Polarization measurement in B meson decays

Justyna Mędrala
AGH University of Science and Technology (POL)

Ralph Torres
Ateneo de Manila University (PHL)

Supervisors: **dr hab. Andrzej Bożek & dr Jarosław Wiechczyński**
Department of Leptonic Interactions, IFJ PAN (POL)

Overview

- Introduction
- Methods
- Results
- Conclusion

Intro

Motivation

Standard Model

most promising elementary particle theory, but experimentally challenging

i.e. no new physics found after Higgs discovery

there should be hints of NP

as there are physical phenomena that we are yet to explain

hints → deviations in experimental results

when compared to theoretical predictions in SM

where to search?

what to search?

b quark sector

why?

(1) lots of different decays since it's heavy

→ more opportunities to find something, especially via rare decays

(2) we have efficient b quark sources i.e. B factories

→ hadrons containing b: B mesons (B0, B*, B_s), etc.

SuperKEKB & Belle II

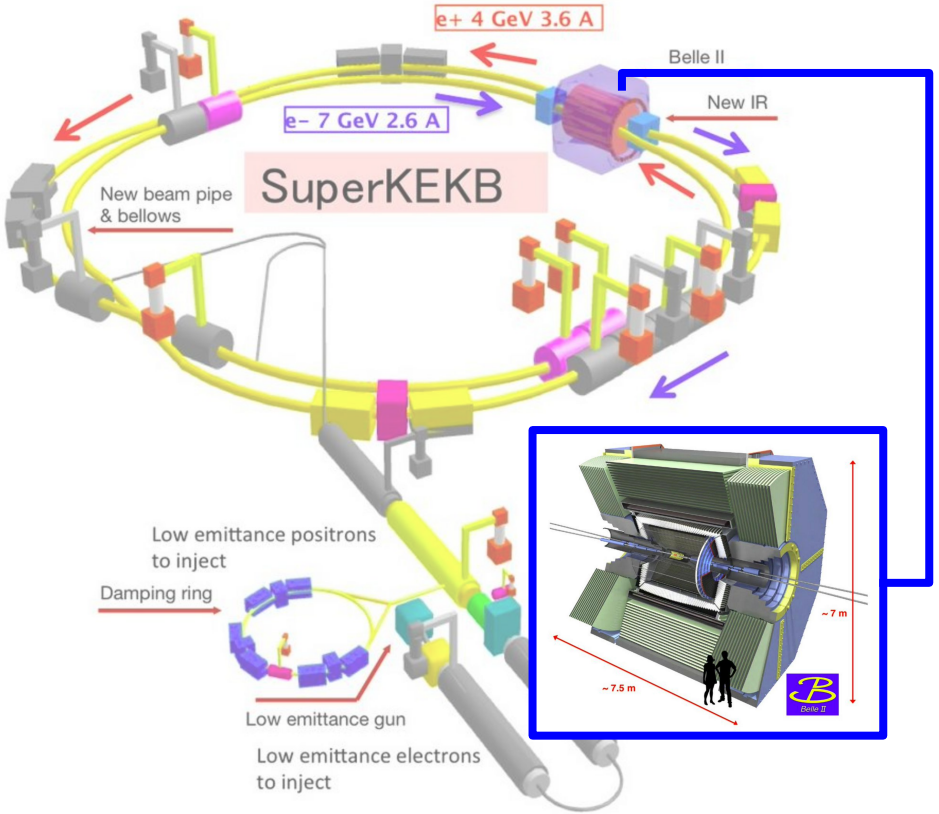
Located in Tsukuba, Japan

A **next-gen b factory** experiment:
lots of B mesons to probe!

Collides **electrons and positrons**
with an **asymmetric energy ratio**
of 7 GeV : 4 GeV, respectively

Expected to have **40 times**
instantaneous luminosity
over the original KEKB accelerator

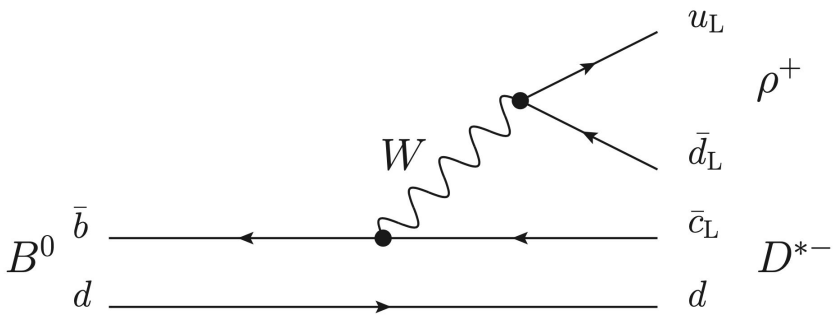
Designed to make **precise measurements**
of weak interaction parameters
and find NP beyond SM

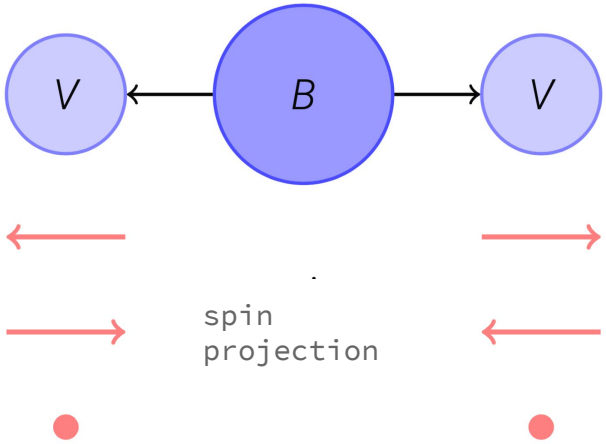


Polarization

B0 → D* ρ

tree-dominant decay
bottom to charm quark
scalar → vector vector (SVV)
compare to SVS decay
e.g. B0 → D* π
accounts for 1% of B decays

