Use of emulsion shifter (multi-stage shifter) for the neutrino target

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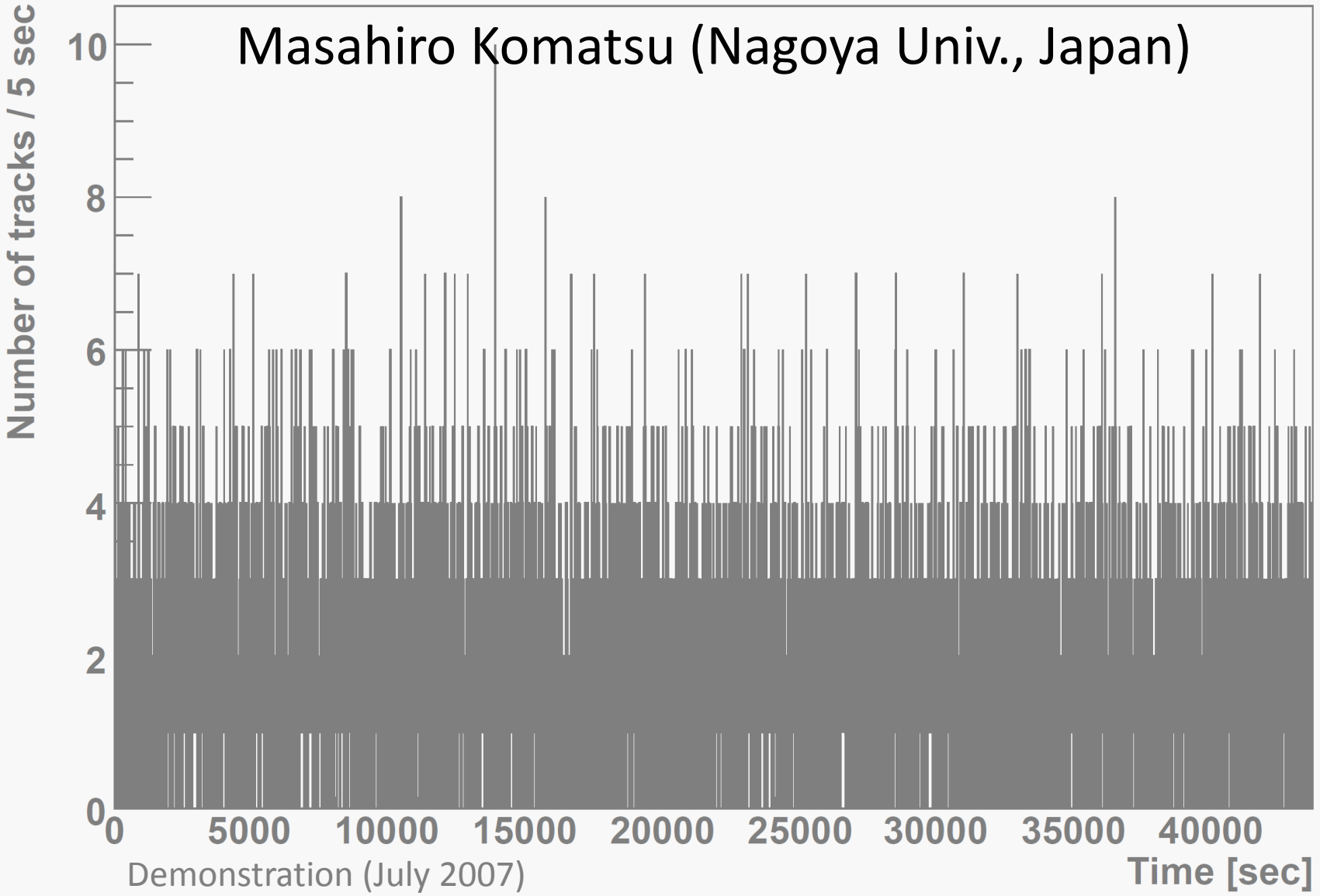


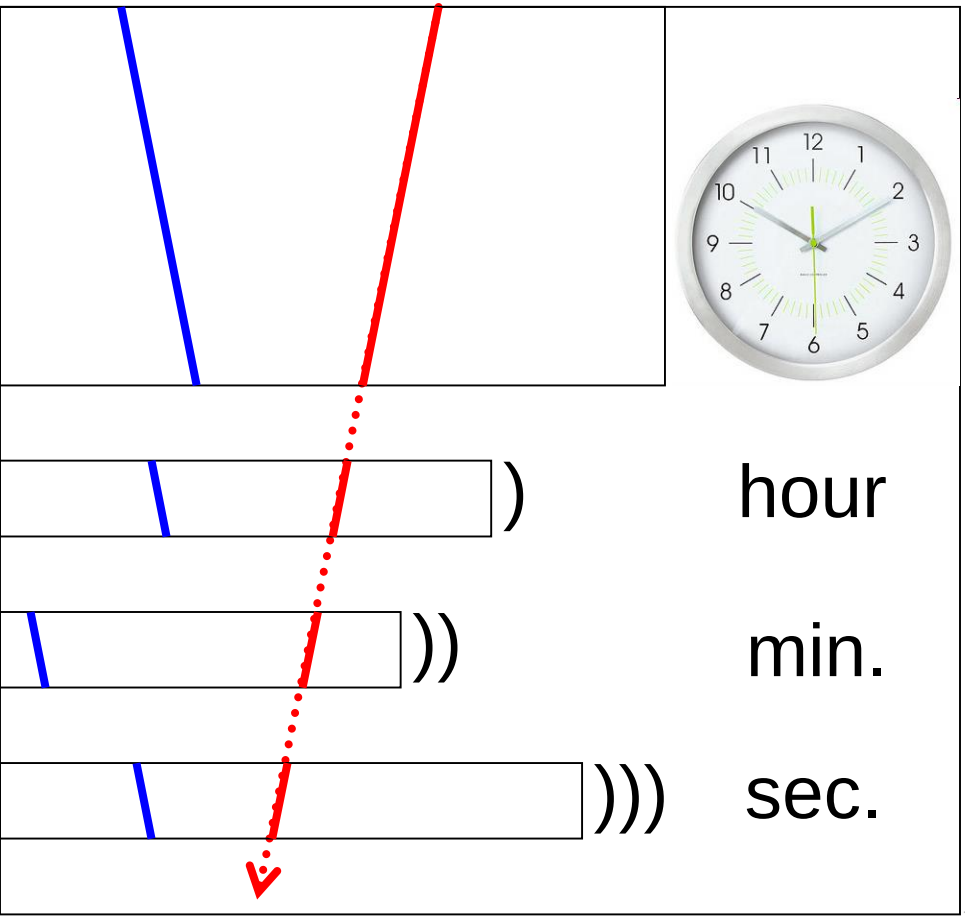
Demonstration (July 2007)

