An optimized tracker design using CO2 cooling

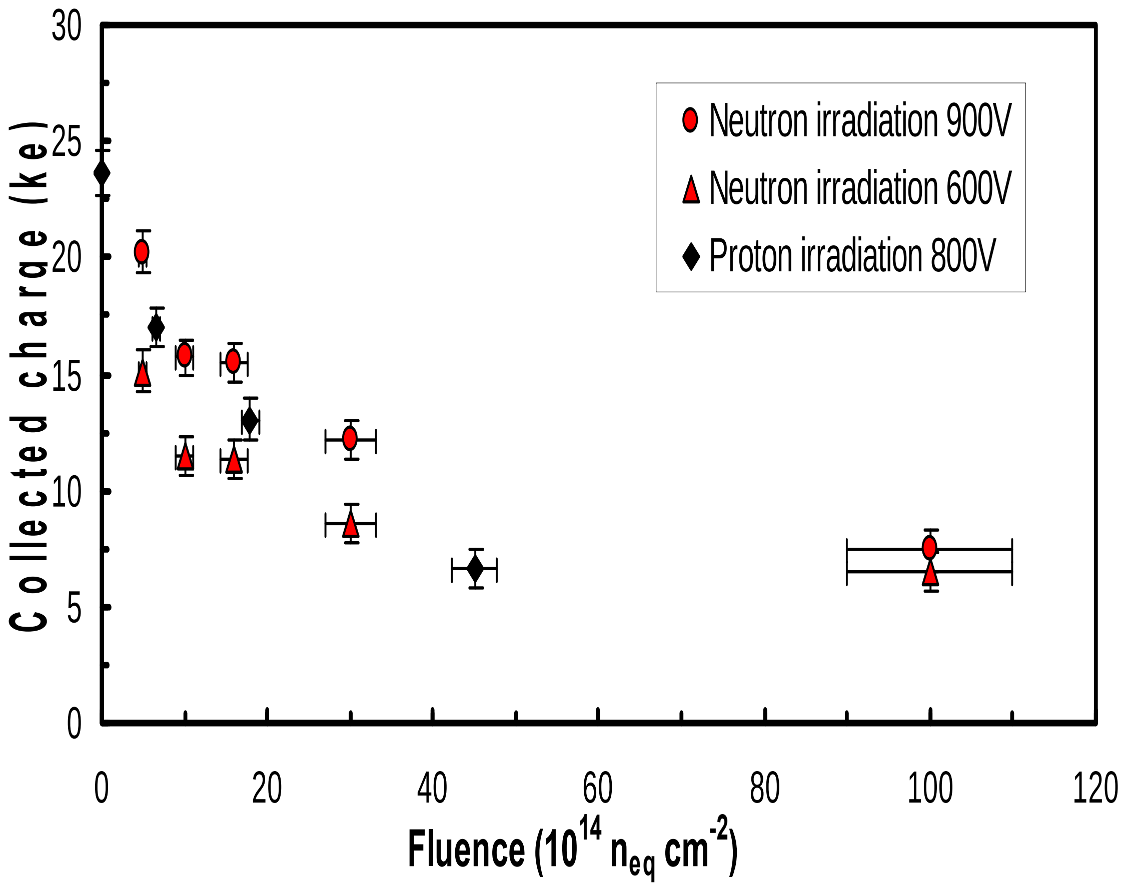
Outline:

1. Requirements for sLHC trackers
   (massless and zero leakage currents)

2. Reduce material budget
   (by combining cooling pipe, mechanical support and current leads into single structure?)

3. Cooling systems

Charge collection efficiency vs fluence for irradiated micro-strip detectors



Casse, Liverpool, RD50

Sufficient signal, but need efficient cooling to avoid large leakage currents (-30 ^{0}C)

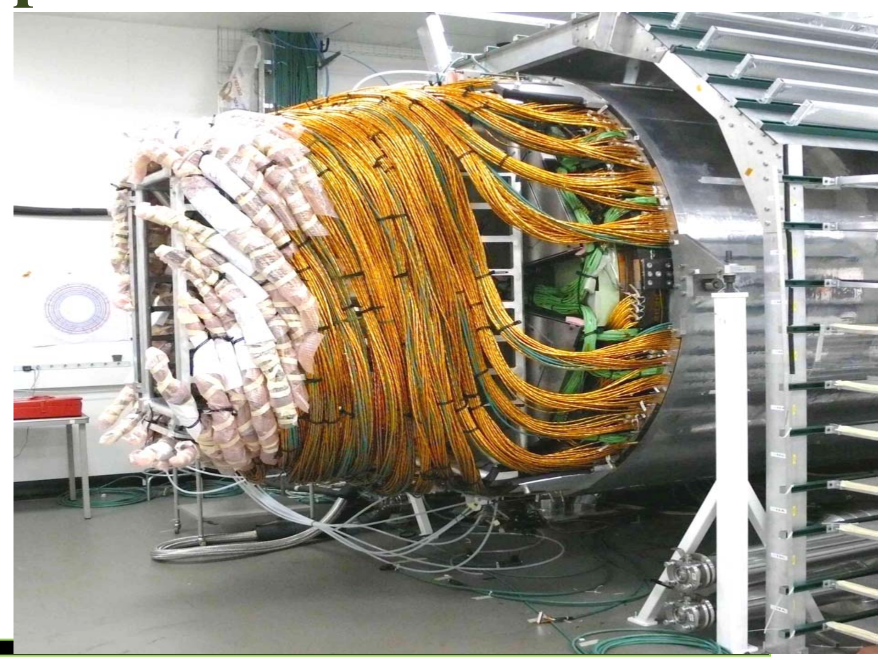
CO_2 efficient to -45 ^{0}C and allows for LONG cooling pipes, because of large heat of evaporation (=small mass flow) and low viscosity-> small pressure drop-> small temp. gradient

Why material budget so high?

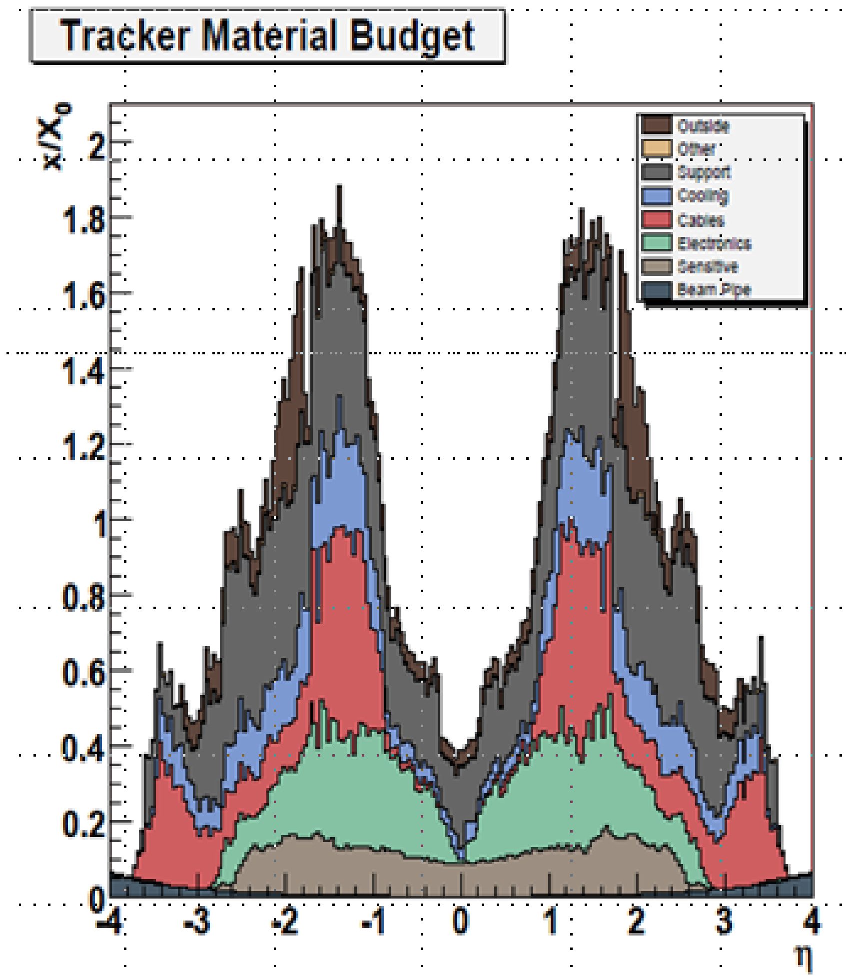
Diversification without communication leads to:

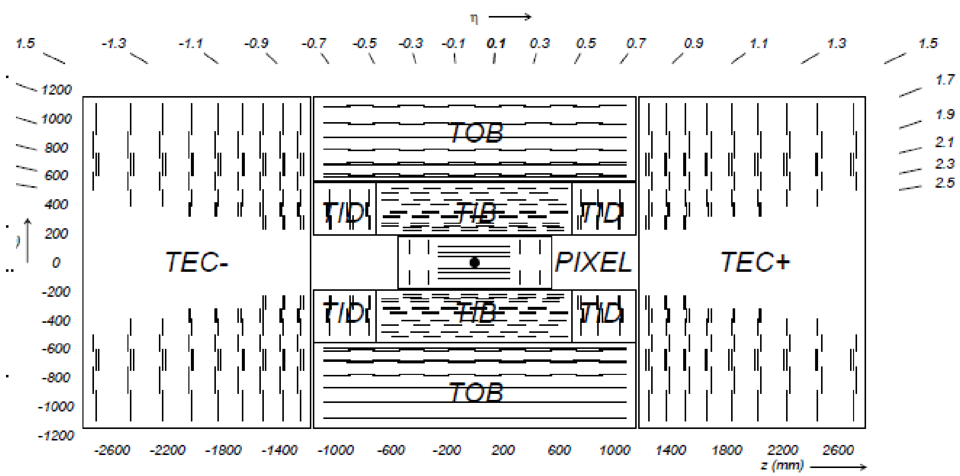
1) Electronics group needs cables
2) HV group needs cables
3) Cooling group needs pipes
4) Gas group needs pipes

Cables and pipes are massive: see CMS →



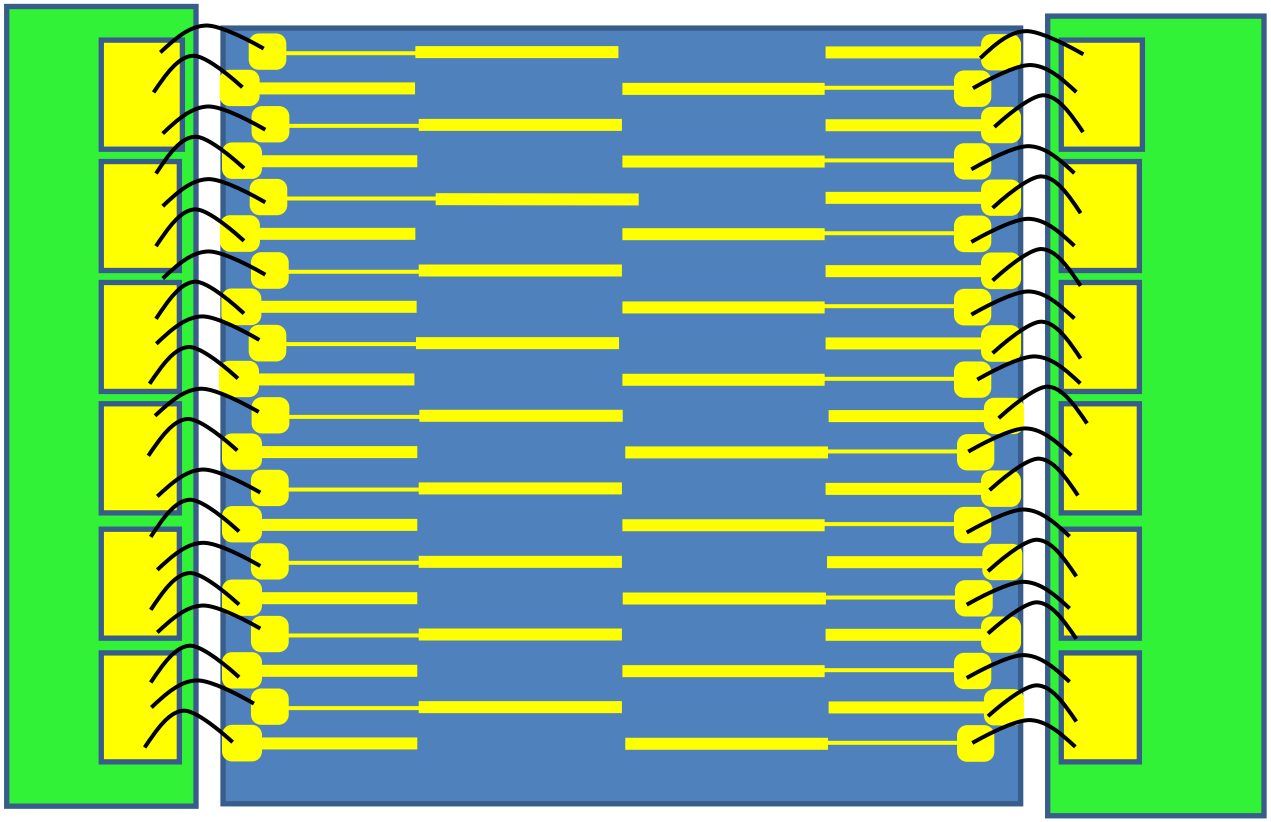
Material budget





Material budget at 1<η<2 can be strongly reduced by LONG barrels, thus avoiding services in front of endcaps

2.2 cm strixel design on 9x10 cm sensor



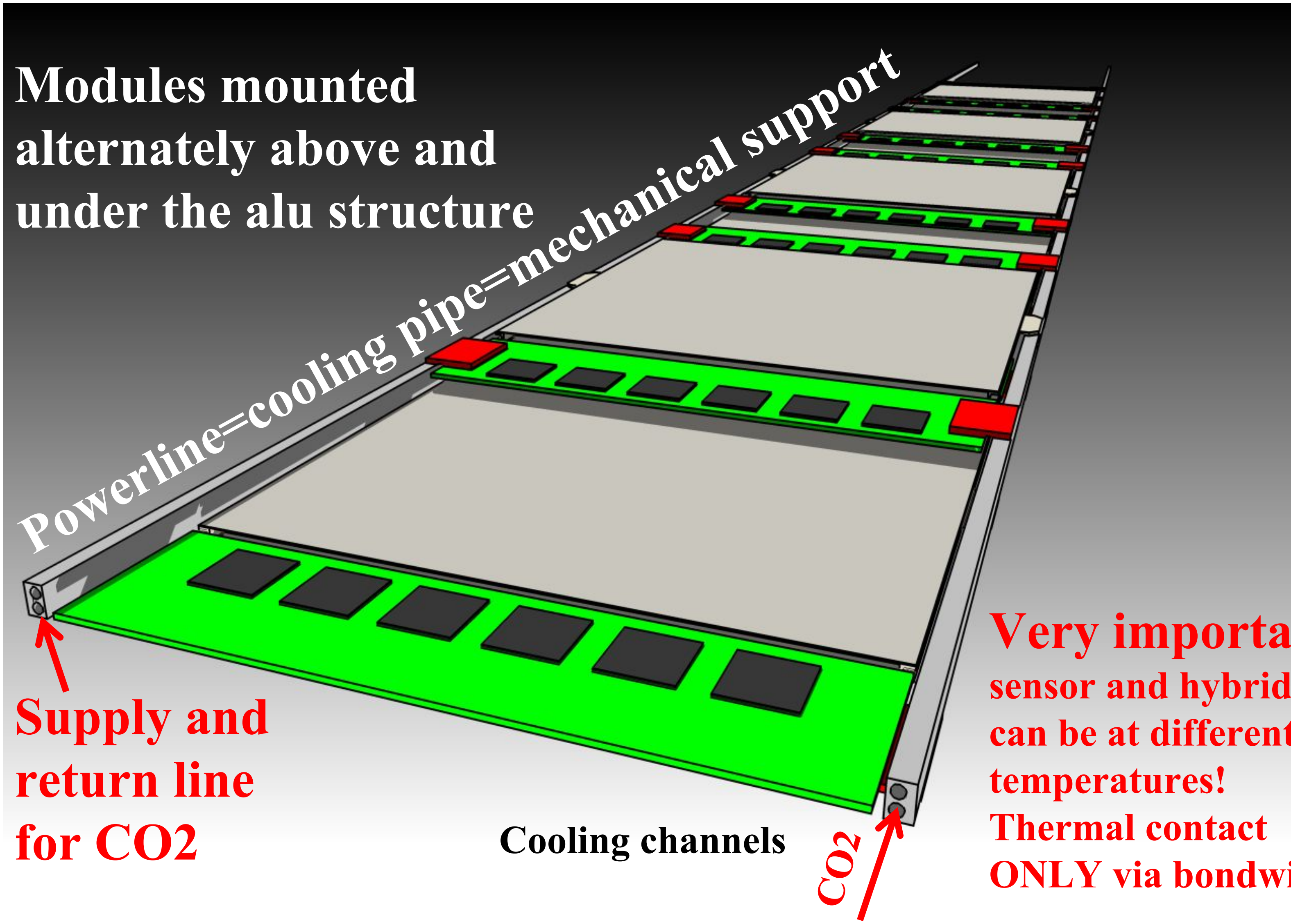
Granularity improved by factor of 8 (before 2 sensors=18 cm strips, now 2.2)
Power for 130 nm electronics factor 5 less/channel, so total power same order.
Can use same technology of hybrids, if 512 ch preamps (before 256)
and pitch of 130 μm (bond pads 65 μm)