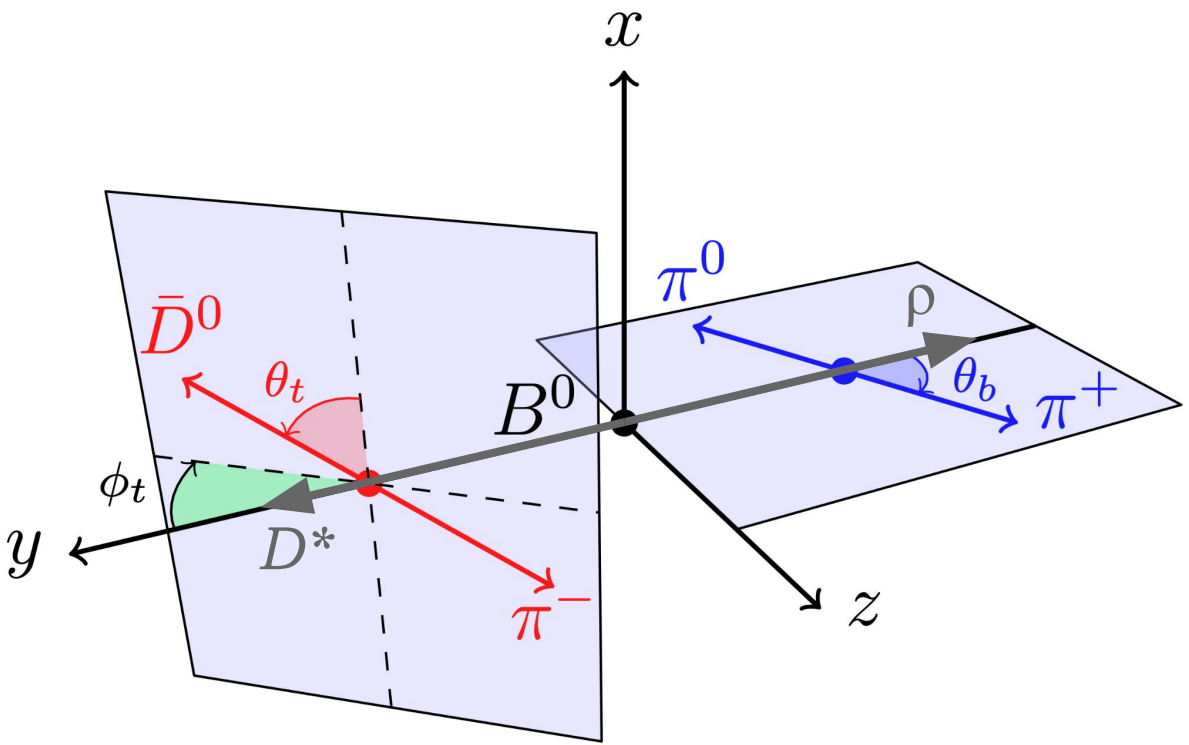




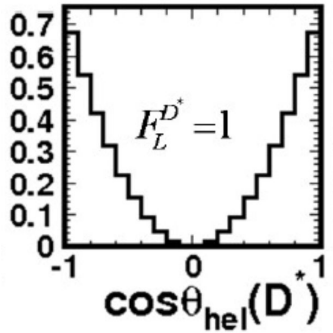
H_+
H_- } transversal polarization

H_0 longitudinal polarization

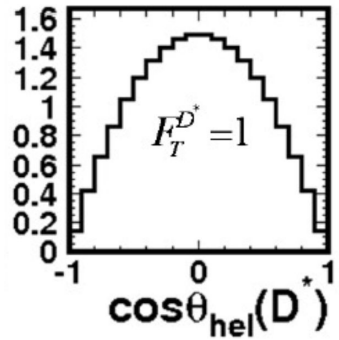
Polarization measurement



longitudinal



transversal



Motivation (revisited)

hints → deviations

where to search? **b quark sector (via b factories)**

what to search? **polarization**

polarization

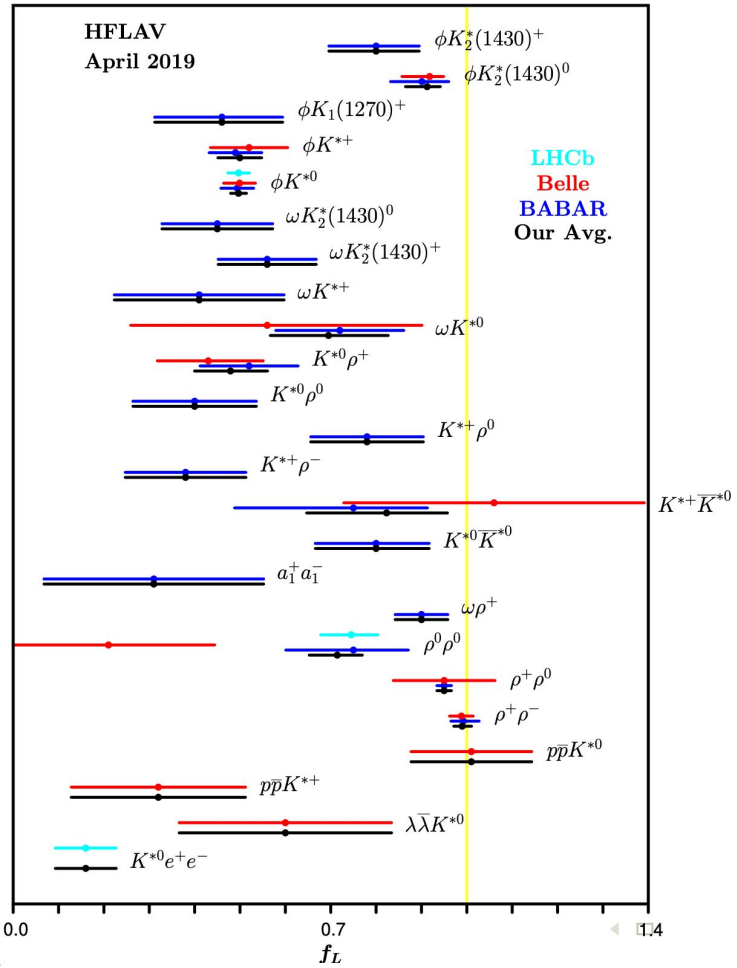
why?

