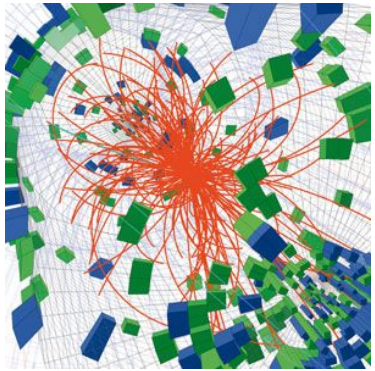
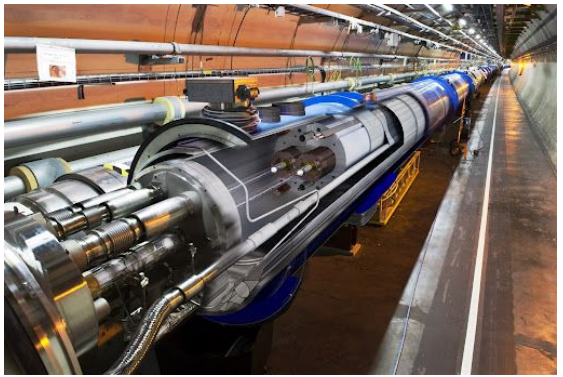
Thesis opportunities for Gruppo 1 INFN

Physics at accelerators

JoinUs@Physics

20/12/2021





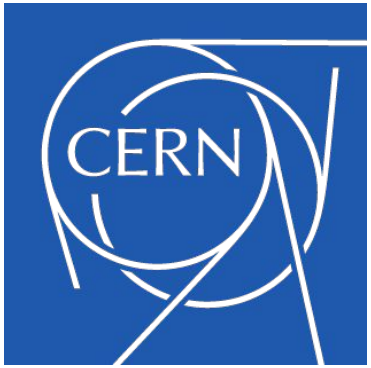
Stefano Lacaprara

INFN Padova

Gruppo 1: Physics at Accelerator and Collider

- Which particles do you collide? Yes.
- **Proton to Proton**
  - LHC (CERN - Geneve - CH/France): **CMS** and **LHCb**
- **Electron to Electron**
  - SuperKEKB (KEK - Tsukuba - Japan): **Belle II**
- **Muon to Electron**
  - MUonE @ CERN
- **Electron to Electron/Muon to Muon @ high energy (someday)**
  - Future Circular Collider
  - Muon Collider
- **Photon to Electron**
  - LUXE at DESY (Hamburg - Germany)
- **Cosmic Muons to anything**
  - Muon Tomography

Disclaimer: a lot of opportunities and proposals, I will not have time to go through most of them. Some material already presented on 29/9/2021



CMS Thesis Topics

Stefano Lacaprara, INFN Padova

Why the CMS experiment ?

- ★ A Nobel Prize experiment
- ★ An international collaboration
- ★ Relevant results in the reach of a thesis work
- ★ Acquisition of a skillset very demanded in the job market
- ★ Possibility of periods at CERN (COVID permitting)

The CMS Padova group has consistently kept a leading role in the experiment with many position of responsibilities in detector construction, physics and even providing a spokesperson.

Theses@CMS - PHYSICS ANALYSES

bachelor
master

working at these analyses may include presentation of results at CMS meetings, and periods at CERN ;)

measurements and searches w/ Run2 data and MC based studies for HL-LHC

- → **Rare decay of Higgs→J/ψγ** Higgs-charm coupling
  Dr. A. Zucchetta alberto.zucchetta@pd.infn.it
- → **FCNC in the top decay** new physics
  Prof. U. Gasparini ugo.gasparini@unipd.it
- → **Search for heavy composite neutrinos** new physics
  Dr. P. Azzi patrizia.azzi@pd.infn.it
- → **New physics effects in events with di-bosons** new physics
  Dr. P. Azzi patrizia.azzi@pd.infn.it



B-Physics topics

flavor physics at the moment shows the most intriguing discrepancies with the Standard Model

- → **Measurement of the production cross section pp -> b-bbar X**
- → **Measurement of the production cross section pp -> gg -> bb+bb+X**
- → **Measurement of the oscillation frequency b->anti-b**
- → **Search for matter-antimatter violation in the oscillations of B mesons**
  Prof. F. Simonetto franco.simonetto@unipd.it

- → **Search for $B_s \to \tau\tau$ with NeuralNetwork**
  Dr. T. Dorigo, Prof. M. Margoni tommaso.dorigo@pd.infn.it


For more information :
https://web.infn.it/cms_padova/index.php/it/cms-padova/tesi-proposte

Theses@CMS - ALGORITHMS DEV.

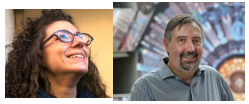
bachelor
master

Advanced and Innovative algorithms are at the core of discoveries in HEP

acquisition of a skillset very demanded in the job market and period at CERN ;)

develop analysis in C++ and Python
(rudimentary knowledge preferred)

→ **Development and optimization of track reconstruction algorithms**
- **for heavy flavor studies**
  Dr. M. Tosi, Prof. M. Margoni, Prof. F. Simonetto mia.tosi@unipd.it
- **in 4D** (addition of timing information)
  Dr. M. Tosi, Prof. R. Carlin mia.tosi@unipd.it
- **in** 4D (addition of timing information) with Graph Neural Network
  Dr. M. Tosi, Dr. T. Dorigo mia.tosi@unipd.it



→ **Development and optimization of jet flavor identification**
- identification of charm jets **Higgs-charm coupling**
  Dr. M. Tosi, Dr. P. Bortignon (UniCA) mia.tosi@unipd.it
- identification of strange jet (in Phase2) **Higgs-strange coupling**
  Dr. P. Azzi, Dr. P. Bortignon, Dr. M. Tosi patrizia.azzi@pd.infn.it

→ **Application of Machine Learning techniques to reduce systematics of top quark cross section measurement**
  Dr. T. Dorigo, Dr. G. Strong tommaso.dorigo@pd.infn.it

→ **Simulation and validation software for Neural Network-based trigger algorithms of muon detectors**

→ **Development and implementation of Machine Learning techniques for muon trigger algorithms**

→ **Stream processing of trigger-less detectors with scalable distributed computing infrastructures**
  Dr. J. Pazzini jacopo.pazzini@unipd.it

For more information :
https://web.infn.it/cms_padova/index.php/it/cms-padova/tesi-proposte

Theses@CMS - DETECTOR STUDIES

bachelor
master

Opportunity to work with a real detector is an incredibly enriching experience and fundamental for a physicist.

student will take measurement in the lab, and develop analysis code and firmware

→ **muon detectors (Drift Tubes, DT)**

- **Noise and linearity characterization of time to digital converters for the muon detector of CMS**
- **Demonstrator of an innovative acquisition system based on remote direct memory transfer over optical links**

Dr. A. Triossi andrea.triossi@unipd.it

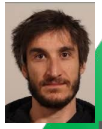
- **Development of NN-based trigger algorithms of muon detectors**
- **Implementation of ML techniques for muon trigger algorithms**
- **Stream processing of trigger-less detectors with scalable distributed computing infrastructures**

Dr. J. Pazzini jacopo.pazzini@unipd.it

→ **timing detectors (MIP Timing Detector, MTD)**

- **Study and Qualification of the power handling thermal interfaces**

Prof. R. Rossin, Dr. M. Benettoni roberto.rossin@unipd.it



- **Optimization of the noise performance of the SiPM at low temperature**

Dr. M. Tosi, Prof. R. Carlin mia.tosi@unipd.it

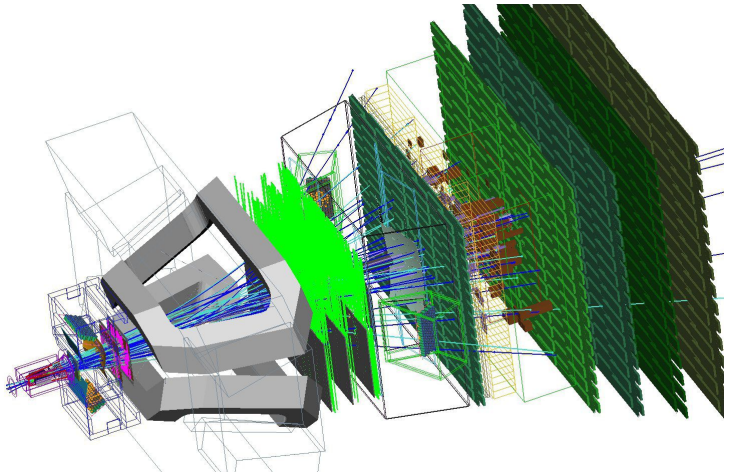
For more information :
https://web.infn.it/cms_padova/index.php/it/cms-padova/tesi-proposte

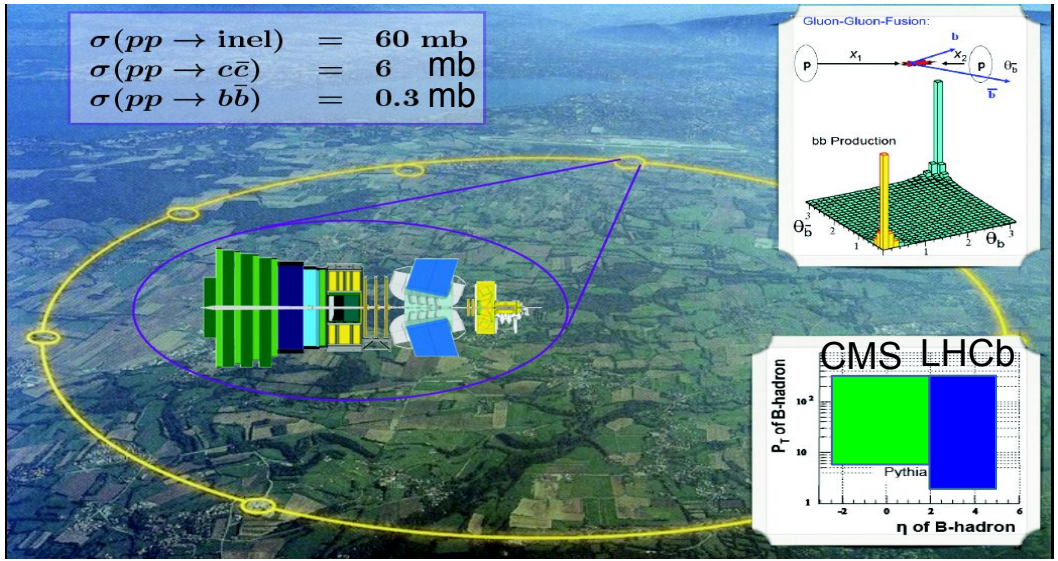
LHCb @ CERN

Stefano Lacaprara, INFN Padova

LHCb Experiment at CERN

- Experiment devoted to B-physics
- Exploiting the large b cross section in the forward region
  - Single arm spectrometer
- Activities/Thesis:
  - **Physics analysis**
  - **Detector studies and development for upgrade**





- **Thesis title**: **LHCb Run 3 data early measurements (a.k.a. 100 /pb challange !)**
- **People involved**: Alessandro Bertolin (INFN), Lorenzo Sestini (INFN)

- The LHCb data taking will resume in Spring 2022 after a major upgrade of the data acquisition system (full software trigger)
- **Main steps:**
  - At present: *validation of the selection algorithms developed so far*
  - Once first data arrive (mid June 2022): *work out the plots that would convince us that the detector is working as expected*
  - Once 100 /pb are collected (after a few weeks of data taking): *measurements of basic cross sections and observables, comparison with the corresponding Run 2 results*

The interested student will be able to work on any of the topics above as member of an international team of analysts

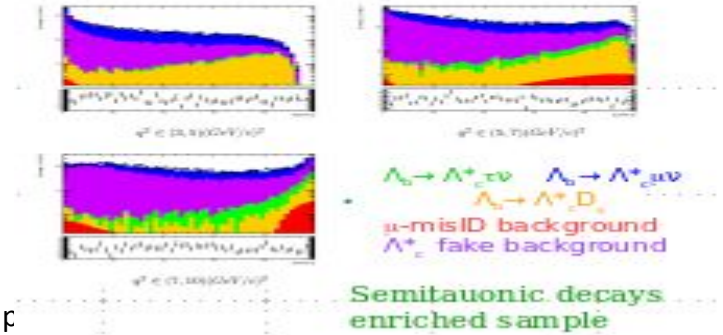
Both Bachelor and Master thesis on this topic are possible

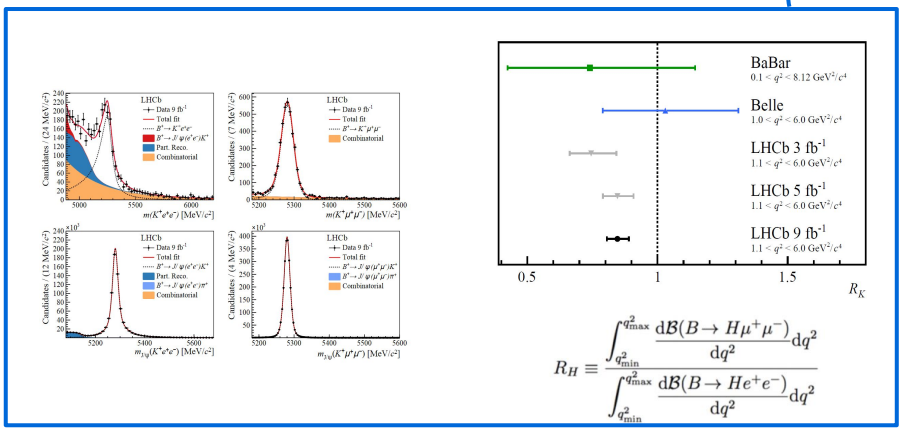
Lepton universality violation

- In Standard Model, all leptons (e/mu/tau) feel fundamental forces in the very same way
  - Only difference in leton mass
  - We do not expect any difference in meson/hadron decays into μ or τ
  - Siziable and intriguing difference seen in some rare B decays
- Look for difference in Λ_b->Λ_c decay

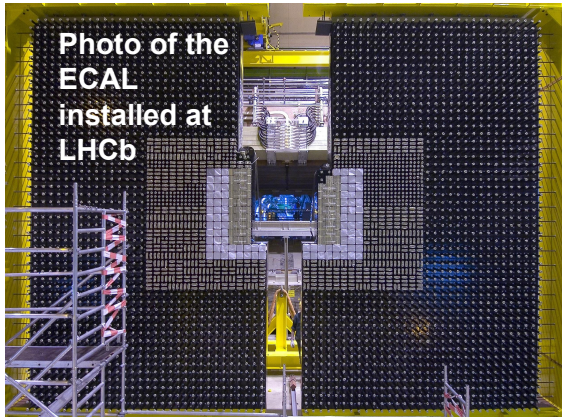
$$R(\Lambda_c^*) = \frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^* \tau^- \bar{\nu}_\tau)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^* \mu^- \bar{\nu}_\mu)} = \frac{N(\Lambda_b^0 \to \Lambda_c^* \tau^- \bar{\nu}_\tau)}{N(\Lambda_b^0 \to \Lambda_c^* \mu^- \bar{\nu}_\mu)} \frac{\epsilon_\mu}{\epsilon_\tau} \frac{1}{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau)}$$

- Prof. G. Simi





- **Thesis title**: **Optimization of the electromagnetic calorimeter for LHCb Upgrade**
- **People involved**: Lorenzo Sestini (INFN), Donatella Lucchesi (UniPD/INFN), Davide Zuliani (UniPD/INFN)

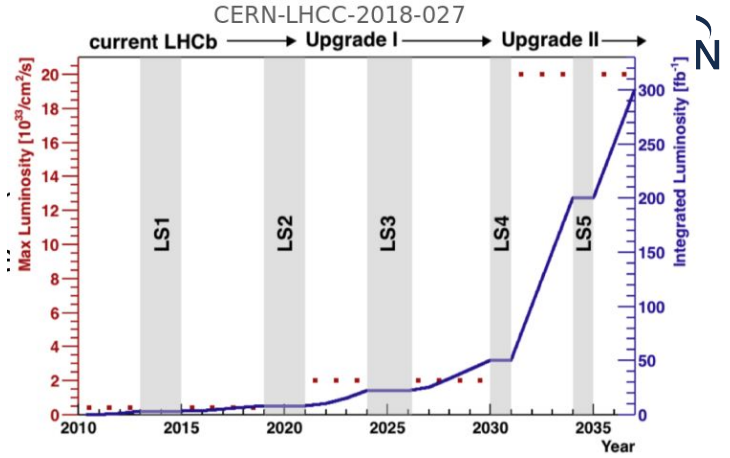


- A major LHCb upgrade has been proposed for the **High-Luminosity** era of LHCb.
- The **electromagnetic calorimeter (ECAL)** is fundamental to **measure electrons and photons energy**.

