Highlights from EPS 2017

Paris Sphicas
CERN & NKUA (Athens)
EPS HEP 2017, Venice, July 12, 2017

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Non-introduction

Thankfully, no-one is expecting a "summary"

I am grateful to the plenary speakers

and session conveners

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HEP Panorama

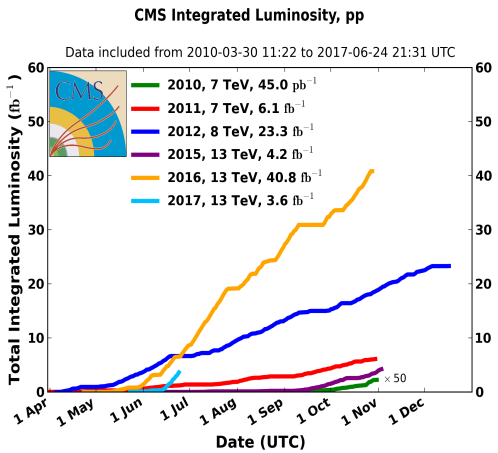
- **The Highest Energies**
  - Our pride, source of great hope(s); SM, Higgs, BSM, Flavor, matter at its extremes
- **The neutrino sector**
  - Cause ν's are so very different; PMNS, fermion nature, BSM, sterility
- **The dark sector**
  - The experimental evidence for physics outside the SM
- **The cosmos**
  - Not strictly always "particle" physics; equally fundamental
- **Dedicated-measurement experiments**
  - Complementary to high E; fundamental symmetries
- **Theory: because we need to understand what we're doing**

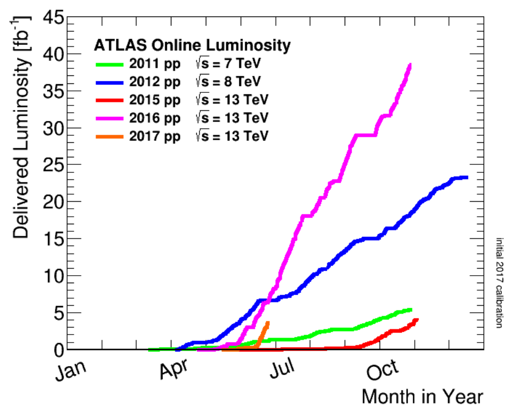
The Standard Model

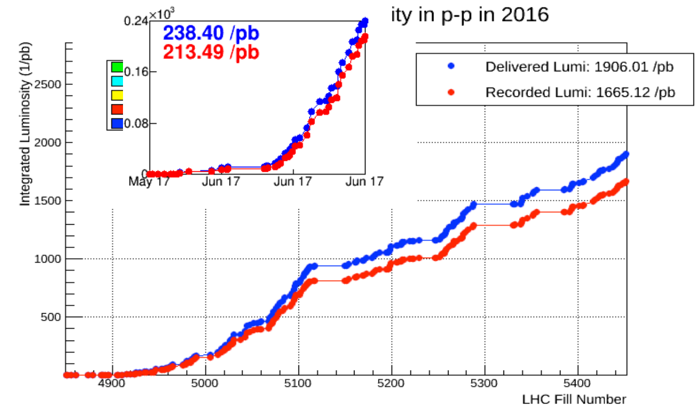
It’s about time we change its name to Standard Theory

The highest energies

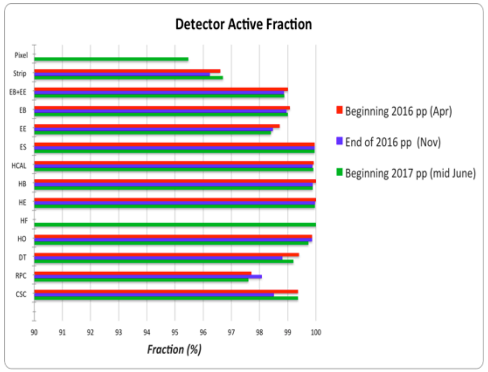
■ The LHC and its experiments Operating Great Again

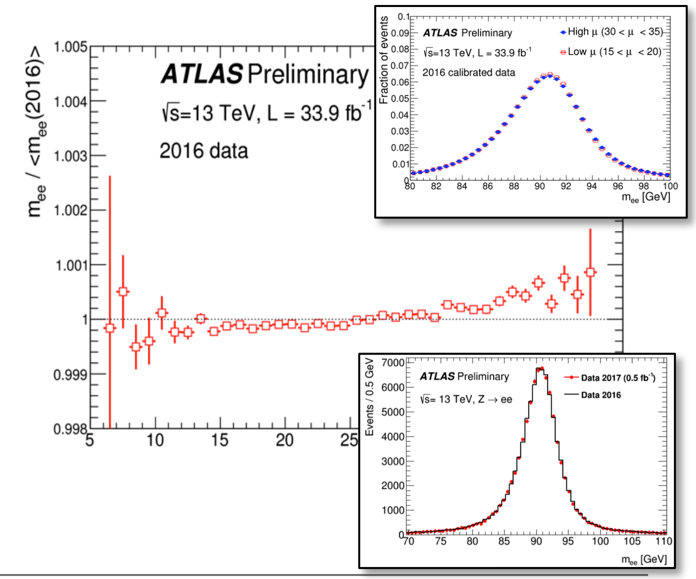






High **machine availability**
~ 50 % (many HW issues fixed)
High **luminosity lifetime** (improved knowledge of machine parameters for operation)
High **peak luminosity** (small beam size from injectors and stronger focussing)
Still room for improvement in 2017&18
More bunches, higher bunch intensity, stronger focussing





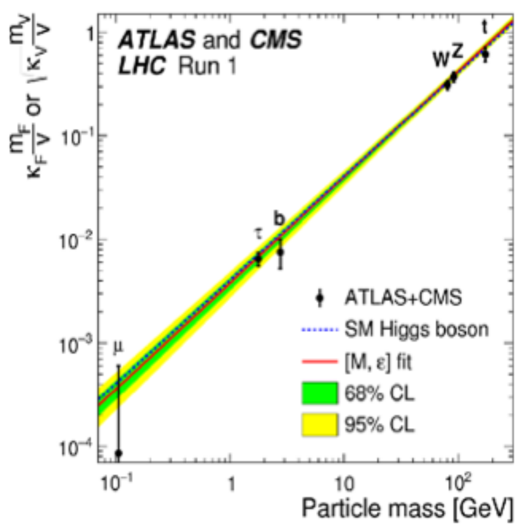
SM Highest E; EWSB ("Higgs" sector) (I)

Beyond All Doubt:

it is a Higgs

$J^P=0^+$

Ultimate non-universal coupling: to mass (!)

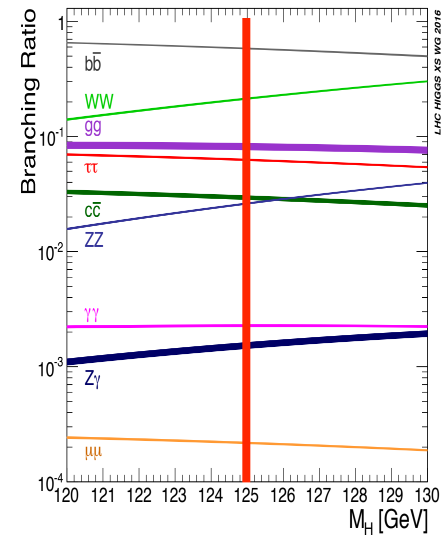


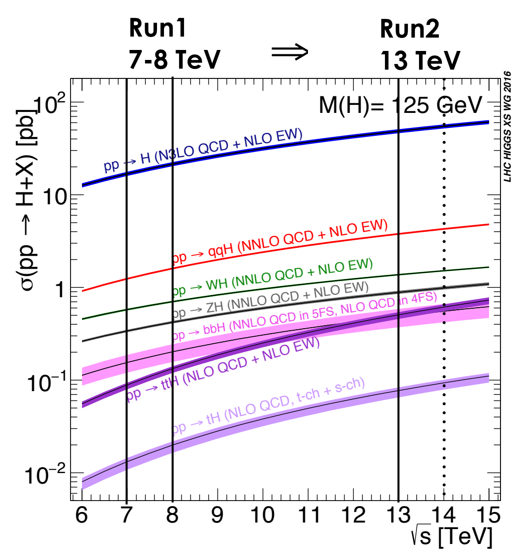
t,b,μ points: slight overstatement

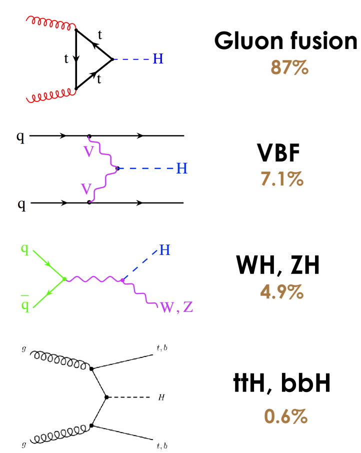
Still in Doubt:

is it *the* Higgs?

→ establish production and decay (AMAP)



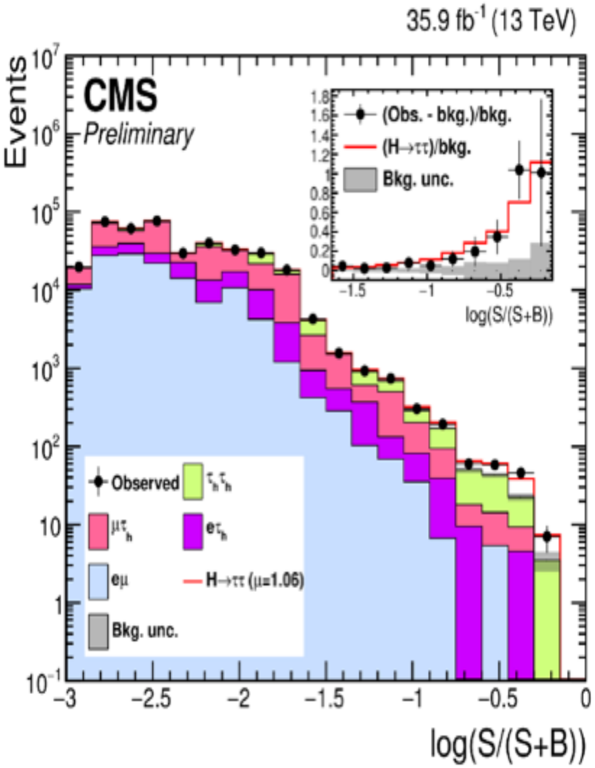


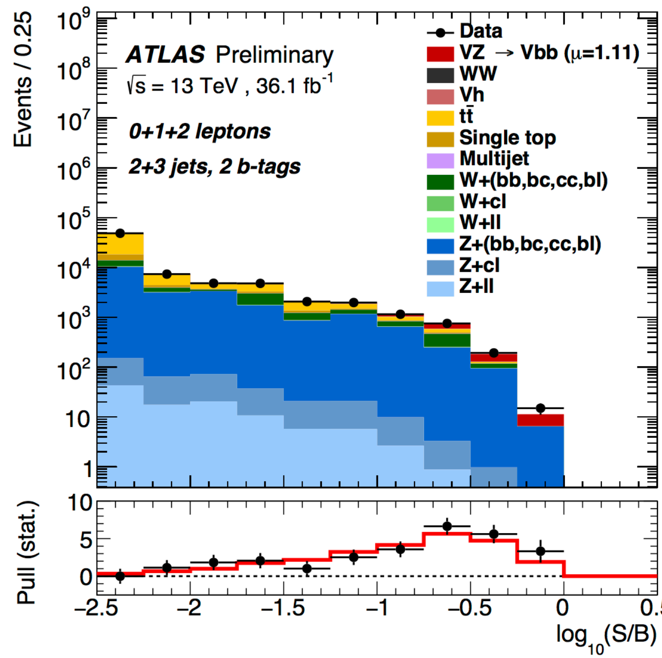


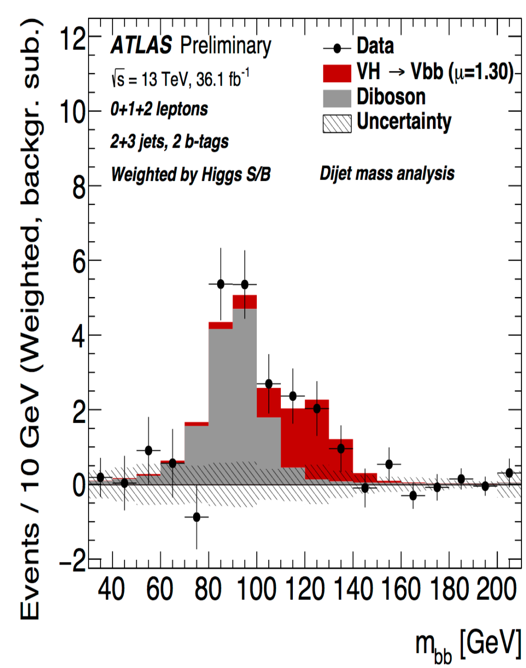
SM EWSB/H sector (II): noteworthy

H-τ coupling @ CMS: Single-expt observ. of H→ττ: 5.9σ (Run1+Run2)

H-b coupling @ ATLAS: Single-expt evidence for H→bb: 3.6σ (3.5 from Run2)



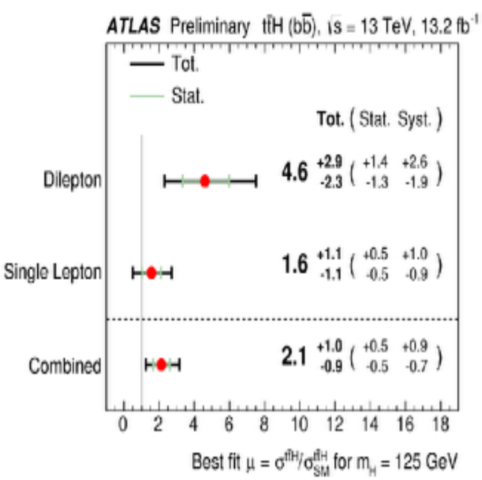


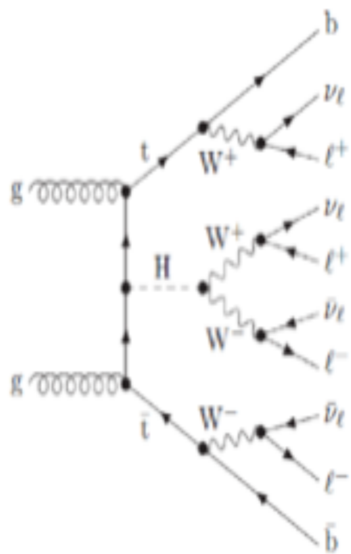


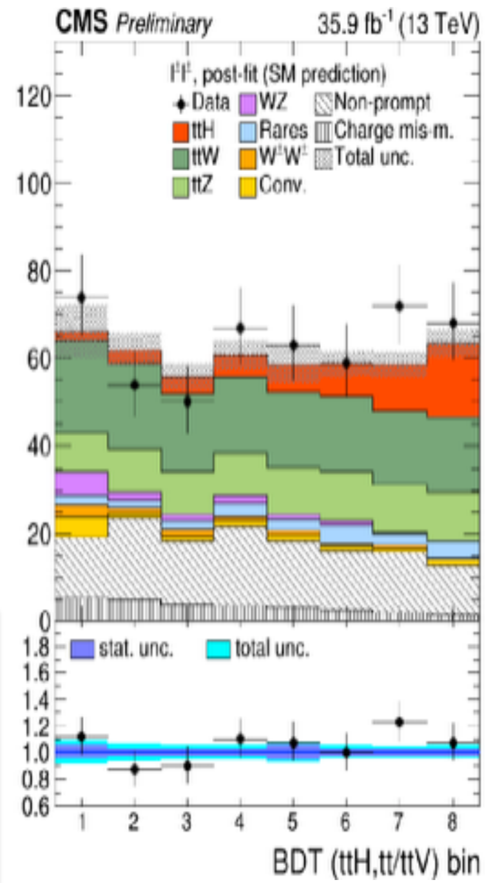
SM EWSB/H sector (III): noteworthy

- **Coupling to the top quark (special: $y_t \approx 1$)**

H-t coupling: ttH production elusive (~1/100 of ggH)
Up to last week: ~hints

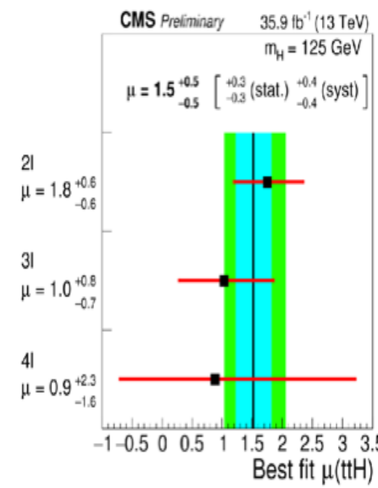






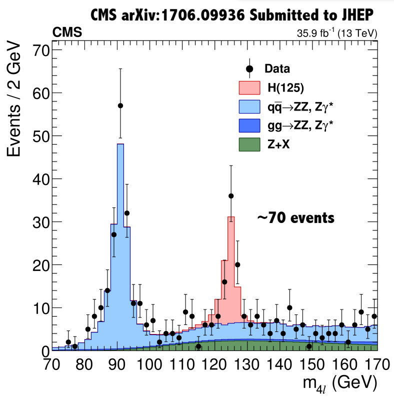
Note: H→WW; so no need to assume SM H→bb

CMS: 3.3 σ (2.5 exp)

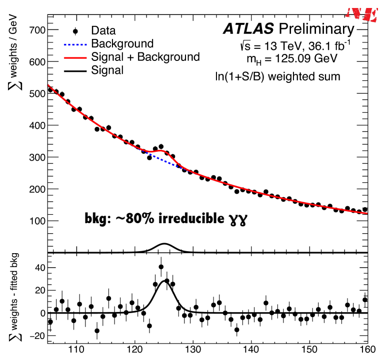


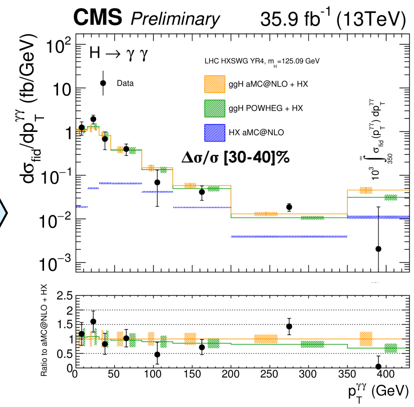
SM EWSB/H sector (IV): for the future

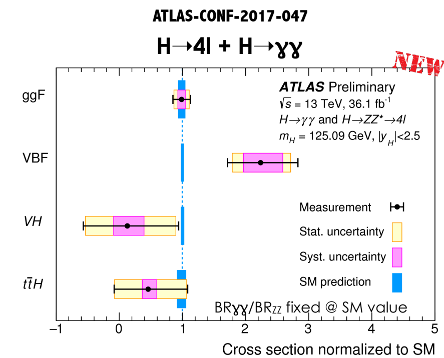
Increased statistics



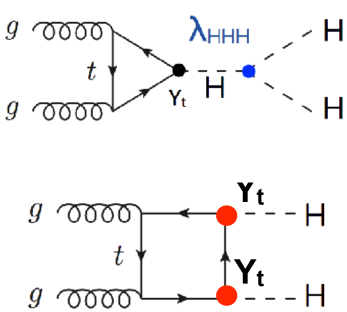
$$\mu = 1.05^{+0.15}_{-0.14}(\mathrm{stat})^{+0.11}_{-0.09}(\mathrm{syst})$$







