P89

Investigation of Fundamental Properties of the $\bar{K}NN$ state

To get the stage-1 status

The 39th J-PARC PAC Meeting
Takumi Yamaga (KEK-IPNS)

Short summary

Beam-time request

2 + (1+8) weeks ⊗ 90 kW @ K1.8BR

(162+648 kW·week @ 90% up-time)

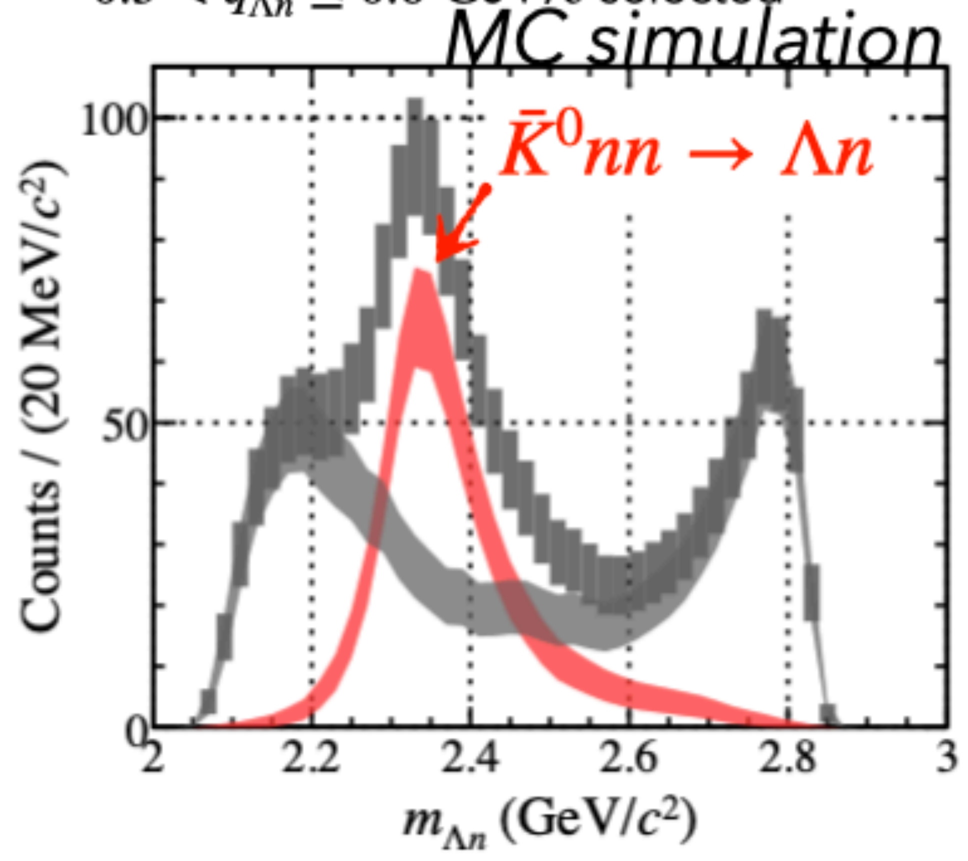
Expected results

2 weeks ⊗ 90 kW

To confirm $I = 1/2\ \bar{K}NN$ doublet

Measurement for Λn pair

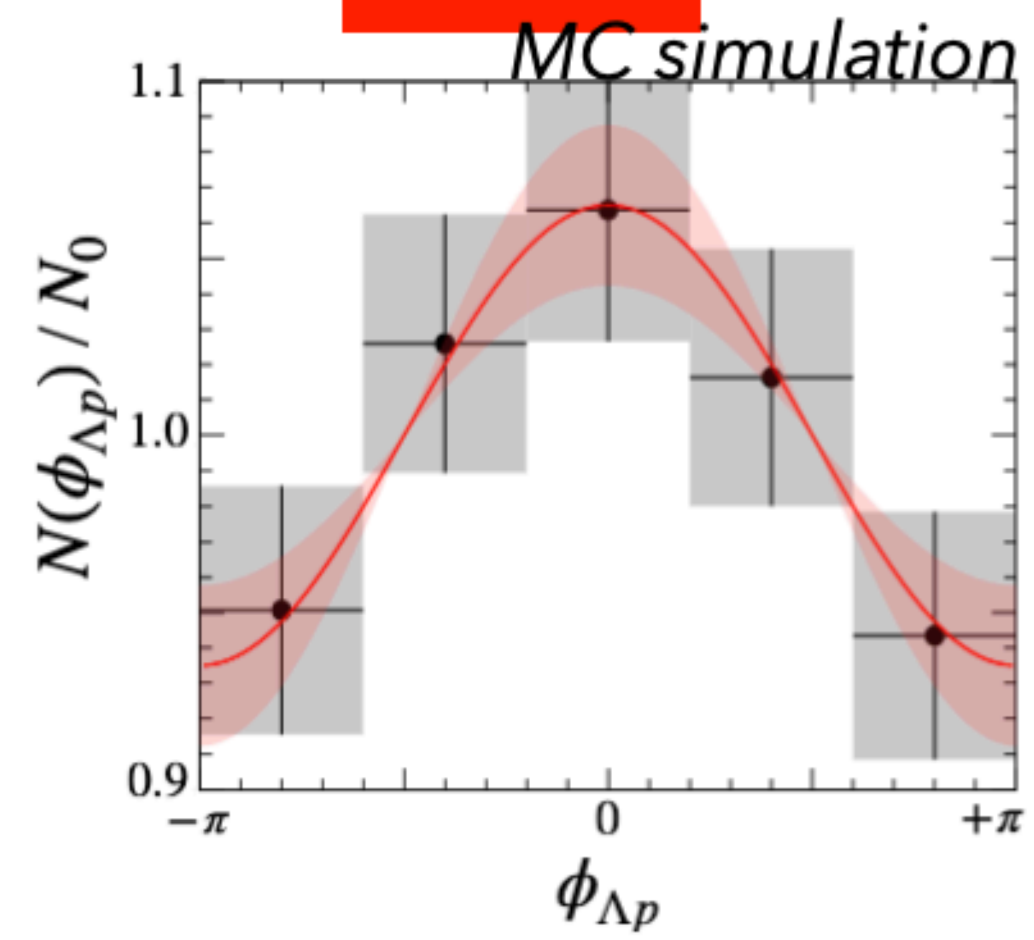
*Assuming $J^P = 0^-$ (strict case)



8 weeks ⊗ 90 kW

To determine J^P of $\bar{K}NN$

$J^P = 0^-$



Comments from the 32nd PAC

…
E80 is at stage-1 status but is not yet stage-2 approved. We await the TDR to be submitted for E80 in due course. Then we would like to see the detailed feasibility of P89.

E80 has been stage-2 approved.
It is time to discuss the feasibility of P89!

(E80 : Experiment for $\bar{K}NNN$)

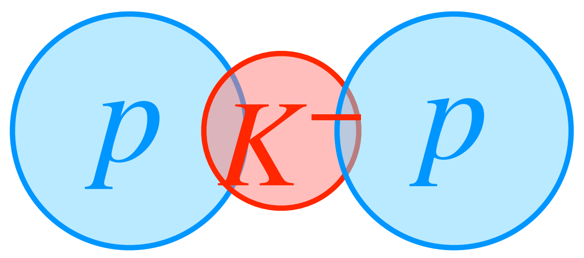
Introduction

The lightest kaonic nucleus, – $\bar{K}NN$ –

$\bar{K}NN$ bound state

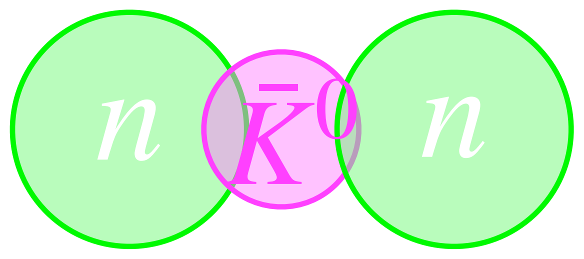
Bound system of anti-kaon and two nucleons

$$\left[\bar{K}_{I=\frac{1}{2}} (NN)_{I=1}\right]_{I=\frac{1}{2}} \quad (J^P = 0^-)$$

$I^{(z)}_{\bar{K}NN} = +1/2$ 

"K^-pp"

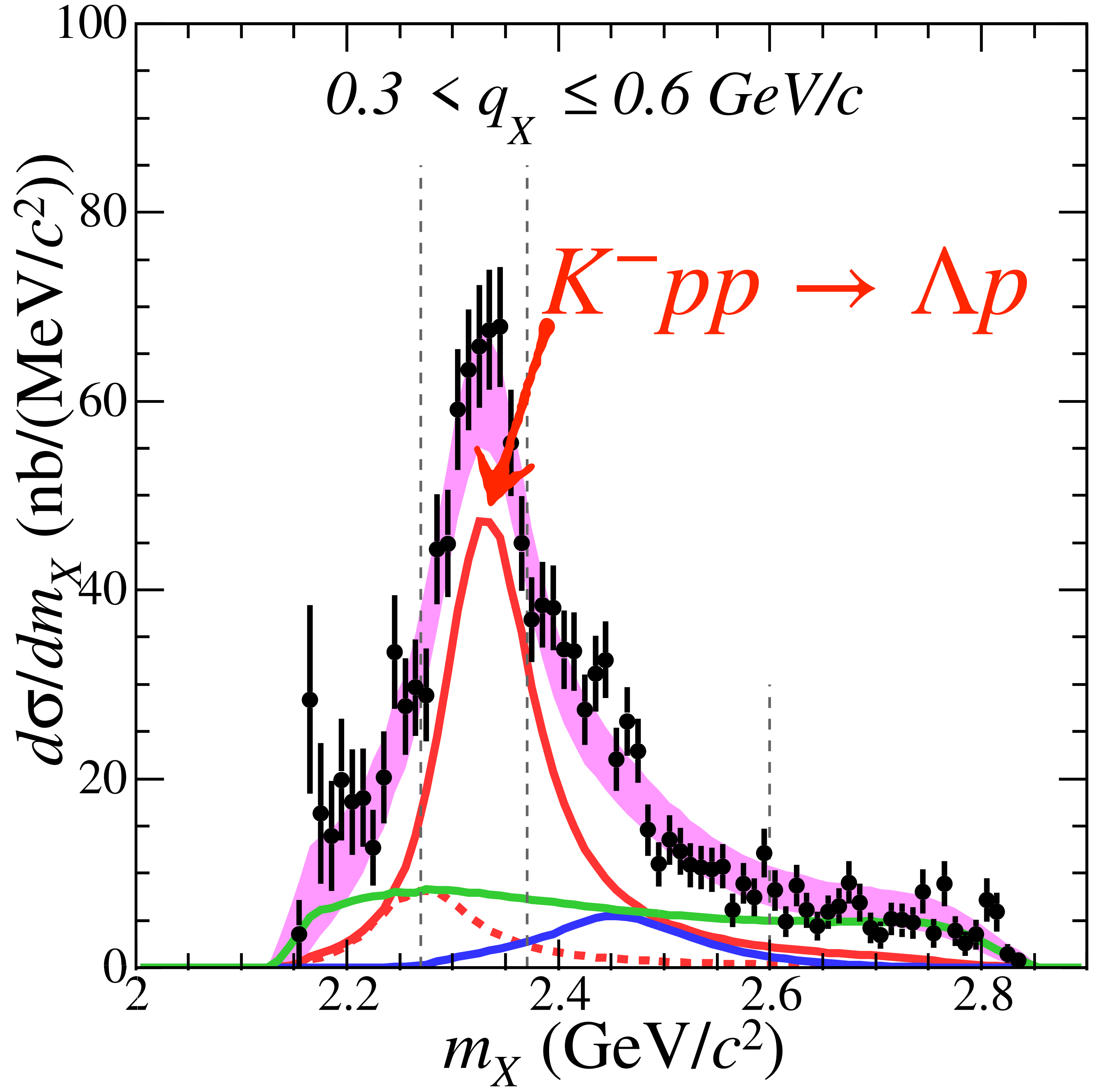
$(K^-pp$ - $\bar{K}^0pn)$

$I^{(z)}_{\bar{K}NN} = -1/2$ 

"$\bar{K}^0nn$"