Further material budget reduction

Combine functionality of

Powerleads
Cooling tubes
Mechanical support

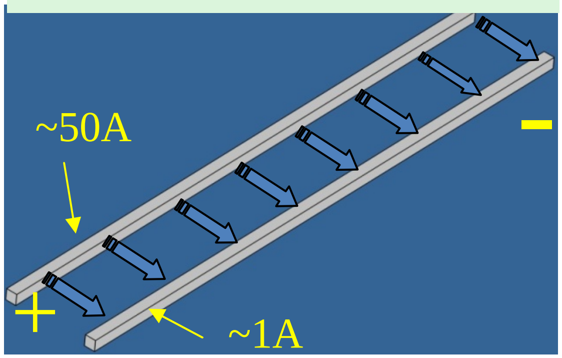
Ladder design by powering via cooling pipes



Very important:
sensor and hybrid can be at different temperatures!
Thermal contact ONLY via bondwires

Voltage compensation in long ladders

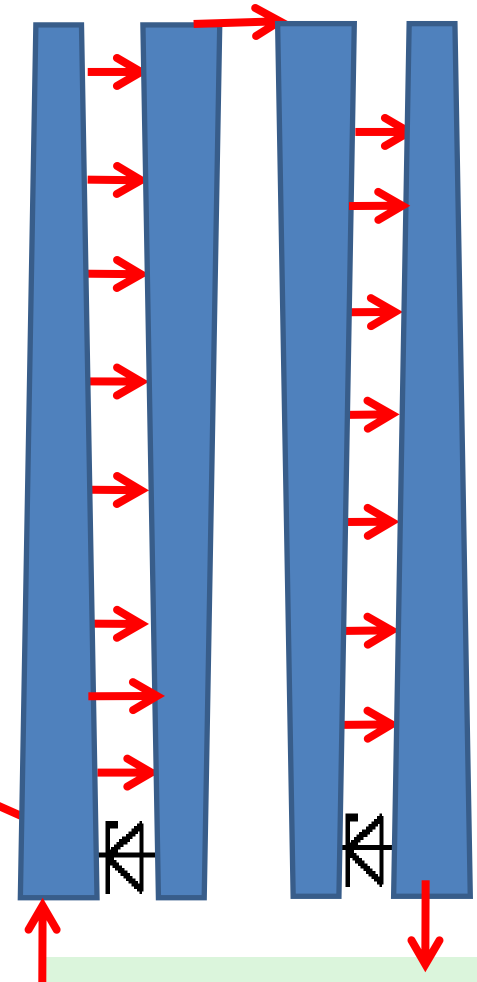
Problem:
every hybrid see´s a different voltage.



2m COLD pure Al only 2.5 mΩ, so voltage drop 100 mV, but similar on + and –

Hybrids see SAME voltage (to +- 20 mV)

No need for DC/DC converters on hybrids

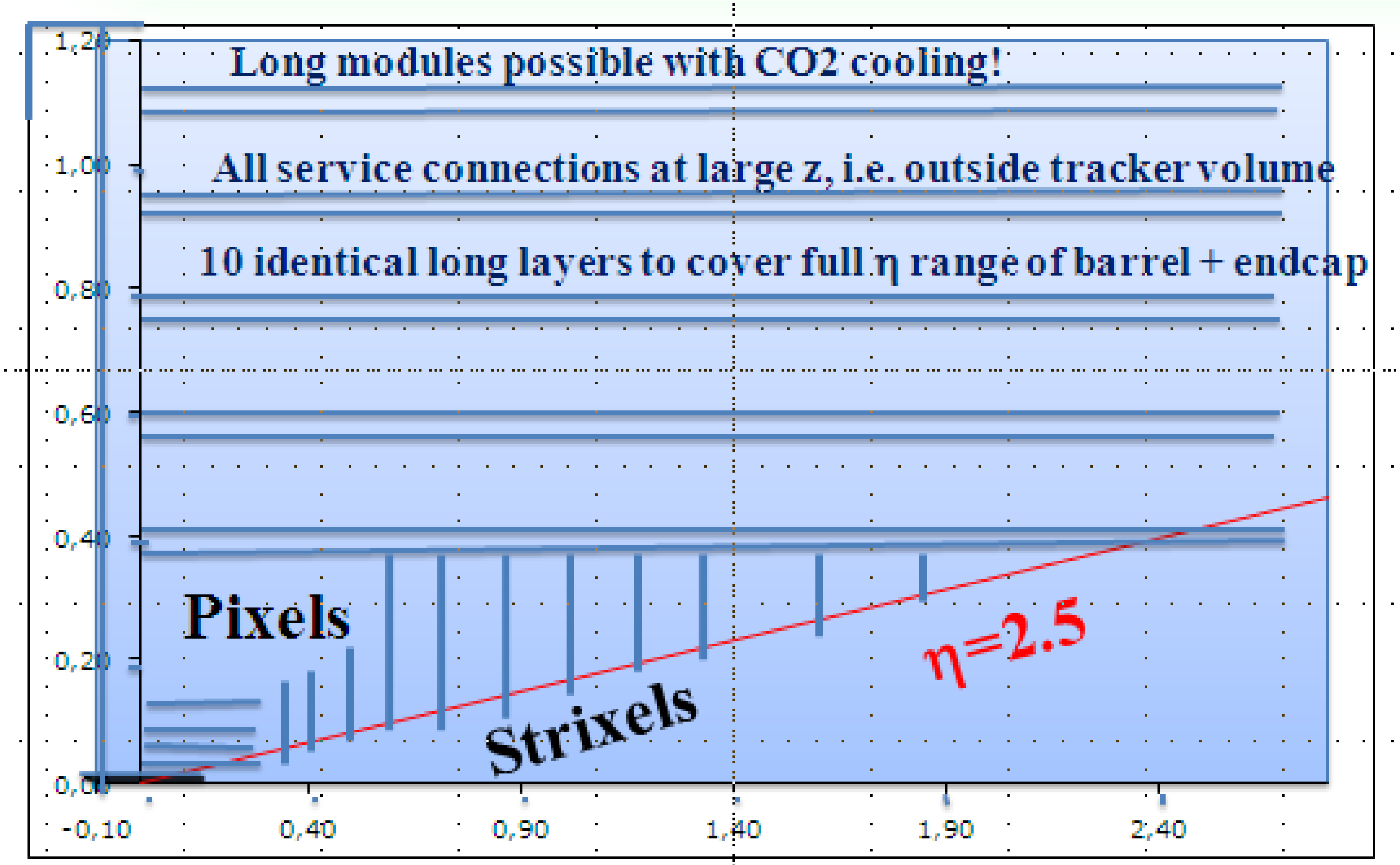


Zener diode stabilizes each ladder at 1.2V (so no change if 1 module fails)

Current back on neighbouring ladder in order to have connections outside and use current twice (combined serial/parallel powering)

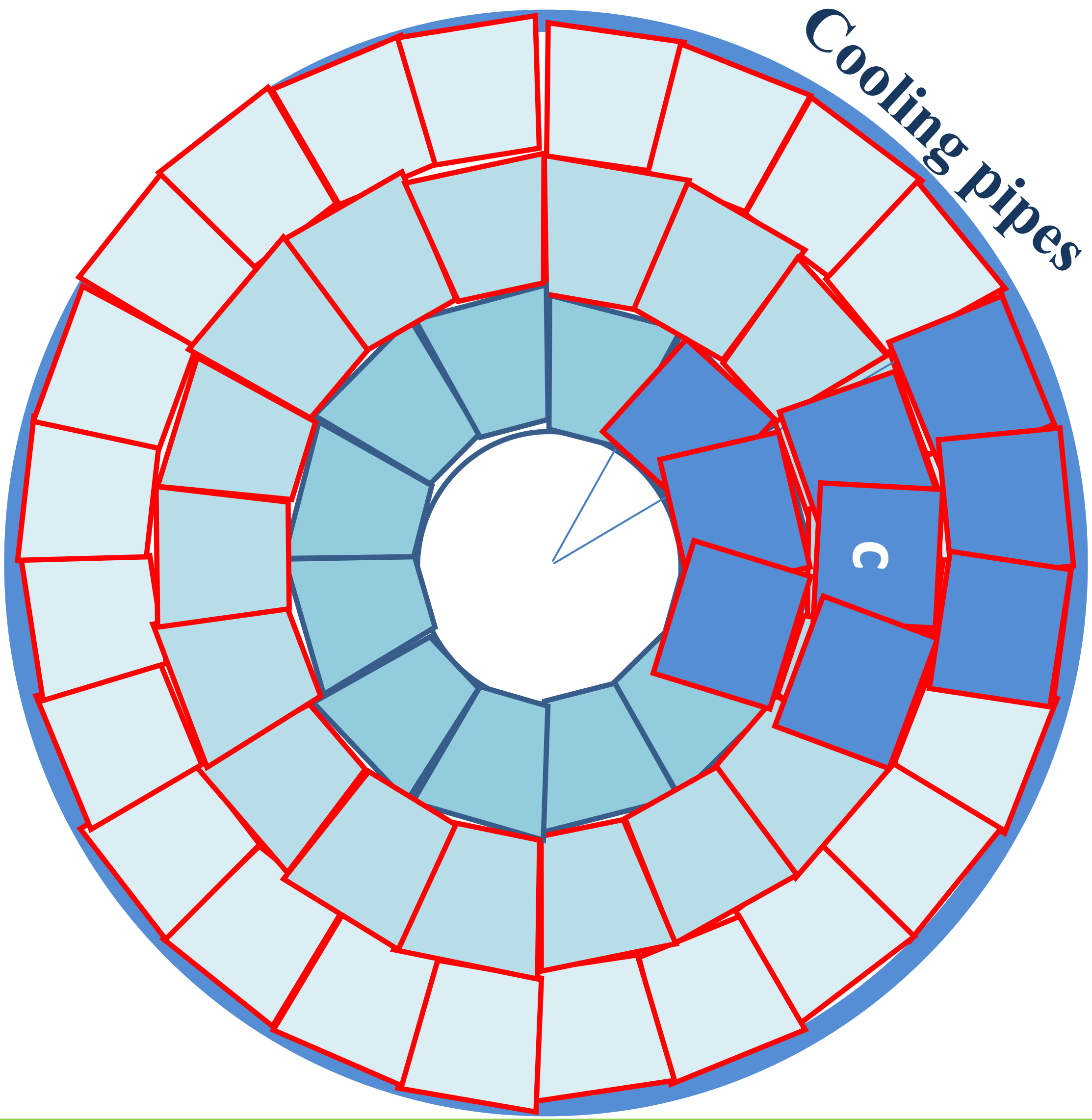
Powersupply: 2.4V, 40A (with sense wire)

