SUSY17
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Physics at a 100 TeV pp collider

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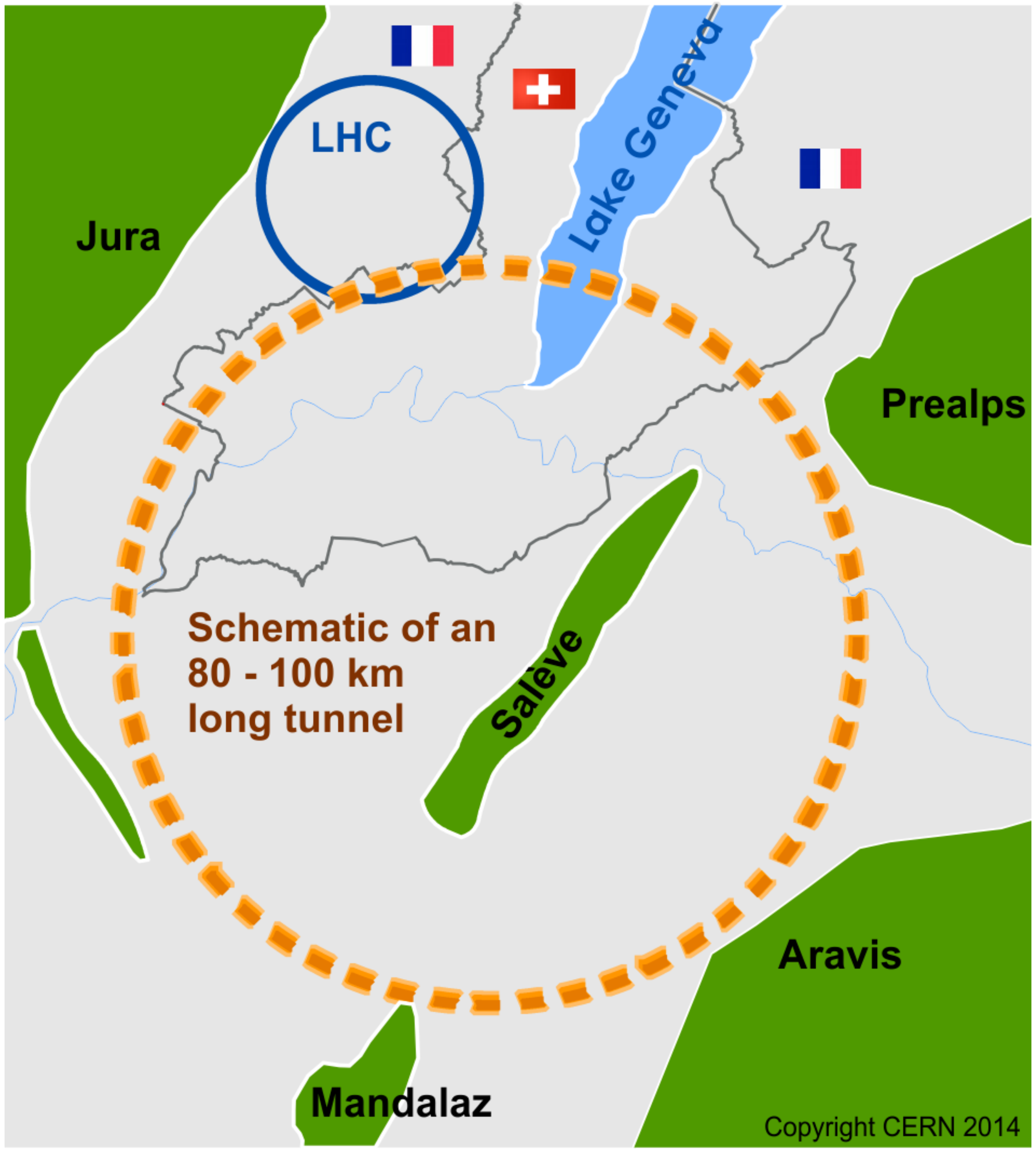
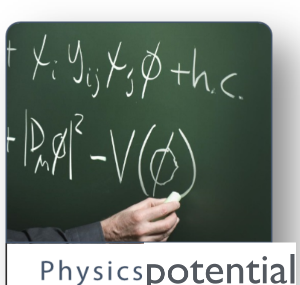
The context of this talk: Future Circular Colliders (FCC)

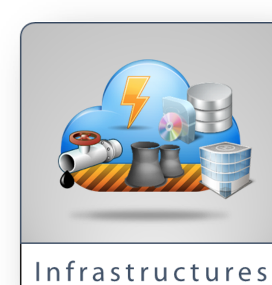


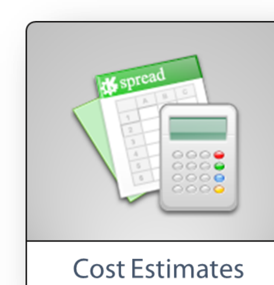
International FCC collaboration (CERN as host lab) to study:

- ***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
- **HE-LHC** with *FCC-hh* technology
- ***p-e* (*FCC-he*) option,** integration of one IP, e from ERL
- **CDR for end 2018**







on the nature of EW symmetry breaking

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- EW and strong interactions have free parameters (the symmetry groups, the strength of couplings, the charges of elementary particles). But at least we do have a <u>deep understanding of their dynamical nature</u>, namely the gauge principle. This allows us to speculate about an even deeper origin, e.g. from string theory or higher-dimensional Kaluza-Klein theories

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- The Higgs mechanism relies of the quartic Higgs potential, in particular on the negative sign of its quadratic component. But we have no clue as to what is its dynamical origin, independently of whether we look at it with a SM or BSM perspective …

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- Understanding the origin of the Higgs potential and the nature of Higgs interactions is a paramount puzzle of modern physics, regardless of whether they eventually match the SM assumption or require new physics

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- EW and strong interactions have free parameters (the symmetry groups, the strength of couplings, the charges of elementary particles). But at least we do have a deep understanding of their dynamical nature, namely the gauge principle. This allows us to speculate about an even deeper origin, e.g. from string theory or higher-dimensional Kaluza-Klein theories
- The Higgs mechanism relies of the quartic Higgs potential, in particular on the negative sign of its quadratic component. But we have no clue as to what is its dynamical origin, independently of whether we look at it with a SM or BSM perspective …
- Understanding the origin of the Higgs potential and the nature of Higgs interactions is a paramount puzzle of modern physics, regardless of whether they eventually match the SM assumption or require new physics
- Having established the existence of the Higgs is similar to having established inflation, through cosmological observations. The real question (for both Higgs and inflation) is now "**where does it come from?**"

a historical example:
superconductivity

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- The relation between the Higgs phenomenon and the SM is similar to the relation between superconductivity and the Landau-Ginzburg theory of phase transitions: a quartic potential for a bosonic order parameter, with negative quadratic term, and the ensuing symmetry breaking. If superconductivity had been discovered after Landau-Ginzburg, we would be in a similar situations as we are in today: an experimentally proven phenomenological model. But we would still lack a deep understanding of the relevant dynamics.

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- For superconductivity, this came later, with the identification of e^-e^- Cooper pairs as the underlying order parameter, and BCS theory. In particle physics, we still don't know whether the Higgs is built out of some sort of Cooper pairs (composite Higgs) or whether it is elementary, and in both cases we have no clue as to what is the dynamics that generates the Higgs potential. With Cooper pairs it turned out to be just EM and phonon interactions. With the Higgs, none of the SM interactions can do this, and **we must look beyond.**

The basic motivation for Future Circular Colliders

- HEP has two priorities:
  - **explore the physics of electroweak symmetry breaking**:
    - experimentally, via the measurement of Higgs properties, Higgs interactions and selfinteractions, couplings of gauge bosons, flavour phenomena, etc
    - theoretically, to understand the nature of the hierarchy problem and identify possible natural solutions (to be subjected to exptl test)
  - **explore the origin of known departures from the SM** (DM, neutrino masses, baryon asymmetry of the universe)

The physics case of FCCs builds on the belief that these two directions are deeply intertwined, and equally worth investigating

Key question for the future developments of HEP: Why don't we see the new physics we expected to be present around the TeV scale ?

- Is the mass scale beyond the LHC reach ?
- Is the mass scale within LHC's reach, but final states are elusive to the direct search ?

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Readiness to address both scenarios is the best hedge for the field:

- *precision*
- *sensitivity (to elusive signatures)*
- *extended energy/mass reach*

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    - *statistics enhanced by several orders of magnitude for BSM phenomena brought to light by the LHC*
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  - benefit from both direct (large Q^2) and indirect (precision) probes
- Provide firm Yes/No answers to questions like:
  - is the SM dynamics all there is at the TeV scale?
  - is there a TeV-scale solution to the hierarchy problem?
  - is DM a thermal WIMP?
  - did baryogenesis take place during the EW phase transition?

Higgs physics

SM Higgs rates at 100 TeV

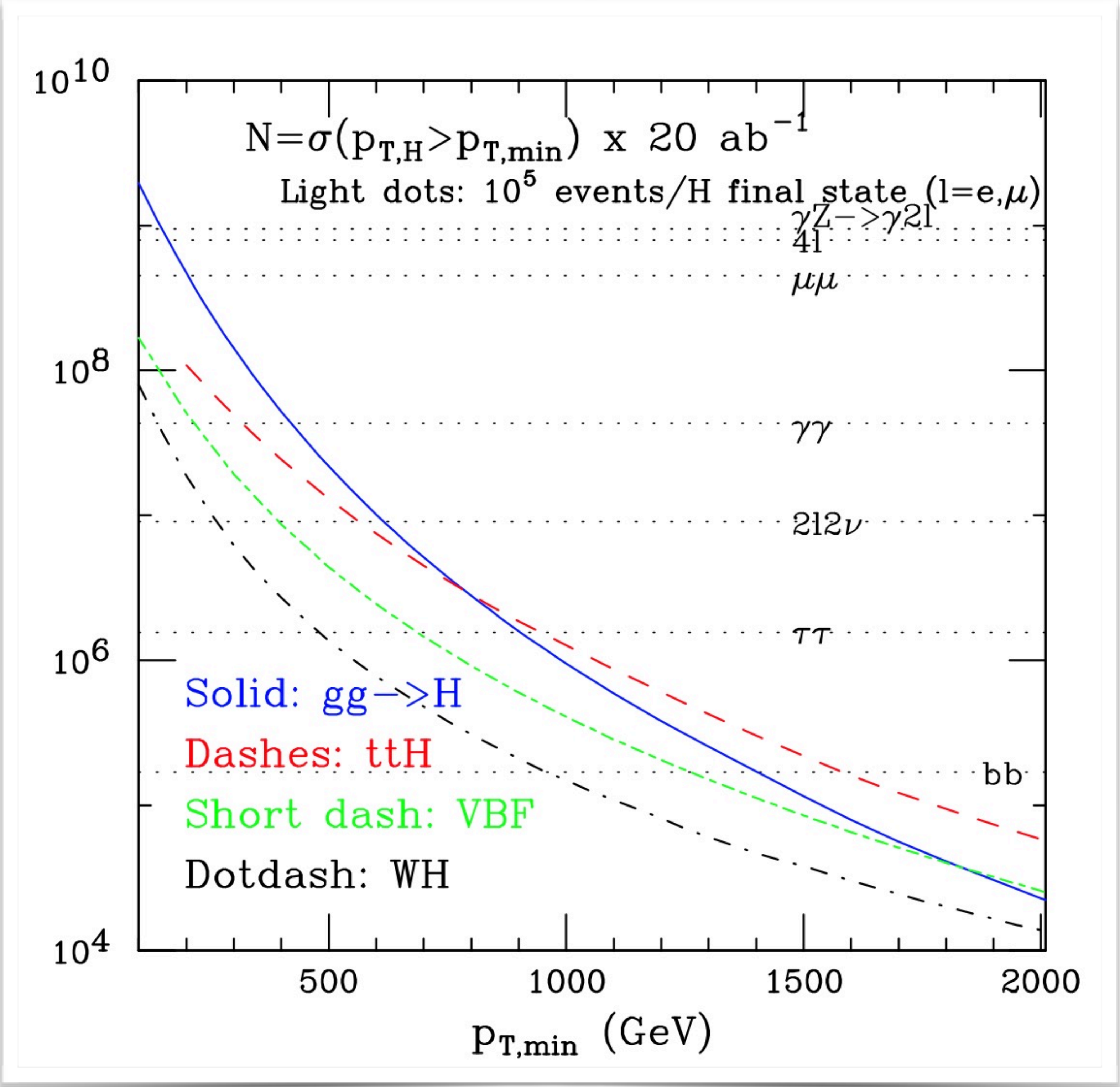
	N_{100}	N_{100}/N_8	N_{100}/N_{14}
$gg \to H$	16×10^9	4×10^4	110
VBF	1.6×10^9	5×10^4	120
WH	3.2×10^8	2×10^4	65
ZH	2.2×10^8	3×10^4	85
$t\bar{t}H$	7.6×10^8	3×10^5	420

$N_{100} = \sigma_{100\,\text{TeV}} \times 20\ \text{ab}^{-1}$

$N_8 = \sigma_{8\,\text{TeV}} \times 20\ \text{fb}^{-1}$

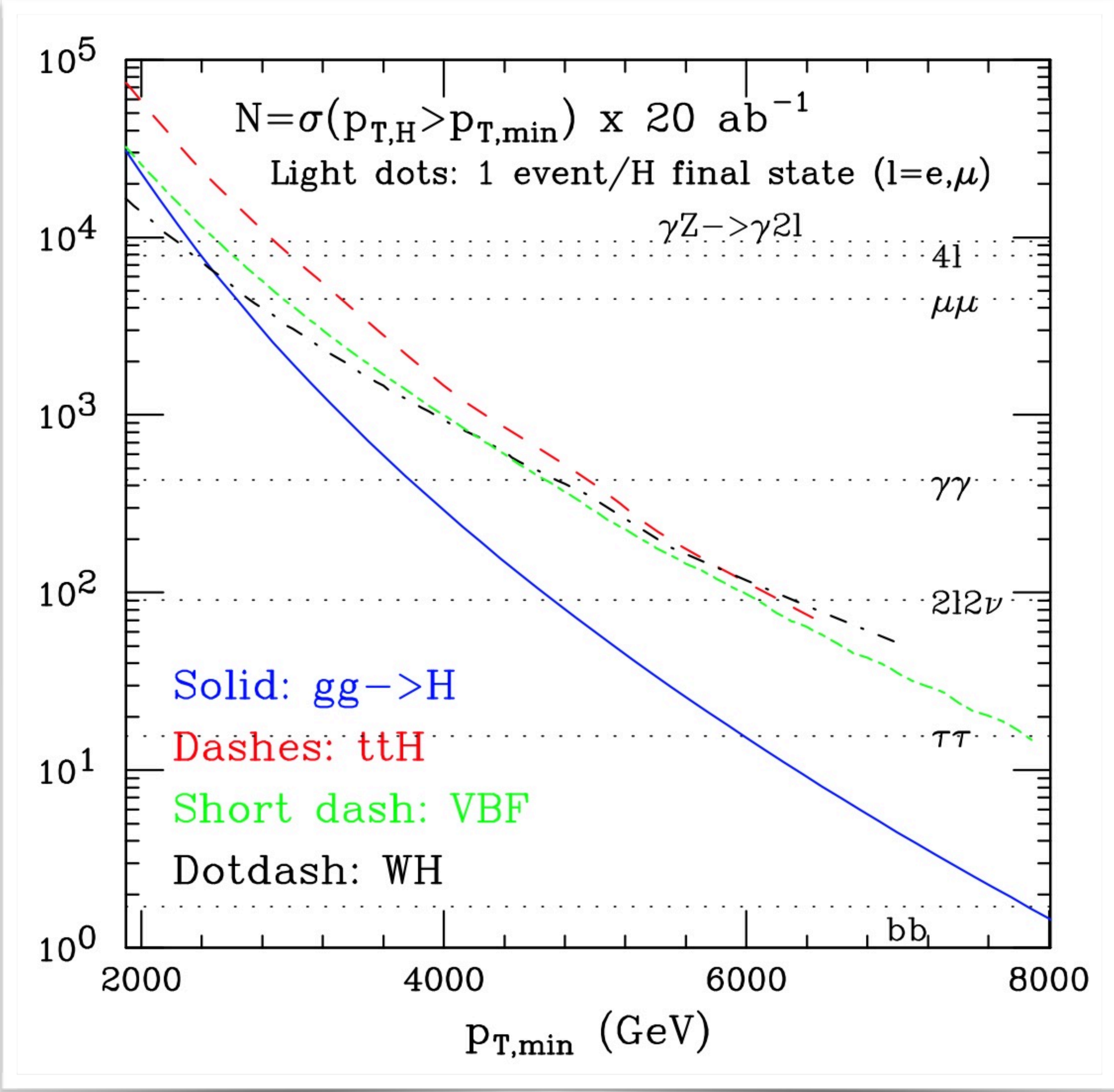
$N_{14} = \sigma_{14\,\text{TeV}} \times 3\ \text{ab}^{-1}$

