Physics with Belle/Belle II@N-Lab

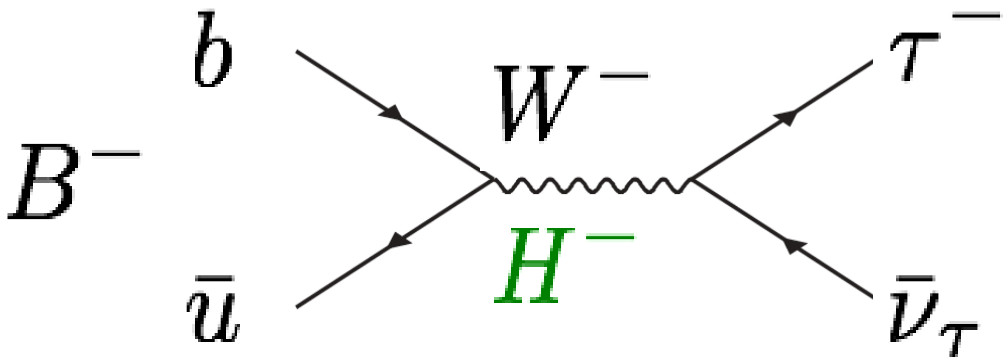
- **B decays** — Y. Sato, S. Hirose
  - -B→τν
  - -B→D(*)τν

- **Tau** — K. Hayasaka, K. Inami
  - -LFV
  - -EDM

- **Hadron** — Y. Kato, O. Seon
  - -Charged charmonium
  - -Double charm systems

- **Computing for Belle II** — K. Hayasaka, Y. Kato

B→τν



- In the SM, branching fraction is small: ~1 × 10^{-4} due to helicity suppression.
- The charged Higgs can contribute and large effect is expected.

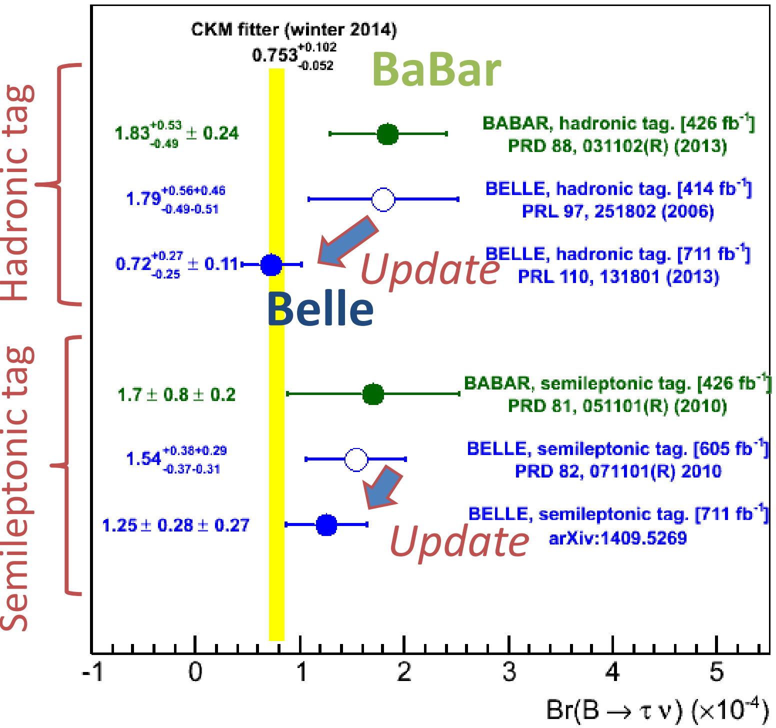
$$\mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau) = \mathcal{B}(B^- \to \tau^- \bar{\nu}_\tau)_{\text{SM}} \times r_H$$

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

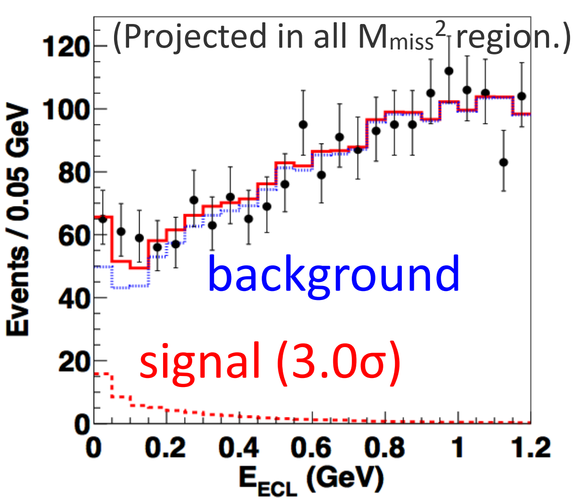
Effect of Type II two Higgs doublet model (2HDM) in the tree level. Destructive interference.
W. S. Hou, Phys. Rev. D 48, 2342 (1993),

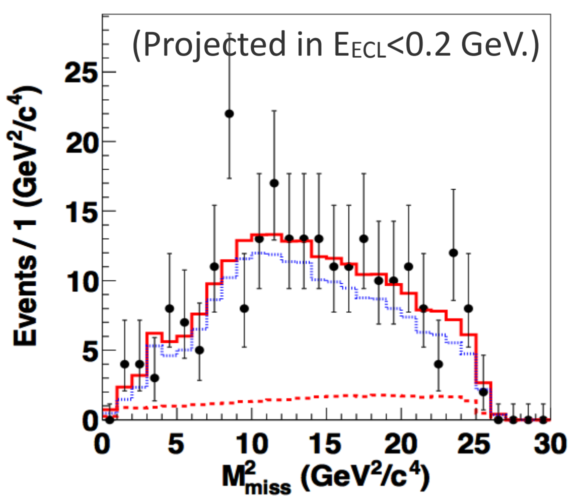
- Experimentally challenging because of multiple neutrinos in the final state.
- In the B-factory, we can make clean environment by tagging another B-meson.

Measurements summary



- Before CHEP2012, tension with SM was observed.
- Now, consistent with SM within 0.6σ.
- Analysis of Belle except for updated semi-leptonic tag were done by Nagoya members





- Use Belle full statistics.
- Hadronic tag with NeuroBayes

PRL 110, 131801 (2013).

