

Muons & FLUKA

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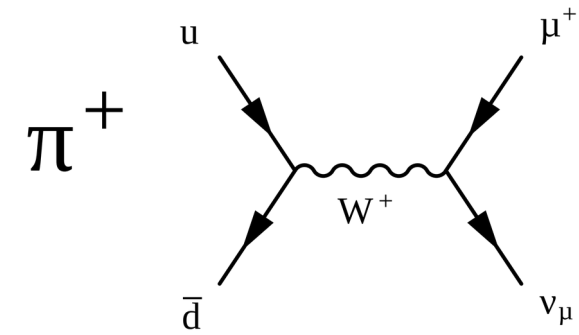
Use of FLUKA for Muons

- MuSR
 - Stopping polarised μ , energy < 4.2 MeV
- Muon beta spectroscopy
 - Stopping μ^-
- Also consider
 - Muon tomography using higher energy muons ($>$ minimum ionising)
 - μ^- catalysed fusion
 - Particle physics applications
 - Stopping μ^\pm for rare decay experiments
 - Muons in flight experiments (e.g. g-2)
 - Neutrino production
 - Muon collider
- **About 15 % of ISIS “science output” from muon beam lines**



Muon Production Model

- Muons are produced from decay of pions (BR 99.99%)
 - $\pi^\pm \rightarrow \mu^\pm + \nu_\mu$
 - Weak force “charged-current” process, calculable from QFT
 - Muons produced in pion rest frame with
 - 4 MeV
 - 100 % polarised
- Pion production is nasty QCD process:
 - $p + N \rightarrow \pi^\pm + X$
 - Some pions reabsorbed via inverse reaction
 - Also double pion production model may be relevant for protons $> O(500-600 \text{ MeV})$
 - $p + N \rightarrow \pi^\pm + \pi^\pm + X$
 - Neutral pions, and other hadrons can also get involved especially at higher energy
 - e.g. kaon production threshold at 1.7 GeV
- Need a Monte Carlo code to calculate flux

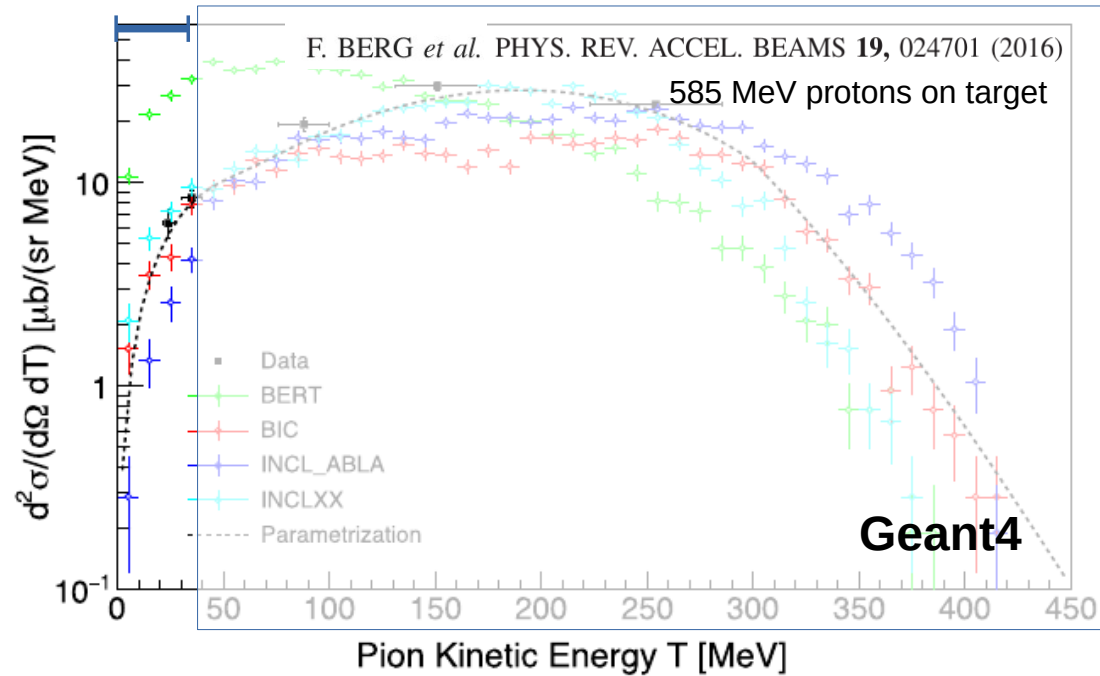


Monte Carlo codes

- Few MC codes out there
 - **FLUKA**
 - Geant4
 - PHITS
 - MARS
- Maintained by regional labs
- Important for radiation safety case for facilities
 - Critical infrastructure



