THE UNIVERSITY OF EDINBURGH

# Hyperon Production at $K_L$-Facility

# &

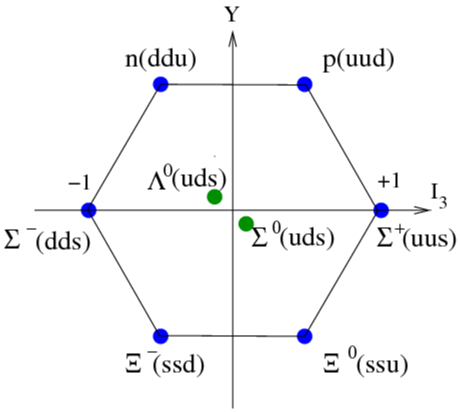
# KL Flux Monitoring

Mikhail Bashkanov

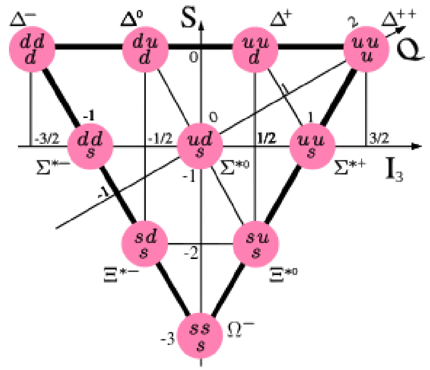
# Outlook

- Why?
- Kaon beams
  - Flux
  - Energy resolution
- Beam-related background
- Kaon induced reactions
  - Simulation & reconstruction
- Beam Monitor
  - Flux
  - Asymmetry

# Hyperons

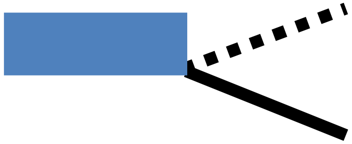


Octet: $N^*$, $\boldsymbol{\Lambda}^*$, $\boldsymbol{\Sigma}^*$, $\boldsymbol{\Xi}^*$
Decuplet: $\Delta^*$, $\boldsymbol{\Sigma}^*$, $\boldsymbol{\Xi}^*$, $\boldsymbol{\Omega}^*$



| | Quark Models Predicted | “Observed”, PDG |
|---|---|---|
| $N^*$ | 64 | 16 |
| $\Delta^*$ | 22 | 10 |
| $\boldsymbol{\Lambda}^*$ | 17 | 14 |
| $\boldsymbol{\Sigma}^*$ | 43 | 10 |
| $\boldsymbol{\Xi}^*$ | 42 | 6 |
| $\boldsymbol{\Omega}^*$ | 24 | 2 |

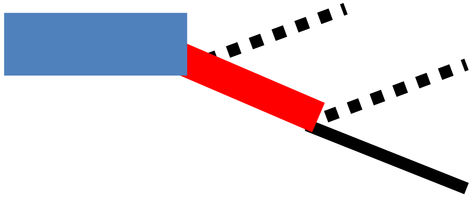
# Theory limitations



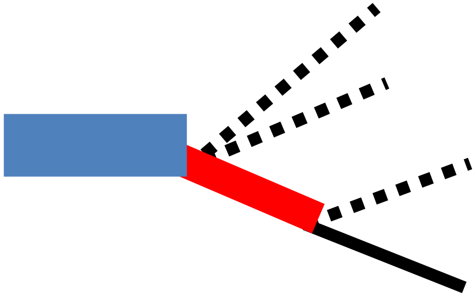
**Good**

Kaon beam brings one unit of strangeness:

- No associated kaons for $\Lambda^*, \Sigma^*$ production
- 1 associated kaon for $\Xi^*$
- 2 associated kaons for $\Omega^*$

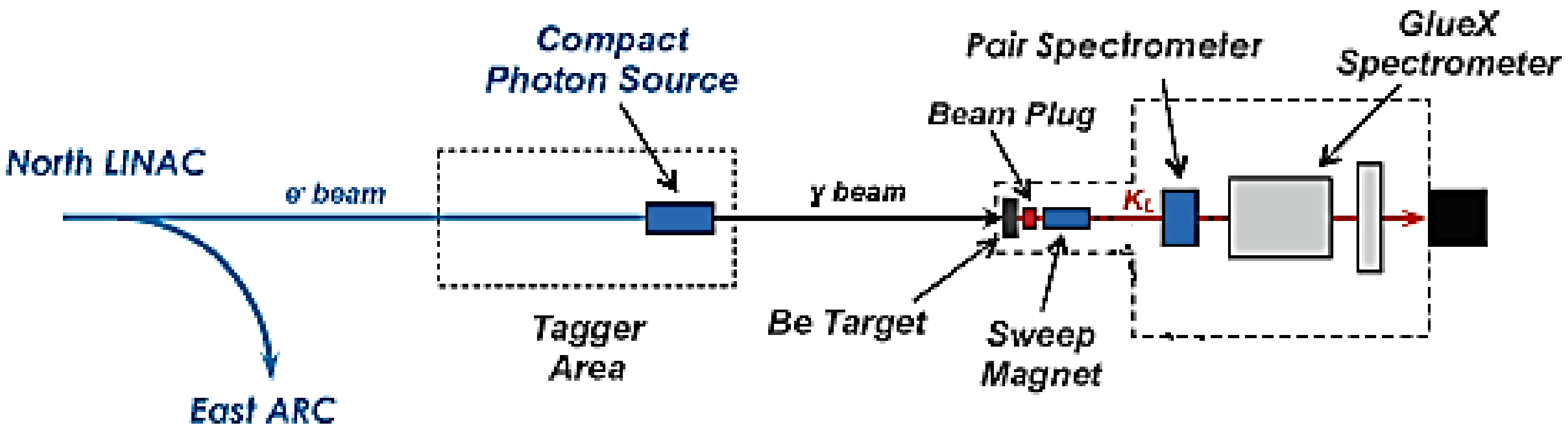


**Acceptable**



**Simplified,**
**model dependent analysis only**

# $K_L$- Facility



- Electron beam:

  $I_e = 5\ \mu A$

  64 ns bunch spacing
- Compact Photon Source:

  radiator 10% r.l.

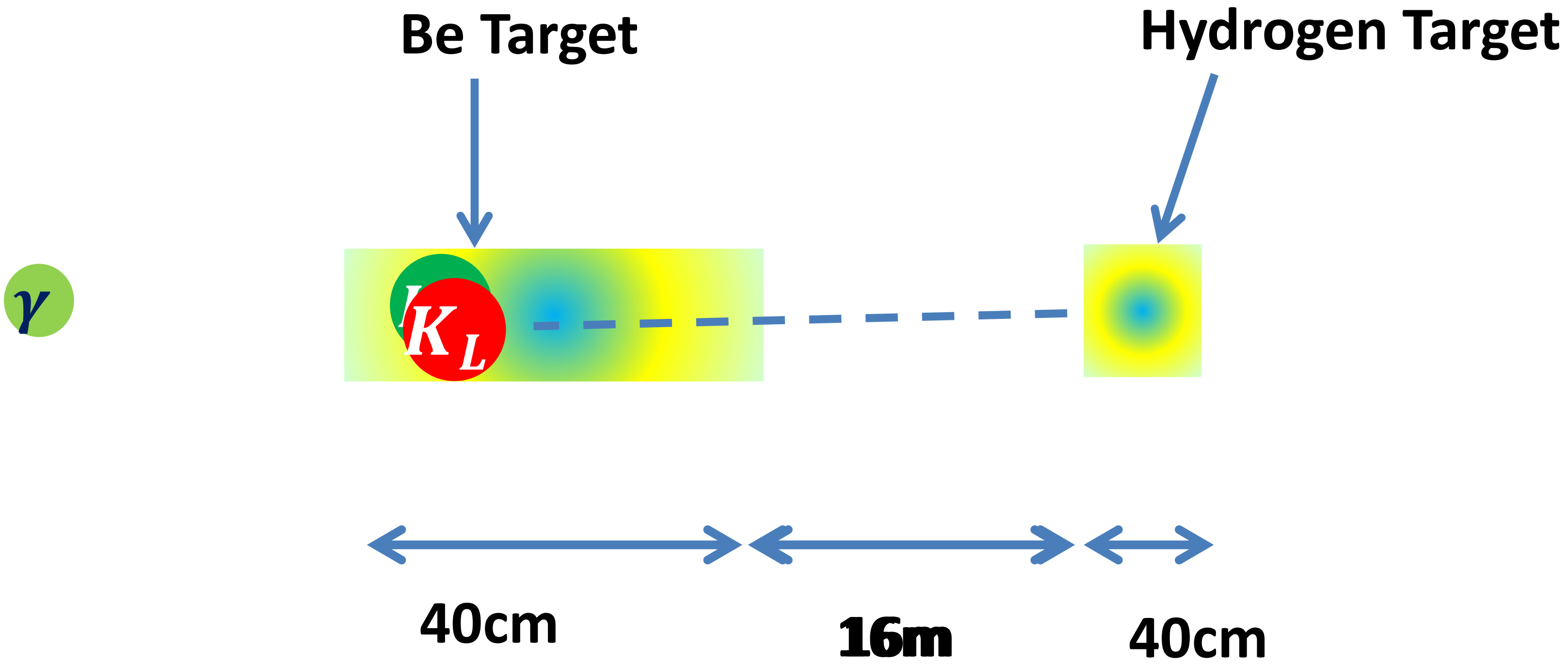
- Be Target:

  40 cm length
- LH2/LD2 Target

  L=40cm, d=6cm
- Be-LH2 distance:

  16 meters

# Experiment



**Be Target**

**Hydrogen Target**

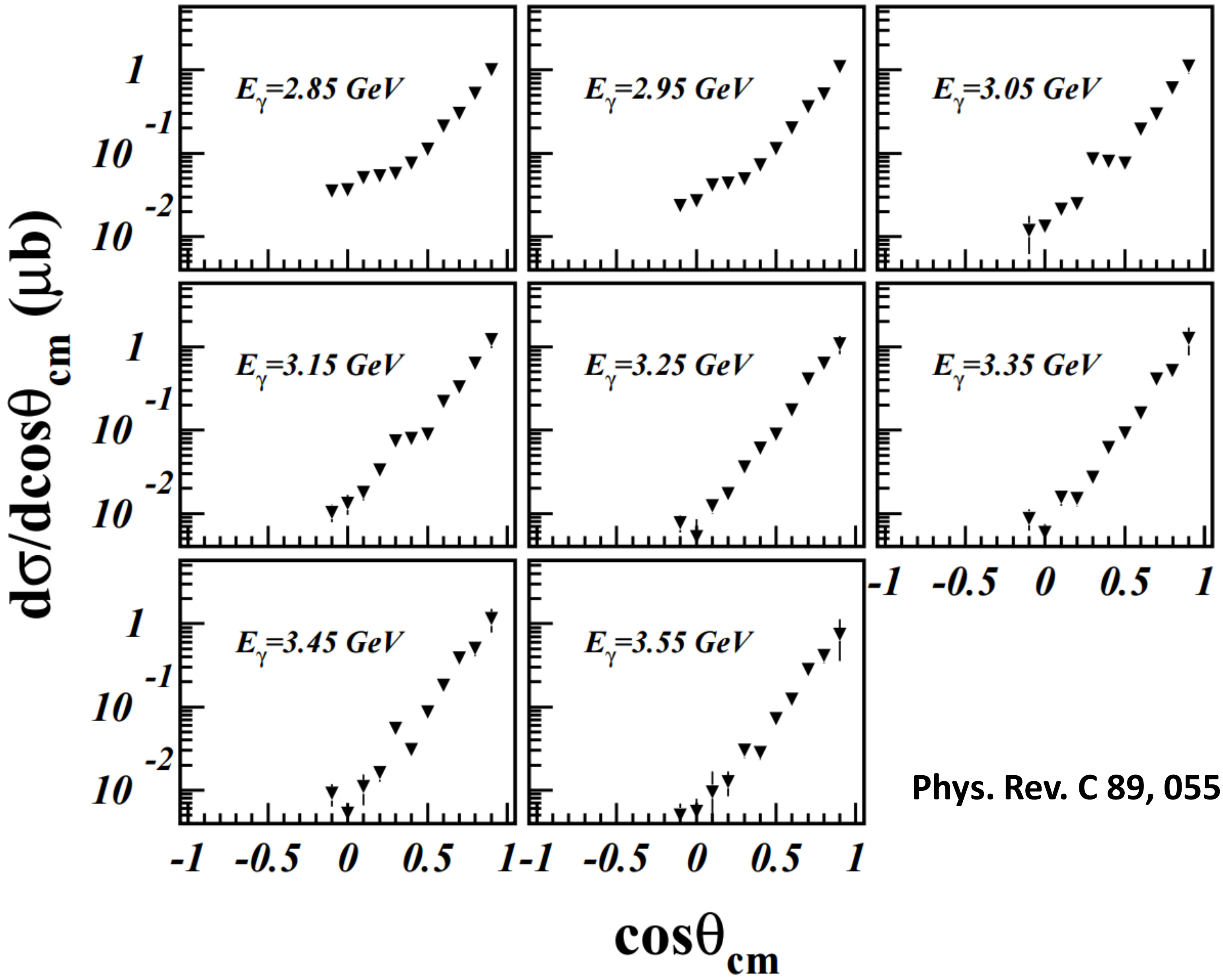
**40cm**

**16m**

**40cm**

$$\gamma Be \to \phi + X \qquad \phi \to K_L K_S \qquad K_L p \to X$$

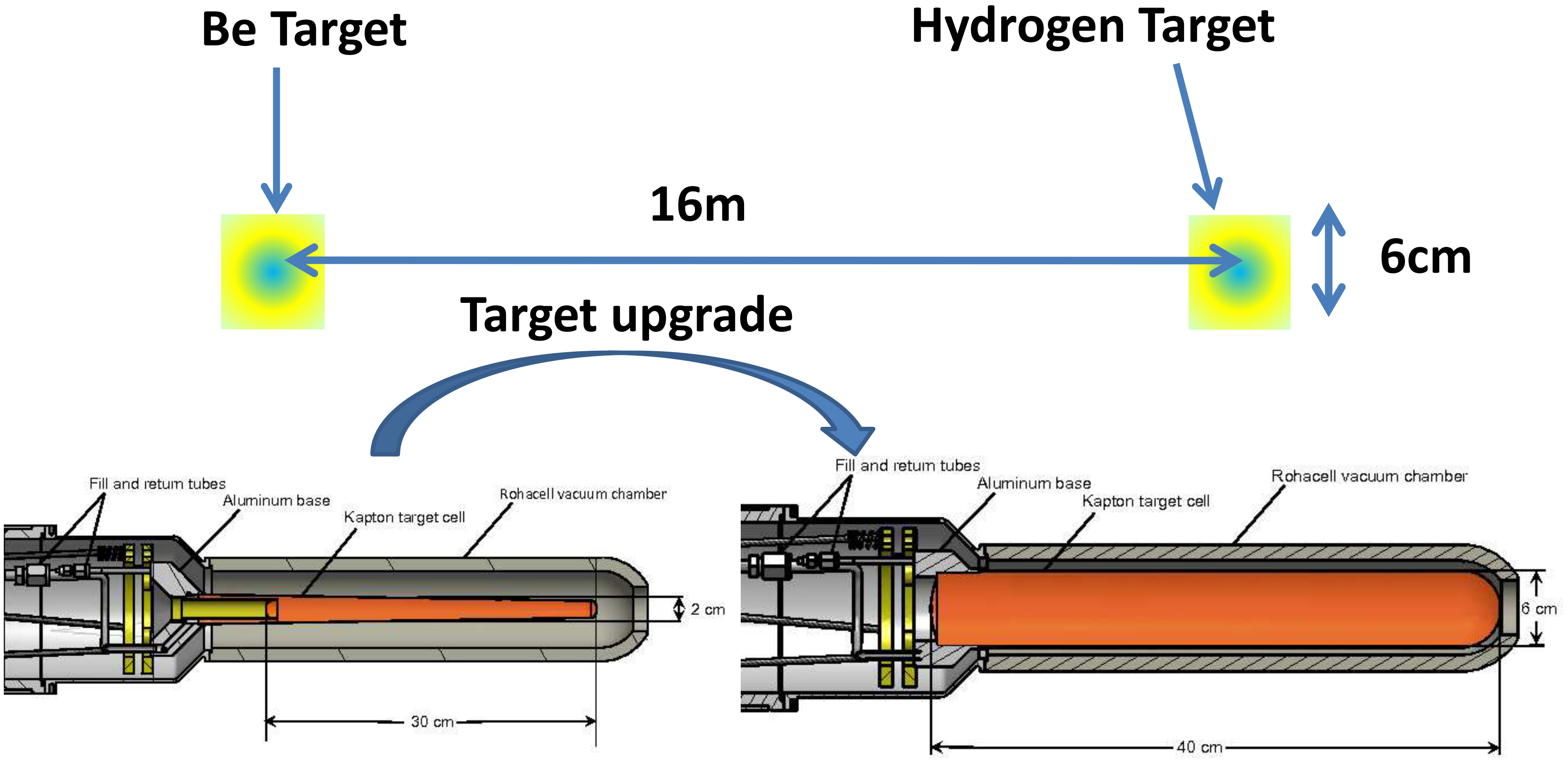
# $\phi$ angle in $\gamma p \rightarrow \phi p$



Phys. Rev. C 89, 055206 (2014)

# $K_l$ flux at LH2/LD2 target

- $K_l$ lifetime is $5.1 \cdot 10^{-8} s.\ c\tau = 15.3m$
- $K^{\pm}$ lifetime is $1.2 \cdot 10^{-8} s.\ c\tau = \ \ 3.7m$
- Be-LH2/LD2 flightpath is 16m



**Be Target**

**Hydrogen Target**

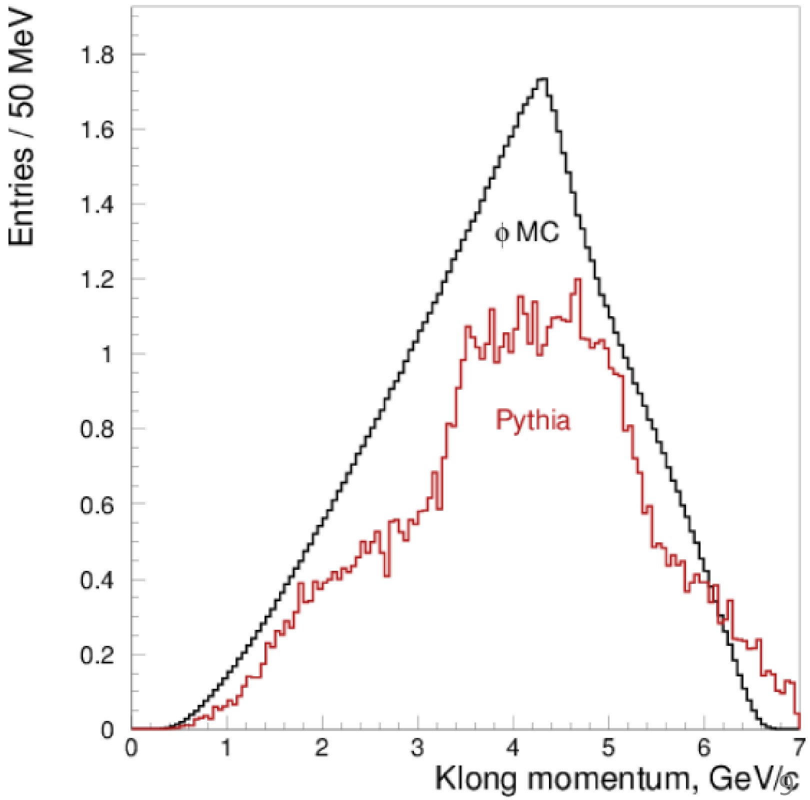
**16m**

**6cm**

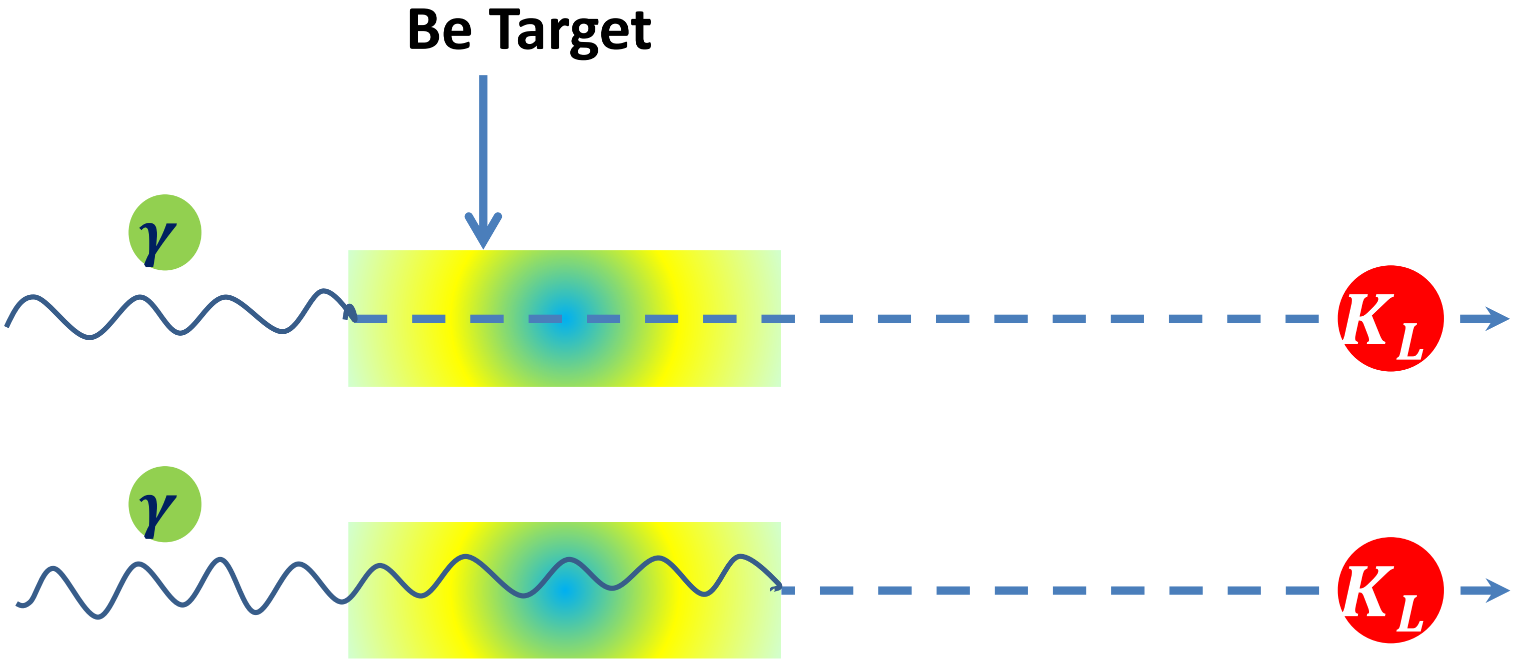
**Target upgrade**

# $K_l$ flux on LH2/LD2 target

- $3 \cdot 10^4$ Kaons/s on a LH/LD target
- 1/3 of kaons decay in 16 m flight
- Large W-range
- $K_L$ momentum reconstructed with TOF Be-LH2/LD2
- Longer flightpath -> better W resolution, but less kaons.



