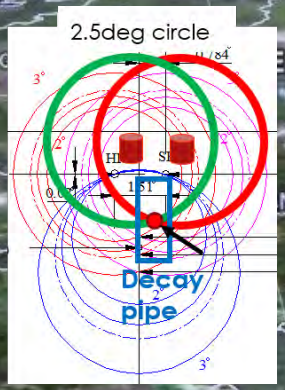
Beam at J-PARC

TAKASHI KOBAYASHI

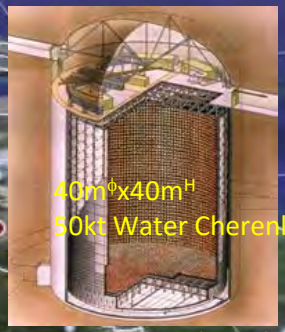
IPNS/KEK, J-PARC

J-PARC neutrino beam for long baseline experiments



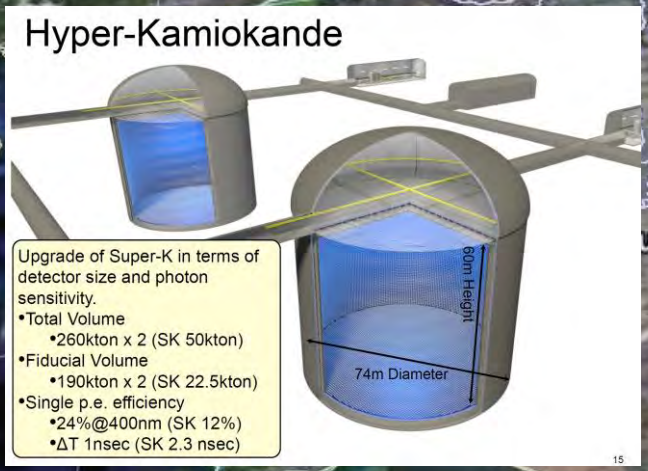
ν_e

Super-K



Super-Kamiokande

Muon neutrino beam
295km

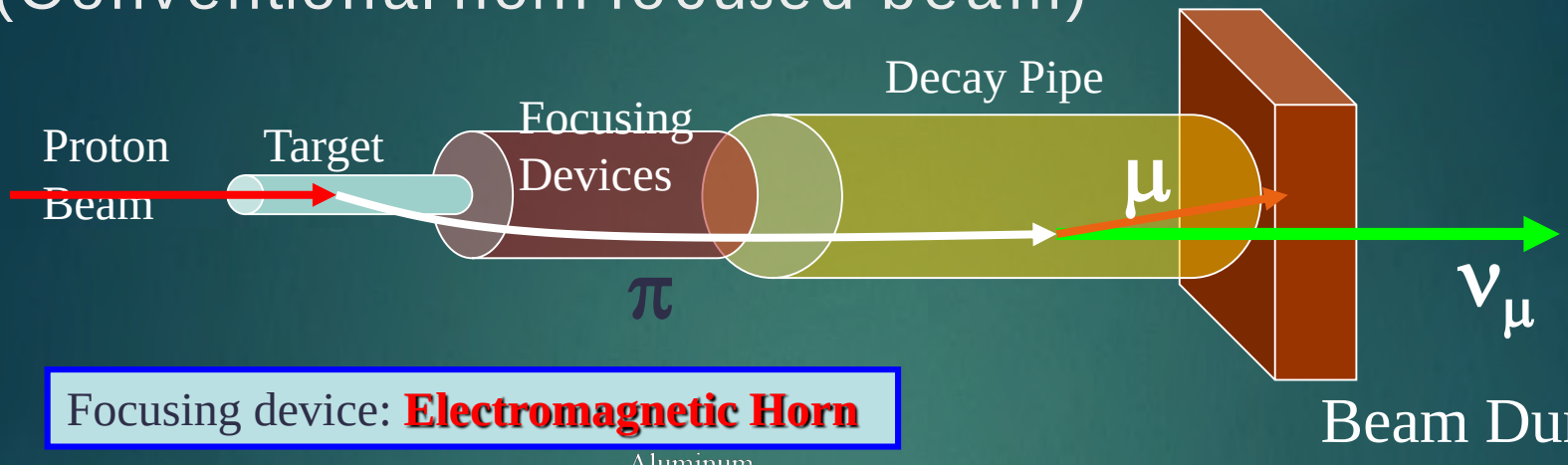


ν_μ

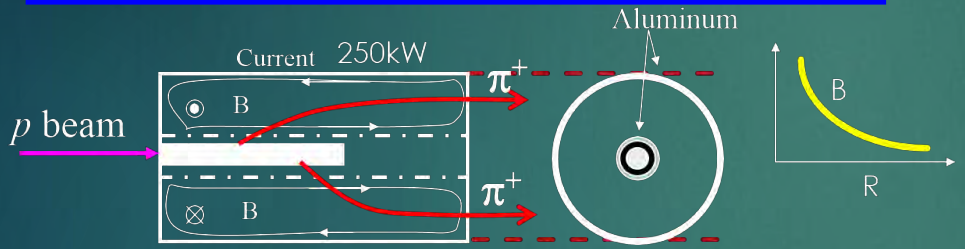
J-PARC

How to make ν_μ beam

(Conventional horn focused beam)



Focusing device: **Electromagnetic Horn**



- Pure ν_μ beam (≳99%)
- $\nu_\mu/\bar{\nu}_\mu$ can be switched by flipping polarity of Horns

For high sensitivity/precise experiment

→ More neutrinos

→ Higher proton beam power
x machine operation time
x running efficiency

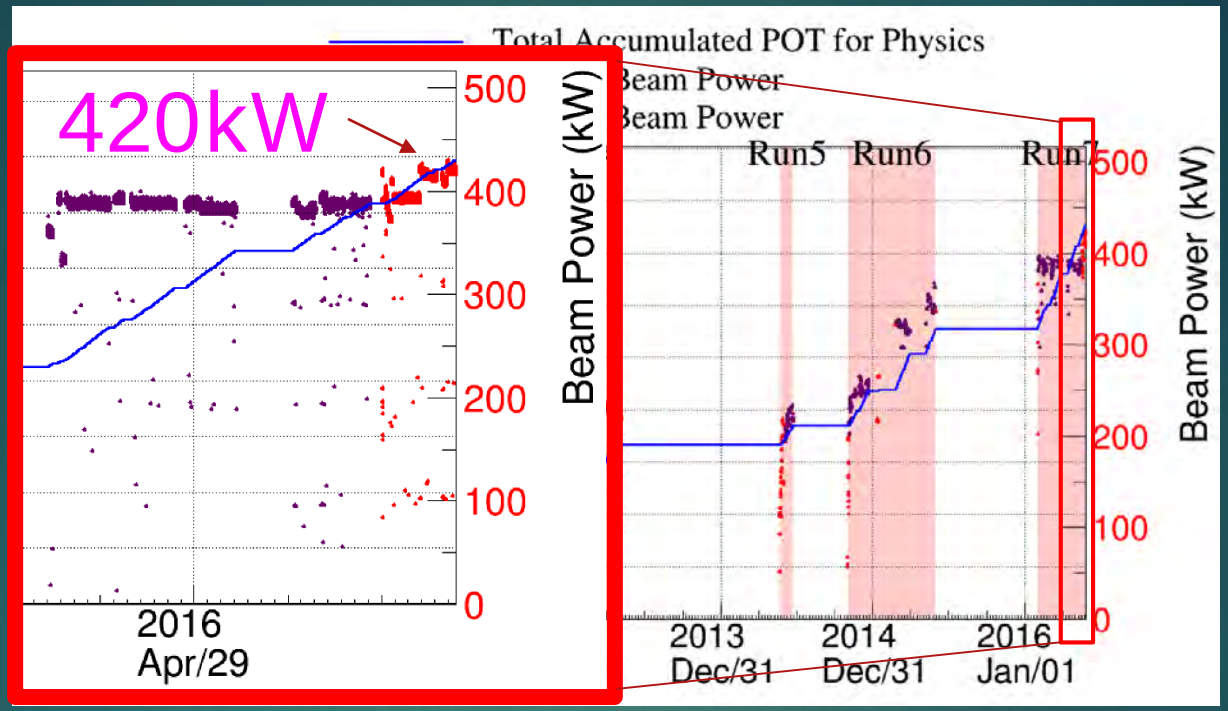

Japan Proton Accelerator Research Complex : J-PARC
181MeV Linac
→400MeV
J-PARC Facility (KEK/JAEA)
South to North
3 GeV RCS
Neutrino Beams (to Kamioka)
Materials and Life Experimental Facility
JAEA
KEK
60km
TOKYO
NARITA
Design intensity
RCS for MLF: 1MW
MR for PN : 750kW
30GeV MR
Hadron Exp. Facility
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

