LHC Crab Cavity Progress & Outlook

R. Calaga, E. Jensen, CERN

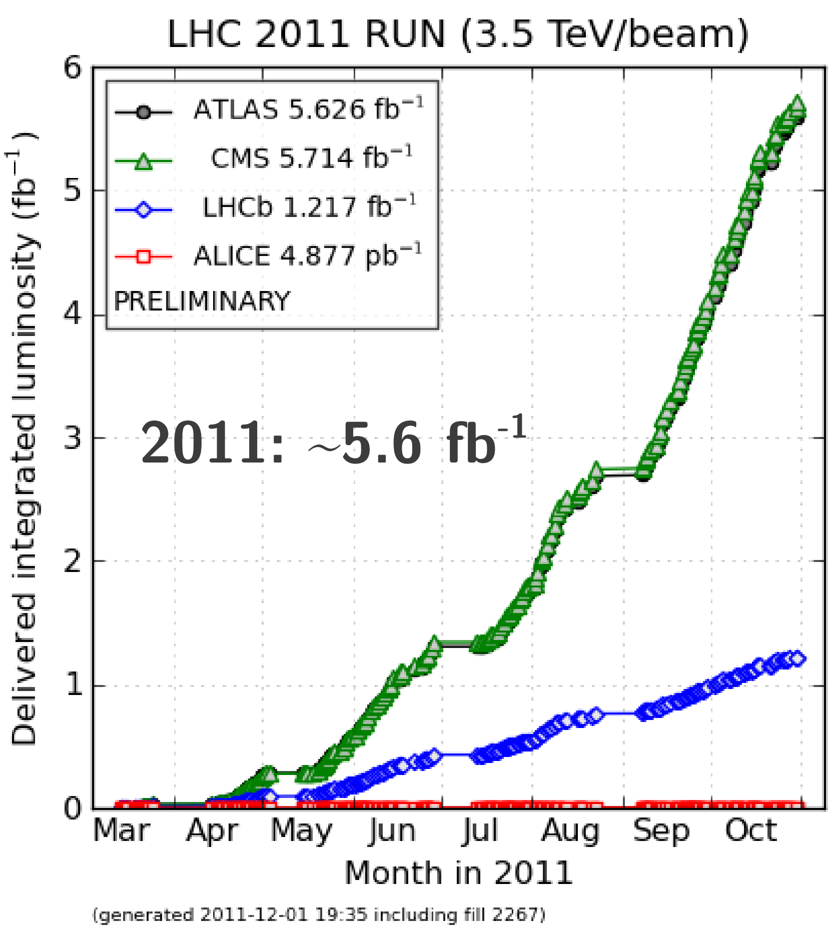
SRF2013, September 27, 2013

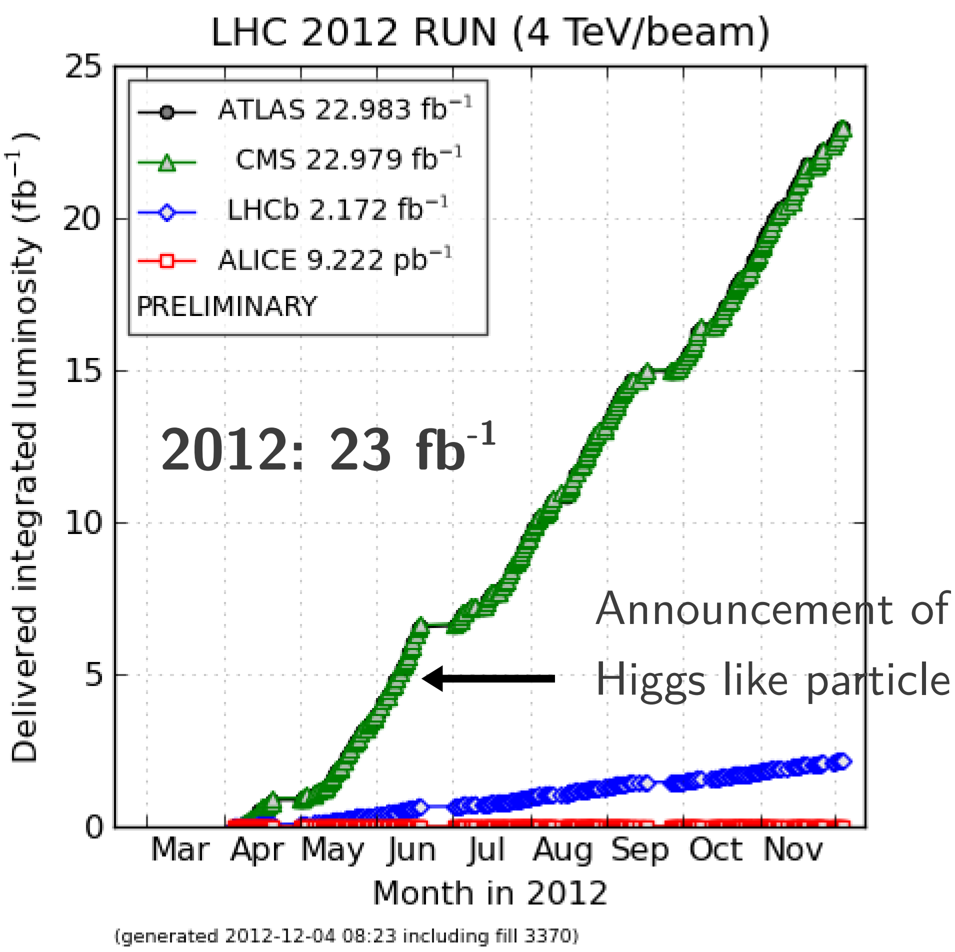
On behalf of the LHC-CC collaboration

Special Ack: CERN, RF, EN & TE Groups

Present Performance,LHC

Courtesy: LHC-OP



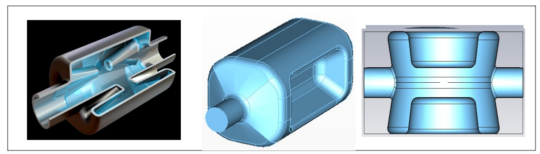


After present shutdown (2014-20) $\rightarrow$ **60 fb^{-1}/yr**

(Higgs mass, spin, indications of strength & couplings to fermions & bosons)

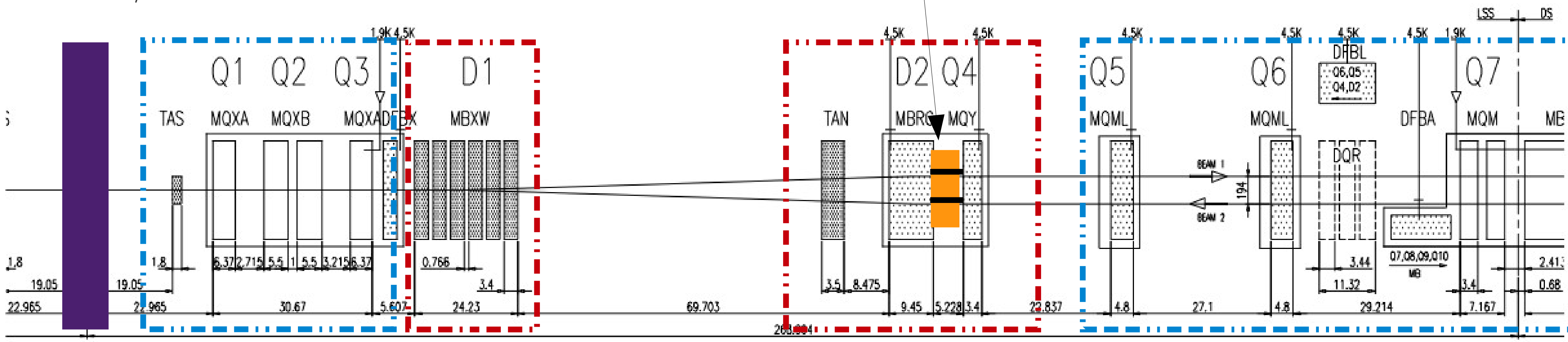
HL-LHC Upgrade (2020-30) **250-300 fb^{-1}/yr**

A total of 1.2 km of the LHC to be upgraded



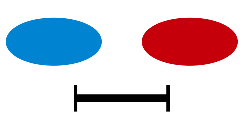
crab cavities, why?

ATLAS/CMS



60m common channel

And Beyond



Collision spacing

3.75m

32 parasitic collisions/IP → Total 128

(need separate beams with crossing angle)

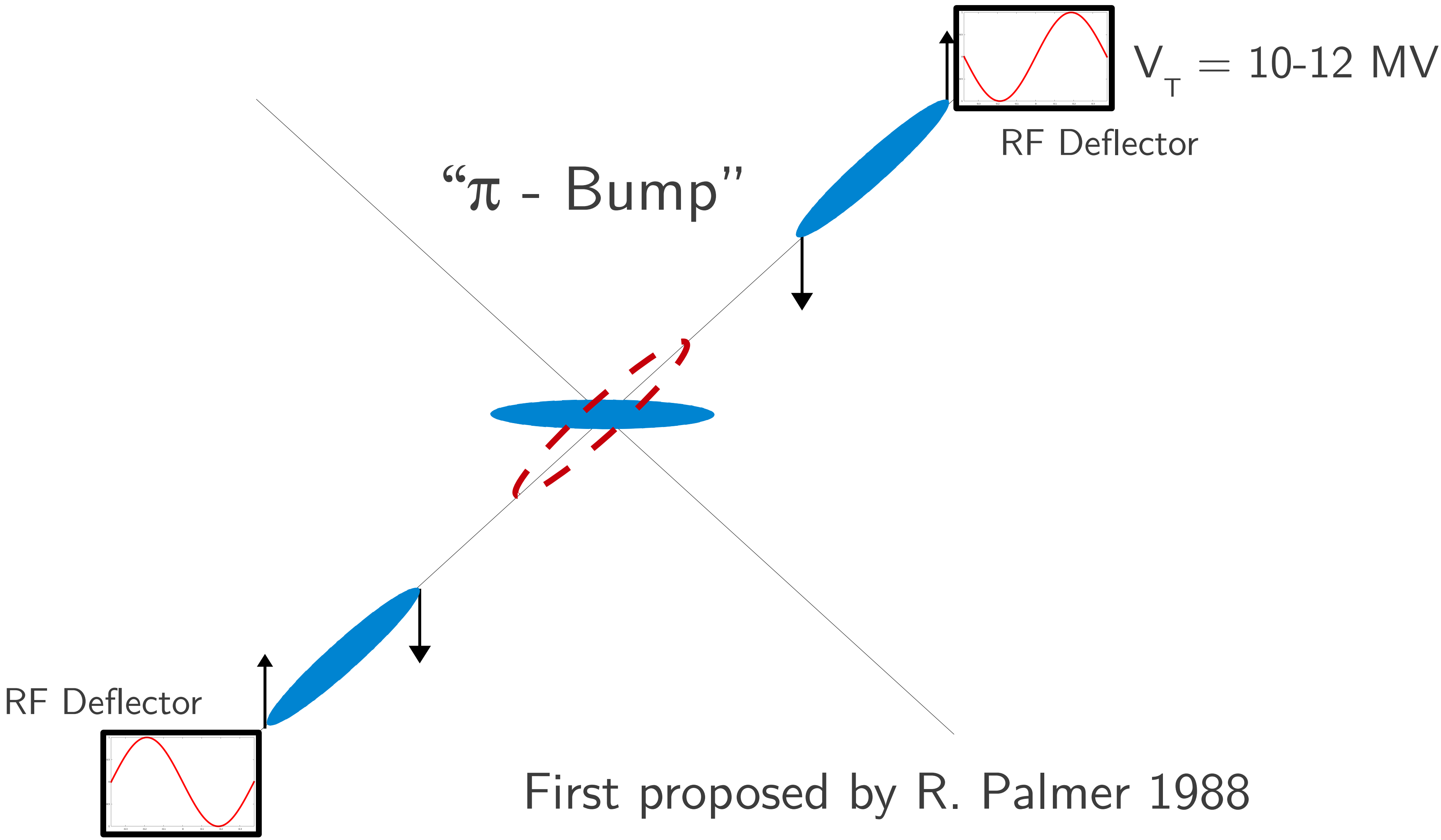
Elucidating the Higgs mechanism...

