LHC Crab Cavity Overview

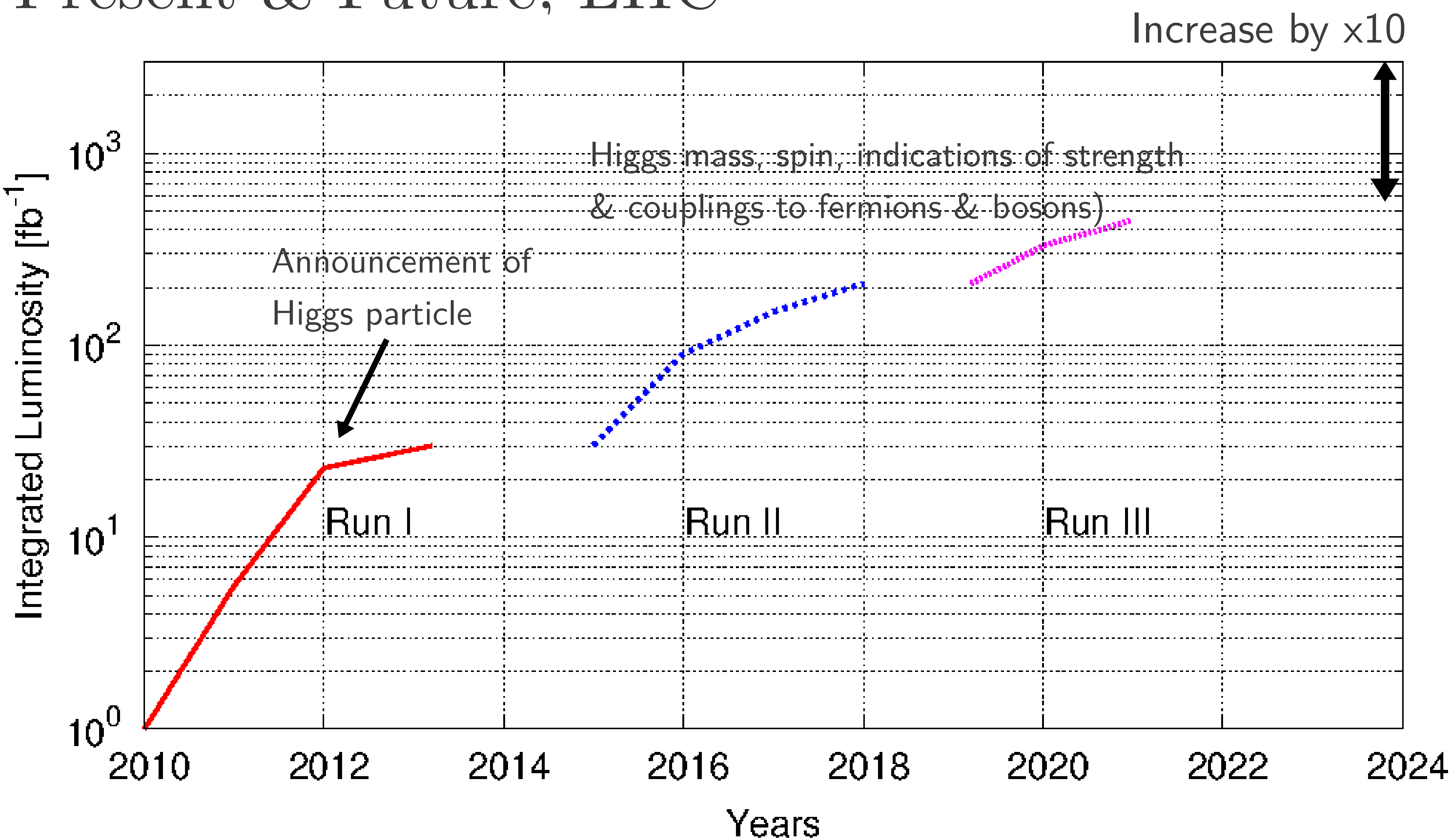
R. Calaga, E. Jensen, CERN

Crab Cavity Review, May 5, 2014

On behalf of the LHC-CC collaboration

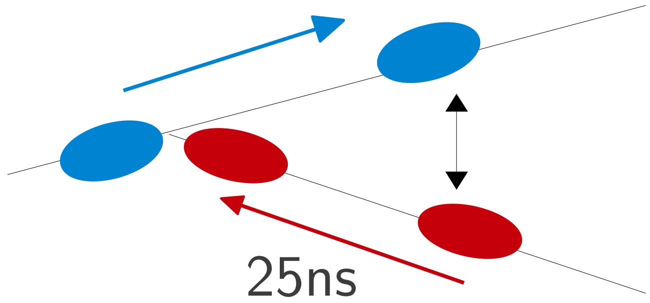
Special Ack: CERN, RF, EN & TE Groups

Present & Future, LHC



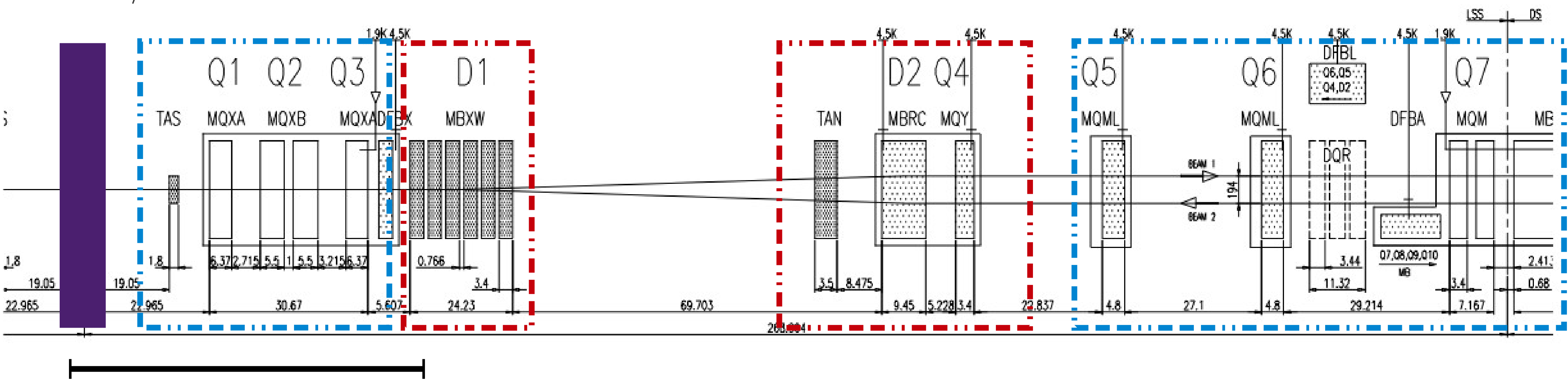
HL-LHC Upgrade (2023-30+) ~**300 fb^{-1}/yr**

1.2 km of the LHC to be upgraded (IR magnets, crab cavities, collimation)



32 parasitic collisions/IP $\rightarrow$ Total 128

ATLAS/CMS



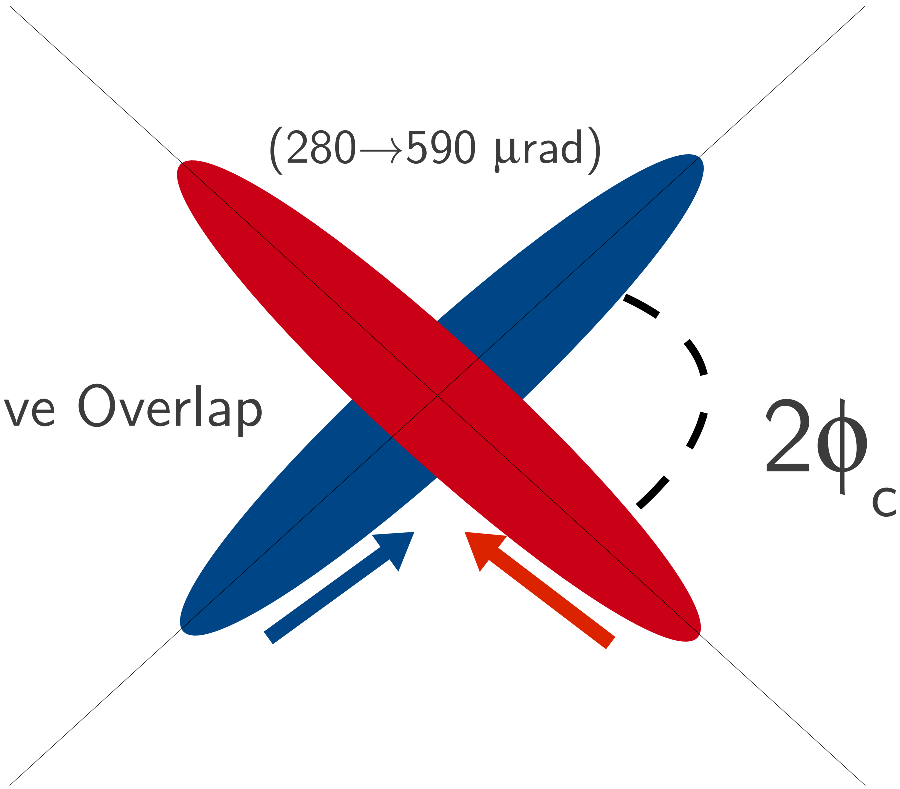
60m common channel

Beams separated by a crossing angle to avoid collisions outside the interaction point