$(\bar{K}^0nn$ - $K^-pn)$

Phys. Rev. C102(2020)044002



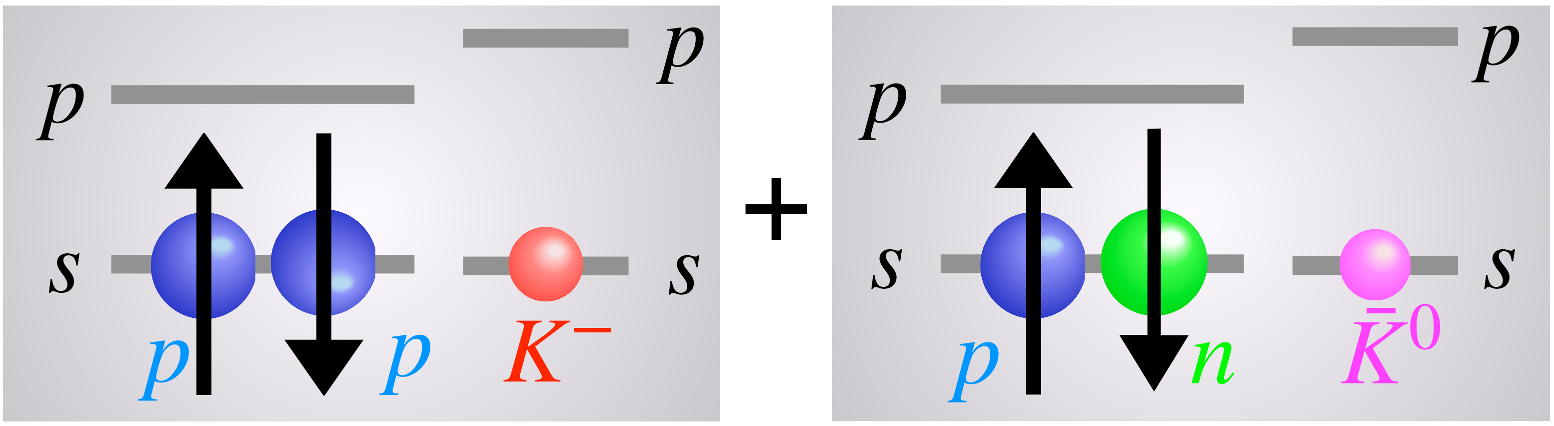
A clear formation signal of K^-pp was observed.

Internal structure & spin-parity

There are two possible J^P as for the $\bar{K}NN$ ground state.

" $(NN)_{(I.sym \times S.asym)} \otimes \bar{K}$ "

$J^P = 0^-$

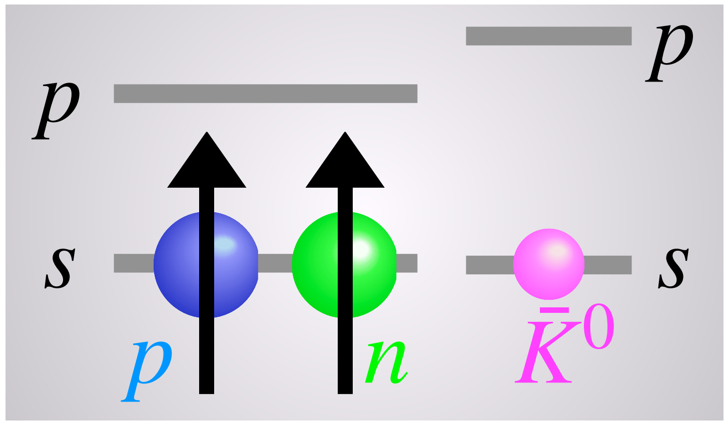


$$\frac{|I_{\bar{K}N} = 0|^2}{|I_{\bar{K}N} = 1|^2} = \frac{3}{1}$$

Deeper bound expected

" $(NN)_{(I.asym \times S.sym)} \otimes \bar{K}$ "

$J^P = 1^-$

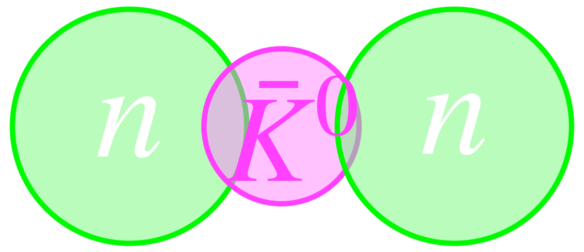


$$\frac{|I_{\bar{K}N} = 0|^2}{|I_{\bar{K}N} = 1|^2} = \frac{1}{3}$$

Shallower bound expected

What we need to do about $\bar{K}NN$

"$\bar{K}^0 nn$"

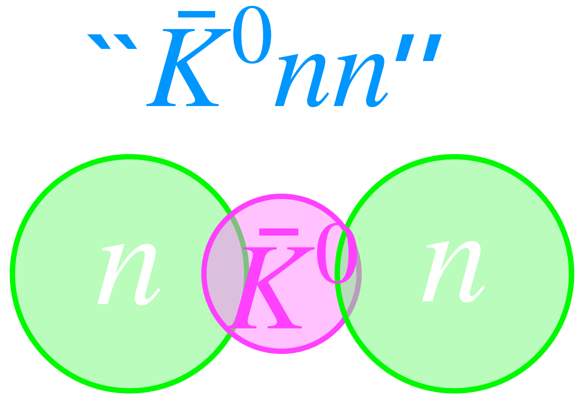


should be observed

to confirm the state is isospin doublet.

J^P should be determined

to understand the internal structure of the state.



should be observed

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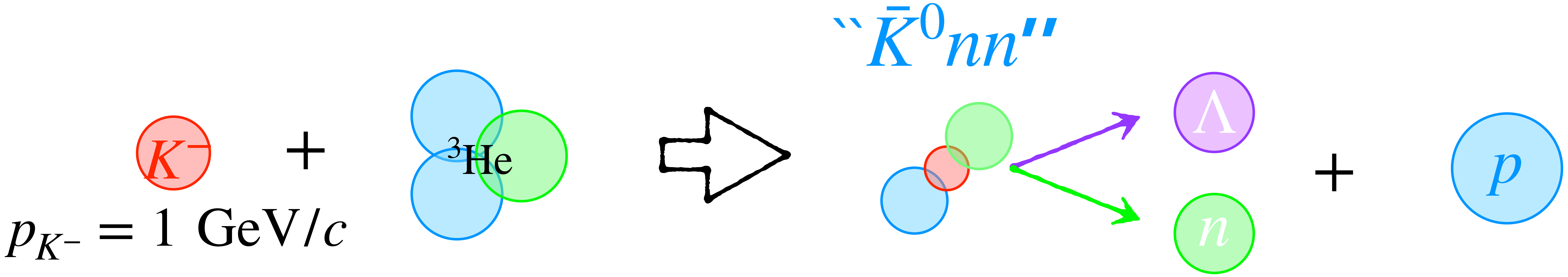
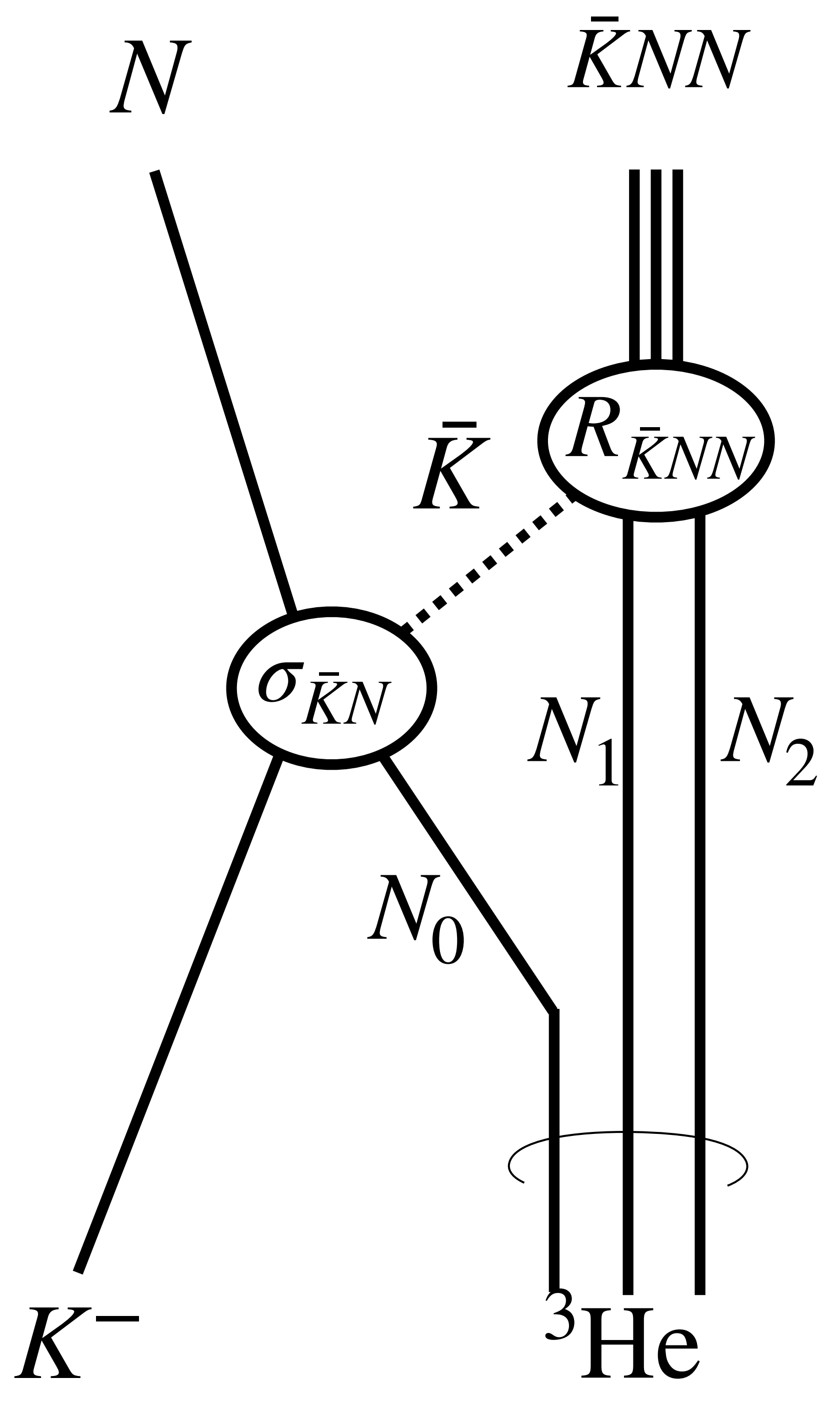


Estimation of Production C.S. of $\bar{K}^0 nn$



$$\sigma^{J^P}_{I^{(z)}_{\bar{K}NN}} = R_{\bar{K}NN} \times \sum_{\bar{K}N} \left(\sigma_{\bar{K}N} \times C^2_{I_{NN}} \times C^2_{I^{(z)}_{\bar{K}NN}} \times \mathscr{A}_N \right)$$

$R_{\bar{K}NN}$: Formation probability – *Common* –

$\sigma_{\bar{K}N}$: Elementary CSs @ $\theta_N = 0°$

$I^{(z)}_{\bar{K}NN} = +1/2$	$\sigma_{K^-n} = 4.7$ (mb/sr) or $\sigma_{\bar{K}^0 n} = 2.4$ (mb/sr)
$I^{(z)}_{\bar{K}NN} = -1/2$	$\sigma_{K^-p} = 1.8$ (mb/sr)

$C^2_{I_{NN}}$: Isospin coupling of $I_{N_1} \otimes I_{N_2}$

	$J^P = 0^-$	$J^P = 1^-$
$I^{(z)}_{\bar{K}NN} = +1/2$	1/2 or 1	1/2 or 0
$I^{(z)}_{\bar{K}NN} = -1/2$	1/2	1/2

$C^2_{I^{(z)}_{\bar{K}NN}}$: Isospin coupling of $I_{\bar{K}} \otimes I_{NN}$

	$J^P = 0^-$	$J^P = 1^-$
$I^{(z)}_{\bar{K}NN} = +1/2$	1/3 or 2/3	1
$I^{(z)}_{\bar{K}NN} = -1/2$	1/3	1

