ECOS-EURISOL Joint Town Meeting
Institut de Physique Nucléaire, Orsay
EURISOL ENSAR October 28-31, 2014

Status of (some) Spoke cavity developments worldwide

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http://ipnweb.in2p3.fr

Proofs of inflation in Spoke cavity use…

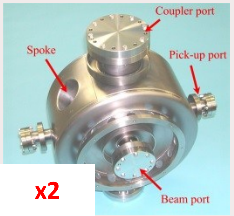
ANL (USA)

From Big Bang to 1992

1 cavity

IPN (F)

LANL (USA)



ANL (USA)

ANL (USA)

ANL (USA)

From 1992 to 2004

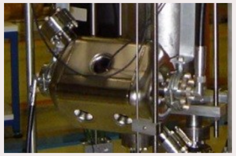
+6 cavities

ANL (USA)

ANL (USA)

IPN (F)

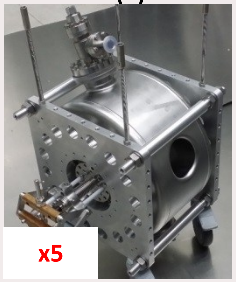
FZJ (D)



FZJ (D)

IPN (F)

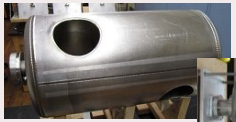
IHEP (C)



IHEP (C)

PKU (C)

ODU/JLAB (USA)



ODU/JLAB (USA)

IMP (C)

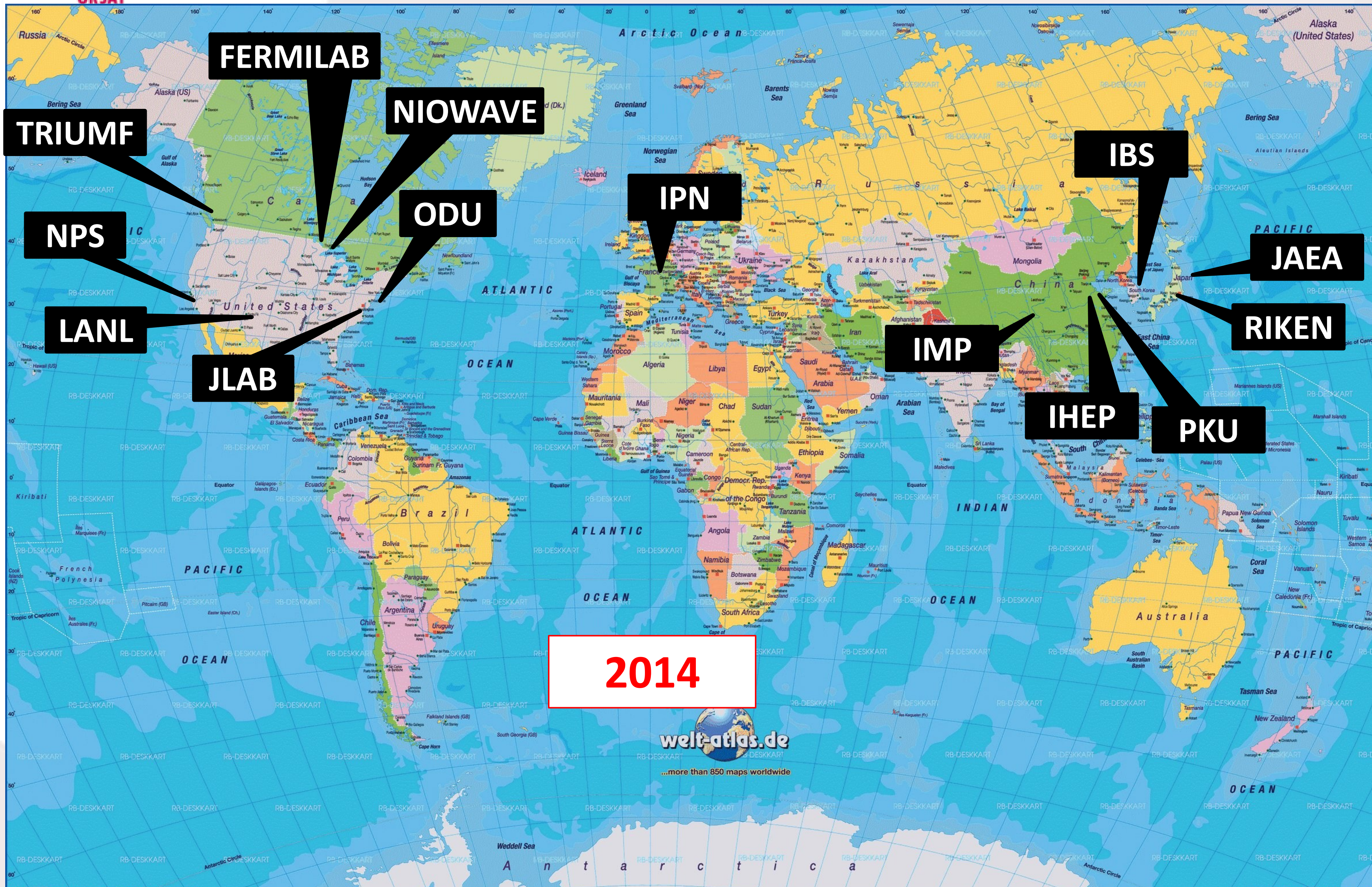
Fermilab (USA)

From 2004 to nowadays

+ >30 cavities

IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

Nowadays…



Developments for **low and medium velocity (β≤0.5)** proton and ion Linacs

Developments **for electron (β=1) and high velocity (β≥0.5)** proton and ion Linacs

IPN involvements

"in-house" R&D

1999-2004

Prototyping (done): 2 Single-Spoke cavities

RIB

2005-2009: EURISOL Design Study

Prototyping (done): 1 Triple-Spoke Cavity

ADS

From 2005: IP-EUROTRANS, CDT, MAX, (MYRTE)

Prototyping (on-going): 2 Single-Spoke cavities

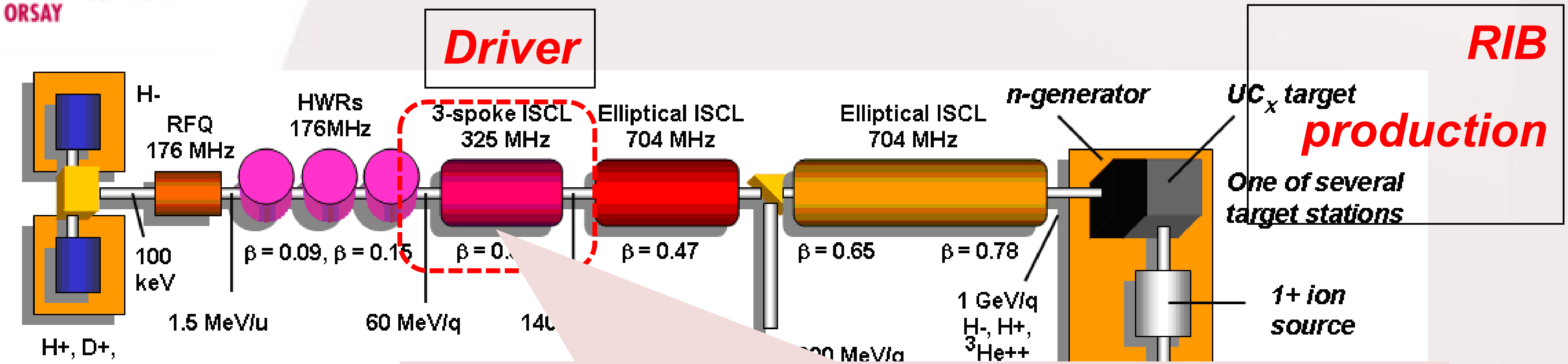
Spallation Source

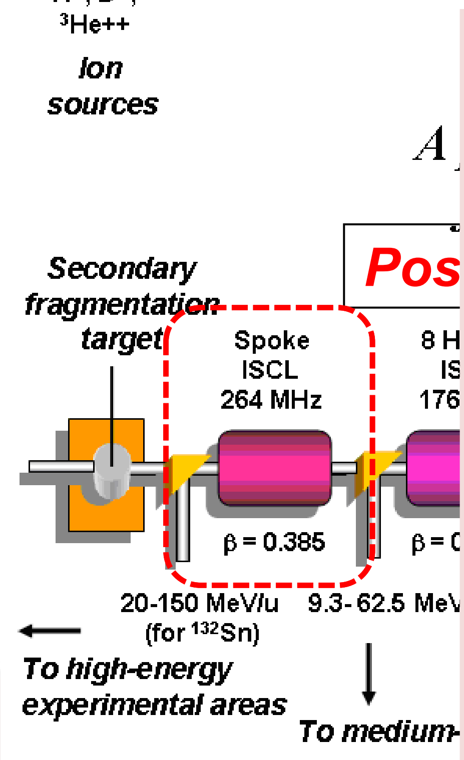
From 2009: ESS

Prototyping phase (on-going): 3 Double-Spoke cavities

Construction phase (in 2016): 26 Double-Spoke cavities

IPN: EURISOL





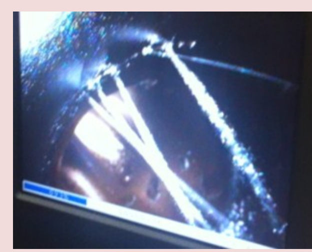
1 prototype built (2011)