(*i.e. from which grape the bottle is made of ?*)

To elucidate the Higgs mechanism all three main contenders use extremely demanding SCRF technology:

- High Luminosity LHC: Accelerating RF and Crab Cavities (novel designs & precision timing)
- A circular Higgs Factory collider: 10 to 20 GV of CW SCRF
- A linear Higgs Factory collider, the ILC: 250 GV of pulsed SCRF

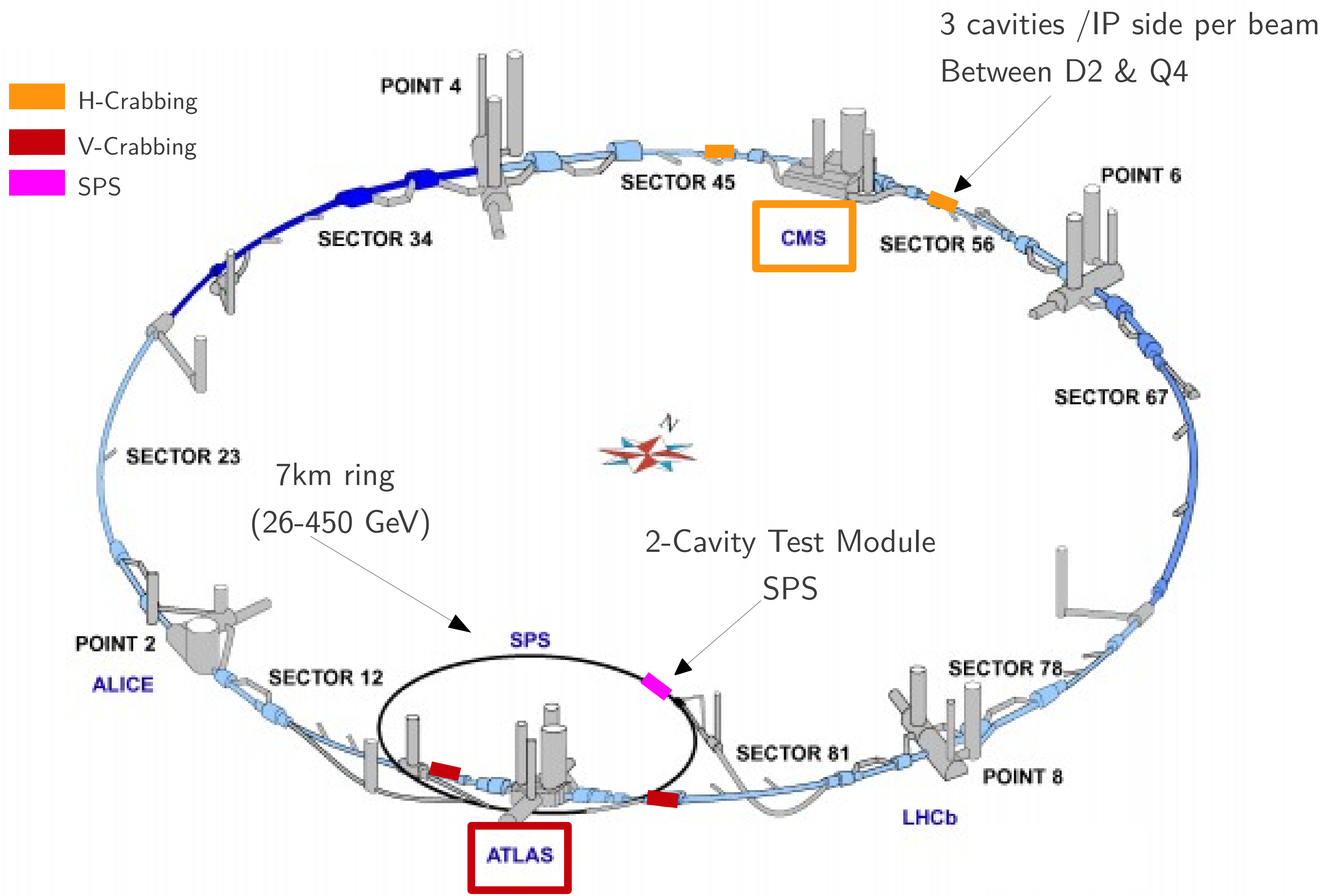
To Maximize Collision Efficiency



First proposed by R. Palmer 1988

Applied to circular e^+e^- collider 2007

LHC Crab Scheme



SPS Test Module

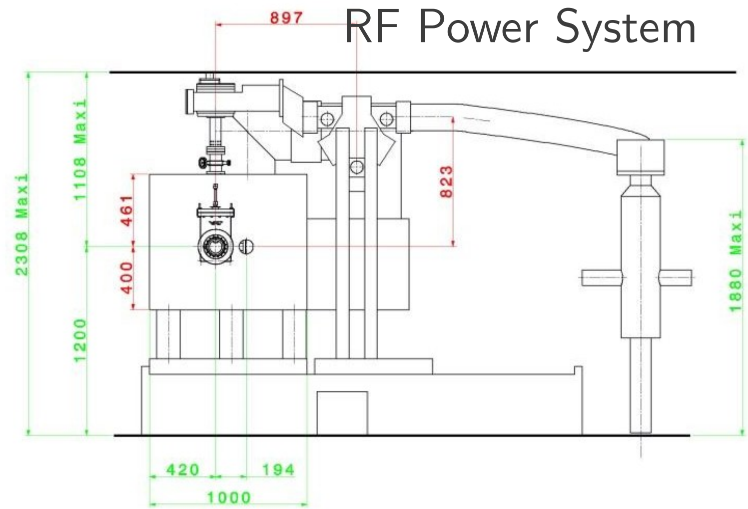
Courtesy: EN-MME

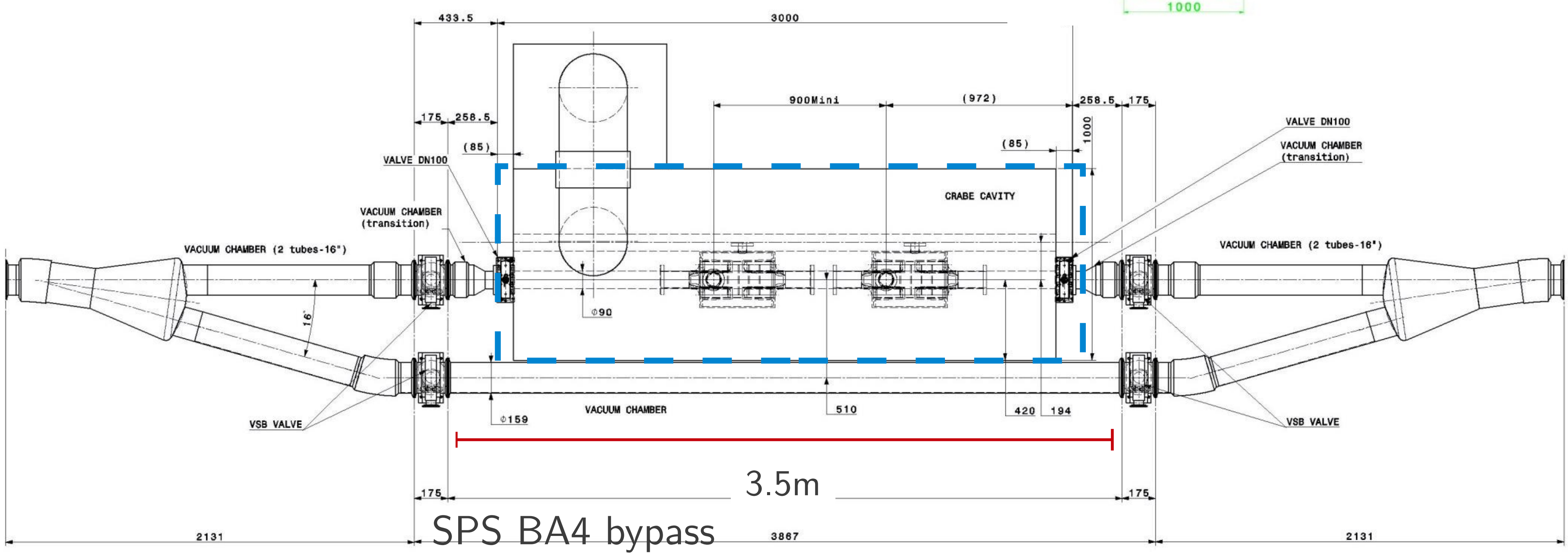
Proof of principle demonstration with protons

Important beam tests

- Technology validation, performance, stability
- Effects on the beam, cavity failures, radiation

RF Power System

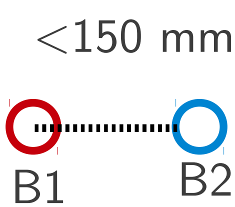


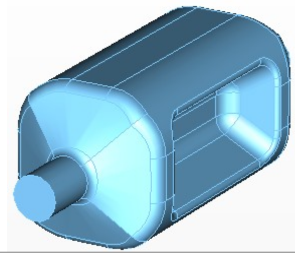


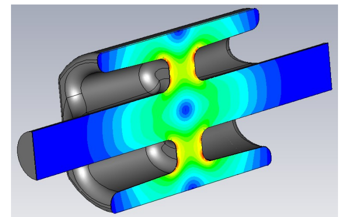
3.5m

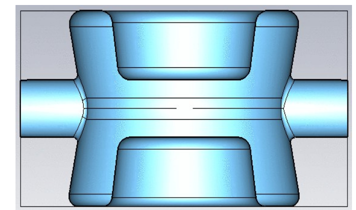
SPS BA4 bypass

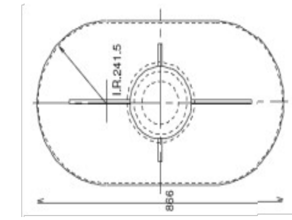
Kick Voltage: 3.4 MV, 400 MHz









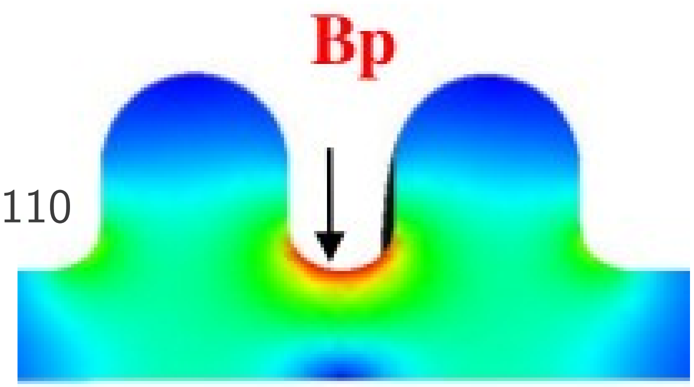


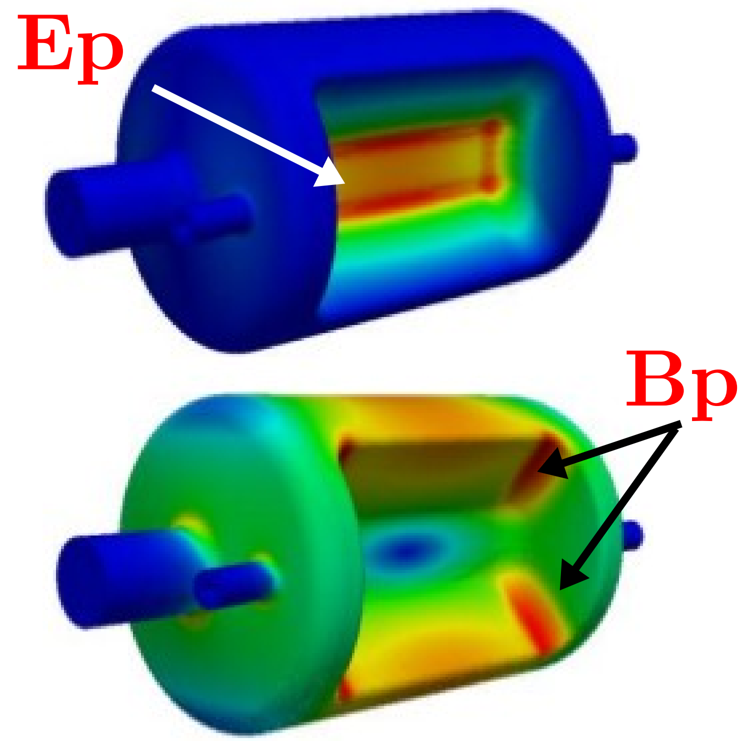
		RF Dipole (ODU-SLAC)	4-Rod (UK)	¼ Wave (BNL)	KEKB
Geometrical	Cavity Radius [mm]	**140.5**	**140**	**139**	**550**
	Cavity length [mm]	535	383	344	375
	Beam Pipe [mm]	84	84	84	305
	Peak E-Field [MV/m]	33	34	38	34
	Peak B-Field [mT]	**56**	**79**	**70**	**98**
RF	R_T/Q [Ω]	427	565	426	47
	Nearest Mode [MHz]	577	371-378	582	~350

