High-energy muons at the Forward Physics Facility

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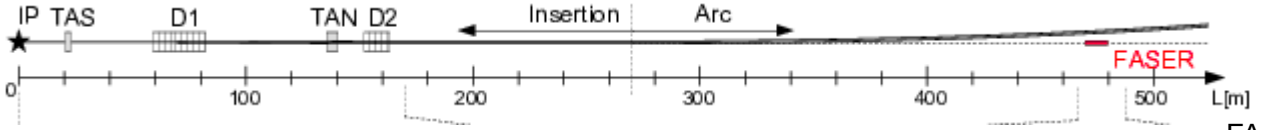
Far-forward muons at the LHC



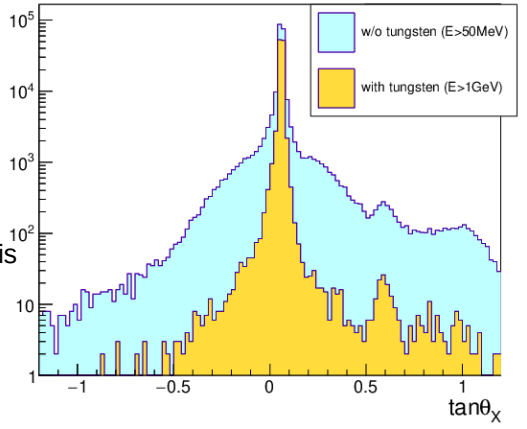
FASER Collaboration,1908.02310

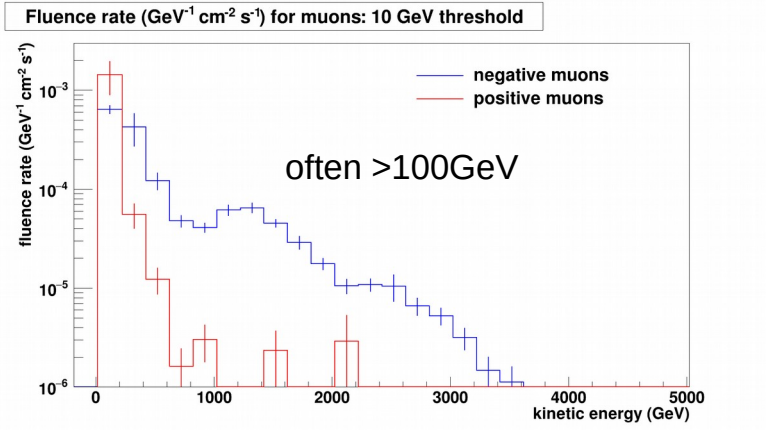
- Production:
- at the *pp* interaction point (IP) and further downstream, e.g. meson decays (charged pions…),
- these muons are often deflected away by strong LHC magnets

- In the TA(X)N neutral particle absorber, 130-140m away from the IP,
- e.g., in photon dimuon pair-production, $\gamma N \rightarrow \mu\mu N$

- Beam-gas collisions close to the Forward Physics Facility (FPF)
- typically soft products and with different directionality

