Lessons learned at the 2019 US Belle II Summer School

Radhakrishna Adhikari
University of Mississippi

Lessons I learned

- CP symmetry and CP Violation
- Belle II and it’s improvement over Belle
- Computing skills

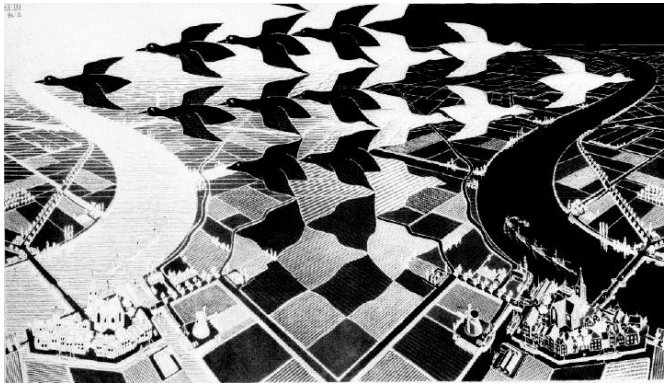
C-Symmetry and P-Symmetry

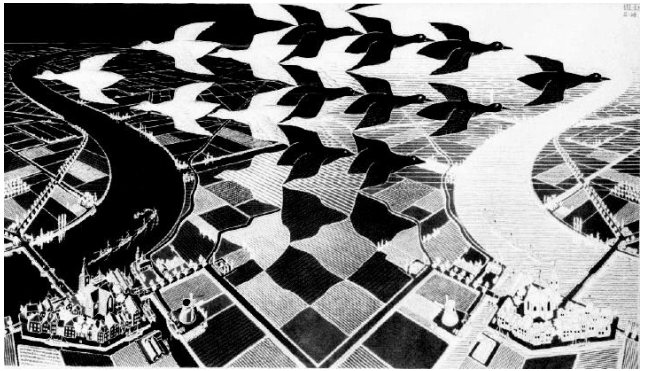
- Parity Symmetry (P): The physical laws are conserved when all the signs of a particle's spatial coordinates are flipped.
- Charge Conjugation (C): Transformation that switches all particles with their corresponding anti particles.

- Most of the physical laws are symmetric under the C and P transformations.

CP-Symmetry

- In 1956 Cobalt-60 was found to be violating Parity conservation laws as suggested by Lee and Yang.
- Similarly, scientists thought that Charge conjugation symmetry must be violated as well.
- Hence, they brought the idea that even though the Charge and Parity are not conserved in certain interaction sometimes, Charge and parity when applied together are always conserved.





LH ν

Charge Inversion

Particle-antiparticle mirror

C

P

RH ν

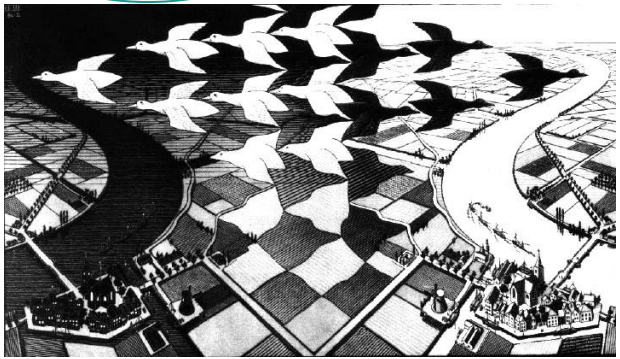
LH anti-ν

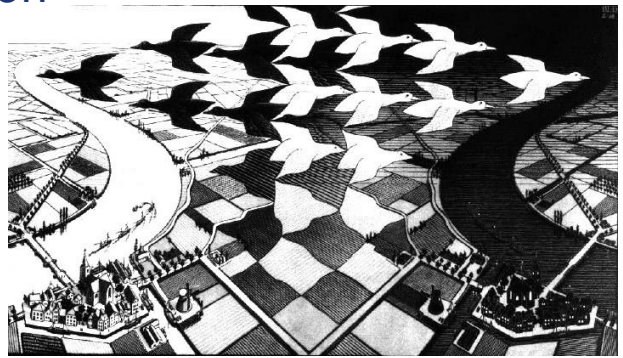
Parity Inversion

Spatial mirror

CP ok

RH anti-ν





T. Browder

CP-Violation

- Again, CP symmetry wasn’t the fundamental truth.

