On behalf of the HI Working Group of FCC-hh/Physics&Exp

Heavy Ions at the Future Circular Collider

Carlos A. Salgado

IGFAE - Santiago de Compostela

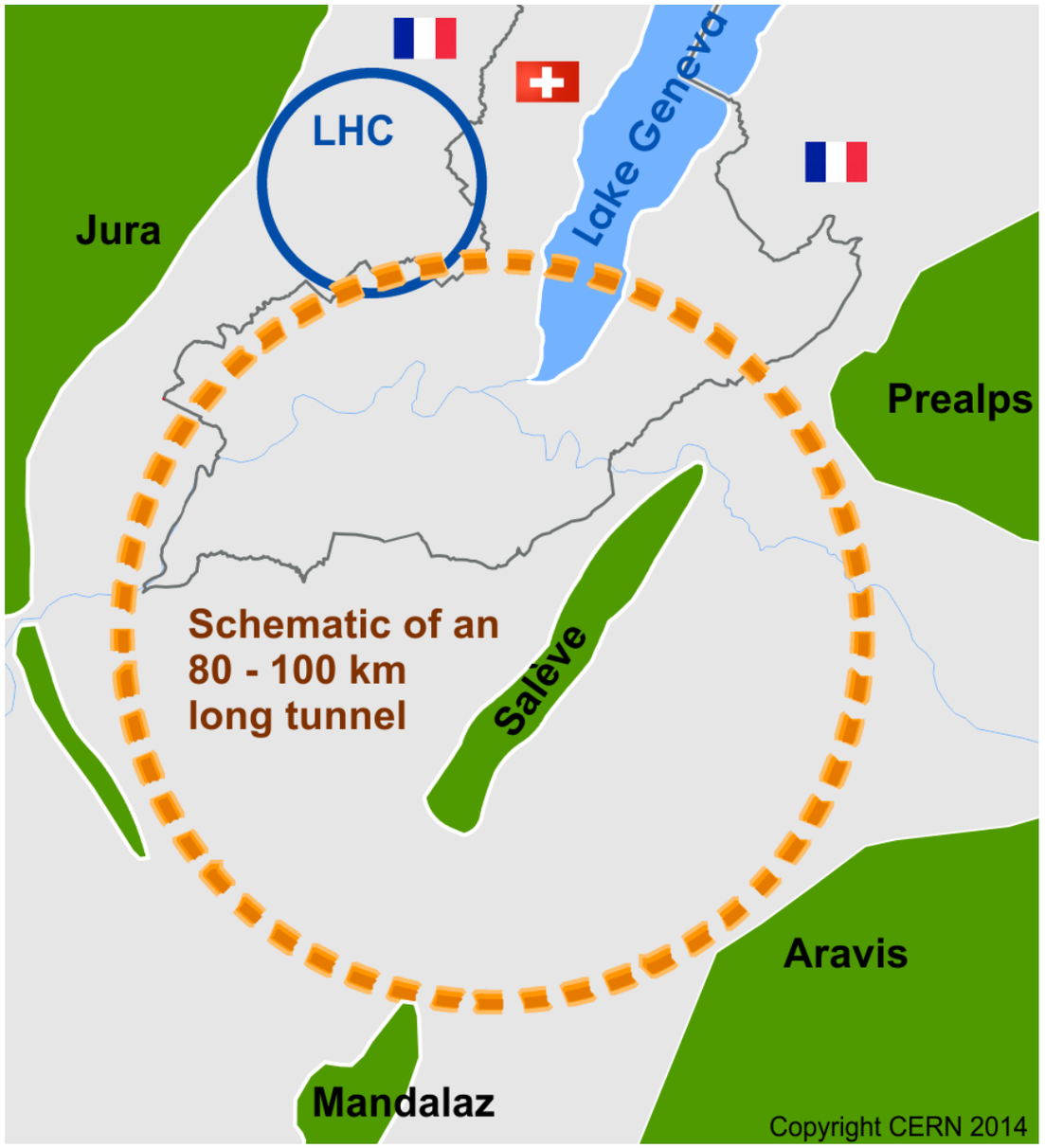
EPS-HEP 2017 - Venezia

@CASSalgado @HotLHC

European Research Council

Established by the European Commission

Scope of FCC study



International FCC collaboration (CERN as host lab) to study:

- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

  ~16 T ⇒ 100 TeV *pp* in 100 km
- **~100 km tunnel infrastructure** in Geneva area, site specific
- **e^+e^- collider (*FCC-ee*),** as potential first step
- ***p-e* (*FCC-he*) option,** integration one IP, e from ERL
- **HE-LHC** with *FCC-hh* technology
- **CDR for end 2018**

[Slide from Michael Benedikt - FCC week Berlin 2017]

HIC - Organization

Ions at FCC-hh Working Group:

Coord: A. Dainese, S. Masciocchi, CAS, U. Wiedemann
Sub-group of "FCC-hh Physics, Experiments, Detectors"
Participation of CERN Beams dep. (J. Jowett, M. Schaumann)
Contact with HI theory group of chinese project CEPC-SppC

Twiki https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HeavyIons

6 workshops/meetings 2013-15

https://indico.cern.ch/event/331669/ and links therein

Report included in the CERN Yellow Report in FCC-hh Physics [arXiv:1605.01389, CERN Yellow Report (2017) no.3, 635-692]

60 pages, about 50 authors
Section editors: N. Armesto, A. Dainese, D. d'Enterria, J. Jowett, J.P.Lansberg, G. Milhano, C. Salgado, M. Schaumann, M. van Leeuwen, U. Wiedemann

PbPb/pPb parameters

Operation mode		Pb–Pb	p–Pb
Beam energy	[TeV]	4100	50
$\sqrt{s_{\mathrm{NN}}}$	[TeV]	39.4	62.8
No. of bunches per LHC injection	-	518	518
No. of bunches in the FCC	-	2072	2072
Initial luminosity	$[10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	24.5	2052
Peak luminosity	$[10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}]$	57.8	9918
Integrated luminosity per fill	$[\mu\mathrm{b}^{-1}]$	553	158630
Average luminosity	$[\mu\mathrm{b}^{-1}]$	92	20736
Time in collision	[h]	3	6
Assumed turnaround time	[h]	1.65	1.65
Integrated luminosity/run	$[\mathrm{nb}^{-1}]$	33	8000

Michaela Schaumann
FCC week Berlin - May 2017

110

29.000

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10x the whole LHC heavy ion program (~100 nb^{-1}) in 1 run…

