Performance validation of the FALSTAFF first arm:

$^{252}$Cf and $^{235}$U fission fragment characterisation

D. Doré$^1$), E. Berthoumieux$^1$), Q. Deshayes$^1$), L. Thulliez$^1$), M.O. Frégeau$^2$), X. Ledoux$^2$), J. Pancin$^2$), S. Oberstedt$^3$)

1) Irfu, CEA, Université Paris-Saclay, France
2) GANIL, Caen, France
3) European Commission, Joint Research Centre, Geel, Belgium

Outlook

- Goals and Motivations
- Detectors
- $^{252}$Cf and $^{235}$U results
- Perspectives and Summary
Goals and Motivations

Study of actinide fission in the fast energy domain

Fragments in coincidence
- Kinetic energies
- Final masses (after n evaporation)
- Initial masses (before n evaporation)
- Charge

Actinides to study: $^{238,235}$U, $^{239}$Pu, $^{237}$Np, $^{232}$Th, $^{233}$U, ...
Experiment to be performed at NFS, ...

Data needed :
- Few data in the fast energy domain
  - Neutron multiplicity and fission yields important for ND libraries
  - Important for the understanding of the fission process: energy sharing, deformation, ...

Terrell et al., 1957

Naqvi et al.
**FF mass before evaporation \( (A_{\text{pre}}) \rightarrow \text{The 2V method} \)
- Hyp: n evaporation does not modify velocity in average

**Measurement using time-of flight (TOF) method**
- Timing resolution : \( \sigma_t \sim 150 \text{ ps} \)
- Spatial resolution : \( \sigma_{x,y} \sim 2 \text{ mm} \)

\[ \text{Emissive foils + MWPC} \]
**Method**

**Measurement using time-of flight (TOF) method**
- Timing resolution: $\sigma_t \sim 150 \text{ ps}$
- Spatial resolution: $\sigma_{X,Y} \sim 2 \text{ mm}$

**Measurement using an energy detector + TOF**
- Timing & position resolution similar to 2V
- Energy resolution $\Delta E/E \sim 1\%$
- Energy loss profile $\rightarrow \sim Z$

**FF mass before evaporation ($A_{pre}$) $\rightarrow$ The 2V method**
- Hyp: n evaporation does not modify velocity in average

**FF mass after evaporation ($A_{post}$) $\rightarrow$ The EV method**
- Energy loss corrections

**Fragment energy losses**
- Thickness/homog. of materials
- Track reconstruction
- Good calc. of $\Delta E$

**Axial ionization chamber**

**Emissive foils + MWPC**
**Method**

**FF mass before evaporation ($A_{pre}$) → The 2V method**
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- Timing & position resolution similar to 2V
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  profile $\sim Z$

Emissive foils + MWPC

Axial ionization chamber

$D. \: \text{Doré}$
Stop (20x14 cm²)

Analysis in progress
**ToF Detectors**

Stop (20x14 cm²)

$^{252}$Cf source

**Analysis in progress**

Yield (a.u.)

Velocity (cm/ns)

This work

D. Doré

Wonder 2018
Stop (20×14 cm²)

**252**Cf source

MWPC

Analysis in progress
Energy Detector

FF2
Target
Start
Stop
Energy
d = 50 cm
Energy Detector

Energy (channels)

Yields (a.u.)

$^{252}\text{Cf}$

This work

Anode
Pont diviseur de tension
Connecteur haute tension
Grille de Frisch
Anneaux dégradeurs de champ
Fenêtre d'entrée
Grille de maintien
Tuyau d'acheminement du gaz vers la cathode
Energy Detector

This work

Meierbachtol et al.

Frégeau et al.
Energy Detector

![Diagram of energy detector components]

- Anode
- Grille de Frisch
- Cathode

Energy vs. Time (ns)

Amplitude vs. Time (ns)

Yields (a.u.) vs. Energy (channels)

252Cf

This work

D. Doré

Wonder 2018
Calibration experiment at IPNO

- Energy and energy loss profile studies

- (Br, I) between 60-100 MeV
- Elastic scattering at 30°  

E. Berthoumieux & A. Zamel

D. Doré
First Arm of FALSTAFF
With a $^{252}$Cf source and using the EV method…

Iterative procedure
Energy loss corrections

This work

Analysis in progress

Loss of heavy fragments due to start detector problem
With a $^{252}$Cf source and using the EV method...

