Search for BNV, LNV, LFV at (Super-) Belle/KEKB

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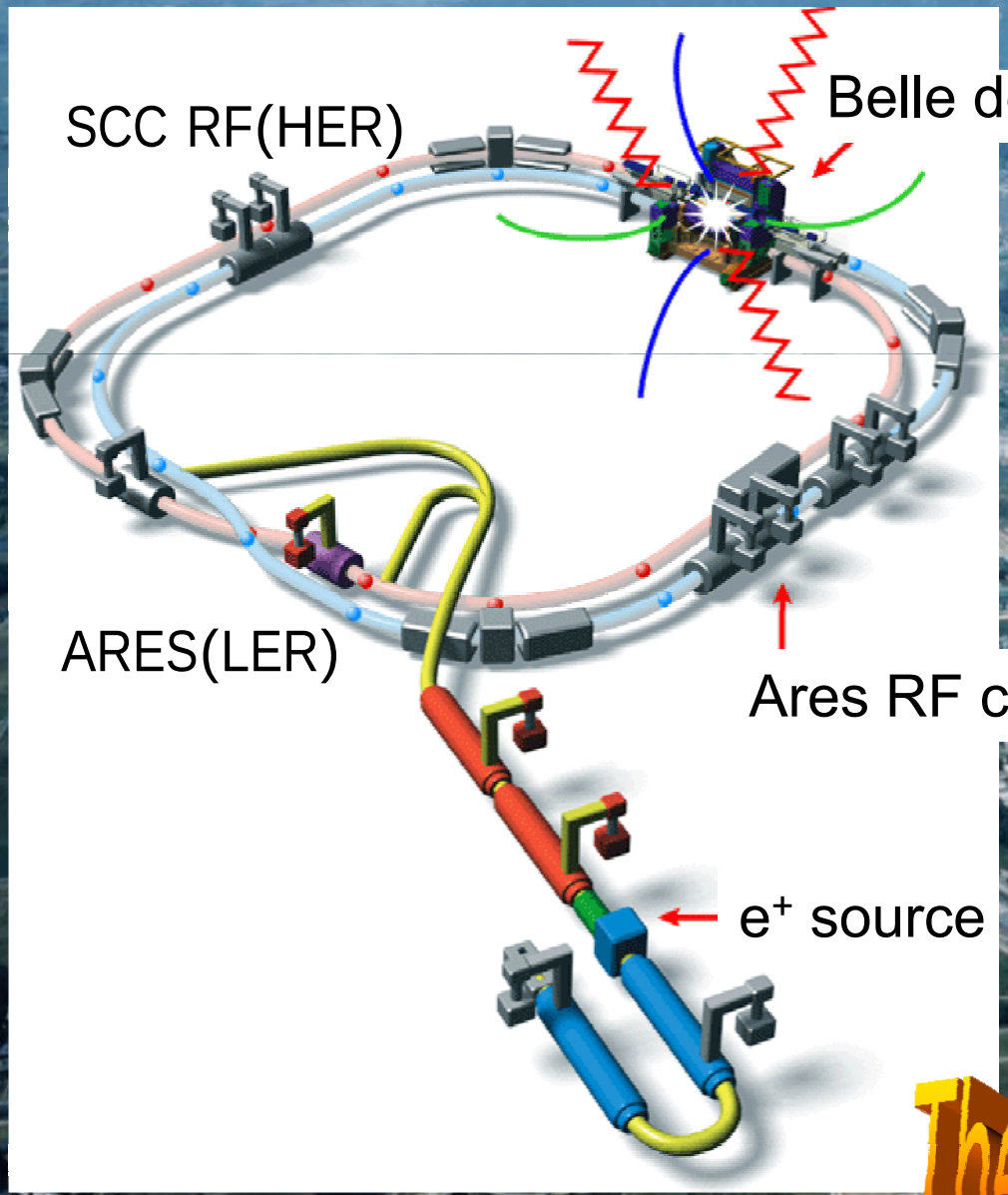
September 22, 2007

Search for Baryon and Lepton Number Violation Int'l Workshop @ LBL

The KEKB Collider



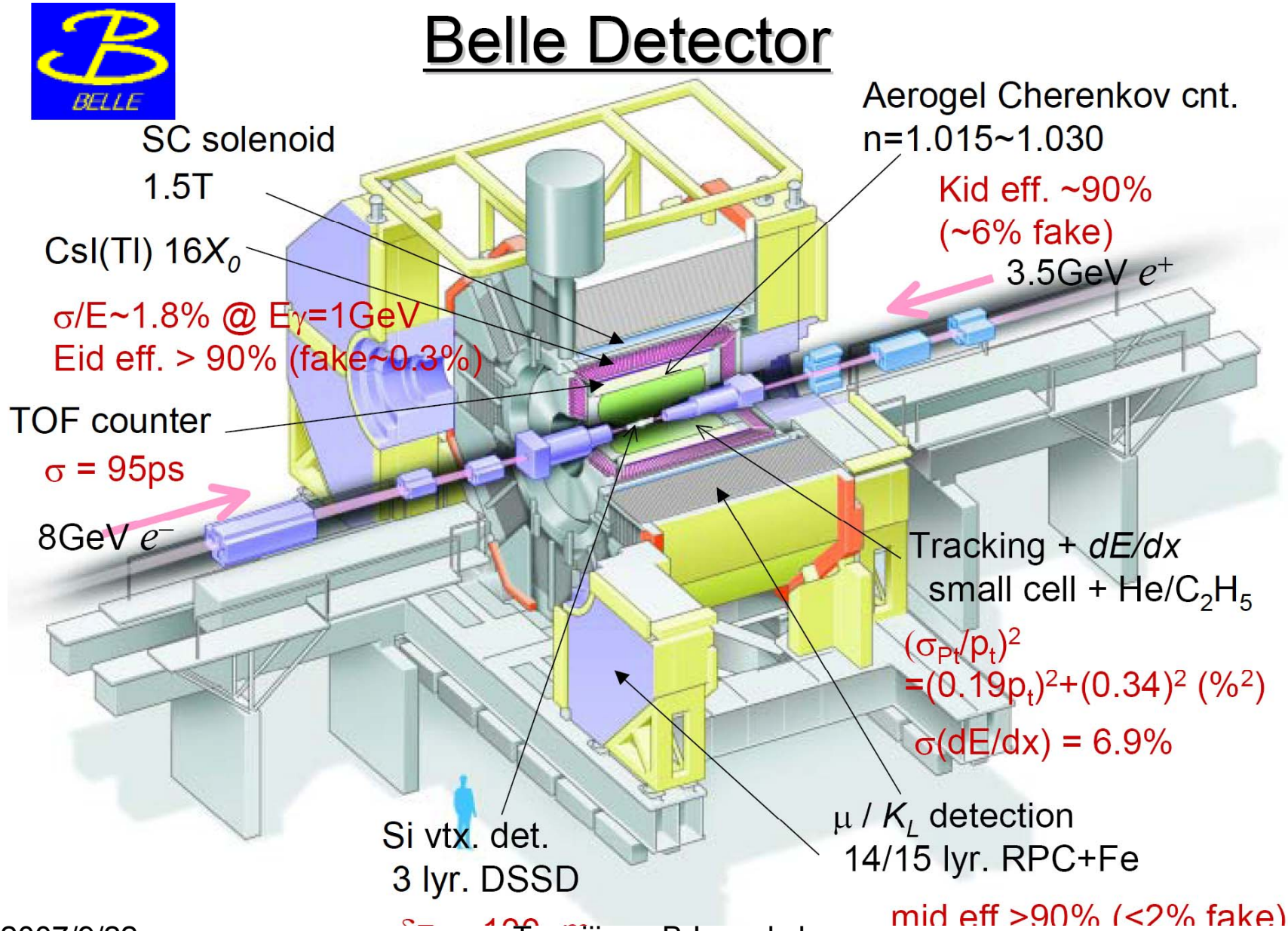
- e^- (8.0GeV) × e^+ (3.5GeV)
  - ⇒Υ(4S) →BB
  - ⇒Lorentz boost: βγ = 0.425
- Finite crossing angle
  - 11mrad ×2
- Operation since 1999.

Peak luminosity

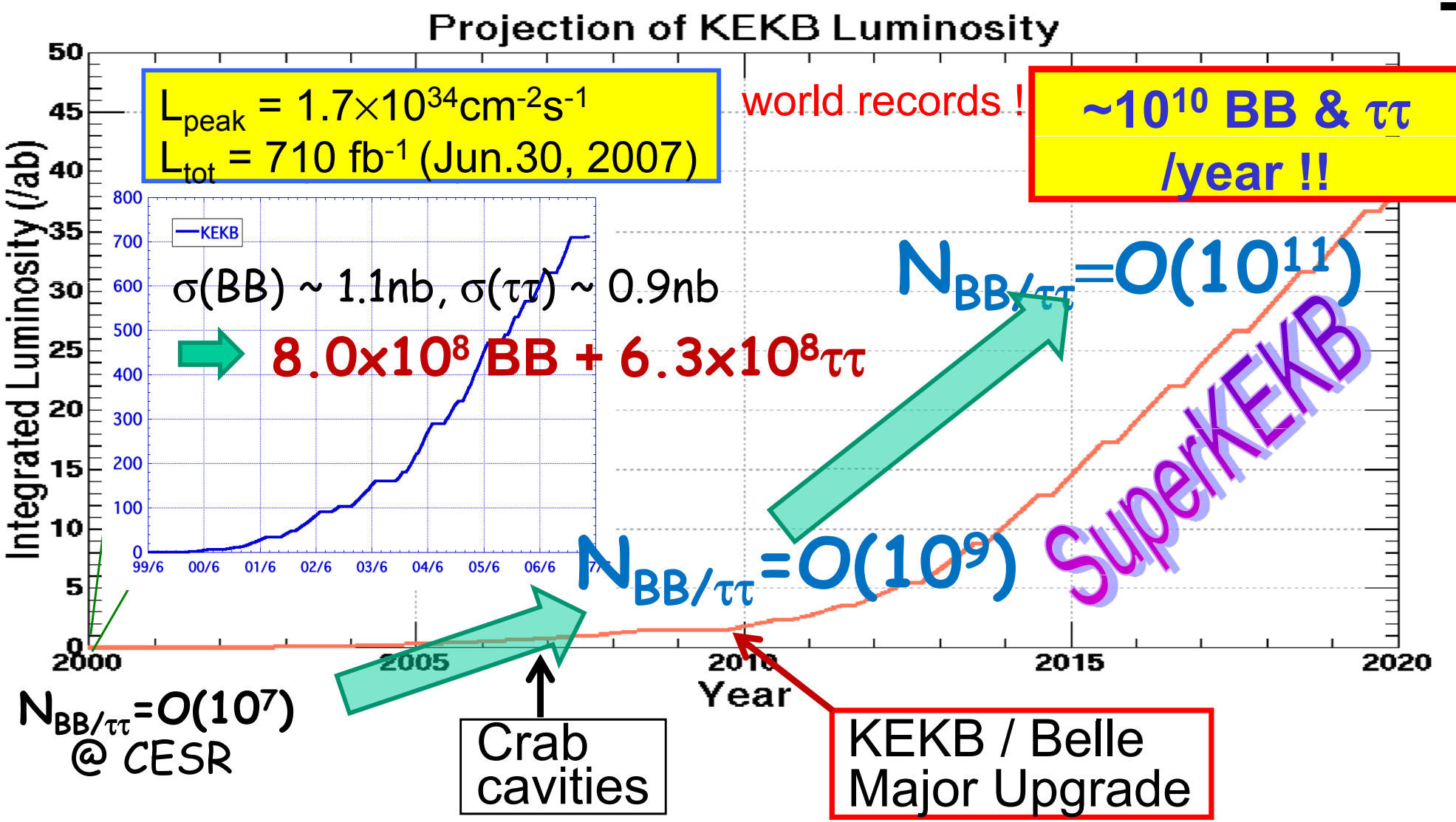
1.71×10^{34} cm^{-2}s^{-1} !

The World Highest Luminosity

Belle Detector



KEKB Integrated Luminosity

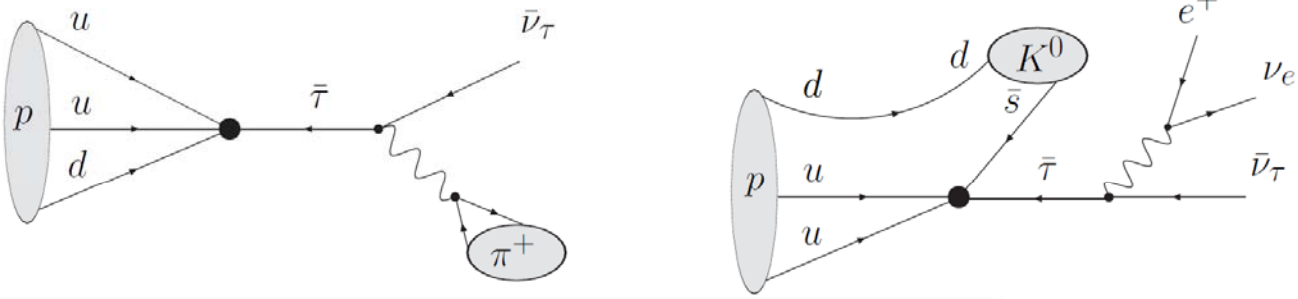


Unique opportunity to study BNV, LNV, LFV in higher generation !

