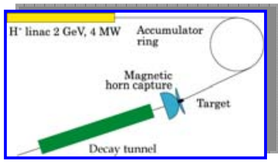
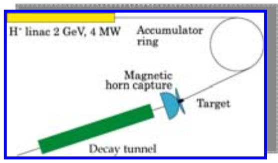


Collector and the SPL Super-Beam Project

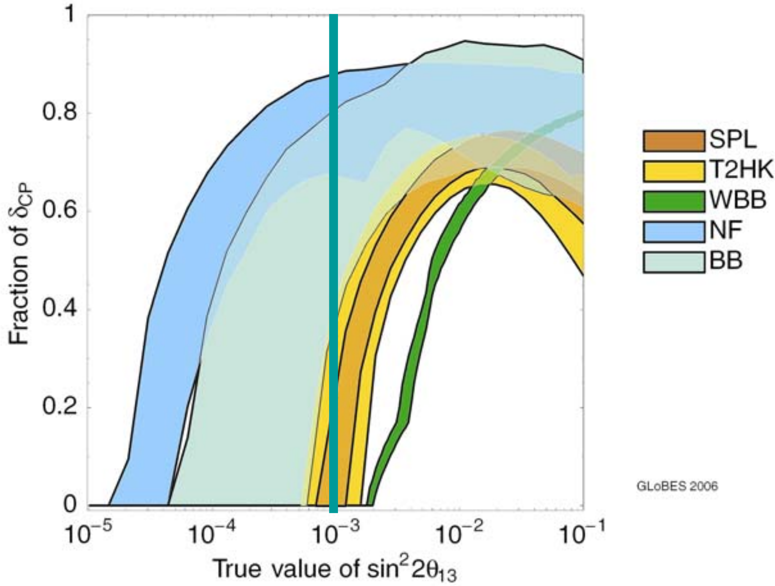
Marcos Dracos

IPHC-IN2P3/CNRS Strasbourg

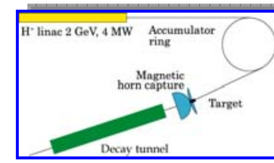
Why this SB?

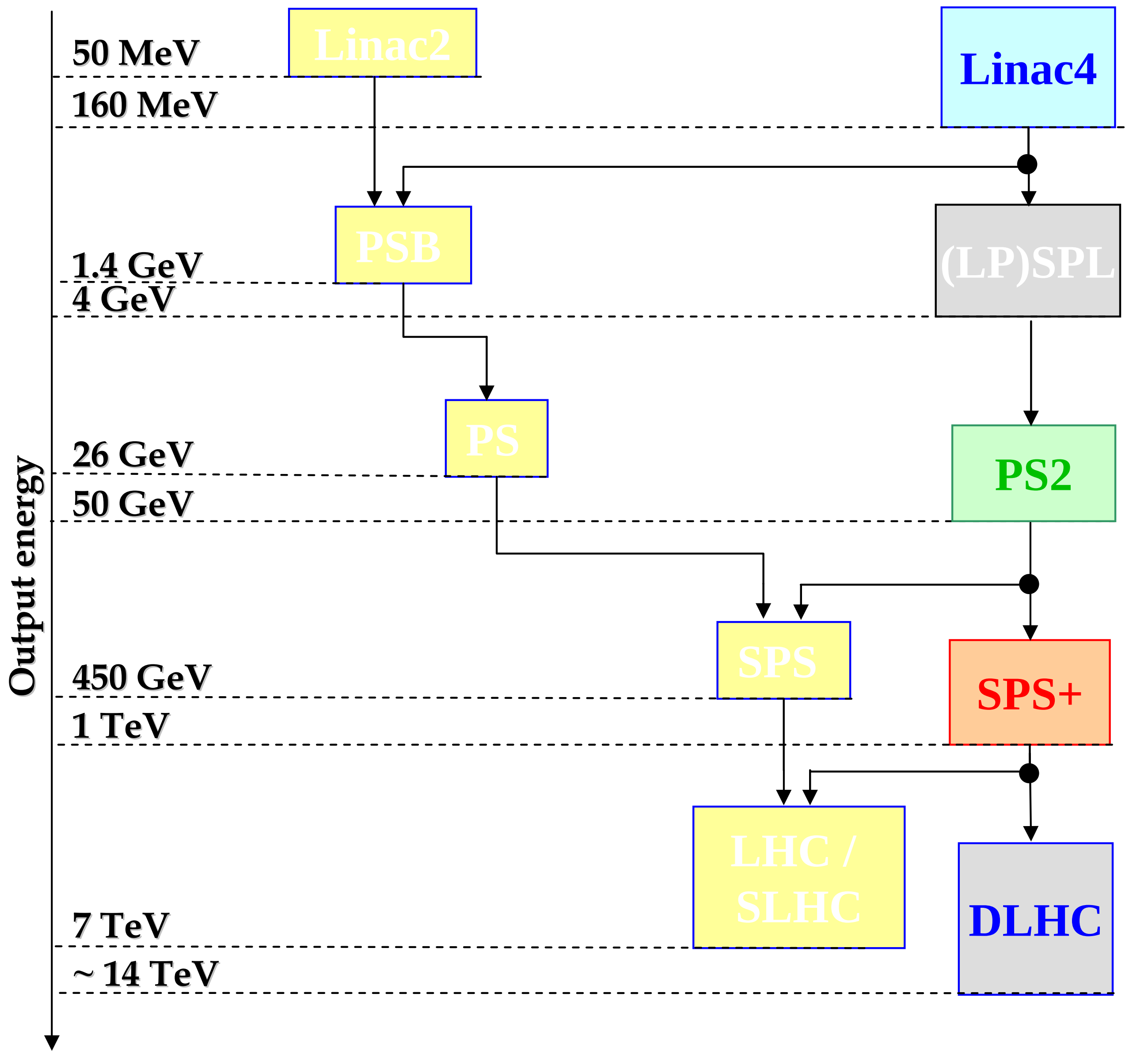


- Staging neutrino facilities towards the NF
- Cover "high" θ_{13} range
- Cost effective facility
  - Low intensity SPL already approved,
  - Detector could already be approved to cover other physics subjects (proton life-time, cosmological neutrinos…)



Present and future injectors





Proton flux / Beam power

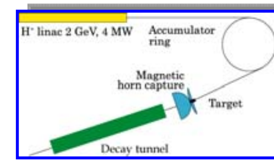
Stage 1 (2013)

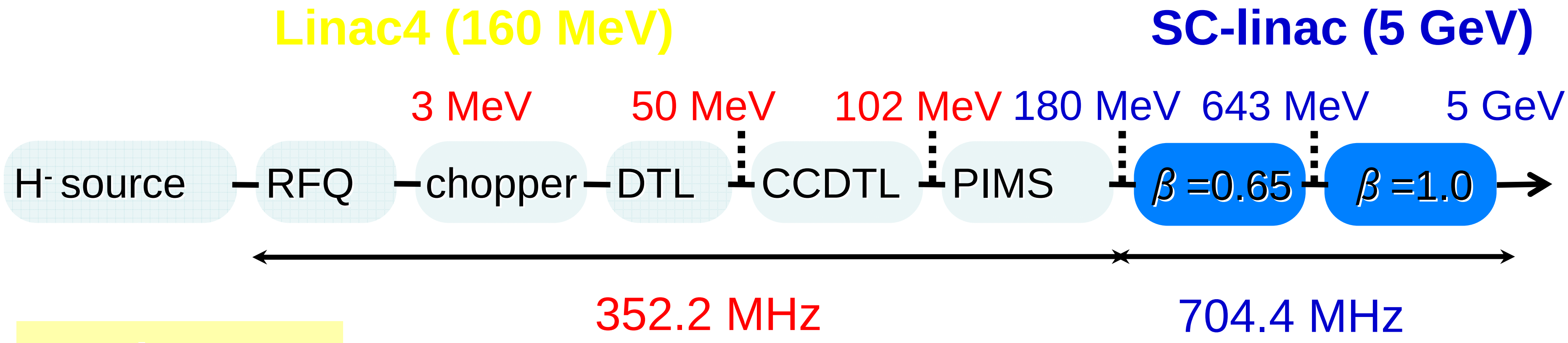
Stage 2 (2017)

(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 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

