Funneling π's and μ's

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Proton Beam Parameters

Number of bunches	140
Protons per bunch	1.6×10^{12}
Bunch spacing [ns]	22.7
Bunch length (4σ) [ns]	6
ε_{tn} [μm]	50
Pulse length [μs]	3.3
Repetition frequency [Hz]	50
Beam power [MW]	4

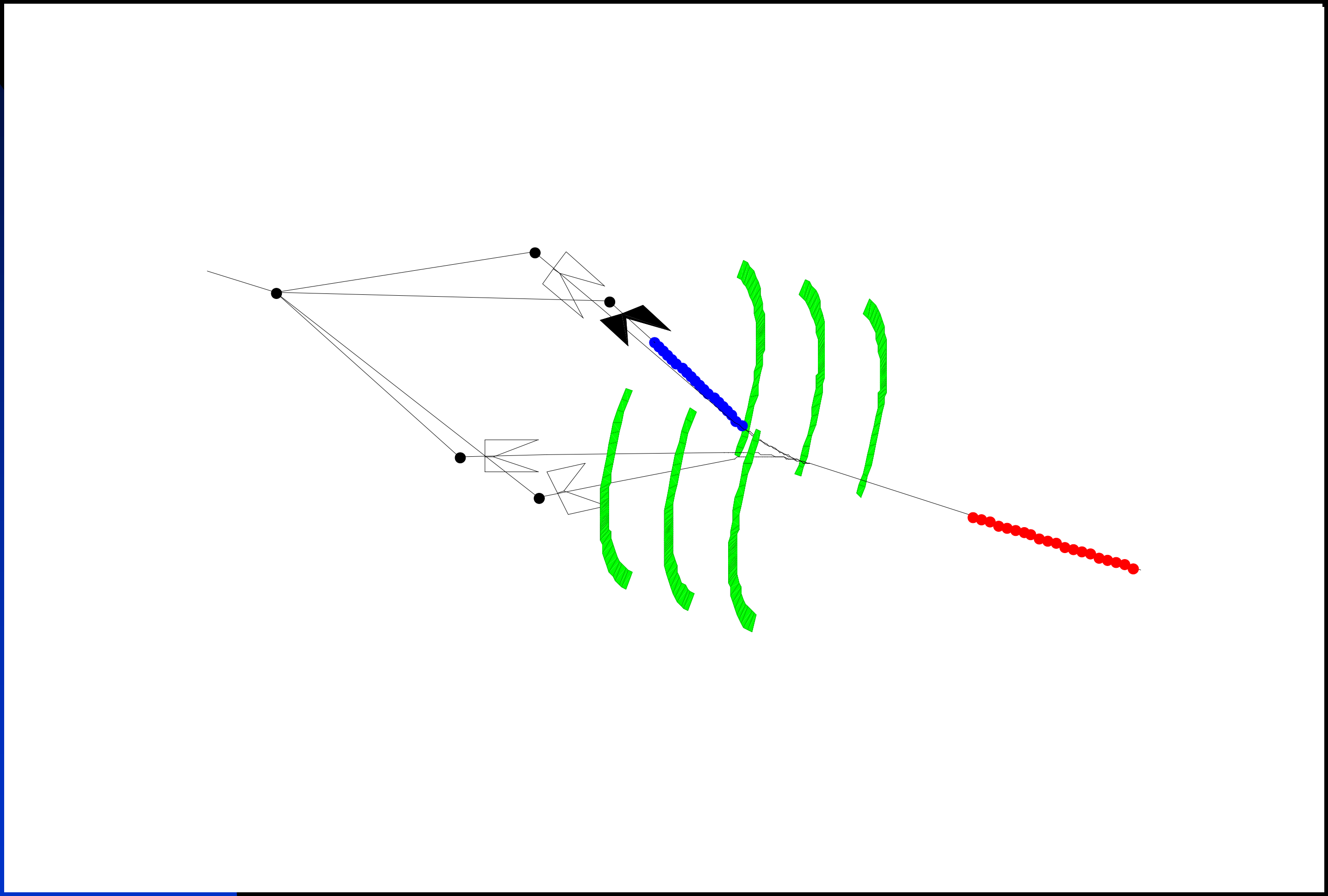
Why a funneling system?

