Tau physics and EW physics with taus

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At FCCee , it is estimated a production of 1.7×10^{11} $\tau+\tau-$

Some example of tau physics

Tau decays

Search for NP

Tau neutrino mass

High lumi. allows to have a large stat. of tau decays to $5\pi^{\pm}$ (or $7\pi^{\pm}$?)

Tau CC universality , Michel parameters

e vs μ , even at very low energy

Control sample of PID efficiency (easy with Z decays)

Tau as polarimeter

for Z decays to τ τ , polarization and AFB(Pol) , which could be affected by Z' somewhere
BUT ALSO for a very important piece of the program at FCCee : the CP violation in Higgs decays

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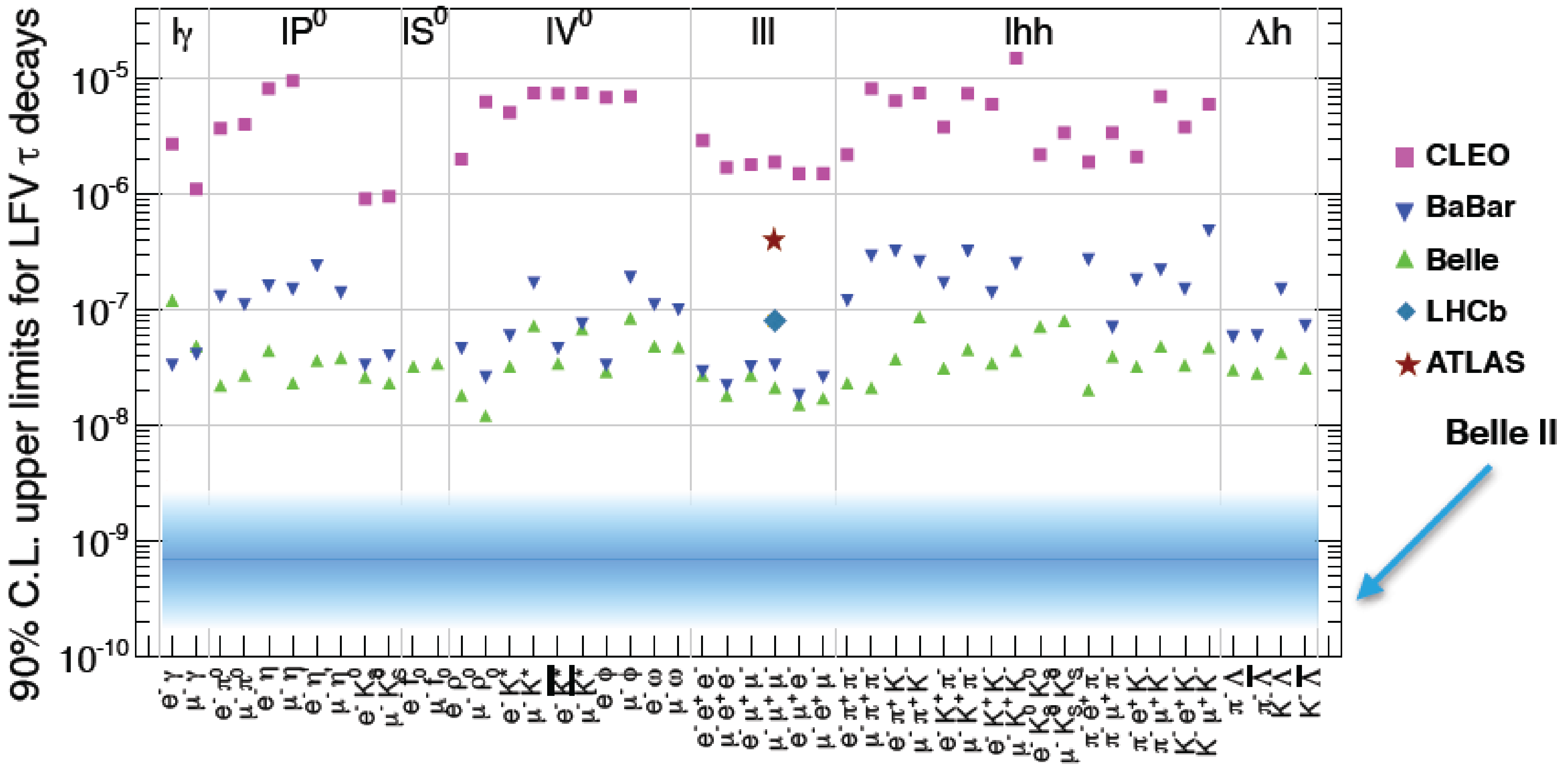
Rare tau decays , search for NP

