Thesis opportunities at the Belle II Experiment

Alessandro Gaz (DFA)
on behalf of the Belle II Padova Group

Outline

- The Belle II Experiment and its mission;
- The Time Of Propagation (TOP) sub-detector;
- Physics analysis topics;
- Our group;
- Thesis opportunities.

The mission

- Belle II is a big experiment, with 1200 collaborators from 28 countries (from Italy: ~80 members from 8 institutions);

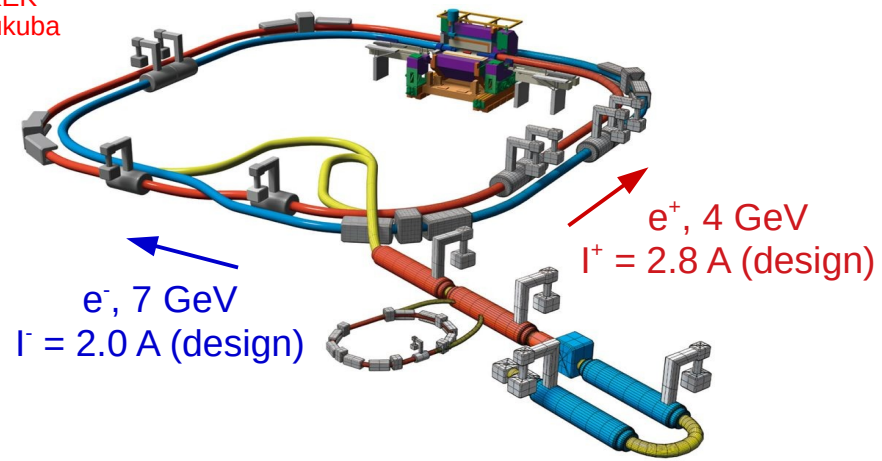
- The physics program is very vast:
  - B-mesons physics:

    $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$ (in a quantum entangled state)
  - abundant production of charmed mesons and τ leptons;
  - searches for exotic hadrons;
  - searches for Dark Sector particles;

- An entire analysis can be performed from start to finish by a very small number of people;
- Also opportunities for detector development and upgrade;

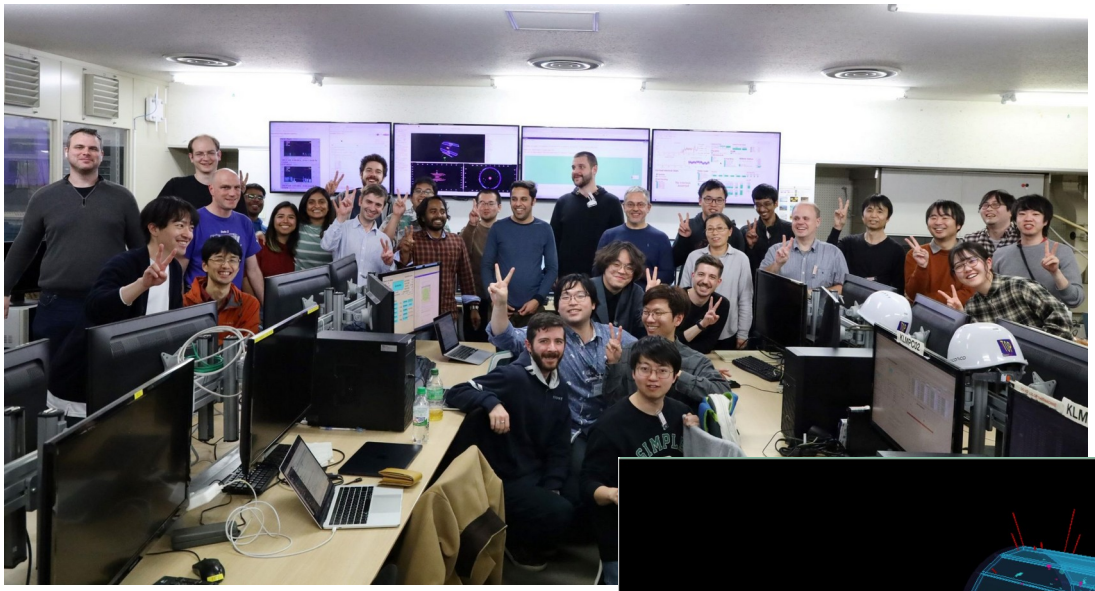
A large data set is already available for physics analysis and detector studies, and much more will come!