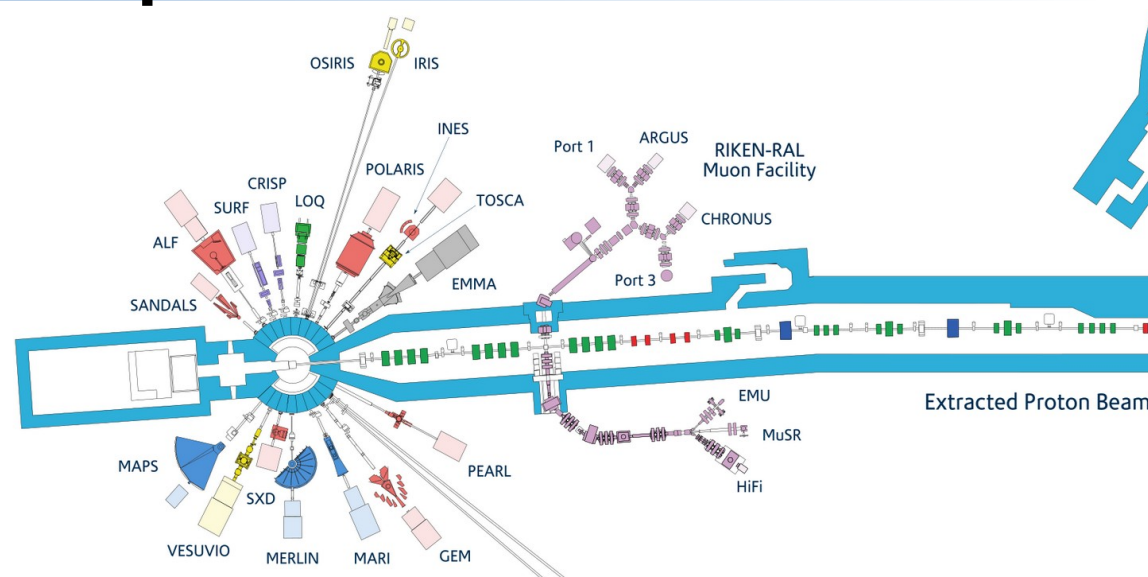
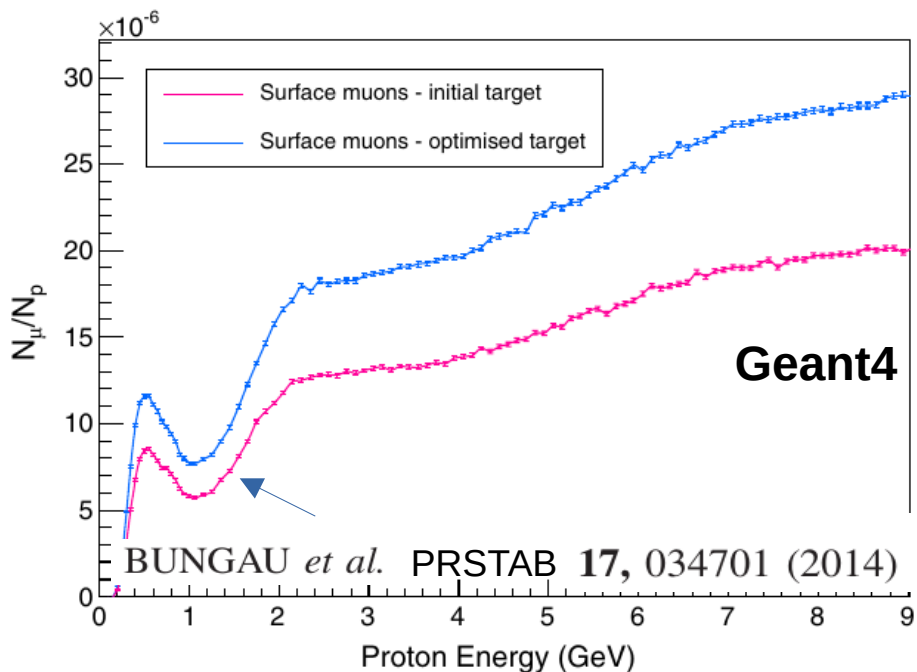
Pion flux



