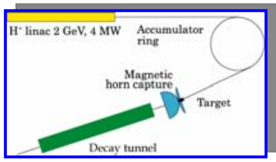
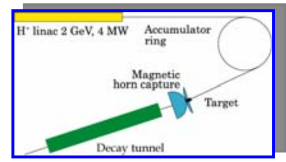
Challenges and Progress on the SuperBeam Horn Design



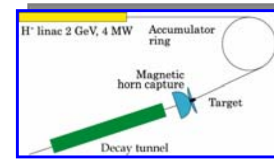
Marcos DRACOS
IN2P3/CNRS Strasbourg

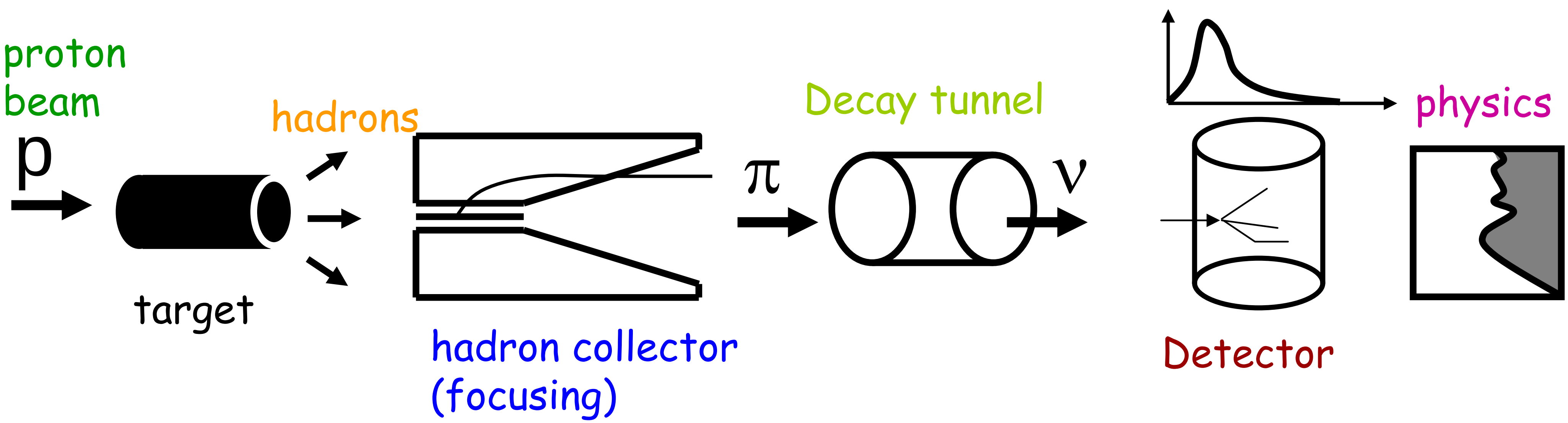
Super-Beam Studies in Europe



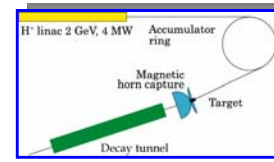
- Super Proton Driver at CERN (SPL)
- Target and collector integration
- Hadron Collector
- Pulser
- Conclusion

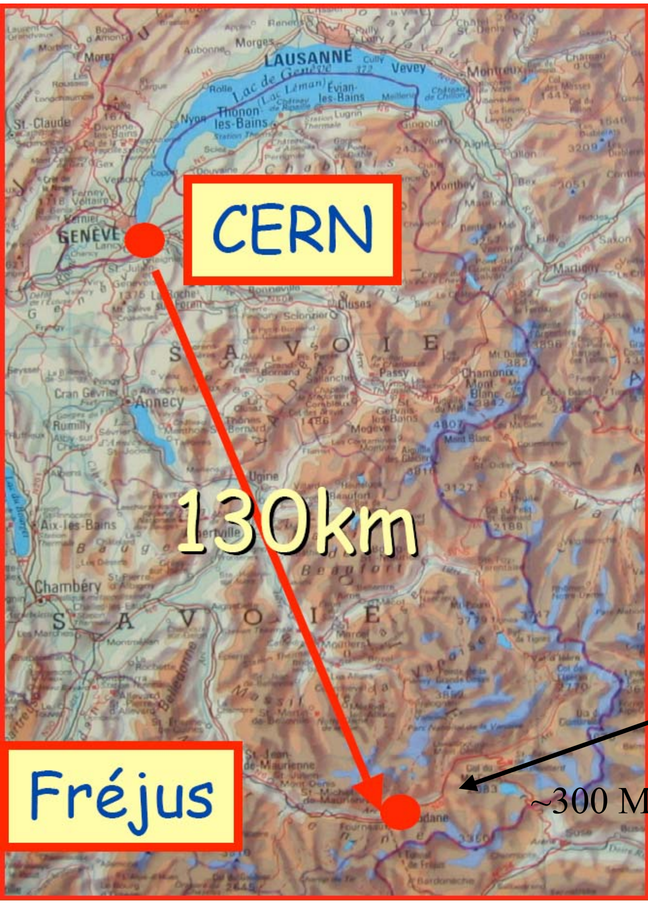
Conventional Neutrino Beams

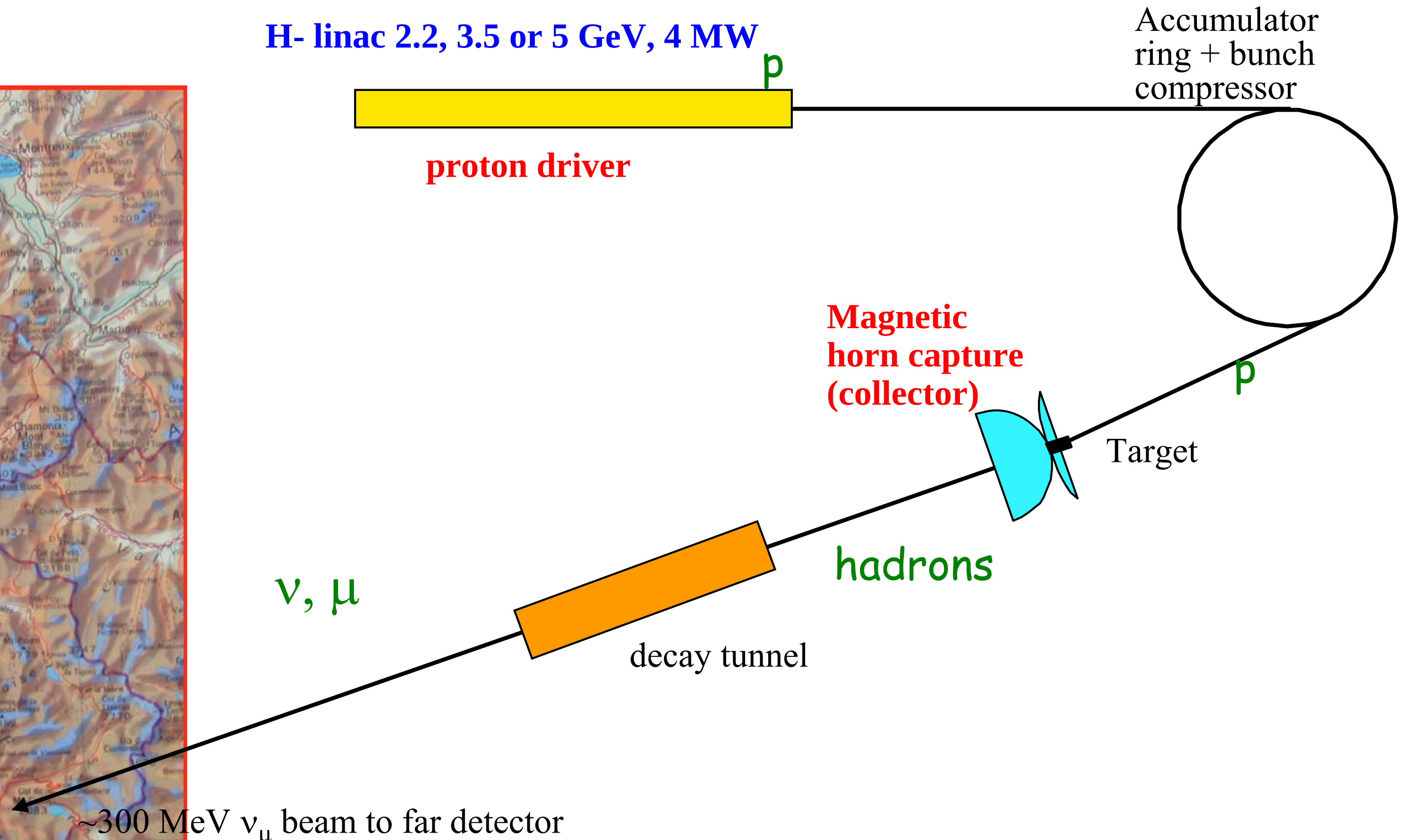




SPL Super-Beam Project

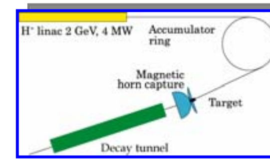






to be studied in EUROν WP2

Super Proton Linac at CERN



SPL

CERN–2006–006
12 July 2006

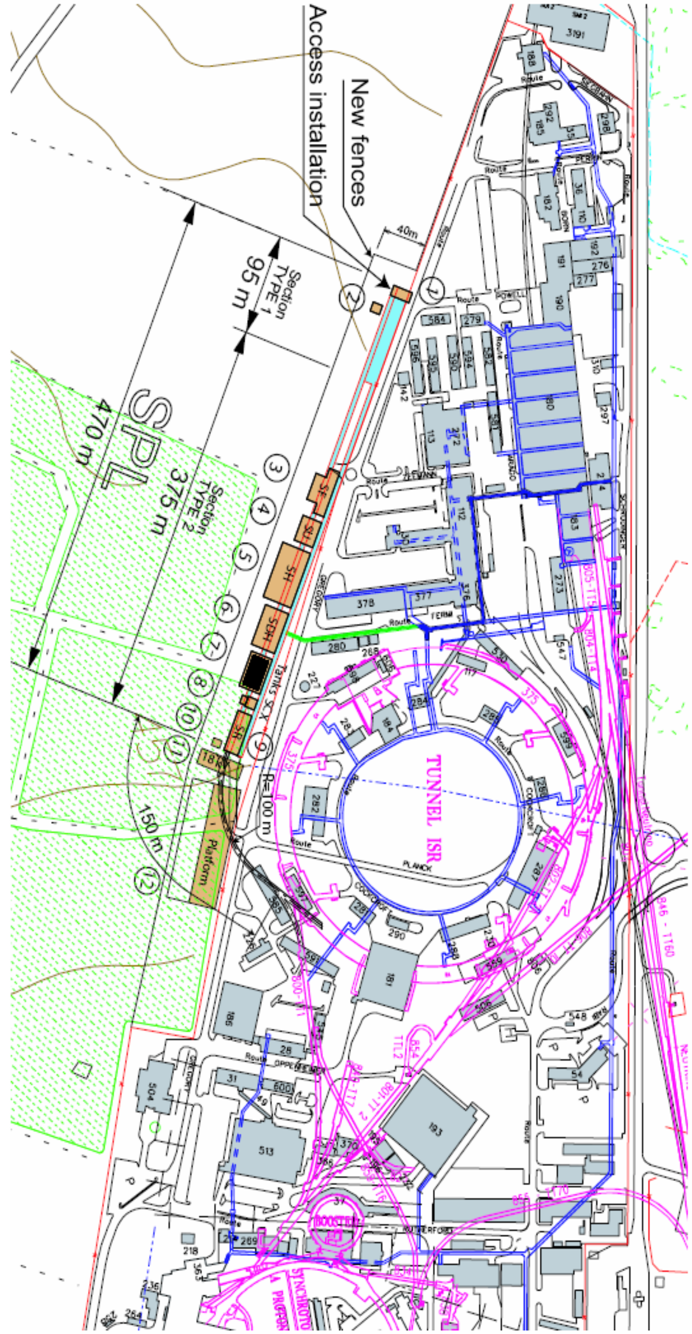
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

(http://doc.cern.ch/yellowrep/2006/2006-006/full_document.pdf)

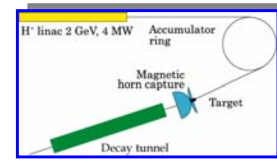
Conceptual design of the SPL II

A high-power superconducting H⁻ linac at CERN

F. Gerigk (Editor), M. Baylac[1], E. Benedico Mora, F. Caspers, S. Chel[2], J.M. Deconto[1], R. Duperrier[2], E. Froidefond[1], R. Garoby, K. Hanke, C. Hill, M. Hori[3], J. Inigo-Golfin, K. Kahle, T. Kroyer, D. Kuechler, J.-B. Lallement, M. Lindroos, A.M. Lombardi, A. López Hernández, M. Magistris, T.K. Meinschad, A. Millich, E. Noah Messomo, C. Pagani[4], V. Palladino[5], M. Paoluzzi, M. Pasini, P. Pierini[4], C. Rossi, J.P. Royer, M. Sanmarti, E. Sargsyan, R. Scrivens, M. Silari, T. Steiner, J. Tückmantel, D. Uriot[2], M. Vretenar