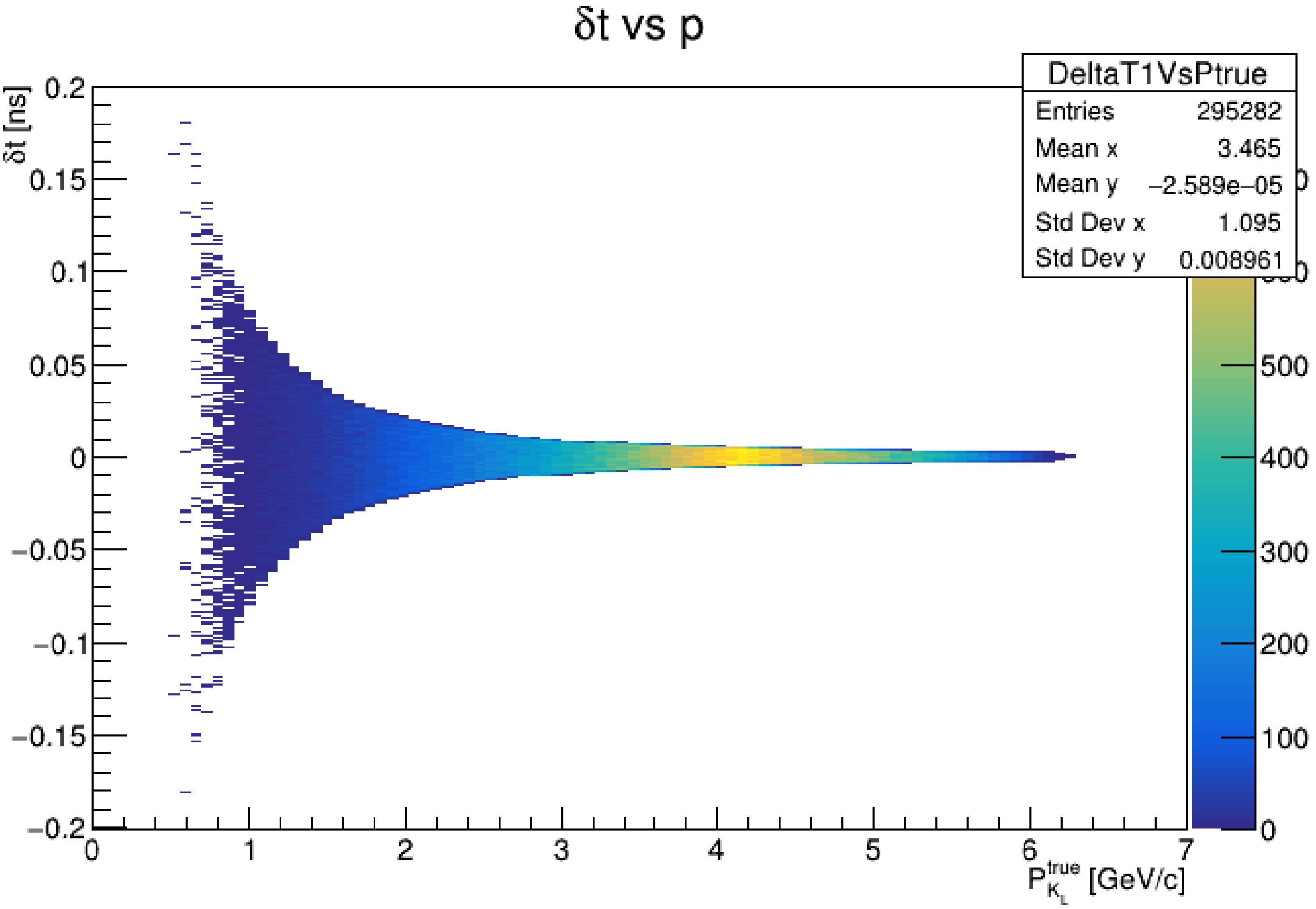
# $K_l$ time resolution due to position in Be



$$\Delta t = \frac{L}{c\beta_{K_l}} - \frac{L}{c} = \frac{L}{c}\left(\frac{1}{\beta_{K_l}} - 1\right)$$

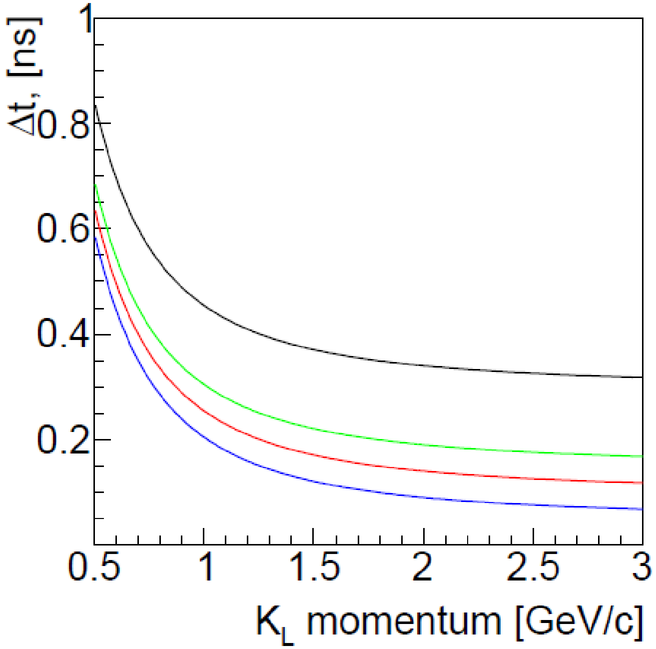
For L=40cm and $p_{K_l} > 800 MeV/c$,$\Delta t < 150 ps$

# $K_l$ time resolution due to position in Be



# $K_l$ momentum resolution

Driven by Start Counter time resolution

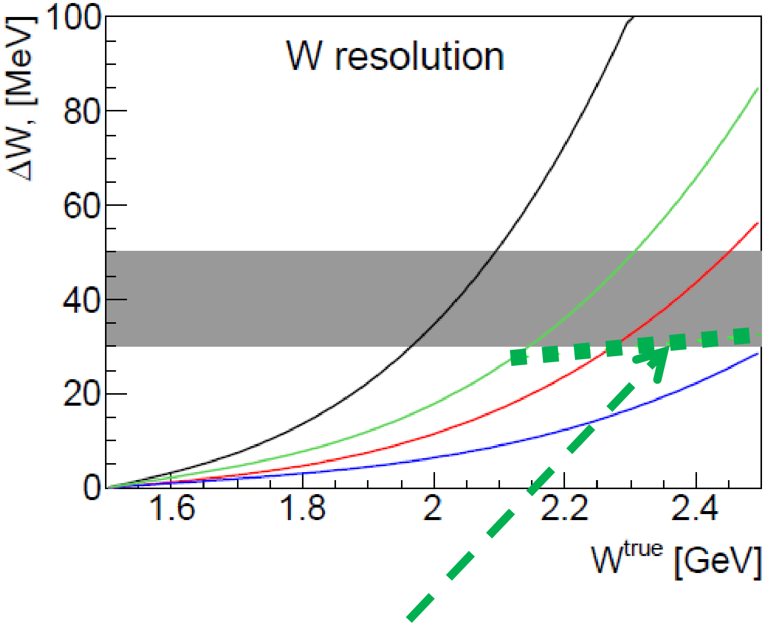


300 ps

150 ps

100 ps

50 ps



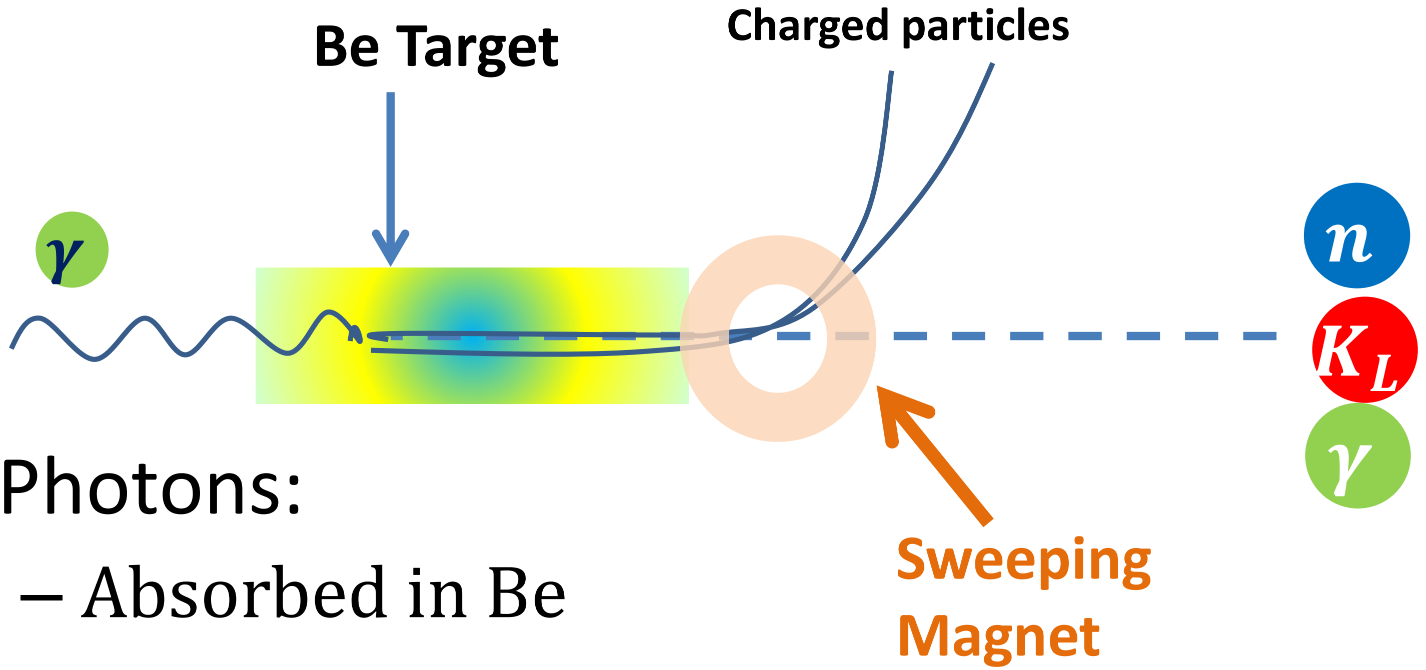
150 ps

& final state reconstruction

**Unimportant, since**

**we do not hunt bumps – we do PWA**

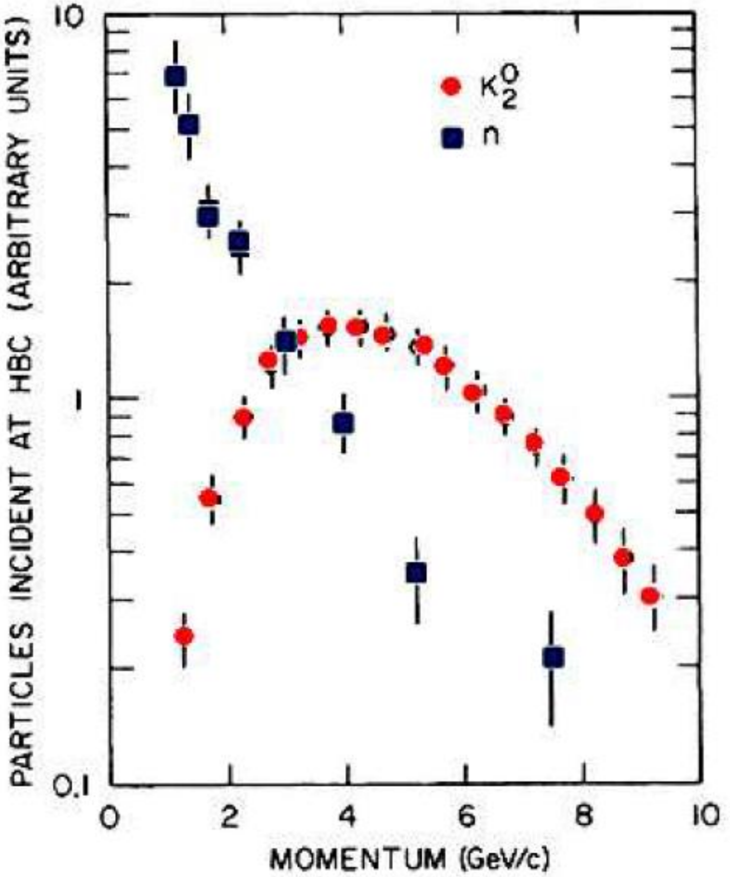
# Possible backgrounds

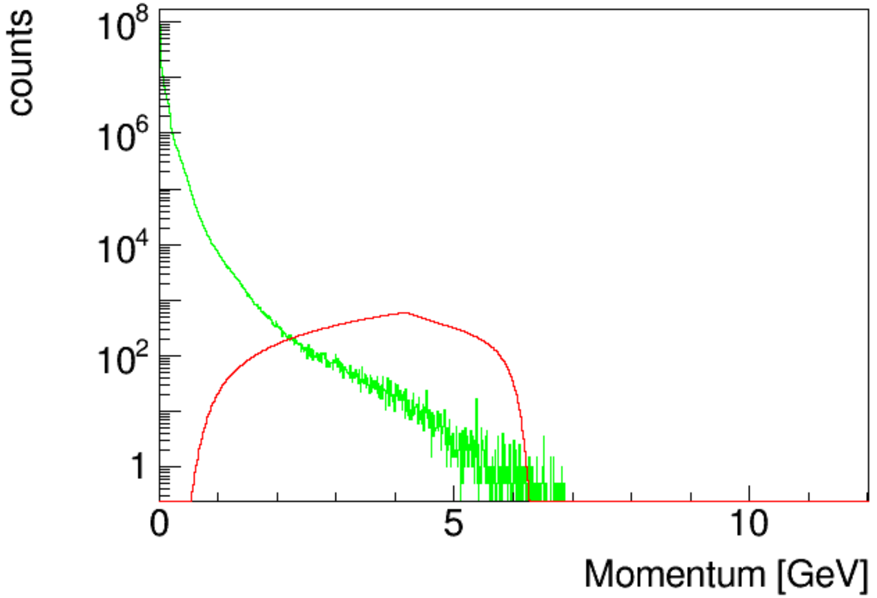


- Photons:
  - Absorbed in Be
  - $v = c$
  - Small x-section
- Neutrons:
  - $v_n \ll v_{K_L}$
  - Different kinematics