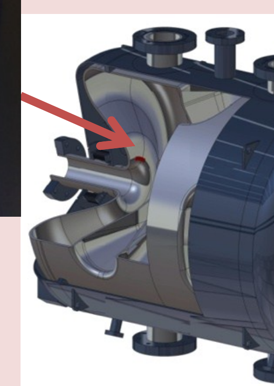
@300K

- tested with several tuning systems

@2K

- 1st RF test showed strong multipacting barriers
- Recent RF test failed because of cracks (weld seam)



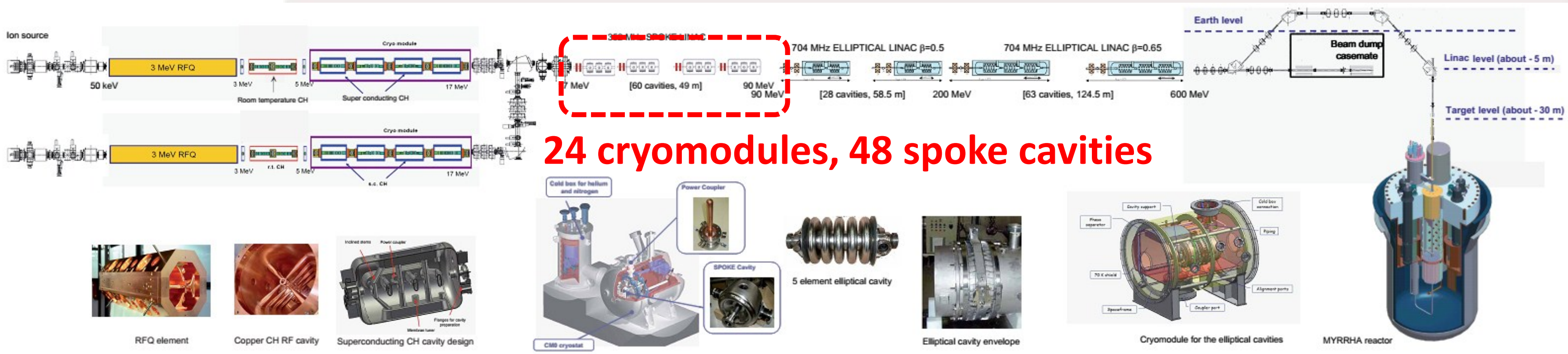


H.Saugnac, J.L. Biarrotte, S. Blivet, P. Duchesne, N. Gandolfo, J. Lesrel, G. Olry, E. Rampnoux, D. Reynet, IPNO, Orsay, France

IPN: MYRRHA

http://myrrha.sckcen.be/en/MYRRHA

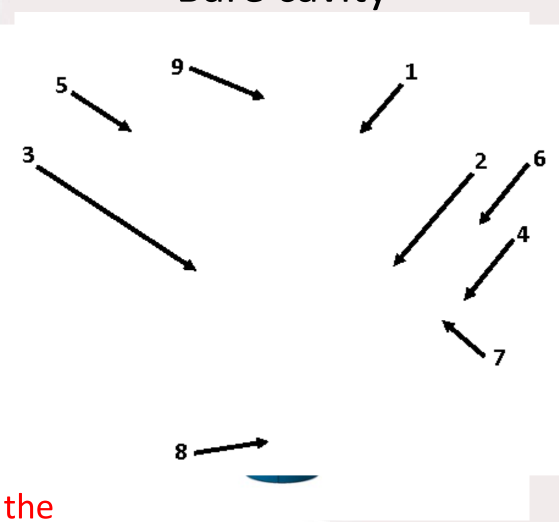
Design of Single-Spoke cavities at 352 MHz with β=0.37



24 cryomodules, 48 spoke cavities

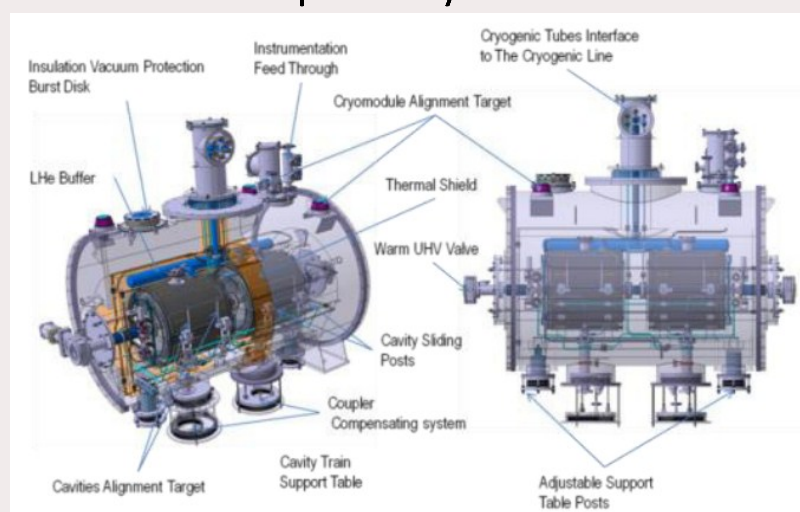
Bare cavity

1. Cavity body
2. Beam tube connection (x2)
3. Spoke bar rib (x2)
4. Internal ring (x2)
5. External ring (x2)
6. Titanium disc (x2)
7. CF63 Flange (x4)
8. Coupler port
9. Pick-up port



Same stiffeners as the ESS Spoke cavity = cost reduction ("standardisation")

Spoke cryomodule



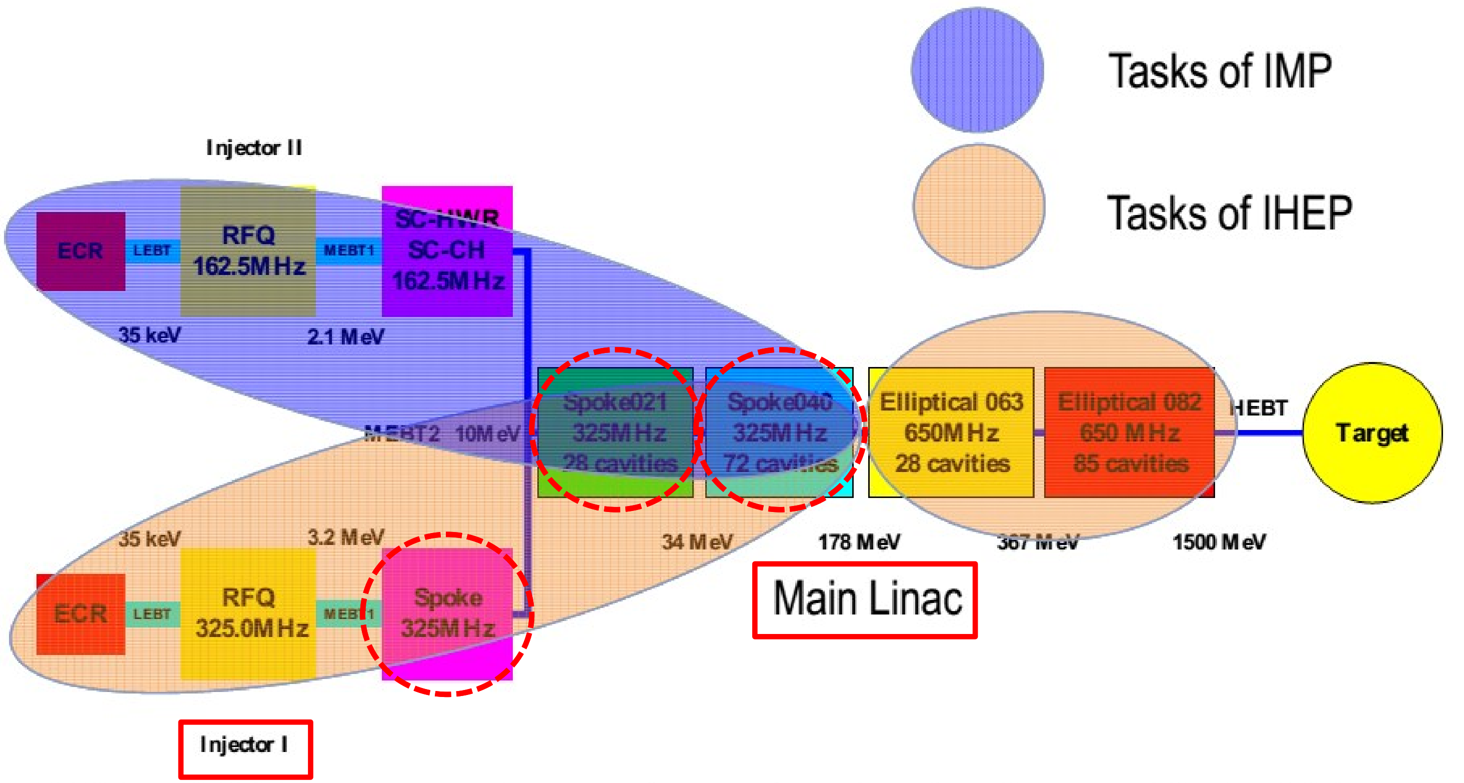
2 fully jacketed Single-Spoke in fabrication (2015)

FIRST CAVITY RECEIVED (October 13, 2014)

IHEP/IMP: C-ADS

SRF 2013
SRF CAVITIES FOR ADS PROJECT IN CHINA*
Y. He#, W.M. Yue, S.H. Zhang, Linac Group, IMP, CAS, Lanzhou, China
J.P. Dai, Z.Q. Li, Z.C. Liu, W.M. Pan†, RF Group, IHEP, CAS, Beijing, China
X.Y Lu, PKU, Beijing, China

- Design of a **Single-spoke cavities at 325 MHz with 3 different betas (0.12, 0.21 & 0.40)**, **more than 100 cavities**
- R&D on other betas and Spoke type



IHEP and IMP co-work on the accelerator. Final project has two identical injectors. Two designs of injector is due to technical uncertainty at very low energy segment.

