Analysis of D meson decays at LHCb

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P-3, High Energy Nuclear Physics

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Research Objective

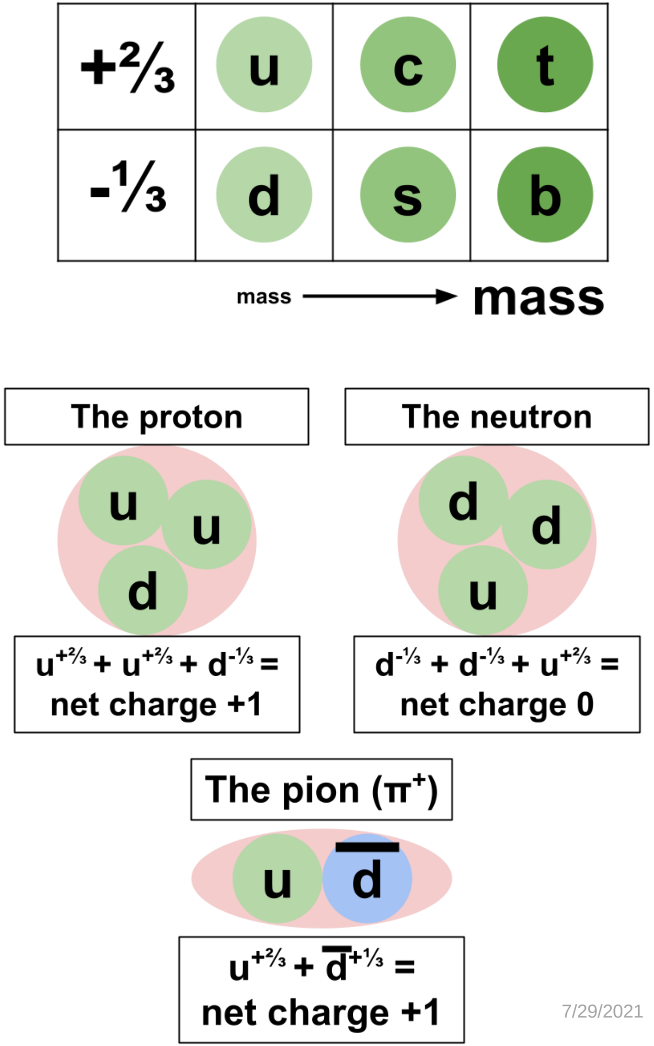
To study the quark-level decays of the D^+ and D_s^+ mesons to search for new particles

Quarks: the building blocks of hadronic matter

- Quarks are not allowed to exist freely, so they are always confined within hadrons.

- Most commonly, quarks form clusters of three, called baryons, or clusters of two, called mesons.

- For every quark, there is a corresponding antiquark with opposite charge.
  - Antiquarks are denoted with a bar.

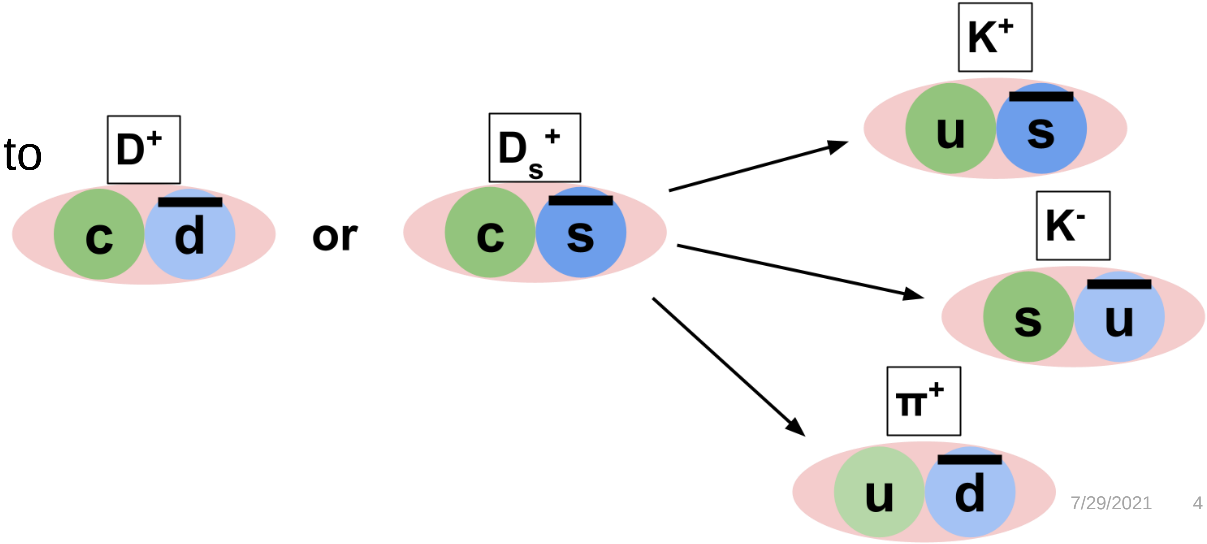


Choosing a dataset: on the hunt for D mesons

- This project looks to compare the D^+ and D_s^+ mesons, so we want a data set that contains both of these particles.

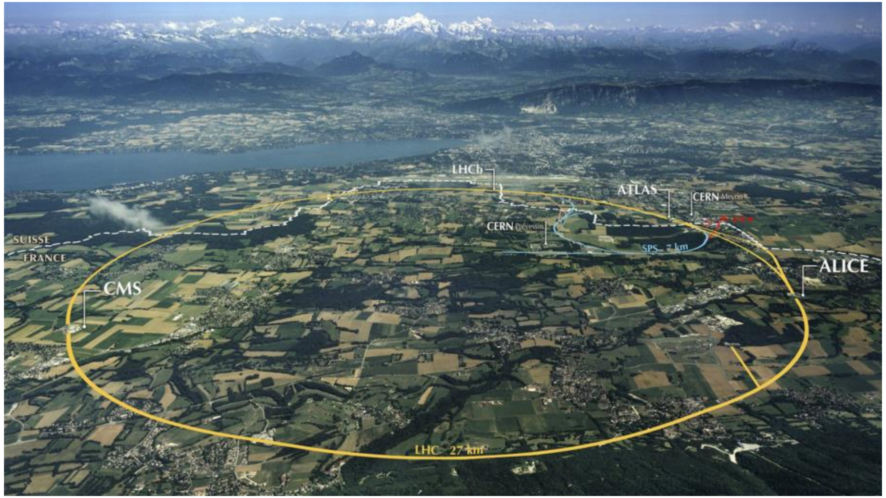
- D^+ and D_s^+ both decay far too quickly to be seen directly, so we look for their decay products.

