Front End Simulations in G4beamline

Pavel Snopok
IIT/Fermilab

March 1, 2011

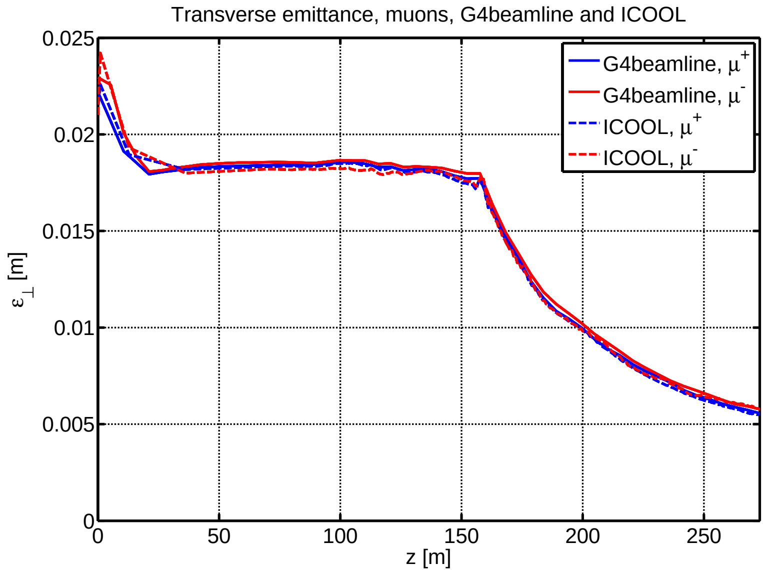
IDS-NF front end in g4beamline

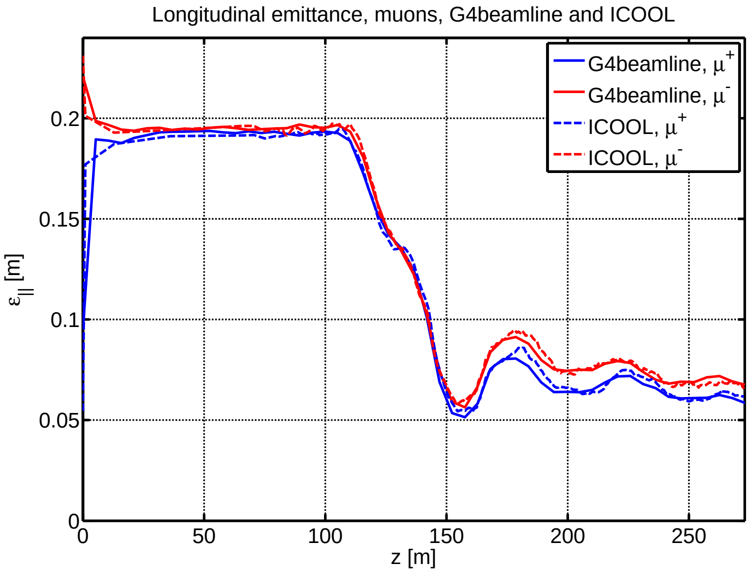
- Task: produce a g4beamline lattice for the NF front end based on the ICOOL deck.
- Lattice: Dave Neuffer, baseline, latest version. (Parameters as discussed by Mike Zisman in his talk).
- Initial data: Harold Kirk, MARS15 simulation, 5e4 protons on target.
- Latest versions of the lattice and inital beam files: `http://hepunx.rl.ac.uk/uknf/wp1/idsfrontend/Beams_and_Lattices/`.
- A total of 354k positive particles (including protons), and 142k negative particles.

