S. BORDONI, P. SALA

VVLE:
PROPOSAL FOR A SUB-GEV BEAMLINE AT CERN

20 JANUARY 2020

OUTLINE

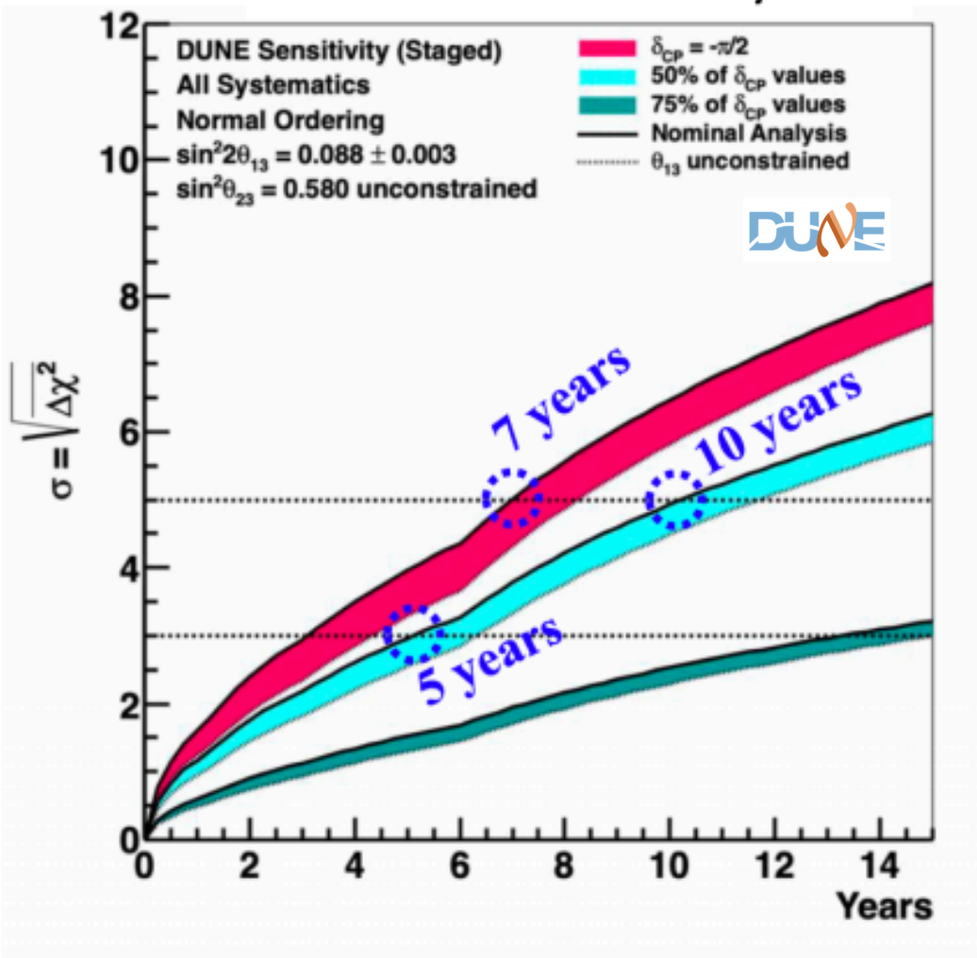
- Physics motivations
- Interest from the community
- Proposal for a sub-GeV beam line
- Answer to preliminary questions from the referees

PHYSICS MOTIVATION

- The next generation of neutrino experiment will be exposed to very intense beam (1.3 MW T2K/T-2HK and 1.2 MW for LBNF/DUNE). **Neutrino-beam physics measurements will be limited by systematics**

- **Large systematics —> more exposure —> larger costs**

CP violation sensitivity DUNE TDR Volume II



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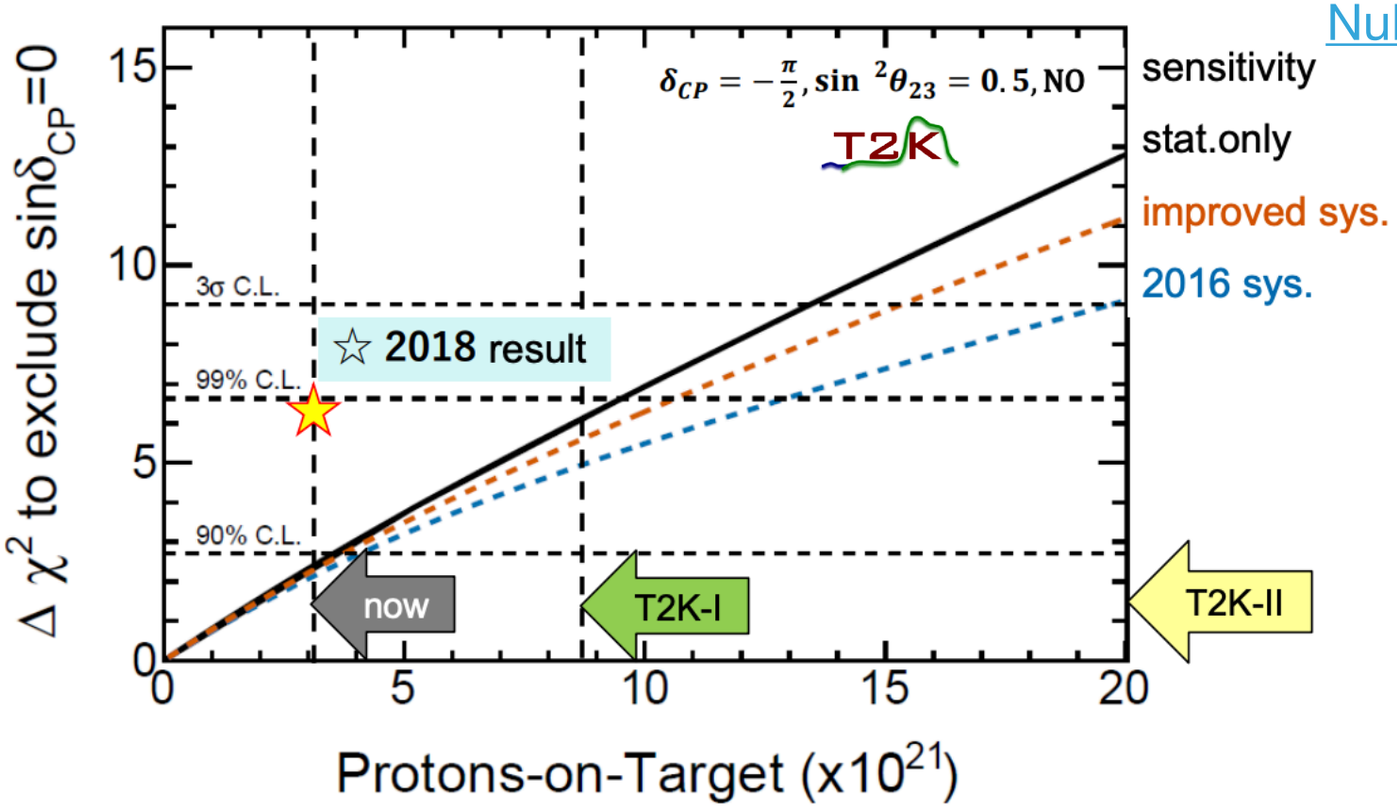
Talk from Ichikawa-san NuPhys2019



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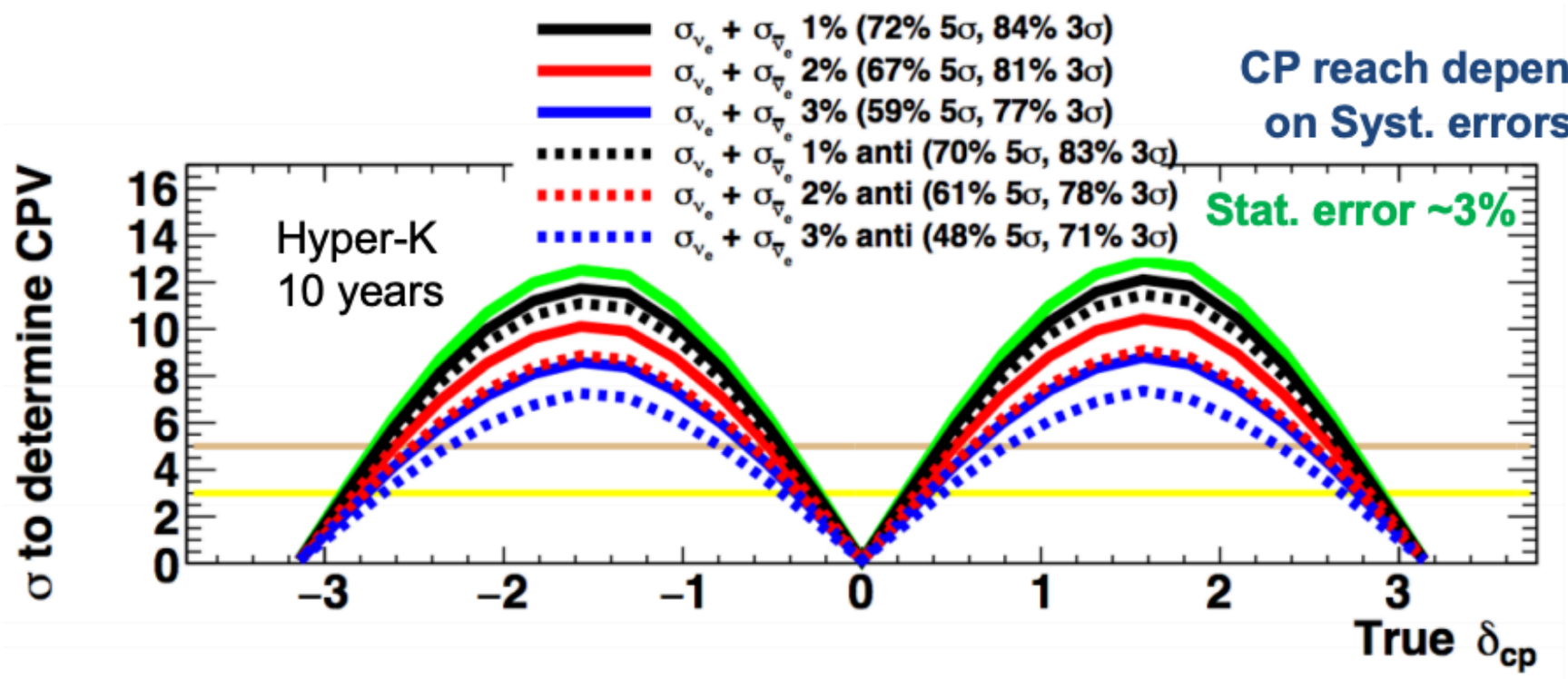


