Overview of the EMuS and review charges

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International Review of the EMuS Conceptual Design,
Nov. 20-21, 2018, Dongguan

Outline

* Introduction to CSNS and multi-platforms
* Opportunity to develop muon sources and μSR applications in China
* Science goals and design schemes of EMuS
* Planning and prospects
* Domestic and international collaboration
* Charges to the review committee

Site for CSNS facility

IHEP Dongguan Branch

- **The site for CSNS is in Dongguan, Guangdong Province.**
- **CSNS is the first large scientific facility in southeastern China, jointly invested by the central government and local government. It will promote advanced researches in the economic developed zone of Guangdong-Hong Kong. Total budget: ~2.3B CNY (or 350M USD)**

Key Milestones

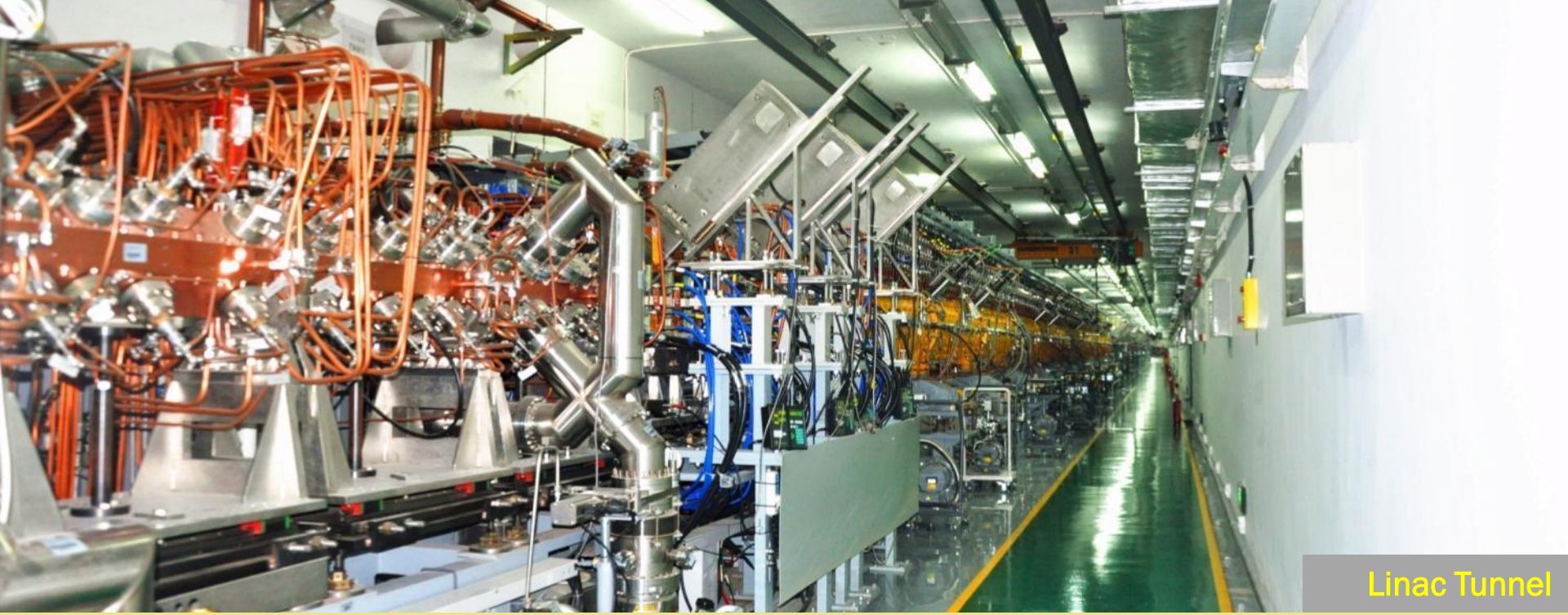
February 2001	CSNS initiative
June 2005	Proposal approved in principle by the central government
January 2006	CAS funded 30M CNY for R&D
July 2007	Guangdong province funded 40M CNY for R&D
December 2007	Review of the CSNS proposal
September 2008	Proposal approved by the central government
October 2009	Review of the feasibility study
September 2011	Ground breaking
August 2017	First beam on target
March 2018	Completion of CSNS-I construction

