FlaviA net

Universität Karlsruhe (TH)
Research University • founded 1825

Experiments at e^+-e^- flavour factories and LHCb

Part 4: Super Flavour Factories

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BELLE

B factories: a success story

- Measurements of CKM matrix elements and angles of the unitarity triangle
- Observation of direct CP violation in B decays
- Measurements of rare decay modes (e.g., $B \to \tau\nu$, $D\tau\nu$) by fully reconstructing the other B meson
- Observation of D mixing
- CP violation in $b \to s$ transitions: probe for new sources if CPV
- Forward-backward asymmetry (A_{FB}) in $b \to s l^+ l^-$ has become a powerfull tool to search for physics beyond SM.
- Observation of new hadrons

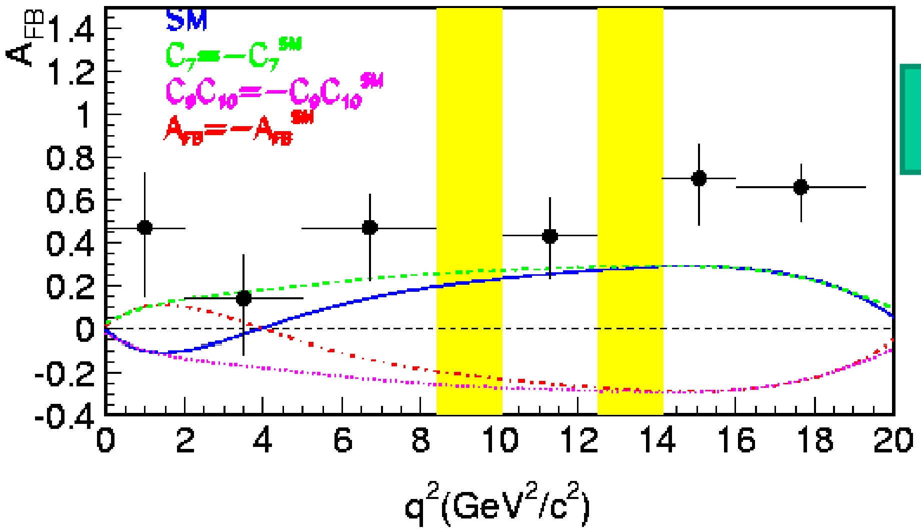
B factories: open questions

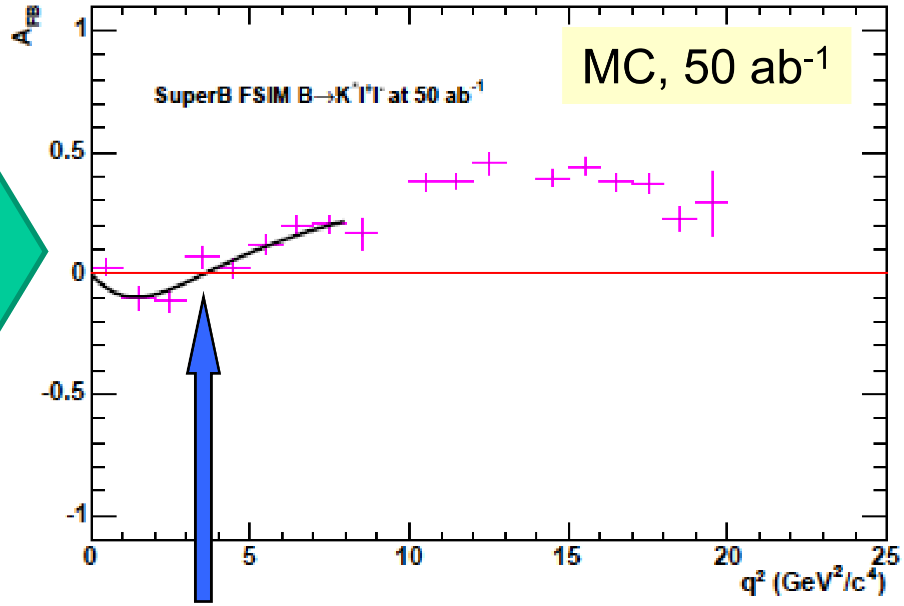
- Several issus have not been fully understood
- Need much more statistics (x100)!

List a few of them →

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

657 M BB

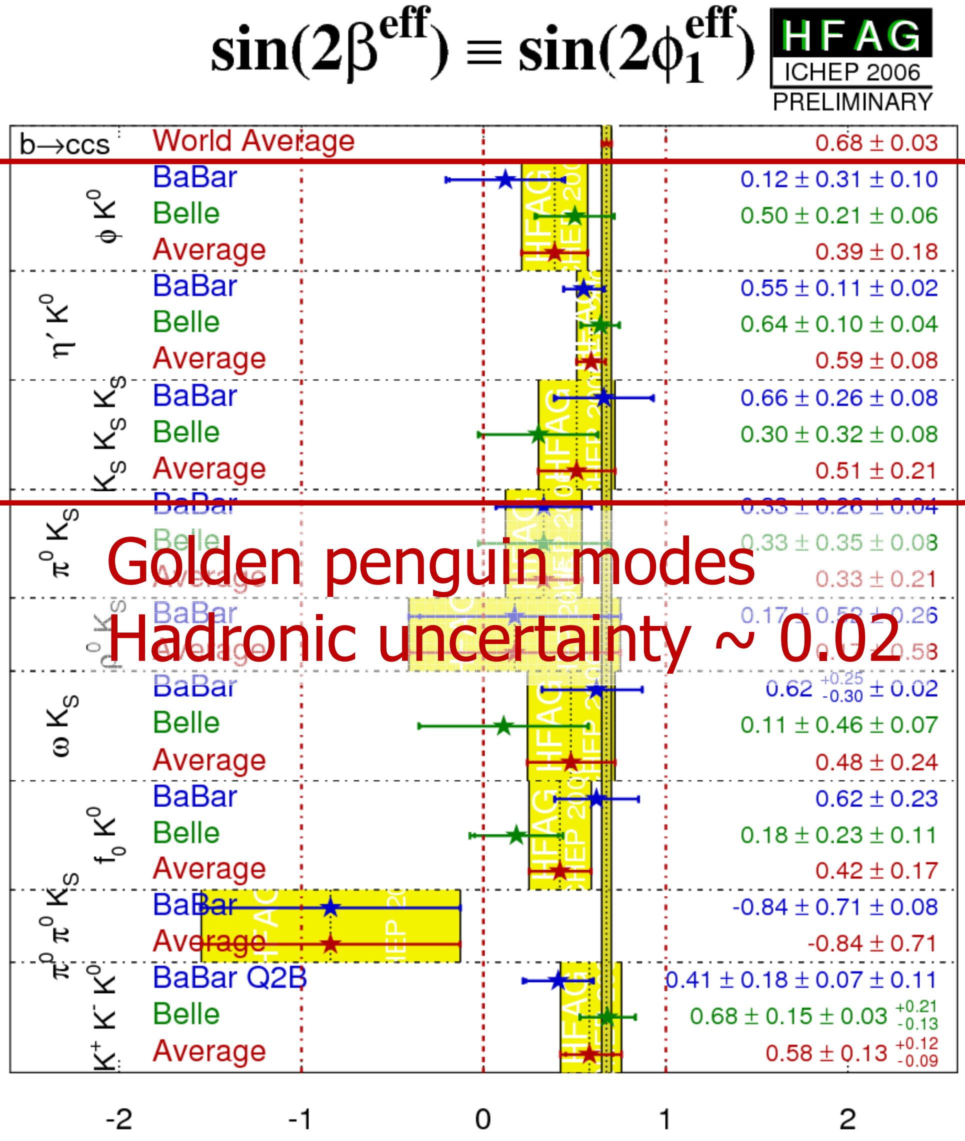




- Zero-crossing q^2 for A_{FB} will be determined with a 5% error with $50ab^{-1}$.

Strong competition from LHCb and ATLAS/CMS

Search for NP: $b \to s\bar{q}$



Golden penguin modes

Hadronic uncertainty ~ 0.02

ICHEP08

BaBar
Belle
Naïve average

$0.26 \pm 0.25 \pm 0.04$
$0.67 \pm ^{0.25}_{0.27} \pm 0.07$
0.45 ± 0.18

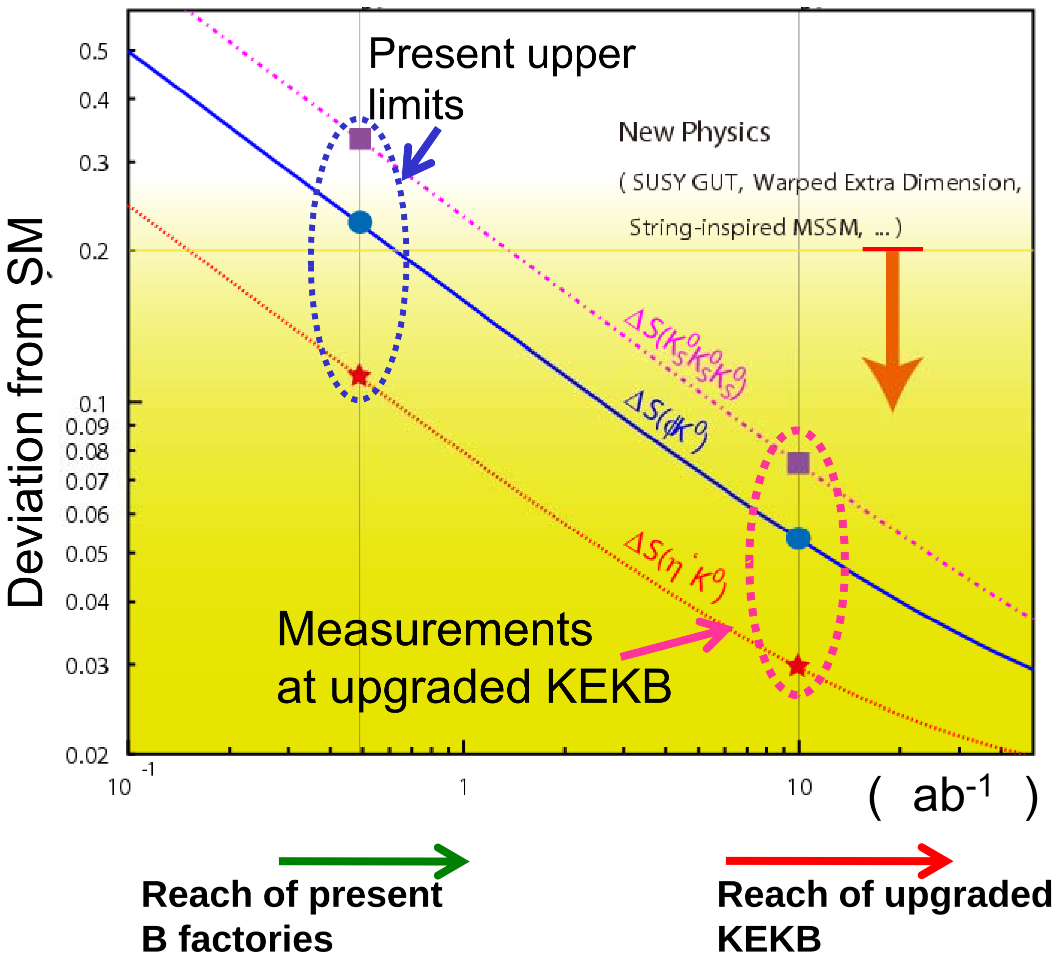
$0.57 \pm 0.08 \pm 0.02$
$0.64 \pm 0.10 \pm 0.04$
0.60 ± 0.07

$0.71 \pm 0.24 \pm 0.04$
$0.30 \pm 0.32 \pm 0.08$
0.57 ± 0.20

Need much more data to clarify the issue

Searches for new sources of quark mixing and CP violation

CP asymmetries of penguin dominated B decays



Deviation from SM

↓

New source of CP violation

↓

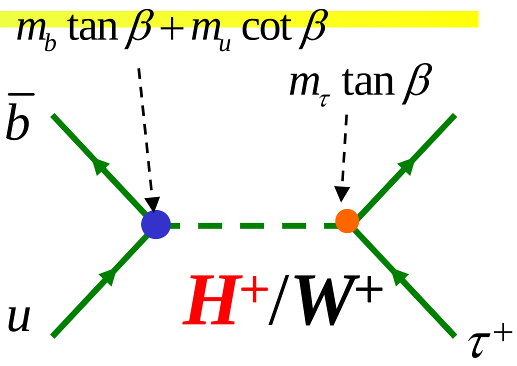
Relevant to baryogenesis?

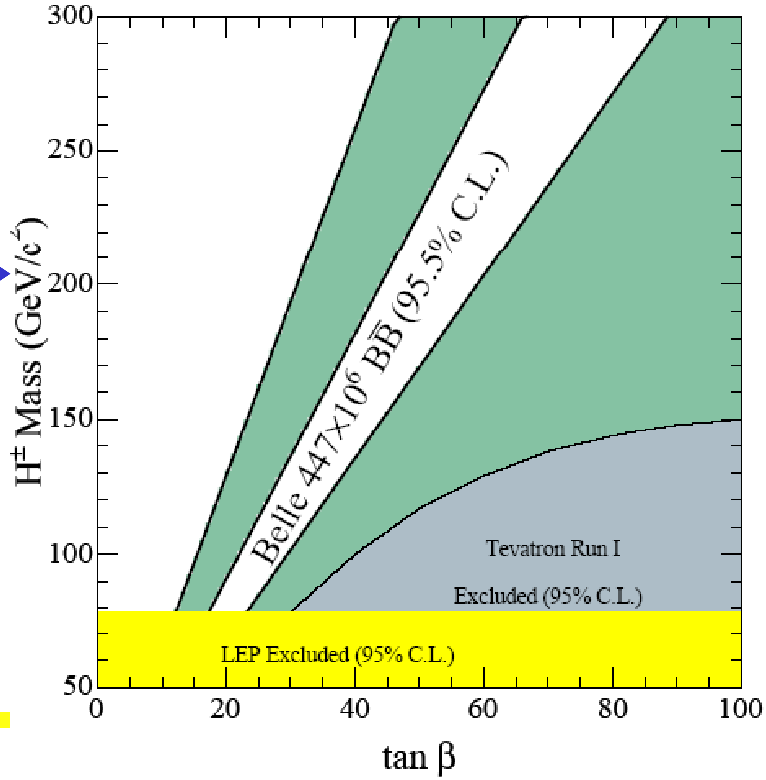
Charged Higgs limits from $B^- \to \tau^- \nu_\tau$

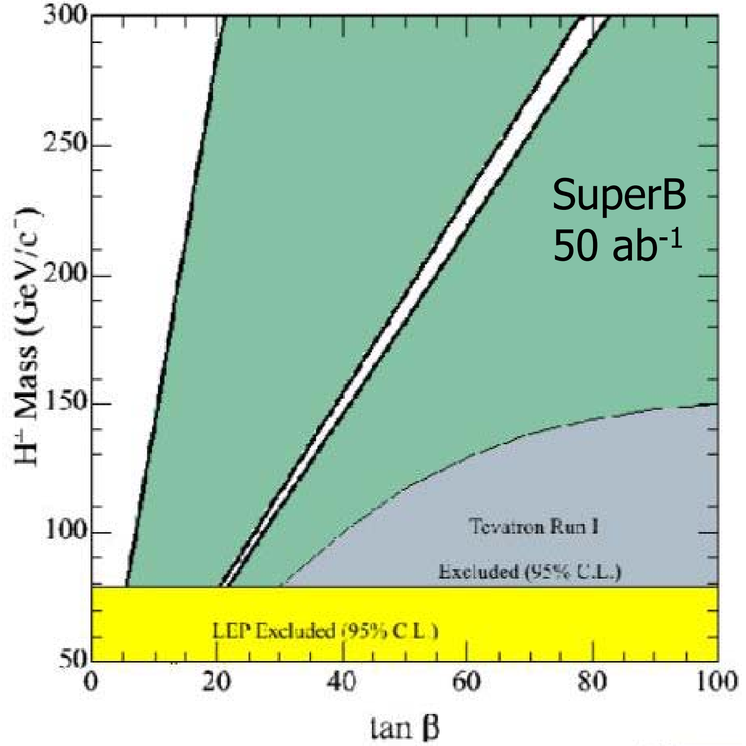
If the theoretical prediction is taken for $\mathbf{f_B}$

→ limit on charged Higgs mass vs. tanβ

$$r_H = \frac{BF(B\to\tau\nu)}{BF(B\to\tau\nu)_{SM}} = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

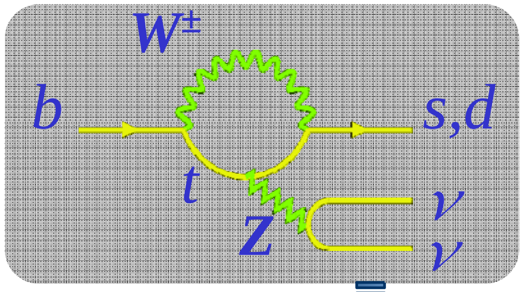


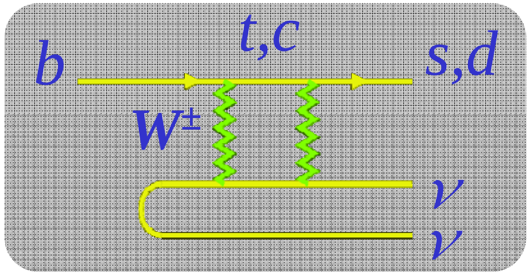


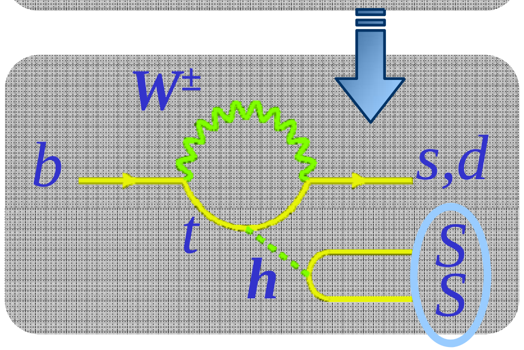


$B \to K^{(*)} \nu\nu$

- Proceed through electroweak penguin + box diagram.
- Sensitive to New Physics in the loop diagram.
- Theoretically clean: no long distance contributions.
- May be sensitive to light dark matter (C. Bird, PRL 93, 201803 (2004))

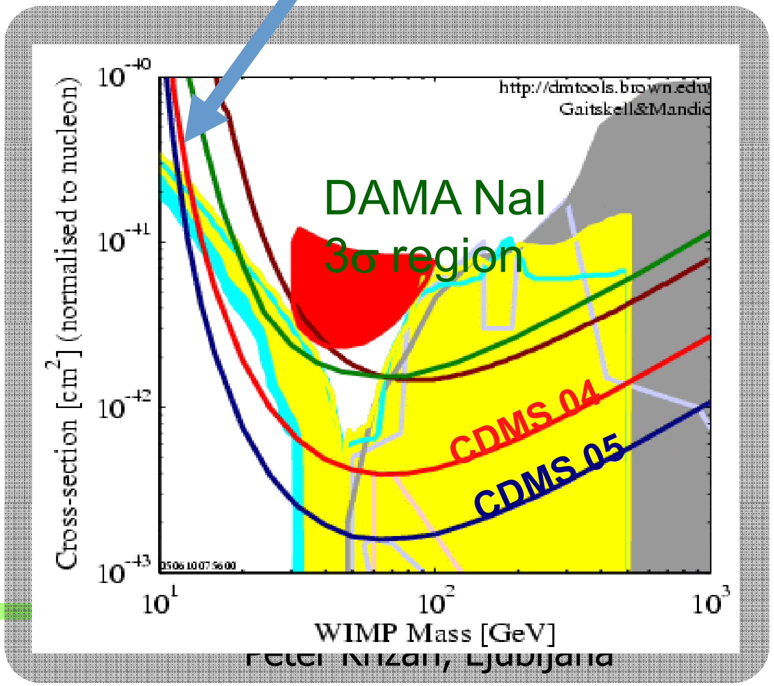






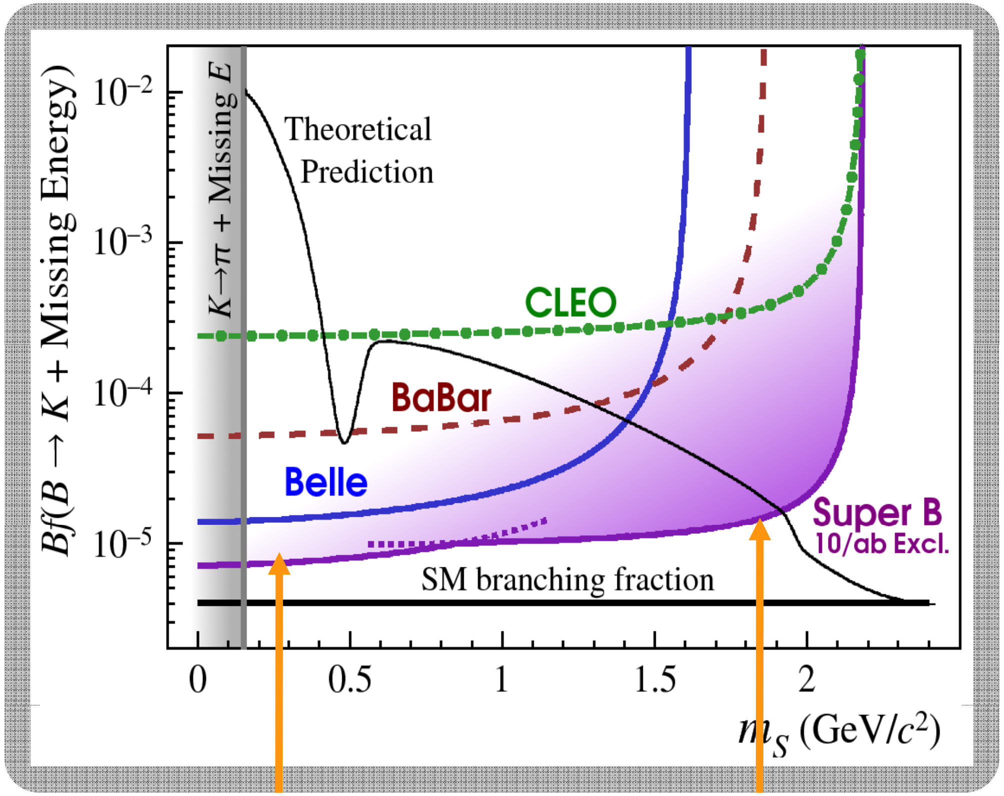
$b \to s$ + Missing E may be enhanced by this extra diagram.