Steve Playfer, NuPhys2019, London

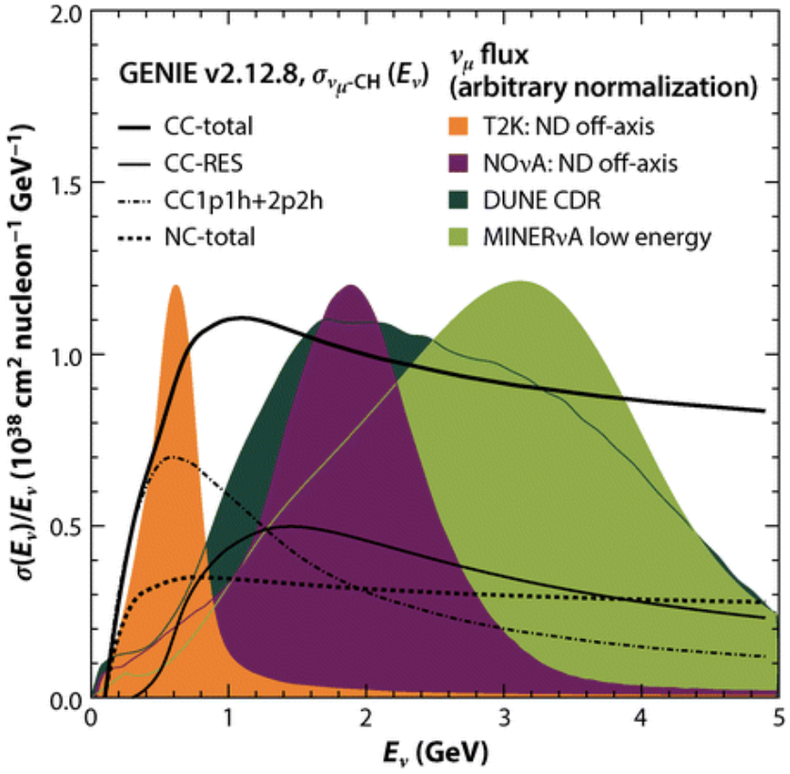
17

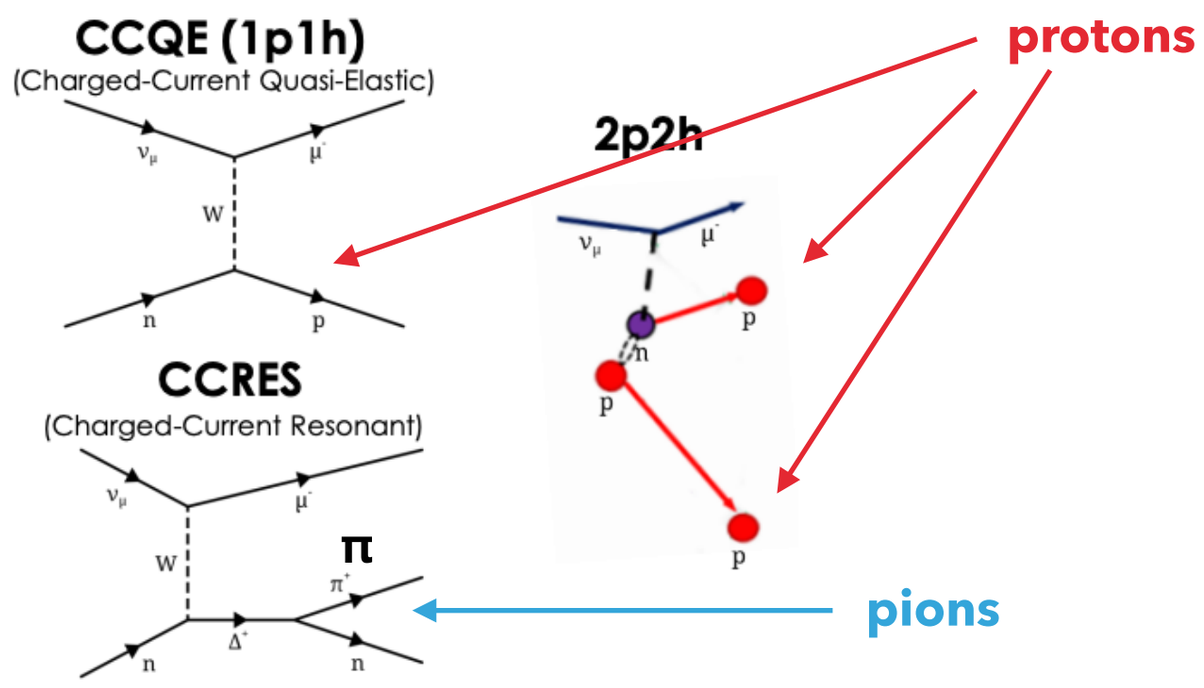
PHYSICS MOTIVATION

- One of the main systematic uncertainties is coming from the understanding of the secondary particle re-interaction with matter (FSI and SI)

- Accurate calibration of the detector and improved understanding of **pion** and **proton** interactions with detector target materials is crucial to reach the aimed systematic (~few %)