Stage 3 (>2017): HP-SPL

Stage 3: HP-SPL



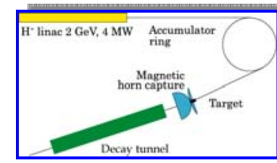


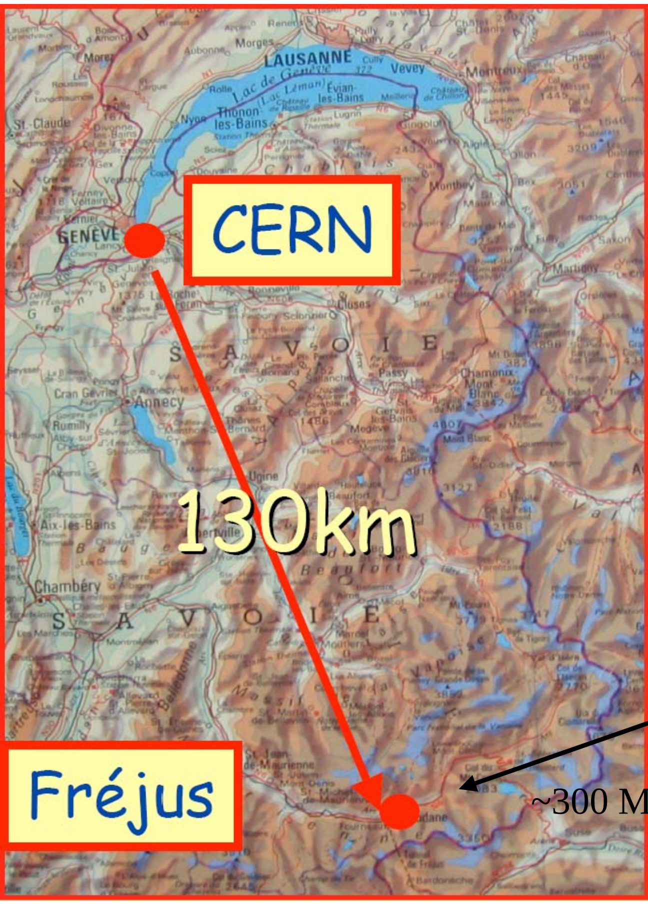
Length: 540 m

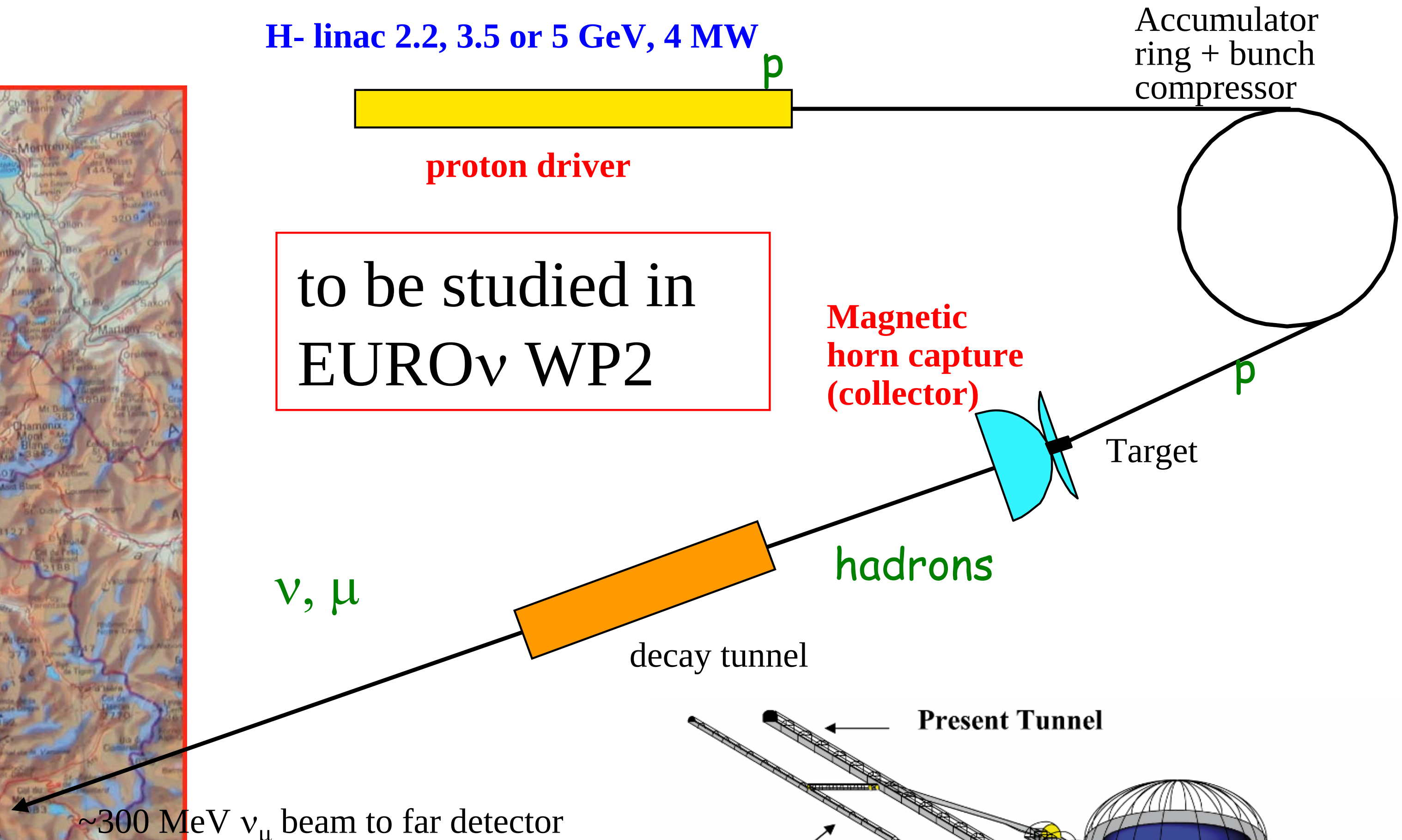
HP-SPL beam characteristics

	Option 1	Option 2
Energy (GeV)	2.5 or 5	2.5 and 5
Beam power (MW)	3 MW (2.5 GeV) or 6 MW (5 GeV)	4 MW (2.5 GeV) and 4 MW (5 GeV)
Rep. frequency (Hz)	50	50
Protons/pulse (x 10^{14})	1.5	2 (2.5 GeV) + 1 (5 GeV)
Av. Pulse current	20	40
Pulse duration (ms)	1.2	0.8 (2.5 GeV) + 0.4 (5 GeV)

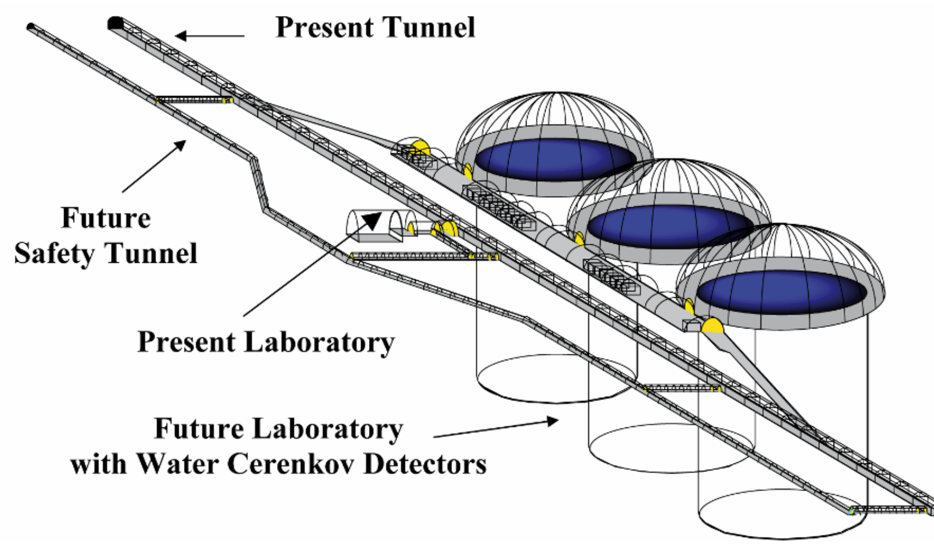
SPL Super-Beam Project





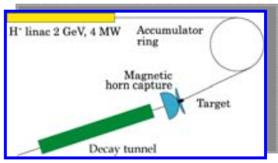


to be studied in EUROν WP2



to be studied by LAGUNA

SPL (CDR2) main characteristics

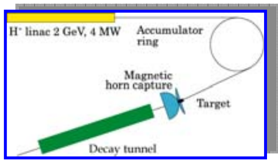


Ion species	H^-	
Kinetic energy	3.5	GeV
Mean current during the pulse	40	mA
Mean beam power	4	MW
Pulse repetition rate	50	Hz
Pulse duration	0.57	ms
Bunch frequency	352.2	MHz
Duty cycle during the pulse	62 (5/8)	%
rms transverse emittances	0.4	π mm mrad
Longitudinal rms emittance	0.3	π deg MeV
Length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

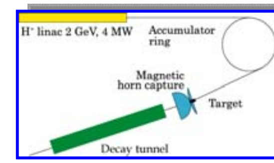
Proton Target



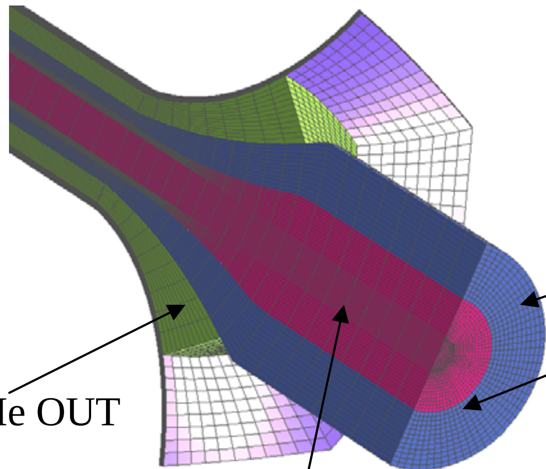
very challenging task

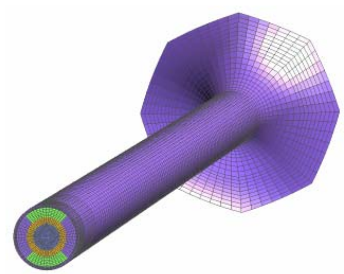
- 300-1000 J cm^{-3}/pulse
- Severe problems from : sudden heating, stress, activation
- Safety issues !
- Baseline for Super-Beam is solid target, mercury is optional (baseline for NF)
  - Extremely difficult problem : need to pursue two approaches :
    - Liquid metal target (Merit experiment)
   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

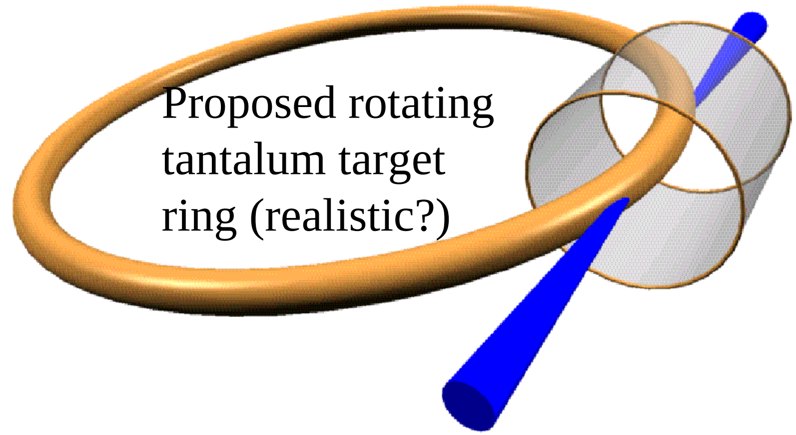
Proton Target



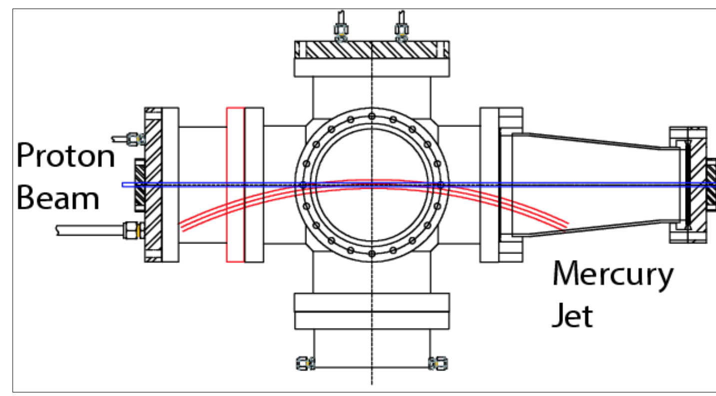
some ideas



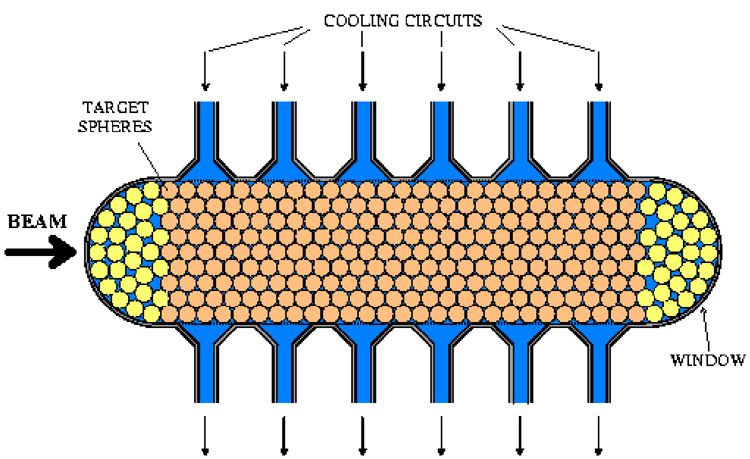




Helium cooling of target



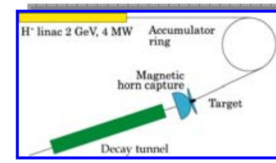
Liquid Mercury (MERIT)