- Both are able to decay into two kaons and a pion.



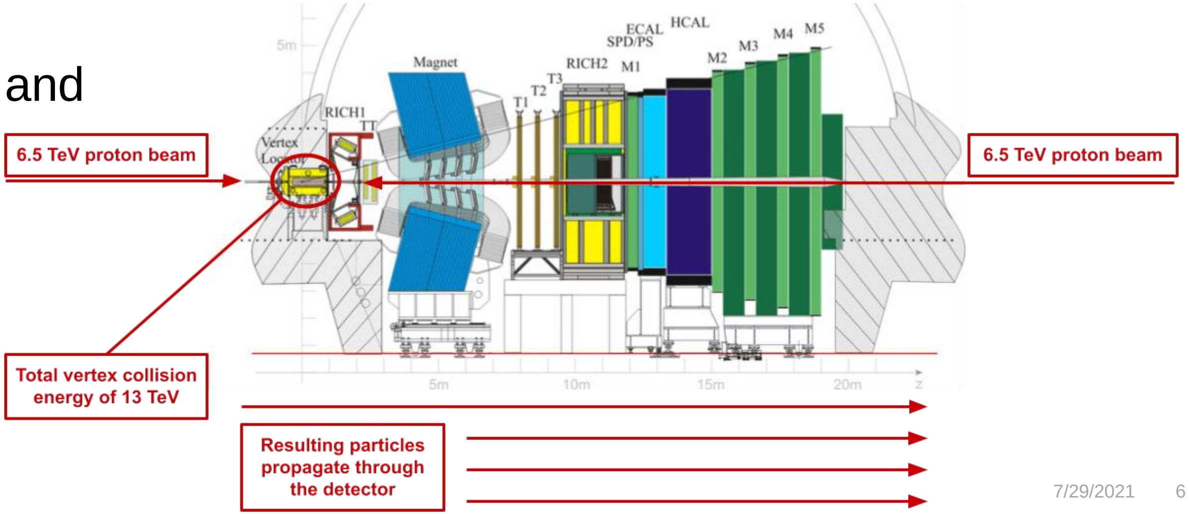
The Large Hadron Collider

- 16.8 mile long loop located 300 feet underground at Geneva, Switzerland.
- The most powerful particle accelerator in the world
- Accelerates two proton beams in opposite directions
  - Proton beams are kept separate, experiments are housed at beam crossing locations



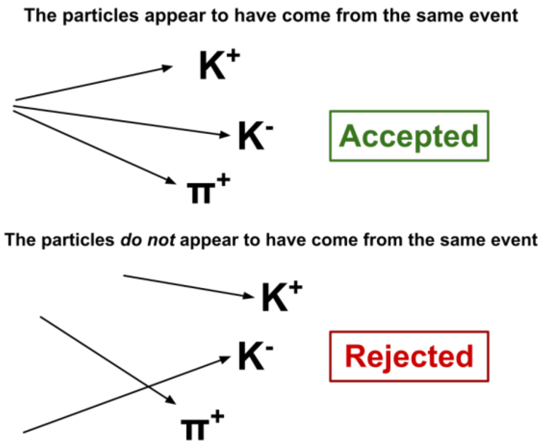
The LHCb Experiment

- Experiment located at the LHC
- As high energy protons collide, their energy is converted into new particles via E = mc^2
- Able to determine energy and momentum of detected particles, as well as particle identity



Placing selection criteria on the data

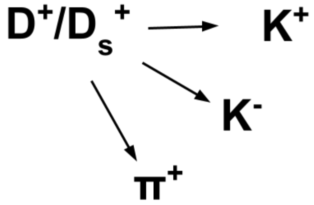
- If we took every single $K^+ K^- \pi^+$ event, we would be left with random, uncorrelated noise.
- We place criteria such as:
  - All 3 particles came from the same location
  - Particle ID criteria from Cherenkov counters
  - Their energies and momenta add up to a mass close to that of the target particle

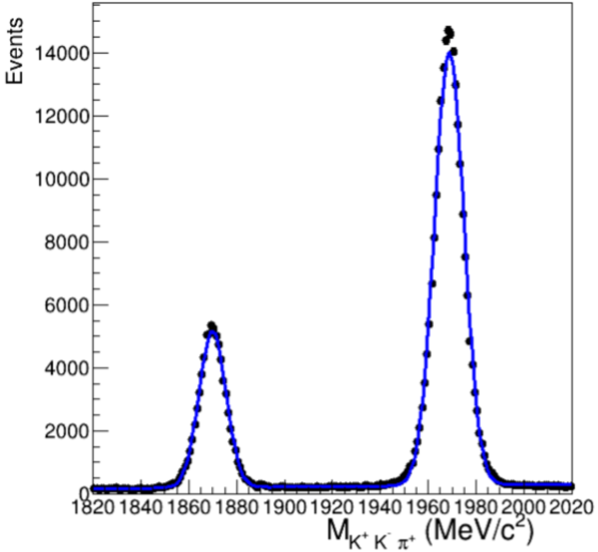


The Data

- The mass of the primary particle is recreated from the energies and momenta of the K^+, K^-, and π^+. This graph is called an invariant mass spectrum.