Upgrade → reduce beam size by factor ~2

Consequence → approx double the crossing angle

Ineffective Overlap



7.55cm

$$\Phi = \frac{\sigma_z}{\sigma_x}\varphi_c$$

~7 μm

$$L = \frac{L_{HO}}{\sqrt{1+\Phi^2}}$$

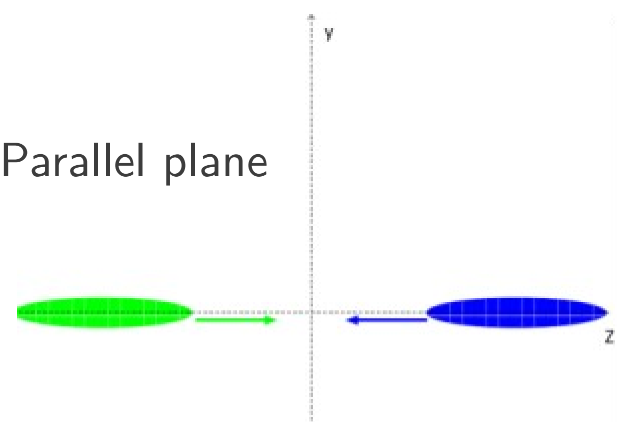
L = exploit only 30% of available L_{HO}

Lumi-Levelling & CK Scheme

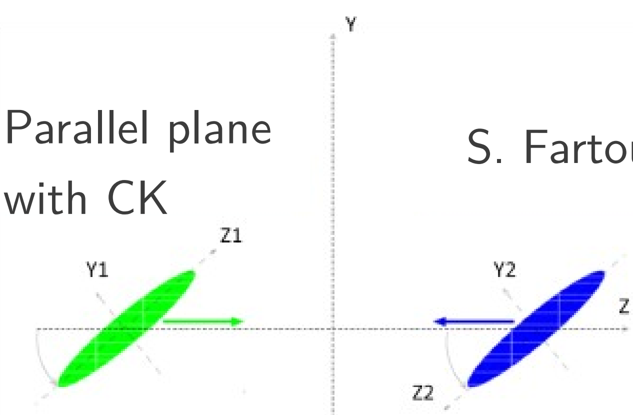
In addition to peak luminosity improvement, a constant (leveled) luminosity is a vital component to maximize the integrated luminosity

- Changing Pwinski-angle along the store using crab cavities
- Changing the beam size at collision point using IR optics
- Changing bunch length using the RF gymnastics
- Changing Pwinski-angle in both transverse planes (CK scheme to density level)

Parallel plane



Parallel plane with CK

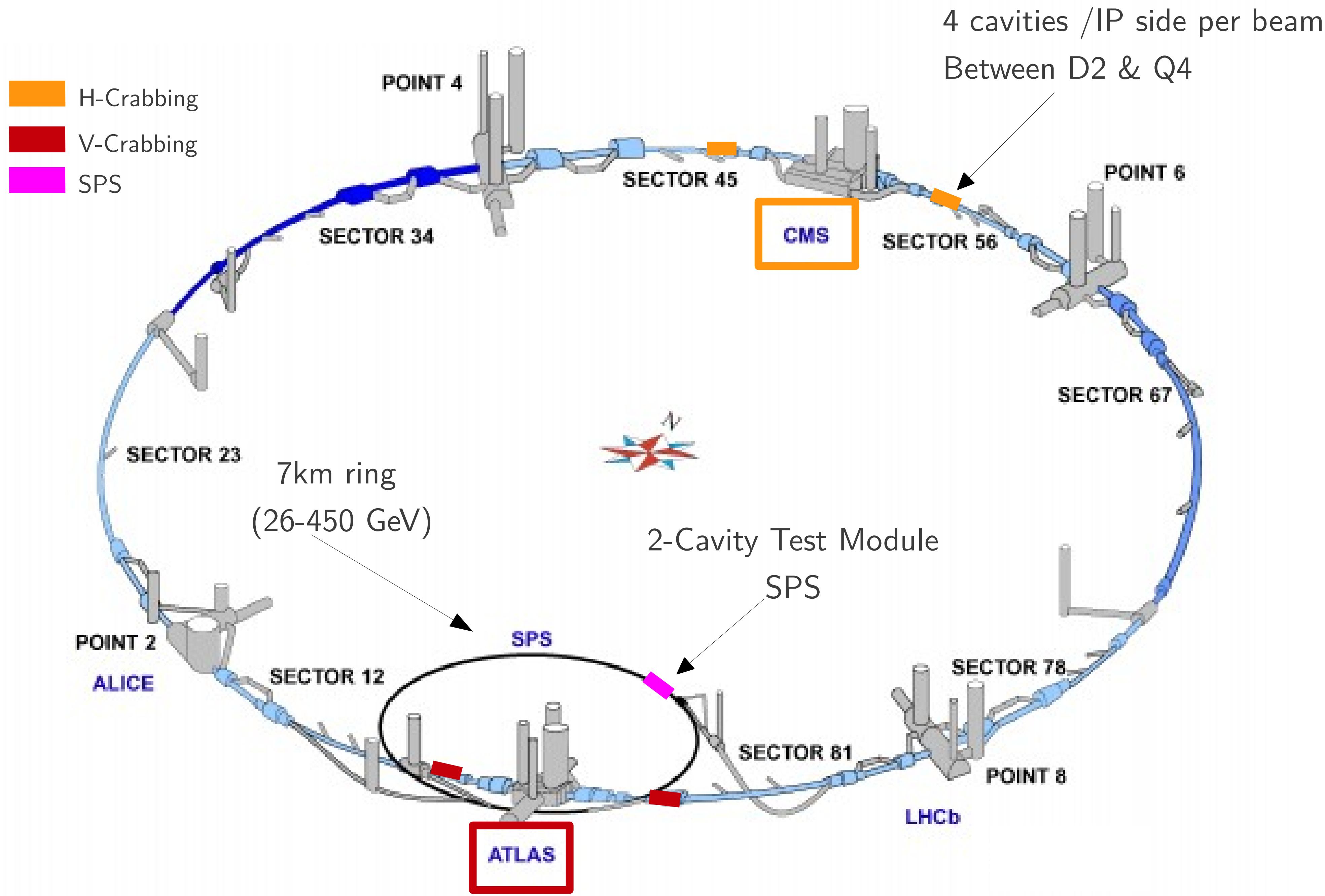


S. Fartoukh, LHC-CC13

Full compensation in crossing plane & approx half the crossing angle in parallel plane

Number of cavities remain same as standard crab compensation (+flat optics + BBLR)