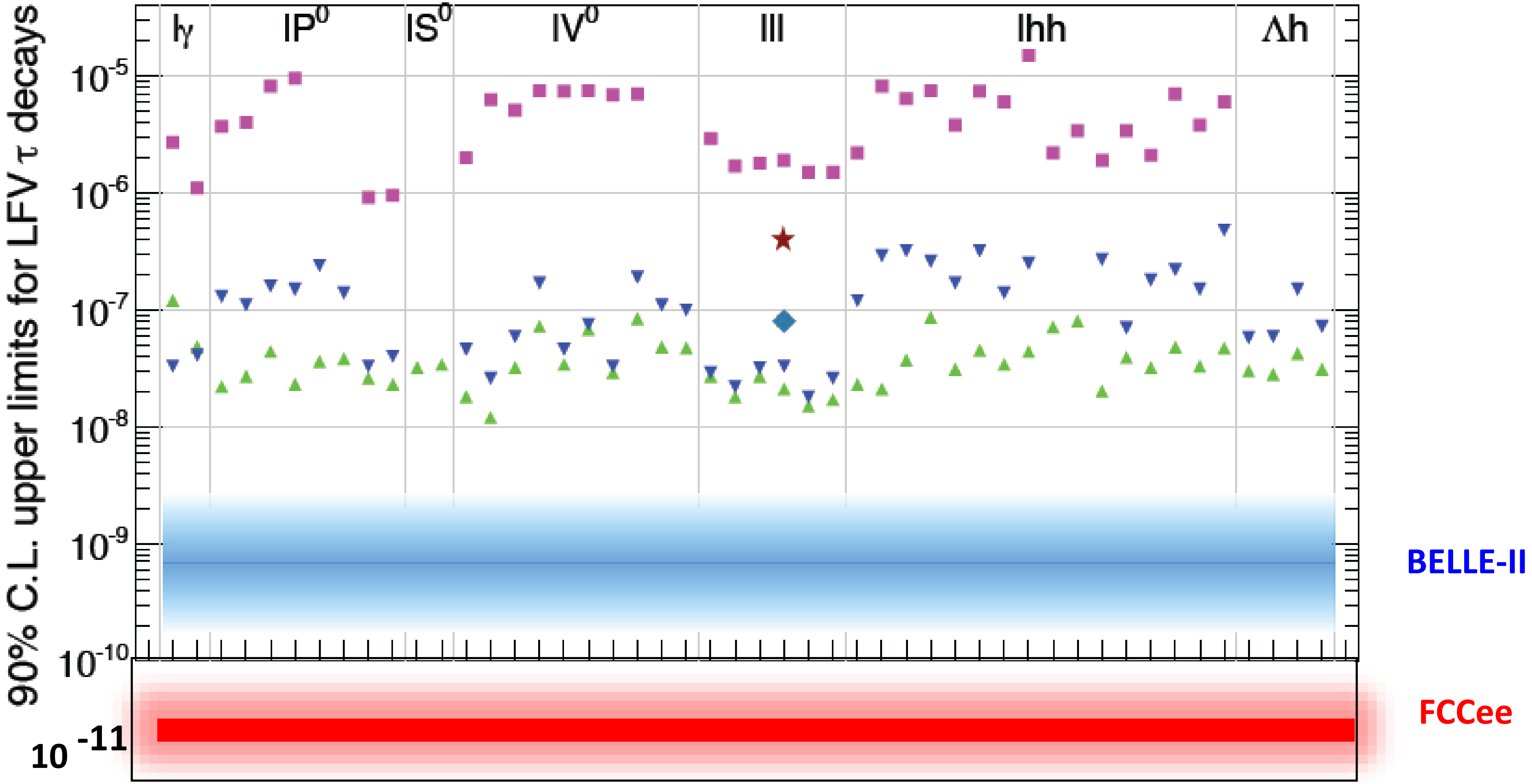
Lepton +
2 photons

Lepton +
2 hadrons chargés



With the right detector, FCCee can do it much better

(more stat. and very clean environment …. ≥ 1 order of magnitude better)



With ε≈50%

It is very pessimistic

Rare decays

Take the example of $BR(\tau^{\pm} \longrightarrow \pi^{\pm} \nu_{\tau} e^{+} e^{-})$

BELLE-II

Contents	Syst. error
MC size	3.7%
$ee \rightarrow \tau\tau$	0.3%
Trigger	1.2%
π^0 veto	1.9%
Br's of BKG	4.4%
Luminosity	4.7%
Tracking	4.7%
PID	11.1%
Total:	14.4%

Meanwhile, it is found that the cut on invariant mass of three prongs has strong model dependence.
For two extreme cases:
$Br\_A = (1.46 \pm 0.13 \pm 0.21) \times 10^{-5}$
$Br\_V = (3.01 \pm 0.27 \pm 0.43) \times 10^{-5}$
And a partial Br ($M > 1.05$ GeV/c^2) is determined:
$(5.09 \pm 0.53 \pm 0.85 \pm 0.11) \times 10^{-6}$
stat. syst. model.

