Front End – gas-filled cavities

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Outline

- Front End for Muon Collider/Neutrino Factory
  - Baseline for MAP
    - 8 GeV proton beam on Hg target
  - 325 MHz
    - With Chicane/Absorber

- Current status
  - New targetry
    - 6.75 GeV on C target
  - New Mars generated beams
    - Mars output much different from previous version
  - Buncher rotator with $H_2$ gas
    - Rematches OK except for loss at beginning of buncher
    - Can cool and rottoe simultaneously
  - Beam for Low-energy muons
    - 150 MeV/c buncher/rotator
325MHz “Collider” front end

- **Drift**
  - 20 T $\rightarrow$ 2 T

- **Buncher**
  - $P_0 = 250 MeV/c$
  - $P_N = 154 MeV/c; \ N = 10$
  - $V_{rf} : 0 \rightarrow 15 MV/m$
    - (2/3 occupied)
  - $f_{RF} : 490 \rightarrow 365 MHz$

- **Rotator**
  - $V_{rf} : 20 MV/m$
    - (2/3 occupied)
  - $f_{RF} : 364 \rightarrow 326 MHz$
  - $N = 12.045$
  - $P_0, P_N \rightarrow 245 MeV/c$

- **Cooler**
  - 245 MeV/c
  - 325 MHz
  - 25 MV/m
  - 2 1.5 cm LiH absorbers /0.75m
New Proton Driver parameters

- **6.75 GeV p, C target**
  - 20 $\rightarrow$ 2 T short taper
    - $\sim$5 m (previously 15)
  - X. Ding produced particles at $z = 2 \rightarrow 10$ m using Mars
  - short initial beam

- **Redo ICOOL data sets to match initial beam**
  - ref particles redefined
    - in for003.dat
    - and for001.dat
Following Scott’s review of front end

- Use initial distributions (obtained by X. Ding)
  - 8 GeV protons on Hg target
    - + and - particles
  - 6.75 GeV protons on C target
  - Start beam from \( z = 10 \) m
    - must retranslate into ICOOL reference particles
  - Early losses on apertures have already occurred
    - 23 cm apertures
ICOOL translation tips

- start at “z = 10 m”
  - (particle time zero is at -1 m)
- reference particles
  - 250 MeV/c ; 154 MeV/c μ⁺
    - 165.75 MeV ; 81.1 MeV μ⁺
  - time set by 1 m as 6.75 GeV proton + 10 m as μ⁺
  - reference particles set in for003.dat, not for001.dat

for003.dat

01-Feb-2015 X. Ding C 10 m-
0.0 0.250 3.95709E-08 0.0 0.154 4.381345E-08 2
1 1 -3 0 4.354479e-008 1.000000e+000 0.03737
0.03656 0 7.861861e-004 2.558375e-002 2.189235e-001 0 0 0
2 1 -3 0 3.712592e-008 1.000000e+000 -0.03459
0.11247 0 1.617131e-001 3.506310e-002 4.670452e-001 0 0 0
3 1 -3 0 3.748837e-008 1.000000e+000 0.00304
0.04460 0 -1.827203e-002 -5.931789e-002 7.809555e-001 0 0 0
4 1 -3 0 3.738523e-008 1.000000e+000 -0.13944
0.13944 0 -4.890422e-002 3.733585e-001 1.515145e+000 0 0 0
5 1 -3 0 3.738523e-008 1.000000e+000 0.07979

In ICOOL for001.dat

REFP
2 0 0 3
REF2
2 0 0
Simulation results

- Hg target 8 GeV - end of cooling
  - $\sim 0.0756 \mu^+/p; \sim 0.0880 \mu^-/p$;

- C target 6.75 GeV p
  - $\sim 0.0613 \mu^+/p; \sim 0.0481 \mu^-/p$;
    - 0.0726 $\mu^+/p; \sim 0.0570 \mu^-/p$ when multiplied by 8/6.75

Previous front ends had $\sim 0.1 \text{ to } \sim 0.125 \mu/p$

- Redo with old initial beams
  - 2010 Hg 8GeV p
    - 0.114 $\mu^+/p$
  - 2014 Hg 8GeV p
    - 0.112 $\mu^+/p$
Progression of beam through system

\[ z = 11 \text{ m} \]

\[ z = 104 \text{ m} \]

\[ z = 135 \text{ m} \]
Simulations capture typically somewhat less than before

- Big difference in MARS production model
  - Mars Inclusive $\rightarrow$ LAQGSM=1
- Drop in production for $\sim 8$ GeV
  - Are previous MARS simulations that showed an advantage in production for $\sim 8$ GeV still true?

- IQGSM=0: exclusive CEM (cascade exciton model?) for $E < 3$ GeV, MARS inclusive for $E > 5$ GeV, LAQGSM for some special cases. Old MARS default.
- IQGSM=1: CEM for $E < 0.3$ GeV, LAQGSM for $0.5$ GeV $< E < 8$ GeV, MARS inclusive for $E > 10$ GeV. New MARS default.
Stratakis et al. have done cooling channel with gas-filled rf
- \( \sim 34 \text{ atm } H_2 \) to stop breakdown

Extrapolate back to include buncher/rotator
- use gas to suppress breakdown in buncher/rotator
- rf in \( \sim 2 \text{ T } \) solenoids
Add gas-filled rf in buncher/rotator

- **34 – 100 atm equivalent**
  - **1.14 MeV/m**
    - 34 atm
  - **3.45 MeV/m**
    - 100 atm
  - for 34 atm
    - add ~2 MV/m to rf

