LHC Collimation Overview

R. Assmann

CERN, AB/ABP

LARP Accelerator Systems Meeting BNL

May 19-20 2004

Introduction

Collimation has become a major design issue in building high energy colliders and making them work.

Why this?

Traditionally: Control the beam core (low e, small b*, good stability) to maximize luminosity!

Keep beam tails from experiments (background)

High intensity machines: High intensity in core and halo!

Halo/tails become “dangerous” for the machine:

➔ Quenches – Activation – Heating – Damage

➔ Required Functionality

- **Efficient cleaning of the beam halo** during the full LHC beam cycle (avoid beam-induced quenches of the SC magnets in routine operation).
- **Minimization of halo-induced backgrounds** in the particle physics experiments.
- **Passive protection** of the machine aperture against irregular beam (beam loss monitors at the collimators detect abnormally high loss rates ➔ beam abort trigger). With MPWG.
- **Scraping** of beam tails and diagnostics of halo population.
- **Abort gap cleaning** in order to avoid spurious quenches after regular beam dumps.

To achieve this important challenges must be met!

→ Some Numbers

• High stored beam energy (melt 500 kg Cu, required for 10^{34} cm^{-2} s^{-1} luminosity)	**~ 350 MJ/beam**
• Small spot sizes at high energy (small 7 TeV emittance, no large beta in restricted space)	**200 μm (at coll.)**
• Large transverse energy density (beam is destructive, 3 orders beyond Tevatron/HERA)	**1 GJ/mm²**
• High required cleaning efficiency (clean lost protons to avoid SC magnet quenches)	**99.998 % (~ 10^{-5} 1/m)**
• Collimation close to beam (available mechanical aperture is at ~10 σ)	**6-7 σ**
• Small collimator gap (impedance problem, tight tolerances: ~ 10 μm)	**~ 3 mm (at 7 TeV)**
• Activation of collimation insertions (good reliability required, very restricted access)	**~ 1-15 mSv/h**
• Big system	**IR3, IR7, other locations**

(nominal design parameters)

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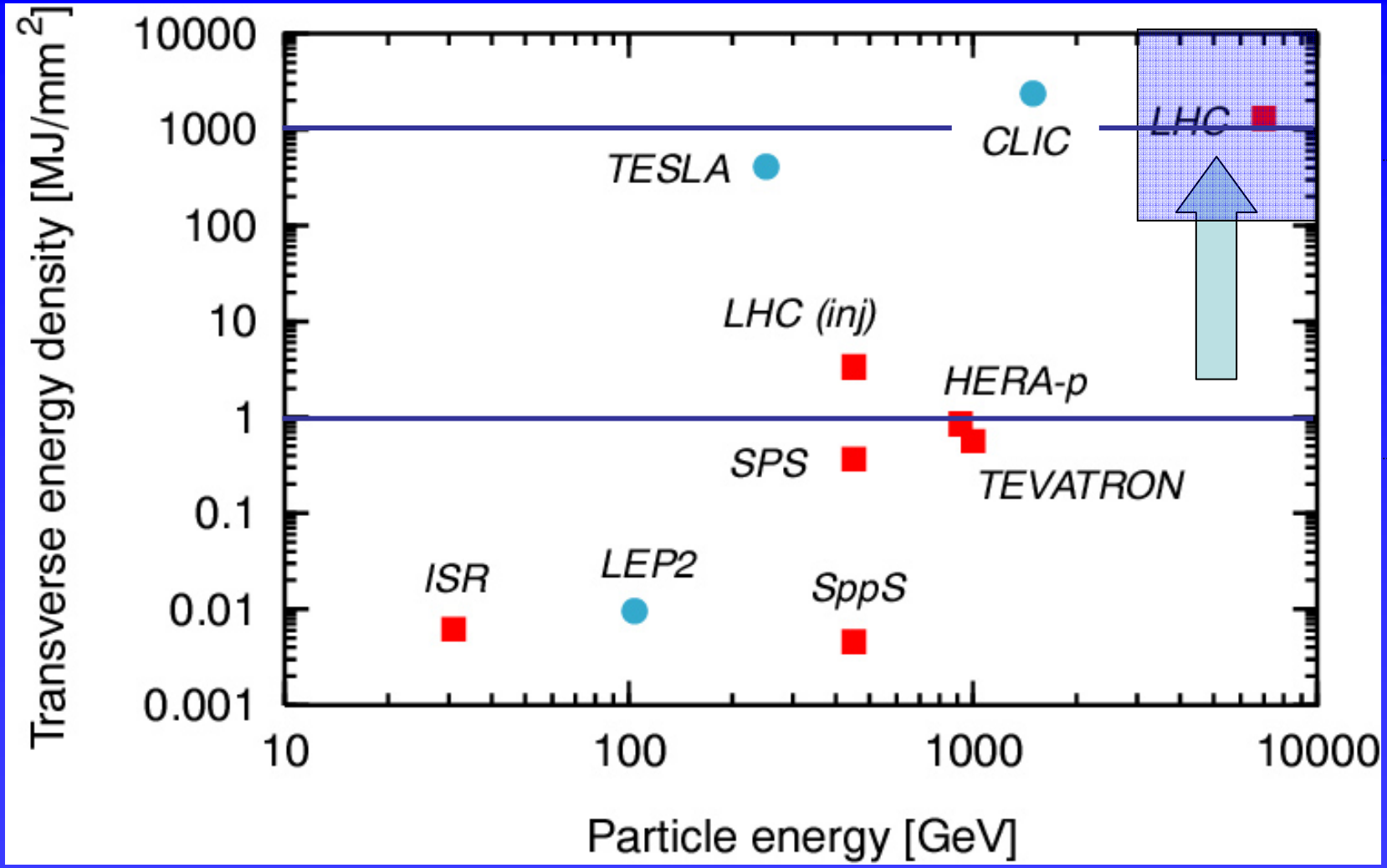

At less than 1% of nominal intensity LHC enters new territory.
There is no easy start-up for collimation!

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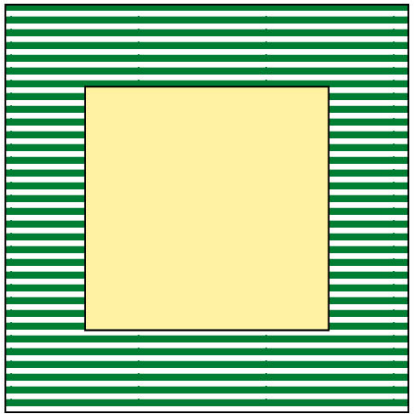
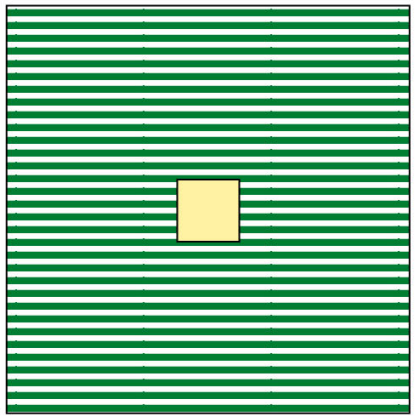
10 mm

Injection



Jaw opening

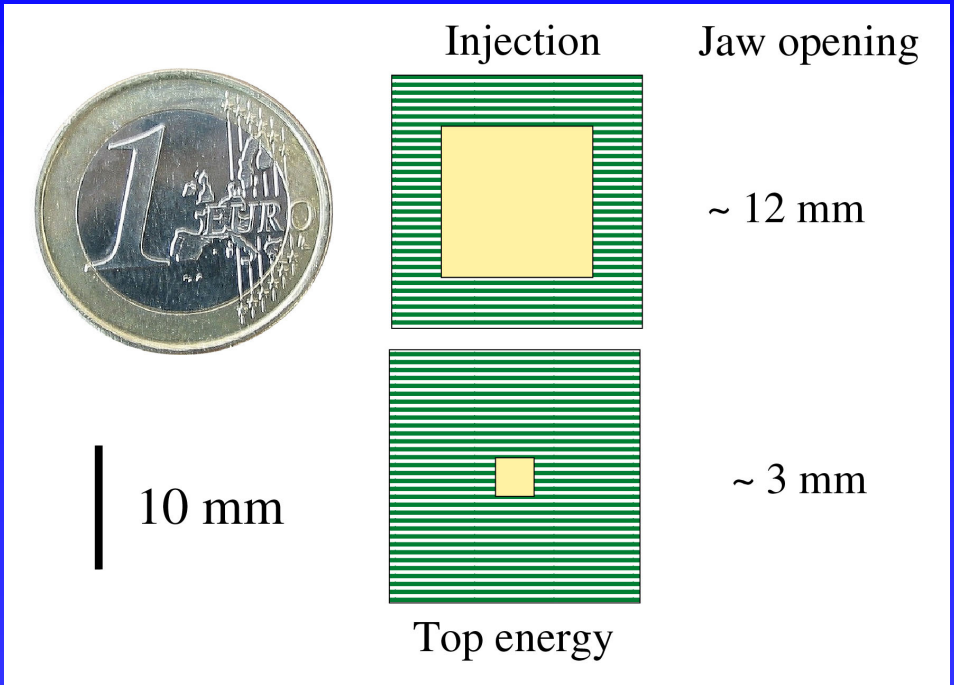
~ 12 mm



~ 3 mm

Top energy

Collimating with small gaps



LHC beam will be physically quite close to collimator material and collimators are long (up to 1.2 m)!

~ 0.15

~ 0.6

$$a_{coll} \leq a_{triplet} \cdot \sqrt{\frac{\beta_{coll}}{\beta_{triplet}}} \cdot \left(\frac{A^{\max}_{primary}}{A^{\max}_{secondary}} \right)$$

Collimator gap must be **10 times smaller** than available triplet aperture for nominal luminosity!

Collimator settings usually defined in sigma with nominal emittance!

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Shaping and Forming the Halo

New challenge: Control population and maximum extension of beam halo:

➔ relevant is **10^{-8}-10^{-9} level** of total intensity

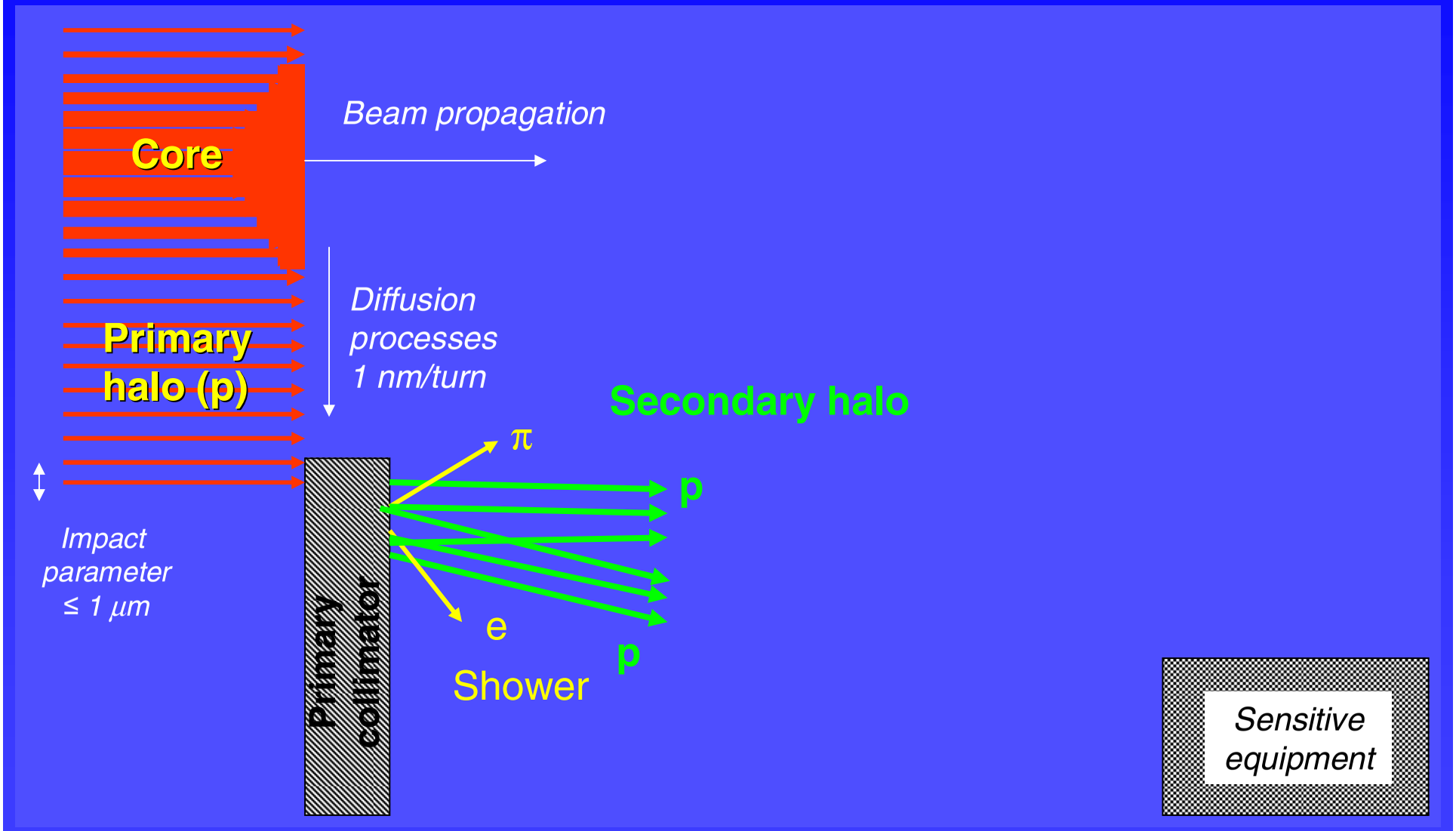
Collimation system:

Local shadow for experiments ➔ Halo shaping and forming in the ring

A collimator is a "halo converter" (sun glass), e.g. converting the primary halo in an attenuated secondary halo.

Collimators are closest to beam: easily damaged…

Collimator as a Halo Converter



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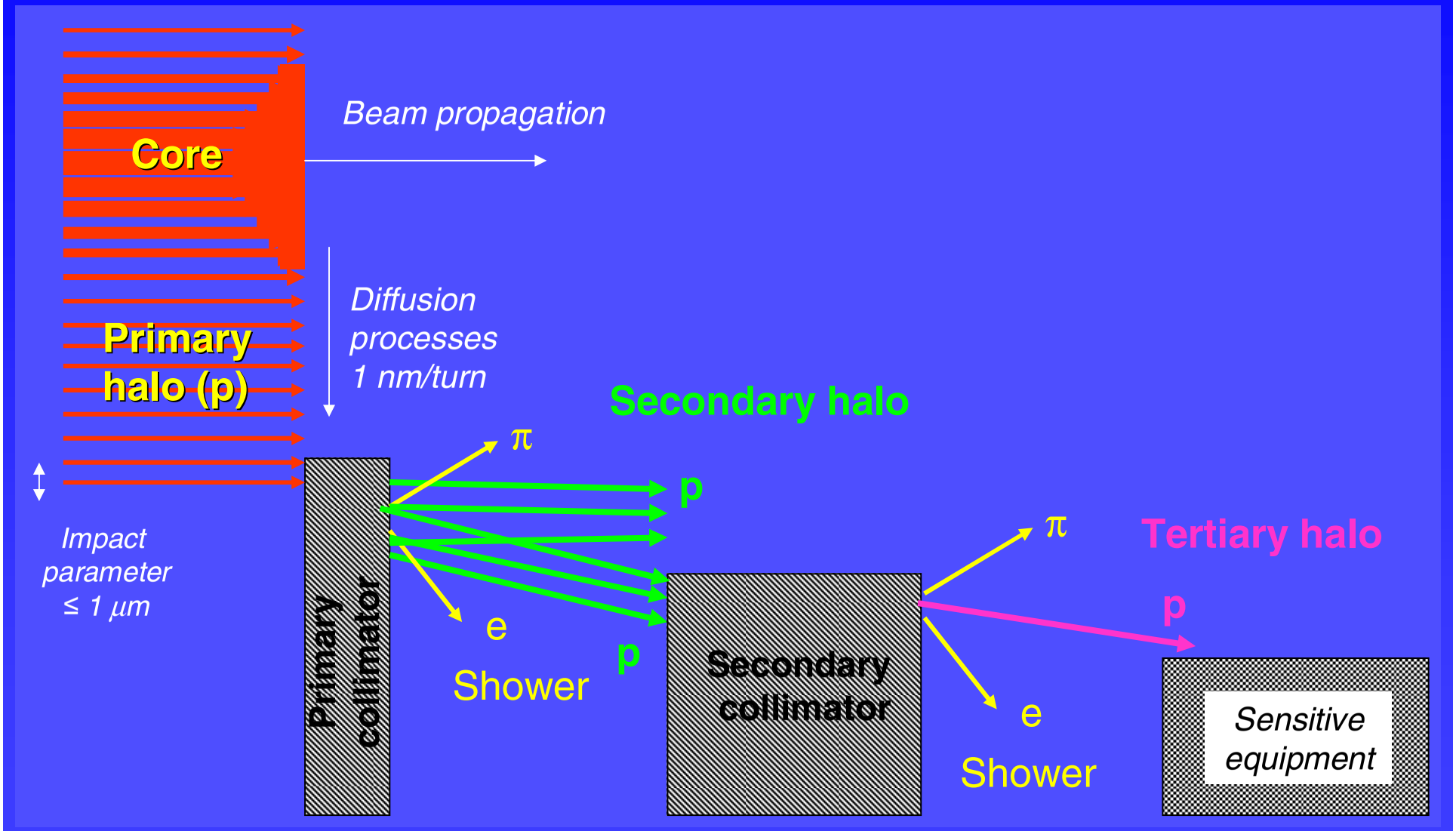
Collimator as a Halo Converter



