Imperial College London

Science & Technology Facilities Council

Welcome and introduction

K. Long, 27 June, 2019

Weclome and introduction

PAPERS

Eur. Phys. J. C (2019) 79:257
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THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

First particle-by-particle measurement of emittance in the Muon Ionization Cooling Experiment

MICE Collaboration

D. Adams[15], D. Adey[25,34], R. Asfandiyarov[13], G. Barber[18], A. de Bari[6], R. Bayes[16], V. Bayliss[15], R. Bertoni[4], V. Blackmore[18,a], A. Blondel[13], J. Boehm[15], M. Bogomilov[1], M. Bonesini[4], C. N. Booth[20], D. Bowring[25], S. Boyd[22], T. W. Bradshaw[15], A. D. Bross[25], C. Brown[15,23], G. Charnley[14], G. T. Chatzitheodoridis[16,21], F. Chignoli[4], M. Chung[10], D. Cline[30], J. H. Cobb[19], D. Colling[18], N. Collomb[14], P. Cooke[17], M. Courthold[15], L. M. Cremaldi[28], A. DeMello[26], A. J. Dick[21], A. Dobbs[18], P. Dornan[18], F. Drielsma[13], K. Dumbell[14], M. Ellis[23], F. Filthaut[11,32], P. Franchini[22], B. Freemire[27], A. Gallagher[14], R. Gamet[17], R. B. S. Gardener[23], S. Gourlay[26], A. Grant[14], J. R. Greis[22], S. Griffiths[14], P. Hanlet[27], G. G. Hanson[29], T. Hartnett[14], C. Heidt[29], P. Hodgson[20], C. Hunt[18], S. Ishimoto[9], D. Jokovic[12], P. B. Jurj[18], D. M. Kaplan[27], Y. Karadzhov[13], A. Klier[29], Y. Kuno[8], A. Kurup[18], P. Kyberd[23], J-B. Lagrange[18], J. Langlands[20], W. Lau[19], D. Li[26], Z. Li[3], A. Liu[25], K. Long[18], T. Lord[22], C. Macwaters[15], D. Maletic[12], B. Martlew[14], J. Martyniak[18], R. Mazza[4], S. Middleton[18], T. A. Mohayai[27], A. Moss[14], A. Muir[14], I. Mullacrane[14], J. J. Nebrensky[23], D. Neuffer[25], A. Nichols[15], J. C. Nugent[16], A. Oates[14], D. Orestano[7], E. Overton[20], P. Owens[14], V. Palladino[5], M. Palmer[24], J. Pasternak[18], V. Pec[20], C. Pidcott[22,33], M. Popovic[25], R. Preece[15], S. Prestemon[26], D. Rajaram[27], S. Ricciardi[15], M. Robinson[20], C. Rogers[15], K. Ronald[21], P. Rubinov[25], H. Sakamoto[8,31], D. A. Sanders[28], A. Sato[8], M. Savic[12], P. Snopok[27], P. J. Smith[20], F. J. P. Soler[16], Y. Song[2], T. Stanley[15], G. Stokes[14], V. Suezaki[27], D. J. Summers[28], C. K. Sung[10], J. Tang[2], J. Tarrant[15], I. Taylor[22], L. Tortora[7], Y. Torun[27], R. Tsenov[1], M. Tucker[14], M. A. Uchida[18], S. Virostek[26], G. Vankova-Kirilova[1], P. Warburton[14], S. Wilbur[20], A. Wilson[15], H. Witte[24], C. White[14], C. G. Whyte[21], X. Yang[30], A. R. Young[21], M. Zisman[26]