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Physics

Very high energies and luminosities

Quark-Gluon Plasma studies

Global and collective

Jet quenching and hard processes

Small-x physics and initial stages

nuclear PDFs

CGC/Saturation

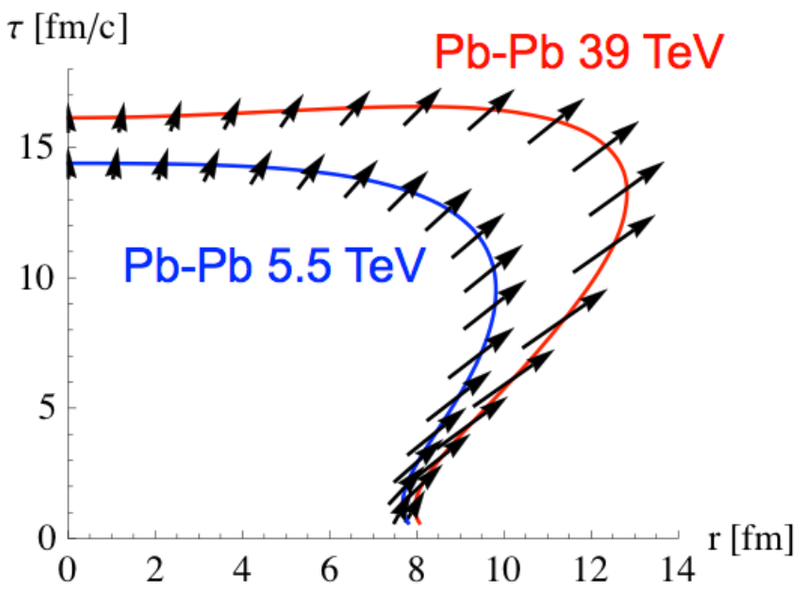
Thermalization

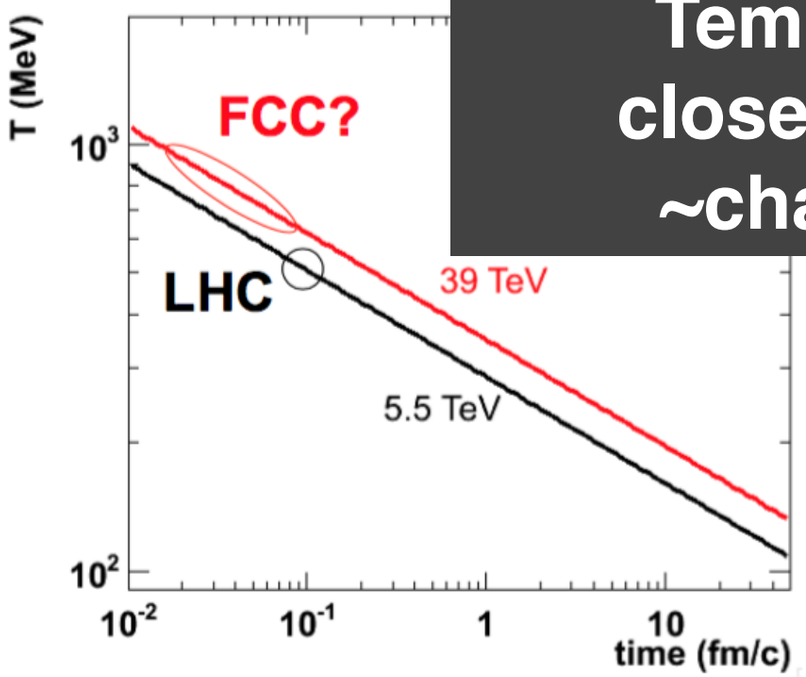
Photon-photon (and other UPC) collisions

Also fixed target, and other opportunities

Global properties

Quantity	Pb–Pb 2.76 TeV	Pb–Pb 5.5 TeV	Pb–Pb 39 TeV
$\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta$ at $\eta = 0$	1600	2000	3600
Total N_{ch}	17000	23000	50000
$\mathrm{d}E_{\mathrm{T}}/\mathrm{d}\eta$ at $\eta = 0$	1.8–2.0 TeV	2.3–2.6 TeV	5.2–5.8 TeV
Homogeneity volume	5000 fm^3	6200 fm^3	11000 fm^3
Decoupling time	10 fm/c	11 fm/c	13 fm/c
ε at $\tau = 1$ fm/c	12–13 GeV/fm^3	16–17 GeV/fm^3	35–40 GeV/fm^3



