Search for ϕ->K^+K^- in HPS data

HPS Collaboration Meeting 2025
Majd Ghrear
June 4, 2025

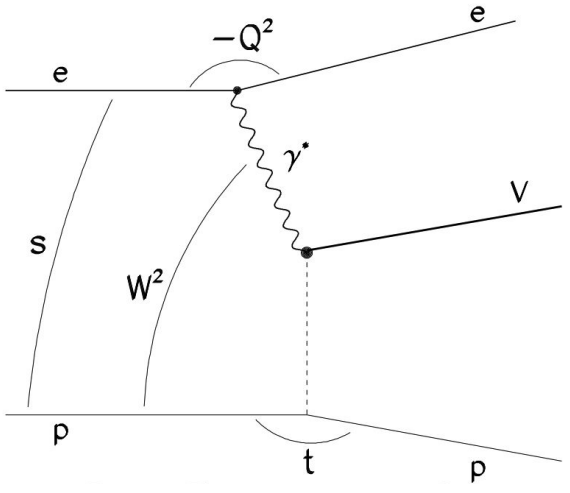
Stanford University
Stanford University

Outline

- $\phi \rightarrow K^+ K^-$
- Previous Work
  - Takashi Maruyama
  - Norman Graf
- Simulation
  - Fluka
  - DIPSI
- Search for Phi -> K+ K- in HPS 2021 data

$\phi \rightarrow K^+ K^-$

- No acceptance for Møller scattering in 2019 data
- Need alternative process for calibrating invariant mass resolution
- Potential process: photoproduction and subsequent decay of ϕ mesons
- $e^- + W \rightarrow e^- + \gamma^* + W \rightarrow e^- + \phi + W$, $\phi \rightarrow K^+ K^-$



$V = \phi \rightarrow K^+ K^-$

Previous Work: Takashi Maruyama (2018)

- Investigated vector meson photoproduction as an alternative to Møller scattering for calibrating invariant mass resolution
- Possible processes:

  $\varrho \rightarrow \pi^+\pi^-$, $\omega \rightarrow \pi^+\pi^-$, $\omega \rightarrow e^+e^-$, $\phi \rightarrow K^+K^-$, $\phi \rightarrow$ KsKL (Ks $\rightarrow \pi^+\pi^-$)
- Used **Fluka** to simulate some events at 4.4 GeV
- Rate estimates suggest $\phi \rightarrow K^+K^-$ is most promising

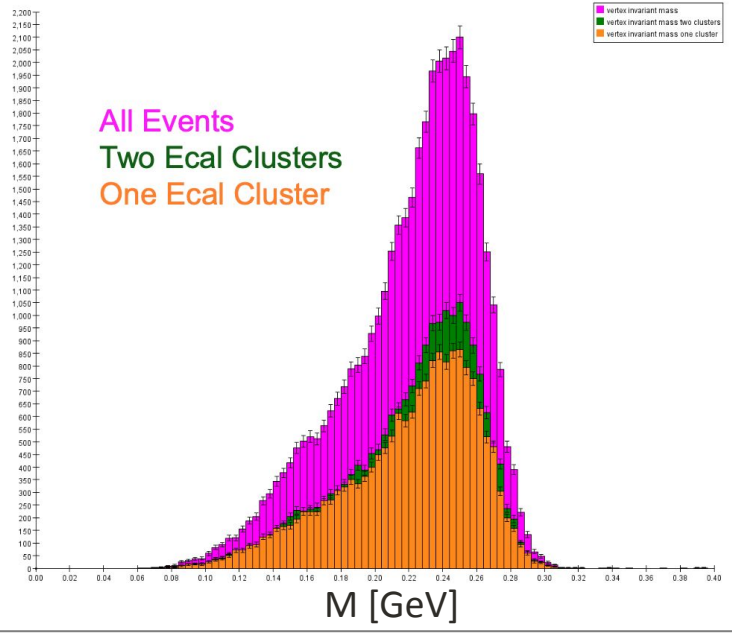
	$\sigma(\gamma p) \cdot BR$	σ(e-W) FLUKA	HPS Acceptance	Trigger Eff. HPS-MC	Rate @ 300 nA
ρ	20 μb	13 mb			
$\omega \rightarrow \pi+\pi-$	5μb · 1.5×10^{-3}	~2 mb	0.7 %	14%	0.3 Hz
$\omega \rightarrow e+e-$	5μb · 7×10^{-5}	~2 mb	0.7 %	100%	0.1
$\phi \rightarrow K+K-$	0.4μb · 0.49	0.13 mb	46 %	14%	420
$\phi \rightarrow$ KsKl	0.4μb · 0.34	0.13 mb	1.2 %	14%	8

This would suggest ~ 5/1000 of the triggers in the 2019 data are $\phi \rightarrow K+K-$

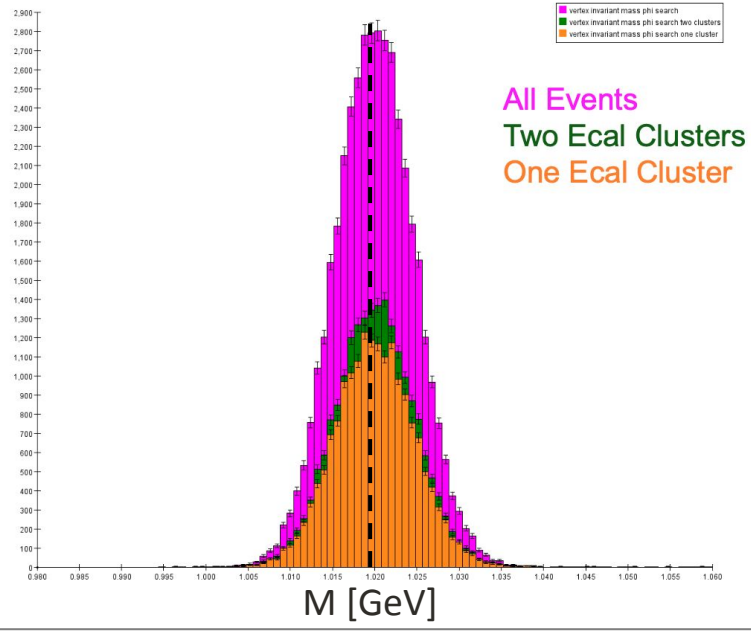
Previous Work: Norman Graf (2019)

- Simulated $\phi \rightarrow K^+ K^-$ at 4.5 GeV (simulations provided by FX Girod)
- Processed events through slic & hps-java
- Plot V0 mass from unconstrained V0Vertices

