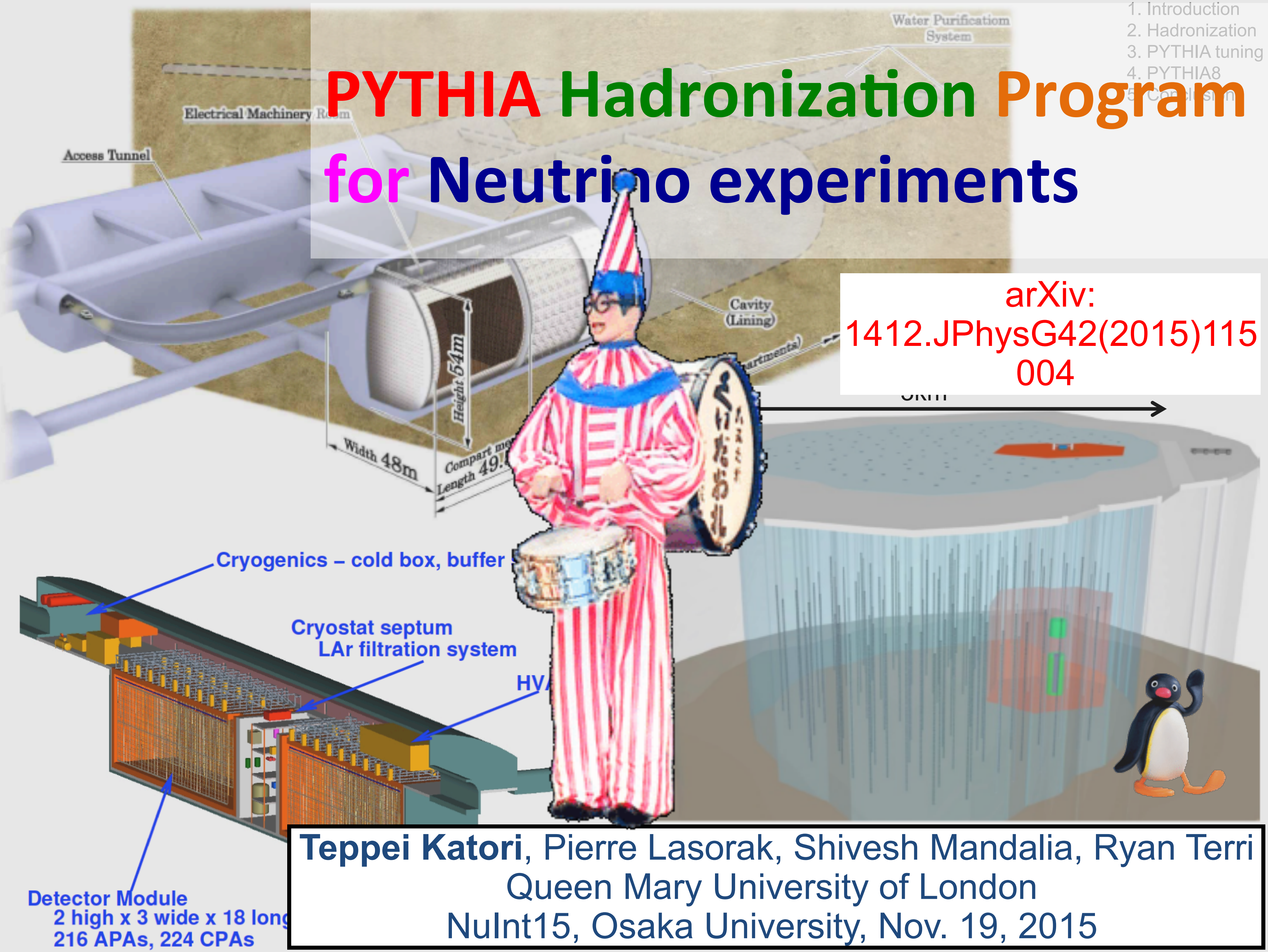
PYTHIA Hadronization Program for Neutrino experiments



arXiv:
1412.JPhysG42(2015)115
004

Teppei Katori, Pierre Lasorak, Shivesh Mandalia, Ryan Terri
Queen Mary University of London
NuInt15, Osaka University, Nov. 19, 2015

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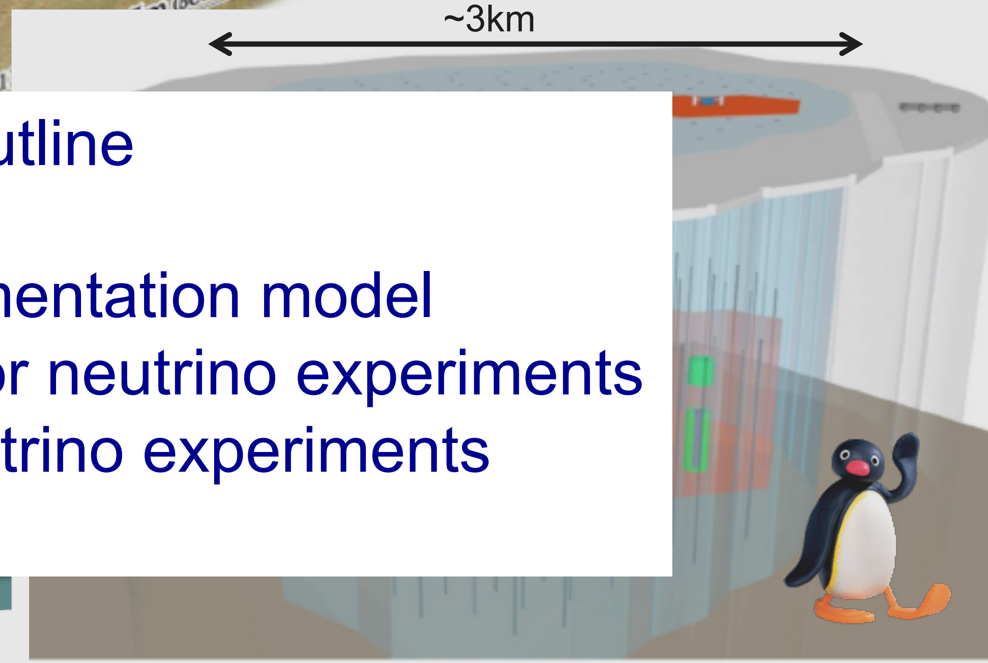
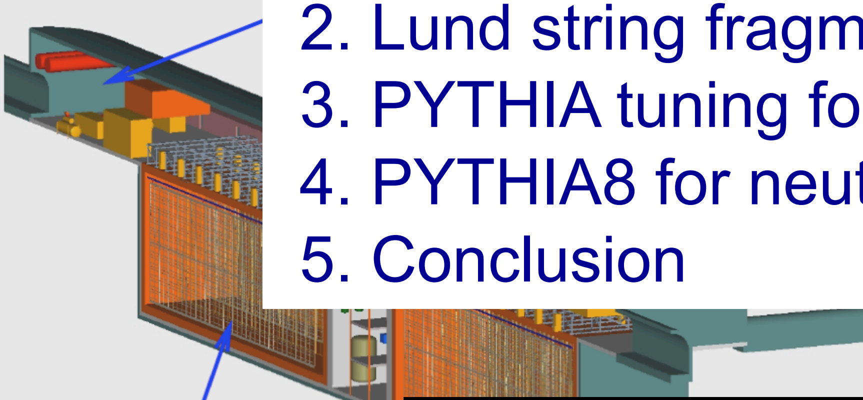
JPhysG42(2015)115004





outline

1. Introduction
2. Lund string fragmentation model
3. PYTHIA tuning for neutrino experiments
4. PYTHIA8 for neutrino experiments
5. Conclusion

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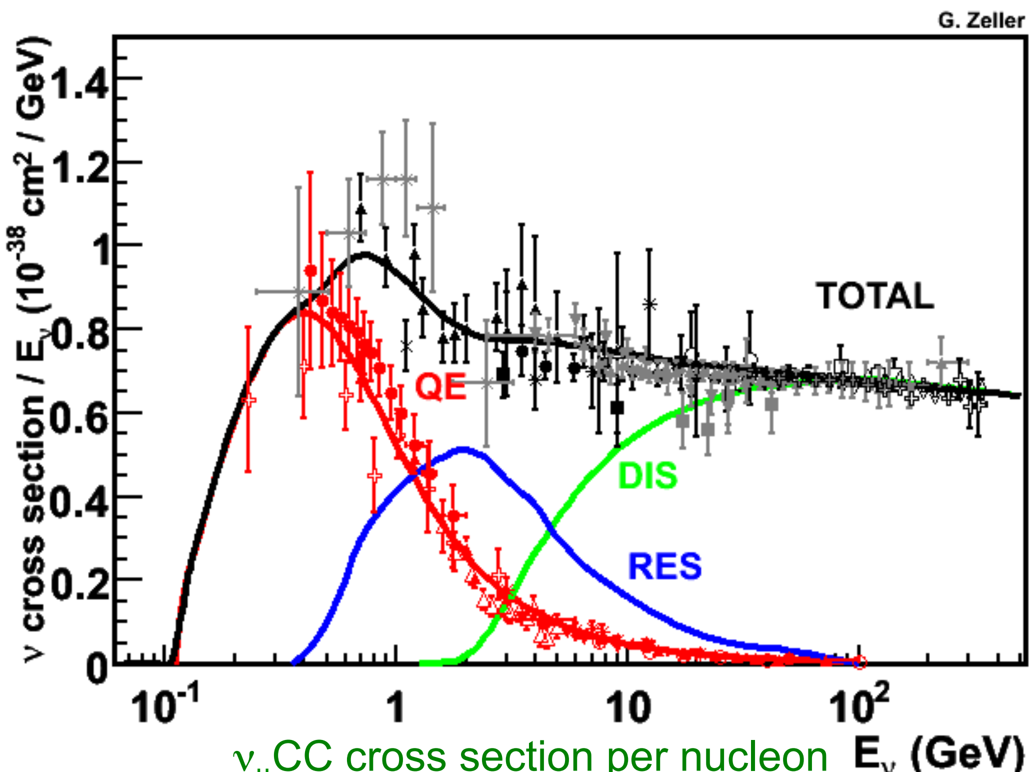
Formaggio and Zeller, Rev.Mod.Phys.84(2012)1307

1. Next generation neutrino oscillation experiments

Neutrino oscillation experiments
- Past to Present: K2K, MiniBooNE, MINOS, T2K
- Present to Future: T2K, NOvA, PINGU, ORCA, HyperK, DUNE



ν_μCC cross section per nucleon

$$P_{\mu\to e}(L/E) = \sin^2 2\theta \sin^2\left(1.27\Delta m^2(eV^2)\frac{L(km)}{E(GeV)}\right)$$

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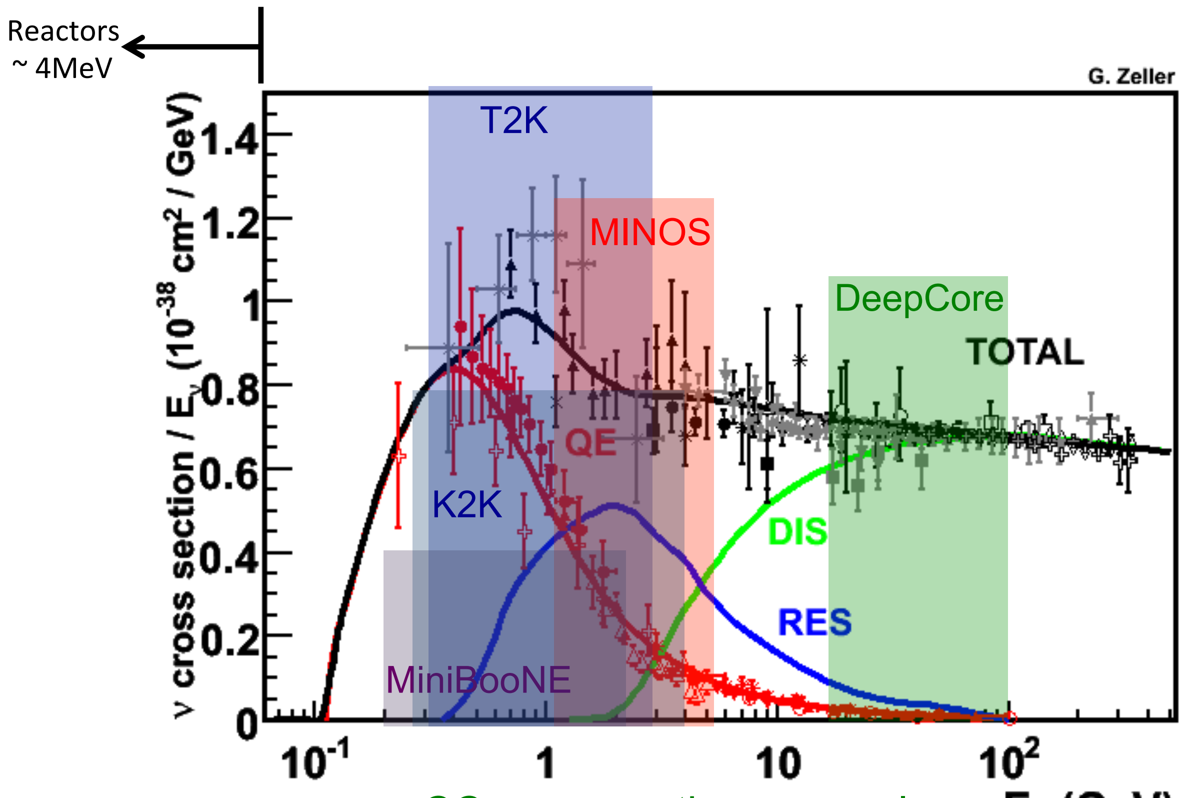

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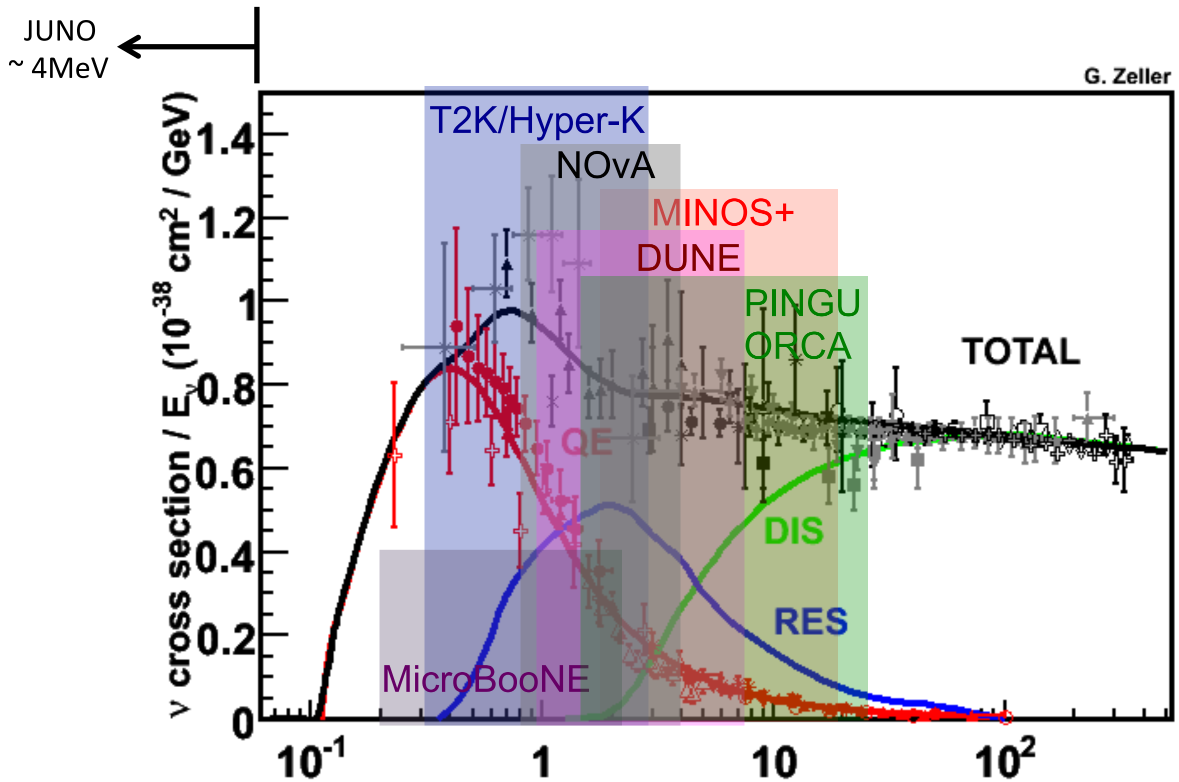

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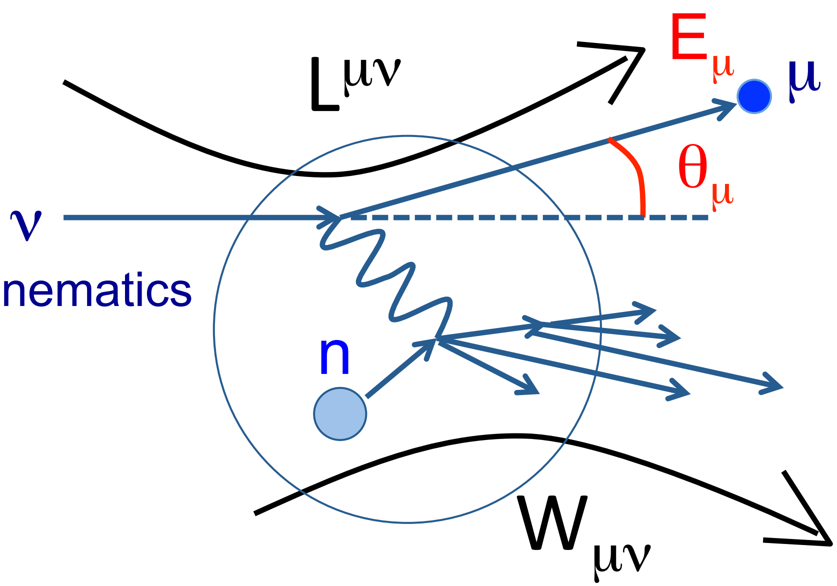
1-10 GeV seems very important

Modelling of hadronic tensor $W_{\mu\nu}$ (inclusive cross section)
- Resonance production
- Shallow inelastic scattering (SIS)
- DIS



Modelling of outgoing hadron multiplicity & kinematics
- FSI
- Hadronization

It's time to try to understand hadron physics!

