$\lambda/4$ and $\lambda/2$ Cavity Status Report Performance and Problems List

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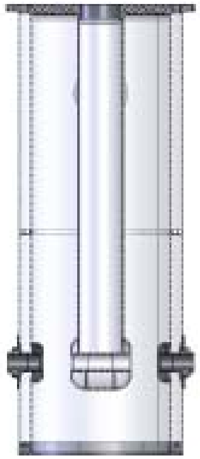
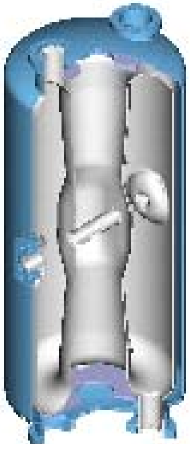
Where are we?

- QWRs
  - very successful from β~0.02 up to β~0.15
  - used in many linacs since many years
  - advanced state of development
  - new projects coming



- HWRs (coaxial)
  - steering free substitute of QWRs
  - lower cost equivalent of 2-gap Spoke cavities
  - used only in 1 linac until now
  - early state of development
  - new projects coming



Treatments applied

- BCP
- EP
- HPR
- grinding
- tumbling (Cu/Nb)
- clean room assembly
- …
- all that is applied to high beta (usually with some delay)

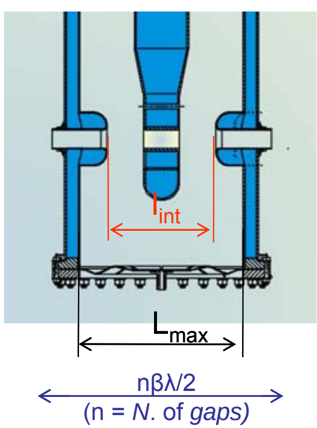
- we have also common vacuum

State of the art in QWRs

- Maximum fields in QWRs at **4.2 K** (selection)

	f	beta	Ep	Bp	Ea	Vmax	Leff	L max	Ea Norm.*	material	year	Vacuum	EP
			MV/m	mT	MV/m	MV	m	m	MV/m				
ANL	109	0.15	48	88	15	3.75	0.25	0.35	**10.7**	Nb	2009	Separate	Y
TRIUMF	108	0.07	55	110	11	2	0.18	0.18	**11.1**	Nb	2002	Common	N,Y
TRIUMF	141	0.11	48	97	11	1.8	0.18	0.18	**10.0**	Nb	2009	Common	N
MSU	81	0.041	67	118	10	1.8	0.18	0.18	**10.0**	Nb	2009	Separate	N
IPNO	88	0.12	60	110	11	4.4	0.41	0.38	**11.6**	Nb	2005	Separate	N
CEA	88	0.07	55	96	11	2.6	0.24	0.23	**11.3**	Nb	2009	Separate	N
INFN	80	0.055	55	110	11	2	0.18	0.18	**11.1**	Nb	1998	Common	N
INFN	80	0.047	58	115	11	2	0.18	0.18	**11.1**	Nb	2000	Common	N
INFN	160	0.11	55	110	11	2	0.18	0.18	**11.1**	Nb/Cu	1998	Common	-

* Ea norm =Vmax/Lmax

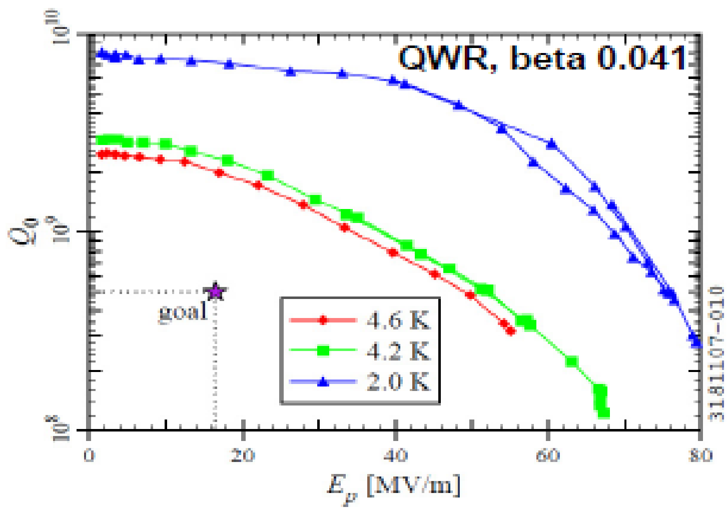


– "Typical best" performances at ~4.2K
  - max E_p: ~67 MV/m
  - max B_p: ~118 mT
  - max E_a : ~11.6 MV/m
  - max operation $E_{a(norm)}$: ~7 MV/m