**99%**of neutrons associated with **T** < **90**MeV while **0.6%**of them are for **T**> **125** MeV.

# Possible backgrounds

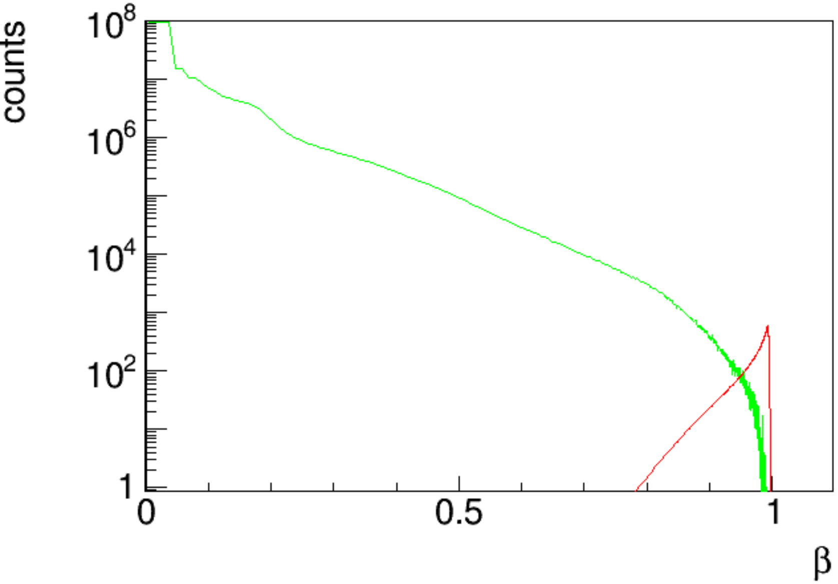


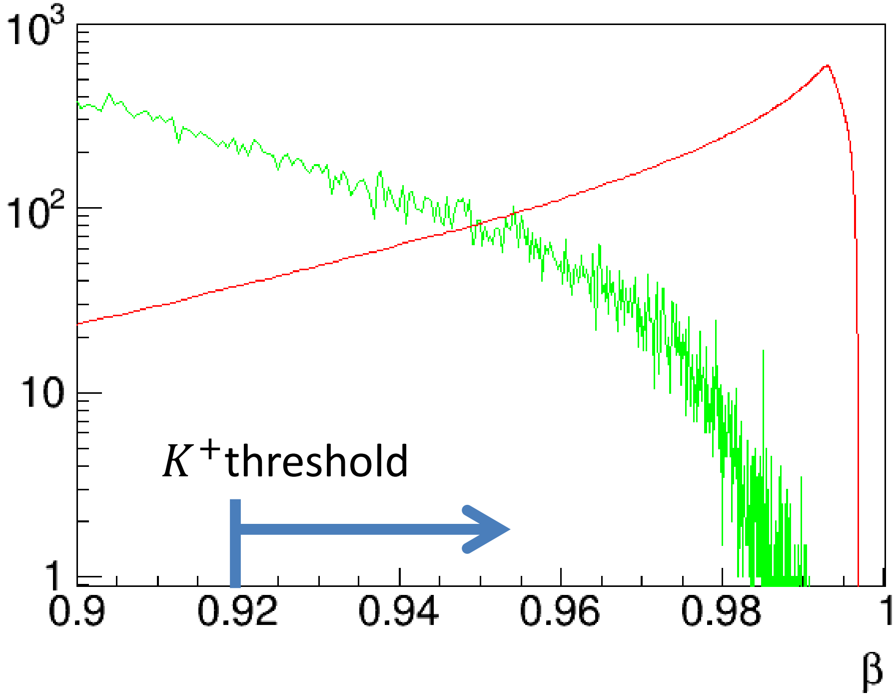


Neutron and K_L momentum spectra

Neutron and K_L momentum spectra from SLAC
A.D. Brody *et al,* Phys Rev Lett **22**, 966 (1969)

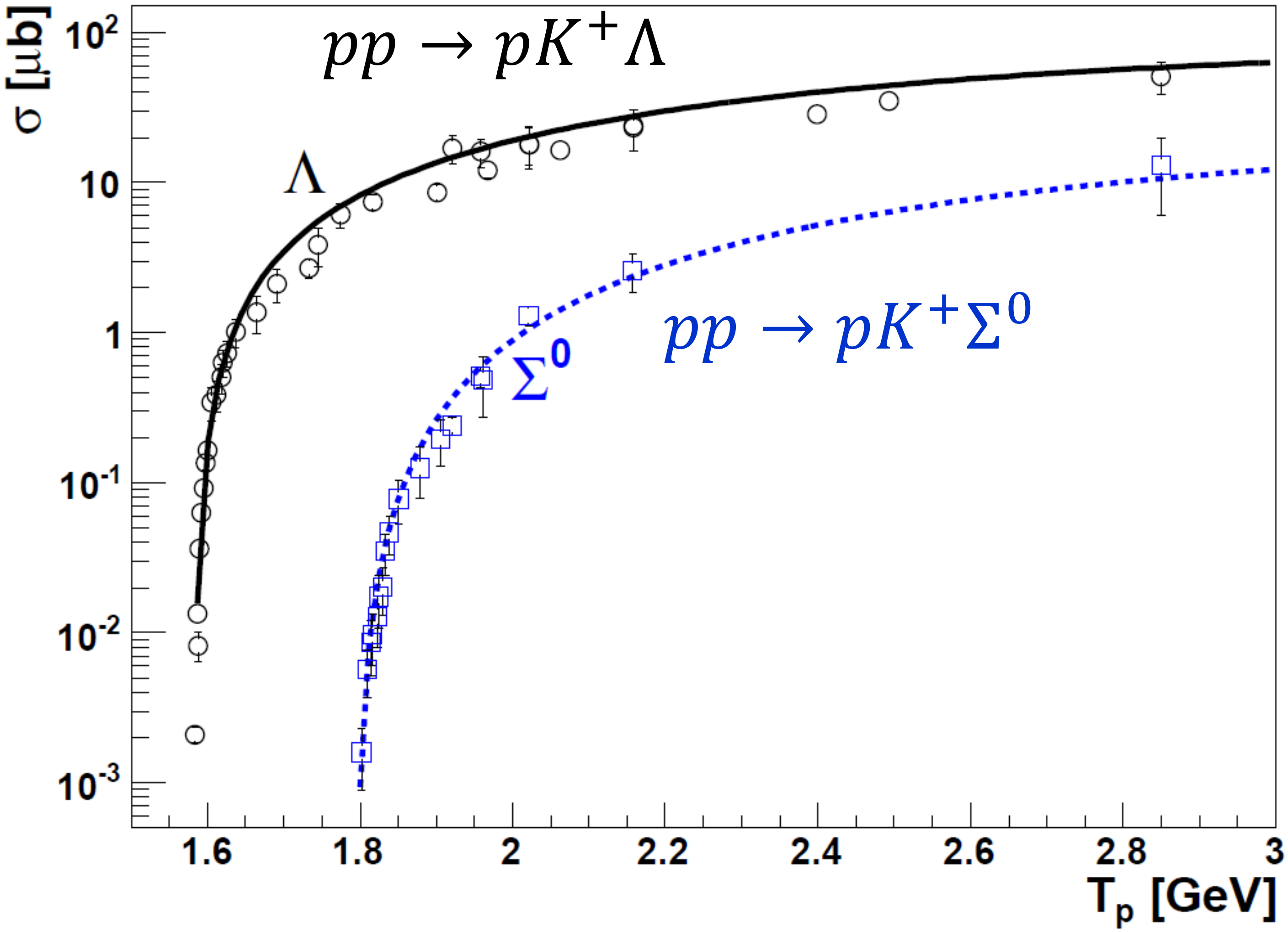
# Neutrons and $K_l$'s as a function of$\beta$





