



New Opportunities in the Physics Landscape at CERN

PS2

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Plans for future injectors: Motivation

1. Improve reliability of injector chain for LHC era:

Ageing accelerators (PS is 49 years old!) operating far beyond initial parameters

⇒ need for new accelerators designed for the needs of SLHC

2. Main performance limitation:

Excessive incoherent space charge tune spreads ΔQ_{SC} at injection in the PSB (50 MeV) and PS (1.4 GeV) because of the high required beam brightness N/ε^* .

$$\Delta Q_{SC} \propto \frac{N_b}{\varepsilon_{x,y}} \cdot \frac{R}{\beta\gamma^2}$$

with N_b : number of protons/bunch

$\varepsilon_{x,y}$: normalized transverse emittances

R : mean radius of the accelerator

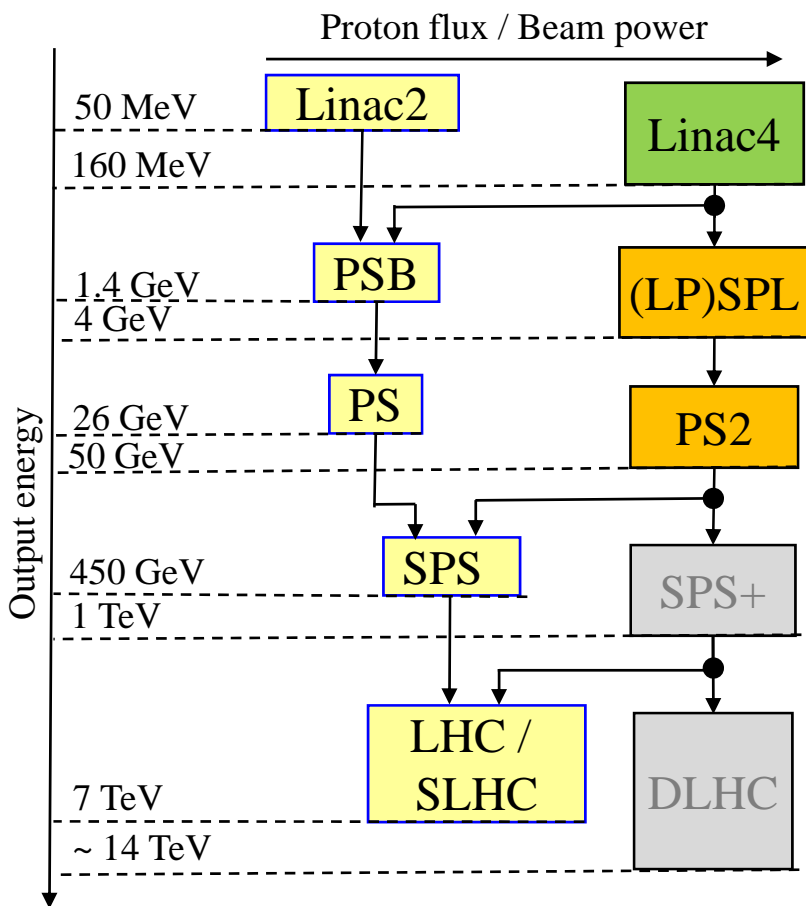
$\beta\gamma$: classical relativistic parameters

⇒ need to increase the injection energy in the synchrotrons

- Increase injection energy in the PSB from 50 to 160 MeV
- Design the PS2 (PS successor) with an acceptable space charge effect for the maximum beam envisaged for SLHC.
- Increase injection energy in the SPS from 25 to 50 GeV.



CERN injector complex upgrade - Overview



Linac4: H- Linac
(160 MeV)
(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS
(~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS
(50 to 1000 GeV)
SLHC: “Superluminosity” LHC
(up to $10^{35} \text{ cm}^{-2}\text{s}^{-1}$)
DLHC: “Double energy” LHC
(1 to ~14 TeV)

Stage 1: Linac4
- **construction 2008 – 2014**

Stage 2: PS2 and SPL: preparation of Conceptual Design Reports for
- **project approval mid 2012**
- **start of construction begin 2013**



