LHC Collimations Phase II: Preliminary Design meeting

LHC Collimation

Phase II

Specification Meeting

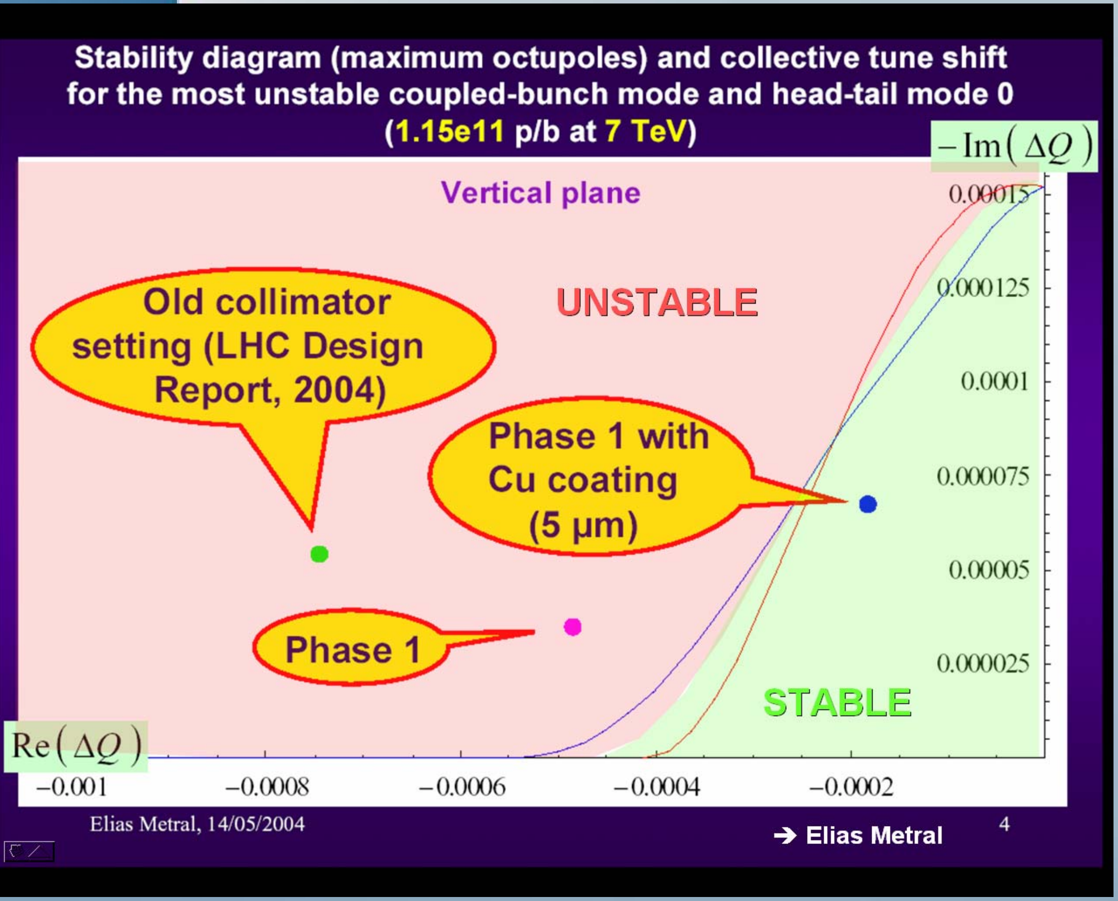
8th February, 2008

CERN Geneva

Alessandro Bertarelli[1]

[1]TS department – Mechanical and Material Engineering Group
CERN, Geneva

Limits of Phase I Collimators



1. **Resistive Impedance**
   According to RF simulations, Phase I Collimator **Impedance** would limit LHC beam intensity to ~40% of its nominal value!

2. **Cleaning efficiency**
   Cleaning efficiency (i.e. ratio escaping protons / impacting protons) should be better than 99.9% to limit risks of quench at SuperConducting triplets

Phase II Design Guidelines

To overcome this limit, new secondary collimators with an improved jaw material /design should complement the existing system (Phase II)

To achieve the new goal, we need a magic material having:

1. **High electrical conductivity to improve RF stability**
2. **High thermo-mechanical stability and robustness, i.e.:**
   a. **Low Coefficient of Thermal Expansion**
   b. **High Yield Strength**
   c. **Low Young's Modulus**
   d. **High Thermal Conductivity**
   e. **High Specific Heat**
3. **High density (high Z) to improve collimation efficiency (i.e. intercepted and stop a higher number of particles), possibly depending on final jaw length …**
4. **Strong resistance to particle radiation …**

Phase II Collimator Materials

Relevant figures of merit:

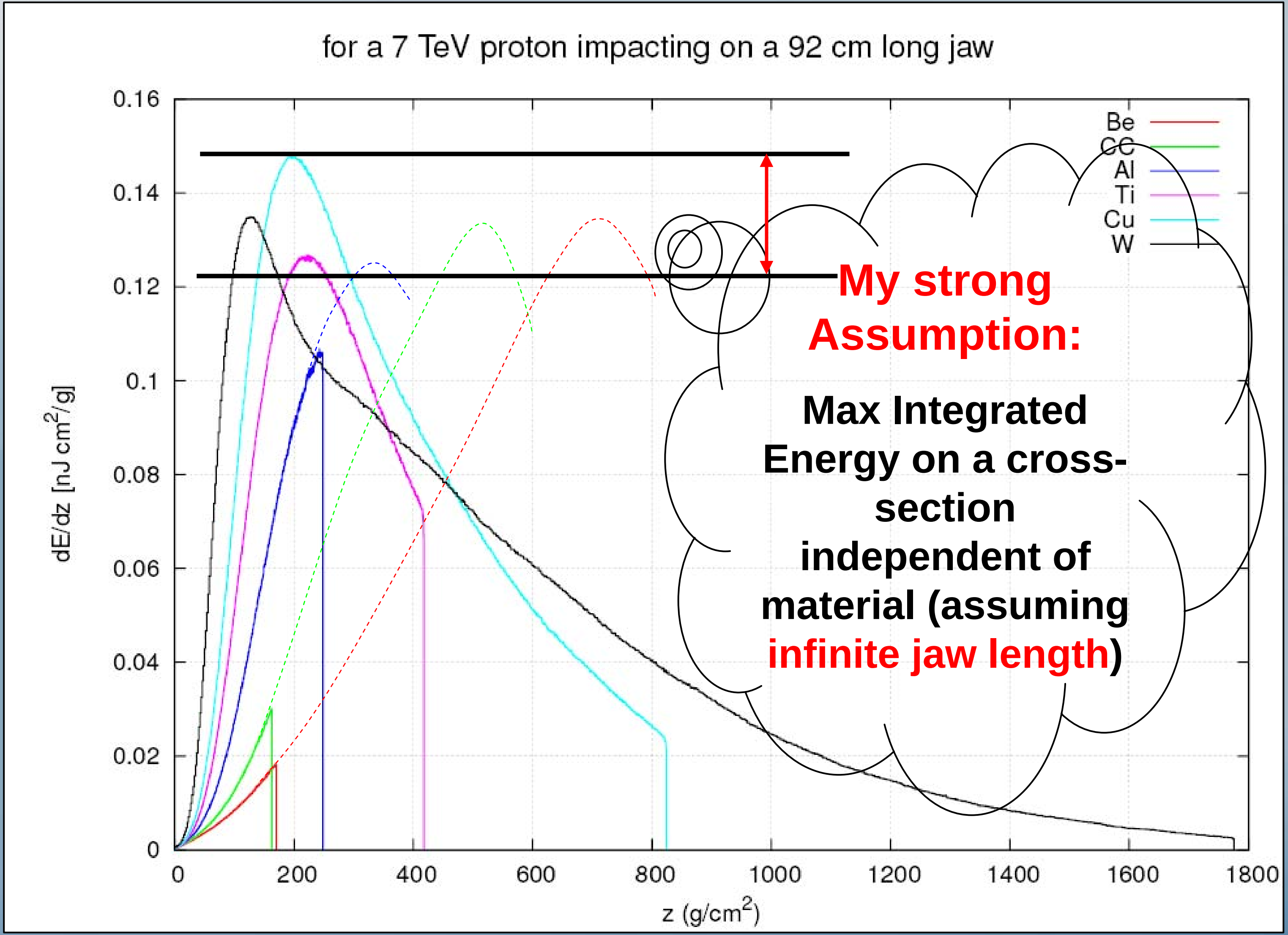
- **Electrical conductivity [1/Ωm]** γ
  Directly related to resistive impedance

- **Steady-state geometrical stability parameter [W/m]** $\frac{k}{\rho\alpha}$
  Indicates power required to induce a given deflection

- **Transient Thermal Shock parameter [J/kg]** $\frac{\sigma_y(1-\nu)c_p}{E\alpha}$
  Gives an indication of the highest acceptable deposited energy per unit mass during a beam impact before damage occurs

- **Mass density [kg/m³]** ρ
  Related to cleaning efficiency

Phase II Collimator Materials



Phase II Collimator Materials

How Geometrical Stability Parameter is obtained:

$$\frac{1}{\rho} = y'' = \frac{\alpha}{I}\int_A \Delta T(y)\,y\,dA = \frac{\alpha \Delta T_B}{B}$$

$$\Delta T_B \div \frac{\rho e B}{k}$$

$$y'' \div \frac{\alpha \rho e}{k} \Rightarrow e_{\max} \div \frac{k}{\alpha \rho}$$