LHC Crab Cavities



Some Basic Parameters

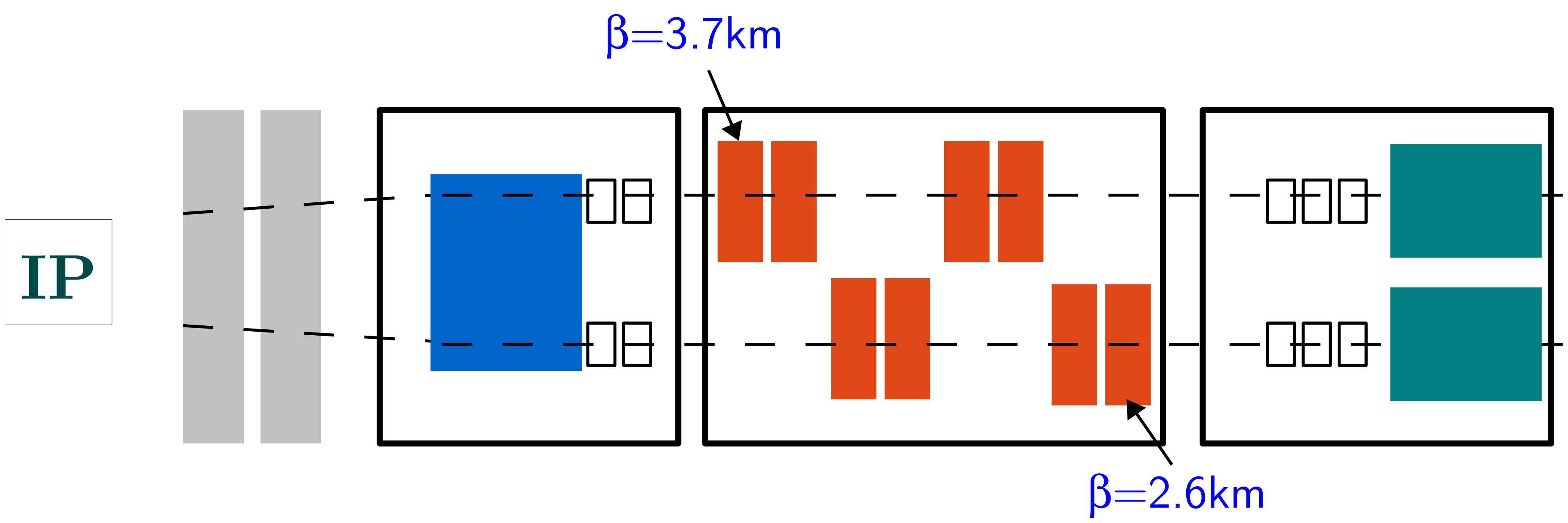
Voltage = 3.4 MV/cavity (4 cavities /beam /IP side)

Frequency = 400.79 MHz

Qext = 3-5x10^5

RF power source = 80 kW

Cavity tuning/detuning ~ ± 1.5kHz (or multiples of it)



Technology Choice

Superconducting cavities to produce ~3.4 MV deflecting voltage

Very compact concepts to allow for integration

Double 1/4-wave

RF Dipole

4-Rod

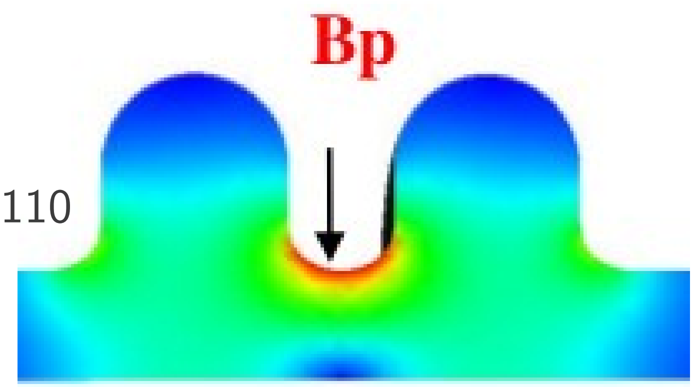
Three proof-of-principle cavities built & tested

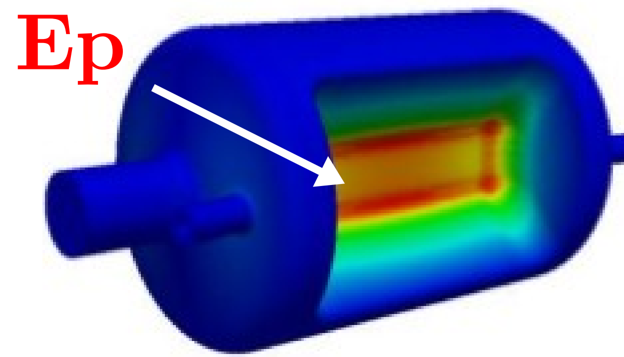
Favorable distribution of peak surface fields

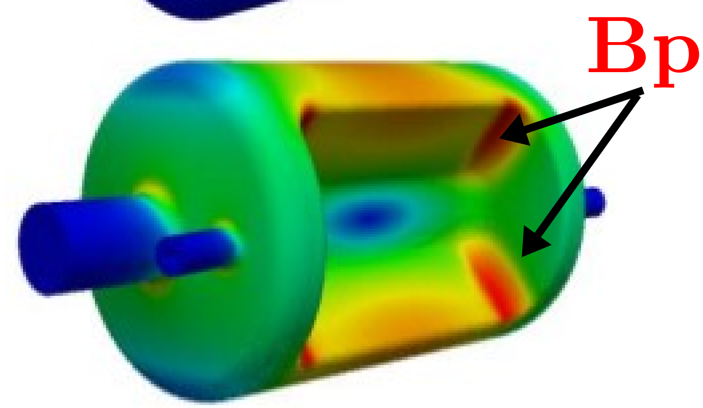
(And compact due to quasi TEM or TE11-like)