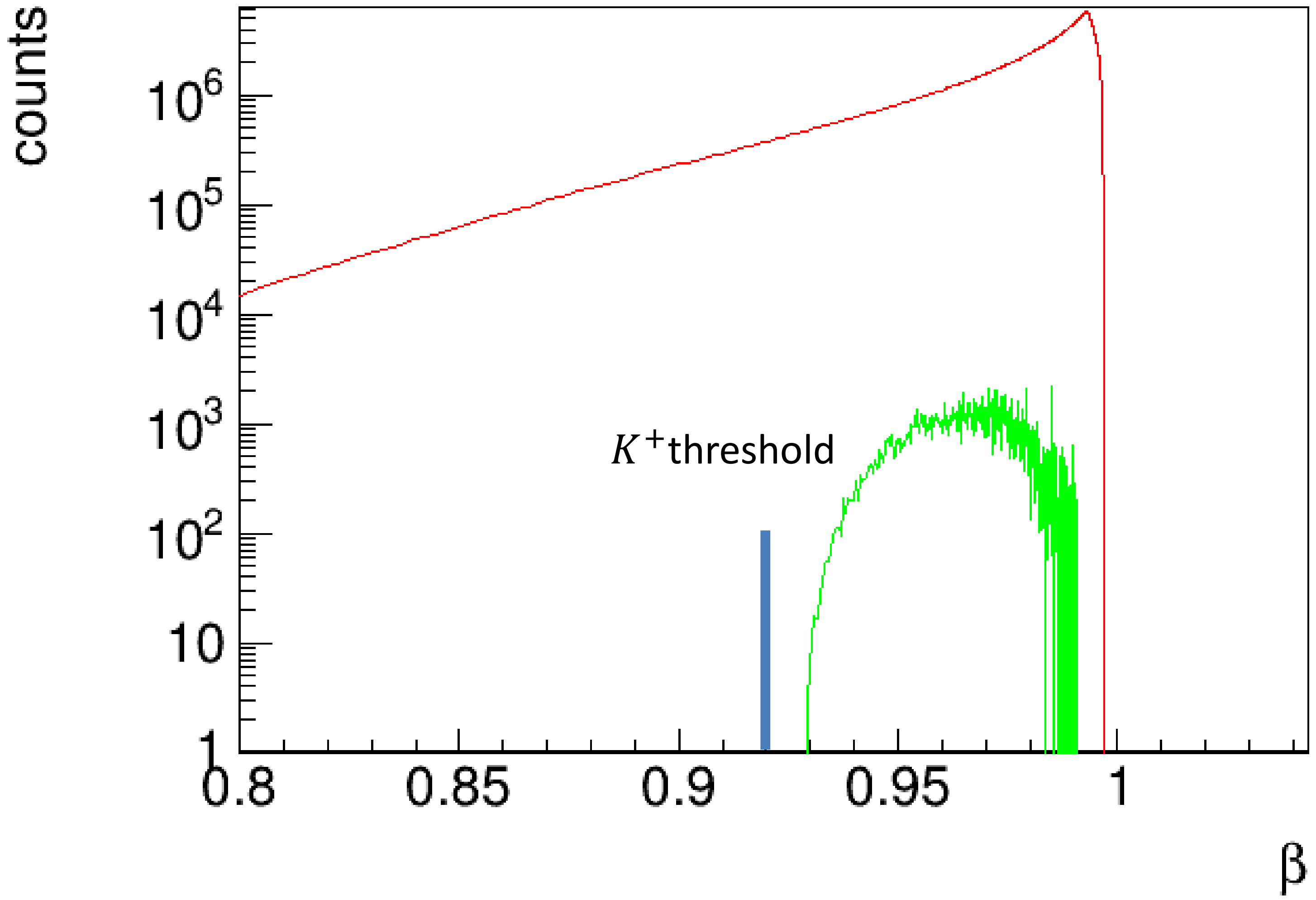
$K^+$threshold

# $K^+$production in NN collisions

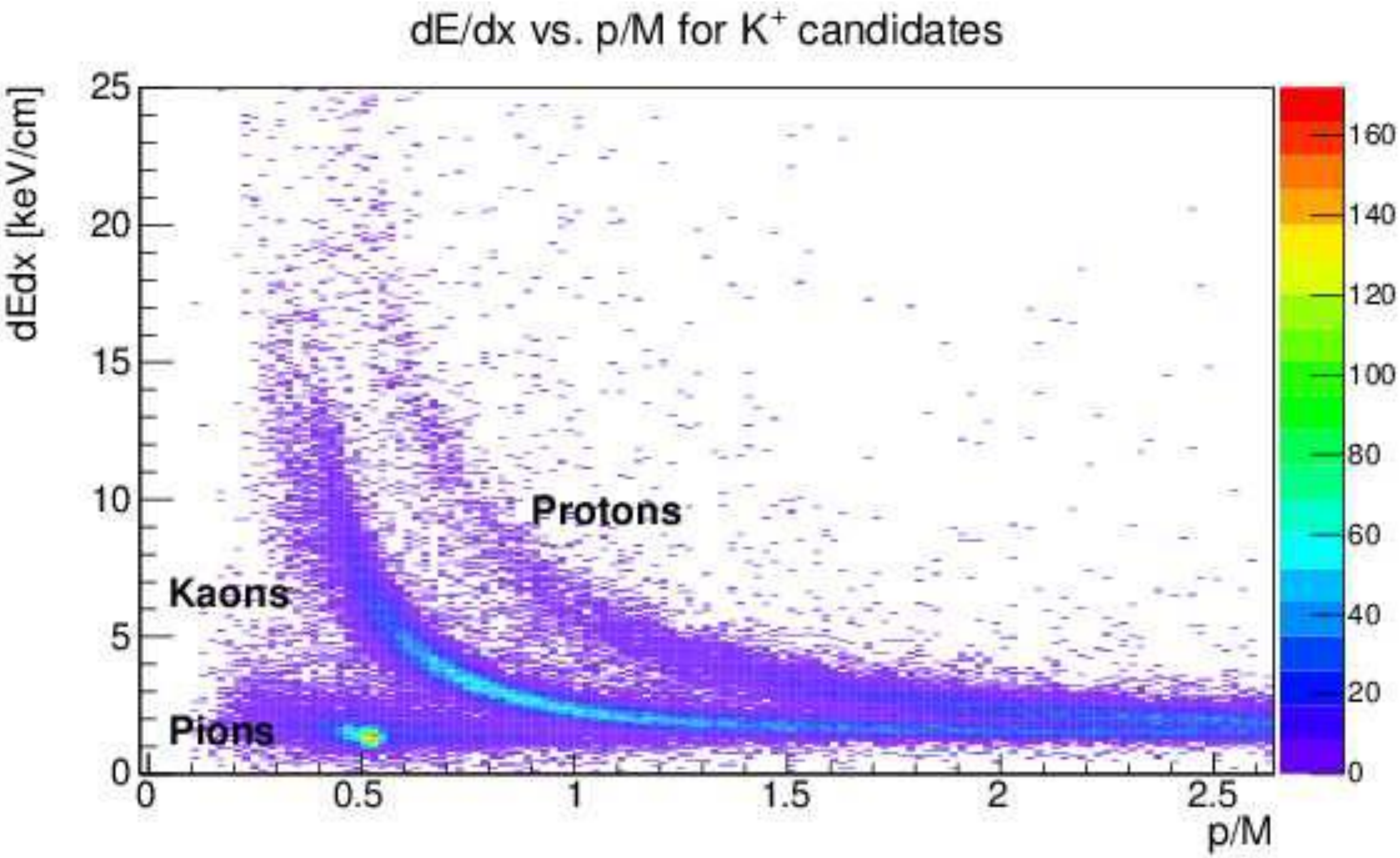


Phys. Rev. C **84**, 055207 (2011)

# $K^+$ countrate from N and $K_l$'s

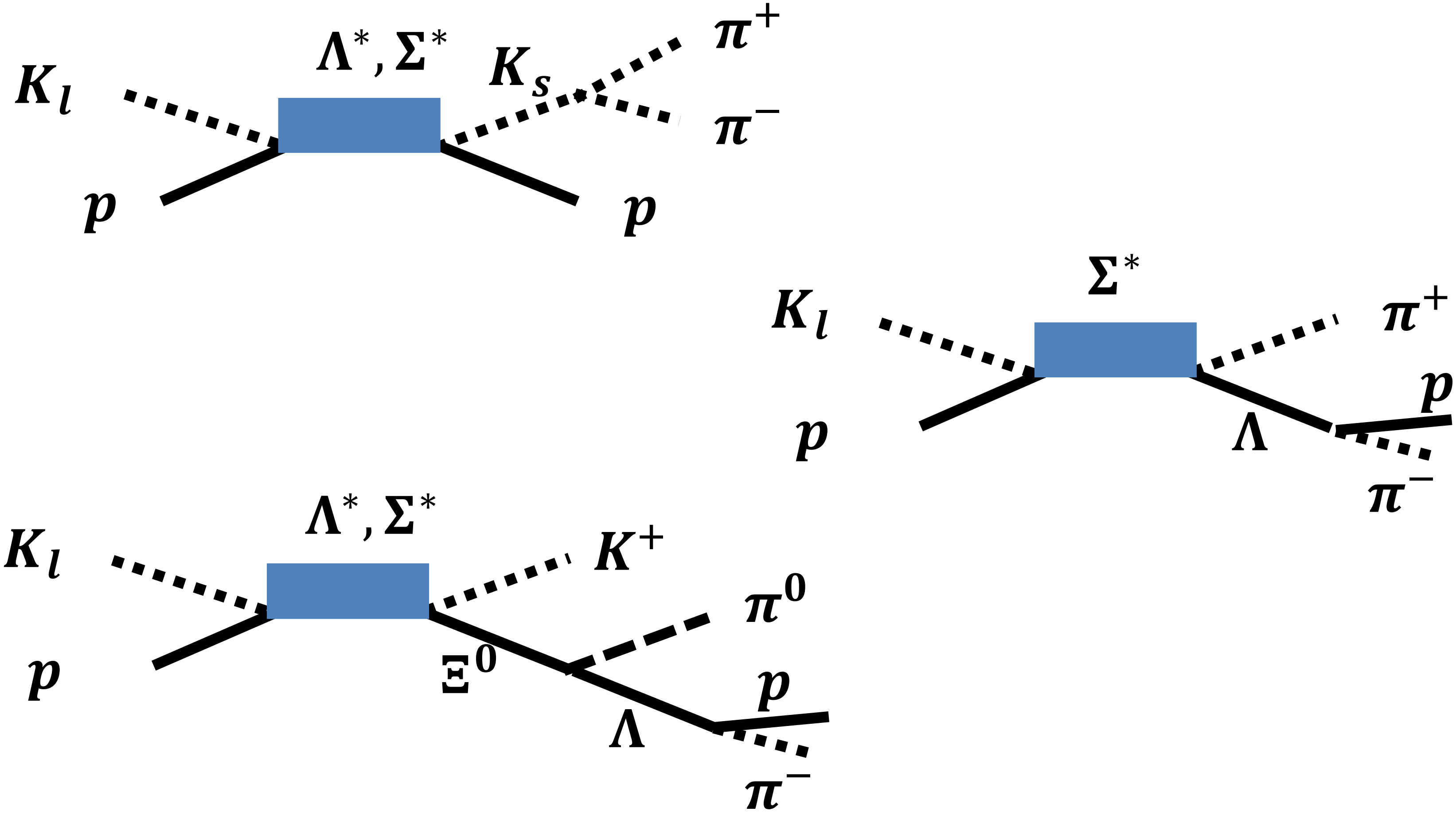


# Particle ID


dE/dx vs. p/M for $K^+$ candidates
dEdx [keV/cm]
p/M
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
Protons
Kaons
Pions
0
20
40
60
80
100
120
140
160

# REACTIONS OF INTEREST

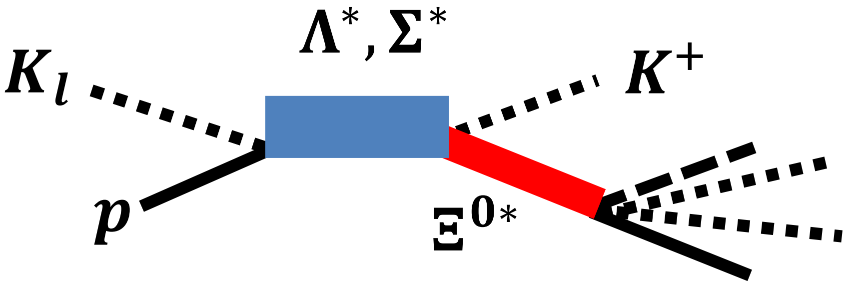
# $\Lambda^* \ \& \ \Sigma^*$ spectrum

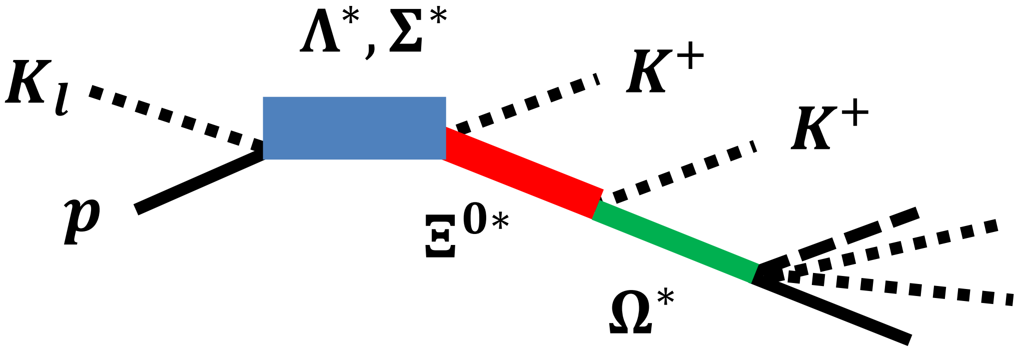


All reactions have charge particle originating from primary vertex:

- Define vertex position
- Set the “stop time” for TOF

# Cascades & Omegas





# General reconstruction remarks

- Vertex position and stopping time are defined by the leading charged particle
- At least one charged particle from the primary vertex

  Except $K_l n \rightarrow K_s n$ & $K_l n \rightarrow \pi^0 \Lambda$ reactions
- Standard particle ID
- higher exclusivity <-> smaller acceptance:

  4M events $K_l p \rightarrow K^+ \Xi^0$, (measured, reconstructed). Enough for $d\sigma/d\Omega$

  0.4M events for $K_l p \rightarrow K^+ \Xi^0 \rightarrow K^+ \Lambda \pi^0$ (to extract $\Xi$ induced polarization)

