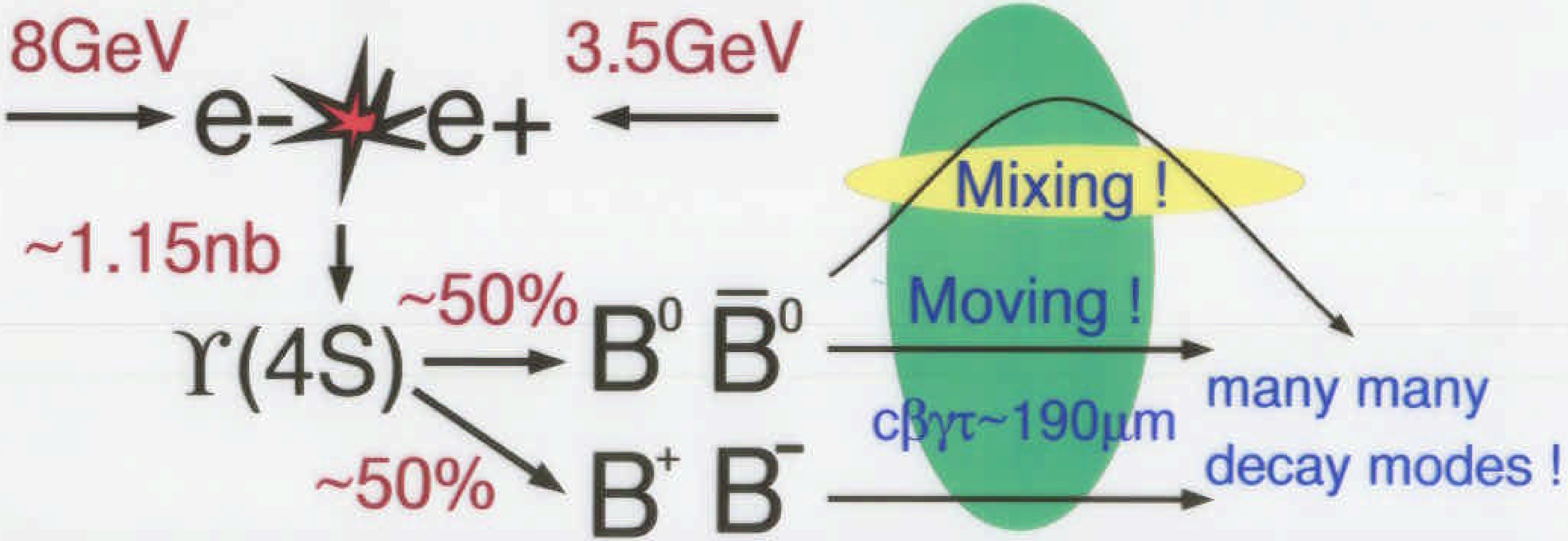
阪大・理・羽澄
2000年7月4日@京大

It was a seemingly crazy idea!

－Bファクトリーの現在(と未来)－

1. Introduction
2. Concept of CP Violation in B Decays
3. Status of Belle
4. おまけ.

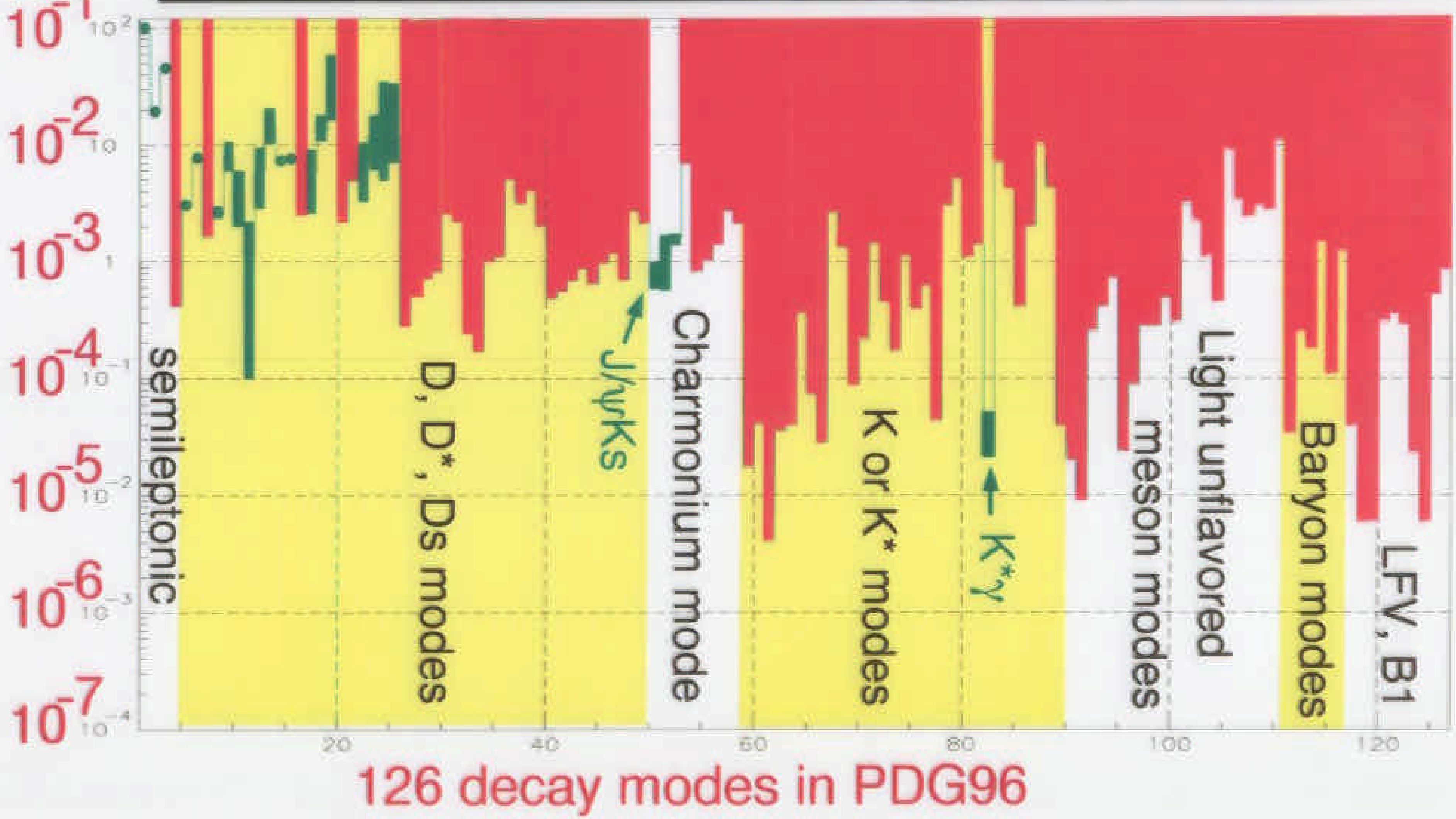
1. Introduction



$\sim 100 fb^{-1}$ /year → $\sim 10^8$ B mesons/year

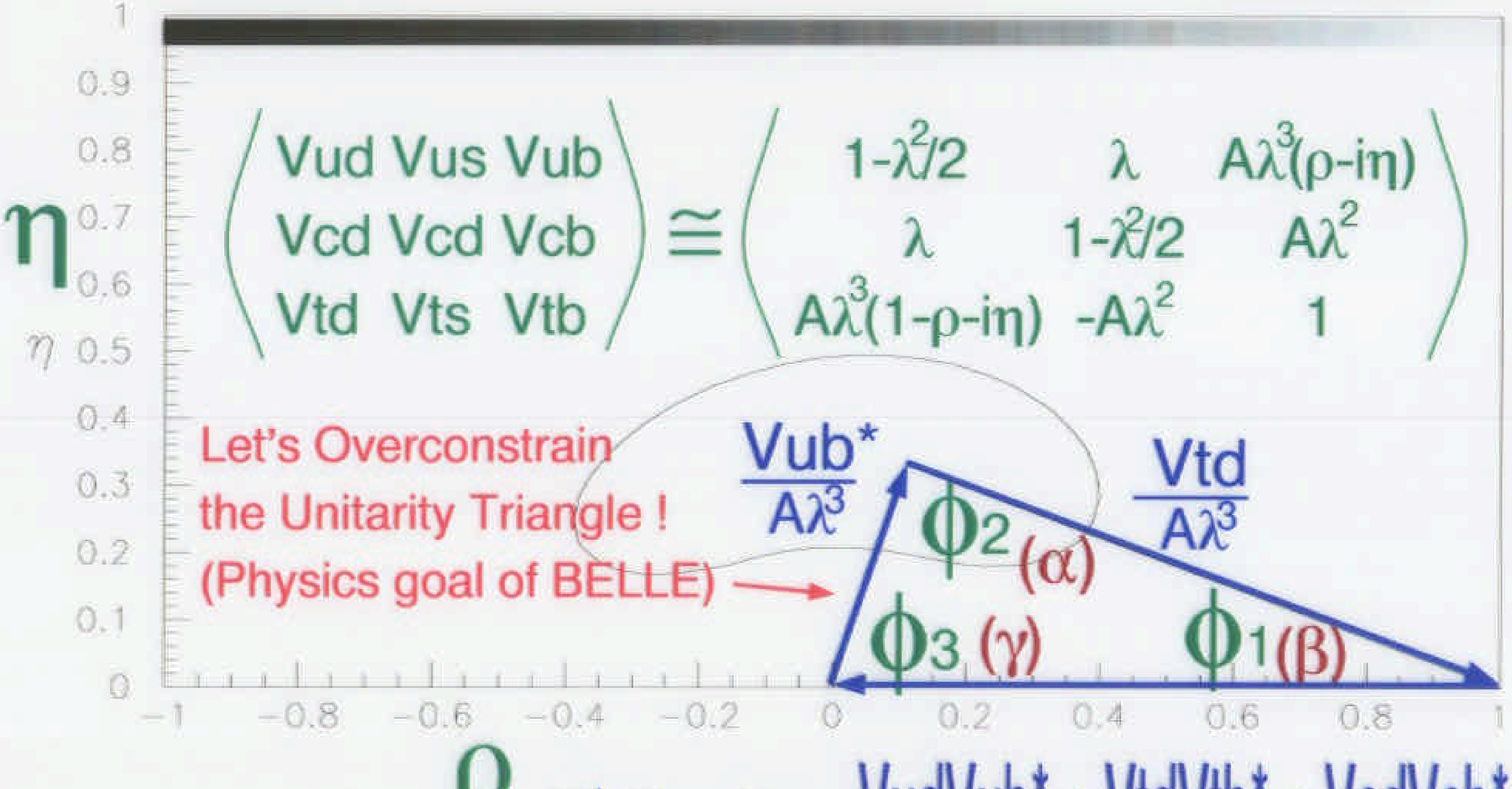
(B factory is "beautiful".)

Branching Fractions of Neutral B (taken from PDG96)



0.9744 (±0.1%)	0.2205 (±0.8%)	0.003(±25%)
0.204 (±8.3%)	1.01 (±18%)	0.038(±8.2%)
0.005 – 0.018	< 0.56	---

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cd} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \cong \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ \lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$



$V^{+}_{KM}V_{KM}=0 \rightarrow V_{ud}V_{ub}^* + V_{td}V_{tb}^* + V_{cd}V_{cb}^* = 0$

Belle Cronology,

Jun. 1991 Conceptual design of machine and detector
Proposal submitted to Monbusho

Apr. 1994 Construction of the machine and detector began.

Oct. 1998 Completion of the detector construction

Dec. 1998 Machine commissioning without BELLE

May 1999 BELLE roll-in

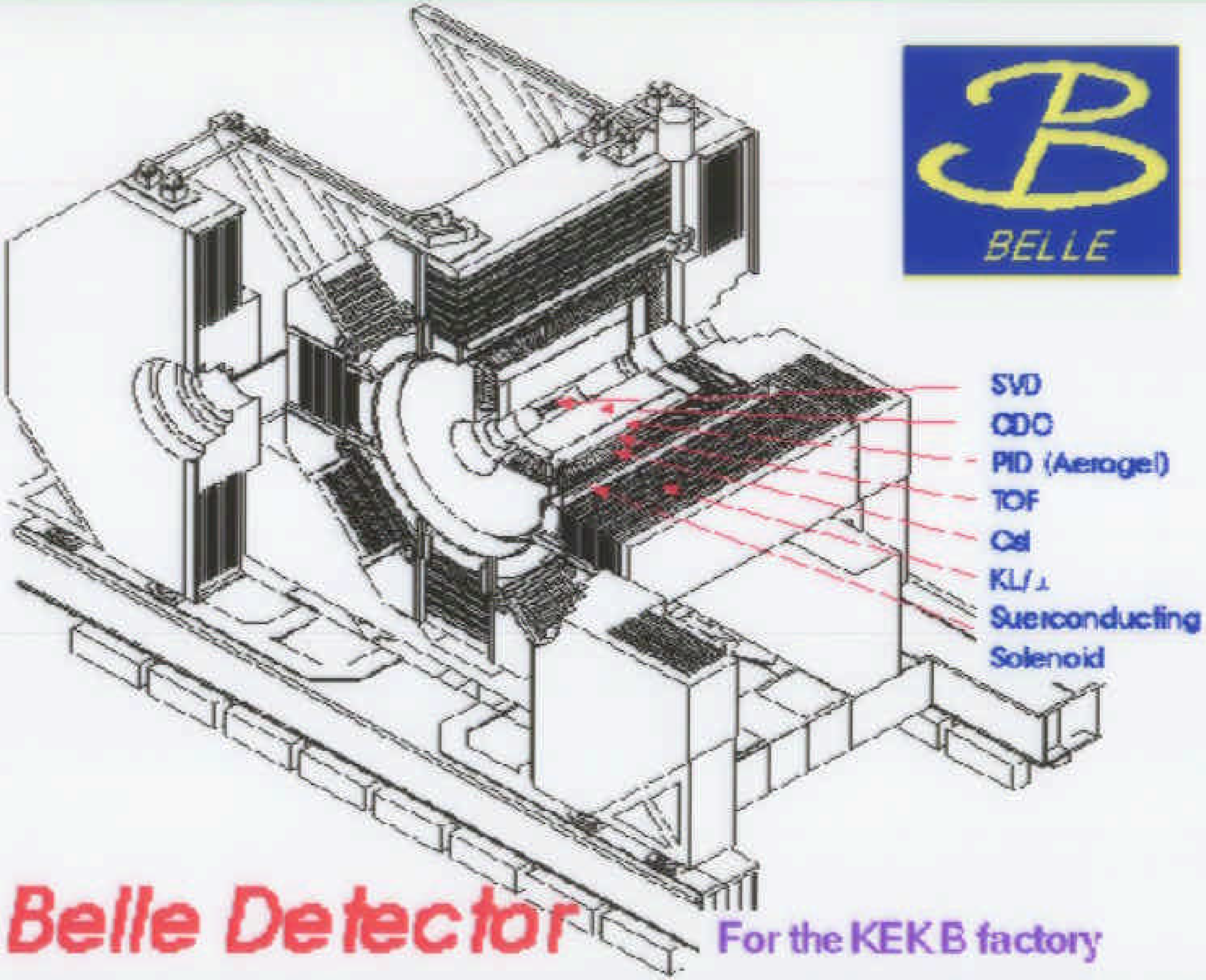
Jun. 1999 First collision observed.

Jul. 1 - Aug.4 Physics run, 25 pb^{-1} accumulated

RF installation, LINAC upgrade, SVD replacement etc.

