Future e^+e^- Flavor Facilities

(Tom Browder, University of Hawaii)

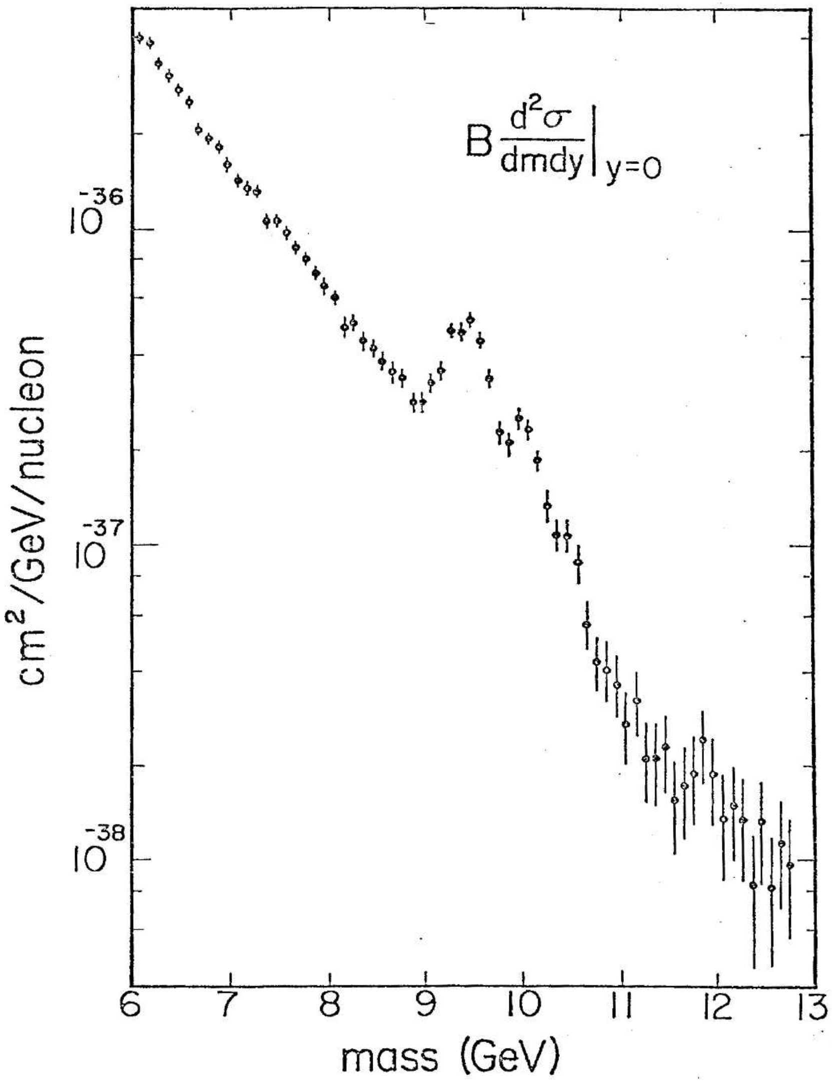
Apologies: Borrowed slides from many hardworking Belle II, SuperB, SuperKEKB collaborators. Used two plots from the massive Physics of B Factories Book (to appear soon). Oversimplified new physics issues and only have time to cover a few examples.

Related talks at SSI 2013 by Zoltan Ligeti on theoretical foundations as well as by Professor Marina Artuso on LHCb and hadron facilities.

Pedagogical Material

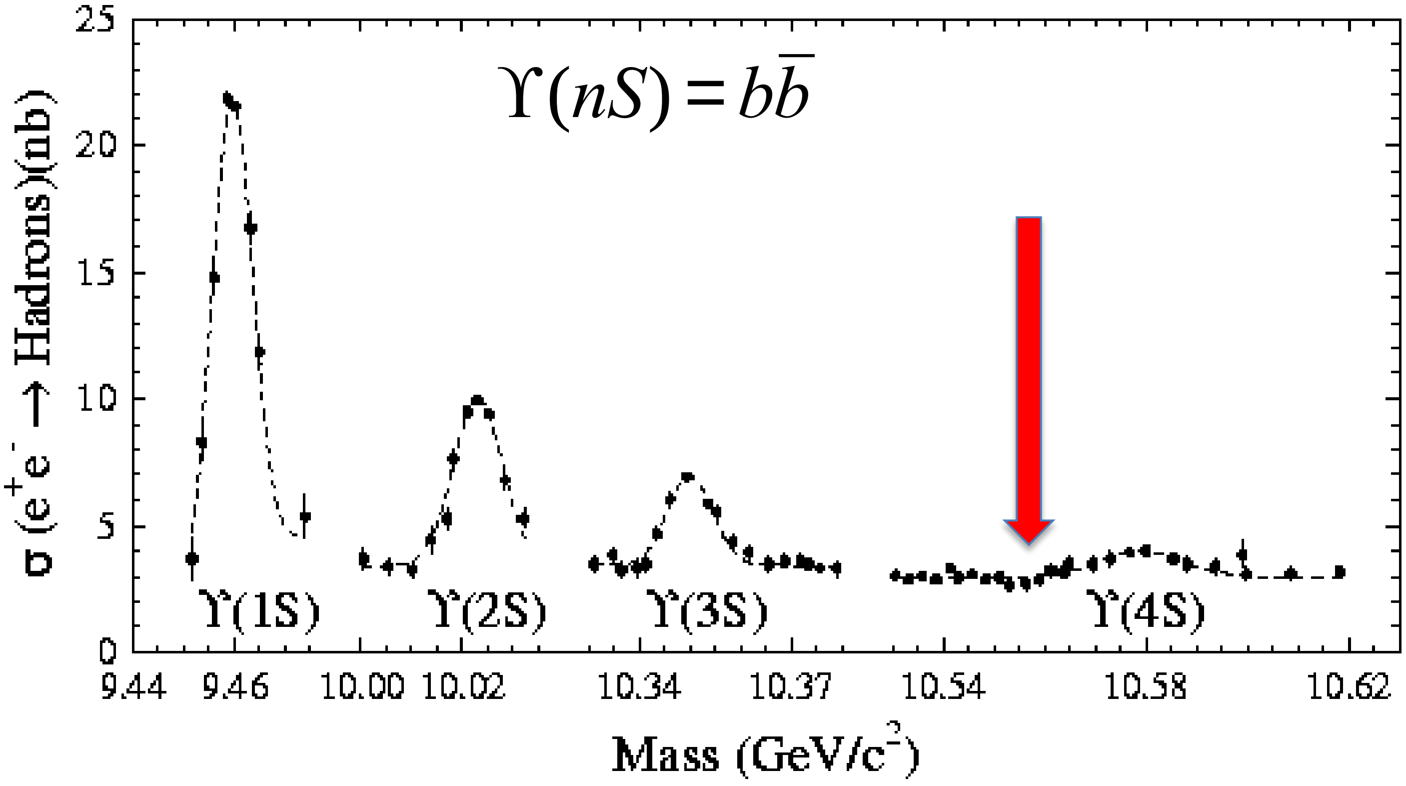
- Need to introduce some basic background material and a few instructive historical highlights first.
- BaBar (or Belle) graduate students or postdocs or theorists: sorry if this is too elementary or excessive……
- Homework exercises are included

400 GeV proton-nucleus collisions at Fermilab. In 1977, Lederman's team find a resonance at 9.5 GeV decaying to pairs of muons.



HADRONS

Radial excitations !



Electron-positron collisions at DORIS (Germany) and CESR (Cornell) allowed the resolution and discovery of these "*positronium-like*" radial excitations.

Review Exercise I: Why are the first three states so narrow ?

Production at threshold

- B meson pairs are produced just above threshold in $e^+ e^-$ collisions at the Y(4S) resonance

$$E_{4S} = 10.580\,\mathrm{GeV}$$

Compare to ~2(5.279) GeV, which is twice the B meson mass. This gives 10.558 GeV.

This implies a B momentum of around ~340 MeV ("B mesons at rest").
No additional particles are produced ("clean").

The Power of Production at threshold

Rather than using invariant mass, one can use “beam-constrained mass” or “energy-substituted mass” to isolate the signal. The resolution is usually about an order of magnitude better !

$$m_{\mathrm{bc}} = \sqrt{E^{\star 2}_{\mathrm{beam}} - p^{\star 2}_{B}},$$

Also use the energy difference (given below in the CM frame) to extract the signal

$$\Delta E = E_{rec} - E_{beam}$$

Much of the background can be removed

BaBar’s definition of m_{ES} is slightly different

MC Plots
from PBFB

Compare
modes with
and without a
π^0

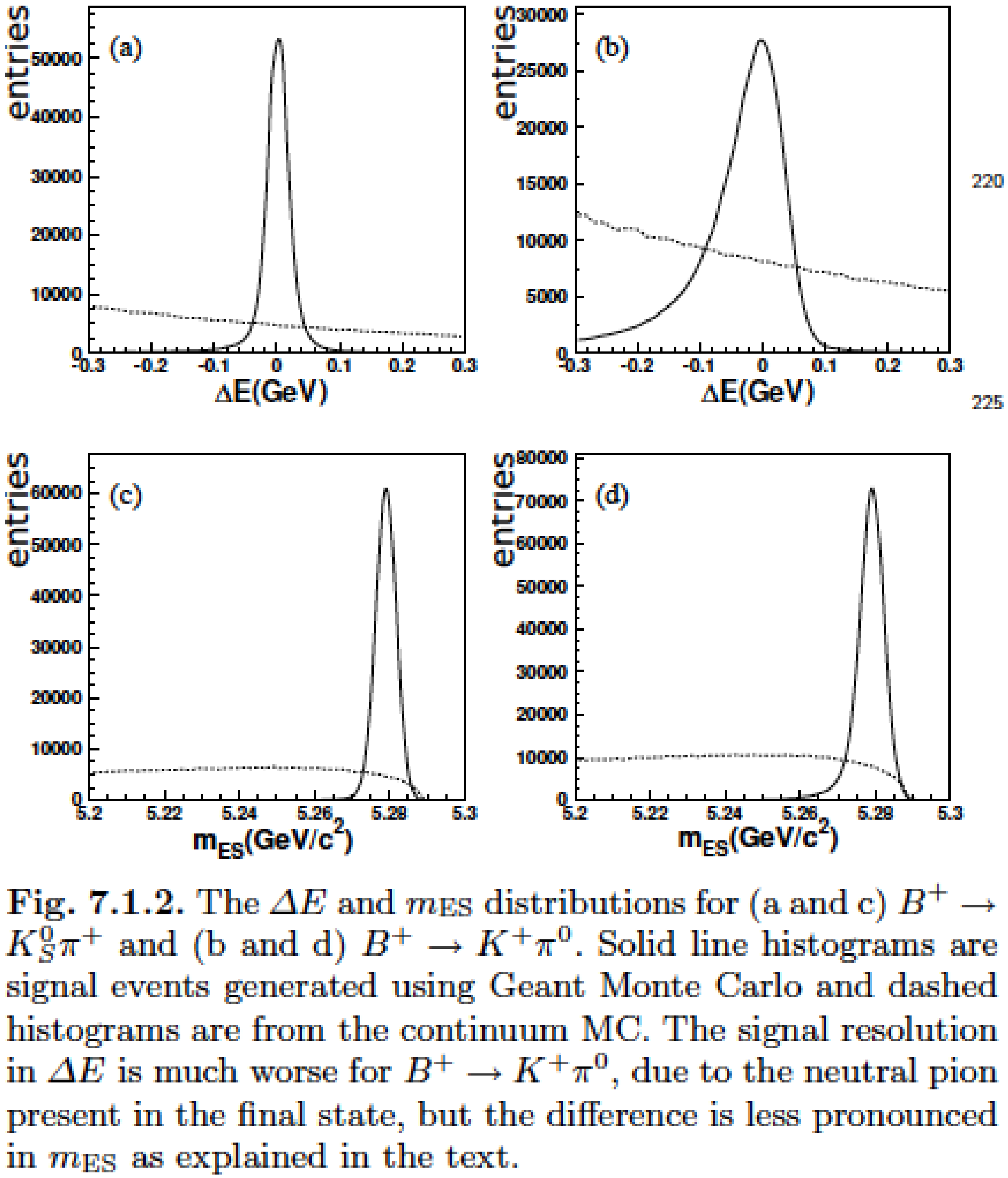
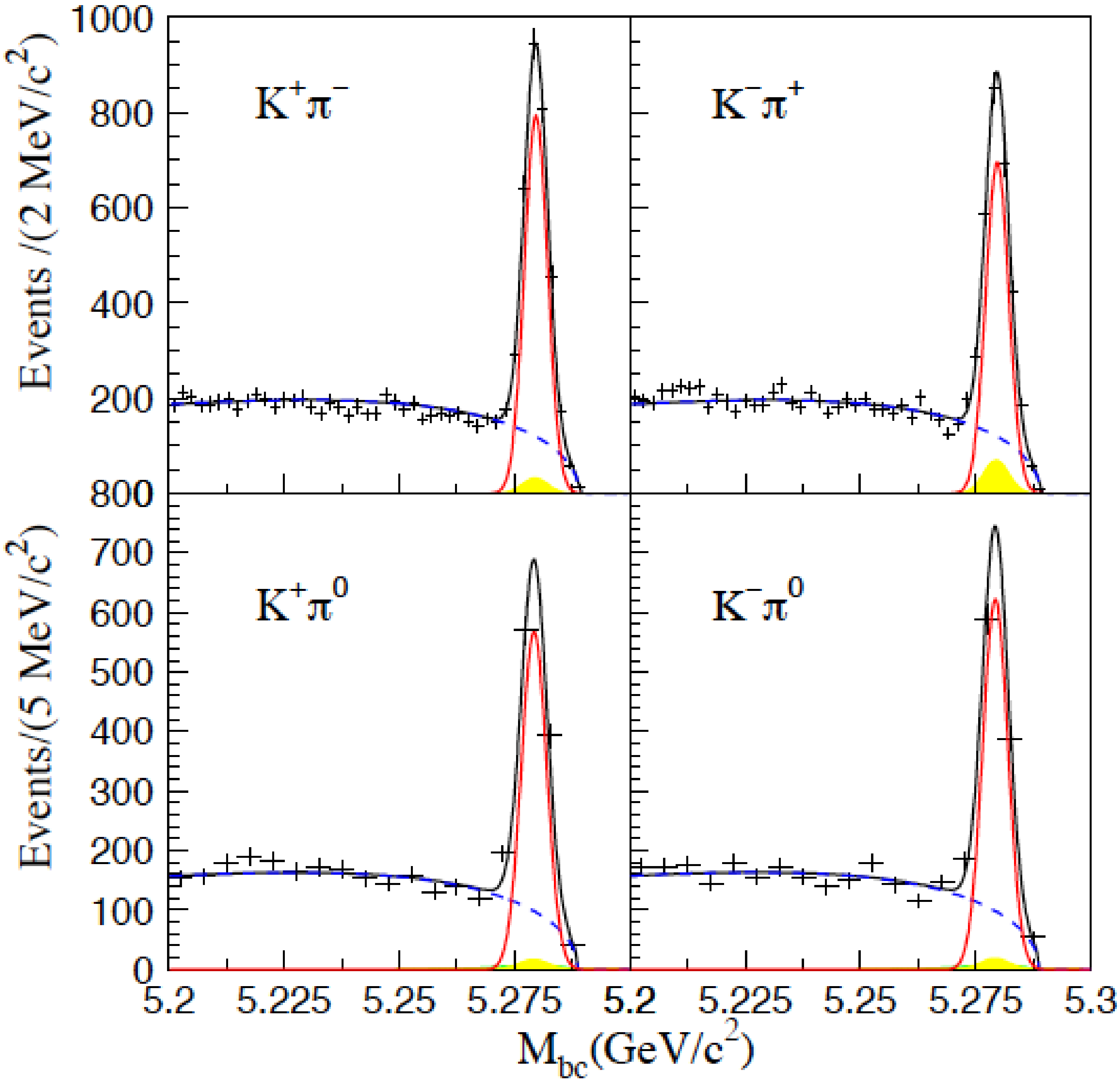


Fig. 7.1.2. The ΔE and $m_{\rm ES}$ distributions for (a and c) $B^+ \to K^0_S\pi^+$ and (b and d) $B^+ \to K^+\pi^0$. Solid line histograms are signal events generated using Geant Monte Carlo and dashed histograms are from the continuum MC. The signal resolution in ΔE is much worse for $B^+ \to K^+\pi^0$, due to the neutral pion present in the final state, but the difference is less pronounced in $m_{\rm ES}$ as explained in the text.


K$^+\pi^-$
K$^-\pi^+$
K$^+\pi^0$
K$^-\pi^0$
Events /(2 MeV/c^2)
Events/(5 MeV/c^2)
1000
800
600
400
200
800
700
600
500
400
300
200
100
0
5.2
5.225
5.25
5.275
5.2
5.225
5.25
5.275
5.3
M$_{bc}$(GeV/c^2)

Belle
Data

Time dependent measurements are difficult or impossible at threshold

- The factor $\beta\gamma=0.0646$ at the Υ(4S)
- This implies that the average decay length is only ~29μm

- Hence the initial measurements of the B lifetime came from *e+e- collisions* at 29 GeV at PEP, here at SLAC.

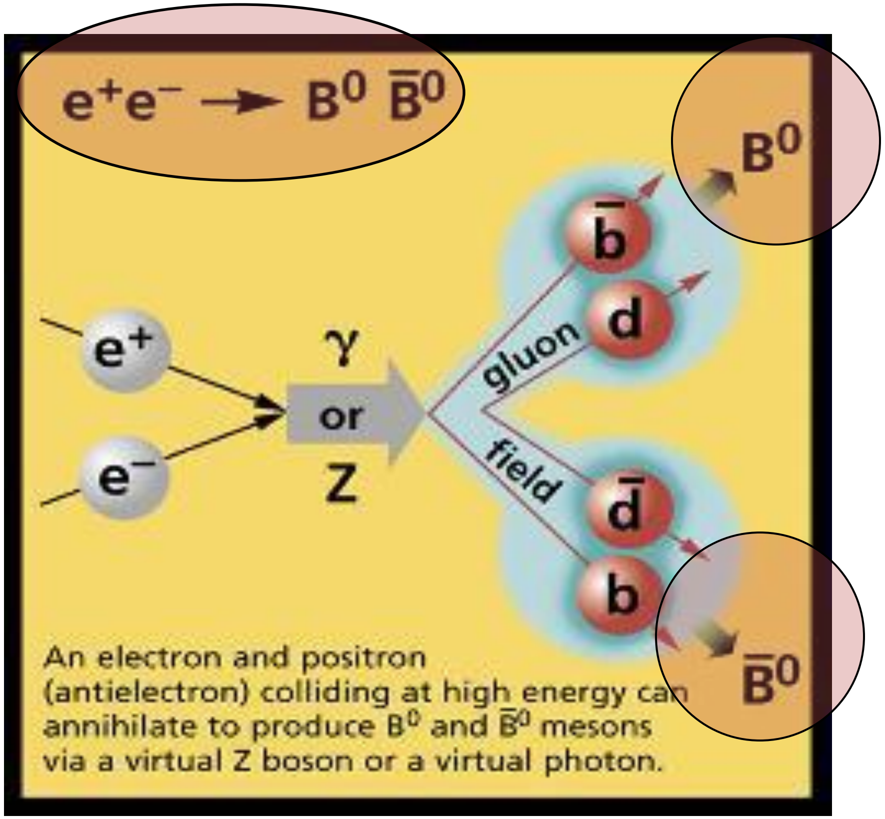
Surprisingly long !

Bill Ford

John Jaros

Nigel Lockyer

B Mesons: *"Laboratory Rats of the Weak Interaction"*



An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.

Exotic bound state of matter and antimatter
(hydrogen-like)
***b* quark mass**
~ 5x proton mass

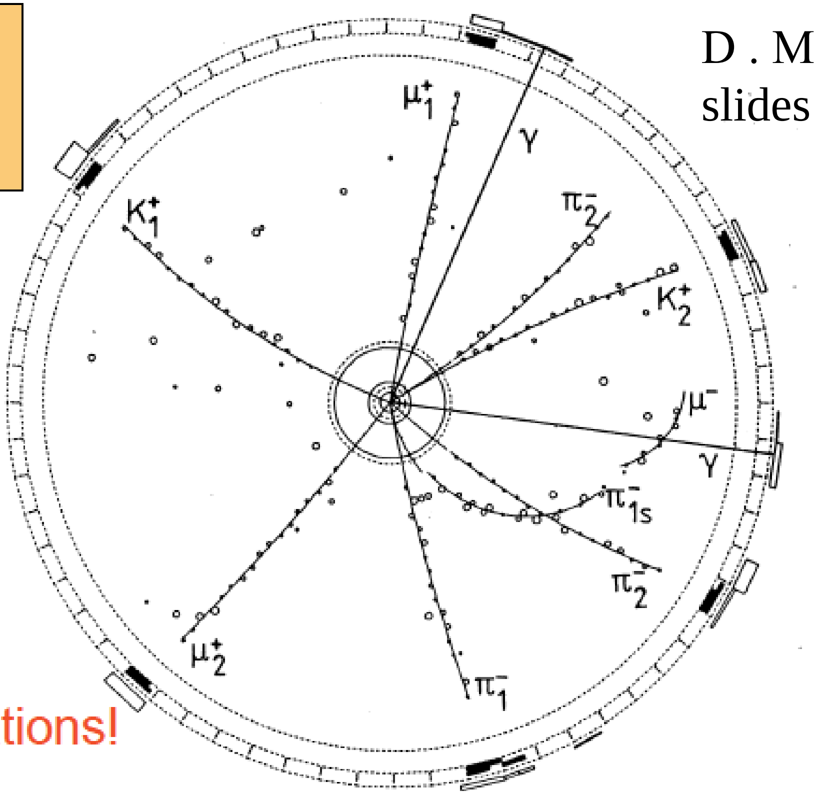
Lifetime ~ 1.5ps

$$\begin{pmatrix} t \\ b \end{pmatrix}$$

1987: ARGUS finds that the neutral B meson can transform into its anti-particle, "B-Bbar mixing"

Produce matter-antimatter pairs in ARGUS at DESY

$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B^0\bar{B}^0$



D . MacFarlane’s slides at SSI2013

By the time of decay

$B^0\bar{B}^0 \rightarrow B_1^0 B_2^0$

Matter-Antimatter oscillations!

Ikaros Bigi and Tony Sanda realized that the long lifetime of the B meson and the possibility of particle-antiparticle mixing could lead to CP non-conservation in the B sector.

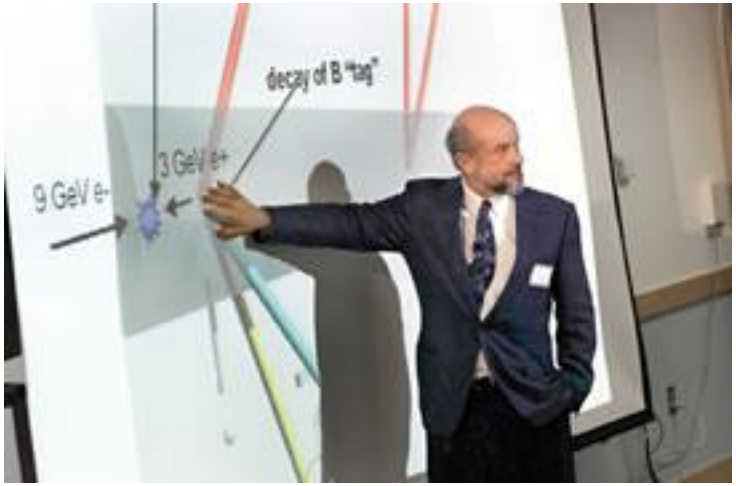
Time dependent measurements are difficult or impossible at threshold

Exercise: Show time integrated CP asymmetries vanish at the Upsilon(4S).
Hint: What is the C parity of the initial state ?

A new idea

At a Snowmass meeting *held in Snowmass, Colorado in 1988* for four weeks Pier Oddone (LBL) proposed using asymmetric energy beams.

Decay lengths are dilated from ~20 microns to ~200 microns. Time integrated CP asymmetries vanish at the Upsilon(4S) but can be measured in this case.



Exercise: Calculate the center of mass energy for 9 x 3 GeV(BaBar) or 8 x 3.5 GeV(Belle) or 7 x 4 GeV (Belle II) . What are the boost factors for each case ?

1988 Snowmass	CERN[4]	Cornell[5]	DESY[6]	KEK[7]	Novosibirsk[8]	SLAC/LBL/ LLNL[9]
Lumin(10^{33}cm^{-2}s^{-1})	1	3	3	2	5	3
Energies (GeV)	8.0,3.5	8.0,3.5	9.3,3.0	8.0,3.5	6.5,4.3	9.0,3.1
Total I's (Amp)	0.56,1.3	0.87,2.0	0.71,1.1	0.22,0.52	0.7,1.0	1.5,2.1
# of bunches	80	230	640	1024	170	1658
Bunch length (cm)	2.0,2.0	1.0,1.0	1.0,1.0	0.5,0.5	0.8,0.8	1.0,1.0
Peak I (kAmp)	0.13,0.31	0.12,0.26	0.10,0.15	0.05,0.12	0.15,0.15	0.08,0.11
RF volt (MV)	13.,2.0	35.,12.	17.,4.5	48.,22.	7.,4.5	18.,9.5
RF power (MW)	4.4,0.7	4.8,2.4	--,1.0	--	2.4,2.4	8.3,4.9
# of RF cells	20,4	12,4	31,9	60,28	6,6	20,10
RF technology	room temp	supercond	supercond	room temp	supercond	room temp
β_v* (cm)	3.0,3.0	1.5,1.5	2.0,1.0	1.0,1.0	1.0,1.0	3.0,1.5
β_h* (m)	1.0,1.0	1.0,1.0	0.4,0.2	1.0,1.0	0.6,0.6	0.75,0.38
η* (m)	0.0,0.0	0.0,0.0	0.0,0.0	0.0,0.0	0.4,0.4	0.0,0.0
ξ_v (10^{-2})	3.0,3.0	3.0,3.0	4.0,4.0	5.0,5.0	5.0,5.0	3.0,3.0
ξ_h (10^{-2})	3.0,3.0	3.0,3.0	4.0,4.0	5.0,5.0	1.2,1.2	3.0,3.0
ε_v (nm)	9.0,9.0	2.0,2.0	2.5,5.0	0.19,0.19	0.25,0.25	1.9,3.9
ε_h (nm)	300.,300.	130.,130.	50.,100.	19.,19.	5.,4.	48.,96.
σ_E/E (10^{-3})	0.84,0.52	0.84,0.65	--	0.72,0.77	1.,1.	0.61,0.95
σ_v (μm)	16.,16.	5.4,5.4	7.0,7.0	1.4,1.4	1.6,1.6	7.6,7.6
σ_h (μm)	550.,550.	360.,360.	140.,140.	140.,140.	400.,400.	190.,190.
Q_s (10^{-2})	5.5,3.4	8.5,8.5	--	--	2.3,2.3	5.2,5.0
δ (10^{-4})	7.0,0.86	6.5,2.2	3.7,2.1	5.3,2.7	4.2,3.5	4.0,4.0
Bunch space (m)	12.0	3.3	3.6	3.0	4.2	1.3
Separation	magnetic	angle	magnetic	magnetic	magnetic	magnetic

Symbols: h,v ≡ horizontal, vertical; β* ≡ amplitude function; η* ≡ dispersion; ξ ≡ beam-beam tune-shift; ε ≡ emittance; σ_E/E ≡ rms fractional energy spread; σ ≡ beam size; Q_s ≡ synchrotron tune; δ ≡ fractional energy loss between collisions.

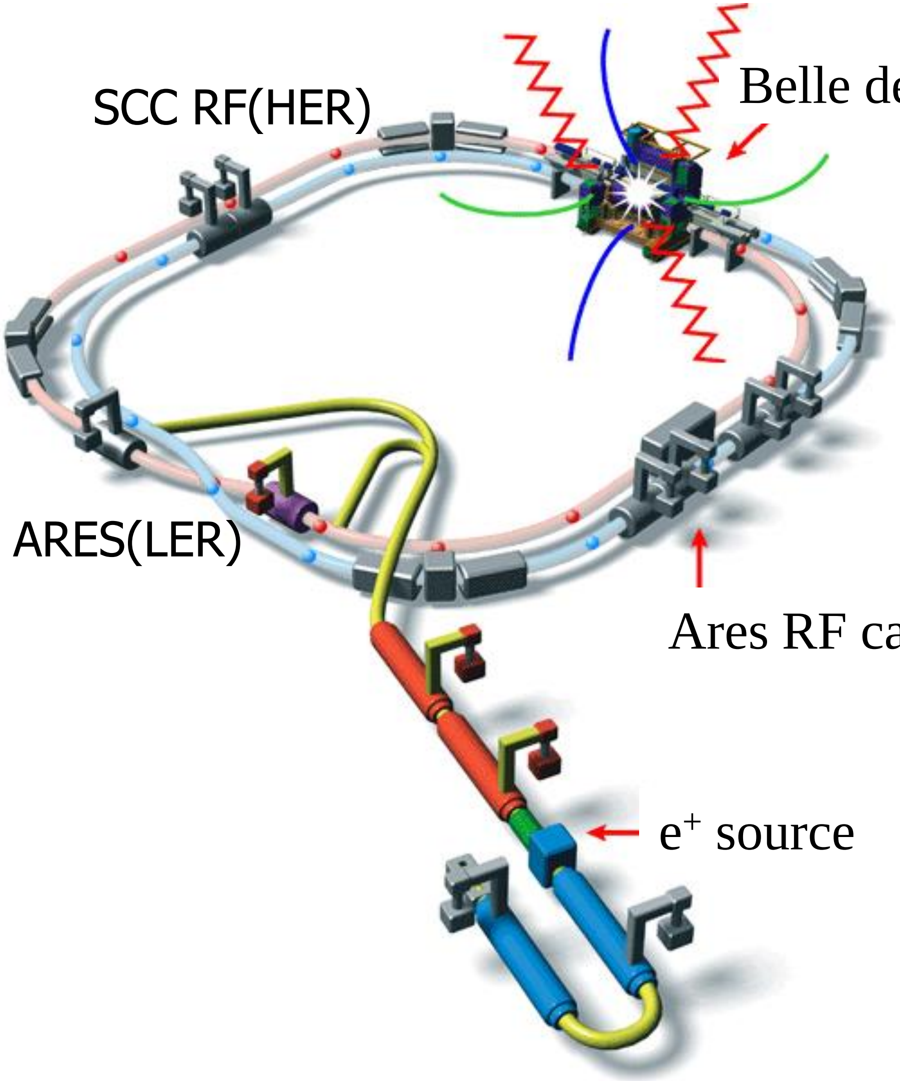
Apres Snowmass

- In the end, SLAC choose magnetic separation and KEK used a ±22 mrad crossing angle. Only two B factories were built.