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Modelling of outgoing hadron multiplicity & kinematics
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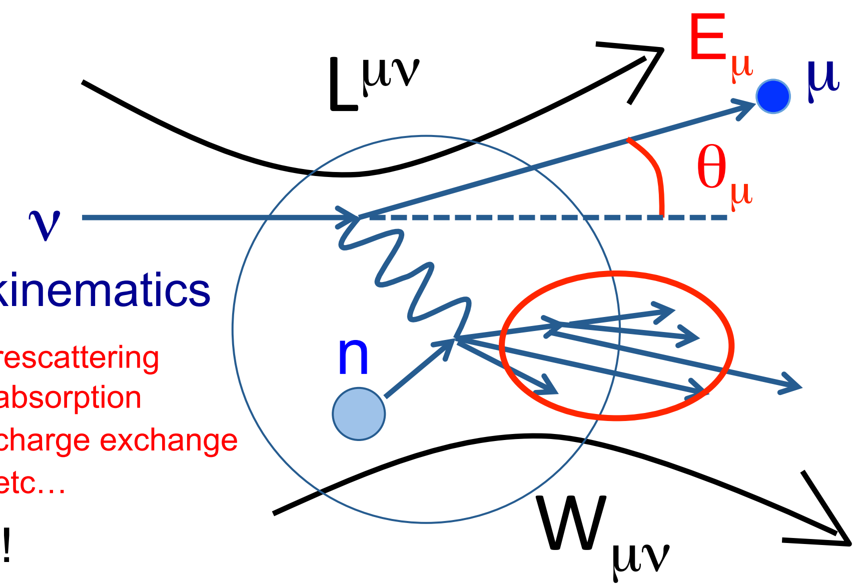
rescattering
absorption
charge exchange
etc…



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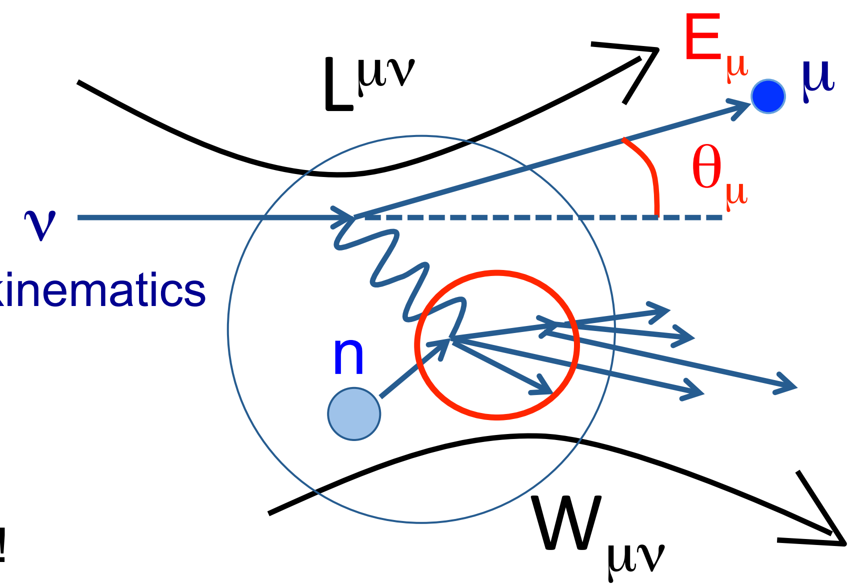

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AGKY, EPJC63(2009)1
TK and Mandalia,JPhysG42(2015)115004

1. GENIE hadronization model (AGKY model)

AGKY model

GENIE hadronization model originally developed by Costas Andreopoulos (Liverpool), Hugh Gallagher (Tufts), Tinjun Yang (Fermilab)

Plots In this talk are made by GENIE hadronization validation tool originally developed by Tinjun Yang (Fermilab), later improved by Gabe Perdue (Fermilab) and Julia Yarba (Fermilab)

More about AGKY model, Talk by Christophe Bronner (Nov. 19, Thursday)

AGKY, EPJC63(2009)1
TK and Mandalia,JPhysG42(2015)115004

1. GENIE hadronization model (AGKY model)

Cross section

W^2<2.9 GeV^2 : RES

W^2>2.9 GeV^2 : DIS

Hadronization (AGKY model)

W^2<5.3GeV^2 : KNO scaling based model

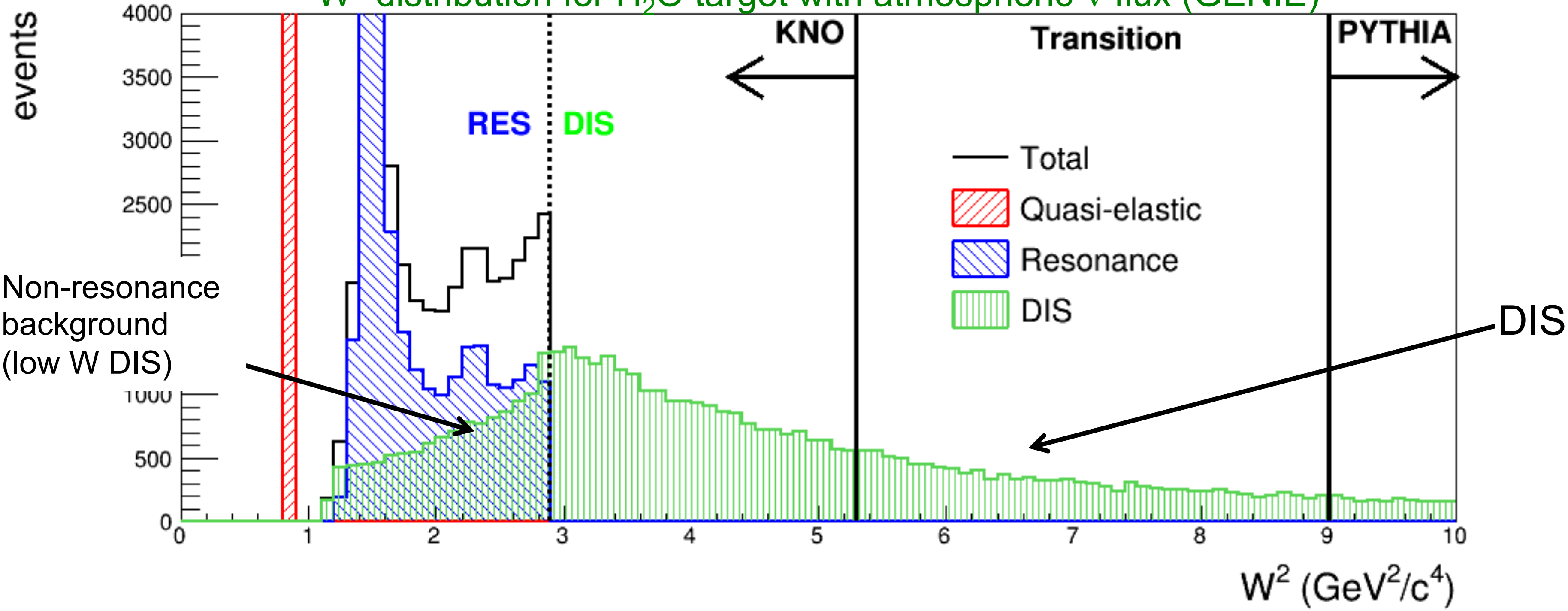
2.3GeV^2<W^2<9.0GeV^2 : transition

9.0GeV^2<W^2 : PYTHIA6

There are 2 kind of "transitions" in SIS region

- cross-section
- hadronization

W^2 distribution for H_2O target with atmospheric-ν flux (GENIE)



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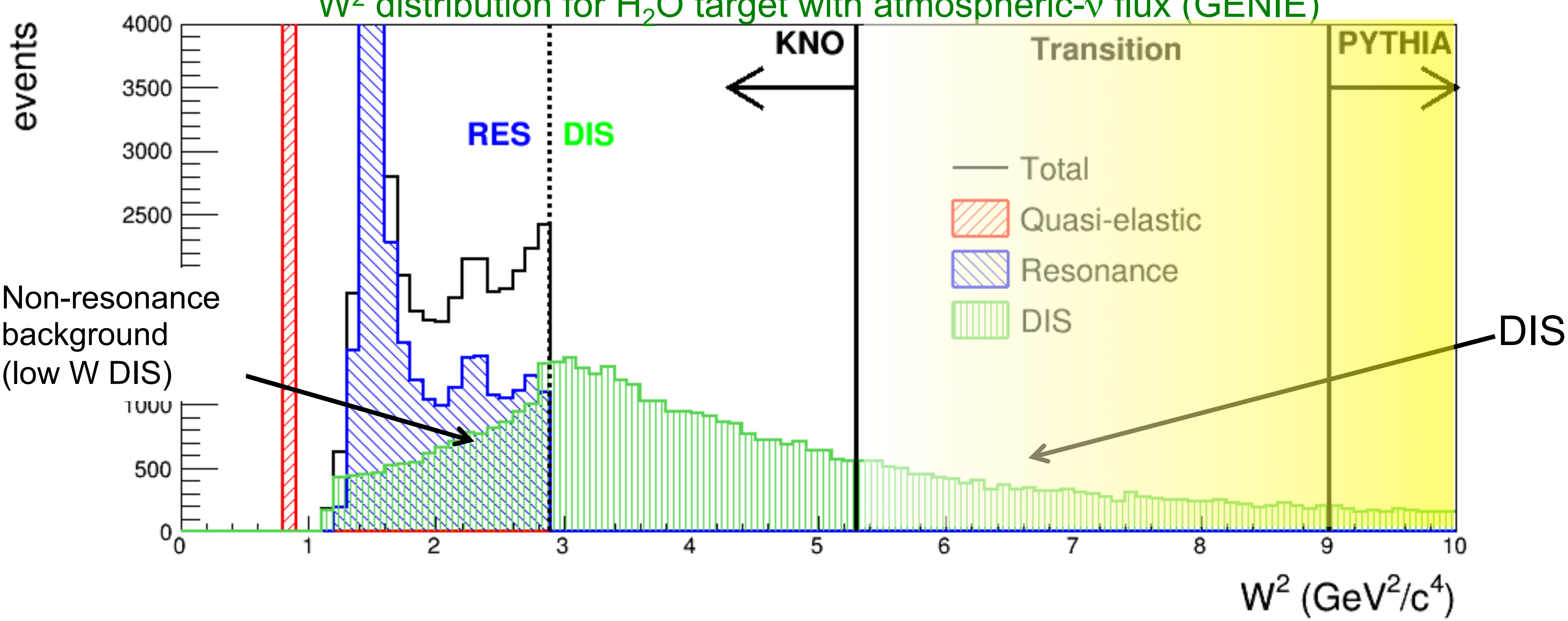
PYTHIA hadronization

- It is used only for high W ($W^2>5.3$GeV^2)
- It may be important for future experiments, especially PINGU, ORCA, Hyper-K, DUNE



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2. Lund string fragmentation model

One dimensional relativistic string model

Lund fragmentation function, f(z), describes distribution of hadrons with z=E/ν, fraction of energy transfer taken by hadron

hadron energy distribution from iterative process

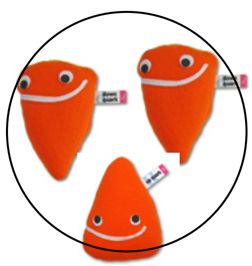
$$f(z) \propto z^{-1}(1-z)^{a} \cdot \exp\left(\frac{-bm_{\perp}^{2}}{z}\right)$$

tunnelling probability

"transverse mass"

$$m_{\perp}^{2} = m^{2} + p_{x}^{2} + p_{y}^{2}$$

Neutron



down-quark

down-quark

up-quark

time

Sjostrand, Lonnblad, and Mrenna, hep-ph/0108264
http://particlezoo.net/

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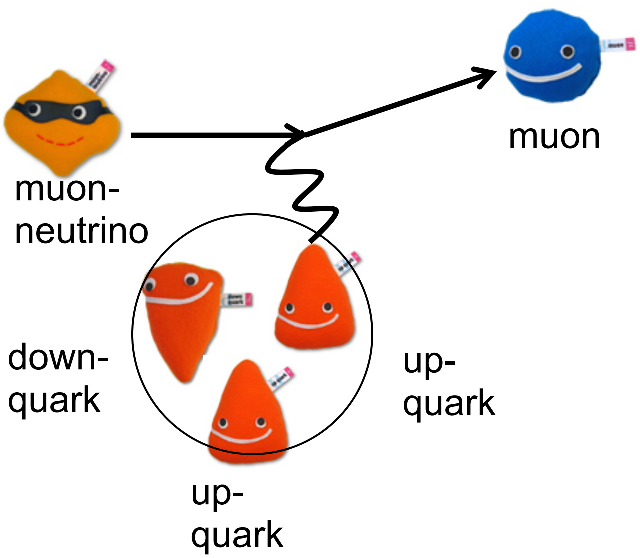

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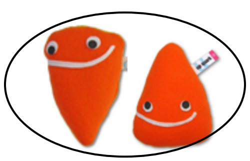
quark

di-quark



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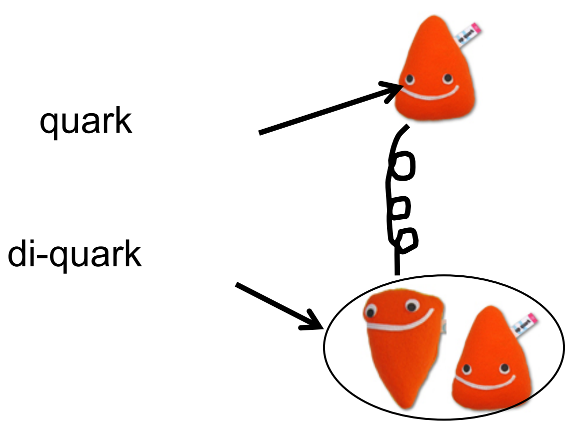
Linear confinement

- colour flux to minimize surface area

→ string

~1GeV/fm



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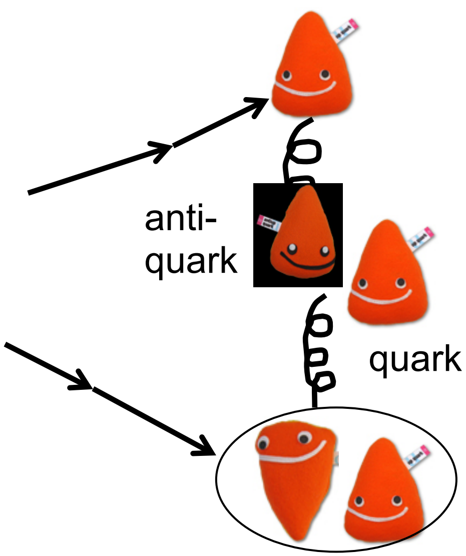

Linear confinement

- colour flux to minimize surface area → string

String breaking

- quantum tunnelling
- enough energy to produce a q-qbar pair

$$u-\bar{u} : d-\bar{d} : s-\bar{s} : c-\bar{c} = 1:1:0.3:10^{-11}$$

time

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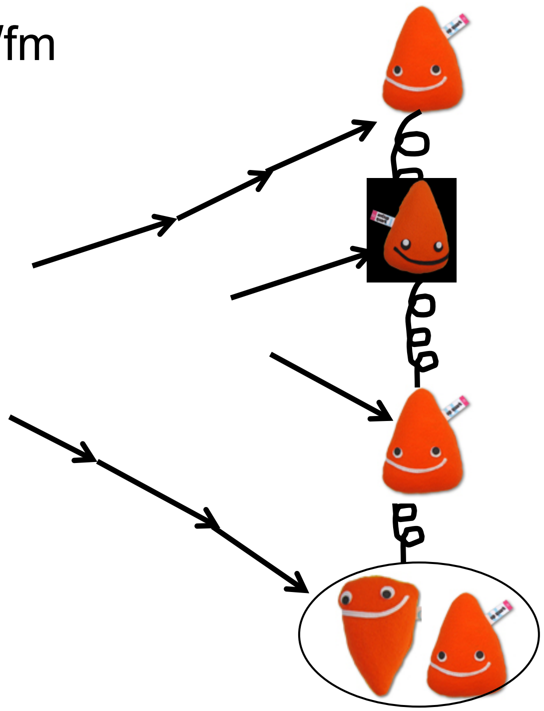

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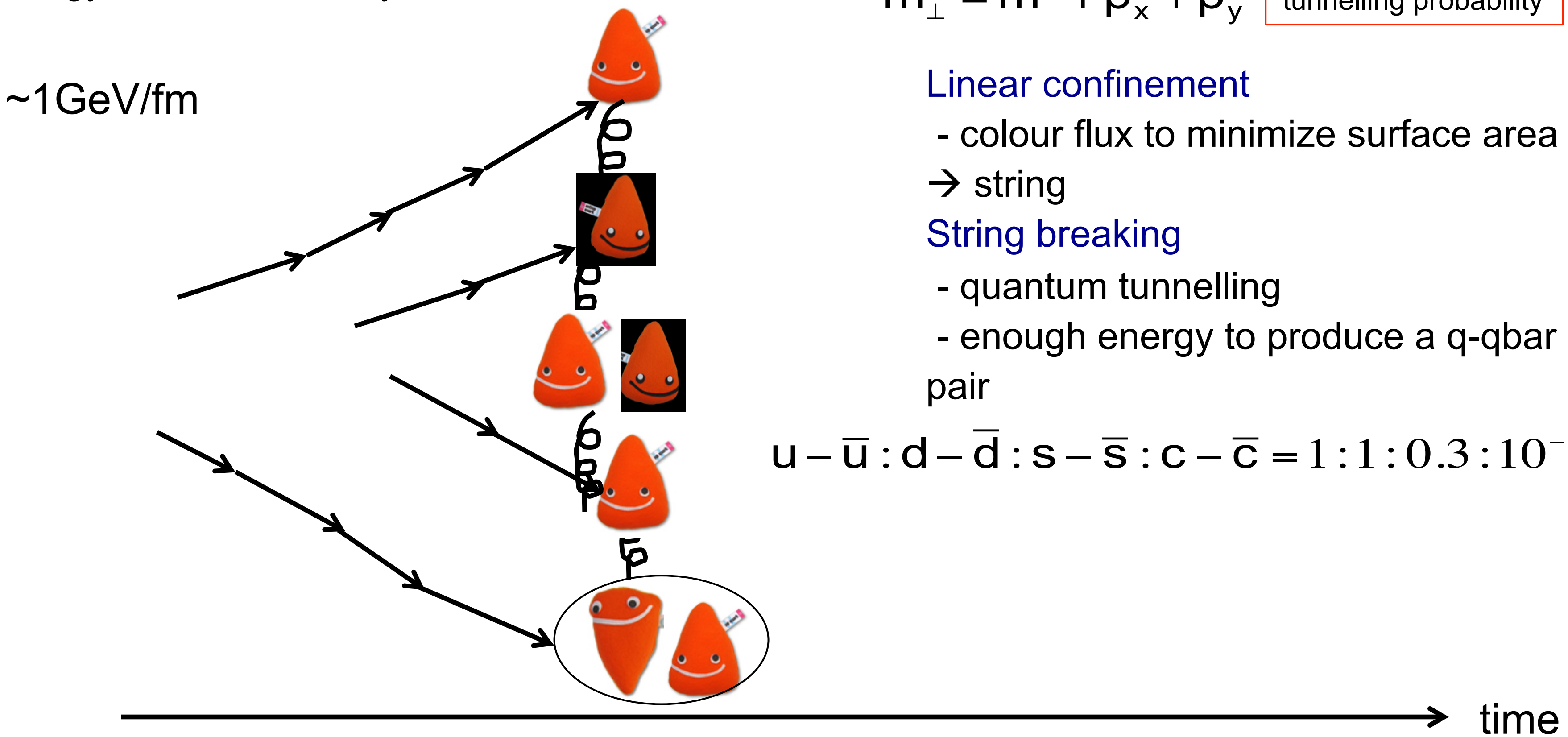