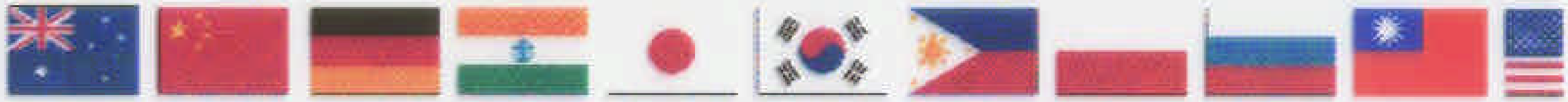
Oct. - Dec.99 Physics run $L_p = 6.0 \times 10^{32}$, $\int L\,dt = 0.3\ fb^{-1}$,
max $\int L\,dt$ per day = 25 pb^{-1}

Jan.00 - now Physics run $L_p = 19.2 \times 10^{32}$, $\int L\,dt = 5.0\ fb^{-1}$,
max $\int L\,dt$ per day = 90 pb^{-1}



Belle Detector

For the KEK B factory



BELLE Collaboration

Aomori University
Budker Institute of Nuclear Physics
Chiba University
Chuo University
University of Cincinnati
Frankfurt University
Gyeongsang National University
University of Hawai
Hiroshima Institute of Technology
Hiroshima College of Maritime Tech.
IHEP, Beijing
ITEP, Moscow
Joint Crystal Collaboration Group
Kanagawa University
KEK
Korea University
Krakow Institute of Nuclear Physics
Kyoto University
University of Melbourne
Mindanao State University
Nagasaki Institute of Applied Science
Nagoya University
Nara Woman's University
National Central University
National Kaoshing University
National Lien-Ho College of Tech. and Commerce
National Taiwan University
Nihon Dental College
Niigata University
Osaka University
Osaka City University
Panjab Uiversity
Princeton University
Saga University
Seoul National University
University of Science and Tech. of China
Sugiyama Woman's College
Sungkyunkwan University
University of Sydney
Toho University
Tohoku University
Tohoku-gakuin University
University of Tokyo
Tokyo Institute of Technology
Tokyo Metropolitan University
Tokyo University of Agriculure and Technology
Toyama National College of Maritime Technology
University of Tsukuba
Utkal Univesity
Virginia Polytechnic Institute and State University
Yonsei University

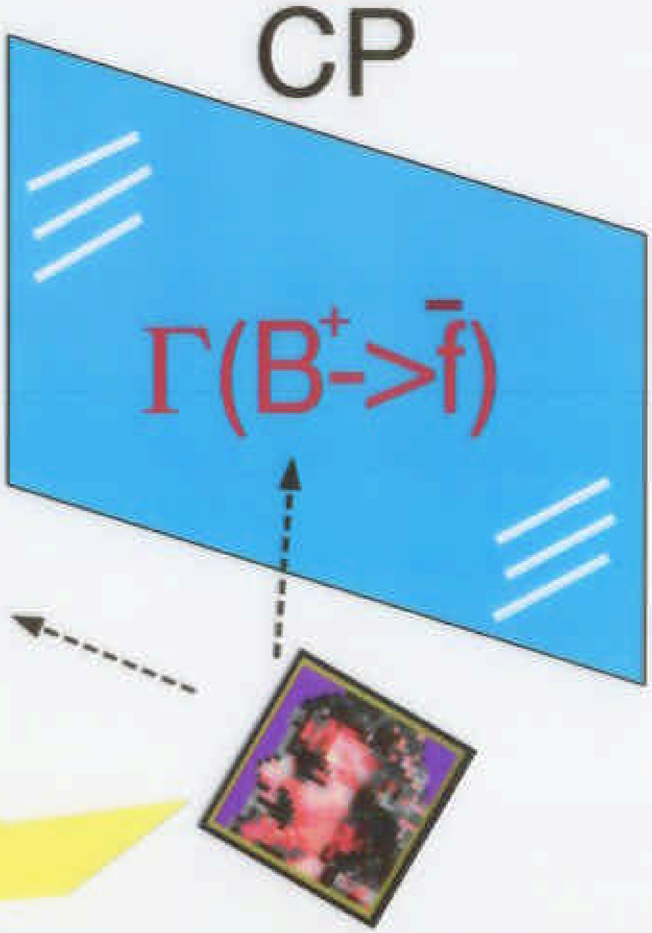
~300 collaborators

Concept of CP Violation in B decays

a guide to the beautiful mechanism

When can you say "I've got ~~CP~~!" ?
or more precisely, what is
"CP-violating particle-antiparticle
partial rate asymmetry ?"

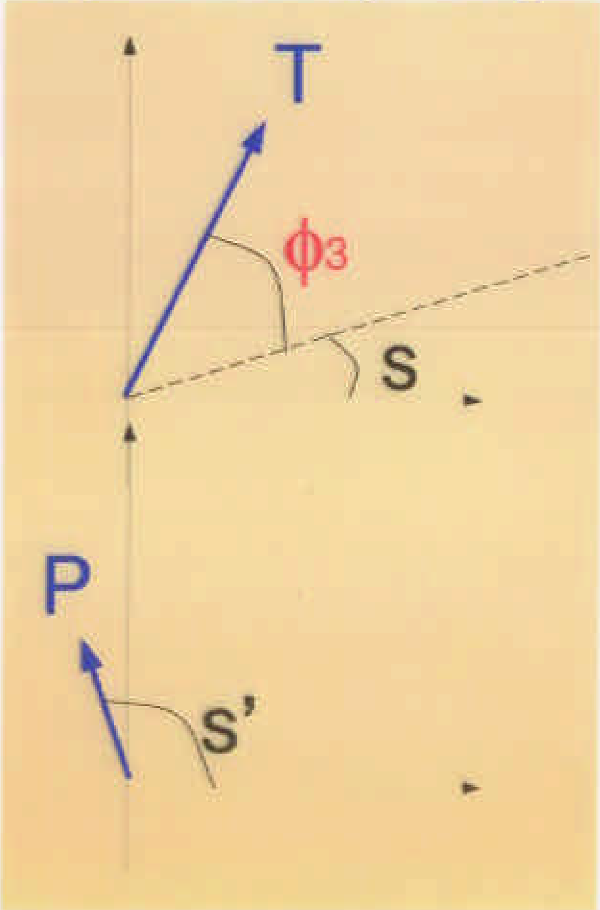
Let's start with charged B
since it is simpler.

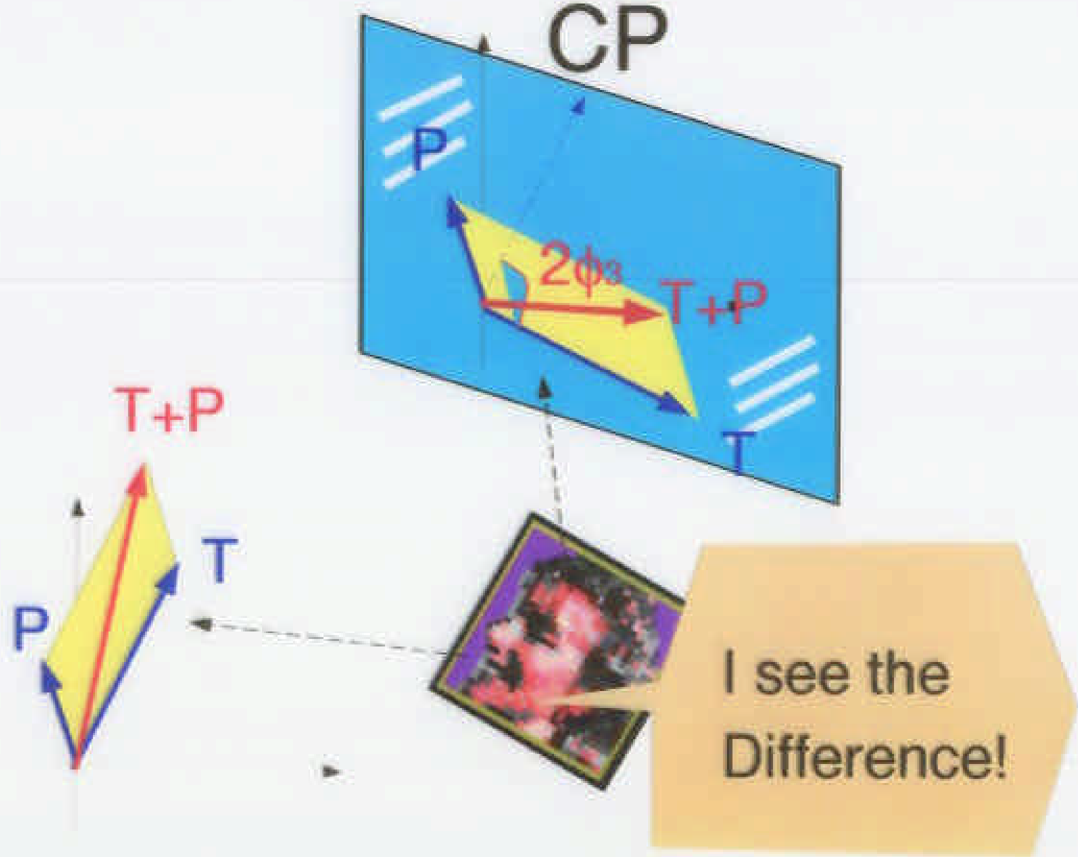


$\Gamma(B^- \to f)$

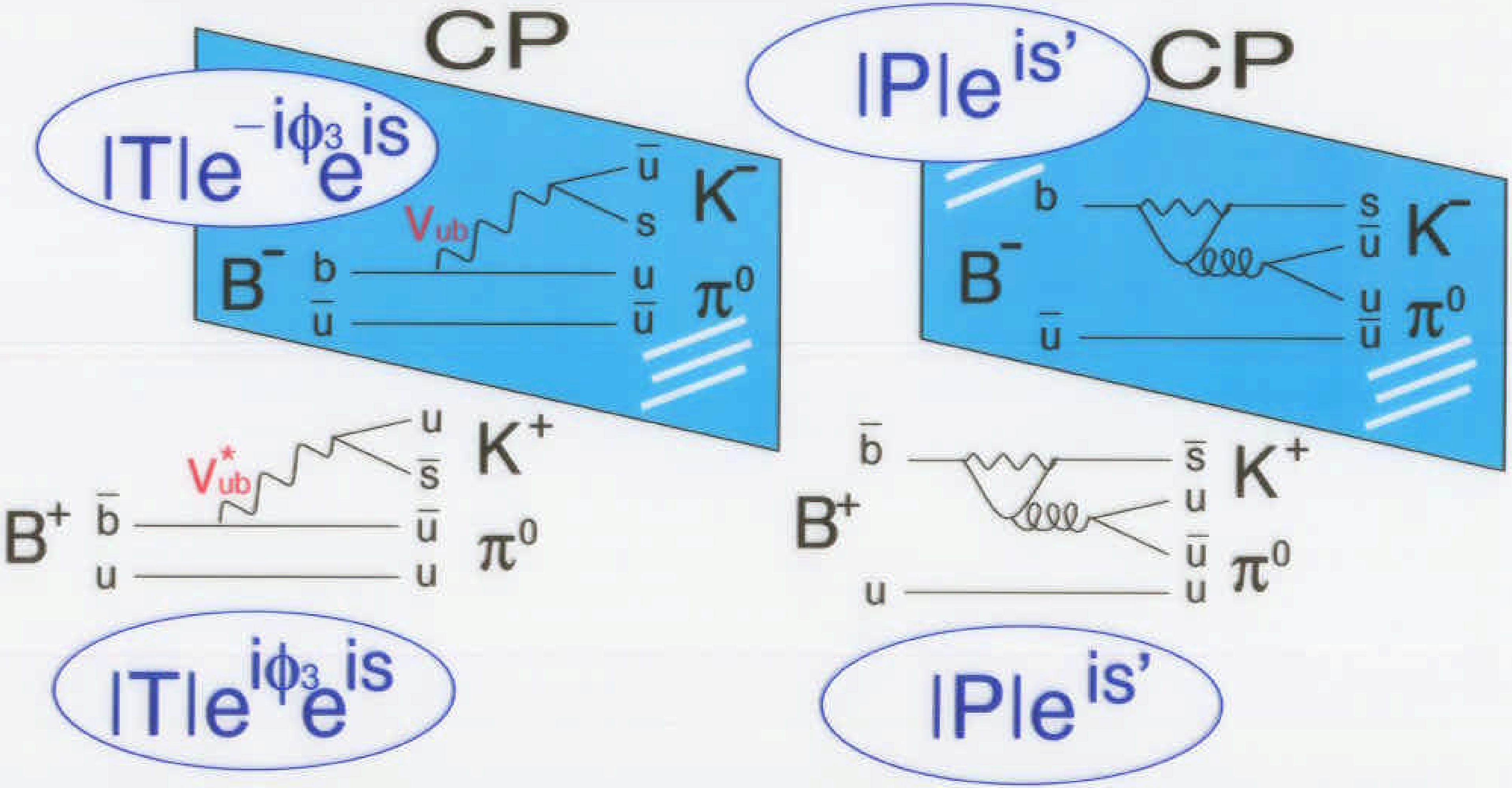
Partial Rate Asymmetry

$$\Gamma(B^+ \to K^+\pi^0) - \Gamma(B^- \to K^-\pi^0) = 4|T||P|\sin(\phi_3)\sin(s'-s)$$



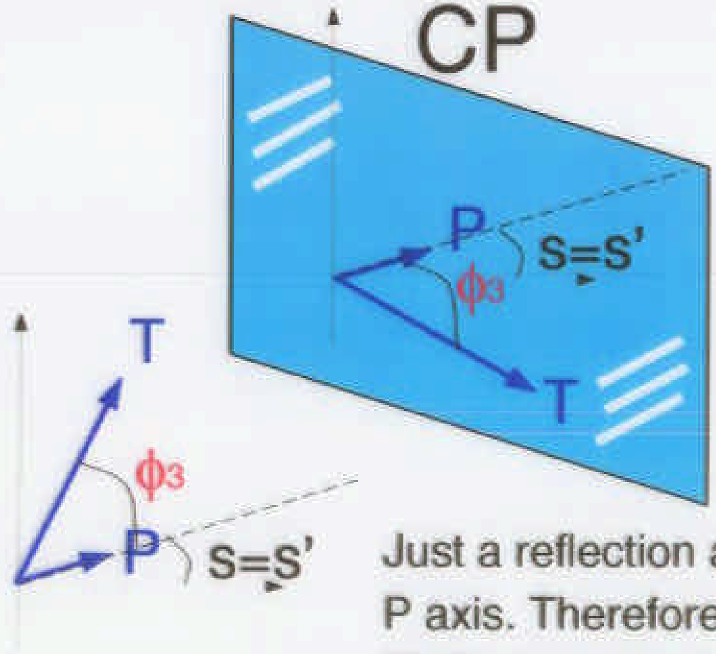


First example
$B^+ \to K^+\pi^0$ and $B^- \to K^-\pi^0$



The rules of the Game

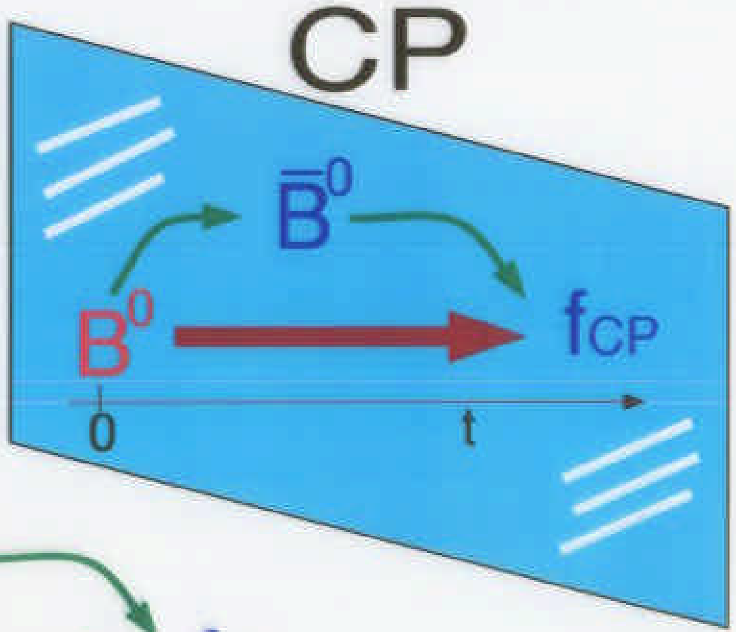
- Find a decay mode which has two "decay paths" with different weak phases (more conveniently, find Vub and/or Vtd as the phases). These two amplitudes should have the similar size.
  <--> You need a sizable interference !
- This is not enough.--------------->>>
- These two amplitudes should have different "Static" phases (which do not change in the "CP mirror".