TM110

TM110







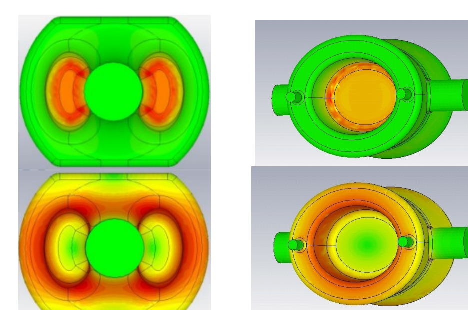
x3-4 bigger transversely

40% higher Bp

x6 smaller R/Q

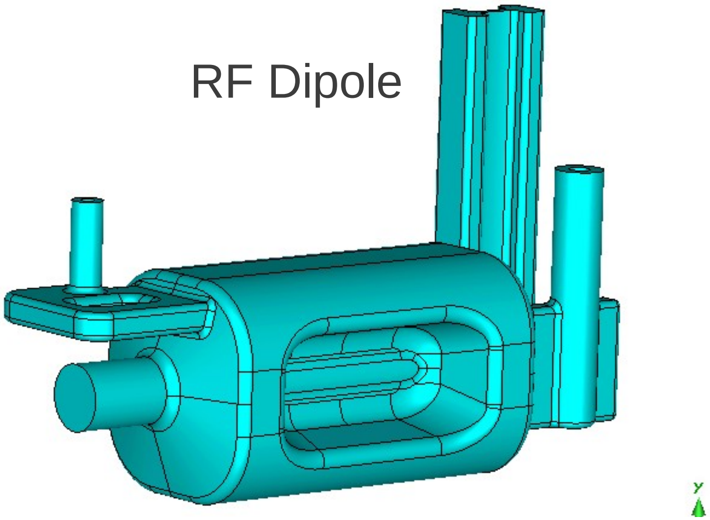
HOMs well separated

Same with other designs

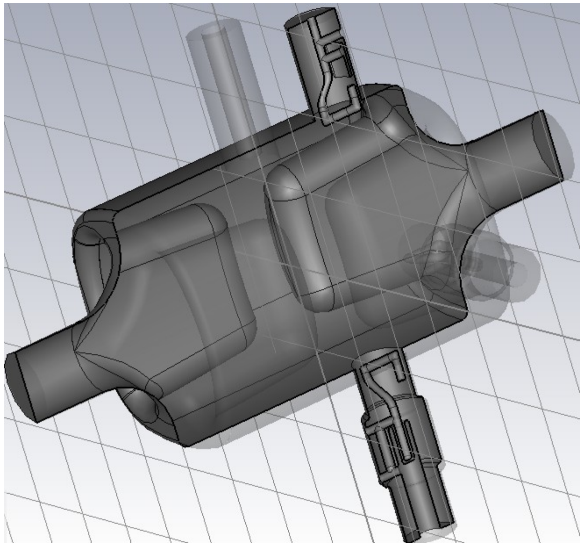


Latest Cavity Designs

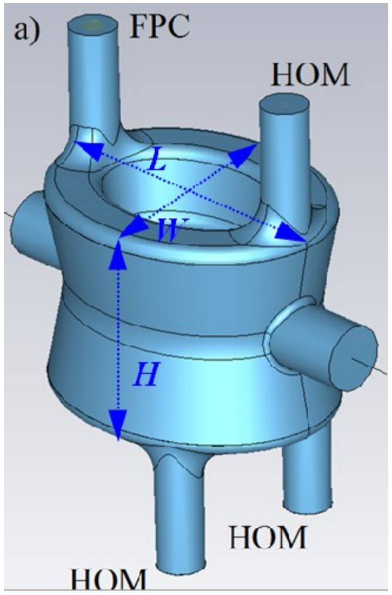
RF Dipole



4-Rod



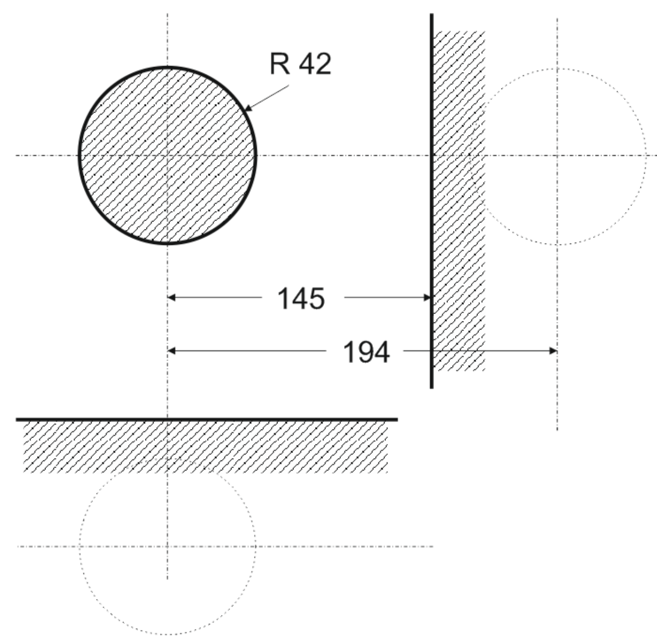
Double Quarter Wave



Next two sessions will address the design and development

Issue #1: Aperture & Cavity Envelope

For a frequency of 400 MHz & the minimum aperture of 84mm
The cavity envelope cannot exceed 145 mm



The 590 μm crossing angle requires about 12-13 MV which is provided by 4-cavities. Three competitive designs (non-classical) under study

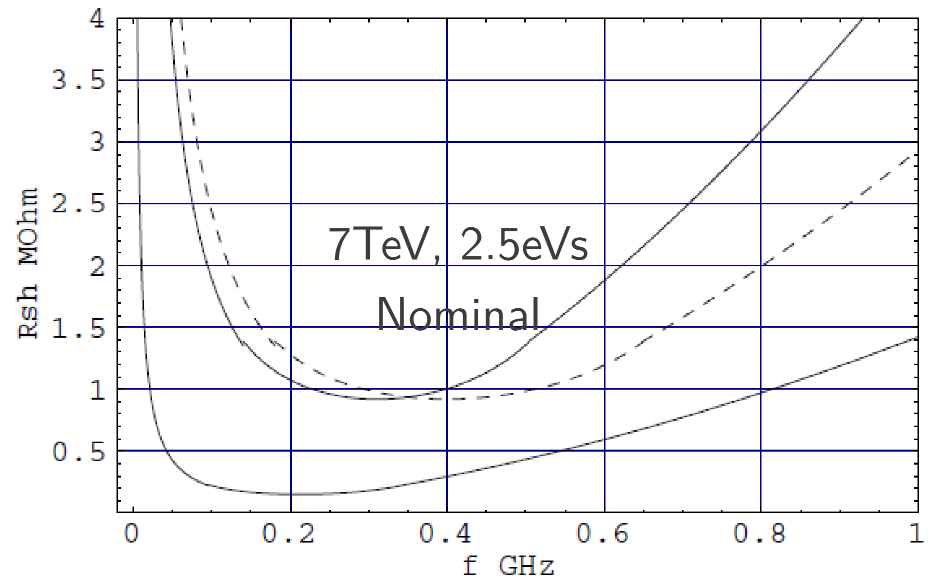
Aspect #2: Impedance

See tomorrow B. Salvant

Longitudinal criteria:

Threshold set at 200 kΩ (E=7TeV, $N_{.}=2.2\text{x}10^{11}$, $4\sigma=1$ns)

Can be relaxed as $f_r^{5/3}$



E. Shaposnikova, LHC-CC10

Transverse criteria:

Threshold of ~5 MΩ/m (determined by damping time of 5ms)

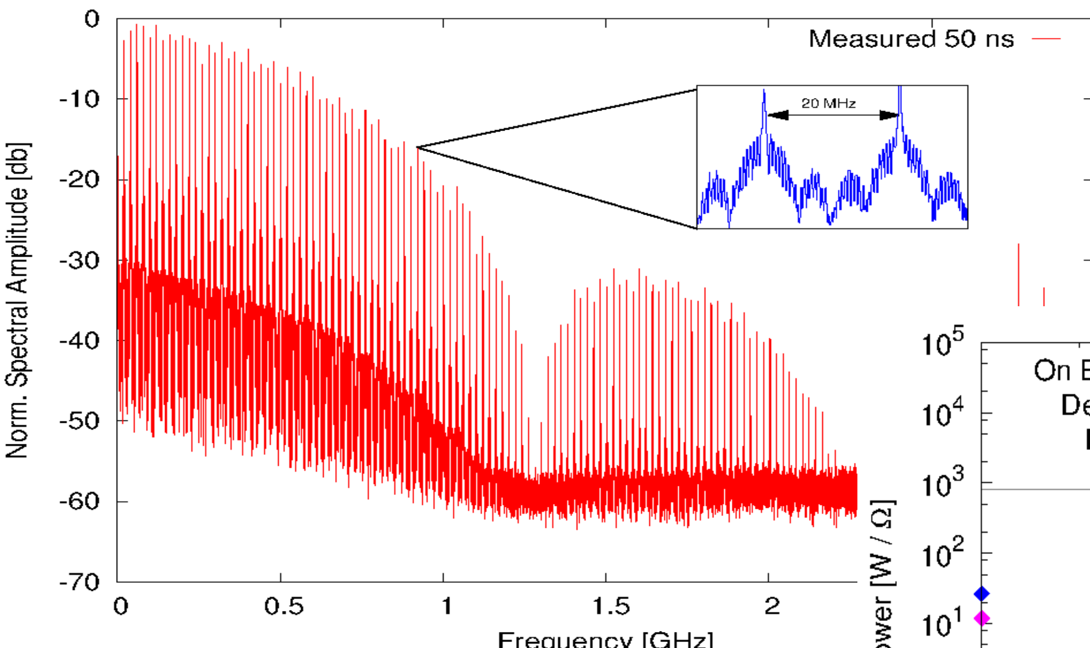
Assuming only narrow-band impedances at β-sidebands

Remark: Main RF cavities are damped to $Q_{ext} \sim 10^2$ - 10^3

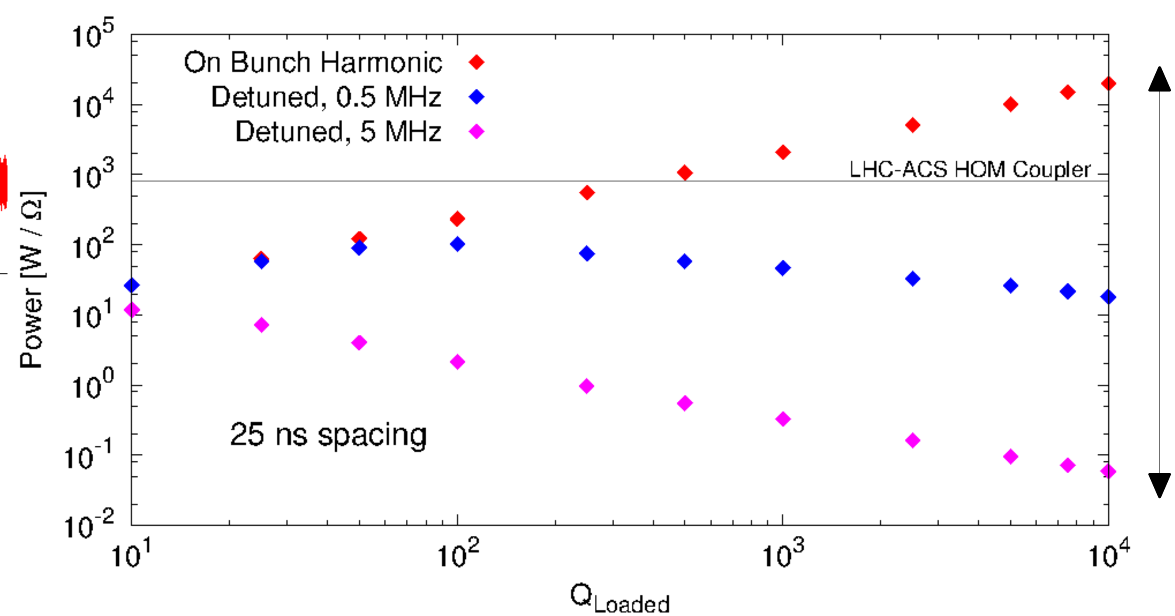
Aspect #3: HOM Power

Beam spectrum very dense due to irregular filling scheme

Uncertainty on both filling scheme & exact HOM freq lead us to choose ~1 kW as an approximate scale for the power handling.