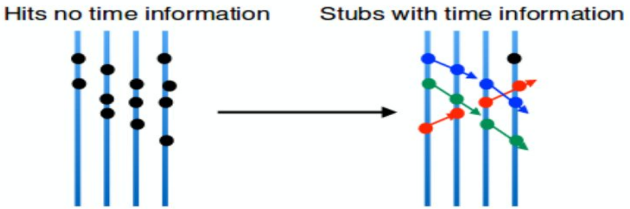
- In this thesis the student will **study the simulation with different calorimeter configurations**, in order to determine the one that gives the **best performance**.
- The results will be compared and validated with **data taken in beam tests at CERN and DESY**, where **calorimeter cell prototypes** are characterized.
- Both Bachelor and Master theses on this topic are possible.

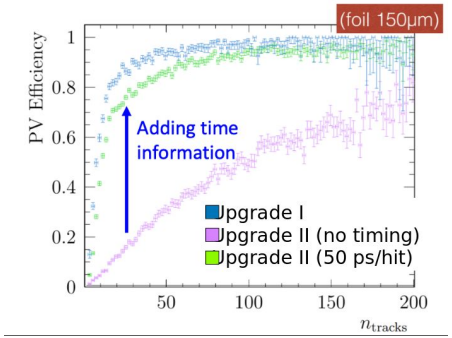
Istituto Nazionale di Fisica Nucleare

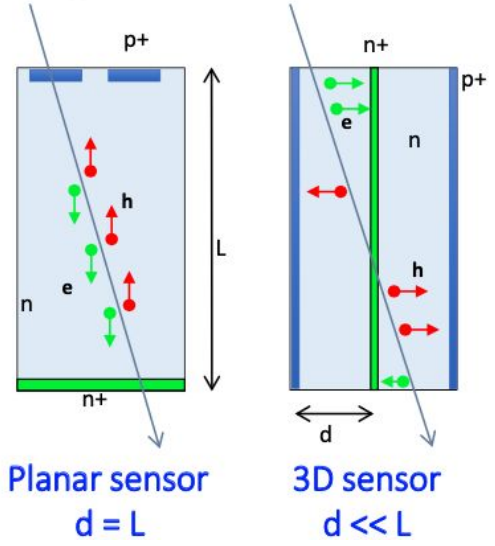
LHCb Upgrade II



- Upgrade High luminosity LHC
  - Radiation hardness
  - Tracks reconstruction in harsh environment
- New type of detector which provides also a precise timing information
- Fully Italian project
- **TIMESPOT**
  - Innovative 3D pixel detector
- Prof. G. Simi, Dott. F. Borgato







Thesis opportunities

- **Observation of $\Lambda_b \to \Lambda_c^* D_s$ decay:**
  - Critical to reduce systematic uncertainties on R(Λ_c^*)
  - Gabriele Simi, in collaboration with Dott. Luca Giambastiani (Univ. Padova)
- **Sensitivity for R(Λ_c^*) on run3 with new form factors:**
  - Preliminary study for R(Λ_c^*) measurement
  - Gabriele Simi, with Anna Lupato (Manchester Univ.)
- **Simulation of LHCb performances with upgraded VELO and RICH detectors**
  - Needed to develop and optimize silicon detectors
  - Relatore: Gabriele Simi, with Dott. Federica Borgato (Univ. Padova)
- **Characterization of new tracking and photon detector for LHCb upgrade**
  - To develop and optimize detectors
  - Relatore: Gabriele Simi, with Dott. Federica Borgato (Univ. Padova)
- **Analysis of first data collected with upgraded detector:**
  - Relatore: A. Bertolin (INFN Padova), with Dott. L. Sestini (INFN Padova)

LHCb Padova Contacts and Group Composition

Principal Investigator LHCb Padova: gabriele.simi@unipd.it,
Via Marzolo 8 stanza 163 , tel 049 8277074

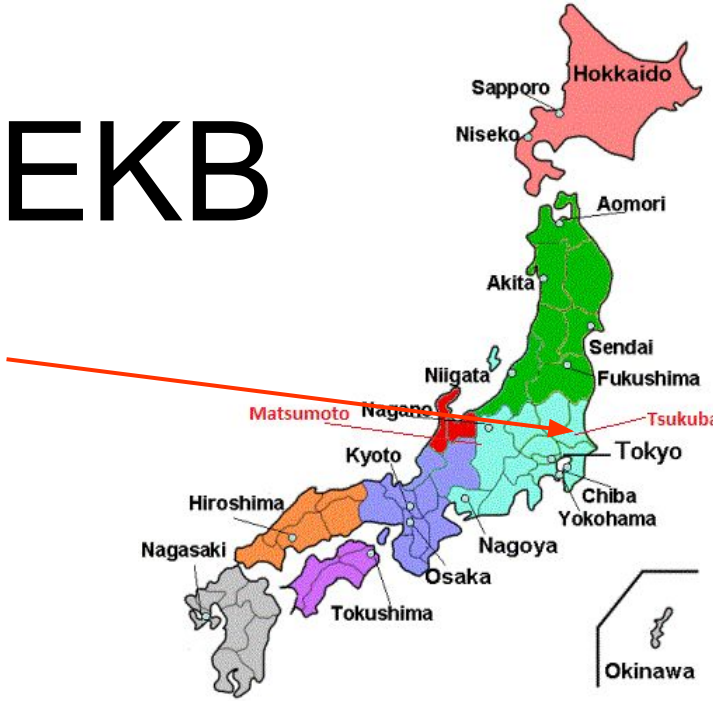
Link to LHCb Padova we page

LHCb Padova group members:

Dott. Alessandro Bertolin alessandro.bertolin@pd.infn.it
Prof. Donatella Lucchesi dontella.lucchesi@unipd.it
Dott. Lorenzo Sestini lorenzo.sestini@pd.infn.it
Prof. Gabriele Simi gabriele.simi@unipd.it (PI del gruppo)

Belle II @ SuperKEKB

KEK - Tsukuba - Japan



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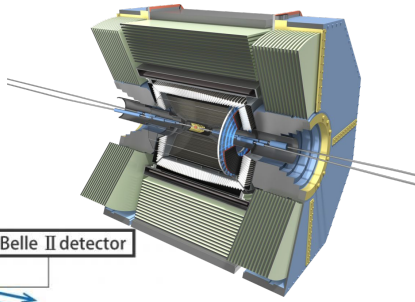
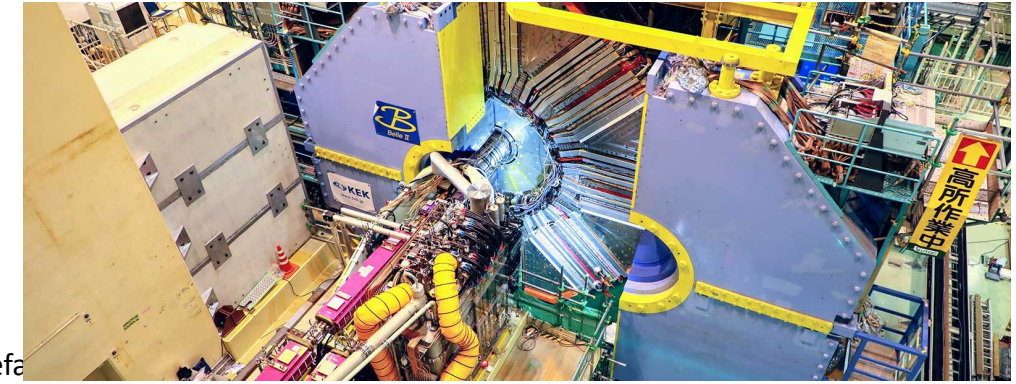
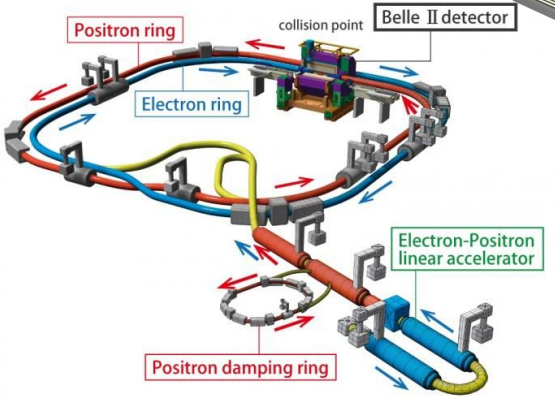
Thesis Opportunity at **Belle II**

- Belle II is an international collaboration involving 26 countries and ~1100 active members;
- The experiment studies the collisions produced by the SuperKEKB e+e- asymmetric energy collider located in Tsukuba (Japan);
- The center of mass energy of the collision is ~10.6 GeV, which allows the production of large quantities of B, D, and other lighter mesons, t leptons, exotic particles, … ;
  - Precision measurements of the parameters of the Standard Model;
  - Discovery of “exotic” particles
  - New Physics search through indirect effects
- Currently (today!) taking data with world record luminosity.

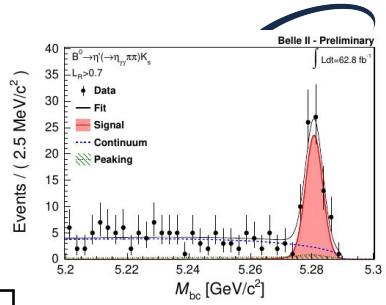


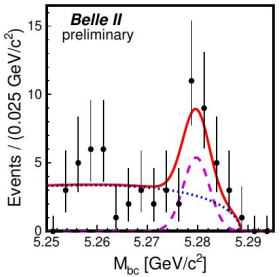


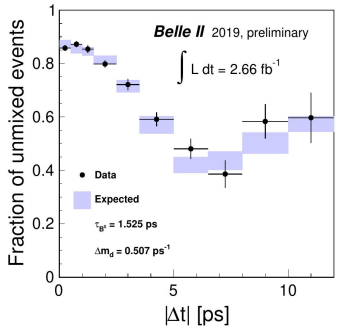


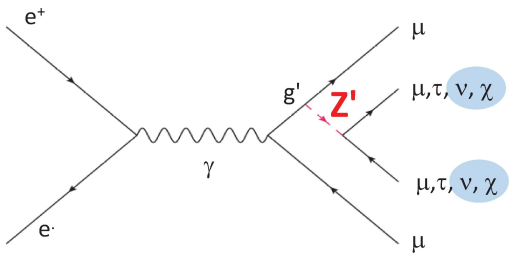
Physics topic at Padova

- **CP violation:**
  - which is the violation of the symmetry between matter and anti-matter
  - 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!
- **Search in Dark Sector:**
  - Possible extension of SM with additional, yet undiscovered (dark) particle, possibly connected to universe Dark Matter
  - Many models can be tested at Belle II
- **Partial reconstruction of $B_0 \rightarrow D^{*-} l^+ \nu$; $D^{*-} \rightarrow \pi^- D_0$**
  - Exploiting kinematic correlation between l and π using Machine Learning
  - Study BBbar mixing and CP violation
  - entanglement and its breaking





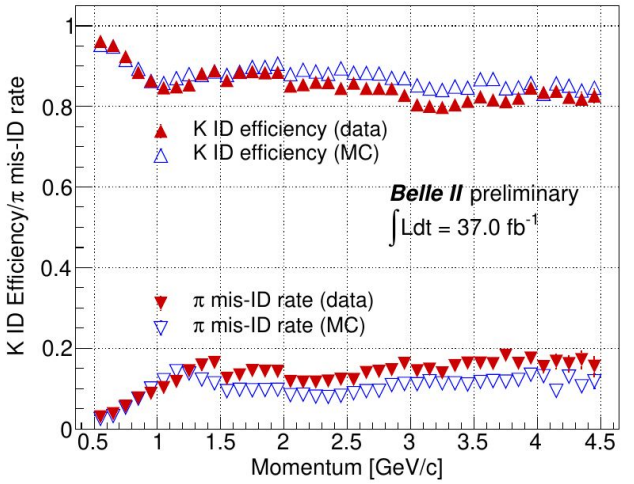


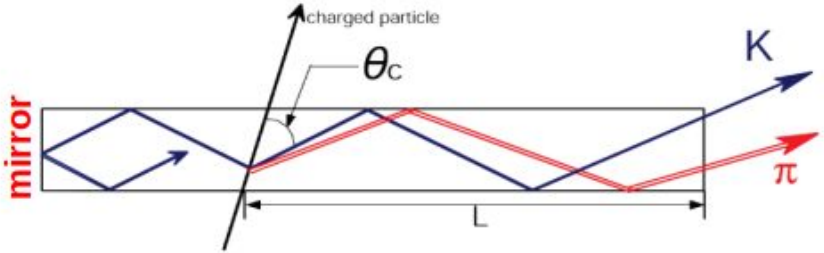


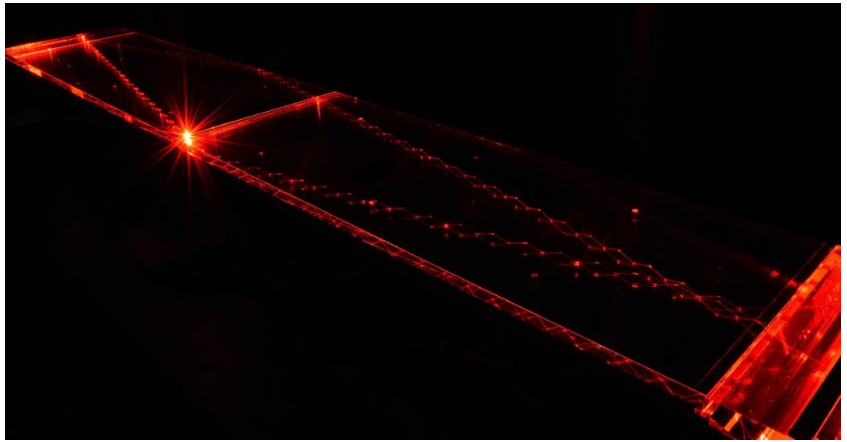
Detector Topic at Padova

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

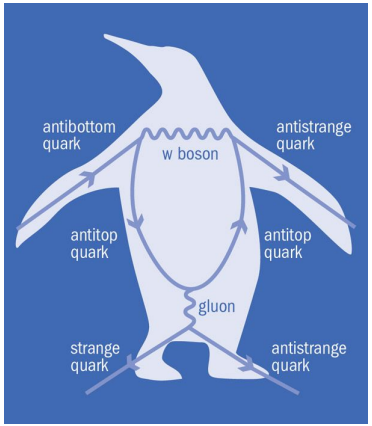
- commissioning;
- calibrations;
- performance improvements;
- future upgrade.