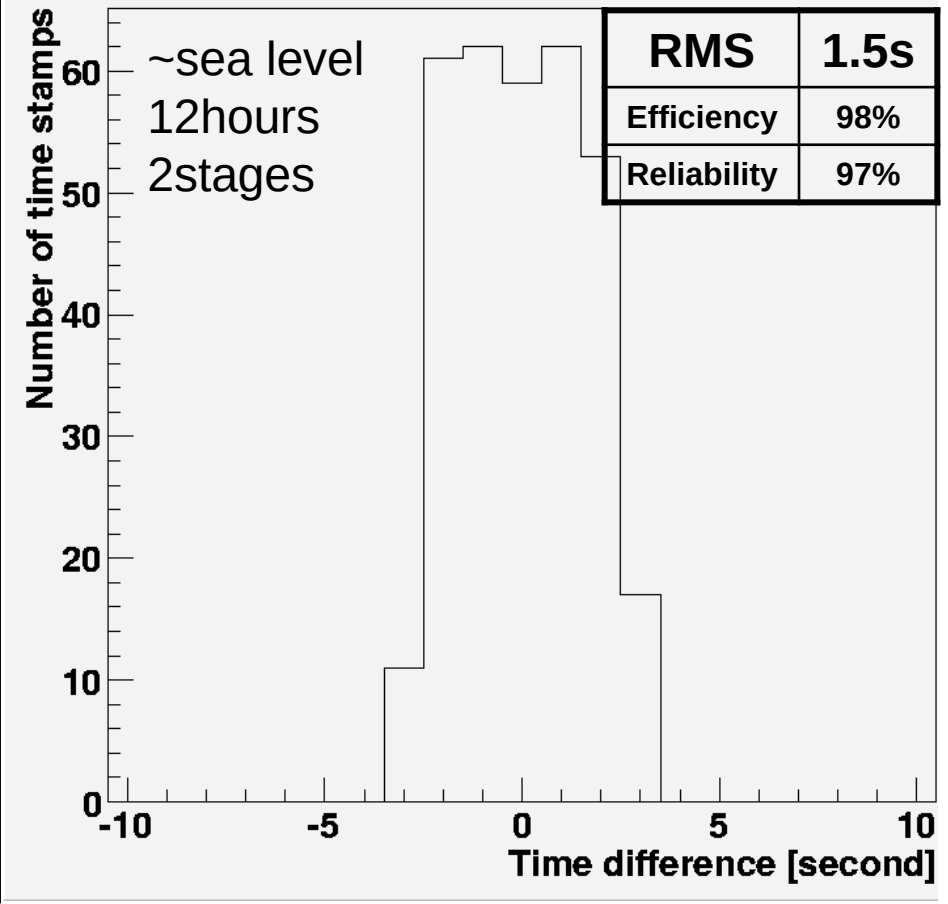
Introduction

- Multi-stage shifter techniques allow us to timestamp to emulsion tracks within ~seconds with high reliability and efficiency for large-scale and inaccessible emulsion experiments.
- For balloon-borne emulsion gamma-ray telescope experiment, GRAINE
  - S. Aoki et al., arXiv:1202.2529.
  - S. Takahashi et al., Proc. 33rd Int. Cosmic Ray Conference, 228 (2013).
- By using multi-stage shifter, Emulsion – Electronic detector hybrid analysis can be performed.
  - Conventional method (Changeable Sheet + Electronic precision-tracker) can be replaced by multi-stage shifter.
- All emulsion tracks has timing information → emulsion event reconstruction with timing information can be performed.
- Powerful technique for accelerator neutrino experiment with nuclear emulsion

June 2007, Proposed
July 2007, Demonstrated

Multi-stage shifter





S.Takahashi et al., Nucl. Instr. And Meth. A, 620 (2010) 192-195

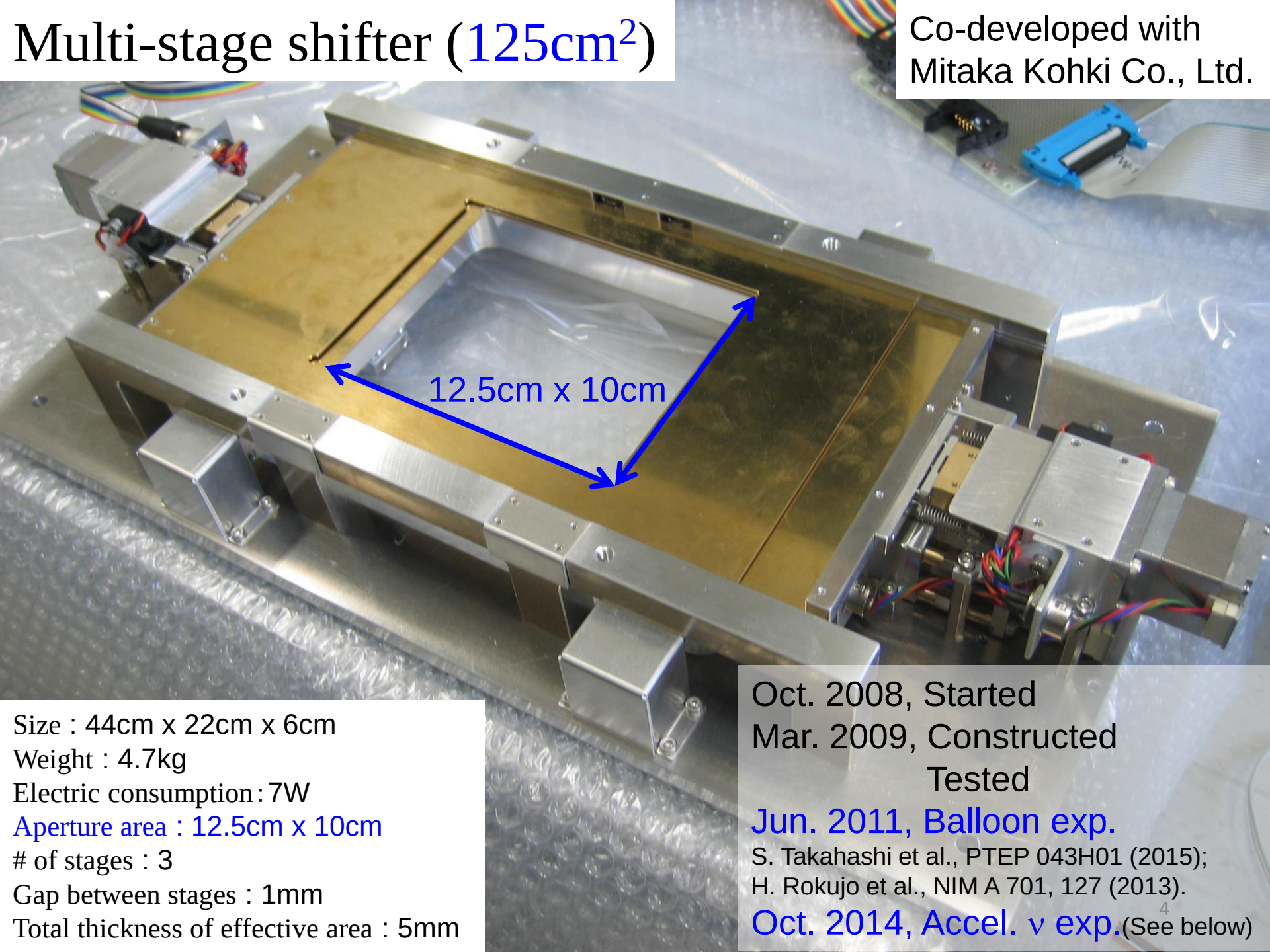
Consists of emulsion films with Small R.L., High spatial resolution

→ Low mom. Threshold ($p\beta_e$~10MeV/c), High reliability & efficiency, Large area

Simple component, Compact, Light, HV free, Low power consumption, Dead time free

Multi-stage shifter ($125cm^2$)

Co-developed with
Mitaka Kohki Co., Ltd.