Phase II Collimator Materials

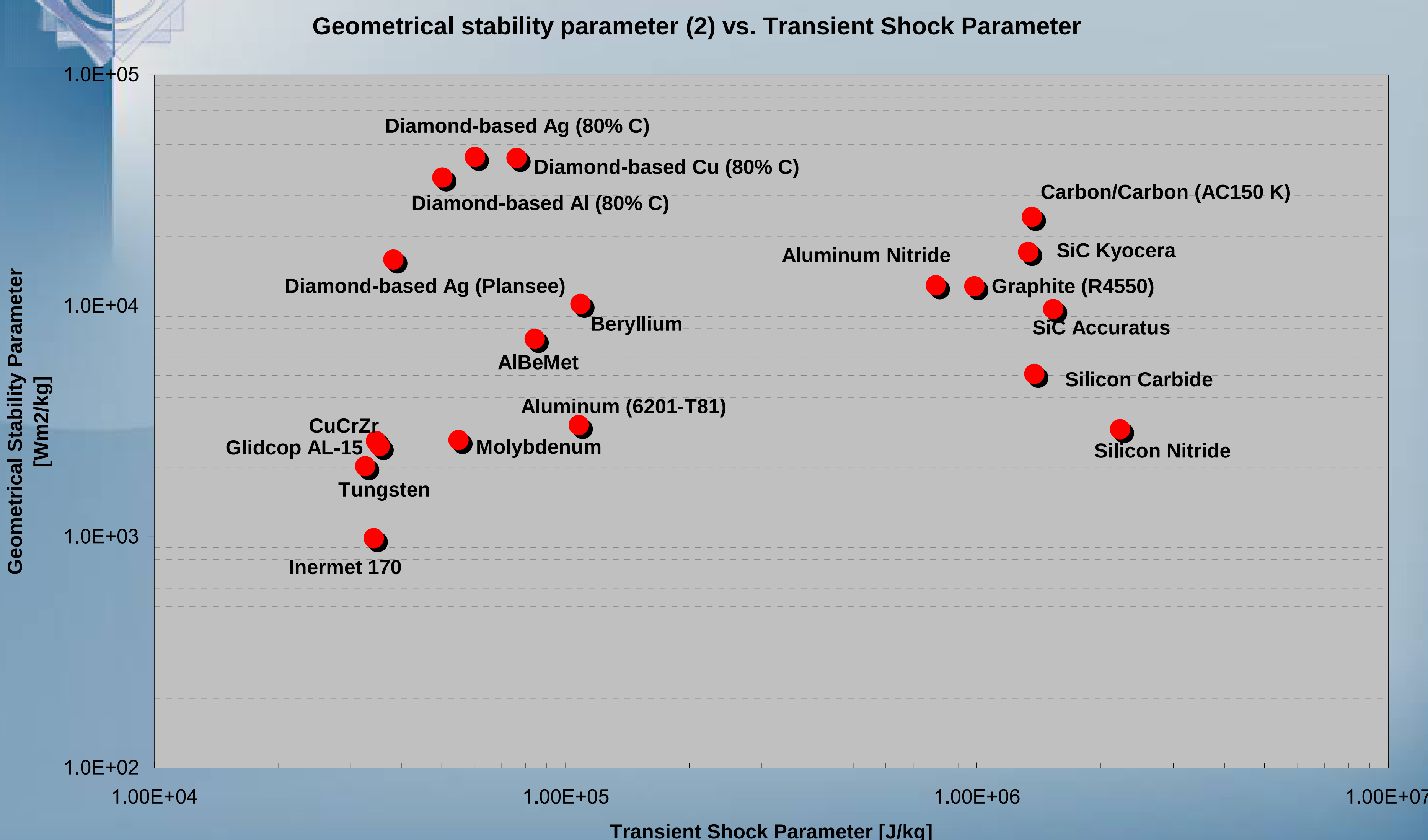
How Thermal Shock Parameter is obtained:

$$\sigma_{\max} = \frac{E\alpha\Delta T_{\max}}{1-\nu}$$

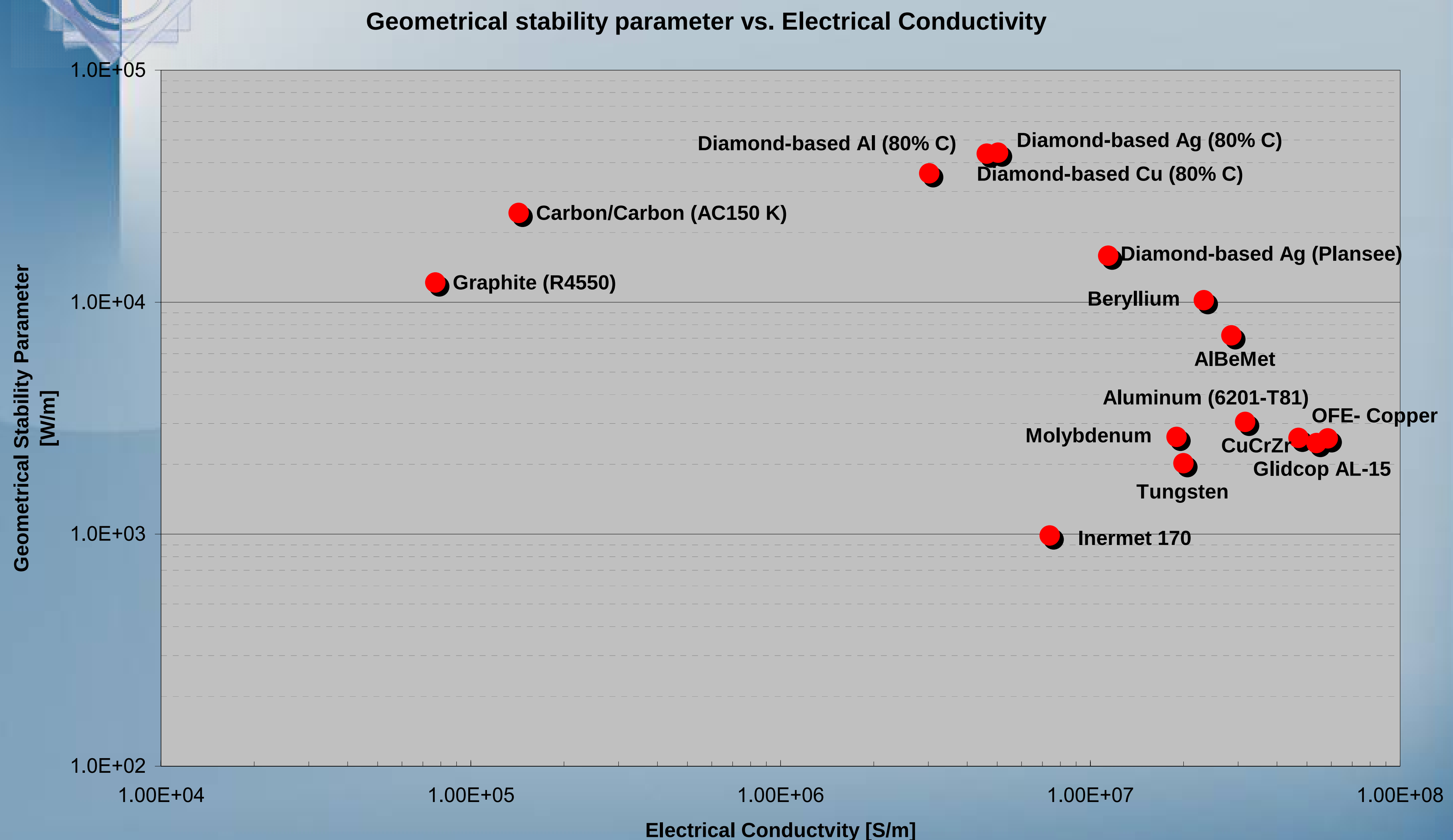
$$\Delta T_{\max} = \frac{U_{\max}\left[J/m^3\right]}{\rho c_p} = \frac{e_{\max}\left[J/kg\right]}{c_p} \Rightarrow$$

$$\sigma_{\max} = \frac{E\alpha e_{\max}}{(1-\nu)c_p} \Rightarrow e_{\max} = \frac{\sigma_{\max} c_p (1-\nu)}{E\alpha}$$

