Alex and NSRRC – Accelerator Physics from **Zero** to **Infinity** in 30 Years

Kuo-Tung Hsu

On-behalf of NSRRC

October 25, 2019

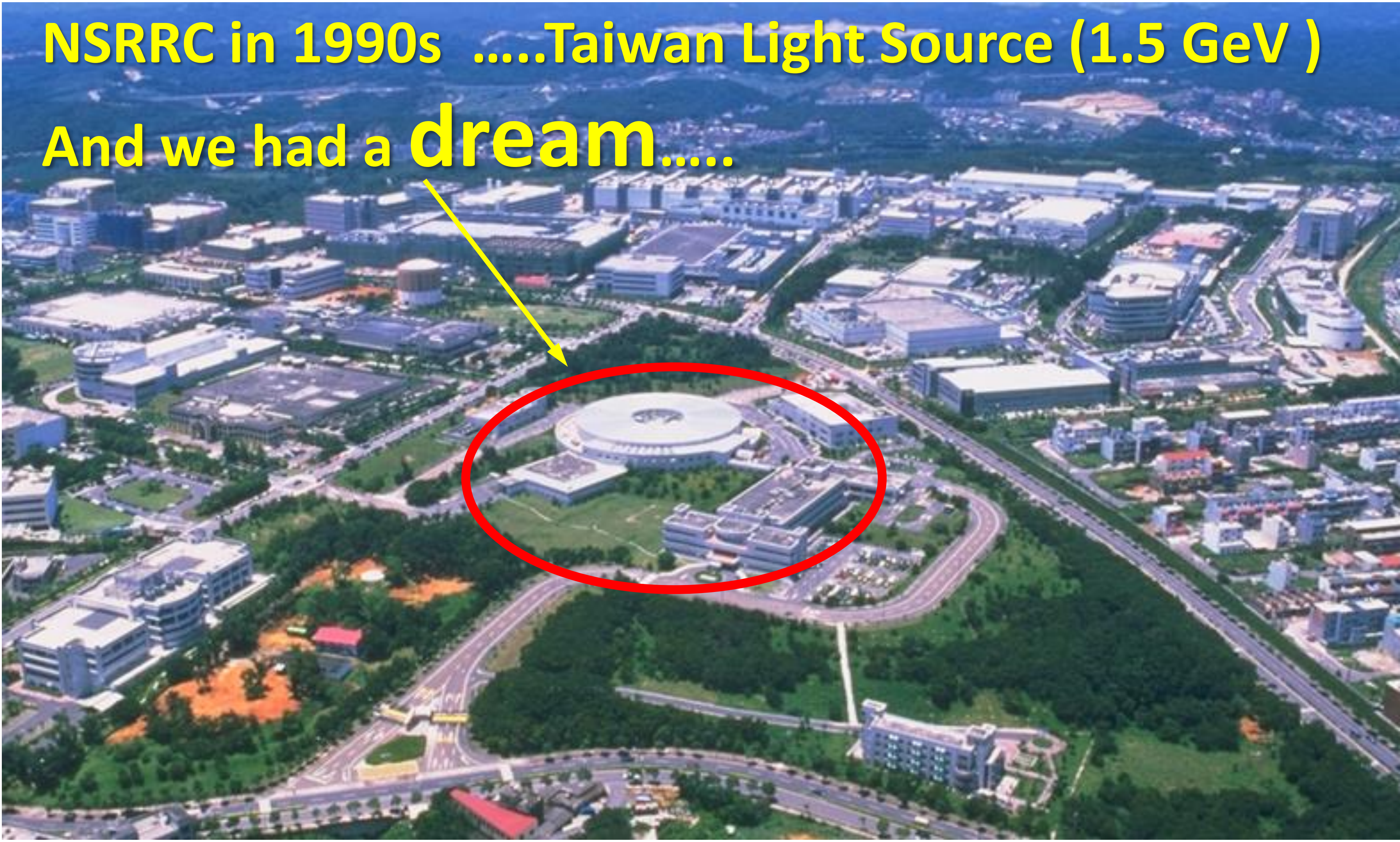
Celebration of Alex's 70th Birthday and Retirement

ONCE UPON A TIME

Taiwan Light Source, 1989

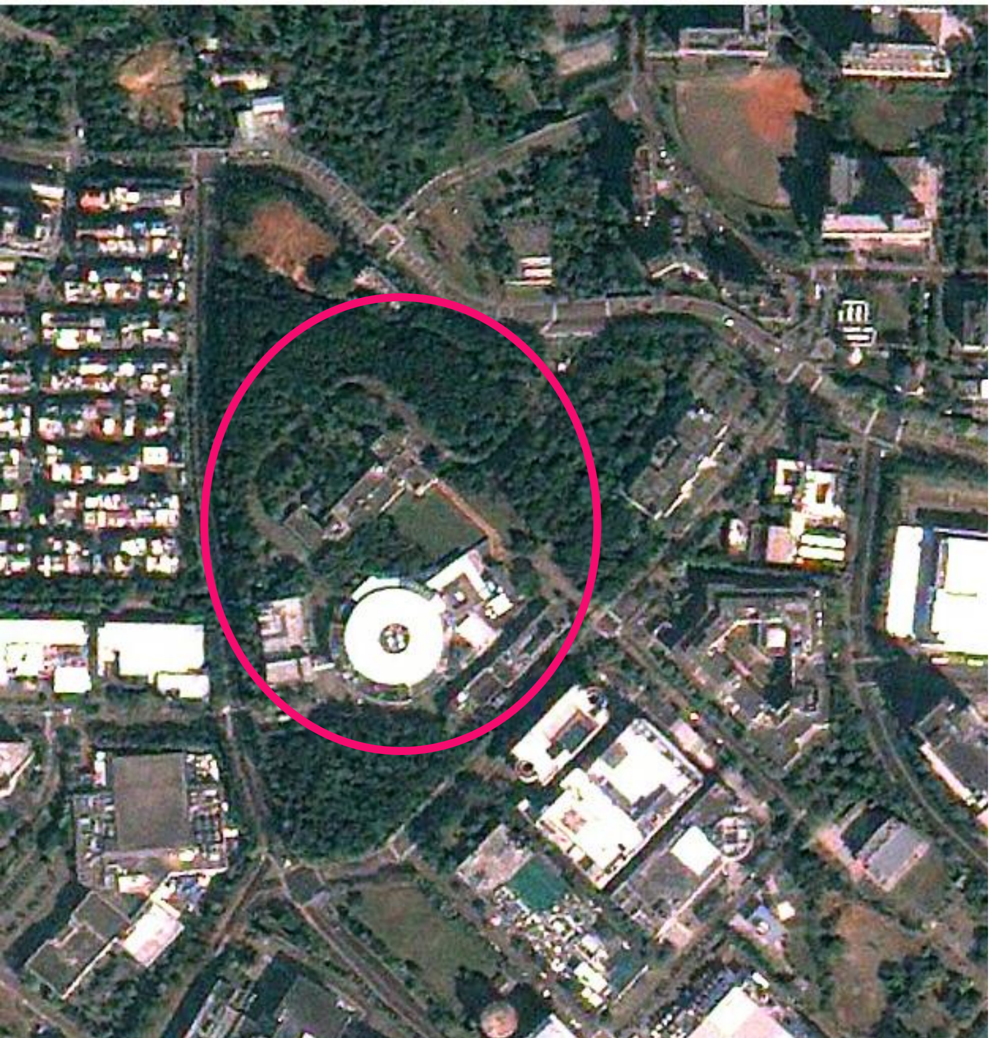
Alex and NSRRC's long history of collaborations