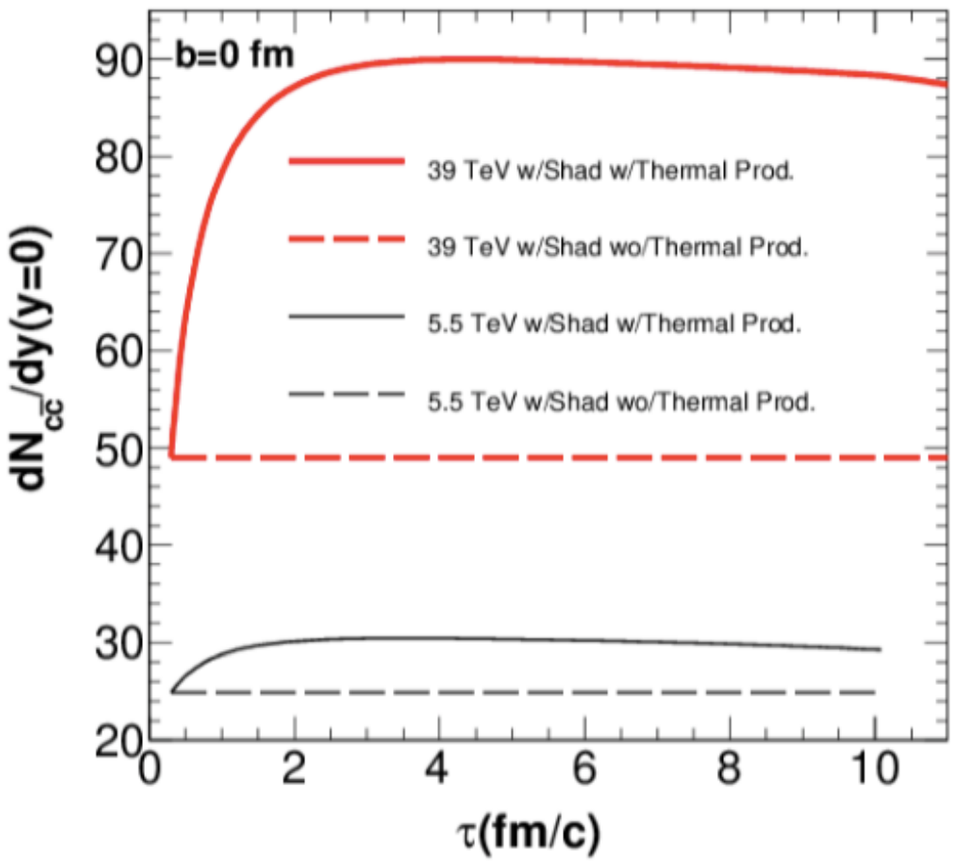


Temperatures close to 1GeV ? ~charm mass

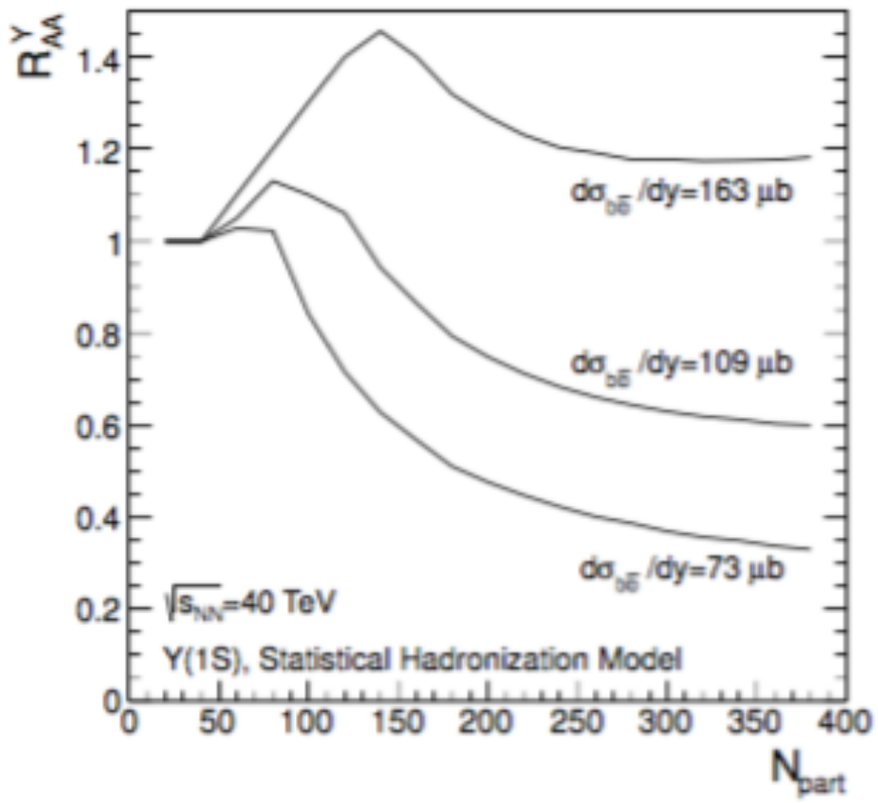
Notice that T~1GeV means eps~2 TeV/fm^3

Heavy quarks

What changes expected if temperatures ~ charm mass?

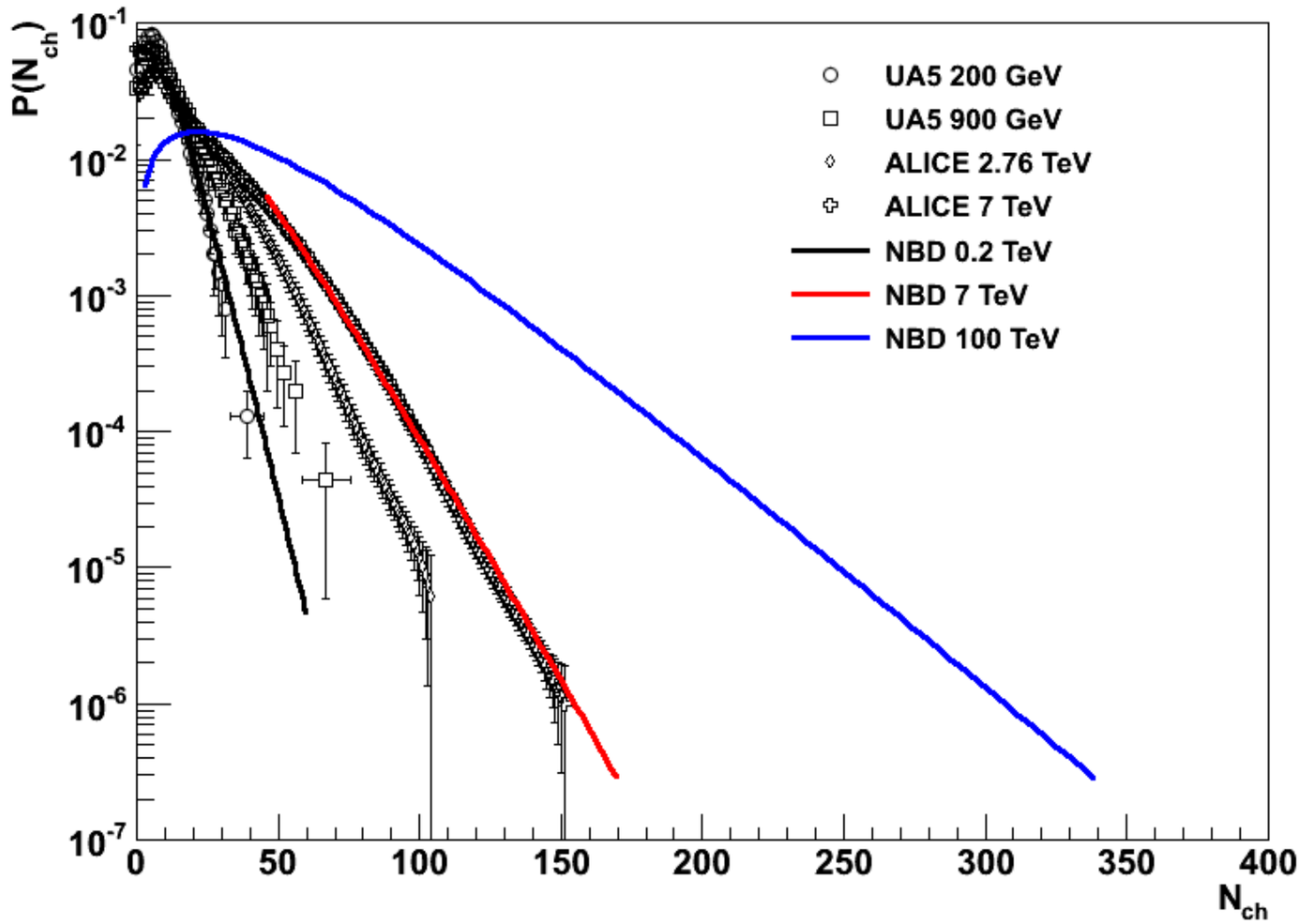


Thermal charm



J/Psi and Upsilon Enhancement?