Constraint on charged Higgs

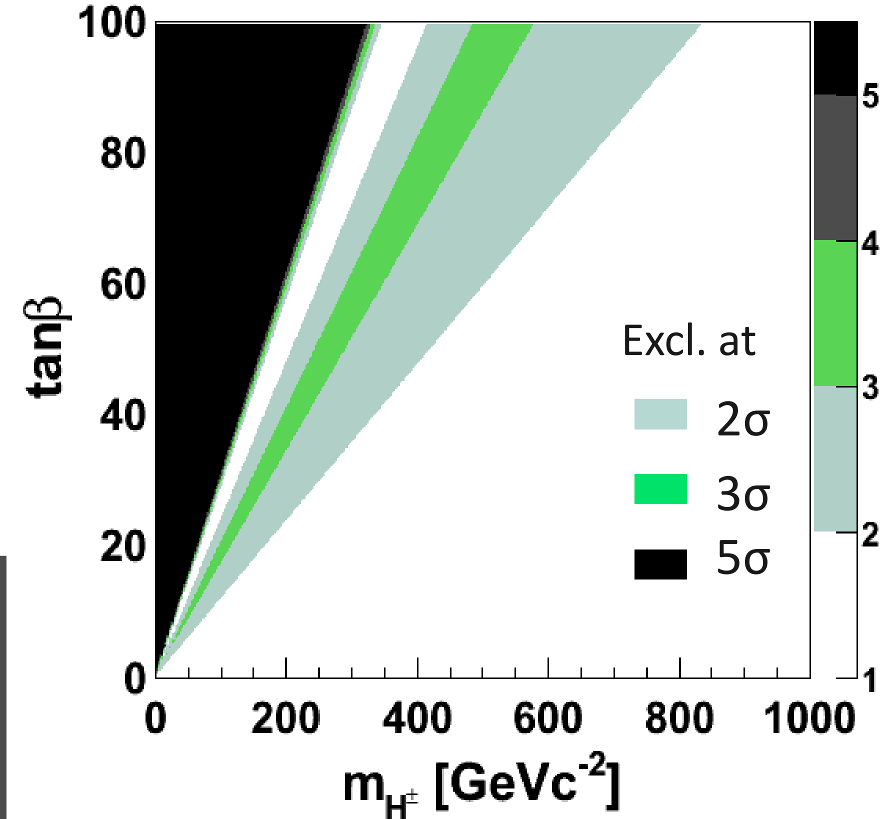
- Assume typeII 2HDM.

- $\mathcal{B}(B \to \tau\nu) = (1.15 \pm 0.23) \times 10^{-4}$
  Latest semileptonic tag result is not included.

- $\mathcal{B}(B \to \tau\nu)_{SM} = (1.11 \pm 0.28) \times 10^{-4}$

$$\mathcal{B}(B \to \tau\nu) = \mathcal{B}(B \to \tau\nu)_{\mathrm{SM}} \times r_H$$

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

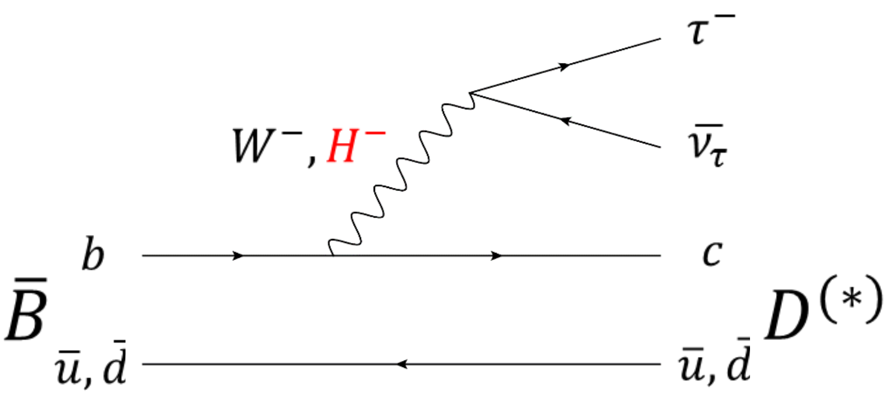


Personal figure by Y. Horii.

- Stringent limit for typeII 2HDM is obtained.

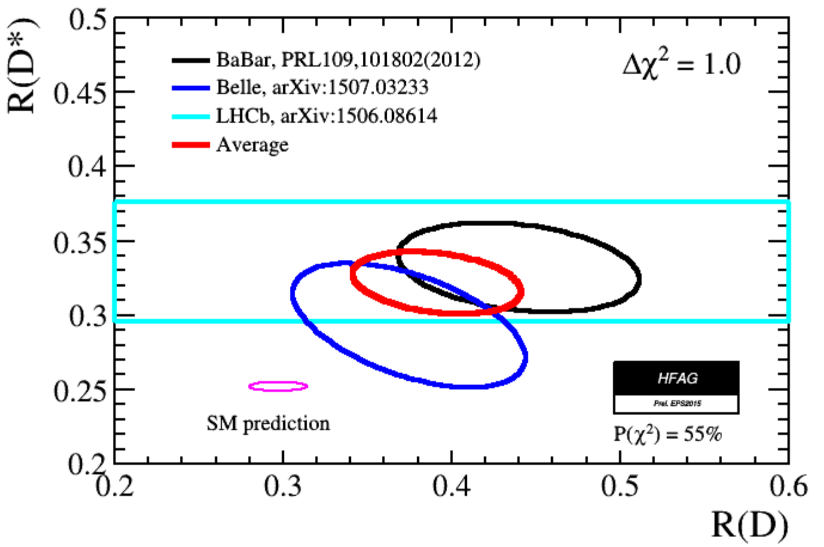
- Important subject in Belle II.