We practically grew up TOGETHER !



The realization of our dream !
And, Alex was there for us.

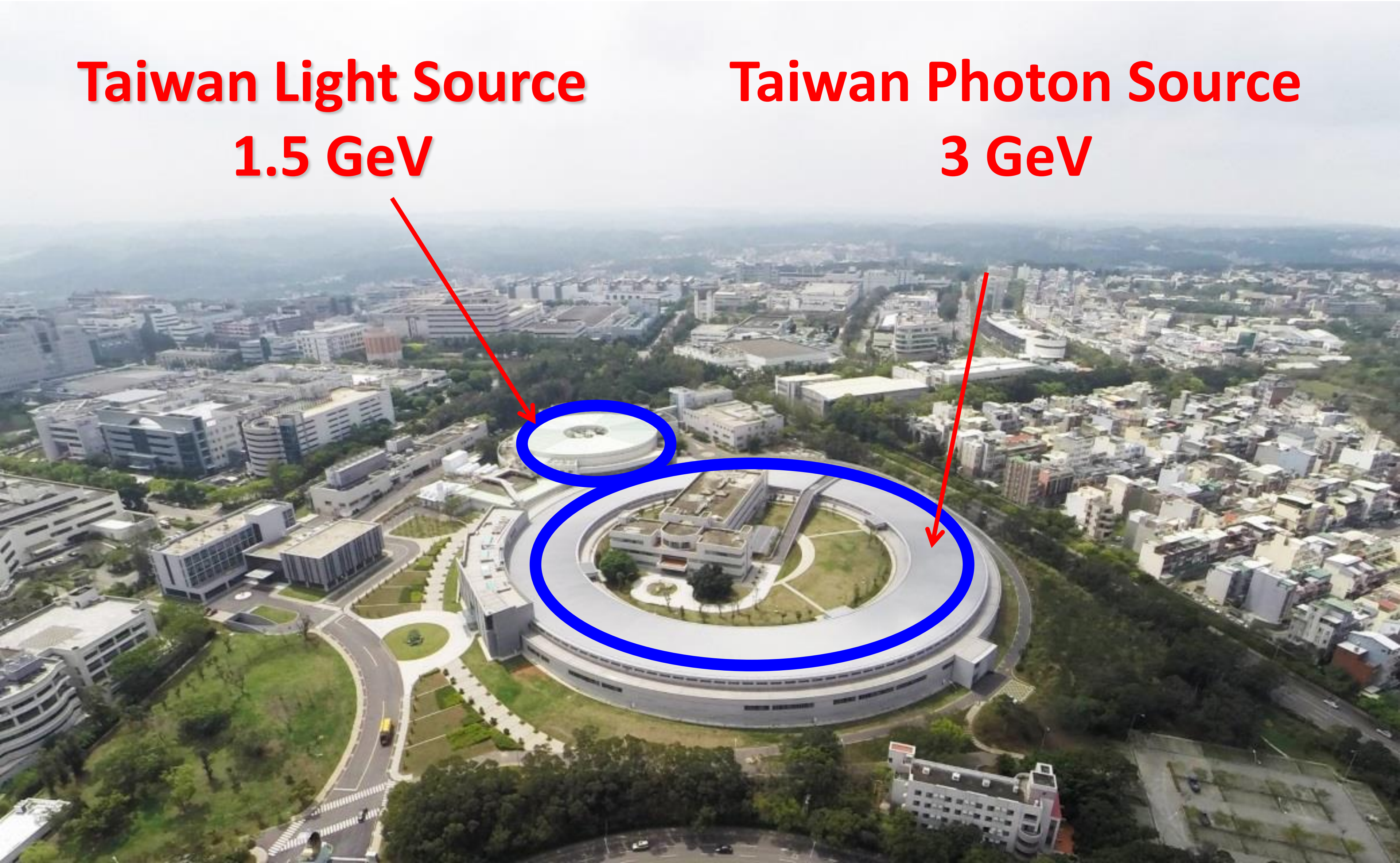
2010-02-10

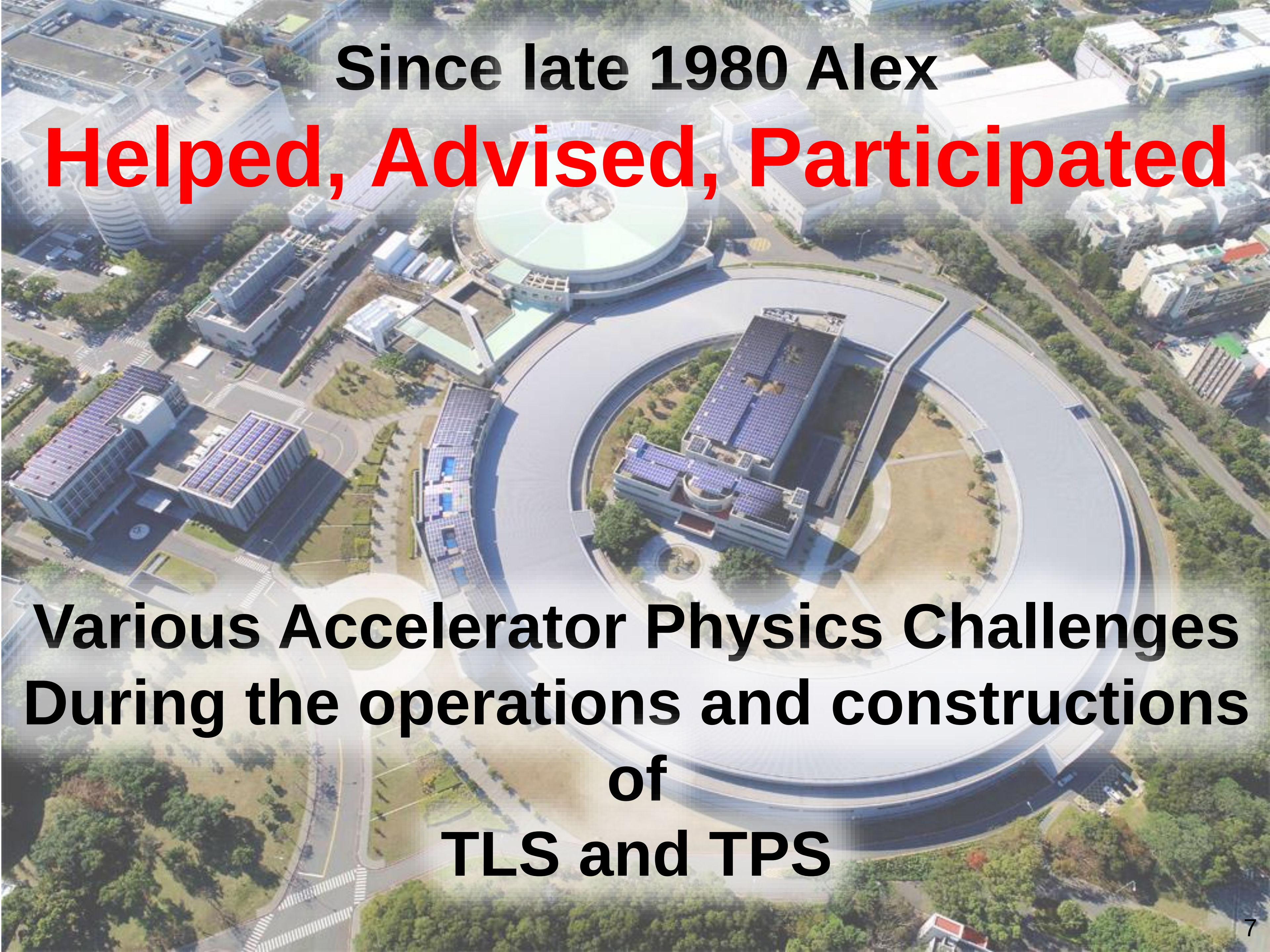


2010-08-04

March 2015

After 20+ Years !





Since late 1980 Alex

Helped, Advised, Participated

Various Accelerator Physics Challenges During the operations and constructions of TLS and TPS

From Zero to Infinity of Accelerator Physics

1981 Feasibility study of the TLS begin

1983 Jul. SRRC Board of Directors organized. TLS project approved by the government.

1986 Mar. Preparatory and Construction Office of SRRC established.

1993 April 1st beam stored in the TLS.

1994 April TLS users operation.

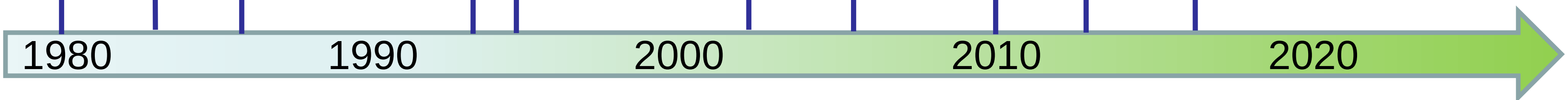
2003 May Reorganization into NSRRC

2007 Mar. TPS project approved by the government.

2010 Feb. Construction of the TPS began.

2014 Dec. 1st beam stored in the TPS.

2016 Sept. TPS user operation.



1.5 GeV TLS synchrotron light source

1980s Design of TLS

1990s Commissioning and performance improvement.

2006 Help to solve instability problems of TLS (transverse and longitudinal)

3 GeV TPS synchrotron light source

2010 Design of TPS

2014 Commissioning of the TPS

2015 Advised accelerator physics study in TPS

2016 Advised low alpha study in TPS

Other Activities

Promote the capability in accelerator to support the development of science and technology in NSRRC accelerator facility.

FEL winter school (2015 ~ now)

SSMB learn (2016 ~ now)

OPCA Accelerator School (1998 ~ now)

In 1990, young and handsome Alex (center)

August 11~15, 1997

The 2nd International Organization of Chinese Physicists and Astronomers (OCPA)