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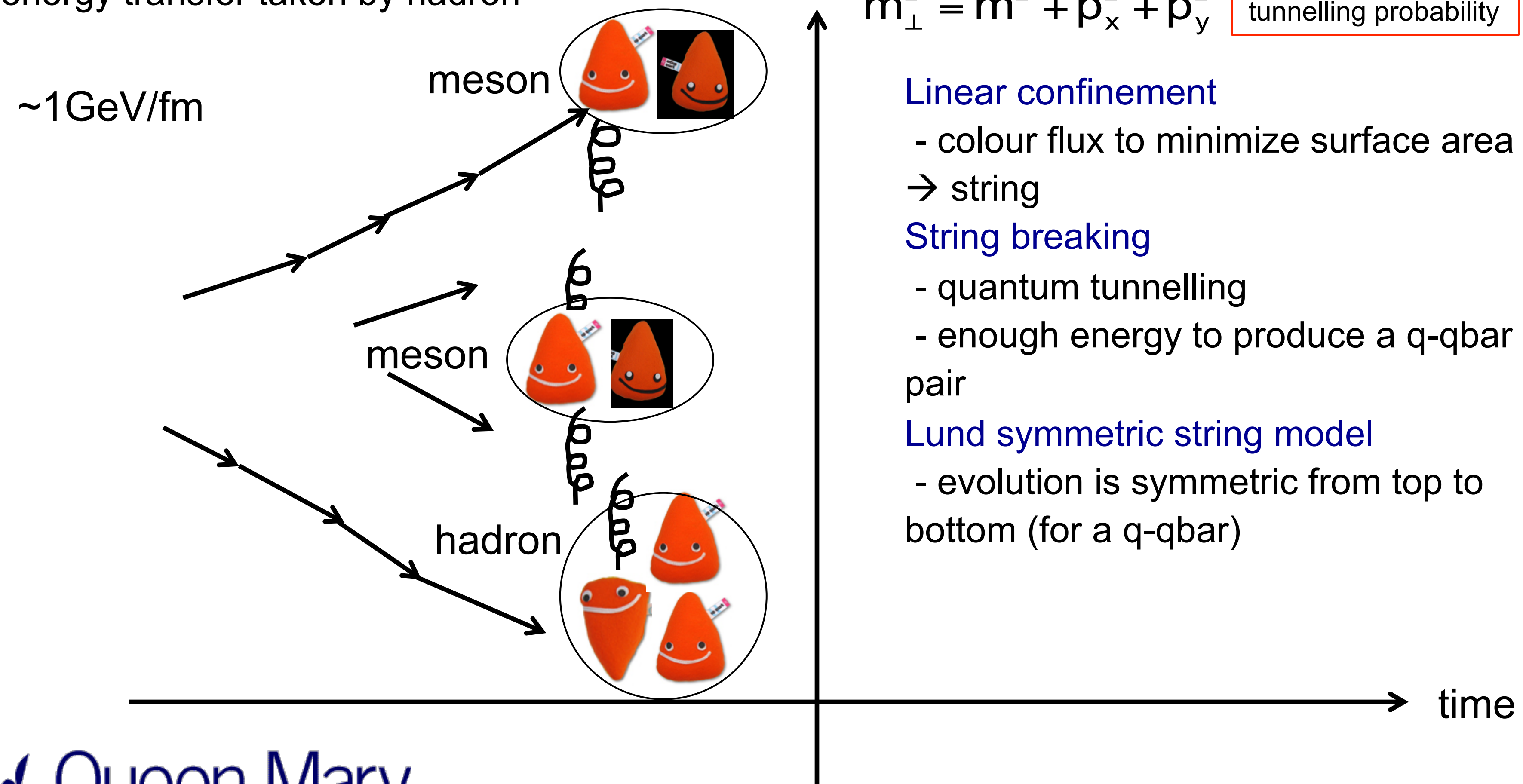

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Lund symmetric string model

- evolution is symmetric from top to bottom (for a q-qbar)

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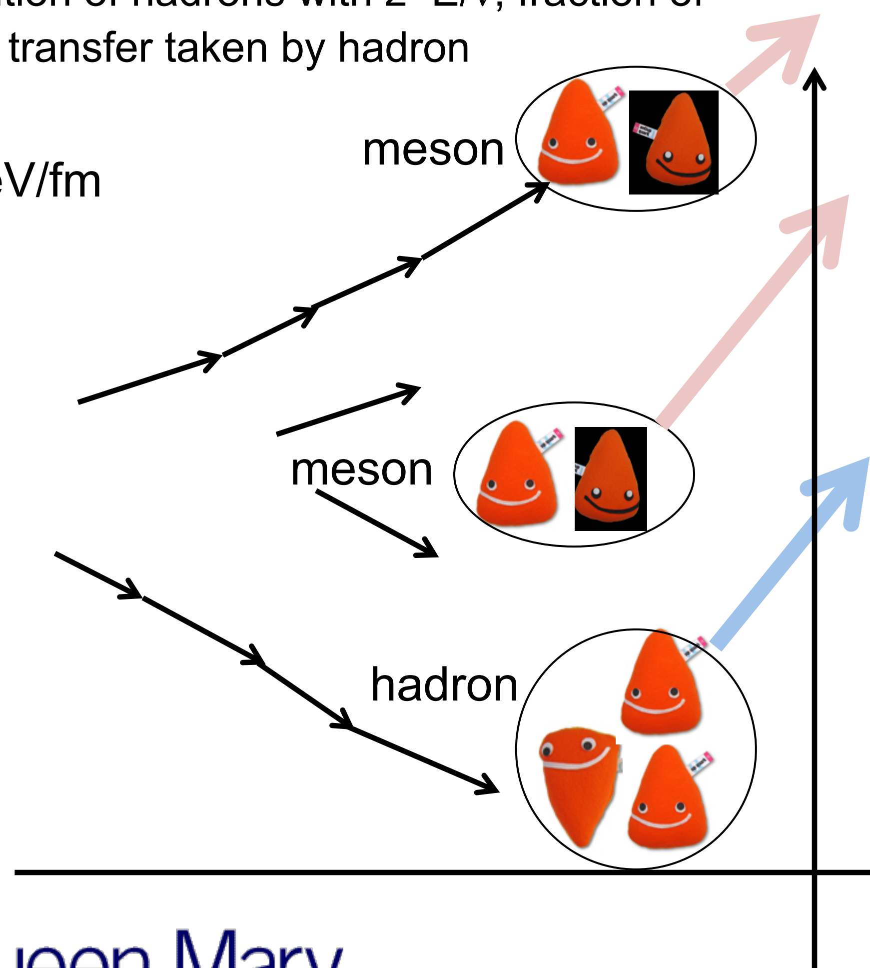

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4 vectors of hadrons are produced

time

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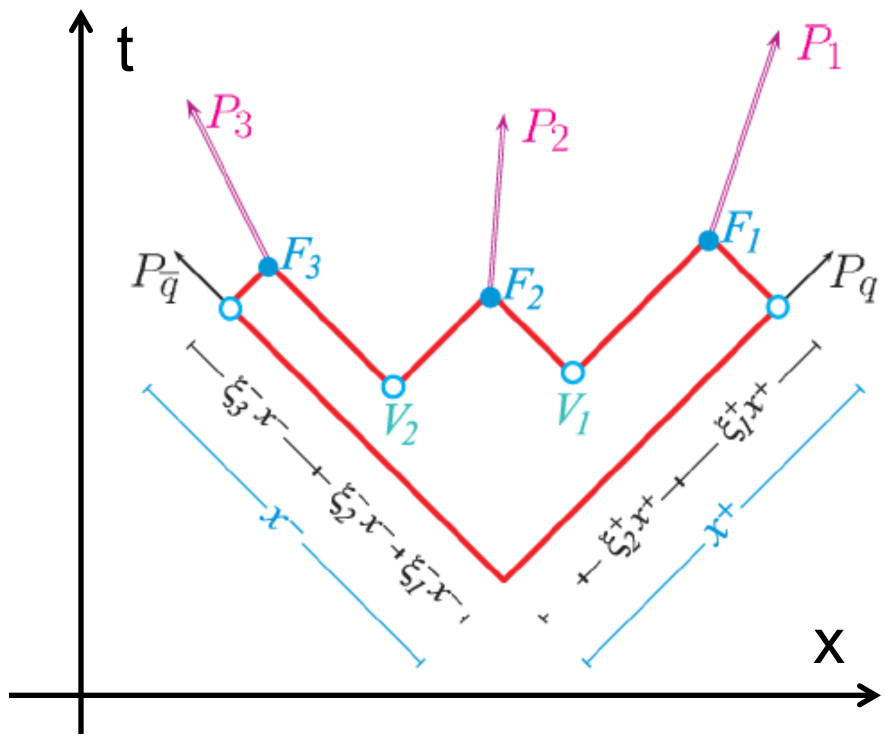
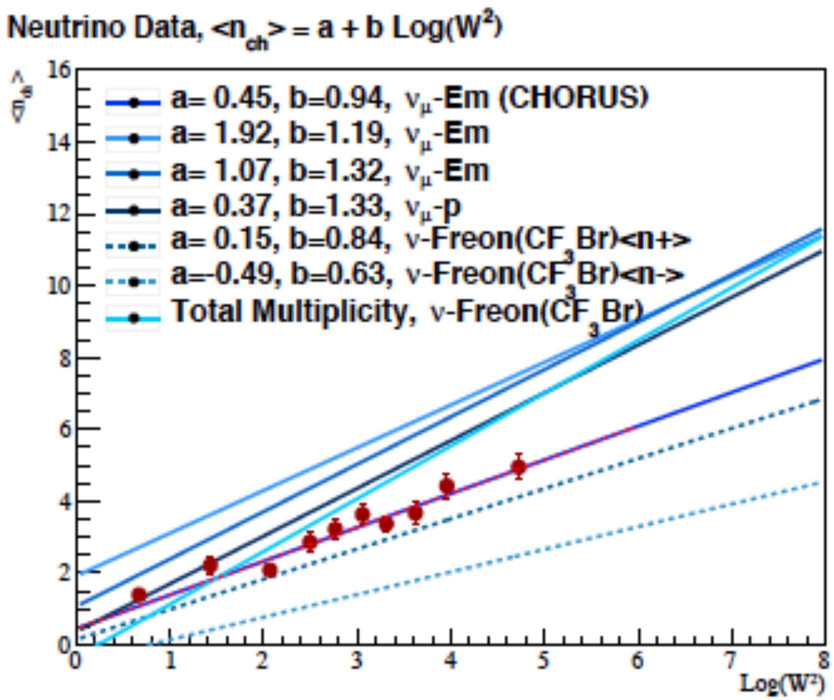
Sketch of fragmentation from q-$\bar{q}$ string breaking



2. Hadronization model

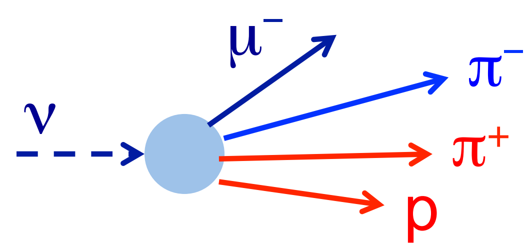
Averaged charged hadron multiplicity <n_{ch}>

- Parameters extracted from data are used to model hadronization process
- The bubble chamber data are not consistent consistent



Averaged charged hadron multiplicity

$$< n_{ch} >= a + bLog(W^2)$$

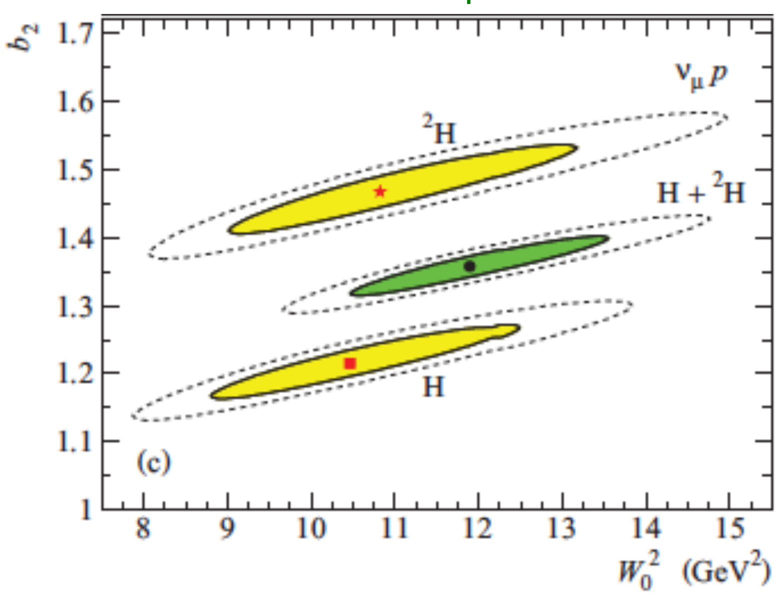


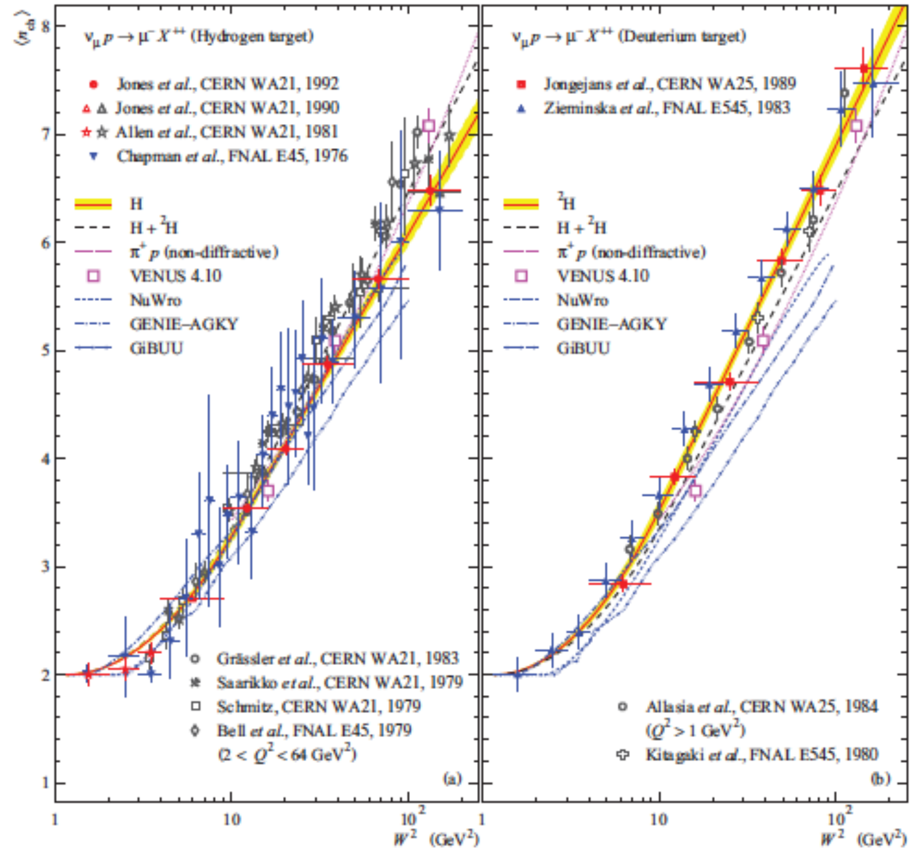
2. Hadronization model

Kuzmin-Naumov fit

- They systematically analysed all bubble chamber data
  - Difference of hydrogen and deuterium data
  - Presence of kinematic cuts
  - Better parameterization