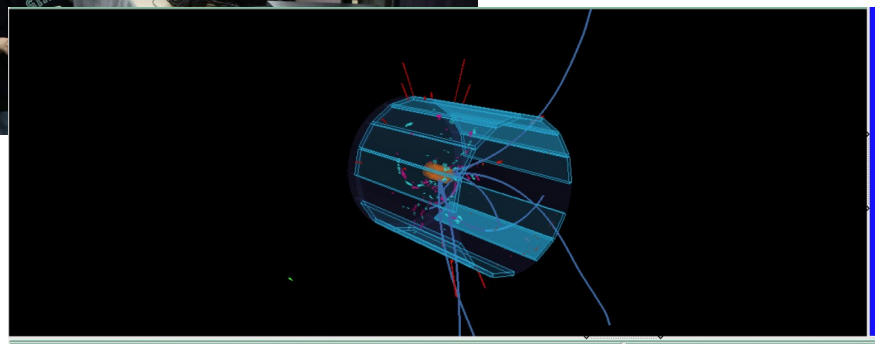
The SuperKEKB e^+e^- collider

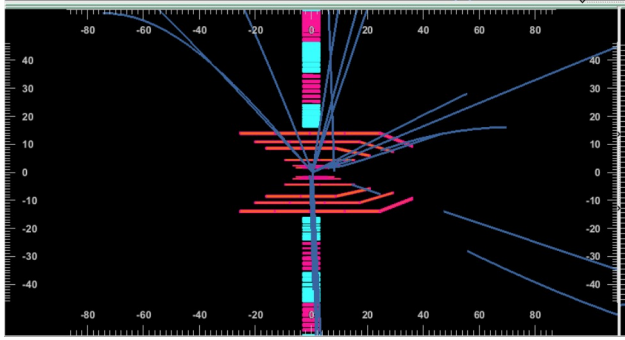


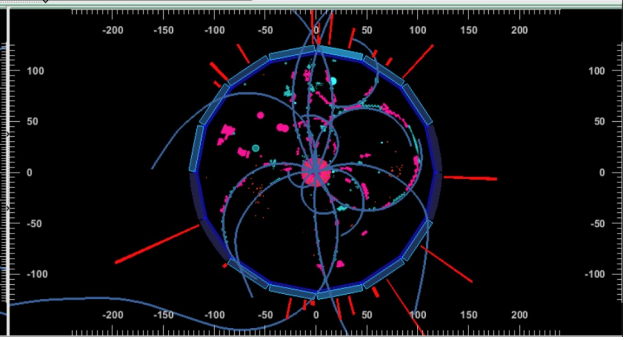
- Asymmetric energy e^+e^- collider, operating at E_{CM} ~ 10.58 GeV = m[Υ(4S)];
- Luminosity goals
  - instantaneous: 6 x 10^{35} $cm^{-2}s^{-1}$ [reached so far 4.7 x 10^{34}]
  - integrated: 50 ab^{-1} [recorded so far 0.424]
- Successfully completed Run1 (2019-2022), and just started Run2!

First Run2 collisions last Tuesday!





