Evaluation of RF pickup antennas for crab cavity (DQW and RFD) LHC-series

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https://indico.cern.ch/event/742082/

Some background

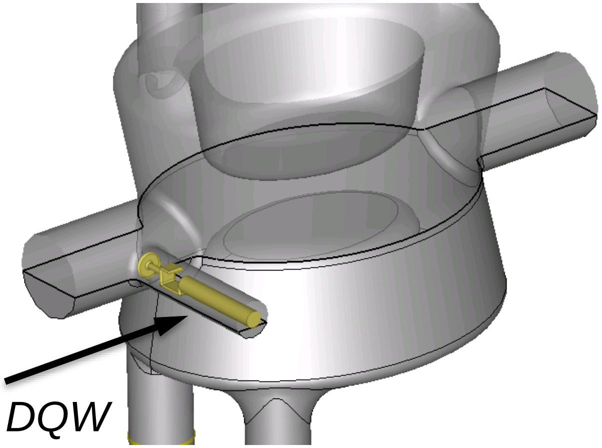
- **Each crab cavity** equipped with **one RF pickup** (field probe) to monitor fundamental mode field in the cavity. The signal:
  - provides **indirect measure of deflecting kick** (Vt) delivered by cavity:

    Vt = sqrt(Pt x Qt x Rt/Q)

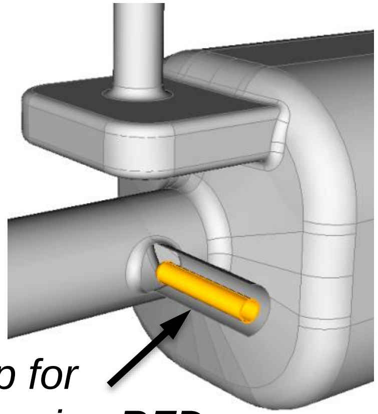
  - used as primary **input for field** (amplitude and phase) **control** in the cavities via RF feedback

- For LHC crab cavities, pickup should **extract about 1 W fundamental mode power** (Pt) when cavity delivers **3.4 MV deflecting kick** (Qt = 2.8e10; Rt/Q ~ 430 Ohm for both DQW and RFD cavities).

- This pickup **already** implemented in DQW and RFD **SPS-series** cavities.



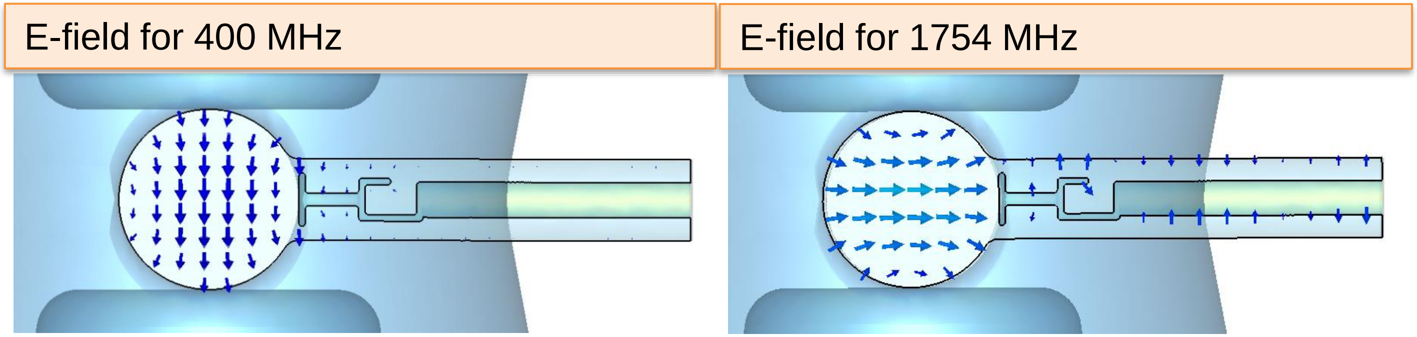
pickup for SPS-series DQW



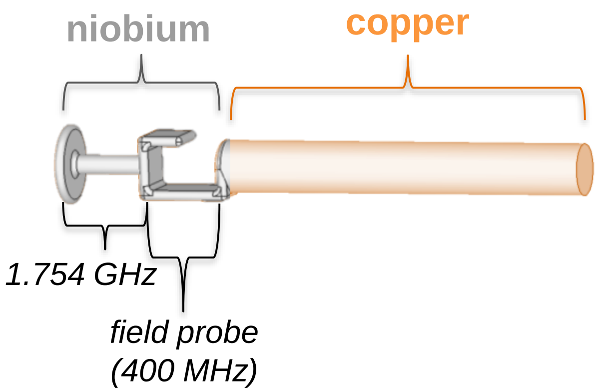
pickup for SPS-series RFD

Some background: *DQW SPS-series pickup*

- The pickup of DQW SPS-series cavities is **dual-purpose**; combines:
  - a **hook** to extract **fundamental mode** power for **monitoring** purposes
  - a '**mushroom**' for **coupling and damping** of the **1754 MHz** mode



- The **pickup tip** exposed to large currents, made of **Nb** to **reduce heat load**; **the rest** fabricated in **Cu**, for better **heat extraction**.