Kuzmin-Naumov parameters





Average charged hadron multiplicity with function of W^2

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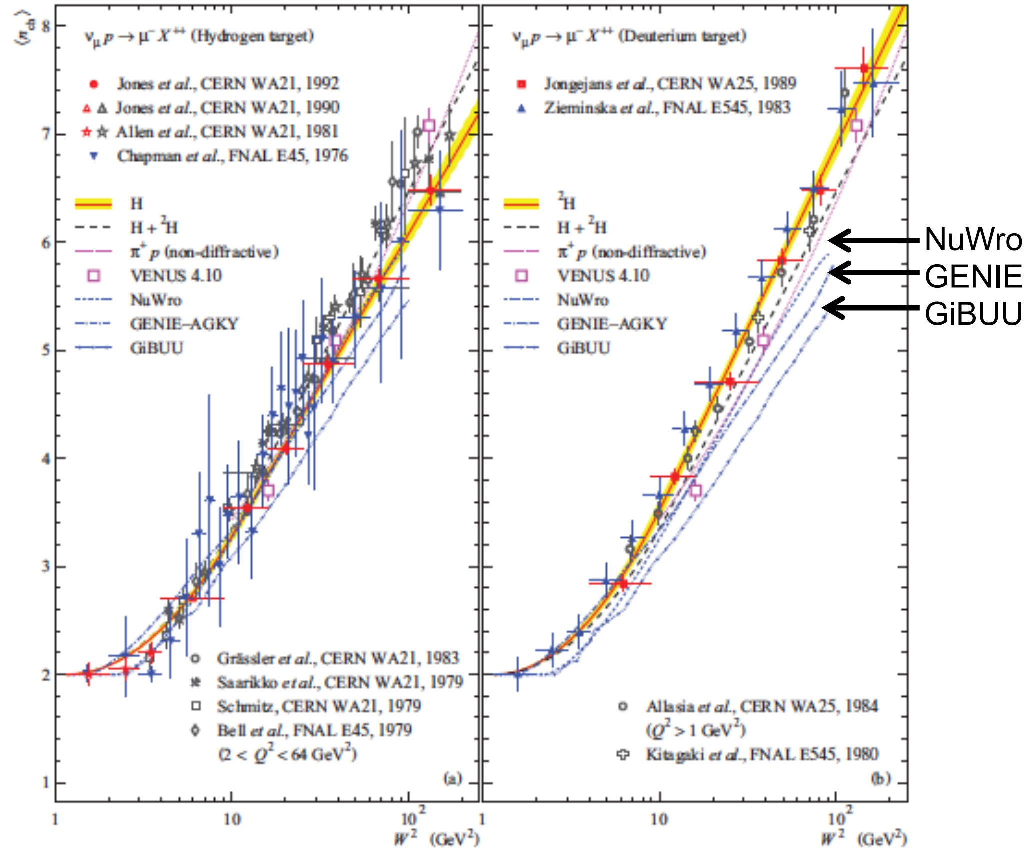
All PYTHIA-based models underestimate averaged charged hadron multiplicity data (GiBUU, GENIE, NuWro)



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Kuzmin and Naumov, PRC88(2013)065501
Connolly, PhD thesis (U-Washington, Seattle, 2014)

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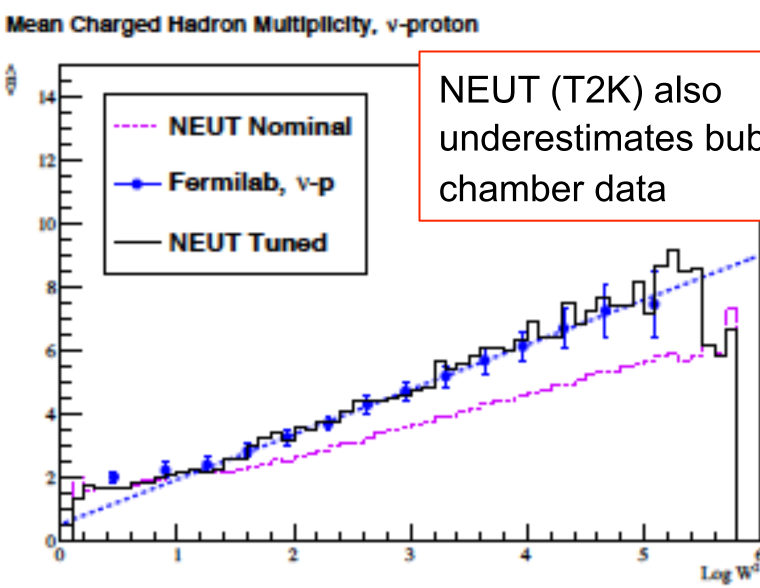
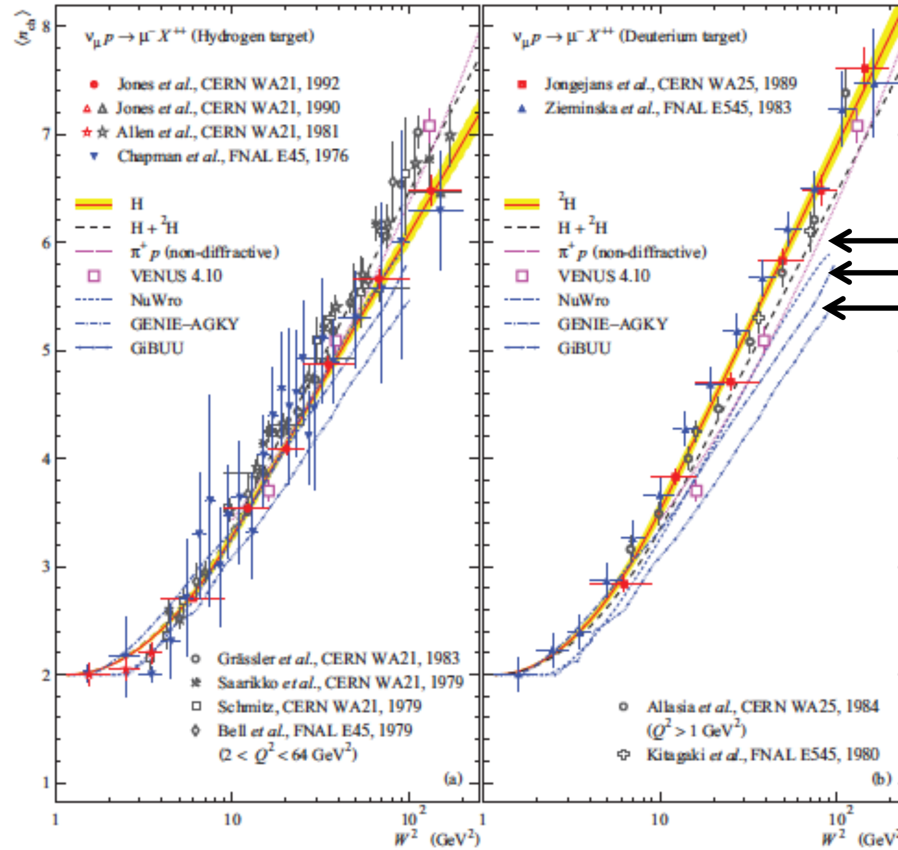


NEUT (T2K) also underestimates bubble chamber data



NuWro
GENIE
GiBUU

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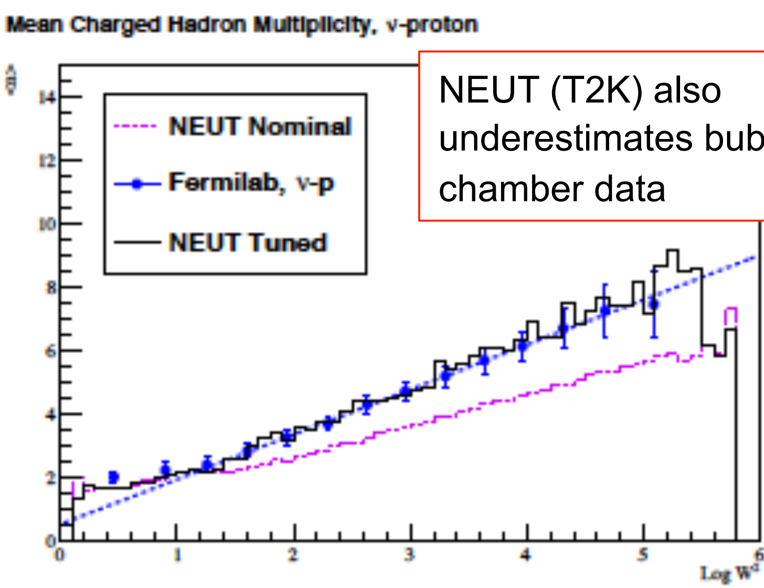

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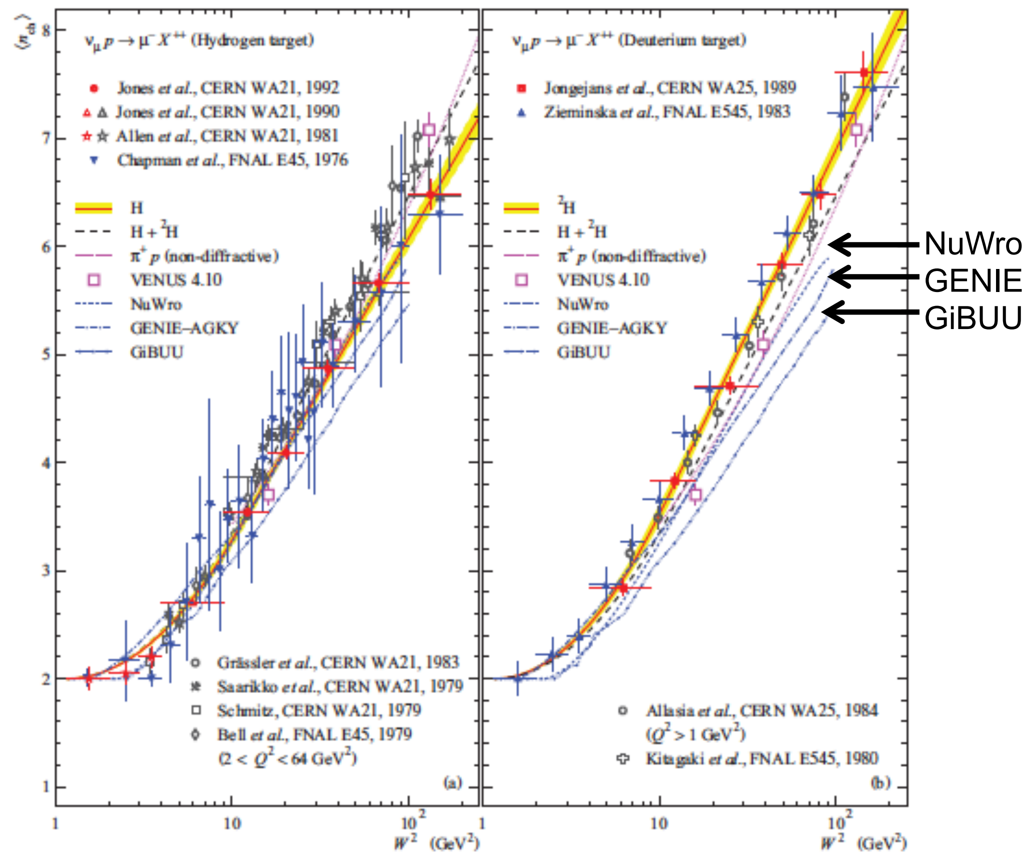

Average charged hadron multiplicity with function of W^2

PYTHIA fragmentation based models tend to underestimate neutrino data.

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3. PYTHIA tuning for neutrino experiments
4. PYTHIA8 for neutrino experiments
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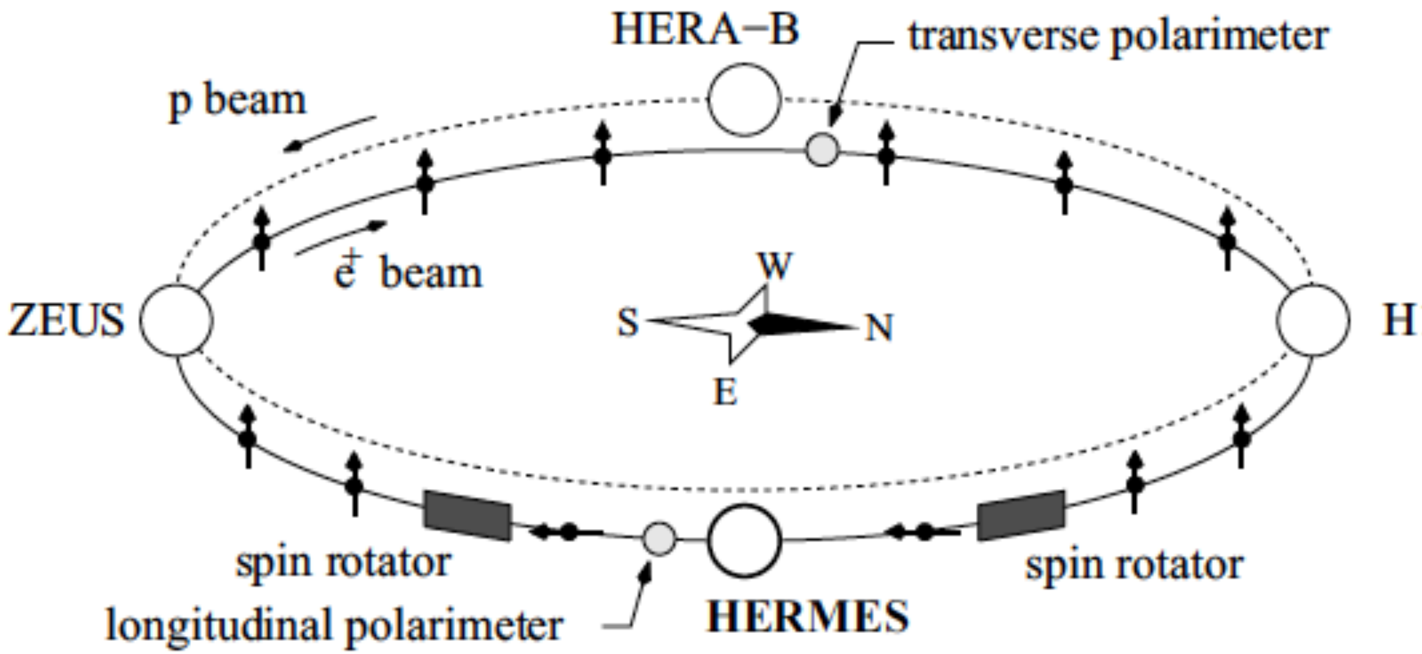
3. HERMES

Fixed target e-scattering experiment at HERA
- E=27.6 GeV
- Gas jet target (H, D, etc)
- Data taking 1995 - 2007



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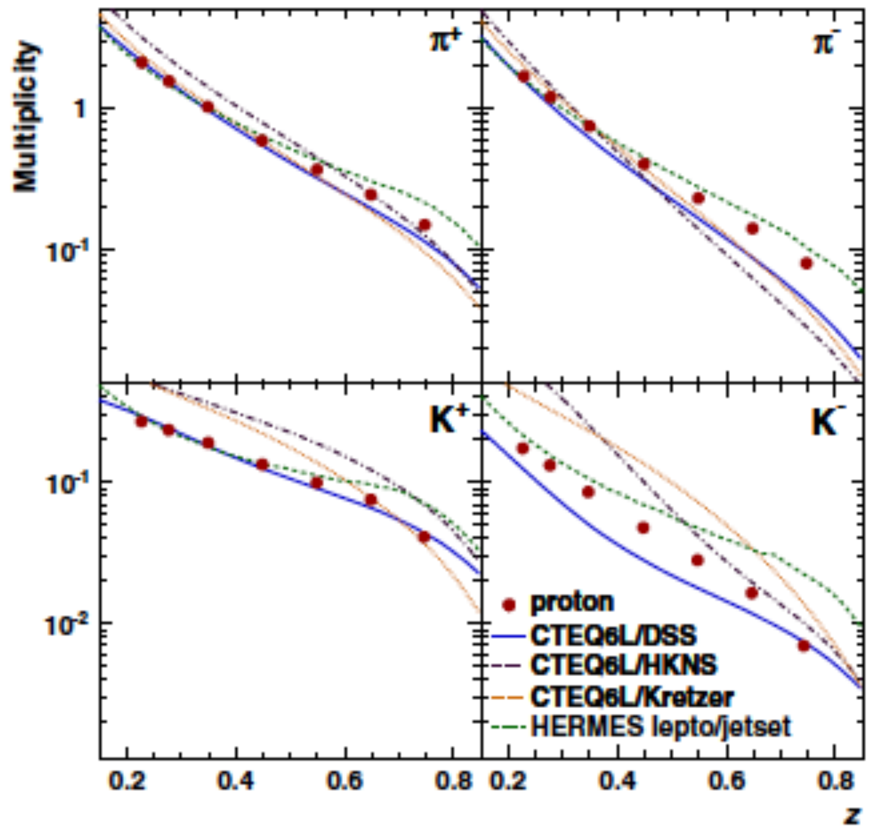
PHYSICAL REVIEW D 87, 074029 (2013)



Rubin, PhD thesis (UIUC, 2009)

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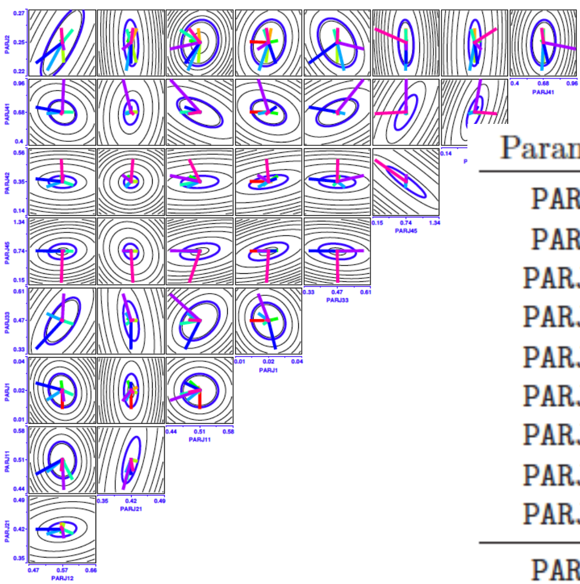
We picked one of the latest parameter set (called “Lund-scan”) and try in GENIE hadronization tool to compare with bubble chamber data



Parameter	$\Delta q(x)$ paper	2004c	“Lund-scan”	Parameter Description
PARJ1	0.02	0.029	0.02	Diquark suppression
PARJ2	0.20	0.283	0.25	Strange quark suppression
PARJ11	0.5*	0.5*	0.51	Vector meson suppression (light mesons)
PARJ12	0.6*	0.6*	0.57	Vector meson suppression (strange mesons)
PARJ21	0.37	0.38	0.42	Width of Gaussian $p_{h\perp}$ distribution [GeV]
PARJ33	0.8	0.8	0.47	String breaking mass cutoff
PARJ41	1.74	1.94	0.68	Lund-String “a” parameter
PARJ42	0.23	0.544	0.35	Lund-String “b” parameter
PARJ45	0.5*	1.05	0.74	“a” adjustment for diquark
PARL3	0.44	0.44	(0.44)	Gaussian width of intrinsic k_T [GeV]
PARJ23	0.03	0.01	(0.01)	Fraction of $p_{h\perp}$ distribution to have additional non-Gaussian tails
PARJ24	2.50	2.0	(2.0)	Strength of non-Gaussian $p_{h\perp}$ tails

