FCC-hh: topics and work plan for phenomenology studies

FCC Design Study kickoff meeting,
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FCC-hh physics activities documented on:

- o https://twiki.cern.ch/twiki/bin/view/LHCPhysics/FutureHadroncollider
- o http://indico.cern.ch/categoryDisplay.py?categId=525

See header of any of the mtgs listed on Indico for registration to mailing list

Will reference as follows to material shown at WG mtgs so far:
FHC 1: Nov 18 2013
FHC 2: Nov 26 2013
FHC 3: Jan 10 2014
FHC 4: Jan 27 2014 FHC 5: Febr 6 2014
BSM@100: Febr 10-11 2014

Priorities

- Stimulate original ideas:
  - BSM
  - SM
- Understand the properties of objects (jets, high-p_T top/W/H, etc) in the extreme kinematical regions of 100 TeV final states
- Define detector requirements emerging from these ideas
- Define an overall programme of measurements across the board, starting from the study of H and EWSB
- Assess reliability of the tools (PDFs, MCs, etc) and plan the progress
- Explore synergies/complementarities with other components of the future programme (FCC-ee/eh, CLIC, ILC, ...)

FHC: physics topics list => WG structure (preliminary)

FHC.1.1 Exploration of EW Symmetry Breaking (EWSB)

FHC.1.1.1 High-mass WW scattering, high mass HH production **MLM, FHC2**

FHC.1.1.2 Rare Higgs production/decays and precision studies of Higgs properties **Gray FHC5, Curtin, BSM@100**

FHC.1.1.3 Additional BSM Higgs bosons: discovery reach and precision physics programme **Craig, BSM@100**

FHC.1.1.4 New handles on the study of non-SM EWSB dynamics (e.g. dynamical EWSB and composite H, etc) **Rattazzi, BSM@100**

FHC.1.2 Exploration of BSM phenomena

FHC.1.2.1 discovery reach for various scenarios (SUSY, new gauge interactions, new quark and leptons, compositeness, etc.) **Doglioni (q*, Mjj) FHC4, Hooberman (EWinos)/Clement (DY)/Mermod (monopoles) Fuks (polarization) FHC5, Battaglia BSM@100**

FHC.1.2.2 Theoretical implications of discovery/non-discovery of various BSM scenarios, e.g. address questions such as:

- FHC.1.2.2.1 what remains of Supersymmetry if nothing is seen at the scales accessible at 100 TeV?
- FHC.1.2.2.2 which new opportunities open up at 100 TeV for the detection and study of dark matter? **Cote FHC1/3, Wang, Schwaller, BSM@100**
- FHC.1.2.2.3 which new BSM frameworks, possibly totally outside of the HL-LHC reach, become accessible/worth-discussing at 100 TeV ? **Cohen, Khoze, Ringwald, ..., BSM@100**

FHC.1.3 Continued exploration of SM particles

Kamenik, Zupan, BSM@100

FHC.1.3.1 Physics of the top quark (rare decays, FCNC, anomalous couplings, ...)
FHC.1.3.2 Physics of the bottom quark (rare decays, CPV, ...)
FHC.1.3.2 Physics of the tau lepton (e.g. tau -> 3 mu, tau -> mu gamma and other LFV decays)
FHC.1.3.2 W/Z physics **Ruderman, BSM@100**
FHC.1.3.3 QCD dynamics

FHC.1.4 Opportunities other than pp physics:
FHC.1.4.1 Heavy Ion Collisions **HI WG**
FHC.1.4.2 Fixed target experiments:
FHC.1.4.2.1 "Intensity frontier": kaon physics, mu2e conversions, beam dump experiments and searches for heavy photons, heavy neutrals, and other exotica... **Jacobsson, FHC5**
FHC.1.4.2.2 Heavy Ion beams for fixed-target experiments

FHC.1.5 Theoretical tools for the study of 100 TeV collisions
FHC.1.5.1 PDFs **Rojo, FHC4**
FHC.1.5.2 MC generators
FHC.1.5.3 N^nLO calculations
FHC.1.5.4 EW corrections

Follows a (very incomplete!) list of (obvious?) tasks.

For more BSM directions, see my talk in the plenary session

Higgs rates at high energy

NLO rates

R(E) = σ(E TeV)/σ(14 TeV)

	σ(14 TeV)	R(33)	R(40)	R(60)	R(80)	R(100)
ggH	50.4 pb	3.5	4.6	7.8	11.2	14.7
VBF	4.40 pb	3.8	5.2	9.3	13.6	18.6
WH	1.63 pb	2.9	3.6	5.7	7.7	9.7
ZH	0.90 pb	3.3	4.2	6.8	9.6	12.5
ttH	0.62 pb	7.3	11	24	41	61
HH	33.8 fb	6.1	8.8	18	29	42

In several cases, the gains in terms of "useful" rate are much bigger.
E.g. when we are interested in the large-invariant mass behaviour of the final states:
$\sigma(ttH, p_T^{top} > 500\ \text{GeV}) \Rightarrow R(100) = 250$

Task: explore new opportunities for measurements, to reduce systematics with independent/complementary kinematics, backgrounds, etc.etc.

Examples: how much can we reduce jet veto systematics by "measuring" jet rates/vetoes in "clean" channels like $H \to ZZ^*$? $H \to bb$ & ττ tagging ? .....