PS2 design goals

- **For LHC operation**
 - Higher beam brightness within nominal transverse emittances
 - Flexibility for generating various bunch spacings and bunch patterns
 - Reduction of SPS injection plateau and LHC filling time
- **General design goals**
 - High reliability and availability
 - Simplification of operation schemes for PS2 and complete complex
 - Low beam losses in operation for PS2 and complete complex
 - Potential for future upgrades of the accelerator complex



Performance requirements and parameters

- **Starting point for the design is brightness (N/ε_n) for LHC beams**
 - Design goal: Twice higher brightness than “ultimate” 25ns beam with 20% intensity reserve for transfer losses
 - $4.0 \times 10^{11} \text{ppb} = 2 \times 1.7 \times 10^{11} \times 1.2$ in transverse emittances of $3 \mu\text{m}$
- **Injection energy**
 - Determined by the beam brightness of the LHC beam
 - Limiting the incoherent space charge tune spread at injection to below 0.2 requires
 - **4 GeV injection energy**
- **Extraction energy**
 - Injection into SPS above transition energy to reduce space charge effects
 - Higher energy gives smaller transverse emittances and beam sizes and therefore reduced losses
 - Potential for long-term SPS replacement with higher energy
 - **~50 GeV extraction energy**



PS2 machine size

- **Constraints from desired extraction energy ~50 GeV**
 - Iron dominated dipoles aiming at $B \leq 1.7$ T
 - **PS2 will have roughly twice PS size i.e. $R \sim 200$ m and $C \sim 1250$ m.**
- **Constraints from filling SPS for physics**
 - Complete filling of SPS circumference is desired for high intensity physics
 - Using a 5-turn multi-turn extraction scheme, similar to PS (2 x 5 turns):
 - **Ideal PS2 length is $1/5$ SPS = $11/5$ PS = 2.2 PS.**
- **Constraints from PS2-SPS synchronisation (rf cogging)**
 - $N \times h_{\text{PS2}} = K \times h_{\text{SPS}}$ is needed for correct synchronisation
 - **$(N/K) = 77/15$ is best choice (5 PS2 slightly shorter than the SPS.)**
 - h (200MHz SPS) = 4620, h (40MHz SPS) = 924, h (40MHz PS2) = 180
- **Optimum length for PS2 from above arguments**
 - $\text{PS2} = 15/77 \text{ SPS} = 15/77 * 11 \text{ PS} = 15/7 \text{ PS}.$
 - **1346.4 m circumference, 214.3 m average radius**



PS2 main parameters

Parameter	unit	PS2	PS
Injection energy kinetic	GeV	4.0	1.4
Extraction energy kinetic	GeV	20 - 50	13 - 25
Circumference	m	1346	628
Max. bunch intensity LHC (25ns)	ppb	4.0×10^{11}	1.7×10^{11}
Max. pulse intensity LHC (25ns)	ppp	6.7×10^{13}	1.2×10^{13}
Max. pulse intensity FT	ppp	1.0×10^{14}	3.3×10^{13}
Linear ramp rate	T/s	1.5	2.2
Repetition time (50 GeV)	s	~ 2.5	1.2/2.4
Max. stored energy	kJ	800	70
Max. effective beam power	kW	320	60