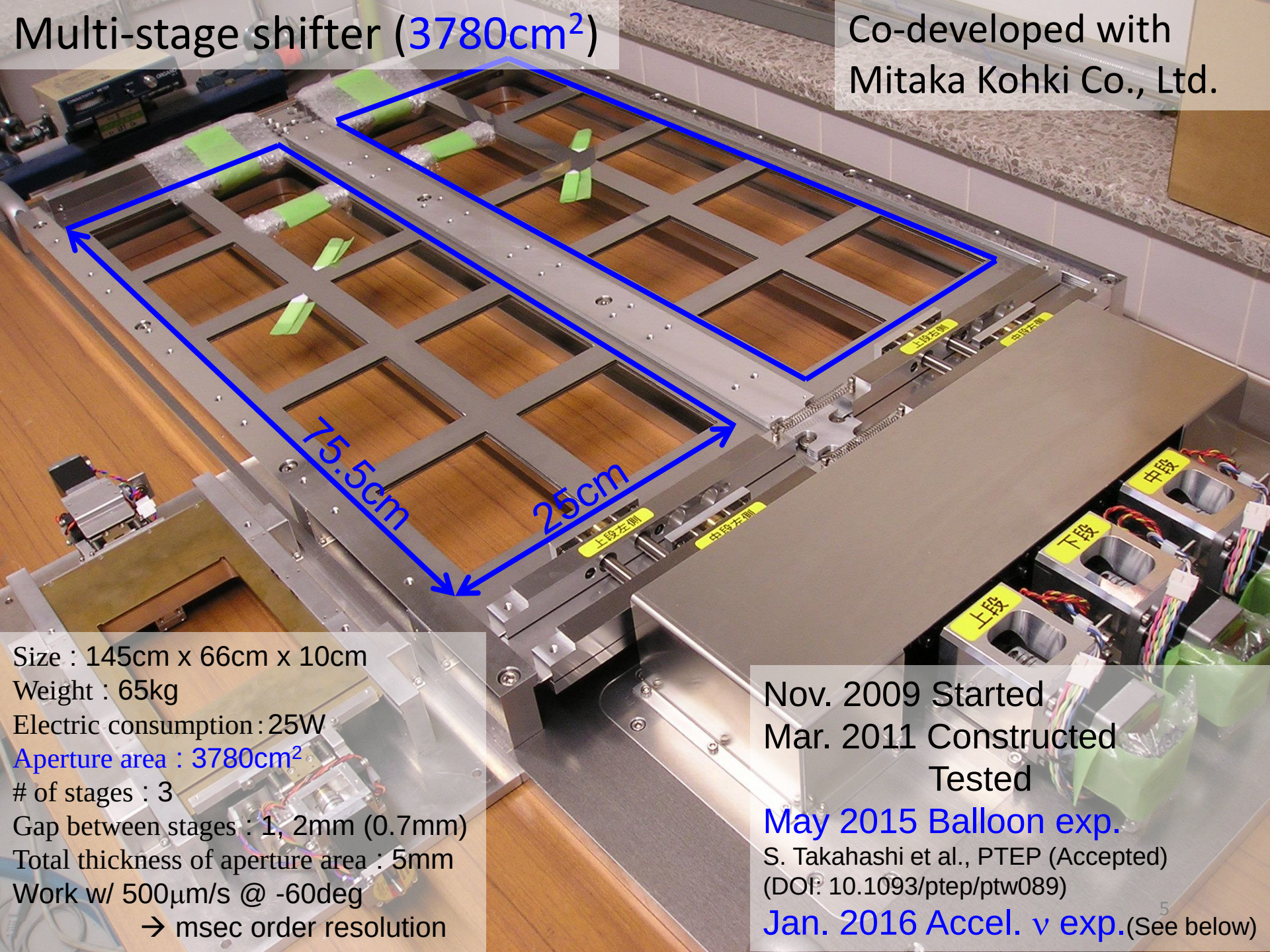


Size : 44cm x 22cm x 6cm
Weight : 4.7kg
Electric consumption : 7W
Aperture area : 12.5cm x 10cm
# of stages : 3
Gap between stages : 1mm
Total thickness of effective area : 5mm

Oct. 2008, Started
Mar. 2009, Constructed
Tested
Jun. 2011, Balloon exp.
S. Takahashi et al., PTEP 043H01 (2015);
H. Rokujo et al., NIM A 701, 127 (2013).
Oct. 2014, Accel. ν exp. (See below)

Multi-stage shifter (3780cm^2)

Co-developed with
Mitaka Kohki Co., Ltd.