Exercise: *The Super B Factory will use a large crossing angle. Why ? [the ILC will also have a crossing angle]*

Exercise: *The LHC upgrade will use "crab cavities" to achieve high luminosity. What are "crab cavities" and how were they used at KEKB* ?

The KEKB Collider (Tsukuba, Japan)



8 x 3.5 GeV
22 mrad crossing angle

World record:

$L = 2.1 \times 10^{34}/cm^2/sec$

Downtown Tsukuba, Izakayas

2008:

Critical Role of the B factories in the verification of the KM hypothesis was recognized and cited by the Nobel Foundation

A single irreducible phase in the weak interaction matrix accounts for most of the CPV observed in kaons and B’s.

CP violating effects in the B sector are O(1) rather than $O(10^{-3})$ as in the kaon system.

Exercise: In the Wolfenstein parameterization of the CKM matrix (e.g. see Zoltan Ligeti’s talk), where does this complex phase appear ?

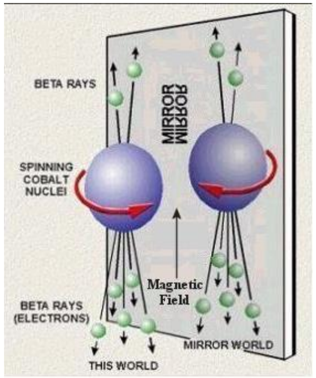
Exercise: if V_{ub} were zero, would there be any CP violation ? How is this exercise relevant to recent neutrino physics results ?

Exercise: Does V_{ts} have a CP violating phase in the KM model ? How is this tested experimentally ? With t quarks ? Or by some other means ?

Nobel Prizes from Surprising Discoveries about Weak Interactions of Quarks

T.D. Lee

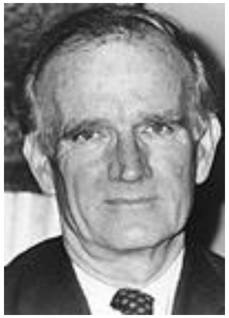
C.N. Yang



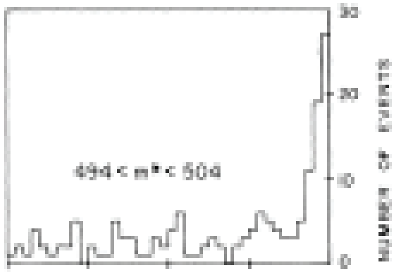
Maximal P violation

1957

J. Cronin



V. Fitch

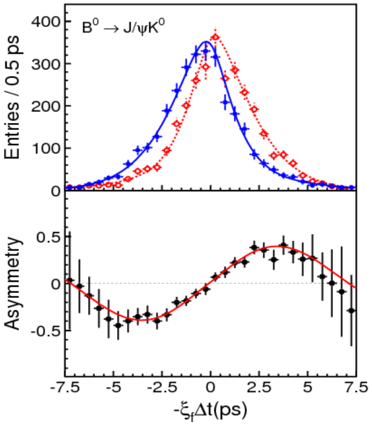


Small CP violation

1980

M. Kobayashi

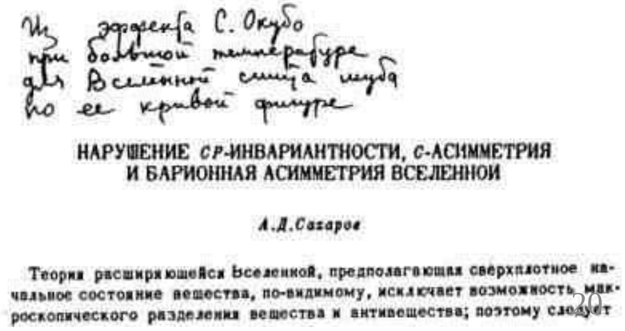
T. Maskawa



O(1) CP violation and 3 generations

2008

Are we done ? (Didn’t the B factories accomplish their mission, recognized by the 2008 Nobel Prize in Physics ?)



из эффекта С. Окубо
при большой температуре
для Вселенной сшита шуба
по ее кривой фигуре

НАРУШЕНИЕ *CP*-ИНВАРИАНТНОСТИ, *C*-АСИММЕТРИЯ
И БАРИОННАЯ АСИММЕТРИЯ ВСЕЛЕННОЙ

А.Д.Сахаров

Теория расширяющейся Вселенной, предполагающая сверхплотное начальное состояние вещества, по-видимому, исключает возможность макроскопического разделения вещества и антивещества; поэтому следует

BAU: KM (Kobayashi-Maskawa) mechanism still short by 10 orders of magnitude !!!

Super B Factory
a.k.a Super Flavor Factory

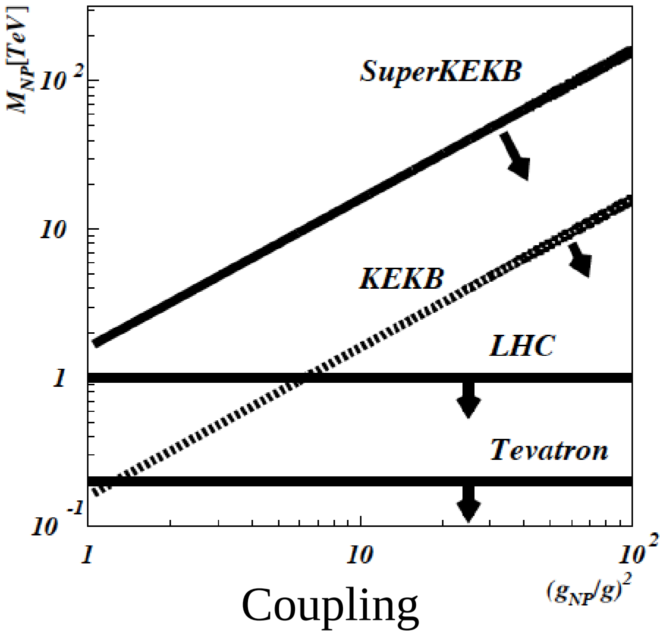
Why the SFF is so important.

A Super Flavor Factory (SFF) studies processes that are 1-loop in the SM but may be O(1) in NP : FCNC, mixing, CPV.

Current experimental bound is O(10-100) TeV depending on NP coupling. Thus if the LHC finds NP at O(1 TeV) it *must* have a non-trivial flavor structure.

Even if no new particles are found at the LHC, current SM couplings provide sensitivity to new particles at a SFF.

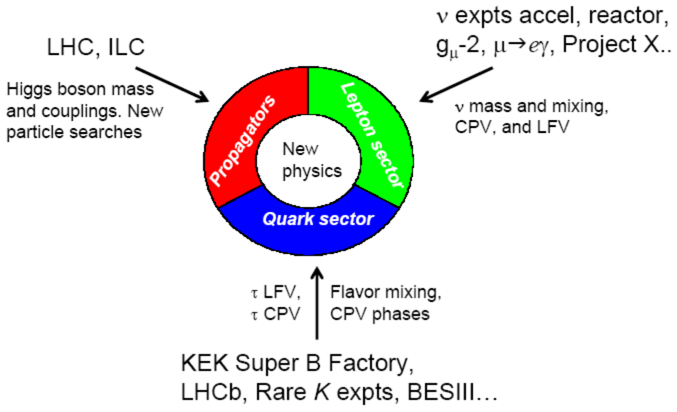
There must be new sources of CPV to explain the BAU *(Baryon Asymmetry of the Universe)*



Minimal Flavor Violating (MFV)

Enhanced Flavor coupling

The Super B Factory is part of a Unified and Unbiased Attack on New Physics



LHC, ILC

Higgs boson mass and couplings. New particle searches

ν expts accel, reactor, g_{μ}-2, $\mu\rightarrow e\gamma$, Project X..

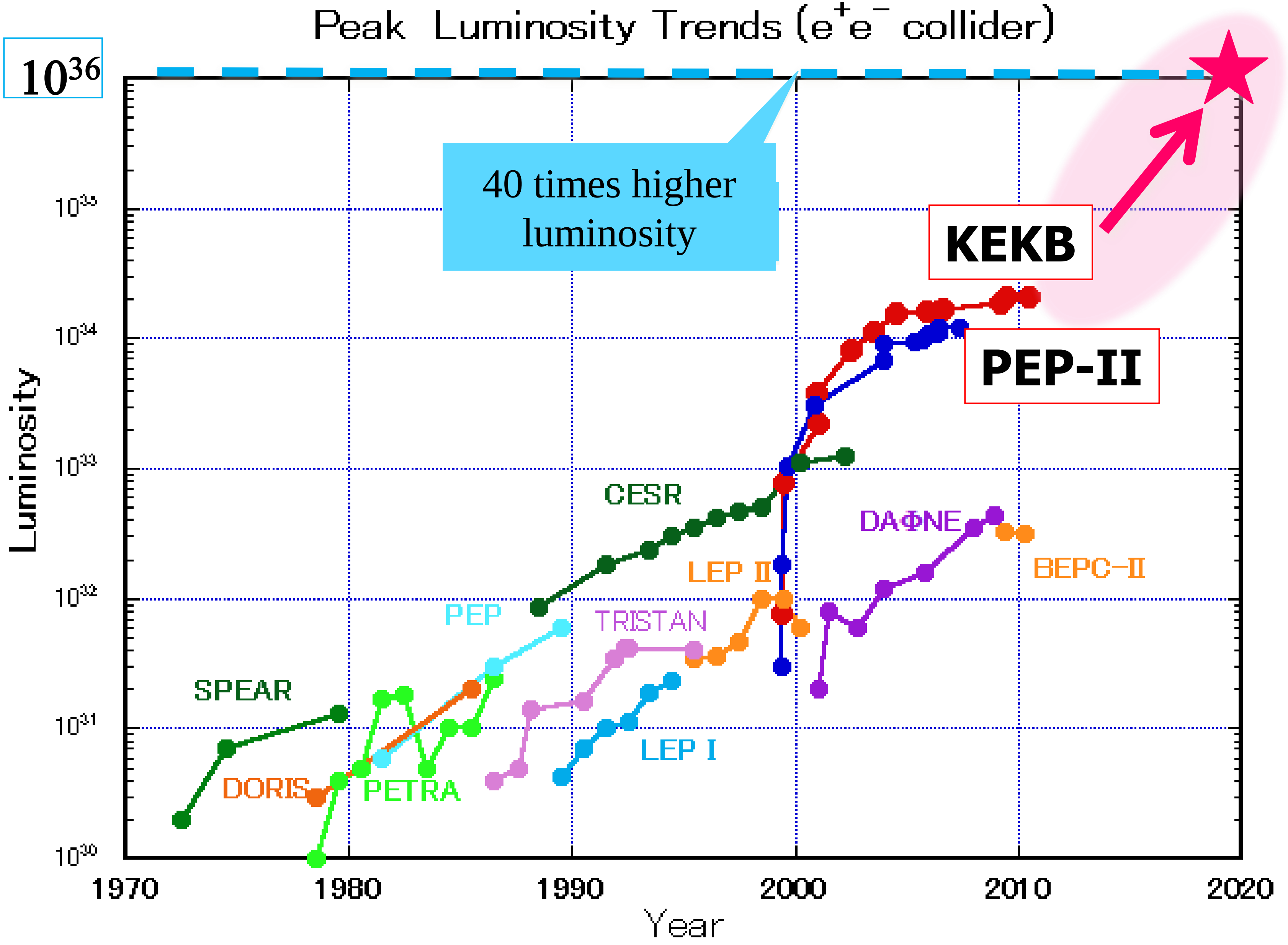
ν mass and mixing, CPV, and LFV

τ LFV, τ CPV

Flavor mixing, CPV phases

KEK Super B Factory, LHCb, Rare *K* expts, BESIII…

SuperKEKB is the e^+e^- intensity frontier

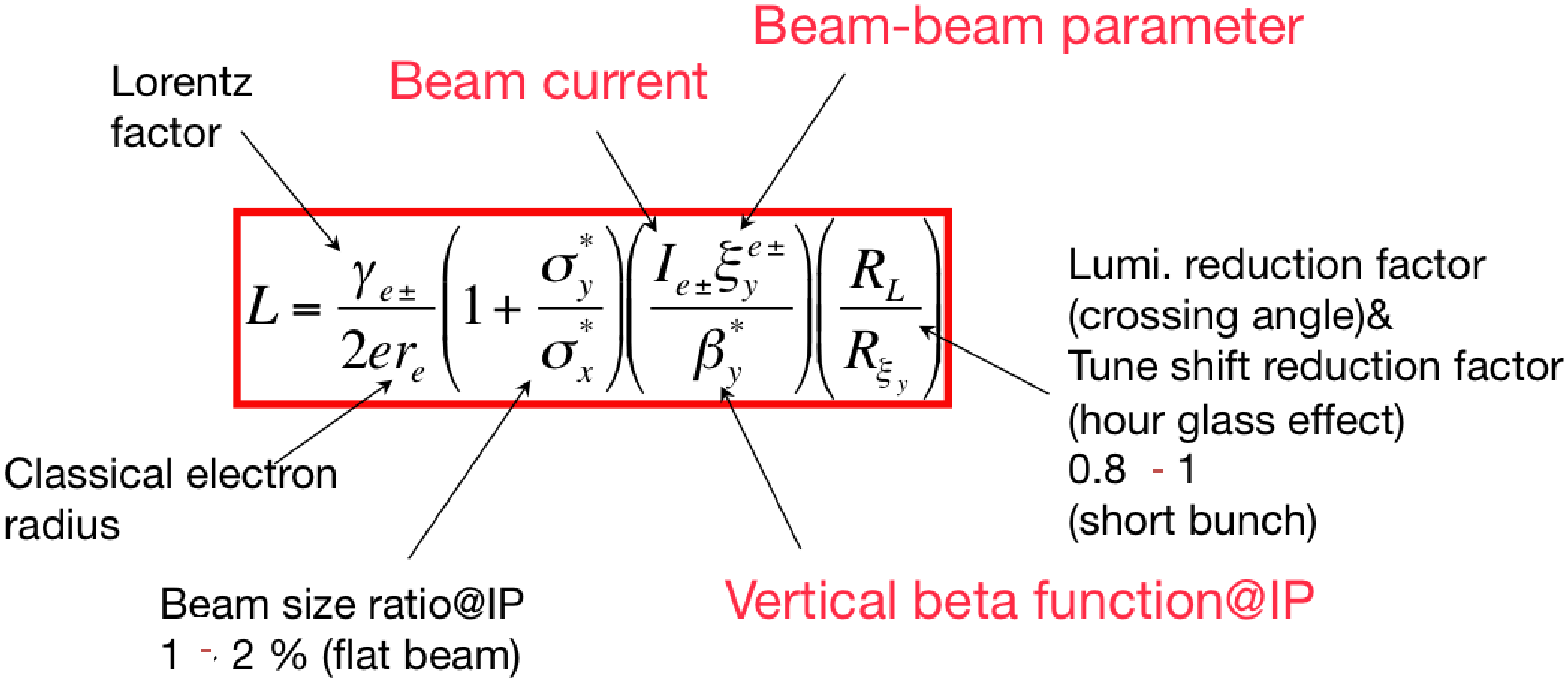


40 times higher luminosity

KEKB

PEP-II

Luminosity Master Equation



Beam-beam parameter

Lorentz factor

Beam current

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

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

Classical electron radius

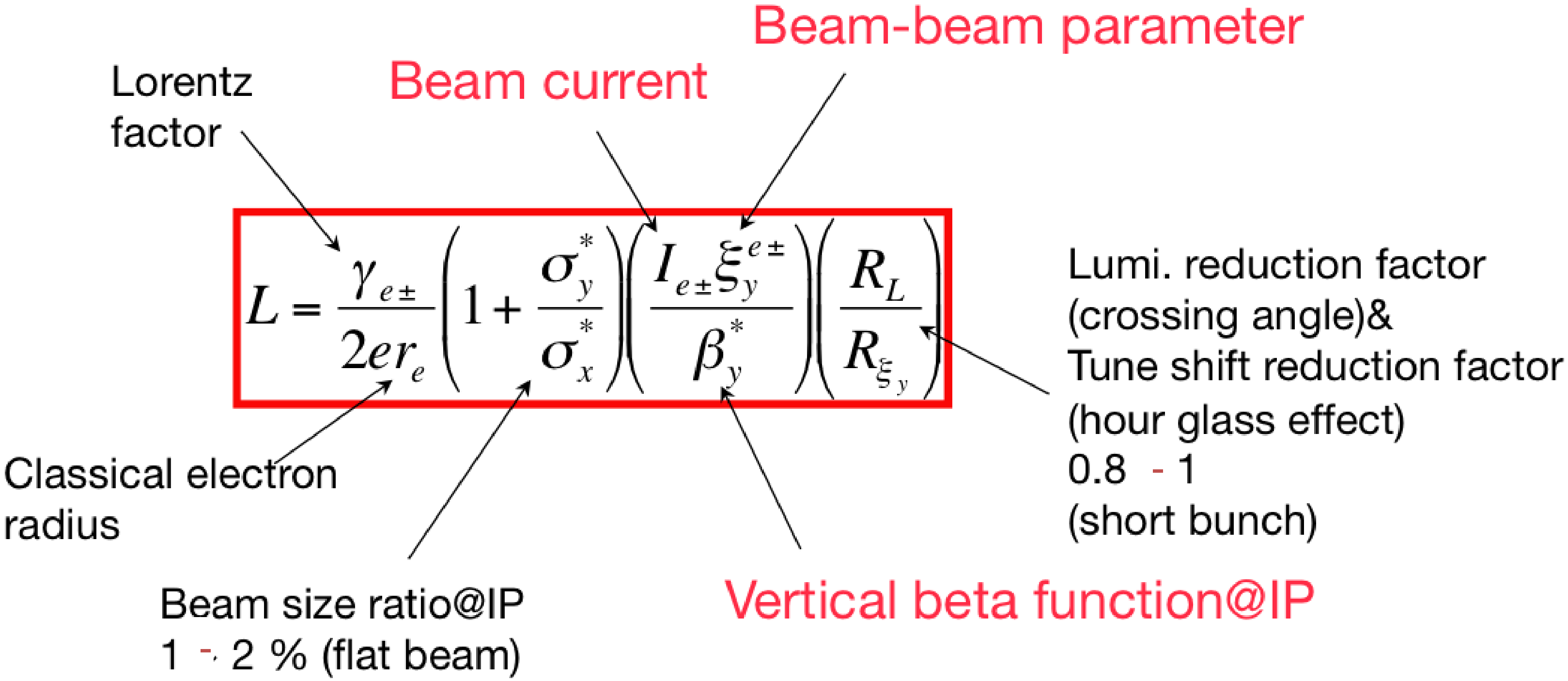
Beam size ratio@IP
1 - 2 % (flat beam)

Vertical beta function@IP

Brute force: Increase beam currents by a factor of 5-10 ! Increase the beam-beam parameter by a factor of a few (crab cavities).

Too hard, too expensive (power, melt beam pipes)

How to make a Super Flavor Factory



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

Lorentz factor

Beam current

Beam-beam parameter

Classical electron radius

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

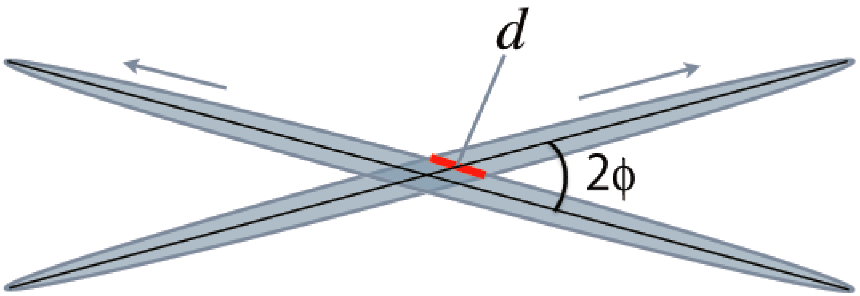
Vertical beta function@IP

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

(1) Smaller β_y^*

(2) Increase beam currents

(3) Increase ξ_y



Schematic view of beam collisions with a large, 83 mrad, crossing angle.

Compare the Parameters for KEKB and SuperKEKB

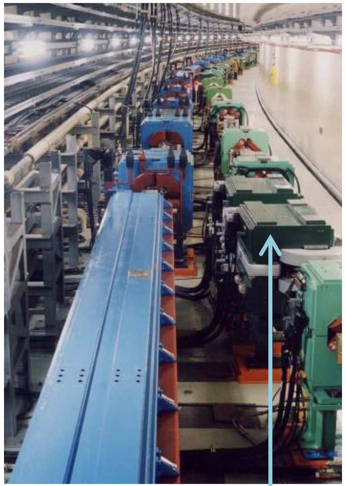
	KEKB Design	**KEKB Achieved : with crab**	**SuperKEKB Nano-Beam**
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	10/10	5.9/5.9	0.27/0.30
β_x^* (mm)	330/330	1200/1200	32/25
ε_x (nm)	18/18	18/24	3.2/5.3
$\varepsilon_y/\varepsilon_x$ (%)	1	0.85/0.64	0.27/0.24
σ_y(μm)	1.9	0.94	0.048/0.062
ξ_y	0.052	0.129/0.090	0.09/0.081
σ_z (mm)	4	6 - 7	6/5
I_{beam} (A)	2.6/1.1	1.64/1.19	3.6/2.6
$N_{bunches}$	5000	1584	2500
Luminosity (10^{34} cm^{-2} s^{-1})	1	2.11	80

Nano-beams are the key (vertical spot size is ~50nm !!)

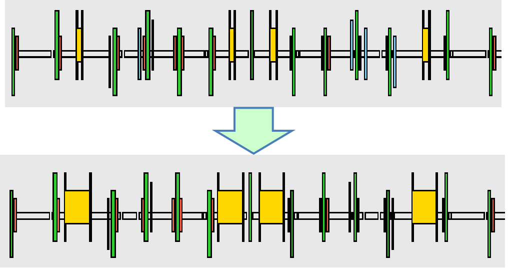
This is not a typo

Y. Ohnishi et al.

KEKB to SuperKEKB

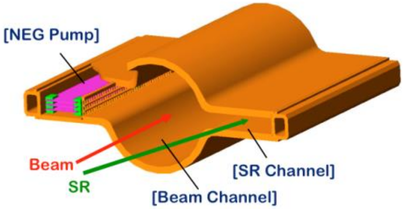


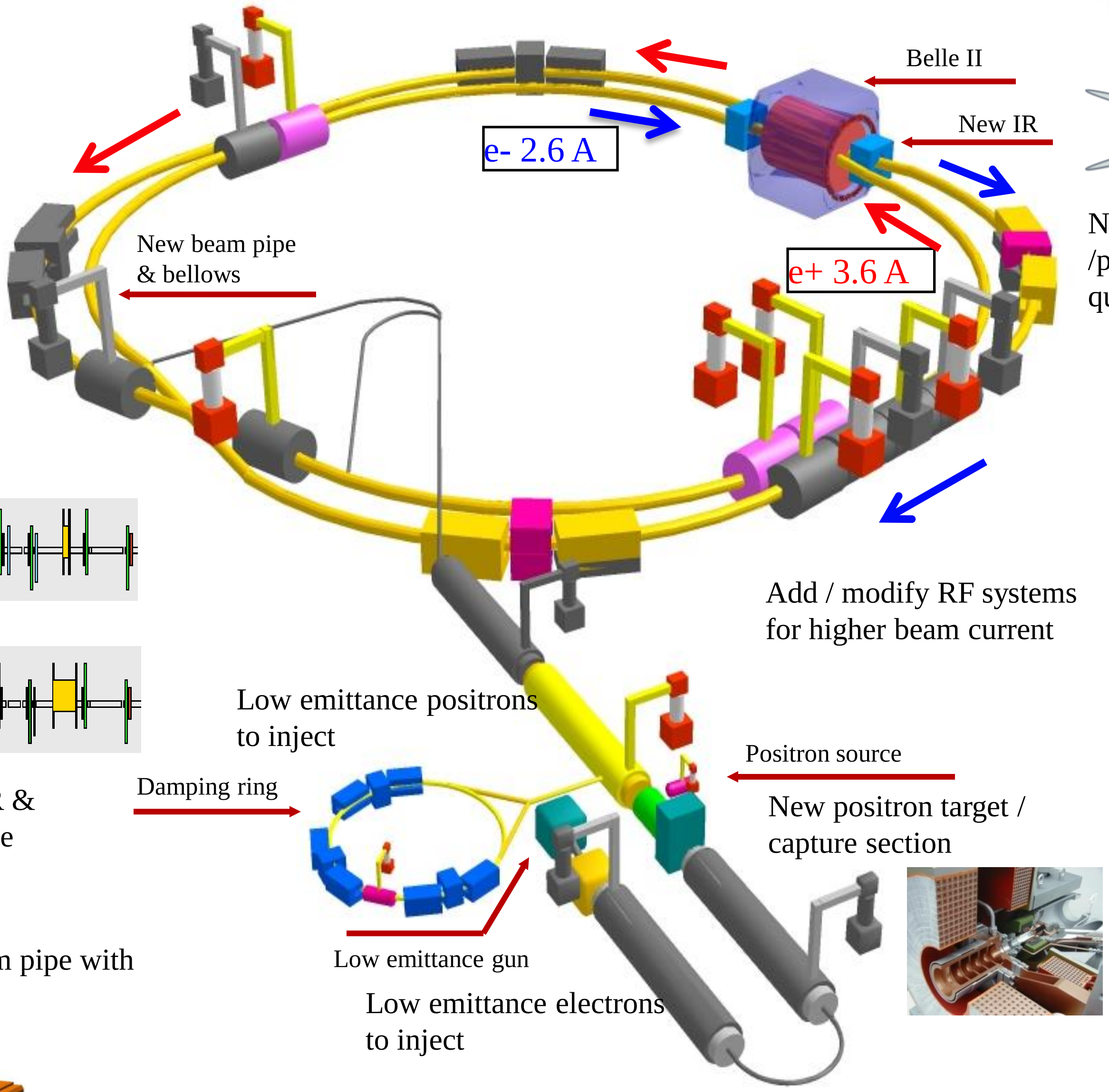
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe with antechambers





Belle II

New IR

e- 2.6 A

e+ 3.6 A

New beam pipe & bellows

Low emittance positrons to inject

Damping ring

Positron source

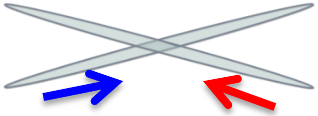
New positron target / capture section

Low emittance gun

Low emittance electrons to inject

Add / modify RF systems for higher beam current

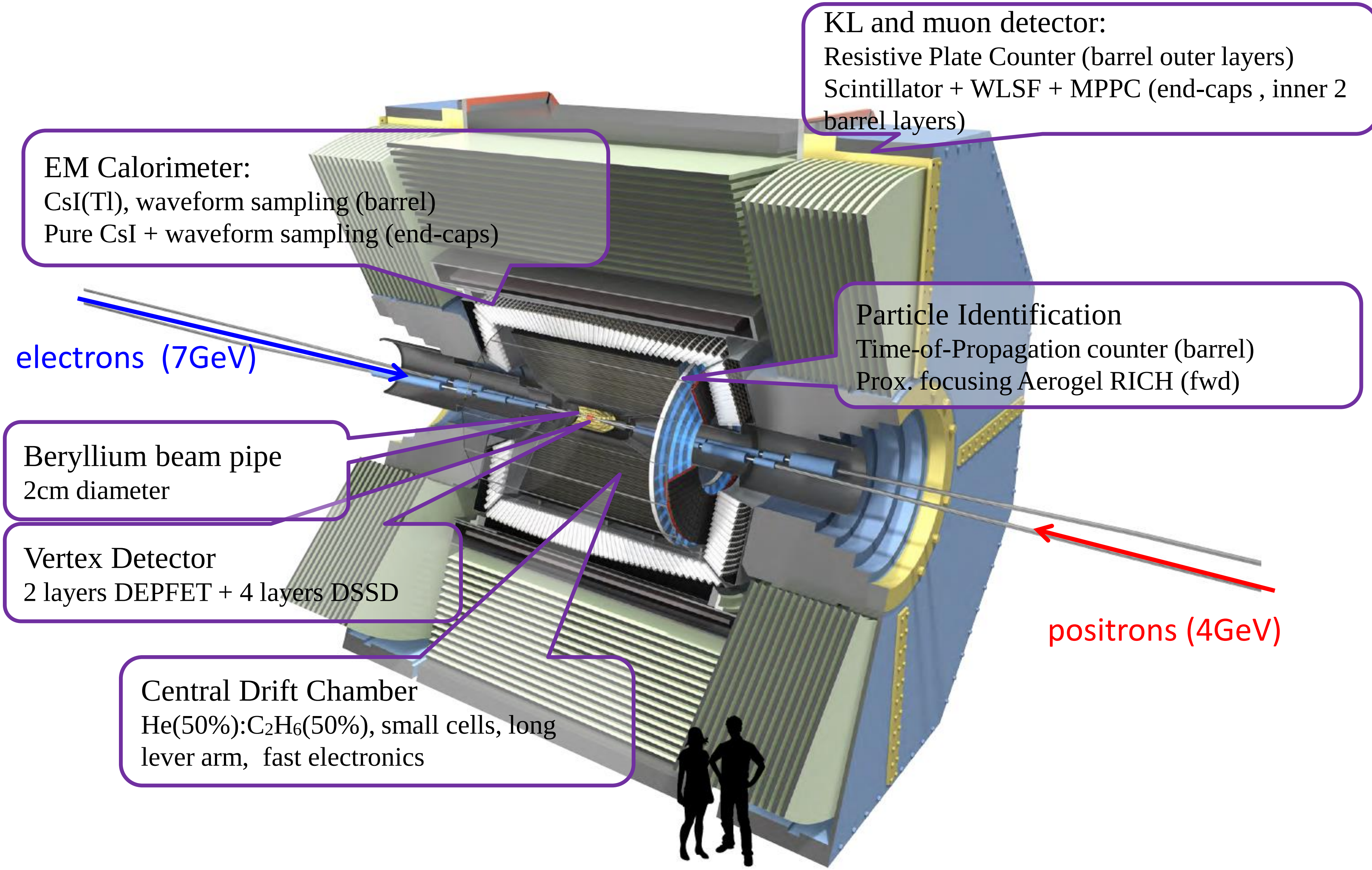
Colliding bunches



New superconducting /permanent final focusing quads near the IP

To obtain x40 higher luminosity

Belle II Detector



KL and muon detector:
Resistive Plate Counter (barrel outer layers)
Scintillator + WLSF + MPPC (end-caps , inner 2 barrel layers)