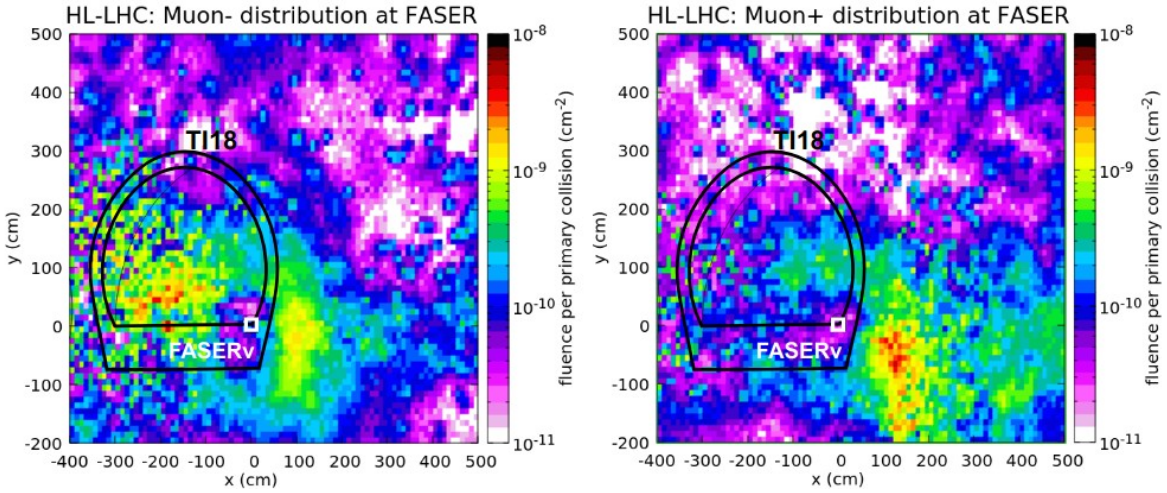
Angular and energy spectrum
FASER Collaboration, 1812.09139
FLUKA simulations, CERN STI Group
M. Sabate-Gilarte, F. Cerutti, and A. Tsinganis





Impact of the LHC optics

- Muons are deflected by the LHC magnets also after the TA(X)N
- About 2 x 10^9 muons expected during Run 3 in FASERν (25cm x 25cm)
- For R=1m transverse size and entire HL-LHC this would grow up to ~10^12 muons
- Could grow even 1-2 orders of magnitude more for larger transverse size
- Some muons can be deflected away by the magnet in front of the FPF (would be challenging for TeV μs)



High-energy forward muon physics program

- … is yet to be defined

- Some possibilities include:

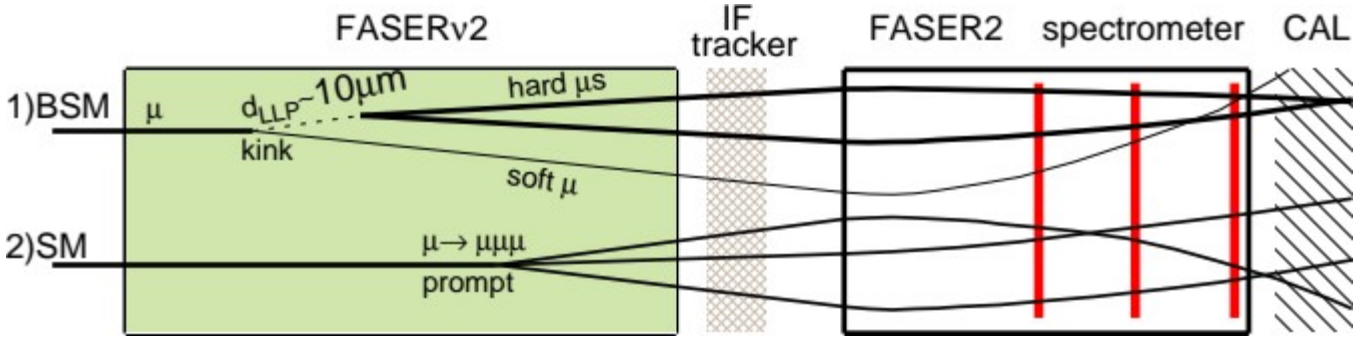
  - **tri-muon signatures** to search for new physics and perform SM measurements (the rest of this talk)

  - muon beam-dump in front of the FPF to probe BSM models with the parent muon deflected away

  - depending on the dominant muon production mechanisms,
  lessons could be learned about the forward muon production in *pp* collisions (relevant for cosmic-ray studies)

- **Definitely open for more ideas** (feel encouraged to email us!)