On-going experiment: T2K (Tokai to Kamioka) experiment (2010~)

- High intensity ν_μ beam from J-PARC MR to Super-Kamiokande
- Evidence → Observation of $\nu_\mu \rightarrow \nu_e$ (2011-2013)
- Goals:
  - Discovery → Precise measurement of ν_e appearance
  - Precise meas. of ν_μ disappearance

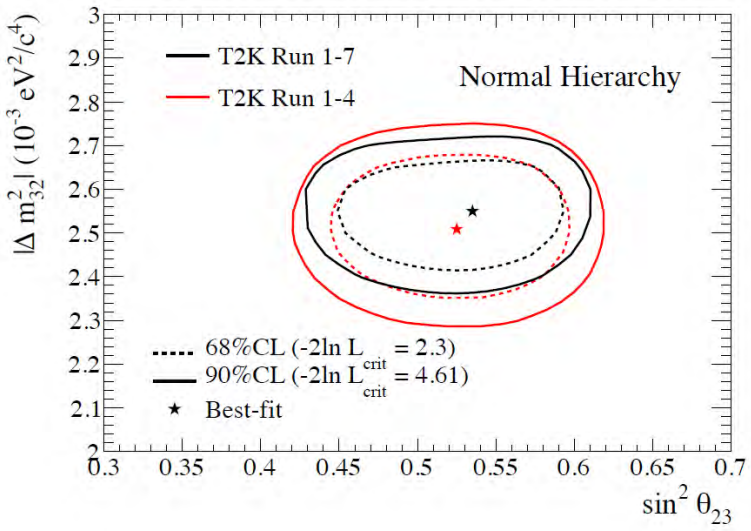
  → Measure CP symmetry, contribution to mass hier. determ.

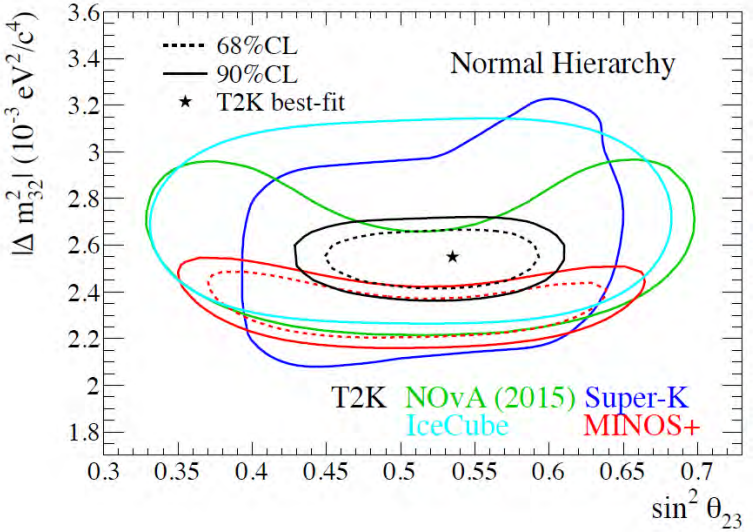
Achievement of proton delivery

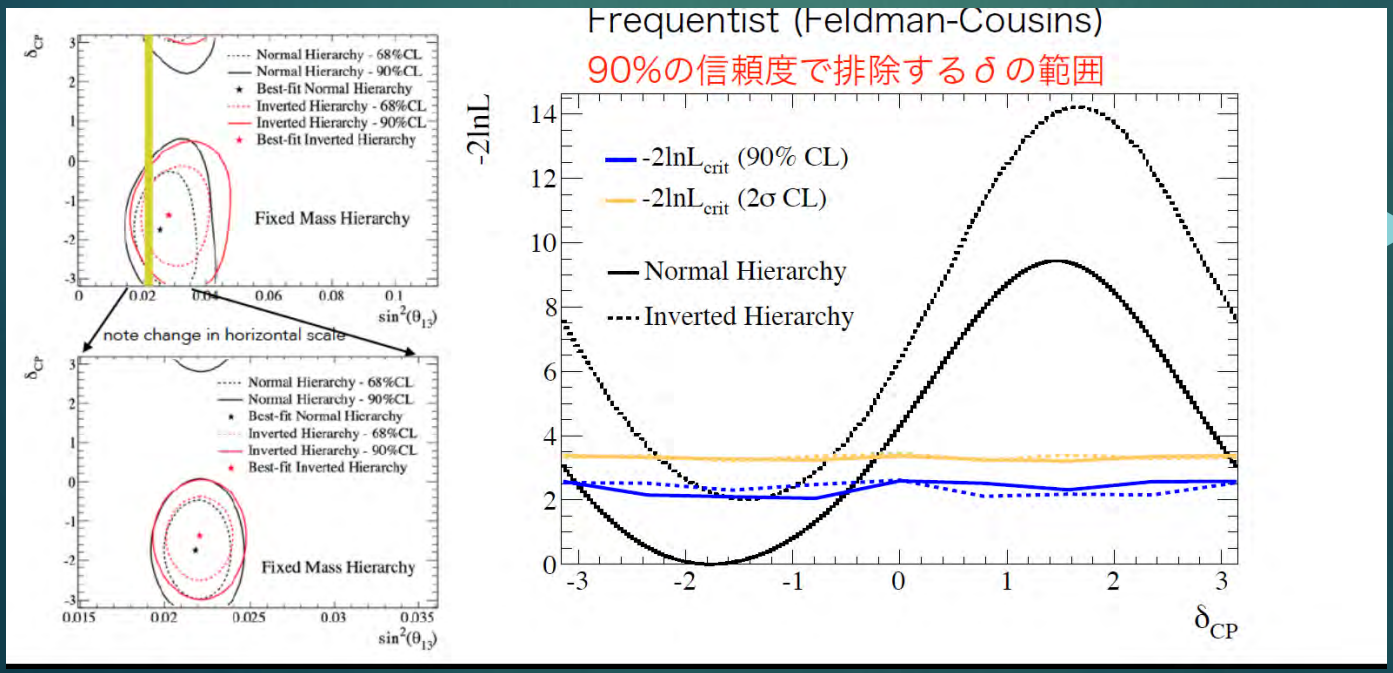


- Stable operation at 420kW achieved (first design goal: 750kW)
  - (Ep=30GeV) x (217Tp/5us pulse) x (2.48sec cycle) World record!
- Number of protons on target (POT)
  - 15.1×10^{20} accumulated (7.6×10^{20} for nu & 7.5×10^{20} anti-nu)
  - 78×10^{20} aimed as original T2K goal
- Aim to operate 440kW and beyond after Summer 2016 at newly established operation parameter with higher stability

T2K latest results (nu2016)