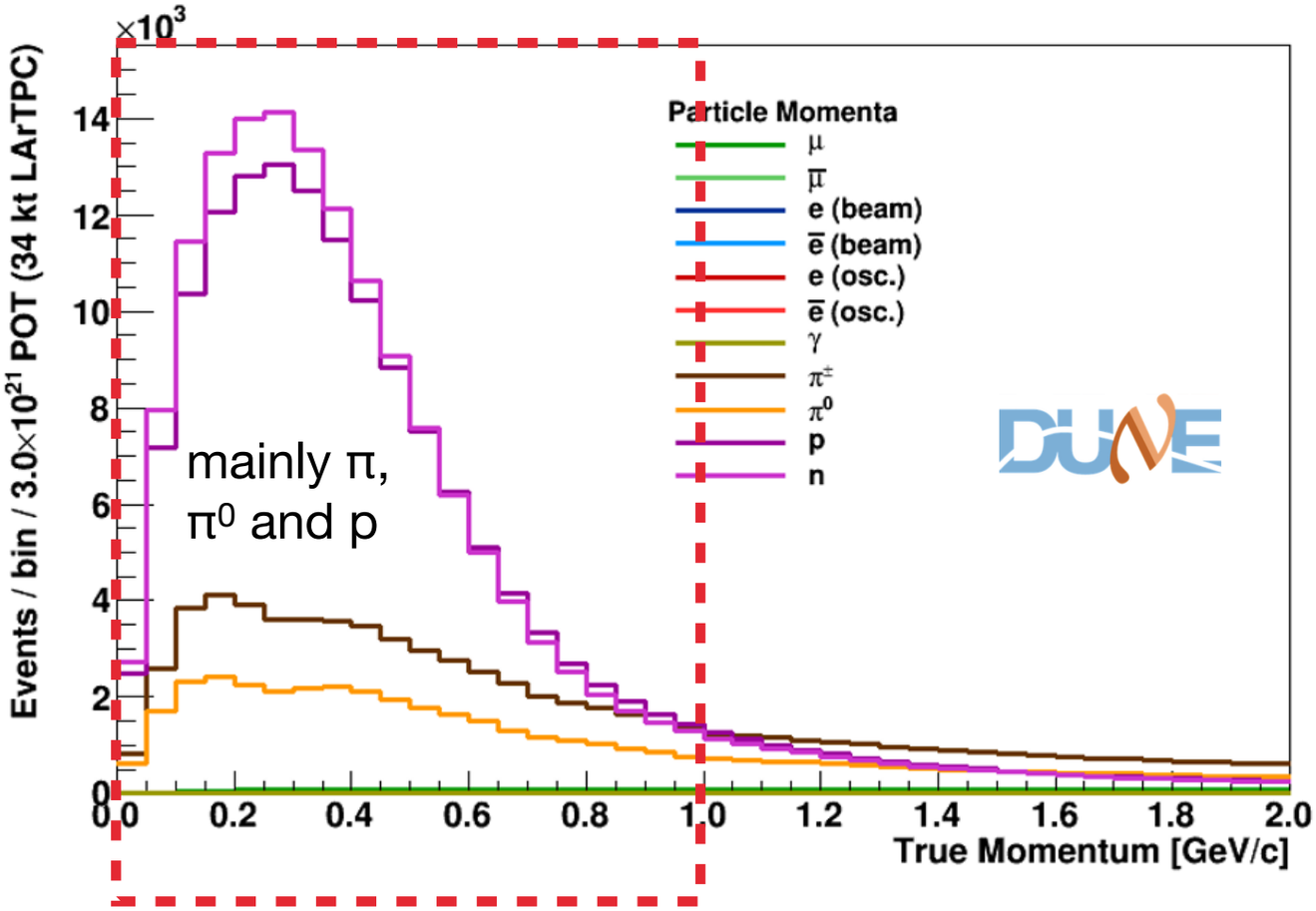
ArXiv: 1803.08848





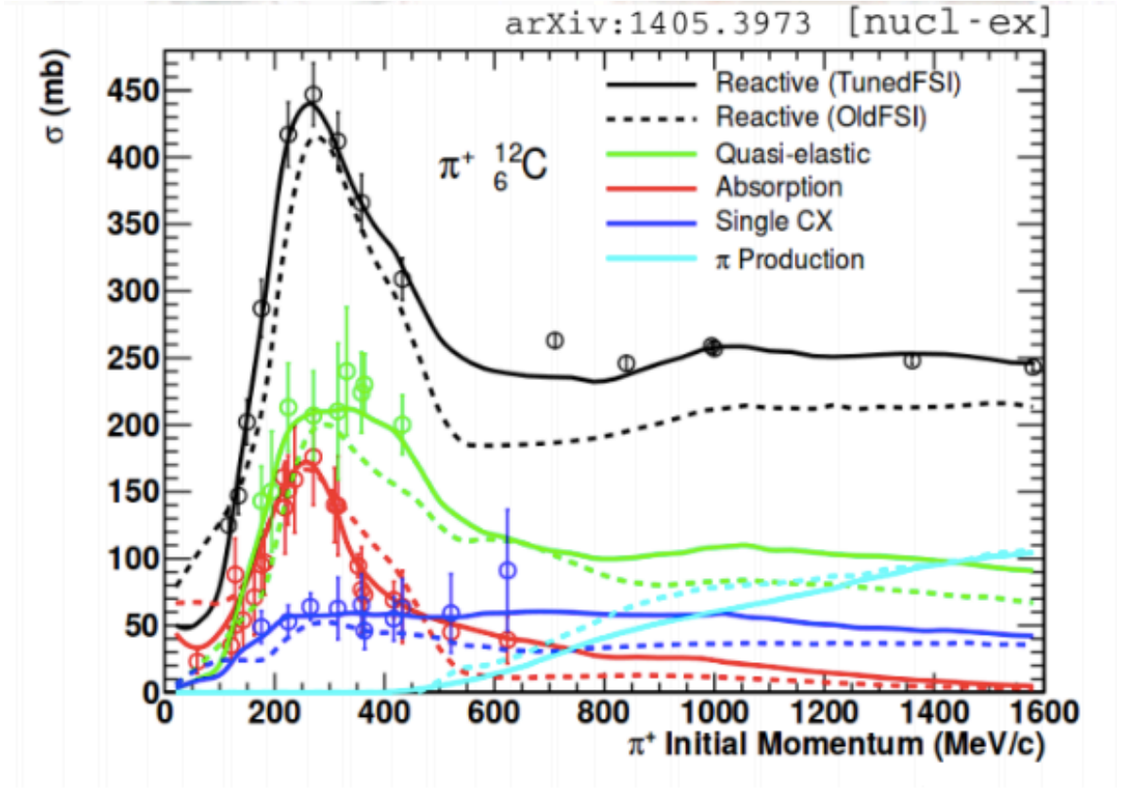
PHYSICS MOTIVATION

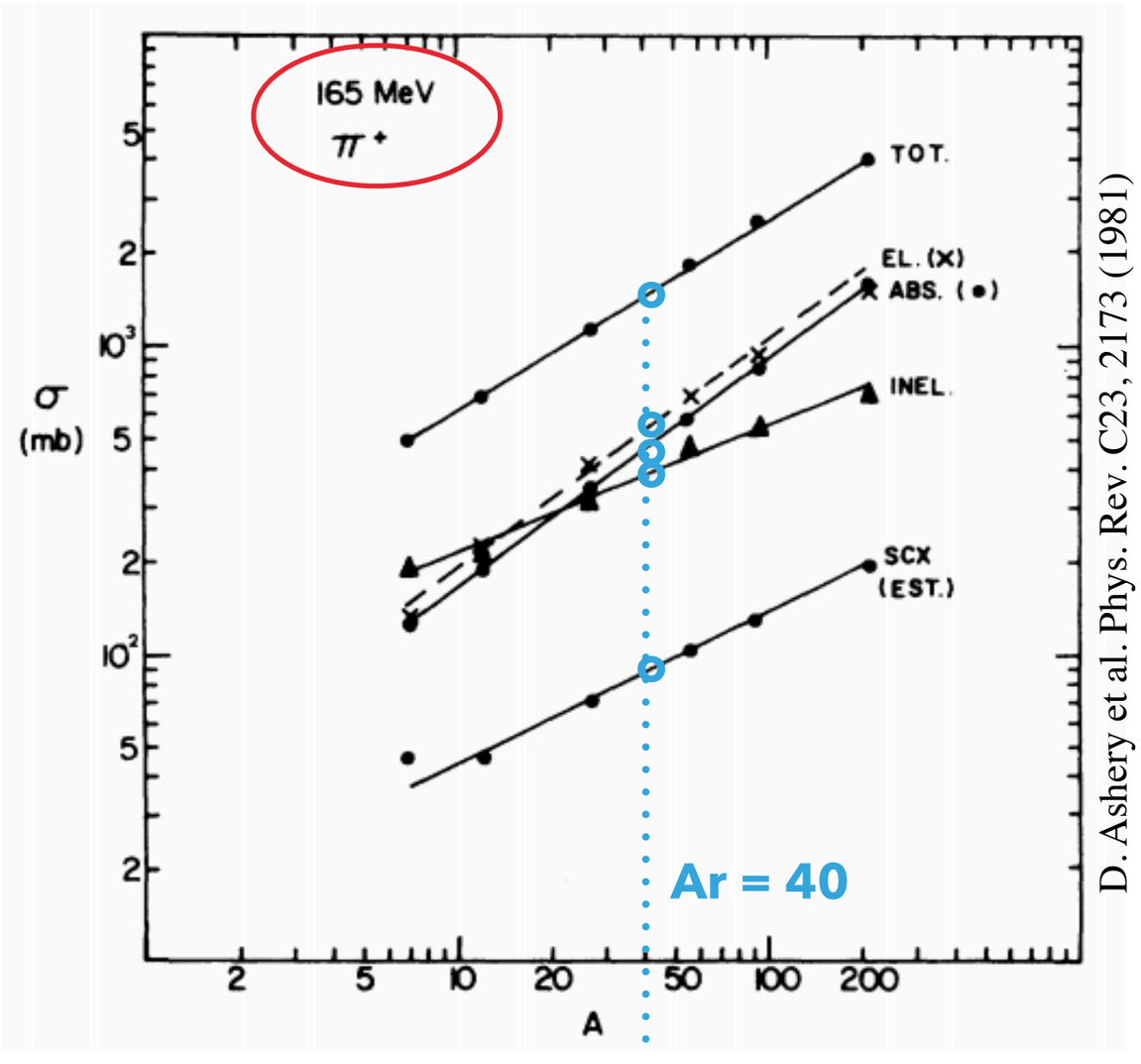
- T2K/T2HK and DUNE secondary particles are in the sub-GeV domain
- Uncertainties exist in current generators particle re-interactions. More data are needed to improve the modelling



PHYSICS MOTIVATION

- About pions:
  - Pion cross section data are used to tune the cascade model in MC generators
  - Compilation of data exist on Light (C, O, Al) and heavy nuclei (Fe, Cu, Pb) between 100 and 2000 MeV/C
  - Almost no data exists for Argon!