IHEP

H. Zhao, "China ADS linac R&D progress", talk given at Linac 2014

J. Dai, private communication

DEVELOPMENT OF A VERY LOW BETA SUPERCONDUCTING SINGLE SPOKE CAVITY FOR CHINA-ADS LINAC* SRF 2013

H. Li[#], J.P Dai, H. Huang, L.H. Li, H.Y. Lin, Q. Ma, W.P. Pan, P. Sha,Y. Sun, Q.Y. Wang, J. Zhang
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

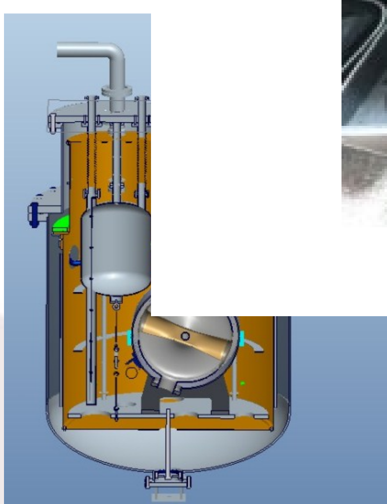
Injector I: Two Single-Spoke 0.12, 325 MHz already built, tested in VT and HT.

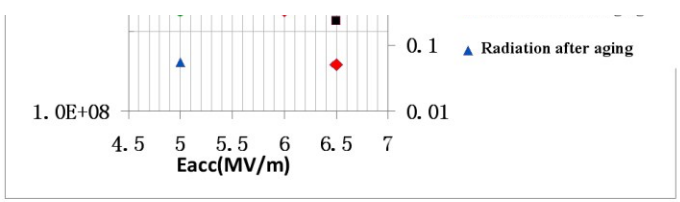
50 um
50 C, 3 hours
0um
C, 48 hours

Mass production has started

→ 4/11 cavities already produced and received!

nitation





6.5 MV/m

Limitation: Heavy MP

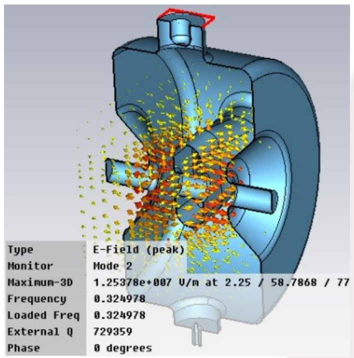
IHEP

DEVELOPMENT OF A VERY LOW BETA SUPERCONDUCTING SINGLE SPOKE CAVITY FOR CHINA-ADS LINAC* SRF 2013

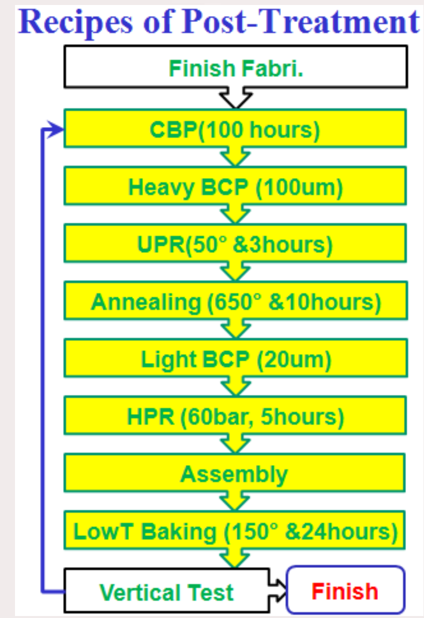
H. Li[#], J.P Dai, H. Huang, L.H. Li, H.Y. Lin, Q. Ma, W.P. Pan, P. Sha,Y. Sun, Q.Y. Wang, J. Zhang
Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

J. Dai, private communication

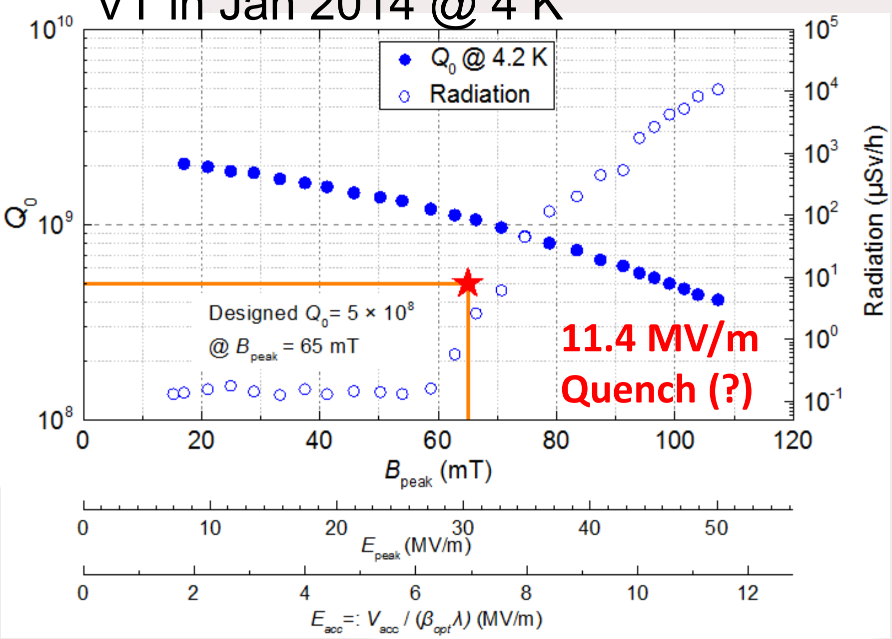
Main linac: Vertical test of one (over 5) Single-Spoke 0.21, 325 MHz

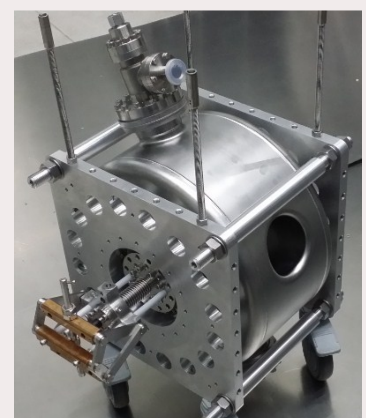


From design to fab.



VT in Jan 2014 @ 4 K





Jacked with adjustable antenna

IHEP

H. Zhao, "China ADS linac R&D progress", talk given at Linac 2014

THE RESEARCH ON SPOKE 0.40 CAVITY*
SRF 2013
P. Sha#, H. Huang, W. M. Pan, X. Y. Zhang, IHEP, Beijing, China

Main Linac: design of a Single-Spoke 0.40, 325 MHz

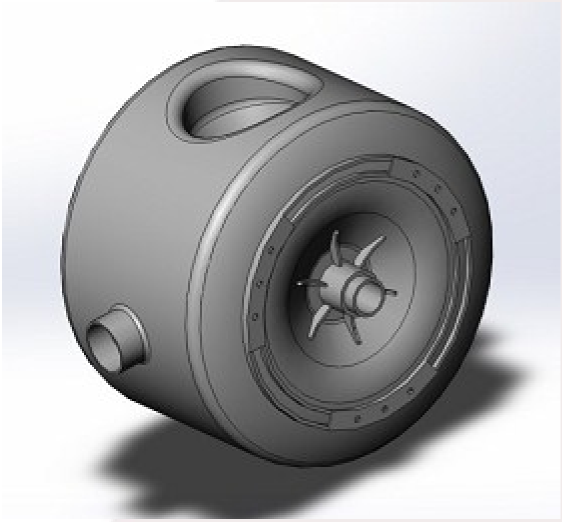


Table 1: Main Parameters of Spoke040 Cavity

Parameters	Value	Units
Diameter	556	mm
length	386.5	mm
Beam aperture	50	mm
R/Q	250	Ω
G	104	Ω
E_{peak}/E_{acc}	3.6	
B_{peak}/E_{acc}	8.2	mT/(MV/m)

