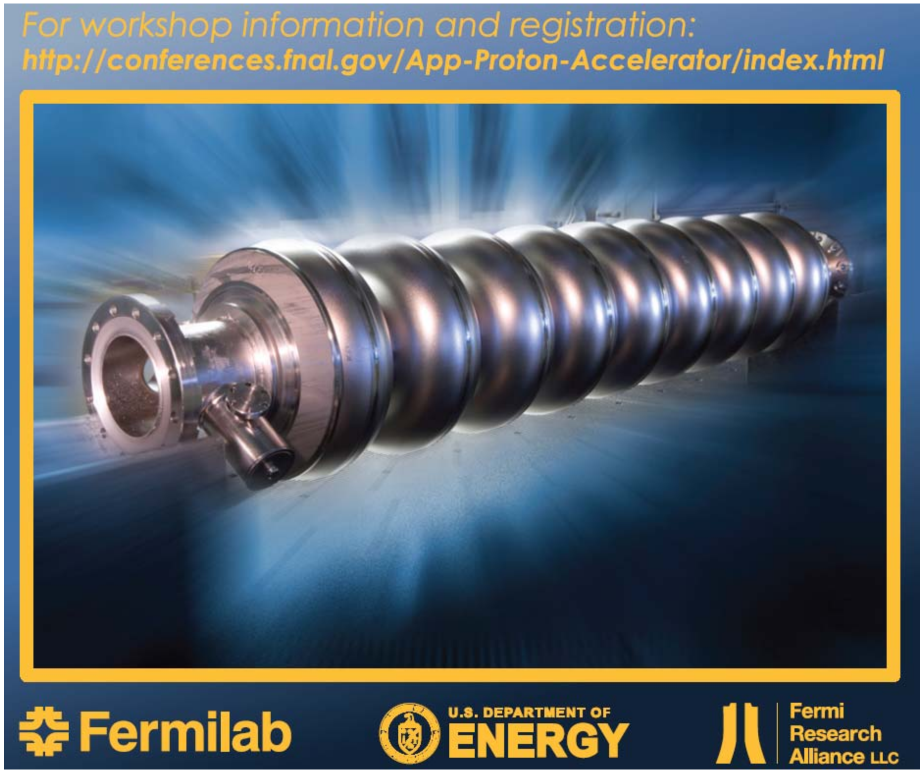
Accelerator Parameters for Project X ICD-1&2

Valeri Lebedev
Fermilab



Workshop on Applications of High Intensity Proton Accelerators
Fermilab
October 19-21, 2009