SPL (CDR2) main characteristics

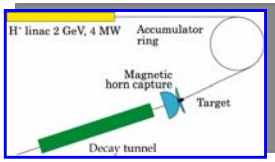


Ion species	H^-	
Kinetic energy	3.5	GeV
Mean current during the pulse	40	mA
Mean beam power	4	MW
Pulse repetition rate	50	Hz
Pulse duration	0.57	ms
Bunch frequency	352.2	MHz
Duty cycle during the pulse	62 (5/8)	%
rms transverse emittances	0.4	π mm mrad
Longitudinal rms emittance	0.3	π deg MeV
Length	430	m

butch compressor to go down to 3.2 μs (important parameter for hadron collector pulsing system)

(possible energy upgrade to 5 GeV could be the subject of a 3rd CDR)

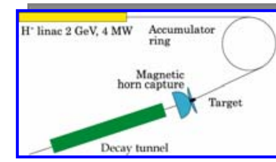
Proton Target

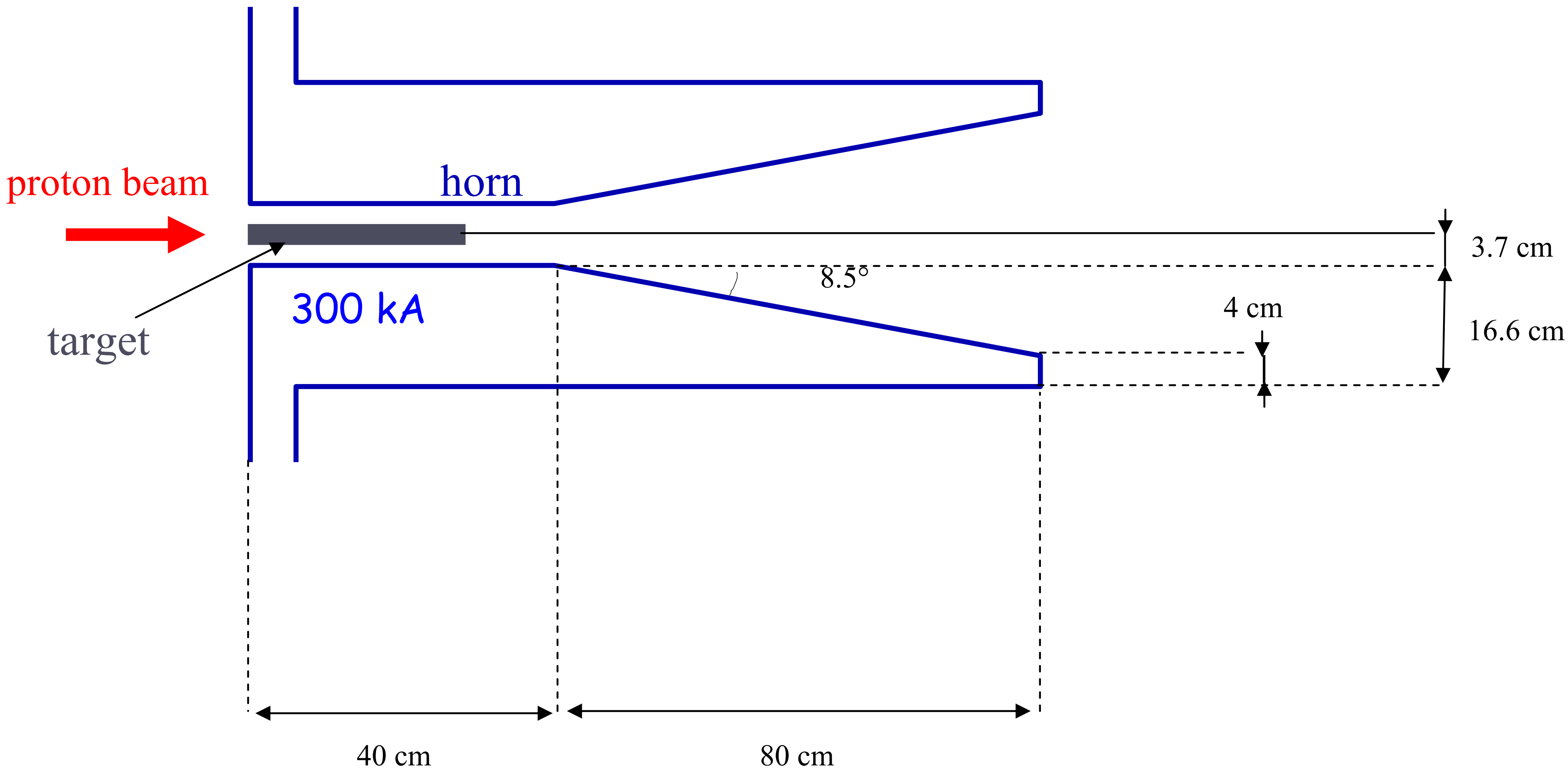


very challenging task

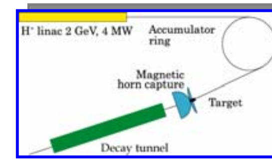
- 300-1000 J cm^{-3}/pulse
- Severe problems from : sudden heating, stress, activation
- Safety issues !
- Baseline for Super-Beam is solid target, mercury is optional (baseline for NF)
  - Extremely difficult problem : need to pursue two approaches :
    - Liquid metal target (Merit experiment)
    - Solid target (extensive R/D program at CCLRC and BNL)
- Envisage alternative solutions

Proposed collection system



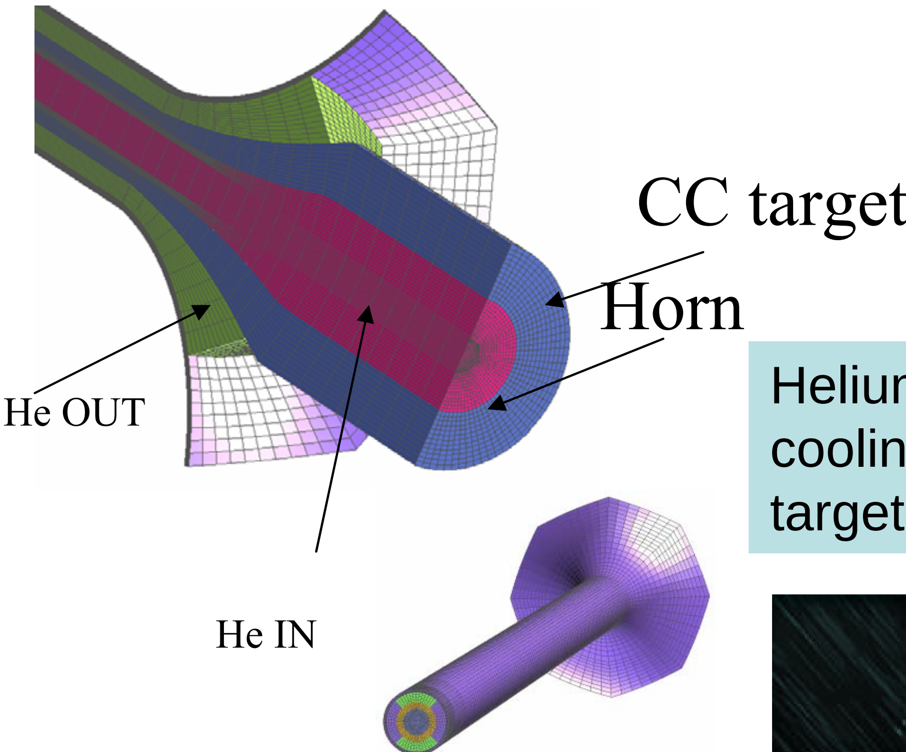


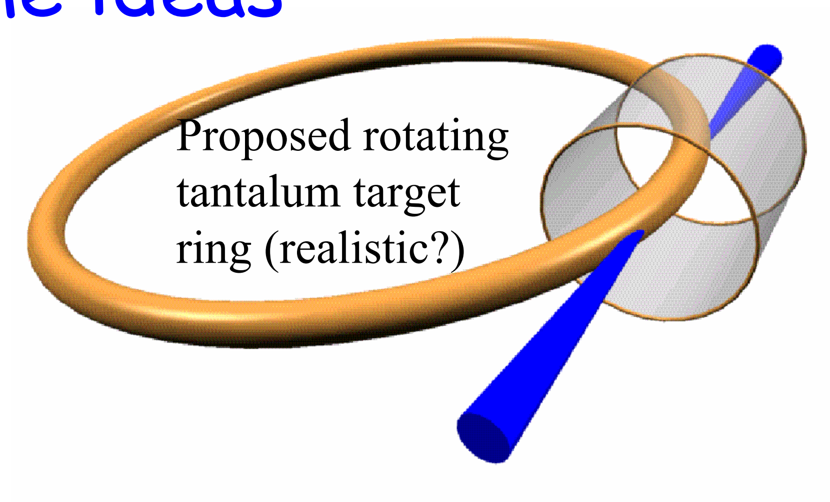
⇒ taking into account the proton energy and collection efficiency, the target must be inside the horn



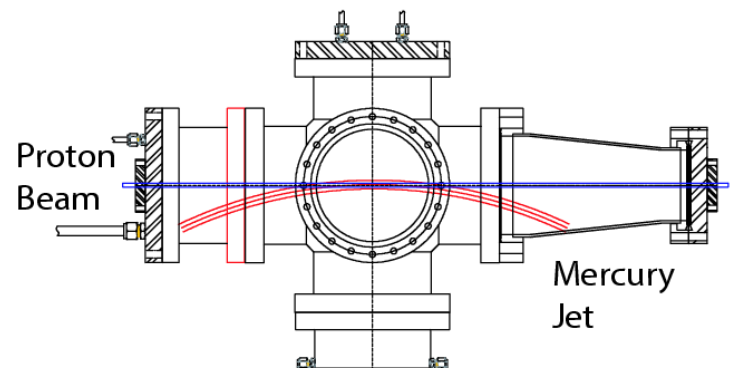
Proton Target

some ideas

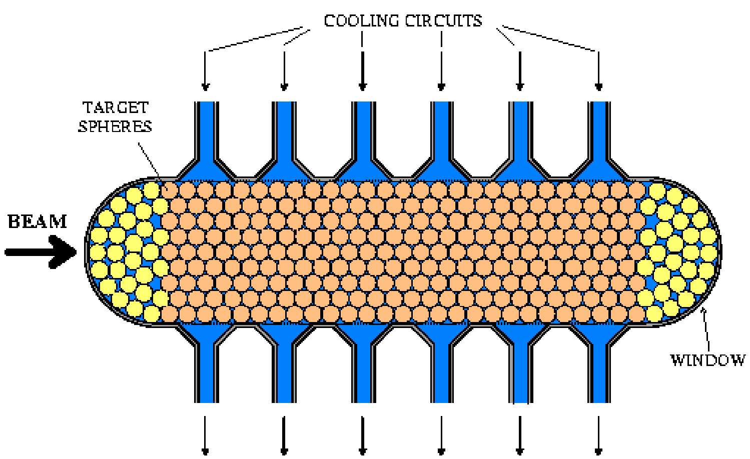




Helium cooling of target



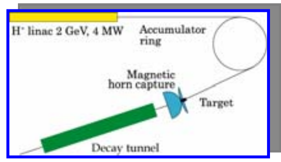
Liquid Mercury (MERIT)