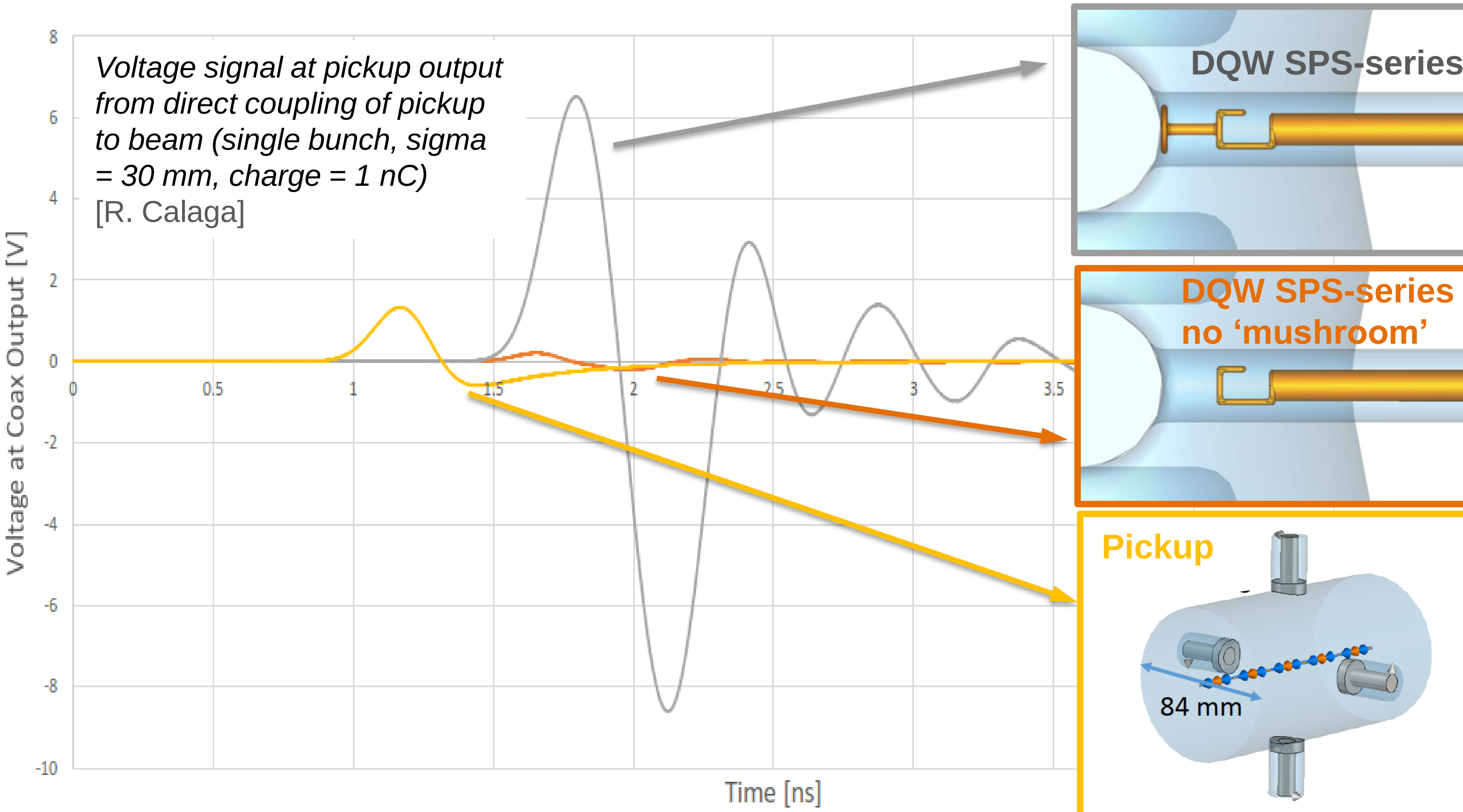
The pickup revisited: *Motivation*

- **SPS beam tests of DQWs evidence direct coupling** of beam to pickup, with consequent **impact on the RF feedback** (see P. Baudreghien's talk).

Cavity 1 antenna signal, MD#02 (30 May 2018), 1 MHz span;
***about 41.538 kHz** (SPS rev. freq. = 43.450 kHz) **from beam-induced voltage**.*

The pickup revisited: *Motivation*

- **SPS beam tests of DQWs evidence direct coupling** of beam to pickup, with consequent **impact on the RF feedback**.
- CST simulations reveal **'mushroom'** to be **responsible** for **direct coupling**.



The pickup revisited: *Proposal, design goals*

- Equip the **DQW LHC-series** cavity with **two horizontal tubes**, each connected to one of the beam pipes and **revisit pickup** design [R. Calaga]**:**

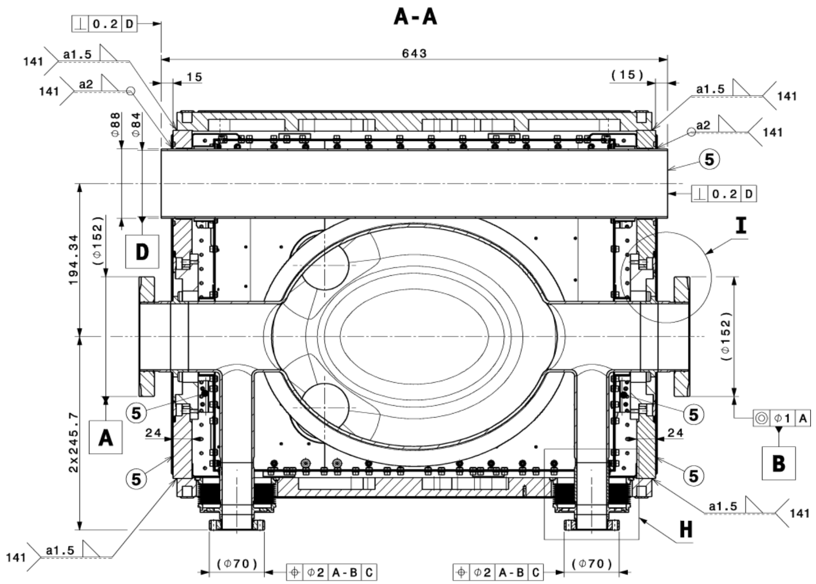
1) Adopting **simple hook** to extract **1 W fundamental mode** at Vt = 3.4 MV

   ➔ *Requirements:* reduced beam coupling, adequate Qe (2.8e10), high Q0 (reduced dissipation, copper preferred), consider machining.