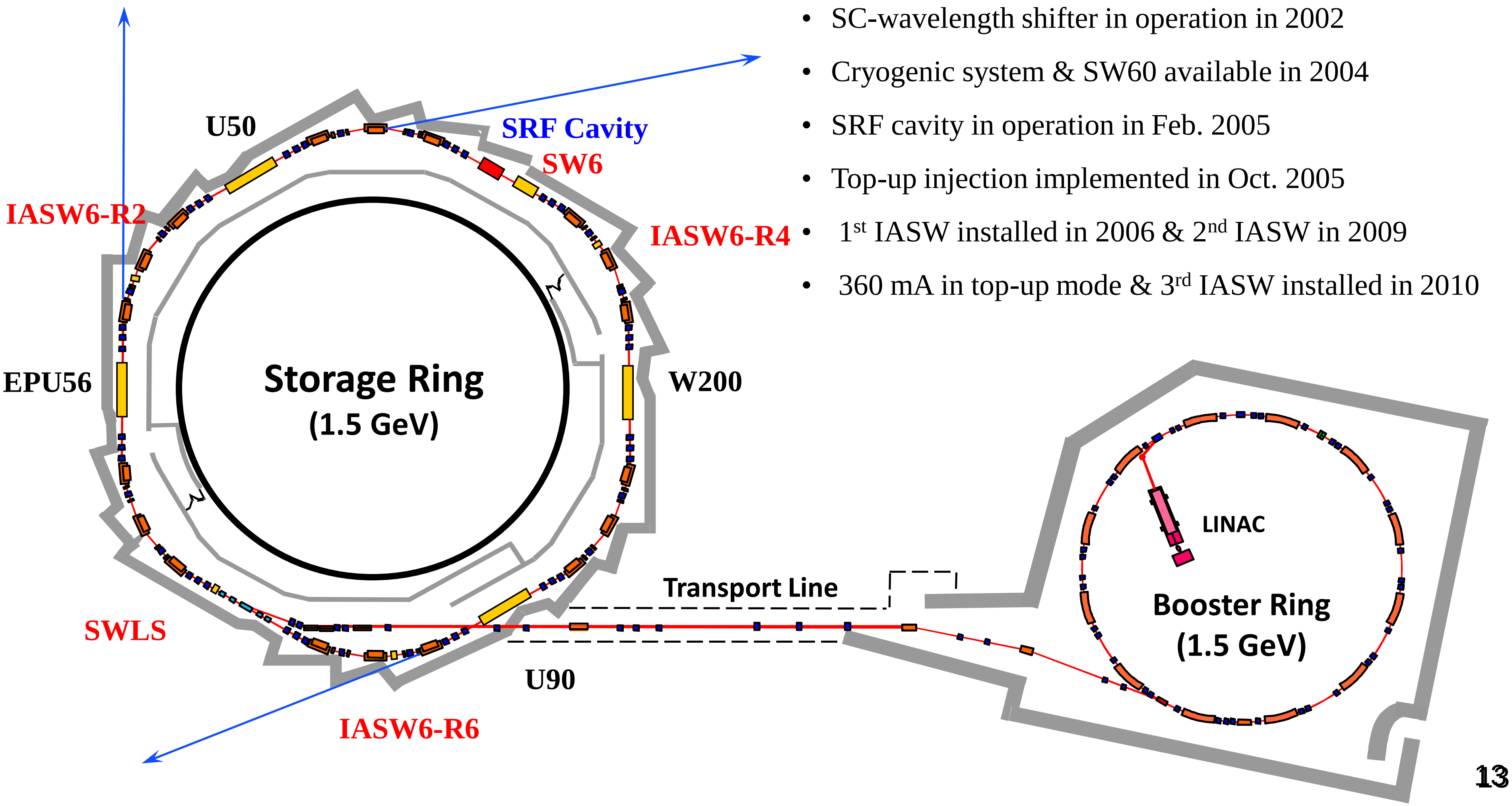
2014

January 2017

TLS Accelerator Layout and Key Milestones

- The 1st 3rd generation LS in Asia (1993)
- The 2nd LS using the SRF cavity (2005)
- The 3rd LS running full time with top-up injection (2005)
- The most densely-packed SR with the highest number of superconducting IDs!

- Commissioned in Apr. & opened to users in Oct. 1993
- 1.3 to 1.5 GeV ramping in operation in 1996
- 240 mA operation beam current in 1996
- Booster in full energy injection in 2000
- SC-wavelength shifter in operation in 2002
- Cryogenic system & SW60 available in 2004
- SRF cavity in operation in Feb. 2005
- Top-up injection implemented in Oct. 2005
- 1st IASW installed in 2006 & 2nd IASW in 2009
- 360 mA in top-up mode & 3rd IASW installed in 2010



Assist Many Issues for Taiwan Light Source (TLS) Research and Development

- **Beam stability**
  - Improve power supply performance
  - Orbit feedbacks
- **Beam instability**
  - Analog transverse feedbacks
  - Temperature control to shift HOMs’ frequency
  - RF gap voltage modulation (1998 ~ 2004）
- **Nonlinear accelerator physics**
- **Dynamic aperture/Lifetime**

Taiwan Light Source (TLS) - Longitudinal Instability

Suffered by HOM of RF cavities longitudinal instability

- Temperature control to shift HOMs' frequency
- RF gap voltage modulation (1998 ~ 2004）
- Superconducting RF cavity (2004/2005)
- However, there is still one mode existed (from vacuum chamber structure) => Longitudinal feedbacks (2005)

Taiwan Photon Source (TPS) Construction Project

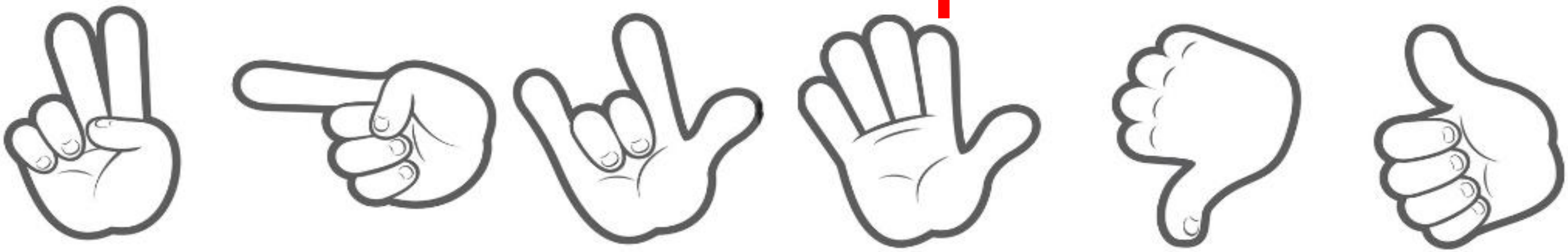
Timeline

2010 Feb. TPS Ground-breaking

From 2012 ~ 2014,

Alex served as the Chairman of TPS MAC.

.. Rolled up his sleeves and got his hands dirty ...



2013 Oct. Accelerator installation started

2014 Aug. System test and commissioning started

2015 Mar. Phase I commissioning completed

2016 Open to public user

" No. No. No.   You go first ! "

"Action !"

