Status and Prospects of the KOTO Experiment

Yu-Chen Tung (Univ. of Chicago)
for the KOTO collaboration

Who are We?

- We have around 50 collaborators from 17 institutes
  - Arizona, Chicago, Chonbuk, Jeju, JINR, KEK, Kyoto, Kyungpook, Michigan, NDA, NTU, Okayama, Osaka, Pusan, Saga, Seoul, & Yamagata

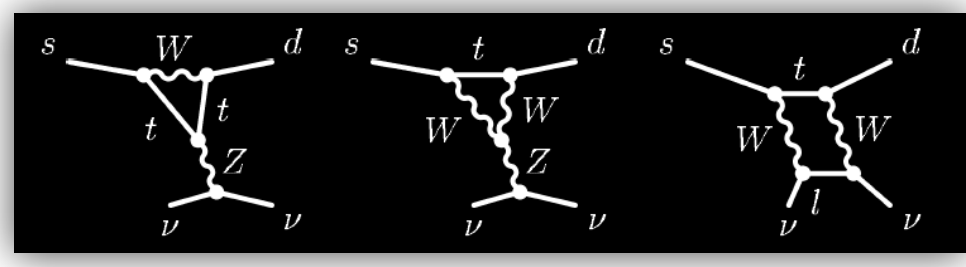
Where are We?


Oga
男鹿
AKITA
Morioka
盛岡
Akita
秋田
IWATE
Kitakami
北上
Oshu
奥州
MIYAGI
Sendai
仙台
Yamagata
山形
Niigata
新潟
Fukushima
福島
FUKUSHIMA
NIIGATA
Iwaki
いわき
Nagano
長野
TOCHIGI
GUNMA
IBARAKI
Japan Atomic
Energy Agency
NAGANO
SAITAMA
Tokyo
東京
Fuji
富士
KANAGAWA
CHIBA
SHIZUOKA
Hamamatsu
浜松


JPARC

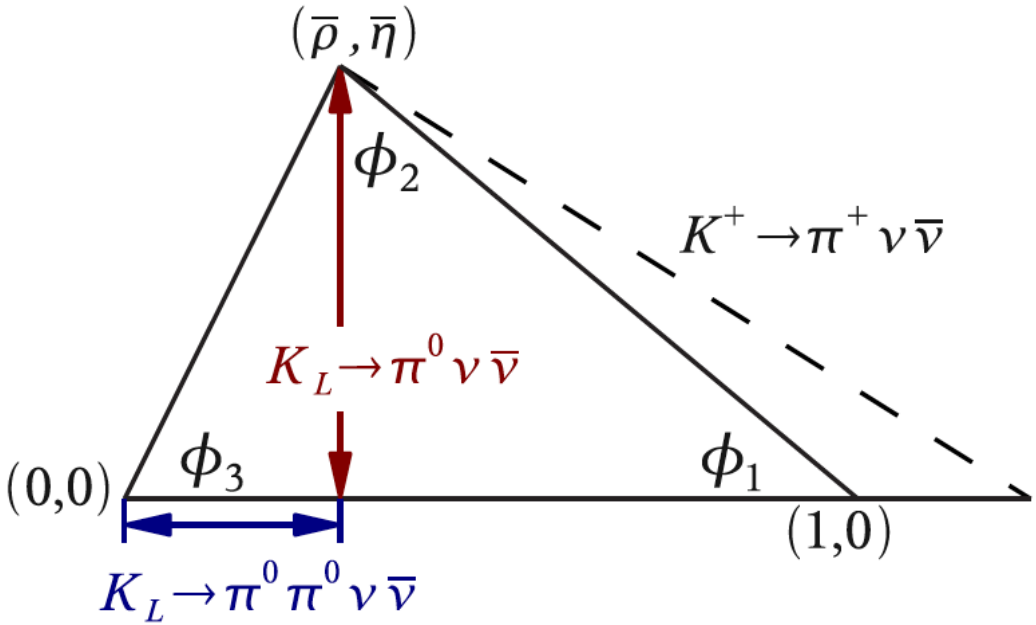

Hadron Hall
SKS
K1.8
KL
K1.8BR
K1.1
T1標的
K1.1BR
30(50)GeV
一次陽子ビーム

What are We Measuring?

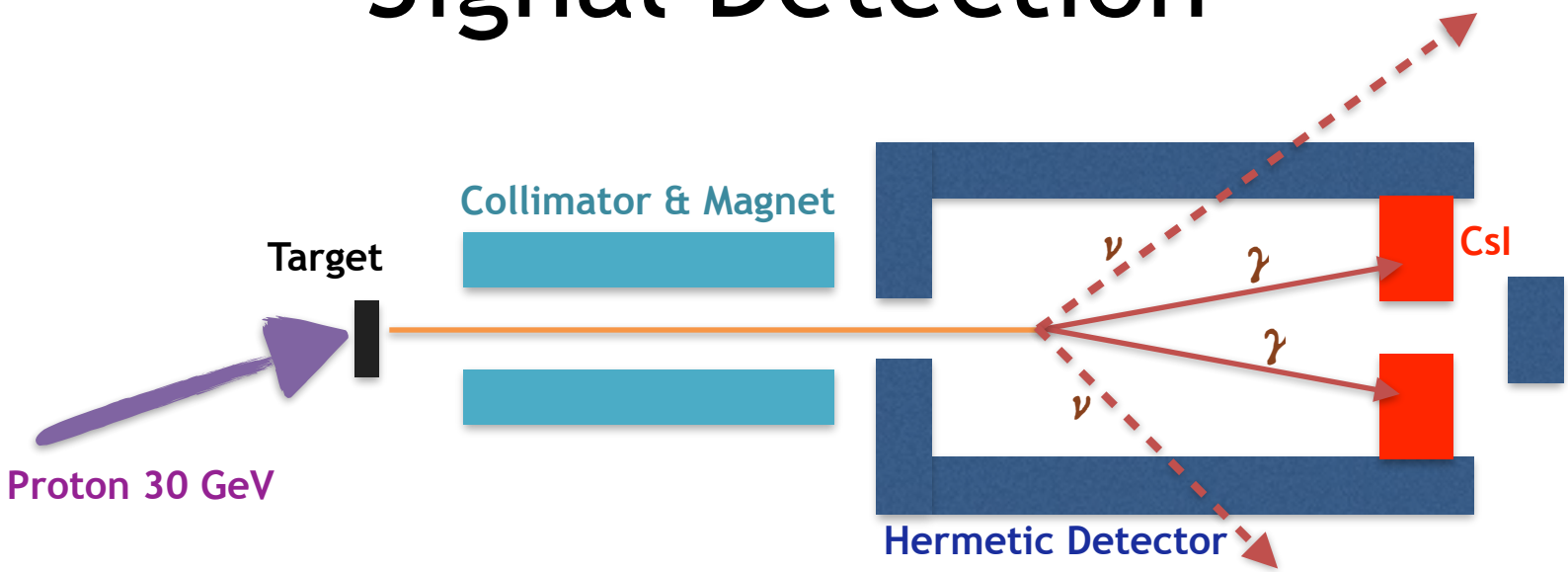


$K_L \rightarrow \pi^0 \nu\nu$ decay

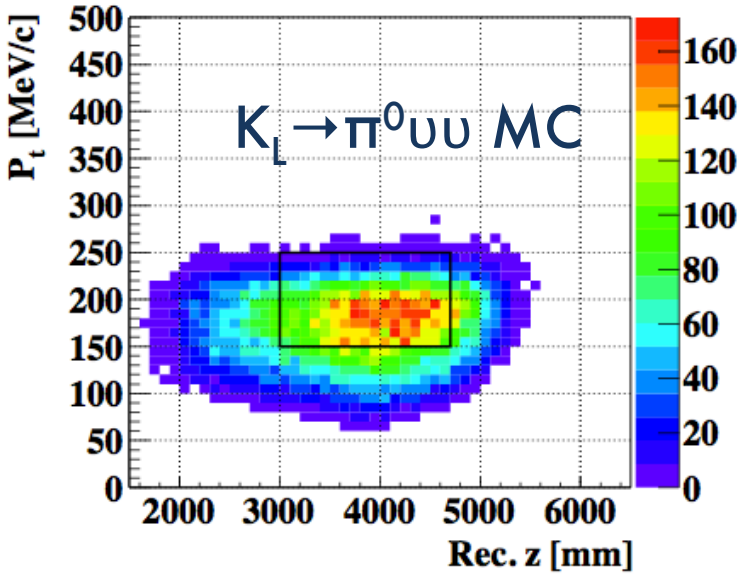
- direct CP violating process
- FCNC via loop diagram
- branching ratio from SM: 2.4×10^{-11} with 2% uncertainty
- excellent mode to test SM and beyond

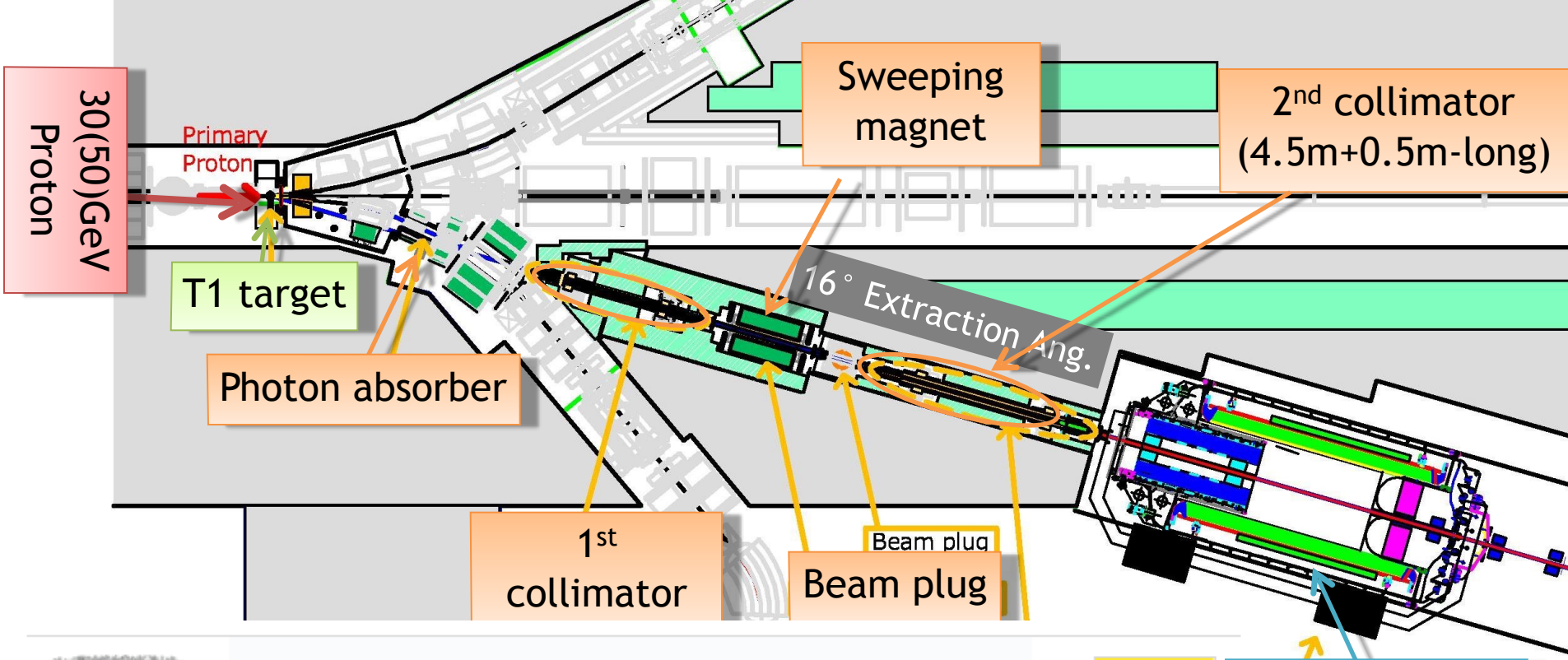


Signal Detection



- 2 γ in CsI + 0 in others
- High Pt + Fiducial Z





ELSEVIER

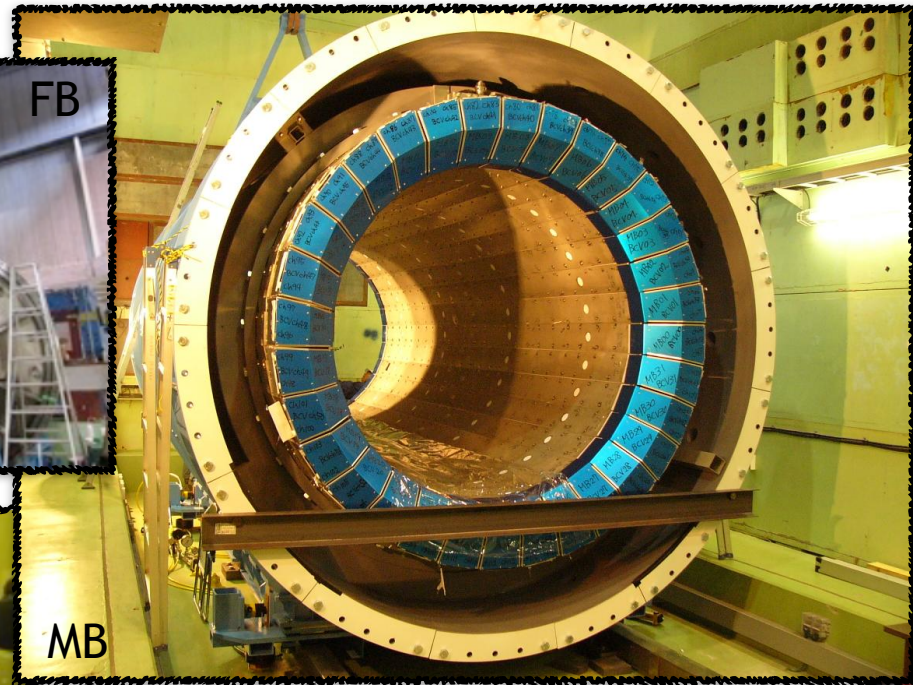
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 664, Issue 1, 1 February 2012, Pages 264–271

