High intensity accelerators (with focus on ESS)

on behalf of the ESS

CERN 26 June 2013

Caveat

- My “own” best understanding of the present status of the field based on input from many colleagues
- Reservations for recent changes in plans at different labs, much input from autumn 2012 and work on European roadmap for particle physics
- My apologies to all labs not mentioned in my brief overview of the field
- Omissions and errors are all mine

Outline

Particle accelelerators at the high intensity frontier:

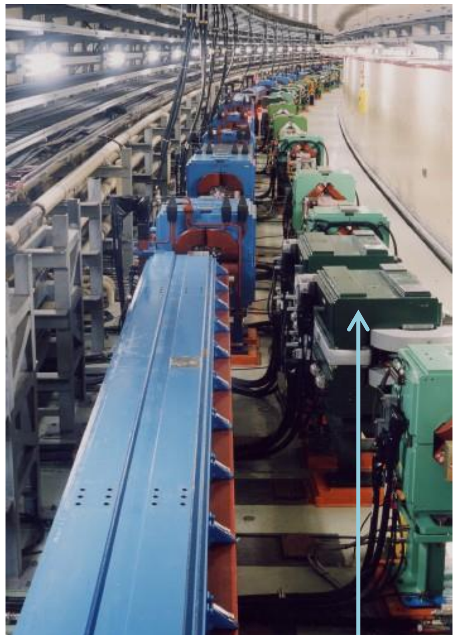
High average intensity

- High intensity linacs (for high intensity single beams e.g. neutrinos, anti-protons, muons and neutron EDM)
  - Examples in Europe are ESS, SPL study and MYRRHA
- High intensity cyclotrons (for high intensity single beams e.g. neutron EDM and muons)
  - Examples in Europe are PSI

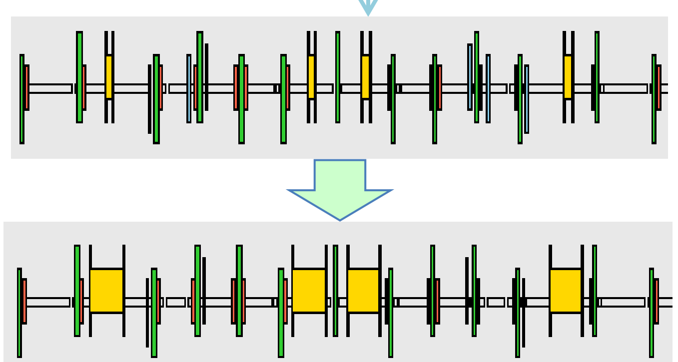
High instantaneous intensity

- High intensity hadron rings (for high intensity single beams and flavor factories e.g. anti-protons, neutrinos, muons, rare-deacys and CP violation)
  - Examples in Europe are **PS/SPS at CERN, ISIS** and FAIR
- High intensity electron/positron rings (for high luminosity flavor factories)
  - Examples in Europe are DAΦNE

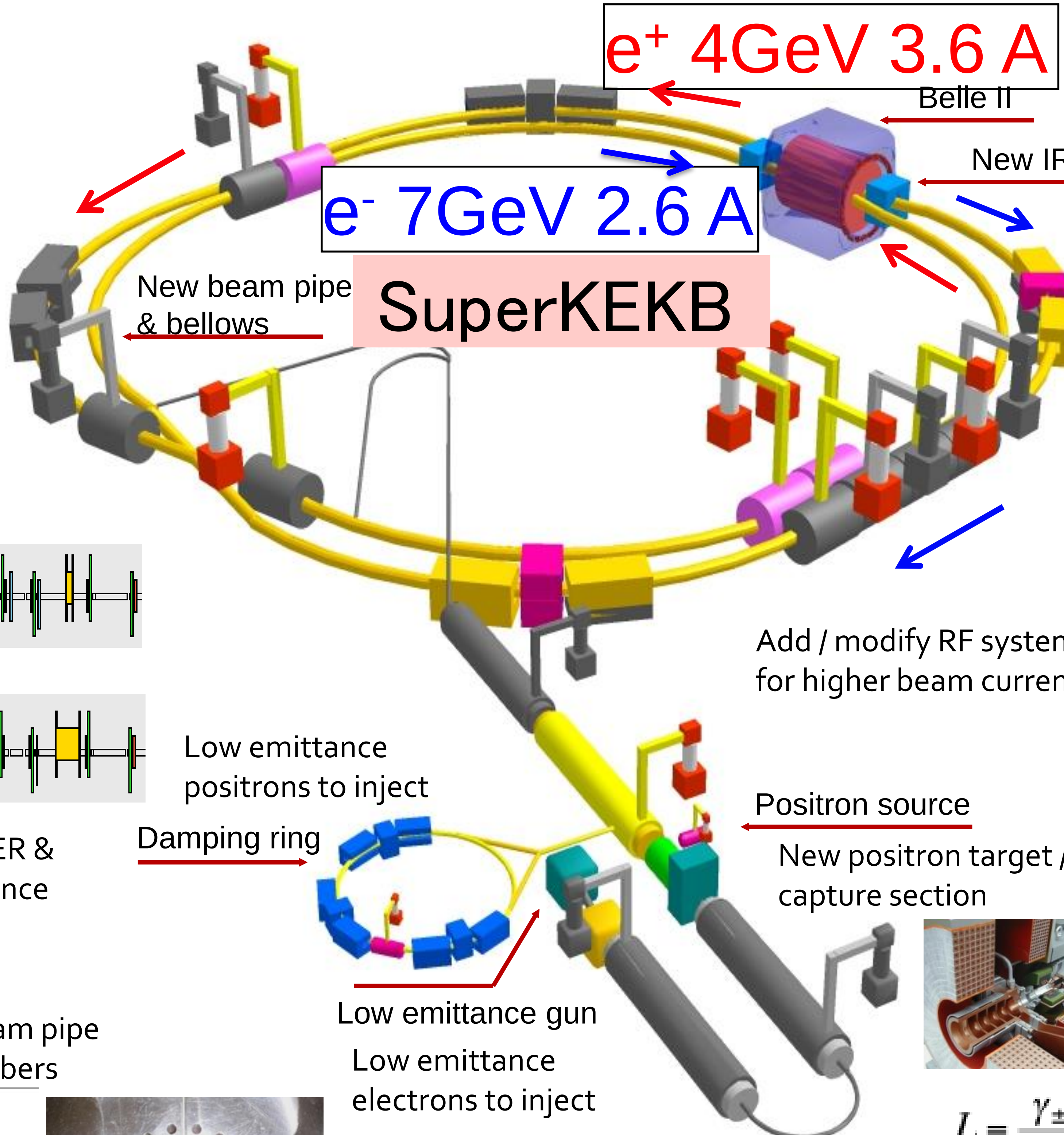
SuperKEKB collider

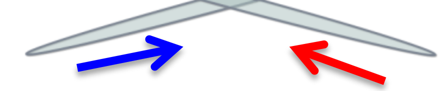


Replace short dipoles with longer ones (LER)

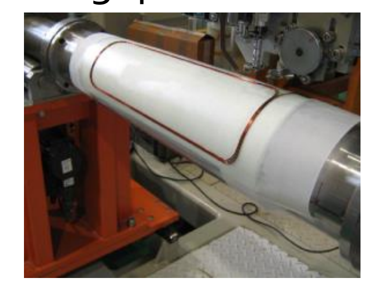


Redesign the lattices of HER & LER to squeeze the emittance





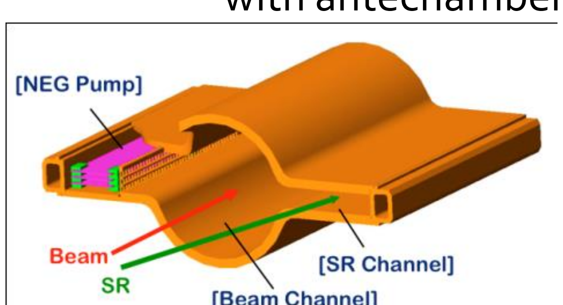
New superconducting /permanent final focusing quads near the IP

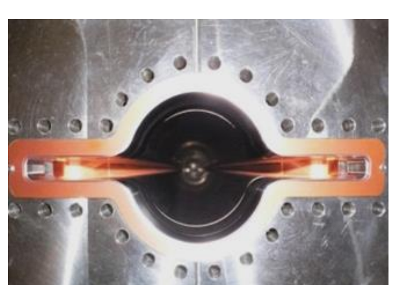


Add / modify RF systems for higher beam current

New positron target / capture section

TiN-coated beam pipe with antechambers



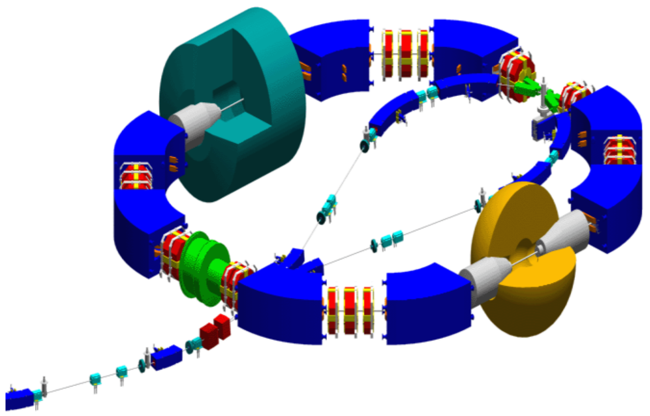


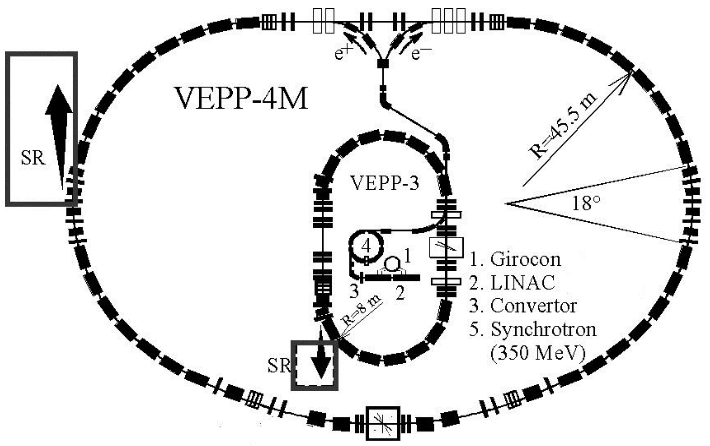
$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

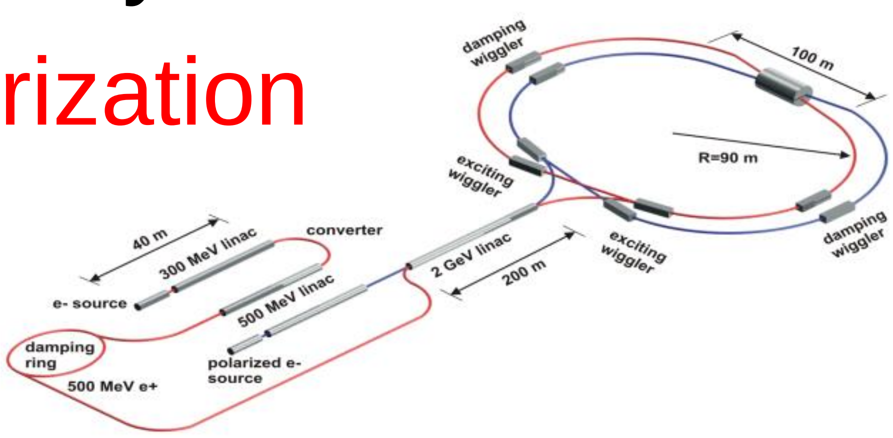
Target: $L = 8\times10^{35}/cm^2/s$

Flavor Physics at Budker INP

- **Collaborations:**
  - LHCb, BELLE, BaBar, Super-B, BES-III
- **Domestic programs (with e^+e^- colliders):**
  - VEPP-2000 (SND and CMD-3 detectors)
    - In operation since 2009; E_{cm}=0.3÷2 GeV
  - VEPP-4M (KEDR detector):
    - Large energy region E_{cm} = 2÷11 GeV
    - High precision energy resolution and tagging
  - Planning stage: Super –Tau/Charm factory
    - $L > 10^{35}$ cm^{-2} s^{-1}, longitudinal polarization





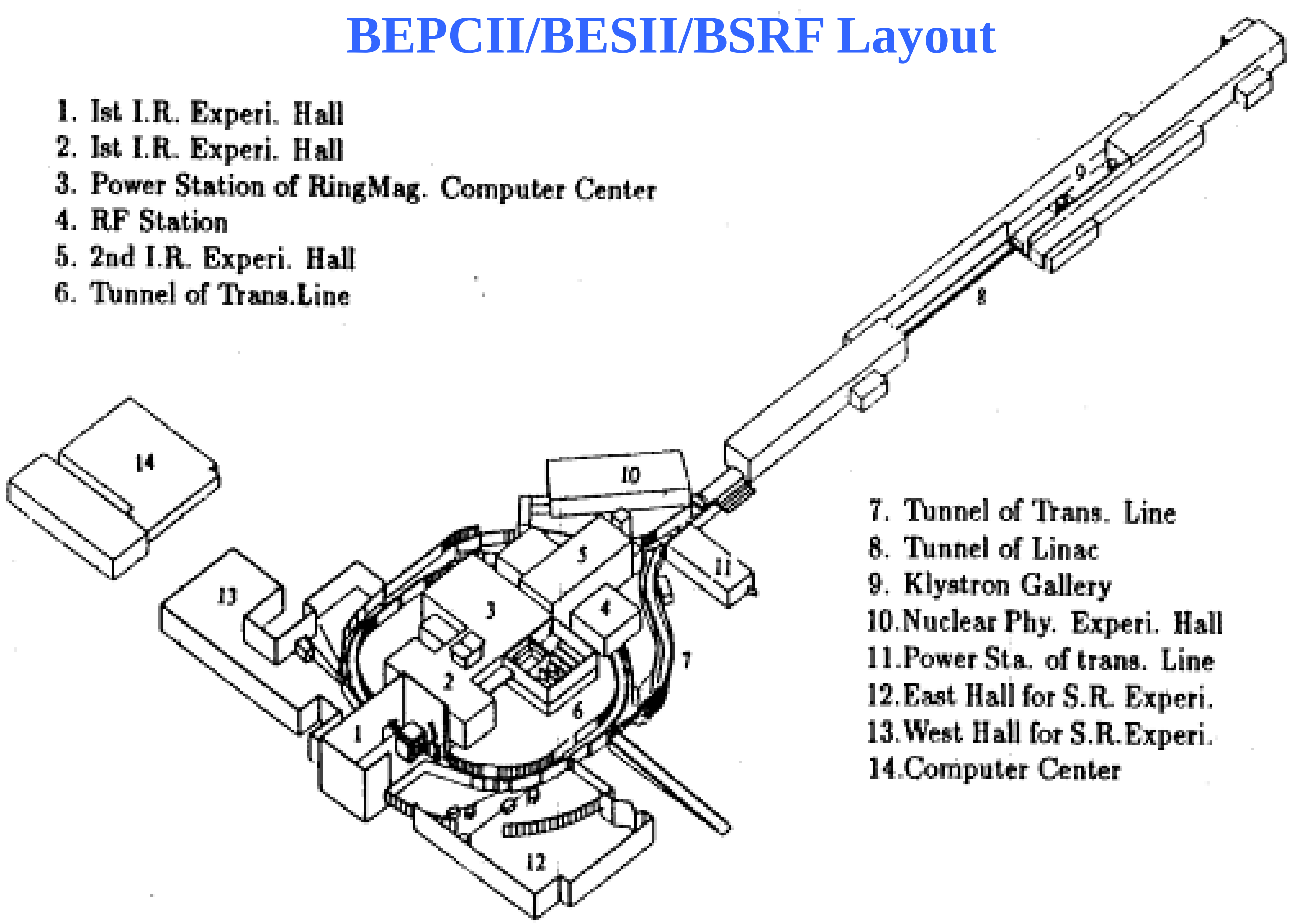


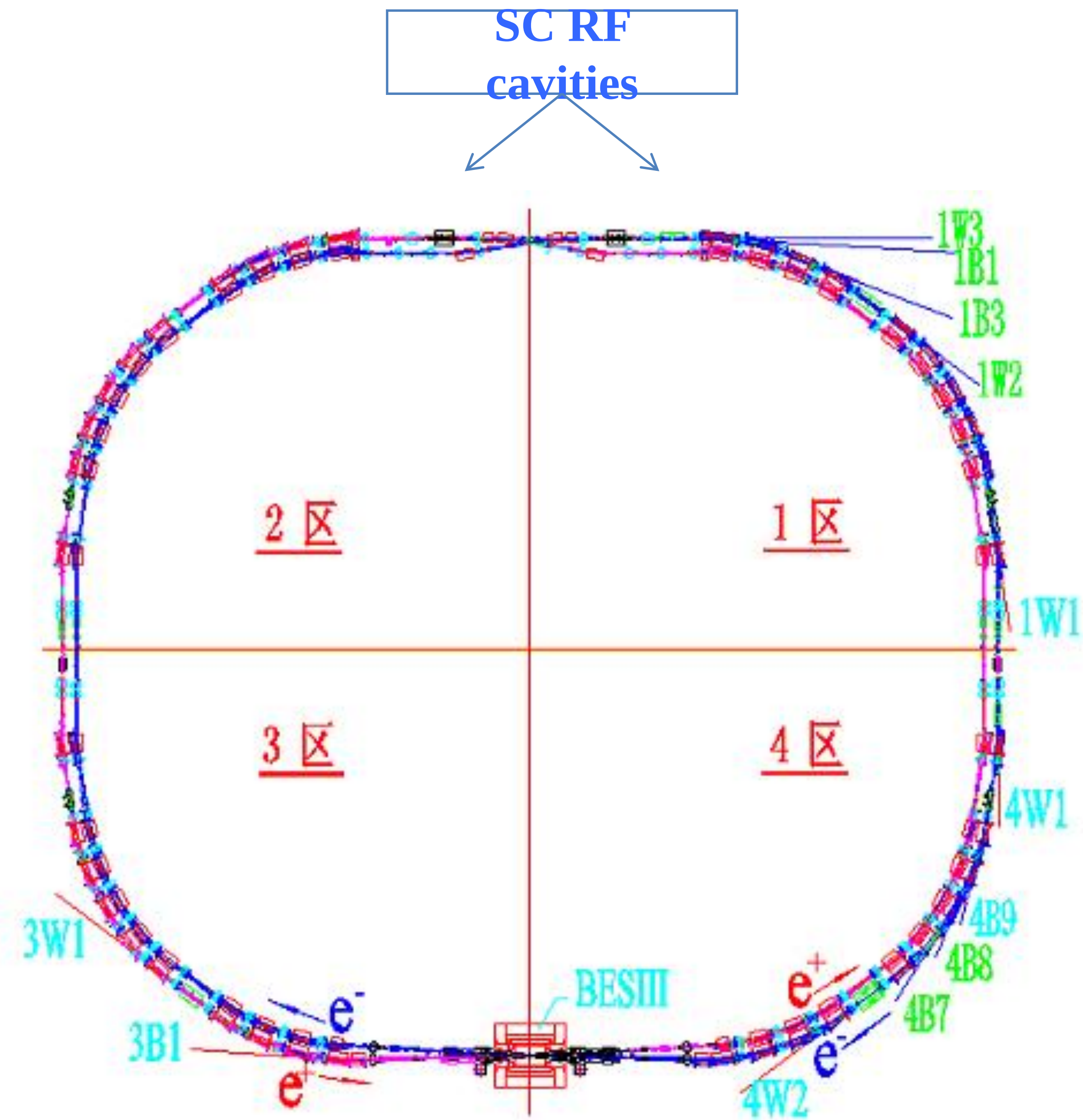
BEPCII in Beijing

BEPCII/(BESIII): upgrade of BEPC, constructed in 2004-2008.

- A two-ring factory style machine
- Provide beams to HEP & SR

Luminosity @1.89GeV: 6.49 $\times 10^{32} cm^{-2}s^{-1}$





Summary electron/positrons

- High intensity electron/positron rings (for high luminosty flavor factories)
  - DAΦNE at LNF, operational
    - The «Large Piwinski Angle» and «crab-waist sextupoles» option was first developed by P. Raimondi and tested at DAFNE (LNF)
  - Super KEKB, under construction, will be operational in JFY2014, L = $8x10^{35}/cm^2/s$
  - VEPP-2000 at BINP, operational, luminosity $2x10^{31}$ $/cm^2/s$ at 1 GeV and $2x10^{33}$ $/cm^2/s$ at 2 GeV (energy range of this mashine is 0.3-2.0 GeV)
  - Super tau-charm factory at BINP, L=$1x10^{35}$ $/cm^2/s$ (energy range is 2-5 GeV)
    - Project is preliminary approved by the Russian government
    - Critical R&D: Large Pivinsky Angle/Crab Waist approach with i) extremely low (200 - 800 microns) vertical beta-function at IP and ii) high current with low emittance.
  - BEJP (Tau and Charm), operational
    - Future plans: Continue to improve the peak luminosity aiming to $10\times10^{32}cm^{-2}s^{-1}$ and enhance the efficiency and stability of operation.