Potential Thesis Titles



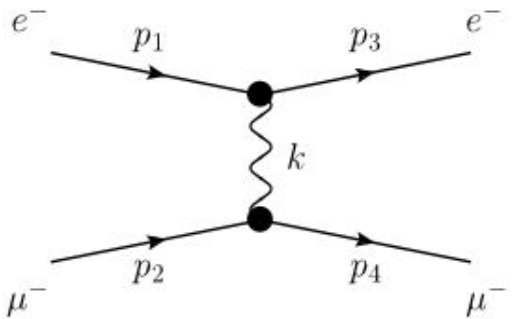
- *"Time dependent CP violation on penguin dominated modes"*
- *"Search for CP violation in $B\bar{B}$ mixing using inclusive dilepton events"*
- *"Physics with partial B^0 reconstruction"*
- *"Search for new light vector boson Z' in rare B-meson multiple muon decays"*
- *"Particle identification with the Belle II TOP detector using machine learning techniques"*
- *"Upgrade of the Time Of Propagation particle ID detector"*

Belle II contacts

Belle II Padova Group (senior) members:

Alessandro Gaz	alessandro.gaz@unipd.it
Stefano Lacaprara	stefano.lacaprara@pd.infn.it
Franco Simonetto	franco.simonetto@unipd.it
Roberto Stroili	roberto.stroili@unipd.it
Ezio Torassa	ezio.torassa@pd.infn.it

The MUonE experiment

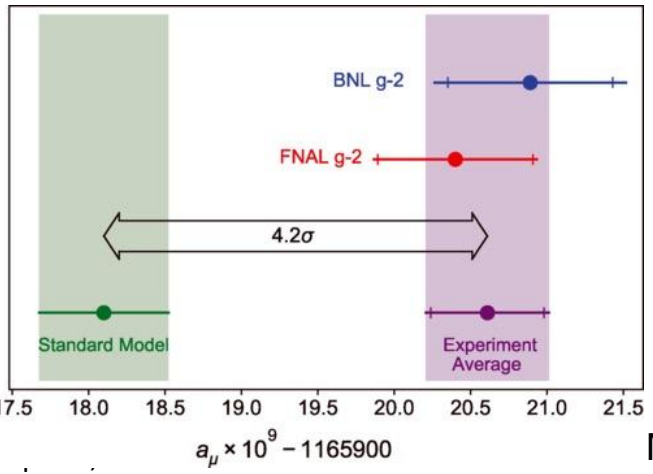


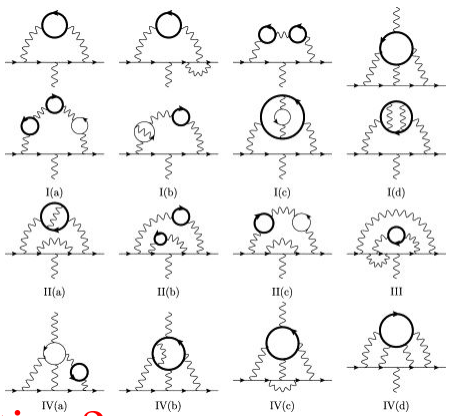
Muon *g-2* : the problem

- High precision measurements are a powerful tool to test physics theories
  - they can spot problems in the comprehension of a physical process
  - they can drive to the discovery of new phenomena
- Gyromagnetic factor *g* defines the coupling of the particle spin with a magnetic field.

It is computed with a high degree of precision within QED theory.
For the *muon* particle, *g* is computed with a precision of $6 \cdot 10^{-10}$.

Experimental measurements **differ by more than 4σ** from theory!

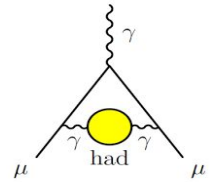




What's wrong?
- the theoretical computation?
- the experimental measurements?
- hint of NEW PHYSICS?

Muon *g-2* : the idea

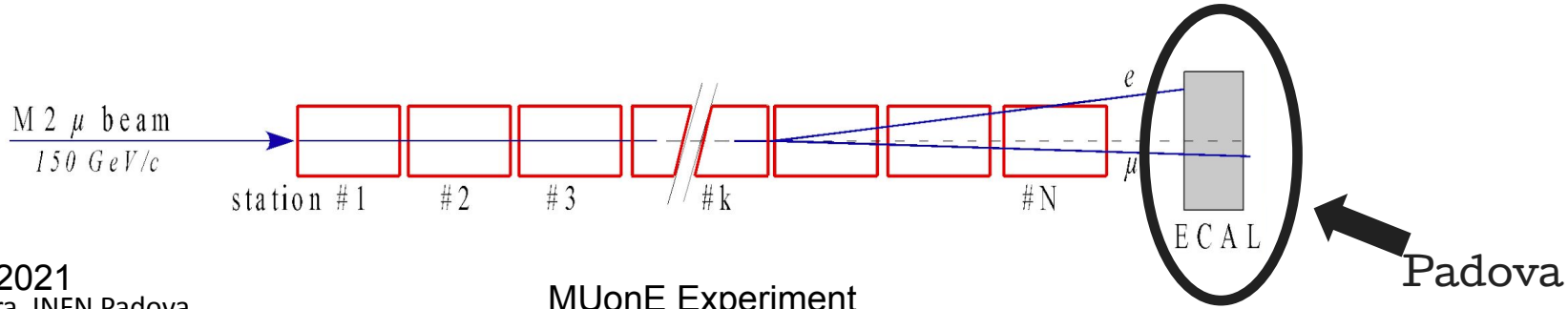
- The highest uncertainty in the theoretical computation comes from the virtual contribution of the strong force (QCD)



Idea: we can MEASURE this contribution, through a high precision *O(10^{-5})* measurement of the **muon-electron elastic scattering cross section**
σ (μ+e → μ+e) with the **CERN SPS *μ* beam**

C.M.Carloni, M.Passera, L.Trentadue, G.Venanzoni, Phys. Lett. B746 (2015), 325

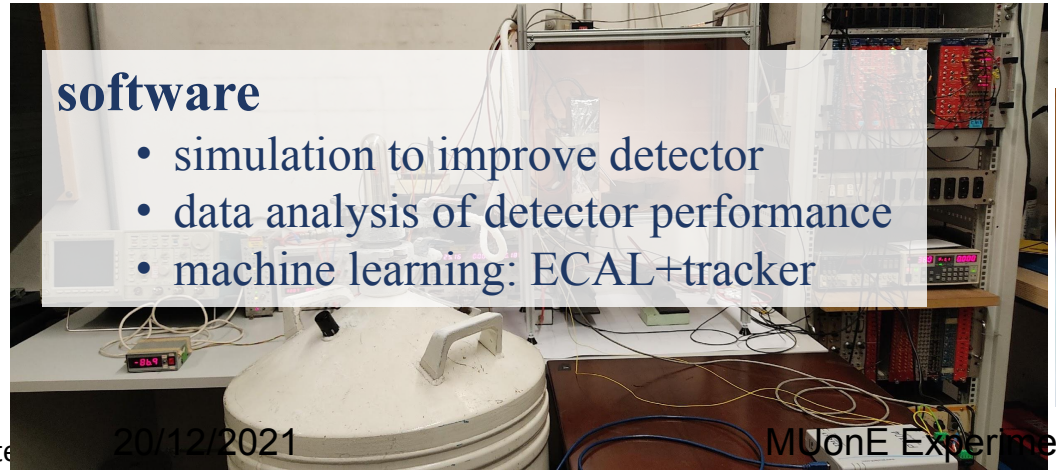
- The measure is challenging. **MUonE apparatus** composed by
  - 40 stations: target + tracking system (Si strips) → ***μ* and *e* tracks**
  - Electromagnetic Calorimeter ECAL → **electron energy**



Thesis available for students both *triennale* and ***magistrale***

hardware

- detector prototype setup
- electronics, data acquisition
- calibration with electron beam @CERN
- run with muon beam (CERN test beam 2022)



software

- simulation to improve detector
- data analysis of detector performance
- machine learning: ECAL+tracker

We want  you

- Do not hesitate to contact:
  - Dr. Enrico Conti
    INFN
    room 128 (1st floor G.Galilei building)
    conti@pd.infn.it
  - Prof. Franco Simonetto
    room 129 (1st floor G.Galilei building)
    franco.simonetto@unipd.it

* picture for illustration purpose only
Actual person may vary

website: **https://web.infn.it/MUonE/**

Letter of Intent: **https://cds.cern.ch/record/2677471/files/SPSC-I-252.pdf**

FUTURE CIRCULAR COLLIDER

INFN

Future Collides

Future Circular Collider
Muon Collider

International MUON Collider Collaboration

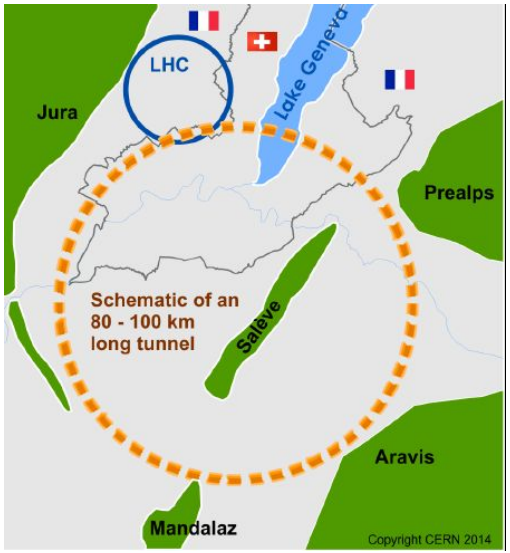
Stefano Lacaprara, INFN Padova

Thesis at FCC-ee

- **A future electron-positron collider in a new 100km tunnel at CERN producing all the heaviest SM particles (W,Z,H,top)**
- Ongoing work to get the project approved before 2030
- A fantastic machine not only for the study of the Higgs and the Standard Model but for new discoveries

https://fcc.web.cern.ch/

- Possible thesis topics (Triennale/Magistrale):
  - **Study a DNN jet flavour tagging algorithm for the strange tagging (adding the information from a timing detector)**
  - **Study the Z->ss coupling**
  - **Study the H->ss coupling**
- Tools available:
  - Simulated data.
  - C++, Python used and ML tools
  - Collaboration with other institutes: DESY, Zurich, CERN
- Contact: Dr. P. Azzi patrizia.azzi@cern.ch



Muon Collider Studies

Muon Collider is a new groundbreaking accelerator machine , it can change the way energy frontier physics is investigated:

- Muons are elementary particles ⇒ center of mass energy entirely available to produce short-distance reactions
- Muons are heavier than electrons ⇒ do not suffer of radiation losses

Very high center of mass energy can be reached

It will be possible to study:

- Higgs couplings and Higgs potential at different center of mass energy
- New detector (calorimeter), and new reconstruction algorithms based on ML techniques
- Advanced techniques to reduce the effect of the beam background in the detector

Collaboration with CERN and US, Fermilab.
Possible stay at the labs if average mark>26/30

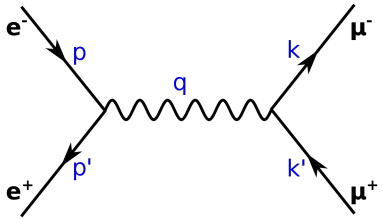
Muon Collider Studies

Contatti: Donatella Lucchesi, Lorenzo Sestini

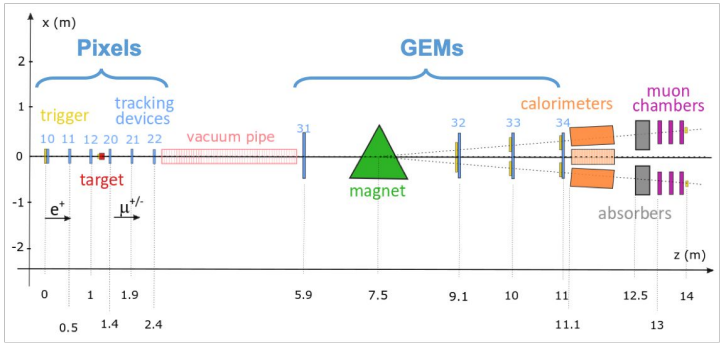
Relatore: Donatella Lucchesi donatella.lucchesi@pd.infn.it e
edificio Paolotti, terzo piano stanza 317

Membri del gruppo
Lorenzo Sestini lorenzo.sestini@pd.infn.it
edificio Paolotti, terzo piano stanza 316

LEMMA-TB: an experiment to measure collimated muon beam



- Thesis topics:
  - Simulation of the apparatus, development of strategy to measure cross section and beam emittance
  - Pixel detector electronics: development and testing
  - DAQ/trigger integration
- References:
  - M. Zanetti, J. Pazzini, A. Triossi, A. Zucchetta
  - marco.zanetti@pd.infn.it



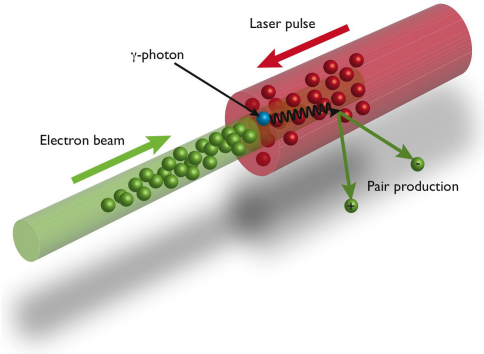
LUXE

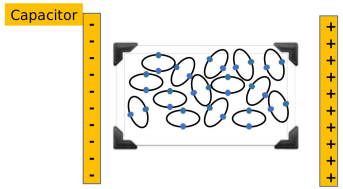
@ DESY (Hamburg - Germany)