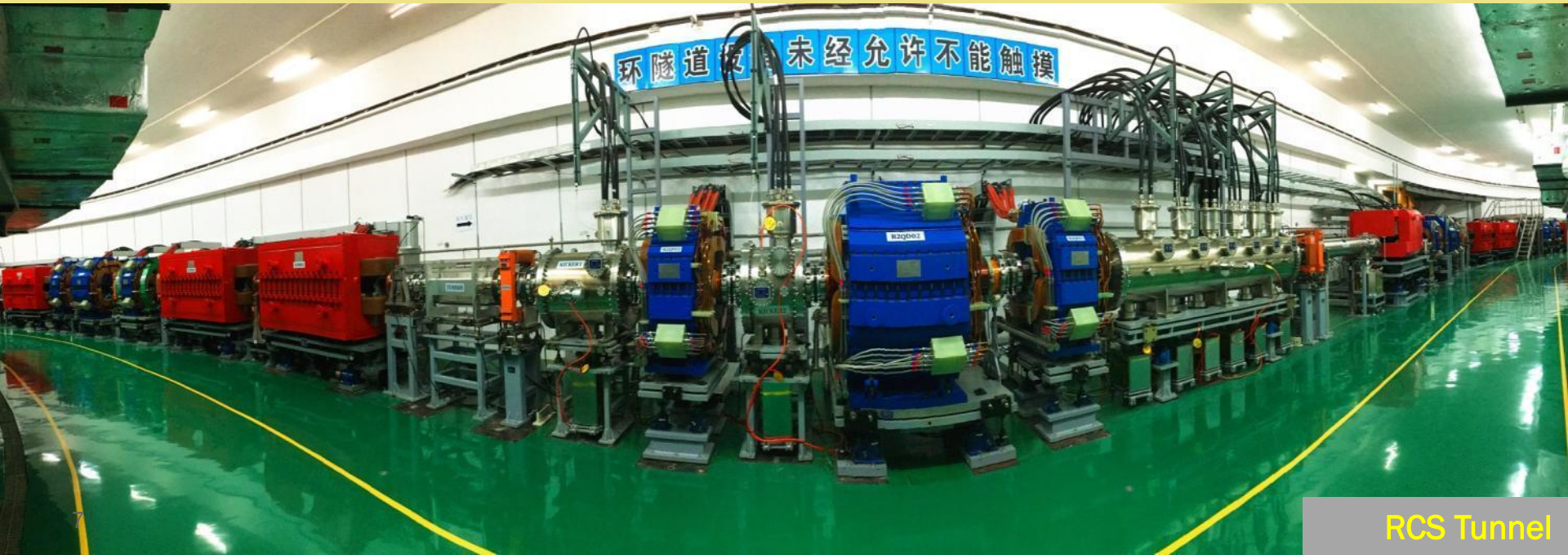
Eastern part of Pearl river delta

Target and experiment hall

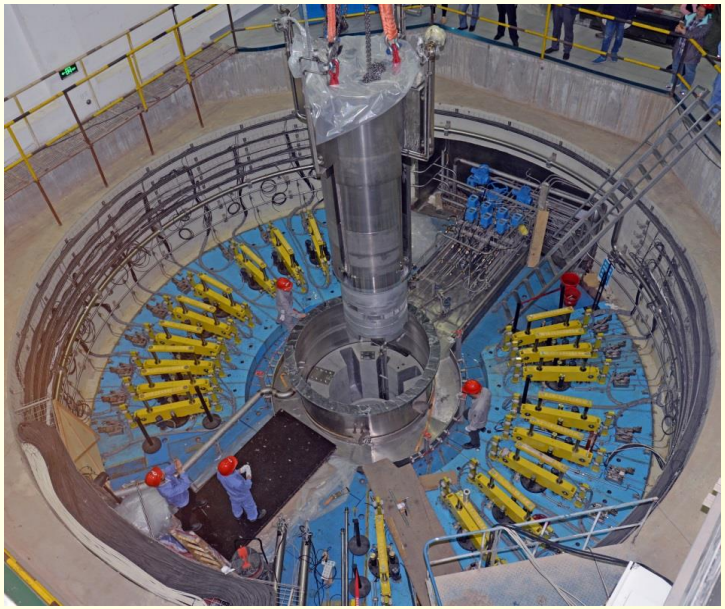
LINAC service building

RCS service building


Linac Tunnel


环隧道
未经允许不能触摸
RCS Tunnel

Target Station



Target in Hot-cell

South Exp. Hall

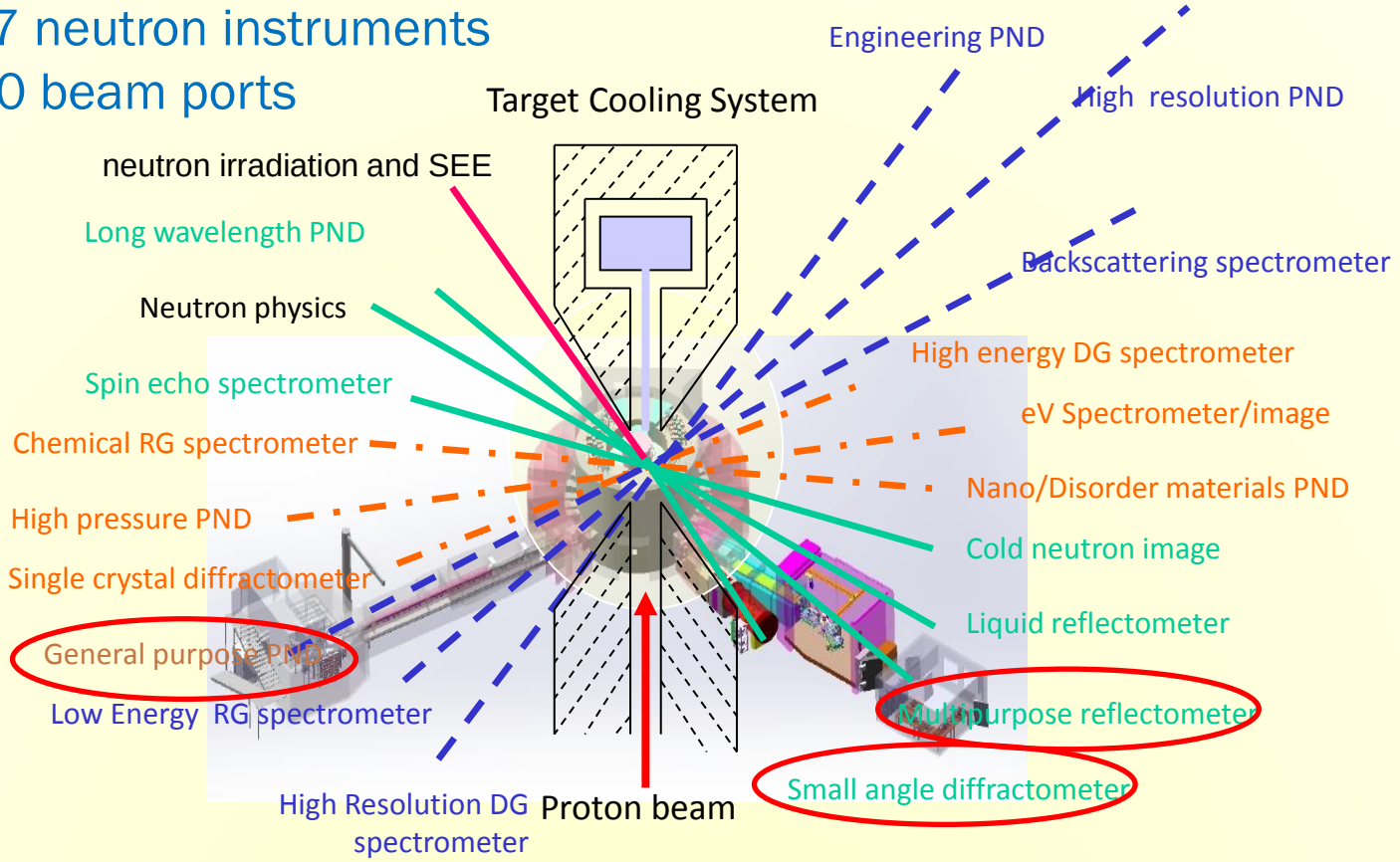
North Exp. Hall

Commissioning and initial operation

- First beam on target: Aug.28, 2017
- Accelerator-target-instruments joint commissioning: November 1-9, 2017
- Accelerator reached the acceptance beam power of 10 kW: Nov. 9, 2017
- Instrument tuning and Day-one experiments: from January to March, 2018
- Initial operation: Since April 2018
- First physics paper including CSNS neutron scattering experiment published: April 17, 2018
- Present beam power: 20-25 kW
- Open to general users: from September 2018

Neutron instruments

- 20 beam ports
- Built: BL1: SANS; BL2: MR; BL18: GPPD
- To start: 7 neutron instruments
- Future: 10 beam ports



(PND: Powder Neutron Diffractometer; RG/DG: Reversal/Direct Geometry)