PRD. 100, 071101(R) (2019)

$\tau^{\pm} \to \pi^{\pm} \nu_{\tau}\, e^{+} e^{-}$

e/π PID for 3 close charged tracks !!
POSSIBLE solution
- dE/dX ??
- Timing in calo@O(10ps) ??

For FCCee ?

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$\tau^{\pm}\to\pi^{\pm}\nu_{\tau}\,\mu^{+}\mu^{-}$

From BELLE-II

Systematics for BELLE-II measurement

Syst. of N_{BKG}		
MC size	1.7%	x
Luminosity	1.4%	
$ee \to \tau\tau$	0.3%	
Tracking	1.4%	x
Trigger	0.3%	
$\boxed{\text{PID}}$	$\boxed{3.7\%}$	x
Br's of BKG	1.0%	
π-μ mis-id	1.5%	x
Total	4.9%	

Uncertainty of the branching fraction

$$\boldsymbol{Br}(\tau^{\pm}\to\pi^{\pm}l^{+}l^{-}\nu_{\tau}) = \frac{N_{\rm obs}-N_{\rm BKG}}{\sigma_{\tau\tau}\cdot\mathcal{L}\cdot\epsilon_{\rm sig}} \qquad N_{\rm BKG}=\mathcal{L}\cdot(\sum_i \sigma_i\cdot\epsilon_i) \qquad \epsilon = \epsilon_{initial}\cdot R_{trk}\cdot R_{PID}$$

$$\frac{\Delta\mathcal{B}}{\mathcal{B}} = \sqrt{(\frac{\Delta\sigma_{\tau\tau}}{\sigma_{\tau\tau}})^2+(\frac{\Delta\mathcal{L}}{\mathcal{L}})^2+(\frac{\Delta\epsilon_{sig}}{\epsilon_{sig}})^2+(\frac{\Delta R_{sig}}{R_{sig}})^2+(\frac{\Delta N_{BKG}}{N_{obs}-N_{BKG}})^2+(\frac{\Delta N_{obs}}{N_{obs}-N_{BKG}})^2}$$

The systematics uncertainty includes:

- **Cross section of ττ**: 0.919 ± 0.003 nb, by KKMC.
- **Luminosity**: 1.4% using Bhabha events.
- **Statistic error of MC**: Poisson variance
- **Tracking efficiency**: Using partially reconstructed $D^{*}\to D^{0}\pi_{\rm slow}$, $D^{0}\to K^{0}_{S}\,\pi^{-}\pi^{+}$, $K^{0}_{S}\to\pi^{-}\pi^{+}$ (one daughter here allowed not to be reconstructed). Comparing track finding in MC and EXP, 0.35% per track. Low momentum region is checked by $B^{0}\to D^{*-}\pi^{+}$, $\pi_{\rm slow}$ in D^{*-} serves as probe.
- **Particle identification**: $D^{*+}\to D^{0}\,\pi^{+}_{\rm slow}\to K^{-}\,\pi^{+}\,\pi^{+}_{\rm slow}$ for πID ($\pi^{+}_{\rm slow}$ serve as tag; K^{-}, π^{+} as probe), $\gamma\gamma\to l^{+}l^{-}$ and $J/\psi\to l^{+}l^{-}$ for lepton ID
- **Trigger**: by Belle simulation study
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30

$\tau^\pm \to \pi^\pm \nu_\tau \mu^+ \mu^-$

For FCCee

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π-μ mis-id	1.5%
Total	4.9%

x

x

x

x

But for FCCee , it is not obvious,
PID for 3 close tracks !!
(due to boost of the 3 prongs in tau decays @Z peak)