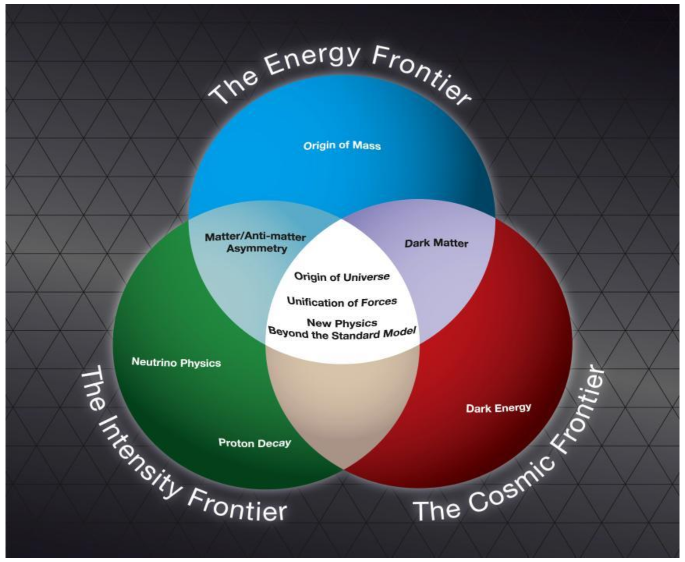
Fermilab Long Range Plan

www.fnal.gov/directorate/plan_for_discovery

The U.S. strategy for particle physics is organized around three frontiers. As the sole remaining U.S. laboratory providing facilities in support of accelerator-based particle physics, Fermilab is fully aligned with this strategy.

⇒ ***The Fermilab strategy is to mount a world-leading program at the <u>intensity frontier</u>, while using this program as a bridge to an <u>energy frontier</u> facility beyond LHC in the longer term.***

Project X is the key element of this strategy



- ***Project X is a unique facility for providing MW-class beams to multiple experiments simultaneously***
- ***R&D is underway with significant investment in srf development and front systems test***
- ***Ready to initiate construction before the end of the decade.***

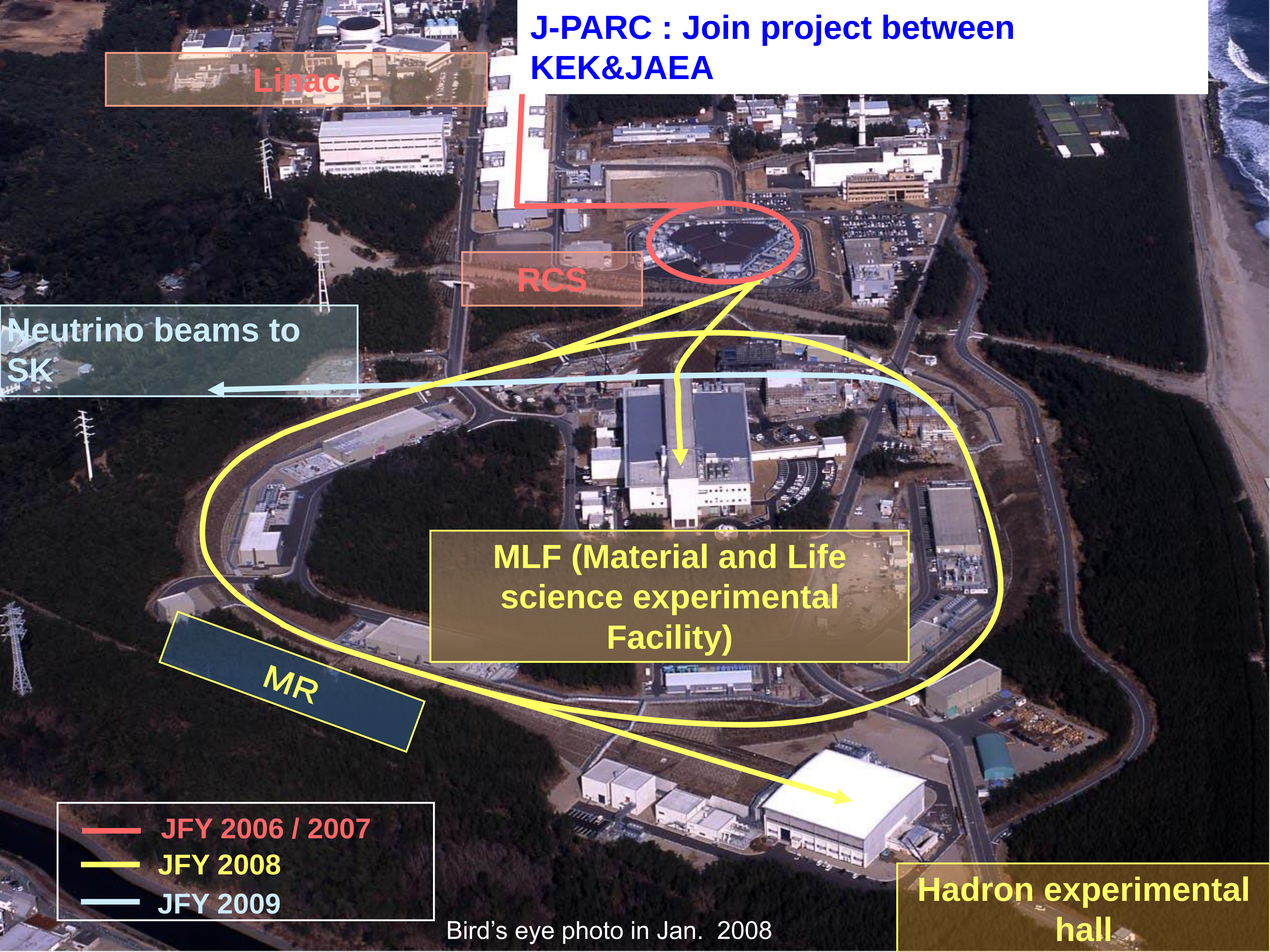
Staged Physics Program

Project X Campaign

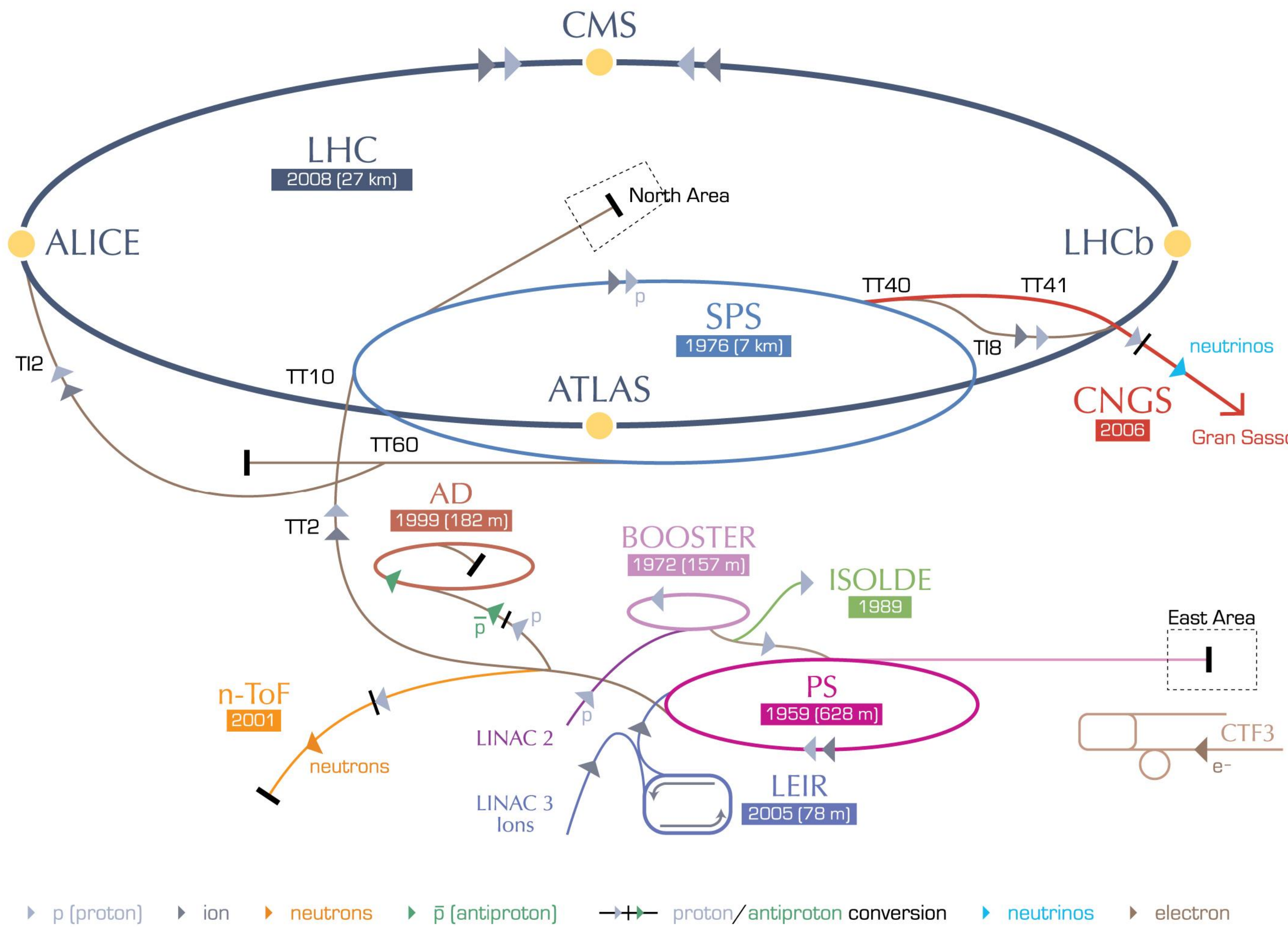
Program:	NOνA + Proton Improvement Plan	Stage-1: 1 GeV CW Linac driving Booster & Muon, n/edm programs	Stage-2: Upgrade to 3 GeV CW Linac	Stage-3: Project X RD	Stage-4: Beyond RD: 8 GeV power upgrade to 4MW
MI neutrinos	470-700 kW**	515-1200 kW**	1200 kW	2450 kW	2450-4000 kW
8 GeV Neutrinos	15 kW + 0-50 kW**	0-42 kW* + 0-90 kW**	0-84 kW*	0-172 kW*	3000 kW
8 GeV Muon program e.g, (g-2), Mu2e-1	20 kW	0-20 kW*	0-20 kW*	0-172 kW*	1000 kW
1-3 GeV Muon program, e.g. Mu2e-2	-----	80 kW	1000 kW	1000 kW	1000 kW
Kaon Program	0-30 kW** (<30% df from MI)	0-75 kW** (<45% df from MI)	1100 kW	1870 kW	1870 kW
Nuclear edm ISOL program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Ultra-cold neutron program	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
Nuclear technology applications	none	0-900 kW	0-900 kW	0-1000 kW	0-1000 kW
# Programs:	4	8	8	8	8
Total max power:	735 kW	2222 kW	4284 kW	6492 kW	11870kW

* Operating point in range depends on MI energy for neutrinos.

** Operating point in range is depends on MI injector slow-spill duty factor (df) for kaon program.


J-PARC : Join project between
KEK&JAEA
Linac
RCS
Neutrino beams to
SK
MLF (Material and Life
science experimental
Facility)
MR
JFY 2006 / 2007
JFY 2008
JFY 2009
Bird's eye photo in Jan. 2008
Hadron experimental
hall

CERN accelerator complex



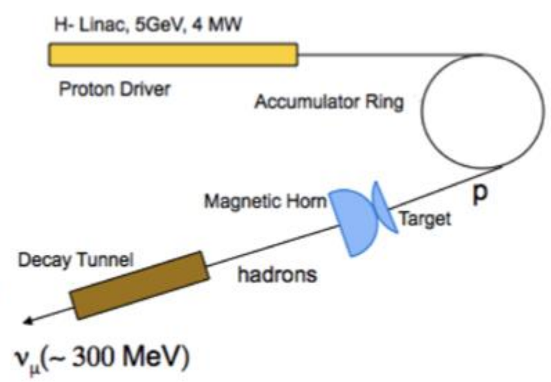
Summary rings

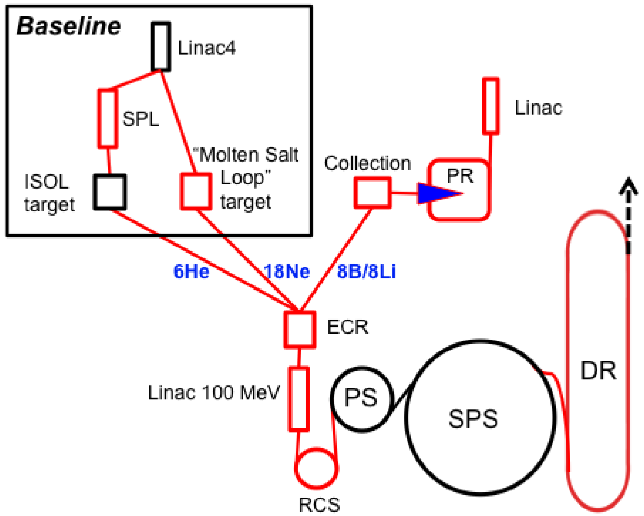
- High intensity hadron rings (for high intensity single beams and flavor factories e.g. anti-protons, neutrinos, muons, rare-deacys and CP violation)
  - PS/SPS at CERN, operational
    - Critical R&D needed on PS to SPS extraction/injection for continued high intensity operation of SPS, SPS beam stability, available power and extraction kicker
  - MI at FNAL without Project X injector is operational
    - Proton improvement program
    - Project X needed to go to high intensity
  - J-PARC
    - Power upgrade at 30 GeV to >700 kW for 2014

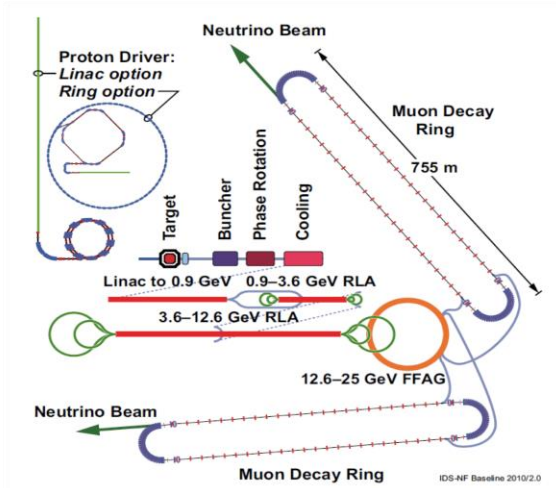
Neutrinos: EUROnu DS

Design
Cost
Safety
Risk
Time scale

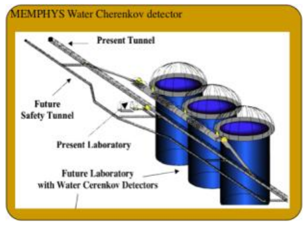
Facility







Detectors



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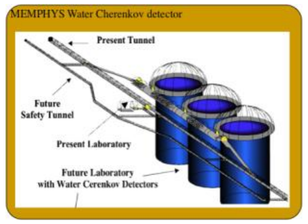
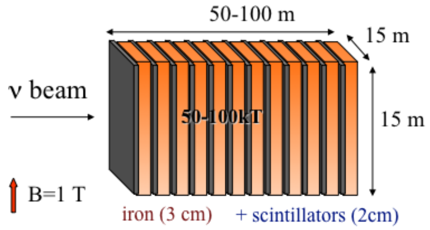


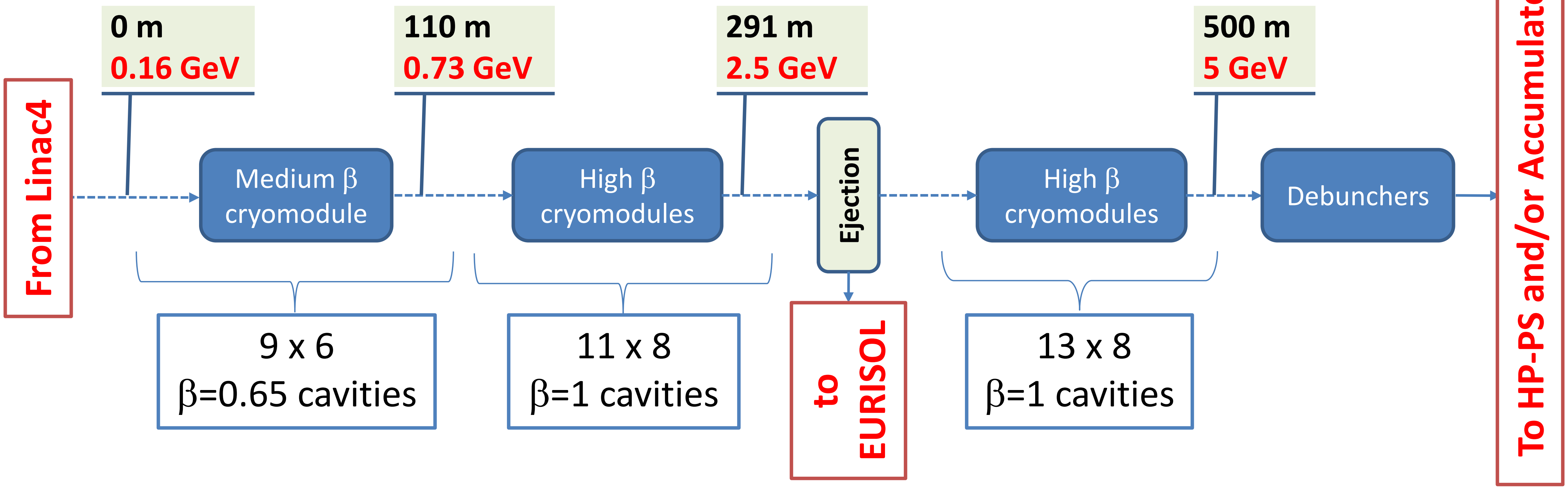


Civil
engineering

Comparison: performance – cost – safety – risk

Input to the definition of a Road Map for neutrino physics in Europe (together with other neutrino facilities studies)
Report to CERN Council via Stragey Group and ECFA

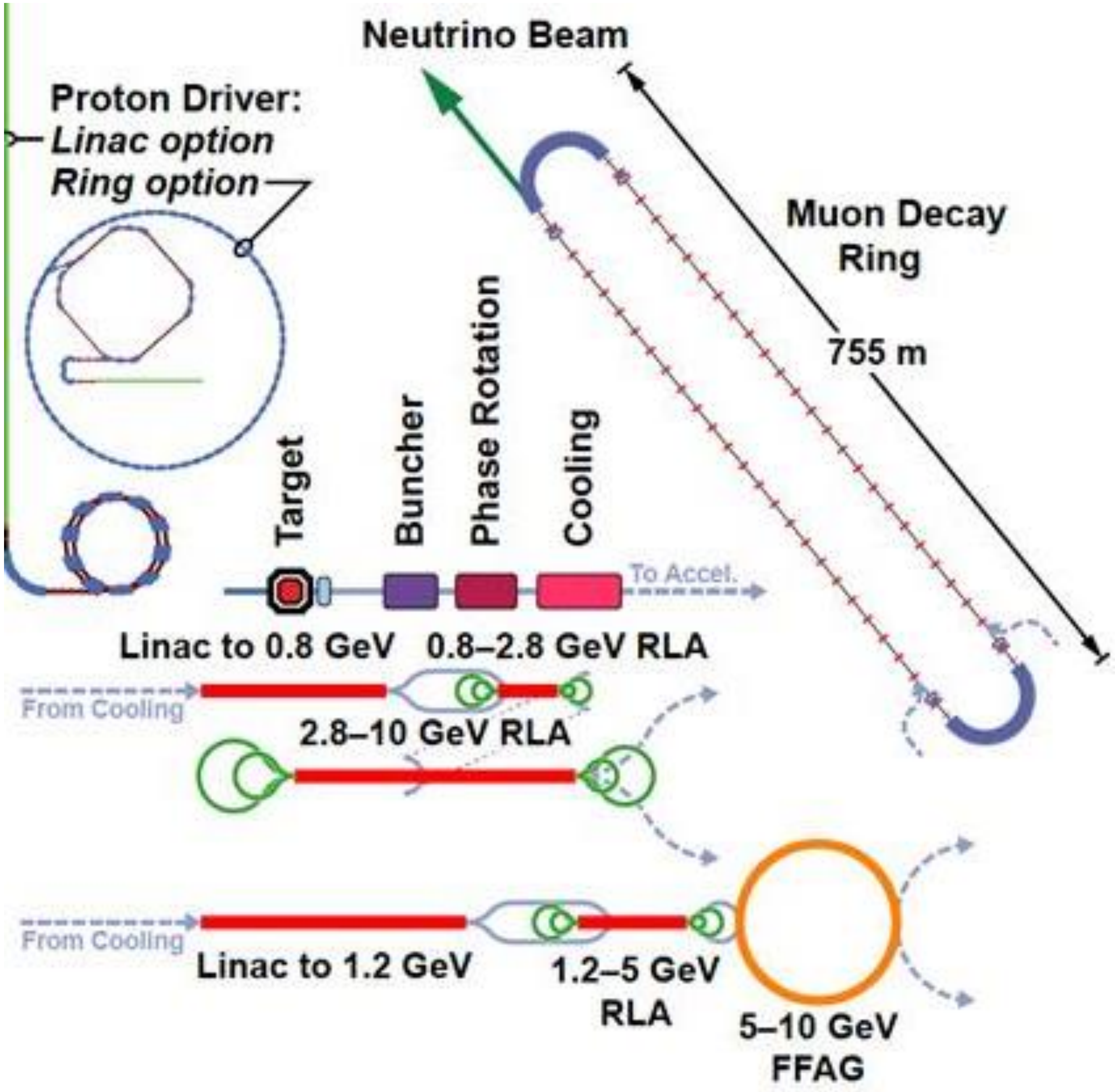
HP-SPL: Block Diagram
MW and ms



Segmented cryogenics / separate cryo-line / room temperature quadrupoles:
-Medium β (0.65) – 3 cavities / cryomodule
-High β (1) – 8 cavities / cryomodule