- T2K started measurement of CP symmetry

Next big goal: CP violation

Neutrino

ν_e ← 295km ← ν_μ

Neutrino Facility at J-PARC

$\bar{\nu}_e$ ← 295km ← $\bar{\nu}_\mu$

Anti-neutrino

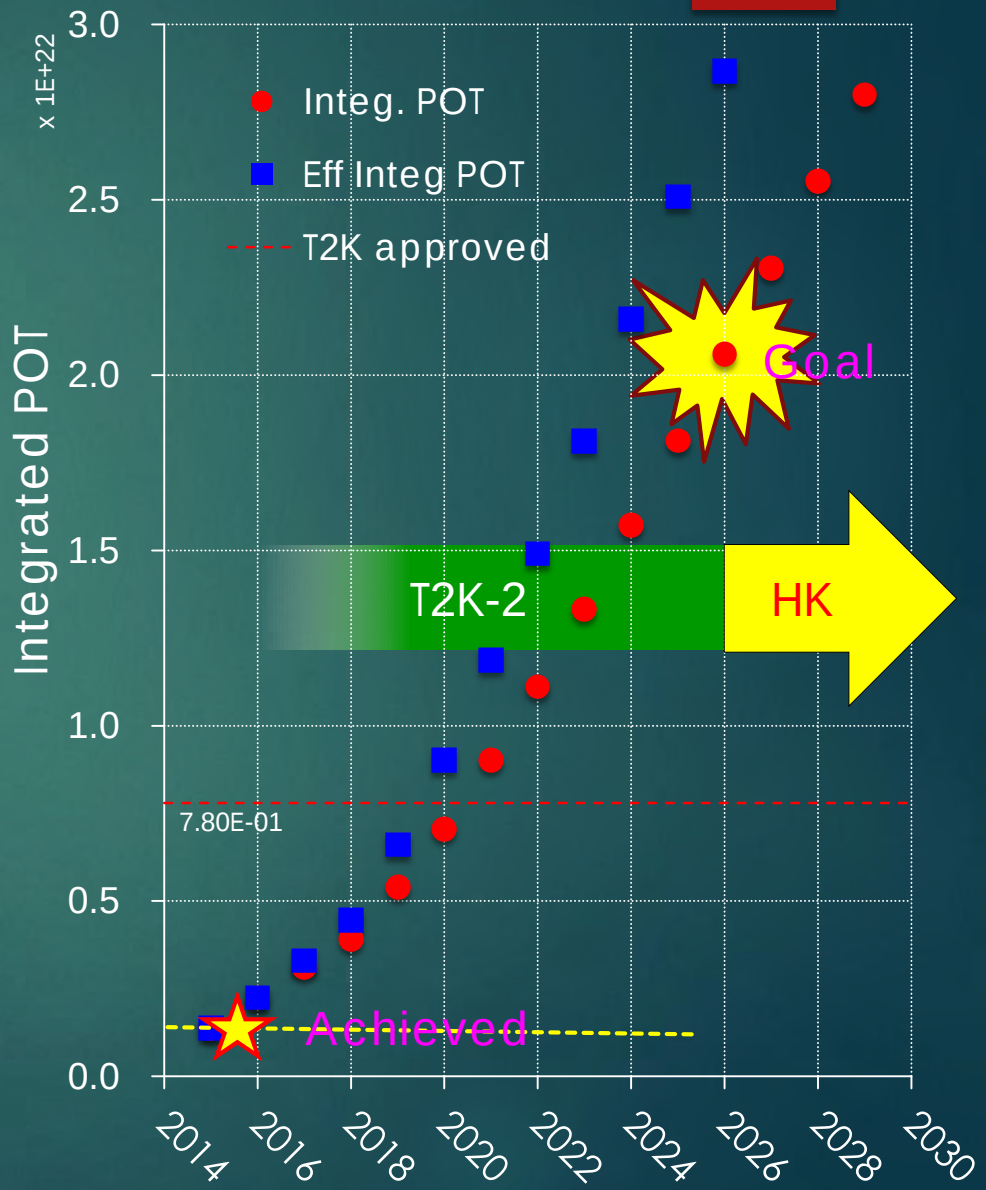
Origin of Matter

Search for CP Violation beyond CKM

Extension of T2K≡"T2K-II"

Proposal submitted

- Plan
  - Extend T2K running with
    - Upgraded beam power upto 1.3MW
    - improve +50% statistics by hardware/analysis improvements
  - ~2e22pot (x2.6 of original T2K)
  - To disover CPV >3σ for maximum CPV (which is now weakly indicated)
- This proposal
  - Extract best possible physics outputs with existing facilities/modest upgrade
  - Interconnect "desert" between T2K/NOVA and DUNE/HK era
  - Provide necessary learning ground for next generation experiments
    - >1MW operation
    - Syst. errors down to a few %
- Need to realize 1.3MW before HK



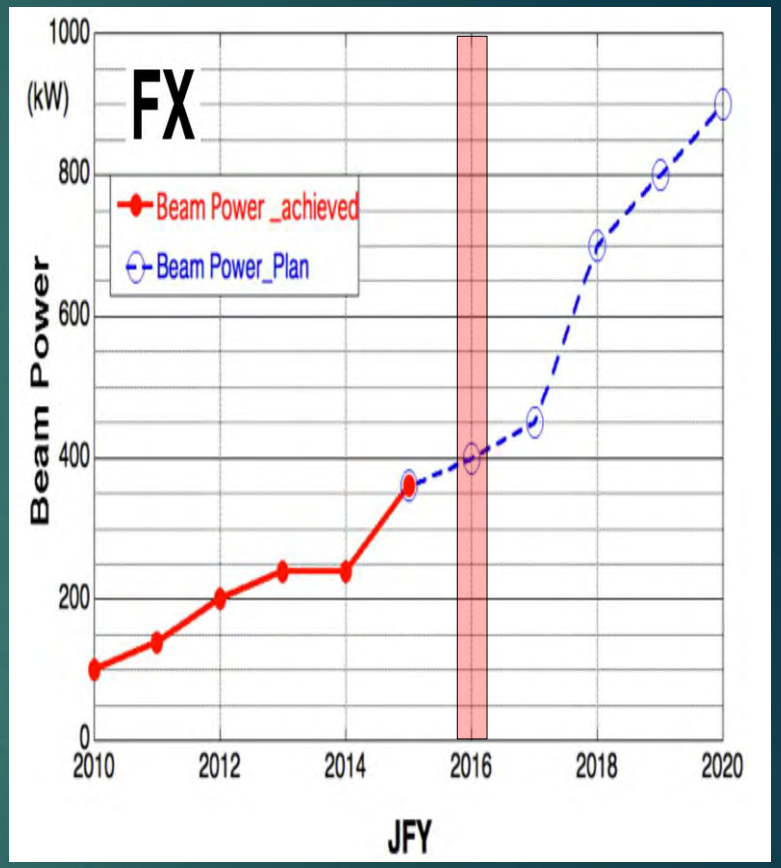
MR power upgrade scenario

PAC1507 presentation by F.Naito

Mid-term plan of MR

FX: **The high repetition rate scheme is adopted to achieve the design beam intensity, 750 kW. Rep. rate will be increased from ~ 0.4 Hz to ~1 Hz by replacing magnet PS's and RF cavities.**
SX: Parts of stainless steel ducts are replaced with titanium ducts to reduce residual radiation dose. The beam power will be gradually increased toward 100 kW watching the residual activity.

JFY	2014	2015	2016	2017	2018	2019	2020
	Li. current upgrade		New PS buildings			New	
FX power [kW] (study/trial)	320	> 360	400	450	700	800	900
SX power [kW] (study/trial)	-	33 - 40	50	50-70	50-70	100	100
Cycle time of main magnet PS New magnet PS	2.48 s R&D	Large scale 1st PS	Mass production installation/test		1.3 s Higher rep rate	1.3 s	1.2 s
High gradient rf system 2nd harmonic rf system VHF cavity	Manufacture, installation/test R&D, manufacture, installation/test R&D						
Ring collimators		Add.collimators	Add.collimators (3.5kW)				
Injection system FX system	Kicker PS improvement, Septa manufacture /test Kicker PS improvement, LF septum, HF septa manufacture /test						
SX collimator / Local shields			Local shields				
Ti ducts and SX devices with Ti chamber	Beam ducts	ESS					



- Increase repetition rate to ~1Hz by upgrading MR-PS & RF cavities
- Funding for MR PS upgrade started

