Feasibility study of the distribution of 4x1 MW beam power onto the 4-horn system of the EUROnu SPL Super Beam

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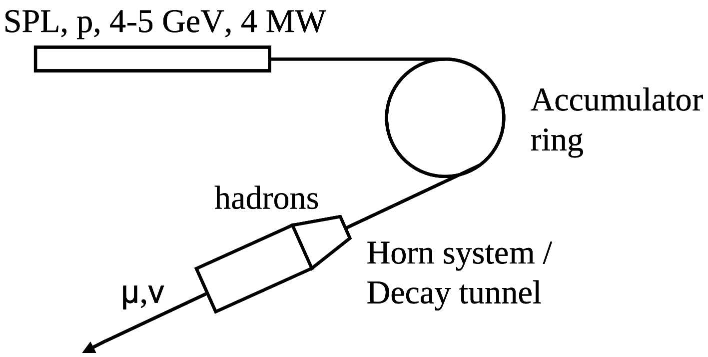
Neutrino Beams & Instrumentation (NBI),
CERN, Nov. 8, 2012

EUROν: Super Beams (WP2)

The Work Package 2 addresses the issues concerning the proton energy and the beam profile specific to neutrino beams



Use of a proton driver (4MW mandatory), an accumulator, a target and the hadron collector:

- Design study based on the Superconducting Proton Linac (SPL) at CERN

Use of four targets (instead of one):

- To decrease the power dissipated and then minimize the radiation issues
- To reduce stress on target via lower frequency (12.5 Hz)

Main task of this present work: Define an optical system to ensure the beam distribution onto the 4 targets of the horn system

SPL/accumulator: what we know

SPL

• Use of the High Power Super Conducting Proton Linac (HP-SPL) under study at CERN
• Essential element of the staged approach towards renewing the CERN proton injector complex
• The current design studies foresee a beam power of 4 MW at 50 Hz repetition frequency with protons of about 4.5 GeV kinetic energy and a pulse duration of about 400 μs for neutrino physics applications
• Pulse duration of the proton beam delivered on the SPL-Super Beam target-horn station ≤ 5 μs to limit the energy stored in the magnetic field generated by the pulsed current of the horn
• For this reason an additional accumulator ring is required interfacing the SPL and the target-horn station

Parameters	SPL
Energy	4.5 GeV
Beam power	4.0 MW
Rep. rate	50 Hz
Average pulse current	40 mA
Peak pulse current	64 mA
Chopping ratio	62 %
Beam pulse length	0.6 ms
Protons per pulse for PS2	1.5×10^{14}
Beam duty cycle	2.0 %
Number of klystrons (LEP)	14
Number of klystrins (704 MHz)	57
Peak RF power	219 MW
Average power consumption	38.5 MW
Cryogenics av. Power consumption	4.5 MW
Cryogenic temperature	2.0 K
Length	534 m

Parameters of the HP-SPL*

Accumulator

• Dedicated design studies exist only for the Neutrino Factory
• Requires a combination of accumulator and compressor ring (to achieve a bunch length of 2 ns rms after compression)
• For the SB the accumulator ring is sufficient
• A 6-bunch per pulse option is most suited: allows the lowest values of the local power distribution inside the target
• Circumference of the ring 318.5 m*

**Feasibility Study of Accumulator and Compressor for the 6-bunches SPL based Proton Driver*, M. Aiba, CERN-AB-2008-060-B1

Beam switchyard (SY)

Energy	4.5 GeV
Beam power	4 MW
Protons per pulse	1.1 x 10^{+14}
Rep. rate	50 Hz
Pulse duration	3.2 μs
Beam shape	Gaussian
Emittances rms	3 π mm mrad**

Target length	4.5 GeV
Target radius	4 MW
Beam shape	Gaussian
Rep. rate / line	12.5 Hz
Pulse duration	3.2 μs
Sigma*	4 mm