- For most ISIS applications we only care about low energy tail
 - Pions with $E > O(30)$ MeV do not stop in the target
- Numerically difficult working point **Note log plot!**

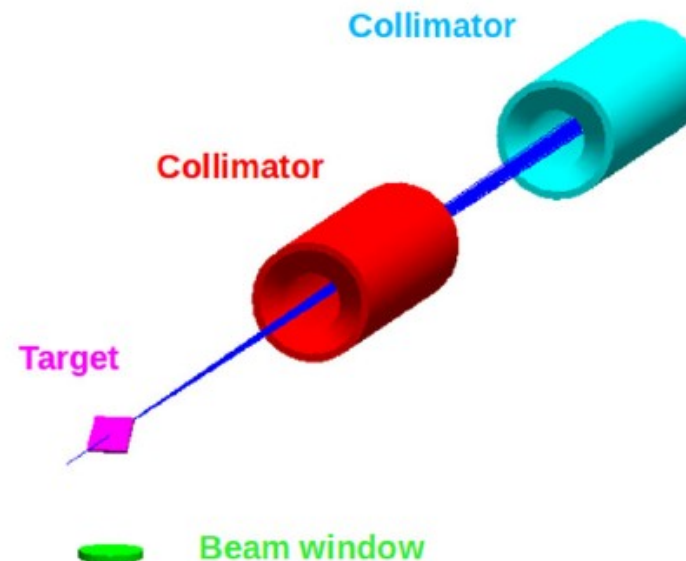


Flux – energy dependence



- Interesting possible results

- Is the dip at 1.2 GeV real? Some weird feature of double pion production?? Geant4 artifact?
- Surely important for future facility designs

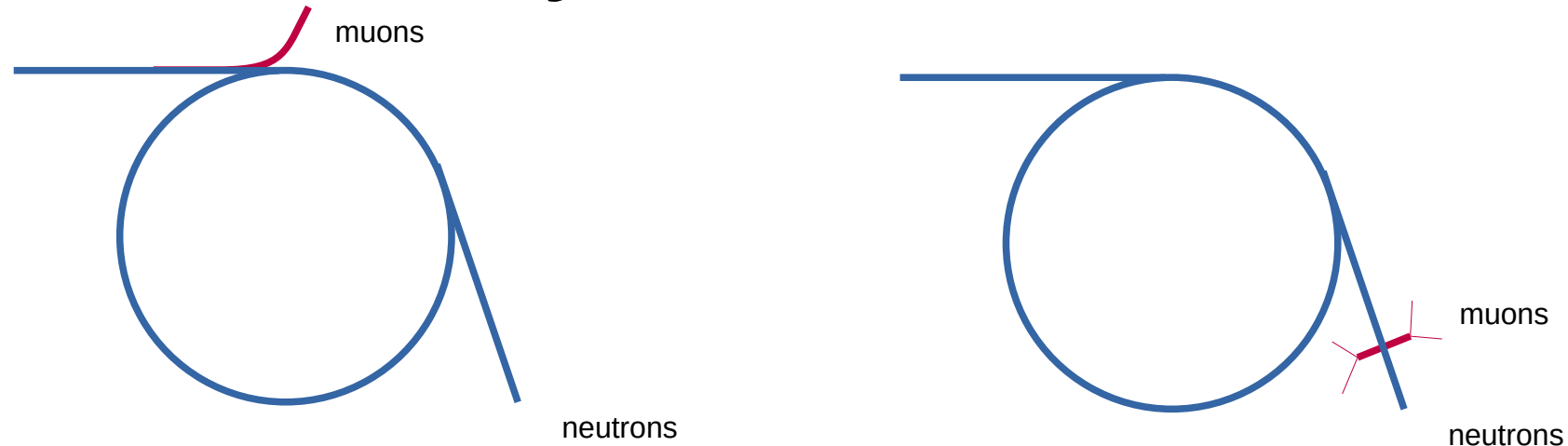


ISIS Upgrades & Improvements

- Few considerations ongoing for improvements to ISIS muons
 - From improved target design
 - To large scale facility upgrade
- Consideration of facility energy is important
 - Is there a “muon gap” for facility energy 0.5 – 2 GeV