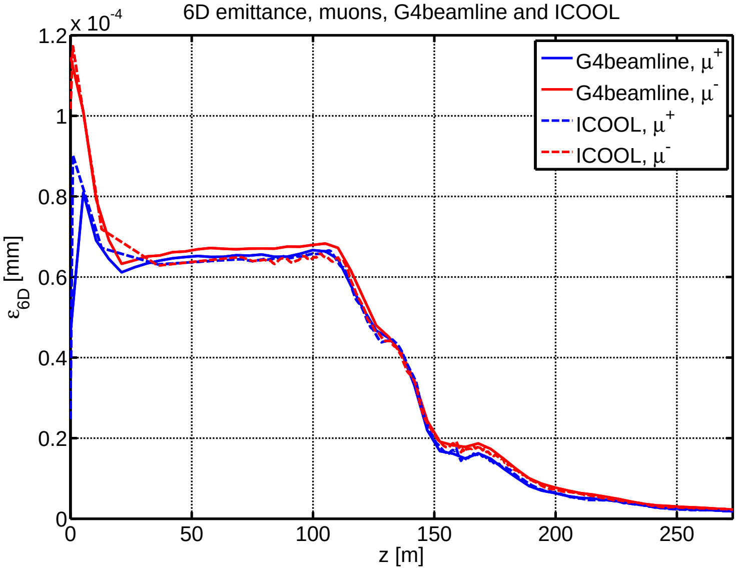
G4beamline lattice for the front end

- Derived from the baseline ICOOL lattice.
- RF timing partially derived from analytic expressions, partially tuned using the reference particle immune to E field and energy loss in material (only works in version 2.04+).
- Checked for consistency: magnetic field, geometry, emittances, particle yield, particle loss.
- Versions used for comparison: ICOOL 3.20 and G4beamline 2.06.

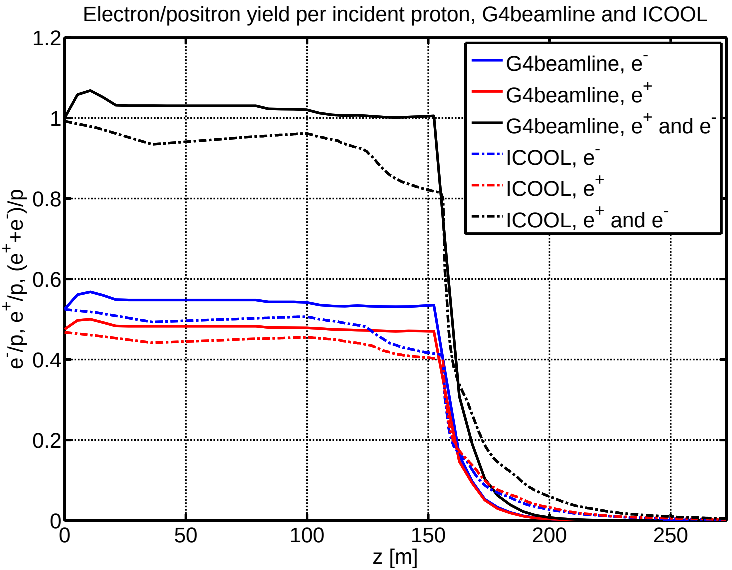
Emittances

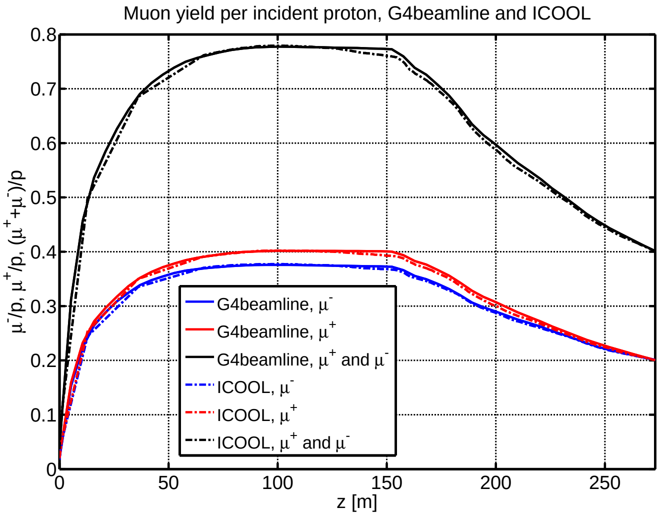

Transverse emittance, muons, G4beamline and ICOOL
0.025
0.02
0.015
0.01
0.005
0
0
50
100
150
200
250
ε⊥ [m]
z [m]
G4beamline, μ+
G4beamline, μ-
ICOOL, μ+
ICOOL, μ-