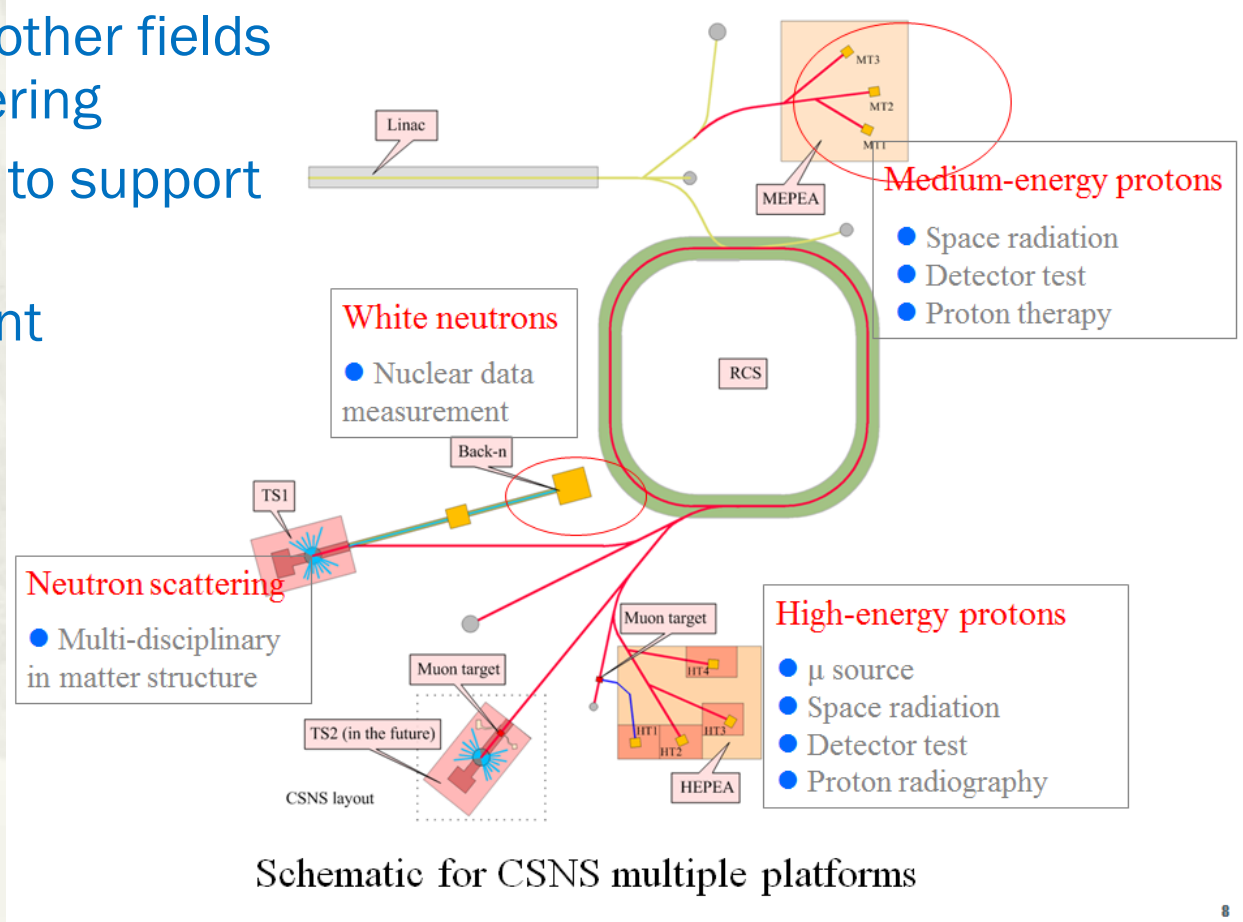
Moderator：

D+P, LH2 (20K）　C,LH2 (20K)　D, Water (300K)

CSNS as multiple platforms

CSNS is the only large-scale proton accelerator in China today

- Strong needs from other fields than neutron scattering
- Excellent capability to support multiple platforms
- Phased development

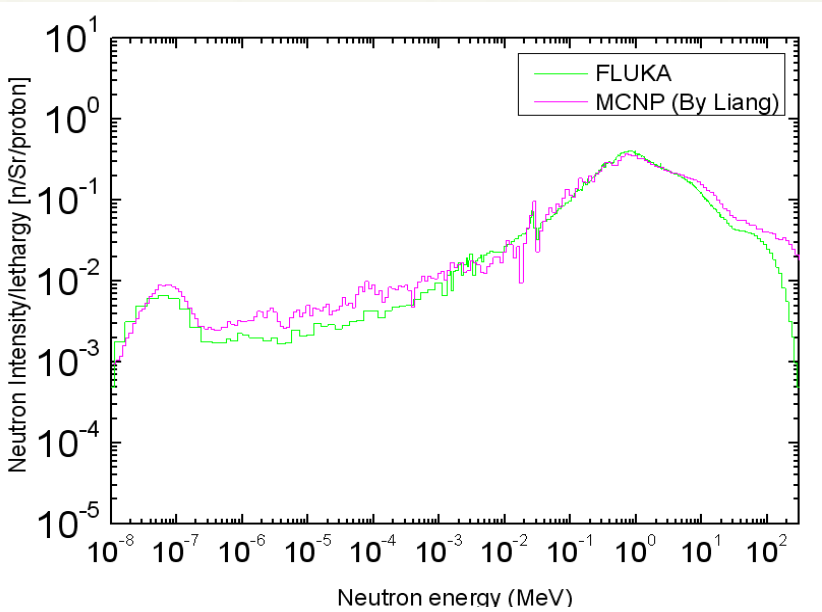


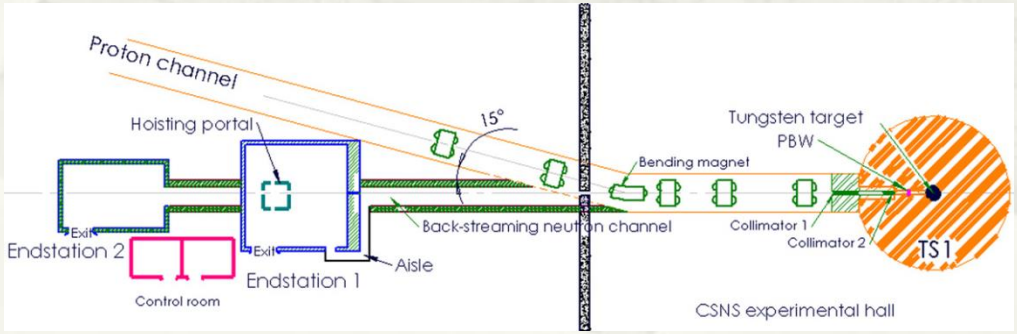
Schematic for CSNS multiple platforms

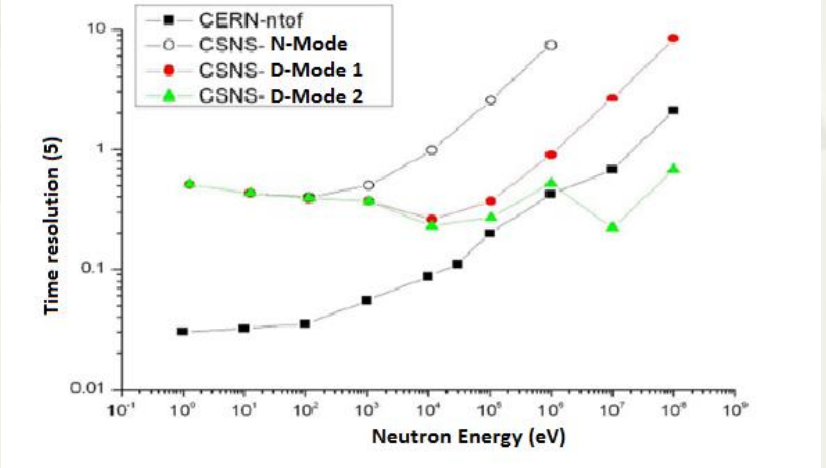
Back-streaming neutrons from the CSNS target

- Back-streaming neutrons from the CSNS target into the RTBT channel
  - Very intense, harmful to the devices in RTBT, should be carefully treated Good energy spectrum and time structure, exploited as white neutron source (first its kind in the world)

(10^7 n/cm^2/s at 50 m)



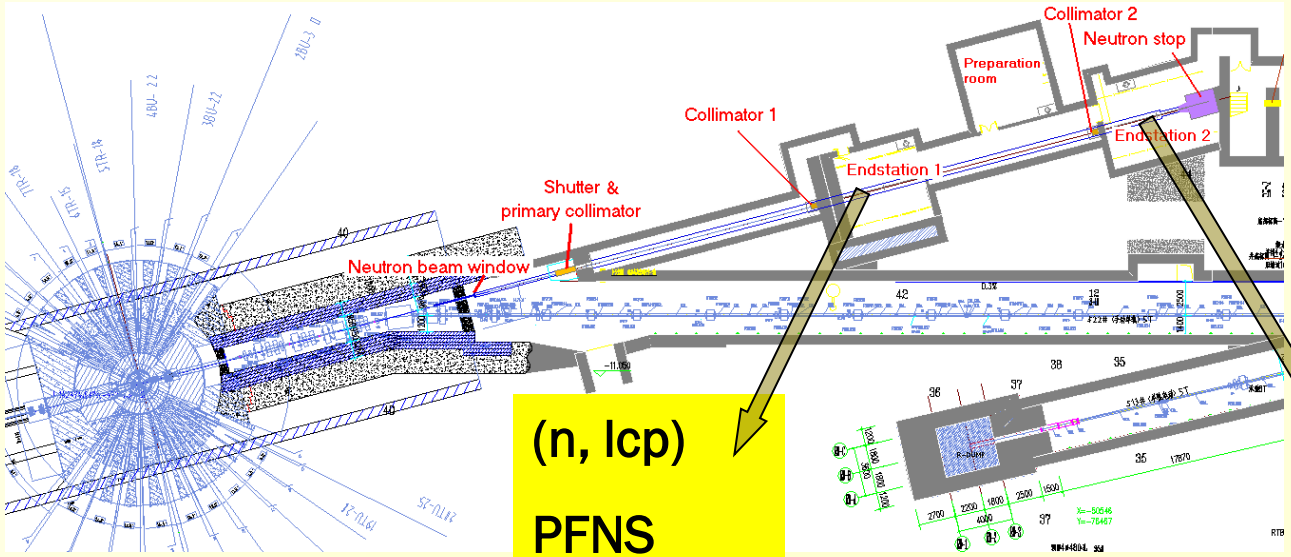




World 3rd WNS based on spallation after LANL/LANSCE, CERN/n_TOF

Spectrometers for different measurements

- All major data measurements suitable for TOF method are planned at the Back-n
  - Planned spectrometers: Multi-layer ionization chamber for (n,f) and (n,t), 4π BaF_2 and 4-unit C_6D_6 for (n,γ), ΔE-ΔE-E array for light charged particles emission, 4π HPGe for (n, n'γ/2nγ), PPAC+scintillators for Prompt-Fission Neutron Spectrum (PFNS)
- Other applications: high-energy neutron irradiation, detector tests