(1) deviation from theoretical predictions
of SM based on various experimental results
→ f_L = longitudinal polarization fraction
f_L ~ 0.5 for penguin dominant
f_L ~ 1.0 for tree dominant

(2) still need to decouple QCD from weak int.
→ understanding the results may give insight

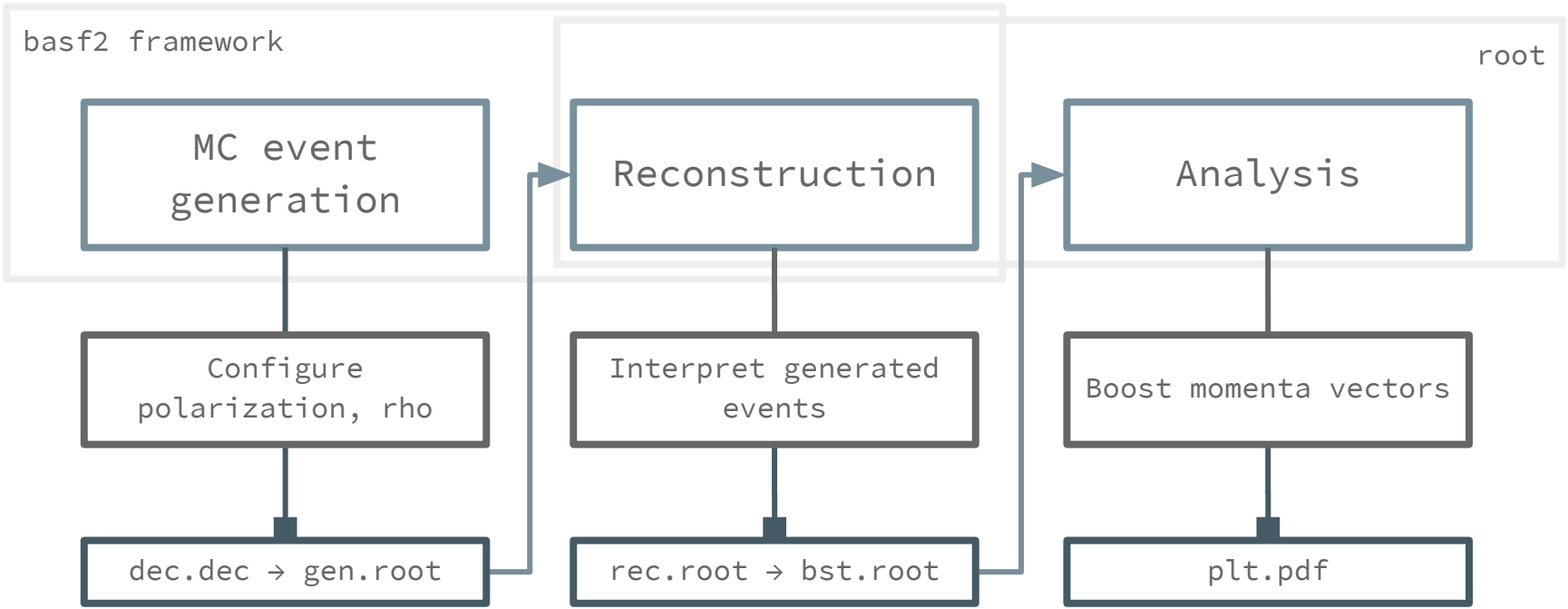
thus, polarization measurement in B meson decays

among decay modes, we choose the well-known ones
B -> D* π (SVS)
B -> D* ρ (SVV)



Methods

Overview



cases: pi, rho (→ rhoS, rhoT, rhoL)
events: 40000 per case
tools: basf2, root, qsub; py, cpp

Configuring polarization

/src/dec-pi.dec
Decay of B0 -> D*- pi+

```
Decay myB0
1.0  myD*- pi+      SVS;
Enddecay
CDecay myanti-B0
```

/src/dec-rhoX.dec — X ∈ {S,T,L}
Decay of B0 -> rho+ D*-

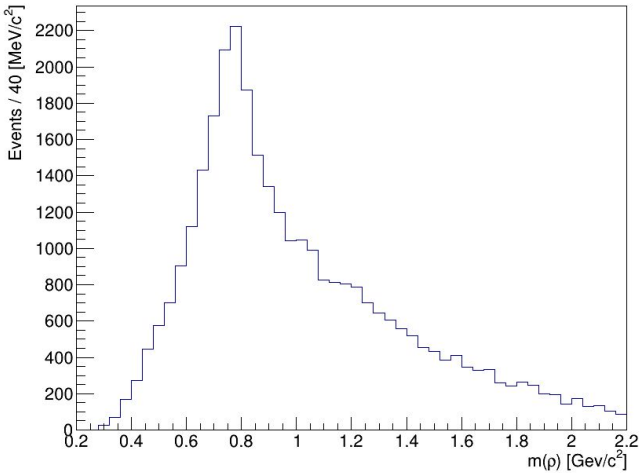
```
Decay myB0
1.0  rho+ myD*-     SVV_HELAMP 0.317 0.19 0.936 0.0 0.152 1.47;
Enddecay
CDecay myanti-B0

Standard       1.0  rho+ myD*-     SVV_HELAMP 0.317 0.19 0.936 0.0 0.152 1.47;
Transversal    1.0  rho+ myD*-     SVV_HELAMP 1 0 0 0 1 0;
Longitudinal   1.0  rho+ myD*-     SVV_HELAMP 0 0 1 0 0 0;
```