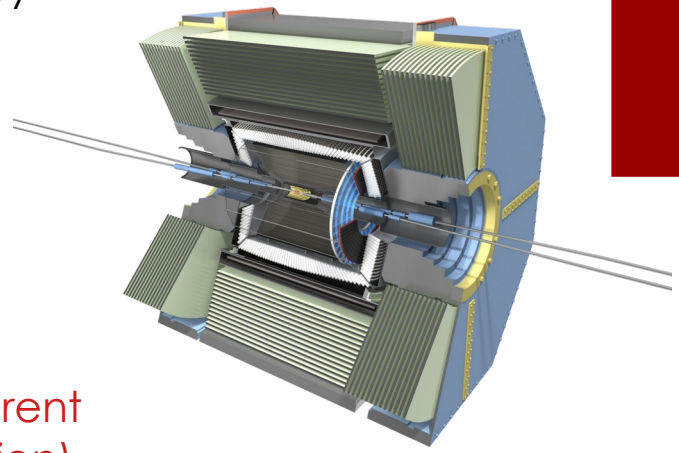


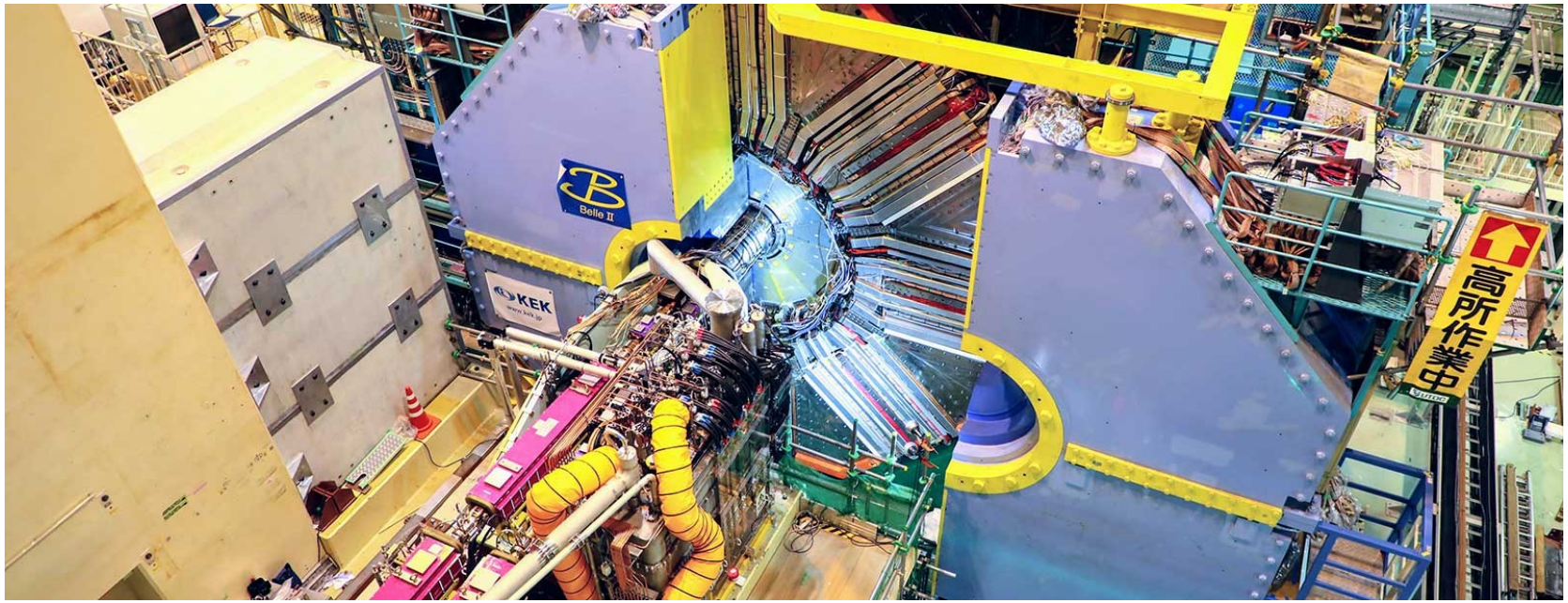


The Belle II Detector

A modern HEP detector with several key features:

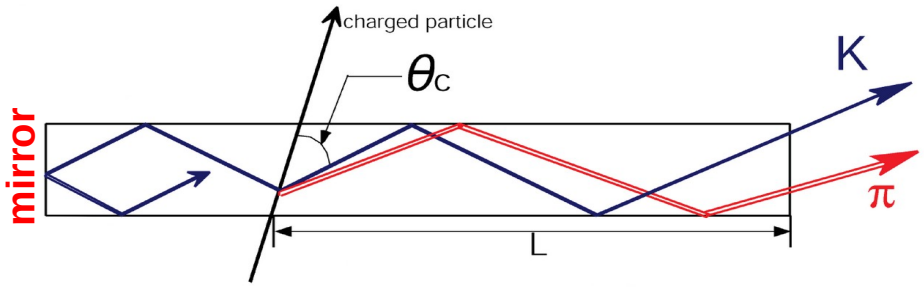
- good hermiticity and efficient reconstruction of charged tracks;
- great decay vertex resolution;
- efficient reconstruction of neutral particles (π^0's, $\eta^{(\prime)}$'s, K^0_L's, ...);
- reliable discrimination between different kinds of particles (**P**article **ID**entification).

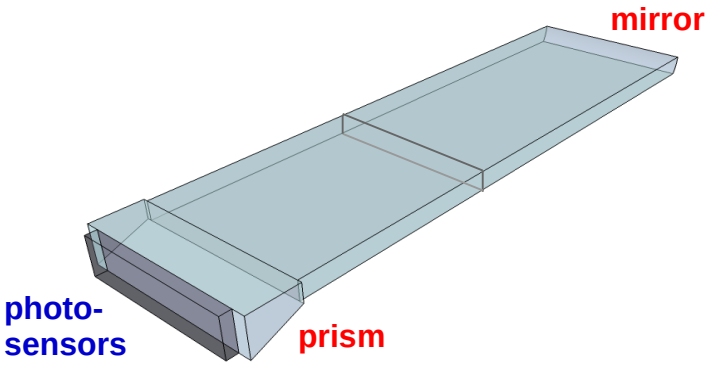




The Time Of Propagation (TOP) sub-detector

The Belle II Padova Group contributed to the construction, commissioning, and operations of the TOP detector, which is (mostly) dedicated to the identification of π's and K's;





