WG3 Summary

Conveners:
J. Pasternak, Imperial College London/RAL-STFC
P. Snopok, Illinois Institute of Technology (presenter)
J. Tang, Institute of High Energy Physics

Layout

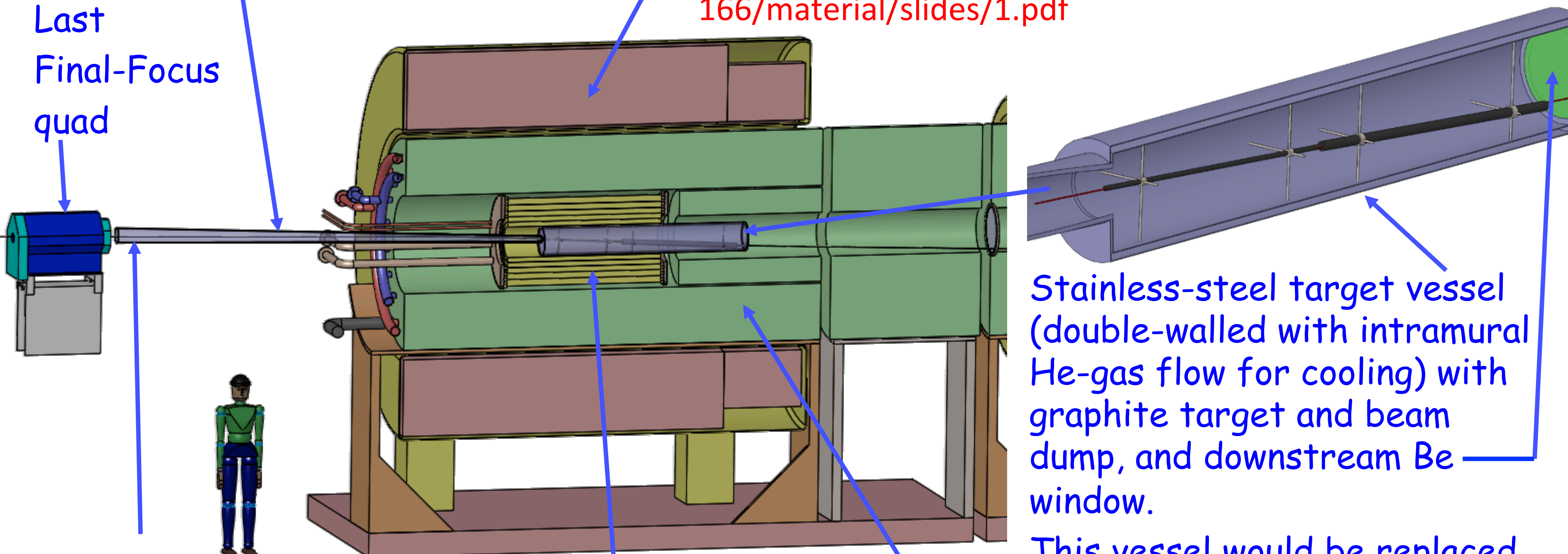
- We will
  - Address the questions we inherited from NuFact'13
  - Pose new questions based on the outcome of presentations and discussion during NuFact'14
  - Highlight some of the results reported

Target/capture

- What is the path to a multi-MW target/capture system?
  - What are the options to mitigate energy deposition and shielding problems for multi-MW solenoid capture systems?
    - Depends on the power on target and proton energy
    - Use carbon target instead of liquid Hg
    - Preliminary He-gas cooled W-bead shielding has been proposed
  - Are there outstanding target handling issues for multi- MW designs? How do material properties evolve with time (radiation, strain, stress and temperature)?
    - Topics of ongoing studies (RaDIATE collaboration). Solid targets are much easier to handle than liquid. Magents are bigger issue than the target itself.
  - Is our modeling of pion production sufficiently complete to address proposed accelerator projects?
    - Uncertainties at 20% level were reported previously, no update at this NuFact.
  - While there is progress, we can't completely eliminate any of the questions above.
- New question: what are the limits of the carbon target.

Target System Concept

Presentation by K. McDonald on Friday, Aug 29 @ 11:00 am
https://indico.cern.ch/event/300521/session/4/contribution/166/material/slides/1.pdf



Target System Optimizations

- High-Z favored.

- Optima for graphite target: length = 80 cm,
  radius ~ 8 mm (with σ_r = 2 mm (rms) beam radius),
  tilt angle = 65 mrad,
  nominal geometric rms emittance $\varepsilon_\perp$ = 5 μm.
  $\beta^* = \sigma_r^2 / \varepsilon_\perp = 0.8$ m.

- Graphite proton beam dump, 120 cm long, 24 mm radius to intercept most of the (diverging) unscattered proton beam.

- The 20 T field on target should drop to the ~ 2 T field in the rest of the Front End over ~ 5 m.

- However, difficult to deliver a beam of 5 μm emittance with over
  1 MW power.

Future Target Studies

Muon Collider/Neutrino Factory studies in the USA being ramped down.

Interest remains in high-power targetry for various applications.

See, for example, the 5th High Power Targetry Workshop (FNAL, 2014),
https://indico.fnal.gov/conferenceDisplay.py?ovw=True&confId=7870
[These workshops were initiated by H. Kirk.]

A particular issue: how much beam power can a graphite target stand?

- Lifetime against radiation damage much better at high temperature.
- Resistance to "thermal shock" from pulsed beams also better at high temperature.