2) Opening **another** port **for** damping of **1.754 GHz** mode (also **backup pickup**)

   ➔ see J. Mitchell's talk

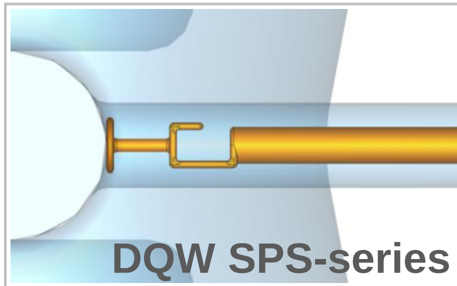
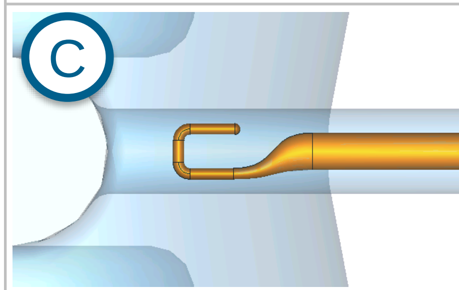
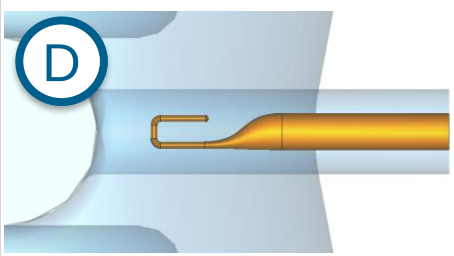
- **Second port integration validated** (LHCACFHT0258) [P. Marcillac, R. Leuxe]



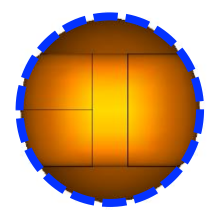
DQW LHC-series cavity equipped with two horizontal tubes integrated into its helium vessel.

The pickup revisited: *DQW LHC-series pickup*

- DQW SPS-series **pickup w/o 'mushroom'** provides **insufficient coupling** (Qe = 5.5e10). **Models below** provide **adequate field coupling** (Qe ~ 2.8e10)

	Penetration (mm)	Clearance (mm)	Heat loss (mW, Cu)	Max. beam coupling (V)
	0	6.8	<1 (Cu part)	8 (100%)
	-25	6.5	5	0.25 (3%)
	-19.5	10.8	22	0.25 (3%)

D) Hook envelope contained within stem thickness:



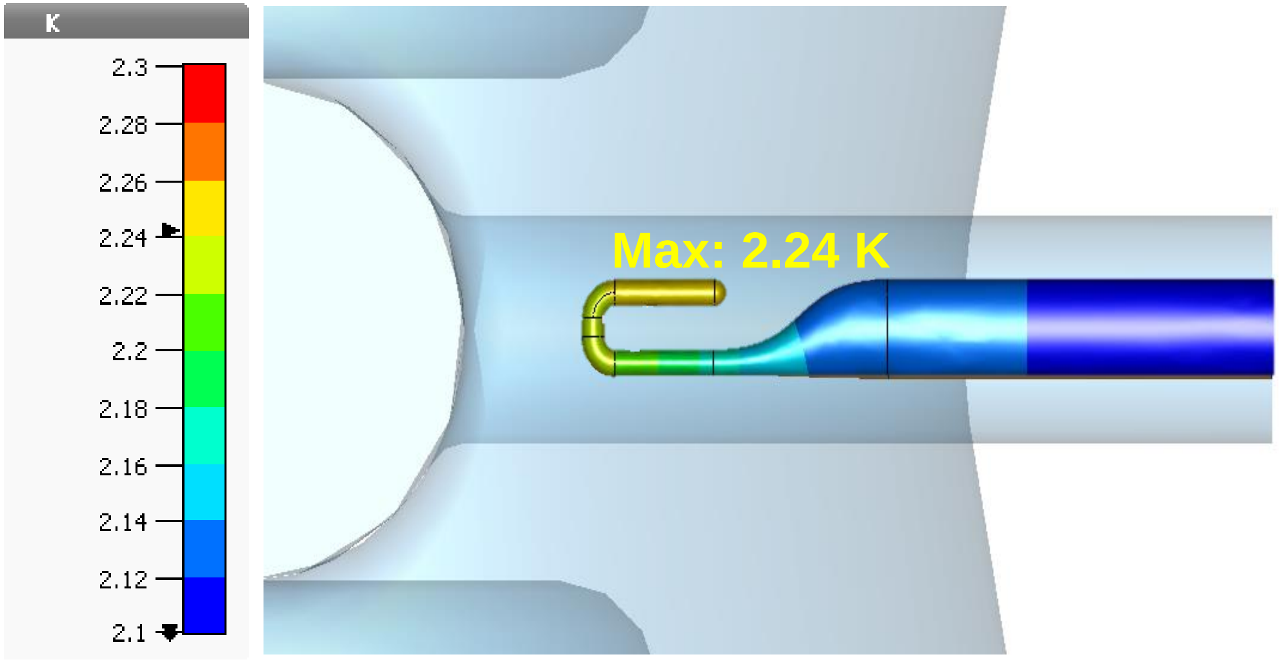
- Assumed **Rs (Cu, 2K) = 1 mOhm** for heat loss calculation
  (anomalous skin effect + 30% extra to account for surface roughness …)
- About **4 W/m2 dissipated** power density **localized in hook section**.

The pickup revisited: *DQW LHC-series pickup*

CST SIMULATION SETTINGS

Non-iterative (thermal properties of materials not updated with temperature)

<u>Pickup model: D</u>
Vt = 3.4 MV
T0 = 2.1 K
σ(Cu) = 5.8e7 S/m
K(Cu)= W/K/m



PRELIMINARY RESULTS

Most penetrating, thinnest wall hook leads to ΔT~0.14 K, in principle, acceptable.