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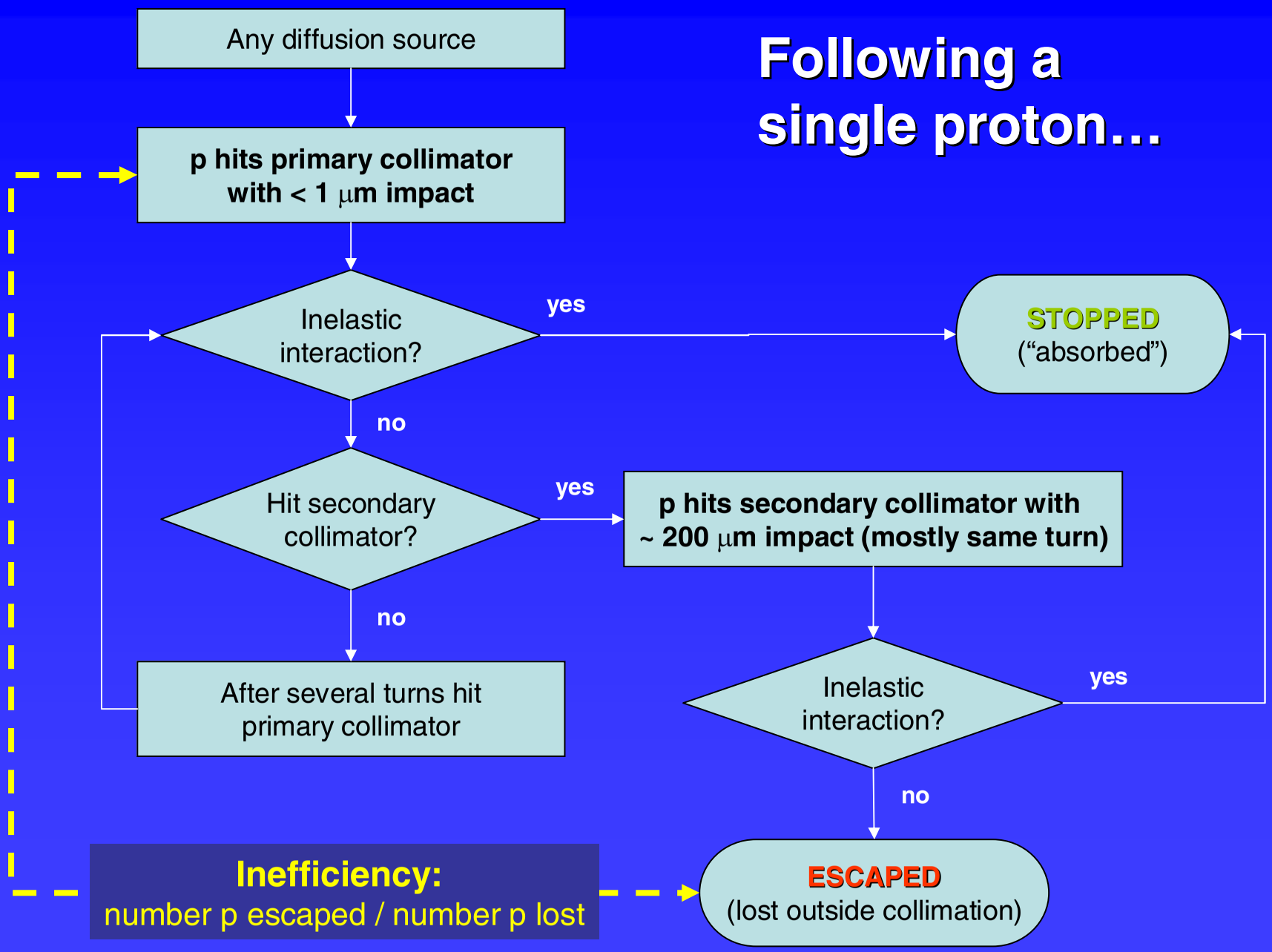
Following a single proton…



Inefficiency:
number p escaped / number p lost

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Inefficiency and Allowable Intensity

Allowed intensity

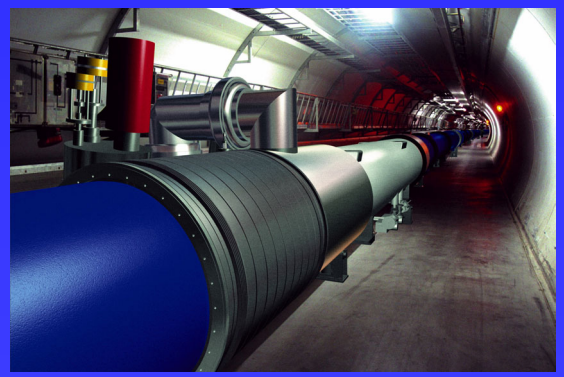
Quench threshold
(7.6 ×10^6 p/m/s @ 7 TeV)

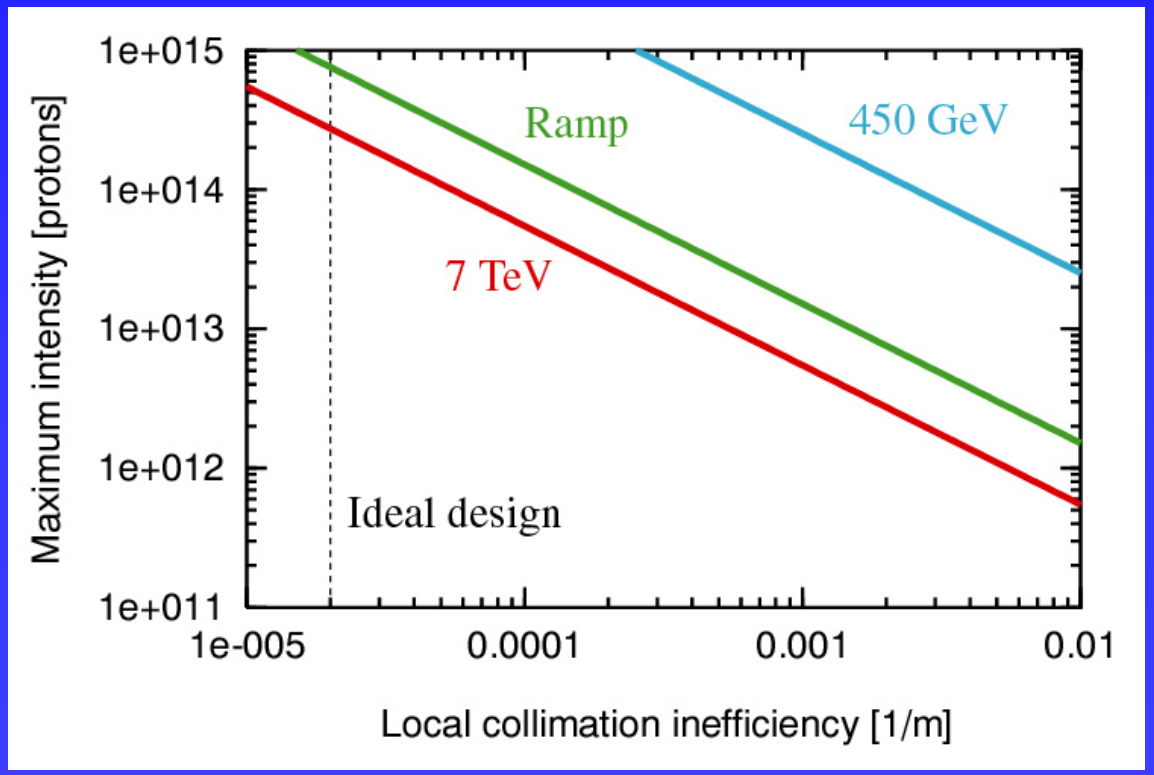
Cleaning inefficiency
=
Number of escaping p (>10σ) / Number of impacting p (6σ)

$$N_p^{\max} \approx \tau \cdot R_q \cdot L_{dil} / \eta_c$$

Beam lifetime
(e.g. 0.2 h
minimum)

Dilution
Length
(50 m)





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➔ Notes on collimation process…

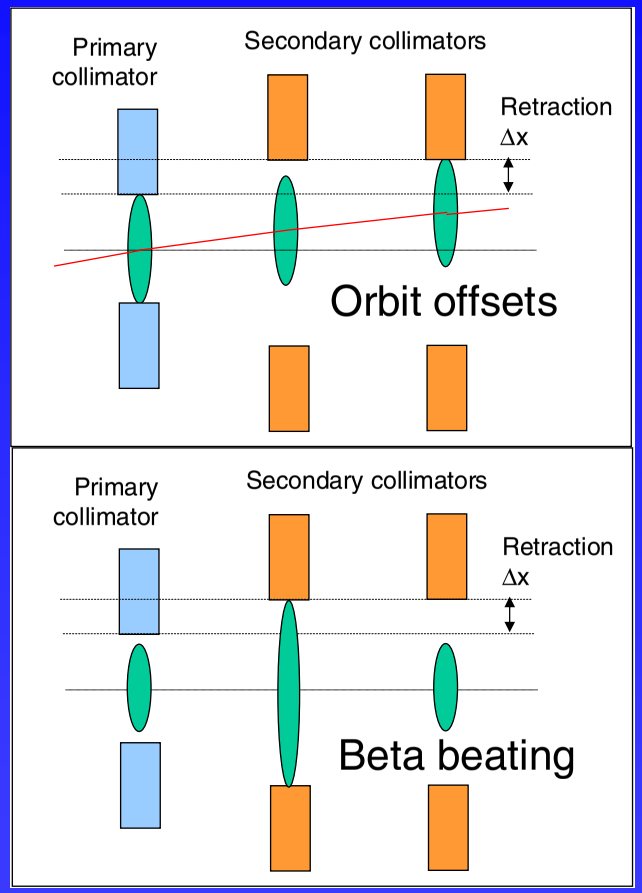
- Protons have very **small impact parameter** on primary collimator:
  ➔ they see only a small length and inelastic interaction cannot be achieved with good probability!
- Primary collimators can be short and **must be complemented by several secondary collimators** each!
- Secondary collimators have bigger impact parameter:
  ➔ They must be **long with good surface flatness t**o assure inelastic interaction!
- **Shower products** are assumed to be lost locally in collimator insertion (warm magnets).
- Collimation process is characterized by **inefficiency** (leakage rate).

➔ Notes on machine constraints

Small available length for collimation insertions:

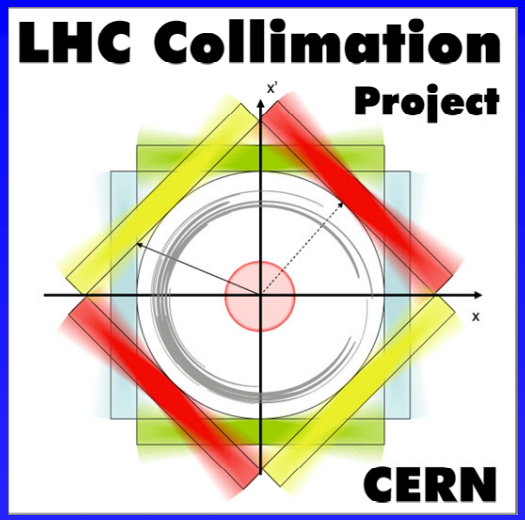
➔ limited phase advance allows only for one primary collimator per plane (**mis-kicked beam can bypass primary collimator and hit secondary collimator**).

➔ small beta functions impose **small collimation gaps**!



Secondary collimators can be damaged!

Getting the LHC Solution



- LHC collimation design evolved significantly.
- Great LHC challenges: Constantly being reviewed and improved!
- Last review since 2001 (CWG)
- Collimation Project started 1.5 years ago.
- Mandate:

  - Finalize the design of the LHC collimation system in IR3 and IR7, taking into account all relevant requirements concerning robustness, performance, fabrication, installation, maintenance, machine protection, and beam operation.
  - Produce prototype collimator tanks for TCP, TCS, and TCL type collimators and verify their performance.
  - Supervise production and installation of the full system.
  - Commission the system without and with beam. Support routine operation.

LHC Collimation Project

Home of the Project for the LHC Collimation System

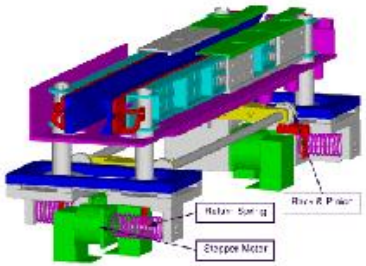
Top	Project Team	Notes	Tasks	Data files	Meetings
Links	Papers	Talks (WG)	IR7 files	AB Departm.	Workflow

MANDATE

Finalize the design of the LHC collimation system in IR3 and IR7, taking into account all relevant requirements concerning robustness, performance, fabrication, installation, maintenance, machine protection, and beam operation. Produce prototype collimator tanks for TCP, TCS, and TCL type collimators and verify their performance. Supervise production and installation of the full system. Commission the system without and with beam. Support routine operation.

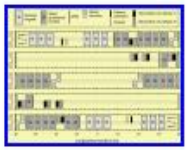
Link to LHC COLLIMATION WG web site

Why LHC collimation? Click for a short introduction!