- No exotic and expensive technology.
- Lifetime in excess of one year.
- Evolutionary design.

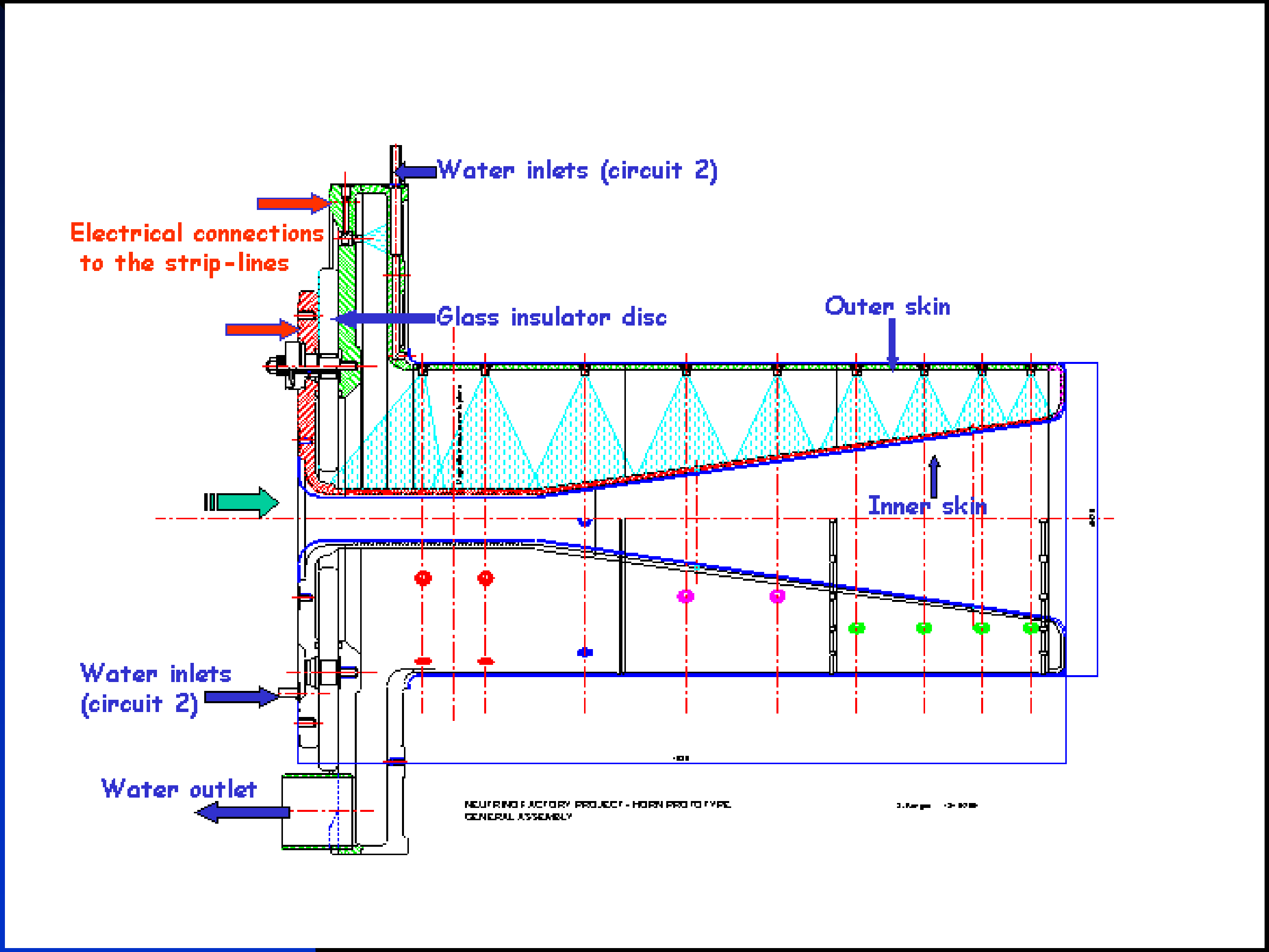
How it works?

- The proton beam is switched to 4 targets in sequence.
- Each of the 4 pion lines contains an integrated system of target, magnetic horn and cooling.
- The funnel is made of large aperture magnets with quadrupolar and pulsed dipolar coils.