No sensitivity to light dark matter (M<10 GeV) in direct searches



$B \to K^{(*)} \nu\nu$: prospects for 10/ab

- Assuming no changes in the analysis & detector:

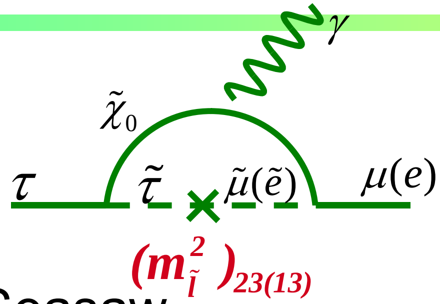


with the same $P^*(K)$ threshold (1.6 GeV)

with a lower $P^*(K)$ threshold (0.7 GeV)

LFV and New Physics

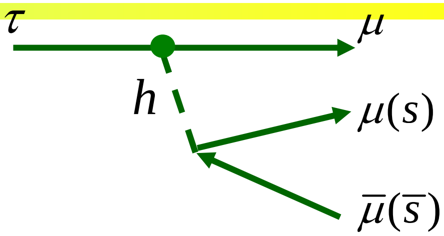
τ→lγ



- SUSY + Seasaw
- Large LFV Br(τ→μγ)=O($10^{-7\sim9}$)

$$Br(\tau \to \mu\gamma) \approx 10^{-6} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{1TeV}{m_{SUSY}} \right)^4 \tan^2\beta$$

τ→3l,lη



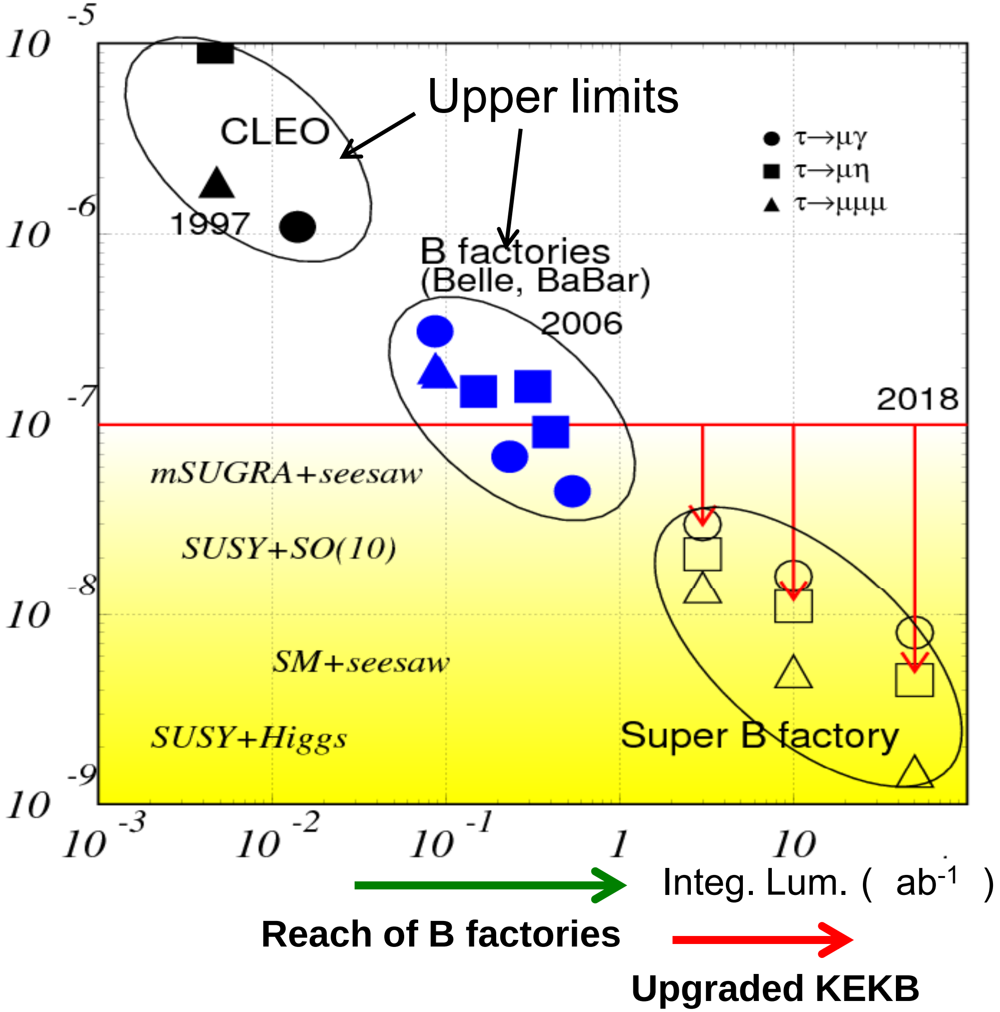
- Neutral Higgs mediated decay.
- Important when MSUSY >> EW scale.

$$Br(\tau \to 3\mu) = 4 \times 10^{-7} \times \left(\frac{(m^2_{\tilde{L}})_{32}}{\bar{m}^2_{\tilde{L}}} \right) \left(\frac{\tan\beta}{60} \right)^6 \left(\frac{100GeV}{m_A} \right)^4$$

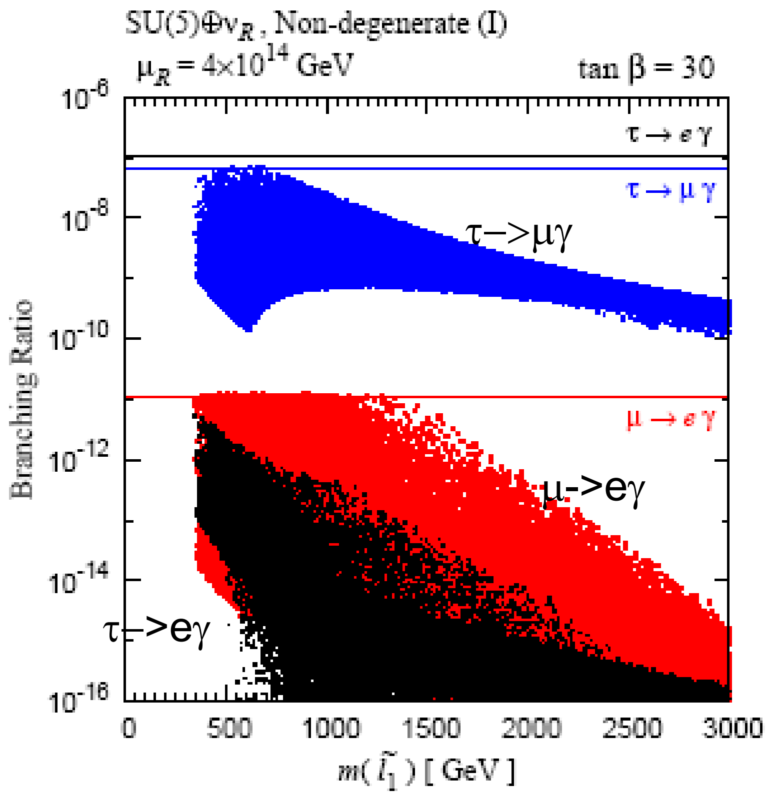
model	Br(τ→μγ)	Br(τ→lll)
mSUGRA+seesaw	10^{-7}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-Universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-7}

Precision measurements of τ decays

LF violating τ decay?



Theoretical predictions compared to present experimental limits



T.Goto et al., 2007

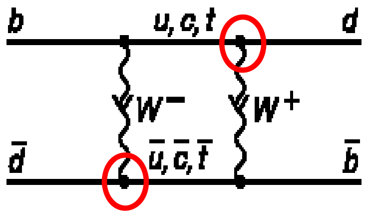
Physics at a Super B Factory

- There is a good chance to see new phenomena:
  - **CPV in B decays from the new physics (non KM)**
  - **Lepton flavor violations in τ decays.**
- They will help to diagnose (if found) or constraint (if not found) new physics models.
- Even in the worst case scenario (such as MFV), $B \rightarrow \tau\nu$, $D\tau\nu$ can probe the charged Higgs in large $\tan\beta$ region.
- **Physics motivation is independent of LHC**.
  - If LHC finds NP, precision flavour physics is compulsory.
  - If LHC finds no NP, high statistics B/τ decays would be an unique way to search for the TeV scale physics.

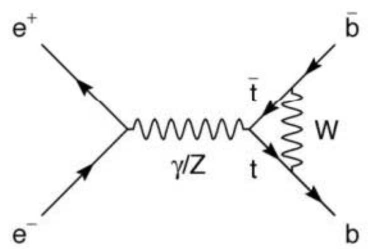
Super B Factory Motivation 2

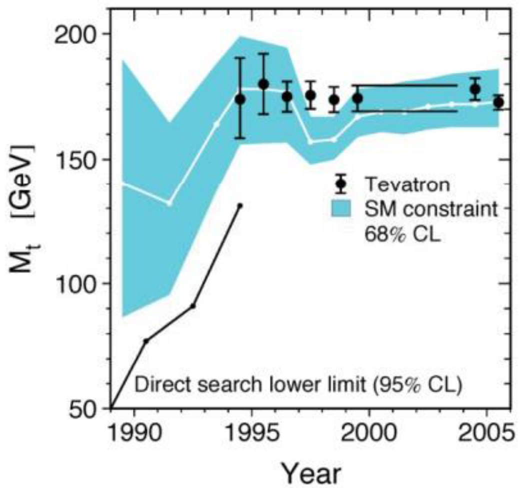
- Two lessons from history: the top quark

<u>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



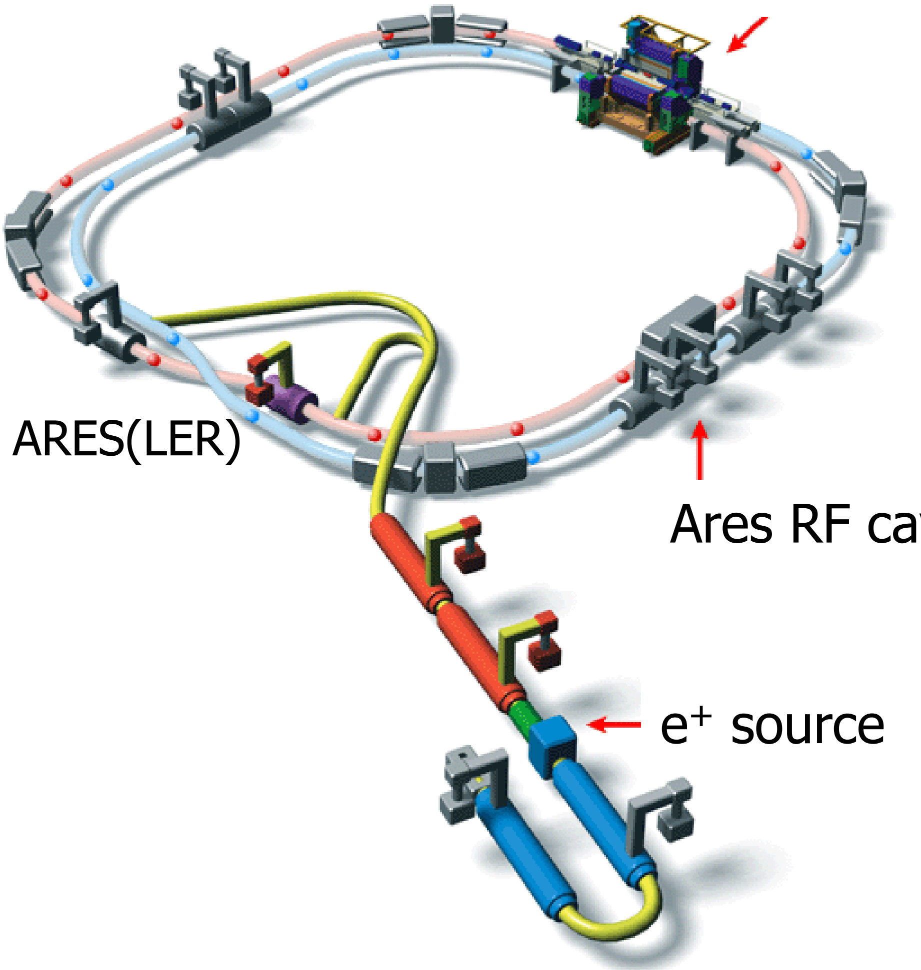
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$





- There are many more topics: CPV in charm, new hadrons, …

The KEKB Collider & Belle Detector



- e^- (8 GeV) on e^+(3.5 GeV)
  - $\sqrt{s} \approx m_{\Upsilon(4S)}$
  - Lorentz boost: $\beta\gamma=0.425$
- 22 mrad crossing angle
- Operating since 1999

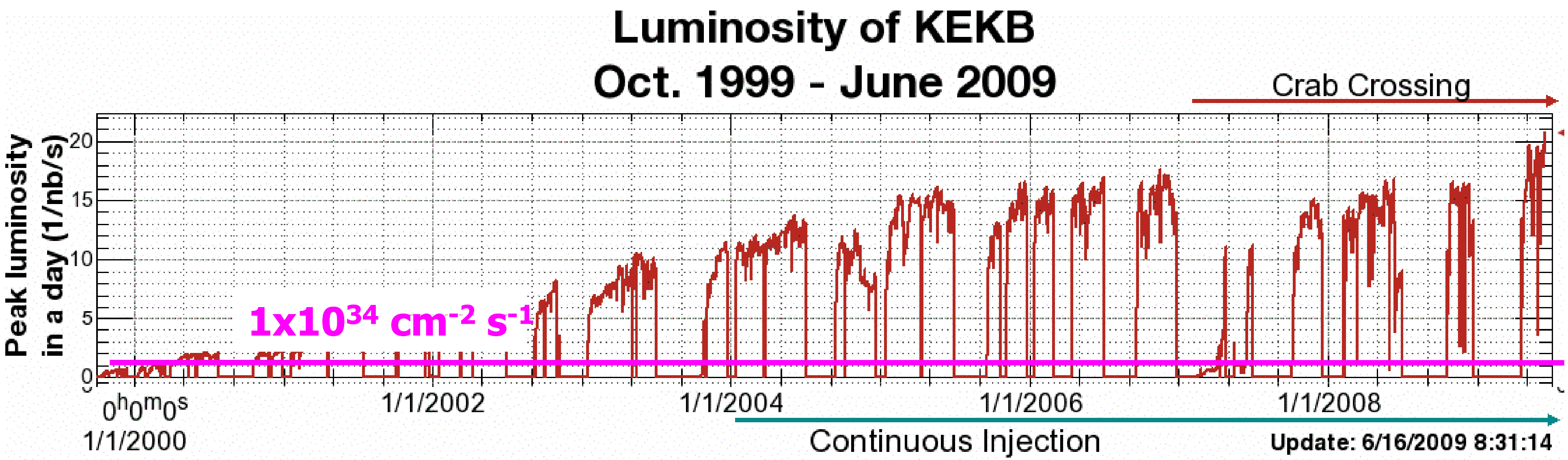
Peak luminosity (WR!) :

$2.1 \times 10^{34}\ cm^{-2}s^{-1}$

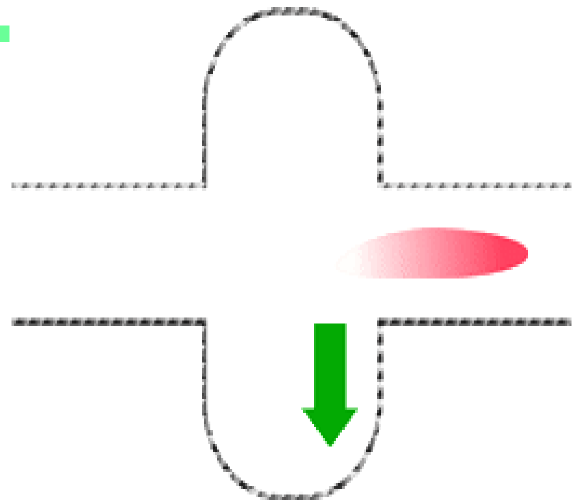
The KEKB Performance

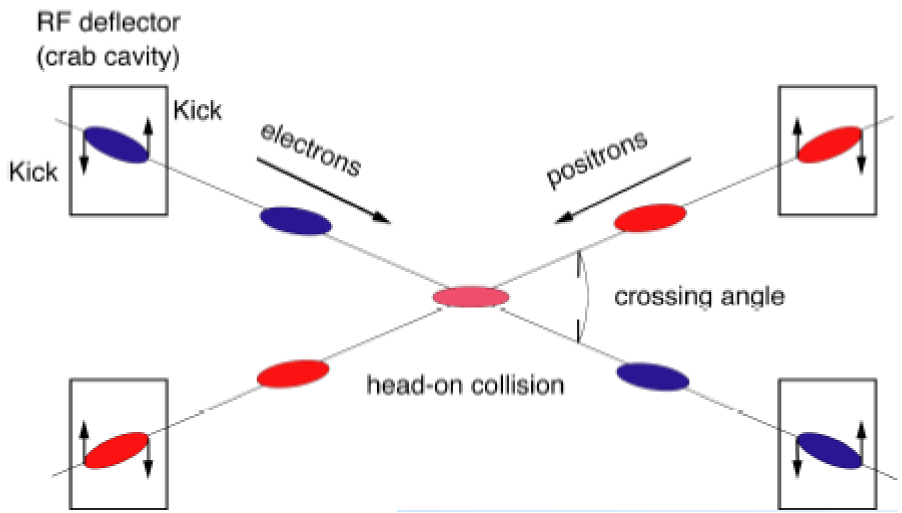
Luminosity Records:

- **Peak L = 2.1x10^{34} cm^{-2} s^{-1}** (2x the design value)
- **Daily ∫Ldt = 1.5 fb^{-1}** (2.5 x the design value)
- **Total ∫Ldt ~ 950 fb^{-1}** (as of July 2009)



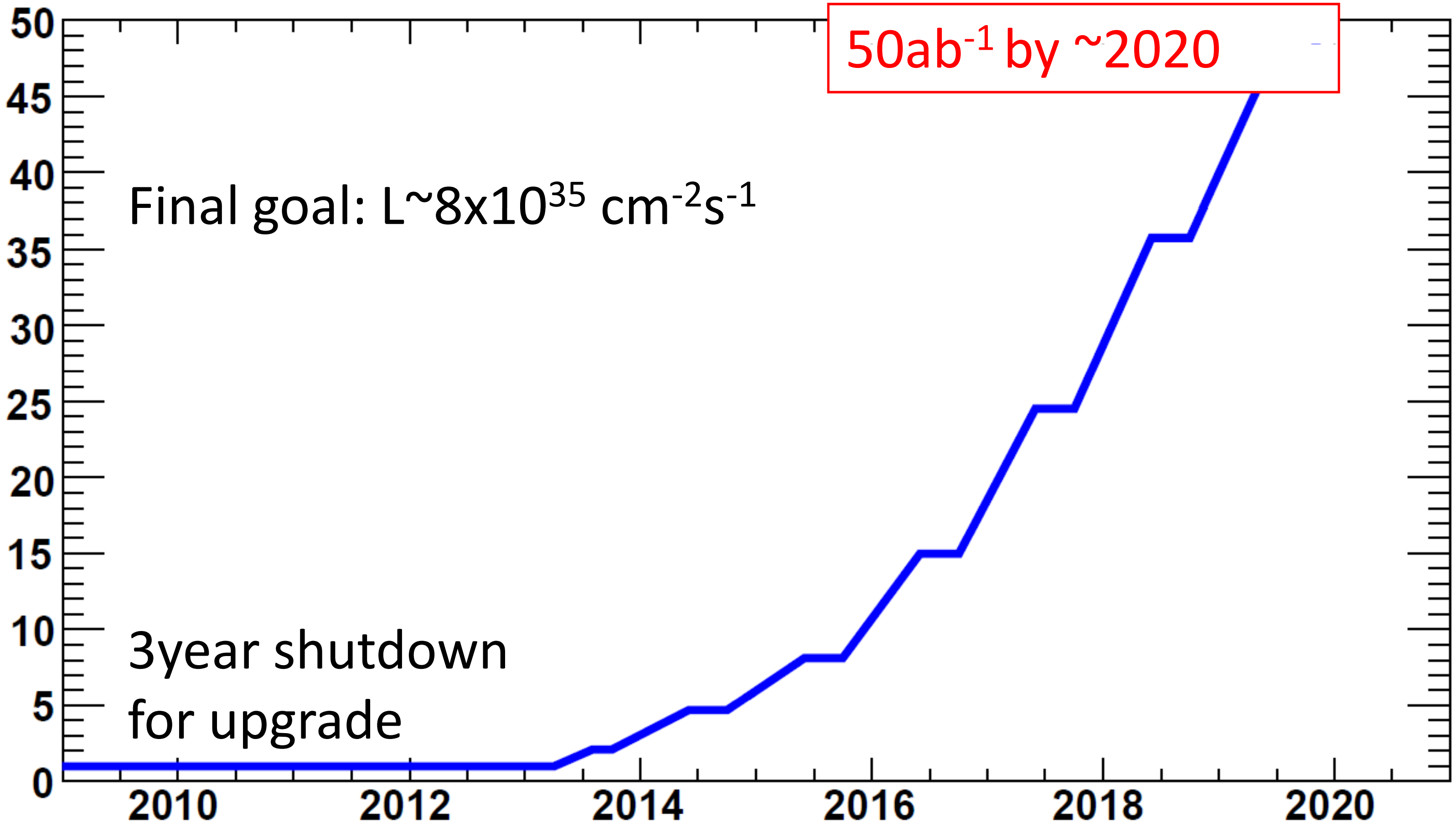
Crab Cavities





Installed in KEKB (Feb. 2007)

Luminosity Prospects



Strategies for Increasing Luminosity

$$L = \frac{\gamma_{e\pm}}{2 e r_e}\left(1 + \frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{e\pm}\xi_y^{e\pm}}{\beta_y^*}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

Beam current

Beam-beam parameter

Lumi. reduction factor (crossing angle)&
Tune shift reduction factor (hour glass effect)
0.8 ~ 1
(short bunch)

Classical electron radius

Beam size ratio@IP
1 ~ 2 % (flat beam)

Vertical beta function@IP

High-Current Option → (1), (2), (3)

(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y

Nano-Beam Option → (1), (2)

Luminosity: Two Options

High Current	Nano-Beam
Slightly smaller β_y^*	Smaller β_y^*
6.5(LER)/5.9(HER)→ 3.0/6.0	6.5(LER)/5.9(HER)→ 0.21/0.37
Increase beam currents	Slightly increase beam currents
1.8A(LER)/1.45A(HER) → 9.4A/4.1A	1.8A(LER)/1.45A(HER) → 3.6A/2.1A
	Close to original KEK design
Increase ξ_y	Keep ξ_y
0.1(LER)/0.06(HER) → 0.3 or more	0.1(LER)/0.06(HER) → 0.09/0.09
Evolution of design in original Letter of Intent (LoI) for SuperKEKB (2004)	Proposed by P. Raimondi et al., along with Crab Waist, for use at the SuperB in Frascati

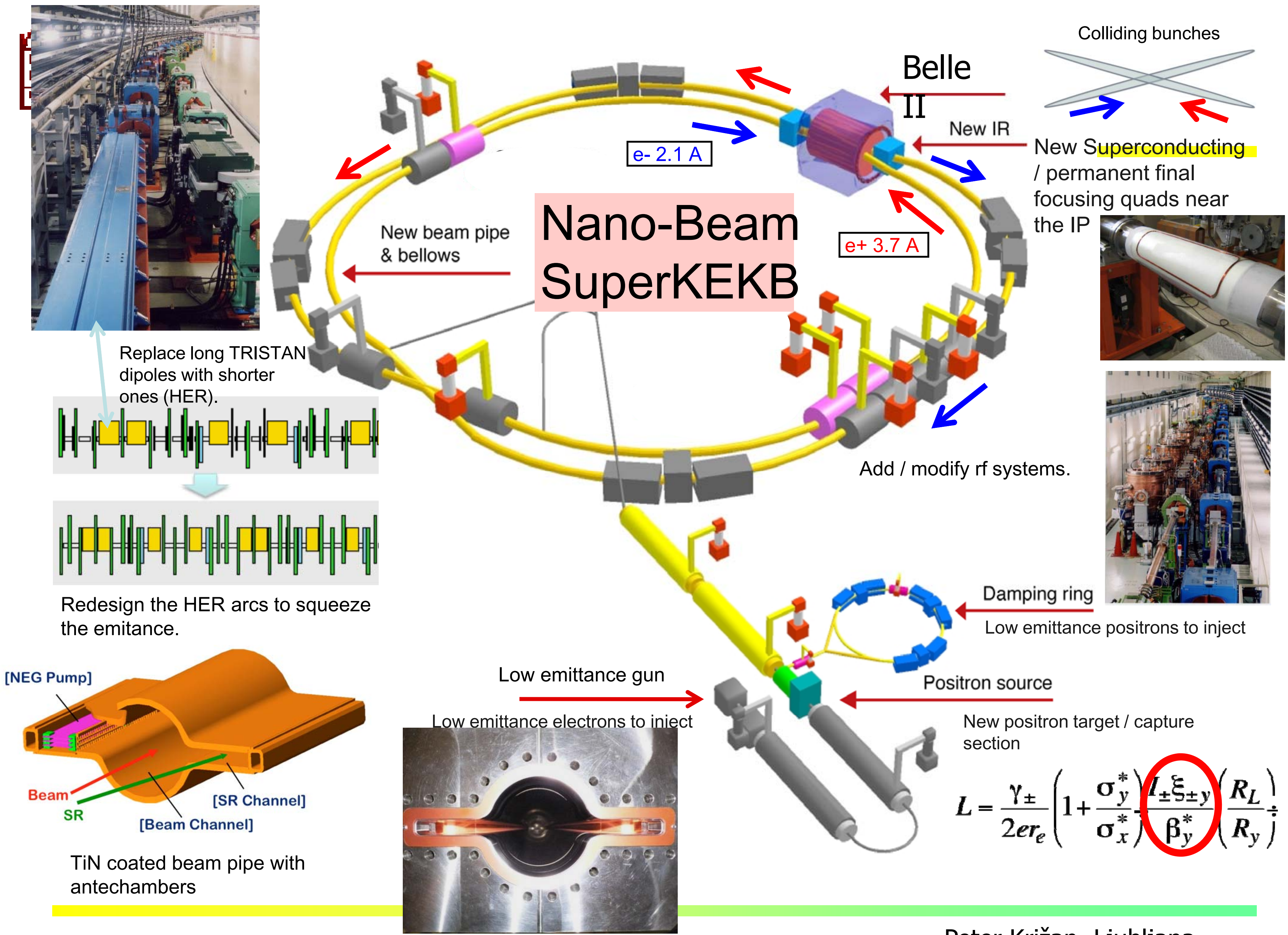
Decision expected by the end of 2009

Comparison of Parameters

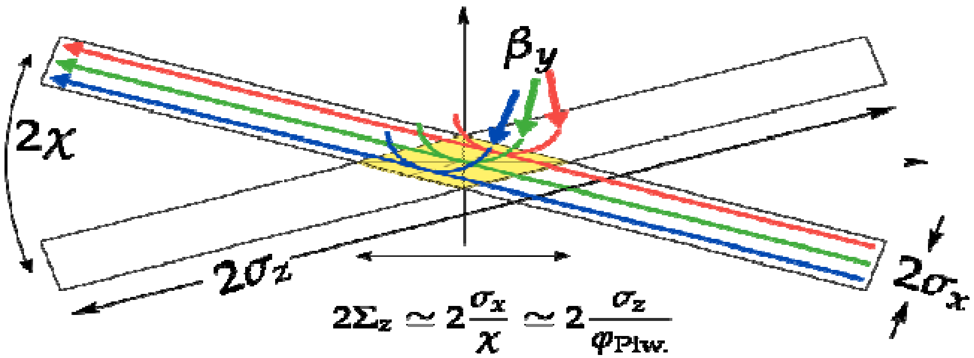
Preliminary

	KEKB Design	KEKB Achieved (): with crab	SuperKEKB High-Current Option	SuperKEKB Nano-Beam Scheme
β_y^* (mm)(LER/HER)	10/10	6.5/5.9 (5.9/5.9)	3/6	0.24/0.37
ε_x (nm)	18/18	18(15)/24	24/18	2.8/2.0
κ(%)	1	0.8-1	1/0.5	1.0/0.7
σ_y(μm)	1.9	1.1	0.85/0.73	0.084/0.072
ξ_y	0.052	0.108/0.056 (0.101/0.096)	0.3/0.51	0.09/0.09
σ_z (mm)	4	~ 7	5(LER)/3(HER)	5
I_{beam} (A)	2.6/1.1	1.8/1.45 (1.62/1.15)	9.4/4.1	3.6/2.1
$N_{bunches}$	5000	~1500	5000	2119
Luminosity (10^{34} cm^{-2} s^{-1})	1	1.76 (2.08)	53	80

High Current Option includes crab crossing and travelling focus.


Colliding bunches
Belle II
New IR
New Superconducting / permanent final focusing quads near the IP
e- 2.1 A
e+ 3.7 A
Nano-Beam SuperKEKB
New beam pipe & bellows
Replace long TRISTAN dipoles with shorter ones (HER).
Redesign the HER arcs to squeeze the emitance.
Add / modify rf systems.
Damping ring
Low emittance positrons to inject
Positron source
New positron target / capture section
Low emittance gun
Low emittance electrons to inject
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
TiN coated beam pipe with antechambers
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Crab Waist :The SuperB solution



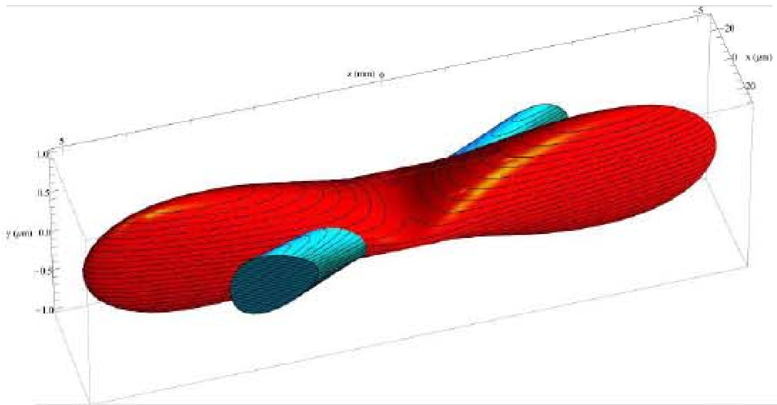
- Crab waist: modulation of the y-waist position, particles collides a same β_y realized with a sextupole upstream the IP.
- Minimization of nonlinear terms in the beam-beam interaction: reduced emittance growth, suppression of betatron and sincro-betatron coupling
- Maximization of the bunch-bunch overlap: luminosity gain
- Low wall power

SuperB and Super c-τ are based on the crabwaist concept invented in 2006 by P.Raimondi in 2006.

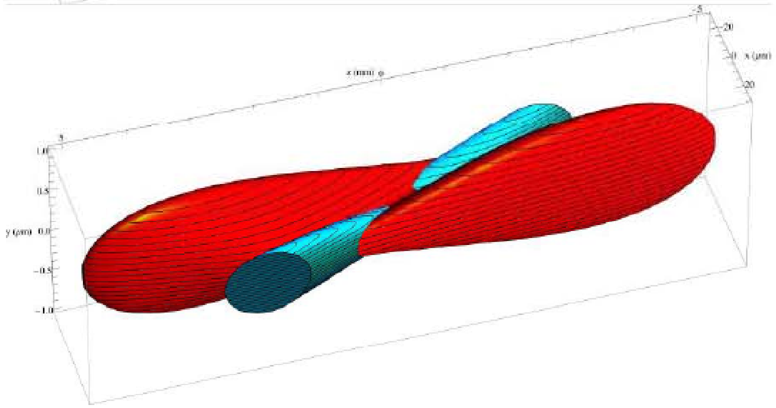
TESTED IIN LNF WITH DAFNE (500 MeV beams)

Beams distribution at IP

E. Paoloni



Without
Crab-sextupoles



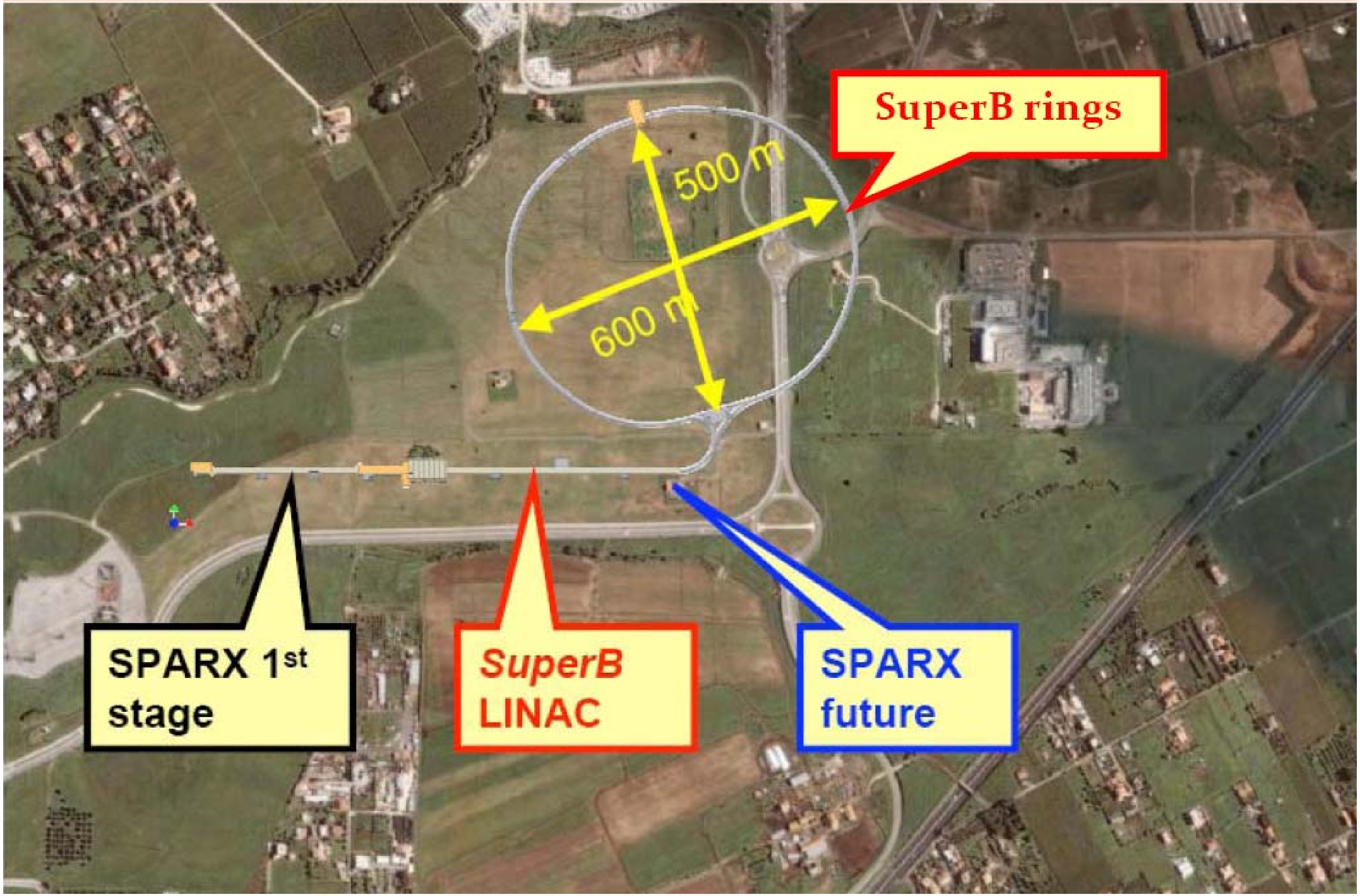
With
Crab-sextupoles

All particles from both beams collide in the minimum β_y region, with a net luminosity gain