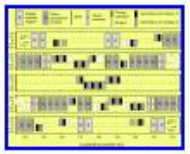


Sketch of the preliminary design for an LHC collimator (Collimator Design Meetings)

LAYOUT SKETCHES IR3 AND IR7



IR3 layout



IR7 layout

NEWS

Apr 04 — **Information on V6.5 layout:** Find HERE

Mar 04 — **Download:**
Final drawing IR3 (.dwf) Final drawing IR7 (.dwf)

Feb 04 — **Download:**
Collimation chapter of LHC design report with new reference design (1.6 MB)

http://www.cern.ch/lhc-collimation-project

The people involved…

PROJECT TEAM	R. Assmann	AB/ABP	Project Leader	75231 16-4543

- Project Management
- Engineering/Technical Support
- Material Shower Simulations for Collimator Jaws
- Showering Studies/Energy Deposition/Radiation
- Collimation system Design/Theory/System Simulations
- Operation/Instrumentation/MD's
- Impedance Estimates for Collimators
- Additional Link Persons

PROJECT MANAGEMENT

R. Assmann	AB/ABP	Project Leader	75231
E. Chiaveri	AB/ATB	Project Steering/GL ATB/Resources	76617
O. Aberle	AB/ATB	Project Engineer	75297
M. Mayer	TS/MME	Coordination TS Engineering	74499
J.P. Riunaud	AB/ABP	GL ABP/Resources	73496

ENGINEERING/TECHNICAL SUPPORT

O. Aberle	AB/ATB	Mechanical engineering	75297
A. Bertarelli	TS/MME	Mechanical engineering	72337
S. Calatroni	TS/MME	Coating, heating test	73070
F. Decorvet	AB/ATB	Motorization, Local Control	75240
M. Jimenez	AT/VAC	Vacuum quality	79489
M. Mayer	TS/MME	Mechanical engineering	74499
R. Perret	TS/MME	Mechanical design	76947
C. Rathjen	AT/VAC	Vacuum layout IR3/IR7	73427
P. Sievers	AT/MTM	Mechanical engineering	74810

MATERIAL SHOWER SIMULATIONS FOR COLLIMATOR JAWS

A. Ferrari	AB/ATB	FLUKA calculations (coordination)	76119
V. Vlachoudis	AB/ATB	FLUKA calculations	79851

SHOWERING STUDIES?ENERGY DEPOSITION/RADIATION

I. Baichev	IHEP	Energy deposition IR3 - link IHEP	
M. Brugger	SC/RP	Radiation impact	76556
I. Kurotchkine	IHEP	Energy deposition IR3	
M. Magistris	AB/RF	Energy deposition IR7	72208
M. Silari	SC/RP	Energy deposition IR7	72208
S. Roesler	SC/RP	Radiation impact	79891
H. Vincke	SC/RP	Radiation modeling IR3	78069

COLLIMATION SYSTEM DESIGN/THEORY/SYSTEM SIMULATIONS

R. Assmann	AB/ABP	Theory/simulations, Operational studies	75231
H. Braun	AB/ABP	Ion collimation	78040
J.B. Jeanneret	AB/ABP	Theory/simulations, Radiation	73190
V. Kain	AB/CO	Simulations, Protection	79032
D. Kaltchev	TRIUMF	IR3/IR7 optics	
S. Redaelli	AB/ABP	Theory/simulations, Operational studies	72539
T. Risselada	AB/ABP	IR3/IR7 optics	73309
G. Robert-Dem.	AB/ABP	Theory/simulations, Operational studies	72539

OPERATION/INSTRUMENTATION/MD's

H. Burkhardt	AB/ABP	1st turn injection, SPS MD's, TL coll.	75464
B. Dehning	AB/BDI	BLM system, Beam Instrumentation	75541
B. Holzer	AB/BDI	BLM system, Beam Instrumentation	72919
M. Lamont	AB/OP	Link Operation/Controls	74806
R. Schmidt	AB/CO	Link Machine Protection	75217
J. Wenninger	AB/OP	Orbit stabilization IR3/7	73715

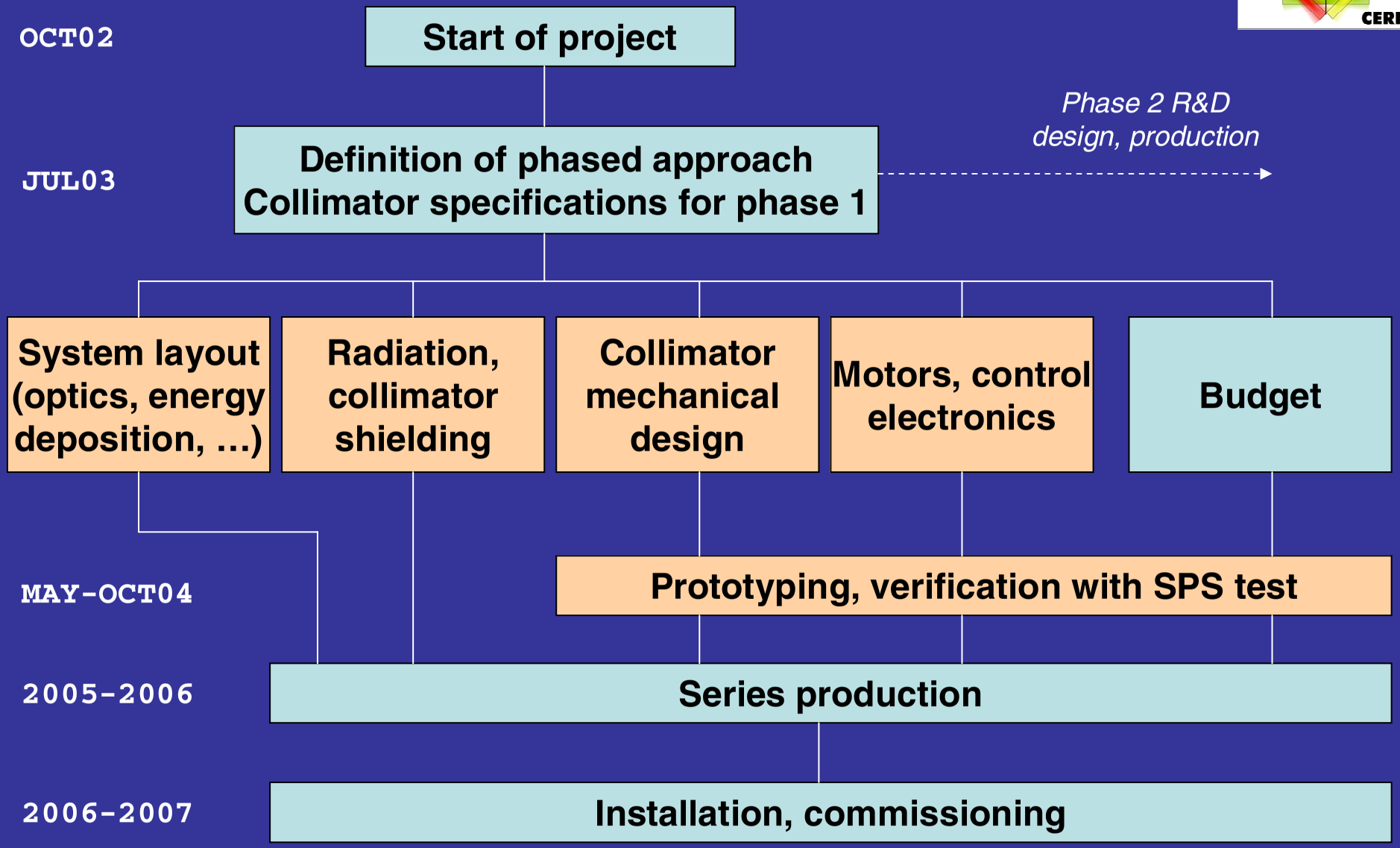
IMPEDANCE ESTIMATES FOR COLLIMATORS (collective effects team ABP)

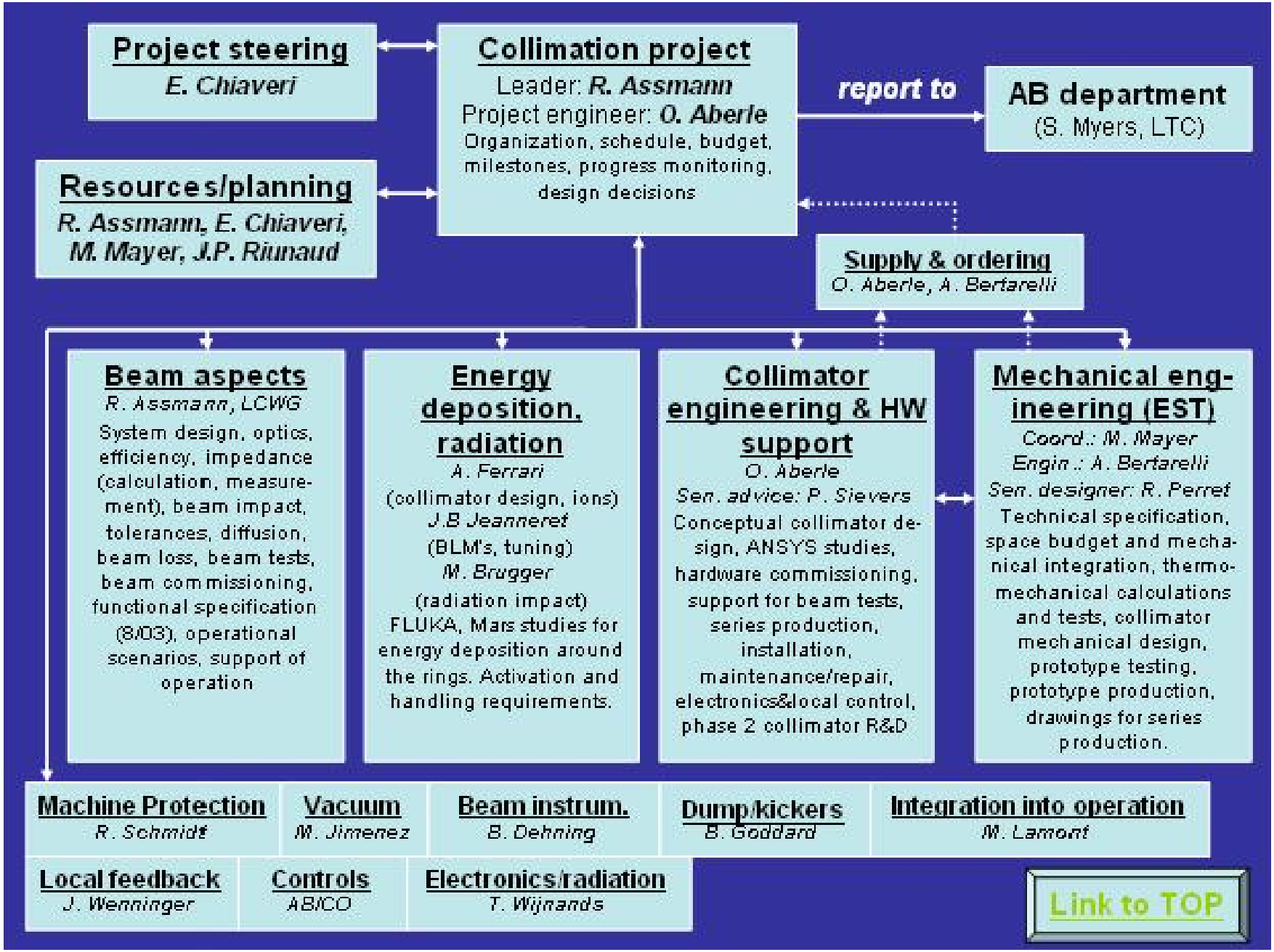
E. Metral	AB/ABP	Analytical Calculations	72560
F. Ruggiero	AB/ABP	Theory, Coordination	73726
D. Schulte	AB/ABP	3D Numerical Impedance Models	75323

ADDITIONAL LINK PERSONS

S. Chemli	TS/IC	Link Integration & Layout	78538
B. Goddard	AB/BT	Link TCDQ, beam dump layout	75484
D. Gasser	ST/CV	Link Cooling IR3/7	72125
J.C. Guillaume	TS/EL	Link Cabling IR3/7	75340
R. Ostojic	AT/MEL	Link LHC layout	75146
R. Principe	TS/CV	Link Ventilation IR3/7	73239
J.P. Quesnel	TS/SU	Link Survey & Alignment Group	75153
W. Kalbreier	AT/MEL	Link Warm Magnets	75278
J. Uythoven	AB/BT	Link beam dump failure	74170
W. Weterings	AB/BT	Link TCDQ engineering	74897

Main work flow




Project steering
E. Chiaveri
Collimation project
Leader: R. Assmann
Project engineer: O. Aberle
Organization, schedule, budget, milestones, progress monitoring, design decisions
report to
AB department
(S. Myers, LTC)
Resources/planning
R. Assmann, E. Chiaveri, M. Mayer, J.P. Riunaud
Supply & ordering
O. Aberle, A. Bertarelli
Beam aspects
R. Assmann, LCWG
System design, optics, efficiency, impedance (calculation, measurement), beam impact, tolerances, diffusion, beam loss, beam tests, beam commissioning, functional specification (8/03), operational scenarios, support of operation
Energy deposition, radiation
A. Ferrari
(collimator design, ions)
J.B Jeanneret
(BLM's, tuning)
M. Brugger
(radiation impact)
FLUKA, Mars studies for energy deposition around the rings. Activation and handling requirements.
Collimator engineering & HW support
O. Aberle
Sen. advice: P. Sievers
Conceptual collimator design, ANSYS studies, hardware commissioning, support for beam tests, series production, installation, maintenance/repair, electronics&local control, phase 2 collimator R&D
Mechanical engineering (EST)
Coord.: M. Mayer
Engin.: A. Bertarelli
Sen. designer: R. Perret
Technical specification, space budget and mechanical integration, thermo-mechanical calculations and tests, collimator mechanical design, prototype testing, prototype production, drawings for series production.
Machine Protection
R. Schmidt
Vacuum
M. Jimenez
Beam instrum.
B. Dehning
Dump/kickers
B. Goddard
Integration into operation
M. Lamont
Local feedback
J. Wenninger
Controls
AB/CO
Electronics/radiation
T. Wijnands
Link to TOP

Challenges for LHC Collimation

Good robustness

High efficiency

Low impedance

SOLUTION?

Low activation

Reasonable cost
Fast schedule

Reasonable tolerances

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No ONE General Purpose System

Tradeoffs:

Good robustness (carbon)	←→	Low impedance (metal)
High efficiency (good absorption)	←→	Good robustness (bad absorption)
Low impedance (short jaws)	←→	High efficiency (long jaws)

1. **Advancing state-of-the-art by 2-3 orders of magnitude.**
2. **Conflicting requirements.**

→ No unique solution for everything (injection, ramp, collision, …):

Various sub-systems with dedicated usages, targeted at specific requirements (e.g. maximum robustness at injection/ramp, minimum impedance at collision).

Staged approach for minimum initial investment, minimum number of components, assuring to be ready in time. Possibility of upgrades.

Imagine **collimation as a game of golf…**

You can do it with one club only. However, **if you want to win you better have more than one club**:

- **Best chances to win** the “collimation game” with specially adapted, specialized sub-systems.
- **More effort to understand** what “club” to use for what.
- However, **easier and better “playing”** (operation) though there are more clubs (collimators).
- One club is enough to start learning the game (phase 1).

➔ The collimation "clubs"

1) **Maximum robustness, minimum cost IR3/IR7 collimation system** (C) for injection&ramping, commissioning, early physics (running at impedance limit). Thin metallic coating for going further (survival of coating unclear).

2) **"Tertiary" collimators in IR1, IR2, IR5, IR7** for local protection and cleaning at the triplets.

3) Thin targets for **beam scraping**.

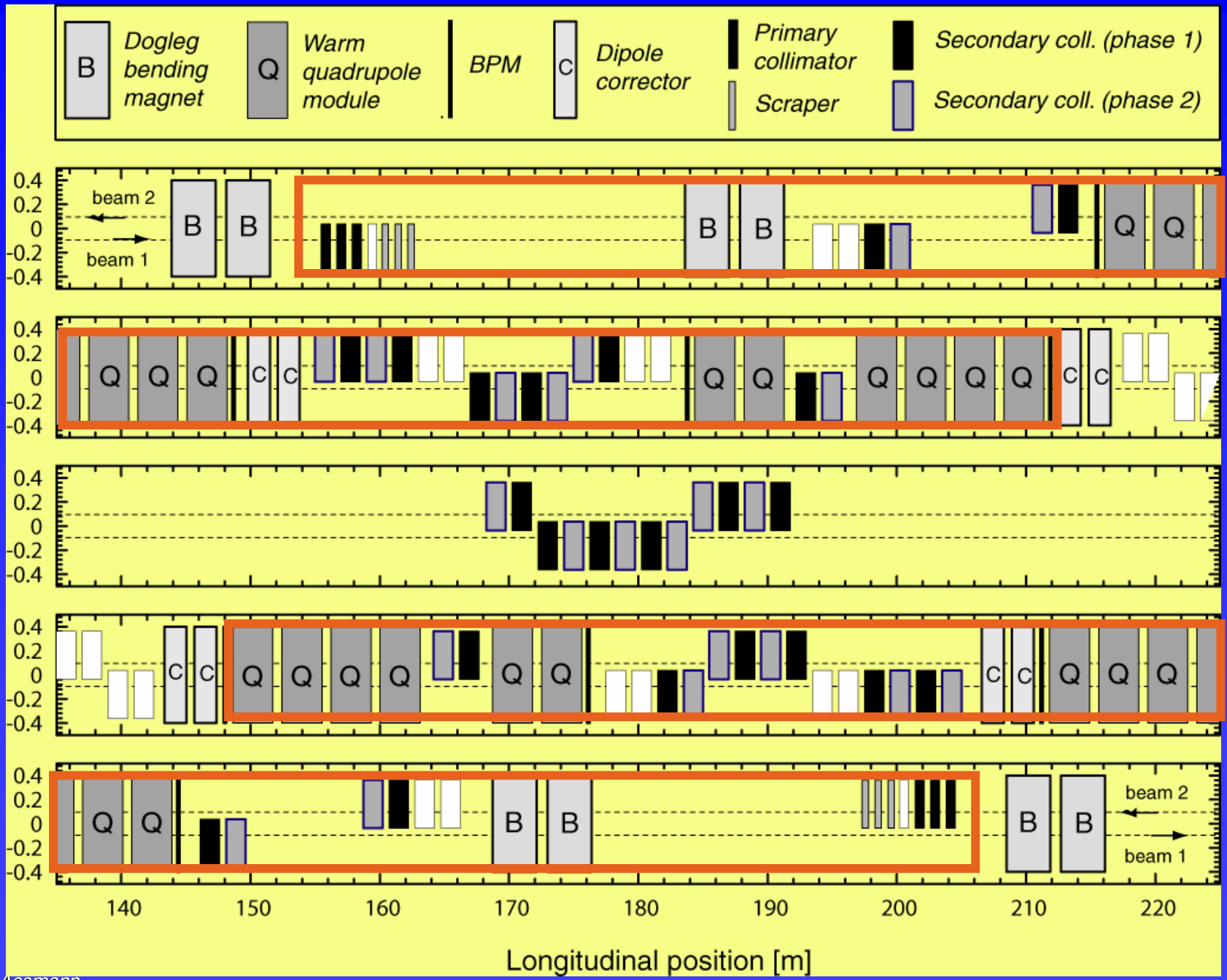
Phase 1

4) **Metallic "hybrid" secondary collimators in IR7** for nominal performance, used only at end of squeeze and stable physics.