$B \to \bar{D}^{(*)} \tau \nu$

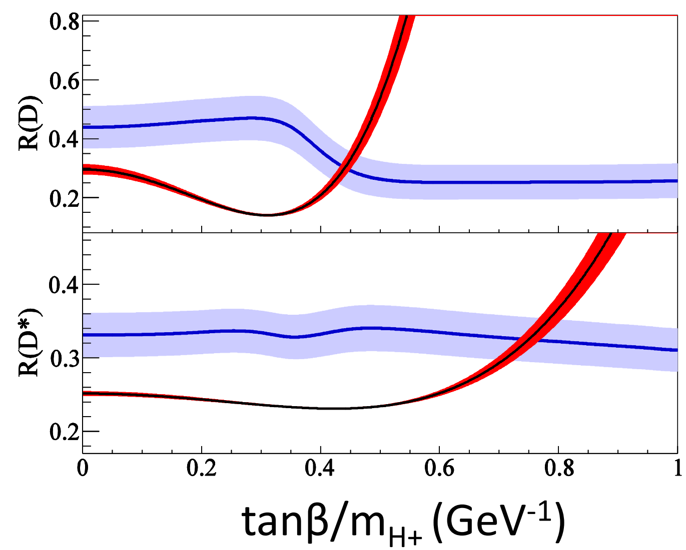


- Sensitive to the scaler field (ex charged Higgs)
- Relatively large branching fractions.
- Many kinematic variables.
- Taking ratio with e,μ channel cancels uncertainty from hadronic contribution etc.

$$R\left(D^{(*)}\right) \equiv \frac{Br(B \to \overline{D^{(*)}} \tau \nu)}{Br(B \to \overline{D^{(*)}} l \nu)}$$



3.9σ deviation from SM



Current measurements are inconsistent with both SM and typeII 2HDM.

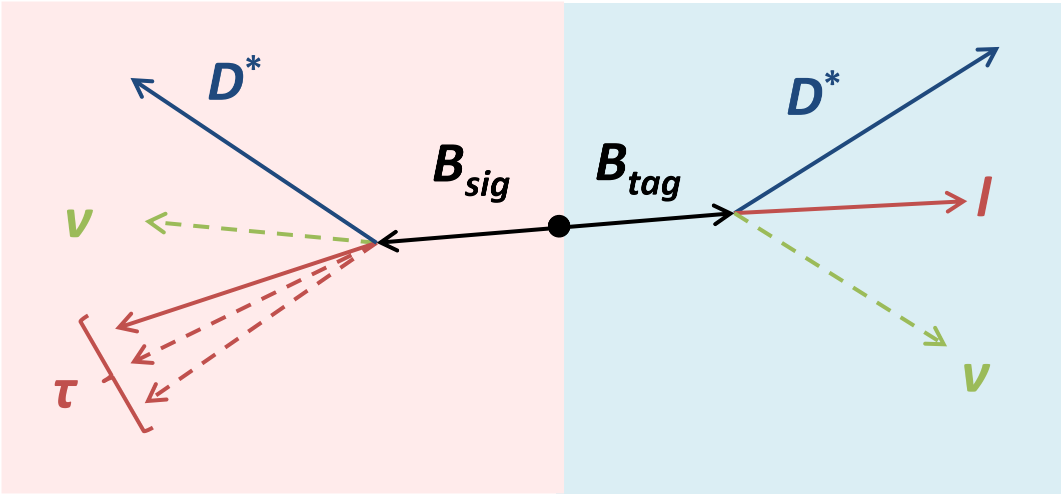
More detailed studies on going

Two directions to clarify the situation for $B \rightarrow D(*)\tau\nu$

- Improve the accuracy of branching fraction. → Semileptonic tagging.
- Measure the kinematic distributions → Hadronic decay of τ, hadronic tag

BaBar has measured with hadronic tag only.
Belle had measured with hadronic and inclusive tag.

} No measurement with semi-leptonic tagging so far.



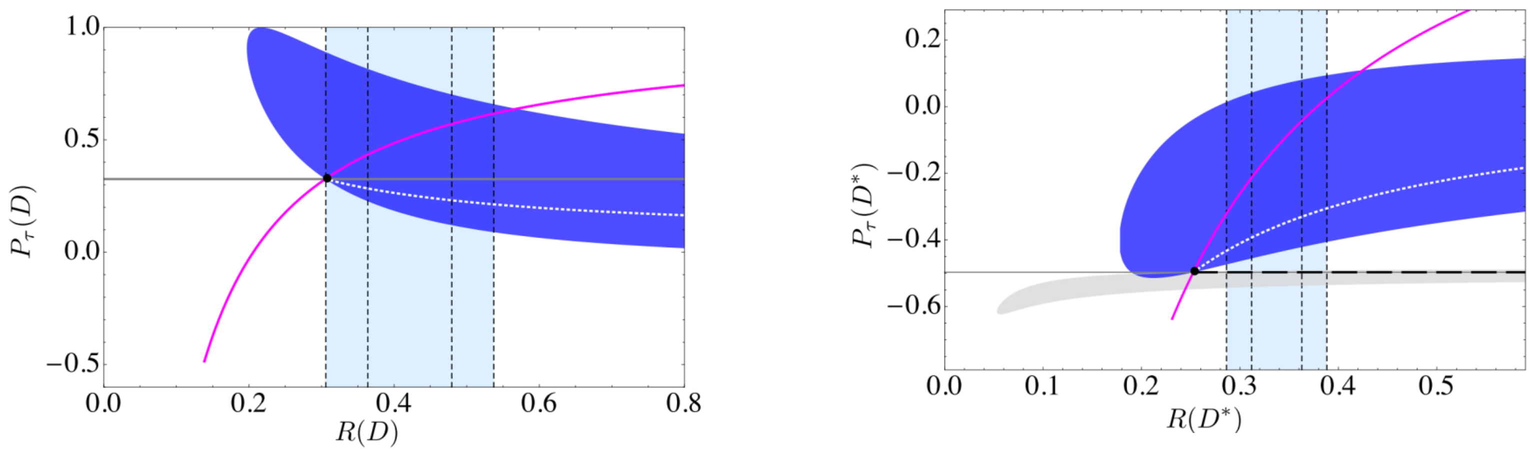
- Focused on $B^0 B^{0bar} \rightarrow (D^{*-} l^+)\ (D^{*+} l^-)$
- **Estimated accuracy is found to be similar to that for hadronic tag.**

Hadronic decay of τ

All the current measurements has been done with leptonic decay of τ.
→ New analysis with hadronic decay of τ (πν, ρν) is underway.

- B→D**lν, which brings largest systematics in leptonic decay is not problem.
- Polarization of τ can be measured.

Model independent analysis assuming only one Wilson coefficient contributes



<u>Polarization of τ is useful to discriminate different models</u>

Phys. Rev. D **87**, 034028

Experimentally challenging due to large background from hadronic B decays.

