Simulation and Reconstruction of $K_L + p \rightarrow K_s + p$ and $K_L + p \rightarrow K^+ + n$ using GlueX tracker and KLF software.

Vitaly Baturin, ODU, 08/29/2024

Outlook

1. Simulated Detector performance: examples dE/dx vs momentum etc.
2. Reconstruction of K_L+p and K^++n final states

   $K_L + p \rightarrow K_s + p$ at **low /high** beam momenta

   $K_L + p \rightarrow K^+ + n$ at **low/high** beam momenta
3. Background from other halls.
4. Conclusion

Identification of final particles. $K_L + p \to K_s + p$ and $K_L + p \to K^+ + n$

Hadronic decays, lifetimes, and detector dimensions.

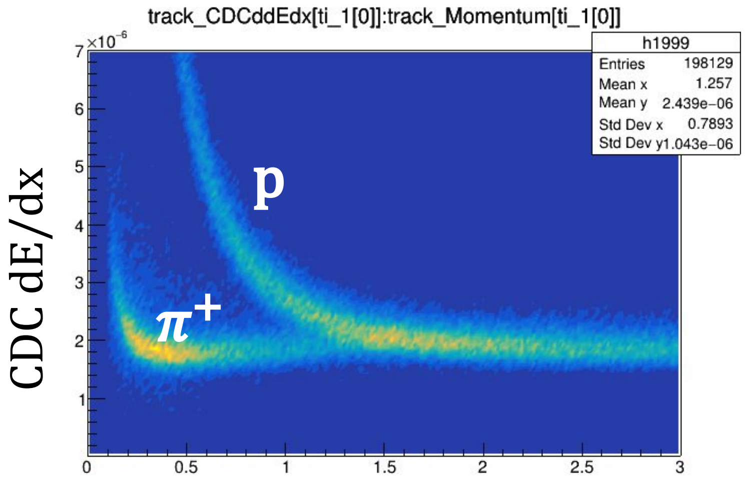
$K_s \to \pi^+ \pi^-$ **69.2 %** $c\tau$ = 2.9 cm => **decays mostly inside LH2** target and close to it.
$\to \pi^0 \pi^0$ 30.7 %

$K^+ \to \pi^+ \pi^+ \pi^-$ 5.6 % $c\tau$ =371.2 cm =>**K^+ almost "stable"** within the LH2 Target and CDC.
$\to \pi^+ \pi^0$ 20.7 %

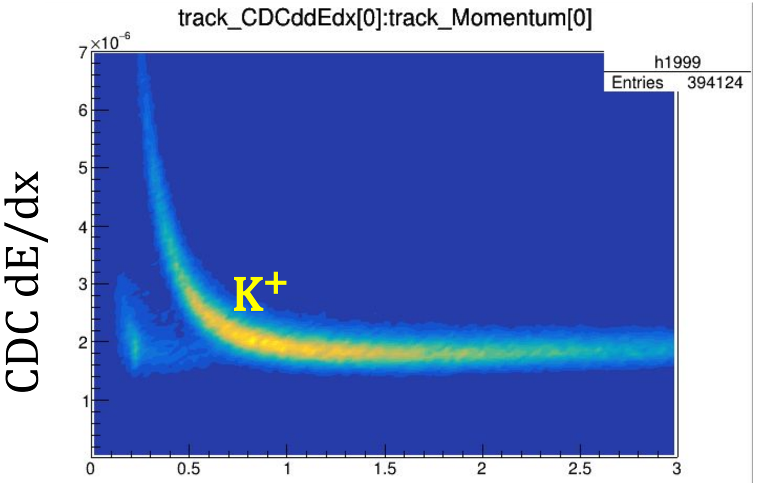
- K_s +p reconstruction: via $\pi^+\pi^-$ tracks; **EM($\pi^+\pi^-$)** for K_s and **MM($\pi^+\pi^-$)** for proton.
- K^++n reconstruction: via K^+-track and **MM(K^+)** for neutron.
- Using dE/dx in CDC.

Example. dE/dx in CDC of Gluex Detector .vs. particle momentum for

$K_L + p \rightarrow K_s + p$ and $K_L + p \rightarrow K^+ + n$



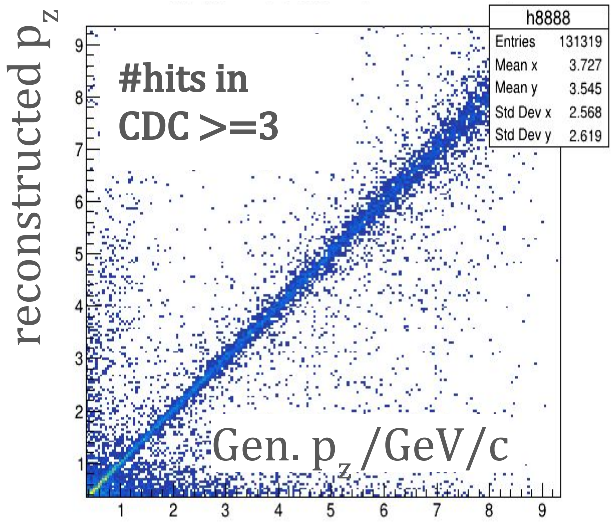
Rec. Track momentum, GeV/c

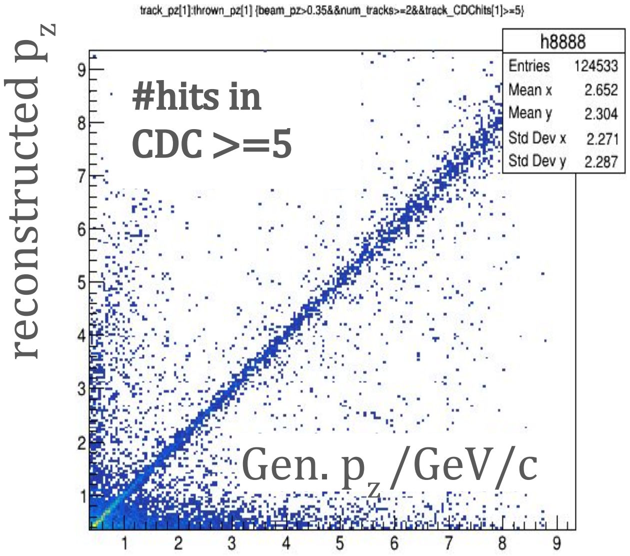


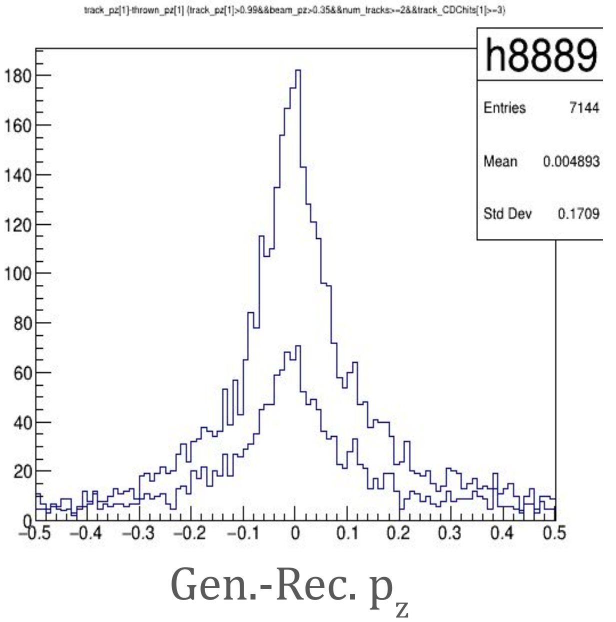
Rec. Track momentum, GeV/c

- Good separation of pions below ~1.4 GeV/c and ~0.7 GeV/c for K^+.