Favorable distribution of peak surface fields
(And compact due to quasi TEM or TE11-like)

TM110

TM110





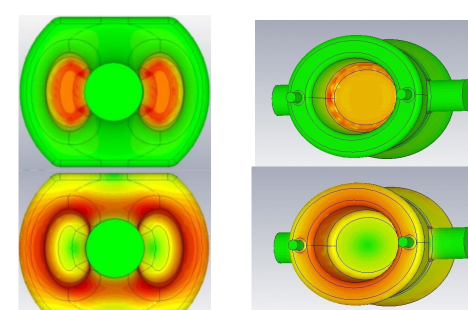
x3-4 bigger transversely

40% higher Bp

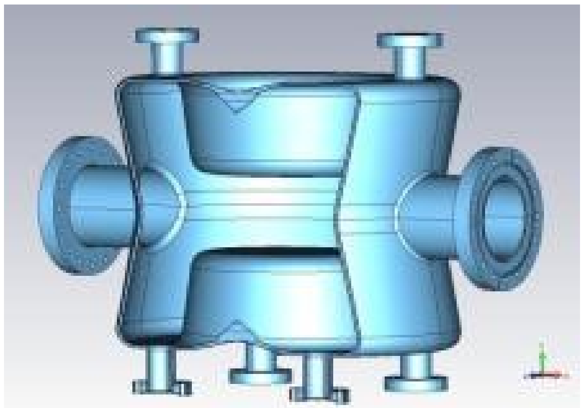
x6 smaller R/Q

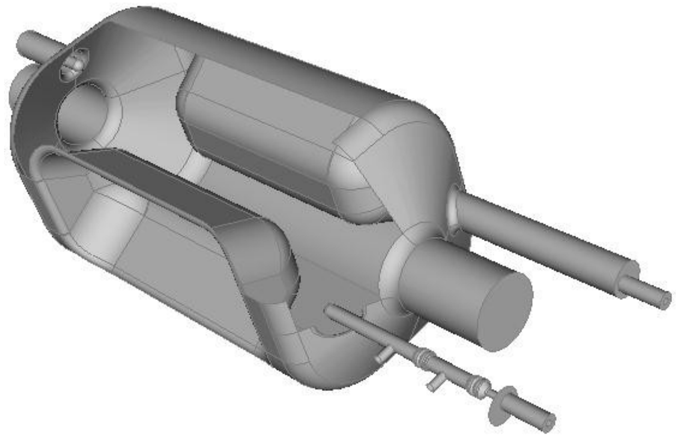
HOMs well separated

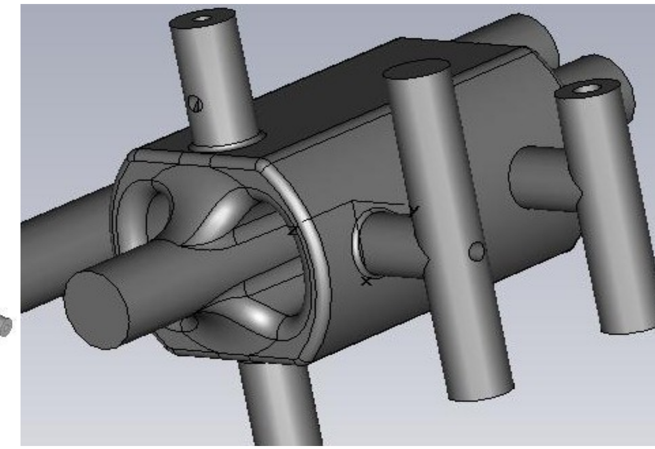
Same with other designs



All Prototypes in Bulk Niobium (2011-12)







Summary of Cavity Tests:

All cavities built by Niowave Inc. in bulk Niobium

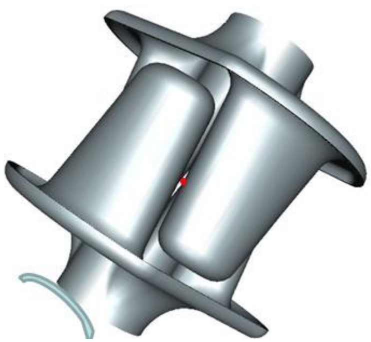
Surface treatment and first RF tests in the last 6 months

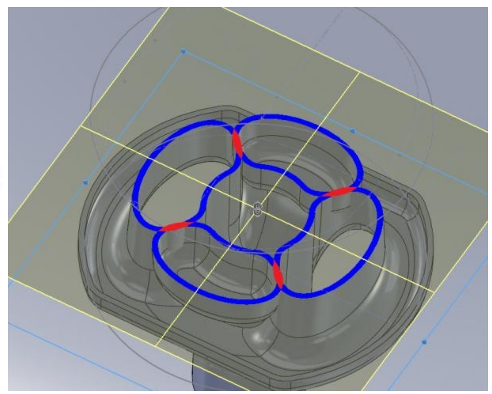
1 very good result, 2 moderate-to-good results

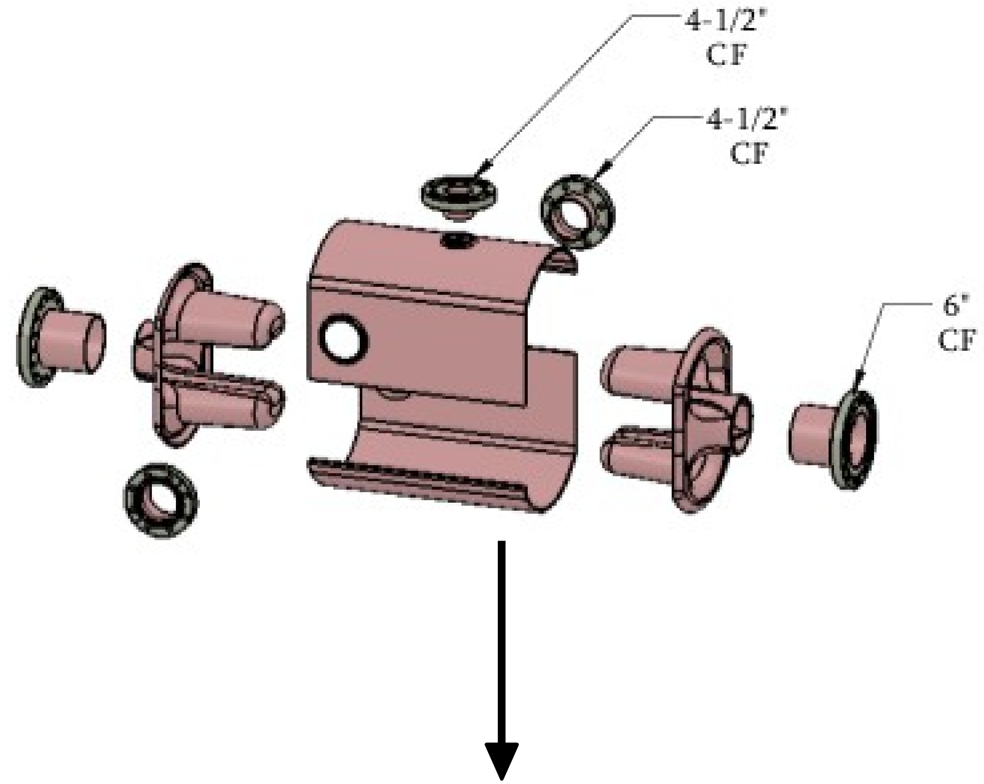
Only 4Rod cavity results are presented, see next talks for the other cavities

4Rod Prototype

Courtesy: Lancaster U, Niowave Inc.







End plates from solid ingot

Wire EDM pre-forms from ingot

Machine all surfaces

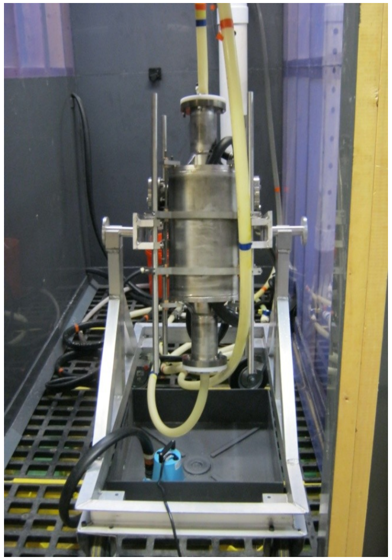
Outer shell in two-part sheet metal

4Rod Cavity Treatment-Testing

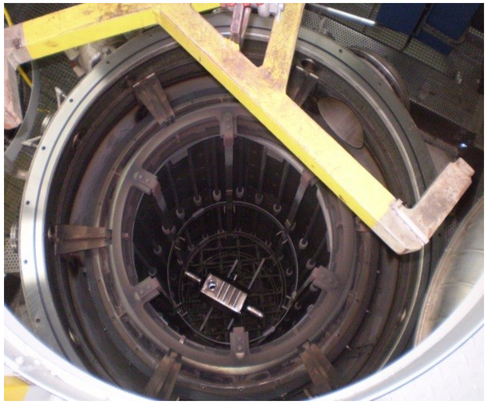
(Ack: BE-RF, TE-VSC, EN-MME)

