Mu2e-II: Sensitivity Estimate

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Working Group Report for
Mu2e-II Workshop
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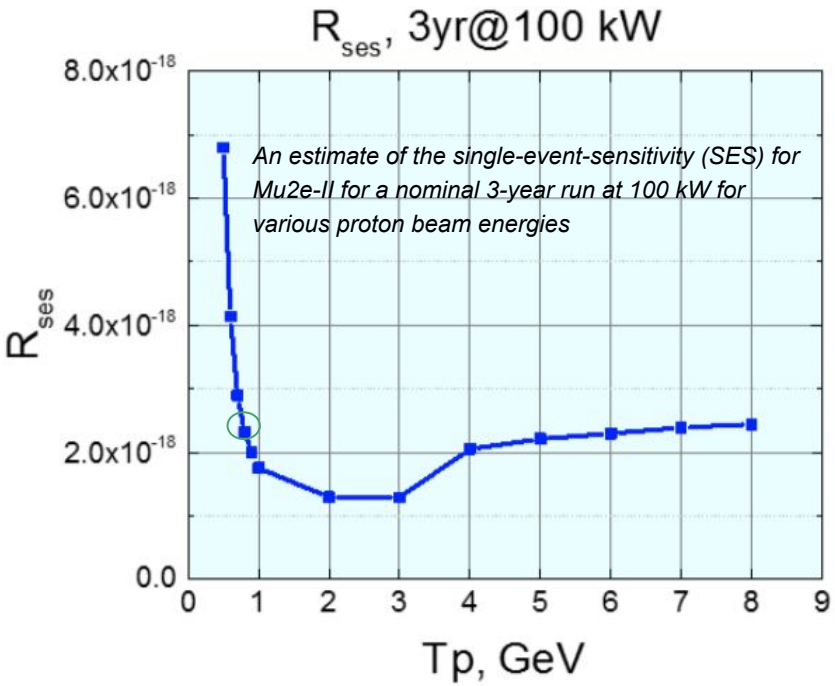
Physics Goals

- Mu2e-II would utilize the increased intensity provided by the Fermilab PIP-II (800 MeV, H-) upgrade to improve the sensitivity for neutrinoless conversion of muon-to-electron by at least a factor of 10.
- Improvements in apparatus required to accommodate the increased beam intensity and cope with resulting radiation and increase in backgrounds. Extensive analysis required.
- Our working group will :
    - Upgrade & optimize the detector and solenoid geometries in the Offline code to reflect the technologies required to cope with the PIP-II environment.
    - Produce simulations of the relevant backgrounds.
    - Quantify the expected sensitivity for neutrinoless muon-to-electron conversion in Mu2e-II.
    - Mu2e-II also offers the opportunity to study mu->e+. Simulation effort to understand this.
    - Understand stopping target optimization and alternative material choices.

Previous Works

- Previous work produced estimates of SES for range of beam energies.
- For Snowmass 2021 a large scale effort to update detector geometries, solenoids, targets and calculate backgrounds is required.
- R&D will lead to updates in Offline software.



arxiv-1802.02599 (Mu2e-II EOI)