EM Calorimeter:
CsI(Tl), waveform sampling (barrel)
Pure CsI + waveform sampling (end-caps)

electrons (7GeV)

Particle Identification
Time-of-Propagation counter (barrel)
Prox. focusing Aerogel RICH (fwd)

Beryllium beam pipe
2cm diameter

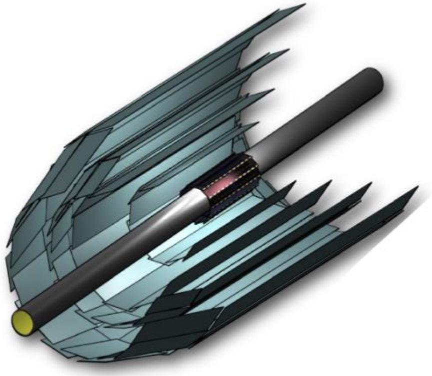
Vertex Detector
2 layers DEPFET + 4 layers DSSD

positrons (4GeV)

Central Drift Chamber
He(50%):C_2H_6(50%), small cells, long lever arm, fast electronics

Vertex Detector

DEPFET:
http://aldebaran.hll.mpg.de/twiki/bin/view/DEPFET/WebHome

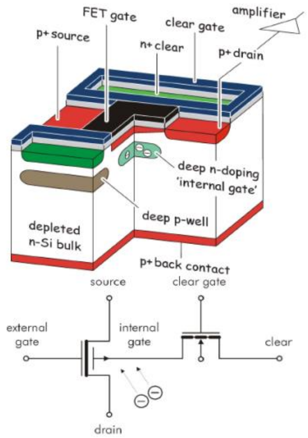


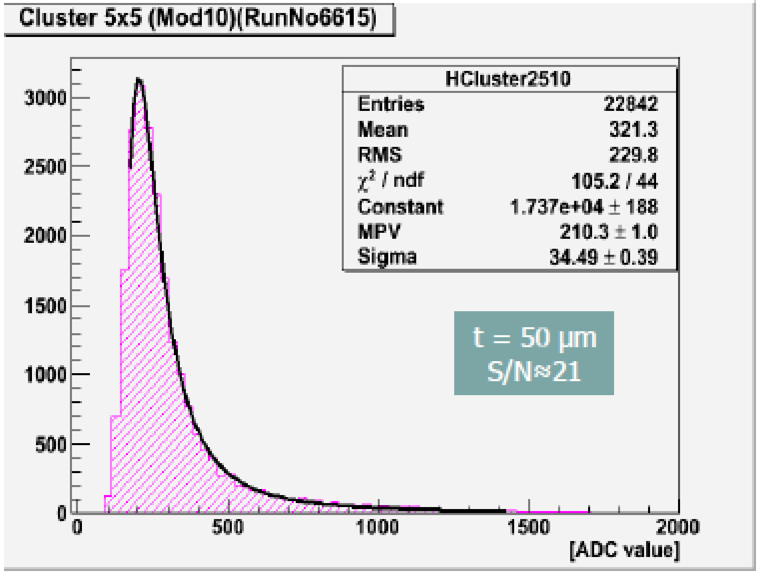
Beam Pipe		**r = 10mm**
DEPFET		
	Layer 1	**r = 14mm**
	Layer 2	**r = 22mm**
DSSD		
	Layer 3	**r = 38mm**
	Layer 4	**r = 80mm**
	Layer 5	**r = 115mm**
	Layer 6	**r = 140mm**

Mechanical mockup of pixel detector

DEPFET pixel sensor

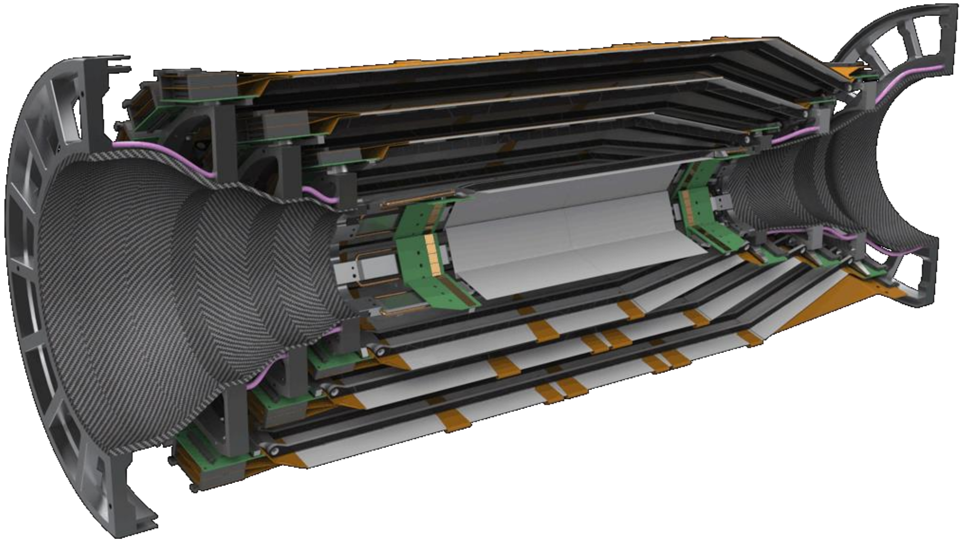
DEpleted P-channel FET

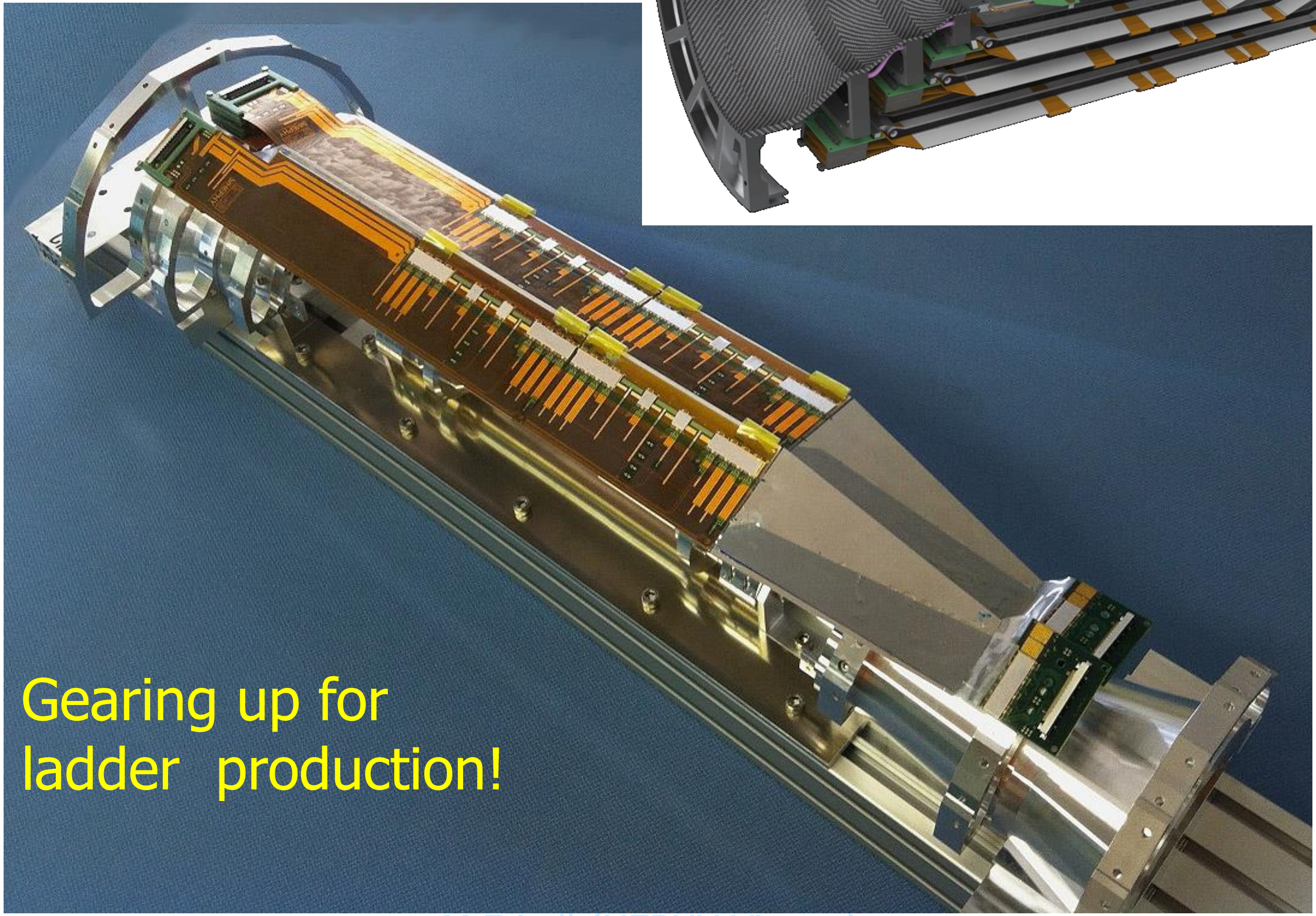




DEPFET sensor: very good S/N

SVD Mechani

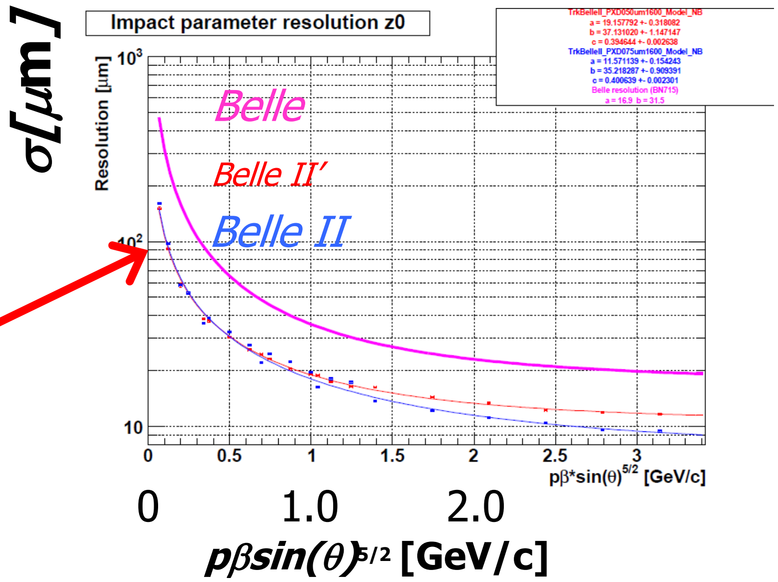




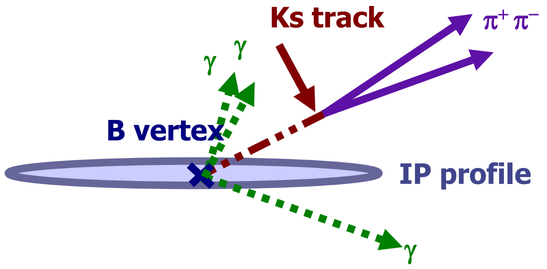
Gearing up for ladder production!

$$\sigma = a + \frac{b}{p\beta \sin^{\nu}\theta}$$

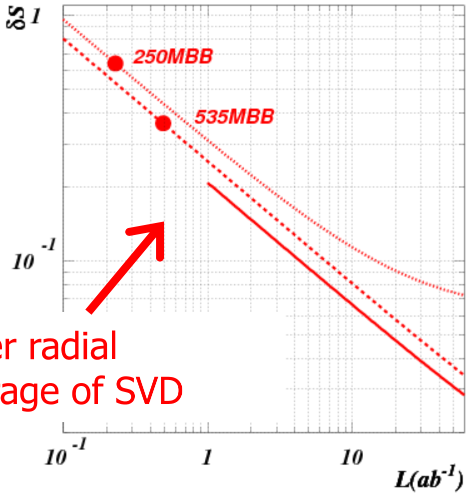
In e+e- scattering at 10-11 GeV, the critical issue for vertexing is multiple scattering



Significant improvement in $\Delta S(K_S\pi^0\gamma)$

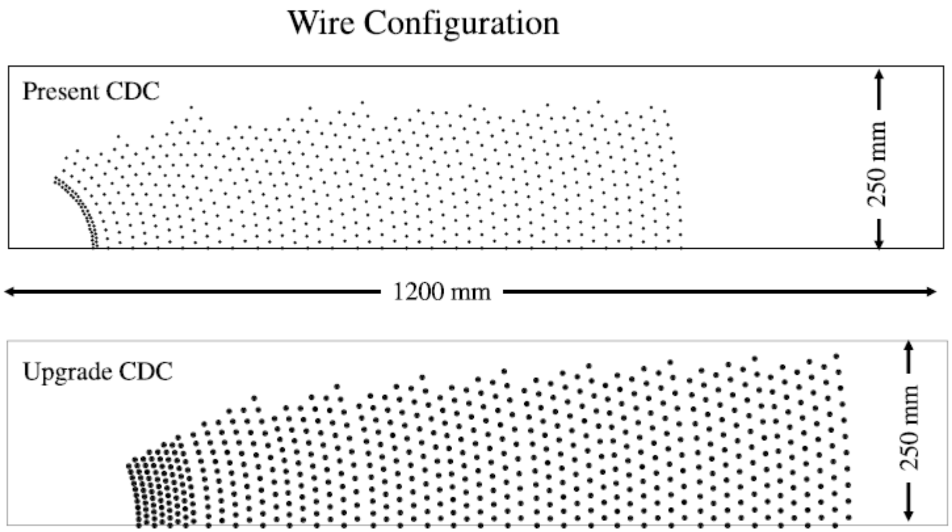


B decay point reconstruction with K_S trajectory

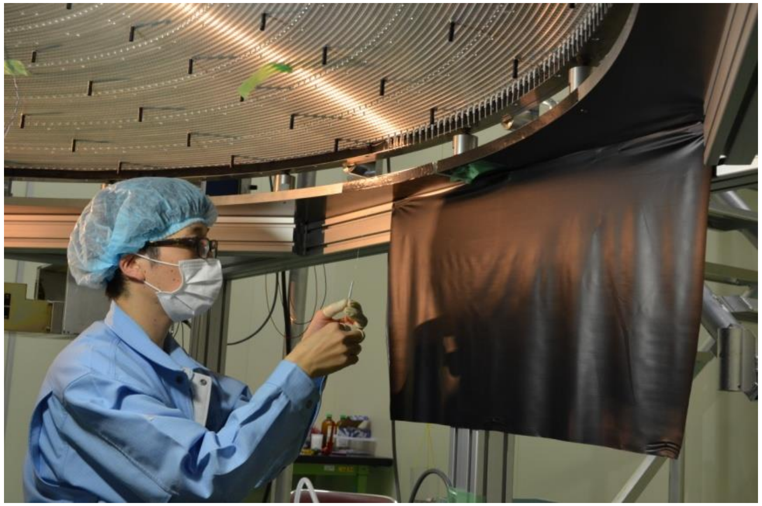


Larger radial coverage of SVD

Belle II Central Drift Chamber



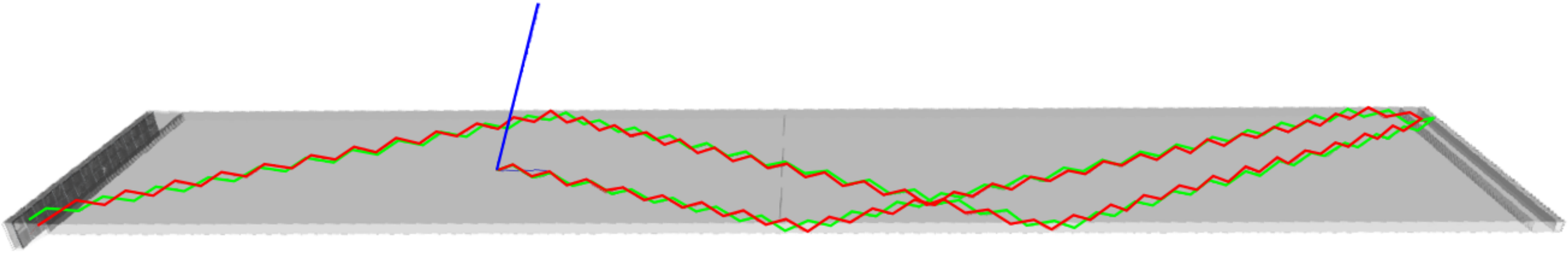
Much larger than in Belle!

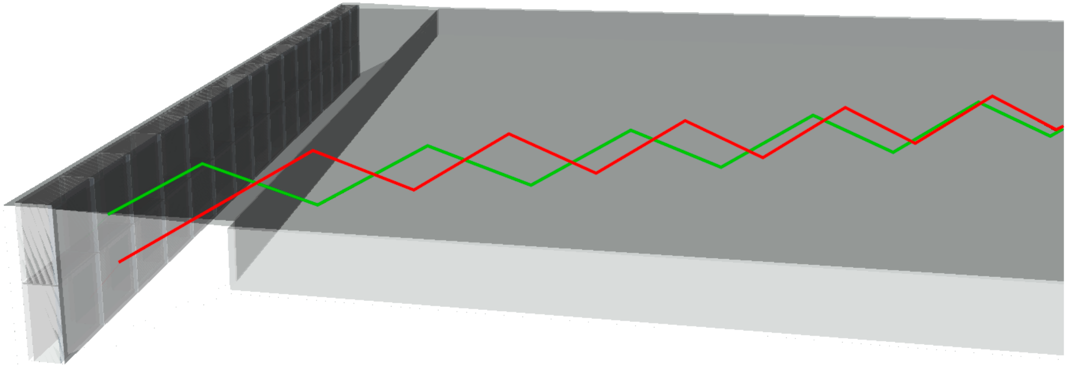


Wire stringing in a clean room

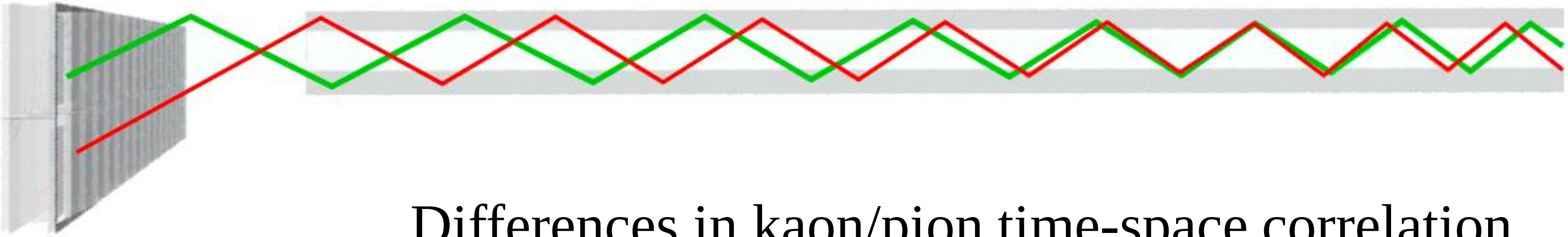
- thousands of wires,
- 1 year of work...

Kaon/Pion(s) in an iTOP GEANT4 simulation





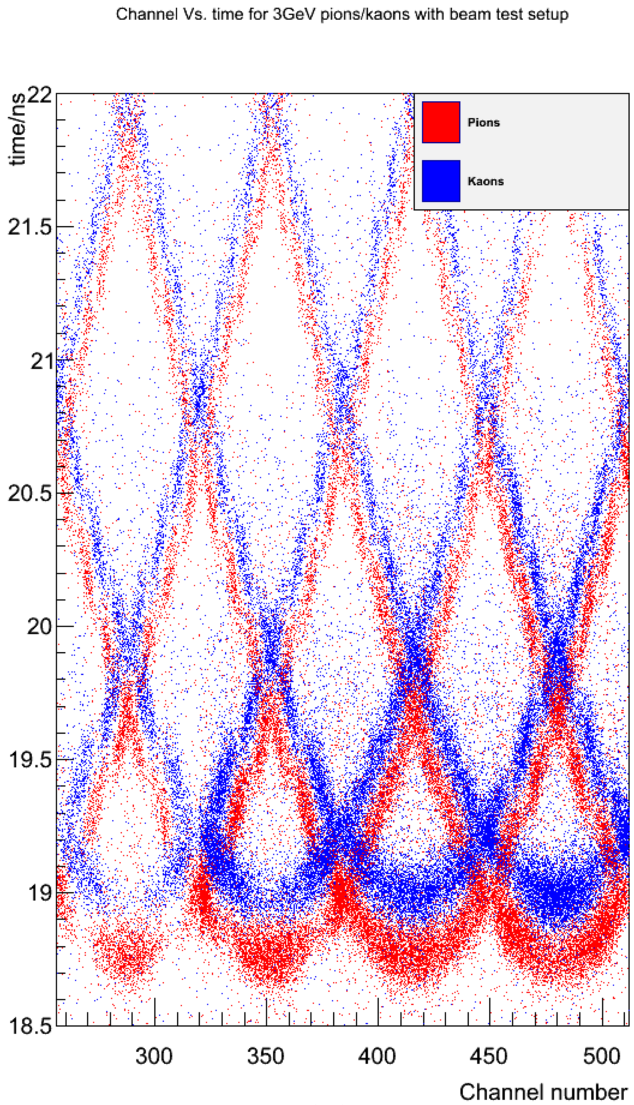
Based on total internal reflection of Cherenkov light.



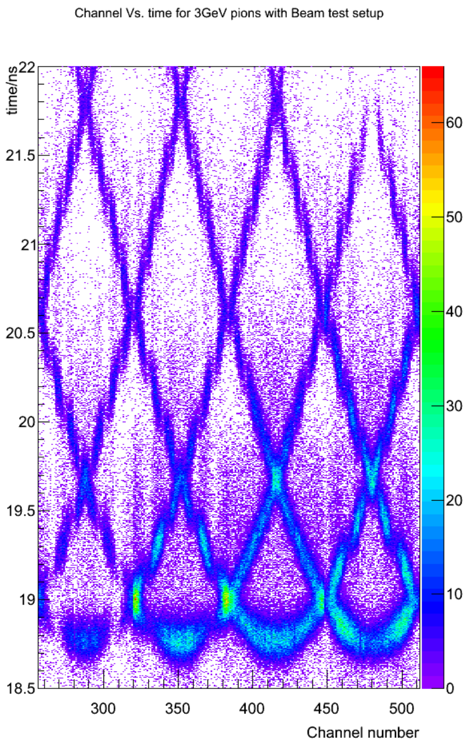
Differences in kaon/pion time-space correlation are used. (100 ps time resolution is needed for two-body modes)

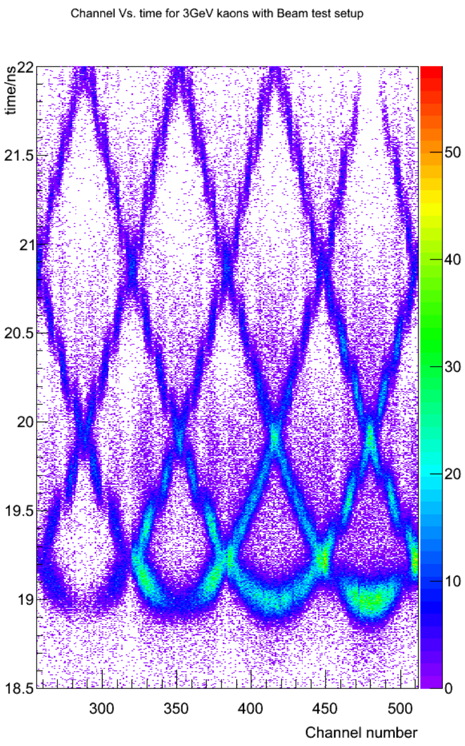
Kaons vs pions: distributions in the iTOP

Time in ns



X position





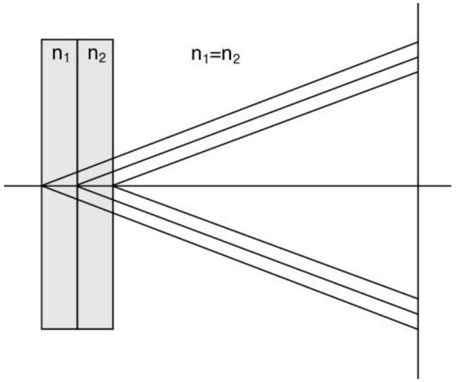
Matt Barrett

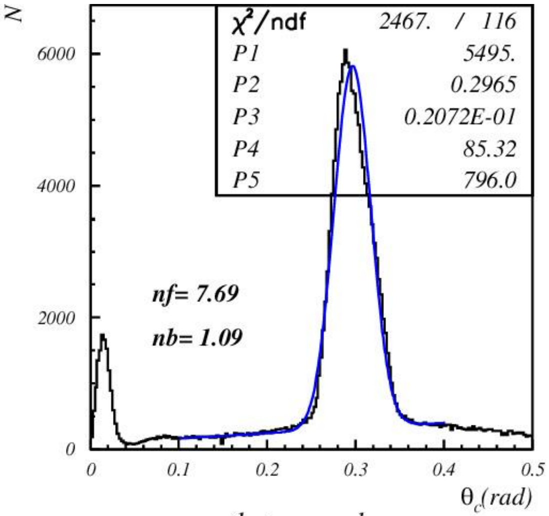
Forward endcap PID uses an aerogel ring imaging Cerenkov counter

Increases the number of photons without degrading the resolution

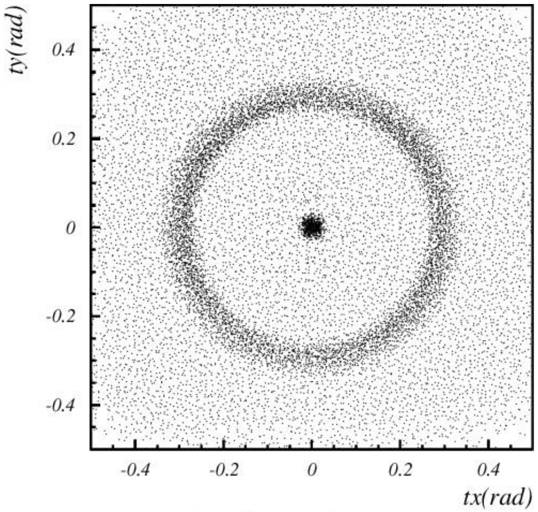
Data

4cm aerogel single index



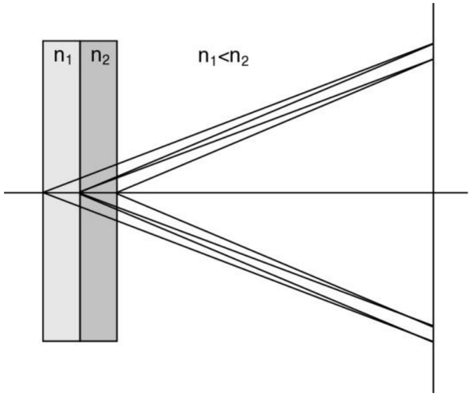


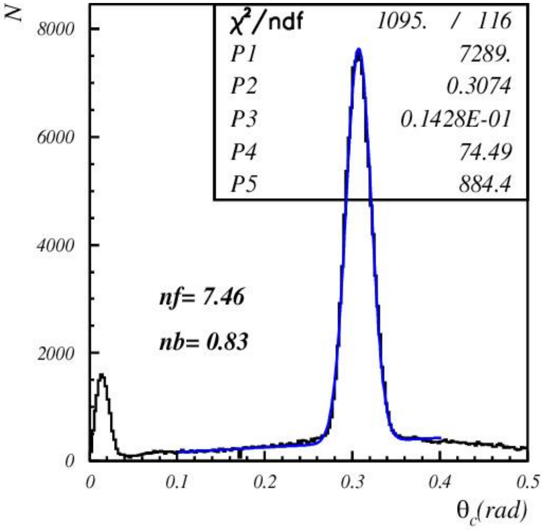
theta cerenkov

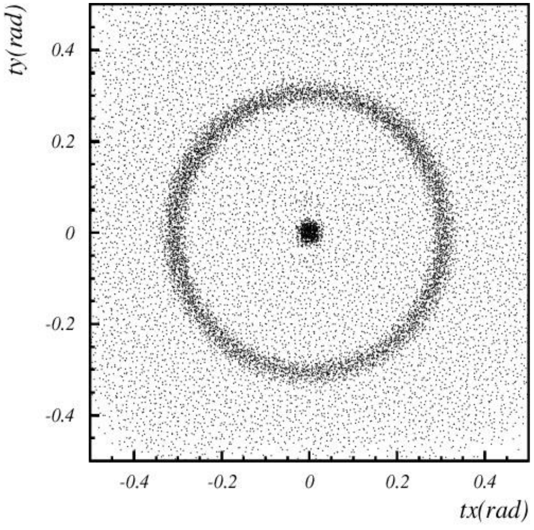


ring in cerenkov space

2+2cm aerogel







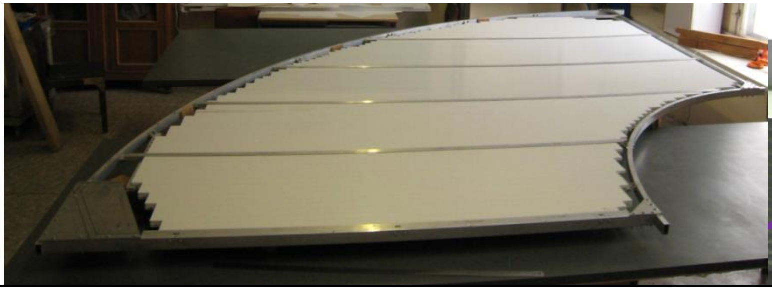
→NIM A548 (2005) 383

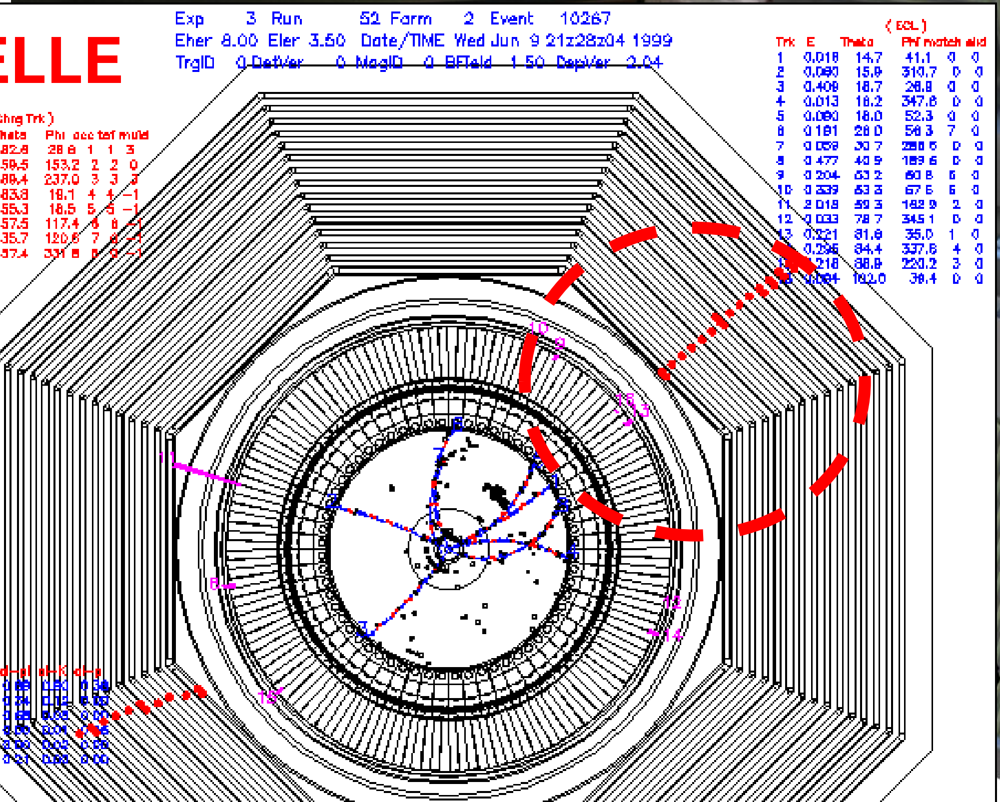
Detection of muons and KLs: Endcap RPCs and two layers of the barrel have to be replaced with scintillators to handle higher backgrounds (mainly from neutrons).