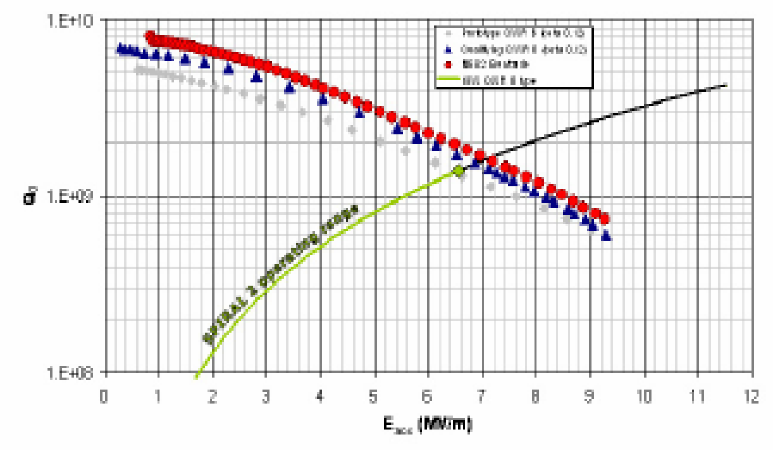
– Remark: similar performances for
  - – BCP and EP
  - – common and separate vacuum
  - – bulk and sputtered Nb

QWR recent achievements

- Max E_p, B_p
  - MSU 80 MHz cavity at 2K:
    - E_p ~80 MV/m, B_p ~160 mT at
    - Close to β~1 cavities results
    - QWR operation at 2K is becoming interesting



- Q-slope processing
  - 120 °C baking in IPNO 88 MHz QWRs
    - reduction of Q-slope
    - $\times$2 Increase of Q at high field
  - now documented also in QWRs



Limiting problems in QWRs

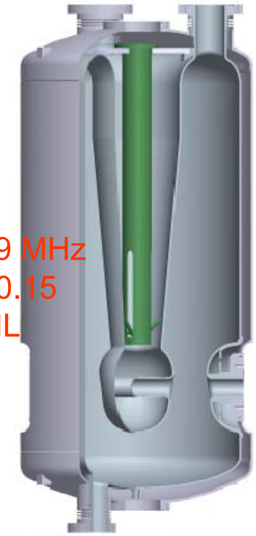
1. **Q-slope** $\Rightarrow$ operation gradients limited by high rf power dissipation
   - possible remedies:
     - 120 K baking can reduce the slope
2. **Mechanical instabilities in lower-β cavities** $\Rightarrow$cavity phase unlock
   - possible remedies and drawbacks:
     - overcoupling
       - limited by rf system and rf power cost
     - mechanical damper:
       - vibrations reduced in amplitude but not eliminated completely
     - VCX
       - limiting operation gradient
       - adding complexity and cost (electronics, cryogenics, maintenance,…)
     - piezo
       - not yet implemented satisfactorily in operating QWRs
3. **Beam steering**
   - possible remedies:
     - beam axis misalignment
     - beam port shaping

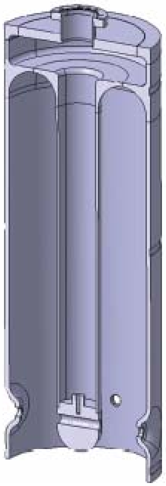
Latest trends in QWRs

- Using large cavities and low frequency also for β~0.1 QWRs
  - larger longitudinal acceptance, larger aperture, larger energy gain…
  - cavity more expensive, but less cavities are needed
  - more convenient when Rf system cost is dominant (e.g. for high current beams)

Remark: good perspectives for Nb sputtering in QWRs

- sputtering easier in large cavities
- cost saving vs. bulk Nb in cavity material and magnetic shielding
- sputtering have shown better results at lower frequencies