Example. Generated .vs. Reconstructed momenta in $K_L + p \rightarrow K_s(\pi^+\pi^-) + p$.

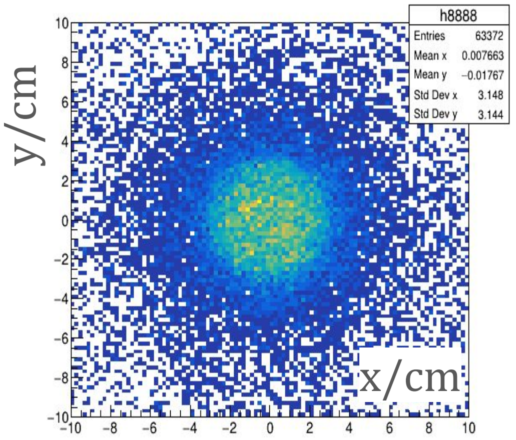


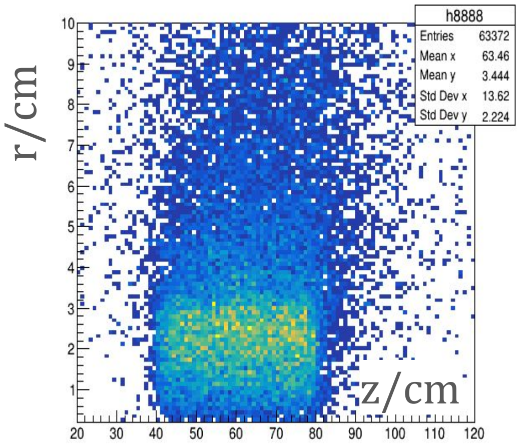


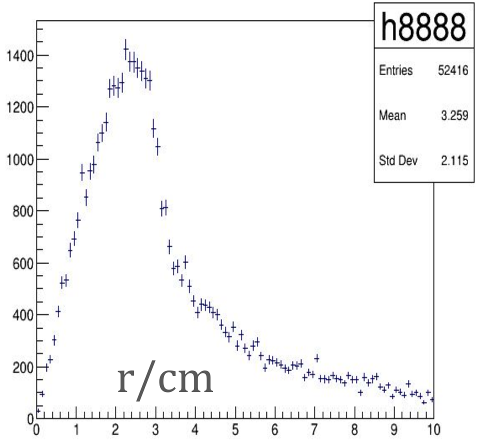


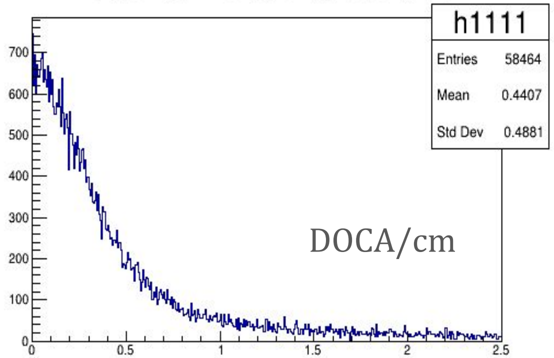
- Good reconstruction at all generated momenta.

Example. Reconstruction of $\boldsymbol{\pi^+\pi^-}$ vertex for $K_L + p \rightarrow K_s(\pi^+\pi^-) + p$.



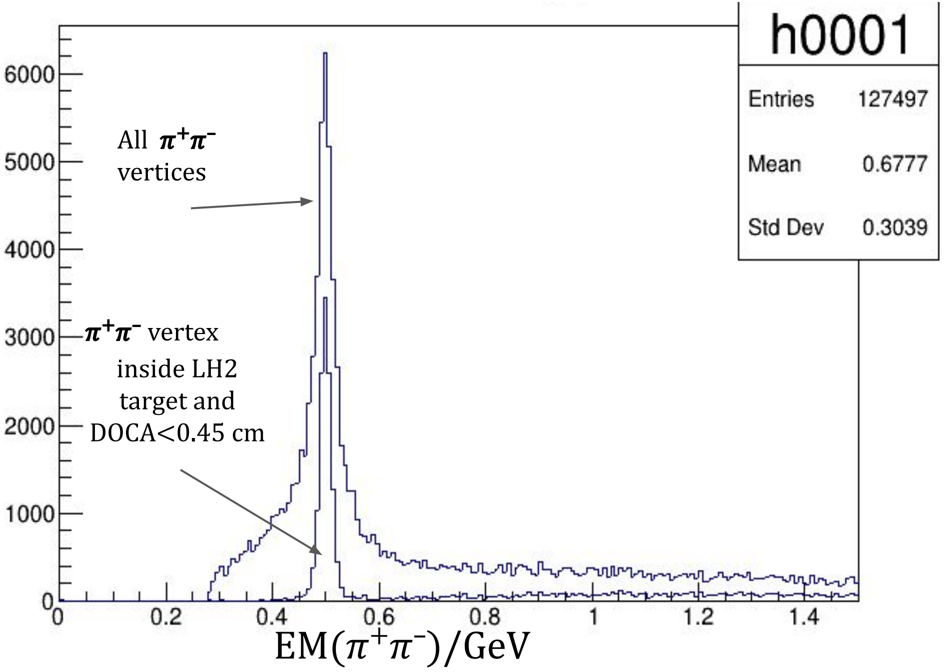


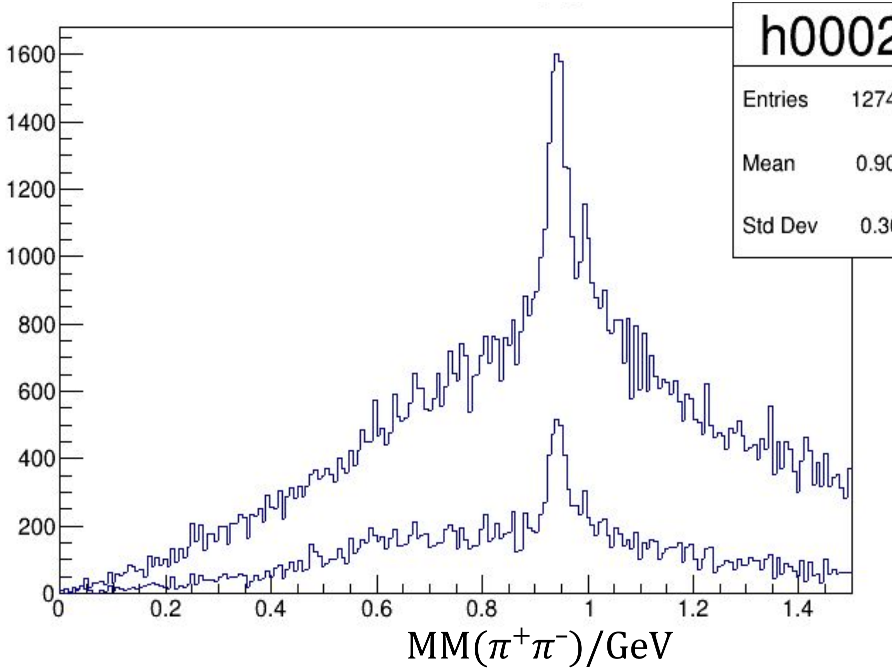




- LH2 target sized in cm as $r \times z = 3$ cm $\times 40$ cm.
- LH2 target is well reproduced by the $\pi^+\pi^-$ vertex coordinates.
- Diffuse area around r=3 cm is of 1 cm (=>sigma ~0.25 cm).
- Long exponential r-tail is due to K_s lifetime ($c\tau$=2.9 cm)

