THEORETICAL SUMMARY

Frontiers in Particle Physics: From Dark Matter to the LHC and Beyond

ASPEN, Jan 19-24 2014

Michelangelo L. Mangano

TH Unit, Physics Department, CERN

michelangelo.mangano@cern.ch

The best Theory Summary of this mtg, and more, has already been given, on day 1:

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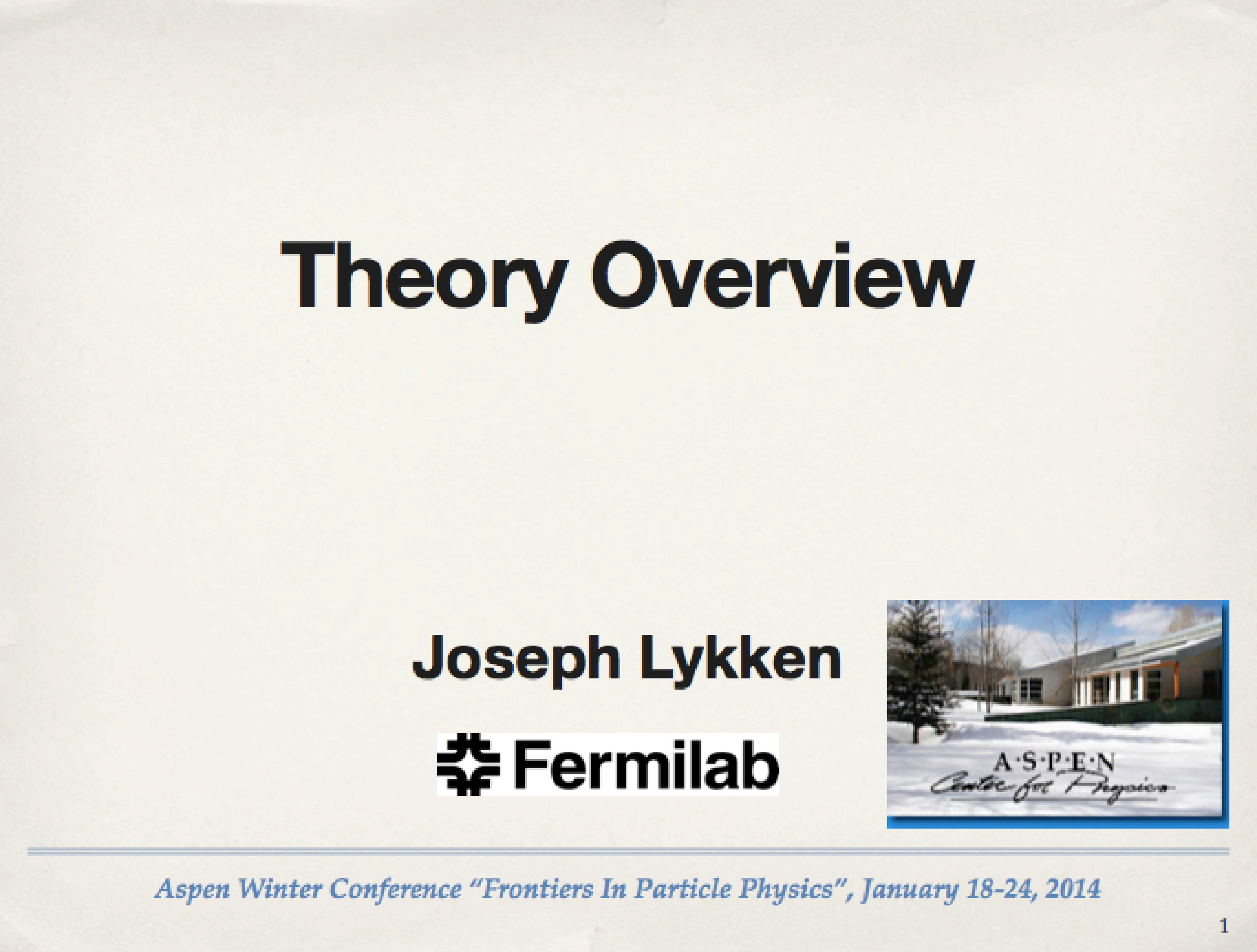

Theory Overview

Joseph Lykken

Fermilab

A·S·P·E·N Center for Physics

Aspen Winter Conference "Frontiers In Particle Physics", January 18-24, 2014

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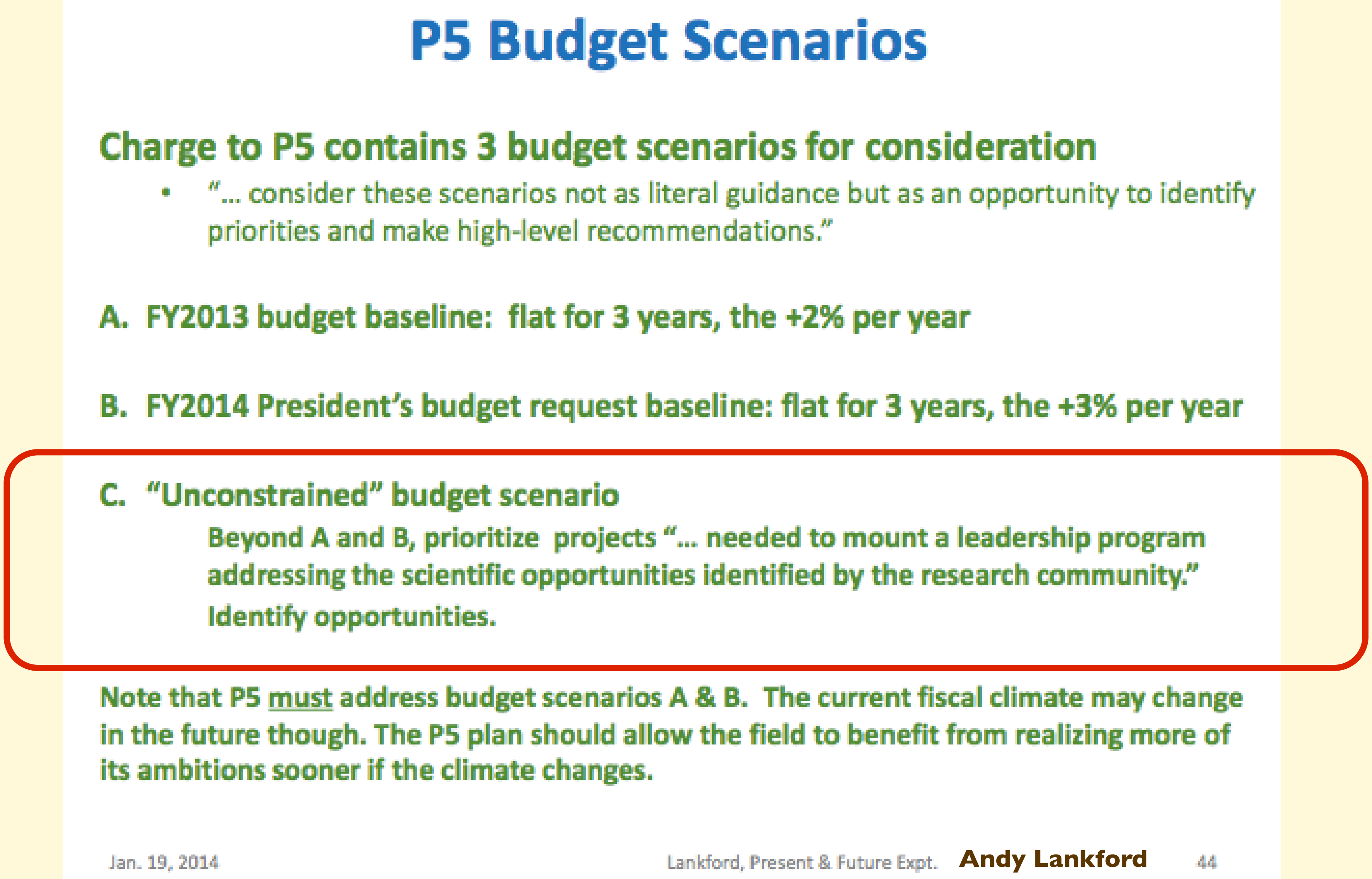
.... so I offer what follows to those who came late

My key message

- The days of “guaranteed” discoveries or of no-lose theorems in particle physics are over, at least for the time being ....
- .... but the big questions of our field remain wild open (hierarchy problem, flavour, neutrinos, DM, BAU, ...)
- This simply implies that, more than for the past 30 years, future HEP’s progress is to be driven by experimental exploration, possibly renouncing/reviewing deeply rooted theoretical bias
- This has become particularly apparent in the DM-related sessions:
  - Direct detection experiments and astrophysics are challenging the theoretical DM folklore as much as the LHC is challenging the theoretical folklore about the hierarchy problem.
- But great opportunities lie ahead, and the current challenges are simply hardening theorists’ ingenuity, creativity and skills



P5 Budget Scenarios

Charge to P5 contains 3 budget scenarios for consideration

- "... consider these scenarios not as literal guidance but as an opportunity to identify priorities and make high-level recommendations."

A. FY2013 budget baseline: flat for 3 years, the +2% per year

B. FY2014 President's budget request baseline: flat for 3 years, the +3% per year

C. "Unconstrained" budget scenario

Beyond A and B, prioritize projects "... needed to mount a leadership program addressing the scientific opportunities identified by the research community."

Identify opportunities.

Note that P5 must address budget scenarios A & B. The current fiscal climate may change in the future though. The P5 plan should allow the field to benefit from realizing more of its ambitions sooner if the climate changes.

Jan. 19, 2014 Lankford, Present & Future Expt. **Andy Lankford** 44

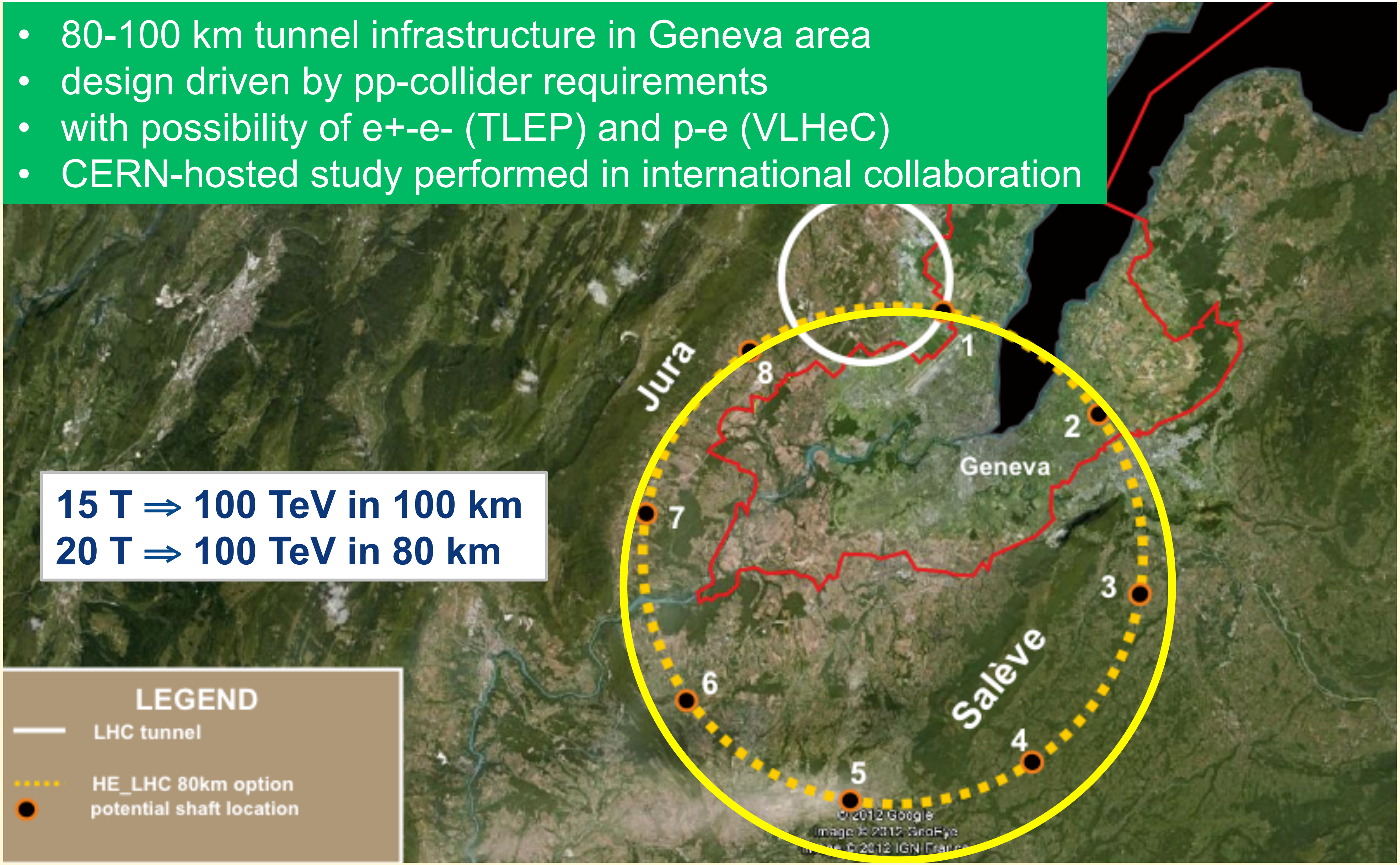
At this time of great excitement and confusion, it is crucial to be **ambitious** in defining the programmes that will truly push the boundaries of our knowledge, possibly waiting for better times to see them funded