Accellerator parameters

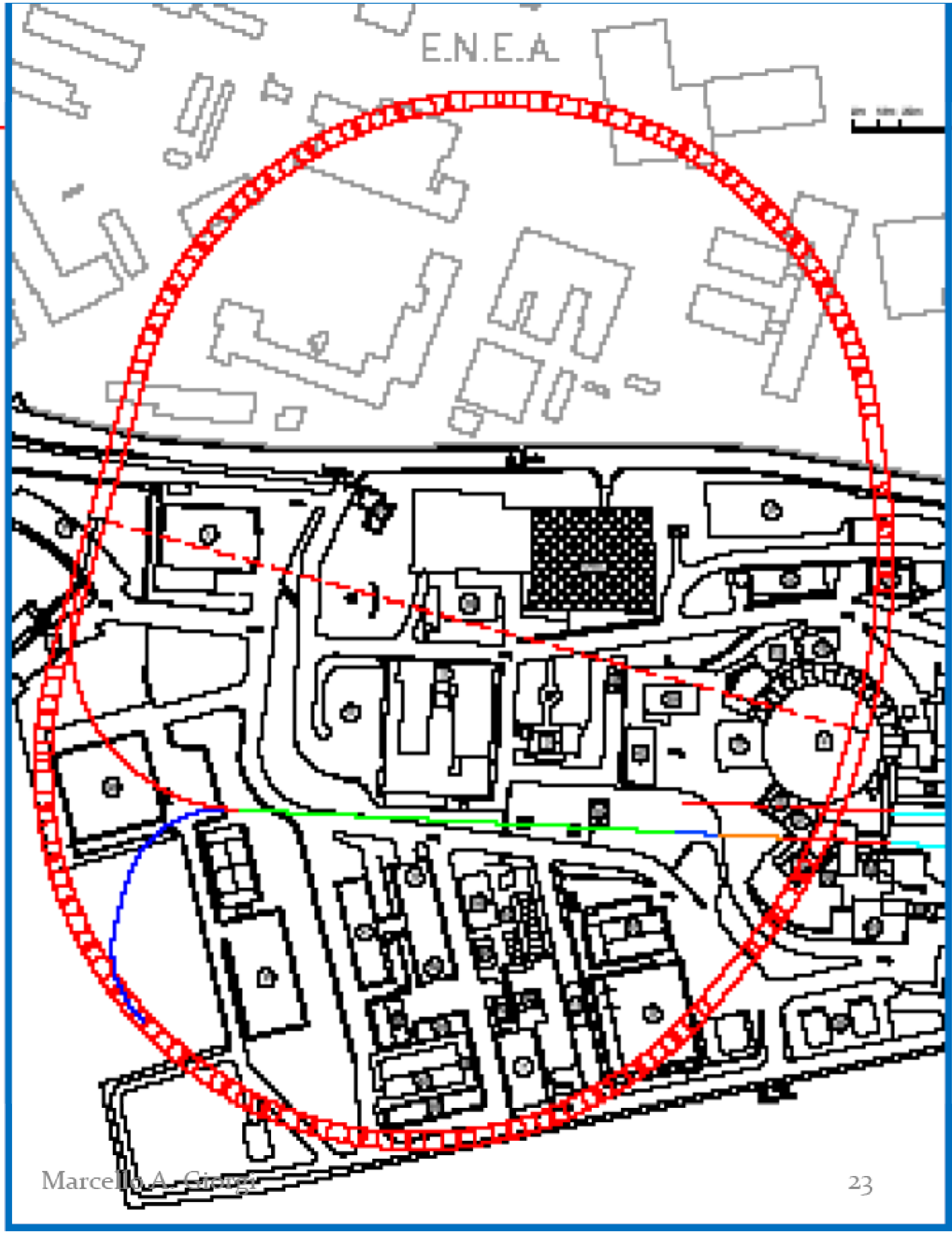
Parameter	Units	SuperB	Super-KEKB Old scheme	Super-KEKB Italian scheme
Energy	GeV	4x7	3.5x8	3.5x8
Luminosity	$10^{36}/cm^2/s$	1.0	0.5 to 0.8	0.8
Beam currents	A	2.0x2.0	9.4x4.1	3.8x2.2
$N_{bunches}$		2400	5000	2230
Ey* (L/H)	pm	7/4	240/90	34/11
Ex* (L/H)	nm	2.8/1.6	24/18	2.8/2
By* (L/H)	mm	0.21/0.37	3	0.21/0.37
Bx* (L/H)	cm	3.5/2.0	20	4.4/2.5
Sz (L/H)	mm	5/5	5/3	5/5
Crossing angle (full)	mrad	60	30 to 0	60
RF power (AC line)	MW	26	90	>50
Tune shifts (L/H)		0.125/0.125	0.3/0.51	0.081/0.081

Another candidate: SuperB near Frascati



Or FRASCATI

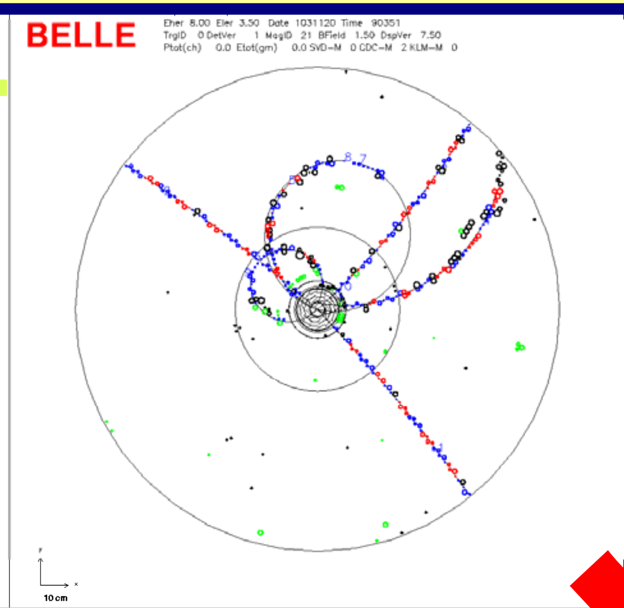
With slightly different parameters

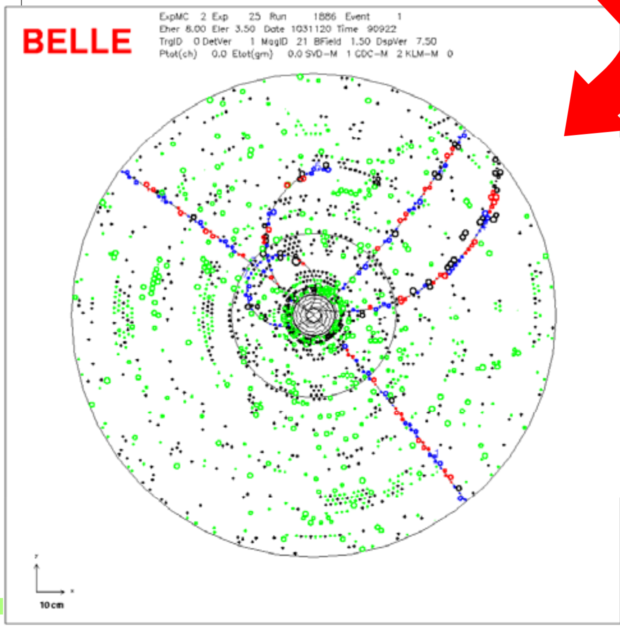


Requirements for the Detector

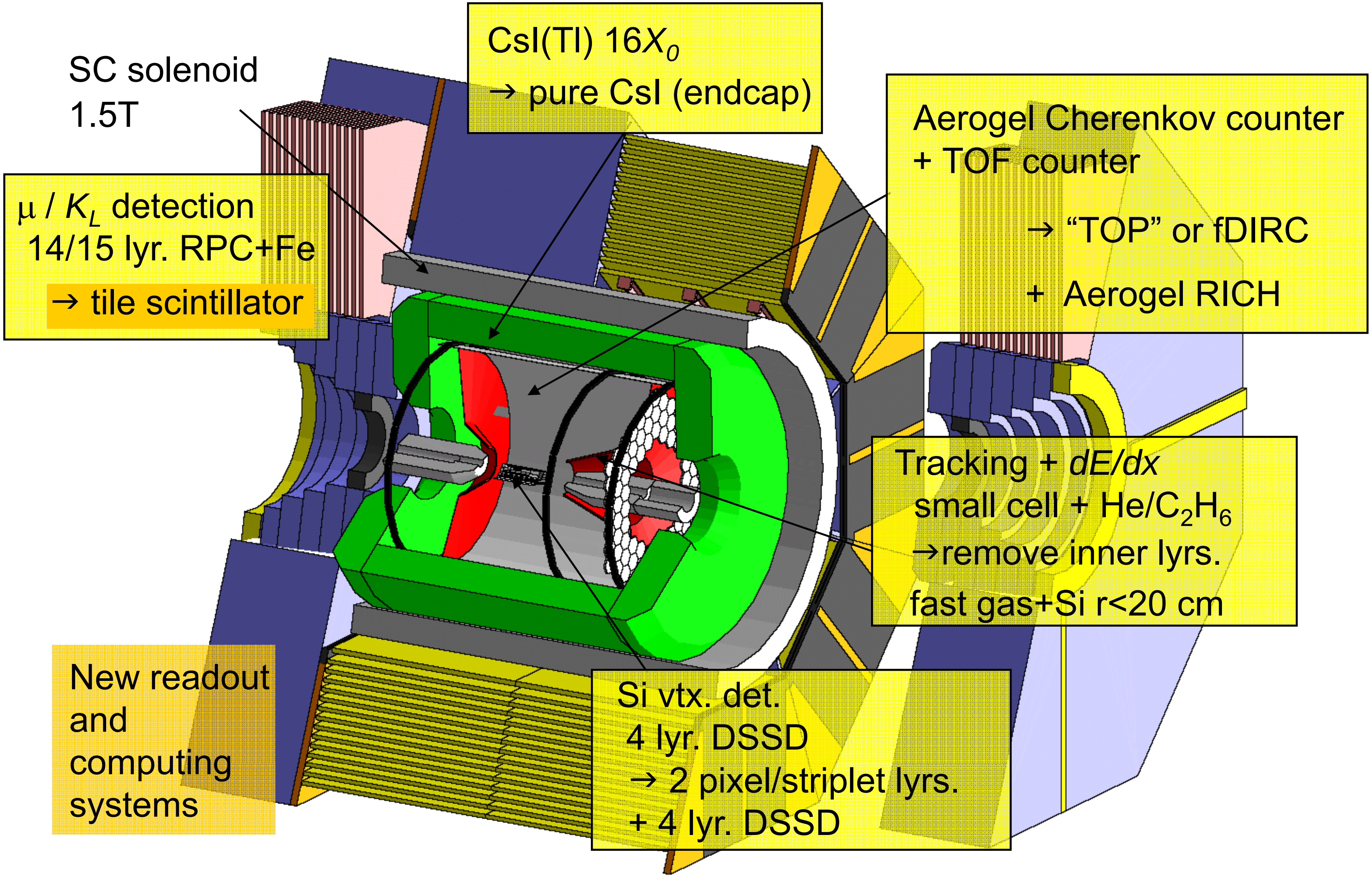
Critical issues at L= 8 x 10^{35}/cm^2/sec

- **Higher background**
  - radiation damage and occupancy
  - fake hits and pile-up noise in the EM
- **Higher event rate**
  - higher rate trigger, DAQ and computing
- **Require special features**
  - low p μ identification $\rightarrow$ $s\mu\mu$ recon. eff.
  - hermeticity $\rightarrow$ ν "reconstruction"



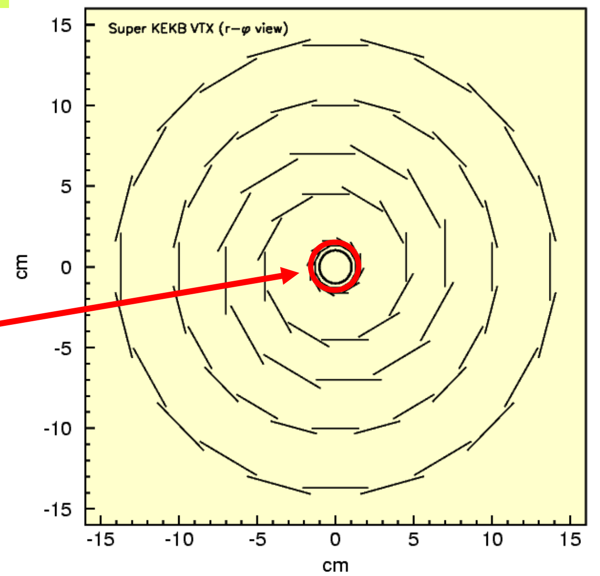


Belle Upgrade for Super-B

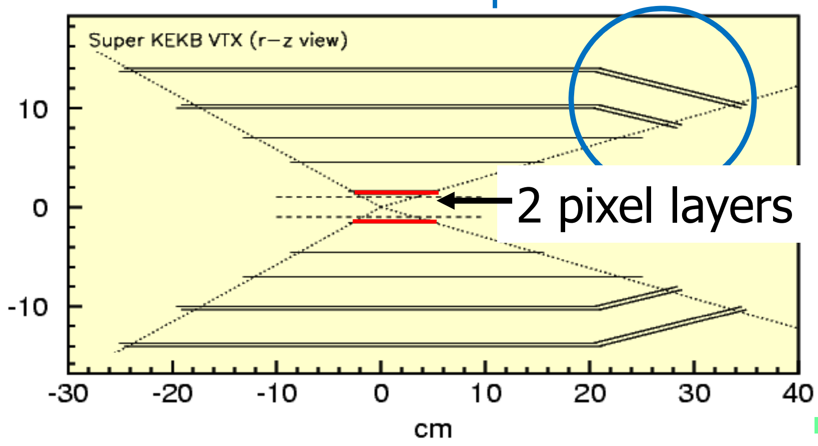


PXD+SVD Upgrade

- Sensors of the innermost layer:
  Normal double sided Si detector (DSSD) → DEPFET Pixel sensors
- Configuration: 4 layers → 6 layers (outer radius = 8cm→14cm)
  - More robust tracking
  - Higher Ks vertex reconstruction efficiency
- Inner radius: 1.5cm → 1.3cm
  - Better vertex resolution
- Strip Readout chip: VA1TA → APV25
  - Reduction of occupancy coming from beam background.
  - Pipeline readout to reduce dead time.



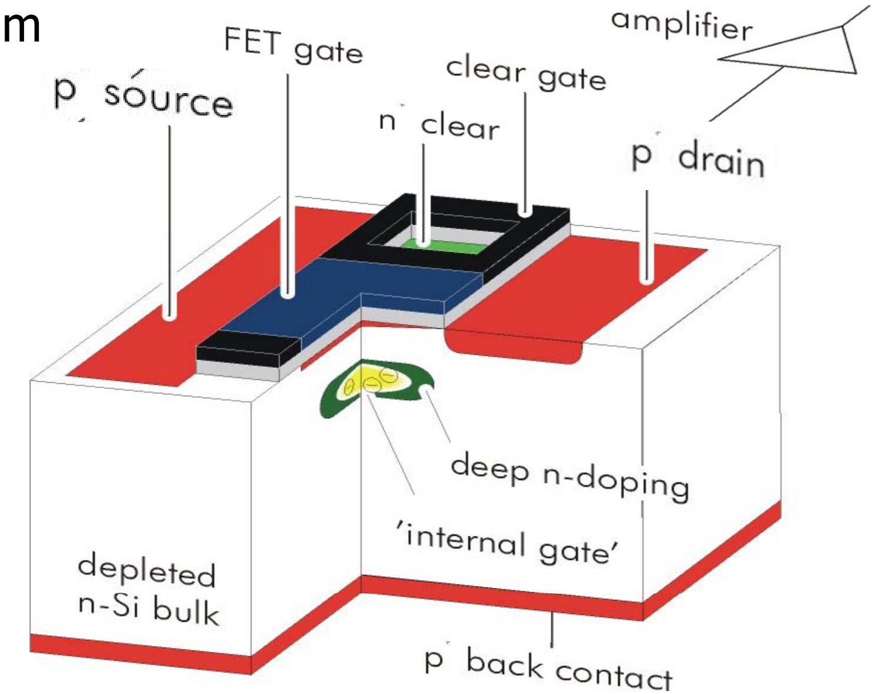
Slant layer to keep the acceptance



DEPFET Principle

p-channel FET on a completely depleted bulk

Depleted p-channel FET



A deep n-implant creates a potential minimum for electrons under the gate ("internal gate")

Signal electrons accumulate in the internal gate and modulate the transistor current (g_q ~ 400 pA/e^-)

Accumulated charge can be removed by a clear contact ("reset")

Invented in MPI Munich

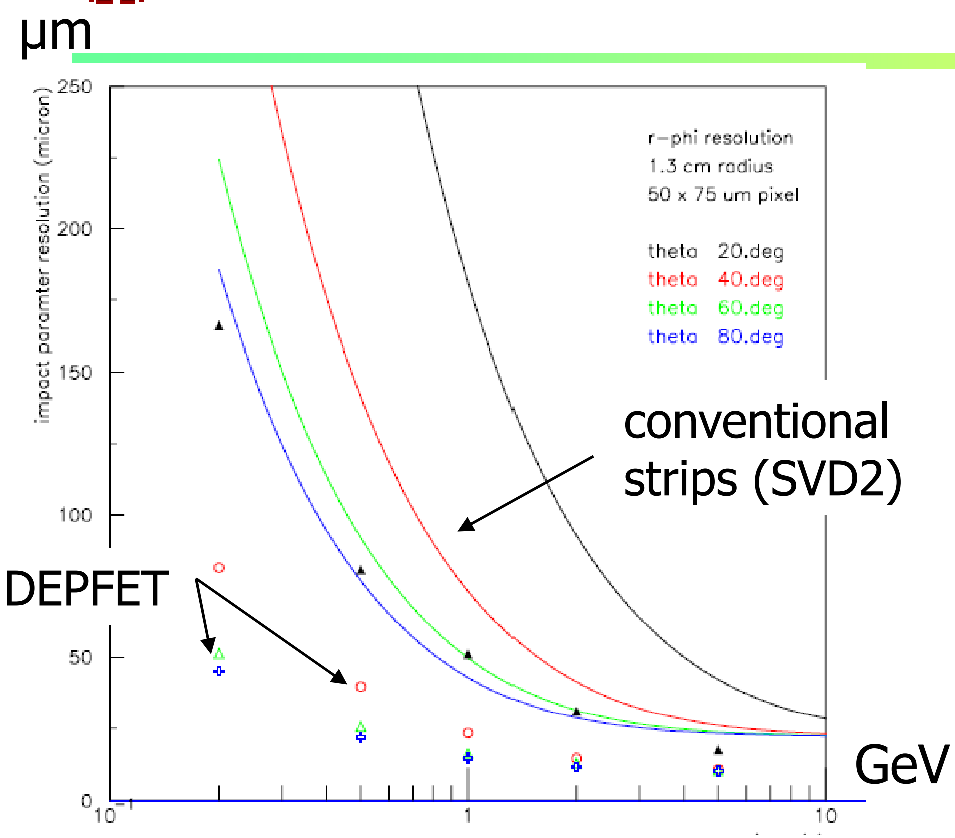
Fully depleted:
→ large signal, fast signal collection

Low capacitance, internal amplification → low noise

Transistor on only during readout: low power

Complete clear → no reset noise

DEPFET Performance



Impact parameter resolution
(dots: DEPFET)

Very preliminary
(single tracks, no background)

DEPFET:
L1 1.3 cm (32μm x 50μm)
L2 1.6 cm (32μm x 50μm)
thickness: 50μm, noise 100e