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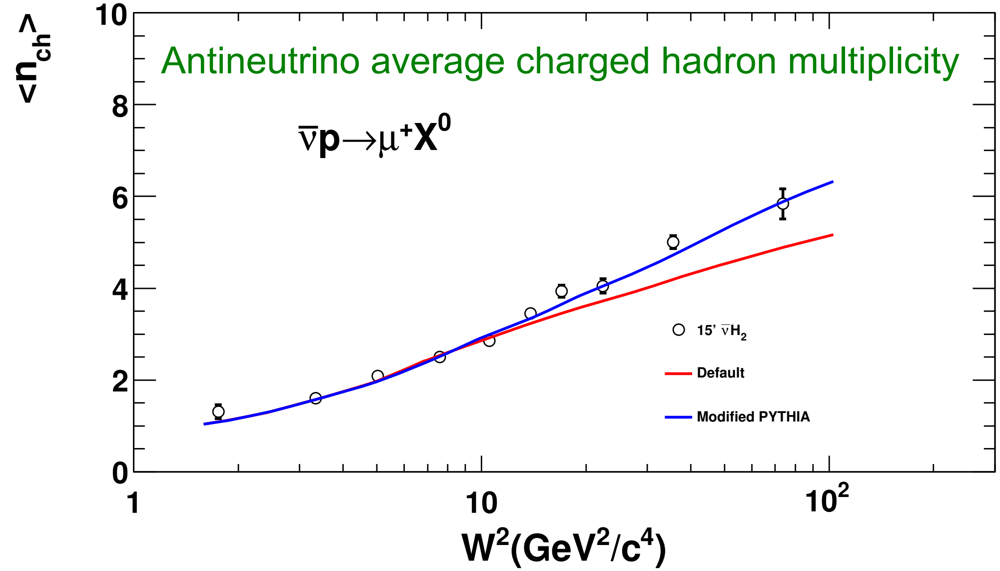
TK and Mandalia, JPhysG42(2015)115004

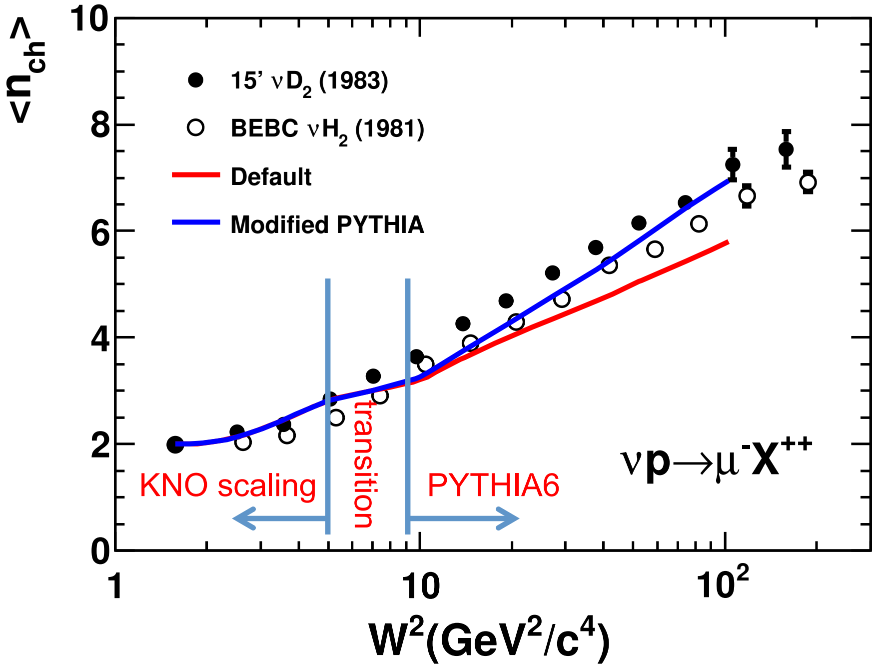
Red: PYTHIA default
Blue: HERMIES PYTHIA

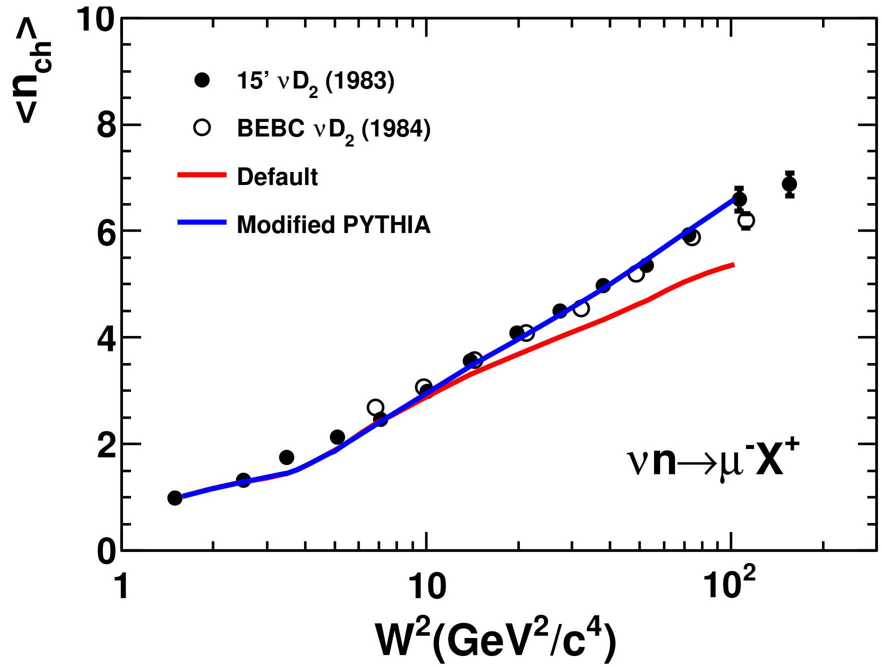
3. HERMES tuned PYTHIA6

Averaged charged hadron multiplicity $\langle n_{ch} \rangle$
- Lund-scan increases $\langle n_{ch} \rangle$ (→ better agreement with bubble chamber data) both neutrino and antineutrino.



Neutrino average charged hadron multiplicity





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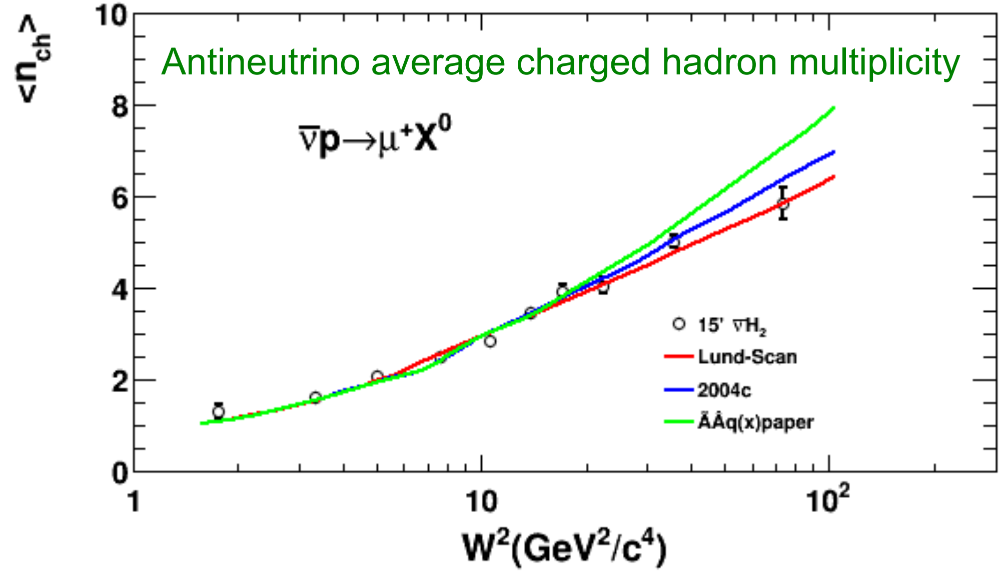
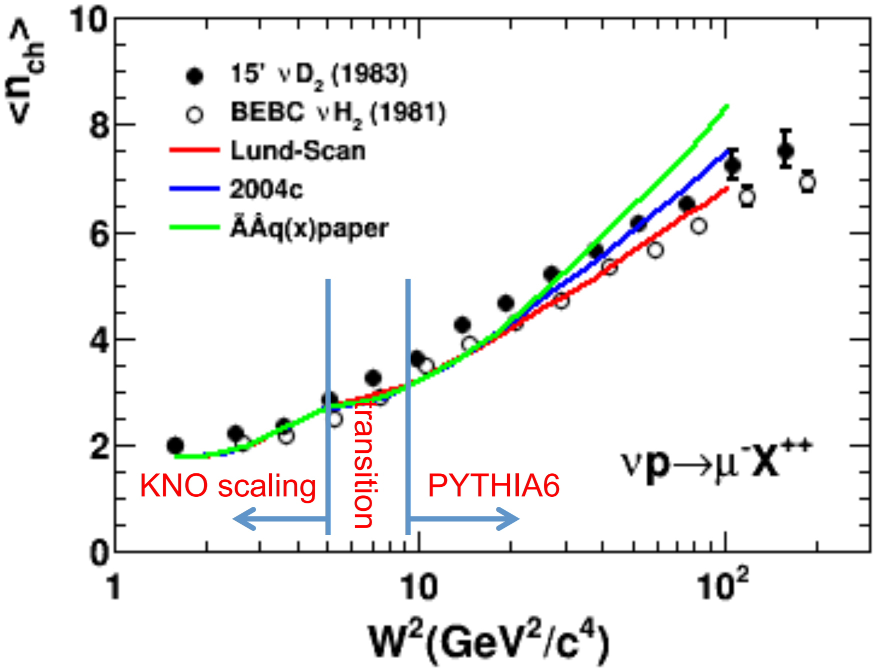
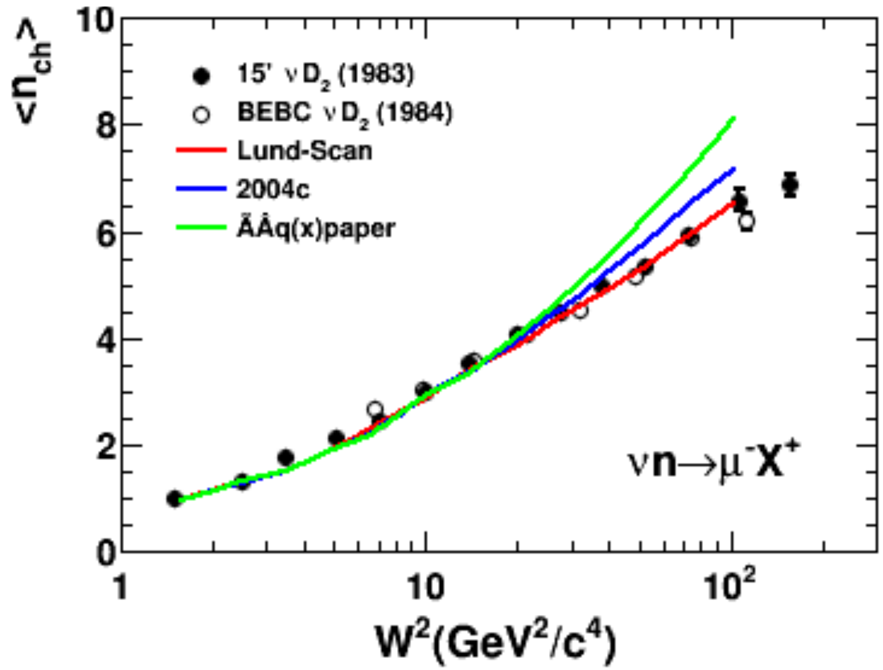
Red: HERMIES PYTHIA (Lund scan)
Blue: HERMES 2004c tuning
Green: HERMES $\Delta q(x)$ paper



Neutrino average charged hadron multiplicity





3. HERMES tuned PYTHIA6

PARJ41 = Lund "a" parameter
PARJ42 = Lund "b" parameter

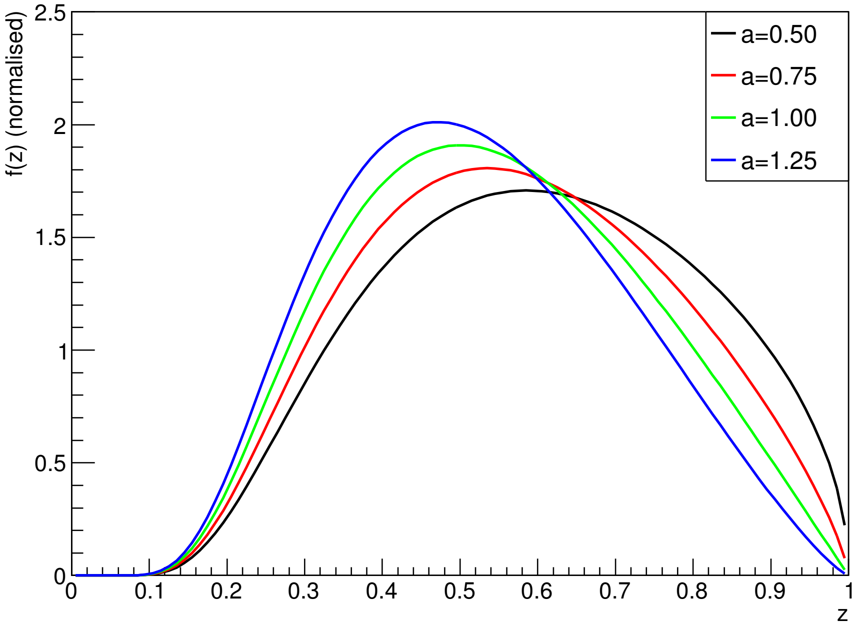
Charged Lund symmetric fragmentation function

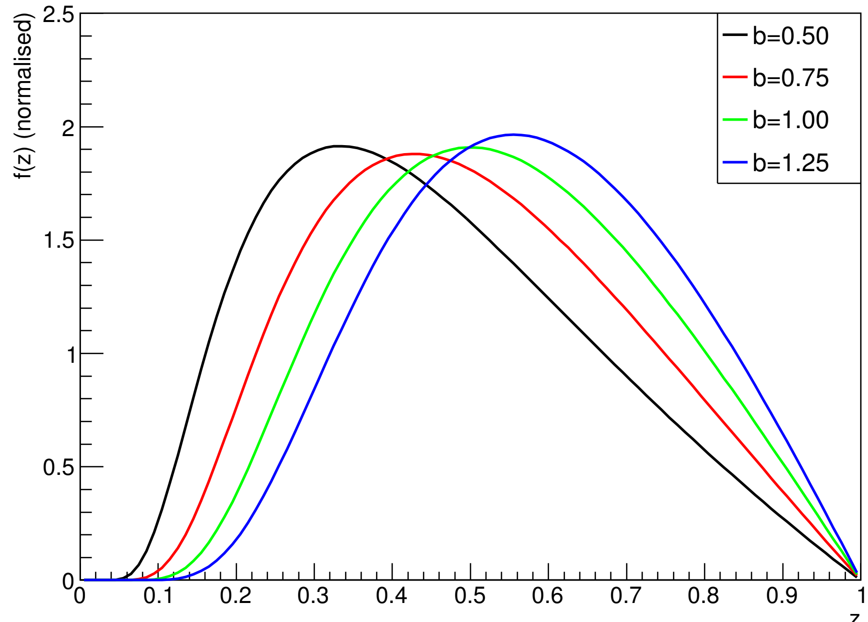
- Neutrino data prefer large "a" and small "b"
- These choices shift Lund function to lower z
- This enhances lower E hadron production

$$f(z) \propto z^{-1}(1-z)^a \cdot exp\left(\frac{-bm_\perp^2}{z}\right)$$

Parameter	PYTHIA	GENIE	Lund-scan	$\Delta q(x)$	2004c
PARJ1	0.10		0.02		0.029
PARJ2	0.30	0.21	0.25	0.20	0.283
PARJ11	0.50		0.51		
PARJ12	0.60		0.57		
PARJ21	0.36	0.44	0.42	0.37	0.38
PARJ23	0.01			0.03	
PARJ33	0.80	0.20	0.47		
PARJ41	0.30		0.68	1.74	1.94
PARJ42	0.58		0.35	0.23	0.544
PARJ45	0.50		0.74		1.05