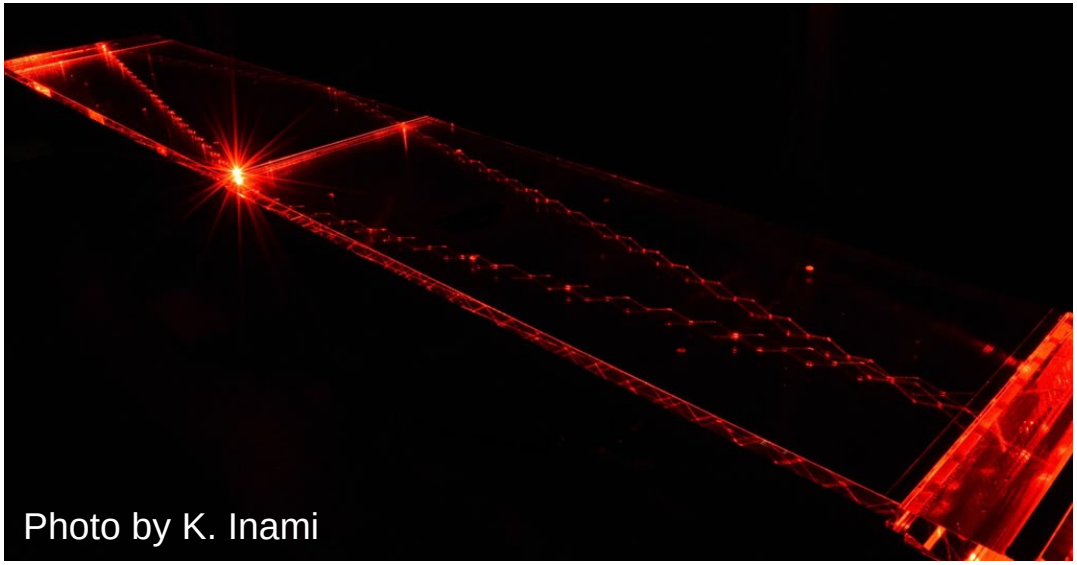
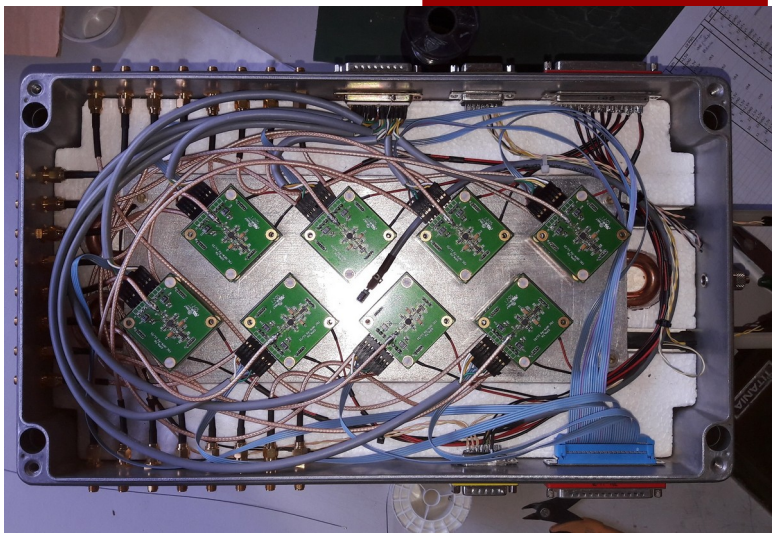