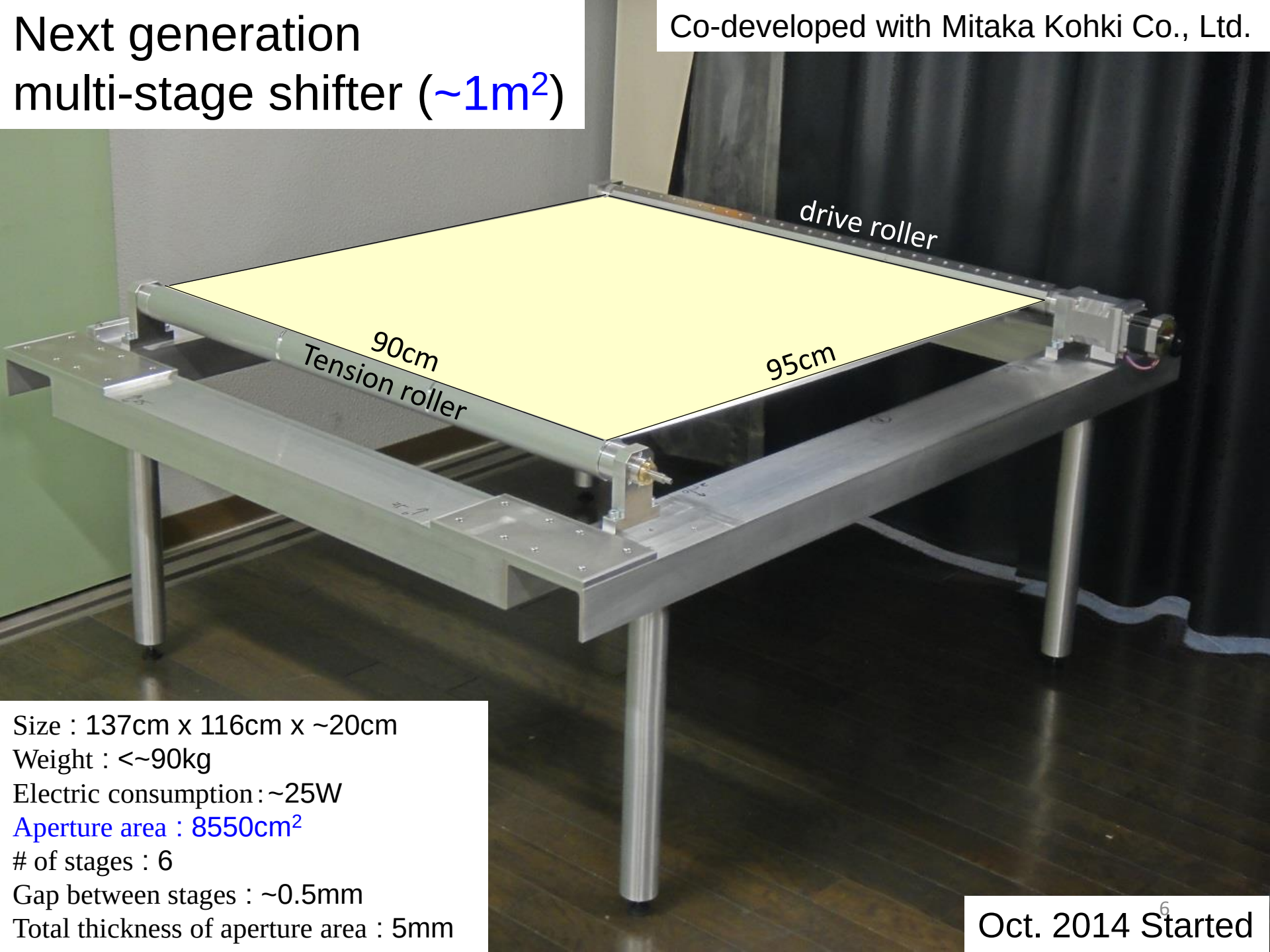


Size : 145cm x 66cm x 10cm
Weight : 65kg
Electric consumption : 25W
Aperture area : 3780cm^2
# of stages : 3
Gap between stages : 1, 2mm (0.7mm)
Total thickness of aperture area : 5mm
Work w/ 500μm/s @ -60deg
→ msec order resolution

Nov. 2009 Started
Mar. 2011 Constructed
Tested
May 2015 Balloon exp.
S. Takahashi et al., PTEP (Accepted)
(DOI: 10.1093/ptep/ptw089)
Jan. 2016 Accel. ν exp.(See below)

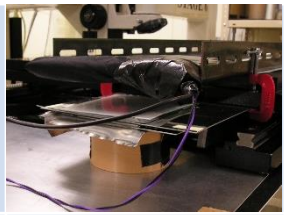
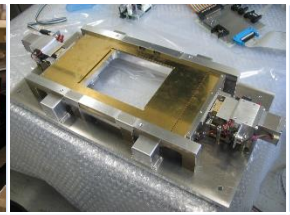
Next generation multi-stage shifter (~1m^2)

Co-developed with Mitaka Kohki Co., Ltd.



Size : 137cm x 116cm x ~20cm
Weight : <~90kg
Electric consumption : ~25W
Aperture area : 8550cm^2
# of stages : 6
Gap between stages : ~0.5mm
Total thickness of aperture area : 5mm

Oct. 2014 Started

	Demon-stration	125cm² model	3780cm² model	New model (Prototype)	Aim
					
Since	2007	2008	2009	2014	
For timestamping performance: Gap [mm]	4	x1/2.7 → 1.5	(x1/2.1) → (0.7)1.5	x1/3 → 0.5	<0.5
For timestamping performance: # of stages	2	x1.5 → 3	3	x2 → 6	>4
For large-scale: Aperture area [m²]	.0125	.0125	x29 → .3780	x2.3 → .8550	>10.
For large-scale: Size [m²]	-----	0.44 x 0.22	1.45 x 0.66	1.37 x 1.16	-----
For large-scale: Size/10m²[m²]	-----	77	x1/3.1 → 25	x1/1.3 → 18.6	<25
For large-scale: Weight [kg]	-----	4.7	65	90 (50)	-----
For large-scale: Weight/10m²[kg]	-----	3760	x1/2.2 → 1700	x1/1.6 (x1/2.8) → 1050 (600)	<1000
For large-scale: Power [W]	-----	7	25	25	-----
For large-scale: Power/10m²[W]	-----	5600	x1/12 → 660	x1/2.3 → 290	<500
For large-scale: Cost ratio	-----	1	1.46	1.34	-----
For large-scale: Cost ratio/10m²	-----	1	x1/21 → 1/20.7	x1/2.5 → 1/51.2	≤1/30

() b/w 2nd – 3rd stages () pipe-roller case

Accelerator ν experiment with nuclear emulsion, J-PARC T60

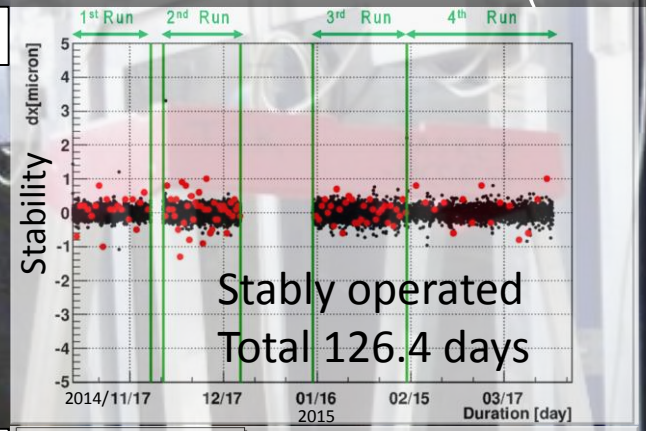
Kobe Univ., Kyoto U, Nagoya U, Nihon U, Toho U, U of Tokyo

Test experiment for

- Precise measurement of νN int.
- Search for sterile neutrino

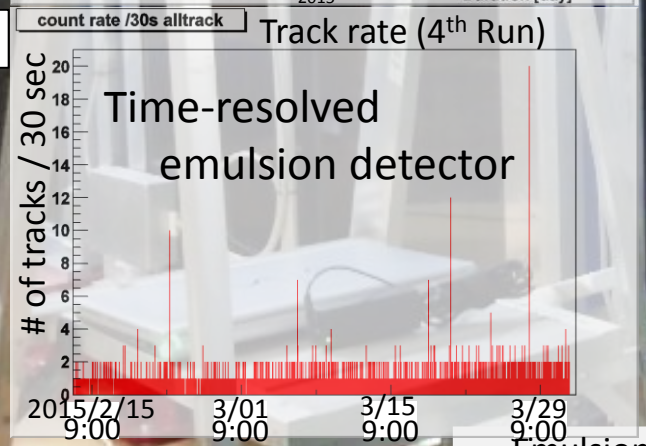
The first demonstration of multi-stage shifter for accelerator neutrino experiment on J-PARC T60 (Feasibility run in 2014 – 2015)

1



Stably operated
Total 126.4 days

2



Track rate (4th Run)