H at large p_T



- Hierarchy of production channels changes at large $p_T(H)$:
  - $\sigma(ttH) > \sigma(gg \to H)$ above 800 GeV
  - $\sigma(VBF) > \sigma(gg \to H)$ above 1800 GeV

H at large p_T



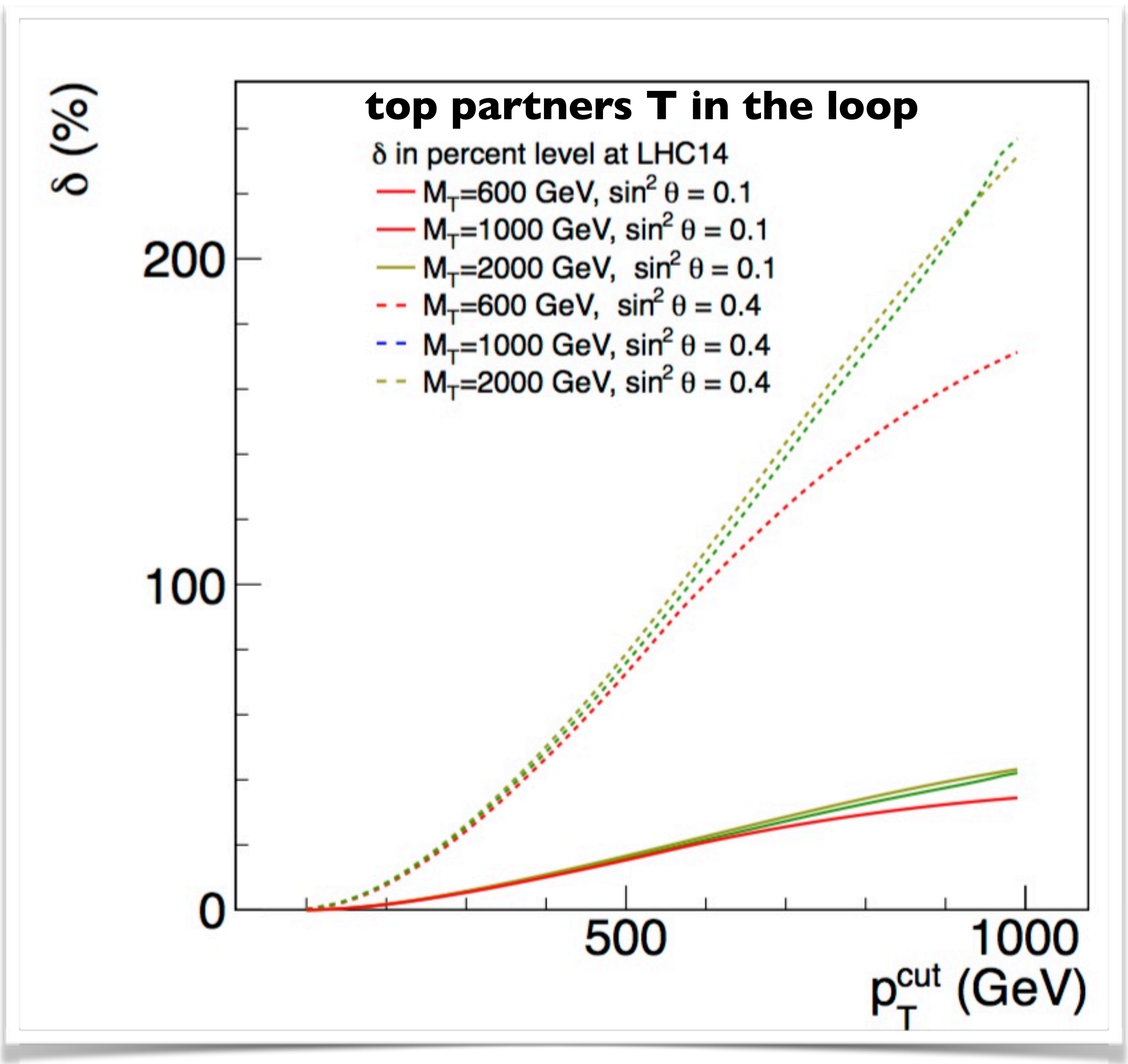
- Statistics in potentially visible final states out to several TeV

Examples of deviations of the Higgs p_T spectrum from SM, in presence of new particles in the ggH loop

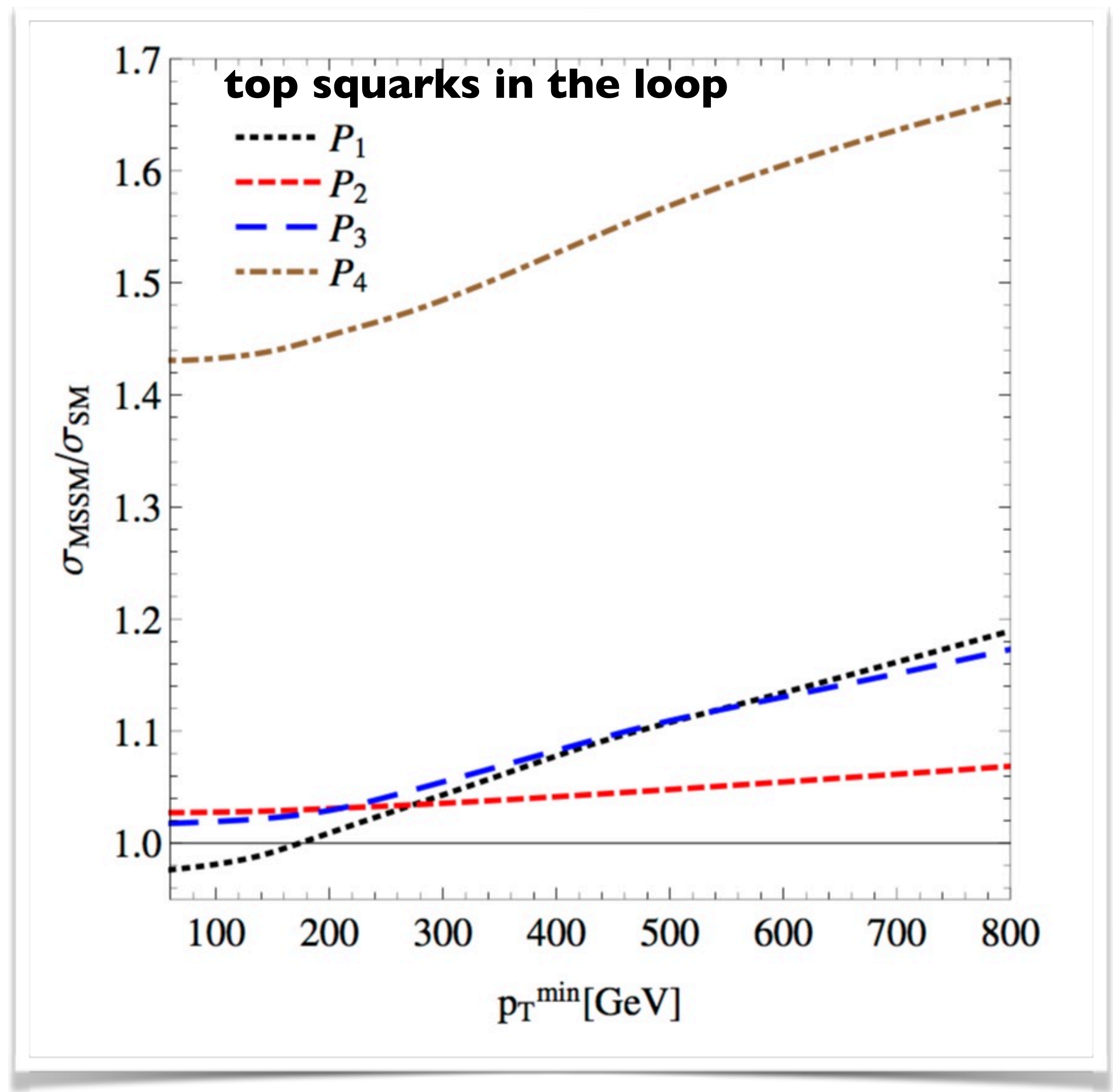
Table 3: The benchmark points shown in Fig. 7. We set $\tan\beta = 10$, $M_{A^0} = 500\,\text{GeV}$, $M_2 = 1000\,\text{GeV}$, $\mu = 200\,\text{GeV}$ and all trilinear couplings to a common value A_t. The remaining sfermion masses were set to 1 TeV and the mass of the lightest CP-even Higgs was set to 125 GeV.

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	226	484	532	0.015
P_4	226	484	0	0.18

(See also
Azatov and Paul arXiv:1309.5273v3)

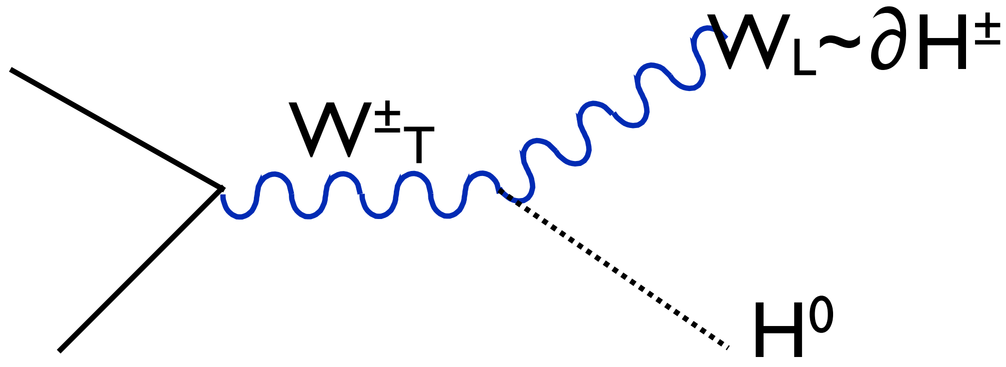


Banfi Martin Sanz, arXiv:1308.4771



Grojean, Salvioni, Schlaffer, Weiler arXiv:
1312.3317

VH prodution at large m(VH)

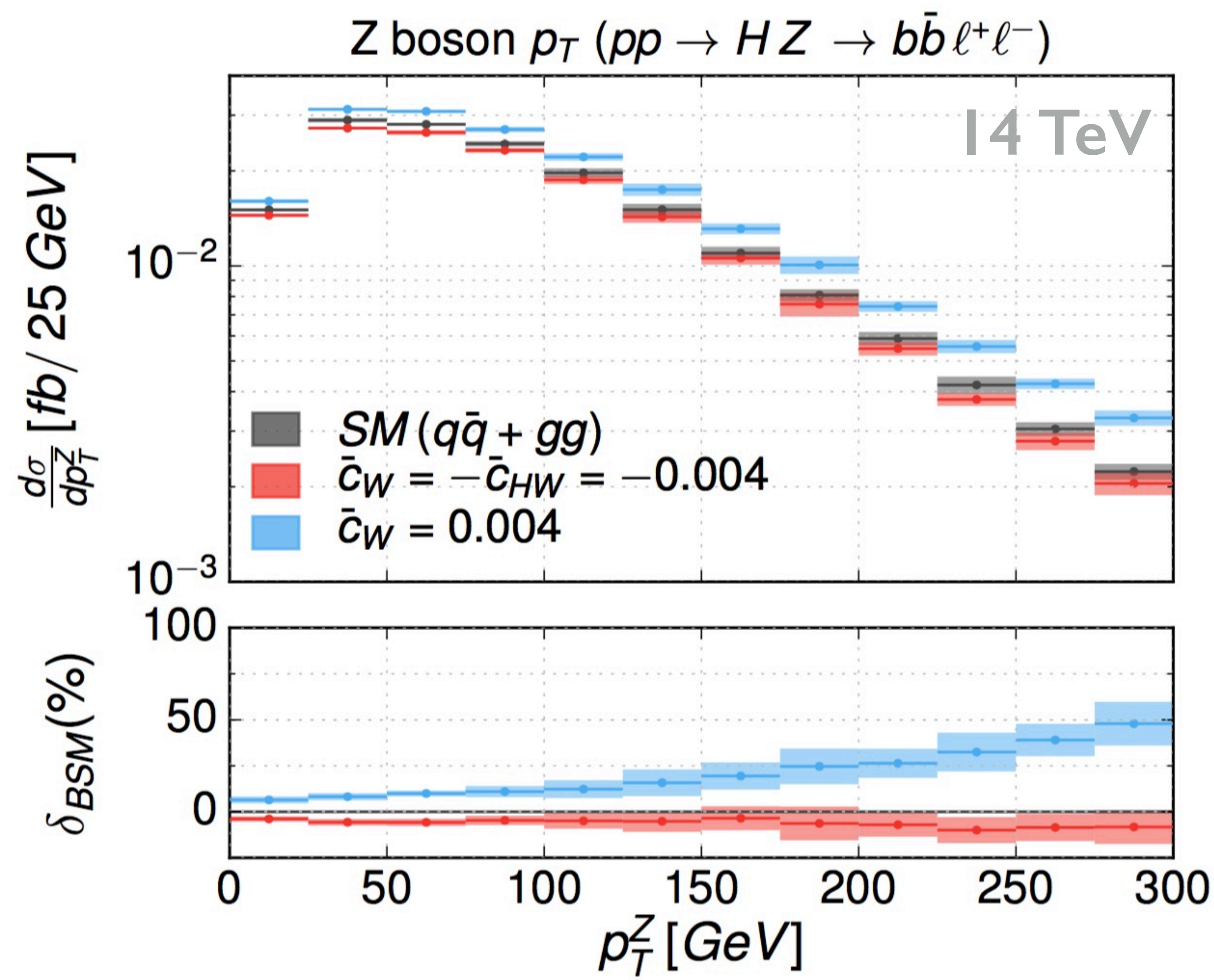


See e.g.
Biekötter, Knochel, Krämer, Liu, Riva, arXiv:1406.7320

In presence of a higher-dim op such as:

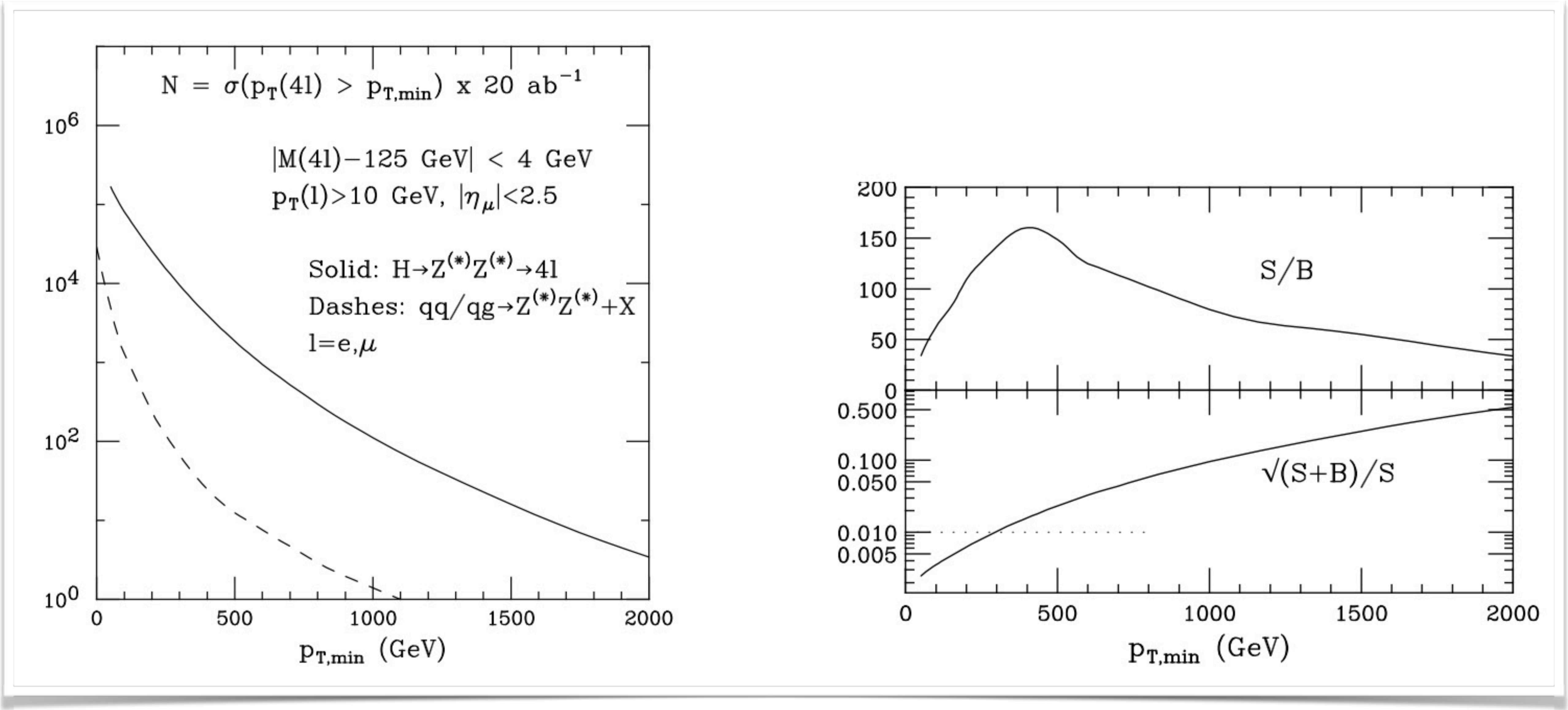
$$L_{D=6} = \frac{ig}{2}\frac{c_W}{\Lambda^2}\left(H^\dagger\sigma^a D^\mu H\right) D^\nu V^a_{\mu\nu}$$

$$\frac{\sigma}{\sigma_{SM}} \sim \left(1 + c_W \frac{\hat{s}}{\Lambda^2}\right)^2$$