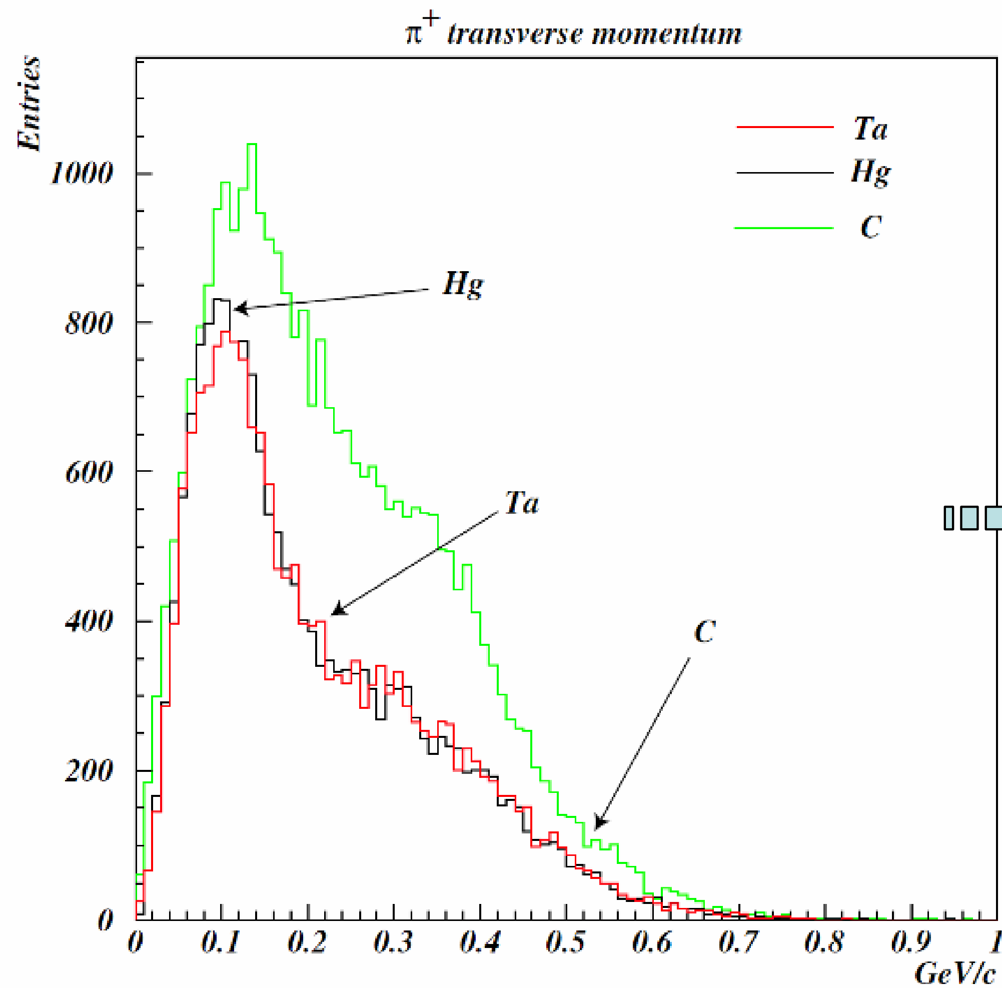
cooling is a main issue…

Work at BNL and RAL
Experience on T2K target (750 kW) very useful

Hadron production



2.2 GeV protons



p_T

Particles coming out of the target

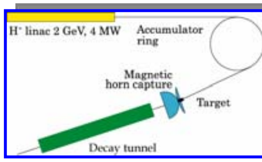
p_T distribution not the same for all targets

⇒

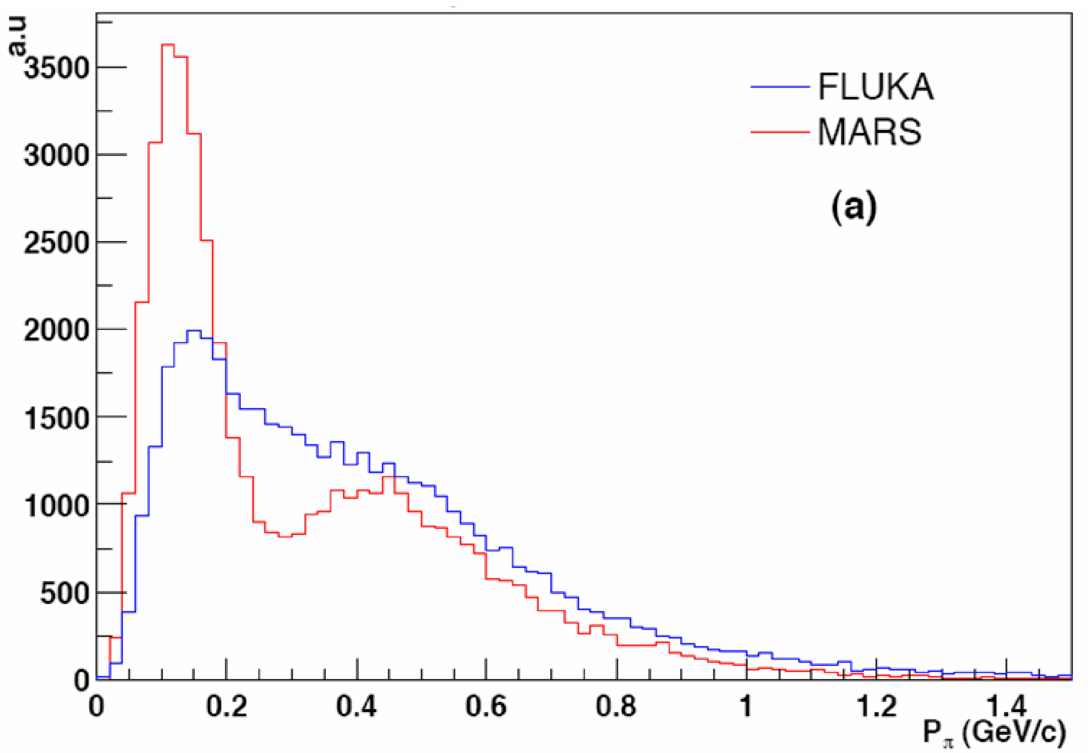
the choice of the target could influence the hadron collection system (horn shape)

From now on Hg will be considered

Hadron production uncertainties



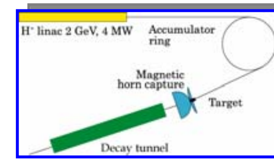
2.2 GeV protons

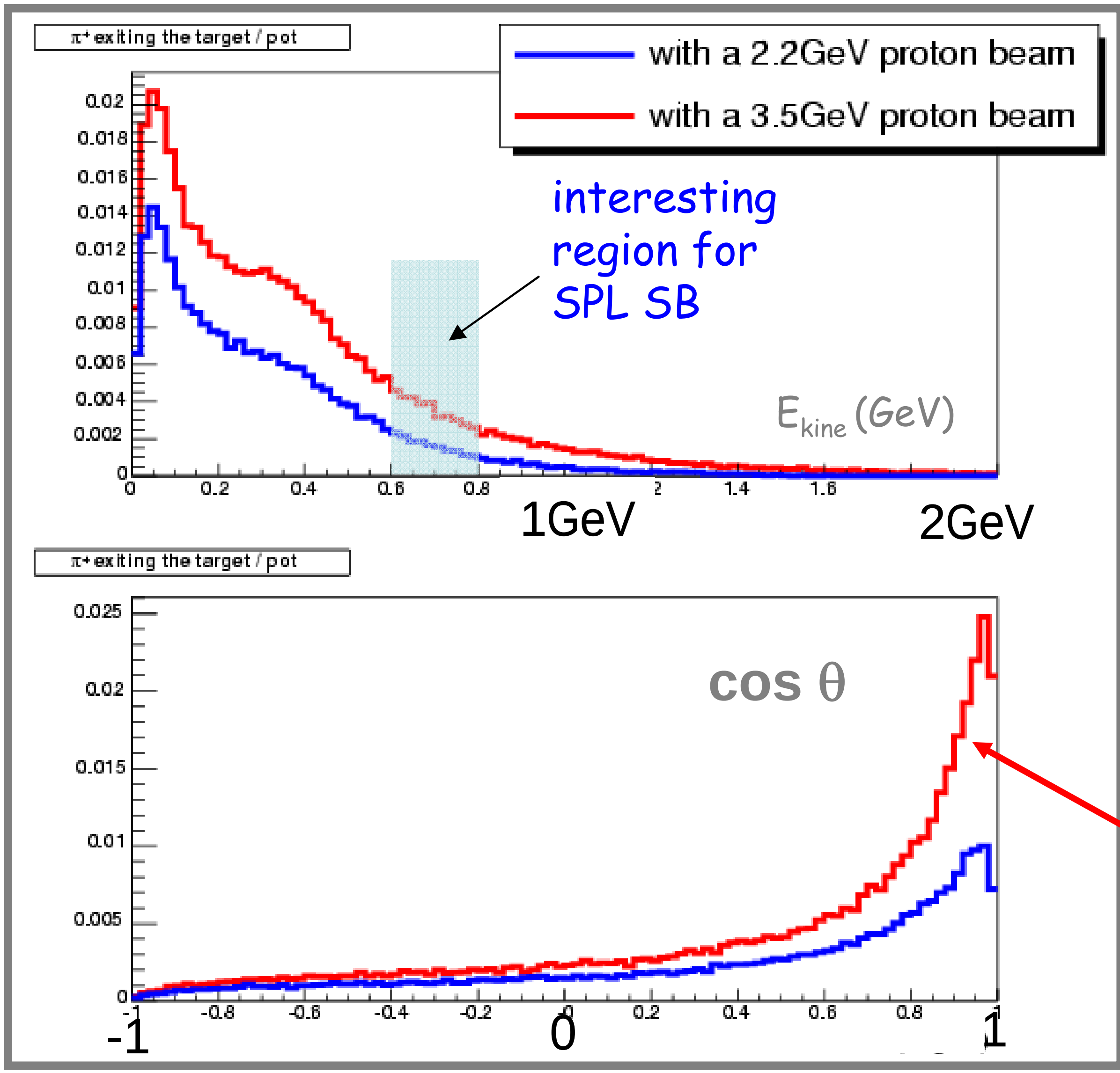


disagreement between models (Monte Carlo production, interaction and transport codes)

more development is needed (simulation, measurements)

Proton Energy and Pion Spectra

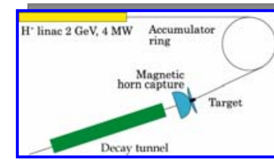




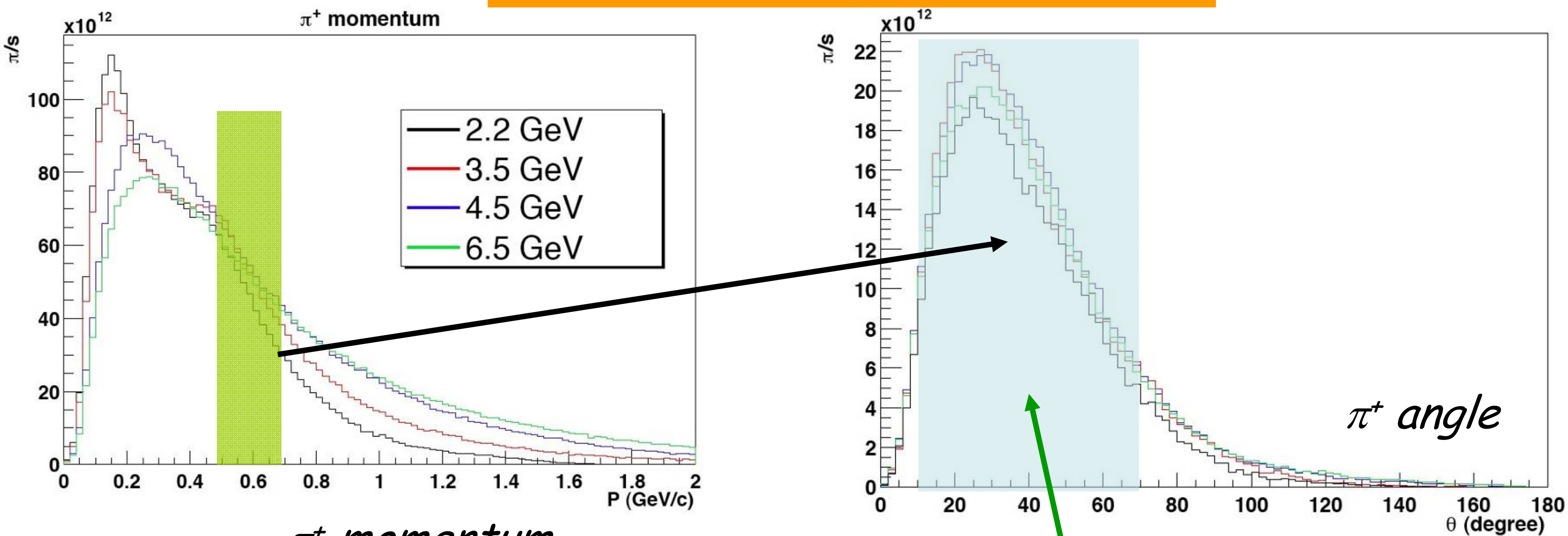
- pions per proton on target.
- Kinetic energy spectrum
  - 2.2 GeV:
    - $<E_k>$=300MeV
  - 3.5 GeV:
    - $<E_k>$=378MeV

hadrons boosted forward

Proposed design for SPL



for pions coming out of the target



π^+ *momentum*

horn region

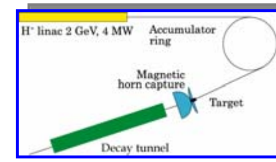
for a Hg target, 30 cm length, ∅15 mm ($\times 10^{16}$/sec)

E_k (GeV)	p	n	γ	e^+	e^-	π^+	π^-	μ^+	μ^-	K^+	K^0
2.2	1.4	17	5.0	0.08	0.17	0.24	0.18	4	1	7	6
3.5	1.8	23	7.0	0.15	0.28	0.41	0.37	10	3	35	30
4.5	2.3	25	7.7	0.21	0.35	0.57	0.39	11	3.3	93	68
8	3.1	33	11.0	0.41	0.63	1.00	0.85	30	9.5	413	340