Back-n facility at work

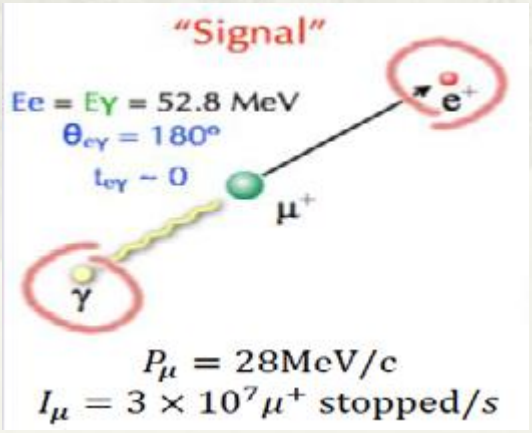
- Neutron source: beamline, conventional facilities, controls, common electronics and DAQ
- Four spectrometers are available for user experiments:
  - C6D6: for neutron capture
  - FIXM: for fission cross-section
  - NTOX: for total cross-section
  - LPDA: for charged particle emission
- Three spectrometers under upgrading and available by end 2019
  - FIXM and LPDA with full designed specifications
  - GTAF-II (40-unit BaF_2 array)

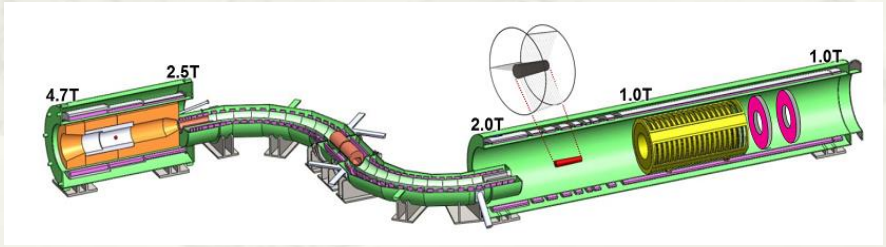
Opportunity to develop muon sources and μSR applications in China

- High intensity μ sources are very important in particle/nuclear physics and multidisciplinary research
- Particle physics: μ as a fundamental particle, μ sources are very important facilities in different research fields
  - Muon physics: rare decays and leptonic flavor violation experiments (Mu2e, COMET, MEG), μ g-2/EDM experiments
  - Neutrino factory: neutrino oscillation experiments
  - Muon collider: future energy -front facility