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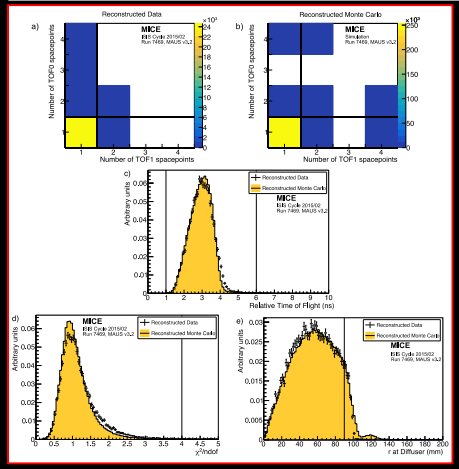
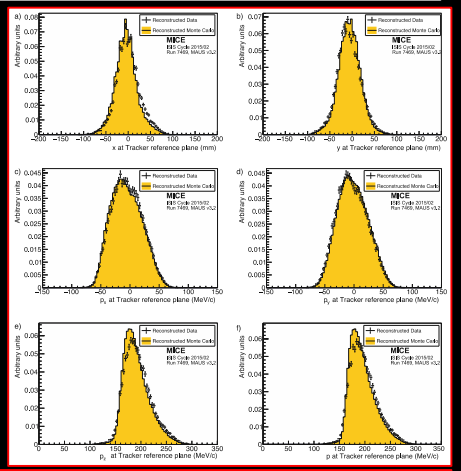
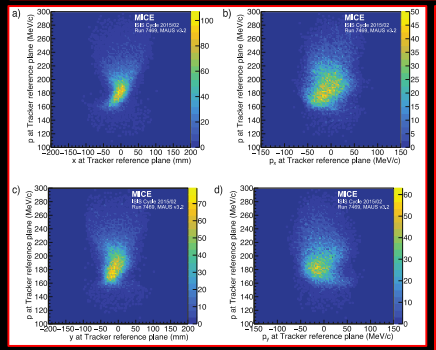
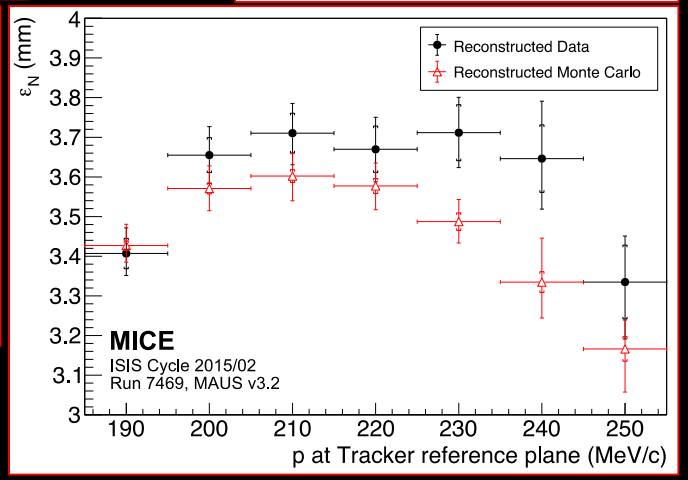
Emittance paper: [RAL-P-2018-005; arXiv:1812:02674, Eur.Phys.J.C (2019) 79:257]

- **Published in EuPJC – Victoria Blackmore**









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Muon Accelerators for Particle Physics — MUON

MAUS: the MICE analysis user software

R. Asfandiyarov,[a] R. Bayes,[b] V. Blackmore,[c] M. Bogomilov,[d] D. Colling,[c] A.J. Dobbs,[c] F. Drielsma,[a] M. Drews,[h] M. Ellis,[c] M. Fedorov,[e] P. Franchini,[f] R. Gardener,[g] J.R. Greis,[f] P.M. Hanlet,[h] C. Heidt,[f] C. Hunt,[c] G. Kafka,[h] Y. Karadzhov,[a] A. Kurup,[c] P. Kyberd,[g] M. Littlefield,[g] A. Liu,[j] K. Long,[c,n] D. Maletic,[k] J. Martyniak,[c] S. Middleton,[c] T. Mohayai,[h,j] J.J. Nebrensky,[g] J.C. Nugent,[b] E. Overton,[l] V. Pec,[l] C.E. Pidcott,[f] D. Rajaram,[h,1] M. Rayner,[m] I.D. Reid,[g] C.T. Rogers,[n] E. Santos,[c] M. Savic,[k] I. Taylor,[f] Y. Torun,[h] C.D. Tunnell,[m] M.A. Uchida,[c] V. Verguilov,[a] K. Walaron,[b] M. Winter[h] and S. Wilbur[l]

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Abstract: The Muon Ionization Cooling Experiment (MICE) collaboration has developed the MICE Analysis User Software (MAUS) to simulate and analyze experimental data. It serves as the primary codebase for the experiment, providing for offline batch simulation and reconstruction as well as online data quality checks. The software provides both traditional particle-physics functionalities such as track reconstruction and particle identification, and accelerator physics functions, such as calculating transfer matrices and emittances. The code design is object orientated, but has a top-level structure based on the Map-Reduce model. This allows for parallelization to support live data reconstruction during data-taking operations. MAUS allows users to develop in

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MAUS paper: [RAL-P-2018-007; arXiv:1812:02674, JINST 14 T04005]
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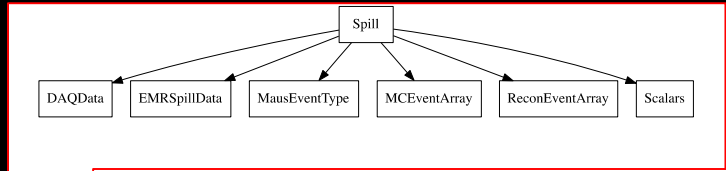
- ***Published*** **by JINST [Durga Rajaram];**