- In 1964, a research group led by James Cronin and Val Fitch discovered in an experiment at Brookhaven National Laboratory that CP is violated, too

Belle and Belle II

- Fundamental question: why is there is so much more matter than anti-matter in the universe?
- Belle experiment was conducted to study CP violation in decays of composite particles called B mesons.
- Experimental confirmation of CKM mechanism as source of CPV in the SM.
- Now, we have the upgraded version of Belle, i.e Belle II.

Improvement/Challenges of Belle II over Belle

Improvements

- 40X luminosity of KEKB
- Very narrow beam(only few 100 atomic layers)
- Improved particle ID

Challenges

- Higher Background
- Higher event rate

Computing Skills

- Learned the basics of basf2 for MC analysis.
- Learned pandas dataframe.
- Intro to different Machine Learning Algorithms.

Tau Lepton reconstruction: $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$

Using tau pair from MC 12 with BGx1

Tracks:

dr<1.0 cm, |dz|<5.0 cm, CDC hits >0

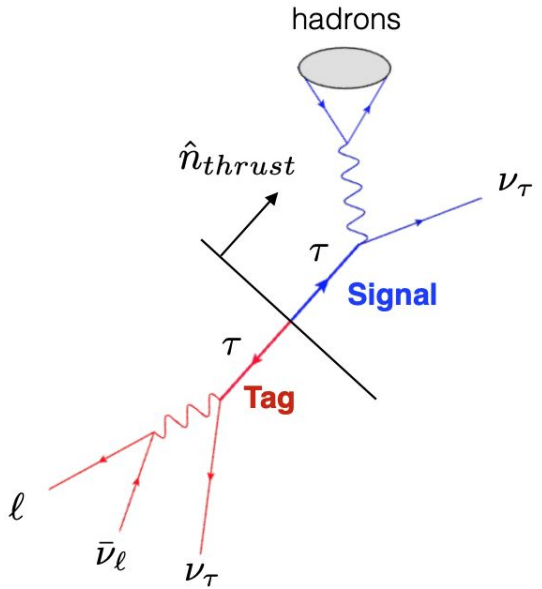
Photons:

E>0.2 GEV, -0.8660<cosθ<0.9563

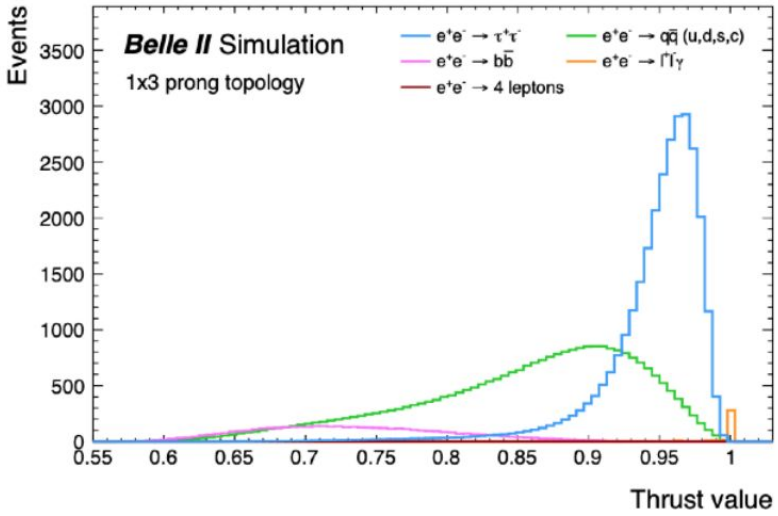
#tracks=2

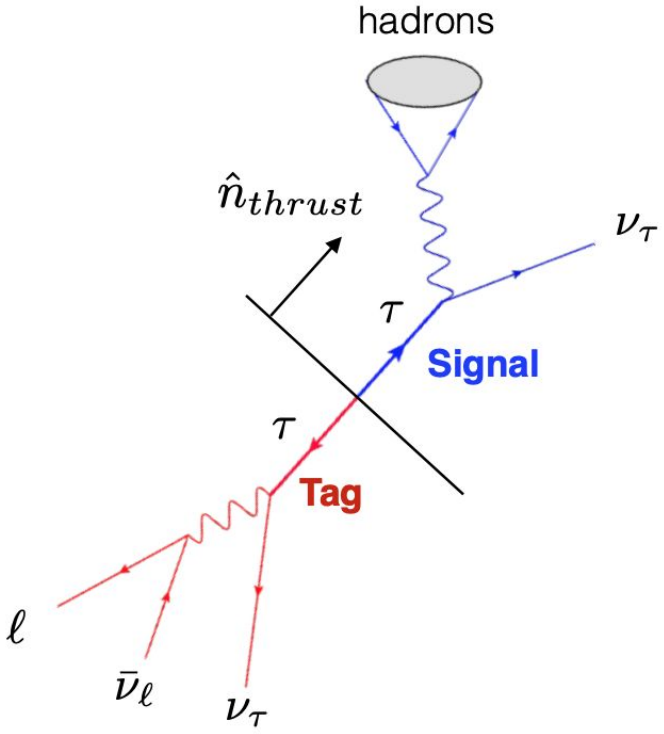
For Pions: E/P<0.8

0.8<Thrust<0.99



- Event is divided in two sides (signal and tag) using a plane defined by a **thrust axis**, build with all the final state particles:
- $$V_{thrust} = \frac{\sum_i |\vec{p}_i{}^{cm} \cdot \hat{n}_{thrust}|}{\sum_i |\vec{p}_i{}^{cm}|}$$
- Thrust axis: $\hat{n}_{thrust}$ such that V_{thrust} is maximum.