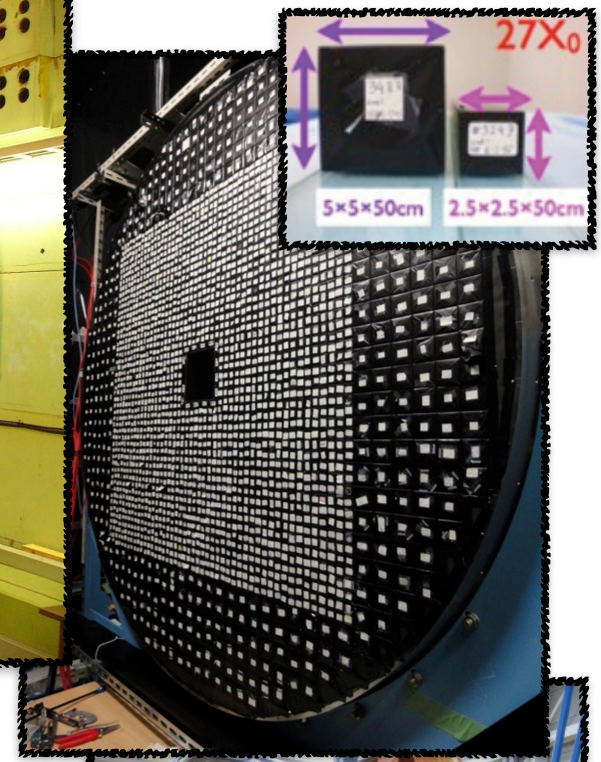
Measurement of K_L^0 flux at the J-PARC neutral-kaon beam line

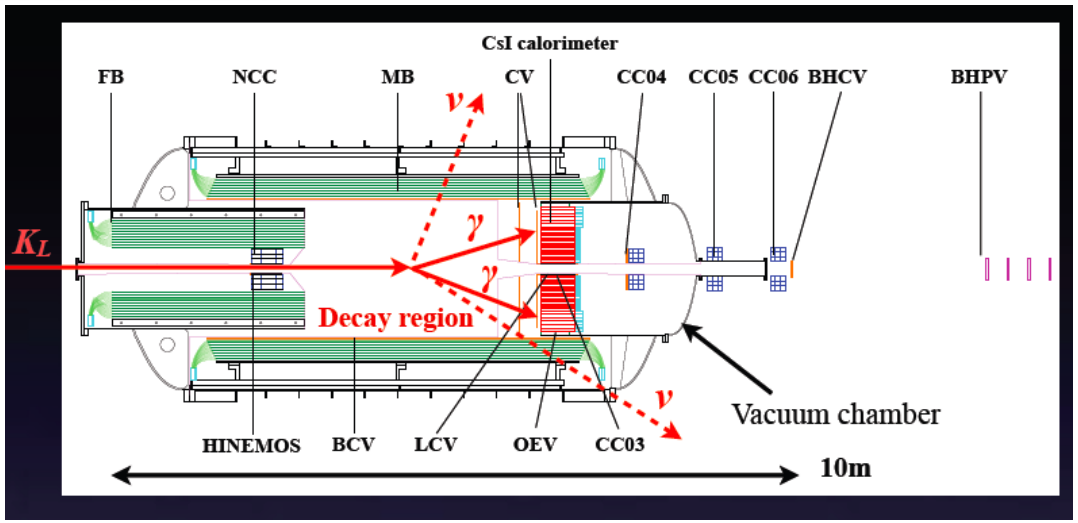
K. Shiomi[a], K.Y. Baek[b], J. Comfort[c], E. Iwai[d], N. Kawasaki[a], J.W. Ko[e], T.K. Komatsubara[f], J.W. Lee[d], G.Y. Lim[f], Y. Maeda[a], T. Masuda[a], D. Naito[a], Y. Nakaya[d, 1], H. Nanjo[a], T. Nomura[f], M. Sasaki[g], N. Sasao[h], K. Sato[d], T. Shimogawa[i], Y. Sugiyama[d], Y. Tajima[g], G. Takahashi[a], M. Togawa[d], H. Watanabe[f], T. Yamanaka[d], Y. Yanagida[d], H.Y. Yoshida[g]

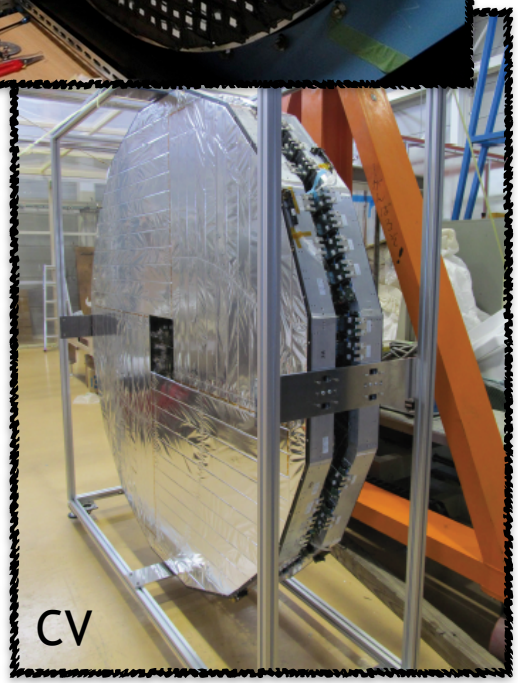

FB


MB


NCC


27X0
5×5×50cm
2.5×2.5×50cm


CsI calorimeter
FB
NCC
MB
CV
CC04
CC05
CC06
BHCV
BHPV
K_L
ν
γ
γ
ν
Decay region
Vacuum chamber
HINEMOS
BCV
LCV
OEV
CC03
10m


CV

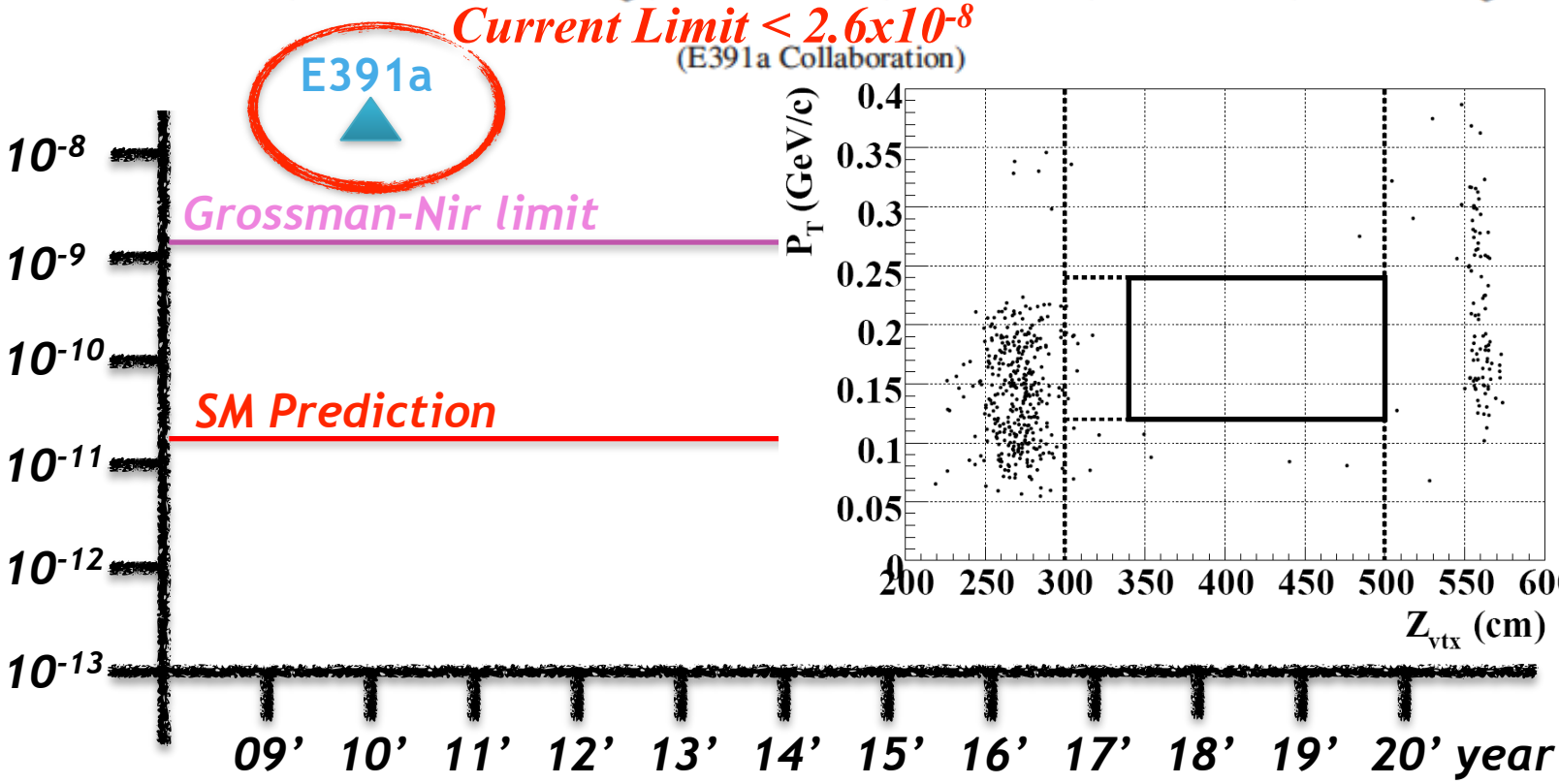
PHYSICAL REVIEW D 81, 072004 (2010)

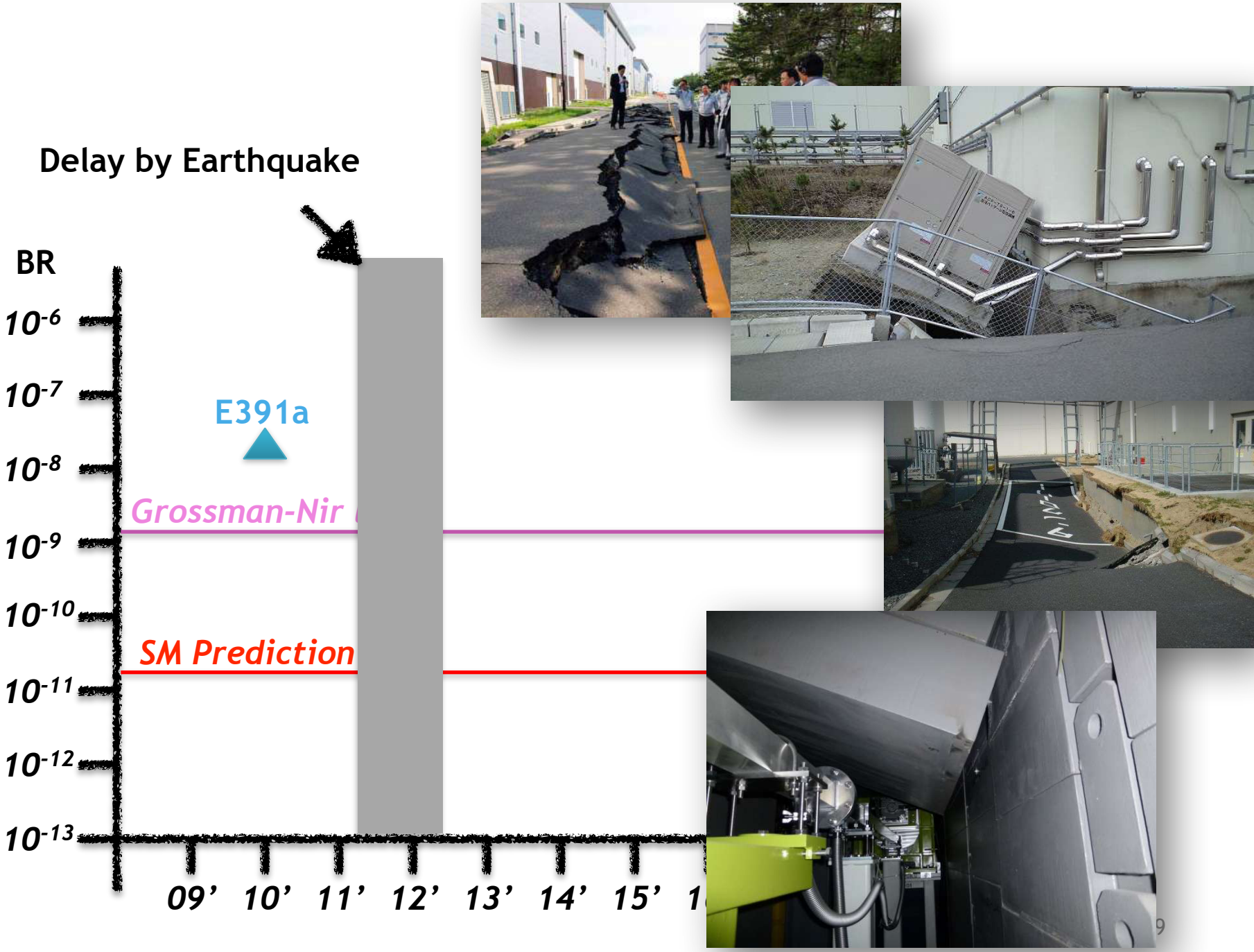
Experimental study of the decay $K_L^0 \to \pi^0 \nu \bar{\nu}$