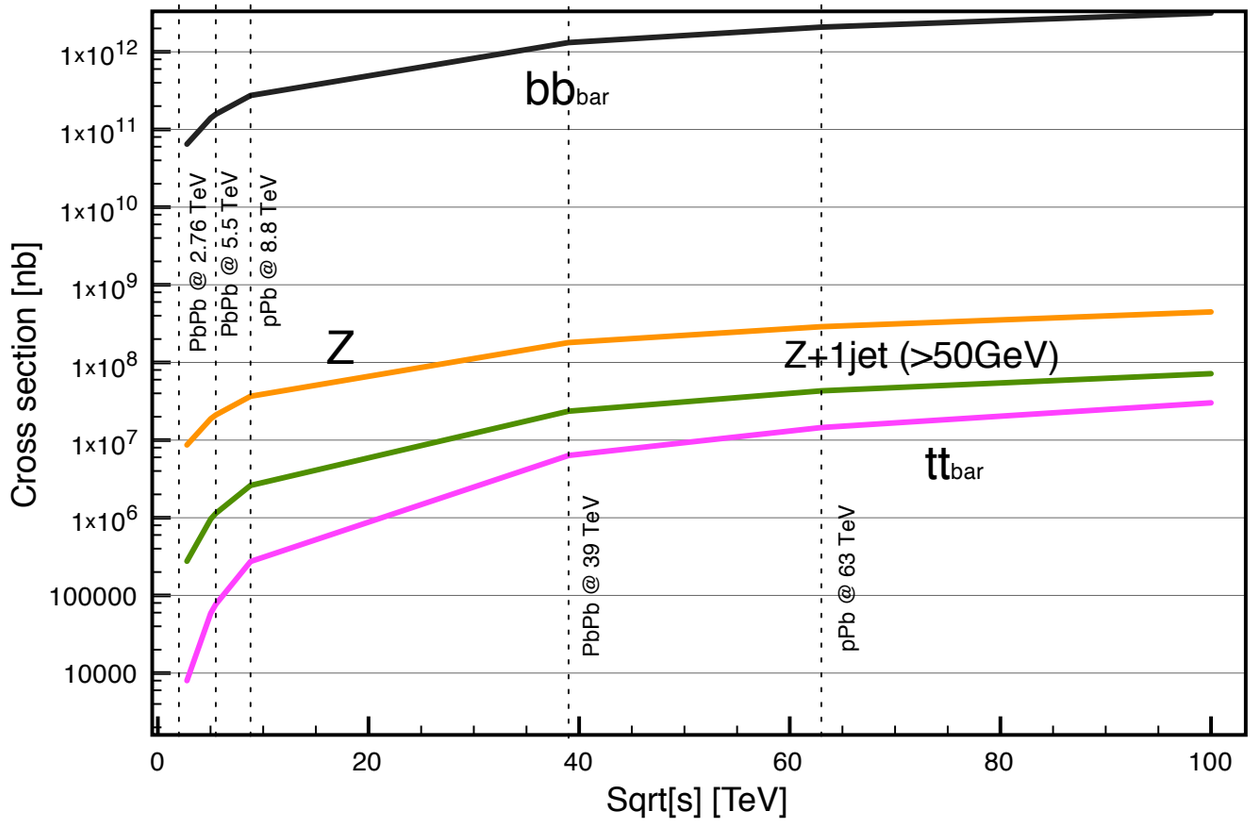
Small vs large systems

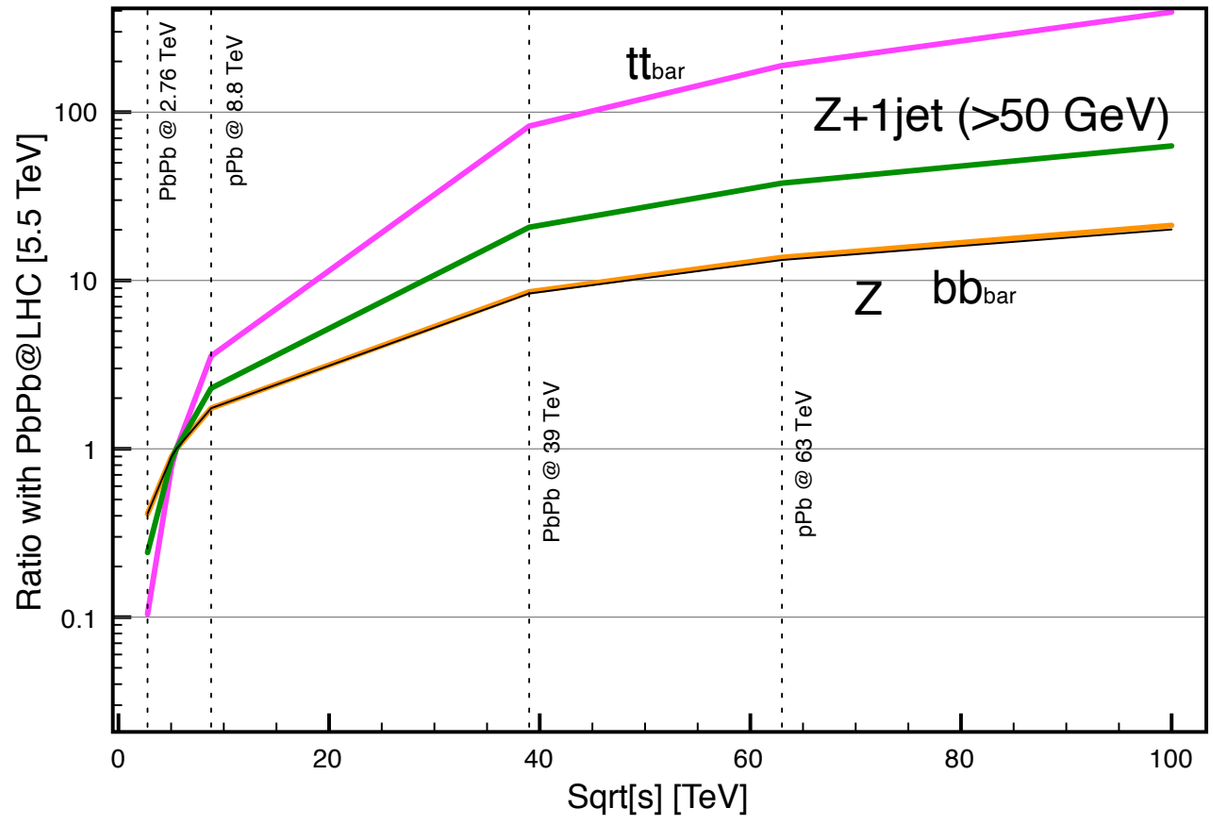


- **Large multiplicities also in pp (or pPb)**
  - Hydrodynamization/thermalization in small systems?
  - Full thermalization in large systems?

Hard Probes

Huge cross section growth for harder probes



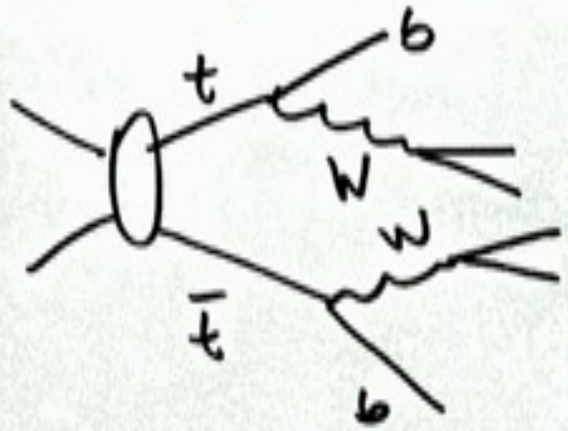


All calculations for pp collisions, computed with MCFM

- *Large enhancements for larger masses*
- *80x for ttbar; 40x for Z+1jet (pt>50 GeV); 20x for bbar or Z*