Uncertainty of the branching fraction

$$\boldsymbol{Br}(\tau^\pm \to \pi^\pm l^+ l^- \nu_\tau) = \frac{N_{\rm obs} - N_{\rm BKG}}{\sigma_{\tau\tau} \cdot \mathcal{L} \cdot \epsilon_{\rm sig}} \qquad N_{\rm BKG} = \mathcal{L} \cdot (\sum_i \sigma_i \cdot \epsilon_i) \qquad \epsilon = \epsilon_{initial} \cdot R_{trk} \cdot R_{PID}$$

$$\frac{\Delta\mathcal{B}}{\mathcal{B}} = \sqrt{(\frac{\Delta\sigma_{\tau\tau}}{\sigma_{\tau\tau}})^2 + (\frac{\Delta\mathcal{L}}{\mathcal{L}})^2 + (\frac{\Delta\epsilon_{sig}}{\epsilon_{sig}})^2 + (\frac{\Delta R_{sig}}{R_{sig}})^2 + (\frac{\Delta N_{BKG}}{N_{obs} - N_{BKG}})^2 + (\frac{\Delta N_{obs}}{N_{obs} - N_{BKG}})^2}$$

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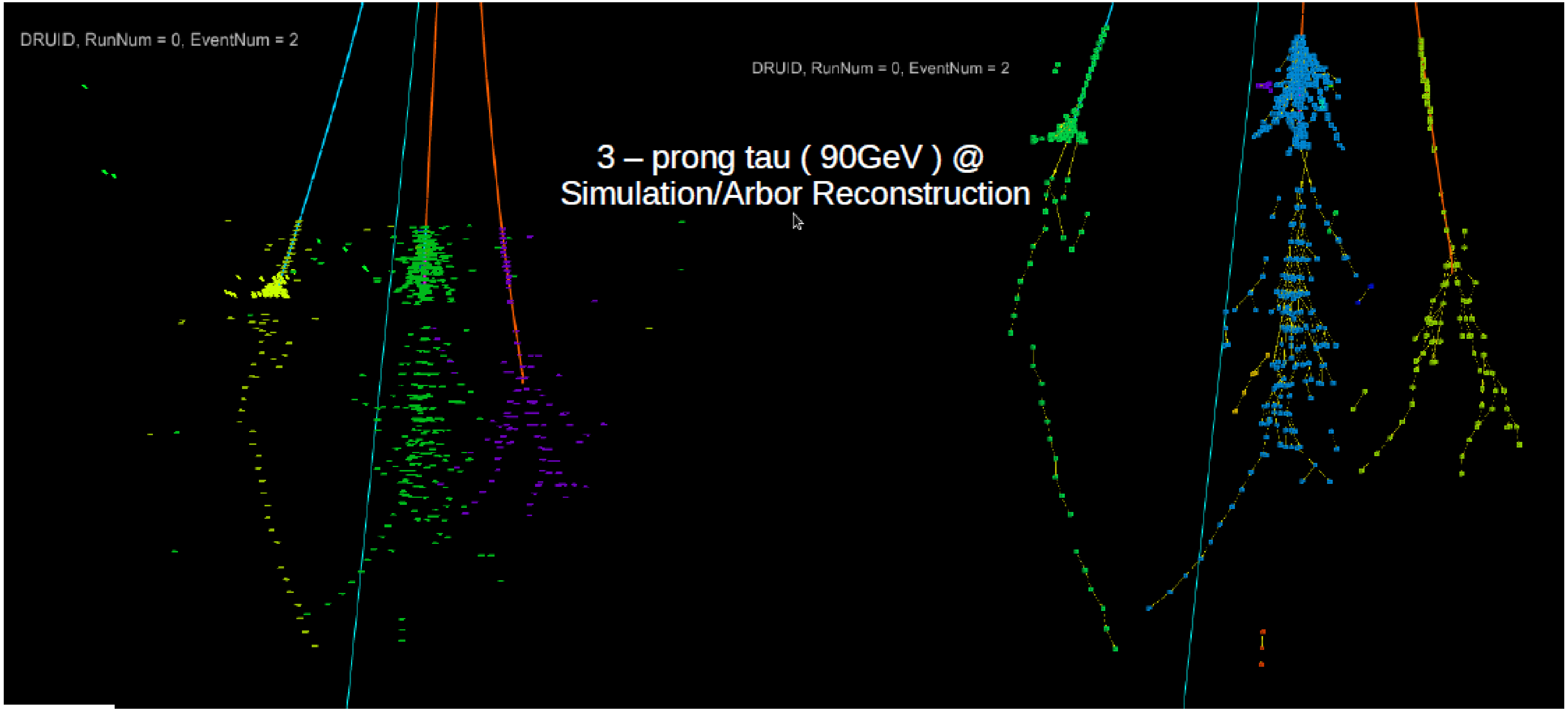
POSSIBLE solution : TRACKING in CALO (Verified in ALEPH real data)