arXiv:1612.08931

Status & Requirements

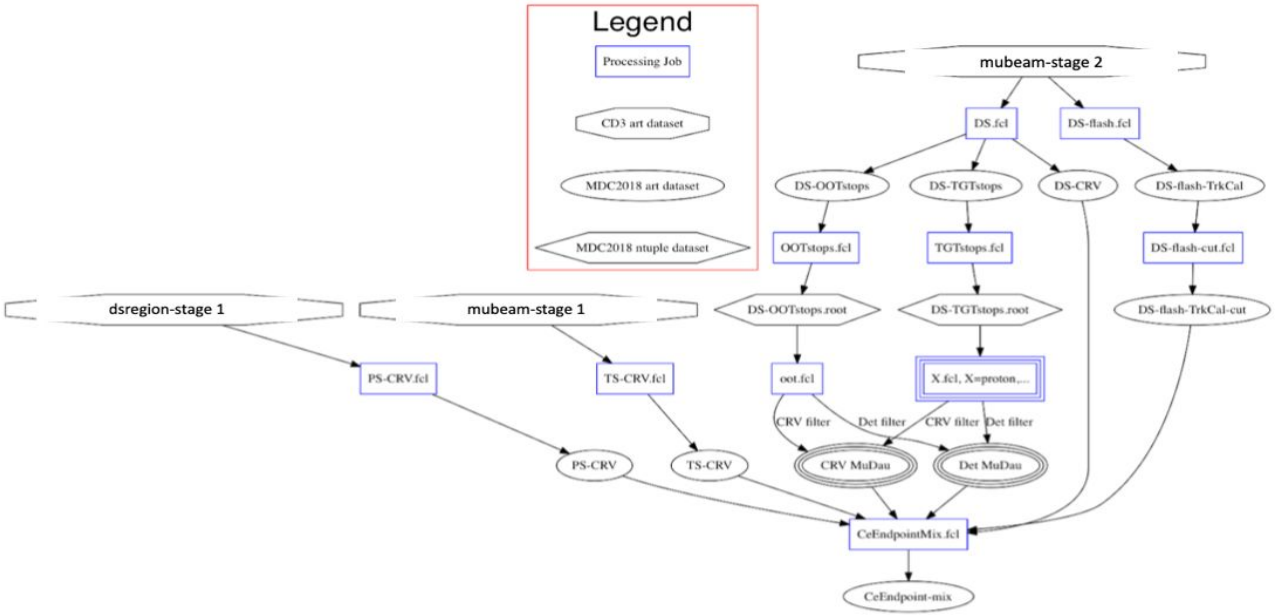
1. Geometry Upgrades:
    a. Solenoids - requires input from geometry experts:
        i. PS: HRS must maintain acceptable levels of radiation damage and heat load in coils. Further study of radiation damage to the PS at high beam power is required.
        ii. No upgrades for TS and DS foreseen, except pbar windows removal
    b. Detectors - requires input from sub-system experts:
        i. Enhanced shielding for the CRV is already implemented in Offline.
        ii. Tracker upgrade and BaF_2 calorimeter geoms will require work.
    c. Targets (stopping and production)
2. Physics Simulations:
    a. DIO, RPC, Decay-in-Flight, cosmics... - we can utilize the skills learned in SU2020.
    b. mu-->e+ etc. (should maintain contact with theory working group)
    c. May require multiple rounds to optimize stopping target. We have tools for this.
3. Software: need to understand performance in new environment.
4. Analysis & Statistics: Utilize existing tools and expertise from SU2020.

Code and Practices

- Will have our own repo in here: https://github.com/Mu2e .
- Interested participants can clone, and pull requests placed when work is ready.
- Will require computing resources to complete our simulation effort - we expect these to be a mix of grid and HPC resources
- For the Production campaign we will follow that for standard production https://mu2ewiki.fnal.gov/wiki/MCProdWorkflow.

Muon Beam Production & Mixing (Workflow)

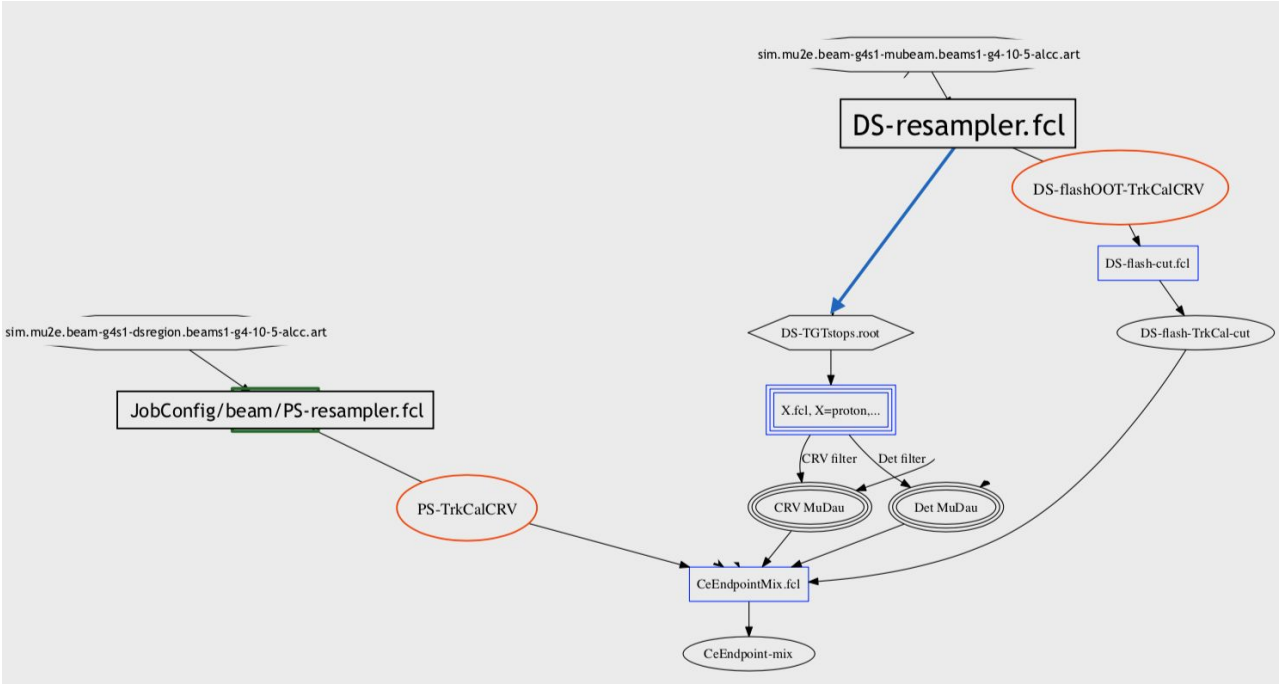
Production workflow
for MDC2018:



Original diagram from Mu2e doc-db 22693

Proposed New Production Workflow

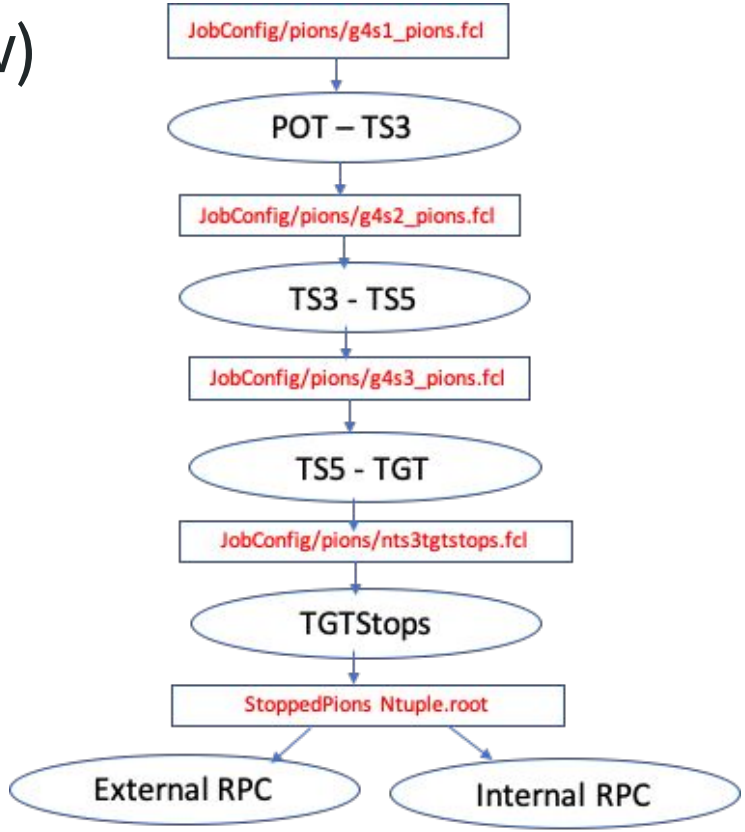
Proposal to simplify this workflow for 2020: **Mu2e doc-db 31652.**



Pion (RPC) Simulations (Workflow)

RPC included separately. Here assume pion fcl files are those recently upgraded.

Note - these are just preliminary plans for the workflow.