J. K. Ahn,[1] Y. Akune,[2] V. Baranov,[3] K. F. Chen,[4] J. Comfort,[5] M. Doroshenko,[6,*] Y. Fujioka,[2] Y. B. Hsiung,[4] T. Inagaki,[6,7] S. Ishibashi,[2] N. Ishihara,[7] H. Ishii,[8] E. Iwai,[8] T. Iwata,[9] I. Kato,[9] S. Kobayashi,[2] S. Komatsu,[8] T. K. Komatsubara,[7] A. S. Kurilin,[3] E. Kuzmin,[3] A. Lednev,[10,11] H. S. Lee,[1] S. Y. Lee,[1] G. Y. Lim,[7] J. Ma,[11] T. Matsumura,[12] A. Moisseenko,[3] H. Morii,[13] T. Morimoto,[7] Y. Nakajima,[13] T. Nakano,[14] H. Nanjo,[13] N. Nishi,[8] J. Nix,[11] T. Nomura,[13,†] M. Nomachi,[8] R. Ogata,[2] H. Okuno,[7] K. Omata,[7] G. N. Perdue,[11,¶] S. Perov,[3] S. Podolsky,[3] S. Porokhovoy,[3] K. Sakashita,[8,†] T. Sasaki,[9] N. Sasao,[13] H. Sato,[9] T. Sato,[7] M. Sekimoto,[7] T. Shimogawa,[2] T. Shinkawa,[12] Y. Stepanenko,[3] Y. Sugaya,[8] A. Sugiyama,[2] T. Sumida,[13,‡] S. Suzuki,[2] Y. Tajima,[9] S. Takita,[9] Z. Tsamalaidze,[3] T. Tsukamoto,[2,§] Y. C. Tung,[4] Y. W. Wah,[11] H. Watanabe,[11,†] M. L. Wu,[4] M. Yamaga,[7,8,‖] T. Yamanaka,[8] H. Y. Yoshida,[9] Y. Yoshimura,[7] and Y. Zheng[11]

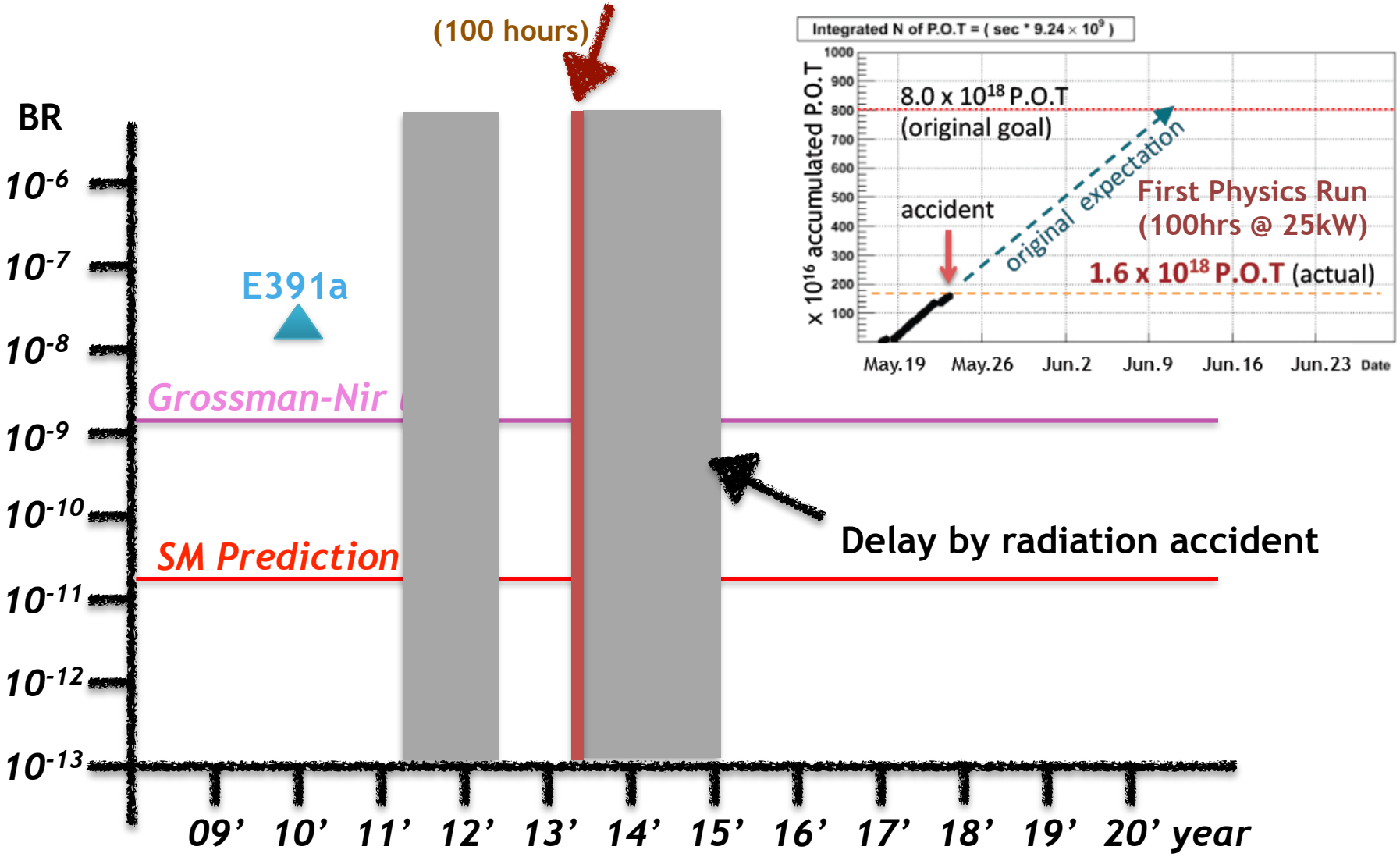
(E391a Collaboration)

Current Limit < 2.6x10^{-8}

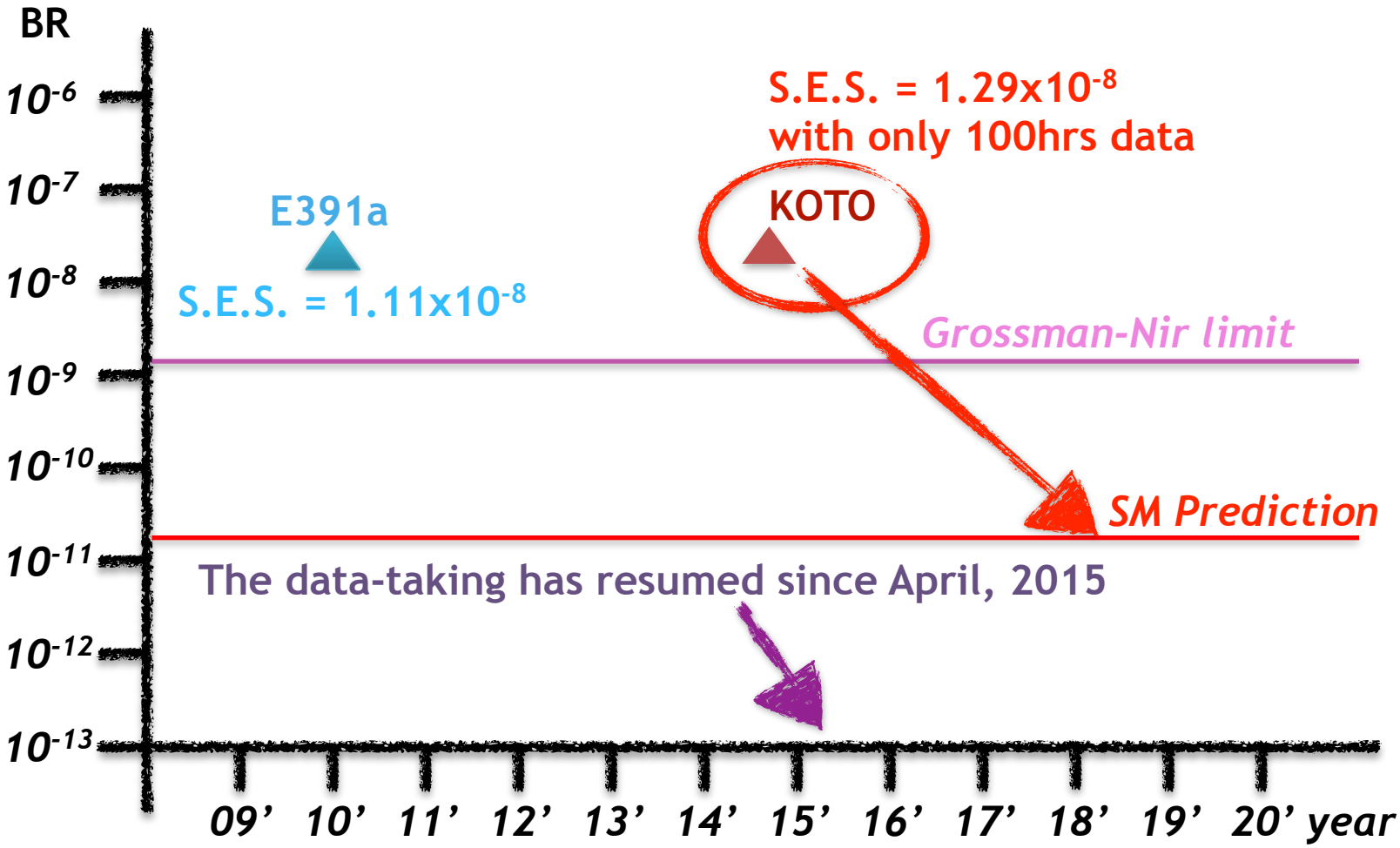



Delay by Earthquake
BR
10-6
10-7
10-8
10-9
10-10
10-11
10-12
10-13
E391a
Grossman-Nir
SM Prediction
09’
10’
11’
12’
13’
14’
15’

First Physics Run (May 2013)



Where We Are & Where We Go

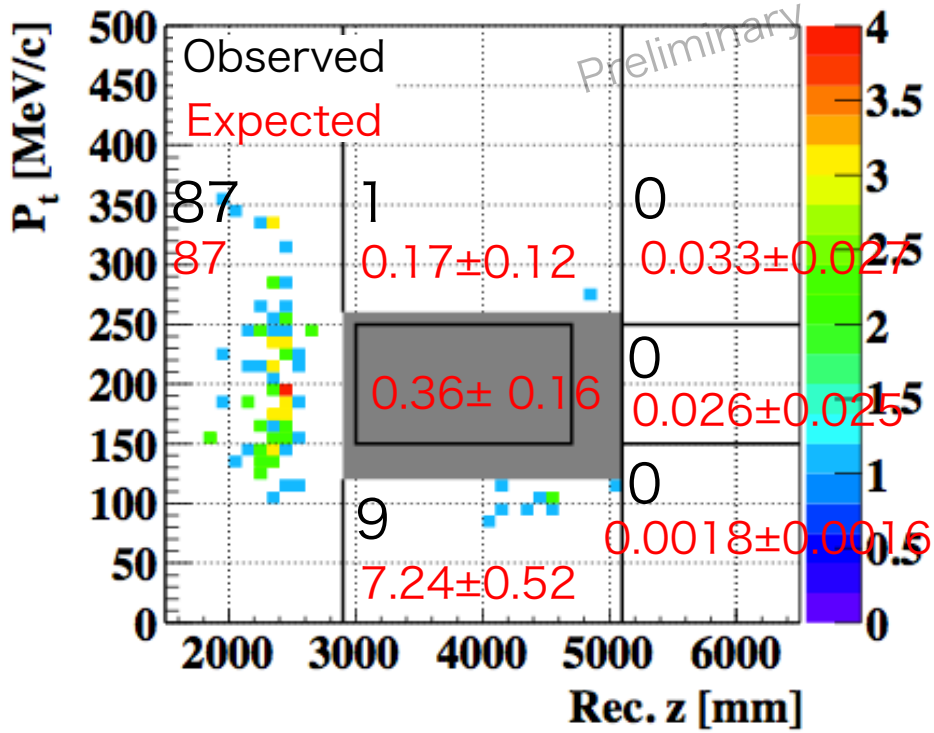


First Physics Run (May 2013)