HH : within factor 20 of SM→HL-LHC

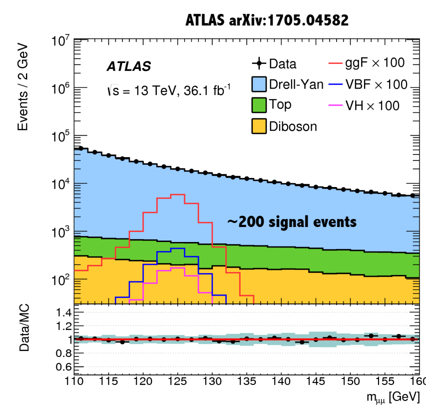


Run 2 Obs. (exp) 95% CL limits on σ/σ_{SM}

	ATLAS	CMS
bbbb	29 (38)	342 (308)
bbWW		79 (89)
bbττ		28 (25)
bbγγ	117 (161)	19 (17) NEW
WWγγ	747 (386)	

3 fb⁻¹ | 13 fb⁻¹ | 36 fb⁻¹

H→μμ: same

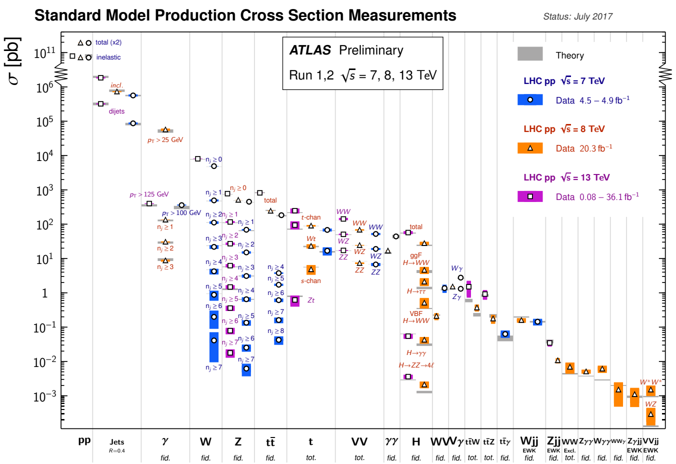


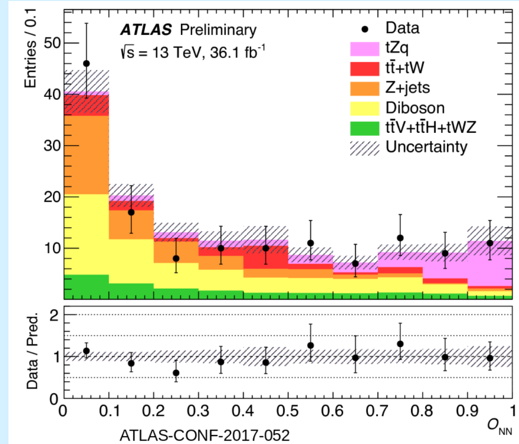
Rare decays…

Process	σ/σ_{SM} (95% CL)
H→Zγ (ATLAS) 36fb⁻¹@ 13 TeV	<6.6
H→Zγ (CMS) Run1	<9
H→γ*γ (CMS) Run1	<7.7
H→J/Ψγ (ATLAS) Run1	<540
H→J/Ψγ (CMS) Run1	<540
H→ργ (ATLAS) 36 fb-1 @ 13 TeV	<52
H→φγ (ATLAS) 36 fb-1 @ 13 TeV	<208
H→ee (CMS) Run1	<~10^5

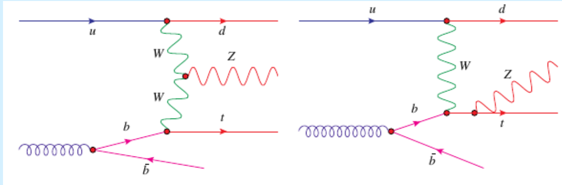
Run1
Run2 36 fb⁻¹

SM, Highest E; SM minus Higgs

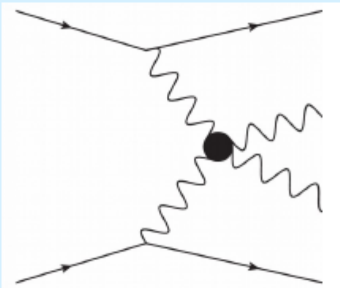




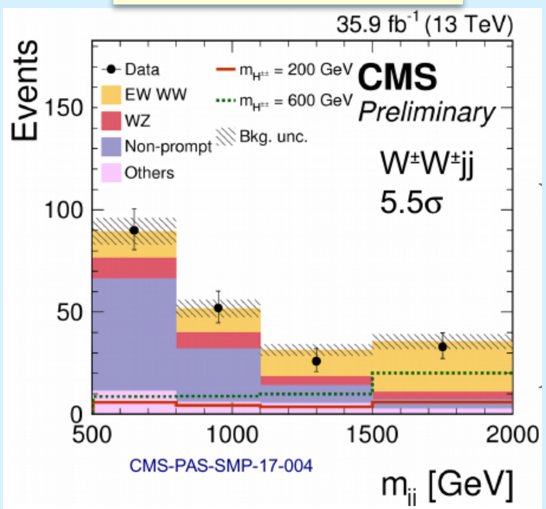
tZq! 4.3σ



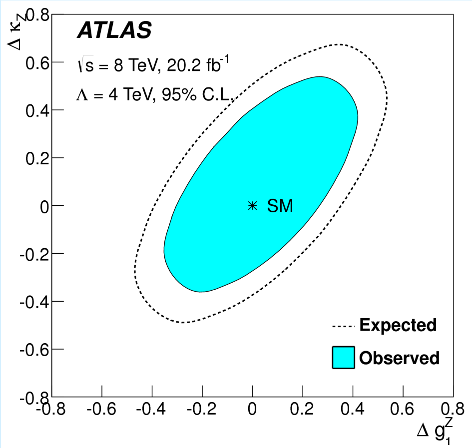
The real thing!



W±W±! 5.3σ!

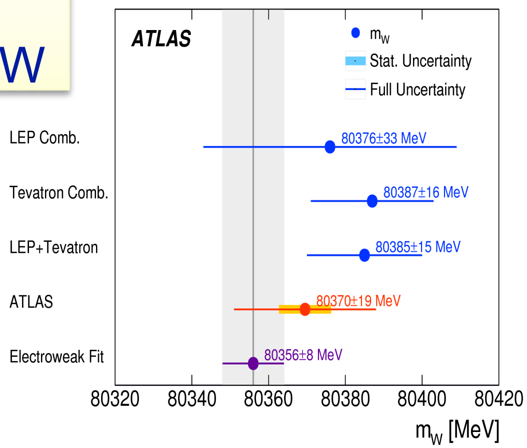


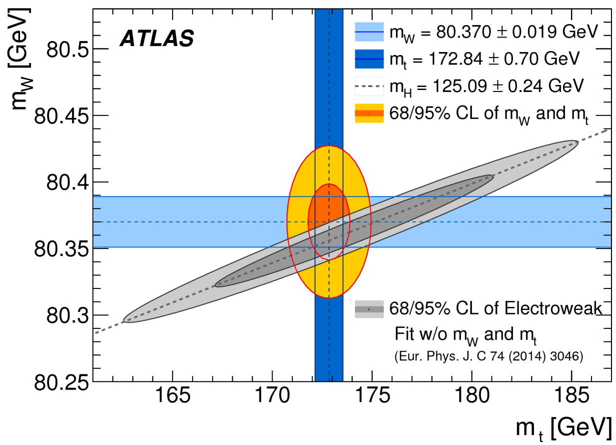
aTGC – limits



SM, Highest E; EWK precision tests

m_W





So what next?
Theory errors:

M_W = 80.358±0.008 GeV

M_t = 177.0+2.3–2.4 GeV

$\Delta m_t^{exp} < \Delta m_t^{the}$

→ Experiment: more work on m_W needed!

ATLAS and CMS in good agreement:

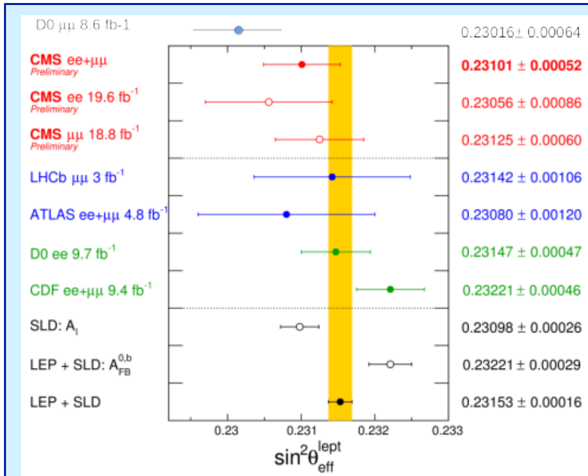
- $m_t^{\mathrm{ATLAS}} = 172.84 \pm 0.70$ GeV
- $m_t^{\mathrm{CMS}} = 172.44 \pm 0.48$ GeV

m_t

Some tension with Tevatron average:

$m_t^{\mathrm{Tev}} = 174.30 \pm 0.65$ GeV

But beware:
m^{pole} vs m^{MC} &
$O(\Lambda_{QCD})$ effects



± 0.00052

$\sin^2\theta_W$

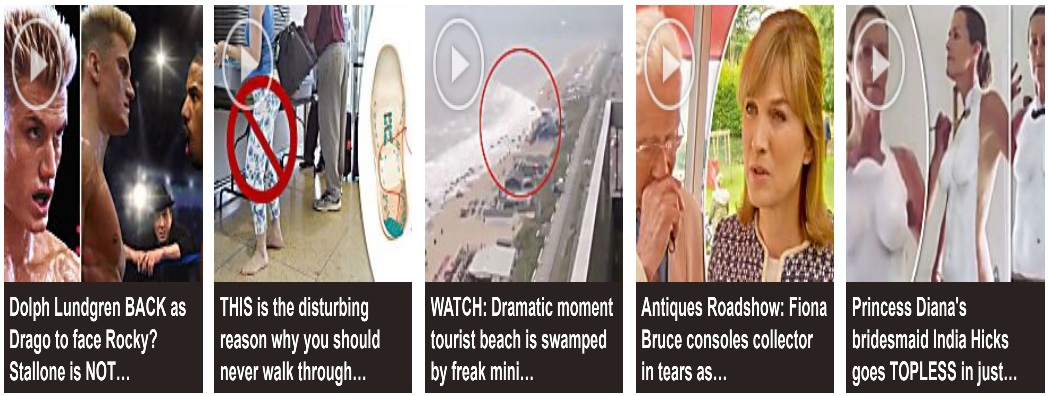
No match, but surprisingly good (and no discrep…)

±0.00016

SM Strong Interaction (I)

EXPRESS
Home of the Daily and Sunday Express

In this universe



CERN scientists one step closer to unlocking key to Universe after LHC breakthrough

SCIENTISTS investigating the origins of the Universe through the Large Hadron Collider (LHC) are celebrating a major breakthrough.

http://www.express.co.uk/news/science/825660/CERN-Large-Hadron-Collider-discovers-baryons

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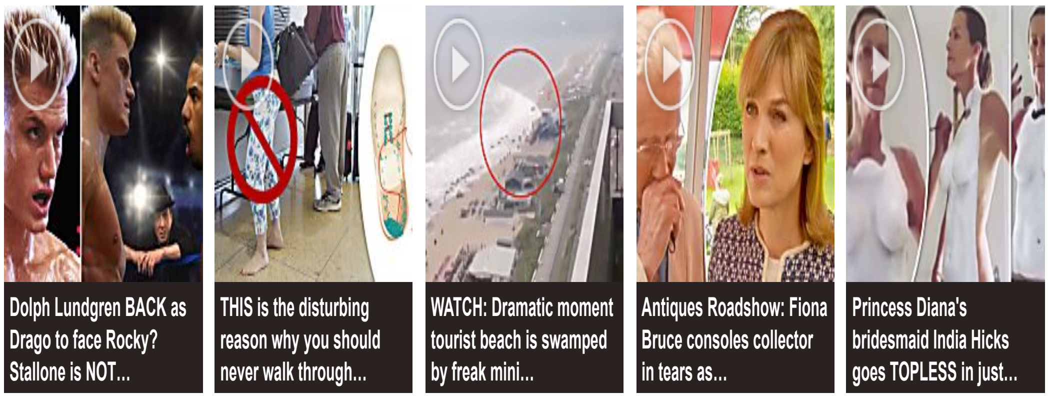

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At the bottom, the reader can speak up:

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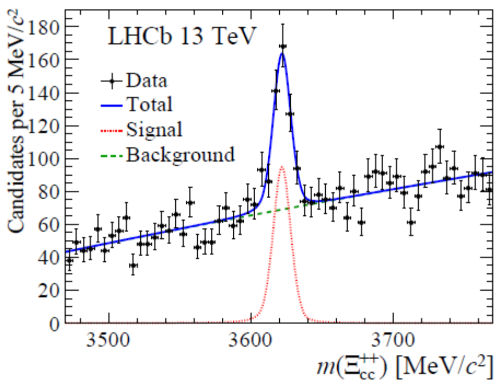
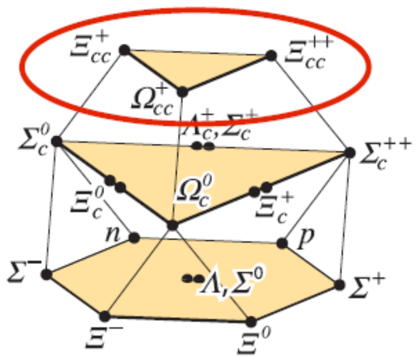
In a || universe





SU(4) flavor multiplets, PDG Review of Particle Physics, Phys.Rev. D86, 010001.

Food for thought for the Lattice

Food for thought for Outreach

Quantitative testers of QCD rejoice!
First observation of doubly-charmed baryon, the Ξ_{cc}^{++}

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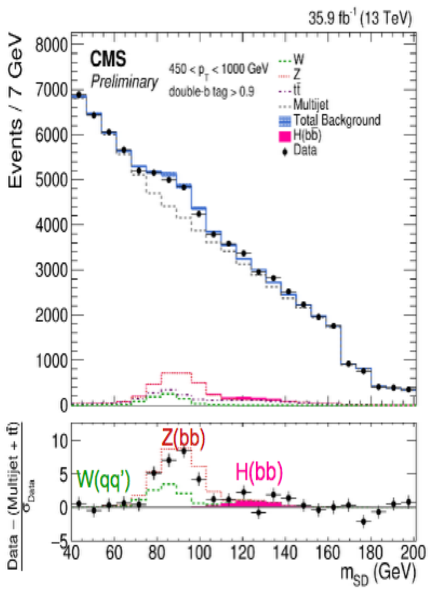
SM Strong Interaction (II)



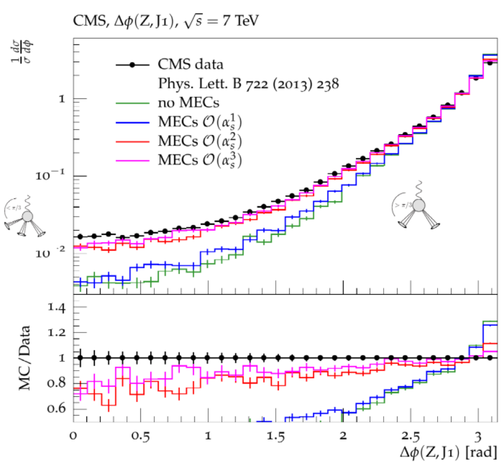
Jet substructure: a major new tool

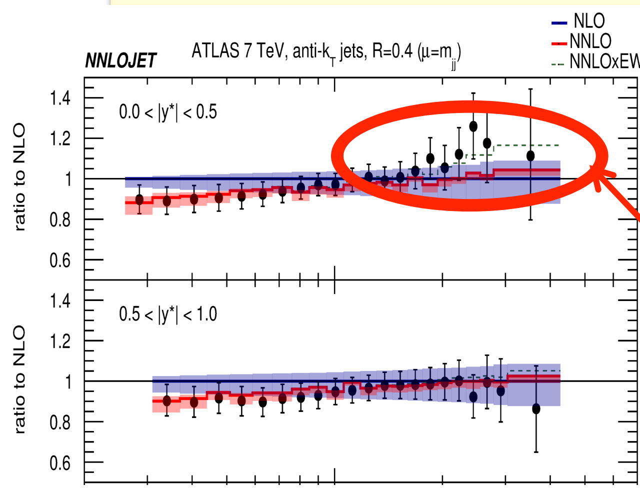
Cool stuff: W/Z→qq

Opens up possibility of inclusive gg→H→bb (!)