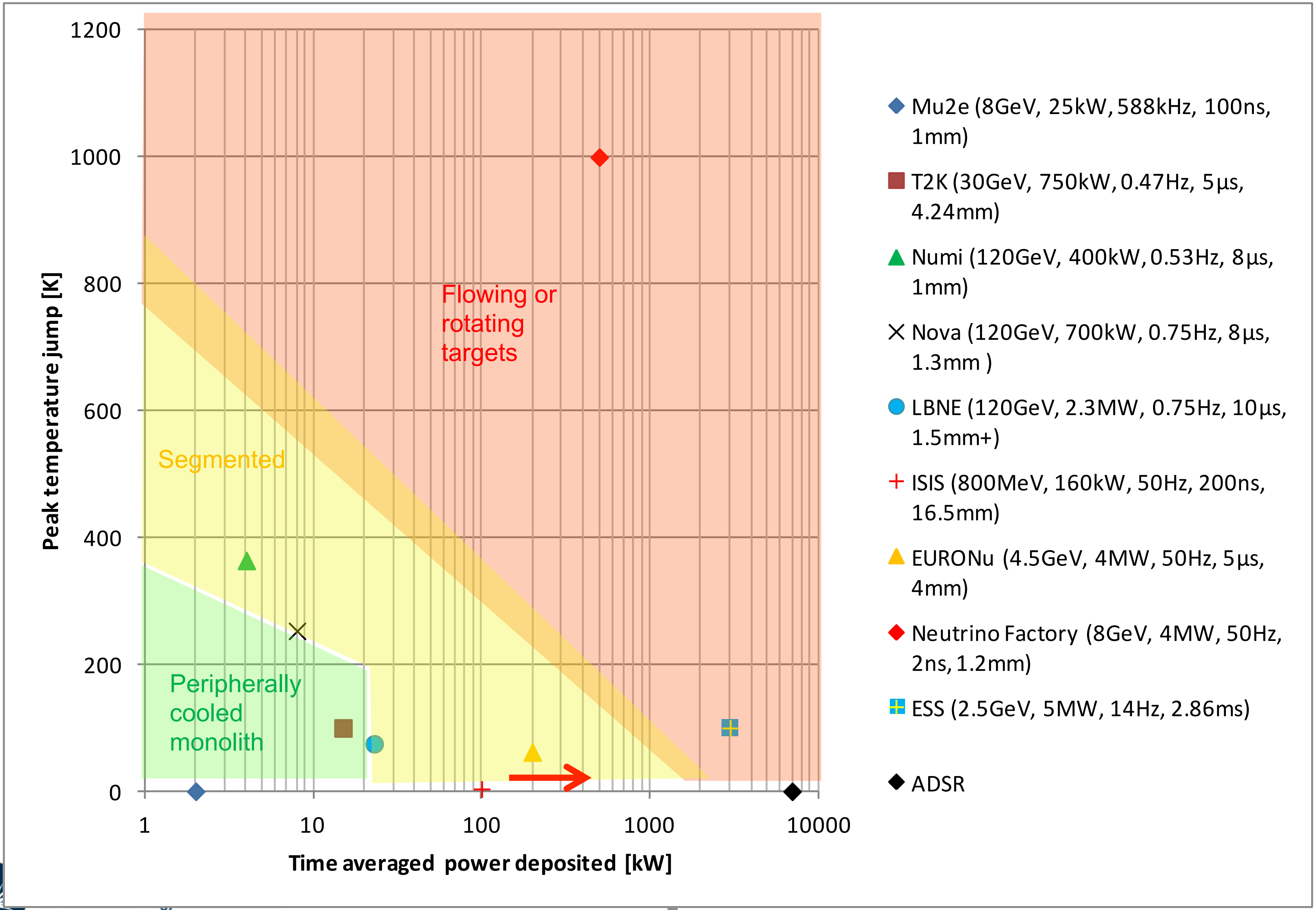
Firm up these trends with data from beam irradiations of high-temperature graphite. (The Muon Collider/Neutrino Factory group participated in beam irradiations of water-cooled graphite and many other target materials in 2002-2006.)

GARD proposal(s) being generated by BNL and FNAL for such studies.

New diagnostic: x-ray diffraction of irradiated samples.

Presentation by C. Densham on Friday, Aug 29 @ 11:20
https://indico.cern.ch/event/300521/session/4/contribution/167/material/slides/1.pdf

Heat Removal and Thermal Stress Summary



Presentation by C. Densham on Friday, Aug 29 @ 11:20
https://indico.cern.ch/event/300521/session/4/contribution/167/material/slides/1.pdf

Conclusions

Peripherally cooled cylindrical **monolith targets** have limited heat dissipation capability and experience high steady state and dynamic stresses.

Segmented internally cooled stationary targets can accommodate much higher heat loads and higher power densities.

A **pebble bed target** such as that proposed for EURONu or ESS-SB is probably the ultimate segmented target and may be relevant for other facilities where a solid cylindrical target is not viable. R & D in pebble bed and other segmented targets would be beneficial for future neutrino facilities and neutron sources alike.

At higher beam powers it may become necessary to employ **flowing** (powder and liquid metals) or rotating targets and that is why research in this area is required.

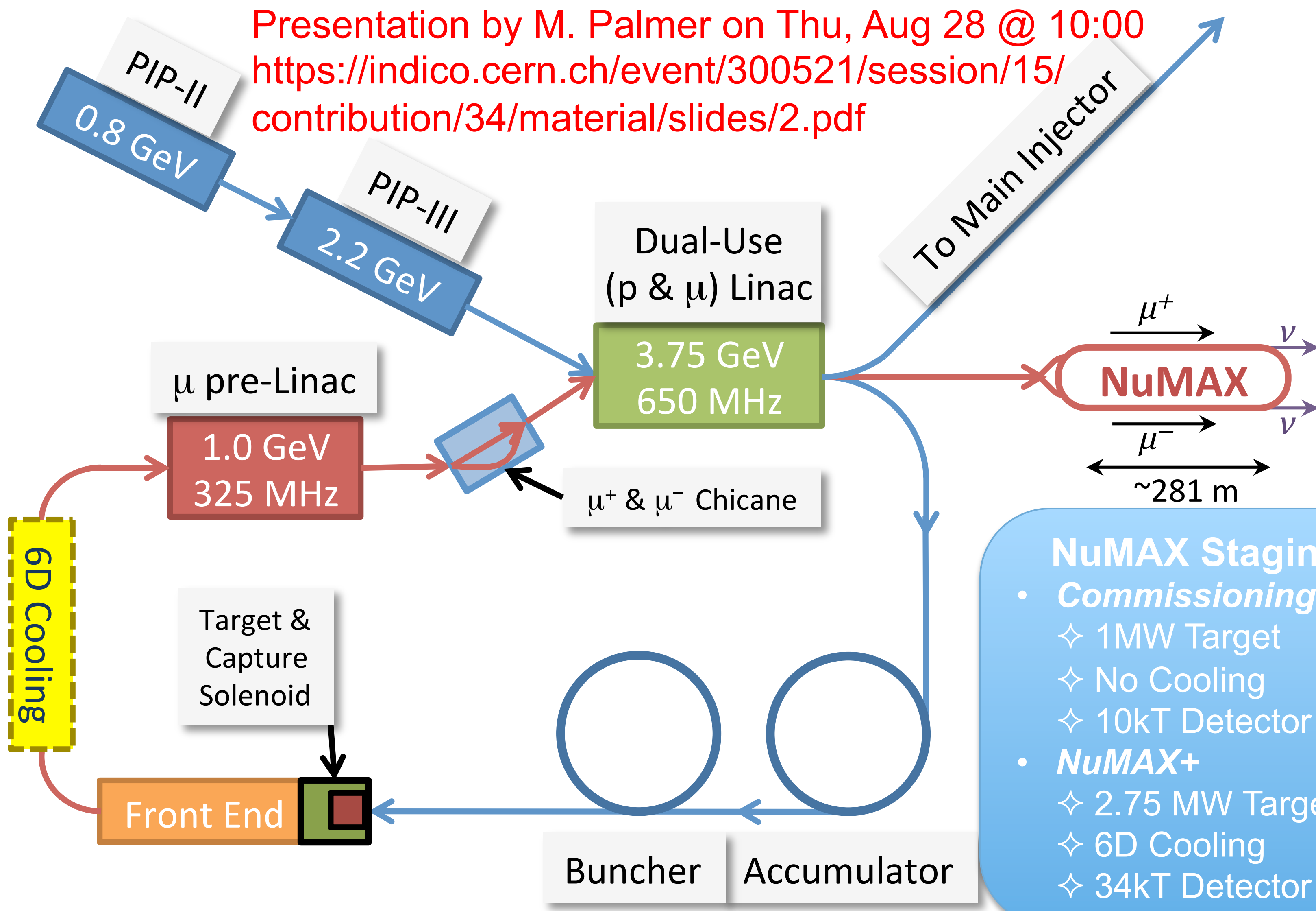
Physics performance is a function of reliability as well as optimum particle yield so the simplest target design possible is often the best choice.