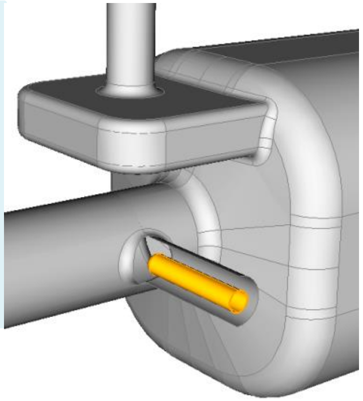
CONCLUSION

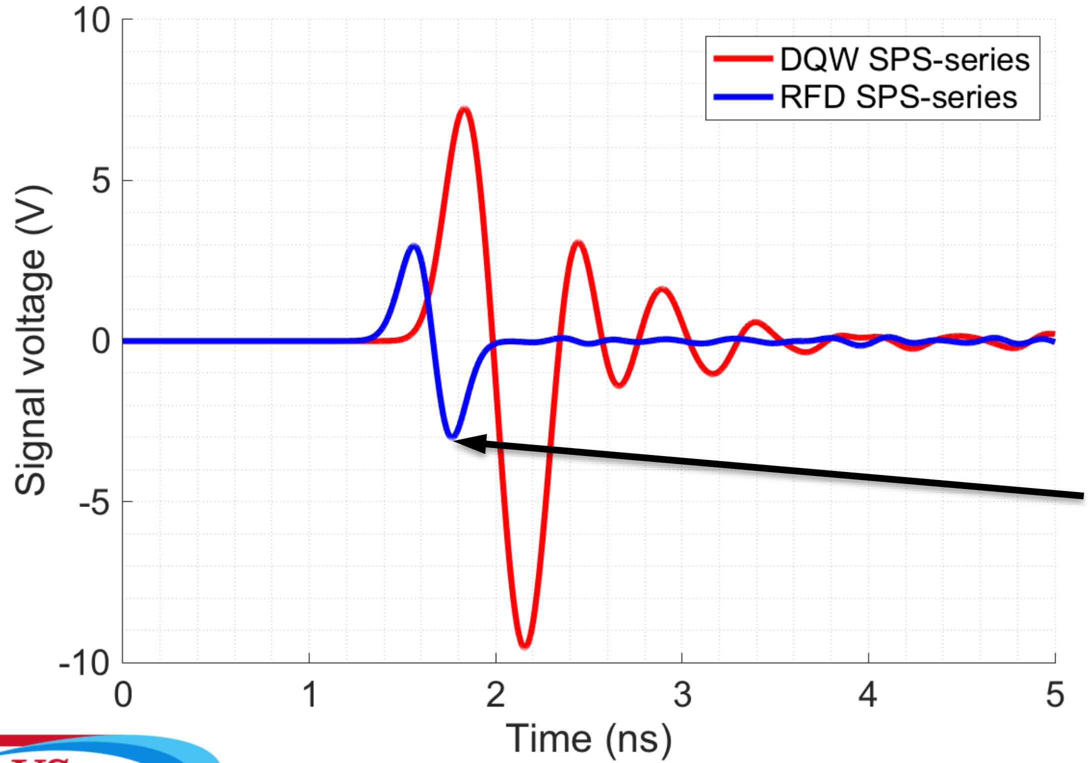
- Found a possible pickup with reduced beam coupling, heat loss, adequate field coupling. Can be made in copper. Good clearance to ease insertion.
- Repeat RF and thermal simulations incl. RF feedthrough, T-dependent material properties; compare with other software.

The pickup revisited: *What about the RFD?*

From the PDR (2018) ➔ see also Z. Li's talk

The **field pickup** is placed on the VHOM side of the cavity using straight probe coupling […]. The designed power extraction by the field pickup is **1.5 W at** the **3.34 MV** deflection voltage, which corresponds to a **Qext** value **of 1.7x10^{10}**. […] has a **negligible effect on the field symmetry**.

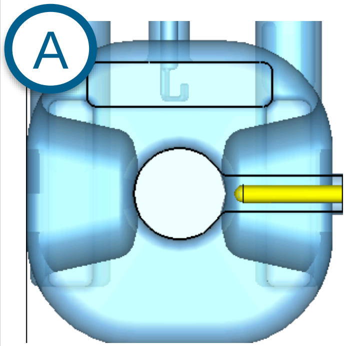
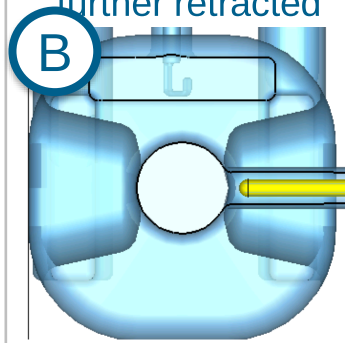
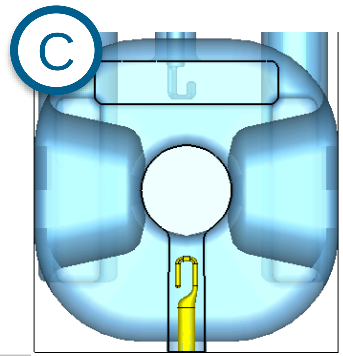
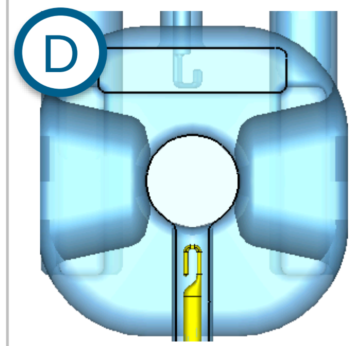




Voltage signal from RFD pickup coupling to beam is <u>not negligible</u>

The pickup revisited: *RFD LHC-series pickup*

All below ***provide 1 W*** *fundamental mode power* ***at 3.4 MV deflecting kick****.*

	RFD SPS pickup, more retracted	RFD SPS pickup, tube close to cavity, further retracted	Hook, vertical tube	Contained hook, vertical tube
				
Penetration (mm)	-7.6	-9.8	-20.5	-15.4
Heat loss (mW, Cu)	13	22	10	15
Max. beam coupling (V)	2.2 (30% DQW)	1.5 (20% DQW)	0.6 (8% DQW)	0.6 (8% DQW)

Insufficient retraction to significantly reduce coupling to beam.