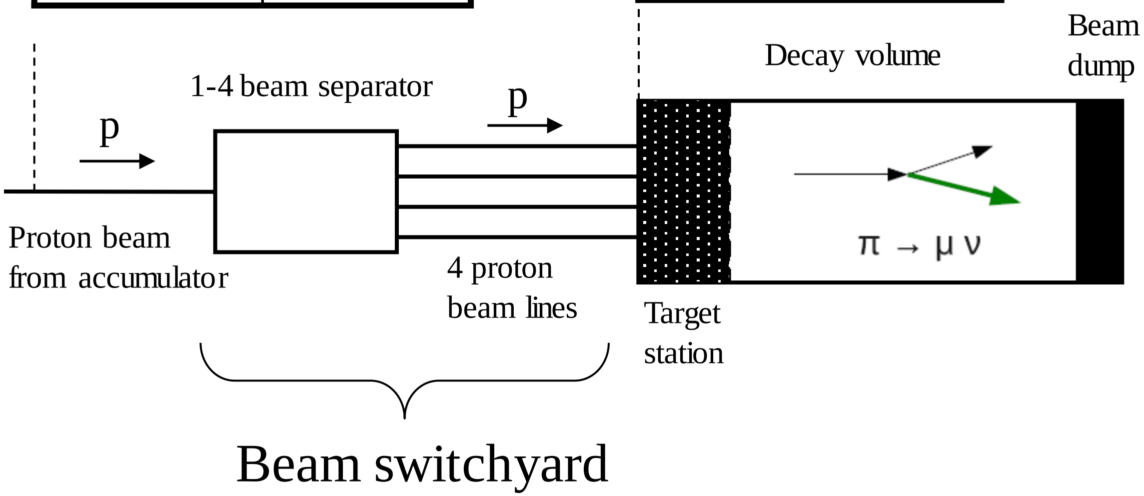
$$B \cdot \rho = \frac{1}{q \cdot c}\sqrt{E_k (E_k + 2E_0)}$$

kinetic energy rest energy

Beam rigidity:

16.16 T.m (4 GeV)

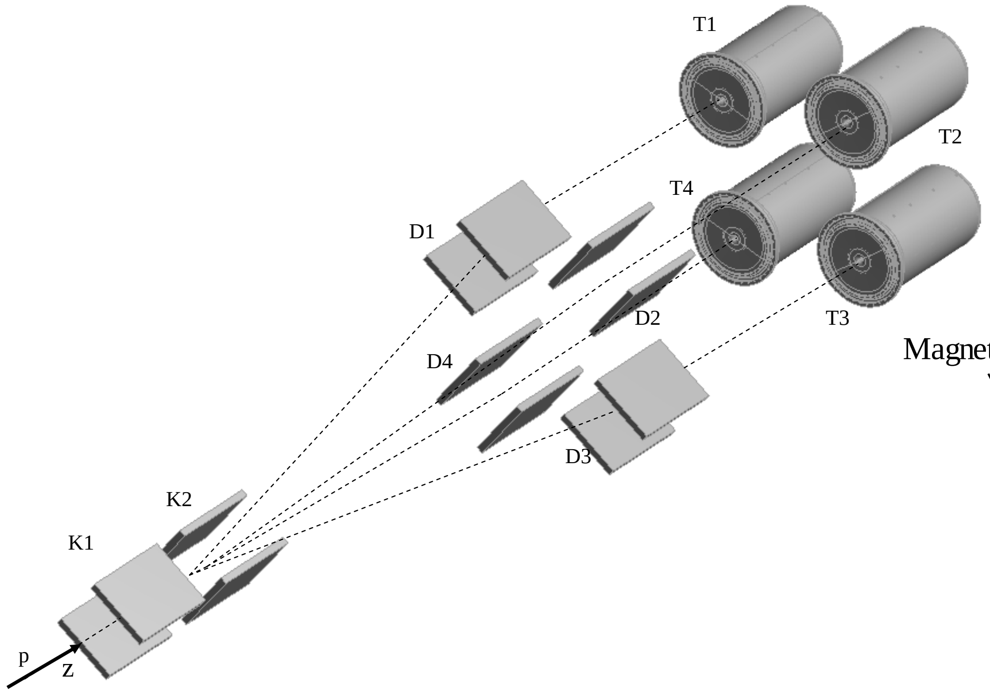
17.85 T.m (4.5 GeV)