Mimasu, Sanz, Williams, arXiv:1512.02572v

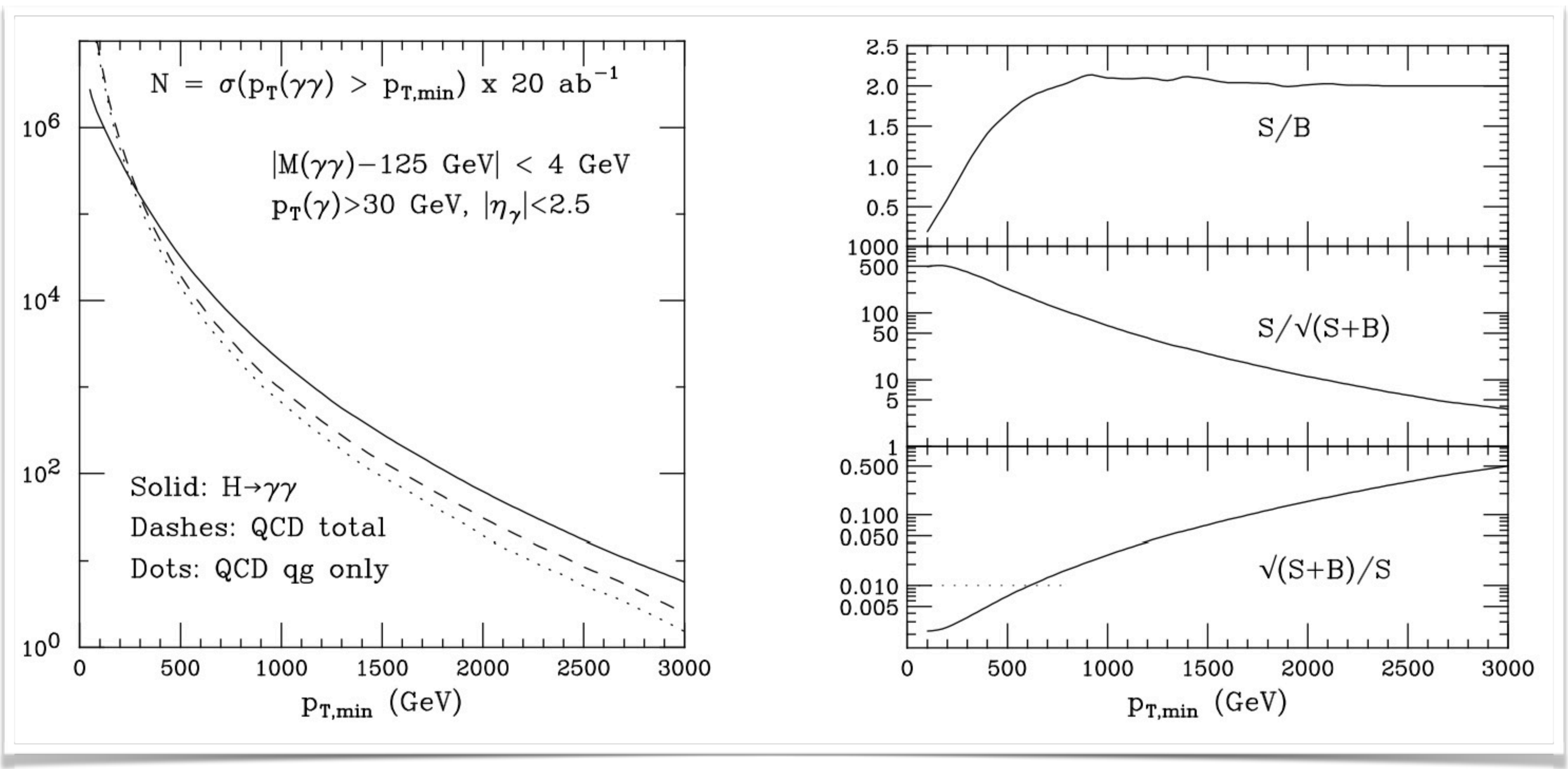
$gg \to H \to ZZ^* \to 4l$



- S/B ~ 1 for inclusive production at LHC
- Practically bg-free at large p_T at 100 TeV, maintaining large rates

$p_{T,min}$ (GeV)	δ_{stat}
100	**0.3%**
300	**1%**
1000	10%

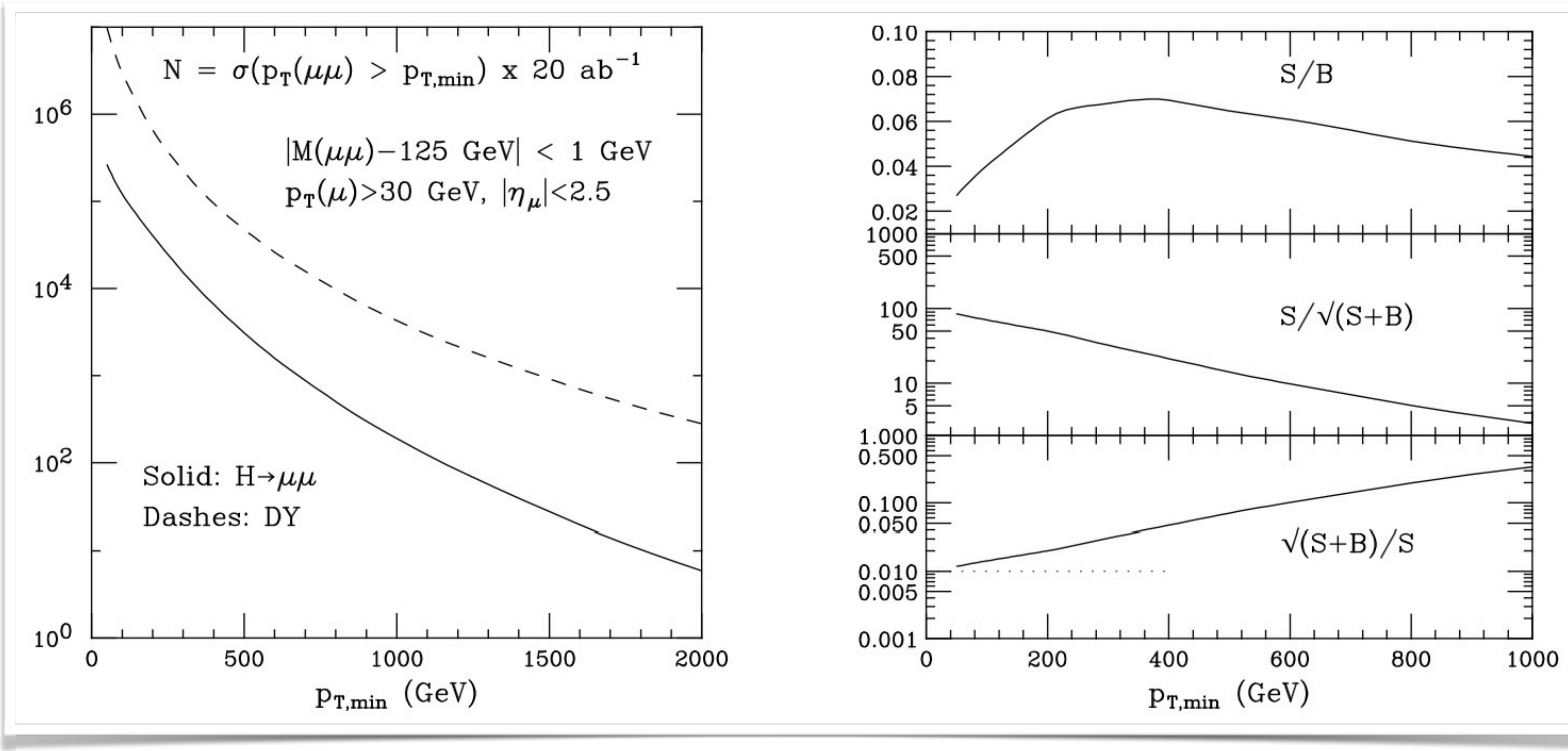
gg→H→γγ



- At LHC, S/B in the H→γγ channel is O(few %)
- At FCC, for $p_T(H)>300$ GeV, S/B~1
- Potentially accurate probe of the H pt spectrum up to large pt:
  - What is a best BSM probe: BR(γγ) or shape of pT(H)?
    - answer likely BSM-model dependent
    - ==> synergy/complementarity !!

$p_{T,min}$	δ_{stat}
100	**0.2%**
400	**0.5%**
600	**1%**
1600	10%

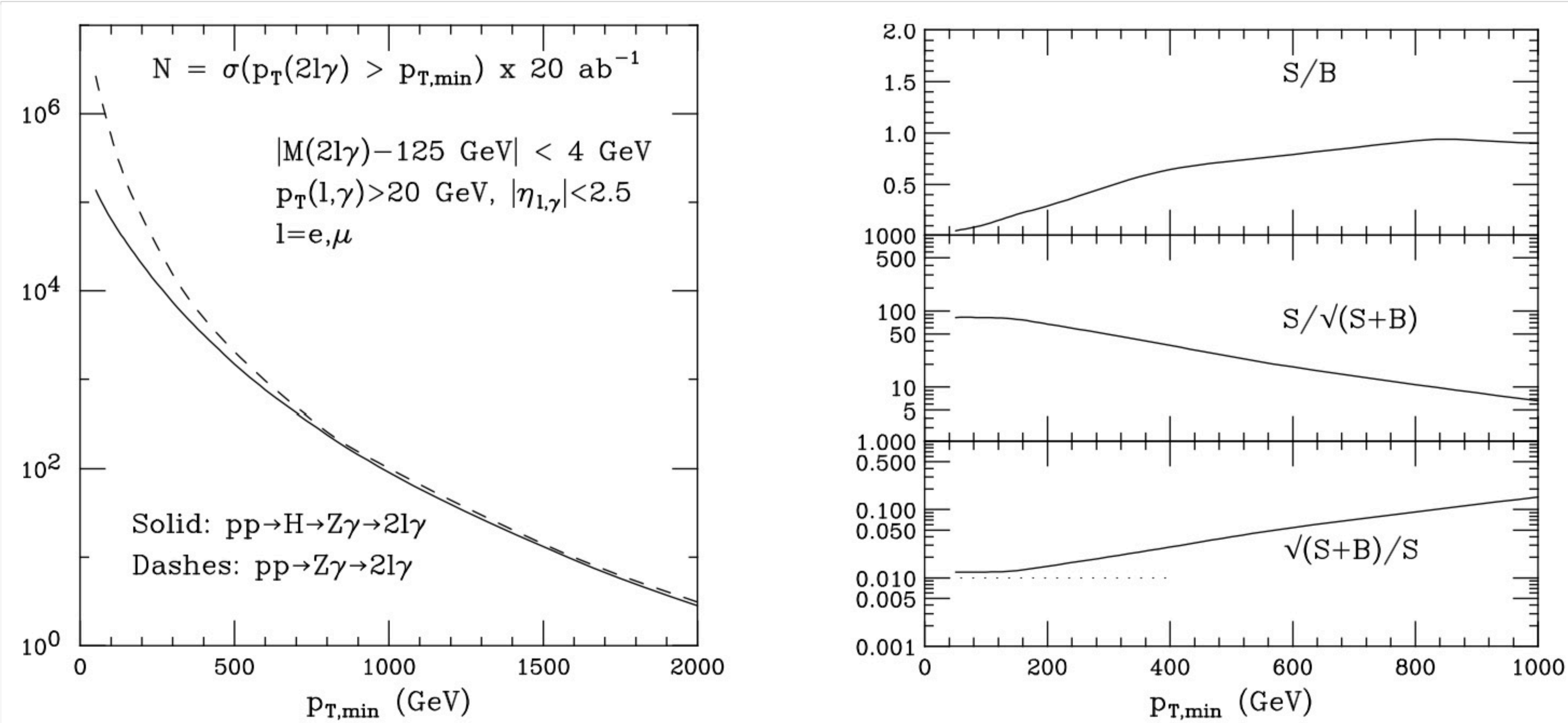
$gg \to H \to \mu\mu$



- Stat reach ~1% at p_T~100 GeV
- Exptl systematics on BR(μμ)/BR(γγ)? (use same fiducial selection to remove H modeling syst's)

$p_{T,min}$ (GeV)	δ_{stat}
100	**1%**
500	10%

$gg \to H \to Z\gamma \to \ell\ell\gamma$

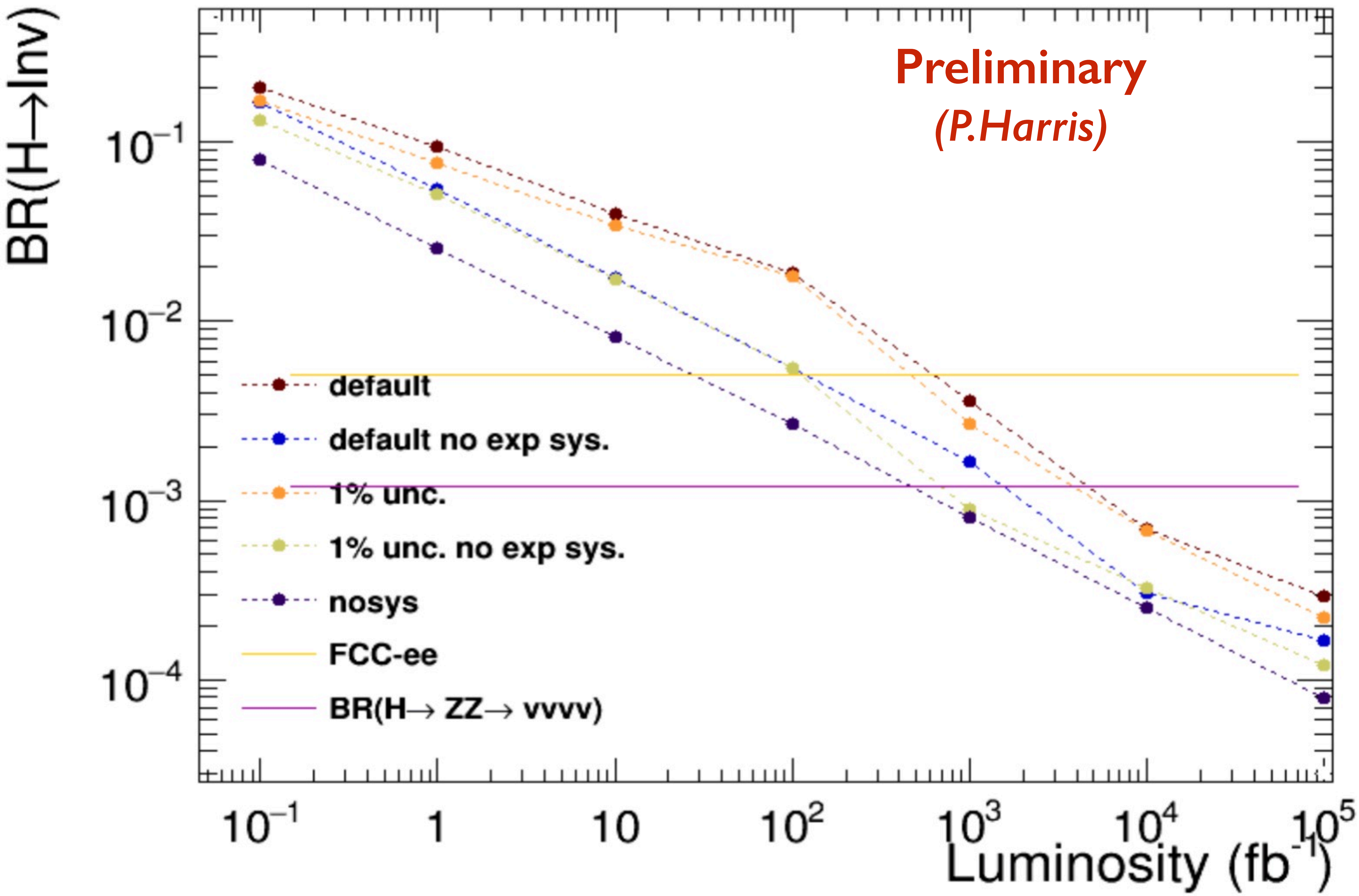


- S/B → 1 at large p_T
- Stat reach ~1% at pT~100 GeV
- Exptl systematics on BR(Zγ)/BR(γγ)?