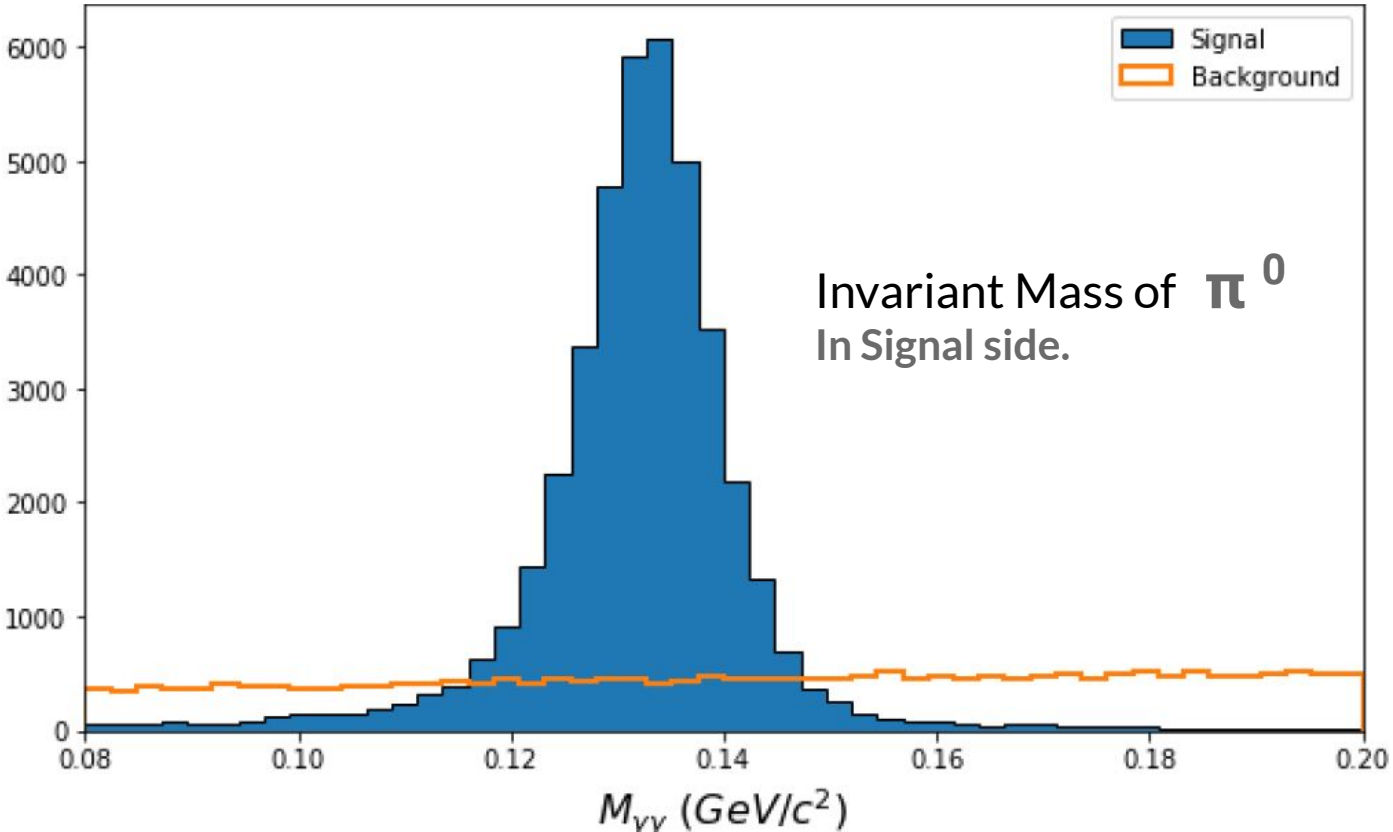
Snippets of code

```
# Apply a cut in the number of tracks.
ma.applyEventCuts('countInList(pi+:good) == 2', path=myPath)
```

```
from variables import variables

# The cluster E / p is very efective to separate electrons and other charged
variables.addAlias('EoverP', 'formula( ifNANgiveX( clusterE, -1 )/p )')
# Use the variable EoverP to identify pions
ma.copyList('pi+:sig', 'pi+:good', path=myPath)
ma.applyCuts('pi+:sig', 'EoverP < 0.8', path=myPath)
```

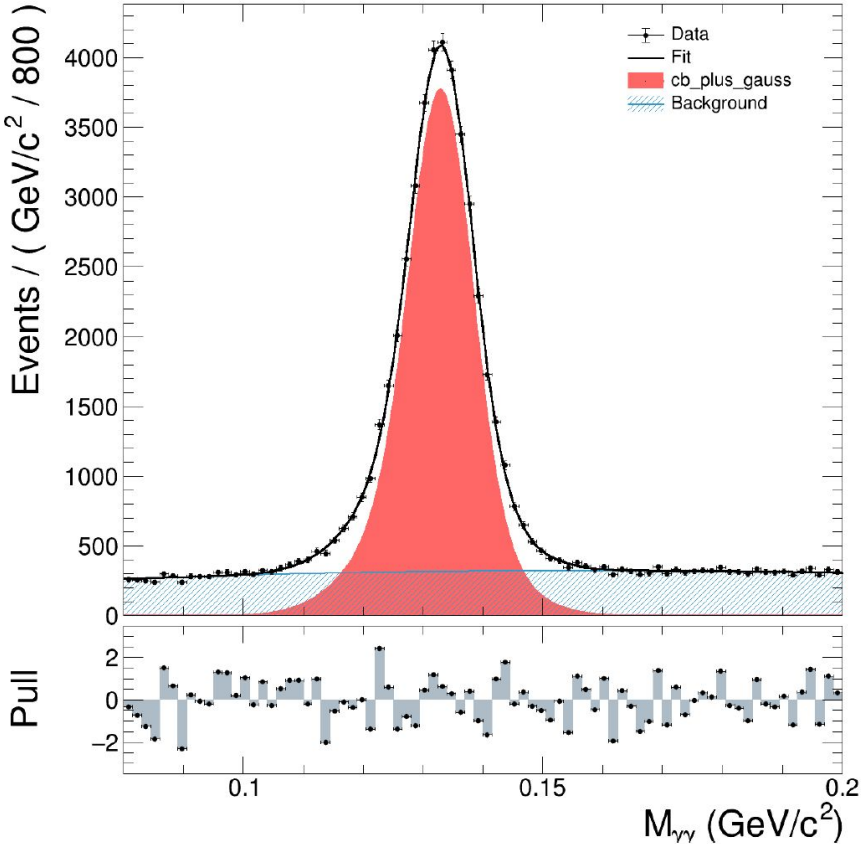
MC Analysis of $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$