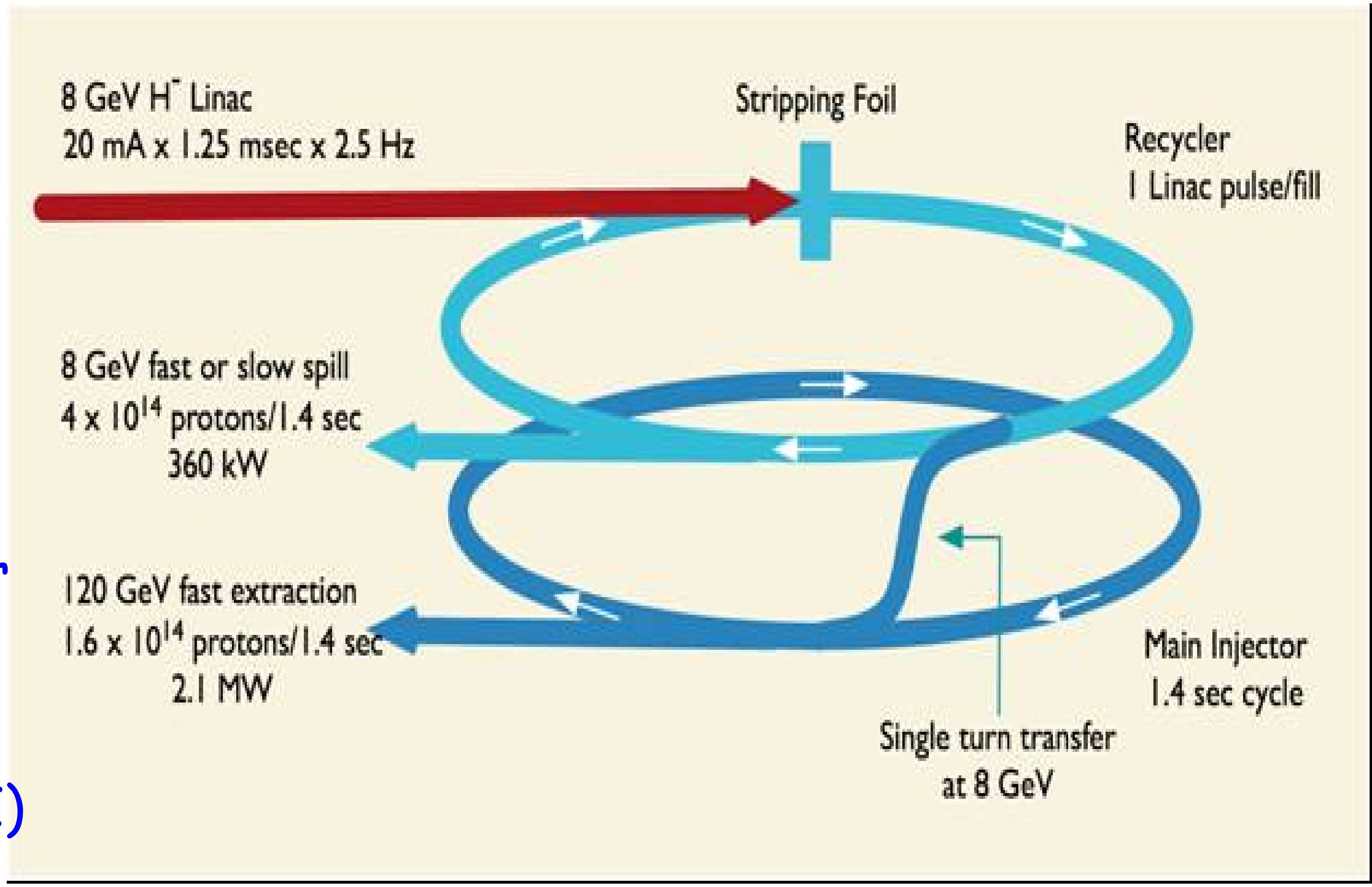
Where are we, and Where would we go with ICD-1?

- Neutrino program 300 kW → 2 MW (Project X)
  - Present
    - Numi, MiniBooNE, SciBooNE
  - Future*
    - MINERvA(2011), NOvA (2014), MicroBooNe (2014), LBNE(2018)
- Collider program
  - Present
    - CDF + D0 = **~1500 people for both collaborations**
  - Future
    - Participation in LHC (CMS, …)
- Possible future HEP experiments additional to the neutrino program
  - Mu2e (2016) - high priority, problem with power upgrade with SlowExtr
  - g-2(2012- 2016?) not approved, high probability of time conflict with Mu2e (competes for the same hardware – antiproton source)
- Short conclusions
  - Some increase in neutrino physics effort;
  - CDF + D0 (1500)→Mu2e (100) + decommissioning of antiproton source
  - The program in HEP does not look too ambitious

*All hands meeting, Pier Oddone, March 20, 2009

Project X ICD-1

- Based on
  - 8 GeV pulsed linac (~7 GeV, ILC type)
  - And upgrades in MI and Recycler
- Delivers
  - 2 MW at 60-120 GeV (MI)
  - 500 kW at 8 GeV (1.25 ms × 20 mA × 2.5 Hz)



Pros and Cons

\+ Develops ILC technology
looks like a promising upgrade for muon collider or neutrino factory