Larger coupling, allows retracting pickup further. Small coupling to beam.

Conclusion: *a* hook into vertical tube provides adequate field coupling, reduced beam coupling and reduced heat dissipation to be made in copper.

Summary and outlook

- **Each crab cavity** equipped with **one pickup** to **monitor field** in the cavity.
- **SPS beam tests of DQW** cryomodule evidence **direct coupling** of **beam to pickup**. **Simulations also** predict beam coupling to SPS-series **RFD pickup**.
- Investigated alternative pickup locations and designs; found possible solutions for DQW and RFD LHC-series that show small coupling to beam.
- The proposed **DQW LHC-series pickup** provides **adequate Qe** (2.8e10), **reduced beam coupling** and **reduced heat dissipation** to be made **in Cu.**
- Pickup **tube orientation** and **antenna type** of **RFD cavity may need to change** (vertical tube, hook coupler) **to limit coupling to beam** (to be discussed).
- Possibility to **use the same pickup design** for **both DQW and RFD** cavities (check length difference) . **Further studies needed** (RF, thermal, including RF feedthrough).

Thanks for your attention

Acknowledgements

Thanks to Zenghai Li (SLAC) for providing the RFD cavity 3D model.

Funding agencies

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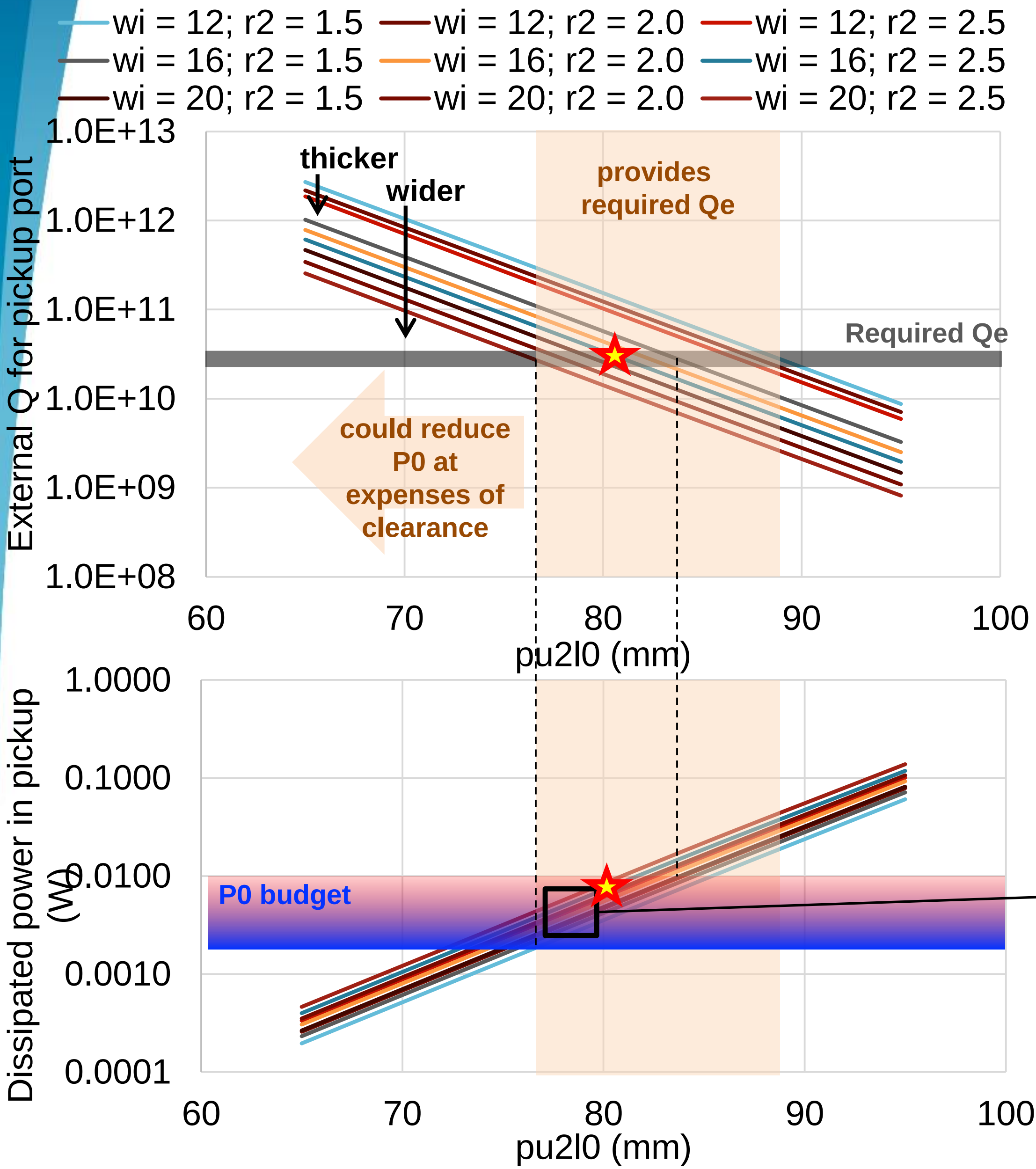
Back-up

The pickup revisited: *DQW LHC-series pickup*

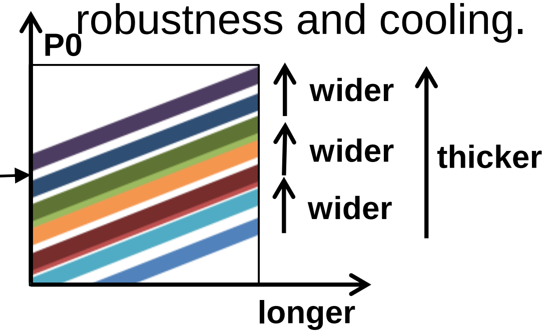


Observations:

- P0 varies greatly with antenna length (penetration).
- Qe mainly given by antenna length and hook width.
- Could further reduce P0 at expenses of clearance (wi = 20 leaves 6.5 mm distance between hook and tube wall; wi = 16 leaves 8.5)

Selection criteria – select…

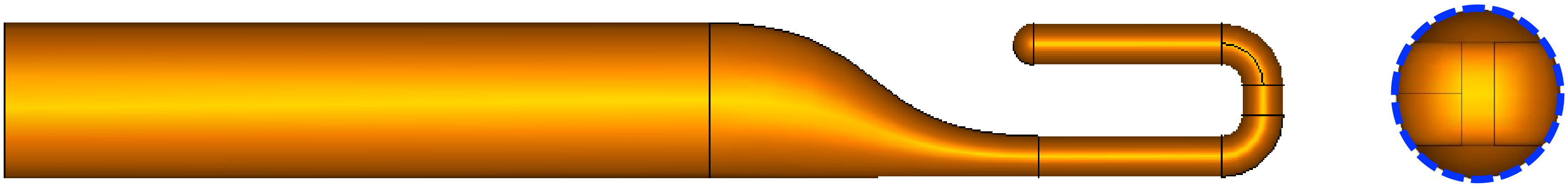
1) parameter sets providing required Qe.
2) length to meet P0 budget (<10 mW).
3) hook width and thickness as per required Qe; thicker preferred for robustness and cooling.



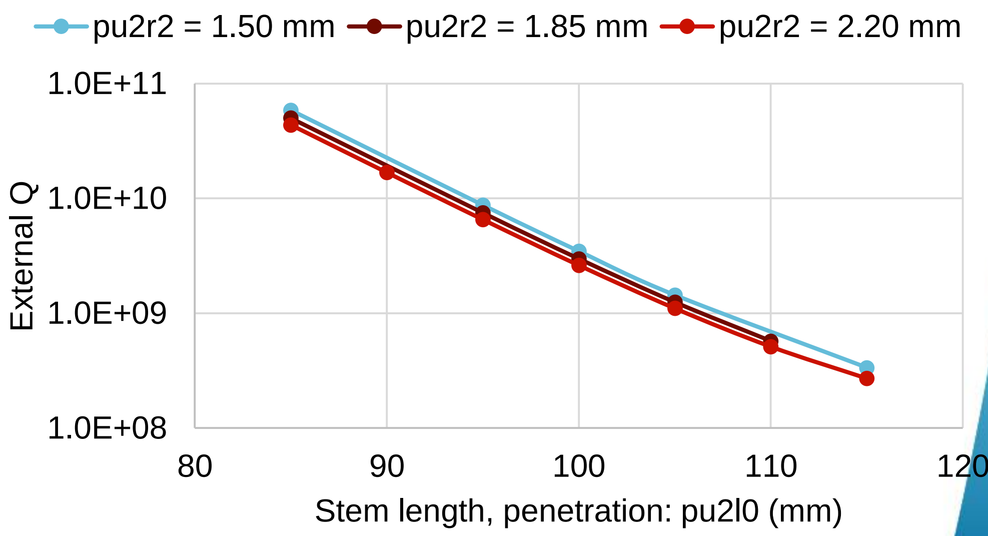
The wider and the thicker, the shorter to reach required Qe.

The pickup revisited: *DQW LHC-series pickup*

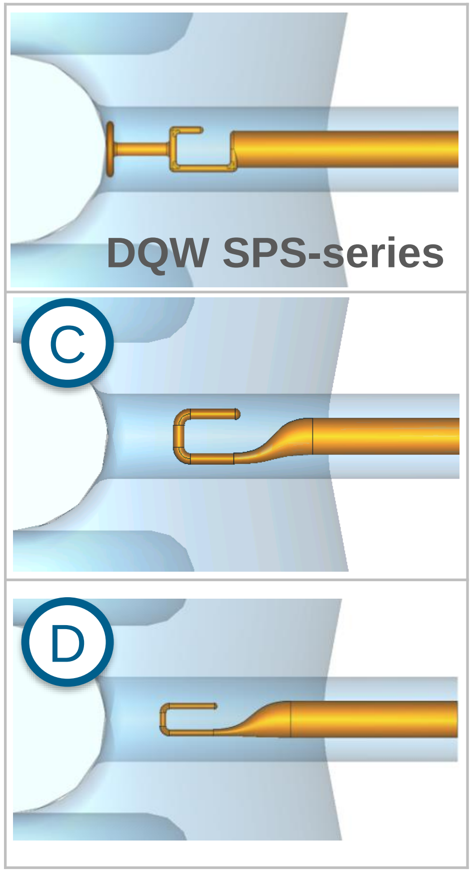
- For 3 mm minor diameter section, pu2l0 ~ 89 mm provides 1 W fundamental mode power and 20 mW dissipated in hook. About 4 W/m2 dissipated power density localized in hook section (actually power density calculated using power dissipated in the whole pickup, but using only surface area in the hook section).
- Increased **minor diameter of ellipse** from 3 mm to **4.4 mm to ease manufacturing**. Tried to **keep hook within envelope** of stem section (see **blue-dashed** line below).