A possible future

FCC Study (Future Circular Colliders)

CDR and cost review for the next ESU (2018)

- 80-100 km tunnel infrastructure in Geneva area
- design driven by pp-collider requirements
- with possibility of e+-e- (TLEP) and p-e (VLHeC)
- CERN-hosted study performed in international collaboration

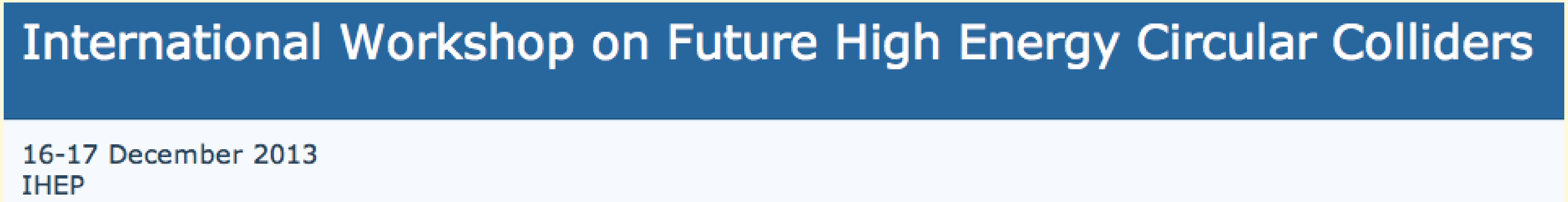


15 T ⇒ 100 TeV in 100 km
20 T ⇒ 100 TeV in 80 km

Future Circular Collider Study Kickoff Meeting

12-15 February 2014
University of Geneva, Geneva
Europe/Zurich timezone

Future Circular Collider Kickoff Meeting



International Workshop on Future High Energy Circular Colliders

16-17 December 2013
IHEP

THINK BIG, THINK BROAD

THE FRONTIERS OF THEORETICAL HEP:

- **BSM MODEL BUILDING**
- **PRECISION**

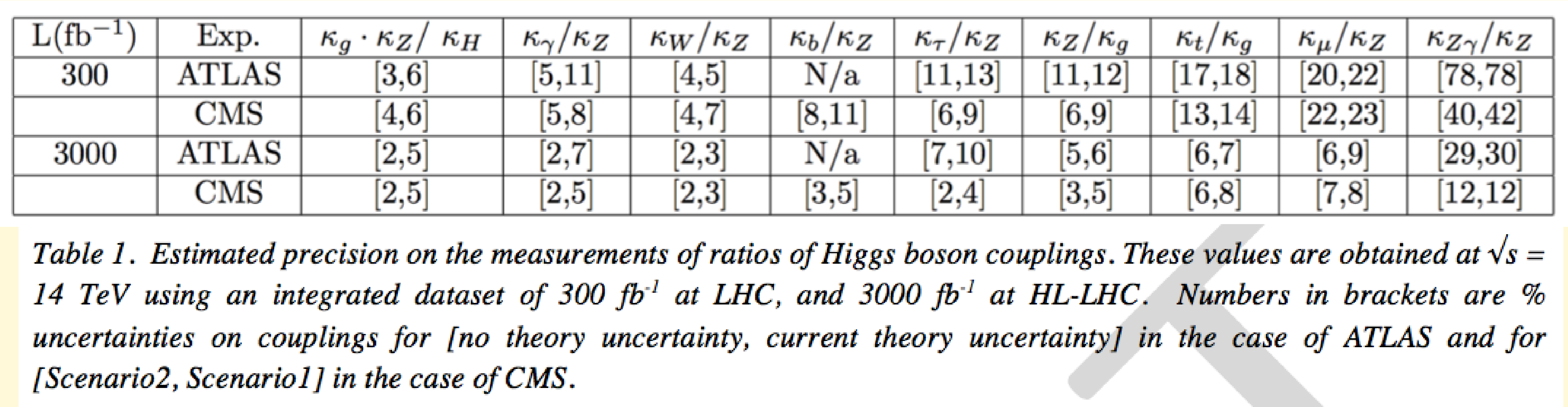
As in the case of the three experimental HEP frontiers, the theory frontiers support and stimulate each other, providing complementary perspectives in the interpretation and exploitation of the rich variety of experimental data

Precision physics

- Precision calculations demand years of dedicated and often frustrating work
  - high-Q physics
    - improve Perturbation Theory (**Petriello)**
    - implement perturbative knowledge in realistic descriptions of physical final states (resummation, shower MCs) (**Alioli)**
  - low-Q physics (e.g. for flavour) (**Jaeger)**
    - non-perturbative brick walls
    - lattice, HQET, models for power corrections, ... => validation w. data
- The reward is the comparison against data, and the knowledge that the results can be key to the progress of the field.
- Limited accuracy in some predictions does not mean that they cannot be improved
- Experimental progress is often a trigger for theoretical precision improvements

Higgs decays

Biglietti, Kroha



L(fb^{-1})	Exp.	$\kappa_g \cdot \kappa_Z / \kappa_H$	κ_γ/κ_Z	κ_W/κ_Z	κ_b/κ_Z	κ_τ/κ_Z	κ_Z/κ_g	κ_t/κ_g	κ_μ/κ_Z	$\kappa_{Z\gamma}/\kappa_Z$
300	ATLAS	[3,6]	[5,11]	[4,5]	N/a	[11,13]	[11,12]	[17,18]	[20,22]	[78,78]
	CMS	[4,6]	[5,8]	[4,7]	[8,11]	[6,9]	[6,9]	[13,14]	[22,23]	[40,42]
3000	ATLAS	[2,5]	[2,7]	[2,3]	N/a	[7,10]	[5,6]	[6,7]	[6,9]	[29,30]
	CMS	[2,5]	[2,5]	[2,3]	[3,5]	[2,4]	[3,5]	[6,8]	[7,8]	[12,12]

Table 1. Estimated precision on the measurements of ratios of Higgs boson couplings. These values are obtained at $\sqrt{s}$ = 14 TeV using an integrated dataset of 300 fb^{-1} at LHC, and 3000 fb^{-1} at HL-LHC. Numbers in brackets are % uncertainties on couplings for [no theory uncertainty, current theory uncertainty] in the case of ATLAS and for [Scenario2, Scenario1] in the case of CMS.

Note: assume no invisible Higgs decay contributing to the Higgs width

CMS Scenario 2: same systematics as 2012 (TH and EXP)
CMS Scenario 1: half the TH syst, and scale with 1/sqrt(L) the EXP syst

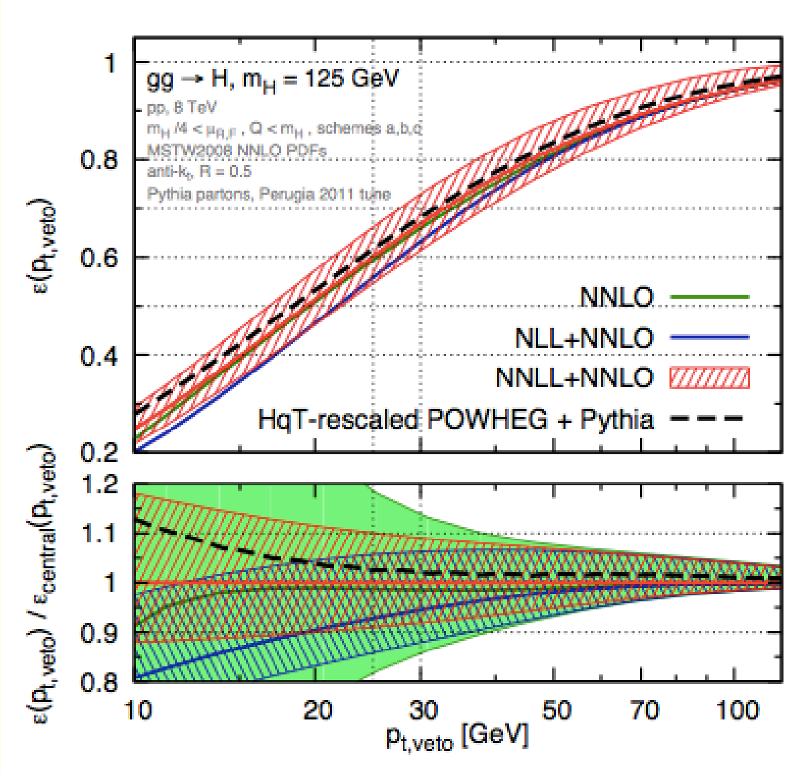
ATLAS Scenario 2: same TH systematics as 2012, EXP syst driven by stats scaled accordingly
ATLAS Scenario 1: same as 2, but TH syst →0

TH uncertainties here are driven by

- **calculation of absolute rates**
- **modeling (e.g. jet vetoes)**

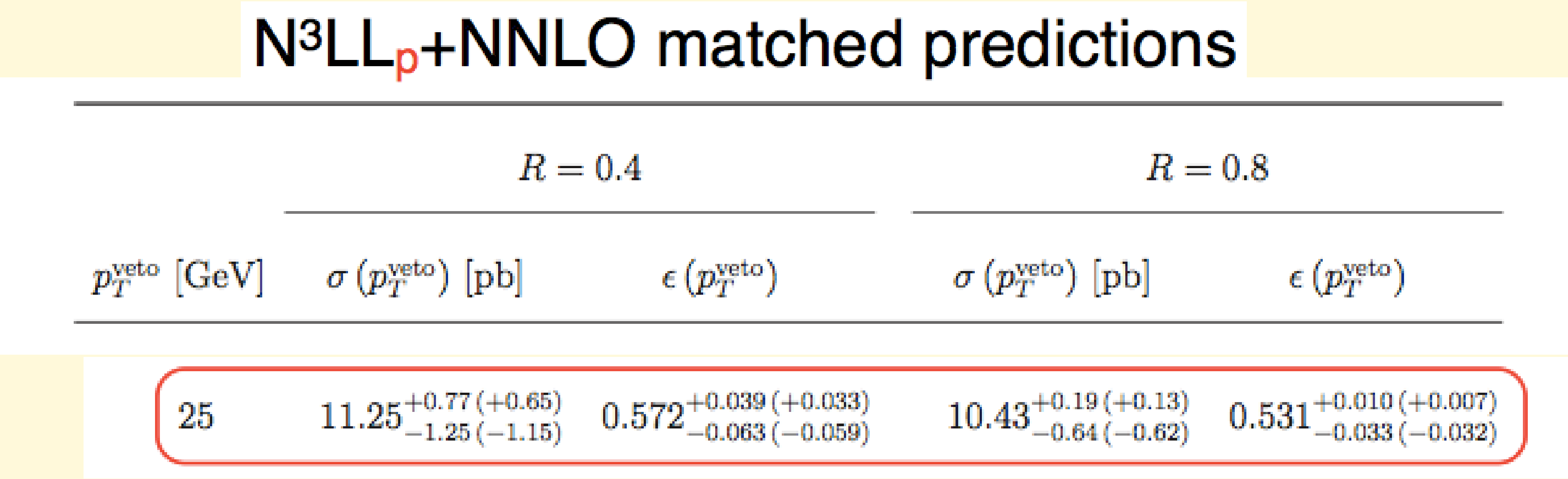
Ex. jet veto efficiency, required to reduce bg's to H→WW*