Long Barrel with endcap at small radii



All connections for cooling and current outside tracking volume

Strixel disks: bent ladders



Can use same sensors as in barrel, if some more overlap allowed.
Can have SAME hybrids and same “circular” ladders for each ring

Will have middle ring at back of rohacell, so enough space for mounting on cooling rings

Note: disks in two halves in order to mount with beam pipe in place

Numbers for Strawman C

layer	Radius mm	Ladders +Z	APV's/ sensor 256 ch/APV	Pitch um	Strixel mm	sensors/ ladder	sensors/ layer	APV's/ layer	Mchan	Power/ layer W	Current at 2.4V A	Current/ ladder A	Power/ ladder W	theta last point	eta
single	393	26	12	129	25	32	832	9984	2,56	1278	532	41	49	8,60	2,59
single	484	32	12	129	25	32	1024	12288	3,15	1573	655	41	49	10,54	2,39
stereo	570	38	3	258	50	32	1216	3648	0,93	467	195	10	12	12,36	2,23
stereo	575	38	3	258	50	32	1216	3648	0,93	467	195	10	12	12,46	2,22
stereo	660	44	3	258	50	32	1408	4224	1,08	541	225	10	12	14,25	2,08
stereo	665	44	3	258	50	32	1408	4224	1,08	541	225	10	12	14,35	2,08
single	756	50	12	129	25	32	1600	19200	4,92	2458	1024	41	49	16,21	1,96
pt	842	56	3	258	50	32	1792	5376	1,38	688	287	10	12	17,94	1,85
pt	847	56	3	258	50	32	1792	5376	1,38	688	287	10	12	18,04	1,85
pt	932	62	3	258	50	32	1984	5952	1,52	762	317	10	12	19,73	1,76
pt	937	62	3	258	50	32	1984	5952	1,52	762	317	10	12	19,83	1,75
single	1028	68	12	129	25	32	2176	26112	6,68	3342	1393	41	49	21,58	1,67
stereo	1114	74	3	258	50	32	2368	7104	1,82	909	379	10	12	23,19	1,60
stereo	1119	74	3	258	50	32	2368	7104	1,82	909	379	10	12	23,28	1,59
		724					23168	120192	30,77	15385	6410		317		
		724					23168	120192	30,77	15385	6410		317		
sLHC		**1448**	**0**				**46336**	**240384**	**61,54**	**30769**	**12820**		**635**		
LHC								72784	9,32	31079	15000				

All numbers similar to present tracker, except for #ch*7, power and current similar

Note 1: only 2 types of sensors and all ladders the same. 32 sensors/ladder const.

Note 2: Sensors and hybrids very similar to present ones, except i) strixels
ii)parallel powering
iii) CO2 cooling. In total 1448 ladders, so if two in series fail, only 0.2% lost.

Strixel Disks for Strawman C

Ring nr	Rmin mm	Rmax mm	Rings +Z mm	sensor/ ring	APV's/ sensor 256 ch/ APV	Pitch um	Strixel mm	APV's	Mchan x10^6	Power/ ring W	Current at 2.4V A	Power/ ring W	eta min	eta max
1	75	165	450	9	12	129	25	108	0,03	14	6	14	2,49	1,74
1	160	250	450	15	12	129	25	180	0,05	23	10	23	1,77	1,37
1	245	335	450	21	12	129	25	252	0,06	32	13	32	1,39	1,14
2	90	180	540	10	12	129	25	120	0,03	15	6	15	2,49	1,83
2	175	265	540	16	12	129	25	192	0,05	25	10	24	1,85	1,48
2	260	350	540	22	12	129	25	264	0,07	34	14	34	1,49	1,25
3	105	195	630	11	12	129	25	132	0,03	17	7	17	2,49	1,90
3	175	265	630	16	12	129	25	192	0,05	25	10	24	2,00	1,61
3	260	350	630	22	12	129	25	264	0,07	34	14	34	1,63	1,37
4	120	220	720	13	12	129	25	156	0,04	20	8	20	2,49	1,91
4	175	265	720	16	12	129	25	192	0,05	25	10	24	2,13	1,74
4	260	350	720	22	12	129	25	264	0,07	34	14	34	1,75	1,49
5	135	235	810	14	12	129	25	168	0,04	22	9	21	2,49	1,96
5	175	265	810	16	12	129	25	192	0,05	25	10	24	2,24	1,84
5	260	350	810	22	12	129	25	264	0,07	34	14	34	1,86	1,59
6	165	265	990	16	12	129	25	192	0,05	25	10	24	2,49	2,03
6	175	265	990	16	12	129	25	192	0,05	25	10	24	2,44	2,03
7	260	350	1550	22	12	129	25	264	0,07	34	14	34	2,49	2,20
	Z+			299				3588	0,92	459	191	456		
	Z-			299				3588	0,92	459	191	456		
	Total			**598**				**7176**	**1,84**	**919**	**383**	**913**		

Suppose 2 pixel disks at z=270 and z=360 mm
and 7 strixel disks between z=450 and z=1550 mm
Strixels add only 2Mch to 58 Mch for long barrel
The rings in the disk can be build as (bent) ladders with same sensors as barrel!
All services from disks and pixels OUTSIDE tracking volume