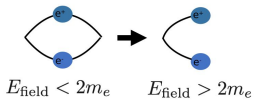
Stefano Lacaprara, INFN Padova

LUXE (Laser Und XFEL) at DESY

- **New experiment** proposed at DESY (Hamburg) by an international collaboration comprising two INFN groups (**Padova** and Bologna)
- Goal: study electron-photon interactions (QED) in a **non-perturbative** regime, characterized be extremely large e.m. fields, (strong-field QED), never explored before.
  - Production of a e+e- pair from the vacuum when the electric field is stronger than ε_{crit} (Schwinger's limit)
- **Exciting exploration of a new regime**
- relevant for understanding phenomena
  - **gravitational collapse of Black Holes**
  - the surface of **strongly magnetised neutron stars**
  - interactions at future **linear high energy lepton colliders**
  - **atoms** with an atomic number Z > 137



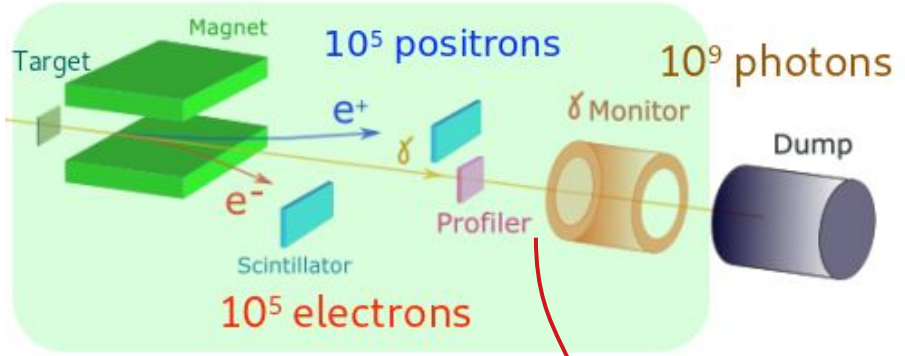


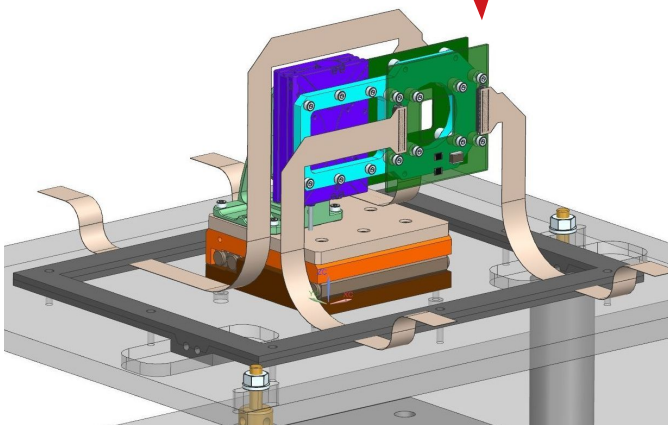


$$\varepsilon_{crit} = \frac{m_e^2 c^3}{\hbar e} \simeq 1.3 \cdot 10^{18}\,\text{V/m}$$

Padova group involvement

- The LUXE experiment is challenging but its main components can be built in a couple of years and should take first data **at DESY in 2024**
- the Padova group is developing a new detector, aimed at **monitoring the intensity of the laser pulses** by measuring the angular dispersion of the **gamma beam** produced in the electron-laser interactions (Profiler)
- it's based on newly developed **sapphire micro-strip** detectors





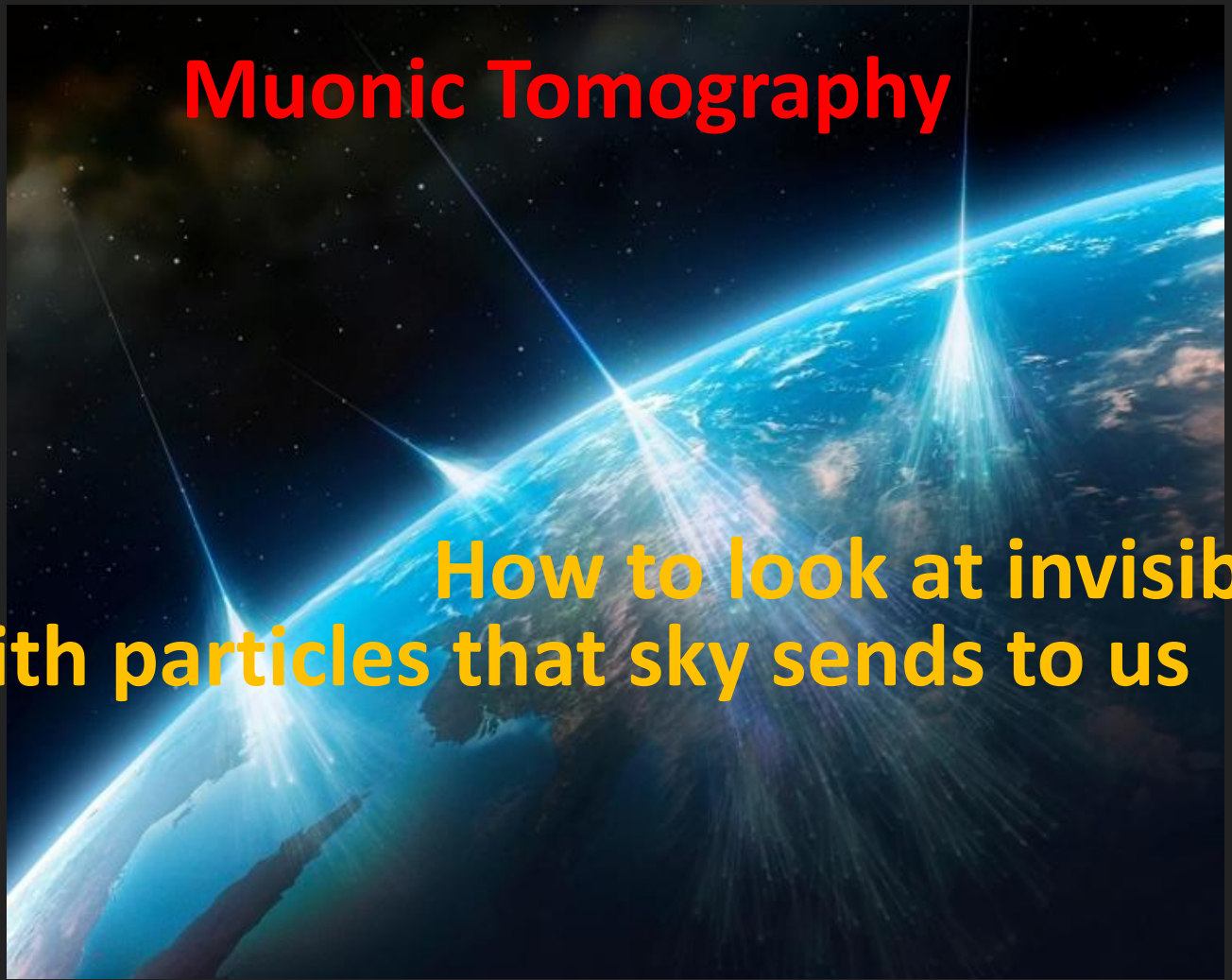
Opportunities

- There are several activities that could offer nice opportunities for Physics students internships in 2022:
- **laboratory R&D**: development and characterization of the sapphire micro strip sensors
  - for **master degree** thesis: research program comprising the preparation and the execution of a measurement campaign and the related full data analysis needed to extract the results
  - for **three-year degree** thesis: participation in the execution of one of the tests and/or in carrying out the related data analysis
  - key activities foreseen to take place in 2022:
  - measurements of **sapphire wafer properties** with an alpha source (Padova) and a 70 keV electron gun (Legnaro Lab.), [from Jan. 22]
  - **radiation hardness tests** at the Elbe SC electron linear accelerator (HZDR - Dresden) [April '22]
  - **detector prototype** assembling and commissioning in Padova [July '22]
  - prototype tests at an **electron accelerator** [Oct. '22]
- **development of Monte Carlo simulations** and comparison with laboratory measurements [from Jan. 22]
  - for **master degree** thesis: participation in the development of the sensor response MC simulation, based on the specific modelling of the charge transport mechanisms in the sapphire and optimization of the parameters through the comparison with experimental measurements
  - for **three-year degree** thesis: examine one specific aspect of the detector performance by generating simulation data and analyzing them
- study of the **gamma beam detector properties** and **profiler performance** [from March '22]
  - for master degree thesis: study the physics models used to generate the inverse Compton gammas and develop optimal estimators of the laser intensity derived from the characteristics of the gamma beam by exploiting the available MC detector simulations

The Padova group

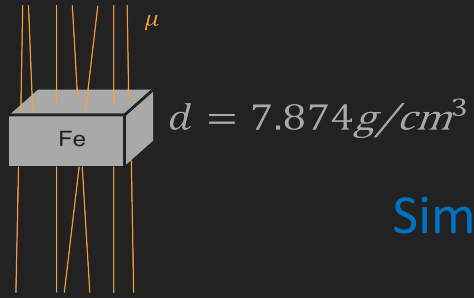
- Physicists
- U. Dosselli, P. Grutta, S. Mattiazzo, M. Morandin, G. Simi
- Electronics, mechanics and detector experts
- M. Benettoni, F. Dal Corso, D. Pantano, M. Giorato

- For additional information, please **send a message** to:
- **mauro.morandin@pd.infn.it**
- Or **come by room 130** of the Physics Department


Muonic Tomography
How to look at invisible
with particles that sky sends to us

Muonic Tomography: how does it work?

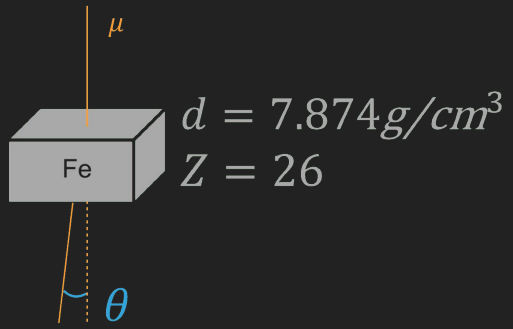
Absorption

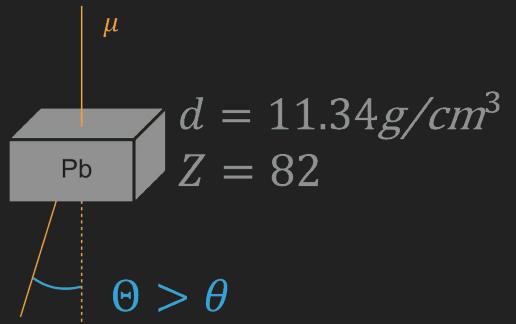


Similar to X-rays

And multiple scattering

$$\sigma_\theta \sim \frac{13.6\ MeV}{\beta cp} z \sqrt{\frac{x}{X_0}}$$



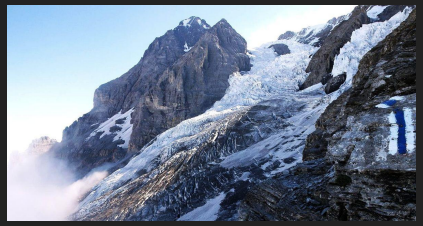


Muons are highly penetrant, using multiple scattering we can build 3D maps of inaccessible, large volumes

Muon Tomography

A particle physics application: use cosmic rays to look inside inaccessible objects



A technique usable in architecture, geology, archeology, glaciology

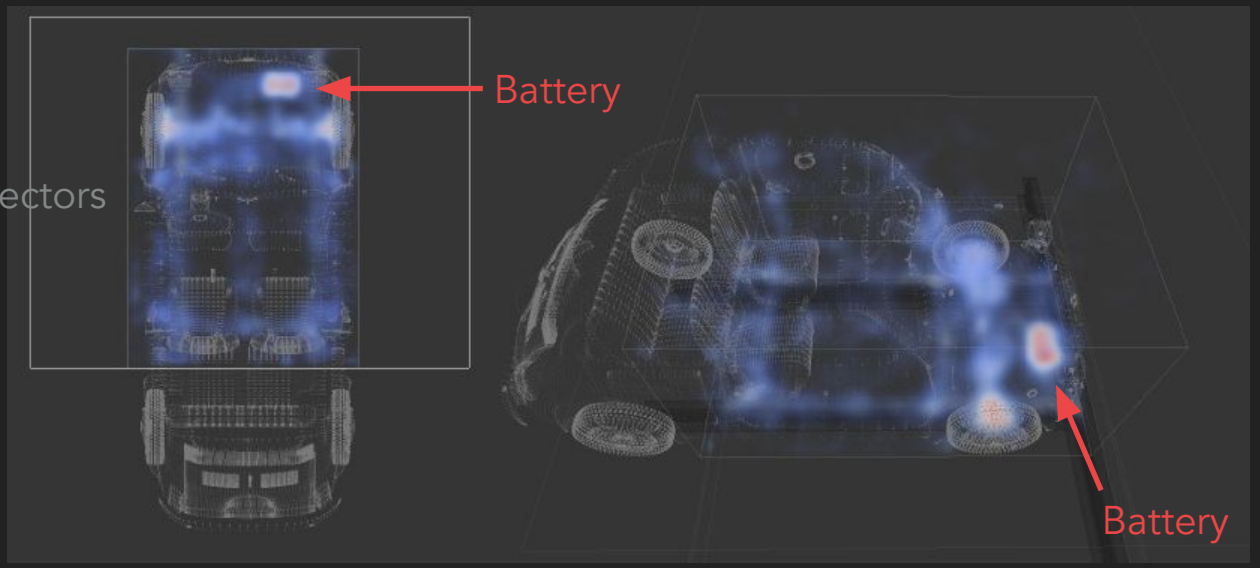


As well as in transportation control, industrial processes, and nuclear waste treatment

An example

- A test measurement of the insides of a “modern” vehicle with a demo
  Legnaro National INFN Laboratory:

Fiat 500 (1967!)



3D reconstruction

Activities in Padova

- Group: about ten people
- International Project: in particular (but not limited to) on test on exhausted nuclear combustible
- Thesis opportunities:
  - a) muon detector construction
  - b) development of tomography algorithm and technique (large interest in extra research world)
  - c) development of “machine learning” techniques
  - d) field test in Germany (2022): a real complete experiment .
- The group has experience of bachelor/master thesis, as well as PhD and post-Doc position
- The topic is worth a full seminar in its own, you can find an interesting presentation at https://www.youtube.com/watch?v=00sPksC1Uyo
- Contact person: paolo.checchia@pd.infn.it

A lot of activities!

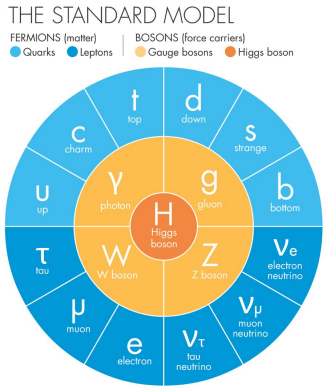
- You are welcome to ask for more informations to the thesis proponents.
- Or ask me stefano.lacaprara@pd.infn.it and I will give some more infos and/or get you in touch with relevant people.