$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

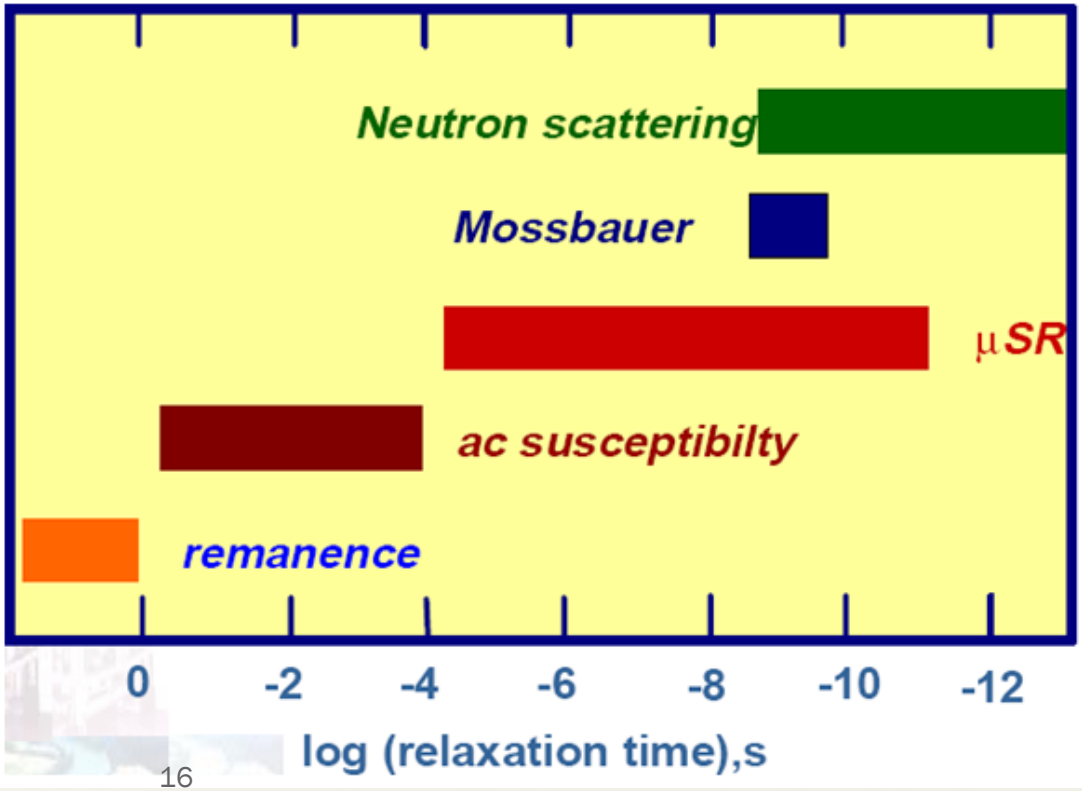


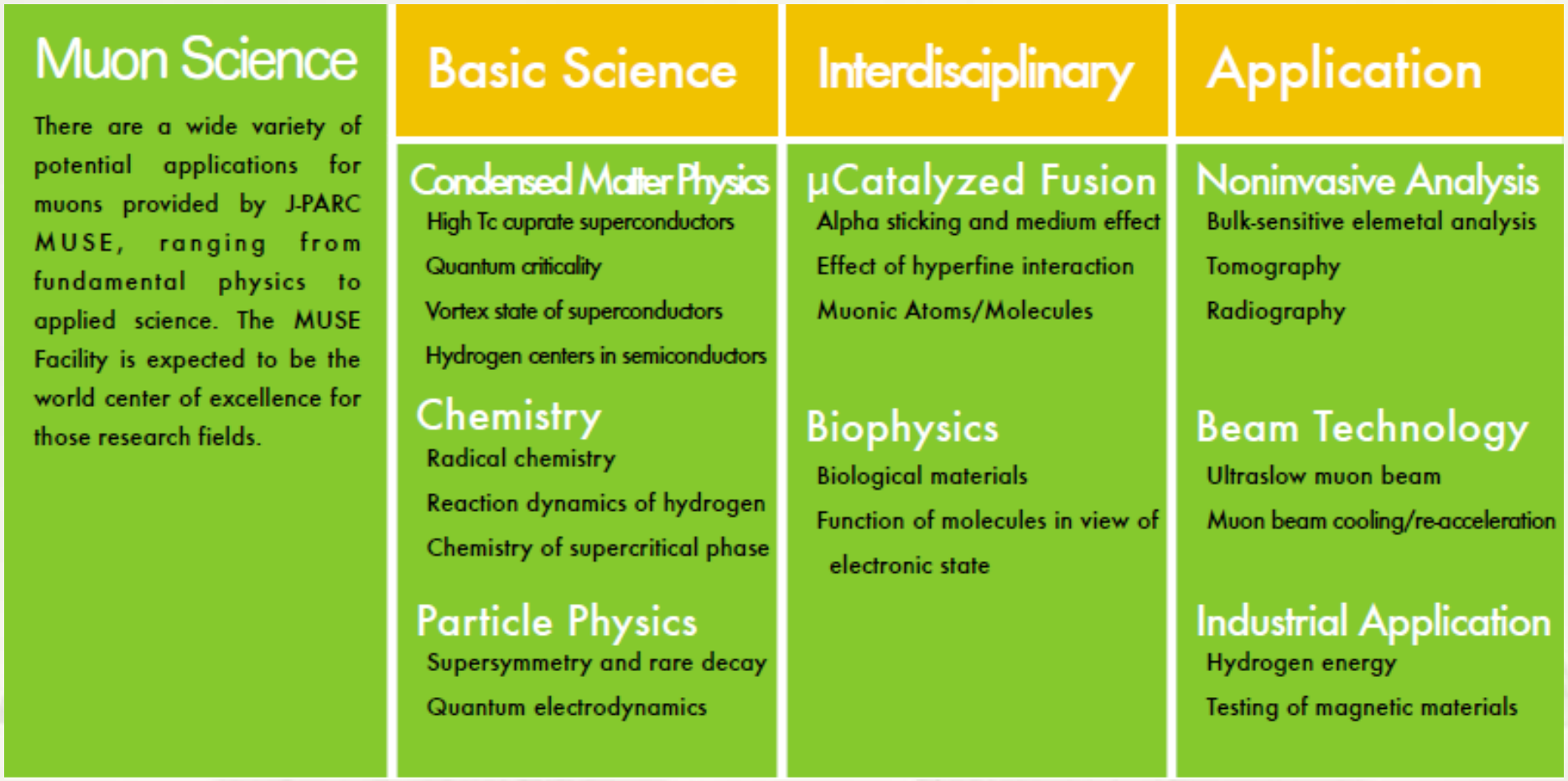


Fermilab: Mu2e experiment

* Multidisciplinary applications: μ's special properties (surface μ 100% polarized, 2.2 μs lifetime） can be exploited via μ spin rotation, relaxation and resonance (or μSR) to study the structure of different materials (gas, liquid and solid) and also dynamics, covering condensed matter physics, materials, chemistry and biology.

μSR is a collection of methods that uses the muon spin to look at structural and dynamical processes in the bulk of a material on an atomic scale.





Science and technology based on muon sources

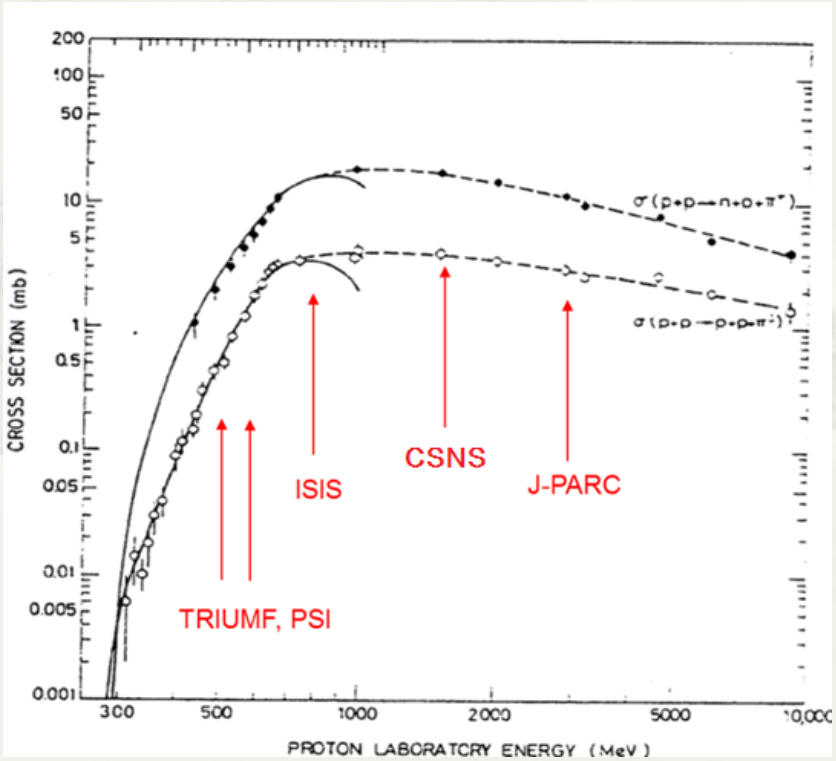
（Courtesy: J-PARC/MUSE）

Interests in muon sources in China

- No muon source in China now
- Chinese researchers on condensed matter have to go to international labs
  - Applying beam times (Lei Shu from Fudan U., Fanlong Ning from Zhejiang U., a few groups from IOP, Chengnan Wang from Peking U., etc.)
  - Sending samples: more practices (IOP, USTC, …)
- A few groups (including IHEP) participating in COMET and Mu2e
- Many researchers expressed to have Chinese muon sources
- People are also discussing a future muon facility at CiADS (newly approved project, 500MeV-2.5MW)

- China has a good community in particle physics – neutrino physics and muon physics
  - Neutrino physics (Daya Bay, JUNO, MOMENT)
  - The particle physics community is interested in a Chinese muon facility besides participation in COMET and Mu2e
- μSR and technical applications
  - Researchers are using international μSR facilities
  - We have a numbers of users using positron annihilation method, willing to go to muon techniques

- High-power proton accelerator for μ source
  - Precious resources in the world
  - CSNS just completed, very much suitable to start the construction of a muon source

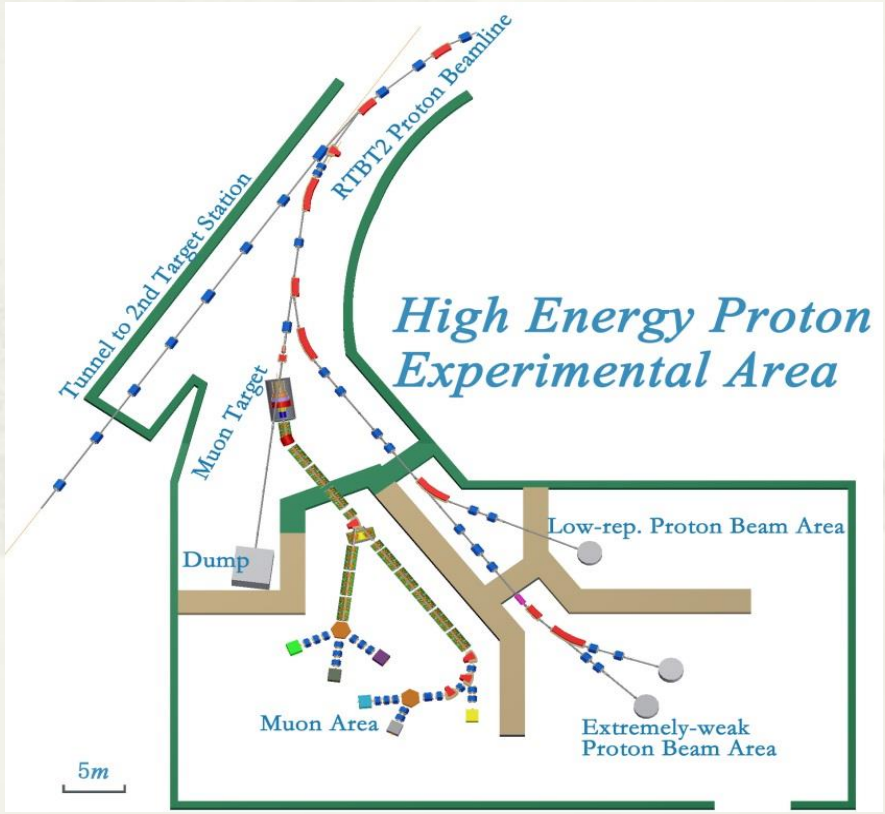


Single π production cross-section vs proton energy

Experimental Muon Source (EMuS) at CSNS

* CSNS EMuS located in the high-energy proton application hall, together with other direct proton beam applications