K_L and muon detector:

Resistive Plate Counter (barrel)

Scintillator + WLSF + MPPC (end-caps + barrel 2 inner layers)

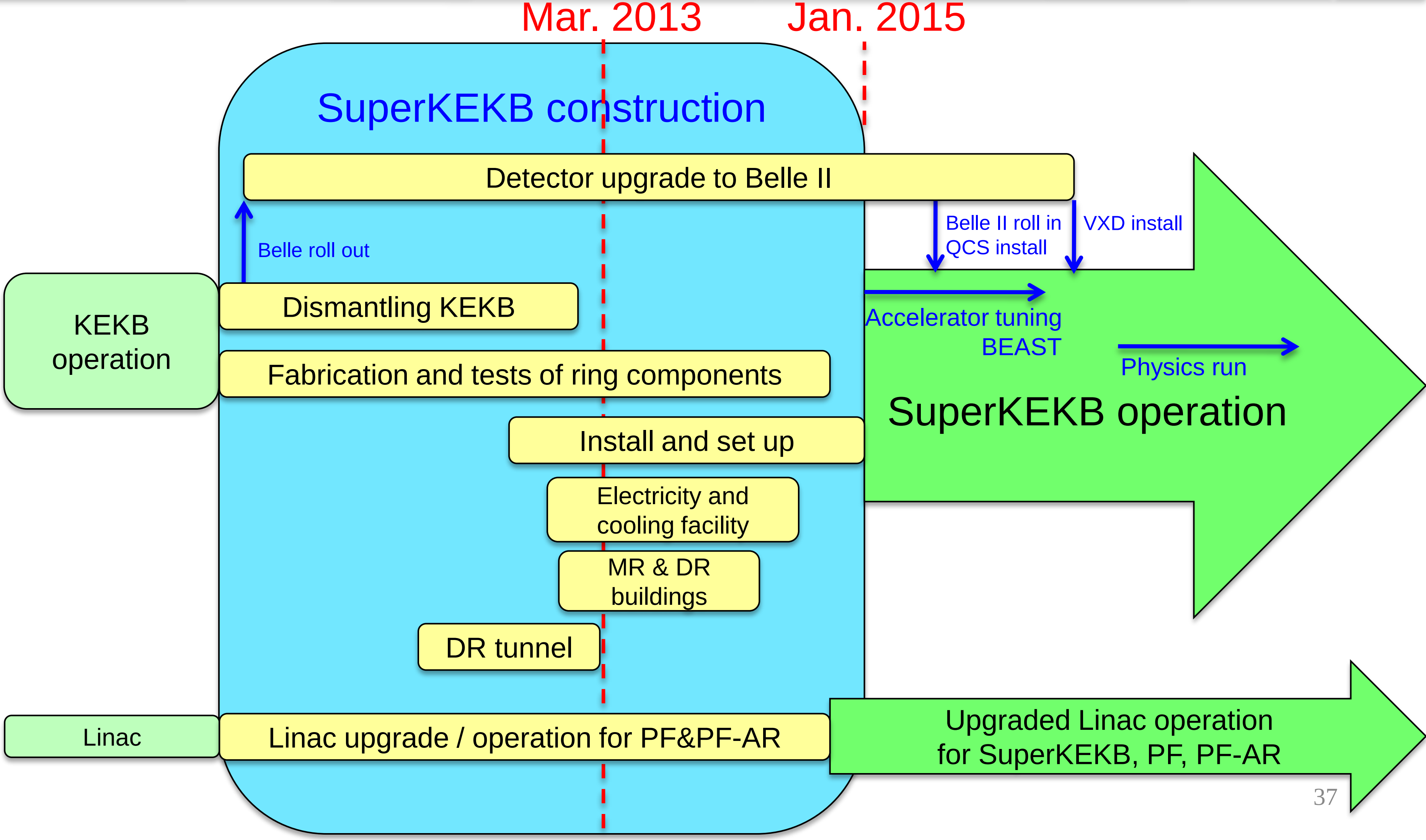




Detectors to be installed this fall and in spring 2014

SuperKEKB/Belle II schedule

Calendar	2010	2011	2012	2013	2014	2015	2016	2017	· · ·
Japan FY	2010	2011	2012	2013	2014	2015	2016	2017	· ·



Mar. 2013

Jan. 2015

SuperKEKB construction

Detector upgrade to Belle II

Belle roll out

Belle II roll in
QCS install

VXD install

KEKB
operation

Dismantling KEKB

Fabrication and tests of ring components

Install and set up

Electricity and
cooling facility

MR & DR
buildings

DR tunnel

Accelerator tuning
BEAST

Physics run

SuperKEKB operation

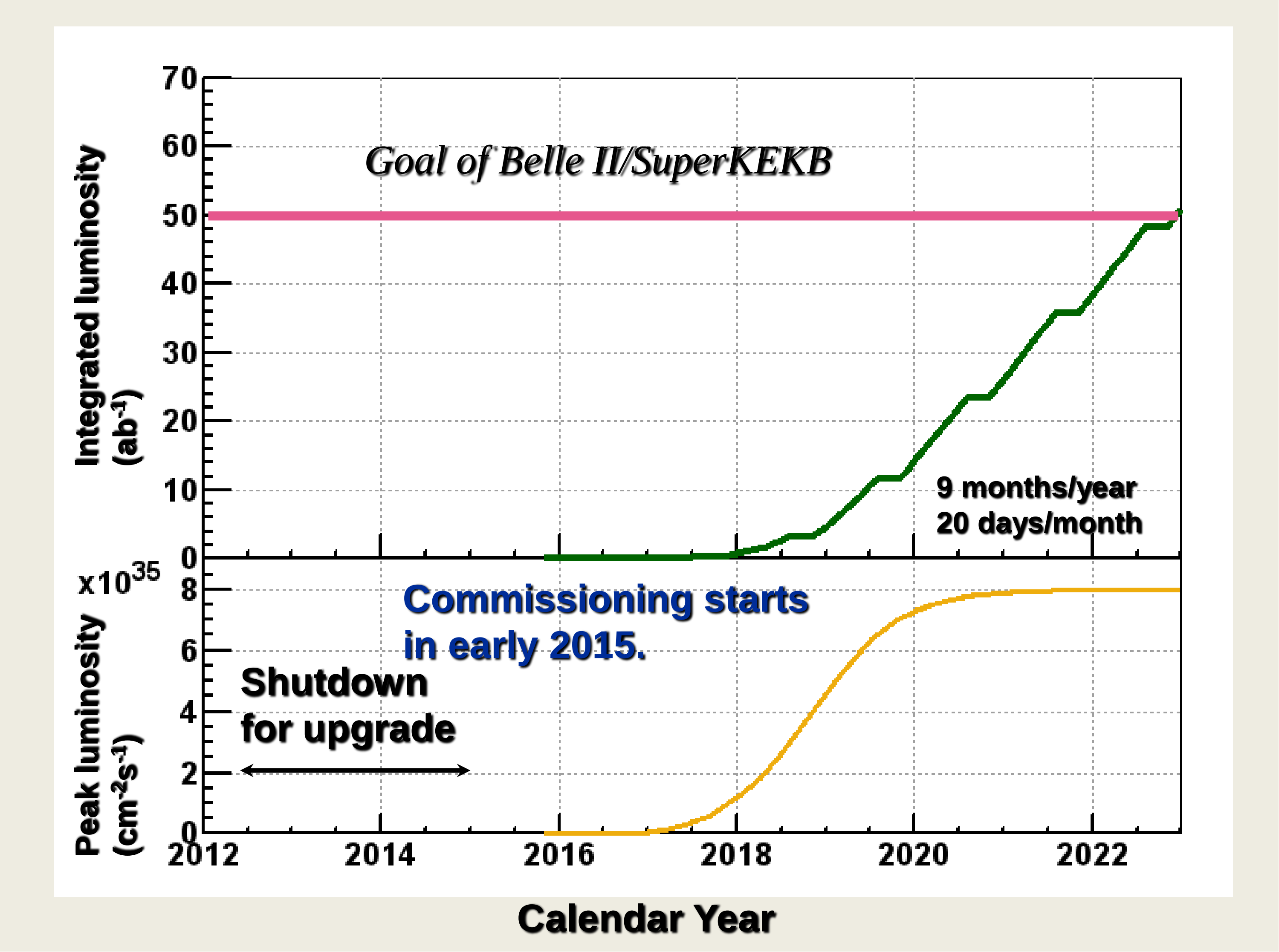
Linac

Linac upgrade / operation for PF&PF-AR

Upgraded Linac operation
for SuperKEKB, PF, PF-AR

SuperKEKB luminosity projection

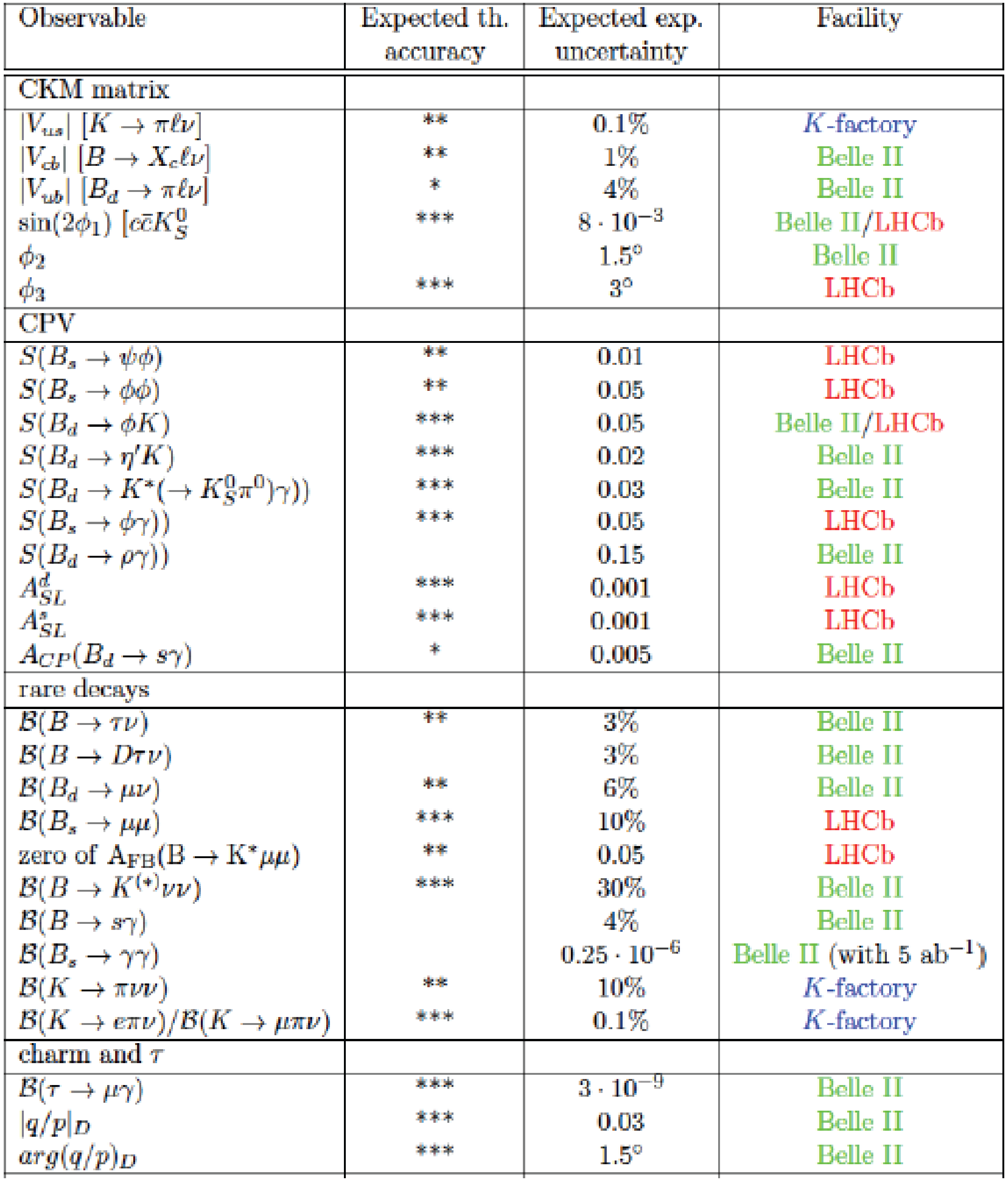
Belle/KEKB recorded ~1000 fb^{-1} . Now change units to ab^{-1}



Physics at the Super Flavor Factory

Complementarity of Belle II SFF physics reach and LHCb upgrade

Hard to reduce this table of diverse physics capabilities to a simple and memorable message.

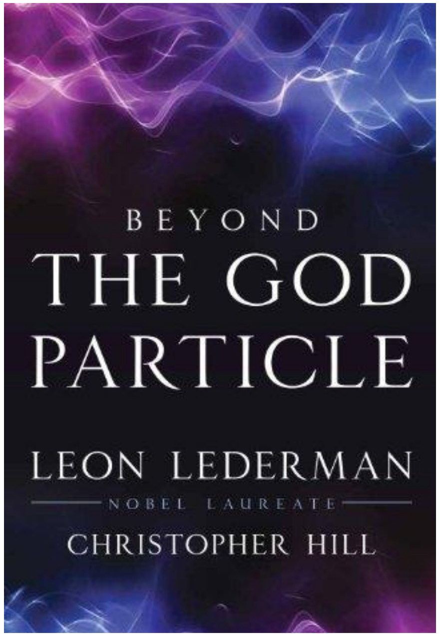


Observable	Expected th. accuracy	Expected exp. uncertainty	Facility
CKM matrix			
$\lvert V_{us}\rvert$ $[K \to \pi \ell \nu]$	**	0.1%	K-factory
$\lvert V_{cb}\rvert$ $[B \to X_c \ell \nu]$	**	1%	Belle II
$\lvert V_{ub}\rvert$ $[B_d \to \pi \ell \nu]$	*	4%	Belle II
$\sin(2\phi_1)$ $[c\bar{c}K_S^0$	***	$8 \cdot 10^{-3}$	Belle II/LHCb
ϕ_2		1.5°	Belle II
ϕ_3	***	3°	LHCb
CPV			
$S(B_s \to \psi\phi)$	**	0.01	LHCb
$S(B_s \to \phi\phi)$	**	0.05	LHCb
$S(B_d \to \phi K)$	***	0.05	Belle II/LHCb
$S(B_d \to \eta' K)$	***	0.02	Belle II
$S(B_d \to K^*(\to K_S^0\pi^0)\gamma))$	***	0.03	Belle II
$S(B_s \to \phi\gamma))$	***	0.05	LHCb
$S(B_d \to \rho\gamma))$		0.15	Belle II
A_{SL}^d	***	0.001	LHCb
A_{SL}^s	***	0.001	LHCb
$A_{CP}(B_d \to s\gamma)$	*	0.005	Belle II
rare decays			
$\mathcal{B}(B \to \tau\nu)$	**	3%	Belle II
$\mathcal{B}(B \to D\tau\nu)$		3%	Belle II
$\mathcal{B}(B_d \to \mu\nu)$	**	6%	Belle II
$\mathcal{B}(B_s \to \mu\mu)$	***	10%	LHCb
zero of $\mathrm{A_{FB}}(\mathrm{B} \to \mathrm{K}^*\mu\mu)$	**	0.05	LHCb
$\mathcal{B}(B \to K^{(*)}\nu\nu)$	***	30%	Belle II
$\mathcal{B}(B \to s\gamma)$		4%	Belle II
$\mathcal{B}(B_s \to \gamma\gamma)$		$0.25 \cdot 10^{-6}$	Belle II (with 5 ab^{-1})
$\mathcal{B}(K \to \pi\nu\nu)$	**	10%	K-factory
$\mathcal{B}(K \to e\pi\nu)/\mathcal{B}(K \to \mu\pi\nu)$	***	0.1%	K-factory
charm and τ			
$\mathcal{B}(\tau \to \mu\gamma)$	***	$3 \cdot 10^{-9}$	Belle II
$\lvert q/p\rvert_D$	***	0.03	Belle II
$arg(q/p)_D$	***	1.5°	Belle II

Based on a slide from B. Golob

The Higgs boson is now established by experimental results from ATLAS and CMS.

.



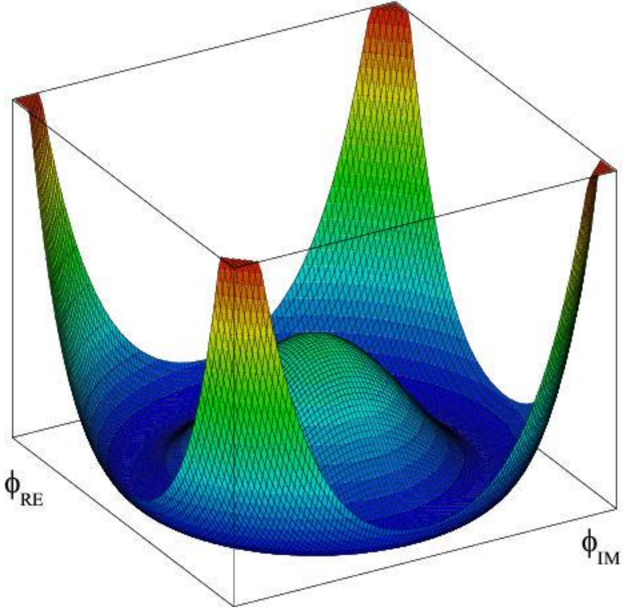
BEYOND THE GOD PARTICLE

LEON LEDERMAN

NOBEL LAUREATE

CHRISTOPHER HILL

Does the GP have a “brother” i.e. the charged Higgs ?



Measurements at a “Super B factory” and direct searches at hadron colliders take complementary approaches to this important question.

Extended Higgs sector ?

The Higgs boson should have not only relatives: $\tilde{t},\ \tilde{b},\ \tilde{H}^{\pm,0};\ \ T',$

But also siblings: $H_i^0,\ A_j^0,\ H^{\pm},\ H^{\pm\pm},\ldots.$

- Two Higgs Doublet Model (2HDM):
  rich phenomenology, Type II SUSY option

Haber, 2012
Branco, Ferreira, Rebelo,
Sher, Silva, arXiv:1106.0034;
Coleppa, Kling, Su, arXiv:1305.0002.

- Plus a singlet:
  NMSSM, solve the μ-problem, relax fine-tune, light DM.

Ellwanger, Gunion et al., 2012
S. King et al., 2012
R. Barbieri et al., 2013, ……

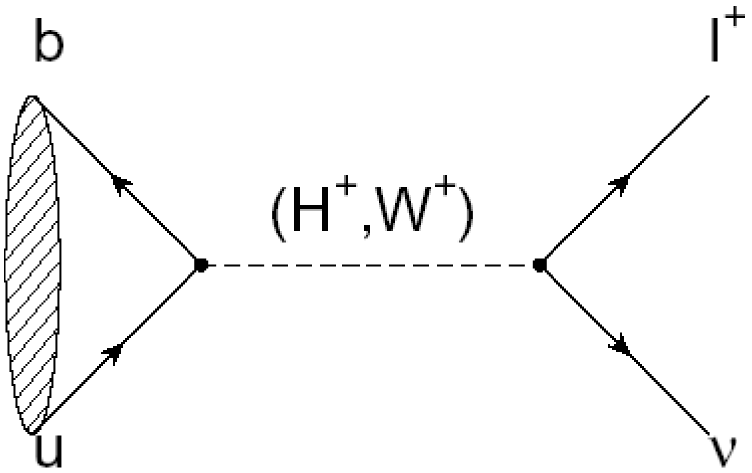
- Triplet Model:
  m_ν , L-R symmetric theories, LH …

Slide from a review by theory professor Tao Han at the Lepton-Photon Symposium two weeks ago.

$B^+ \to \tau^+ \nu_\tau$

(Decays with *Large* Missing Energy)

Sensitivity to new physics from a <u>*charged Higgs*</u>



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

$$\mathcal{B}_{(B\to\tau\nu)} = \mathcal{B}_{SM} \times \left(1 - \tan^2\beta \frac{m_{B^\pm}^2}{m_{H^\pm}^2}\right)$$

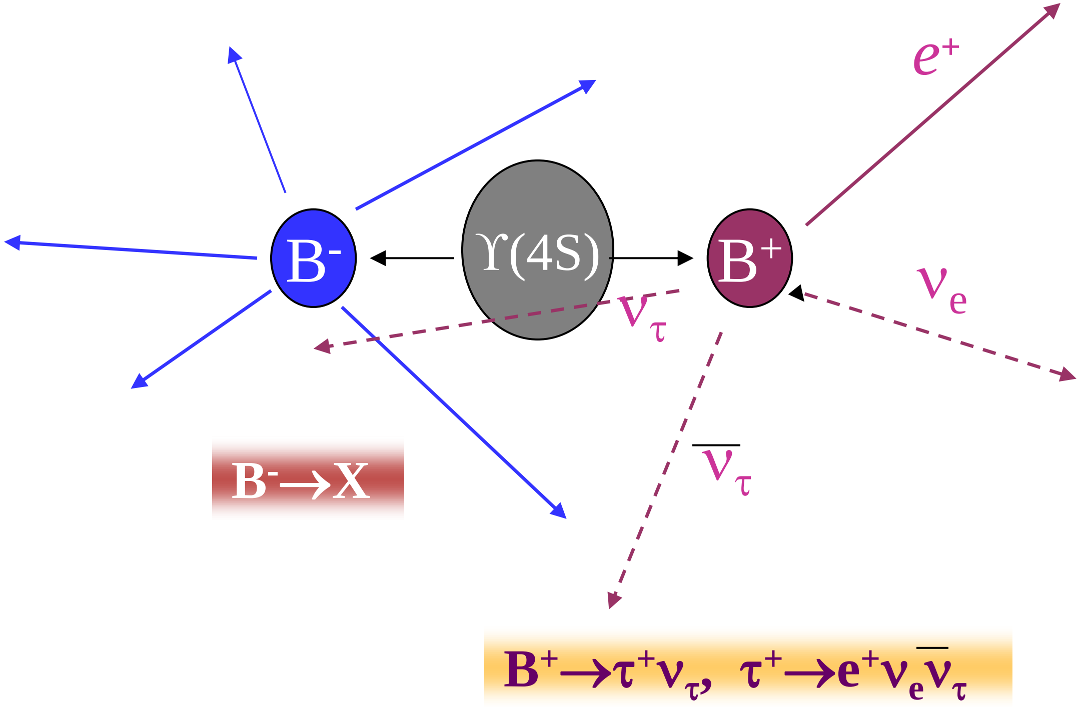
The B meson decay constant, determined by the B wavefunction at the origin

($|V_{ub}|$ taken from indep. measurements.)

Consumer’s guide to charged Higgs

- *Higgs doublet of type I* (couples with equal strength to upper and lower generations)
- *Higgs doublet of type II* (couples with different strength to u and d-type quarks, tan(β) = v_u/v_d (favored NP scenario e.g. MSSM)
- *Higgs doublet of type III* (not type I or type II; anything goes)

Why measuring $B \to \tau\nu$ is non-trivial



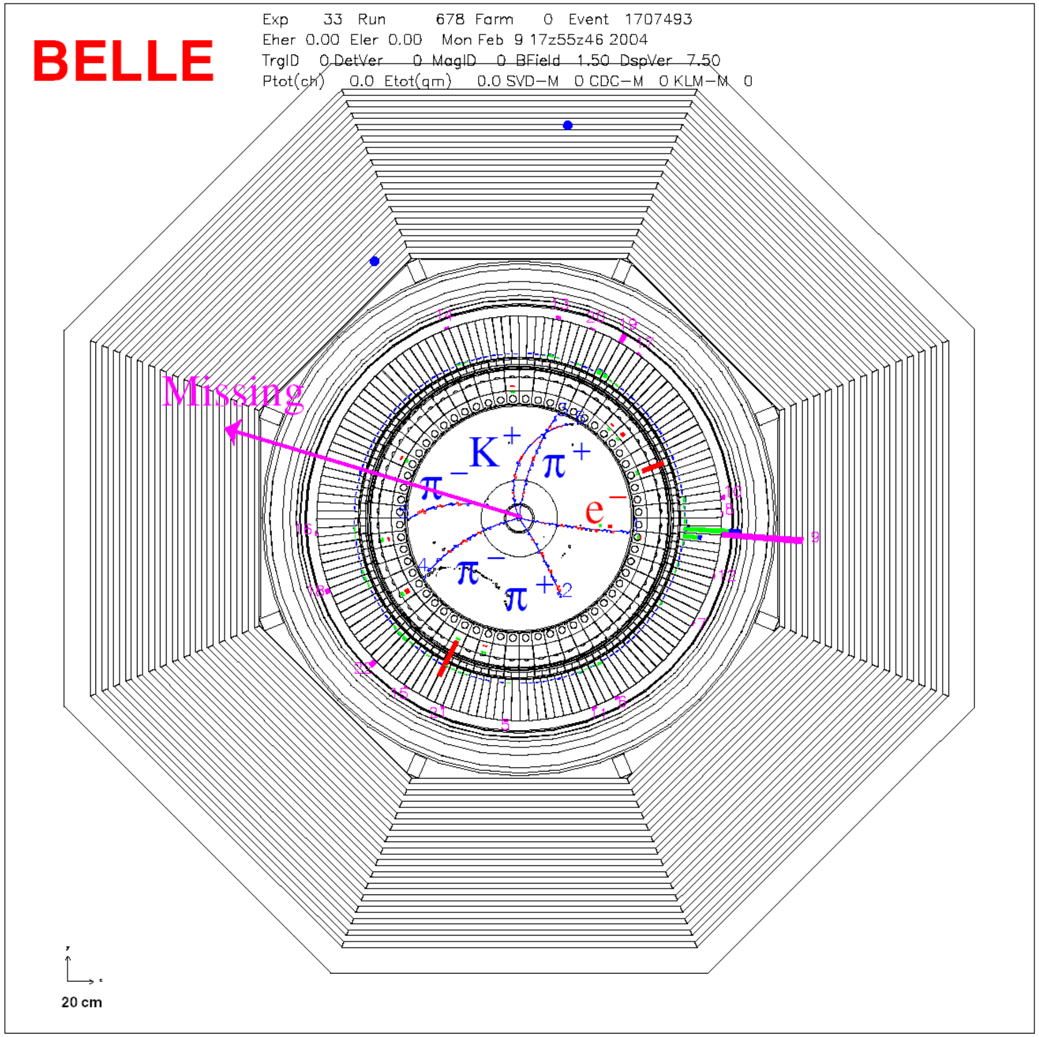
Most of the sensitivity is from tau modes with 1-prong

The experimental signature is rather difficult:
B decays to a single charged track + nothing

(This will be difficult at a hadron collider)

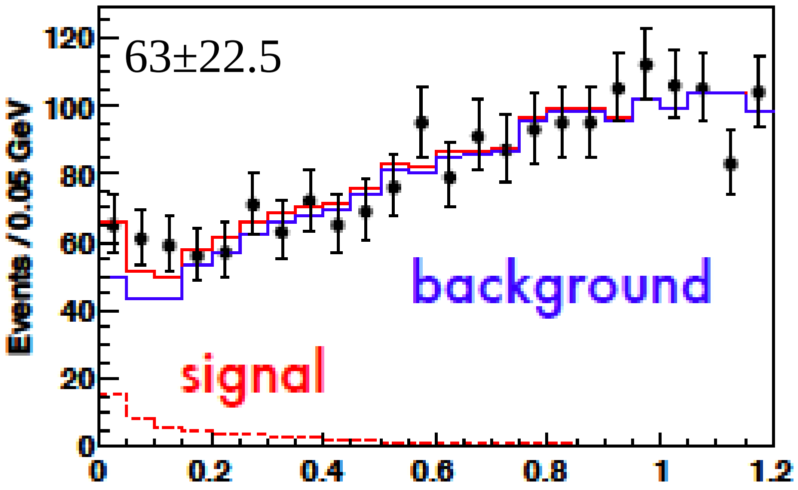
Example of a Missing Energy Decay ($B^- \rightarrow \tau^- \nu_\tau$) in Data

$$
\begin{aligned}
B^+ &\to D^0\pi^+ \\
&\quad (\to K\pi^-\pi^+\pi^-) \\
B^- &\to \tau(\to e\nu\bar{\nu})\nu
\end{aligned}
$$



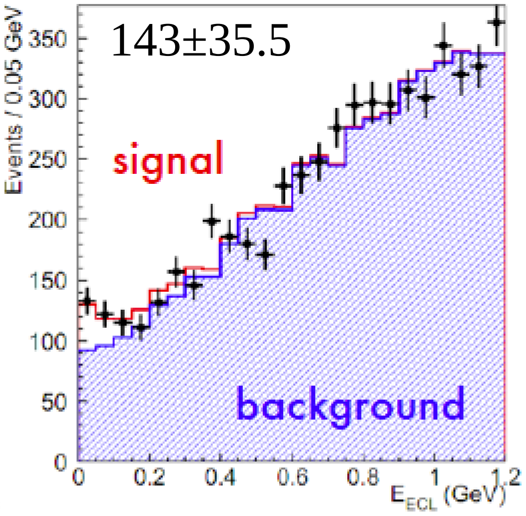
The clean e+e- environment makes this possible

Belle measurement with full data sample and hadronic tags



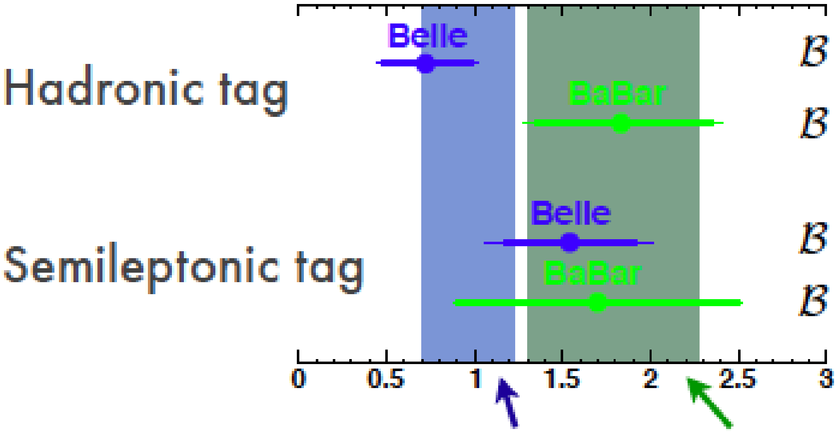
Idea: With the "single B meson beam", we look for a single track from a τ, missing energy/momentun and extra calorimeter energy close to zero.