$\mathscr{A}_N$: Effective nucleon number

neutron	1
proton	$2^{2/3} \sim 2$

Estimation of Production C.S. of $\bar{K}^0 nn$

$\sigma_{K^- pp} \cdot Br_{\Lambda p}$

$9.3\ \mu b$

Measured in E15

$\sigma_{\bar{K}^0 nn} \cdot Br_{\Lambda n}$

*Assuming $\mathscr{A}_p = 2^{2/3}$, $Br_{\Lambda n} = Br_{\Lambda p}$

$J^P = 0^-$

$1.2\ \mu b$

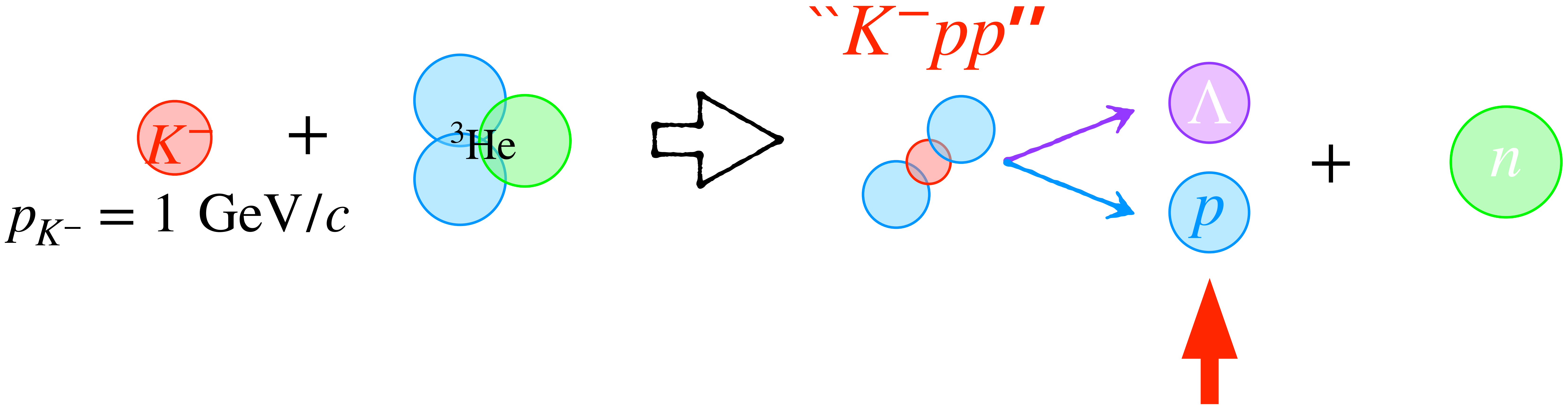
$J^P = 1^-$

$7.0\ \mu b$

Production C.S. of $\bar{K}^0 nn$ is expected to be large enough.

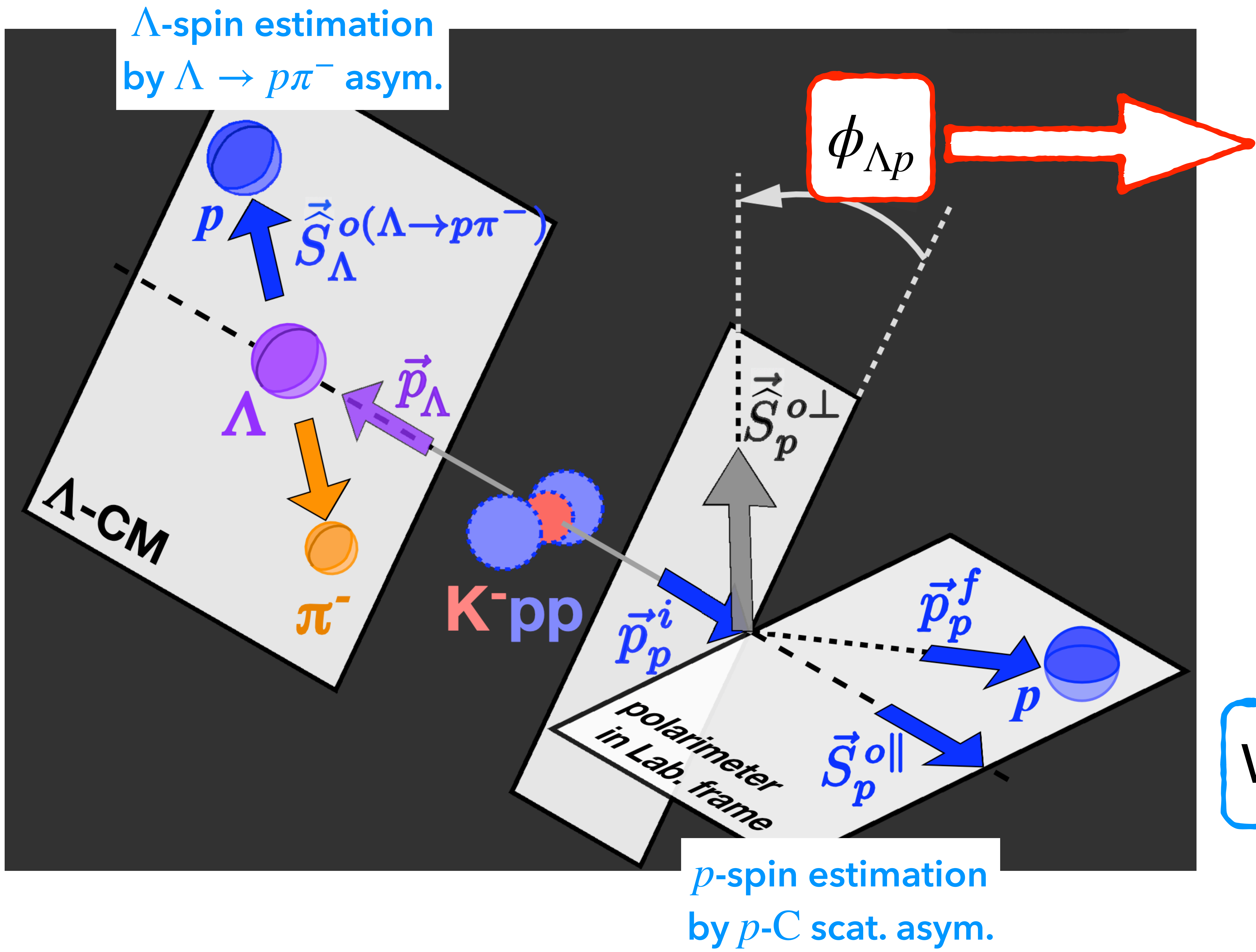
J^P should be determined

to understand the internal structure of the state.



Measuring the spin-spin correlation of Λ & p

How to measure the spin-spin correlation



Spin-spin correlation on ϕ-asymmetry

$$N(\phi_{\Lambda p}) = N_0 \cdot (1 + r^{(J^P)} \cdot \alpha_{\Lambda p} \cos \phi_{\Lambda p})$$

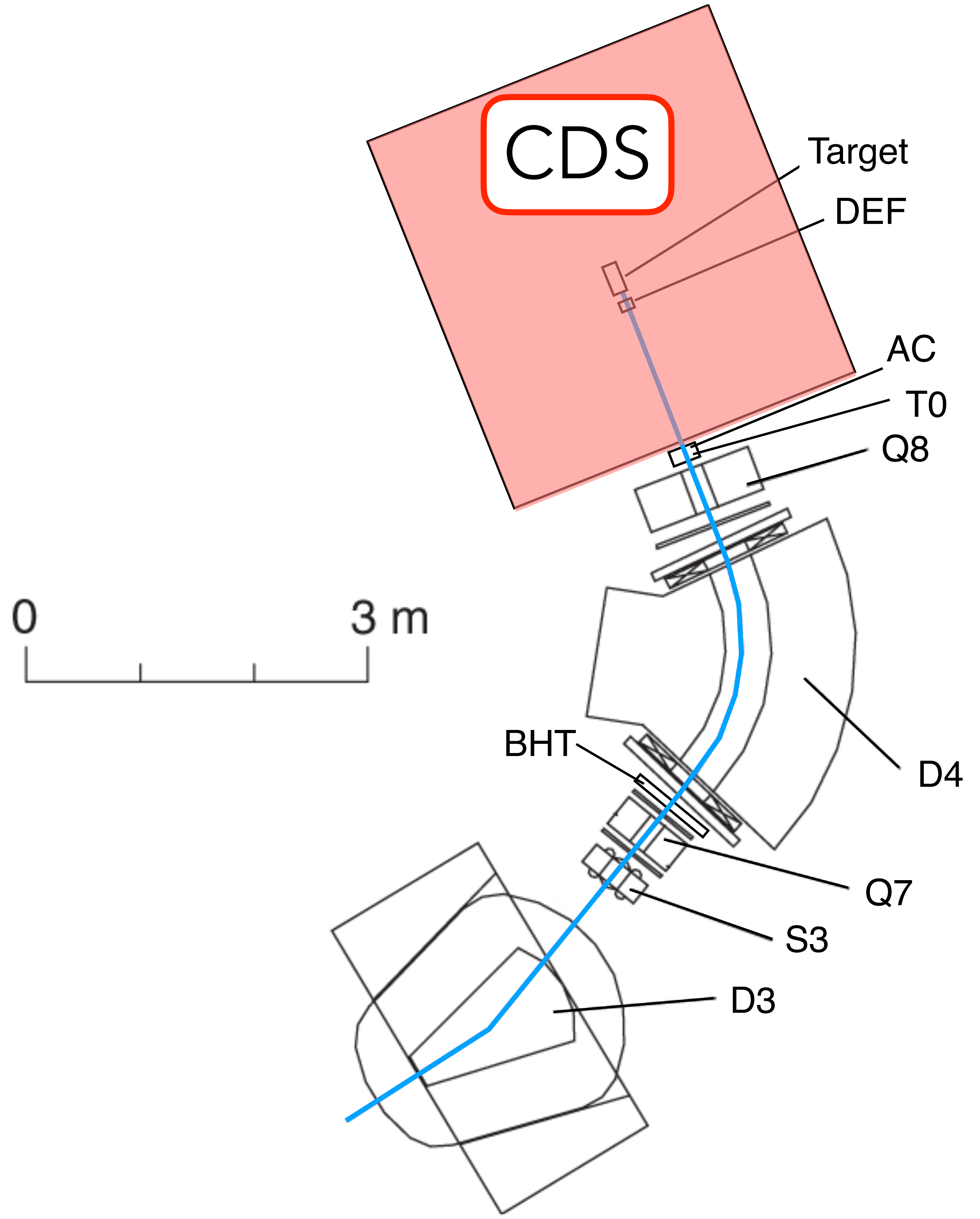
$r^{(J^P)}$: asymmetry reduction factor defined by;

- α_- : Λ asym. parameter
- A_{pC} : Analyzing power
- $f_{\vec{S}_\Lambda}$: Spin distribution
- B : Magnetic field
- $B_{\bar{K}}$: Binding energy
- q : Momentum transfer

We can deduce $\alpha_{\Lambda p}$ from $\phi_{\Lambda p}$-distribution.

Experiment

K1.8BR Beamline



Conceptual design in E80 proposal

https://j-parc.jp/researcher/Hadron/en/pac_2007/pdf/P80_2020-10.pdf

Expected K^--beam intensity (1 GeV/c)

$\sim$ 250 k /spill on target (@ 90kW)