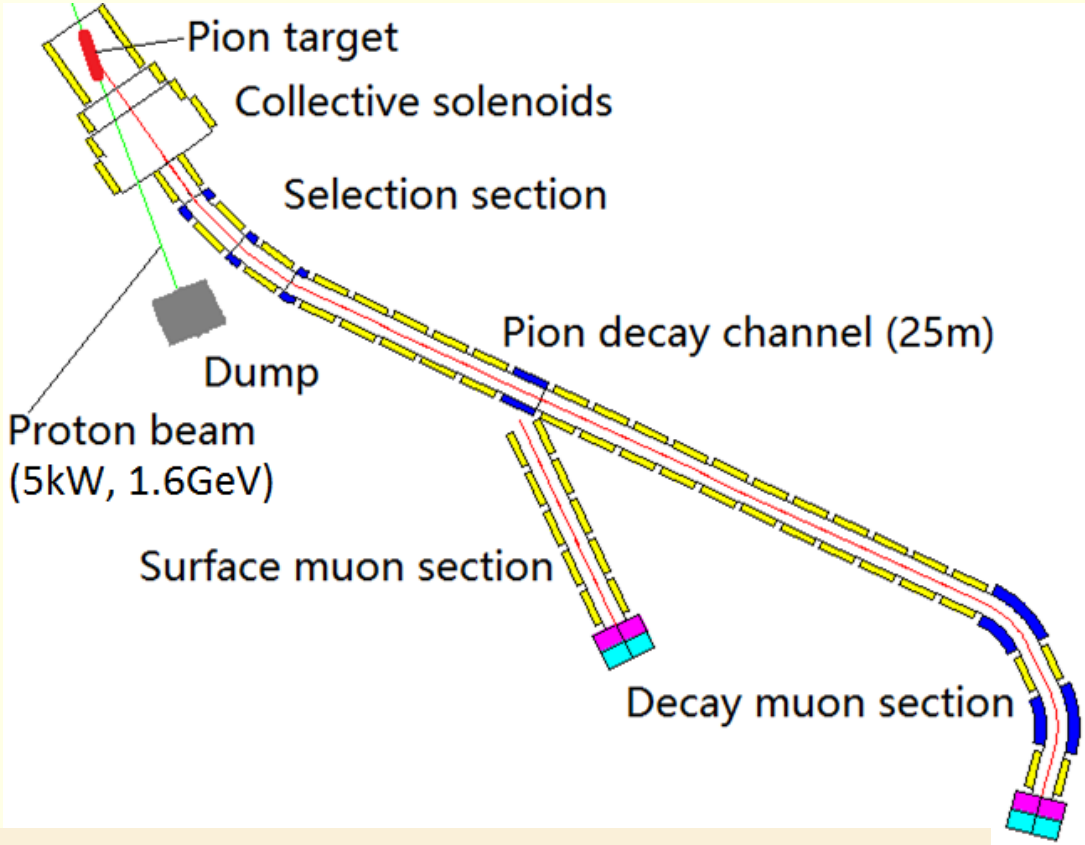
- Proton beam: 1.6 GeV, 5 kW (5% of total), single bunch per pulse (2.5Hz)
- Target: carbon, 300 mm in length, conical shape, forward extraction
- Capture solenoid: 1-5 T (Al-based NbTi wires)
- Science goals: μSR applications, muon beam techniques, MOMENT R&D, Neutrino cross-section meas.



Science goals of EMuS

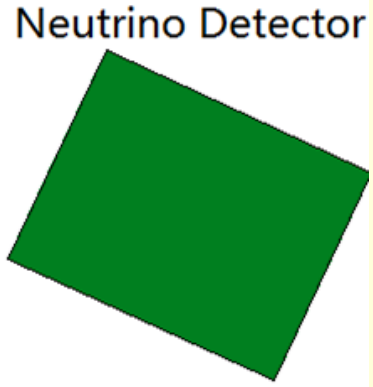
- μSR applications
  - Multidisciplinary research, complementary to neutron scattering
  - Surface muon beams, decay muon beams and future slow muon beams
- Muon techniques
  - Muon imaging (high momentum up to 450 MeV/c)
  - Muon irradiation
  - Muonic X-ray analysis
- Nuclear and particle physics
  - Looking for good proposals, currently investigating neutrino cross-section measurements and muonium to anti-muonium conversion

EMuS Layout and Working Modes



Working modes (indep.):

1. **Surface μ mode**
   a) Δp/p: <±5%
   b) Ref. Pμ=29 MeV/c
2. **Decay μSR mode**
   a) Δp/p: <± 10%
   b) Ref. Pμ =40-150 MeV/c
3. **High-momentum μ mode**
   a) μ imaging, neutrinos
   b) Ref. Pπ=200-450 MeV/c



Planning for future: slow muons

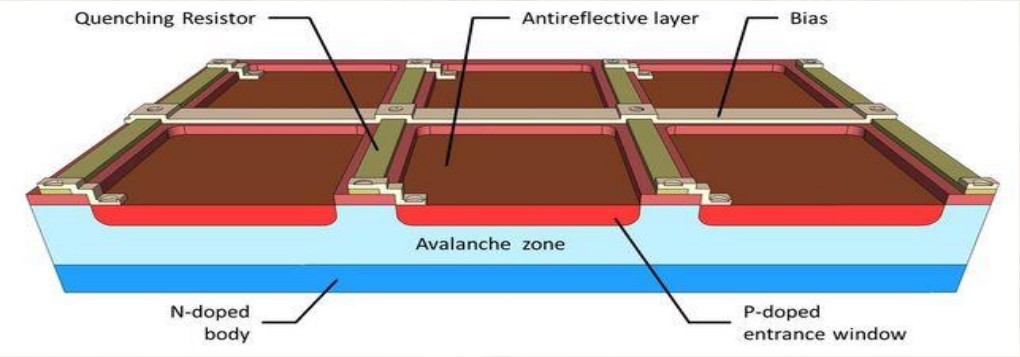
Major design features

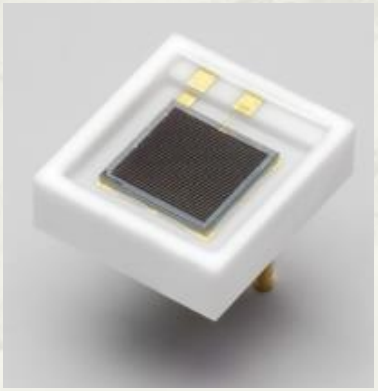
- EMuS will share the same experimental area with other high-energy proton applications:
  - Proton beam: 1.6 GeV, 5 kW (Phase-I), 2.5 Hz
- Target station
  - Carbon target: 300 mm in length, conical shape
  - Capture SC solenoid: 1-5 T (NbTi) (15° w.r.t. target)
  - Forward collection: proton beam separated (higher momentum muons)
- Muon/pion beam transfer line
  - Trunk beamline: SC solenoids based, μSR beam line SC or RT magnets
  - Large momentum range: surface muons (& slow muons), decay muons and high-momentum muons (also neutrino beam)
- μSR spectrometers
  - High asymmetry or more detecting channel (2560) design coping with low-repetition and high flux muon pulses