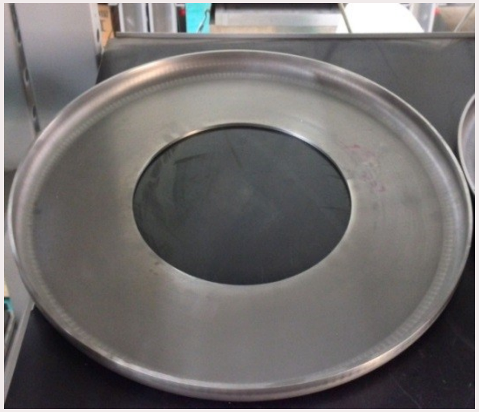
Fabrication started last year

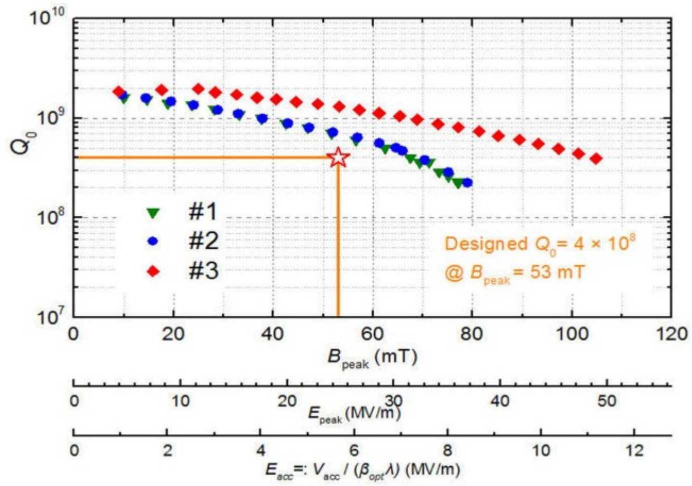
H. Zhao, “China ADS linac R&D progress”, talk given at Linac 2014

Y. He, private communication

IMP

Main Linac: Single-Spoke 0.21, 325 MHz: 3 cavities built and tested in vertical cryostat





✓Max. B_{peak}=107 mT @ Q_0=4.0x10^8

IMP

RF Design of a Double Spoke Cavity for C-ADS

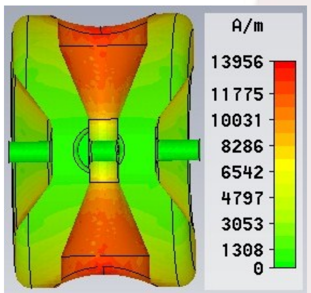
JIANG Tian-Cai (蒋天才)[1,2] HUANG Yu-Lu (黄玉璐)[1,2] HE Yuan(何源)[1]
ZHANG Sheng-Hu (张生虎)[1] LU Xiang-Yang (鲁向阳)[1,3]
[1] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, China
[2] University of Chinese Academy of Science, Beijing 100049, China
[3] State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China

Chinese Physics C, submitted

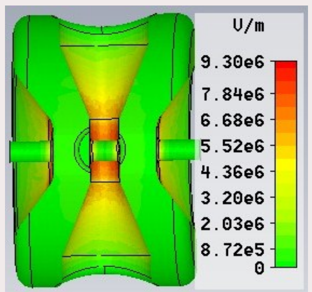
→ On-going R&D activities on cavity design

Design of Single-Spoke 0.32, 325 MHz

magnetic field distribution



electric field distribution



Y. He, private communication

Design of Double-Spoke 0.37, 325 MHz (as an alternative to Spoke 0.40)

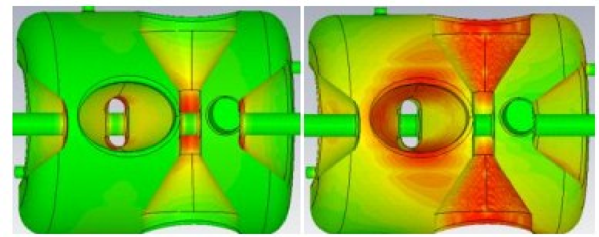
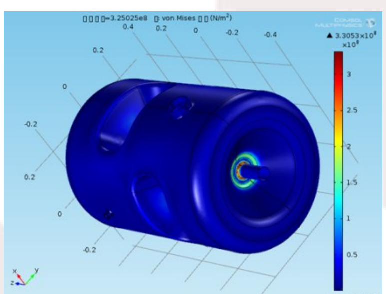
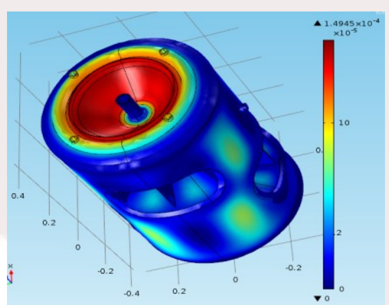


Fig.11. Electric (left) and magnetic (right) field

Design of Double-Spoke 0.52, 325 MHz



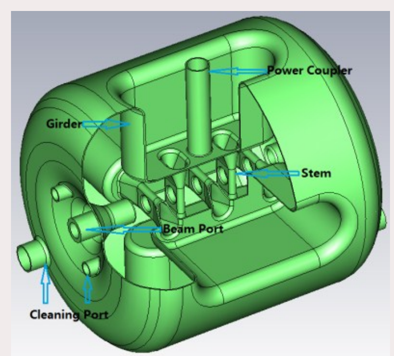
Without Stiffeners



With Stiffeners

Y. He, private communication

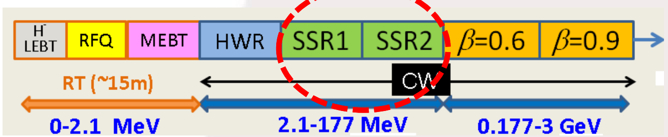
Design of CH-type 0.067, 162.5 MHz



Y. He, private communication

FERMILAB: PXIE

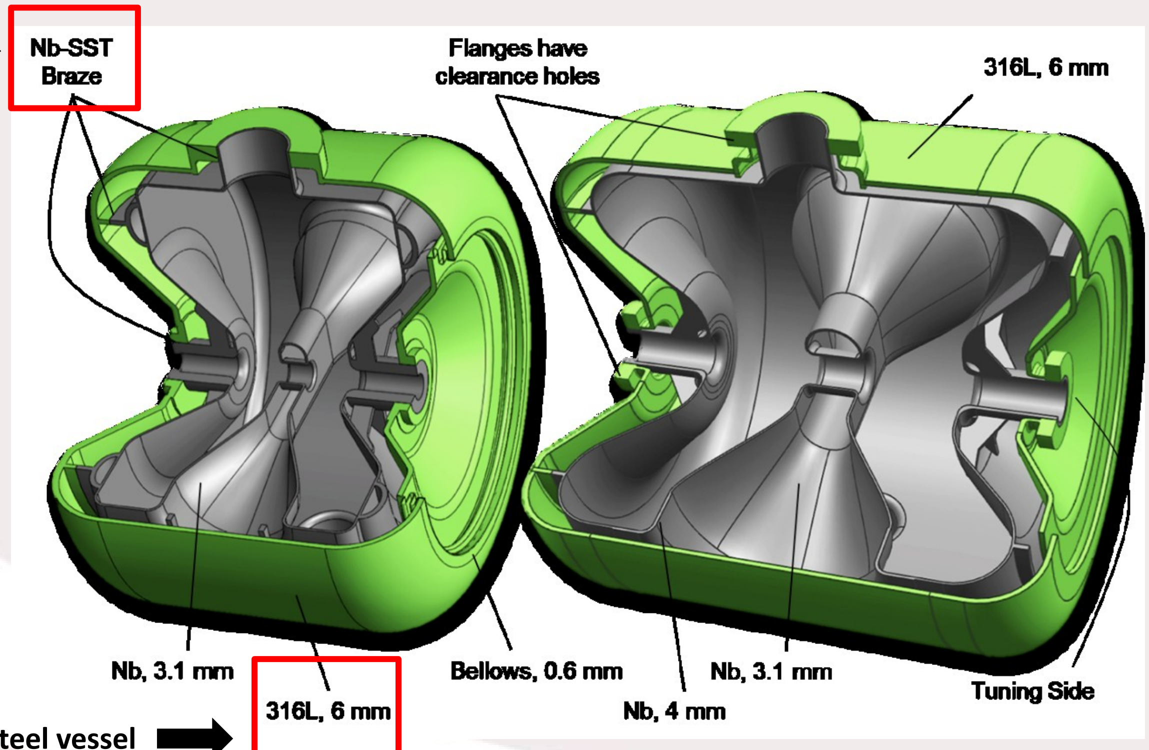
For PXIE, 25 MeV, 1 mA (=Injector of Project X)



SSR1 **Single-Spoke Resonator at 325 MHz with β=0.22**

SSR2 **Single-Spoke Resonator at 325 MHz with β=0.51**

No bellows



Stainless Steel vessel

FERMILAB

2 SSR1 prototypes and 10 SSR1 series cavities ⇒ **largest series of Spoke cavities in the world**

Spoke with collars

Finished end-wall

Prototype: jacketed cavity

Series: bare cavity

FERMILAB

COLD TESTS OF SSR1 RESONATORS FOR PXIE
SRF 2013
A. Sukhanov*, M. Awida, P. Berrutti, C.M. Ginsburg, T. Khabiboulline, O. Melnychuk, R. Pilipenko, Yu. Pischalnikov, L. Ristori, A. Rowe, D. Sergatskov, and V. Yakovlev, Fermilab†, Batavia, IL 60510, USA