BNV in Higher Generation

Hou, Nagashima, Soddu, PRD72,095001 (2005)

- B,L violating τ, D, B decays with right-handed four-fermion couplings.



$\mathrm{Br}(\tau \to \bar{p}\pi^0) \le 1.6\times10^{-4}$ $\left|C^R_{\mathrm{uudu}}\right|^2 \le 5.9\times10^{-39}$

proton decay limits;

τ

D

$\mathrm{Br}(D^0 \to p\ell^+) \propto \left|C^R_{\mathrm{ucd}\ell}\right| \le 4.0\times10^{-}$

$\mathrm{Br}(\bar{b} \to uu\ell^-) \propto \left|C^R_{\mathrm{uub}\ell}\right|^2 \le 2.4\times10^{-27}$

BNV τ/D/B decays are strongly suppressed by the proton stability,

But

Experimental redundancy is still important !

NP search in τ decays

τ lepton is the charged lepton, which is …

- In the 3rd generation
  - Probe for the NP flavor mixing between 3⇔1/3⇔2 gen.
- Heavy
  - Rate enhancement
  - Q>0 for decays to baryonic final states.

⇒ **τ lepton is an unique laboratory to study…**

- **BNV** B-L conserving. B-L violating.

  $\tau^- \to \bar{p}\gamma,\ \bar{p}\pi^0,\ \bar{p}K^0,\ \bar{\Lambda}\pi^-,\ \Lambda\pi^-$ ⋱

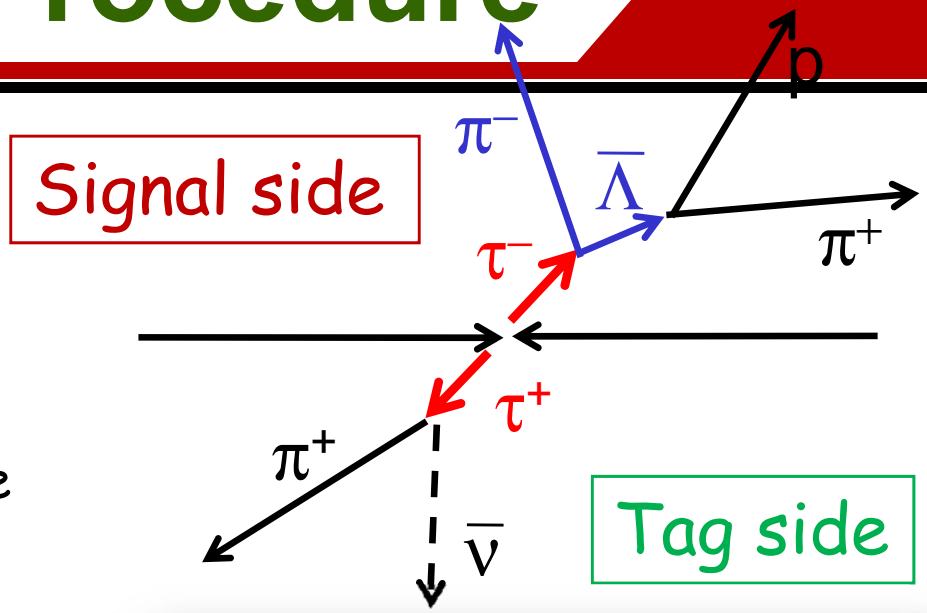
- **LNV** $\tau^- \to e^+/\mu^+ + h^-h^-$ $(h=\pi,K)$

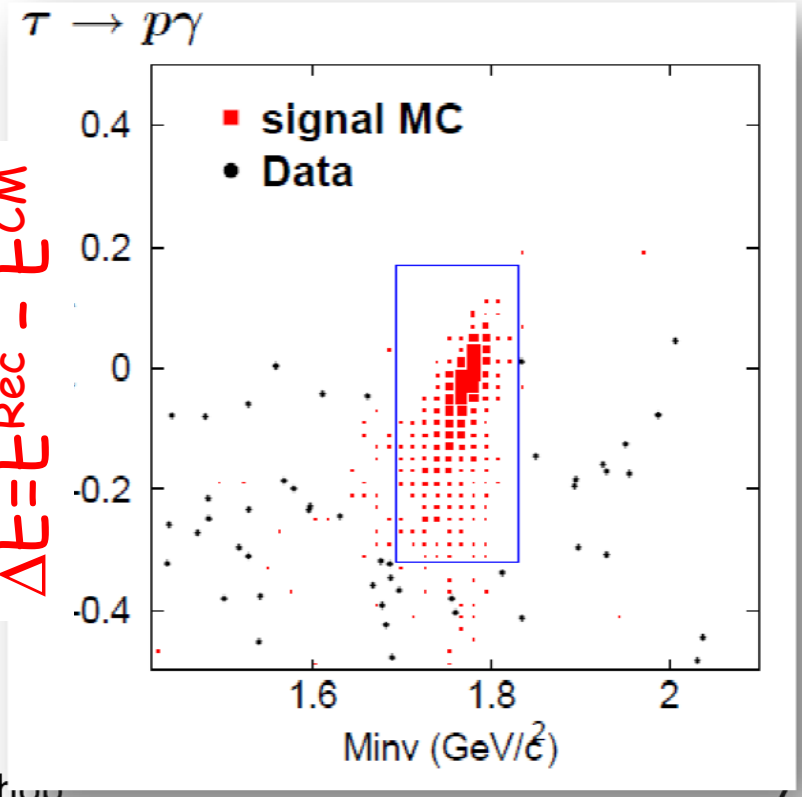
  BAU Leptogenesis

- **LFV** $\tau^- \to e^-/\mu^- + g,\ l^+l^-,\ h^+h^-,\ h^0,\ V^0$

General Analysis Procedure

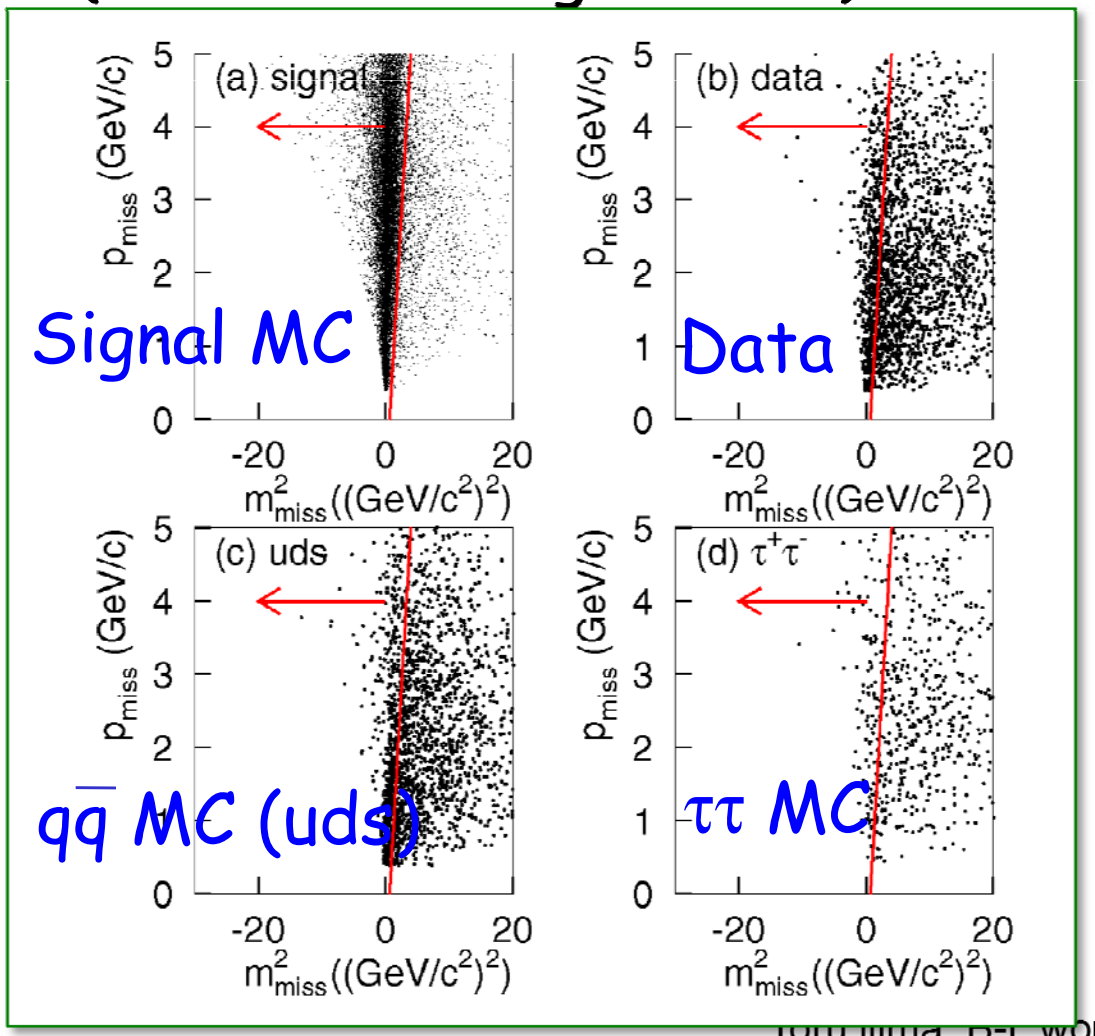
- Signal side:
  $\tau \rightarrow$ decay of interest
- Tag side:
  $\tau \rightarrow$ 1 trk w/ n γ + missing
  - 1-prong decays occupy >80% of the τ decay.
  - Loose constraint on ν based on P_{miss}, M^2_{miss}.
- Background
  - $\tau\tau$, continuum ($q\bar{q}$), $\mu\mu$, ee, ...
- Particle ID
- Signal evaluation based on
  $M_{inv} \sim M\tau$ & $\Delta E \sim 0$
- Signal region is open after analysis cuts are finalized.

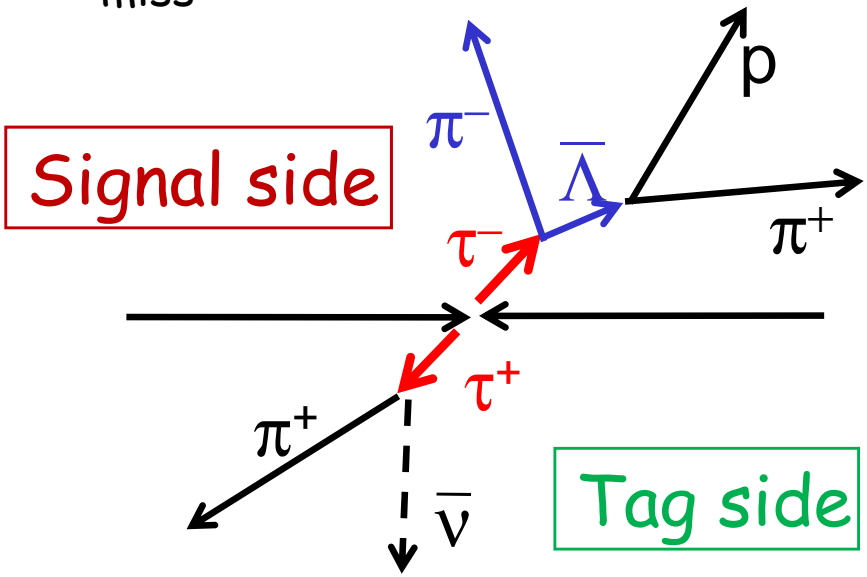




Kinematical Constraint

- Use correlation between m^2_{miss} and p_{miss}.
- Signal decays distribute around m^2_{miss} ~ zero (no. ν on the signal side).