Electron particle hypothesis

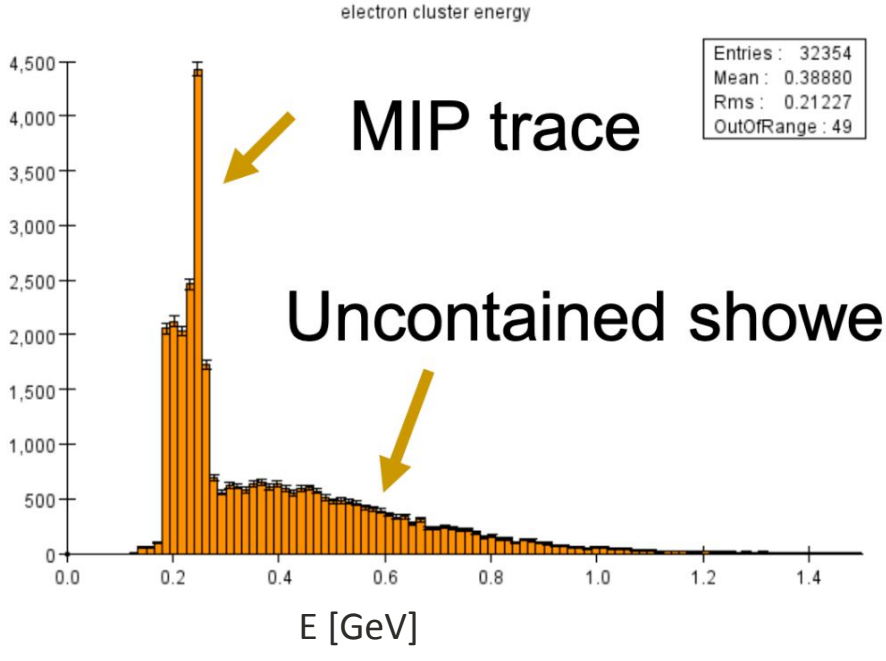


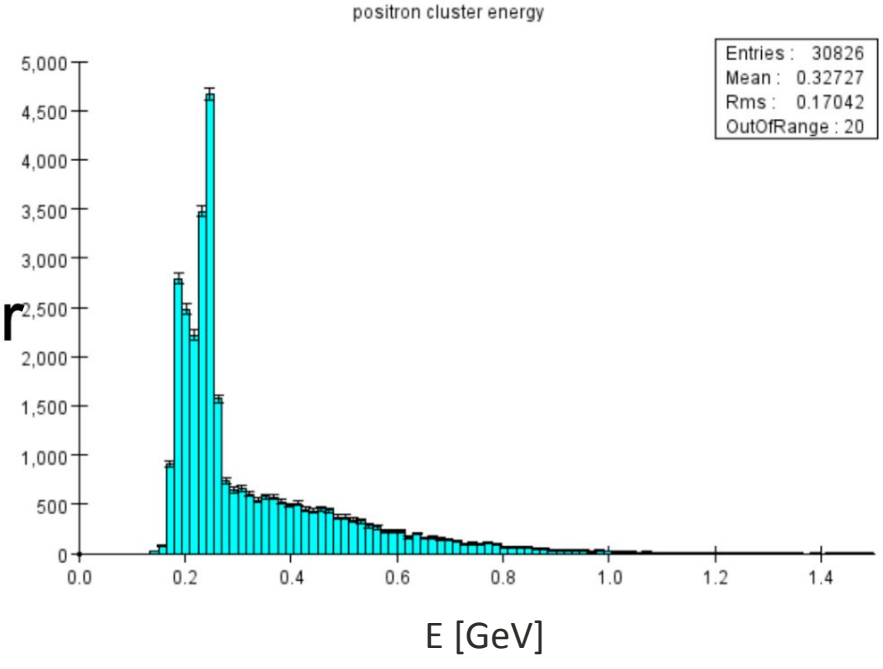
Kaon particle hypothesis



Previous Work: Norman Graf (2019)

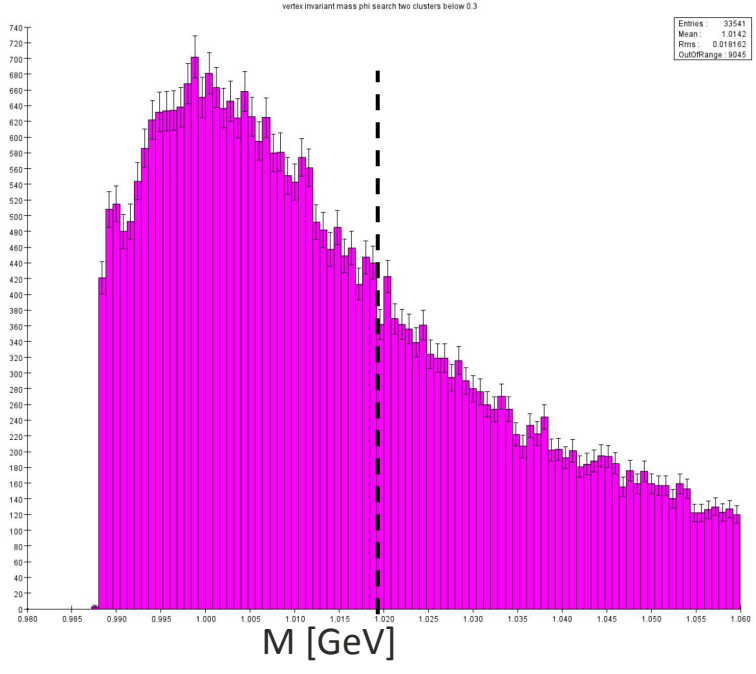
- Checked Ecal performance on simulated K^+ K^-
- As expected, the Ecal does not measure the energy of hadrons well

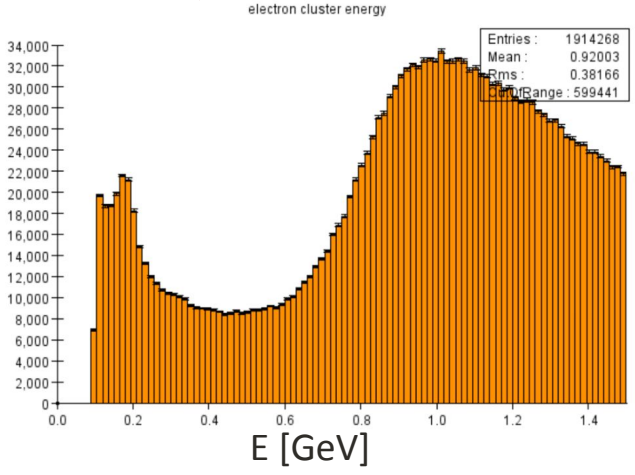


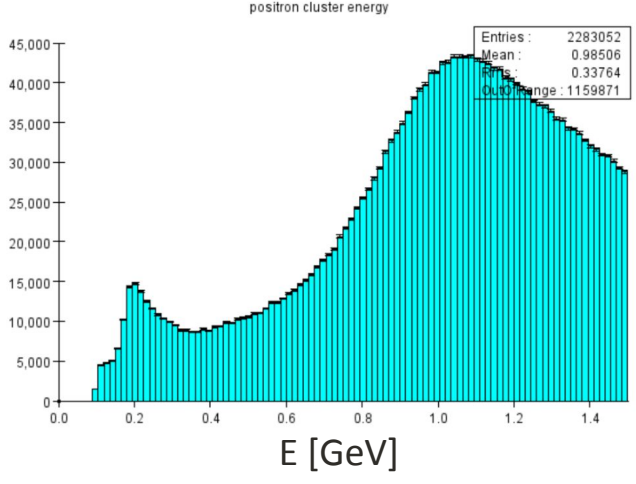


Previous Work: Norman Graf (2019)

- Checked electron & positron cluster energies in data
- Selection for 2 MIP clusters in Ecal

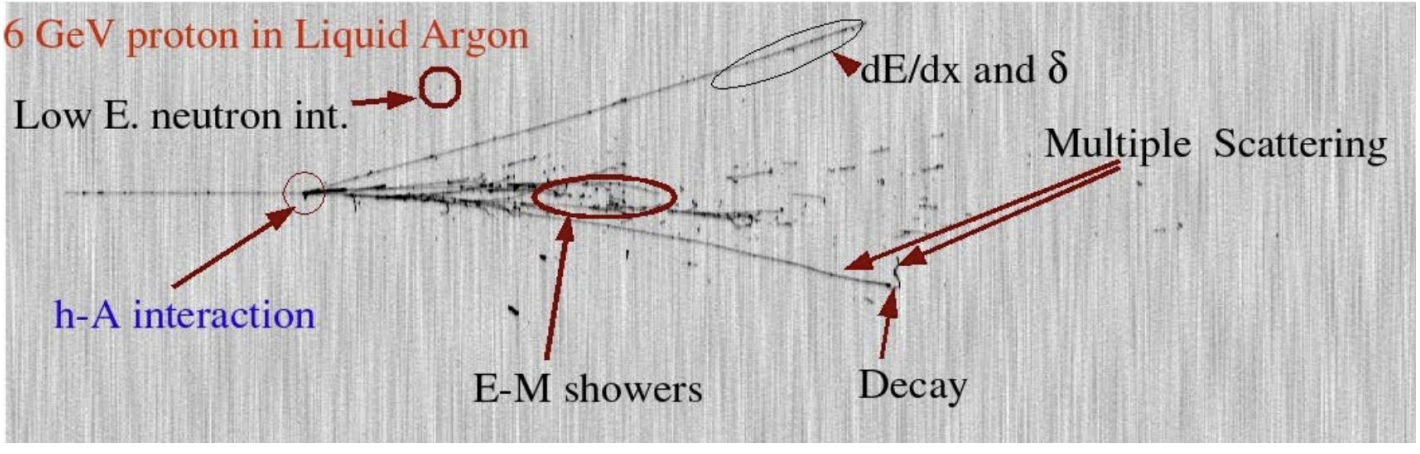






Simulation: Fluka

- Fully integrated Monte Carlo simulation package for simulating particle interactions and transport
  - hadron-hadron and hadron-nucleus interactions, nucleus-nucleus interactions, **photon interactions (>100 eV)**, **electron interactions (> 1 keV; including electronuclear)**, muon interactions (including photonuclear), neutrino interactions, low energy (<20 MeV) neutron interactions and transport, **particle decay**, ionization and multiple (single) scattering (including all ions down to 250 eV/u)
- Considers photoproduction of vector mesons, but does not transport them, decay immediately upon production (see here)