Surface Treatment

Niowave



H_2 Degassing, CERN



600^0C, 48 hrs

High Press Rinsing

CERN

RF Measurements

CERN-SM18

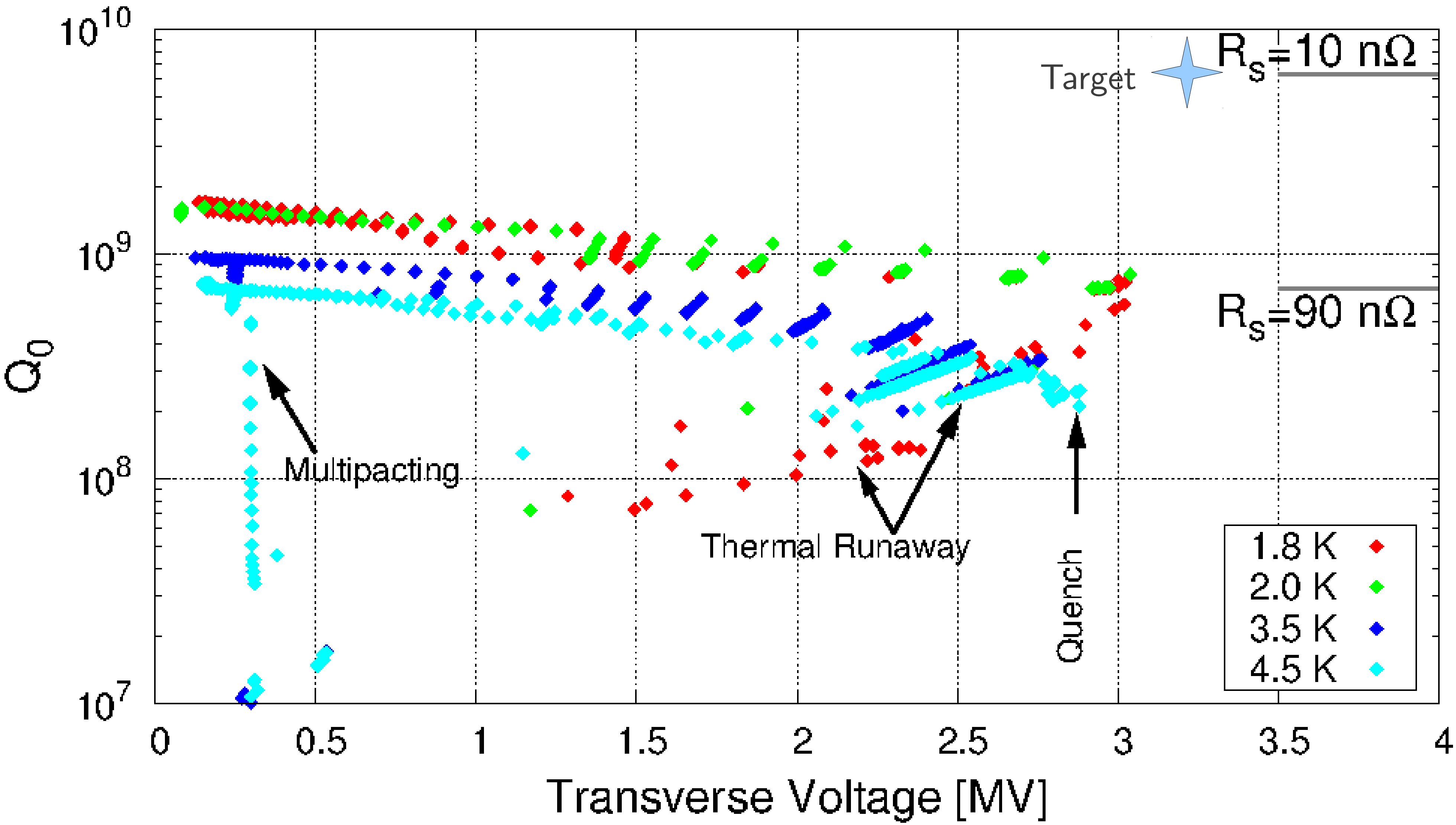
1st test performed Nov 2012

2nd test in Aug-Sep 2013

4Rod Cavity Qvs.$V_\perp$

Second test after light BCP (2013)

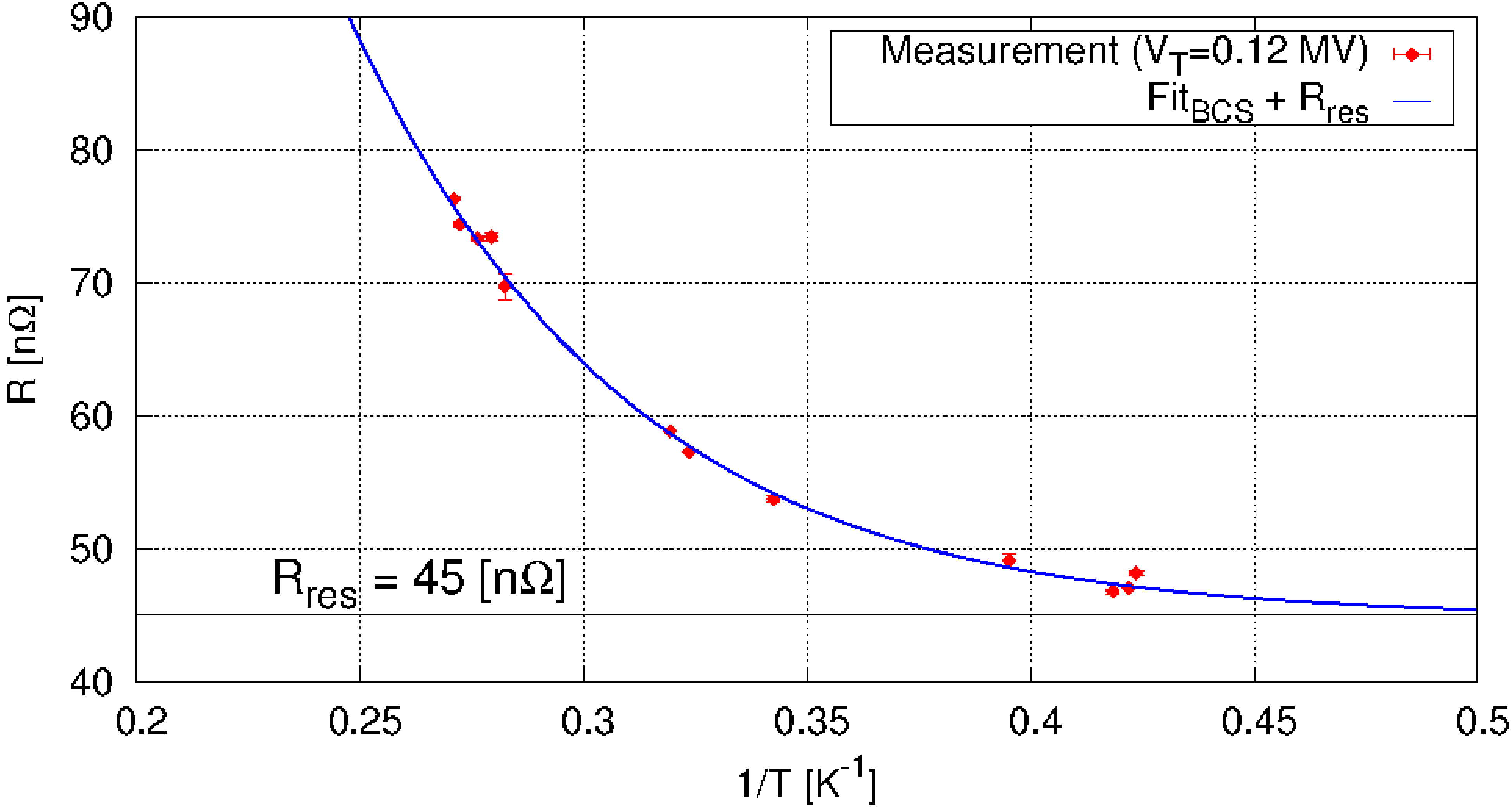
(Vacuum leak persists but better)