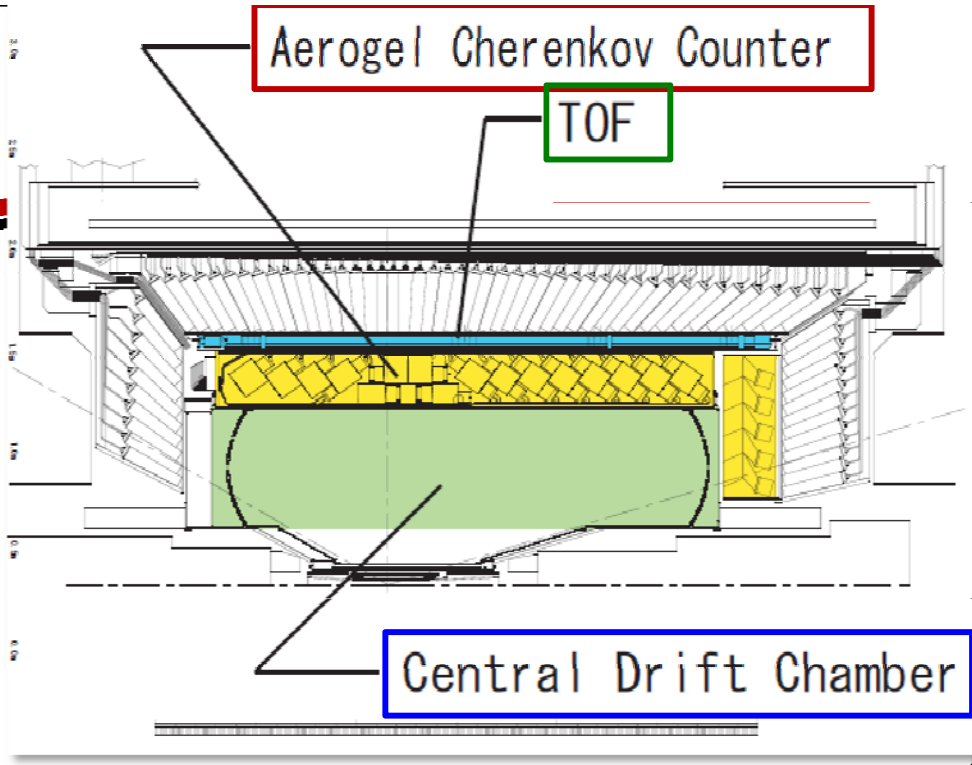




Y.Miyazaki et al., PLB632(2006)51-57

This cut removes 81% of $\tau\tau$ and 77% of $q\bar{q}$ backgrounds, while keeping 89% of the signal.

Hadron-ID @ Belle



- Hadron-ID @ Belle is based on the response of sub-detectors;
  - Threshold-type Aerogel Cherenkov Counter (ACC)

    n = 1.01→1.03 depending on θ

    $P_{th}(\pi)$ = 0.99 → 0.57 GeV/c
    $P_{th}(p)$ = 6.6 → 3.8 GeV/c
  - Time-Of-Flight (TOF)
  - Ionization loss in CDC (dE/dx)

- Combined to form a likelihood;

$$L_i = L_i(ACC) \times L_i(TOF) \times L_i(dE/dx)$$

- Use a cut on the likelihood ratio;

$$P(i:j) = \frac{L_i}{L_i + L_j}$$

Proton-ID performance w/ a nominal cut

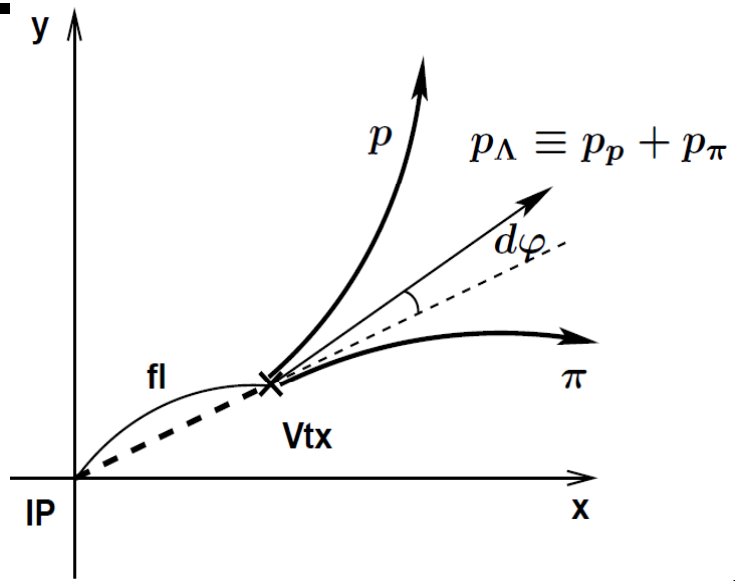
Eff(p)	= 70%
Fake(π→p)	= 4%
Fake(K→p)	= 11%

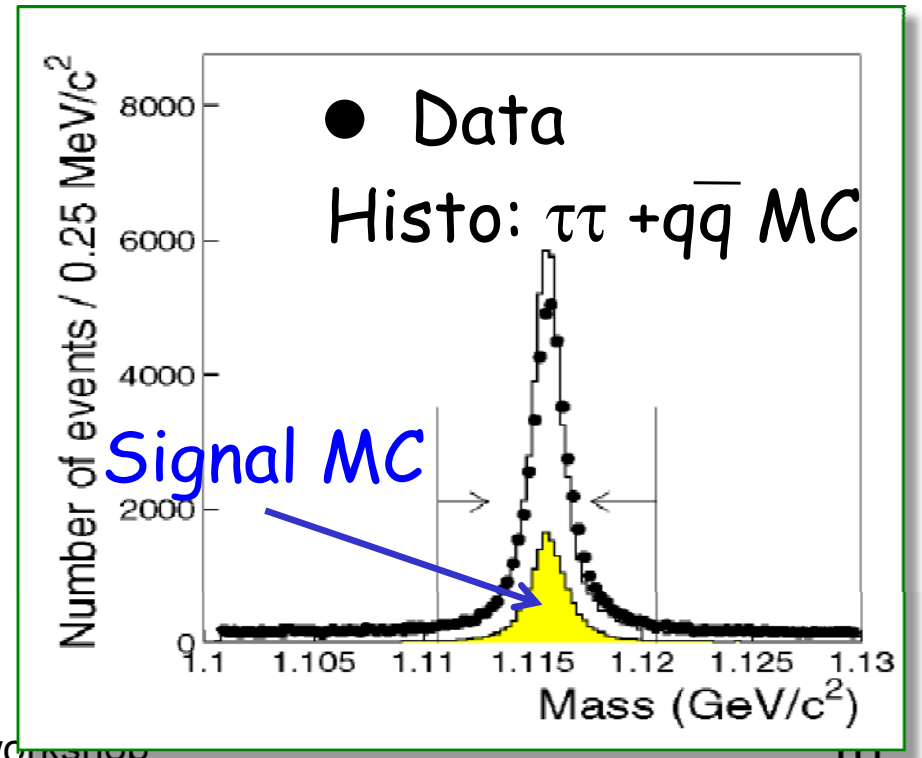
τ→ pγ, pπ^0 analyses use a different cut

At Super-Belle, large improvement is expected by using Ring imaging type Cherenkov detectors

Λ Reconstruction

- The Λ candidates are reconstructed via $p\pi^-$ decay channel.
- Selection parameters;
  - Angle difference between $\overrightarrow{P_\Lambda}$ and $\overrightarrow{IP\text{-}VTX}$.
  - Flight distance of Λ
  - Closest approach of the Λ daughter tracks to IP.
- Particle ID cut for daughter tracks.





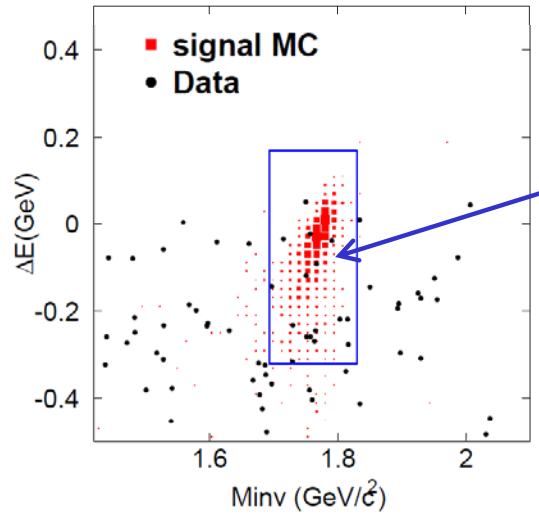
Λ selection efficiency ~ 80%
Purity ~ 90%

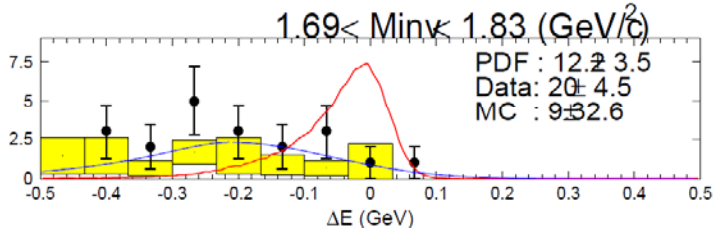
Y.Miyazaki et al.,
PLB632(2006)51-57

$\tau \to p\gamma$, $p\pi^0$

BELLE-CONF-0433
hep-ex/ 0408117

- $\tau \to p\gamma$ (86.7fb^{-1})

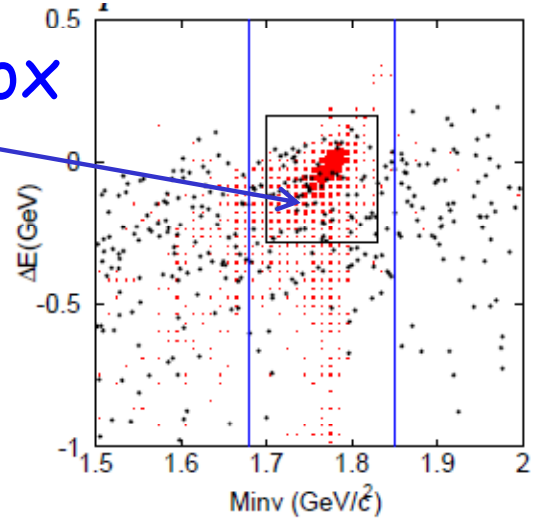


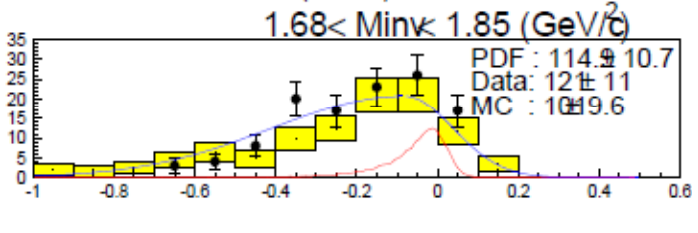


- N_{obs} = 16 Δ=6.9±4.3
  N_{bkg} = 9.1±1.7 (expected)
  Br ($\tau^- \to \bar{p}\gamma$) < 3.0×10^{-7}

5σ signal box

- $\tau \to p\pi^0$ (153.8fb^{-1})





- N_{obs} = 70 Δ=17.8±11.1
  N_{bkg} = 52.2±7.3 (expected)
  Br ($\tau^- \to \bar{p}\pi^0$) < 6.5×10^{-7}

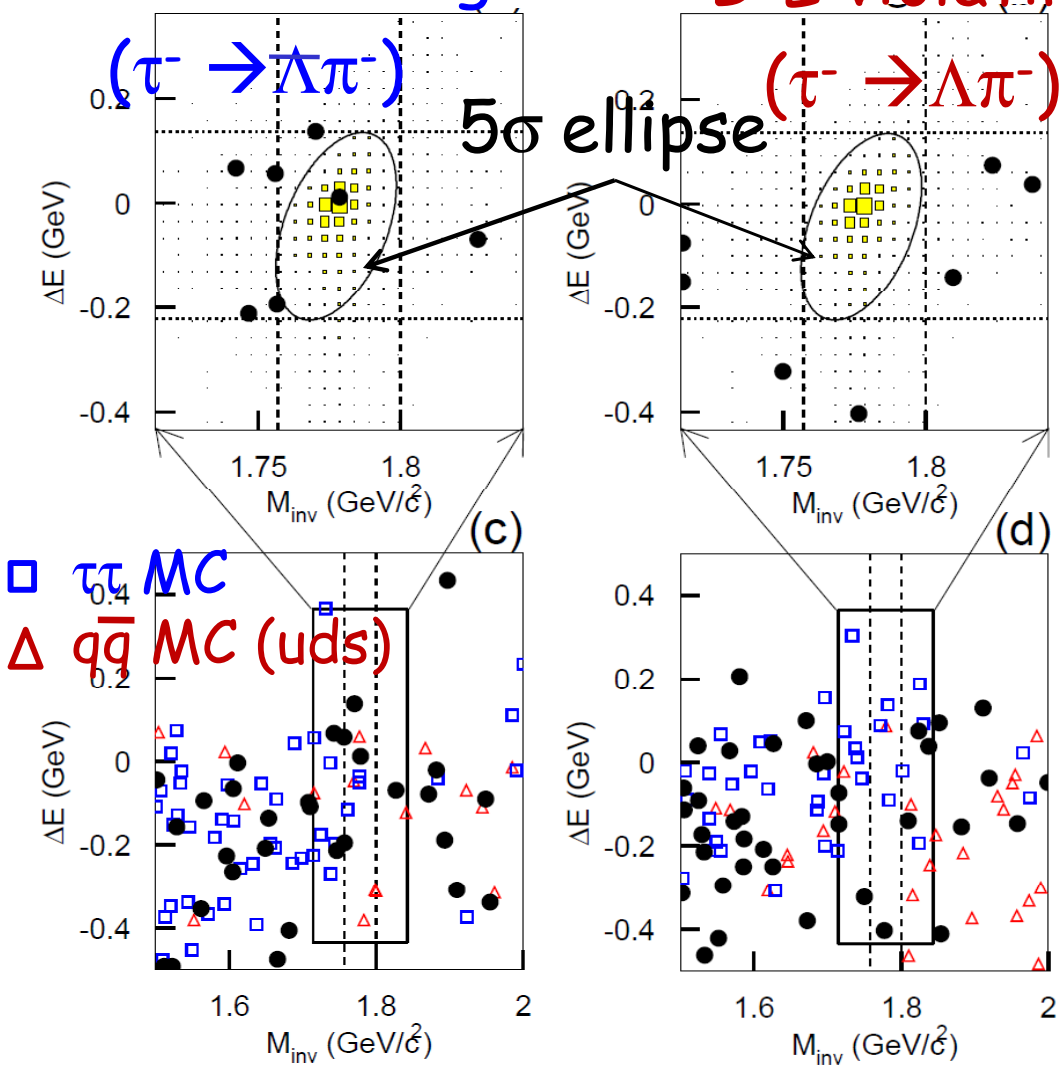
(UL determined by an unbinned ML fit)

$\tau \to \Lambda\pi$ @154fb^{-1}

Y.Miyazaki et al.,
PLB632(2006)51-57

B-L conserving ($\tau^- \to \bar{\Lambda}\pi^-$)

B-L violating ($\tau^- \to \Lambda\pi^-$)



BKG: ττ (~1/2) + $q\bar{q}$ (~1/2)

We evaluate UL using 5σ ellipse. BKG are extrapolated from 15σ box assuming flat dist.