Semileptonic tags



With the full B factory statistics only "evidence". No single observation.

The horizontal axis is the "Extra Calorimeter Energy"



$$\mathcal{B} = [0.72^{+0.27}_{-0.25}(\mathrm{stat}) \pm 0.11(\mathrm{syst})] \times 10^{-4}$$

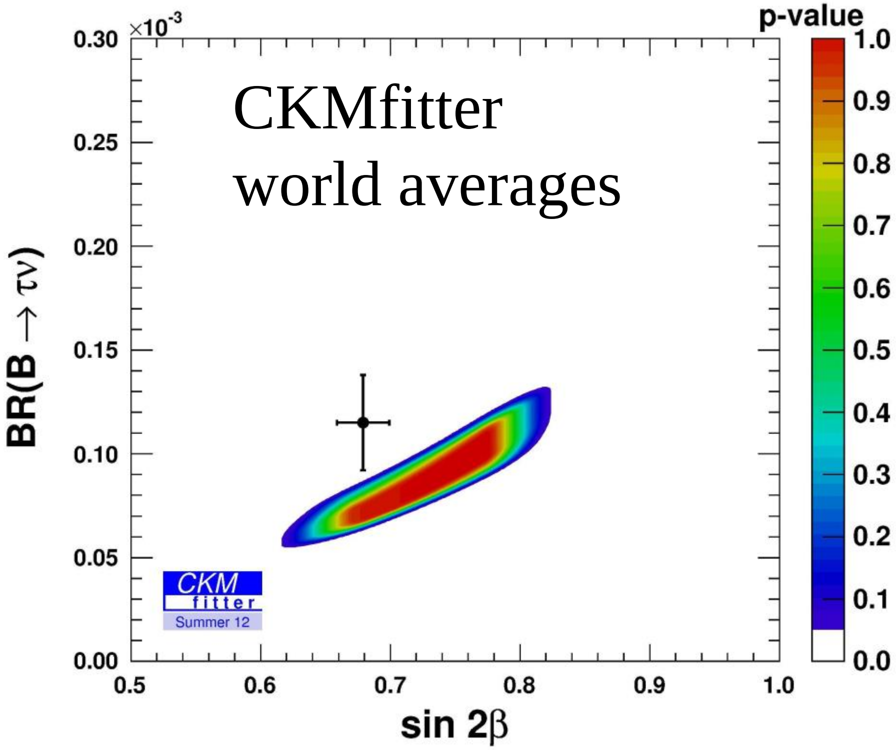
$$\mathcal{B} = [1.83^{+0.53}_{-0.49}(\mathrm{stat}) \pm 0.24(\mathrm{syst})] \times 10^{-4}$$

$$\mathcal{B} = [1.54^{+0.38}_{-0.37}(\mathrm{stat})^{+0.29}_{-0.31}(\mathrm{syst})] \times 10^{-4}$$

$$\mathcal{B} = [1.7 \pm 0.8(\mathrm{stat}) \pm 0.2(\mathrm{syst})] \times 10^{-4}$$

Belle combined: $\mathcal{B}=(0.96\pm0.26)\times10^{-4}$ BaBar combined: $\mathcal{B}=(1.79\pm0.48)\times10^{-4}$

A naive world average: $\mathcal{B}=(1.15\pm0.23)\times10^{-4}$

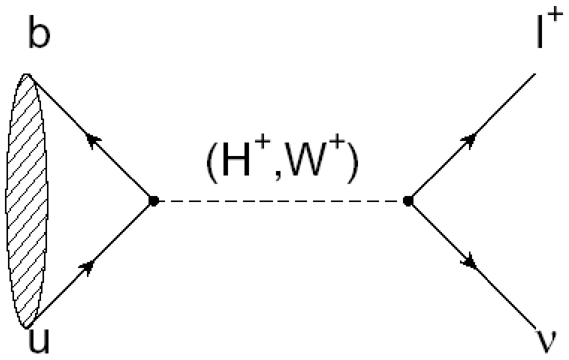


CKMfitter
world averages

Complementarity of SFF and LHC

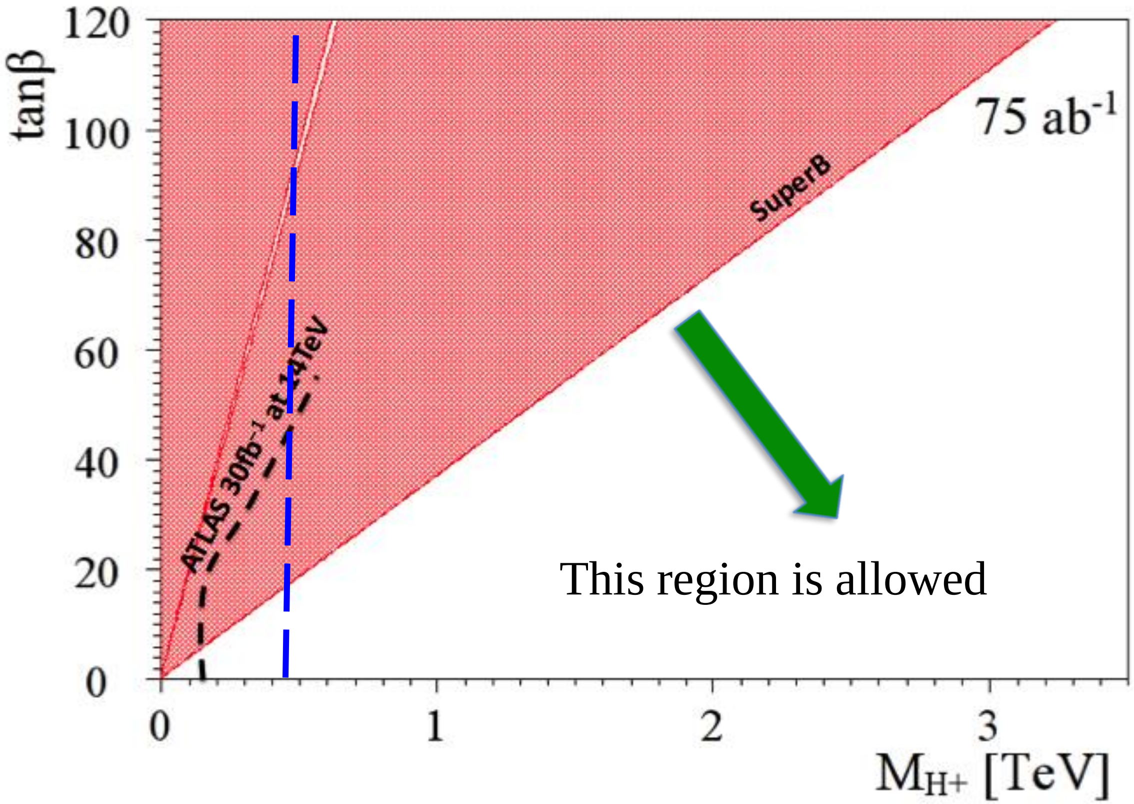
(Slide adapted from A. Bevan)

The current combined limit places a stronger constraint than direct searches from LHC exps. for the next few years.



$$r_H = \frac{\mathcal{B}_{SM+NP}}{\mathcal{B}_{SM}}$$

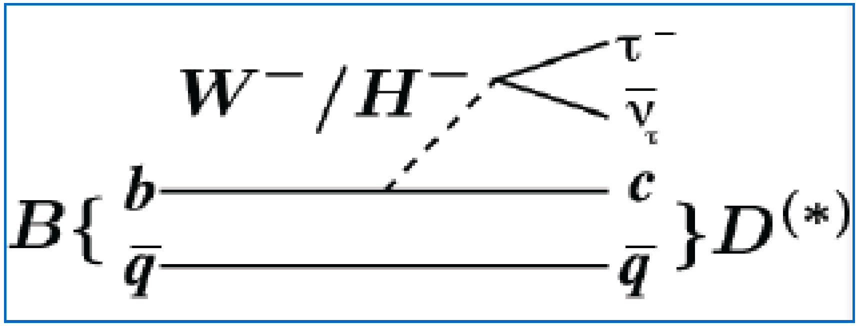
$$r_H = \left(1 - \frac{m_B^2}{m_H^2}\tan^2\beta\right)^2$$

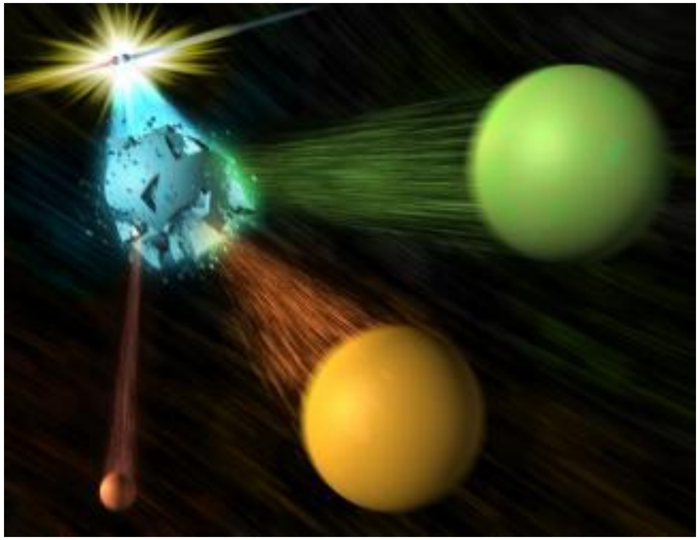


This region is allowed

Currently inclusive b to sγ rules out m_{H+} below ~400 GeV/c^2 range (independent of tanβ)

http://arxiv.org/abs/1208.2788





$$\mathcal{R}(D^{(*)})_{\mathrm{2HDM}} = \mathcal{R}(D^{(*)})_{\mathrm{SM}} + A_{D^{(*)}} \frac{\tan^2\beta}{m_{H^+}^2} + B_{D^{(*)}} \frac{\tan^4\beta}{m_{H^+}^4}$$

	Dτν	D*τν
$A_{D^{(*)}}$ (GeV^2)	-3.25 ± 0.32	-0.230 ± 0.029
$B_{D^{(*)}}$ (GeV^4)	16.9 ± 2.0	0.643 ± 0.085

$$R(D^{(*)}) = \frac{\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)}{\mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)}$$

$\longrightarrow$ Signal

$\longrightarrow$ Normalization ($l = e$ or μ)

Slide adapted from A. Soffer

Example from a recent BaBar paper

Signals in $B \rightarrow D^{(*)} \tau\upsilon$ (489±63, 888±63)

Missing mass variable:

$$m_{miss}^2 = p_{miss}^2 = (p[e^+e^-] - p_{tag} - p_{D(*)} - p_l)^2$$

P_l^* = momentum of lepton in B rest frame

Production of B meson pairs at threshold is critical to the separation of backgrounds from the missing energy/ momentum signal.

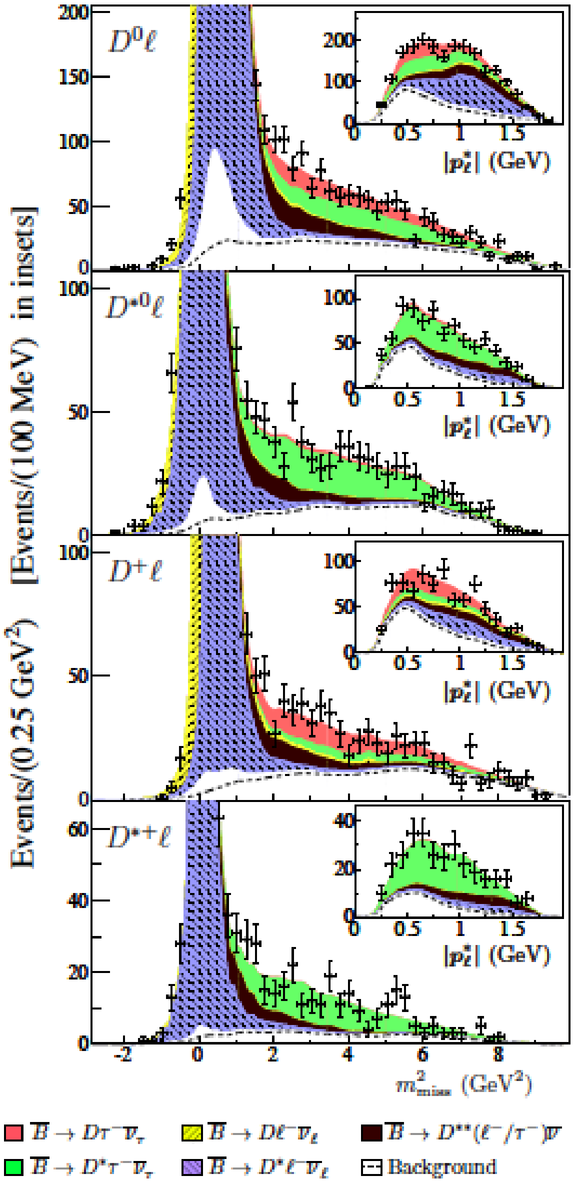
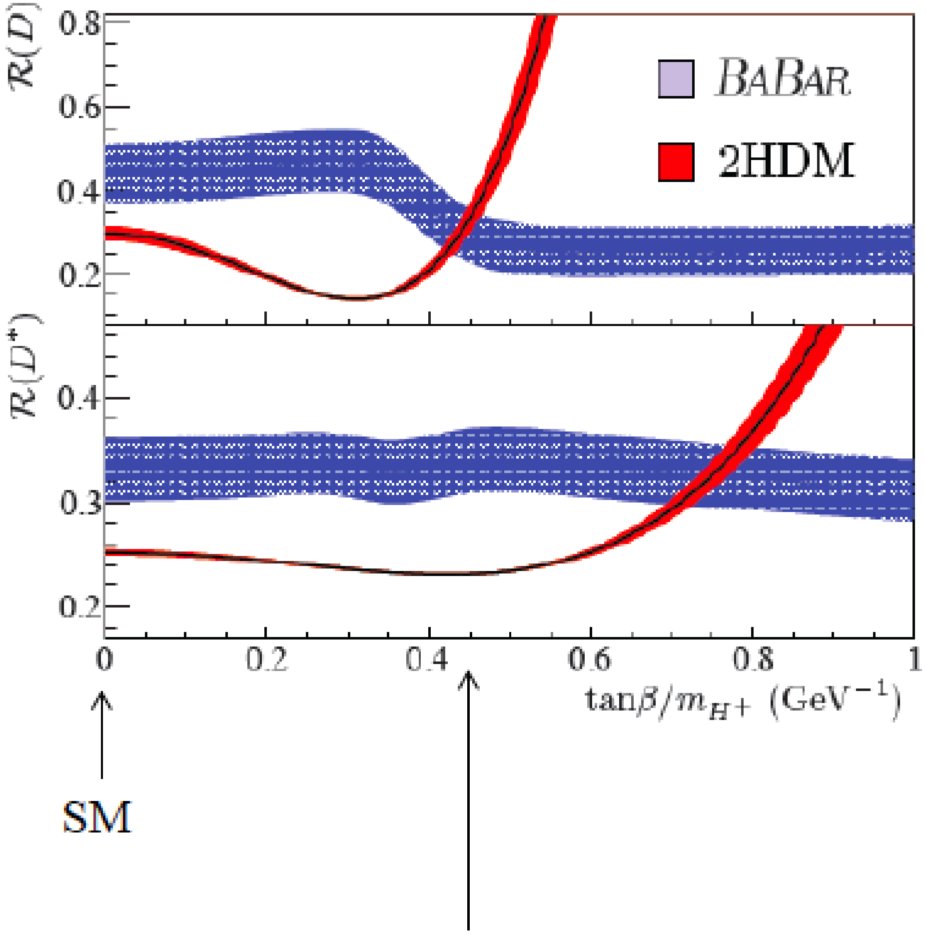


FIG. 1. (Color online) Comparison of the data and the fit projections for the four $D^{(*)}\ell$ samples. The insets show the $|p^*_\ell|$ projections for $m^2_{miss} > 1\,\mathrm{GeV}^2$, which excludes most of the normalization modes. In the background component, the region above the dashed line corresponds to charge cross-feed, and the region below corresponds to continuum and $B\bar{B}$.

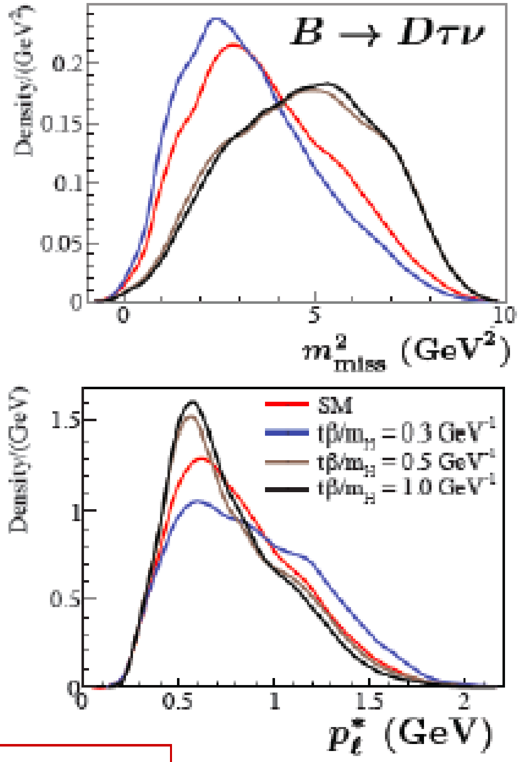
Limits on type-II 2HDM



$\tan\beta/m_{H^+} =$
$0.44 \pm 0.02\ \mathrm{GeV}^{-1}$

$\tan\beta/m_{H^+} =$
$0.75 \pm 0.04\ \mathrm{GeV}^{-1}$

2HDM modifies fit-variable distribution and hence the efficiency



Best point is $\tan\beta/m_{H^+} = 0.45\ \mathrm{GeV}^{-1}$, excluded at 99.8% CL (3.1 σ). All other values (with $m_{H^+} > 15$ GeV) are worse.

BaBar collaboration, Phys. Rev. Lett. 109, 101802 (2012)

“However, the combination of R(D) and R(D*) excludes the type II 2HDM charged Higgs boson with a 99.8% confidence level for any value of tan(β)/m_{H+}”

In other words, found NP but have killed the 2HDM model

In other words, found NP but have killed the 2HDM model

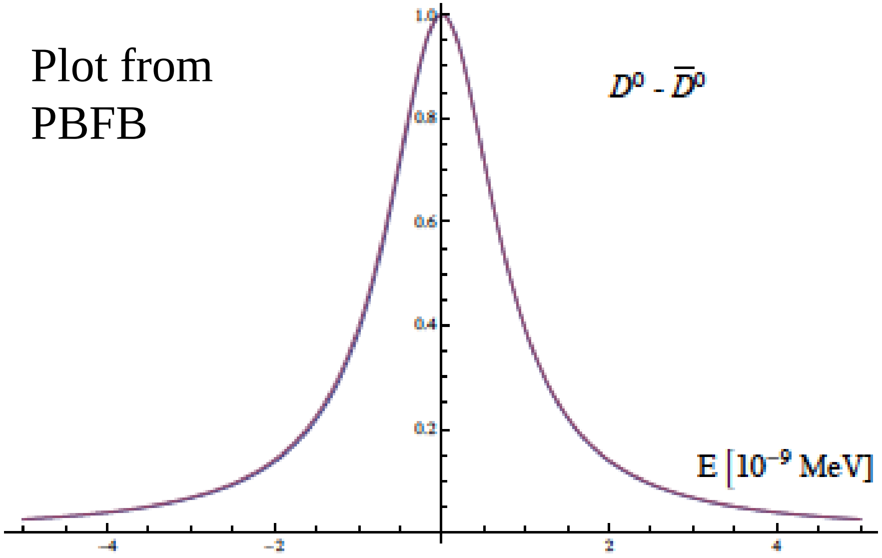
The original
cynic

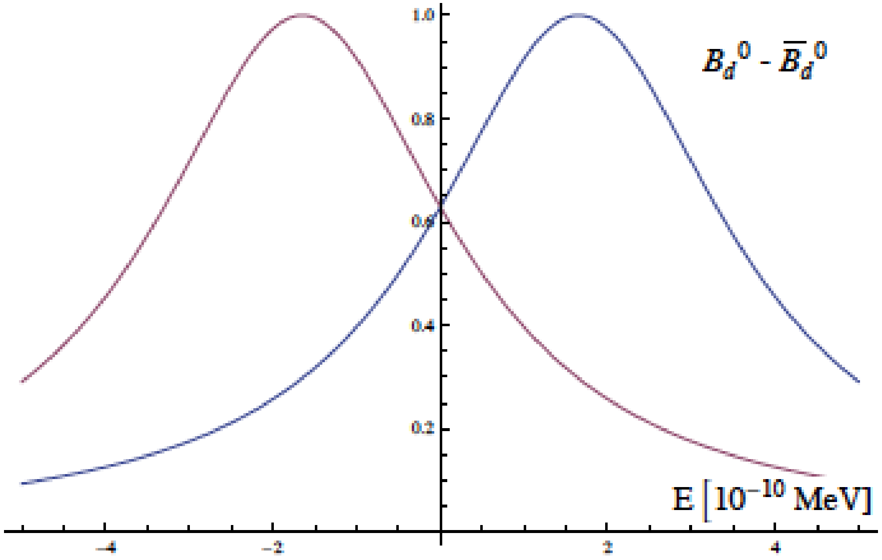
BaBar B→$D^{(*)}\tau\upsilon$ excess at the 3.5σ level. Belle will report their final results on this mode fairly soon. Could the two-Higgs NP model be viable again ?

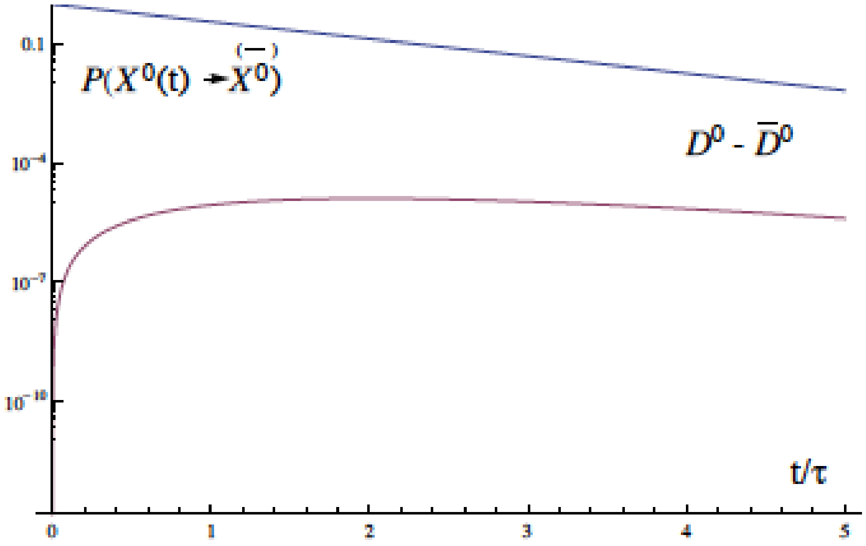
To resolve these new physics issues related to the charged Higgs, need Super Flavor Factory statistics (reduce statistical errors by ~x10).

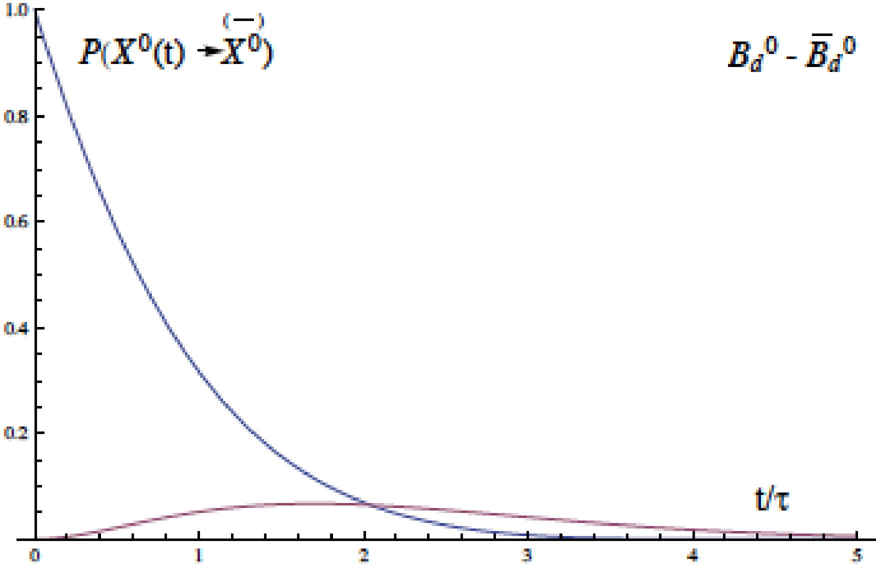
D mixing is very small (note scales)