Ack: BE-RF-SRF/PM

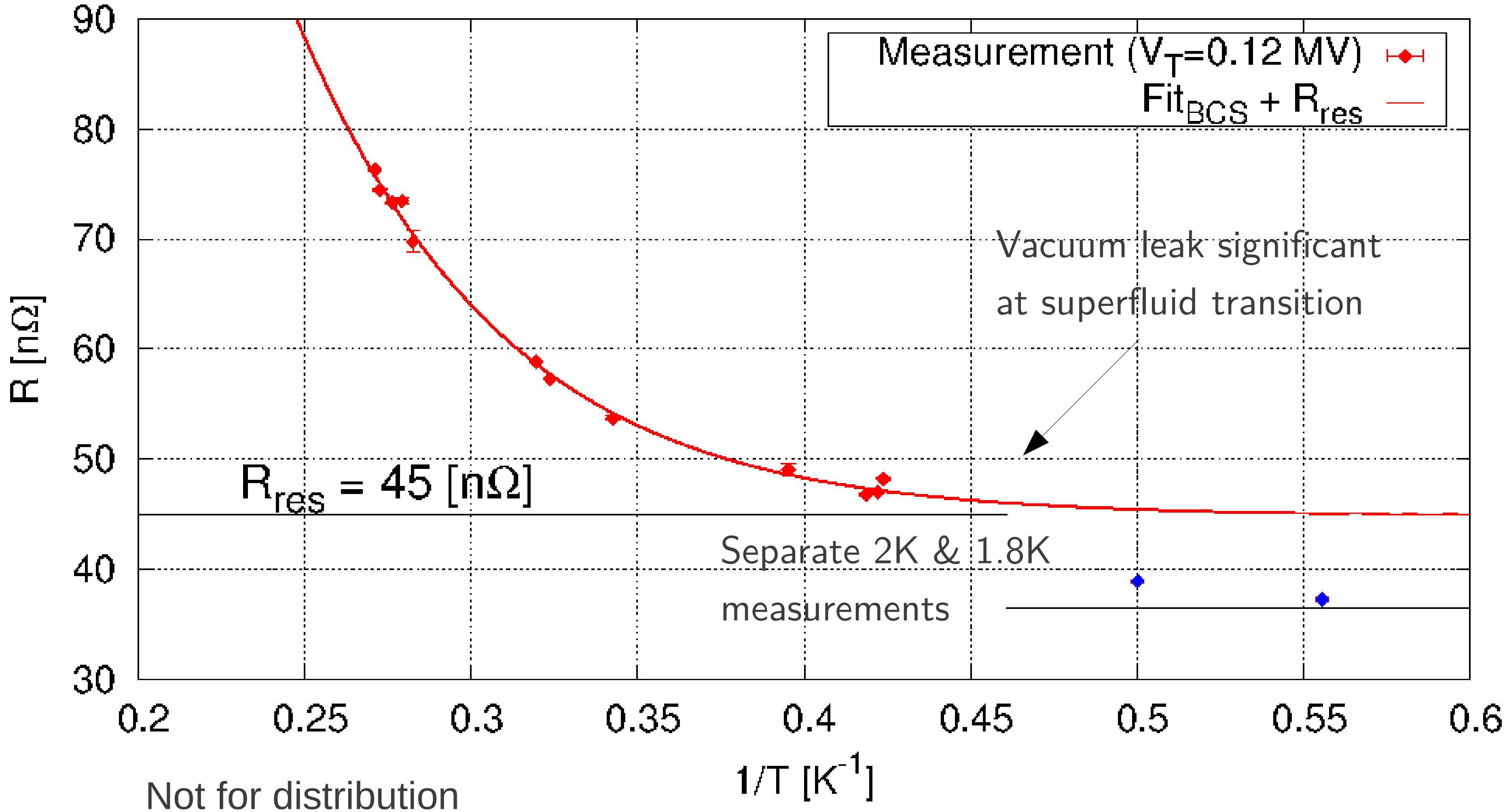
4Rod: R vs.T Curve

Rs from the classical BCS fit ~ 45 nΩ



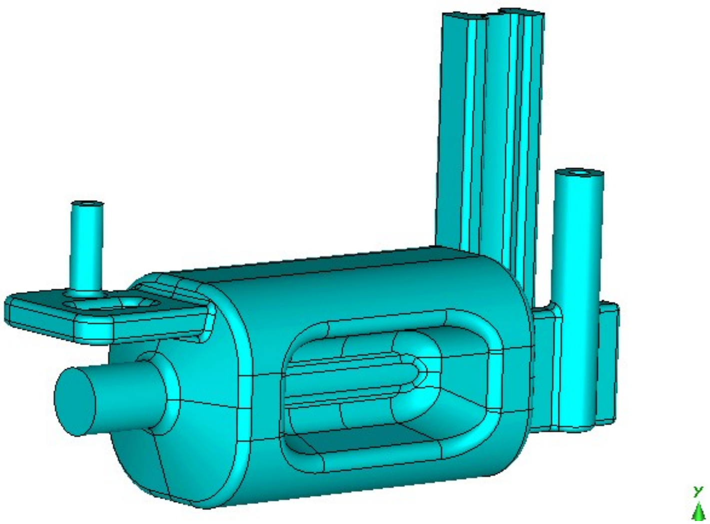
Ack: BE-RF-SRF/PM

Enzo! I only answered "maybe" to your questions

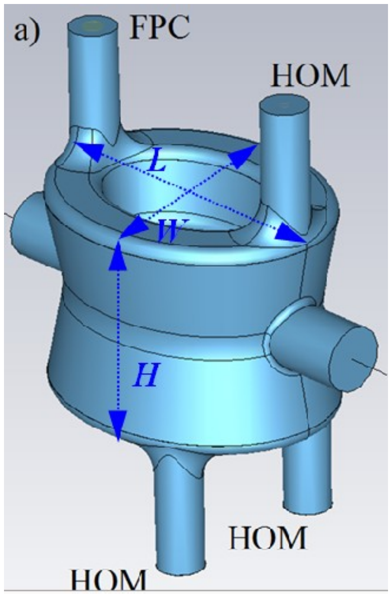


Not for distribution

Latest Cavity Designs

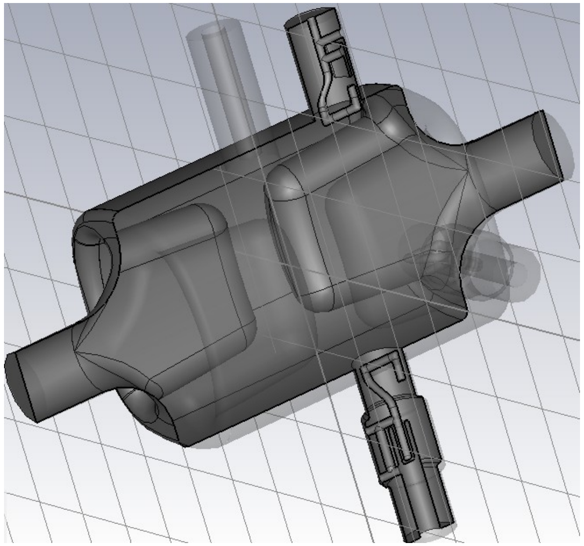


Waveguide or
waveguide-coax couplers



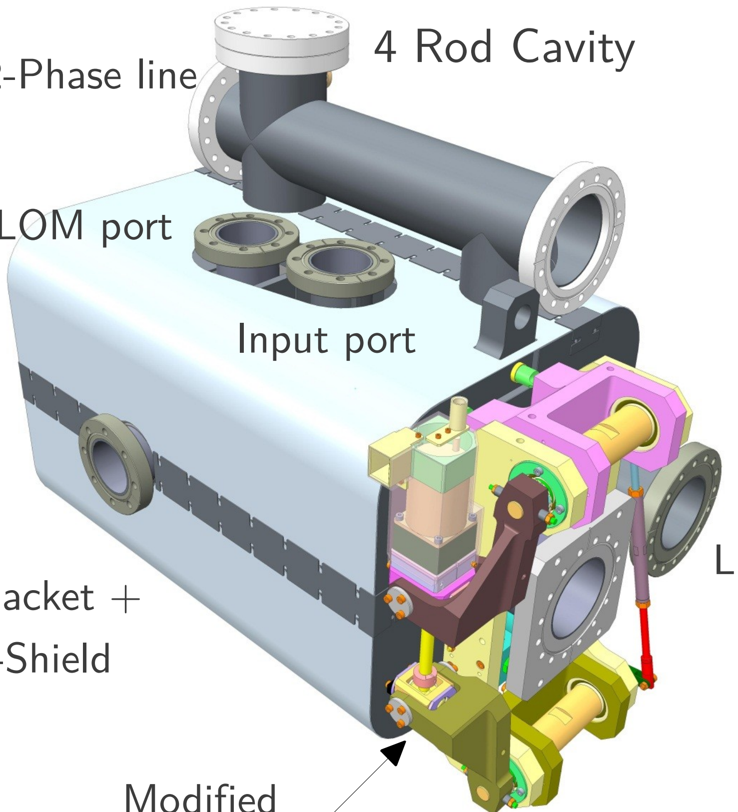
Coaxial couplers with
hook-type antenna

Coaxial couplers with
different antenna types



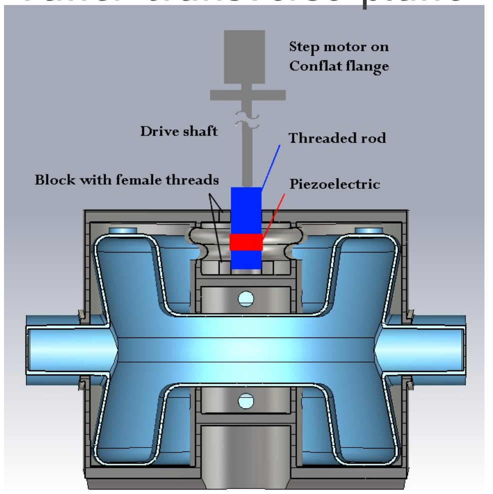
COMPLEX
FABRICATION

Dressed Cavity Concepts



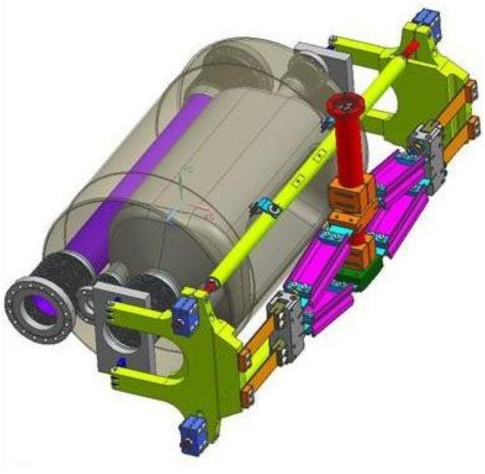
Double Quarter Wave

Tuner transverse plane



RF Dipole

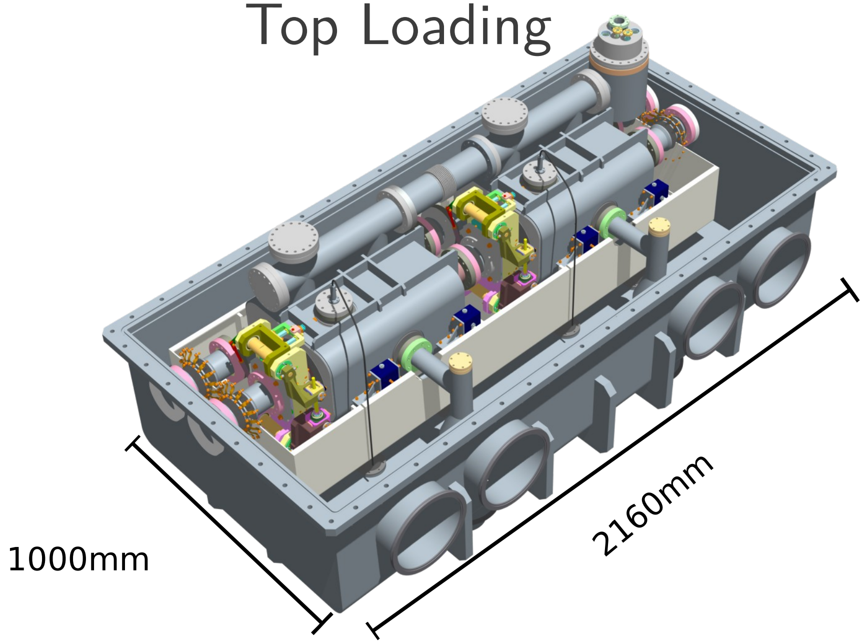
Longitudinal tuning



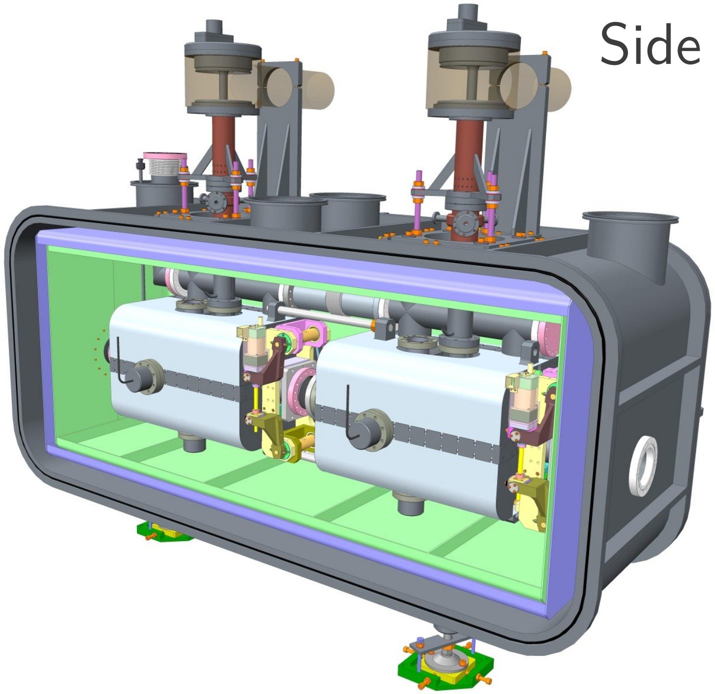