⇒ relatively better collection when p_{proton} ↗

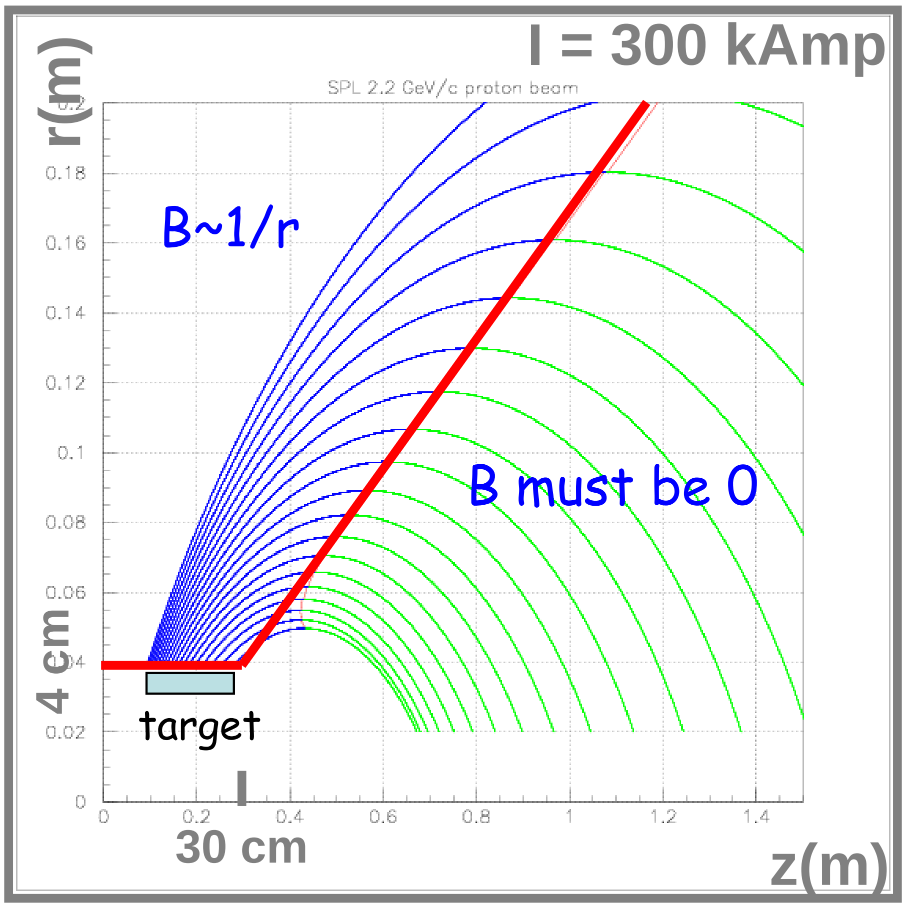
⇒ the target must be inside the horn

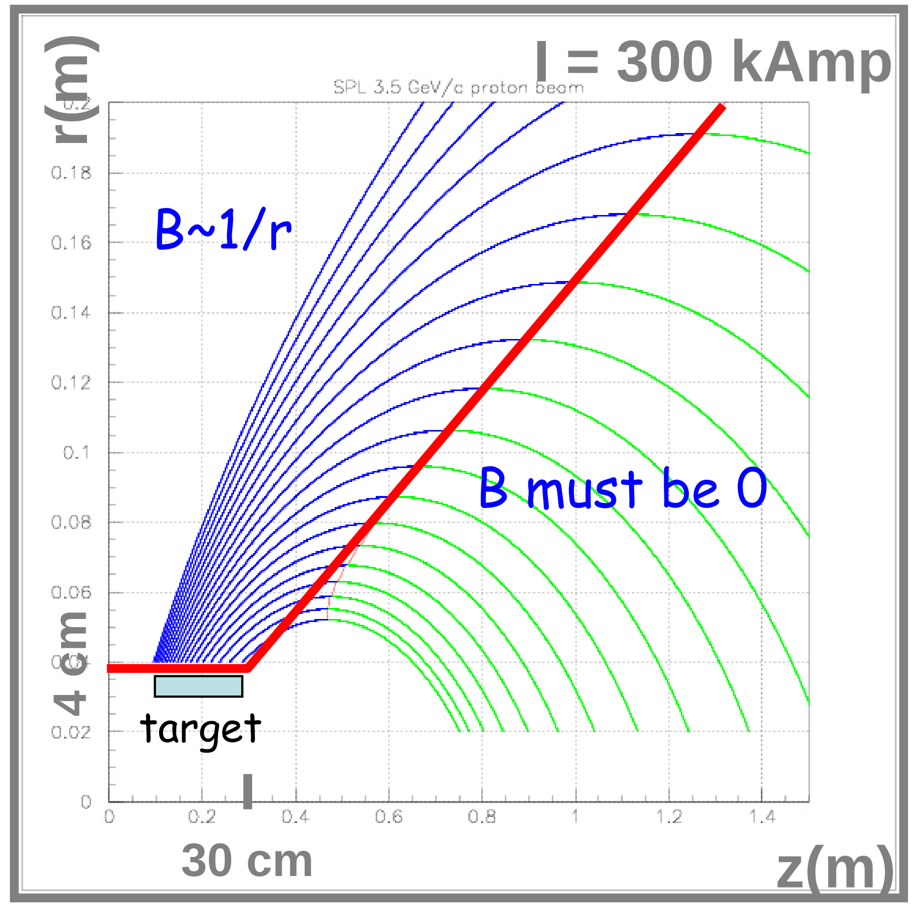
Horn geometry



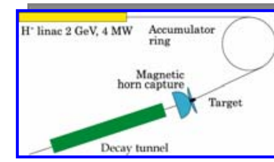
- 2.2 GeV proton beam :
  - $<p_\pi>$ = 405 MeV/c
  - $<\theta_\pi>$ = 60°

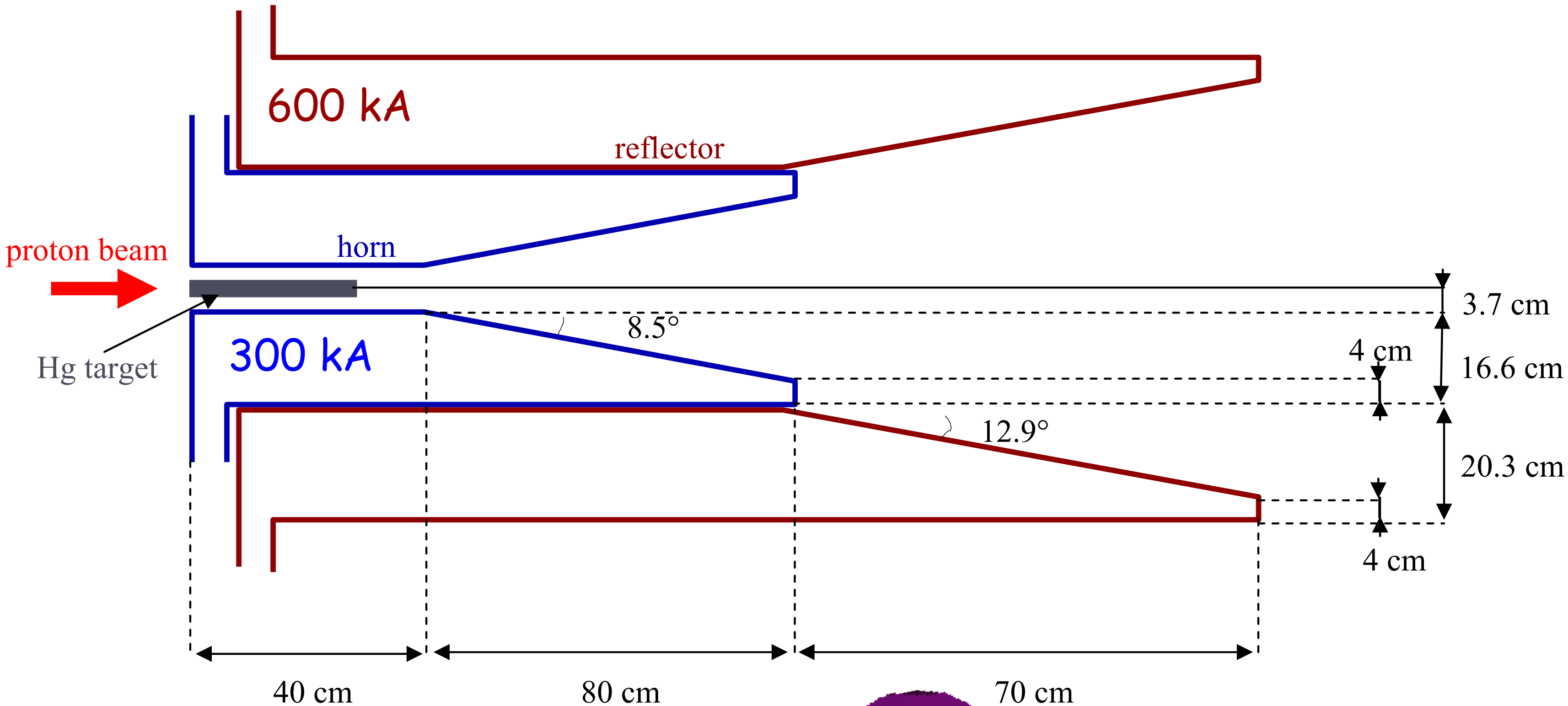
- 3.5 GeV proton beam :
  - $<p_\pi>$ = 492 MeV/c
  - $<\theta_\pi>$ = 55°