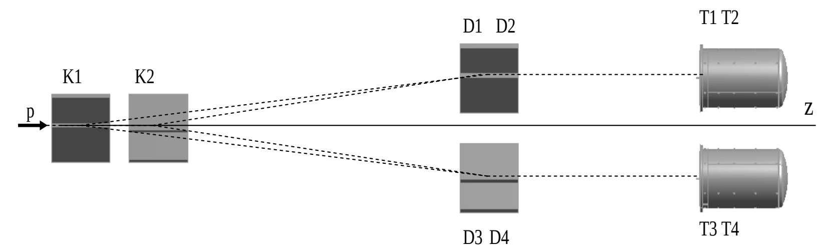
The target and horn for the SPL-based Super-Beam: preliminary design report, C. Bobeth, M. Dracos, F. Osswald, EUROnu WP2 Note 11-01

***Feasibility Study of Accumulator and Compressor for the 6-bunches SPL based Proton Driver, M. Aiba, CERN-AB-2008-060-B1*

SY: Principle



oblique view



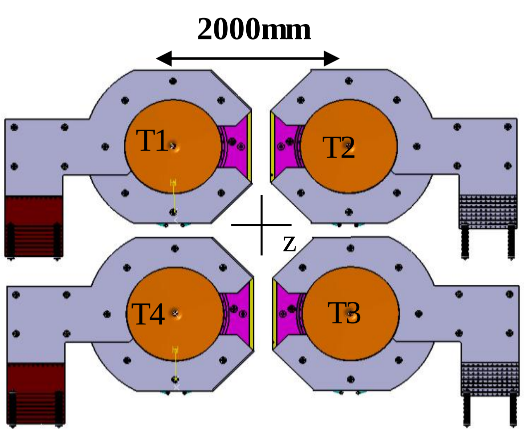
side view

Magnetic field (T) — Angle of deflection (rad)

$$B = \frac{\sin(\alpha)}{0.2998 \cdot L_{eff}} \cdot E_k$$

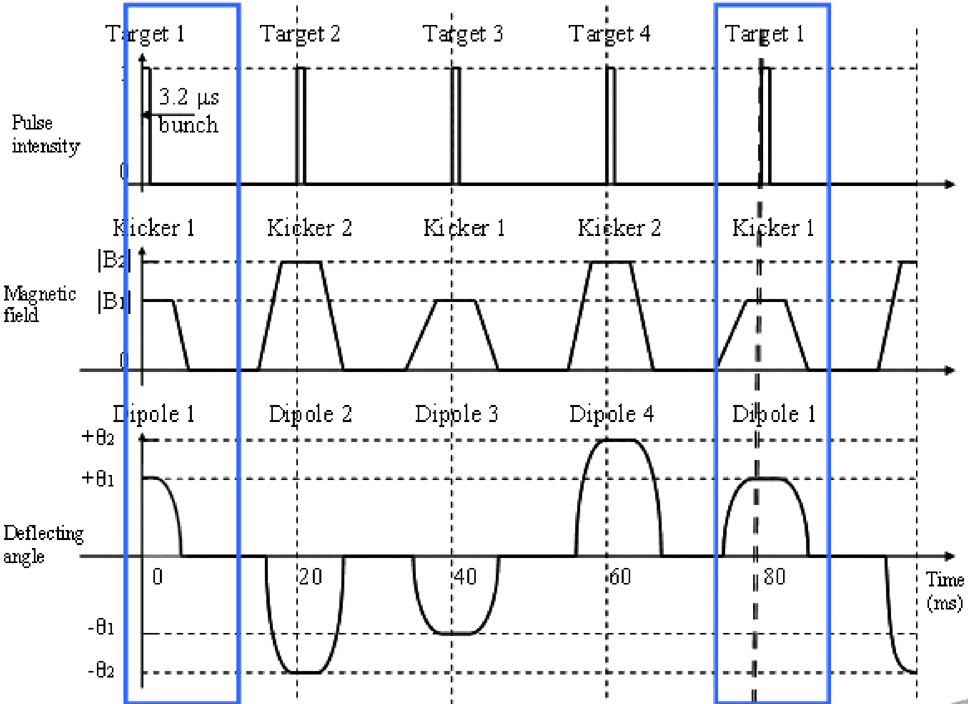
Magnetic length (m) — Kinetic energy (GeV)