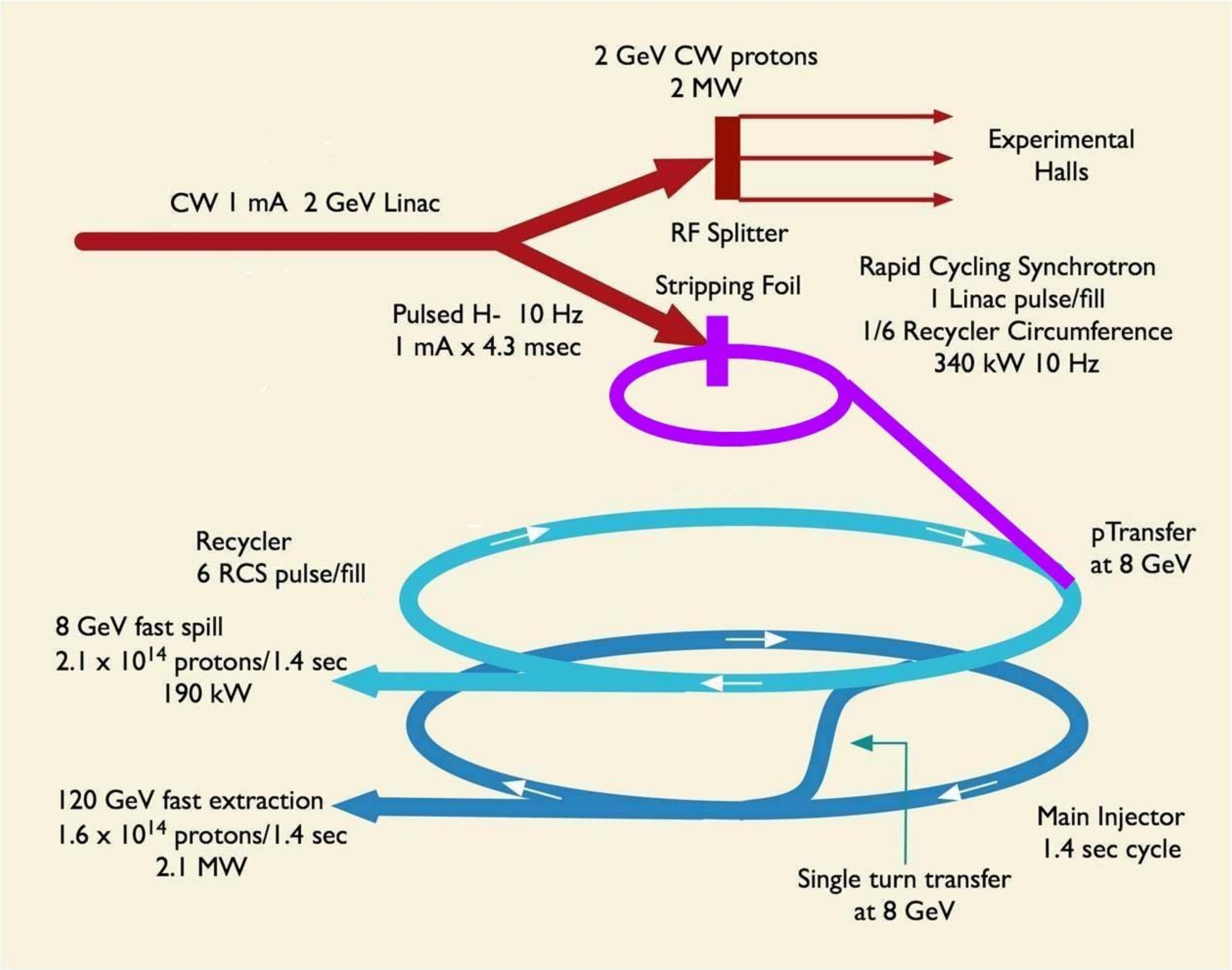
\- Does not open a diverse physics program for near future
  - Can support only 1 experiment for any given time
  - Problems with beam packaging (pulse length, repetition rate)

Project X ICD-2

- ICD-2 tries to address the deficiencies of ICD-1
- Recent developments
  - First discussions – end of March, 2009
  - Directorate created a committee to look into physics program, Apr.2009
  - Strong support of ICD-2 from Physics Advisory Committee (Jun. 2009)
  - ICD-2 document and cost estimate is expected by the end of Oct. 2009
    - Drafts are ready
  - Workshop on physics, November 2009
- ICD-2 is based on 2 MV CW linac
  - Energy of 2.X GeV is set by kaon production threshold (1.6 GeV)
  - Beam current of 1 mA is set by a compromise between
    - Fast growing problem of beam injection into RCS or Recycler/MI with current reduction
    - Reasonably small total power

      ⇒ Larger beam current would make injection easier but presently there are no users capable to use larger power
  - RF separation allows one to run a few experiments with independently controlled time structures of the beam