Lund symmetric function with "a" and "b" parameter variations



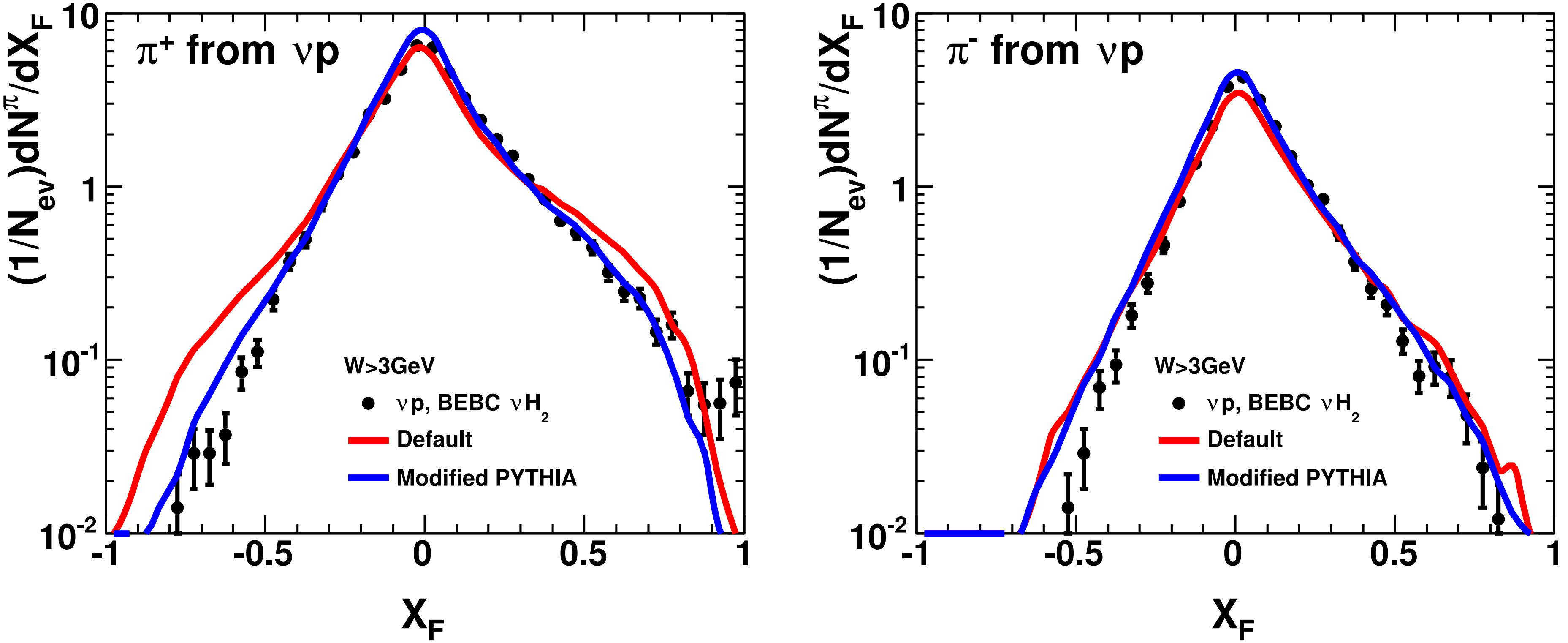


Red: PYTHIA default
Blue: HERMIES PYTHIA

3. HERMES tuned PYTHIA6

Charged hadron x_F distribution
- HERMES parameters also improve x_F distribution

x_F distribution for π^+ and π^-



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3. HERMES tuned PYTHIA6

Summary of hadronization tuning

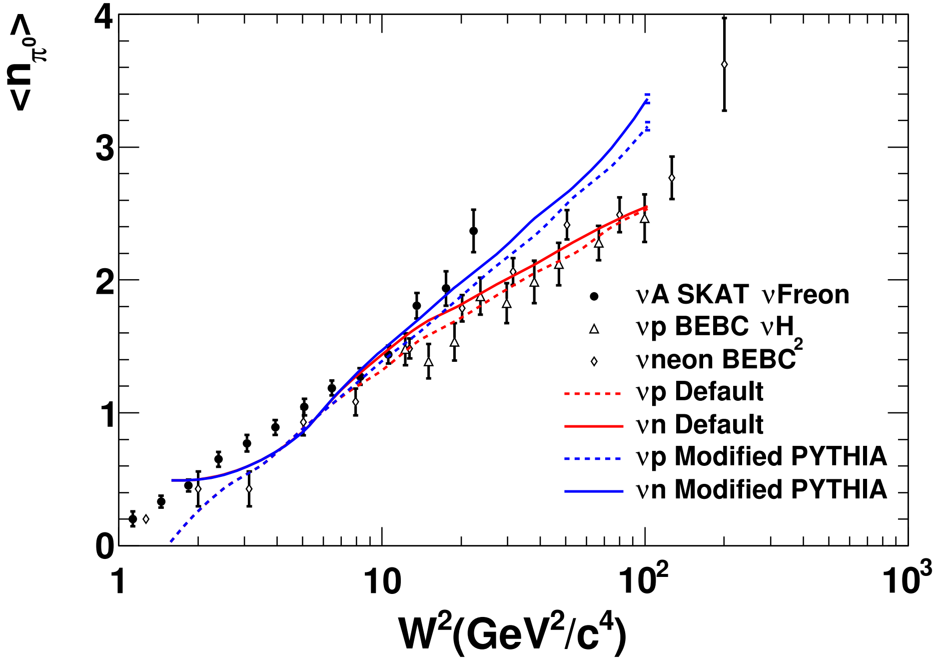
In general, HERMES parameter set improves all charged hadron distributions.

We also find some difficulties

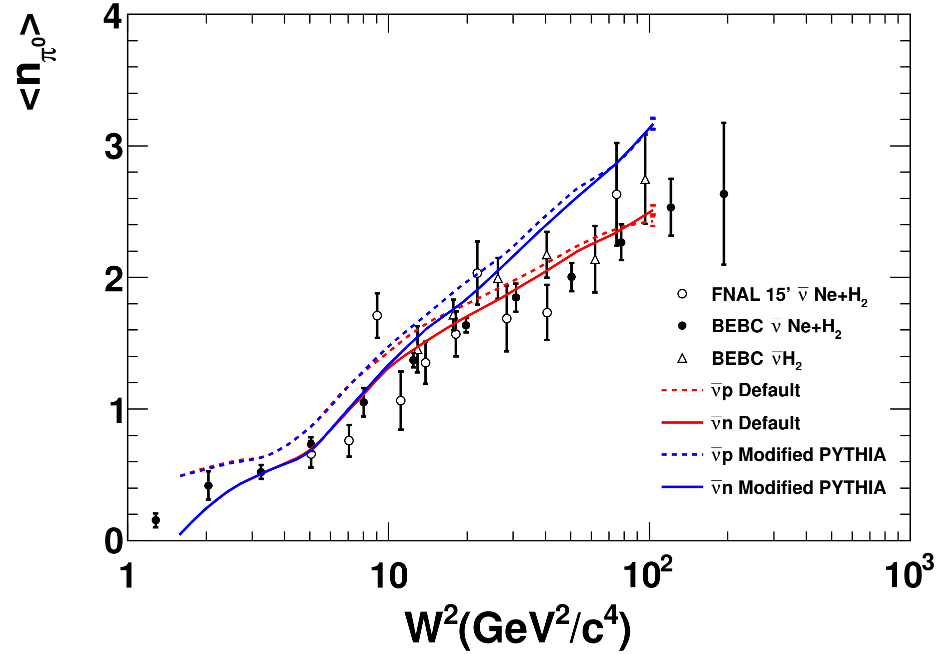
- neutral hadron distribution
- dispersion of hadrons

Averaged π^o multiplicity is tied with average charged pion multiplicity by isospin symmetry (1:2). Increase of averaged charged hadron multiplicity by PYTHIA tuning

Neutrino average π^o multiplicity



Antineutrino average π^o multiplicity



TK and Mandalia,JPhysG42(2015)115004
Joosten, PhD thesis (UIUC, 2013)

3. HERMES tuned PYTHIA6

Red: PYTHIA default
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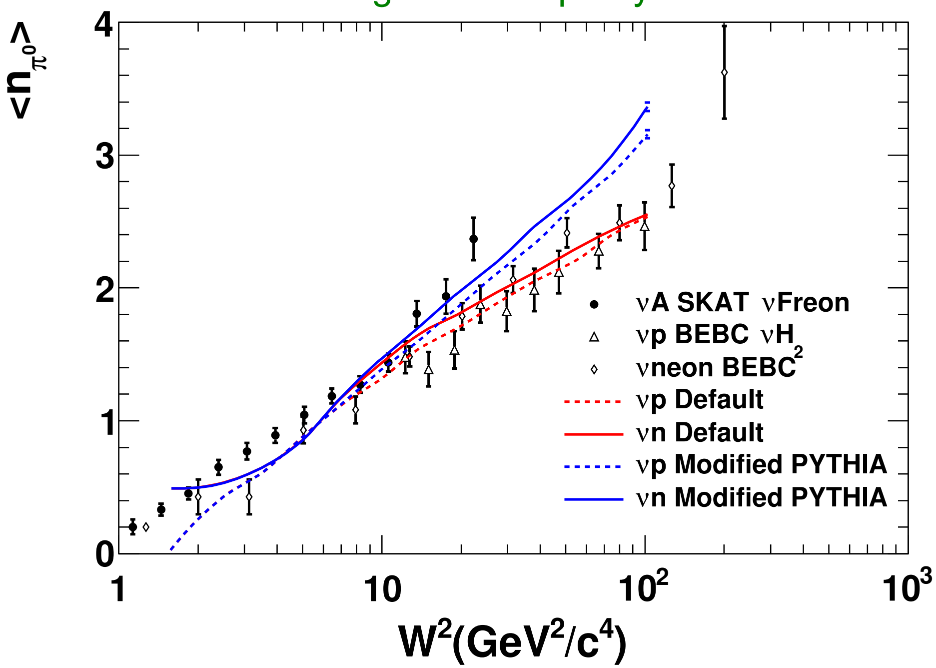
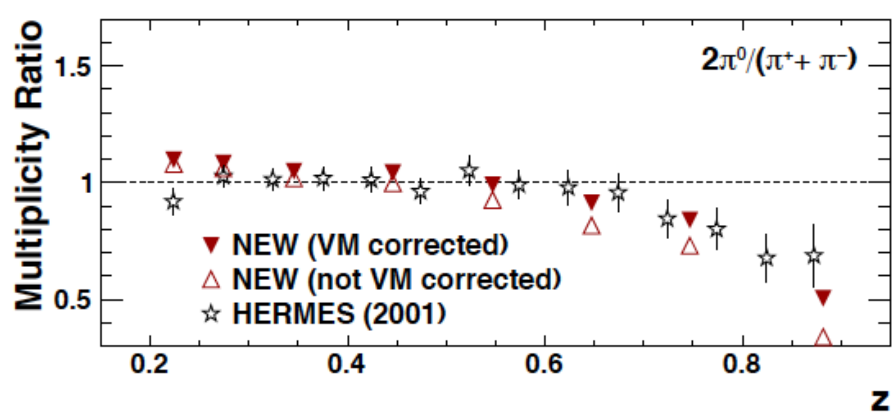


HERMES hadron multiplicity ratio



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Summary of hadronization tuning

In general, HERMES parameter set improves all charged hadron distributions.

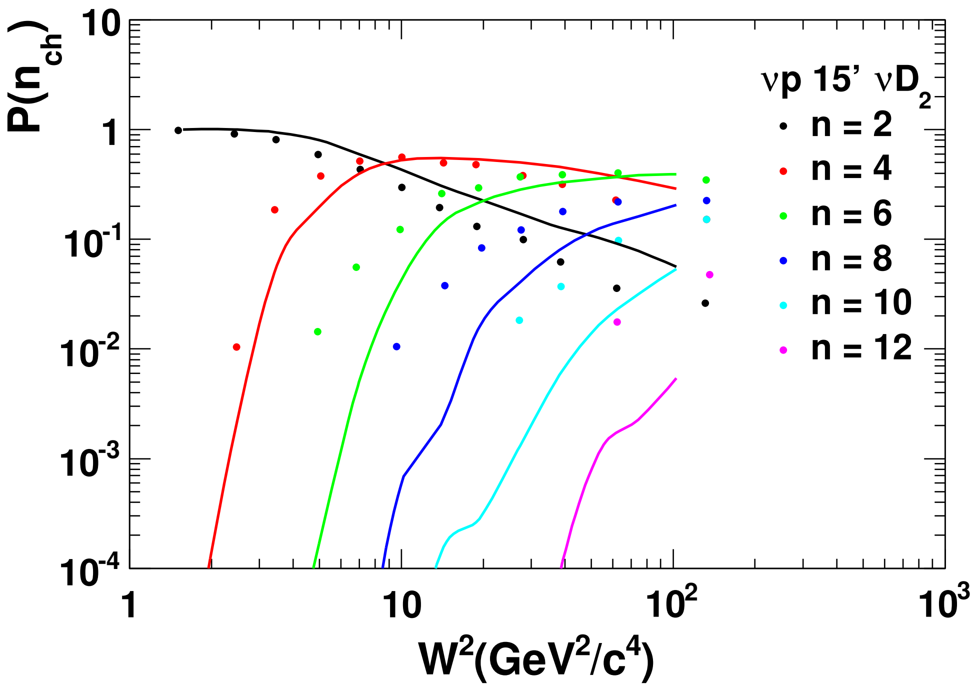
We also find some difficulties
- neutral hadron distribution
- dispersion of hadrons

Although tuned PYTHIA can reproduce averaged hadron multiplicity, hadron multiplicity dispersion predicted by PYTHIA is not easy to control, and we have trouble to reproduce large hadron multiplicity.

This is a problem since next generation neutrino experiments will measure hadron multiplicity event-by-event.

Further tuning is ongoing.

Neutrino topological cross section by PYTHIA6



1. Introduction
2. Lund string fragmentation model
3. PYTHIA tuning for neutrino experiments
4. PYTHIA8 for neutrino experiments
5. Conclusion

4. PYTHIA8 tuning for LHC

Monash 2013 tune

- a standard(?) tuning of PYTHIA8

Table 3 Final-state radiation (FSR) parameters

FSR parameters	Monash 13	(Default)	Comment
TimeShower:alphaSvalue	= 0.1365	= 0.1383	! Effective alphaS(mZ) value
TimeShower:alphaSorder	= 1	= 1	! Running order
TimeShower:alphaSuseCMW	= off	= off	! Translation from $\overline{\text{MS}}$ to CMW
TimeShower:pTmin	= 0.50	= 0.40	! Cutoff for QCD radiation
TimeShower:pTminChgQ	= 0.50	= 0.40	! Cutoff for QED radiation
TimeShower:phiPolAsym	= on	= on	! Asymmetric azimuth distributions

Table 4 String-breaking parameters

HAD parameters	Monash 13	(Default)	Comment
# String breaks: pT and z distributions			
StringPT:sigma	= 0.335	= 0.304	! Soft pT in string breaks (in GeV)
StringPT:enhancedFraction	= 0.01	= 0.01	! Fraction of breakups with enhanced pT
StringPT:enhancedWidth	= 2.0	= 2.0	! Enhancement factor
StringZ:aLund	= 0.68	= 0.3	! Lund FF a (hard fragmentation supp)
StringZ:bLund	= 0.98	= 0.8	! Lund FF b (soft fragmentation supp)
StringZ:aExtraSquark	= 0.0	= 0.0	! Extra a when picking up an s quark
StringZ:aExtraDiquark	= 0.97	= 0.50	! Extra a when picking up a diquark
StringZ:rFactC	= 1.32	= 1.00	! Lund-Bowler c-quark parameter
StringZ:rFactB	= 0.855	= 0.67	! Lund-Bowler b-quark parameter
# Flavour composition: mesons			
StringFlav:ProbStoUD	= 0.217	= 0.19	! Strangeness-to-UD ratio
StringFlav:mesonUDvector	= 0.5	= 0.62	! Light-flavour vector suppression
StringFlav:mesonSvector	= 0.55	= 0.725	! Strange vector suppression
StringFlav:mesonCvector	= 0.88	= 1.06	! Charm vector suppression
StringFlav:mesonBvector	= 2.2	= 3.0	! Bottom vector suppression
StringFlav:etaSup	= 0.60	= 0.63	! Suppression of eta mesons
StringFlav:etaPrimeSup	= 0.12	= 0.12	! Suppression of eta' mesons
# Flavour composition: baryons			
StringFlav:probQQtoQ	= 0.081	= 0.09	! Diquark rate (for baryon production)
StringFlav:probSQtoQQ	= 0.915	= 1.000	! Strange-diquark suppression
StringFlav:probQQ1toQQ0	= 0.0275	= 0.027	! Vector diquark suppression
StringFlav:decupletSup	= 1.0	= 1.0	! Spin-3/2 baryon suppression
StringFlav:suppressLeadingB	= off	= off	! Optional leading-baryon suppression
StringFlav:popcornSpair	= 0.9	= 0.5	!
StringFlav:popcornSmeson	= 0.5	= 0.5	!

Table 5 Parton-distribution (PDF) and matrix-element (ME) parameters

PDF and ME parameters	Monash 13	(Default)	Comment
PDF:pSet	= 13	= 8	! PDF set for the proton
SigmaProcess:alphaSvalue	= 0.130	0.135	! alphaS(MZ) for matrix elements
MultiPartonInteractions:alphaSvalue	= 0.130	0.135	! alphaS(MZ) for MPI

Table 6 Initial-state radiation (ISR) and primordial-k_T parameters

ISR parameters	Monash 13	(Default)	Comment
SpaceShower:alphaSvalue	= 0.1365	= 0.137	! Effective alphaS(mZ) value
SpaceShower:alphaSorder	= 1	= 1	! Running order
SpaceShower:alphaSuseCMW	= off	= off	! Translation from $\overline{\text{MS}}$ to CMW
SpaceShower:samePTasMPI	= off	= off	! ISR cutoff type
SpaceShower:pT0Ref	= 2.0	= 2.0	! ISR pT0 cutoff
SpaceShower:ecmRef	= 7000.0	= 1800.0	! ISR pT0 reference ECM scale
SpaceShower:ecmPow	= 0.0	= 0.0	! ISR pT0 scaling power
SpaceShower:rapidityOrder	= on	= on	! Approx coherence via y-ordering
SpaceShower:phiPolAsym	= on	= on	! Azimuth asymmetries from gluon pol
SpaceShower:phiIntAsym	= on	= on	! Azimuth asymmetries from interference
TimeShower:dampenBeamRecoil	= on	= on	! Recoil dampening in final-initial dipoles
BeamRemnants:primordialKTsoft	= 0.9	= 0.5	! Primordial kT for soft procs
BeamRemnants:primordialKThard	= 1.8	= 2.0	! Primordial kT for hard procs
BeamRemnants:halfScaleForKT	= 1.5	= 1.0	! Primordial kT soft/hard boundary
BeamRemnants:halfMassForKT	= 1.0	= 1.0	! Primordial kT soft/hard mass boundary

Table 7 Multi-parton-interaction (MPI), colour-reconnection (CR), and diffractive parameters

MPI parameters	Monash 13	(Default)	Comment
MultipartonInteractions:pT0Ref	= 2.28	= 2.085	! MPI pT0 IR regularization scale
MultipartonInteractions:ecmRef	= 7000.0	= 1800.0	! MPI pT0 reference ECM scale
MultipartonInteractions:ecmPow	= 0.215	= 0.19	! MPI pT0 scaling power
MultipartonInteractions:bProfile	= 3	= 3	! Transverse matter overlap profile
MultipartonInteractions:expPow	= 1.85	= 2.0	! Shape parameter
BeamRemnants:reconnectRange	= 1.8	= 1.5	! Colour Reconnections
SigmaTotal:zeroAXB	= on	= on	! Carried over from 4C
SigmaDiffractive:dampen	= on	= on	! Carried over from 4C
SigmaDiffractive:maxXB	= 65.0	= 65.0	! Carried over from 4C
SigmaDiffractive:maxAX	= 65.0	= 65.0	! Carried over from 4C
SigmaDiffractive:maxXX	= 65.0	= 65.0	! Carried over from 4C
Diffraction:largeMassSuppress	= 4.0	= 2.0	! High-mass diffraction suppression power

4. PYTHIA8

"We do not support PYTHIA6"
- Stephen Mrenna (Fermilab, PYTHIA author)

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Hadronization in collider physics

- Among hadronization programs (PYTHIA8, SHERPA, HERWIG++, Epos, etc…), PYTHIA8 is the standard one.
- Automated PYTHIA tuning software (RIVET, PROFESSOR)