	H	Z
Observed best fit	$\mu H = 2.3^{+1.8}_{-1.6}$	$\mu Z = 0.78^{+0.23}_{-0.19}$
Expected significance	0.7σ ($\mu H = 1$)	5.8σ ($\mu_Z = 1$)
Observed significance	1.5σ	5.1σ

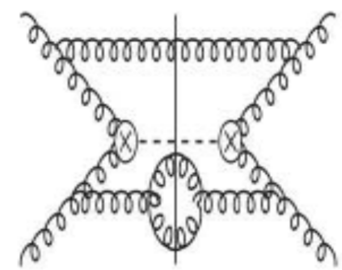
Theory: Incredible strides





Sensitive to EWK corrs!

gg→H at NNNLO



Beyond the SM

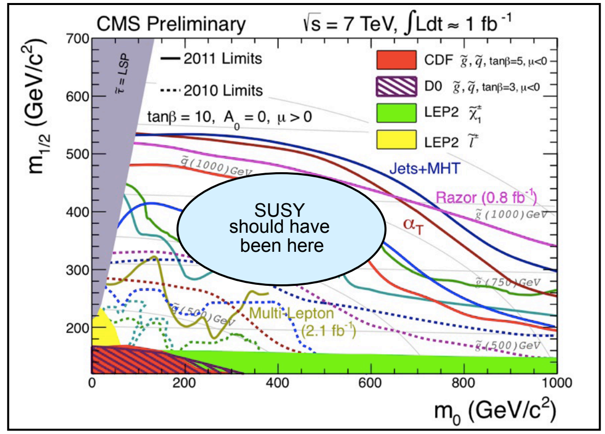
Supersymmetry

Others

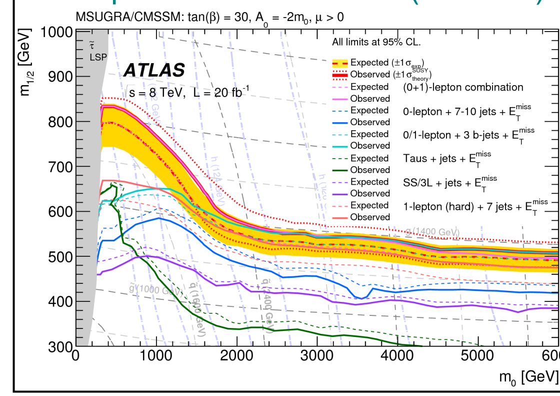
Supersymmetry: how we got here

SUSY Summary

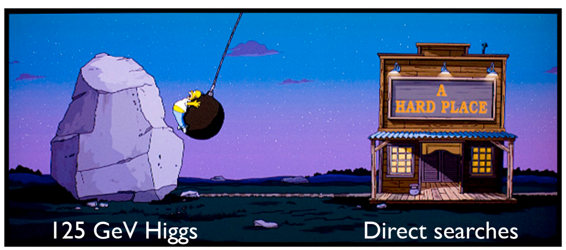
- SUSY discovery (should be) easy and fast
  - Expect very large yield of events in clean signatures (dilepton, diphoton).
    - Establishing mass scale is also easy (M_{eff})
- Squarks and gluinos can be discovered over very large range in SUGRA space $(M_0, M_{1/2})$~(2,1)TeV
  - Discovery of charginos/neutralinos depends on model
  - Sleptons difficult if mass > 300 GeV
  - Evaluation of new benchmarks (given LEP, cosmology etc) in progress
- Measurements: mass differences from edges, squark and gluino masses from combinatorics
- Can extract SYSY parameters with ~(1-10)% accuracy



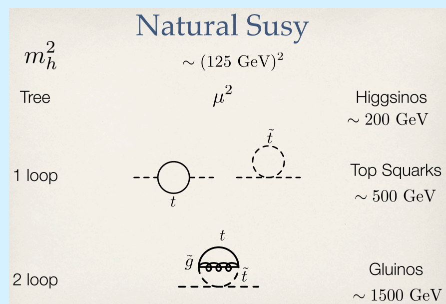
Specific SUSY Models (CMSSM)

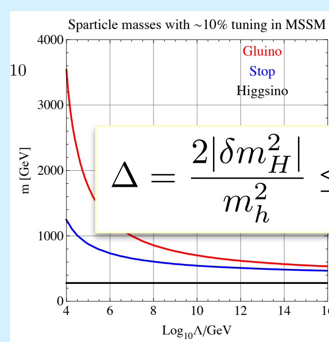


Then, in 2012, we found a H boson at 125 GeV…

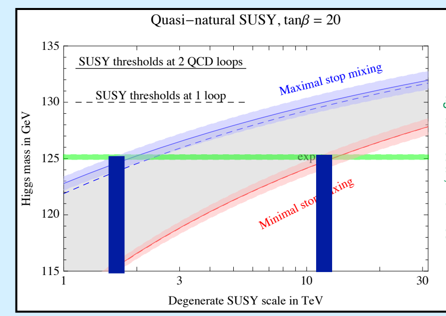


The 2012's: Full models too ambitious… [SUSY] only needs to be "natural"



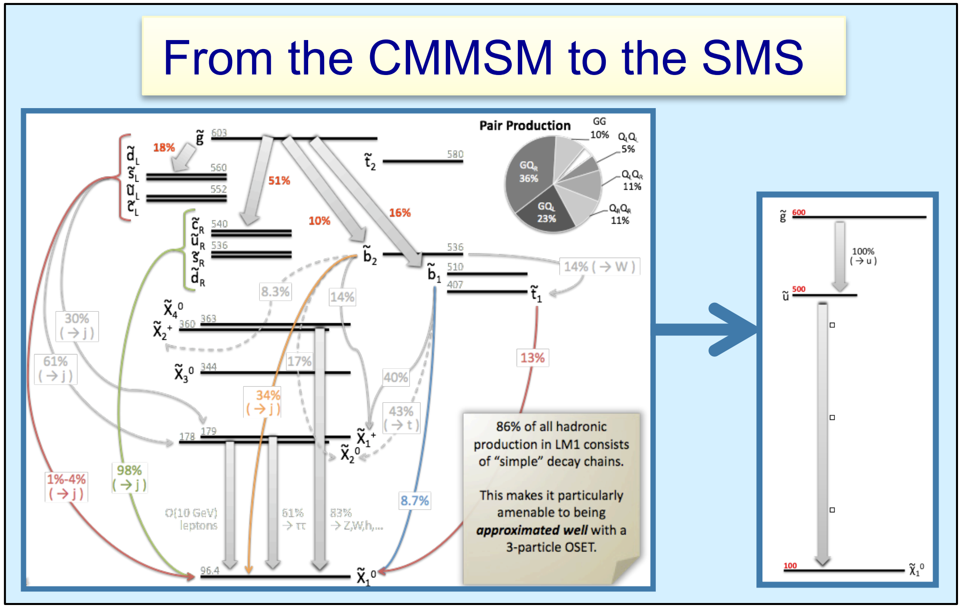


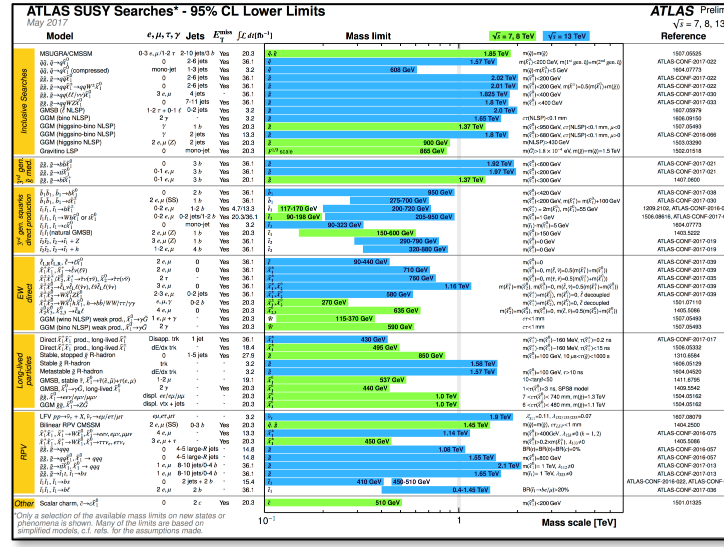
$$\Delta = \frac{2|\delta m_H^2|}{m_h^2} \leq 10$$

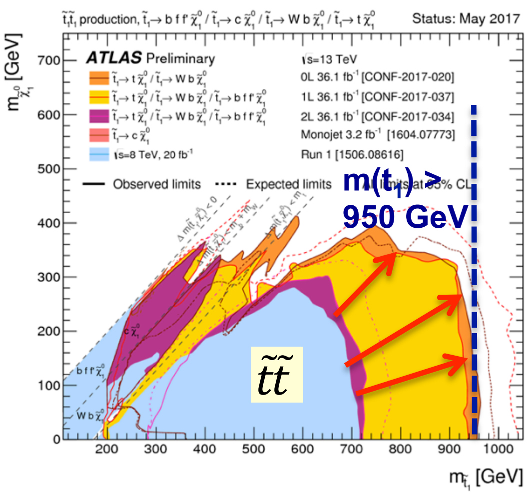


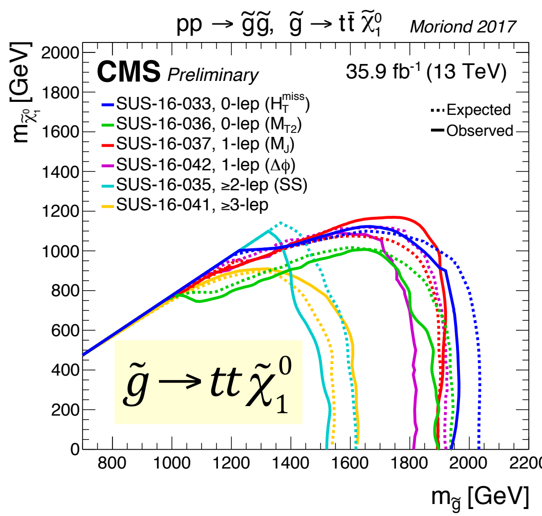
Optimist's view: high A_t. Theorist's view: not-so-easy to generate (large A_t) Experimentalist's view: clearly, an SEP*

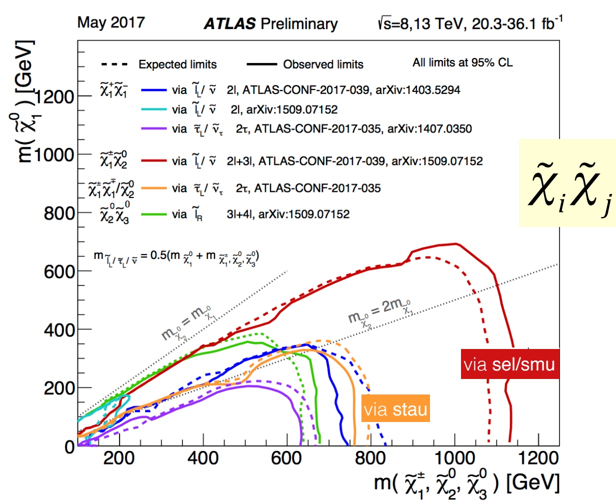
Supersymmetry: were we are today





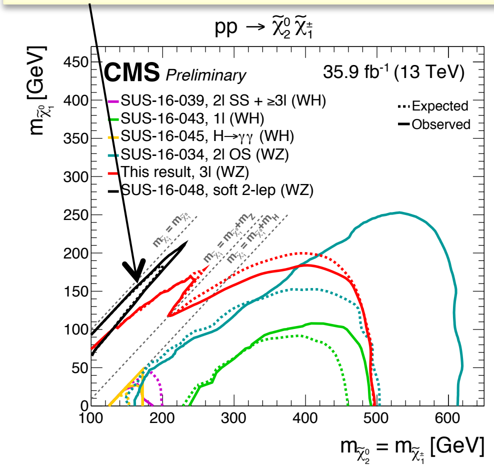




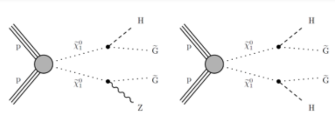


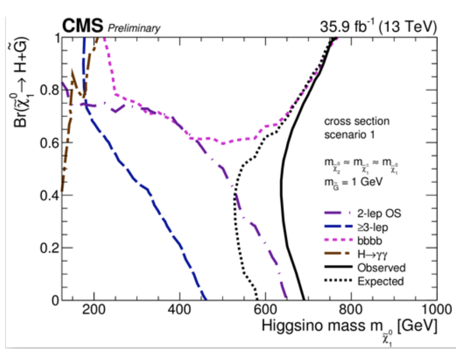
Supersymmetry: what to do next

Compressed spectra



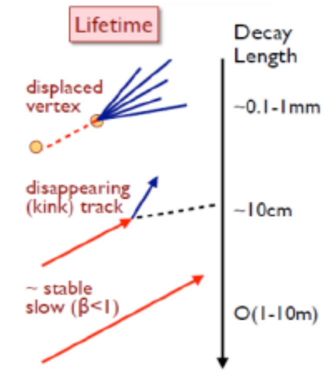
We will always have Higgsinos…
μ term must be ~O(M_H)



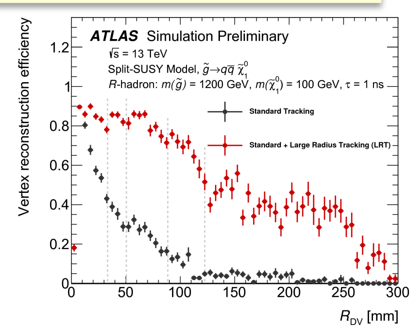


Long Lifetimes

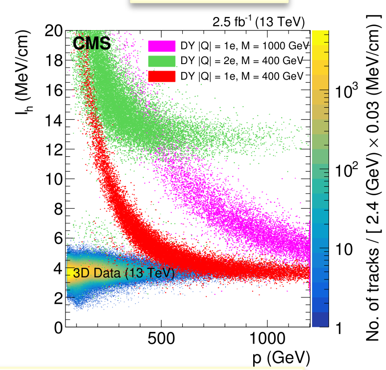
- Small couplings: RPV decays, dark sector coupling
- Small Δm: almost degenerate NLSP heavy messenger: Z', split SUSY
- Hidden valleys…

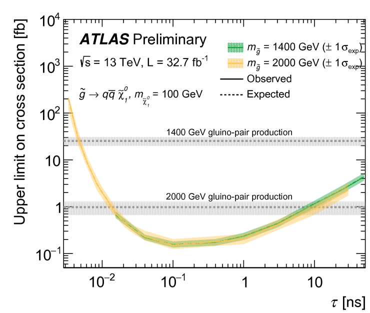


Dedicated (re)tracking

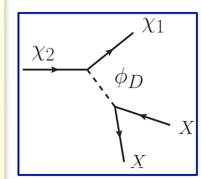


dE/dx





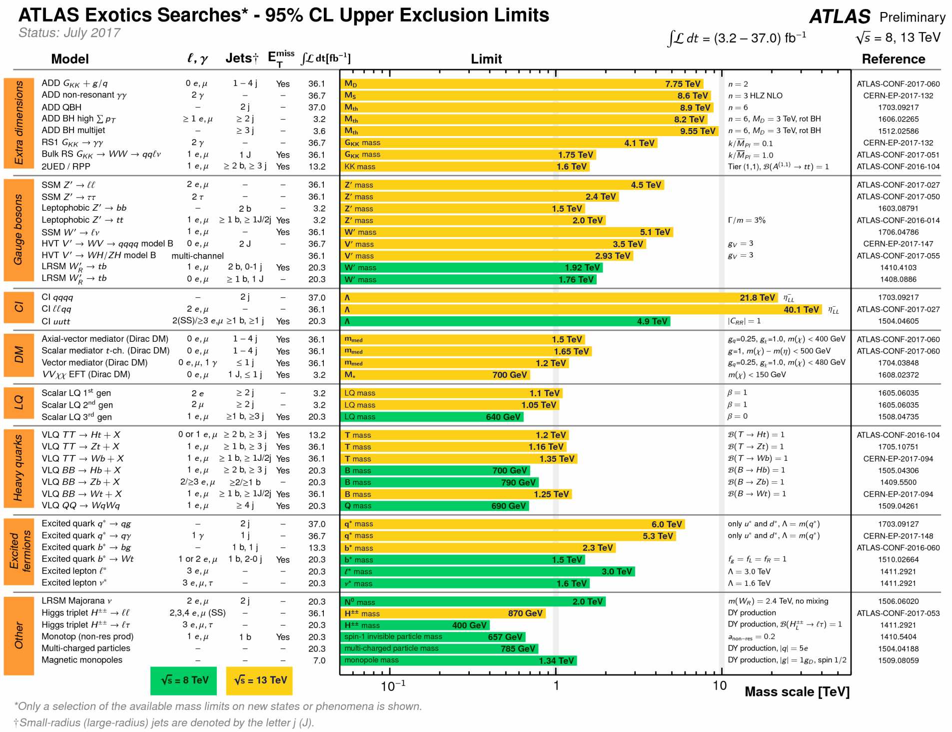
What is really needed: Systematic study of all SUSY and DM space under long-τ hypothesis

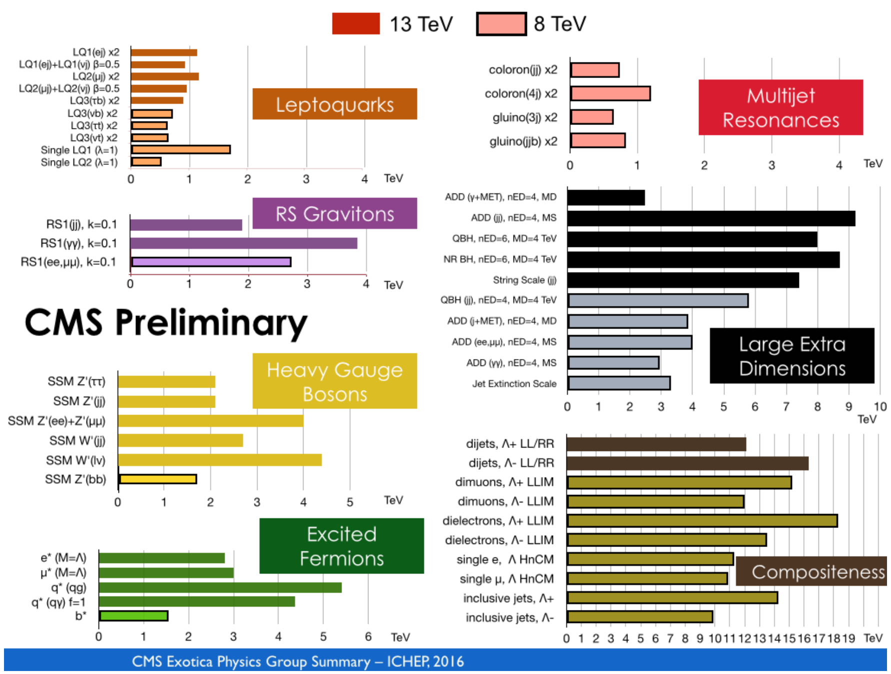


CERN LLP Workshop

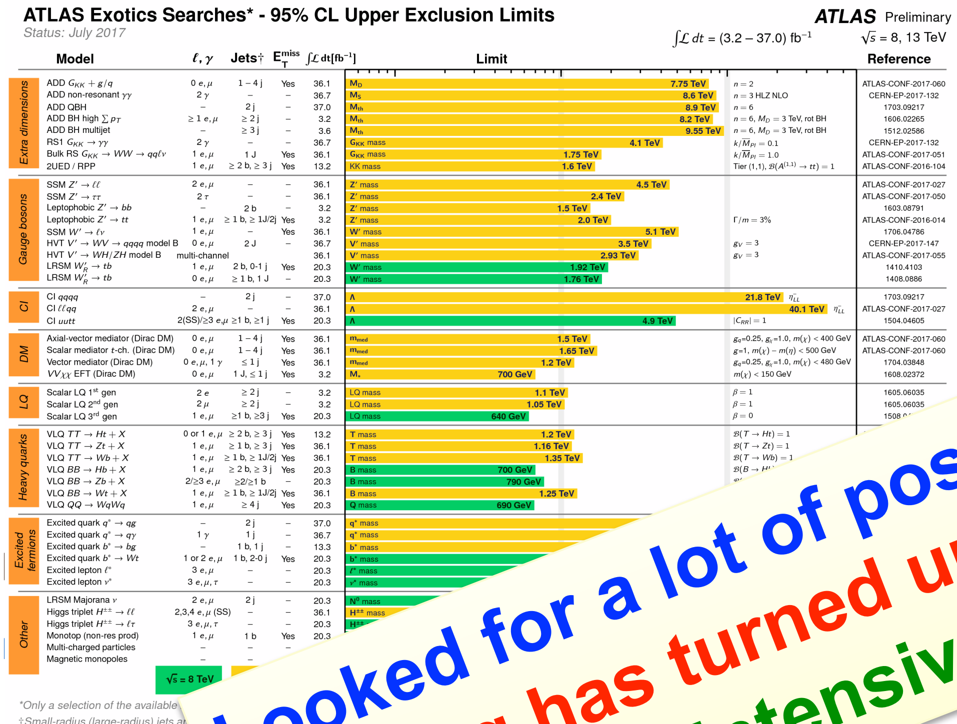
arXiv:1704.06515

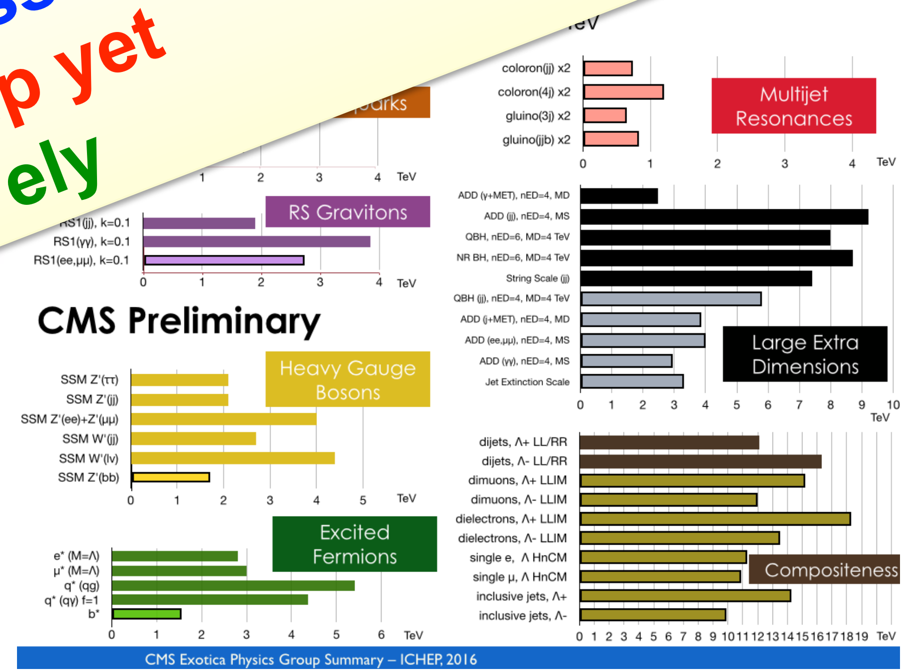
Non-SUSY BSM: vast, simply vast…





Non-SUSY BSM: vast, simply vast…





Looked for a lot of possible new things

Nothing has turned up yet

Still looking intensively

Physics of Flavor

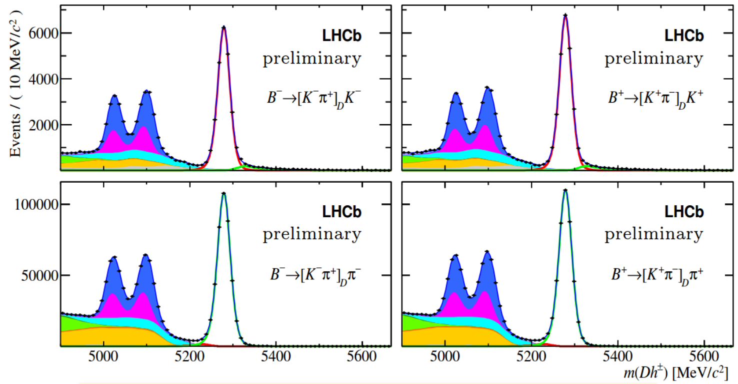
CP violation, CKM triangle(s)

Rare processes

Windows to new physics? (or lessons in statistics and/or systematics in theory calculations)?