Longitudinal emittance, muons, G4beamline and ICOOL
G4beamline, μ+
G4beamline, μ-
ICOOL, μ+
ICOOL, μ-
0.2
0.15
0.1
0.05
0
$\varepsilon_{||}$ [m]
0
50
100
150
200
250
z [m]

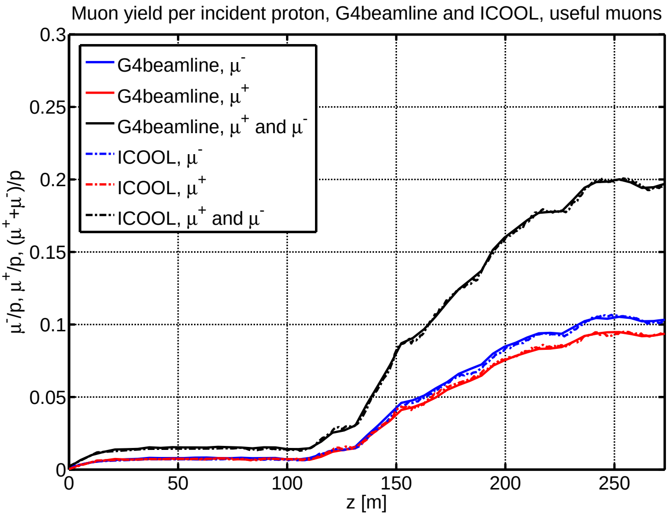

6D emittance, muons, G4beamline and ICOOL
x 10^-4
1.2
1
0.8
0.6
0.4
0.2
0
ε6D [mm]
0
50
100
150
200
250
z [m]
G4beamline, μ+
G4beamline, μ-
ICOOL, μ+
ICOOL, μ-

Particle yields

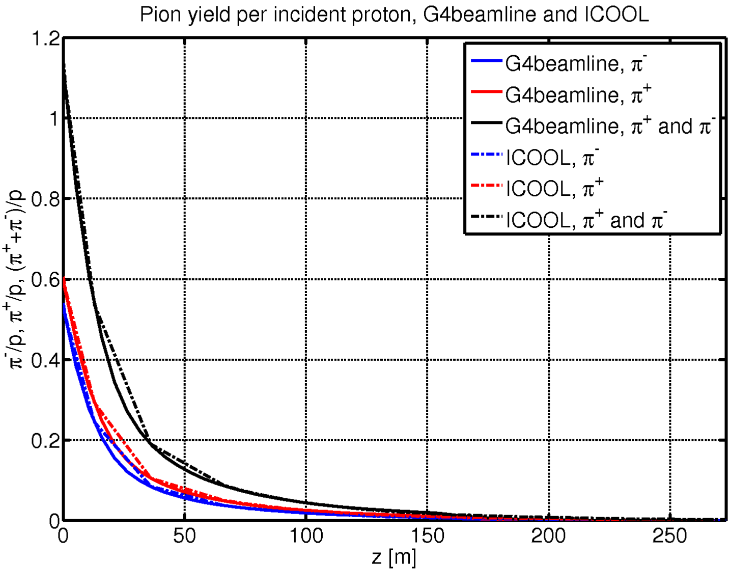

Electron/positron yield per incident proton, G4beamline and ICOOL
e^-/p, e^+/p, $(e^++e^-)/p$
z [m]
0
0.2
0.4
0.6
0.8
1
1.2
0
50
100
150
200
250
G4beamline, e^-
G4beamline, e^+
G4beamline, e^+ and e^-
ICOOL, e^-
ICOOL, e^+
ICOOL, e^+ and e^-


Muon yield per incident proton, G4beamline and ICOOL
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
μ-/p, μ+/p, (μ++μ-)/p
0
50
100
150
200
250
z [m]
G4beamline, μ-
G4beamline, μ+
G4beamline, μ+ and μ-
ICOOL, μ-
ICOOL, μ+
ICOOL, μ+ and μ-