ULTRA GRANULAR CALORIMETER

Manqi RUAN (LLR) *

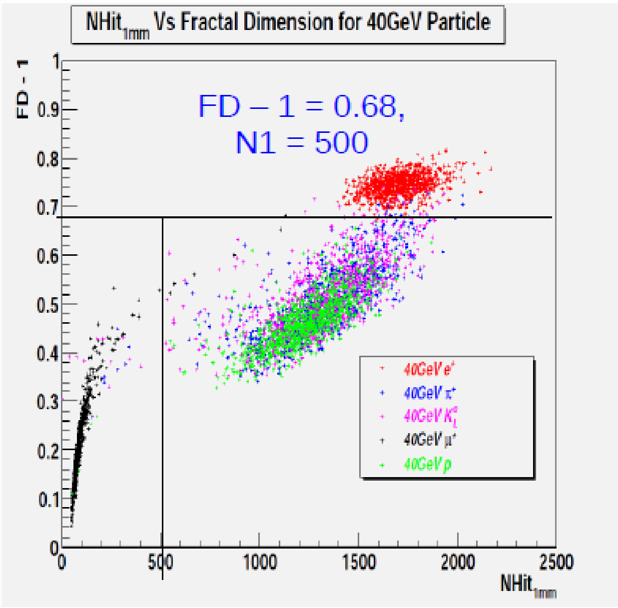
Arbor: pion reconstruction

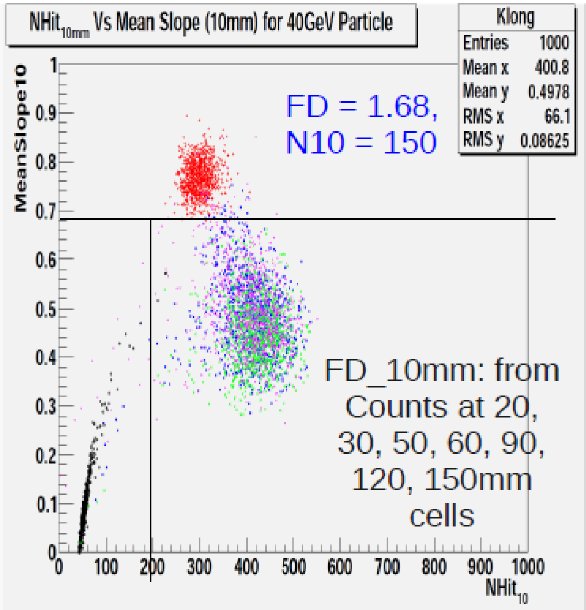


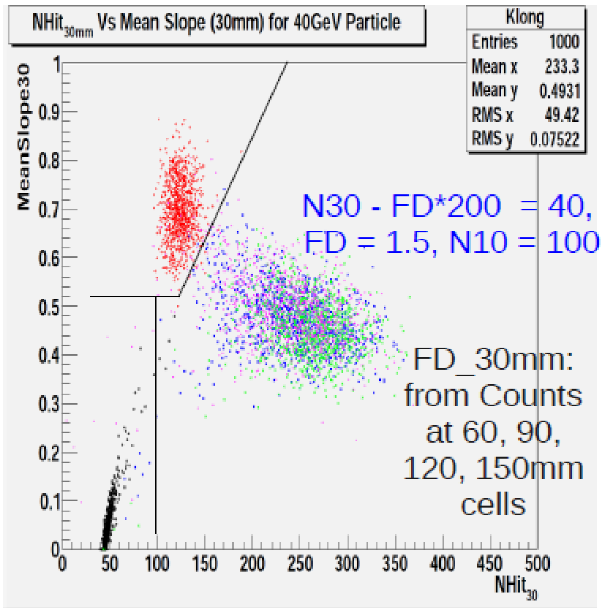
* now at IHEP(Beijing)

Potential tool for PID

SIMULATION







FD together with other info (Nhits): Clear separation at different scales

Remark: Energy dependent Cuts, easier for charged particles

Not a dream !!!

PID high quality

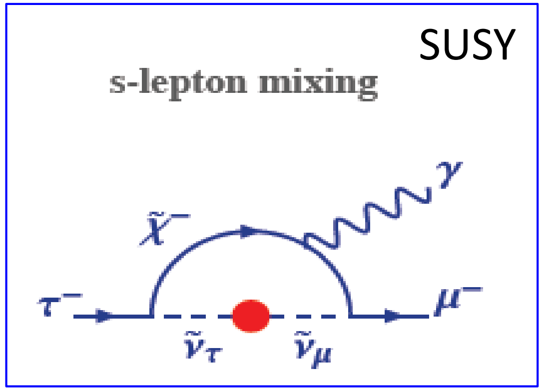
1mm	e+	u	h
e+	998	0	2
u	1	994	5
h	15	14	971