# Exclusivity vs statistics

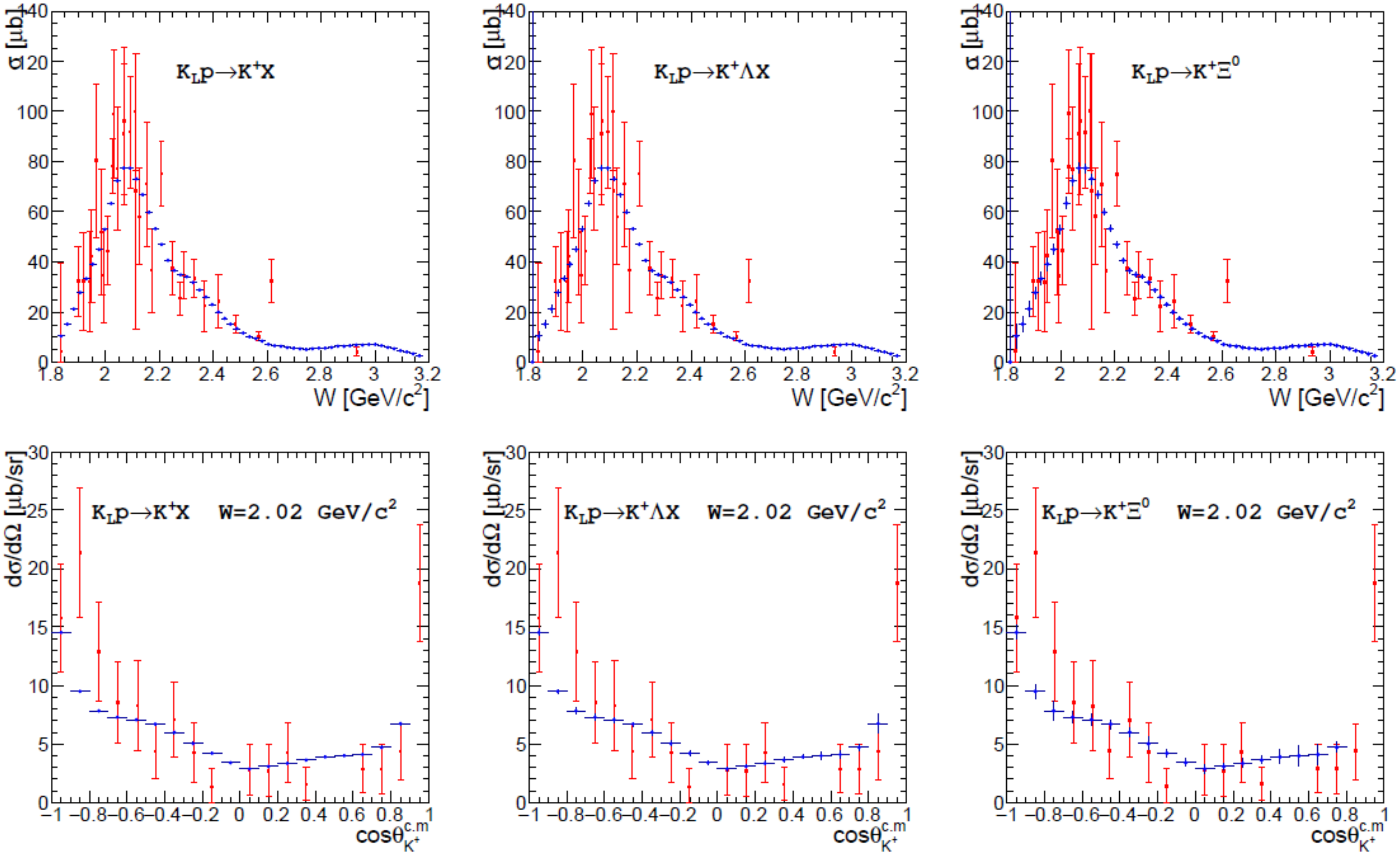
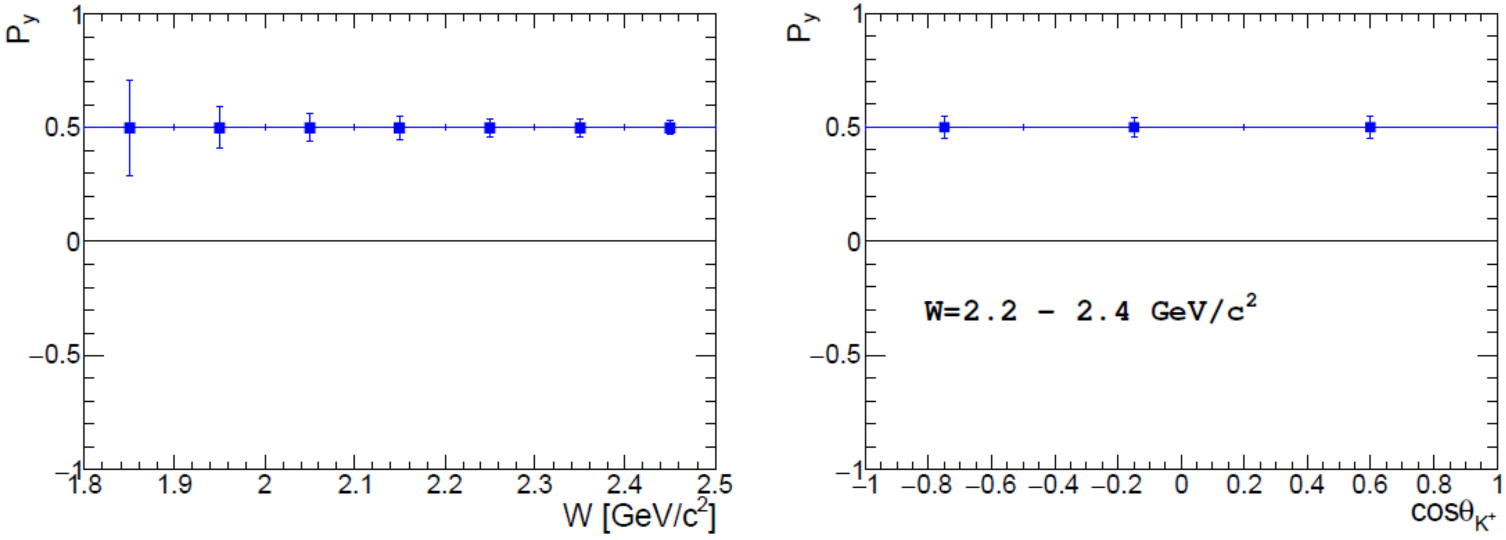


Figure 33: Total and differential cross section statistical uncertainty estimates (blue points) for the three topologies (column 1: only $K^+$ reconstructed, column 2: $K^+\Lambda$ reconstructed, and column 3: $K^+\Xi^0$ reconstructed) in comparison with data taken from Ref. [143] (red points).

# Recoil polarization

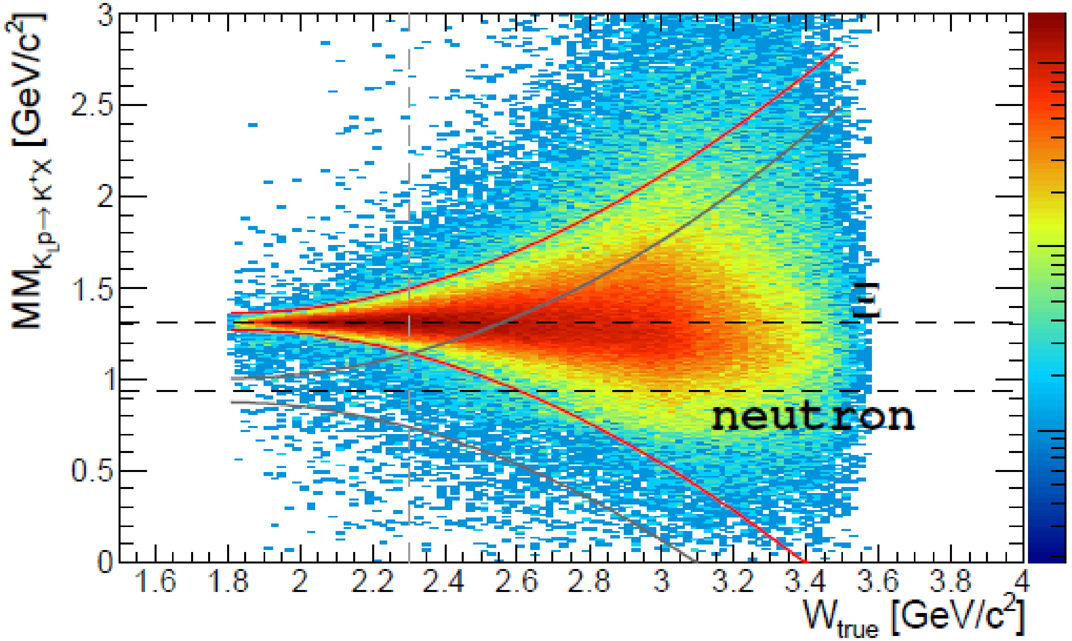
$$K_l p \rightarrow K^+ \overrightarrow{\Xi^0} \rightarrow K^+ \vec{\Lambda} \pi^0 \rightarrow K^+ p \pi^- \pi^0$$



(measured, reconstructed)

Estimates of the statistical uncertainties of the induced polarization of the cascade as a function of W (one-fold differential) and $\cos(\Theta_{K^+})$ (two-fold differential)

# $K_l p \to K^+ \Xi^0$ Background



- $K_l p \to K^+$n
- $K_l p \to \pi^+ X$ with pion misidentification
- $np \to K^+ X$
- $np \to \pi^+ X$ with pion misidentification

# Expected statistics in 100 days beamtime

| | Expected statistics | |
|---|---|---|
| **Reaction** | $\frac{\boldsymbol{d\sigma}}{\mathrm{d}\boldsymbol{\Omega}}$ | $\boldsymbol{P_y}$ |
| $K_l p \rightarrow K_s p$ | 8M | |
| $K_l p \rightarrow \Lambda\pi^+$ | 24M | |
| $K_l p \rightarrow K^+\Xi^0$ | 4M | 400k |
| $K_l p \rightarrow K^+ n$ | 200M | |
| $K_l p \rightarrow K^-\pi^+ p$ | 2M | |
| | | |
| | | |

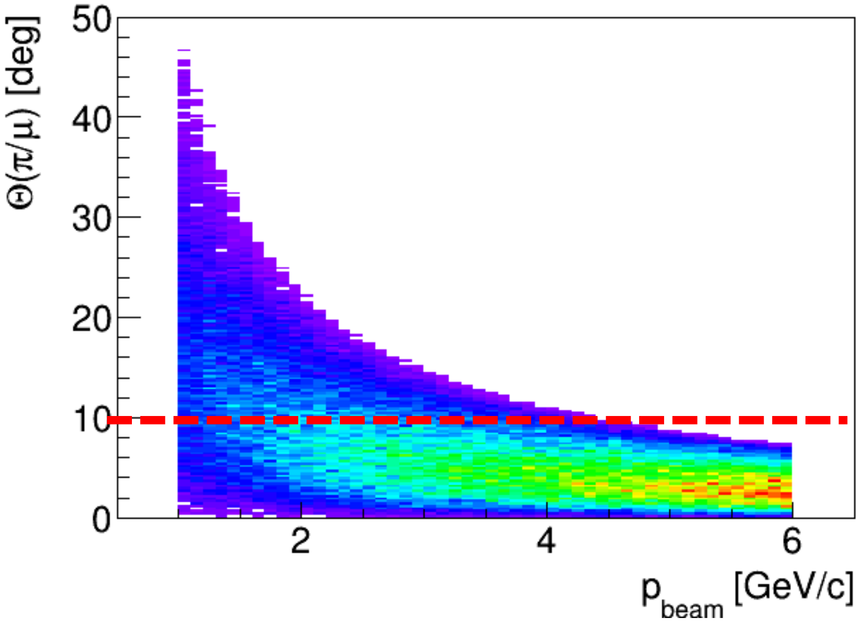
Similar statistics on neutron for 100 days LD2 target experiment

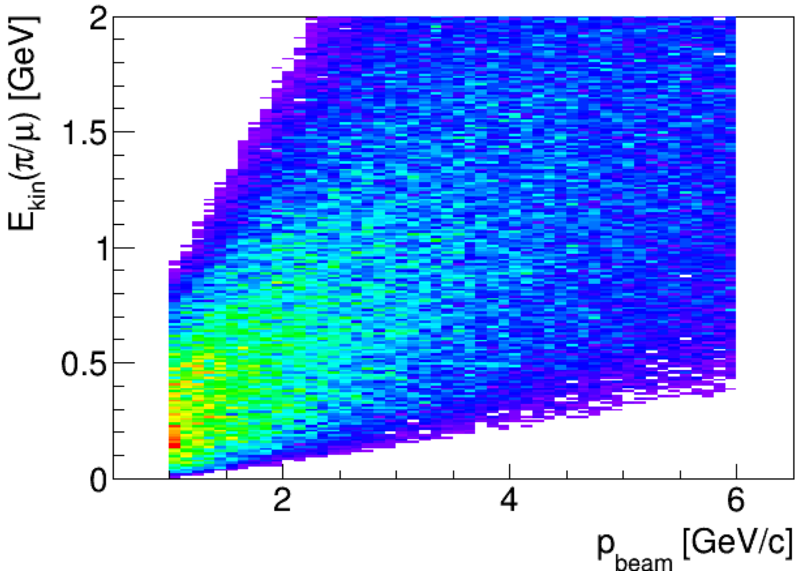
# FLUX MONITOR

# $K_l$ flux monitoring

- To get absolute cross section
- Flux = $f(W)$ – needs to be measured
- 30% of $K_l$decay on the way from Be to LH2
- Inflight $K_l \rightarrow \pi^{\pm}\mu^{\mp}\nu_{\mu}$ is an optimal choice
  - $\pi$ and $\mu$ masses are close -> same acceptance
  - Large branching $\mathrm{Br}(K_l \rightarrow \pi^{\pm}\mu^{\mp}\nu_{\mu}) = 27\%$
  - Can be measured precisely and accurately
  - Access to physics beyond the SM
    - $\pi^{+}\mu^{-}$vs $\pi^{-}\mu^{+}$ asymmetry
    - Search for sterile neutrino

