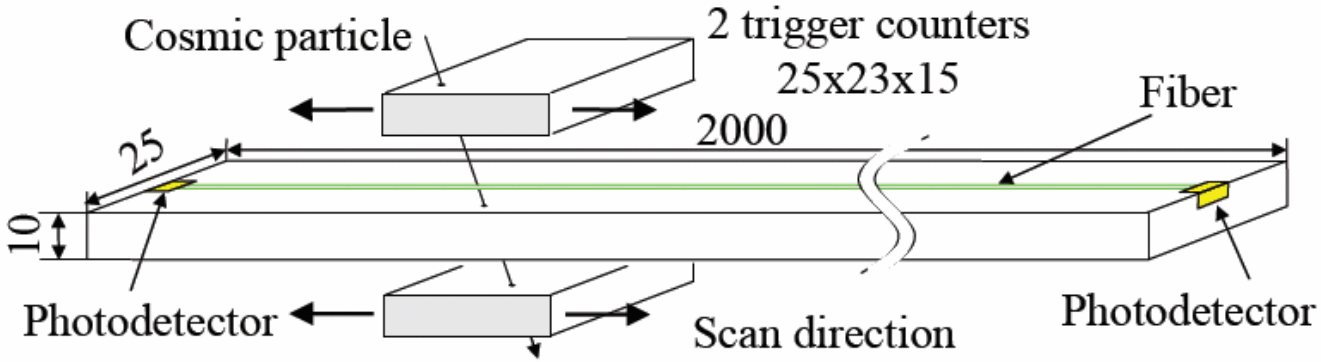
~125k scintillator tiles

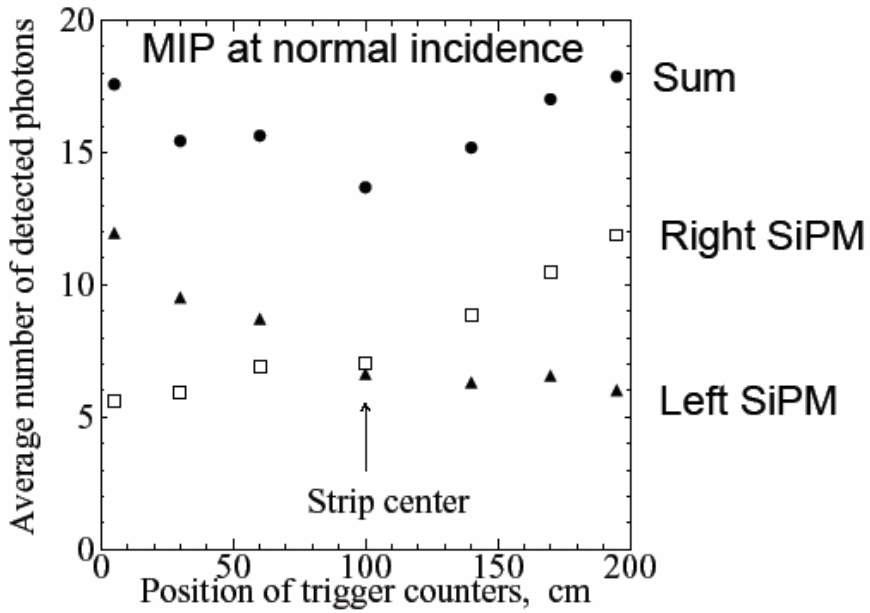
- Coincidence between two layers ⇒ lower background rate even if single layer occupancy is higher.
- No dead time ⇒ higher efficiency, independent on occupancy.

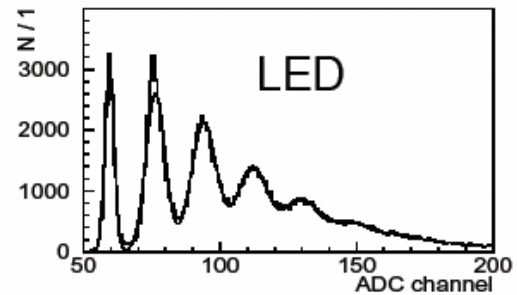
Additional ~25k strips required for barrel

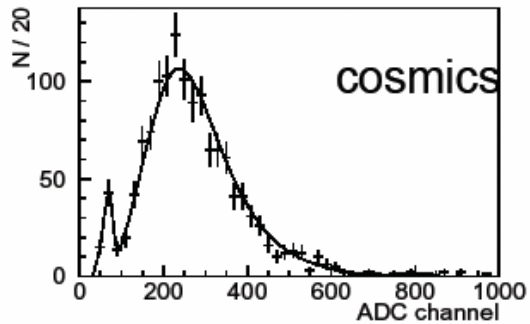
Test of Strip Option

Strip Test Results









Sufficient light yield for more than 99% efficiency at <10kHz noise rate

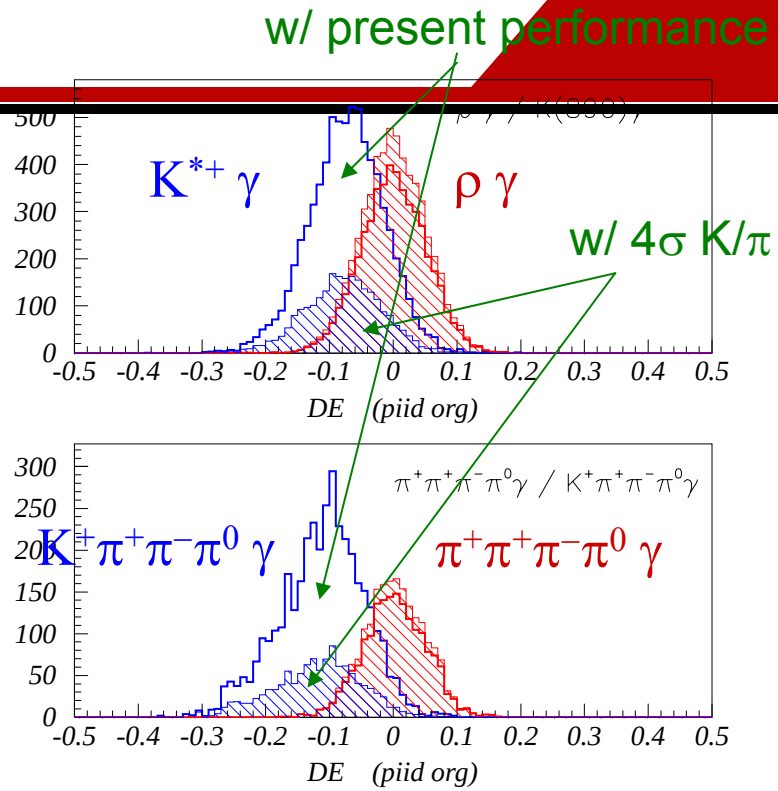
Tile option gives even better results

Particle ID

- Present Belle PID
  - Eff/fake ~ 90/10%
  - No high mom. PID for endcap
  - Material (ACC+TOF ~ 0.35X_0)
- With x20 background
  - TOF cannot survive
  - ACC is OK
- Benefits of improved PID