Plot from
PBFB





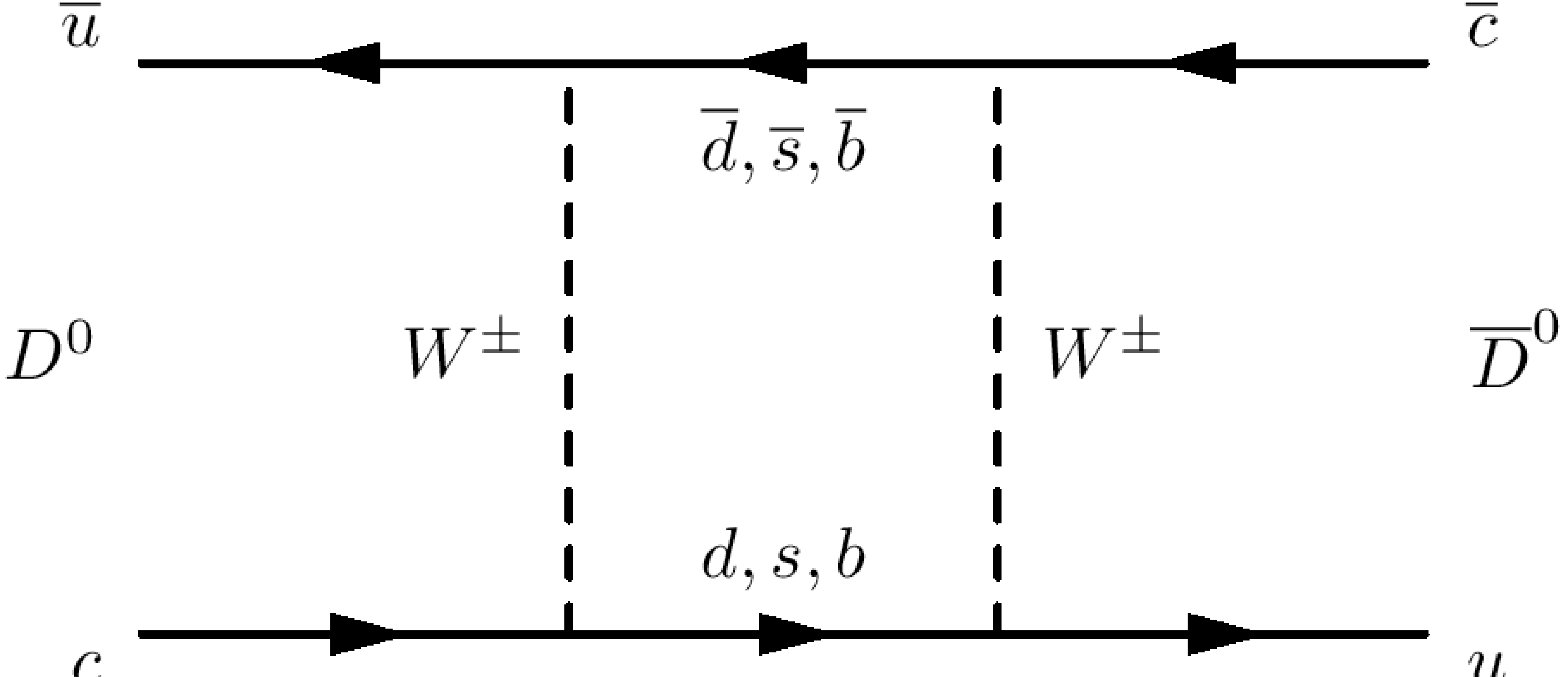




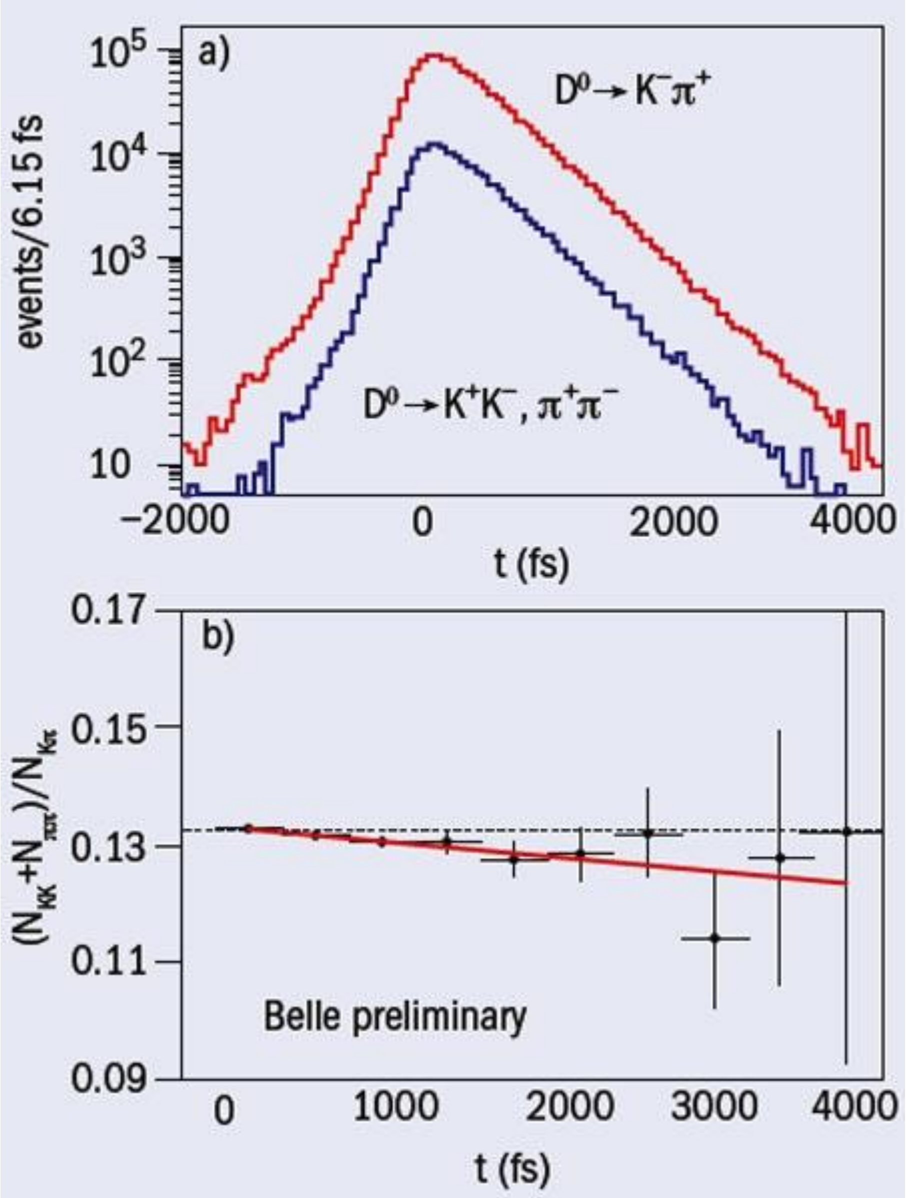
HW Exercise

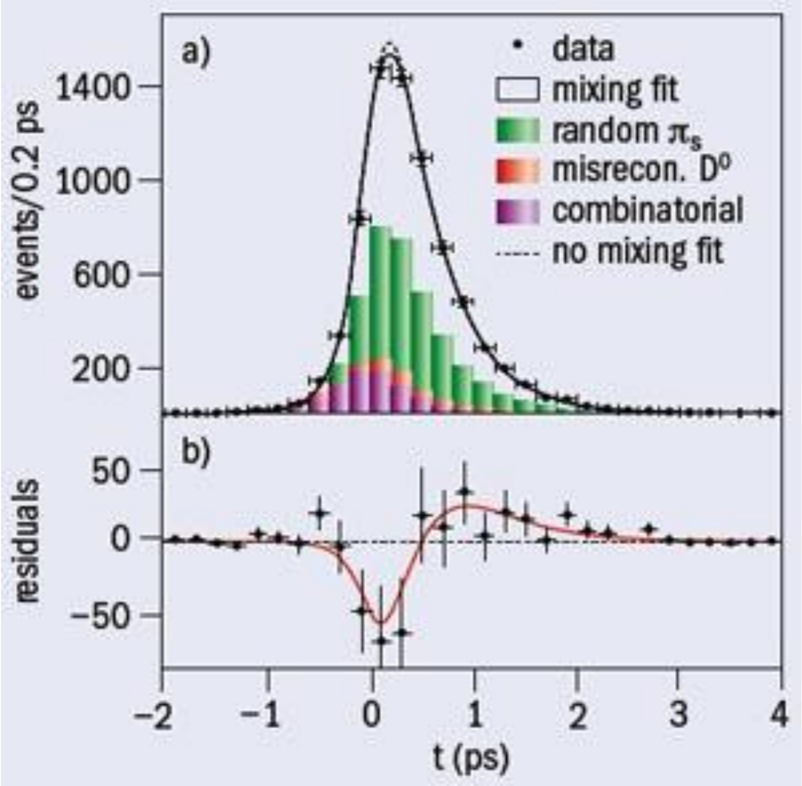
Explain the hierarchy of particle-antiparticle mixing using counting arguments with the appropriate box diagrams.

Why does the Bs oscillate faster than Bd ? Why is D mixing small ? Which mixing diagrams involve top quark coupling constants ?



First signals for D mixing from Belle and BaBar in 2007



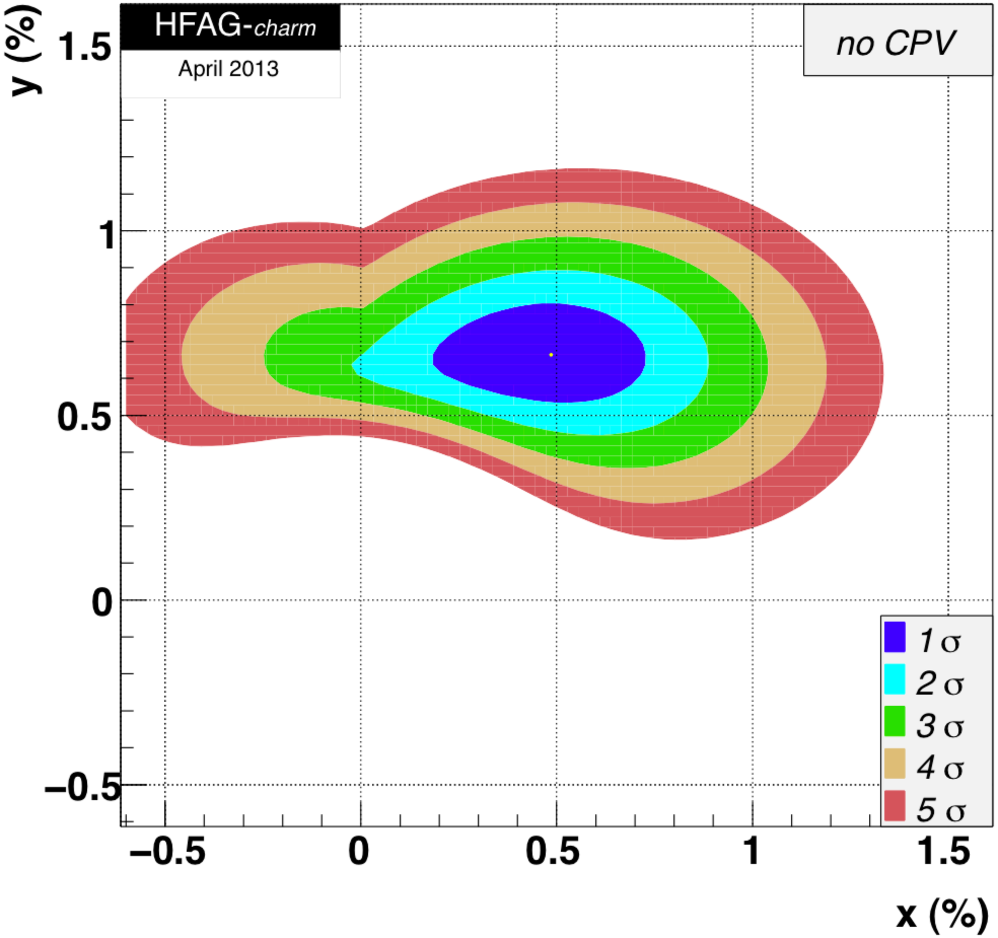


Lifetime of CP eigenstate and Favored decay differ

Executive summary of D - $\bar{D}$ mixing

$$x = \frac{m_1 - m_2}{\Gamma_D}, \qquad y = \frac{\Gamma_1 - \Gamma_2}{2\Gamma_D},$$

There are also "primed versions" of x and y, which correspond to a rotation through a strong interaction phase



So far, a strong signal for y not much (<2σ) for x

D mixing: Another new physics phase !

$$\varphi \sim \frac{2\eta A^2 \lambda^5}{\lambda} \sim O(10^{-3})$$

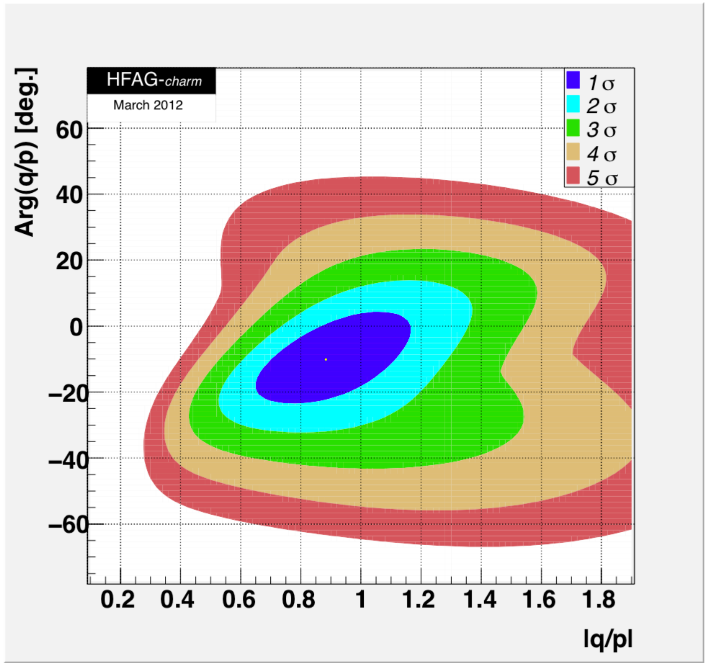
CPV in D system negligible in SM

CPV in interf. mix./decay:

$$\mathrm{Im}\frac{q}{p}\frac{\bar{A}_f}{A_f} \equiv (1+\frac{A_M}{2})e^{i\varphi} \neq 0; \varphi \neq 0$$

The existence of D mixing (if x is non-zero) allows us to look for another poorly constrained new physics phase but this time from up-type quarks.

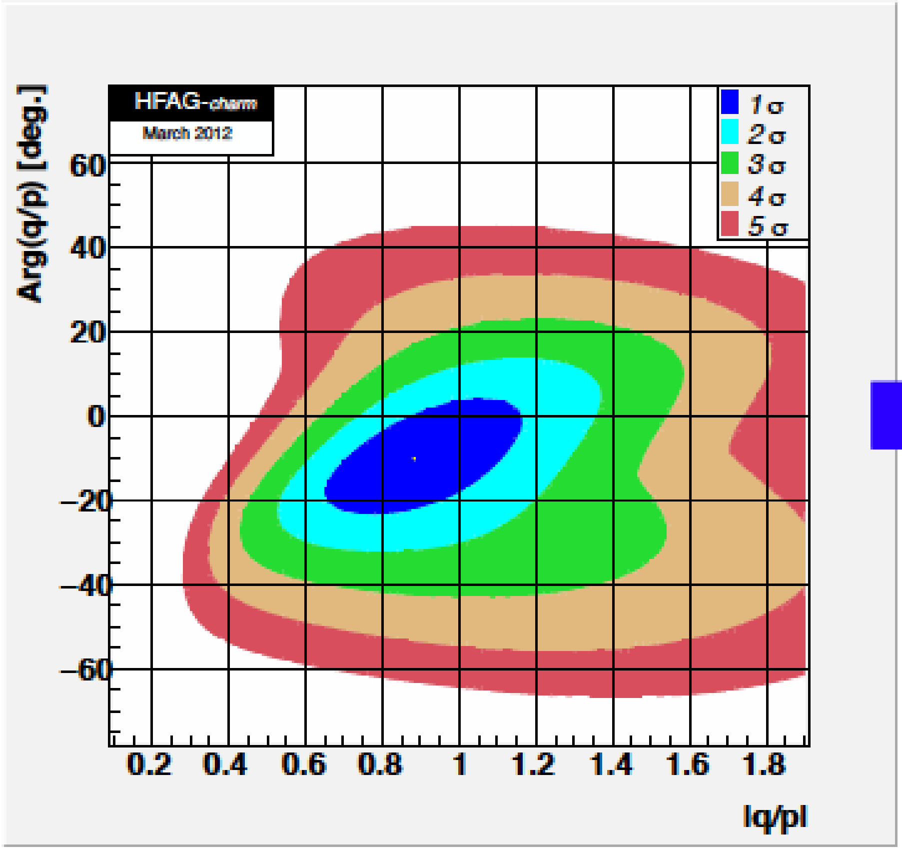
(c.f. CPV in B_s mixing)



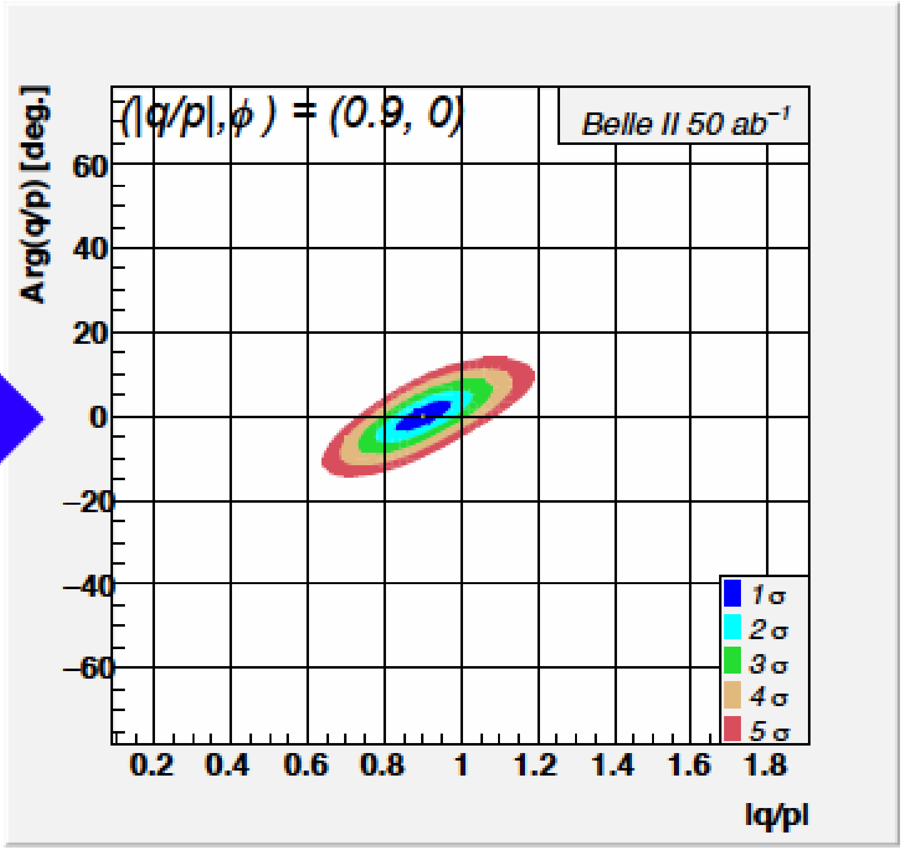
Current WA sensitivity ~±15^0, 50 ab^{-1} go below 2^0

CP Phase in D mixing at Belle II

Now:



50 ab^{-1}:



Based on a slide by Alan Schwartz

Homework exercises:

What is the definition of direct CPV ? How does it differ from CPV induced by mixing ? (review Zoltan's slides)

What is the experimental evidence for direct CPV in B, B_s and kaon decays ?

What is the "superweak model" of Lincoln Wolfenstein ? How has it been ruled out ?

Enigma of charm direct CPV

$$\Delta A_{CP} = A(K^+K^-) - A(\pi^+\pi^-)$$

Semileptonic: $\Delta A_{CP} = (+0.49 \pm 0.30(stat.) \pm 0.14(syst.))\ \%$

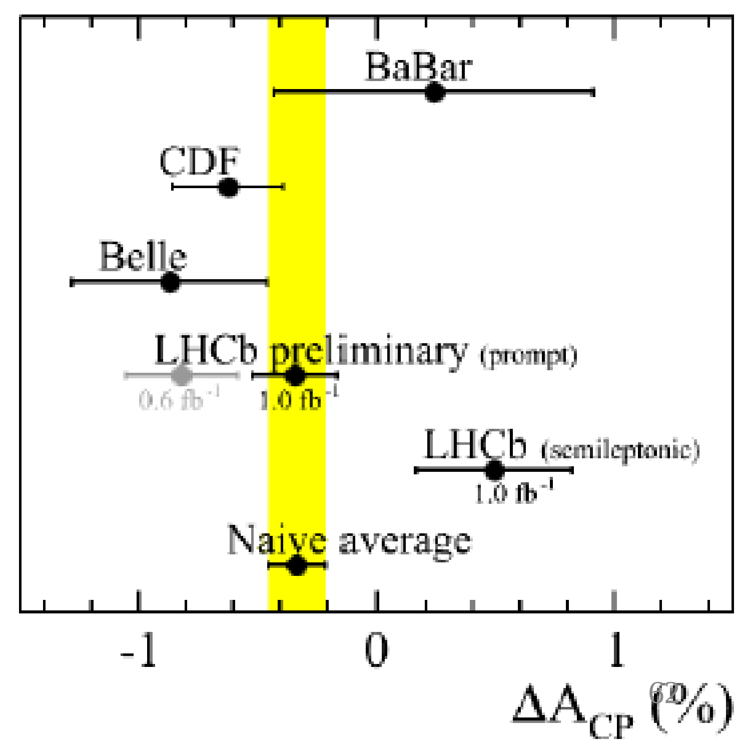
Prompt:
(preliminary) $\Delta A_{CP} = (-0.34 \pm 0.15(stat.) \pm 0.10(syst.))\ \%$

Naïve average from LHCb alone

$$\Delta A_{CP,LHCb} = (-0.15 \pm 0.16)\%$$

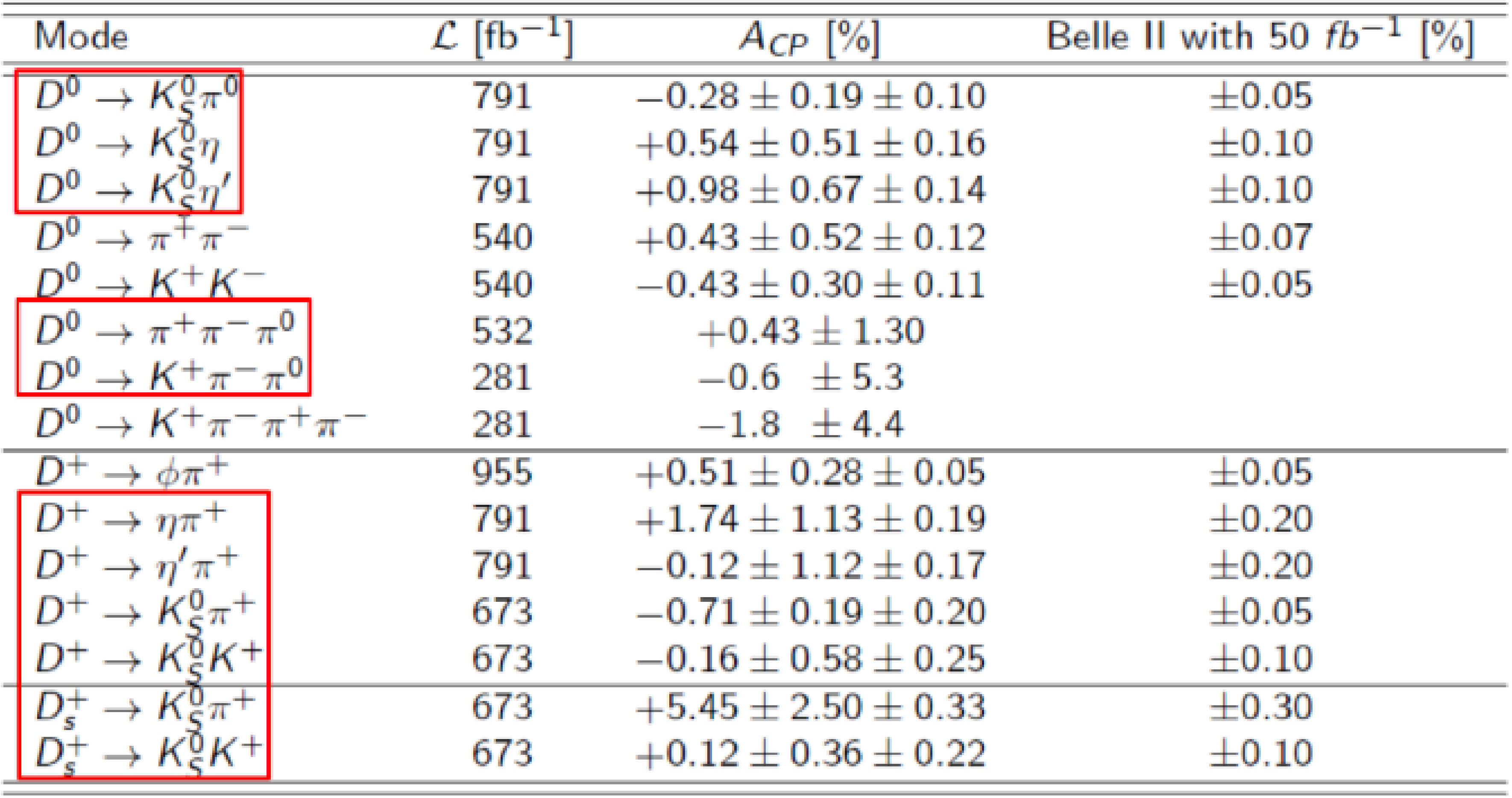
Is there an effect ? Are systematics under control ?

If the result stabilizes at 0.3%, is NP still required ?



Belle II Direct CPV reach in charm and potential for NP diagnosis

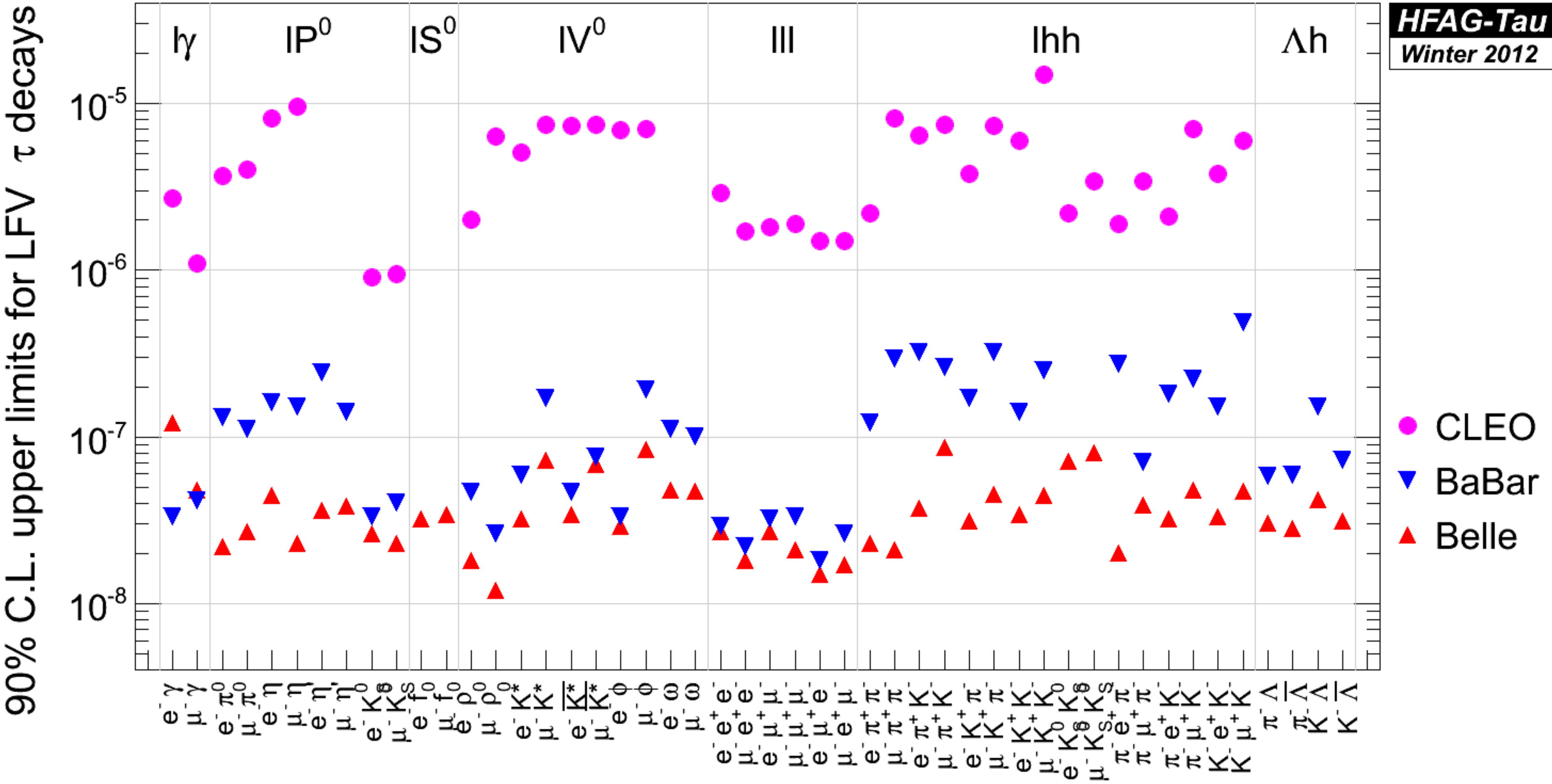
(Missing entry D→π^0 π^0 below)



Mode	$\mathcal{L}$ [fb^{-1}]	A_{CP} [%]	Belle II with 50 fb^{-1} [%]
$D^0 \to K^0_S \pi^0$	791	$-0.28 \pm 0.19 \pm 0.10$	± 0.05
$D^0 \to K^0_S \eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.10
$D^0 \to K^0_S \eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.10
$D^0 \to \pi^+ \pi^-$	540	$+0.43 \pm 0.52 \pm 0.12$	± 0.07
$D^0 \to K^+ K^-$	540	$-0.43 \pm 0.30 \pm 0.11$	± 0.05
$D^0 \to \pi^+ \pi^- \pi^0$	532	$+0.43 \pm 1.30$	
$D^0 \to K^+ \pi^- \pi^0$	281	-0.6 ± 5.3	
$D^0 \to K^+ \pi^- \pi^+ \pi^-$	281	-1.8 ± 4.4	
$D^+ \to \phi \pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.05
$D^+ \to \eta \pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.20
$D^+ \to \eta' \pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.20
$D^+ \to K^0_S \pi^+$	673	$-0.71 \pm 0.19 \pm 0.20$	± 0.05
$D^+ \to K^0_S K^+$	673	$-0.16 \pm 0.58 \pm 0.25$	± 0.10
$D_s^+ \to K^0_S \pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.30
$D_s^+ \to K^0_S K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.10

Can achieve useful sensitivity in a variety of modes. Measures <u>individual CP asymmetries</u> rather than differences of asymmetries. <u>*Systematics are small and can be calibrated from data*</u>.

Current experimental status of tau lepton flavor violation



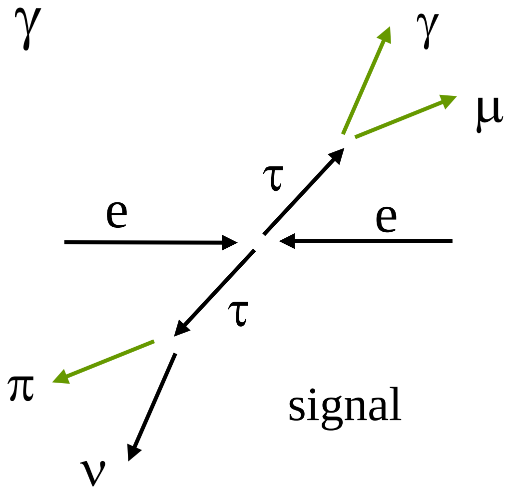
A Super Flavor Factory moves some of the ULs or sensitivities to the 10^{-9} level.