Higgs production: TH uncertainty

Higgs XS WG: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HiggsEuropeanStrategy#6_Plots

	$\sqrt{S}$=14 TeV	M_H=125 GeV				$\sqrt{S}$=33 TeV	M_H=125 GeV			
Process	Cross section	Scale uncertainty		PDF+α_s uncertainty		Cross section	Scale uncertainty		PDF+α_s uncertainty	
ggF [a]	50.35 pb	+7.5%	-8.0%	+7.2%	-6.0%	178.32 pb	+7.8%	-8.2%	+7.4%	-7.2%
VBF [b]	4.172 pb	+0.4%	-0.3%	+1.9%	-1.5%	15.47 pb	+0.6%	-0.6%	+1.7%	-1.4%
WH [c]	1.504 pb	+0.3%	-0.6%	+3.8%	-3.8%	4.272 pb	+0.2%	-0.7%	+2.4%	-2.4%
ZH [c]	0.8830 pb	+2.7%	-1.8%	+3.7%	-3.7%	2.780 pb	+4.8%	-3.2%	+2.5%	-2.5%
ttH [c]	0.6113 pb	+5.9%	-9.3%	+8.9%	-8.9%	4.377 pb	+8.1%	-8.9%	+5.4%	-5.4%
bbH [d]	0.5805 pb	+13.0%	-24.0%	+6.1%	-6.1%	2.132 pb	+7.0%	-34.0%	+5.9%	-5.9%

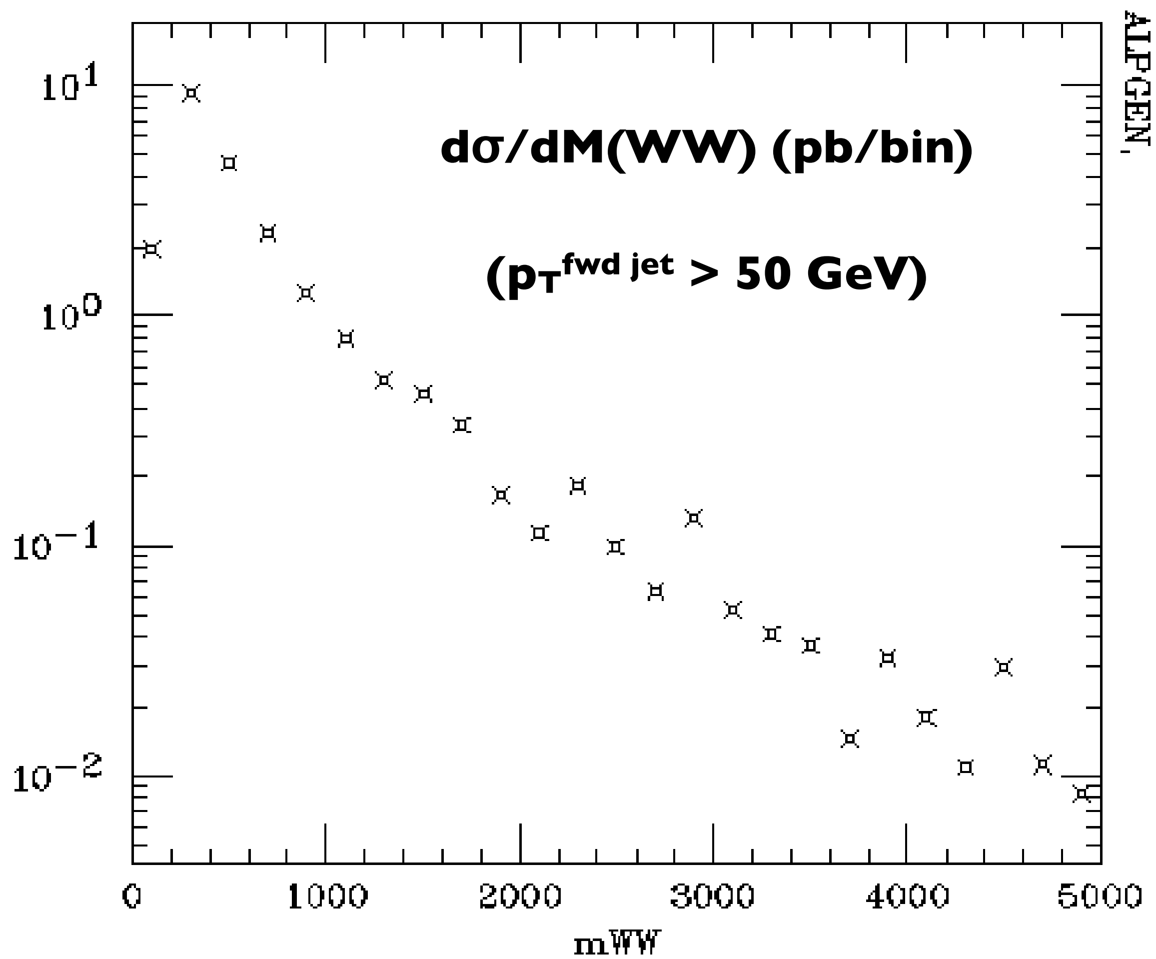
o scale systematics degrades slightly when 14→33 TeV