$p_{T,min}$ (GeV)	δ_{stat}
100	**1%**
900	10%

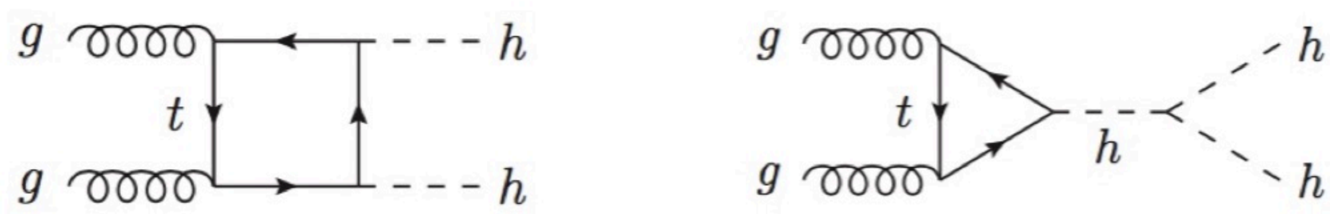
BR(H→inv) in H+X production at large p_T(H)

Constrain bg pt spectrum from Z→νν to the % level using NNLO QCD/EW to relate to measured Z→ee, W and γ spectra



SM sensitivity with 1ab^{-1}, can reach few x 10^{-4} with 30ab^{-1}

H selfcoupling determination, from gg→HH→γγbb



	$\Delta_S = 0.00$	$\Delta_S = 0.01$	$\Delta_S = 0.015$	$\Delta_S = 0.02$	$\Delta_S = 0.025$
$r_B = 0.5$	2.7%	3.4%	4.1%	4.9%	5.8%
$r_B = 1.0$	3.4%	3.9%	4.6%	5.3%	6.1%
$r_B = 1.5$	3.9%	4.4%	5.0%	5.7%	6.4%
$r_B = 2.0$	4.4%	4.8%	5.4%	6.0%	6.8%
$r_B = 3.0$	5.2%	5.6%	6.0%	6.6%	7.3%

- overall rescaling of background rate $n_B \to r_B \times n_B$
- uncertainty on signal rate $\Delta_S = \dfrac{\Delta\sigma(pp \to hh)}{\sigma(pp \to hh)}$

Results updated/confirmed with improved analysis by M.Selvaggi, https://indico.cern.ch/event/613195/

Higgs couplings @ FCC

g_{HXY}	ee [240+350 (4IP)]	pp [100 TeV] 30ab^{-1}	ep [60GeV/50TeV], 1ab^{-1}
ZZ	**0.15%**	under study	
WW	**0.19%**		
bb	**0.42%**		0.2%
cc	**0.71%**		1.8%
gg	**0.80%**		
ττ	**0.54%**		
μμ	**6.2%**	<1%	
γγ	**1.5%**	<0.5%	
Zγ		<1%	
tt	**~13%**	1%	
HH	**~30%**	3.5%	under study
uu,dd	H->ργ, under study		
ss	H->ϕγ, under study		
BR_{inv}	**< 0.45%**	< 0.1%	
Γ_{tot}	**1%**		

- detailed study, stat+syst
- rather detailed, stat only (understood/limited/negligible theory syst)
- parton level S and B (from ratios, negligibleTH syst, small exp syst)
- very preliminary estimates of exp/th syst (not stat-limited)

One should not underestimate the value of FCC-hh standalone precise "ratios-of-BRs" measurements:

- independent of α_S, m_b, m_c, Γ_{inv} systematics
- sensitive to BSM effects that typically influence BRs in different ways. Eg

BR(H→γγ)/BR(H→ZZ*)

loop-level tree-level

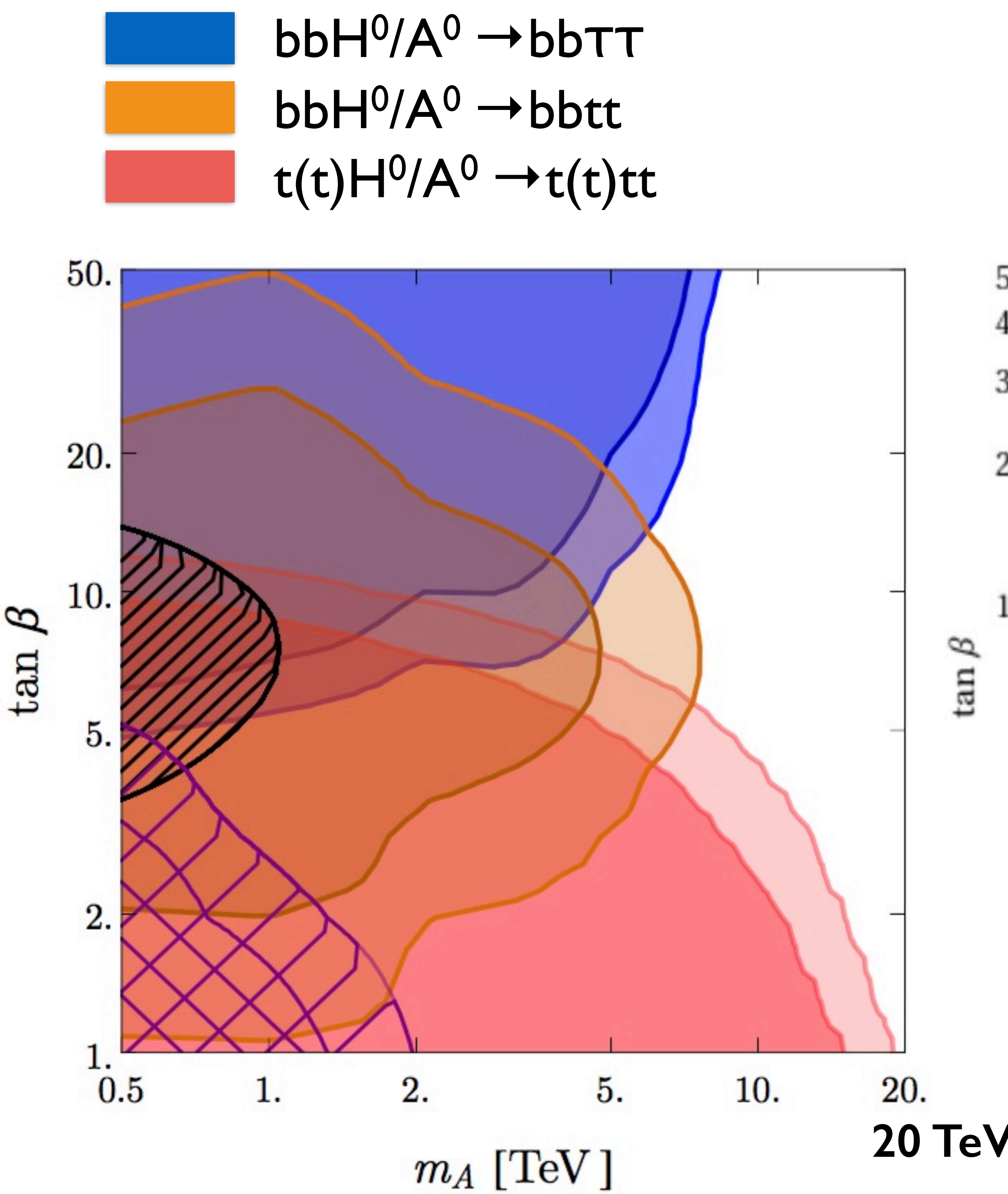
BR(H→μμ)/BR(H→ZZ*)

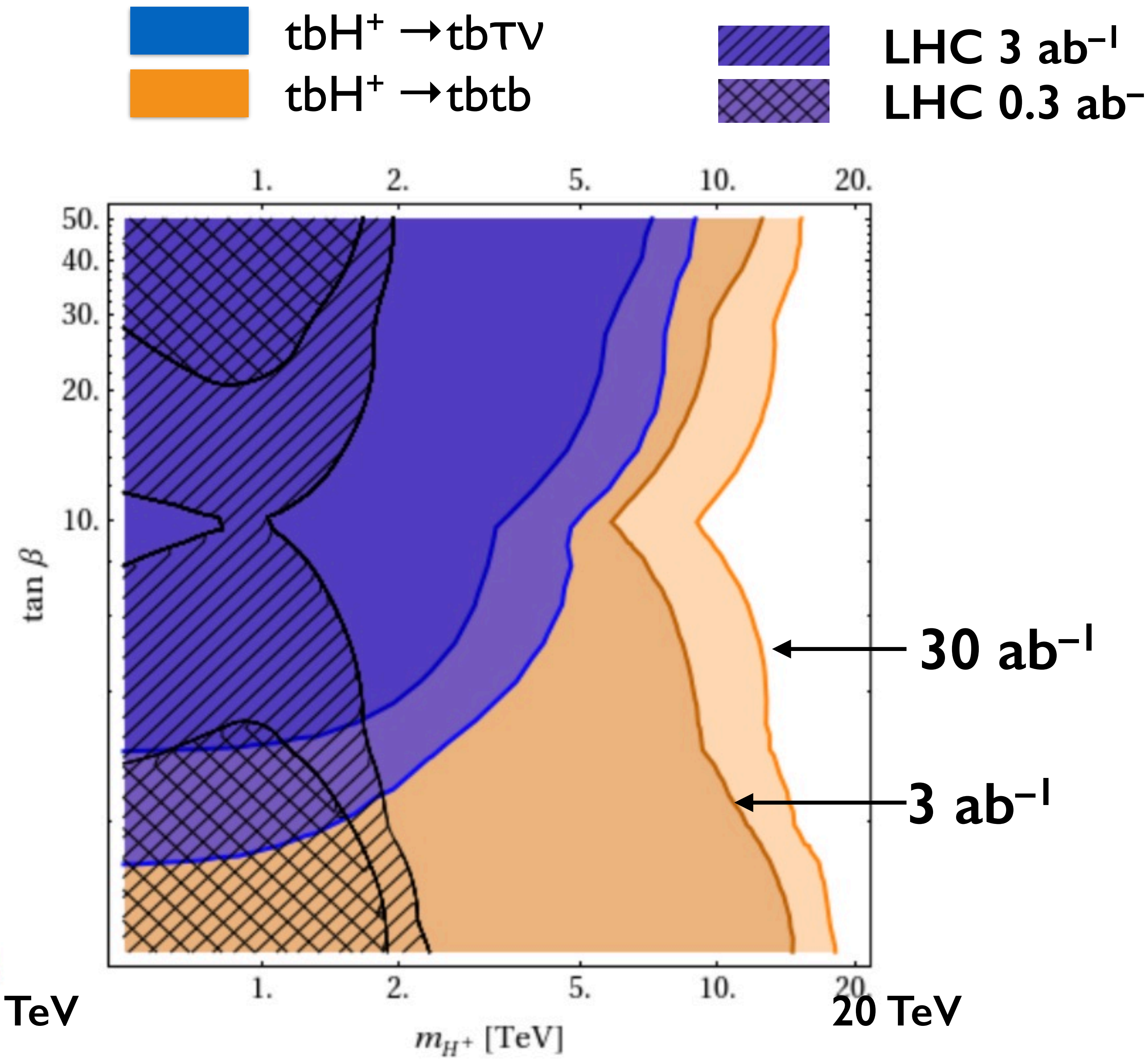
2nd gen'n Yukawa gauge coupling

BR(H→γγ)/BR(H→Zγ)

different EW charges in the loops of the two procs

MSSM Higgs @ 100 TeV





N. Craig, J. Hajer, Y.-Y. Li, T. Liu, H. Zhang, arXiv:1605.08744

J. Hajer, Y.-Y. Li, T. Liu, and J. F. H. Shiu, arXiv:1504.07617

Minimal stealthy model for a strong EW phase transition: *the most challenging scenario for discovery*

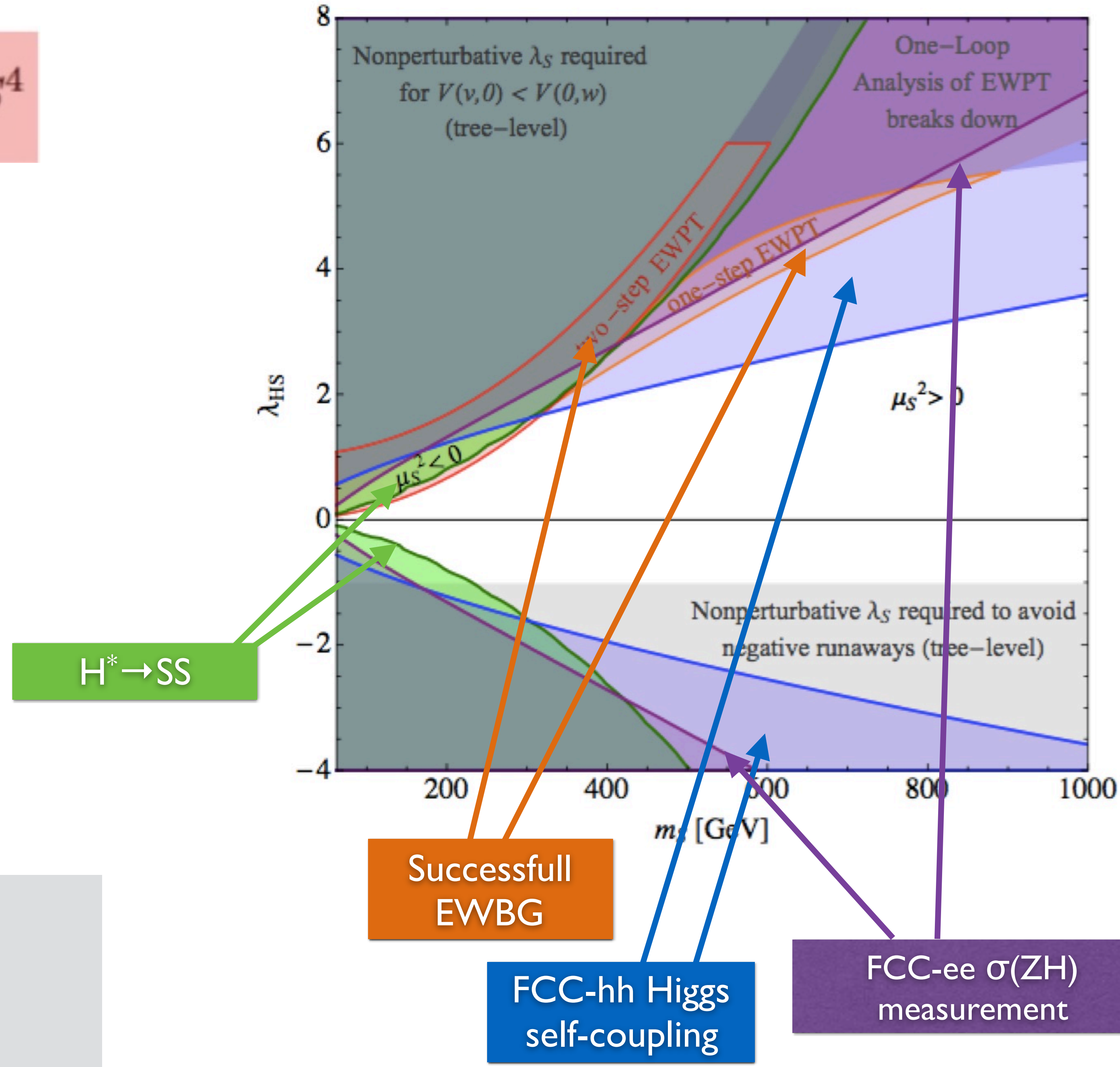
$$V_0 = -\mu^2|H|^2 + \lambda|H|^4 + \frac{1}{2}\mu_S^2 S^2 + \lambda_{HS}|H|^2 S^2 + \frac{1}{4}\lambda_S S^4$$