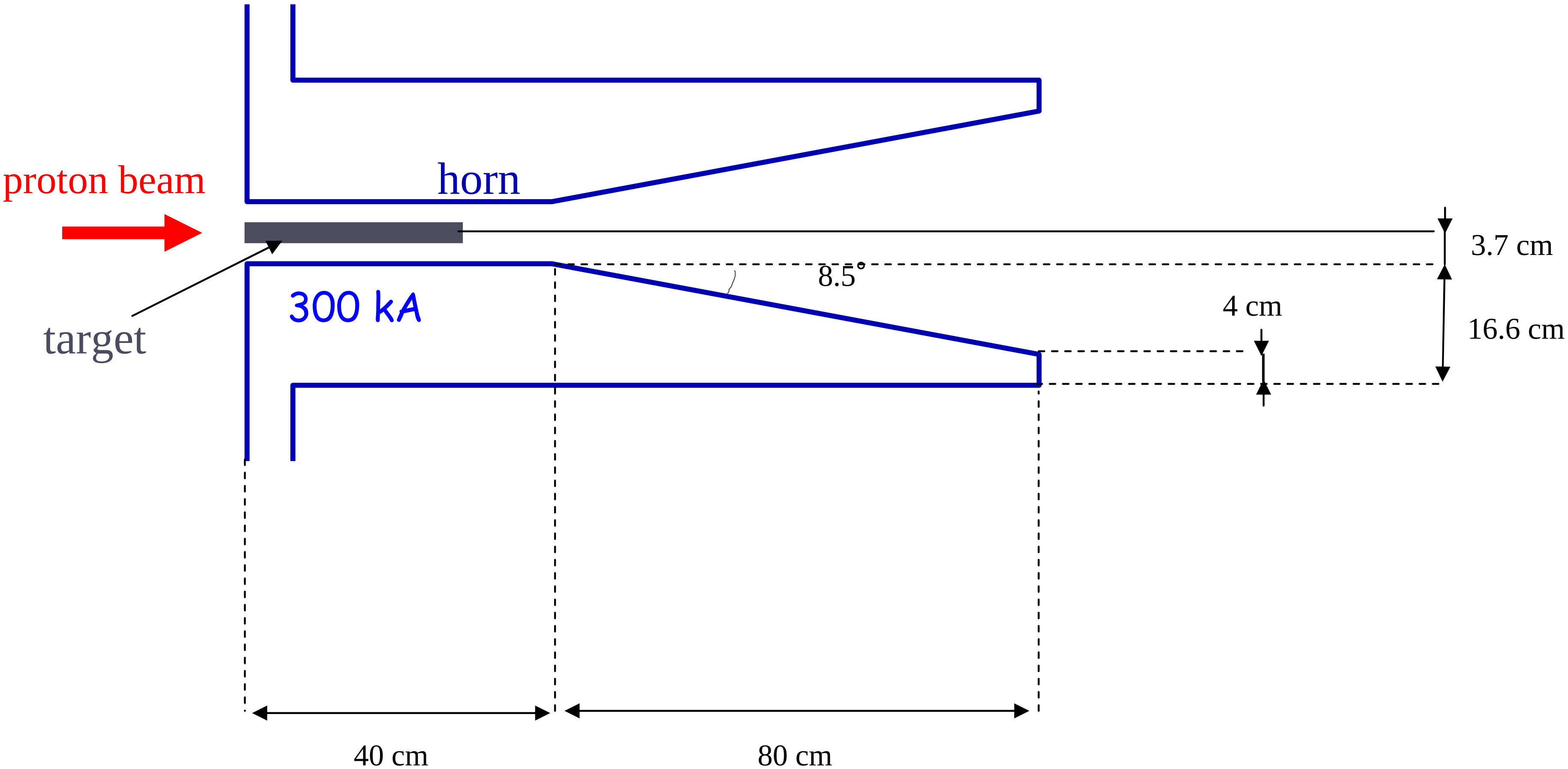


cooling is a main issue…

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

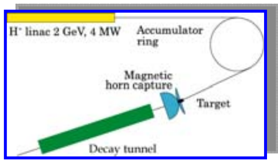
Proposed collection system



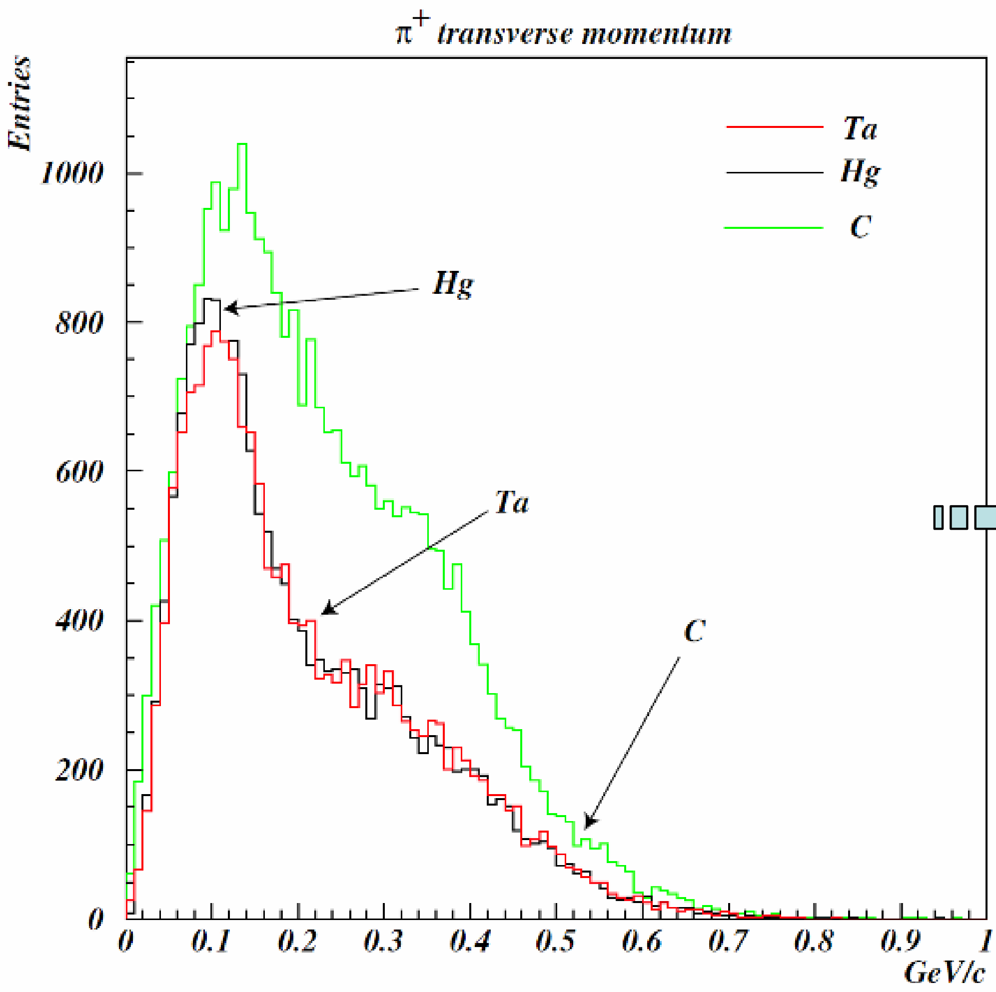


taking into account the proton energy and collection efficiency, the target must be inside the horn

Hadron production



2.2 GeV protons



p_T

Particles coming out of the target

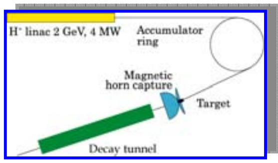
p_T distribution not the same for all targets

⇒

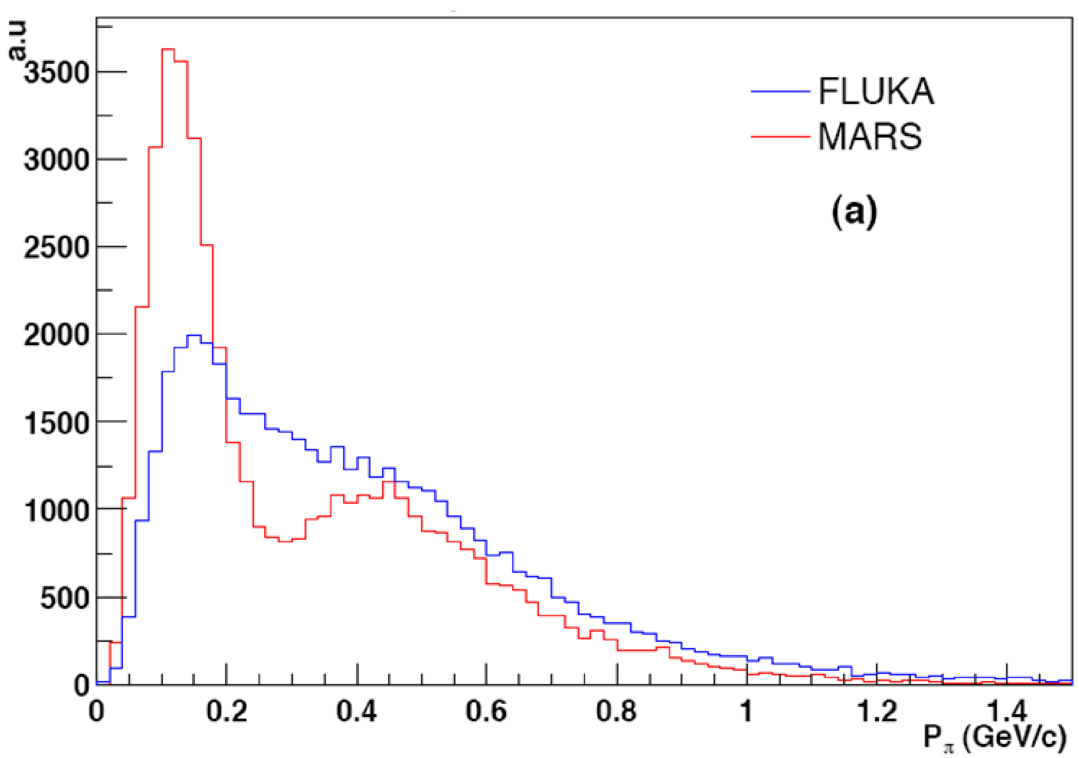
the choice of the target could influence the hadron collection system (horn shape)

From now on Hg will be considered

Hadron production uncertainties



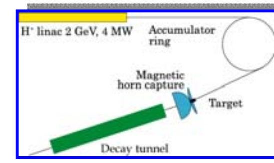
2.2 GeV protons

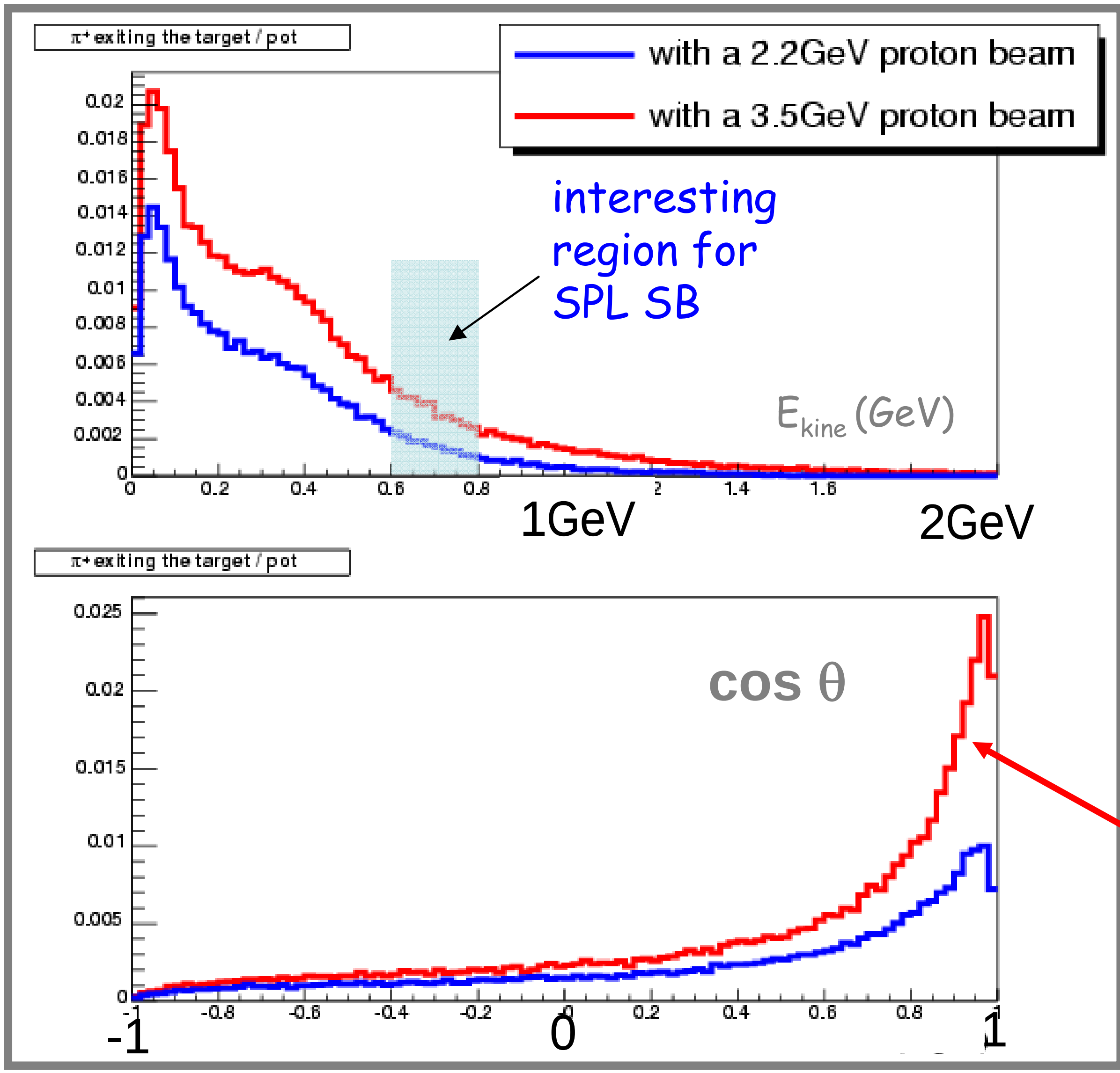


disagreement between models (Monte Carlo production, interaction and transport codes)

more development is needed (simulation, measurements)