Acceleration

- What is the optimum muon acceleration scheme for the Neutrino Factory with respect to feasibility, performance and cost (FFAG, RLAs with FFAG arcs, linac)?
  - Cost-saving concept: dual-use linac for the NuMAX scheme
  - Single FFAG type arc replacing multiple arcs in RLA
  - Studies are ongoing, item persists.

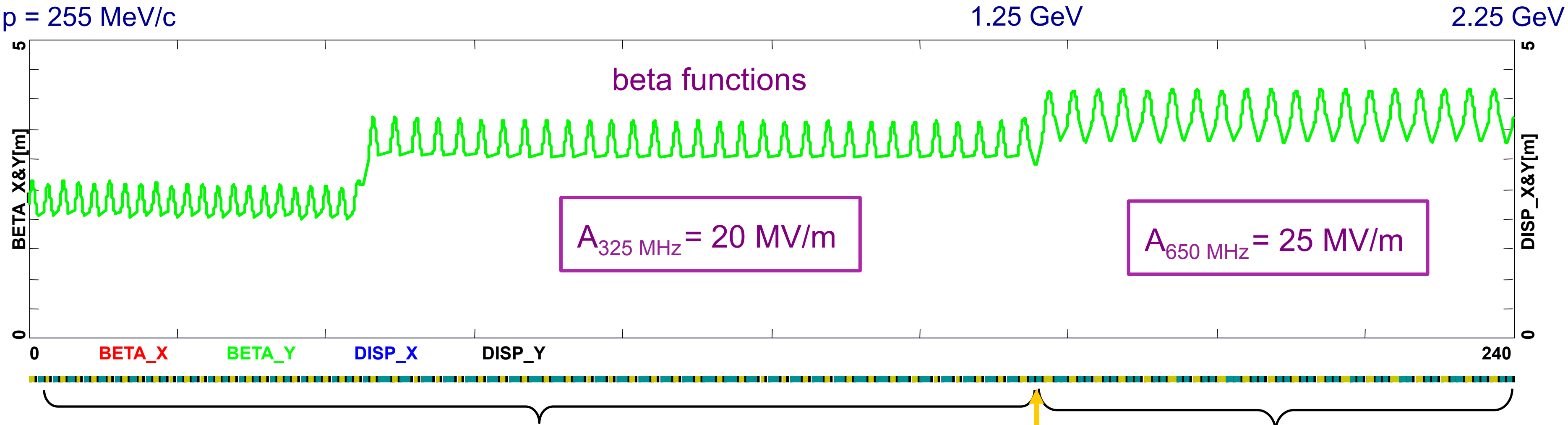
The MAP Muon Accelerator Staging Study ⇨ NuMAX

Presentation by M. Palmer on Thu, Aug 28 @ 10:00
https://indico.cern.ch/event/300521/session/15/contribution/34/material/slides/2.pdf

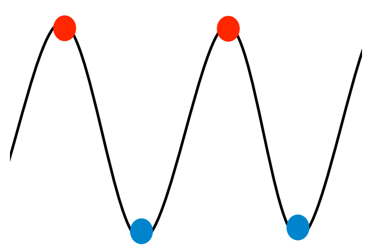


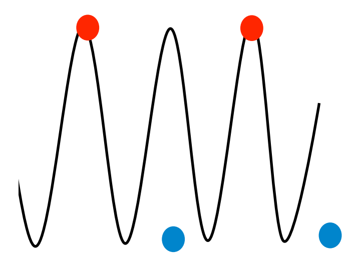
NuMAX Staging:
- ***Commissioning***
  - ✧ 1MW Target
  - ✧ No Cooling
  - ✧ 10kT Detector
- ***NuMAX+***
  - ✧ 2.75 MW Target
  - ✧ 6D Cooling
  - ✧ 34kT Detector

325 MHz – 650 MHz Transition

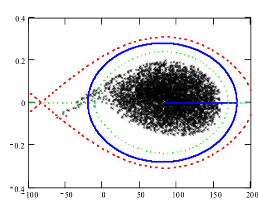


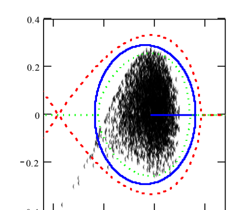
$m^{\pm}$ time structure





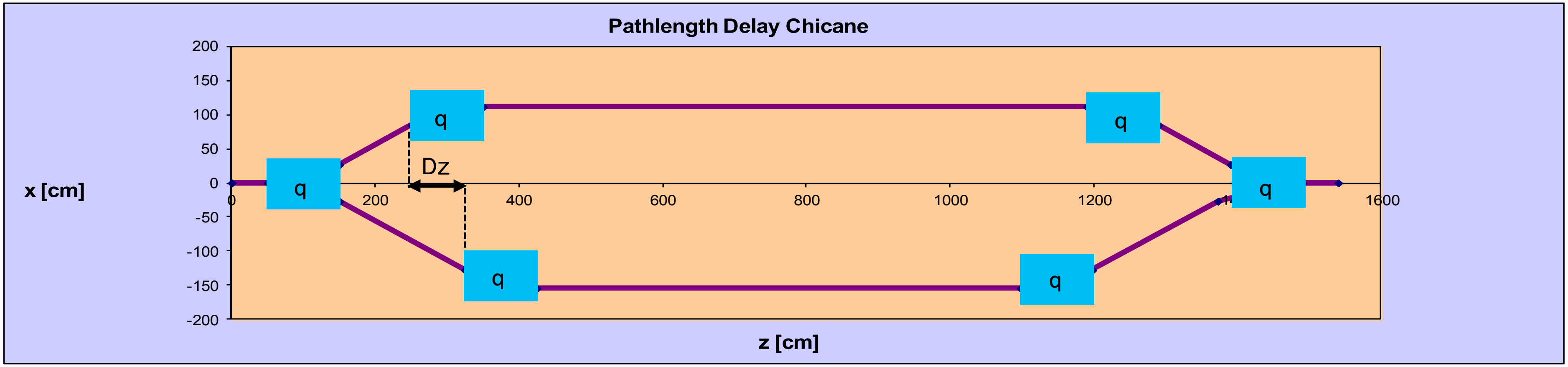
RF bucket





Presentation by A. Bogacz on Tue, Aug 26 @ 14:40
https://indico.cern.ch/event/300521/session/4/contribution/156/material/slides/1.pdf