10mm	e+	u	h
e+	1000	0	0
u	0	995	5
h	17	14	969

30mm	e+	u	h
e+	1000	0	0
u	0	996	4
h	18	11	971

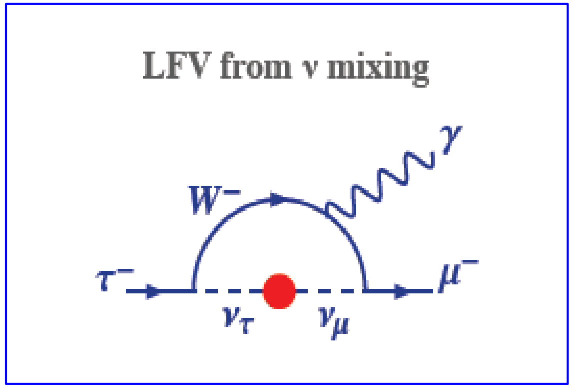
Another rare decays $\tau^{\pm} \longrightarrow \mu^{\pm}\gamma$

BSM



Any signal means NP

SM



$$\mathcal{B}(\ell_1 \to \ell_2\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\ell_1 i} U_{\ell_2 i} \frac{\Delta m^2_{i1}}{M^2_W}\right|^2$$

Unmeasurable small rates (10^{-54}-10^{-49})

Do we need a good ECAL energy resolution for a good resolution in the mass ($\mu^{\pm}\gamma$) ?

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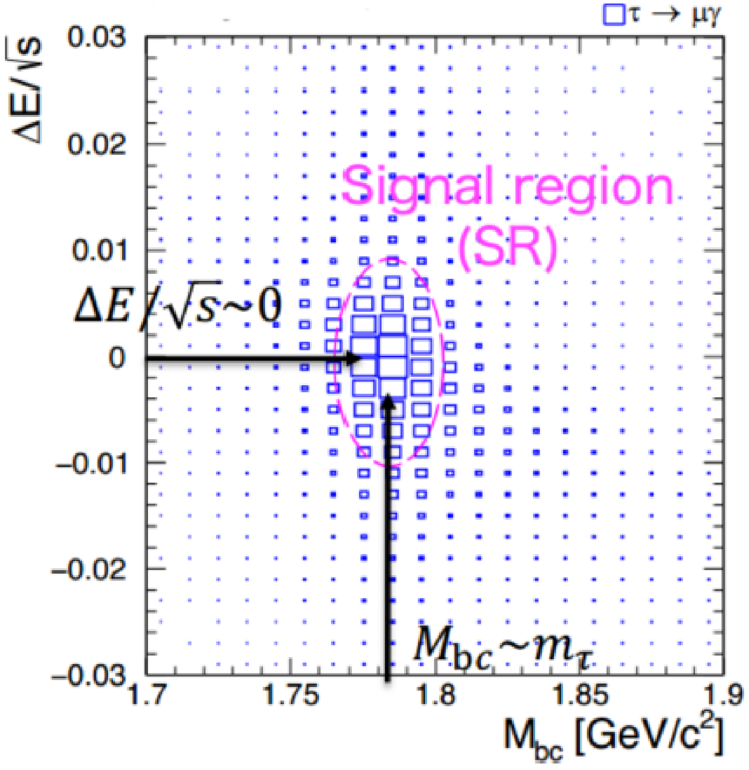
NO



signal region

- $M_{\rm bc} = \sqrt{(E^{\rm CM}_{\rm beam})^2 - \left(p^{\rm CM}_{\ell\gamma}\right)^2} \sim M_\tau$
- $\Delta E = \left(E^{\rm CM}_{\ell\gamma} - E^{\rm CM}_{\rm beam}\right) \sim 0$ GeV
- for background $M_{\rm bc}$ distribution will vary smoothly without peaking