Proton Energy and Pion Spectra

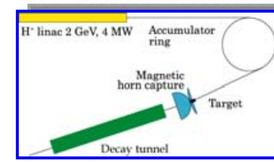




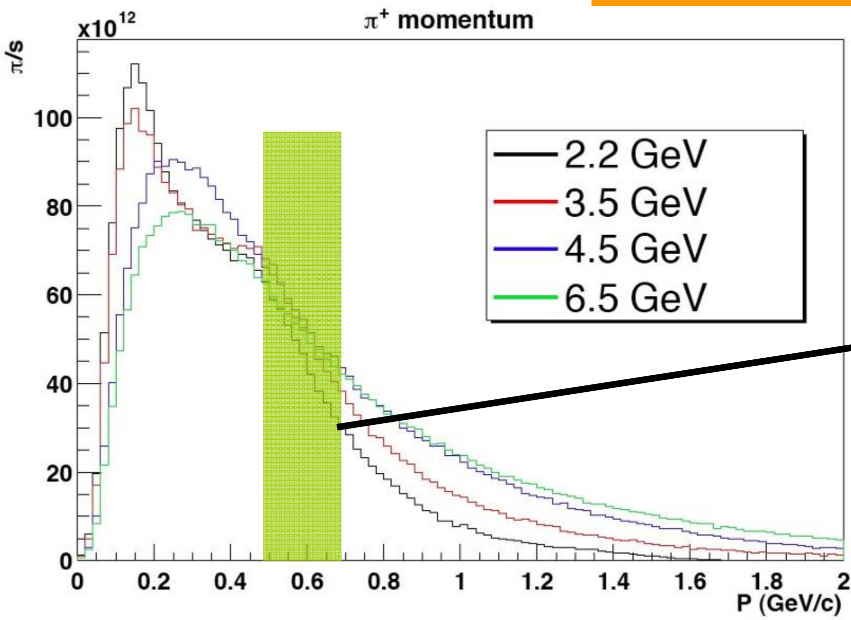
- pions per proton on target.
- Kinetic energy spectrum
  - 2.2 GeV:
    - <E_k>=300MeV
  - 3.5 GeV:
    - <E_k>=378MeV

hadrons boosted forward

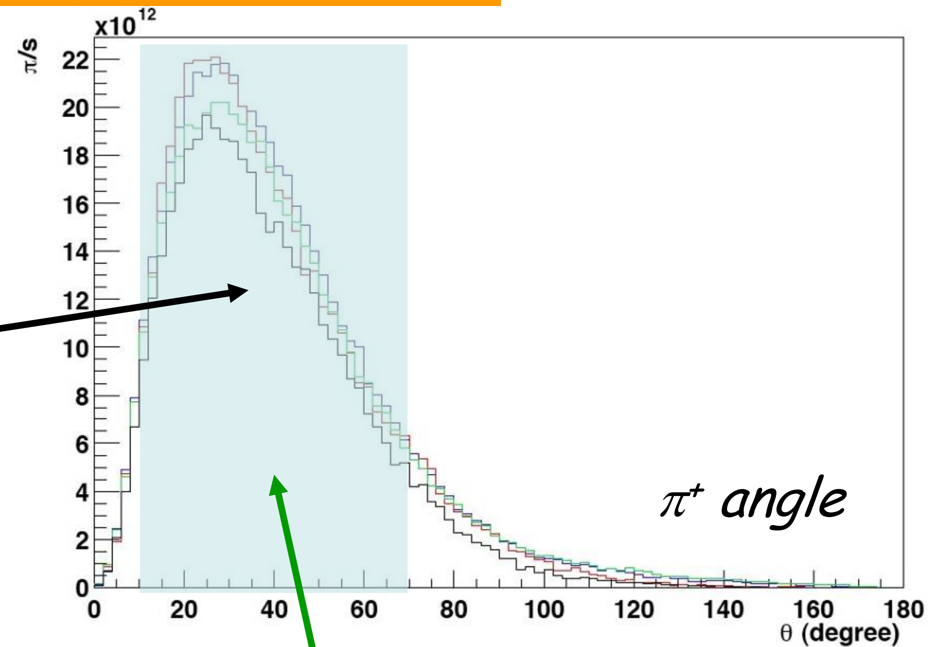
Proposed design for SPL



for pions coming out of the target



π^+ momentum



horn region (0.26-1.22 rad)

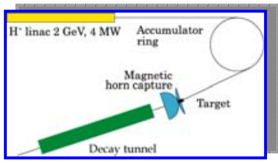
for a Hg target, 30 cm length, ∅15 mm
($N_{particles}$x10^{16}/sec, FLUKA)

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} ↗

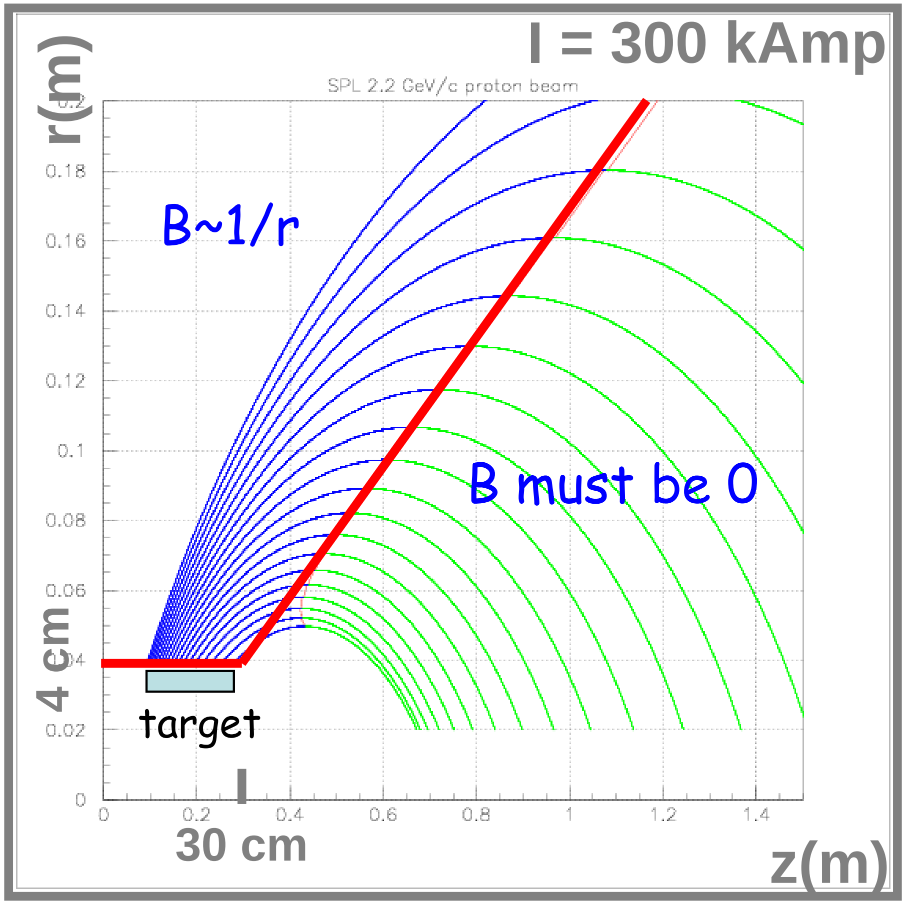
the target must be inside the horn

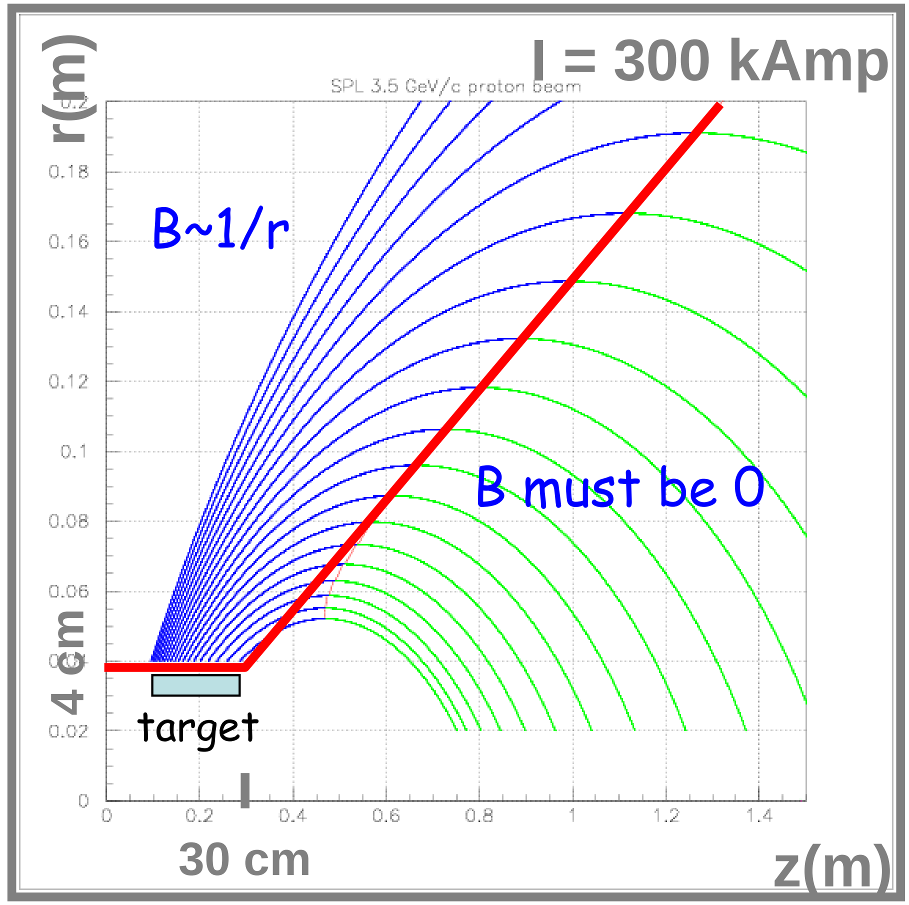
Horn geometry



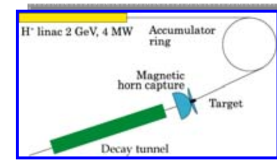
- 2.2 GeV proton beam :
  - $\langle p_\pi \rangle$ = 405 MeV/c
  - $\langle \theta_\pi \rangle$ = 60°