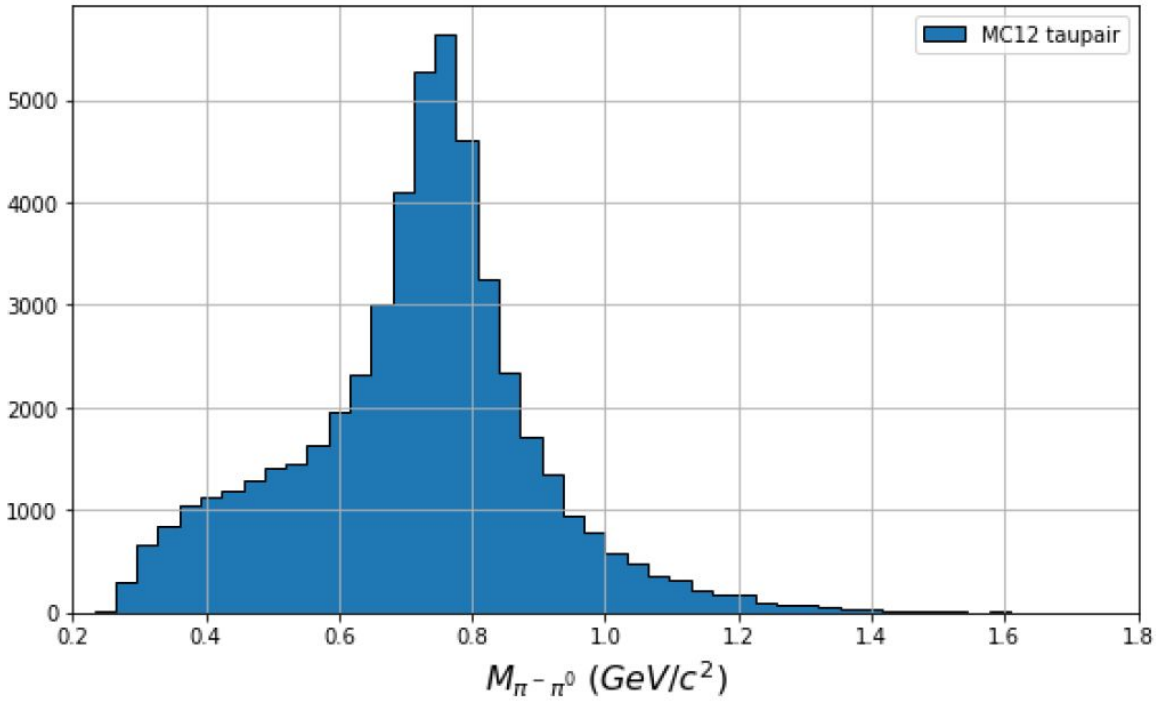
Invariant Mass of π^0
In Signal side.

Statistical Analysis of pi_0 invariant mass

- Using PyRooFit, a fit is performed in the Pi_0 invariant mass distribution.
- We use a Crystal Ball function + Gaussian for signal, and polynomial for bkg.
- A mass window of 3 sigma is defined.



Pi- pi_0 invariant mass



- After selecting pi_o events, we reconstructed pi, pi_0 invariant mass
- We observed clear peak, which corresponds to rho resonance

Summary

- I performed my first analysis using Basf2 .
- It was a great opportunity to interact with senior physicists and scientists.
- Learned that there are a lot of things I don’t know yet, and I should work really hard.
- Learned that Particle Physics is cool.


Thank
you!!