Unmixed SM+Singlet.
No exotic H decay, no H-S mixing, no EWPO, …

Two regions with strong EWPT

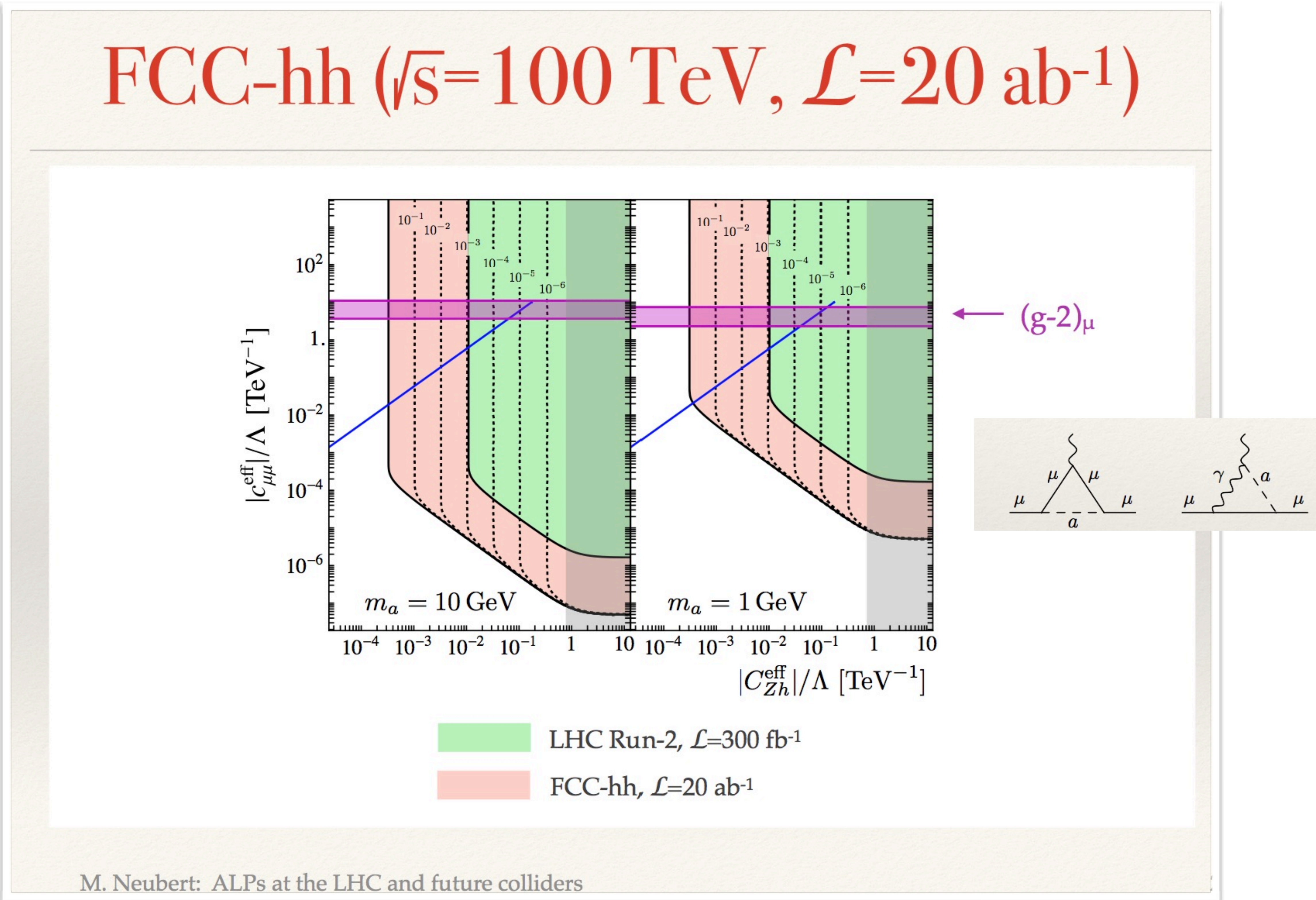
Only Higgs Portal signatures:
h*→SS direct production
Higgs cubic coupling
σ(Zh) deviation (> 0.6% @ TLEP)

Curtin, Meade, Yu, arXiv:1409.0005



⇒ Appearance of first "no-lose" arguments for classes of compelling scenarios of new physics

pp→H→aZ→ℓℓγγ, 4ℓ



Bauer, Neubert, Thamm 1704.08207, 1708.00443

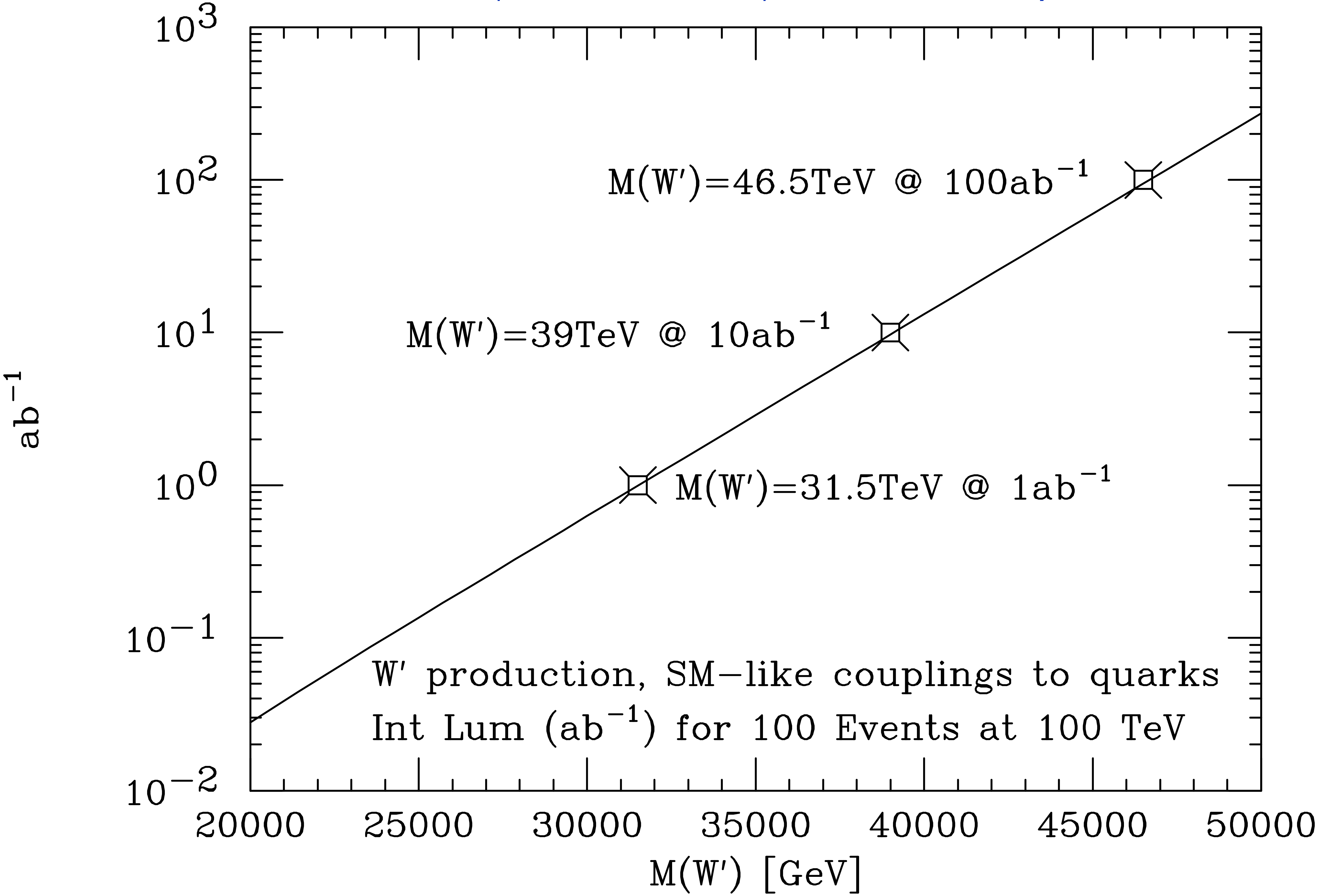
Direct discovery potential at the highest masses

at high mass, the reach of FCC-hh searches for BSM phenomena like Z', W', SUSY, LQs, top partners, etc.etc. scales trivially by ~5-7, depending on total luminosity …

New gauge bosons: discovery reach

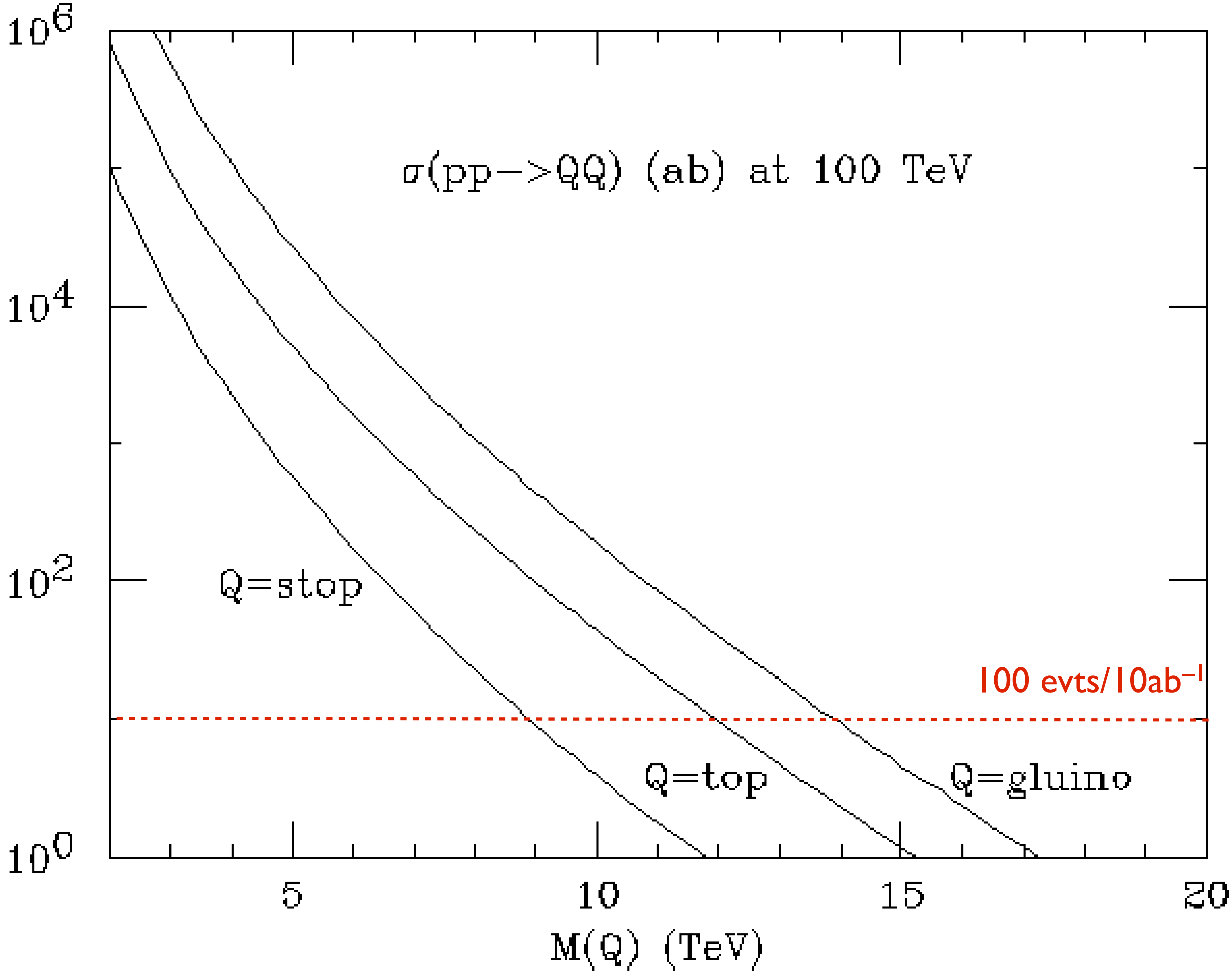
Example: **W' with SM-like couplings**

NB For SM-like Z', $\sigma_{Z'}\, BR_{lept} \sim 0.1 \times \sigma_{W'}\, BR_{lept}$, ⇒ rescale lum by ~ 10



At $L = O(ab^{-1})$, Lum x 10 ⇒ ~ M + 7 TeV

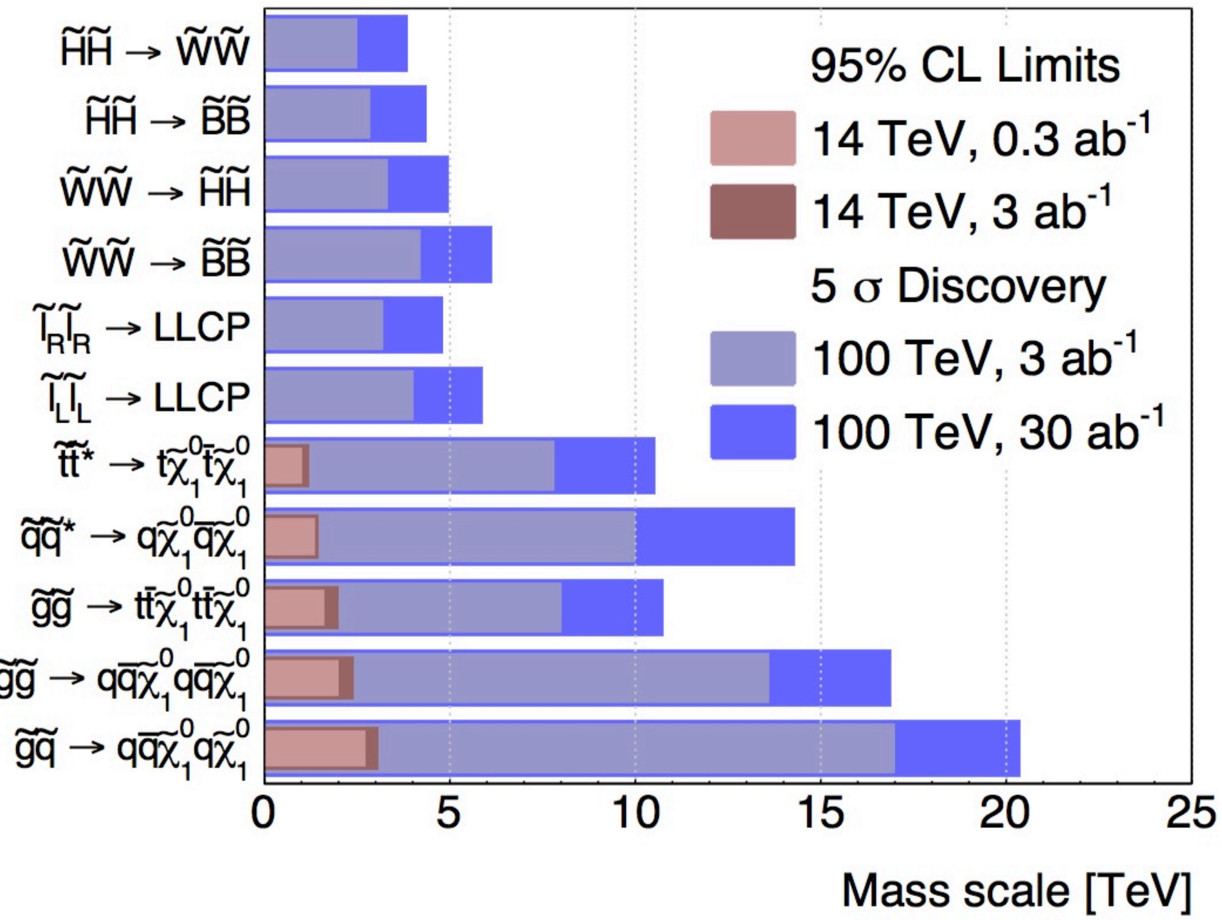
Discovery reach for pair production of strongly-interacting particles

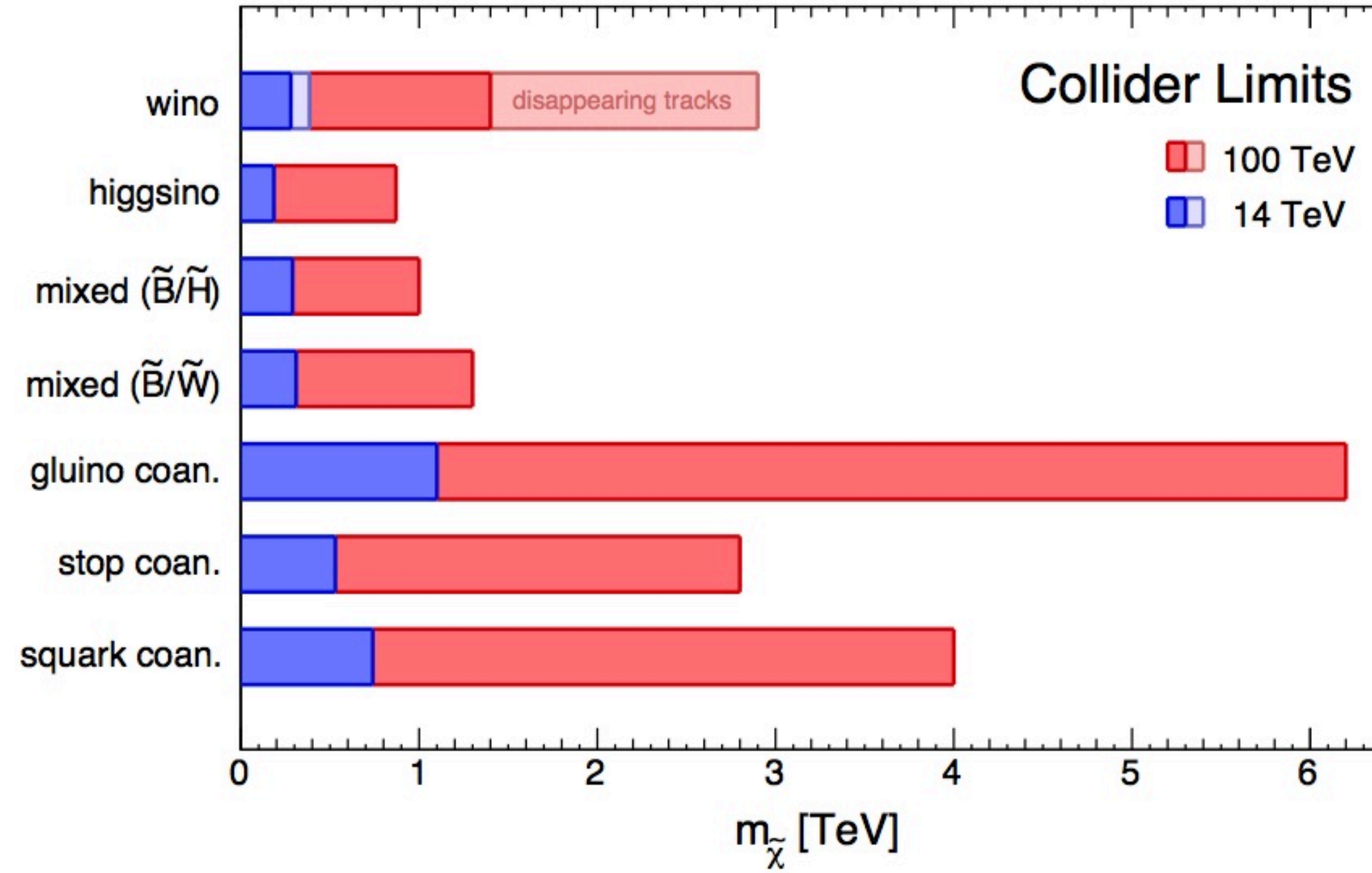


Dark Matter

- DM could be explained by BSM models that would leave no signature at any future collider (e.g. axions).
- More in general, no experiment can guarantee an answer to the question ”what is DM?”
- Scenarios in which DM is a WIMP are however compelling and theoretically justified
- **We would like to understand whether a future collider can answer more specific questions, such as:**
  - do WIMPS contribute to DM?
  - can WIMPS, detectable in direct and indirect (DM annihilation) experiments, be discovered at future colliders? Is there sensitivity to the explicit detection of DM-SM mediators?
  - what are the opportunities w.r.t. new DM scenarios (e.g. interacting DM, asymmetric DM, ...)?