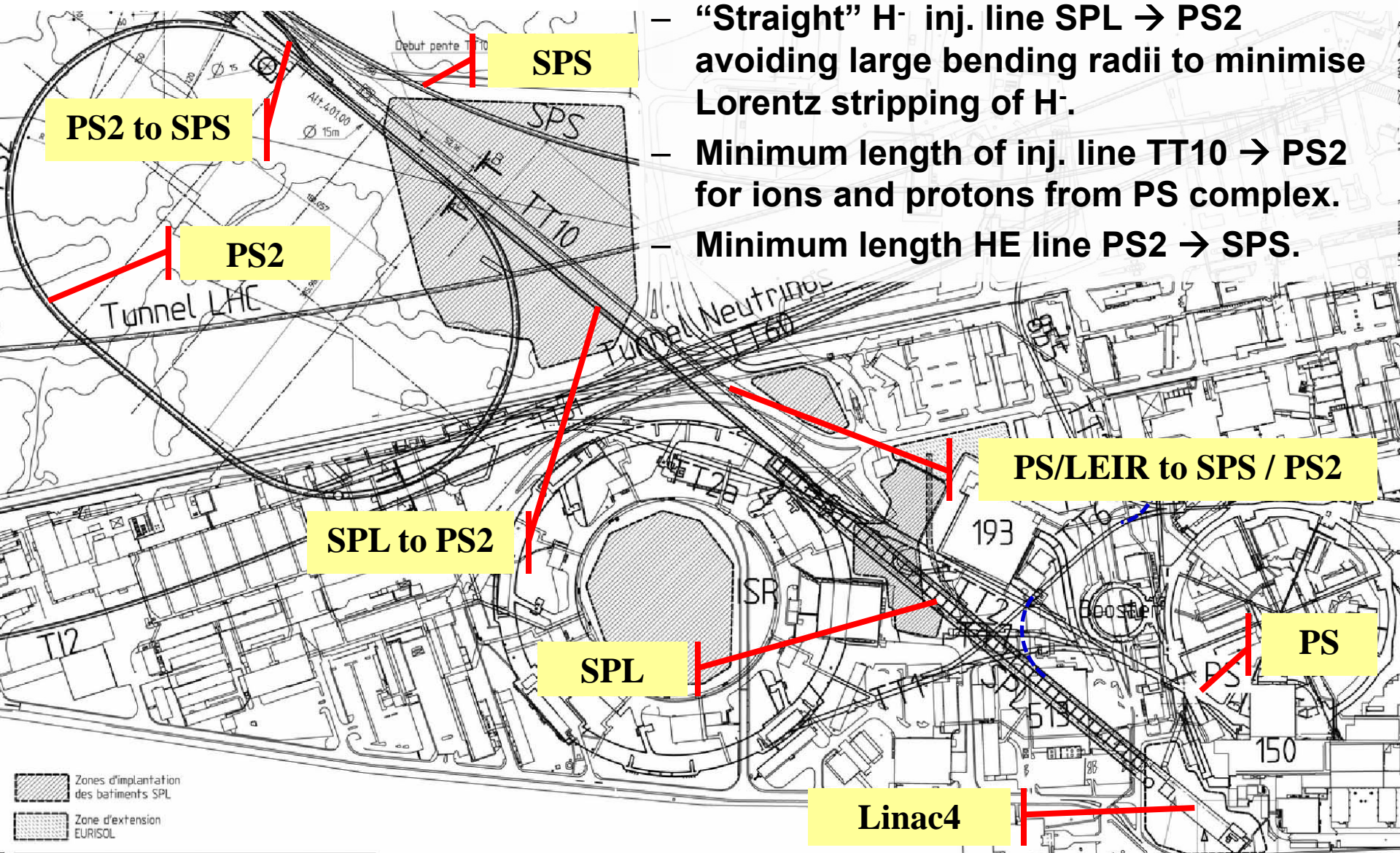


PS2 integration and machine shape

- **Integration requirements**
 - H⁻ Injection from LPSPL
 - Injection of ions from LEIR via TT10 transfer line
 - Injection of protons from PS complex via TT10 for commissioning
 - Extraction towards the SPS via TT10
- **Region at end of TT10 transfer line from PS to SPS was identified as optimum location for PS2**
- **Machine shape**
 - Optimisation leads towards a racetrack shape of the machine
 - Two compact arcs and two long zero-dispersion straight sections
 - One long straight section for all injection and extraction systems
 - Second long straight section dedicated for RF and collimation