Simulation: Fluka Input Card

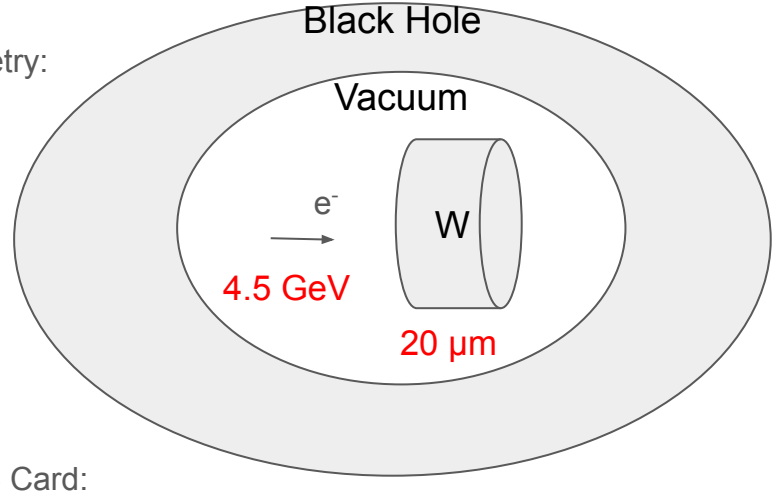
```
TITLE

*Set the defaults for precision simulations
DEFAULTS                                                        PRECISIO
*Define the beam characteristics
BEAM            4.5                                             ELECTRON
*Define the beam position
BEAMPOS
GEOBEGIN                                                        COMBNAME
    0    0
*Black body
SPH blkbody    0.0 0.0 0.0 100000.0
*Void sphere
SPH void       0 0 0 10000.0
*Cylindrical target
RCC target     0 0 0 0 0 0.002 5.0
END
*Black hole
BLKBODY      5 +blkbody -void
*Void around
VOID         5 +void -target
*Target
TARGET       5 +target
END
GEOEND
*..+....1....+....2....+....3....+....4....+....5....+....6....+....7..
ASSIGNMA    BLCKHOLE   BLKBODY
ASSIGNMA      VACUUM      VOID
ASSIGNMA    TUNGSTEN    TARGET
PHOTONUC           2       0.0       0.0    VACUUM  TUNGSTEN       1.0
LAM-BIAS         0.0 0.0000005               PHOTON       RAY       0.0
USRBIN            10   KAONS+-       -21      0.01      0.01     0.02AllPart
USRBIN         -0.01     -0.01        0.       800       800       800 &
*Set the random number seed
RANDOMIZ         1.0
*Set the number of primary histories to be simulated in the run
START        2000000
STOP

```

Define beam:
4.5 GeV electron beam in the z-direction starting at z = -10cm

Define geometry:



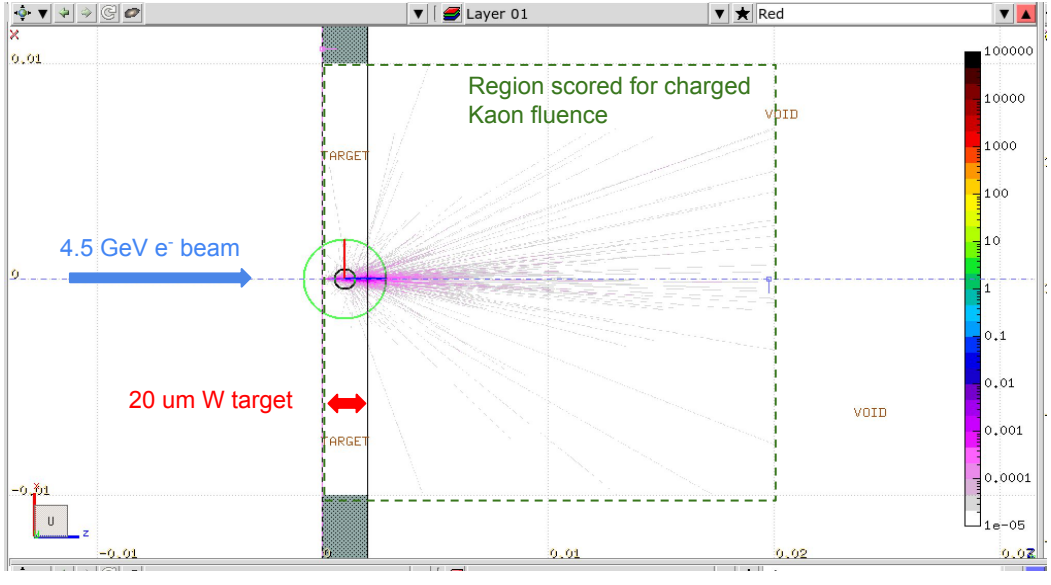
PHOTONUC Card:
Activates gamma, electron, and positron interactions with nuclei real and virtual photonuclear interactions (fluka interaction models)

Simulation: Fluka Input Card

```
PHOTONUC           2       0.0       0.0    VACUUM  TUNGSTEN       1.0
LAM-BIAS         0.0 0.0000005              PHOTON       RAY       0.0
USRBIN            10   KAONS+-       -21      0.01      0.01     0.02AllPart
USRBIN         -0.01     -0.01        0.       800       800       800 &
*Set the random number seed
RANDOMIZ         1.0
*Set the number of primary histories to be simulated in the run
START        2000000
STOP
```

LAM-BIAS Card:
Photon hadronic interaction length is shortened

Scoring Card:
Bin Kaon+- tracks throughout the run



Simulation: Fluka Advanced Scoring

- Want coordinates and 4-Momenta of Kaons to pass on to SLIC
- Standard FLUKA cards provide quantities collected along entire run
- By modifying the source code (MGDRAW.f) users can dump information of interest
- With no similar examples to copy, gearing up for deep dive into
  - Fortran primer
  - Fluka advanced user workshop https://indico.cern.ch/event/1200922/timetable/#20230605

Simulation: DIPSI

- https://arxiv.org/pdf/hep-ph/9610286
- Monte Carlo generator for exclusive vector meson production in charged lepton-proton interactions
- Based on a QCD leading logarithm model calculation
- Generator for both fixed target and collider

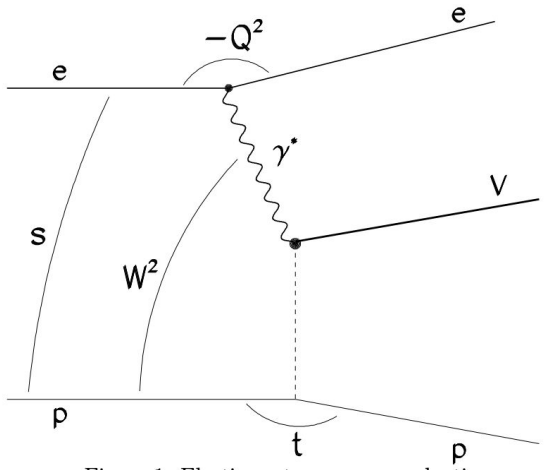


Figure 1: Elastic vector meson production.

DIPSI generates events according to reaction (1) in which V can be,

- $\rho^0 \to \pi^+\pi^-$,
- $\omega \to \pi^+\pi^-\pi^0$ or $\pi^+\pi^-$,
- $\phi \to K^+K^-$, $K^0_L K^0_S$ or $\pi^+\pi^-\pi^0$,
- $\rho(1450) \to \pi^+\pi^-$, $\pi^+\pi^-\rho^0$ or $\pi^0\pi^0\rho^0$,
- $\rho(1700) \to \pi^+\pi^-$, $\pi^+\pi^-\rho^0$ or $\pi^0\pi^0\rho^0$,
- $J/\psi \to e^+e^-$, $\mu^+\mu^-$ or $\pi^+\pi^-\pi^0$,
- $\psi'(3600) \to e^+e^-$, $\mu^+\mu^-$, $\pi^+\pi^- J/\psi$ or $\pi^0\pi^0 J/\psi$,
- $\Upsilon \to e^+e^-$, $\mu^+\mu^-$ or $\pi^+\pi^-\pi^0$.

3.3 Implementation and usage

DIPSI is written in standard FORTRAN 77 and uses the PATCHY offline editor [29] to allow easier modifications. All routines are contained in a PAMfile; a short "cradle" program contains the list of the routines that the user wants to include and the modifications to the code, if any, that need to be applied. By running PATCHY on the PAMfile a FORTRAN program is produced.

The CERN libraries PACKLIB and KERNLIB [30] are necessary; extensive use is made of the format free reading package FFREAD [31] and of the histogramming package HBOOK [32] (which is a part of PACKLIB). The parton distribution package PDFLIB [33] may be needed (cf. appendix B.1).

Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

- 0.5% of the 2021 dataset
- latest v7 alignment, unskimmed
- Apply Sarah Gaiser's preselections with minor change

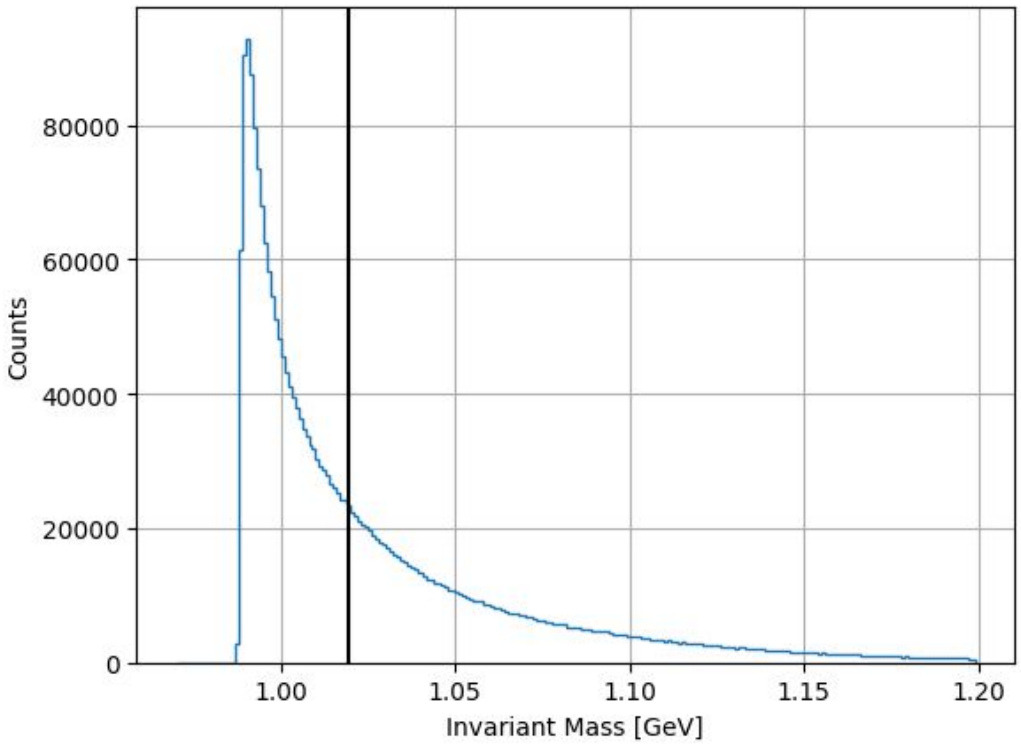
cut	skimming	preselection
$E_{e^+,\mathrm{clu}}$	–	> 0.2 GeV
$N_{\mathrm{2D\ hits}}$	≥ 9	≥ 9
χ^2_{vtx}	< 30.0	< 20.0
p_{sum}	< 4.5 GeV	< 4.0 GeV
p_{e^-}	< 4.5 GeV	< 2.9 GeV
	–	> 0.4 GeV
p_{e^+}	< 4.5 GeV	–
	–	> 0.4 GeV
$\Delta(t_{\mathrm{trk},e^-}, t_{\mathrm{trk},e^+})$	< 20.0 ns	–
$\Delta(t_{\mathrm{trk},e^-}, t_{\mathrm{clu},e^+})$	–	< 6.9 ns
$\Delta(t_{\mathrm{trk},e^+}, t_{\mathrm{clu},e^+})$	–	< 6.0 ns
$\chi^2_{\mathrm{trk},e^-}$	< 80.0	–
$\chi^2_{\mathrm{trk},e^+}$	< 80.0	–
$\chi^2_{\mathrm{trk},e^-}/\mathrm{ndf}$	–	< 20.0
$\chi^2_{\mathrm{trk},e^+}/\mathrm{ndf}$	–	< 20.0

Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

Invariant mass distribution before any selections

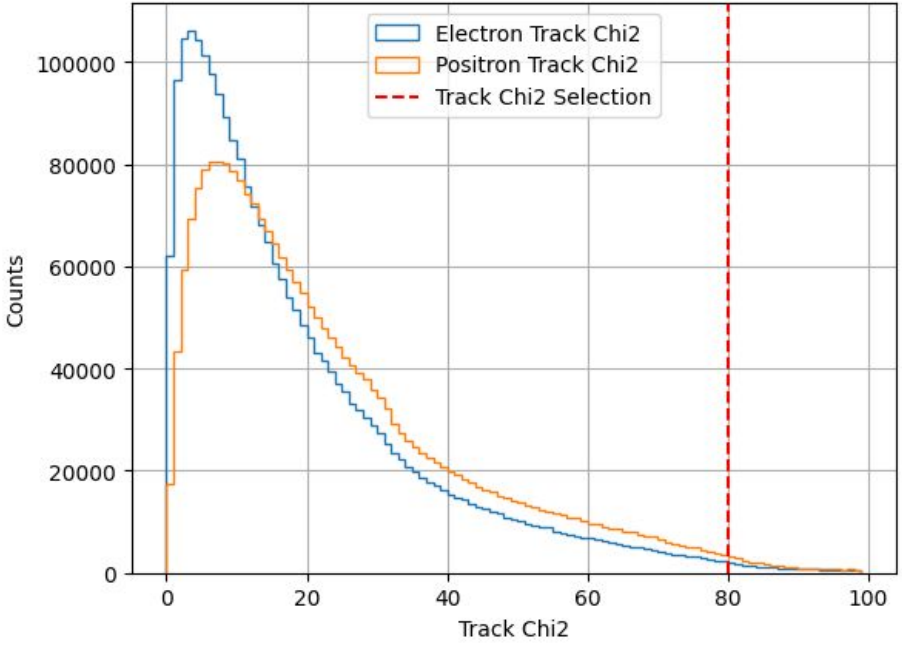
- K+ K- are not well-measured by Ecal
- Energy must be inferred from SVT momentum measurement + mass hypothesis

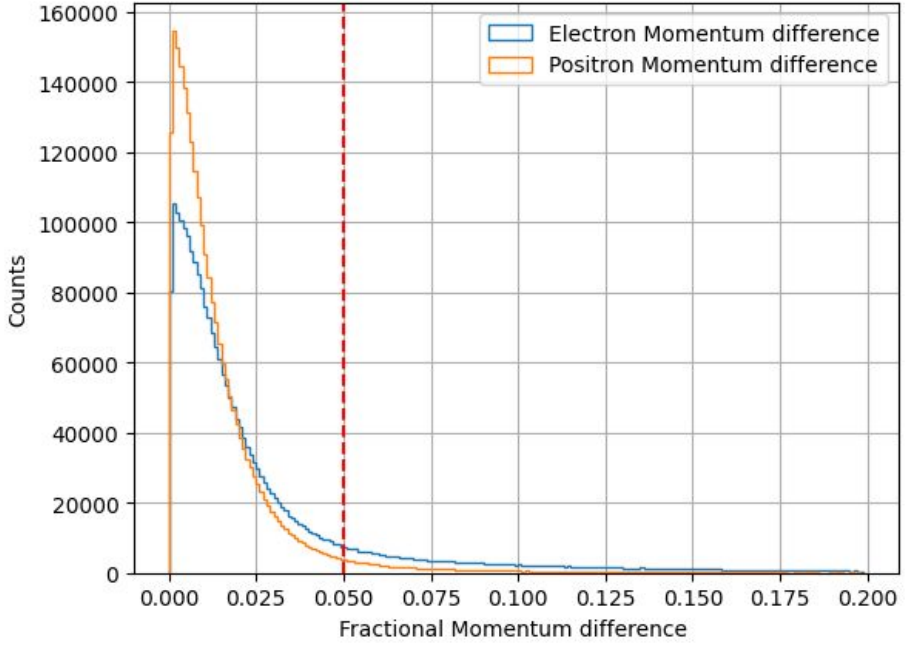
$$E_{SVT} = \frac{m_K}{\sqrt{1 - \frac{P^2}{m_K^2 + P^2}}}$$



Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

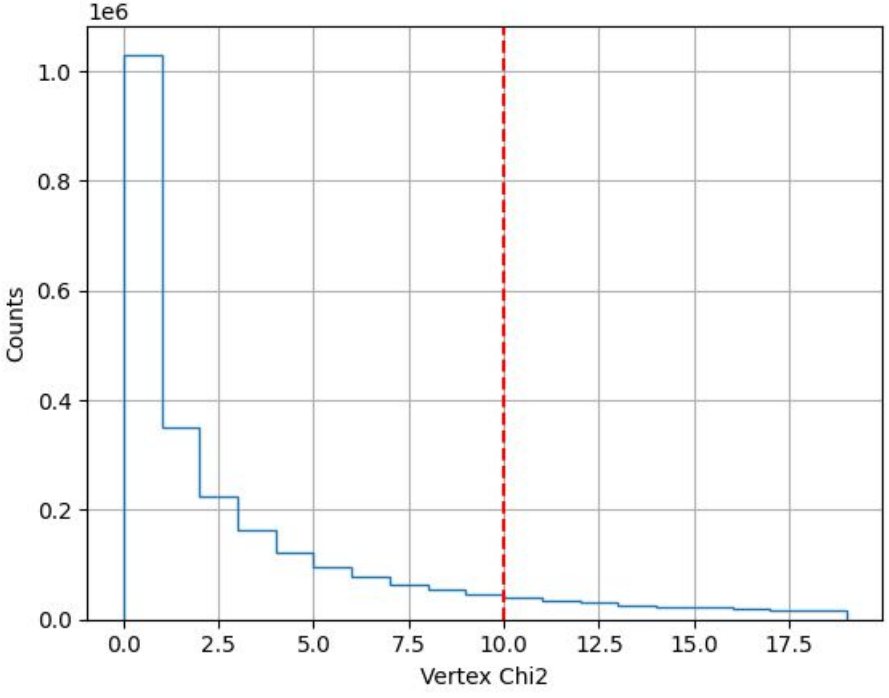
Some “cleaning” selections

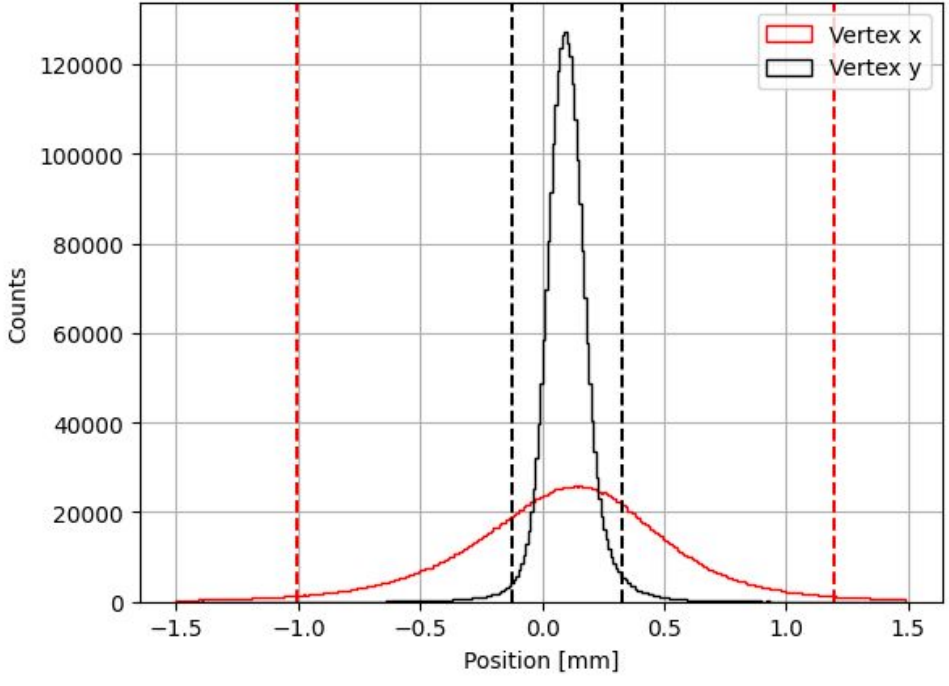




Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

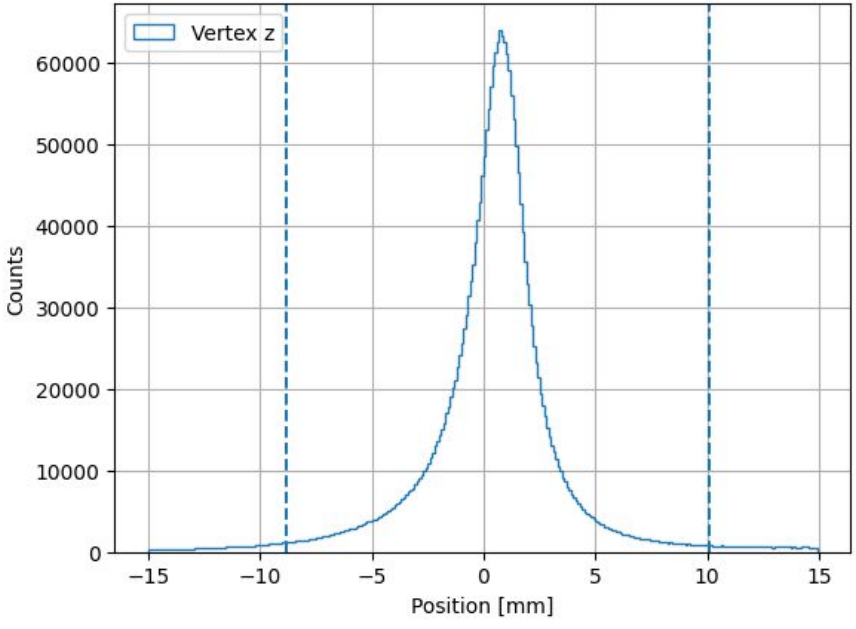
Some “cleaning” selections

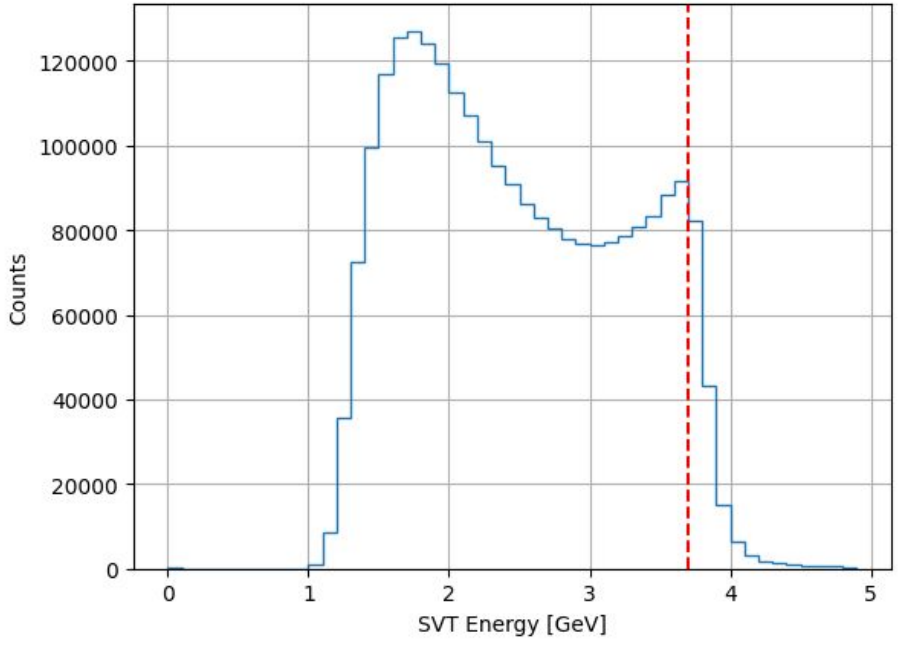




Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

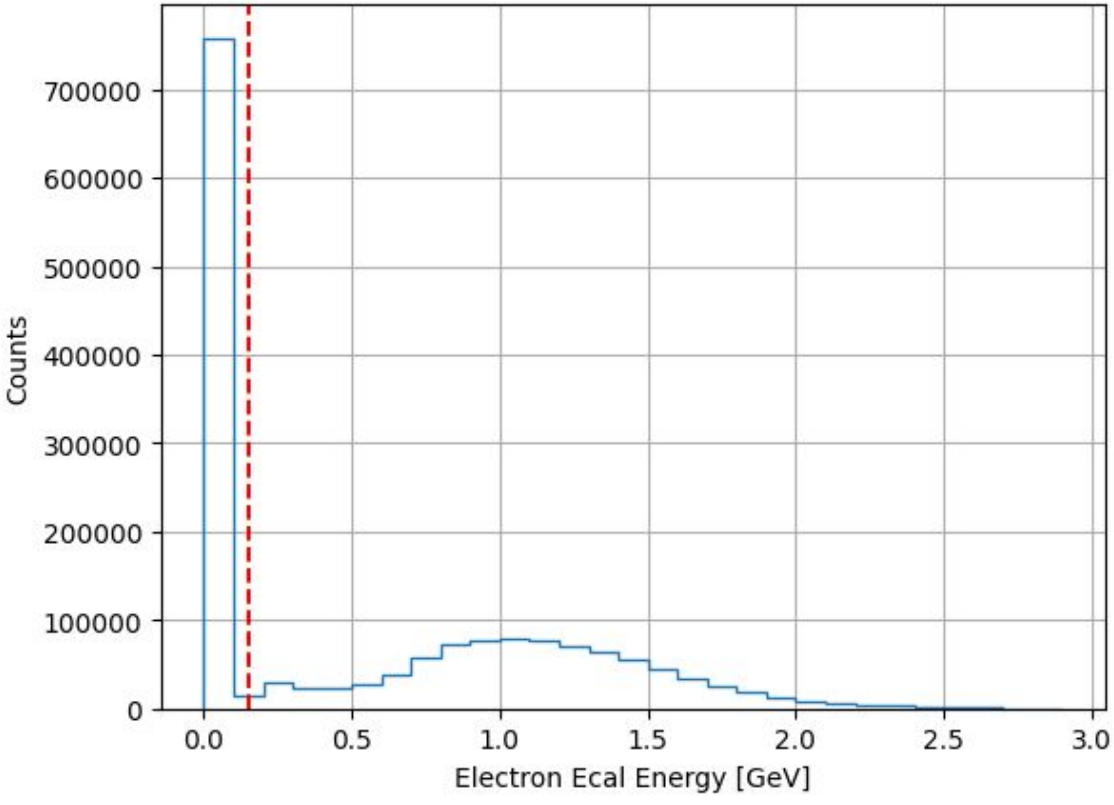
Some “cleaning” selections





Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

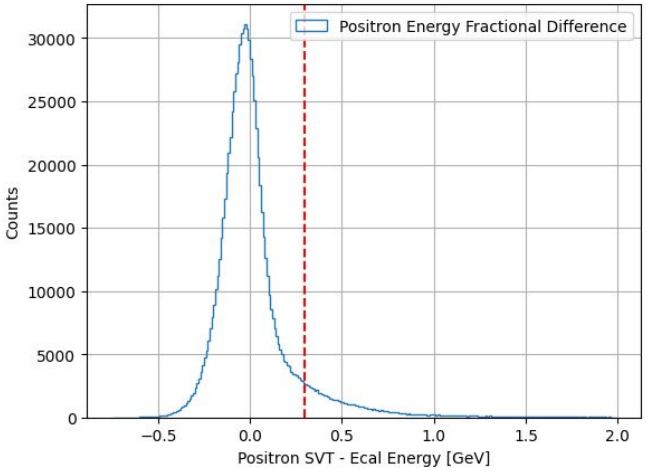