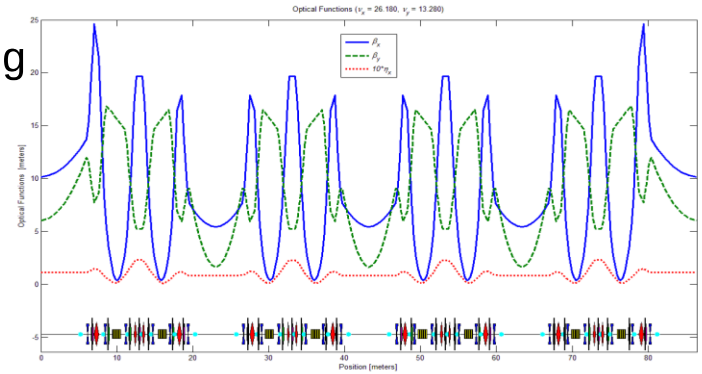
2012 MAC members

Major Parameters of Taiwan Photon Source

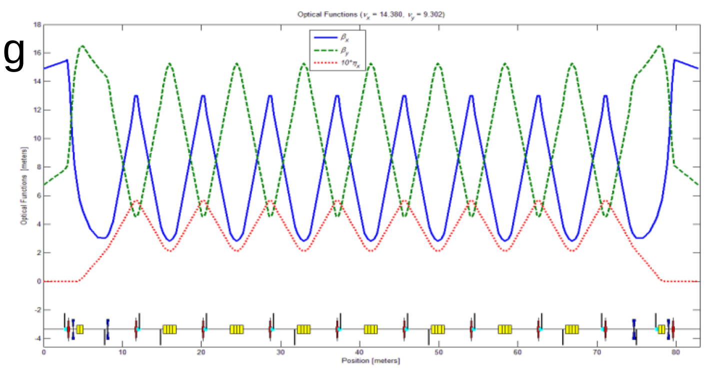
Energy	3 GeV (maximum 3.3 GeV)
Current	500 mA at 3 GeV (Top-up injection)
SR circumference	518.4 m (h = 864 = $2^5 \cdot 3^3$, dia.= 165.0 m)
BR circumference	496.8 m (h = 828 = $2^2 \cdot 3^2 \cdot 23$, dia.= 158.1 m)
Lattice	24-cell DBA
Straight sections	12 m x 6 (σ_v = 12 μm, σ_h = 160 μm) 7 m x 18 (σ_v = 5 μm, σ_h = 120 μm)

Storage Ring Circumference (m)	518.4
Energy (GeV)	3.0
Beam current (mA)	500
Natural emittance (nm-rad)	1.6
Straight sections (m)	12 (x6) + 7 (x18)
Radiofrequency (MHz)	499.654
Harmonic number	864
RF voltage (MV)	3.5
Energy loss per turn (dipole) (keV)	852.7
Betatron tune	26.18 /13.28
Momentum compaction (α_1, α_2)	2.4×10^{-4}, 2.1×10^{-3}
Natural energy spread	8.86×10^{-4}
Damping time (ms)	12.20 / 12.17 / 6.08
Natural chromaticity	-75 / -26
Synchrotron tune	0.00609
Bunch length (mm)	2.86

Storage Ring



Booster Ring



TPS Milestones

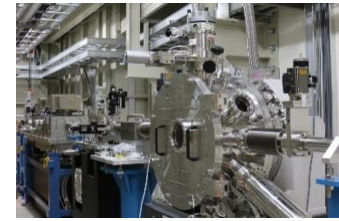
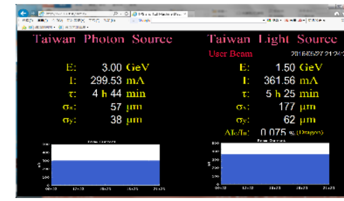

Construction

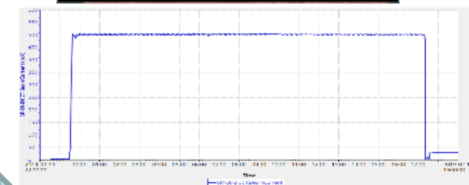


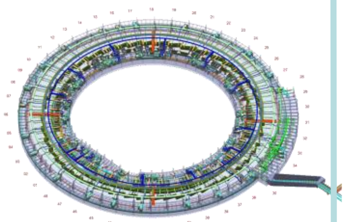

Installed 2 SRF cavities and 10 IDs

First light delivered to the experimental station (port 5A) on Nov. 19, 2015

Available for users

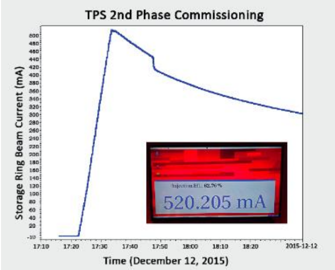




Design

1st SR from the TPS (3 GeV, 1 mA)
Dec 31, 2014

Phase I Commissioning up to 100 mA (with two 5-cell PETRA Cavities)



Up to 520 mA
Dec 12, 2015

Phase II Commissioning (with two SRF Cavities)

300 mA Top-up

Vacuum Improvement

400 mA Long-term Test Run

400 mA Top-up

SRF#3 Kicked off and 500 mA Test

500 mA Operation License

500 mA Top-up

2007 | 2010 | Q4 2014 - Q1 2015 | Q3/Q4 2015 | Q4 2015 | Mar. 2016 | May 2016 | Q3 2016 | Feb. 2017 | Nov. 2017 | 2018 | Feb. 2019 | Oct. 2019

Low a Mode Study at TPS

Involving study of low α mode at TPS to support short bunch users .

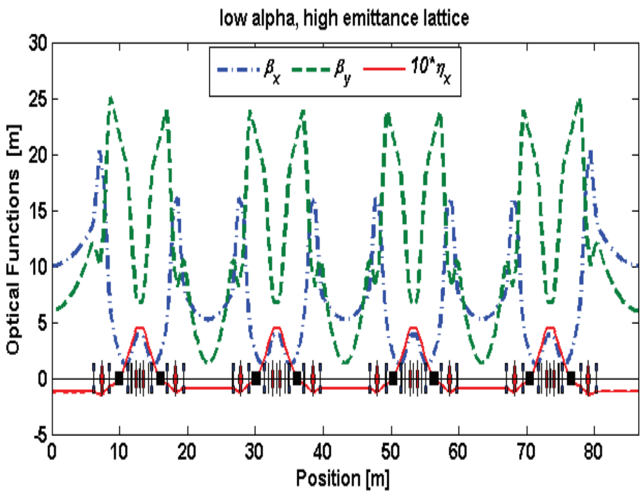


Figure 1: Optical functions for high emittance lattice.