BACKUP

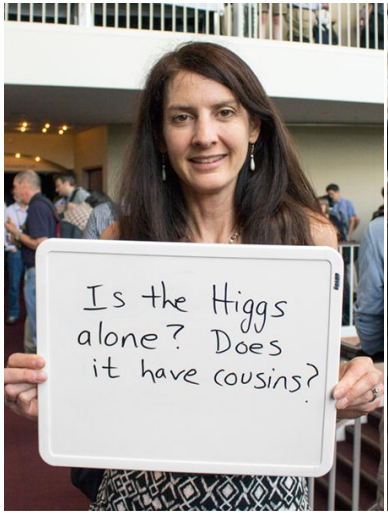
CMS

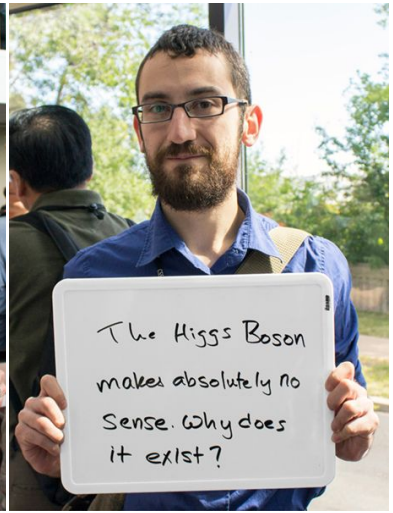
Backup

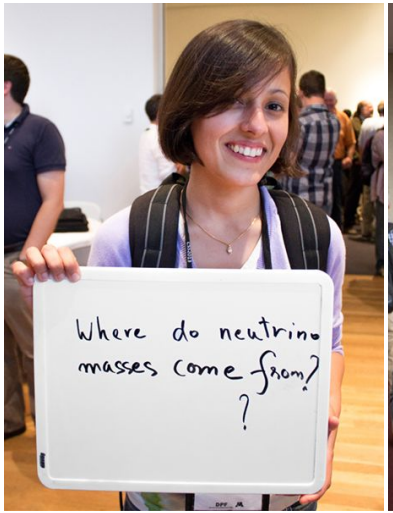
Why the CMS experiment ?

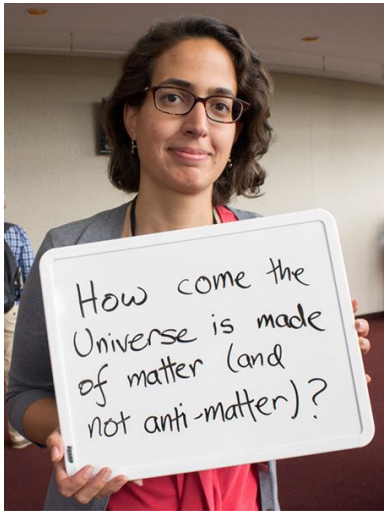


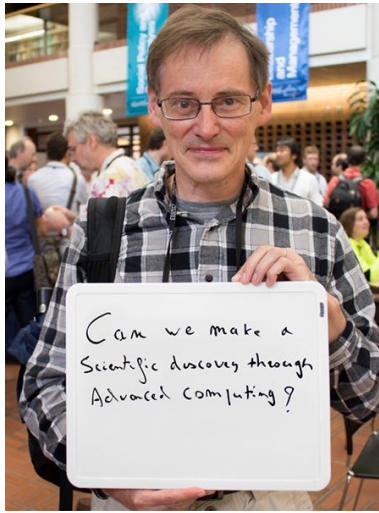
The Standard Model of particle physics works pretty well, but











..any many other questions are still open !

https://www.symmetrymagazine.org/image/image-unanswered-questions-poster-0

Machine Learning per misure con CMS

Il problema di estrarre una misura di sezione d'urto da un campione d dati multidimensionali contenente segnale e background può essere ottimizzato con la rete neurale INFERNO, rendendo l'output del classificatore «robusto» agli effetti sistematici

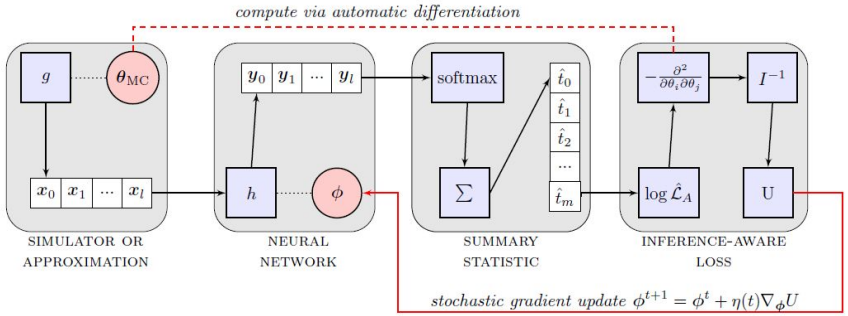
Tesi proposta 1: «Reduction of systematics of a CMS top quark cross section measurement with deep learning»

- Supervisors **T. Dorigo, G. Strong**
- In collaborazione con un assegnista (G. Strong) e un dottorando (L. Layer)
- Utile la conoscenza del linguaggio Python
- Pubblicazione prevista autunno 2022

Processi rari finora mai osservati e potenziali segnali di nuova fisica sono estraibili con nuove tecniche semi-supervisionate (RanBox)

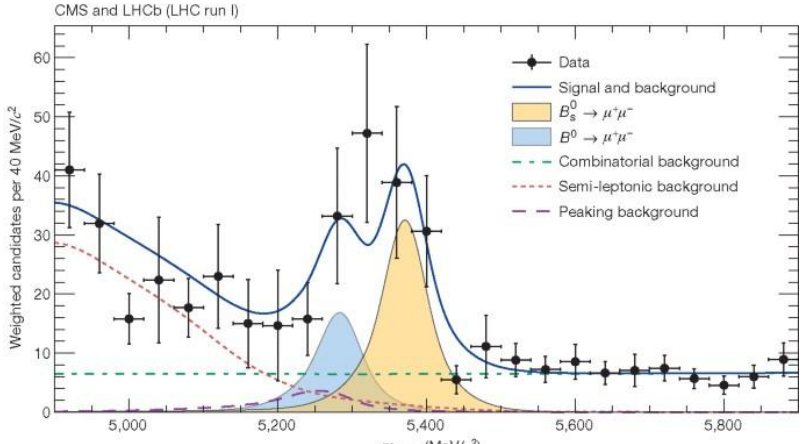
Tesi proposta 2: «Semi-supervised learning for the $B_s \to \tau\tau$ search in CMS»

- Supervisor **T. Dorigo**
- In collaborazione con un dottorando (H. Yarar)
- Utile la conoscenza di c++/root
- Possibile missione al CERN



***In alto**: pipeline di INFERNO, che ottimizza l'output della rete neurale con la minimizzazione dell'errore di misura*

***In basso**: il segnale del decadimento $B_s \to \mu\mu$, osservato da CMS e LHCb nel 2012, come il processo $B_s \to \tau\tau$ può indicare l'esistenza di nuovi fenomeni rari*



Physics Analyses - HighPt-physics

- The data collected by CMS in Run2 are a fantastic tool for searches of rare processes or new physics (beyond the Standard Model)
- The CMS groups has always maintained expertise in these topics. Working at these analyses includes presentation of results at CMS meetings, period at CERN
- TIMELINE: to start between now and December 2023
- DATA: can be Run 2 real data or simulated data for the High Luminosity
- ACTIVITY: student will develop analysis in C++ and Python (some rudimentary knowledge preferred)

Rare decay of Higgs→J/ψγ to extract a measurement of the charm coupling to Higgs

- Dr. A. Zucchetta
- Triennale/Magistrale

FCNC in the top decay

- Prof. U. Gasparini
- Triennale/Magistrale

New physics effects in events with di-bosons

- Dr. P. Azzi
- Magistrale

Search for heavy composite neutrinos

- Dr. P. Azzi
- Triennale/Magistrale

Algorithms development

- Discoveries in HEP rely on the development of powerful algorithms for reconstruction and analysis. In particular with the application of modern Machine Learning technologies.
- Acquisition of a skillset very demanded in the job market. Period at CERN.
- TIMELINE: to start between now and December 2023
- DATA: Run 2 real data, Open data, simulated data
- ACTIVITY: student will develop analysis in C++ and Python (some rudimentary knowledge preferred)

Development and optimization of track reconstruction algorithms

- For heavy flavor studies - M. Tosi, M. Margoni, F. Simonetto
- 4D (addition of timing information) - M. Tosi, R. Carlin
- 4D (addition of timing information) with Graph NN - M. Tosi, T. Dorigo

Development and optimization of jet Flavor identification:

- Identification of charm jets (H->cc) - M. Tosi, P. Bortignon
- Identification of Strange jet in Phase2 - P. Azzi, P. Bortignon, M. Tosi

Application of Machine Learning techniques to reduce systematics of top quark cross section measurement

- T. Dorigo, G. Strong

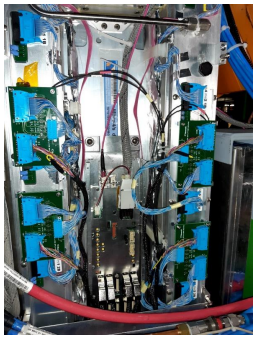
Detector studies

- Opportunity to work with a real detector is an incredibly enriching experience and fundamental for a physicist. In Padova the CMS group works with muon detectors (Drift Tubes) and timing detectors (Barrel Timing Layer).
- TIMELINE: to start between now and December 2023
- DATA: Test beam data, laboratory acquisition
- ACTIVITY: student will take measurement in the lab, and develop code to analyze the data (C++, Python). Work would be supported by electronic engineers as well.

Barrel Timing Layer

- Study and Qualification of the thermal interfaces for the CMS BTL
- R. Rossin, M. Benettoni

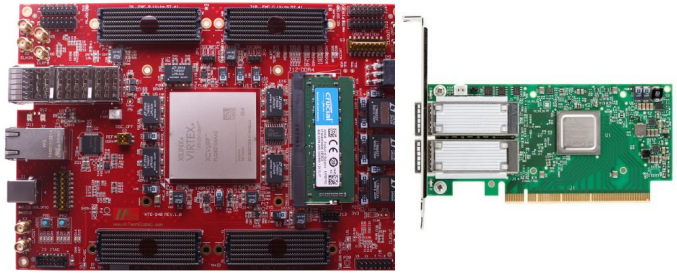
FOTO
QUI?



Muon Detectors

- Noise and linearity characterization of time to digital converters for the muon detector of CMS
- Demonstrator of an innovative acquisition system based on remote direct memory transfer over optical links

A. Triossi



Physics Analyses - B-physics

- Flavor physics at the moment shows the most intriguing discrepancies with the Standard Model. Hot topic!
- The CMS groups has an exceptional expertise in B physics analyses. Working at these analyses includes presentation of results at CMS meetings, period at CERN.
- TIMELINE: to start between now and December 2023
- DATA: Run 2 real data
- ACTIVITY: student will develop analysis in C++ and Python (some rudimentary knowledge preferred)

- Measurement of the production cross section pp -> b-bbar X (comparison with QCD)
- Measurement of the production cross section pp -> gg -> bb+bb+X (double gluon splitting) comparison with QCD
- Measurement of the oscillation frequency b->anti-b, study of fragmentation process of beauty quarks into hadrons
- Search for matter-antimatter violation in the oscillations of neutral B mesons
  - Prof. F. Simonetto

See also presentation here: https://elearning.unipd.it/dfa/course/view.php?id=1209

- Search for $B_s \rightarrow \tau\tau$ with NN
  - Dr. T. Dorigo, Prof. M. Margoni

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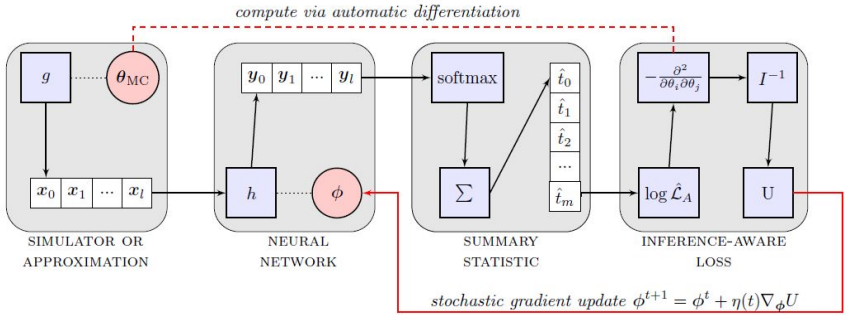

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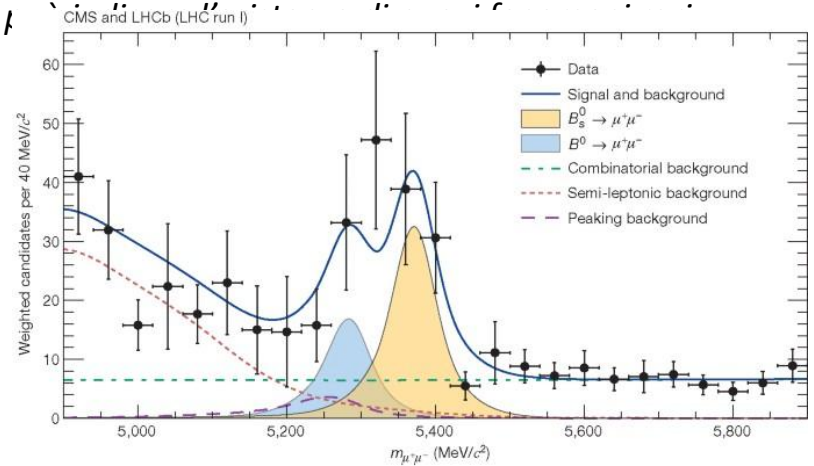
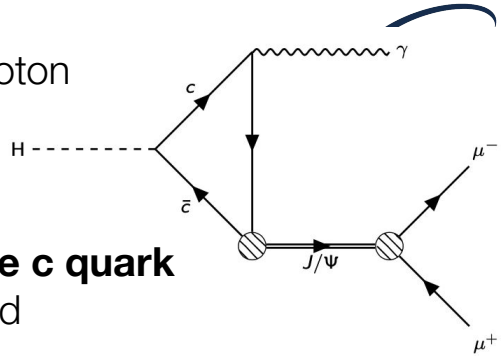
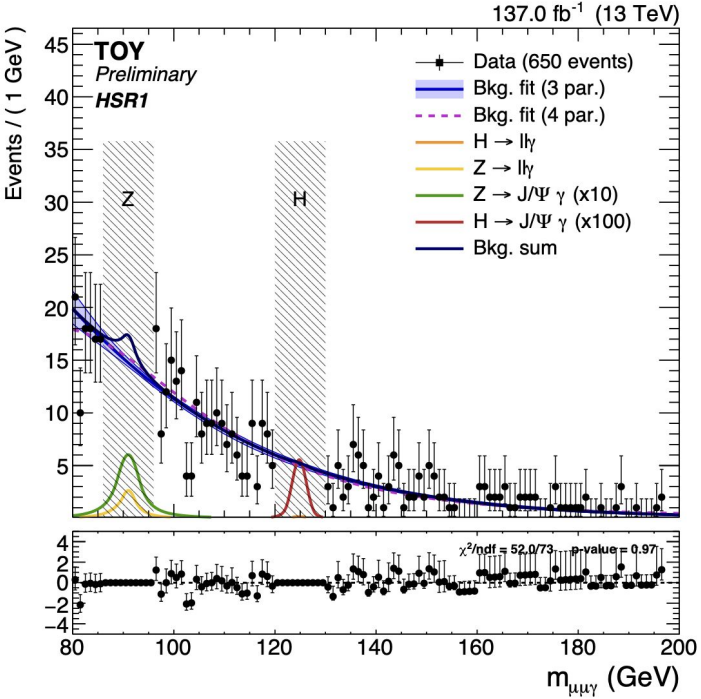