>>KEY PARAMETER<<

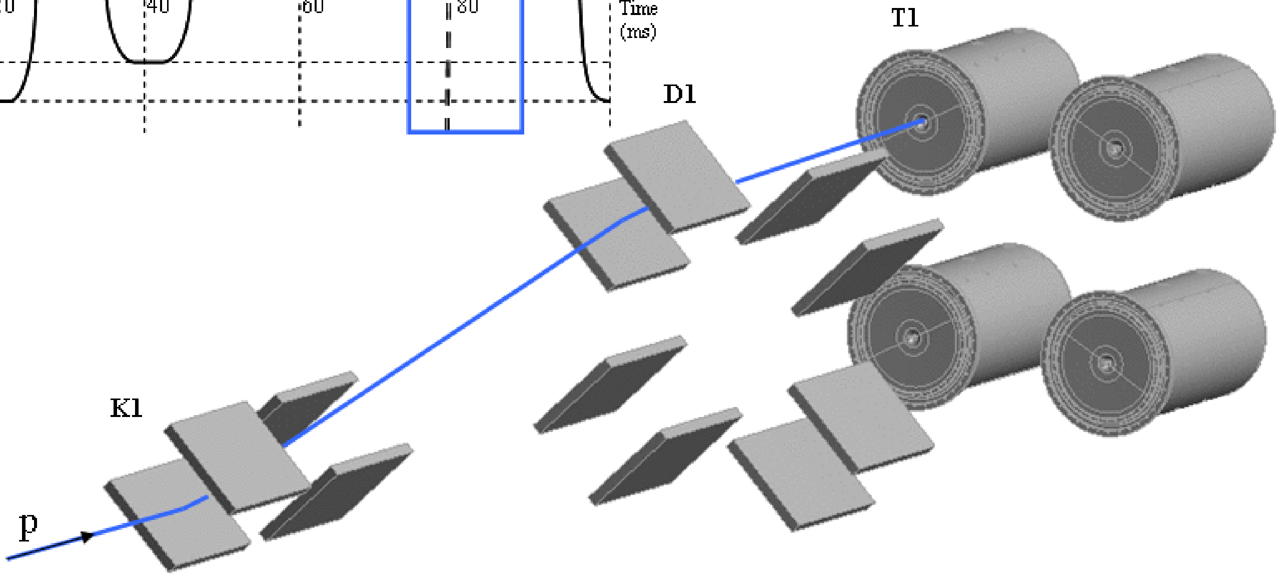


- Use of 2 bipolar kickers (or bipolar pulsed magnets): ± 45° rotation wrt the z axis
- K1 (K2) deflects to D1 and D3 (D2 and D4)
- Need of 1 compensating dipole per beam line (1 angle for each target): Apply a symmetry in the system