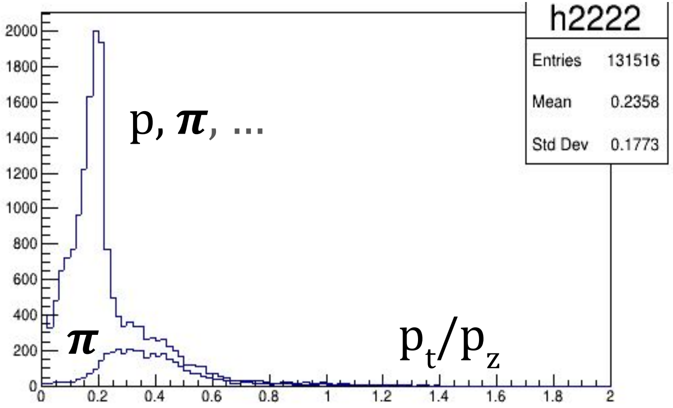
Example. Reconstruction of $\pi^+\pi^-$ vertex in $K_L + p \rightarrow K_s(\pi^+\pi^-) + p$. MM($\pi^+\pi^-$) and EM($\pi^+\pi^-$) inside LH2 target.

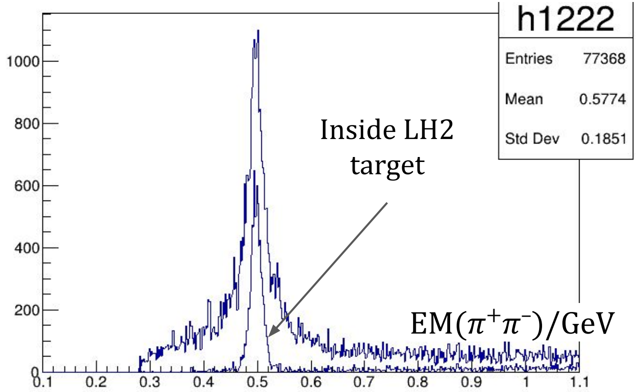


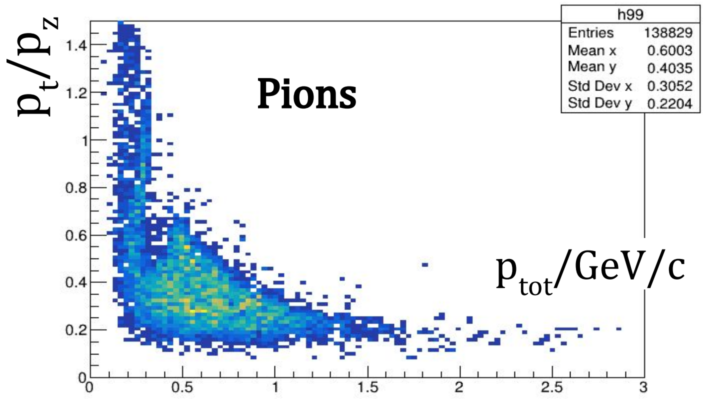


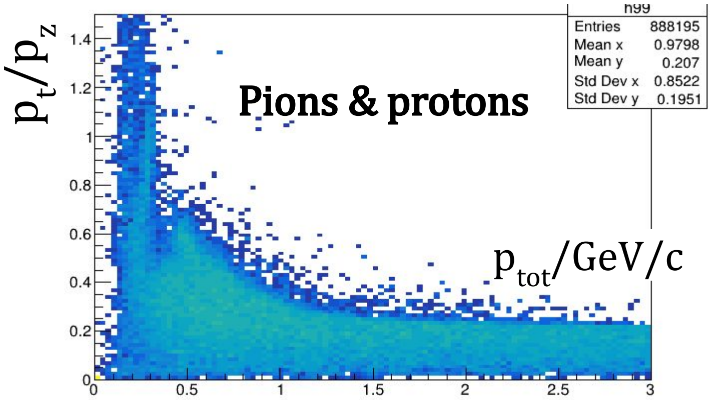
- EM($\pi^+\pi^-$) resolution is obviously better inside the LH2 target while the background is significantly lower.

Example. Angular distribution of π^+, π^- , and p. $K_L + p \rightarrow K_s(\pi^+\pi^-) + p$.







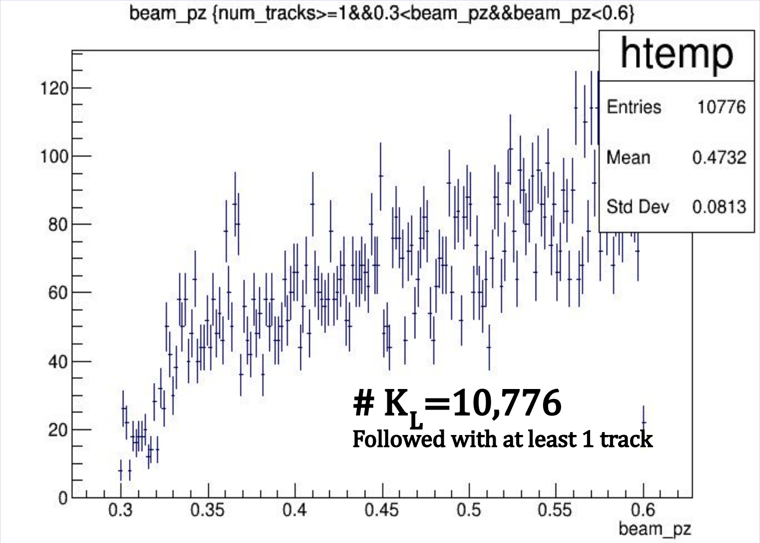


Reconstruction of $K_L + p \to K_s(\pi^+\pi^-) + p$ at K_L momentum (0.3,0.6) GeV/c.

Effect of $\pi^+\pi^-$ vertex.