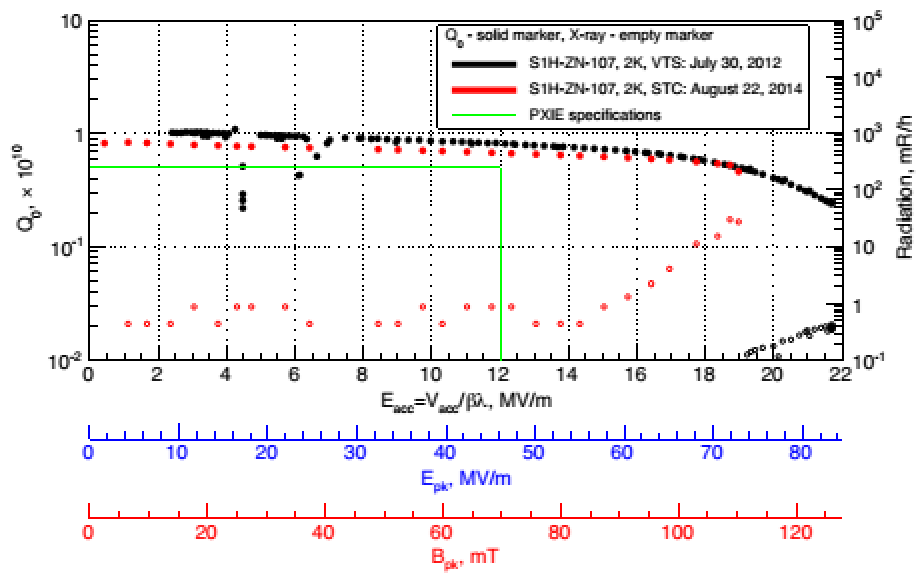
RESULT OF COLD TESTS OF THE FERMILAB SSR1 CAVITIES
LINAC 2014
A. Sukhanov*, M. Awida, P. Berrutti, E. Cullerton, B. Hanna, A. Hocker, T. Khabiboulline, O. Melnychuk, D. Passarelli, R. Pilipenko, Yu. Pischalnikov, L. Ristori, A. Rowe, W. Schappert, D. A. Sergatskov, Fermilab†, Batavia, IL 60510, USA

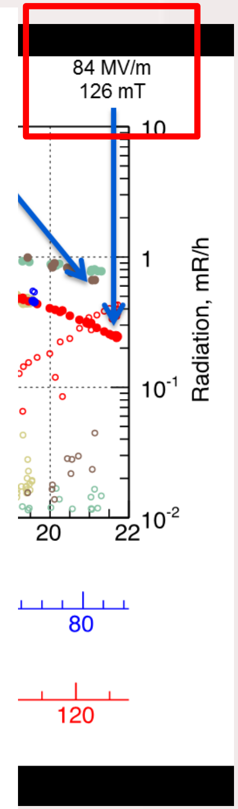
Vertical tests @ 2K of the 9 received SSR1: all validated

Very high Epk

1. Inspection –
2. BCP 120-15
3. HPR
4. 600 °C, 10 h
5. RF Tuning
6. BCP 20-30
7. HPR (horiz
8. Assemble
9. Evacuate +
10. Vertical Tes
11. Helium Ves
12. HPR
13. BCP 20-30
14. HPR
13. Assemble
14. Evacuate +
15. Horizontal T
16. Ready for S

No severe degradation from bare cavity tested in VC (black dots) to jacketed cavity tested in HC (red dots)





Highest Eacc (22 MV/m) and Epk (84 MV/m) ever reached in Spoke cavity in CW mode

IBS: RISP

SUPERCONDUCTING LINAC FOR THE RARE ISOTOPE SCIENCE PROJECT

H. J. Kim, H. J. Cha, M. O. Hyun, H. J. Jang, H. C. Jung,
Y. K. Kim, M. K. Lee, G.-T. Park, Institute for Basic Science, Daejeon, Korea

LINAC 2014

RAON CRYOMODULE DESIGN FOR QWR, HWR, SSR1 AND SSR2*

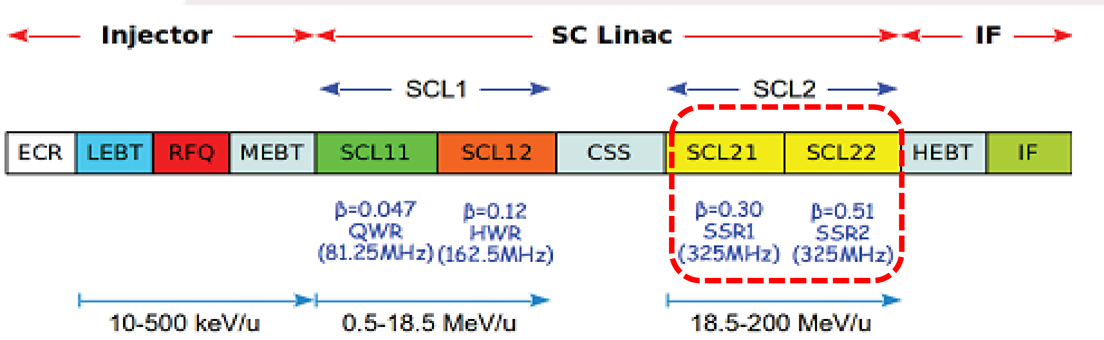
Woo Kang Kim#, Heetae Kim, Min Ki Lee, Young Kwon Kim, Gunn-Tae Park and Hyung Jin Kim
Rare Isotope Science Project, Institute for Basic Science, Daejeon 305-811, Republic of Korea

LINAC 2014

H.J. Kim, "Status of the RAON Heavy Ion Accelerator Project", talk given at Linac 2014

- **2 SC Linacs (SCL1 and SCL2) for ions acceleration: proton (600 MeV) to Uranium (200 MeV/u)**
- **1 SC Linac for RIB acceleration (18.5 MeV/u)**

RAON (Driver Linac SCL1 and SCL2)



23 SSR1 Single-Spoke Resonators at 325 MHz with β=0.30

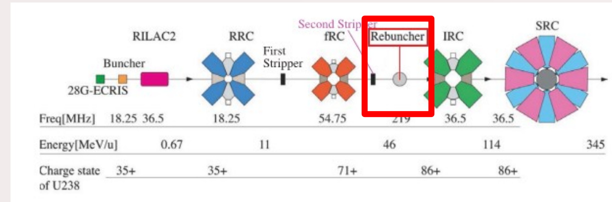
23 SSR2 Single-Spoke Resonators at 325 MHz with β=0.51

RIKEN Nishina Center

DESIGN OF A TRIPLE-SPOKE CAVITY AS A REBUNCHER FOR RIKEN RI-BEAM FACTORY

SRF 2013

L. Lu*, O. Kamigaito, N. Sakamoto, K. Suda†, and K. Yamada
RIKEN Nishina Center for Accelerator-Based Science, Wako-shi, Saitama 351-0198, Japan



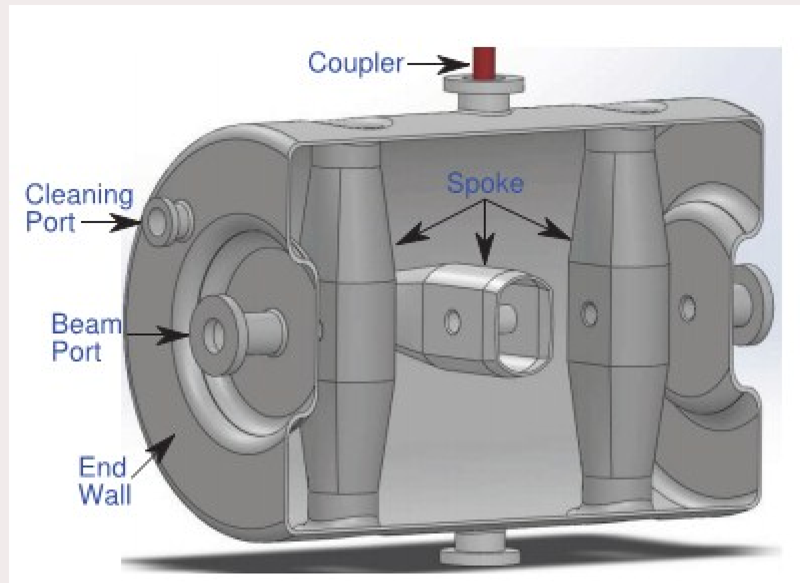
Rebuncher for intense heavy ions

Triple-Spoke Resonator at 219 MHz with β=0.303

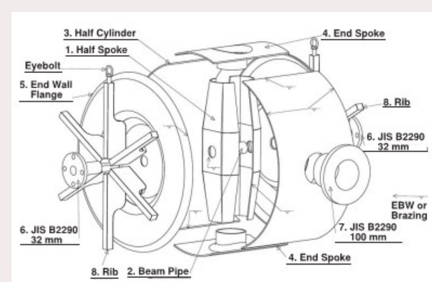
Table 1: Parameters of Triple-Spoke Cavity

Frequency	219 MHz
$\beta(=v/c)$	0.303
Voltage (V_{total})	3 MV
Cavity Length	829 mm
Effective Length (L_{eff})	829 mm
Cavity Diameter	580 mm
Beam Bore Diameter	30 mm
R/Q	665 Ω
G (=QR_s)	74.0 Ω
E_{acc}	3.62 MV/m
E_{pk}/E_{acc}	4.42
B_{pk}/E_{acc}	11.01 mT/(MV/m)
R_s @ 4.5 K	48 nΩ
Q	1.54×10^9
Power Dissipation	8.8 W

Low frequency for better phase acceptance



First Single-Spoke model in Copper under fabrication



Developments **for low and medium velocity (β≤0.5)** proton and ion Linacs

Developments **for electron (β=1) and high velocity (β≥0.5)** proton and ion Linacs