Time-resolved emulsion detector

INGRID

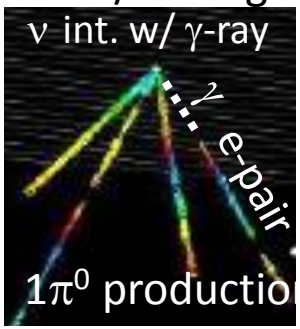
Multi-stage shifter

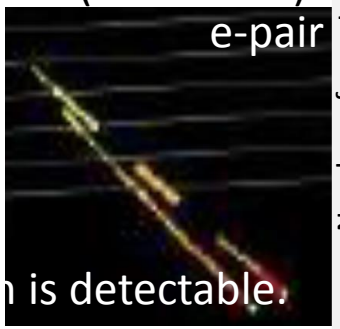
ν

ECC, ~kg
(12.5x10cm^2)
~month exposure

3

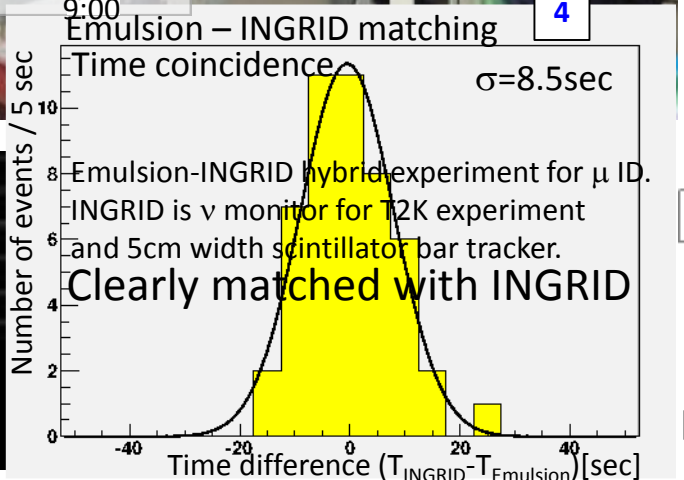
Emulsion event reconstruction w/ timing info. (See below)



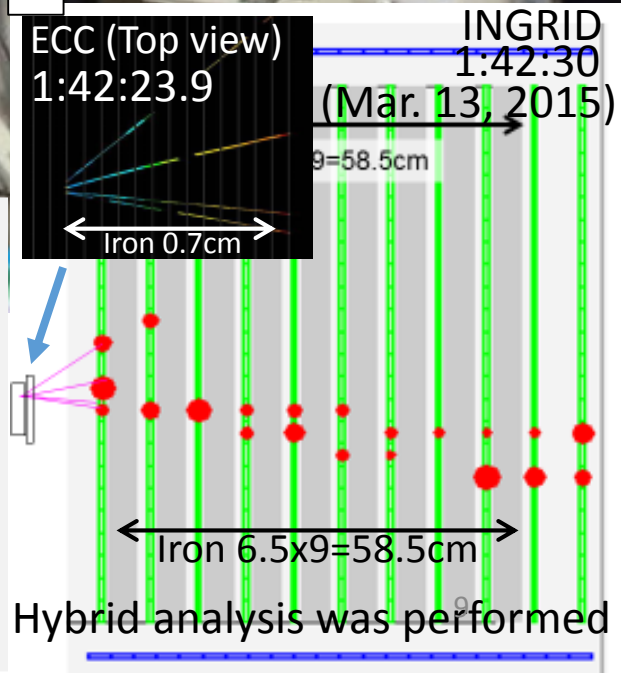


$1\pi^0$ production is detectable.

4



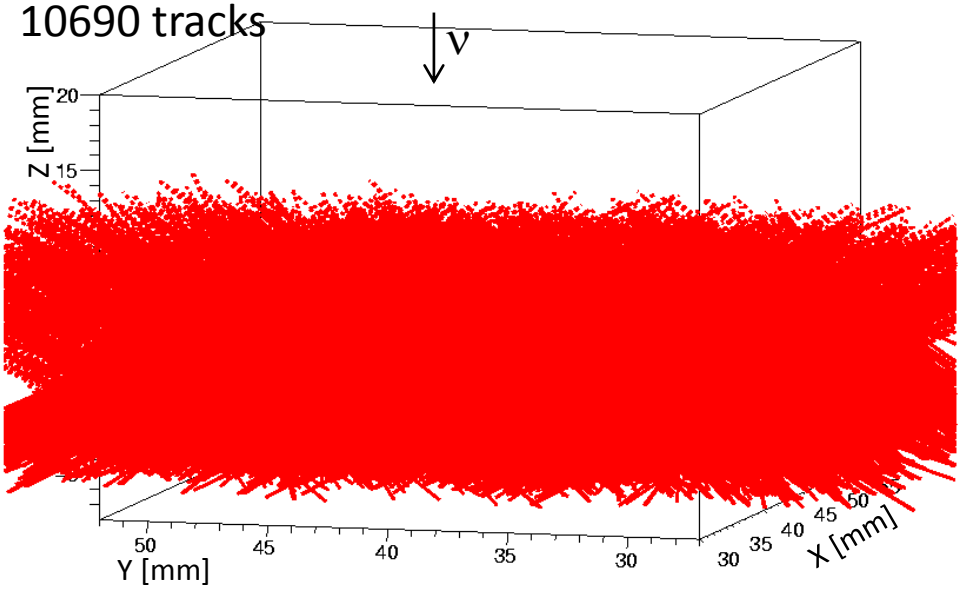
5



Hybrid analysis was performed

Emulsion event reconstruction w/ timing info.

Fig1 Accumulated for 83days (7.2×10^6sec)
(14^{th}/Jan-8^{th}/Apr/2015)
10690 tracks



J-PARC T60
3^{rd}, 4^{th} run (2015)
emulsion data
3cm X 3cm

Fig2 36hours (1.3×10^5sec)
(14:26:12 24^{th} — 2:26:34 26^{th}/Mar/2015)
50 tracks