  Typical examples
  - B→dγ/sγ
  - B→Kμμ

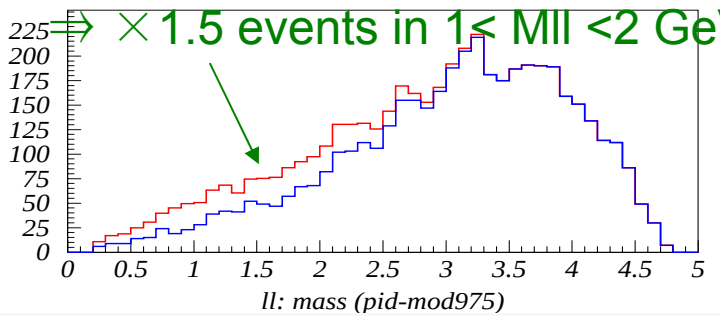
B→Kμμ



MUID w/ KLM + Cherenkov
(97.5% @ p<1GeV/c)

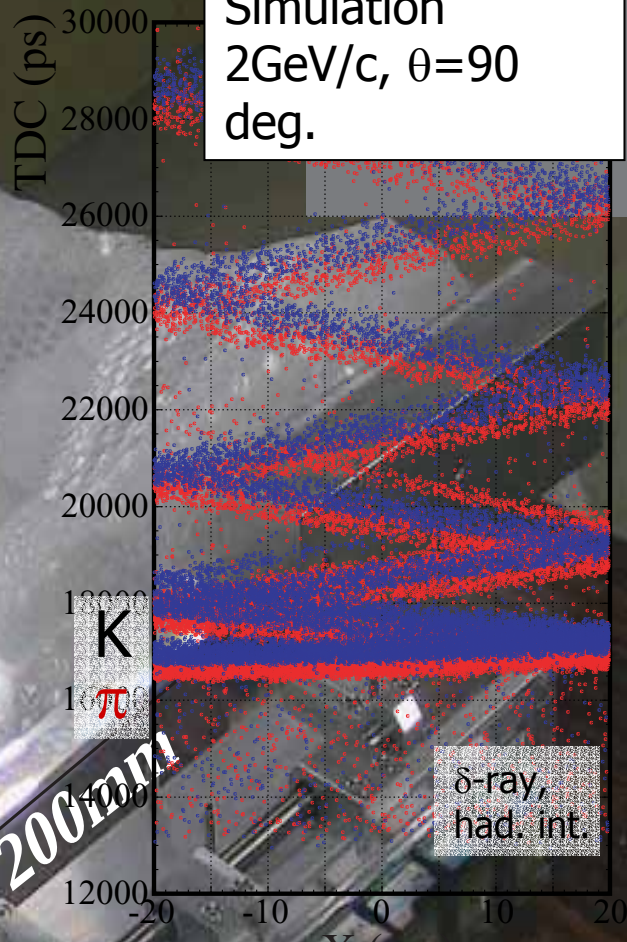
⇒ ×2 events in Mll < 1 GeV

⇒ ×1.5 events in 1< Mll <2 GeV

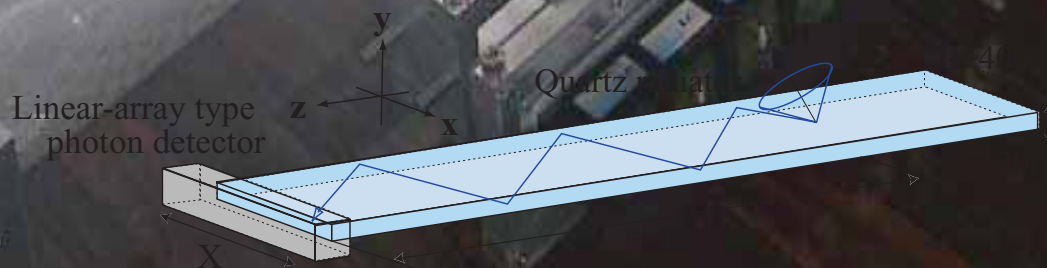


TOP counter

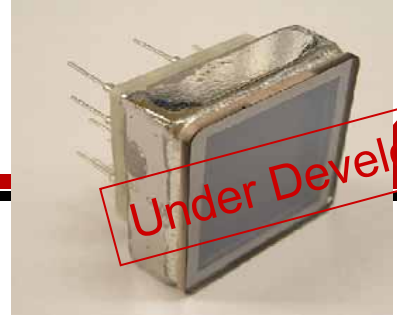
- Cherenkov ring imaging
  with precise time measurement
  - Quartz radiator (2cm^{t})
    - Basic study was already done.
  - Photon detector (MCP-PMT)
    - Good time resolution < ~40ps
    - Single photon sensitive under 1.5T

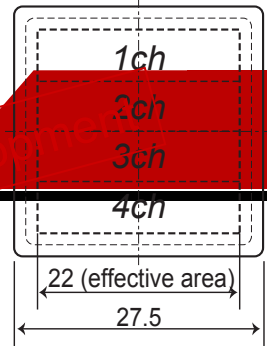


200mm



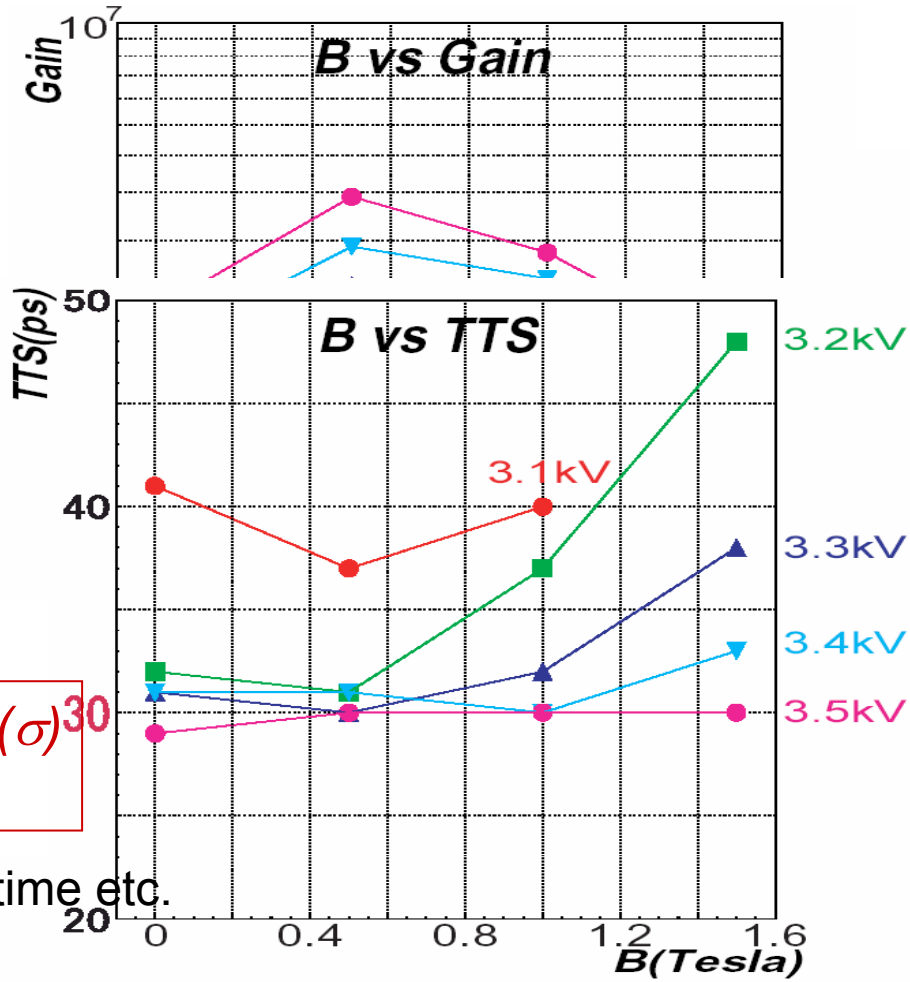
MCP-PMT





- 1x4 linear-anode MCP-PMT newly developed for TOP readout.