Cryostat Proposal for SPS

S. Pattalwar, T. Jones
(4Rod Cavity)

Top Loading



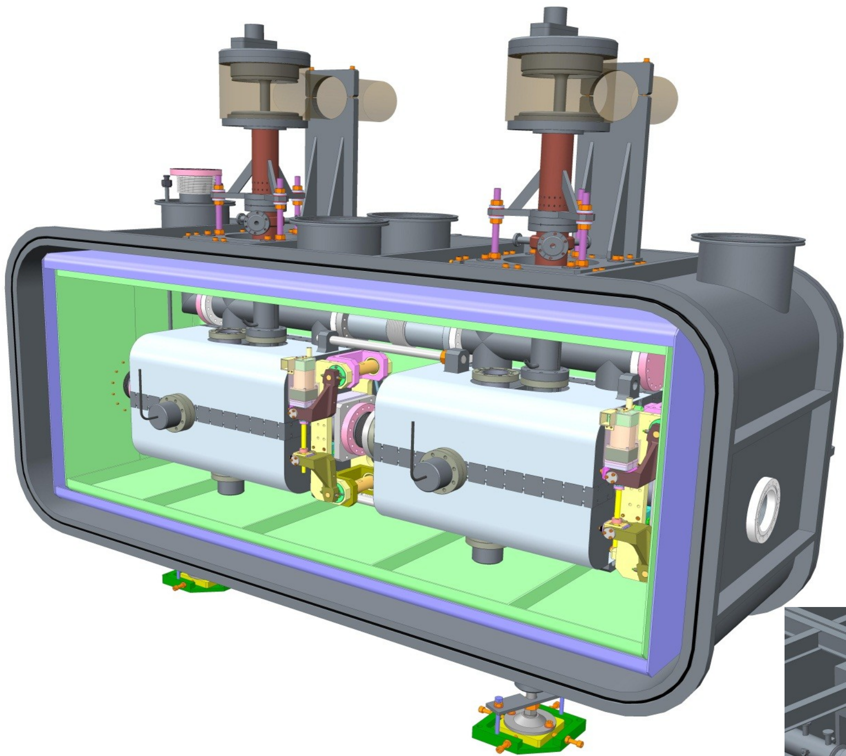
Side Loading



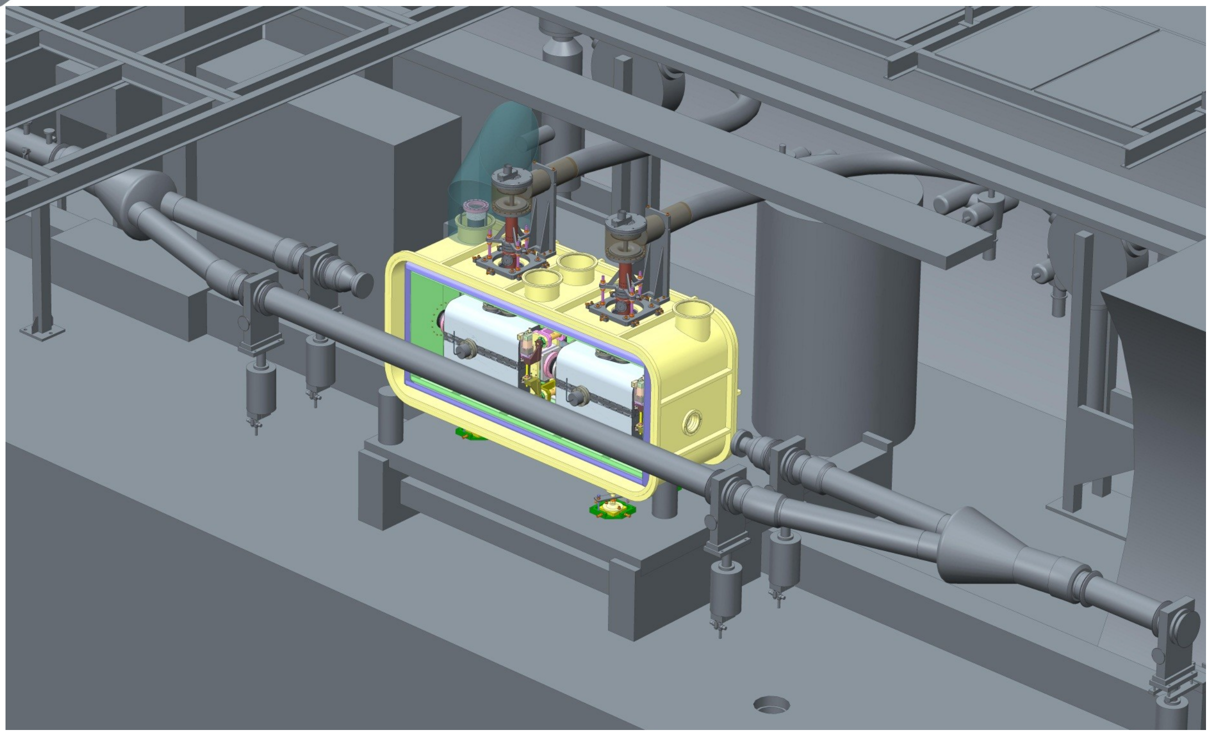
Simplified cryostat for easy assembly/access/maintenance
(LHC system would be a natural extension)

Cryostat Integration into SPS

CERN-EN-MME & Daresbury
(4Rod Cavity)

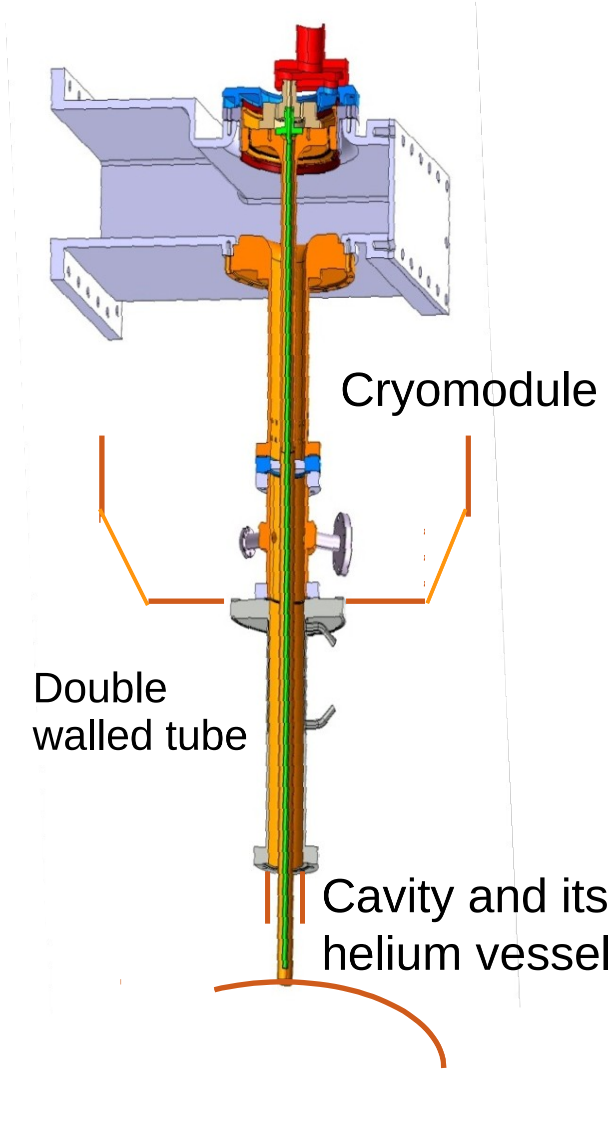


Integration into SPS Bypass



Input Coupler Interface

E. Montesinos



Common Vertical Power Coupler interface imposed for all cavities

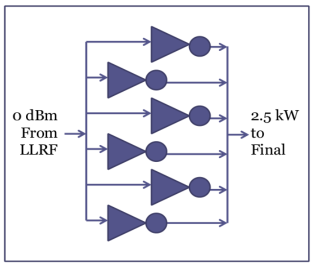
SPS type disk ceramic adapted for 62mm, 50Ω coxial coupler (with coax-waveguide transition WR2300)

Double-wall tube interface between cavity-vacuum vessel

RF Layout

E. Montesinos, P. Baudrenghien

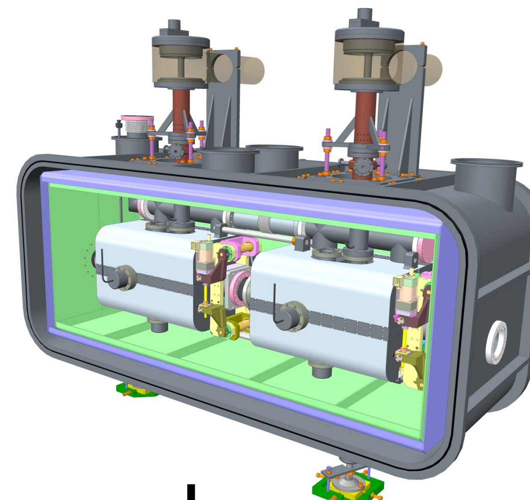
Driver: 2.5kW (6x500W)