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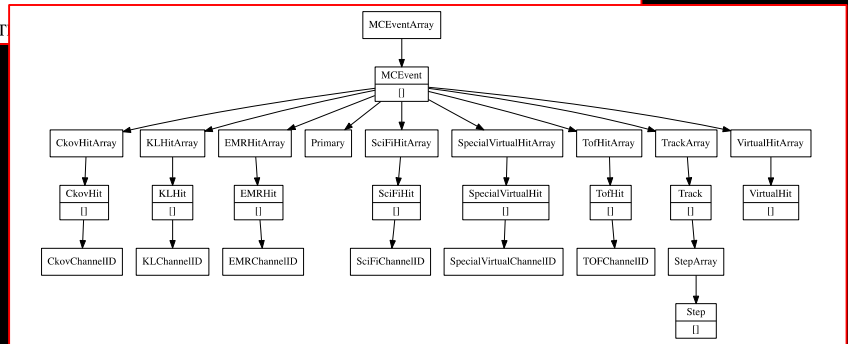
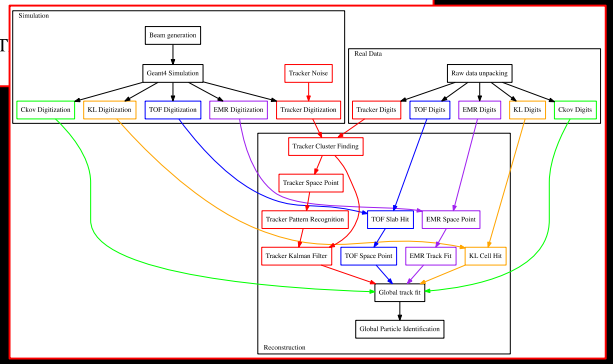


Figure 5. The MAUS data structure for MC events. T
indicates that child objects are array items.



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2019 JINST 14 T04005

- Published in JINST special-topic volume on muon accelerators
- By default, open access is only granted for one year
- Need to work out how to make the paper open access into perpetuity (without paying)!

Papers

		27-Jun-19	v17	
Title	**Contact**	**Target date**		**Comments**
		Preliminary	**Final**	**Jan-19**
Phase-space density/emittance evolution; rapid communication	C. Rogers	Apr18 w/s	Apr19	Second draft with collaboration
Measurement of multiple Coulomb scattering of muons in lithium hydride	J. Nugent	Jun18; CM51	Apr19	Unfolding issues resolved? Move forward CM54
Performance of the MICE diagnostic systems	P. Franchini	Feb19; CM53		Complete draft. Move forward CM54
Phase-space density/emittance evolution review paper	C. Hunt	TBD		Full analysis chain in place.
Phase-space density/KDE/6D-emittance evolution	C. Brown	TBD		Thesis published on initial analysis; taken over by C.Brown
Measurement of multiple Coulomb scattering of muons in LH2	J. Nugent	TBD		Awaits completion of LiH paper
Field-on measurement of multiple Coulomb scattering	A. Young	TBD		Analysis underway

Note: important discussion of publication plan later today.

New & updated results

- Emittance evolution paper:
  - Rogers, Drielsma: paper in second period of collaboration review
- LiH scattering paper:
  - Nugent et al:
    - Principal issues now believed to be resolved. CM54 (28/29Jun19) will review progress
- System performance paper:
  - Franchini et al: compressed draft available
- Field-on scattering:
  - Young et al:
    - Progress being made
- Emittance exchange (wedge absorber):
  - Brown:
    - Student of Rogers and Kyberd; making progress
- Long cooling paper:
  - Hunt, Jurj et al:
    - Analysis underway, hampered by uncertainty created by Hunt's move to CERN

Welcome and introduction

OUTREACH TO GO ALONGSIDE NATURE PUBLICATION

To: C. Jamieson (Head of Particle and Nuclear Physics, STFC) May 30, 2019
D. Newbold (Director, Particle Physics Department, STFC)
From: K. Long (Spokesperson, MICE) Draft 1

Proposed outreach activities to accompany the publication in Nature of the MICE collaboration's first observation of ionization cooling

The MICE paper presenting the collaboration's first observation of ionization cooling will soon be submitted to the collaboration for review. The outreach programme that the collaboration proposes to execute in partnership with STFC to enhance the impact of the publication is summarised below. P. Kyberd (Brunel), the Collaboration Board chair, will be the principal contact with representatives of the collaborating institutes.