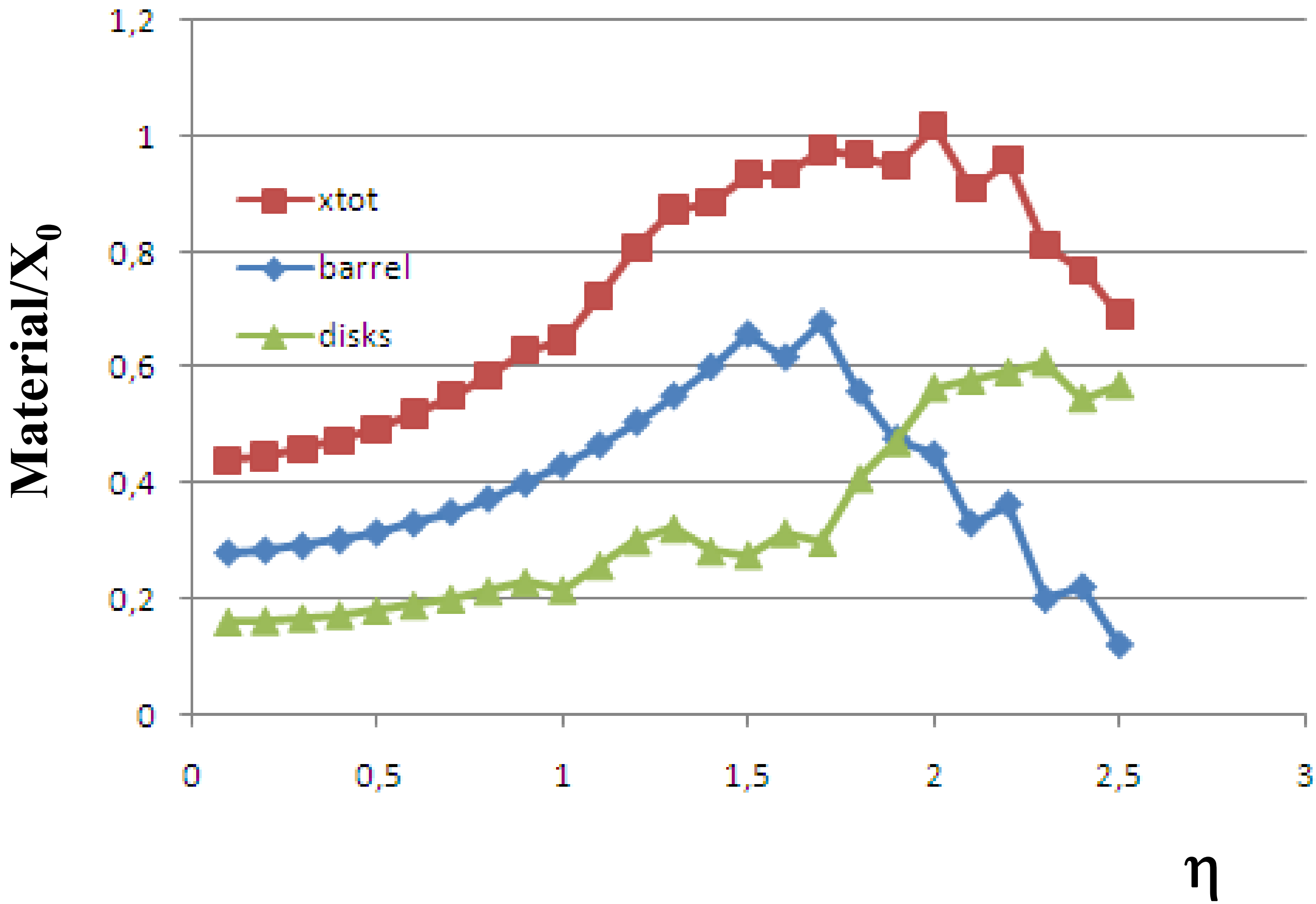
Material Budget

Material budget :

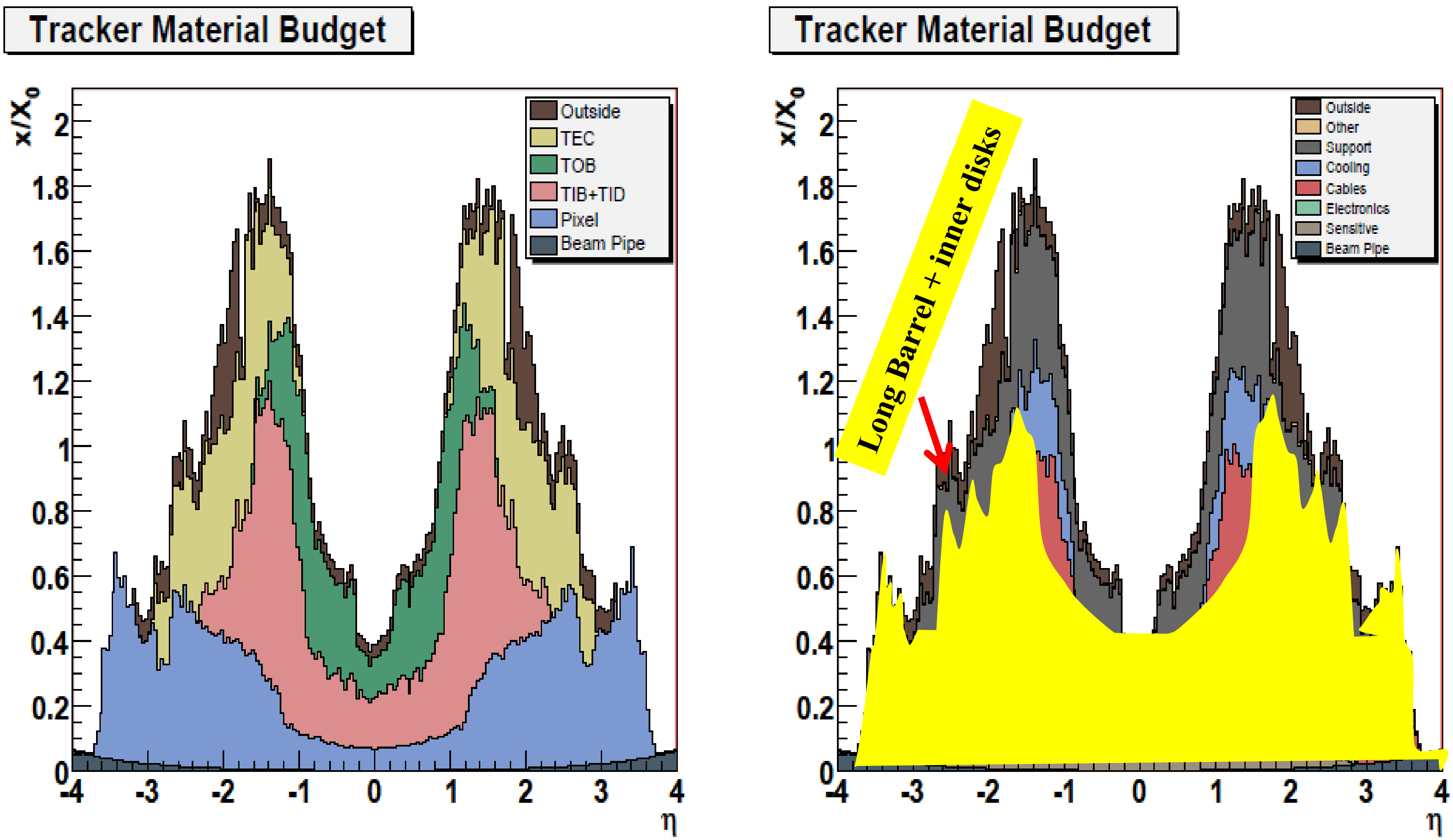
- **Mechanical structure: 0. 6%X_0 / layer**
- **Si sensors: 0.4% X_0/layer**
- **Hybrid + control lines: 1% X_0/layer**

Total: 2,0% X_0/layer

Material budget with "endcaps" as inner discs



Material budget



Summary of cooling liquids at LHC

Experiment	Cooling liquid	Cooling method	Cooling power per g
CMS	C6F14	Single phase	5 J/g (assuming 5K temperature increase)
ATLAS	C3F8	Two-phase evaporative	100 J/g
LHC-B	CO2	Two-phase evaporative	300 J/g

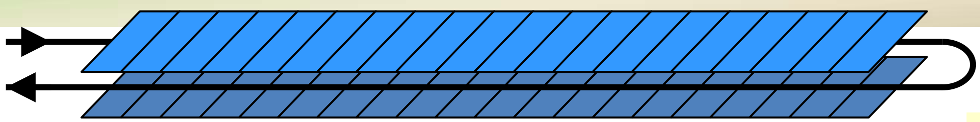
Notes:

- **Single phase cooling simplest, but large pumps needed (Pumps: CMS: 1 floor, ATLAS: 1 room, LHC-b: 1 rack)**
- **Two-phase evaporation in principle much better, because heat of evaporation much larger than specific heat, but any pressure changes means a temperature change, so be careful about tube bending, tube sizes etc.**
- **CO_2 has largest heat of evaporation, is non-toxic, non-flammable, industrial standard, liquid at room temperature, but high pressure (73 bar at 31 C)**