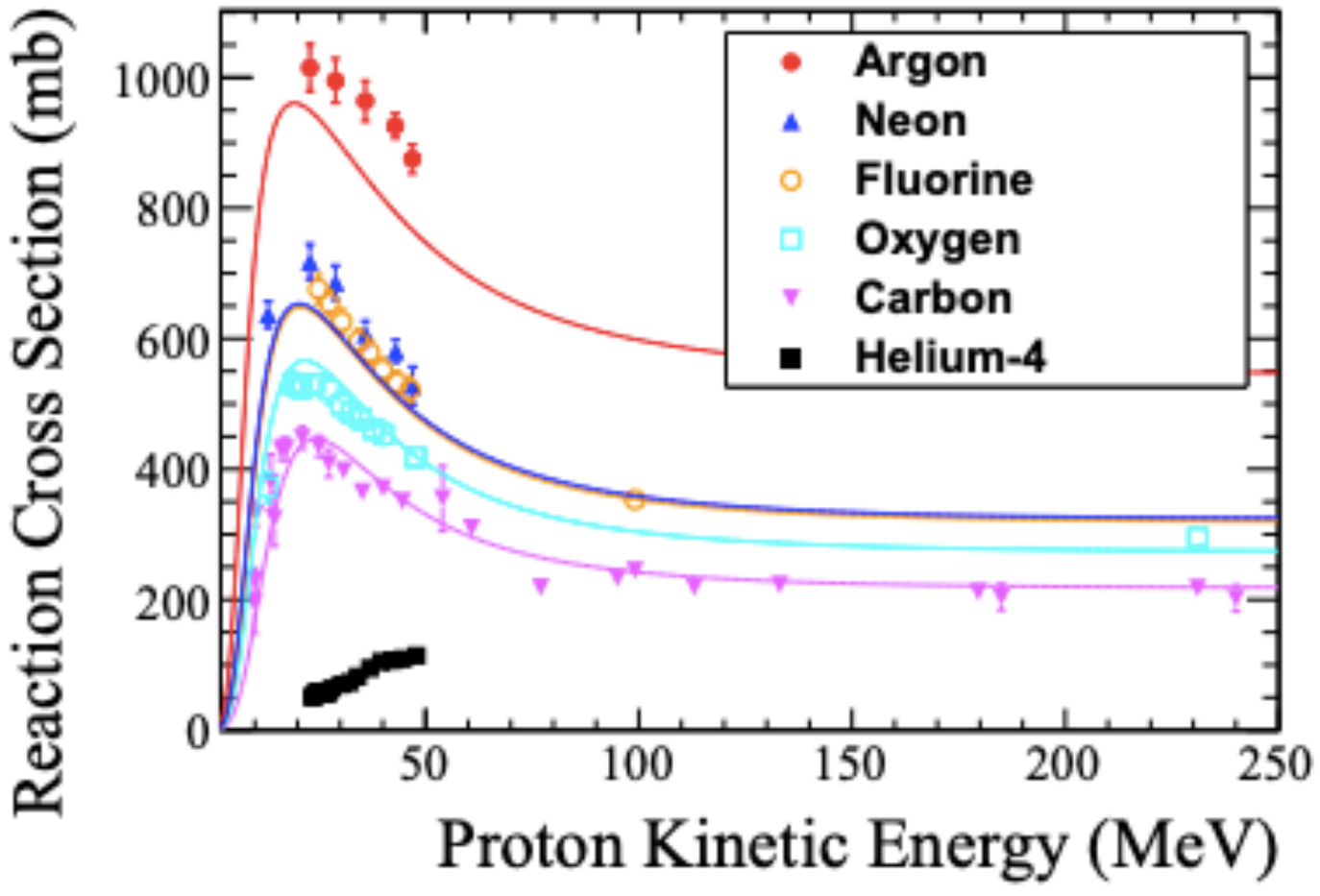




PHYSICS MOTIVATION

- About protons:
  -

https://cds.cern.ch/record/2284748/files/SPSC-P-355.pdf



Data shown against the semi-empirical model (Physical Review C 54, 1329 (1996))

PHYSICS MOTIVATION

- Current total systematics are of the order of 5 - 6 %.
- DUNE and T2K-II/T2HK aims for total systematics <3%

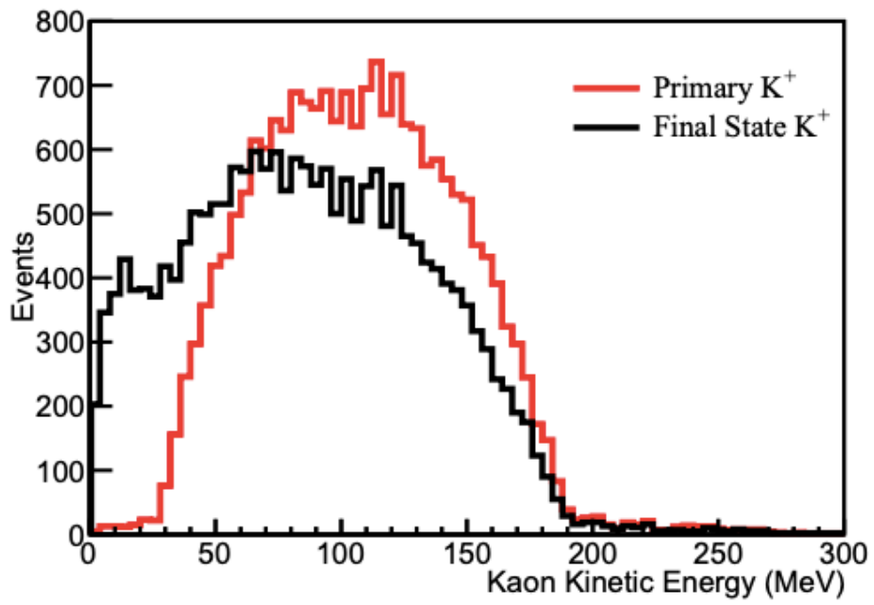
Error Source	% Error on neutrino/ antineutrino rate
Pion Interactions	1,58
Neutral Current Background	1,50
Electron (anti)neutrino cross section	3,03
Extrapolation from near detector	2,31
Removal Energy	3,74
Far Detector model	1,47
Total	5,87

Sources of systematics which would benefit from measurements with sub-GeV beams

PHYSICS MOTIVATION

- There are other measurements which can benefit of an improved understanding of secondary particles in the detector medium
  - atmospheric neutrinos in the sub-GeV region interesting for δ_{CP} measurement for LAr based (calorimetry-based) detectors. More challenging for Cherenkov detectors (kinematic-based). It can provide a cross-check of δ_{CP} measurement with neutrino of different energy and baseline

- proton decay: $p \rightarrow \bar{\nu} + K^+$ main channel in DUNE



INTEREST FROM THE COMMUNITY

- Wide interest collected from the neutrino community:
  - DUNE ND (HPTPC, 3DST, ECAL, LAr TPC, STT)
  - T2K ND (gas TPC , superFGD)
  - HK via the WCTE
  - ENUBET
  - ESSnuSB

- Each 'community' has sent us a short Expression of Interest together with a preliminary list of requirements to provide a starting point for feasibility studies

THE VVLE PROPOSAL

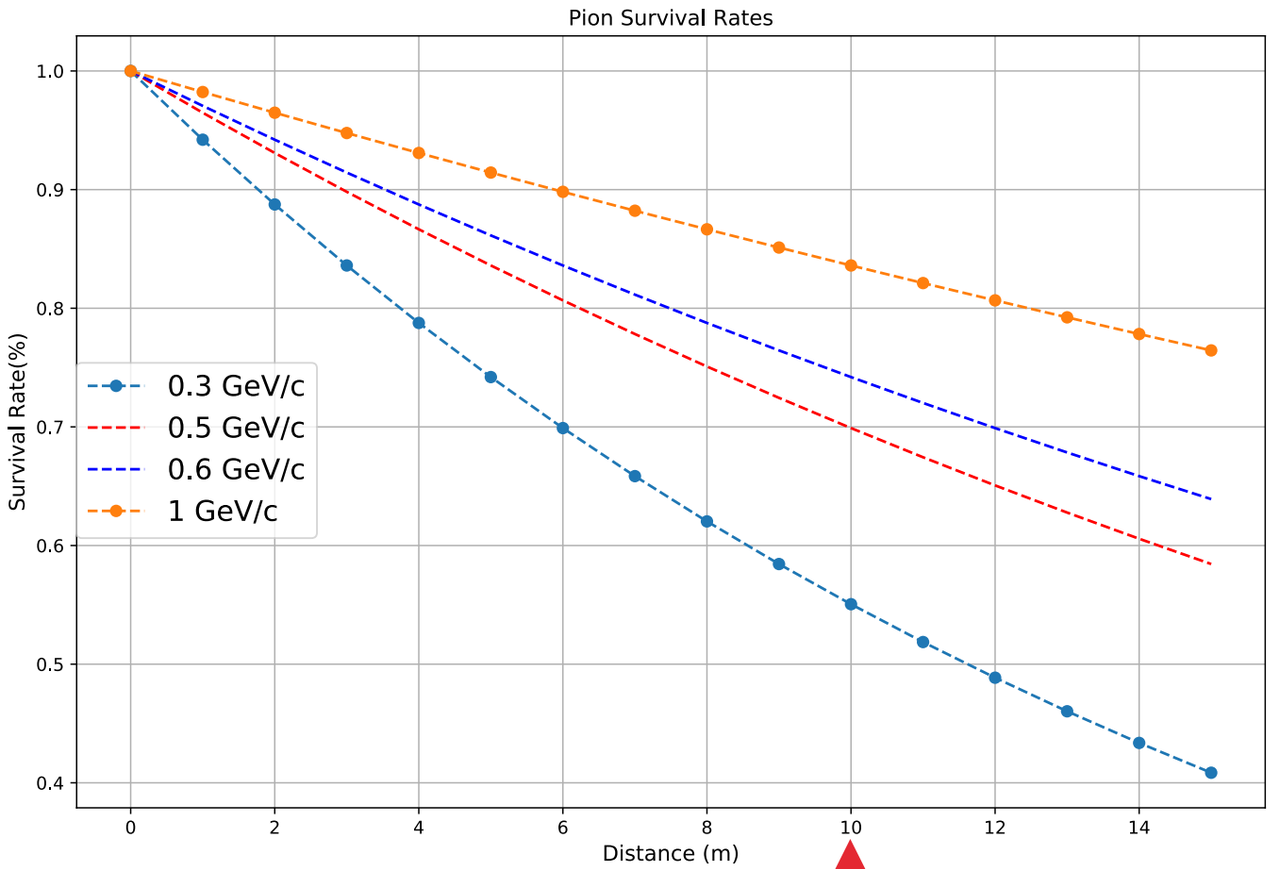
Report to the SPSC the interest from the community for a sub-GeV beam line ([0.2-1] GeV) at CERN and propose to start feasibility/cost estimation studies.