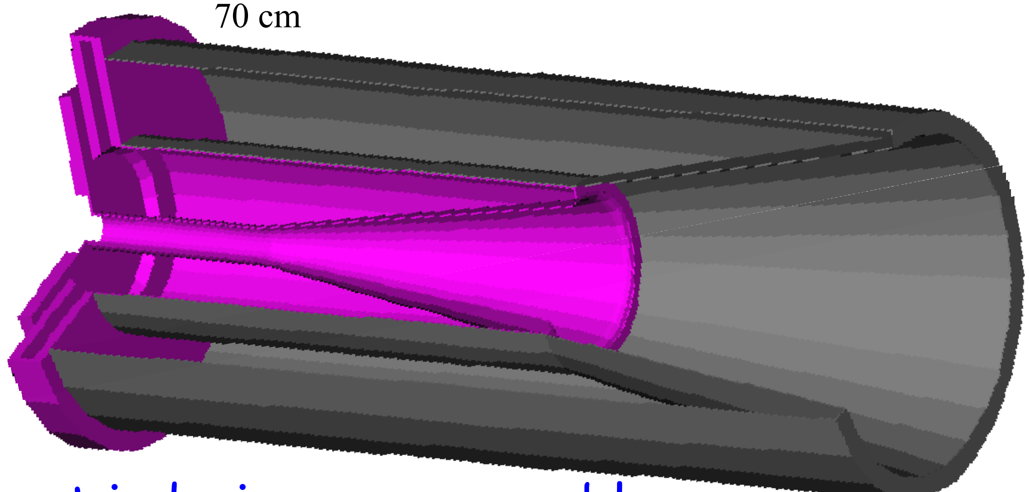




Proposed design for SPL

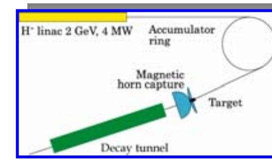




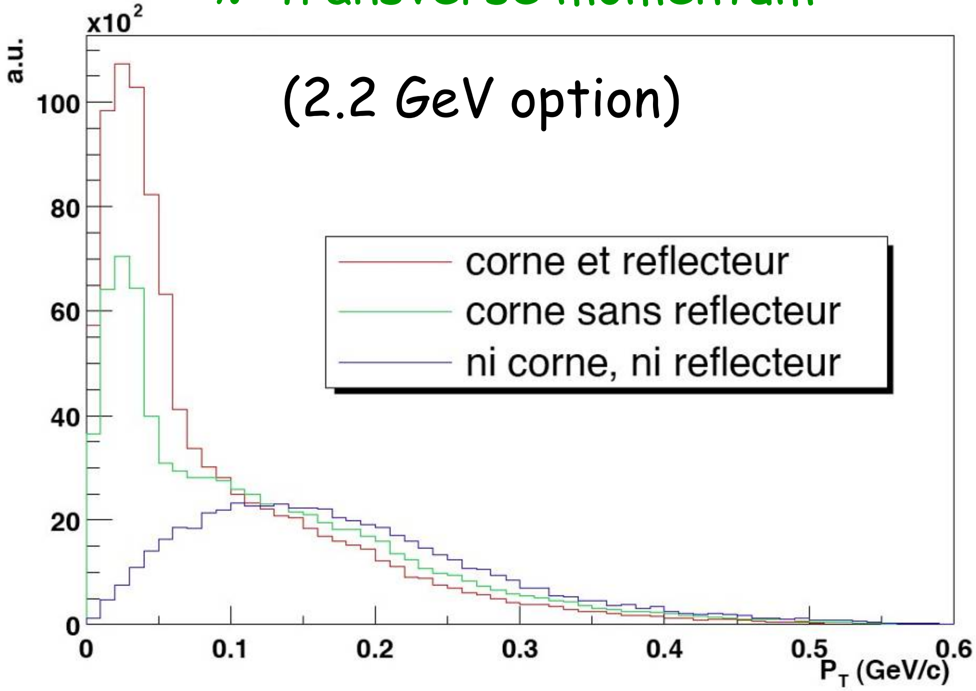


very high current inducing severe problems

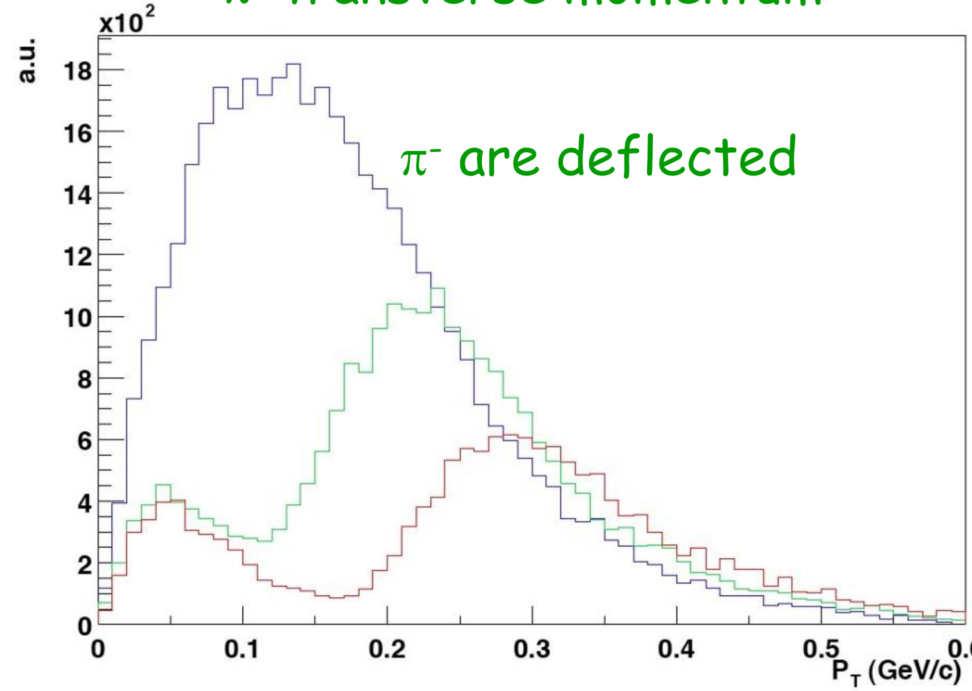
Focusing Power



π^+ transverse momentum

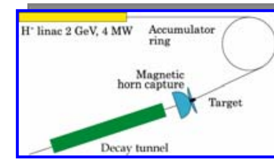


π^- transverse momentum

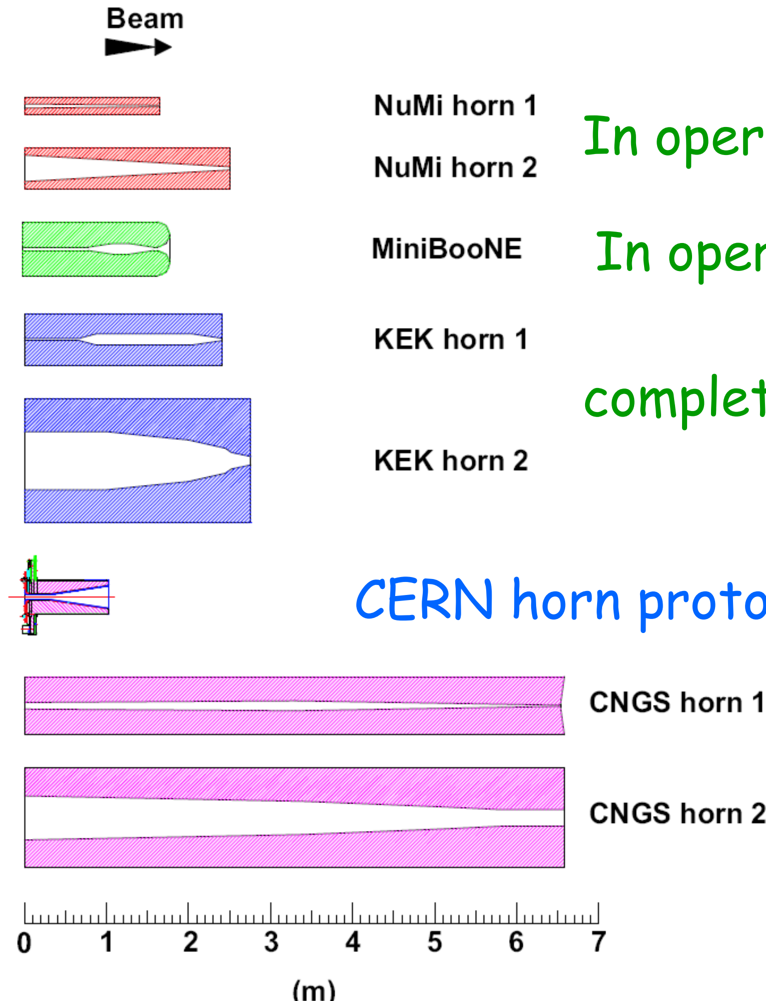


20% more π^+ with reflector

Present Collectors



Experiment	Current	Rep. Rate	Pulses per time period
Numi (120 GeV)	200 kA	0.5 Hz	6 Mpulses 1 year
MiniBoone (8 GeV)	170 kA	5 Hz	11 Mpulses 1 year
K2K (12 GeV)	250 kA	0.5 Hz	11 Mpulses 1 year
Super-Beam (3.5 GeV)	300 kA	50 Hz	200 Mpulses 6 weeks
CNGS (400 GeV)	150 kA	2 pulses/ 6 sec	42 Mpulses 4 year



In operation

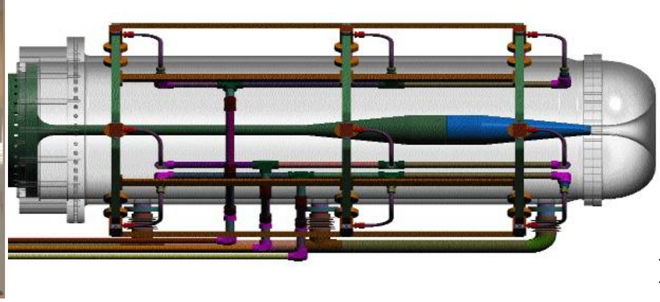
In operation

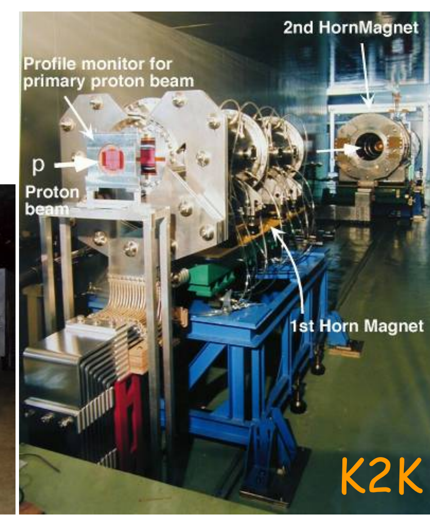
completed

CERN horn prototype for SPL

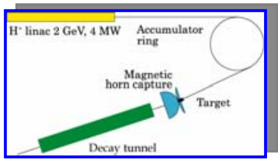
In operation

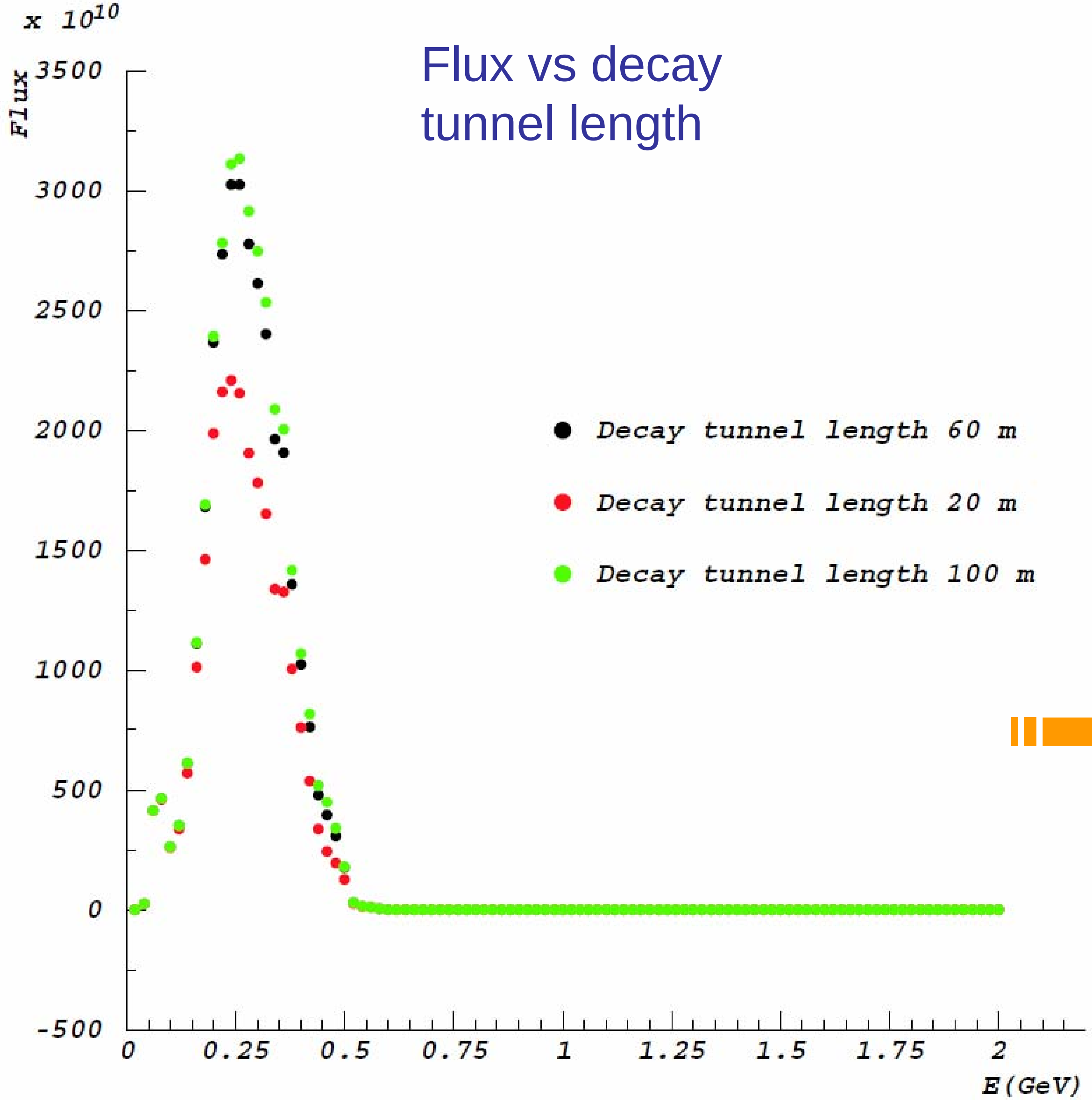
MiniBooNE





Decay Tunnel



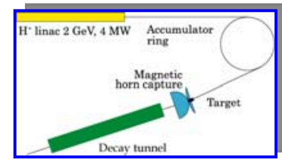


Flux vs decay tunnel length

(2.2 GeV option)

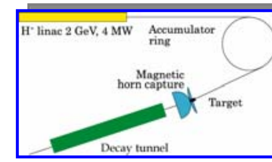
short decay tunnel

More about previous studies



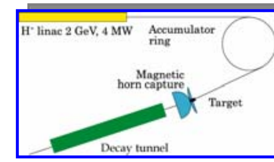
- S. Gilardoni: Horn for Neutrino Factory and comparison with a solenoid
  - http://doc.cern.ch/archive/electronic/cern/preprints/thesis/thesis-2004-046.pdf
  - http://newbeams.in2p3.fr/talks/gilardoni.ppt
- A. Cazes: Horn for SPL
  - http://tel.ccsd.cnrs.fr/tel-00008775/en/
  - http://slap.web.cern.ch/slap/NuFact/NuFact/nf142.pdf
  - http://slap.web.cern.ch/slap/NuFact/NuFact/nf-138.pdf