Iterative procedure
Energy loss corrections

Analysis in progress

Loss of heavy fragments due to start detector problem
Distortion of the distribution
Experiment at the Orphée reactor (Saclay)

✓ Target: $^{235}$U (8 & 20 µg, φ= 1 cm), CEA/DIF
✓ Thermal beam: $10^8$ n/cm$^2$/s
✓ Two parts: June 2018, Sept-Oct 2018
Experiment at the Orphée reactor (Saclay)

- Target: $^{235}$U (8 & 20 $\mu$g, $\phi$= 1 cm), CEA/DIF
- Thermal beam: $10^8$ n/cm$^2$/s
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Analysis in progress
Experiment at the Orphée reactor (Saclay)

- Target: $^{235}\text{U}$ (8 & 20 $\mu$g, $\phi=1$ cm), CEA/DIF
- Thermal beam: $10^8$ n/cm$^2$/s
- Two parts: June 2018, Sept-Oct 2018

Analysis in progress
Comparisons Data & G4 Simulations

G4 simulations
- adjust simulated resolutions to reproduce 1-arm data
- perform 2-arm simulations and check if the results are good enough to study the correlation between neutron multiplicity and pre-fragment mass with 2 arms
Comparisons Data & G4 Simulations

Velocity

<table>
<thead>
<tr>
<th></th>
<th>G4 Simu</th>
<th>This work</th>
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</thead>
<tbody>
<tr>
<td><strong>Velocity (cm/ns)</strong></td>
<td><img src="image1" alt="Graph" /></td>
<td><img src="image2" alt="Graph" /></td>
</tr>
<tr>
<td><strong>Yield (a.u.)</strong></td>
<td><img src="image3" alt="Graph" /></td>
<td><img src="image4" alt="Graph" /></td>
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<tr>
<td><strong>235U</strong></td>
<td>Preliminary</td>
<td>Preliminary</td>
</tr>
</tbody>
</table>

This work

D. Doré

Wonder 2018
Comparisons Data & G4 Simulations

Velocity

- **G4 Simu**
- **This work**

Energy

- **G4 Simu**
- **This work**

<table>
<thead>
<tr>
<th>Velocity (cm/ns)</th>
<th>Yield (a.u.)</th>
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<tbody>
<tr>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>1.0</td>
<td>150</td>
</tr>
<tr>
<td>1.5</td>
<td>250</td>
</tr>
<tr>
<td>2.0</td>
<td>150</td>
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<tr>
<td>2.5</td>
<td>50</td>
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<table>
<thead>
<tr>
<th>Energy (channels)</th>
<th>Yield (a.u.)</th>
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<tr>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>100</td>
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<td>90</td>
<td>250</td>
</tr>
<tr>
<td>120</td>
<td>150</td>
</tr>
<tr>
<td>150</td>
<td>50</td>
</tr>
</tbody>
</table>

- Preliminary 235U
Comparisons Data & G4 Simulations

- **Velocity**
  - G4 Simu
  - This work

- **Energy**
  - G4 Simu
  - This work

- **Yield (a.u.)**
  - This work
  - 235U

- **252Cf**
  - Simu
  - Rec (120 ps, 2 mm, 1%)

- **Exp. resolutions probably suitable for 2-arm studies ...**

- **GEANT4 simulations**

- **Ø**
  - Rather good agreement
  - Inhomogeneities not taken into account
  - Other variables to be compared

... at NFS
NFS (SPIRAL2)

Use of radioactive samples
A < 1 GBq for thin layers
A < 10 GBq for thick samples

Neutron beam dump

TOF area

D. Doré

Wonder 2018
≥ 2021 : FALSTAFF @ NFS
- 2\textsuperscript{nd} arm to fund and build

- Mult neut vs fragment mass
- $^{238-235}U$, $^{239}Pu$, $^{232}Th$, $^{237}Np$
FALSTAFF @ FIPPS (gamma ray spectrometer of ILL)

FIPPS

FALSTAFF

T. Materna et al.
Project to be proposed to the next ILL subcommittee
Calibrate Falstaff with well produced fully identified fission fragments
Calibrate Falstaff with well produced fully identified fission fragments

Nuclear data with \((\gamma, \gamma, f)\) measurement in thermal fission with the best identification ever

Method:
- FALSTAFF : \(E,V\) of one fragment \(\rightarrow\) filter events with \(A_1\) with \(\delta A_1 = 2\)
- FIPPS : - identification of one \(\gamma\)-ray transition to the second fragment \(\rightarrow (A_2, Z_2)\)
  - study of other \(\gamma\)-rays from the cascade in the second fragment

\(\rightarrow\) Study of FF de-excitation and measurement of the fission yields
Summary

- First arm of FALSTAFF is running with source AND neutron beam
- Expected resolutions seem to be reached
  - Very promising results with the first arm of FALSTAFF
  - Room for improvement
- Expecting the funding of the second arm
- Preparation of the experiment at FIPPS

Open to new collaborations!
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- DPN/CEA-DIF : A. Chatillon, G. Bélier, V. Méot
- Orphée Team
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ToF Detectors

### 252Cf

![Graph showing yield vs. velocity for 252Cf](image1)

*Meierbachtol et al.*

### 235U

#### Yield vs. Velocity

![Graph showing yield vs. velocity for 235U](image2)

*This work*  
*Shiraishi et al.*

#### Yield vs. Energy

![Graph showing yield vs. energy for 235U](image3)

*Müeller et al.*