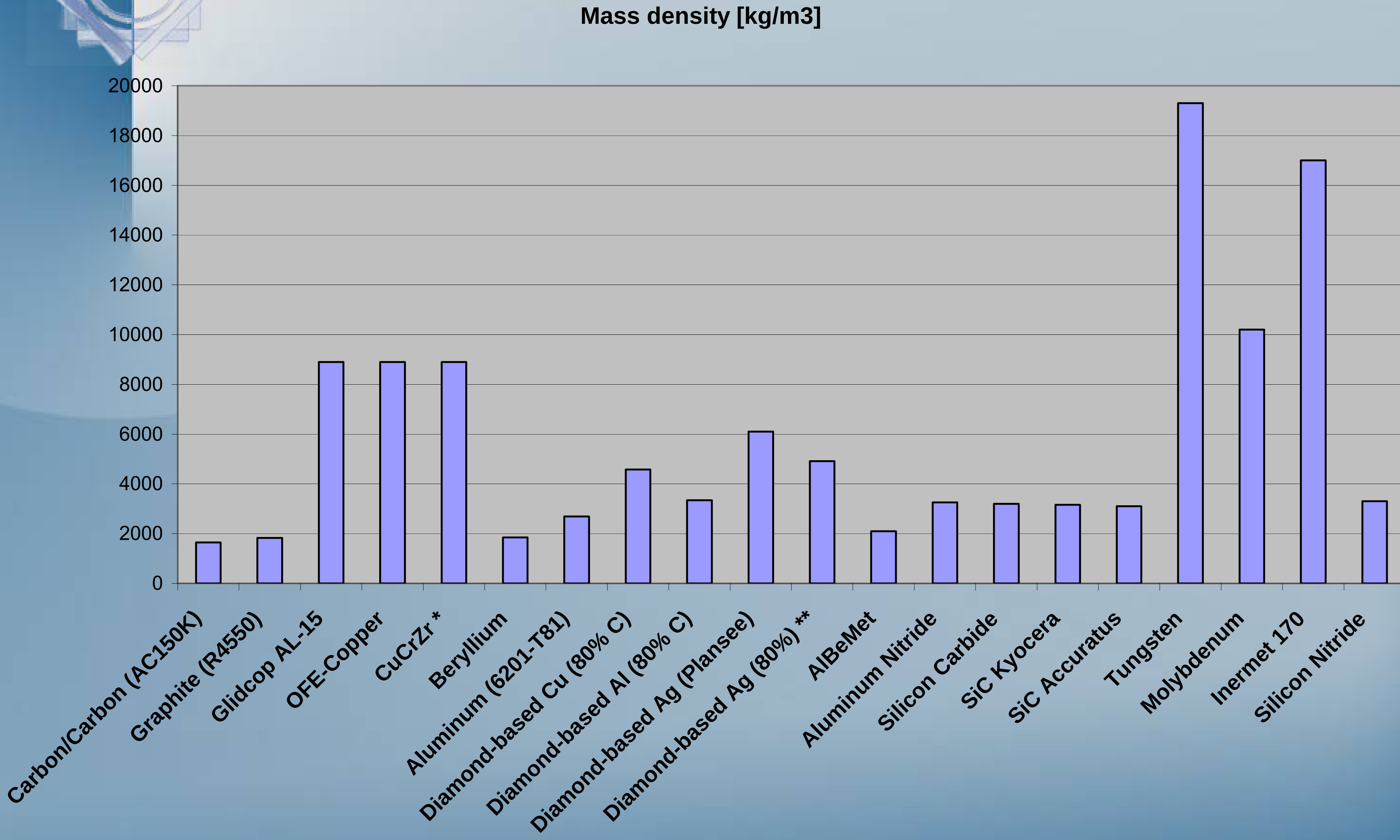
Phase II Collimator Materials



Phase II Collimator Materials



Phase II Collimator Materials



Liquid metals compatible with UHV

TABLE 2 Vapor-pressure Data for the Solid and Liquid Elements*

Symbol	Element	Data temp range, °K	Temperatures (°K) for vapor pressures, torr														
			10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10^{1}	10^{2}	10^{3}
Ac	Actinium	1873, est.	1045	1100	1160	1230	1305 ⊙	1390	1490	1605	1740	1905	2100	2350	2660	3030	3510
Ag	Silver	958–2200	721	759	800	847	899	958	1025	1105	1195 ⊙	1300	1435	1605	1815	2100	2490
Al	Aluminum	1220–1468	815	860	906 ⊙	958	1015	1085	1160	1245	1355	1490	1640	1830	2050	2370	2800
Am	Americium	1103–1453	712	752	797	848	905	971	1050 ⊙	1140	1245	1375	1540	1745	2020	2400	2970
As	Arsenic(s)		323	340	358	377	400	423	447	477	510	550	590	645	712	795	900
At	Astatine	Est.	221	231	241	252	265	280	296	316	338	364	398	434	480	540 ⊙	620
Au	Gold	1073–1847	915	964	1020	1080	1150	1220	1305 ⊙	1405	1525	1670	1840	2040	2320	2680	3130
B	Boron	1781–2413	1335	1405	1480	1555	1640	1740	1855	1980	2140	2300 ⊙	2520	2780	3100	3500	4000
Ba	Barium	1333–1419	450	480	510	545	583	627	675	735	800	883 ⊙	984	1125	1310	1570	1930
Be	Beryllium	1103–1552	832	878	925	980	1035	1105	1180	1270	1370	1500 ⊙	1650	1830	2080	2390	2810
ΣBi	Bismuth		510	540 ⊙	568	602	640	682	732	790	860	945	1050	1170	1350	1570	1900
ΣC	Carbon(s)	1820–2700	1695	1765	1845	1930	2030	2140	2260	2410	2560	2730	2930	3170	3450	3780	4190
Ca	Calcium	730–1546	470	495	524	555	590	630	678	732	795	870	962	1075 ⊙	1250	1475	1800
Cd	Cadmium	411–1040	293	310	328	347	368	392	419	450	490	538	593 ⊙	665	762	885	1060
Ce	Cerium	1611–2038	1050 ⊙	1110	1175	1245	1325	1420	1525	1650	1795	1970	2180	2440	2780	3220	3830
Co	Cobalt	1363–1522	1020	1070	1130	1195	1265	1340	1430	1530	1655 ⊙	1790	1960	2180	2440	2790	3220
Cr	Chromium	1273–1557	960	1010	1055	1110	1175	1250	1335	1430	1540	1670	1825	2010 ⊙	2240	2550	3000