Funneling step by step



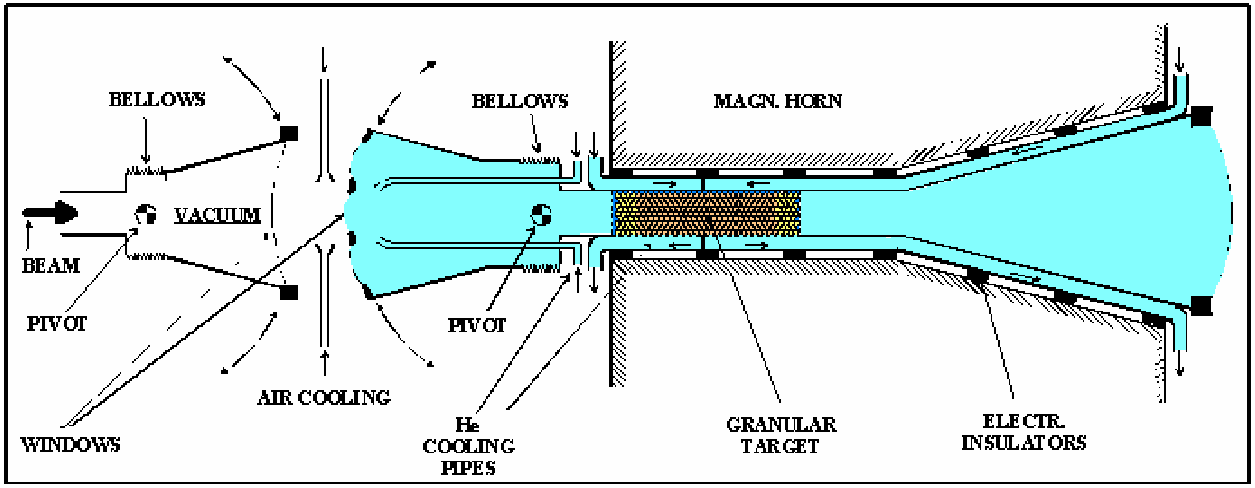
Magnetic horn



Horn Parameters

Radius of the waist [mm]	40
Voltage on the horn [kV]	4.2
Skin depth [mm]	1.25
Pulse length [μs]	93
Peak current [kA]	300
Repetition frequency [Hz]	50 → 12.5
rms current in the horn [kA]	14.5 → 3.6
Power dissipation by current [kW]	39 → 9.7

Target in Horn



Target dynamics 1

- Condition for shock

Energy deposited in a time short wrt sound propagation time. Typical scales:

Distance ~ 1 cm, v_s ~ 3000 m/s, t_s ~ 3 μs.

Synchrotron: bunch length ~ 5 ns

Accumulator: pulse length ~ 1 km ~ 3 μs.

- Escape from shock

Fragment the target: Distance ~ 1 mm, t_s ~ 0.3 μs.

Good for accumulator. Insufficient for synchrotron.

Target dynamics 2

- Condition for rupture (P. Drumm et al., νFact00)

Stress induced by shock exceeds elastic limit of target material. Typical scales:

$\Delta\sigma \sim E\,\alpha\,\Delta T \sim$ 3500 MPa at 10 Hz in Ta

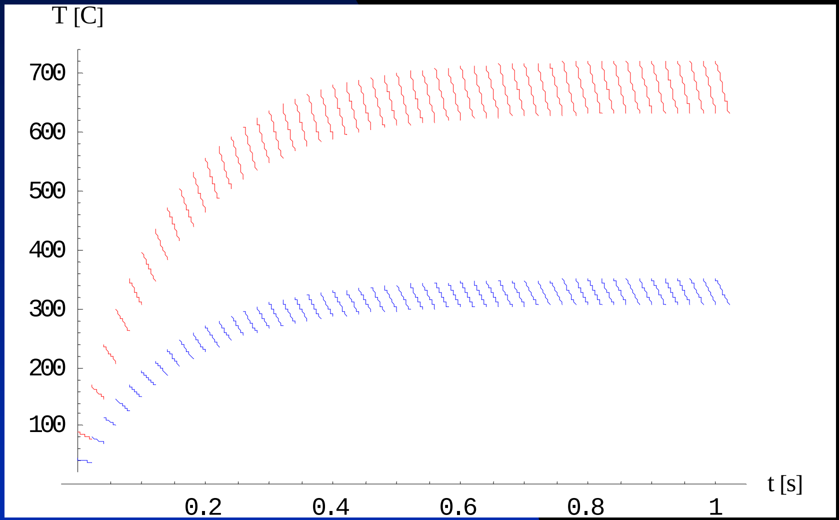
Elastic limit ~ 400 MPa at room temperature.