Tri-muon signature



Incident muon (front veto activation) | vertex reconstruction | ←matching | 3 muons going through the detector

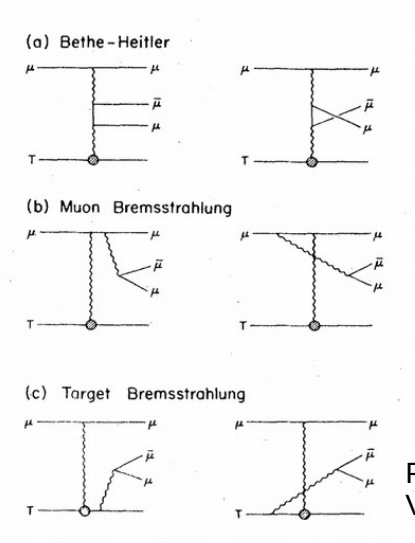
Main SM processes:

- **μN → μγN** (photon bremsstrahlung), followed by a di-muon pair production, **γN → μμN**

- direct di-muon production, **μN → μμμN**

Example of a BSM process:

- **μN → μXN** (brem of LLP X), followed by a decay, **X → μμ**



Phys.Rev.D 20 (1979) 630,
V.D. Barger, W.-Y. Keung, R.J.N. Phillips

SM vs BSM trimuons

SM backgrounds for the BSM search:

- **Prompt $\mu \to 3\mu$ process** This is mostly due to a di-muon pair production in the nuclear Coulomb field.[1]
- **Displaced di-muon pair production** from bremmed photon, $\mu \to \mu(\gamma \to \mu\mu)$.

BSM signal (**μN → μXN, X → μμ**) favors:

- Catastrophic energy loss of the incident muon ($m_X > 2m_\mu$)

Identified based on the "opposite-charge" muon energy

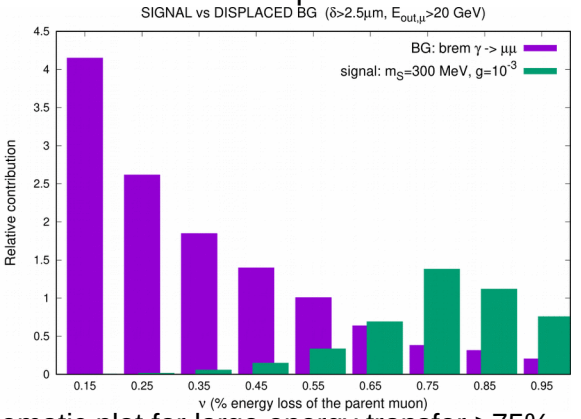
- Small displacement, but within the emulsion detector capabilities:

- direct **μN → μμμN** BG is prompt

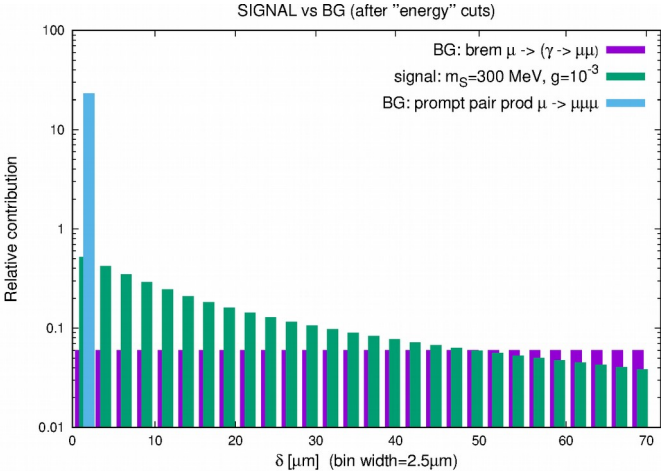
- BG from photon-induced muon pair prod. **μN → μγN, γN → μμN** is spread over the radiation length ~0.35cm in tungsten

• other handles e.g. kink angle

Results for a BSM muon-philic scalar



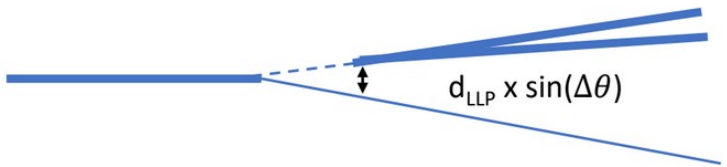
Schematic plot for large energy transfer >75%