ΣCs	Cesium	300–955	213	226	241	257	274	297 ⊙	322	351	387	428	482	553	643	775	980
Cu	Copper	1143–1897	855	895	945	995	1060	1125	1210	1300 ⊙	1405	1530	1690	1890	2140	2460	2920
Dy	Dysprosium	1258–1773	760	801	847	898	955	1020	1090	1170	1270	1390	1535 ⊙	1710	1965	2300	2780
Er	Erbium	1773, est.	779	822	869	922	981	1050	1125	1220	1325	1450	1605 ⊙	1800	2060	2420	2920
Eu	Europium	696–900	469	495	523	556	592	634	682	739	805	884	981 ⊙	1100	1260	1500	1800
Fr	Francium	Est.	198	210	225	242	260	280 ⊙	306	334	368	410	462	528	620	760	980
Fe	Iron	1356–1889	1090	1050	1105	1165	1230	1305	1400	1500	1615	1750 ⊙	1920	2130	2390	2740	3200
Ga	Gallium(l)	1179–1[illegible] 303 ©	755	796	841	892	950	1015	1090	1180	1280	1405	1555	1745	1980	2300	2730
Gd	Gadolinium	Est.	880	930	980	1035	1100	1170	1250	1350	1465 ⊙	1600	1760	1955	2220	2580	3100
ΣGe	Germanium	1510–1885	940	980	1030	1085	1150 ⊙	1220	1310	1410	1530	1670	1830	2050	2320	2680	3180
Hf	Hafnium	2035–2277	1505	1580	1665	1760	1865	1980	2120	2270 ⊙	2450	2670	2930	3240	3630	4130	4780
Hg	Mercury	193–575	170	180	190	201	214	229 ⊙	246	266	289	319	353	398	458	535	642
Ho	Holmium	923–2023	779	822	869	922	981	1050	1125	1220	1325	1450	1605 ⊙	1800	2060	2410	2910
In	Indium(l)	646–1[illegible] 430 ©	641	677	716	761	812	870	937	1015	1110	1220	1355	1520	1740	2030	2430
Ir	Iridium	1986–2600	1585	1665	1755	1850	1960	2080	2220	2380	2560 ⊙	2770	3040	3360	3750	4250	4900
K	Potassium	373–1031	247	260	276	294	315 ⊙	338	364	396	434	481	540	618	720	858	1070
La	Lanthanum	1655–2167	1100	1155 ⊙	1220	1295	1375	1465	1570	1695	1835	2000	2200	2450	2760	3150	3680
Li	Lithium	735–1353	430	452 ⊙	480	508	541	579	623	677	740	810	900	1020	1170	1370	1620
Lu	Lutetium	Est.	1000	1060	1120	1185	1260	1345	1440	1550	1685	1845 ⊙	2030	2270	2550	2910	3370
Mg	Magnesium	626–1376	388	410	432	458	487	519	555	600	650	712	782	878 ⊙	1000	1170	1400

⊙ indicates melting point.