Flavor Physics: CKM

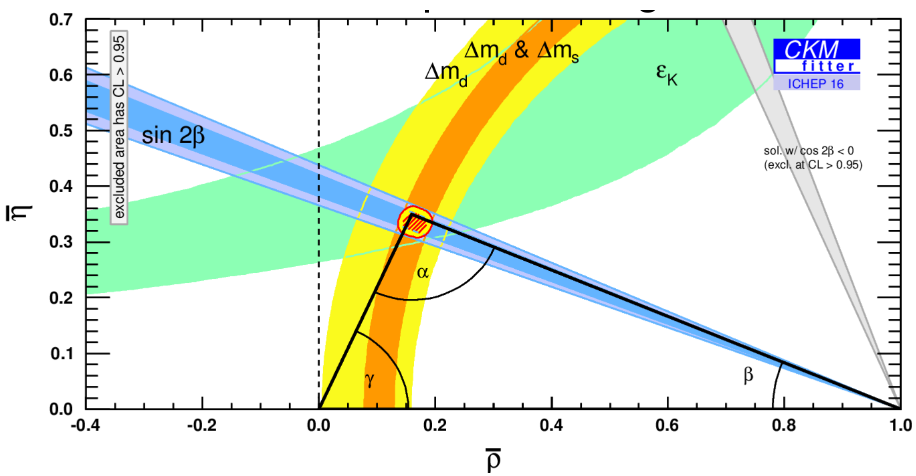
γ: arg(V_{ub});
aka “the tough one”
aka “the DK angle”
(D_sK, DK, D*K…)
Tricks to correct for
penguins/FSI…



New: D*K; $D^* \to D\pi^0/\gamma$

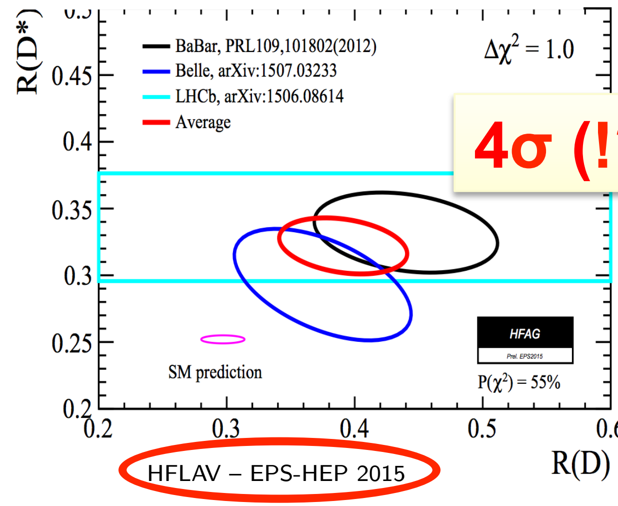
$$\gamma = (76.8\,^{+5.1}_{-5.7})^\circ$$

!!!



But… Trouble (?)
in semileptonics

$$\mathcal{R}(D^{(*)}) = \frac{\mathcal{B}(B \to D^{(*)}\tau\nu)}{\mathcal{B}(B \to D^{(*)}\ell\nu)}$$

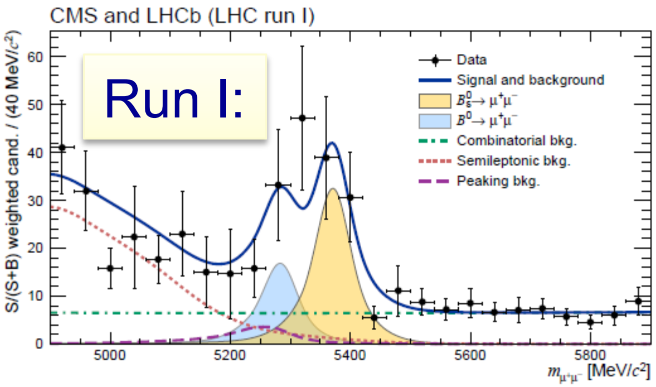


4σ (!?)

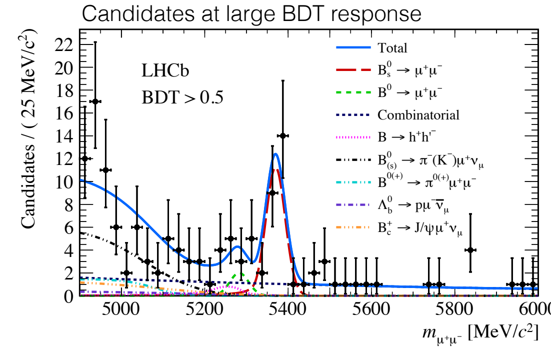
V_{cb} & V_{ub} Tension in inclusive vs exclusive determinations: still there; but hard to get excited given uncertainties, D**, etc

Flavor Physics: rare processes (I)

Run I:



LHCb alone: >7σ

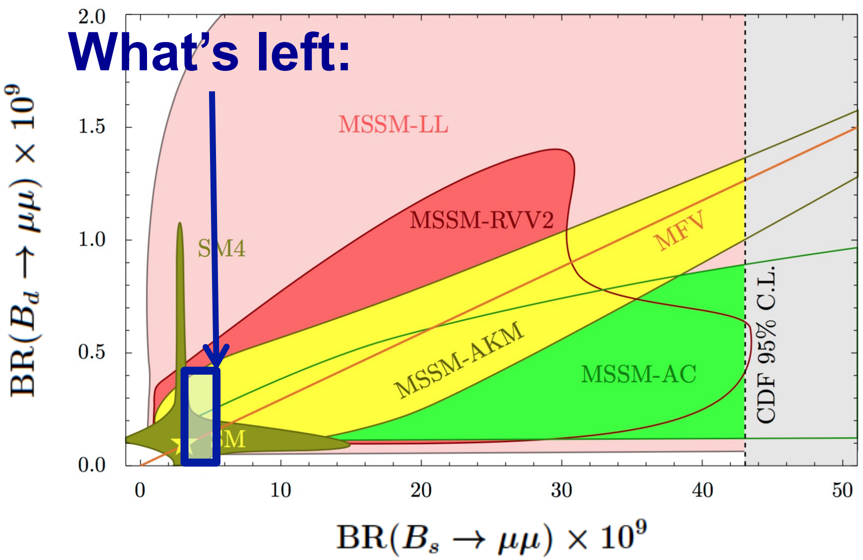


$$\Gamma + \bar{\Gamma} \sim \quad e^{-t/\tau_{B_s}} \left\{ \cosh\left(\frac{\Delta\Gamma_s}{2} t\right) + A_{\Delta\Gamma} \sinh\left(\frac{\Delta\Gamma_s}{2} t\right) \right\}$$

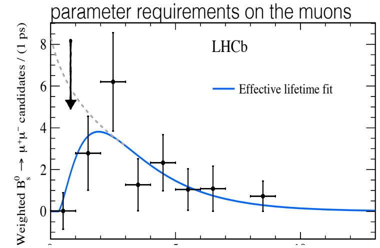
… and did away with many hopes for signs of NewPhys

$$\tau_{\mu^+\mu^-} = \frac{\tau_{B_s^0}}{1-y_s^2}\left[\frac{1+2A_{\Delta\Gamma}^{\mu^+\mu^-} y_s + y_s^2}{1+A_{\Delta\Gamma}^{\mu^+\mu^-} y_s}\right]$$

What's left:

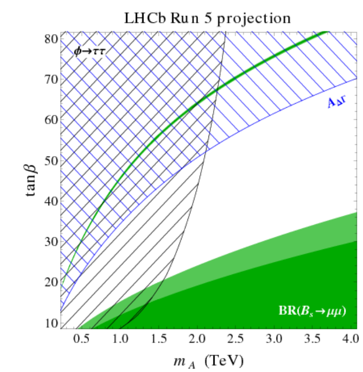


lifetime acceptance, due to impact parameter requirements on the muons



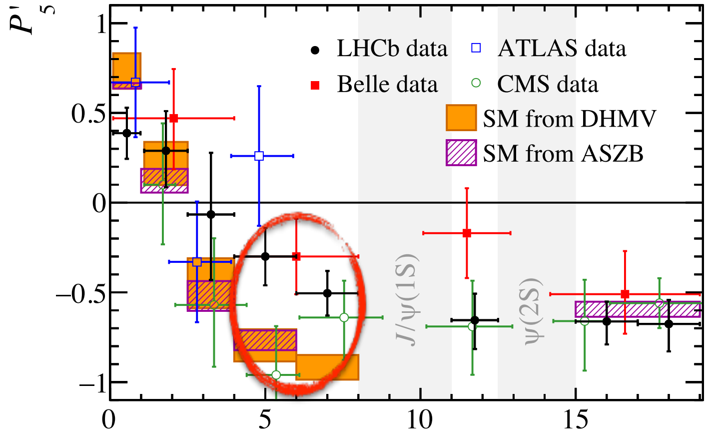
$$\tau[B_s^0 \to \mu^+\mu^-] = 2.04 \pm 0.44 \pm 0.05\ \mathrm{ps}$$

Not sensitive to A, yet, but getting there…



Future: info on extended scalar sector

Flavor Physics: rare processes (II)

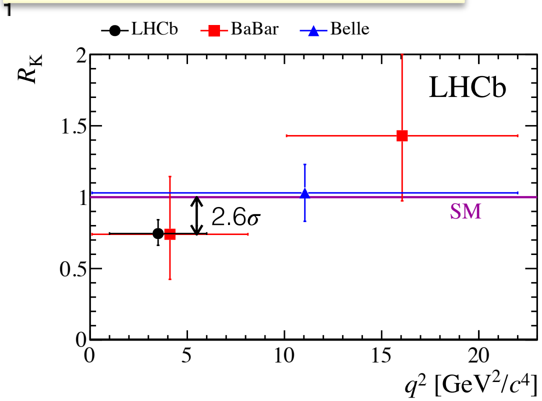


2.8 and 3.0 σ from SM

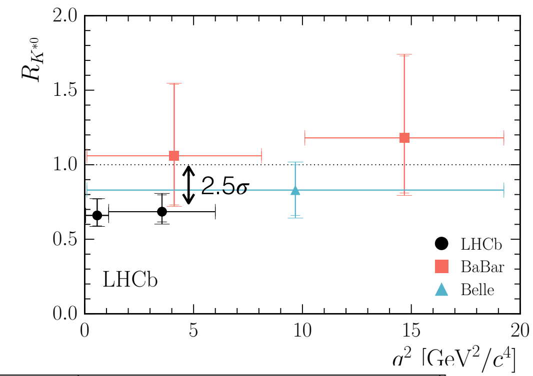
- JHEP 02 (2016) 104
- PRL 118 (2017)
- ATLAS-CONF-2017-023
- CMS-PAS-BPH-15-008

S. Bifani

R(K)=μμK/eeK



R(K*)=μμK*/eeK*



	SM	Exp.
$R_K^{[1-6]}$	1.00 ± 0.01	$0.745^{+0.090}_{-0.074} \pm 0.036$
$R_{K^*}^{[1.1-6]}$	1.00 ± 0.01	$0.685^{+0.113}_{-0.069} \pm 0.047$
$R_{K^*}^{[0.045,1.1]}$	0.91 ± 0.03	$0.660^{+0.110}_{-0.070} \pm 0.024$

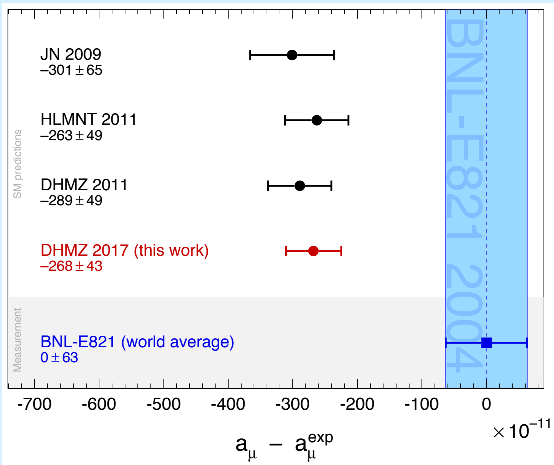
Is there a connection to the R(D*) issue?
AND to the μμK* angular distributions?
Some think so; e.g. see A.Greljo at this conference
(https://indico.cern.ch/event/466934/contributions/2585682/)

Supposedly "clean" observables
But are we ready to give up on universality?

The bad news: ATLAS+CMS cannot help in R(K), R(K*) (eeK$^{(*)}$ very, very hard)…

Flavor: Non-b sector

Hadron Vacuum Polarisation: effect on g_μ

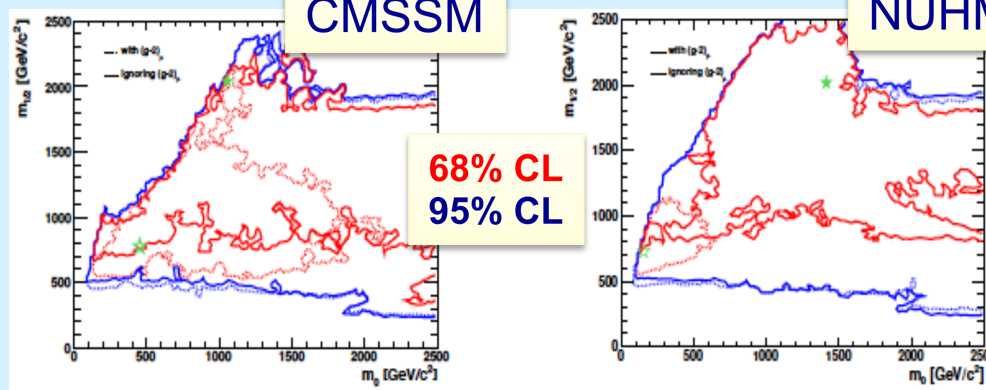


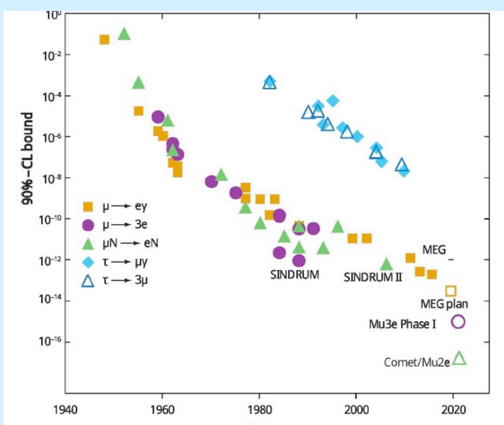
Reminder: g-2 effect

CMSSM

NUHM1

68% CL
95% CL





Muon LFV searches by dedicated experiments
Final MEG upper limit $B(\mu \to e\gamma) < 4.2\ 10^{-13}$ @90% CL
2017: relatively quiet year
Exciting times ahead with MEGII, Mu2e, COMET, Mu3e

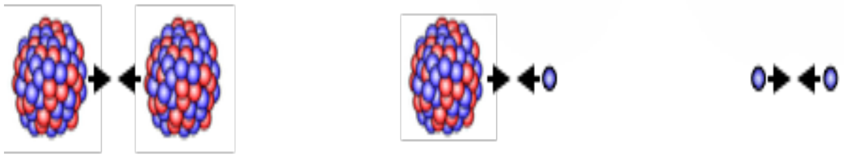
Extreme Matter

Evolution: physics studies of matter at its extreme started with Heavy Ions.