- Escape from rupture

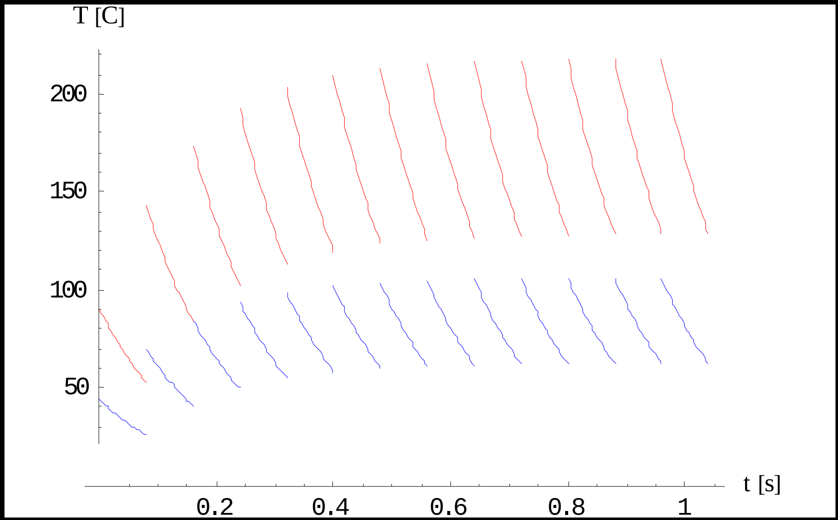
No shock, no stress.

Reduce ΔT by increasing repetition frequency and beam size.