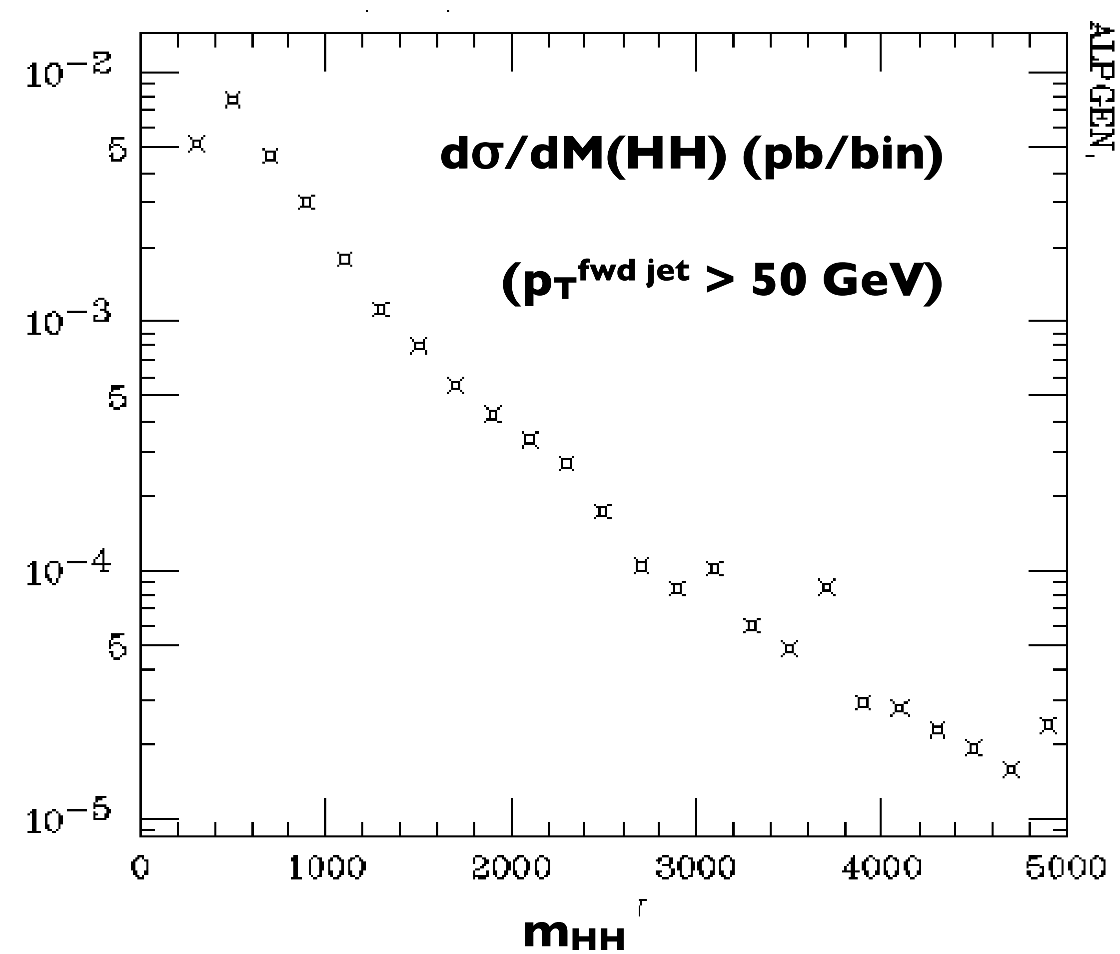
o At 33 TeV x-range closer to HERA-constrained region ⇒ reduced PDF syst at 33 TeV

Task: extend studies to 100 TeV

EWSB probes: high mass WW/HH in VBF

MLM, FHC 2





Tasks:

o study the mass reach for SM production

o test impact of BSM effects

o compare to reach of precise BR(H), VBF, λ_{HHH} measurements (TLEP, CLIC)

o compare to reach for direct manifestation of BSM particles

o .....

Multi-gauge boson production (no BR included)

WW	**σ=770 pb**
WWW	**σ=2 pb**
WWZ	**σ=1.6 pb**
WWWW	**σ=15 fb**
WWWZ	**σ=20 fb**
....	

Tasks:

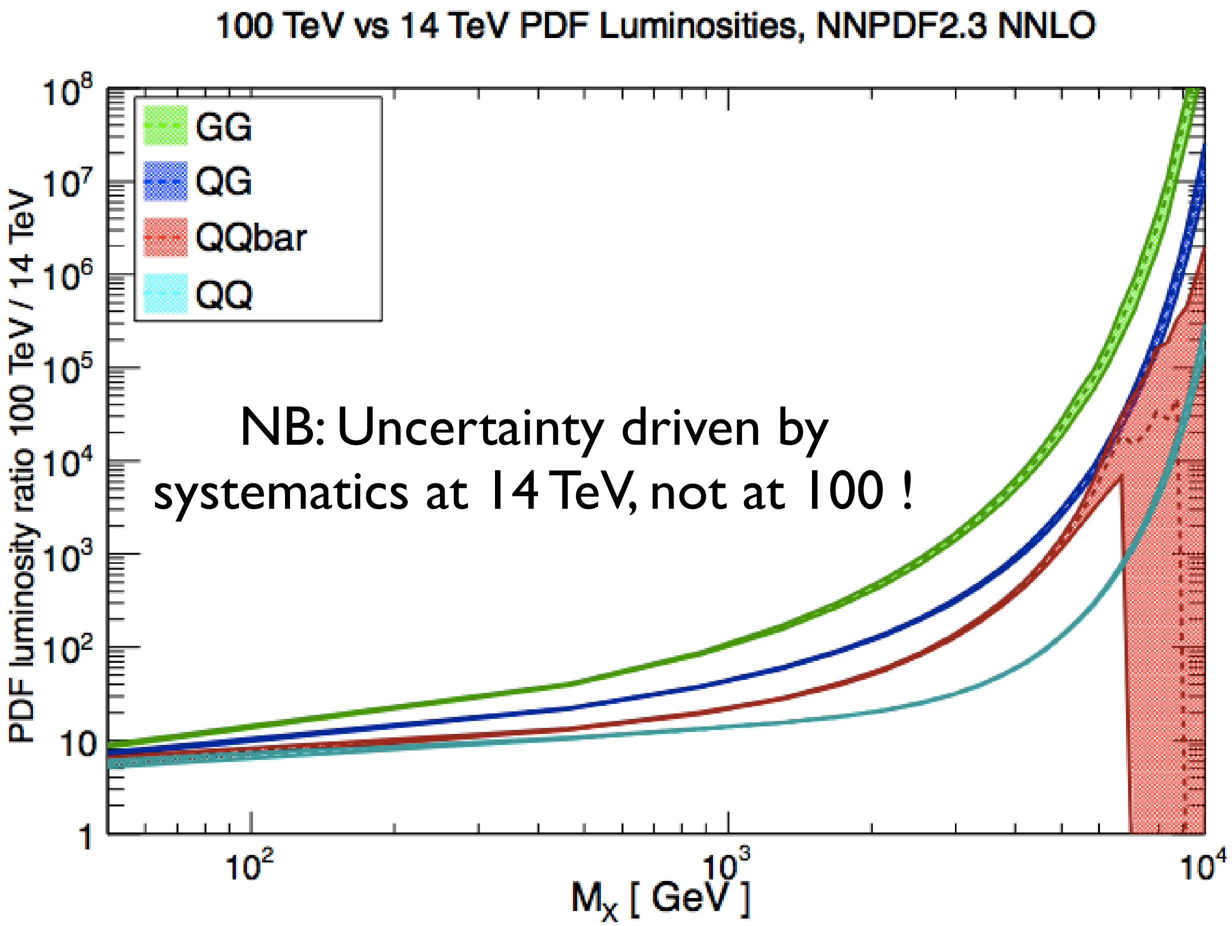
o determine experimental accept/eff's: how high can we go in multiplicity?
o what can we learn on EW interactions at high energy from these studies?
o which variables/correlations to consider?
o can we use dijet decays at high pt(W) ?