Kaon purity

$K/\pi \sim 1/2$

Luminosity per week

As a result of
increasing beam intensity & ^{3}He amount

$\sim 6\ \mathrm{nb}^{-1}/\mathrm{week}$

c.f.) Integrated luminosity in E15

$2.89\ \mathrm{nb}^{-1}$

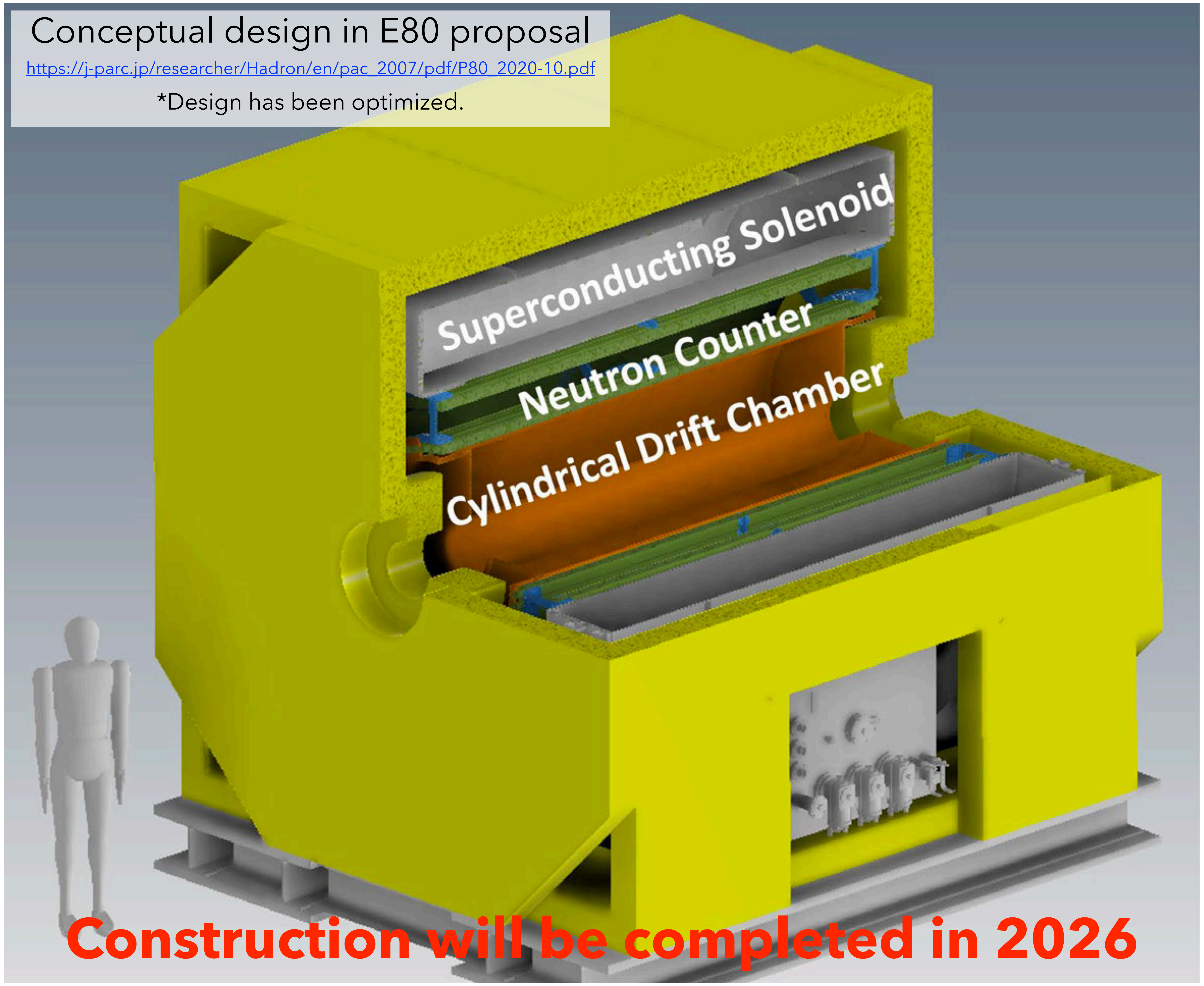
Expected trigger rate

$\sim$ 10000 /spill

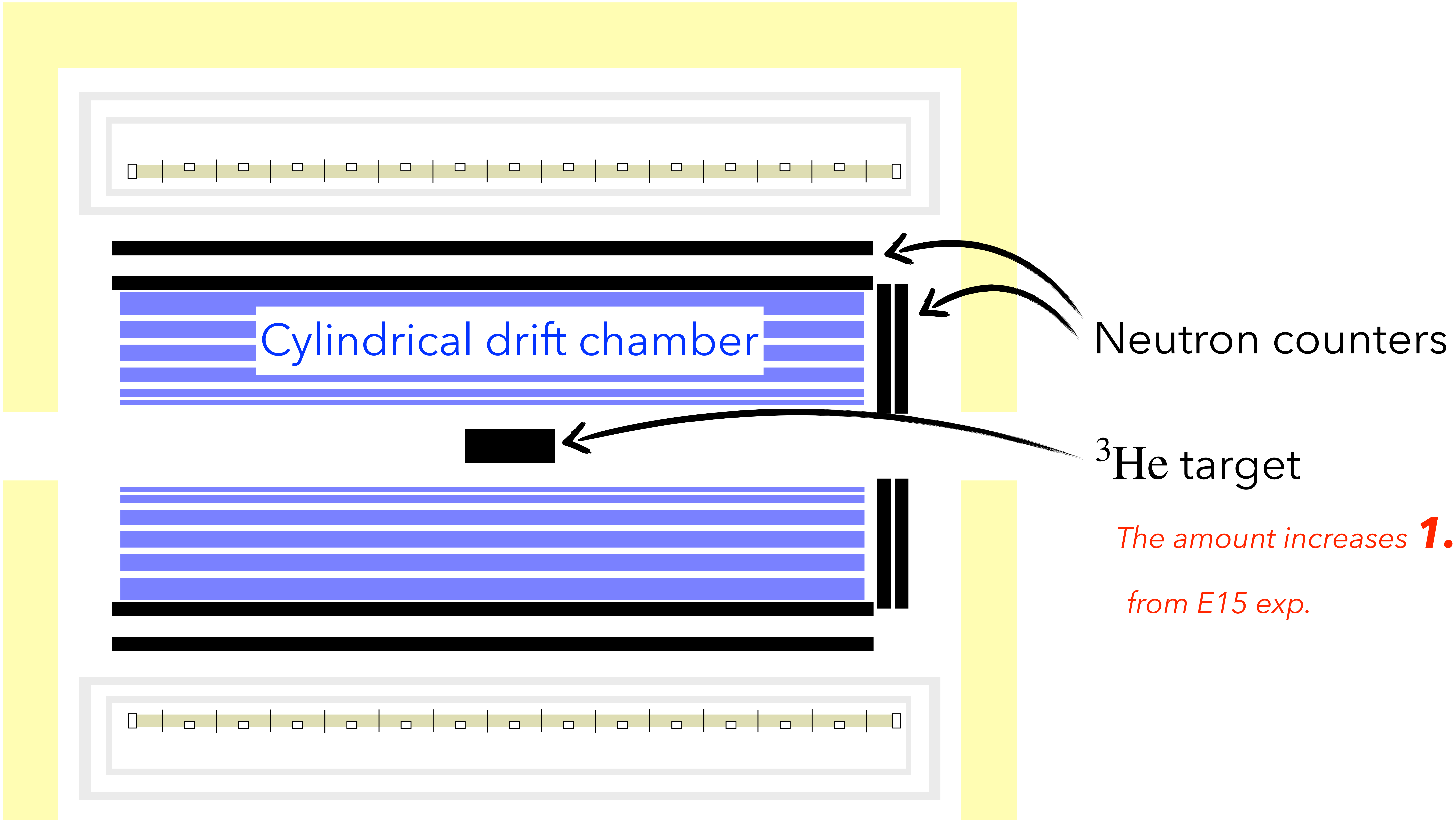
Rate capability of existing DAQ

>90% efficiency up to $\sim$ 10000/spill

Cylindrical Detector System for E80



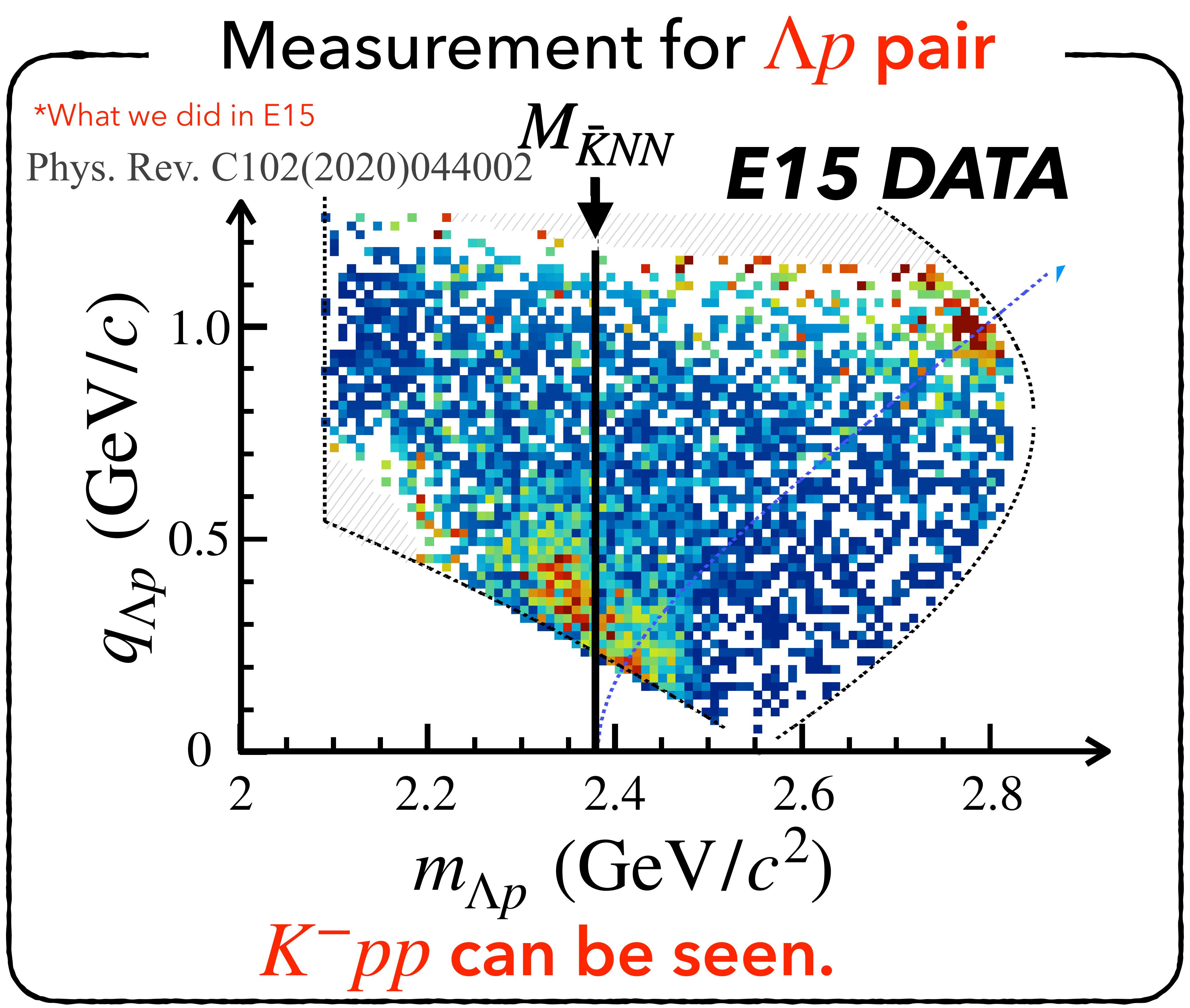
Cylindrical Detector System for E80

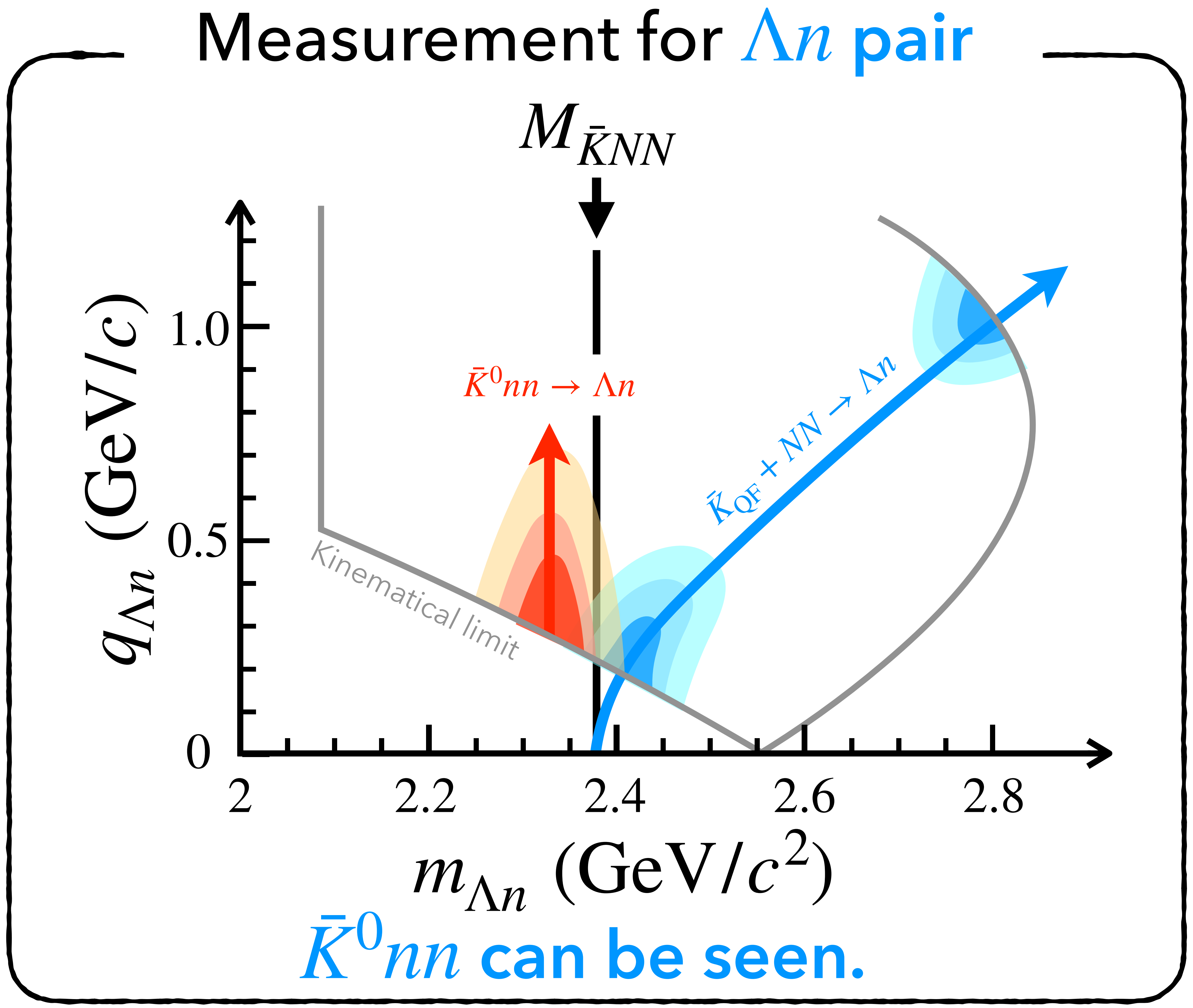


The amount increases ***1.5 times***

from E15 exp.