1 slide on **CP violation, Higgs sector**

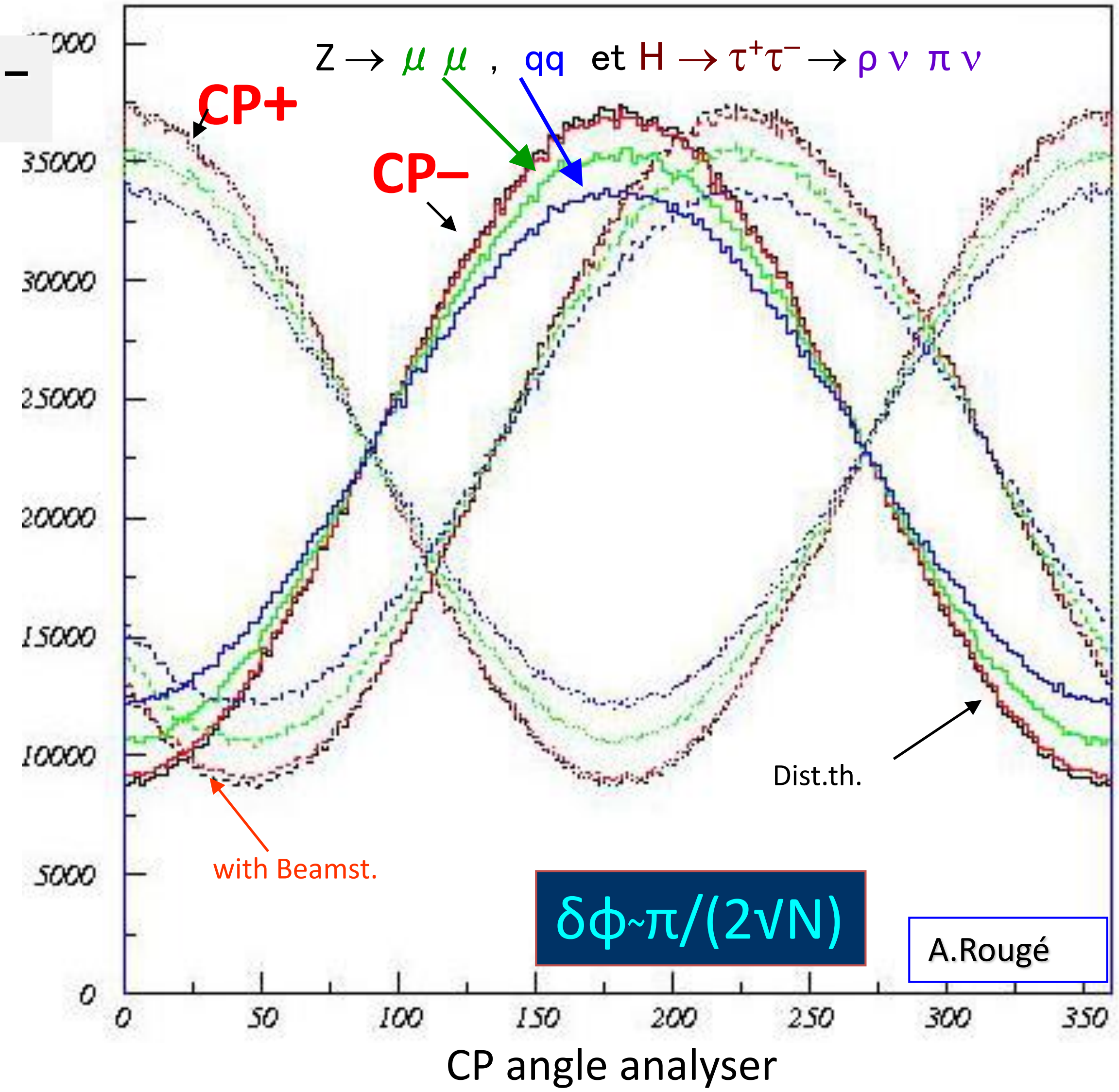
$\sqrt{s}$ = 250 GeV and $e^+ e^- \to ZH \to Z\,\tau^+\tau^-$