- Black dots are data points, the blue curve is the model
  - The data is modeled by the sum of two Gaussian curves and a linear background





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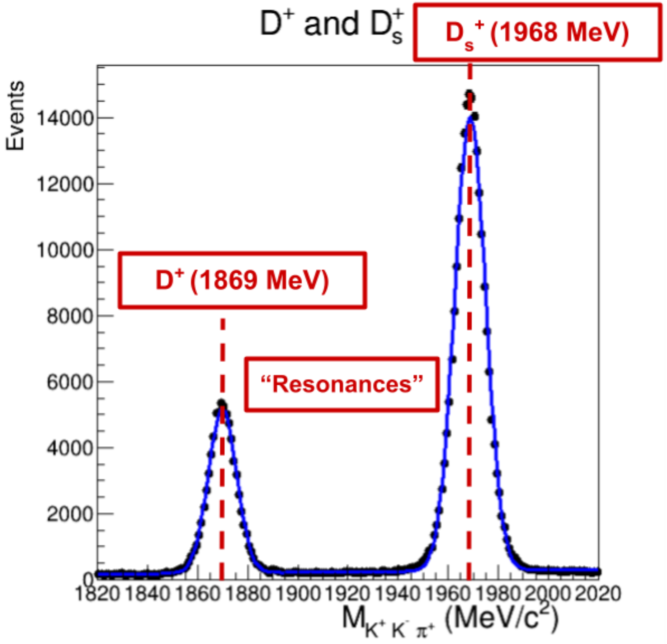
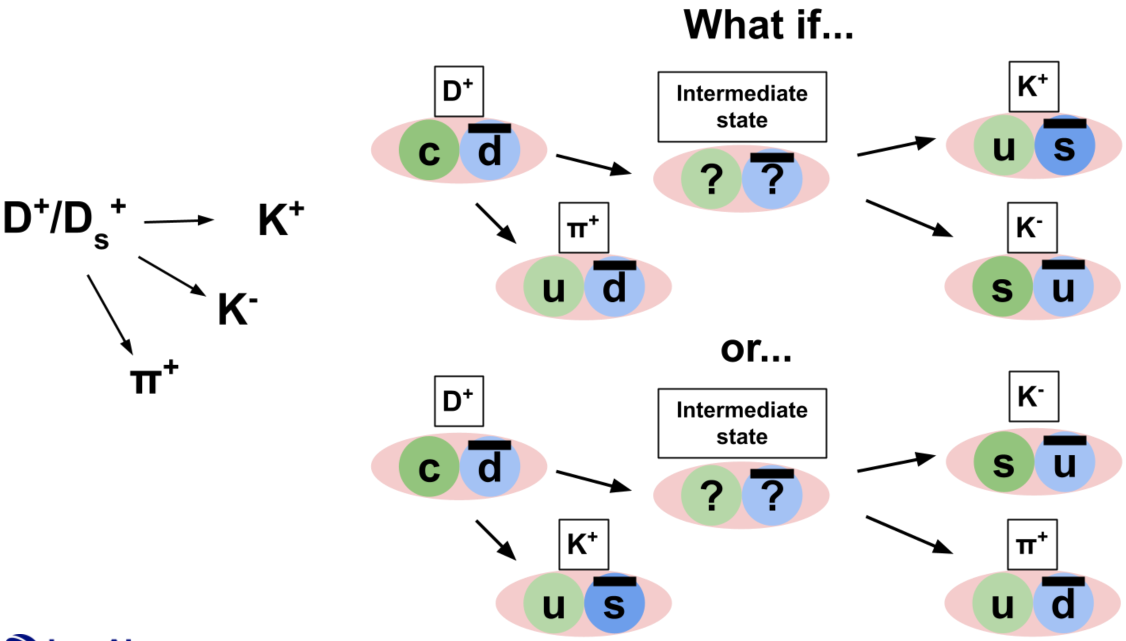


What about intermediate decay states?

- Do the D^+ and D_s^+ really decay directly to K^+ K^- π^+, or is there some sort of "stepping stone" in between?



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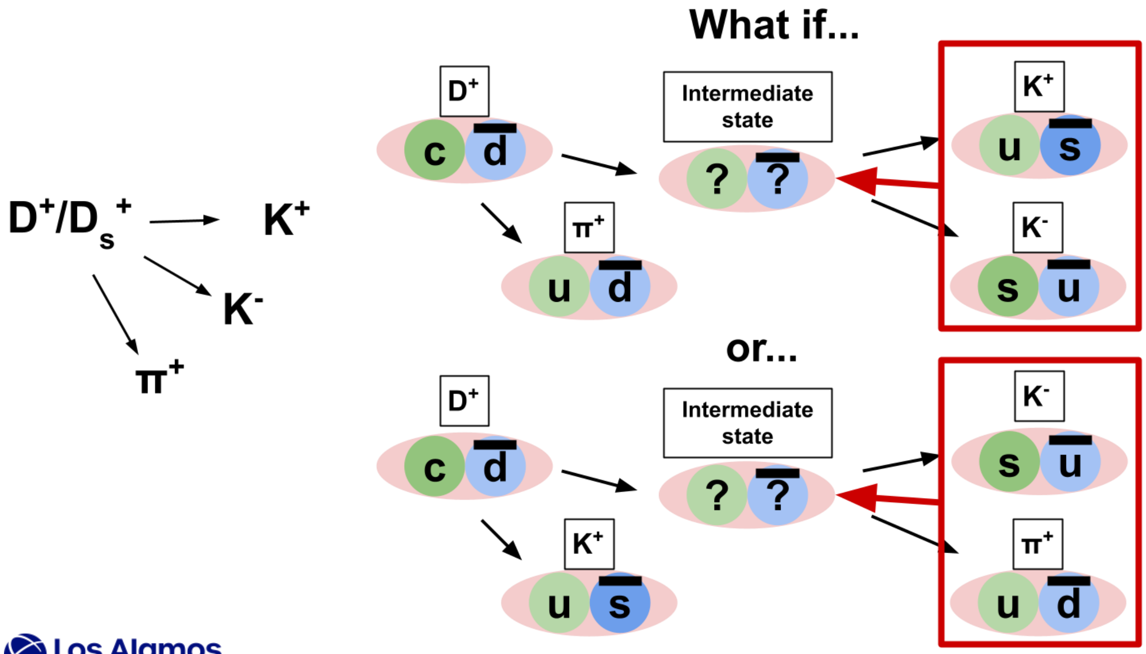