Expected spectra of $\bar{K}NN$





$\bar{K}^0 nn$ can be seen by the same manner as $K^- pp$

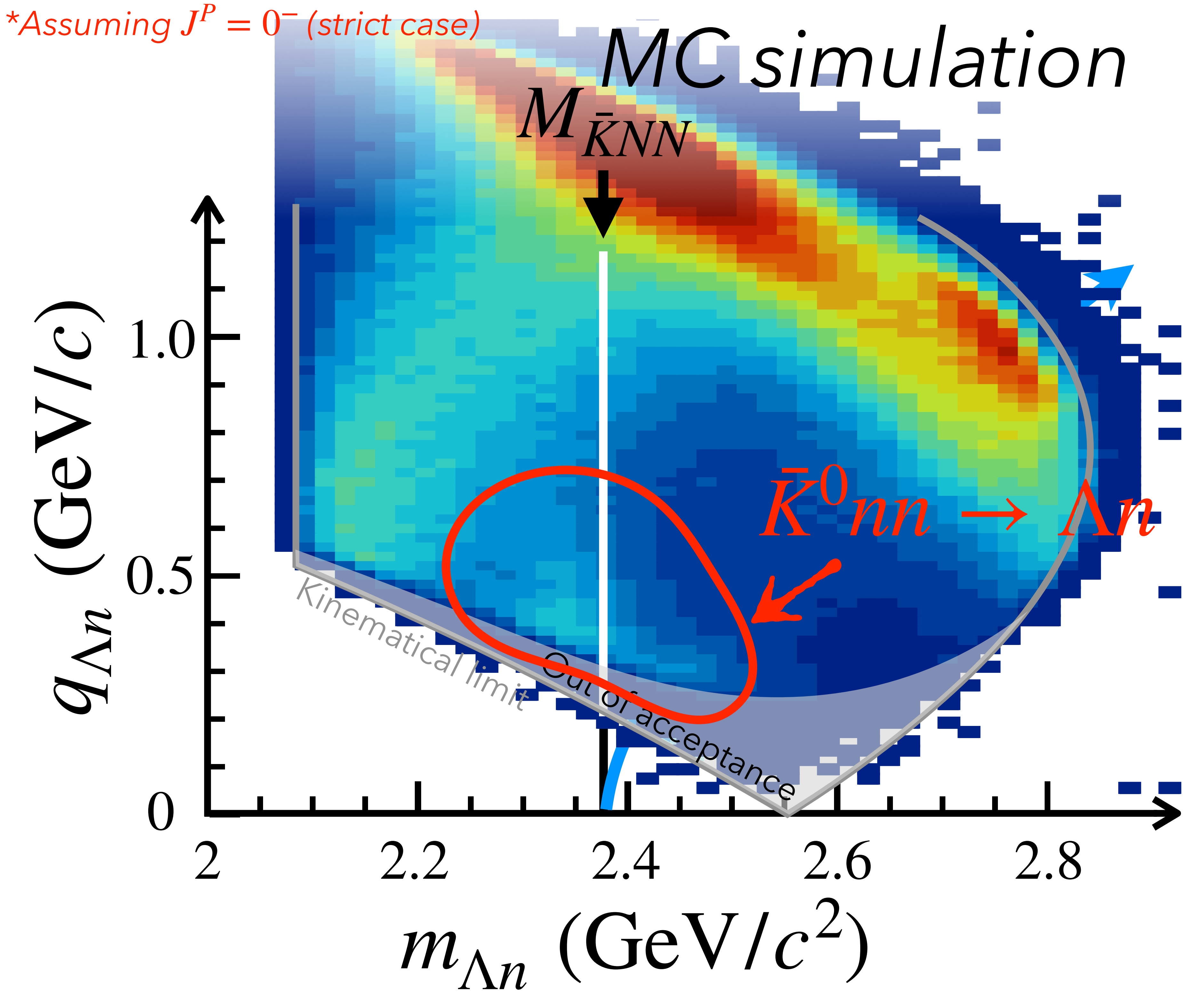
Expected spectra of $\bar{K}^0 nn$

$J^P = 0^-$

1.2 μb

2 weeks $\otimes$ 90 kW

Measurement for Λn pair



Expected spectra of $\bar{K}^0 nn$

$J^P = 0^-$

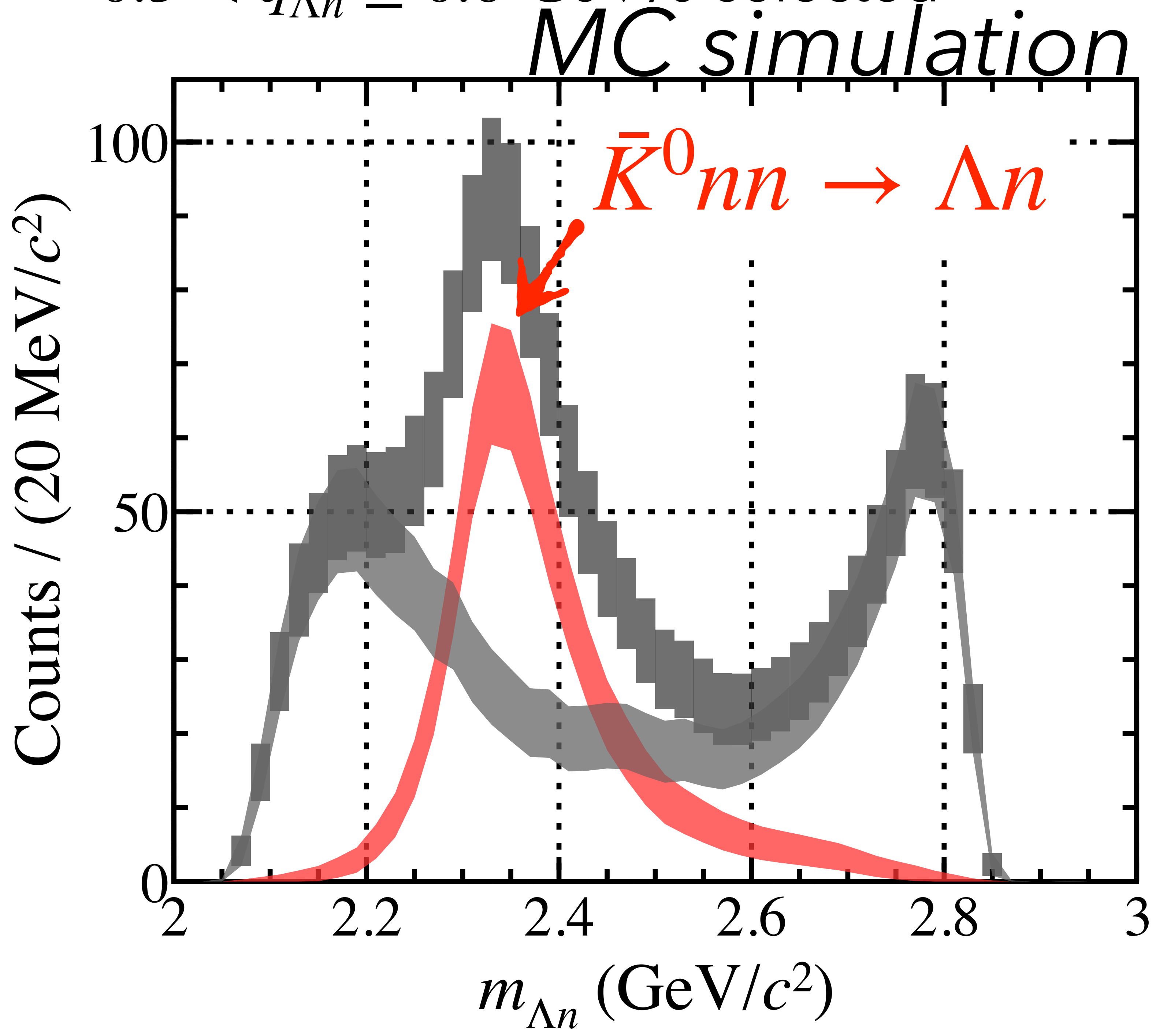
1.2 μb

2 weeks $\otimes$ 90 kW

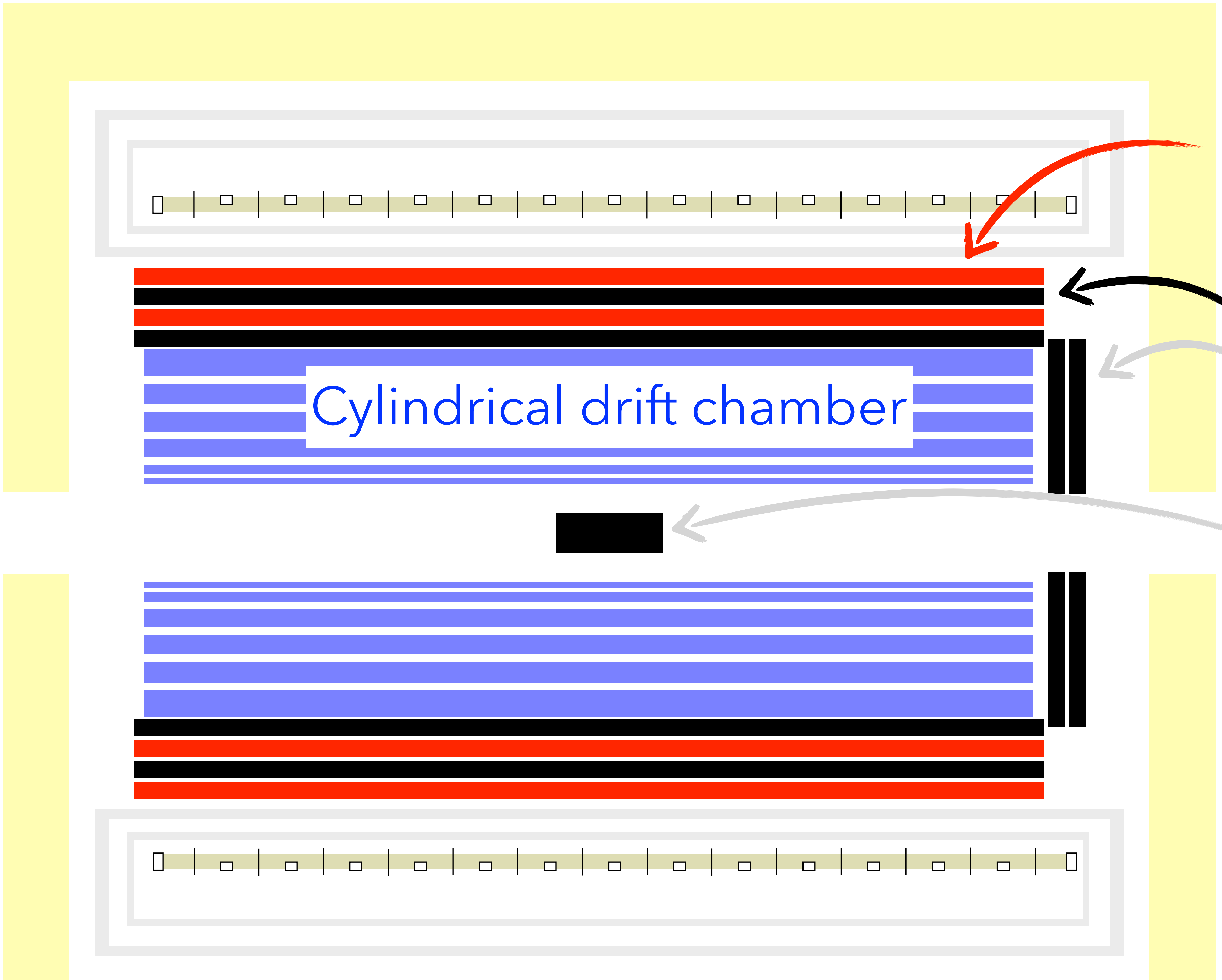
Measurement for **Λn pair**

*Assuming $J^P = 0^-$ (strict case)

$0.3 < q_{\Lambda n} \leq 0.6$ GeV/c selected



Polarimeter for spin-spin corr. Measurement



Tracker for polarimeter

The optimal configuration is under consideration.