(Boosted) Top quark

The tops & the W's



BOOST: $\frac{P_T}{M}$

Andrea's estimate $L \sim 1\,\text{fm}\,p_T[\text{TeV}]$

Take: $P_T \simeq 0.5$ TeV $\Rightarrow \frac{P_T}{M} \sim \frac{1}{3}$

0 fm/c $t\bar{t}$ produced

~ 0.5 fm/c each $t \to Wb$

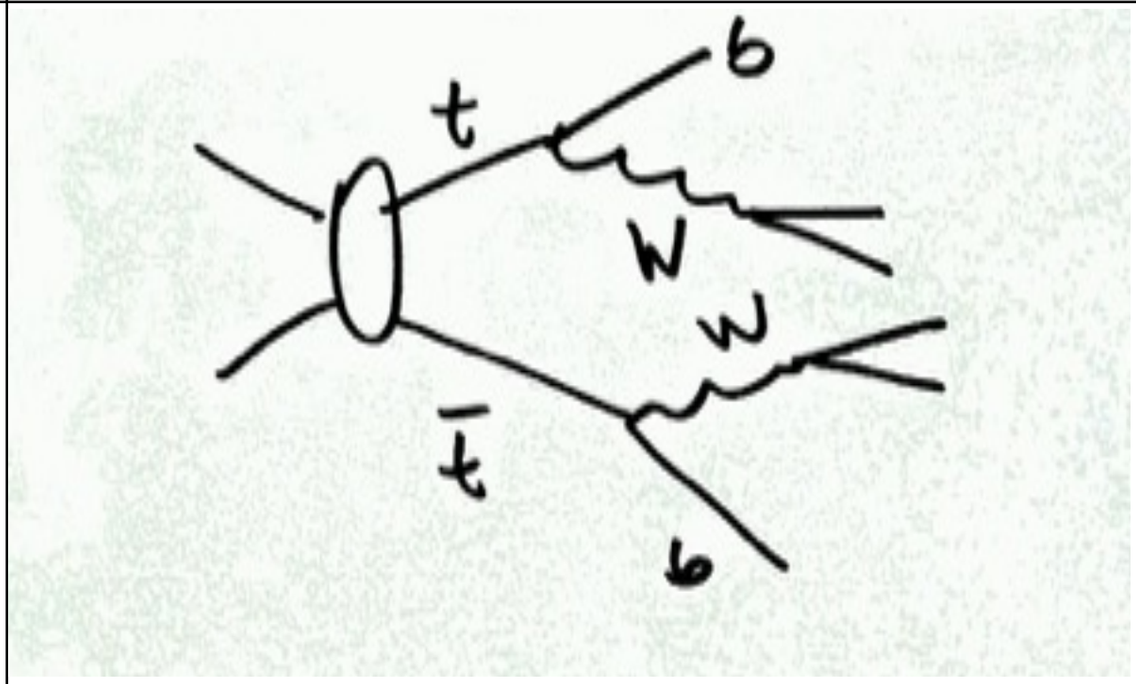
~ 0.8 fm/c W decay

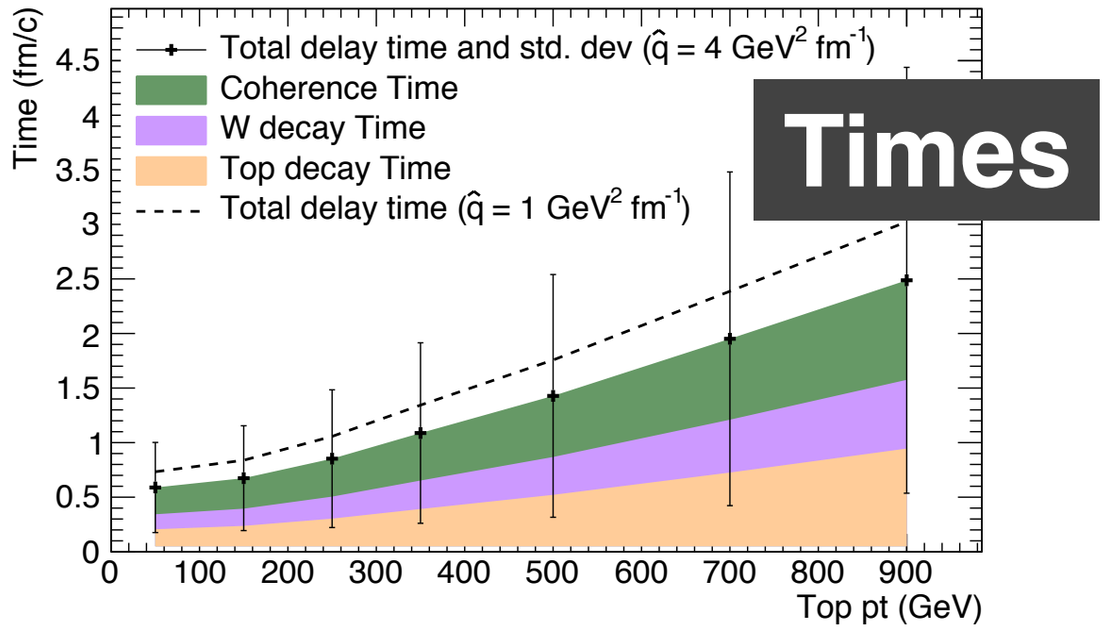
$\longrightarrow$ Take hadronic decay for one of them

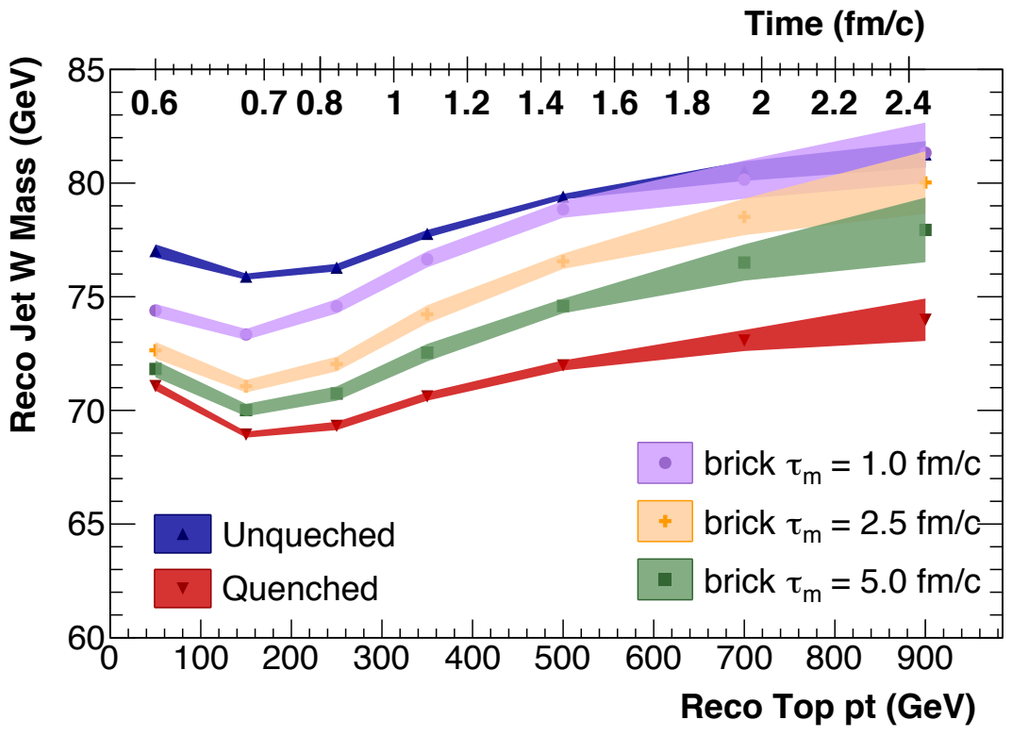
$t_{min} \sim \left[\frac{12}{\hat{q}\,\theta^2_{q\bar{q}}}\right]^{1/3} \simeq 0.5$ fm $\Rightarrow$ 1.8 fm $W \to q\bar{q}$ rest