Rare SM Higgs and Z decays

- The Higgs and Z bosons are expected to decay to a J/Ψ meson and a photon
- Never observed before, because branching ratios are small:
  - B(Z→J/Ψ γ) = 9 x 10^{-8}
  - B(H→J/Ψ γ) = 3 x 10^{-6}
- The observation would allow a measurement of the **Higgs coupling to the c quark**
- With the J/Ψ decaying to $\mu\mu$, the final state is clean and the bkg very limited





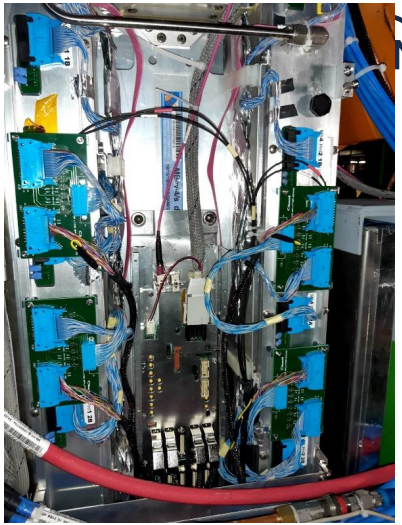
- The strategy is to model the QCD (dominant) background with analytic functions (à la H→$\gamma\gamma$)
  - Minor resonant backgrounds controlled in a dedicated control region
- Analysis is under scrutiny of the CMS Collaboration
  - [**Z**]: expected small excess (0.5σ), or to exclude 7 times the SM
  - [**H**]: expected exclusion approximately 50 times the SM, becomes candidate for end of HL-LHC
- Lot of room for improvements:
  - Design a <u>new, dedicated trigger</u> algorithm for the upcoming LHC run (now the bottleneck of the analysis)
  - Better <u>signal discrimination</u>, full 2D ($m_{\mu\mu}$, $m_{\mu\mu\gamma}$) fit

Title: Noise and linearity characterization of time to digital converters for the muon detector of CMS

Cycle degree: First/Second (Bachelor or Master)

Activities: The Electronics for the Drift Tube (DT) chambers of CMS will be significantly upgraded during the 3rd LHC Long Shutdown (LS3). DTs are responsible for the tracking and triggering of muons in the central region of CMS. As a consequence of the higher rate set by High Luminosity LHC, the new CMS Trigger requirements will exceed the present capabilities of the DT on-detector electronics. . For this reason DTs will replace all their electronics during LS3. It will be asked to the candidate student to qualify the time to digital converters of the new electronics in terms of linearity and input noise taking into account different grounding schemas. All the activities will be carried out supported by a dynamic team of physicists and engineers.

Contact person: Andrea Triossi andrea.triossi@unipd.it

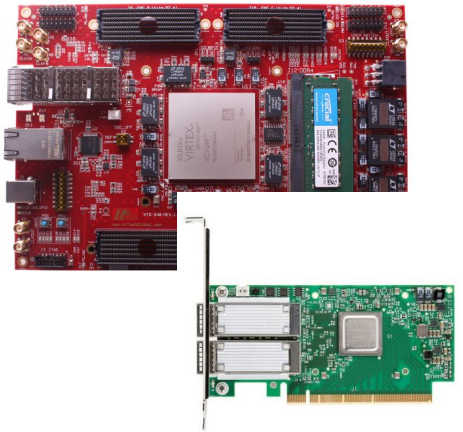


Title: Demonstrator of an innovative acquisition system based on remote direct memory transfer over optical links

Cycle degree: Second (Master)

Activities: The majority of high energy physics experiments relies on a trigger system applying selection criteria before sending data to the acquisition system (DAQ). To limit or even exclude the bias introduced by such approach alternative solutions are under study. They mainly focus on innovative DAQ able to acquire the entire stream of data and process it online. The challenge of moving large quantity of data can be tackled employing network protocol based on the concept of remote direct memory access. This would unburden the processor from the low level management of the data movement and protocol stack stripping, but it would require a more intelligent hardware on the front end side. The activities will be focused around the implementation of a demonstrator of an innovative DAQ implemented by means of Field Programmable Gate Arrays (FPGAs). The candidate student will be flanked by Phd students and will be supported by electronic engineers.

Contact person: Andrea Triossi andrea.triossi@unipd.it



Simulation and validation software for Neural Network-based trigger algorithms of muon detectors

Cycle degree: First (Bachelor)

Activities: Most physics experiments collect data based on algorithms implemented on programmable electronics boards (FPGAs) deemed to take fast decisions on whether data is to be collected or rejected. Modern Trigger algorithms based on Neural Networks are being developed to improve the performances of the online particle identification and reconstruction. Student(s) will be asked to contribute to the development of the software used to simulate and validate the Neural Networks triggers. These algorithms will be tested and validated on a set of detectors at the Legnaro INFN Laboratory, and possibly deployed at the CMS experiment at CERN.

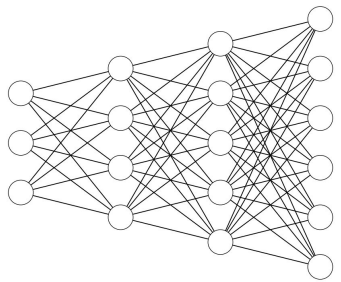
Contact person: Jacopo Pazzini (jacopo.pazzini@unipd.it)

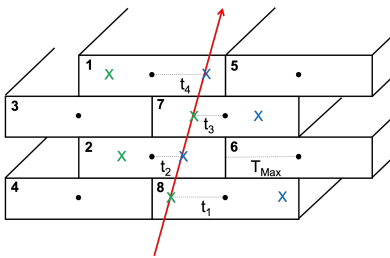
Development and implementation of Machine Learning techniques for muon trigger algorithms

Cycle degree: Second (Master)

Activities: Recent applications of Machine Learning allows to deploy Neural Networks on programmable electronic boards (FPGAs), capable of extremely fast inference time (O(100) ns). Such implementations can be employed for the online reconstruction and trigger selection for particle physics detectors such as the CMS experiment at CERN. Due to the limited available FPGA resources however, specific optimization techniques and network topologies have to be implemented to exploit the hardware capabilities. The proposed activity will see the student(s) working on the development of models to identify and reconstruct the passage of charged particles (muons) through a set of detectors, and their optimization for an implementation on FPGAs. The models will be developed targeting the CMS Drift Tube detector and tested using a realistic mock-up installed at the Legnaro INFN Laboratory.

Contact person: Jacopo Pazzini (jacopo.pazzini@unipd.it)



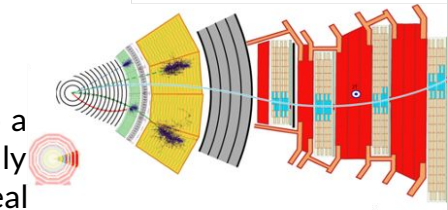


Stream processing of trigger-less detectors with scalable distributed computing infrastructures

Cycle degree: Second (Master)

Activities: The processing of continuous streams of data from a set of sources is a common issue to a number of fields, from experimental physics to IoT applications. Particle physics detectors especially produce large amounts of data at high-rate, making the online processing of the stream a real computational challenge. The student(s) will be asked to familiarize and use distributed computing frameworks widely employed in Big-Data applications, such as Dask or Apache Spark, to implement particle reconstruction and anomaly-detection algorithms and benchmark their performances in high-throughput streaming conditions. The application will target the Drift Tube detector of the CMS experiment, and will possibly extend to integrate the use of accelerators such as GPUs.

Contact person: Jacopo Pazzini (jacopo.pazzini@unipd.it)



L1/DAQ : 40 MHz scouting

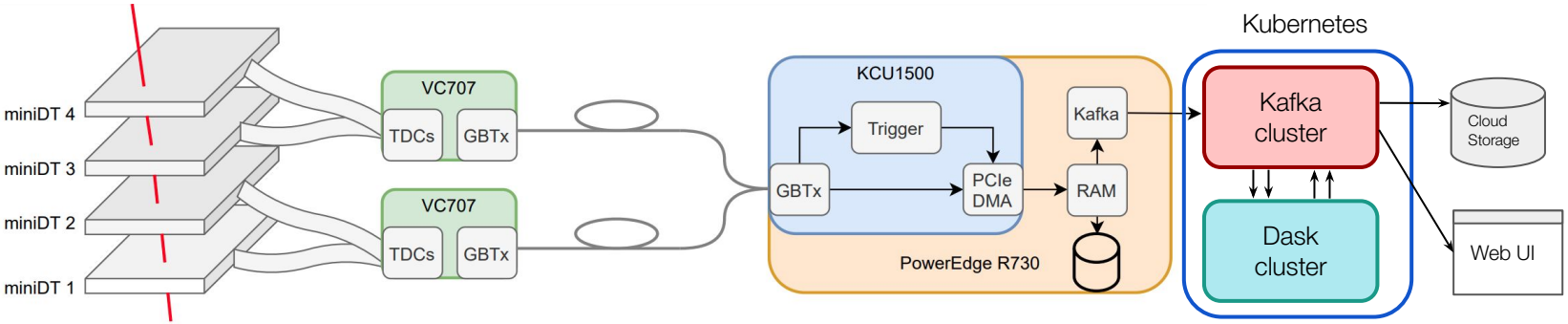
repliche a footprint ridotto (~ 0.5 m^2) delle DT @LAE in LNL
→ readout compatibile con Phase2 upgrade di CMS
⇒ testbed per elettronica di Phase2 di CMS-DT (OBDT)

→ sviluppo sistema DAQ "trigger-less" ed online processing

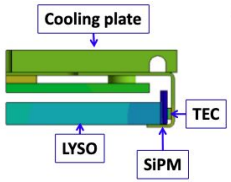
- readout di tutti gli hit prodotti dalle camere
- processing online usando risorse
  - *in-situ* : strumenti di calcolo distribuito (Apache Kafka, Apache Spark/Dask)
  - *off-site* : cloud (INFN Cloud e/o Cloud Veneto)
- sviluppo di architetture per il processing **scalabili** e facilmente **portabili** a molteplici use-cases [Kubernetes]

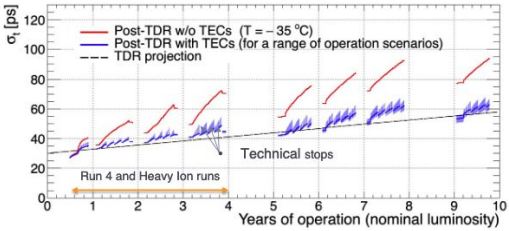
→ sviluppo di algoritmi di trigger basati su NN su FPGA

- ricostruzione veloce in FW di segmenti per il trigger locale delle DT ["alto" combinatorio]
  - tempi di inferenza della rete di O(2) clock (→ ~50 ns)
  - latenza fissa indipendentemente dalla complessità degli input
  - elasticità e portabilità potenzialmente vantaggiose anche per lo sviluppo di processing online per esperimenti locali e test beams



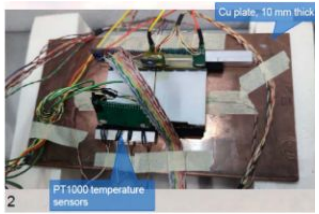
MTD : thermal tests timeline

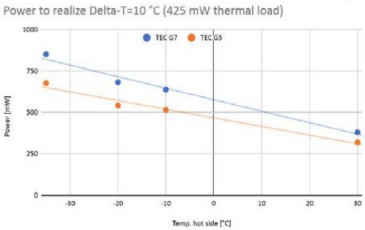




Thermoelectric Coolers (TECs) integrated on SiPM array
to further reduce the SiPM operating temperature [from -35°C to -45°C]

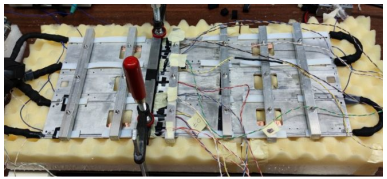
- test of the interface between TECS and copper housing
  → probably the most critical part of the interface
  - in progress in our Gr1 lab w/ different thermal coupling materials
  - need to converge in the first half of 2022

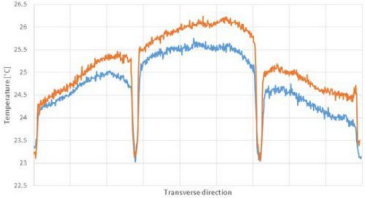




both designed by PD

- test of the interface between CO2 cooling pipes and cold plates
  - test in our Gr1 lab w/ a cold plate and water cooling
    → detailed test of different grooves dimensions and thermal interfaces being performed in the heat transfer lab of the department of engineering in Vicenza





- test of a fully equipped readout unit (a cold plate w/ 12 readout modules) w/ glicole cooling at -35C in our specially equipped fridge in our Gr1 lab
  → system overhauled, expected in the first months of 2022

- other test planned in 2022
  - verify mechanical and thermal stability of thermal interfaces w/ radiation
  - verify mechanical stability of all interface w/ thermal cycles between -40C and +40C
    → plan to use the climate chamber in the electronics lab