Selection 6: Electron ECal energy must be > 0.15 GeV

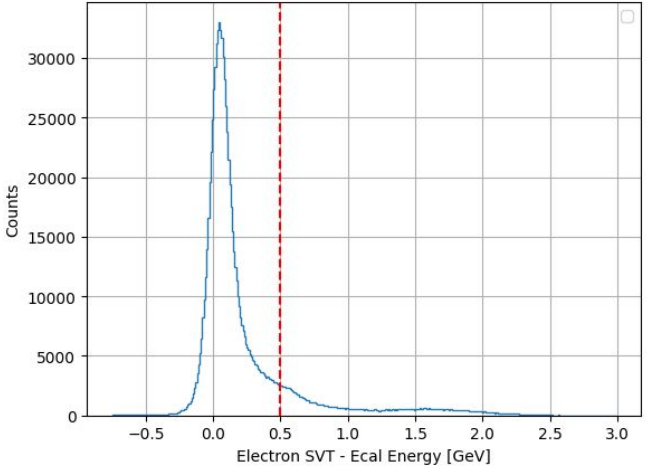


Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

Selection 7: electron/positron consistency veto

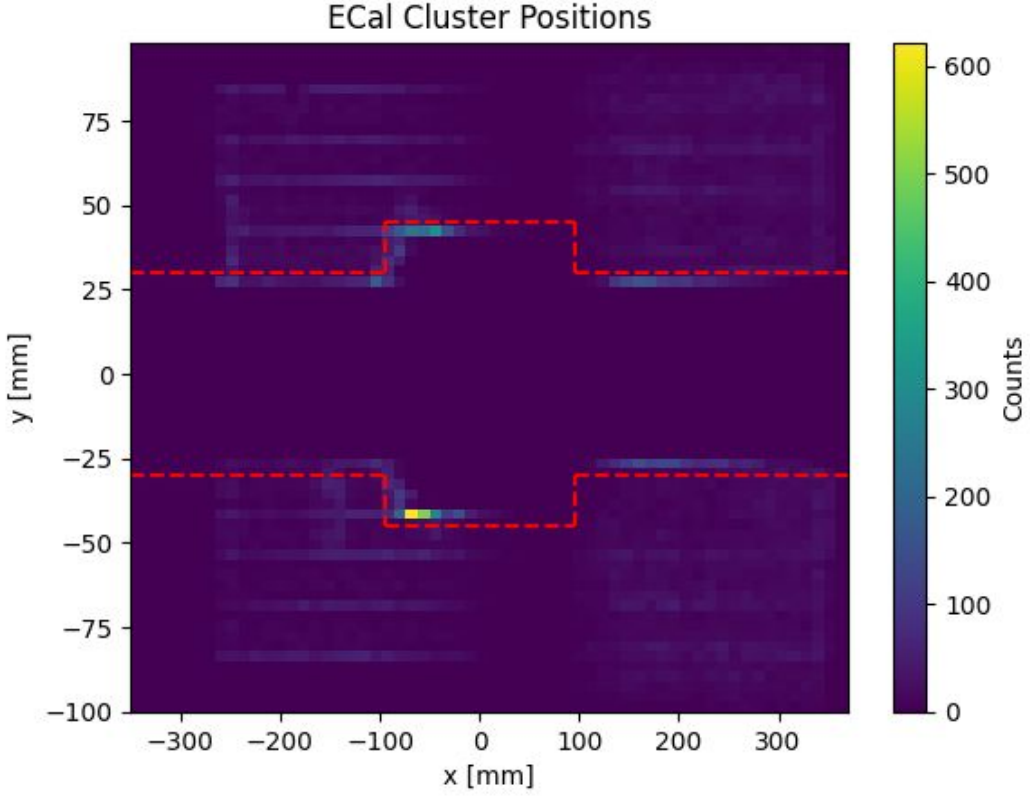
- Two ways to measure energy:
  - Ecal
  - Momentum (SVT) + mass hypothesis
- Using the electron mass hypothesis calculate energy (E_{SVT})
- Check $E_{SVT} - E_{Ecal}$
  - for electrons we expect $E_{SVT} - E_{Ecal} = 0$
  - for $K^+ K^-$ expect $E_{SVT} - E_{Ecal} > 0$





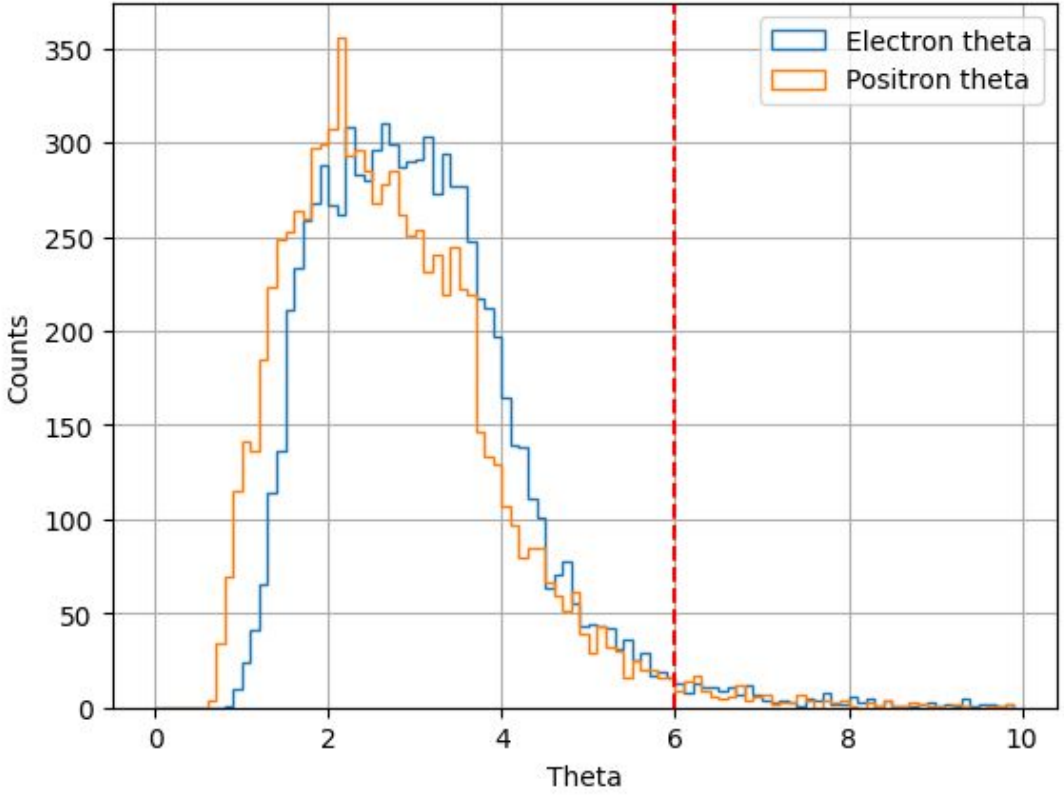
Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