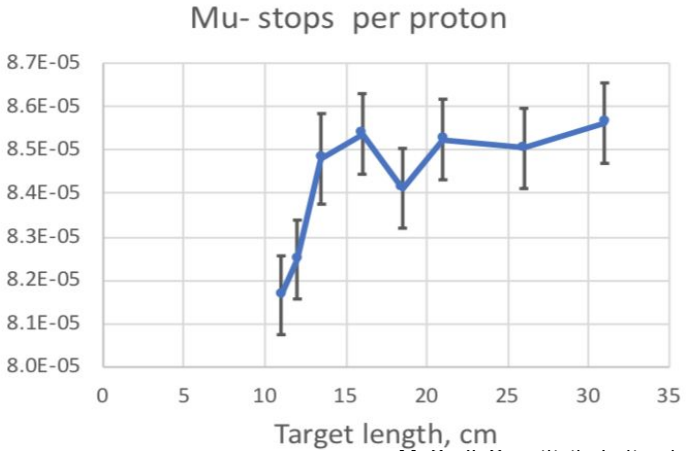


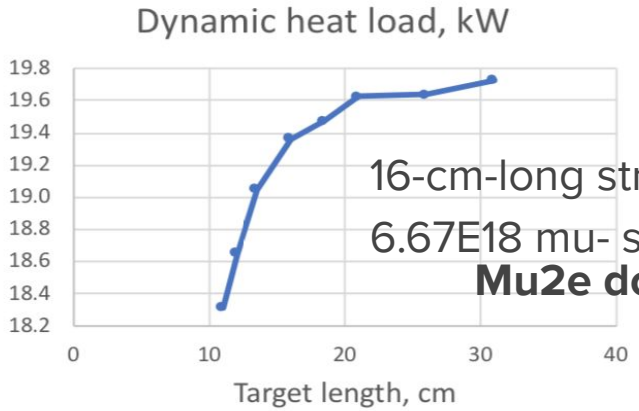
Problems to Solve

- Solenoid/Detectors:
  - Geometries of PS, CRV, Tracker, Calorimeter will all need upgrades.
- Tracking/Software:
  - Understand performance in new environment.
  - Need to understand sample that is required to study DIO tails in new tracker.
- Targets and Optimization:
  - Can we improve our SES by using different stopping target geometries? Alternative material?
  - Production Target designs - high intensity, recent simulation effort can be used (next slide)
- Analysis:
  - A large simulation effort: previous slides outlined workflow, a large-scale production needed, need to produce mixed samples etc.
  - Request computing resources.
  - Will learn from SU2020/MDC2020.

Production Target/HRS

- Problem: There is no Mu2e upgrade target concept satisfying Mu2e-II requirements i.e a 100-kW, 800-MeV proton beam. HRS must also be redesigned: arXiv:1612.08931.
- Simulate: Material? Size? Shape (rotating, conveyor, fixed granular)?
- Measures: Stopping rate, production rate, radiation damage, thermal stress all need evaluating.
- Status:





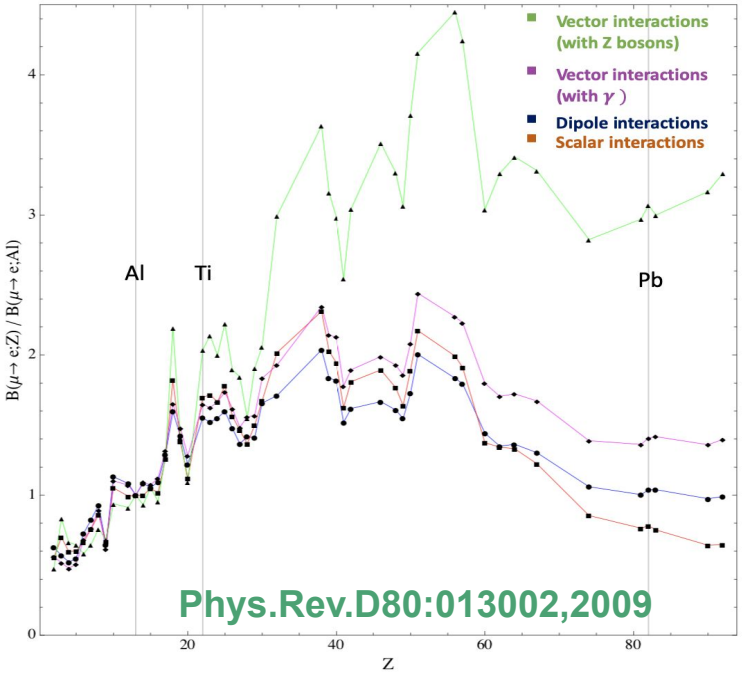
16-cm-long straight W target.

6.67E18 mu- stops/5yr - factor of 10.