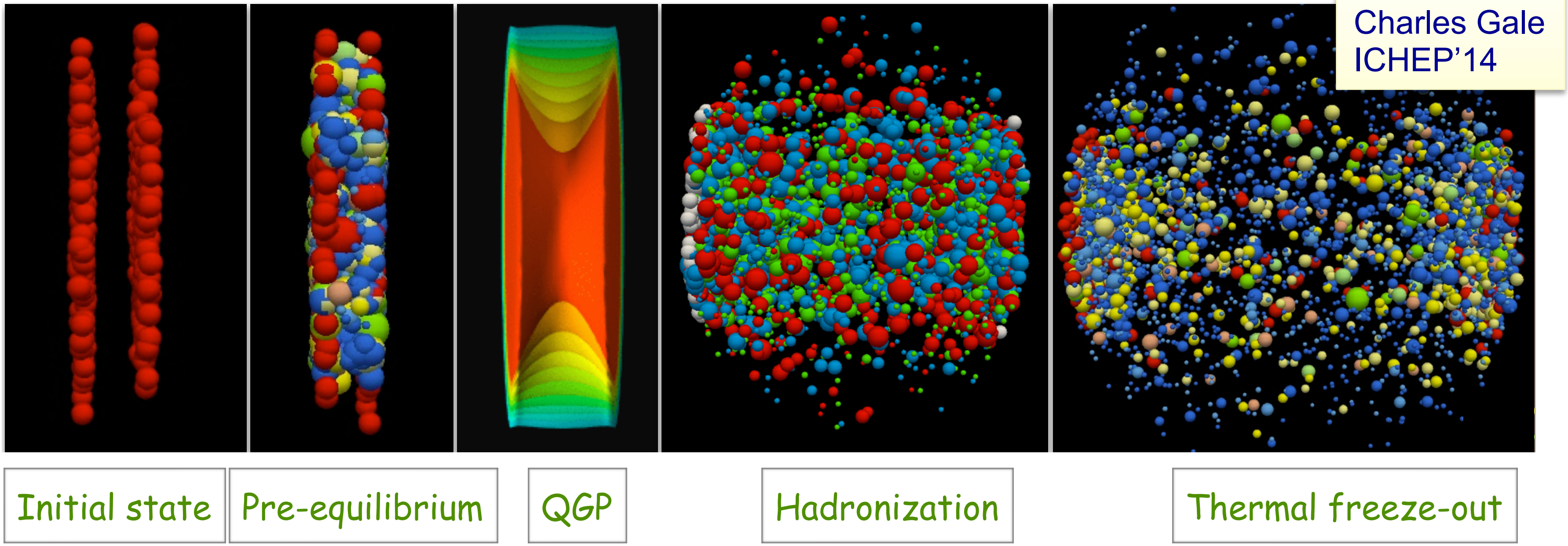
Then it spilled over to nucleon-nucleon…

and then to nucleon-HI…

Emerging picture of describing all three



Heavy Ion Physics

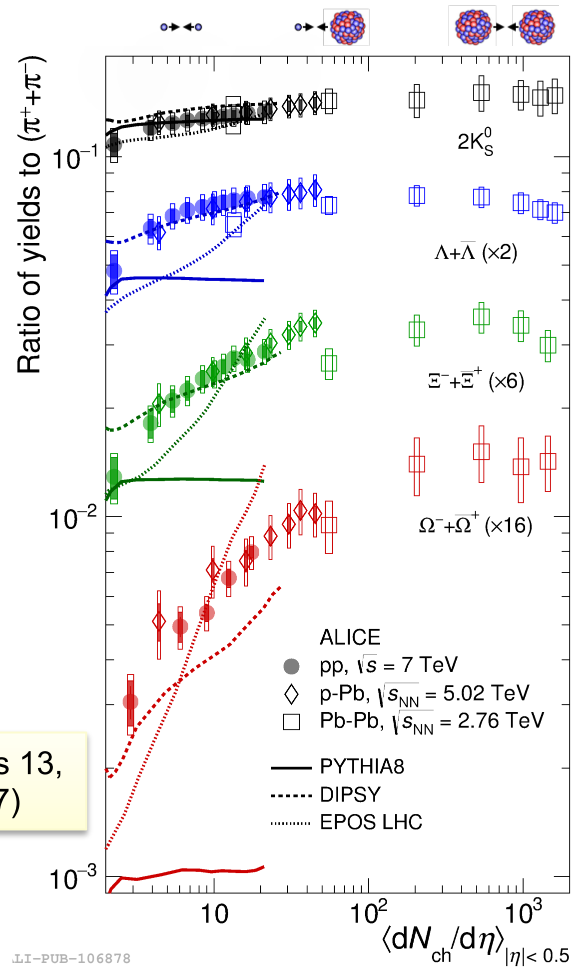


- **Soft Probes (strangeness enhancement)**
  - **Reason behind building a TPC…**
- **Collective phenomena**
- **Suppression phenomena**
  - **J/ψ (since ~ever in the field) and Y production**
  - **Rich physics in Hard Probes (jets vs γ/W/Z); a present from RHIC to the LHC**

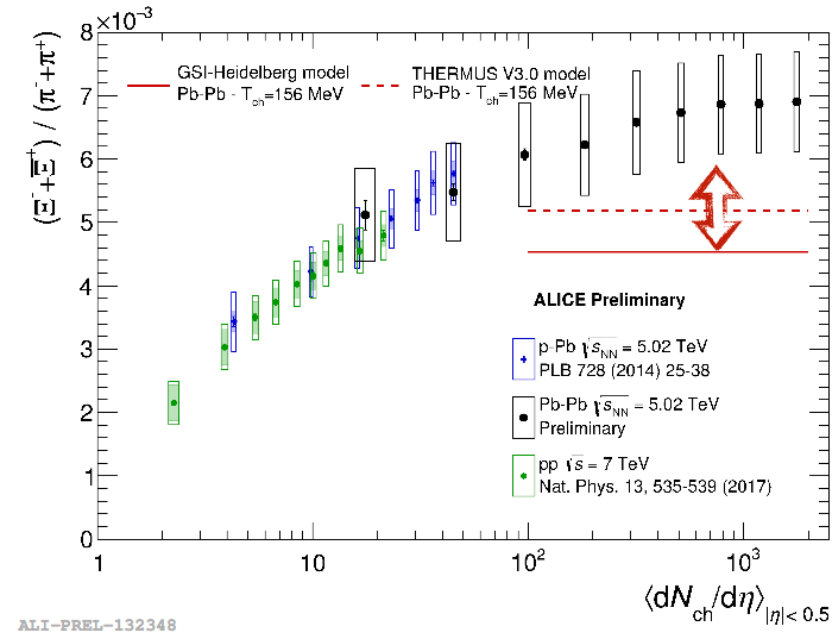
From pp to pPb to PbPb

s enhancement

Strangeness increases with multiplicity also in pPb AND in pp



Nature Physics 13, 535–539 (2017)

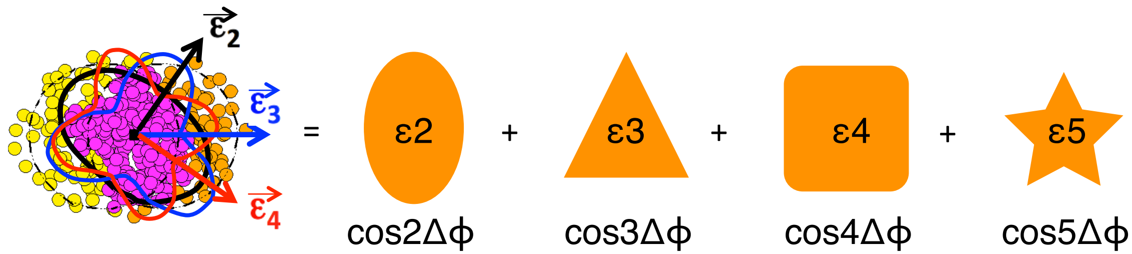


Will **pp ratios** converge to **Pb-Pb values**?

Heavy Ions: collectivity (flows)

Multipole expansion

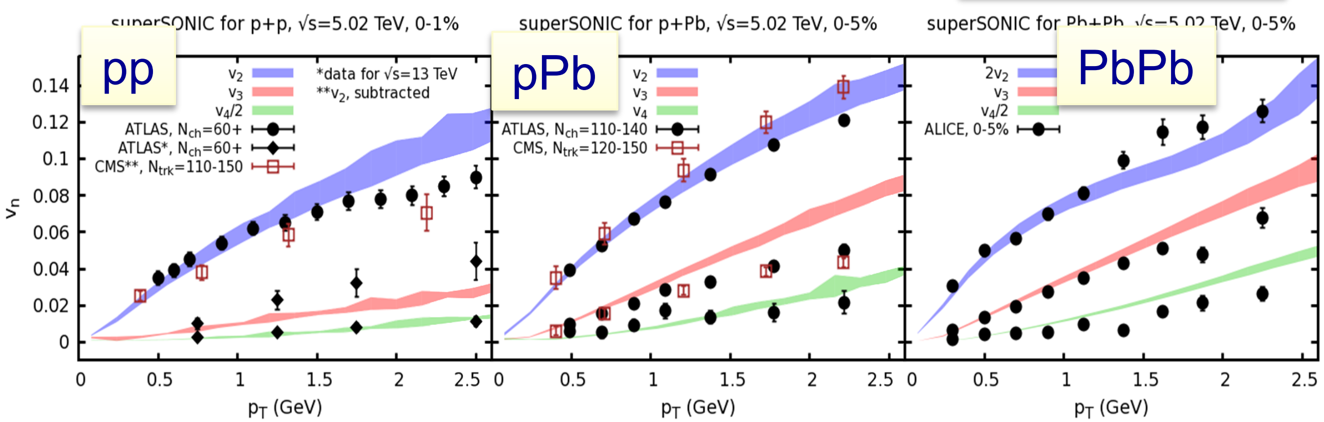
$$\frac{d^3N}{dyd^2p_T} = \frac{d^2N}{dydp_T^2}\left[1+2\sum_{n=1}^{\infty} v_n(p_T)\cos(\phi-\psi_n)\right] \qquad \psi_n = \frac{1}{n}\arctan\left(\frac{\langle p_T \sin n\phi\rangle}{\langle p_T \cos n\phi\rangle}\right)$$

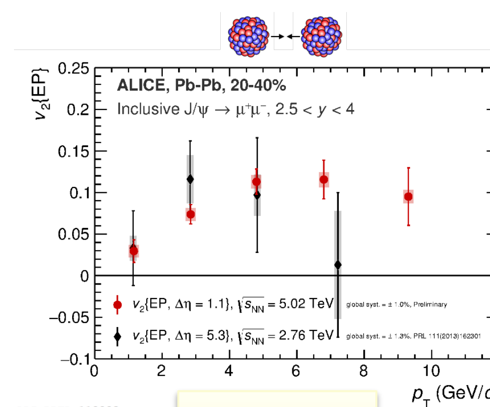


"One fluid to rule them all"

P. Romatschke

Charm flows too

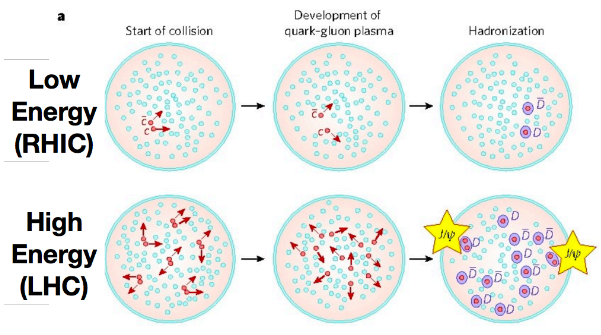




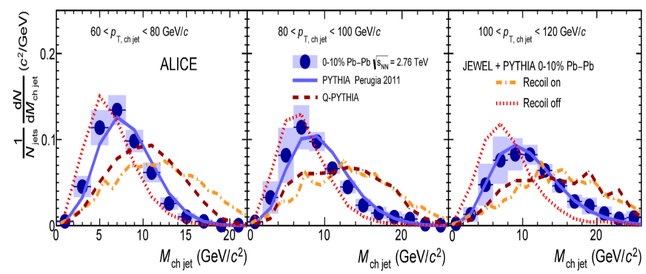
$v_2(D)$: old

Heavy ions: suppression & hard(er) probes

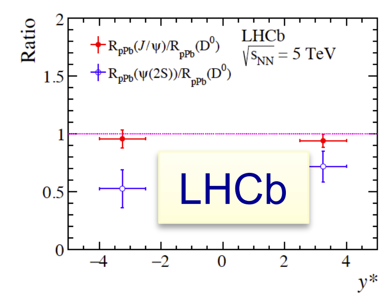
$$R_{AA} = \frac{AA}{\text{rescaled pp}} = \frac{d^2N_{AA}/dp_{\mathrm{T}}dy}{\langle N_{coll}\rangle d^2N_{pp}/dp_{\mathrm{T}}dy}$$



Jet production; evolution

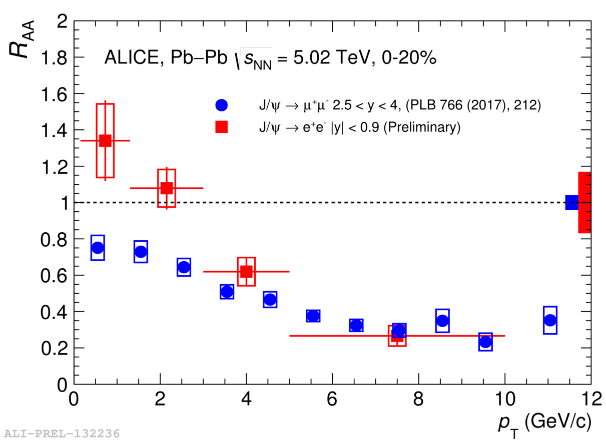


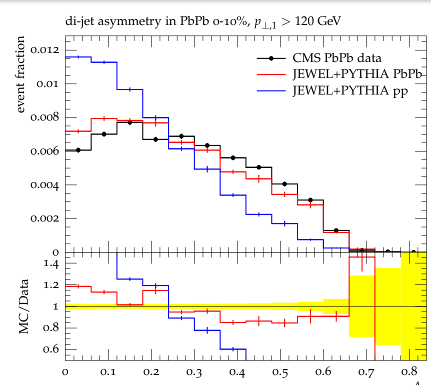
pPb: Suppr(J/ψ) ≈ Suppr(D⁰)



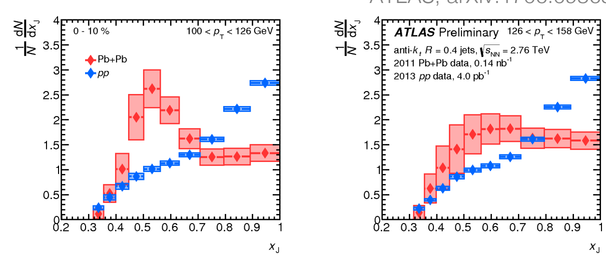
J/ψ via cc **coalescence or recombination**

dijet imbalance: due to “fragmentation” and not “path length”?





ATLAS, arXiv:1706.09363



The elusive neutrino(s)

The very nature:

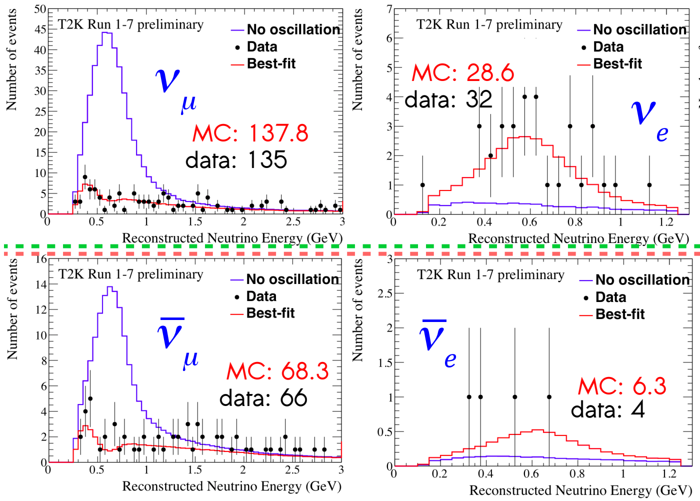
Oscillations, more mass generation questions (beyond EWSB?)

Richness of the lepton sector (PMNS, CP violation)

Majorana/Dirac…

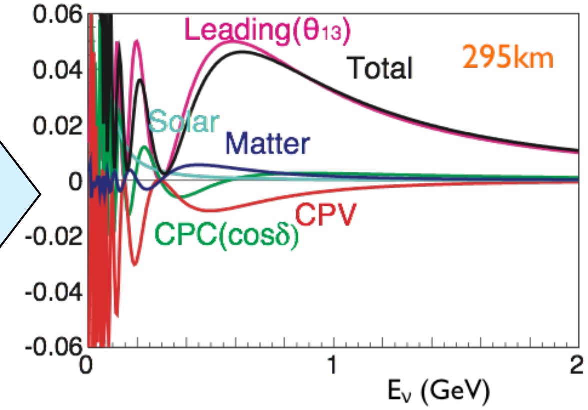
Sterile neutrinos?

Neutrinos: oscillations (I)

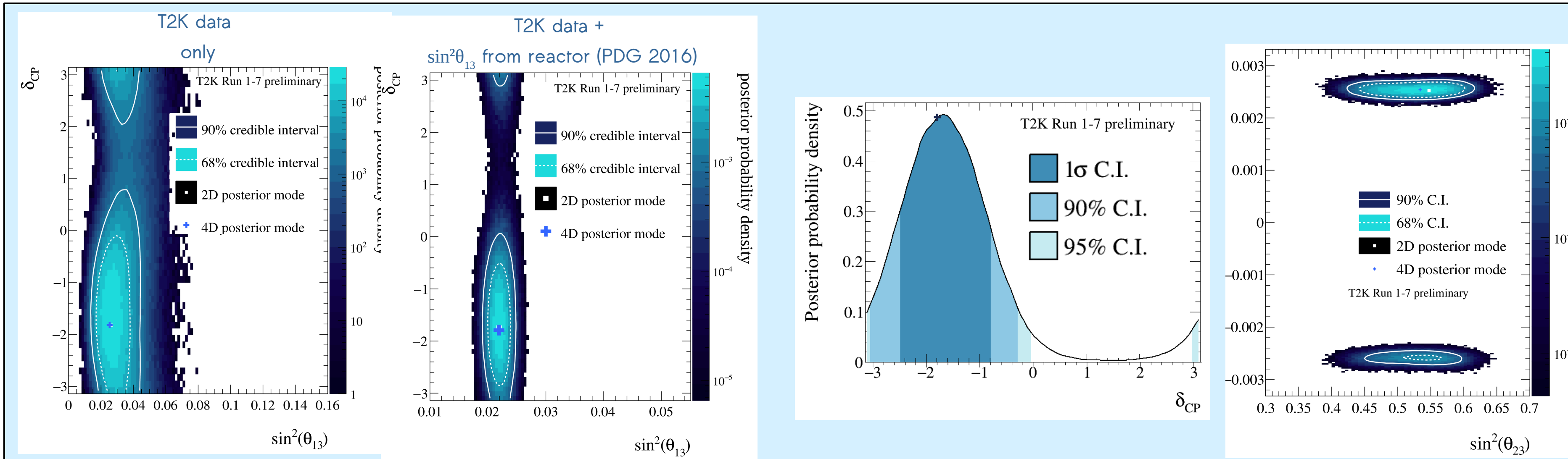


T2K churning away

Fit

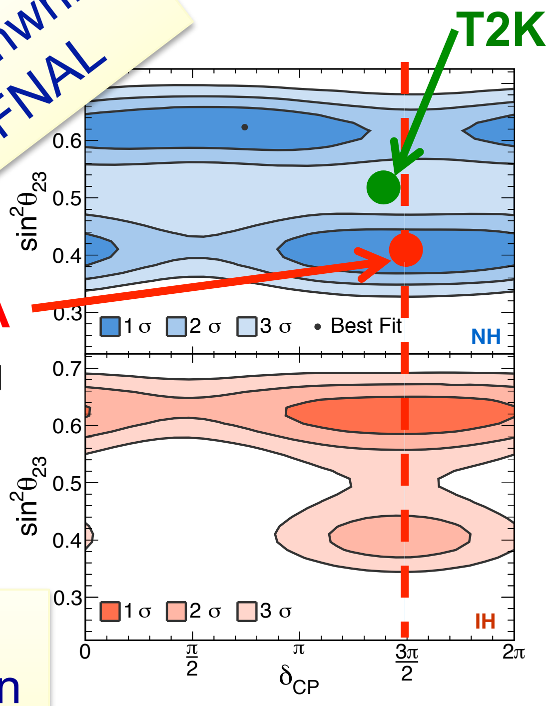


Fit

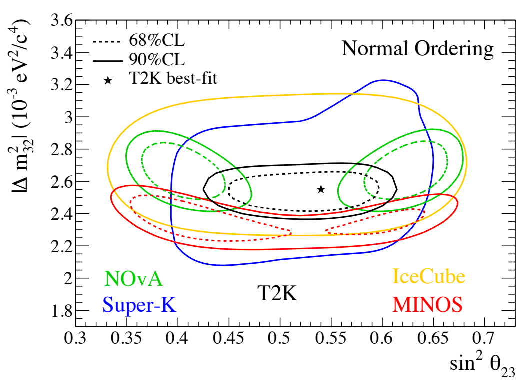


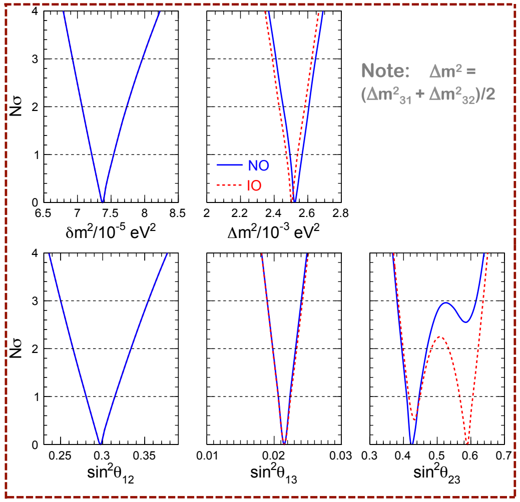
Neutrinos: oscillations (II)