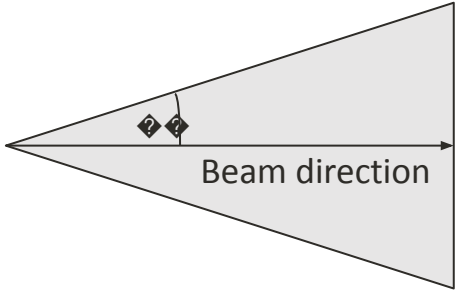
Selection 8: ECAL edge hit removal



Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

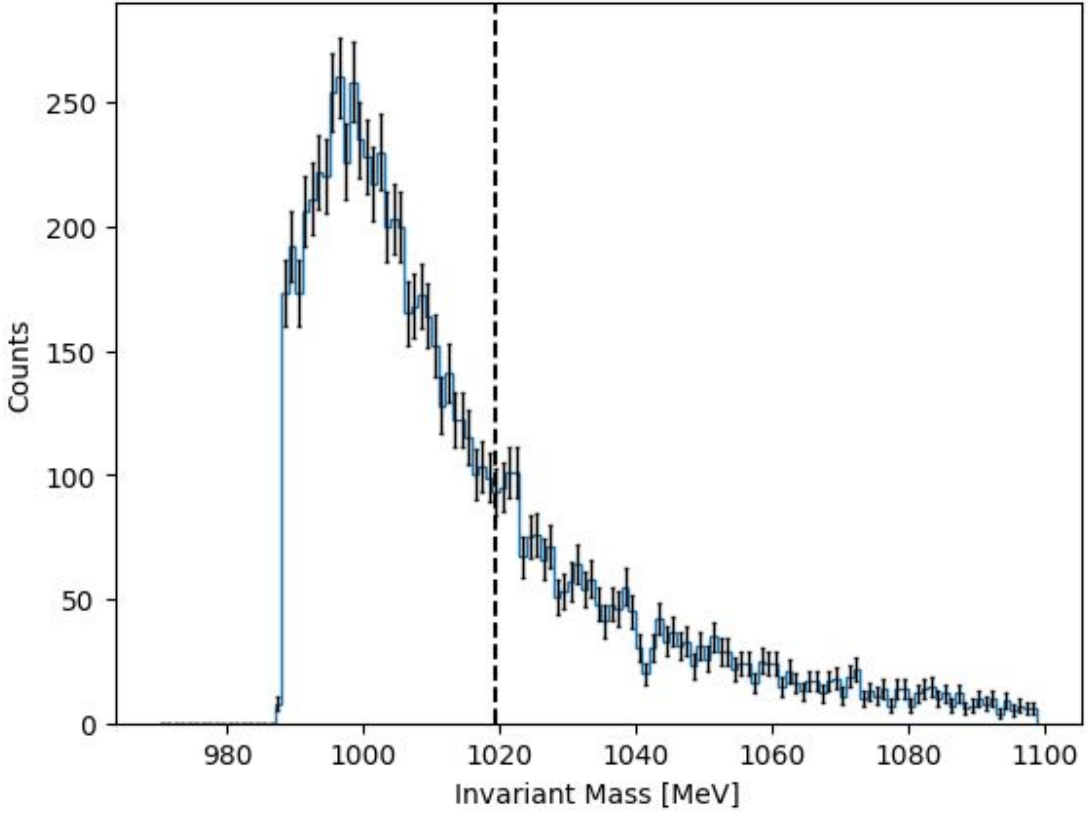
Selection 9: Remove electrons / positrons with large theta





Search for $\phi \rightarrow K^+ K^-$ in 2021 HPS data

Final invariant mass distribution



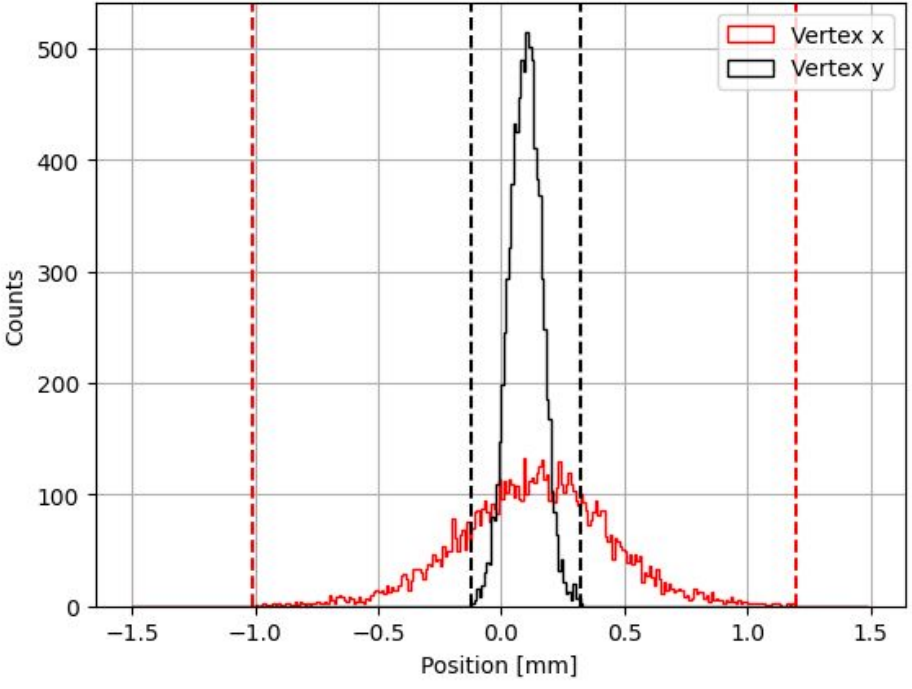
The invariant mass resolution in the 2021 data v7 detector ~ 3 MeV

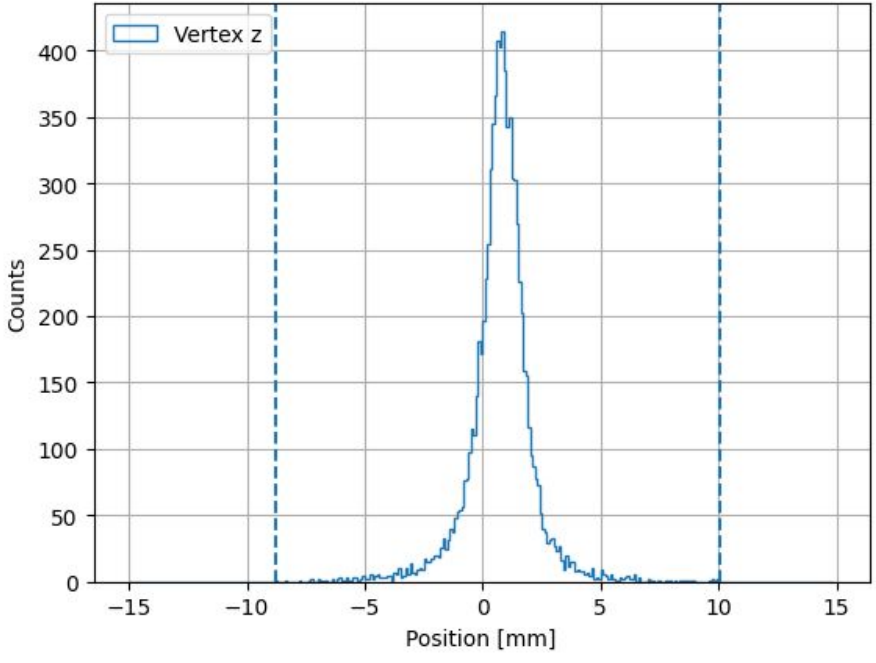
Moving Forward

- Simulation
  - Fluka
    - Fortran primer + deep dive into fluka advanced course
  - DIPSI
  - Norman's .lhe files
    - Could be used to inform selections for 2019 data
- Search in HPS data
  - Improve selections
  - 2019 data