#MCP stage	2
Gain (HV)	2×10^6 (-3.5KV)
MCP hole dia.	10μm
Geometrical collection eff.	50%
#pixel /size	1x4 / 5mmx22mm
Effective area/ Total area	64%



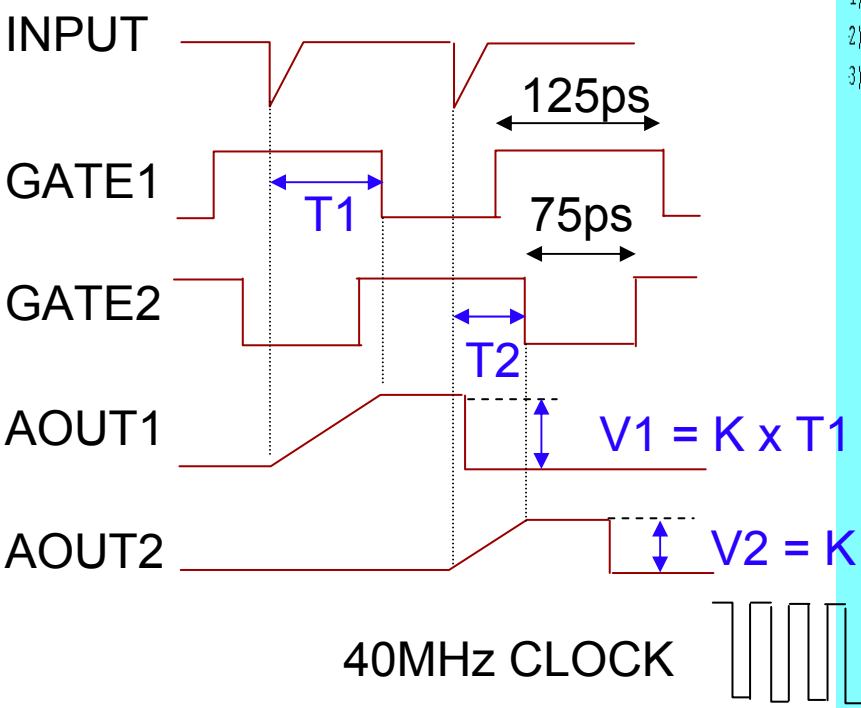
Confirmed gain > 10^6 and TTS = 30ps(σ)
In B=1.5T magnetic field.

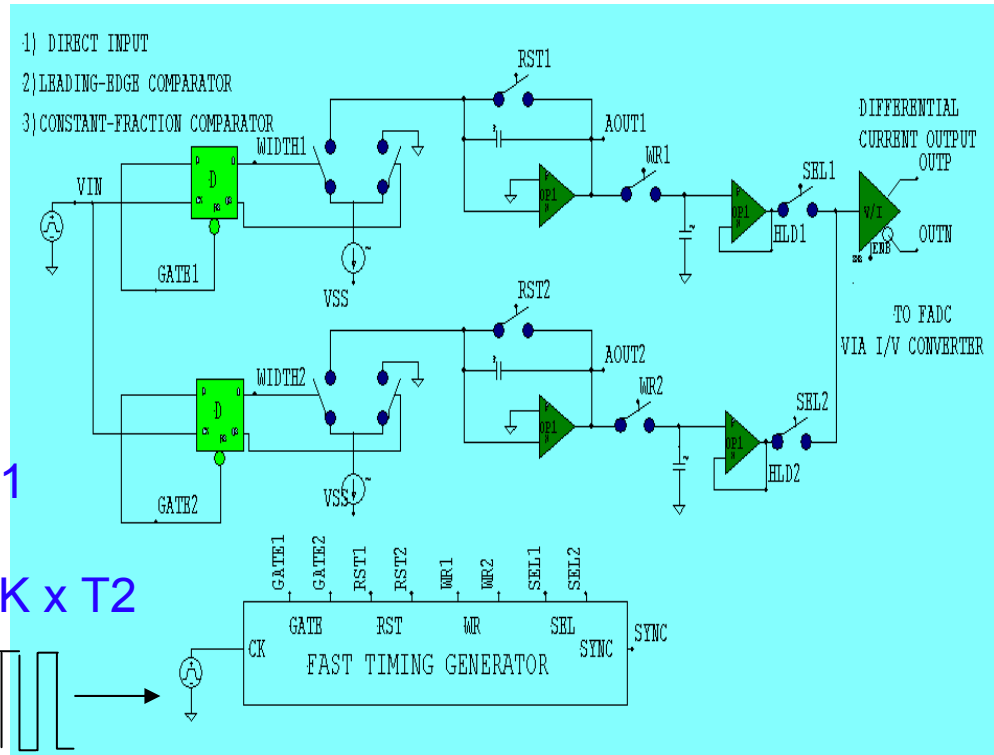
※ Remaining issues: cross talk, life, deadtime etc.

R&D for Readout ASIC

- Time-to-Analog Converter → Time resolution <~20ps.
- Double overlap gates → Less dead time (~100ns).
- 0.35m CMOS process.