Path toward 1.3MW

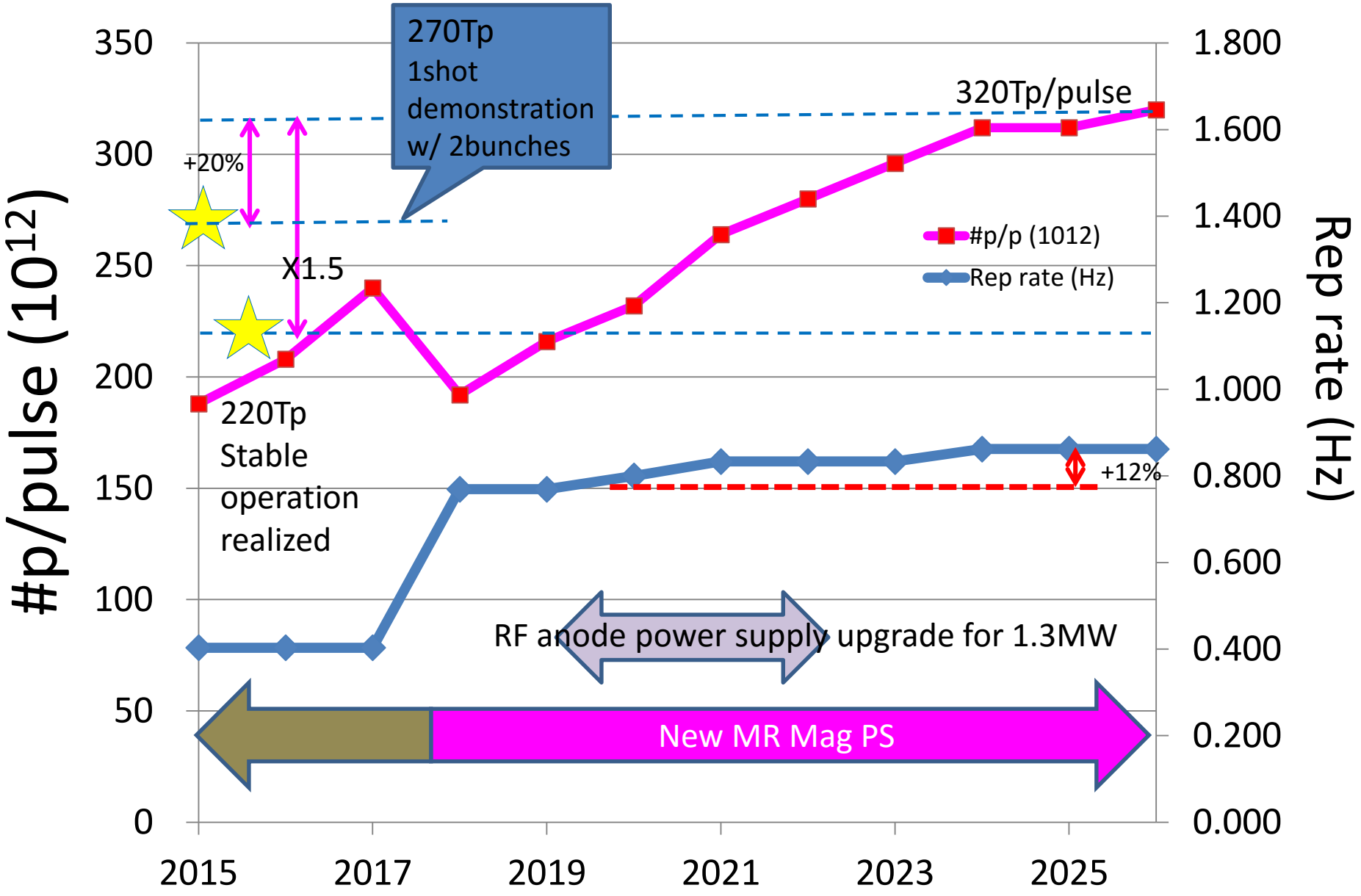
- Strategy

Beam Power (kW)	420 (Achieved)	800	Demonstrated	1326 (Goal for T2K-II)
#p/p(10^{12})	217	217	270	320
#p/b(10^{12})	27	27	34	40
Rep T (s)	2.48	1.3	shots	1.16

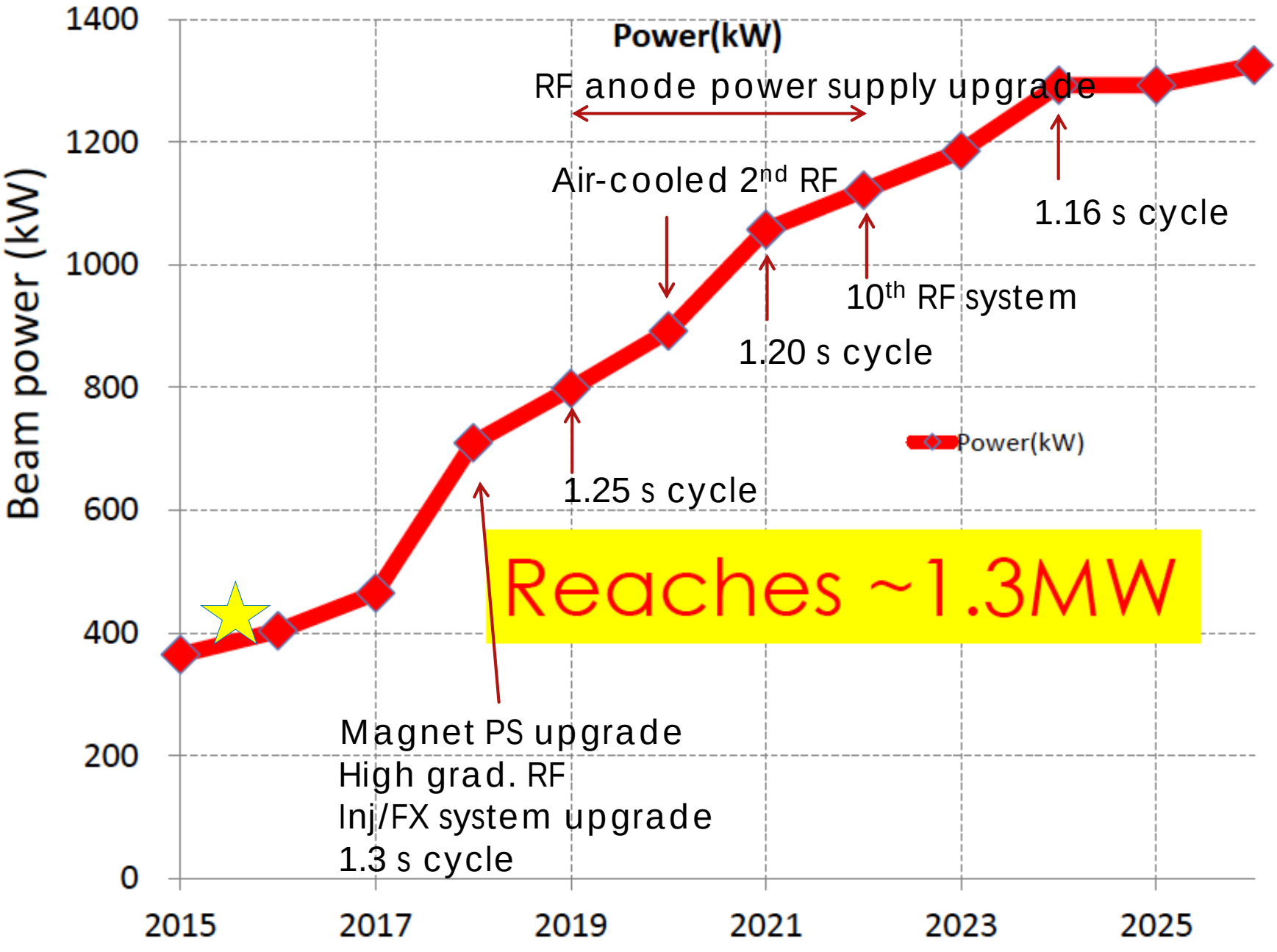
- Method
  - Higher rep rate: Funding started
    - MR magnet power supply upgrade
    - MR RF upgrade (High grad/PS)
    - MR Fast Extraction Kicker upgrade
  - Higher #p/p
    - MR RF upgrade (PS)
    - MR Beam monitor upgrade
      - Precise beam control for Higher ppp

After funding for 750kW design power is secured, only with modest investment mainly on RF PS enables >1.3MW

Assumed #p/p & rep cycle



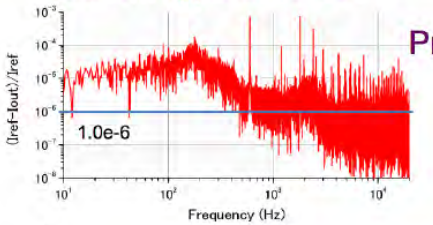
Beam power projection



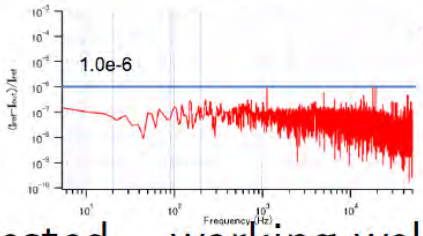
MR Power Supply Upgrade Status

- All MR magnet power supplies are being upgraded for 1 Hz operation
  - Currently run at 2.48 s repetition rate
  - Main issue towards quick upgrade was budget – budget has been approved for upgrade from JFY2016 !

Current ripple at 30 GeV



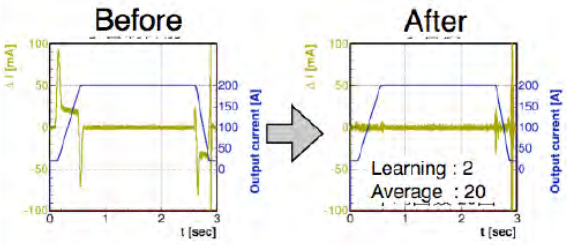
Present IGBT-PS



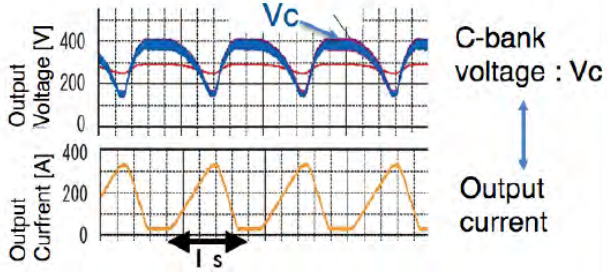
The new PS

- Prototype system has been fabricated, tested – working well
- Now working on infrastructure, large-scale production
- Plan to finish installation, turn on at 1.3 s repetition rate in 2018