- Unbiased blind analysis
- Expected 0.36±0.16 BKGD events

Preliminary

BG Source	# of Events
Downstream	0.18±0.15
Low Pt	0.11±0.04
Upstream	0.06±0.06
Total	0.36±0.16

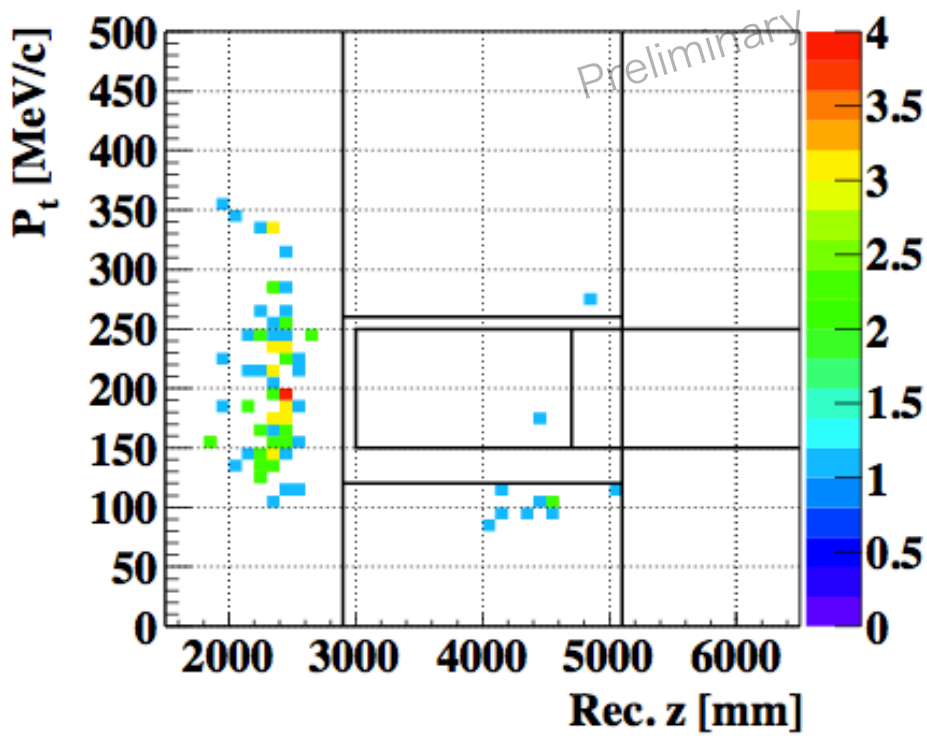


First Physics Run (May 2013)

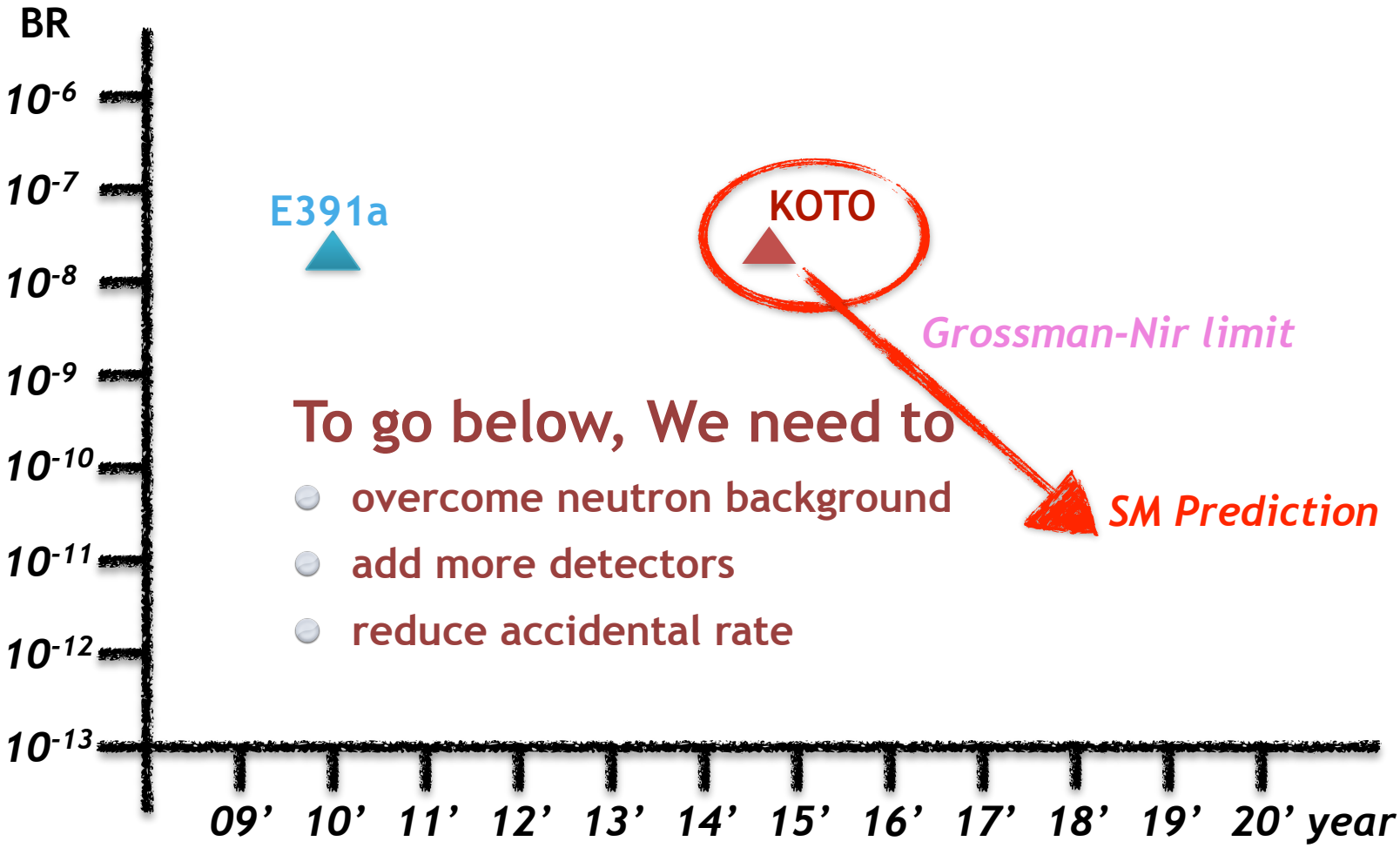
- Unbiased blind analysis
- Expected 0.36±0.16 BKGD events
- **One event in the signal box**

Preliminary

BG Source	*# of Events*
Downstream	*0.18±0.15*
Low Pt	*0.11±0.04*
Upstream	*0.06±0.06*
Total	*0.36±0.16*



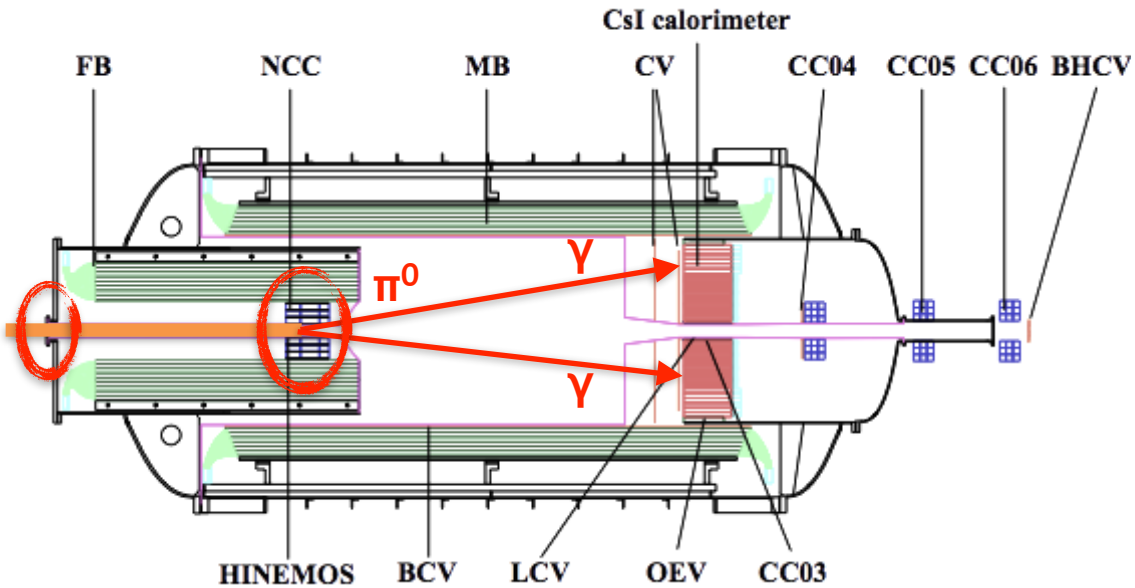
Where We Are & Where We Go

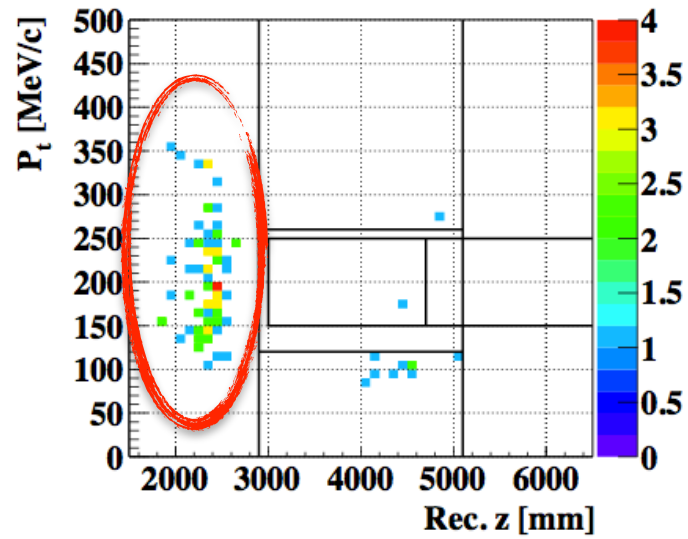


To go below, We need to

- overcome neutron background
- add more detectors
- reduce accidental rate

2013 to 2015

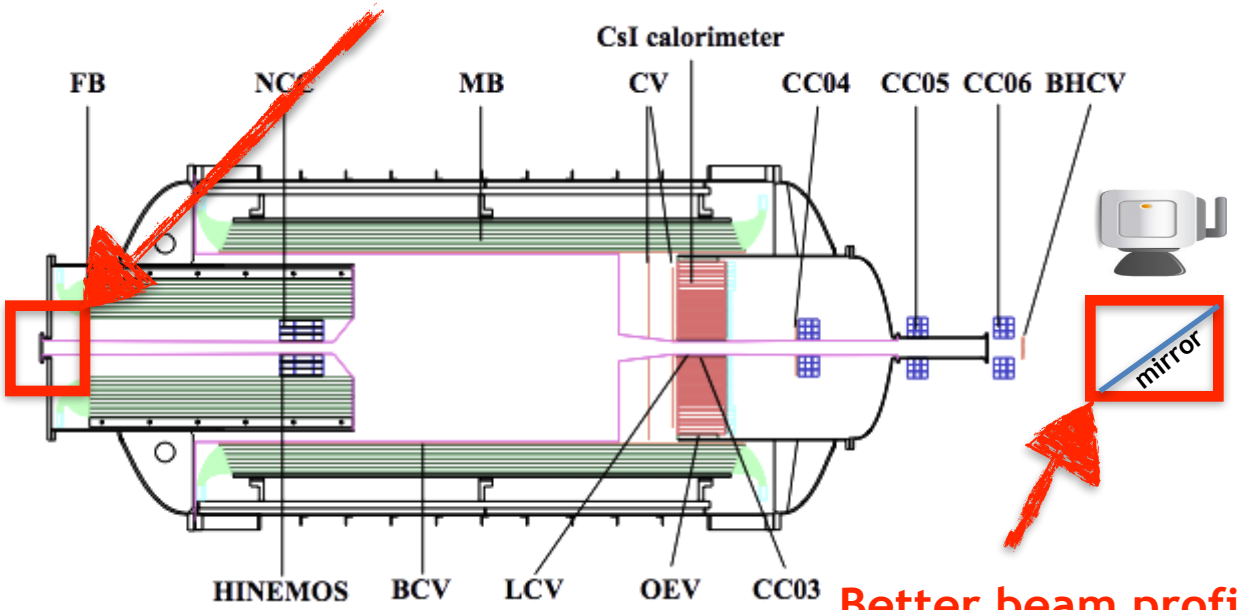


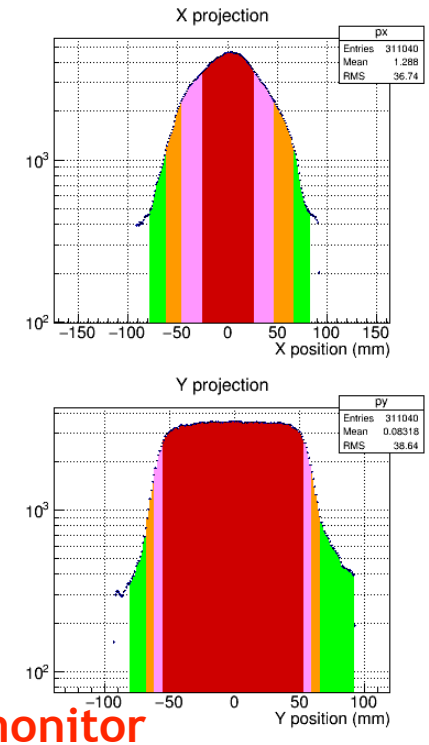


BG Source	# of Events	Possible Mechanism
Upstream	0.06±0.06	Halo neutron interacted with upstream detector: $n+A\rightarrow\pi^0+X$
Low Pt	0.11±0.04	$K_L\rightarrow\pi^0\pi^+\pi^-$ with two undetected charged pions in beam pipe
Downstream	0.18±0.15	Neutron scattered in CsI and produced two clusters
Total	0.36±0.16	