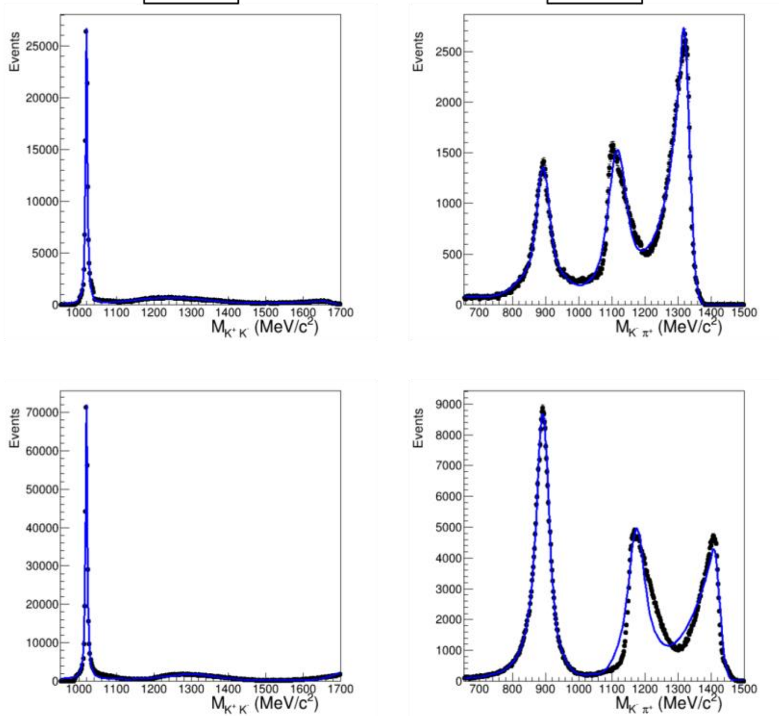
Two-body invariant mass spectra

- We can create invariant mass spectra of $K^+ K^-$ and $K^- \pi^+$ to search for intermediate states.

$K^+ K^-$ $K^- \pi^+$

D^+

D_s^+



Two-body invariant mass spectra

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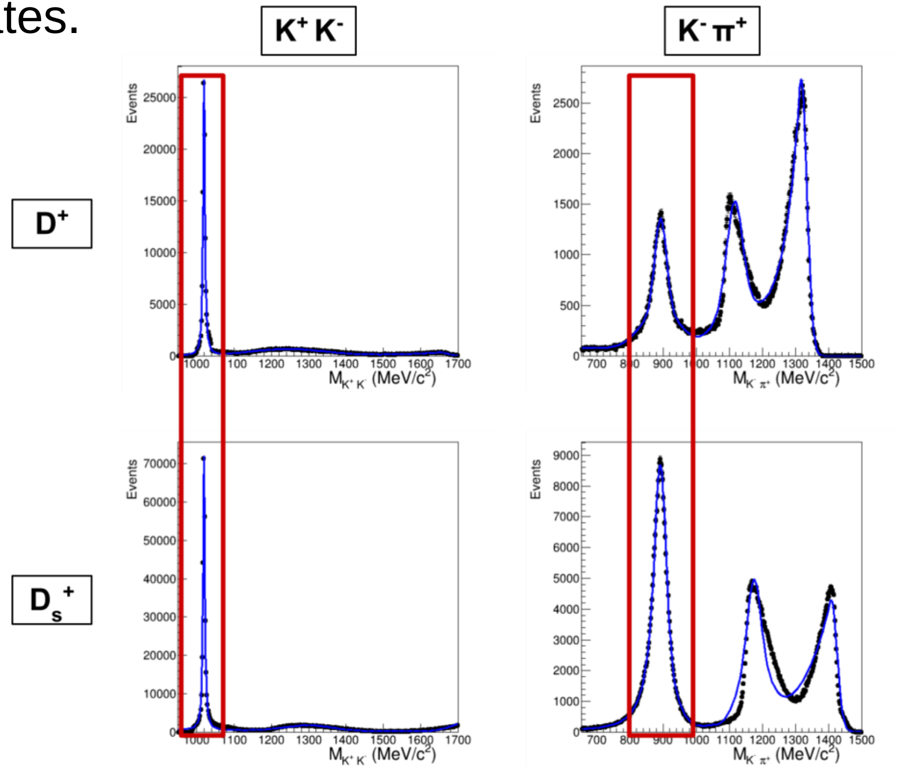
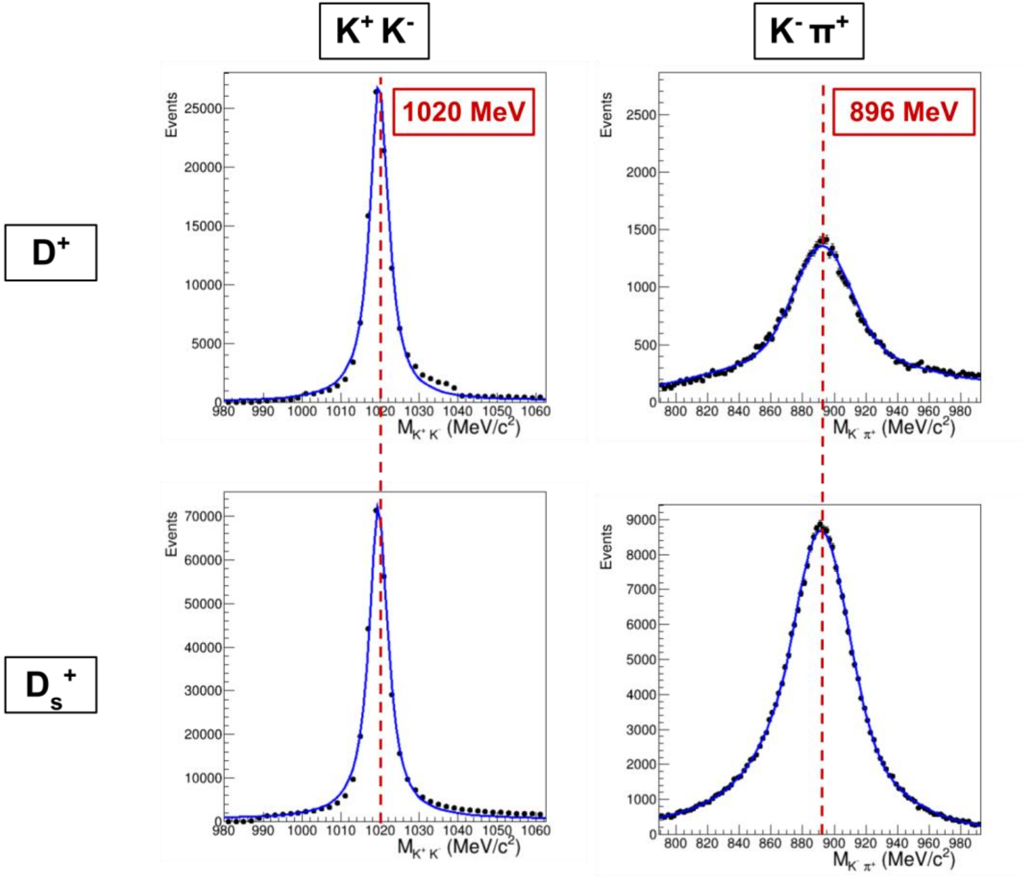
- Let's have a closer look at these leftmost peaks…