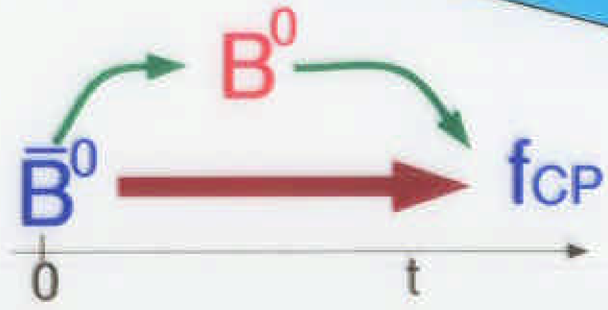


Just a reflection about P axis. Therefore |T+P| does not change.

Joy of Mixing
(case for neutral B mesons)

Let's turn to neutral B mesons and apply the rules of the game.
Although there is a possibility of having the "direct CP violation" also in the neutral B decays,
let's pay attention to the large
B^0-$\bar{B}^0$ mixing which gives us the "2nd path"
to a final state "f",
if both "B^0 -> f" and "$\bar{B}^0$ -> f" are allowed.
This is satisfied if
"f" is a CP-eigenstate
(denoted as "f_{CP}").





The rules of the Game

applied to neutral B mesons

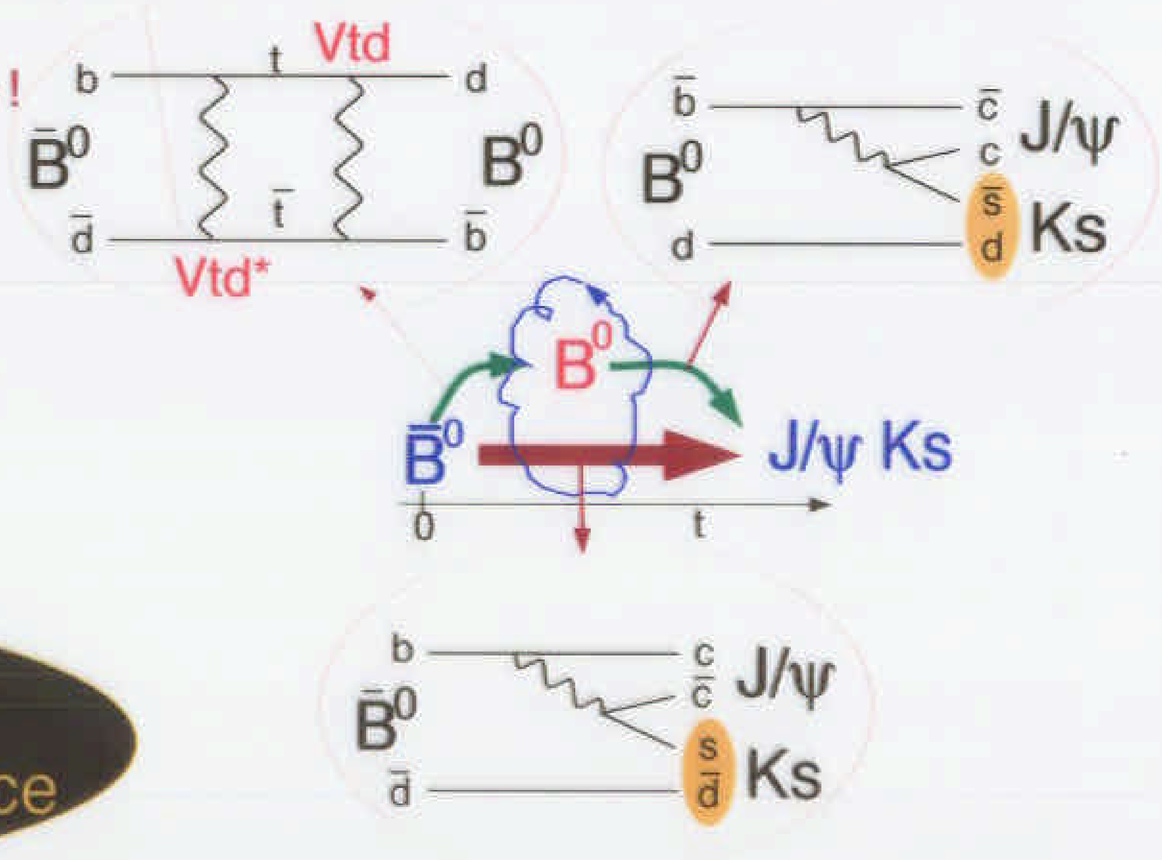
-----> It is reeeeeeeally promising !

- Find a decay mode which has two "decay paths" with different weak phases (more conveniently, find Vub and/or Vtd as the phases). These two amplitudes should have the similar size.
  <--> You need a sizable interference !

"Speed" of mixing fast enough ! (and not too fast)

- These two amplitudes should have different "Static" phases (which do not change in the "CP mirror".

Guaranteed ! w/o using final-state phase difference



"J/ψ Ks" Asymmetry

$|B(t)\rangle = \quad g_+(t)|B\rangle + (q/p)g_-(t)|\overline{B}\rangle$

$|\overline{B}(t)\rangle = (p/q)g_-(t)|B\rangle + \quad g_+(t)|\overline{B}\rangle$

$g_+(t) = \exp(-\Gamma t/2)\exp(-iMt)\cos(\delta M t/2)$

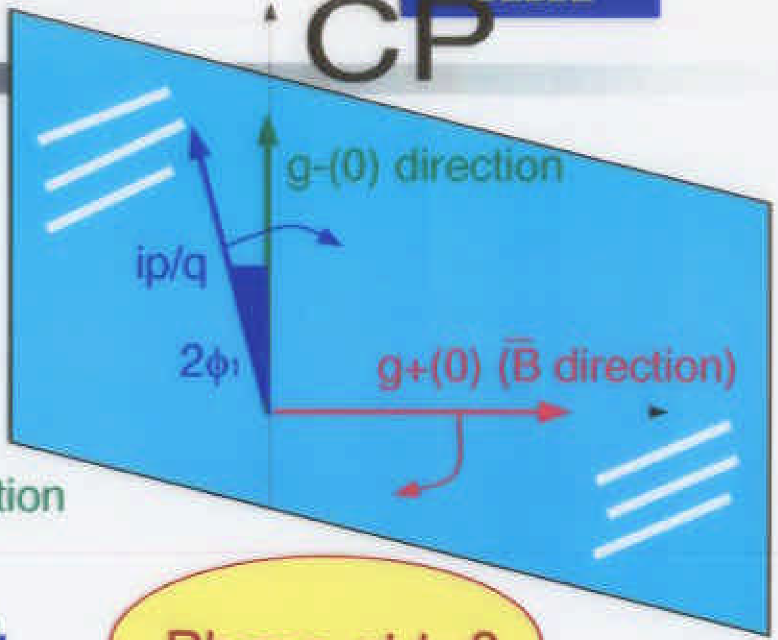
$g_-(t) = i\cdot\exp(-\Gamma t/2)\exp(-iMt)\sin(\delta M t/2)$

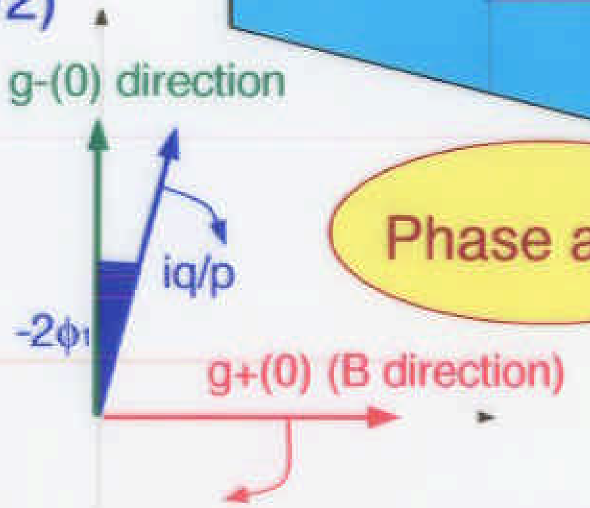
$M \equiv (M_H+M_L)/2,\ \delta M \equiv (M_H-M_L)$

$q/p = V_{td}/V_{td}^* = \exp(-2i\phi_1)$

$A = \langle f_{cp}|H|B\rangle$

$\quad = \langle f_{cp}|H|\overline{B}\rangle = \overline{A}$





Phase at t=0

$\Gamma(B(t)\to J/\psi K_s) - \Gamma(\overline{B}(t)\to J/\psi K_s)$

$$= -2|A|^2\sin(2\phi_1)\sin(\delta M t)\exp(-\Gamma t)$$

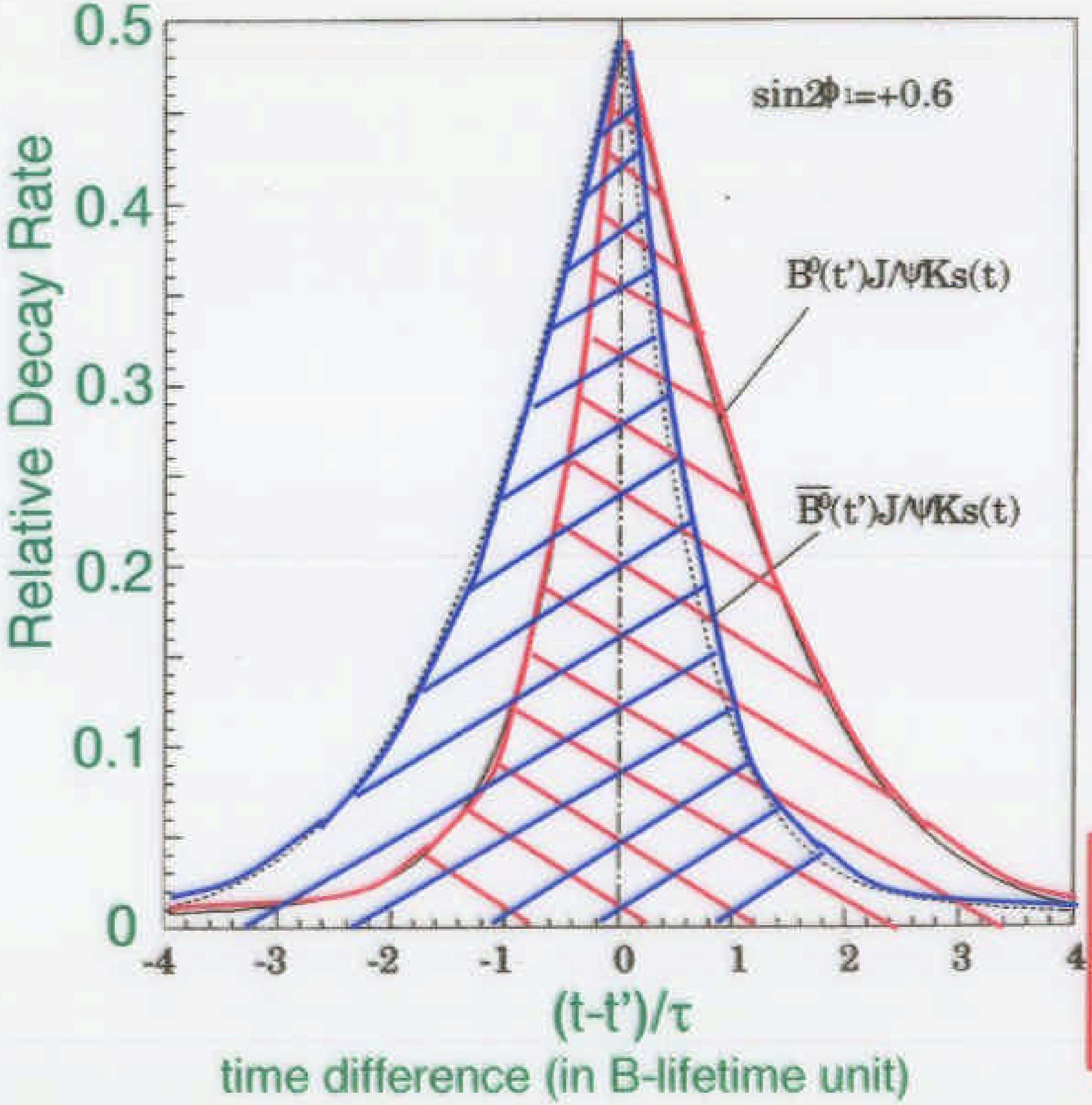
$B\bar{B}$ produced in a coherent state at the $\Upsilon(4S)$ with C=-1

A final remark is required on the real experimental environments.

At the $\Upsilon(4S)$, mixing can start when one of B mesons decays.
Before that the possible state is either $|B\rangle|\bar{B}\rangle$ or $|\bar{B}\rangle|B\rangle$ only.
$|B\rangle|B\rangle$ or $|\bar{B}\rangle|\bar{B}\rangle$ not allowed.
Therefore at $\Upsilon(4S)$, you don't have to know the absolute time interval from the production of $B\bar{B}$ to the time at the decay point (we can't know it).
Instead you can observe CP violation by tagging the b-flavor of the other B (flavor tagging) as well as measuring the time difference of two B-decays (one is $J/\psi K_s$, the other is b-flavor-taggable mode such as semi-leptonic decays)

--> Finally the proper-time distribution is --> next

We want to see this !



$\Gamma(B^0(t)\text{->}J/\psi\ Ks)$

where $B^0(0)=B^0$

$\Gamma(\bar{B}^0(t)\text{->}J/\psi\ Ks)$

where $\bar{B}^0(0)=\bar{B}^0$

How can we measure this ?
-> next section

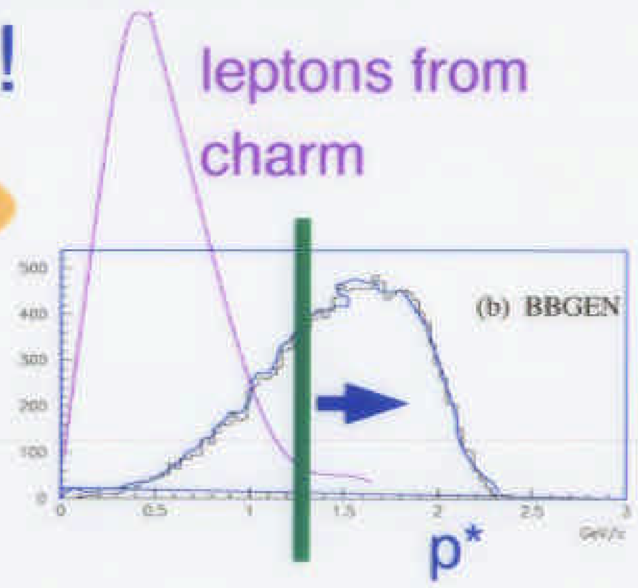
2. Measurements on the Unitarity Triangle

1) Angle measurements

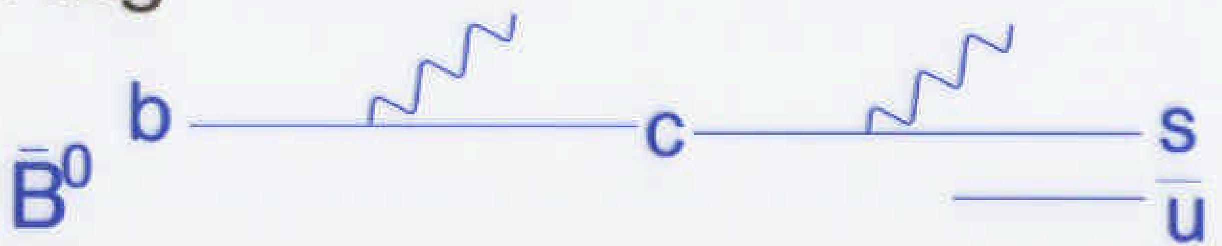
$B \to X \ell \nu$

Flavor Tagging is so important !