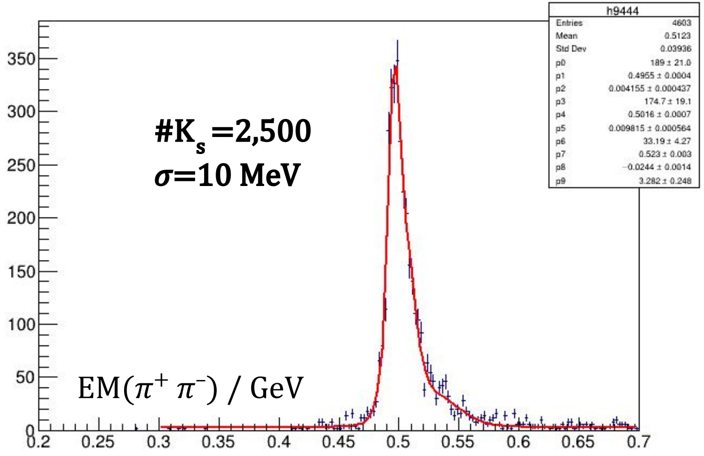
Hadronic decays and lifetimes

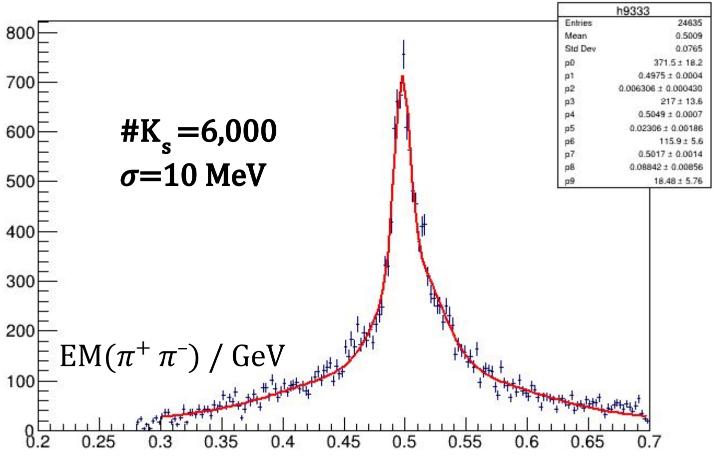
$K_s \to \pi^+\pi^-$	69.2 %	$c\tau$ = 2.9 cm
$\to \pi^0\pi^0$	30.7 %	



Effect of vertex on $K_s(\pi^+\pi^-)$ reconstruction in $K_L + p \rightarrow K_s(\pi^+\pi^-) + p$ at K_L momentum (0.3,0.6) GeV/c.

Inside LH2 target **r<3 cm**, **DOCA<0.45 cm**

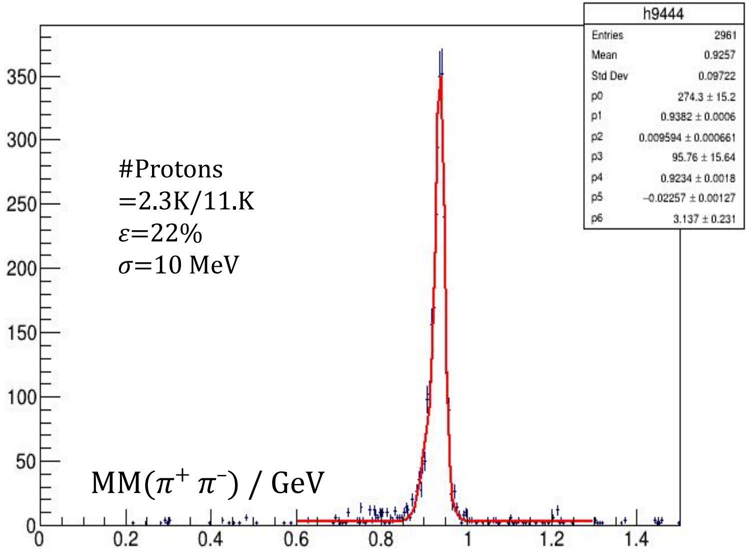




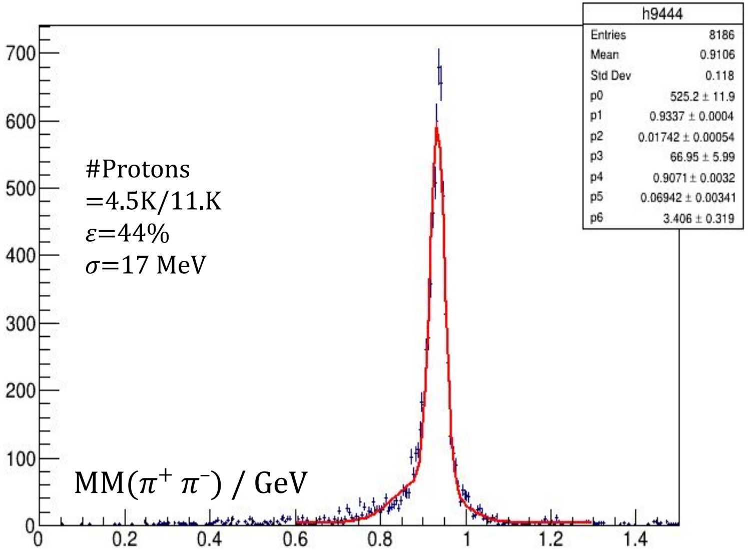
- With **vertex cuts** (left) Rec. Eff. **~25%** (=2500/11000), while the sensitivity (=peak/pedestal)= **~100**.
- No cuts (right) **~50%** (=6000/11000) ; the sensitivity ~**10 times lower** .

Effect of $\pi^+\pi^-$ vertex on **proton** reconstruction in $K_L+p \rightarrow K_s(\pi^+\pi^-)+p$ at beam momentum (0.3,0.6) GeV/c.

K_s-mass cut, vertex r<3 cm, DOCA<0.45 cm.

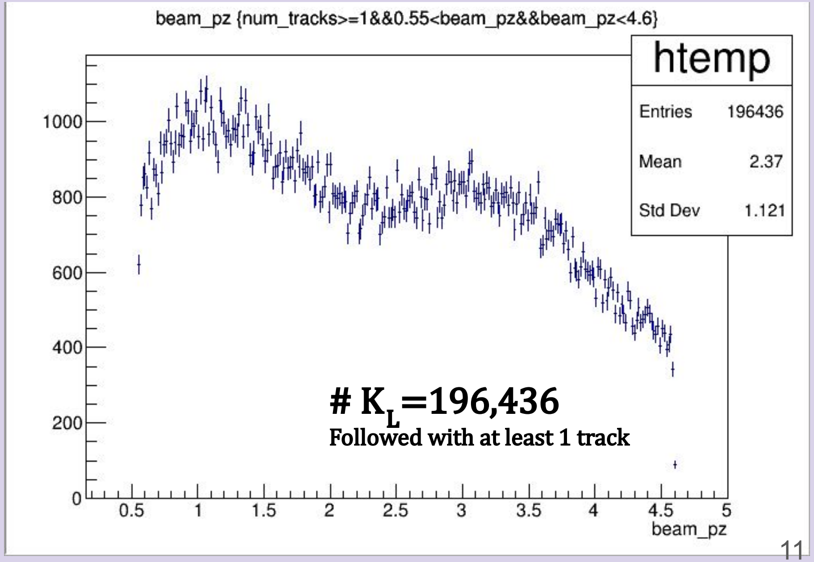


K_s-mass cut via EM($\pi^+\pi^-$). No vertex cuts.