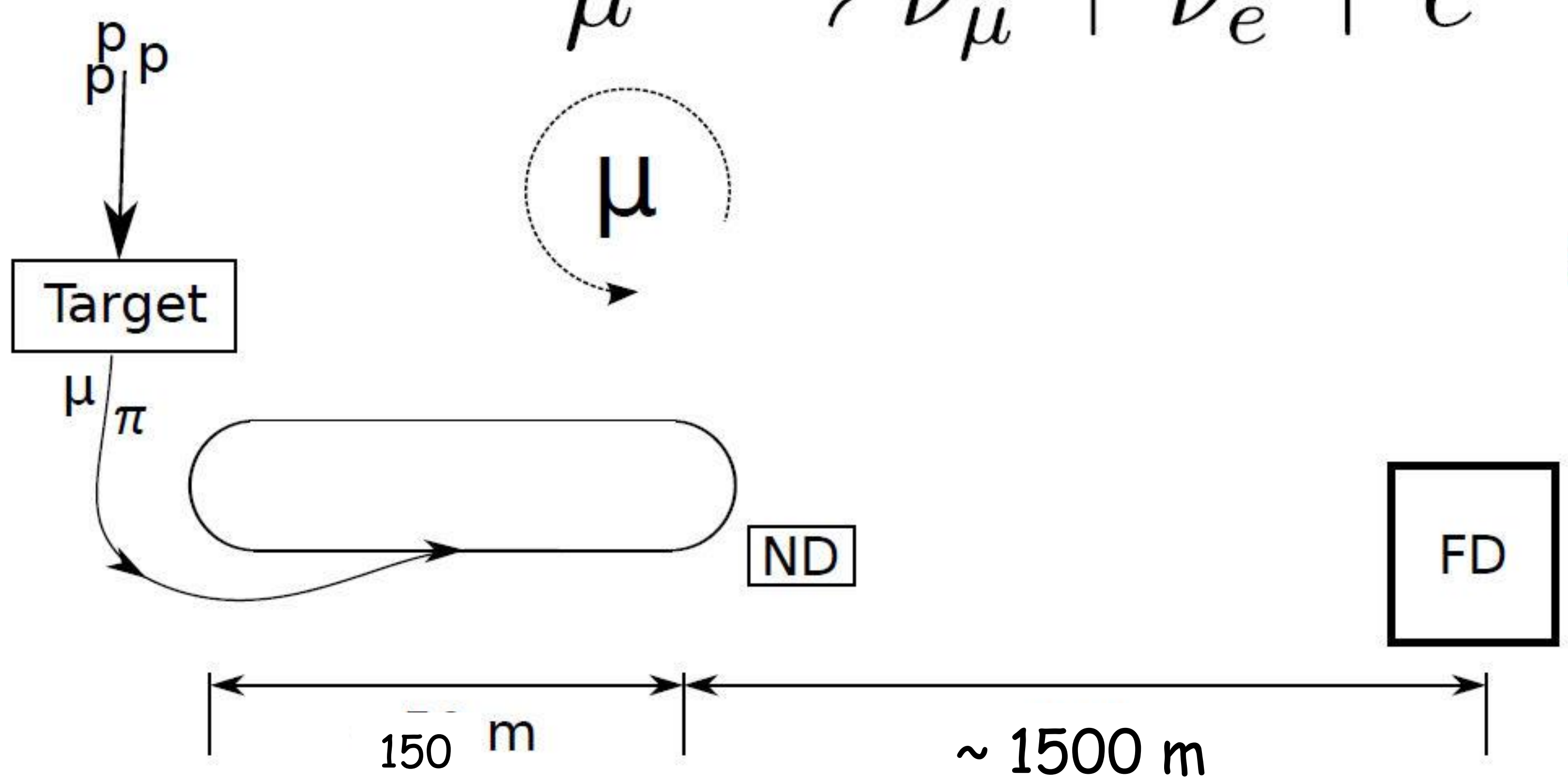
	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	2.25 MW (2.5 GeV) or 4.5 MW (5 GeV)	5 MW (2.5 GeV) and 4 MW (5 GeV)
Protons/pulse (x 10^{14})	1.1	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current (mA)	20	40
Pulse duration (ms)	0.9	1 (2.5 GeV) + 0.4 (5 GeV)

The Neutrino Factory



Experimental Layout

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



Appearance-only (though disappearance good too!)

$$Pr[e \rightarrow \mu] = 4|U_{e4}|^2|U_{\mu 4}|^2 \sin^2(\frac{\Delta m_{41}^2 L}{4E})$$

Appearance Channel:

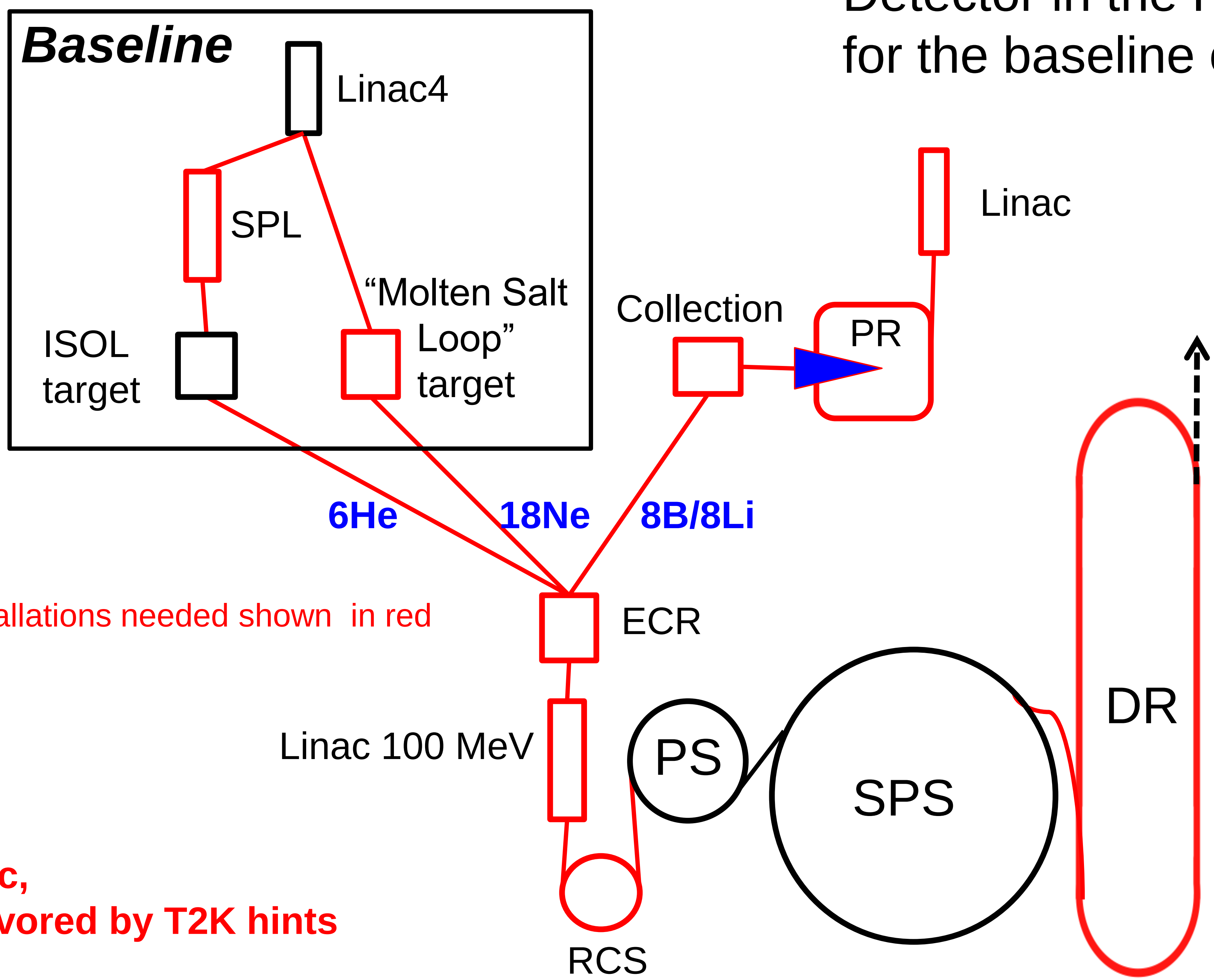
$\nu_e \rightarrow \nu_\mu$

Golden Channel

Must reject the "wrong" sign μ with great efficiency

Why $\nu_\mu \rightarrow \nu_e$ Appearance Ch. not possible

The CERN Beta Beam



Detector in the Fréjus tunnel for the baseline option

New installations needed shown in red

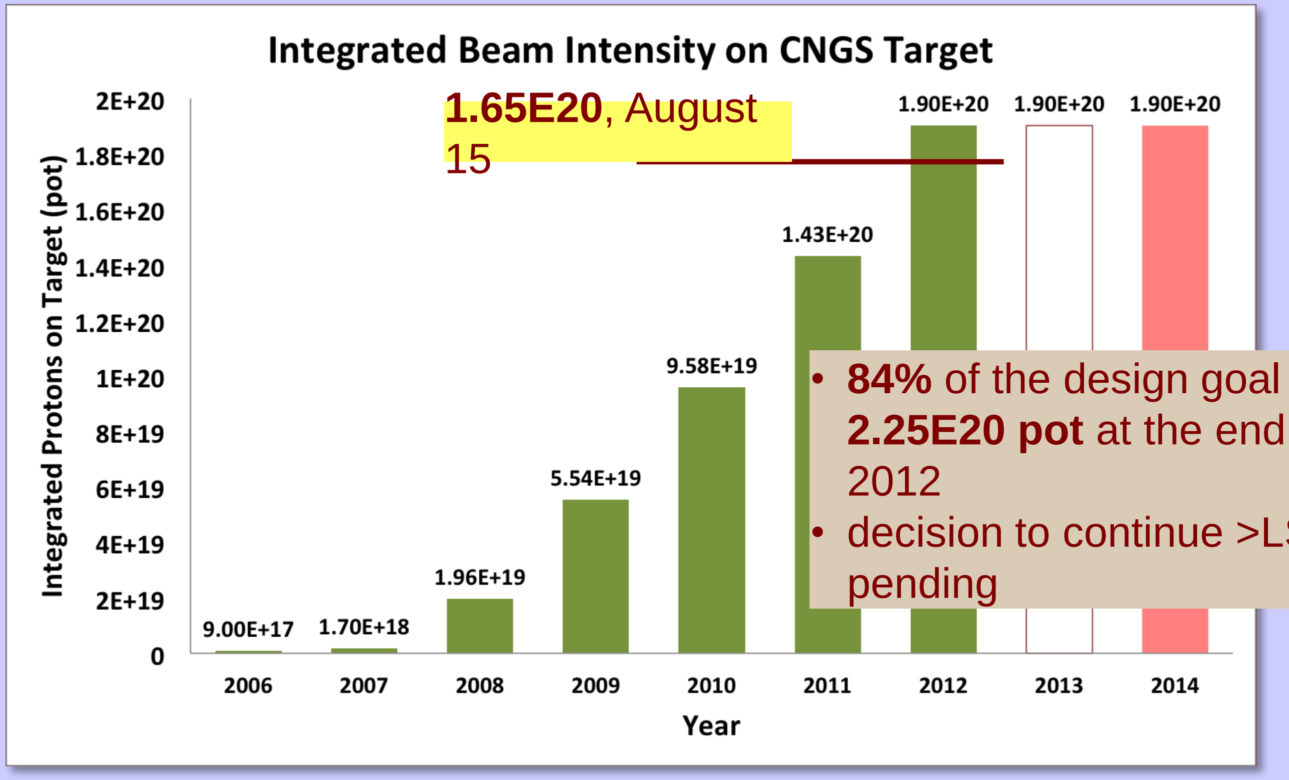
CERN Specific,
Beta Beam favored by T2K hints

Decay Ring: Bρ ~ 500 Tm, B = ~6 T, C = ~6900 m, L_{ss}= ~2500 m, γ = 100, all ions

Future ν-beams at CERN - The potential !

Present :

- CNGS : successful operation for five years
- SPS a key asset for CERN
  - **510 kW** nominal beam power today
    - 4.8 10^{13} prot @ 400 GeV, 6s cycle
  - operation at **~365kW**, 4.5÷4.7 10^{19} pot/y achieved
    - Limitations due to beam losses in PS and SPS, beam sharing with FT experiments and LHC



- **84%** of the design goal of **2.25E20 pot** at the end of 2012
- decision to continue >LS1 pending

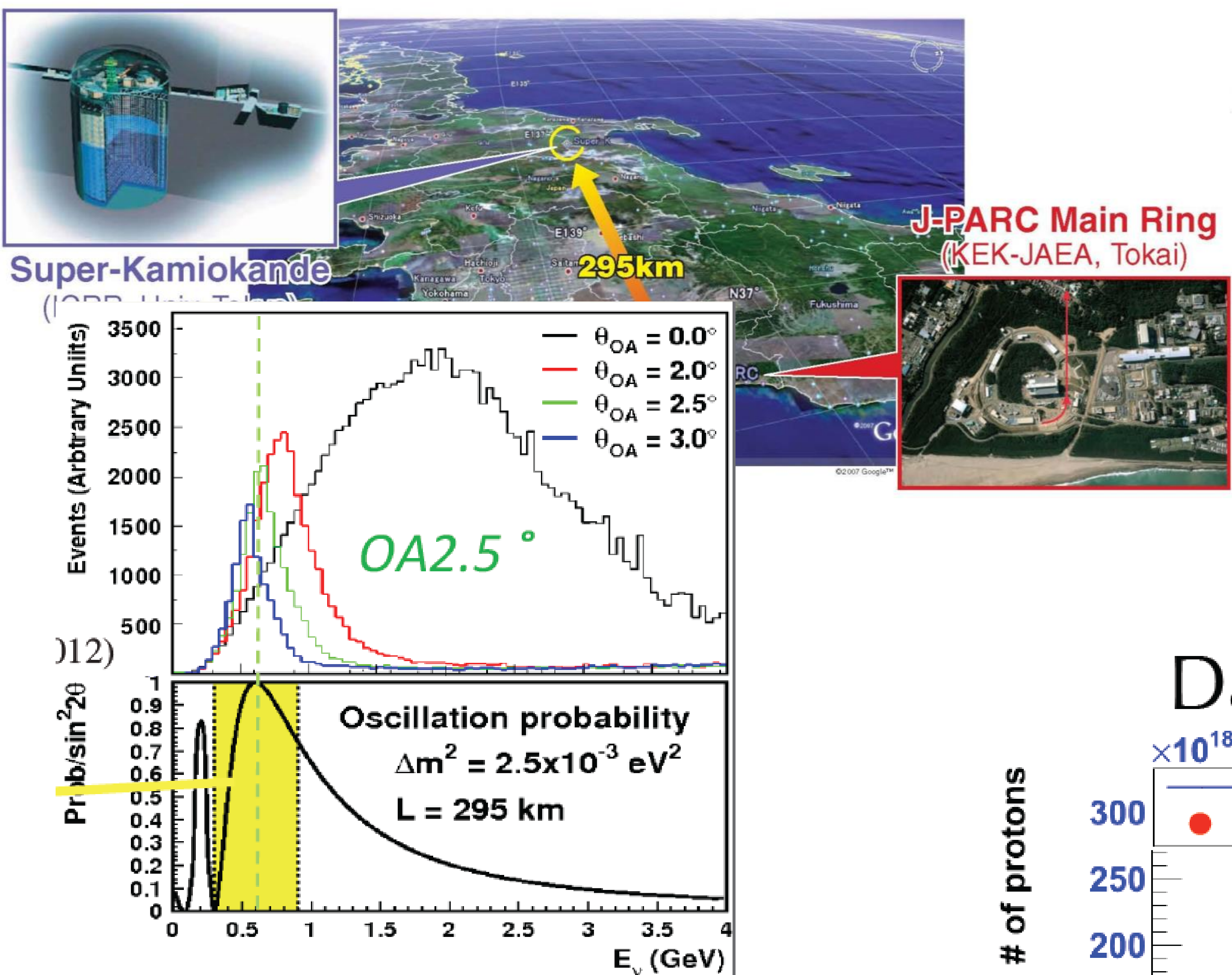
Future-I :

- Sub-MW conventional ν-beams from SPS
  - Short-baseline beam in the SPS North Area – CENF
  - (very)Long-baseline beam to a far LAGUNA detector in the Pyhasalmi mine in Finland, 2300km – CN2PY
  - SPS operation following upgrades (>LS2) up to **750 kW**, 7.0 10^{13} prot @ 400 GeV, 6s cycle

Future-II (>2025?) :

- High-power upgrades with new accelerators
  - High-power (2MW) upgrade of the Long-baseline CN2PY beam: LP-SPL + HP-PS
  - New Medium-baseline beam (130km) using a **β**-beam (1MW) or a Super-beam (4MW)
  - A Neutrino Factory (4MW) for a Long-baseline ν-beam to the Pyhasalmi site

T2K experiment

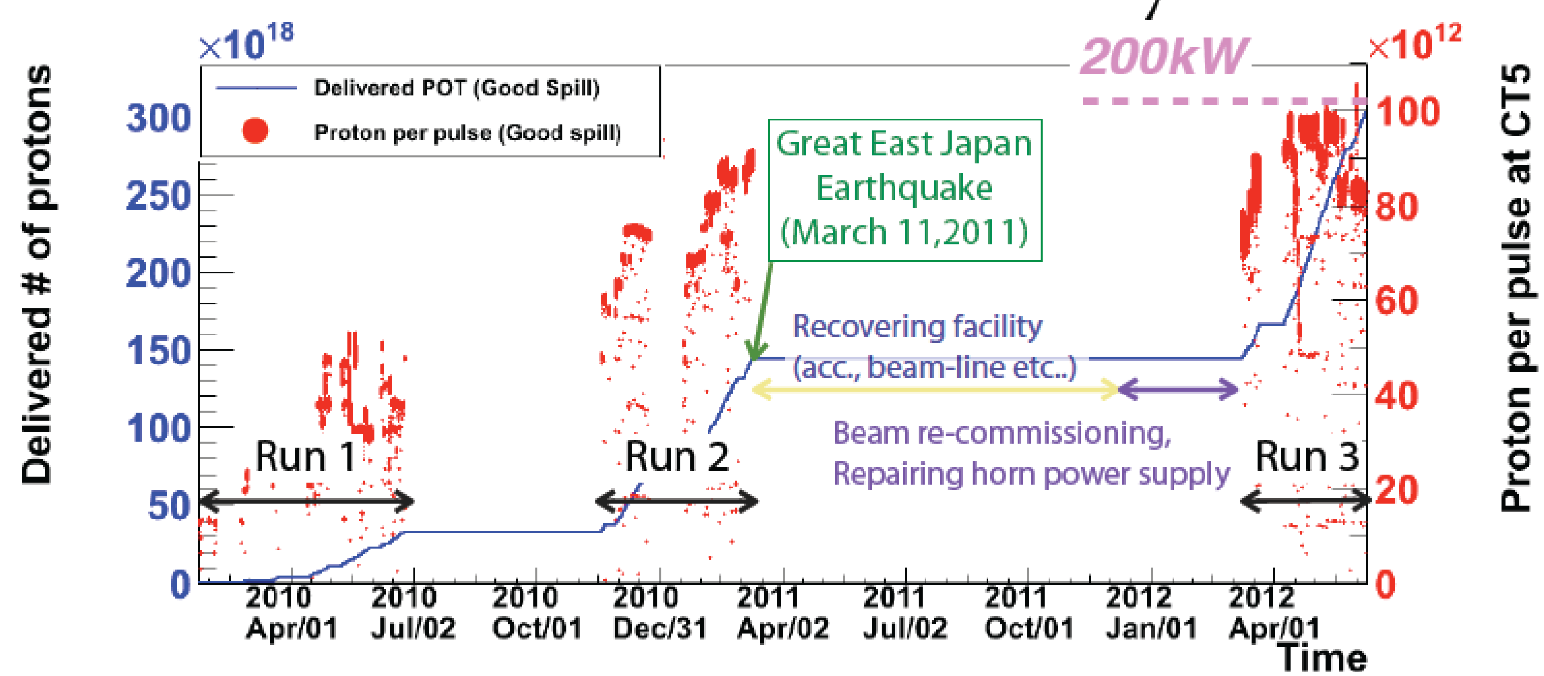


- Started data taking in Jan 2010
- **Resumed data taking in Mar. 2012**
- New results w/ data until June 9, 2012 (**3.01×10^{20}pot**)

- Off-axis ν_μ beam @ ~600MeV from J-PARC 30GeV MR
  - 200kW achieved (>100T p/pulse)
- Super-Kamiokande @ 295km
- Main physics goals
  - **νe appearance**
  - ν_μ disappearance

K.Sakashita

Data collected and analyzed



Run1 + 2 (2010-2011)
1.43×10^{20} p.o.t.