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

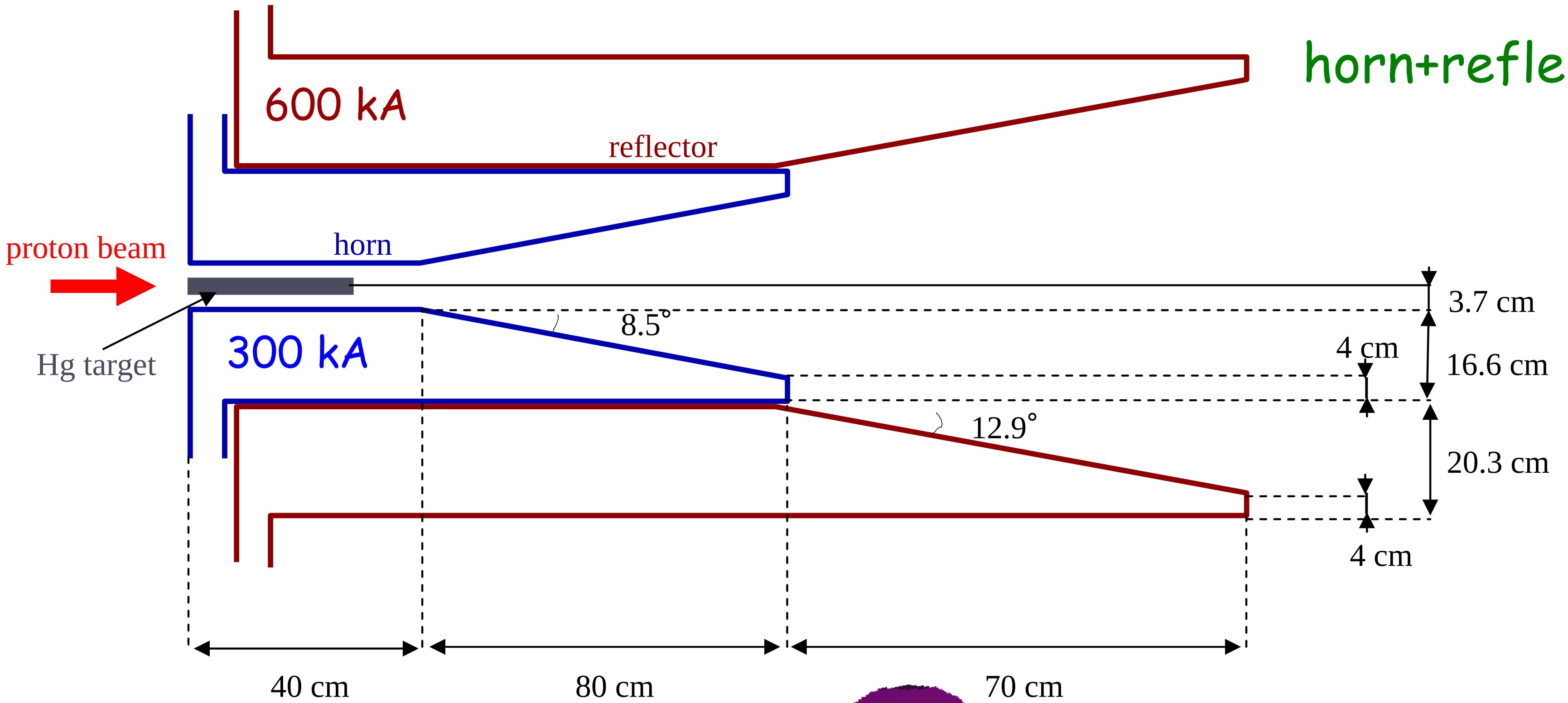


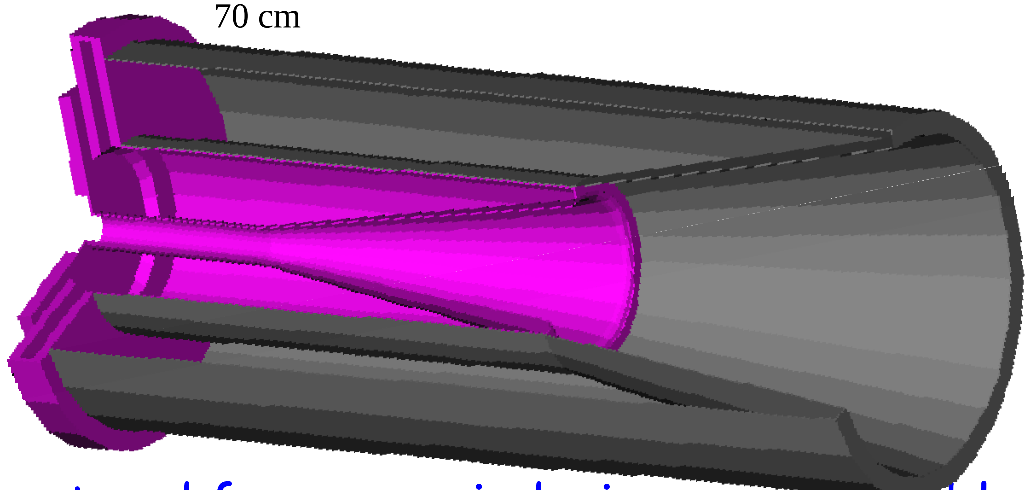


Proposed design for SPL



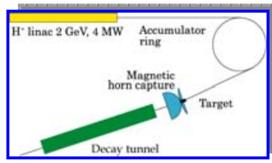
horn+reflector



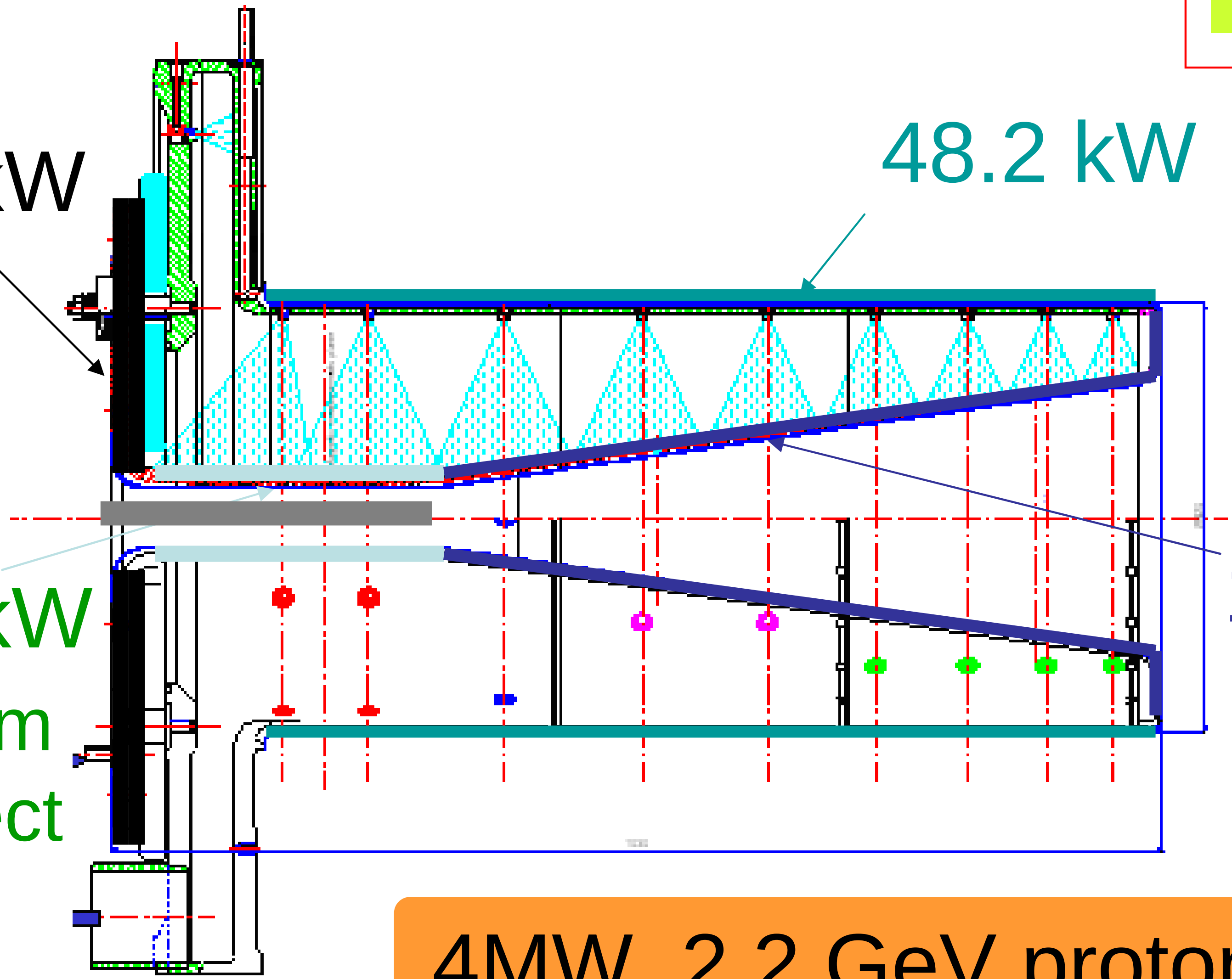


➡ very high current and frequency inducing severe problems

Energy deposition in the conductors



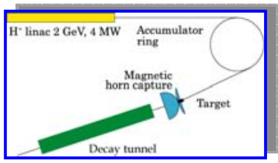
MARS



4MW, 2.2 GeV proton beam

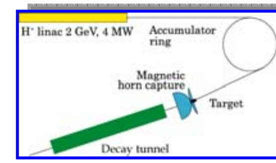
(1MeV = 1.82 kW)

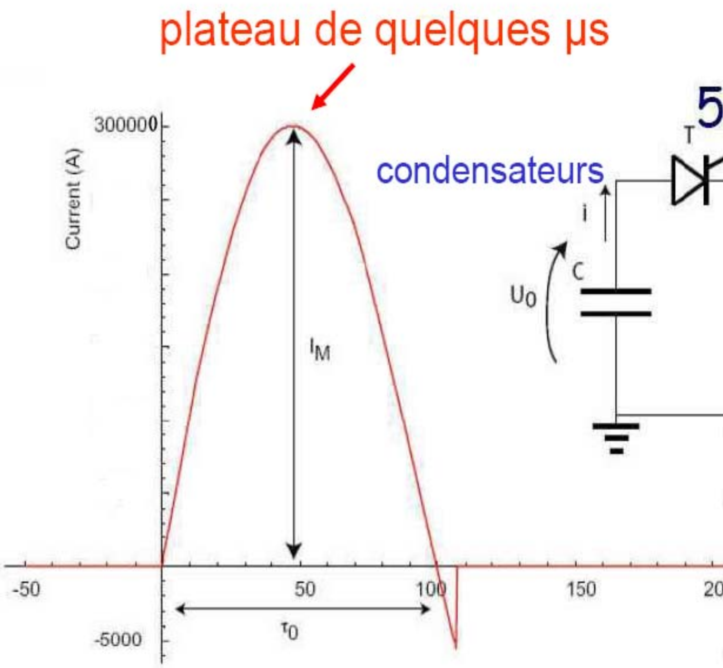
Main Technical Challenges

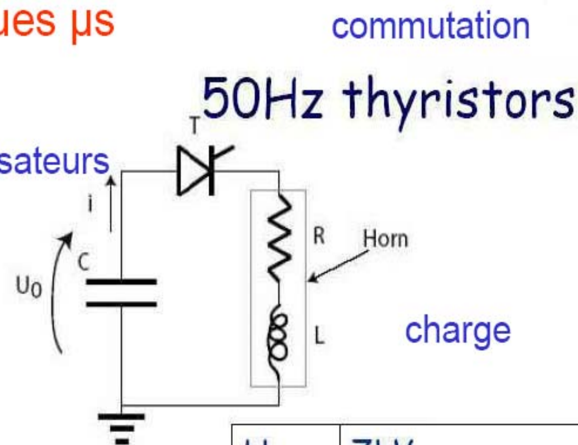


- Horn : as thin as possible (3 mm) to minimize energy deposition,
- Longevity in a high power beam (currently estimated to be 6 weeks!),
- 50 Hz (vs a few Hz up to now),
- Large electromagnetic wave, thermo-mechanical stress, vibrations, fatigue, radiation damage,
- Currents: 300 kA (horn) and 600 kA (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.

Power Supply for horn pulsing (major issue)

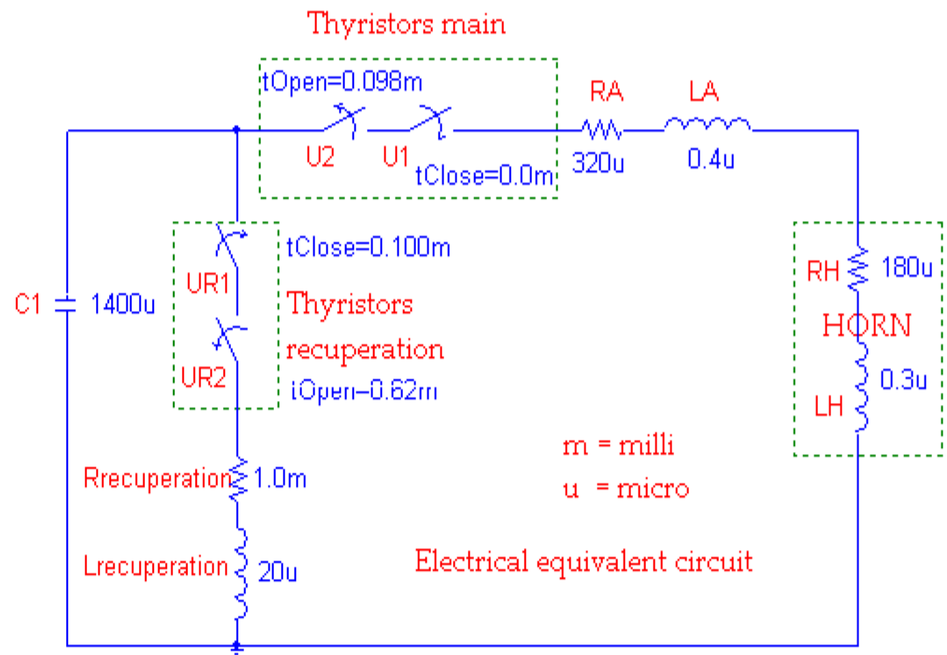




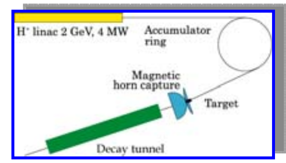


U_o	7kV
I_M	300kA (14,5 rms)
τ_o	100µs
L	0.6 (0.4 Horn)µH
R	500 (180 Horn) µΩ
C	1500µF