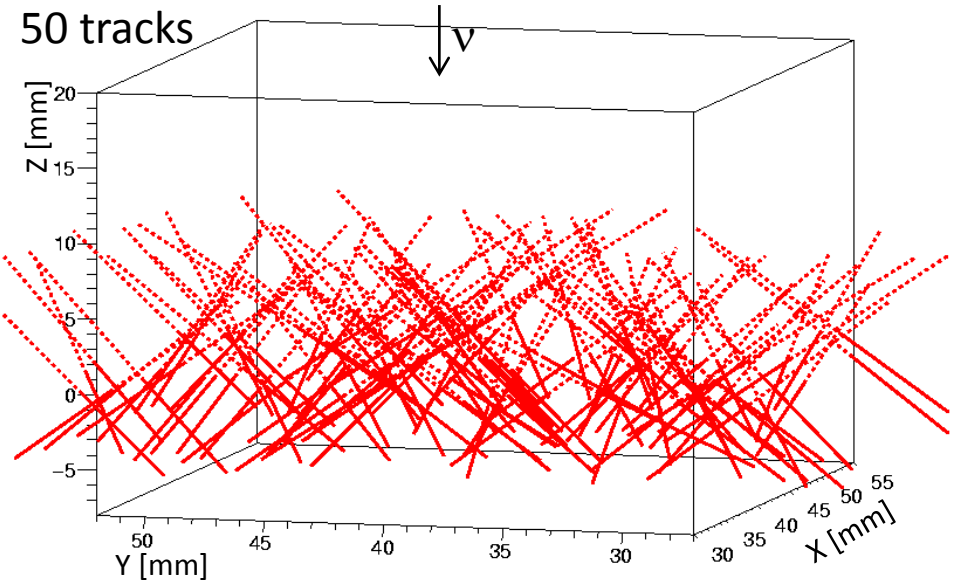
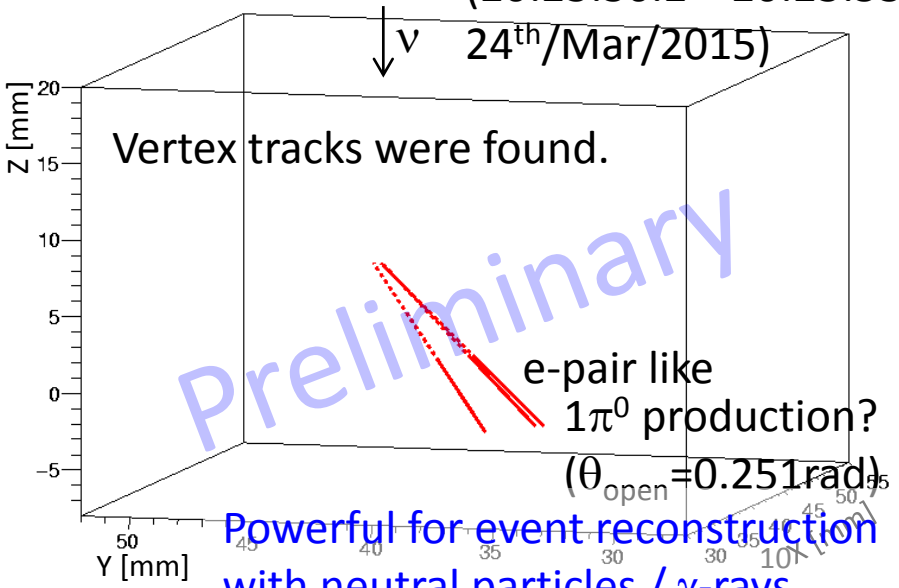
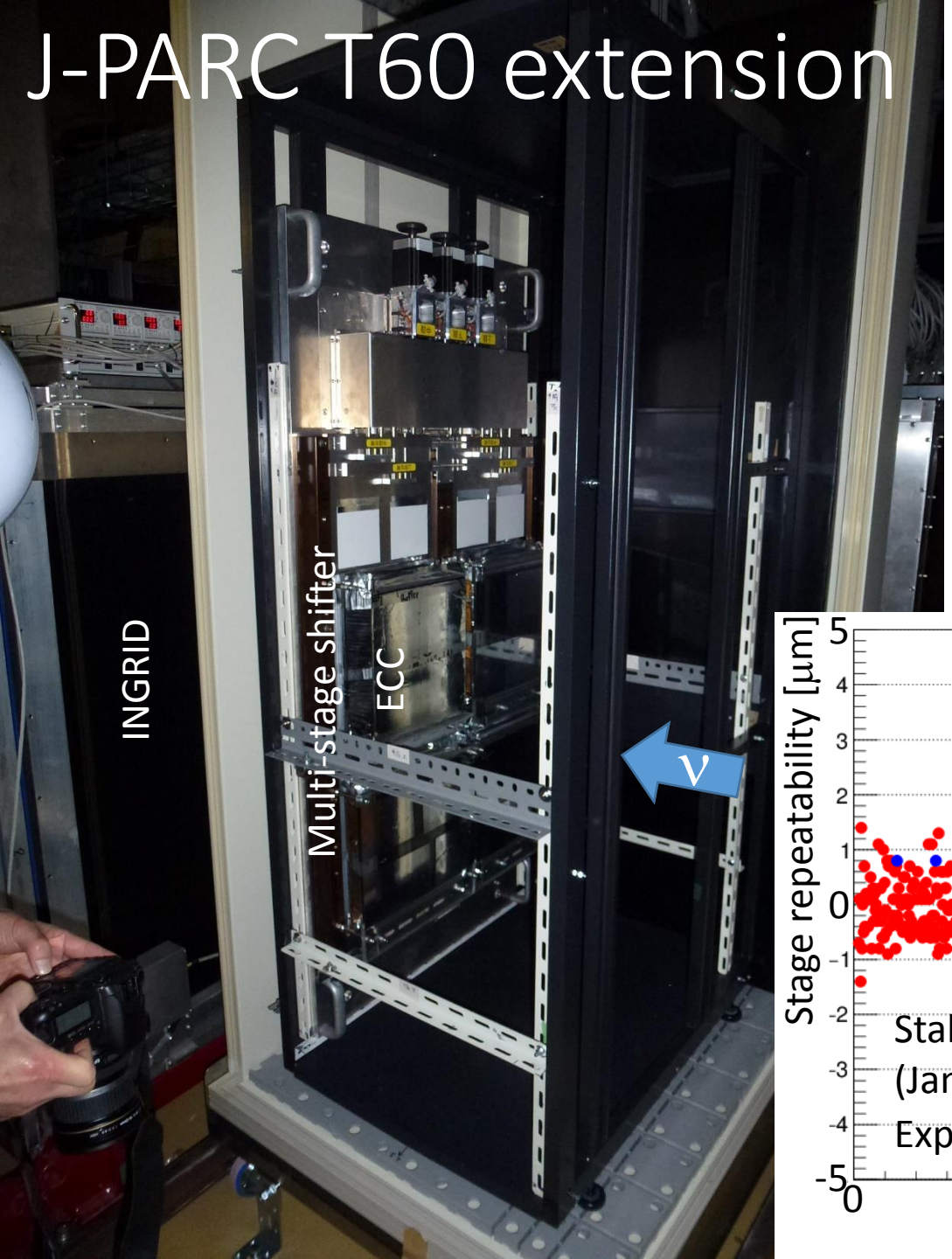


Fig3 23sec
(20:23:30.2—20:23:53.5
24^{th}/Mar/2015)