SUSY and DM reach at 100 TeV





$$M_{\mathrm{WIMP}} \leq 1.8\ \mathrm{TeV}\left(\frac{g^2}{0.3}\right)$$

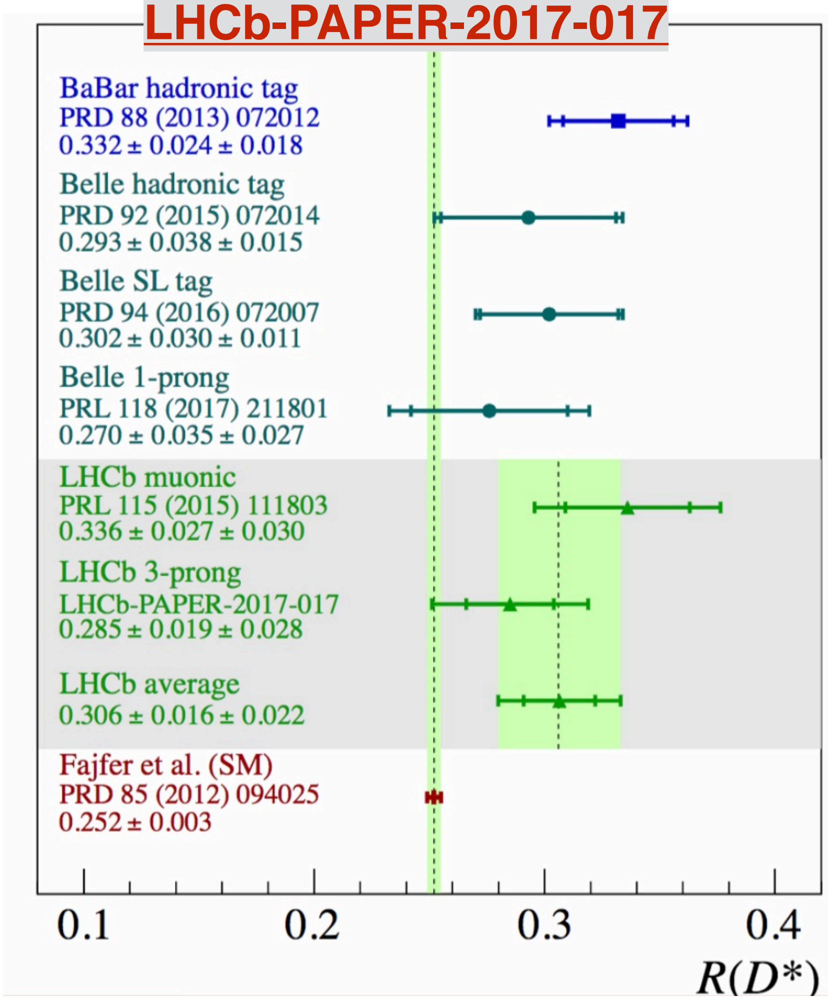
possibility to find (or rule out) thermal WIMP DM candidates

Flavour anomalies at LHC & Bfact's

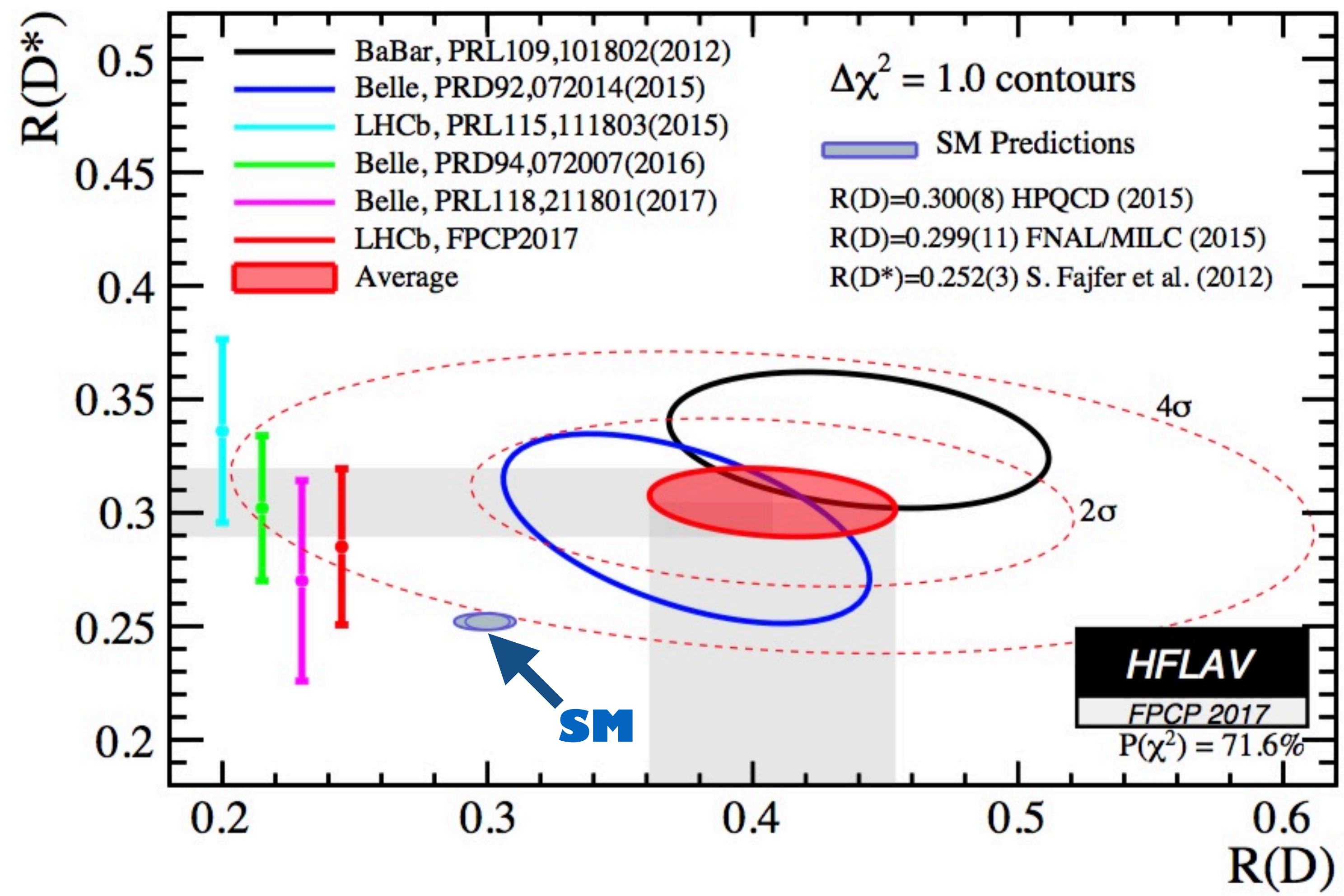
b→cℓν

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

LHCb-PAPER-2017-017



Overall combination of R(D) and R(D*) is 4.1σ from SM



b→sℓℓ

$$R_{K^{(*)}} = \frac{BR(B \to K^{(*)}\mu\mu)}{BR(B \to K^{(*)}ee)}$$

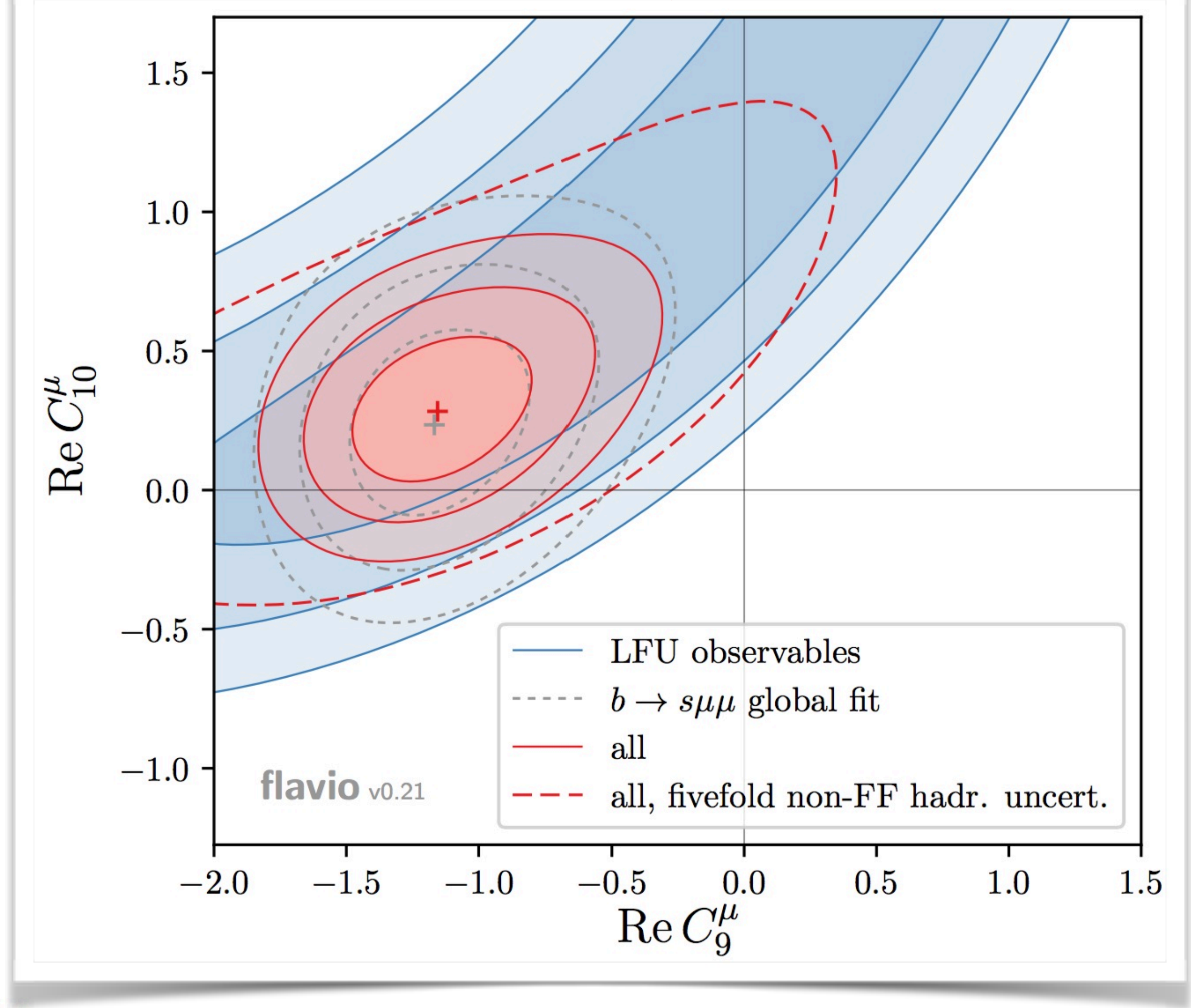
m_{ll} [mass range]	SM	Exp.
$R_K{}^{[1-6]}$	1.00 ± 0.01	$0.745^{+0.090}_{-0.074} \pm 0.036$
$R_{K^*}{}^{[1.1-6]}$	1.00 ± 0.01	$0.685^{+0.113}_{-0.069} \pm 0.047$
$R_{K^*}{}^{[0.045,1.1]}$	0.91 ± 0.03	$0.660^{+0.110}_{-0.070} \pm 0.024$

LHCb, PRL 113 (2014) 151601 , arXiv:1705.05802

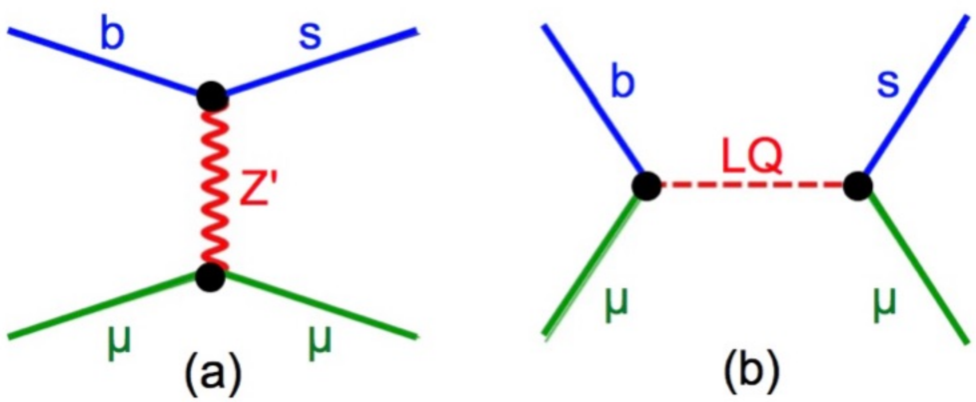
Example of EFT interpretation of R_K

$$O_9^\ell = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,,$$
$$O_{10}^\ell = (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \gamma_5 \ell)$$