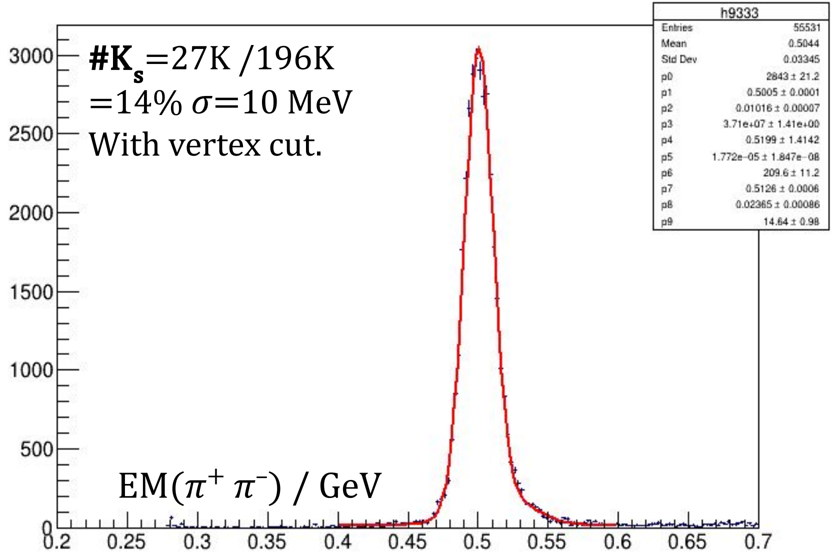


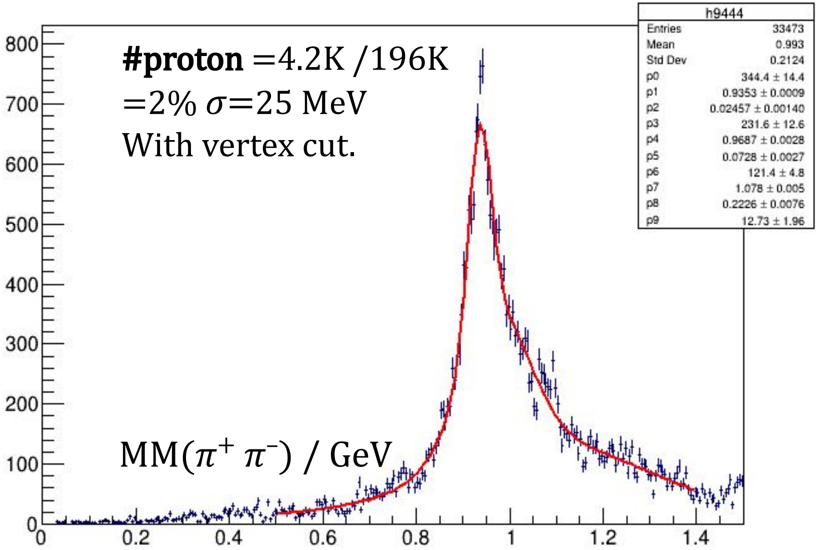
- Inside LH2 reconstruction efficiency of proton drops from **~44%** to **~22%.**
- Little change of the background, but better MM resolution.

Effect of $\pi^+\pi^-$ (K_s) vertex reconstruction $K_L + p \rightarrow K_s(\pi^+\pi^-) + p$ at hig K_L beam momenta (0.55,4.55) GeV/c.



Reconstruction of K_s and p in K_L+p→K_s + p at K_L momentum (0.55,4.55) GeV/c. Vertex cuts.

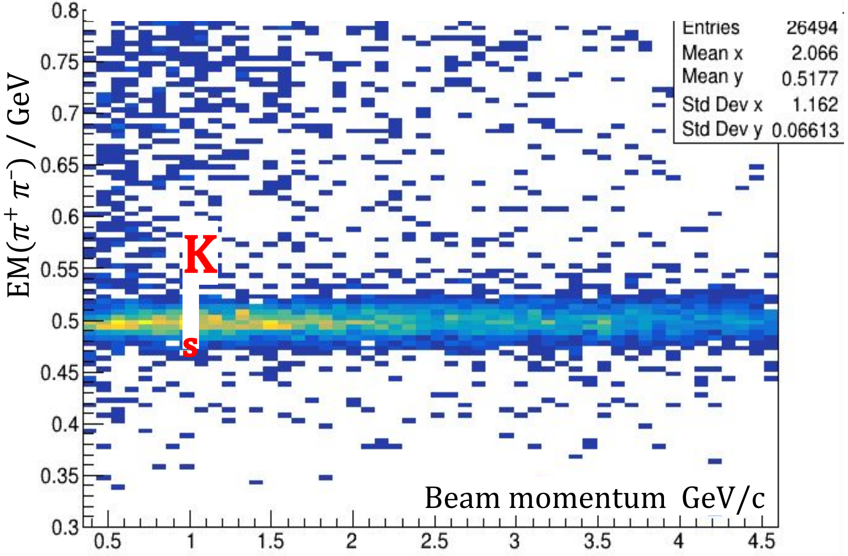




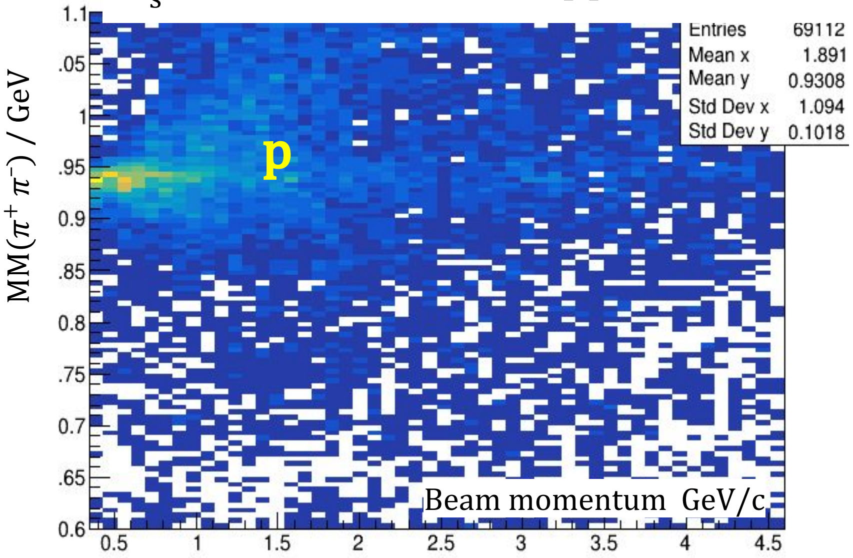
- **In wide** domain of beam momentum Reconstruction Efficiencies are ~14% for K_s and ~2% for protons.

Reconstruction of K_s and p in $K_L + p \to K_s + p$ at K_L momentum (0.35,4.55) GeV/c. Effective and Missing mass of $\pi^+\pi^-$ pairs vs beam momentum.