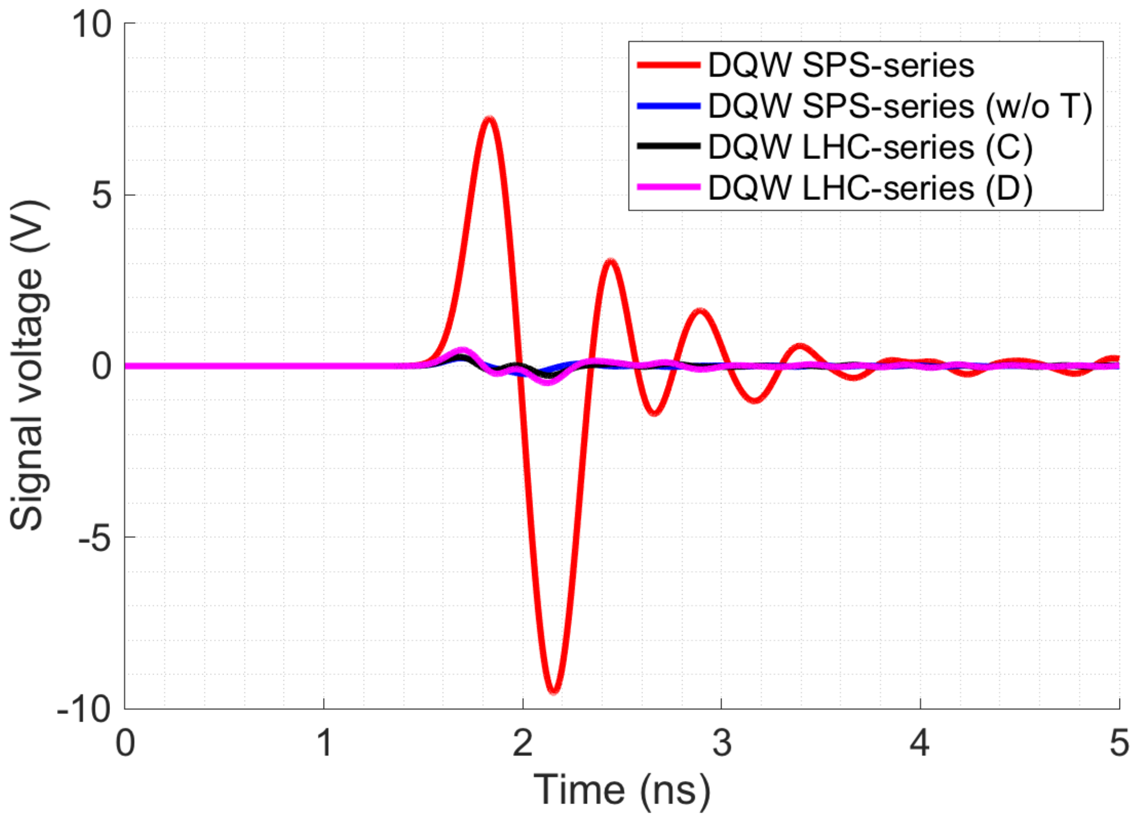


- Evaluated Qe for different values of minor radius ellipse (pu2r2 = 1.5%2.2 mm) and stem length (pu2l0 = 85%115 mm). Observations: coupling barely changes with pu2r2 but does change dramatically with pu2l0. As required Qe is 2.75e10 to extract 1 W fundamental mode power, then it is convenient to choose the hook model with **thicker section (pu2r2 = 2.2 mm)** for expected improved heat extraction (however, it will lead to **higher dissipated power of 21 mW with pu2l0 = 87.2 mm and qe = 2.86e10**).