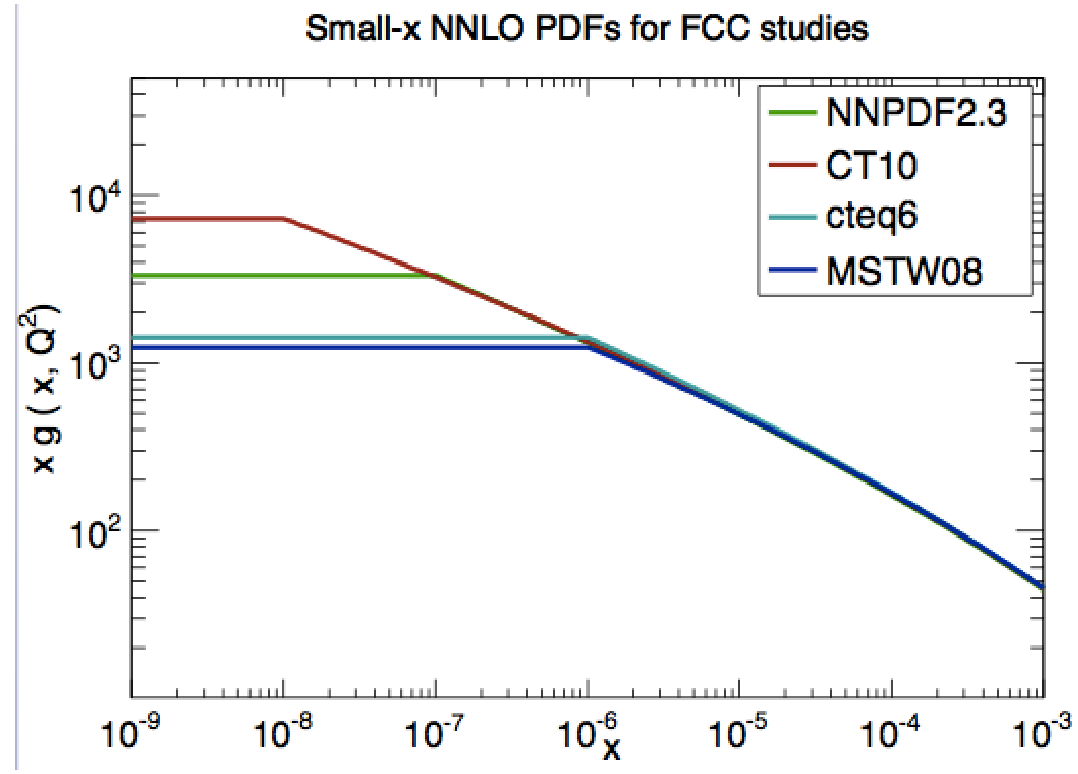
M.Pierini, FHC 5

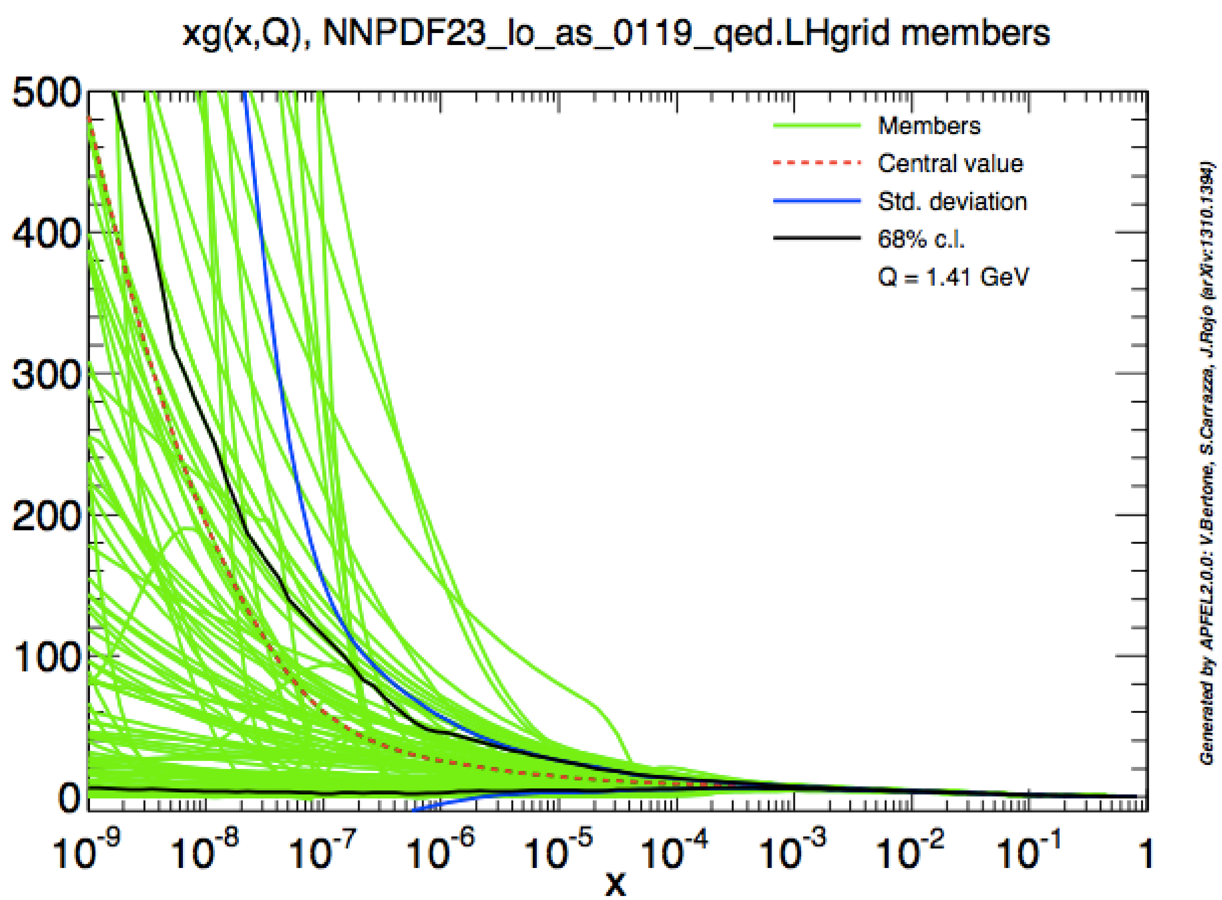
PDF issues

J.Rojo, FHC 4

Warnings







Tasks:

o document issues that may appear in 100 TeV studies

o prepare suitable PDF sets

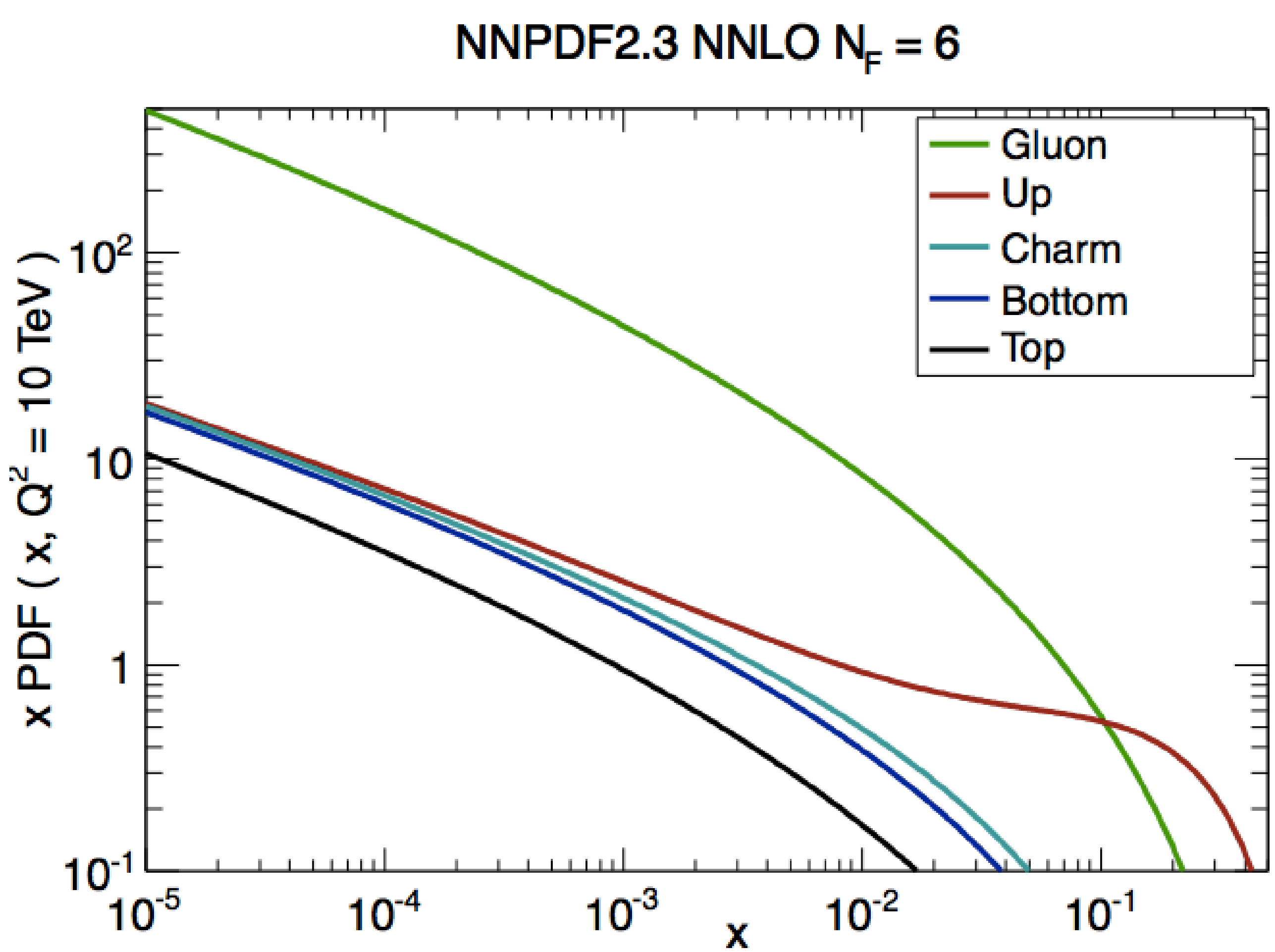
o quantify uncertainties

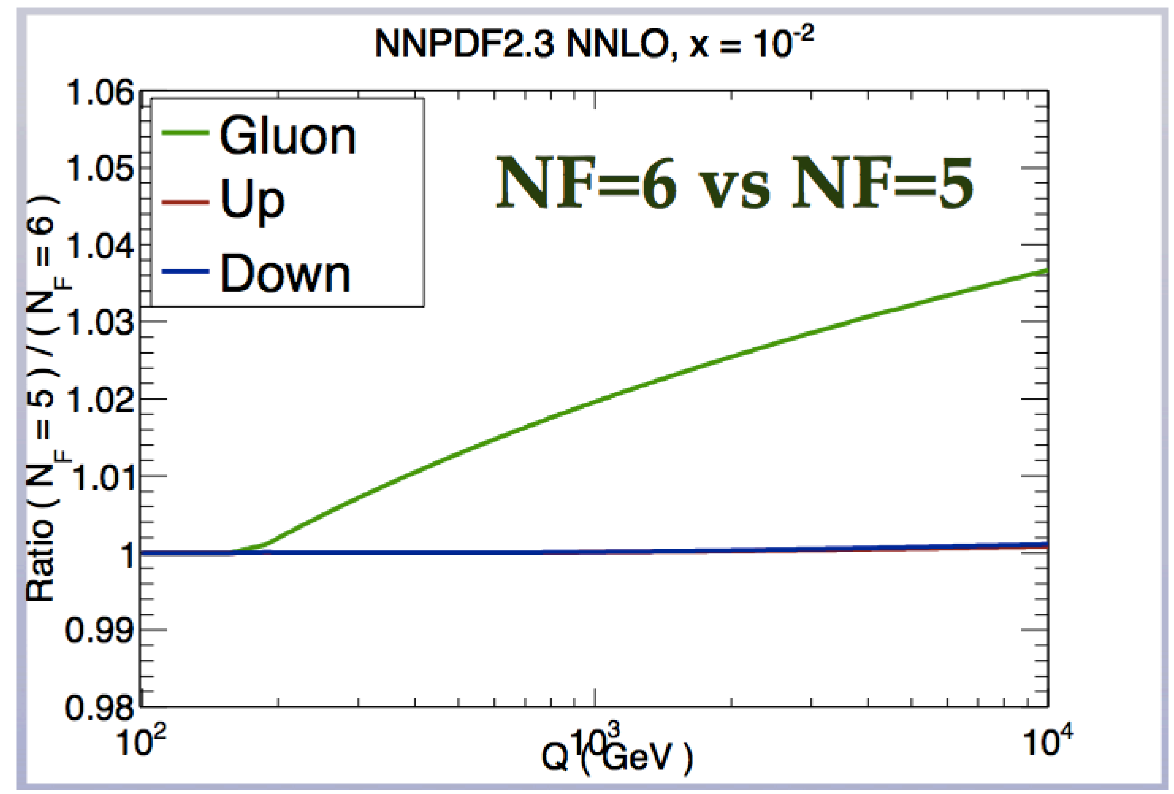
o outline programme of measurements to reduce syst's

o ....

PDF issues: heavy flavours

J.Rojo, FHC 4





Tasks:

o quantify systematics

o detailed comparisons of results obtained using NF=5 vs NF=6 approaches