Phase 2

5) **Additional placeholders** for upgrading to maximum cleaning efficiency.

Phase 4


B
Dogleg bending magnet
Q
Warm quadrupole module
BPM
C
Dipole corrector
Primary collimator
Scraper
Secondary coll. (phase 1)
Secondary coll. (phase 2)
beam 2
beam 1
0.4
0.2
0
-0.2
-0.4
140
150
160
170
180
190
200
210
220
Longitudinal position [m]

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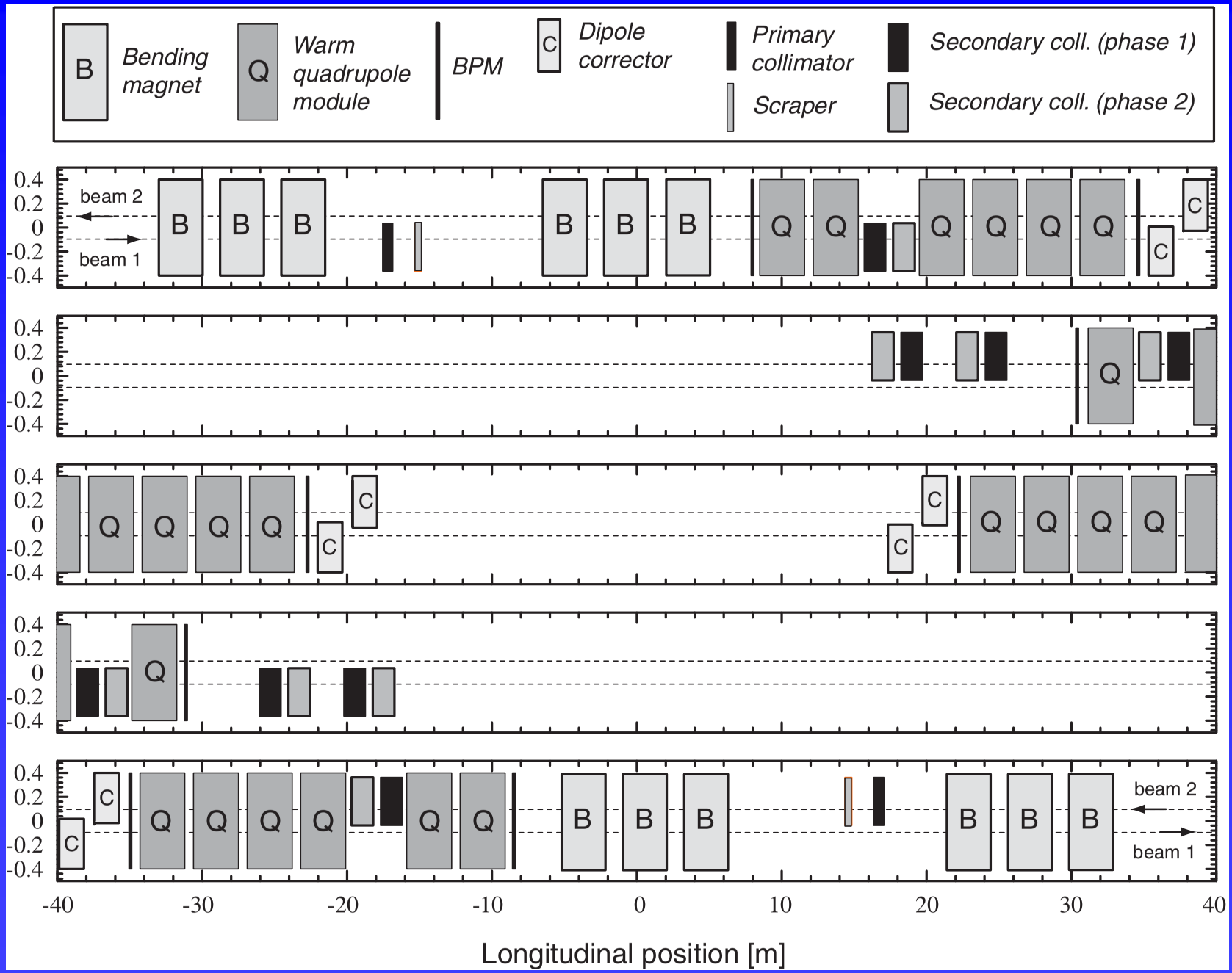
IR3



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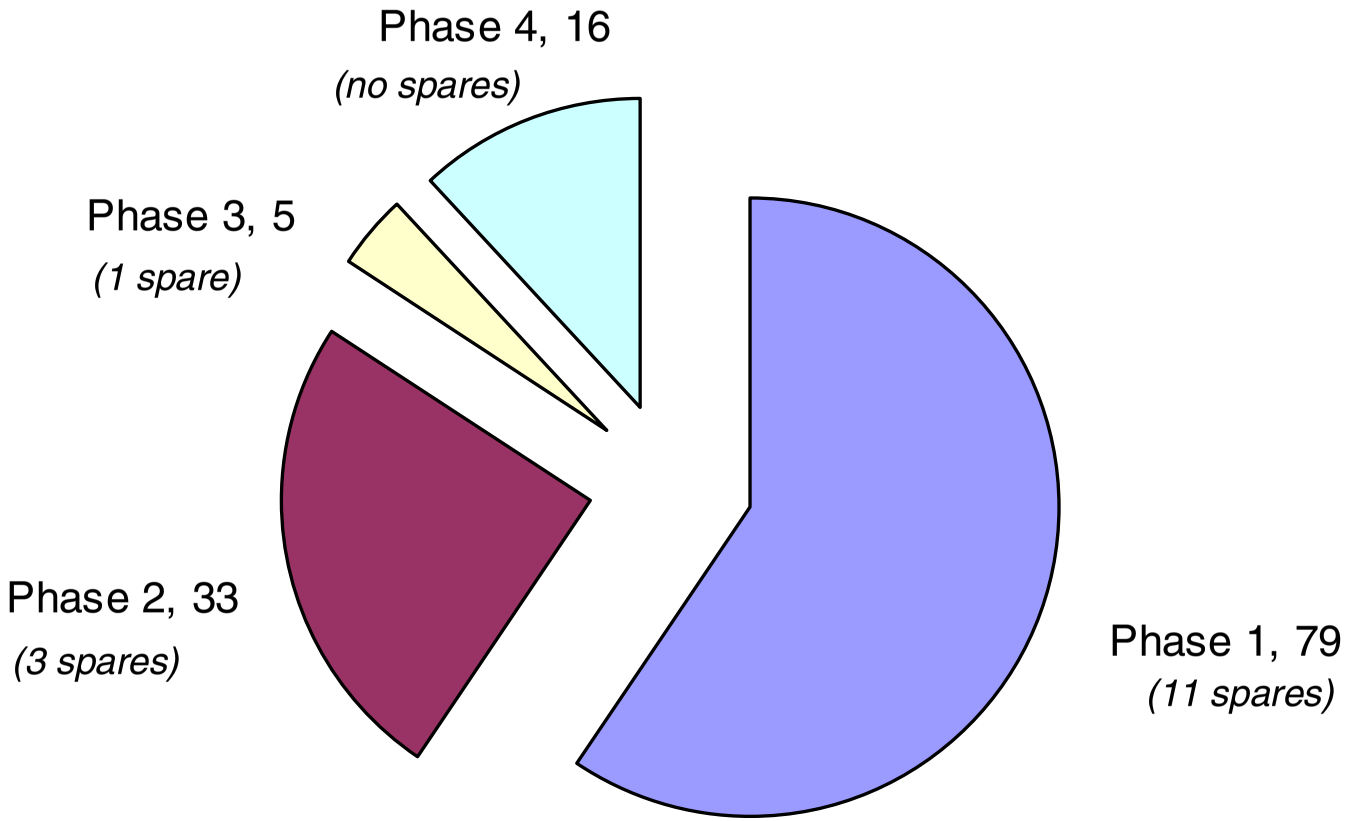
➔ Machine layout in LHC

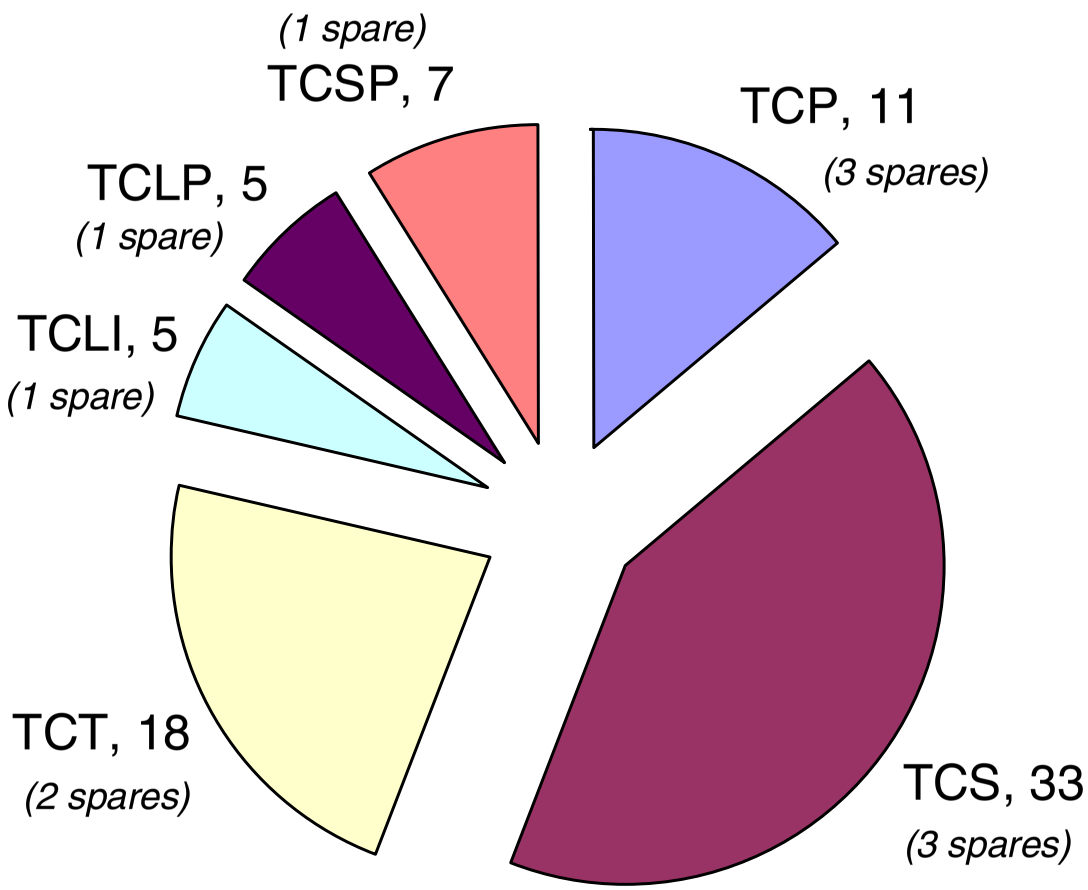
- Now cleaning insertions **IR3 and IR7 practically frozen** what concerns optics and collimation design!
- New collimation is practically **approved including phase 2 locations and space reservations**.
- Formal procedure under way.
- Final presentation **28 May 2004**.
- Further changes:
  ➔ Placement of absorbers for shower products.
  ➔ Optimization for radiological impact.
- **Final layout by Summer** with above changes!?

Phasing of ring collimators (including spares)



Ultimate efficiency: With **optional "Phase 4"** (not required for nominal – to be confirmed for new optics).

Collimators for Phase 1 (including spares)



Phase 1 is a big system:

- Total 79 components (95 in worst unlikely case).
- Much work overhead: 6 different types, not counting different azimuthal orientations for TCS!

TCP	*Primary collimator*
TCS	*Secondary collimator*
TCT	*Tertiary collimator*
TCSP	*Scraper*
TCLI	*Injection protection*
TCLP	*Physics protection*

Concentrating on design of secondary collimators (TCS):

➔ most components and most difficult!

TCS design will serve as basis for TCP, TCSP, TCLP, and TCLI designs!

Maximum Robustness Jaws for Phase 1

Parameter	Unit	TCP	TCS
Azimuthal orientation		X, Y, S	various
Jaw material		C or C-C	C or C-C
Jaw length	cm	20	100
Jaw tapering	cm	2×10	2×10
Jaw dimensions	mm^2	65×25	65×25
Jaw coating		1 μm Cu	1 μm Cu
Jaw resistivity	$\mu\Omega$m	minimal	minimal
Surface roughness	μm	≤ 1	≤ 1.6
Surface flatness	μm	25	25
Heat load	kW	1.5	7
Max. operational temperature	°C	50	50
Outbaking temperature	°C	250	250
Maximum full gap	mm	60	60
Minimum full gap	mm	0.5	0.5
Knowledge of gap	μm	50	50
Jaw position control	μm	≤ 10	≤ 10
Control jaw-beam angle	μrad	≤ 15	≤ 15
Reproducibility of setting	μm	20	20
DOF movement (hor. collimator)		X, X', Y	X, X', Y
DOF movement (vert. collimator)		Y, Y', X	Y, Y', X
Positional installation accuracy	μm	100	100
Angular installation accuracy	μrad	150	150

Driving criteria for material:

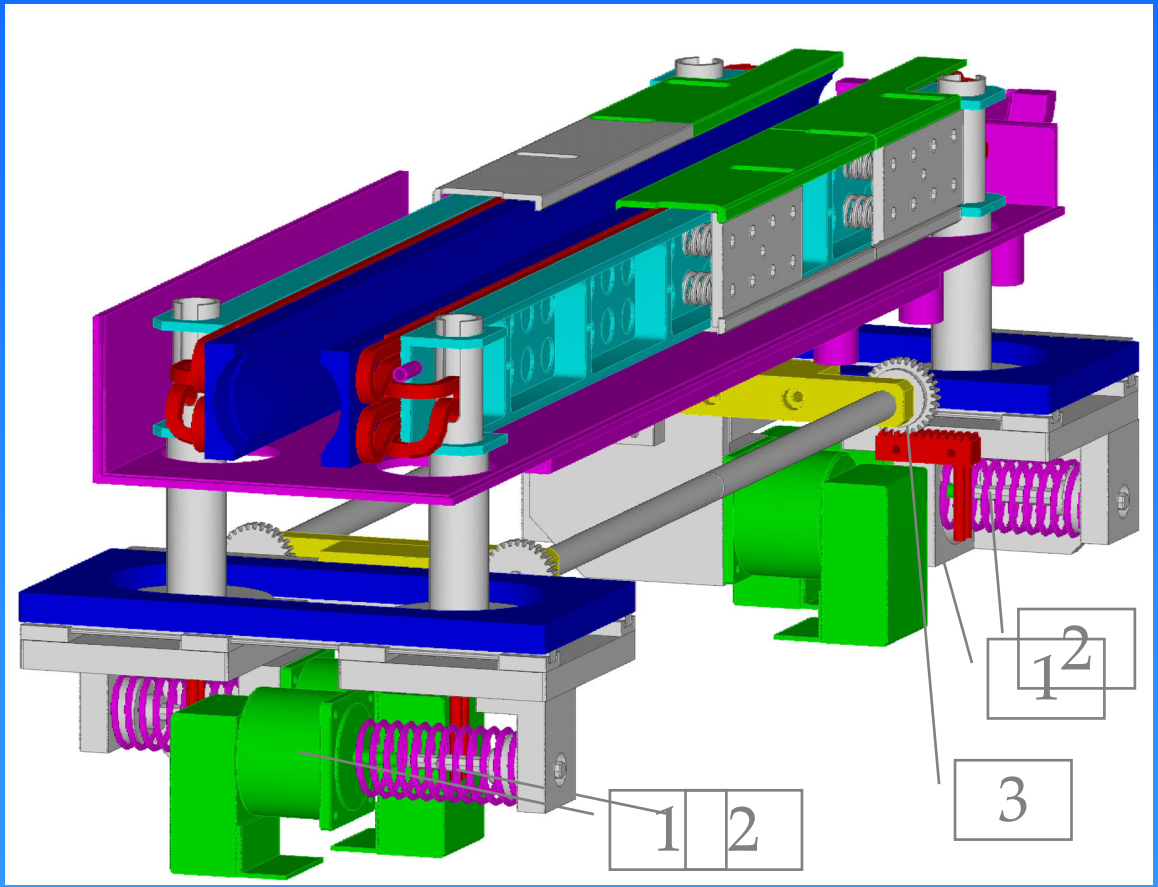
Resistivity (7-25 μΩm)
Short lead times
Samples ordered and partly arrived

Design work and prototyping under way
(EST leads effort, AB)

➔ Our “phase 1” secondary collimators

- More **conventional design** (next iteration on LEP concept) with advanced features.
- Two graphite jaws, movable in angle and position, **maximum robustness**, concept of spare surface.
- **Full redundant read-out** of gap at both ends, gap center, jaw positions. In addition temperature sensors and sensors for damage detection.
- **Thin coating** for impedance reduction (coating destroyed in case of direct beam hit, graphite unaffected).
- Mechanical “automatic” opening with motor failure (motor pressing against spring).
- **Quick plug-ins** for electrical and water connections. Fast exchange flanges. Short installation and replacement time! Crucial for radiological reasons!
- **Three prototypes** being constructed now (500k$ including design work). **Problems with surface flatness (miss factor 2-5).**
- Tests of prototypes with **SPS beam** after Aug 2004.