Some experimental issues

(to be remembered also when studying different ideas)

• (displaced) **vertex reconstruction** resolution will depend on the kink angle of the incident muon



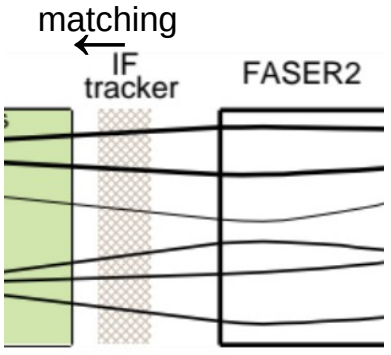
• opening angle of two “daughter” muons also impacts the analysis

Thanks to A. Ariga, T. Ariga

• **trigering** based on tri-muon signal in the spectrometer
Backward matching to emulsion – event pile-up needs to be overcome

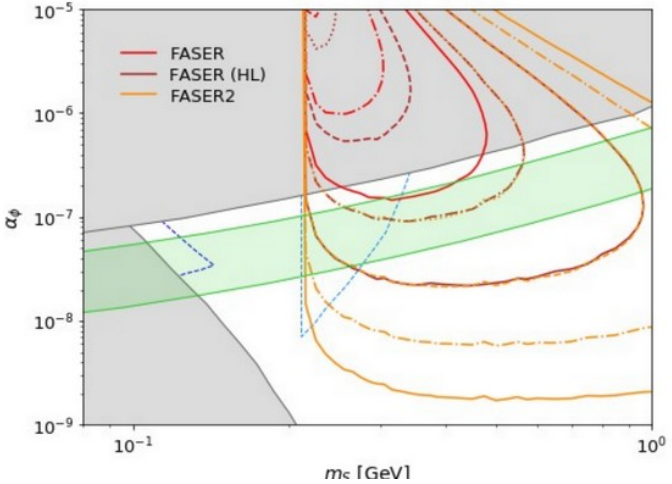
In emulsion: 6x10^5 tracks/cm^2 (Run 3)

If the tracker resolution is ~tens of μm
then a few tracks per pixel are present in emulsion
resulting in ~few tens of combinations to check
when searching for the vertex (managable)



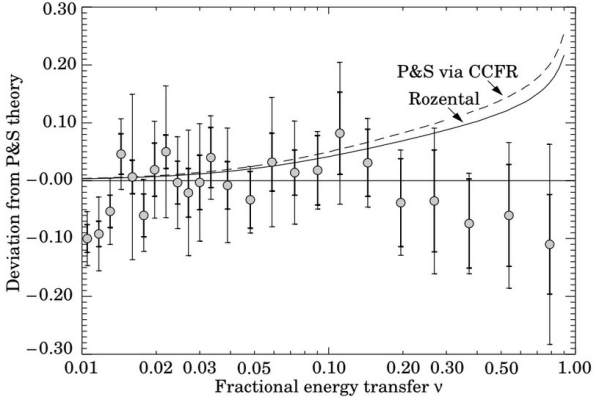
Tri-muon signature prospects

Muon-philic BSM scalar



SM measurement
of tri-muon production

CERN RD3 collaboration, 150GeV muons in iron



PDG, Muon stopping power

- Muon energy loss: Kelner etal (P&S theory) results favored, but there are relatively large error bars at large ν
- Possibility to measure this for trimuons

and to disentangle prompt vs displaced such signal

- also, measurements at TeV energies

Concluding remarks

- Lots of muons produced in the far-forward region of the LHC

- They typically constitute BG for other searches, and can be used to calibrate the detectors but...

- … they can also offer opportunity to initiate the entire new physics program

- We have discussed issues related to BSM and SM searches for the tri-muon signature

- Other ideas awaiting to be discovered! (happy to discuss now and by email)

THANK YOU !!!