A thin insertion target upstream for only surface muons also under study

Super - μSR spectrometer based on SiPM

PMT	SiPM
Large volume, expensive	Small size, cheap, possible for array of thousand units
Sensitive to B field, needing optical guide	Non-sensitive to B field, more compact
Low quantum efficiency, slow risetime	High quantum efficiency, faster risetime
High gain	Gain close to PMT





- Successful application at PSI and J-PARC
- Very much suitable for the low-repetition rate EMuS (2560-ch Super-μSR)

- Wide applications:
  - Surface muons, slow muons: μSR applications
  - Negative muons: muonic X-ray, muon catalyzed fusion
  - Decay muons: μSR, μ imaging and irradiation, muon physics
  - Pions: neutrino cross-section

* Main target
  * Surface muon area: 3 μSR spectrometers planned
  * Decay muon area: 1 μSR spectrometer, 1 muon imaging/irradiation, 1 port tbd
* Thin target (vertical beamline)
  * 1 μSR spectrometer
* Baby scheme
  * In case of low construction budget in the beginning, we will build a simplified muon source (called Baby Scheme), in order to start muon applications as early as possible.
    * Thick - free target, side collection, short muon beamline (RT magnets), one modest μSR spectrometer

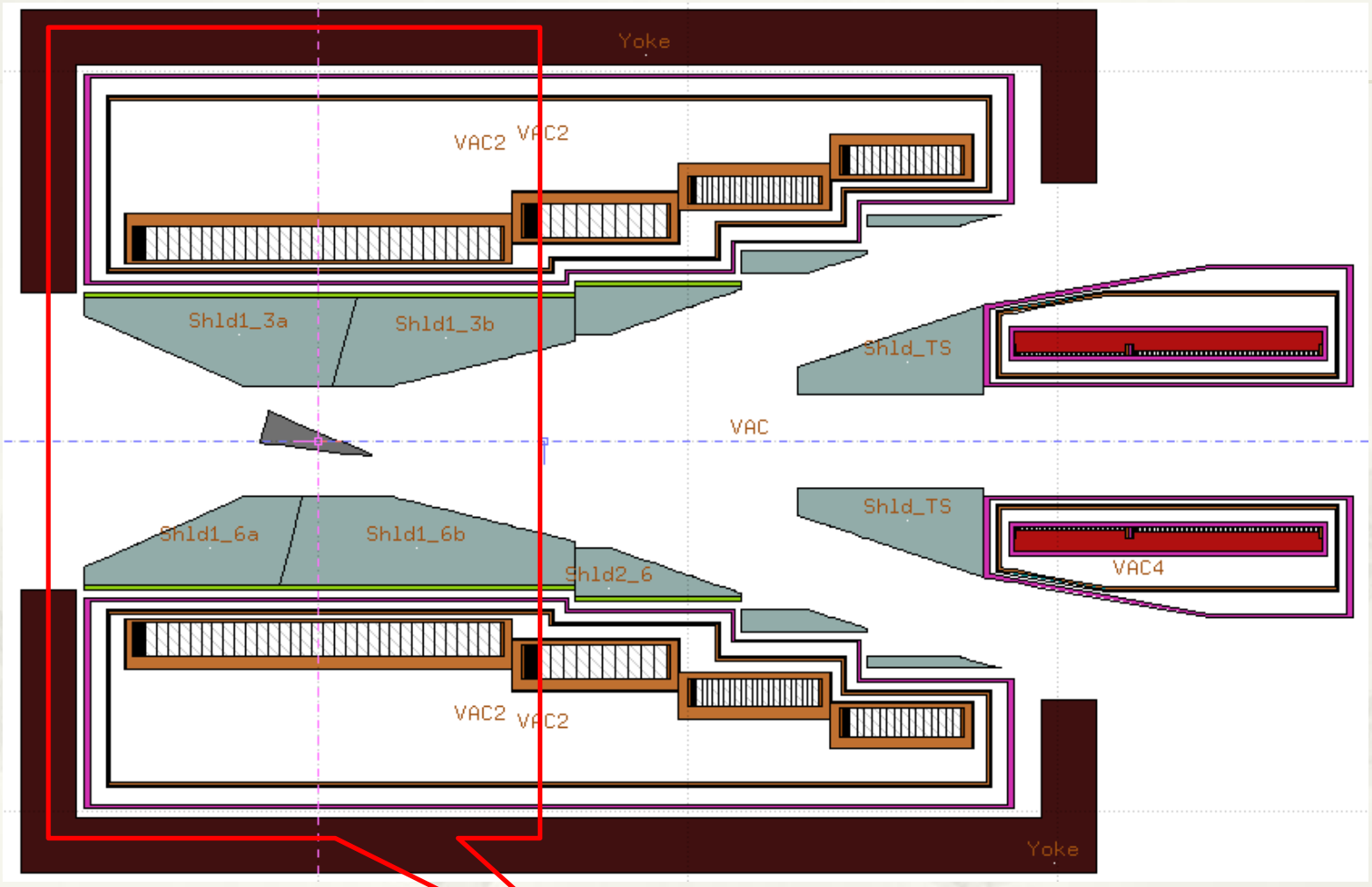
Status of design and R&D

- Since 2007, we have been studying to add a muon source to CSNS, but until 2015 we obtained a major NSFC fund 'Development of National Major Scientific Instruments' to support the design and R&D
  - Study team: researchers and students from different IHEP divisions, USTC and Sun Yat-Sen University
- As we do not have any experience in building muon sources and EMuS has a special design to serve multiple purposes, it is very challenging in the design and construction.
  - Learning from international experts and labs
  - R&D efforts are indispensable
- Communication with potential users and influential top scientists is also in progress.

Major R&D efforts

- Challenging issues
  - Compromised layout to support different programs
  - Low repetition rate of the proton beam
- Target assembly prototype
  - Mechanical structure design
  - Inner shielding with Tungsten
  - Target support and cooling
  - Collimators for both pions/muons and protons
  - Compatibility with SC solenoids
- Technique on large-aperture, high-field and radiation-hard superconducting solenoid
  - Preferably Al-based NbTi conductors
  - A prototype of the capture solenoid
- A μSR spectrometer prototype of two rings
  - Sampling condition is also under consideration