Example of an Atlas upgrade stave

2x 20 wafers à 17 Watt

Cooling

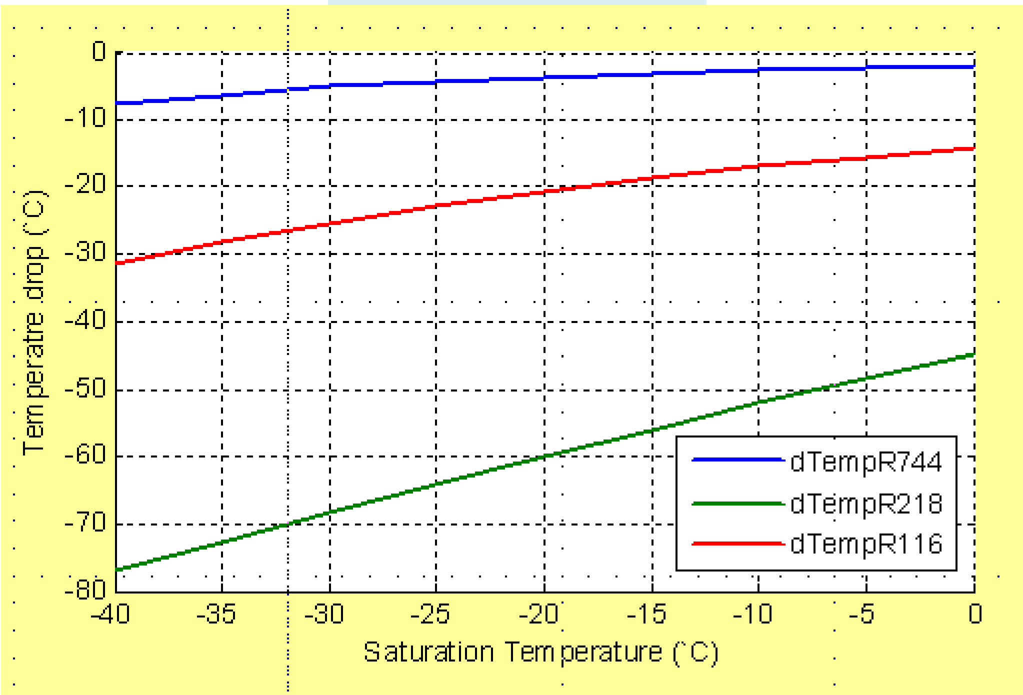


1 Atlas stave : 2 meter length

Q = 680 Watt
Tube = 4 meter

Refrigerant "R" numbers:
R744=CO_2
R218=C_3F_8
R116=C_2F_6

2mm ID Tube



dP calculation according to Friedel/Blasius

Calculations based on 75% Vapor quality at exit

Mass flow @ -35°C

Φ_{R744}= 2.9 g/s

Φ_{R218}= 8.7 g/s

Φ_{R116}= 9.6 g/s

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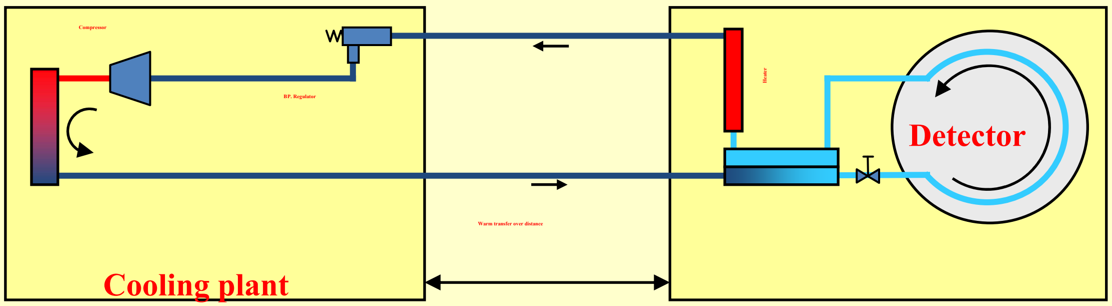
04-03-2008

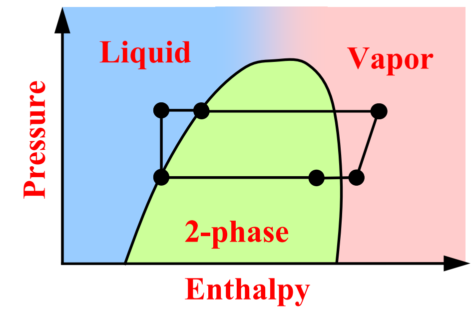
How to get the ideal 2-phase flow in the detector?
From B. Verlaat, NIKHEF

Atlas method:

- Direct expansion into detector with C_3F_8 compressor
- Warm transfer lines
- Boil-off heater and in detector
- Temperature control by back-pressure regulator

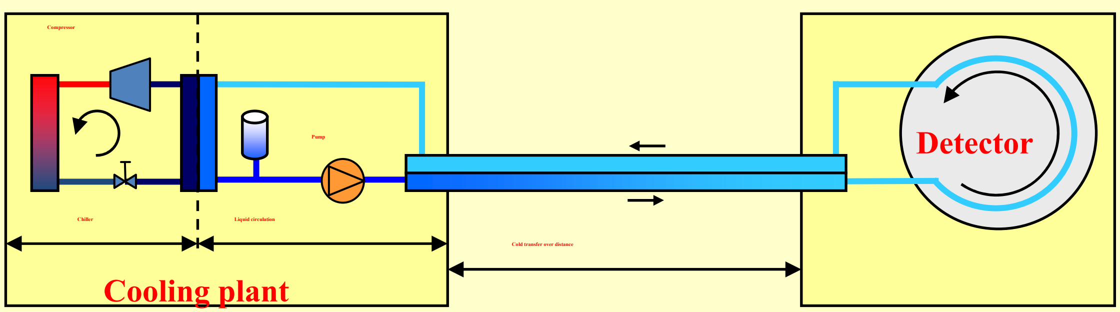


Vapor compression system
- Always vapor needed
- Dummy heat load when switched off
- Oil free compressor, hard to find

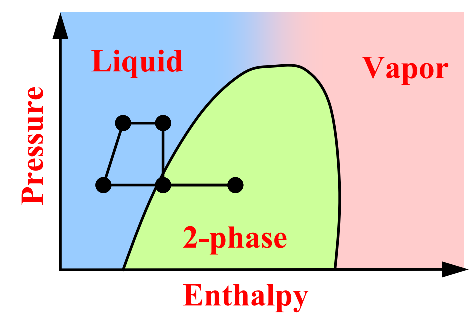


LHCb method:

- CO_2 liquid pumping
- Cold concentric transfer line
- No components in detector
- Temperature control by 2-phase accumulator

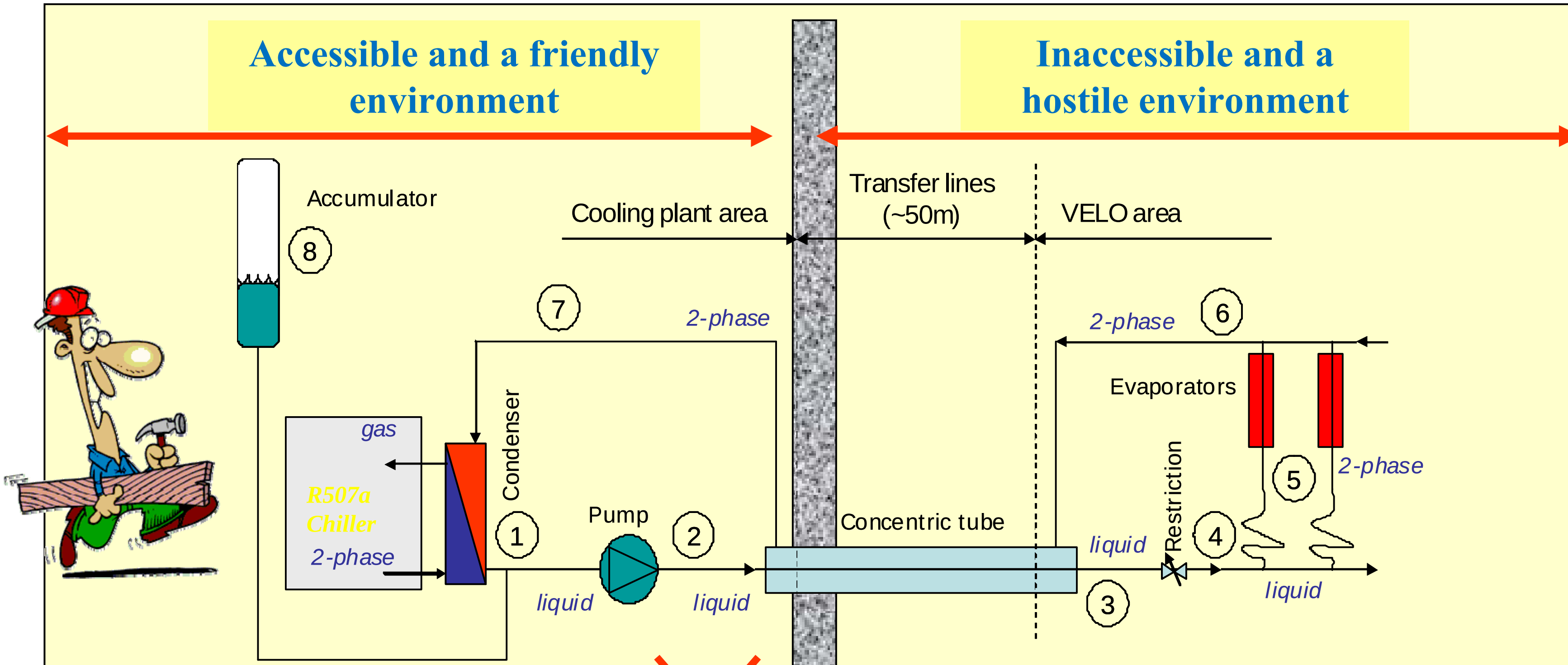


Pumped liquid system
- Liquid overflow, no vapor needed
- No actuators in detector
- Oil free pump, easy to find
- Standard commercial chiller



LHCb-VTCS Overview (B. Verlaat)

A 2-Phase Accumulator Controlled Loop



Cooling plant:

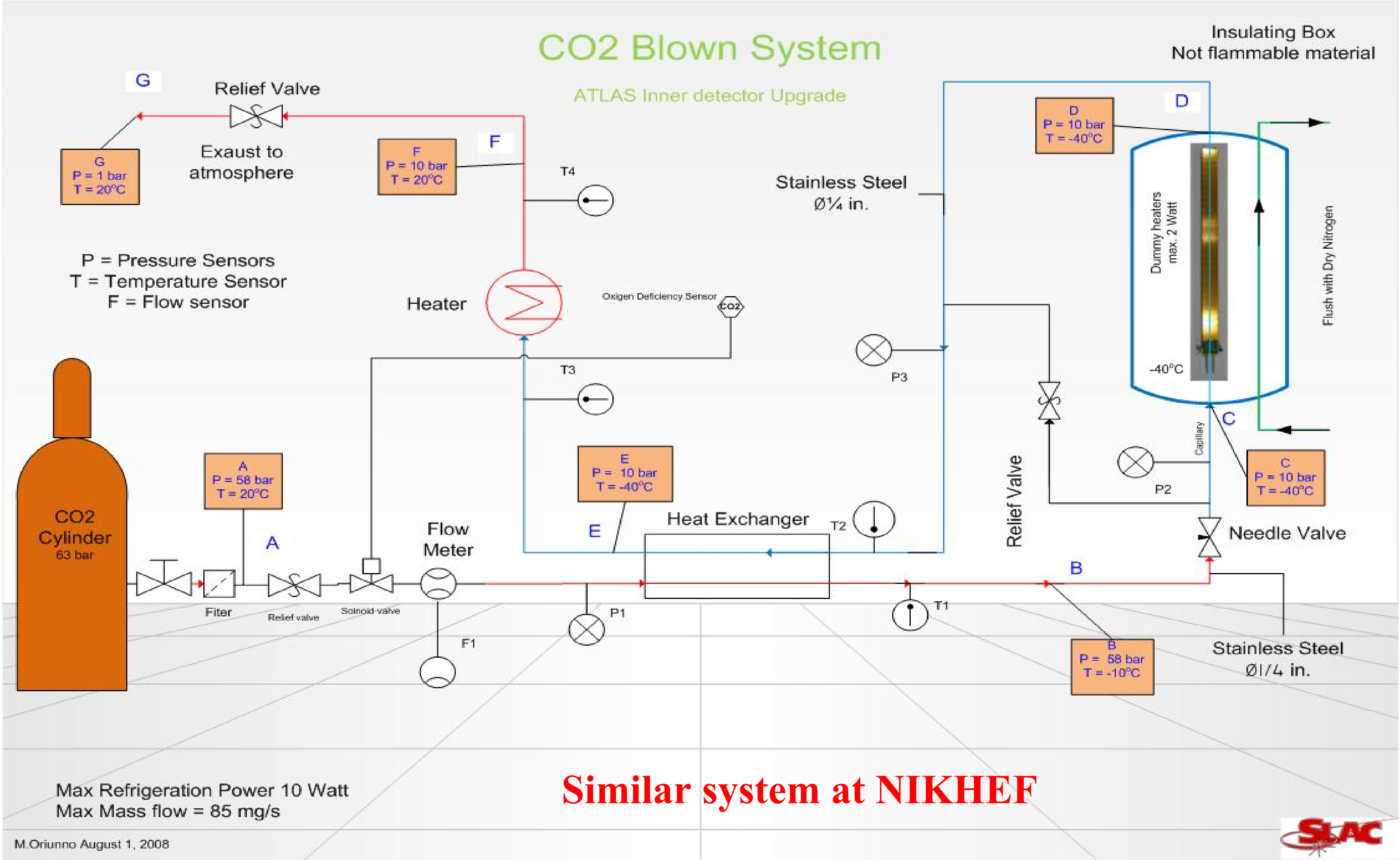
- *Sub cooled liquid CO_2 pumping*
- *CO_2 condensing to a R507a chiller*
- *CO_2 loop pressure control using a 2-phase accumulator*

Evaporator :

- *VTCS temperature ≈ -25ºC*
- *Evaporator load ≈ 0-1600 Watt*
- *Complete passive*

Test systems: CO_2 Blow System at SLAC

Marco Oriunno



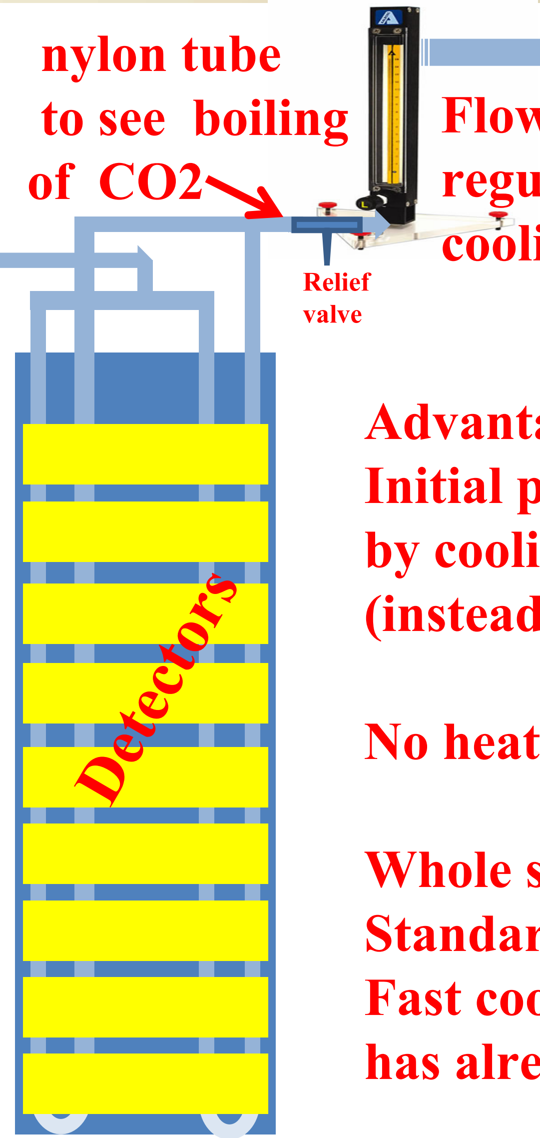
Similar system at NIKHEF

The simplest CO_2 cooling system you can image AND IT WORKS!

Pressure reducer regulates temperature

CO_2 bottle in household freezer

nylon tube to see boiling of CO_2



Flowmeter regulates flow, i.e. cooling power

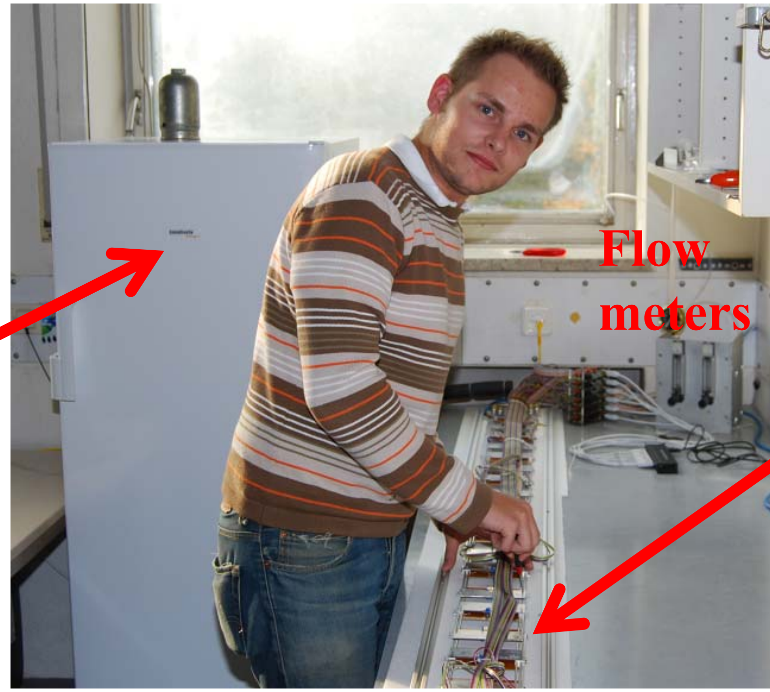
long nylon tube to air

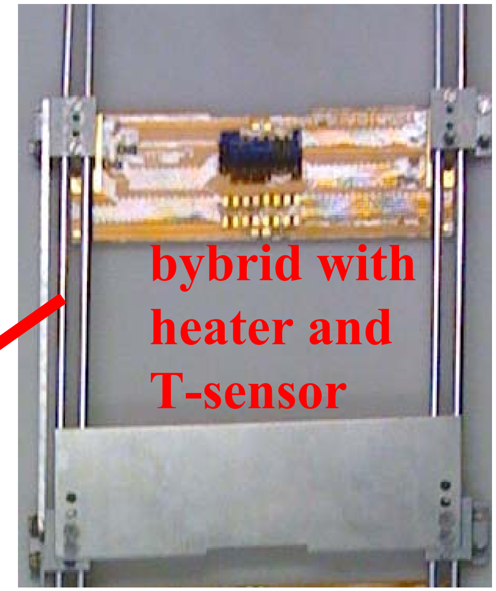
Advantage:
Initial pressure reduced by cooling of CO_2 to 12 bar (instead of 70 bar at room temp)