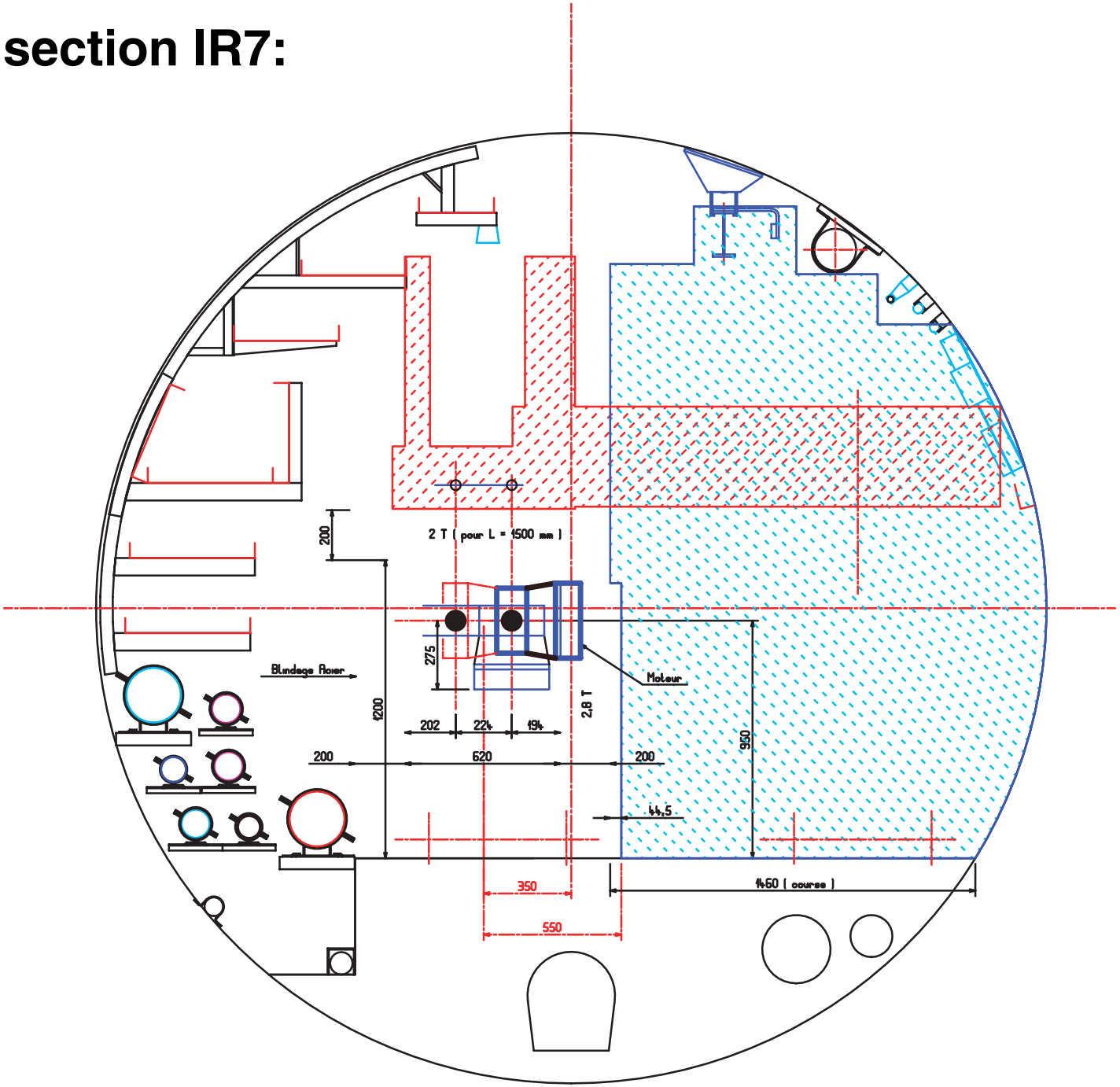
Technical concept
(A. Bertarelli et al)
Actuating system



- 1. Each jaw actuated by 2 step motors
- 2. Return spring for automatic pullback in case of motor failure
- 3. Rack-pinion system to prevent excessive misalignments
- Lateral translation and angular correction (tilt) allowed
- Sliding of the jaw surface (+/- 10mm) by a third motor
- Automatic recovery of mechanical plays.
- Jaw advancement per motor step: 10 μm

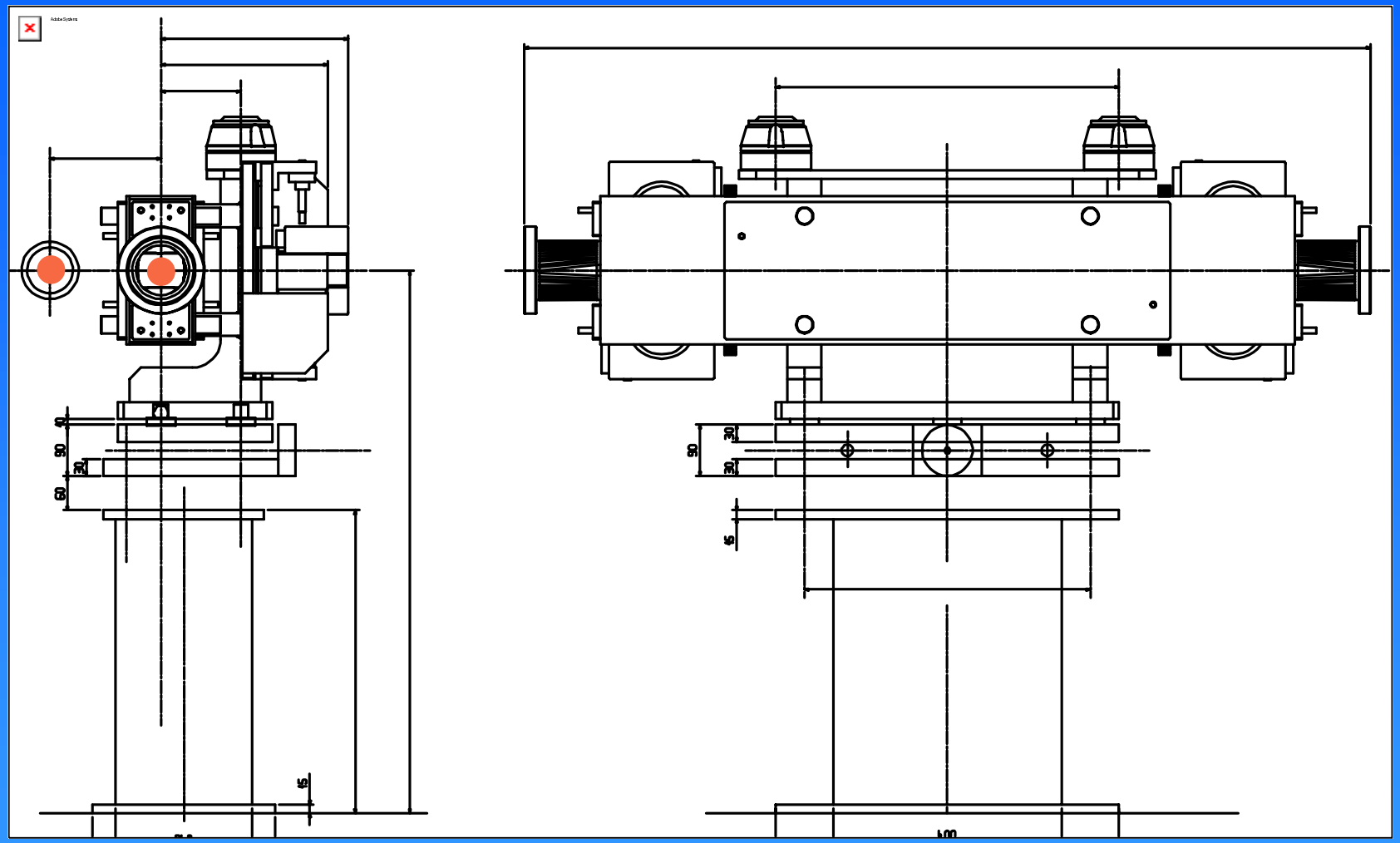
First 2 prototypes by May 2004.

Tunnel cross section IR7:



Dimensions…

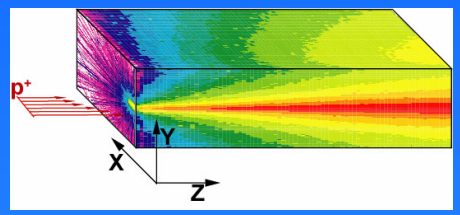
R.Perret, A. Bertarelli et al

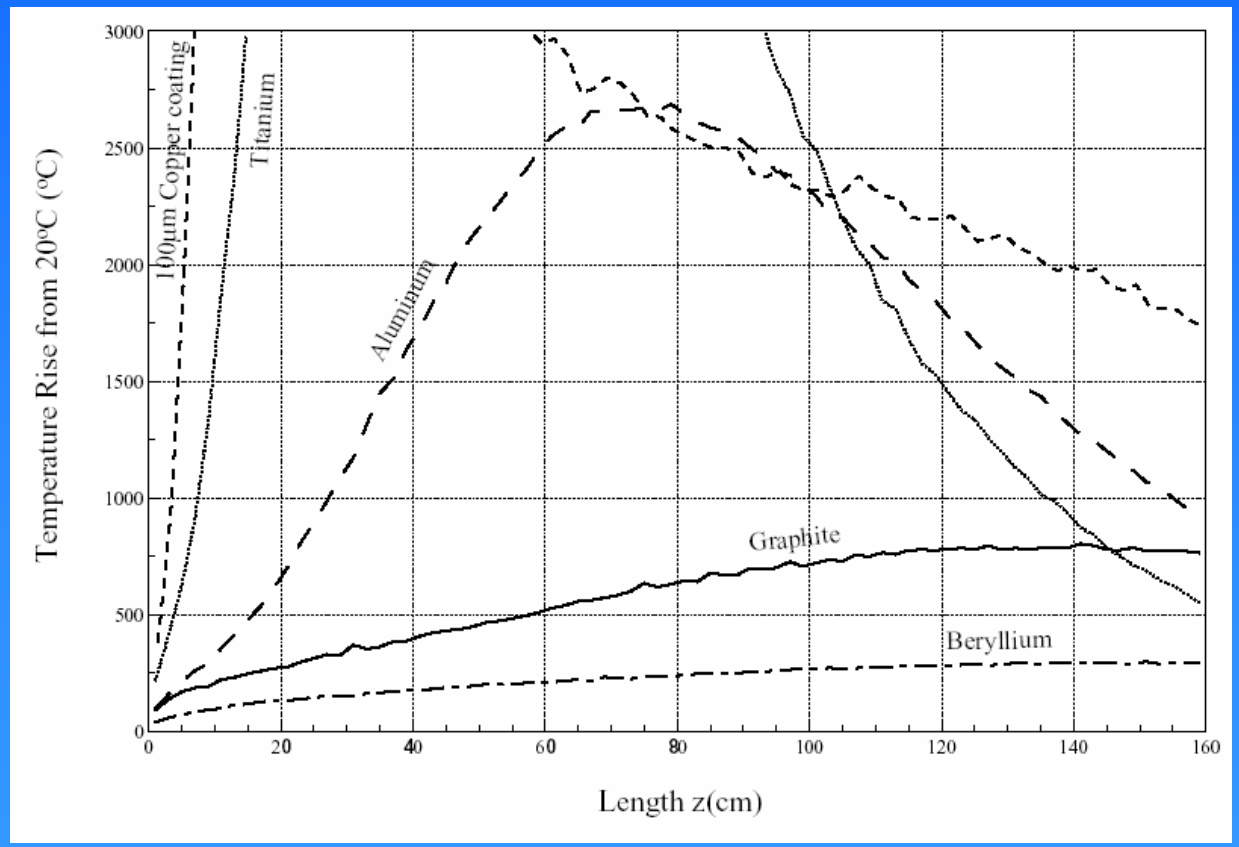


Longitudinal space per secondary collimator:	2.0 m instead of 0.7 m
Plus space for hybrid secondary collimator:	2.0 m
Total required longitudinal space:	**4.0 m** instead of 0.7 m

Material and Length of Jaws

Design is driven by several irregular conditions:
➔Injection errors ➔ Asynchronous beam dumps ➔ Single module pre-fire
Analyzed with beam tracking, FLUKA and ANSYS.





Only low Z considered after FLUKA study!

Only graphite-based materials are adequate!

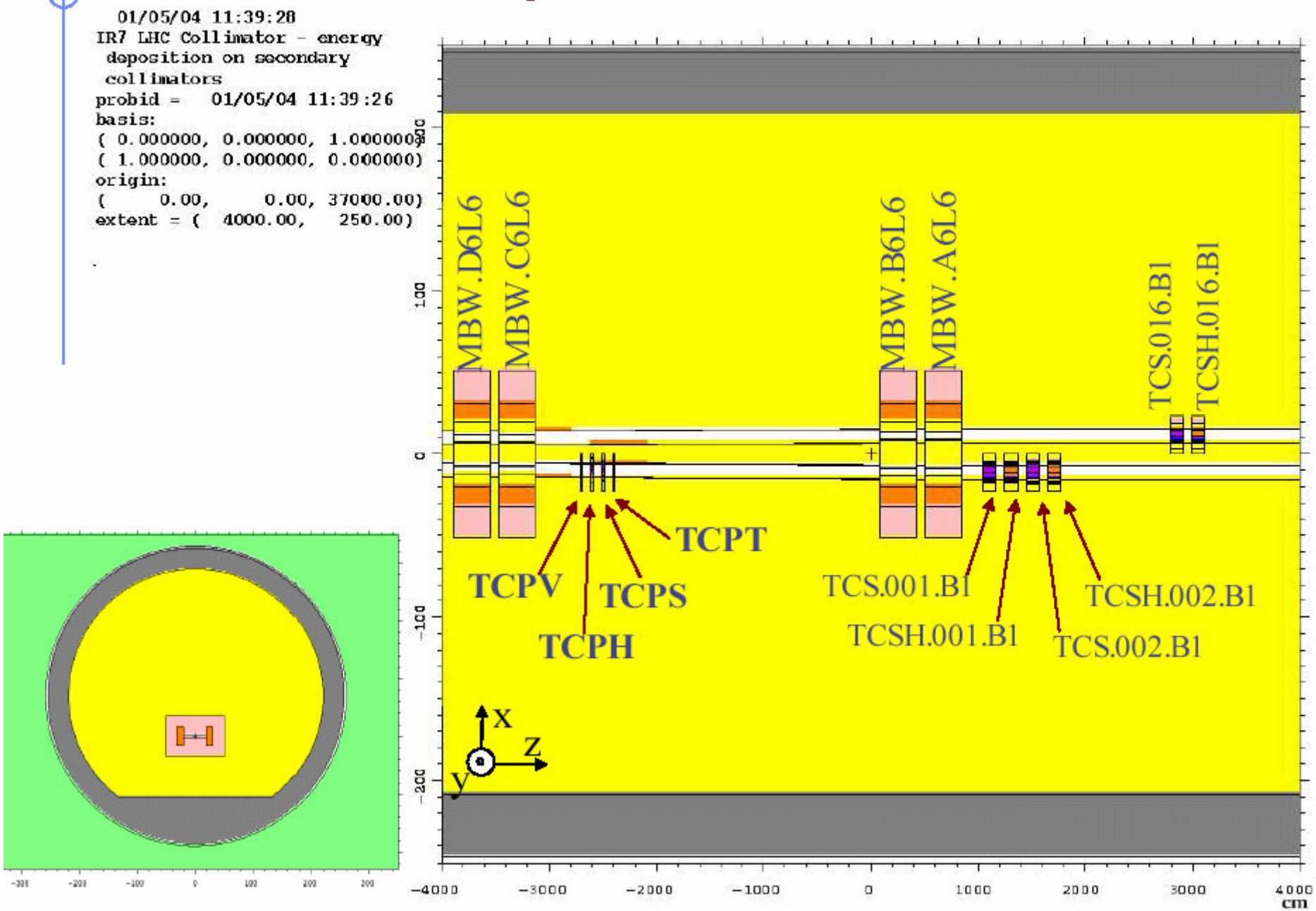
A. Ferrari,V. Vlachoudis

➔ Heating of components

- Peak beam loss ➔ **0.5-1.0 MW for 10 s**. 100 kW continuously.
- Peak loss rate corresponds to **1% of beam lost over 10s** ➔ nothing extraordinary!
- Part of beam power goes into equipment!
- Problem of **component heating**, in particular collimator heating (flatness…).
- More severe for long collimators / high Z (phase 2)!
- Detailed showering studies…