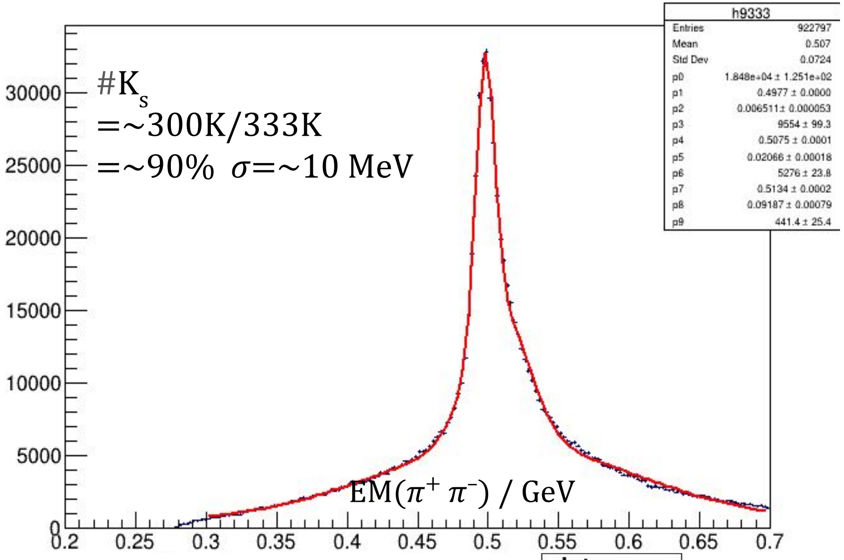
LH2 cuts applied

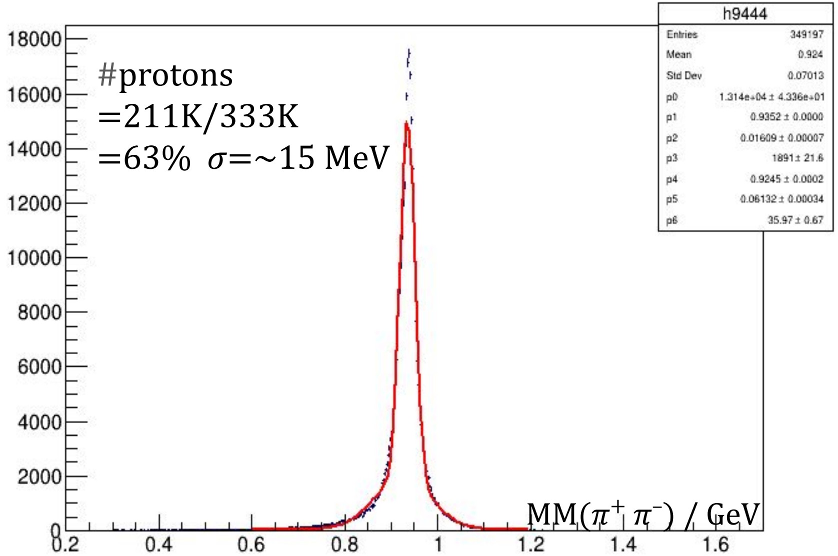


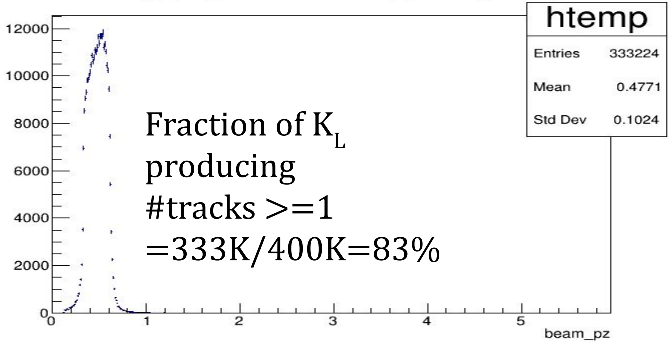
K_s mass and LH2 cuts applied



Reconstruction of **proton** in $K_L+p \rightarrow K_s(\pi^+\pi^-)+p$ at generated K_L energy (0.1,0.3) **GeV**







- #tracks>=1 & $|EM(\pi^+\pi^-)-m_K|<20$ MeV. **No vertex cuts** .
- Overall Rec. Efficiency = 0.83*0.63=**~53% for protons** and **~75% for K_s**

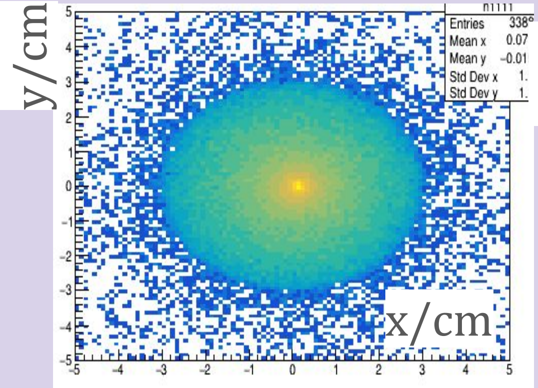
Reconstruction of K^{+}+n state in

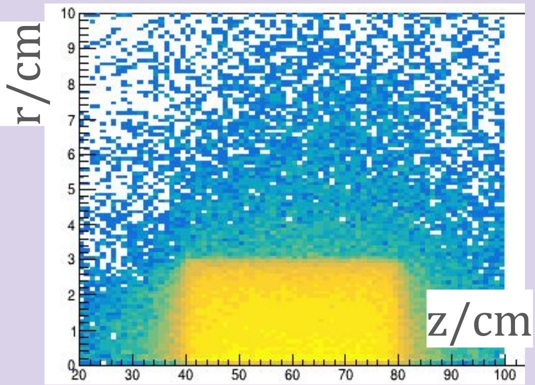
$K_L + p \to K^{+} + n$ at K_L momentum (0.35,0.55) GeV/c.

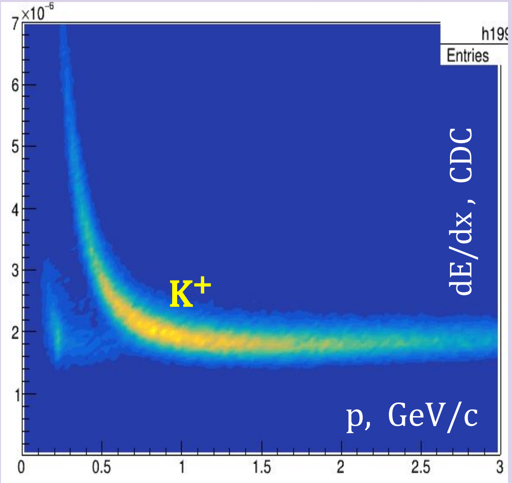
Hadronic decay

$K^{+} \to \pi^{+}\pi^{+}\pi^{-}$ 5.6 % $c\tau$ =371.2 cm (“stable”)