Effect of funneling on target parameters



1 target



4 targets

T_{target}

T_{Helium}

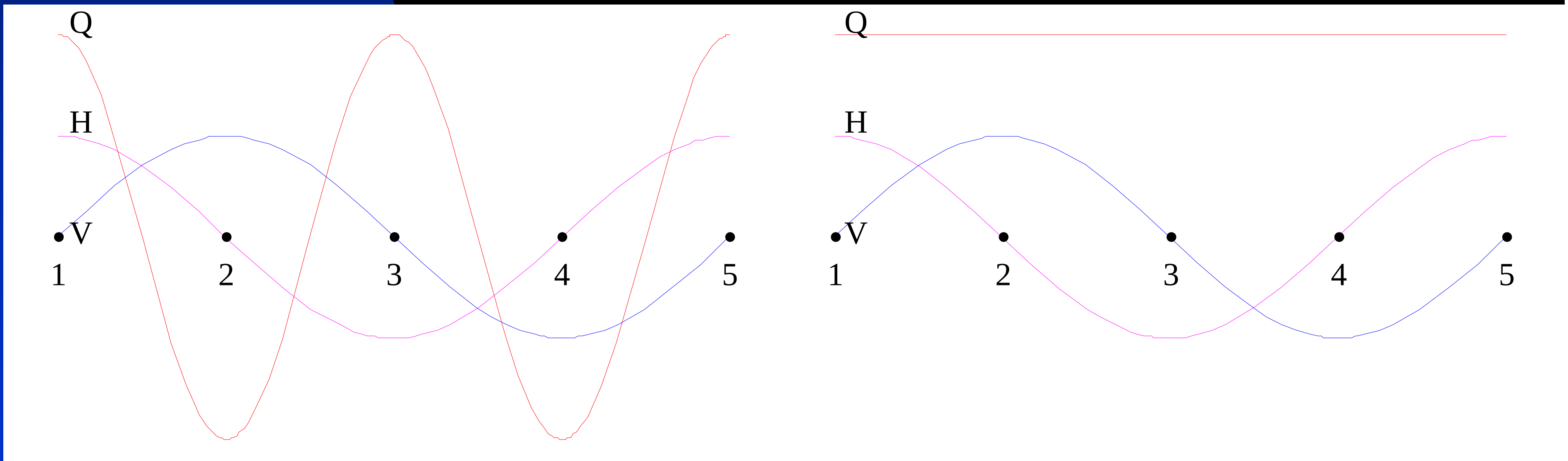
Pion Beam Parameters

Number of bunches	140
Pions per bunch	$< 1.4\times10^{10}$
Bunch spacing [ns]	22.7
Bunch length (4σ) [ns]	14
Transverse admittance [π cm]	1 (no cooling) 4 (cooling)
Longitudinal emittance [eV s]	0.5
Momentum spread [MeV/c]	200 - 500

Polarities

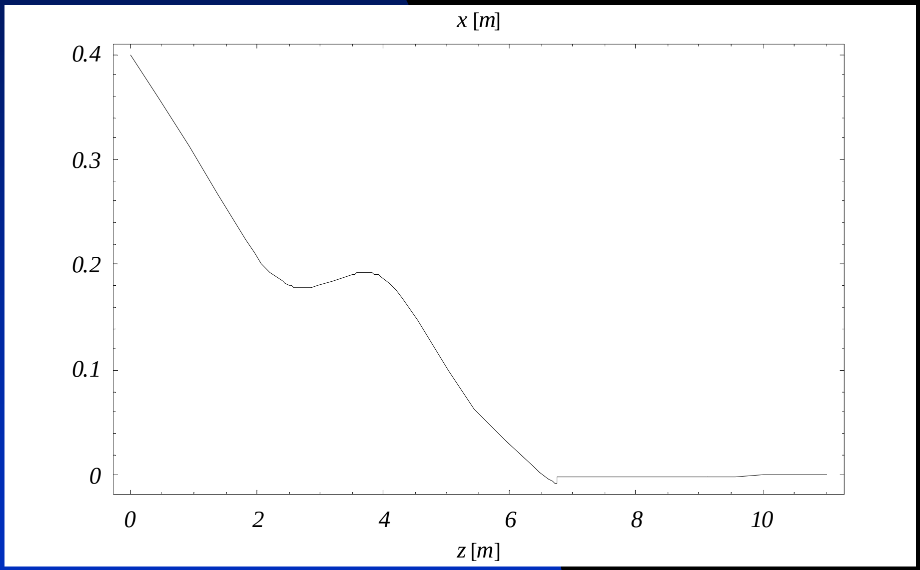
Scheme 1: AC quadrupoles
Good transmission.
Complicated power supplies due to high stored magnetic energy.

Scheme 2: DC quadrupoles
Reduced transmission (2/3).
Conventional power supplies.