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PYTHIA8 features

- C++ based (PYTHTIA6 is Fortran)
- More than 2 particles (quark-diquark) can initiate hadronization
- Default setting is suitable for 14TeV p-p collision (from LEP)
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- No longer support other fragmentation methods

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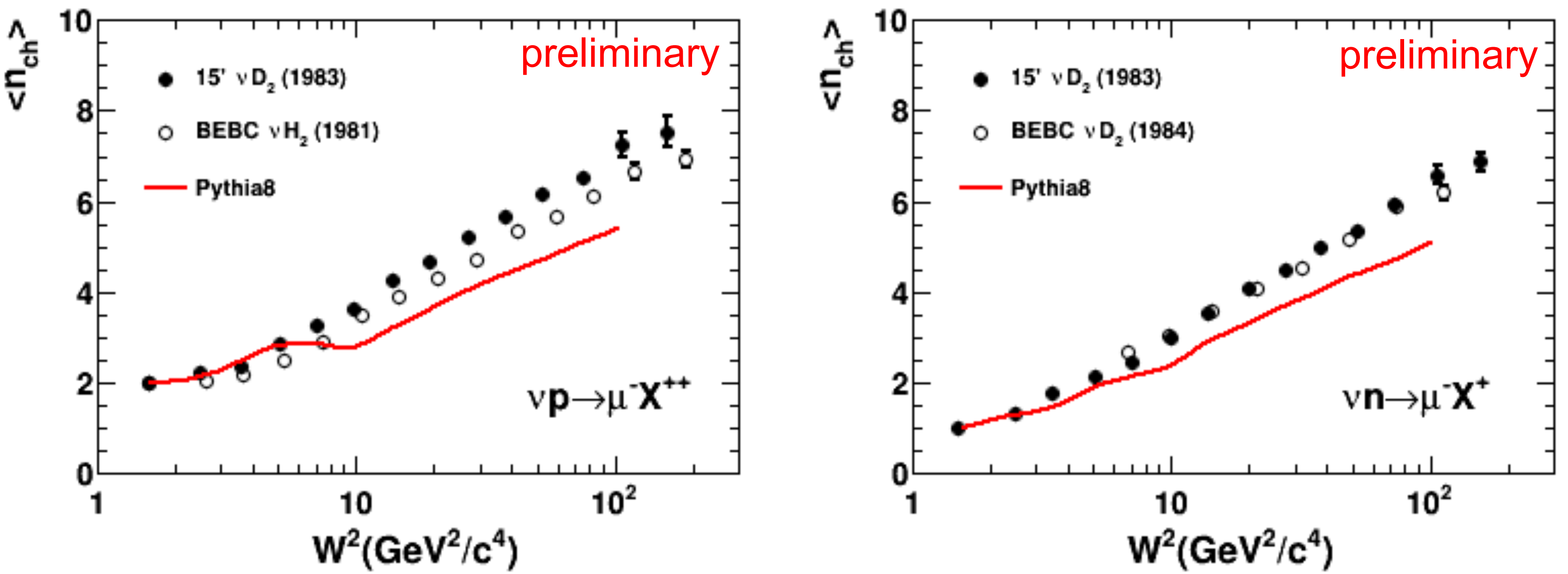
PYTHIA8-GENIE

- Implement 2 particle model (PYTHIA6 style)
- No tuning

4. PYTHIA8 in GENIE

2 particle string model in PYTHIA8 (PYTHIA6 style hadronization)
- PYTHIA8 is successfully implemented in GENIE v2.8.0
- initial test shows PYTHIA8 have harder fragmentation model (consistent with LHC energy)
- HERMES style tuning (shift fragmentation function by tuning Lund string function)

PYTHIA8-GENIE average charged hadron multiplicity



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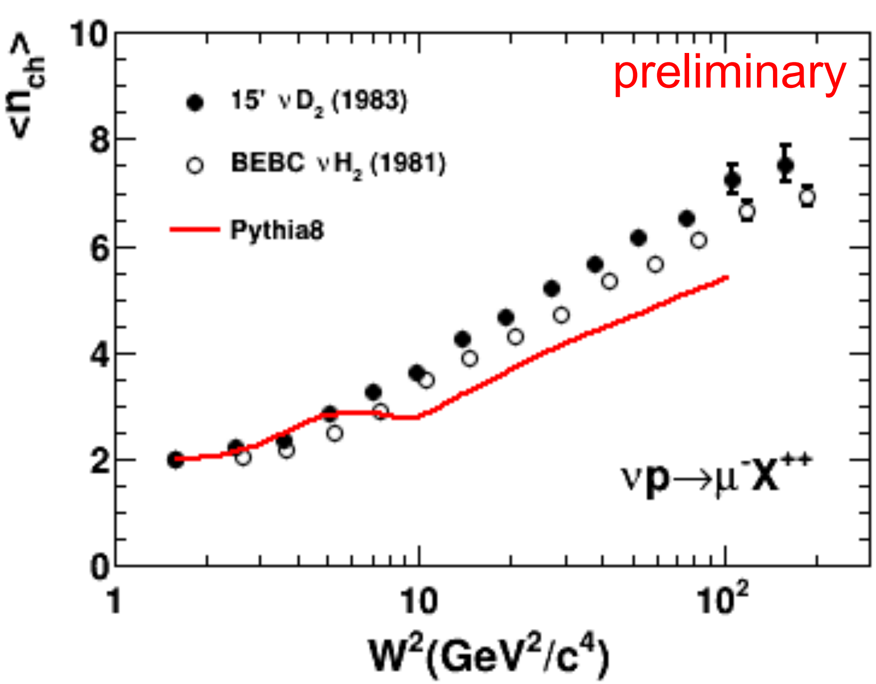

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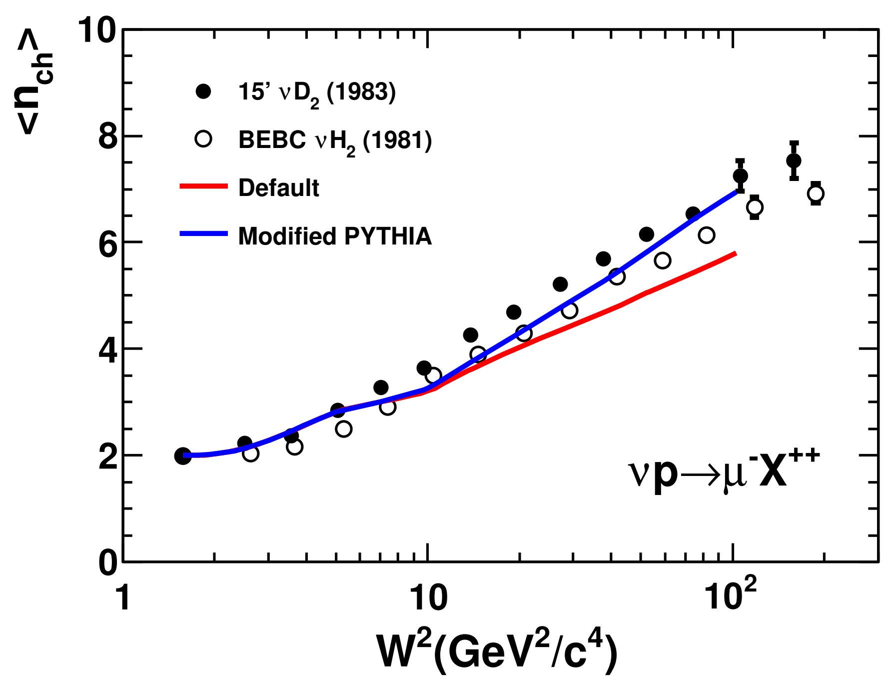

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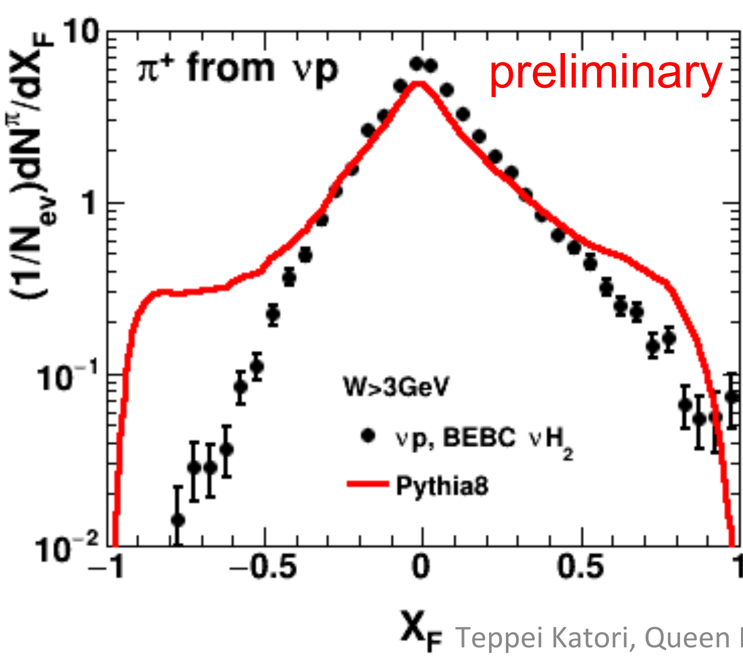
PYTHIA8-GENIE x_F distribution for π^+



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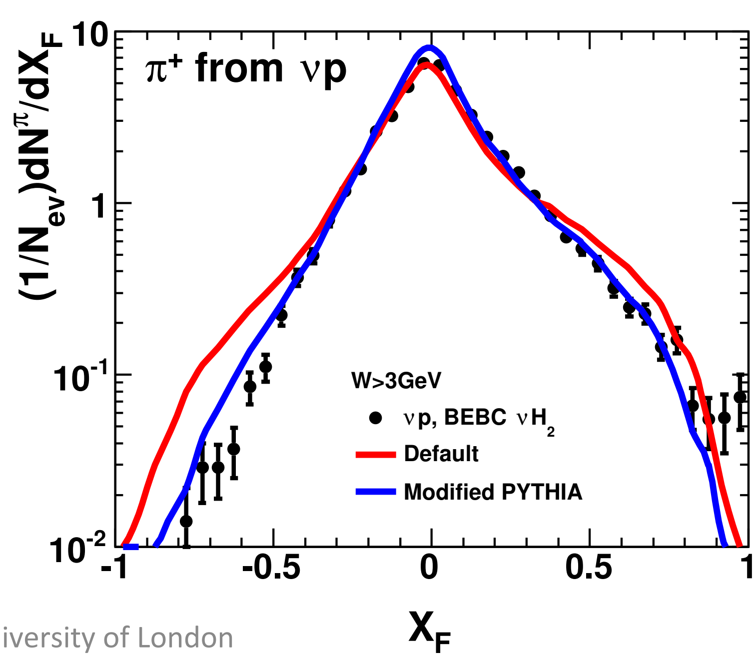

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Path to use PYTHIA8 in GENIE
- Implement 2-particle model of PYTHIA8 (done)
- Tuning of PYTHIA8, based on PYTHIA6 experience
- Implement multi-particle model
- Tuning of PYTHIA8

4. PYTHIA8 in NEUT

Few technical problems, but maybe not a big problem

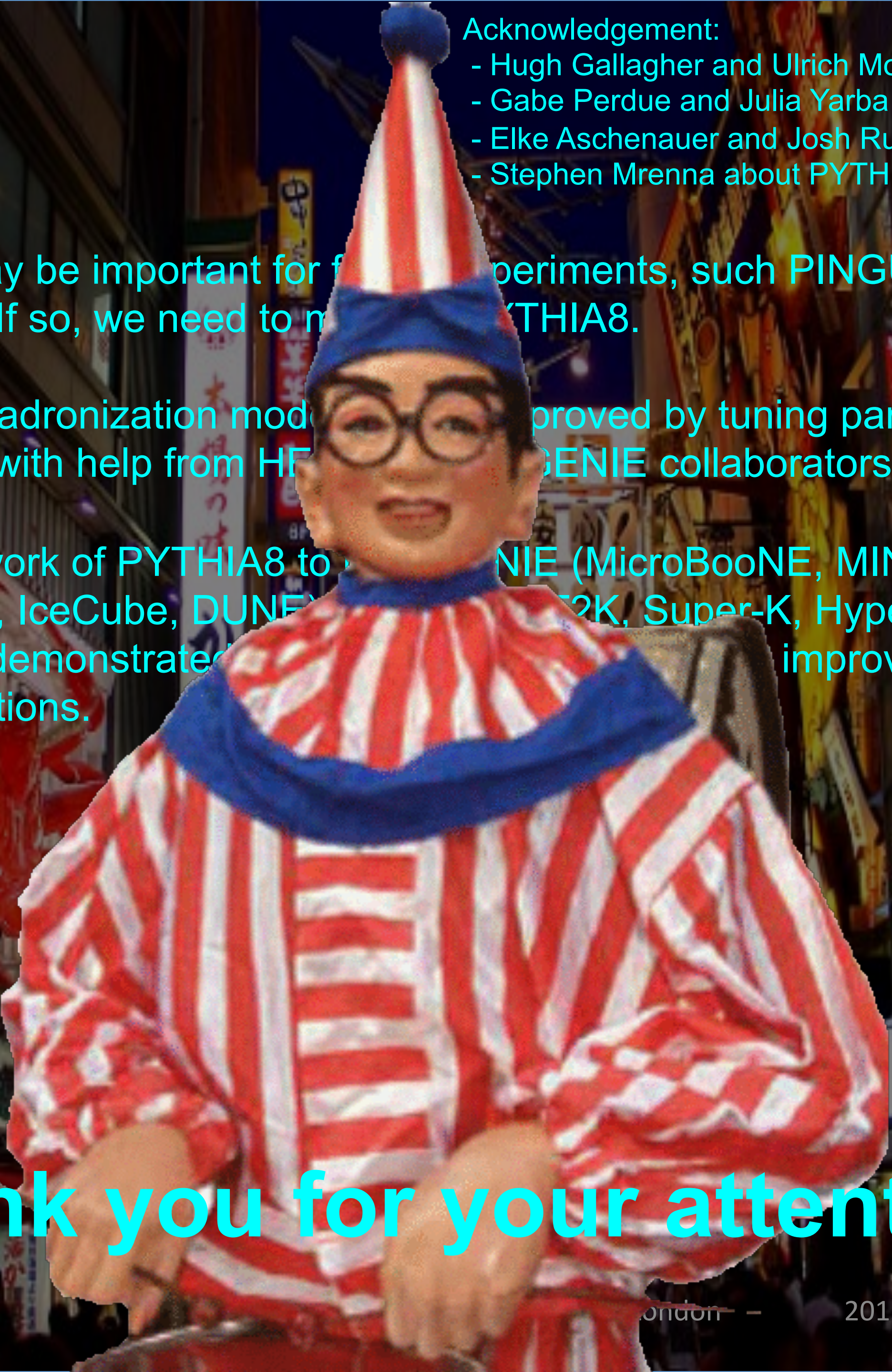
- NEUT uses lepton scattering in PYTHIA6 which is not supported by PYTHIA8
- NEUT is Fortran (PYTHIA8 is C++)

Path to use PYTHIA8 in NEUT

- Modify PYTHIA6 interface in NEUT
- Tune PYTHIA6 in NEUT
- Write some “wrapper” for Fortran→C++
- Implementation work of PYTHIA8

Acknowledgement:
- Hugh Gallagher and Ulrich Mosel to introduce this subject
- Gabe Perdue and Julia Yarba about GENIE hadronization tool
- Elke Aschenauer and Josh Rubin about HERMES
- Stephen Mrenna about PYTHIA

5. Conclusion



Hadronization may be important for f… …periments, such PINGU, ORCA, Hyper-K, DUNE. If so, we need to m… …THIA8.

PYTHIA-based Hadronization mod… …proved by tuning parameters. This work is on-going with help from HE… …ENIE collaborators.

Implementation work of PYTHIA8 to … …NIE (MicroBooNE, MINOS, MINERvA, NOvA, IceCube, DUNE… …2K, Super-K, Hyper-K) are ongoing. Tuning demonstrated… …improve neutrino interaction predictions.

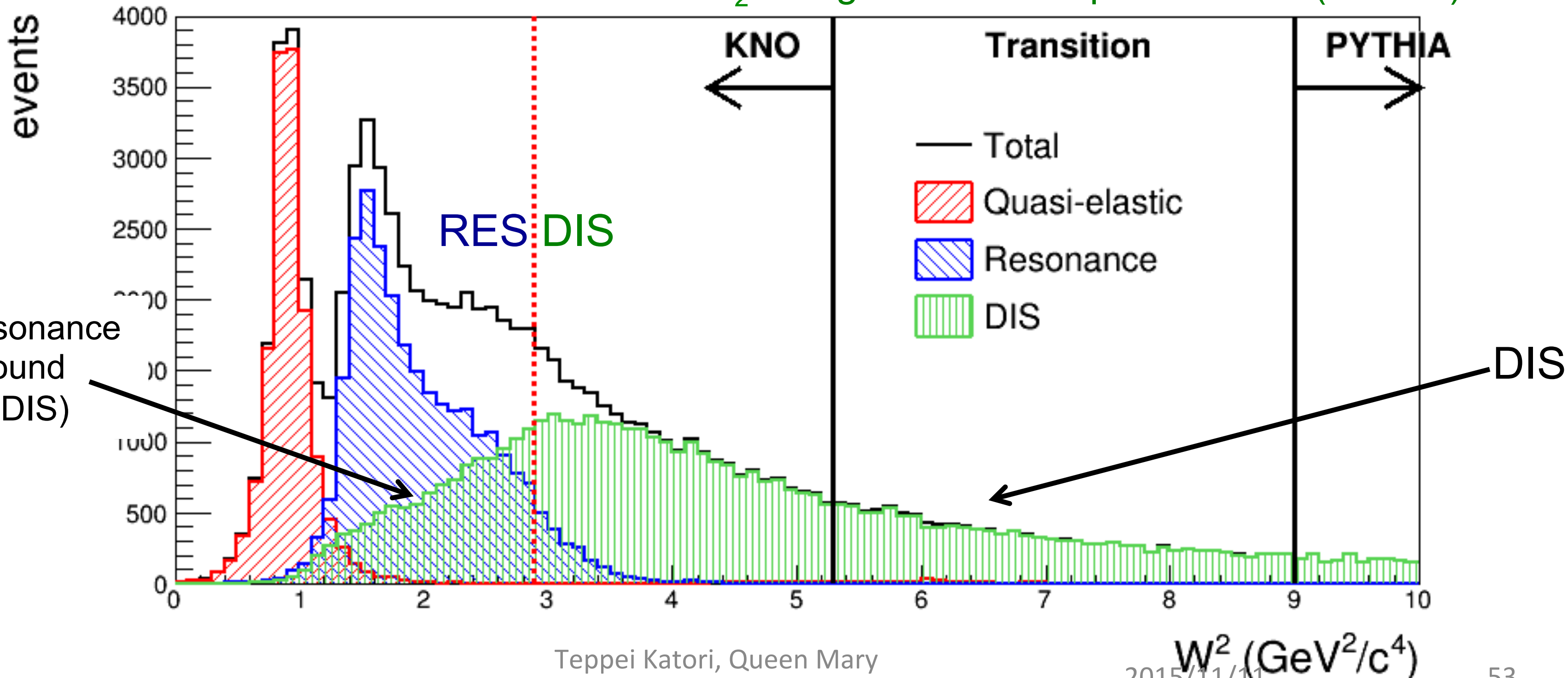
Thank you for your attention!