$\to \pi^{+}\pi^{0}$ 20.7 %

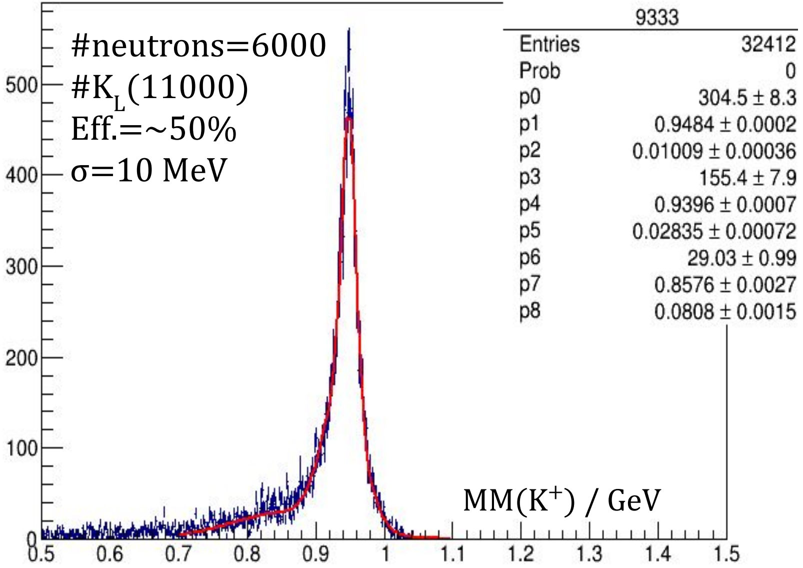




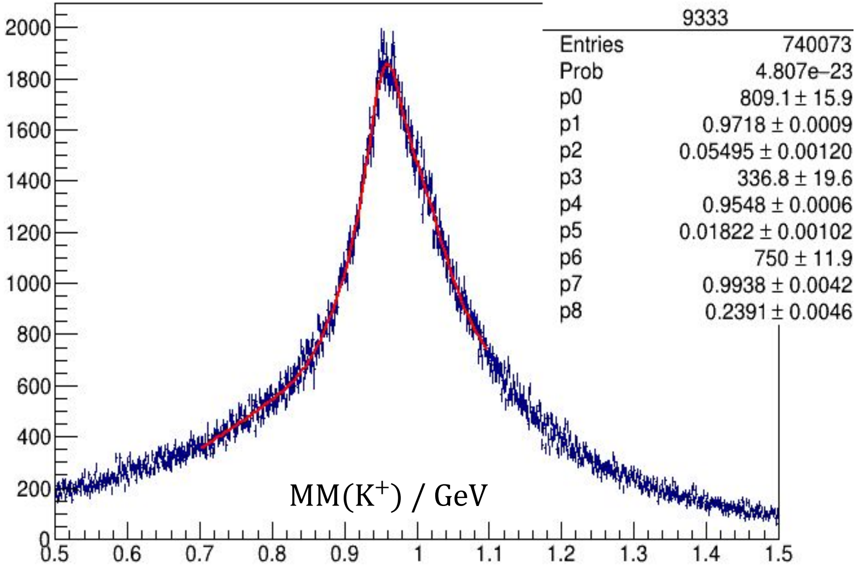


Reconstruction of neutron in $K_L + p \rightarrow K^+ + n$ with vertex cuts.

K_L momentum (0.35,0.55) GeV/c



K_L momentum (0.55,4.55) GeV/c



- Reconstruction efficiency of neutrons ~50%.

Backgrounds to $K_L + p \rightarrow K^+ + n$

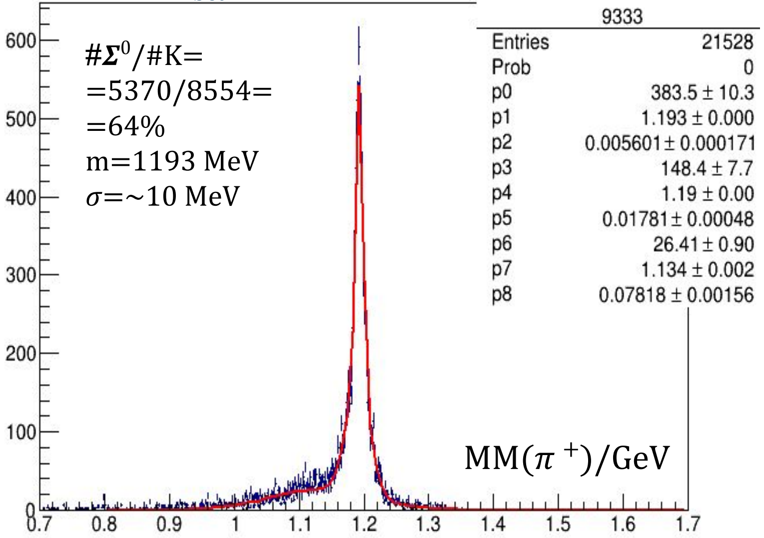
(1) $\mathbf{K_L} + p \rightarrow \pi^+ + \boldsymbol{\Sigma}^0(1192)$ or $\boldsymbol{\Lambda}(1115)$; $p_{Kaon} > 0$

(2) $\mathbf{n} + p \rightarrow K_s + \boldsymbol{\Sigma}^+ + n$; $p_{neutron} > 2.6$ GeV/c => low n-flux.

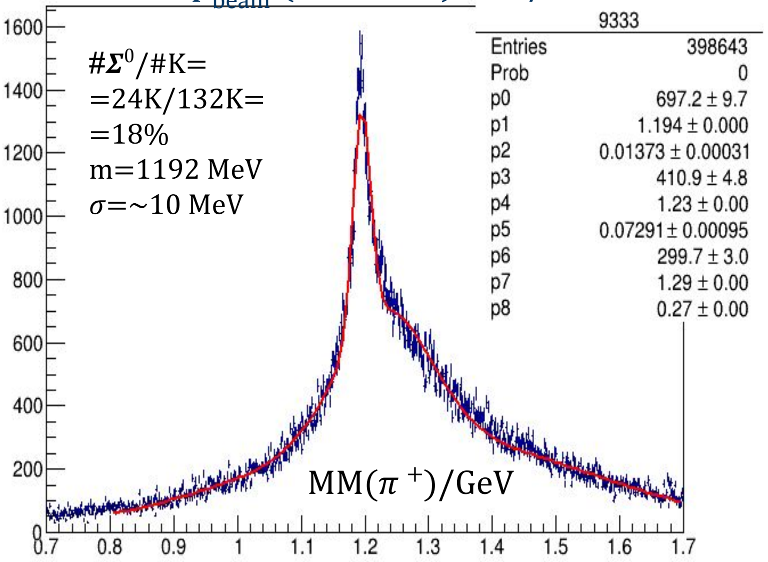
(3) Beam leak from other halls and reconstruction of $K_L + p \rightarrow K^+ + n$

Background reaction $K_L + p \rightarrow \pi^+ + \Sigma^0$ (1192)