Essential to distinguish the tau decays

$$\tau^{\pm} \longrightarrow \rho^{\pm}\nu_{\tau}$$

versus

$$\tau^{\pm} \longrightarrow \pi^{\pm}\nu_{\tau}$$

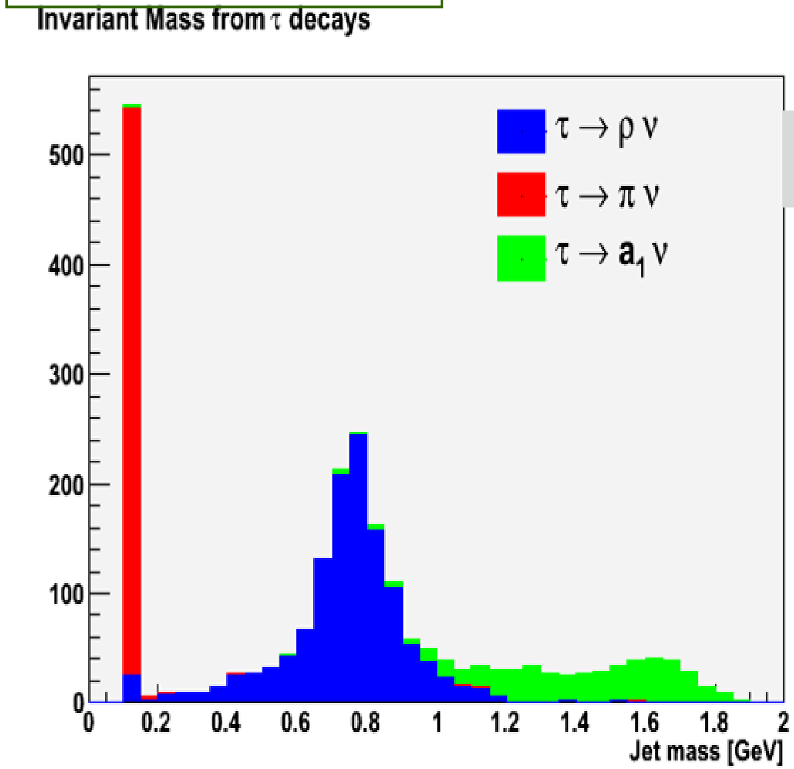


Second item : Tau polarisation for EW measurements

$\tau^{\pm}$ as a polarisation analyser

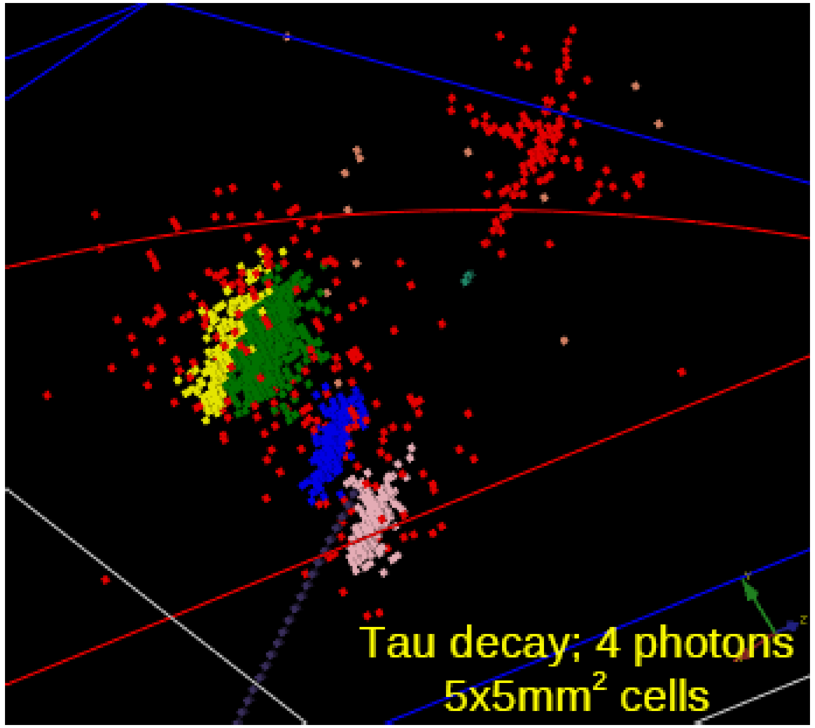
Full Simulation GEANT4
& Reconstruction with PFA

→ Need to reconstruct photon(s) in dense environment…. Even at Z peak



Cluster energy cut at 200 MeV

Is there photon(s) or not in the hemisphere ?



	Jet mass < 0.2	Jet mass in 0.2-1.1	Jet mass >1.1
$\tau \to \pi\nu$	90.2 %	1.7 %	8.1 %
$\tau \to \rho\nu$	1.7 %	87.3 %	7.4%
$\tau \to a_1\nu$	0.6 %	7.4 %	92.0 %

Performances depends strongly on ECAL granularity

- Asymmetry of polarisation could be largely improved (very low syst.).

- A dedicated study must be performed for the syst. On polarisation itself

- To obtain this performance on the separation of tau decays ,

the efficiency to tag the presence of low energy photon(s) is ESSENTIAL

The comparison between ALEPH and L3 performances on EW measurements
is telling you what is important ,

S/N for low energy photon(s)

Or

ECAL Energy resolution

(efficiency versus fake photon rate)

Most of the case, It apply ALSO to flavour physics

Conclusion

- FCCee could do much better than BELLE-II or HL-LHC for many measurements
- The purity of the selected tau pairs is very high (nothing to do with BELLE-II or LHCb)
- FCCee can address rare decays as well as other aspects , like EW measurements (tau polar)
- The systematics are “probably” easier to control (vs BELLE or LHC)
- TAKE CARE of ECAL imaging performances (not to the stochastic term of energy resolution of ECAL)

Thanks to

Yfan Jin (BELLE-II)

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Amy Rostomyan (BELLE-II)

Manqi Ruan (IHEP for ARBOR rec.)