Timetable

The collaboration's rules are that the draft paper must be circulated to the collaboration twice: the first time with a two-week deadline for comments, the second time with one week for final comments. Including time for corrections, and assuming no major analysis issues are identified, this process is likely to close within a month. The paper will then be submitted to Nature.

The Nature review process is believed to be efficient, so the planning assumption is that there are between 6 and 8 weeks to put the outreach activity in place.

Proposed outreach activities

Press release:
STFC should take the lead in the development of a press release that sets the results in the scientific context defined at the recent ESPPU Open Symposium in Granada. The existing particle-physics laboratory outreach network should be used to disseminate the press release. Early contacts should be made with the press office at CERN, FNAL, IHEP, INFN, NIKHEF, and KEK/J-PARC. Coordination of the outreach activities at the participating institutions should proceed through the MICE Collaboration Board.

Peer-group seminar at RAL:
A seminar should be organised to coincide with publication. The seminar should be presented by C. Rogers (ISIS, RAL), should take place at RAL and be streamed live at DL.

Event at RAL/DL:
The Nature publication provides an opportunity to set the MICE programme in a broader context. We therefore propose a scientific meeting at which the challenges of of the energy frontier, neutrino, and, perhaps, nuclear physics are presented alongside contributions on MICE, the US MAP programme, LEMMA, and the opportunities presented by nuSTORM. Ideally the peer-group event will be followed by an early-evening public lecture in the series organised by R. Bingham (RAL).

Film with Science Animated:
The collaboration has been contacted by Science Animated "...a creative agency [that works] directly with research teams internationally to provide a resource which aids research impact and outreach activity." A short film explaining the MICE programme and the broader scientific context can be produced for around £4k.

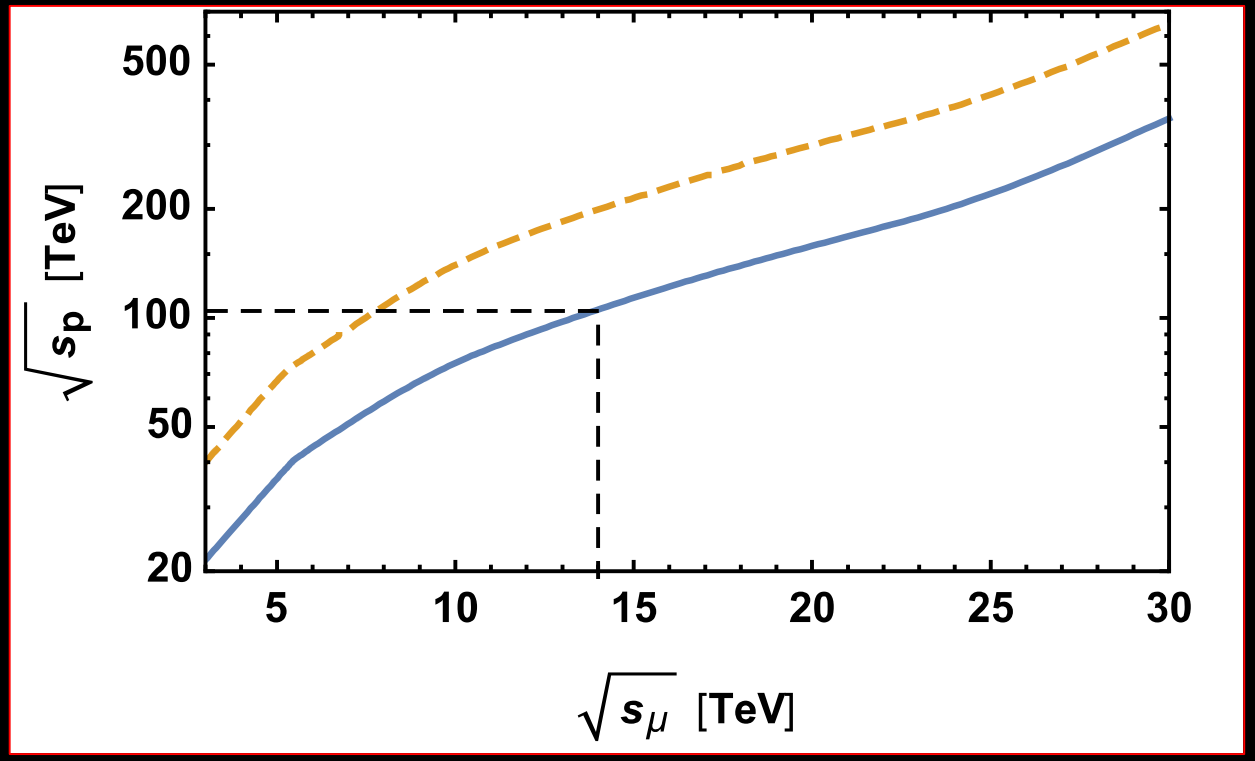
News article in, e.g., CERN Courier and Symmetry magazine:
M. Chalmers (CERN), editor of the CERN Courier, is interested to publish a news article to run alongside the Nature publication. The opportunity to place a news item in the FNAL Symmetry magazine should also be pursued.