Banfi, Monni, Salam, Zanderighi, arXiv:1206.4998



± 20% at NNLO, for pt=25 GeV

Neubert



N^3LL_p+NNLO matched predictions

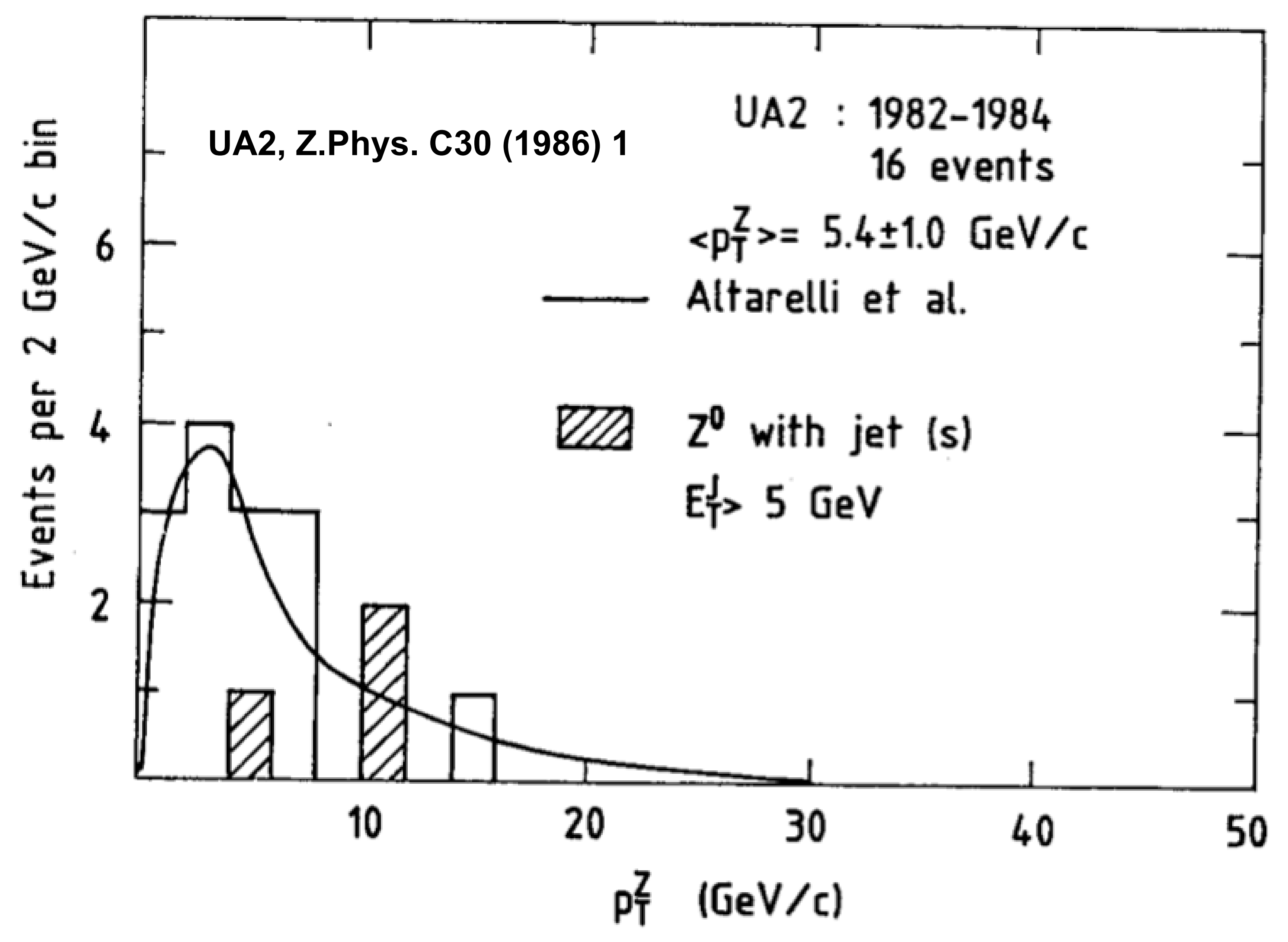
	$R = 0.4$		$R = 0.8$	
p_T^{veto} [GeV]	$\sigma\left(p_T^{veto}\right)$ [pb]	$\epsilon\left(p_T^{veto}\right)$	$\sigma\left(p_T^{veto}\right)$ [pb]	$\epsilon\left(p_T^{veto}\right)$
25	$11.25^{+0.77\,(+0.65)}_{-1.25\,(-1.15)}$	$0.572^{+0.039\,(+0.033)}_{-0.063\,(-0.059)}$	$10.43^{+0.19\,(+0.13)}_{-0.64\,(-0.62)}$	$0.531^{+0.010\,(+0.007)}_{-0.033\,(-0.032)}$

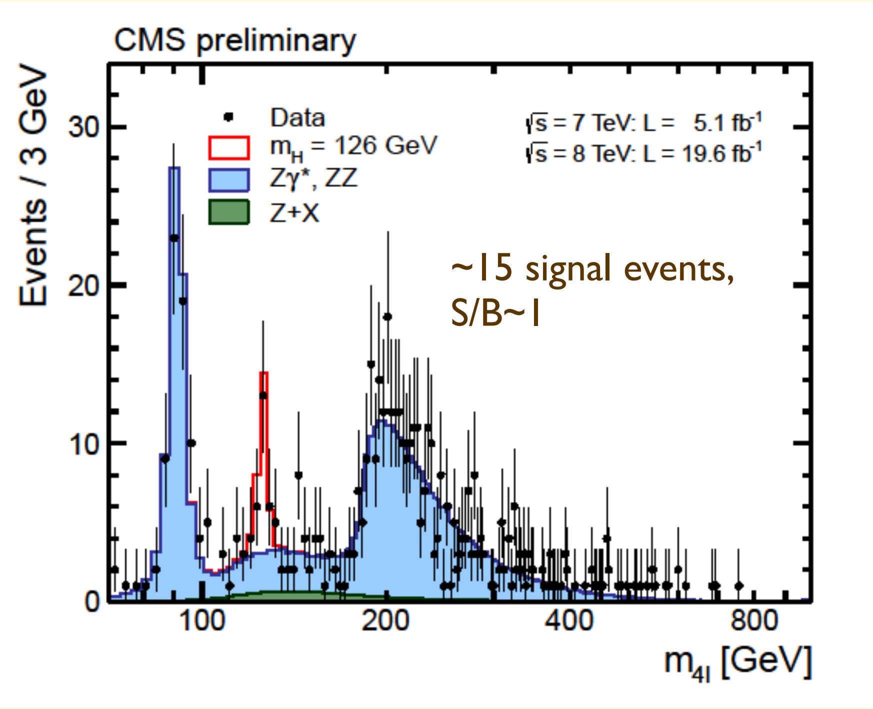
± 5%

± 4%

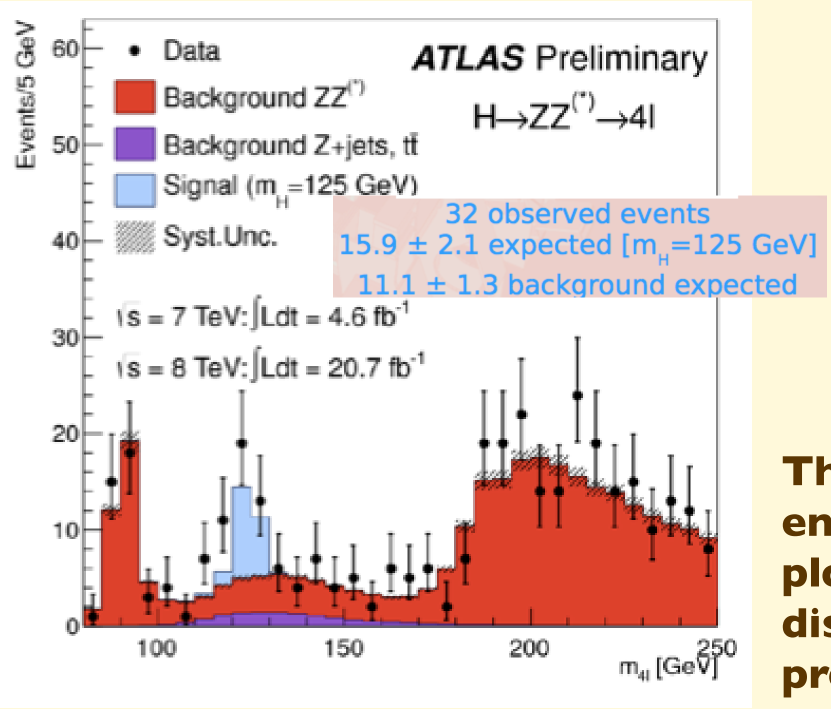
Towards experimental constraints on Higgs production dynamics ....

To put it in perspective, W/Z physics started like this ....., from a score of events:


UA2, Z.Phys. C30 (1986) 1

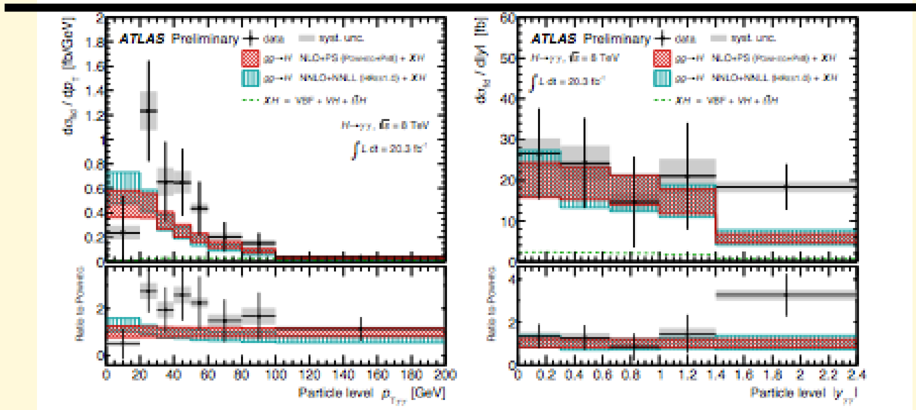


~15 signal events, S/B~1

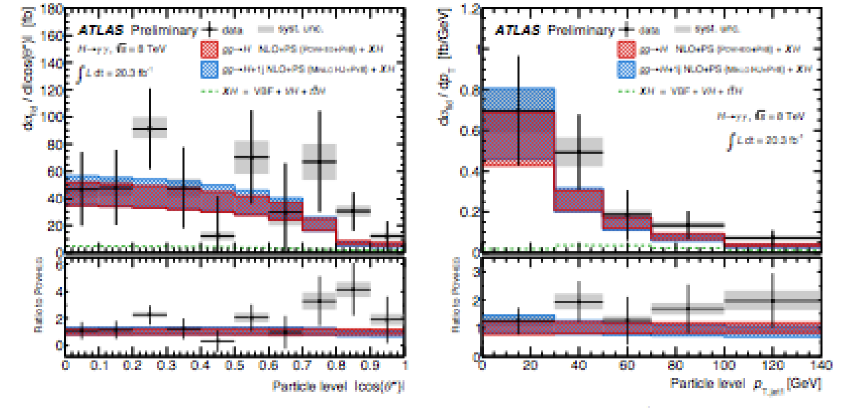


32 observed events
15.9 ± 2.1 expected [m_H=125 GeV]
11.1 ± 1.3 background expected

There is already enough to start plotting pt(H), N_{jet} distribution in H production, etc.