- Results of the middle scale prototype PS -



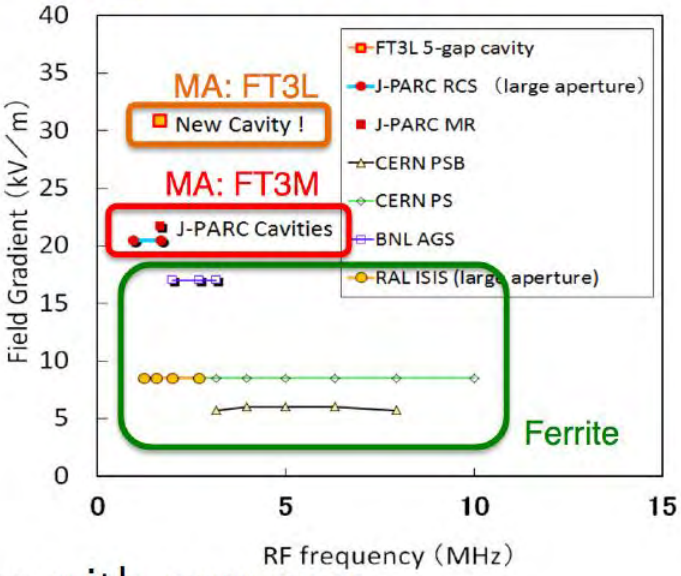
Self-learning control system



Power recovery by C-bank

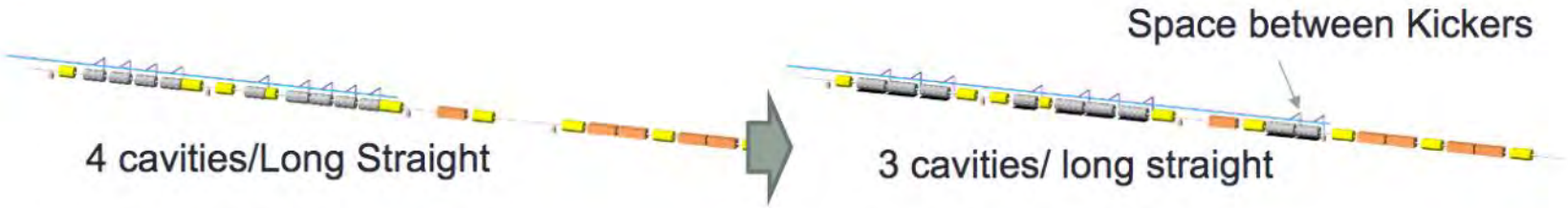
MR RF Upgrade Status

- New, high gradient RF cavity development, large-scale fabrication is also under-way
- New cavities use a new type of magnetic alloy core (FT3L) allowing for increased impedance
  - Field gradient increased by ~50%



- Gradually replacing current/old cavities with new ones
- 5 new RF cavities have been in use and working well since last year
  - 4 more to be installed this year

MR RF Upgrade Plan



Before Replacement

After Replacement

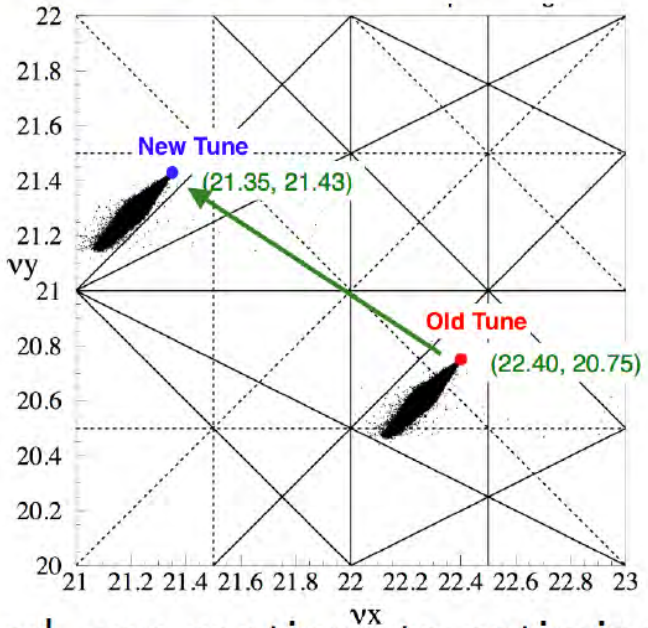
	2013	2014	2015	2016	2017	2018
	Li 400 MeV	*Li 50mA*				*MR 1.3-sec operation*
Present FT3M cavities	9	8	4	0	0	0
New FT3L Cavities	0	1	5	9	9	9
New FT3L 2nd cavity	0	0	0	0	2	2
Available voltage	315 kV	355 kV	485 kV	602 kV	602 kV	602 kV
(2nd Harmonic)	(35 kV)	(70 kV)	(70 kV)	(70 kV)	(70 kV)	80 kV
Number of cavity cells	27	29	36	43	43	43+8(2nd)

Required voltage: 280 kV(~2017), 540 kV(2018~)

M.Friend, Nu2016

New MR Betatron Tune for Higher Power

- Resonance diagram shows tune regions (points), betatron resonances (lines)
  - Avoid resonances (lines) to enhance accelerator stability
  - Left plot: J-PARC MR betatron tune resonance diagram

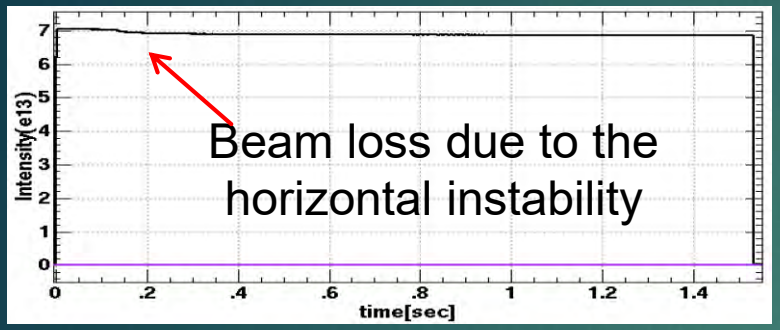


- Now that new tune has been established, can continue to optimize :
  - RCS beam parameters (painting, tune, and chromaticity) for MR
  - RF voltage pattern for fundamental and 2nd harmonic
  - Compensation kicker for new tune point
  - Collimators for loss localization
  - Octupole magnets (Currently 2 magnets are being used)
  - Trim quadrupole and trim sextupole patterns
  - Beam optics at extraction timing for beam loss reduction
  - Instability damping with intra-bunch feedback and chromaticity

High Intensity beam study in MR

- at the new betatron tune (22.239, 21.310) -

High power trial with two bunches



Extracted beam : 6.82e13 ppp (132 kW eq.)

Beam loss[Watt]		
INJ(K1+K2+K3+K4)	144	7.43e+11
P2 --> +90ms	241	1.00e+12
P2+90ms --> +120ms	31	1.30e+11
P2+100ms ---> EXT		1.83e+11

Total beam loss ~ 420 W

Great step toward >1MW

Near future tunable knobs to reduce beam loss:
Injection kicker improvement, BxB feed-back,
2nd harmonic cavity, VHF cavity, etc.

Bunch number	repetition period (sec)	#p/pulse $(10^{12})_{equiv}$	Beam power (kW)	Beam loss (kW)	Notes
2	2.48	270	132	0.42	measurement
8	2.48	270	530	1.7	estimation
8	1.3	270	1000	3.2	estimation