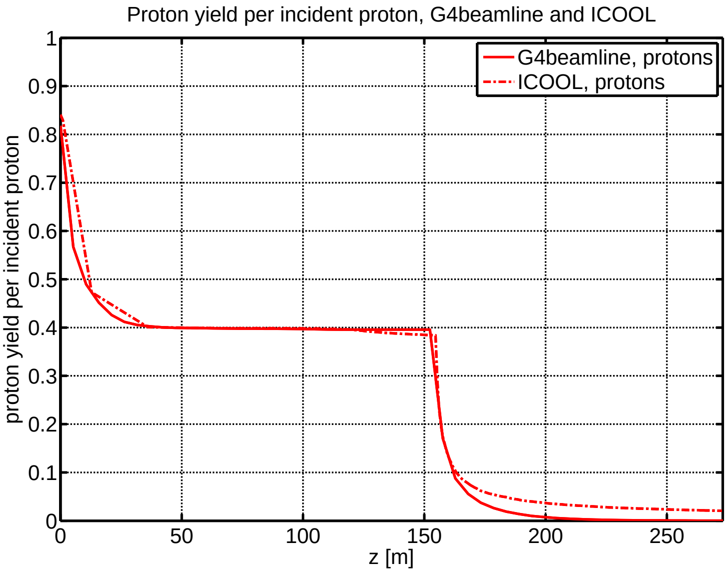
All muons



Useful muons ($p \in [100, 300]$ MeV/c, trans. cut 0.03, long. cut 0.15)

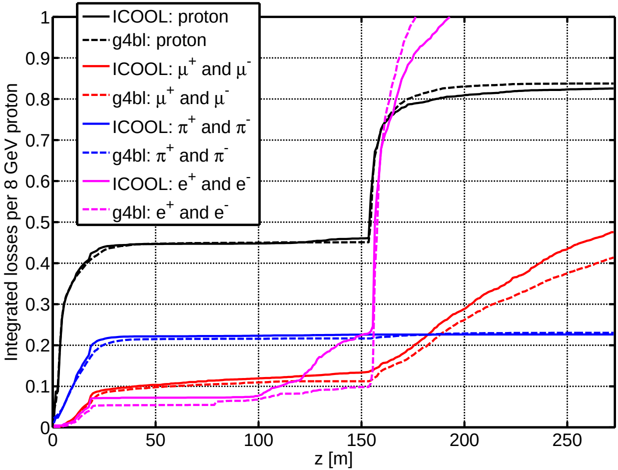


Pion yield per incident proton, G4beamline and ICOOL
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
z [m]
π⁻/p, π⁺/p, (π⁺+π⁻)/p
G4beamline, π⁻
G4beamline, π⁺
G4beamline, π⁺ and π⁻
ICOOL, π⁻
ICOOL, π⁺
ICOOL, π⁺ and π⁻


Proton yield per incident proton, G4beamline and ICOOL
G4beamline, protons
ICOOL, protons
proton yield per incident proton
z [m]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250

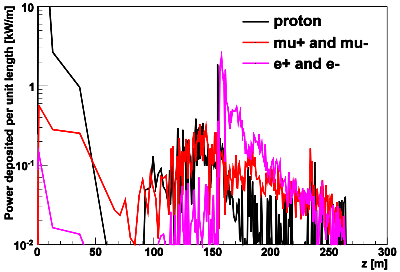
Particle loss

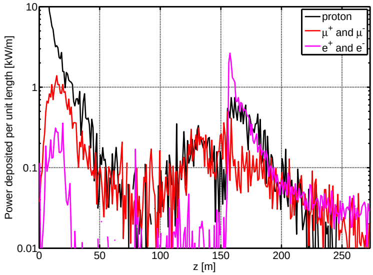
ICOOL vs G4beamline



Energy deposition

Energy deposition





Power deposited per unit length (ICOOL, courtesy C. Rogers)

Power deposited per unit length (G4beamline)

- More than 1 kW/m in the capture region + the beginning of cooling.
- In general, energy deposition O(0.1 kW/m), ⇒ need a solution.