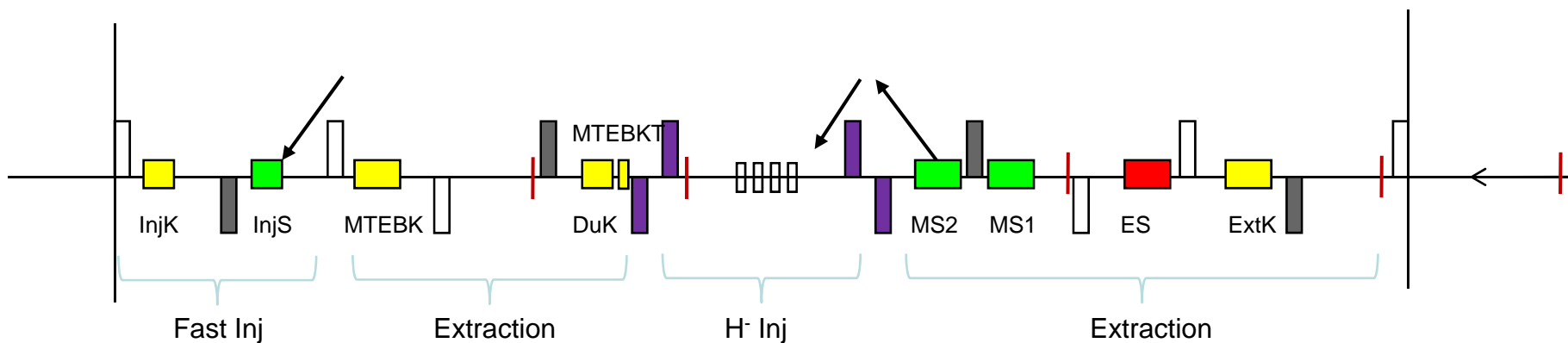
PS2 integration





Long injection/extraction straight section

- Regular FODO similar to arc with ~ 90 deg hor phase advance.
- Split-triplet insertion in the centre, to house H- injection



- **Common usage of single channel for all extractions**
 - Fast extraction to SPS (LHC beams)
 - Multi Turn Extraction (MTE – five turns) to SPS for fixed target physics
 - Slow extraction (if required) for physics at PS2
 - **May have impact on machine design (2 or 3-fold symmetry)**
 - **Minimisation of equipment and machine impedance and space requirements**