TABLE 2 Vapor-pressure Data for the Solid and Liquid Elements*

Symbol	Element	Data temp range, °K	10^{-11}	10^{-10}	10^{-9}	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}	10^{-1}	1	10^{1}	10^{2}	10^{3}
			Temperatures (°K) for vapor pressures, torr														
Mn	Manganese	1523–1823	660	695	734	778	827	884	948	1020	1110	1210	1335	1490 ⊙	1695	1970	2370
Mo	Molybdenum	2070–2504	1610	1690	1770	1865	1975	2095	2230	2390	2580	2800 ⊙	3060	3390	3790	4300	5020
Na	Sodium	496–1156	294	310	328	347	370 ⊙	396	428	366	508	562	630	714	825	978	1175
Nb	Niobium	2304–2596	1765	1845	1935	2035	2140	2260	2400	2550	2720 ⊙	2930	3170	3450	3790	4200	4710
Nd	Neodymium	1240–1600	846	895	945	1000	1070	1135	1220 ⊙	1320	1440	1575	1770	2000	2300	2740	3430
Ni	Nickel	1307–1895	1040	1090	1145	1200	1270	1345	1430	1535	1655 ⊙	1800	1970	2180	2430	2770	3230
Os	Osmium	2300–2800	1875	1965	2060	2170	2290	2430	2580	2760	2960	3190	3460	3800	4200	4710	5340
P_4	Phosphorus(s)		283	297	312	327	342	361	381	402	430	458	493	534	582	642	715
Pb	Lead	1200–2028	516	546	580 ⊙	615	656	702	758	820	898	988	1105	1250	1435	1700	2070
Pd	Palladium	1294–1640	945	995	1050	1115	1185	1265	1355	1465	1590	1735 ⊙	1920	2150	2450	2840	3380
ΣPo	Polonium	711–1286	332	348	365	384	408	432	460	494 ⊙	537	588	655	743	862	1040	1250
Pr	Praseodymium	1423–1693	900	950	1005	1070	1140 ⊙	1220	1315	1420	1550	1700	1890	2120	2420	2820	3370
Pt	Platinum	1697–2042	1335	1405	1480	1565	1655	1765	1885	2020 ⊙	2180	2370	2590	2860	3190	3610	4170
Pu	Plutonium(*l*)	1392–1 912 ©	931	983	1040	1105	1180	1265	1365	1480	1615	1780	1975	2230	2550	2980	3590
Ra	Radium	Est.	436	460	488	520	552	590	638	690	755	830	920 ⊙	1060	1225	1490	1840
Rb	Rubidium		227	240	254	271	289	312 ⊙	336	367	402	446	500	568	665	802	1000
Re	Rhenium	2494–2999	1900	1995	2100	2220	2350	2490	2660	2860	3080	3340 ⊙	3680	4080	4600	5220	6050
Rh	Rhodium	1709–2205	1330	1395	1470	1550	1640	1745	1855	1980	2130 ⊙	2310	2520	2780	3110	3520	4070
Ru	Ruthenium	2000–2500	1540	1610	1695	1780	1880	1990	2120	2260	2420	2620 ⊙	2860	3130	3480	3900	4450
ΣS	Sulfur		230	240	252	263	276	290	310	328	353	382 ⊙	420	462	519	606	739
ΣSb	Antimony	693–1110	477	498	526	552	582	618	656	698	748	806	885 ⊙	1030	1250	1560	1960
Sc	Scandium	1301–1780	881	929	983	1045	1110	1190	1280	1380	1505	1650 ⊙	1835	2070	2370	2780	3360
ΣSe	Selenium	550–950	286	301	317	336	356	380	406	437	472 ⊙	516	570	636	719	826	972
ΣSi	Silicon	1640–2054	1090	1145	1200	1265	1340	1420	1510	1610 ⊙	1745	1905	2090	2330	2620	2990	3490
Sm	Samarium	789–833	542	573	608	644	688	738	790	853	926	1015	1120	1260 ⊙	1450	1715	2120
Sn	Tin(*l*)	1424–1 505 ©	805	852	900	955	1020	1080	1170	1270	1380	1520	1685	1885	2140	2500	2960
Sr	Strontium		433	458	483	514	546	582	626	677	738	810	900	1005 ⊙	1160	1370	1680
Ta	Tantalum	2624–2948	1930	2020	2120	2230	2370	2510	2680	2860	3080 ⊙	3330	3630	3980	4400	4930	5580
Tb	Terbium	Est.	900	950	1005	1070	1140	1220	1315	1420	1550 ⊙	1700	1890	2120	2420	2820	3370
Tc	Technetium	Est.	1580	1665	1750	1840	1950	2060	2200	2350	2530 ⊙	2760	3030	3370	3790	4300	5000
Te_2	Tellurium	481–1128	366	385	405	428	454	482	515	553	596	647	706 ⊙	791	905	1065	1300
Th	Thorium	1757–1956	1450	1525	1610	1705	1815	1935 ⊙	2080	2250	2440	2680	2960	3310	3750	4340	5130
Ti	Titanium	1510–1822	1140	1200	1265	1335	1410	1500	1600	1715	1850 ⊙	2010	2210	2450	2760	3130	3640
Tl	Thallium	519–924	473	499	527	556 ⊙	592	632	680	736	803	882	979	1100	1255	1460	1750
Tm	Thulium	809–1219	624	655	691	731	776	825	882	953	1030	1120	1235	1370	1540	1760 ⊙	2060
U	Uranium	1630–2071	1190	1255	1325 ⊙	1405	1495	1600	1720	1855	2010	2200	2430	2720	3080	3540	4180
V	Vanadium	1666–1882	1235	1295	1365	1435	1510	1605	1705	1820	1960	2120 ⊙	2320	2560	2850	3220	3720
W	Tungsten	2518–3300	2050	2150	2270	2390	2520	2680	2840	3030	3250	3500 ⊙	3810	4180	4630	5200	5900
Y	Yttrium	1774–2103	1045	1100	1160	1230	1305	1390	1490	1605	1740	1905	2105	2355	2670	3085	3650
Yb	Ytterbium	Est.	436	460	488	520	552	590	638	690	755	830	920	1060	1225	1490	1840
Zn	Zinc	422–1089	336	354	374	396	421	450	482	520	565	617	681	760	870	1010	1210
Zr	Zirconium	1949–2054	1500	1580	1665	1755	1855	1975	2110	2260	2450	2670	2930	3250	3650	4170	4830

⊙ indicates melting point.