a) high p* Lepton tag



b) Kaon tag

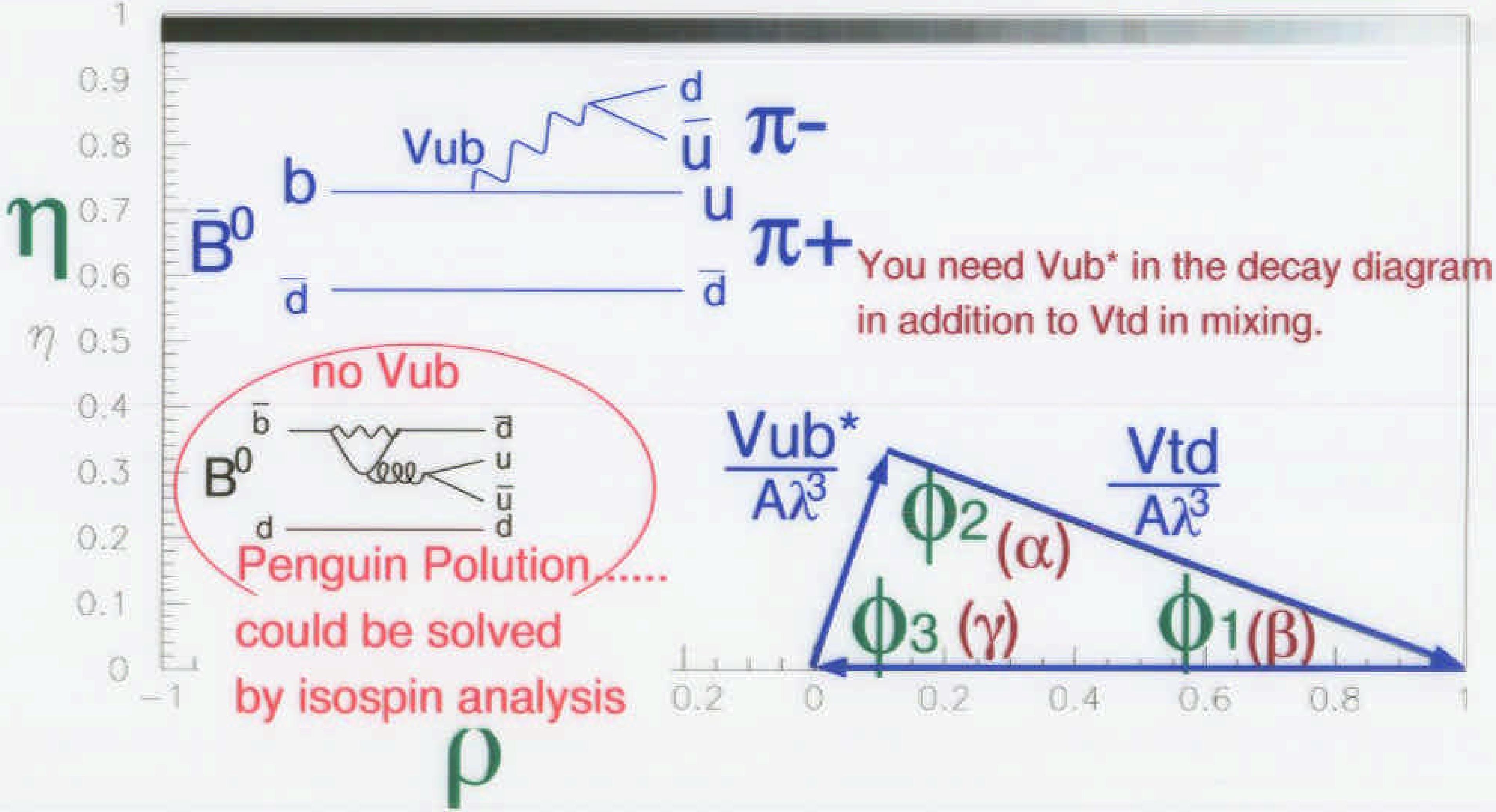


tagging with dE/dx, TOF, PID (DIRC, Aerogel, RICH)

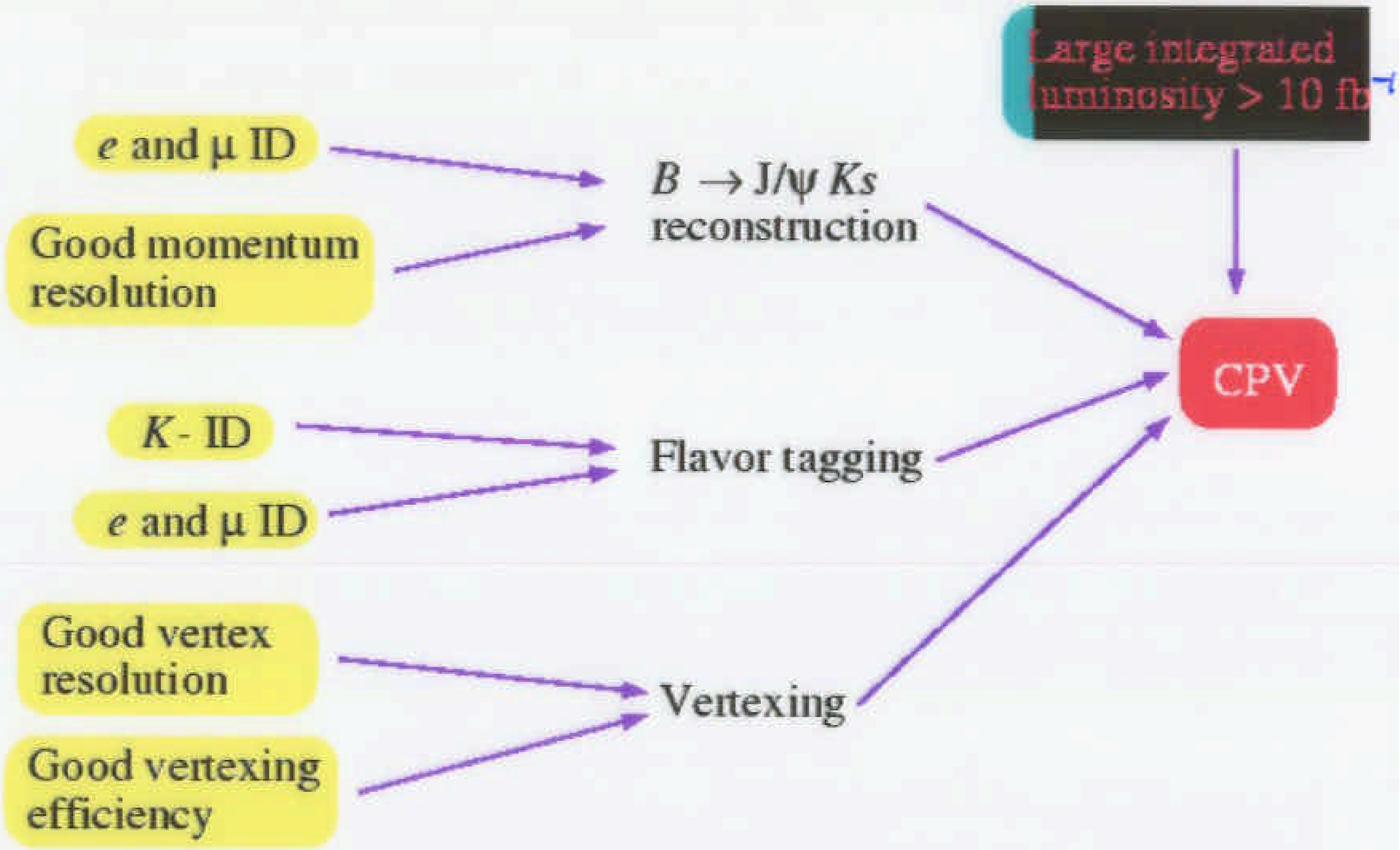
ϕ_2 $\pi\pi$ and $\rho\pi$

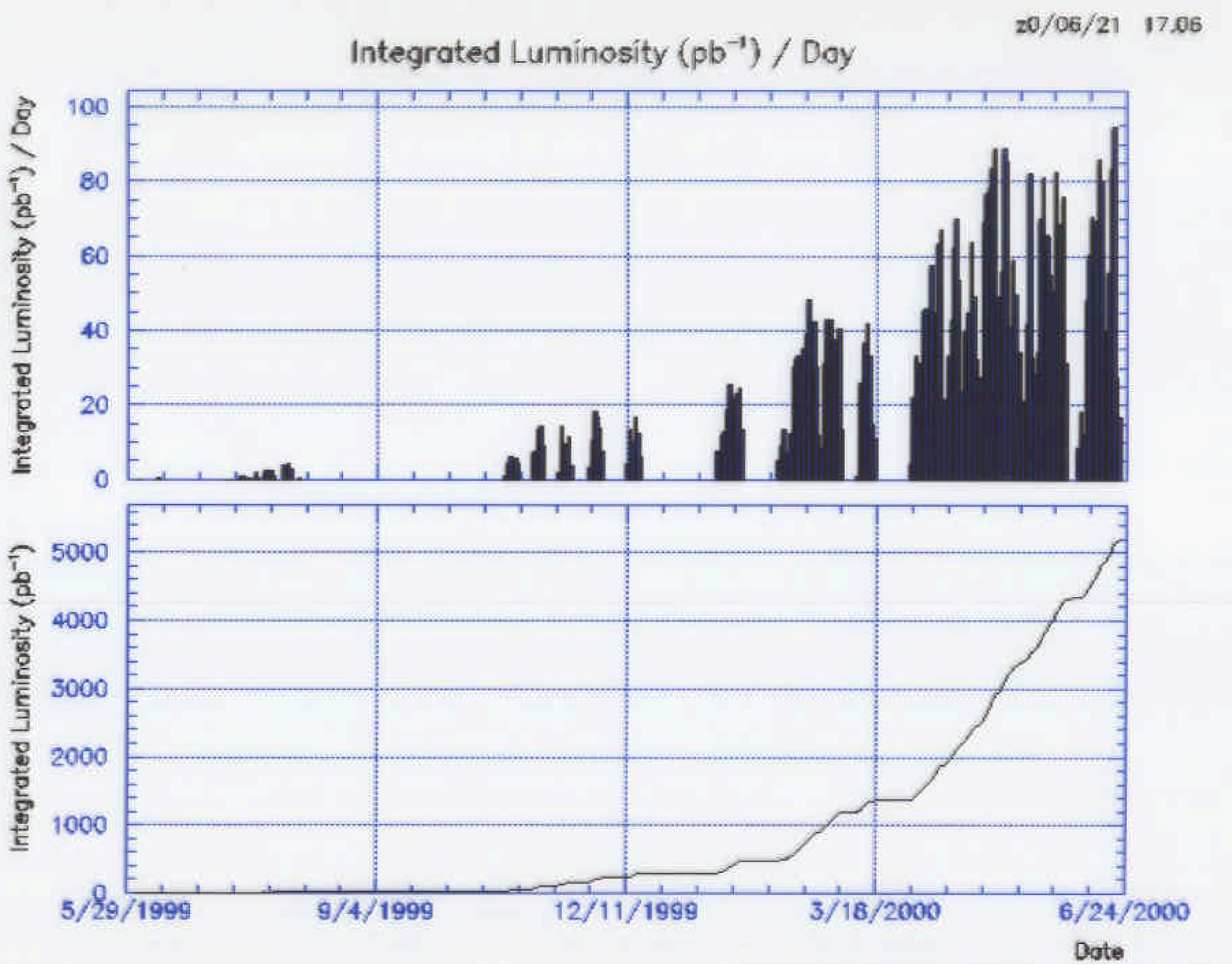
CP eigenstate

Both B and Bbar can decay into $\rho\pi$ (flavor nonspecific)



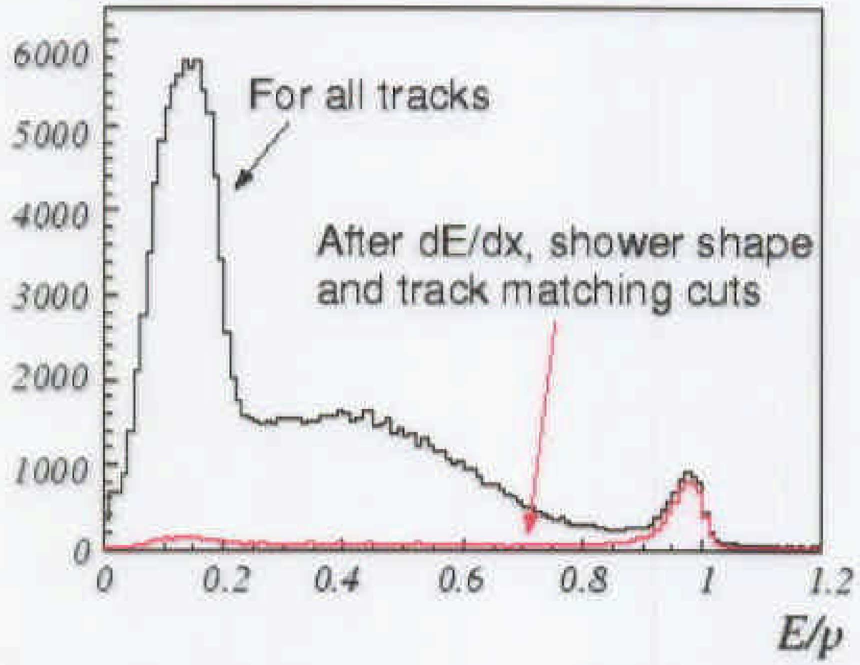
Roadmap to CPV in $B \to J/\psi\ K_S$



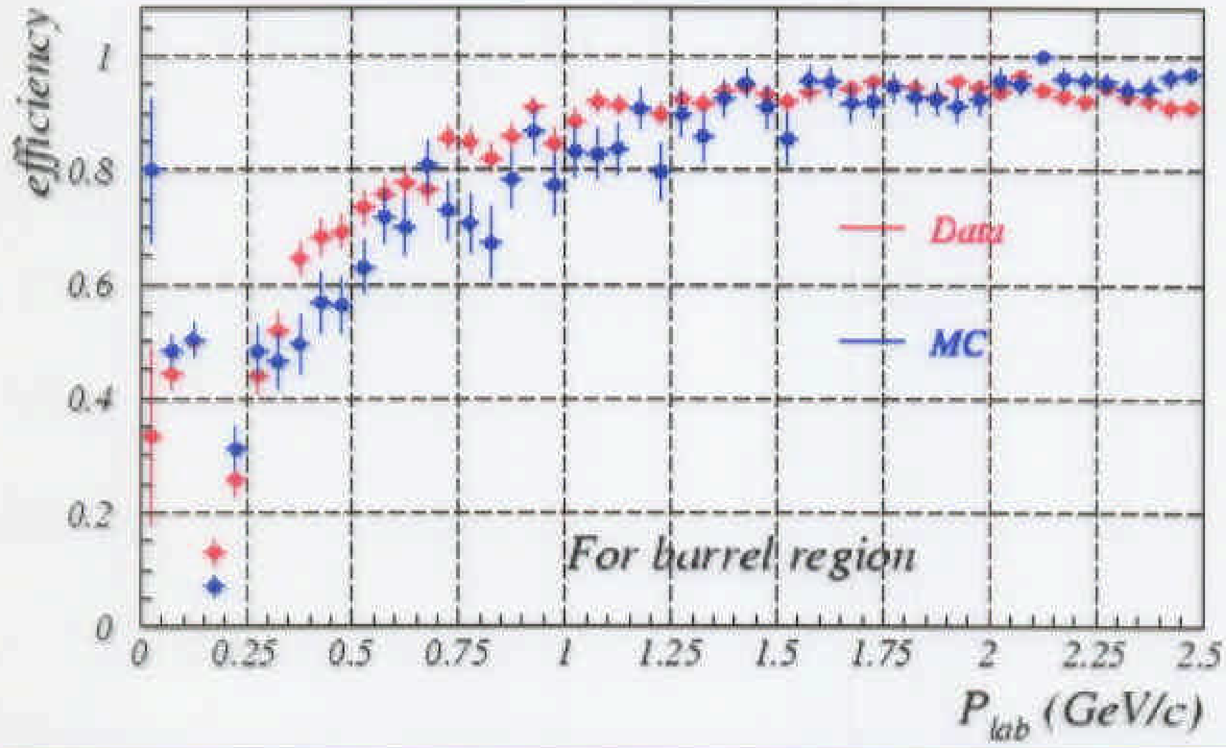


z0/06/21 17.06
Integrated Luminosity (pb⁻¹) / Day
Integrated Luminosity (pb⁻¹) / Day
0
20
40
60
80
100
Integrated Luminosity (pb⁻¹)
0
1000
2000
3000
4000
5000
5/29/1999
9/4/1999
12/11/1999
3/18/2000
6/24/2000
Date