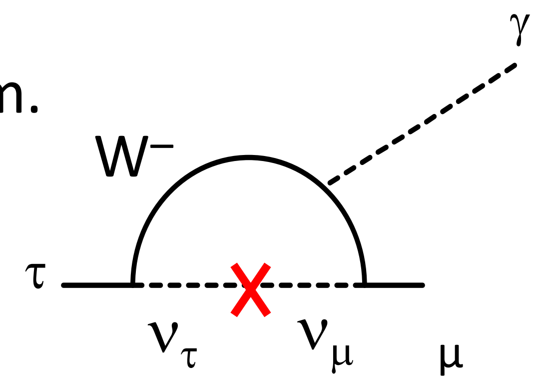
- We find current Belle data has sensitivity to measure branching fraction.
- Measurement of polarization is also possible.

Tau Lepton Flavor Violation (LFV)

- There has been no evidence for the charged lepton flavor violation.

- In SM, it is highly suppressed by GIM mechanism.

$$Br(\tau \to \mu\gamma)_{SM} \propto \left(\frac{\delta m_\nu^2}{m_W^2} \right)^2 < 10^{-54}$$



- The observation of cLFV is a clear signature of NP.

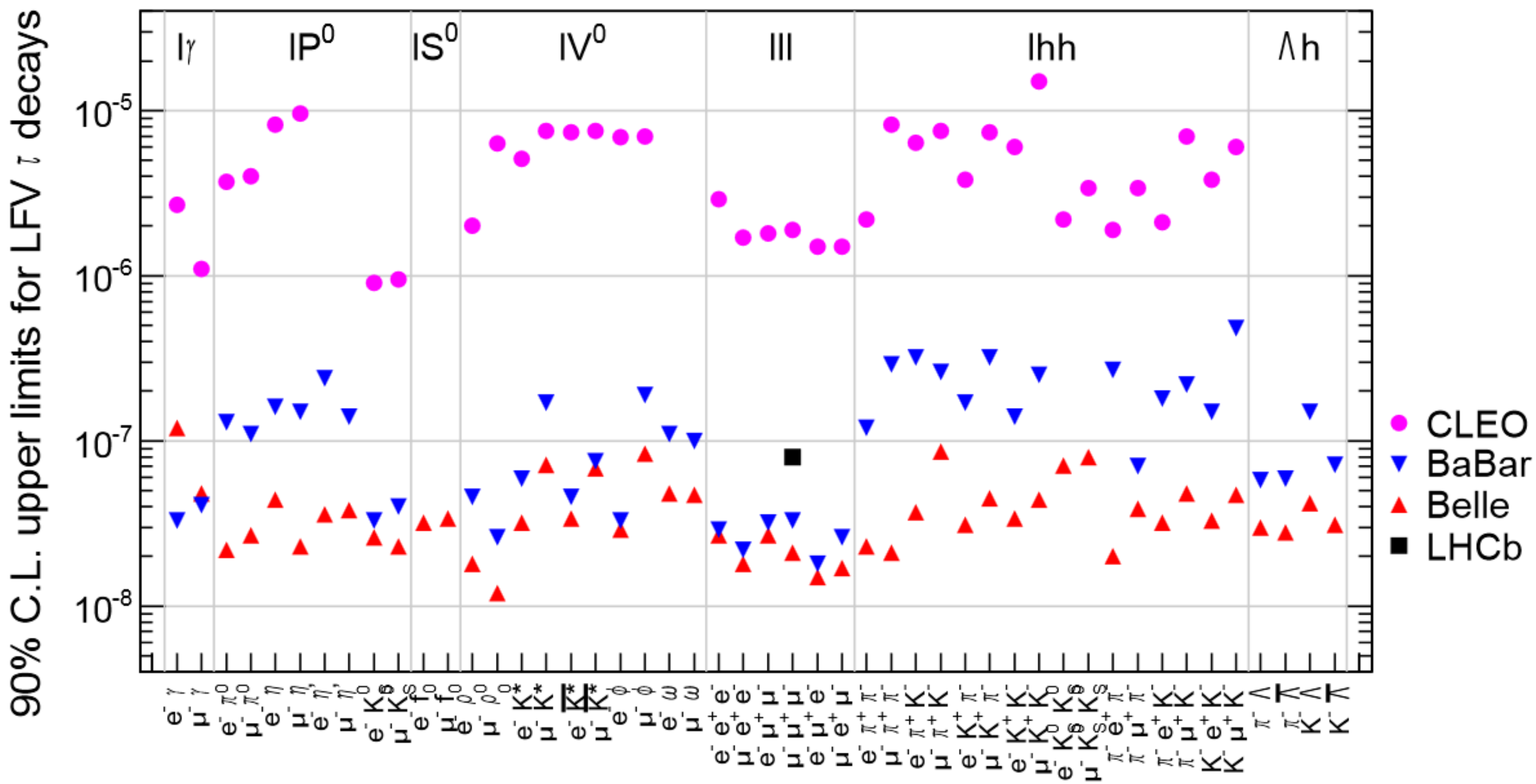
- Belle has about 10^9 tau pairs→ sensitivity of $O(10^{-8})$

- By combining many LFV modes, we can discriminate different models.

$\left(\frac{\tau \to \mu\mu\mu}{\tau \to \mu\gamma} \right)$	SUSY+GUT (SUSY+Seesaw)	Higgs mediated	Little Higgs	non-universal Z' boson
	$\sim 2 \times 10^{-3}$	0.06~0.1	0.4~2.3	~16

JHEP05(2007)013 PLB 547(2002) 252

Summary of recent tau LFV searches



- Totally 48 modes are measured.
- Belle $\tau \rightarrow \mu\gamma$ result with 545fb^{-1} data sample.
  Result with final data sample will come soon.
- LHCb has sensitivity for $\tau \rightarrow \mu\mu\mu$ and comparable with B-factories.