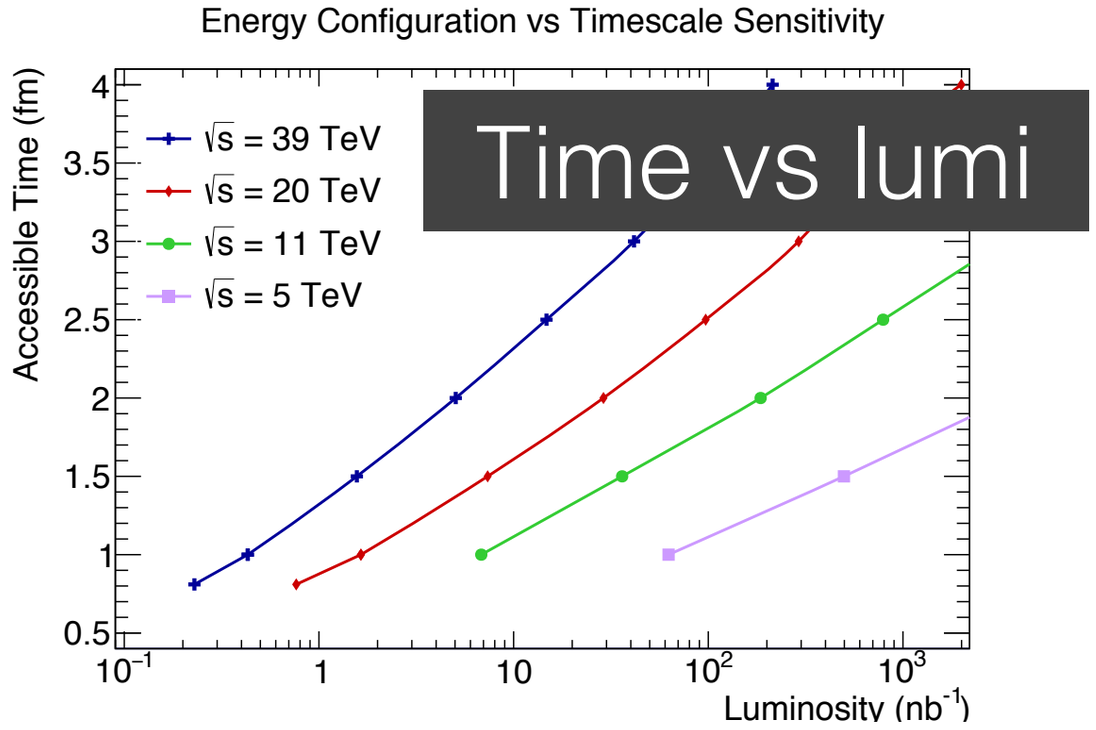
(Boosted) Top quark

L. Apolinario, G. Milhano, G. Salam, CAS in preparation

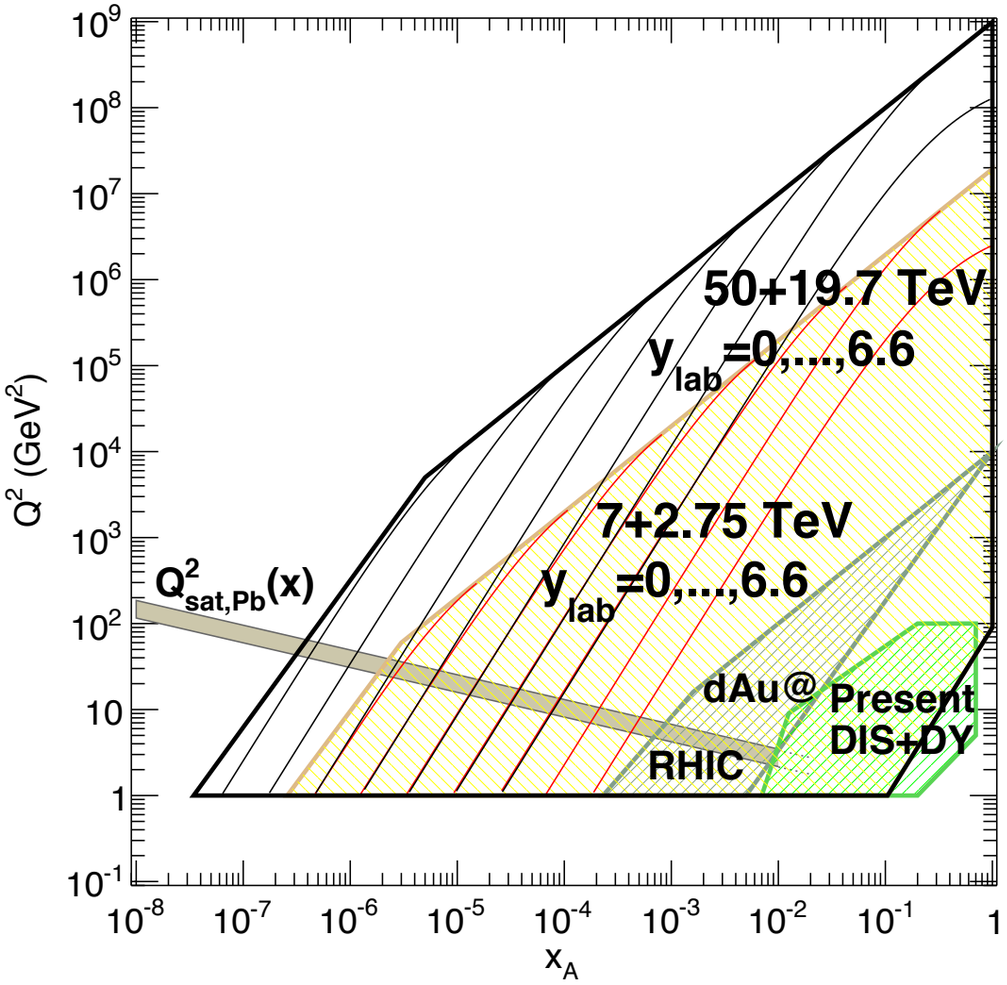


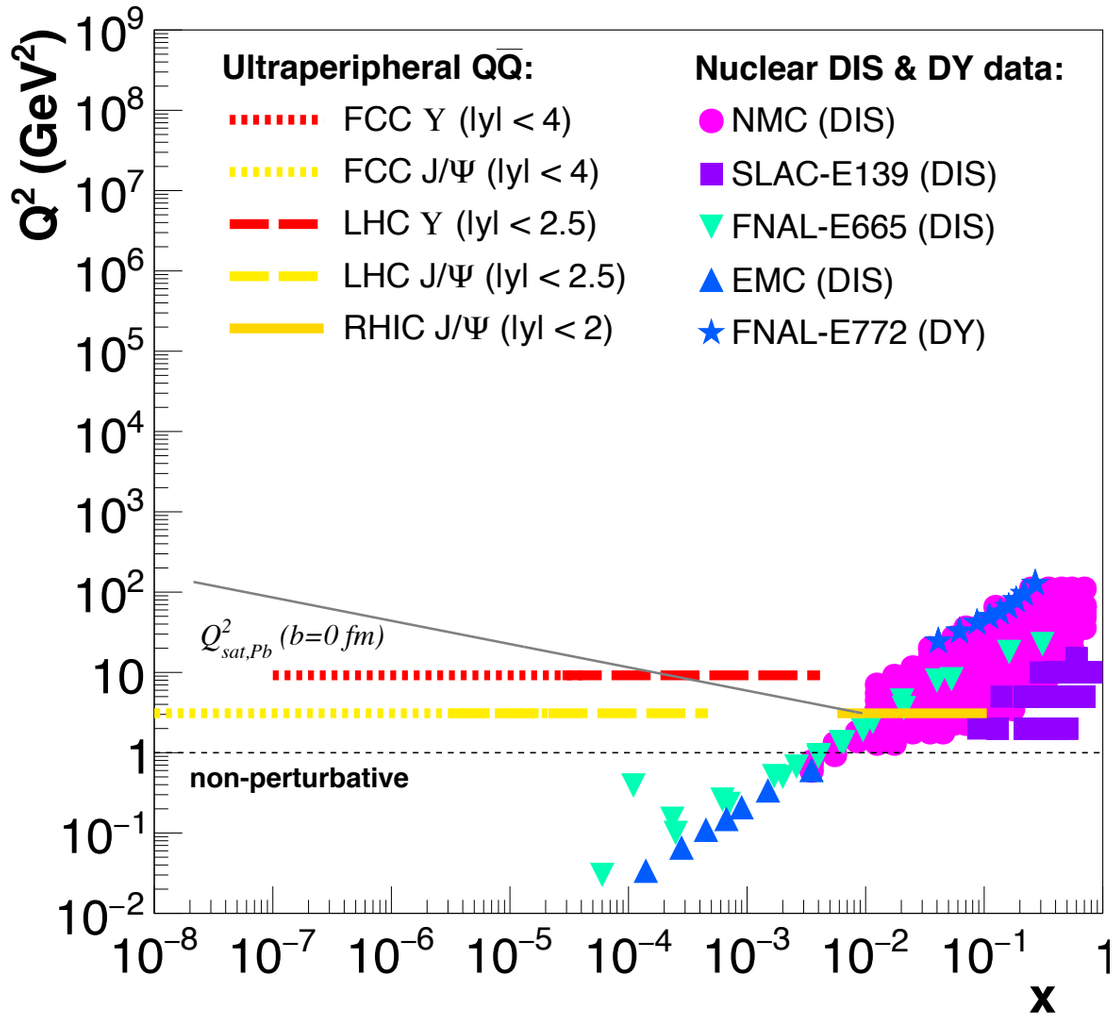






Small-x studies

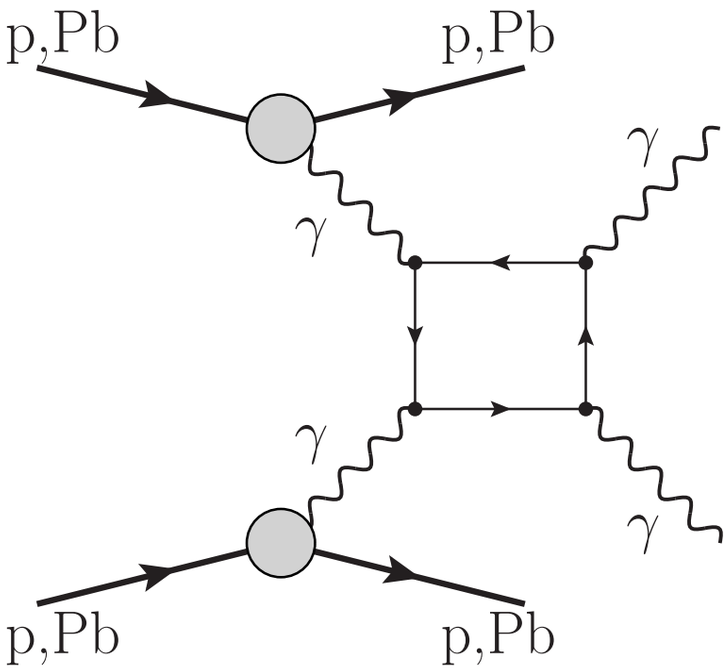


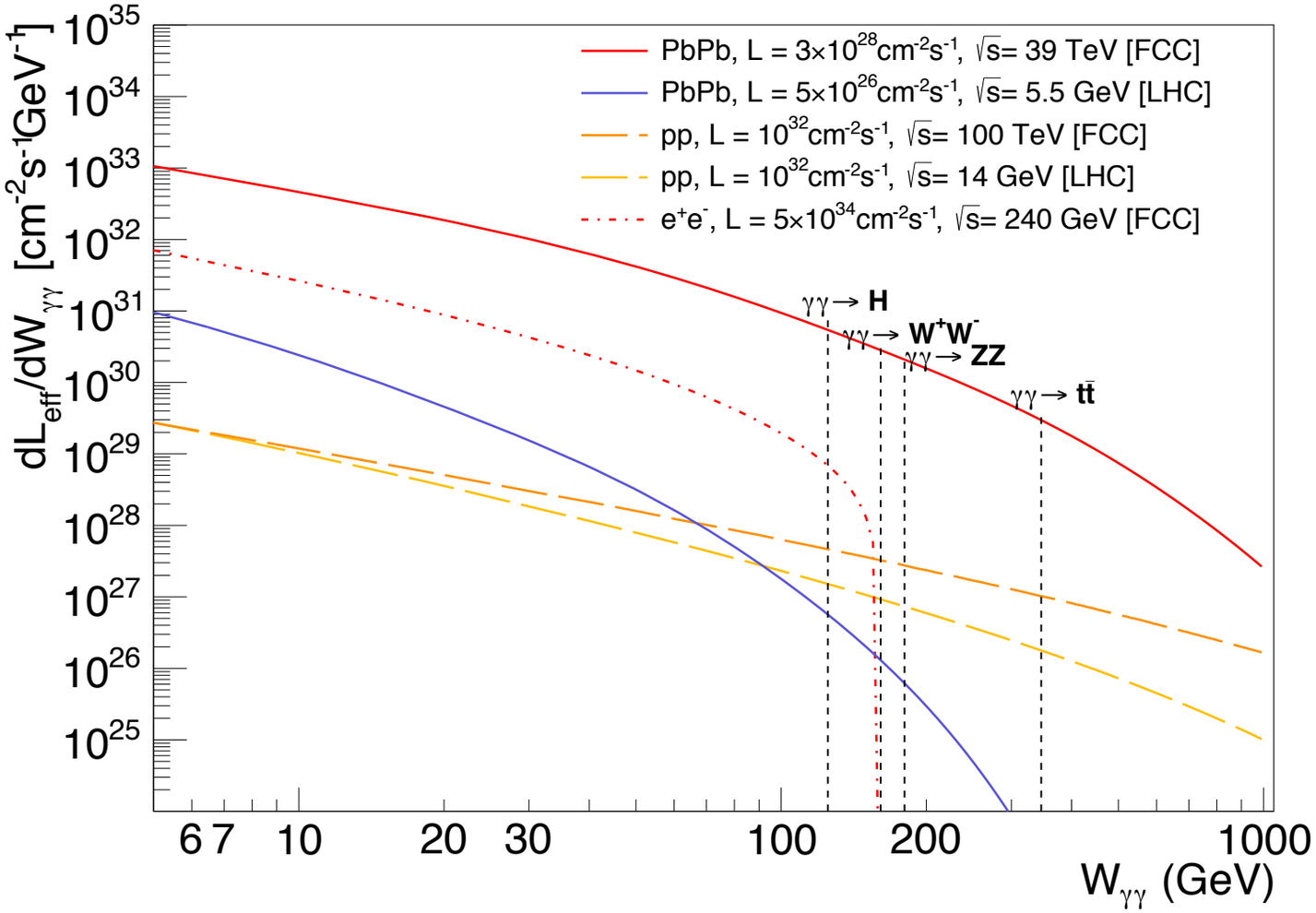


Humongous increase in small-x reach

Improvements in nuclear PDFs and Saturation searches
(also at large-x with tops or Higgs - new in HIC)

photon-photon collider