See tomorrow B. Salvant



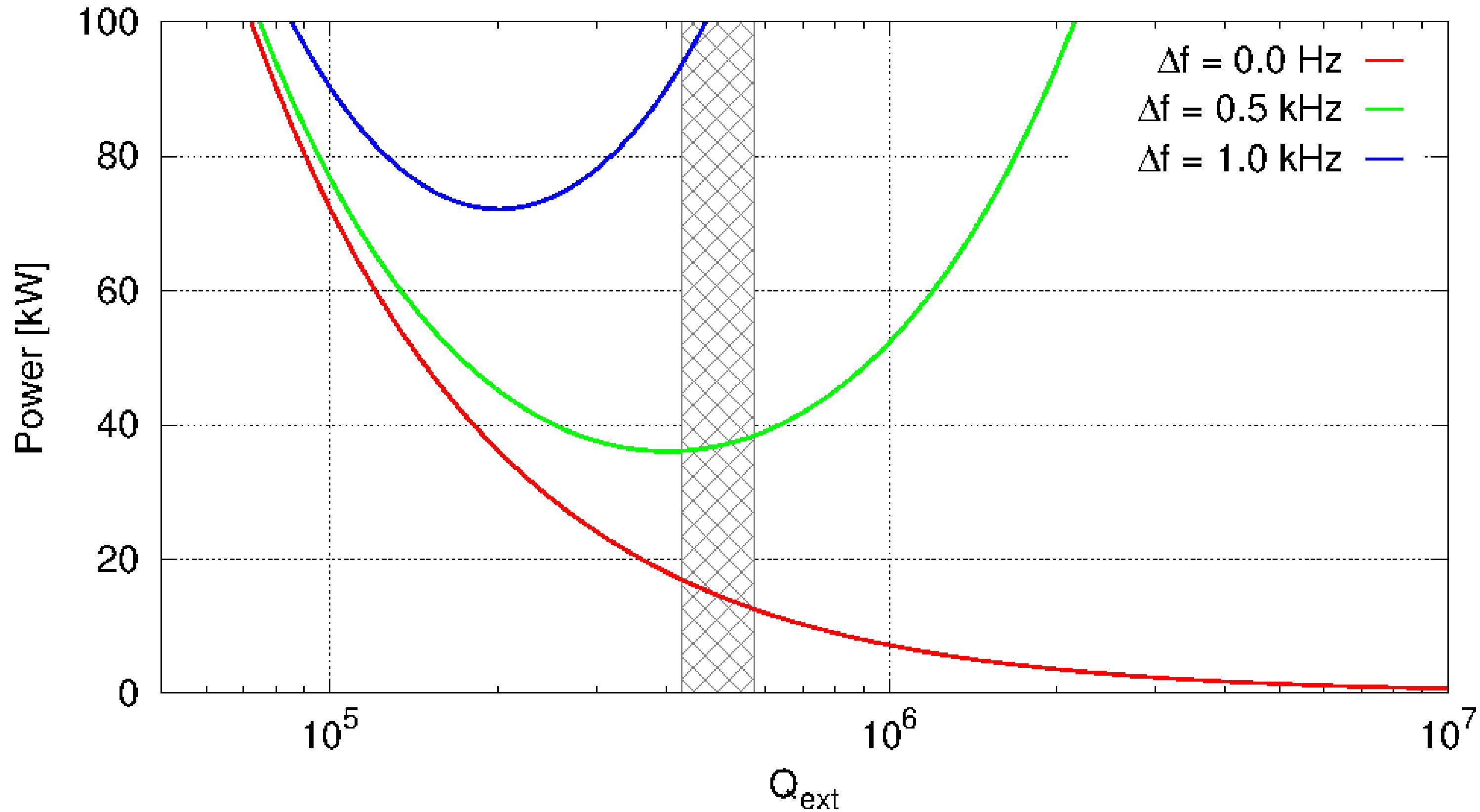
Aspect #4: Precise control of Frequency

See tomorrow P. Baudrenghien

Precise & reproducible cavity tuning

- Stability → fundamental mode impedance driving CBI
- Power overhead

Installed power



Aspect #5: Control of voltage & phase

Independent cavity control of amplitude & phase for stability & noise

Strong feedback across IP to mitigate cavity failure effects

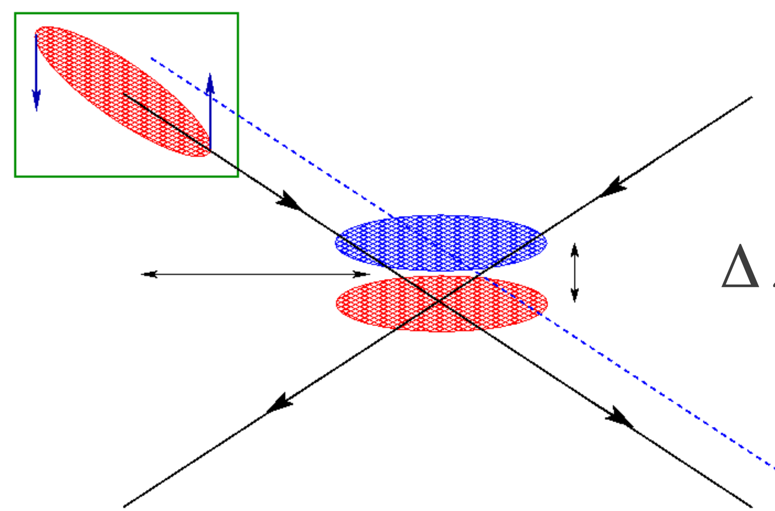
Cavity transparency when not in use

RF phase jitter

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

For Crabs (θc=590μrad):

Δx_{IP} = 300 nm (5% of σ_x^*)



$$\Delta x_{IP} = \frac{\theta_c}{2k_{RF}} \Delta \varphi$$

Amplitude jitter

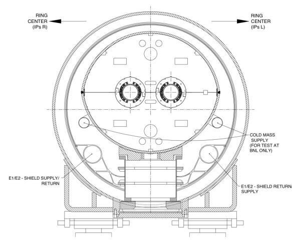
$\Delta V/V = 4\text{x}10^{-4} \rightarrow$ Residual angle 0.25μrad