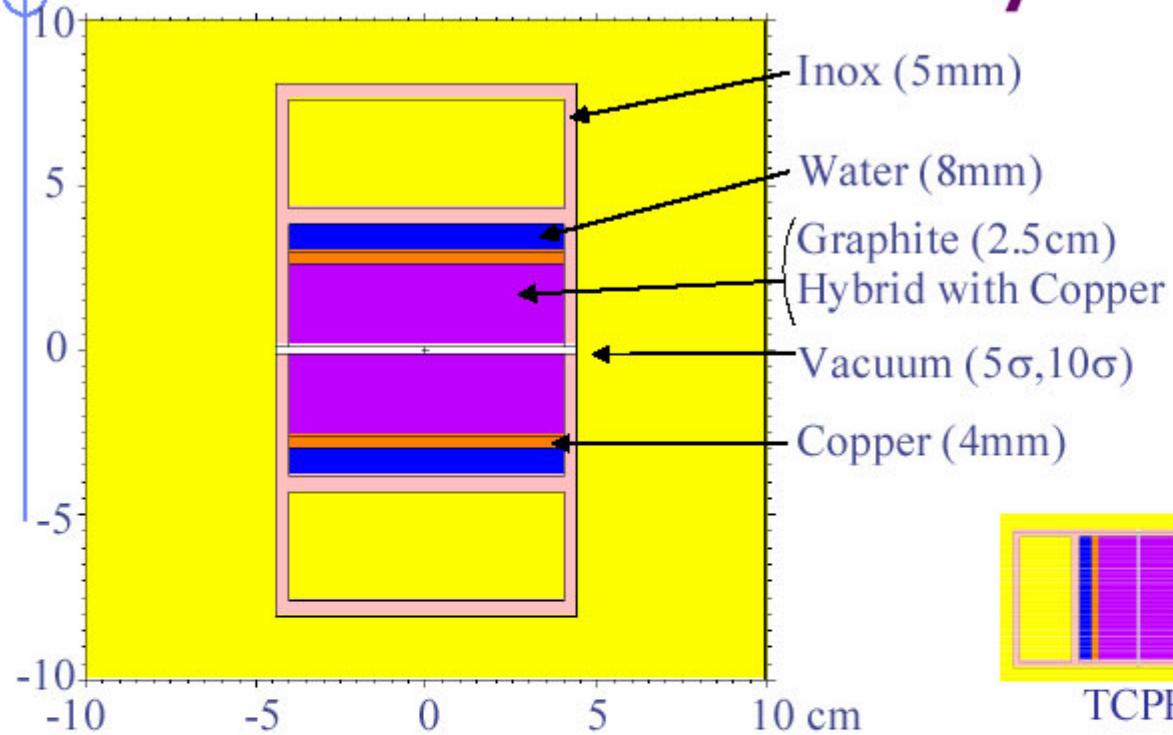
IR7 Geometry

V. Vlachoudis & A. Ferrari

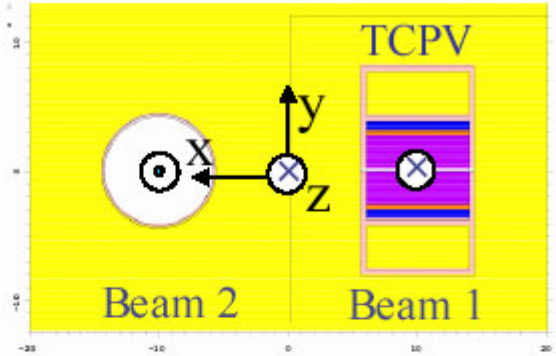


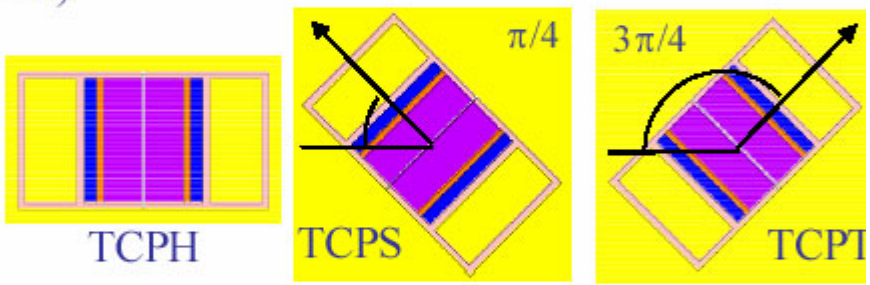
Collimator Geometry

V. Vlachoudis & A. Ferrari



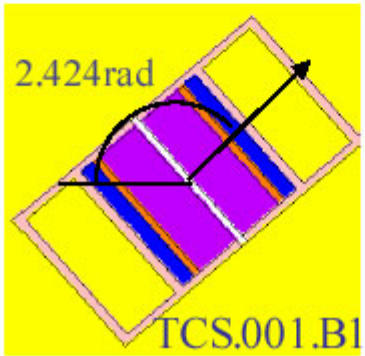
Primary Collimators

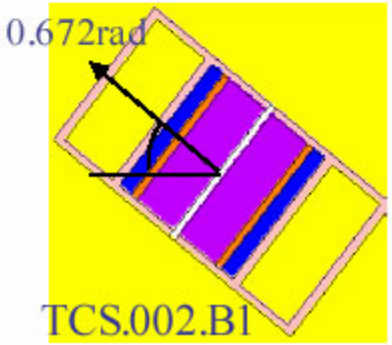




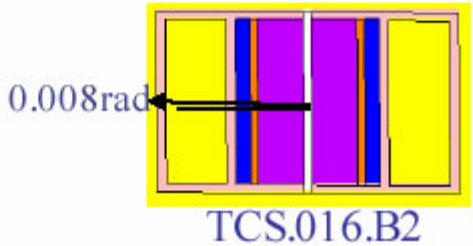
Length 20 cm

Secondary Collimators





Length 120 cm



Phase #1: Beam tube

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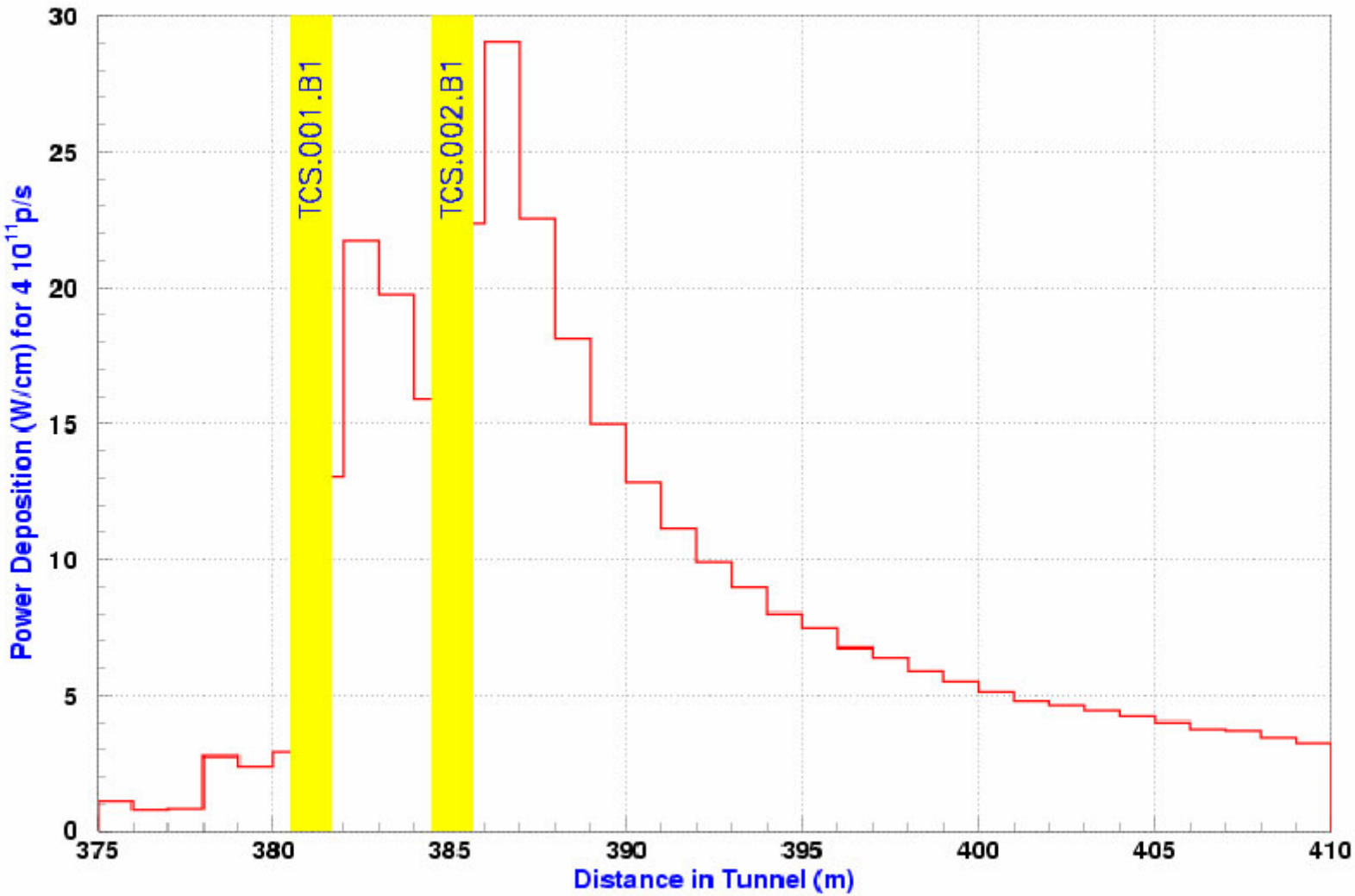

* Not weighted with the loss map

Phase #1: Power Distribution

- TCP1 Loss scenario
- Total power intercepted 233 kW (52 %)
-
- MBW
  - Iron: 21 kW, 9.5 kW
  - Copper 6 kW, 1.5 kW
- Beam Tubes
  - Beam1: 34 kW
  - Beam2: 2.4 kW
- Primary Collimators
  - TCPV: 10 W
  - TCPH: 290 W
  - TCPS: 700 W
  - TCPT: 1.7 kW
- Secondary Collimators
  - TCS.001.B1 12 kW
  - TCS.002.B1 27 kW
  - TCS.003.B1 245 W
- Motors
  - < 200 W

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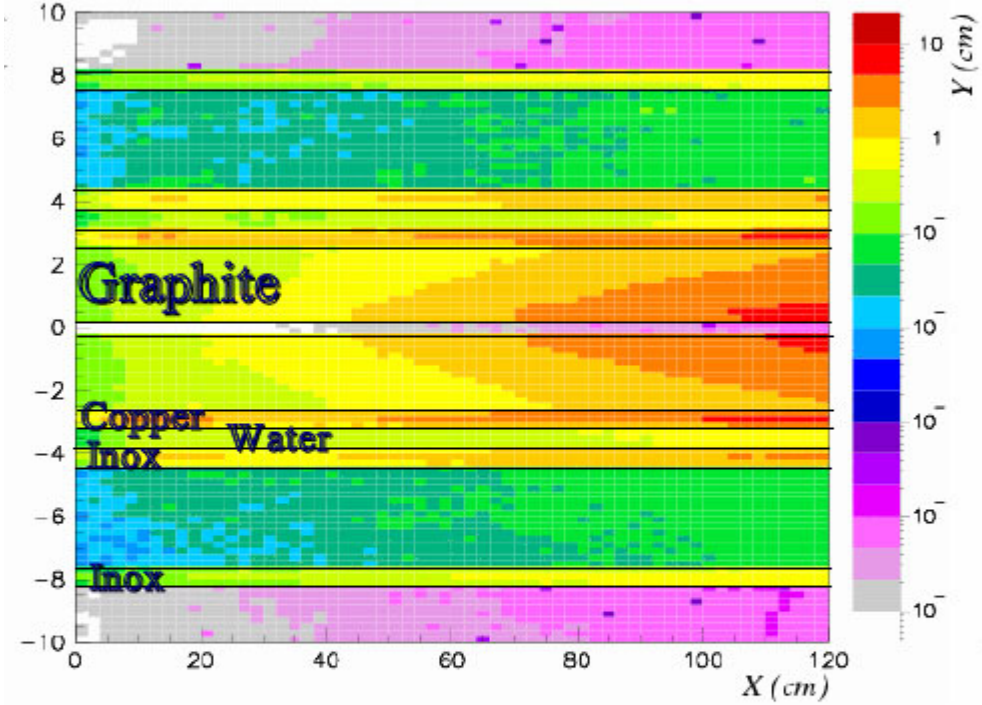
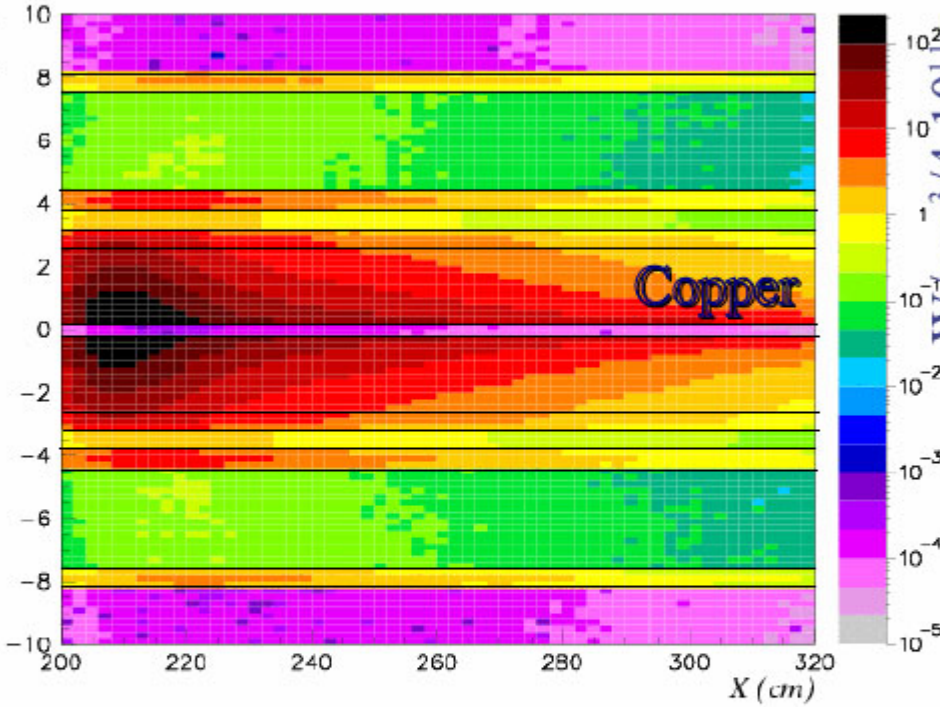
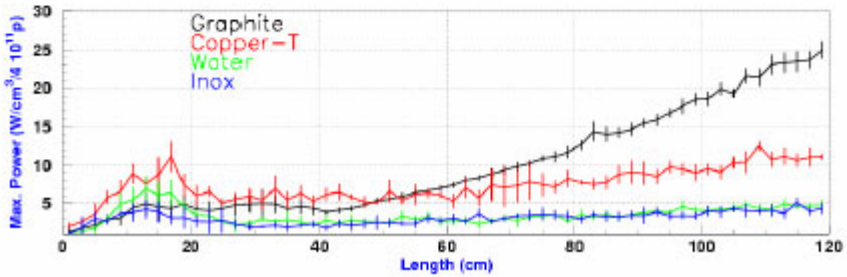
Phase #2: With Hybrid