Leftmost peaks

- Similar resonances appear in both the D^+ and D_s^+ spectra.

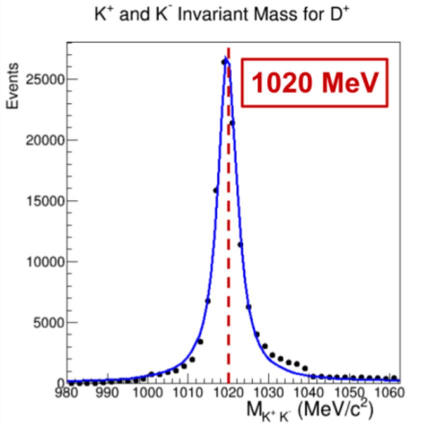
- We can search the literature for particles that satisfy the mass and decay criteria:
  - 1020 MeV and decays to $K^+ K^-$
  - 896 MeV and decays to $K^- \pi^+$

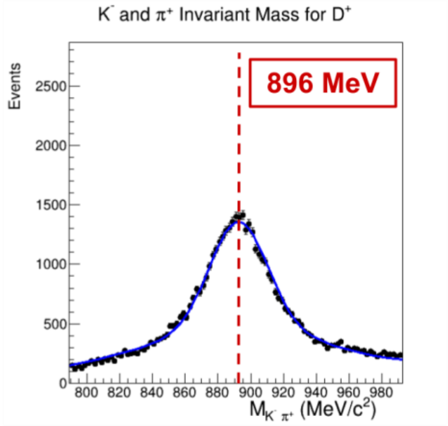


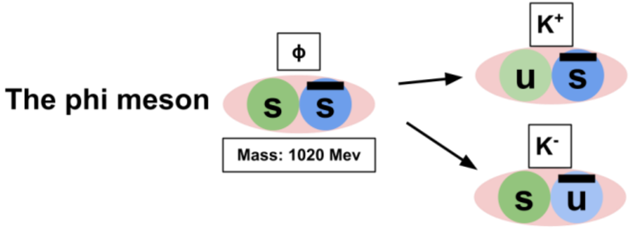
The culprits

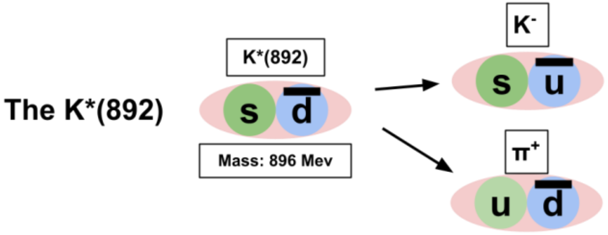
- We find two particles that fit these descriptions exactly.

  - The phi meson is appearing in the K^+ K^- spectrum while the K*(892) is appearing in the K^- π^+ spectrum.





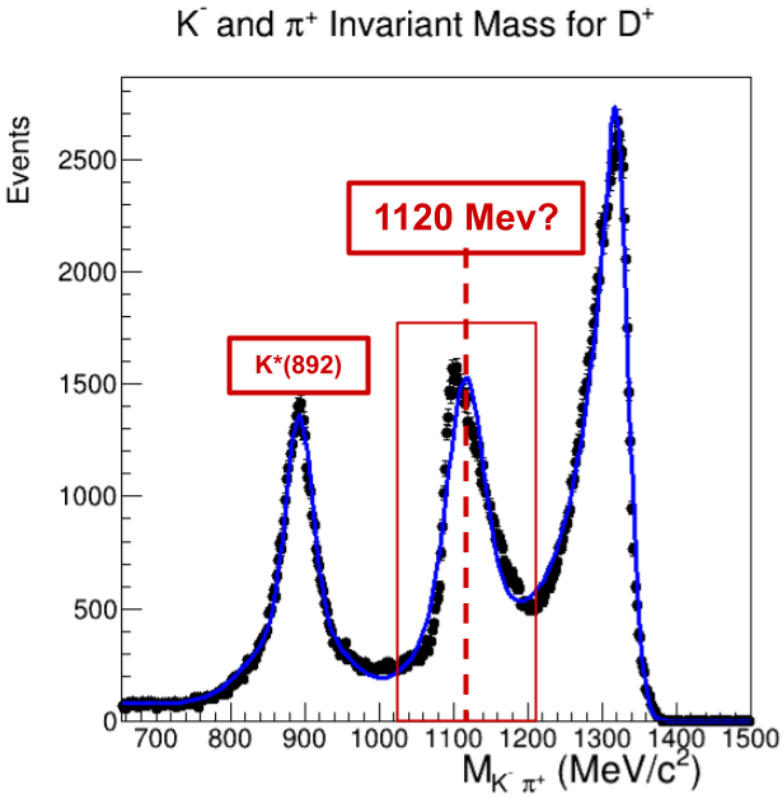




But what about those other peaks?