"TAC-IC" Concept

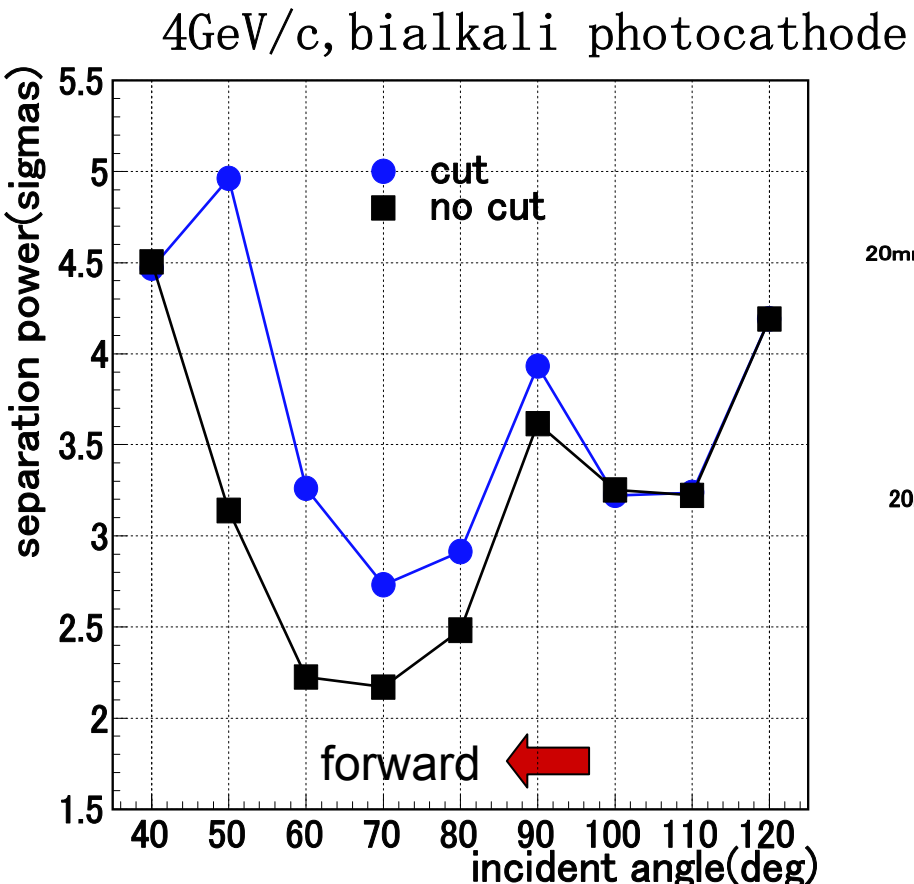




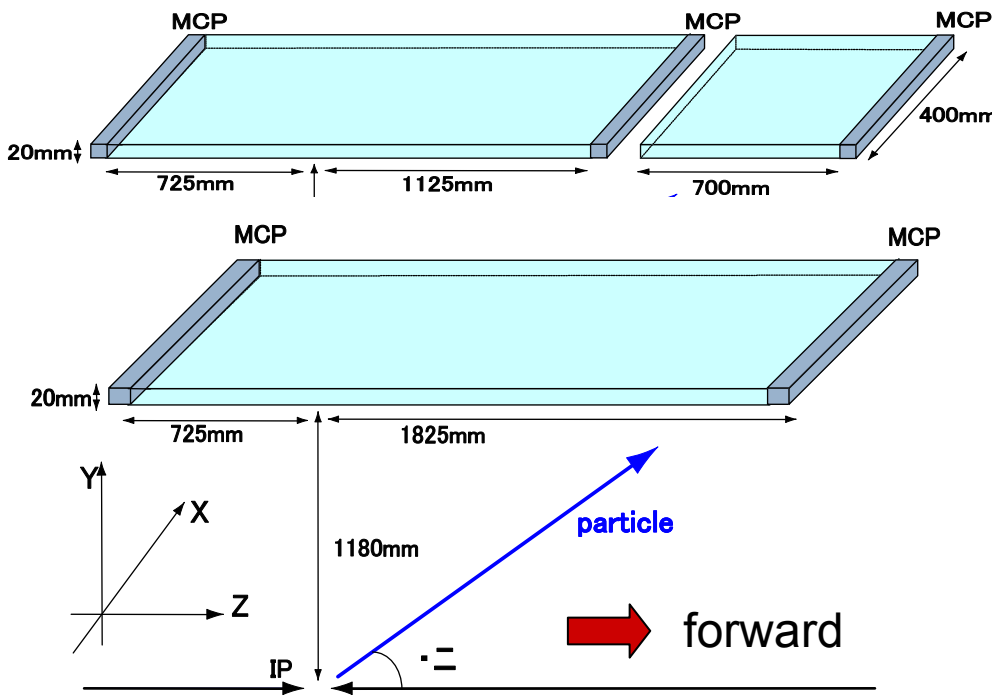
Performance w/ 3 read-out plane

Design optimization

- Long propagation distance → Large chromatic error.
- Read-out at both ends → better performance in q>90deg.
- Another read-out at q=46deg. → better performance in q<90deg.

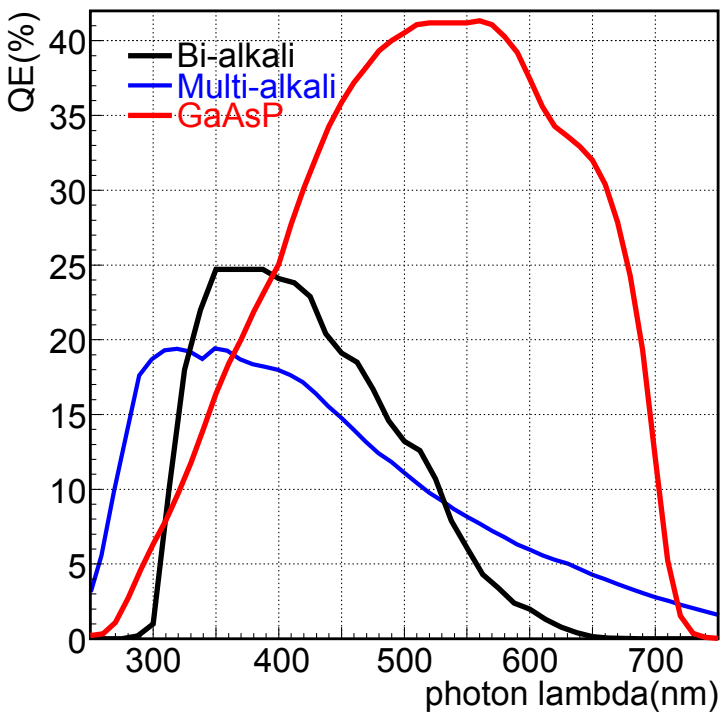


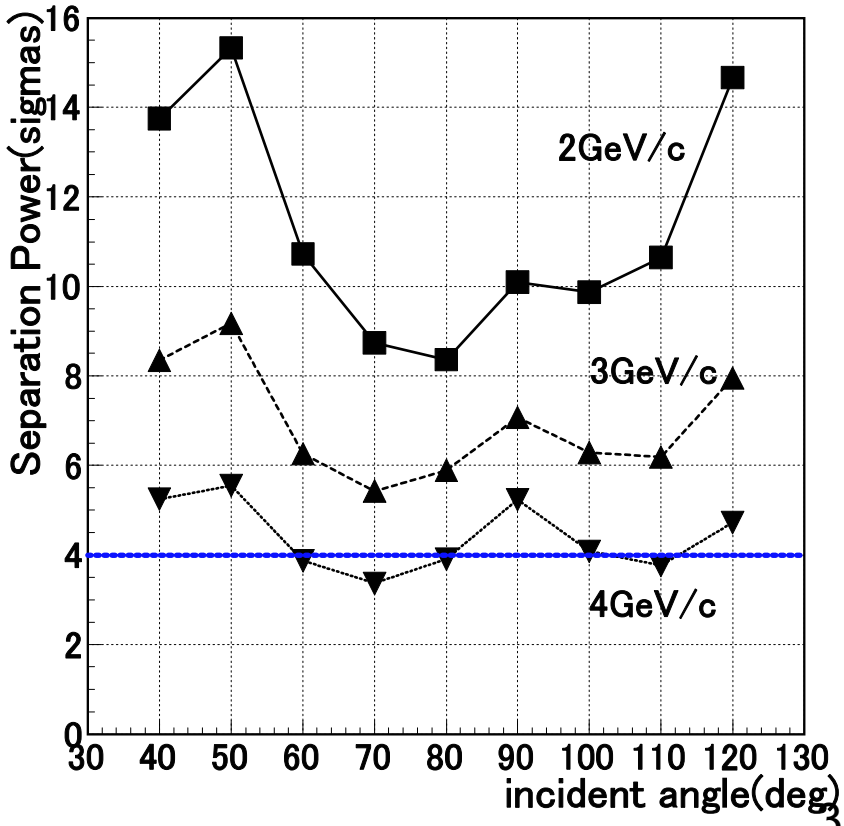
Geometrical acceptance loss
= 6.3% for 5cm gap.