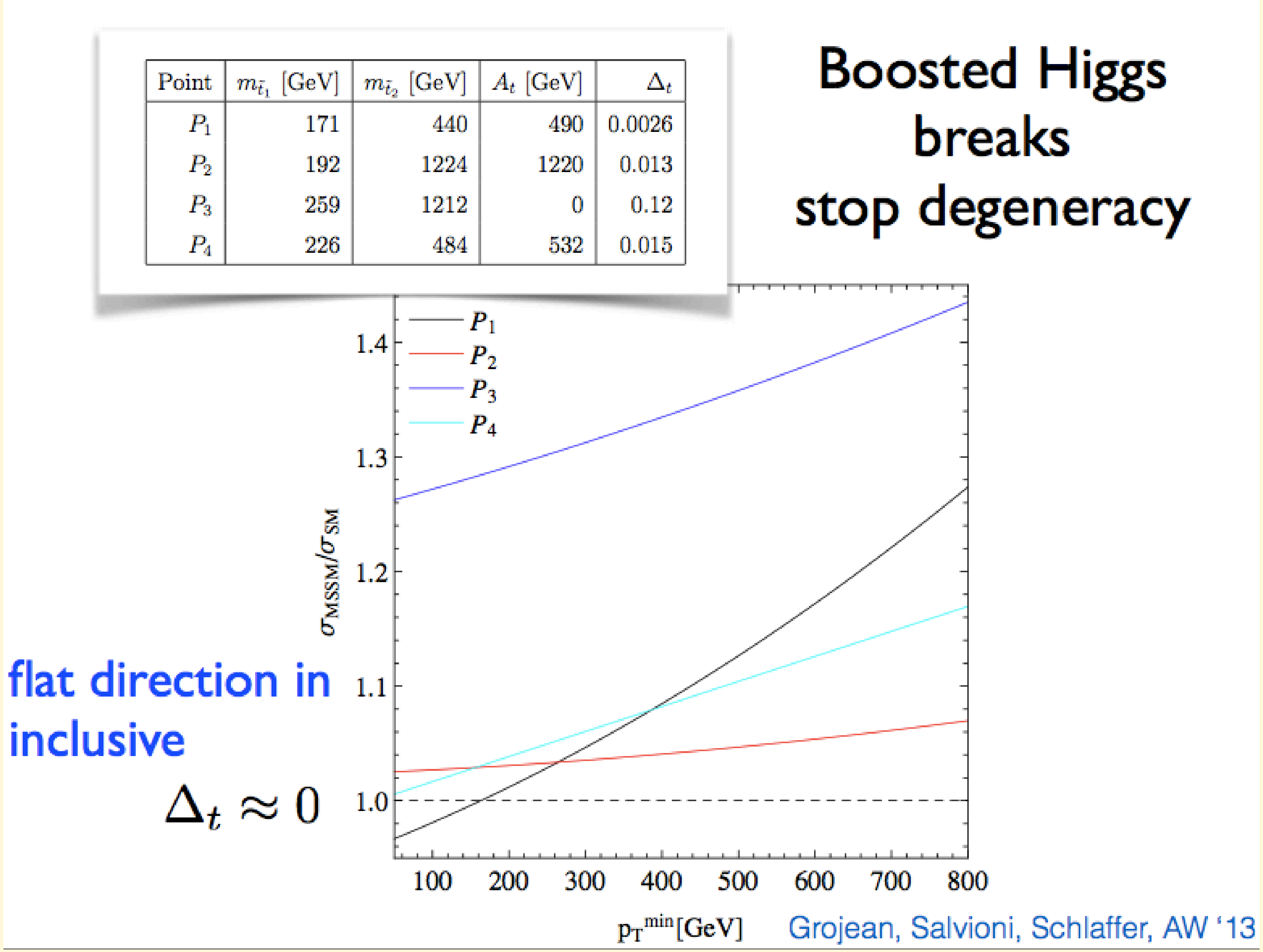
(a) $p_T^{\gamma\gamma}$ (b) $|y^{\gamma\gamma}|$



Differential cross sections of the Higgs boson measured in the diphoton decay channel with the ATLAS detector using 8 TeV proton-proton collision data, ATLAS-CONF-2013-072

Theoretical control on the pT(H) spectrum, at pT≫m_{top} , constrains also the presence of new physics in the gg→H loop

Weiler



Point	$m_{\tilde{t}_1}$ [GeV]	$m_{\tilde{t}_2}$ [GeV]	A_t [GeV]	Δ_t
P_1	171	440	490	0.0026
P_2	192	1224	1220	0.013
P_3	259	1212	0	0.12
P_4	226	484	532	0.015

Boosted Higgs breaks stop degeneracy

flat direction in inclusive

$\Delta_t \approx 0$

Grojean, Salvioni, Schlaffer, AW '13

Theoretical uncertainties on inclusive production rates (Higgs XS WG, arXiv:1101.0593)

14 TeV	δ(pert. theory)	δ(PDF, α_S)
gg→H	± 10 %	± 7%
VBF (WW→H)	± 1 %	± 2%
qq→WH	± 0.5 %	± 4%
(qq,gg)→ZH	± 2 %	± 4%
(qq,gg)→ttH	± 8 %	± 9%

Improve with higher-loop calculations:
gg->H @ NNNLO
ttH @ NNLO

Petriello

Improve with dedicated QCD measurements, and appropriate calculations

Huston

Theory is however improving at a fast pace!

Petriello

Available differential NNLO results:

- **pp → H** [Anastasiou, Melnikov, Petriello (**2005**); Catani, Grazzini (**2007**)]
- **pp → V** [Melnikov, Petriello (**2006**); Catani, Cieri, Ferrera, de Florian, Grazzini (**2009**)]
- **pp → WH** [Ferrera, Grazzini, Tramontano (**2011**)]
- **pp → γγ** [Catani, Cieri, de Florian, Ferrera, Grazzini (**2011**)]
- **pp → dijet (gg channel)** [Gehrmann-De Ridder, Gehrmann, Glover, Pires (**2013**)]
- **pp → tt (total cross section)** [Czakon, Mitov (2012); Czakon, Fiedler, Mitov (**2013**)]
- **pp → H + jet (gg channel)** [Boughezal, Caola, Melnikov, Petriello, Schulze (**2013**)]
- **pp → (Z →$\ell^+\ell^-$) + γ** [M. Grazzini, S. Kallweit, D.Rathlev, A. Torre, (**2013**)]

and the first partial results for H production at NNNLO are appearing ....

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Petriello

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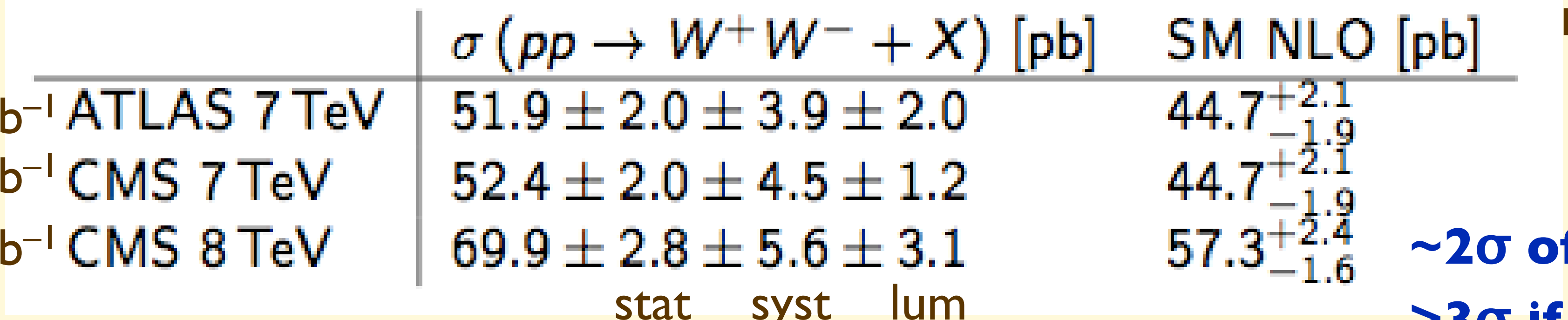
The reliability of absolute predictions, and the proper assignment of systematic uncertainties, are crucial for the use of TH calculations in the context of Higgs studies or BSM searches. Robustness of predictions will emerge from "circumstantial evidence", relying on a large number of complementary studies (e.g. SM XS measurements and tests of PDF)

Inclusive “SM” cross sections

Examples

Berryhill

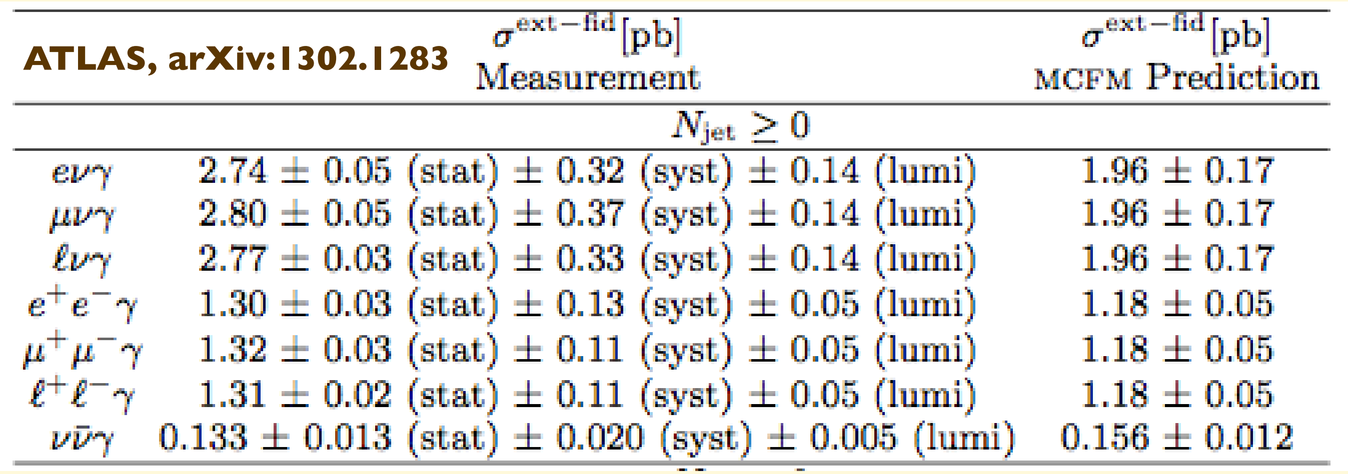


	$\sigma(pp \to W^+W^- + X)$ [pb]	SM NLO [pb]
4.6fb^{-1} ATLAS 7 TeV	$51.9 \pm 2.0 \pm 3.9 \pm 2.0$	$44.7^{+2.1}_{-1.9}$
4.6fb^{-1} CMS 7 TeV	$52.4 \pm 2.0 \pm 4.5 \pm 1.2$	$44.7^{+2.1}_{-1.9}$
3.5fb^{-1} CMS 8 TeV	$69.9 \pm 2.8 \pm 5.6 \pm 3.1$	$57.3^{+2.4}_{-1.6}$
	stat syst lum	

~2σ off

>3σ if combined

Exptl syst’s is theory dominated (jet veto efficiencies, PDFs, ...)



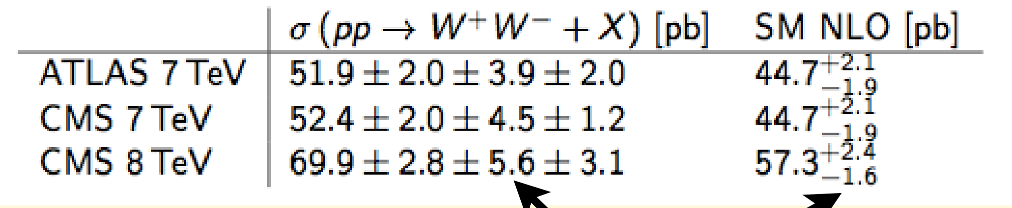
ATLAS, arXiv:1302.1283	$\sigma^{\text{ext-fid}}$[pb] Measurement	$\sigma^{\text{ext-fid}}$[pb] MCFM Prediction
	$N_{\text{jet}} \geq 0$	
$e\nu\gamma$	2.74 ± 0.05 (stat) ± 0.32 (syst) ± 0.14 (lumi)	1.96 ± 0.17
$\mu\nu\gamma$	2.80 ± 0.05 (stat) ± 0.37 (syst) ± 0.14 (lumi)	1.96 ± 0.17
$\ell\nu\gamma$	2.77 ± 0.03 (stat) ± 0.33 (syst) ± 0.14 (lumi)	1.96 ± 0.17
$e^+e^-\gamma$	1.30 ± 0.03 (stat) ± 0.13 (syst) ± 0.05 (lumi)	1.18 ± 0.05
$\mu^+\mu^-\gamma$	1.32 ± 0.03 (stat) ± 0.11 (syst) ± 0.05 (lumi)	1.18 ± 0.05
$\ell^+\ell^-\gamma$	1.31 ± 0.02 (stat) ± 0.11 (syst) ± 0.05 (lumi)	1.18 ± 0.05
$\nu\bar{\nu}\gamma$	0.133 ± 0.013 (stat) ± 0.020 (syst) ± 0.005 (lumi)	0.156 ± 0.012

Wγ: ~ 2σ off

Zγ: OK to < 1σ

- How far can we take similar discrepancies, should they increase to the 3σ level and be confirmed at 14 TeV ? *They could be hiding charginos, sleptons, ...*

- They appear to be syst limited: what more can be done to reduce the syst?