Neutron counters

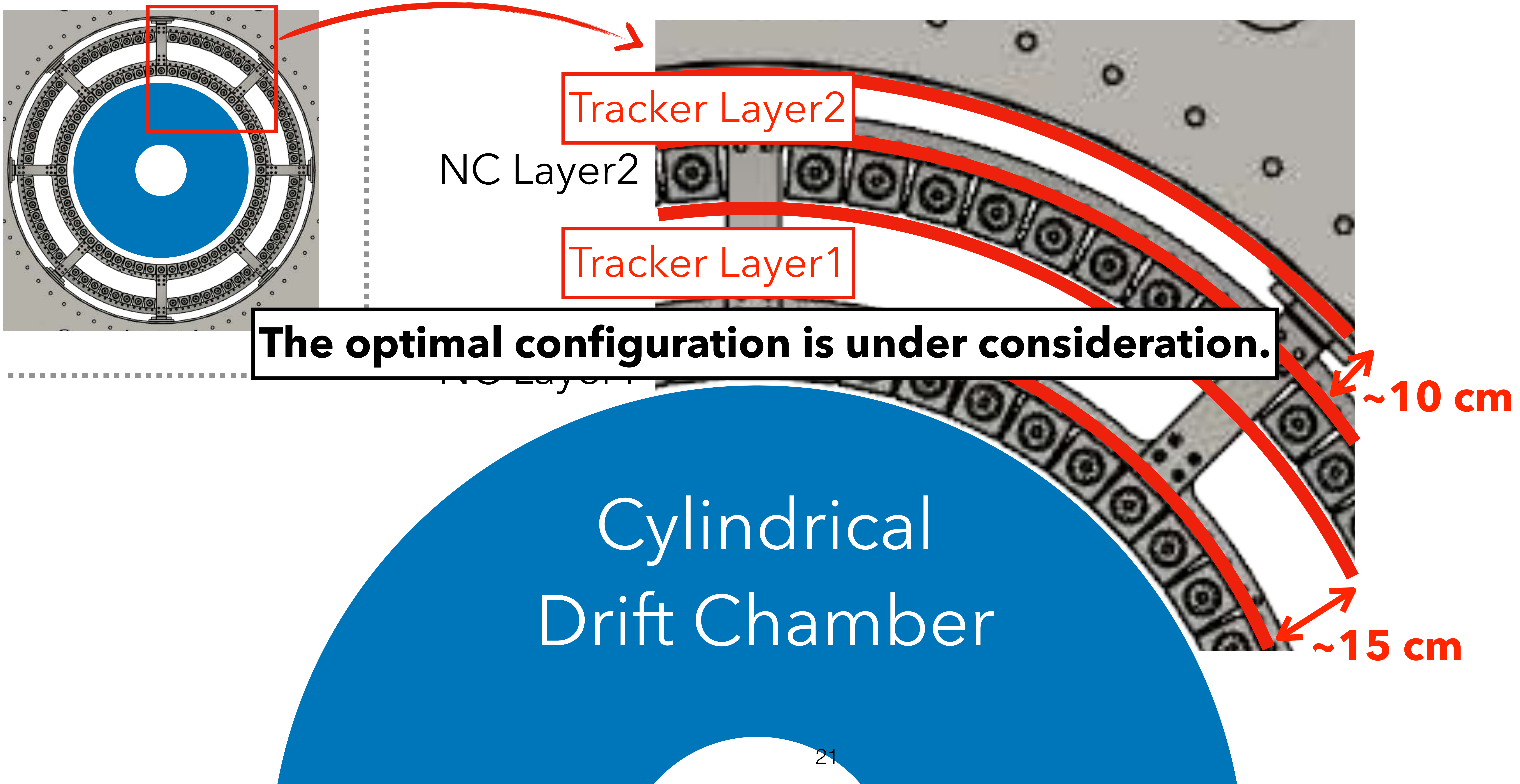
as scattering target

^{3}He target

The amount increases ***1.5 times***

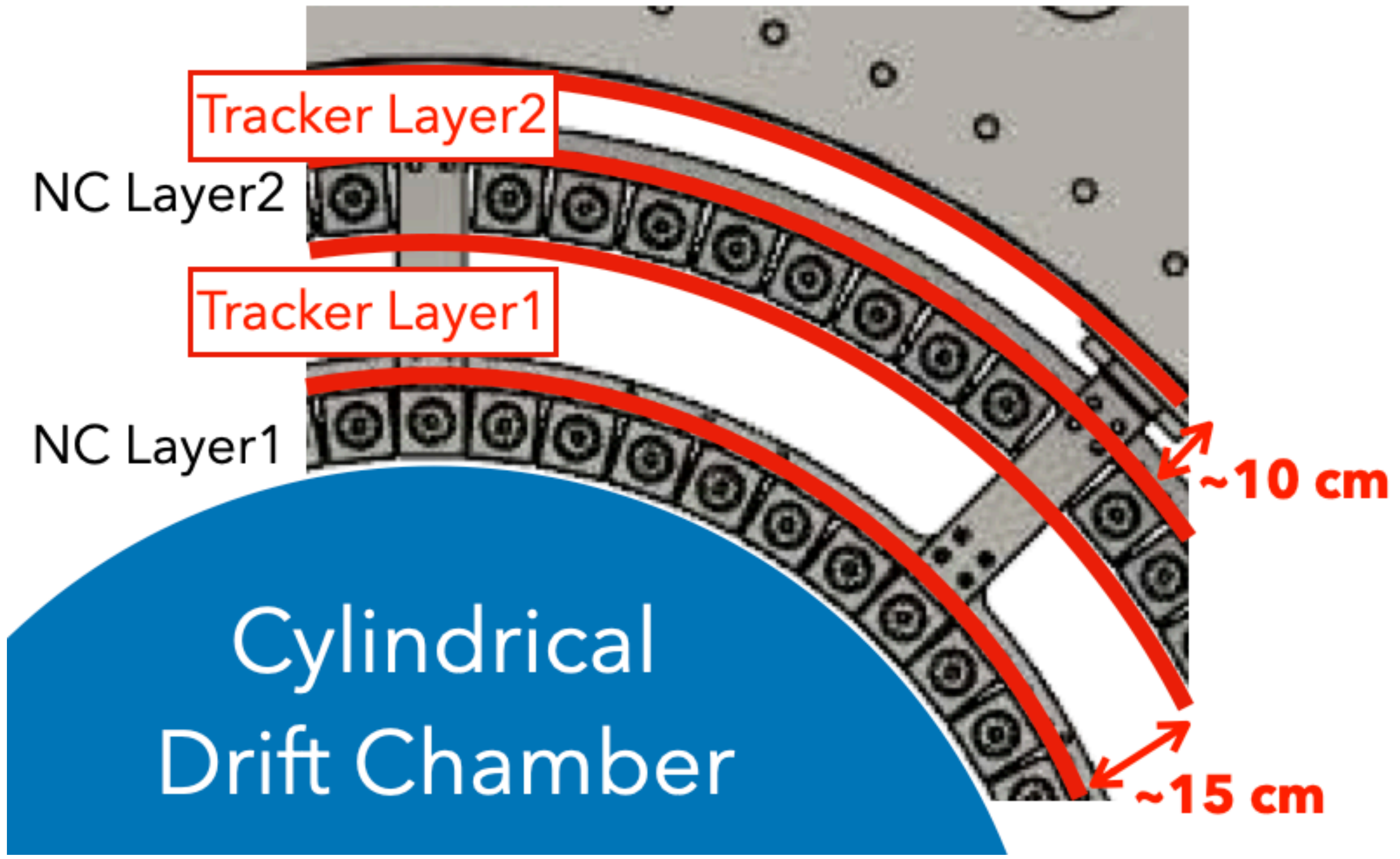
from E15 exp.

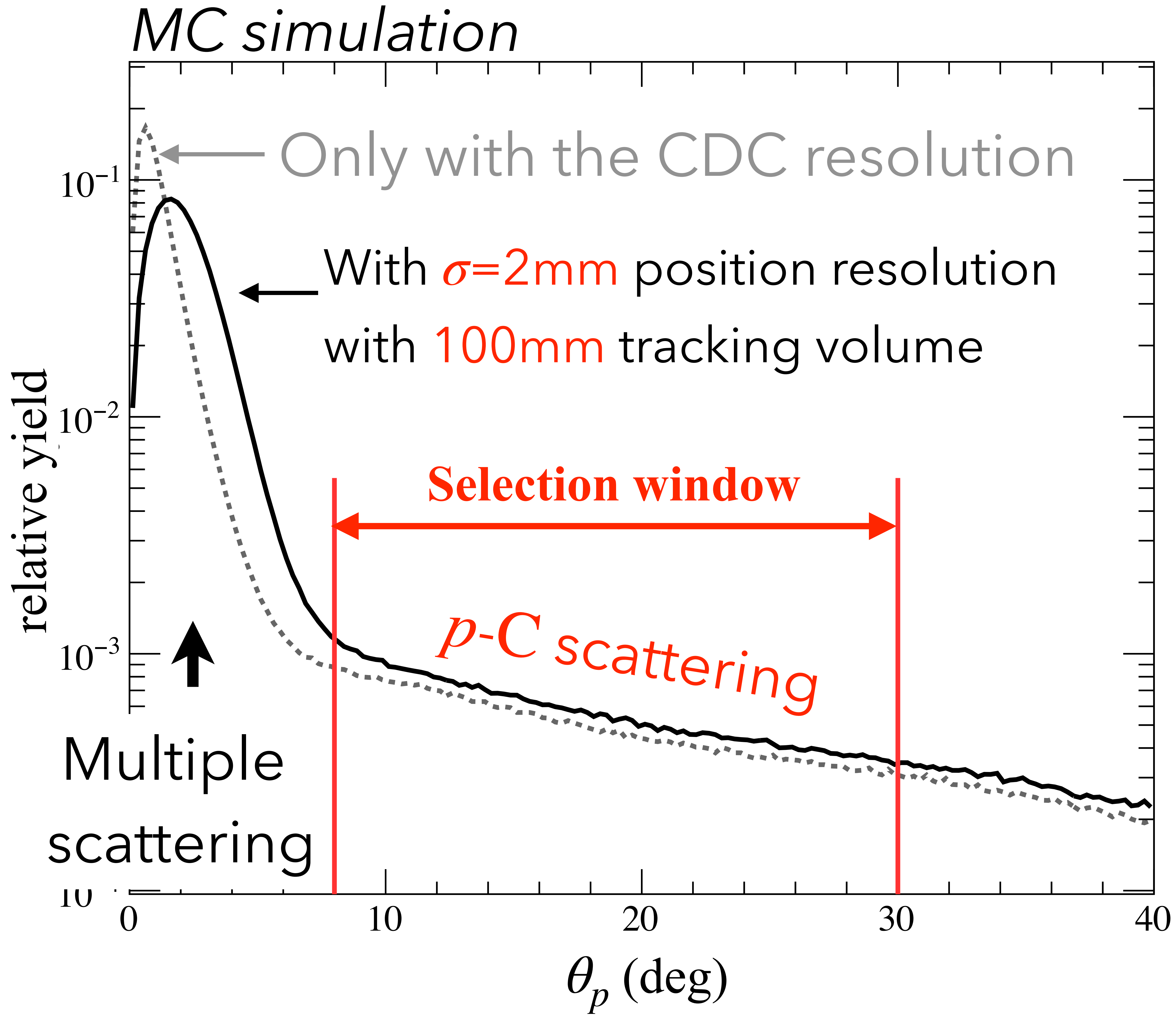
Conceptual Design of the Polarimeter



The optimal configuration is under consideration.