- CERN is providing since 2015 strong support to the LBN experiments
- The Neutrino Platform work is deeply appreciated by the community, widely (European Institutes and others).
- As the Experiments progress (e.g. new generation of LBN), needs evolve. CERN and the Neutrino Platform represents a key location to help to address the new challenges
  - Forefront beam line facilities : infrastructure and know-how available
  - People are used to come to CERN, already confident with regulations, safety, modus-operandi

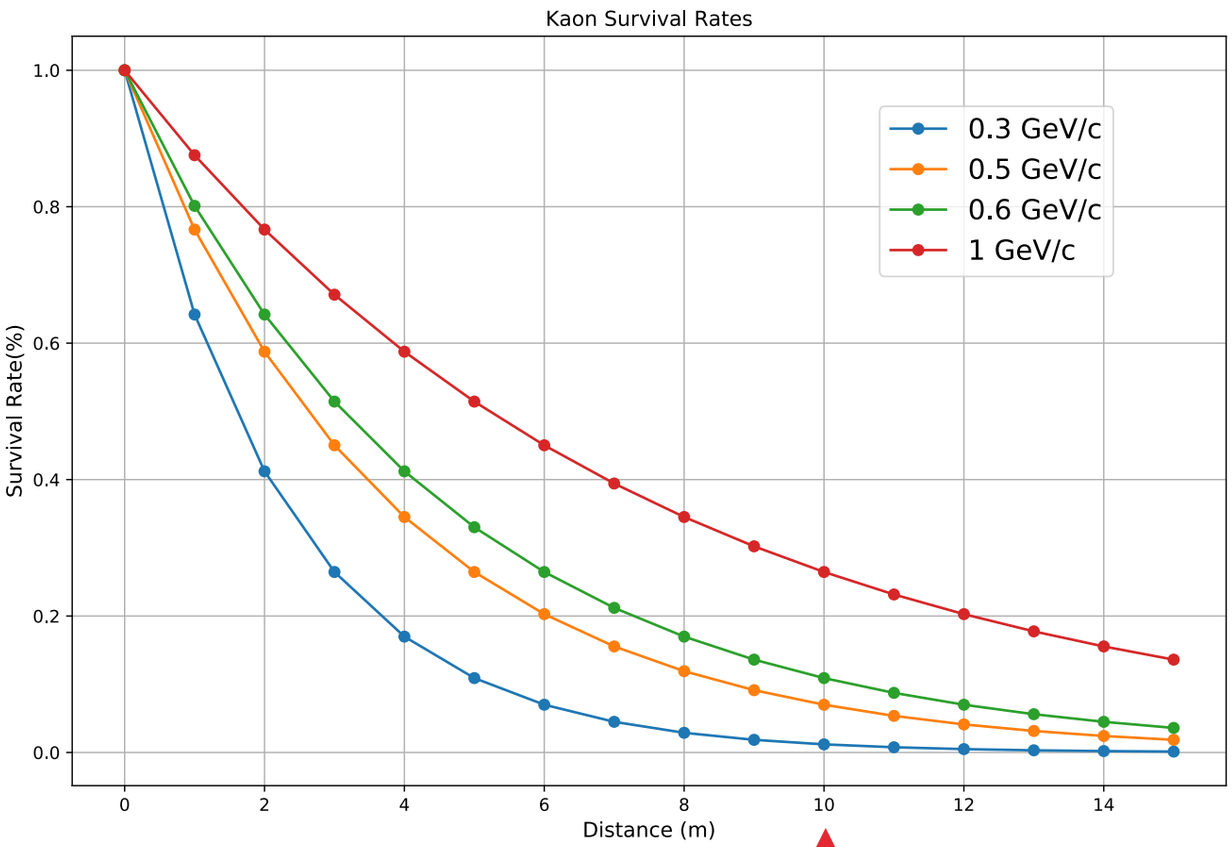
BEAM LINE FUNDAMENTAL REQUIREMENT

To have a decent pion and Kaon rate in the detectors, the beam line should be rather short

Pions Survival rate



Kaon Survival rate

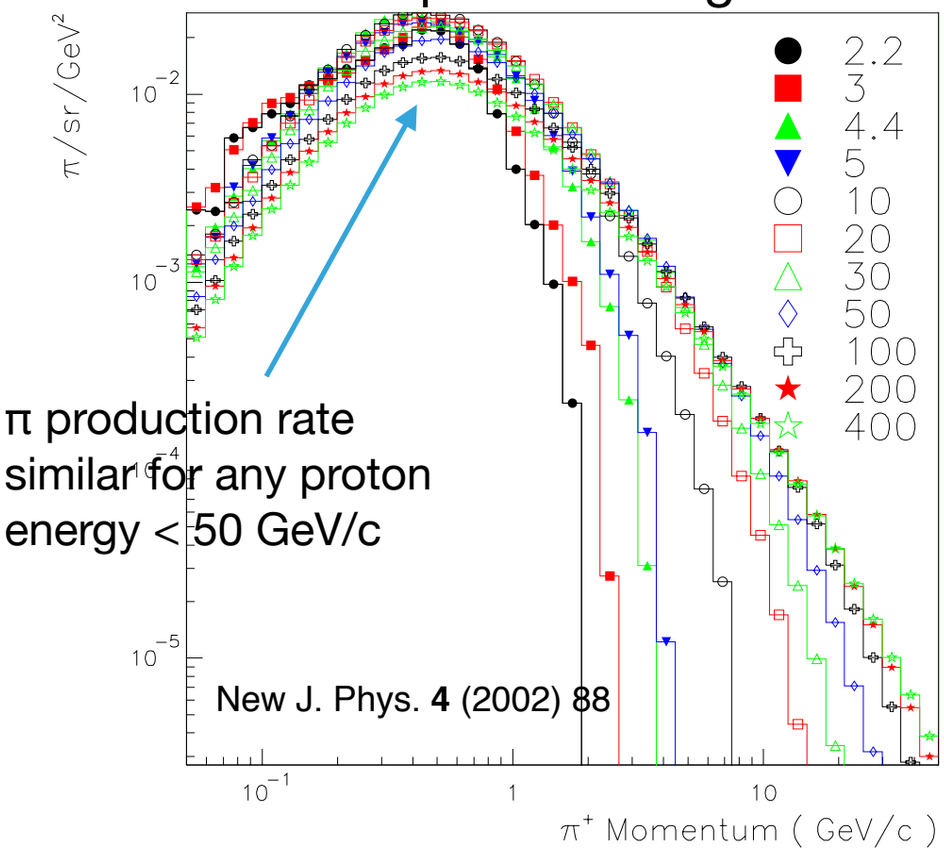


courtesy of N. Charitonidis

POSSIBLE LOCATIONS

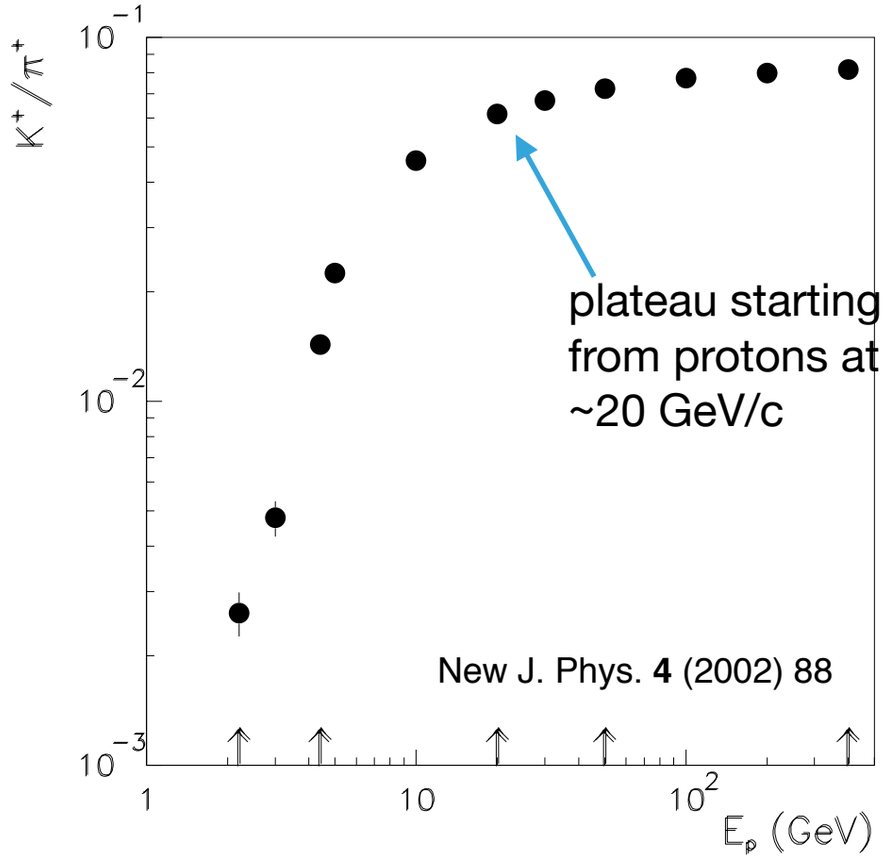
- East area : 10 GeV/ c secondary beam
- North area: starting from 400 GeV/c primary beam but tertiary beam [1-7]GeV/c already available