MCP-PMT with GaAsP

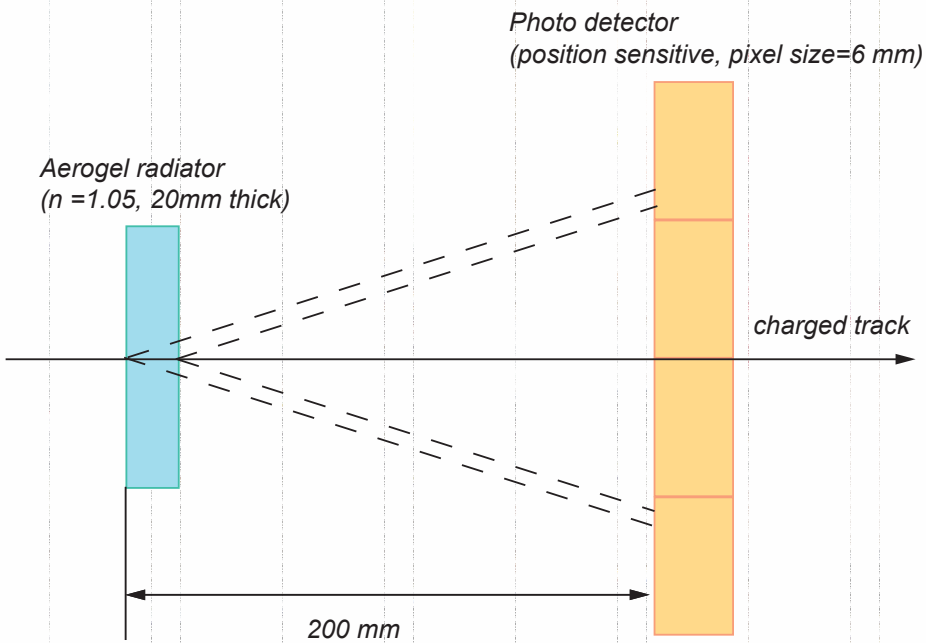
- Further reduction of chromatic dispersion
  → GaAsP photo-cathode
  - Higher Q.E. (~40%@540nm)
  - at longer wave length → less chromatic error

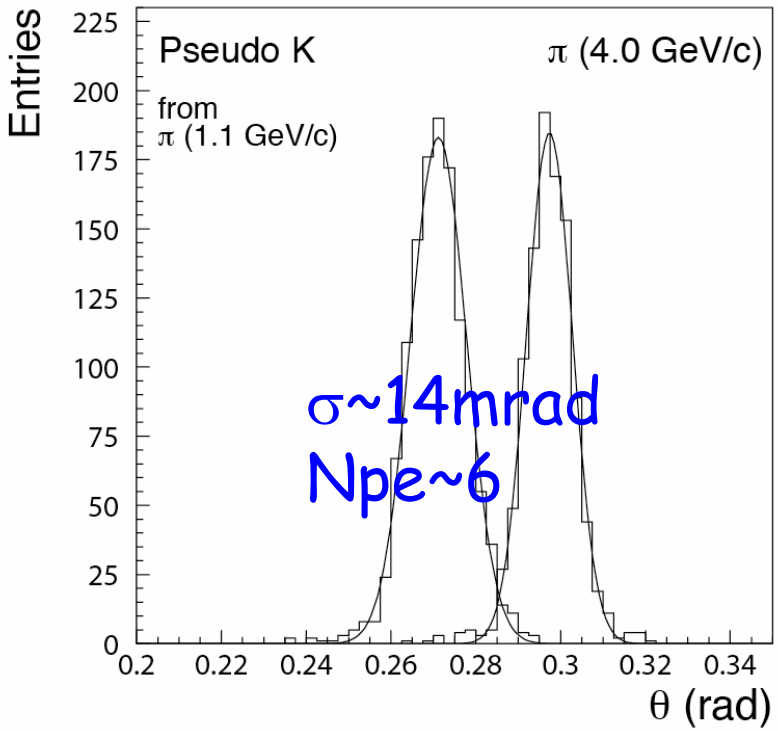




Aerogel RICH

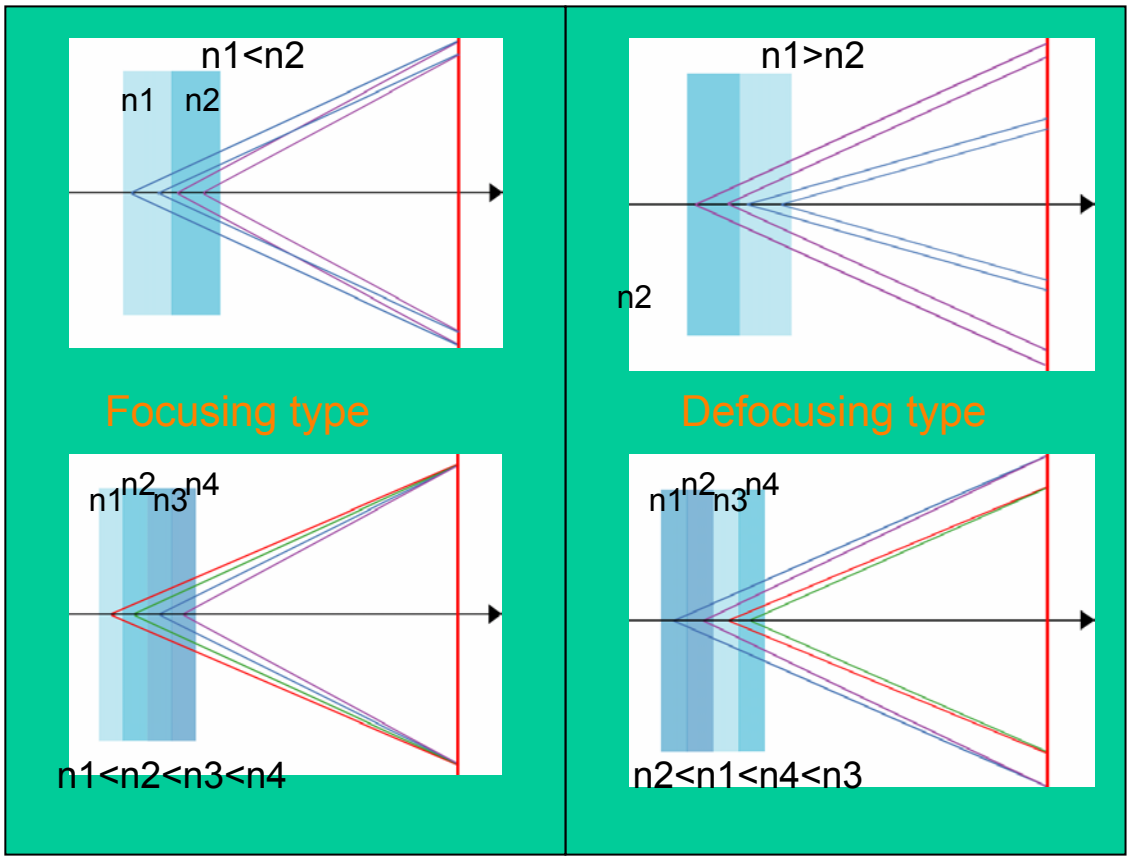
- Proximity focusing RICH with aerogel radiator
- Series of test beam experiments in 1999~2003
  - Confirmed principle of operation
  - Demonstrated >4σ π/K separation at 4GeV/c