- We still have many peaks yet unidentified! Let's have a look at the middle peak.

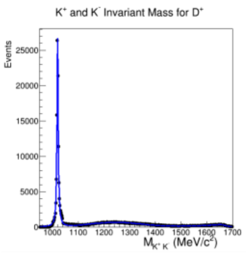
- There are no known mesons with mass ~1120 MeV which decay to $K^- \pi^+$.
  - Clearly I've discovered a new particle! Where's my Nobel prize?
  - Or maybe not…

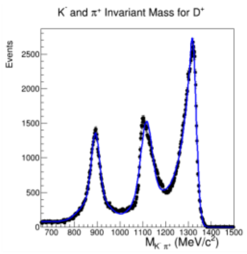


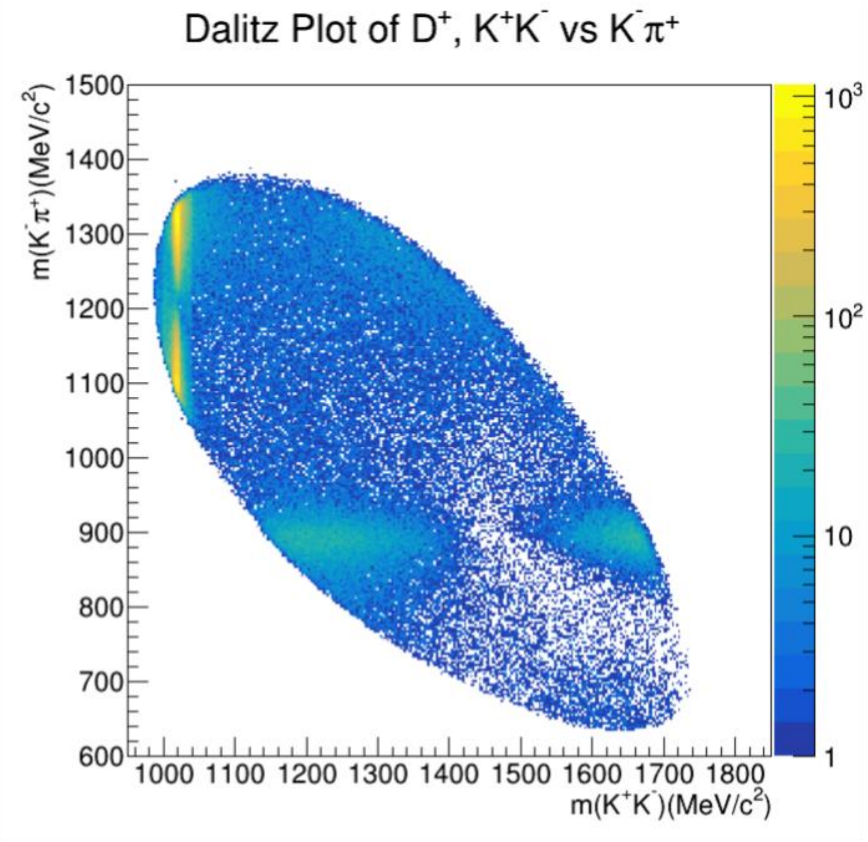
This is where Dalitz plot analysis comes in handy

- Named after Richard Dalitz

- Widely used in the study of three-body decays of D mesons, like in our case of $K^+ K^- \pi^+$.



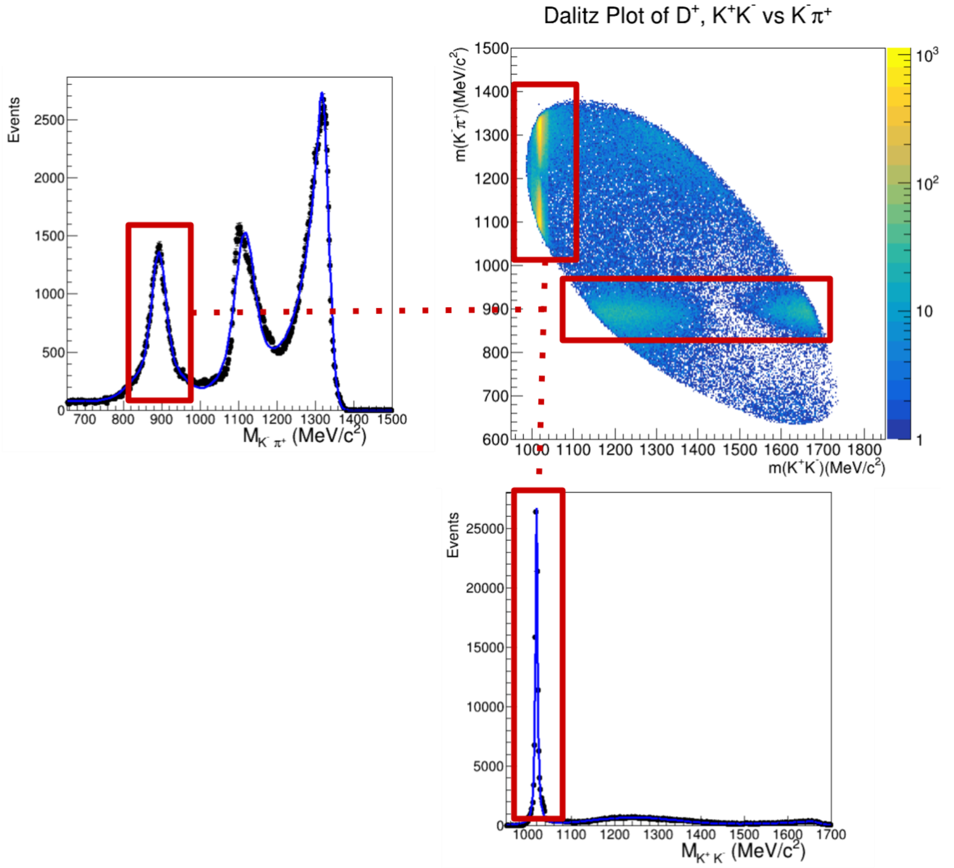




Resonances appear on a Dalitz plot as a band

- The phi appears as a stripe at 1020 MeV on the $K^+ K^-$ axis, while the K* appears at 896 MeV on the $K^- \pi^+$ axis.