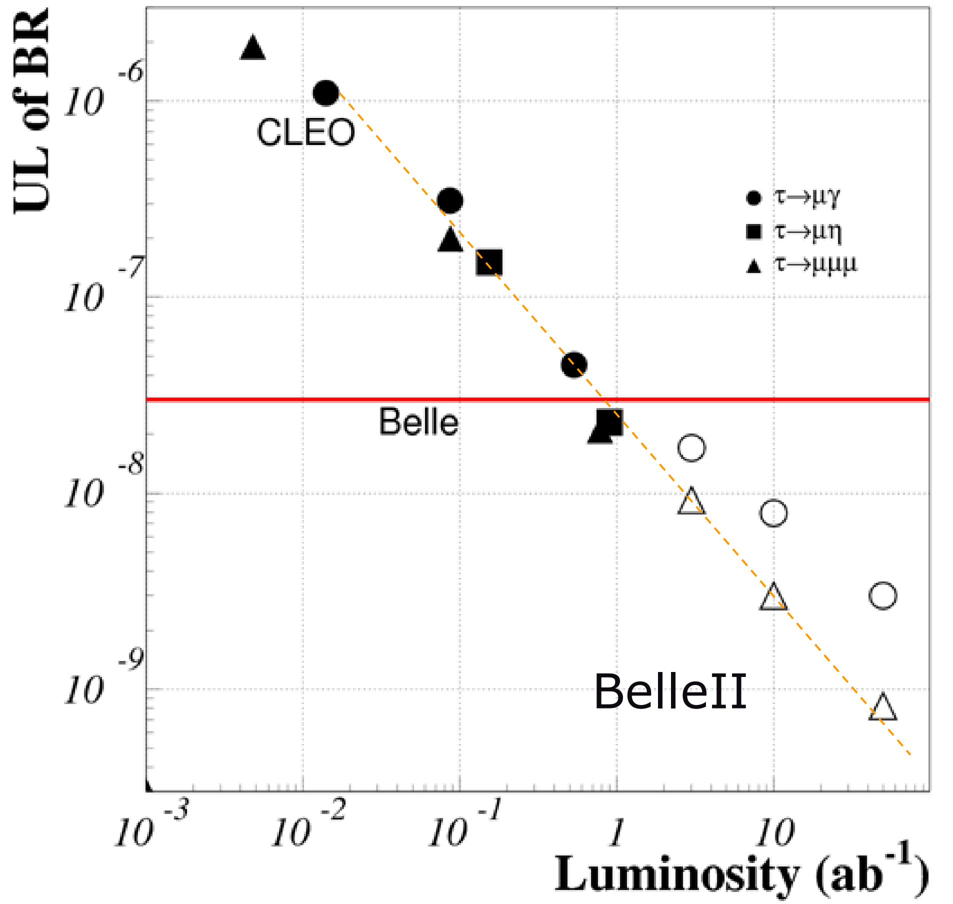
Prospect for BelleII

$\tau \to \mu\mu\mu$ is BG free even for Belle II

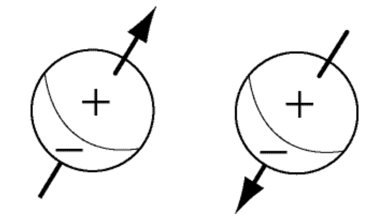
Sensitivity $\propto 1/L$: $O(10^{-10})$.

$\tau \to \mu\gamma$ is not BG free

Sensitivity $\propto 1/\sqrt{L}$: Sensitivity $O(10^{-9})$

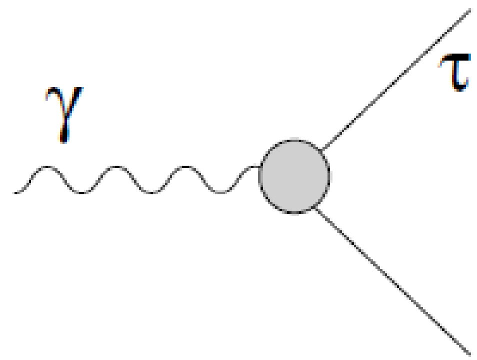


τ Electric Dipole Moment (EDM)



- Charge asymmetry along the spin.
  →CP-odd.

- In the SM, 3 loops with quarks induce EDM via CKM matrix.
  $|d_\tau| <= 10^{-34}$ ecm, which is not accessible by experiment.



- Many NP models predict sizable lepton EDM
  -SUSY
  -Multi Higgs doublets
  -Leptoquarks

$$\mathcal{L}_{CP} = -\frac{i}{2}\bar{\tau}\sigma^{\mu\nu}\gamma_5\tau d_\tau(s)F_{\mu\nu}$$

- These models predict $|d_l| \propto$ Nth power of mass of lepton.
  →High sensitivity for τ lepton.

Measurements

- Current best upper limit

  Belle 29.5 fb^{-1} data [PLB 551(2003)16]

$$-2.2 < Re(d_\tau) < 4.5 \ (10^{-17}\, e\, \mathrm{cm})$$

$$-2.5 < Im(d_\tau) < 0.8 \ (10^{-17}\, e\, \mathrm{cm})$$

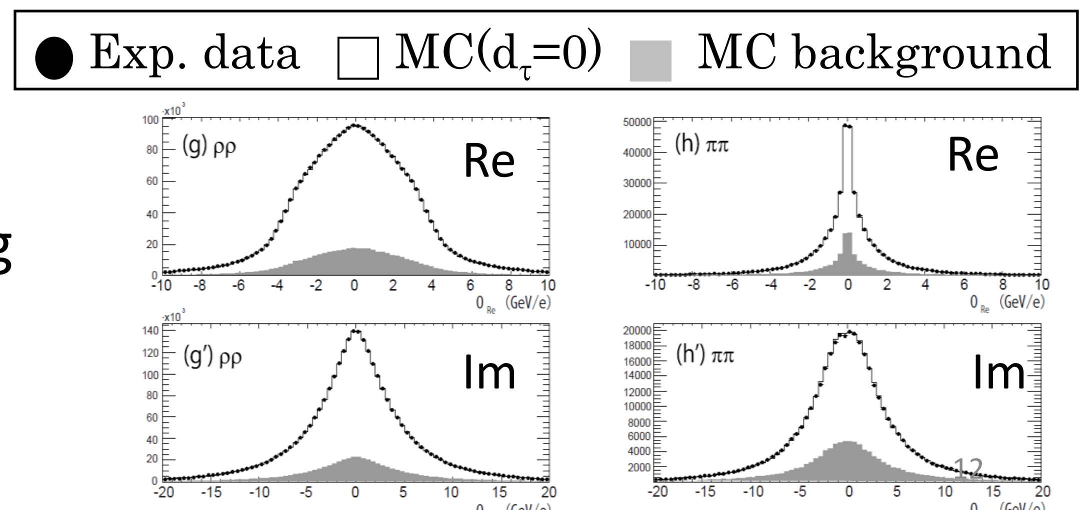
- Analysis with data sample of 825 fb^{-1} will be finalized soon.