* ND280 Run1+2 data is used for oscillation analysis

Run3 (2012) : 1.58×10^{20} p.o.t

* including 0.21×10^{20} p.o.t. with 200kA horn operation (13% flux reduction at peak) (250kA horn current for nominal operation)

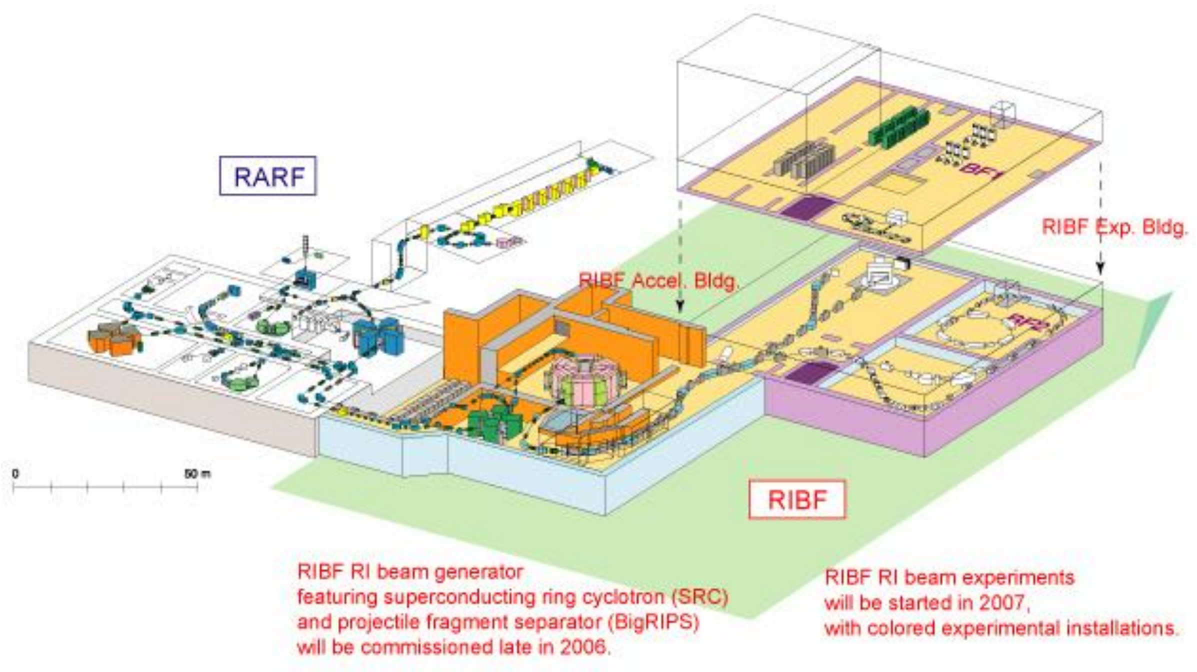
* ND280 Run3 data is checked and consistent with Run1+2

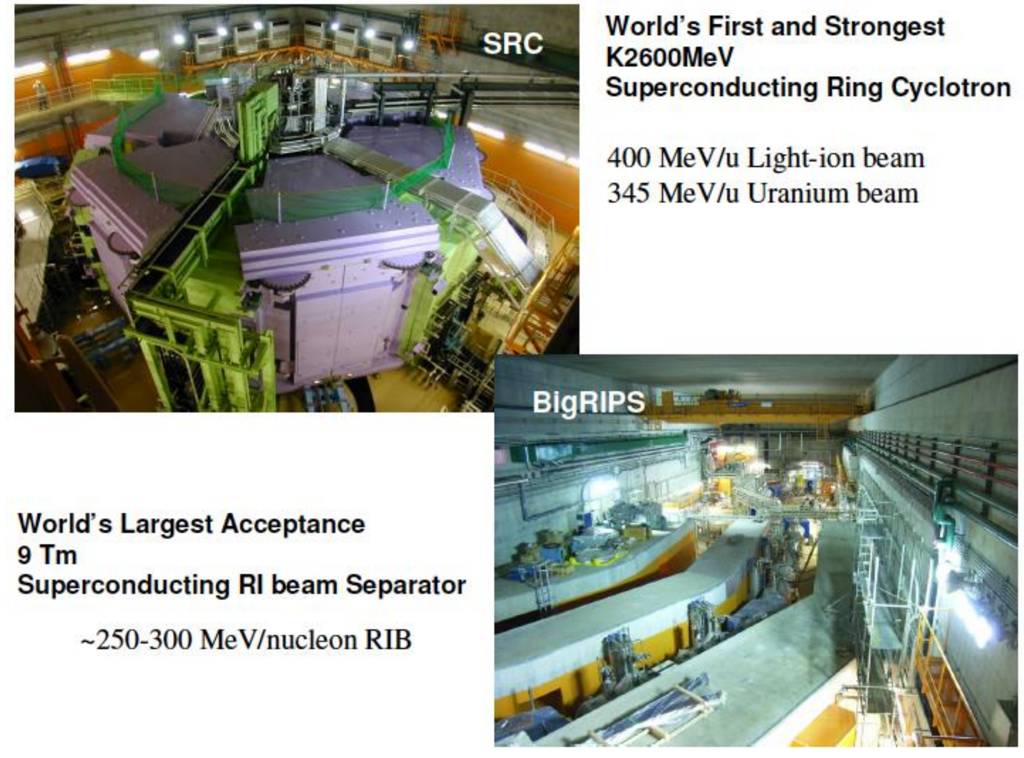
Data for today's talk (full data set up to now) = 3.01×10^{20} p.o.t.
(18% of increase from Neutrino2012)

Summary neutrinos

- Facilities to provide neutrino beams
  - Neutrino factory, proposal
    - Critical R&D before decision: Muon cooling (MICE), Muon storage ring (NuSTorm), target technology, fast acceleration schemes, pion capture systems
  - Beta-beam for neutrino physics, proposal
    - Critical R&D needed on: Target technology, beam stability in hadron rings, large aperture SC dipoles
  - Super-beams, **operational** and proposed
    - Critical R&D: Target technology, all aspects of very high power (high space charge) accumulation ring for shorter pulses from linac drivers, beam dumps

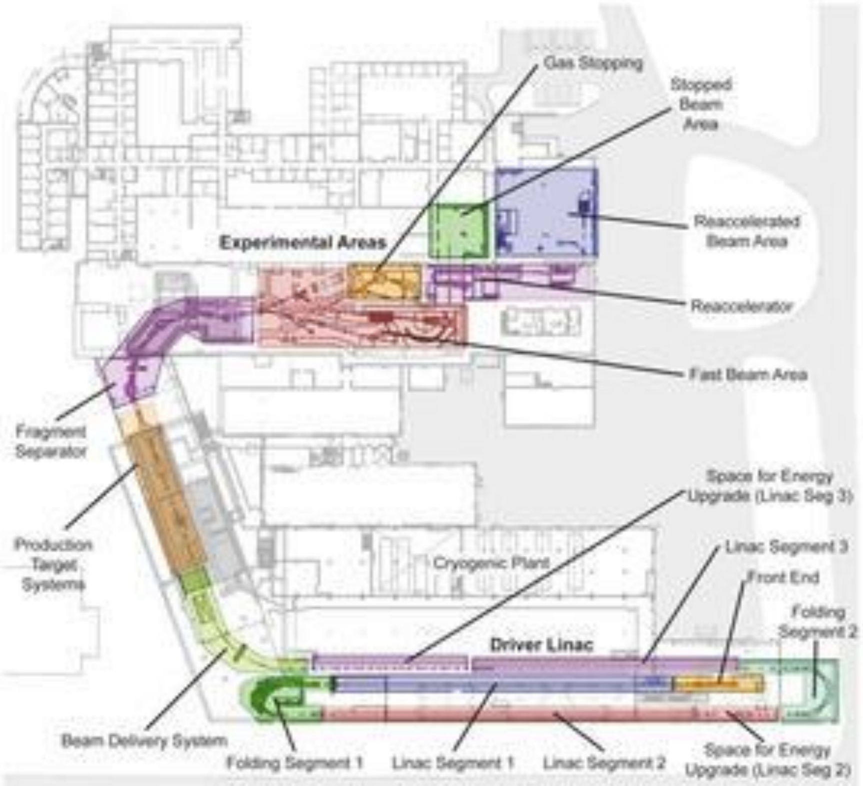
RIKEN





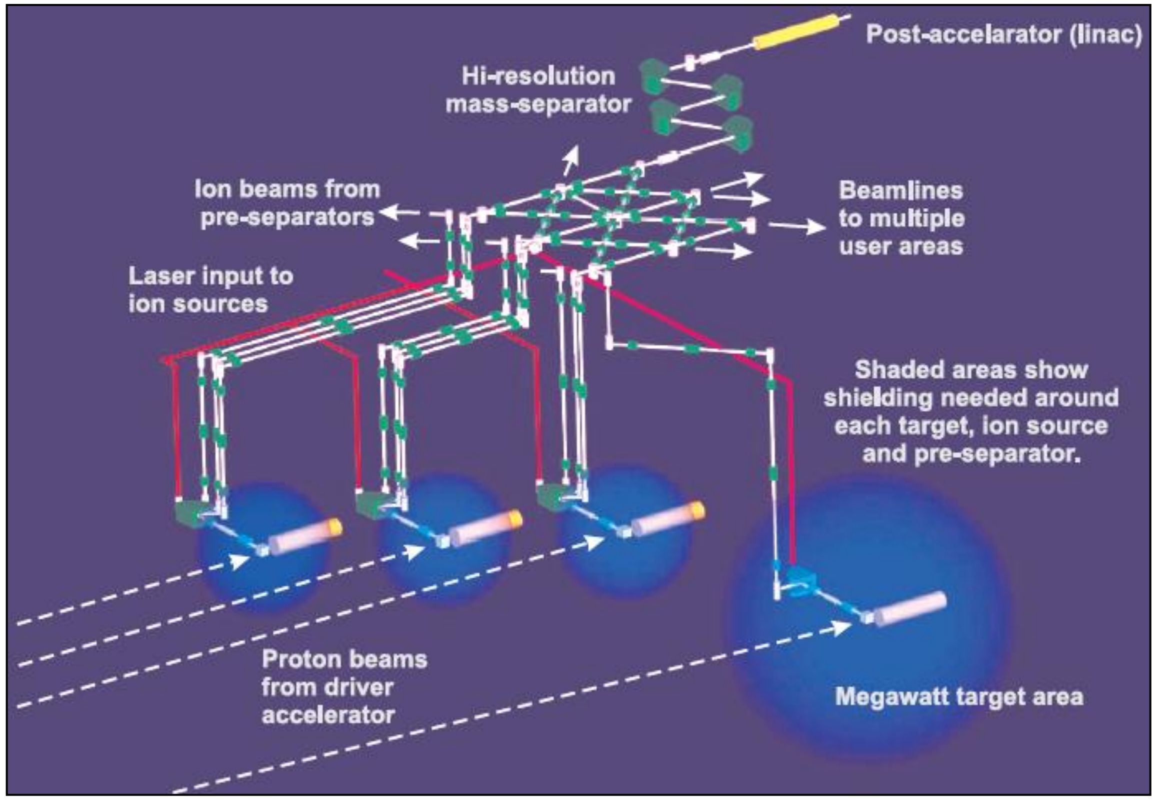
- RIKEN, Radioactive beam facility, Fragmentation of ions, ion up to Uranium available, 440 MeV/nucleon for light ions and 350 MeV/nucleon, up to 1 pμA, very advanced instrumentation for nuclear physics
- Examples of challenges: High K SC cyclotron for Heavy Ions

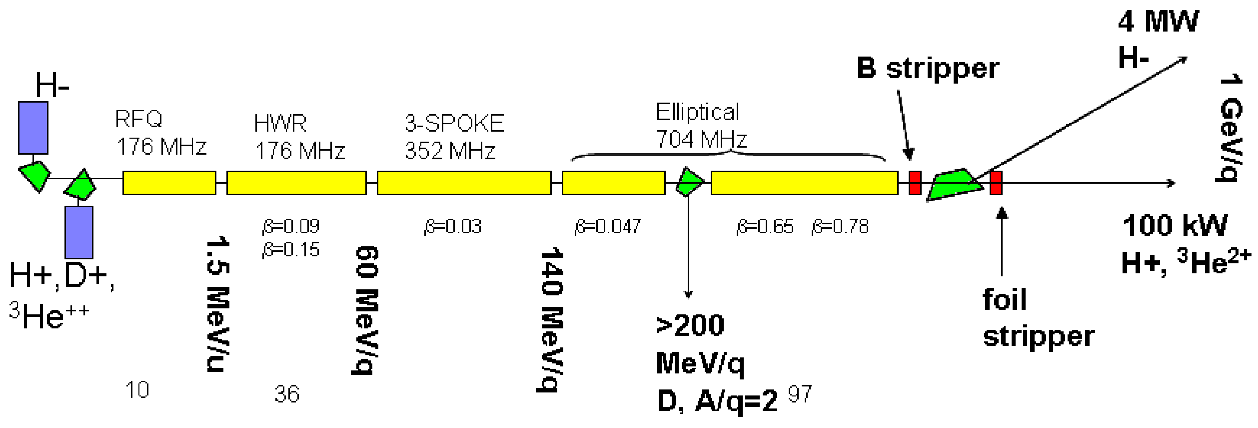
FRIB

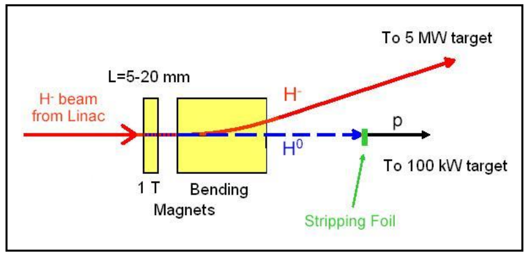


- FRIB at MSU, Radioactive beam facility, Fragmentation of ions, ion up to Uranium available, 610 MeV/nucleon for protons and 210 MeV/nucleon for Uranium, up to 400 kW, very advanced instrumentation for nuclear physics
- Examples of challenges: very intense heavy ion beams in folded SC linac

EURISOL



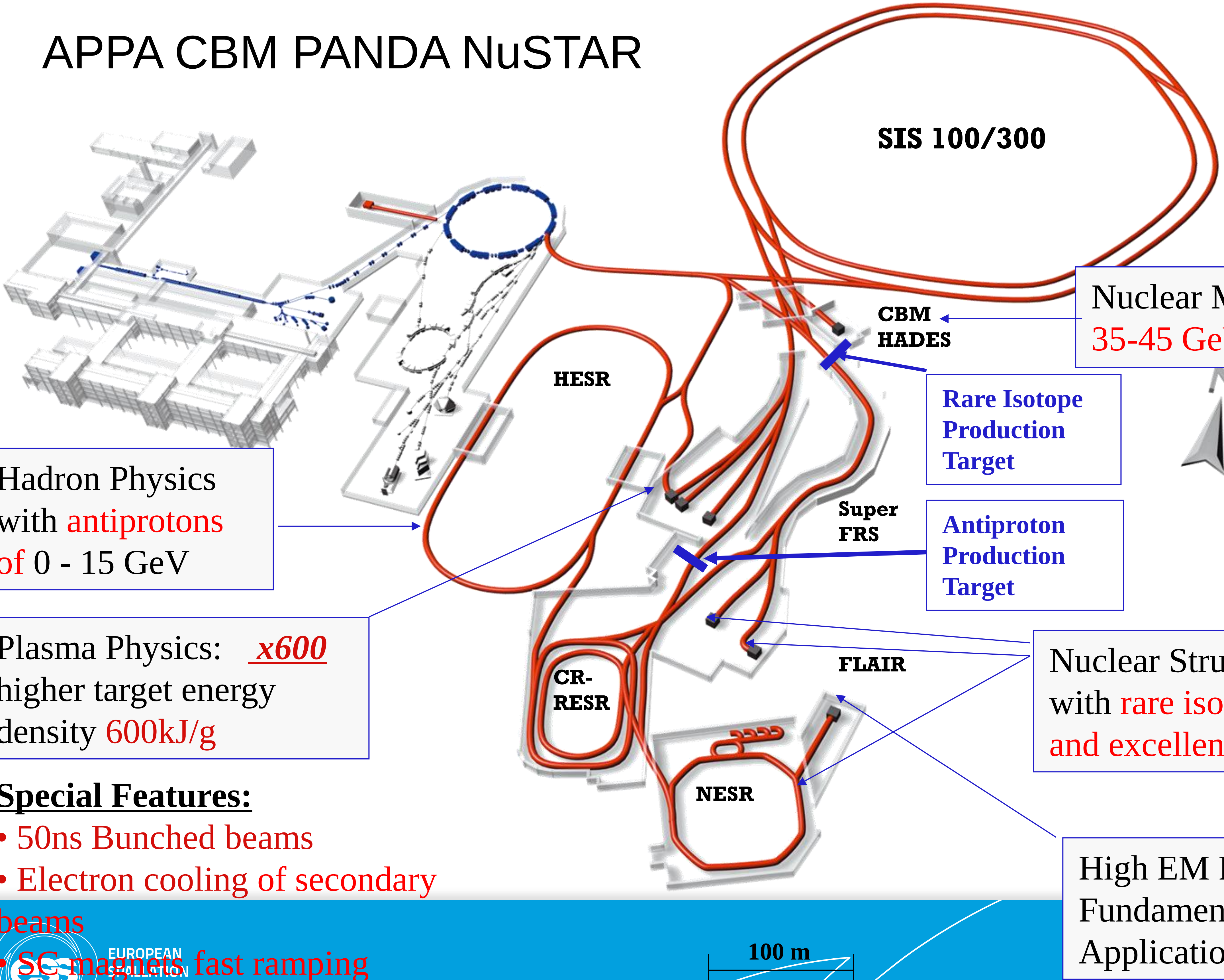




- EURISOL, H-, 5 MW, 1 GeV, 5 mA, Continuos
- Example of challenges: Beam splitting at high energy of high power beam