Path-length Delay Chicane



$$\Delta S = 2 \times \Delta z \frac{1-\cos\theta}{\cos\theta}$$

$$\Delta S = \frac{\lambda}{2}$$

$$\Delta z = \frac{\lambda}{4} \times \frac{\cos\theta}{1-\cos\theta}$$

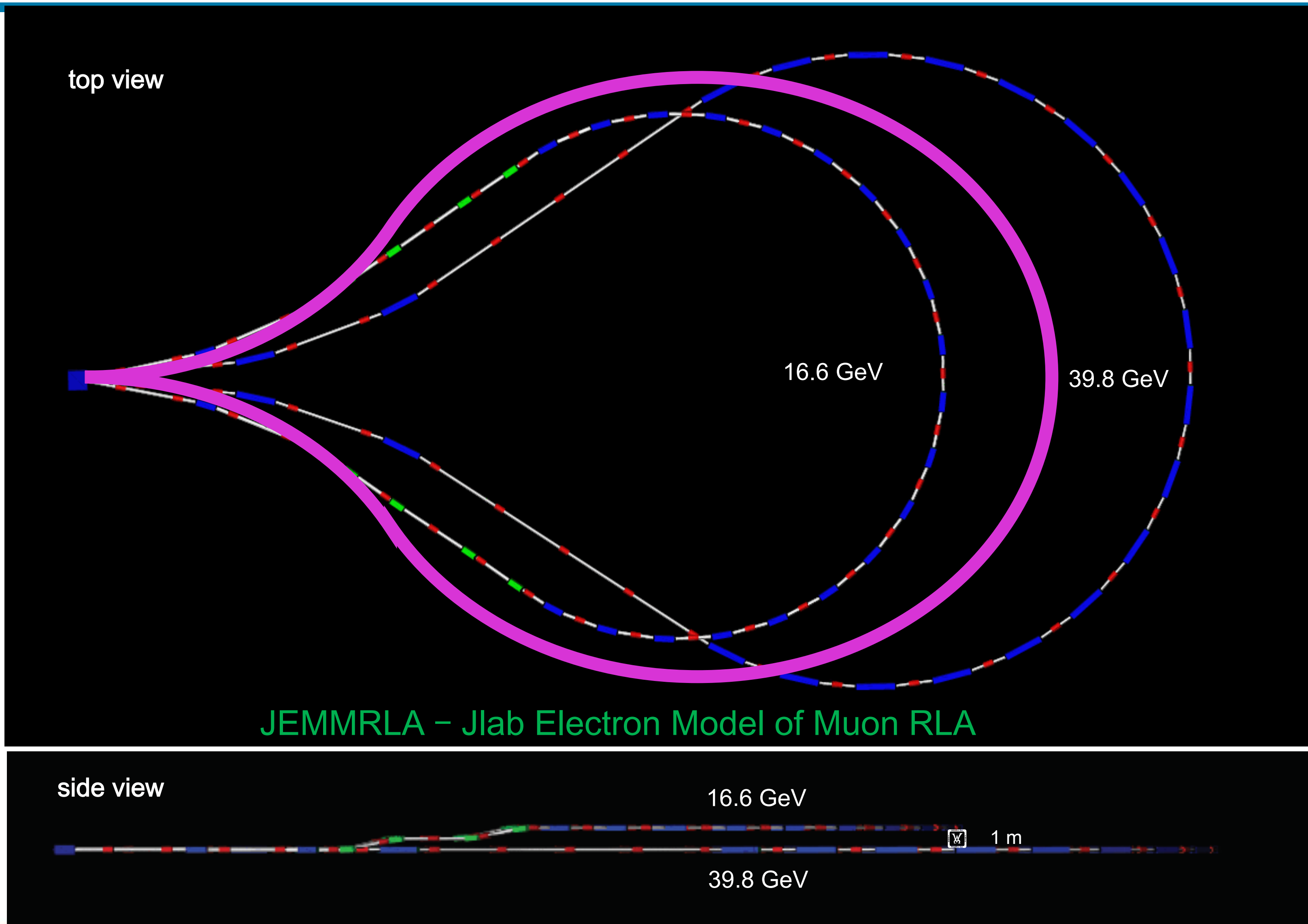
$$\lambda = 46.122 \text{ cm}$$

$$\theta = 30^0$$

$$\Delta z = 74.534 \text{ cm}$$

$$\frac{\cos\theta}{1-\cos\theta} = \frac{1}{2}\left(c\tan^2\frac{\theta}{2} - 1\right)$$

Single- vs Multi- pass Droplet Arcs



nuSTORM

- What is the best solution/design for the nuSTORM facility (performance, cost)?
  - Ongoing analysis of FFAG vs FODO solutions
  - FFAG ring: DFD triplet vs doublet in the straights, optimization
  - Item persists
- New questions:
  - How to generate short proton pulse for nuSTORM at CERN?
  - What is the location of the far detector at CERN?