Meanwhile at FNAL



some tension



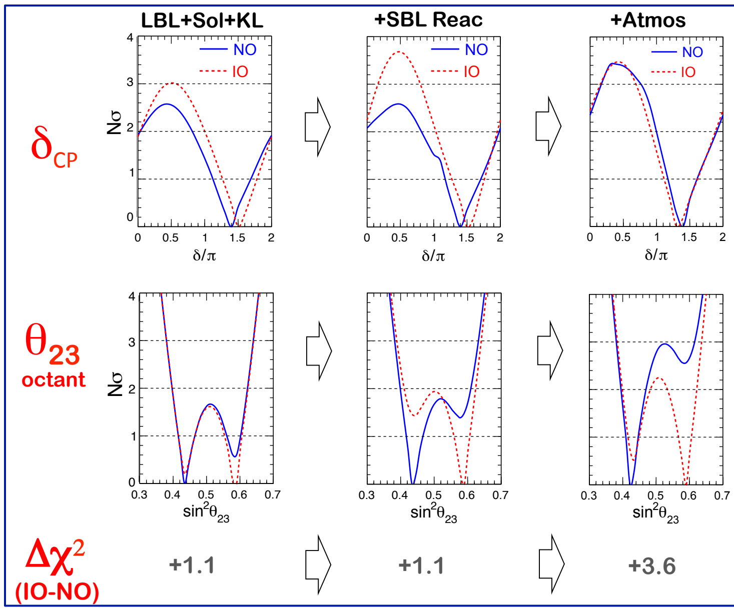


Known parameters

δm^2	2.3 %
Δm^2	1.6 %
$\sin^2\theta_{12}$	5.8 %
$\sin^2\theta_{13}$	4.0 %
$\sin^2\theta_{23}$	~ 9 %

all < 10%...

Precision Era!



$\sin\delta \sim -1$ (or $\sin\delta < 0$) favored; $\sin\delta \sim +1$ excluded

Max-mixing disfavored; octant flips with NO/IO

Intriguing! NO favored

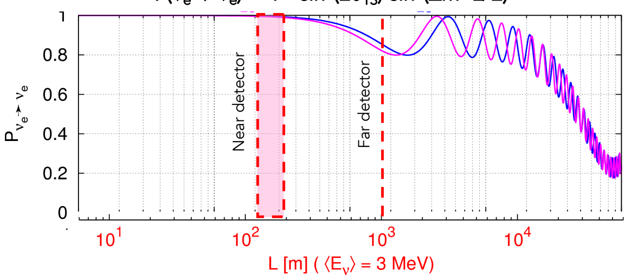
Unknown params

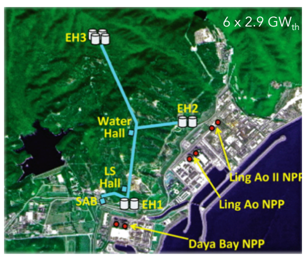
E.Lisi

Neutrinos: Reactor expts, Short Baselines

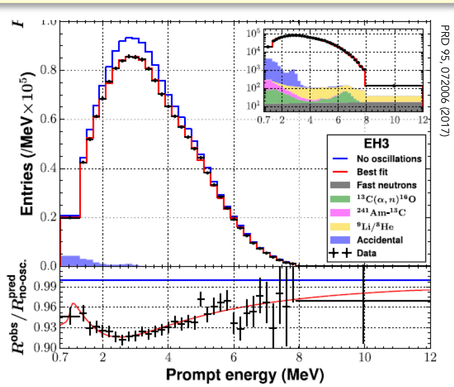
Principle: θ_{13}

$P(\nu_e \to \nu_e) = 1 - \sin^2(2\theta_{13}) \sin^2(\Delta m^2 L/E)$

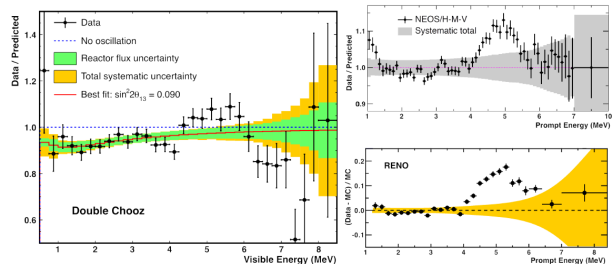




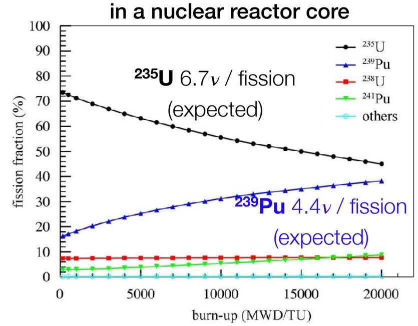
The prized measurement

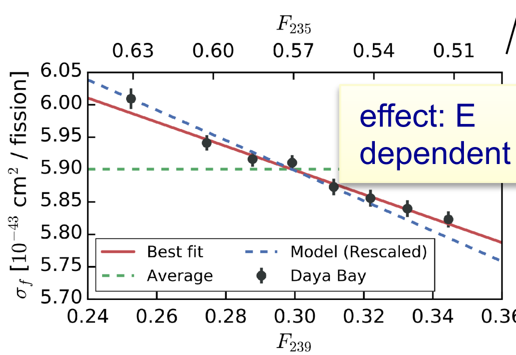


The “reactor anomaly”

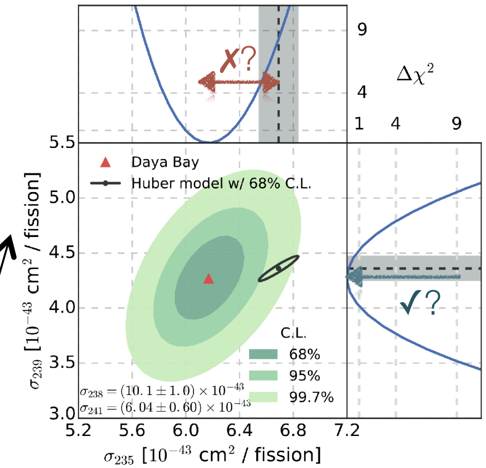


Evolution of fission fractions in a nuclear reactor core

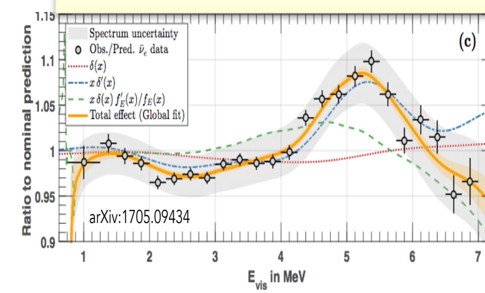




effect: E dependent



Or: 1% E miscalibration?



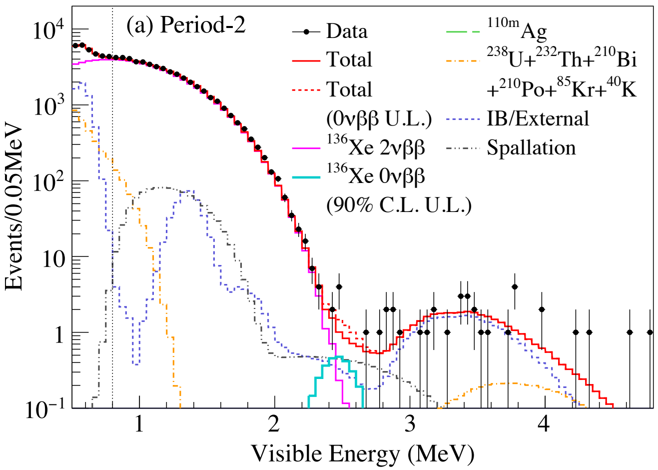
→ Damps enthusiasm

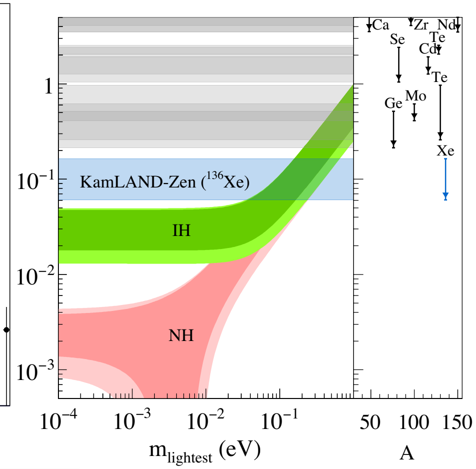
But not for Sterile νs…

Neutrinos: Majorana/Dirac ($0\nu\beta\beta$)

As fundamental as a question can get

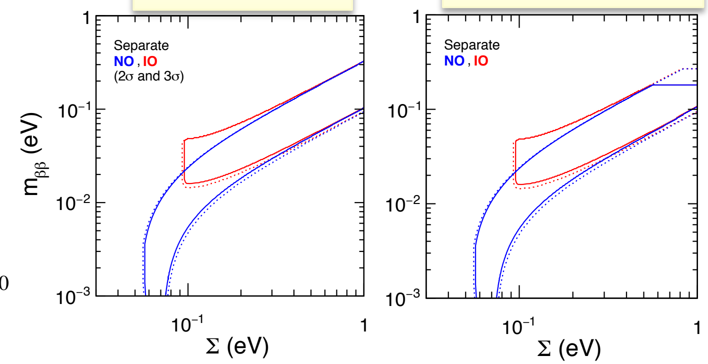
$$m_{\beta\beta} = \left|c_{13}^2 c_{12}^2 m_1 + c_{13}^2 s_{12}^2 m_2 e^{i\phi_2} + s_{13}^2 m_3 e^{i\phi_3}\right|$$
$$\Sigma = m_1 + m_2 + m_3$$





Only osc.

Osc + $0\nu\beta\beta$



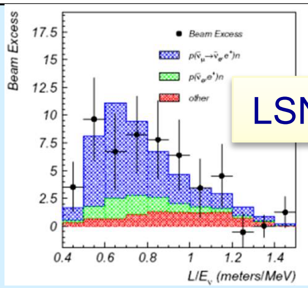
Extremely active field

	Source	Mass (kg)	Detector	Sensitivity $\tau_{1/2}$ (yr)	Sensitivity $m_{\beta\beta}$ (meV)	Background (/kev/kg/yr)
* GERDA	^{76}Ge	43.4	HPGe	5.3×10^{25}	150-330	10^{-3}
* CUORE/Cuoricino	^{130}Te	206	Bolometers	9×10^{25}	50-130	0.01
* NEXT	^{136}Xe	100	HP-TPC	6×10^{25}	200	4×10^{-4}
CUPID	^{82}Se	5.2	Bolometers			~0
SNO+	^{130}Te	1300	Lq. Scinti	2×10^{25}	40	5×10^{-5}
* SuperNEMO	^{82}Se	100	Tracker	10^{26}	40-110	
* KamLAND-Zen	^{136}Xe	383	Lq. Scinti	1×10^{26}	61-165	1.6×10^{-4}
AXEL	^{136}Xe	100	HP-TPC			
PANDAX-III	^{136}Xe	200	HP-TPC	5×10^{25}	90-230	1×10^{-4}
* EXO	^{136}Xe	76.5	Lq-TPC	1.1×10^{25}	190-450	1.7×10^{-3}
LEGEND	^{76}Ge	1000	HPGe			

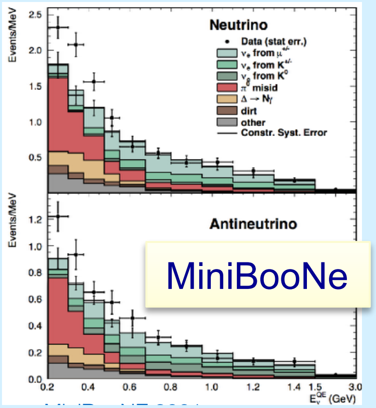
Often said: "ν masses a clear indication of New Physics"; because if Dirac, need $y_\nu \sim 10^{-12}$;
Yet, we do accept: $y_e \sim 10^{-6}$ ($y_t \sim 1$)

While the addition of a ν_R would be a "change to the SM", it would be a very minor one. The REAL NP would be in the alternate mechanisms…

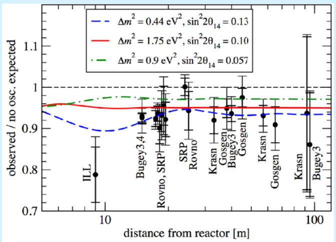
Neutrinos: sterile sector (?)



LSND



MiniBooNe



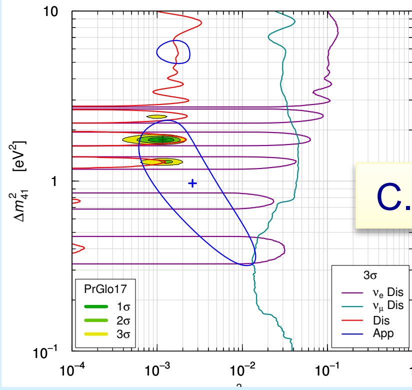
ν_e shortage in reactor expts

ν_e DIS
$\sin^2 2\vartheta_{ee} \simeq 4|U_{e4}|^2$

ν_μ DIS
$\sin^2 2\vartheta_{\mu\mu} \simeq 4|U_{\mu4}|^2$

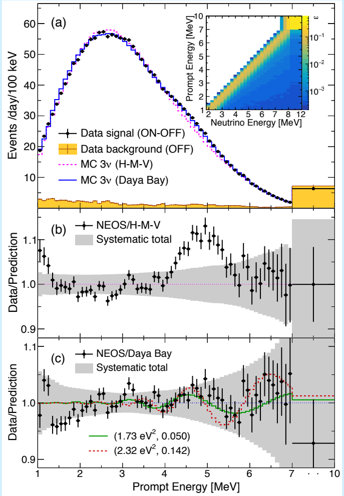
$\nu_\mu \to \nu_e$ APP
$\sin^2 2\vartheta_{e\mu} = 4|U_{e4}|^2|U_{\mu4}|^2 \simeq \frac{1}{4}\sin^2 2\vartheta_{ee}\sin^2 2\vartheta_{\mu\mu}$

[Okada, Yasuda, IJMPA 12 (1997) 3669; Bilenky, CG, Grimus, EPJC 1 (1998) 247]

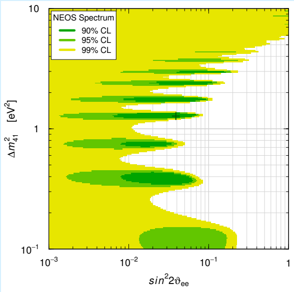


C.Giunti

Taking 5 MeV bump as due to sterile ν

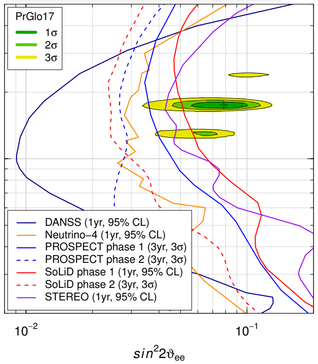


NEOS

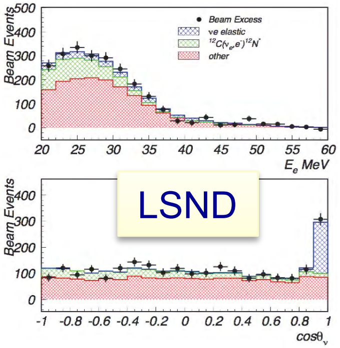


Experiment	Reactor Power/Fuel
DANSS (Russia)	3000 MW LEU fuel
NEOS (South Korea)	2800 MW LEU fuel
nuLat (USA)	40 MW ^{235}U fuel
Neutrino4 (Russia)	100 MW ^{235}U fuel
PROSPECT (USA)	85 MW ^{235}U fuel
SoLid (UK Fr Bel US)	72 MW ^{235}U fuel
Chandler (USA)	72 MW ^{235}U fuel
Stereo (France)	57 MW ^{235}U fuel

Very active field



A reminder…

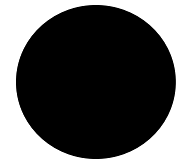


LSND

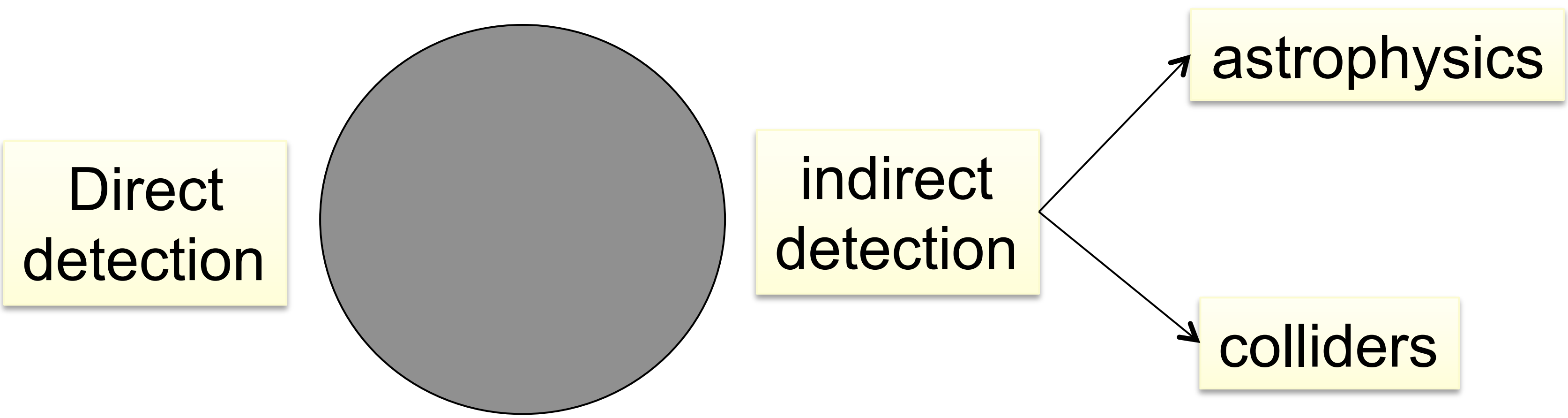
The Dark Sector

The Dark Sector

- **An experimental Fact & still a TOTAL mystery**
- **Nightmare scenario: totally dark**
  - **Only Gravity to play with…**

