CPS spallation source – filling the gap for neutron rich nuclei ?

CPS - underpin major new programmes at JLAB
e.g. Kaon beam facility (KLF)

Strong UK leadership, simulation expertise, …

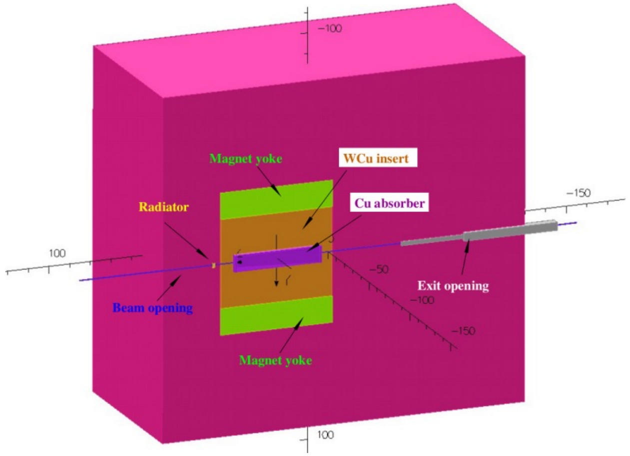
10^{13} γ sec^{-1} for 1st gen devices – 10^{19} feasible (c.f 10^{8} in CLAS@JLAB)

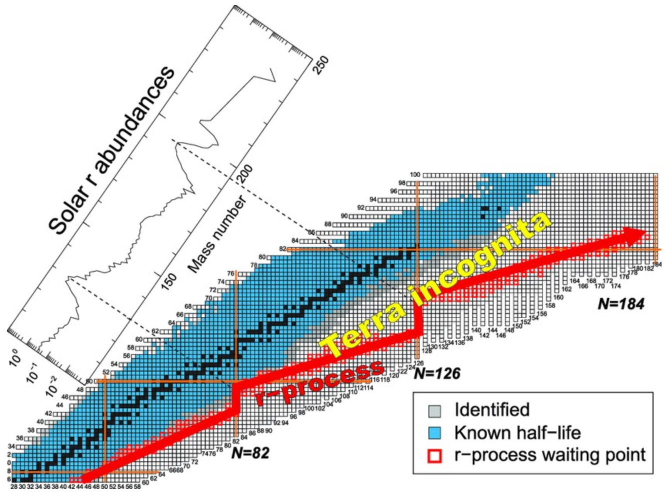
-> Progressing a new CPS γ spallation concept through TLR levels

γ–spallation has significant advantages:

- Greatly reduced heat deposition cf strong beams (protons/pions)
- EM backgrounds forward peaked (e^-e^+)
- Interaction throughout volume rather than surface < ang mom

Recent work to benchmark models amenable to gamma spallation predictions

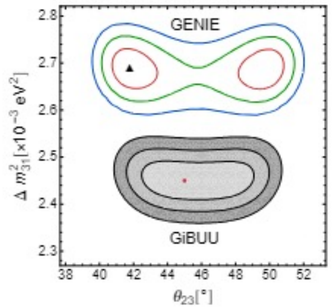




Benchmarking spallation modelling

GiBUU - unified theory and transport framework (MeV/GeV scales)

Also a leading model for next generation neutrino facilities e.g. DUNE



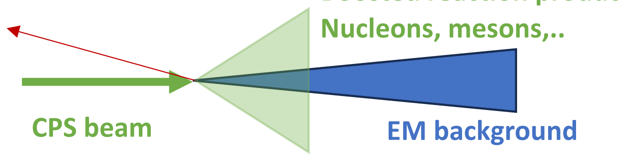
GiBUU

Key spallation reactions e.g. many-proton knockout - need benchmarking

Key seed reactions are initial multiple meson (M) production off a nucleon

- ➔ Mesons can decay in the medium e.g. ω->3π
- ➔ subsequent (M,3N), (M,4N) interactions
- ➔ Subsequent (N,N')
- ➔ Can knock out a lot of nucleons in a direct reaction process
- ➔ Similar mechanisms in proton spallation – but more diffractive and peripheral

Separate backward going recoils (isotropic, ~Fermi momentum)
T, t (MR-TOF?)
Interdisciplinary collaborations
(Cubis, Doherty, Jenkins)



- BUU equ.: space-time evolution of phase-space density F (from gradient expansion of Kadanoff-Baym eq.)