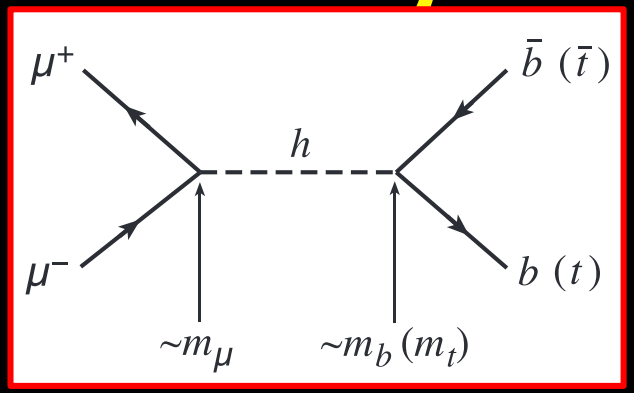
- Press release:
  - Contact made with Jake Gilmore (STFC press officer):
    - Exploit inter-lab network for dissemination
  - "Quotes from all"
- Peer-group seminar:
  - Sep19: to be arranged
- Event at RAL:
  - Oct/Nov19:
    - Peer meeting on energy frontier and muon accelertors
    - John D Lawson lecture:
      - Hope Fabiola Ianotti will accept
- Short film on context and science:
  - In house, or, Science Animated
- Thanks to:
  - Chris Rogers & Paul Kyberd
  - An opportunity for all to become involved

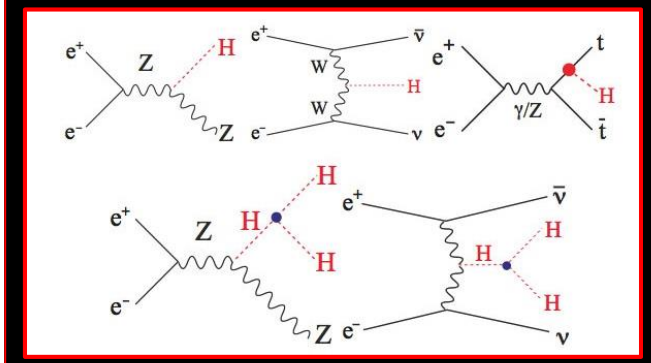
Welcome and introduction

MUON ACCELERATORS FOR PARTICLE PHYSICS

The Standard Model and beyond







- Energy frontier: big advantage over pp because fundamental fermion
- Future study of the Higgs:
  - Line width; establish single resonance (?) in s-channel with $\mu^+\mu^-$
  - Couplings; requires > 1 TeV for complete, precise study

Answers to the Key Questions

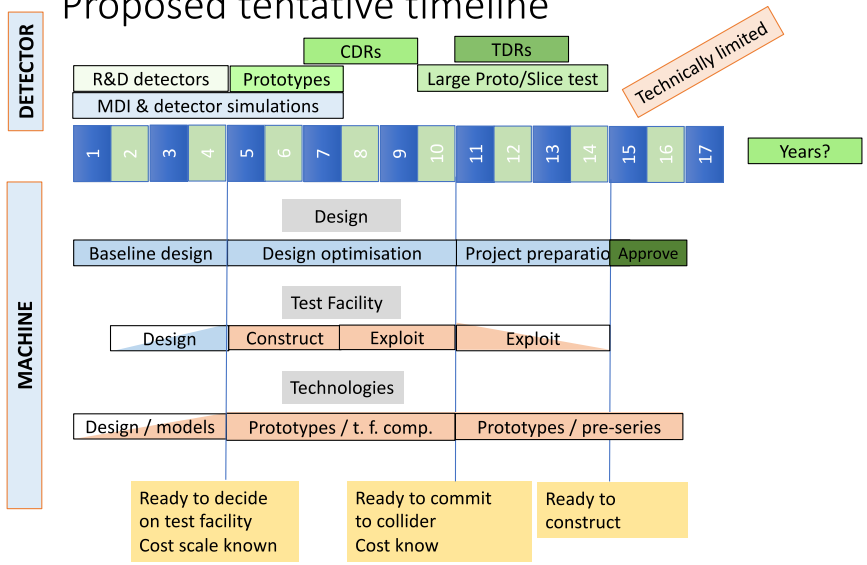
- **Can muon colliders at this moment be considered for the next project?**
  - Enormous progress in the proton driven scheme and new ideas emerged on positron one
  - But at this moment not mature enough for a CDR, need a careful design study done with a coordinate international effort