	Con.	Vio.
Eff(%)	11.8	11.7
N_{side}	5	5
N_{bka}(exp'd)	1.7±0.8	1.7±0.8
N_{obs}	1	0
S_{90}	2.77	1.47
Br ($\times 10^{-7}$)	<1.3	<0.70

S_{90}: Feldman-Cousins UL of #signals @ 90% CL. including systematic errors (POLE)

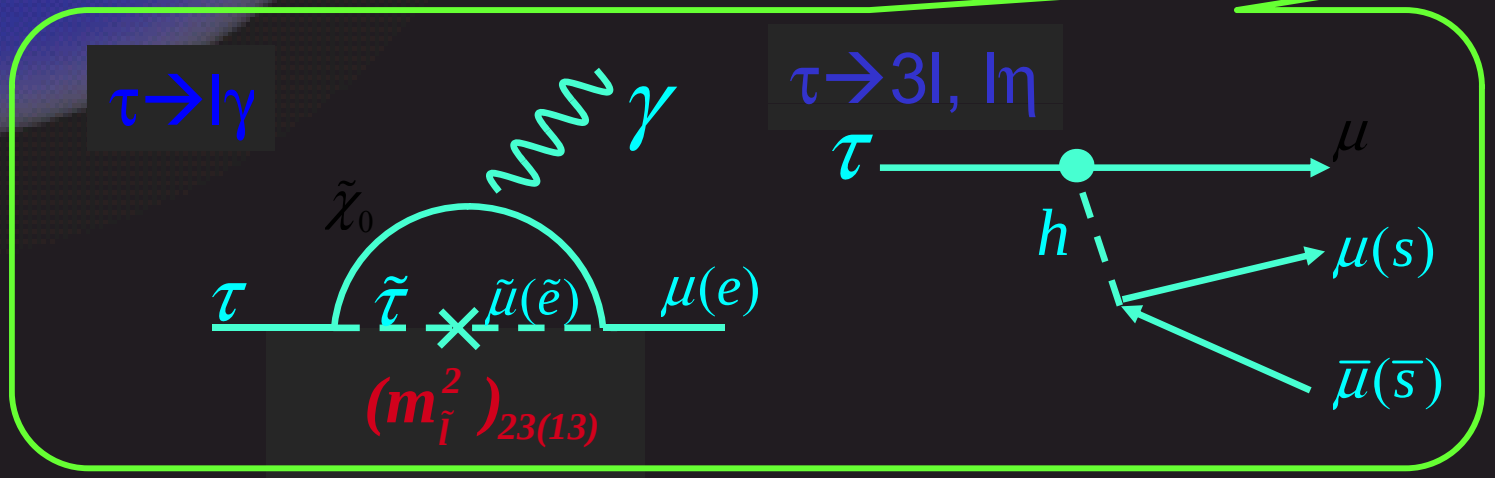
Only a few background
→ Will be improved by $1/L_{int}$

LFV in τ Decays

- Probe for 3⇔1/3 ⇔2 gen. mixing in the charged lepton sector.

Slepton mass matrix

$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & m^2_{\tilde{e}\tilde{\mu}} & m^2_{\tilde{e}\tilde{\tau}} \\ m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & m^2_{\tilde{\mu}\tilde{\tau}} \\ m^2_{\tilde{\tau}\tilde{e}} & m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$



- Br(τ) = O($10^{3\text{-}5}$) x Br(μ). Enough chance to see τ→μγ or τ→lll.
- The two decays have different sensitivity for different NP models.

Models	$\tau \to \mu\gamma$	$\tau \to \ell\ell\ell$
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}

$\tau \to l\gamma$, $l\eta$,$l\eta'$,$l\pi^0$

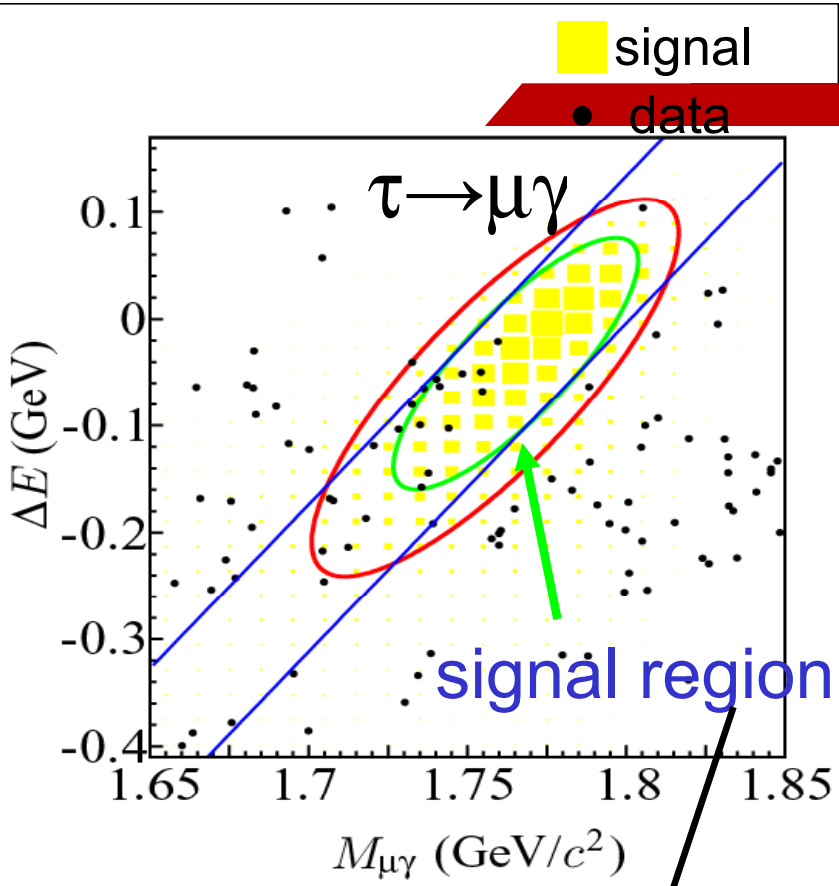
$\tau \to \mu\gamma, e\gamma$ @535fb^{-1}

(hep-ex/0705.0650 submittedd to PLB)

Br($\tau \to \mu\gamma$)<4.5x10^{-8} (90%C.L.)

Br($\tau \to e\gamma$)<1.2x10^{-7} (90%C.L.)

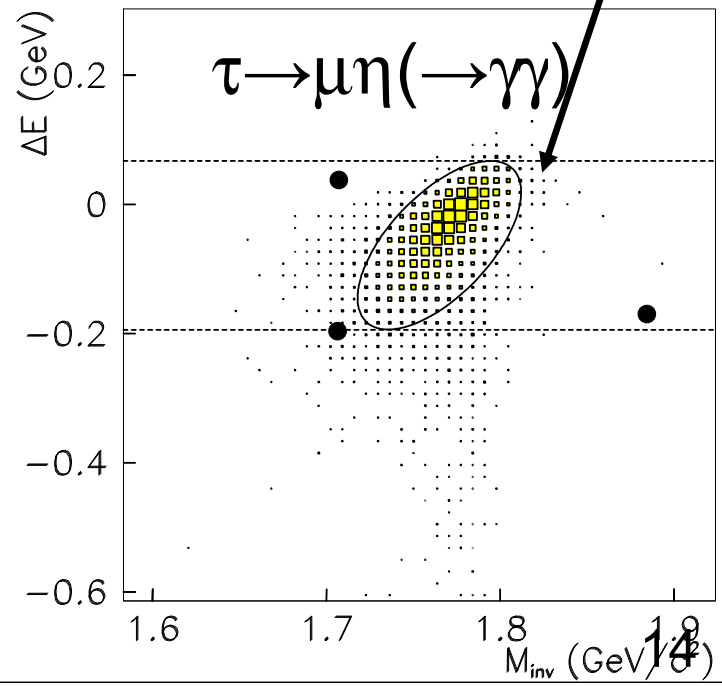
Bkg. from $\tau\tau/\mu\mu$ + initial state γ



$\tau \to e/\mu + \eta,\eta',\pi^0$ @ 401fb^{-1}

(PLB648, 341 (2007))

Br($\tau \to l\eta, l\eta', l\pi^0$) <(6.5-16)x10^{-8} 90%C.L.



⇒Upper limits for LFV τ decays are approaching $O(10^{-8})$

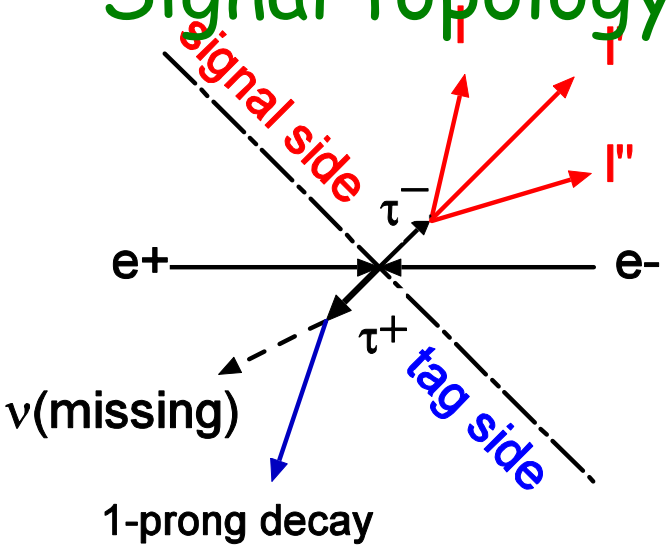
$\tau \to e/\mu + \eta,\eta',\pi^0$

Only a few background

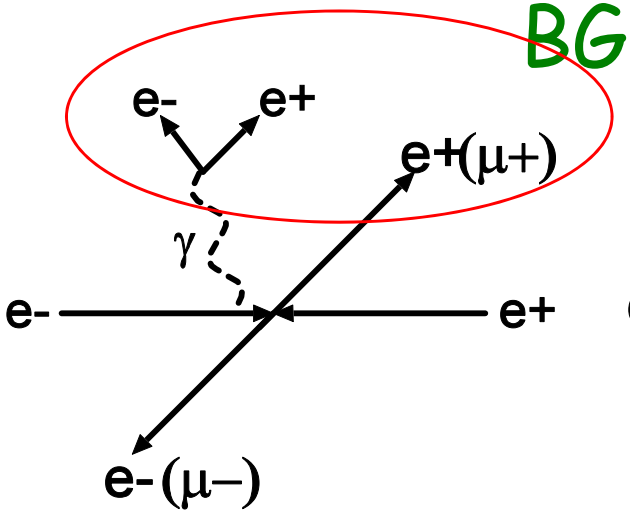
→ Will be improved by $1/L_{int}$

τ→lll: Background suppression

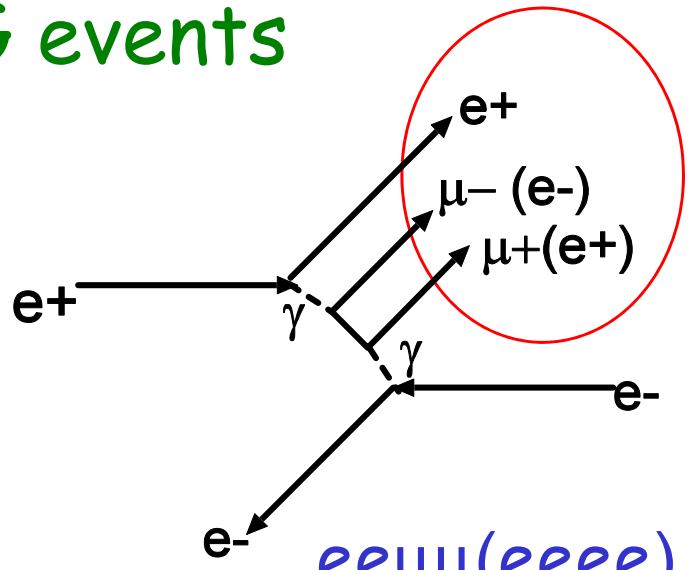
Signal topology



BG events



Bhabha(μμ)



eeμμ(eeee)

electron-veto on the tag-side

(e-e+e- and e-μ+μ-)