o explore opportunities offered by large HF content of proton at high Q

Example G.Perez, BSM@100

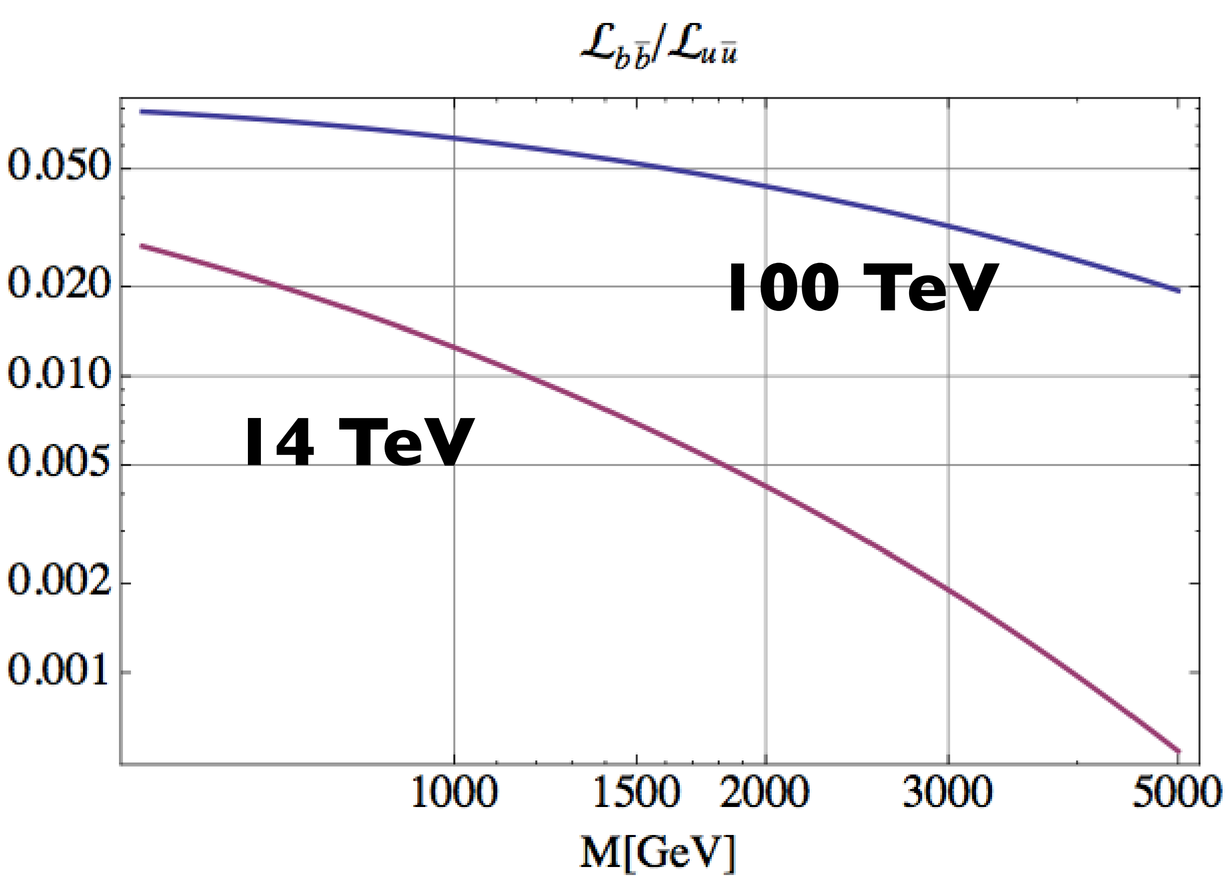
Minimal Ingredients for Natural Composite/Little Higgs

- Top partners => couple to 3rd generation quarks & ElectroWeak/Higgs sector.

- EW partners that couples to SM EW/Higgs + 3rd generation sectors.

- No immediate natural pressure regarding the first 2 generations.