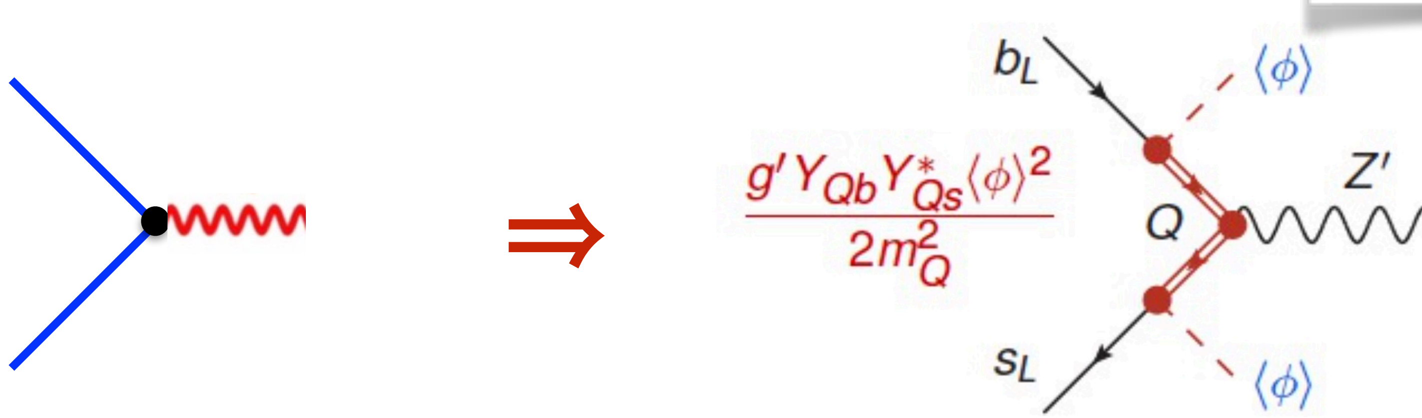
Altmannshoffer et al, arxiv:1704.05435



Possible explicit realizations:



where, e.g. ,

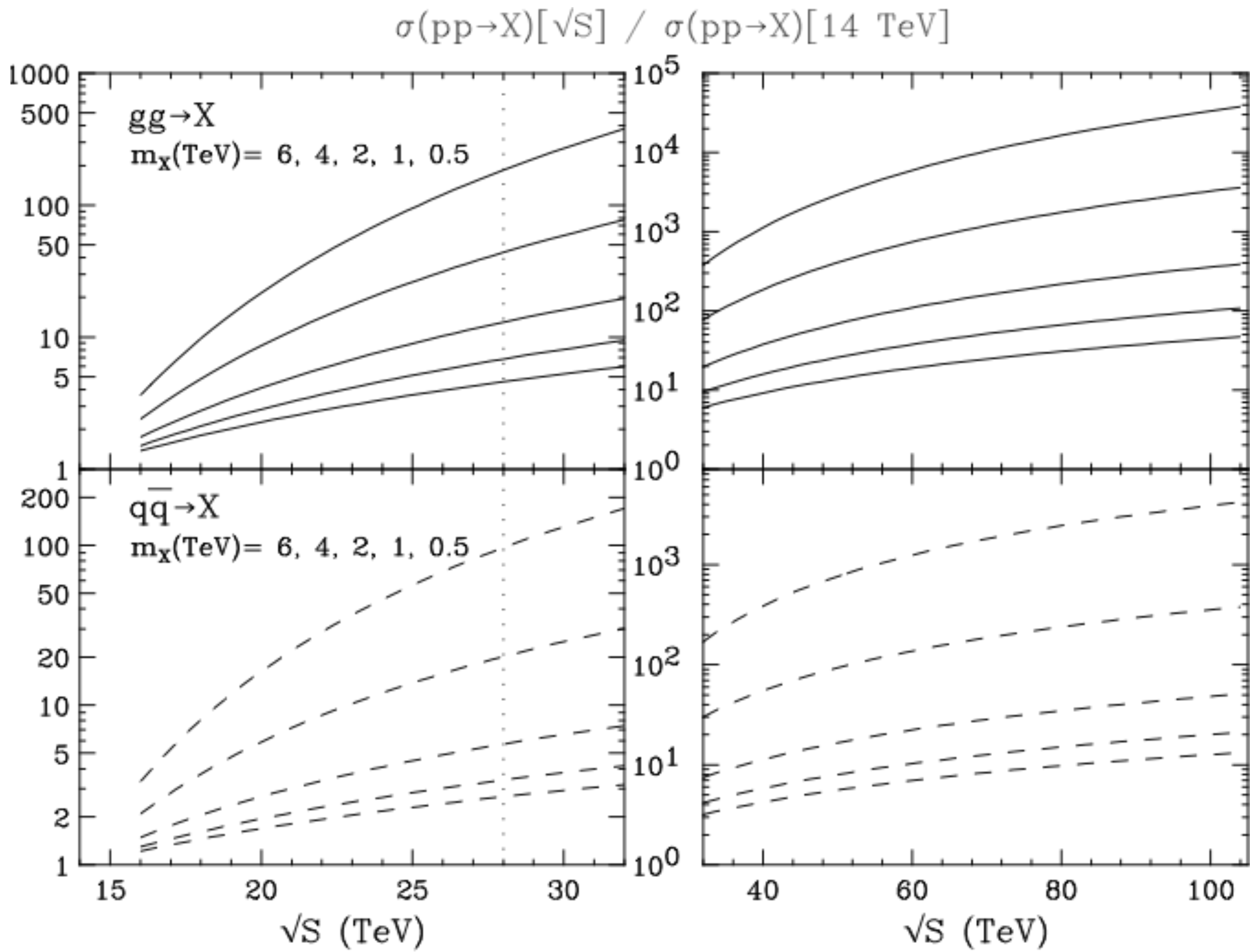


Upper limits on Z' and Leptoquark masses are model-dependent, and constrained also by other low-energy flavour phenomenology, but the mass range is upper limited

⇒ if anomalies confirmed, we may want a no-lose theorem to identify the next facility!

See eg Allanach, Gripaios & You, 1710.06363

Evolution, with beam energy, of scenarios with the discovery of a new particle at the LHC



CERN Yellow Reports: Monographs
Volume 3/2017

CERN-2017-003-M

Physics at the FCC-hh, a 100 TeV *pp* collider

Editor: M. L. Mangano

https://cds.cern.ch/record/2270978

Chapter 1: Standard Model Processes
M. L. Mangano et al.
10.23731/CYRM-2017-003.1

Chapter 2: Higgs and EW Symmetry Breaking Studies
R. Contino et al.
10.23731/CYRM-2017-003.255

Chapter 3: Beyond the Standard Model Phenomena
T. Golling et al.
10.23731/CYRM-2017-003.441

Chapter 4: Heavy Ions at the Future Circular Collider
A. Dainese et al.
10.23731/CYRM-2017-003.635

Chapter 5: Physics Opportunities with the FCC-hh Injectors
B. Goddard et al.
10.23731/CYRM-2017-003.693

2nd FCC Physics Workshop

15-19 January 2018
CERN
Europe/Zurich timezone

Search...

Starts 15 Jan 2018, 09:00
Ends 19 Jan 2018, 18:00
Europe/Zurich

CERN
222-R-001

CERN hostel booking form
CERN hostel booking form

Block booking at the CERN hostel is **guarantee until 11 December 2017** (see Accommodation)

Registration
Registration for this event is currently open.

84 Register now

https://indico.cern.ch/event/618254/

Final remarks

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- FCC-hh physics studies today focus on exploring possible scenarios, assessing the physics potential, defining benchmarks for the accelerator and detector design and performance, in order to better inform the discussions that will take place when the time for decisions comes...

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- The physics case of a 100 TeV collider is very clear as a long-term goal for the field, simply because no other proposed or foreseeable project can have direct sensitivity to such large mass scales.

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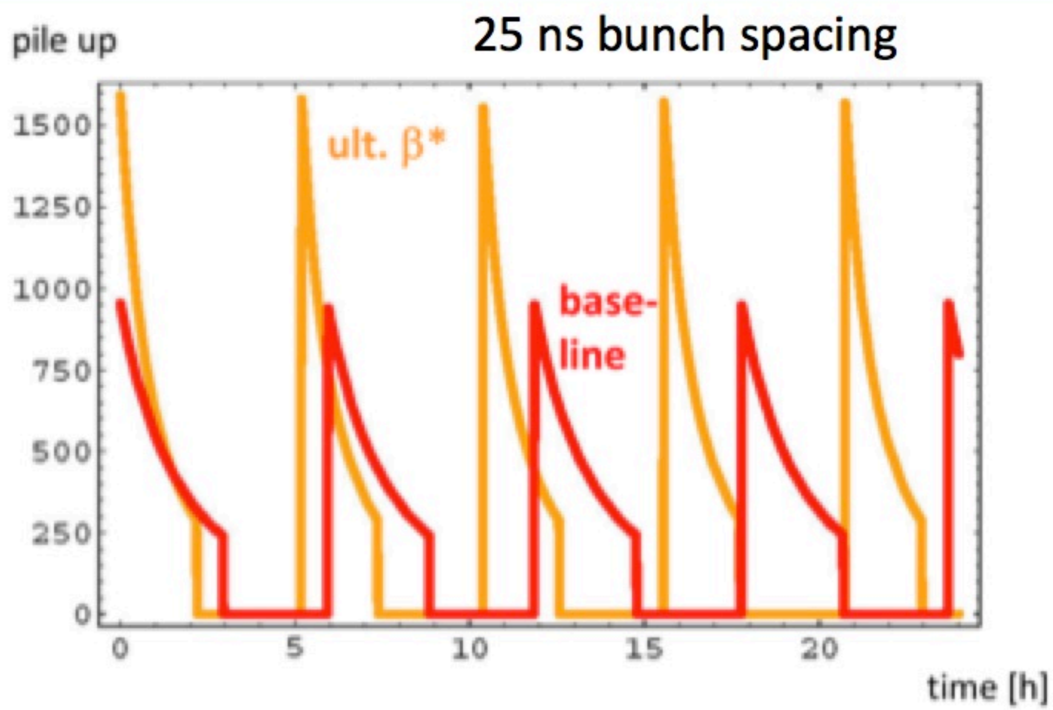
- The physics case of a 100 TeV collider is very clear as a long-term goal for the field, simply because no other proposed or foreseeable project can have direct sensitivity to such large mass scales.

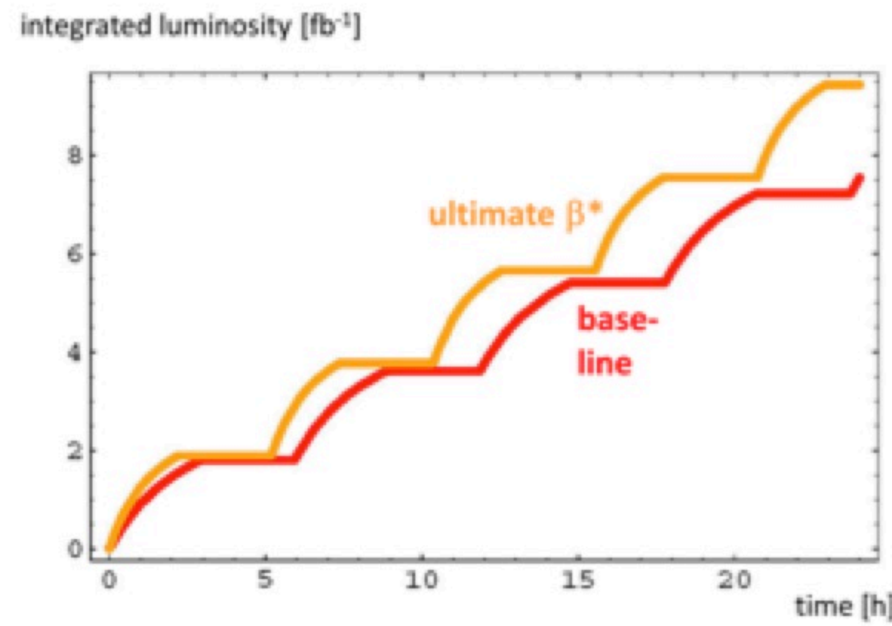
- Nevertheless, the precise route followed to get there must take account of the fuller picture, to reflect the future data (and the impact they will have on the theoretical thinking) from the LHC, as well as other current and future experiments in areas ranging from flavour physics to searches for dark matter, axions, ALPs, ….

Additional material
(1) HE-LHC

HE-LHC (27 TeV), prelim performance estimates

HE-LHC: pile up & performance





with 160 days of physics, 70% availability, 3 h turnaround time

β^*=25 cm: 920 fb^{-1}/year

β^*=15 cm: 1100 fb^{-1}/year

pile up of 1000 or shorter (e.g. 5 ns) bunch spacing – what is easier?

M. Benedikt, S. Fartoukh, F. Zimmermann

=> O(15 ab^{-1}) over 15-20 years

Systematics studies* of the full physics potential at O(28) TeV, with O(15 ab^{-1}), need to be carried out

* except for straightfwd mass-reach extrapolations from LHC

E.g. HH at 28 TeV (back of the envelope)

σ_{HH}(28 TeV)/σ_{HH}(14 TeV) ~ 4 Lum(28)~ 4 Lum(14 TeV)

=> N_{HH}(28) ~ 16 N_{HH}(14)

=> $\delta\lambda_{HHH}$ (28) ~ $\delta\lambda_{HHH}$ (HL-LHC) / 4 ~ 10%

Expect to carry out an overall evaluation of the physics potential during 2018
(in the context of the HL-LHC Physics workshop, https://indico.cern.ch/event/647676)

What does the HE-LHC entail?

- **Necessary:**
  - empty the tunnel (more time & $s than removing LEP)
  - full replacement of the magnets (today's cost ~4xLHC. First prototypes in ~2026)
  - upgrade of RF, cryogenics, collimation, beam dumps, …
- **Very likely:**
  - major upgrade of SPS, if need to inject at O(1 TeV) (magnets, RF, transfer lines, cryo if SC, …)
  - major overhaul of detectors (radiation damage after HL-LHC, use of new technologies)

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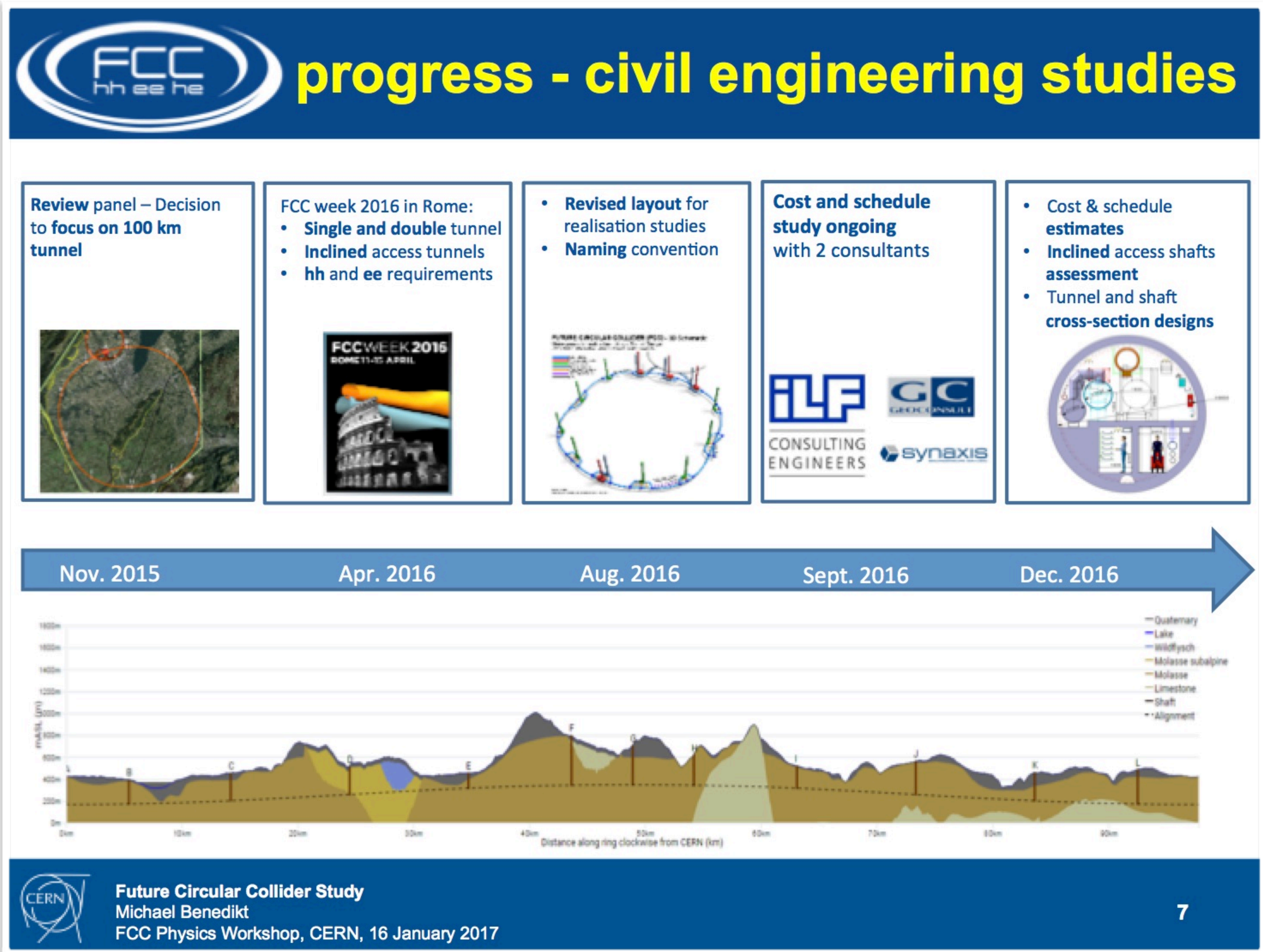
=> it's like building the LHC ex-novo

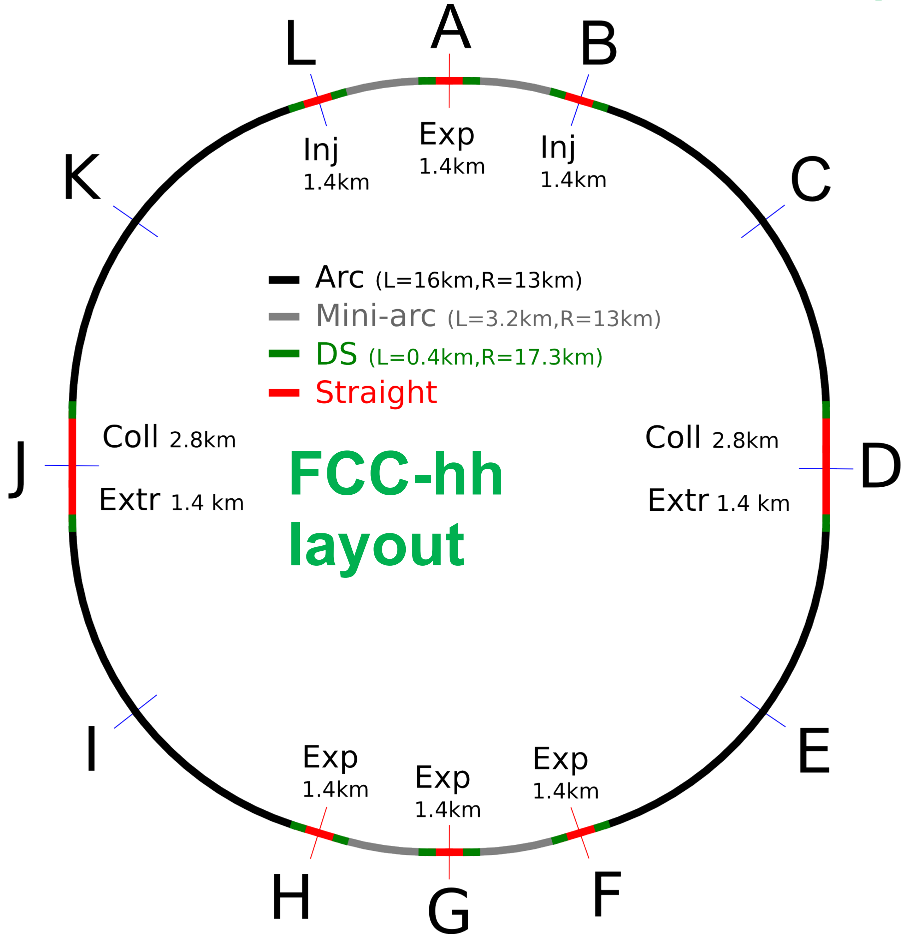
- very unlikely to be cheaper …
- … but not incompatible with a ~constant CERN budget
- nevertheless feasibility to be proven (eg magnets bigger than LHC's: will they fit in the tunnel ??)