FAIR

- APPA CBM PANDA NuSTAR



Nuclear Matter Physics with 35-45 GeV/u HI beams, ***x1000***

Rare Isotope Production Target

Antiproton Production Target

Hadron Physics with antiprotons of 0 - 15 GeV

Plasma Physics: ***x600*** higher target energy density 600kJ/g

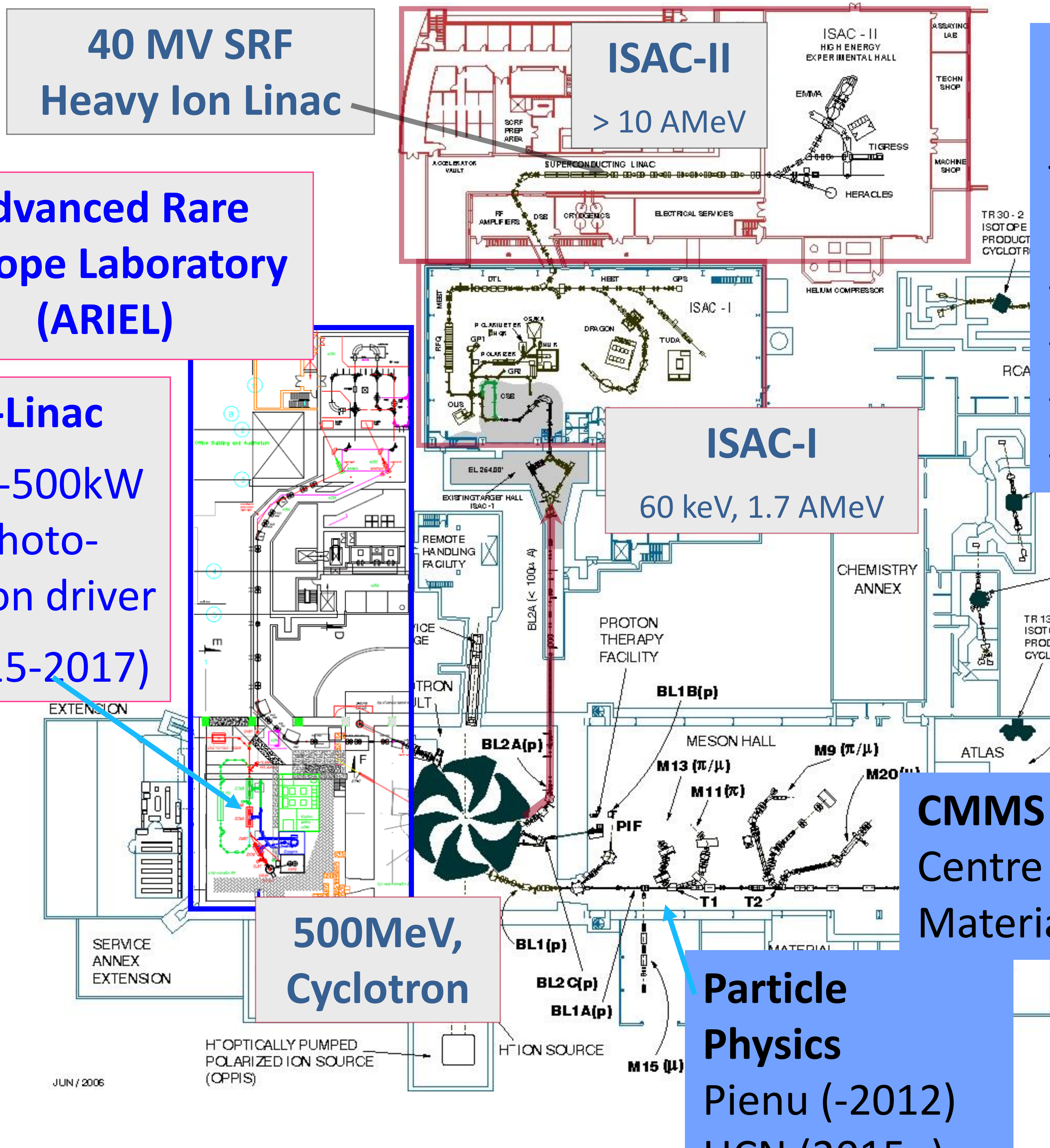
Nuclear Structure & Astrophysics with rare isotope beams, ***x10 000*** and excellent cooling

High EM Field (HI) _ Fundamental Studies(HI & p) Applications (HI)

Special Features:

- 50ns Bunched beams
- Electron cooling of secondary beams
- SC magnets, fast ramping
- Parallel operation

TRIUMF



40 MV SRF Heavy Ion Linac

ISAC-II

> 10 AMeV

Advanced Rare Isotope Laboratory (ARIEL)

e-Linac

300-500kW photo-fission driver

(2015-2017)

ISAC-I

60 keV, 1.7 AMeV

500MeV, Cyclotron

ISAC

Highest power ISOL RIB facility

Programs in

- Nuclear Structure
- Nuclear Astrophysics
- Fundamental Symmetries
- CMMS (β–NMR)

Nordion

Commerical medical isotope production

3 cyclotrons

CMMS

Centre for Molecular and Material Science (μSR)

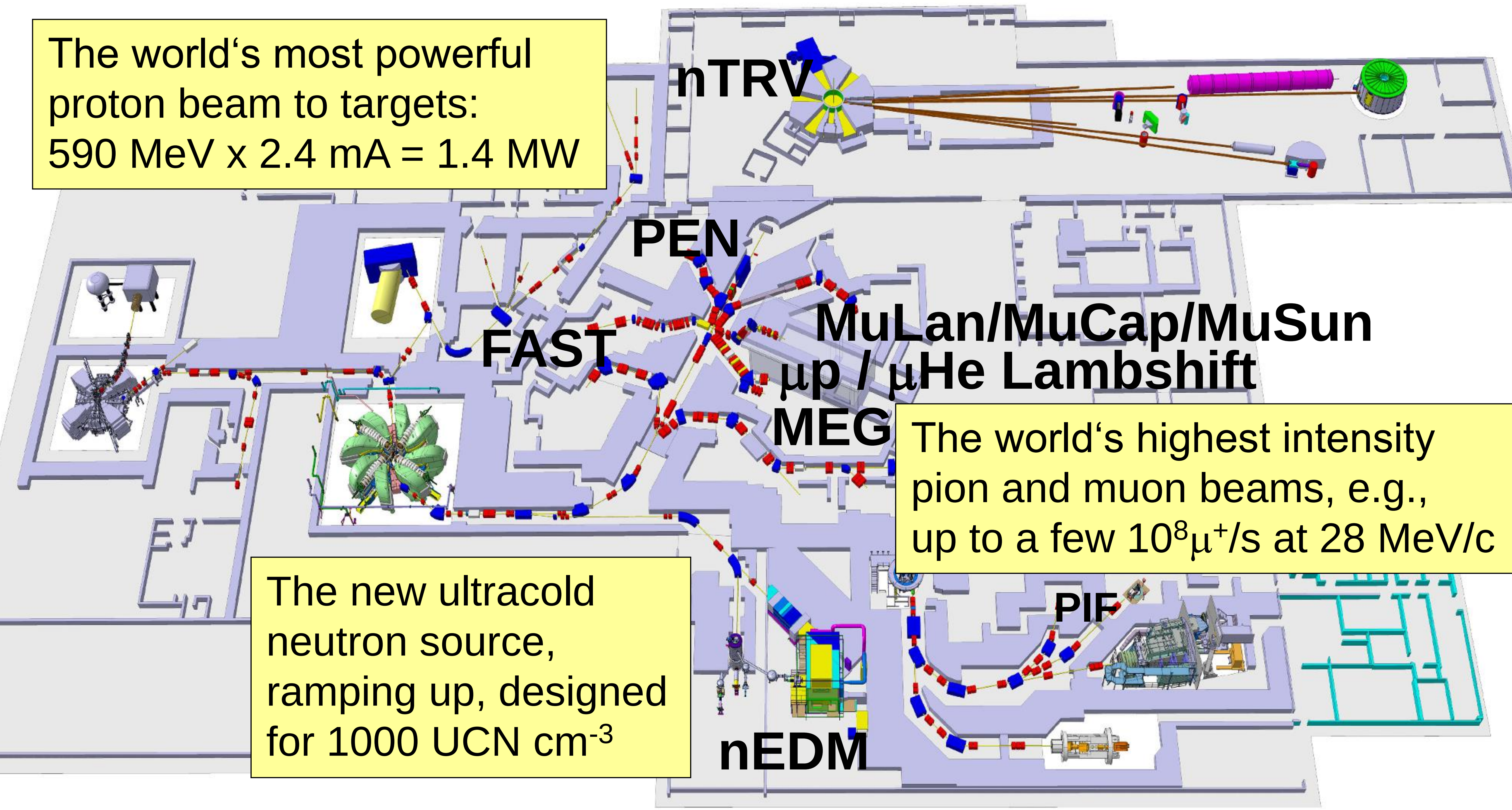
Particle Physics

Pienu (-2012)

UCN (2015 -)

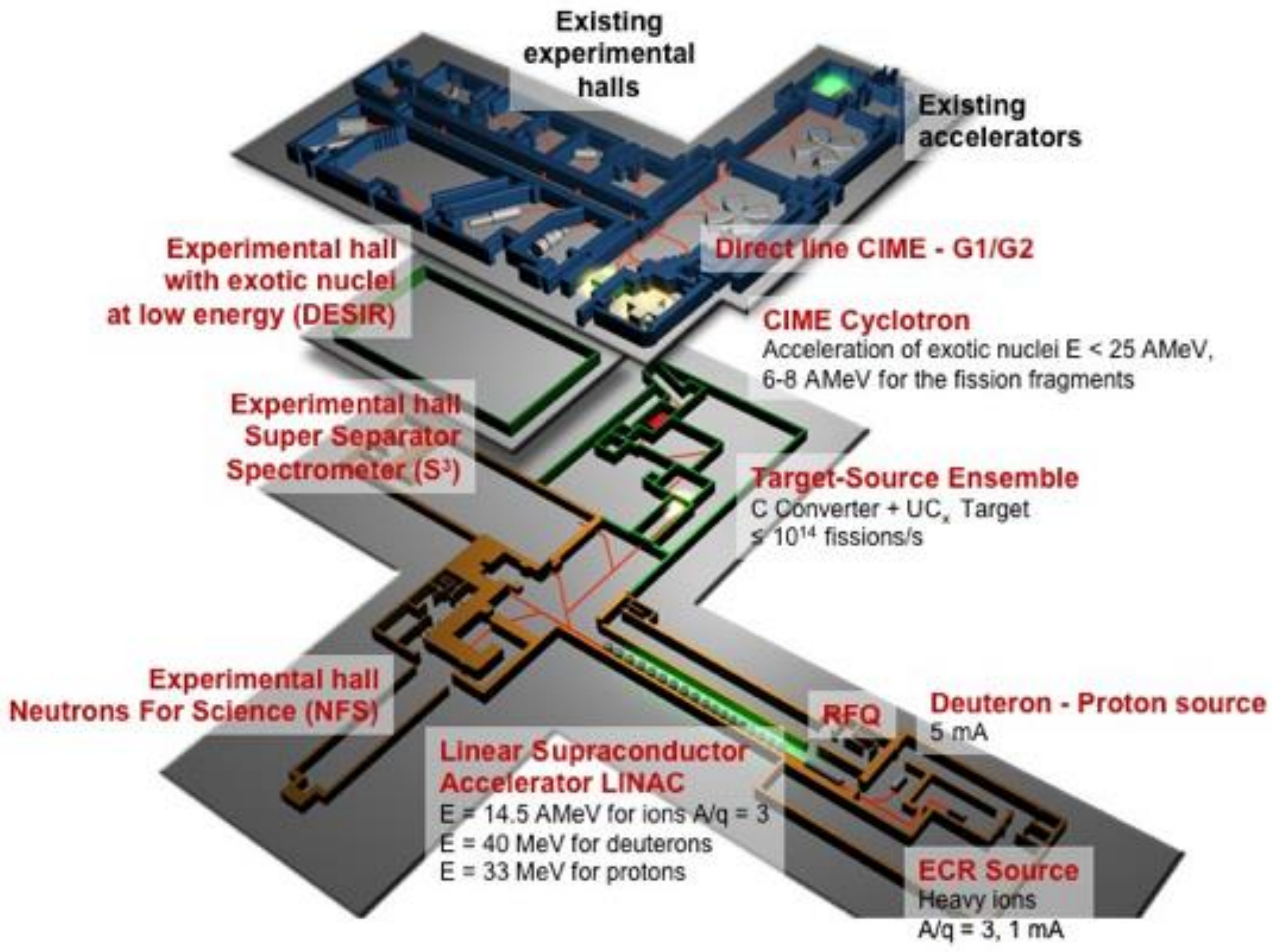
The intensity frontier at PSI: π, μ, UCN

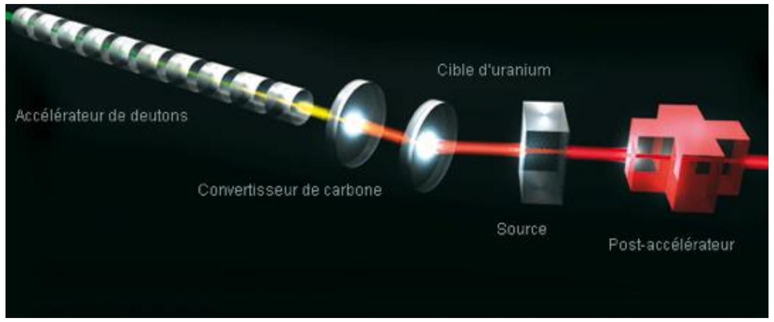
Precision experiments with **the lightest unstable particles** of their kind



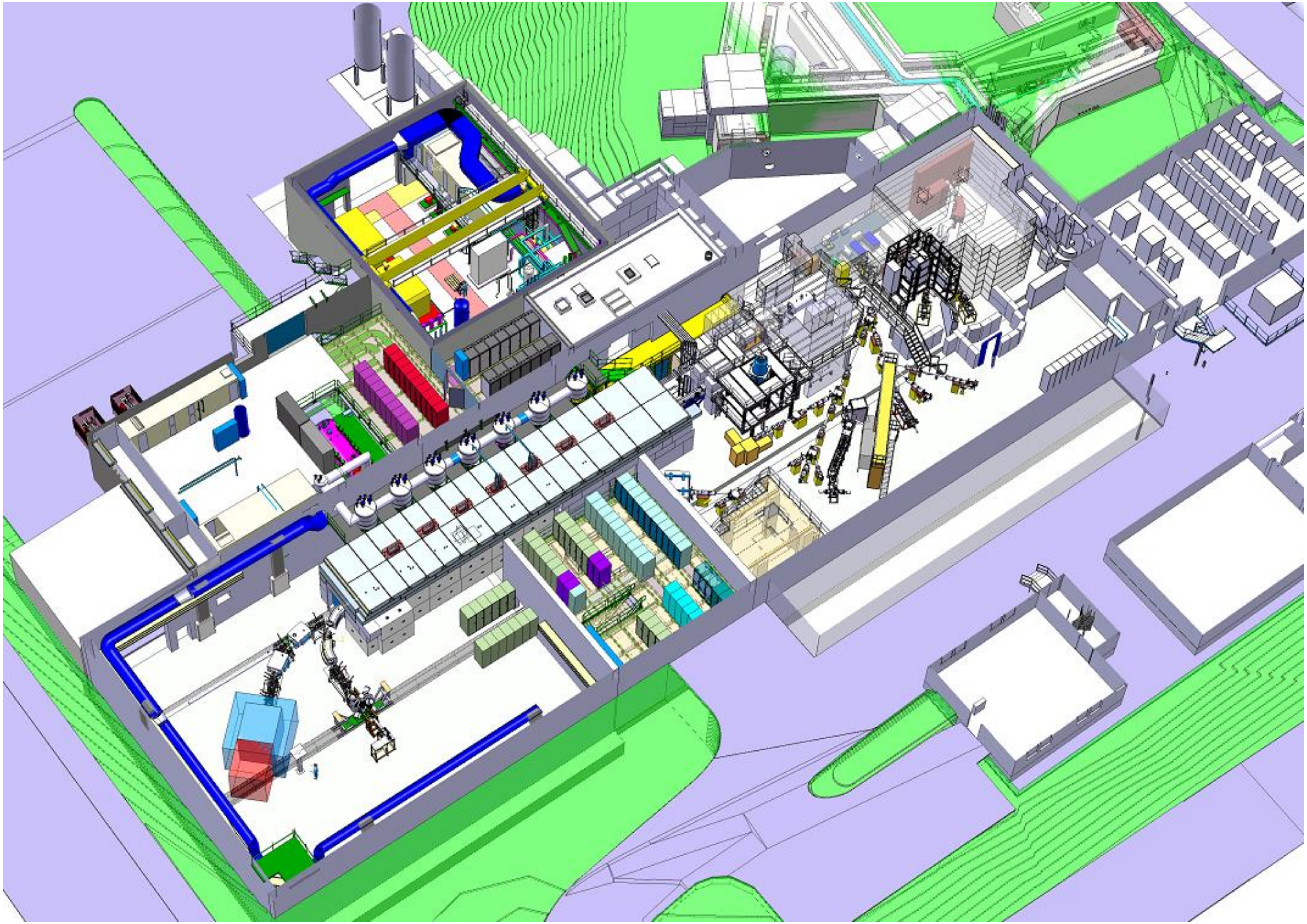
Swiss national laboratory with <u>strong international collaborations</u>

SPIRAL II


Existing experimental halls
Existing accelerators
Experimental hall with exotic nuclei at low energy (DESIR)
Direct line CIME - G1/G2
CIME Cyclotron
Acceleration of exotic nuclei E < 25 AMeV, 6-8 AMeV for the fission fragments
Experimental hall Super Separator Spectrometer (S^3)
Target-Source Ensemble
C Converter + UC_x Target
≤ 10^{14} fissions/s
Experimental hall Neutrons For Science (NFS)
RFQ
Deuteron - Proton source
5 mA
Linear Supraconductor Accelerator LINAC
E = 14.5 AMeV for ions A/q = 3
E = 40 MeV for deuterons
E = 33 MeV for protons
ECR Source
Heavy ions
A/q = 3, 1 mA


Cible d'uranium
Accélérateur de deutons
Convertisseur de carbone
Source
Post-accélérateur

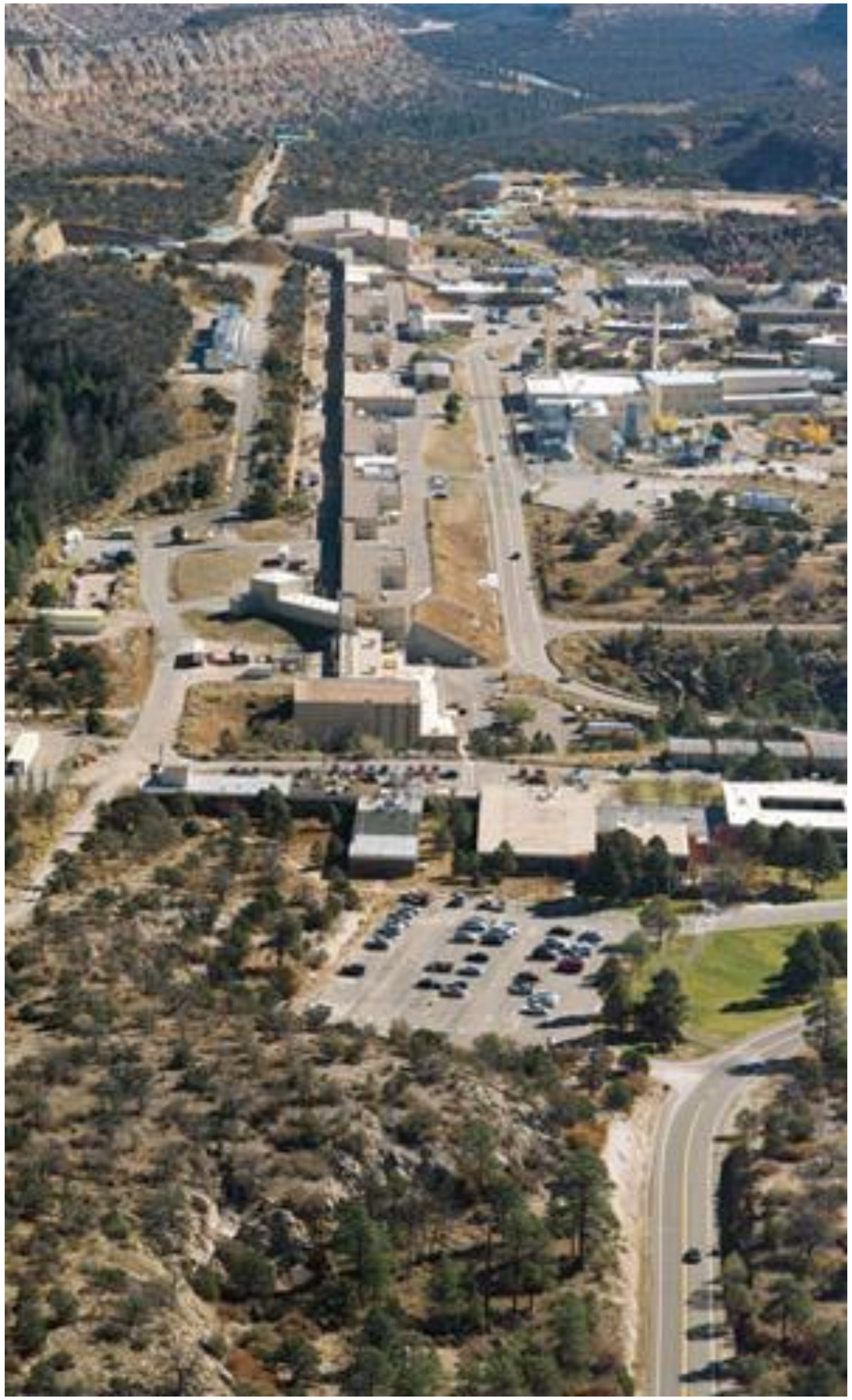
HIE ISOLDE evolution

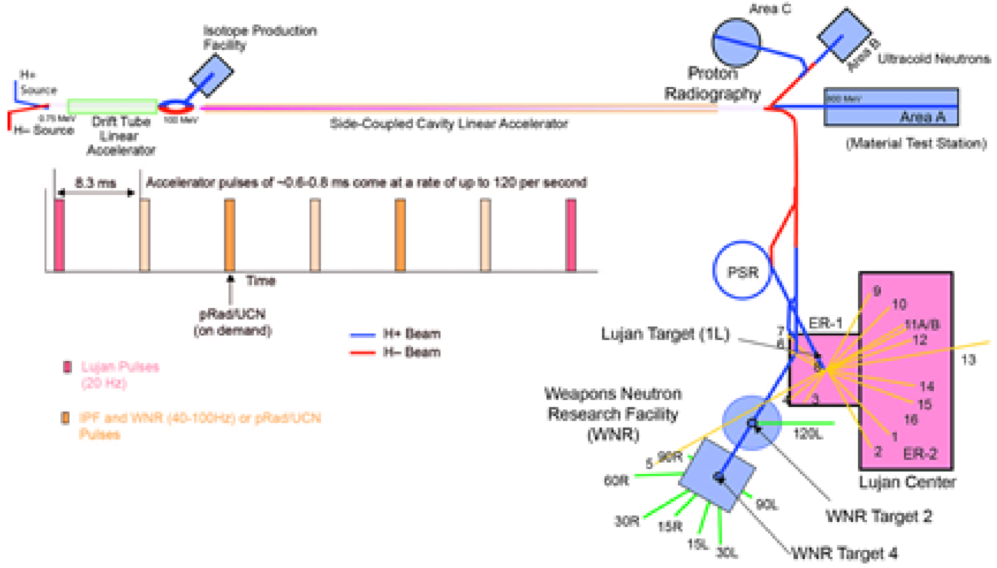


Short pulse neutron sources-SNS

- SNS, SC LINAC/Storage ring, 2007, 1.4 MW, 1 GeV, 26 mA in linac, 627 ns long pulse, 60 Hz
- Examples of challenges: Better understand stripping reaction in linac, accumulation in storage ring