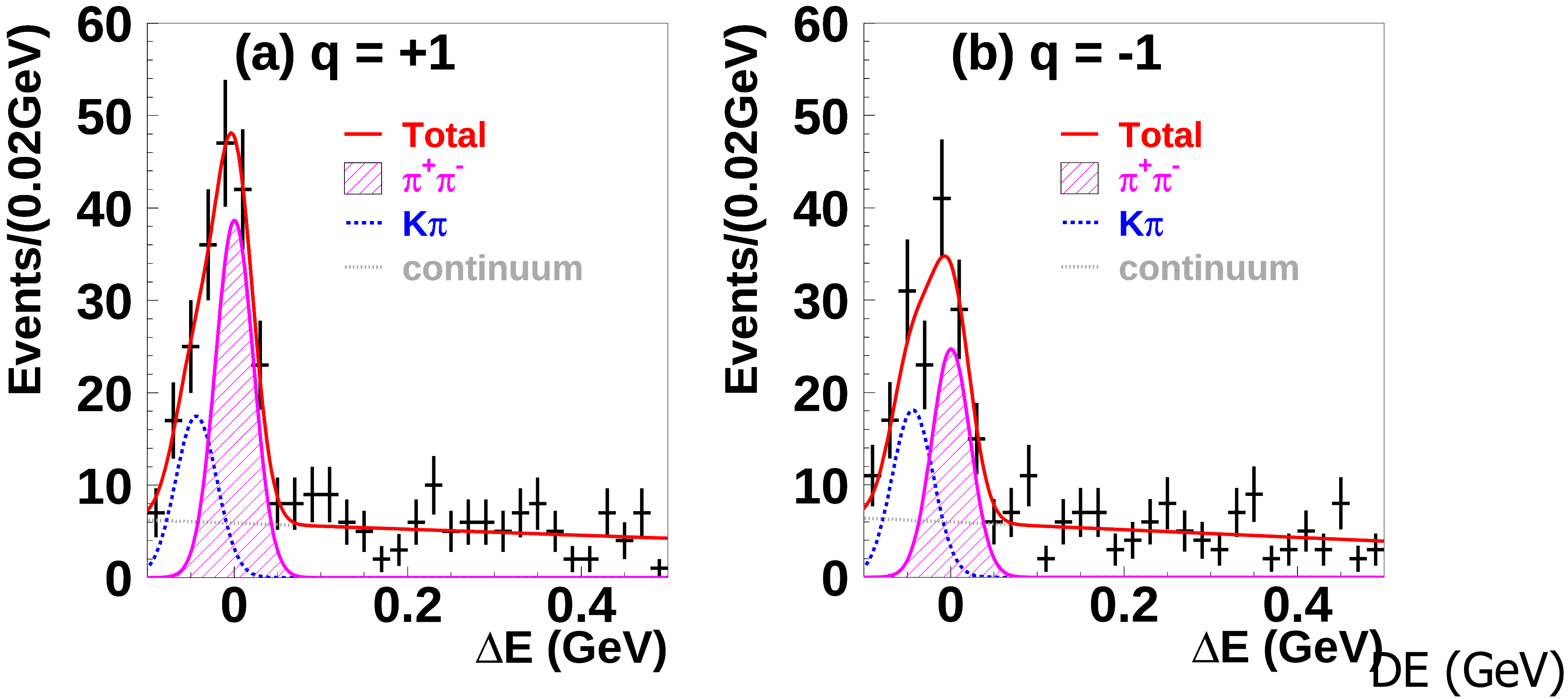
DSSD L3/L4/L5/L6:
4.5/7.0/10/13.8cm
(50μm x 75μm)
thickness 300μm,
noise 1600e
beam pipe radius:
1cm (Be with 10mm Au layer)

Substantial improvement compared to Belle SVD2

PXD will be delivered by European groups

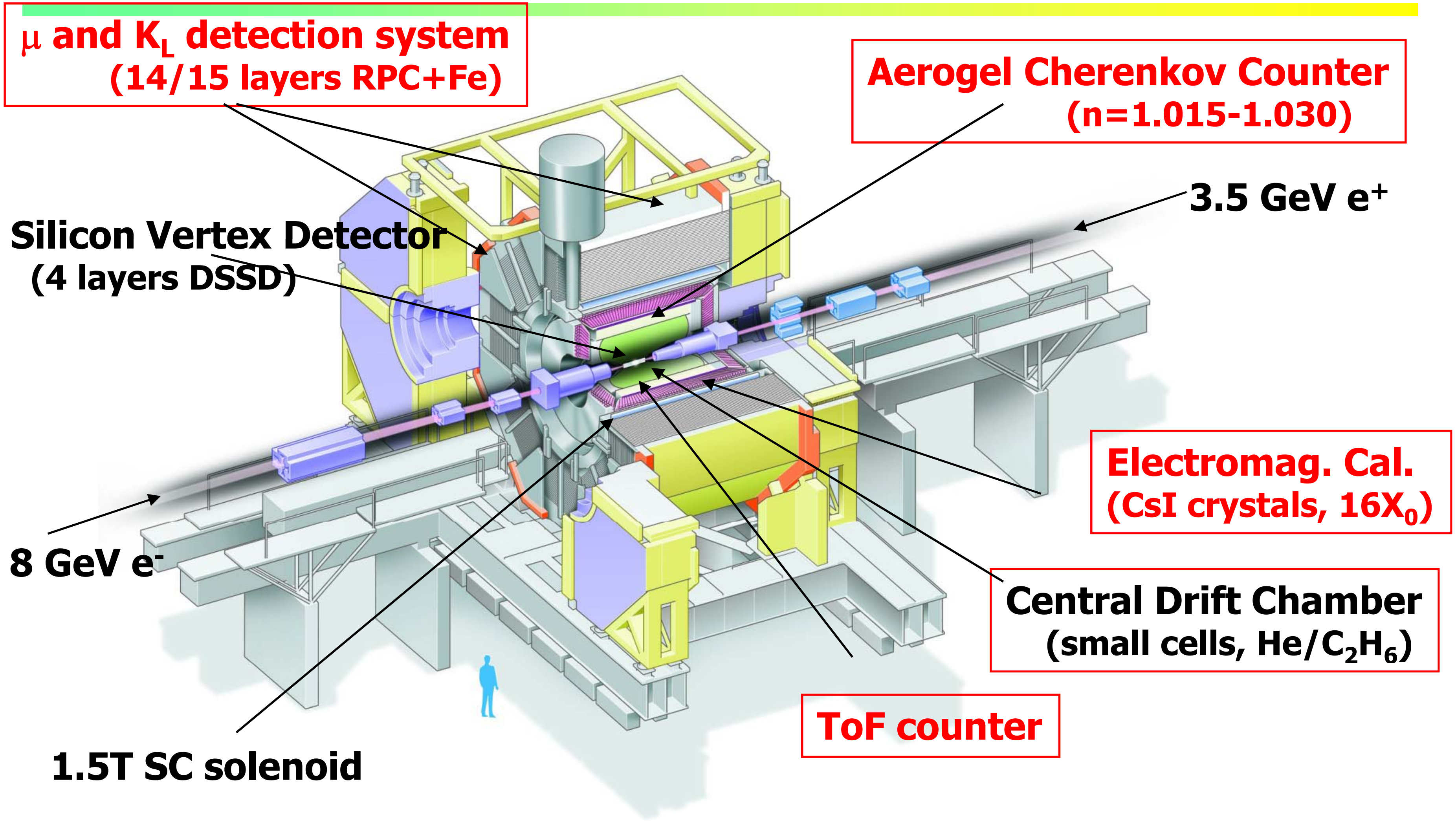
Why excellent particle identification?

Remember B→ππ decays: B→πK rate 10x bigger than B→ππ!



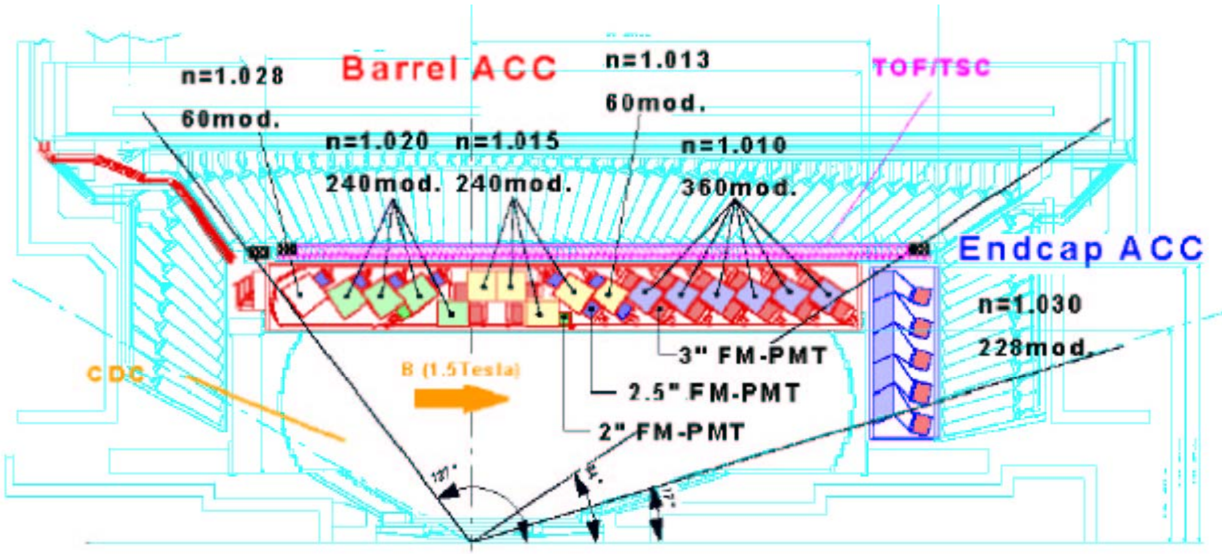
→ We would see no effect without excellent PID!

Particle identification systems in Belle

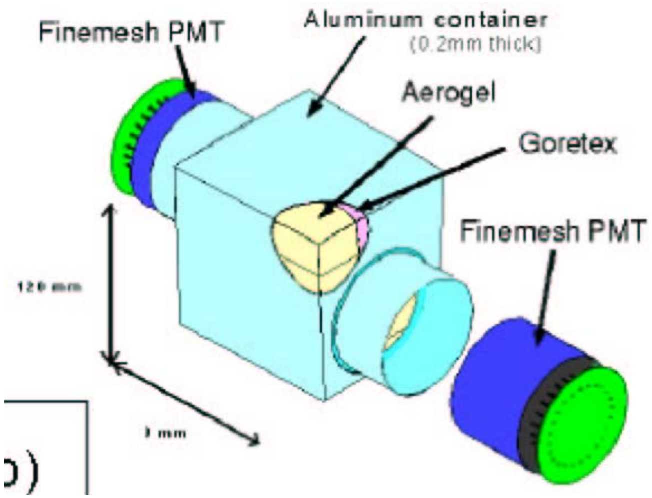


Present Belle: threshold Cherenkov counter ACC (aerogel Cherenkov counter)

K (below threshold) vs. π (above) by properly choosing n for a given kinematic region (more energetic particles fly in the 'forward region')



Detector unit: a block of aerogel and two fine-mesh PMTs

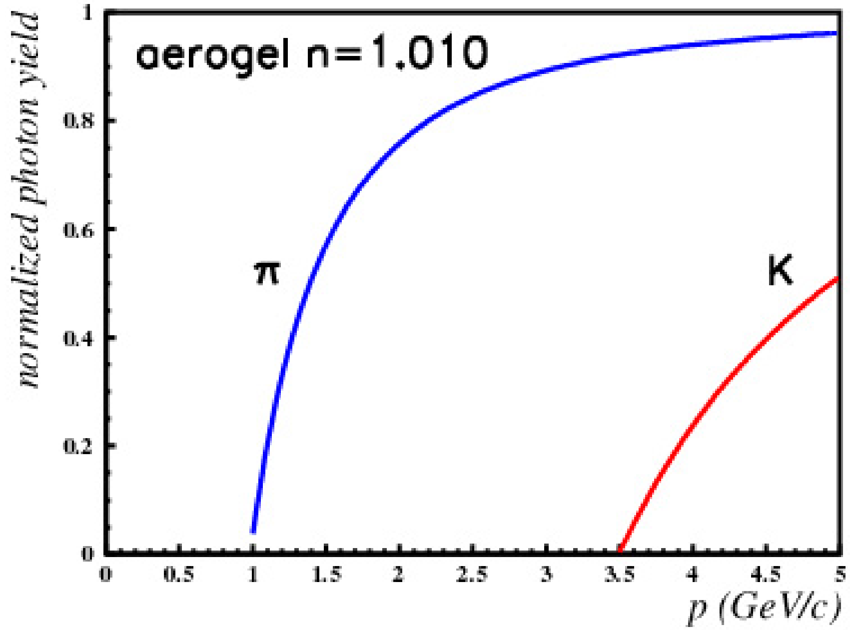


Fine-mesh PMT: works in high B fields

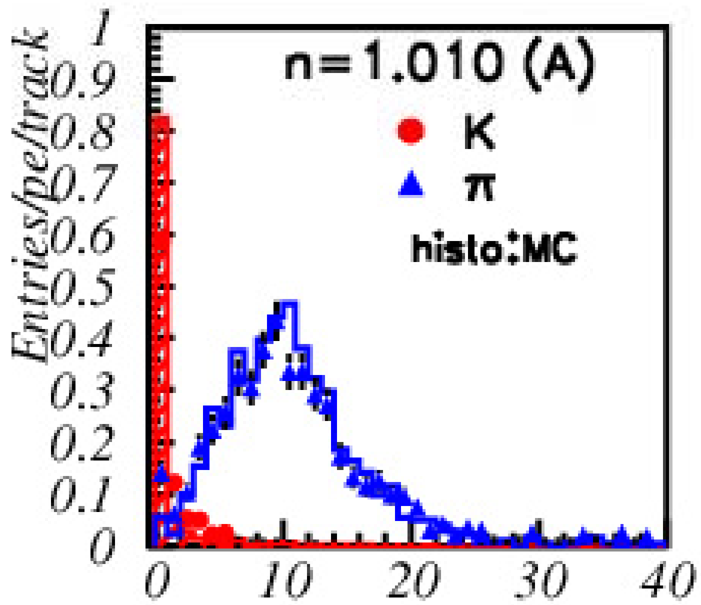
Belle ACC : threshold Cherenkov counter

expected yield vs p

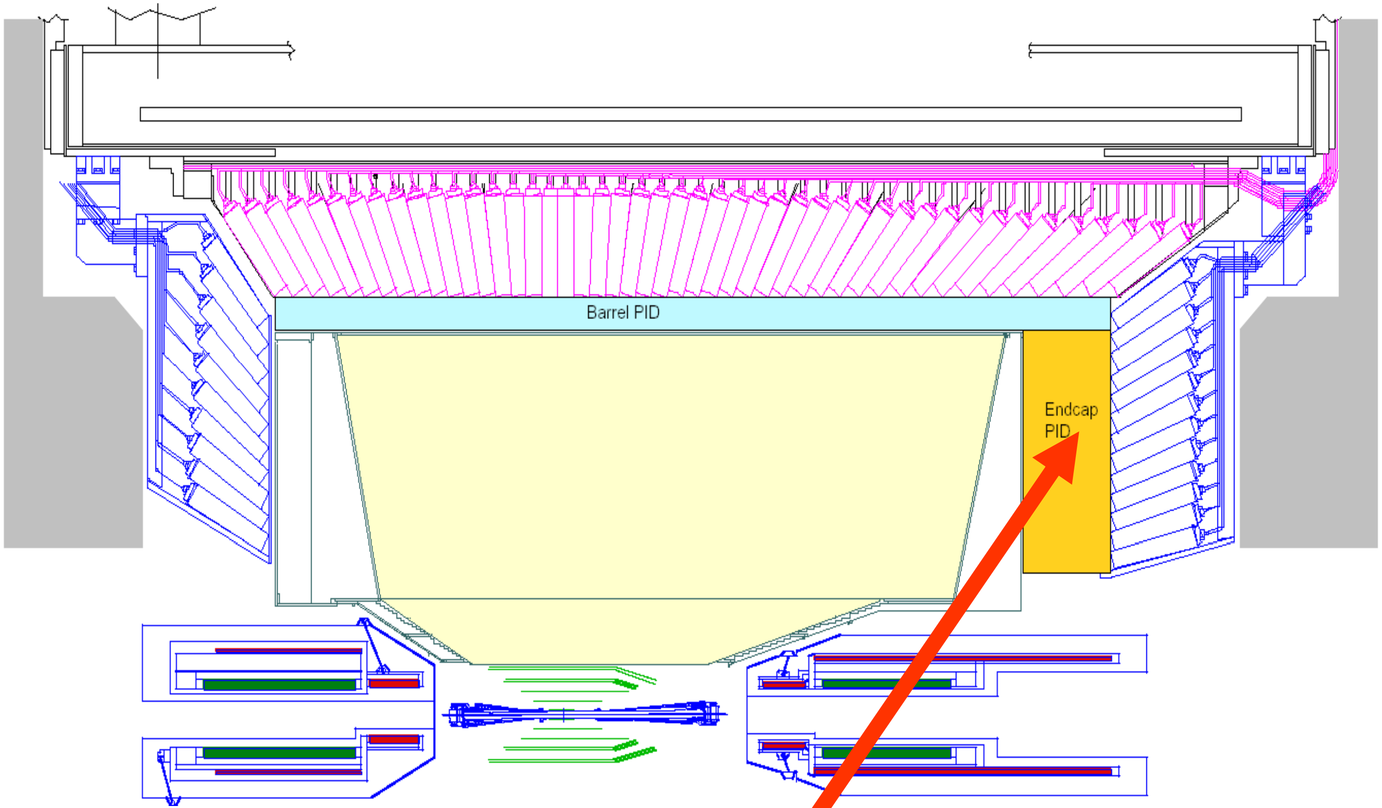
NIM A453 (2000) 321



yield for 2GeV<p<3.5GeV:
expected and measured
number of hits



Belle upgrade – side view

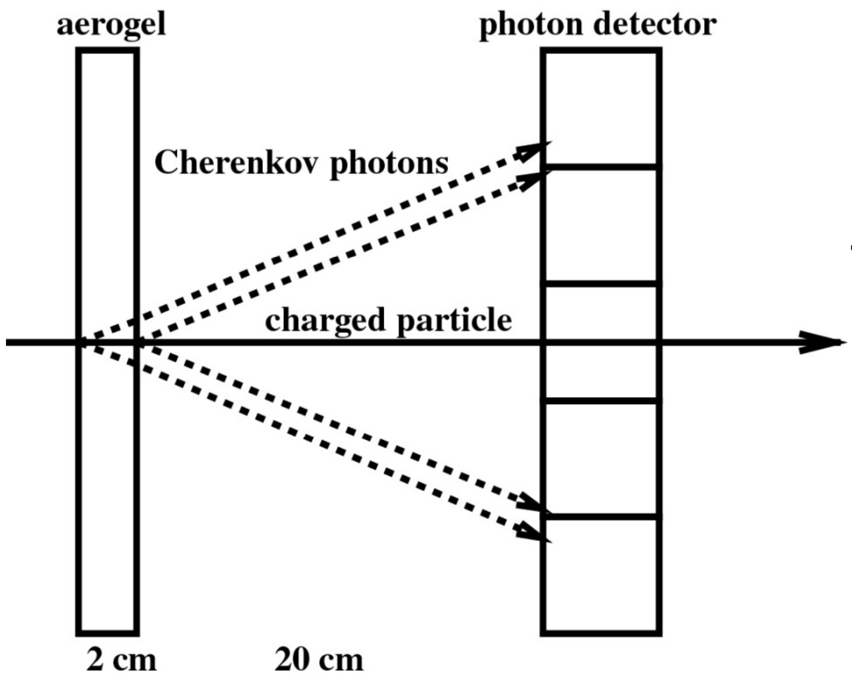


Two new particle ID devices, both RICHes:

Barrel: TOP or focusing DIRC

Endcap: proximity focusing RICH

Endcap: Proximity focusing RICH



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

For single photons:
$\delta\theta_c$(meas.)$=\sigma_0 \sim 14$ mrad,
typical value for a 20mm thick radiator and 6mm PMT pad size