- **First tries with ICOOL**
  - GH in buncher 1 atm
    - no change in capture
  - Change to 34 atm by
    - DENS GH 34.0
  - Runs OK but
    - reduces capture by 20%
    - mostly from low-E muons
      - shorter bunch train
Updated gas-filled front end

- added gas in rotator
  - 34 atm
    - $dE/dx$
- Increased rf a bit
  - Buncher 15z $\rightarrow$ $2+20(z/24)$ MV/m
  - Rotator 20 $\rightarrow$ 25
    - ref particles decelerate to 230MeV/c
  - Cooler 25 $\rightarrow$ 28 MV/m
- Results are not so bad
  - 8GeV Hg + $\rightarrow$ 0.0718 $\mu$/p
  - 8GeV Hg - $\rightarrow$ 0.0773 $\mu$/p
  - 6.75 GeV C + $\rightarrow$ 0.0539 $\mu^{+}$/p
  - 6.75 GeV C - $\rightarrow$ 0.0430 $\mu^{-}$/p
  - ~10% worse than baseline

- Tweak of reference particle to fit ICOOL features (for 100atm)
  - REFP
  - 2 0.250 0. 1.55 4
  - REF2
  - 2 0.154 0. 6.9
  - use phase model 4
    - tracks reference particles energy loss in drft/absorber but not in rf
    - fixed energy gain.loss in rf
  - ref particle acceleration fitted to end at ~245 MeV/c
FrontEnd variations

- Reduce buncher gas to 17 atm
  - ~ 10% better
  - back to ~ baseline
  - ~0.062 μ⁺/p

- decelerating rotator or constant energy rotator?
  - C → ~0.063 μ⁺/p
  - about the same
  - no real advantage/disadvantage in deceleration

- Note initial beam is “cooled”, but only in one dimension
  - B = 2 T - no field flip
  - Angular momentum increases

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Compare 17/34

34 --- 34 atm

600 MeV/c

0.058 $\mu^+/p$

$z = 72$ m

$z = 108$ m

$z = 150$ m

17 --- 34 atm

0.065 $\mu^+/p$
Increase rotator to 100atm

- **Buncher at 17atm**
  - LESS INITIAL LOSS
- **With V = 20/25/28**
  - ~0.059 μ/p (C 6.75)
  - ~10% less than 17/34
- **Increase Rotator gradient to 28 MV/m**
  - to compensate energy loss
- **Fairly good performance**
  - ~0.063 μ/p (C 6.75)
- **Buncher at 34 atm**
  - ~0.058 μ/p (C 6.75)
  - V = 22/28/30 MV/m
  - worse than 17/100 case
- **More cooling in Rotator**
  - 1-D cooling (2T solenoid)
  - one mode highly damped
- **Significant initiation of cooling**
  - (integrating rotator/cooler)
  - shortens following cooler

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Beam difference notes

- Most of loss in intrinsic performance is from gas in buncher
  - Beam enters completely unbunched
  - Initial rf is weak; and slowly increases

- After some initial loss, SIMILAR TO GAS-FREE BASELINE

![Graph showing mu's within acceptances](image)
Continue Cooling with H2 Gas

- Previous cases used baseline front end cooling
  - 2 LiH 1.5 cm absorbers per cell
- 240 atm of H₂
  - ~8.3 MV/m loss from gas

- Preliminary results
  - Throughput improved to ~0.068 μ⁺/6.75 GeV proton C target
Low-E capture

- Capture at low momentum
  - prepare beam for low-E $\mu$ experiment
- Somewhat scaled back version of front end
  - 30.4m drift
  - shorter buncher / rotator
    - 12 m / 13.5 m
    - $0 \rightarrow 15$ MV/m, 15 MV/m
      - vacuum rf
    - $B=2T$
- Parameters
  - 150 MeV/c ... 100 MeV/c reference particles
  - 77.8 // 39.8 MeV
- Bunch to 150 MeV/c
- Cooling at 2 T

![Diagram of Low-E capture system with beamline and energy distribution plots for $\pi^+$ and $\mu^+$ particles.]
Used Ding initial beam
- initial beam cut off at ~70 MeV/c
  - 21 MeV kinetic energy
- bunch train formed

Cooling from 60m ➔ 100m
- longitudinal antidamping
  - \( g_L = \sim -0.5 \)
- \( B = 2T, 2\text{cm} \)
- more used to separate captured from uncaptured beam
- \( \sim 0.05 \mu/p \) within acceptance ??
  - not sure what acceptance criteria to use
LHC discoveries motivate future research...

YOUR COMMENTS ON MY TECHNOLOGY STRATEGY ARE AMBIGUOUS.

YOU COMPARED IT TO A "SQUIRREL LOOKING FOR A NUT IN THE LARGE HADRON COLLIDER."

SO...?

HOW MANY NUTS ARE IN THERE?
Simulation Results

- Simulation obtains
  - \( \sim 0.125 \mu/p \) within acceptances
  - with \( \sim 60\text{m Cooler} \)
  - 325 MHz - less power
  - shorter than baseline NF

- But
  - uses higher gradient
  - higher frequency rf \( \rightarrow \) smaller cavities
  - shorter than baseline NF
  - more bunches in bunch train

\[ N : 0.15 < P < 0.35 \text{ GeV/c} \]

\[ N : \varepsilon_T < 0.03; A_L < 0.2 \text{ c} \]

\[ N : \varepsilon_T < 0.015; A_L < 0.2 \]

Useful cooling