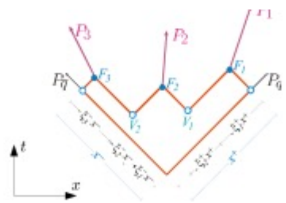
$$\frac{\partial(p_0-H)}{\partial p_\mu}\frac{\partial F(x,p)}{\partial x^\mu} - \frac{\partial(p_0-H)}{\partial x_\mu}\frac{\partial F(x,p)}{\partial p^\mu} = C(x,p)$$

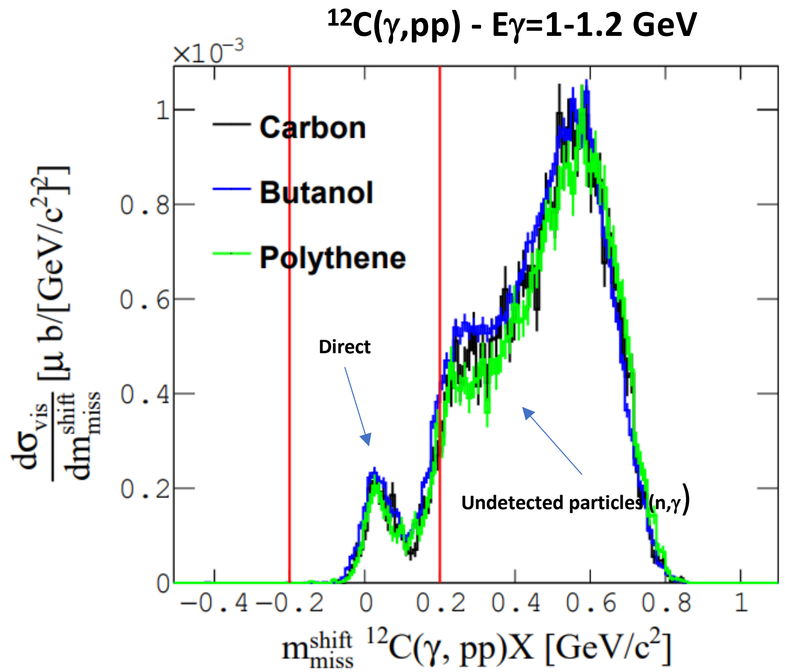
- Hamiltonian H:
  - hadronic mean fields, Coulomb, "off-shell potential"
- collision term $C(x,p)$:
  - decays and scattering processes (2- and 3-body)
  - low energy: resonance model, high energy: string fragment.

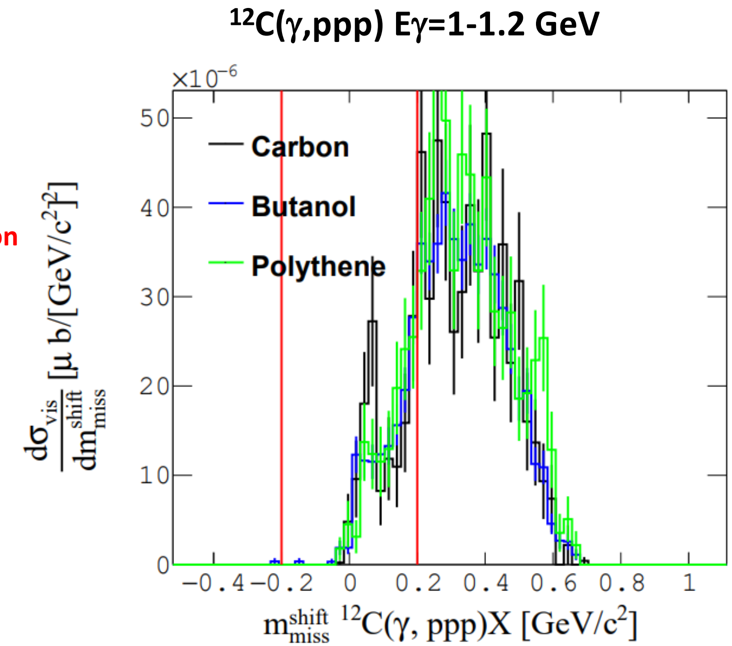
- included hadronic states:
  - 61 baryons
    - non-strange: N, Δ, 16 N^*, 13 Δ^* states
    - single-strange: Λ, Σ, 12 Λ^*, 7 Σ^* states
    - multi-strange/charmed: Ξ, Ω, Λ_c, Σ_c, Ξ_c, Ω_c
  - 22 mesons
    - non-strange pseudo-scalars: π, σ, f_2, η, η', η_c
    - non-strange vectors: ρ, ω, ϕ, J/Ψ
    - strange: K, K^*
    - charmed: D, D^*, D_s, D_s^*

high energies: Lund string model

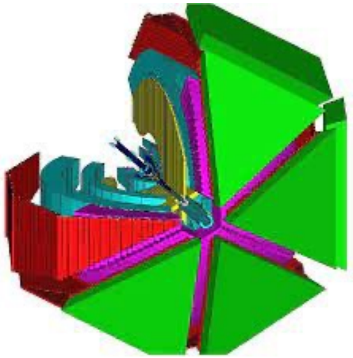
- PYTHIA 6.4 (or FRITIOF)
- hard pQCD interactions plus string fragmentation