  Estimated error is :

  $Re(d_\tau)$: ($\pm$0.33) $\times 10^{-17}$ecm : almost scaled by 1/sqrt(L)

  $Im(d_\tau)$: ($\pm$0.30) $\times 10^{-17}$ecm : systematic dominates

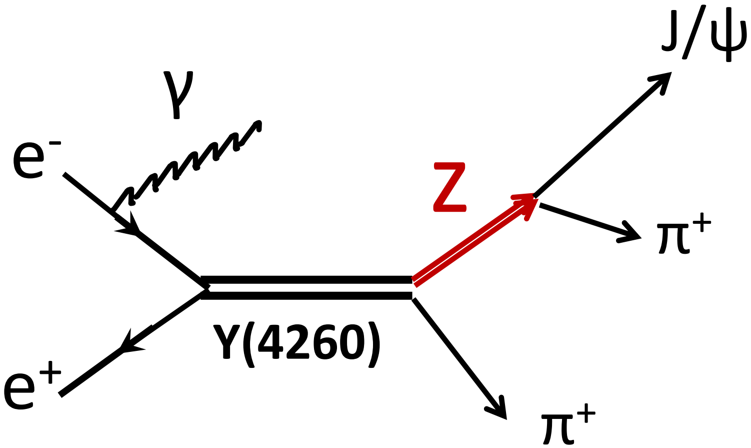
- In BelleII, more understanding of detector important.



Hadron physics

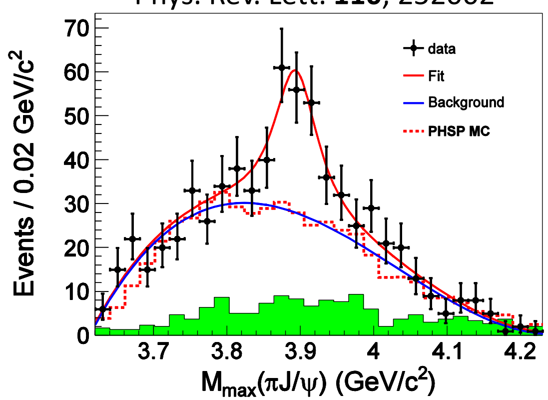
Belle has discovered ~20 "new hadrons".
Nagoya contributes observation of $Z_c(3900)$

<u>**ISR $e^+e^- \rightarrow Y(4260)\gamma \rightarrow J/\psi\pi\pi\ \gamma$**</u>



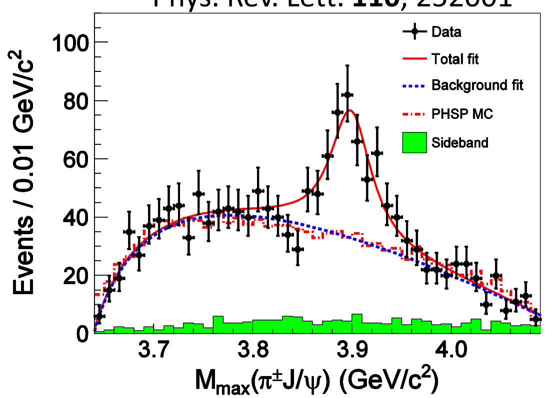
Belle

Phys. Rev. Lett. **110**, 252002



BESIII

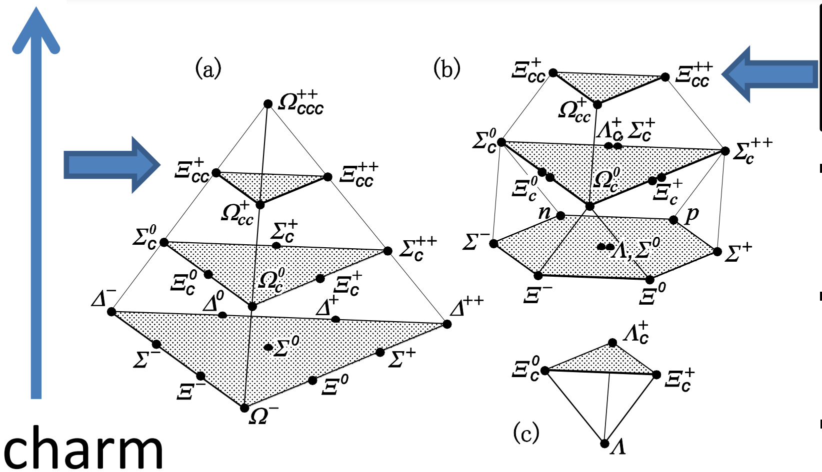
Phys. Rev. Lett. **110**, 252001



A charmonium-like state **which has charge**.
→ Minimal quark number is 4.

- Z_c (3900) is the **first established charged charmonium state**.
(first observed charged charmonium state is Z_c(4430))

Double charm systems

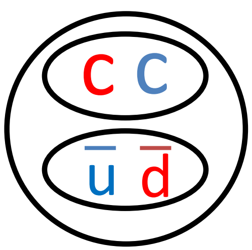


Baryon = Ξ_{cc}

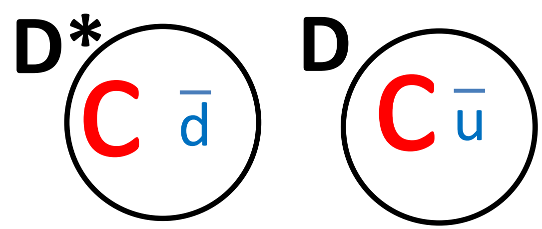
- There has been no established baryon which have more than one heavy (>=charm) quark.
- We can learn **QQ potential** from doubly charmed baryons (similar to QQ^{bar} from charmonium)
- Search for ground state, $\Xi_{cc.}$

Meson = T_{cc}

Di-quarks



Meson molecule



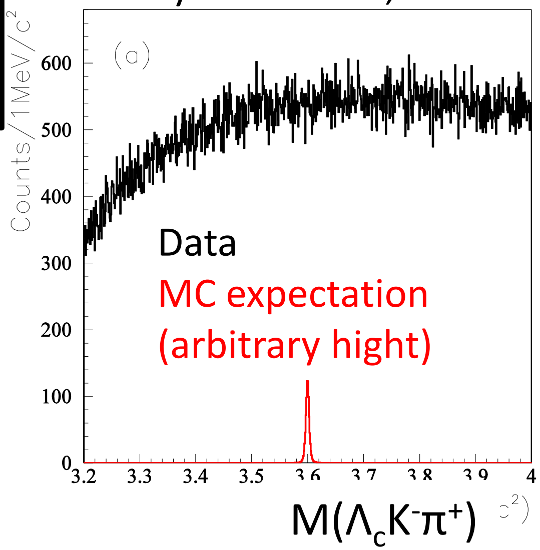
Doubly charmed meson is a genuine tetra-quark system.