Event interpretation

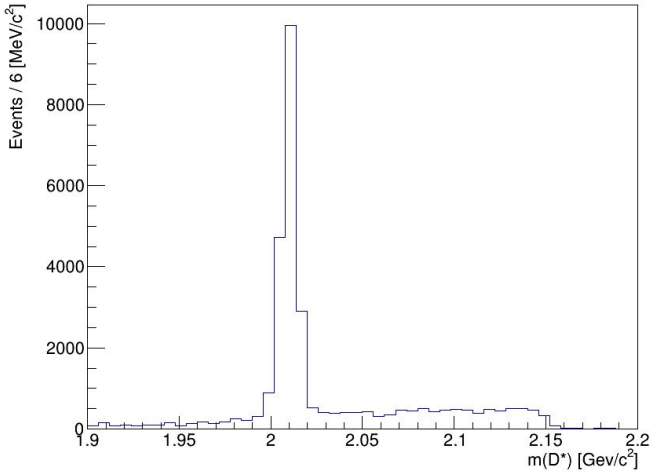
B0 → D* π
↳ D0 π
↳ K π

B0 → D* ρ
↳ D0 π
↳ K π

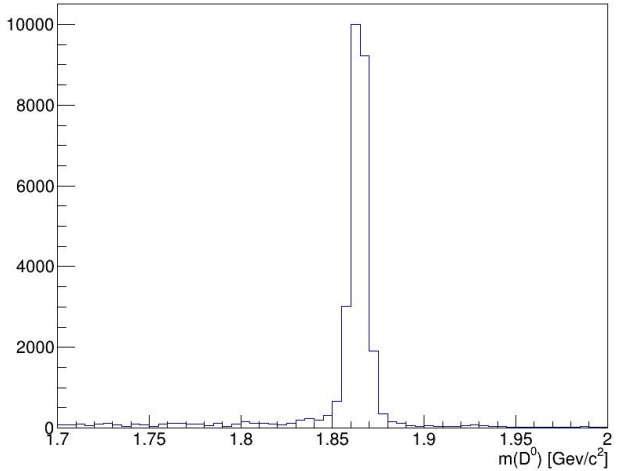
ρ → π π



D* → D0 π



D0 → K π



Boosting momenta vectors

/src/bst.c

Measure polarization of decay products
→ Load momenta components (p_x, p_y, p_z, E) and put in a TLorentzVector object
→ Boost via vec.Boost() in a loop so momenta vectors are put in same frame

```
TLorentzVector pB, pDst, pDstb, pD0, pD0b;
Double_t deltaM, ang, cosang;

⋮
        pDstb = pDst;
        pD0b = pD0;
        pDstb.Boost(-pB.BoostVector());
        pD0b.Boost(-pDst.BoostVector());

        deltaM = DstM - D0M;
        ang = pD0b.Angle(pDstb.Vect());
        cosang = cos(ang);
```

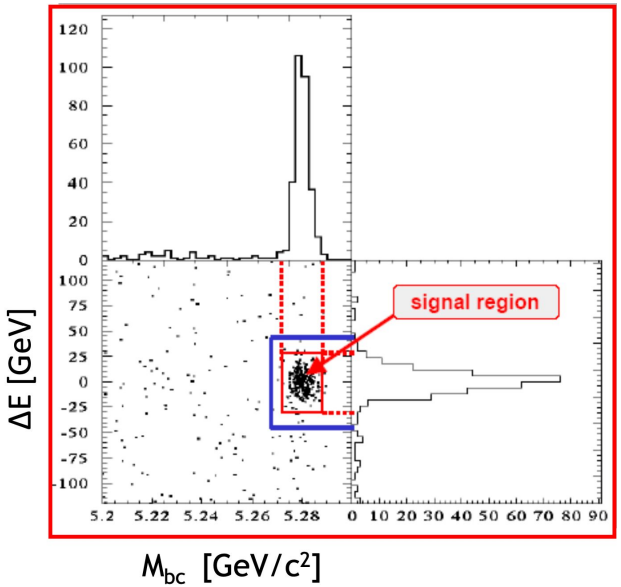
Kinematic variables

deltaE : energy difference ΔE
specific to B-factories
E_i = sum of energies of B decay products in CMS
E_beam = energy of the beam in CMS

$$\Delta E = \Sigma_i E_i^* - E_{\text{beam}}^*$$

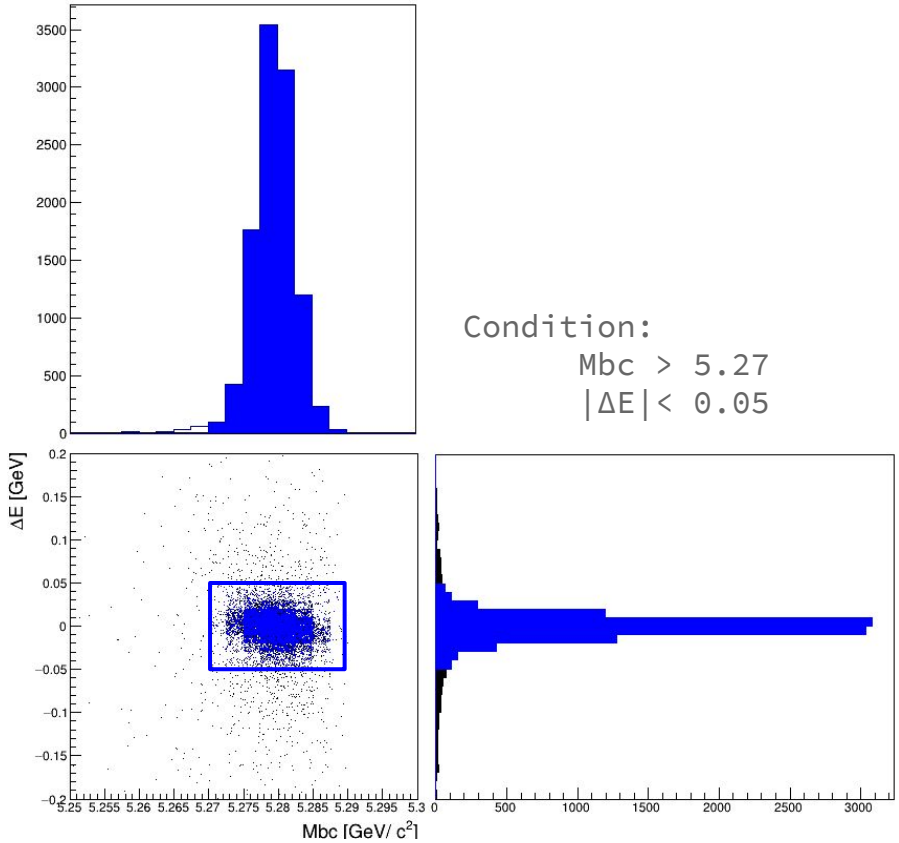
Mbc : analog of invariant mass
specific to B-factories
makes reconstruction easier
p_i = momenta of B decay products