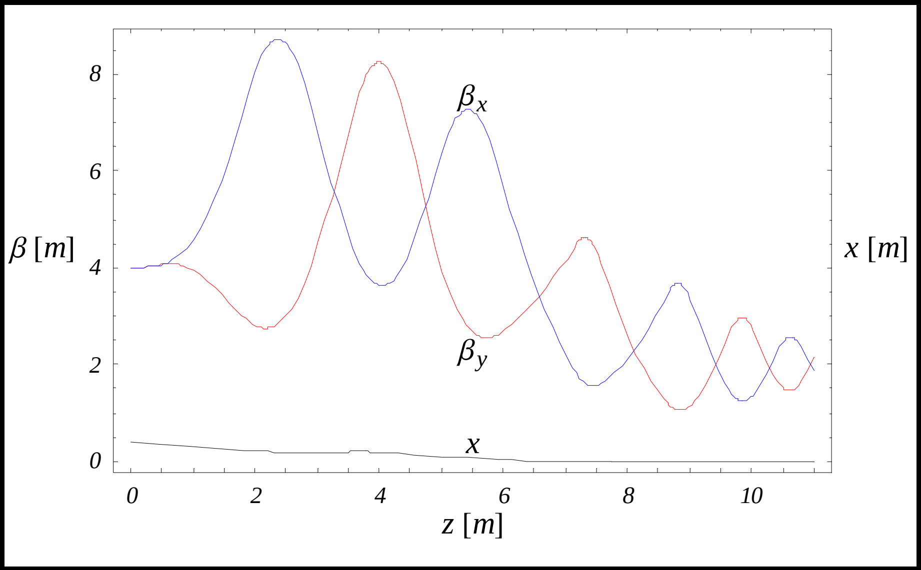


Optical functions

Center of mass trajectory



β-functions

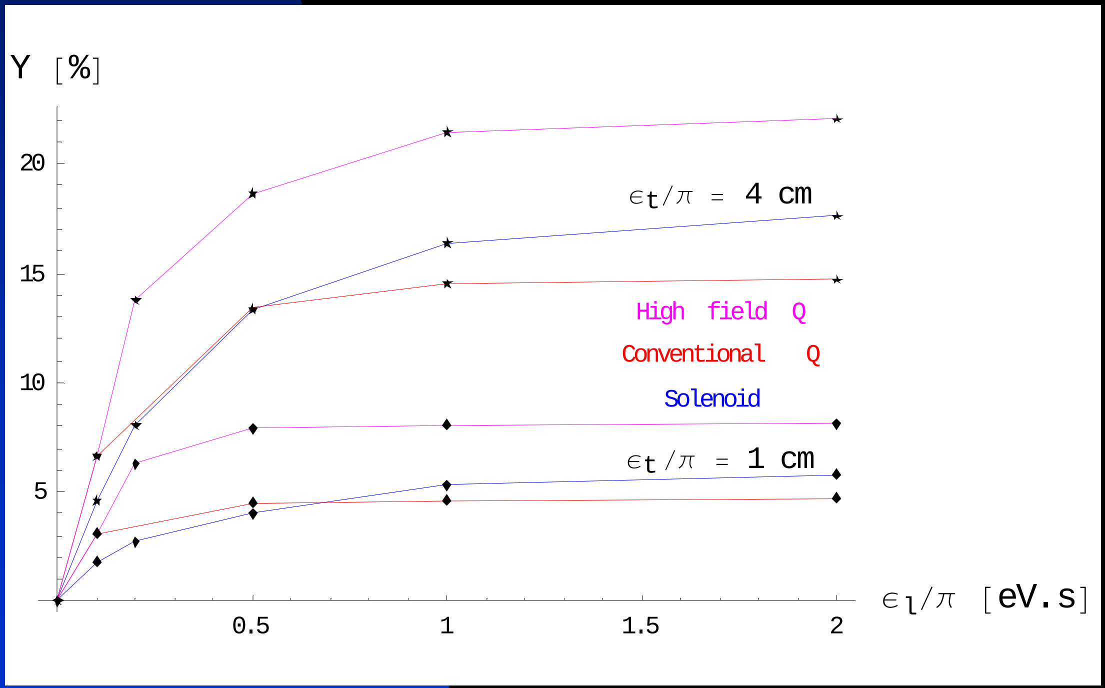


Magnet Parameters

Section	Magnet	Current distributions	Length [m]	Radius [m]	B [T] Scheme 1 ($\varepsilon = 4\pi$ cm)	B [T] Scheme 2 ($\varepsilon = 4\pi$ cm)
Funnel	D1+Q1	$\cos\theta$, $\sin\theta$ $\cos 2\theta$	1	0.6	1	0.65
	Q2	$\cos 2\theta$	1	0.6	1.2	1
	D2+Q3	$\cos\theta$, $\sin\theta$ $\cos 2\theta$	1	0.6	1.5	1.25
	Q4	$\cos 2\theta$	1	0.6	1.3	1.4
	D3	$\cos\theta$, $\sin\theta$	0.4	0.6	0.4	0.8
Decay channel	Q5, Q6, F, D	$\cos 2\theta$	0.4	0.4	3.4	2.9

Muon production

- $Y = N_\mu / N_\pi$ versus longitudinal emittance for :
  - two transverse admittances $\varepsilon_t = 1\pi$ cm (no cooling), 4π cm (cooling)
  - three regimes: solenoid, conventional and high field quadrupoles.



Conclusions

- Muon production for neutrino factories is on the way of being solved within the context of low energy, high repetition frequency proton driver.
- Target and horn developments have started but not at the wanted pace.
- Pending topics: magnet design, proton dump.