Powerful for event reconstruction with neutral particles / γ-rays

J-PARC T60 extension



Detector run

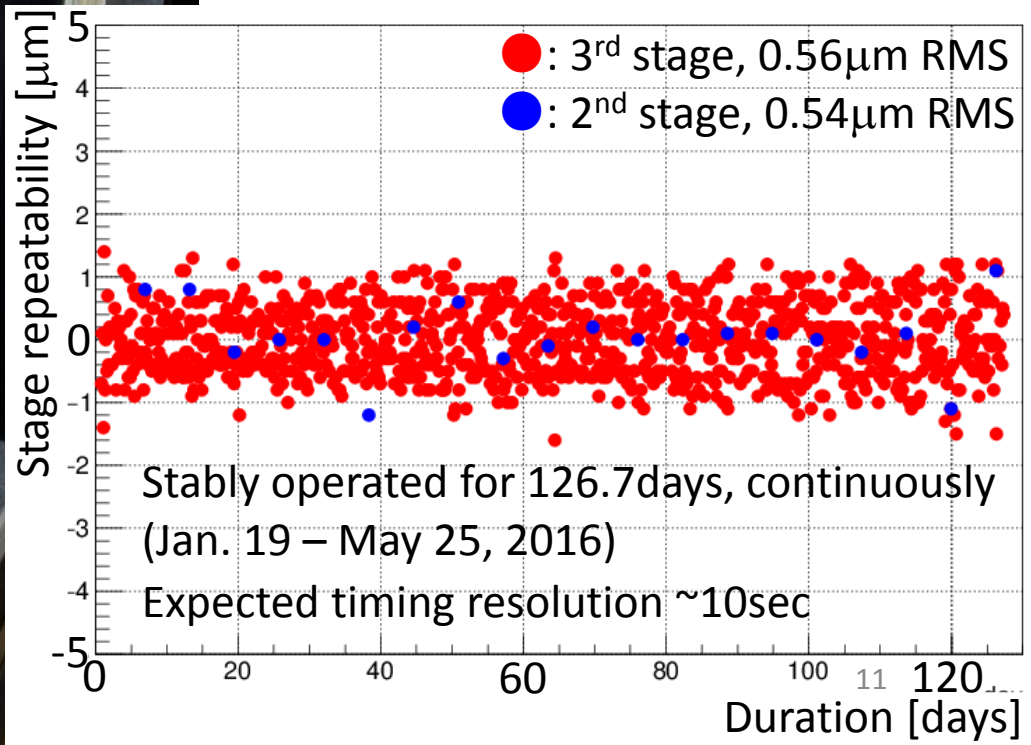
ECC Iron target: ~60kg

Put for ~4 months

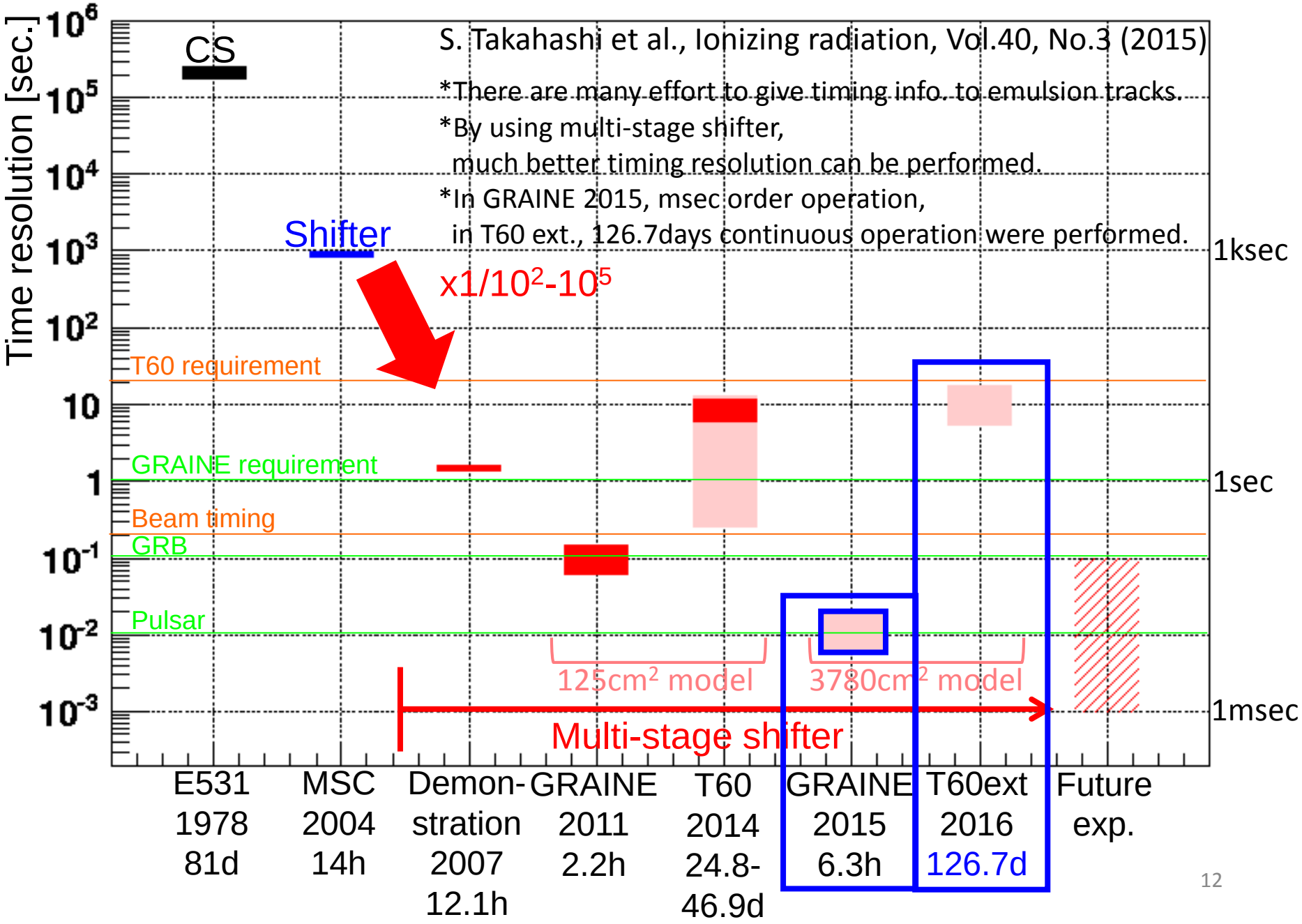
(Jan. 19 – May 30 2016)