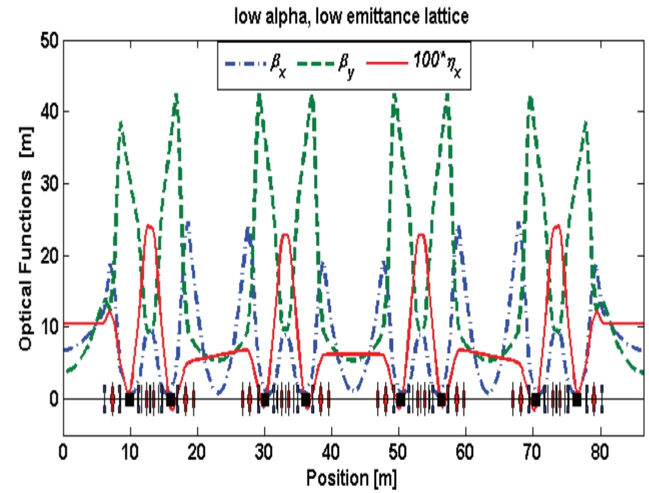
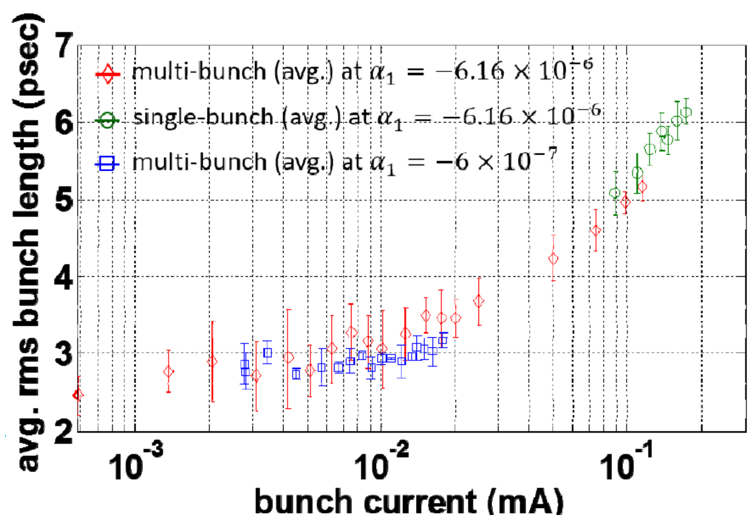


Figure 2: Optical functions for low emittance lattice.

Table 1: Major Parameters of Low Alpha Lattices

Parameter	High emittance 32.5 nm-rad	Low emittance 3.2 nm-rad
α_1	-1.95×10^{-6}	2.55×10^{-5}
α_2 (with/without sextupoles)	-3.66×10^{-4} / 1.08×10^{-2}	2.66×10^{-4} / 5.02×10^{-3}
α_3 (with/without sextupoles)	-2.49×10^{-2} / -1.70×10^{-1}	-3.61×10^{-3} / 6.16×10^{-3}
ν_x/ν_y	21.220/12.360	29.386/8.265
Bunch length σ_l (3.5MV)	0.86 ps	3.12 ps
Nat. Chromaticity ξ_x/ξ_y	-35.47/-32.35	-50.02/-53.42



Alex also served as the NSRRC

Distinguished Visiting Scholar 2009 + (2011~ 2019).

Thank you, Alex.

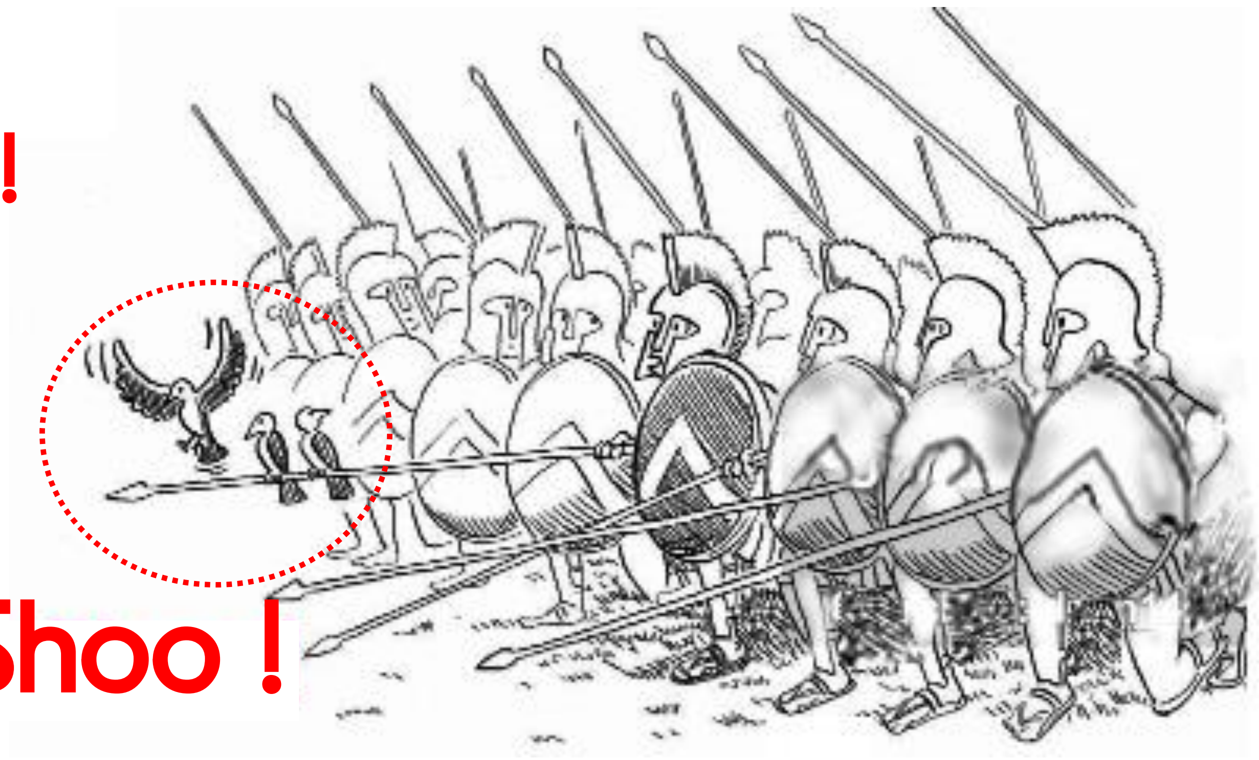
You are awesome!