Old Dominion University

4 different frequencies

- 325 MHz, β= 0.82 and 1, single and double
  - Collaboration with JLab
- 352 MHz, β= 0.82 and 1, single and double
  - Collaboration with JLab
- 500 MHz, β= 1, double
  - Collaboration with Niowave
  - Collaboration with JLab
- 700 MHz, β= 1, single, double, and triple
  - Collaboration with Niowave, Los Alamos and NPS

3 different spoke type

ODU/JLAB

Superconducting spoke cavities for high-velocity applications

PhysRev STAB

C. S. Hopper* and J. R. Delayen†

Center for Accelerator Science, Department of Physics, Old Dominion University, Norfolk, Virginia 23529, USA, and Accelerator Division, Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606, USA

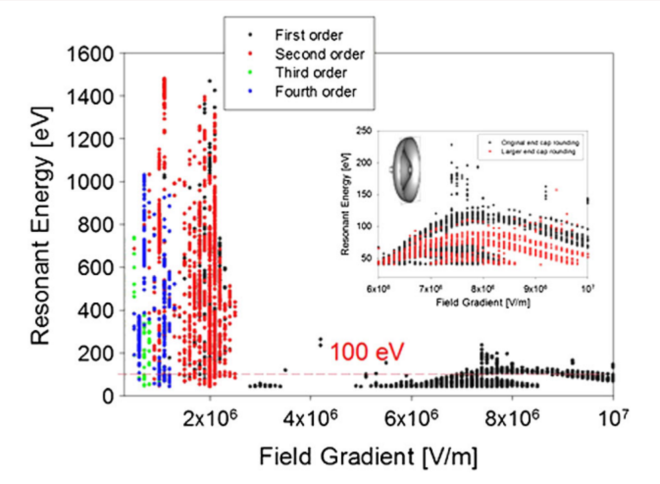
(Received 12 July 2013; published 3 October 2013)

Generic studies for high velocity protons and ions linac

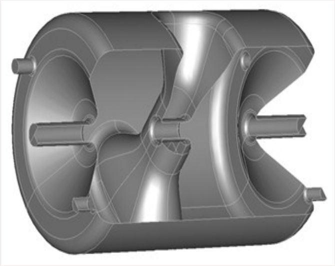
- Design and optimization of **double-spoke cavities at 325 and 352 MHz with β=0.82 and 1**

RF properties	325 MHz, β_0 = 0.82 *Low Ep,Bp*	325 MHz, β_0 = 1.0 *High R*	352MHz, β_0 = 0.82 *Low Ep,Bp*	352 MHz, β_0 = 1.0 *High R*	Units
Energy gain at β_0	757	922	699	852	kV
R/Q	625	744	630	754	Ω
QRs	168	195	169	193	Ω
(R/Q)*QRs	1.05×10^5	1.45×10^5	1.07×10^5	1.46×10^5	Ω^2
Ep/Eacc	2.6	2.8	2.7	2.75	-
Bp/Eacc	4.97	5.6	4.9	5.82	mT/(MV/m)
Bp/Ep	1.9	2.0	1.8	2.12	mT/(MV/m)
Energy Content	0.45	0.56	0.35	0.43	J
Power Dissipation*	0.37*	0.43*	0.33**	0.36**	W
At Eacc = 1 MV/m and reference length $\beta_0\lambda$ *Rs = 68 nΩ **Rs = 73 nΩ					

MP soft barriers study
End-wall shape optimisation



First prototype under fabrication: 325 MHz, β_0 = 0.82 Single-Spoke cavity



ODU/JLAB

CHARACTERIZATION AND FABRICATION OF SPOKE CAVITIES FOR HIGH-VELOCITY APPLICATIONS*

SRF 2013

C. S. Hopper†, H. Park, and J. R. Delayen
Center for Accelerator Science, Department of Physics,
Old Dominion University, Norfolk, VA, 23529, USA and
Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

FABRICATION AND MEASUREMENTS OF 500 MHz SUPERCONDUCTING DOUBLE SPOKE CAVITY*

LINAC 2014

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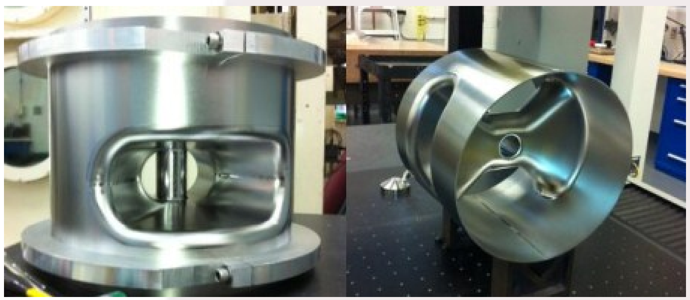
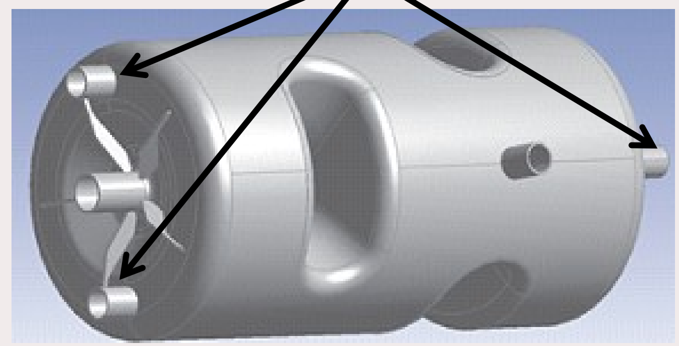
For Compact Light Source (CLS)

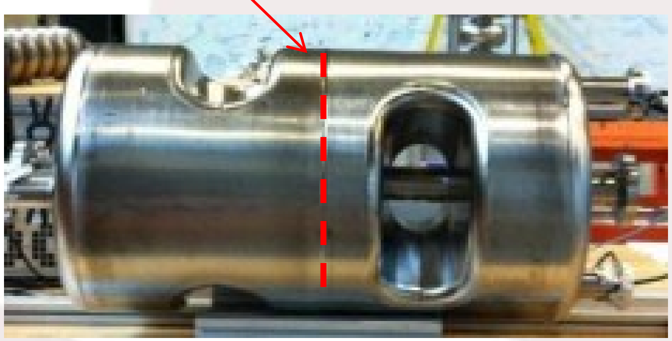
- Goal: energy gain > 25MeV with 4 **double-spoke cavities at 500 MHz with β_0=1**

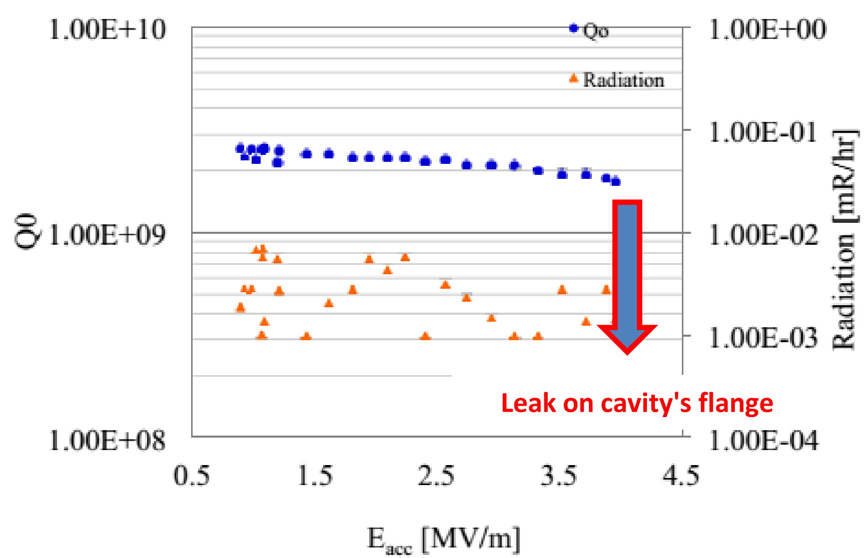
Extra ports on end-wall cavity preparation like the ESS Double-Spoke cavity





Interesting point: cavity in 2 pieces and final welding in the centre





JAEA

DESIGN OF ERL SPOKE CAVITY FOR NON-DESTRUCTIVE ASSAY RESEARCH — ERL 2011

M. Sawamura#, R. Hajima, R. Nagai, N. Nishimori, JAEA, Tokai, Ibaraki 319-1195, Japan

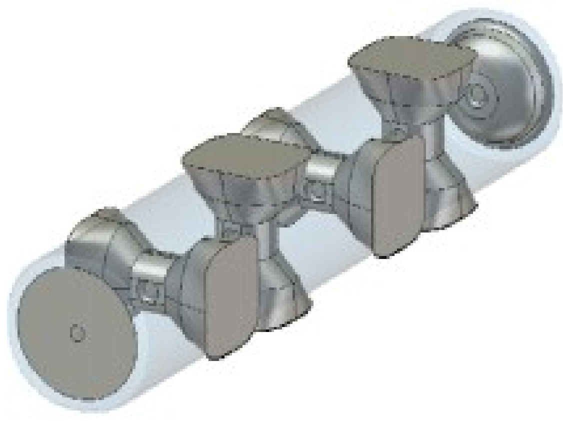
RF Characteristics of Spoke Cavity Model for ERL