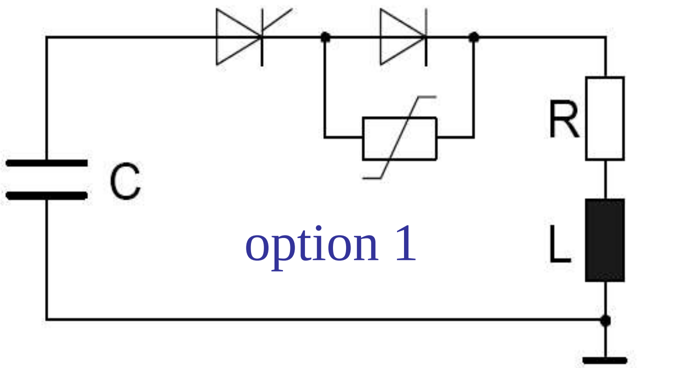
values considered by CERN



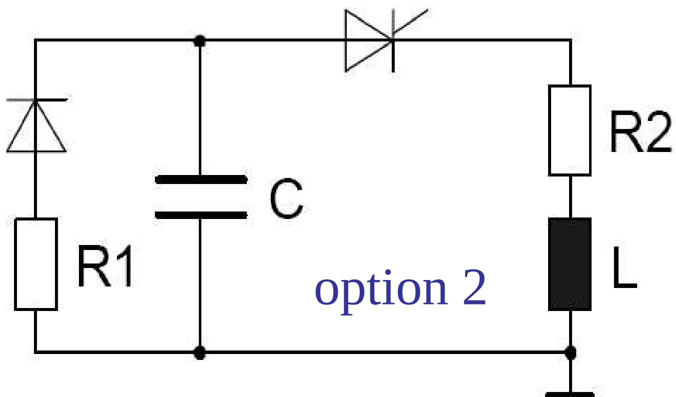
3 Solutions proposed by ABB



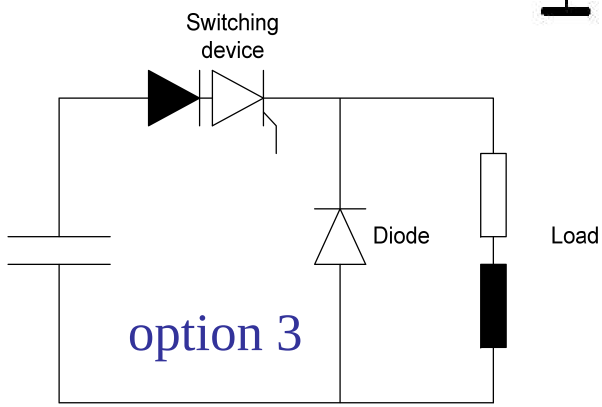
schematic versions



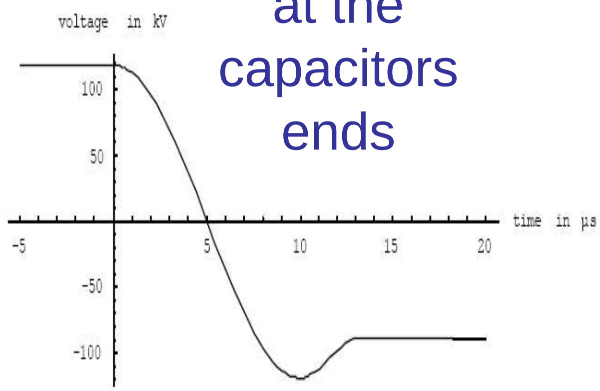
option 1



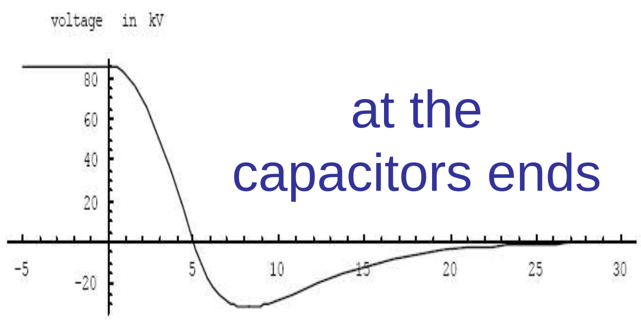
option 2



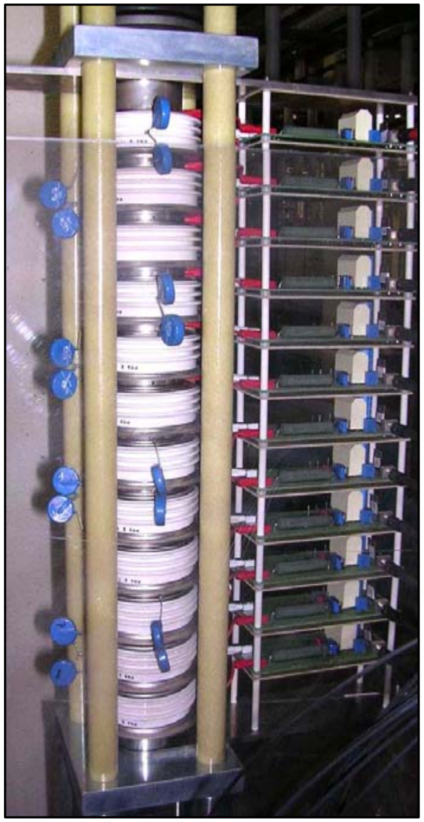
option 3

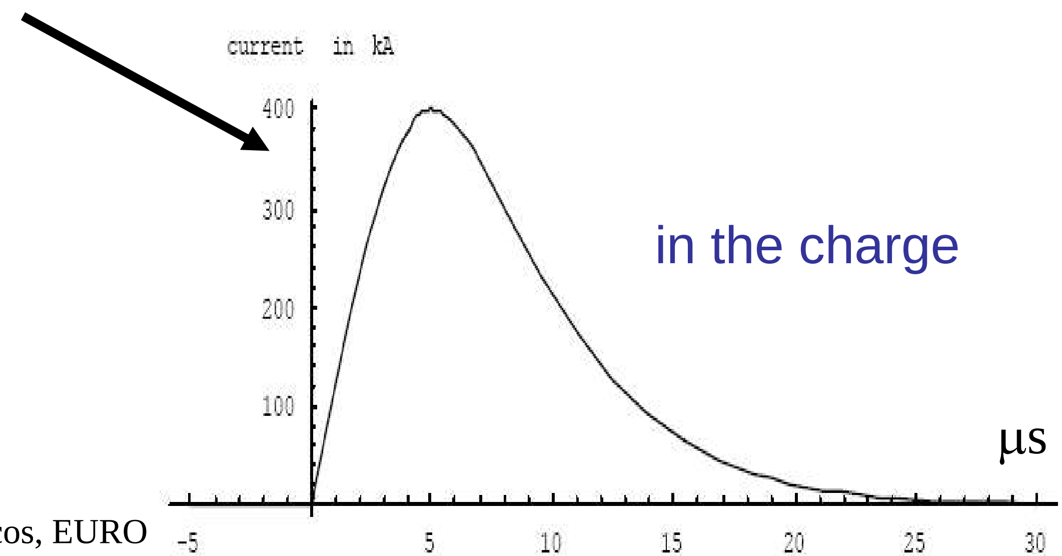


at the capacitors ends



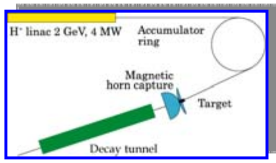
at the capacitors ends





in the charge

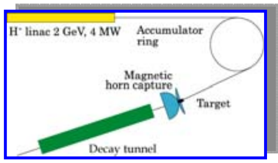
θ_{13} Sensitivity

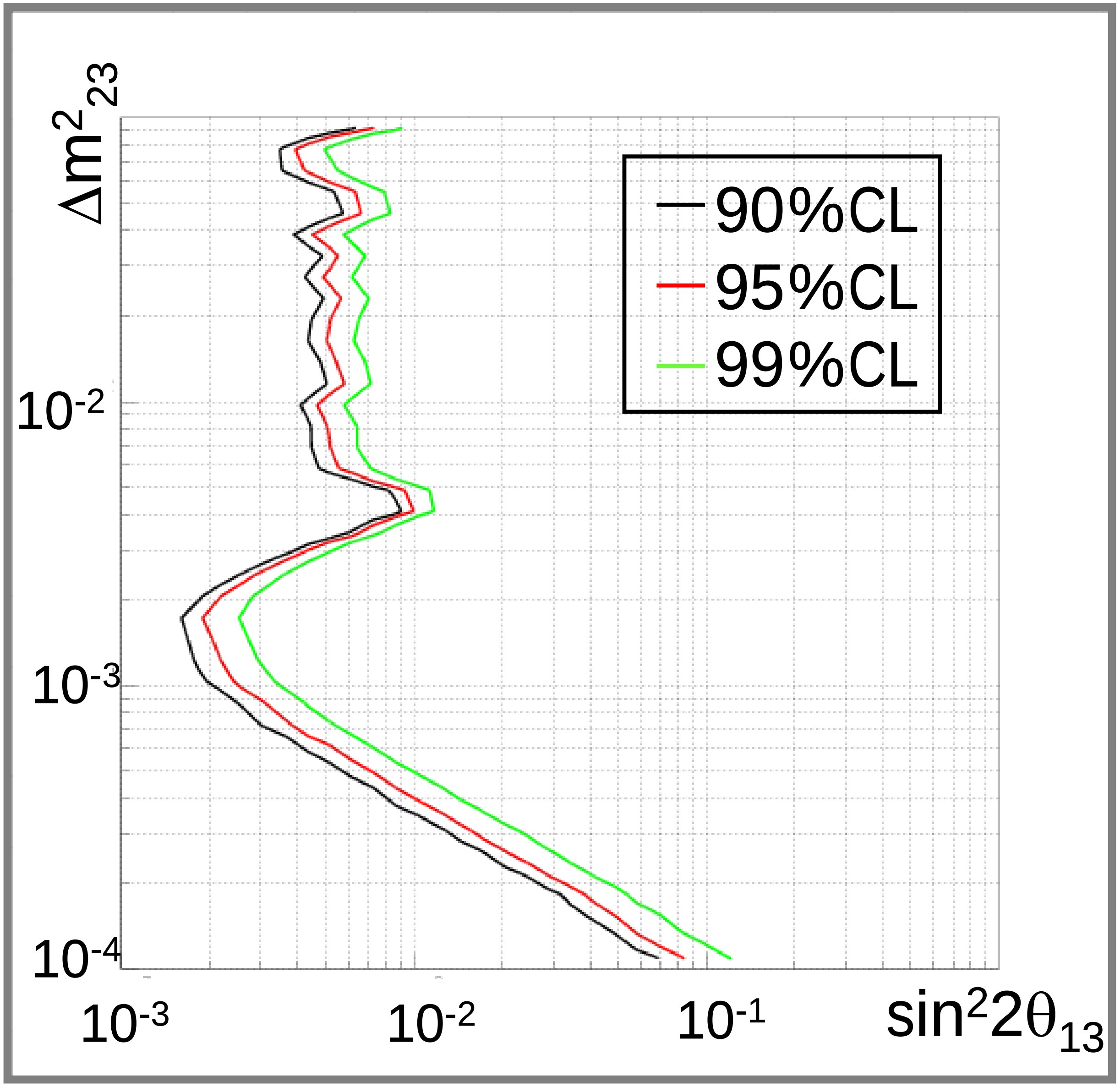


simulation inputs

- Detector:
  - Water Cerenkov
  - 440 kt
  - at Fréjus (130 km from CERN)
- Run:
  - 2 years with positive focusing.
  - 8 years with negative focusing.
- Computed with δ_{CP}=0 (standard benchmark) and $\theta_{13} = 0$
- parameter…
  - $\Delta m_{23} = 2.5\ 10^{-3} eV^2$
  - $\Delta m_{12} = 7.1\ 10^{-5} eV^2$
  - $\sin^2(2\theta_{23}) = 1$
  - $\sin^2(2\theta_{12}) = 0.8$

Sensitivity 3.5GeV



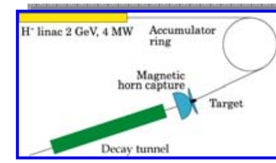


A.Cazes thesis

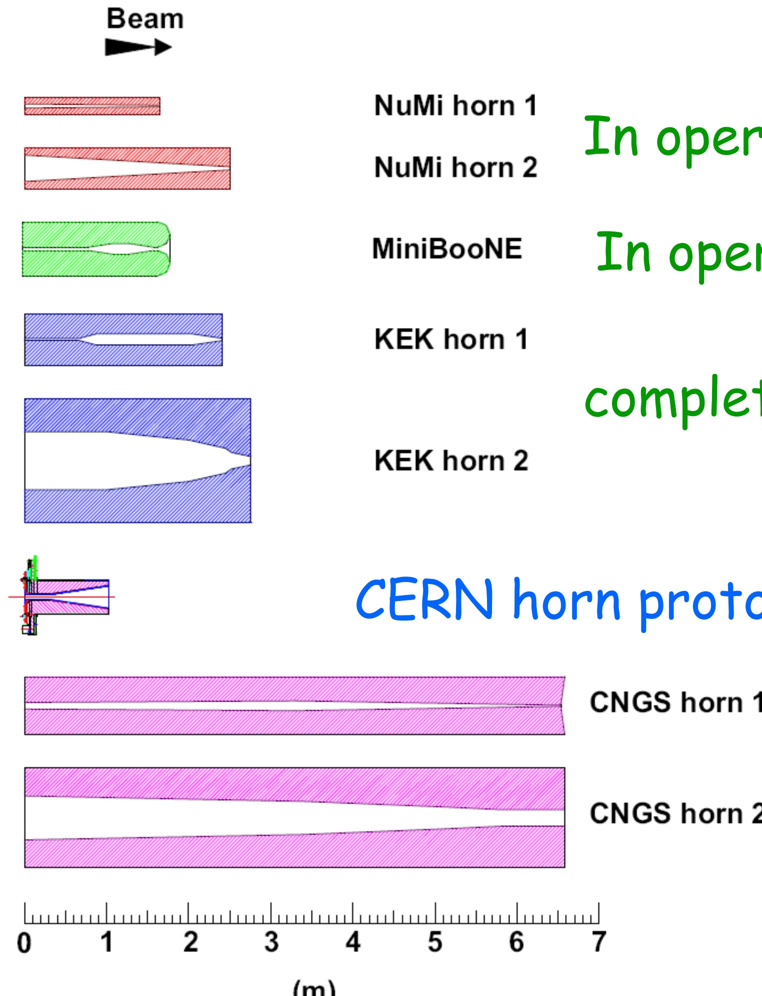
Minimum:
θ_{13}= 1.2°
(90%CL)