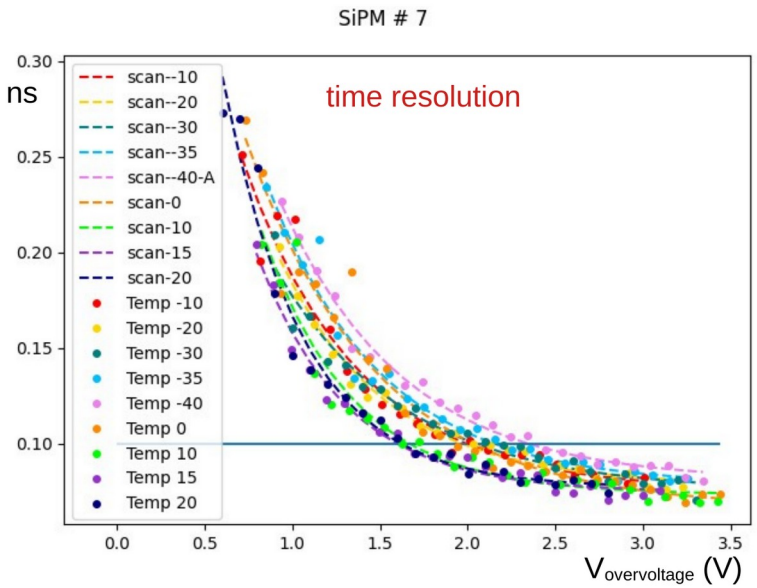
Photo by K. Inami

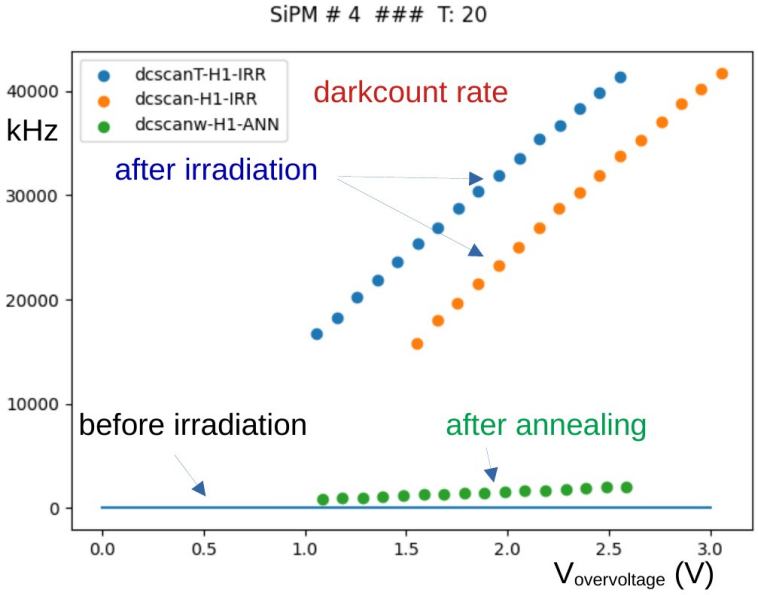
Micro-channel plate photomultipliers (MCP PMT's)

Development on SiPM

- We are considering to replace the MCP PMT's (which suffer from radiation damage) with Silicon Photomultipliers;
- In Padova we are working on the full characterization of SiPM's response under controlled conditions;
- We are also studying the radiation damage and possible mitigation strategies.

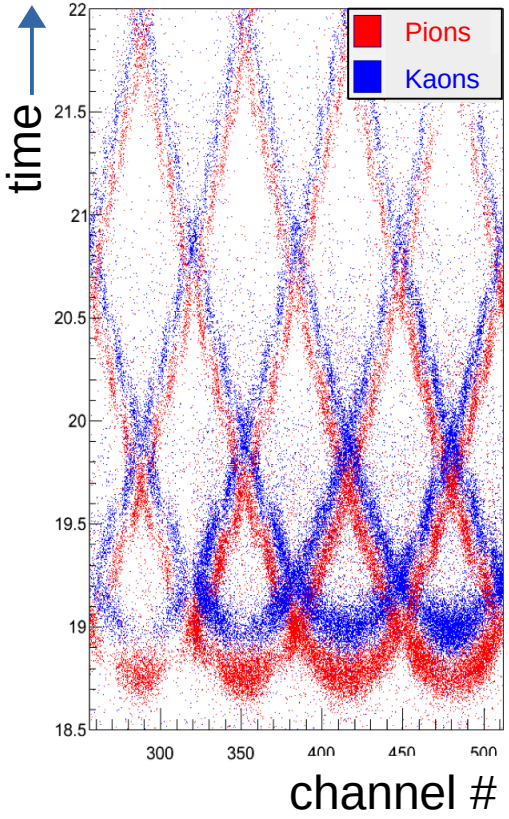


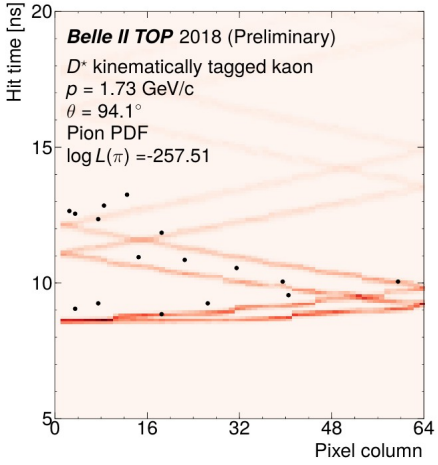


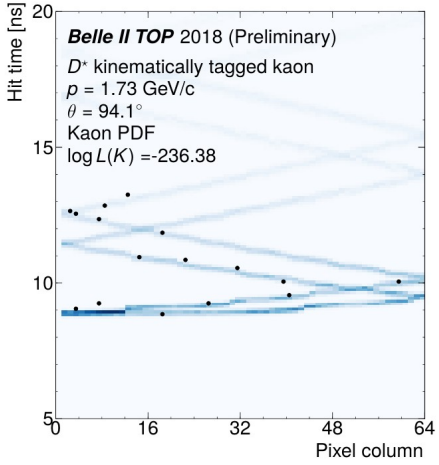


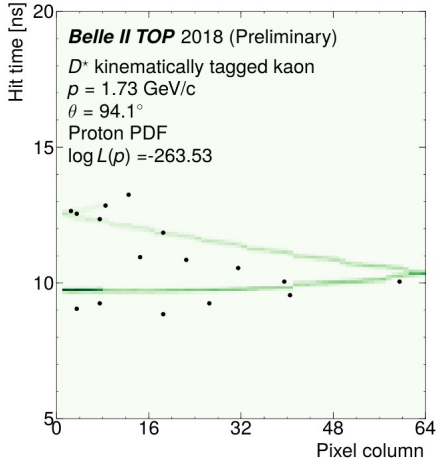
The Time Of Propagation (TOP) sub-detector