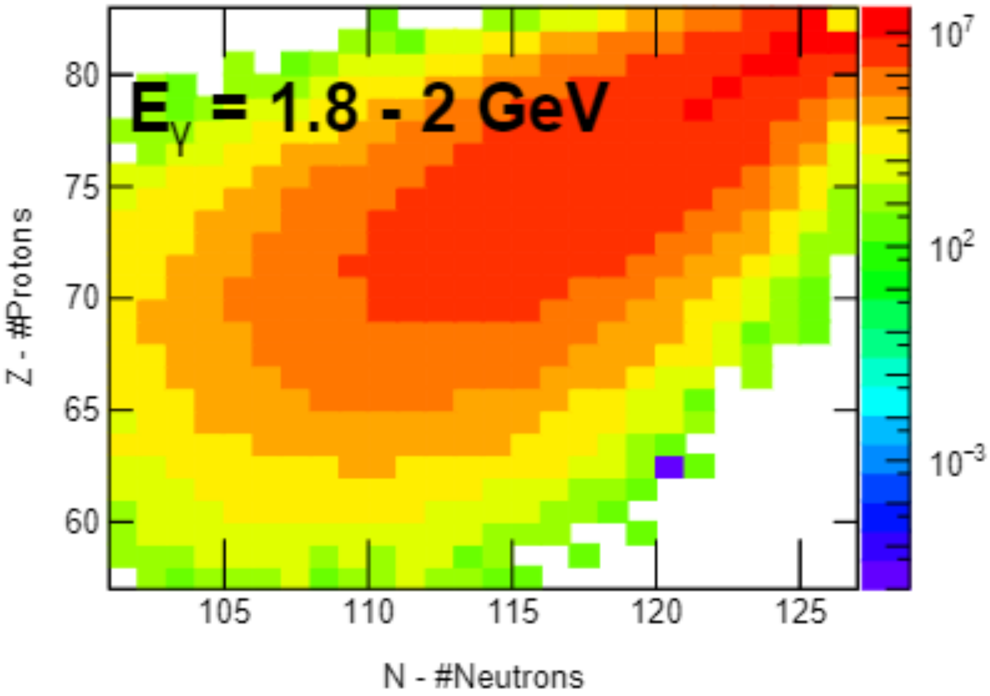
For recoils at potential location of ion separator
low transverse momentum,
backward hemisphere



GiBUU passed through CLAS detector acceptance and compare with data
– GiBUU predictions for direct process within factor ~2
-- Predicts strength up to 6 protons knocked out from 12C

Williams, PhD York

GiBUU prediction for CPS spallation source



Production rates per hour with current CPS beam (μA)
(factor 10^6 increase with 3A EIC linac modules)

Yield map will expand further (limited by simulation time)

Physics drivers
Potential to access swathes of unobserved nuclei with UK-led facility
Potential to reach r-process path -> SN, neutron star mergers
Wealth of new (unobserved) nuclear isotopes for astro/structure information
Drip line studies (e.g. ~pure neutron systems)
Wide range of targets can be used – isotopes tuned to desired region of study

Next steps
Pb data to further challenge GiBUU
HpGe/SI array analysis of lead target exposed high gamma flux
GEANT4 simulation and design of separator - using GiBUU generated recoils and backgrounds

Project scope, what is benefit to UK community
UK lead on a potential next generation spallation facility
CPS technologies are on an upward trajectory -
Electron accelerator technologies at heart of CPS – strong profile of UK (Daresbury, Cockcroft). ELI-NP, EIC
Potential for a UK based facility?
New opportunities for medical isotope production

Timescale: 2027/2028
Estimated cost: £5M : (Assuming hosted at JLAB CPS with £3.5M UK contribution to low energy recoil isotope separation apparatus, simulations programme and target aspects, £1.5M UK contribution to detector stations). Would expect significant additional DOE and NSF investment if hosted at JLAB)