$$M_{bc} = \sqrt{E_{\text{beam}}^{*2} - (\Sigma_i \vec{p}_i^*)^2}$$



Results

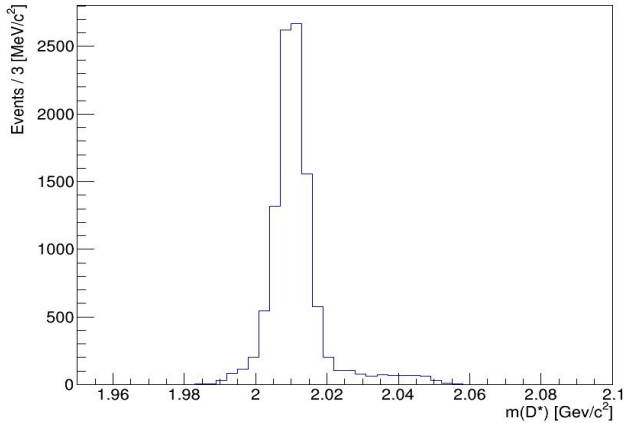
B0 → D* π
Energy difference ΔE and Mbc

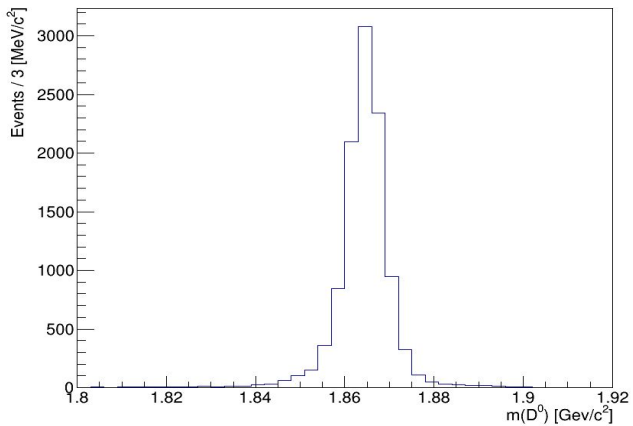


Condition:
Mbc > 5.27
|ΔE|< 0.05

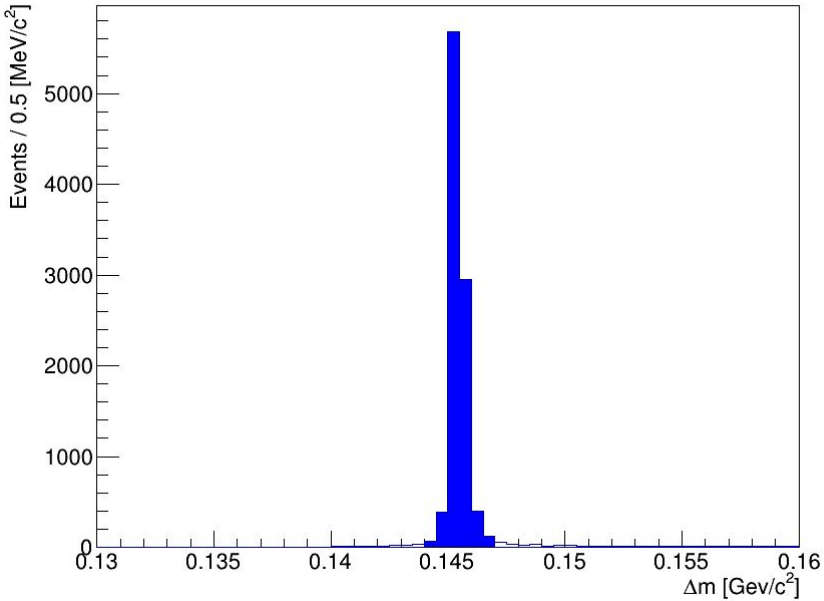
B0 → D* π

D* and D0 mass distribution





Mass difference ΔM

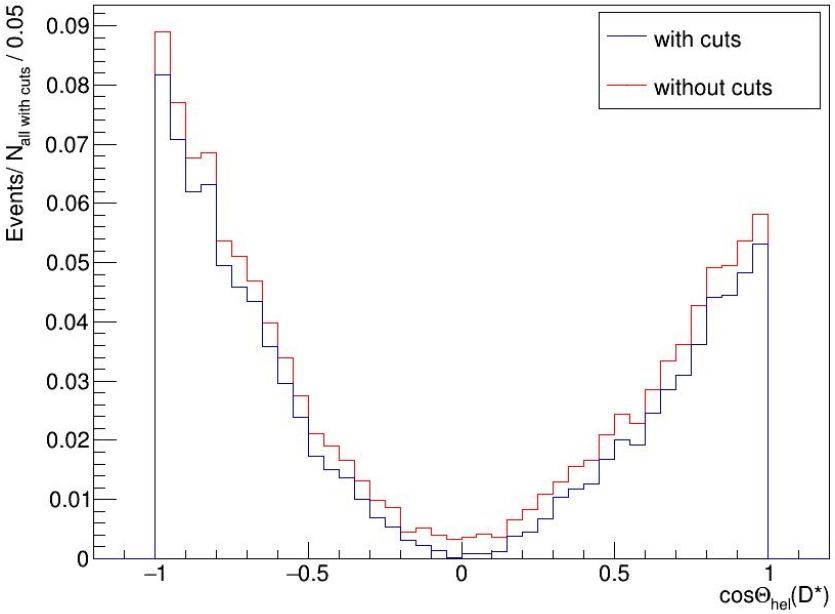


Condition: 0.144 < ΔM < 0.147

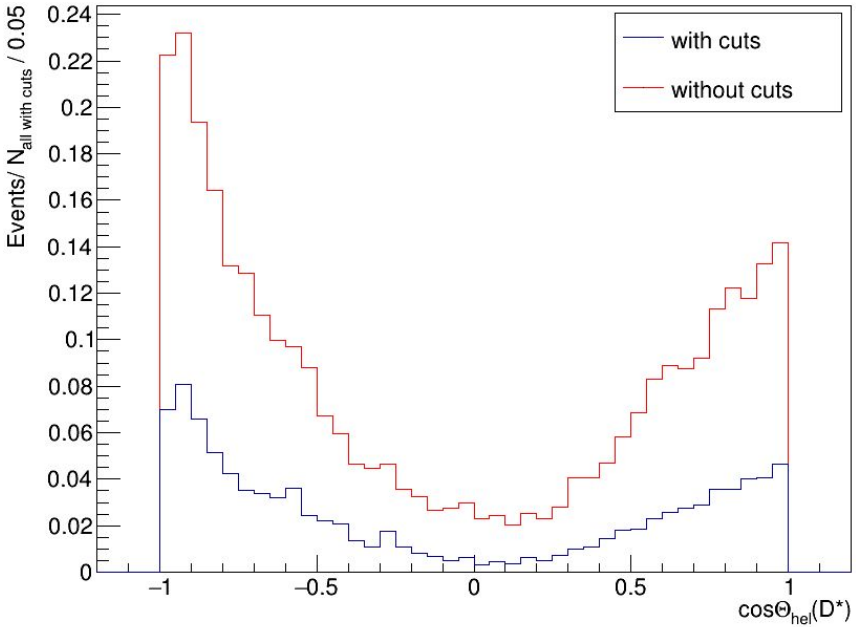
$$\Delta M = m_{D^*} - m_{D^0}$$

Polarization measurements of D*

B0 → D* π



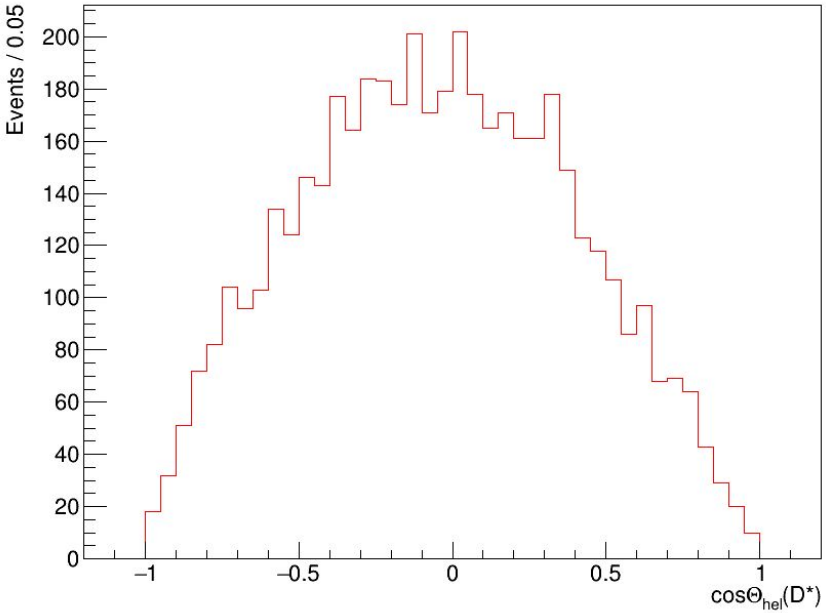
B0 → D* ρ



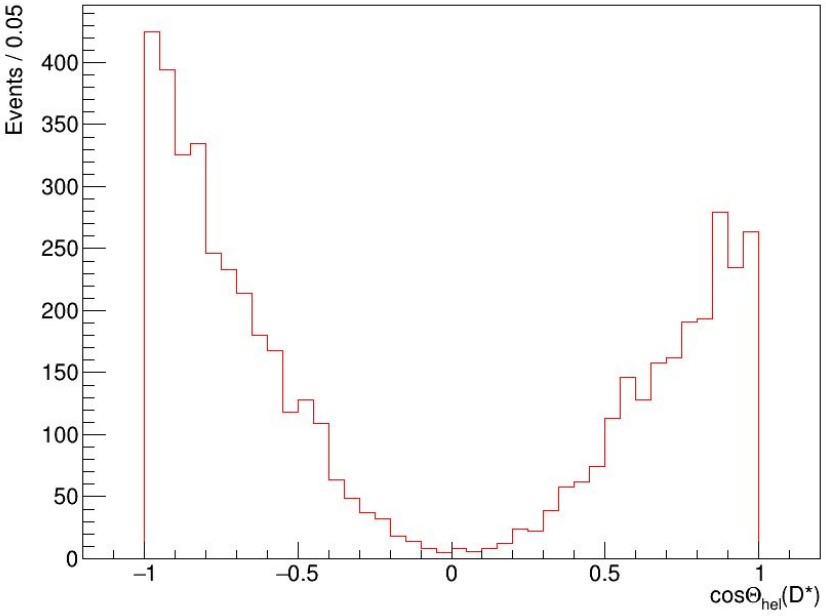
Polarization measurements of D*

B0 → D* ρ

transversal

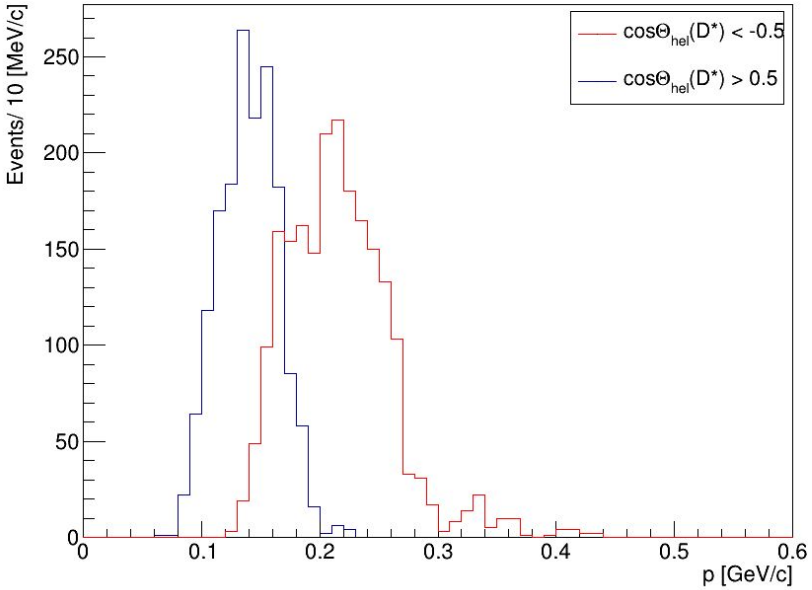


longitudinal