SY: Operation mode



Repetition rate:
50/4 = **12.5 Hz**



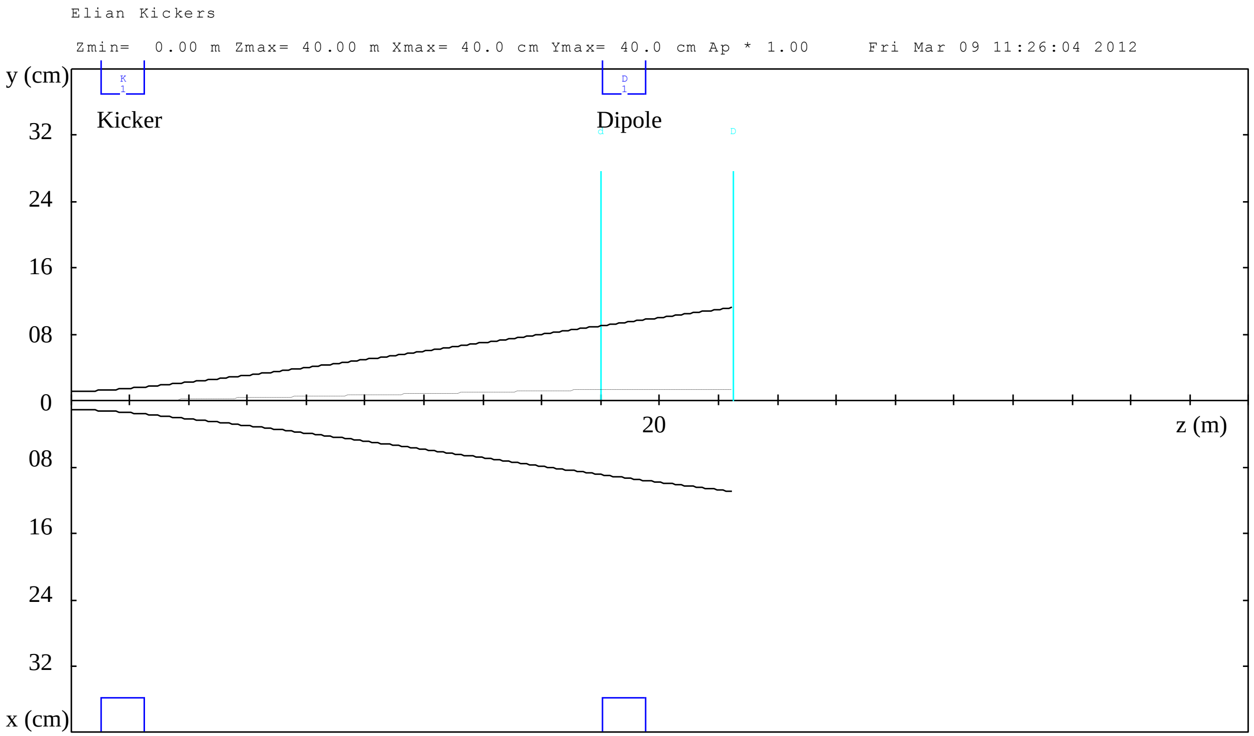
SY: Beam optics investigations

Configuration
Kicker – Dipole - Target

Simulations done with TRANSPORT code**

		s (m)	B (T)	Eff. length (m)	Half aperture (cm)	Beam radius at element (cm) rx	ry	disp. r16 (cm/%)
Kicker	**K**	1.75	0.83*	1.5	37	1.73	1.73	0.06
Dipole	**D**	18.8	-0.83*	1.5	37	9.71	9.82	-1.40
Target	**T**	22.5	x	x	x	**11.06**	**11.31**	-1.38

**83mrad deflection angle*



Transverse beam envelop (1 beam line)

- Radius of the beam at target location 7 times greater than the original size (target radius: 1.5cm)
- High dispersion term value (1.38 cm/%)

Need to design a beam focusing system !!

=

Addition of quadrupoles

***PSI Graphic Transport Framework by U. Rohrer based on a CERN-SLAC-FERMILAB version by K.L. Brown et al*

SY: Beam focusing

Aim and wanted conditions at target:

- Beam waist at the middle of each target (σ = 4mm)
- Beam circular cross section, Gaussian distribution

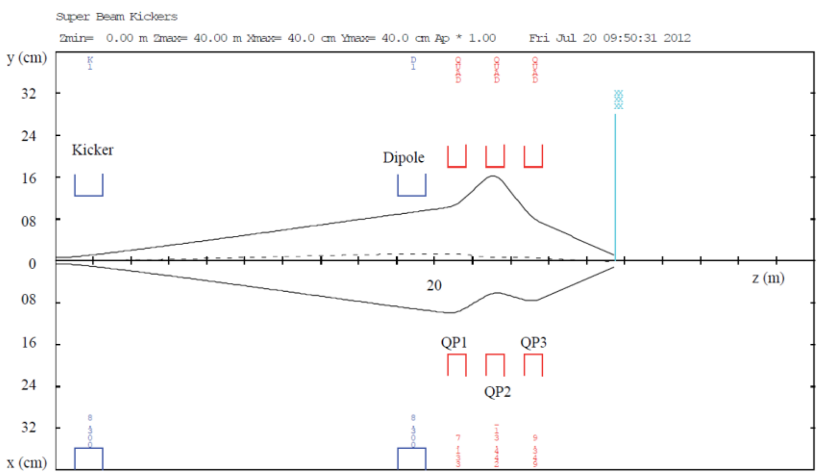
Several possible configurations studied with TRANSPORT:

1-	K-Q-Q-D-T	Two quadrupoles located between the kicker and the dipole,
2-	K-Q-Q-Q-D-T	Three quadrupoles located between the kicker and the dipole,
3-	K-D-Q-Q-Q-D-T	Three quadrupoles located between the dipole and the target,
4-	K-Q-Q-Q-D-Q-Q-Q-T	Three quadrupoles located between the kicker and the dipole and 3 between the dipole and the target

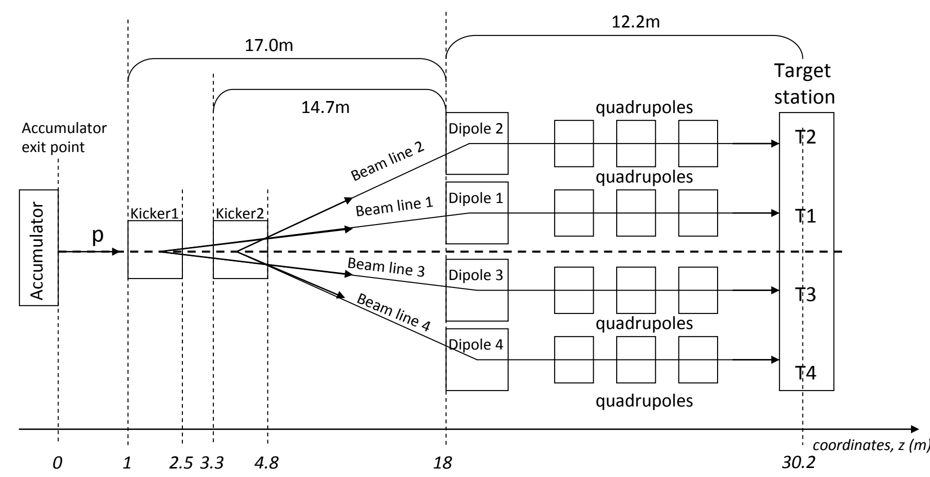
K stands for kicker
Q stands for quadrupole
D stands for dipole
T stands for target

SY: Beam focusing

Suitable solution up to now: 3 quadrupoles between the dipole and the target station



Beam envelopes (1 beam-line)



Total volume 960m^3

	Kicker1	Dipole1,3	Kicker2	Dipole2,4
Field strength (T)	0.83	0.83	0.96	0.96
Angle of deflection (mrad)	±83.0	-	±96.0	-
Magnetic length (m)	1.5	1.5	1.5	1.5
Aperture H/V (mm/mm)	250/350	250/250	250/600	250/250
Total intensity (kA)	115.6	82.6	152.6	95.4

	Quadrupole1	Quadrupole2	Quadrupole3
Field gradient (T/m)	0.71	1.34	0.93
Aperture radius (mm)	180	180	180
Magnetic length (m)	1	1	1
Function	F	D	F
Total intensity (kA)	20.3	38.4	26.6

Summary of the physical parameters

SY: modes

• **Failure of 1 target**, rep. rate becomes 16.6 Hz for each target (same intensity):
Power of the incoming beam becomes 1.33 MW instead of 1MW (still tolerable for targets)
Tolerance on the field errors of the optical elements: 1%.