no strong dependence on proton energy for 2.2<p<5 GeV

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

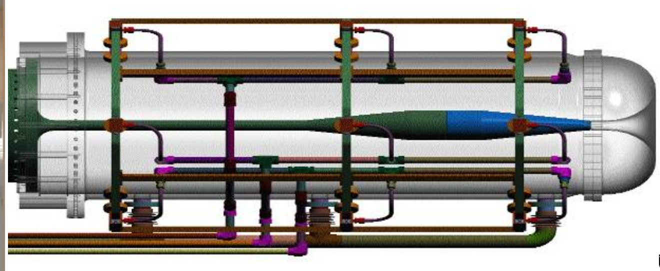
In operation

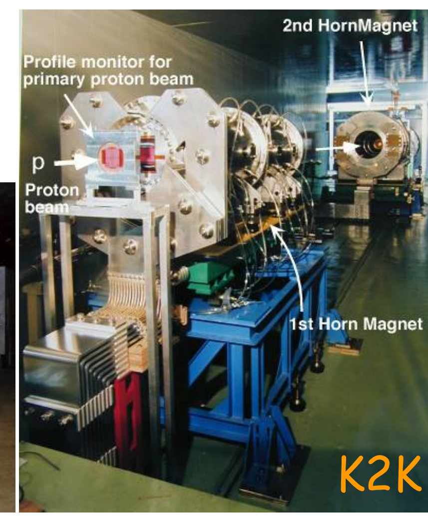
completed

CERN horn prototype for SPL

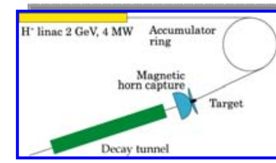
In operation

MiniBooNE

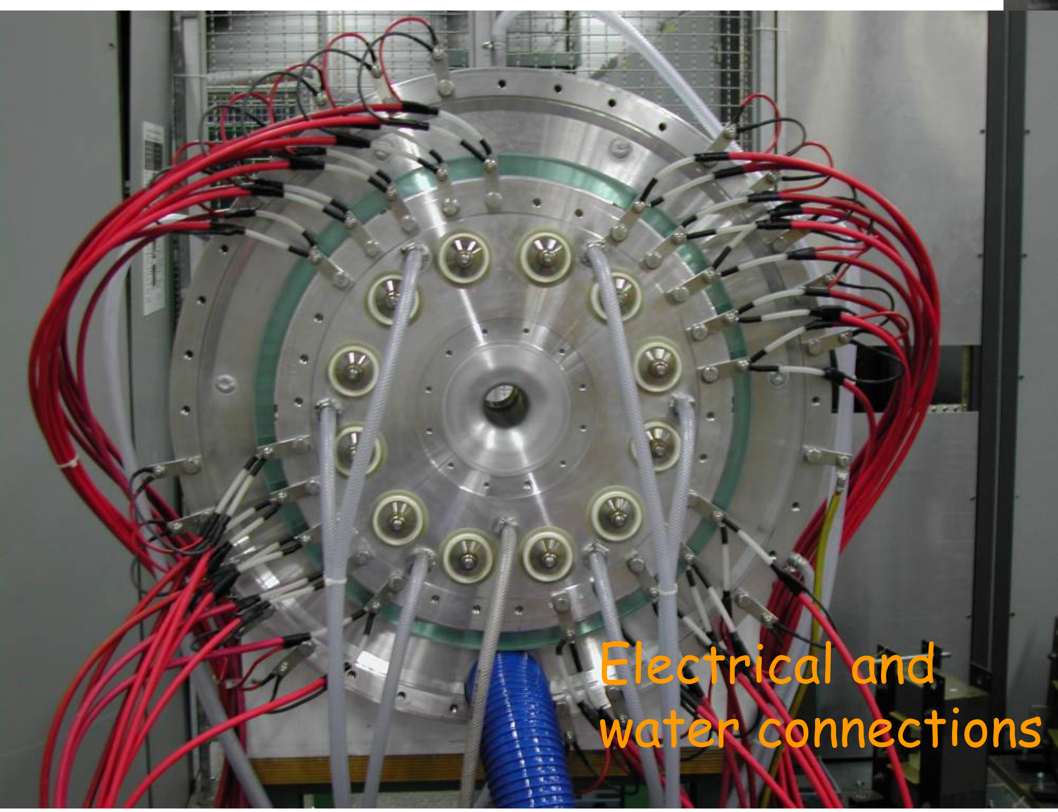




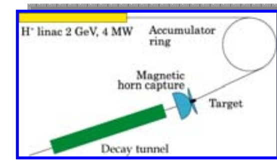
Horn prototype



- **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



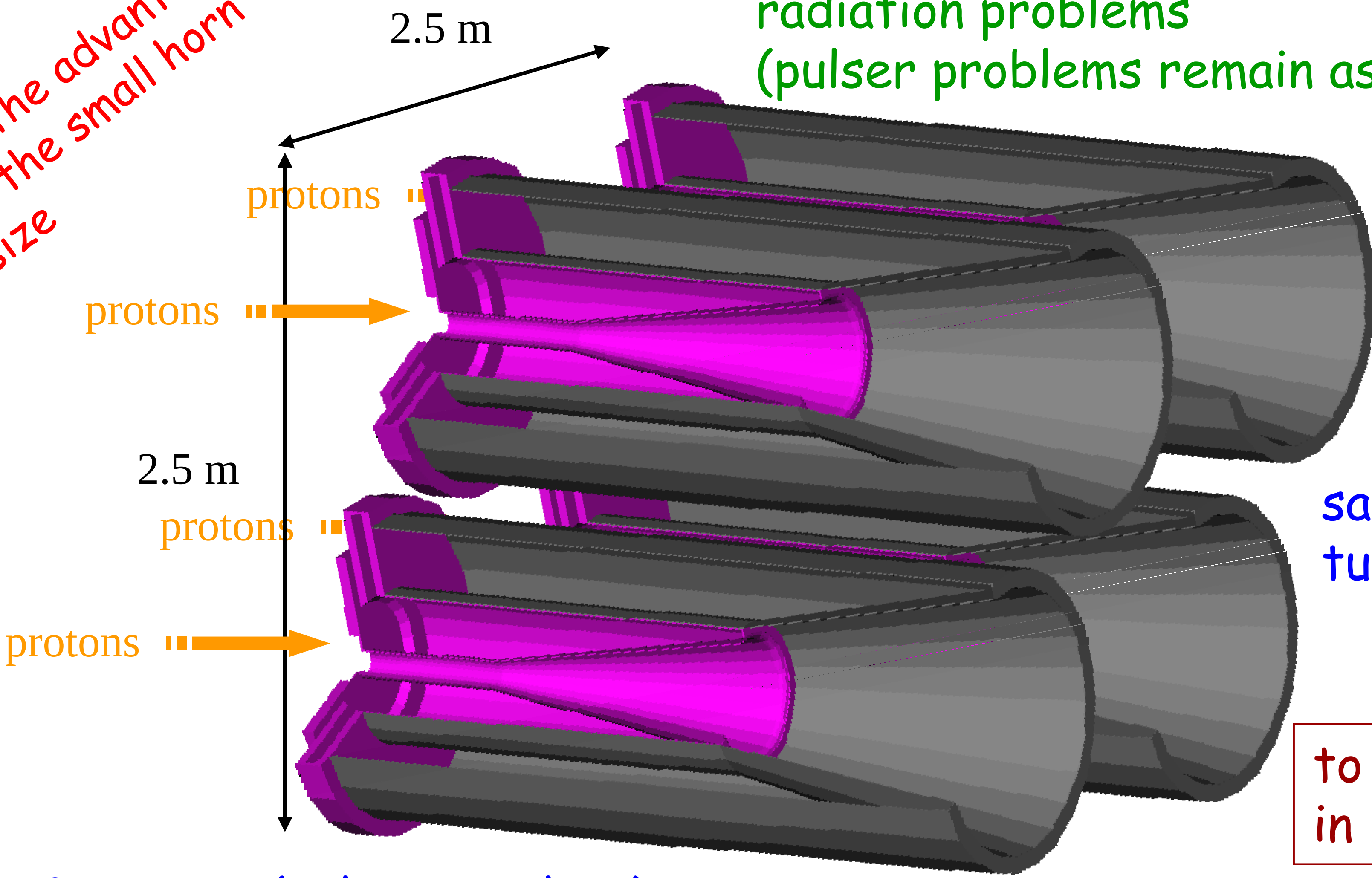
- tests done with: 30 kA and 1 Hz, pulse 100 μs long
- new tests to be done with 50 Hz



New ideas

use the advantage of the small horn size

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

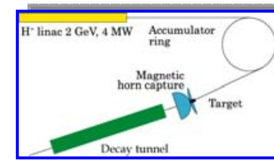


same decay tunnel Ø 3 m

to be studied in EUROν

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

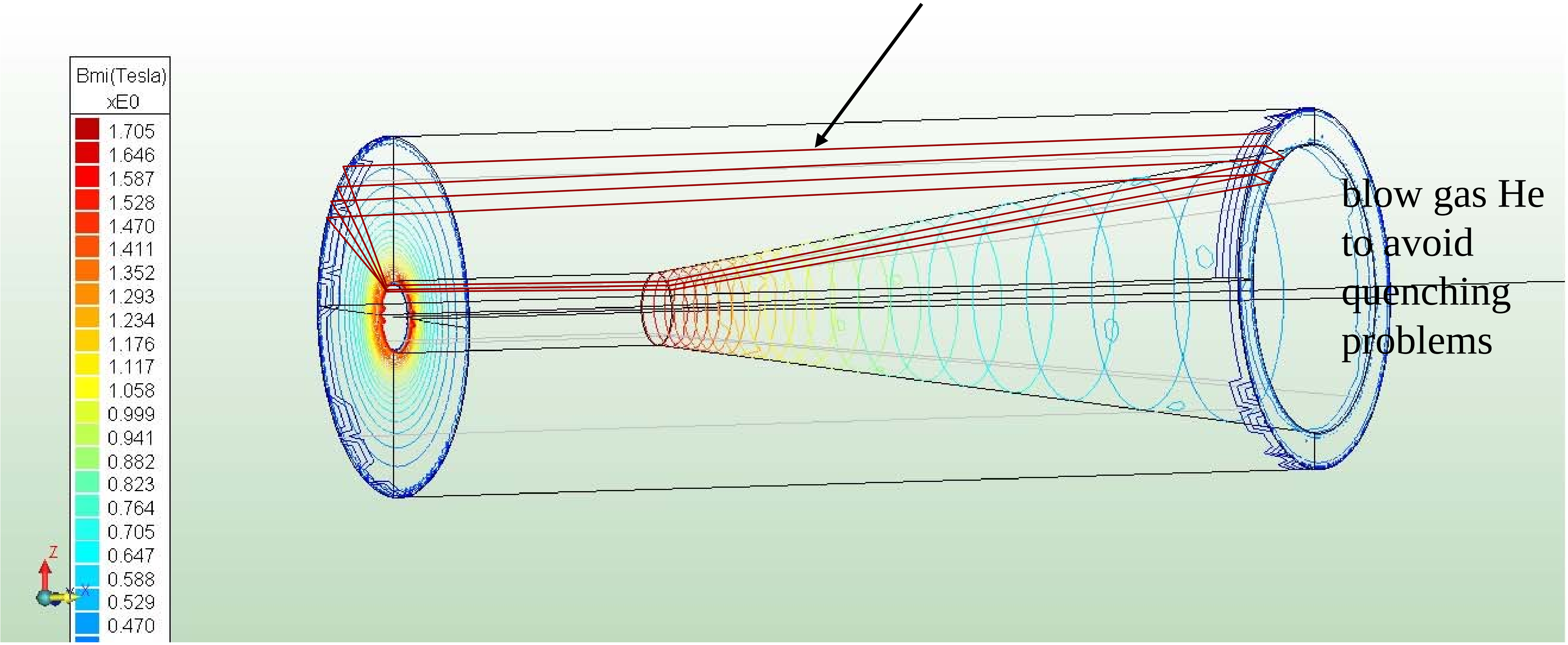
possibility to use solid target?