γ-conversion veto

(e-e+e- and μ-e+e-)

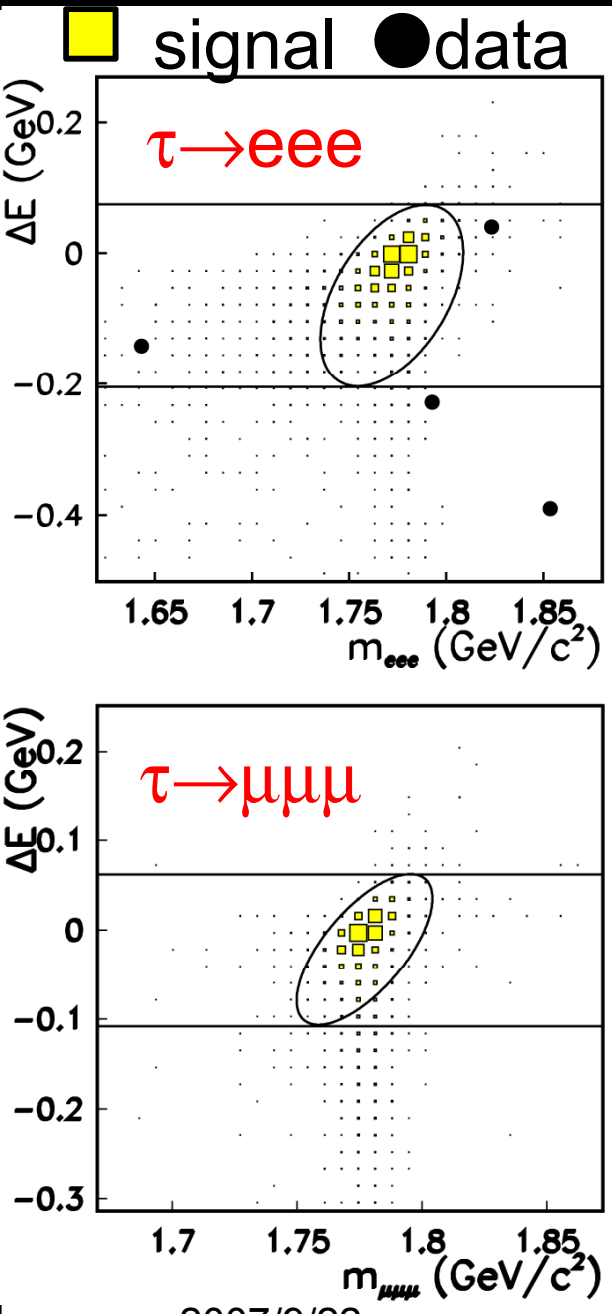
m^2_{miss} and p_{miss}

(e-e+e-, μ-μ+μ-, e-μ+μ-, μ-e+e-)

mode	$\mu^-\mu^+\mu^-$	$e^-e^+e^-$	$\mu^-e^+e^-$ $e^-\mu^+\mu^-$	$\mu^+e^-e^-$ $e^+\mu^-\mu^-$
Dominant bkg.	ττ qq μμμμ	Bhabha eeee ττ	eeμμ ττ μμ	ττ qq

$\tau \to lll$ @535fb^{-1}

New !



- Efficiency: 6.0% - 12.5%
- N_{bkg} (expected) = 0 – 0.4 events
- No event found in the signal region
- Obtained upper limit (90%CL)

$Br < (2.0\text{-}4.1) \times 10^{-8}$

Improved by 4.9-7.0 from Belle previous results @ 90fb^{-1}

preliminary

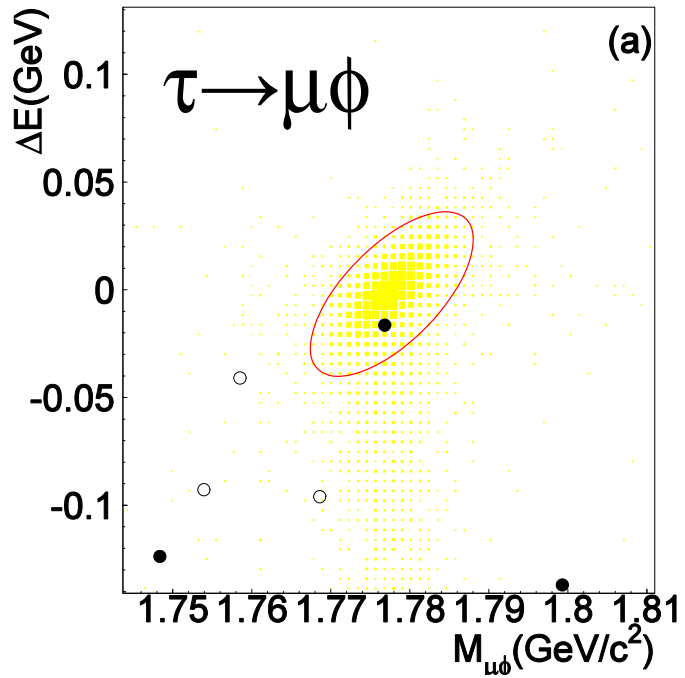
mode	U.L. of Br @90%C.L.
$\tau^- \to e^- e^+ e^-$	3.6×10^{-8}
$\tau^- \to \mu^- \mu^+ \mu^-$	3.2×10^{-8}
$\tau^- \to e^- \mu^+ \mu^-$	4.1×10^{-8}
$\tau^- \to \mu^- e^+ e^-$	2.7×10^{-8}
$\tau^- \to e^+ \mu^- \mu^-$	2.3×10^{-8}
$\tau^- \to \mu^+ e^- e^-$	2.0×10^{-8}

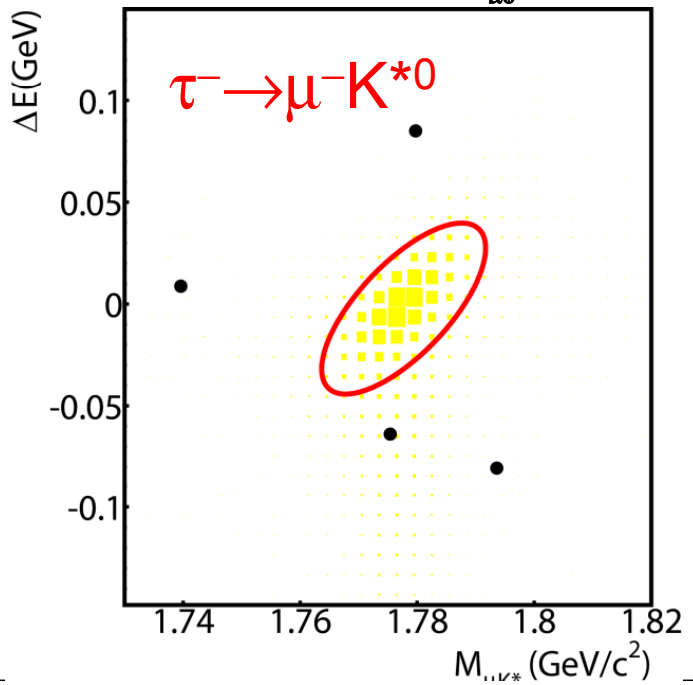
The most stringent upper limits among LFV τ decays

Still a few background
→ Will be improved by $1/L_{int}$

$\tau \to l V^0$ @543fb^{-1}

New !





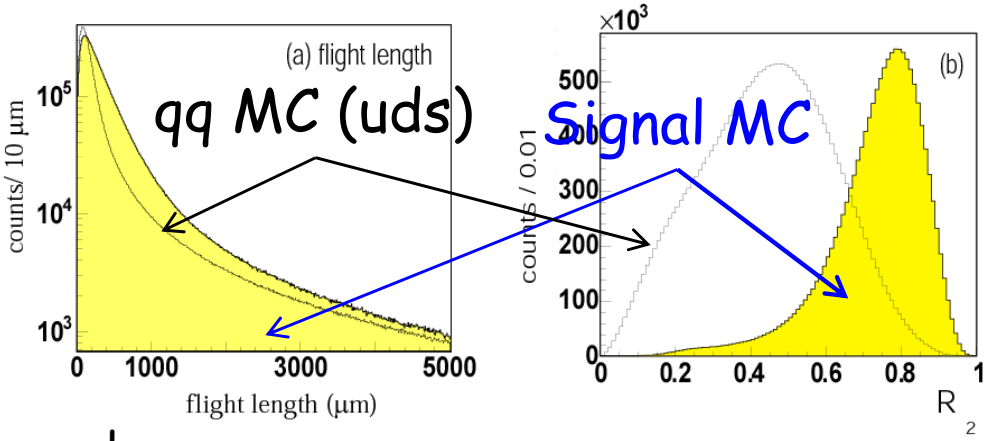
mode	Belle(158fb^{-1}) @90%C.L.	Belle(543fb^{-1}) @90%C.L.
$\tau^- \to \mu^- \phi$	7.7×10^{-7}	**1.3×10^{-7}**
$\tau^- \to e^- \phi$	7.3×10^{-7}	**7.6×10^{-8}**
$\tau^- \to \mu^- \omega$	-	**9.0×10^{-8}**
$\tau^- \to e^- \omega$	-	**1.8×10^{-7}**
$\tau^- \to \mu K^{*0}$	3.9×10^{-7}	**6.1×10^{-8}**
$\tau^- \to e^- K^{*0}$	3.0×10^{-7}	**8.0×10^{-8}**
$\tau^- \to \mu^- K^{*0}$	4.0×10^{-7}	**1.1×10^{-7}**
$\tau^- \to e^- K^{*0}$	4.0×10^{-7}	**7.7×10^{-8}**
$\tau^- \to \mu^- \rho^0$	2.0×10^{-7}	
$\tau^- \to e^- \rho^0$	6.5×10^{-7}	

Still a few background
→ Will be improved by $1/L_{int}$

$\tau \rightarrow lhh$ @158fb^{-1}

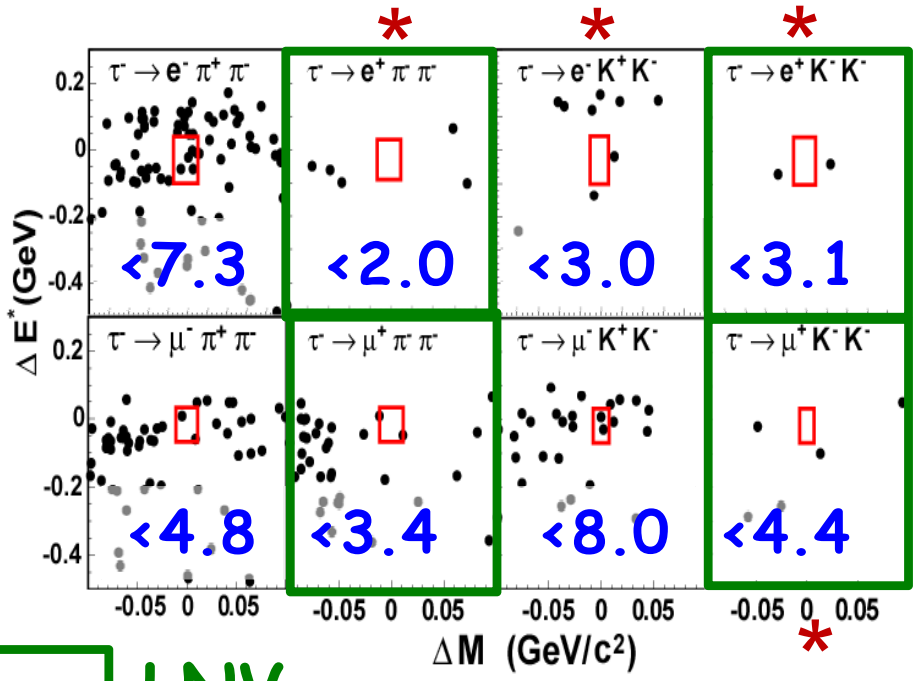
Y.Yusa et al.,
PLB640(2006)138-144

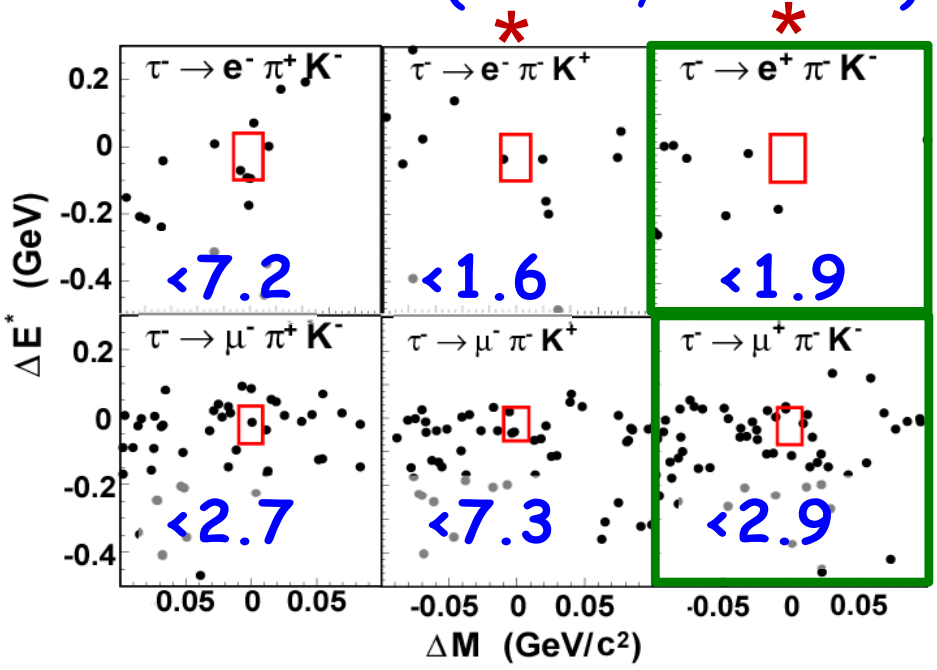
- τ_{signal} → μ/e + 2 chg. tracks
  τ_{tag} → μ/e + nγ
- Background: $\tau\tau$, qq
- Continuum bkg. suppression by
  τ flight length & R_2
  →2D PDF → Likelihood ratio



$$R = \frac{L_{\tau\tau}}{L_{\tau\tau} + L_{qq}} > 0.45$$

UL (x10^{-7}, 90%CL)