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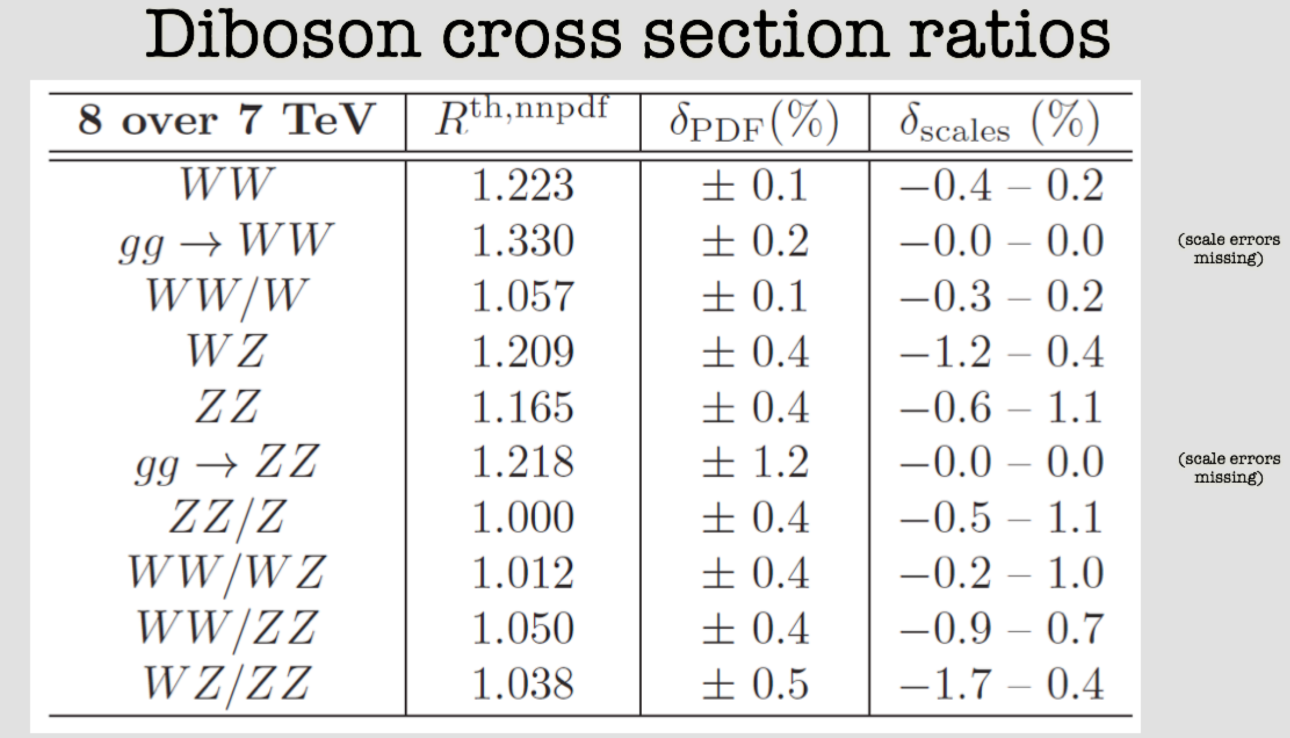
CMS 8 TeV	$69.9 \pm 2.8 \pm 5.6 \pm 3.1$	$57.3^{+2.4}_{-1.6}$

(1) Theory syst's in the prediction and in the measurement are correlated

(2) TH syst's in σ(WW)/σ(W) is much reduced, and syst(Lumi)=0

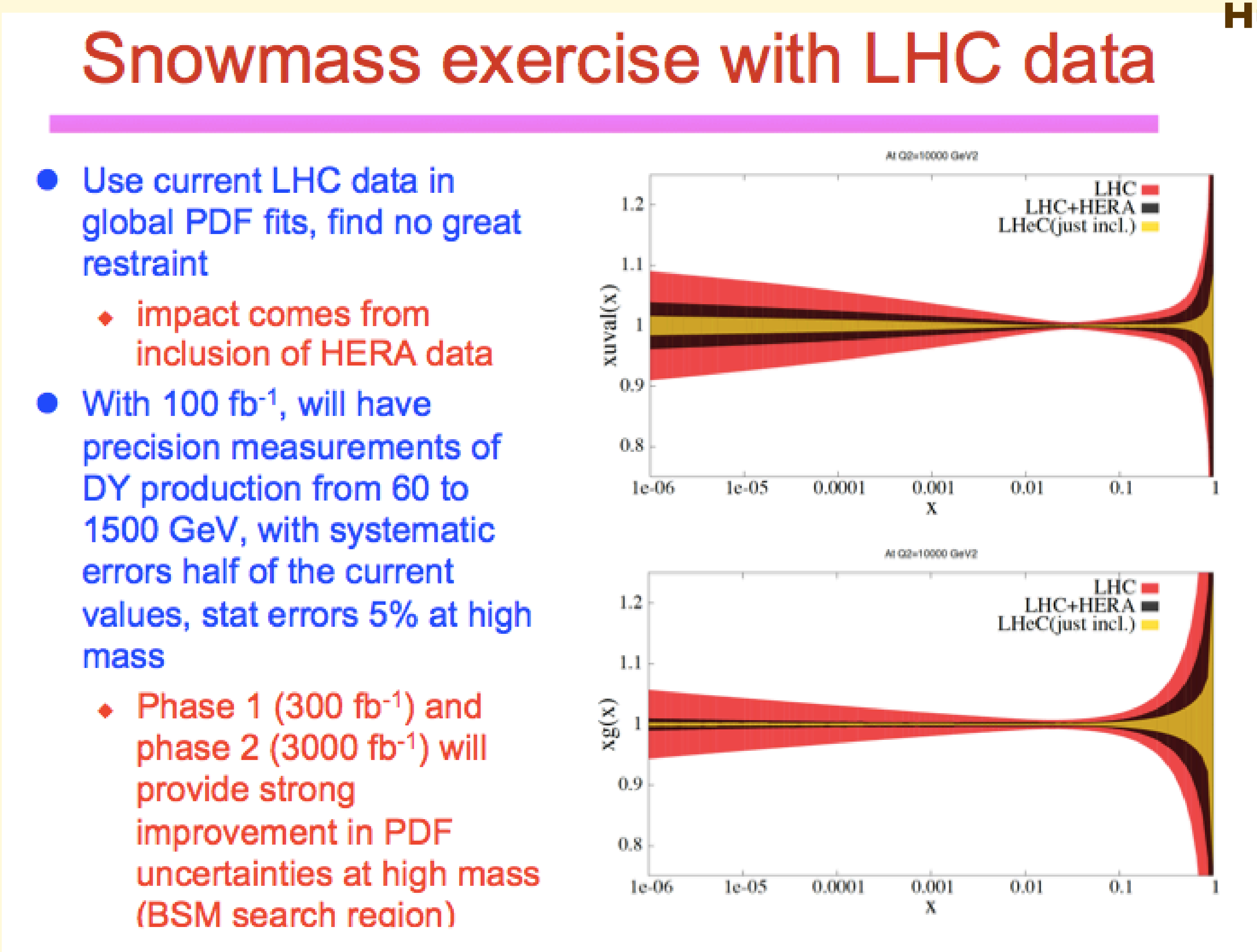


Diboson cross section ratios

8 over 7 TeV	$R^{\rm th,nnpdf}$	$\delta_{\rm PDF}(\%)$	$\delta_{\rm scales}$ (%)	
WW	1.223	$\pm$ 0.1	-0.4 – 0.2	
$gg \to WW$	1.330	$\pm$ 0.2	-0.0 – 0.0	(scale errors missing)
WW/W	1.057	$\pm$ 0.1	-0.3 – 0.2	
WZ	1.209	$\pm$ 0.4	-1.2 – 0.4	
ZZ	1.165	$\pm$ 0.4	-0.6 – 1.1	
$gg \to ZZ$	1.218	$\pm$ 1.2	-0.0 – 0.0	(scale errors missing)
ZZ/Z	1.000	$\pm$ 0.4	-0.5 – 1.1	
WW/WZ	1.012	$\pm$ 0.4	-0.2 – 1.0	
WW/ZZ	1.050	$\pm$ 0.4	-0.9 – 0.7	
WZ/ZZ	1.038	$\pm$ 0.5	-1.7 – 0.4	

(3) TH syst's in 8 /14 TeV XS ratios are down to the permille level

(4) Can we turn these into sub-percent measurements?



Snowmass exercise with LHC data

- Use current LHC data in global PDF fits, find no great restraint
  - impact comes from inclusion of HERA data
- With 100 fb^{-1}, will have precision measurements of DY production from 60 to 1500 GeV, with systematic errors half of the current values, stat errors 5% at high mass
  - Phase 1 (300 fb^{-1}) and phase 2 (3000 fb^{-1}) will provide strong improvement in PDF uncertainties at high mass (BSM search region)

Ask not what the PDF can do for the LHC, but what the LHC can do for the PDF

Continued progress taking place also at low-Q^2

Emmanuel Stamou

We revisited and improved the SM prediction of the rare decay $B_s \to \mu^+\mu^-$

(actually of all $B_{s,d} \to \ell^+\ell^-$ decays)

- NNLO QCD corrections reduce μ_0 dependence from $m_t(\mu_0)$
  from 1.8%@NLO QCD → 0.2%@NNLO QCD
- NLO EW corrections reduce EW scheme dependence
  from 8%@LO → 0.6%@NLO EW
- the size of the NLO EW corrections is
  (3 – 5)% depending on μ_0 and scheme
- the theory uncertainty of the BR is
  ≤ 7% mainly from $f_{B_s}(4\%)$, $V_{cb}(4.3\%)$, non.-param.(1.5%)

$$\mathrm{BR}(B_s \to \mu^+\mu^-)^{\mathrm{exp}} = (2.9 \pm 0.7) \times 10^{-9}$$

[LHCb-CONF-2013-013,CMS-PAS-BPH-13-007]

$$\mathrm{BR}(B_s \to \mu^+\mu^-)^{\mathrm{SM}} = (3.65 \pm 0.23) \times 10^{-9}$$

[Bobeth, Gorbahn, Hermann, Misiak, ES, Steinhauser '13, arXiv:1311.0903]

Error Budget

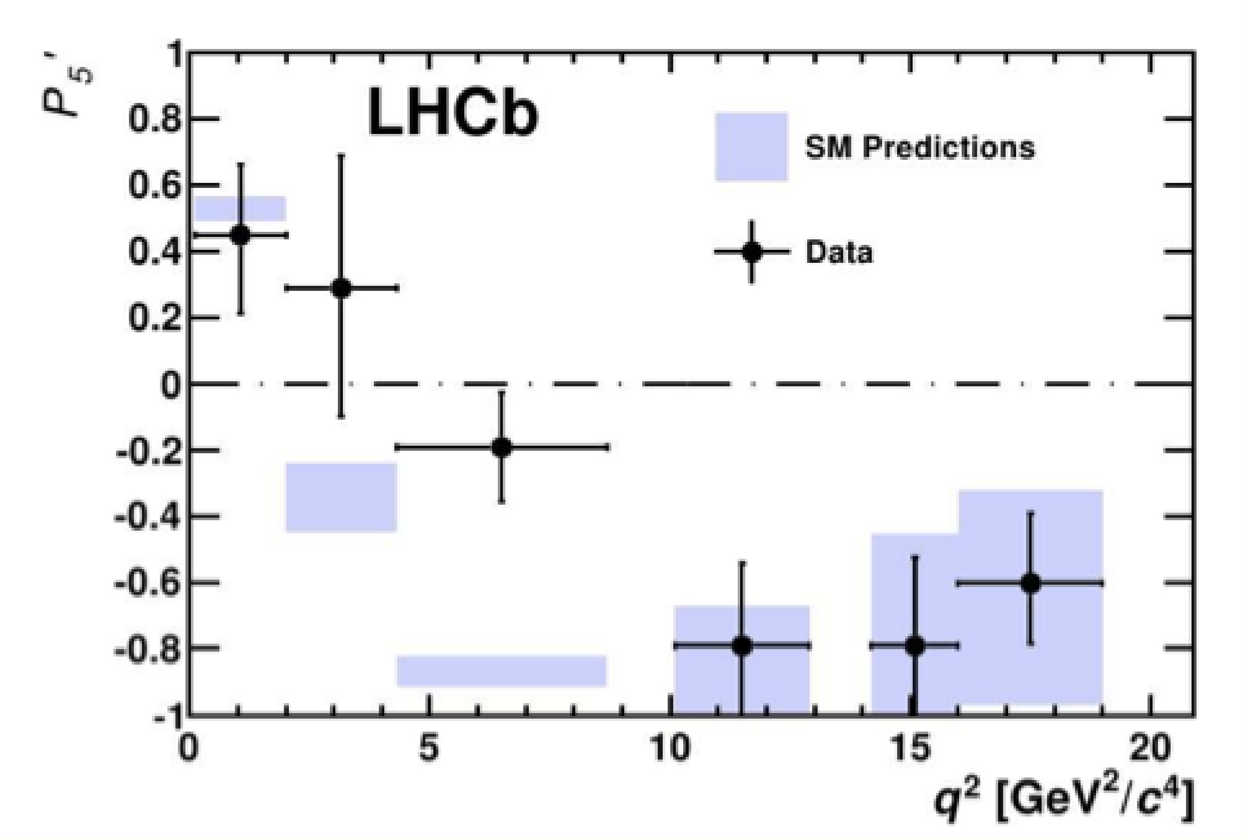
f_{B_s}	CKM	τ_H^s	M_t	α_s	other param.	**non-param.**	Σ
4.0%	4.3%	1.3%	1.6%	0.1%	< 0.1%	1.5%	6.4%