Prototyping of main capture solenoid and target assembly

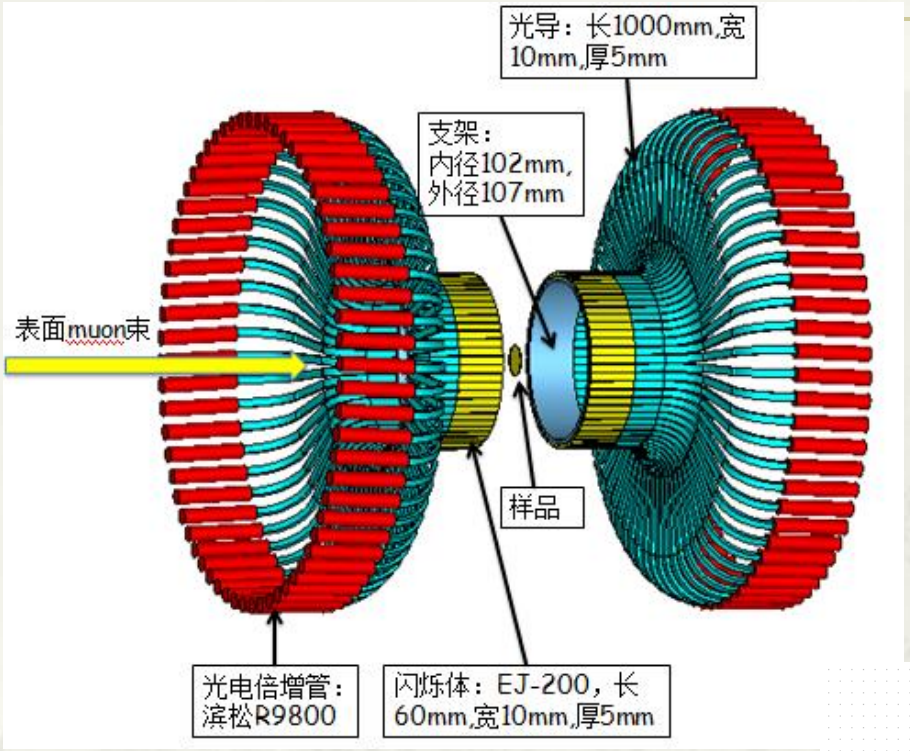


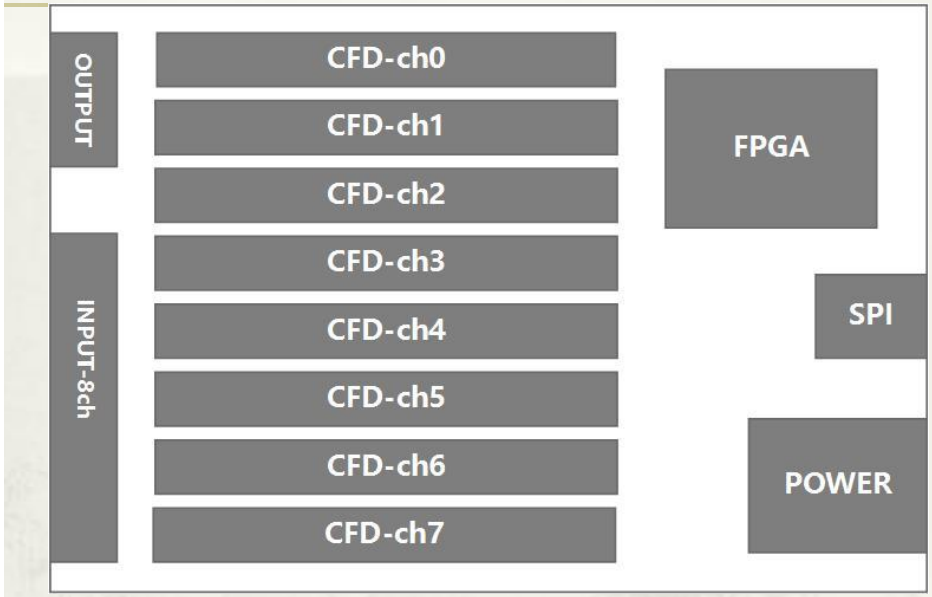
Selected for prototyping

Talk: Hou Zhilong

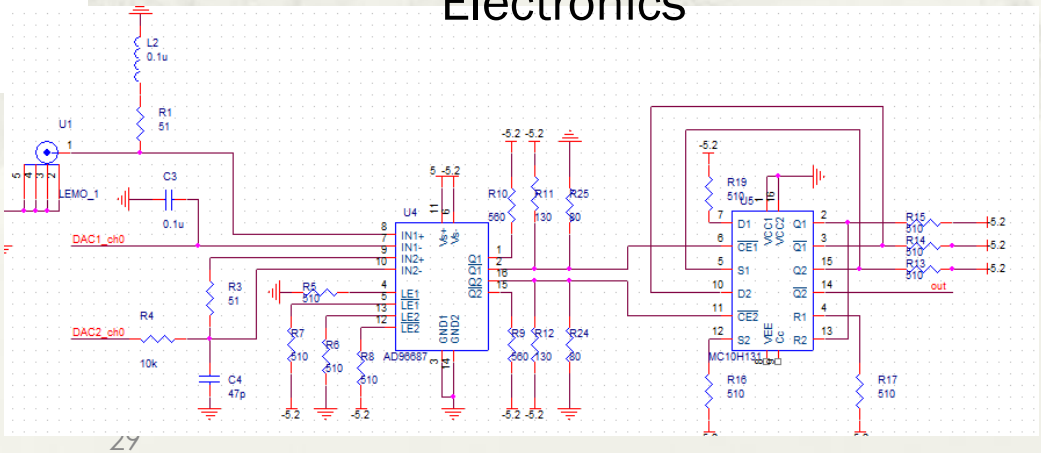
Prototyping of a μSR spectrometer

Talk: Ni Xiaojie





Electronics



Prototype:
One ring based on 64-unit scintillators, another on 64-unit SiPM

Planning and prospects

- Continuing design and R&D (-2020)
- Applying for construction budget (from 2019)
  - Financial support from the local government (Dongguan City and/or Guangdong Province)
  - In the package of CSNS upgrade project applied to the NDRC
  - A larger NSFC fund 'Development of National Major Scientific Instruments'
- Phased construction
  - Optional start-up (Baby Scheme): starting with proton beamline, experimental hall, free target, a short muon beamline with RT magnets, one surface μSR spectrometer
  - Baseline: replacing the "Baby target + muon beamline" with the baseline design scheme, adding a Super-μSR spectrometer
  - More spectrometers: adding the vertical beamline; more spectrometers (7 in total) with participation of other partners (universities)

Domestic collaboration

- Attracting high-level users is essential for a common facility
  - muSR users in China: IOP, Fudan U., Zhejiang U., USTC, Peking U., SUSTech, SYSU, Beijing Normal U., RUC, …
- EMuS study team is composed of researchers and students from different institutions and IHEP divisions:
  - A group from USTC collaborating with us since 2007, on the design and R&D (4 PhD graduated, 5 PhD students)
  - Different IHEP divisions (Dongguan Branch, Exp. Particle Physics Div., Multidisc. Appl. Div., Acc. Div.) are involved
  - Sun Yat-Sen Uni. (SYSU) collaborating on application in particle physics, now to include μSR applications
- In the future:
  - μSR spectrometers and muon beam applications: user facility, but also possible user-funded spectrometers
  - For nuclear/particle physics at EMuS, domestic collaboration is even more important.

International collaboration

- We have been contacting with international muon labs
- CSNS has very close relationship with RAL/ISIS
  - Past: accelerators and neutron scattering, now also muon source
  - ISIS helped the detector test for our μSR spectrometer prototype
  - IHEP made significant contribution MICE hosted at ISIS
- We are discussing with RIKEN about establishing a close collaboration:
  - A RIKEN delegation visiting CSNS in 2017 and more other visits
  - Discussion about signing a MOU
- Other collaborations
  - PSI/SμS: once one postdoc and one PhD student there in the past, now discussing to collaborate on muon moderation
  - J-PARC/COMET, MUSE: IHEP contributing on COMET, long-time contact with MUSE

Open questions to the committee

- What is useful momentum range for decay muons in muSR applications?
- Is a surface muon beam of very large emittance and high intensity useful for muon moderations?
- Is the vertical beamline from the thin target but with low intensity (10^4 mu/s, 2.5 Hz) worth pursuing?

Review charges to the committee

- Give the general comments about the EMuS project, including science goals, design schemes, and technical solutions.
- Give general comments to the quality of the work of the EMuS team.
- Comment on the phased construction plan of EMuS and application priorities.
- Evaluate on the current R&D efforts and give comments on other important R&D studies.
- Comment on how to proceed the following studies
- Answer specific questions proposed by the EMuS team during the review
- Suggestions to the IHEP/CSNS management and funding agencies
- Important questions to be answered by the EMuS team

Summary

- EMuS as the first muon source in China and a competitive muon facility in the world is in good hope, to serve both μSR applications and particle/nuclear physics
- Conceptual design of EMuS and R&D efforts are presented for review
- Expecting extraordinary comments from the review committee to improve the current design and future technical design, as well the R&D.