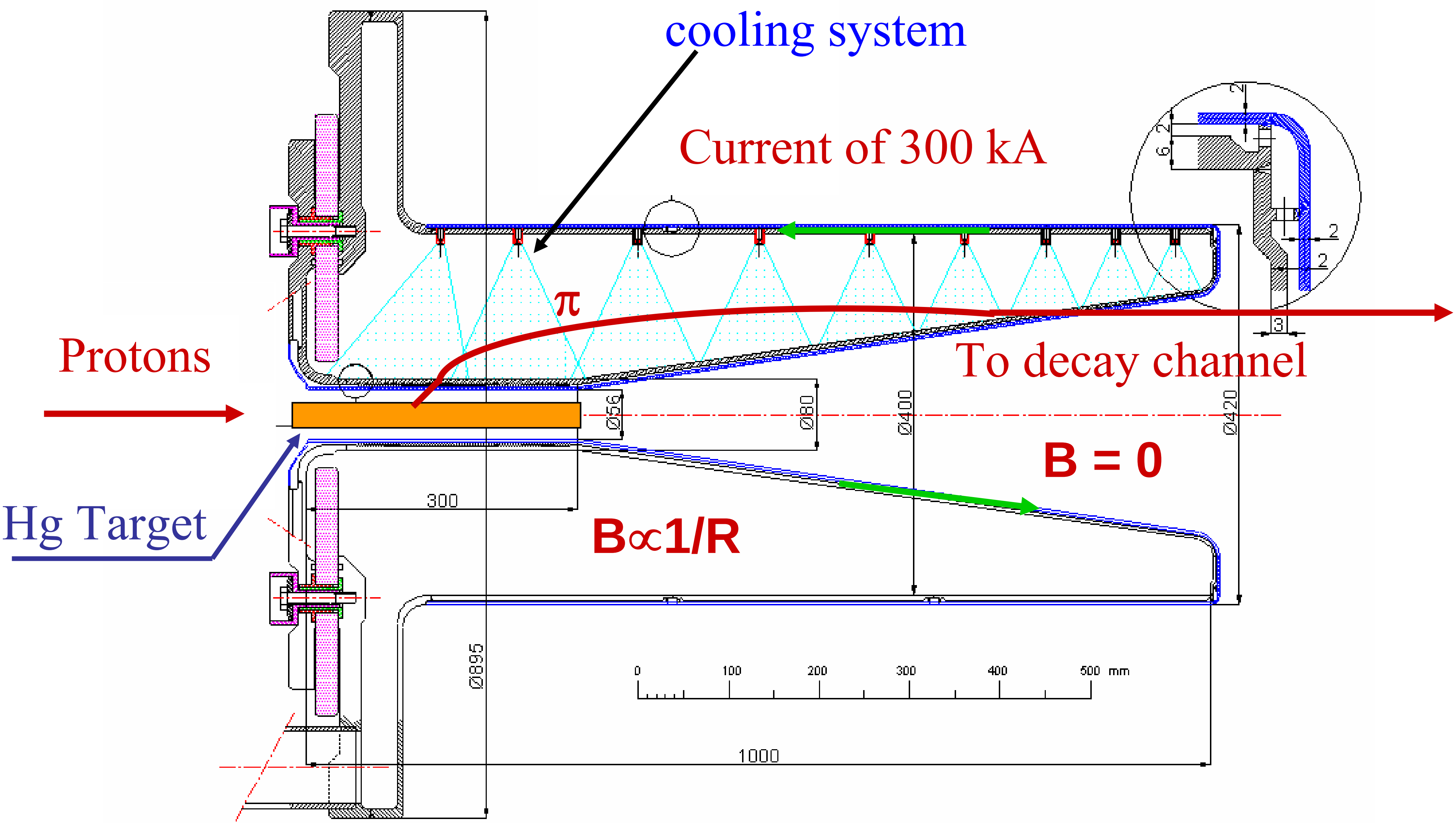
Main Technical Challenges



- Horn : as thin as possible (3 mm) to minimize energy deposition,
- Longevity in a high power beam (currently estimated to be 6 weeks!),
- 50 Hz (vs a few Hz up to now),
- Large electromagnetic wave, thermo-mechanical stress, vibrations, fatigue, radiation damage,
- Currents: 300 kA (horn) and 600 kA (reflector)
  - design of a high current pulsed power supply (300 kA/100 μs/50 Hz),
- cooling system in order to maintain the integrity of the horn despite of the heat amount generated by the energy deposition of the secondary particles provided by the impact of the primary proton beam onto the target,
- definition of the radiation tolerance,
- integration of the target.

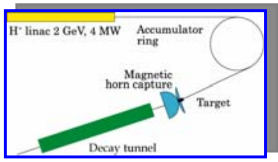
CERN horn prototype



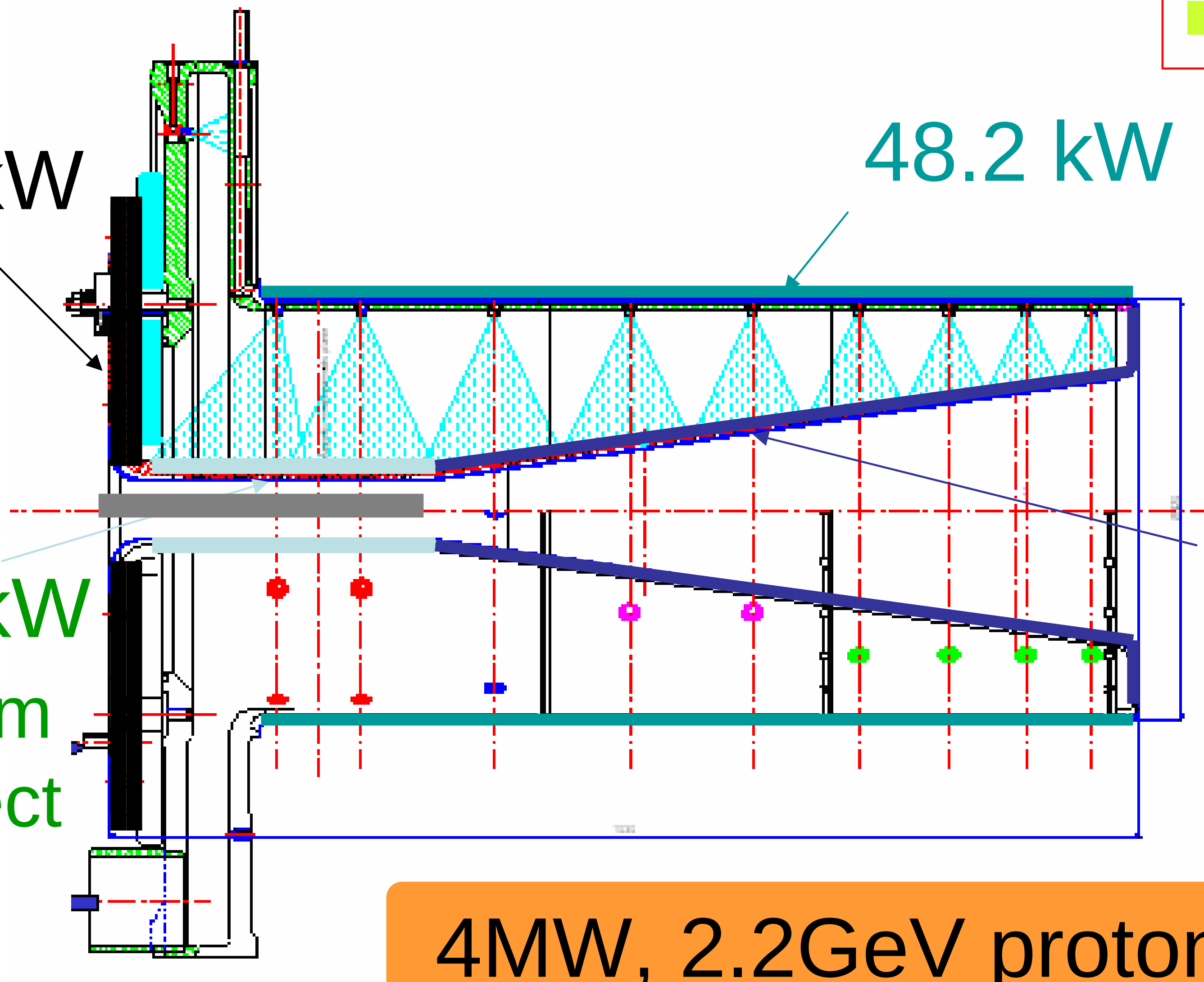


initial design satisfying both, neutrino factory and super-beam

Energy deposition in the conductors



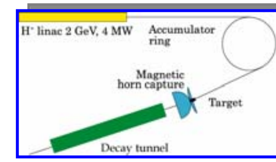
MARS

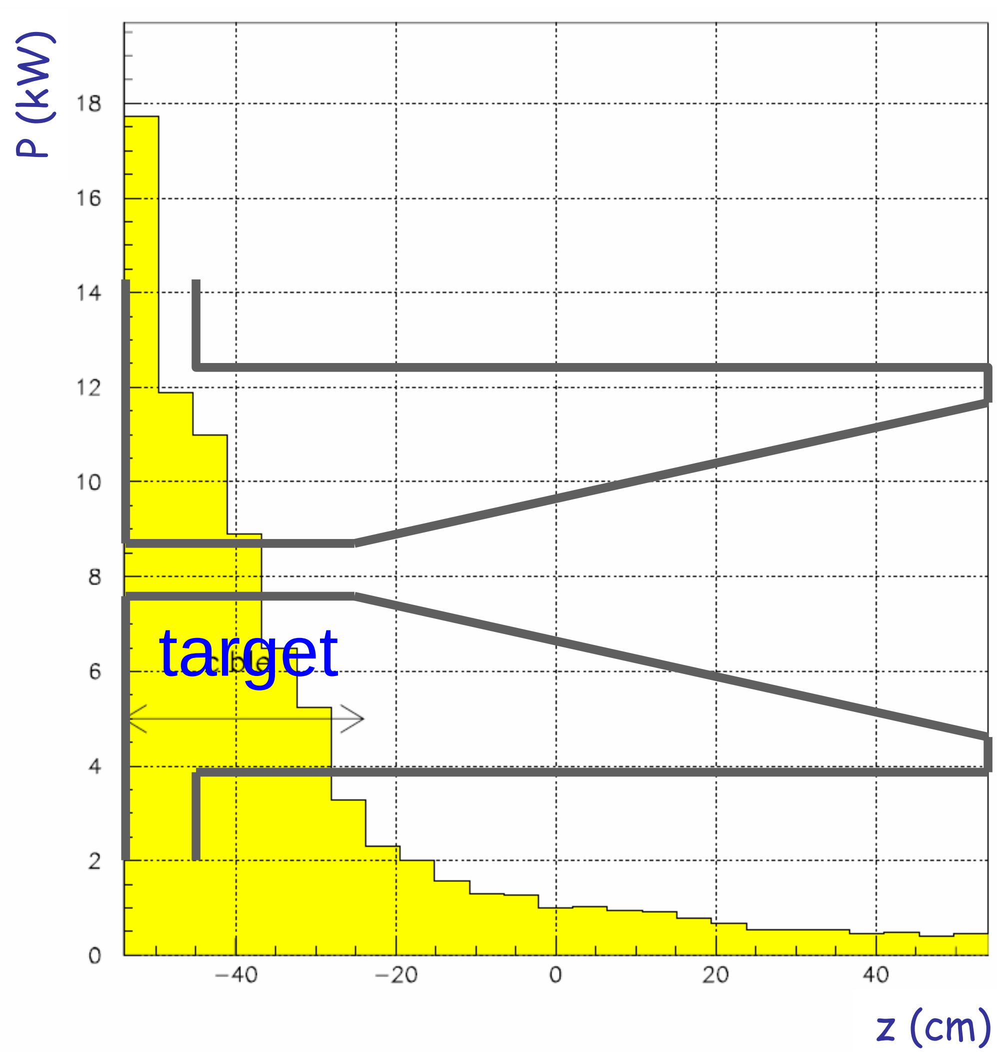


4MW, 2.2GeV proton beam

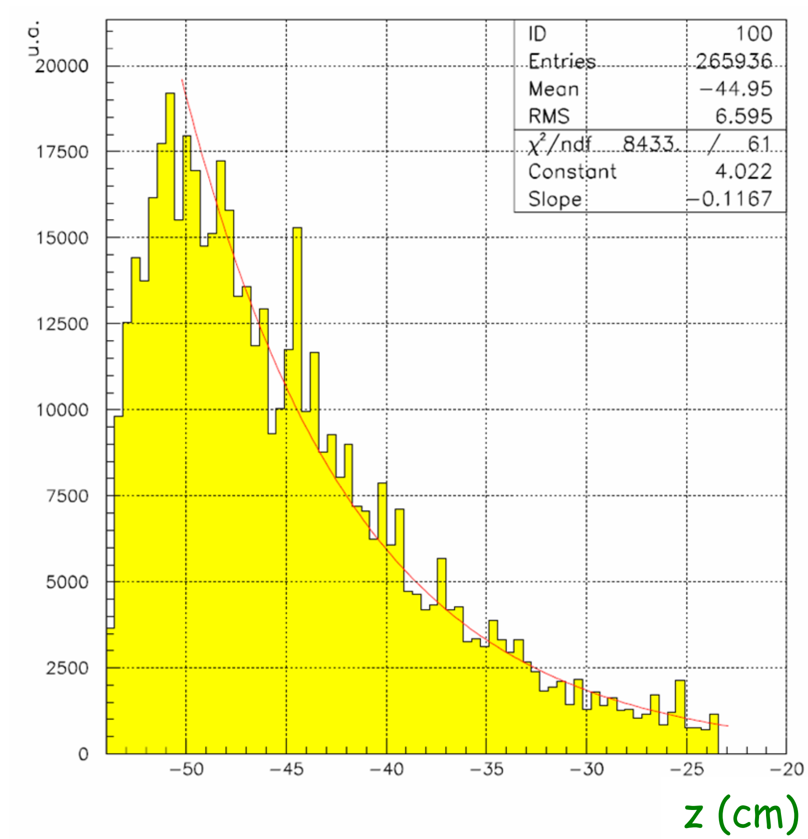
(1MeV = 1.82 kW)