π production (normalised to beam energy) for different incident proton energies



π production rate similar for any proton energy < 50 GeV/c

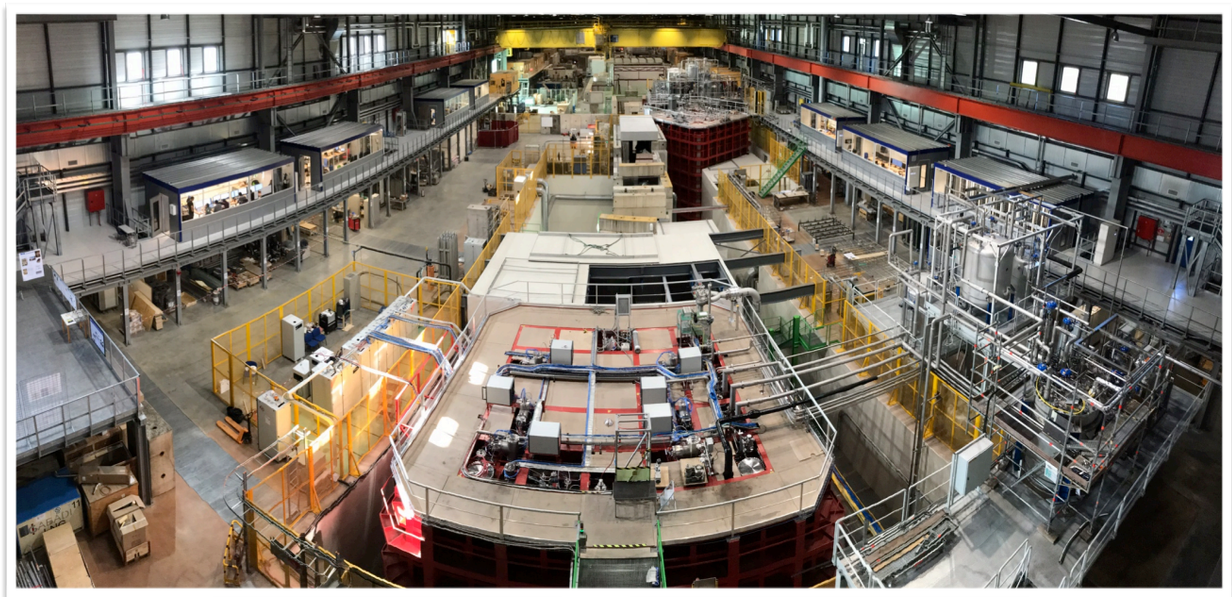
K/π production



simulation with : graphite target, density 1.8 g cm^{-3}, 1 m long, 2 mm radius

THE NORTH AREA AS POSSIBILE LOCATION

- The East area might seems to be the natural location for a sub-GeV beamline. However the North area would not offer very different conditions. Furthermore at the North area we have:
  - **Space**: Large extension of the 887 building entirely dedicated to the Neutrino Platform activities capable to accomodate other detectors than already planned (protoDUNEs, T2KUpgrade, PHASER)
  - Several **infrastructures** already present: LAr cryogenics system, gas system, water, workshops, wifi and also a TPC and possibly a magnet (HARP).
  - Possibility to have H4 **parasitic beam** : same beam time than to pDUNEs



PRELIMINARY BEAMLINE DESIGN STUDIES

- With EN-EA-LE department, first thoughts about a VVLE beamline (see Nikos and Lau's slides)
  - considering elements already existing (keep costs down)
  - considering new elements (ideal beamline)

- More quantitative studies starting from dedicated simulation and engineering studies has to be done. Cost estimation will be derived once defined a possible layout

- To proceed with the studies and continue with close collaboration with the EN-EA - LE department we ask to the SPSC to encourage the project

FIRST QUESTIONS FROM REFEREES

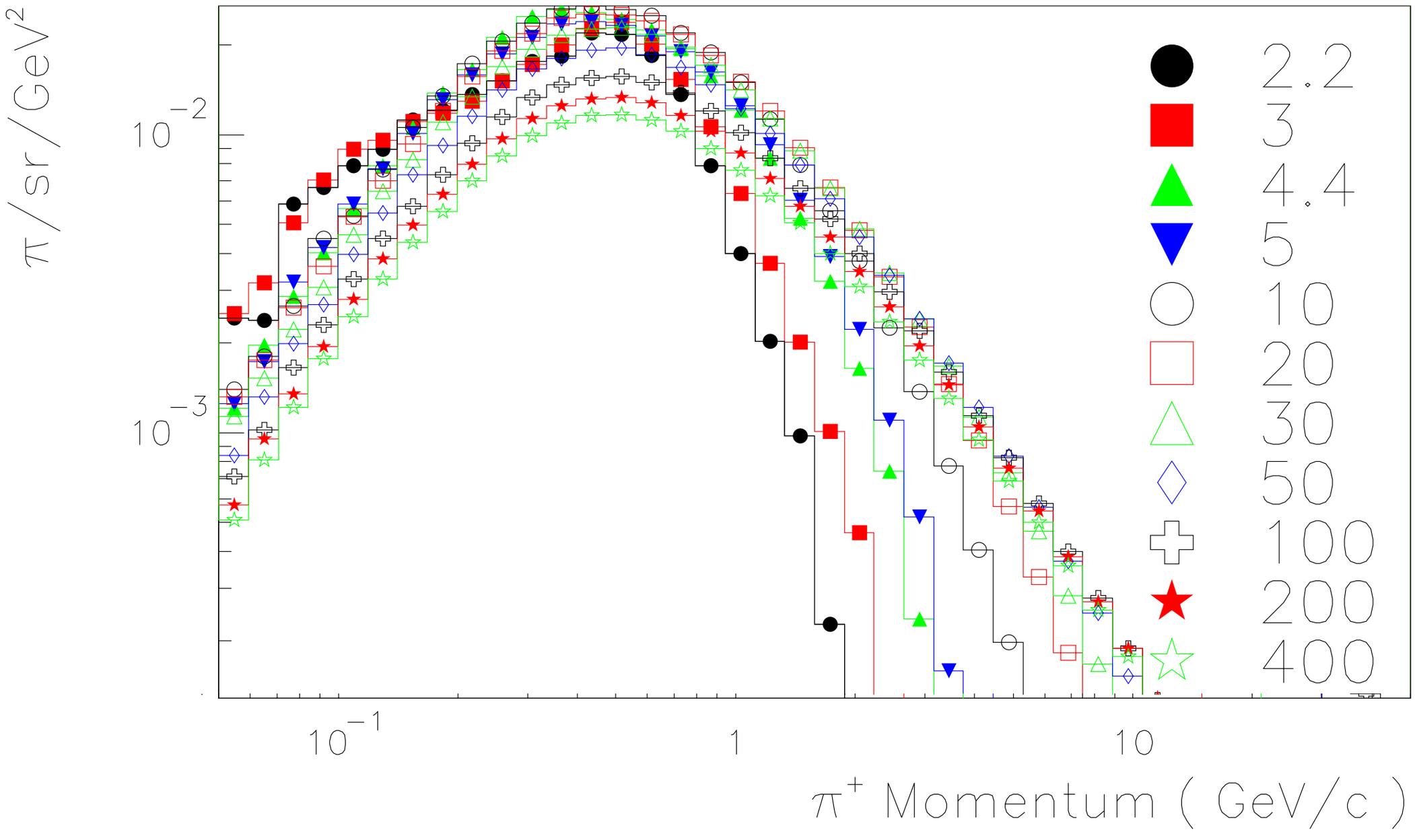
1. Do you have a quantification of the envisioned improvement wrt to calibration or other observable?
   We do not have those studies now. Evident benefits are demonstrated by the past experience (e.g. DUET with pion cross-section for FSI model in T2K)

2. Atmospheric neutrinos
   In the introduction we mention the importance of atmospheric neutrinos specifically in the sub-GeV region. Those neutrinos can provide a cross-check to δ_{CP} measurement using different energy range and baseline.
   See slide 11 and reference

3. What are the requirements based on?
   Each detector representative has sent a preliminary list of requirements based on their needs. Many of those are aligned (e, mu, hadrons with 1-10kHZ and a dp/p < 5%).