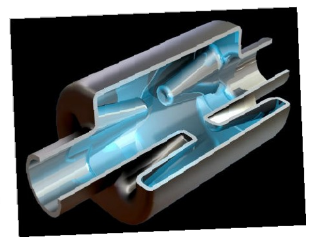
See tomorrow P. Baudrenghien

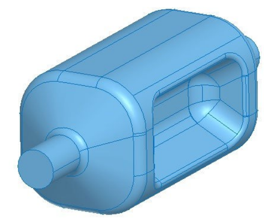
On wed. T. Mastoridis

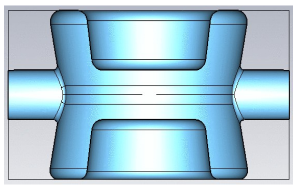
Aspect #6: Field Quality

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



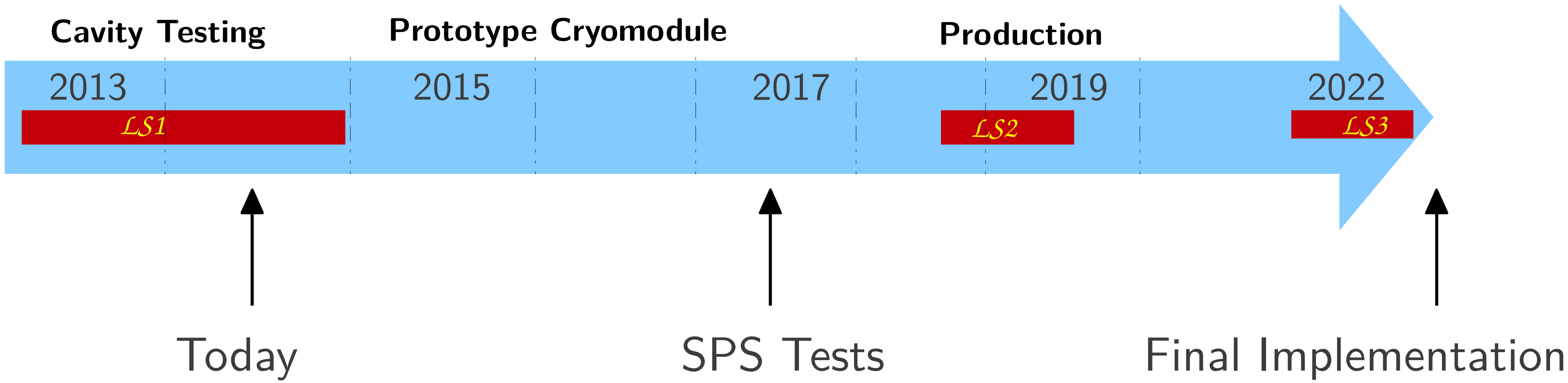






mTm/m^{n-1}	MBRC	4-Rod	Pbar/DRidge	¼-wave
b_2	55	0	0	0
b_3	7510	1162	455	1076
b_4	82700	84	24.6	92
b_5	2.9×10^6	-2.29×10^6	-2.1×10^6	-0.1×10^6
b_6	52×10^6	0	0	0
b_7	560×10^6	-638×10^6	700×10^6	7×10^6

Aspect #7: Schedule & Implementation



Three proof-of-principle cavities fabricated & tested

- Two funded in US (SBIR-USLARP) & third in Europe (all built by Niowave)

Advanced stage of SPS test cryomodule (nominally designs frozen today, but...)

- Detailed schedule in place both for fabrication & installation

How many types to be retained for the LHC ? Remember alternating crossing

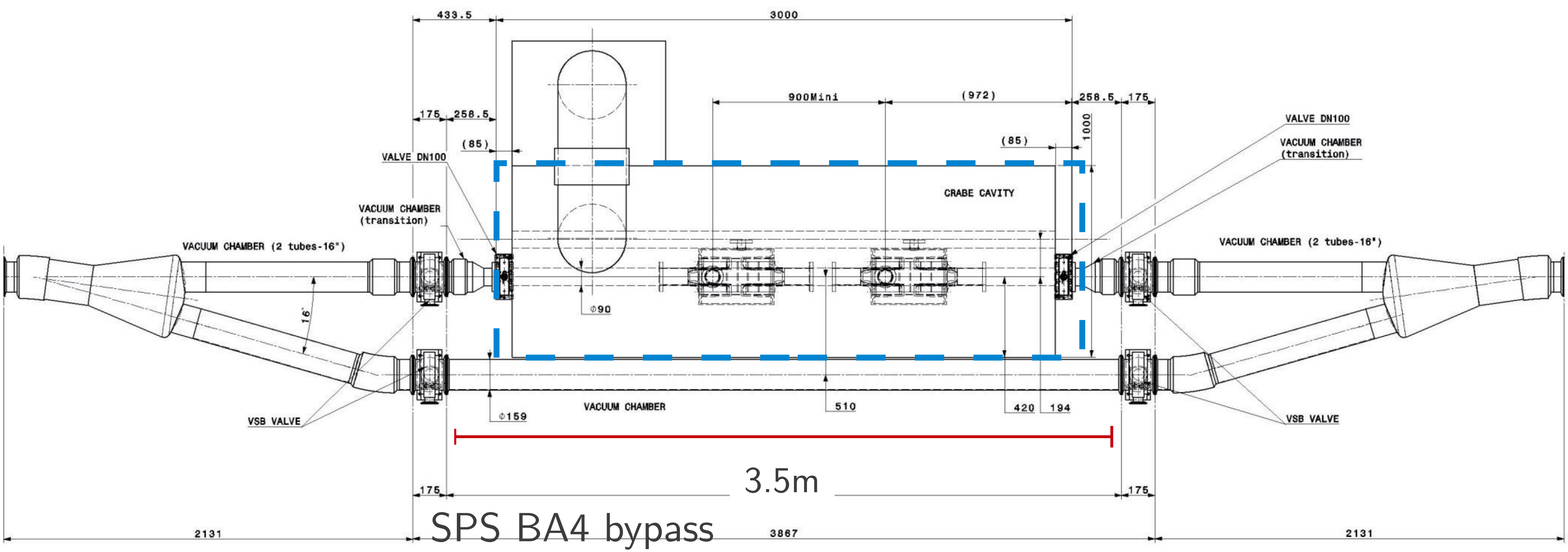
Aspect #8: SPS Test Module

See today/tomorrow O. Capatina

Proof of principle demonstration with protons

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

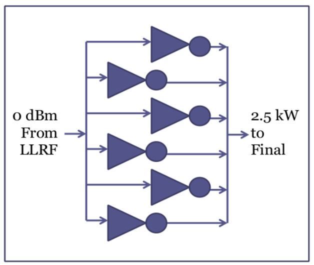
Produce a beam ready module (standards, safety, vacuum, integration...)



RF Layout

See talks tomorrow: E. Montesinos, P. Baudrenghien

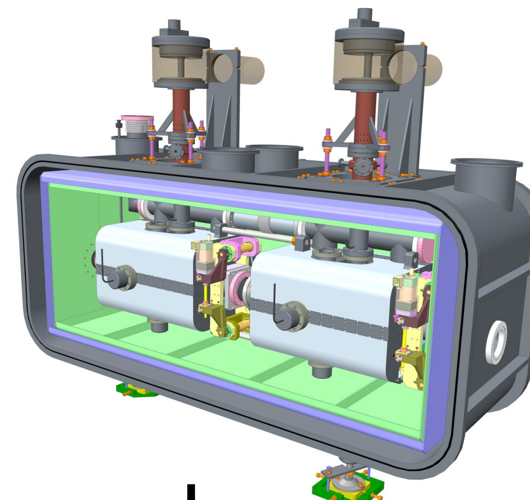
Driver: 2.5kW (6x500W)