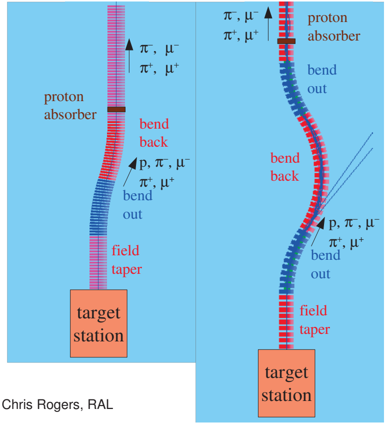
Mitigation strategies under study

- Low momentum protons may be removed using a proton absorber.
- Particles with high momenta outside of the acceptance of the front end may be removed using a single or double chicane.
- Particles with transverse amplitude outside of the acceptance of the front end may be removed using transverse collimators.

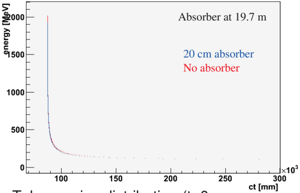
Chicane simulations by C. Rogers (not in g4beamline yet)

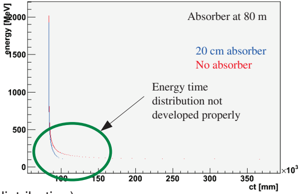
Particle Selection

- Two items required for particle selection scheme
  - Proton absorber to remove low energy protons
    - "Low energy" means <~ 500 MeV/c momentum
  - Chicane to remove all high energy particles
    - "High energy" means >~ 500 MeV/c momentum
- Followed by transverse collimator system
  - Clean up any mess before it is dumped on sensitive equipment



Proton absorber – position





Take a naive distribution (t=0, energy=square distribution)

Plot energy-time at z=90 m

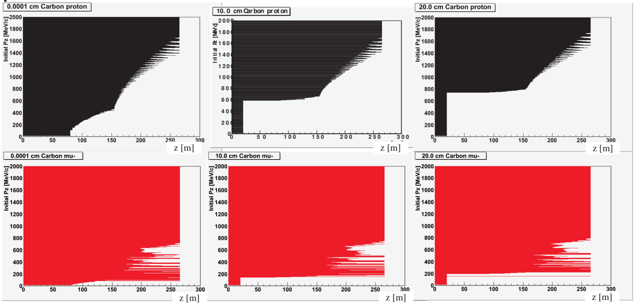
Try for absorber near target and absorber at end of drift

If we put the absorber at end of drift, energy-time distribution does not develop properly

But this is required for the buncher to operate

Therefore put proton absorber near to target

Proton absorber – thickness

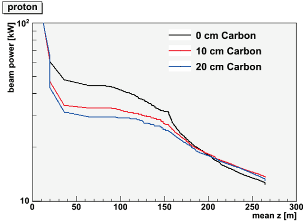


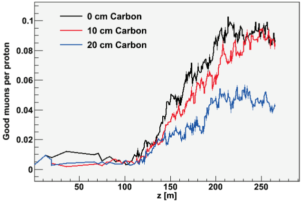
Look at initial momentum vs z

How much material is appropriate?

More material ruins muon rate but gets rid of more protons

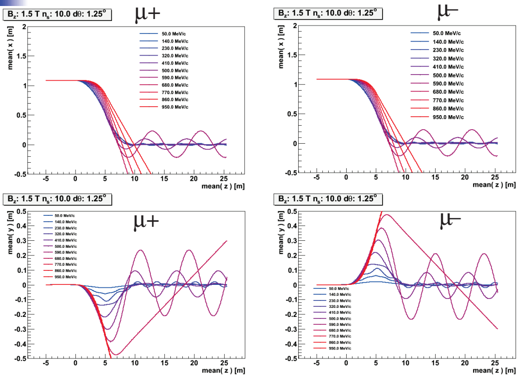
Proton absorber





- Now take a realistic simulation (5k particles)
  - Not much difference between 10 cm and 20 cm in terms of proton beam power reduction
  - Both take out about 30-40% of proton beam power
- Big difference between 10 cm and 20 cm in terms of muon rate
  - 10 cm is ~ comparable with baseline but 20 cm is much worse

Note on particle charge vs orbit

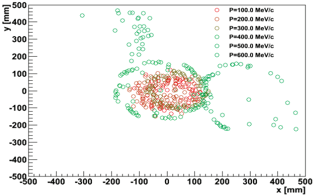


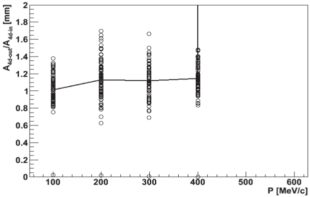
Finite beam

What happens when a finite beam is passed through the chicane?