- **Is it worthwhile to do muon collider R&D?**
  - Yes, it promises the potential to go to very high energy
  - It may be the best option for very high lepton collider energies, beyond 3 TeV
  - It has strong synergies with other projects, e.g. magnet and RF development
  - Has synergies with other physics experiments
  - **Should not miss this opportunity?**

- **What needs to be done?**
  - Muon production and cooling is key => A new test facility is required.
    - Seek/exploit synergy with physics exploitation of test facility (e.g. nuSTORM)
  - A conceptual design of the collider has to be made
  - Many components need R&D, e.g. fast ramping magnets, background in the detector
  - Site-dependent studies to understand if existing infrastructure can be used
    - limitations of existing tunnels, e.g. radiation issues
    - optimum use of existing accelerators, e.g. as proton source
  - **R&D in a strongly coordinated global effort**

Muon collider

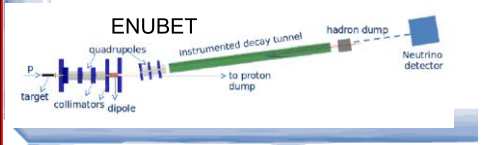
Proposed tentative timeline

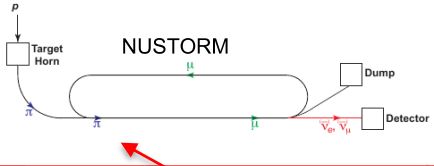


Neutrinos

Precision program in Europe

- Squeezing every bit of information out of the future experiments requires a complementary program (special rôle for Europe) to
  - Measure hadroproduction for the neutrino flux prediction (NA61)
  - Understand the neutrino-nucleus cross-section at the % level, both theoretically and with new facilities (Enubet, Nustorm)
  - Collaboration to be developed with nuclear physicists
- Next-to-next generation facilities (ESSnuSB, …) are also under study





Neutrino Physics
(accelerator and non-accelerator)
summary of the session

Conveners: Stan Bentvelsen, Marco Zito

ESPPU Open Symposium Granada
May 16, 2019

In the session we also covered astroparticle physics

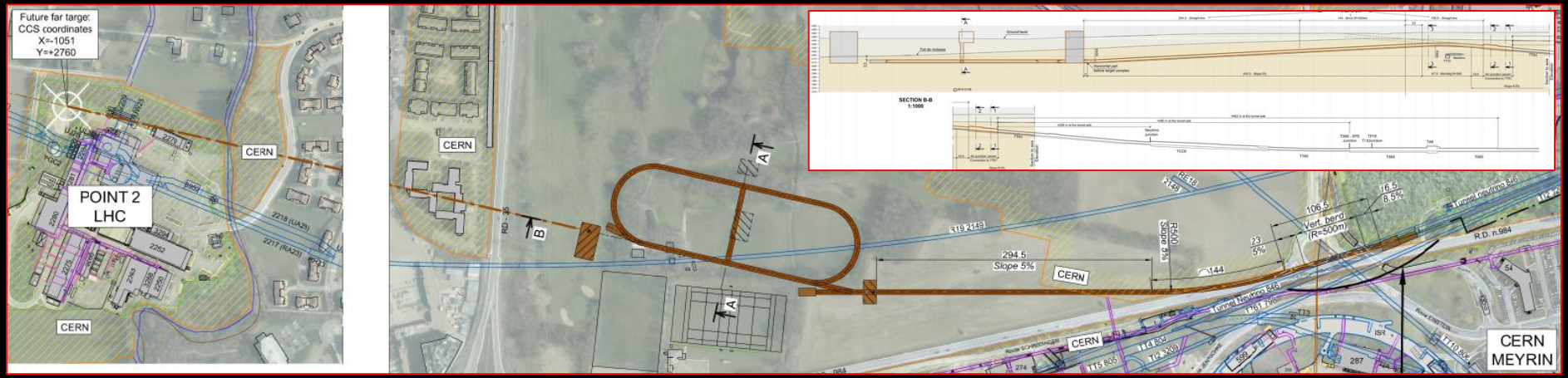
Neutrino oscillations

- Vibrant program (DUNE, Hyper-Kamiokande, JUNO, ORCA) to fully measure the PMNS mixing matrix and especially the Mass Ordering and the CP violation phase delta, with strong European contribution. Perceived by the community as a priority.
- Neutrino experiments need cutting-edge detectors and % precision on the flux and cross-sections: leading rôle for Europe (NA61, Neutrino Platform). New facilities currently under study.
- Long term future for high precision LBL measurements with new techniques. Time to prepare for it !