Mu2e doc-db 33926

Stopping Target

- If no signal in Mu2e:
  - Mu2e-II will further constrain new physics parameters.
- If signal in Mu2e with < 5σ:
  - Mu2e-II will allow us to fully establish signal.
- If signal in Mu2e with > 5σ:
  - Mu2e-II could make a precision measurement of effect and operate with different stopping targets (such as Ti).
  - Measuring Z dependence of $R_{\mu e}$ can elucidate structure of new physics.
  - Work ongoing to understand alternative materials.
- For mu->e+:
  - Could investigate Si, Ca or Ti target.



Al Stopping Target Design

- Primary target will be Aluminium.
- Problem: optimal target geometry: change foil number, thickness, use mesh alternative? etc.
- Simulations Required: The design of the target will alter stopped muon (CE, RMC and DIO) and pion rates and we must optimize for best SES, BFUL or stopped muons possible based on possible CE, RPC and DIO yields.
- Additions: Cosmics - different target would have different rates? Previous study ignored cosmics in optimization - should we?
- Status: Studies are beginning, building on: **Mu2e doc db 3435**. Recently tested an upgraded analysis tool based on this study.

R&D and Technology

- Technology: We will feed off the R&D of detector subgroups. Final designs must be added into Offline.
- Our R & D:
  - Beginning Simulation studies to optimize Stopping Target technology, optimize design for best signal:background and increased SES/BFul.
  - Recent Production Target simulations can be utilized and we will consult with relevant experts to get the chosen design into the Offline code.
  - PS upgrades will branch off from Radiation Studies group.

People

- Will need input from experienced people with particular focus on geometry upgrades and physics analysis.
- Already approached several people but more help is welcome.

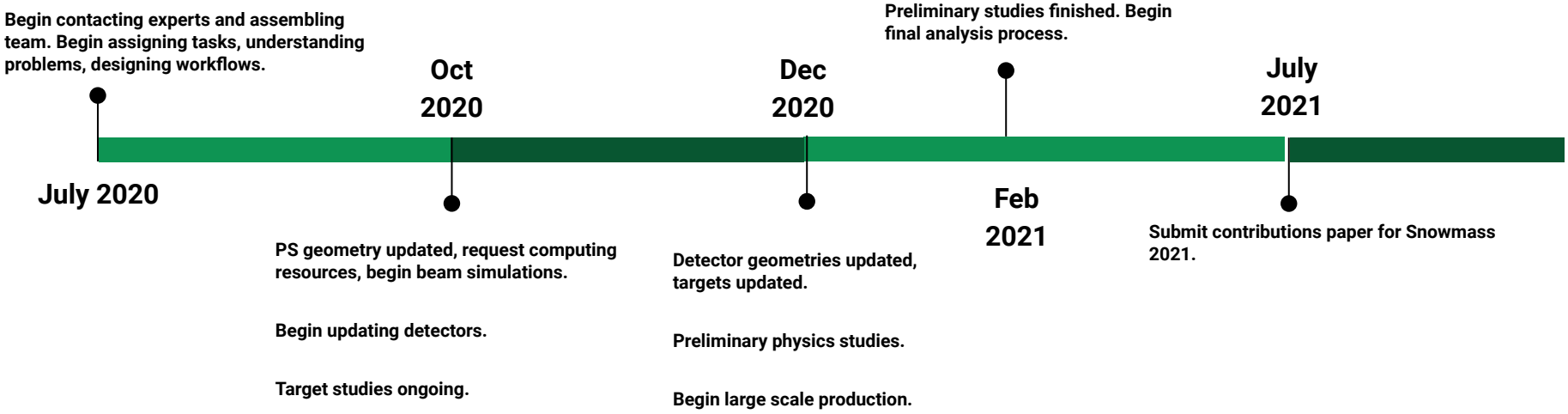
Team so far: L. Goodenough, S. Middleton, Y. Oksuzian, R. Chislett, M. Hedges, C. Kampa, M.Kargiantoulakis, M.Mackenzie

We need: Tracker and Calorimeter experts to help with this process.

- Please make contact with the convenors to get involved.

Estimated Timeline

Note: this is purely a guide, these early dates are flexible and will depend on when other groups converge on their designs too.



Summary

- A lot of work to be done, we are beginning to assemble our core team.
- Must keep contact with detector working groups and radiation studies group.
- Wiki Link: https://mu2eiiwiki.fnal.gov/wiki/Sensitivity_estimates
- Also have a Slack channel for anyone interested in following progress: #mu2e-ii_sensitivity_and_simulations.