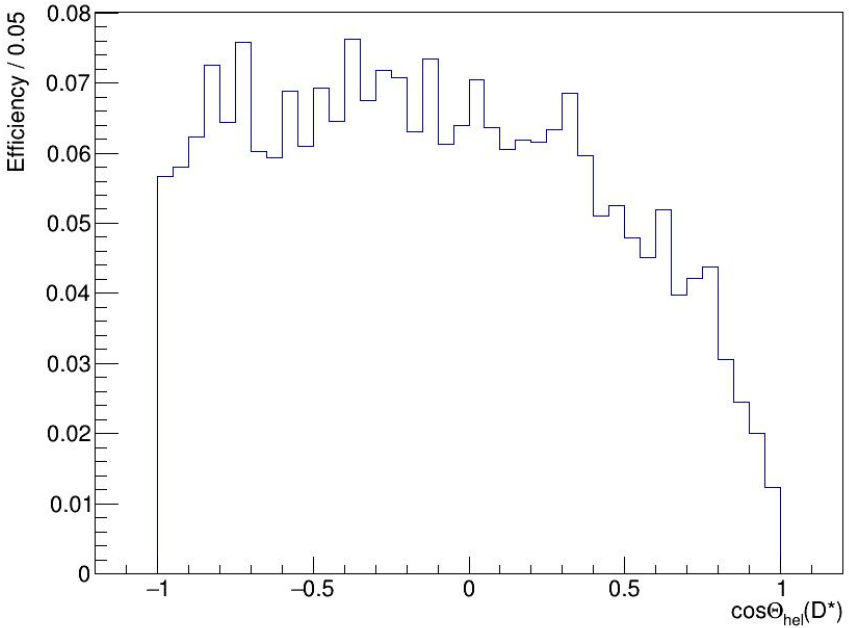
B0 → D* ρ

Pion momenta distribution



Condition: cosθ < -0.5, cosθ > 0.5

Reconstruction efficiency



$$\epsilon = N_{\mathrm{rec}}/N_{\mathrm{gen}}$$

Conclusions

We learned modern analysis tools employed in modern particle physics: Monte Carlo event generation, detector simulation, final reconstruction, and analysis.

We were able to reconstruct the polarization of B meson decays: $B0 \to D^* \pi$ and $B0 \to D^* \rho$.

Upon measuring the polarization, we observe that the corresponding plots have different features as discussed:

- For π, the polarization tends to be longitudinal since the minimum is at $\cos\theta = 0$ while the maximum is at both $\cos\theta = \{-1, 1\}$. This confirms what is expected.