# $K_l \rightarrow \pi^{\pm}\mu^{\mp}\nu_{\mu}$reaction kinematics



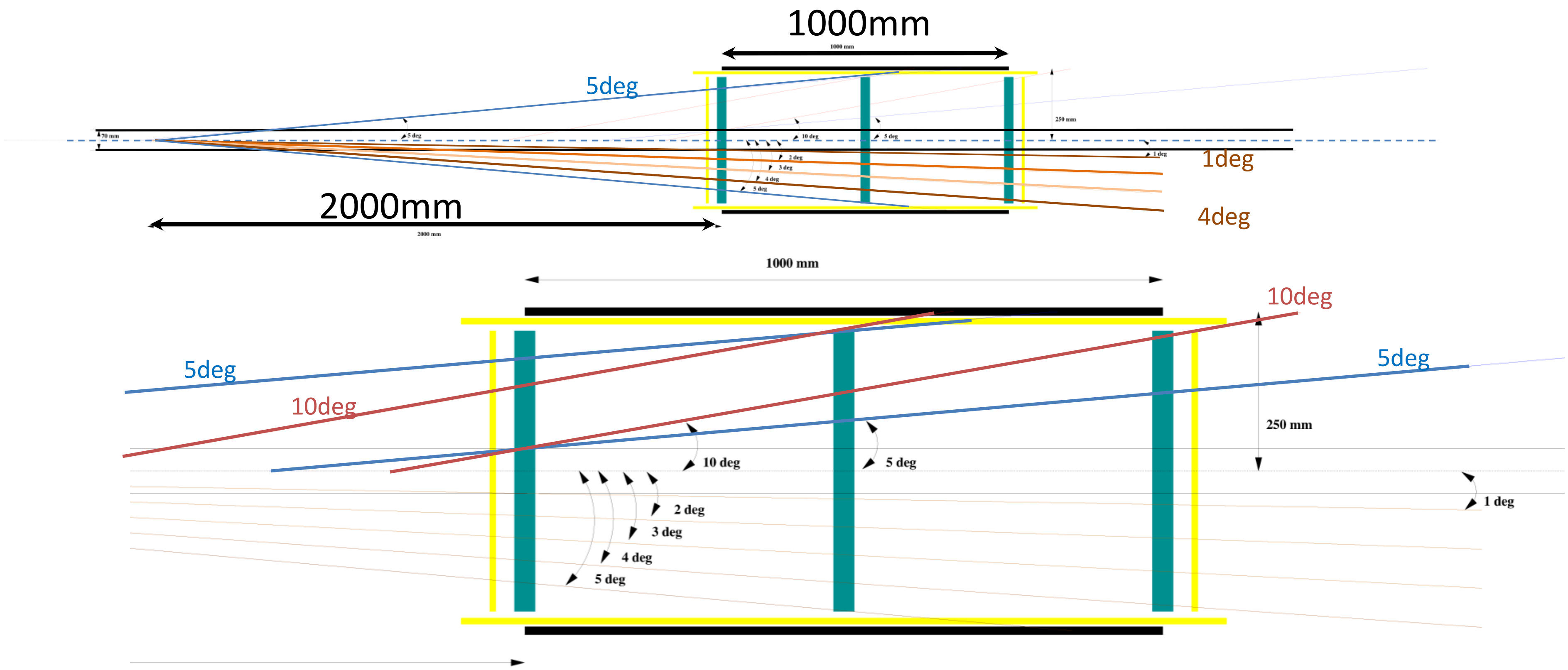


# Monitor requirements

- Simple, uniform geometry
  - Complicated acceptance would not allow accurate flux determination
- Cylindrically symmetrical
  - To avoid acceptance induced +/- asymmetries
  - Simplifies analysis
- Magnetic field (solenoid)
- Good timing for ToF $K_l$measurement
- Position determination

# $K_l F$ Monitor

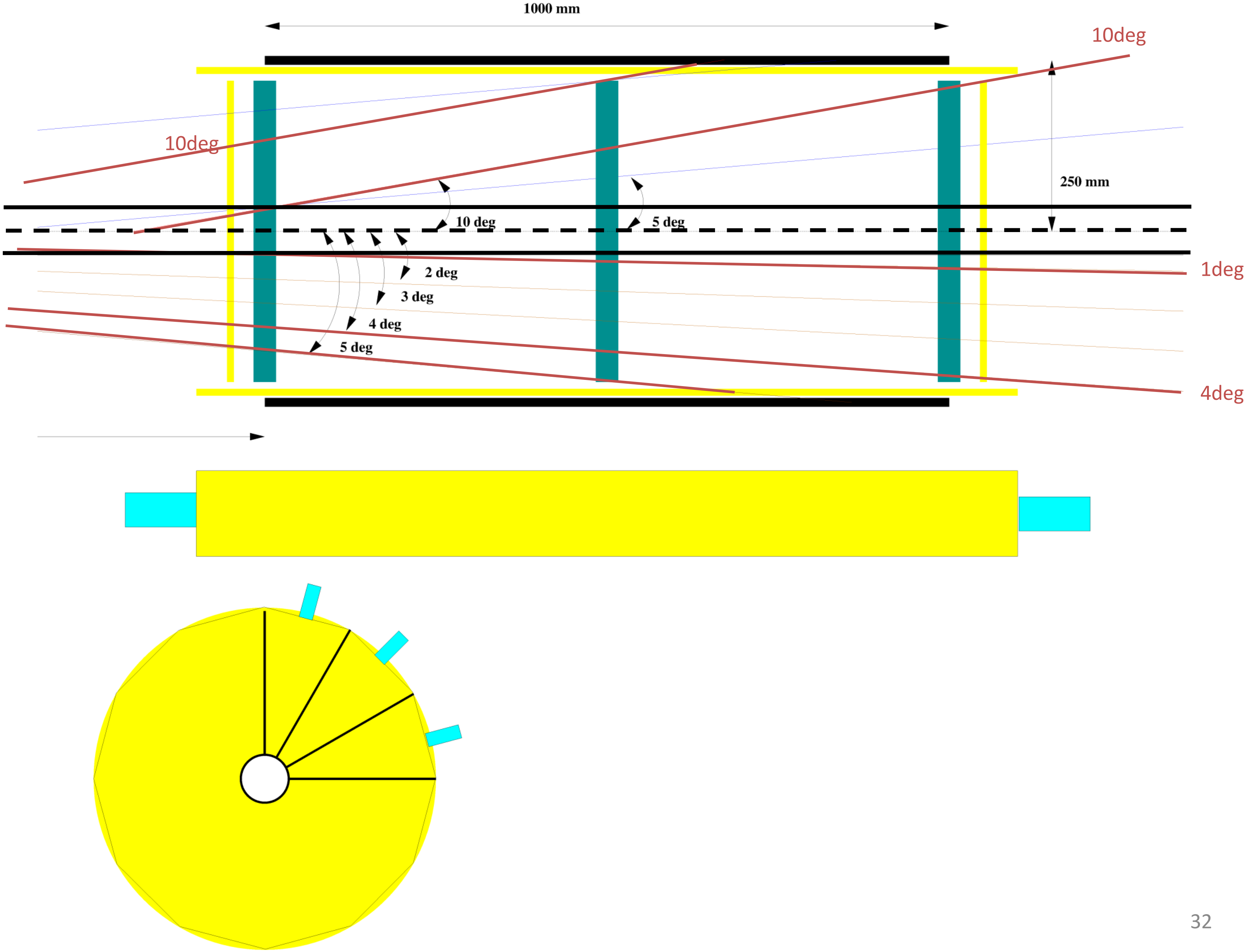
## Magnet, 1m long, 50 cm diameter



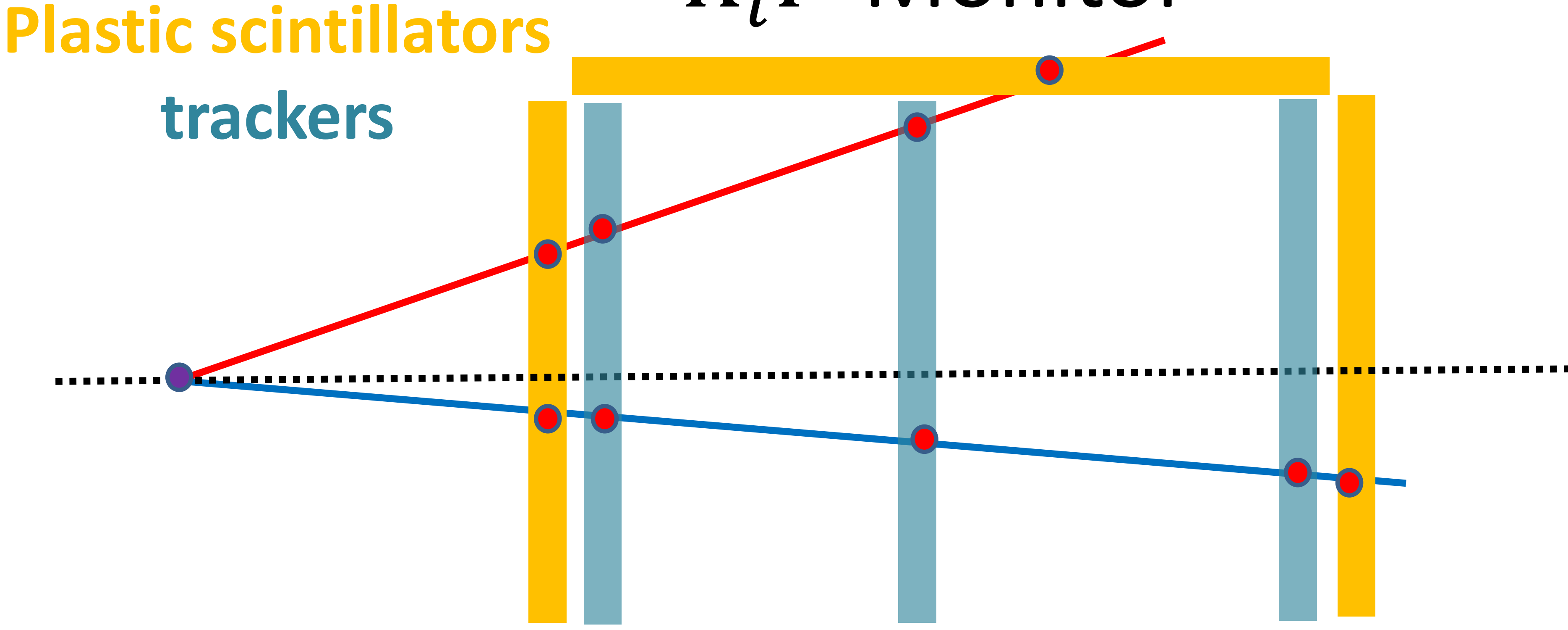
**Plastic scintillator**

**1 barrel, 2 end-cap Pizzas**

**3 trackers (MicroMeGaS)**


1000 mm
10deg
10deg
250 mm
10 deg
5 deg
2 deg
3 deg
4 deg
5 deg
1deg
4deg

# $K_l F$ Monitor



- Does not add material in beamline
- Will not influence the $\gamma$-beam experiments
- Precise $K_l$ momentum reconstruction
  - 10 MeV or better CM energy resolution
- Goal $\sim 1\%$ flux accuracy