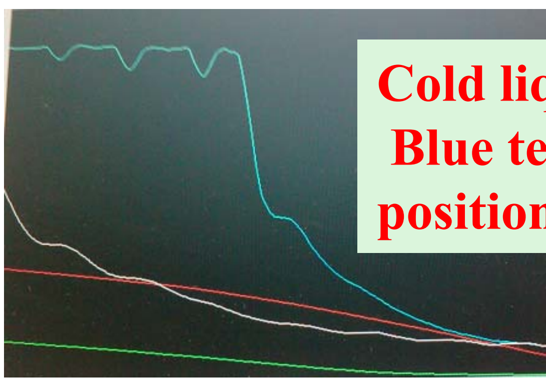
No heat exchanger needed

Whole system <500 Euro
Standard Swagelock connectors
Fast cooldown since liquid has already detector temperature

Some pictures

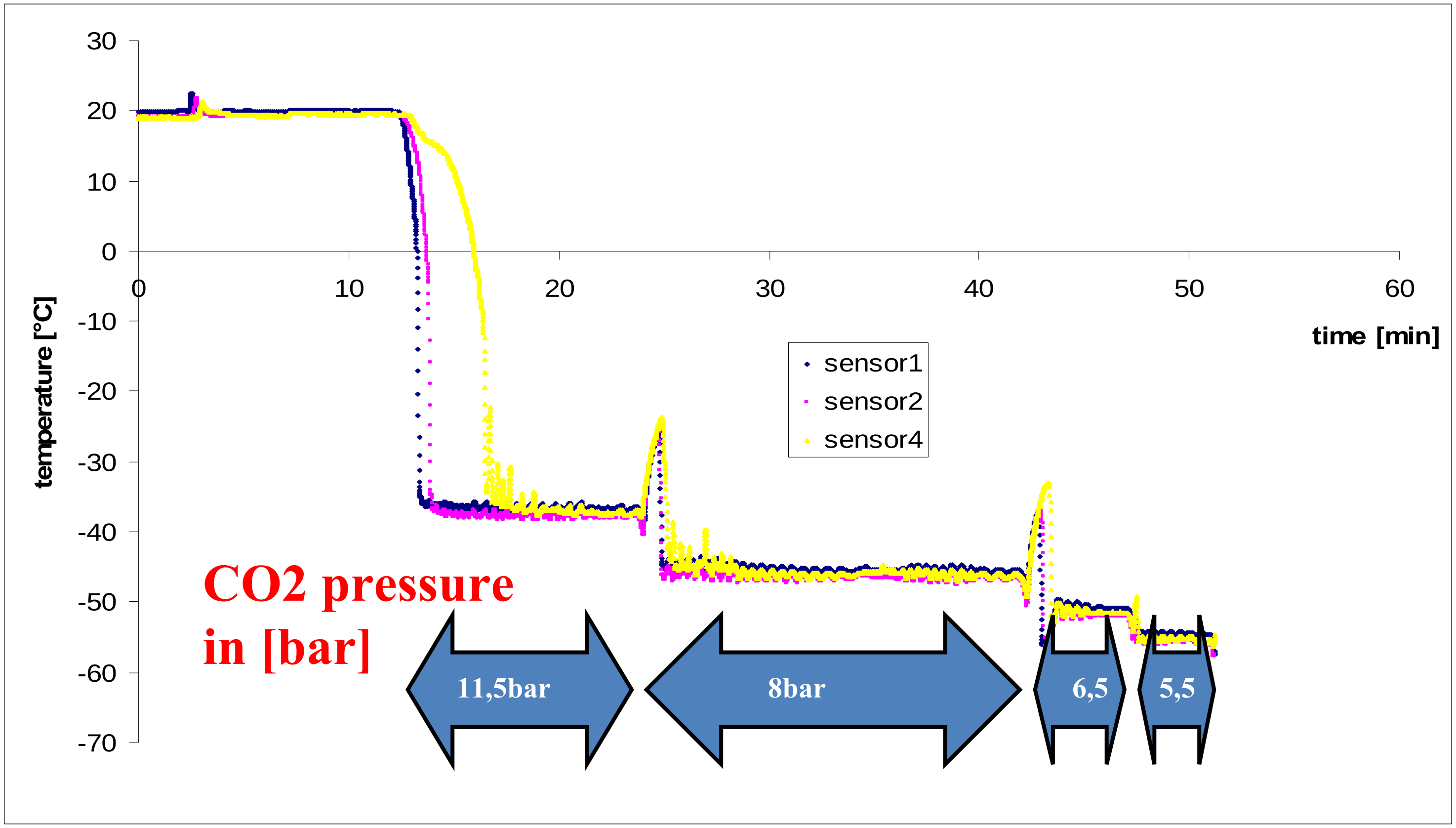






Cold liquid sent through ladder. Blue temperature curve shows position of liquid.

Regulating temperature with pressure



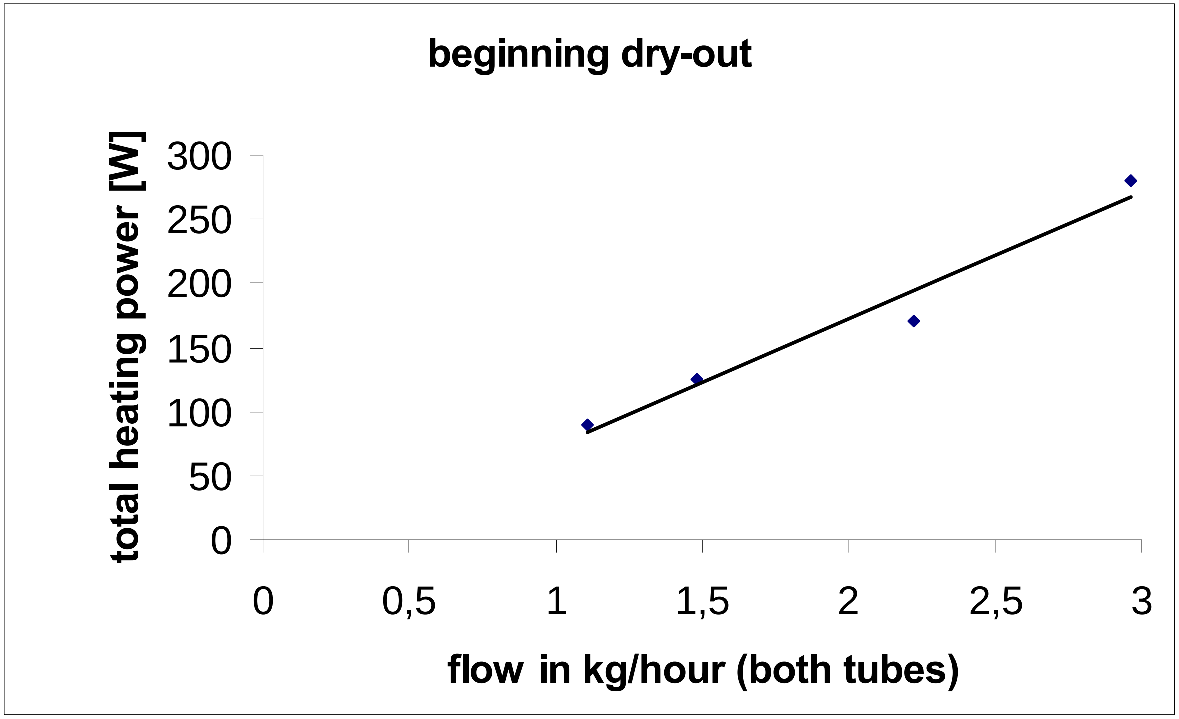
➢very easy to set and hold temperature: just keep pressure constant

Test results

easy to cool large powers with little flow of CO_2,

flow was tested up to 3,7 kg/hour (max. of flowmeters) with negligible pressure drop

Even much bigger flow seems possible with tolerable pressure drop



Summary

• n-on-p sensors radiation hard enough for sLHC (>10^16/cm2)

• Requires cooling of sensors below -25 ^{0}C to get leakage current noise down

• Requires strixels of 2.2 cm to get S/N similar as for LHC
(signal down by ¼, so capacitance down by ¼)

• Reduction of material budget possible by combining cooling, support and current leads into single structure

• Low temperatures and all connections outside volume possible by CO2 cooling, which allows 6m long cooling pipes

• Using CO2 allows to build outer barrel tracker from long ladders with only one type of sensor shape and endcaps at small radii with ALL service connections outside tracking volume
(reduces material budget INSIDE tracker, not so much total!!!)