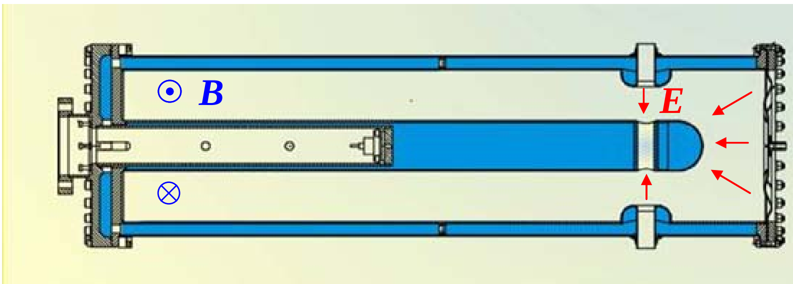


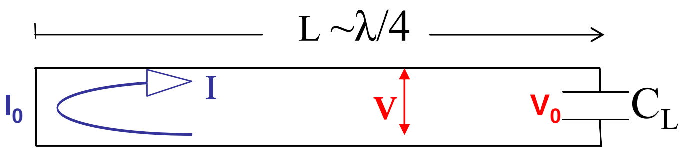


Main ongoing projects with QWRs

- New accelerators under construction:
  - Spiral 2 (Ganil, France) 40 QWRs, 88 MHz
  - REA3+REA12 (MSU, USA) 47 QWRs, 80.5 MHz
  - HIE –ISOLDE (CERN, CH) 32 QWRs, 101 MHz (Nb/Cu)
- In preparation
  - FRIB (MSU, USA) 112 QWRs, 80.5 MHz (+ 222 HWRs)
- Recently upgraded, or under upgrade, with new cavities
  - ISAC3 (TRIUMF, Canada) 20 QWRs, 107 MHz
  - Atlas (ANL,USA) 7 QWRs, 109 MHz
  - Srf linac (IUAC, India) 16 QWRs, 97 MHz
  - ALPI (LNL, Italy) 4 QWRs, 80 MHz
- Existing accelerators with superconducting QWRs
  - 6 heavy ion linacs in operation
  - 3 dismantled

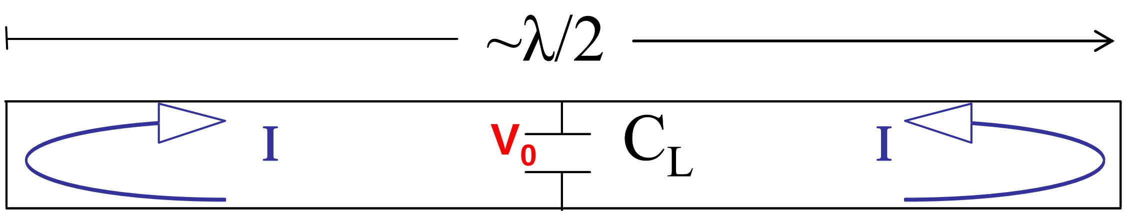
QWRs vs. HWRs

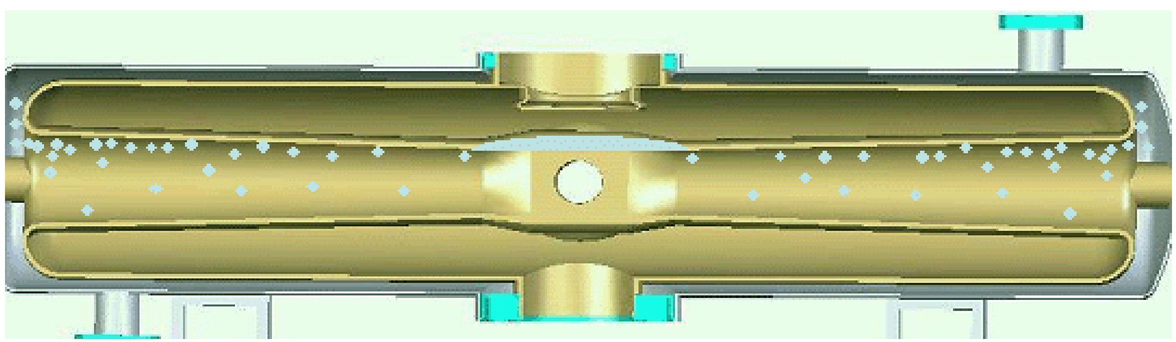




$$P_{HWR} \sim 2\, P_{QWR}$$

…but steering free!