- Thus EW partners direct production can be exclusively through H/EW phys. or via 3rd generation fusion.



pp →Z'→t tbar

$$(S/\sqrt{B})^{14\,\mathrm{TeV},\,3000\,\mathrm{fb}^{-1}}_{u\bar{u},b\bar{b},WW} = 2, 1, 0.15;$$

$$(S/\sqrt{B})^{100\,\mathrm{TeV},\,100\,\mathrm{fb}^{-1}}_{u\bar{u},b\bar{b},WW} = 1.5, 30, 0.4.$$

10 ab^{-1} at 100 TeV imply:

10^{10} Higgs bosons => 10^4 x today **Curtin (exotic H decays) BSM@100**

10^{12} top quarks => 5 10^4 x today

=> 10^{12} W bosons from top decays

=> 10^{12} b hadrons from top decays (particle/antiparticle tagged)

=> 10^{11} t → W → taus

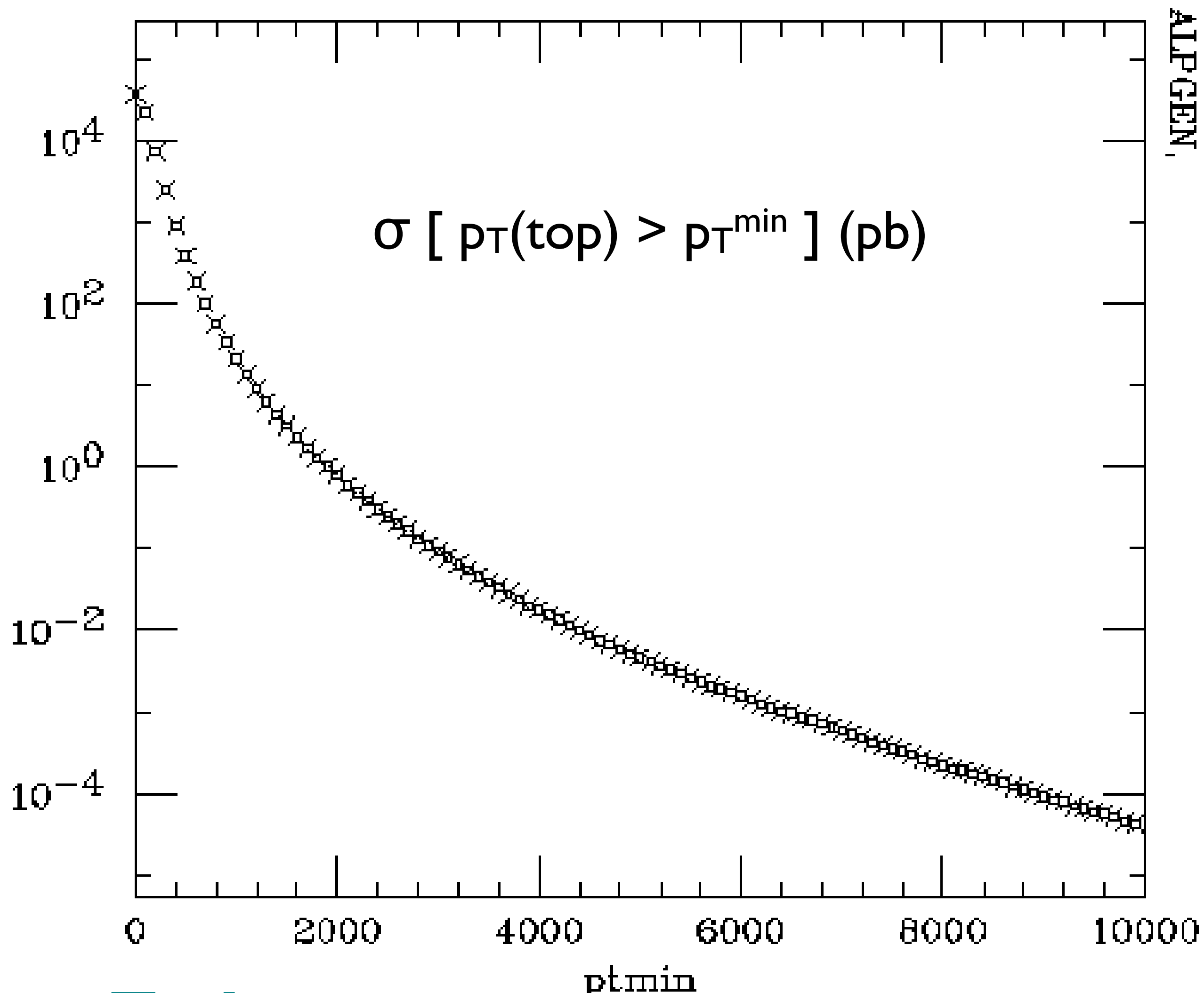
=> few x10^{11} t → W → charm hadrons

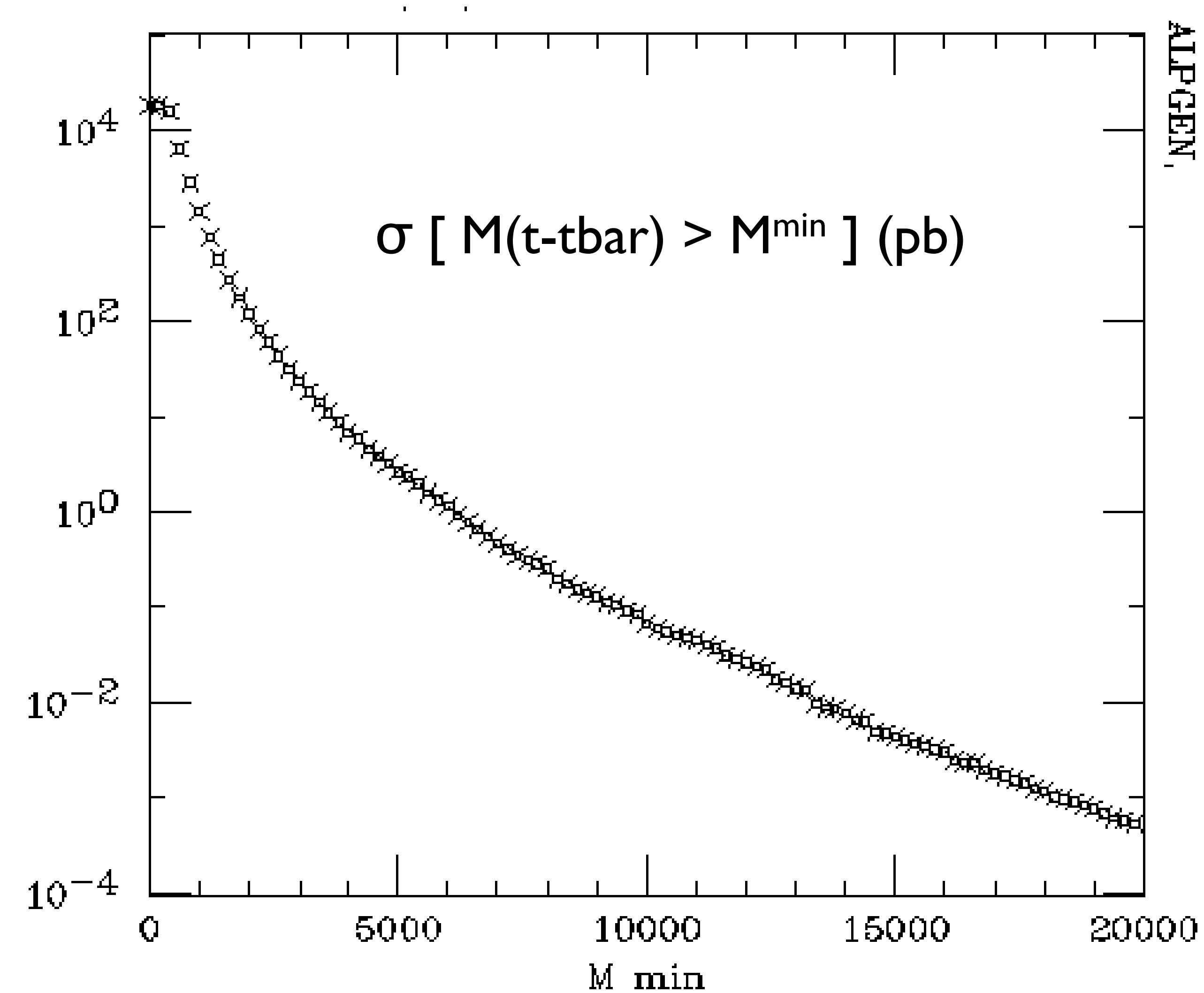
Tasks:

o countless list ! .... plus

o examine the possibility of detectors dedicated to final states in the 0.1 - 1 TeV region, with focus on Higgs, DM and weakly interacting new particles, top, W

Inclusive t-tbar production: distributions





Tasks:

o explore tagging of multi-TeV tops

o study mass resolution for resonance searches, define search potential (σ_{BSM} vs M_{BSM})

o explore opportunities for top coupling studies at large Q

Example: what can we learn from
10^4 pp → W^* → top+ bottom with M(tb) > 7 TeV ?

W decays

- W mass ??
- SM rare decays -- Examples:

$W^{\pm} \rightarrow \pi^{\pm} \gamma$ BR$_{SM}$ ~ 10^{-9}, CDF$\leq$ 6.4 x 10^{-5}

$W^{\pm} \rightarrow D_s^{\pm} \gamma$ BR$_{SM}$ ~ 10^{-9}, CDF$\leq$ 1.2 x 10^{-2}