TOP PID is currently based on a (quite complicated) analytic calculation of the probability density function of the times of arrival of the Cherenkov photons:









Ongoing activity: move from the analytical approach to a new one, relying on machine learning for pattern recognition

Belle II Physics Topics

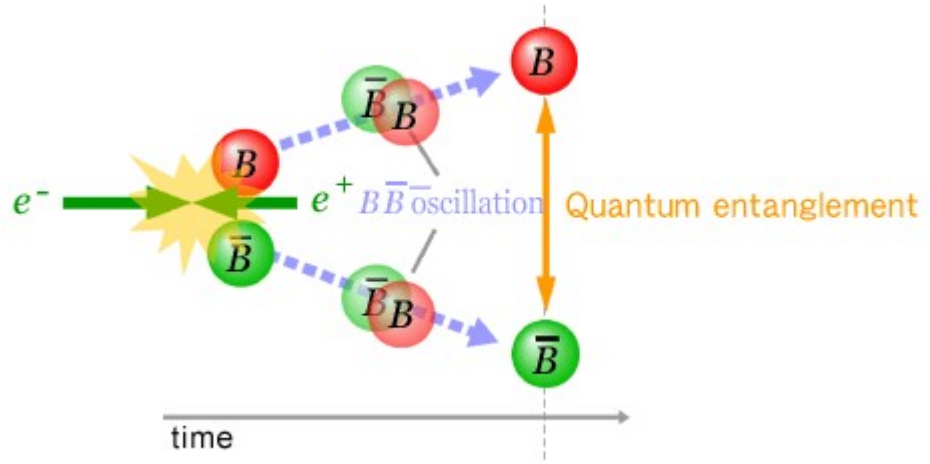
- The main topic in physics analysis for our group is:

CP violation

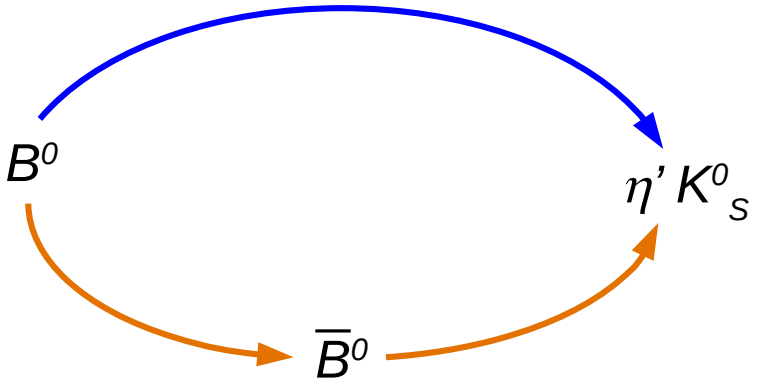
(which is the violation of the symmetry between matter and anti-matter)

- B mesons are an ideal place to study this kind of phenomena as:
  - CP violation happens in different forms and in many decay channels;
  - the Standard Model can make precise predictions, so any discrepancy with the experimental value is a potential evidence for New Physics!
  - at Belle II we can really take advantage of the **quantum entanglement** of the two neutral B mesons:

If one of the two B's is a B^0, in the same instant the other B must be a $\bar{B}^0$