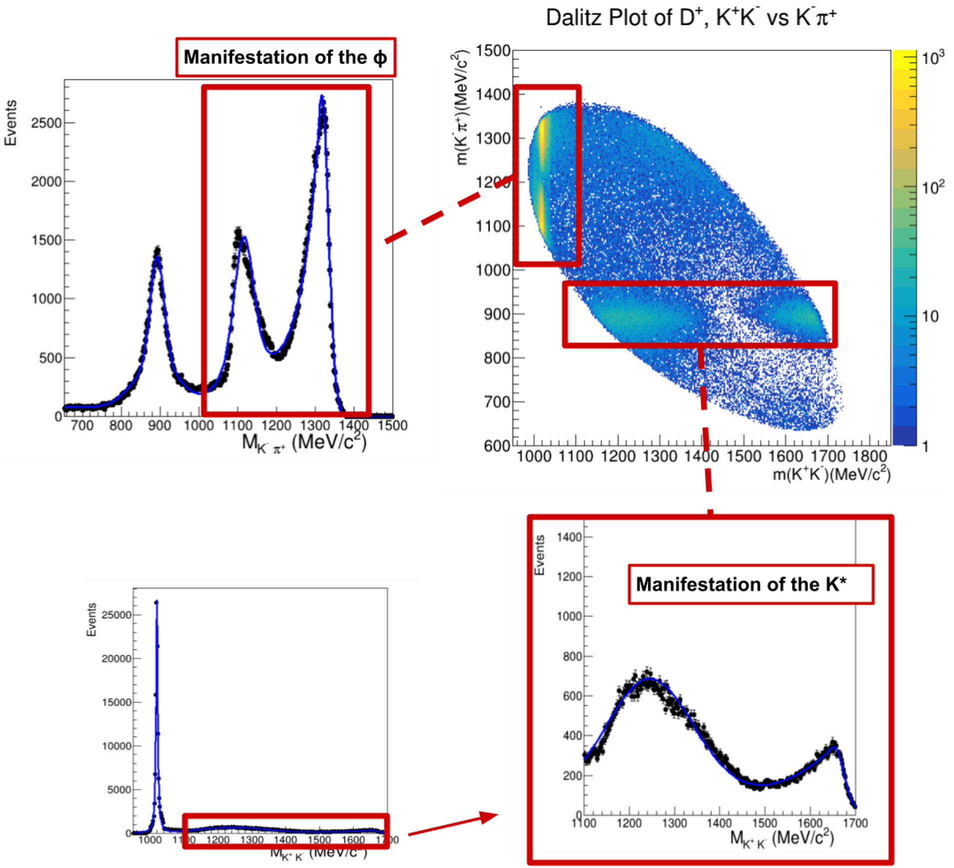
- The keen-eyed observer might be able to see where this is going…



Resonances can manifest themselves on both axes

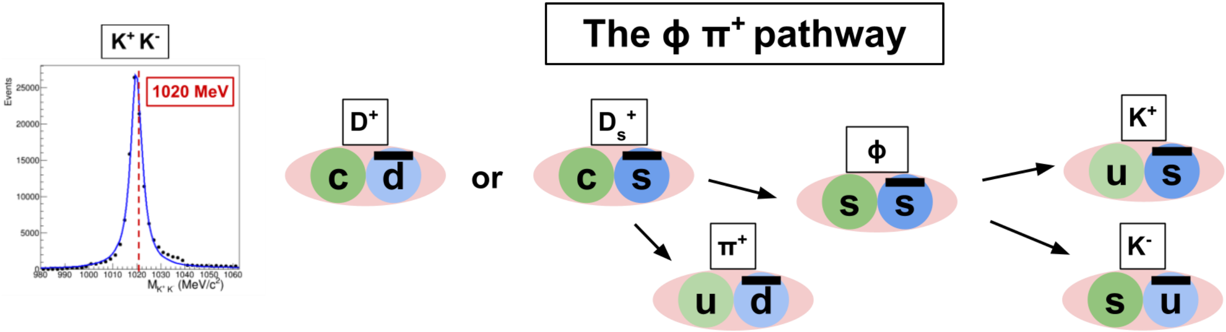
- The unidentified peaks are not new particles, but rather the phi and K* creating signals on both axes.

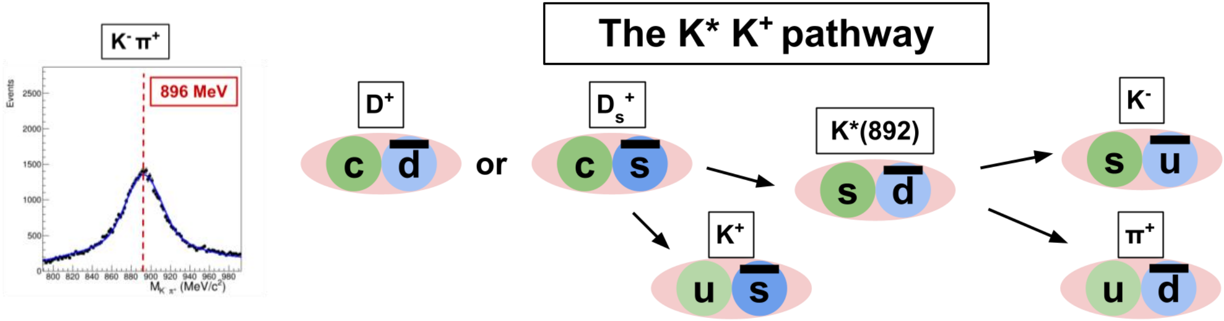
- Particles are correlated due to the decay process, and the Dalitz plot offers a method to study this correlation



Conclusions

- The decays of the D^+ and D_s^+ mesons to $K^+ K^- \pi^+$ proceed via two distinct pathways: one with a psi meson and one with a K*(892) meson.