Status of MICE

NUSTORM

Overview

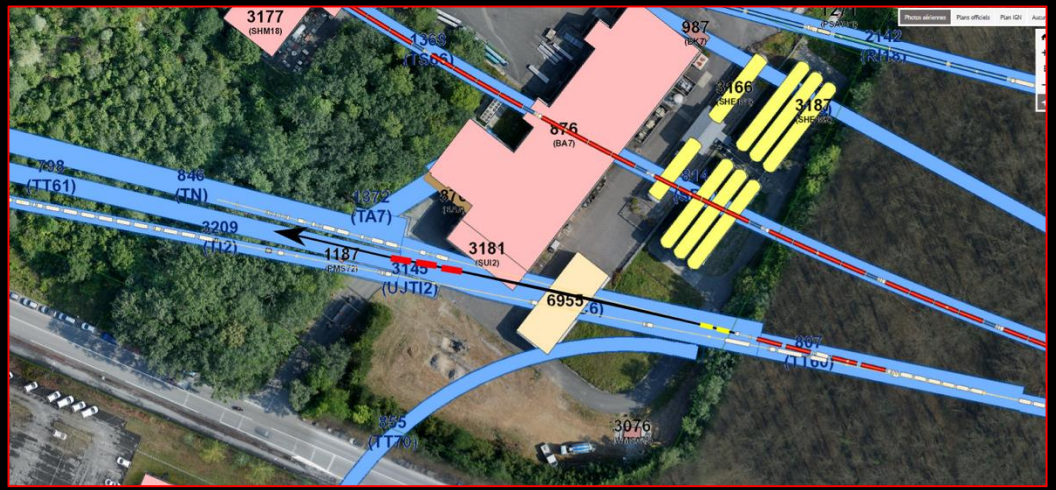


- Extraction from SPS through existing tunnel
- Siting of storage ring:
  - Allows measurements to be made ‘on or off axis’
  - Preserves sterile-neutrino search option

Extraction and *p*-beam transport to target

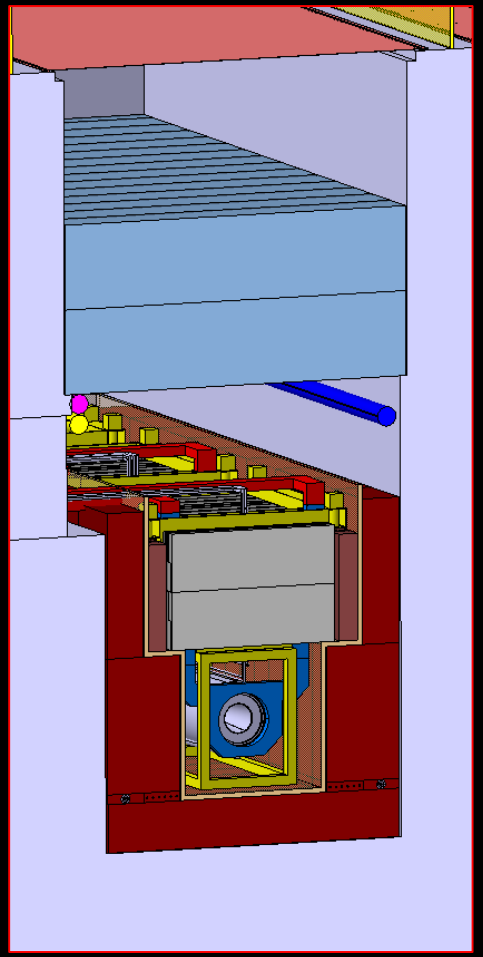
- Fast extraction at 100 GeV:
  - CNGS-like scheme adopted;
    - Apertures defined by horizontal and vertical septa reasonable
    - Pulse structure (2 x 10.5 ms pulses) requires kicker upgrade

- Beam transport to target:
  - Extraction into TT60:
    - Branch from HiRadMat beam line at 230 m (TT61)
  - Require to match elevation and slope
  - New tunnel at junction cavern after 290 m
  - 585 m transport to target