Beyond ISIS

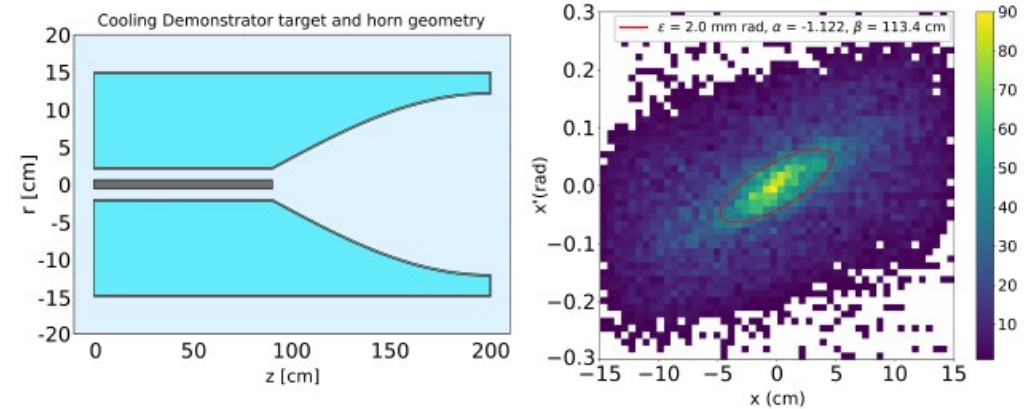


- Should we have a standalone target station in linac?
 - What linac energy?
- Should we have a “parasitic” target station in EPB?
 - What ring energy?

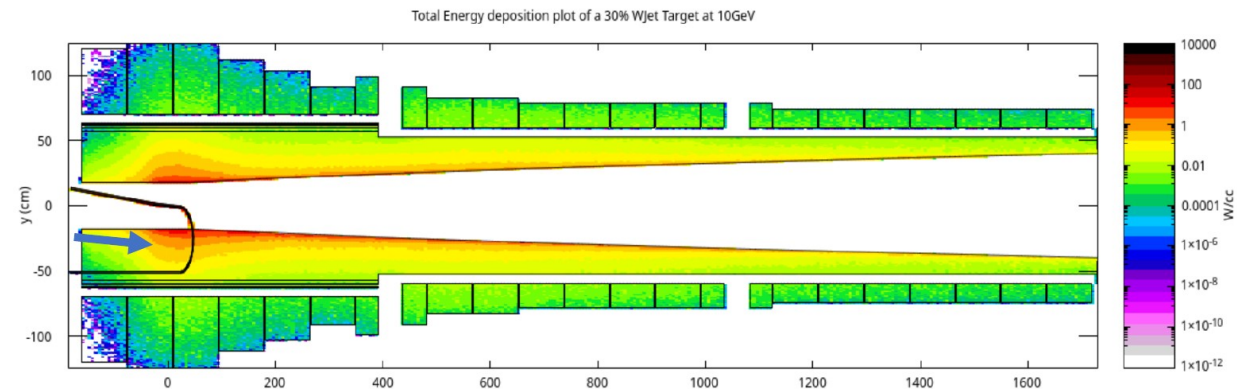


Other activities

- Consideration of other physics at ISIS
 - Neutrino production
 - Muon catalysed fusion
- Participation in international projects
 - DUNE, T2K, ESSuSB, uSTORM
 - $\mu 2e$, COMET
 - Muon collider



P-B Jurj et al, mops023, IPAC2025



W. Bishop et al, IMCC Target meeting

So...

- ISIS has a vibrant muon science community
- Dependent on monte carlo codes for planning future upgrades
 - Mostly Geant4-based up to now
 - Challenging physics environment
 - Low energy tail of a wide distribution
 - Feeds into important “top level” facility parameters
- FLUKA can play a key role in our planning
 - Excited to collaborate further