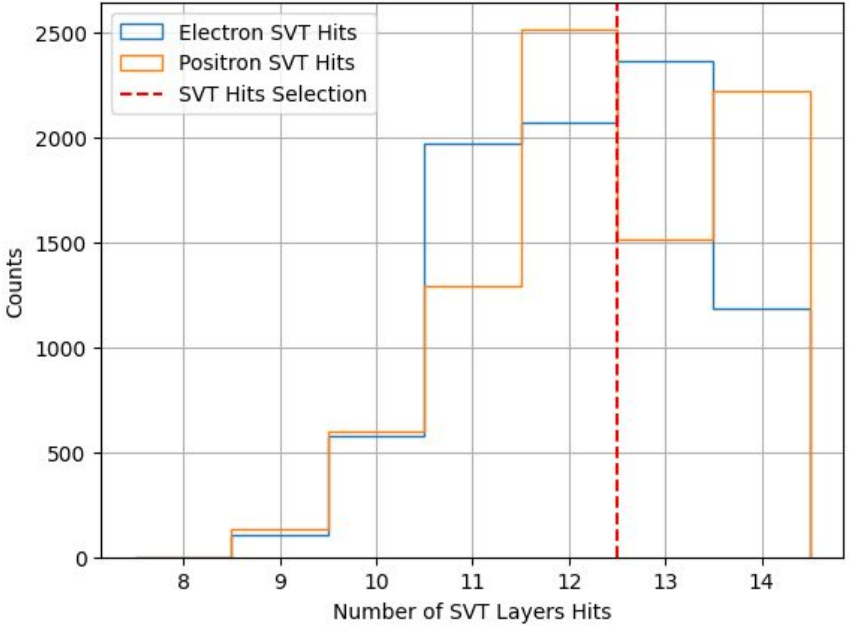
Thank You

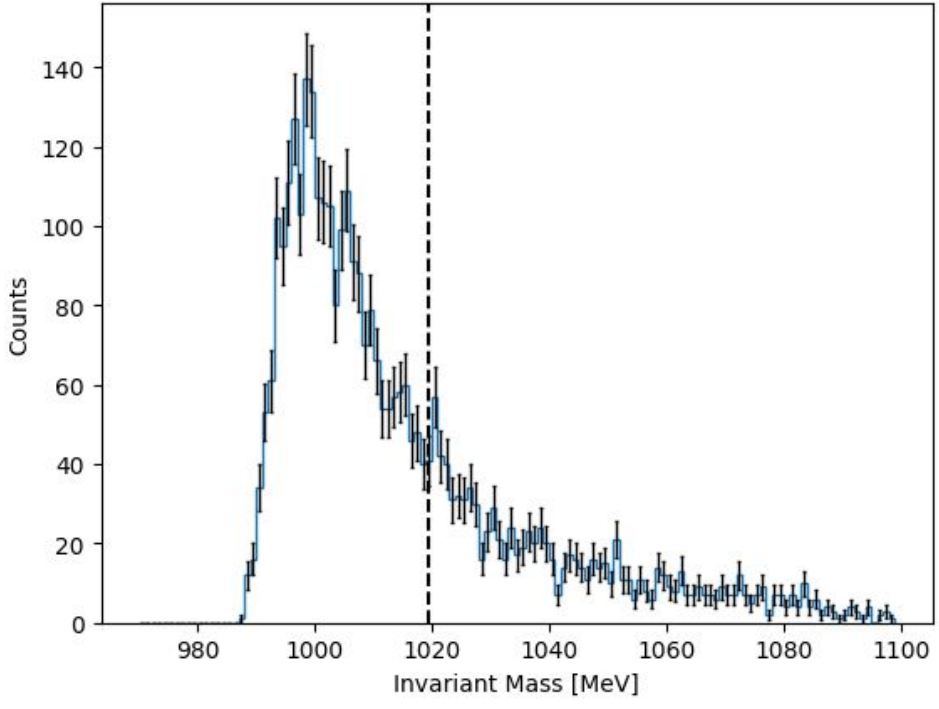
Vertex position after selections



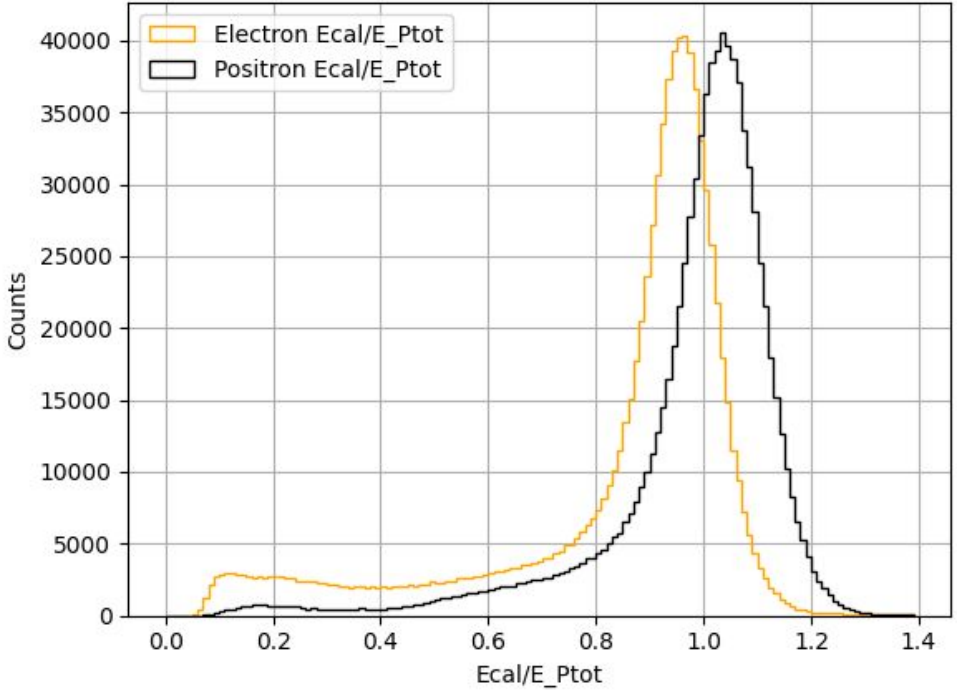


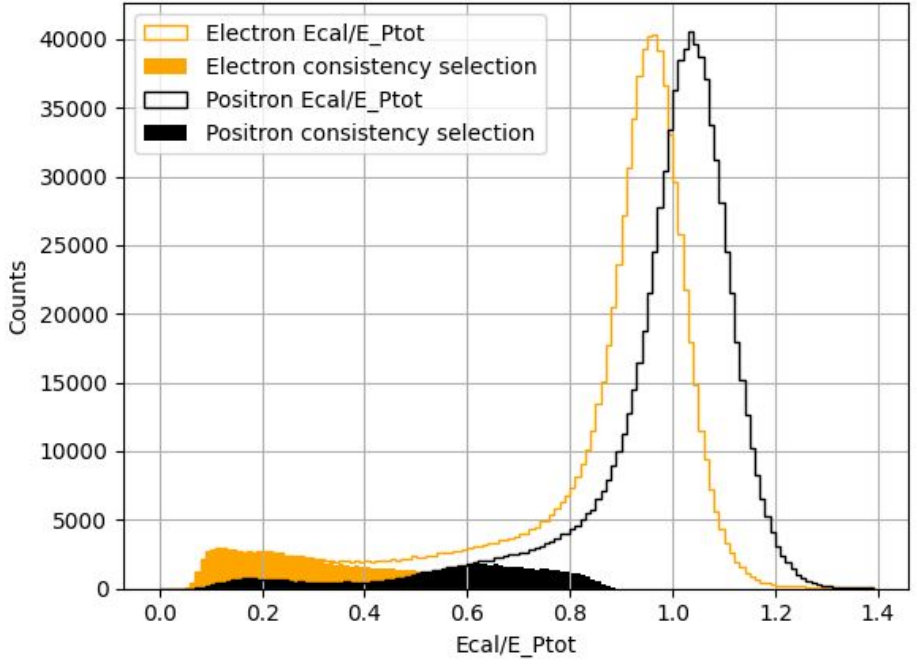
Additional selection on # of SVT layers hit





What about E/P?





What about E/P?