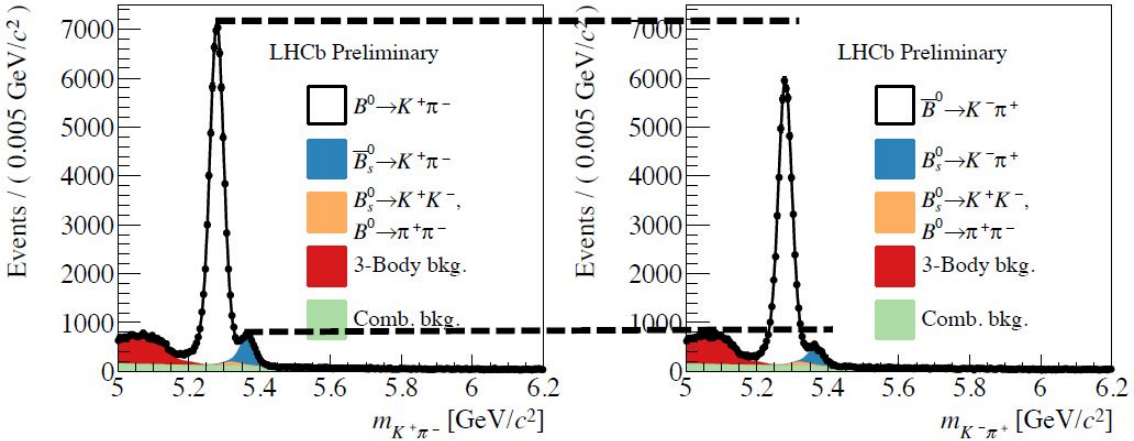
needed for the SiPM annealing

LHCb

Backup

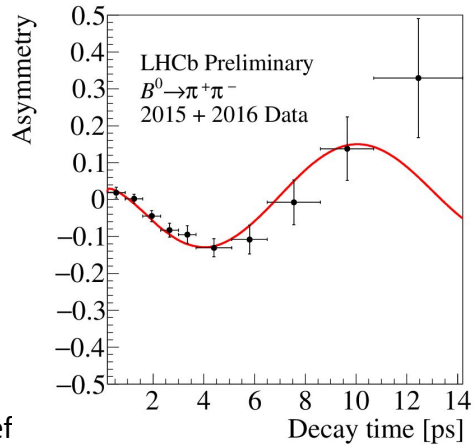
La fisica di LHCb

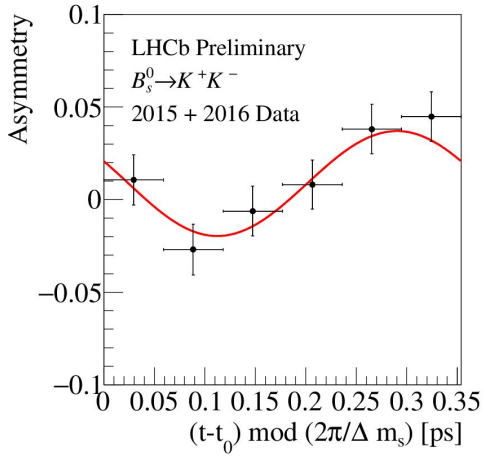
- Violazione di CP
  - Dove e' finita l'antimateria dell'universo?
  - Asimmetria materia anti-materia necessaria per



La fisica di LHCb

- Violazione di CP
  - Dove e' finita l'antimateria dell'universo?
  - Asimmetria materia anti-materia necessaria per spiegarne l'assenza

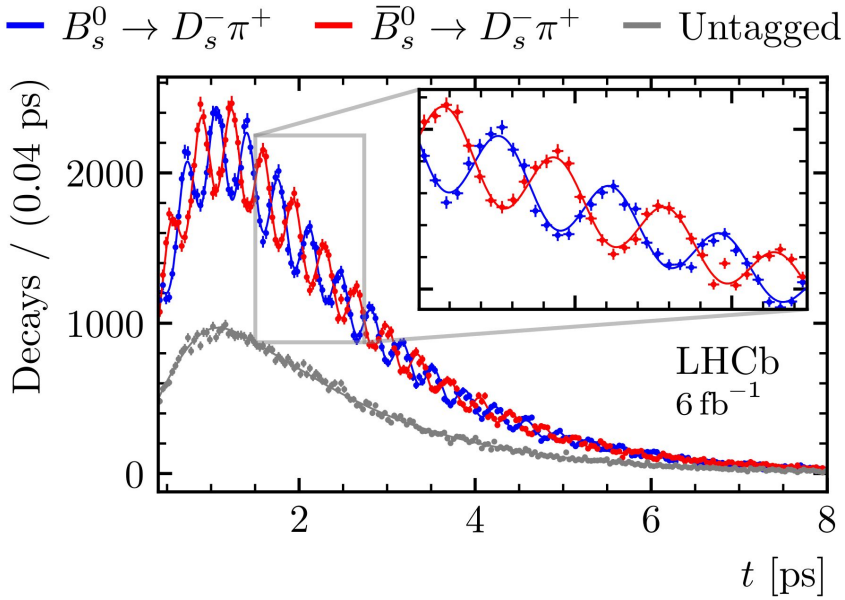




Stef

La fisica di LHCb

- Il mixing dei mesoni B



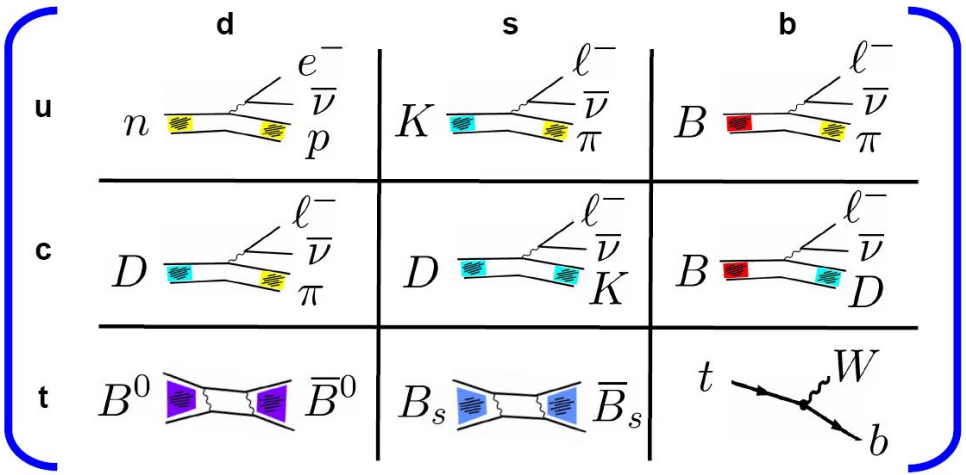
A. Bertolin

Published in Nature Physics

La fisica di LHCb

- La matrice di mixing dei quarks

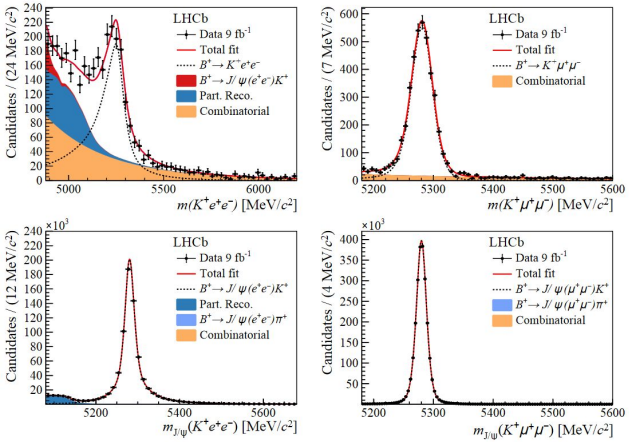
$V =$

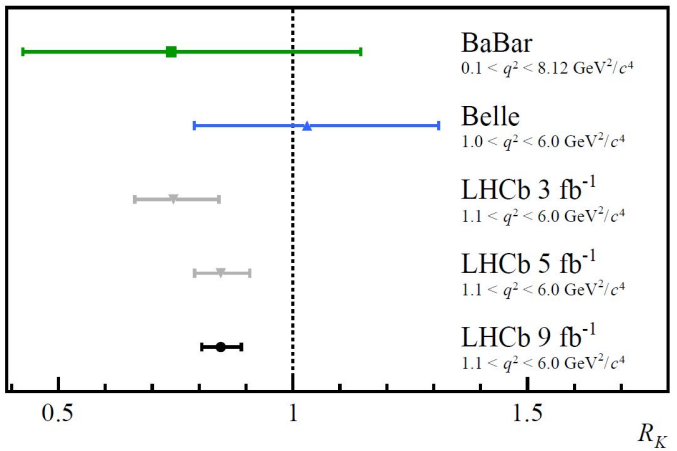


La fisica di LHCb

- Violazione dell'universalità leptonica
  - Tutti i leptoni risentono in maniera identica delle forze fondamentali del modello standard
  - Non ci si aspettano differenze tra decadimento in e^+e^- e $\mu^+\mu^-$

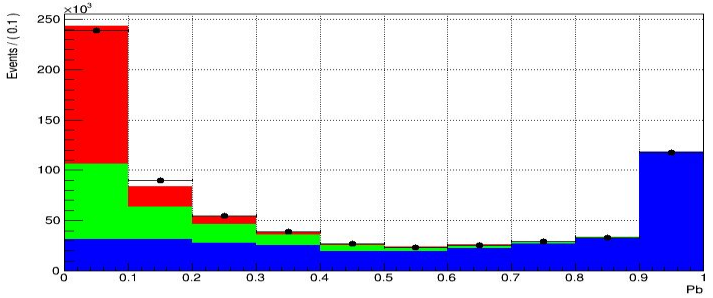
$$R_H \equiv \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B \to H\mu^+\mu^-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B \to He^+e^-)}{dq^2} dq^2}$$

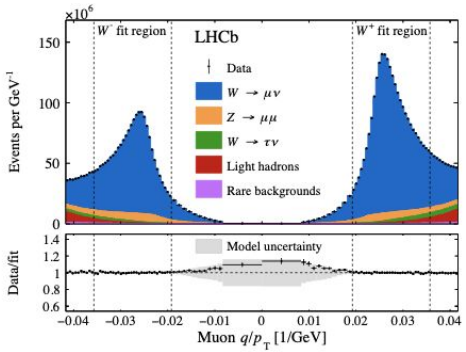


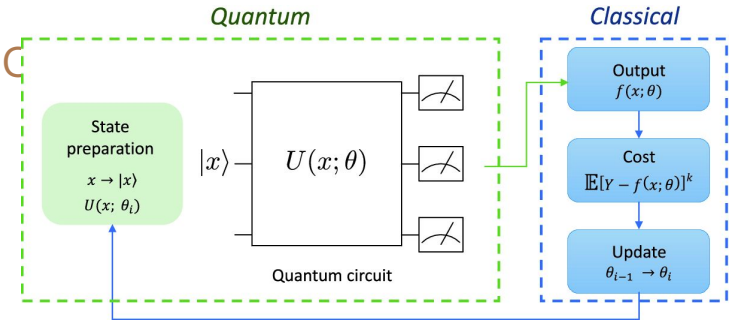


La fisica di LHCb

- Jet flavor tagging with DNN
- Tagging with quantum inspired algorithms and
- Quantum machine learning
- boson mass at LHC