Electron ID

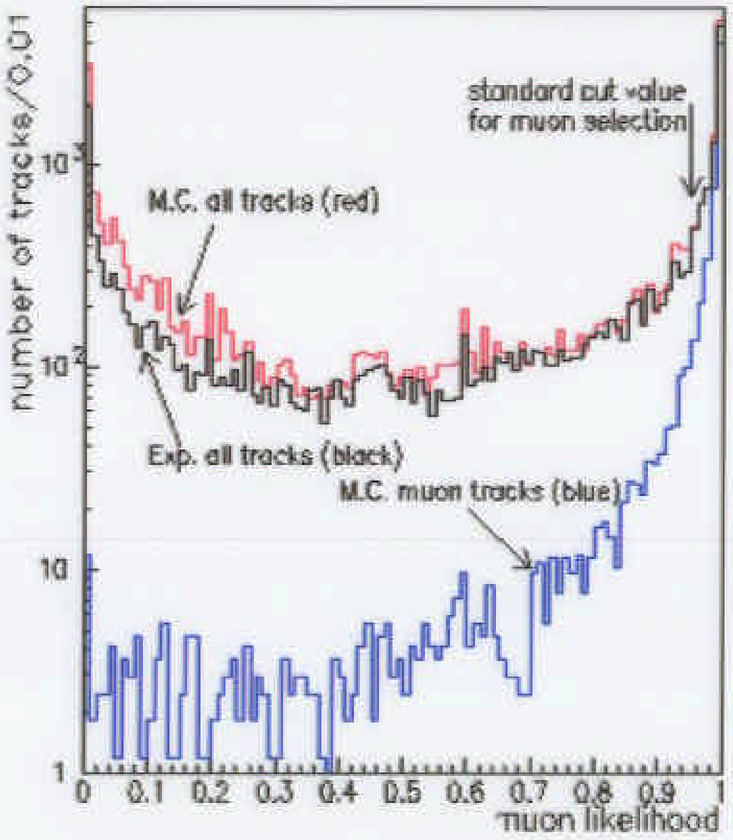


Test of electron ID
$e^+e^- \to e^+e^-\gamma$

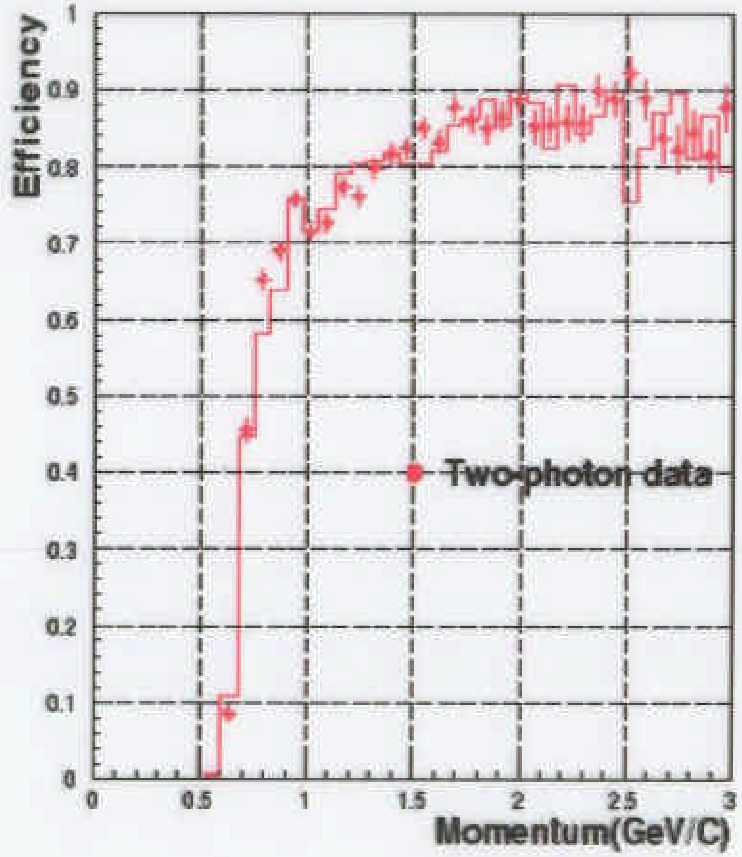


μ *identification*

"μ likelihood" distribution

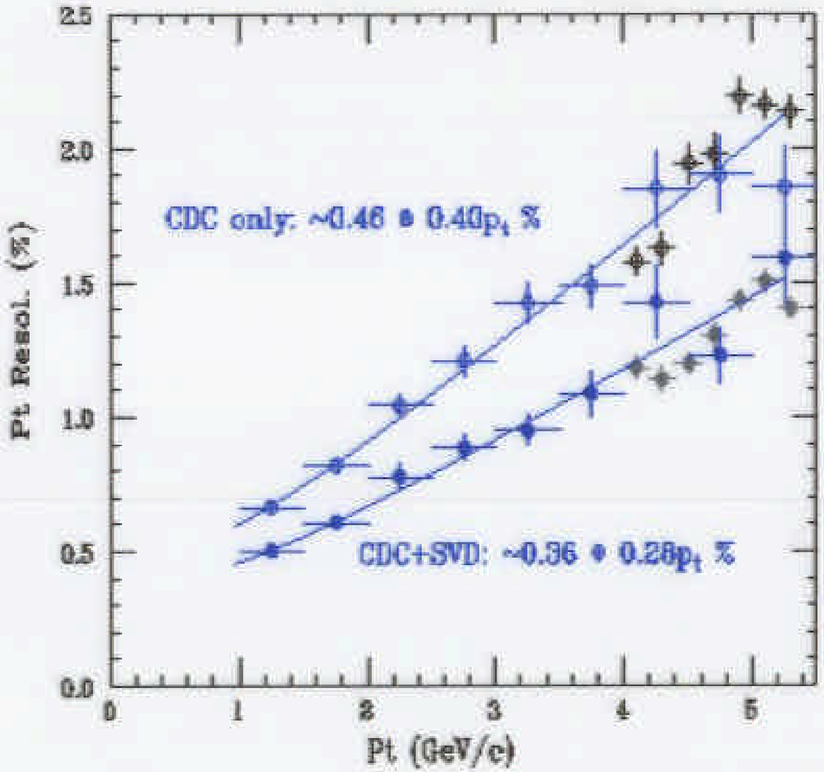


μ-ID efficiency measured with eeμμ events

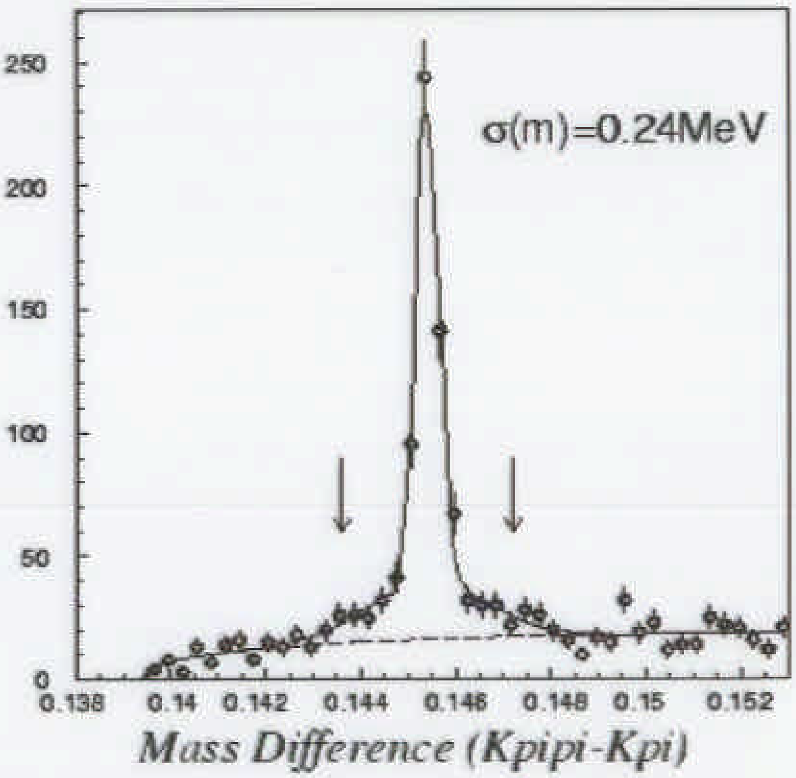


Tracking performance

Momentum resolution

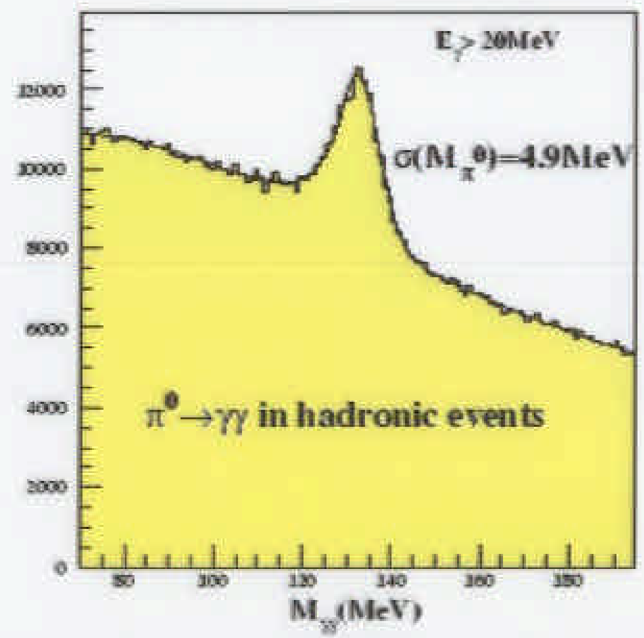


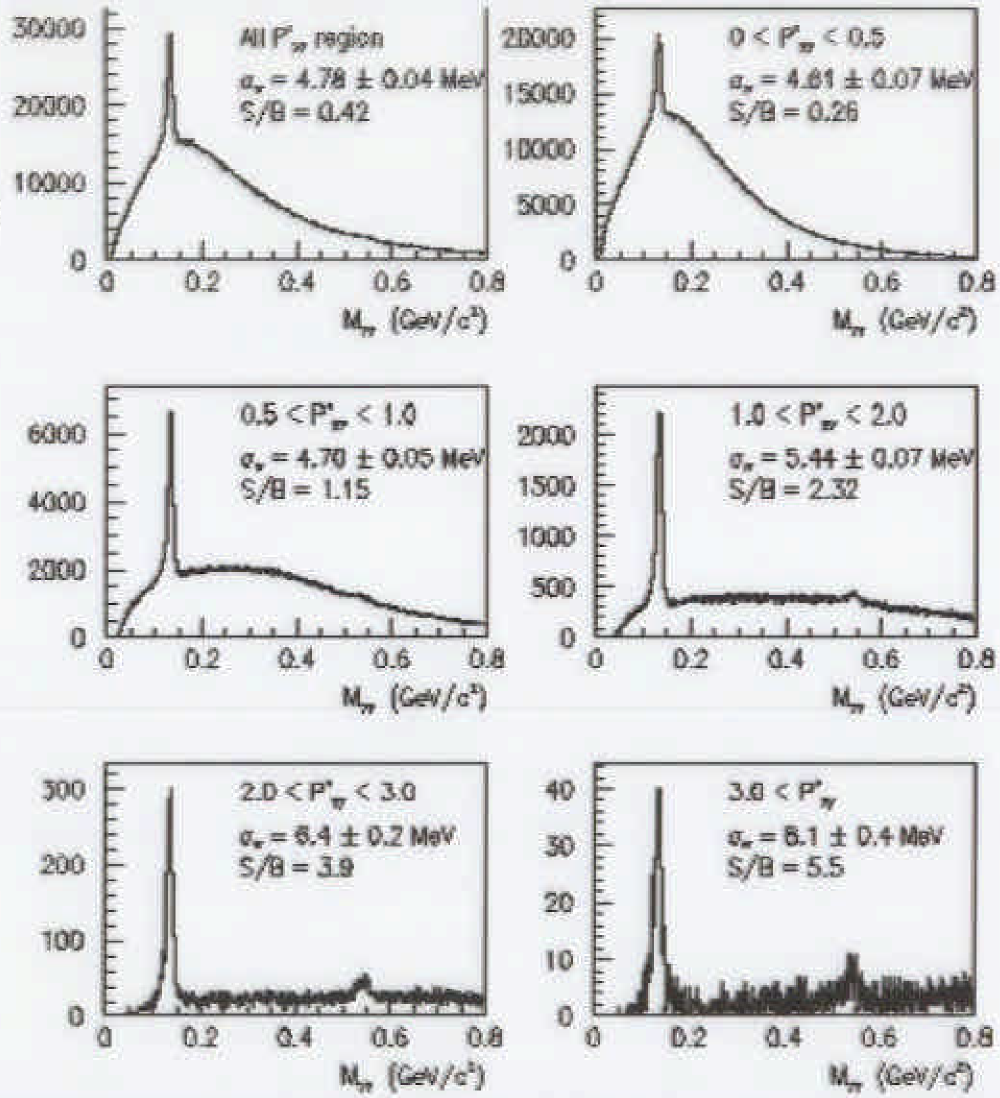
D* reconstruction

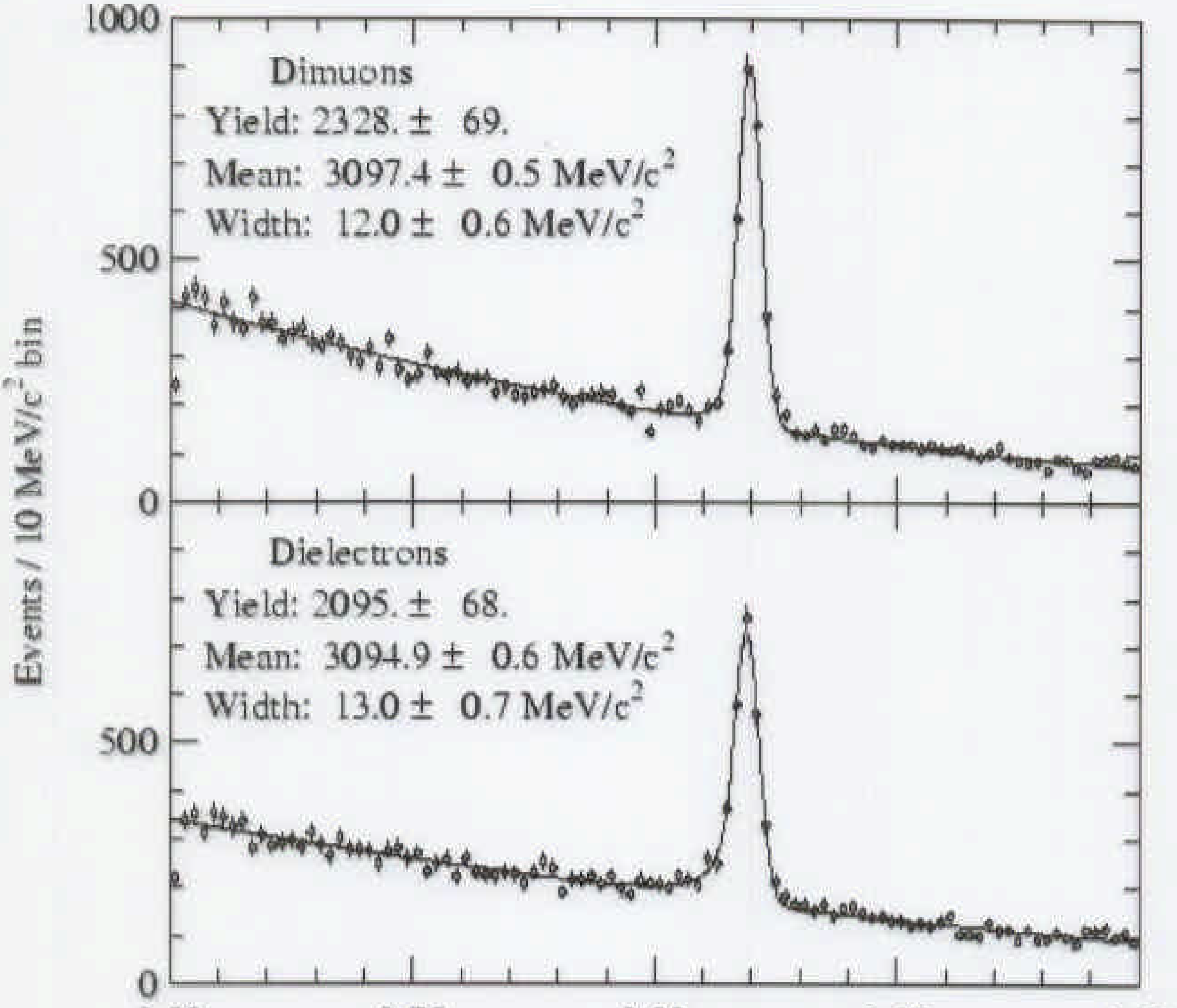


Calorimeter performance

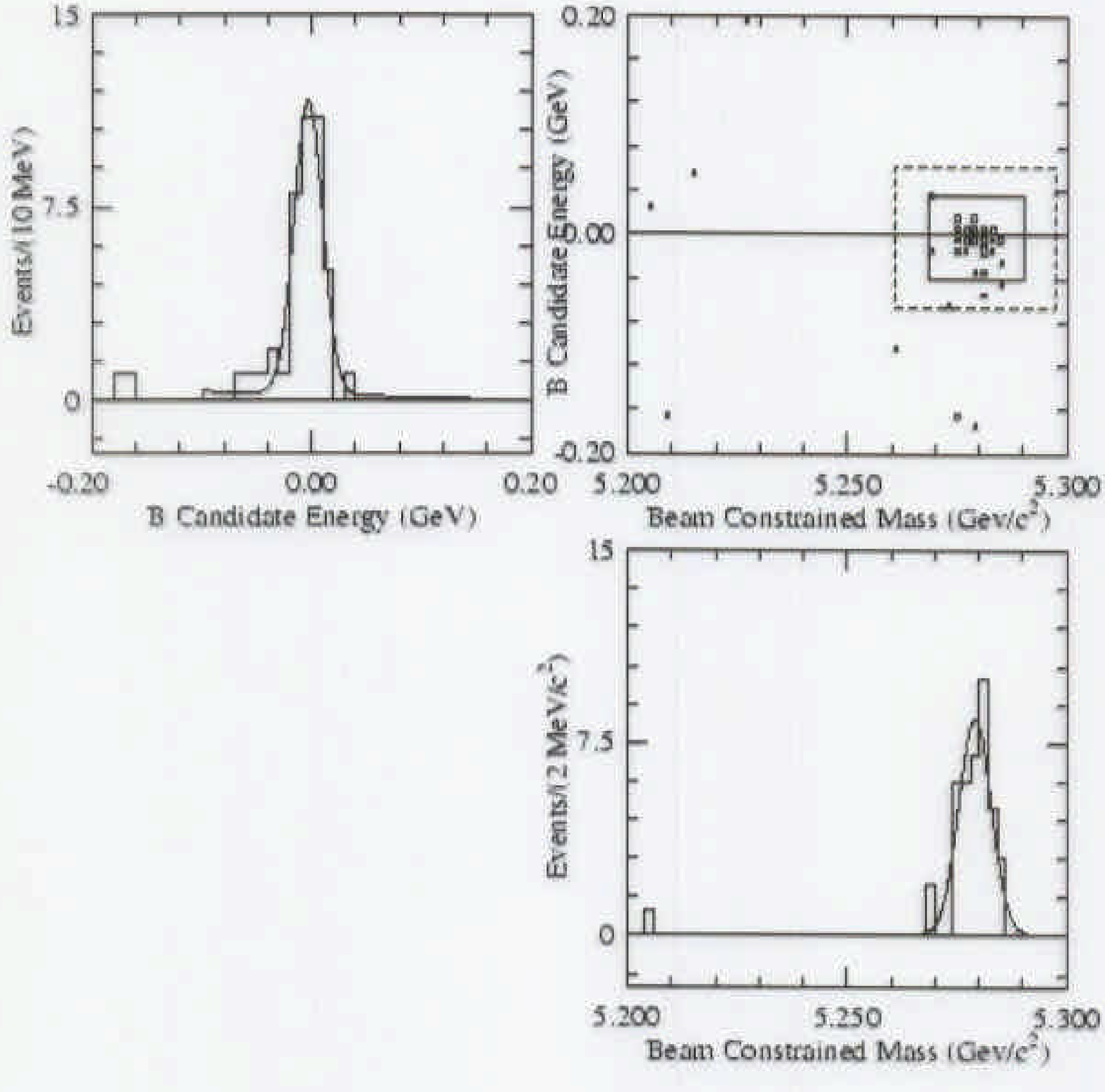
σ/E
$= (1.34^2 + (0.066/E)^2 + (0.81/E^{1/4})^2)^{1/2}$






Dimuons
Yield: 2328. ± 69.
Mean: 3097.4 ± 0.5 MeV/c^2
Width: 12.0 ± 0.6 MeV/c^2
Dielectrons
Yield: 2095. ± 68.
Mean: 3094.9 ± 0.6 MeV/c^2
Width: 13.0 ± 0.7 MeV/c^2
Events / 10 MeV/c^2 bin
Dilepton mass (GeV/c^2)
1000
500
0
500
0
2.50
2.75
3.00
3.25
3.50

$B \to J/\psi K_s$ Candidate