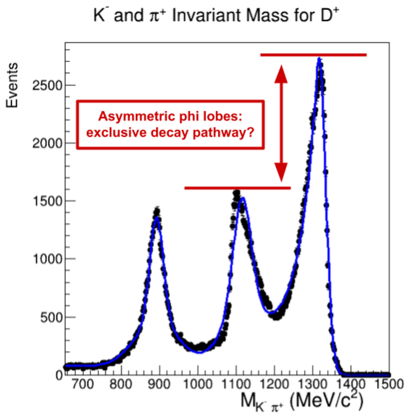


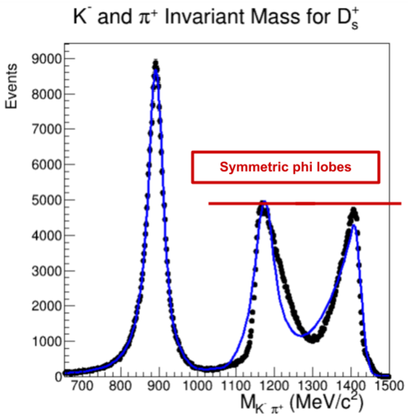


Future steps

- Several other analyses quote the presence of several additional particle resonances so the inclusion of these resonances in my model might improve the fit to data.

- The asymmetric phi lobes in the $K^- \pi^+$ spectrum for the D^+ implies a decay pathway exclusive to the D^+. Further study could reveal the particle that mediates this pathway.





Thank you for your time! Any questions?

Backup Slides

The starring cast

Hadrons

D^+

c $\bar{d}$

Mass: 1869.7 MeV
Charge: +1
Spin: 0

D_s^+

c $\bar{s}$

Mass: 1968.4 MeV
Charge: +1
Spin: 0

π^+

u $\bar{d}$

Mass: 139.6 MeV
Charge: +1
Spin: 0

K^+

u $\bar{s}$

Mass: 493.7 MeV
Charge: +1
Spin: 0

K^-

s $\bar{u}$

Mass: 493.7 MeV
Charge: -1
Spin: 0

$K^*(892)$

s $\bar{d}$

Mass: 895.6 MeV
Charge: 0
Spin: 1

φ

s $\bar{s}$

Mass: 1019.5 MeV
Charge: 0
Spin: 1

Quarks

up

u

Mass: ~2.2 MeV
Charge: +⅔
Spin: ±½

charm

c

Mass: ~1270 MeV
Charge: +⅔
Spin: ±½

down

u

Mass: ~4.7 MeV
Charge: -⅓
Spin: ±½

strange

s

Mass: ~93 MeV
Charge: -⅓
Spin: ±½

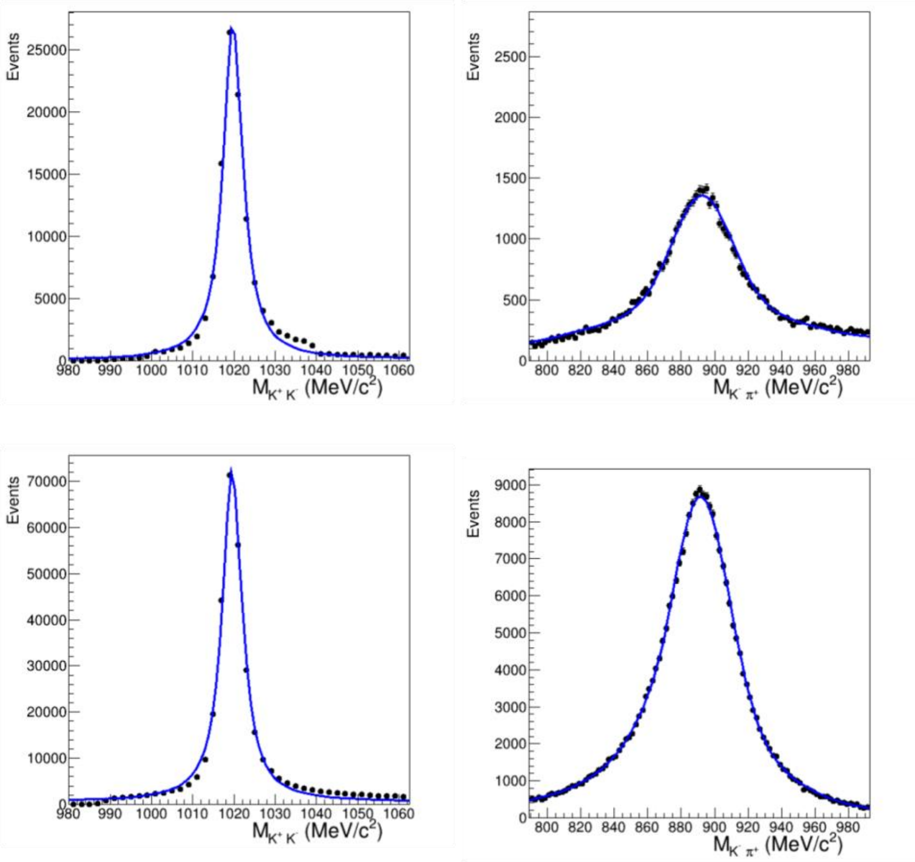
Leftmost peaks

- Similar resonances appear in both the D^+ and D_s^+ spectra.

$K^+ K^-$ $\quad$ $K^- \pi^+$

D^+

D_s^+



Analysis Tools

- ROOT
  - Built on C++
  - A powerful tool used to analyze large datasets
  - Created by CERN, tailored specifically for particle physics applications
    - All histograms in this presentation were created using ROOT

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