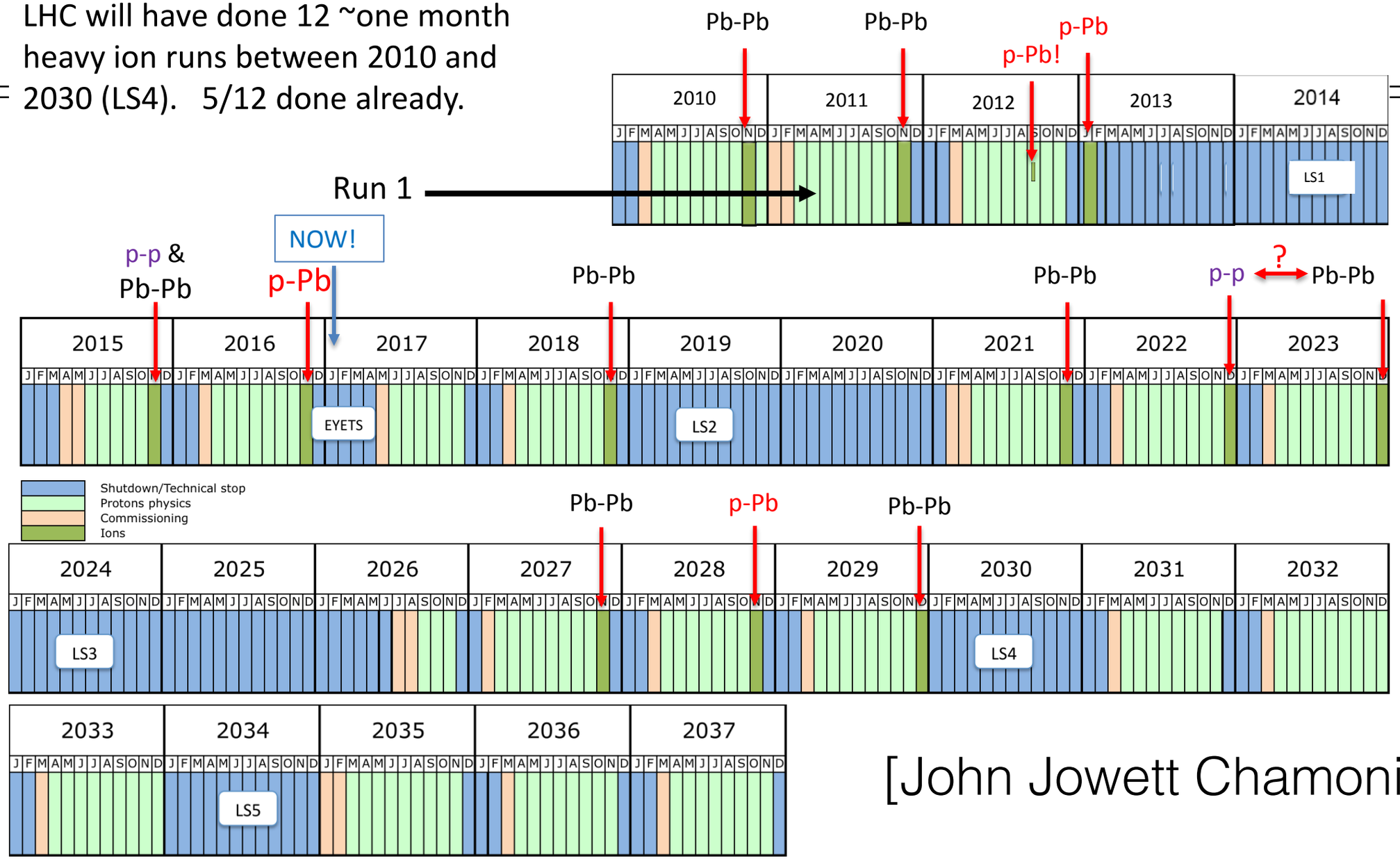


LO photon-photon to diphoton cross section

Some example thresholds in the EWK sector of the SM

LHC heavy-ion runs, past & approved future
+ species choices according to ALICE 2012 LoI (could vary if required)

LHC will have done 12 ~one month heavy ion runs between 2010 and 2030 (LS4). 5/12 done already.



[John Jowett Chamonix 2017]

J.M. Jowett, LHC Performance Workshop, Chamonix, 25/1/2017 5

Workshop on the physics of HL-LHC, and perspectives at HE-LHC

https://indico.cern.ch/event/647676/

Summary

- Physics using HI in a 100TeV collider [arXiv:1605.01389]
- New opportunities in Quark Gluon Plasma studies
  - Temperatures close to 1GeV? Charm/bottom
  - **Hydrodynamization/thermalization** form small to large systems
  - Completely new (hard) probes of the medium (e.g. tops or Higgs)
- Access to the very small-x region - **Saturation/nPDFs**
- **Use HIC for new purposes** - e.g. light-by-light scattering