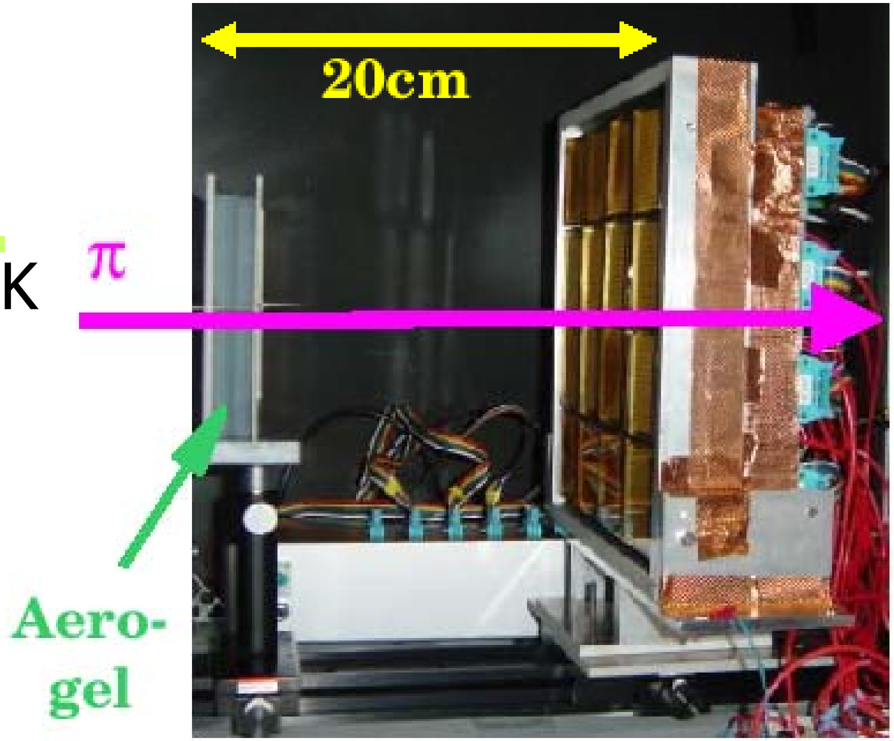
Per track: $$\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$$

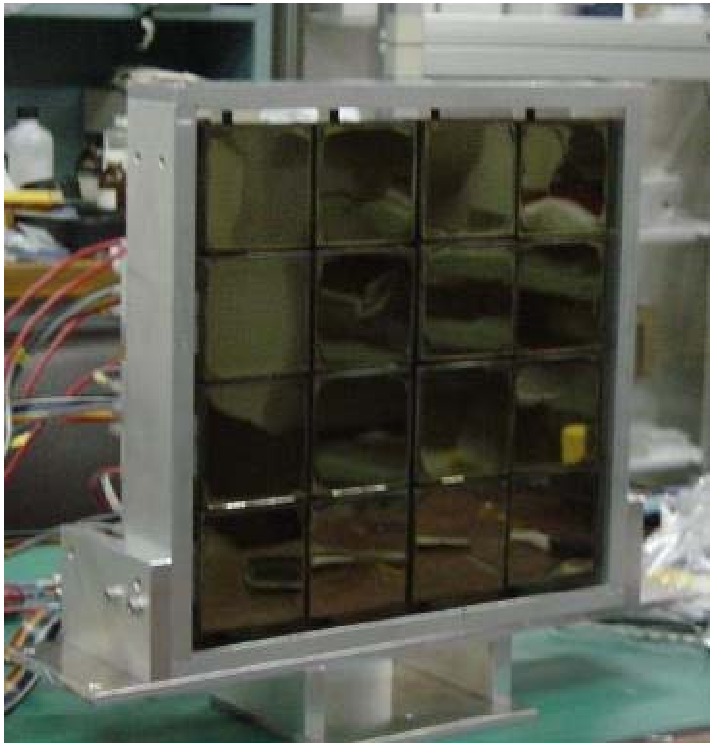
Separation: $[\theta_c(\pi) - \theta_c(K)]/\sigma_{track}$

→ 5σ separation with $N_{pe} \sim 10$

Beam tests

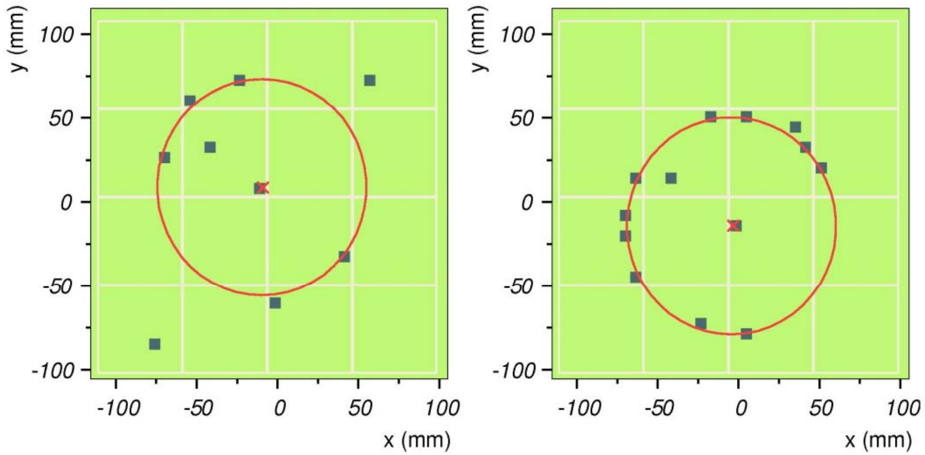
pion beam (π2) at KEK





Photon detector: array of 16 H8500 PMTs

Clear rings, little background

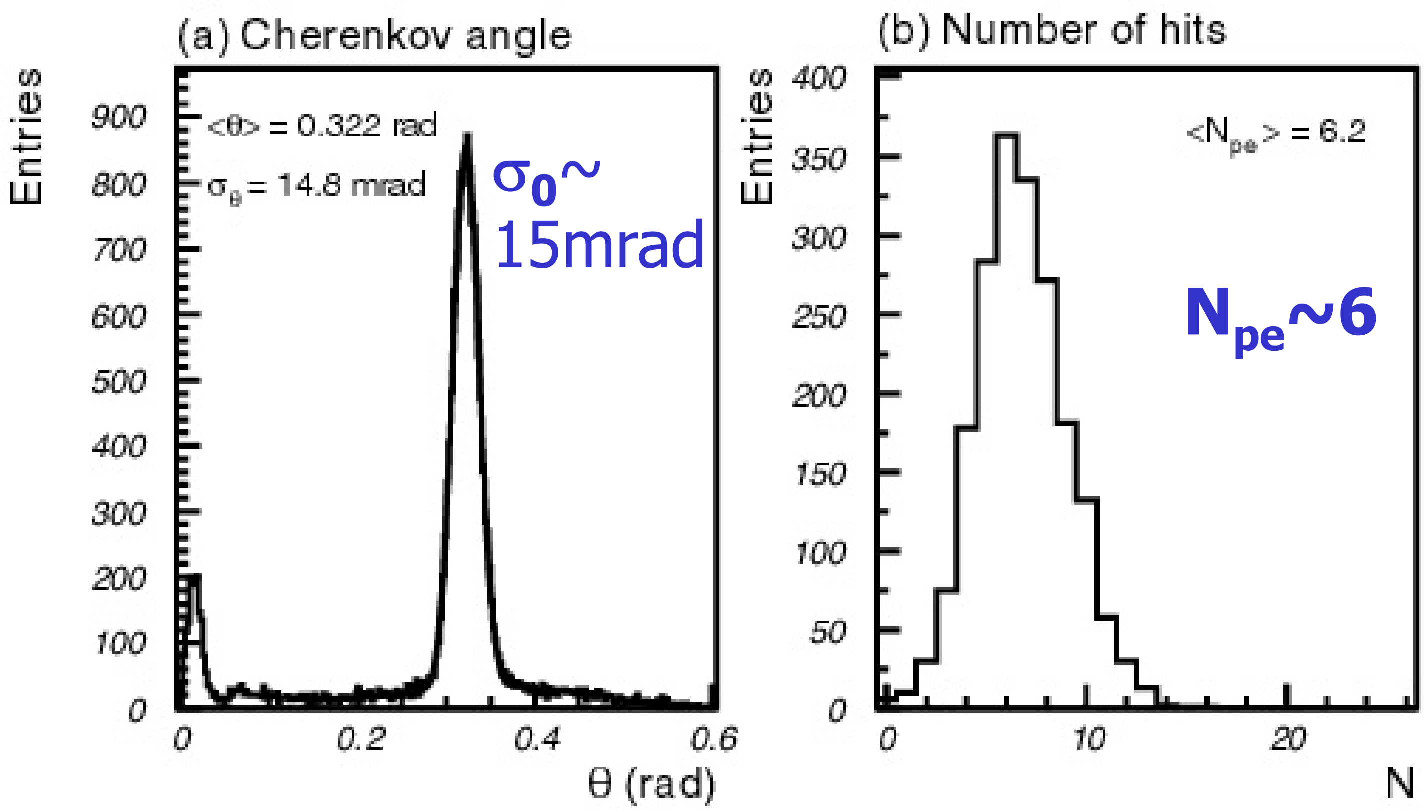


Beam test: Cherenkov angle resolution and number of photons

NIM A521(2004)367; NIM A553(2005)58

Beam test results with 2cm thick aerogel tiles:

$>4\sigma$ K/π separation

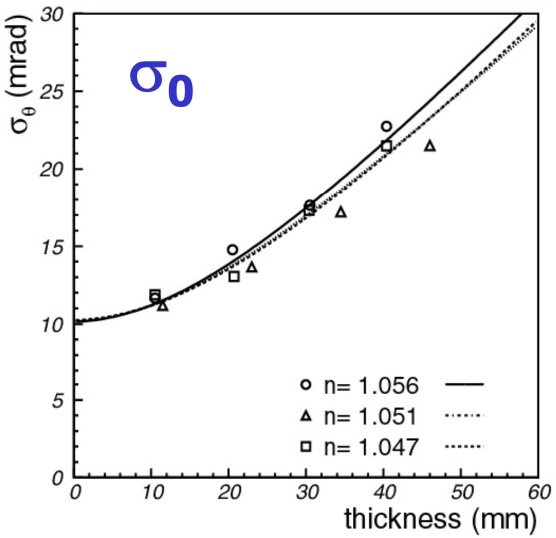


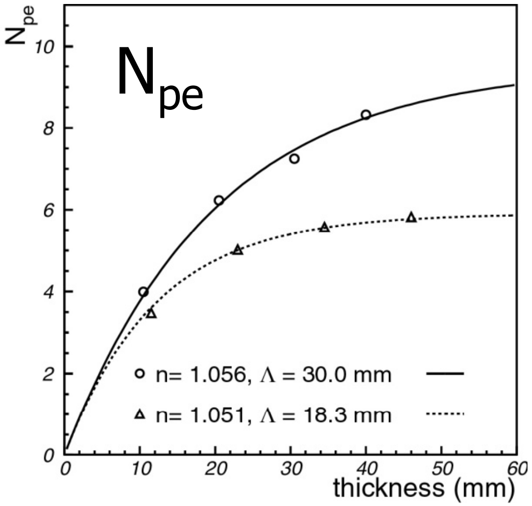
→ Number of photons has to be increased.

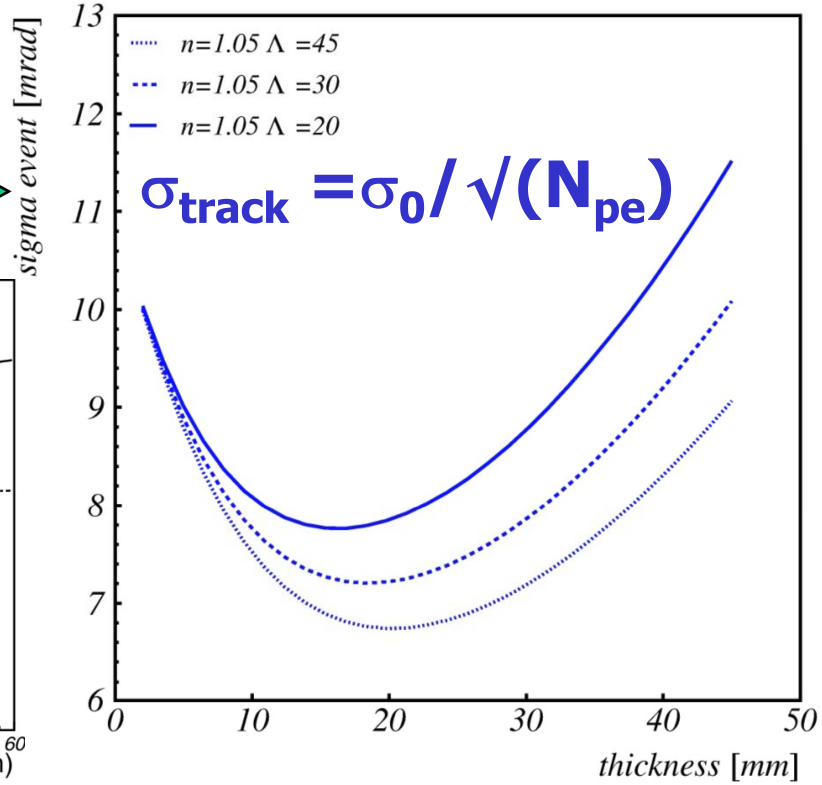
How to increase the number of photons?

What is the optimal radiator thickness?

Use beam test data on σ_0 and N_{pe}







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

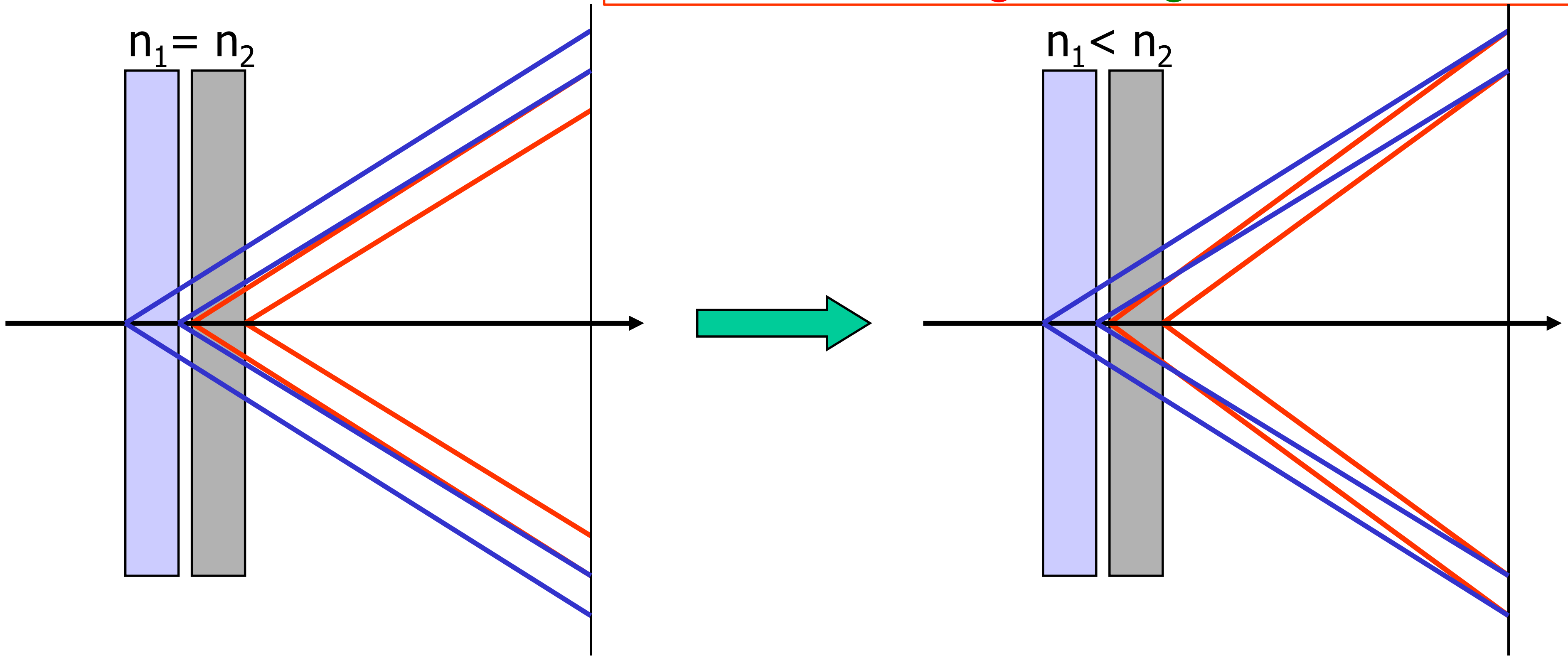
Optimum is close to 2 cm

Radiator with multiple refractive indices

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

→ stack two tiles with different refractive indices: "focusing" configuration

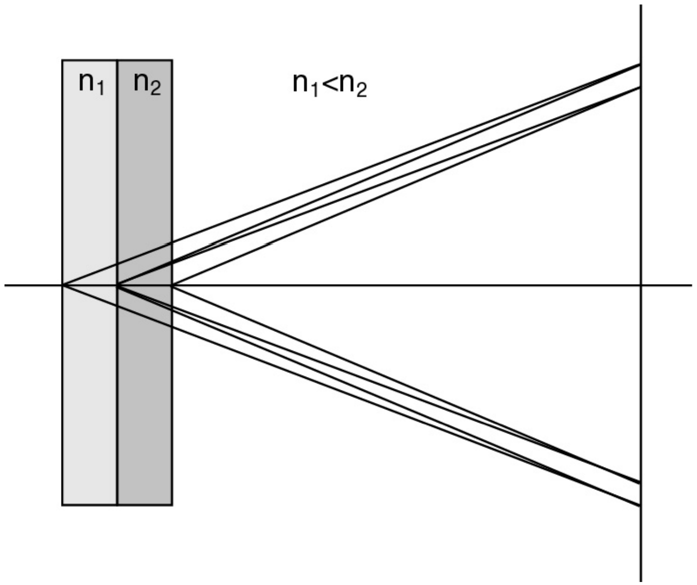
normal

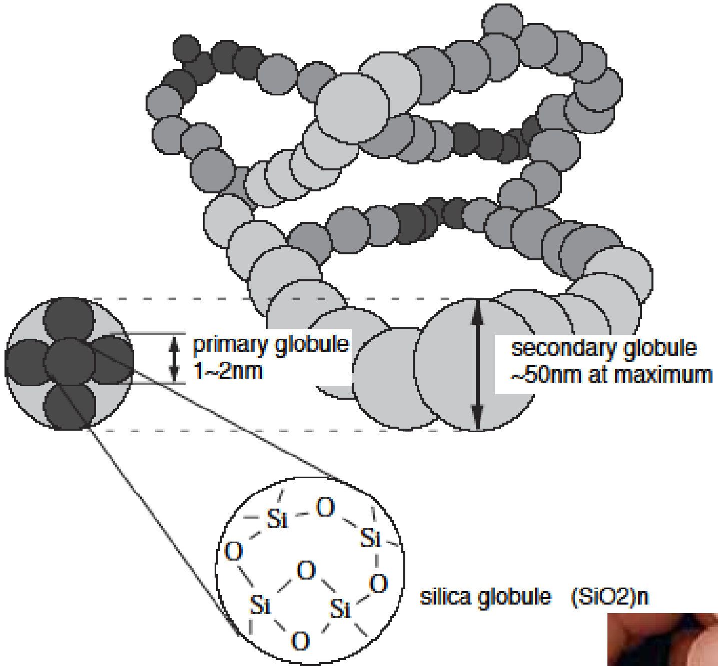


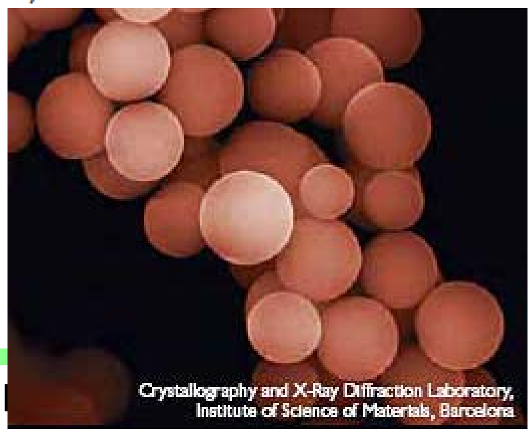
→ focusing radiator

Radiator with multiple refractive indices

Such a configuration is only possible with aerogel (a form of Si_xO_y) – material with a tunable refractive index between 1.01 and 1.13.