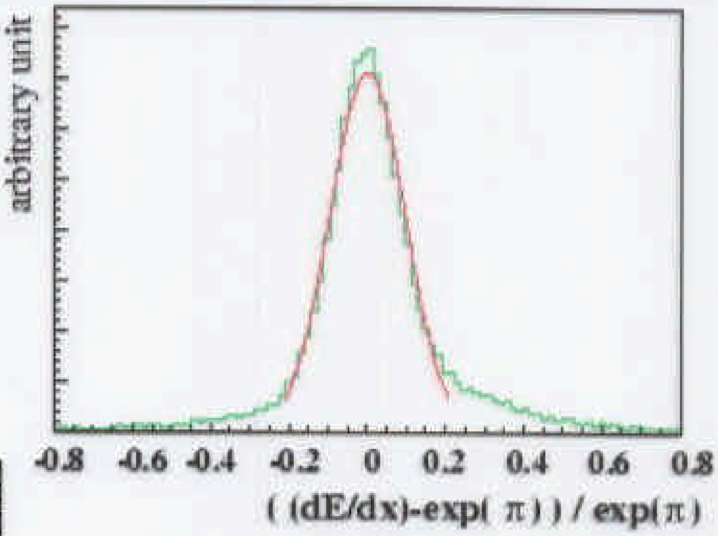
K/π separation

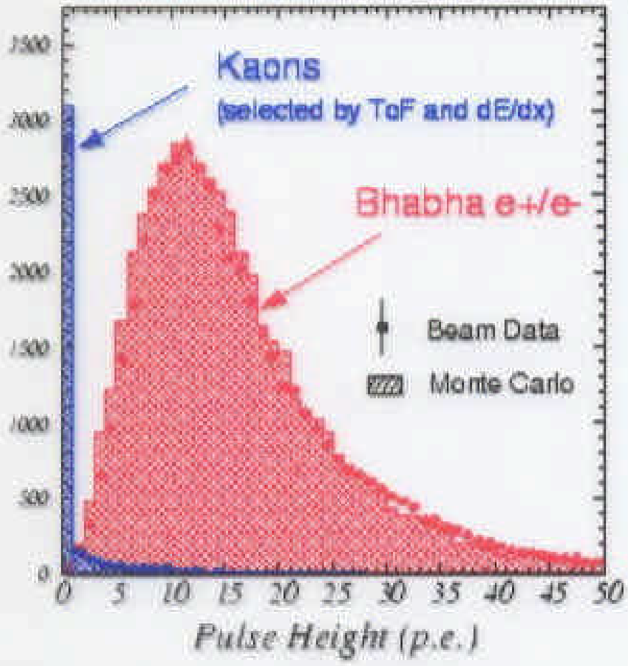
dE/dx meas. by CDC

80% truncated mean of 50 layers

$0.3 < P < 0.7$ GeV

$\sigma(dE/dx) = 6.8$ %





Aerogel Cherenkov counter

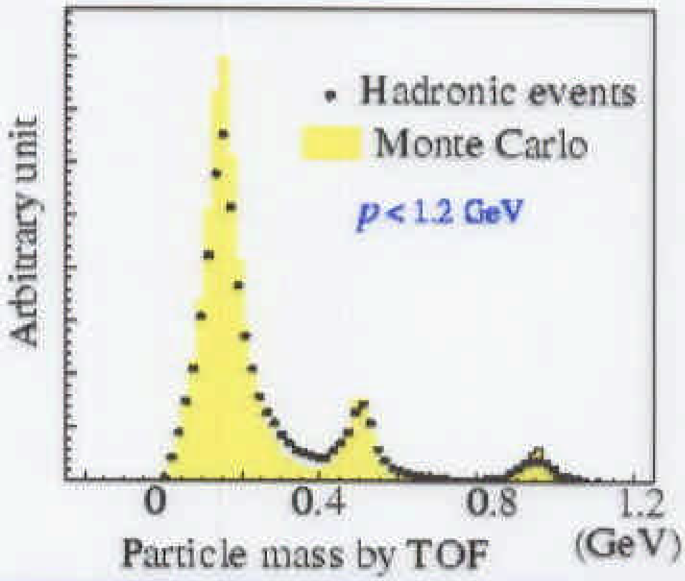
n=1.010 - 1.03 depending on θ

$N_{p.e.} = 20.0$ for $\beta=1$ part. (with n=1.015)

Time-of-flight measurement

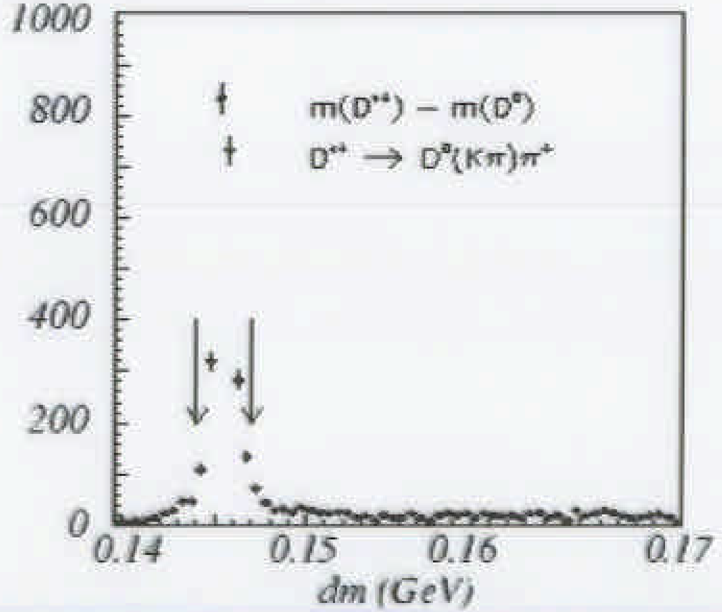
$\sigma_{TOF} = 100$ psec

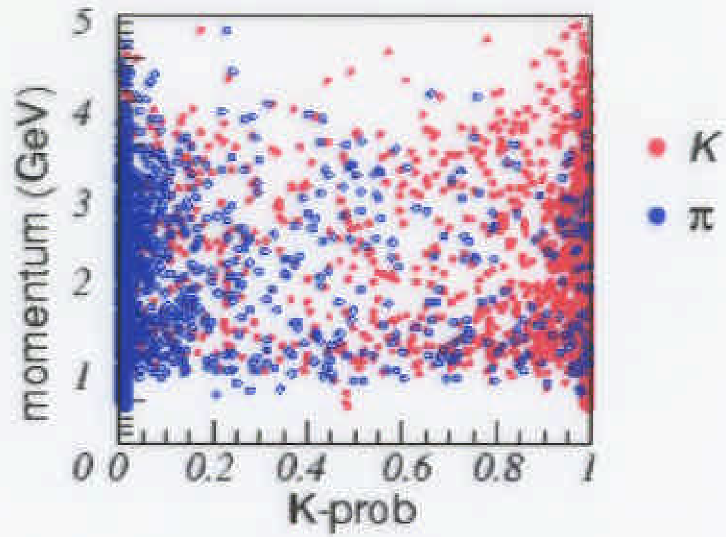
Track matching eff. ≅ 90 %

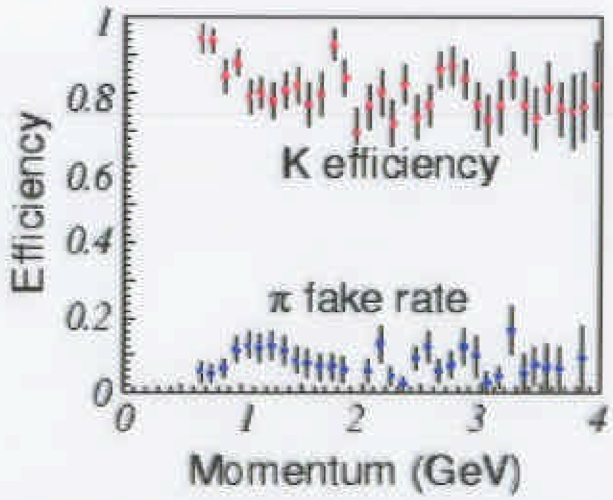


Test of π/K separation

$$D^{*+} \to \pi^+ D^0 \,,\quad D^0 \to K^- \pi^+$$







Flavor tagging

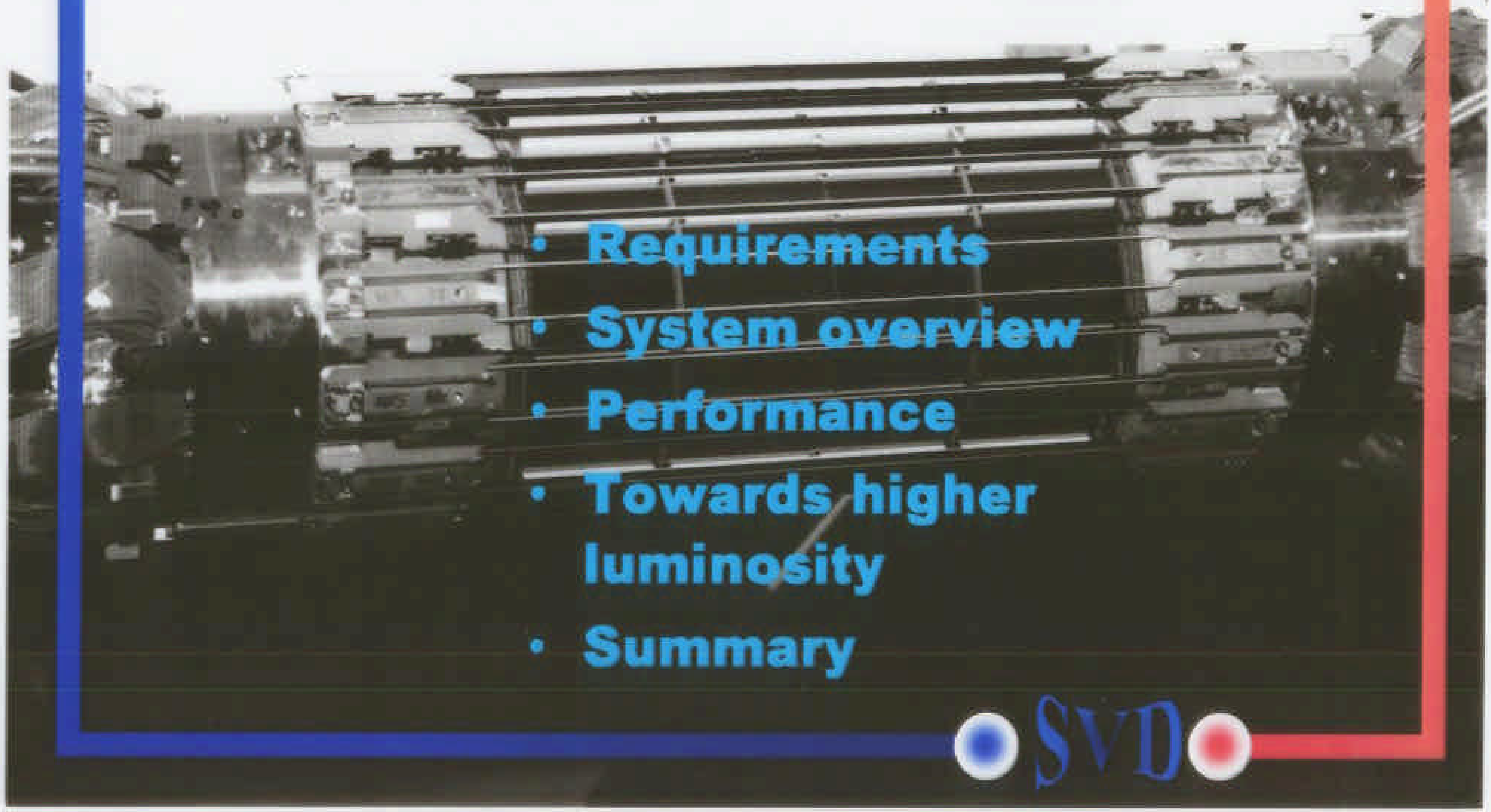
Monte Carlo ε w $\varepsilon(1-2w)^2$

method	efficiency (%)	wrong tag prob. (%)	effective eff. (%)
electron	6.1	9.3	5.0 ± 0.03
muon	6.3	9.4	4.8 ± 0.03
kaon	29.9	14.2	15.1 ± 0.06
total			24.86 ± 0.07