Presented by E. Wildner on Tue, Aug 26 @ 11:40 am,
https://indico.cern.ch/event/300521/session/4/contribution/152/material/slides/1.pdf

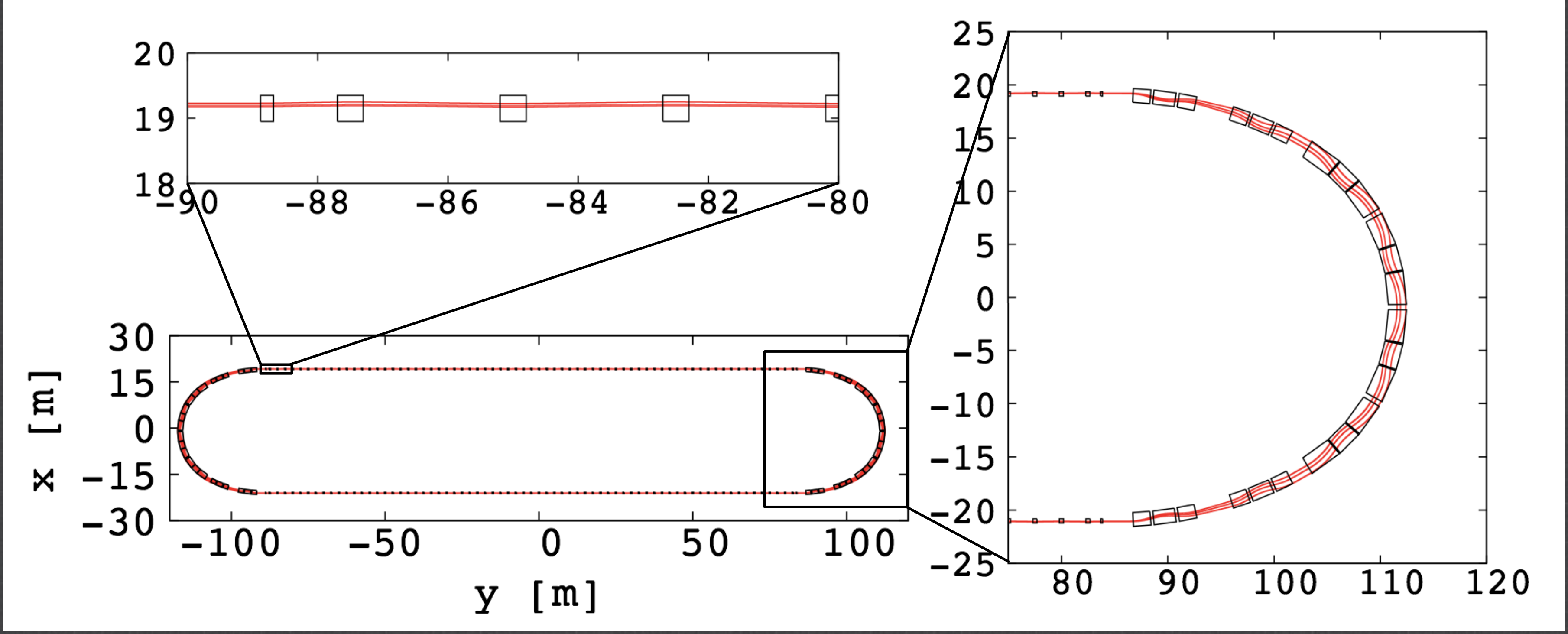
Lattice option comparison

Parameters	FODO (Jun. 2013)	RFFAG "FODO-like"	RFFAG "low-cost"
$L_{straight}$ [m]	185	175	156
Circumference [m]	480	500	460
Dynamical acceptance A_{dyn}	0.6	0.95	0.95
Momentum acceptance	±10%	±16%	±16%
π/POT within momentum acceptance	0.094	0.171	0.171
Fraction of π decay in one straight (F_s)	0.48	0.47	0.43
Straight-circumference ratio (Ω)	0.39	0.35	0.34
A_{dyn} x π/POT x F_s x Ω	**0.011**	**0.027**	**0.024**

Paris, Jan. 2014

Doublet solution

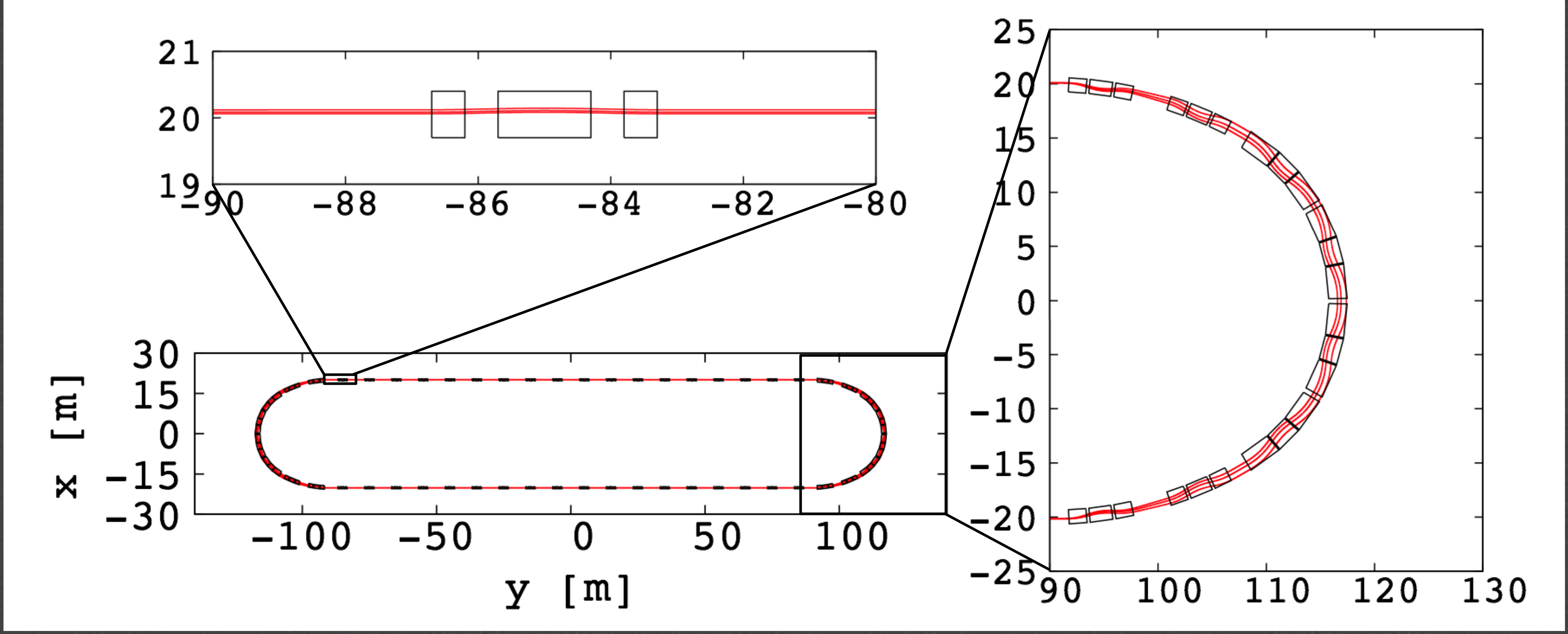
Straight: **175 m**, maximum scallop angle: **12 mrad**



From presentation by JB Lagrange on Tue, Aug 26 @ 11:20
https://indico.cern.ch/event/300521/session/4/contribution/151/material/slides/0.pdf

Triplet solution

Straight: **180 m,** maximum scallop angle**: 24 mrad**



Muon experiments

- What are the optimum beam designs for next generation muon experiments based on current and future proton beams?
  - Had a discussion on Thursday, split question into subtopics
  - Preparing a consolidated table of parameters (example of COMET is shown in the next few slides)
  - Will draw conclusions based on the results of the exercise [kudos to those who sent their input so far]
- New question:
  - What are the possible applications of (cooled) muon beams?