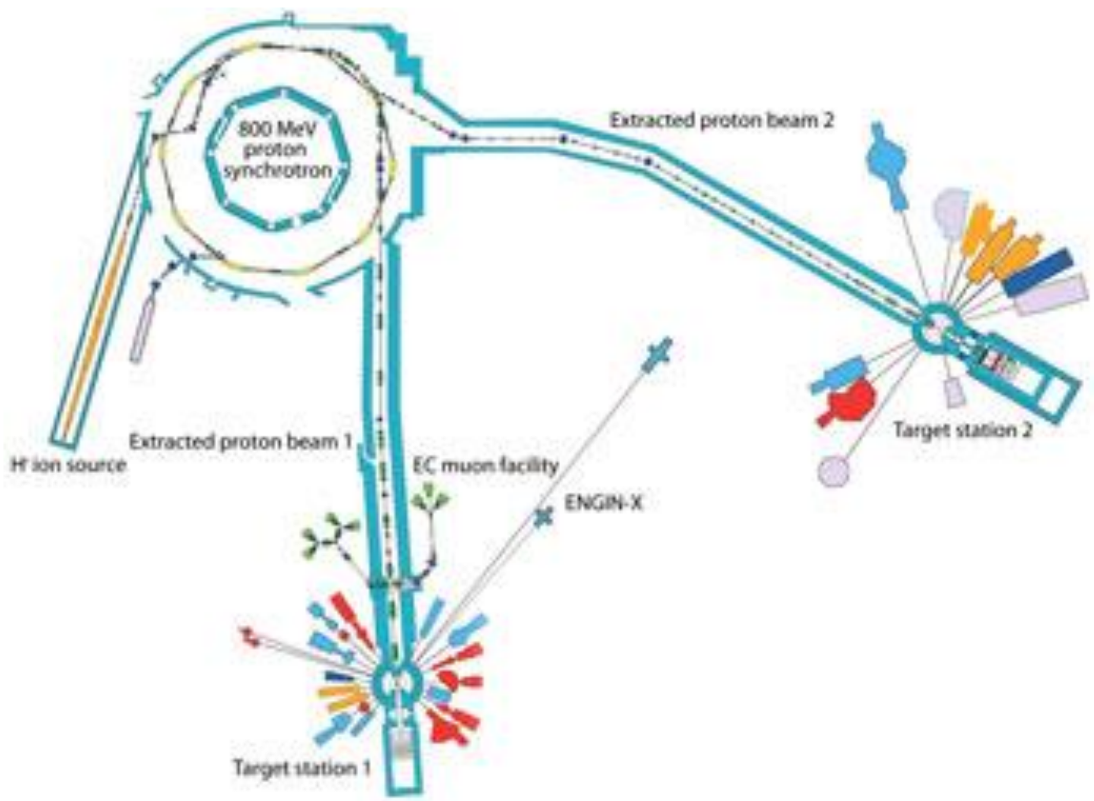
Short pulse sources-LANCSE





- LANCSE, NC LINAC /Storage ring, 1972, 100 kW, 800 MeV, 17 mA in linac, 600 ns, 20 Hz
- Examples: Combined H- and H+ acceleration

Science & Technology Facilities Council
ISIS



Accelerated intensity at 800 MeV:

2.5x10^{13} ppp - 3.75x10^{13} ppp

(200 µA) (300 µA)

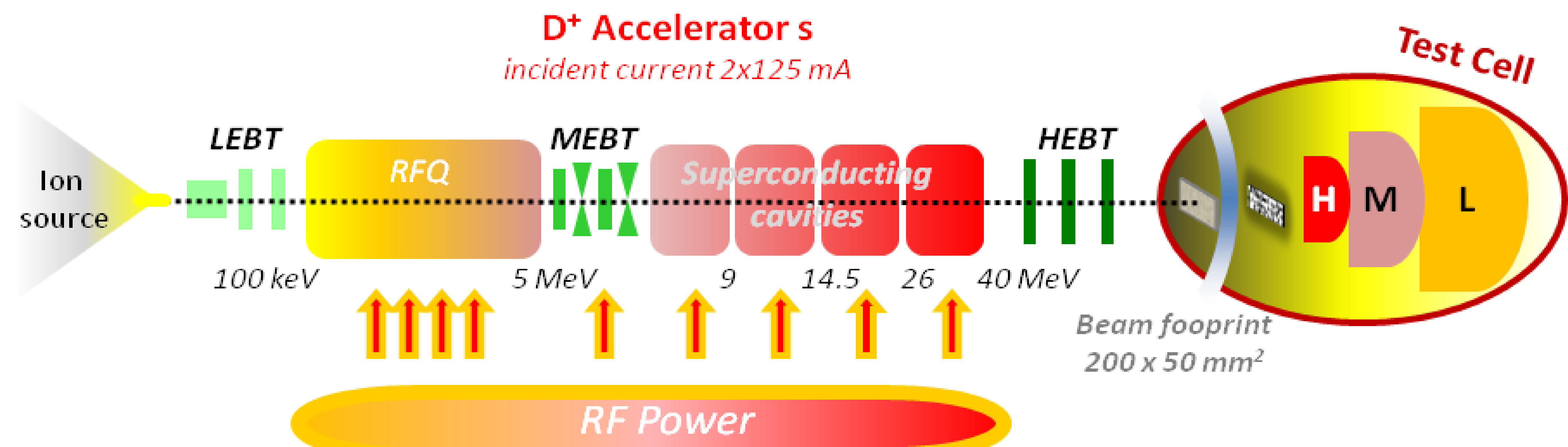
- Neutron scattering facility
- Two target stations
- Muon facility

Examples of challenges: Ceramic vacuum chambers, high space charge synchrotron

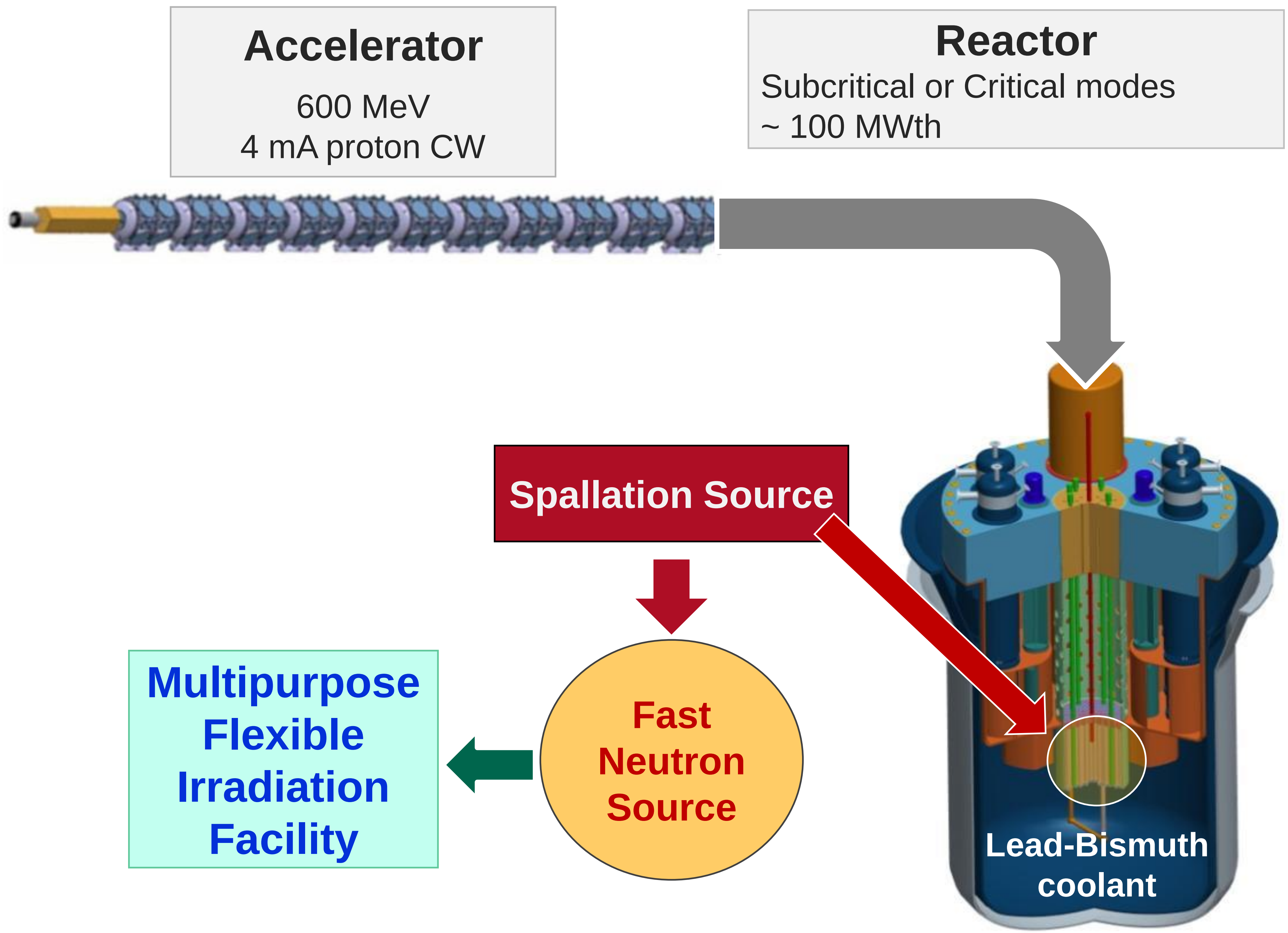
Accelerator facility

2 x 5 MW beams

Individual availability >90%



Accelerator Driven System



17 nations committed to build ESS

Cash contributions from Sweden, Denmark and Norway
50% of construction and 20% of operations costs

In-kind contributions from the other 14 nations

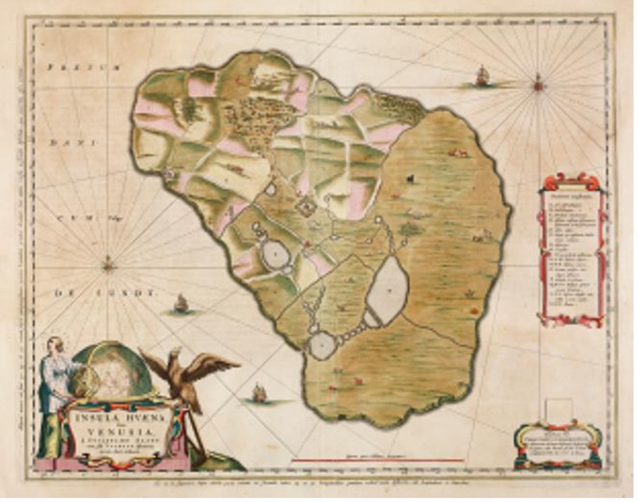
Construction cost: 1843 M€
Operation cost: 140 M€
Decommissioning cost: 177 M€

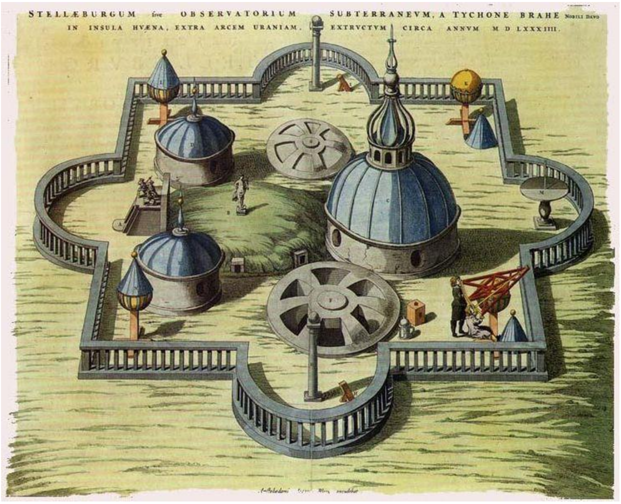
EUROPEAN SPALLATION SOURCE

ESS and MAX-IV:
Biggest investment in Science ever in Scandinavia?

In modern time, definitely YES!

However, Tycho Brahe’s Stjärneborg costed the Danish king 1% of the state budget in 1580.



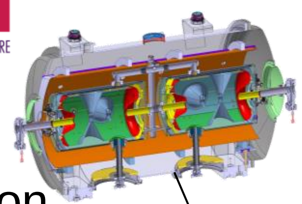


Or you could for 1.8 Billion Euros pay the US bankers bonuses for <24 days!

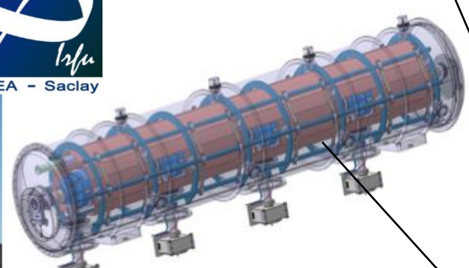
Collaborative projects

- ESS is an emerging research laboratory with (still) very limited capacity in-house
- Two possibilities:
  - Limit the scope of the project so that it can be done with in-house resources
  - Work in a collaboration where the scope of the project can be set by the total capacity (distributed) of the partners
- The accelerator part of the project well suited for this as this community has a strong tradition of open collaboration (European commission framework programs such as EUCARD, OPAC and TIARA, EC design studies such as EURISOL and EURONU, Projects such as XFEL, FAIR, LINAC4,...)
- To keep cost down and to optimize schedule this requires that investments in required infrastructure is done at the partner with best capacity to deliver

Prototyping the ESS accelerator

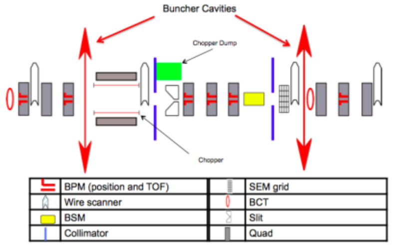



Sebastien Bousson

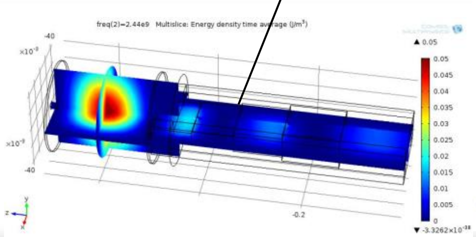


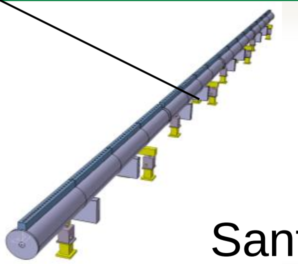

Pierre Bosland

CERN

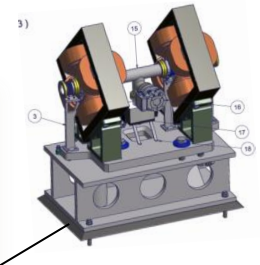


Ibon Bustinduy

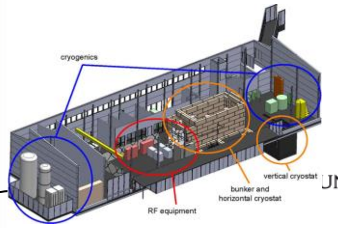




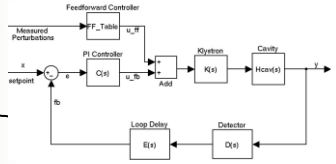
Santo Gammino




Søren Pape Møller




Roger Ruber



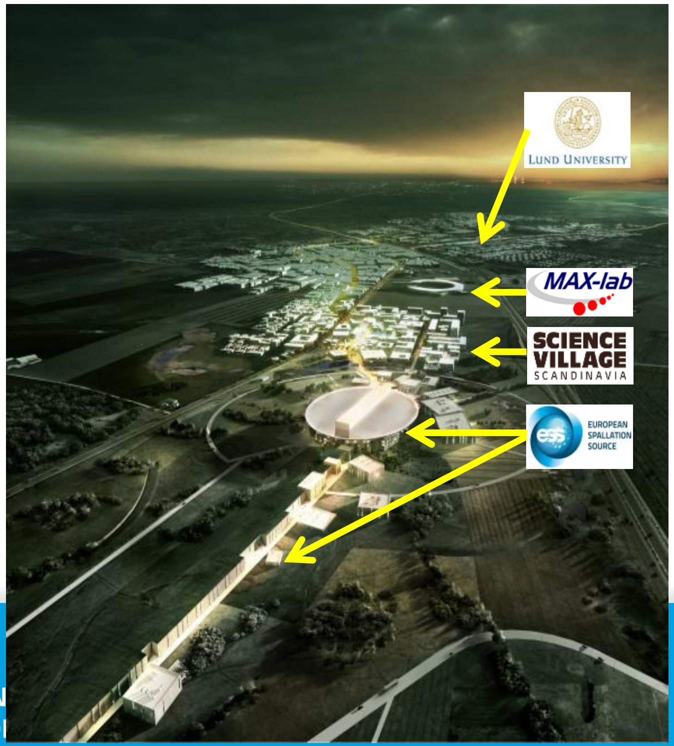

Anders J Johansson

The National Center for Nuclear Research, Swierk

ESS accelerator

Design Drivers:

- High Average Beam Power
  - 5 MW
- High Peak Beam Power
  - 125 MW
- High Availability
  - > 95%



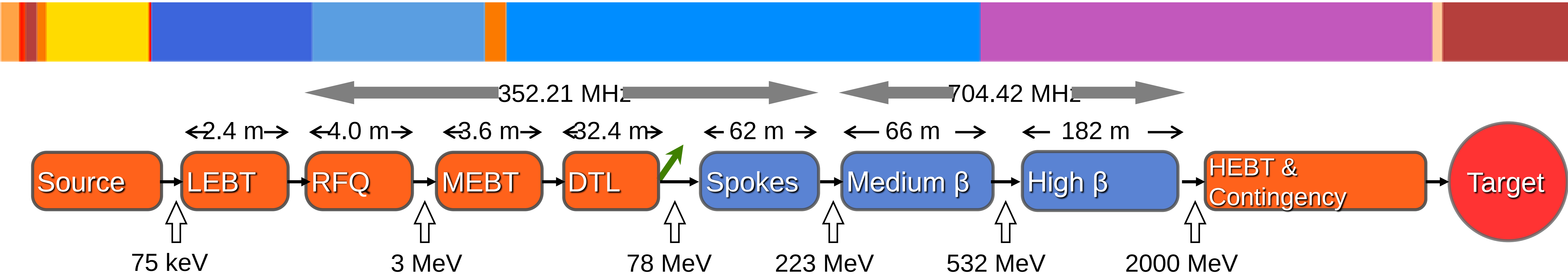
Key parameters:

- -2.86 ms pulses
- -2 GeV
- -63 mA
- -14 Hz
- -Protons (H+)
- -Low losses
- -Low heat loss cryostats for minimum energy consumption
- -Flexible design for future upgrades

Linac Design Choices

- The energy of the linac is a tradeoff of
  - Linac length
  - Beam current:
    - Space charge forces
    - Halo losses
- Copper Linac
  - Low construction costs but high operational costs
  - Small bore radius < 3 cm
  - Long linac > 750 meters for 2 GeV
- Superconducting Linac
  - High construction costs but low operational costs
  - Large bore radius > 7 cm
  - Short Linac < 360 meters for 2 GeV

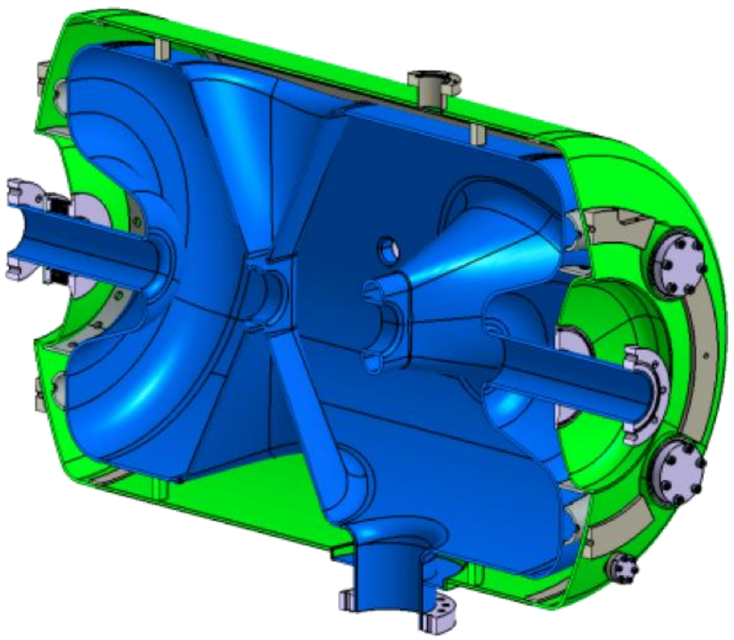
ESS Linac

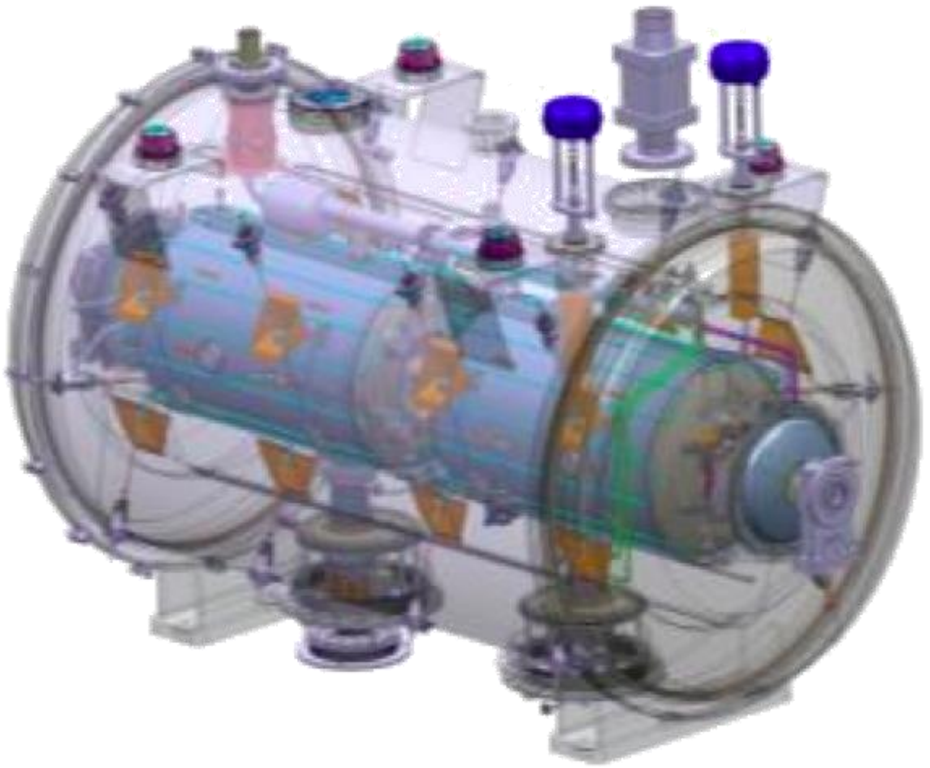


	Energy (MeV)	No. of Modules	No. of Cavities	βg	Temp (K)	Cryo Length (m)
Source	0.075	1	0	–	~300	–
LEBT	0.075	–	0	–	~300	–
RFQ	3.6	1	1	–	~300	–
MEBT	3.6	–	3	–	~300	–
DTL	79	5	5	–	~300	–
Spoke	220	15	2 (2S) × 15	0.5 β_{opt}	~2	4.14
Low β	520	8	4 (6C) × 8	0.67	~2	8.28
High β	2000	22	4 (5C) × 22	0.86	~2	8.28
HEBT	2000	–	0	–	~300	–

Spoke Cavities

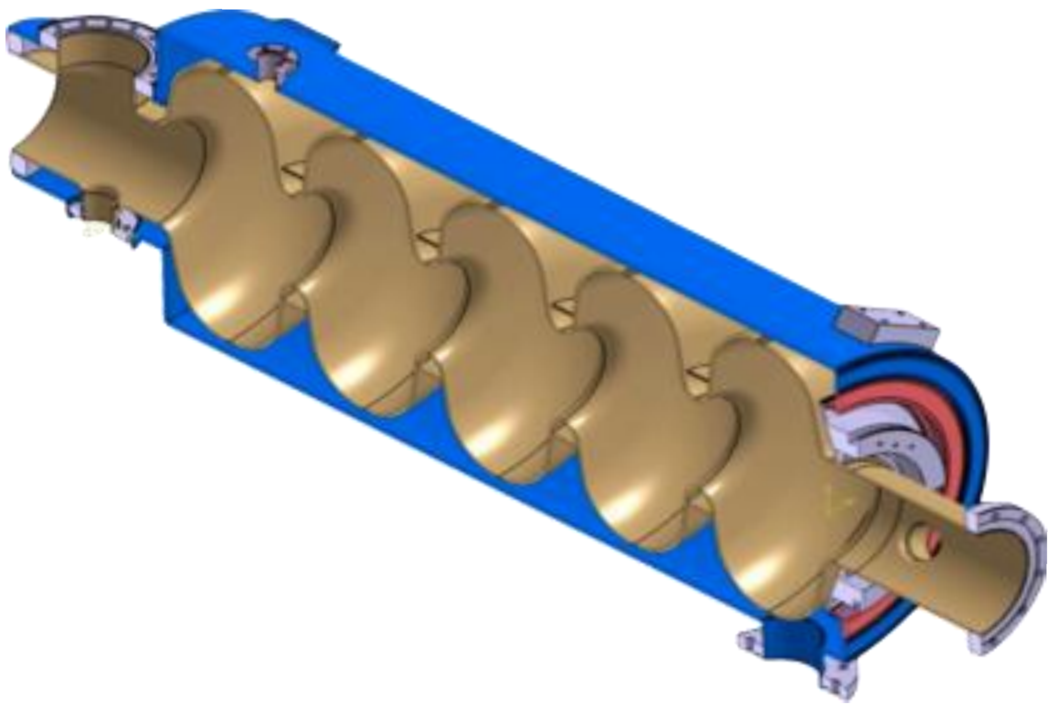
- IPNO
  - A double spoke cavity, the coupler, helium vessel, ancillaries and cryomodule.
    - Cavity made of 4 mm thick bulk niobium
    - 4 HPR ports on one end
    - Helium vessel made of 4 mm thick titanium
    - Coupler is the EURISOL design
  - The production of 3 prototypes had started in March 2013





Courtesy of Guillaume Olry

Elliptical cavities



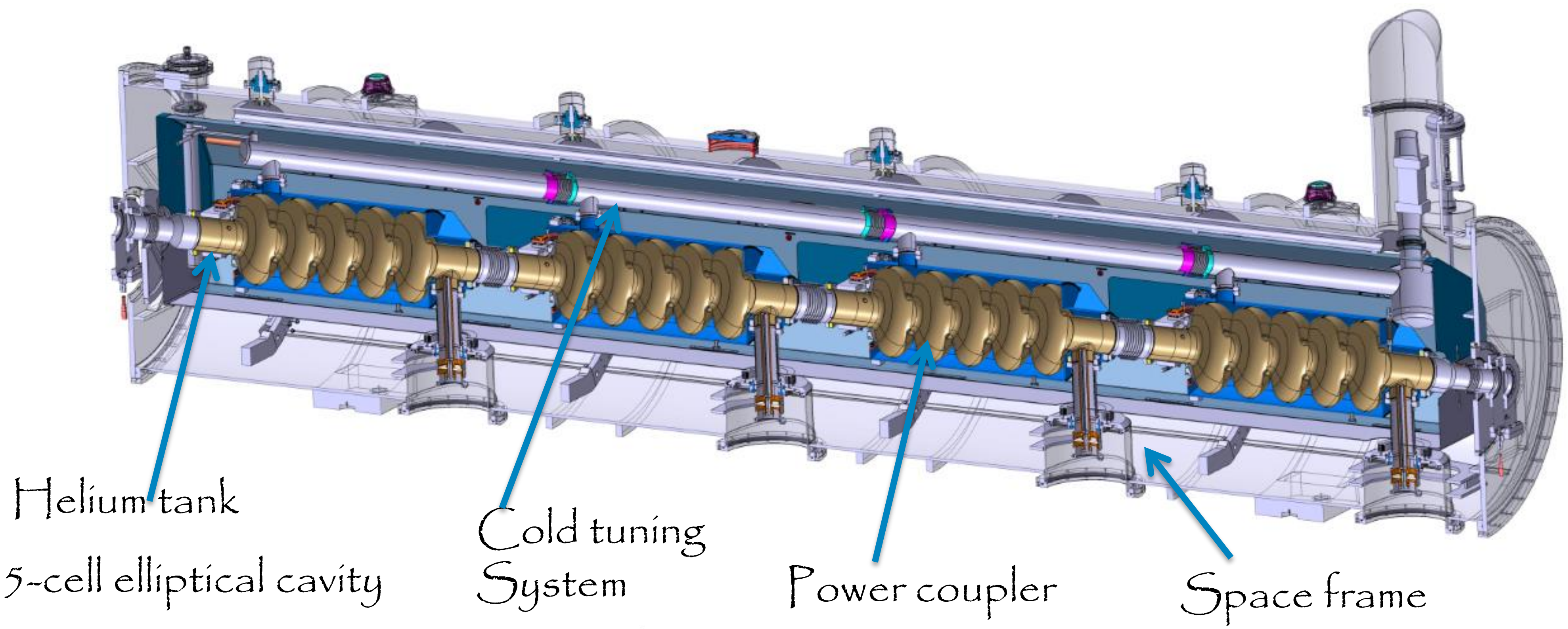
- CEA
- IPNO
  - The prototyping activities at Orsay/Saclay is planned
    - Two cavities to be prototyped
    - Niobium is provided
    - Clean room 50% complete

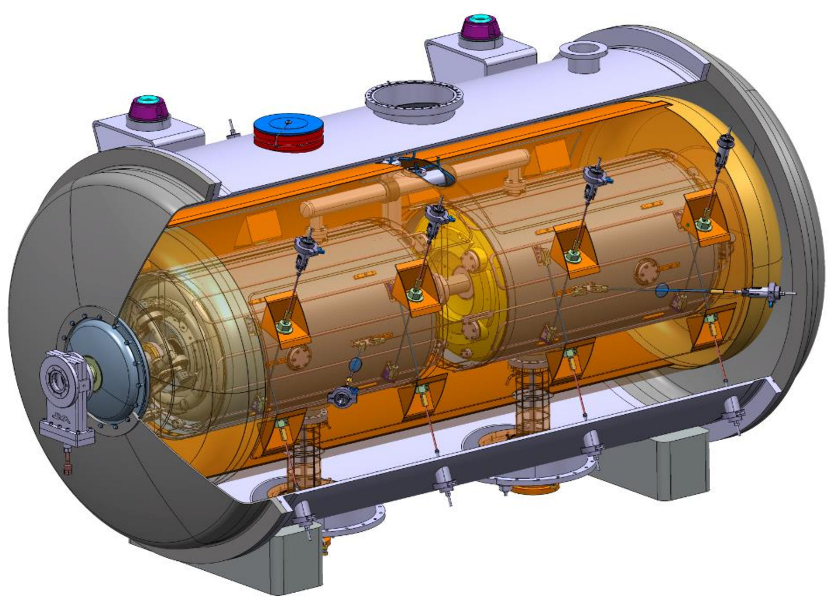
  – An ESS PhD student at Lund Uni. is designing a medium β cavity

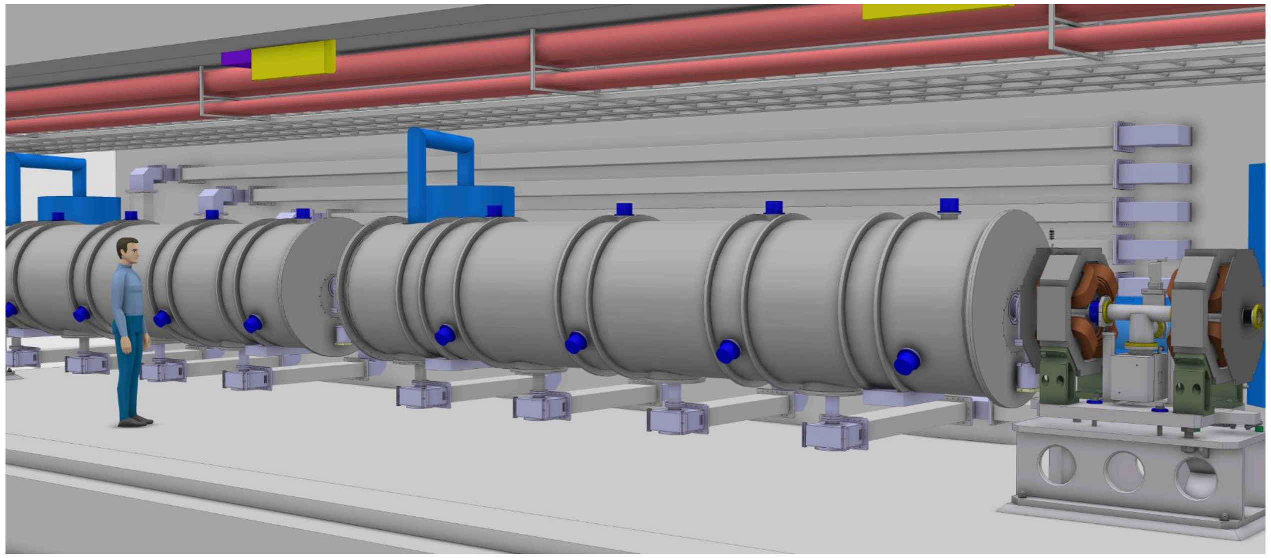
βg	E_{acc} (MV/m) Ver. Test	E_{acc}^{*} (MV/m) linac	Q_0 @ E_{acc}	N Cells
0.67	17	16.7	5×10^9	6
0.86	20	19.9	6×10^9	5