2013 to **2015**

Thiner beam window to reduce neutron interaction

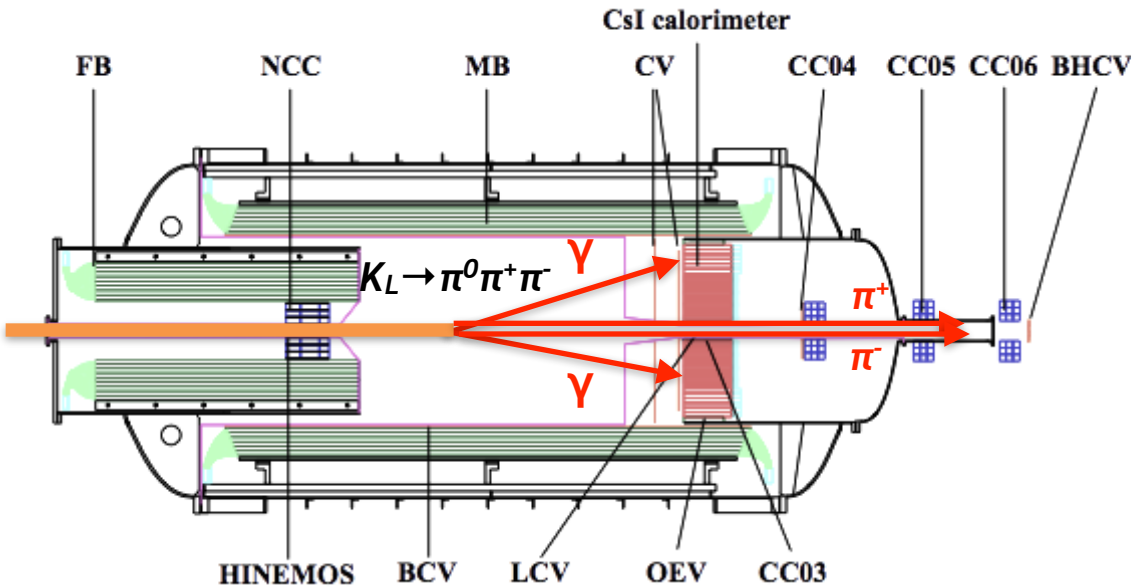


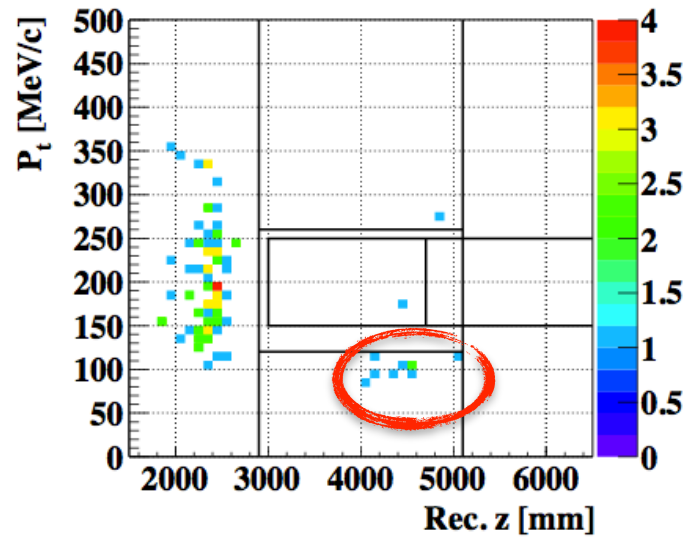


Better beam profile monitor for beam alignment.

BG Source	*# of Events*	*Possible Mechanism*
Upstream	*0.06±0.06*	*Halo neutron interacted with upstream detector: $n+A\rightarrow\pi^0+X$*
Low Pt	*0.11±0.04*	*$K_L\rightarrow\pi^0\pi^+\pi^-$ with two undetected charged pions in beam pipe*
Downstream	*0.18±0.15*	*Neutron scattered in CsI and produced two clusters*
Total	*0.36±0.16*	

2013 to 2015





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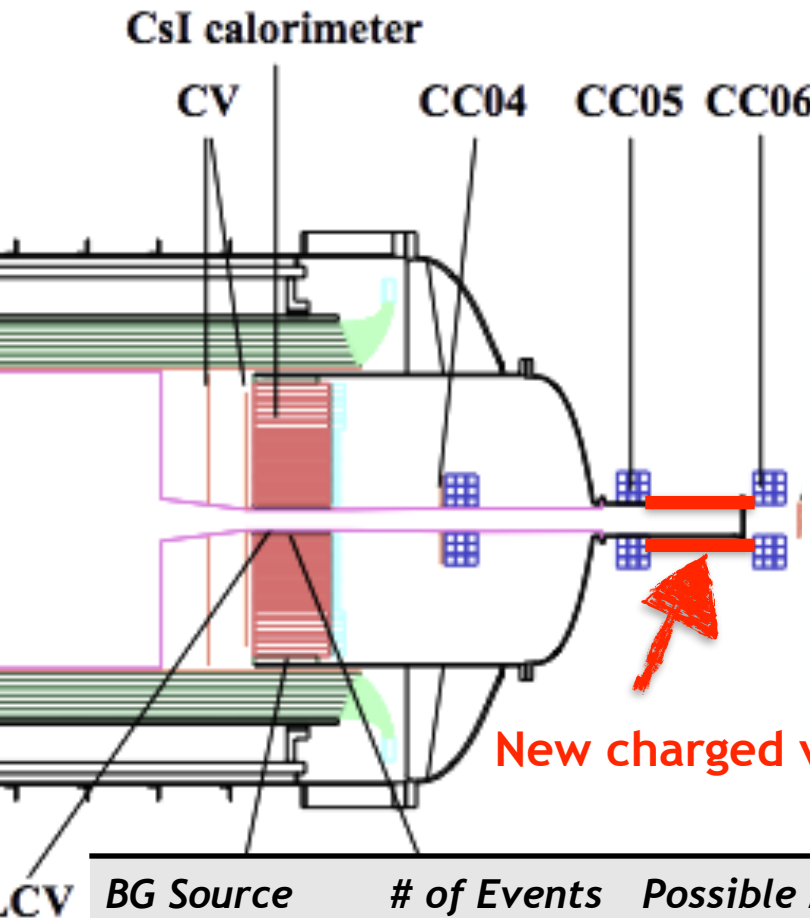
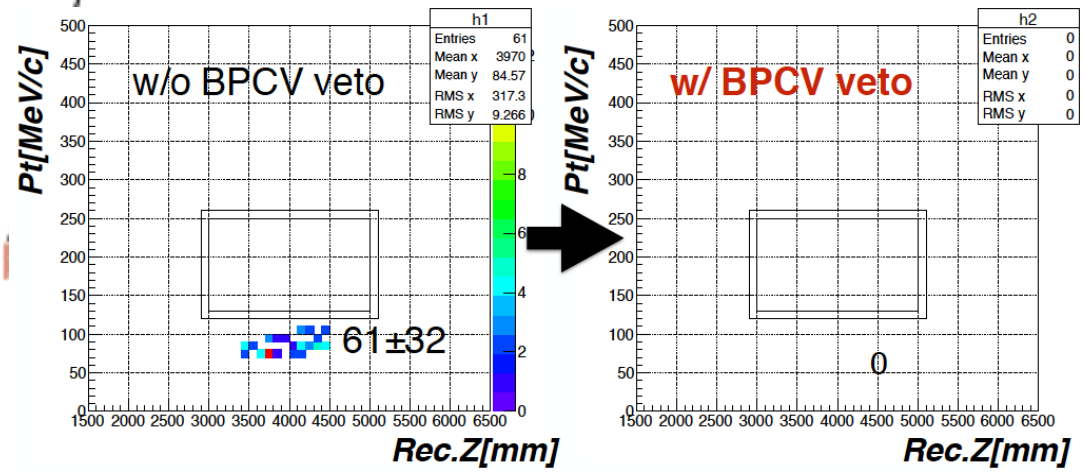
2013 to **2015**



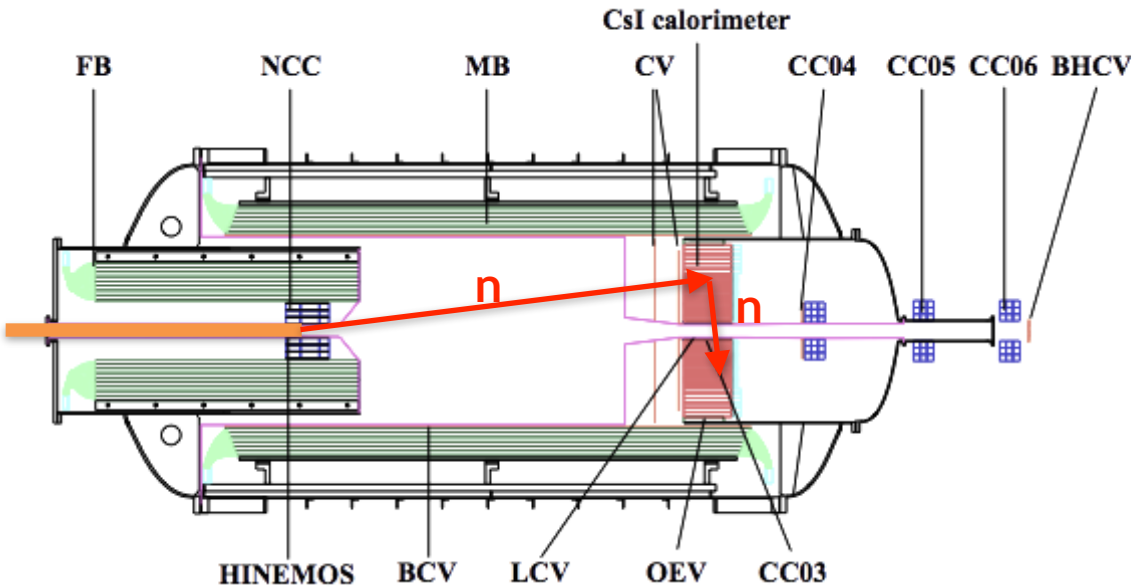
MC Simulation of $K_L \rightarrow \pi^0\pi^+\pi^-$
with x10 Statistics of 2013 Data

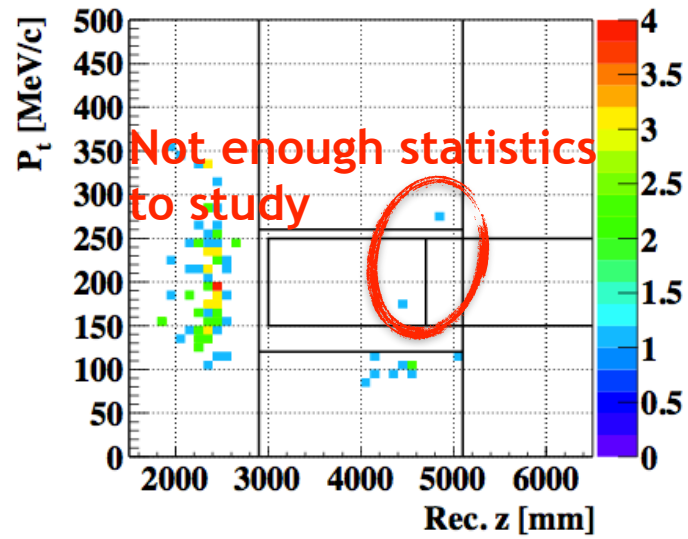


New charged veto detector along beam pipe (BPCV)