New (crazy) ideas

use a cryogenic horn (toroidal coil)

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

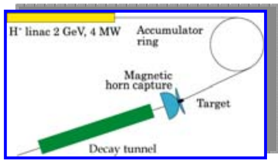


blow gas He to avoid quenching problems

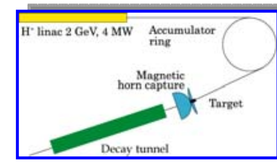
- No problem with power supply (pulser no more needed)
- Proton compressor no more needed

to be studied in EUROν

Conclusions

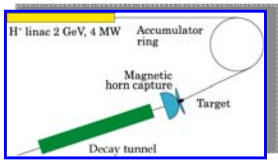


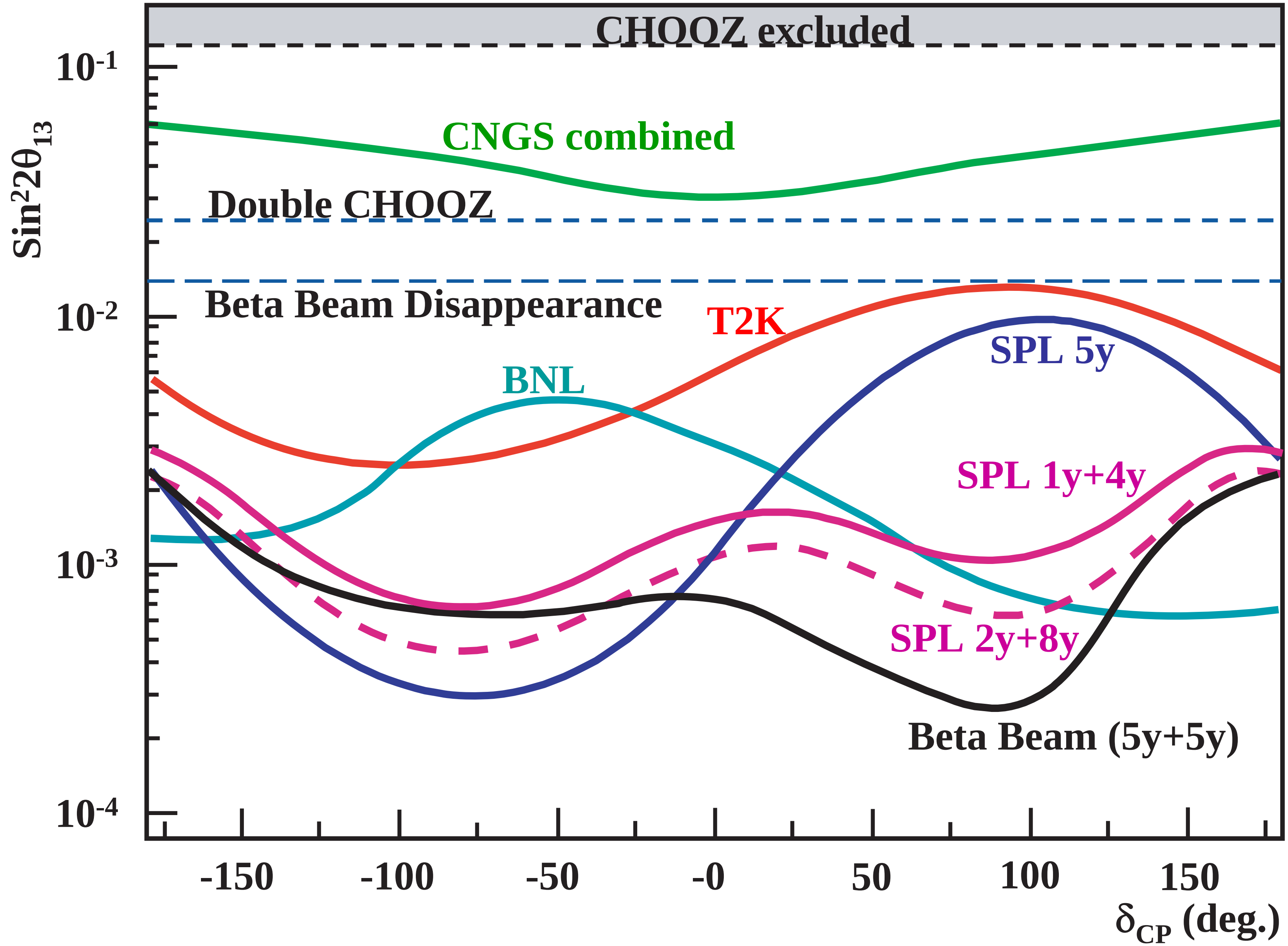
- LP-SPL already approved, HP-SPL possible before 2020.
- Many studies needed on targets.
- Collector studies are necessary to increase the system lifetime.
- Target/horn integration to be considered since the beginning.
- New studies have started in the framework of EUROν FP7 project.
- New ideas are welcome…


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

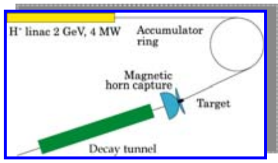
End

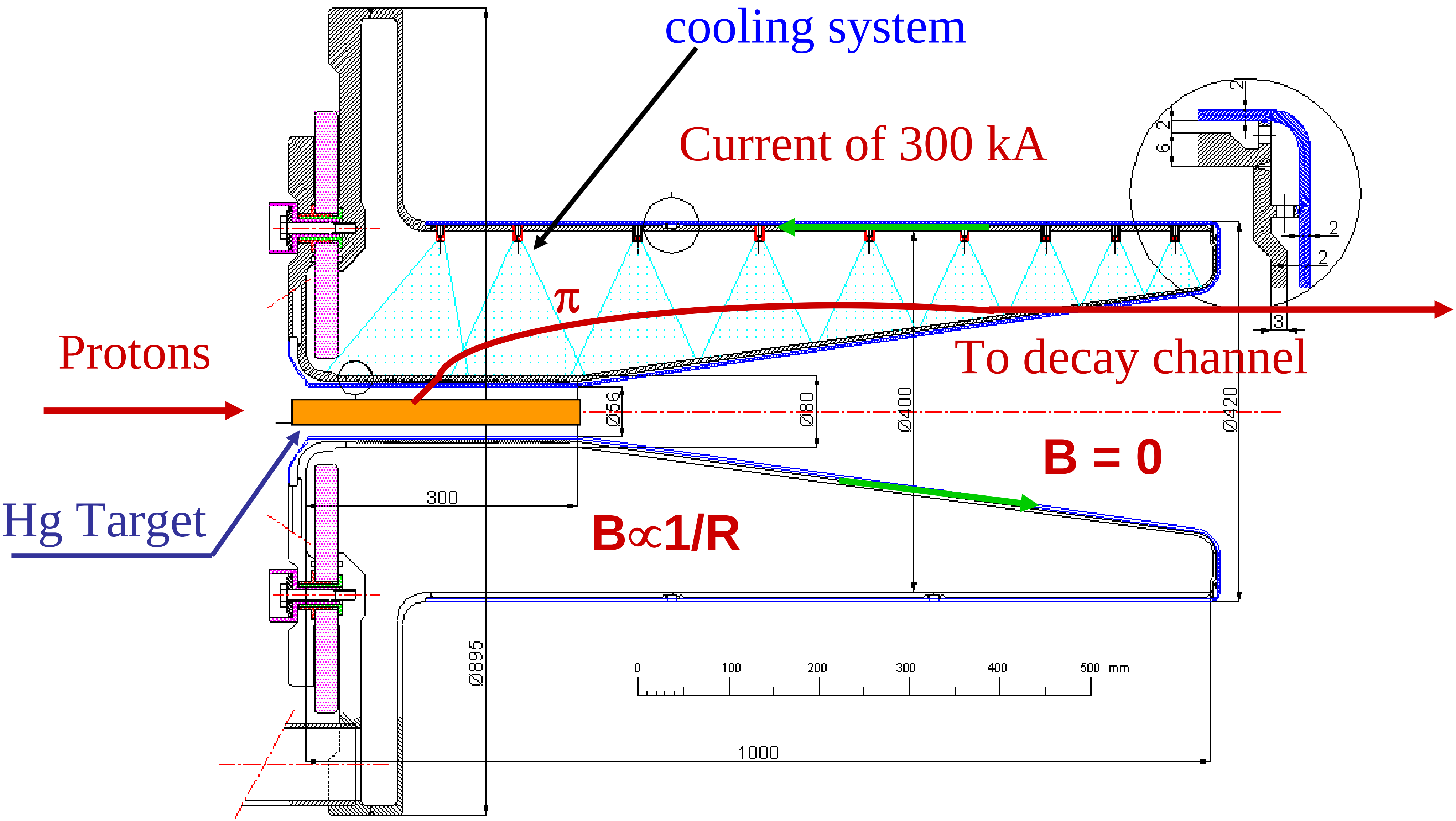
Comparisons





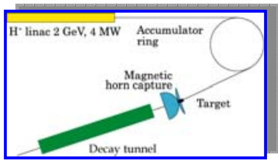
CERN horn prototype

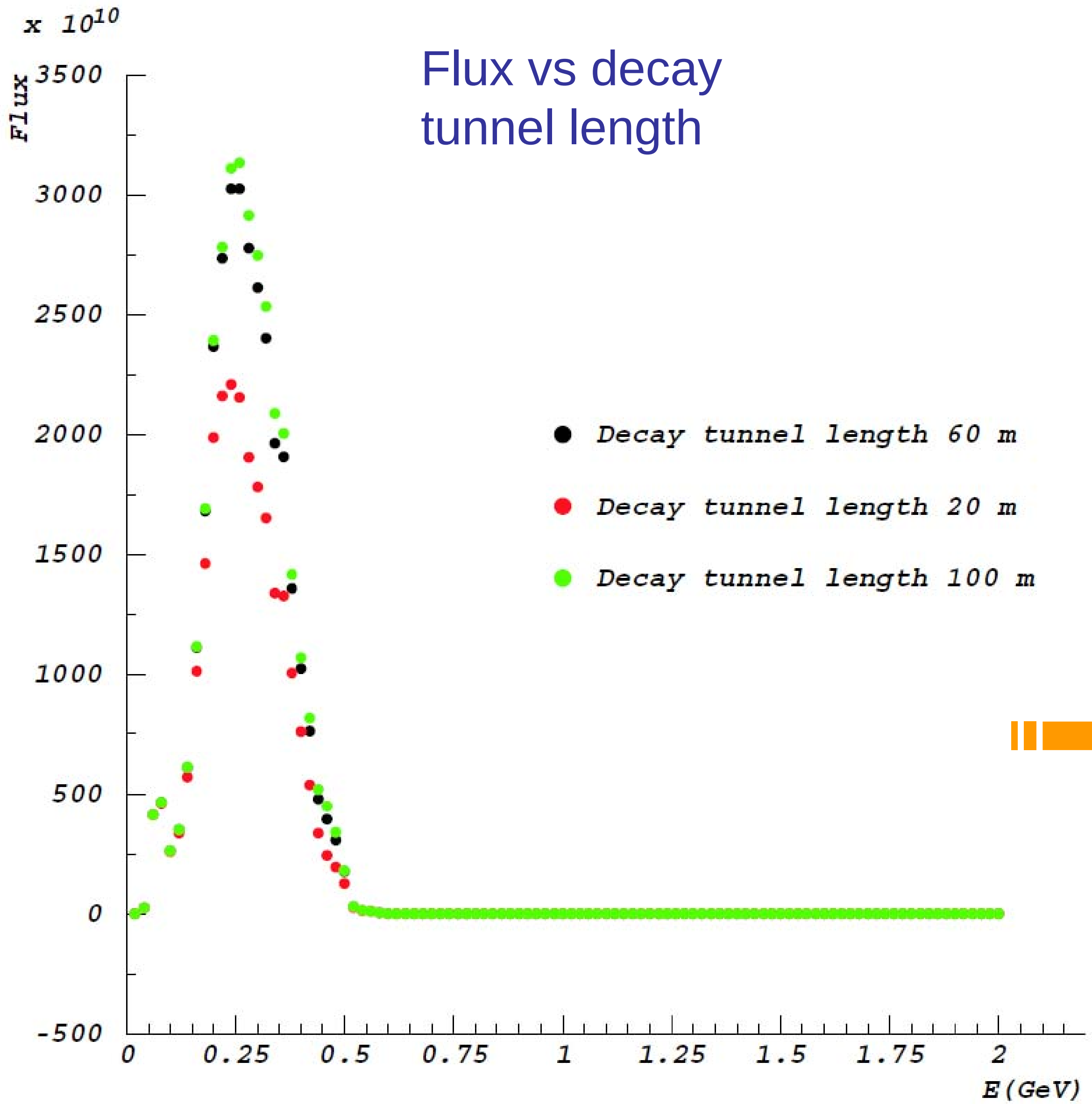




initial design satisfying both, neutrino factory and super-beam

Decay Tunnel





Flux vs decay tunnel length

(2.2 GeV option)

short decay tunnel