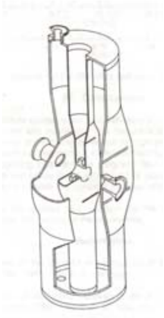


State of the art in coaxial HWRs

- Maximum fields in QWRs at 4.2 K (selection)

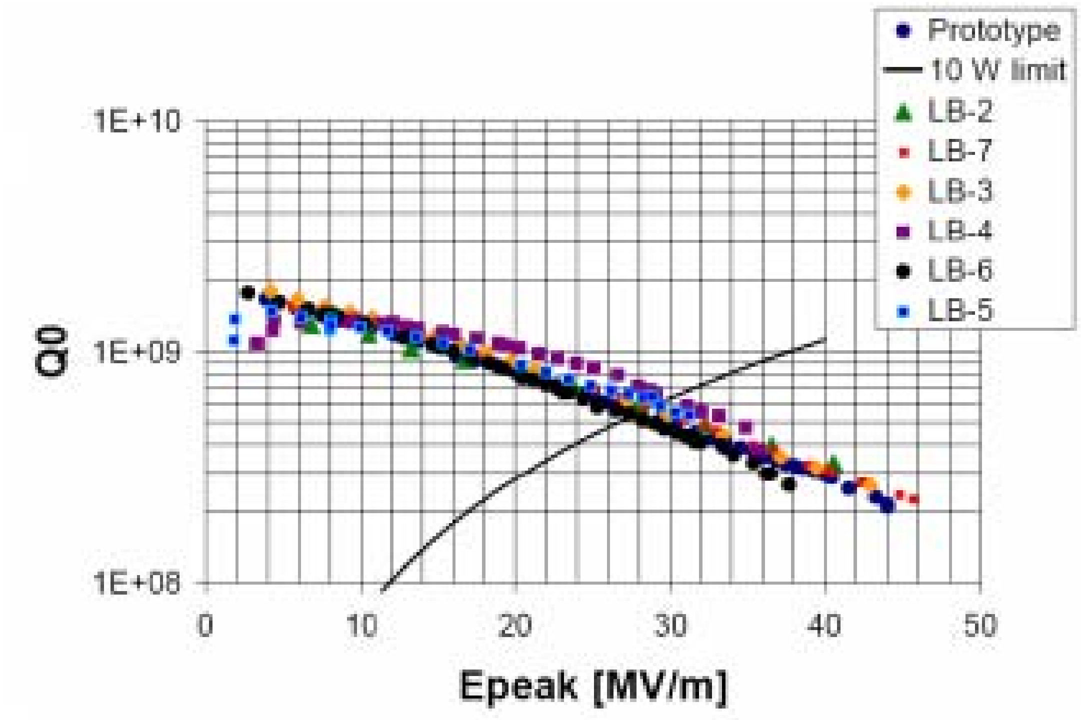
	f	beta	Ep	Bp	Ea	Vmax	Leff	Lmax	Ea norm*	material	year	Vacuum	EP	HPR
	MHz		MV/m	mT	MV/m	MV	m	m	MV/m					
ANL	170	0.27	29	78	10	3	0.3	0.35	**8.6**	Nb	2004	separate	Y	Y
ANL	355	0.12	57.6	93.6	18	1.26	0.07			Nb	1991	separate	N	N
ACCEL/R	176	0.09	45	95	15.5	1.5	0.099	0.18	**8.3**	Nb	2006	separate	N	Y
INFN	352	0.31	31	82	7.9	1.8	0.224	0.224	**7.9**	Nb	2004	common	N	N
INFN	352	0.17	39	81	6.8	1.2	0.18	0.18	**6.8**	Nb	2006	common	N	N
Juelich	160	0.11	26.5	66	6.3	1.3	0.21	0.18	**7.2**	Nb	2004	separate	N	Y
MSU	322	0.285	27	74	7.1	1.7	0.24	0.24	**7.2**	Nb	2002	separate	N	Y