What is the theoretical interest in measuring these rates? What else ?

- SM inclusive decays -- Examples:

R = BR$_{had}$ / BR$_{lept}$: what do we learn ? Achievable precision for CKM, α_S , ... ?

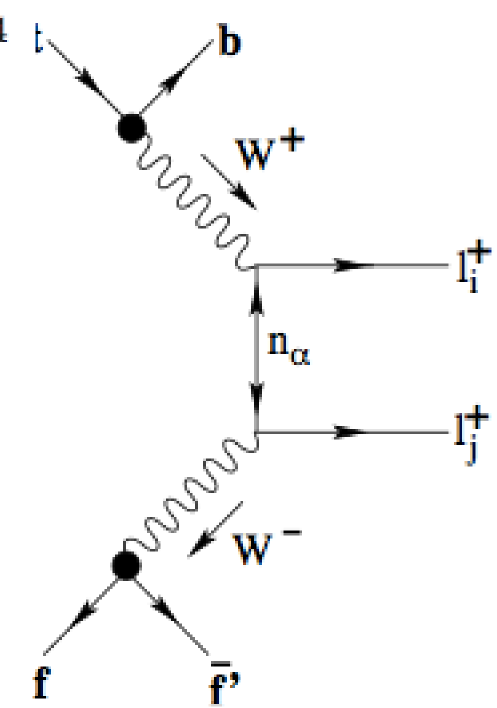
- BSM decays -- Are there interesting channels to consider?

-- Example

BNL-HET-06/9
OITS-784

Majorana neutrinos and lepton-number-violating signals in top-quark and W-boson rare decays

Shaouly Bar-Shalom[a,*] Nilendra G. Deshpande[b,†] Gad Eilam[a,‡] Jing Jiang[b,§] and Amarjit Soni[c,¶]



Top decays and interactions

Rare decays: $t \rightarrow W Z b$, ...
FCNC probes: $t \rightarrow cV$ ($V=Z,g,\gamma$), $t \rightarrow cH$
CP violation: spin/momentum correlations of decay products, ...

BSM@100:
Zupan (FCNC top int's)
Kamenik (CPV top int's)

Top as a tool for BSM searches

Tasks:

o quantitative exploration of measurement potential (statistics, systematics, dedicated detector/trigger requirements)

Plan

- Continue informal mtgs, with a 1/few-weeks schedule
- Looking for WG conveners (TH+exp)
- Form WG's on topics indicated in previous slide. Engage/collect material from whoever is working on 100 TeV topics
- Organize 2/3-day workshops, with a ~6-month frequence, to bring all WGs together
- Prepare a report documenting the physics opportunities at 100 TeV, on the time scale of end-2015, ideally in cooperation with efforts in other regions