BG Source	*# of Events*	*Possible Mechanism*
Upstream	*0.06±0.06*	*Halo neutron interacted with upstream detector: $n+A \rightarrow \pi^0+X$*
Low Pt	*0.11±0.04*	*$K_L \rightarrow \pi^0\pi^+\pi^-$ with two undetected charged pions in beam pipe*
Downstream	*0.18±0.15*	*Neutron scattered in CsI and produced two clusters*
Total	*0.36±0.16*	

2013 to 2015





BG Source	# of Events	Possible Mechanism
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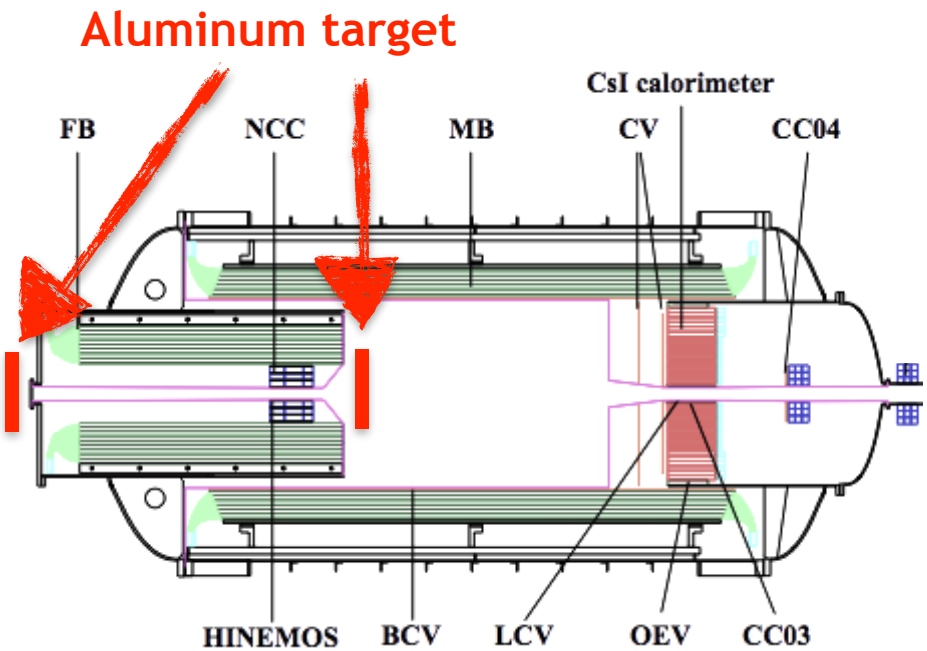
2013 to **2015**



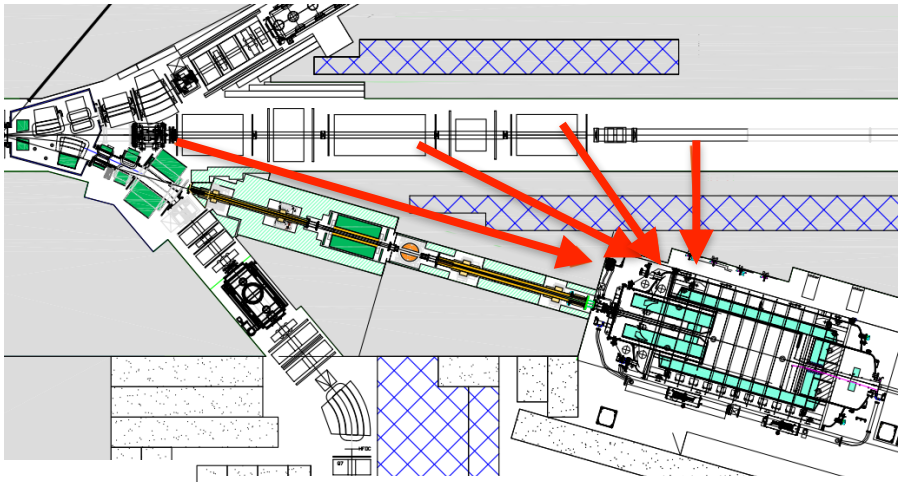
- Collect more neutron events
- Cluster shape to identify γ/n

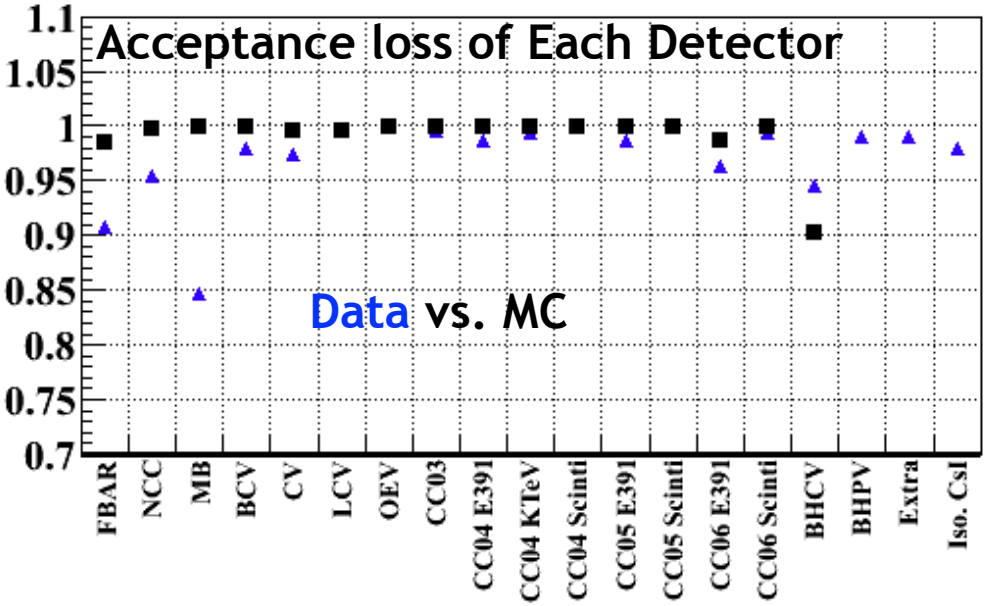
BG Source	*# of Events*	*Possible Mechanism*
Upstream	*0.06±0.06*	*Halo neutron interacted with upstream detector: $n+A\rightarrow\pi^0+X$*
Low Pt	*0.11±0.04*	*$K_L\rightarrow\pi^0\pi^+\pi^-$ with two undetected charged pions in beam pipe*
Downstream	*0.18±0.15*	*Neutron scattered in CsI and produced two clusters*
Total	*0.36±0.16*	

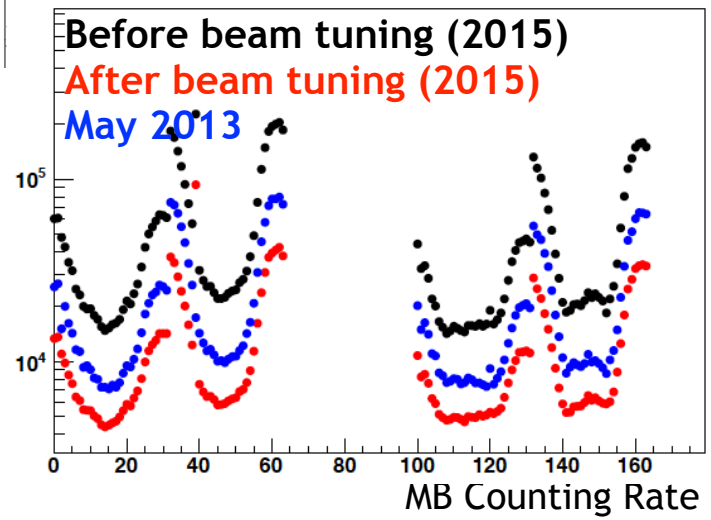
Accidental Loss: Beam Line

Accidental loss / 2 after

- beam tuning
- add shielding



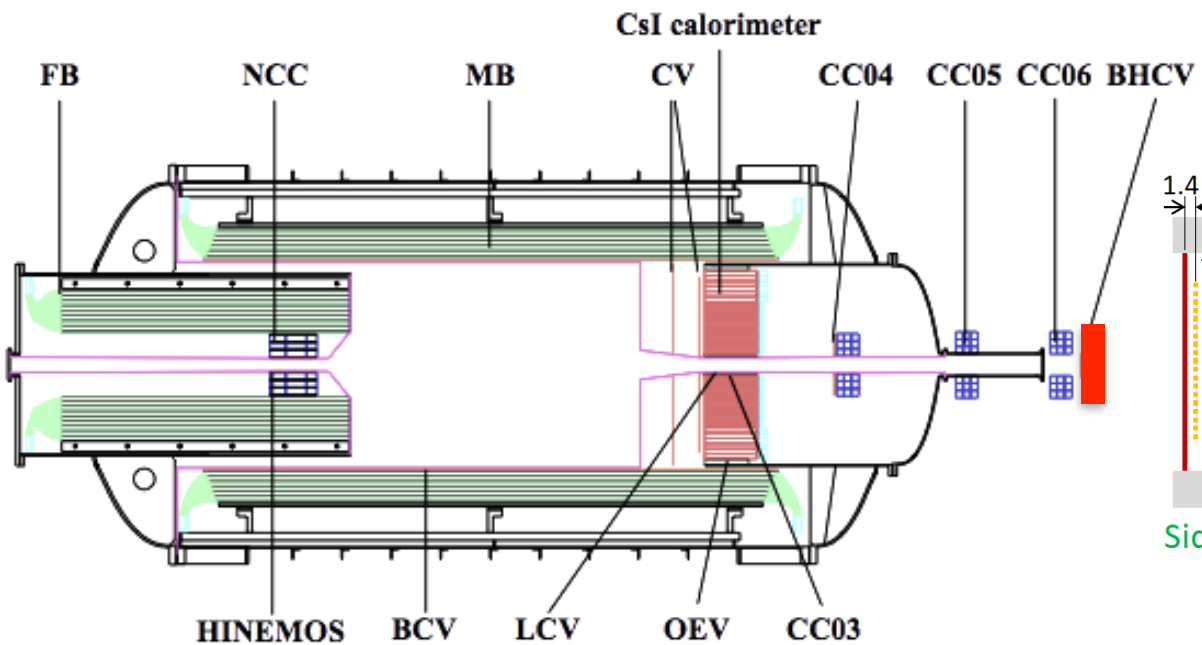


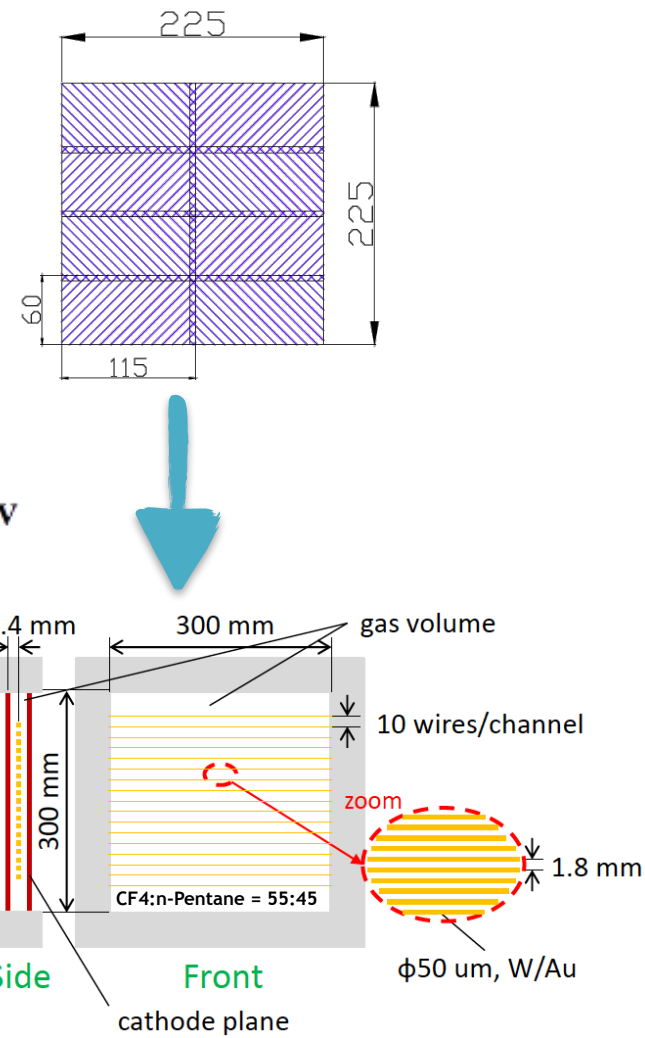


Accidental Loss: Detector

New Beam Hole Charged Veto (BHCV)

- 30x30cm x 3 wire chambers
- efficiency > 99.5%
- Rate > 100kH/cm^2
- accidental loss: 30% ➜ 15%