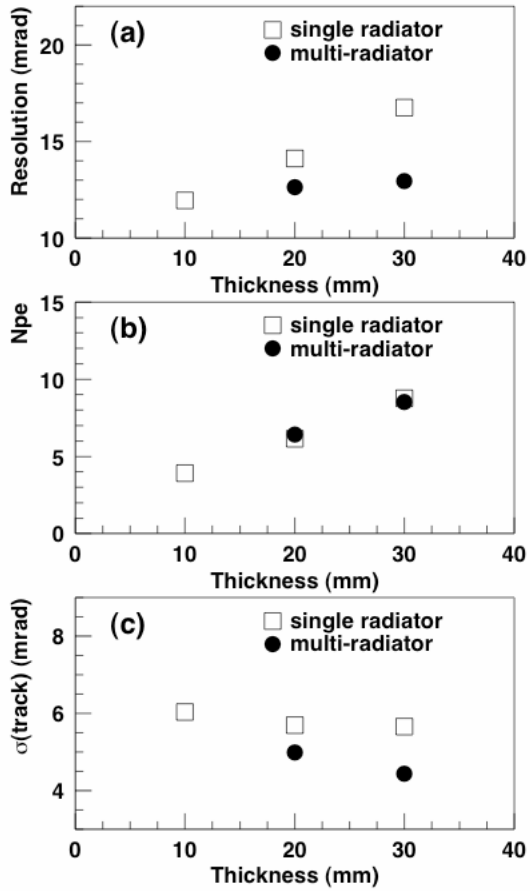




Focusing Aerogel-RICH

- New imaging technique by introducing multiple radiators



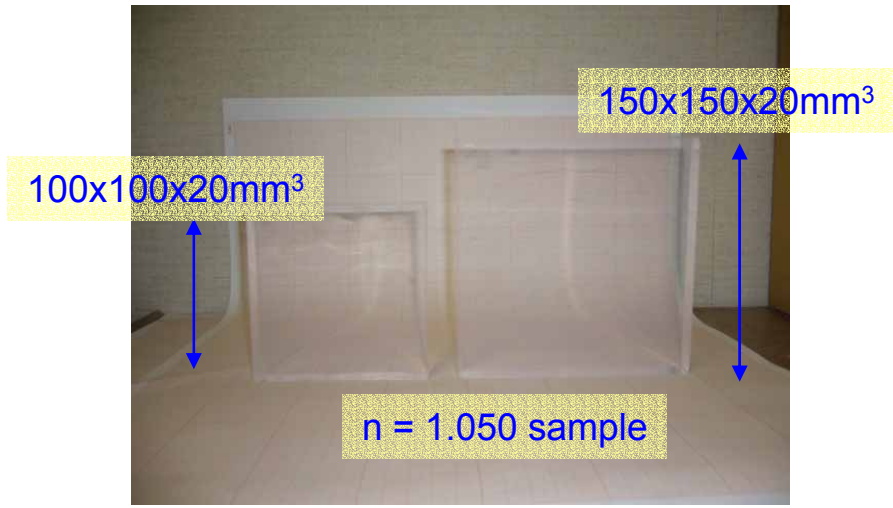


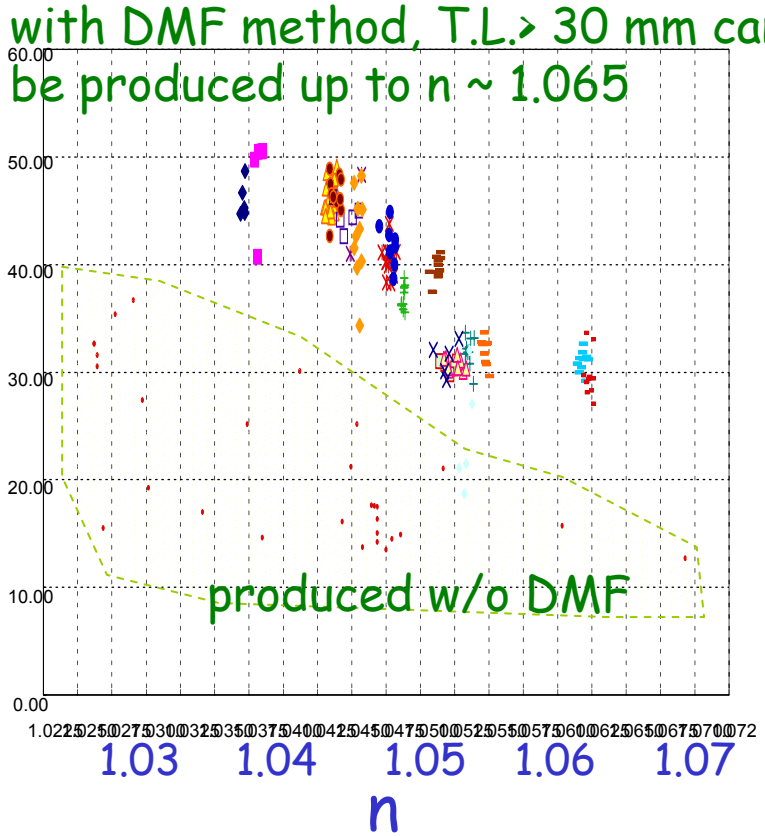
Increase Cherenkov photons without loosing single angle resolution due to emission point uncertainty

Take full advantage of controllable index of aerogel

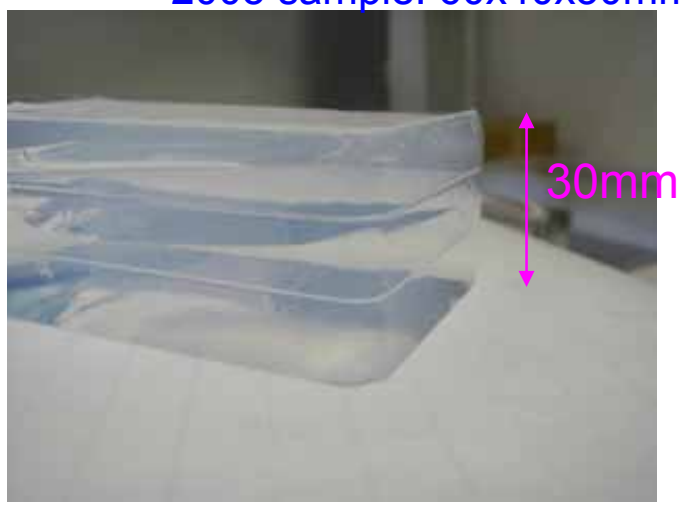
Optical Properties(3)

- Improved transparency w/ new solvent (DMF)
- Trials for larger size tile.
- Trials for multi-index tile.