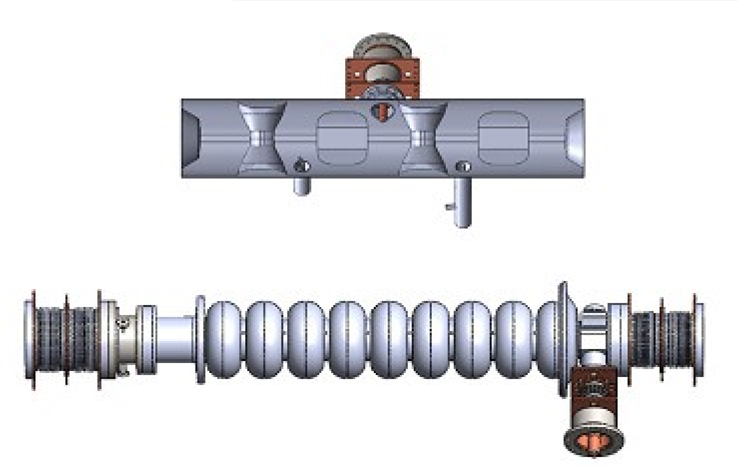
Masaru Sawamura[1], Ryoji Nagai, Nobuyuki Nishimori, Ryoichi Hajima
Japan Atomic Energy Agency
2-4 Shirakata-Shirane, Tokai, Ibaraki 319-1195 PASJ 2012

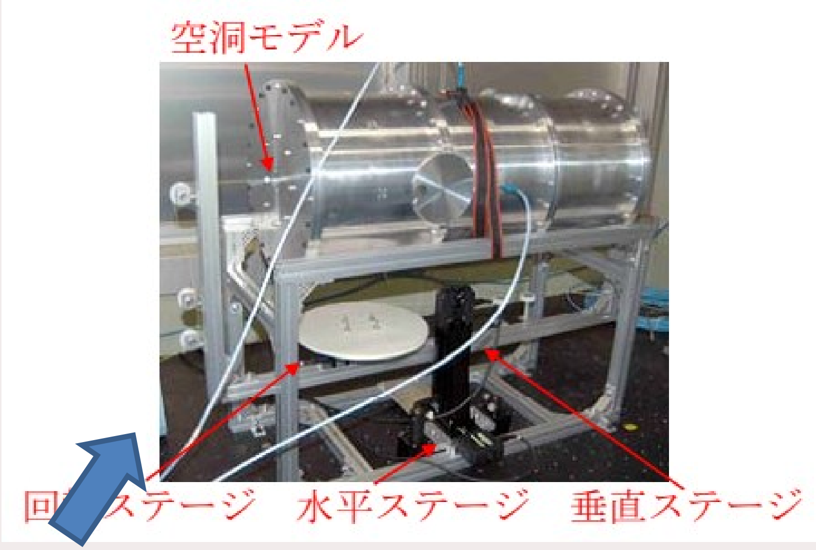
For ERL

- Design of a **5-gap spoke cavities at 650 MHz with β_0=1**

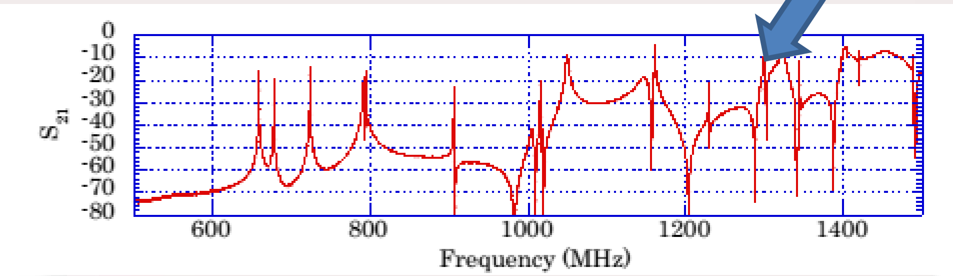
→ Compactness and easier HOM extraction compared to 9-cell elliptical cavity







First Aluminum cavity model for RF and HOM studies



KEK/KYOTO/JAEA

DEVELOPMENT OF SUPERCONDUCTING SPOKE CAVITY FOR ELECTRON ACCELERATORS*

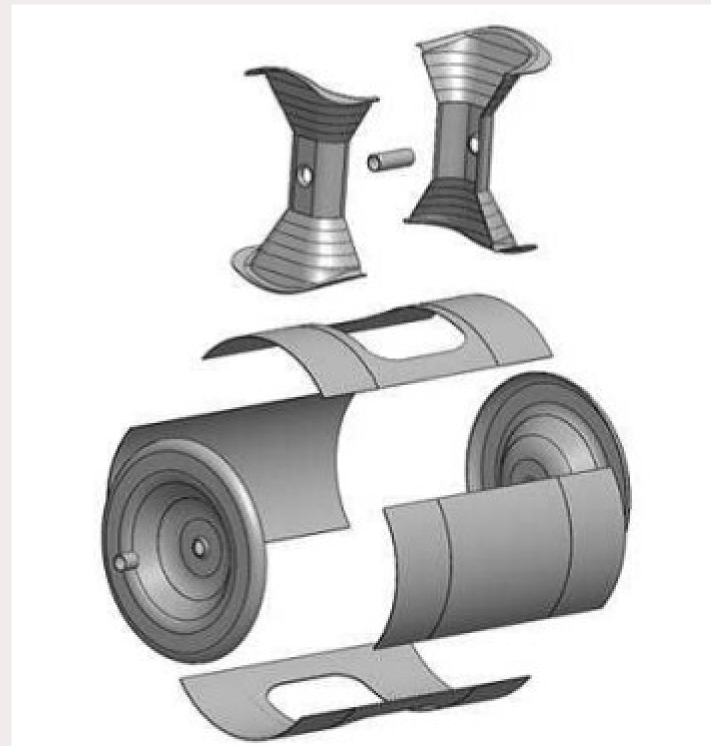
LINAC 2014

T. Kubo†, T. Saeki, KEK, High Energy Accelerator Research Organization, Tsukuba, Ibaraki, Japan
E. Cenni, H. Fujisawa, Y. Iwashita, H. Tongu, Kyoto University, Uji, Kyoto, Japan
R. Hajima, M. Sawamura, Japan Atomic Energy Agency, JAEA, Tokai, Ibaraki, Japan

For compact industrial-use X-ray source

- Design of a **2-gap spoke cavitiy at 325 MHz with β_0=1**

Parameter	Value	Unit
Frequency	325	MHz
Cavity diameter	609.5	mm
Cell length	461.2	mm
Cavity length	1383.6	mm
E_{peak}/E_{acc}	3.7	
B_{peak}/E_{acc}	7.5	mT/(MV/m)
R/Q	691	Ω
Transit time factor	0.81	



Fabrication has just started

Thank you for your attention

TRIUMF: Balloon Spoke cavity

B. Laxdal, private communication

Z.Y. Yao, V. Zvyagintsev, R.E. Laxdal, B.S. Waraich, TRIUMF, R. Edinger, PAVAC

Balloon geometry motivation

- suppresses multipacting for single spoke resonators
- may find a useful application for proton and ion accelerator projects
- TRIUMF has completed initial RF, mechanical studies on this special geometry for both low (β=0.12) and medium (β=0.3) β geometries
- The RF properties are comparable with that of traditional spoke cavities but with improved RF efficiency in addition to the reduced multipacting
- The balloon geometry supplies a better mechanical strength than the traditional bare spoke cavity. Good mechanical parameters are obtained by a compact stiffeners design based on the electro-magnetic and deformation compensation
- The mechanical study on the β=0.3 balloon resonator is still ongoing. Fully study of balloon variant spoke cavity on the low and medium β region will make an in-depth understand of this new kind of spoke geometry

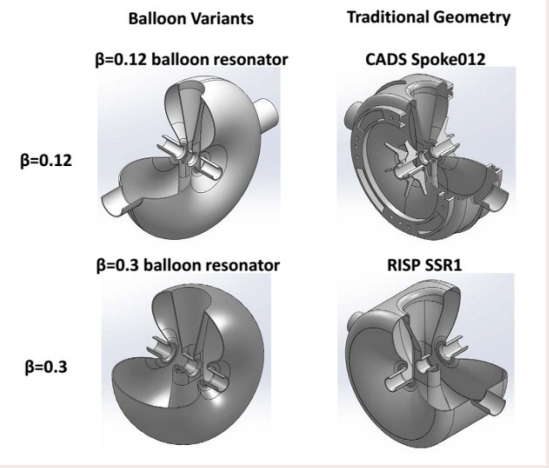
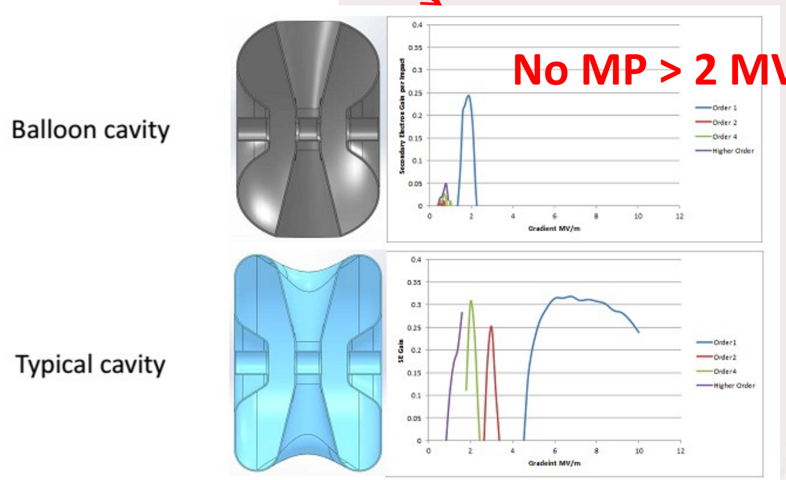


Table 1: RF parameters comparison at the low and medium β region.