Assume Twiss parameters are more-or-less correct

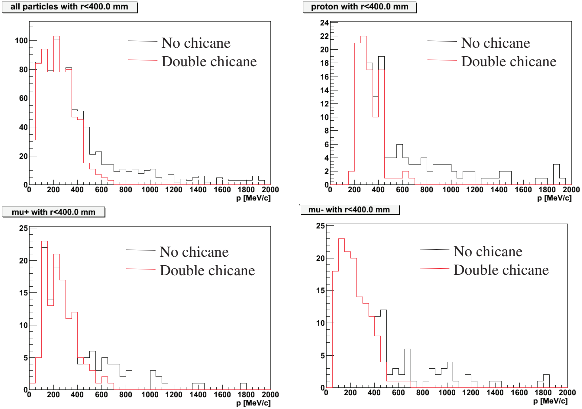
- Look at emittance increase of a shell of particles on 4D hyperellipsoid
  - Initial amplitude typical of particles in our beam~ 50 mm
  - Shell in x-px-y-py phase space, initially matched to 1.5 T solenoid
- Get only small emittance increase below ~ 500 MeV/c





Chris Rogers, RAL

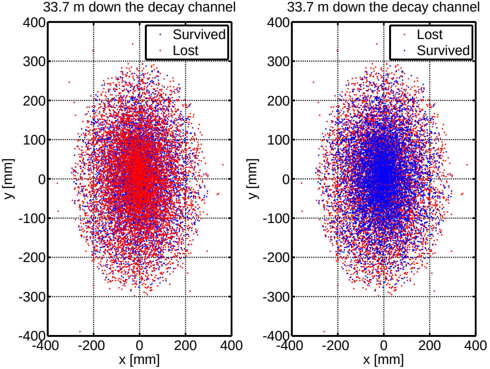
Transmission vs p (double chicane)



Plans

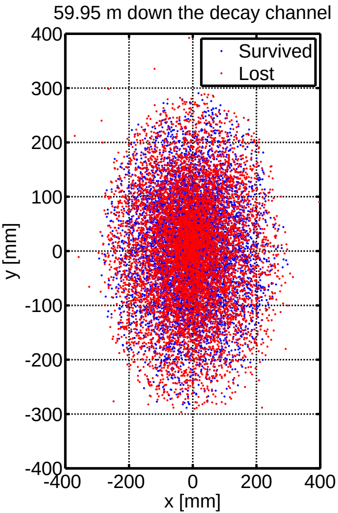
- Reasonable optics design for the chicane
  - Not too much emittance growth
  - Good transmission below momentum cut-off
  - Good collimation above momentum cut-off
- Next consider beam dumps
- Reconsider proton absorber in context of chicane
  - Probably need some optimisation in tandem
- Have a look at transverse collimation (Snopok)

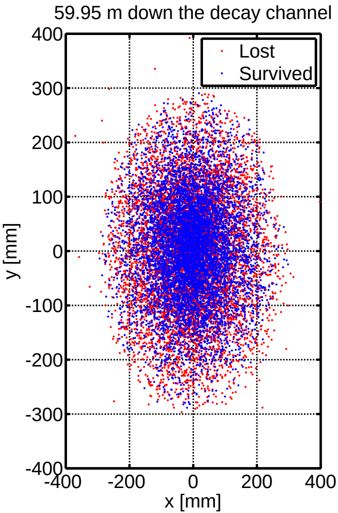
Start at 33.7 m down the decay channel, go to the end of cooler:



- All particles: σ_x=105 mm, σ_{p_x}=27 MeV/c;
- Survivors: σ_x=94 mm, σ_{p_x}=26 MeV/c;
- Lost particles: σ_x=115 mm, σ_{p_x}=28 MeV/c.

Start at 59.95 m down the decay channel, go to the end of cooler:





- Surviving and lost particles have essentially the same distributions.
- Transmission is $\approx$50%.
- Analysis of losses underway.

Thank you!