- For ρ, the polarization tends to be a mix of both transversal and longitudinal in the standard generated case. In particular, its longitudinal component is more dominant than the transversal.

- For the case of ρ with transversal polarization, we observe a behavior that is exclusively opposite to that of longitudinal polarization, that is minimum at both $\cos\theta = \{-1, 1\}$ and maximum at $\cos\theta = 0$.

For both π and ρ, the polarization plots reveal an asymmetric feature, see $\cos\theta = \{-1, 1\}$. This is due to the variation of reconstruction efficiency as the angle varies.

References

“Belle II,” https://www.belle2.org/.

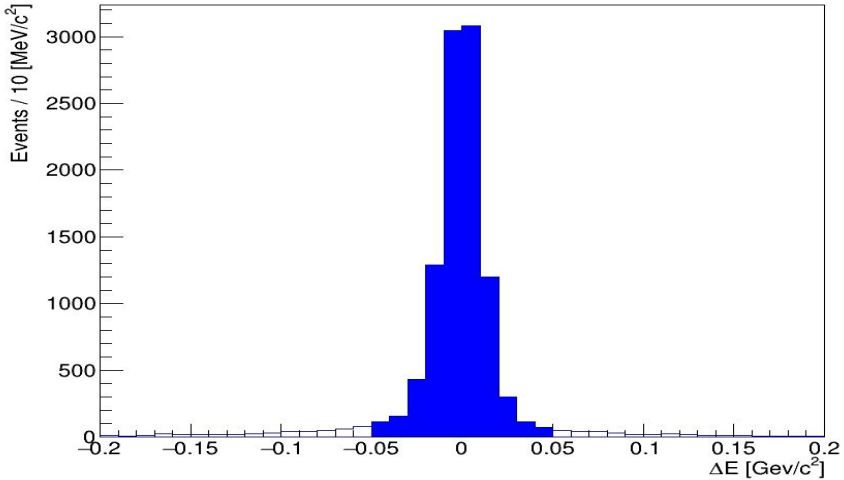
"SuperKEKB". https://www-superkekb.kek.jp/.