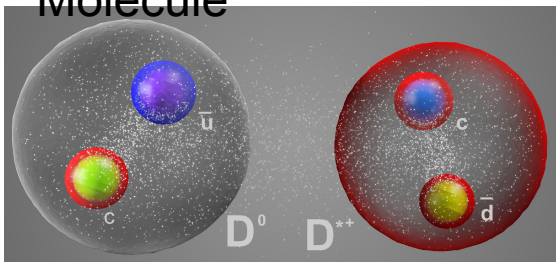




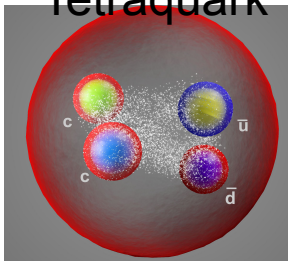
La fisica di LHCb

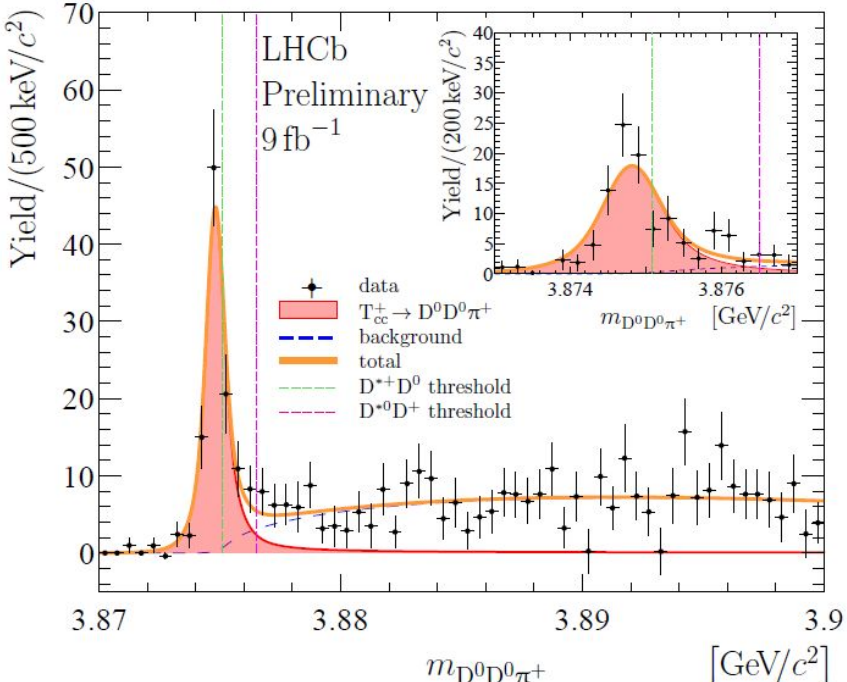
- Exotic states

Molecule

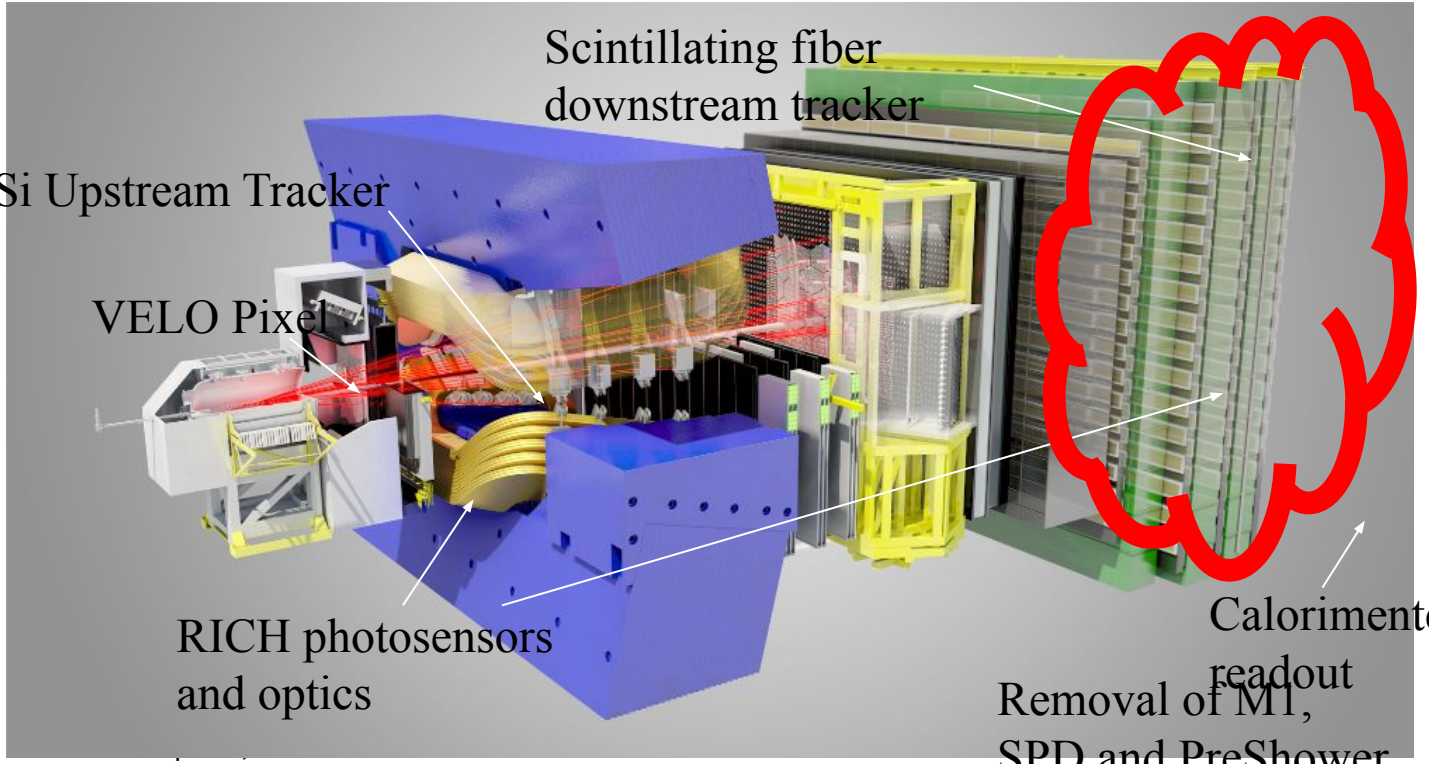


Tetraquark





LHCb Upgrade I



Muon MWPC
Almost compatible

Belle II

Backup

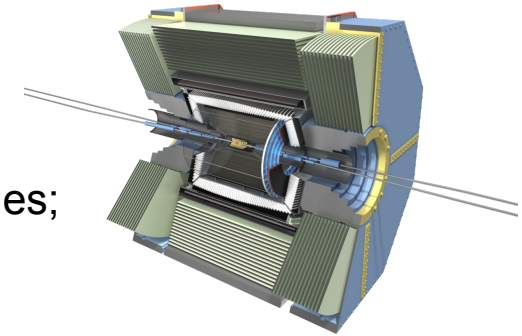
The mission

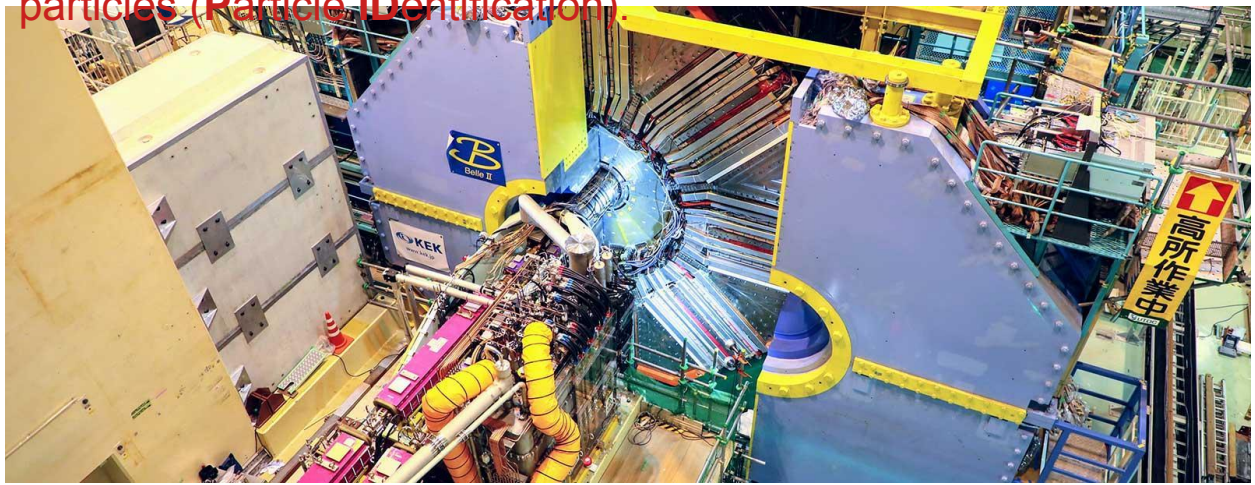
- Belle II is an international collaboration involving 26 countries and ~1100 active members;
- The experiment studies the collisions produced by the SuperKEKB e^+e^- asymmetric energy collider located in Tsukuba (Japan);
- The center of mass energy of the collision is ~10.6 GeV, which allows the production of large quantities of B, D, and other lighter mesons, τ leptons, exotic particles, … ;
- The mission:
  - detection of signatures of physics beyond the Standard Model, especially through indirect effects;
  - precision measurements of the parameters of the theory;
  - discovery of "exotic" particles;

The Belle II Detector

A modern HEP detector has several tasks:

- measuring the momentum of charged particles;
- measuring the energy of (neutral) particles;
- measuring decay vertices;
- discriminating between different kind of particles (**P**article **ID**entification).

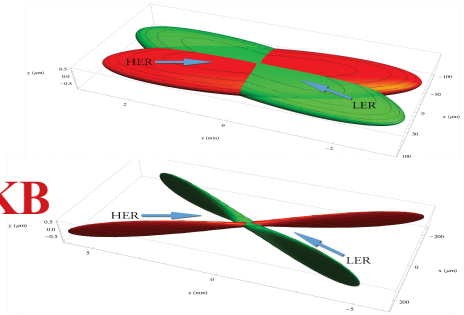




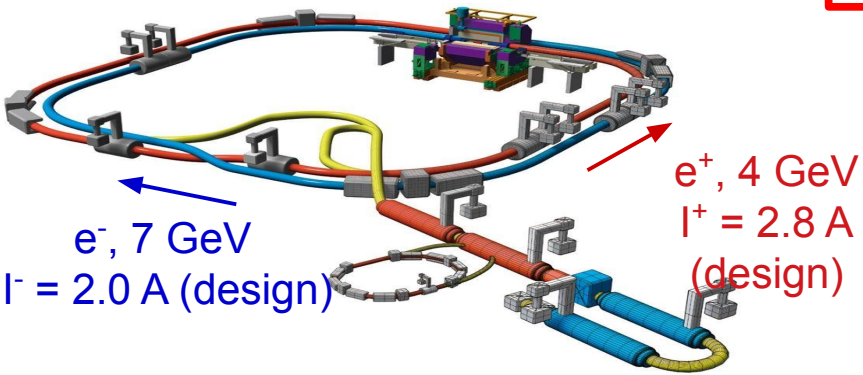
The SuperKEKB Collider

KEKB

SuperKEKB



$$L = \frac{N_+ N_- n_b f_0}{4\pi \sigma^*_{x,\mathrm{eff}} \sqrt{\varepsilon_y \beta^*_y}}$$



e^-, 7 GeV
I^- = 2.0 A (design)

e^+, 4 GeV
I^+ = 2.8 A (design)

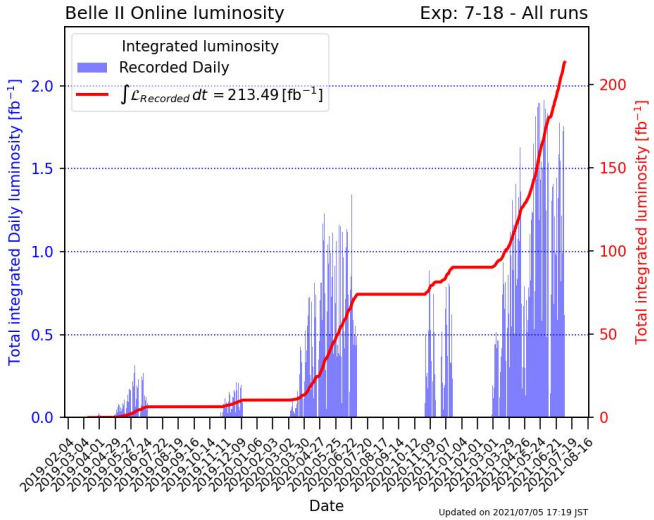
Improvements over KEKB:

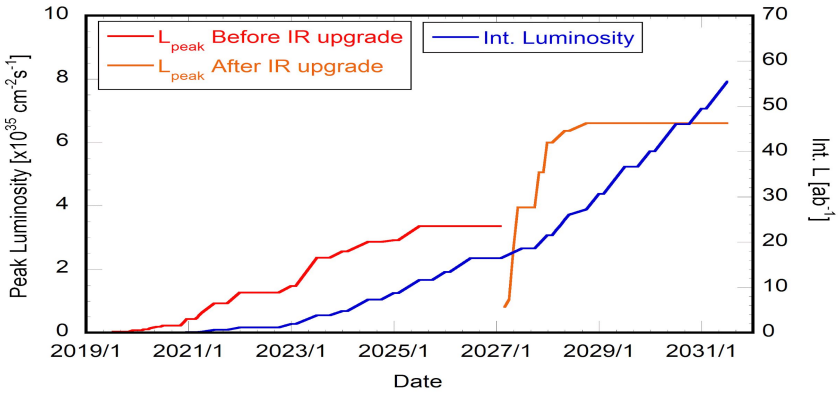
x20 by 'nanobeam scheme';
x1.5 by increasing beam currents.

Goals:

Instantaneous lumi: ~6 x 10^{35} $cm^{-2}s^{-1}$

Data taking





- Data taking efficiency ~90%, so far we recorded **~213 fb^{-1}**;
- The final goal is integrating **50 ab^{-1}** (~50 times more than the previous experiments);
- Record instantaneous luminosity: **3.12 x 10^{34} cm^{-2} s^{-1}**.

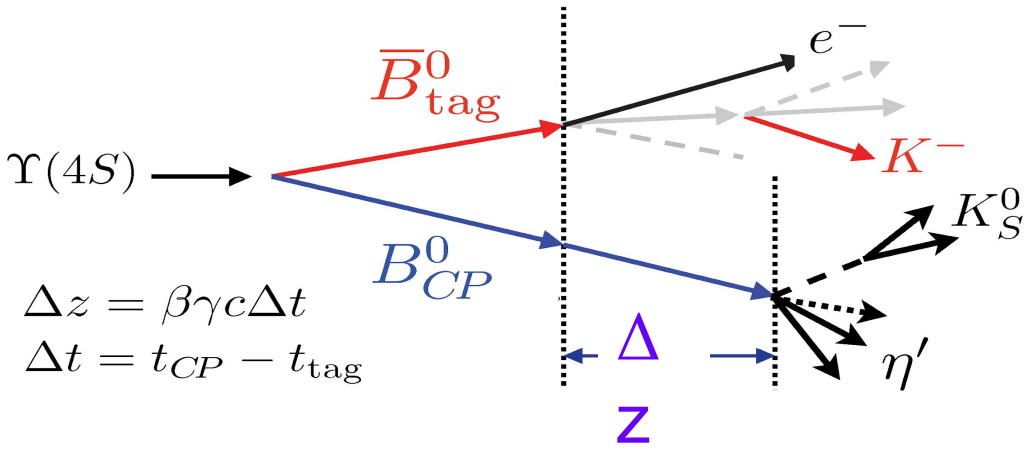
The Belle II Collaboration

- 26 countries;
- 123 institutions;
- ~1100 active members.

Countries (institutions):

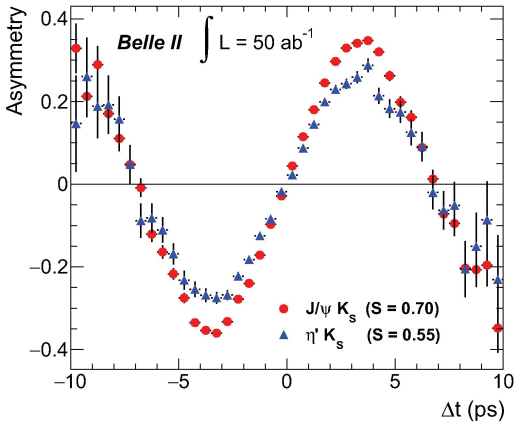
Armenia (1), Australia (3), Austria (1), Canada (5), China (12), Czechia (1), France (3), Germany (12), India (9), Israel (1), Italy (9), Japan (16), Malaysia (1), Mexico (3), Poland (1), Russia (6), Saudi Arabia (1), Slovenia (2), South Korea (9), Spain (1), Taiwan (3), Thailand (2), Turkey (1), USA (18), Ukraine (1), Viet Nam (1).

Time dependent CPV



<Δz> ~ 130 μm at Belle II

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

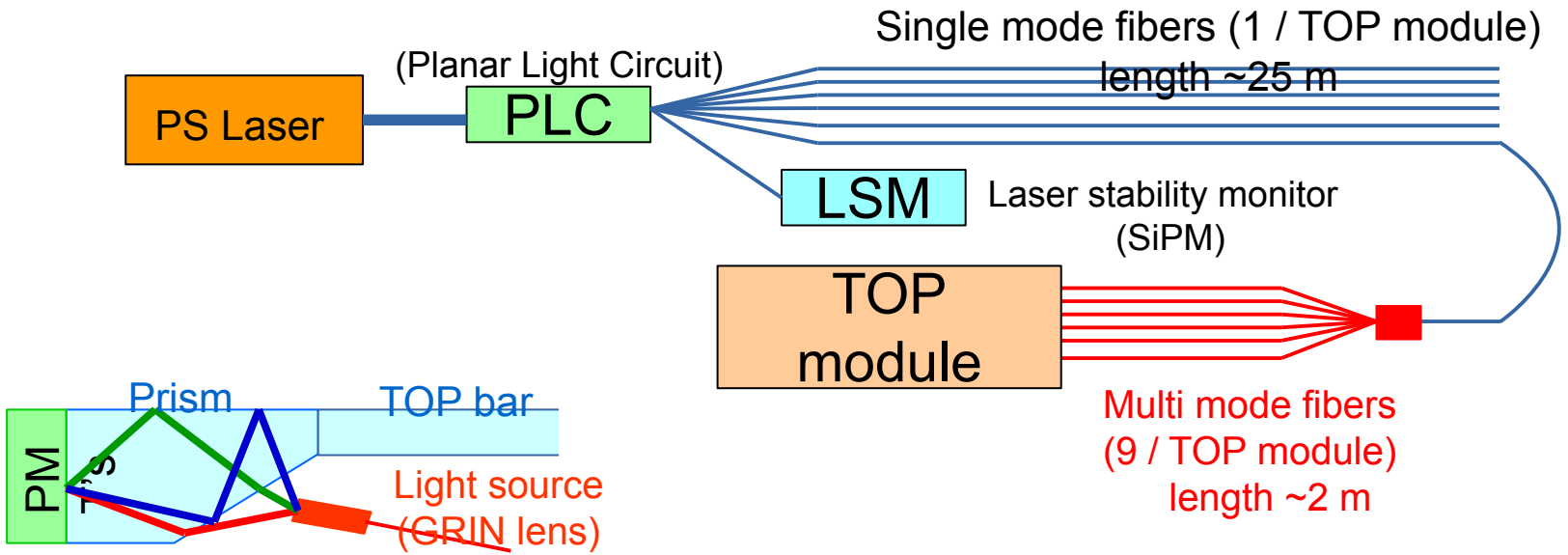


Belle II simulation!

Potential for discovering New Physics in 'penguin' dominated modes

TOP Laser Calibration System

Major contribution from the Padova Group:



A PMT pixel can be reached by different light paths (with different times)