Test with $D^* l \nu$ events

method	efficiency (%)	wrong tag prob. (%)	effective eff. (%)
lepton	11.4 ± 1.5	0.0 ± 8.6	11.4 ± 4.3
kaon	29.5 ± 2.6	18.2 ± 6.4	11.9 ± 4.9
total			23.3 ± 6.5

Silicon vertex detector at KEK B-factory



- Requirements
- System overview
- Performance
- Towards higher luminosity
- Summary

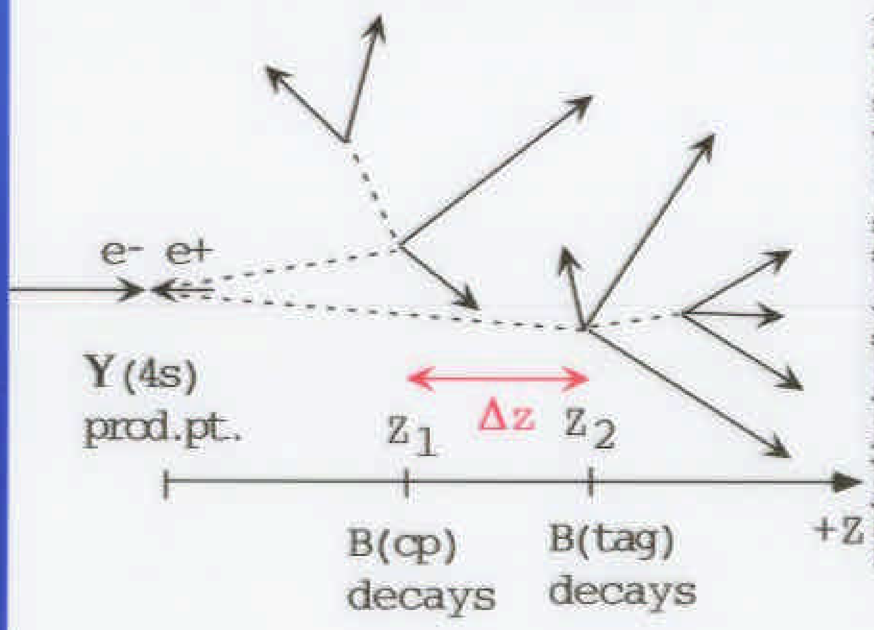
SVD

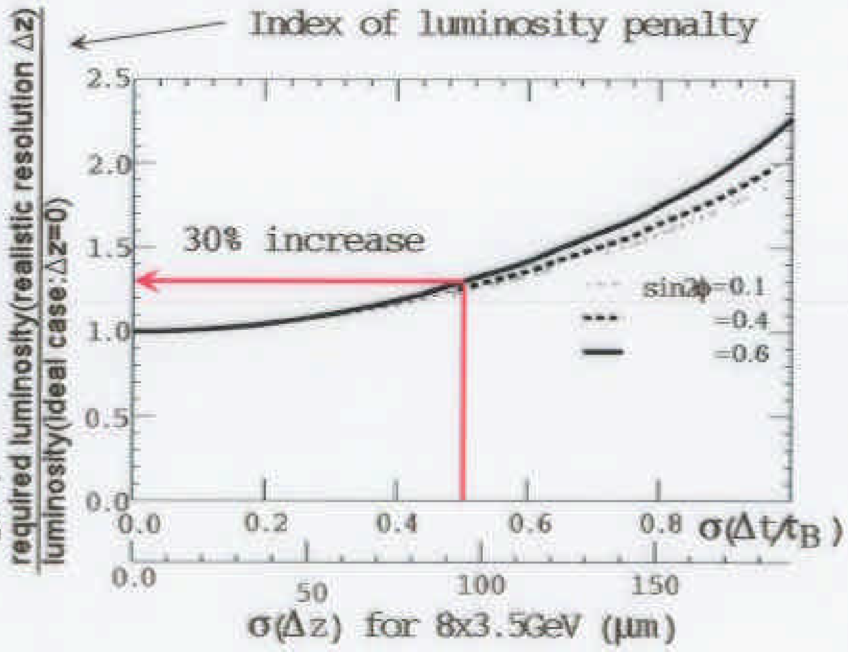
Requirements

- **Primary goal** → proper time difference $\Delta t = \Delta z / \beta\gamma c$

  $\sigma(\Delta z)$ affects required luminosity.

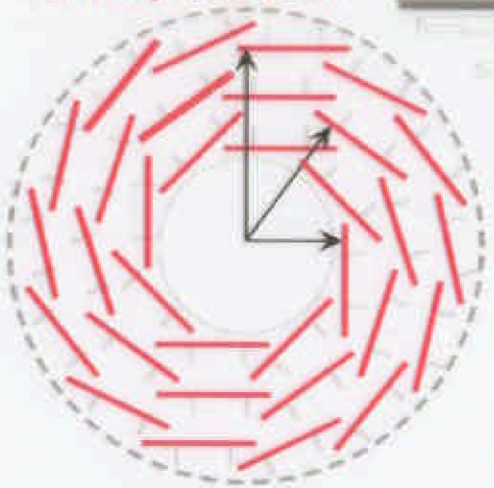
  If $\sigma(\Delta z) \sim 95 \mu m$, luminosity penalty is 30%(acceptable).

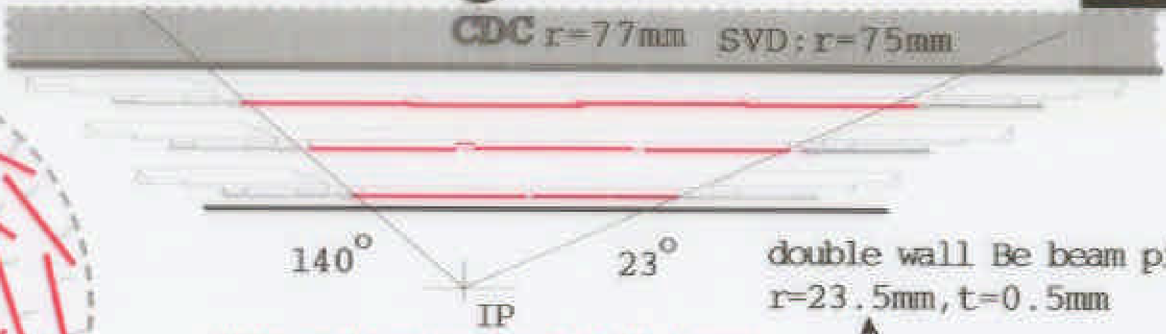




Detector Configuration

three layer structure





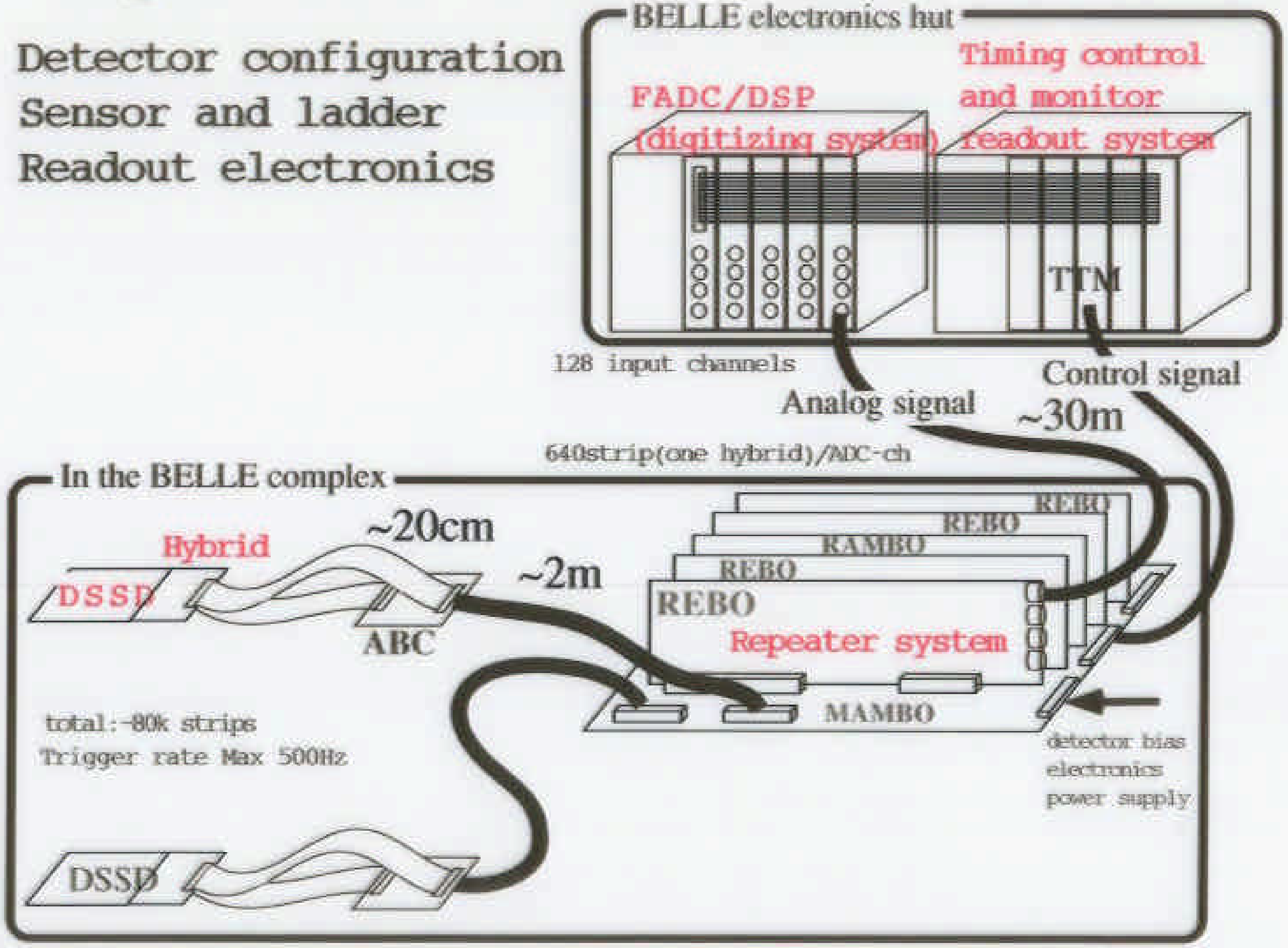
86% angle coverage in C.M. frame

	radius (mm)	DSSD size (mm^2)	DSSD/layer in z	DSSD/layer in r-phi	overlap(%)
layer 1	30.0	33.5x57.5	2(115mm)	8	9.7
layer 2	45.5	33.5x57.5	3(172.5mm)	10	3.8
layer 3	60.5	33.5x57.5	4(230mm)	14	8.7

1) Simple : a single DSSD type saves cost and time.
2) Overlap region : used internal alignment.
3) Acceptance : covers ($23<\theta<140$) , but BELLE acceptance is $17<\theta<150$.
-----> an upgrade issue

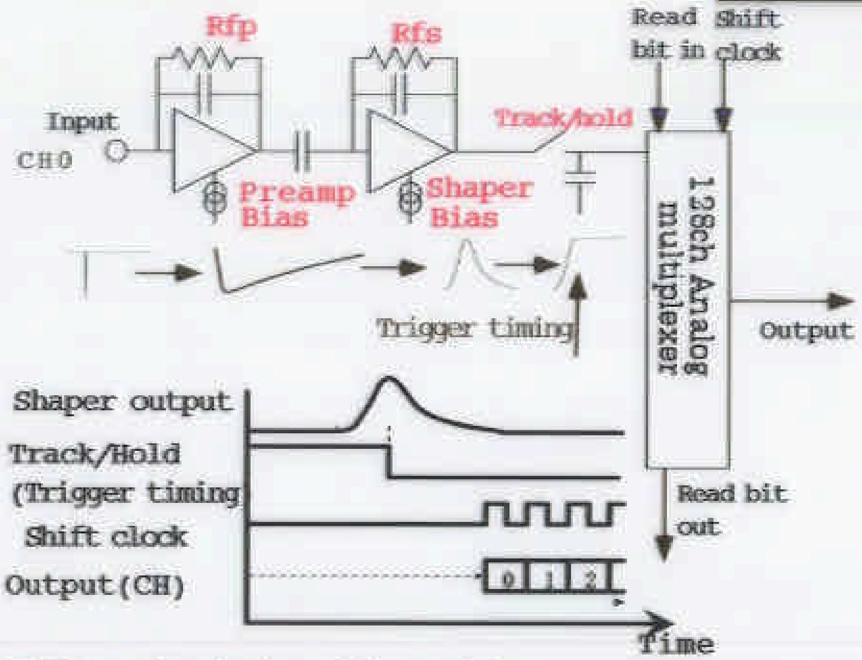
System overview

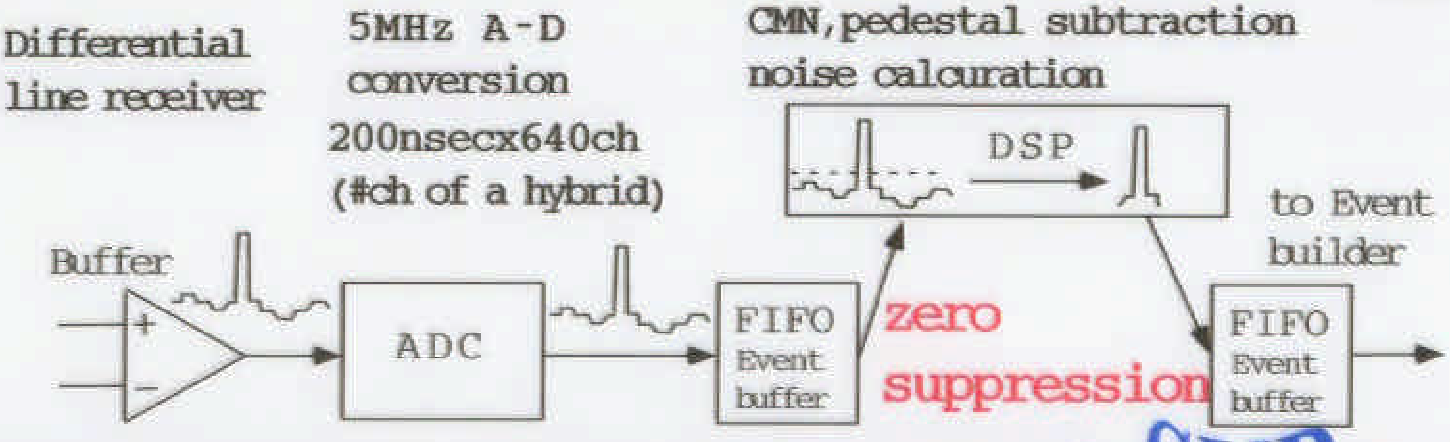
1. Detector configuration
2. Sensor and ladder
3. Readout electronics