- Di-quark systems are favored due to large color spin interaction.

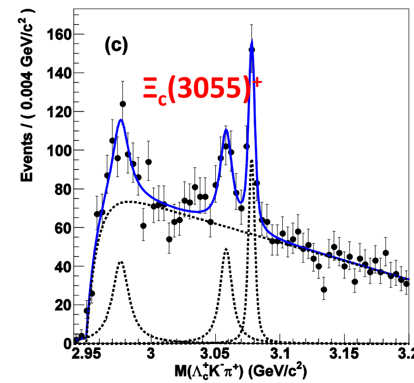
→T_{cc} is a clean sample of di-quark. Extension of quark model

Research status

Ξ_{cc}



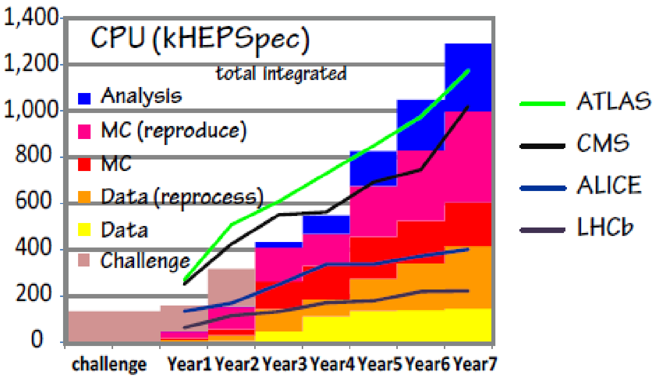
- No evidence observed.
- UL close to the theoretical prediction.
- Good subject for Belle II
- Confirmation of $\Xi_c(3055)^+$ was also done.

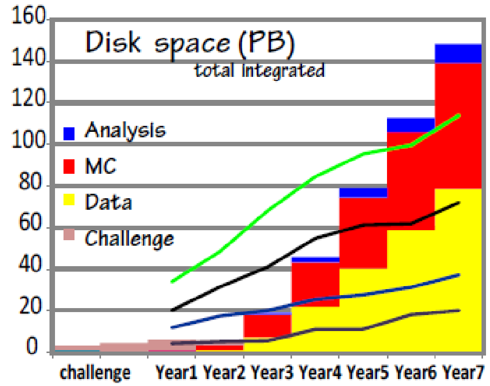


Double charm

- No measurement on the double charm production without J/ψ so far.
- We are working on elementary double charm production using DD final states (D^0D^0, D^0D^+, D^+D^+).
- This will be a benchmark for study of T_{cc} and Ξ_{cc} for BelleII
- Production mechanism of double charm is also interesting

Belle II computing





slide by T. Hara@JPS

Resource requirement
is comparable with ATLAS run1

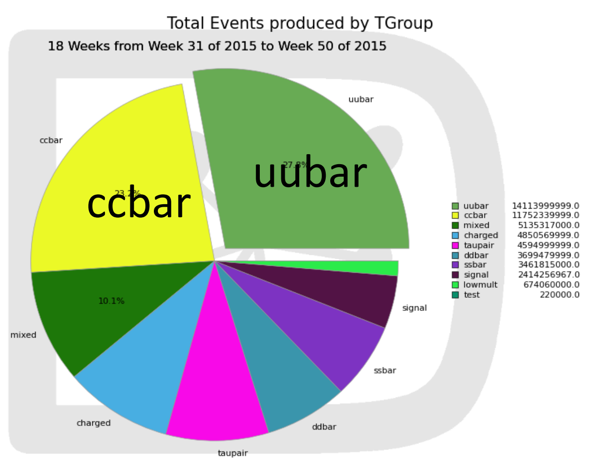
Adapt grid computing.

Nagoya contributes..

- Provide resources
- Develop monitor system
- Excavate hidden resources

Belle II dedicated resource @ Nagoya

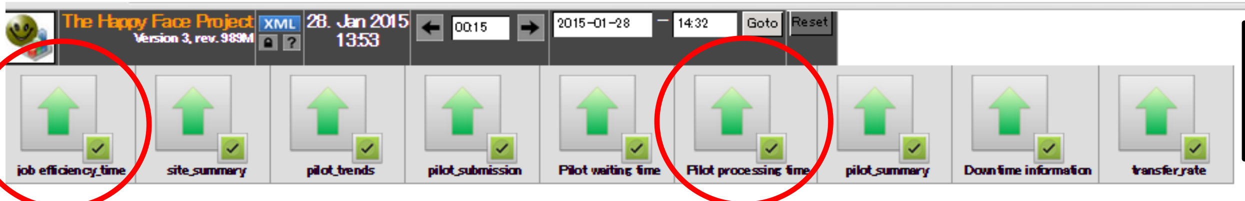
- ~400 cores.
- 250 TB disk.
- EMI3 middleware is installed.
- Maintained by physicists.



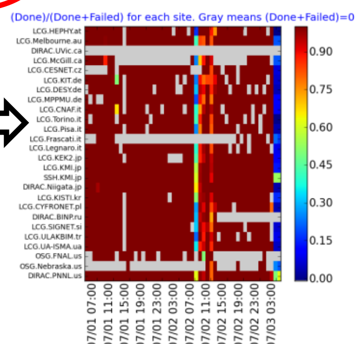
~1G MC events are produced from August by Nagoya computer.

Monitoring system

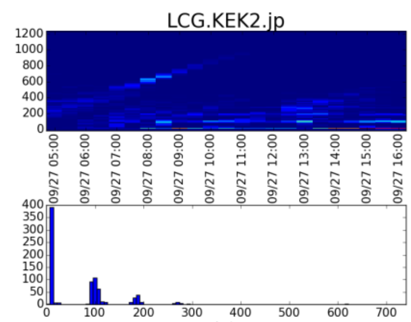
In the beginning of ATLAS experiment, 200/month troubles are reported in the grid.
→Monitoring is important for efficient use of huge computing resources.



Extract job information from DB and visualize in web page.



Job efficiency



Wallclock time of job for each site.