Necessary Position Resolution for the Tracker

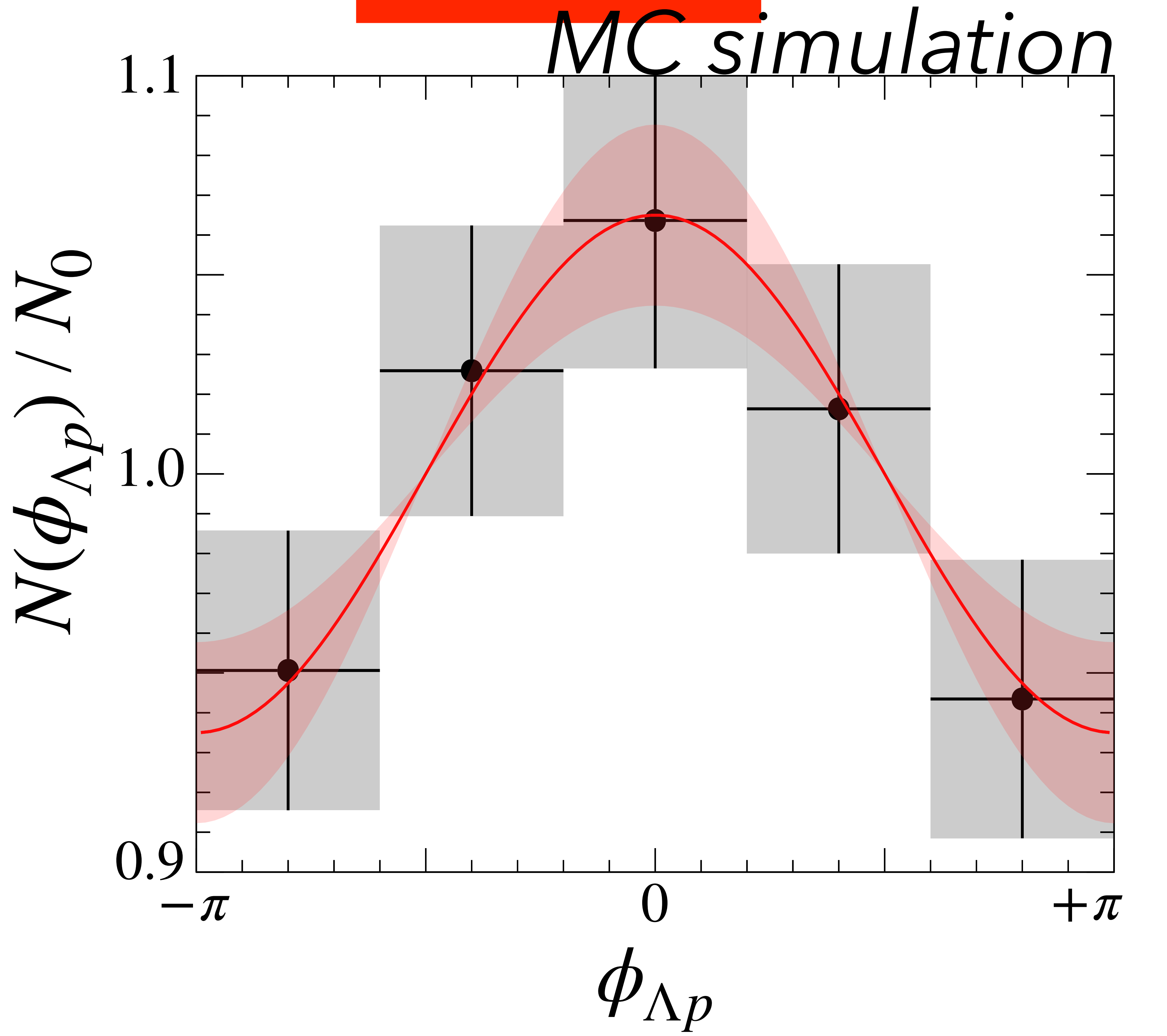




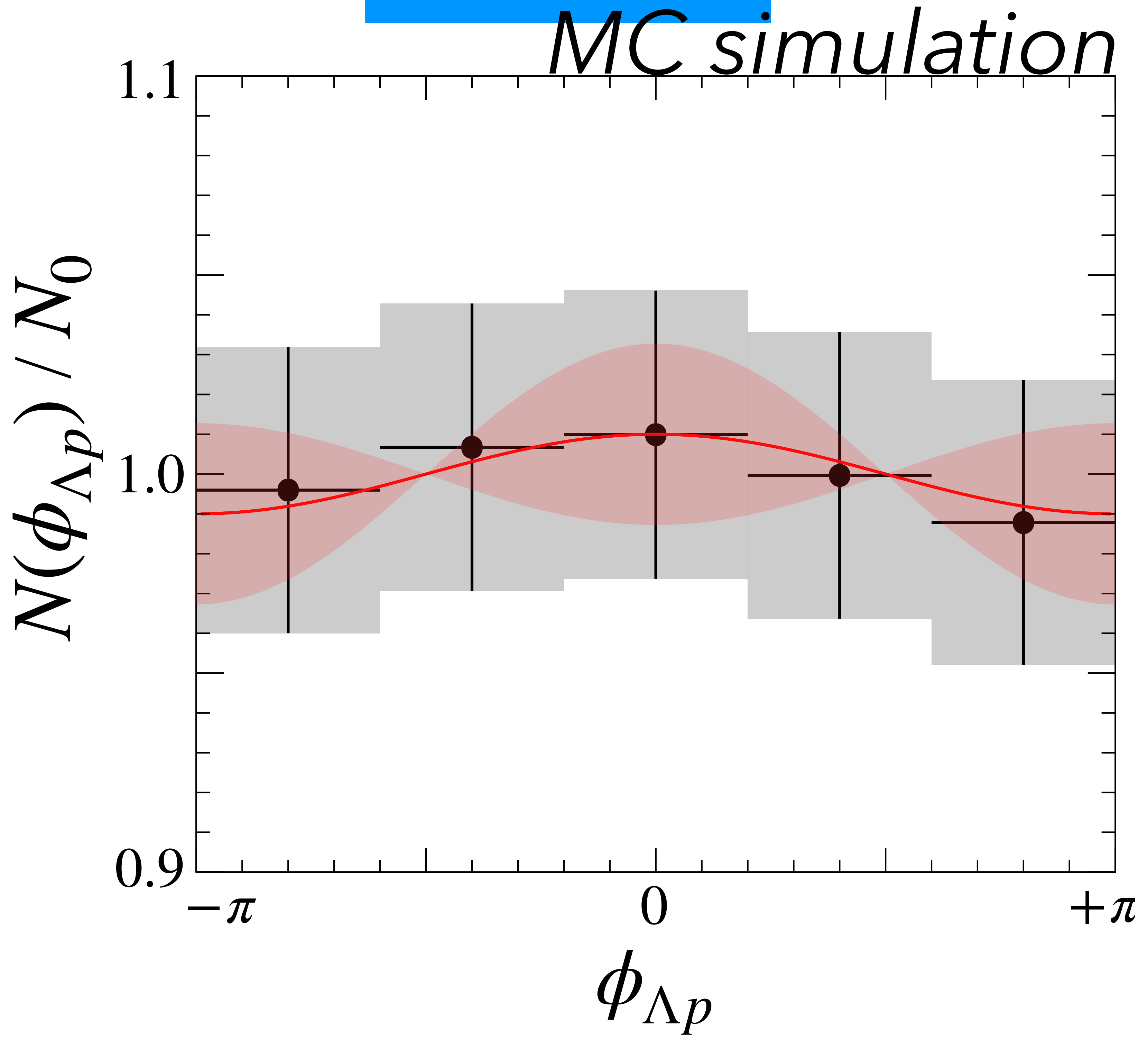
Expected spectra for $\alpha_{\Lambda p}$ measurment

8 weeks $\otimes$ 90 kW

$J^P = 0^-$



$J^P = 1^-$



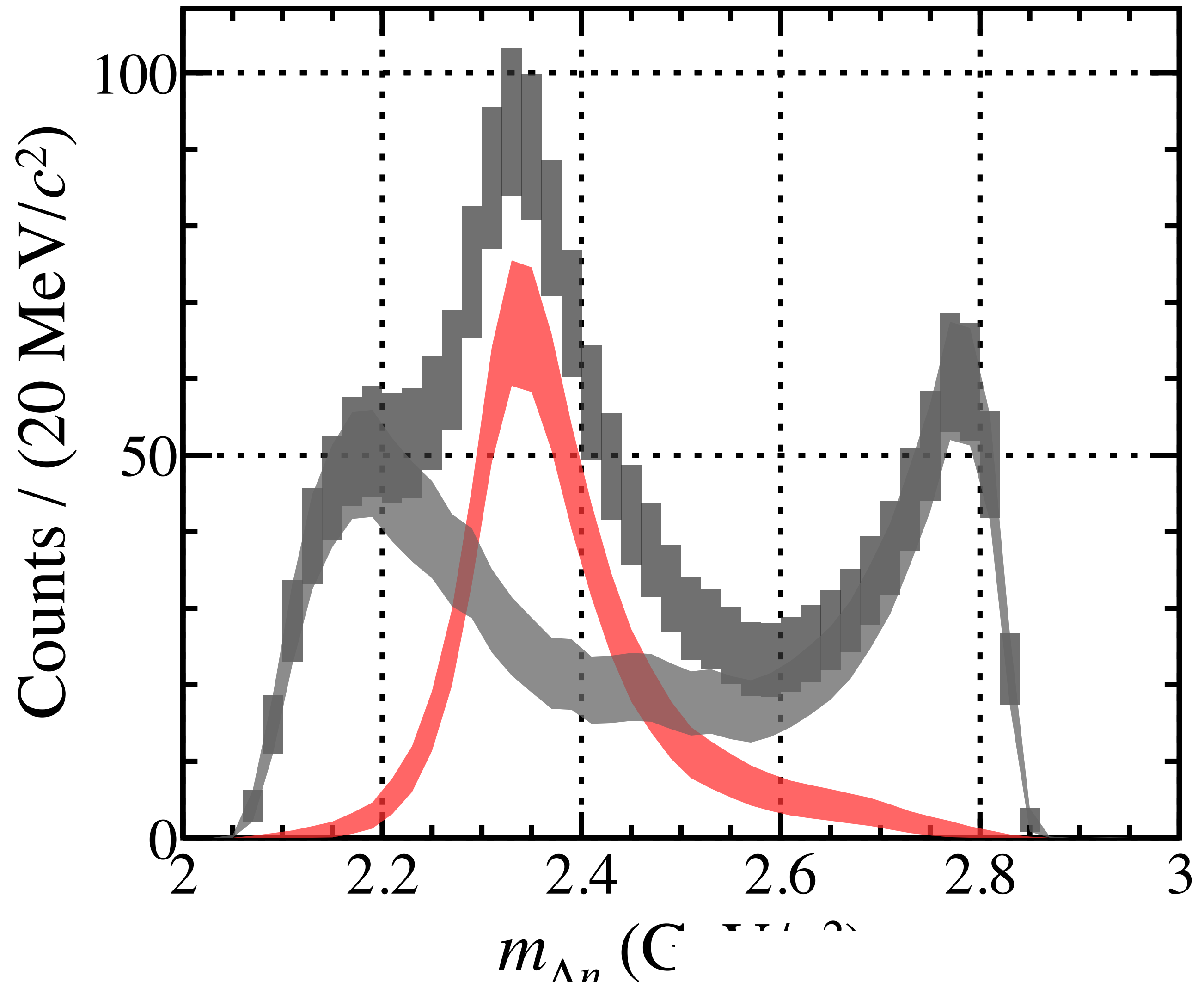
We would exclude $J^P = 1^-$ with **95%** confidence level.