ICD-2 concept



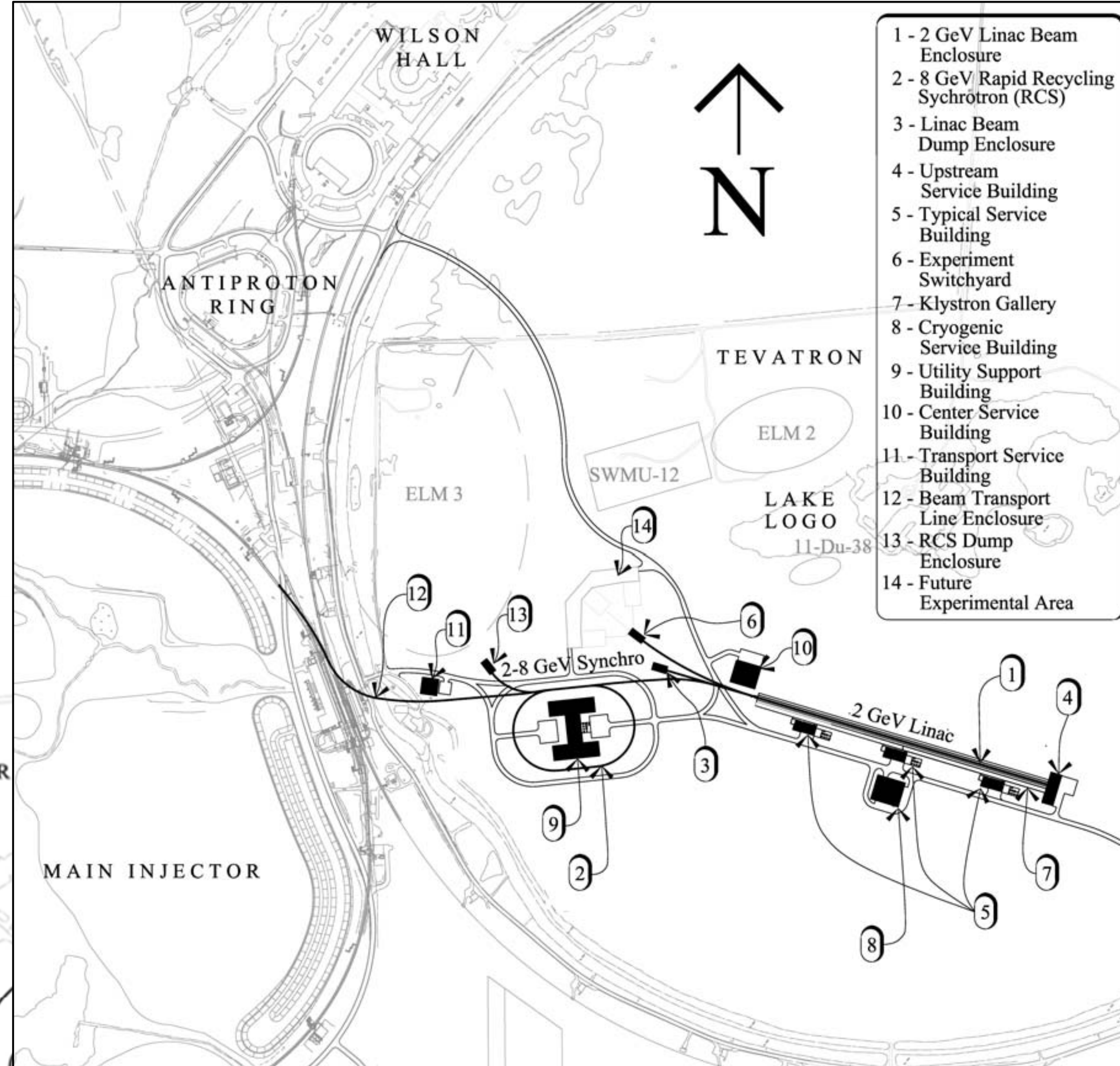
- Replacement of RCS by pulsed linac can be used too
  - price tag will drive the choice (pros and cons are discussed below)