Synergies between muon projects - discussion

- Cold muon beam applications (besides NF/MC):
  - ❑Mu2e or COMET upgrade (event rate in detectors?)
  - ❑muSR, medical applications, material detection
- Polarized muon beams
- **What are the optimum beam designs for next generation muon experiments based on current and future proton beams?**

- **What proton beam power on target is needed (as a minimum)?**
- **What proton energy is needed?**
- **Can your project benefit from ionization cooling, frictional cooling or both?**
- **Can we design the capture/front end system, which would be beneficial for many experiments?**

New question:

Can we design the capture/front end system, which would be beneficial for many experiments?

	Project 1	Project 2
	COMET	
Proton energy	8 GeV	
Proton time structure	100ns width pulses separated by 1.1– 1.6s	
Target type/technology	Tungsten	
Pion capture energy	0-200 MeV	
Pion capture technology (solenoid, horn, backward or forward, etc.)	Solenoid-backward going	
Muon energy at the input to the front end	N/A	
Muon output energy from the front end	40+/-30 MeV/c	

	Project 1	Project 2
Beam manipulations in the front end (RF, collimation, matching, bunching, phase rotation etc.)	Removal of high energy particles and long path length to reduce pion contamination	
Muon beam time structure at the output from the front end	Same as proton.	
Is/could cooling be beneficial?	Only reduction of energy spread.	
Is/could acceleration/deceleration be beneficial?	Only reduction of energy spread.	
Muon intensity required for the experiment/project	~10^{11}/s	
Other comments		

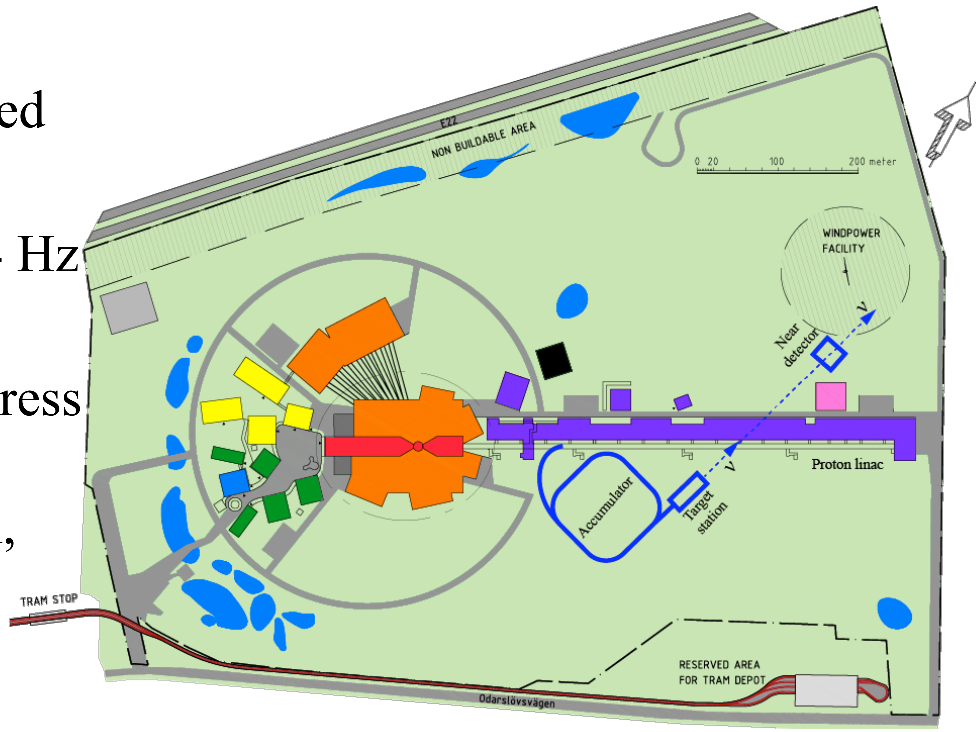
Please send us the information on your muon project/experiment:
Jaroslaw Pasternak [j.pasternak@imperial.ac.uk];
Pavel Snopok [snopok@gmail.com];
Jingyu TANG [tangjy@ihep.ac.cn]

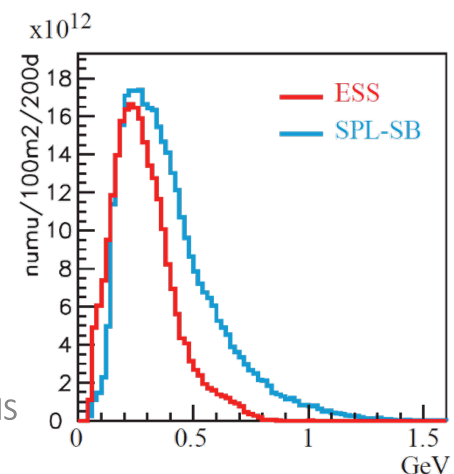
ESS

- Is there a possible solution for an ESS driven proton driver for the SB and/or NF?
  - For SB the answer is definitely ‘yes’
  - For low-energy nuSTORM at ESS:
    - Should it be based on a storage ring or a straight channel (like MOMENT)?
  - For NF:
    - How to provide short bunch structure after accumulator at ESS (do we need a compressor, or accumulator can be used as compressor)?

How to add a neutrino facility?

- The neutron program must not be affected and if possible synergetic modifications
- Linac modifications: double the rate (14 Hz → 28 Hz), from 4% duty cycle to 8%.
- Accumulator (ø 143 m) needed to compress to few μs the 2.86 ms proton pulses, affordable by the magnetic horn (350 kA, power consumption, Joule effect)
  - H^- source (instead of protons)
  - space charge problems to be solved
- ~300 MeV neutrinos
- Target station (studied in EUROν)
- Underground detector (studied in LAGUNA)
- Short pulses (~μs) will also allow DAR experiments





neutrino flux at 100 km (similar spectrum than for EU FP7 EUROν SPL SB)

ESS Neutrino Super Beam

Available online at www.sciencedirect.com
ScienceDirect
Nuclear Physics B 885 (2014) 127–149
NUCLEAR PHYSICS B
www.elsevier.com/locate/nuclphysb

arXiv:1212.5048
arXiv:1309.7022

A very intense neutrino super beam experiment for leptonic CP violation discovery based on the European spallation source linac