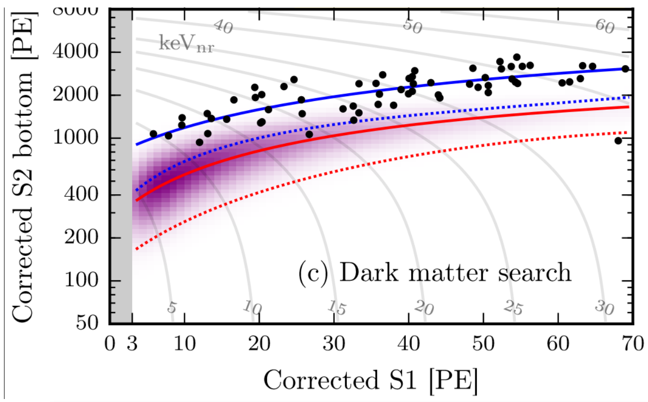


- **More promising: several (3? 20? more?) shades of grey**

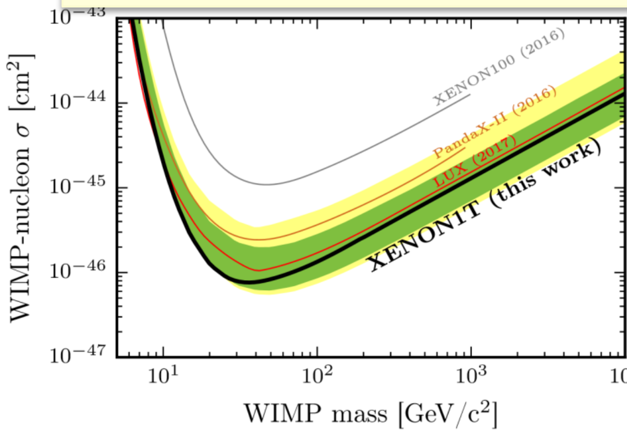


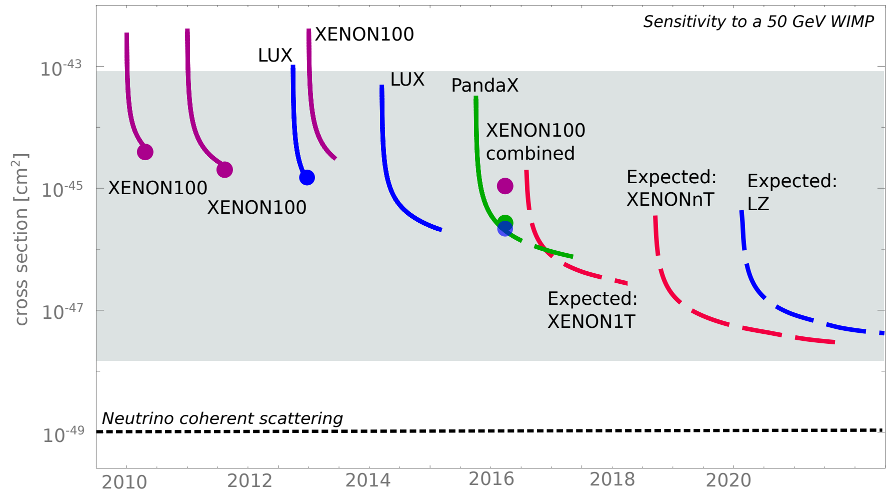
DM: direct detection experiments (I)

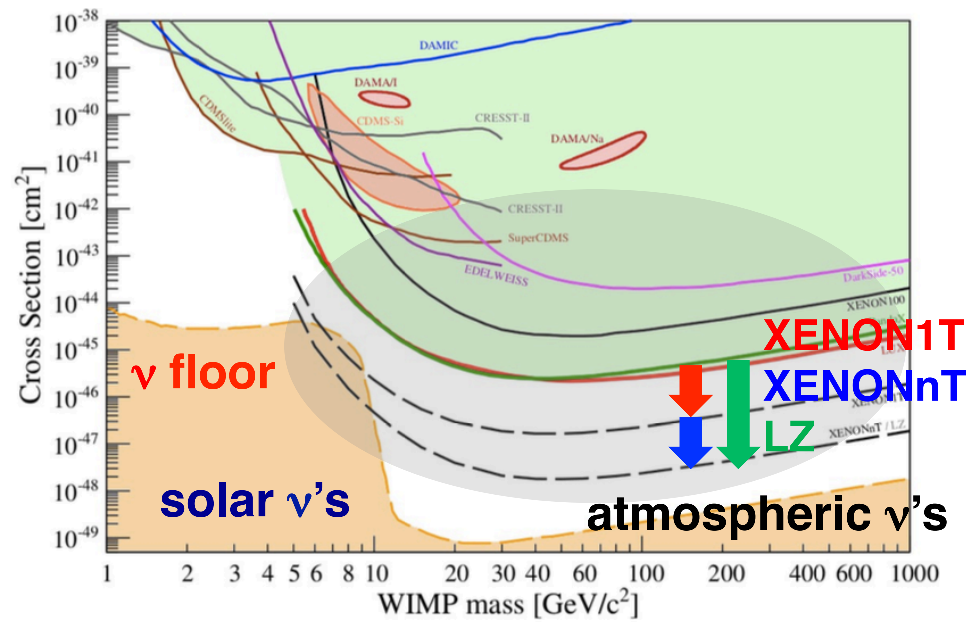
Two-phase Xe expts continuing to increase their sensitivity



Impressive bkg level: 0.2×10^{-3} evt/day/kg/keV

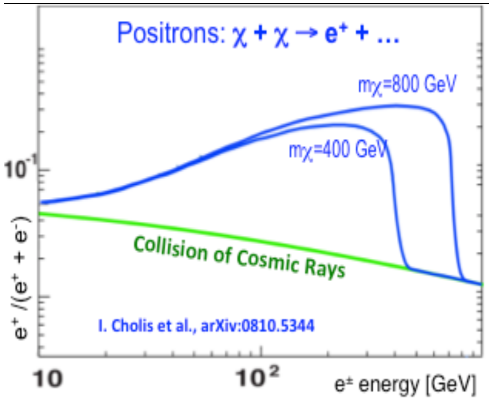




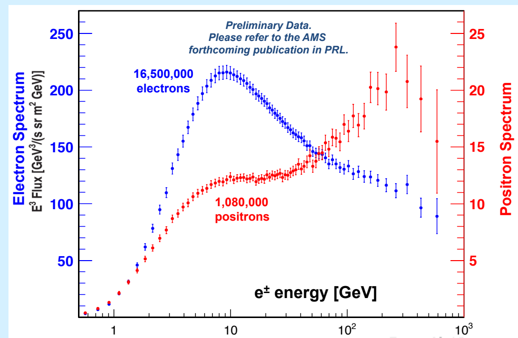


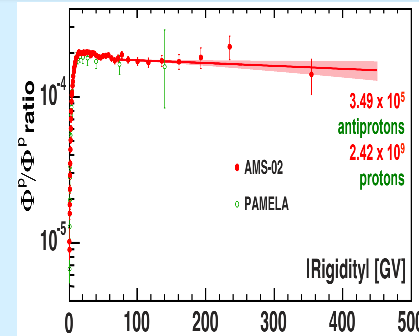
DM indirect searches: cosmic ray expts

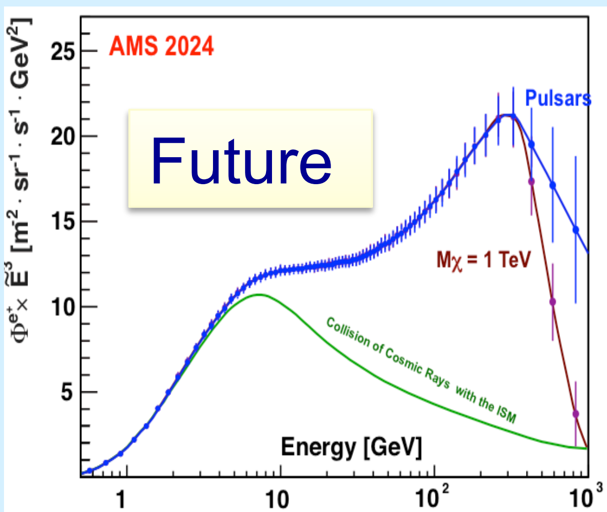
The dream scenario



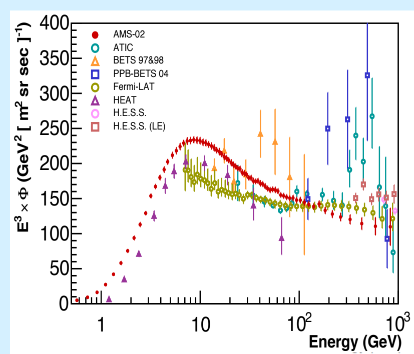
Reality: tantalizing fall (?!). But pulsars? Moreover: antiprotons!

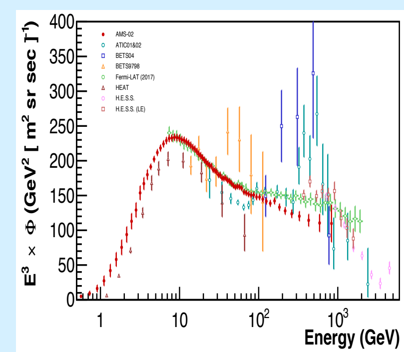




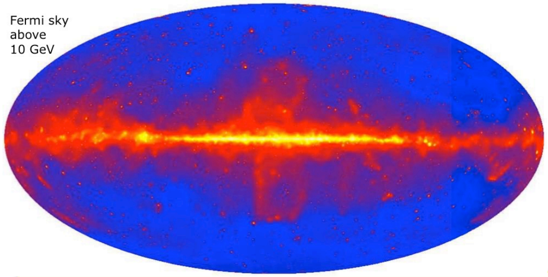


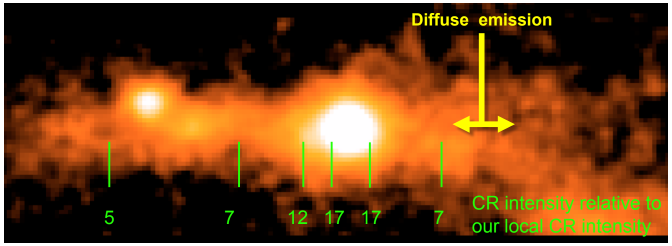
A parting thought: difficult measurements

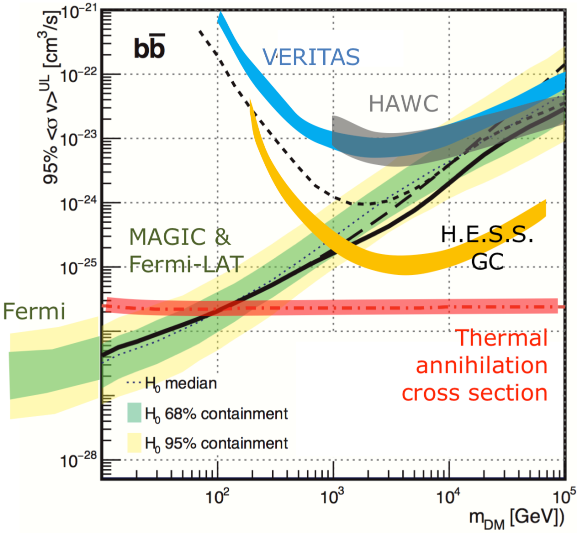




DM indirect searches: γ–ray expts

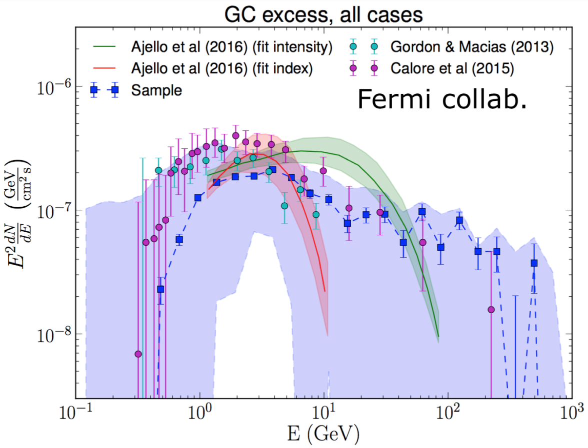




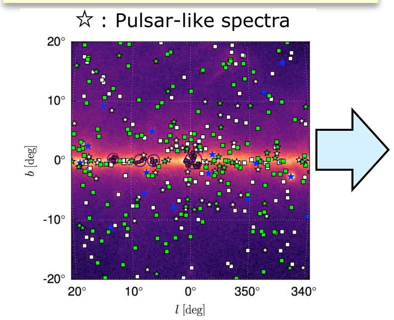


Clearly, experiments have evolved significantly; Caveats: not in control of the beam; not in control of the space between the source and the experiment; “limits are easy; signal very hard!”

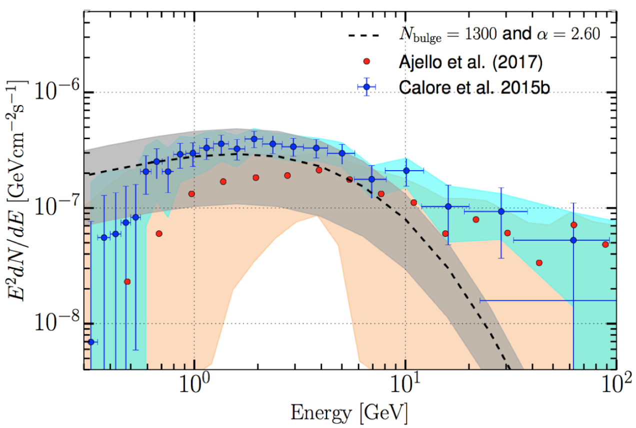
Excess – significant? DM???



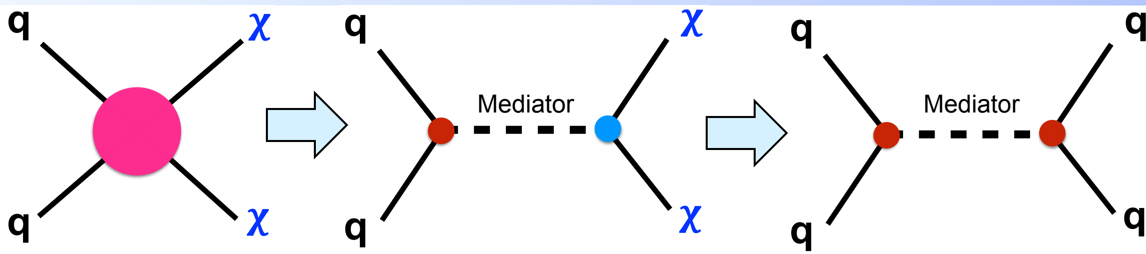
Add pulsars…



Accounts for much of the effect?



DM indirect detection: collider expts

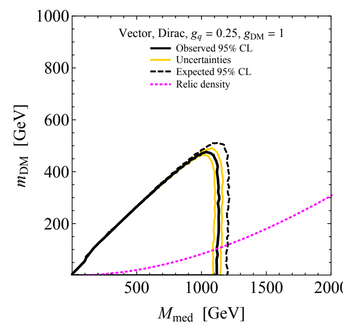


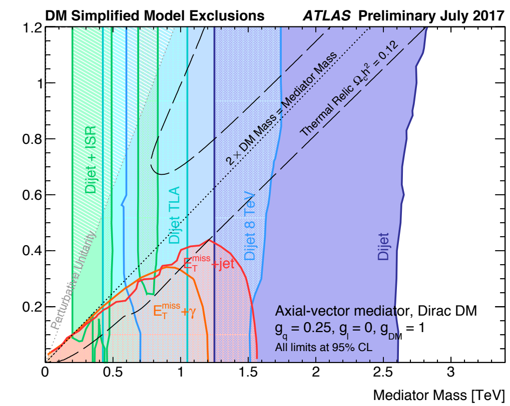
Can interpret all resonance searches in terms of DM

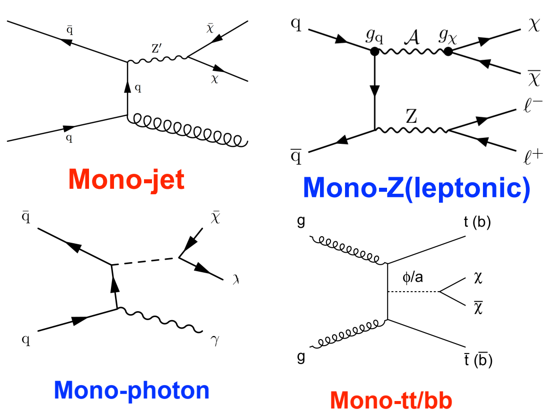
$$\frac{g_q g_\chi}{M^2 - q^2} \approx \frac{g_q g_\chi}{M^2}\left(1 + \frac{q^2}{M^2} + \cdots\right) = \frac{1}{\Lambda^2}\left(1 + \frac{q^2}{M^2} + \cdots\right)$$

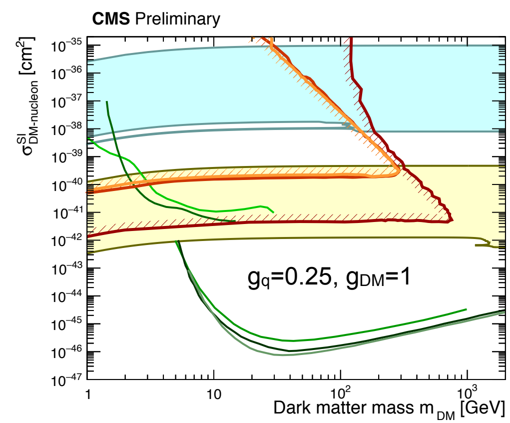
Simplified models

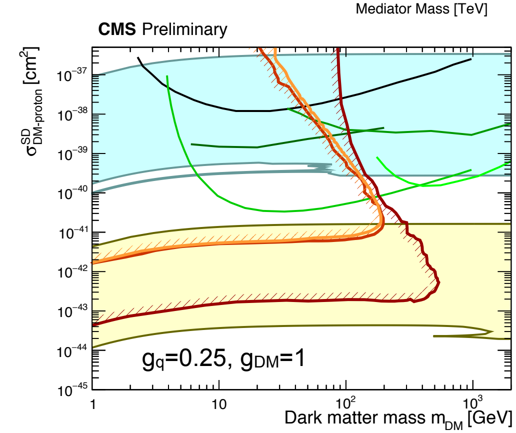
V/A: $g_\chi=1, g_q=0.25$
P/S: $g_\chi=g_q=1$