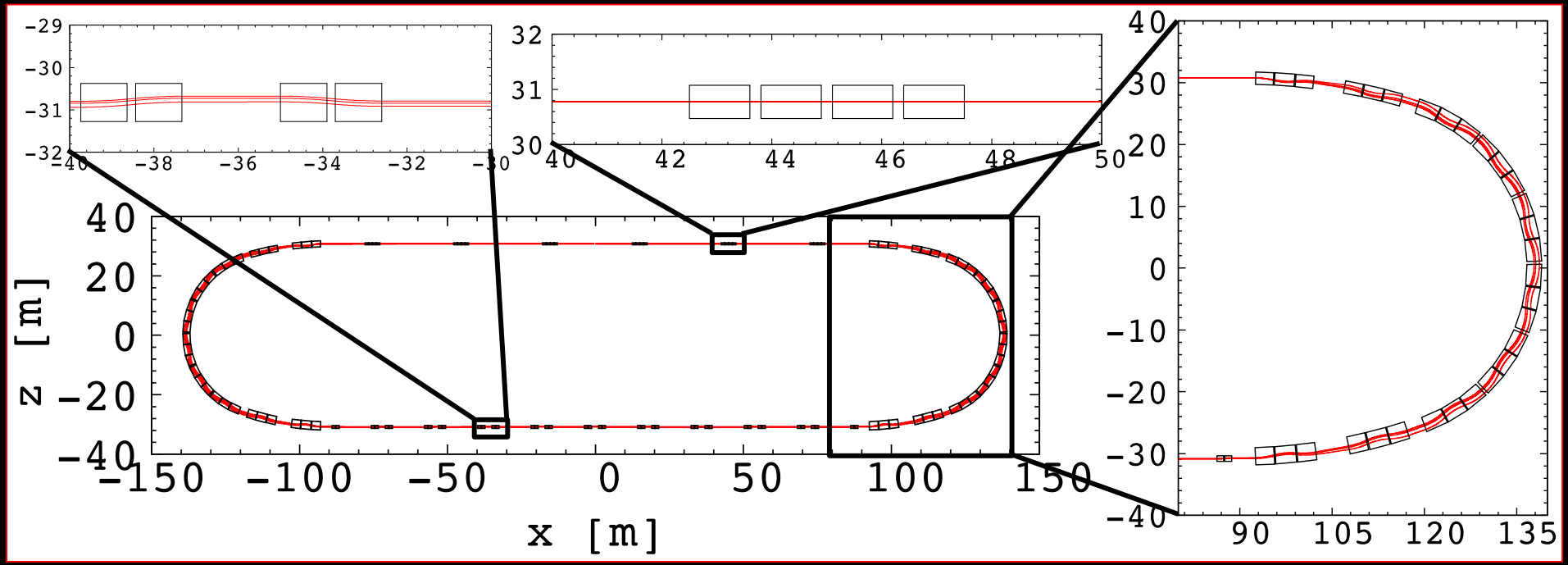
Target and capture

- FNAL scheme adopted:
  - Low-Z target in magnetic horn
  - Pair of quadrupoles collect particles horn focused
  - Target and initial focusing contained in inert helium atmosphere
- Graphite target, based on CNGS experience:
  - Radiation-cooled graphite target embedded in water-cooled vessel
- Containment and transport of pion beam with a 10% momentum spread:
  - Base on scheme used successfully for AD in PS complex
- Target complex design:
  - Exploit extensive work done for CENF



Storage ring

- New design for decay ring:
  - Central momentum between 1 GeV/c and 6 GeV/c;
  - Momentum acceptance of up to ±16%



The three pillars are back!

- nuSTORM unique facility:
  - %-level *electron* and muon neutrino cross-sections
  - Exquisitely sensitive sterile neutrino searches
  - Serve 6D cooling experiment & muon accelerator test bed

- nuSTORM: a step towards the muon collider:
  - News: ionization cooling demonstrated by MICE collaboration
    - Required in *p*-driven neutrino factory and muon collider
  - nuSTORM:
    - Proof-of-principle and test bed for stored muons for particle physics

Planning

- Full report on PBC feasibility study:
  - Expected to be complete by Sep19
- So, now begin to prepare nuSTORM meeting:
  - At CERN;
  - Goal: Oct19 – in advance of next PBC meeting
- Email soon;
  - Please attend!

Status of MICE

ADMINISTRATION

Office in R1

- Continued pressure to reduce footprint:
  - 3 desks now

Over to you!