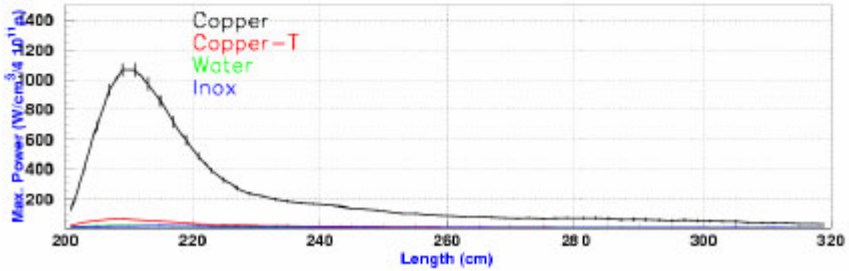
TCS.001.B1



TCSH.001.B1







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Phase #2: Power Deposition

Collimator	Element	GeV/p	%	kW/4e11 p	Total
TCS.001.B1	Graphite	2.77	0.54	7.50	14
	Copper-T	1.01	1.41	2.70	
	Water	0.2	1.69	0.50	
	Inox	1.22	0.77	3.30	
TCSH.001.B1	Copper	42.97	0.69	116.60	130
	Copper-T	1.71	0.50	4.70	
	Water	0.41	0.79	1.10	
	Inox	2.73	0.52	7.40	
TCS.002.B1	Graphite	1.06	1.98	2.90	5
	Copper-T	0.32	2.00	0.90	
	Water	0.07	1.29	0.20	
	Inox	0.44	1.42	1.20	
TCSH.002.B1	Copper	9.83	2.64	26.70	30
	Copper-T	0.35	1.90	1.00	
	Water	0.09	2.31	0.20	
	Inox	6.05E-001	2.03	1.60	
TCS.016.B2	Graphite	8.23E-003	8.45	0.00	0
	Copper-T	8.44E-003	9.38	0.00	
	Water	2.20E-003	4.92	0.00	
	Inox	2.14E-002	6.76	0.10	
TCSH.016.B2	Copper	1.66E-002	16.13	0.00	0
	Copper-T	2.94E-003	5.80	0.00	
	Water	1.13E-003	6.93	0.00	
	Inox	1.23E-002	4.03	0.00	

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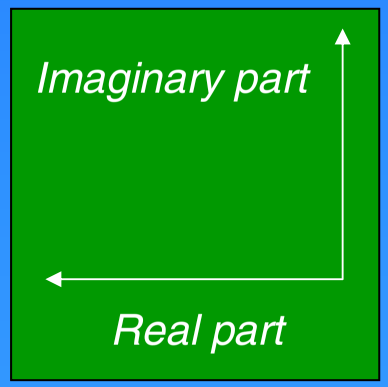
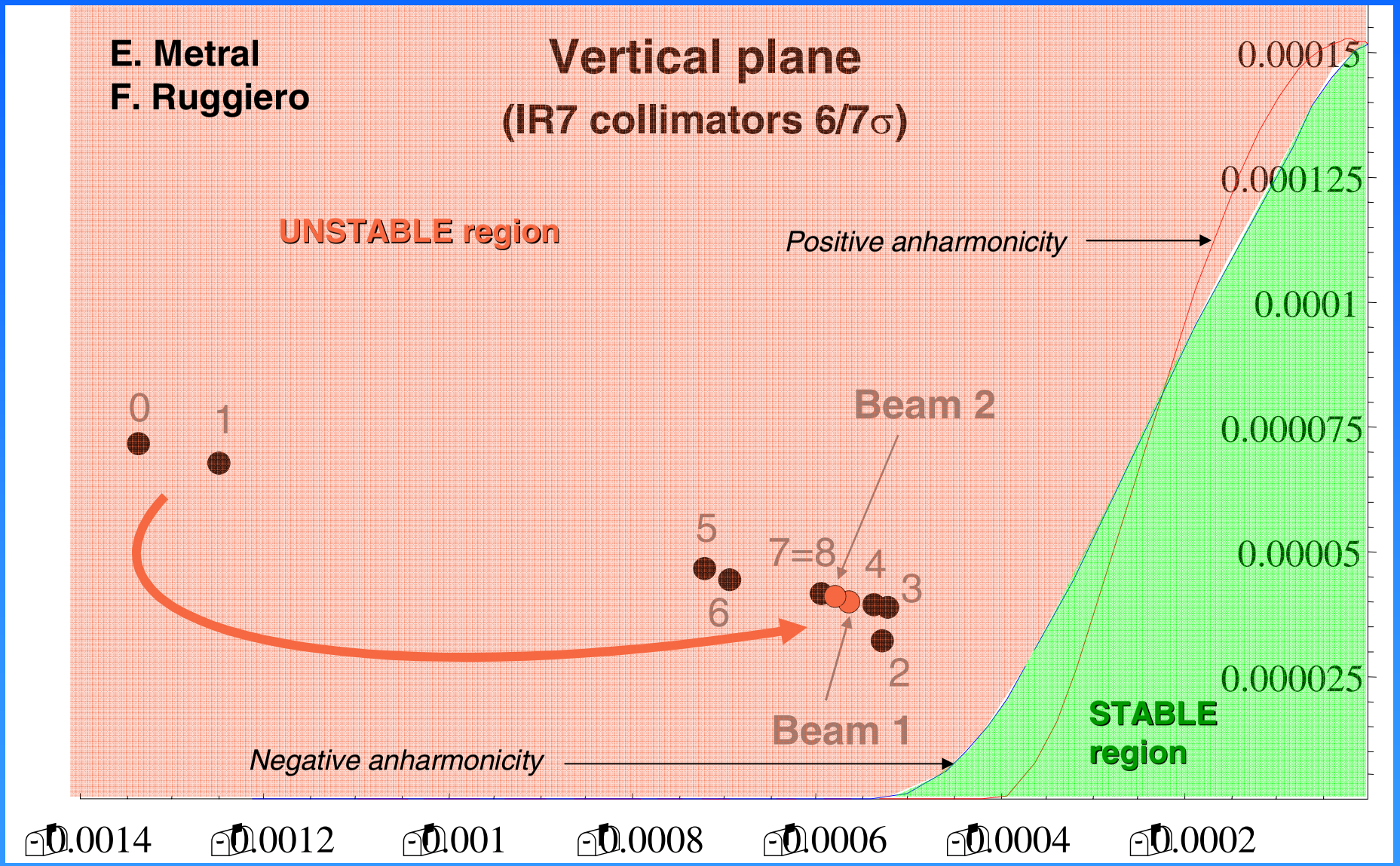
Comparing Impedance to LHC Limits

- Latest summary results by E. Metral & F. Ruggiero (in full agreement with L. Vos & H. Tsutsui)
- Limit at 450 GeV: Transverse damper.
- Limit at 7 TeV: Landau damping with maximum strength of octupoles.
- Observable: **Coherent tune shift for the most unstable coupled-bunch mode and head-tail mode 0**



Results assume:
Nominal bunch intensity and bunch spacing.
Maximum octupole powering with either sign.

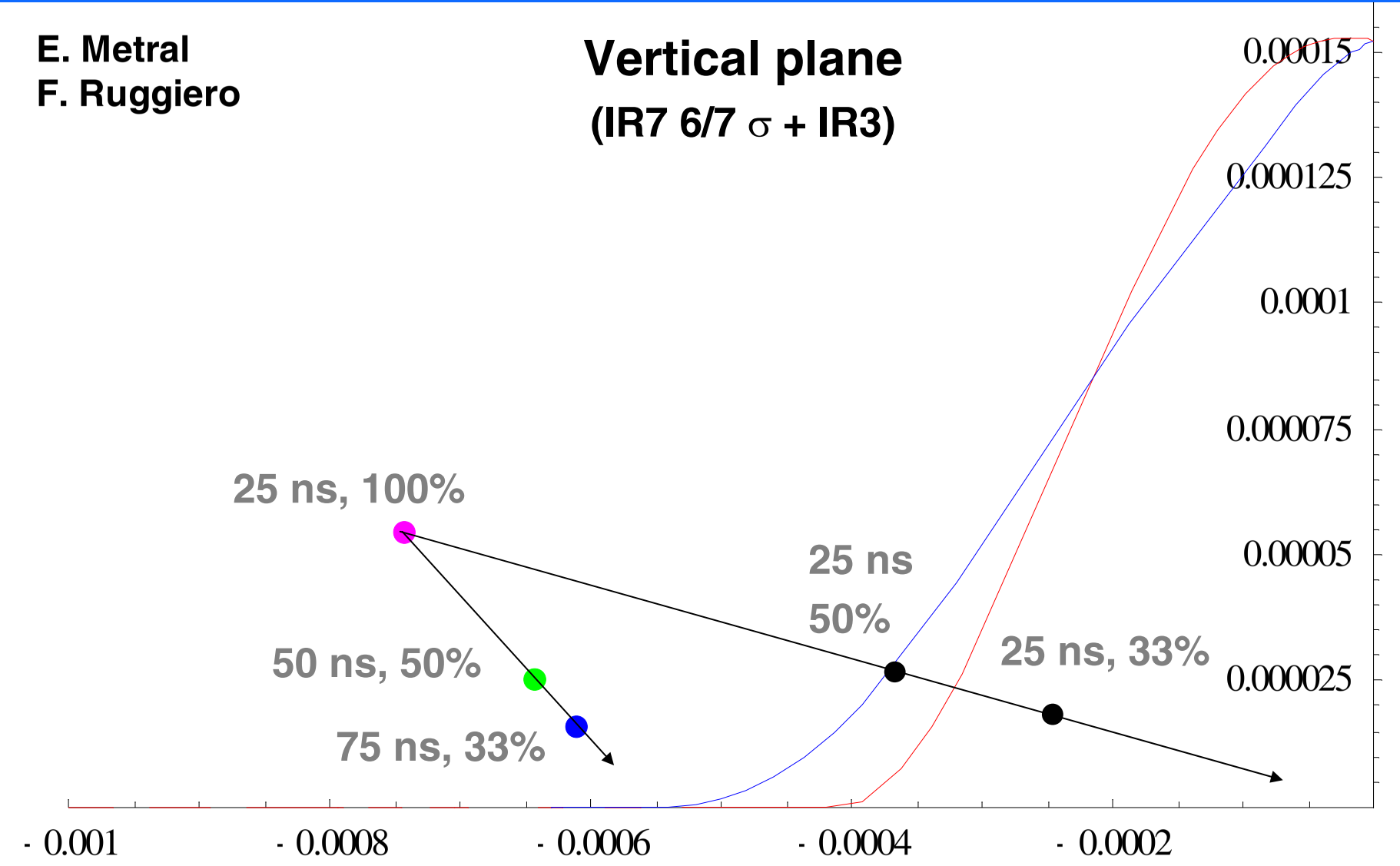
Stable and unstable regions



Observations

- With new IR7: Significant improvement in impedance achieved at all energies and all planes (about factor 2).
- Injection is less critical than top energy:
  ➔ Stability is assured by transverse damper even for old impedance!
- Vertical plane is more important than horizontal plane!
- With collimators at 6/7σ in unstable regime at top energy ➔ Limitation of intensity or β^*…
- With collimators at 7/8.2σ close to stable region…

Scaling with Intensity & Bunch Spacing



Scaling with Resistivity

E. Metral
F. Ruggiero

Vertical plane

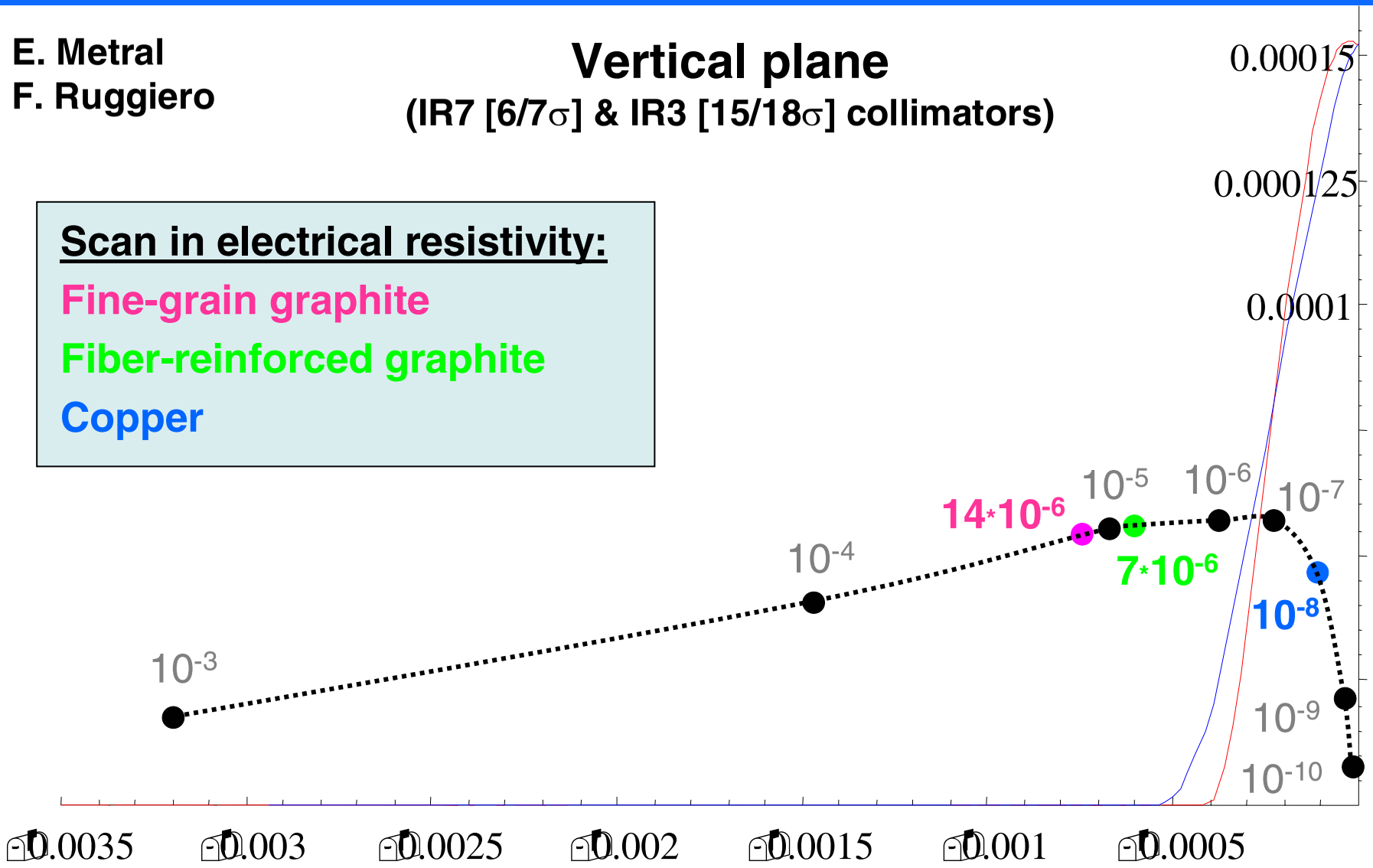
(IR7 [6/7σ] & IR3 [15/18σ] collimators)

Scan in electrical resistivity:

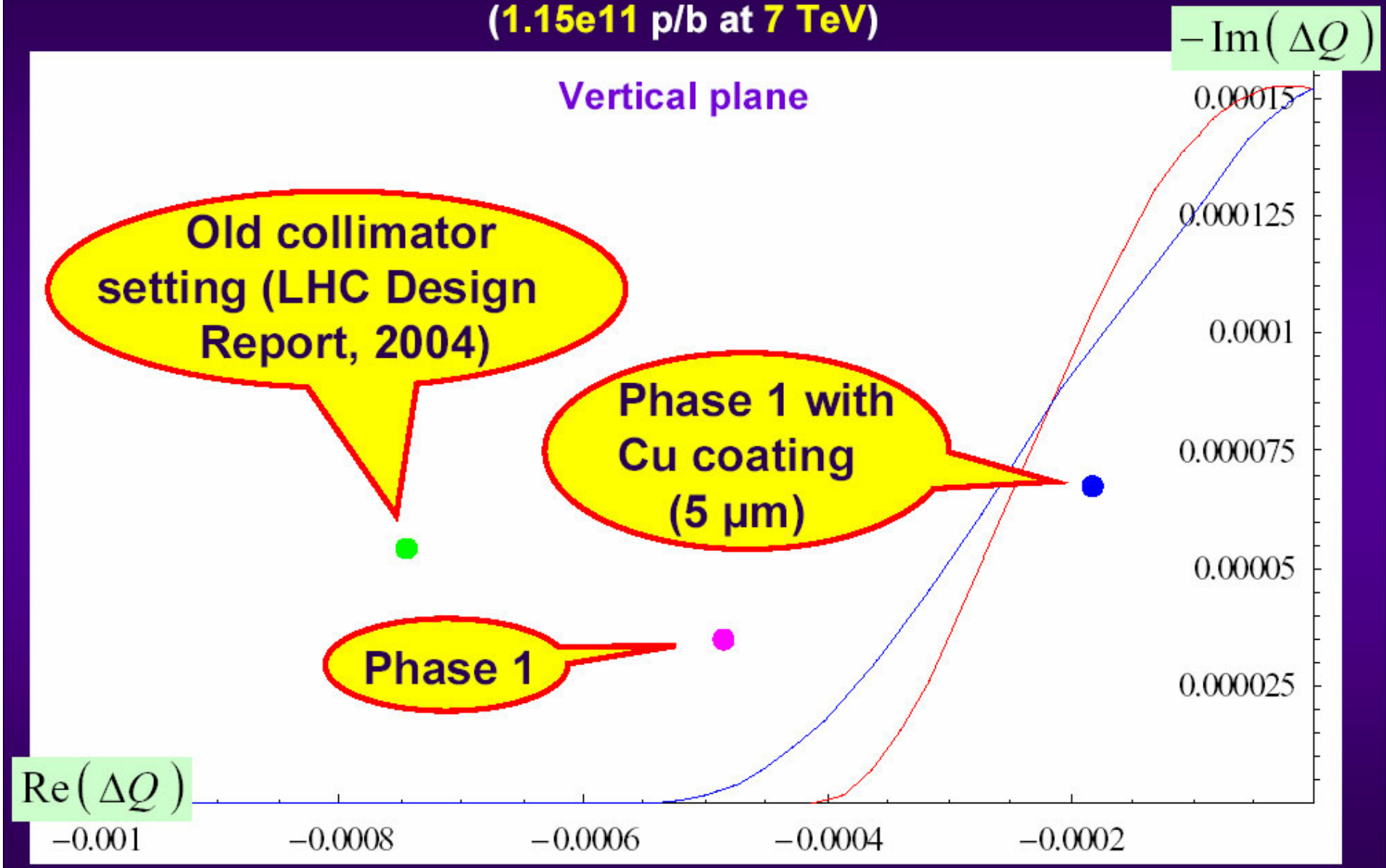
Fine-grain graphite

Fiber-reinforced graphite

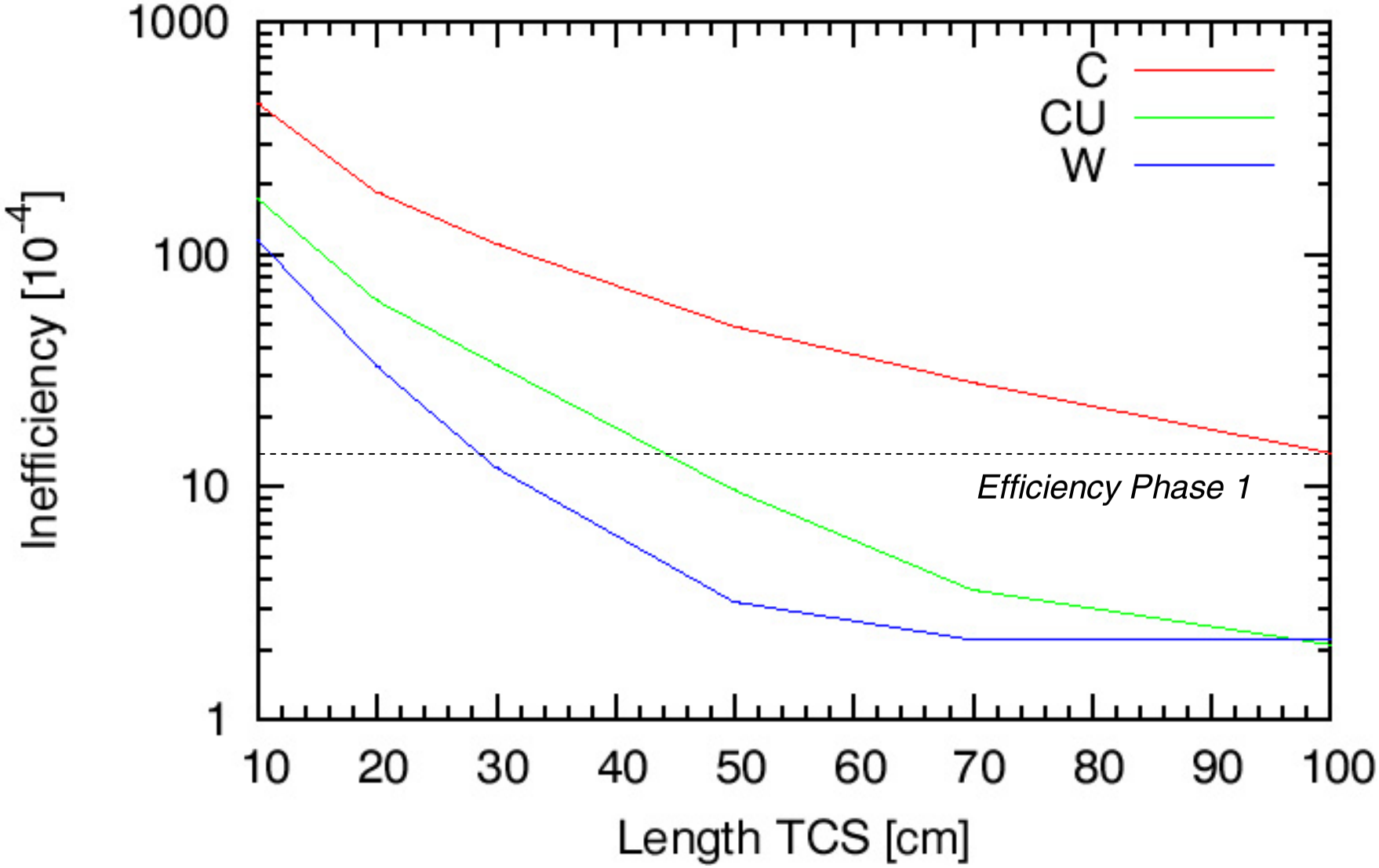
Copper



Stability diagram (maximum octupoles) and collective tune shift for the most unstable coupled-bunch mode and head-tail mode 0 (1.15e11 p/b at 7 TeV)



➔ Inefficiency



Phase 1 in our minds…

- Phase 1 will be ready for 2007 and will allow start-up and first physics runs! Maximum uptime with robust system!
- High collimator impedance will force us to run at impedance limit with full octupole powering (7TeV) or strong feedback action (injection). Nominal at 7TeV not guaranteed, ultimate is out. Limitation on bunch pattern.
- Surface flatness is difficult to be achieved and might impose higher beta* and lower intensities!
- Graphite is not an ideal UHV material.
- Cleaning efficiency seems marginally OK but without margin.
- Jaw material damage from radiation is unclear but possibly severe (collaboration with Kurchatov Institute Moscow).

Our main efforts & interests for phase 1

- Prototyping, test of components, series production, budget, controls.
- **Full showering and radiation studies (FLUKA, Mars).**
- SPS tests (robustness, impedance, set-up).
- Integration into machine (layout, infrastructure, absorbers, …).
- **Performance: Tracking with detailed 1m resolution (longitudinal) aperture model (new AP computing cluster).**
- **Operational models and procedures.**
- **Further beam tests.**

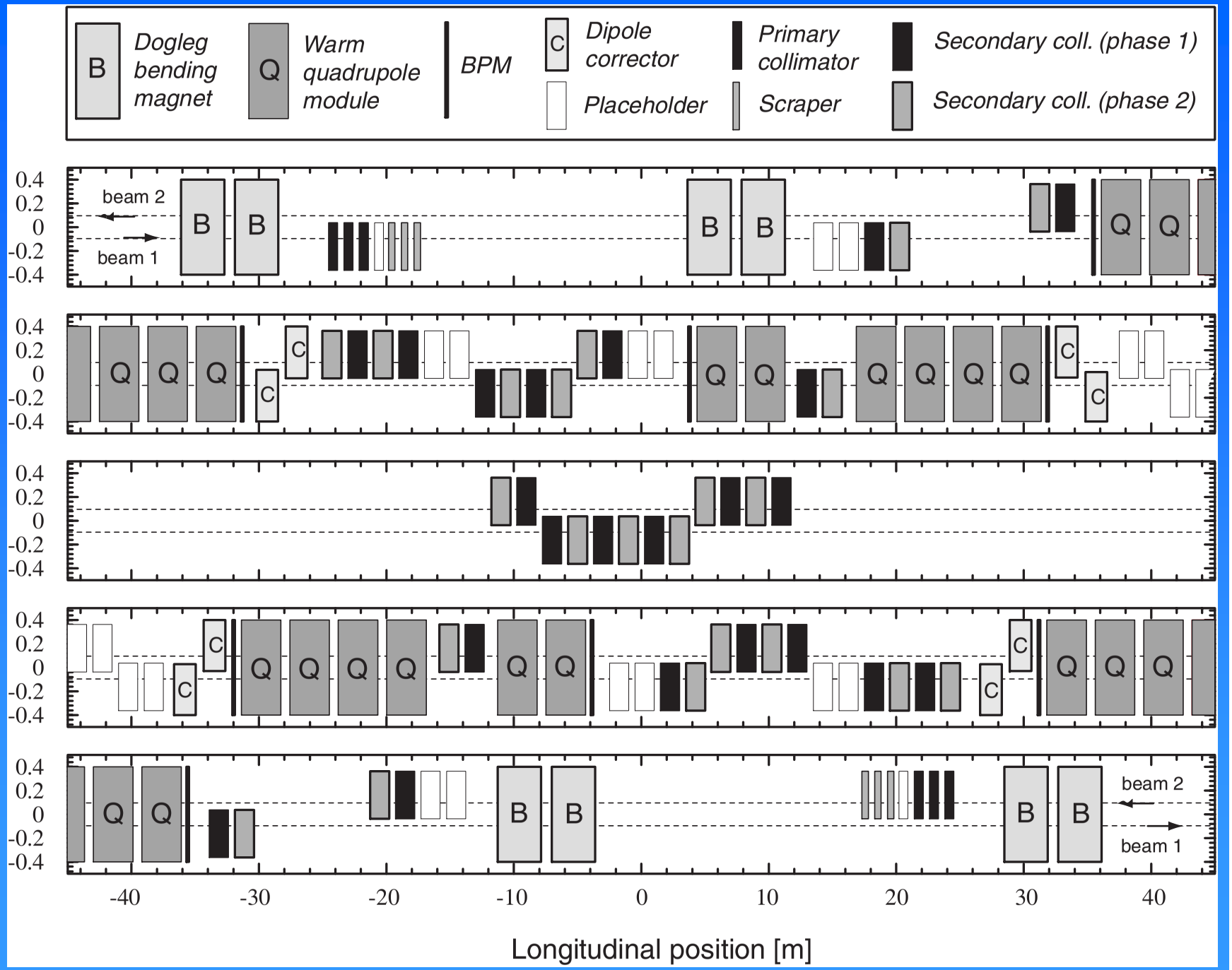
Review of phase 1

- **June 30th 14h30 – July 2nd 16h00 at CERN.**
- External committee review.
- Presentations on June 30th and July 1st are open to all interested colleagues.
- **If you are at CERN before EPAC: Please join the talks and the discussions.**
- Review will be on general concept (phase approach) and phase 1 implementation!
- Do not include details of phase 2 (side meeting or another specific meeting?).

Phase 2 in our minds…

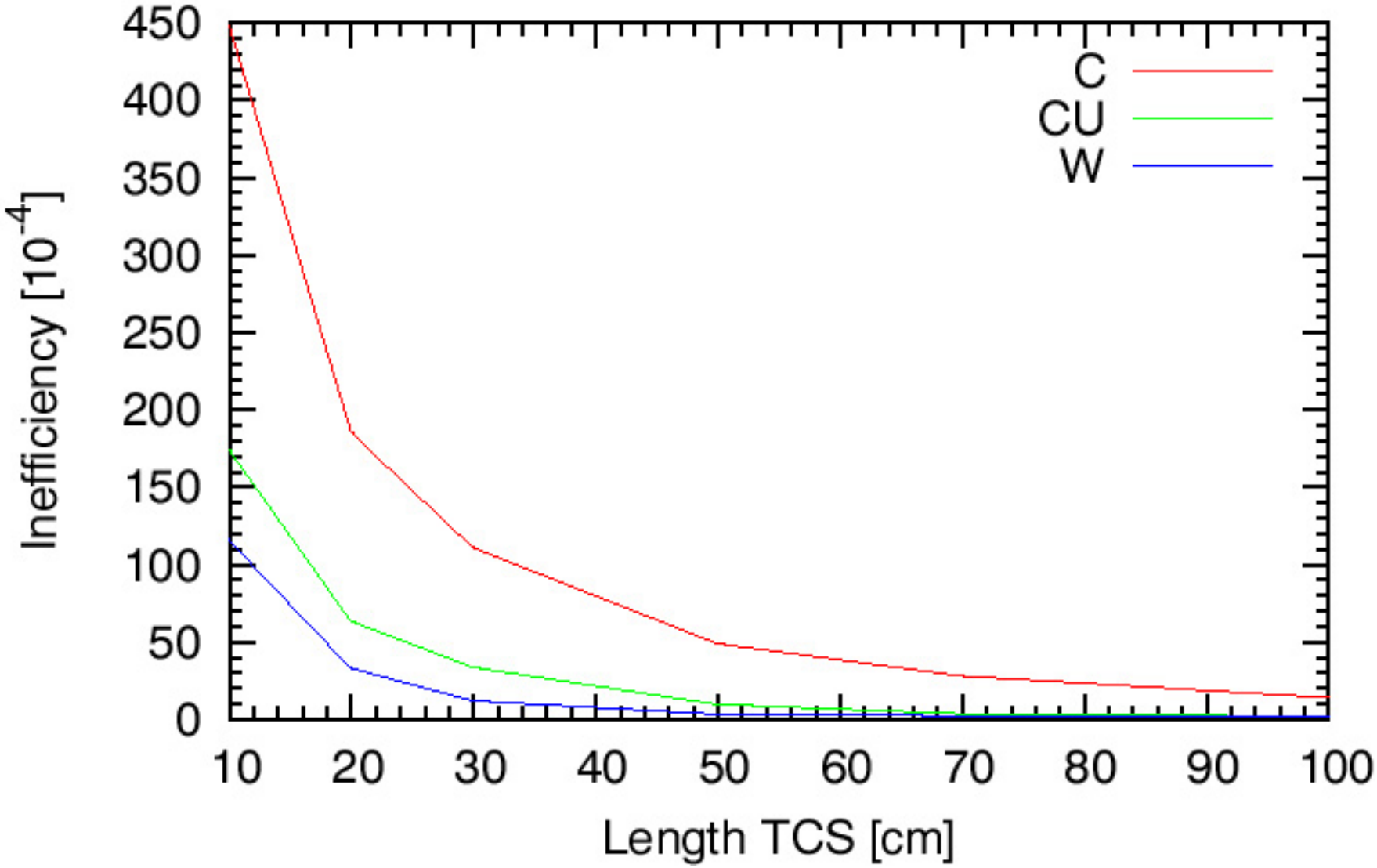
- Phase 2 will reduce the collimator induced impedance (metallic).
- Phase 2 will use a good vacuum material.
- Phase 2 will provide better absorption and lower inefficiency (higher Z and long or double components)!
- Phase 2 will achieve flatness tolerances (25 μm).
- Phase 2 will be less robust but only be used in stable conditions and will provide maximum in-situ spare surface (rotating collimator).

IR7


B Dogleg bending magnet
Q Warm quadrupole module
BPM
C Dipole corrector
Placeholder
Primary collimator
Scraper
Secondary coll. (phase 1)
Secondary coll. (phase 2)
beam 2
beam 1
0.4
0.2
0
-0.2
-0.4
-40
-30
-20
-10
0
10
20
30
40
Longitudinal position [m]

Collimation in LARP

- CERN is very happy about this involvement.
- We want to use all available expertise ➔ we are very open to all suggestions and help…
- We can support work/collaborations by sending people for visits (within limits):
  P. Sievers (senior engineer), S. Readily (fellow),
  G. Robert-Demolaize (PhD student).
- Can we define detailed scope, deliverables, and responsibilities?
- Some decisions are urgent already: Infrastructure for phase 2 collimators (cables, water, supports, …).


450
400
350
300
250
200
150
100
50
0
Inefficiency [10^-4]
10
20
30
40
50
60
70
80
90
100
Length TCS [cm]
C
CU
W