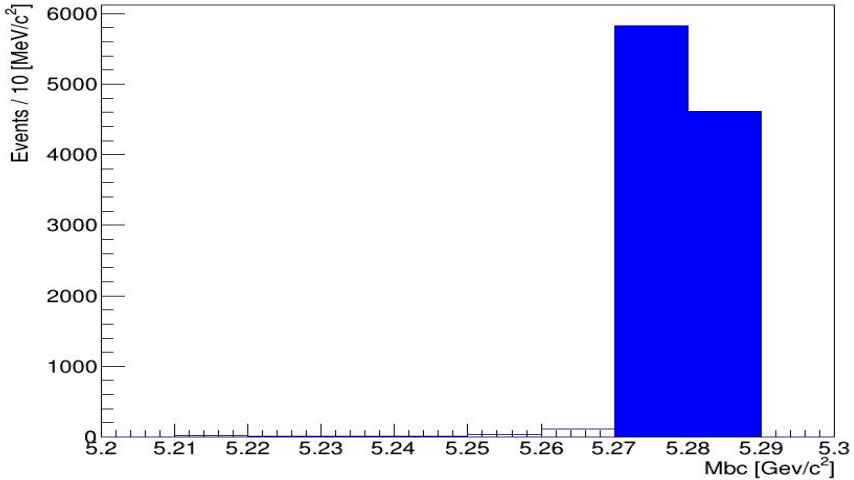
P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020) and 2021 update.

Questions?

Backup slides

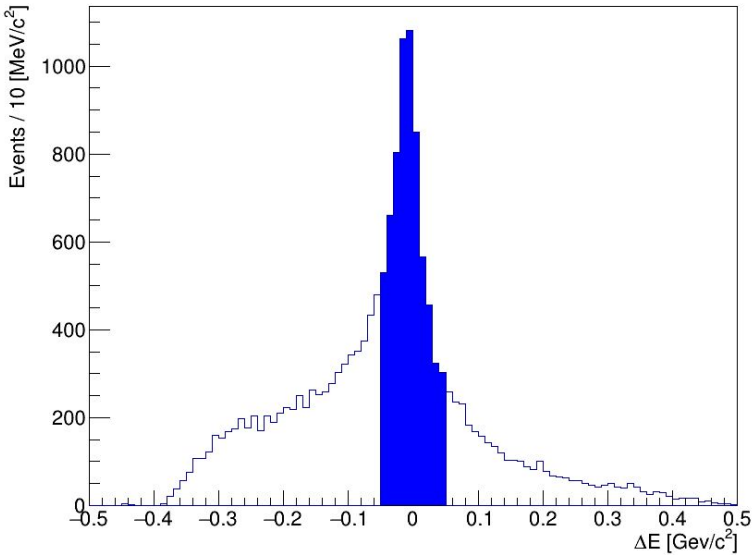
B0 → D* π
Energy difference ΔE and Mbc





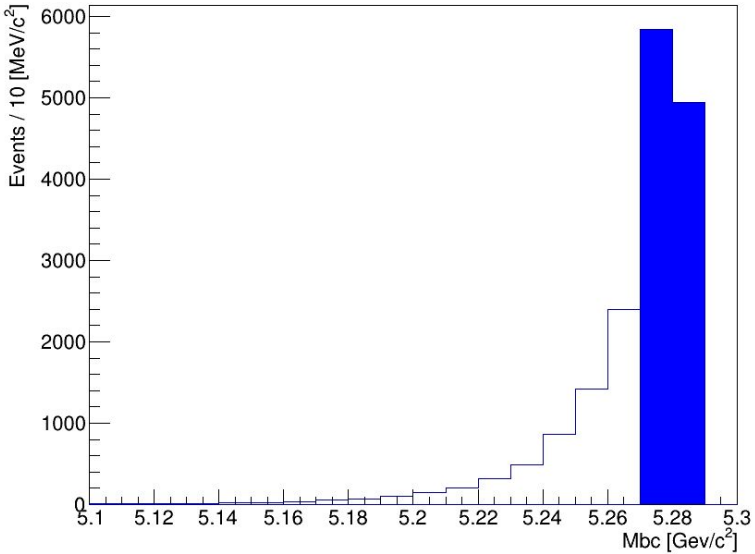
Condition: |ΔE| < 0.05, Mbc > 5.27

D* → D0 ρ
Energy difference ΔE



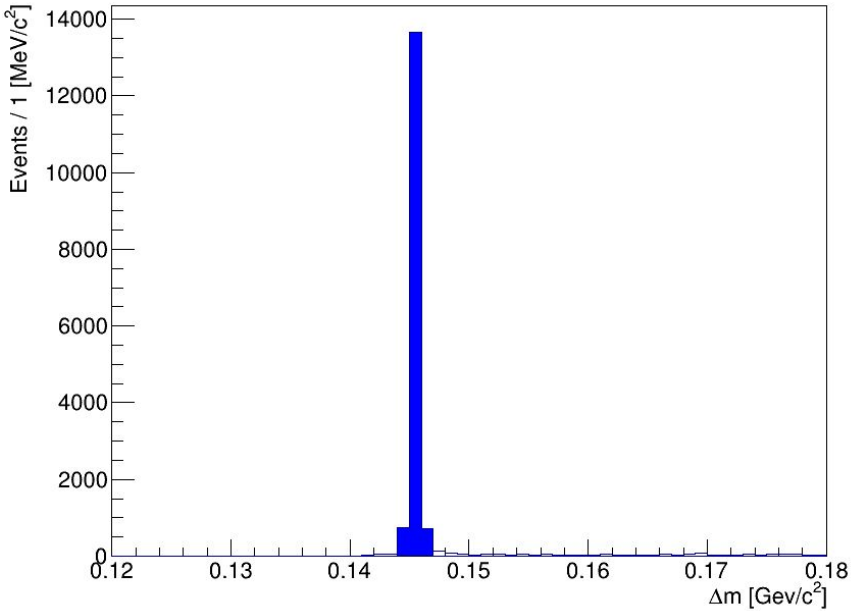
Condition: |ΔE| < 0.05

D* → D0 ρ
Mbc



Condition: Mbc > 5.27

D* → D0 ρ
Mass difference Δm



Condition: 0.144 < Δm < 0.147