Beamtime request

1st RUN – 2 weeks with the E80 setup

just after E80 in JFY2026-27

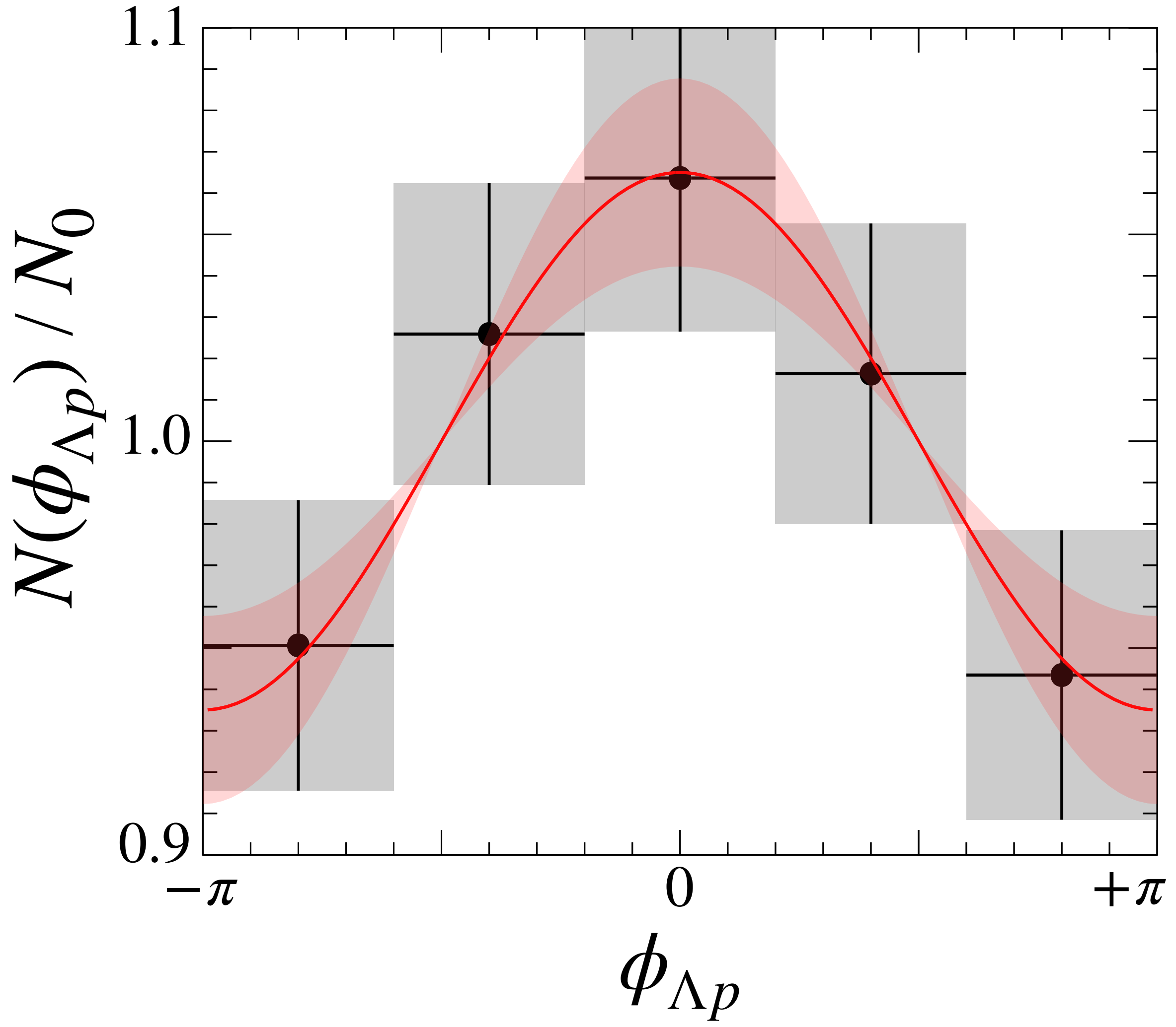
- Searching for "$\bar{K}^0 nn$" → Λn / $\Sigma^- p$ signals
- x30 statistics data than E15 for "$K^- pp$" → Λp



– Preparing the polarimeter (tracking) system –

2nd RUN – 1 week+8 weeks with the Full setup

- Measuring for $\alpha_{\Lambda p}$ to determine J^P



Collaborators

Experimentalists

RIKEN: K. Itahashi, M. Iwasaki, Y. Ma, R. Murayama, F. Sakuma, T. Hashimoto

RCNP: K. Inoue, S. Kawasaki, H. Noumi, K. Shirotori, T. Akaishi

RARiS Tohoku University: H. Ohnishi, Y. Sada, C. Yoshida, Y. Kimura, S. Sasaki

TOHOKU: T. Nanamura

Tokyo Tech: H. Fujioka

JAEA: K. Tanida, M. Fujita

中部大学: S. Okada

INFN Istituto Nazionale di Fisica Nucleare: M. Bazzi, A. Clozza, C. Curceanu, C. Guaraldo, M. Iliescu, M. Miliucci, A. Scordo, D. Sirghi, F. Sirghi

KEK: M. Iio, S. Ishimoto, Y. Makida, H. Ohhata, M. Oonaka, K. Ozawa, K. Sasaki, N. Sumi, S. S. Suzuki, T. Yamaga

SMI: J. Marton, H. Shi, M. Tuechler, E. Widmann, J. Zmeskal

Theorists

Tokyo Tech: D. Jido, K. Murakami

KPU: T. Sekihara

+ Many theoretical supports

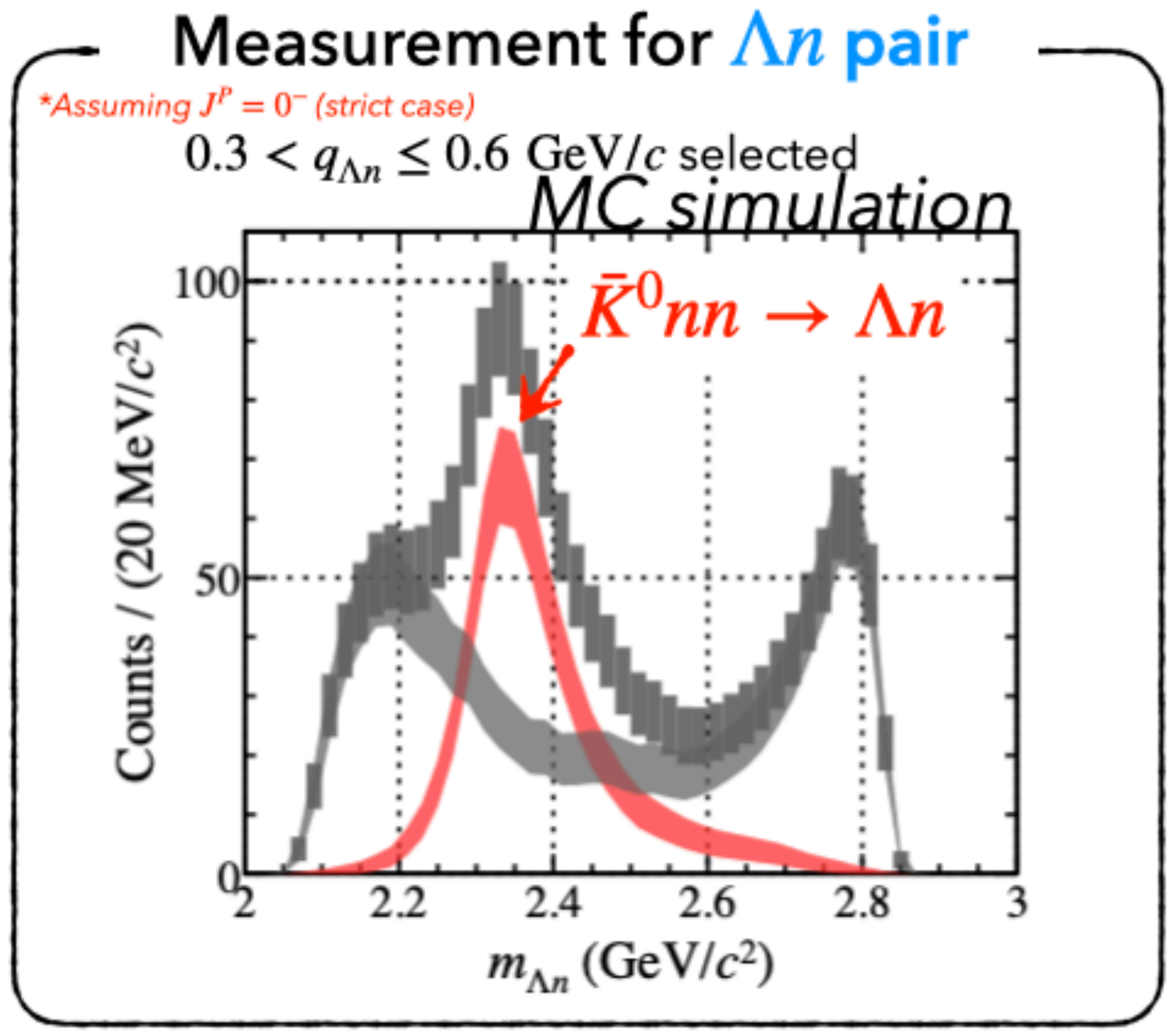
We investigate $\bar{K}NN$ both **experimentally** & **theoretically**.

Summary

Expected results

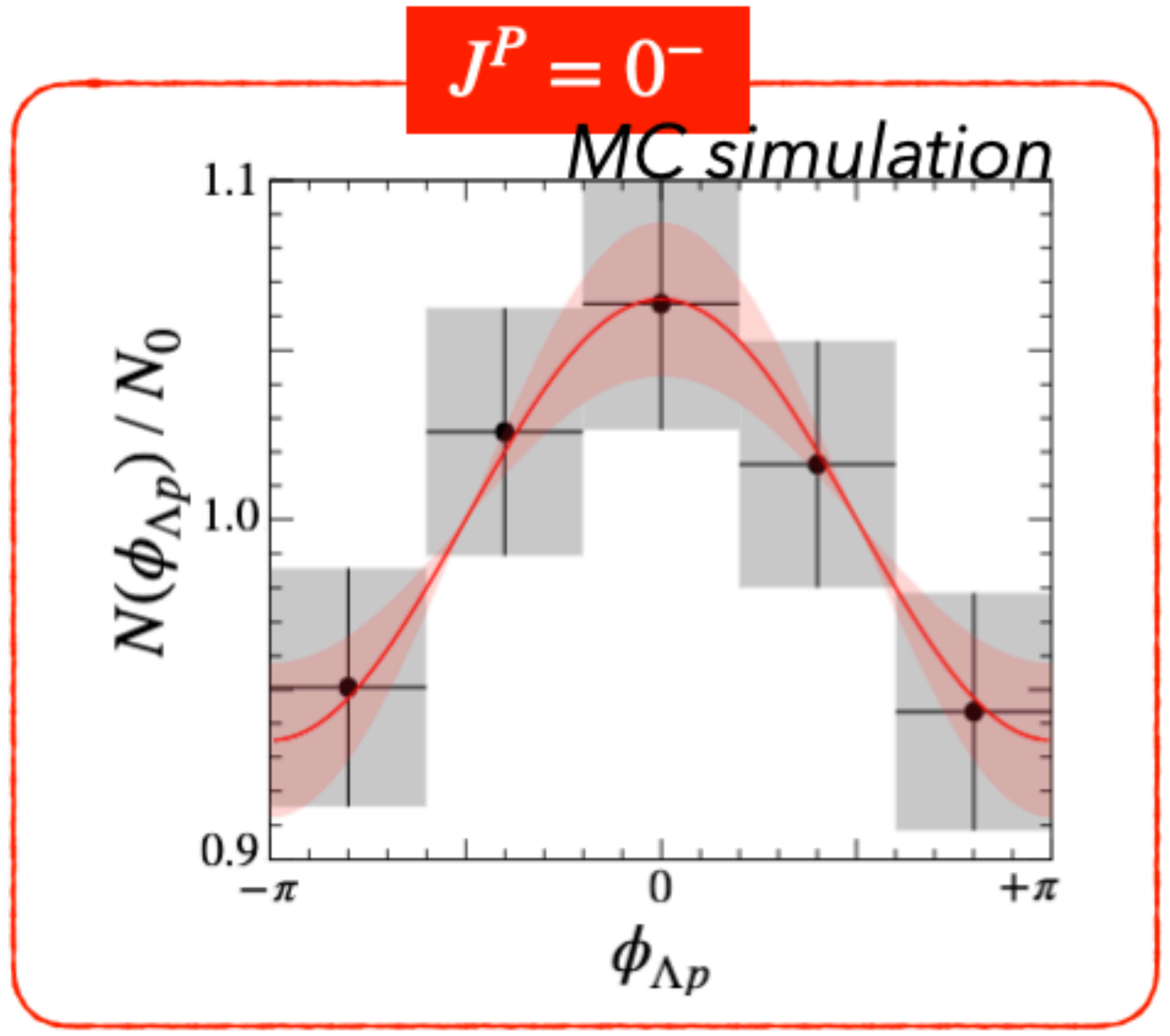
2 weeks ⊗ 90 kW

To confirm $I = 1/2\ \bar{K}NN$ doublet



8 weeks ⊗ 90 kW

To determine J^P of $\bar{K}NN$



We wish to get the stage-1 status to promote the project & to obtain the budget for the polarimeter.

Thank you for your attention!