Site status summary

site	worker node	CPU	#core	memory	OS	Kernel	rpm	cvmfs	releases	CPU Norm.	last updated
DIRAC.BINP.ru	gcf-110-1.belle2	QEMU Virtual CPU version 0.12.1	x2	1443MB/cores	Scientific Linux release 6.6 (Carbon)	2.6.32-504.1.3.el6.x86_64	OK	NI.	OK (build-2014-10-18)	10.6 HS06	2015/01/25 09:34:33
DIRAC.Niigata.jp	ngtbel5.sc.niigata-u.ac.jp	Intel(R) Xeon(R) CPU E5-2660 0 @ 2.20GHz	x32	2013MB/cores	Scientific Linux SL release 5.5 (Boron)	2.6.18-371.6.1.el5	one problem found	Rev. 50	OK (build-2014-10-18)	11.9 HS06	2015/01/28 12:35:27
DIRAC.Osaka-CU.jp	cpu2	Intel(R) Core(TM) i3-3220 CPU @ 3.30GHz	x4	1889MB/cores	Scientific Linux CERN SLC release 6.6 (Carbon)	2.6.32-504.3.3.el6.x86_64	OK	Rev. 50	OK (build-2014-10-18)	13.5 HS06	2015/01/28 12:37:48

Send test job and collect site information.
RPM list, disk/memory usage, Belle II lib etc

Twiki, Inc.

Tags: create new tag, view all tags

Shift Manual

- Shift Manual
  - The largest change from past MC shift
  - Responsibility of shift
  - Shift procedure

Develop shift manual

These are used for MC production test and polishing with many feedbacks.

Excavate hidden resources

DIRAC submit jobs instead of users
It absorbs different grid languages.

Submit jobs

EMI | OSG | Cloud | Local cluster

- DIRAC can send jobs to the sites where grid middleware is not installed via SSH.
- We are contacting to BelleII collaborators which have small computing resources to make their resources to join Belle II computing.

Backup

Research status

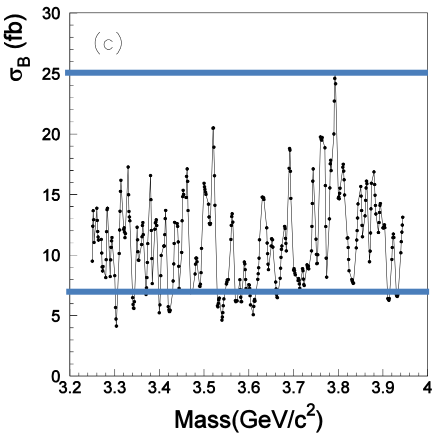
UL for

$\sigma(e^+e^- \to \Xi_{cc}^+ X) \times Br$

Phys. Rev. D **89**, 052003

Ξ_{cc}

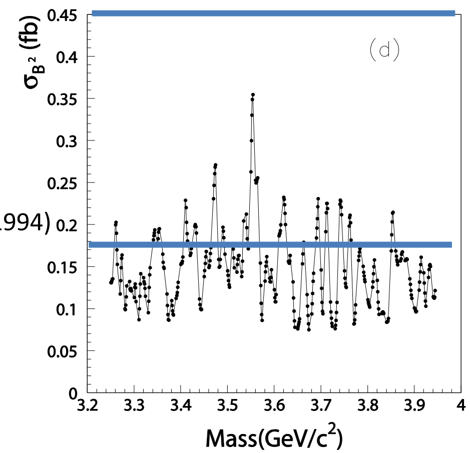
$\Lambda_c^+ K^- \pi^+$



Predictions

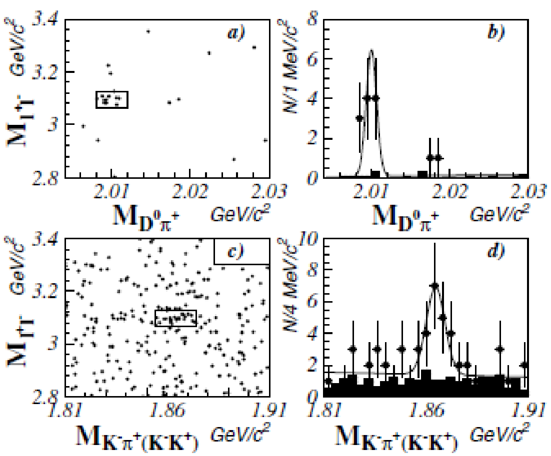
Phys. Lett. B 332, 411 (1994)
Phys. Lett. B 568, 135

$\Xi_c^0 \pi^+$



- Obtained cross section is close to the theoretical predictions (Branching fraction is assumed to be 5%)
- Good subject for BelleII
- Large ambiguity for predictions.

Double charm



$$\sigma(J/\psi + c\bar{c}) = 0.87^{+0.21}_{-0.19} \pm 0.17\,pb \Leftrightarrow 0.006 - 0.012\,pb$$

- No measurement on the double charm production without J/ψ for e^+e^- collision so far.
- We are working on elementary double charm production using DD final states (D^0D^0, D^0D^+, D^+D^+).
- This will be a benchmark for study of T_{cc} and Ξ_{cc} for BelleII
- Production mechanism of double charm is also interesting

Measurement method

- Optimal observable
  [PRD 45(1992)2405]

$$\mathcal{M}^2_{\text{prod}} = \mathcal{M}^2_{\text{SM}} + Re(d_\tau)\mathcal{M}^2_{Re} + Im(d_\tau)\mathcal{M}^2_{Im} + |d_\tau|^2\mathcal{M}^2_{d^2}$$

$$\mathcal{O}_{Re} = \frac{\mathcal{M}^2_{Re}}{\mathcal{M}^2_{\text{SM}}}, \quad \mathcal{O}_{Im} = \frac{\mathcal{M}^2_{Im}}{\mathcal{M}^2_{\text{SM}}}$$

  - Maximize sensitivity (S/N)
  - Calculate event-by-event
  - Average value is proportional to EDM

$$\langle \mathcal{O}_{\text{Re}} \rangle \propto \int \mathcal{O}_{\text{Re}} \mathcal{M}^2_{\text{prod}}\, d\phi$$

$$= \int \mathcal{M}^2_{\text{Re}}\, d\phi + \text{Re}(d_\tau) \int \frac{(\mathcal{M}^2_{\text{Re}})^2}{\mathcal{M}^2_{\text{SM}}}\, d\phi$$

MC simulation (ee → ττ → ππνν) with/without EDM (5×10^{-16}ecm)