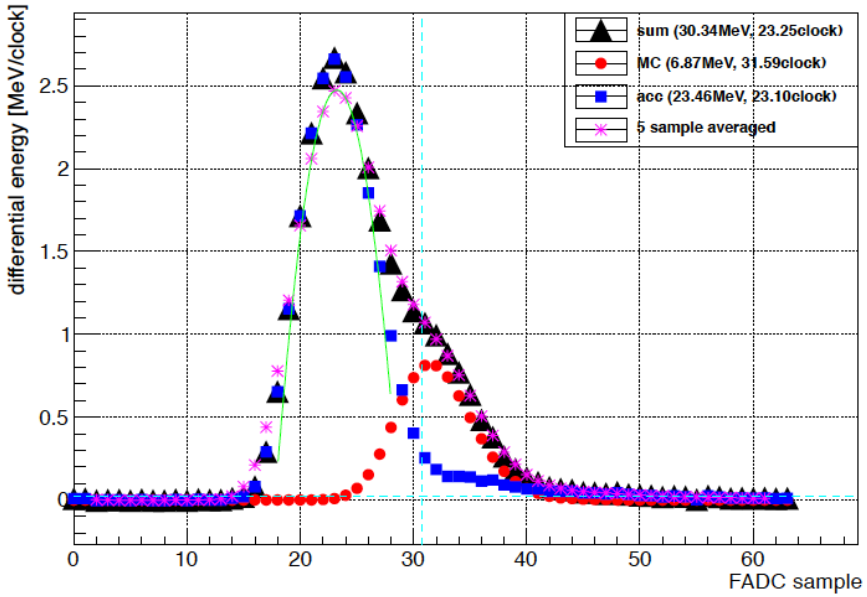


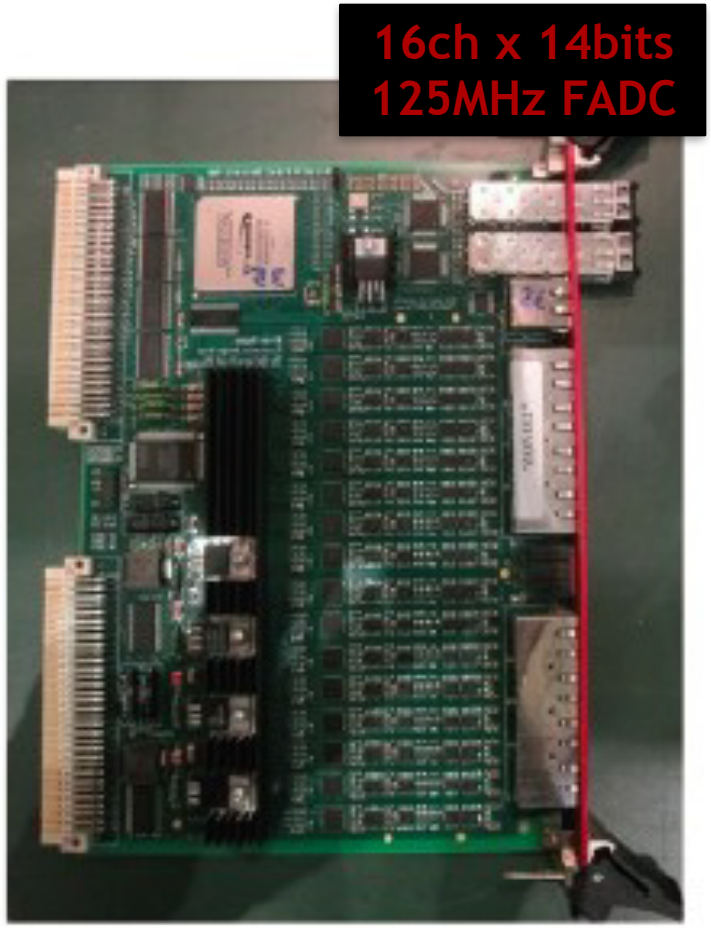


Accidental Loss: Analysis

Full waveform analysis

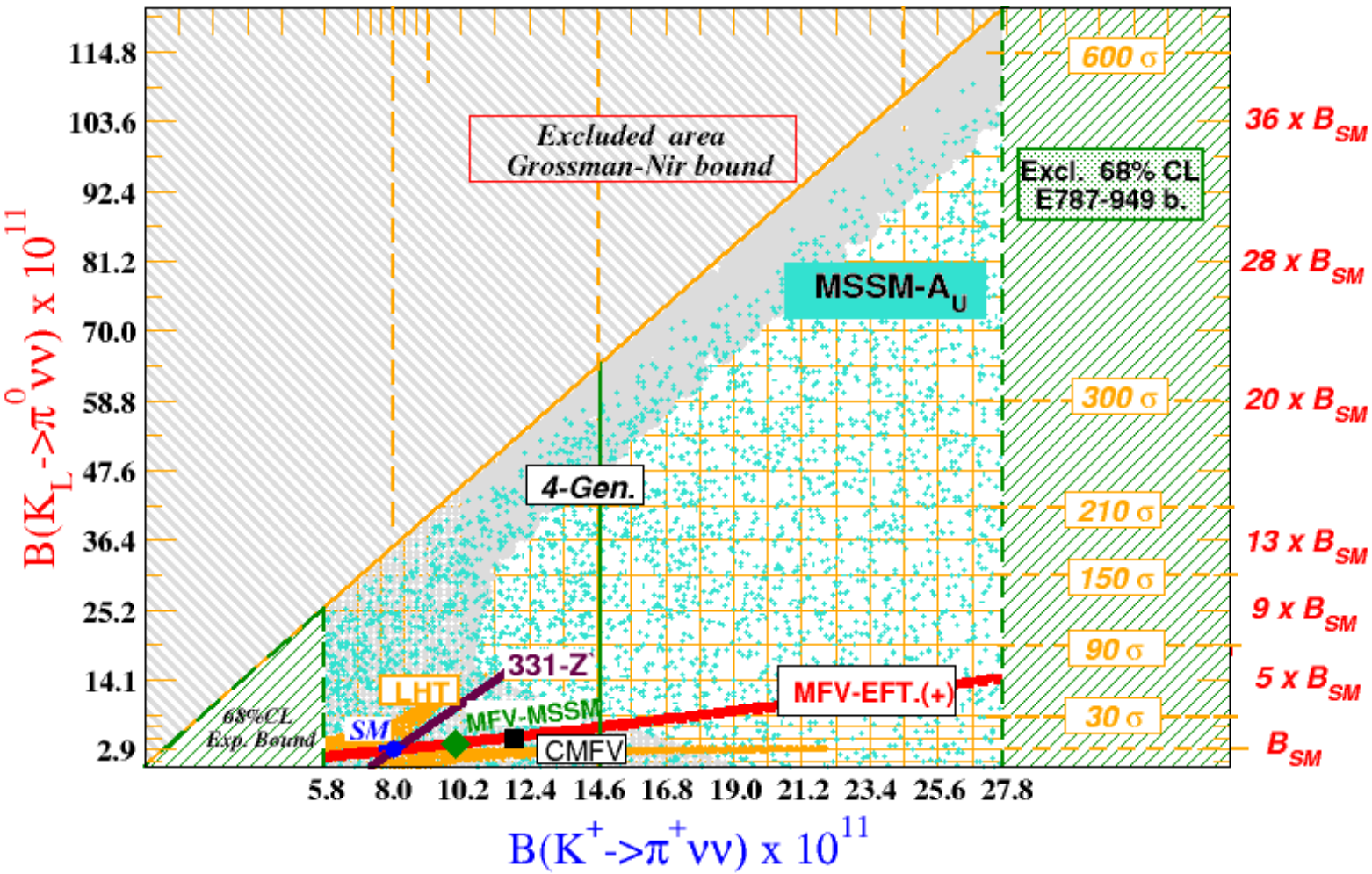
- better timing determination
- signal/accidental discrimination