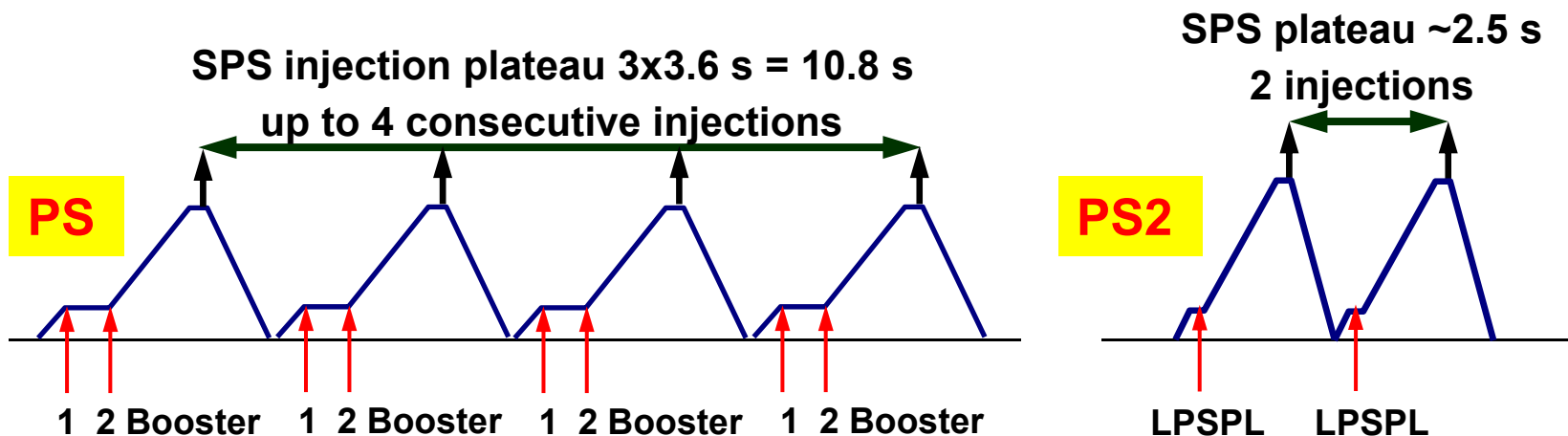
PS2 RF system

- **RF system requirements:**
 - Proton acceleration: revolution frequency ratio : 1,024 (3% tuning)
 - Pb54+ ions revolution frequency ratio in PS&PS2 with injection directly from *upgraded LEIR* at 6.7 Tm: 2,1 (210% tuning range)
 - All LHC bunch spacings and patterns and beams for SPS operation
- **Preferred RF option**
 - Tuneable 40 MHz system (18 – 40 MHz)
 - Motivated by (LP) SPL 40 MHz chopping that will allow direct painting of any LHC bunch pattern up to 40 MHz already at injection
 - **Minimizes rf gymnastics in PS2 and RF systems (→impedance reduction, space requirements, simplified operation)**
 - Feasibility of tuneable 40 MHz system (>octave) to be demonstrated
 - R&D program for PS2 RF system being launched.
- **Characteristic beam structure of 40 MHz (20 MHz from PS2)**
 - Fast extraction:
 - <6E11/bunch, 25 ns bunch spacing, <168 bunches (<1E14 total)
 - <1.2E12/bunch, 50 ns bunch spacing, <84 bunches (<1E14 total)



LHC beam from PS2

- **Example 25 ns beam from LPSPL – PS2:**
 - PS2 will provide “twice ultimate” LHC bunches with 25 ns spacing
 - Bunch train for SPS twice as long as from PS
 - Only 2 injections (instead of 4) from PS to fill SPS for LHC
 - PS2 cycle length 2.5 s instead of 3.6 s for PS
 - Reduces SPS LHC cycle length by 8.3 of 21.6 s ($3 \times 3.6 - 1 \times 2.5$)

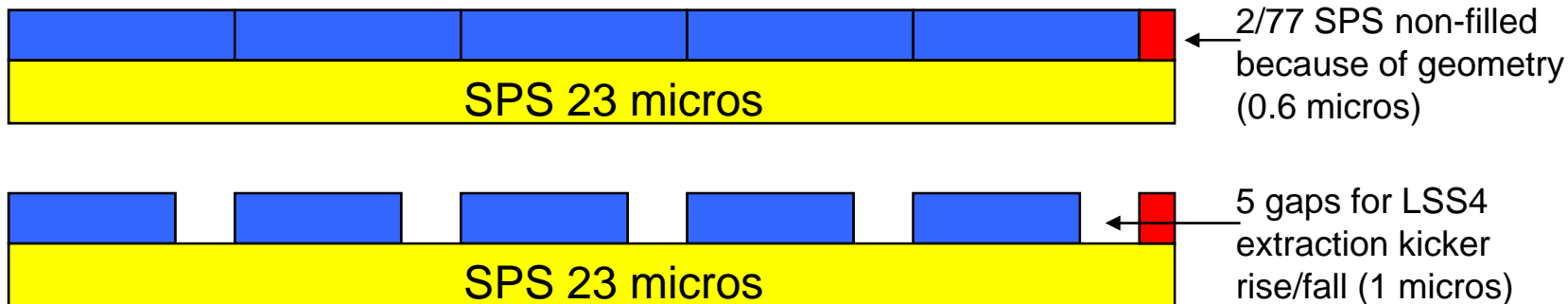




High intensity physics beam for SPS

- PS2 provides up to twice line density of PS high-intensity beam
- Twice circumference gives up to ~4 times more intensity in total
 - ~1.0E14 per PS2 cycle (~1E14 with a longer kicker gap)
- Five-turn extraction will fill SPS with single shot instead of two from PS
 - Twice more intensity in SPS via twice higher line density.
 - No injection flat bottom in the SPS (two shot filling from PS presently)
- Clean bunch to bucket transfer PS2 40 MHz to SPS 200 MHz (cf. LHC)
 - ~6E11 protons per PS2 40 MHz bucket → 1.2E11 in every fifth SPS 200 MHz bucket (extraction kicker gap by leaving buckets unfilled at PS2 injection)

$$\text{PS2} = 15/7\text{PS} = 15/77 \text{ SPS}$$





Summary

- **PS2 main parameters are defined, based on LHC requirements**
- **Design optimised for integration in the existing and future CERN accelerator complex**
- **Preferred options for lattice, RF concept, injection and extractions layout and implementation have been identified**
- **Decision on PS2 experimental area is needed urgently to decide on integration and machine layout**
- **Goal is to provide a conceptual design report for approval by mid 2012 and project start begin 2013**

- **Thanks to all PS2 WG members and all colleagues in LARP and in other labs for contributing to the design study**