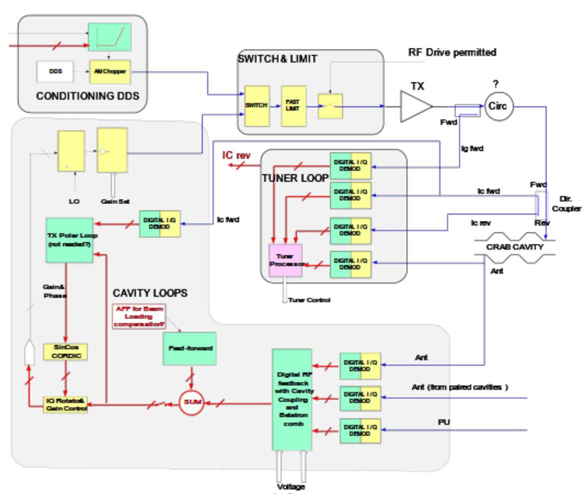


Drivers option with 6 x 500 W SSA

LEP Type 400 MHz, 40kW Tetrode

Cryomodule



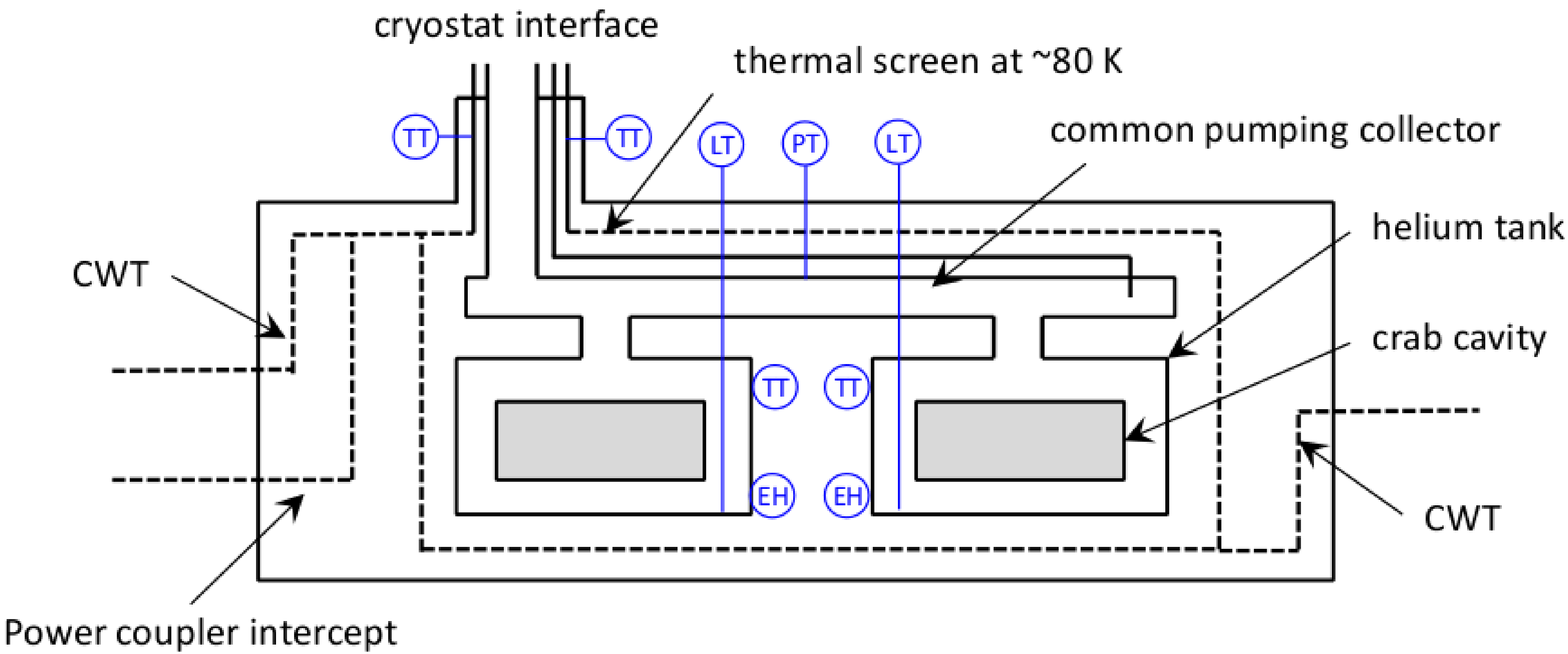


LLRF

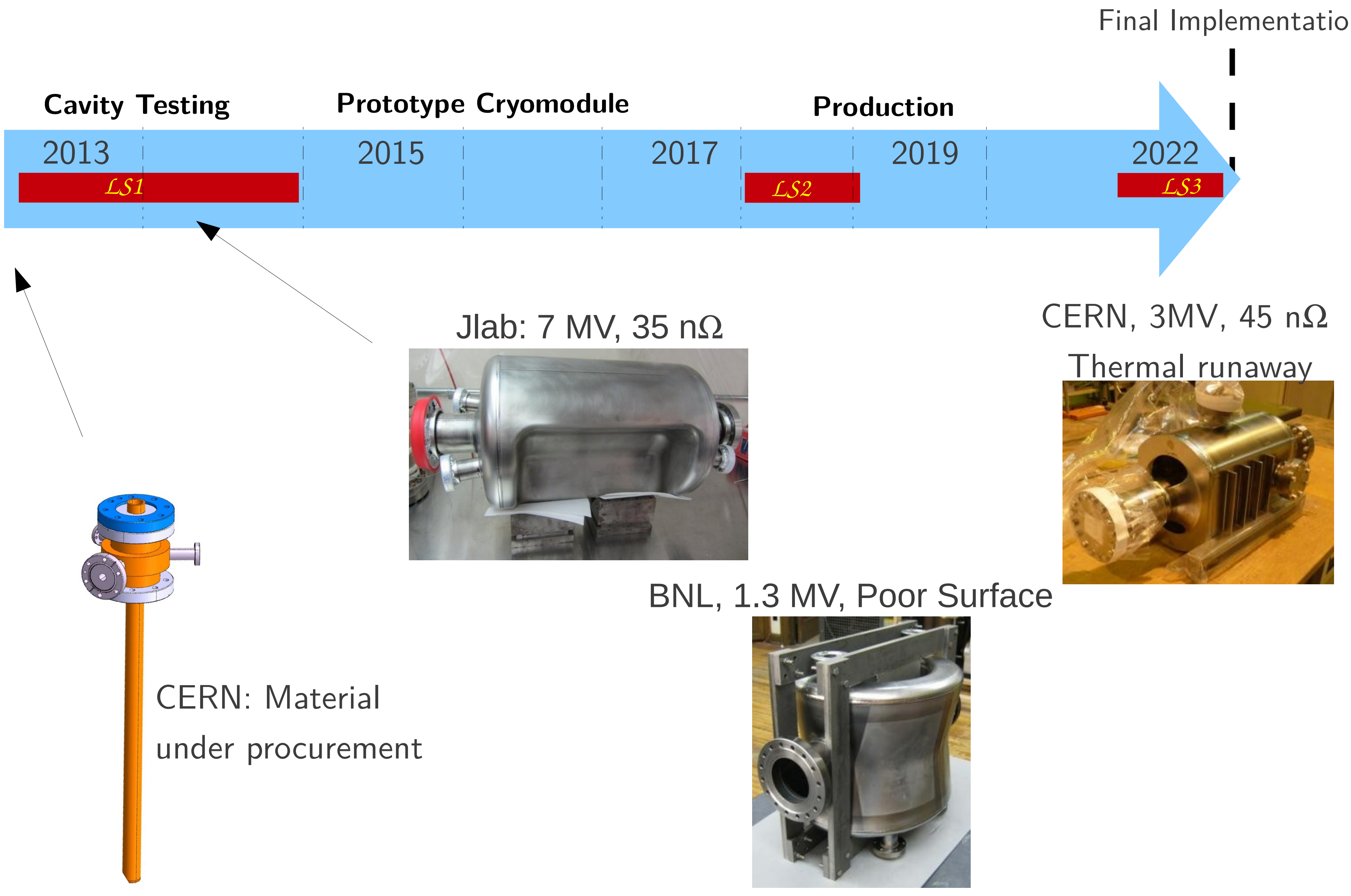
Cryogenics Schematic for SPS

K. Brodzinski

- Two primary circuits 2 K and 80 K (main interface from the top)
  - Cavity operated at 2K saturated Helium
  - Power couplers and Cold/Warm transitions intercepted with LN2 at 80 K.



Planning Overview



Outlook

Today

- A new path for the deflecting (SRF) world, very promising results
- Several emerging applications (colliders, light sources, linacs)

Near Future

- Cryomodule(s) development & integration
- Reliability, transparency & precision RF control with SPS beam
- Potential for thin films for quench mitigation

Key challenge

- To assemble this international puzzle together

A Last Thought

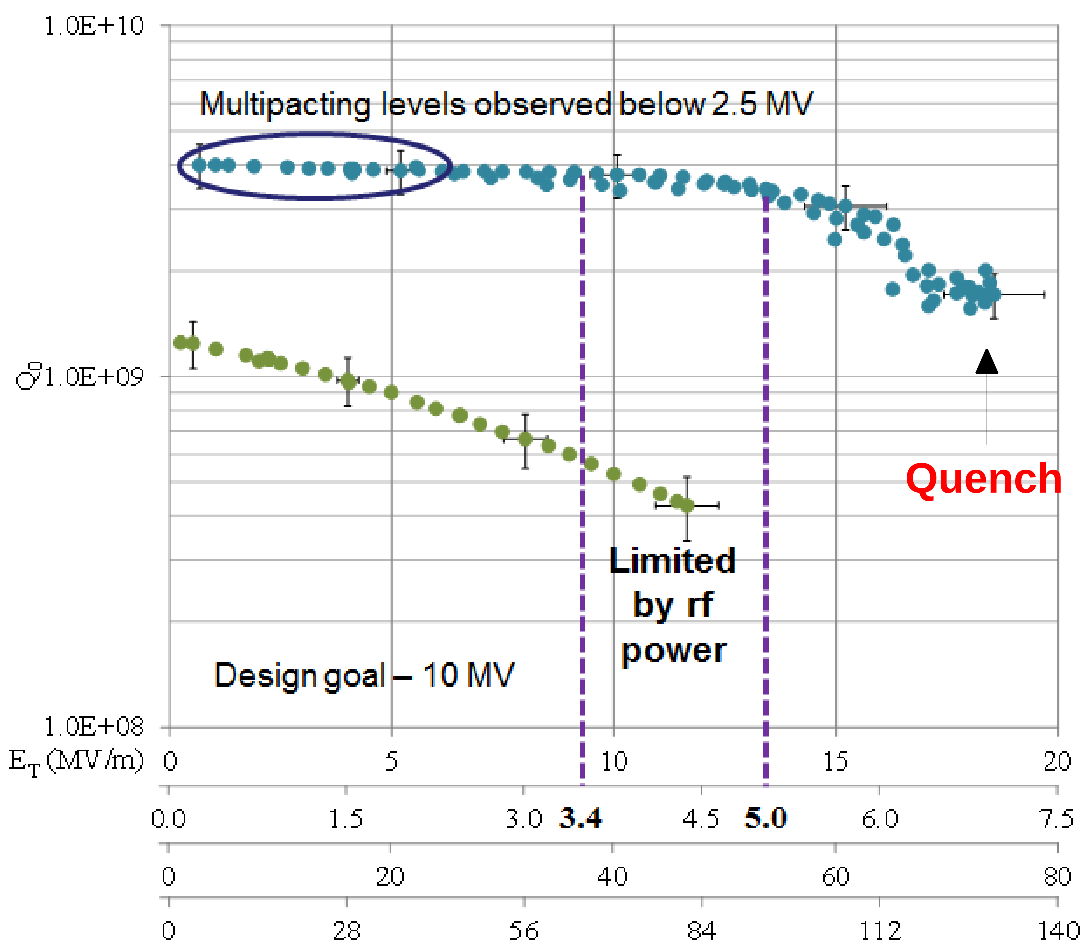
3D-Printing of Nb-Cavities (?)

The klein bottle opener

ODU RF-Dipole

Courtesy: ODU-Jlab

SEE FRIOA04



Low field multipacting easily processed did not reoccur

Achieved fields:

V_T = 7.0 MV !!

E_p=75MV/m, B_p=131mT

Expected $Q_0 = 6.7\text{x}10^9$ (10nΩ)

Achieved $Q_0 = 4.0\text{x}10^9$ (35nΩ)

Calculated Q_0 from SS flanges: $3.7\text{x}10^9$

The slight higher residual resistance likely due to acid contamination

DQW 1st Cavity Test

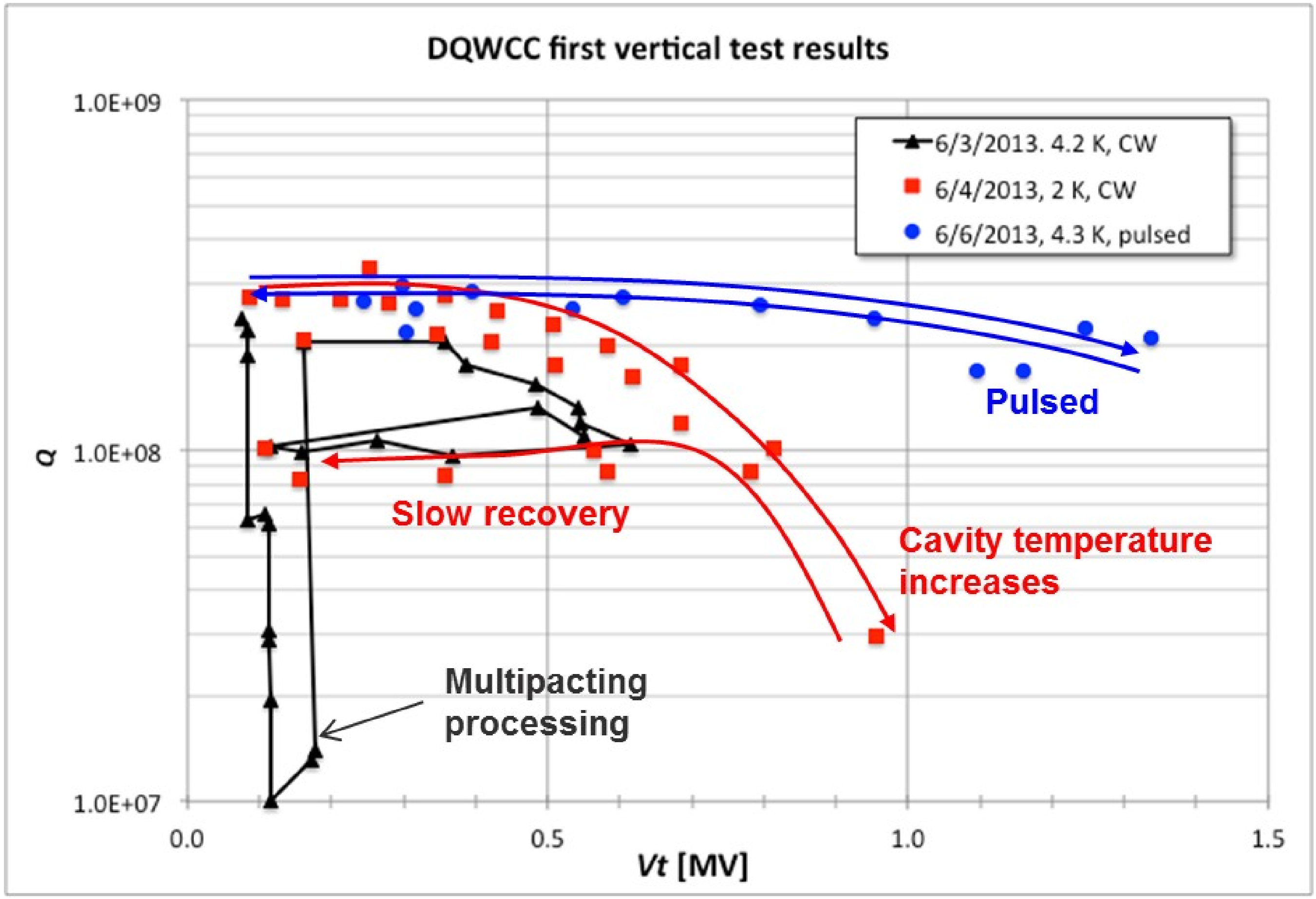
SEE FRIOA02

Courtesy: BNL

Q is low, $\sim 3\times 10^8$ (independent on the temp, expected 8.5×10^9)

No Q-disease or not due to SS flanges

CW mode 0.96 MV (thermal load), pulsed mode reached 1.34 MV (200 W amplifier)