Candidate liquid metals

	Tm (K)	Tm (°C)	DT m to … (K)			Z	A	ρ, Density kg/m³ @ Tm	$A^{1/3}$ / ρ	1 / Z
			10e-10 torr	10e-9 torr	10 torr					
Bi	544	271	-4	24	806	83	208.98	10050	5.90E-04	0.012
Ga	303	30	493	538	1677	31	69.72	6095	6.75E-04	0.032
In	430	157	247	286	1310	49	114.82	7020	6.92E-04	0.020
Li	454	181	-2	26	716	3	6.94	512	3.73E-03	0.333
Sn	505	232	347	395	1635	51	118.69	6990	7.03E-04	0.020
									Interaction length param.	radiation length param.

- Ga, In and Sn have
  - relatively low melting temperature (<250 °C),
  - low Pvap at Tm (< 10e-10 torr) and
  - give a heating margin of >200 K from melting to temp. of Pvap = 10e-10 torr
- To be studied
  - Alloys
  - Activation danger
  - Circuit materials for chemical compatibility
  - Thermal properties
  - Physical properties for liquid curtain or film
  - Availability

Phase II Collimation

Preliminary R&D activity on materials – organization of a working group

...probably this “magic” material does not exist...we should focus our attention on a mixed approach:

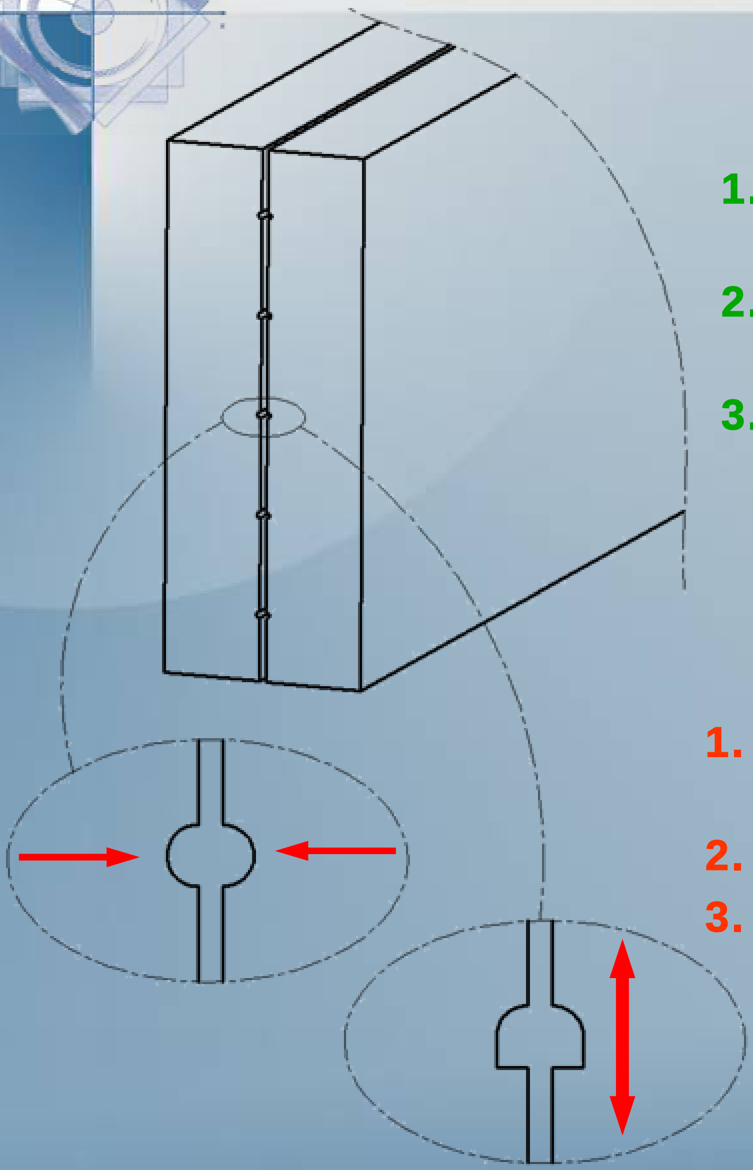
NEW MATERIAL

↕

NEW DESIGN

GOAL: identification of new suitable material(s) and/or jaw assembly integrated design

360° Jaw Concept



Possible Advantages

1. Increase of collimation efficiency (Particles are intercepted on 180° to 360°)...
2. Robustness (a new collimation slit can be used after accidental beam losses)...
3. Geometric stability is improved by pressing the jaws one against the other

Possible Disadvantages

1. Loss of 1 dof (one can play with geometry of collimation pipes)...
2. Minimum aperture is fixed
3. Impedance??...