2005 sample: 60x40x30mm³

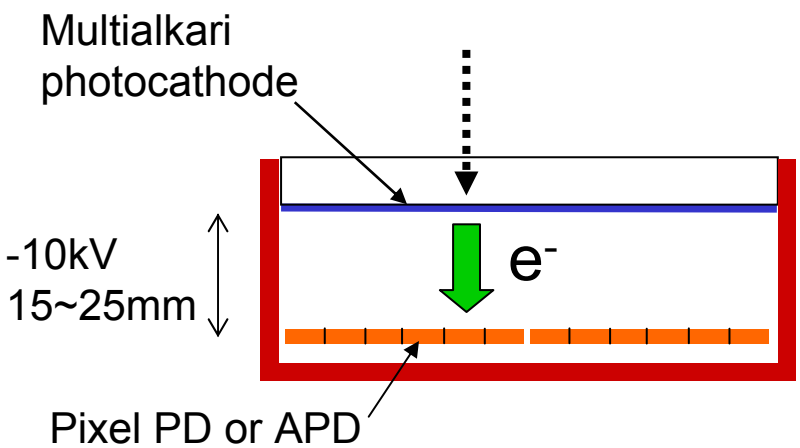


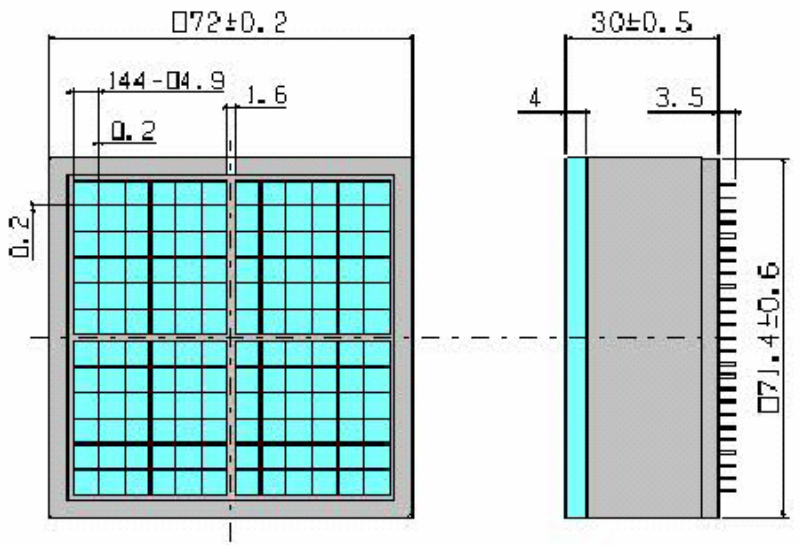
12x12 HAPD

- Optimized for the proximity focusing aerogel RICH.

Package	72x72mm^2
Number of pixels	12x12 (6x6/chip)
Pixel size	5x5mm^2
Effective area	64%
Gain	20000 w/ APD

1st prototype





Comments

- 概算要求

  Preliminary budget request submitted to MEXT.

- 素核研将来計画委員会

  IPNS committee for future planning, consisting of physicists from Super-B, J-PARC and ILC.

- 測定器開発室

  Activity for advanced detector R&D, horizontal to several projects (not project oriented).

Summary

The coming 1-2 years would be important for Super-KEKB.

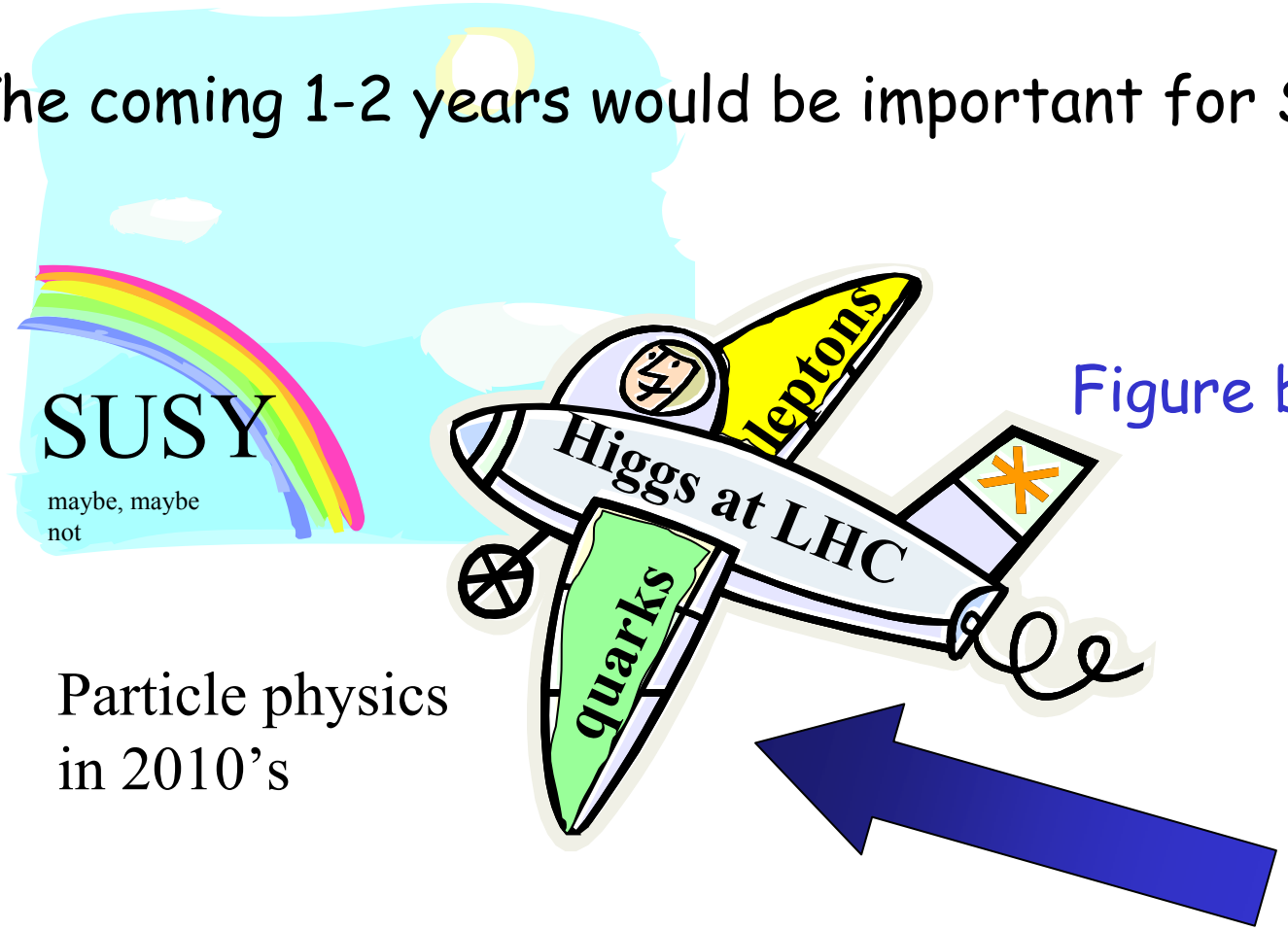


Figure by Hazumi-san

We need make wind blowing in the community, to make the airplane faster (before the "typhoon" come…)