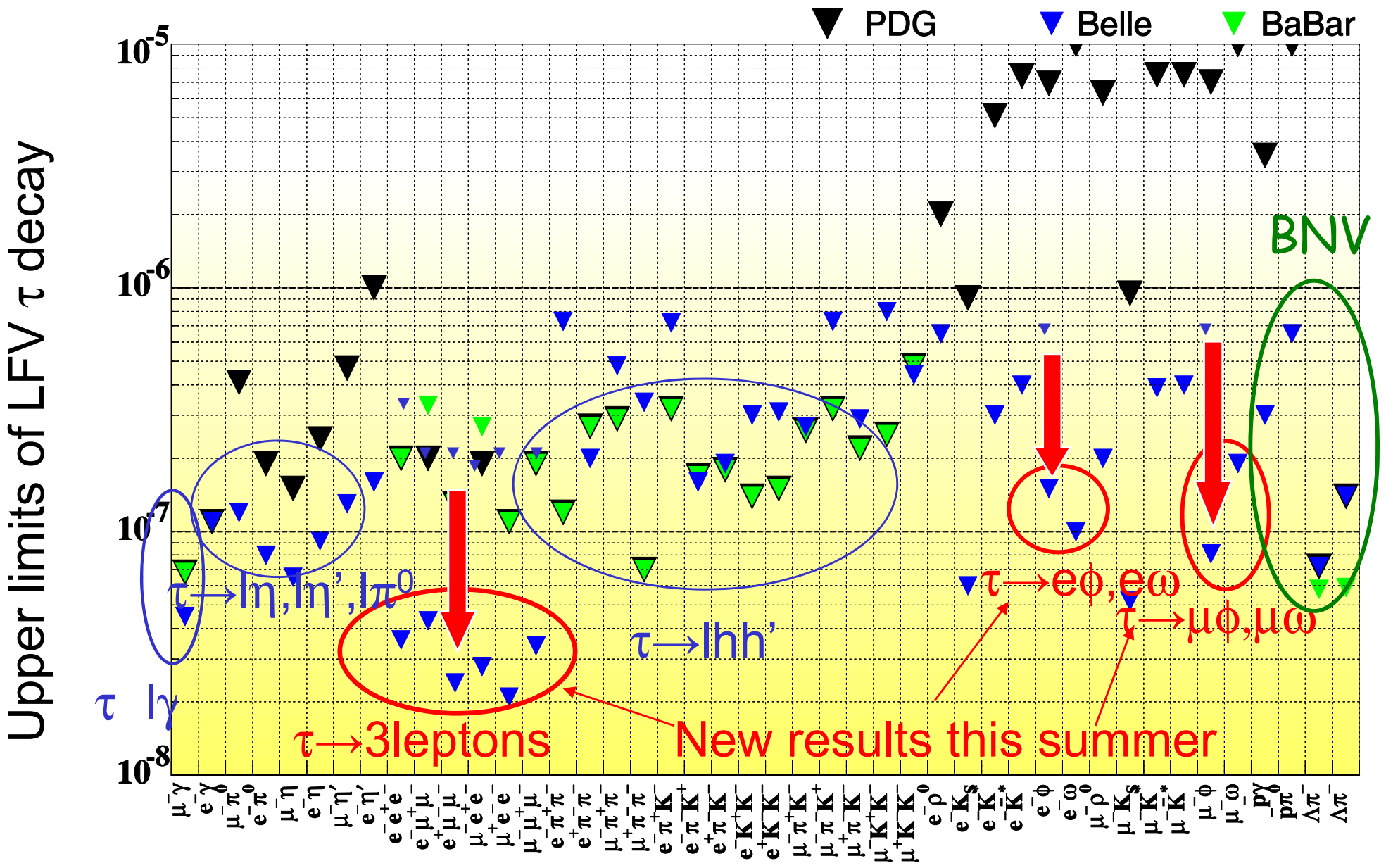




LNV

*Still a few background → Will be improved by $1/L_{int}$

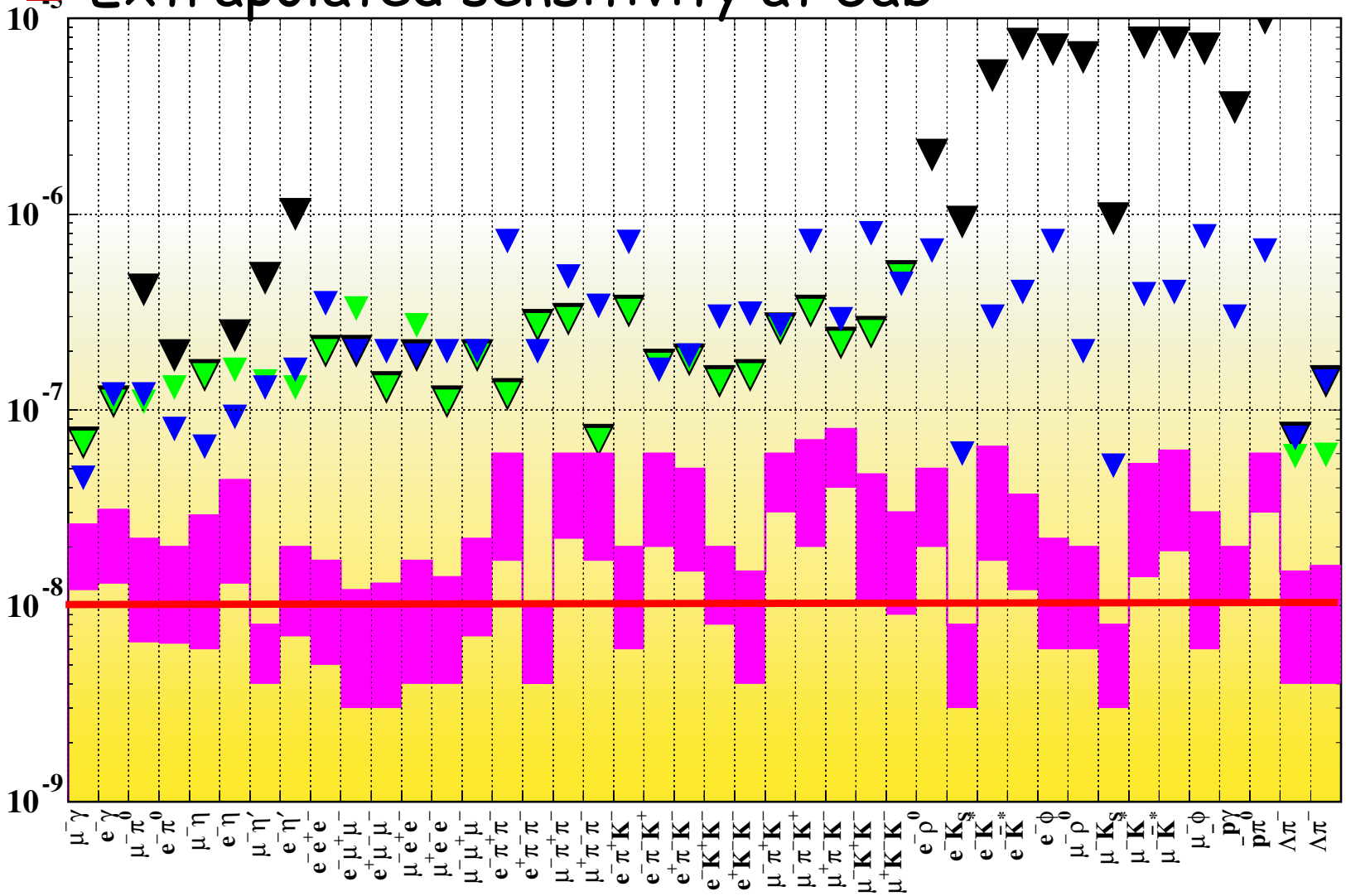
Summary for non-SM τ Decay Search



ULs for all LFV τ decays are approaching the 10^{-8} level

Future prospect

Extrapolated sensitivity at 5ab^{-1}



PDG2006
Belle
Babar

based on eff. and N_{BG} of most sensitive analysis

Estimated upper limit range of Br

Ambiguity due to the stat. error of the bkg. estimation in the preset data.

Super-KEKB

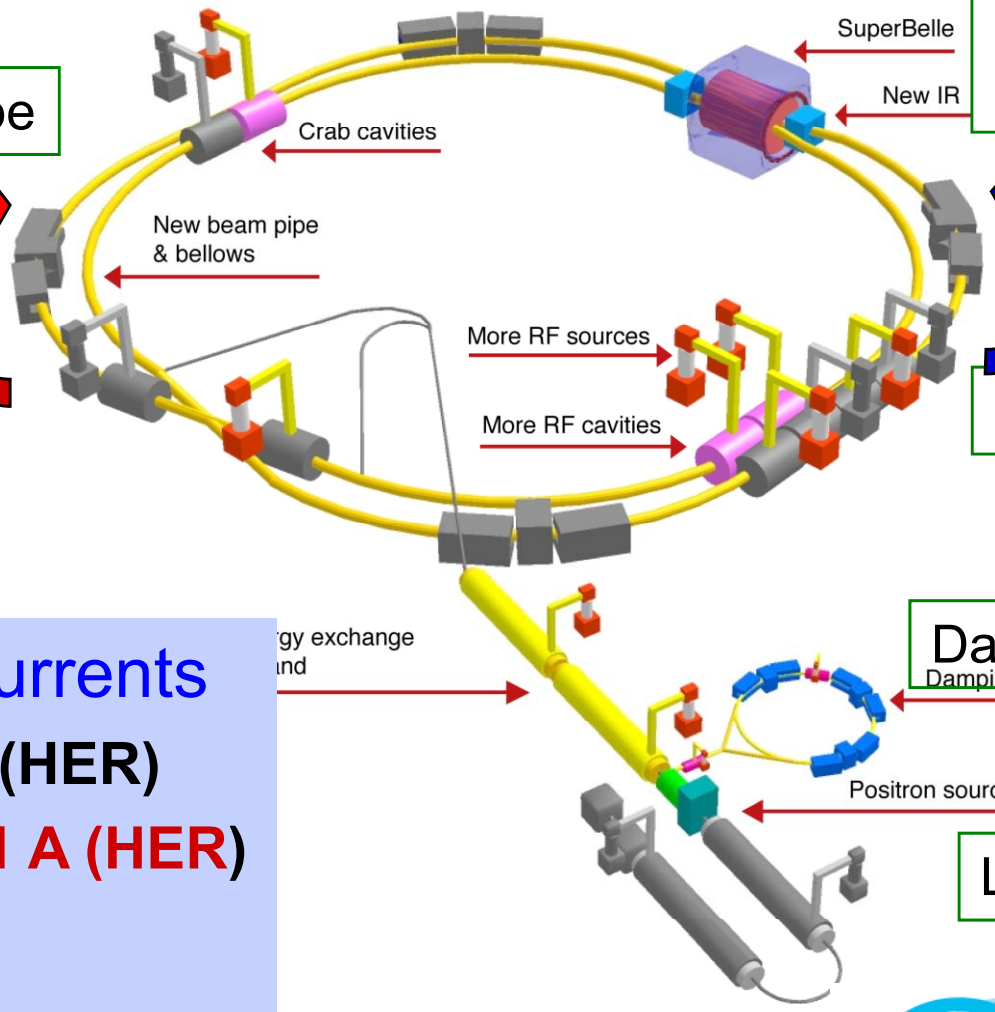
Interaction Region
~~Crab crossing~~
θ=30mrad.
βy*=3mm
New QCS