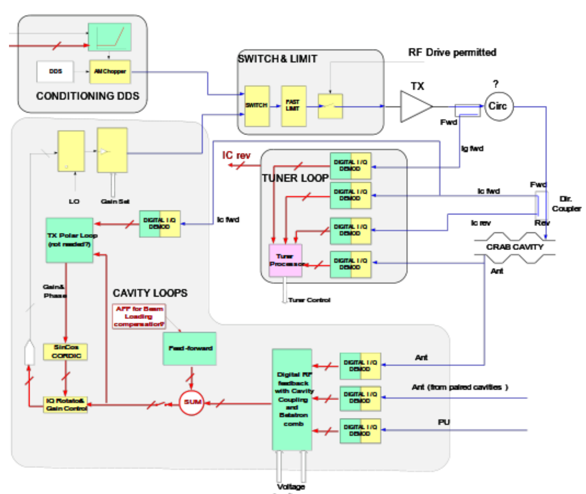


Drivers option with 6 x 500 W SSA

LEP Type 400 MHz, 40kW Tetrode

Cryomodule

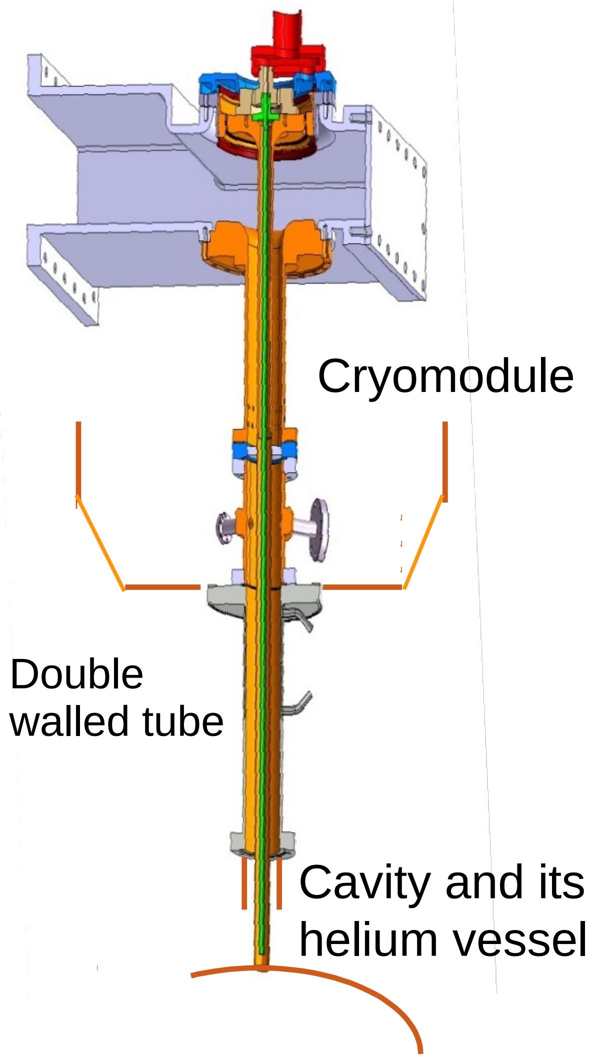




LLRF

Input Coupler Interface

See talk tomorrow: E. Montesinos



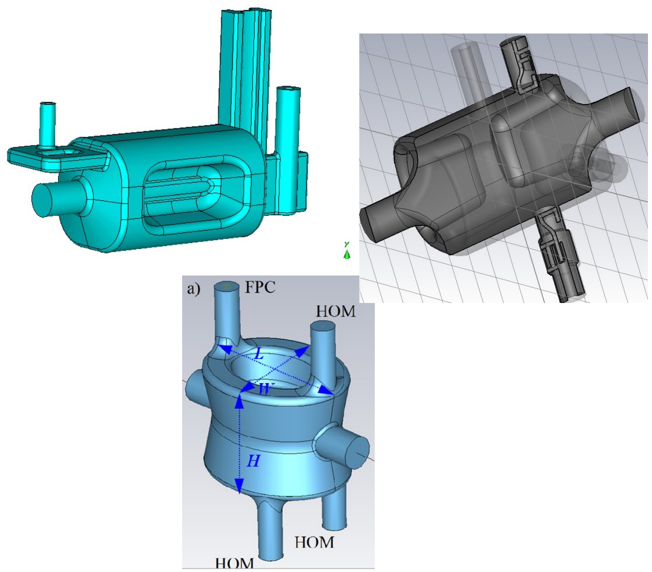
Common Vertical Power Coupler interface imposed for all cavities

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

Double-wall tube interface between cavity-vacuum vessel acting as the supporting system

An important issue is the heat load and heating of the FPC

HOM Couplers



As designs are different, coupling scheme is not imposed

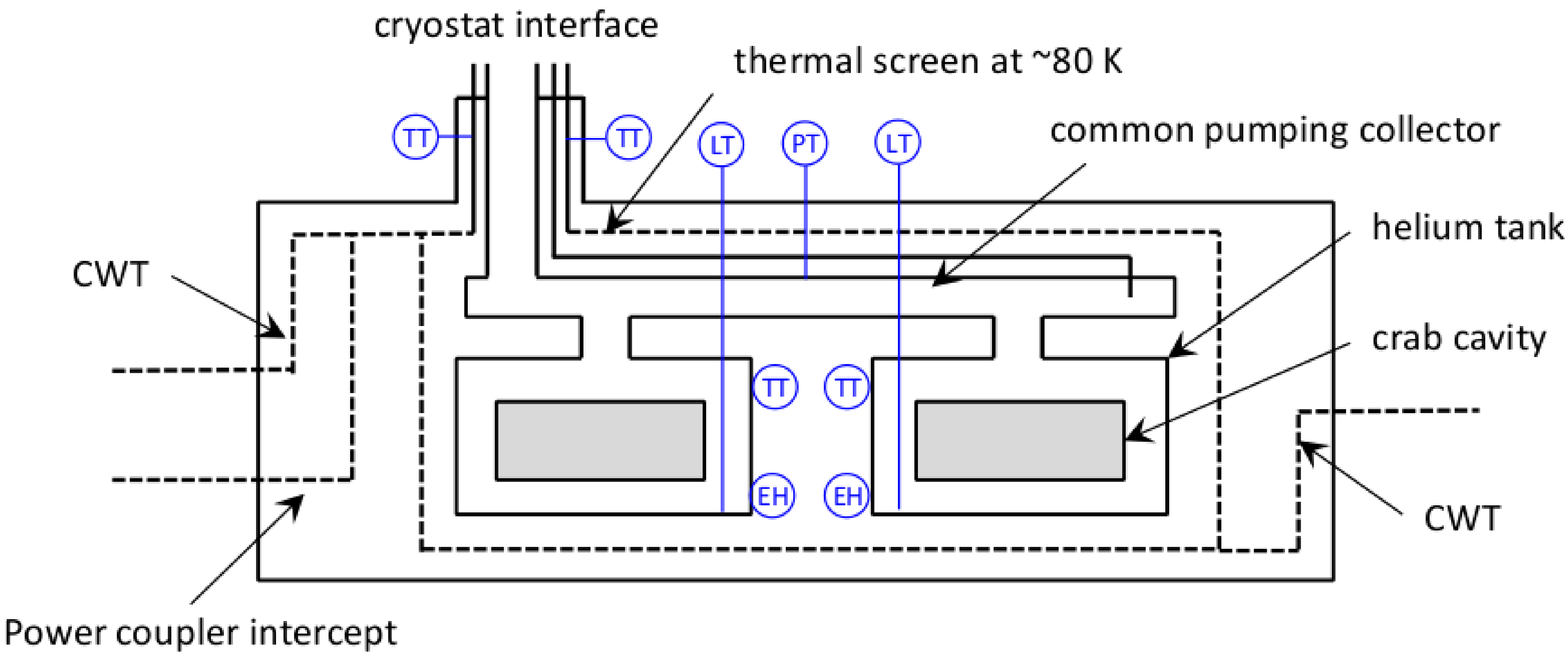
Very strong damping along with potentially high HOM power (~1 kW) is specified as a requirement

As a result both coxial & waveguide type coupling have emerged in various forms all of which are on the cavity body

An important issue is the heat load both for SPS (very limited) & in the LHC in view of the 32 cavities