Back up

1. GENIE hadronization model (AGKY model)

The distribution is not that terrible in terms on reconstructed W^2 distribution…

reconstructed W^2 distribution for H_2O target with atmospheric-ν flux (GENIE)



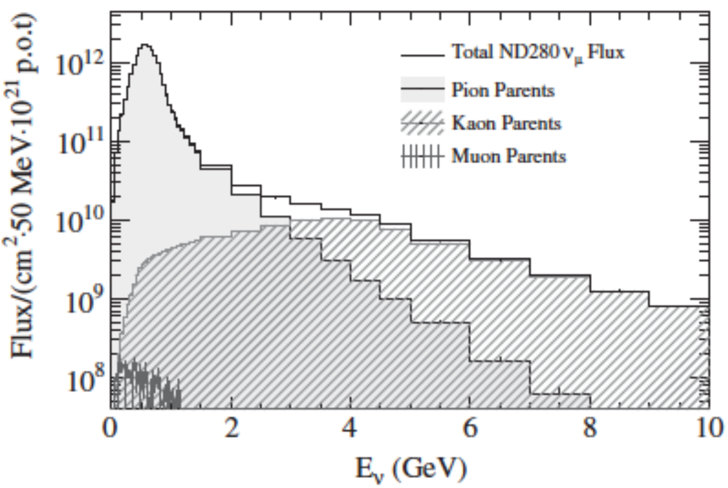
University of London

1. T2K

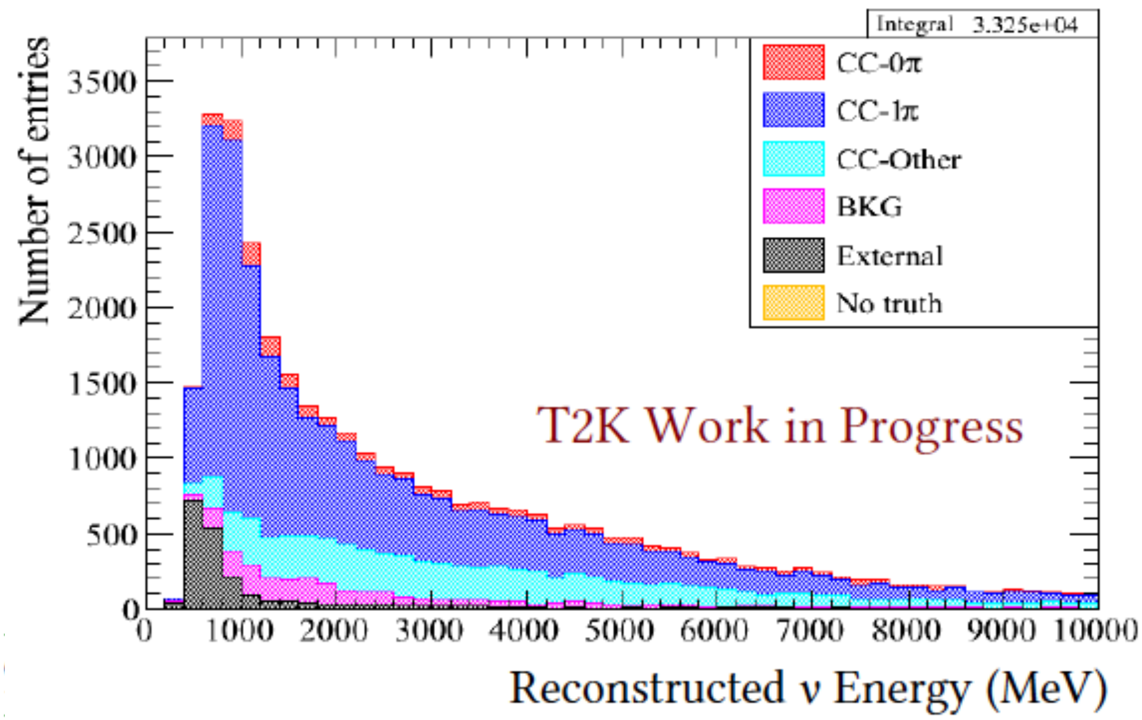
Multi-pion production (CC-Others) background for single pion production measurement

- The largest background to single pion production single pion measurement
  → Single pion production is the major background for CCQE (=oscillation signals)

ν_μ-flux at T2K near detector



Single pion selection in T2K near detector (MC)

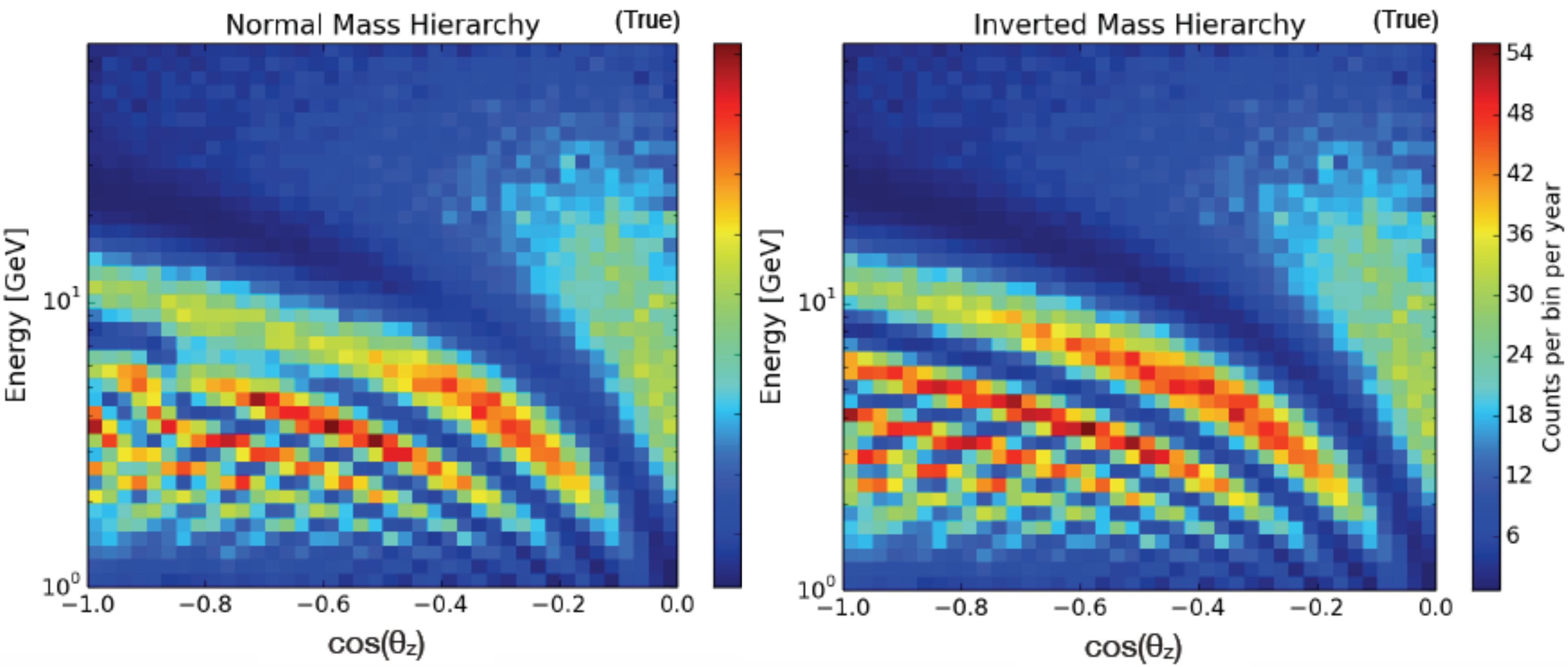


Hadronization in neutrino interaction seems to me an important subject for current and future experiments.

1. PINGU (Precision IceCube Next Generation Upgrade)

More string in smaller region, but still ~3 Mton

- Muon neutrino disappearance measurement for neutrino mass hierarchy (NMH)
- Important energy region is 2-10 GeV



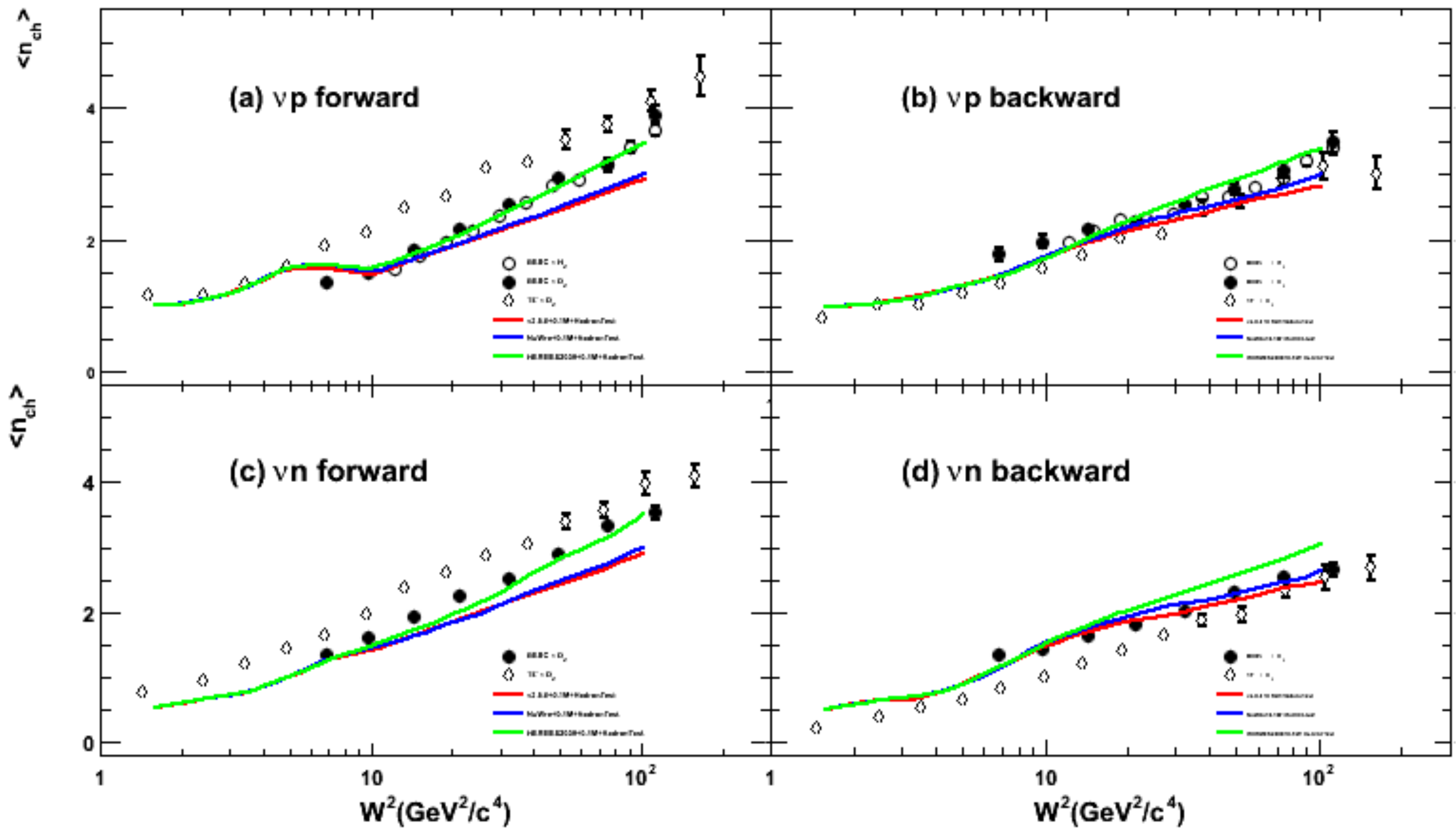
Red: GENIE v2.8.0
Green: Lund-scan

3. HERMES tuned PYTHIA6

Averaged charged hadron multiplicity $<n_{ch}>$

- Lund-scan increases $<n_{ch}>$ (→ better agreement with bubble chamber data) both neutrino and antineutrino.

neutrino forward and backward charged hadron multiplicity



3. HERMES tuned PYTHIA6

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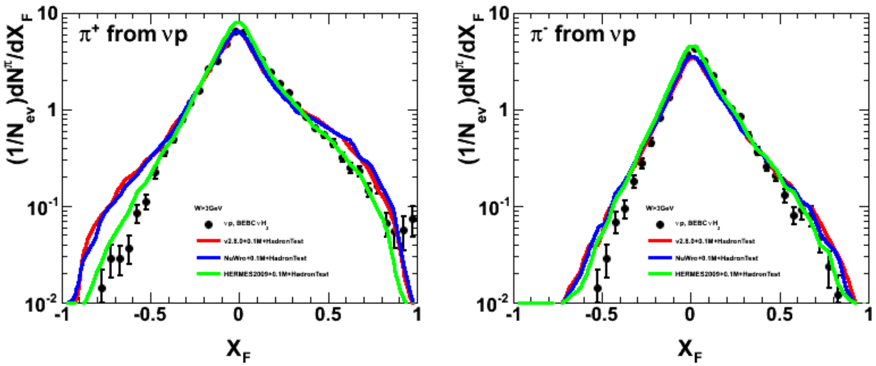
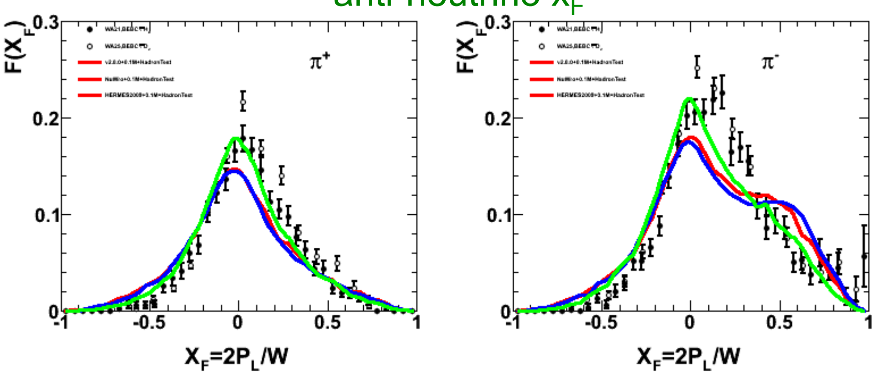
Charged hadron x_F distribution

- HERMES parameters also improve x_F distribution

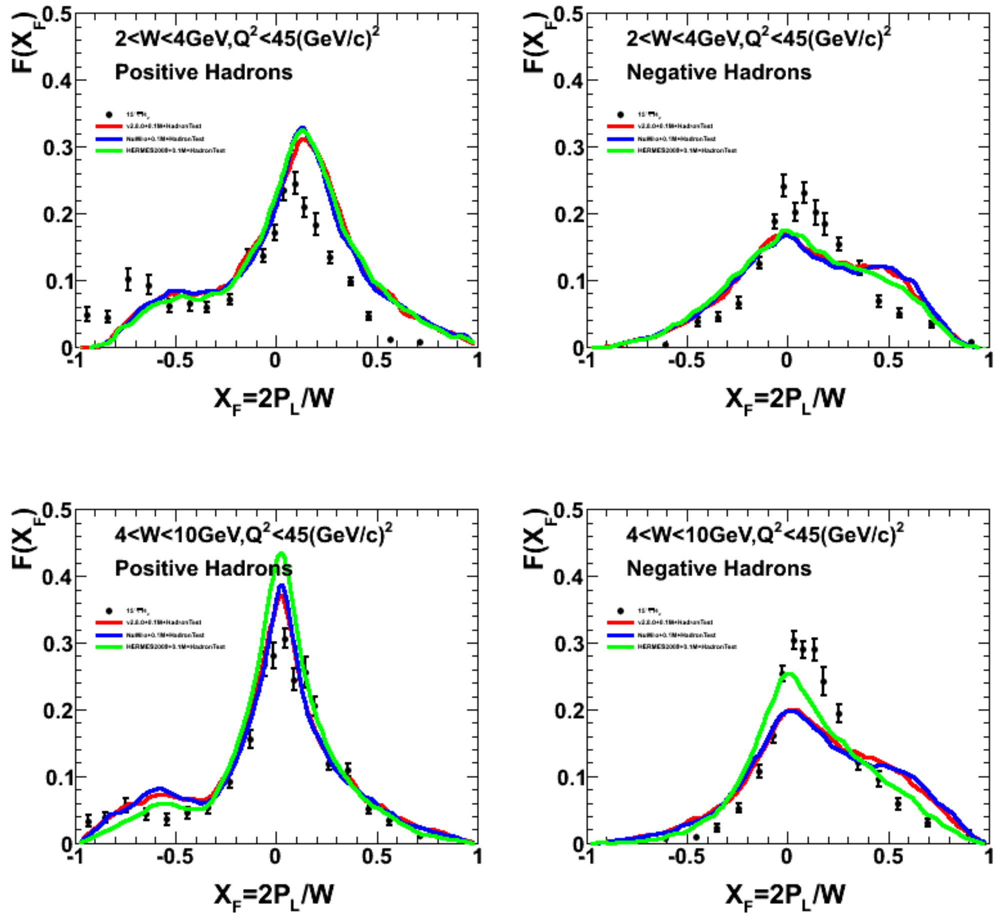
neutrino x_F



anti-neutrino x_F



anti-neutrino x_F with Q^2 bin



Red: GENIE v2.8.0
Green: Lund-scan

3. HERMES tuned PYTHIA6

Dispersion of charged hadron multiplicity
- Dispersion is unchanged(?)