New Beam pipe

8GeV (e+, 4.1A)

3.5GeV (e-, 9.6A)

More RF power



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

Damping ring

Linac upgrade

Increase beam currents

- **1.6 A (LER) / 1.2 A (HER)**
  → **9.4 A (LER) / 4.1 A (HER)**

Smaller β_y^*

- **6 mm→3 mm**

Increase ξ_y

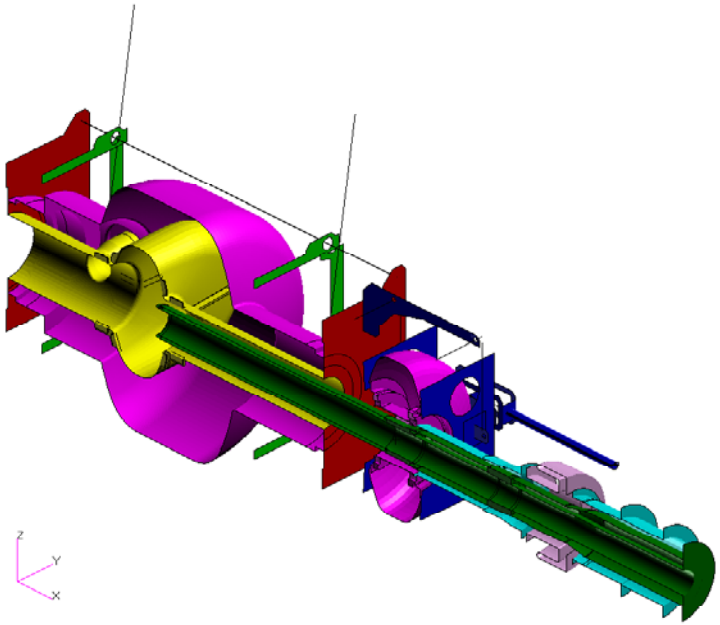
- **0.059→>0.24(W-S)**

$L=8\times10^{35}cm^{-2}s^{-1}$

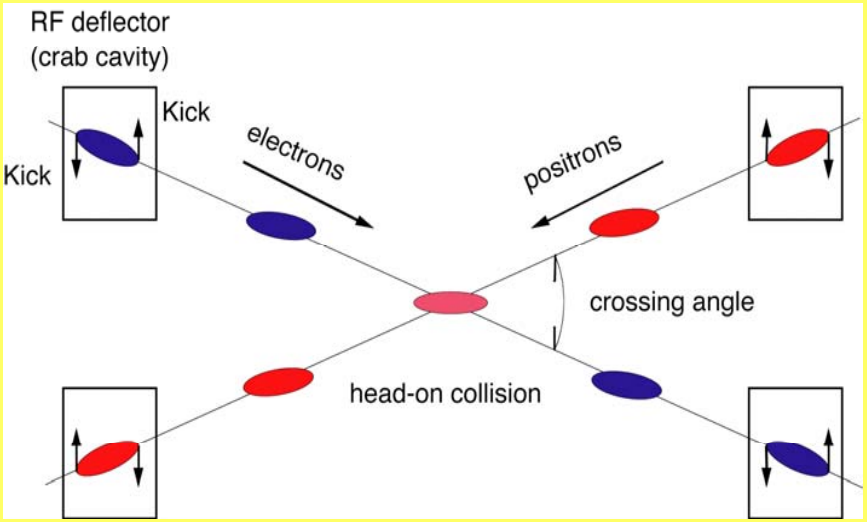
Super KEKB
uest for BSM

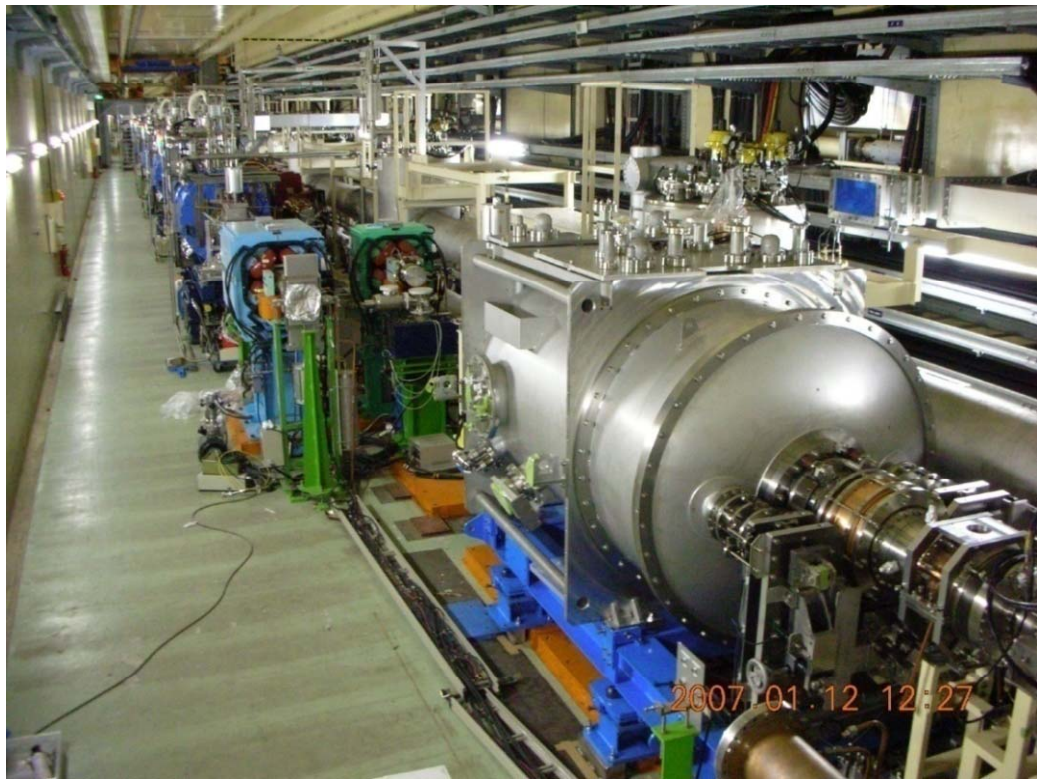
Crab Cavity

- Superconducting crab cavities (1LER and 1HER) have been installed, and being tested at KEKB.



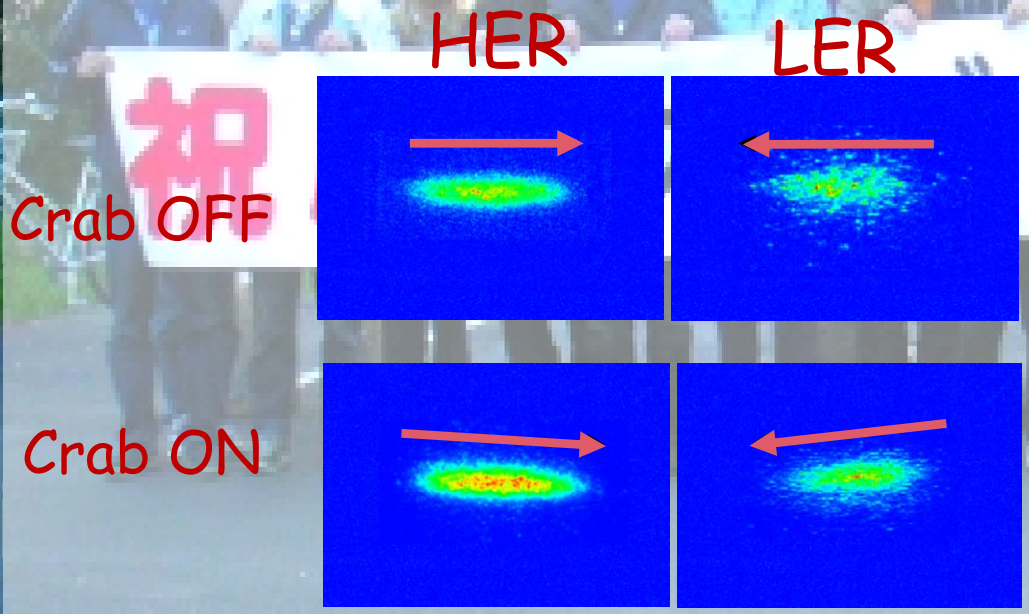
$$L \approx \frac{\gamma_{\pm}}{2er_e}\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}$$

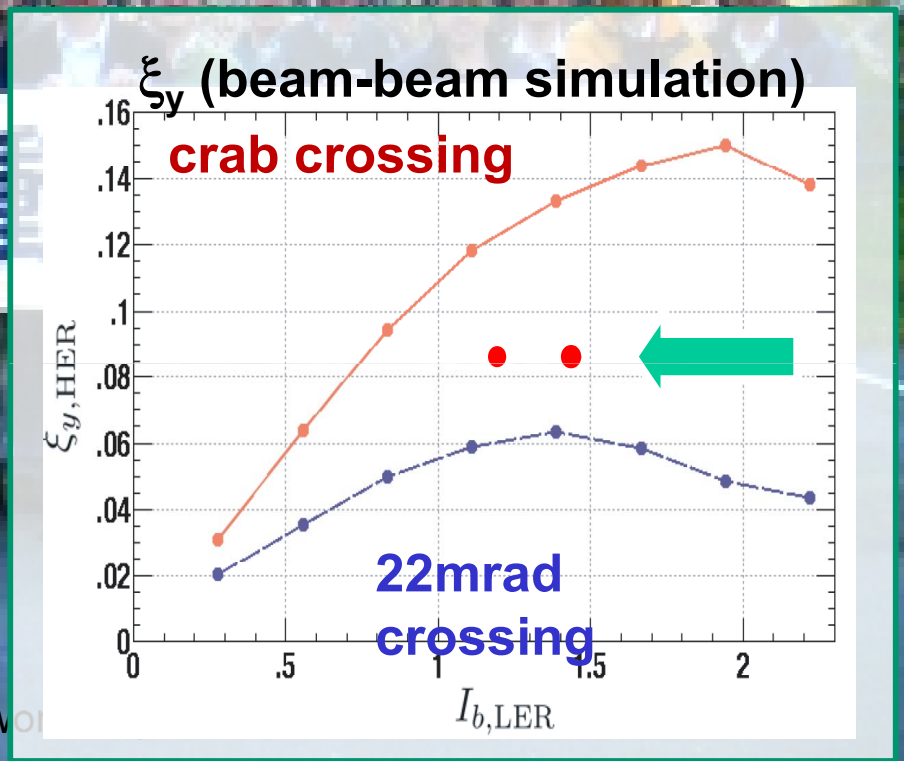




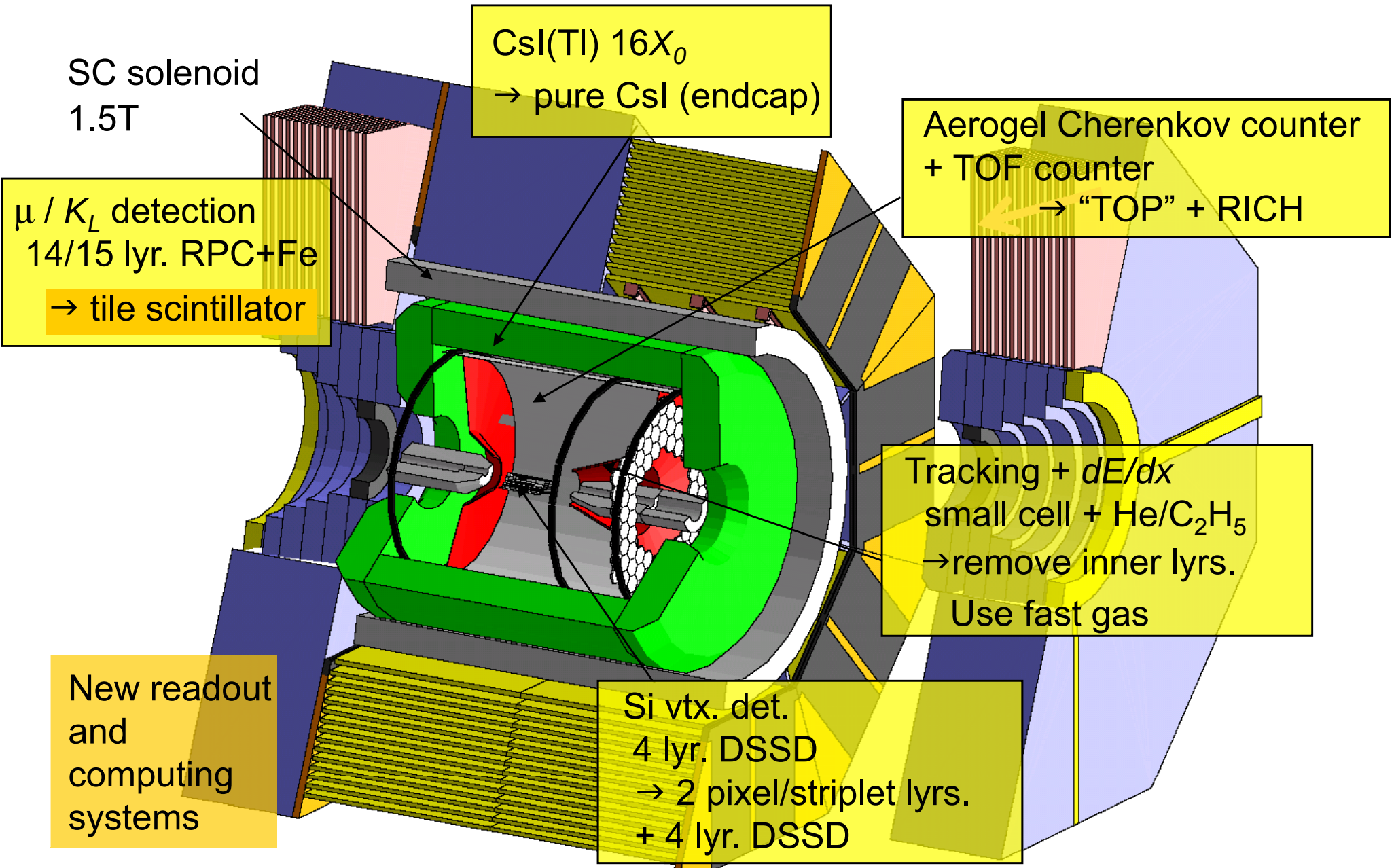
Crab Status

- Crab cavity installed in Jan. 2007.
- Beam-beam tune shift (0.088) achieved at low currents.
- Beam current gradually increased
  → $L=10^{34}cm^{-2}s^{-1}$ with crab crossing by June 2007.
- Still need R&D/tuning to see L improvement (simulation predicts x2).