Lepton Flavor Violation in the τ sector

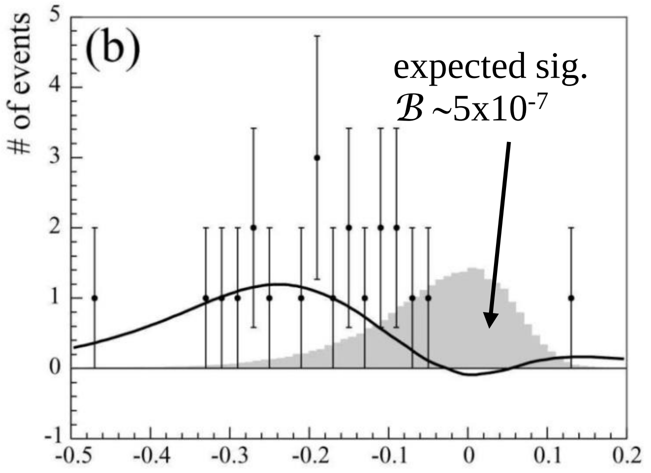
Find or constrain $\tau \rightarrow \mu \gamma$

Belle, PLB66, 16 (2008), 535 fb^{-1}

kinematic variables
for signal isolation:
$\Delta E = E^{CM}(\mu\gamma) - E^{CM}(\text{beam})$
$M_{inv} = m(\mu\gamma)$



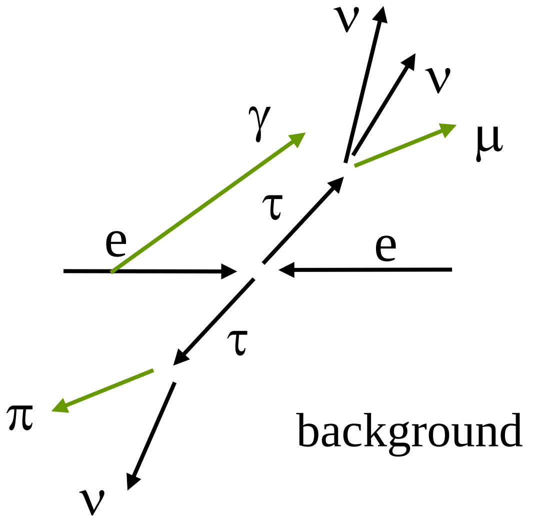
signal



expected sig.
$\mathcal{B} \sim 5\mathrm{x}10^{-7}$

main background from
"ISR", which means
$ee \rightarrow \tau(\mu\nu\nu)\,\tau(\pi\nu)\,\gamma_{ISR}$

polarized beam(s) can
help in reducing this
background
(assuming SM couplings!)



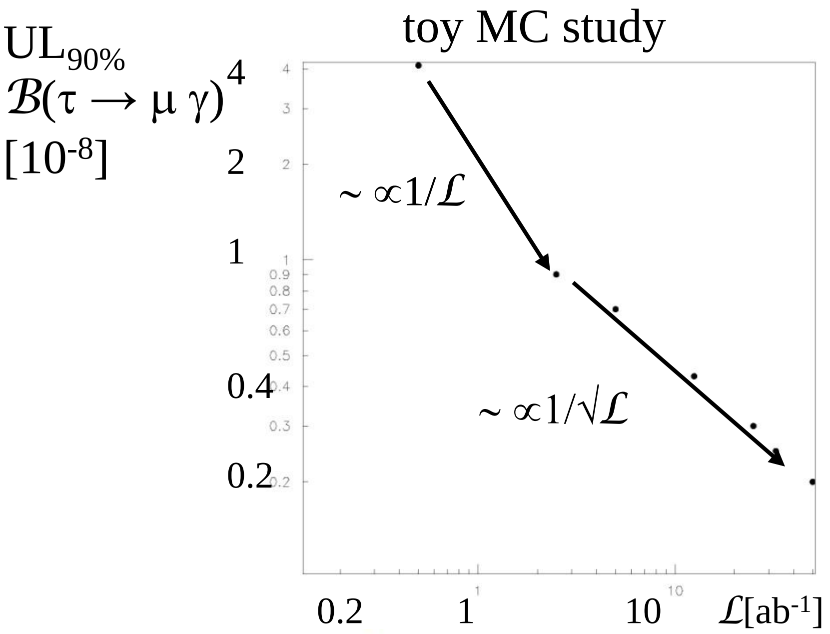
background

N.B. Statistics limited: This is a SFF project not tau-charm

Luminosity scaling of sensitivities for $\tau \to \mu\gamma$

Search for $\tau \to \mu\gamma$

w/o polarization:
$UL_{90\%}(\mathcal{B}(\tau \to \mu\gamma)) \sim 3\text{x}10^{-9}$ @ 50 ab^{-1}

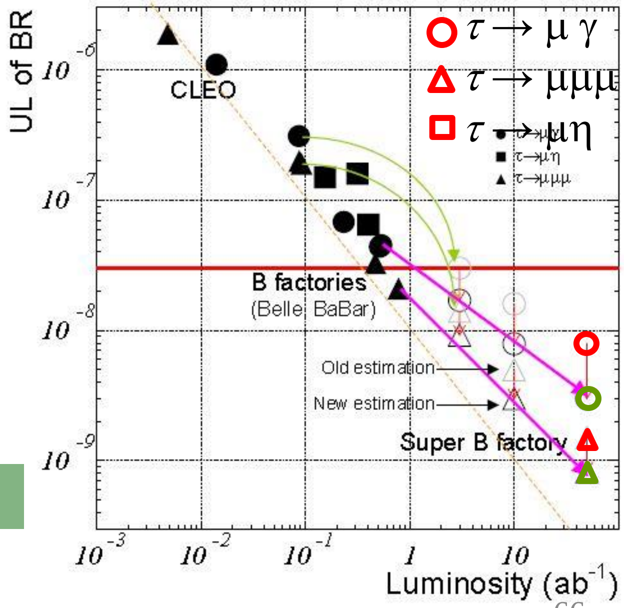


$\tau \to 3\ell, \ell h^0$ decays are background free
$UL_{90\%}(\mathcal{B}(\tau \to \mu\gamma))$ scales as $1/\mathcal{L}$ up to ~10ab^{-1}

$\mathcal{B}(\tau \to \mu\gamma) < 4.4$ x 10^{-8}

Belle, PLB66, 16 (2008), 535 fb^{-1}

Updated expected sensitivities on τ LFV decays



K. Inami, PANIC 2011

$e^+ e^-$ Super Flavor Factory Summary

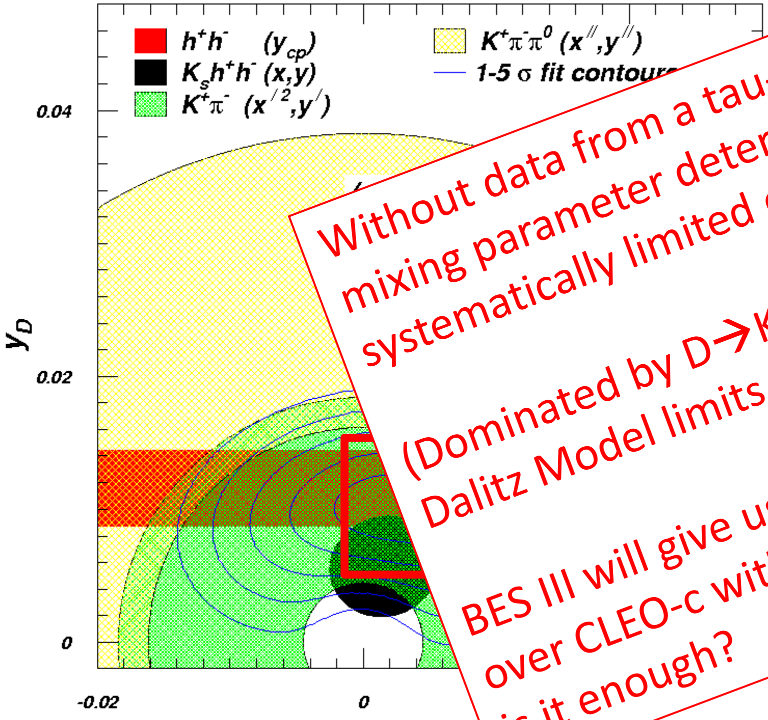
SuperKEKB/Belle II is *the intensity frontier facility* for B mesons, charm mesons and tau leptons.

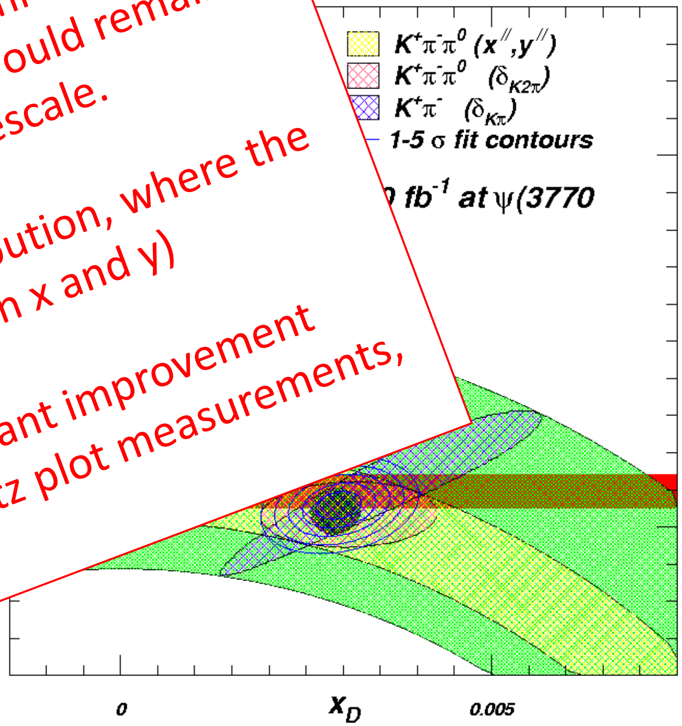
Unique new physics capabilities and unique detector capabilities (“single B meson beam”, neutrals, neutrinos), clean environment with good systematics, which are critical for the next round of NP searches e.g. charged Higgs.)

Backup Slides

SFF/tau-charm factory synergy for Charm Mixing

- Collect data at threshold and at the 4S.
  - Benefit charm mixing and CPV m ents.





Without data from a tau-Charm at threshold the mixing parameter determination would remain systematically limited on this timescale.

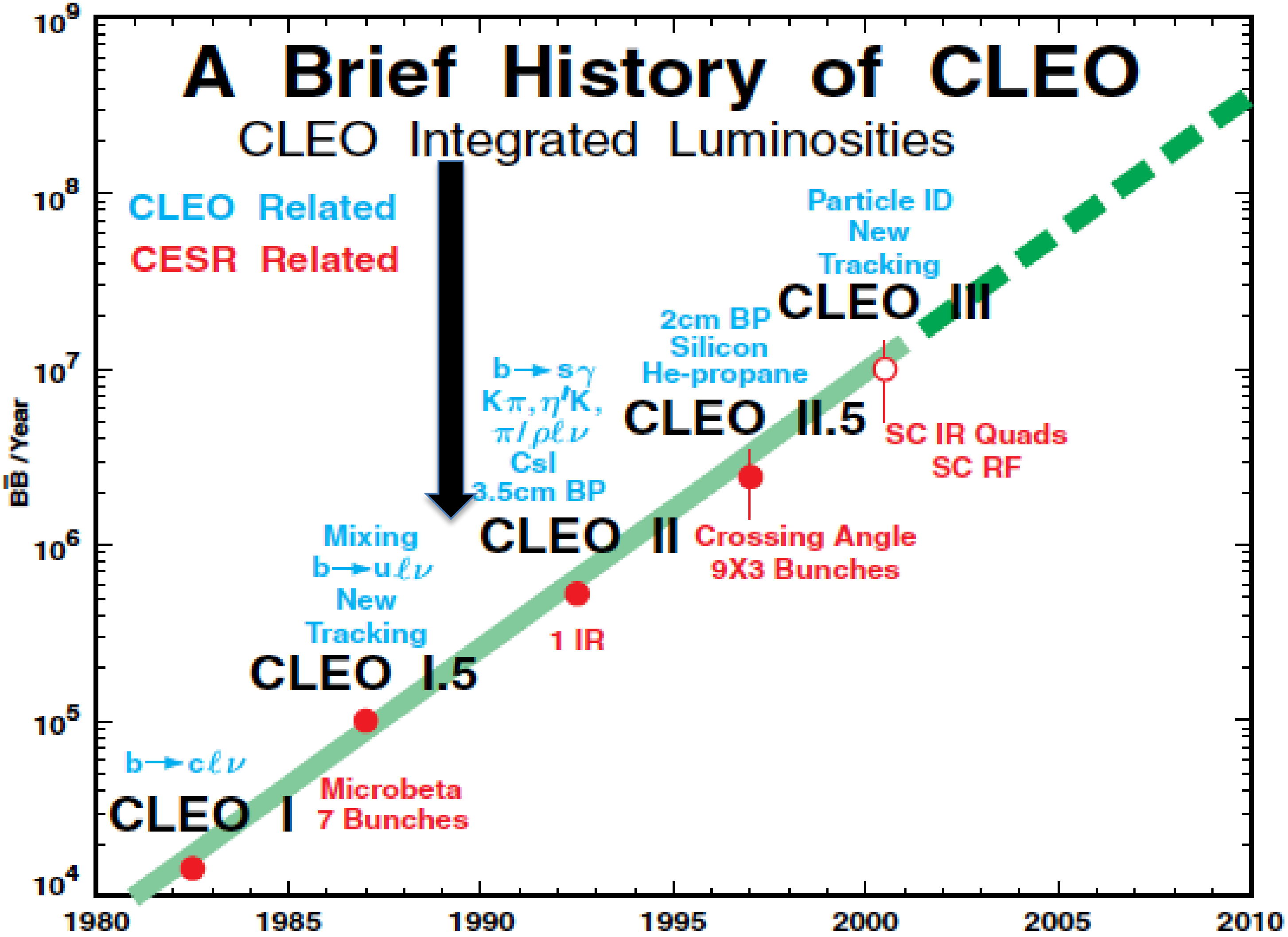
(Dominated by D→$K_S$hh contribution, where the Dalitz Model limits precision on x and y)

BES III will give us an important improvement over CLEO-c with $K_S$hh Dalitz plot measurements, is it enough?

  - Also useful for measuring the Unitarity triangle angle γ/φ_3 (strong phase in D→Kππ Dalitz plot).

Slide from A. Bevan

New accelerator capabilities and neutral detection led to a series of discoveries



A polarized electron beam can produce polarized τ pairs. A proposal was worked out for INFN SuperB.

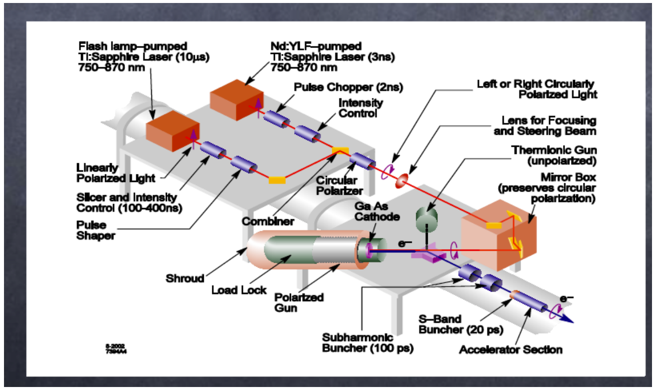
Some basic requirements:

(a) Polarized electron gun (like at SLC)

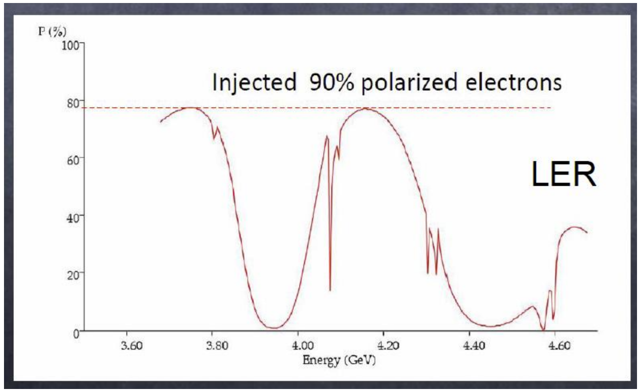
(b) Operation at beam energies away from depolarizing resonances

(c) Spin rotators to rotate the electron spin to the longitudinal direction at the IP. A machine lattice that avoids depolarizing effects from vertical bends and solenoids.

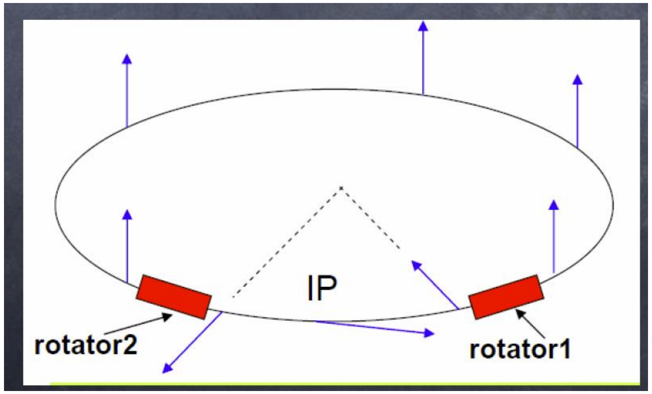
Not practical in initial operation of SuperKEKB (no space in straight sections). Upgrade may be possible (U. Wienands)



a)



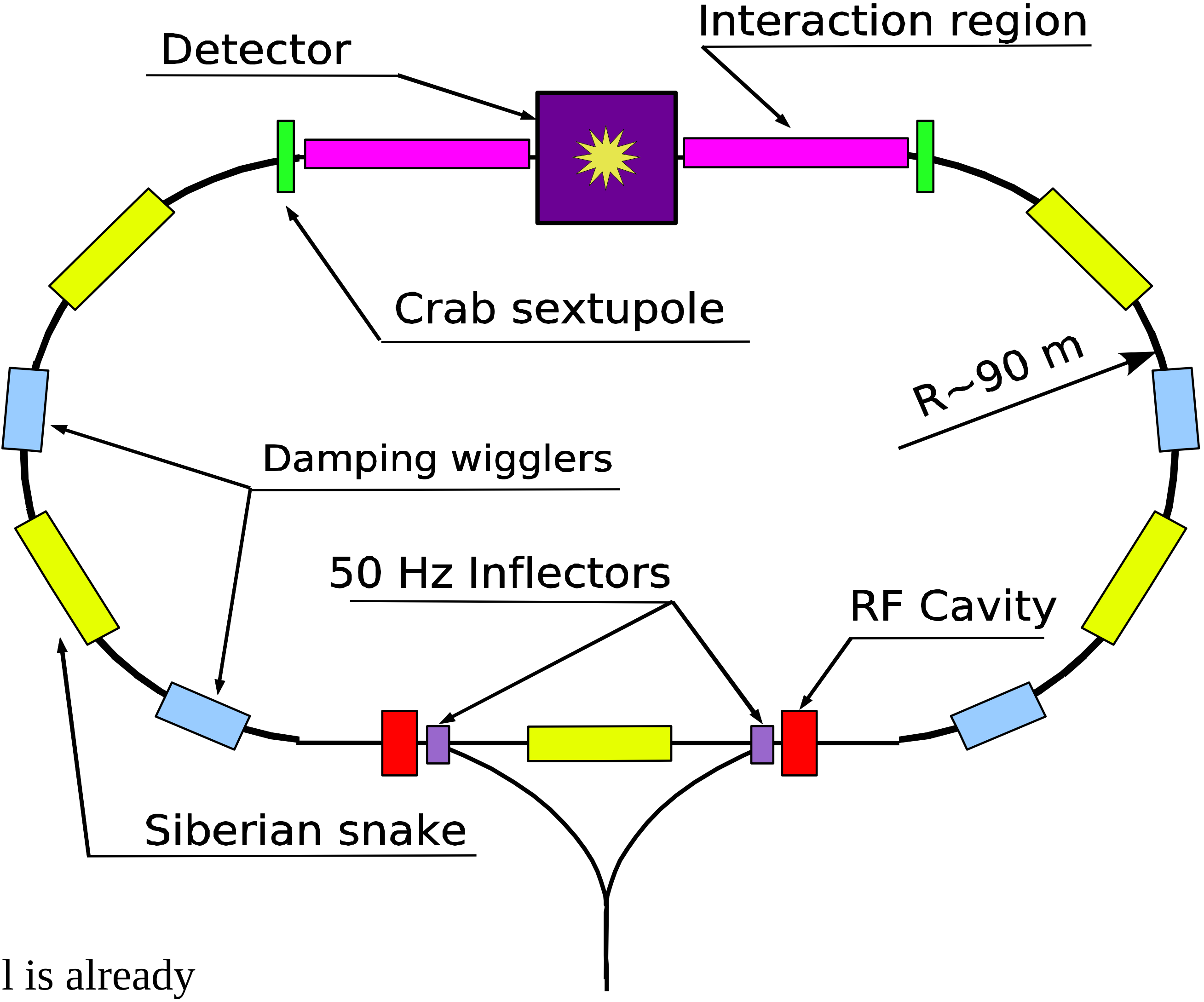
b)



c)

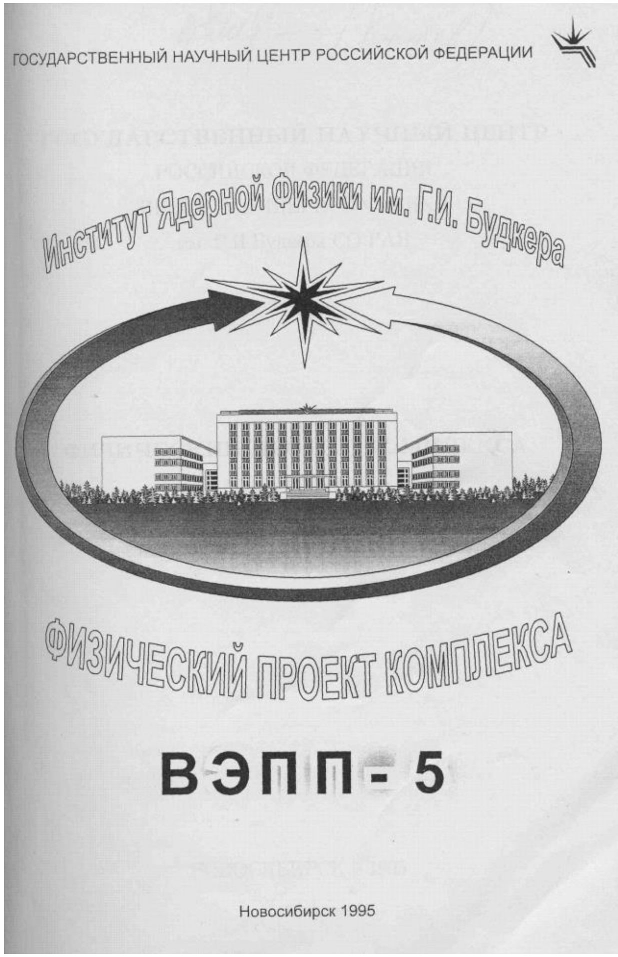
Slide adapated from D. Hitlin

Super-c-tau layout @Novosibirsk



The tunnel is already
available.

Super-c-tau in Novosibirsk



ГОСУДАРСТВЕННЫЙ НАУЧНЫЙ ЦЕНТР РОССИЙСКОЙ ФЕДЕРАЦИИ

Институт Ядерной Физики им. Г.И. Будкера

ФИЗИЧЕСКИЙ ПРОЕКТ КОМПЛЕКСА

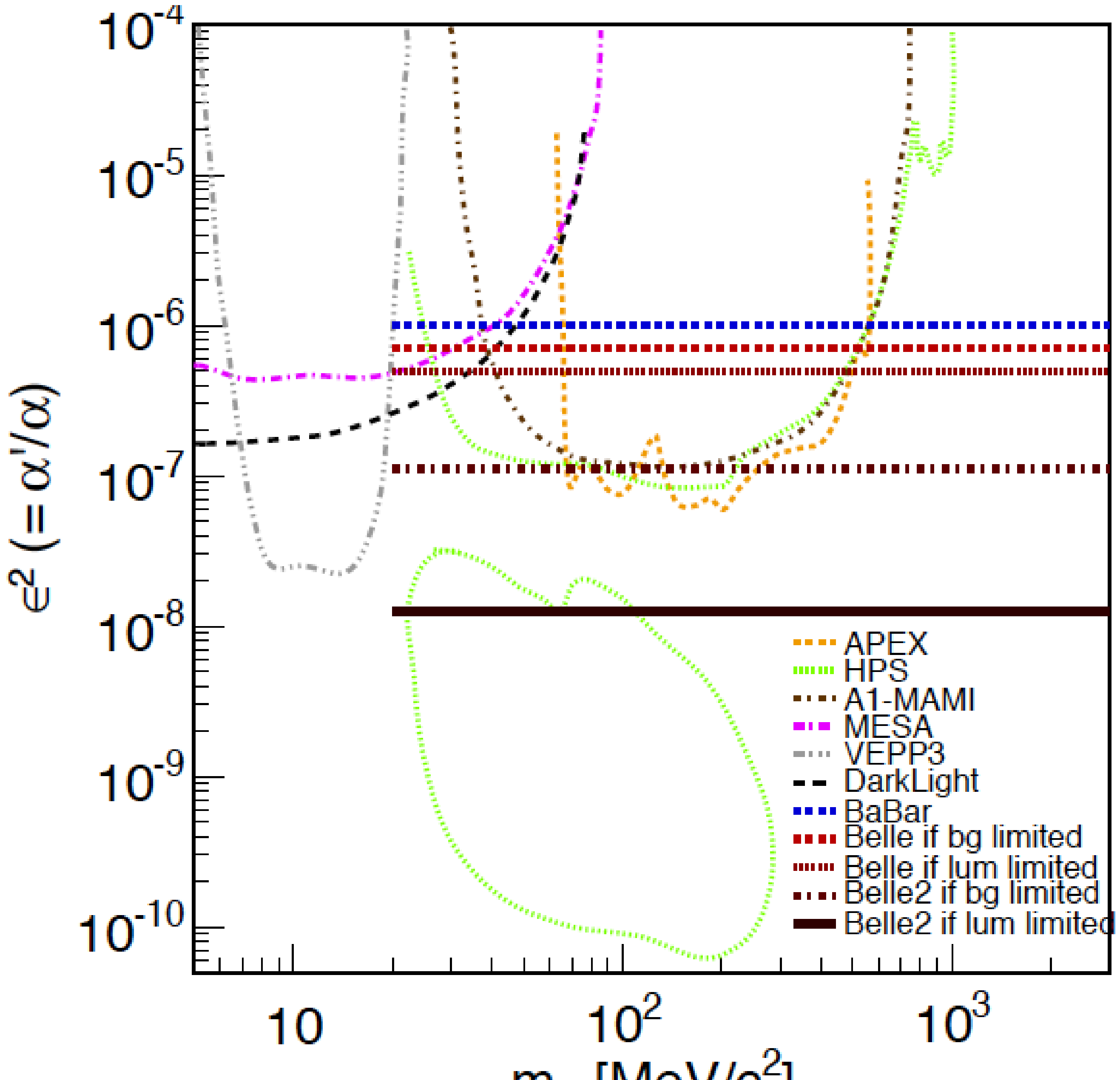
ВЭПП - 5

Новосибирск 1995

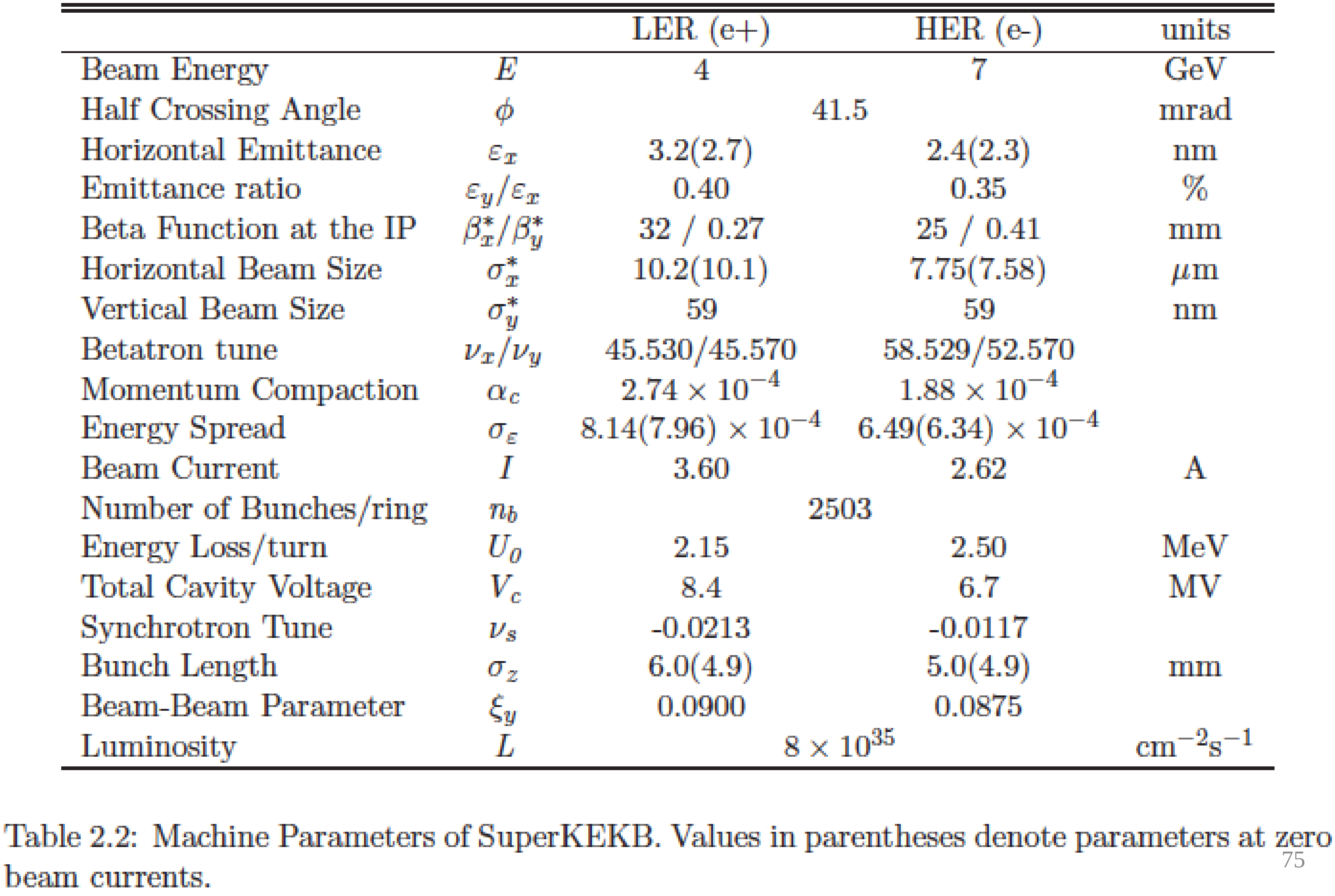
- E = 700 – 2500 MeV
- Round beams L = 10^{34} $cm^{-2}s^{-1}$
- Monochromatization L ~ 10^{32} $cm^{-2}s^{-1}$
- Long. Polarization L ~ 10^{34} $cm^{-2}s^{-1}$
- Transverse polarization for precise energy calibration

There are also proposals for a machine in Turkey, an upgrade of BESIII and a machine at Tor Vegata (INFN, Italy)

Belle II sensitivity for the dark sector



SuperKEKB TDR parameters



		LER (e+)	HER (e-)	units
Beam Energy	E	4	7	GeV
Half Crossing Angle	ϕ	41.5		mrad
Horizontal Emittance	ε_x	3.2(2.7)	2.4(2.3)	nm
Emittance ratio	$\varepsilon_y/\varepsilon_x$	0.40	0.35	%
Beta Function at the IP	β_x^*/β_y^*	32 / 0.27	25 / 0.41	mm
Horizontal Beam Size	σ_x^*	10.2(10.1)	7.75(7.58)	μm
Vertical Beam Size	σ_y^*	59	59	nm
Betatron tune	ν_x/ν_y	45.530/45.570	58.529/52.570	
Momentum Compaction	α_c	2.74×10^{-4}	1.88×10^{-4}	
Energy Spread	σ_ε	$8.14(7.96) \times 10^{-4}$	$6.49(6.34) \times 10^{-4}$	
Beam Current	I	3.60	2.62	A
Number of Bunches/ring	n_b	2503		
Energy Loss/turn	U_0	2.15	2.50	MeV
Total Cavity Voltage	V_c	8.4	6.7	MV
Synchrotron Tune	ν_s	-0.0213	-0.0117	
Bunch Length	σ_z	6.0(4.9)	5.0(4.9)	mm
Beam-Beam Parameter	ξ_y	0.0900	0.0875	
Luminosity	L	8×10^{35}		$\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Table 2.2: Machine Parameters of SuperKEKB. Values in parentheses denote parameters at zero beam currents.