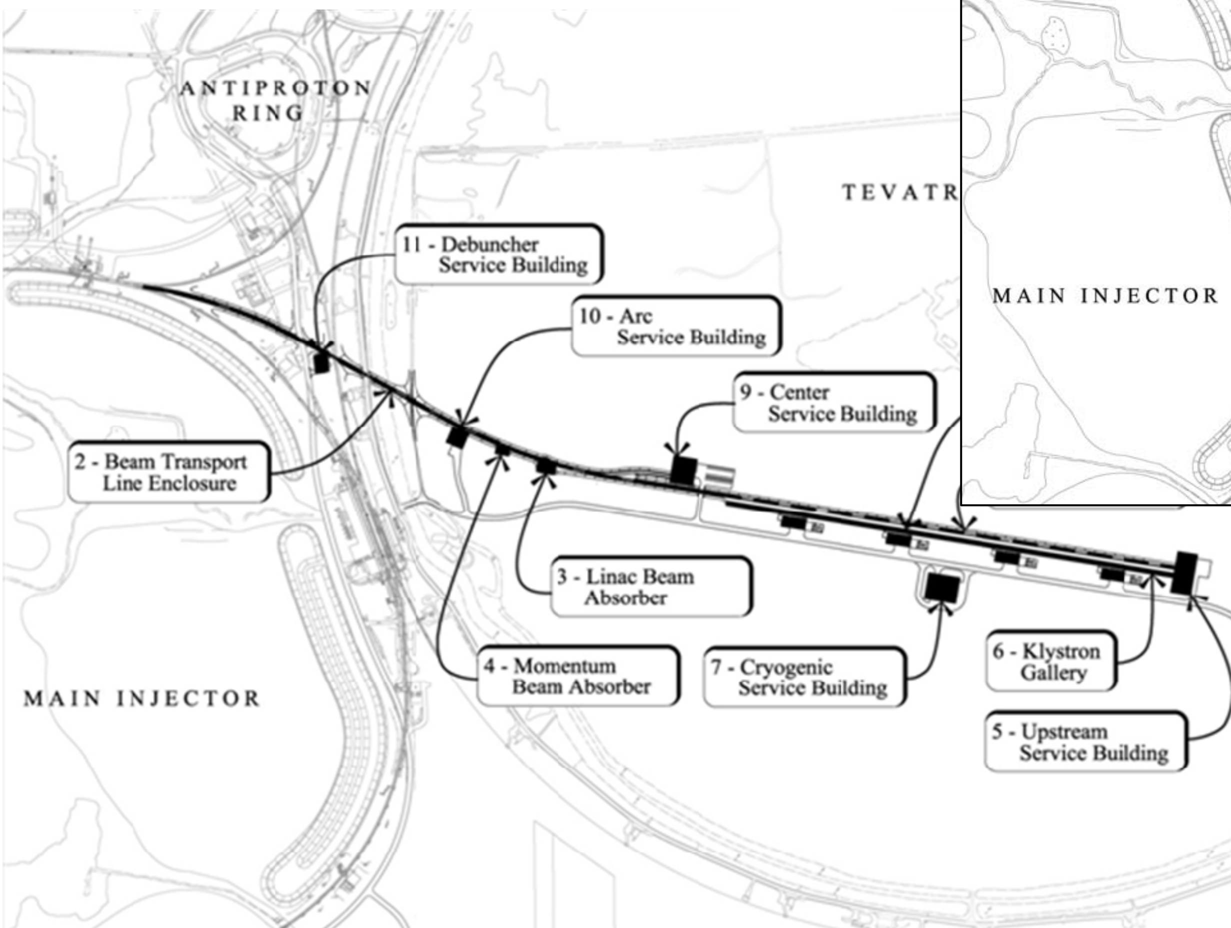
ICD-1 & 2 “wide definitions”

- ICD-1 is based on a pulsed 8 GeV linac (RCS from 2 GeV is also possible)
  - Its infrastructure supports
    - 2 MW in MI
    - Single experiment with slow extraction from Debuncher
    - Fast extraction from Recycler to other experiments
- ICD-2 is based on 2 GeV CW linac
  - Its infrastructure supports
    - 2 MW in MI
    - Few experiments running in parallel for rear decays of muons and kaons
    - Fast extraction from Recycler to other experiments
- Project X evolution reminds the development of CEBAF conception

ICD-1&2 siting

- ICD-1
  - Small fields to bend 8 GeV H^-
- ICD-2
  - Reduced gradient for CW linac





RCS versus pulsed linac for beam acceleration from 2 to 8 GeV

- Pulsed linac advantages
  - Can be upgraded to repetition rate above 20 Hz if required
  - Can be used for muon acceleration
    - Starting from 1 GeV for ε_{n_rms}=60 mm mrad (high emittance MC)

      $\Rightarrow$ 20 GeV for 4 pass recirculator (three 360 deg. arcs) with 1 GeV preaccelerator
- Pulsed linac drawbacks/problems
  - Looks more expensive than synchrotron
  - Requires Recycler anyway if
    - The beam current is limited by CW linac to 1 mA
    - and foil strip injection is used
      - o laser striping with long pulse is risky
  - Inefficiency of strip injection (~3%) at 8 GeV results in 4 times larger beam power at the injection beam damp
- RCS requires additional R&D
- The question, which way to go, has to be addressed soon