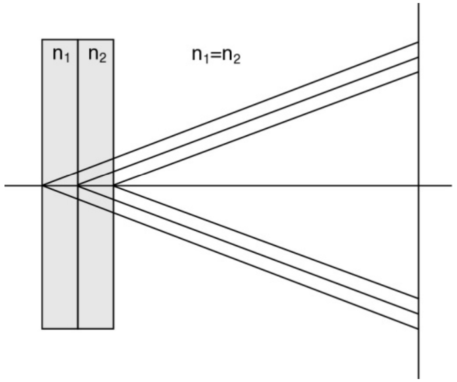


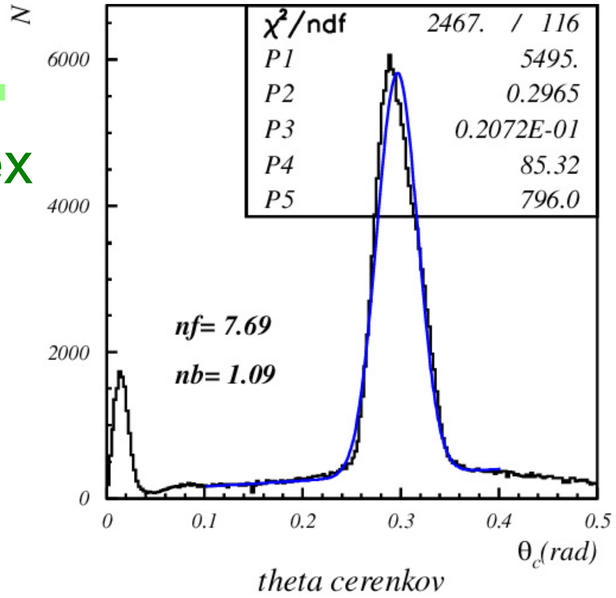


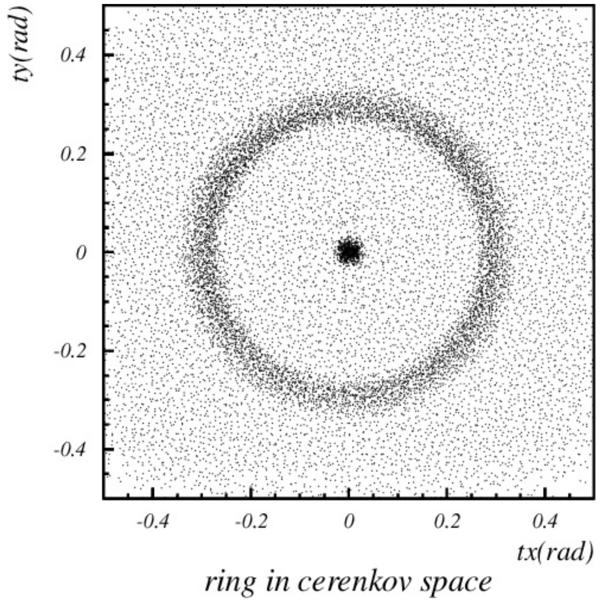


Aerogel RICH – test results

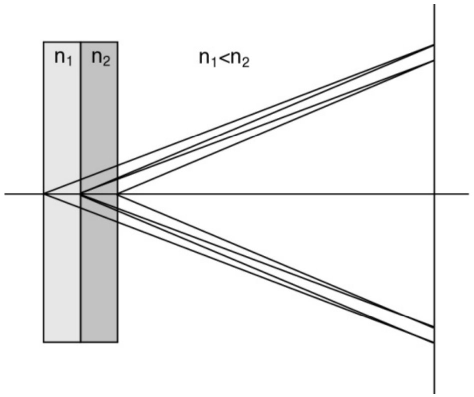
4cm aerogel single index

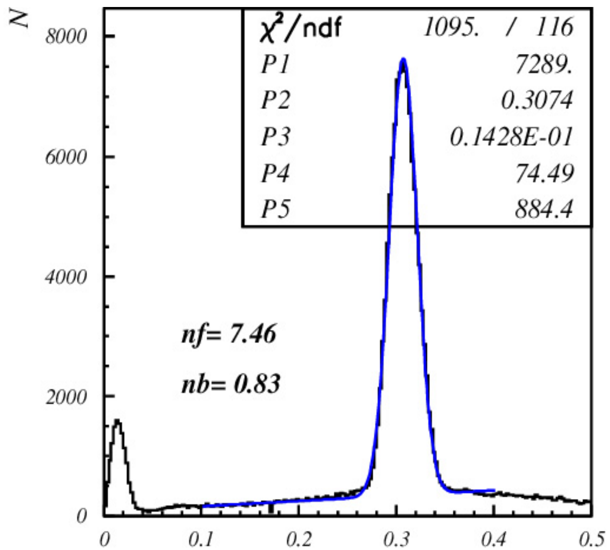


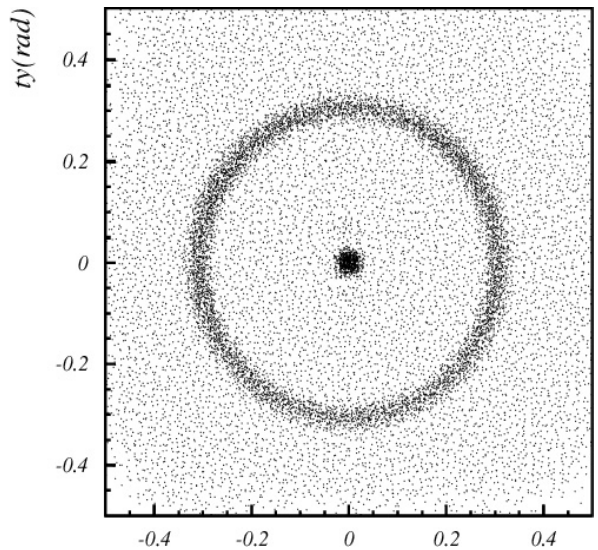




2+2cm aerogel





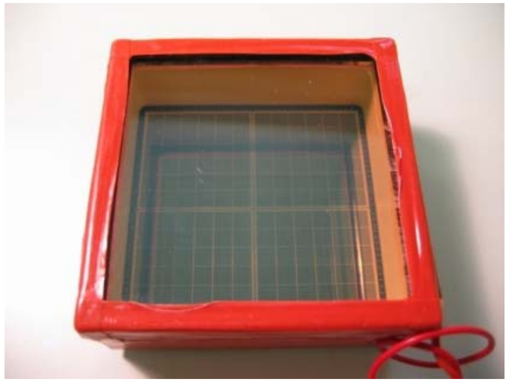


→NIM A548 (2005) 383

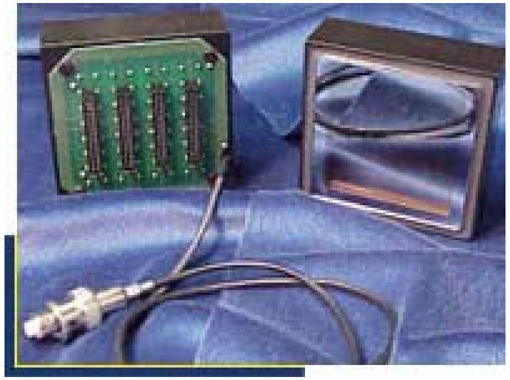
Photon detectors for the Aerogel RICH

Multi-pixel photodetector to measure single photon positions in B=1.5T

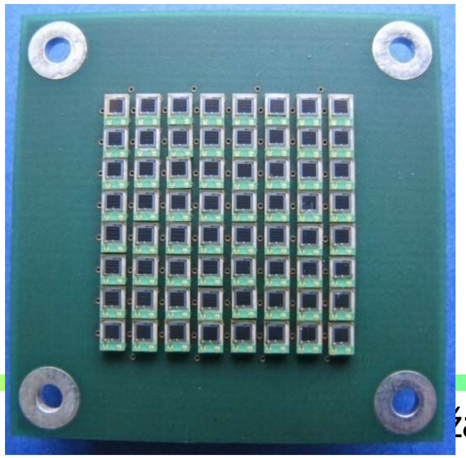
→HAPD



→MCP-PMT



→G-APD

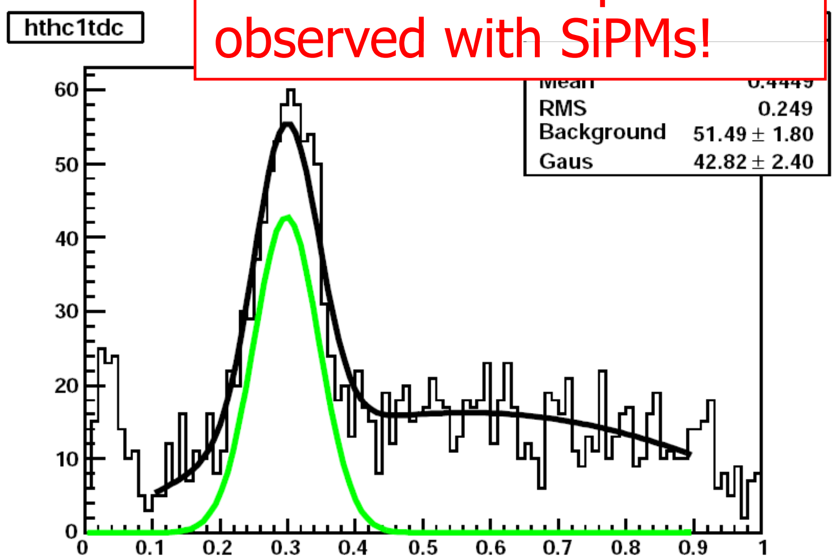


SiPMs for Aerogel RICH

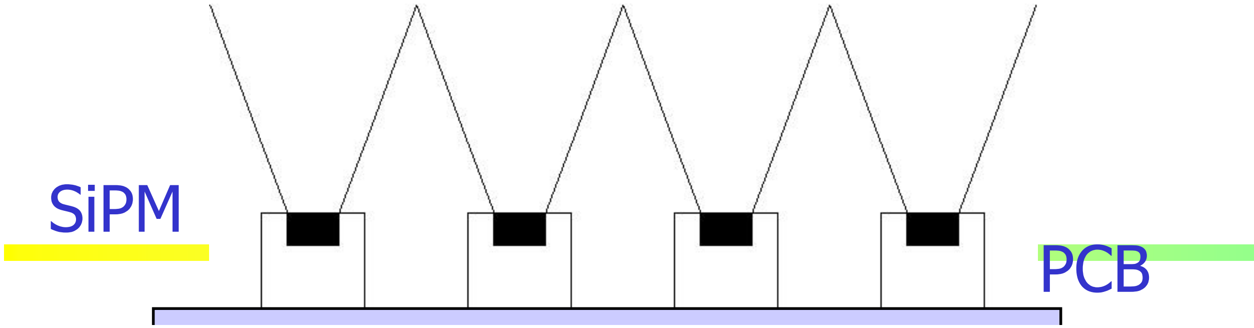
Main challenge: R+D of a photon detector for operation in high magnetic fields (1.5T). Candidates:

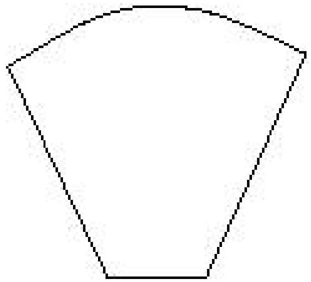
- MCP PMT: excellent timing, could be also used as a TOF counter
- HAPD: development with HPK
- SiPMs: easy to handle, but never before used for single photon detection (high dark count rate with single photon pulse height) → use a narrow time window and light concentrators

First Cherenkov photons observed with SiPMs!



→NIM A594 (2008) 13

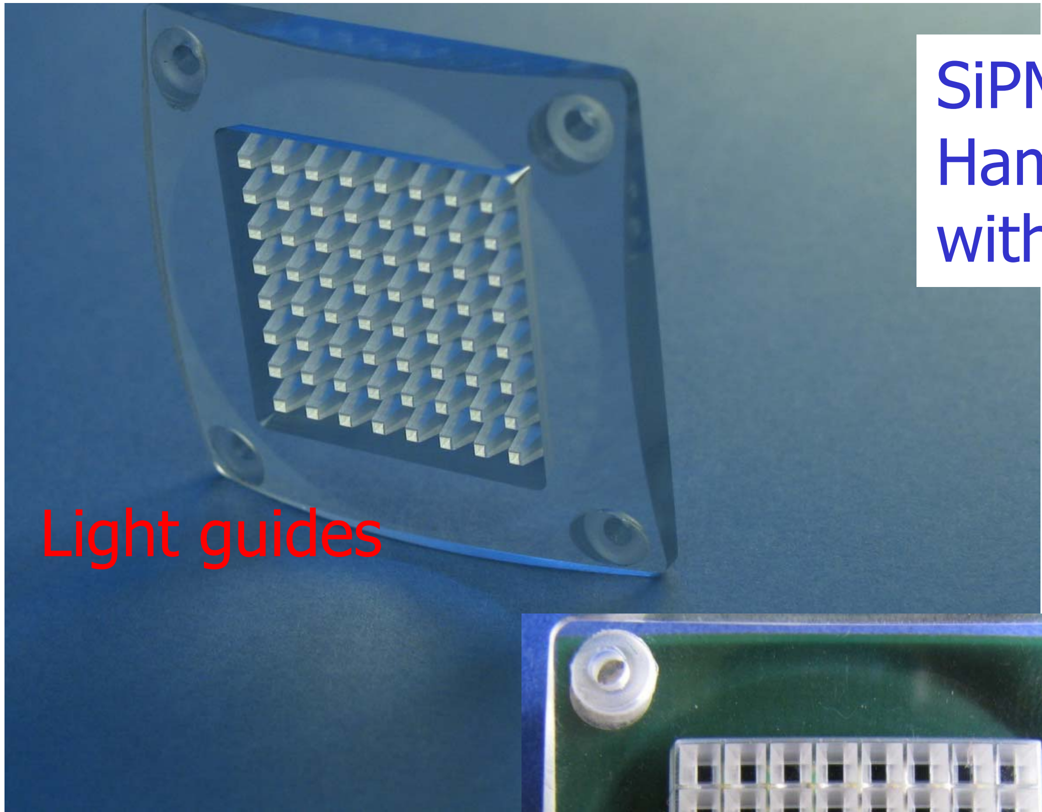


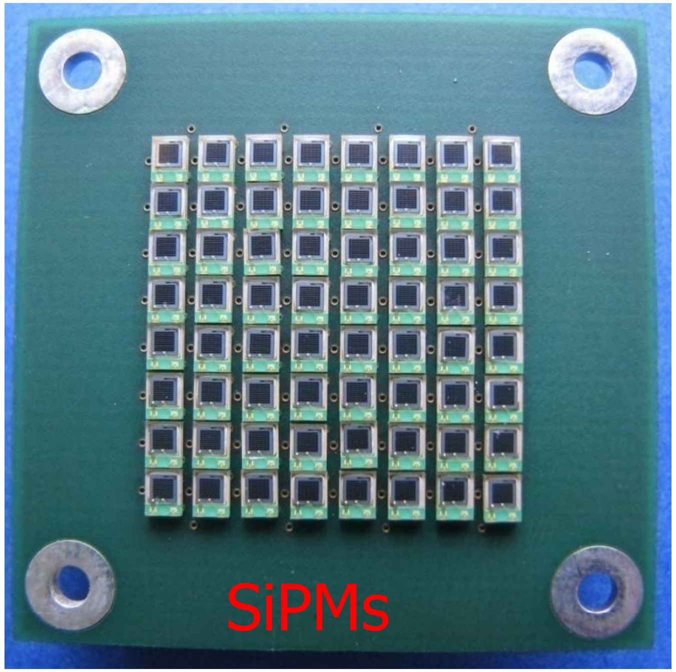


or combine a lens and mirror walls

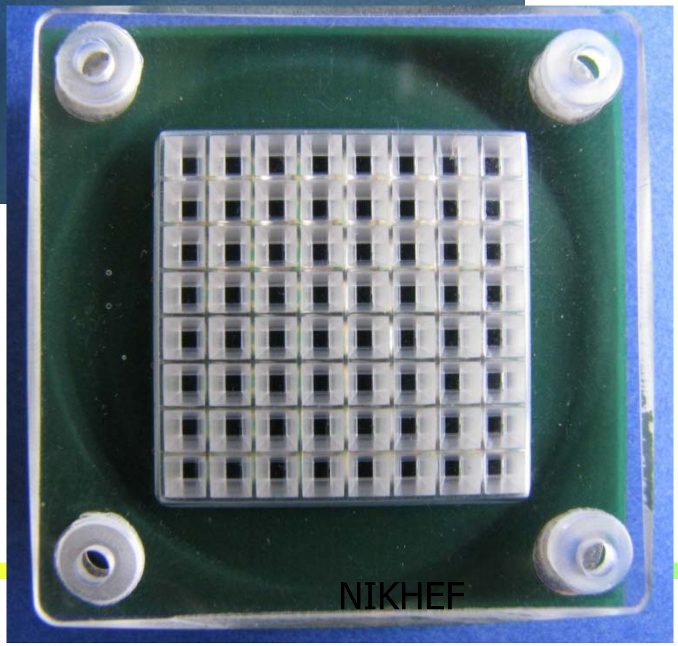
Detector module for beam tests at KEK

SiPMs: array of 8x8 SMD mount Hamamatsu S10362-11-100P with 0.3mm protective layer