4. Why CERN?
   - CERN and Neutrino Platform are playing a well recognised role for the LBN community, both US and Japan, infrastructure and know-how are already available and well established.. (see slide 16).
   - to have Kaons we need high energy primary beam
   - US FermiLab LarIAT line would be a possibility but it's not a facility, plans are not clear

ADDITIONAL


π/sr/GeV²
10⁻²
10⁻³
10⁻¹
1
10
π⁺ Momentum (GeV/c)
2.2
3
4.4
5
10
20
30
50
100
200
400

SUMMARY OF THE SUITABLE REQUIREMENTS FOR THE VVLE

Detector technology	Particle species	p [MeV/c]	Beam spot size	Rate	beam $\Delta p/p$	beam Energy scale	Detector size (cm^3)	Other comments
Cherenkov	e, p, π, K, μ	120 - 1200	$<$ 10 cm RMS	1 - 10 kHz	$<$ 2%	$<$ 0.5%	400 $\times$ 400 $\times$ 400	access to de-ionised water
HP-TPC (DUNE-ND)	π, p	100 - 2000		O(kHz)				
3DST/superFGD	e,p,π, K , μ, γ	$<$ 200 $-$ 1000			$<$ 5%		24 $\times$ 8$\times$48	tests in B field would be a plus
ECAL	e, γ , π	10 - 1000					50$\times$50$\times$50	use of a Magnet (possibly with photon beam
LArTPC (ArgonCUBE)	hadrons, e , γ	$<$ 1000 - 5000		$<$ 1kHz - 10kHz				LAr, cryogenics, possibility to move the detector to get different track angles
gas atmTPC	e,p,π, K , μ	100 - 1000		$<$10kHz			50$\times$50$\times$100	tests in B field would be a plus
ENUBET demonstrator	e,p,π, K , μ	200-6000	broad	high	$<$2%		200$\times$100$\times$300	good PID with a CH pair (a' la T9), no B needed
HPTPC (UK)	π, p, γ	100-1000		$<$1kHz	$<$ 5%	$<$5%	450$\times$450$\times$300	space around, clean area (or clean tent)
STT	e, p, π, K, μ, n	100-5000					200$\times$200$\times$200	irradiation with neutrons would be very useful
Water Cherenkov	e,p,π, μ, γ	50-600		1-10 kHz	$<$5%	$<$1%	200$\times$ 200 $\times$200	
Scintillator tracker	e,p,π, μ, γ	50-600		1-10 kHz	$<$5%	$<$1%	80$\times$50$\times$50	magnetic field needed

COMPILATION OF PION DATA

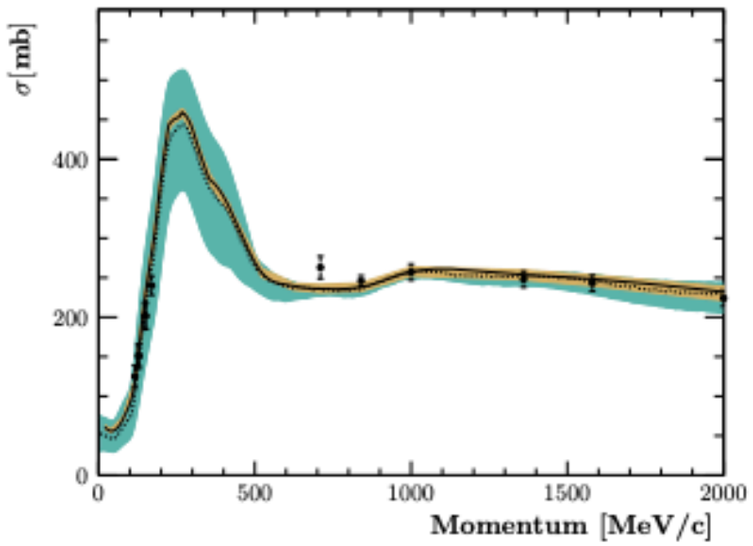
https://arxiv.org/pdf/1812.06912.pdf

List of data used to tune the NEUT cascade model

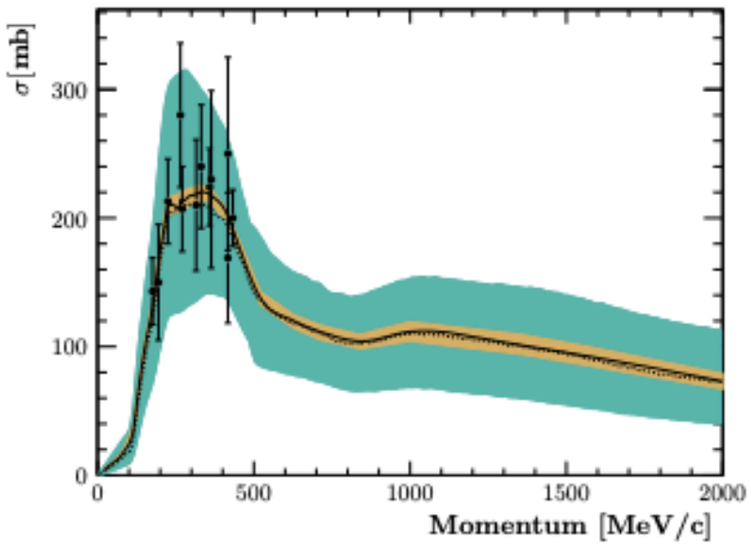
Reference	Polarity	Targets	p_π [MeV/c]	Channel(s)
B. W. Allardyce et al. [11]	$\pi^\pm$	C, Al, Pb	710-2000	REAC
A. Saunders et al. [12]	$\pi^\pm$	C, Al	116-149	REAC
C. J. Gelderloos et al. [13]	π^-	C, Al, Cu, Pb	531-615	REAC
F. Binon et al. [14]	π^-	C	219-395	REAC
O. Meirav et al. [15]	π^+	C, O	128-169	REAC
C. H. Q. Ingram [16]	π^+	O	211-353	QE
S. M. Levenson et al. [17]	π^+	C	194-416	QE
M. K. Jones et al. [18]	π^+	C, Pb	363-624	QE, CX
D. Ashery et al. [19]	$\pi^\pm$	C, Al, Fe	175-432	QE, ABS+CX
H. Hilscher et al. [20]	π^-	C	156	CX
T. J. Bowles [21]	$\pi^\pm$	O	128-194	CX
D. Ashery et al. [22]	$\pi^\pm$	C, O, Pb	265	CX
K. Nakai et al. [23]	$\pi^\pm$	Al, Cu	83-395	ABS
E. Bellotti et al. [24]	π^+	C	230	ABS
E. Bellotti et al. [25]	π^+	C	230	ABS
I. Navon et al. [26]	π^+	C, Fe	128	ABS+CX
R. H. Miller et al. [27]	π^-	C, Pb	254	ABS+CX
E. S. Pinzon Guerra et al. [28]	π^+	C	206-295	ABS, CX