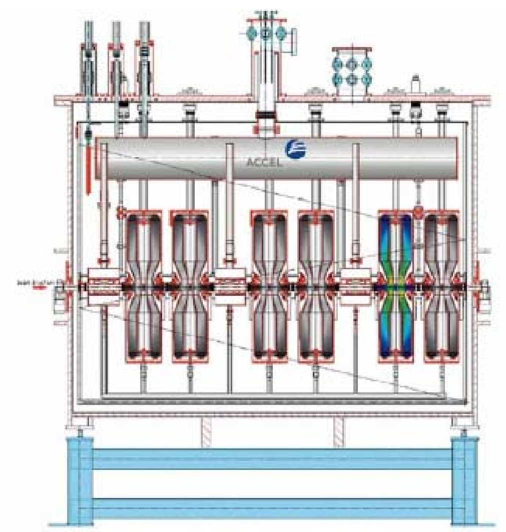
- "Typical best" performances at ~4.2K
  - max E_p: ~57 MV/m *in a cavity of 1991!*
  - max B_p: ~95 mT
  - max $E_{a(norm)}$: ~8.6 MV/m
  - max operation $E_{a(norm)}$: ~5 MV/m



- Remarks:
  - Very low statistics, mostly from single measurements, no recent results

HWR recent achievements





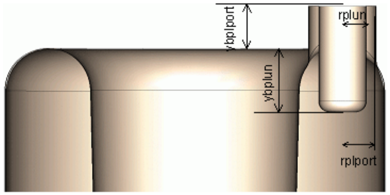
No recent achievements, but we should mention the SARAF cavities test which demonstrated the feasibility of a HWR linac (2006)

Limiting problems in HWRs

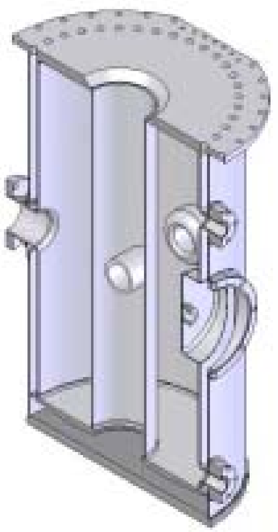
1. **Lower performance than QWRs** ⇐ less R&D until now
   - Let us wait for the imminent FRIB, IFMIF and SARAF HWRs
2. **Q-slope** ⇒ operation gradients limited by high rf power dissipation
   - possible remedies:
     - 120 K baking can reduce the slope
3. **Q degradation from test to linac cryostat**
   - only 1 cryostat until now: too early to draw conclusions
4. **Limited accessibility to inner surface for HPR**
   - solutions:
     - Add large openings at the equator for coupler or for removable tuner
     - Add extra ports at the shorting plates for HPR

Limiting problems in HWRs (cont.)

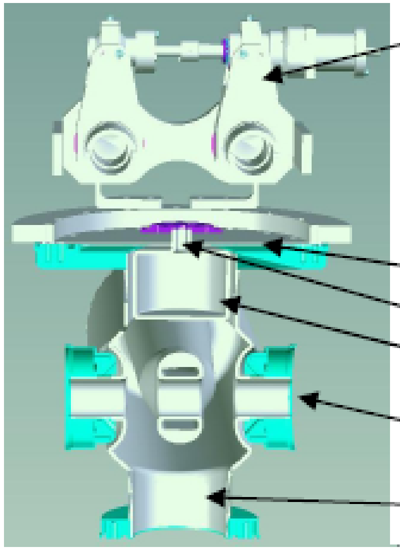
5. **Tuning:** stiff HWRs are hard to tune, soft HWRs have mechanical instabilities. Tuners are either heavy or slow, and require big forces.
   - possible solutions:
     - LNL welded membrane side tuner
       - small tuning range
     - IPNO plunger tuner
       - never tested in HWRs
     - IFMIF removable side tuner
       - not yet tested