p_{beam} (0.25,0.55) GeV/c

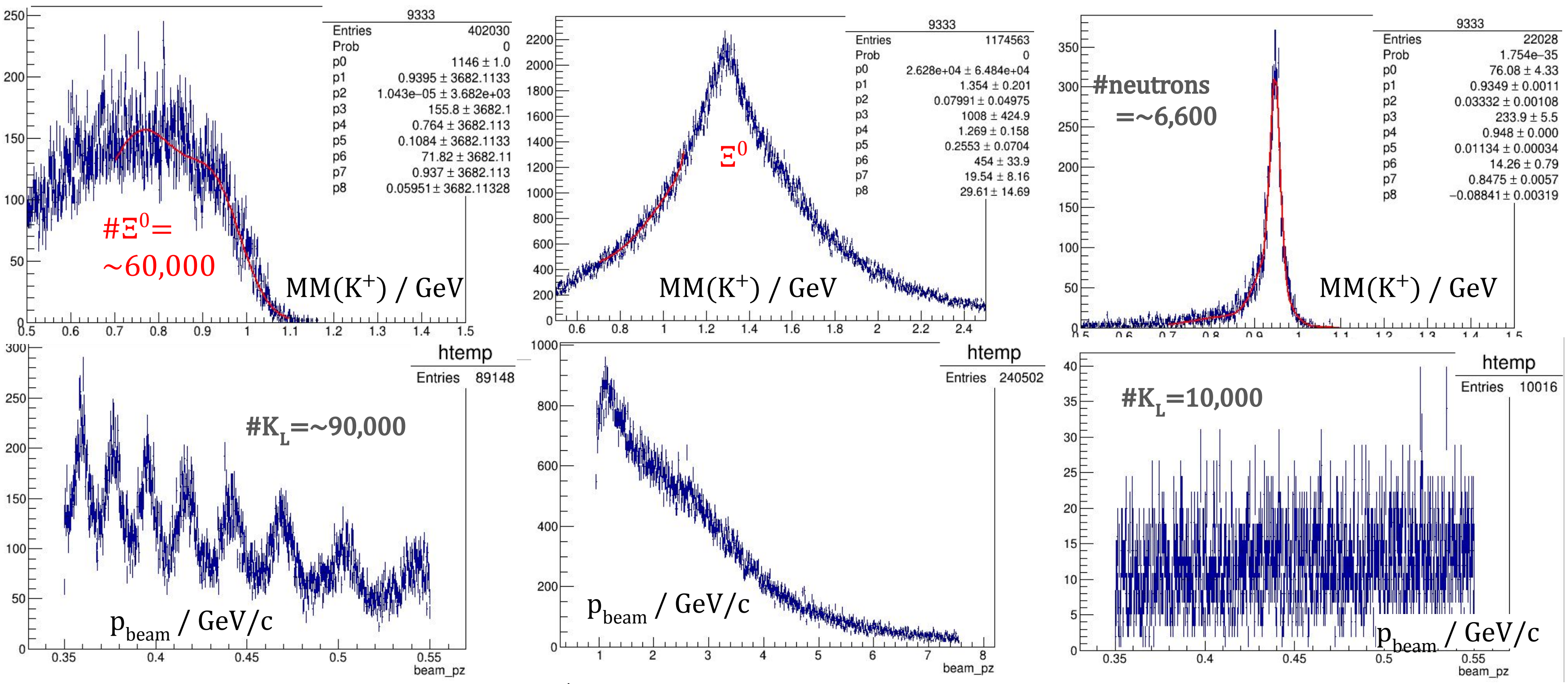


p_{beam} (0.25,4.55) GeV/c



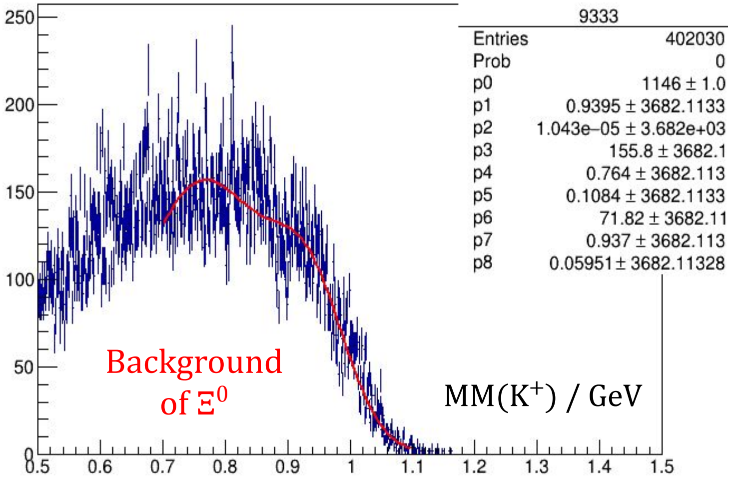
- Well separated from proton and neutron MM peaks at low beam momenta.

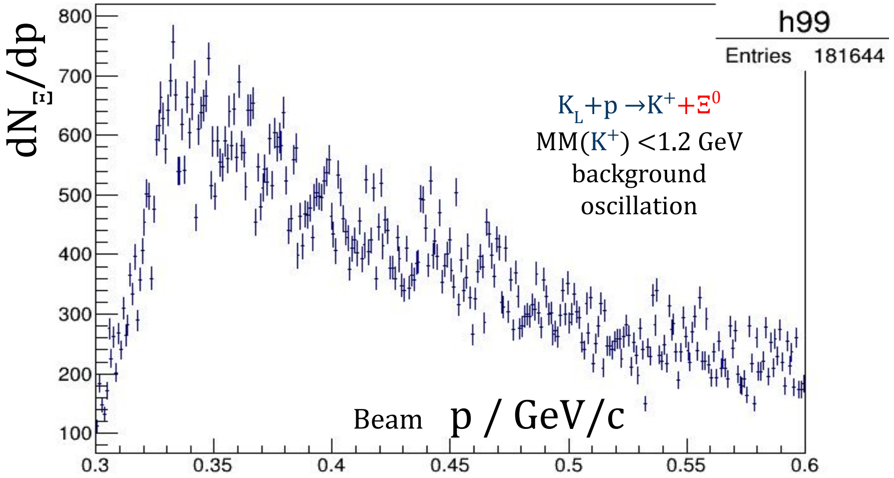
$K_L + p \to K^+ + \Xi^0$ at $0.35 < p_K < 0.55$ GeV/c . Missing Mass of K^+ and beam leak from other halls (left) vs normal Hall D beam (right)



- No structures in Missing Mass of K^+ !
- At p_{beam}=0.45 GeV/c the “leak” /“beam” ratio = ~100/10=~10; we expect ~2 (factor 5).
- The ratio of neutron_peak to leak of ”Ξ^0” =~300/75=~4; we expect ~5*4=20, i.e. ~**5% background.**

$K_L + p \rightarrow K^+ + \Xi^0$. Background oscillation caused by beam leak.

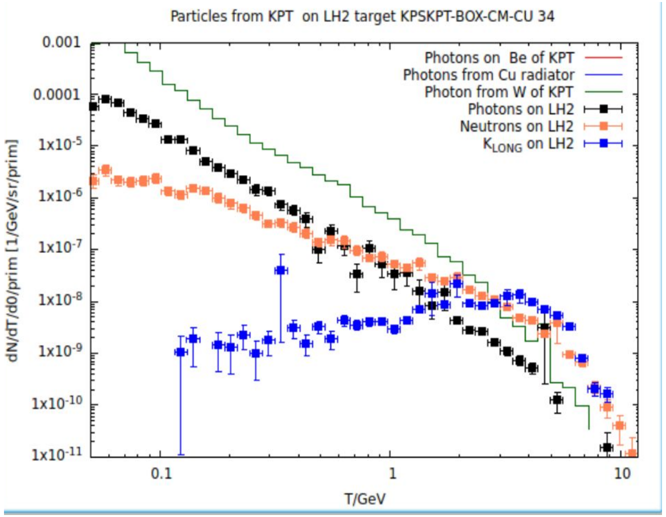




- The background part shows oscillations (10% amplitude) due to beam leak.

What to do with beam leak background?

1. FLUKA shows that **minum energy of K_L** at LH2 target T=0.1 GeV.
   => K_L **momentum** p_K= 0.33 GeV/c
   => $\beta_K = p_K / (T+m_K)$ = 0.33/0.597=0.554
   TOF_K =2400[cm]/(30[cm/ns]*0.554)=**144 ns**
   TOF_γ =2400[cm]/(30[cm/ns]*1.000)= **80 ns**
2. The difference TOF_K- TOF_γ = **64 ns** , therefore
   all **beam K_L**'s with p>0.33 GeV/c do **fit into (0,64) ns** interval!
3. **Provided 128 ns** between bunches the following (64,128) ns interval
   is **filled by beam leak** only. Therefore this interval may be used
   to **permanently measure** /subtract the **background** .



CONCLUSION

Final state	Efficiency / Resol.	Efficiency / Resol.
K_L beam mom.	0.3-0.6 GeV/c	0.5-5.0 GeV/c
$\rightarrow K_s + \ldots$	53 % / 10 MeV	14 % / 20 MeV
$\rightarrow K_s + p$	44 % / 20 MeV	2 % / 25 MeV
$\rightarrow K^+ + n$	50 % / 15 MeV	6 % / 50 MeV
$\rightarrow \pi^+ + \Sigma^0$	64 % / 10 MeV	18 % / 15 MeV

- GlueX CDC is an **ideal detector** at K_L beam momentum (0.3, 0.6) GeV/c.
- Average **reconstruction efficiency** ~50% in this region.
- **Advantage** of $K_L + p \rightarrow K_s(\pi^+\pi^-) + p$ is that it has **3 charged particles** of low momenta, hence - better **resolution** and **vertex** localisation; good cross check for $K_L + p \rightarrow K^+ + n$.
- **Beam leak** background **does not create problems** for neutron reconstruction via MM(K^+).