FSI MODEL TUNING USING EXTERNAL DATA DATA

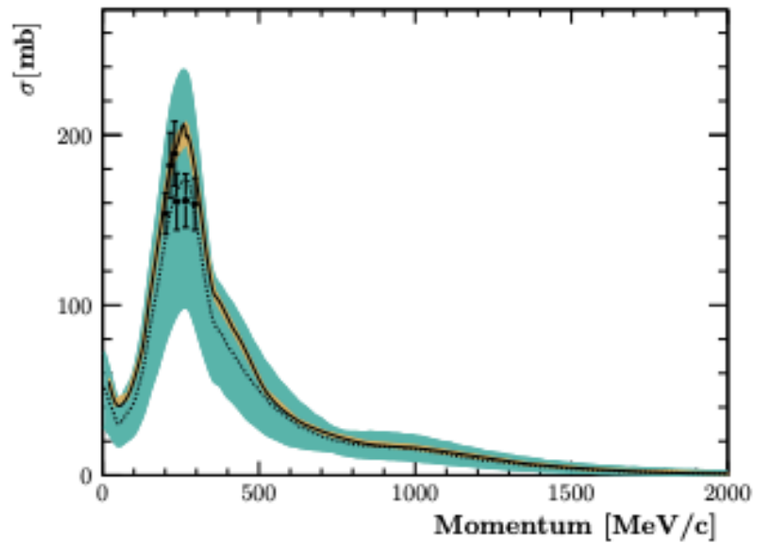
https://arxiv.org/pdf/1812.06912.pdf



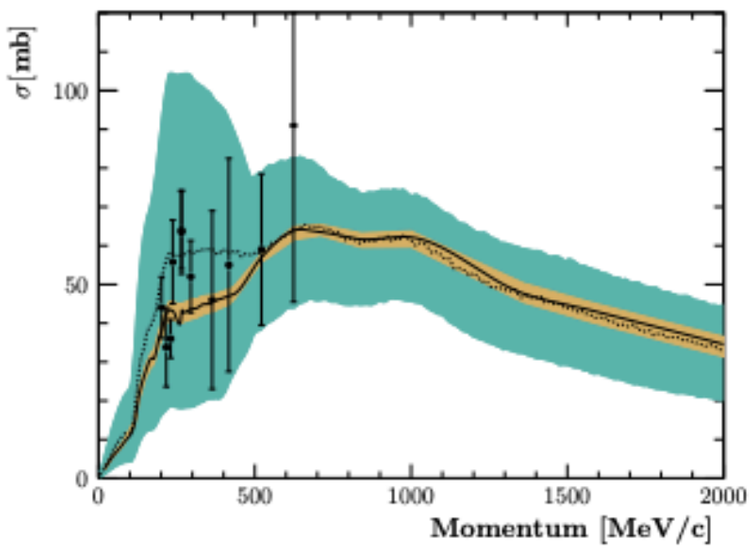
(a) Reactive



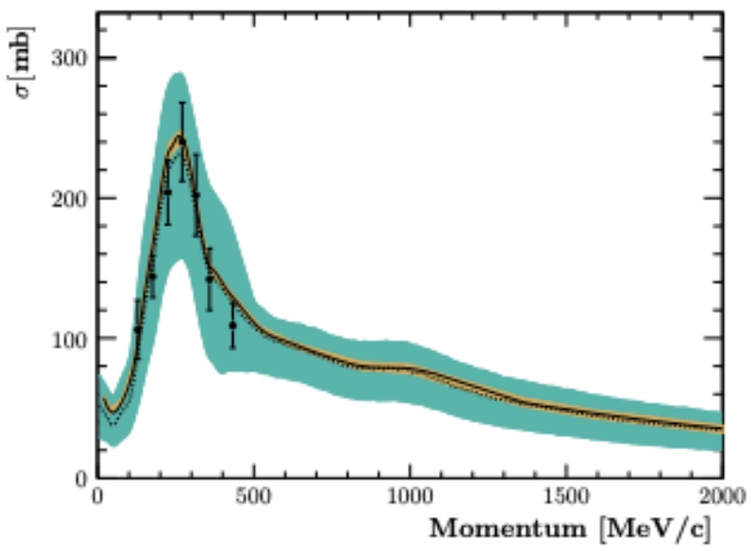
(b) Quasi-elastic



(c) Absorption (ABS)



(d) Charge exchange (CX)



(e) ABS+CX

This Work: Best Fit

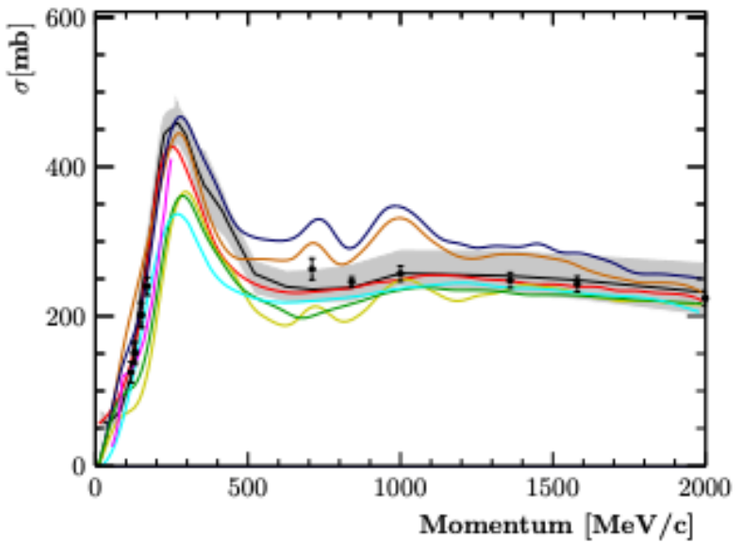
This Work: ±1σ band

Previous: Best Fit (dotted)

Previous: ±1σ band

FSI MODEL TUNING USING EXTERNAL DATA DATA

https://arxiv.org/pdf/1812.06912.pdf



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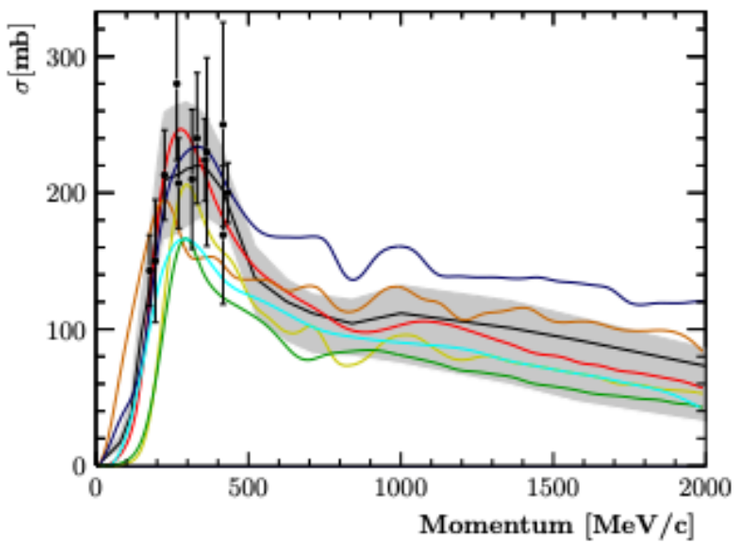

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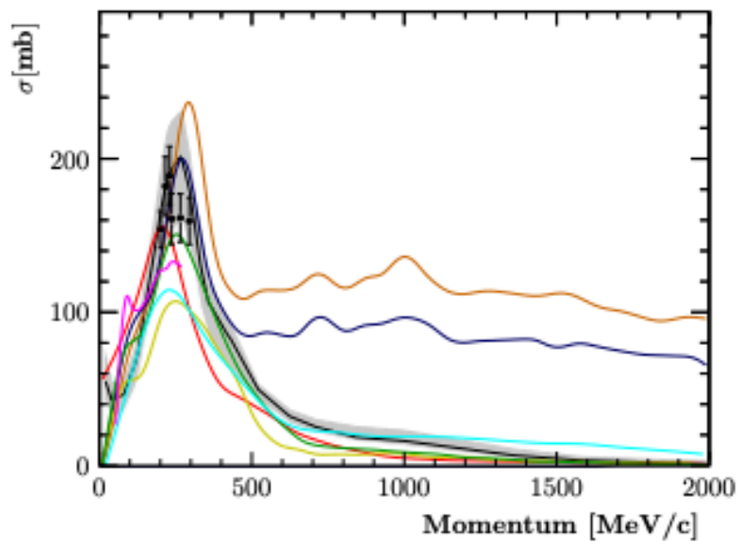

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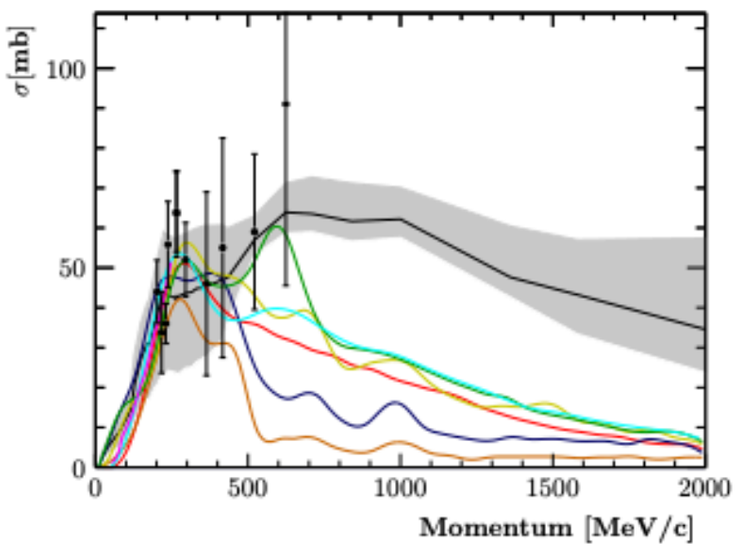

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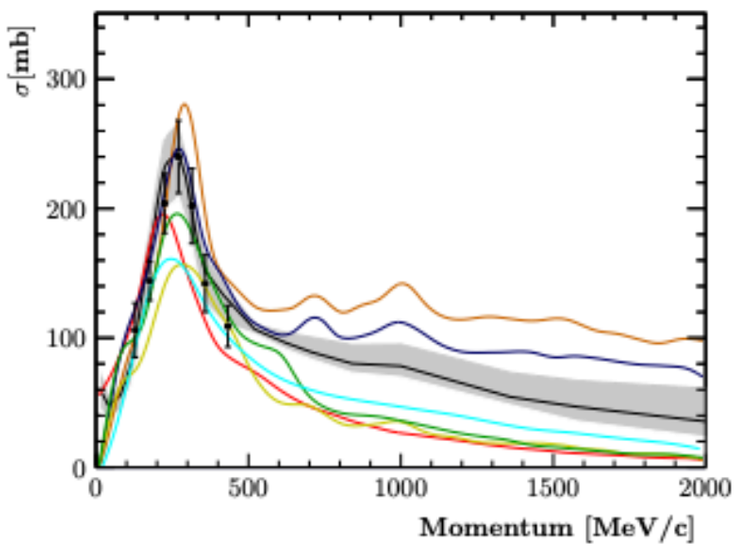

(e) ABS+CX

This Work: Best Fit $\pm 1\sigma$

Geant4 Bertini (4.9.4)

GENIE hA (2.12.4)

GENIE hA2014 (2.12.4)

GENIE hN2015 (2.12.4)

NuWro (17.01.1)

FLUKA (2011.2c.6)

GiBUU (Phys. Rep. 512 (2012) 1-124)