* New design with higher peak surface field

Cryomodules Technology demonstrators

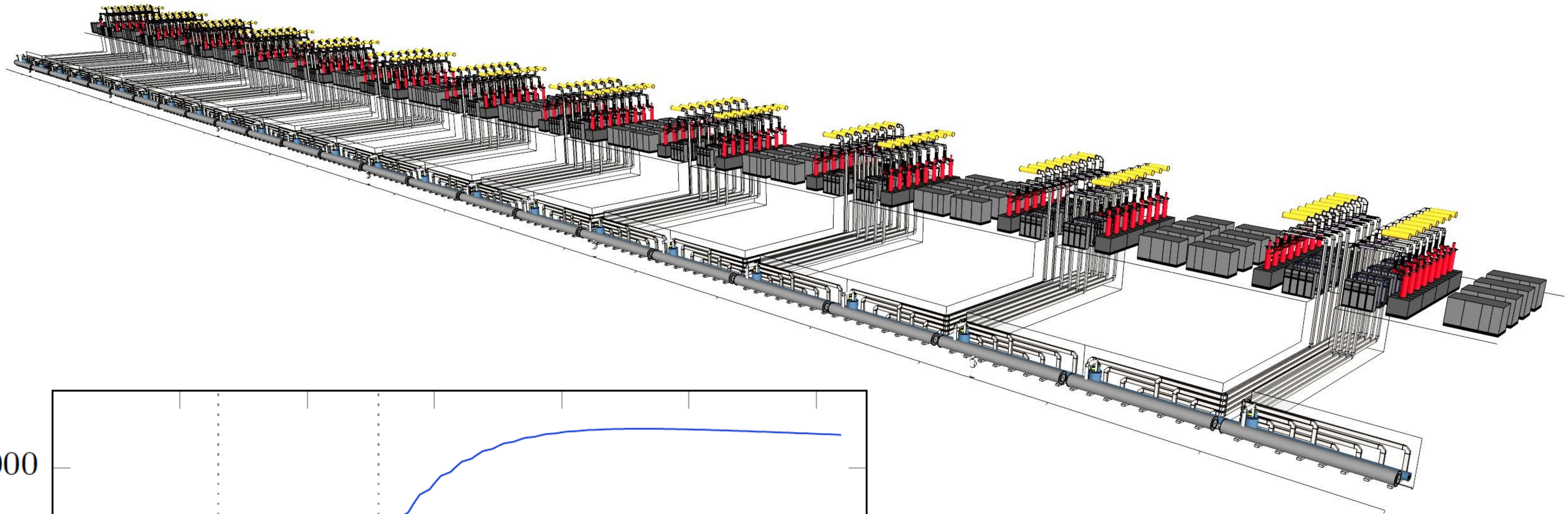


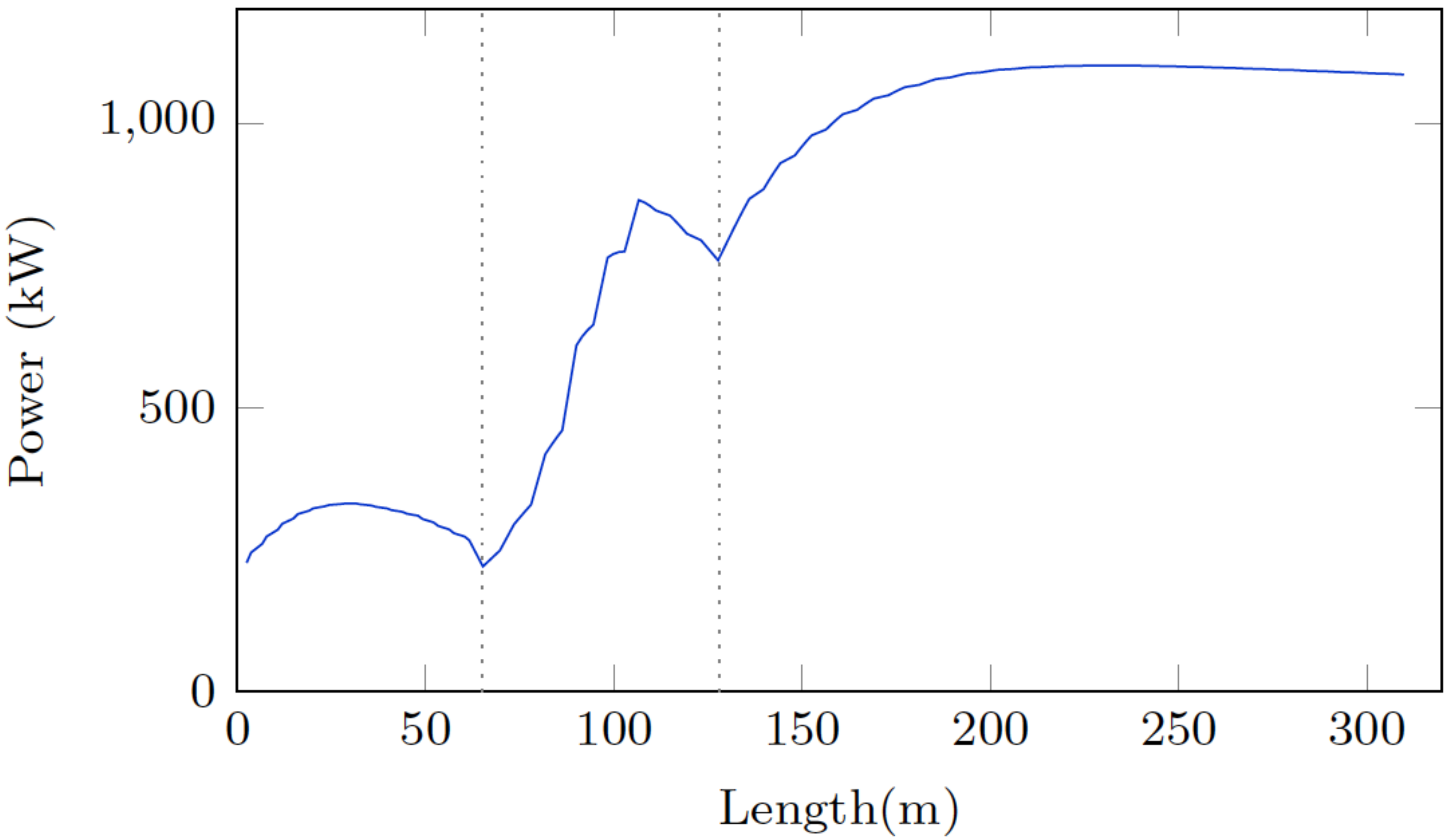




→ Cavities Cryomodule Technology Demonstrator results by the end of 2015

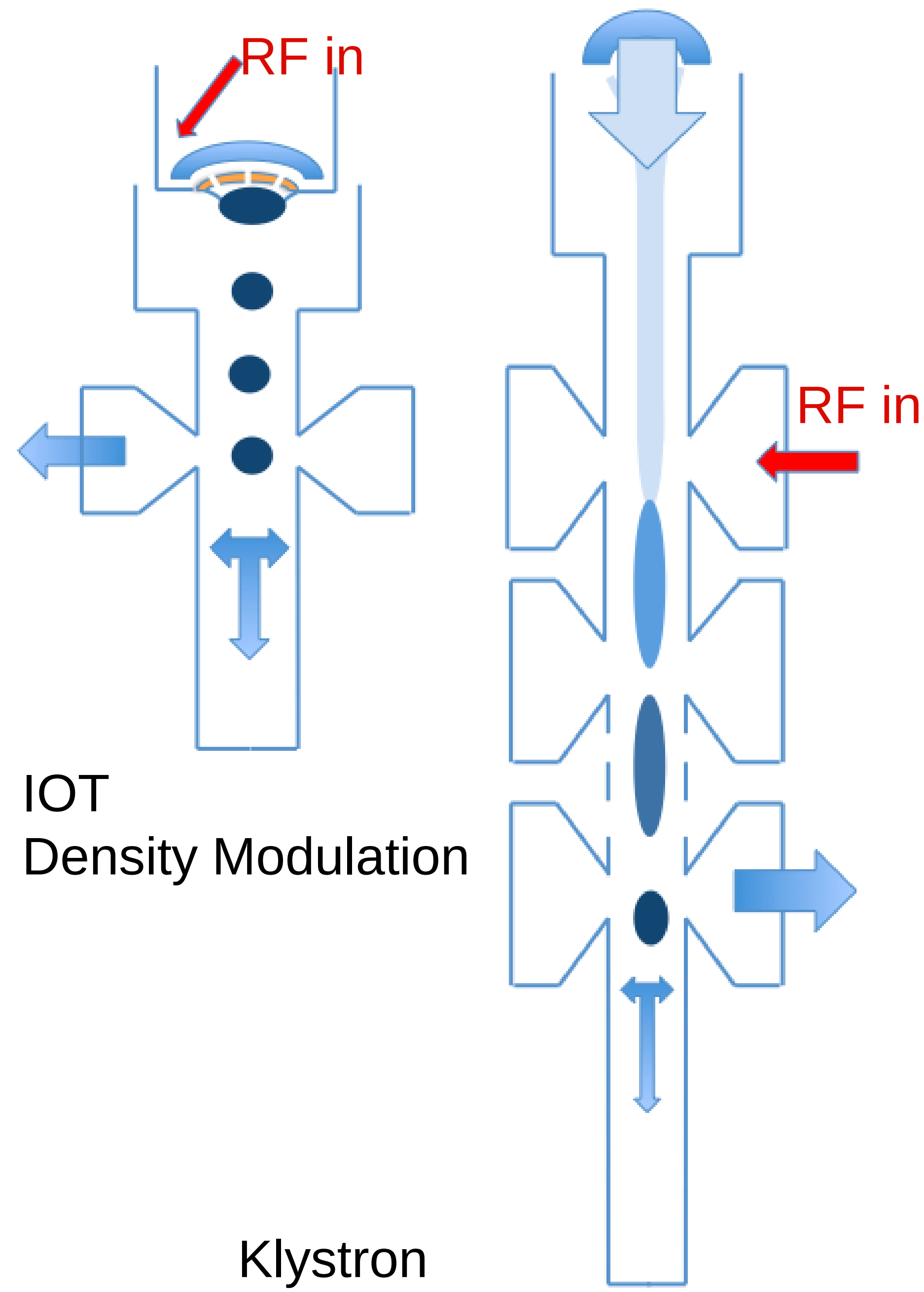
RF efficiency is all!





Inductive Output Tubes or Klystrons?

- ESS
  - Induction Output Tubes, IOTs
    - Higher electrical efficiency
      - They don't conduct in the absence of input drive
    - Compact
    - Short MTTR
    - Cheaper modulator (No high voltage switching)
  - Why suddenly IOTs?
    - Development of Pyrolytic graphite grids
    - Solid state drivers

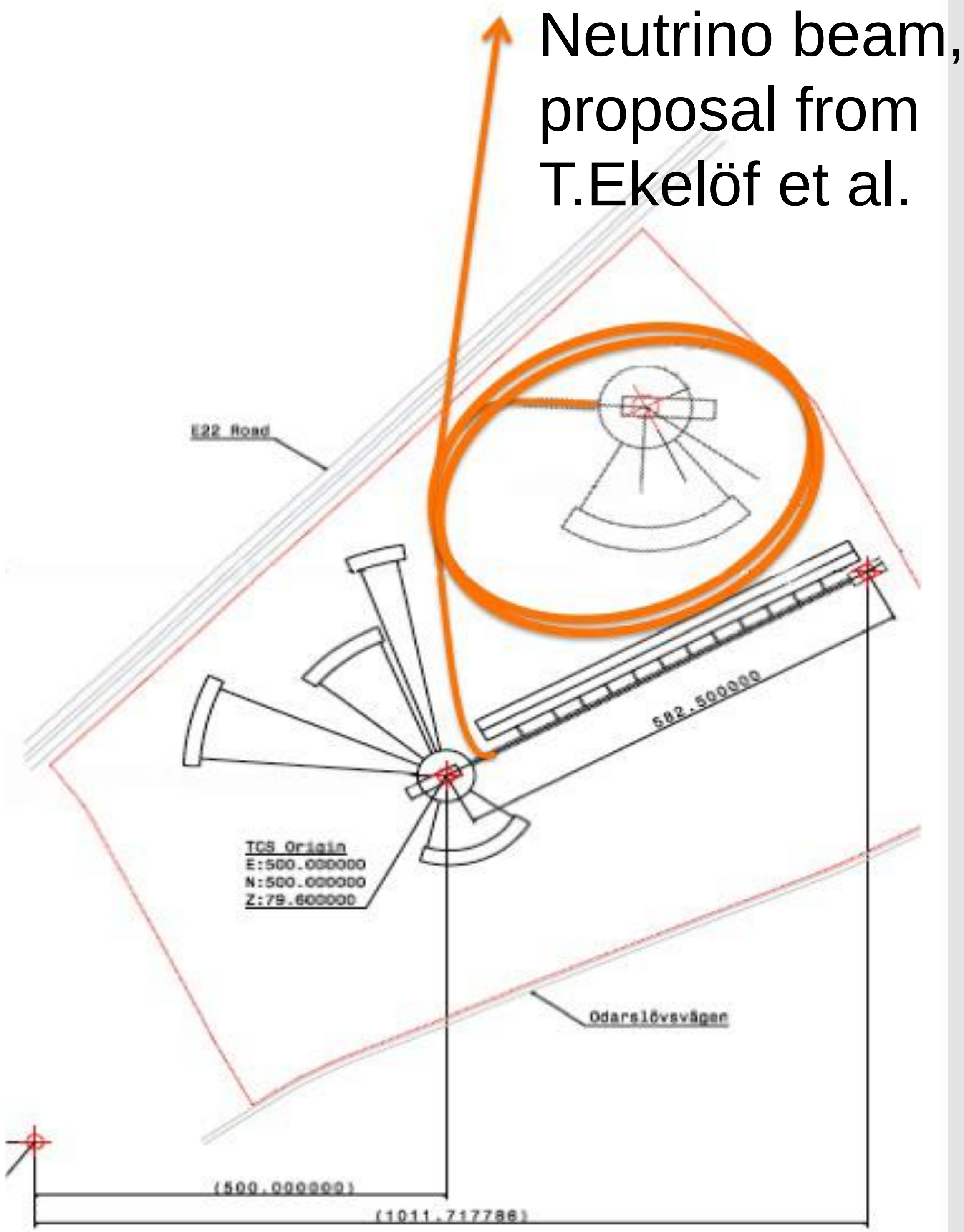


IOT
Density Modulation

Klystron
Velocity Modulation

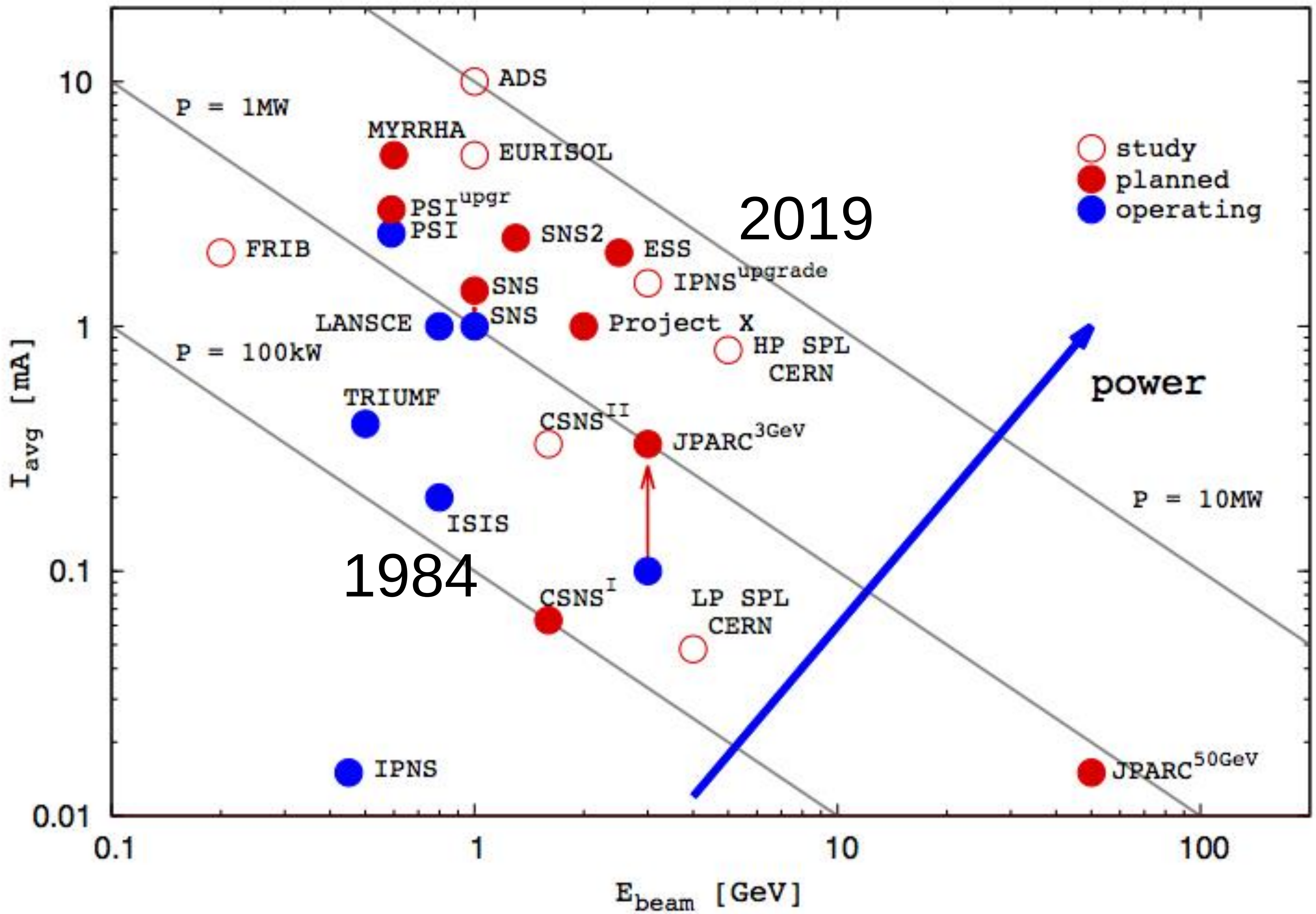
Courtesy of Morten Jensen (ESS) and Eric Montesinos (CERN)

Ideas for ESS upgrade with ring



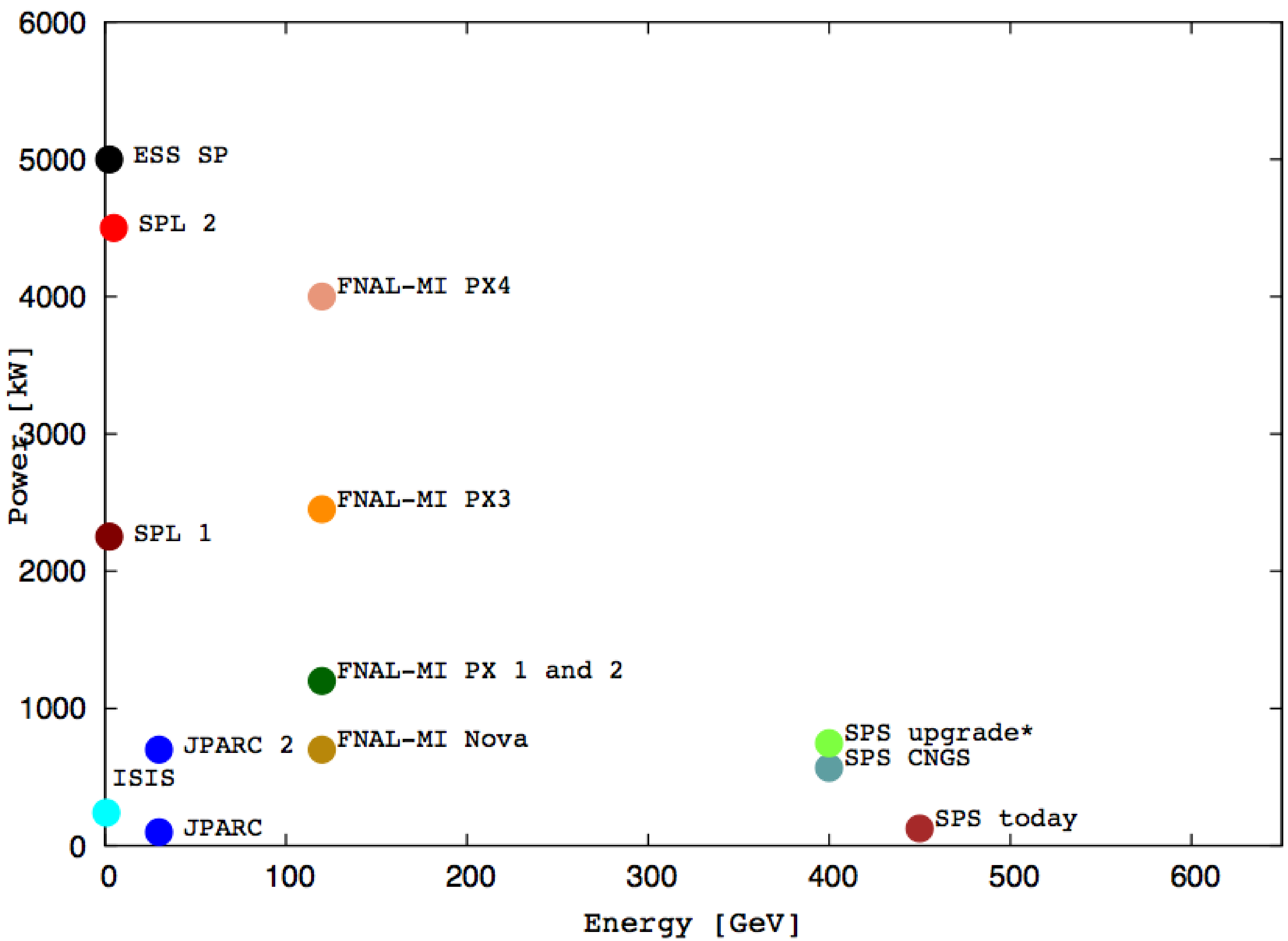
- 5 MW ring for a shorter pulse spallation neutron source
- Four stacked permanent magnet rings, 2.5 GeV, 5 ms revolution time makes for a tune shift of less than 0.25
- Staggered beam extraction using solid state switch driven ILC like strip line kickers of up to 100 pulses to match pulse length to moderators and simplify target design
- Linac operated with H- and at 28 Hz to keep both target station operating at 5 MW
- Neutrino beam extraction possible

The hadron intensity frontier



Courtesy of Mike Seidel (PSI) and Emmanuel Laface (ESS)

Short pulse high intensity frontier



What are the limits?

My guesses today for the 10 year perspective

- High intensity linacs for neutrino beams, anti-protons, muons and neutrons
  - 10-15 MW, limited by losses
  - H^- machines have an additional loss mechanism through intra-beam stripping
- High intensity hadron rings for anti-protons, muons and other fixed target physics
  - 1-5 MW, limited by losses and space charge
- High intensity electron/positron rings
  - Luminosity -> 10^{36} /cm^2/s
- High intensity cyclotrons for neutrons and muons
  - 2-5 MW, limited by losses at extraction and space charge

Collaboration

- Collaborative R&D on accelerators and associated equipment is the single most important factor for the successful construction of new facilities and continued progress of accelerator R&D
  - *ESS is built on a green field site with no existing lab infrastructure on the site and ESS accelerator makes very fast progress thanks to the strong tradition of collaboration in the field of accelerator science*
  - *EC projects: CARE, EUCARD, TIARA, CRISP, PPs, …*
- The funding of accelerator R&D has so far been mainly carried by HEP and NP, new common structures and funds across subject borders are needed for continued strong accelerator R&D in Europe

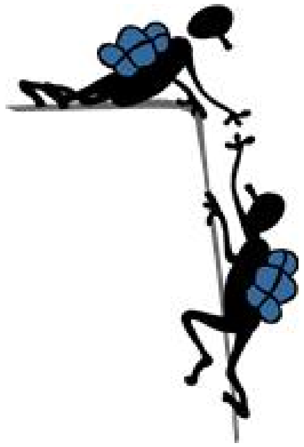
Collaborative R&D

- Collaborative R&D is and would be hugely beneficial in a number of areas:
  - Energy efficient and cheaper RF sources
  - High Q_0 (more energy efficient) superconducting cavities
  - Higher gradient superconducting cavities
  - High space charge accumulation (and accelerating) rings low loss injection and extraction systems
  - New collision schemes for flavor factories
  - Target concepts and technology
  - Radiation protection issues including robotics
  - …

Conclusions

- The high intensity frontier holds many challenges in all disciplines of accelerator science
- Dense and precise beam instrumentation is a condition for successful commissioning and reliable operation of any high intensity facility
- Accelerator science is a very good area for cross-disciplinary collaborations, for R&D, construction and operation
  - It can be seen as a risk…
  - But for me it is an opportunity!
- Thanks to the Marie-Curie

networks and especially OPAC!



Contributors

- Many, many, many thanks to Klaus Kirch (PSI), Mike Seidel (PSI), Oliver Kester (FAIR), Roland Garoby (CERN), Elena Wildner (CERN), Elena Shaposhnikova (CERN), Simone Gilardoni (CERN), Steve Hancock (CERN), Heiko Damerau (CERN), Christian Carli (CERN), Marica Biagini (LNF), Yuriy Tikhonov (BINP), Eugene Levichev (BINP), Yasuhiro Masuda (KEK), Geoffrey Greene (UTK), Steve Holmes (FNAL), Yorick Blumenfeld (IPNO), Yoshi Sakai (KEK), Jiuqing Wang (BEJP), Takashi Kobayashi (KEK), Ilias Efthymiopoulos (CERN), Steve Peggs (ESS), David McGinnis (ESS)
- and all colleagues at ESS