On the other hand, some low-Q^2 QCD effects remain uncalculable from first principles, limiting the possibility to interpret anomalies existing in the flavour sector

- direct CPV in charm decays (LHCb)
- B → K∗μ+μ− anomaly (LHCb)
- like-sign dimuon charge asymmetry (D0)
- excess of B → D(∗)τν decays (BaBar)
- $(g-2)_\mu$

Exp: Shires, Johnson, Kinoshita, Gadfort

- B → K∗μ+μ− anomaly



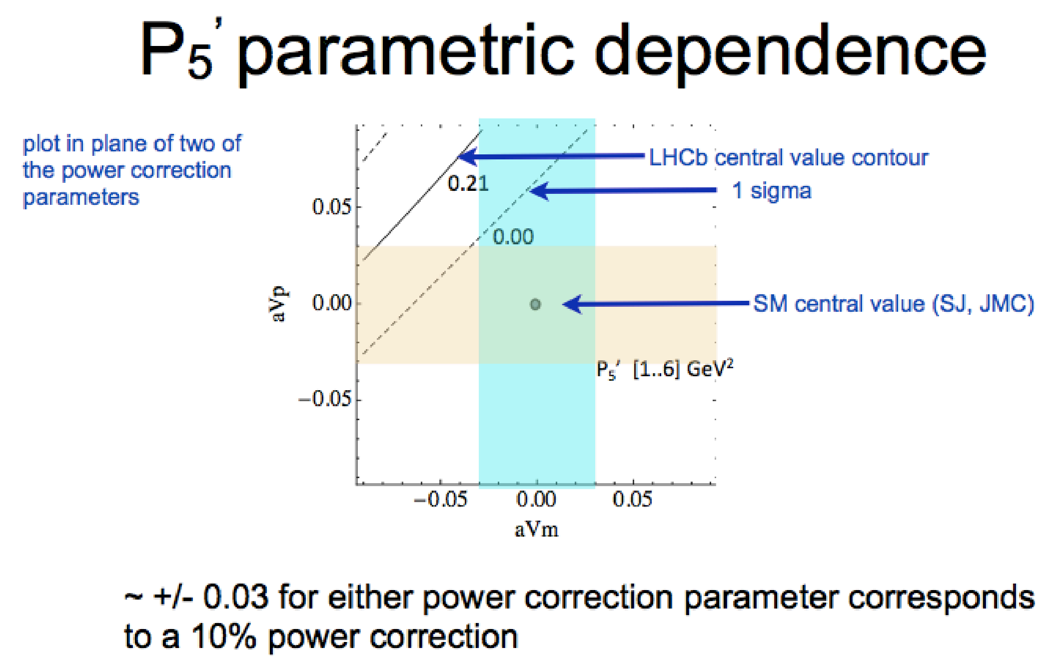
BSM: Altmannshofer

→ consistent NP explanation points to the operators $(\bar{s}\gamma_\mu P_{L/R} b)(\bar{\mu}\gamma^\mu \mu)$ with a generic scale of ∼ 35 TeV

→ models with a flavor changing Z' at (or below) the TeV scale are natural candidates to explain the anomaly

generic tree	$\frac{1}{\Lambda_{NP}^2}(\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{NP} \simeq 35$ TeV
MFV tree	$\frac{1}{\Lambda_{NP}^2} V_{tb} V_{ts}^* (\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{NP} \simeq 7$ TeV
generic loop	$\frac{1}{\Lambda_{NP}^2}\frac{1}{16\pi^2}(\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{NP} \simeq 3$ TeV
MFV loop	$\frac{1}{\Lambda_{NP}^2}\frac{1}{16\pi^2} V_{tb} V_{ts}^* (\bar{s}\gamma_\nu P_L b)(\bar{\mu}\gamma^\nu \mu)$	$\Lambda_{NP} \simeq 0.6$ TeV

SM: Jaeger



P_5' parametric dependence

plot in plane of two of the power correction parameters

~ +/- 0.03 for either power correction parameter corresponds to a 10% power correction

Status of BSM model building

- Until few yrs ago, we had a benchmark model, MSSM, expected to deliver the following:
  - low-mass Higgs h^0, no heavier than ~130 GeV
  - ~TeV scale squarks and gluinos, to be seen rapidly at the LHC
    - ⇒ solution to the naturalness problem
  - extra Higgses (A^0 /H^0 /$H^\pm$) observed at the LHC
  - candidate for DM, confirmed by direct detection
  - interesting flavour phenomenology
    - explanation of $(g-2)_\mu$
    - sizable deviations from SM $B(B_S \to \mu^+ \mu^-)$
    - $\mu \to e\gamma$ observed at MEG, consistent with SUSY neutrino masses induced at the GUT scale
    - CPV in the Higgs or squark/gluino sector, to explain BAU
    - electric dipole moments (e, n) mearued, consistent with previous point

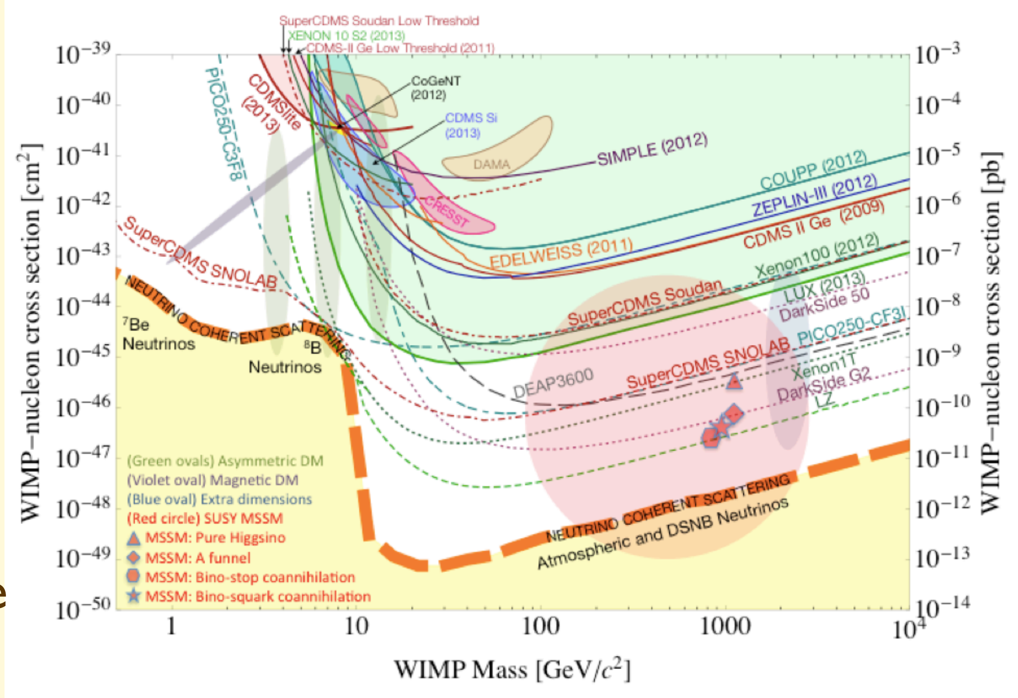
- Given our knowledge 4-5 yrs back, all of this could have happened by now.
- Models alternative to SUSY (extra dim, little Higgs, SILH, ...) were most often developed with the ambitious goal of matching the "natural" predisposition of SUSY to solve problems and to provide rich phenomenological consequences across the fields (LHC, flavour, astro/cosmo)
- None of the above happened.
- It may still happen with a few-year delay, stretching a bit the "naturalness".
- But a radical change in attitude in BSM model building is taking place, focusing on schemes that address individual issues or anomalies, leaving for later the understanding of the "grand picture"

Searches of DM from the sky

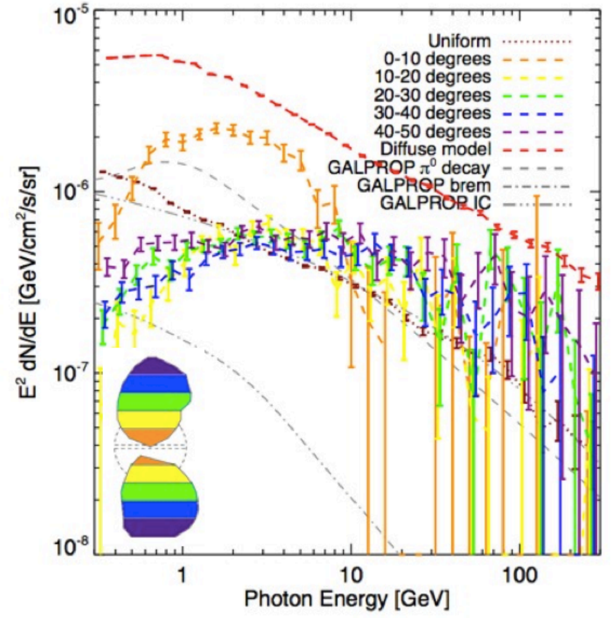
Broad array of direct detection experiments.
Important inconsistencies between their findings:

- lack of understanding of the bgs or efficiencies?
=> improve and extend detector technology (**Freese**)
=> make better use of annual phase info (**Lisanti**)

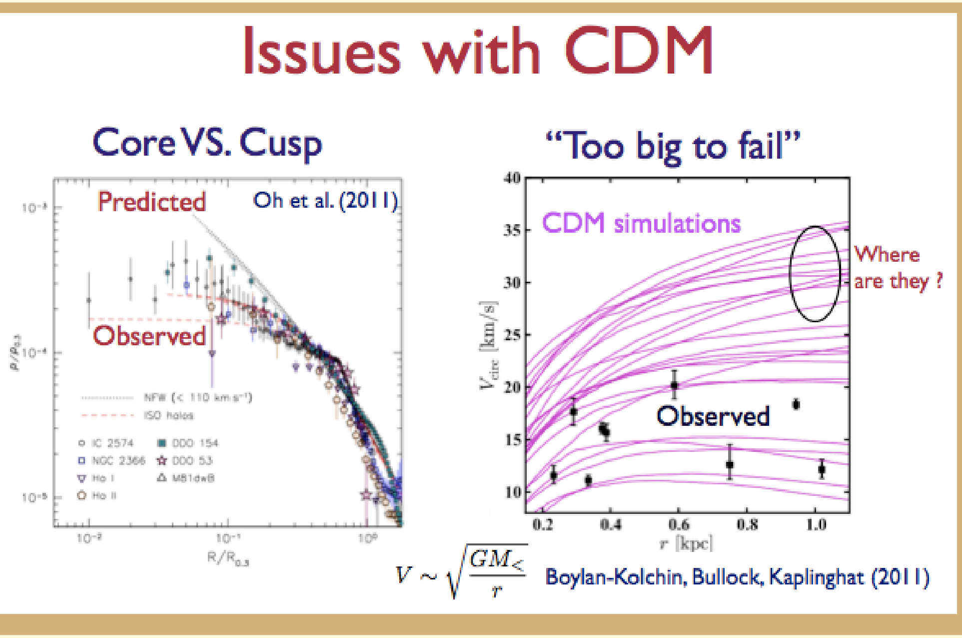
- consequence of the nature of the DM couplings and its interaction with the detectors? => explore more exotic BSM options **Zurek**



Slatyer



Spectral feature in few-GeV gamma rays from the inner Galaxy. It most likely shares an origin with the previously reported Galactic Center signal.
This feature is spectrally distinct from the known backgrounds
Signal consistent with annihilation of ~30 GeV DM into bottom or tau pairs