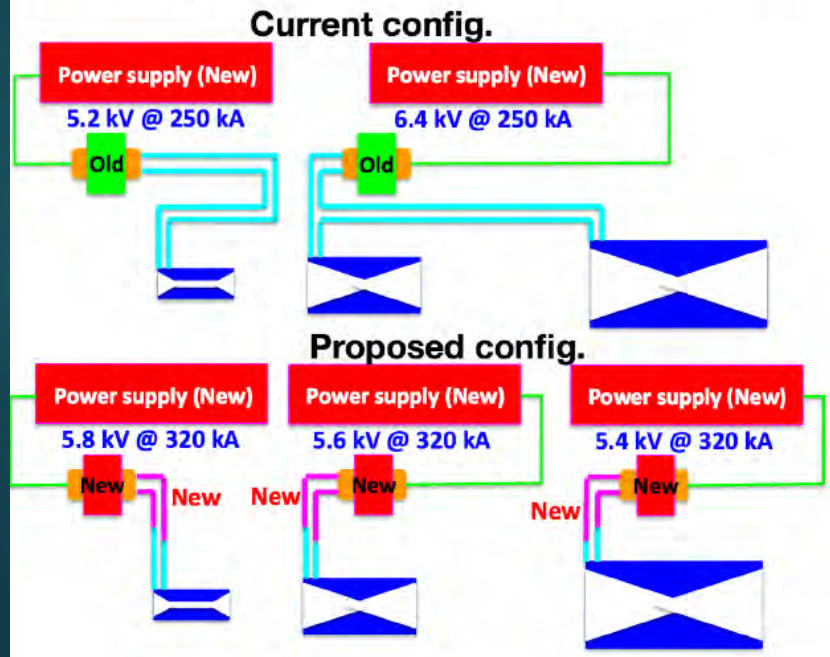
Neutrino beam facility upgrade

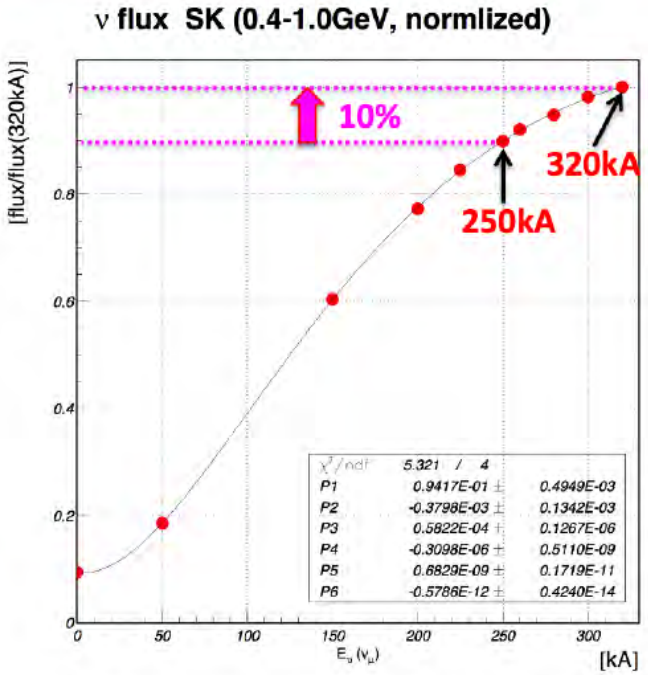
- Original design principle/specification
  - 750kW for replaceable components
  - >3MW for irreplaceable parts (Decay volume, Dump, etc)
  - 750kW = 30GeV x (330Tp/5us pulse) x (2.10s cycle)
- Goal
  - 1.3MW = 30GeV x (320Tp/5us pulse) x (1.16s cycle) : Similar impulse thermal shock!
- To achieve >1.3MW facility
  - Upgrade electromagnetic horns system
    - Add 1 PS, 2 Transformer to operate 3 horns in parallel
  - Cooling capability upgrade for target/horns
  - Upgrade of capacity of radioactive water waste

Beam Power	# of protons/pulse	Rep. rate
350 kW (achieved)	1.8×10^{14}	2.48 sec.
750 kW (proposed) [original plan]	2.0×10^{14} [3.3×10^{14}]	1.30 sec. [2.10 sec.]
1.3 MW (proposed)	3.2×10^{14}	1.16 sec.

J-PARC Horn Power Supply Upgrade for $\pm 250 \rightarrow \pm 320$ kA

- Move from 2 to 3 power supplies
  - New power supplies with energy recovery system
  - New striplines with low R & L
  - New transformers optimized for 320 kA operation
  - 10% increase in neutrino flux at far detector
  - 5~10% reduction of wrong-sign neutrinos around peak energy
- Upgrade planned in ~2017





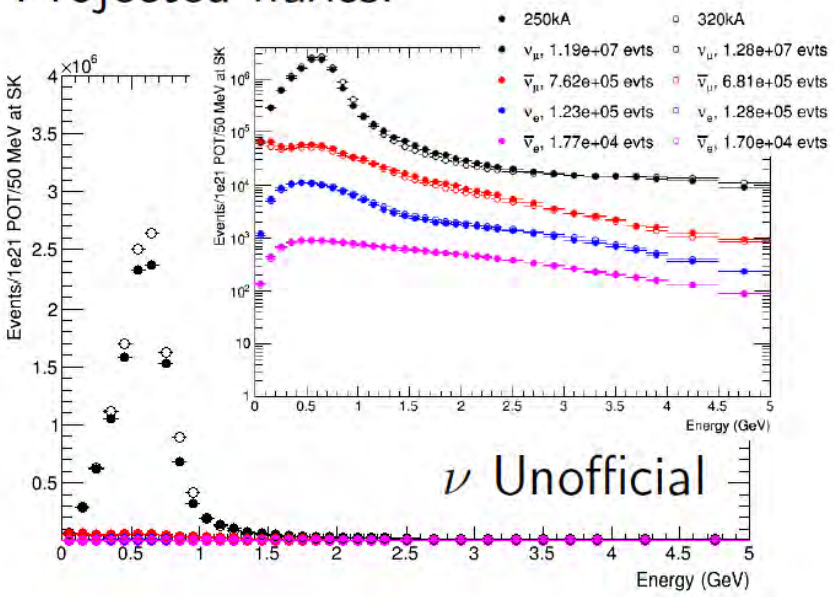
Flux Improvement @ 320 kA

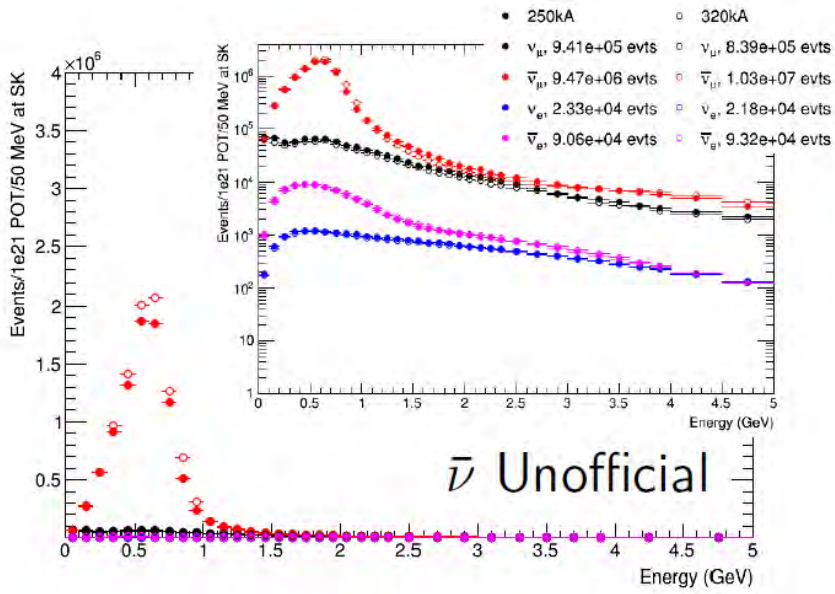
M.Friend, Nu2016

J-PARC Horn Power Supply Upgrade for

- Move from 2 to 3 power supplies $\pm 250 \rightarrow \pm 320$ kA
  - New power supplies with energy recovery system
  - New striplines with low R & L
  - New transformers optimized for 320 kA operation
  - 10% increase in neutrino flux at far detector
  - 5∼10% reduction of wrong-sign neutrinos around peak energy
- Upgrade planned in ∼2017

Projected fluxes:



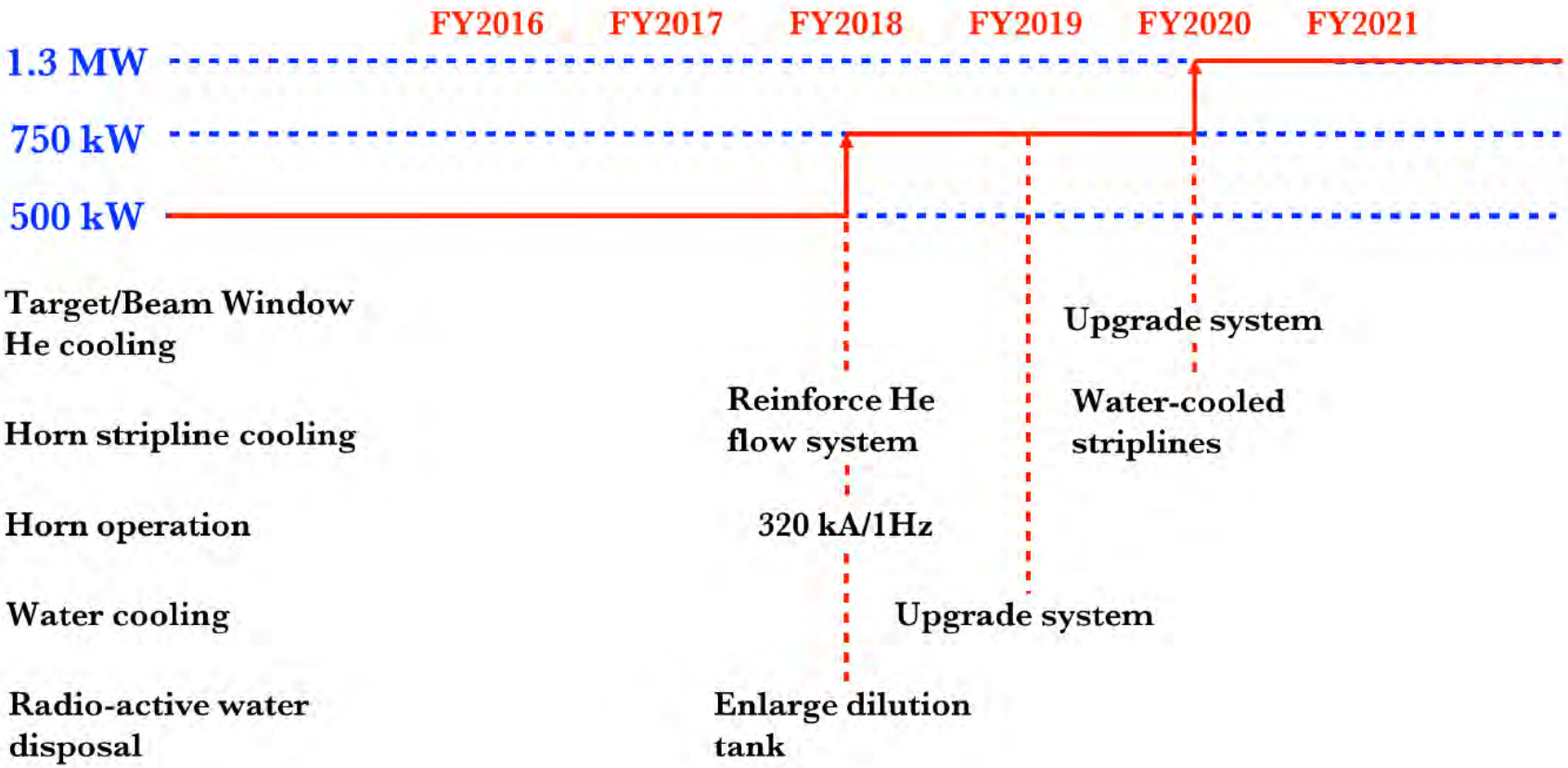


M.Friend, Nu2016

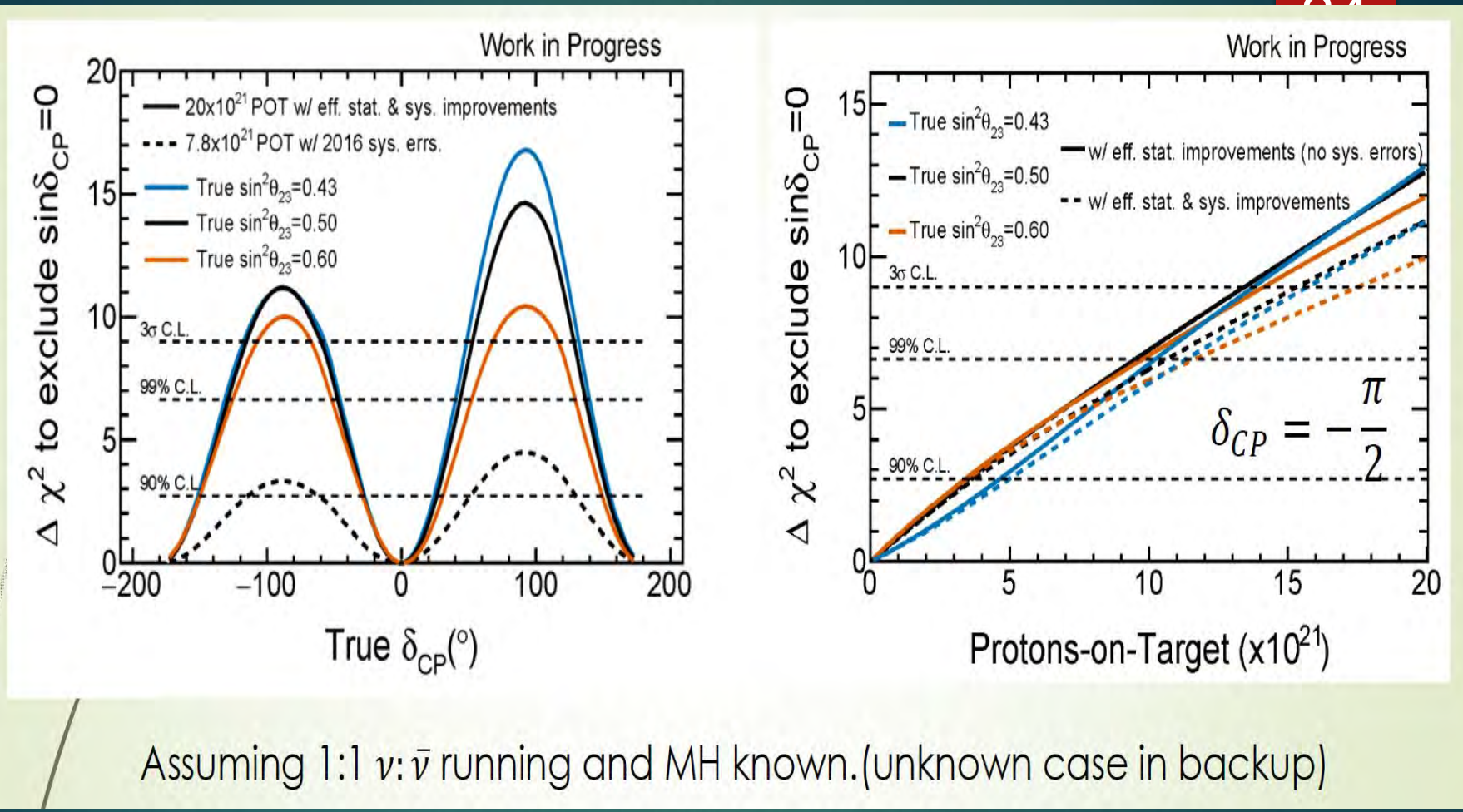
Secondary beam line upgrade

Component	Limiting Factor	Current Acceptable Value	Upgraded Acceptable Value
Target	Thermal Shock	3.3×10^{14} ppp	3.3×10^{14} ppp
	Cooling Capacity	0.75 MW	>1.5 MW
Horn	Conductor Cooling	2 MW	2 MW
	Stripline Cooling	0.54 MW	>1.25 MW
	Hydrogen Production	1 MW	>1 MW
	Operation	2.48 s & 250 kA	1 s & 320 kA
He Vessel	Thermal Stress	4 MW	4 MW
	Cooling Capacity	0.75 MW	>1.5 MW
Decay Volume	Thermal Stress	4 MW	4 MW
	Cooling Capacity	0.75 MW	>1.5 MW
Beam Dump	Thermal Stress	3 MW	3 MW
	Cooling Capacity	0.75 MW	>1.5 MW
Radiation	Radioactive Air Disposal	1 MW	>1 MW
	Radioactive Water	0.5 MW	0.75→1.3 or 2 MW

Secondary Beamline Upgrade Schedule



Sensitivity on CPV of "T2K-2"



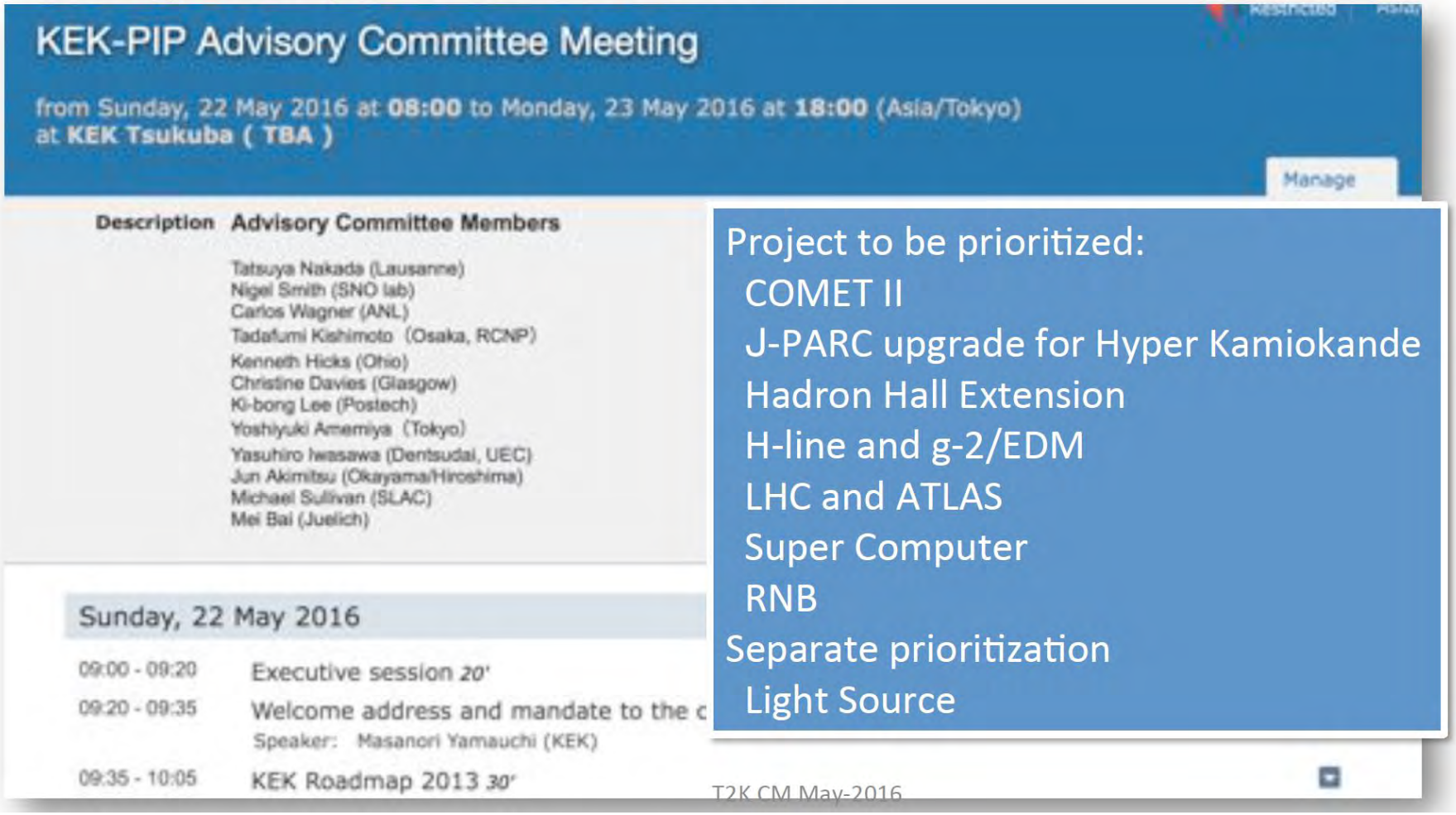
- > 3 sigma CPV sensitivity for maximal CPV