# Conclusion

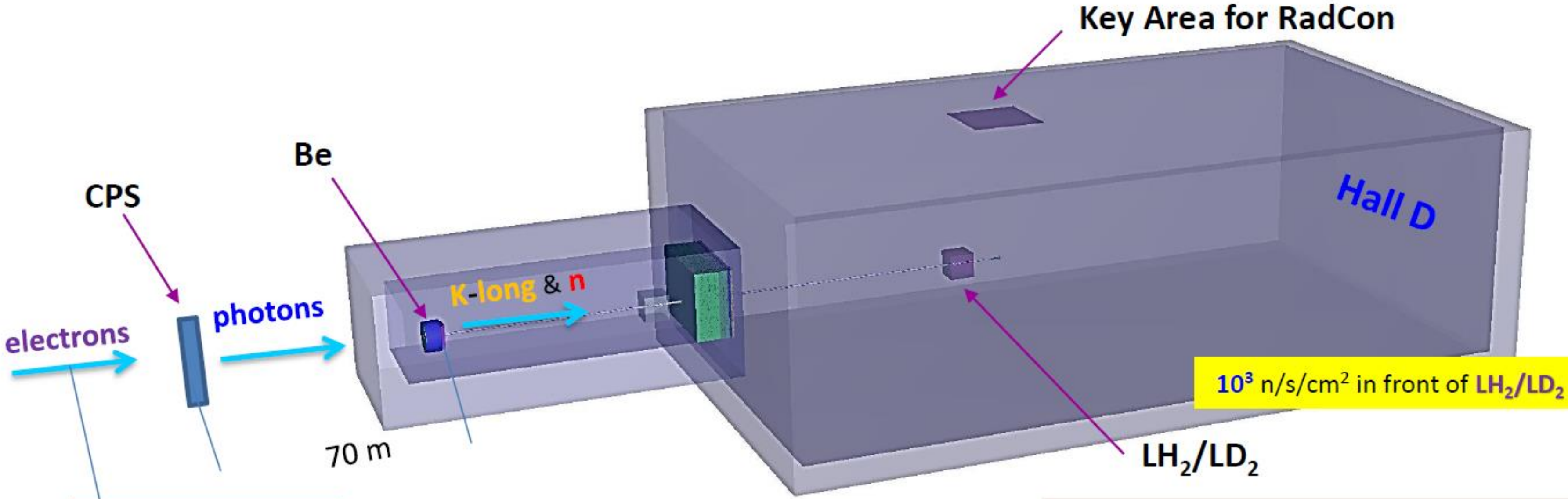
- $K_l$ physics programme is feasible
  - Detailed studies of various $K_l$ induced hyperon production reactions
  - Careful background evaluation
  - Neutron target methods inherited from $\gamma n$ quasi-free measurements on deuteron
- Dedicated $K_l$ Flux Monitor with uniform acceptance and small magnetic field is achievable

KLF proposal https://arxiv.org/pdf/1707.05284.pdf

# BACKUP

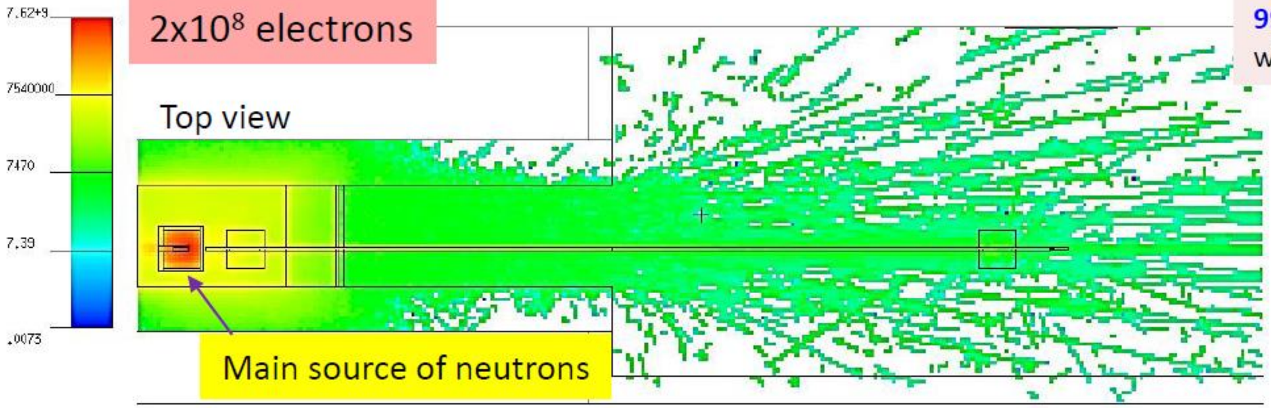
# *Expected Neutron Background*

- Most **important** & **unpleasant** **background** for **$K_L$** comes from **neutrons**.



$10^3$ n/s/cm$^2$ in front of LH$_2$/LD$_2$

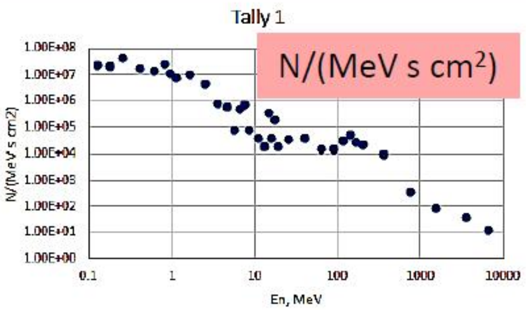
99% of neutrons associated with **T** < 90 MeV while 0.6% of them are for **T** > 125 MeV.



2x10$^8$ electrons

Top view

Main source of neutrons



N/(MeV s cm$^2$)

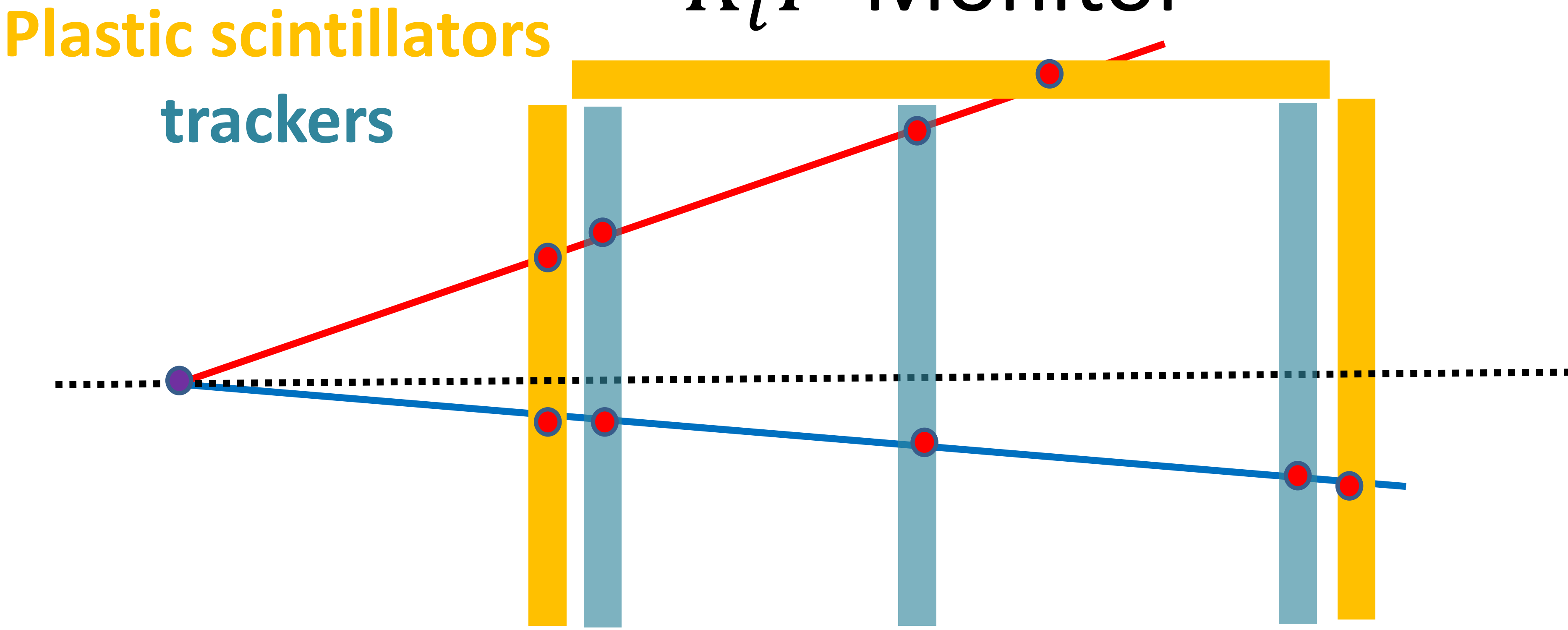
Neutron calculations with MCNP6 transport code

Courtesy to Igor Strakovsky

# $K_l$ decays

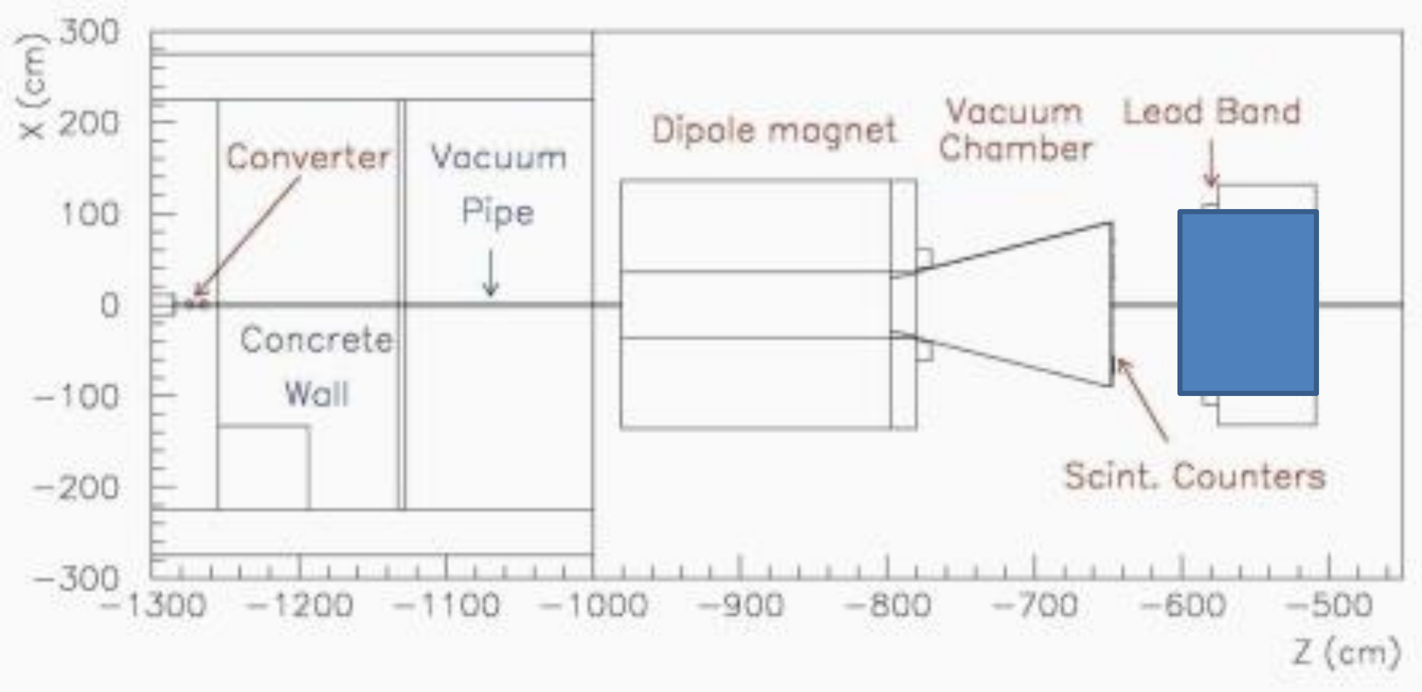
| | **Br, %** |
|---|---:|
| $K_l \to \pi^{\pm} e^{\mp} \nu_{\mu}$ | 40.55 |
| $K_l \to \pi^{\pm} \mu^{\mp} \nu_{\mu}$ | 27.04 |
| $K_l \to \pi^{+} \pi^{-} \pi^{0}$ | 12.54 |
| $K_l \to \pi^{0} \pi^{0} \pi^{0}$ | 19.52 |
| | |
| | |
| | |
| | |

# $K_l F$ Monitor



- **At least 2 double-hits in trackers**
  - **Accurate position determination**
- **2 or 3 time information per track**
  - **2 side readout for the barrel**
  - **6 or 7 time stamps per event**
- **Momentum vs TOF particle id**
- **No $K_l \to K_s$ converter**
  - **Compatible with $\gamma$ beam experiment**

- **$\pi\mu$ kinematics + TOF -> precise $K_l$ momentum reconstruction**
- **Consider 2nd barrel outside magnet for better $\pi/\mu$ separation**
- **10-20 deg $\phi$ displacement at 1T field**
  - **better tracker <-> smaller field**
- **Better than 10 MeV ΔW resolution**
- **Goal $\sim 1\%$ flux accuracy**


X (cm)
300
200
100
0
−100
−200
−300
−1300
−1200
−1100
−1000
−900
−800
−700
−600
−500
Z (cm)
Converter
Vacuum
Pipe
Concrete
Wall
Dipole magnet
Vacuum
Chamber
Lead Band
Scint. Counters


CAUTION
CAUTION
STRONG MAGNETIC FIELD
CAUTION
THIN VACUUM
WINDOW
Hearing Protection
Required Beyond This Point