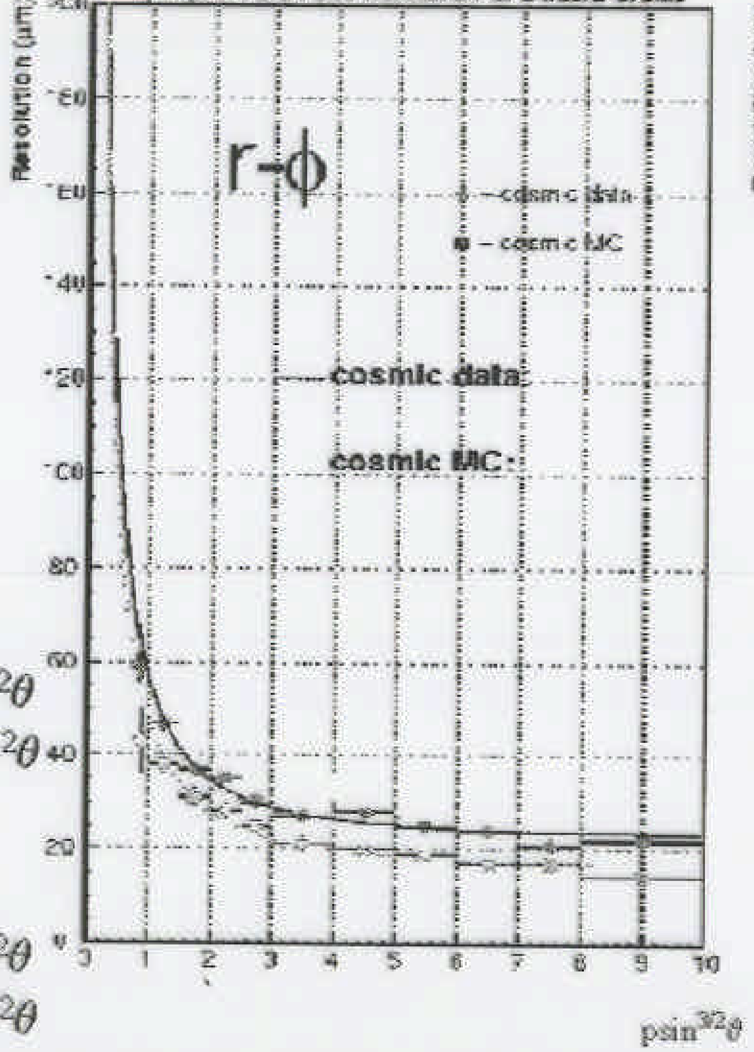
readout electronics

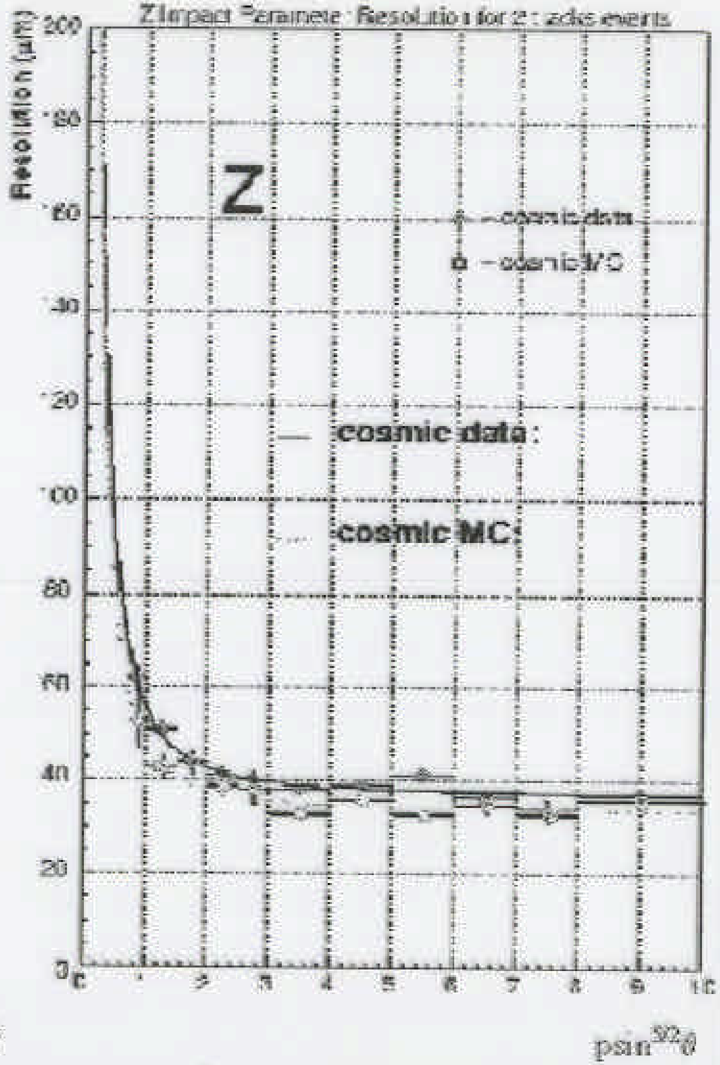
- VA1 is employed as frontend-chip(see. Fig)
- Bias current and shaping time for VA are controlled and monitored in online.
- Data sparsification is done in FADC module. (~0.8msec/event)
- VA1(1.2μm process)Rad-tolerant up to ~200kRad → upgrade issue





Vertex resolution





r-ϕ:

MC:$16+46/p\sin^{3/2}\theta$

data:$23+52/p\sin^{3/2}\theta$

Z:

MC:$34+34/p\sin^{5/2}\theta$

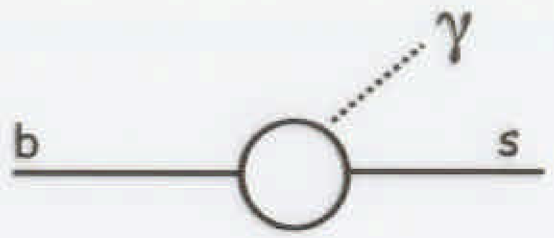
data:$37+43/p\sin^{5/2}\theta$

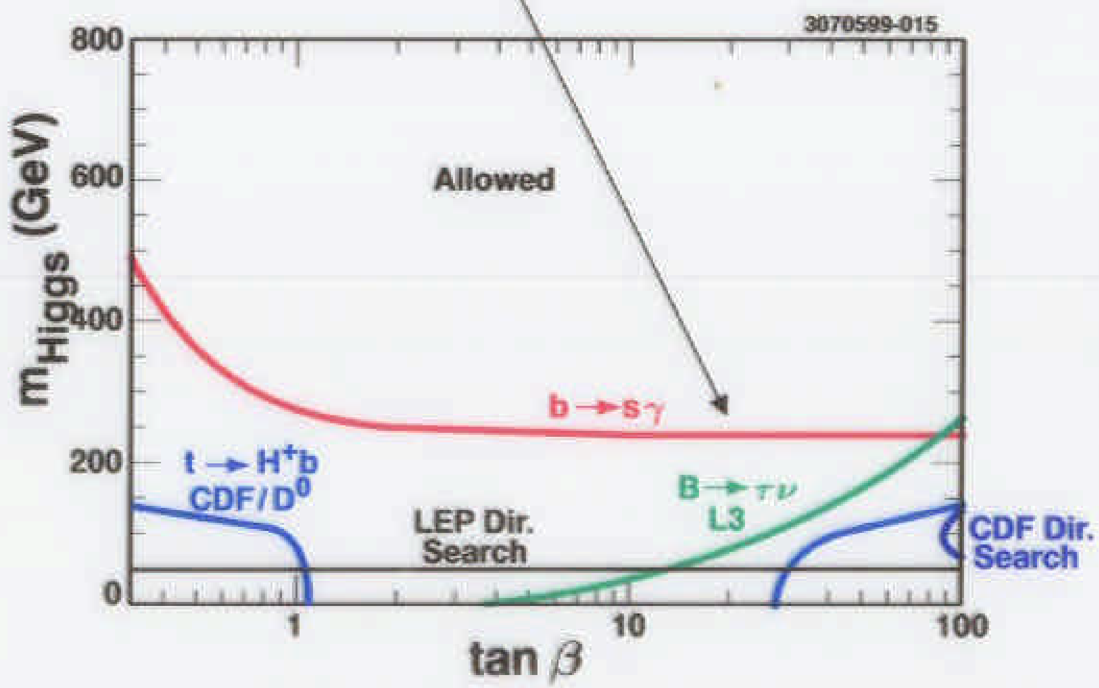
Summary

- BELLE started experiment in June 1999, and has accumulated 5.1 fb^{-1} on $\Upsilon(4s)$. The experiment goes smoothly.
- The detector shows good performance which is close to the design.
- Reconstruction of $B \to J/\psi\ Ks$, vertexing and flavor tagging are successfully done. BELLE is ready to study CP violation and other B physics.
- We hope to accumulate $O(10)\ fb^{-1}$ by the summer 2000 to see an indication of CPV.

Electroweak decays: b->sγ, sl$^+$l$^-$

Measurements of b->sγ set most stringent limits available on charged Higgses:





b->sl$^+$l$^-$ has additional handles through measurement of dilepton invariant mass, F-B asymmetry, and (conceivably) polarization (τ only)

Kurokawa's calendar

☆ Autumn 2000~ Summer 2001 3E33 ~

☆ Autumn 2001~ Summer 2002 5E33 ~

☆ Autumn 2002~ Summer 2003 7E33 ~

Superconducting Crab Cavities will be installed in 2003 summer shutdown

☆ Autumn 2003~ Summer 2004 9E33

βy* has already been reduced from 10 mm to 7 mm→

☆ Autumn 2004~ Summer 2005 1.2E34

~300/fb

☆ Autumn 2005~ 1.4E34

Beyond 1.4E34

Much current (vacuum, RF, …)	×1.3
Smaller β*	×1.1
beam-beam parameter,	× ?
	→2E34(?)
	2×10^{34} (?)

● More studies and experiences are necessary

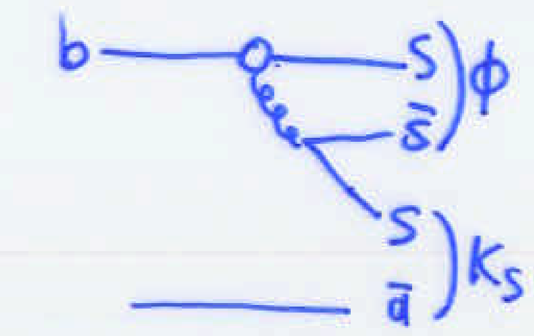
★★★ $B \to \phi K_S$ ($\eta' K_S$ etc. can be tried also.)

BABAR Physics Book → $Br(B \to \phi K_S) = 0.65 \times 10^{-5}$

"Gold-plated Mode to Search for New Physics"

~30 events/$30 fb^{-1}$ before flavor tagging

little background → $\delta \sin 2\phi_1 \cong 0.6$



"Pure" penguin

CP reach (= statistical error of the asymmetry)

Ian's Calendar

Year	N_{BB} (total)	$\delta A(\phi K_S)$	$\delta A(\psi K_S)$	3σ search limit for New Physics $3 \times \sqrt{\delta A(\phi K_S)^2 + \delta A(\psi K_S)^2}$
2005	0.26×10^9	0.22	0.067	0.69
2008	0.86×10^9	0.12	0.037	0.38
2011	2×10^9	0.081	0.024	0.25
	6×10^9	0.047	0.014	0.15

↳ We can explore new region (with 3σ significance) even by 2005.

S. Baek, T. Goto, Y. Okada and K. Okumura
hep-ph/0002141

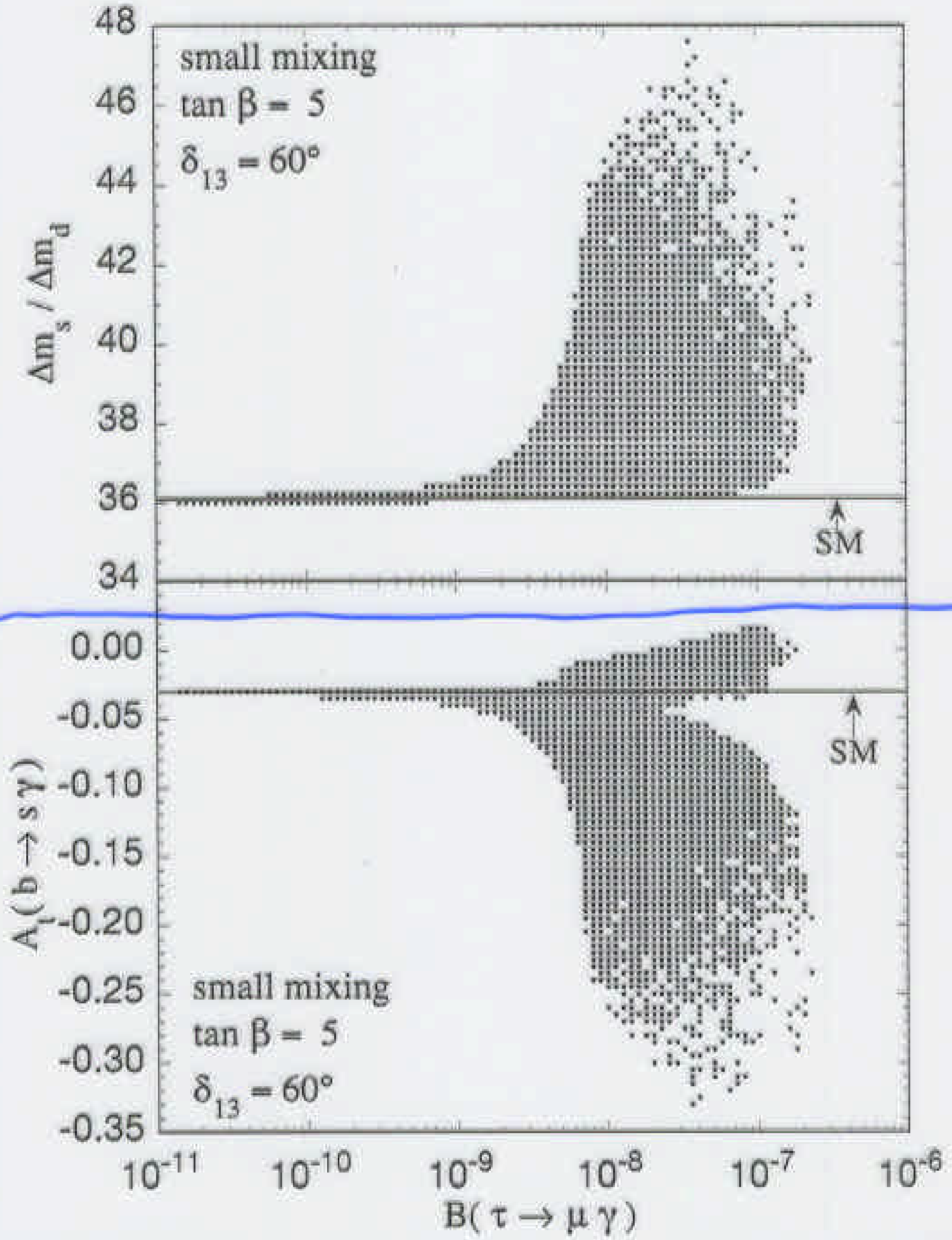


FIG. 2. The ratio of B_s-$\bar{B}_s$ and B_d-$\bar{B}_d$ mass splittings $\Delta m_s/\Delta m_d$ and the magnitude factor A_t of the time-dependent CP asymmetry in the $B \to M_s\,\gamma$ process as a function of $\mathrm{B}(\tau \to \mu\gamma)$ for the small mixing case (i).

→ relation between $A_t(b \to s\gamma)$ and $B_r(\tau \to \mu\gamma)$