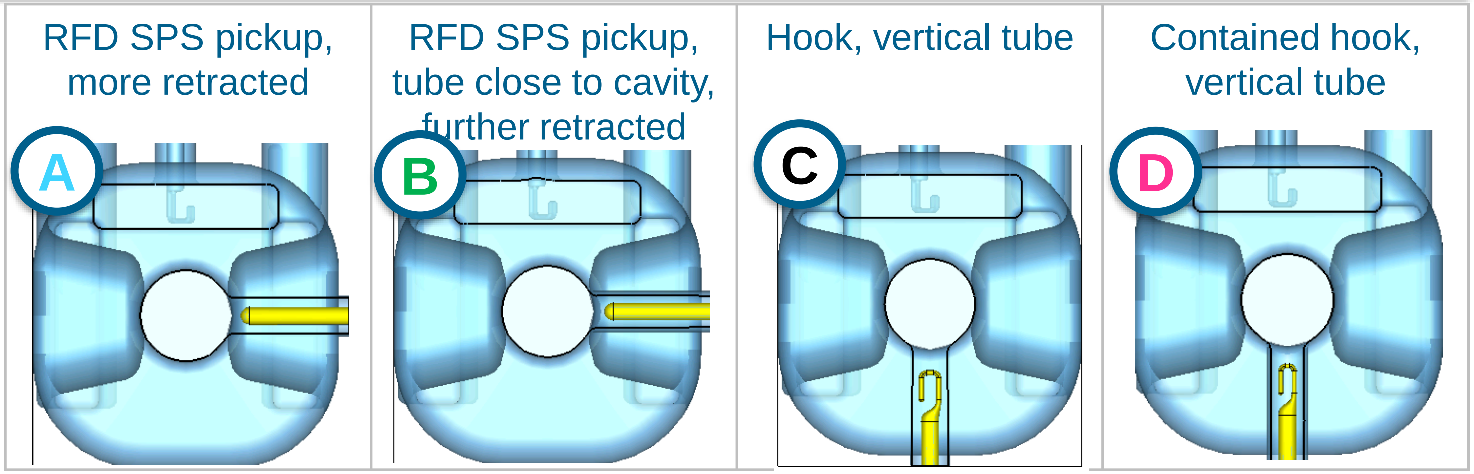


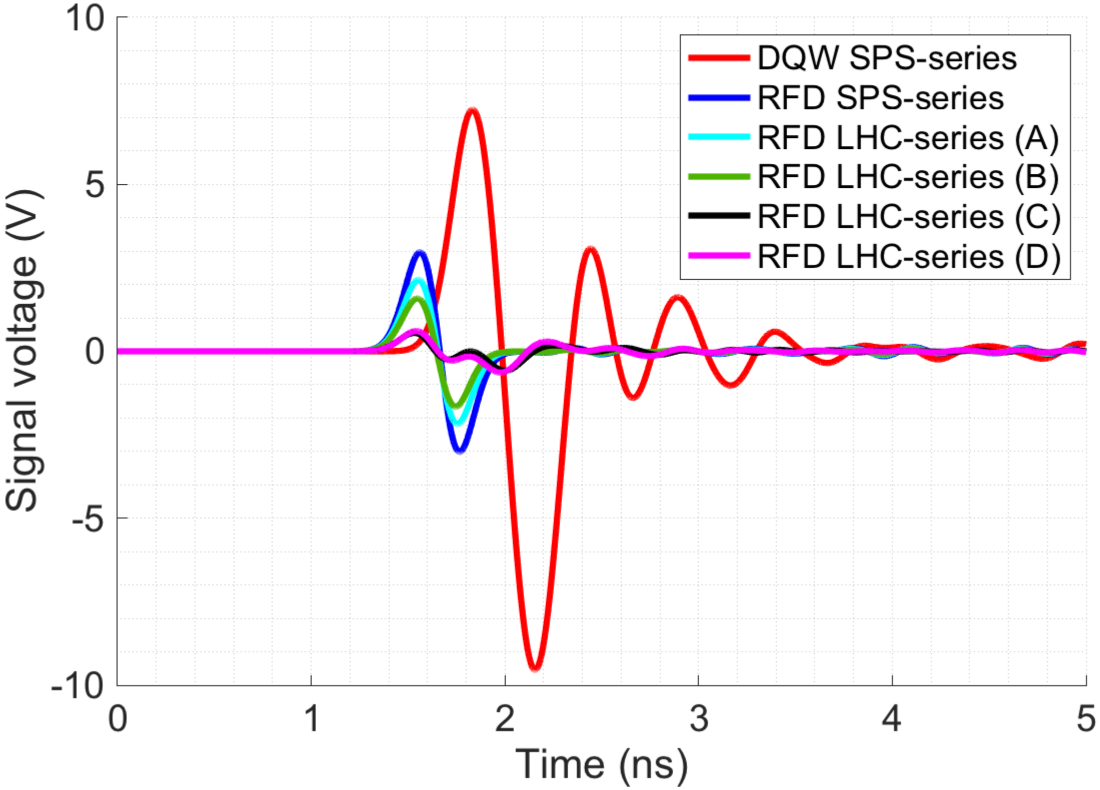
The pickup revisited: *DQW LHC-series pickup*



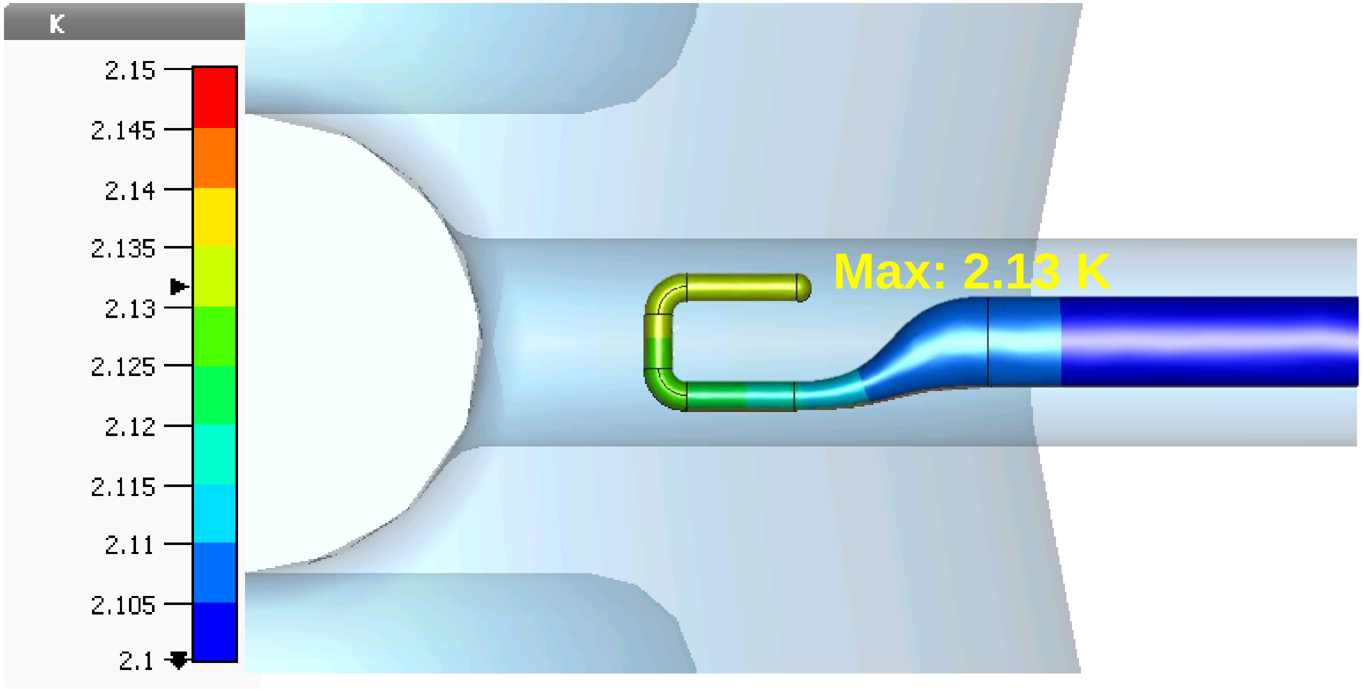


The pickup revisited: *RFD LHC-series pickup*





The pickup revisited: *DQW LHC-series pickup*



Preliminary results: the widest hook provides the lowest temperature increase because it needs to penetrate less into the high field region.

To be done: repeat simulation including RF feedthrough, temperature-dependent material properties and possibly compare with other software's results.