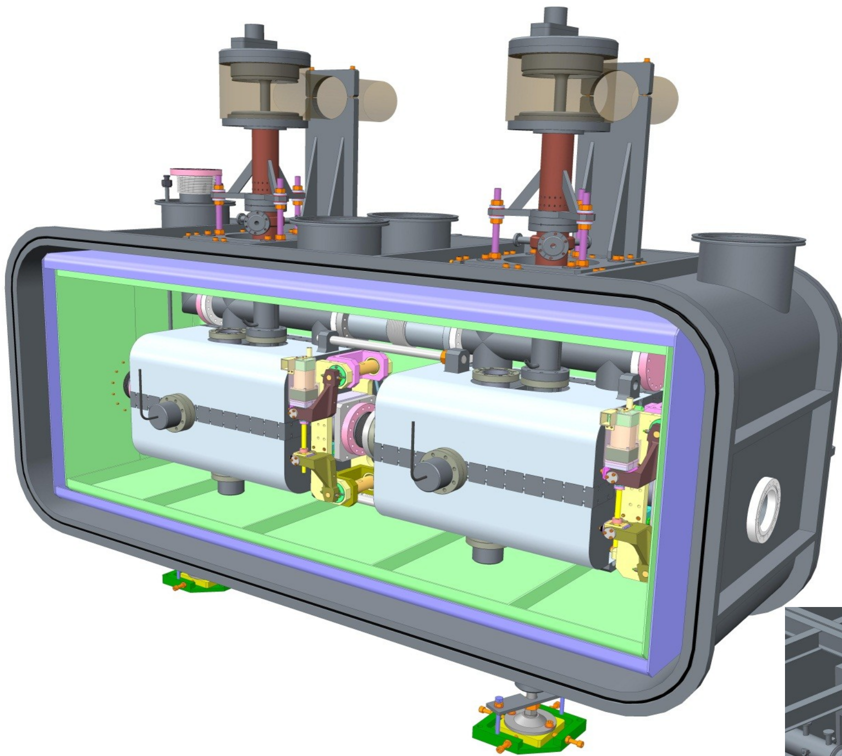
Aspect #9: Cryogenics in SPS

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



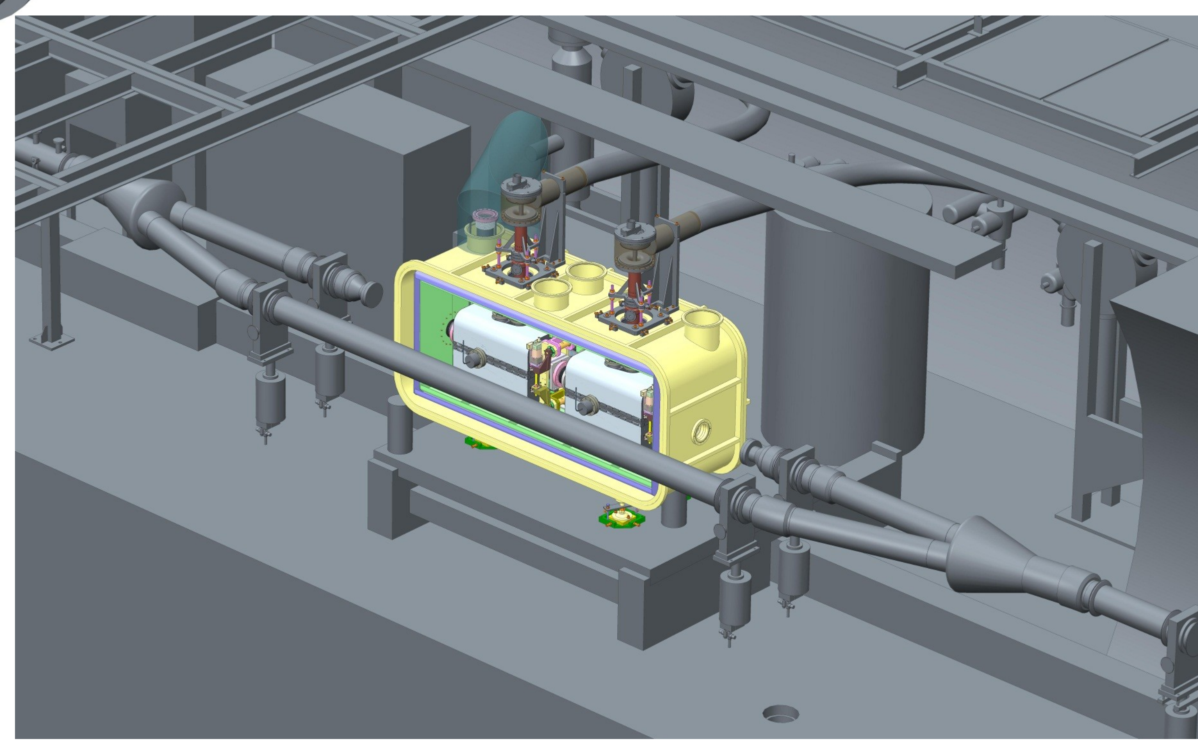
See tomorrow: K. Brodzinski

Cryostat Integration into SPS



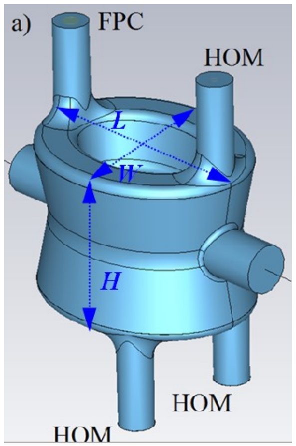
See tomorrow: A. Macpherson's Talk

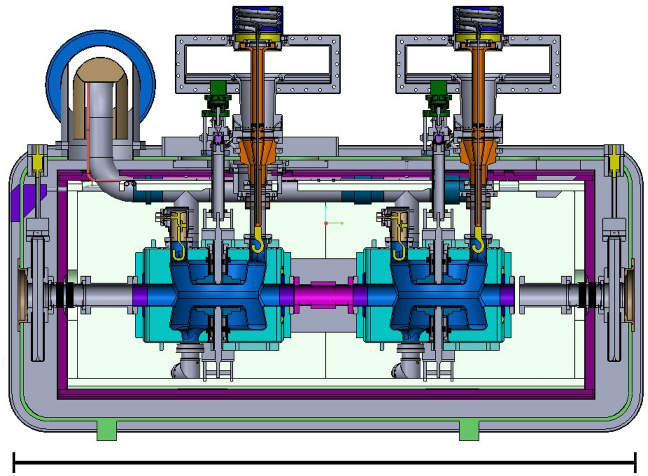
Integration into SPS Bypass



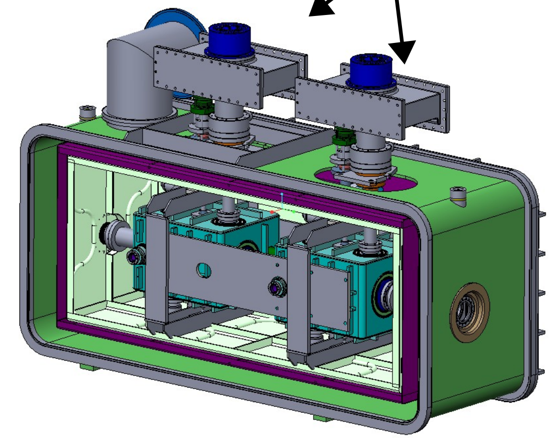
Common Design Approach

Power coupler Interface

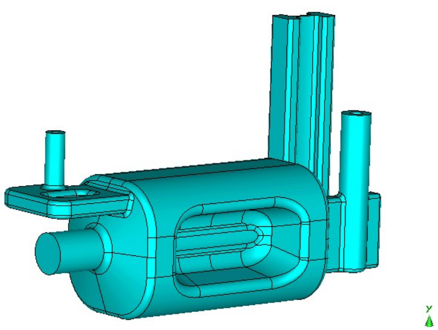


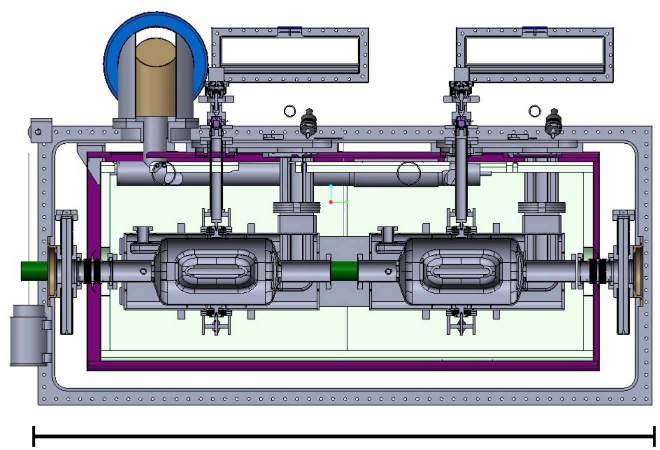


2.75m

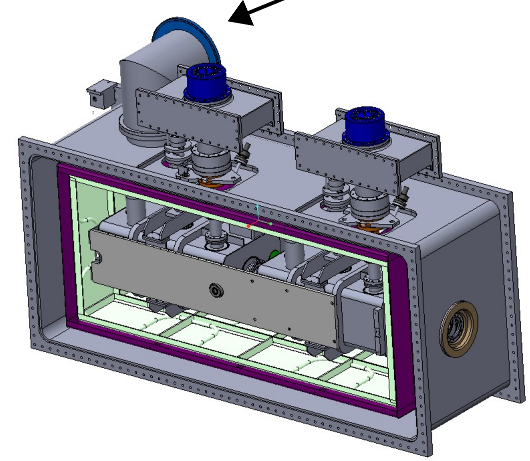


Cryo Interface





2.9m



The next 2 Days

Why we are here

- Review 3 of the most promising deflecting cavity concepts

What we (or I) hope from it

- Can we in a clear and neutral way compare the 3-concepts
- Provocatively should we continue with the 3-design concepts

Key challenge

- To assemble this international puzzle