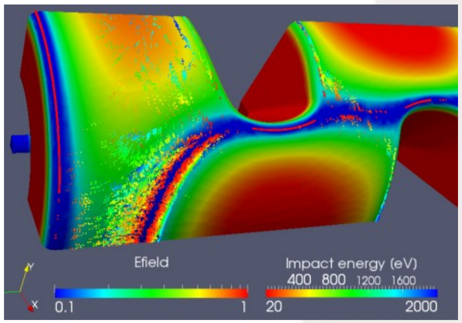
Parameters	Unit	CADS Spoke012	Balloon 0.12	RISP SSR1	Balloon 0.3
Ep/Eacc	1	4.5	4.8	4.7	4.4
Bp/Eacc	mT/(MV/m)	6.4	7.5	6.4	6.8
R/Q	Ω	142	161	234	272
G	Ω	61	63	94	98
Eacc	MV/m	7.1	7.1	7.5	8.0
Ep	MV/m	32	34	35	35
Bp	mT	44	53	48	54

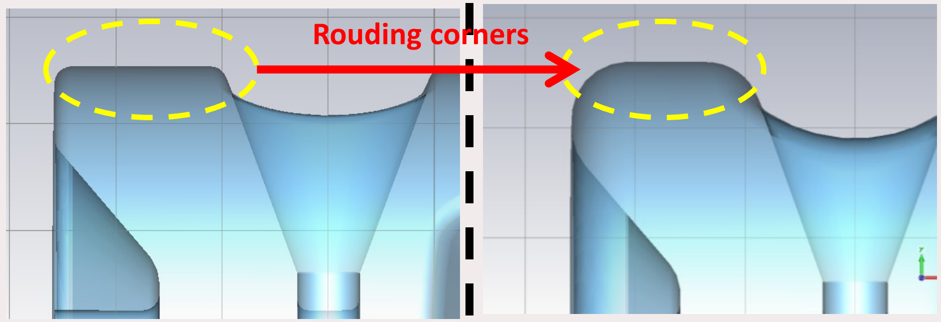


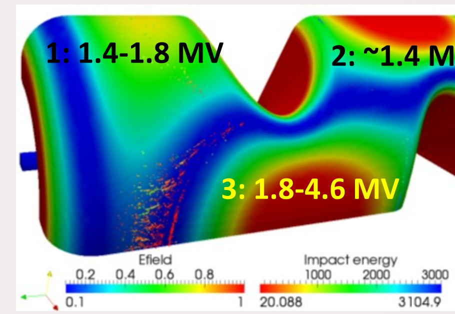
JLAB

F. He et al, Design of a beta=1 double spoke cavity for the BES-CLS ICS light source, FLS2012

Intensive MultiPacting calculations and cavity shape optimizations to reduce MP barriers

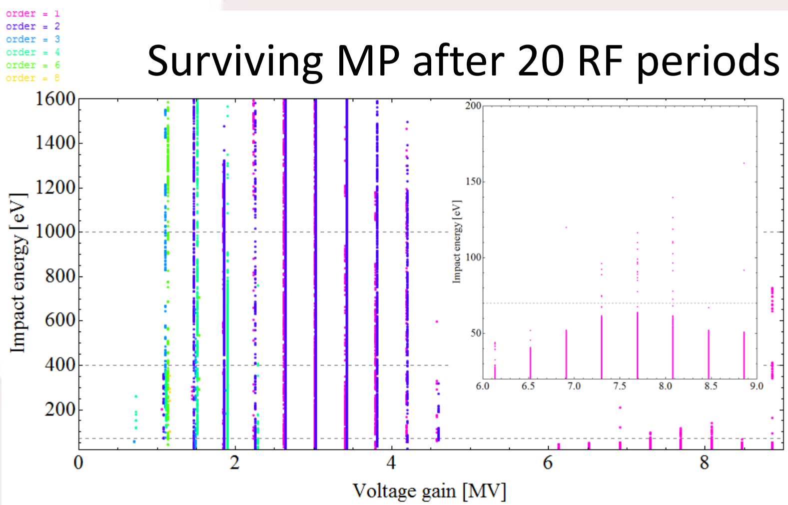


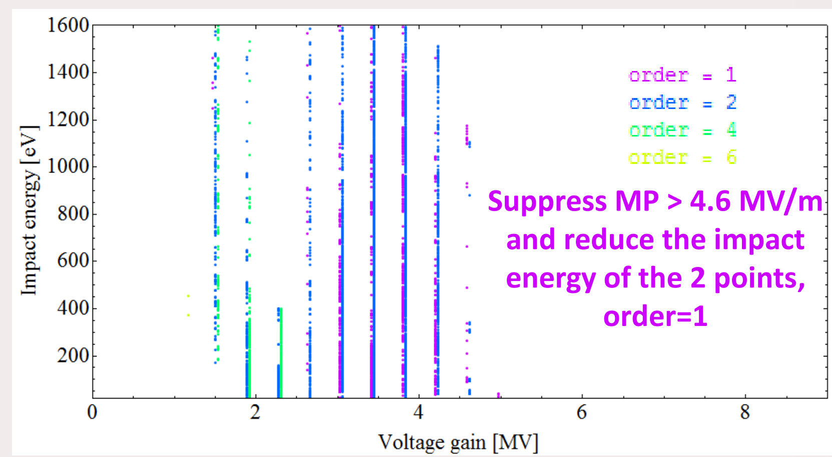




Original geometry

Optimised geometry





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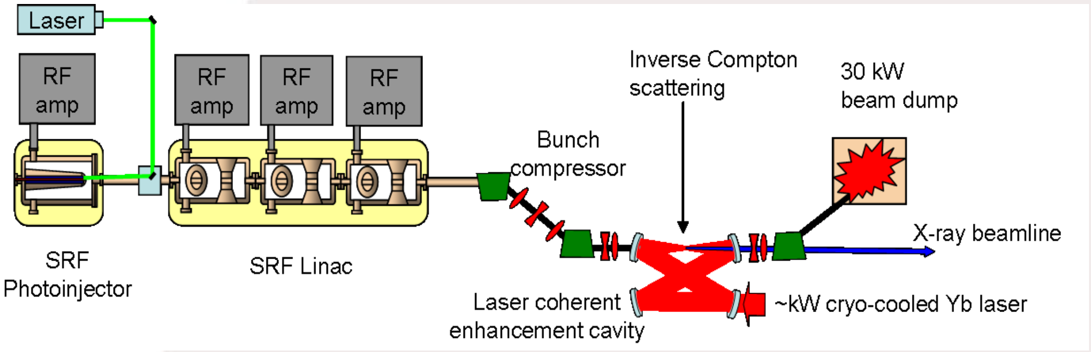
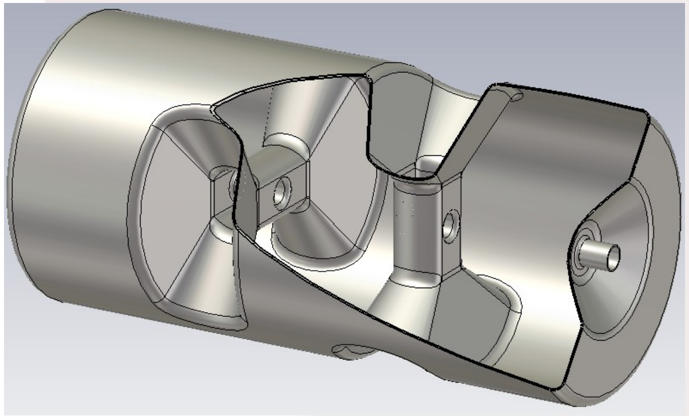
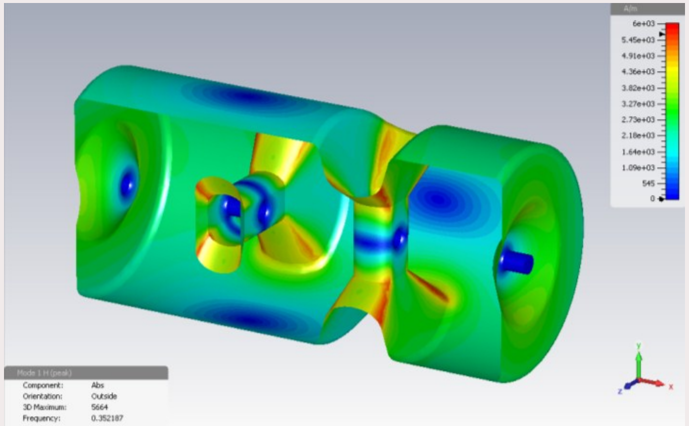
For Compact Light Source (CLS)



- CW Linac at 4 K for 1 mA electron, 4 MeV in, 22 MeV out (20MeV minimum). Linac length <= 4m
- Two **double-spoke cavities at 352MHz with β_0=1** in one cryomodule

Specification: Vacc/cavity = 9 MV, Ep < 30 MV/m, Bp < 80 mT





Single-Spoke cavity as a first prototype.