Belle Upgrade



Summary

- B-factories provide an unique opportunity to study BNV, LNV, LFV in higher generation.
- The present KEKB provides 6×10^8 $\tau\tau$ pairs
  → New results for LFV search using the full data sets are approaching to $O(10^{-8})$.
- Super-KEKB will provide x ~50-100 statistics.
  → The search region will enter into $O(10^{-9})$ for many decays.
  → Good chance to see LFV τ decays.
  → BNV can be tested too.

Backup Slides

International Collaboration: Belle

Aomori U.
BINP
Chiba U.
Chonnam Nat'l U.
U. of Cincinnati
Ewha Womans U.
Frankfurt U.
Gyeongsang Nat'l U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow

IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. /
U. of Ljubljana /
U. of Maribor
U. of Melbourne

Nagoya U.
Nara Women's U.
National Central U.
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Osaka U.
Osaka City U.
Panjab U.
Peking U.
U. of Pittsburgh
Princeton U.
Riken
Saga U.
USTC

Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
Toyama Nat'l College
U. of Tsukuba
VPI
Yonsei U.

13 countries, 55 institutes, ~400 collaborators

Physics Targets at Super-B

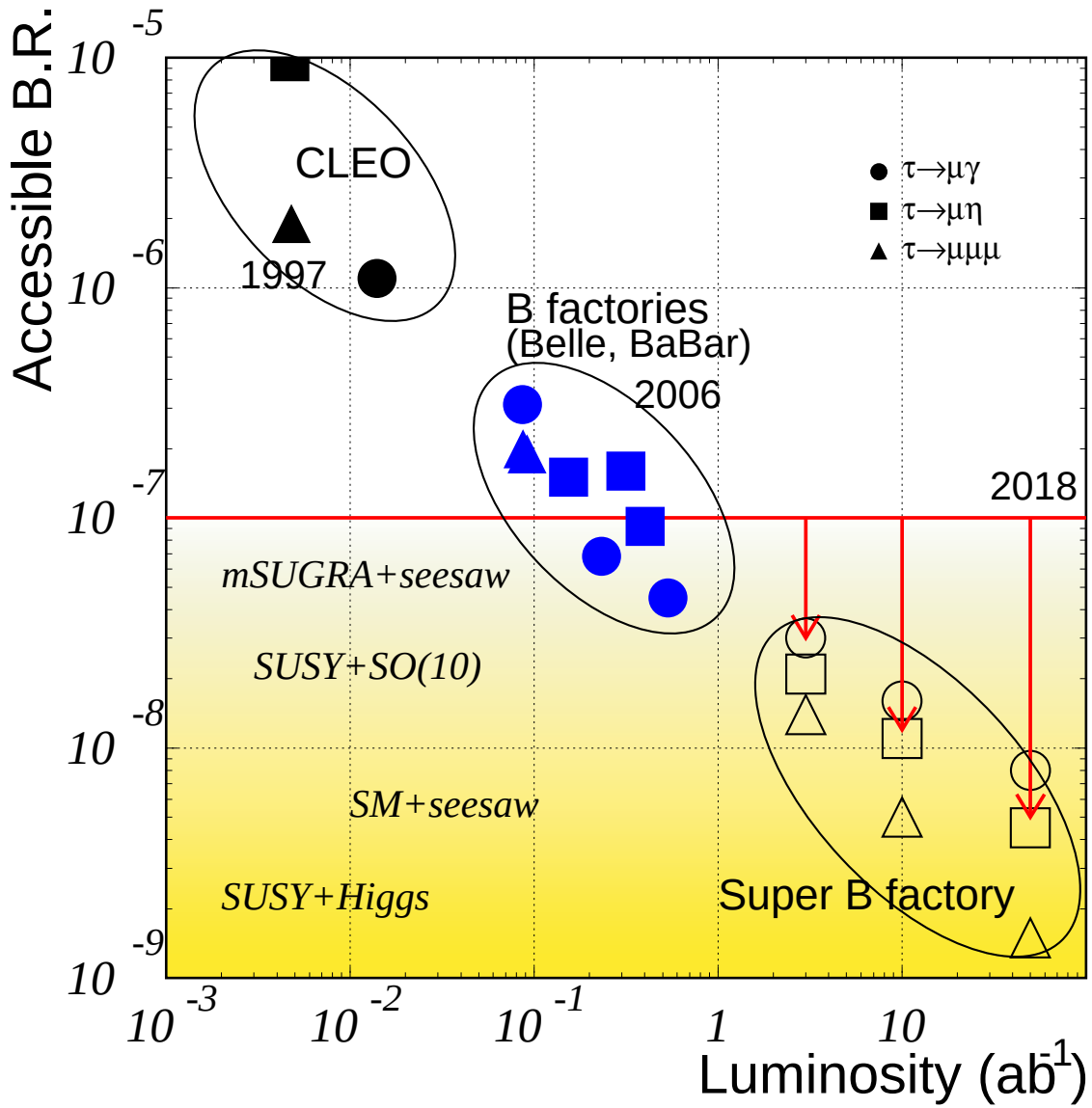
- CP violation
  $B \to \phi K^0, \eta' K^0, K^+ K^- K^0$
- Precise CKM
  $\phi_1, \phi_1, \phi_1, |V_{ub}|, |V_{td}|$
- Rare decays
  - FCNC decays
    $b \to s\ell\ell, s\nu\bar{\nu}$ *etc.*
  - Tauonic decays
    $b \to c\tau\nu, \tau\nu$ *etc.*
- τ decays
  - Lepton flavor violation
    $\tau \to \mu\gamma$ *etc.*
  - CPV in lepton sector

Search for new origin of flavor mixing and CPV.

Using O(10^{10}) B and τ (~100 x now)

T LFV Prospect

- Br~O($10^{-8\to9}$) at Super B factory !



● τ→μγ

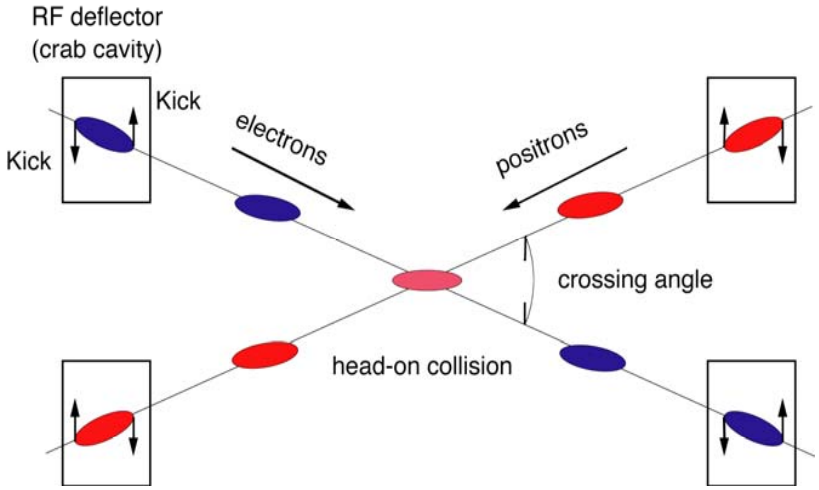
■ τ→μη

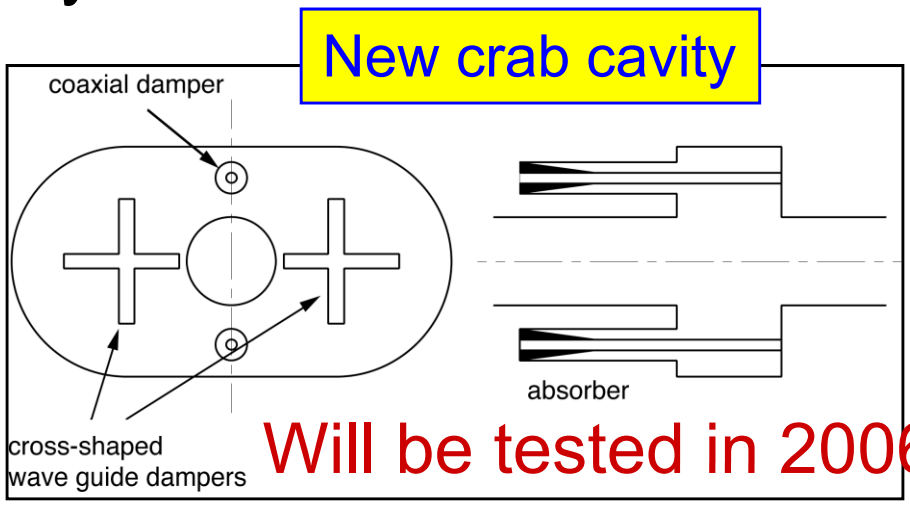
▲ τ→μμμ

τ→μγ suffers from background due to ISR.

Super-KEKB (cont'd)

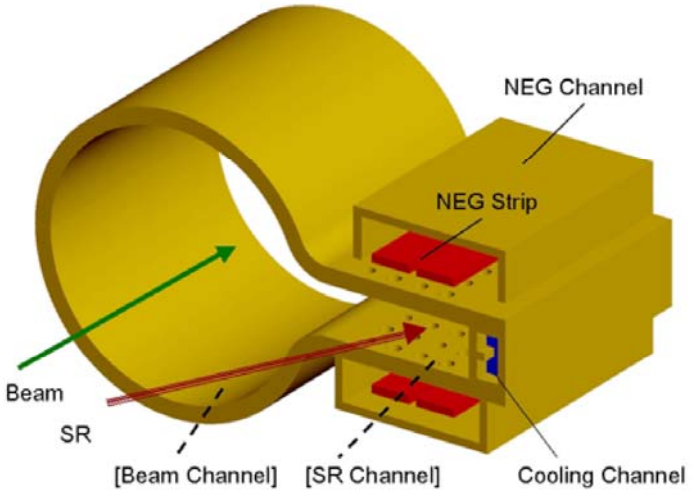
- Head-on collision w/ Crab cavity

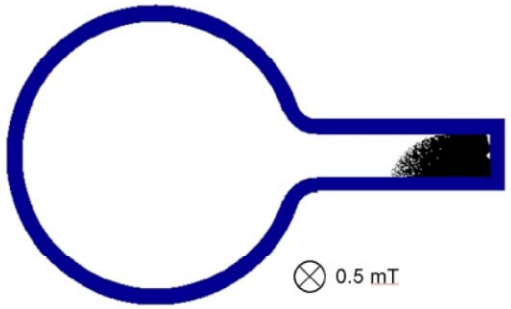




Will be tested in 2006.

- Ante-chamber /solenoid for reduction of electron clouds





Ante-chamber
with solenoid field

Detector Upgrade

Issues

- 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* m identification
  - full recon. eff.
  - hermeticity ; ν “reconstruction”

- Fully pipelined readout
- Large scale computing

New Challenge! Intensive R&Ds!

- Vertexing
  - Pixel det.
- Tracking
  - Small cell
  - Fast gas
  - Si-tracker
- Particle ID
  - F-DIRC+TOP
  - Aerogel RICH
- EM Cal
  - Pure CsI
  - Liquid-Xe etc.
- KL & μ
  - LST
  - Scintillator