E. Baussan [m], M. Blennow [l], M. Bogomilov [k], E. Bouquerel [m], O. Caretta [c], J. Cederkäll [f], P. Christiansen [f], P. Coloma [b], P. Cupial [e], H. Danared [g], T. Davenne [c], C. Densham [c], M. Dracos [m,*], T. Ekelöf [n,*], M. Eshraqi [g], E. Fernandez Martinez [h], G. Gaudiot [m], R. Hall-Wilton [g], J.-P. Koutchouk [n,d], M. Lindroos [g], P. Loveridge [c], R. Matev [k], D. McGinnis [g], M. Mezzetto [j], R. Miyamoto [g], L. Mosca [i], T. Ohlsson [l], H. Öhman [n], F. Osswald [m], S. Peggs [g], P. Poussot [m], R. Ruber [n], J.Y. Tang [a], R. Tsenov [k], G. Vankova-Kirilova [k], N. Vassilopoulos [m], D. Wilcox [c], E. Wildner [d], J. Wurtz [m]

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[h] *Dpto. de Física Téorica and Instituto de Física Téorica UAM/CSIC, Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain*
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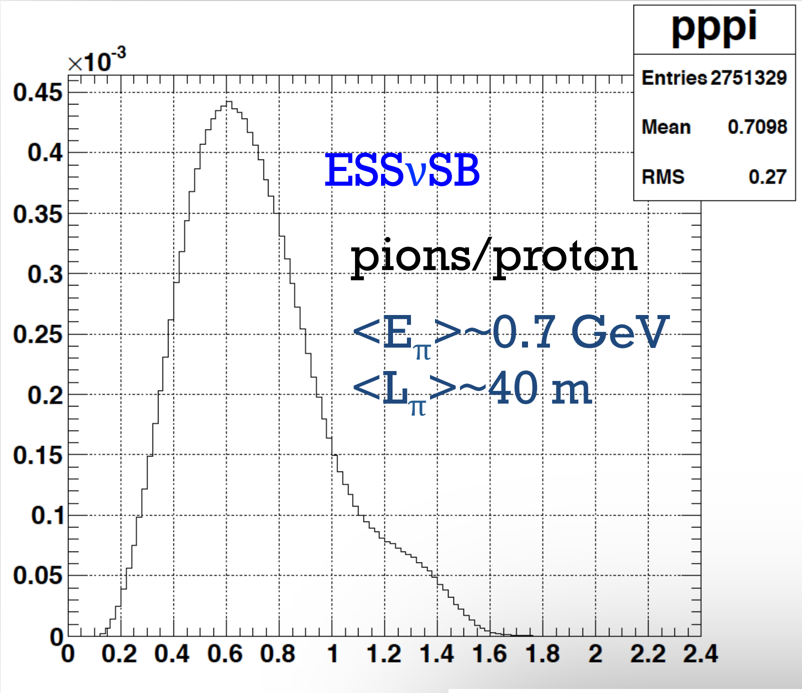
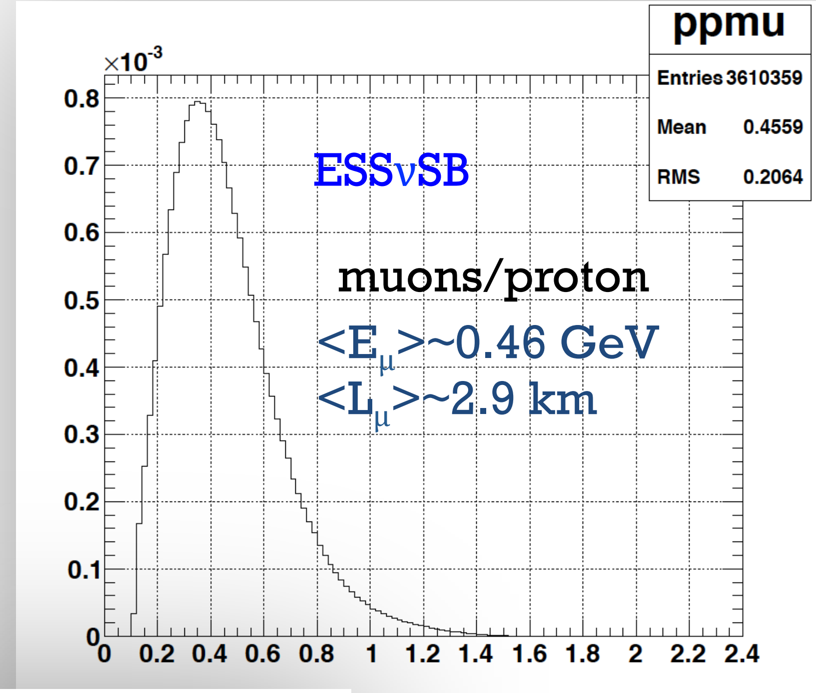
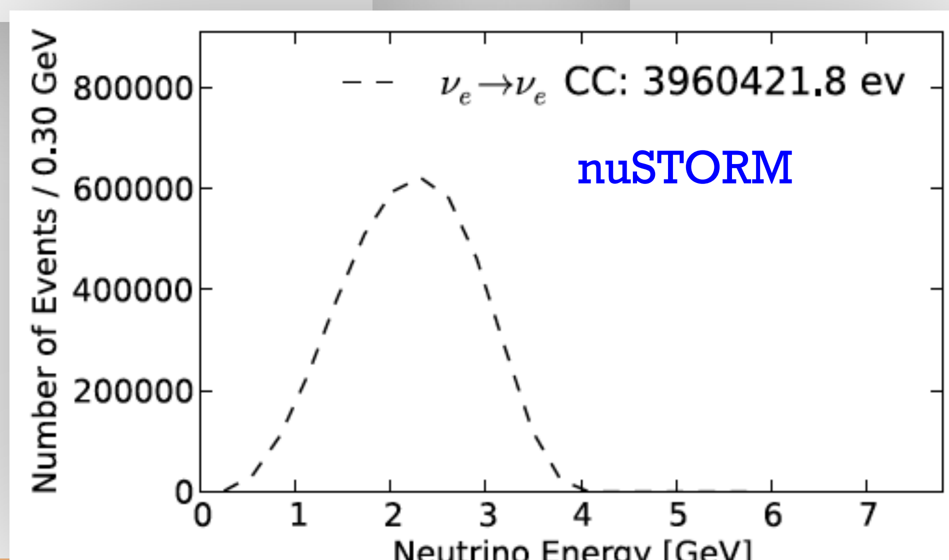
[n] *Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden*