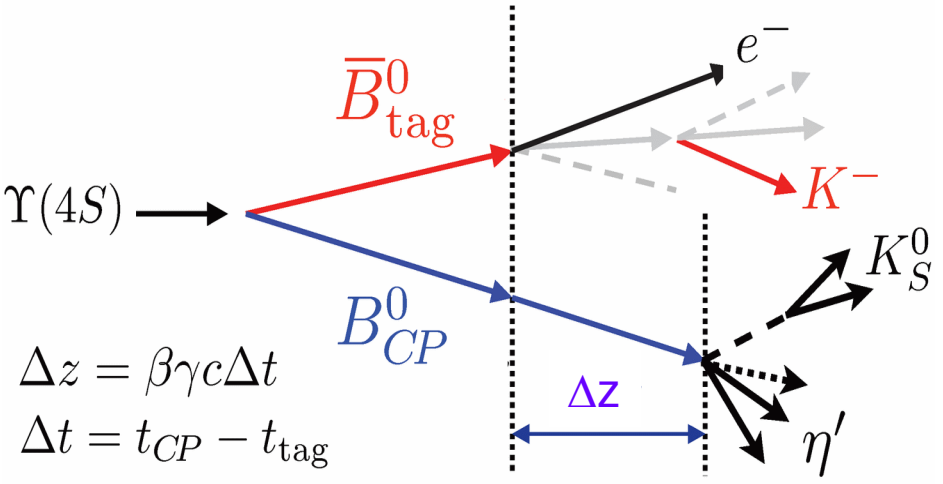


Time dependent CPV



The $\eta' K_S$ final state is a CP eigenstate and is accessible to both B^0 and $\overline{B}^0$.

The interference between the direct decay and the decay through oscillation gives us access to fundamental parameters of the standard model.

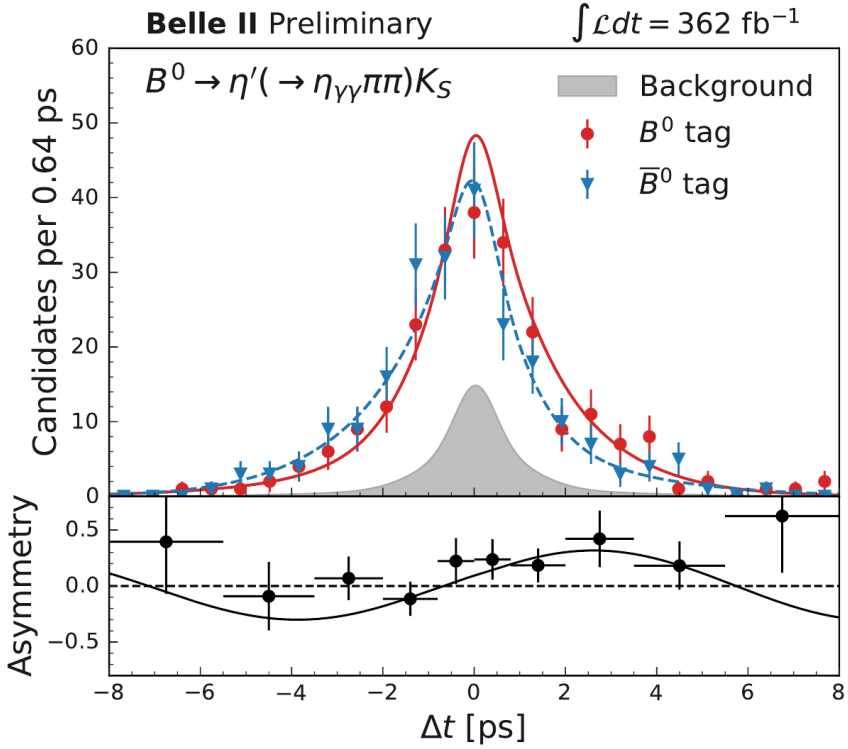


<Δz> ~ 130 μm at Belle II

$$\begin{aligned}\mathcal{A}_f(\Delta t) &= \frac{\Gamma(\overline{B}^0(\Delta t)\to f) - \Gamma(B^0(\Delta t)\to f)}{\Gamma(\overline{B}^0(\Delta t)\to f) + \Gamma(B^0(\Delta t)\to f)} \\ &= S_f \sin(\Delta m_B \Delta t) + A_f \cos(\Delta m_B \Delta t)\end{aligned}$$

Time-dependent CPV in $B^0 \to \eta' K_S$

- Hot off the press: arXiv:2402.03713 [hep-ex], submitted to PRD;
- First time-dependent CPV analysis at Belle II on this channel!

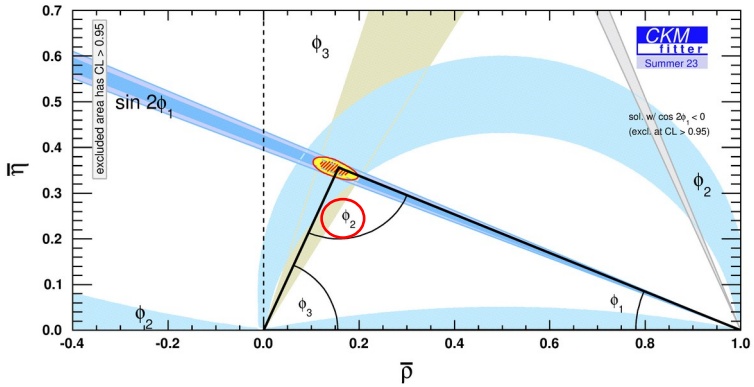


Channel	Signal yield	$C_{\eta' K^0_S}$	$S_{\eta' K^0_S}$
$\eta' \to \eta_{\gamma\gamma}\pi^+\pi^-$	358 ± 20	-0.10 ± 0.13	0.69 ± 0.14
$\eta' \to \rho\gamma$	471 ± 29	-0.24 ± 0.10	0.65 ± 0.13
$\eta' \to \eta_{3\pi}\pi^+\pi^-$	55 ± 8	0.11 ± 0.32	0.25 ± 0.50
Sim. fit	829 ± 35	-0.19 ± 0.08	0.67 ± 0.10