3 – 4k anti-ν_μ events

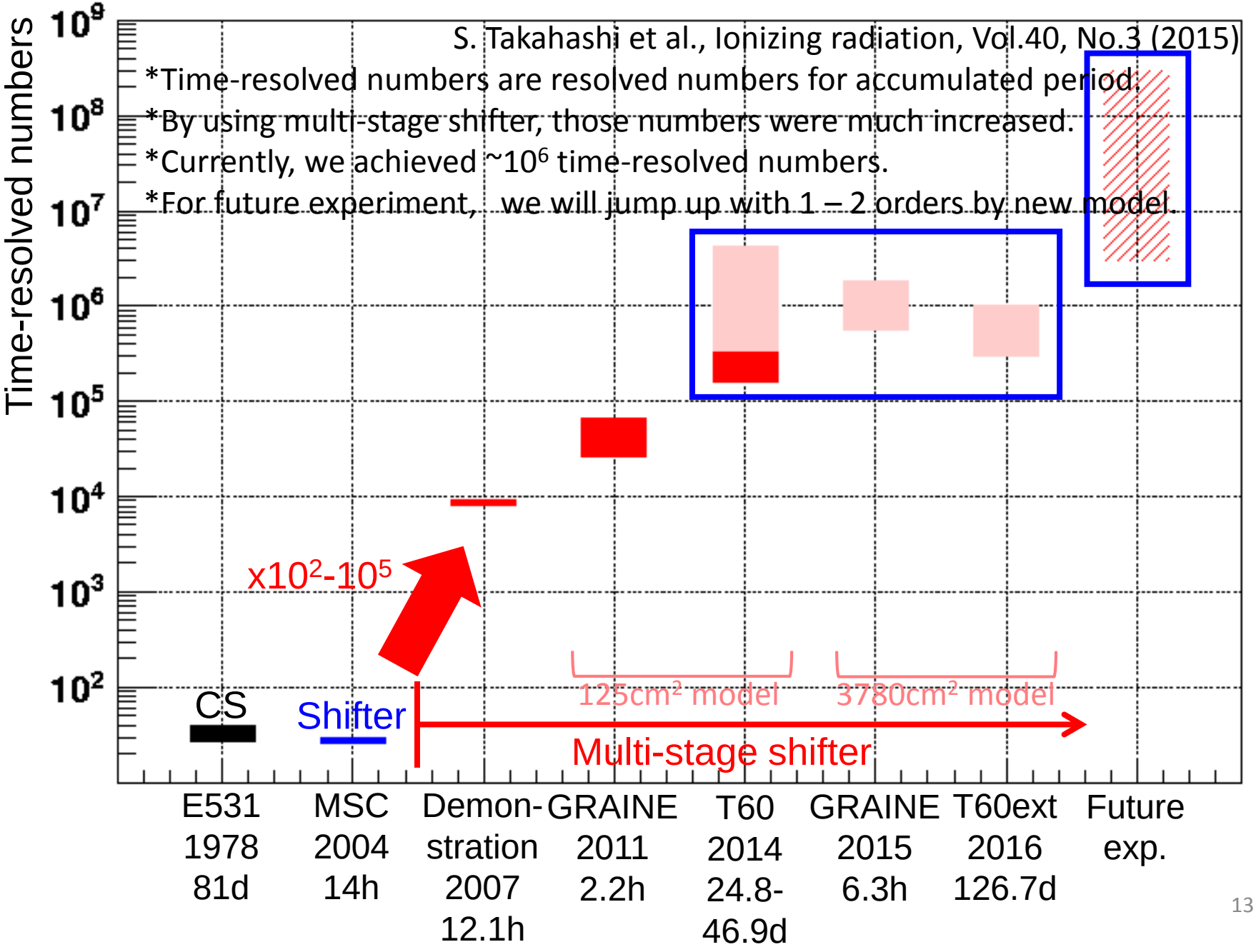
20 – 30 anti-ν_eCC events



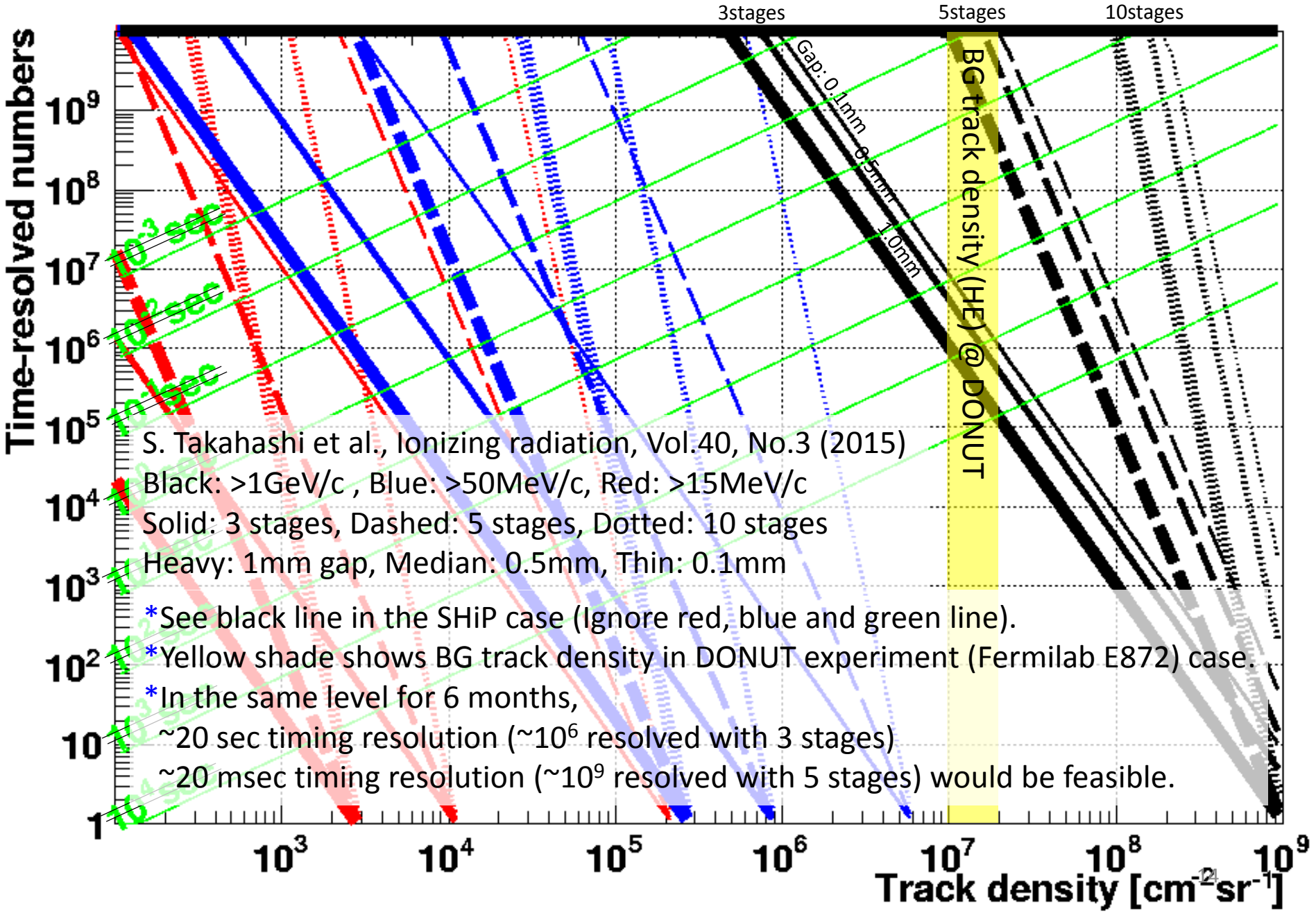
Time resolution of nuclear emulsion



of time-resolved



Feasibility of multi-stage shifter for SHiP



Summary

- We developed multi-stage shifter to timestamp to emulsion tracks within ~seconds with high reliability and efficiency for large-scale and inaccessible emulsion experiments.
- We implemented multi-stage shifter to balloon exp., GRAINE (2011, 2015) and accel. ν exp., T60 (2014, 2016).
- Available for the neutrino target of SHiP experiment
  - Emulsion – Electronic detector hybrid analysis
  - Emulsion event reconstruction with timing info.

Should be checked and considered

- Operation in magnetic field
- Background track rate
- Detail detector configuration (size, clearance, assembling etc.)