Localization of the energy deposition



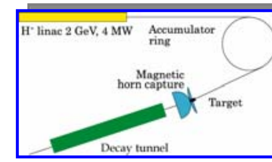


power deposited in the inner conductor as a function of z

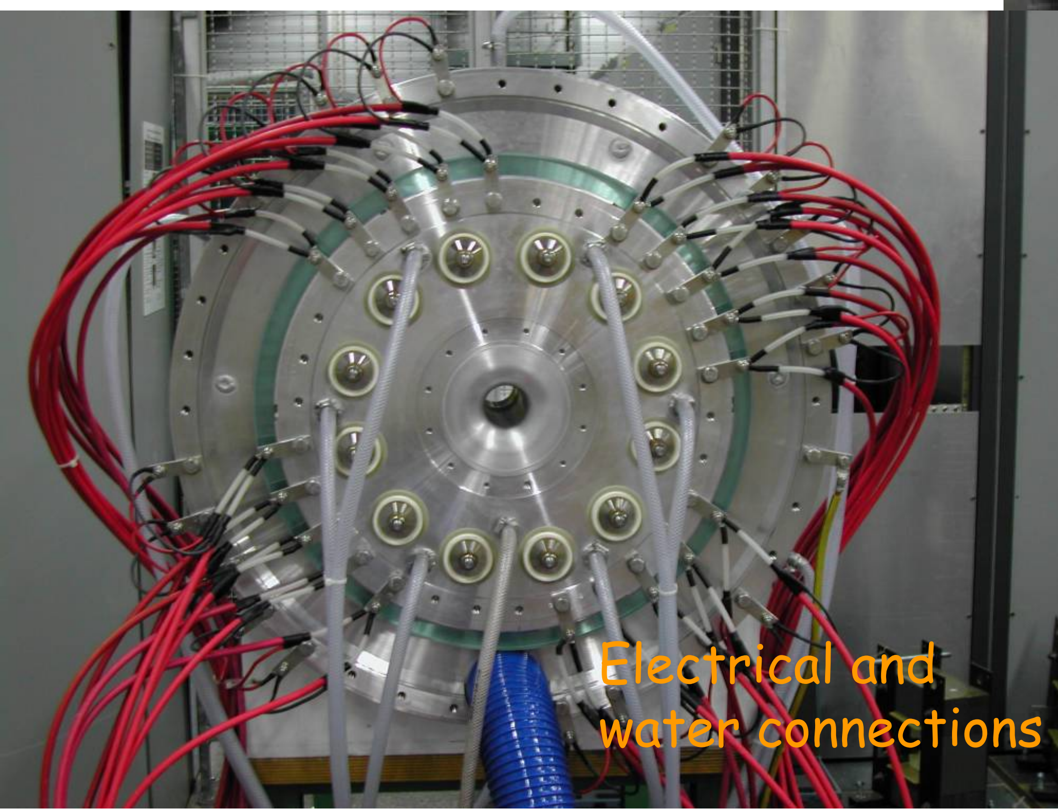


z position of the particles coming out of the target

Horn prototype

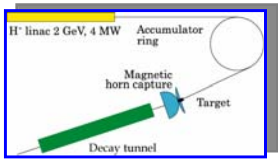


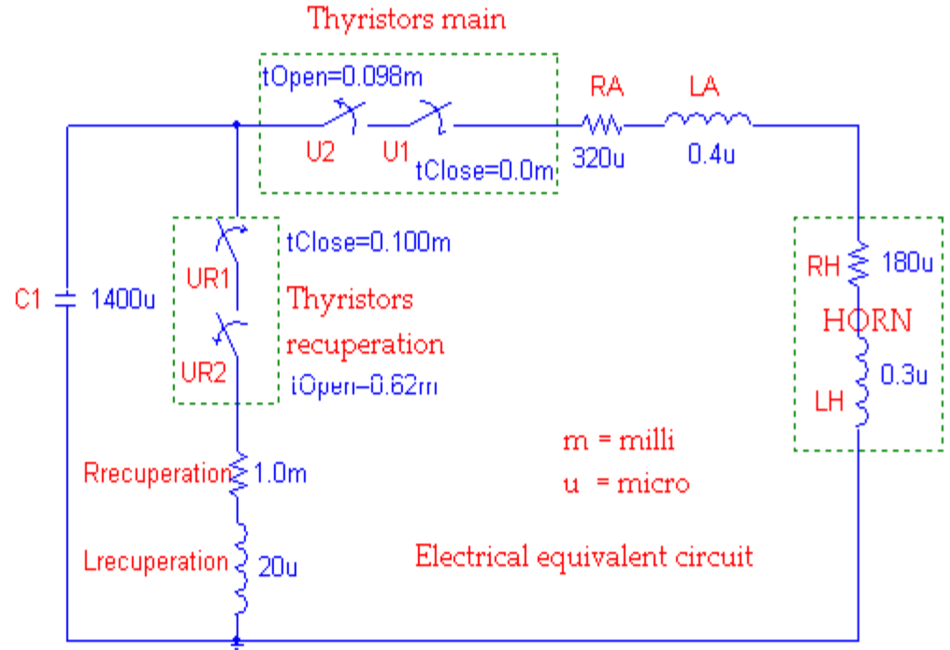
- **For the horn skin AA 6082-T6 / (AlMgSi1) is an acceptable compromise between the 4 main characteristics:**
  - Mechanical properties
  - Welding abilities
  - Electrical properties
  - Resistance to corrosion
  - Same for CNGS

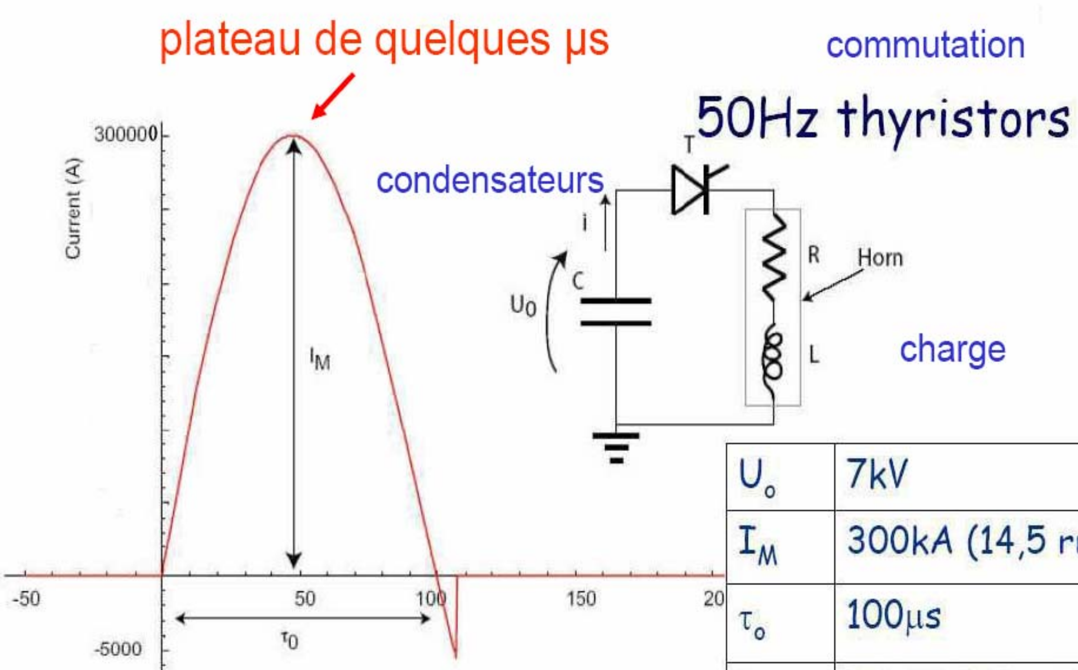


- tests done with: 30 kA and 1 Hz, pulse 100 μs long
- new tests to be done with 50 Hz

Power Supply for horn pulsing (major issue)



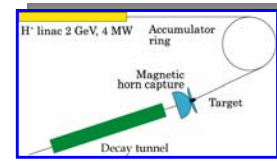




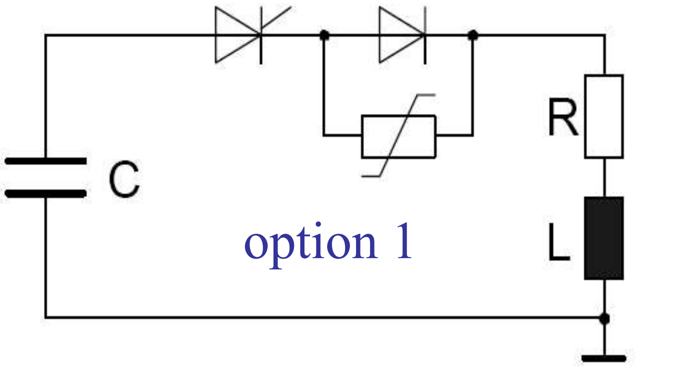
U_o	7kV
I_M	300kA (14,5 rms)
τ_o	100µs
L	0.6 (0.4 Horn)µH
R	500 (180 Horn) µΩ
C	1500µF