BaBar Yields and Experimental Details for final B-→D* tau nu result

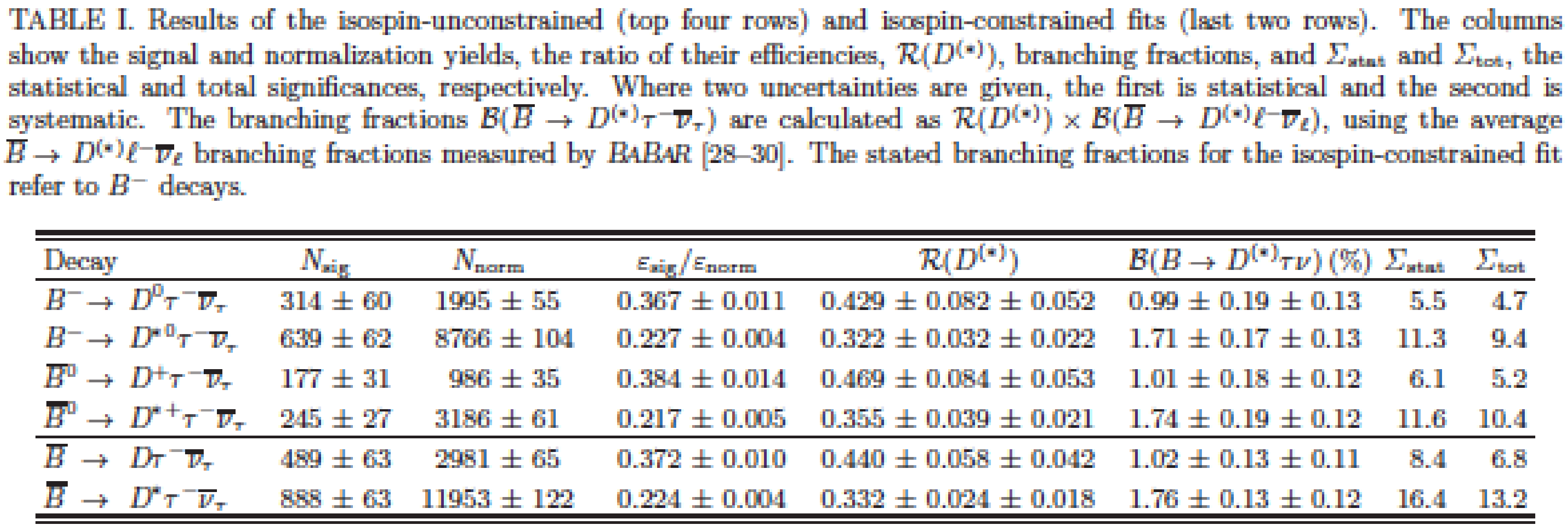
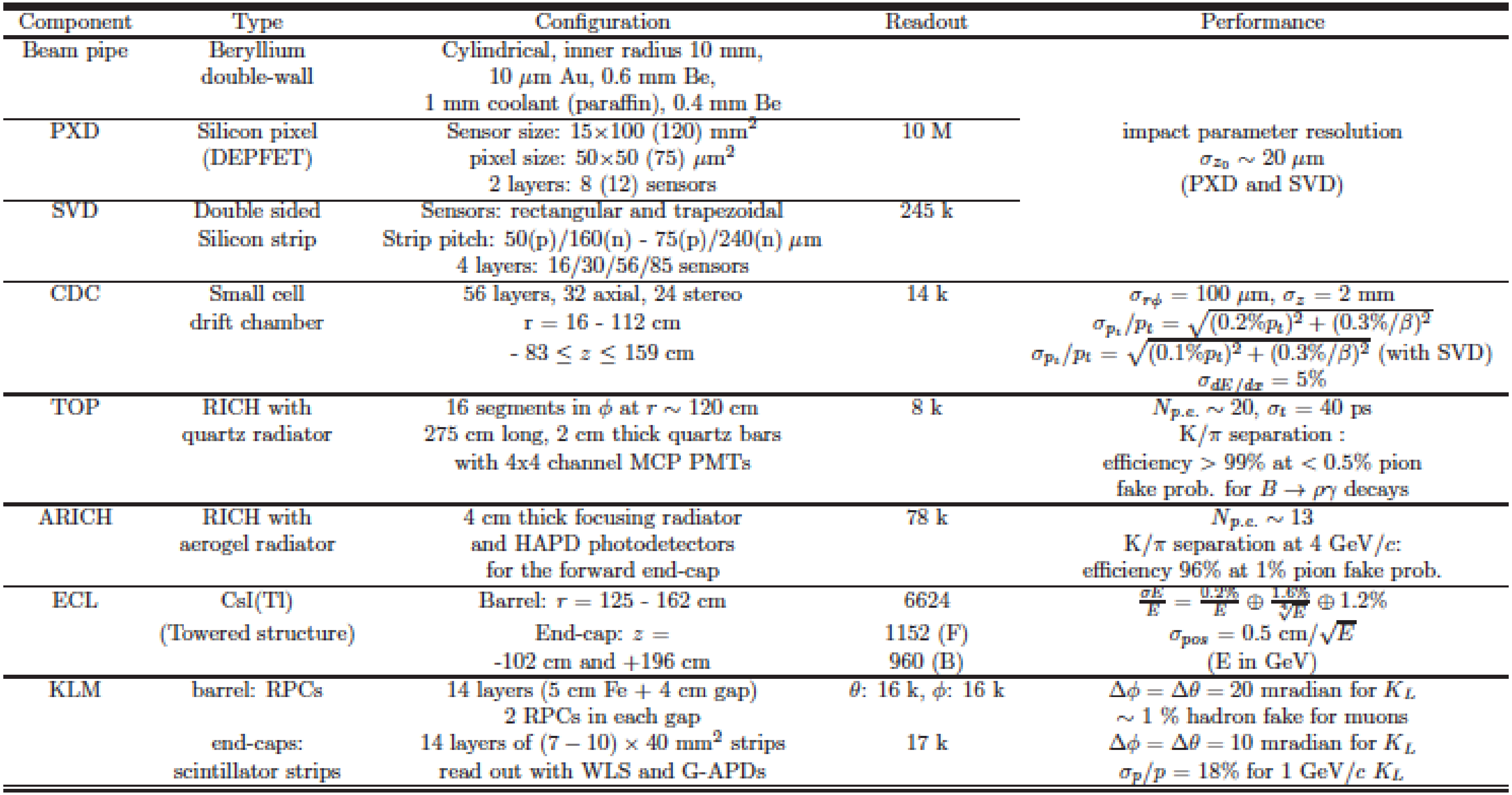


TABLE I. Results of the isospin-unconstrained (top four rows) and isospin-constrained fits (last two rows). The columns show the signal and normalization yields, the ratio of their efficiencies, $\mathcal{R}(D^{(*)})$, branching fractions, and $\Sigma_{\rm stat}$ and $\Sigma_{\rm tot}$, the statistical and total significances, respectively. Where two uncertainties are given, the first is statistical and the second is systematic. The branching fractions $\mathcal{B}(\overline{B} \to D^{(*)}\tau^-\overline{\nu}_\tau)$ are calculated as $\mathcal{R}(D^{(*)}) \times \mathcal{B}(\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell)$, using the average $\overline{B} \to D^{(*)}\ell^-\overline{\nu}_\ell$ branching fractions measured by BABAR [28–30]. The stated branching fractions for the isospin-constrained fit refer to B^- decays.

Decay	$N_{\rm sig}$	$N_{\rm norm}$	$\varepsilon_{\rm sig}/\varepsilon_{\rm norm}$	$\mathcal{R}(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	$\Sigma_{\rm stat}$	$\Sigma_{\rm tot}$
$B^- \to D^0\tau^-\overline{\nu}_\tau$	314 ± 60	1995 ± 55	0.367 ± 0.011	$0.429 \pm 0.082 \pm 0.052$	$0.99 \pm 0.19 \pm 0.13$	5.5	4.7
$B^- \to D^{*0}\tau^-\overline{\nu}_\tau$	639 ± 62	8766 ± 104	0.227 ± 0.004	$0.322 \pm 0.032 \pm 0.022$	$1.71 \pm 0.17 \pm 0.13$	11.3	9.4
$\overline{B}^0 \to D^+\tau^-\overline{\nu}_\tau$	177 ± 31	986 ± 35	0.384 ± 0.014	$0.469 \pm 0.084 \pm 0.053$	$1.01 \pm 0.18 \pm 0.12$	6.1	5.2
$\overline{B}^0 \to D^{*+}\tau^-\overline{\nu}_\tau$	245 ± 27	3186 ± 61	0.217 ± 0.005	$0.355 \pm 0.039 \pm 0.021$	$1.74 \pm 0.19 \pm 0.12$	11.6	10.4
$\overline{B} \to D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	0.372 ± 0.010	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	8.4	6.8
$\overline{B} \to D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	0.224 ± 0.004	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	16.4	13.2

Table of Belle II detector performance parameters



Component	Type	Configuration	Readout	Performance
Beam pipe	Beryllium double-wall	Cylindrical, inner radius 10 mm, 10 μm Au, 0.6 mm Be, 1 mm coolant (paraffin), 0.4 mm Be		impact parameter resolution $\sigma_{z_0} \sim 20\ \mu$m (PXD and SVD)
PXD	Silicon pixel (DEPFET)	Sensor size: 15×100 (120) mm^2 pixel size: 50×50 (75) μm^2 2 layers: 8 (12) sensors	10 M	
SVD	Double sided Silicon strip	Sensors: rectangular and trapezoidal Strip pitch: 50(p)/160(n) - 75(p)/240(n) μm 4 layers: 16/30/56/85 sensors	245 k	
CDC	Small cell drift chamber	56 layers, 32 axial, 24 stereo r = 16 - 112 cm - 83 $\le z \le$ 159 cm	14 k	$\sigma_{r\phi} = 100\ \mu$m, $\sigma_z = 2$ mm $\sigma_{p_t}/p_t = \sqrt{(0.2\% p_t)^2 + (0.3\%/\beta)^2}$ $\sigma_{p_t}/p_t = \sqrt{(0.1\% p_t)^2 + (0.3\%/\beta)^2}$ (with SVD) $\sigma_{dE/dx} = 5\%$
TOP	RICH with quartz radiator	16 segments in ϕ at $r \sim 120$ cm 275 cm long, 2 cm thick quartz bars with 4x4 channel MCP PMTs	8 k	$N_{p.e.} \sim 20$, $\sigma_t = 40$ ps K/π separation : efficiency > 99% at < 0.5% pion fake prob. for $B \to \rho\gamma$ decays
ARICH	RICH with aerogel radiator	4 cm thick focusing radiator and HAPD photodetectors for the forward end-cap	78 k	$N_{p.e.} \sim 13$ K/π separation at 4 GeV/c: efficiency 96% at 1% pion fake prob.
ECL	CsI(Tl) (Towered structure)	Barrel: $r = 125$ - 162 cm End-cap: $z =$ -102 cm and +196 cm	6624 1152 (F) 960 (B)	$\frac{\sigma_E}{E} = \frac{0.2\%}{E} \oplus \frac{1.6\%}{\sqrt[4]{E}} \oplus 1.2\%$ $\sigma_{pos} = 0.5$ cm$/\sqrt{E}$ (E in GeV)
KLM	barrel: RPCs end-caps: scintillator strips	14 layers (5 cm Fe + 4 cm gap) 2 RPCs in each gap 14 layers of $(7-10) \times 40$ mm^2 strips read out with WLS and G-APDs	θ: 16 k, ϕ: 16 k 17 k	$\Delta\phi = \Delta\theta = 20$ mradian for K_L ~ 1 % hadron fake for muons $\Delta\phi = \Delta\theta = 10$ mradian for K_L $\sigma_p/p = 18\%$ for 1 GeV/c K_L

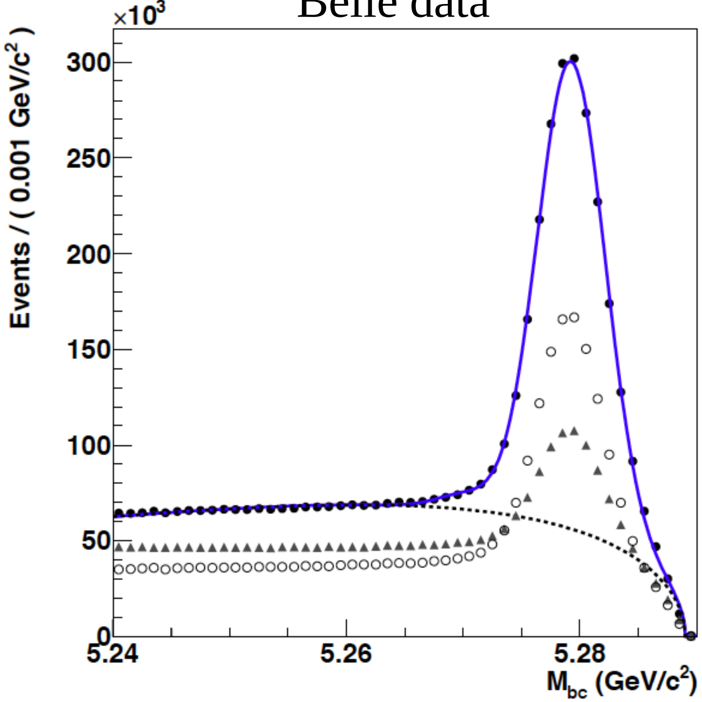
(Skip this slide) For reference only.

Diogenes the Cynic in a painting by Jean-Leon Gerome

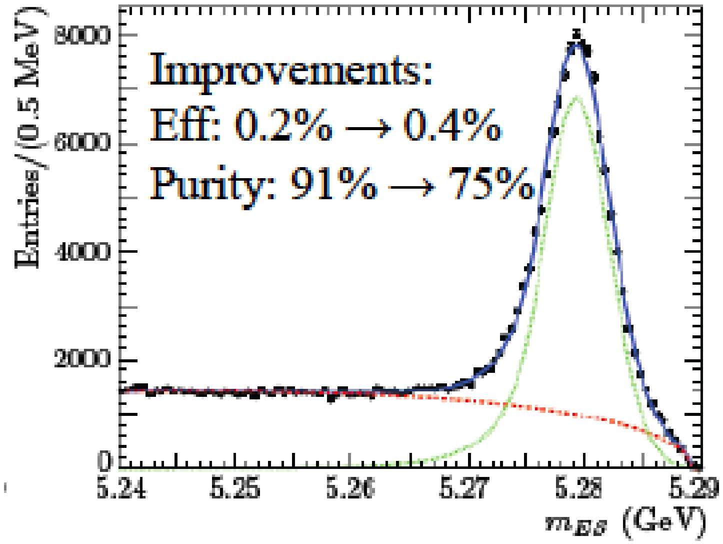
Interview of Diogenes the Cynic with Alexander, painting by Caspar de Crayer

Unique capability

Belle data



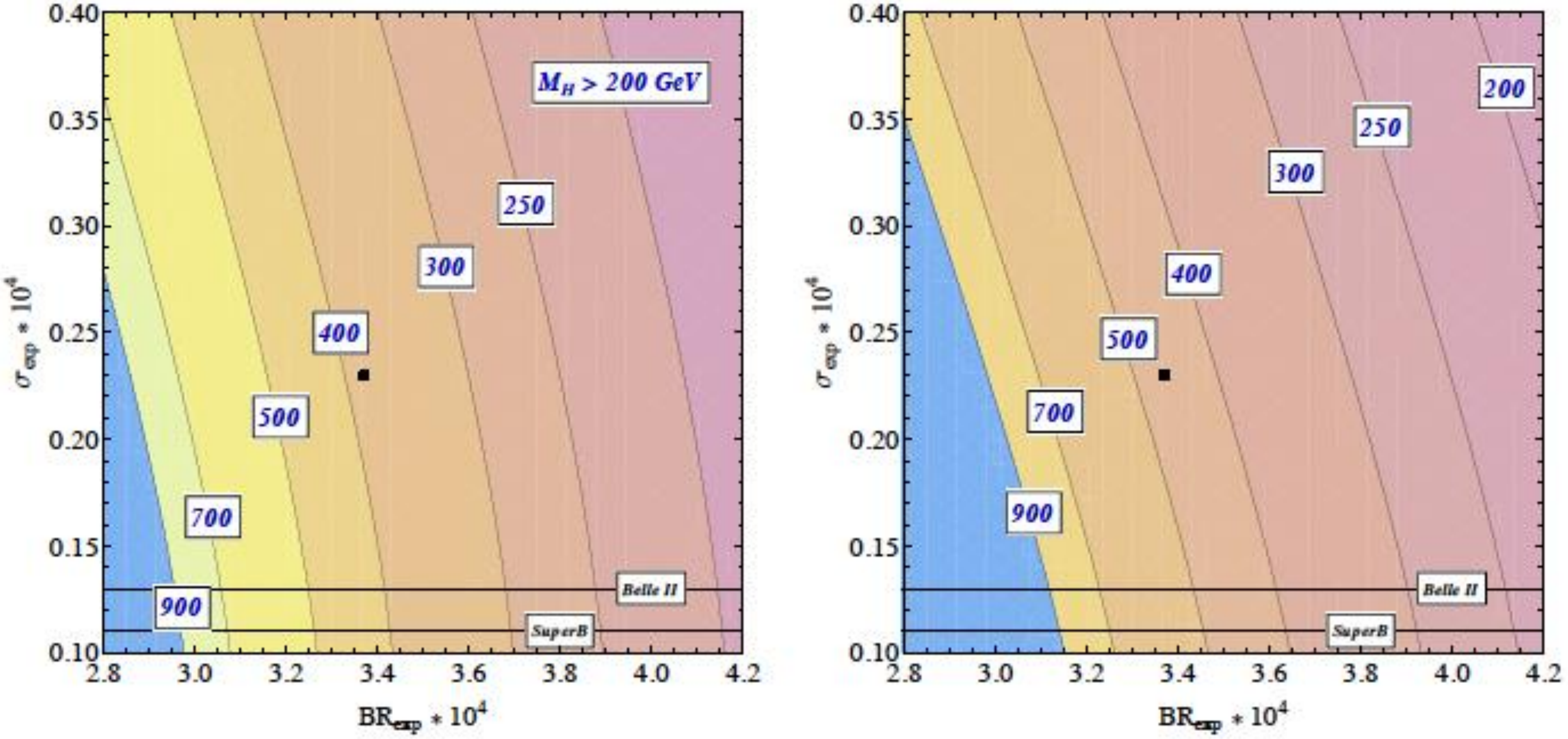
BaBar data



Improvements:
Eff: 0.2% → 0.4%
Purity: 91% → 75%

In addition to excellent neutral detection from a crystal calorimeter, and good Cerenkov particle id, (Super) B-factories can fully reconstruct one B meson. This gives the equivalent of a <u>"single B meson beam "</u>

From paper by T. Hermann, M. Misiak, M. Steinhauser



(a) (b)

Figure 7: Lower bounds on M_{H^+} at the 95% C.L. as a function of the experimentally determined branching ratio (abscissa) and the corresponding uncertainty (ordinate). The current theory uncertainty has been used in panel (a), while panel (b) presents a future projection with assumed reduction of the theory uncertainty by a factor of two.

Charge:

ritchie@physics.utexas.edu to teb@phys.hawaii.edu Mar 19

Hi. At the Argonne Intensity Frontier workshop, we (the Quark Flavor Physics working group) are going to have a joint parallel session with the Charged Leptons working group.

The theme of this session is sort of the unity of flavor physics (quark and lepton) as a coherent field. We're aiming to have four talks, one theory and three experimental talks organized around different types of facilities (e+e-, pp aka LHC, and Project X). We want the emphasis of the theory talk to be showing that new physics may show up in many different flavor (quark and lepton) observables, so that a broad program of B, charm, K, mu, and tau experiments is needed.

For the e+e- talk, we've written this charge for the speaker:
e+e- machines - The goal of the talk is to identify key measurements that are enabled by these facilities (SuperKEKB/Belle II, BES III, other possible tau/charm factories) for B's, charm, and taus (including the effect of longitudinally polarized electrons), and to discuss the likely evolution of these capabilities over the rest of this decade and during the next. The likely evolution over time of luminosities and other important machine or detector parameters should be included.

“Imagine if Fitch and Cronin had stopped at the 1% level, how much physics would have been missed” –A. Soni@Super KEKB at Proto-collaboration meeting

A lesson from history (I)

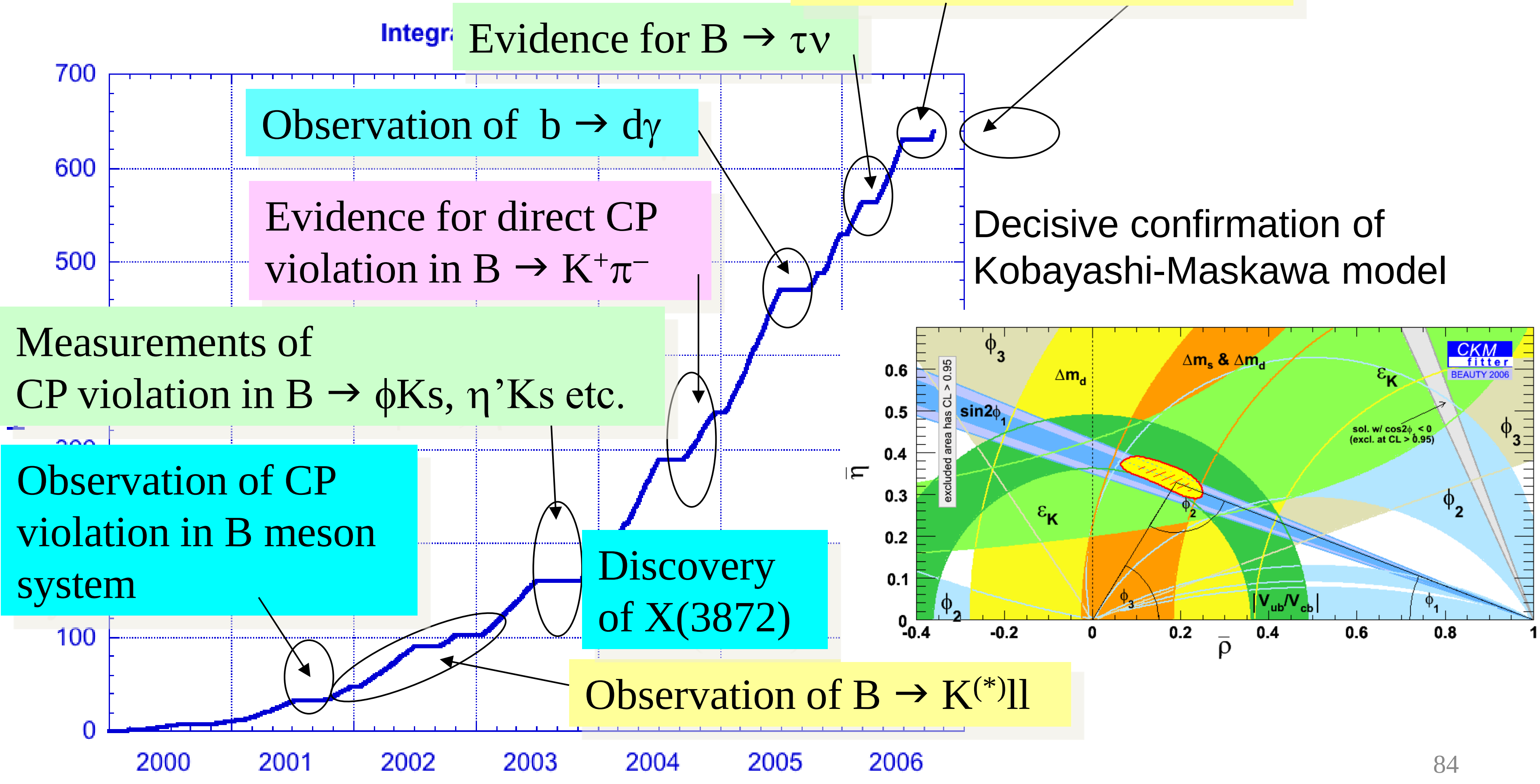
"A special search at Dubna was carried out by E. Okonov and his group. They did not find a single $K_L \rightarrow \pi^+ \pi^-$ event among 600 decays into charged particles [12] (Anikira et al., JETP 1962). At that stage the search was terminated by the administration of the Lab. The group was unlucky."

-Lev Okun, "The Vacuum as Seen from Moscow"

1964: BF= 2×10^{-3}

A failure of imagination ?

Major achievements at Belle (enabled by each succesive jump in luminosity)



Evidence for D^0 mixing

Observation of direct CP violation in $B \to \pi^+\pi^-$

Evidence for $B \to \tau\nu$

Observation of $b \to d\gamma$

Evidence for direct CP violation in $B \to K^+\pi^-$

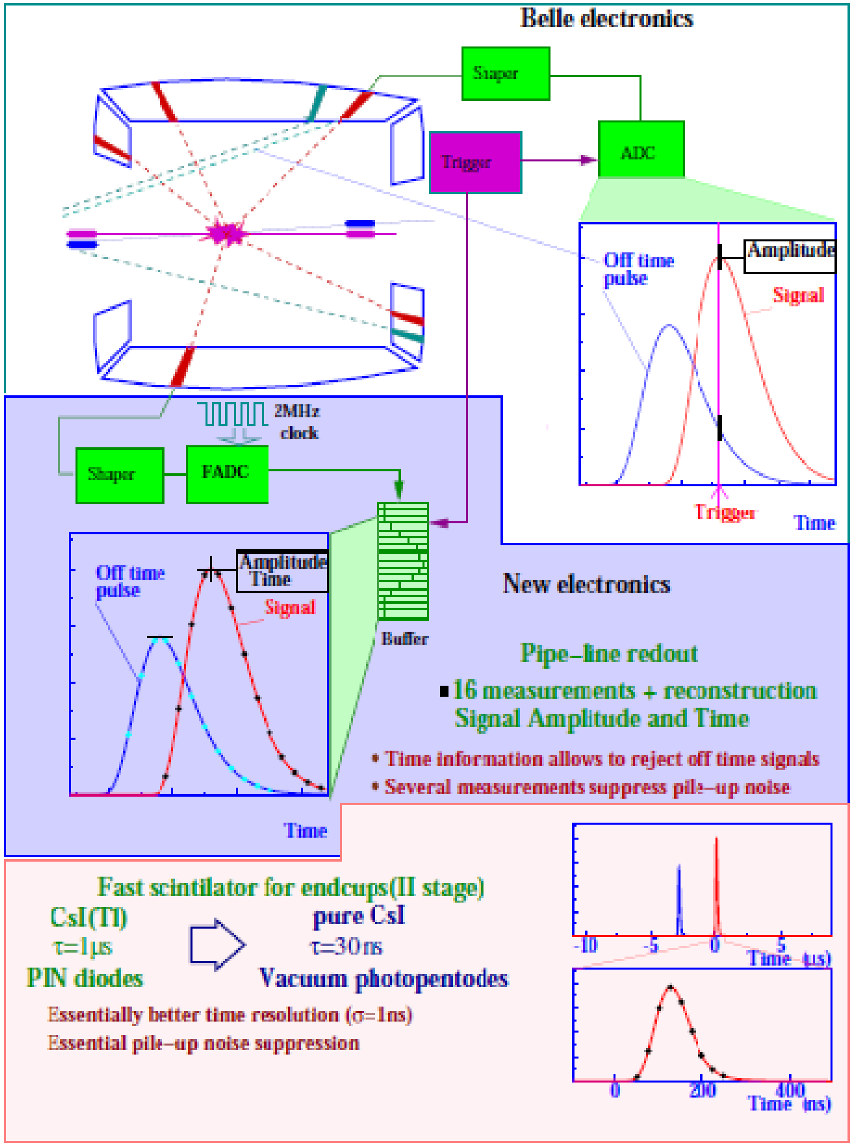
Decisive confirmation of Kobayashi-Maskawa model

Measurements of CP violation in $B \to \phi K_s$, $\eta' K_s$ etc.

Observation of CP violation in B meson system

Discovery of X(3872)

Observation of $B \to K^{(*)}ll$



Pipe–line redout

- 16 measurements + reconstruction Signal Amplitude and Time

- Time information allows to reject off time signals
- Several measurements suppress pile–up noise

Fast scintilator for endcaps(II stage)

CsI(Tl) τ=1µs ⇨ pure CsI τ=30ns

PIN diodes ⇨ Vacuum photopentodes

Essentially better time resolution (σ=1ns)

Essential pile–up noise suppression

- Belle II can get advantage in π^0 and soft photon-detection efficiency and resolution in comparision with LHCb experiment
- Modify electronics for the barrel.
- Pipe-line readout with waveform analysis:
- 16 points within the signal are fitted by the signal function $F(t)$:

$$F(t) = A\ f(t - t_0)$$

A - amplitude of the signal and
t_0 – time of the signal,

$$\chi^2 = \sum (y_i - A\ f(t_i - t_0)) S^{-1}_{ij} (y_i - A\ f(t_i - t_0))$$

- Both amplitude and time information are reconstructed:
- Next stage: Replace the CsI(Tl) by the pure CsI crystals in endcaps.