HKAC chair's summary at closeout

1. The HKAC endorses Hyper-K as a very important experiment for Japan and for the world-wide program of fundamental science, and encourages ICRR and IPNS to fully support it.
2. The newly modified design for Hyper-Kamiokande detector, described in the Design Report, successfully reduces the total project cost without largely compromising its potential to address important questions in particle and astroparticle physics.
3. Its technical and scientific feasibilities, including risks in construction of the cavern and tank and reduction in systematic errors for CP violation measurement, have not been fully demonstrated in the present Design Report. The committee would like to hear updates in these areas in the future meetings.
4. Hyper-Kamiokande Collaboration should continue to optimize the detector design including the size of the detector, the density of photo-sensors and future upgrade possibilities with international contributions.
5. International collaboration and cooperation in physics studies, detector technologies and accelerator and beam line developments should be encouraged, in particular with the DUNE/LBNF Project in the US and the neutrino platform at CERN.
6. In view of the worldwide neutrino research program, the upgrade plan of the J-PARC accelerator toward 1.3 MW beam power and the upgrades of the near detectors and implementation of the intermediate detector, which already benefits the ongoing T2K experiment, should be realized at the earliest possible time.

KEK Project Implementation Plan Review

- Priority of new projects to be promoted with a major budget request was discussed.

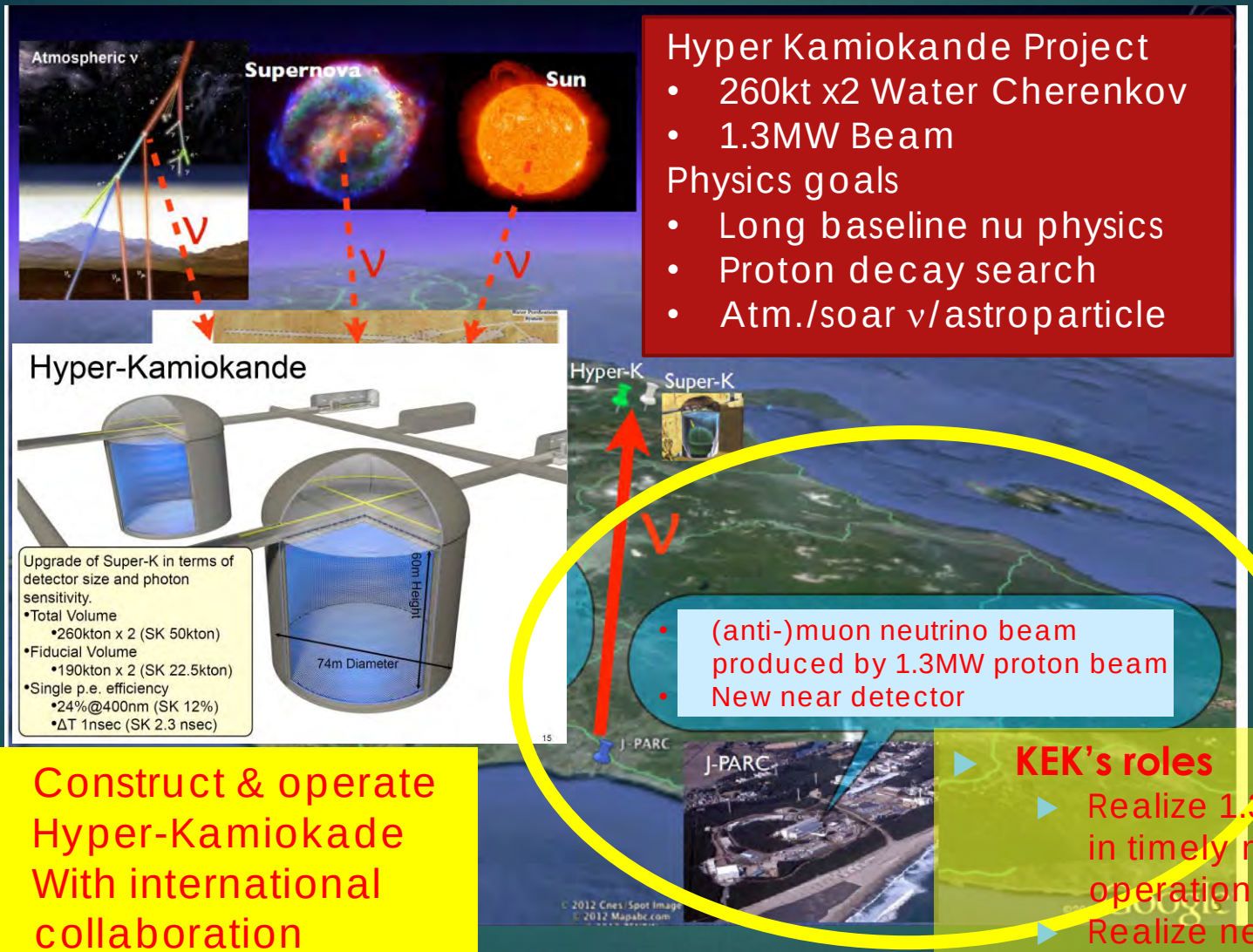


Project to be prioritized:
- COMET II
- J-PARC upgrade for Hyper Kamiokande
- Hadron Hall Extension
- H-line and g-2/EDM
- LHC and ATLAS
- Super Computer
- RNB

Separate prioritization
- Light Source

Overview

International collaboration
KEK&ICRR as host institutes



Hyper Kamiokande Project
- 260kt x2 Water Cherenkov
- 1.3MW Beam

Physics goals
- Long baseline nu physics
- Proton decay search
- Atm./soar ν/astroparticle

- (anti-)muon neutrino beam produced by 1.3MW proton beam
- New near detector

- Construct & operate Hyper-Kamiokade
- With international collaboration

- **KEK's roles**
  - Realize 1.3MW beam power in timely manner and its operation
  - Realize near neutrino detector facility
    - Detectors by international contributions

PIP review close out

- PIP review concluded that “J-PARC upgrade for HK is the highest priority”.
  - It is now set as the highest priority after the completion of the new PS for MR, of which only 1/3 is funded so far.
  - While PIP priority has been set, the PAC discussion should not be bypassed.

Summary

- J-PARC neutrino beam achieved 420kW stable operation
- Demonstrated 270Tp/pulse = 530kW/2.48s = 1000kW/1.3s equiv. shot
  - Many available nobs to further reduce beam loss being applied
- New goal of 1.3MW+ to accumulate 2e22POT by around 2024/2026
- Prescription to achieve 1.3MW+ is clear
  - Modest upgrade and budget from 750kW to 1.3MW
  - No technical breakthrough is required
  - While step-by-step improvements/studies are foreseen as usual
- External committees recommend the J-PARC upgrade to 1.3MW at high priorities
  - KEK will issue KEK-PIP taking into account the PIP review recommendations soon