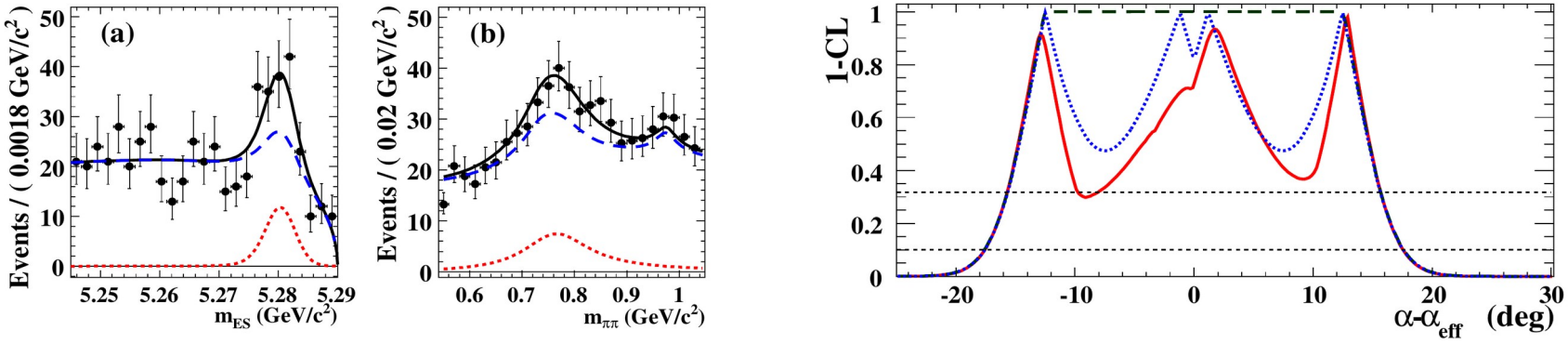
How to improve from here:

- more sub-channels (K^0_L, $K^0_S \to \pi^0\pi^0$, ...);
- better tools;
- more data!

Time-dependent CPV in $B^0 \to \rho^0\rho^0$



- The decay $B^0 \to \rho^0\rho^0$ gives fundamental inputs for the determination of the ϕ_2 (α) angle of the CKM Unitarity Triangle;
- It is a quite rare decay (BR ~ 10^{-6}) and experimentally challenging (wide resonances, polarization, ...);



Plots from BaBar, Phys. Rev. D 78, 071104 (2008)

- With the data that we will have in the next 1-2 years, we will be in a position to make a world leading time-dependent measurement!

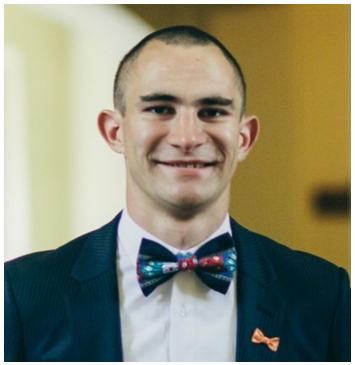
The Belle II Padova group

PhD students

Cecilia Antonioli

Shu-Ping Lin

Postdoc



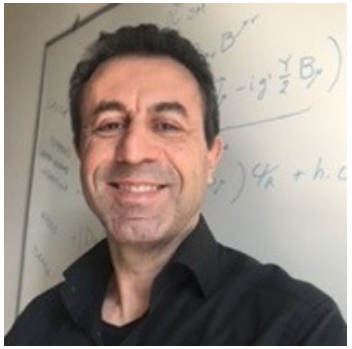
Jakub Kandra

Staff

Alessandro Gaz

Stefano Lacaprara

Roberto Stroili



Ezio Torassa

Thesis opportunities

We have many thesis opportunities for topics related to those I mentioned today that cover:

- hardware development;
- detector performance;
- physics analysis;

Typically the student will work side-by-side with one of the senior members of the group on a project that suits his/her needs (Triennale/Master's), interests, and availability;

For more details, please see the Thesis Portal (https://tesi.dfa.unipd.it) and talk to us:

alessandro.gaz@unipd.it
stefano.lacaprara@pd.infn.it
roberto.stroili@unipd.it
ezio.torassa@pd.infn.it