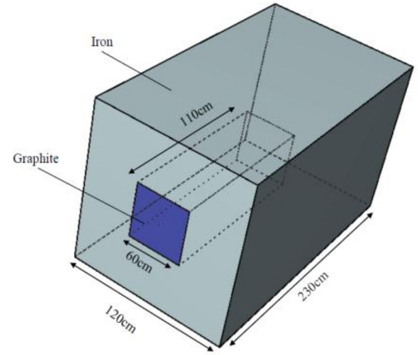
Abnormal conditions

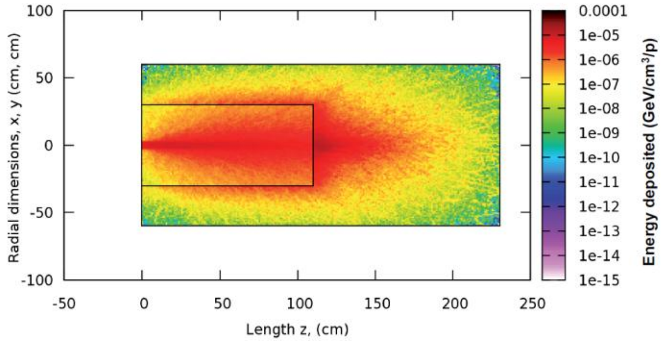
• **The failure of a second target** aborts the experiment:
2 working targets not sufficient for the physics
2MW not tolerable for each target (=radiation safety issues)

• Any **dysfunction or failing** magnet aborts the experiment
Risk of having the beam hitting magnets or not centred/focussed onto the target (= safety issues)
Addition of beam dumps and instrumentations after the pair of kickers and after each dipole to manage safety

Failure modes

Preliminary beam dump design (FLUKA*)

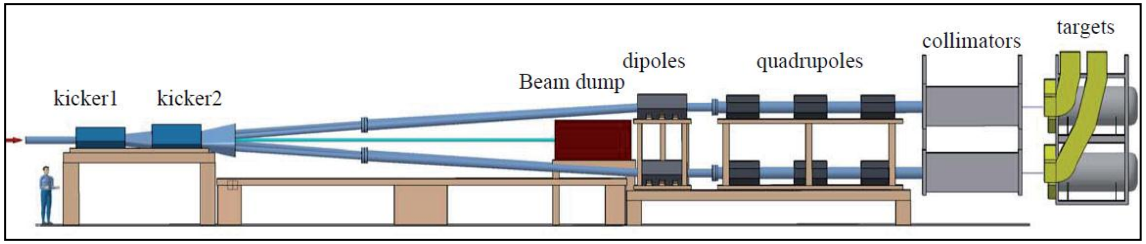




98% of the beam stopped by the dump:
- 45% in C and 53% in Fe (remaining 2% stopped by concrete material)
- Peak of the energy absorbed: $1.2\text{x}10^{-4}$ GeV/cm^3/p (Fe material)