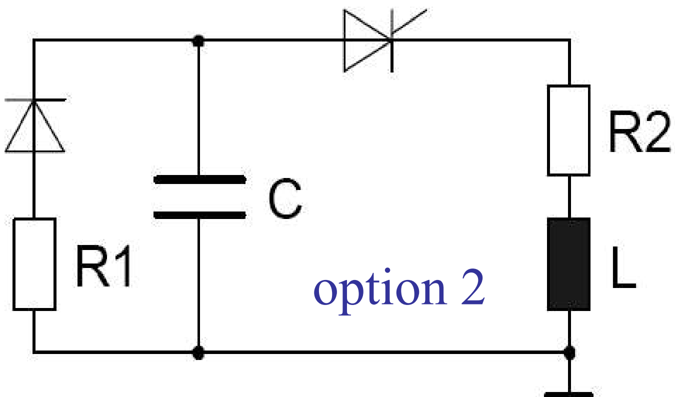
values considered by CERN

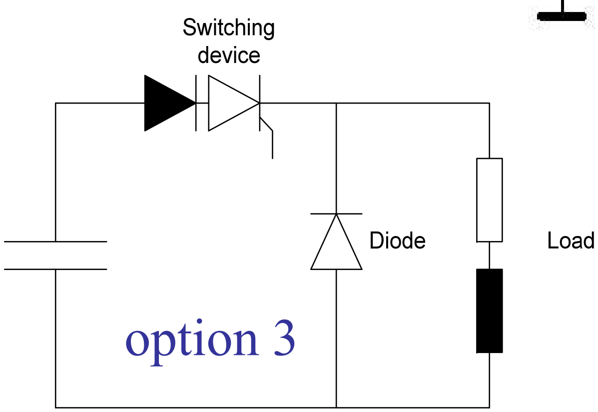
3 Solutions proposed by ABB

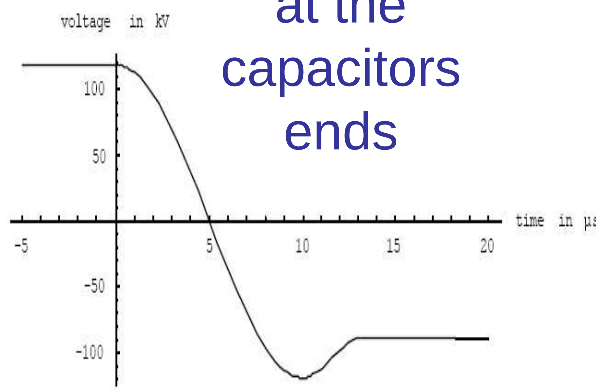


schematic versions

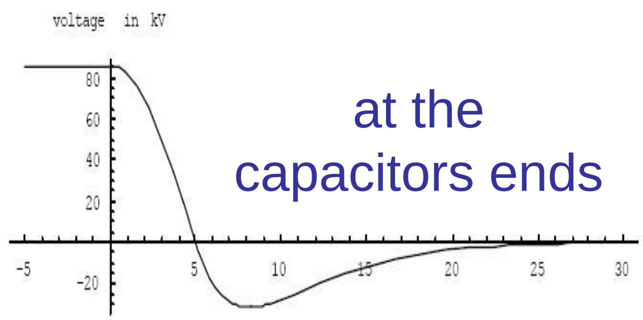




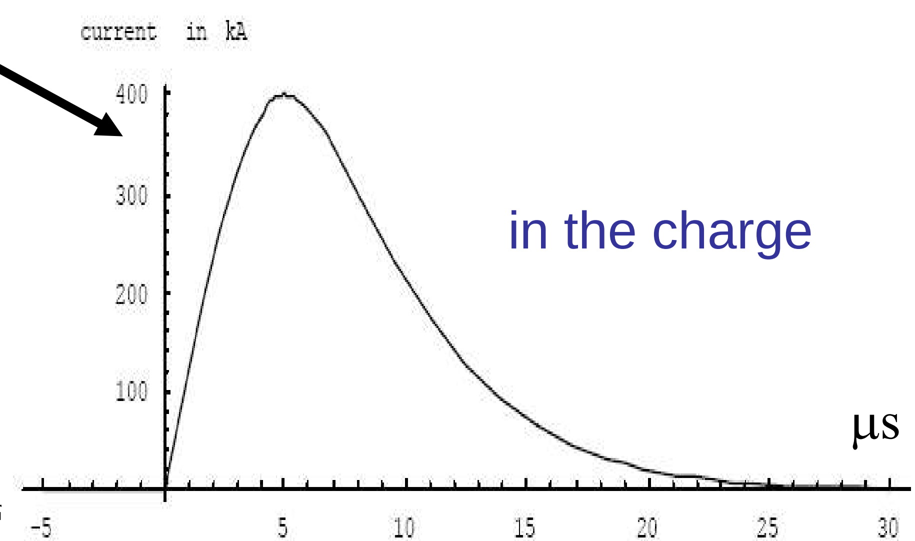




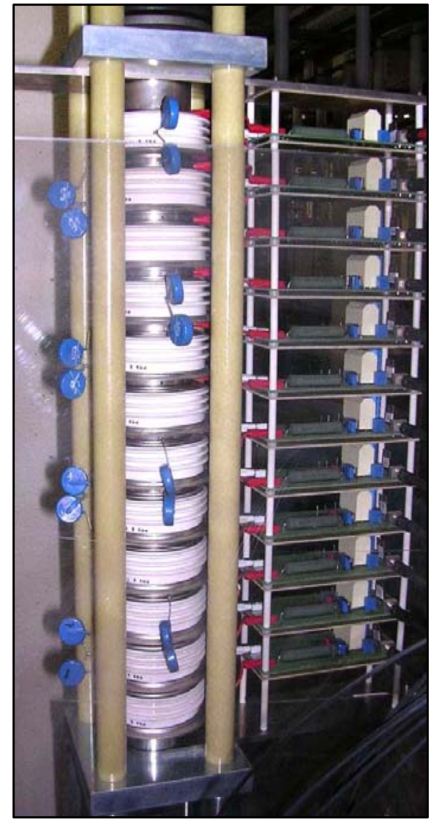
at the capacitors ends



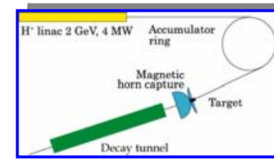
at the capacitors ends



in the charge

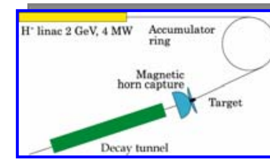


Pulser simulation parameters



- magnetic field with electrical excitation (pulses 100 μs, 50 Hz)
- induced current distributions
- magnetic forces
- temperature and expansion distributions
- mechanical constraints and deformations (static+ dynamical), vibration modes
- non-linear magnetic and thermal effects in the calculation of mechanical constraints
- fatigue (and constraints from radiations if any)

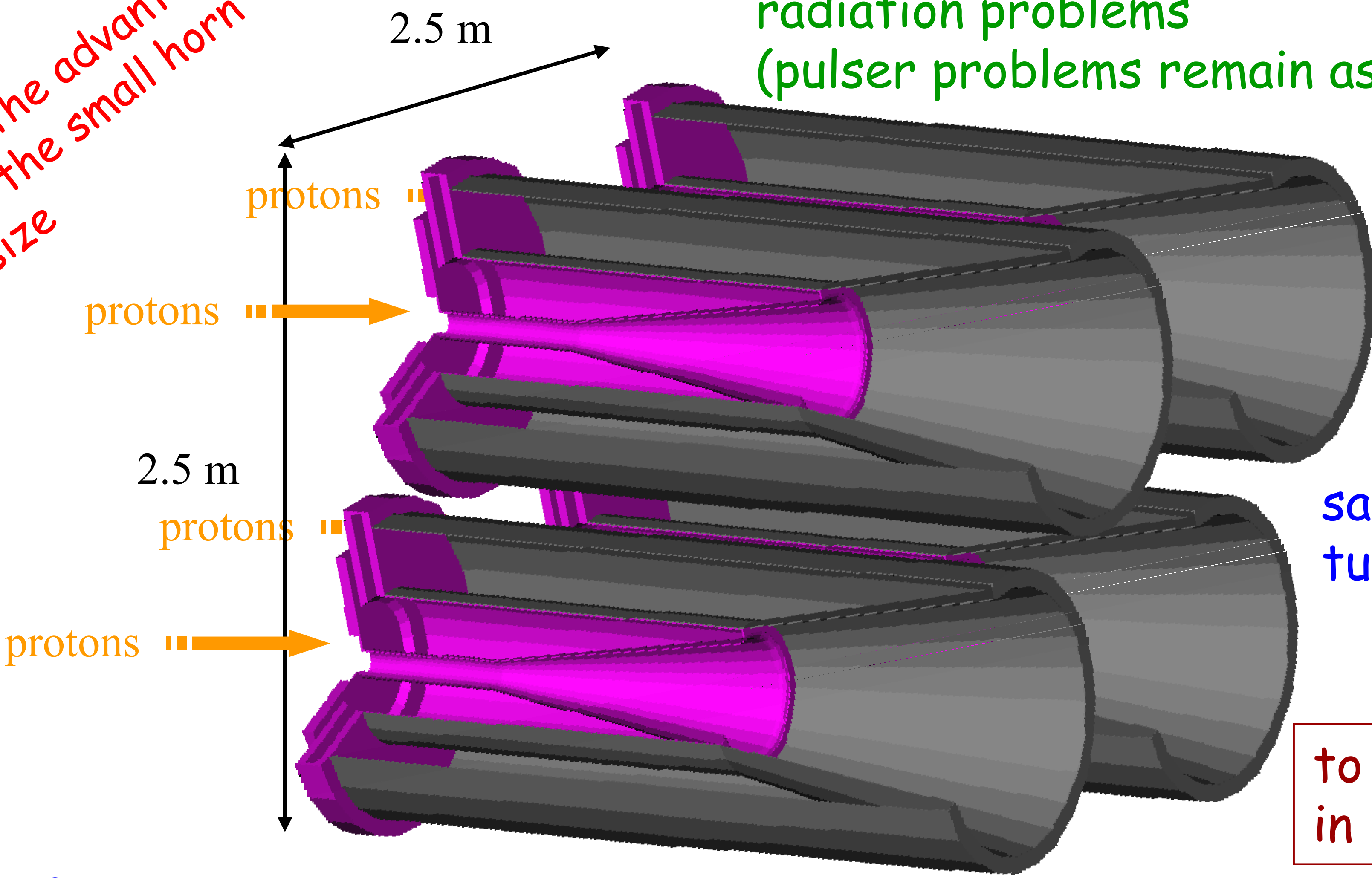
⇒ studies are needed to make the right choice, increase the system lifetime, reduce the cost



New ideas

use the advantage of the small horn size

minimize power dissipation and radiation problems
(pulser problems remain as before)



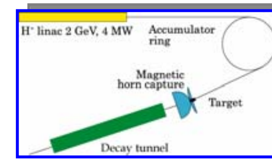
same decay tunnel Ø 3 m

to be studied in EUROν

2 options:
- send at the same time 1 MW per target/horn system
- send 4 MW/system every 50/4 Hz

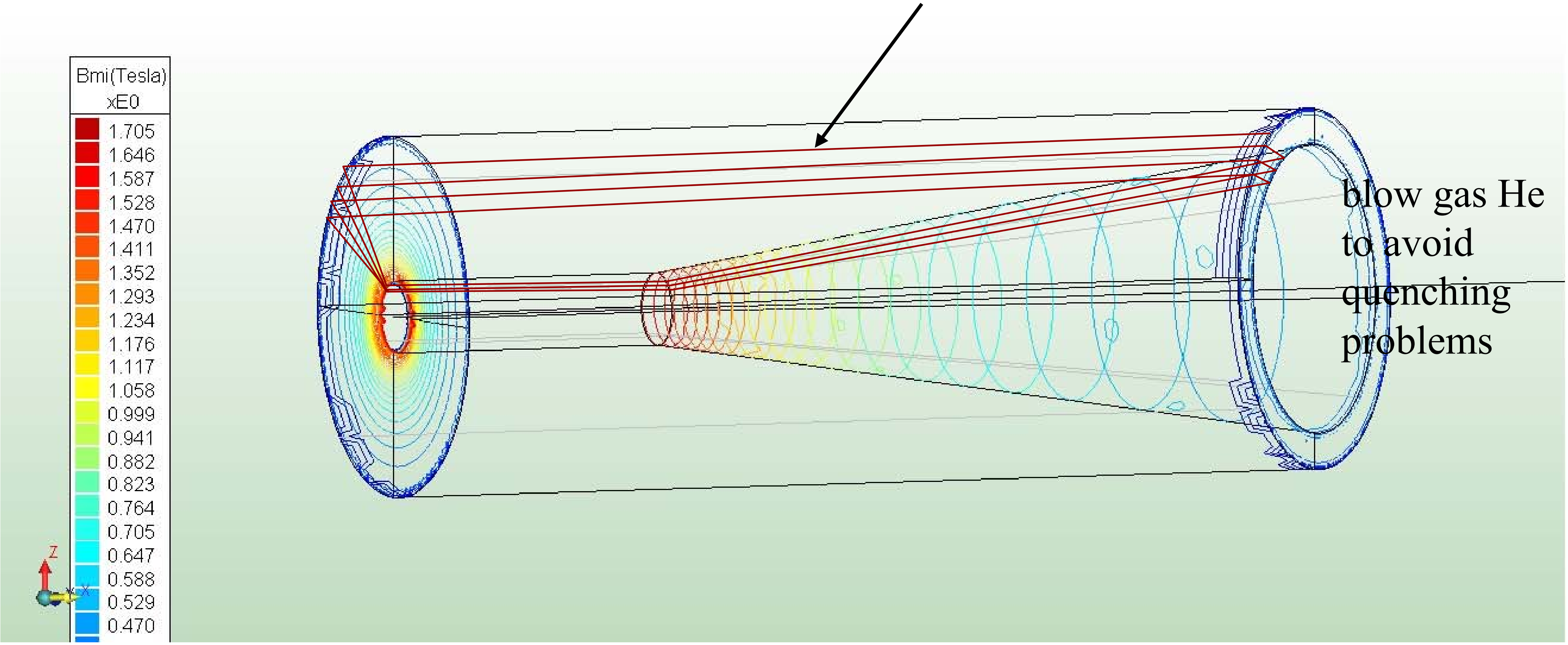
→ possibility to use solid target?

New (crazy) ideas



use a cryogenic horn (toroidal coil)

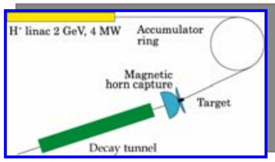
superconducting wire (1 mm Ø) in superfluid He,
DC power supply



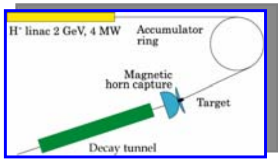
- No problem with power supply (pulser no more needed)
- Proton compressor no more needed

to be studied in EUROν

Conclusions



- Proton driver characteristics and target have to be fixed before horn design.
- Preliminary studies about horn focusing performance for SPL already exist.
- Collector studies are necessary to increase the system lifetime.
- Target/horn integration to be considered since the beginning.
- Multi-physics simulations would be very useful.
- New studies will start soon in the framework of EUROν FP7 project.


H⁻ linac 2 GeV, 4 MW
Accumulator ring
Magnetic horn capture
Target
Decay tunnel

End