IPNO type plunger tuner



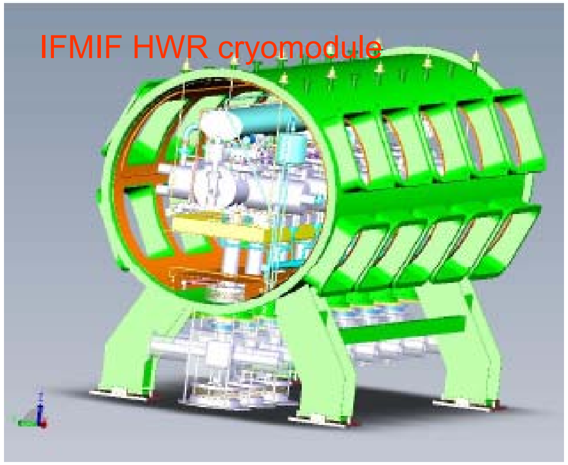
LNL membrane side tuner

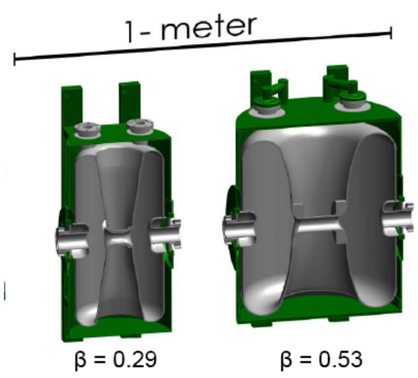


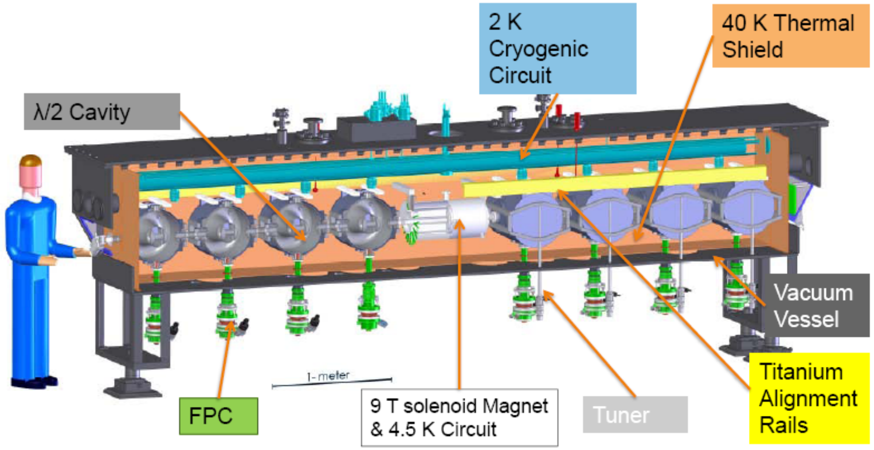
IFMIF removable side tuner

Latest trends in HWRs

- Using HWRs in horizontal position
  - easy to position and align
  - rf coupler from the bottom in vertical position
- Using HWRs at rather high beta
  - β=0.53 in the FRIB driver linac
- Using HWRs (and maybe QWRs) at 2K







FRIB HWRs and β=0.53HWR cryomodule (courtesy of MSU-NSCL)

Main ongoing projects including HWRs

- New accelerators under construction:
  - IFMIF-EVEDA (EU-JA) 8 HWRs, 175 MHz (125 mA cw!)
  - SARAF (SOREQ, Israel) 44 HWRs, 176 MHz
- In preparation
  - FRIB (MSU, USA) 222 HWRs , 322 MHz (+112 QWRs)
  - IFMIF (EU-JA) 84 HWRs, 175 MHz
- Existing HWR accelerators
  - SARAF phase 1 6 HWRs, 176 MHz

Conclusions

- QWRs are nowadays built and treated with similar techniques as β~1 cavities
- They perform not so far from β~1 cavities, taking into account geometrical factor and operation temperature
- Differently from β~1 cavities, however, they all suffer of strong Q-slope, at least at 4.2K
- BCP and EP, common and separate vacuum, bulk and sputtered Nb seem to bring to equivalent performance in QWRs, at least at 4.2K
- HWRs did not perform as good as QWRs until now, because of much less development done. No fundamental reason for that: the next HWRs under development for the new projects are expected to reach the performance of QWRs
- The 2K era is coming also for QWRs and HWRs: will they fill completely the gap still present in performance with the β~1 cavities?

Open questions in QWRs and HWRs

- Can we live without VCX and piezos?
- Can we live without EP in QWRs and HWRs?
- Why common vacuum is looked suspicipusly since the common vacuum linacs are performing as well as separate vacuum ones?
- How close is the sputtering era for QWRs?
- When is it really necessary to use HWRs instead of QWRs?
- Is Beam Port shaping suitable to correct steering in QWRs ?
- Do we have a good tuner for HWRs?

moreover:

- Can we find a common definition of gradient?