Alex is like an ancient warrior to us !

A **warrior** does not give up what he loves,
he finds the love in what he does.

Promote **FEL** to take root in Taiwan.

Believe in us!
Patient with us!
Stand by us!



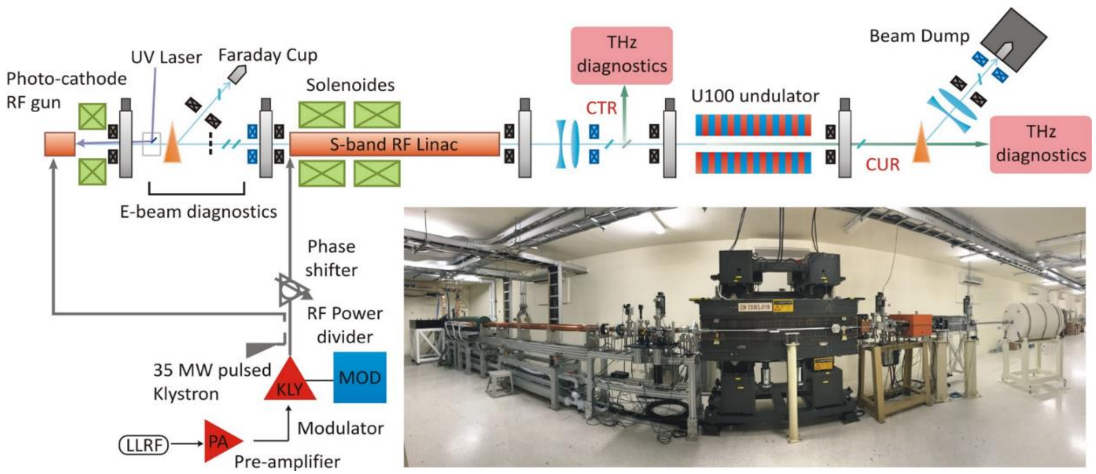
Shoo !

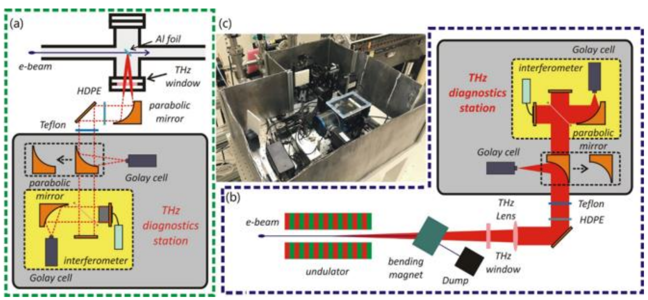
Program of a Small Scale VUV/FEL NSRRC
(A circle, though small, is yet complete.)

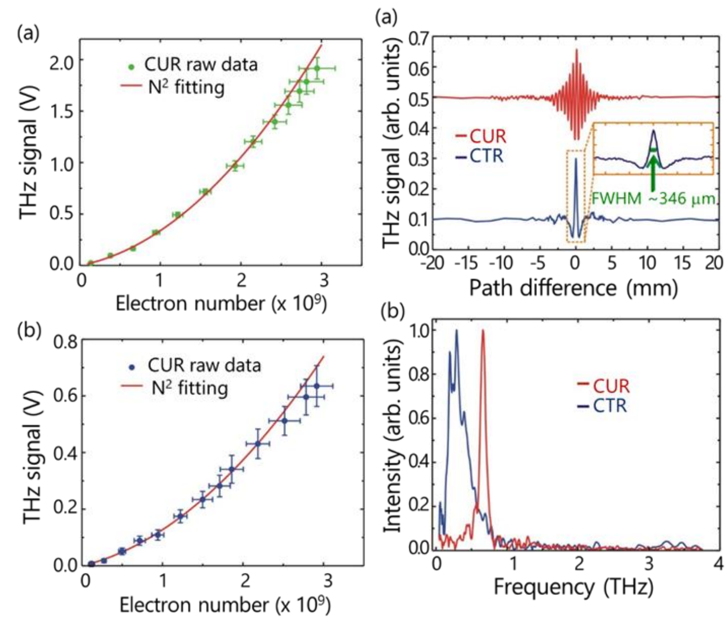
Purposes:

- Beam physics and technology development.
- To support future VUV users.
- Training of accelerator physicist.

Relativistic Femtosecond Electron Beam and Coherent THz Radiation







- **Coherent T-rays are generated successfully from relativistic fs electron pulses (2017)**
- **Intense T-rays found useful applications in biology**
- **Pilot user experiments are being planned in close collaboration with nearby research groups (e.g. NCTU, NCU, …)**
- **mJ-level single cycle THz pulses are under investigation**

Parameters	CUR	CTR
Beam energy (MeV)	17.7	
Bunch charge (pC)	280	210
Bunch length (fs)	490	
Repetition rate (Hz)	10	
Undulator strength K	4.6	--
THz pulse energy (μJ)	26.4	6.7
Central frequency (THz)	0.62	--
Bandwidth	15%	--
THz peak power	530 kW	9.4 MW

NSRRC Coherent THz Source

Conclusion

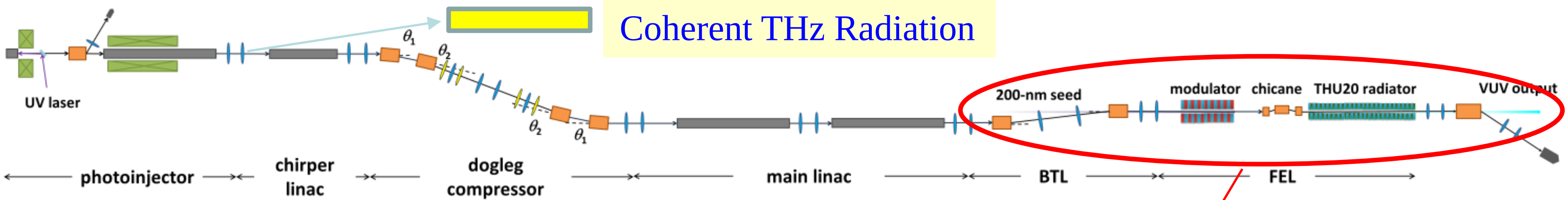
Not a good idea to take photos from a "TOP-DOWN" angle.