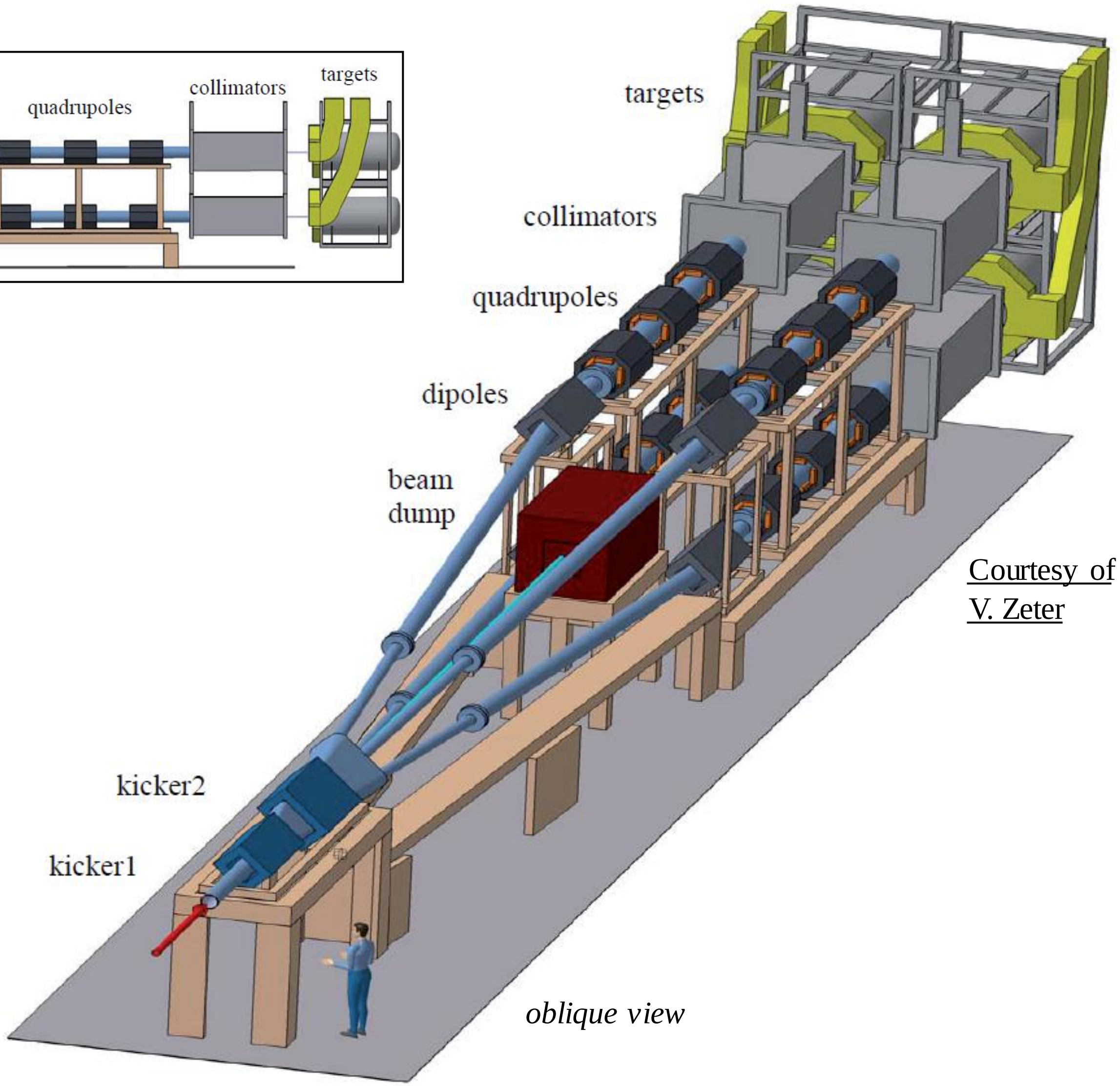
**The FLUKA code: Description and benchmarking*, G. Battistoni, S. Muraro, P.R. Sala, F. Cerutti, A. Ferrari, S. Roesler, A. Fasso`, J. Ranft, Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6--8 September 2006, M. Albrow, R. Raja eds., AIP Conference Proceeding 896, 31-49, (2007)
FLUKA: a multi-particle transport code, A. Ferrari, P.R. Sala, A. Fasso`, and J. Ranft, CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773

Beam Switchyard



side view

Preliminary layout



<u>Courtesy of V. Zeter</u>

oblique view

Additional instrumentations

Additional beam instrumentations if required:

• Beam collimation up stream the kicker 1 to cut off any eventual halo of the beam when leaving the accumulator

• At this stage of the feasibility study no precision exists on the position, the dimensions and the aperture of such collimator yet (Any alignment tuning or remote control to be defined if required

• A consequent variation of the energy of the proton beam coming from the SPL-accumulator may induce chromatic focusing errors within the system (addition of sextupoles may be required for correction)

• Addition of:

- Beam monitors to measure the transverse position of the beam (avoid the beam from not hitting the centre of the targets)
- Collimators to suppress any eventual halo from the beam

Thank you for your attention

Parameters of the accumulator

Parameters	**Value**
Energy	4.5 GeV
Relativistic γ	6.32907
Number of bunches	6
Beam size, σ	2 mm
Transverse emittances (rms)	3π.mm.mrad
Total bunch length	120 ns
RMS momentum spread (dp/p)	0.863 x 10^{-3}
Circumference	318.448 m
Average β function (β_x, β_y)	20,20 m
Momentum compaction, α_0	0.0249643
Nominal tune, Q_x/Q_y	7.77, 7.77
Natural chromaticity, Q'_{nat}	-8.4, -7.9
2^{nd} order momentum compaction, α_1	4.68
Beam pipe half-height	50 mm