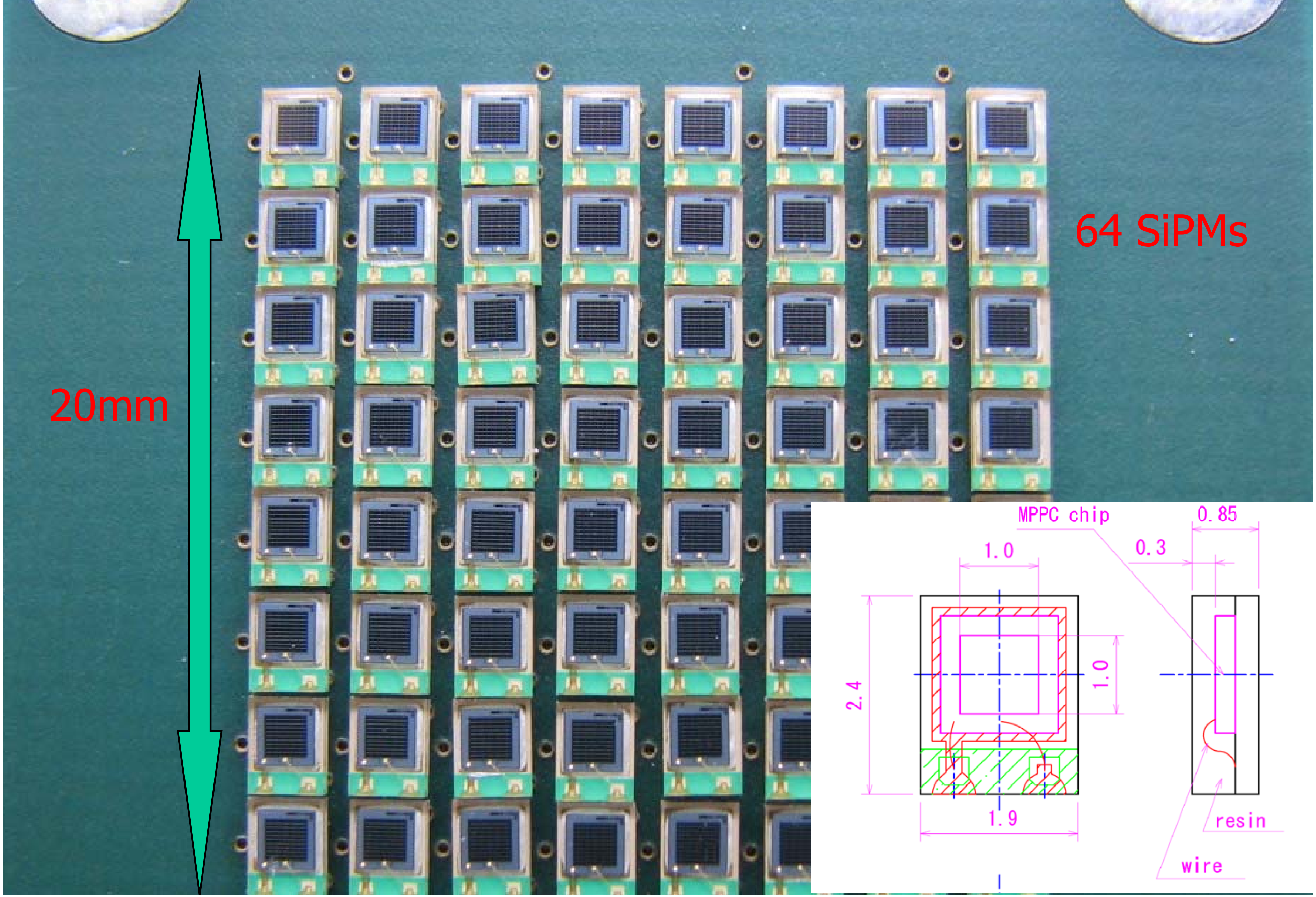


2cm

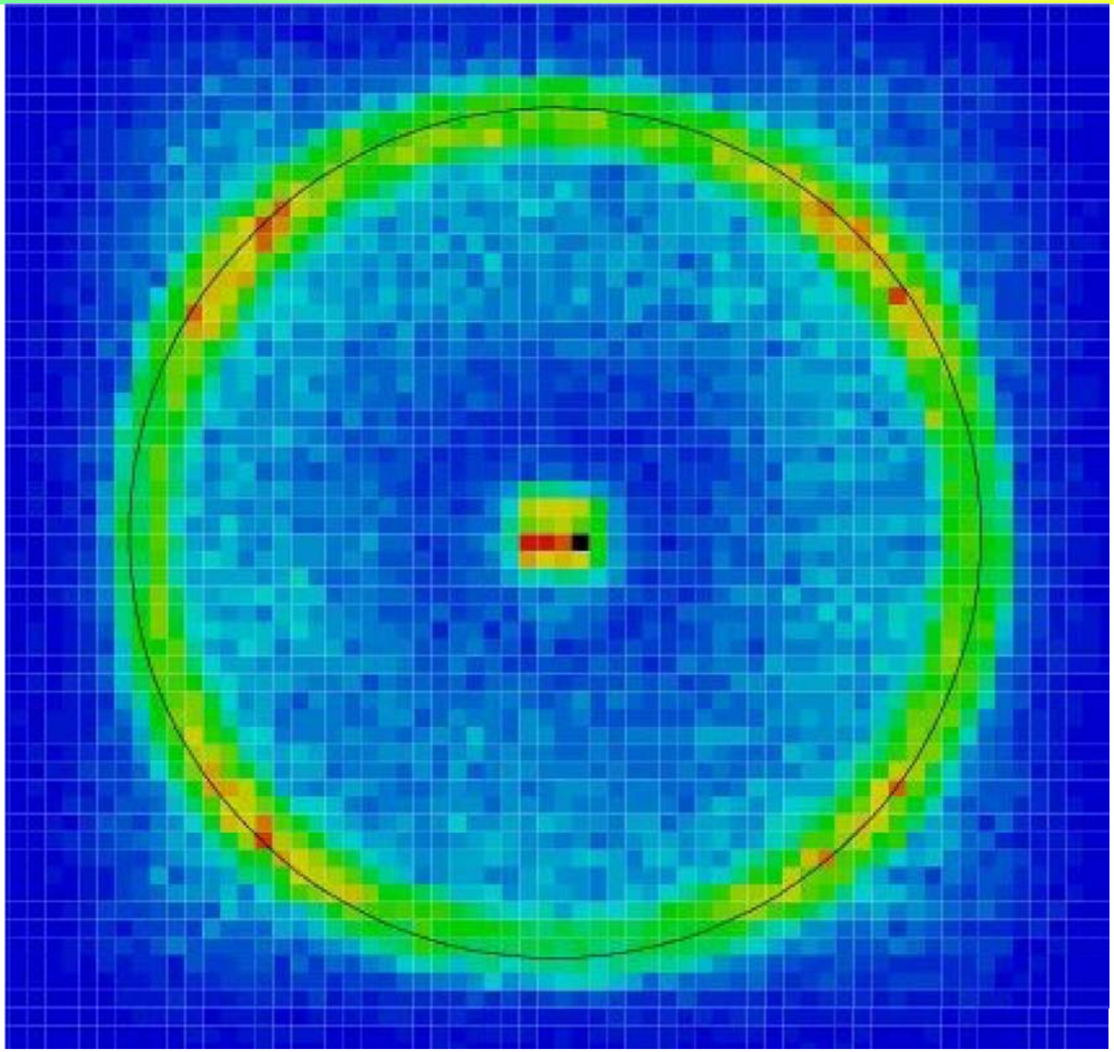


SiPMs + light guides

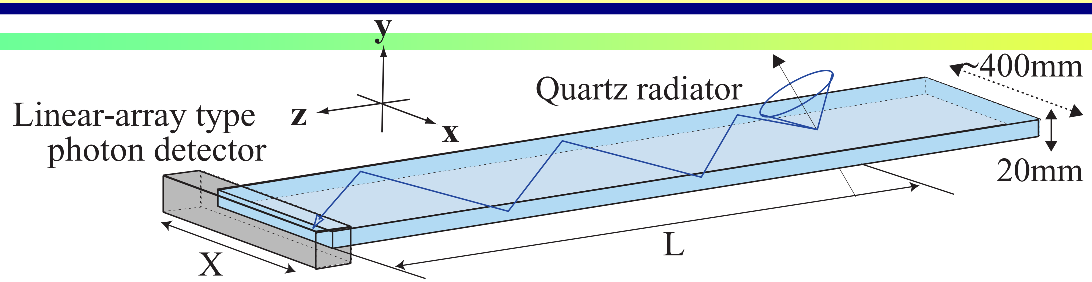
Photon detector for the beam test



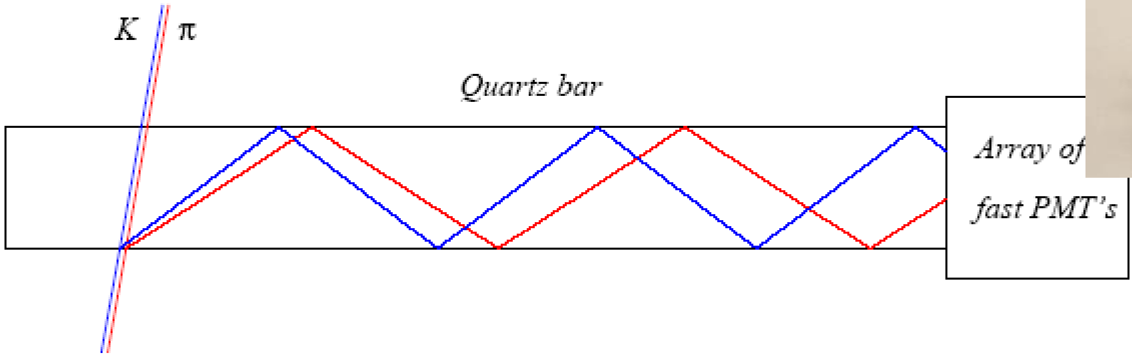
Cherenkov ring with SiPMs

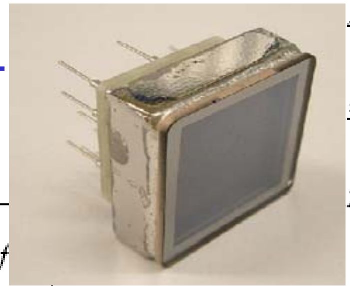


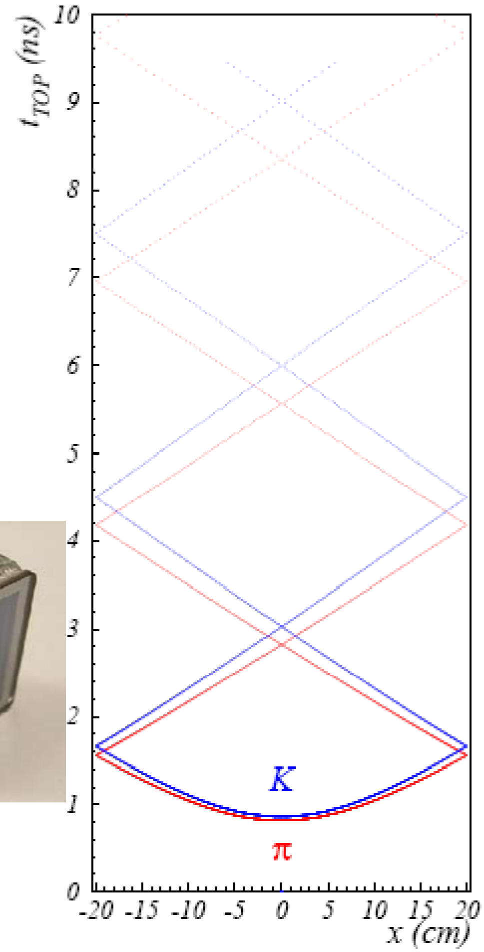
Barrel PID: Time of propagation (TOP) counter



- Cherenkov ring imaging with precise time measurement.
- Reconstruct angle from one coordinate and the time of propagation of the photon
  - Quartz radiator (2cm)
  - Photon detector (MCP-PMT)
    - Good time resolution < ~ 40 ps
    - Single photon sensitive under 1.5 T





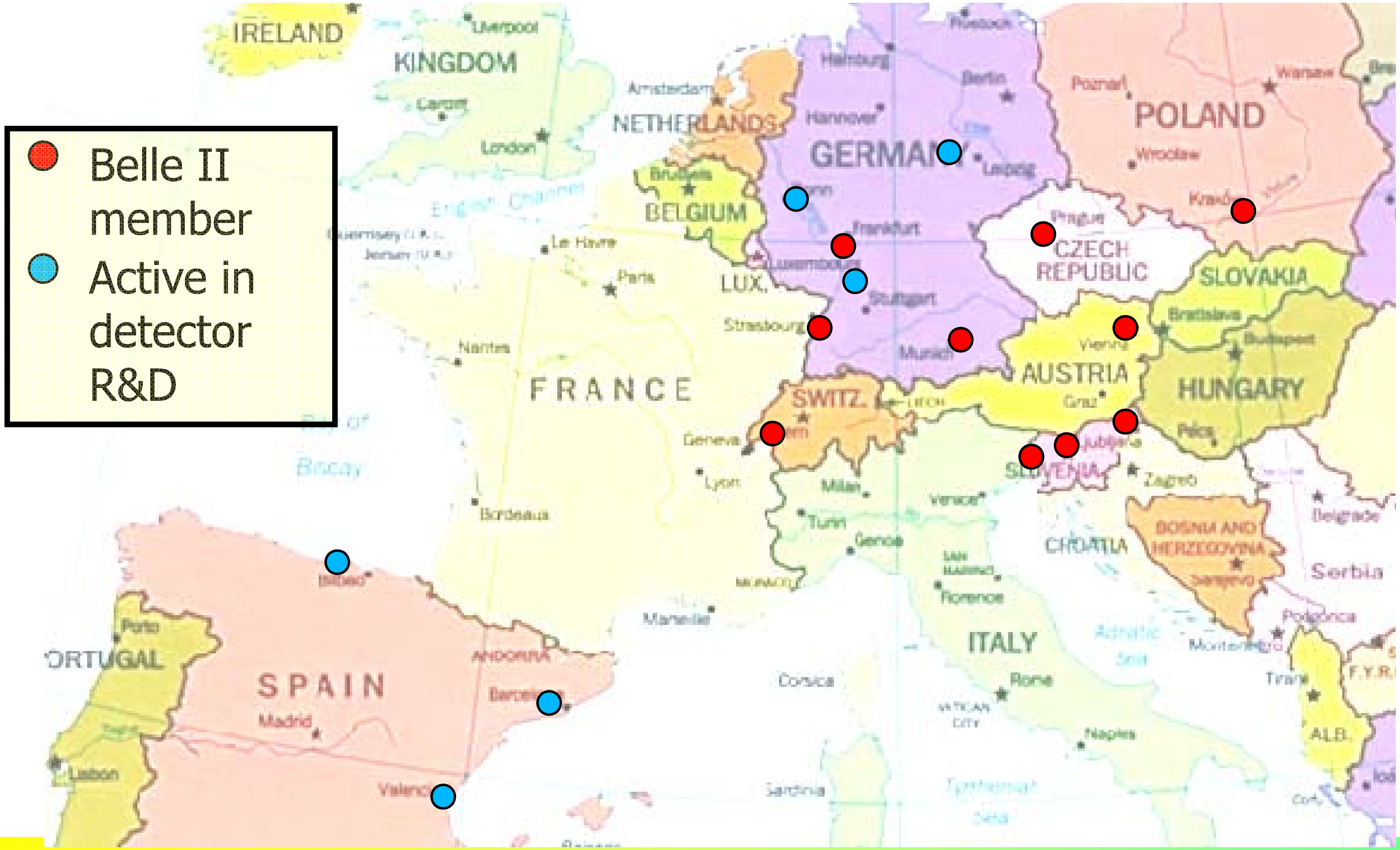


Project Status

- SuperKEKB is a lab priority.
- The Japanese government has allocated 32 oku-yen ($32 M, €23 M) for upgrade R&D in FY 2009, as a part of its economic stimulus package.
- KEK has submitted a budget request for FY 2010 and beyond of $350 M for construction.
- We are proceeding with R&D while awaiting approval of the construction budget request.

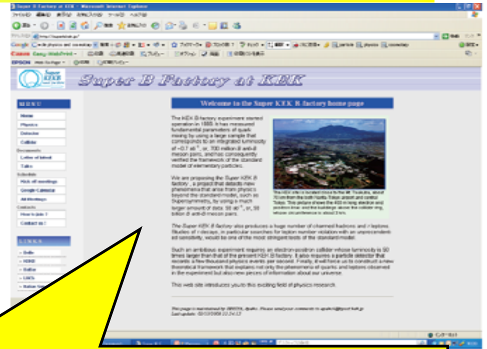
New Collaboration (Belle II)

- Belle II is a new international collaboration
  - Regular collaboration meetings (next 18-19 Nov 2009)
  - Significant European participation (A, CH, CZ, D, PL, RUS, SLO)

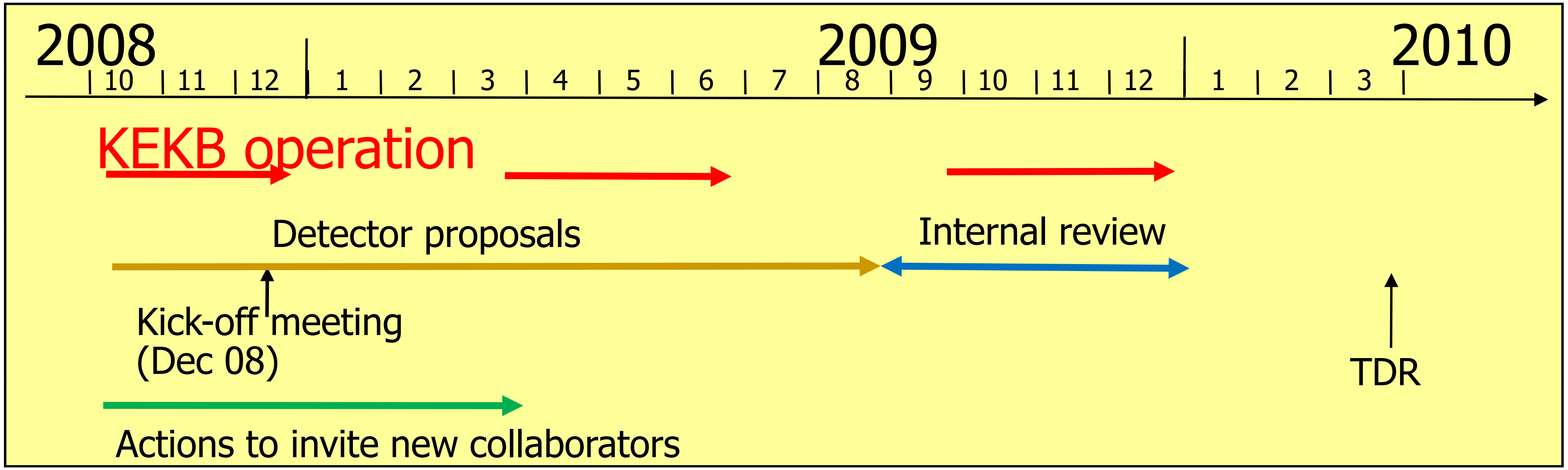


New Collaboration (Belle II)

- Belle II is a new international collaboration.
  - Significant European participation (A, PL, SLO, D, CH, CZ)
  - Regular collaboration meetings (next 18-19 Nov 2009)
- Near-term plan
  - Detector study report has been completed.
  - Detector proposals (by Dec. 2009).
  - TDR by March 2010



Belle II webpage
http://superb.kek.jp/
Mailing list subscription is available.



Summary

- B factories have proven to be an excellent tool for flavour physics, with reliable long term operation, constant improvement of the performance.
- Major upgrade in 2009-12 → Super B factory, L x10 → x40
- Essentially a new project, all components have to be replaced, nothing is frozen...
- A physics reach update is being prepared – to be made public soon
- Expect a new, exciting era of discoveries, complementary to LHC
- You as young flavour theorists could be an important part of it!

More:

http://www-f9.ijs.si/~krizan/sola/flavianet-karlsruhe09/flavianet-karlsruhe09.html

Back-up slides

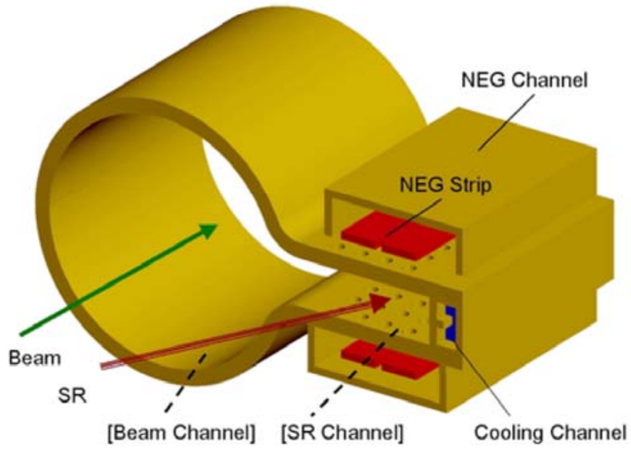
Luminosity gain and upgrade items (preliminary)

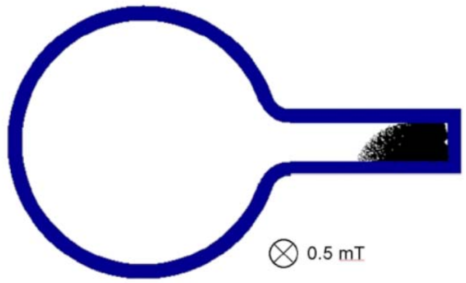
3 years shutdown

Item	Gain	Purpose
beam pipe	x 1.5	high current, short bunch, electron cloud
IR($\beta^*_{x/y}$=20cm/3 mm)	x 1.5	small beam size at IP
low emittance(12 nm) & $\nu_x \rightarrow 0.5$	x 1.3	mitigate nonlinear effects with beam-beam
crab crossing	x 2	mitigate nonlinear effects with beam-beam
RF/infrastructure	x 3	high current
DR/e^+ source	x 1.5	low β^* injection, improve e^+ injection
charge switch	x ?	electron cloud, lower e^+ current

Super-KEKB (cont'd)

- Ante-chamber /solenoid for reduction of electron clouds





Ante-chamber
with solenoid field