Foil striping versus laser stripping

- Laser stripping looks very attractive but
  - It was not demonstrated in real operations
  - It works in a narrow energy region and is not a good choice
    - for RCS or
    - any other ring where the injection energy can be changed
- Foil stripping is simple and well tested in real operations but
  - It has a problem with foil overheating
    - Prefers large injection current
    - Can be mitigated by β-function increase at the foil
- There is no injection scheme which would allow simple transition between laser and foil stripping
  - Foil striping requires large beta-functions
  - Laser striping requires at least one beta-function to be small

RCS versus Proton Driver

- Few design choices resulted in significant cost reduction
  - High injection energy
  - High periodicity and small beta-functions
    - ⇒ Small aperture, small dipoles and quads
- RCS features
  - No transition crossing
  - Zero dispersion in cavities
  - Reasonably small transverse impedance
  - Small aperture – matches MI acceptance (40 mm mrad)
  - Relatively small space charge tune shift (~0.07)
  - Resonantly driven magnets at 10 Hz
  - 6 injections to fill MI
  - Strip foil injection (2200 turns, foil - T_{max}=1500 K°)
    - Laser stripping is difficult due to 1.2% energy change during injection

Upgrades of ICD-1 for Muon Collider

- ICD-1 allows one to have ~0.15 MW power without any upgrade at 2.5 Hz operation
  - Bunch length as required for muon collider
  - Compressor ring is required
- At 8 GeV and 15 Hz repetition rate the beam power with beam quality required by muon collider is limited to ~1 MW,
  - Upgrade of entire linac RF system is required
  - $P \sim \gamma^4$, therefore ~12 GeV beam is required for 4 MW at 15 Hz
- If we want to use linac (β=1) for muon acceleration we need to have space for muon reinjection from the very beginning (can be very expensive to add it later)

Possible savings

- Building initially only a 6 GeV linac is possible
  - Injection goes directly to MI
  - Allows to save money at initial construction

Upgrades of ICD-2 for Muon Collider

- ICD-2 allows one to have ~0.34 MW power without upgrade at 10 Hz
  - Bunch length as required for muon collider
  - Compressor ring is required
- Running an experimental program with CW beam puts severe limitations on possible upgrades
  - Upgrade of 2 GeV CW linac is a serious problem
    - Increasing installed CW power to 8 MW would allow to reach 1 MW power at 8 GeV and 15 Hz repetition rate
      - Does not look as a prudent investment
    - Combination of pulsed and CW RF sources was suggested
      - R&D are required to see a feasibility at required power level
    - The problem originates from small current of CW linac. It can be resolved with
      - long pulse pulsed linac and
      - laser striping
  - An upgrade of RCS or pulsed linac to 1 MW looks straight forward
- Same as for ICD-1, 8 GeV limits the beam power to ~1 MW at 15 Hz

Possible savings for ICD-2

- 1 GeV CW linac is possible if RCS is used but it would require larger frequency sweep in RCS (additional cost and problems)
  - MI power: 2 MW ⇒ 1 MW
  - Mu2e is possible
  - Kaons are not but can be added later
- Reduction of beam energy to 6 GeV linac does not look promising
  - Impossible for RCS
    - need Recycler for beam storage
  - Requires laser stripping in MI for pulsed linac
    - too long injection time
- Reduction of linac beam current below 1 mA does not buy much

Ideal Project X Scenario

- Depending on priority start g-2 experiment or antiproton physics in Accumulator after Tevatron shutdown, 2012-2013.
  - In contrast to mu2e the g-2 experiment does not require decommissioning of Antiproton source
- Build ICD-2 with RCS*
  - Finish 2 GeV linac by 2016
  - Build the civil infrastructure for mu2e and be ready to start the experiment fed by CW linac in 2016
    - 1 GeV is possible but does not look promising. Mu2e can stay at 1 GeV even for 2.X GeV operation
  - Finish RCS by 2018
    - 2 MW in MI should be available shortly after
  - Finish civil construction for kaon and muon physics at 2.X GeV by ~2020
    - First experiments should be ready to go shortly after that

---

* RCS can be replaced by pulsed linac. It increases the cost but positions us better for neutrino factory

Conclusions

- ICD-2 looks as a way to go
  - Choice between RCS and Pulsed linac need to be done soon. It is determined by
    - Cost and
    - Upgradability
- There are no obvious cost reduction schemes without sacrificing machine parameters or paying additional money in the future
  - Suggestions are welcomed