14 participating institutes from 10 different countries, among them ESS and CERN

EU H2020 Design Study application to be submitted next week

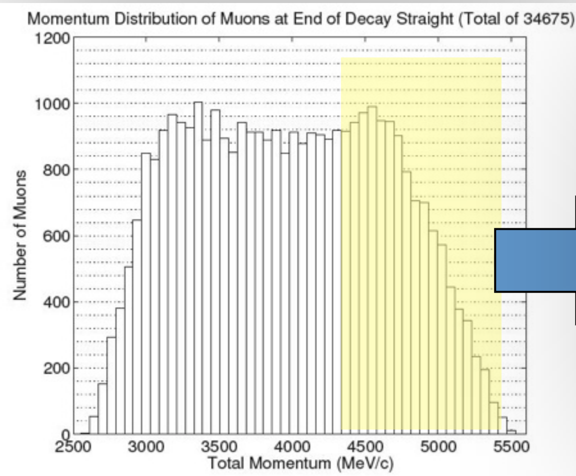


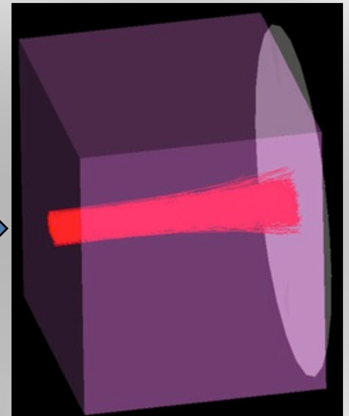


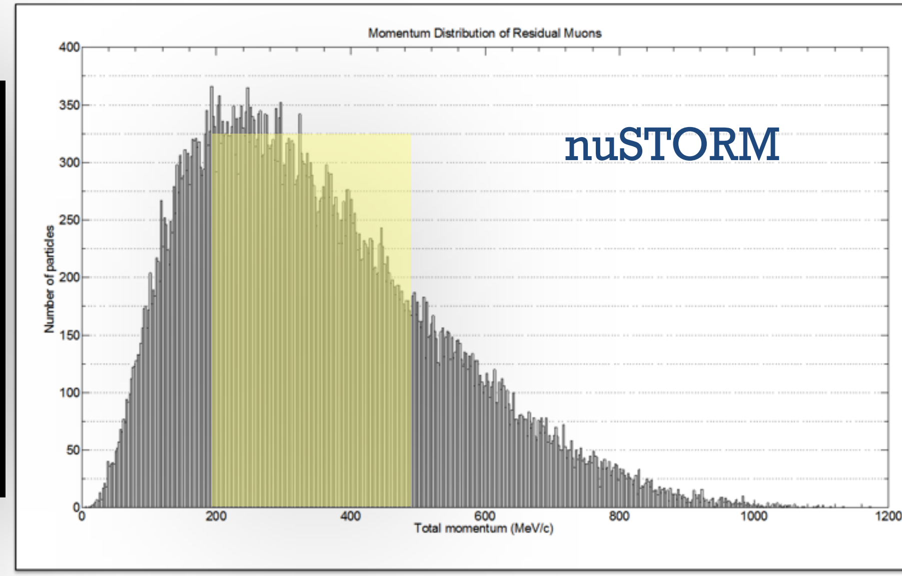


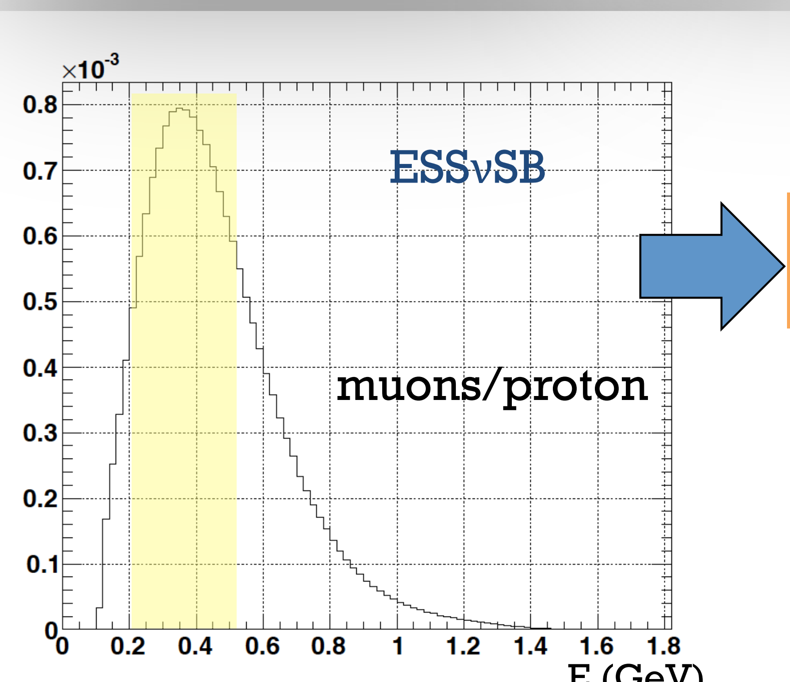
significantly lower energy than nuSTORM muons
good to measure neutrino x-sections around 200-300 MeV

Low energy muon beam









~10^{12} m/pulse in 200 < P(MeV/c) < 500 (for 1 m^2)
(2.6×10^{20} μ/year, at the level of the beam dump)

Input beam for future 6D m cooling experiments

Muon accelerator concept demonstration

- What facilities are needed to demonstrate muon accelerator concepts (MuSIC, MICE, nuSTORM, FNAL-AP0, others)?
  - Continue efforts on MICE, MTA, MuSIC
  - nuSTORM and EMuS (at CSNS) would be beneficial to the community
  - additional funding to continue running EMMA
- See also “synergies” topic above

Summary

- What is the path to a multi-MW target/capture system?
  - What are the options to mitigate energy deposition and shielding problems for multi-MW solenoid capture systems?
  - Are there outstanding target handling issues for multi- MW designs? How do material properties evolve with time (radiation, strain, stress and temperature)?
  - Is our modeling of pion production sufficiently complete to address proposed accelerator projects
  - What are the limits of the carbon target.
- What is the optimum muon acceleration scheme for the Neutrino Factory with respect to feasibility, performance and cost (FFAG, RLAs with FFAG arcs, linac)?
- What is the best solution/design for the nuSTORM facility (performance, cost)?
  - How to generate short proton pulse for nuSTORM at CERN?
  - What is the location of the far detector at CERN?
- What are the optimum beam designs for next generation muon experiments based on current and future proton beams?
  - What are the possible applications of (cooled) muon beams?
- Is there a possible solution for an ESS driven proton driver for the NF?
  - Should low-energy nuSTORM at ESS be based on a storage ring or a straight channel (like MOMENT)?
  - How to provide short bunch structure for NF after accumulator at ESS (do we need a compressor, or accumulator can be used as compressor)?
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Thank you!