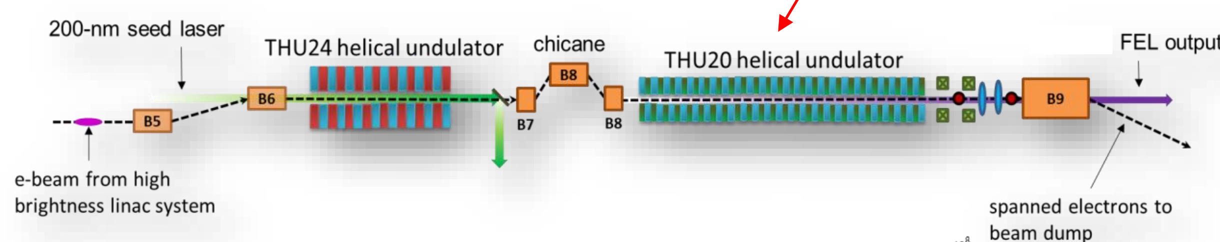
Even handsome men look short

Bunch compression in wrong direction!

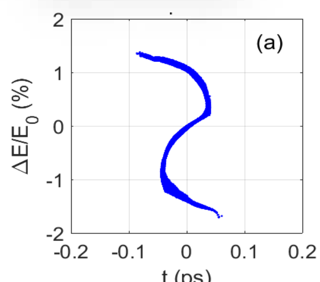
Design of VUV FEL Test Facility

(Short-term goal: CDR)

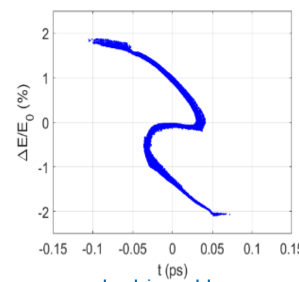




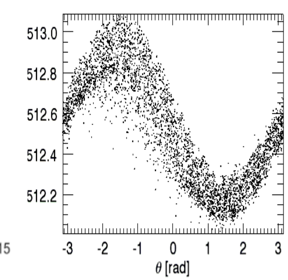
- VUV FEL test facility CDR
  - Start-to-end simulation of seeded VUV FEL
  - driver linac design
  - Seed laser design
  - Magnets and Undulators design
  - Vacuum system
  - RF & timing system design
  - VUV pulse diagnostics



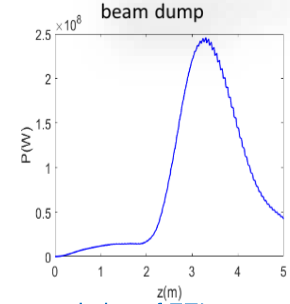
compressed beam



dechirped beam



energy-modulated beam



evolution of FEL power

Beam Parameters	
Energy	250 MeV
Peak current	500
emittance	3 µm
Energy spread	0.08 %

Modulator Parameters	
Modulator Type	Helical
Modulator period length	24 mm
Modulator length	0.24 m
Seed laser wavelength	200 nm
Seed laser power	300 MW

Chicane parameters	
Dipole field strength	0.08T
Dipole length	5 cm
Drift space before chicane	2.5 cm
Drift space after chicane	2.5 cm
Total length	32.5 cm

Radiator Parameters	
Undulator type	Helical
Period length	20 mm
Undulator parameters	0.772
Radiation wavelength	66.7 nm
Saturation power	240 MW

NSRRC FEL Task Force

Alex helped :::

¥ Set-up task force for the project.

¥ Set-up FEL Winter School in NSRRC to train young generation.

the FEL initiative

Look relaxed ? NOT the case !

Intense discussion over the

Fried Rice, Eggroll, Lettuce Wraps

Promote Accelerator Based EUV Sources for Beam Physicist Development and Industry Application

- Promote accelerator based EUV sources (13.5 nm and its harmonics) for semiconductor industry application - working together with accelerator community around the world.

Rayleigh Criterion: $CD = k_1 \times (\lambda/NA)$

- Proposed electron storage ring based EUV source with mechanism of steady-state micro-bunching (SSMB).

- Educate younger generation how to start from concept , develop theory, realization for an SSMB based accelerator design and specifications of technology development. This is a necessary route for Accelerator Physicist development.

Educator and Gardener of Accelerator Physics

- Full of passion and perseverance to promote accelerator physics, technology, and applications.
- He did much to groom and to inspires succeeding generations.
- Show us how to get onto the right way.
- Advised us how to developed capability to overcome obstacles.

OCPA School

International Organization of Chinese Physicists and Astronomers

Alex was the Chair of OCPA school from 1998~2014

1st	OCPA AS Hsinchu, Taiwan, August 3-12, 1998,	Chaired by Alex
2nd	OCPA AS Yellow Mountain, Anhui, July 18-27, 2000	
3rd	OCPA AS Singapore, July 25 to August 3, 2002.	
4th	OCPA AS Yangzhou, Jiangsu, July 27-August 5, 2006,	
5th	OCPA AS Nantou, Taiwan, September 1-10, 2008	
6th	OCPA AS Beijing, July 27-August 5, 2010	
7th	OCPA AS Tianshui, Gansu, July 29-August 7, 2012,	
8th	OCPA AS Xiuning, Anhui, July 27-August 6, 2014	
9th	OCPA AS Shanghai, July 25-August 4, 2016	Chaired by Zhao Zhentang (SINAP)
10th	OCPA AS Kaoshiung, Taiwan, July 23 to August 1, 2018	

OCPA School 1998

NSRRC, Hsinchu @ Northern Taiwan

OCPA School 2008

Xitou, Nantou @ Central Taiwan

OCPA School 2018

Kaohsiung @ Southern Taiwan

NSRRC FEL Winter School

2015

2016

2017

2018

As the size of class grows, Alex's gray hair grows too (still plenty).

Joint of Accelerator Physics and Technology Courses of NTHU / NCTU / NSRRC

- Alex helped NSRRC to set up accelerator physics and technology courses for nearby universities (National Tsinghua University and National Chiao-Tung University) to cultivate younger generation.

- Alex also gave lecture in the accelerators program.

To Alex, our dear friend,

Happy Birthday and Retirement !