Issues with CDM

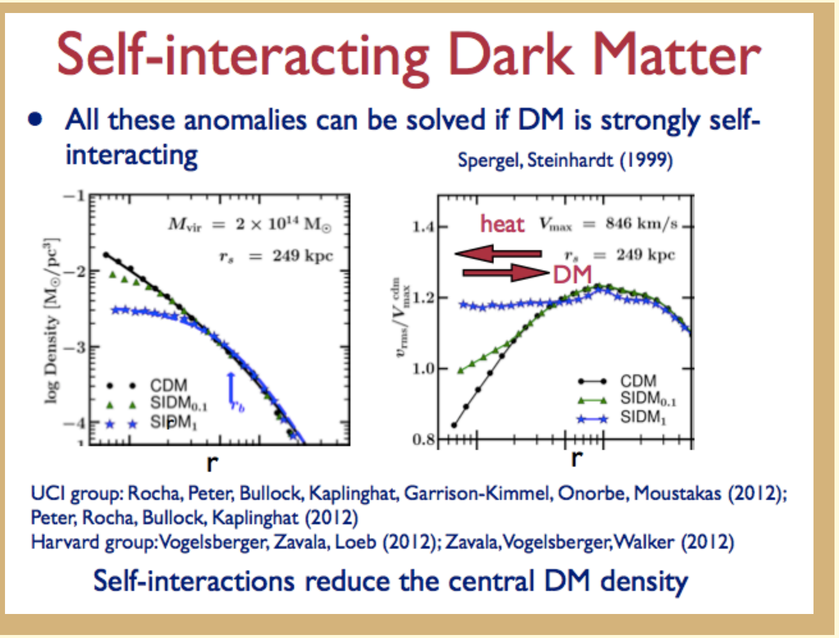
Core VS. Cusp

"Too big to fail"

$$V \sim \sqrt{\frac{GM_<}{r}}$$

Boylan-Kolchin, Bullock, Kaplinghat (2011)

Yu



Self-interacting Dark Matter

- All these anomalies can be solved if DM is strongly self-interacting

Spergel, Steinhardt (1999)

UCI group: Rocha, Peter, Bullock, Kaplinghat, Garrison-Kimmel, Onorbe, Moustakas (2012); Peter, Rocha, Bullock, Kaplinghat (2012)
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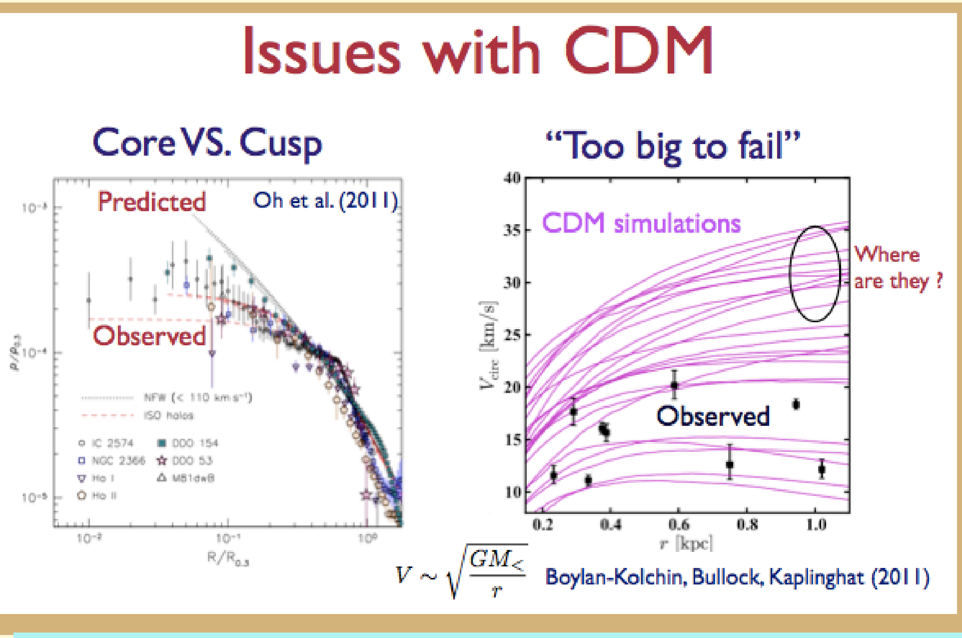
Self-interactions reduce the central DM density



Issues with CDM

Core VS. Cusp

Predicted

Oh et al. (2011)

Observed

"Too big to fail"

CDM simulations

Where are they ?

Observed

$V \sim \sqrt{\frac{GM_<}{r}}$ Boylan-Kolchin, Bullock, Kaplinghat (2011)

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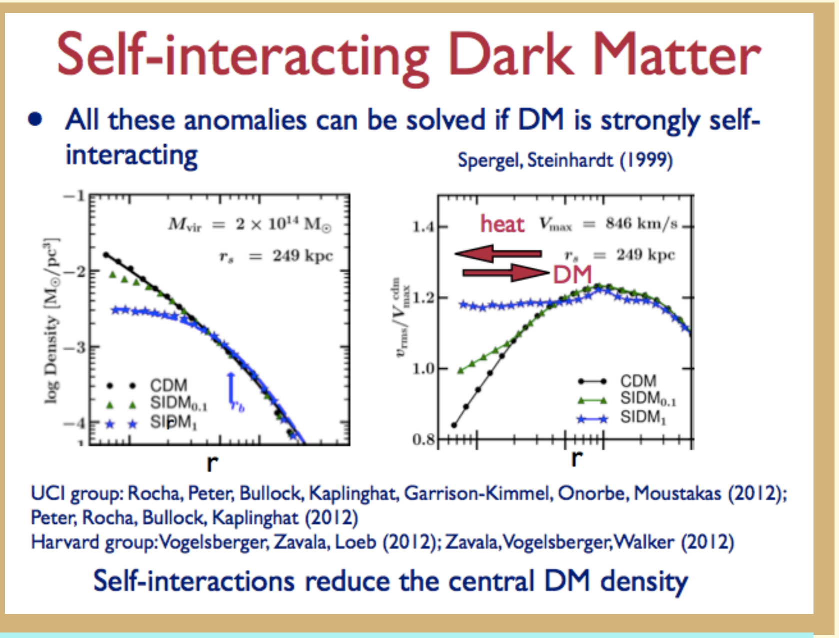

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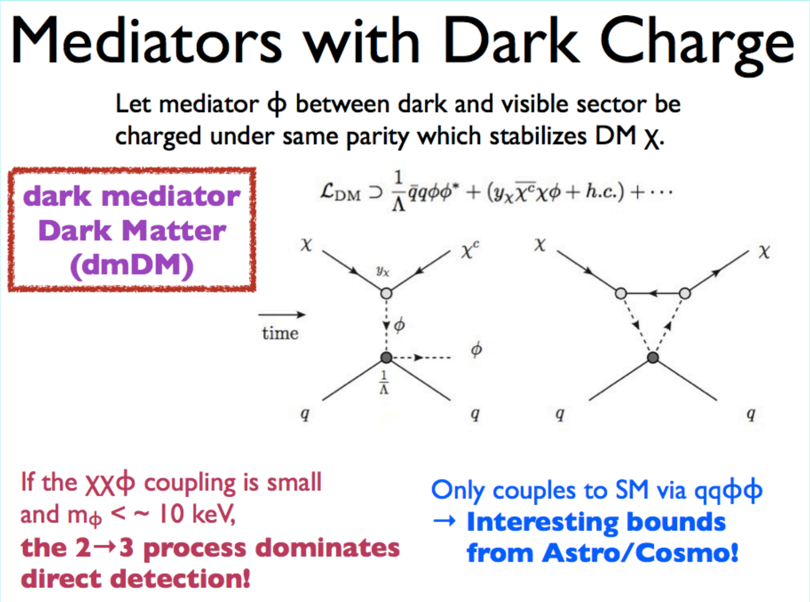


Mediators with Dark Charge

Let mediator φ between dark and visible sector be charged under same parity which stabilizes DM χ.

dark mediator Dark Matter (dmDM)

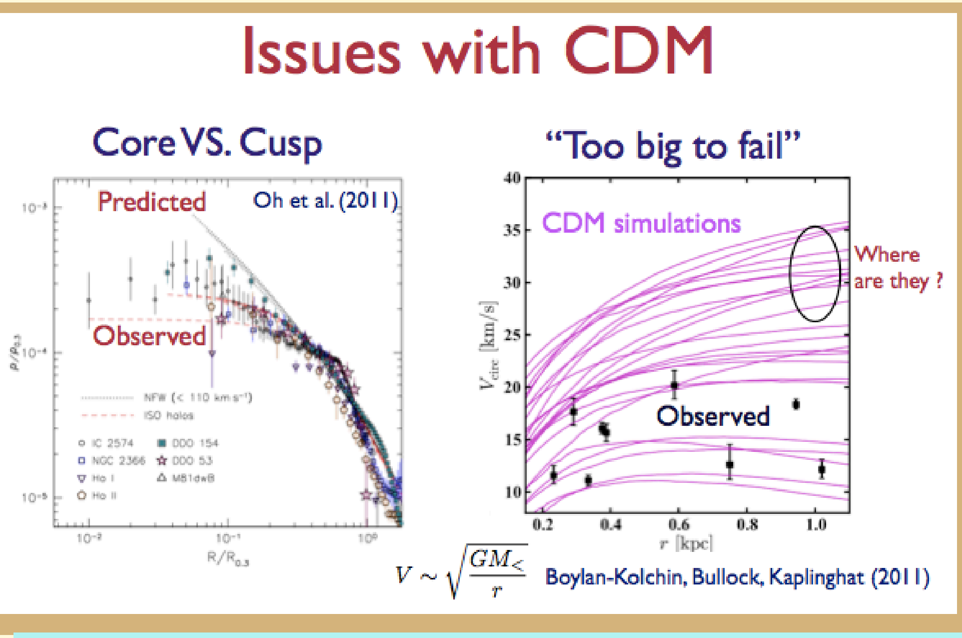
$$\mathcal{L}_{DM} \supset \frac{1}{\Lambda}\bar{q}q\phi\phi^* + (y_\chi \overline{\chi^c}\chi\phi + h.c.) + \cdots$$

If the χχφ coupling is small and m_ϕ < ~ 10 keV, **the 2→3 process dominates direct detection!**

Only couples to SM via qqφφ
→ **Interesting bounds from Astro/Cosmo!**

Curtin

Fake different light WIMPS in different detectors



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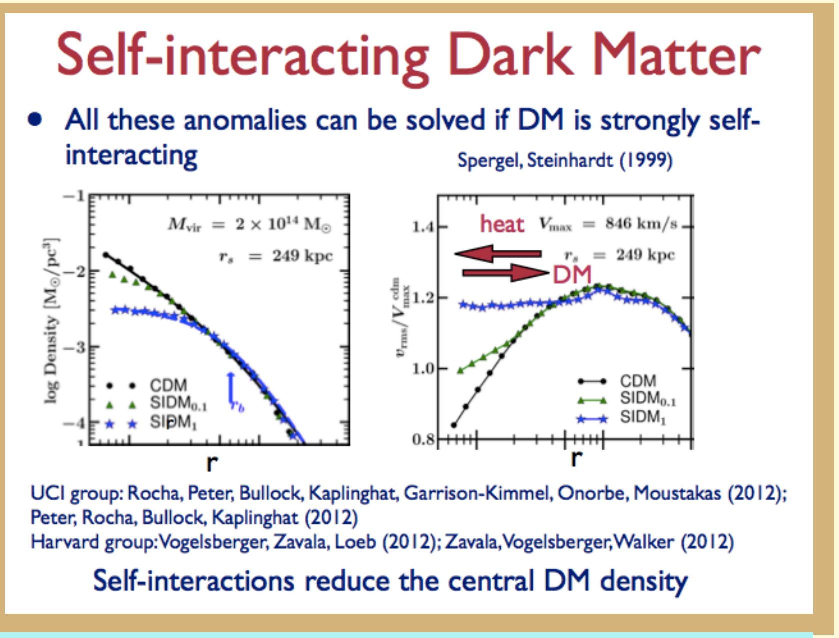

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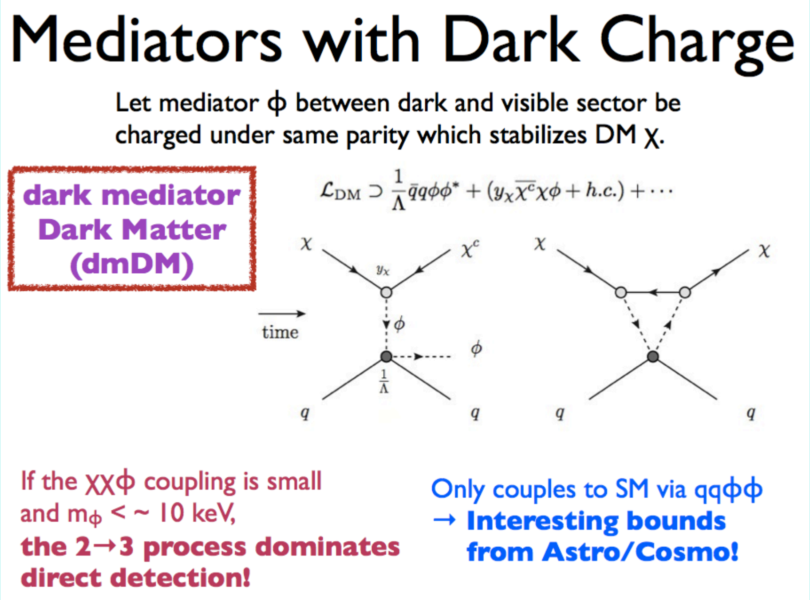