And many many more…

Spin-Independent

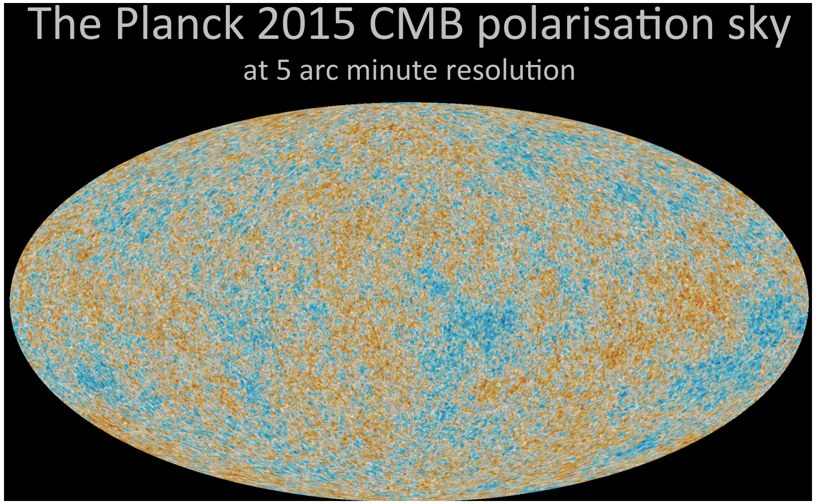
Spin-dependent

The rest of the Universe

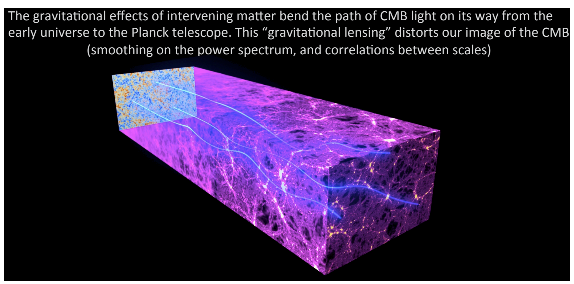
CMB, Dark Energy,

Gravitational physics

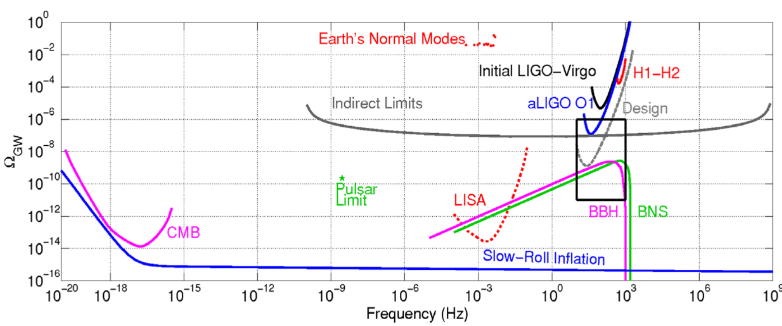
CMB & DE



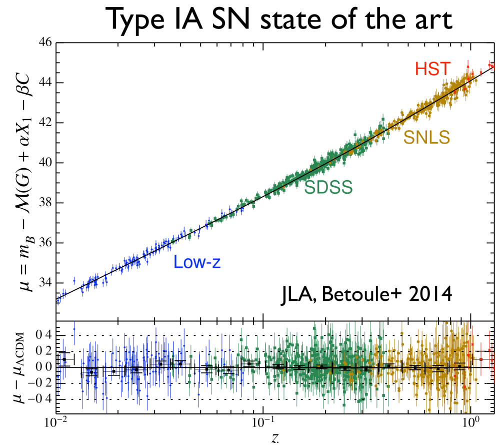
The Planck 2015 CMB polarisation sky
at 5 arc minute resolution



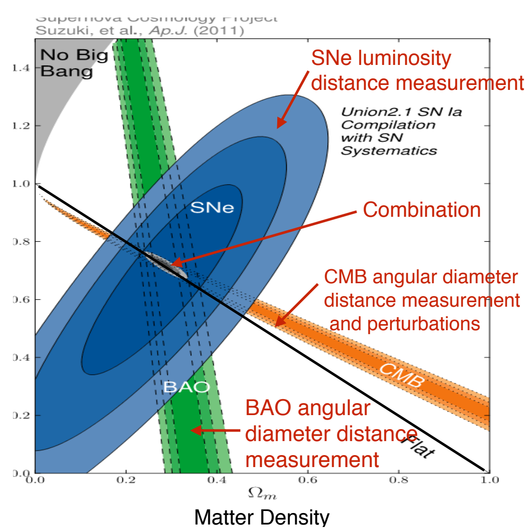
The gravitational effects of intervening matter bend the path of CMB light on its way from the early universe to the Planck telescope. This "gravitational lensing" distorts our image of the CMB (smoothing on the power spectrum, and correlations between scales)



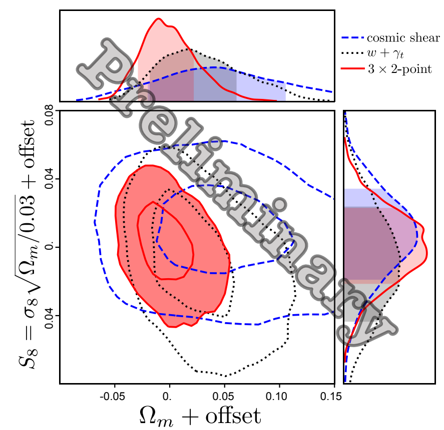
Earth's Normal Modes
Initial LIGO–Virgo
H1–H2
Indirect Limits
aLIGO O1
Design
Pulsar Limit
LISA
BBH
BNS
CMB
Slow–Roll Inflation
Ω_{GW}
Frequency (Hz)



Type IA SN state of the art
HST
SNLS
SDSS
Low-z
JLA, Betoule+ 2014
$\mu = m_B - M(G) + \alpha X_1 - \beta C$
$\mu - \mu_{\Lambda CDM}$
z



Suzuki, et al., Ap.J. (2011)
No Big Bang
SNe luminosity distance measurement
Union2.1 SN Ia Compilation with SN Systematics
SNe
Combination
CMB angular diameter distance measurement and perturbations
CMB
BAO
BAO angular diameter distance measurement
Flat
Ω_m
Matter Density



cosmic shear
$w + \gamma_t$
3×2-point
Preliminary
$S_8 = \sigma_8\sqrt{\Omega_m/0.03}$ + offset
Ω_m + offset

The Cosmos: GW Wave spectrum

The Cosmos & Grav Waves

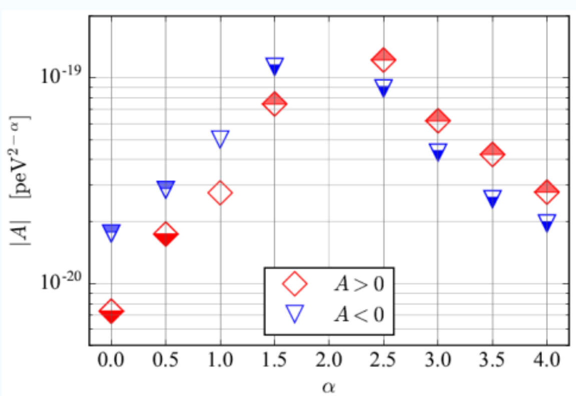
Tests of GR: ok
(classical gravity ok)

Limit on m_g:

$$E^2 = p^2c^2 + A \cdot p^\alpha c^\alpha$$

$$v_g/c = 1 + (\alpha - 1)AE^{\alpha-2}/2$$

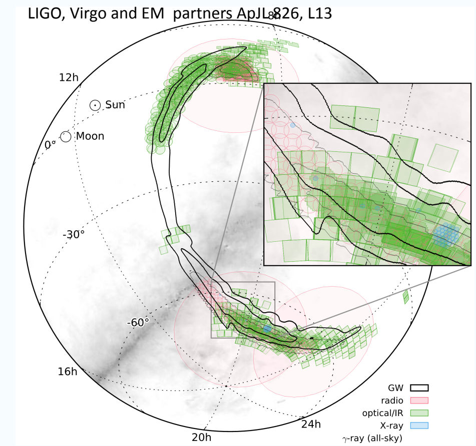
$$\delta\Psi(A,\alpha)$$



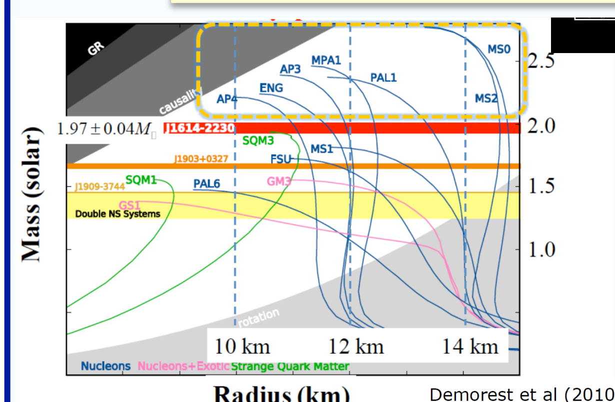
$m_g < 7.7 \times 10^{-23}$ eV/c^2

GW detectors to trigger EM telescopes (radio, γ-rays & ν detectors)

> 80 MOUs signed!



Bright future: LISA, Einstein; even "apps to nuc&part" physics:



Phase transition for collaborations: ~10^3 scientists (and board, committees, MOUs, L1/L2/L3 mgmt…)

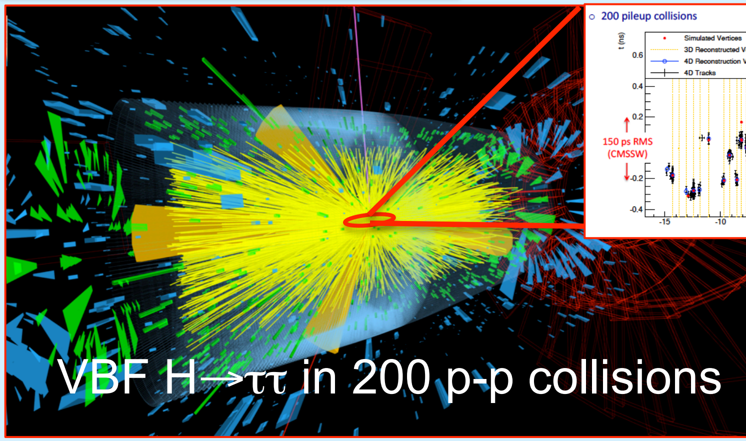
The enablers

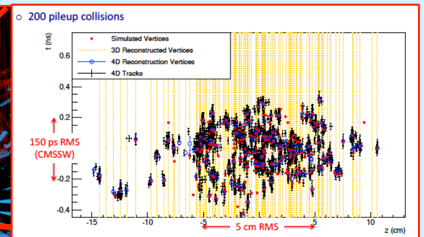
Machines

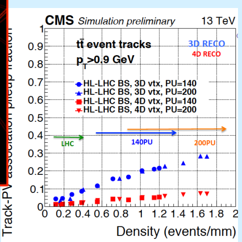
Detectors

Detector developments

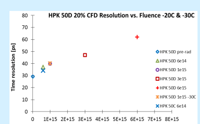
4D reconstruction



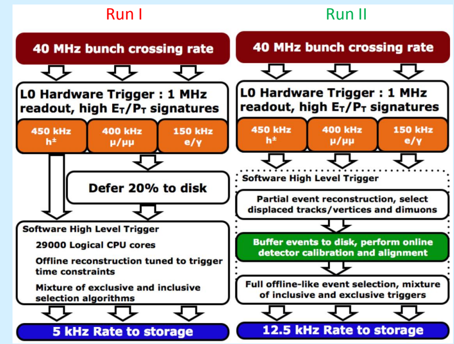




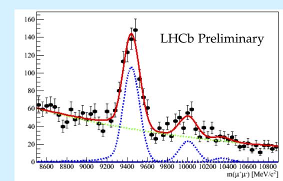
TOF $\sigma \simeq 30$ ps, $|\eta| < 3$, $p_T > 0.7$ GeV
factor 4-5 effective pile-up reduction
≃15% merged vertices → ~1.5%



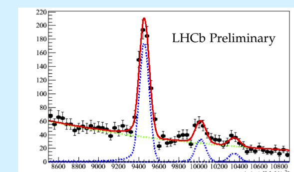
Online reconstruction



LHCb



First alignment: $\sigma_\Upsilon = 92$ MeV/c^2

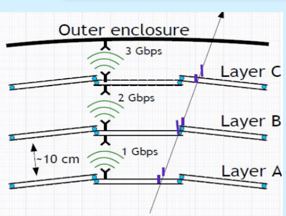


Latest alignment $\sigma_\Upsilon = 49$ MeV/c^2

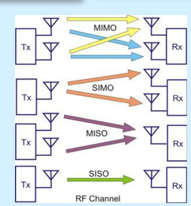
Towards dream of full readout?

Wireless Data Transmission (?)

WADAPT

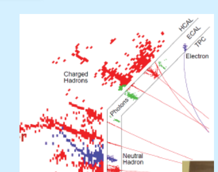


Reduced material
Latency ($v_{mmw} > v_{fiber}$)
Cross obstacles…

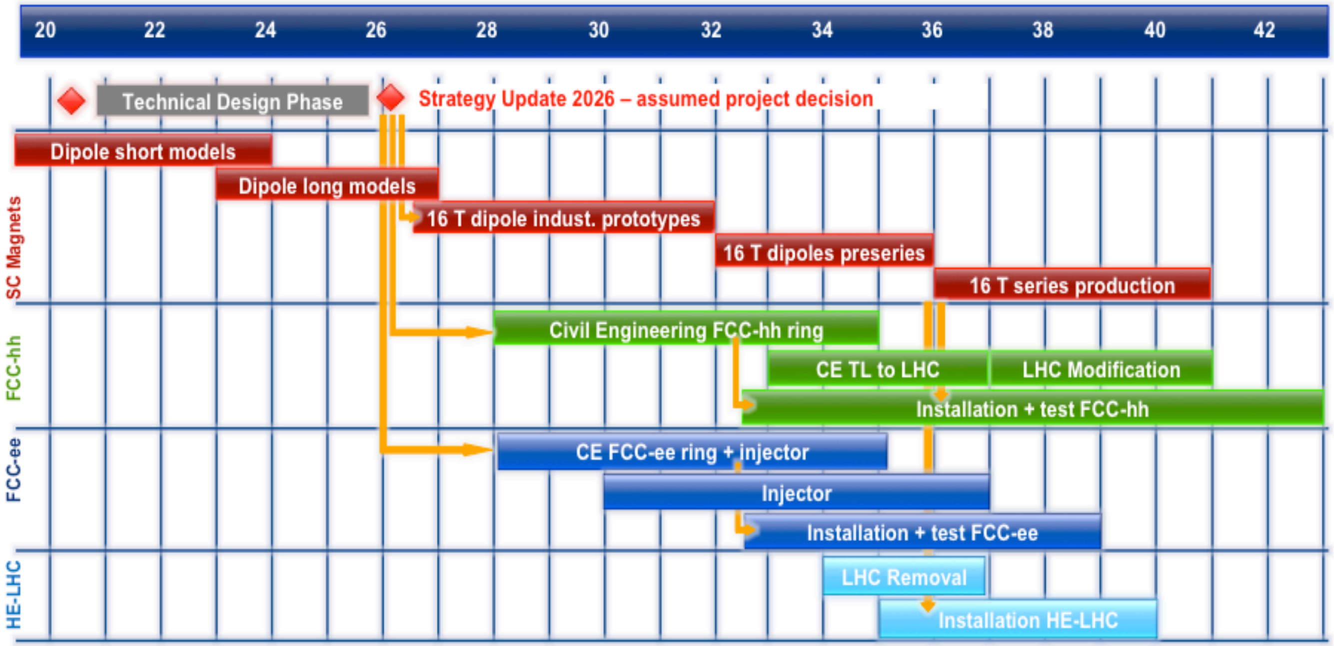


Particle Flow

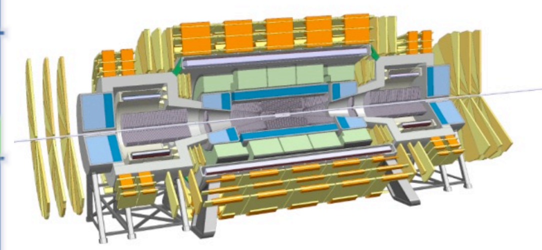
Spread to hadron collisions; now to new detector designs



Towards a new machine



$$\left|\psi_{FCC-hh}\right\rangle = \sum c_i \left|\psi_{LHC,i}\right\rangle$$



"Technically limited schedule"

As for next step in energy: driven by magnets… begs for more investment on this front

And of course on new acceleration methods.

Some parting thoughts

Instead of a summary of the highlighted highlights…

What if we don't find new physics in Run II/Run III? Fundamentalitis

- **Fundamentalitis is "a serious condition that causes its victims to believe that the only thing worth thinking about is the deep nature of reality as manifested through the fundamental laws of physics."**
  - Two notable examples – from giants of physics: Einstein (well known, on GUT) and Oppenheimer. Take the latter:
    - In 1939 (with Snyder) started BH physics: he showed that an in-falling observer on the surface of an object whose mass exceeded a critical mass would appear to be in a state of perpetual free fall to an outsider.
    - Then Oppenheimer forgot all about it and never said anything about black holes for the rest of his life. (Getting distracted by the bomb helped)
  - For Oppenheimer, BHs were mundane: they were but particular solutions of GR; The big deal was GR itself.
- **Freeman Dyson:**
  - "Oppenheimer in his later years believed that the only problem worthy of the attention of a serious theoretical physicist was the discovery of the fundamental equations of physics. Einstein …. felt the same way... Once you had discovered the right equations, then the study of particular solutions of the equations would be a routine exercise for second-rate physicists or graduate students."
  - Similarly, Einstein spent his last few years in a futile search for a Grand Unified Theory (took things to the ultimate, as far as doubting QM)
- **Fast-forward in BH physics: Hawking radiation; Bekenstein entropy; nowadays: link between information theory and BH physics; the firewall (?)… or non-locality (e^{-S})…**

http://blogs.scientificamerican.com/the-curious-wavefunction

The panorama of particle physics, again

- Energy Frontier, the LHC, is en route to
  - Probing the Higgs sector; exploring BSM
  - Completing the physics of flavor in the quark sector
  - Providing a new picture of hadronic matter
  - And on the side: providing important information on DM
- Neutrinos: weakly interacting so least known thus far
  - Exciting sneak preview of CP violation? En route to PMNS…
  - Mass generation mechanism beyond EWSB and H…
  - Very promising program of work and experiments ahead
- Dark Matter: if it’s some shade of grey, we’ll see it
  - Direct experiments are approaching the neutrino wall
  - Tantalizing hint from astrophysics; LHC complementary
- The Cosmos
  - Only place where we can play with gravity; and where densities can be very high
  - The scientific program being laid out holds tremendous promise
- Fundamental measurements
  - They remain so; a surprise can show up at any time

We are advancing on all fronts – and it’s impressive

We are advancing on all fronts – and it's impressive

All in all:

- It's still extremely interesting to be in Particle Physics

We are advancing on all fronts – and it's impressive

All in all:

- It's still extremely interesting to be in Particle Physics
- And it's still an honor and a privilege (to be in Particle Physics)

We are advancing on all fronts – and it's impressive

All in all:

- It's still extremely interesting to be in Particle Physics
- And it's still an honor and a privilege (to be in Particle Physics)

Warm thanks to the organizers for a beautiful and stimulating conference!