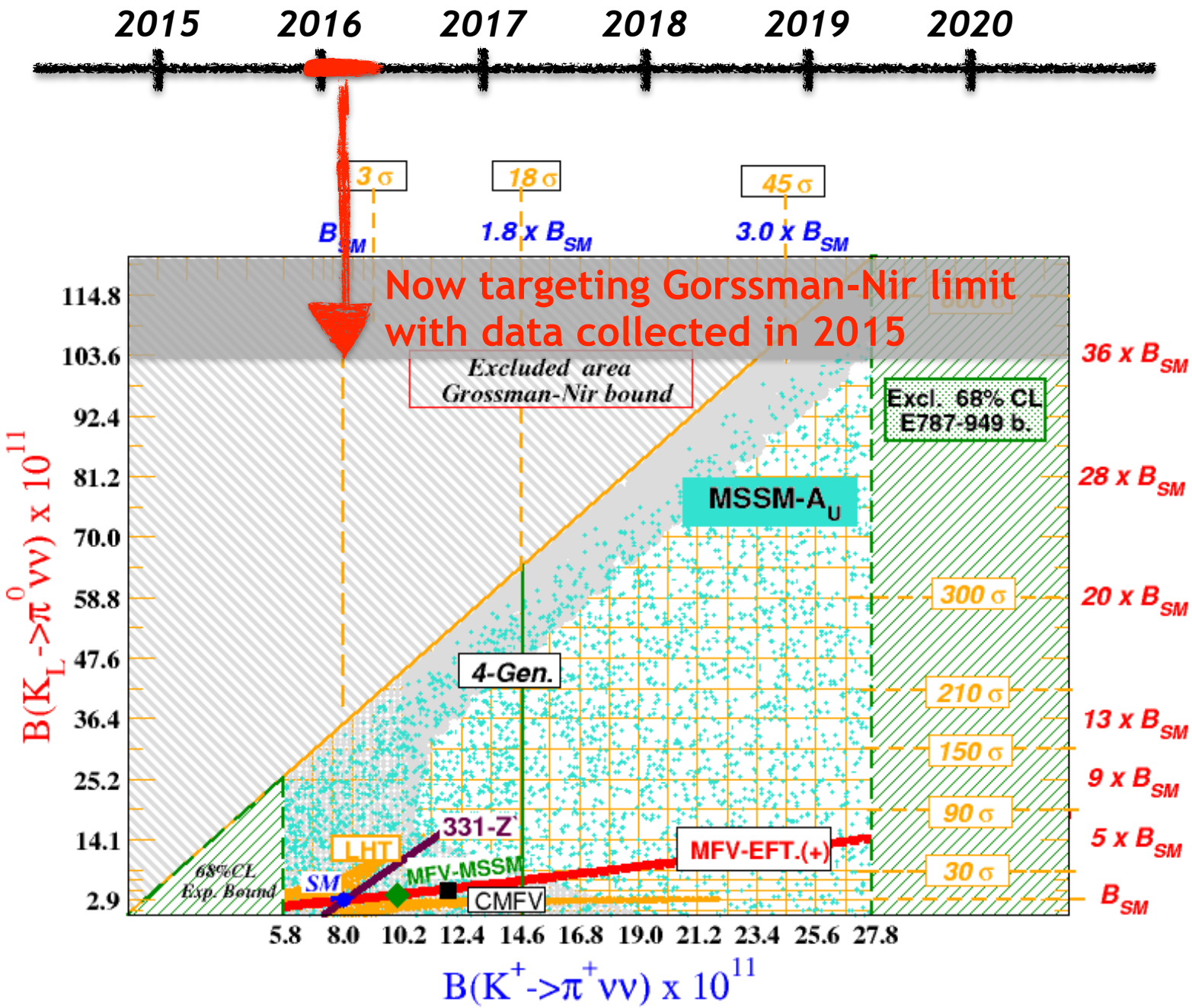




2011 2015 2016 2017 2018 2019 2020

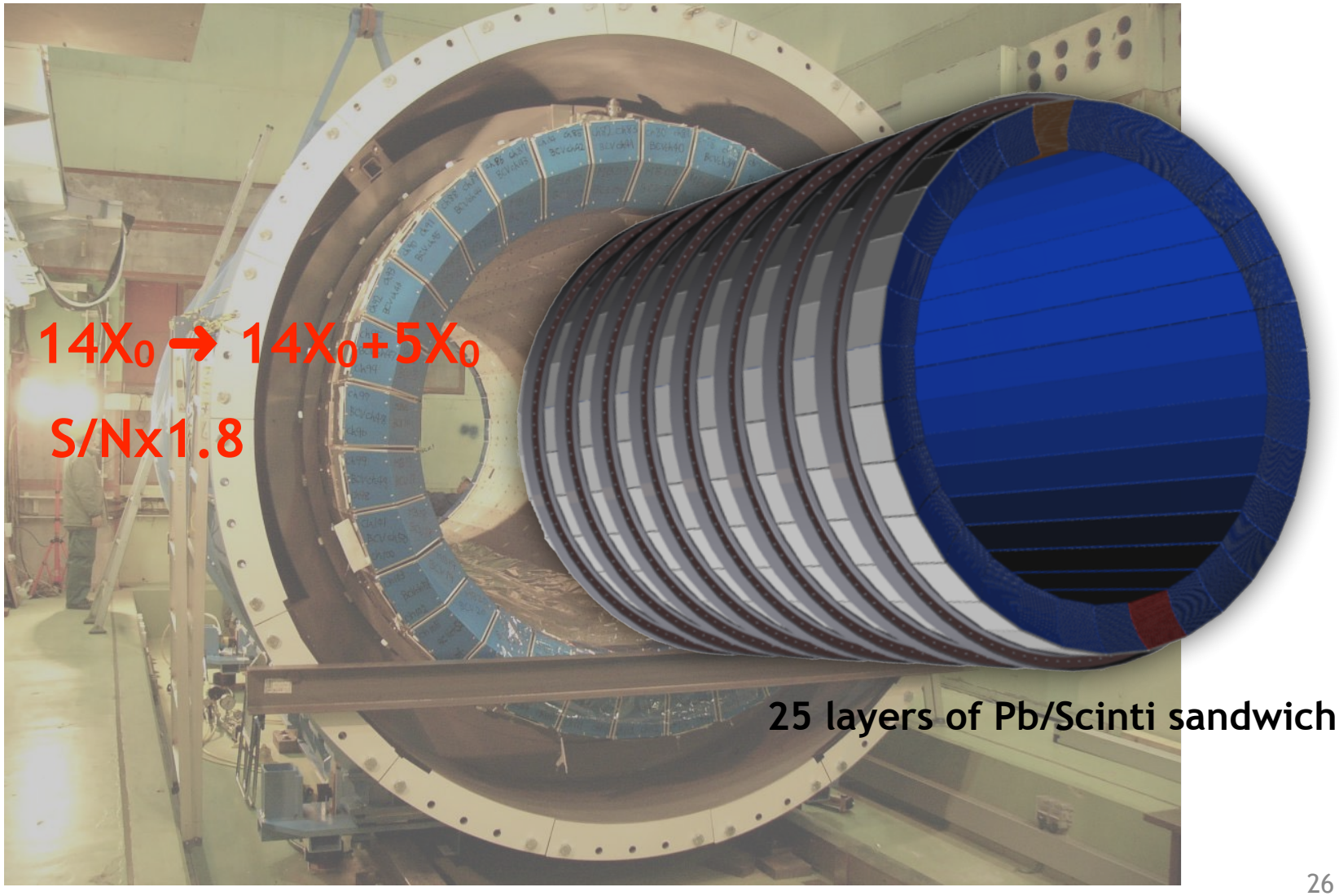
Current Limit by E391a is beyond the Map &
KOTO reached the same sensitivity with only 100hrs of data

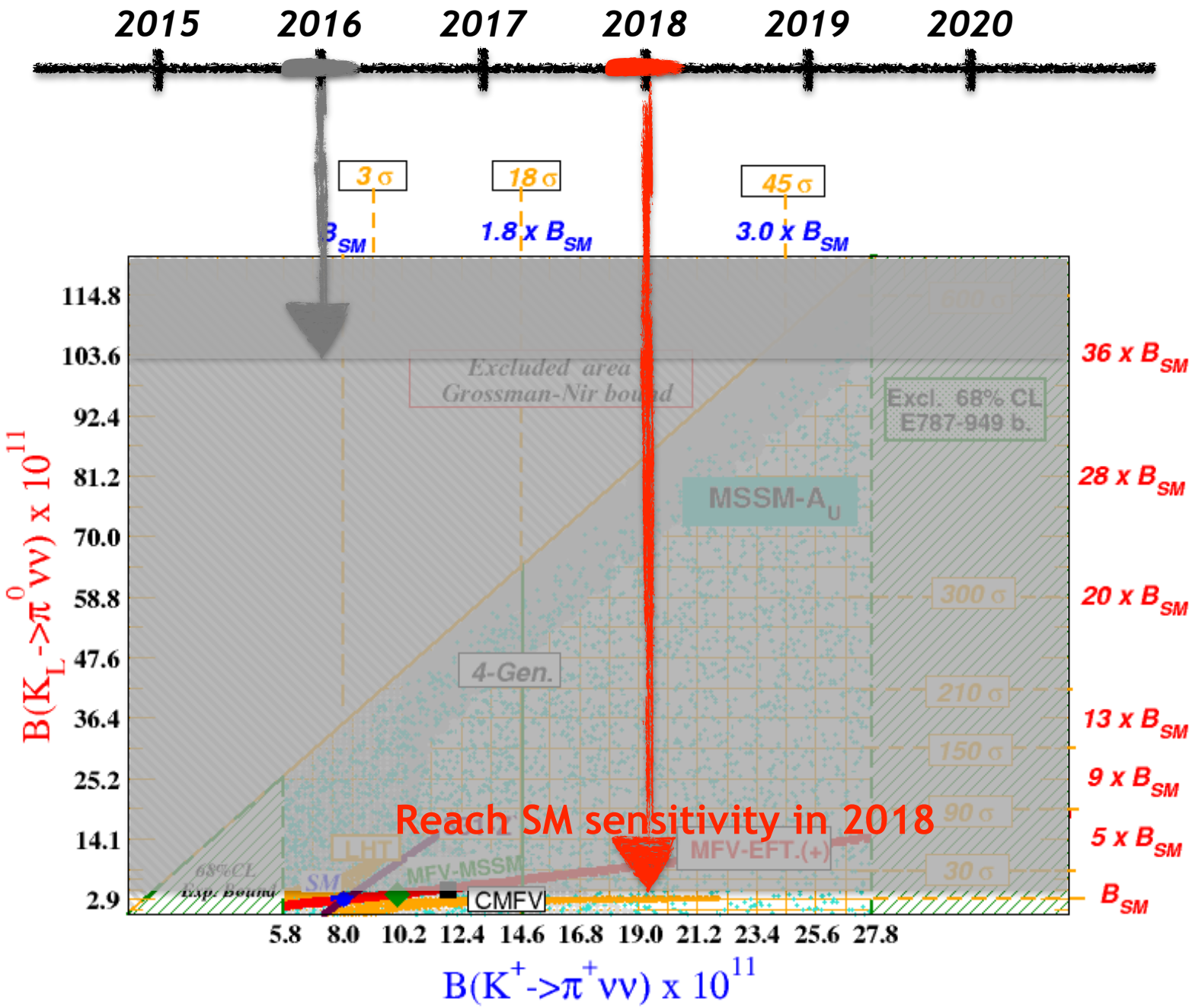


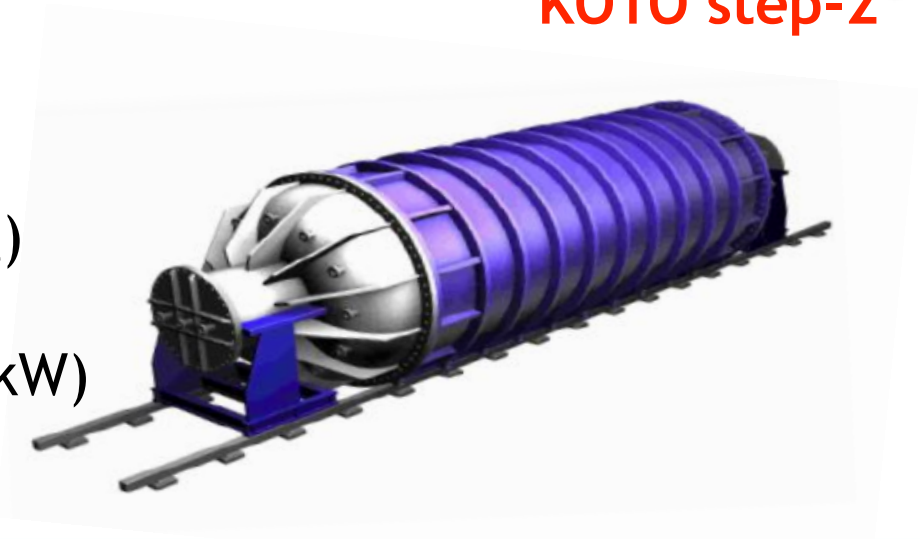

2015
2016
2017
2018
2019
2020
3 σ
18 σ
45 σ
B_SM
1.8 x B_SM
3.0 x B_SM
Now targeting Gorssman-Nir limit
with data collected in 2015
Excluded area
Grossman-Nir bound
Excl. 68% CL
E787-949 b.
MSSM-A_U
4-Gen.
300 σ
210 σ
150 σ
90 σ
30 σ
36 x B_SM
28 x B_SM
20 x B_SM
13 x B_SM
9 x B_SM
5 x B_SM
B_SM
LHT
331-Z'
MFV-MSSM
MFV-EFT.(+)
CMFV
SM
68%CL
Exp. Bound
114.8
103.6
92.4
81.2
70.0
58.8
47.6
36.4
25.2
14.1
2.9
5.8
8.0
10.2
12.4
14.6
16.8
19.0
21.2
23.4
25.6
27.8
B(K_L->π^0 νν) x 10^11
B(K^+->π^+ νν) x 10^11

2015 2016 2017 2018 2019 2020

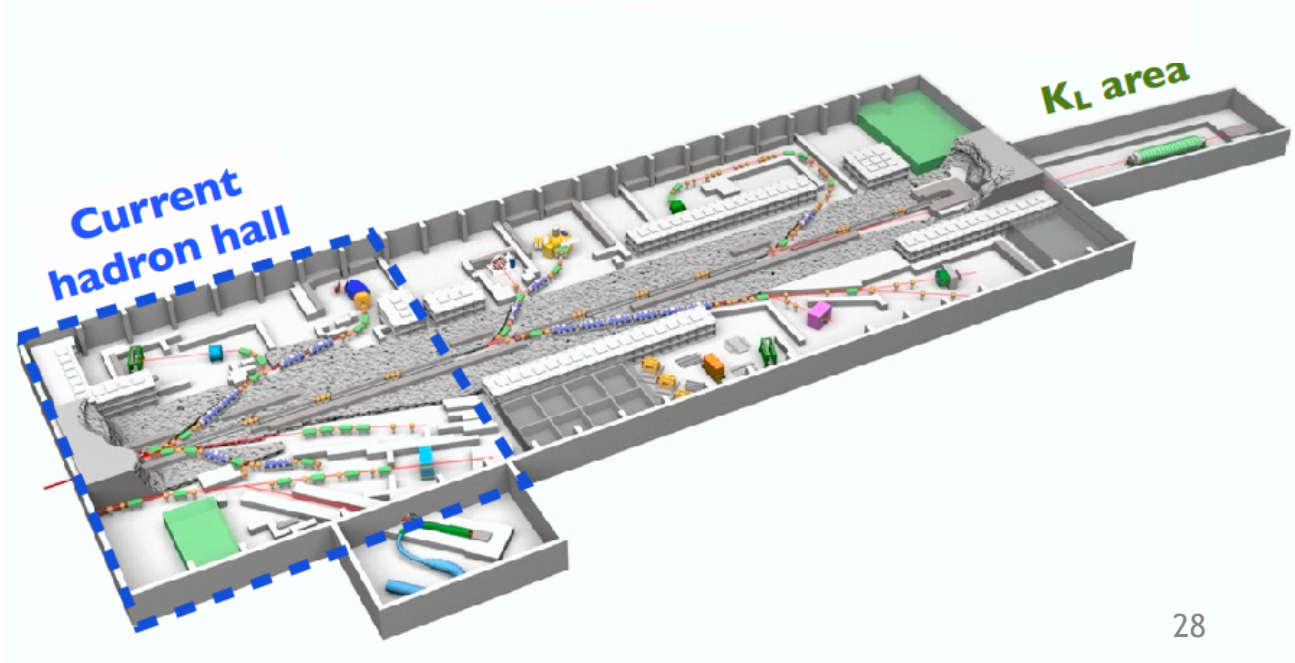
Full Completion of Detector




2015
2016
2017
2018
2019
2020
3 σ
18 σ
45 σ
1.8 x B_SM
3.0 x B_SM
Excluded area
Grossman-Nir bound
Excl. 68% CL
E787-949 b.
MSSM-A_U
4-Gen.
LHT
MFV-MSSM
SM
CMFV
MFV-EFT.(+)
68%CL
Exp. Bound
600 σ
300 σ
210 σ
150 σ
90 σ
30 σ
36 x B_SM
28 x B_SM
20 x B_SM
13 x B_SM
9 x B_SM
5 x B_SM
B_SM
114.8
103.6
92.4
81.2
70.0
58.8
47.6
36.4
25.2
14.1
2.9
B(K_L^0->π^0νν) x 10^11
5.8
8.0
10.2
12.4
14.6
16.8
19.0
21.2
23.4
25.6
27.8
B(K^+->π^+νν) x 10^11
Reach SM sensitivity in 2018



- Larger detector (15m long)
- Higher beam power (>400kW)
- 100 SM events with S/N~5



Summary


2015
2016
2017
2018
2019
2020
KOTO
Cross Grossman-Nir limit in 2016
SM Prediction
Step-1 target: reach 0(10^-11) S.E.S. in 2018
Step-2: 100 SM events