Summary

Let's keep cooperations

- Physics cases in B and τ decays

to demonstrate their impact

- Detector R&D's
- Accelerator
- Beam background

to prove the experimental feasibility

Backup

Super-Belle Strategy

- Vertexing with new SVD
  - Beam pipe radius = 1cm.
  - 2 lyr. striplet/pixel + 4 lyr. DSSD
- Tracking with new CDC
  - Smaller cell size (for inner part) + Faster gas
- Endcap detector replacement
  - Pure CsI for EM calorimetry
  - Strip/tile scintillator or RPC in avalanche mode with new gas mixture.
- PID improvement
  - Ring imaging counters (TOP + Aerogel-RICH)
  - Other options; FDIRC, TOF w/ finer seg.
- DAQ/TRIG/Comp.
  - Full pipeline readout (FINESSE + COPPER)
  - 3-stage event building (new RFARM)
  - Large scale computing with GRID architecture

Same acceptance as Present Belle even with new IP design.

r = 15cm (low p tracking by SVD)

Front-end electronics
- Shoter shaping time
- Wave form sampling (CsI, CDC)
- High timing resolution (TOP/TOF)

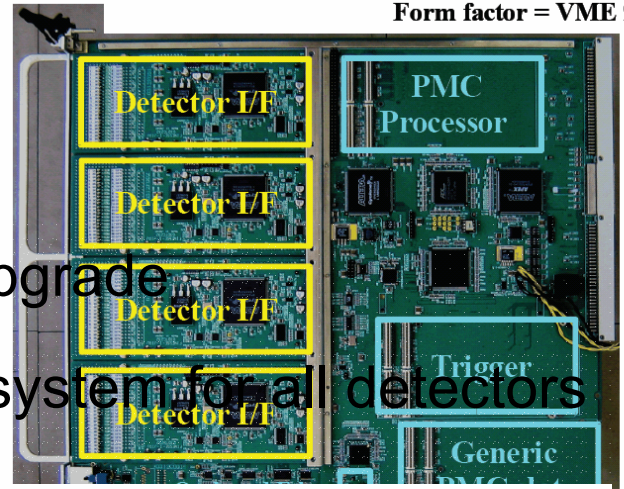
DAQ/TRIG for Super-Belle

Estimated DAQ condition at SuperKEKB

Updated!!

	Belle($L=1.5\times10^{34}$)	SuperKEKB($L=5\times10^{35}$)
L1 trigger rate	500 Hz	20 kHz
Maximum trigger rate	650 Hz	30 kHz
Event size at L1	40 kB/ev	300 kB/ev
Data flow rate at L1	25 MB/s	9 GB/sec
Data flow at storage	13 MB/s	250 MB/sec
Subdetector readout	26	>1000
HLT reduction	2	12

Strategy of DAQ Upgrade



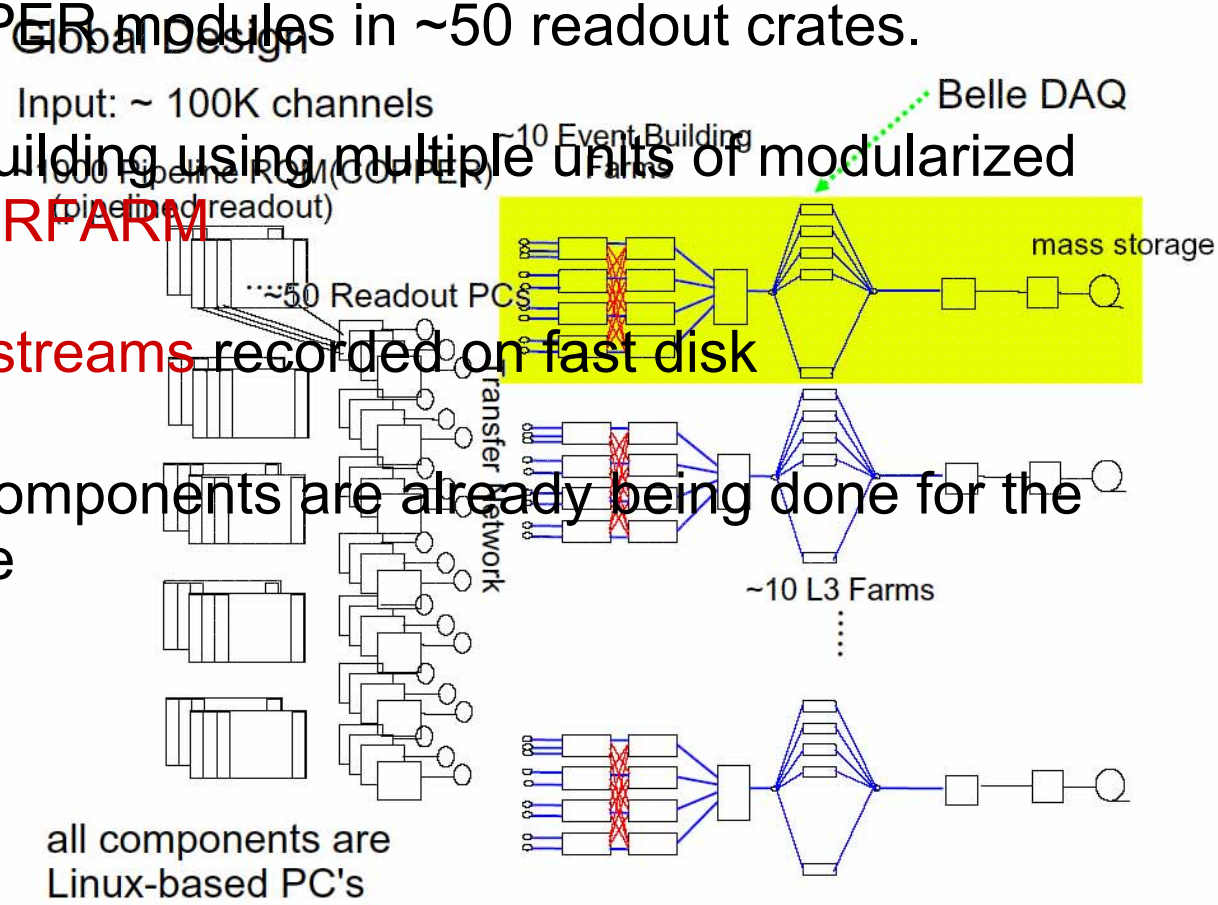
* Achieved by extrapolating the near-term upgrade

  - Fully pipelined COPPER based readout system for all detectors
    + with new FINESSE cards
    + >1000 COPPER modules in ~50 readout crates.

  - 3 stage event building using multiple units of modularized Event Builder + RFARM

  - Multiple output streams recorded on fast disk

* Development of components are already being done for the near-term upgrade



Status of Detector Electronics

- SVD3 : full CMS APV25 -> FINESSE design is on track
- Pixel : CAP option -> needs more R&D
- CDC : 2 approaches
  1) TDC(12bit) + FADC (12bit@20MHz)
     -> FINESSE design on track
  2) FADC for waveform sampling (12bit@>100MHz)
     -> new development necessary
     (high-density 12bit FADC)
- ECL : Wave form sampling is absolutely needed.
  14bit dual-range FADC@43MHz
  -> R&D in progress at BINP, in good shape
- TOP/RICH : Need to manage pixel photo-detector
  HPTDC, Analog pipeline ASIC+FADC@100MHz
  -> not yet fixed. needs more R&D.
- KLM : time-multiplexing of hit info
  Pipeline TDC
  -> unchanged from Belle