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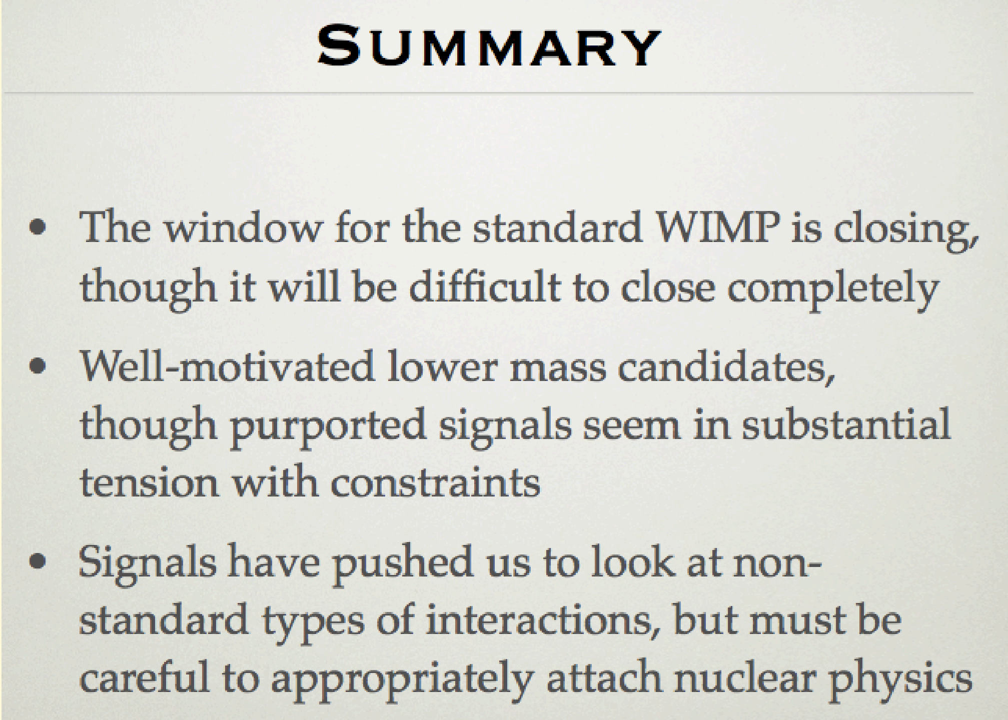
Fake different light WIMPS in different detectors

Pradlin: Entertain a neutrino model that can explain the direct detection anomalies that are often interpreted in terms of light-DM. The model stands fairly unchallenged by LUX.!

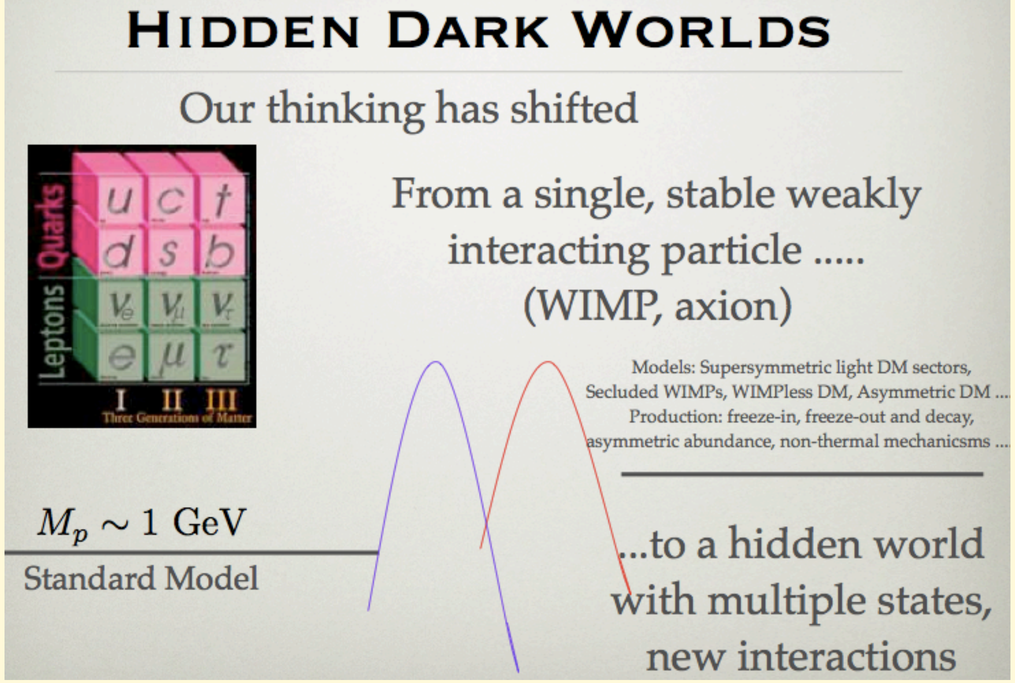
A new neutrino that couples with stronger-than-weak interactions to quarks provides alternative explanation to the dark matter direct detection anomalies; model "wins" when compared to ~10 GeV DM.

Variants of the model may also have interesting implications for the recent non-atmospheric (sub)-PeV IceCube neutrino observations



SUMMARY

- The window for the standard WIMP is closing, though it will be difficult to close completely
- Well-motivated lower mass candidates, though purported signals seem in substantial tension with constraints
- Signals have pushed us to look at non-standard types of interactions, but must be careful to appropriately attach nuclear physics



HIDDEN DARK WORLDS

Our thinking has shifted

From a single, stable weakly interacting particle .....
(WIMP, axion)

Models: Supersymmetric light DM sectors,
Secluded WIMPs, WIMPless DM, Asymmetric DM ...
Production: freeze-in, freeze-out and decay,
asymmetric abundance, non-thermal mechanicsms ...

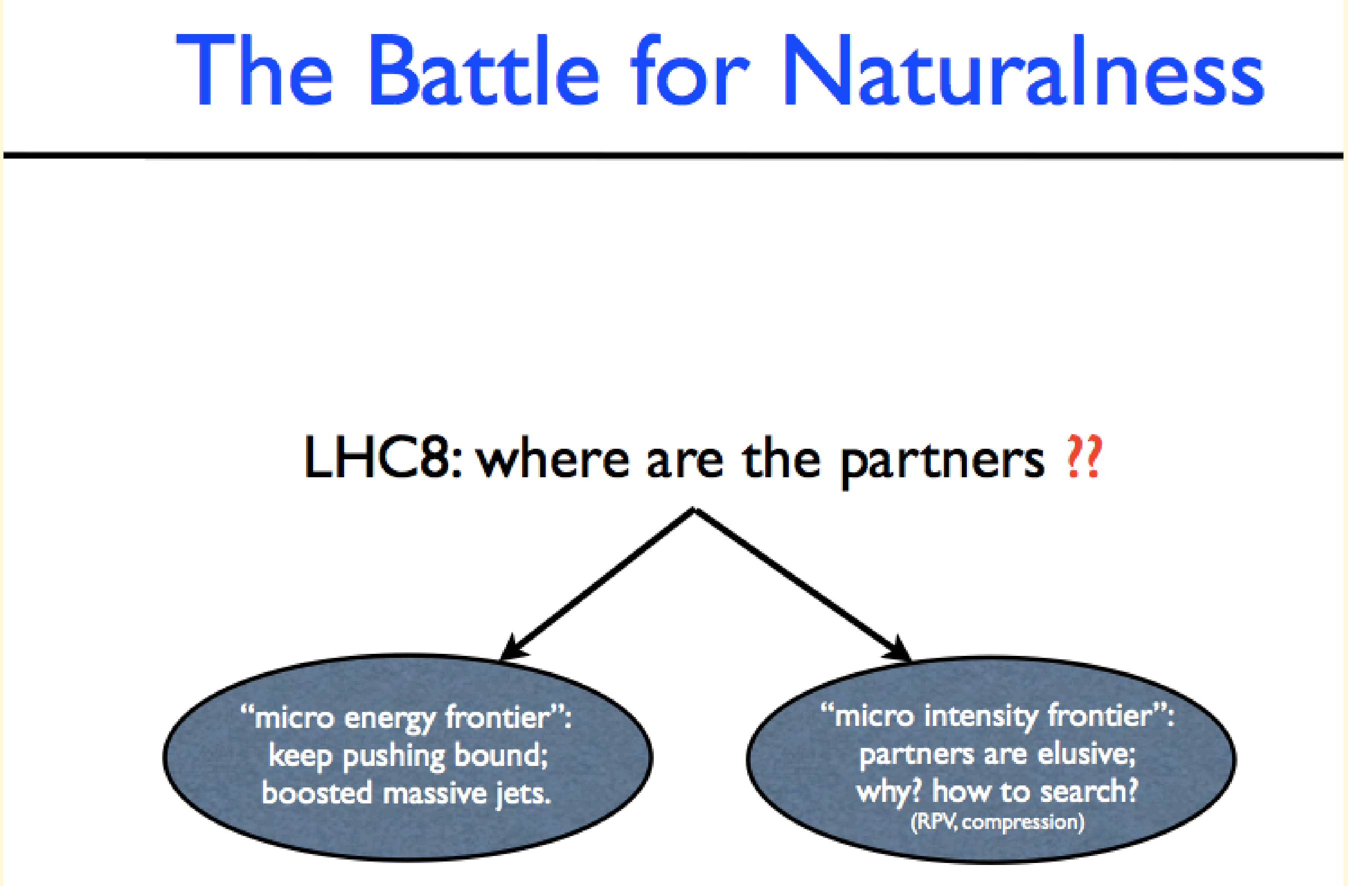
$M_p \sim 1$ GeV

Standard Model

...to a hidden world with multiple states, new interactions

BSM and high-E colliders

Perez



The Battle for Naturalness

LHC8: where are the partners ⁇

"micro energy frontier": keep pushing bound; boosted massive jets.

"micro intensity frontier": partners are elusive; why? how to search? (RPV, compression)

Partners **elusive** because of
- **kinematical issues** (e.g. compressed spectra), or
- **theoretical bias**:
  - o not looking for the right class of models, or in the right place or for the right tags (e.g. not exploiting presence of charm quarks)
  - o overestimating signal efficiency (e.g. degenerate quarks) => overestimating the exclusion ranges (e.g. overstressing "un"-naturalness and thus biasing model building)

The probes of BSM

- **Direct searches:**
  - smoking-gun signatures (e.g. Z’, multi-jet + MET, ...)
  - more or less substantial deviations from SM behaviour:
    - **Kagan** top charge asymmetry
    - **Weiler** slight shape changes (e.g. pT(H))
    - slight rate changes (e.g. EWinos from σ(WW), stop from σ(tt)
    - **Han, Gunion, Galloway** high-mass WW scattering
    - **Perez, Weiler, Kuflik** “stealth” or RPV phenomenology
- **Galloway** **Precision**
  - **Han** Higgs couplings
  - Standard EWPT observabes (mt vs mW vs mH, $\sin\theta_W$, ..)
- **High-statistics searches of rare phenomena**
  - **Perez, Weiler, Altmannshofer** rich interplay of BSM and flavour physics, fully unexplored in the case of top and Higgs:
    - **Hochberg** $t \to Hc$
    - $H \to e\mu$

- Pursuing either of these paths probes different aspects of BSM models
  - BSM model building is thus adapting to experimental opportunities, pursuing models (not necessarily appealing?) that could appear in some of the experimentally accessible final states
  - An approach that few years back would have raised eyebrows, but that today is legitimate and well motivated
- BSM model building is accompanied by the development of new analysis tools, optimized for the relative searches (jet substructure, boosted jets, optimal kinematic variables -- e.g. mT2, Razor, ... (**Buckley**)

- In perspective, pursuing all directions (direct detection, precision, rare phenomena) may not be optimally viable at the LHC. E.g.
    - The highest-mass searches can survive in presence of high pileup, while stealth searches, studies of Higgs properties, etc. will greatly suffer from it.
- More in general, we may soon have to decide on future facilities and, in absence of BSM evidence, have to compare the value of very different options:
    - do we prefer few-% BR(H) measurements from an $e^+ e^-$ colliders, or searches for rare H decays ($H \rightarrow \mu\mu, \mu e$, ...) at very high lum?
    - Will we learn more from 10^{12} Z decays at a Tera-Z factory, or from 10^{11} top decays at a 100 TeV pp collider ?

Final remarks

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- Our planning for the future of the field must be ambitious and farsighted, to be ready with concrete projects when the financial environment improves.
- It may take a long time to get there, and we must be prepared to keep the field healthy and focused as we wait for possibly 10, 20 or more years to achieve the next discovery