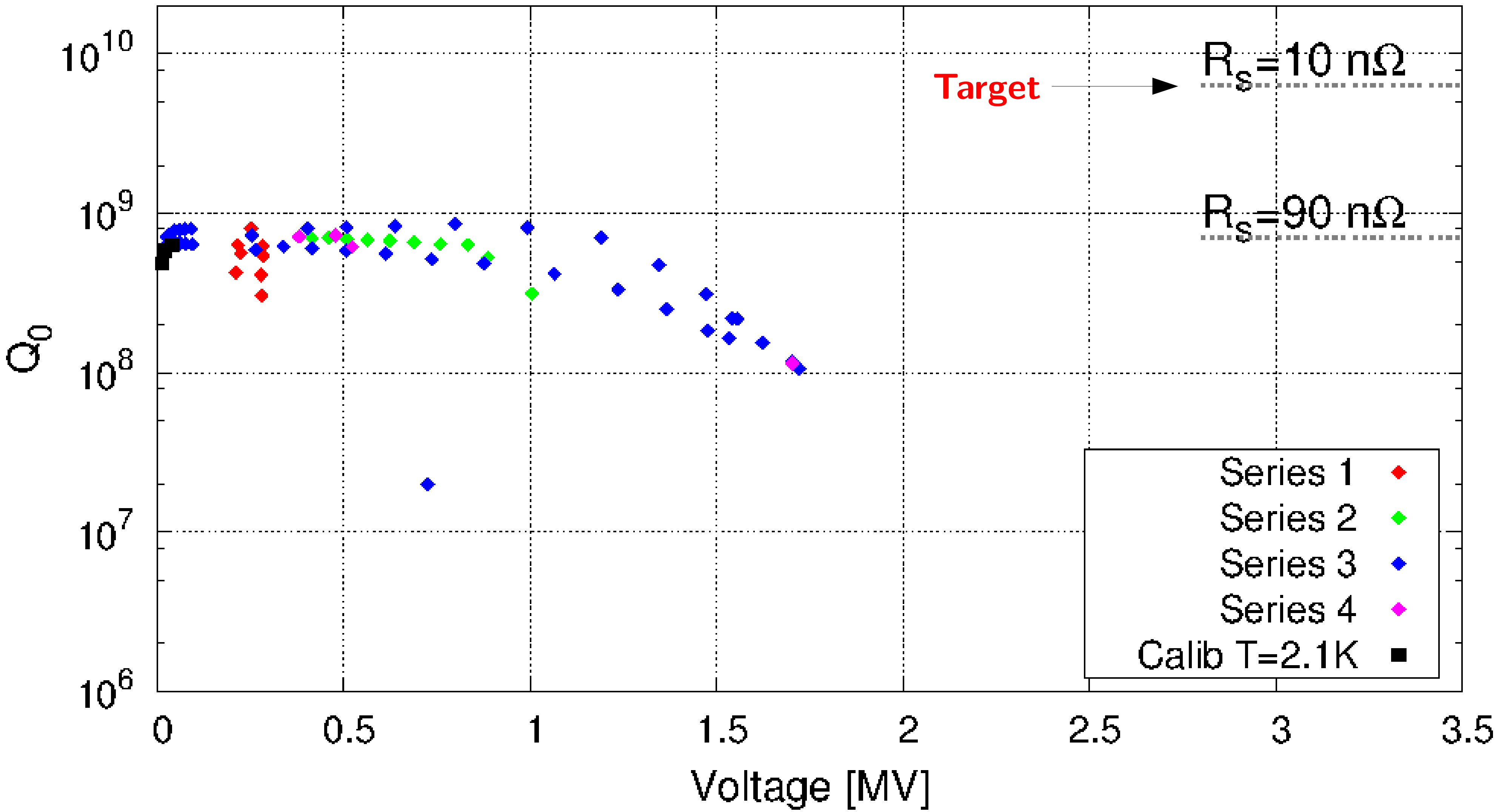


Low field multipacting (~0.1 MV) easily conditioned

4Rod Cavity Q vs. $V_\perp$, Nov 2012

First tests performed w/o final light BCP (2012) at 2K

(Vacuum leak due to bad NbTi flanges)



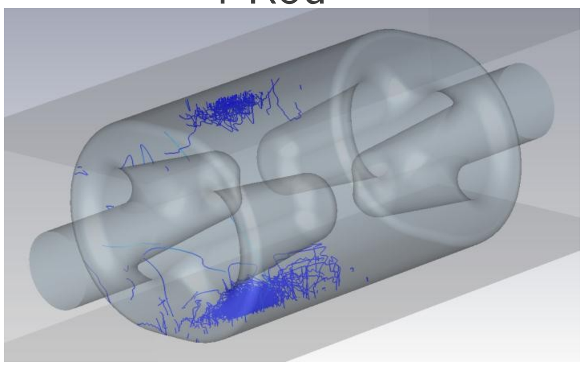
Overcoupled, β~4

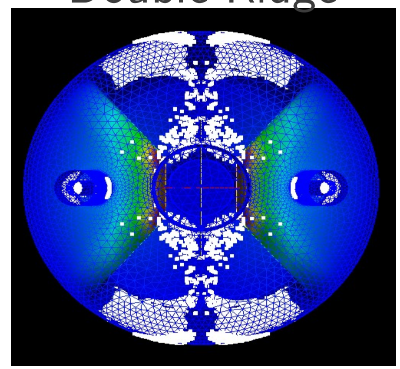
Multipacting of complex 3D geometries

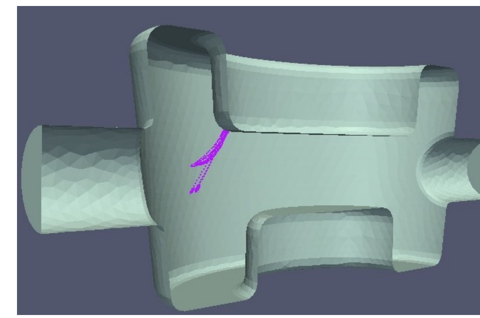
require sophisticated analysis (ex: ACE3P code)

4-Rod | Double Ridge | Quarter Wave

Low Field

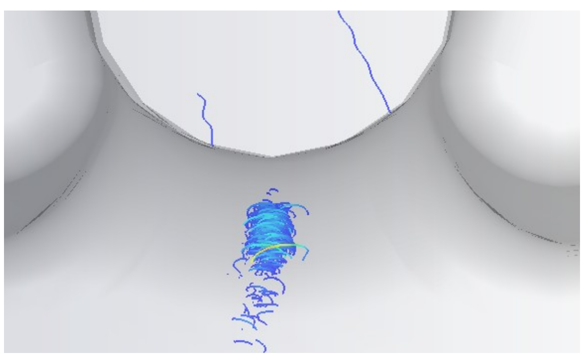


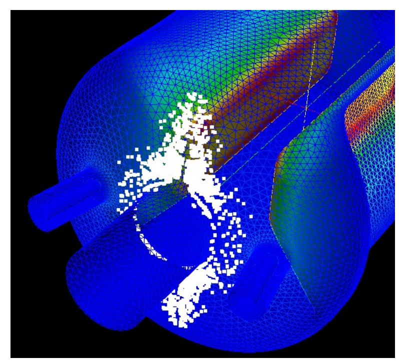


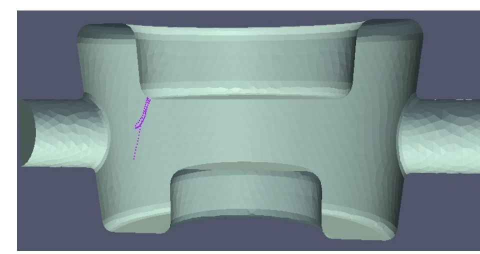


7 MV/m

Medium Field





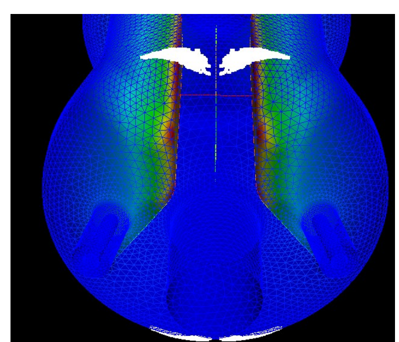


12 MV/m

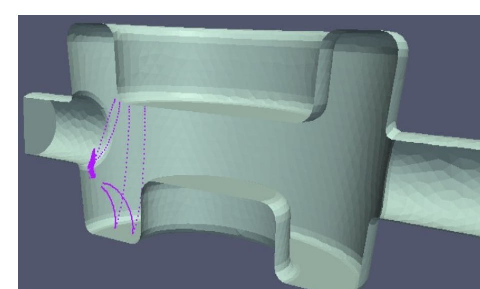
No serious barriers

RF conditioning sufficient

(Courtesy Burt, Li, Wu)



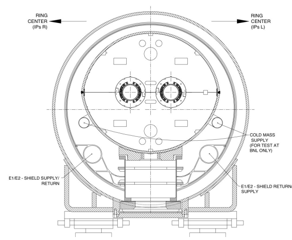
High Field

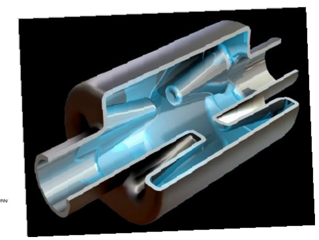


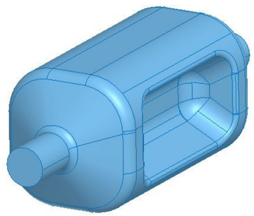
17 MV/m

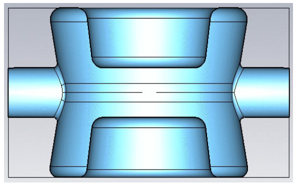
Field Quality (Unusual for Cavities)

Like IR magnets, higher order components of the deflecting field important







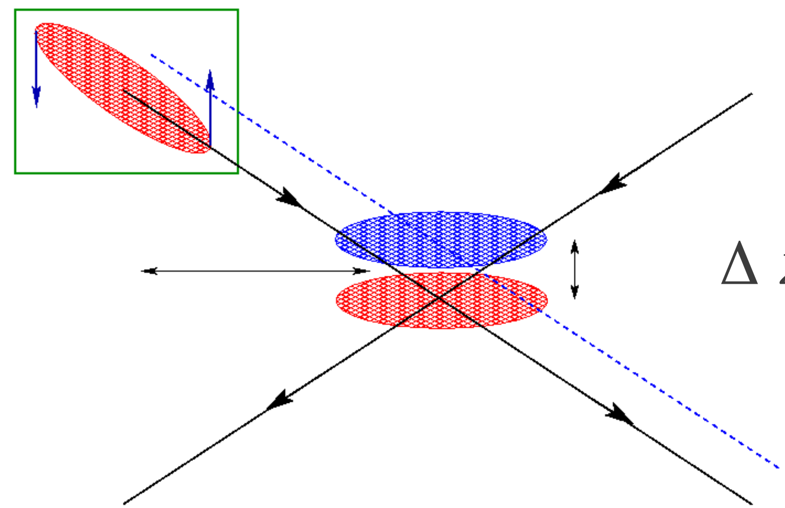


mTm/m^{n-1}	MBRC	4-Rod	Pbar/DRidge	¼-wave
b_2	55	0	0	0
b_3	7510	1162	455	1076
b_4	82700	84	24.6	92
b_5	2.9×10^6	-2.29×10^6	-2.1×10^6	-0.1×10^6
b_6	52×10^6	0	0	0
b_7	560×10^6	-638×10^6	700×10^6	7×10^6

Precise control of voltage & phase

Main RF phase jitter

$\Delta\phi = 0.005^0$ @400 MHz



$$\Delta x_{IP} = \frac{\theta_c}{k_{RF}} \delta\varphi$$

For Crabs (θc=570µrad):

Δx_{IP} = 0.3µm (5% of σ_x^*)

Independent control of ampl/phase

Strong feedback across IP