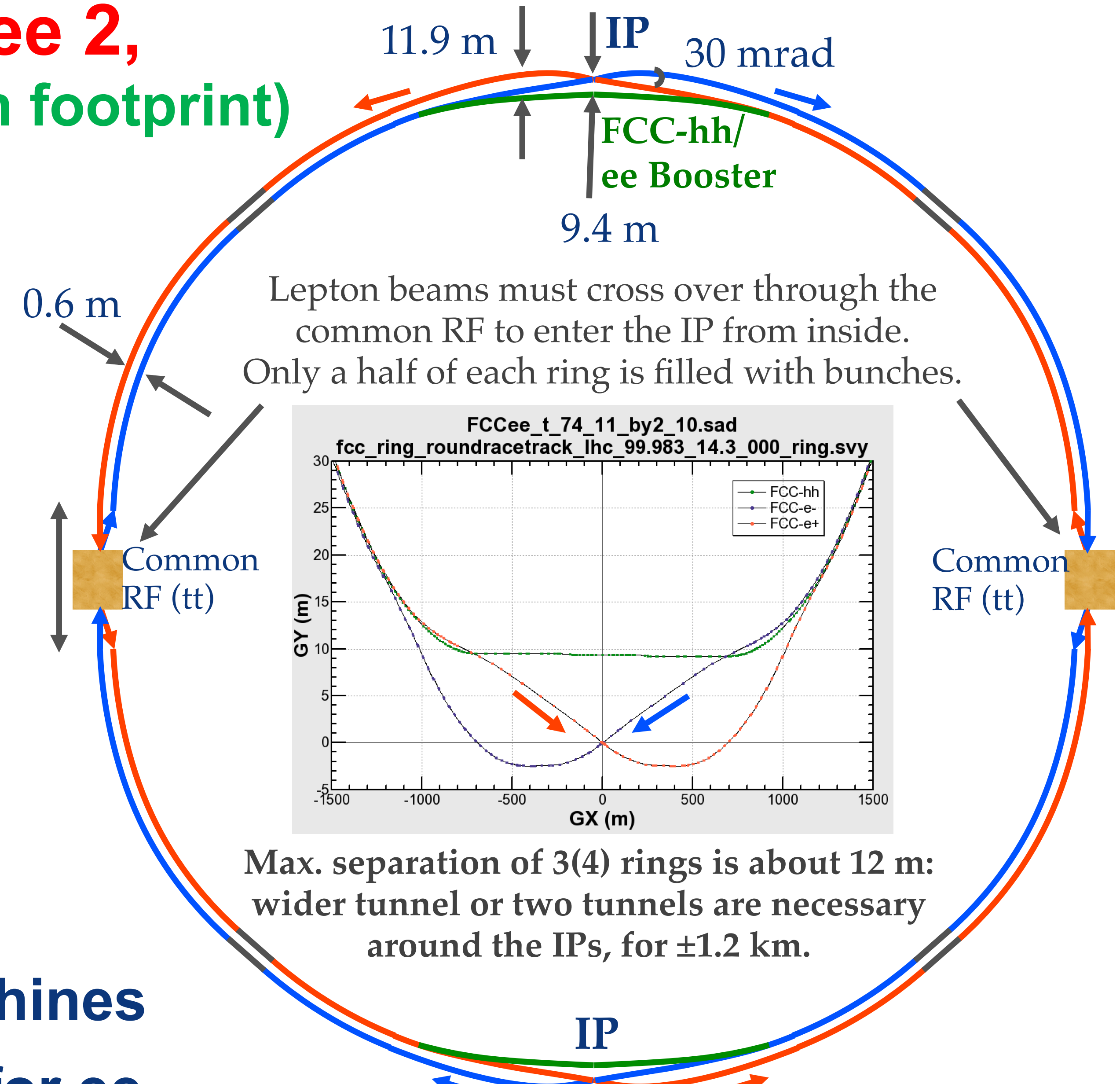
Additional material:
(II) snapshots of the status of the FCC study


progress - civil engineering studies
Review panel – Decision to focus on 100 km tunnel
FCC week 2016 in Rome:
• Single and double tunnel
• Inclined access tunnels
• hh and ee requirements
FCCWEEK 2016
ROME 11-15 APRIL
• Revised layout for realisation studies
• Naming convention
Cost and schedule study ongoing with 2 consultants
ILF
CONSULTING ENGINEERS
synaxis
• Cost & schedule estimates
• Inclined access shafts assessment
• Tunnel and shaft cross-section designs
Nov. 2015
Apr. 2016
Aug. 2016
Sept. 2016
Dec. 2016
Quaternary
Lake
Wildflysch
Molasse subalpine
Molasse
Limestone
Shaft
Alignment
Distance along ring clockwise from CERN (km)
Future Circular Collider Study
Michael Benedikt
FCC Physics Workshop, CERN, 16 January 2017
7

Common layouts for hh & ee

FCC-ee 1, FCC-ee 2, FCC-ee booster (FCC-hh footprint)



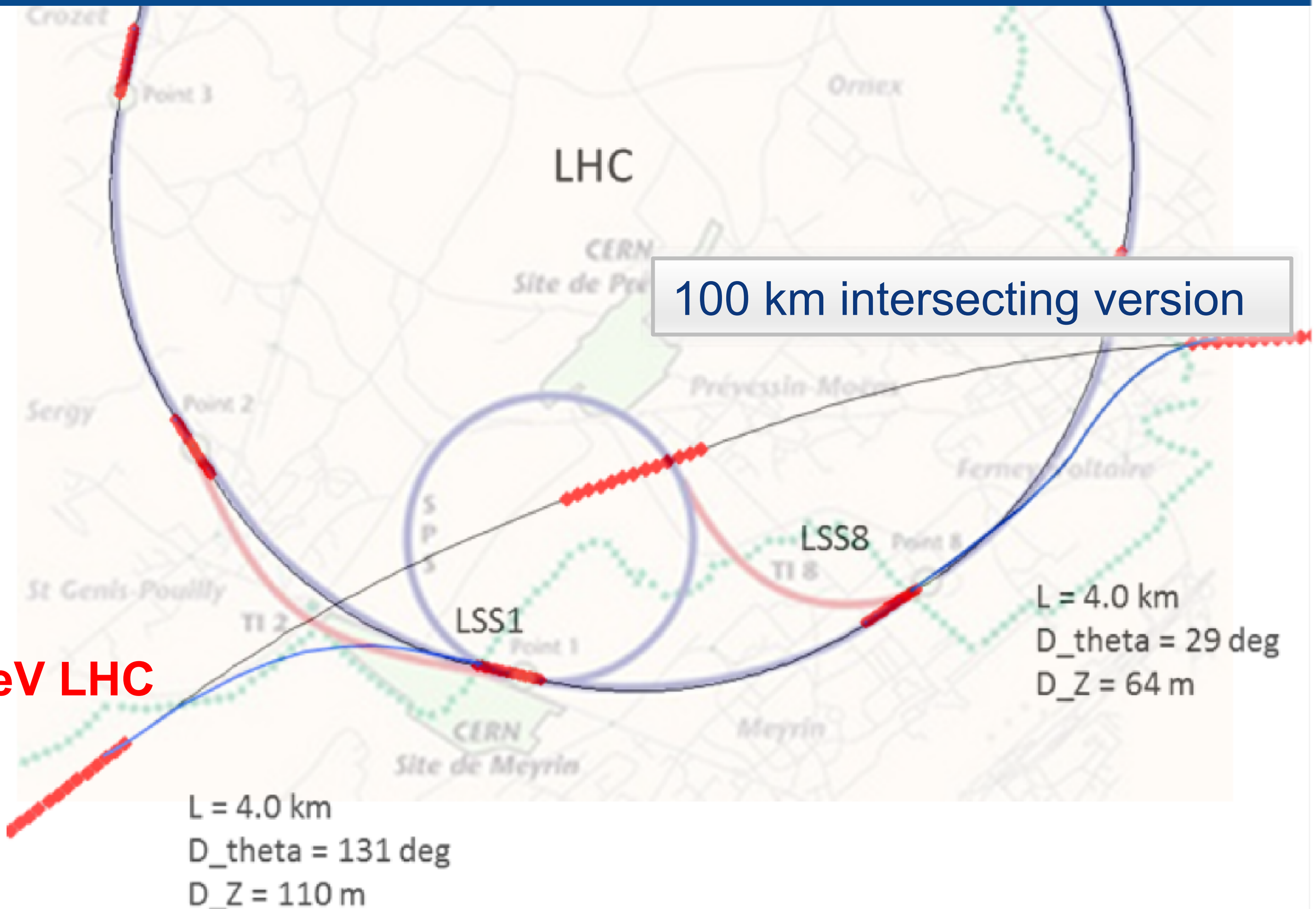


- 2 main IPs in A, G for both machines
- asymmetric IR optic/geometry for ee to limit synchrotron radiation to detector

FCC-hh injector studies

Injector options:

- **SPS → LHC → FCC**
- **SPS/SPS$_{upgrade}$ → FCC**



Current baseline:

- **Injection energy 3.3 TeV LHC**

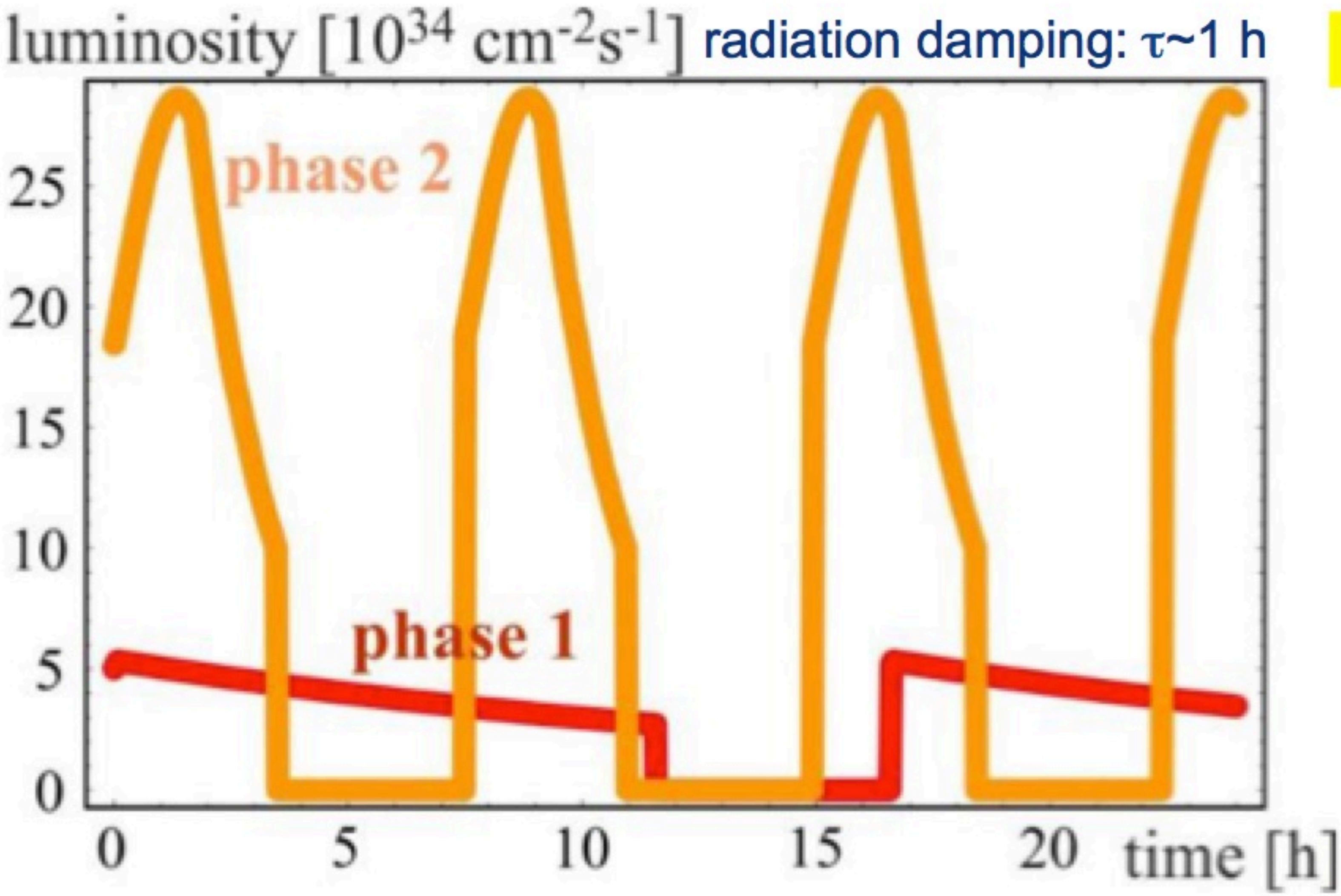
Alternative option:

- **Injection around 1.5 TeV**
- **SPS$_{upgrade}$ could be based on fast-cycling SC magnets, 6-7T, ~ 1T/s ramp**

FCC-pp collider parameters

parameter	FCC-hh		HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		27	14	14
dipole field [T]	16		16	8.33	8.33
circumference [km]	97.75		26.7	26.7	26.7
beam current [A]	0.5		1.12	1.12	0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2 (0.44)	2.2	1.15
bunch spacing [ns]	25	25 (5)	25 (5)	25	25
synchr. rad. power / ring [kW]	2400		101	7.3	3.6
SR power / length [W/m/ap.]	28.4		4.6	0.33	0.17
long. emit. damping time [h]	0.54		1.8	12.9	12.9
beta* [m]	1.1	0.3	0.25	0.20	0.55
normalized emittance [μm]	2.2 (0.4)		2.5 (0.5)	2.5	3.75
peak luminosity [10^{34} cm^{-2}s^{-1}]	5	30	25	5	1
events/bunch crossing	170	1k (200)	~800 (160)	135	27
stored energy/beam [GJ]	8.4		1.3	0.7	0.36

luminosity evolution over 24 h



PRST-AB 18, 101002 (2015)

for both phases:

beam current 0.5 A, unchanged!

total synchrotron radiation power ~5 MW.

phase 1: β^*=1.1 m, ξ_{tot}=0.01, t_{ta}=5 h, 250 fb^{-1} / year

phase 2: β^*=0.3 m, ξ_{tot}=0.03, t_{ta}=4 h, 1000 fb^{-1} / year

look @ Zimmermann's slides for many more details, 25ns vs 5ns, etc

FCC-hh cryogenic beam vacuum system

Synchrotron radiation (~ 30 W/m/beam (@16 T field) (LHC <0.2W/m) **~ 5 MW total load in arcs**

- **Absorption of synchrotron radiation at ~50 K** for cryogenic efficiency (**5 MW →100 MW cryoplant**)
- Provision of beam vacuum, suppression of photo-electrons, electron cloud effect, impedance, etc.

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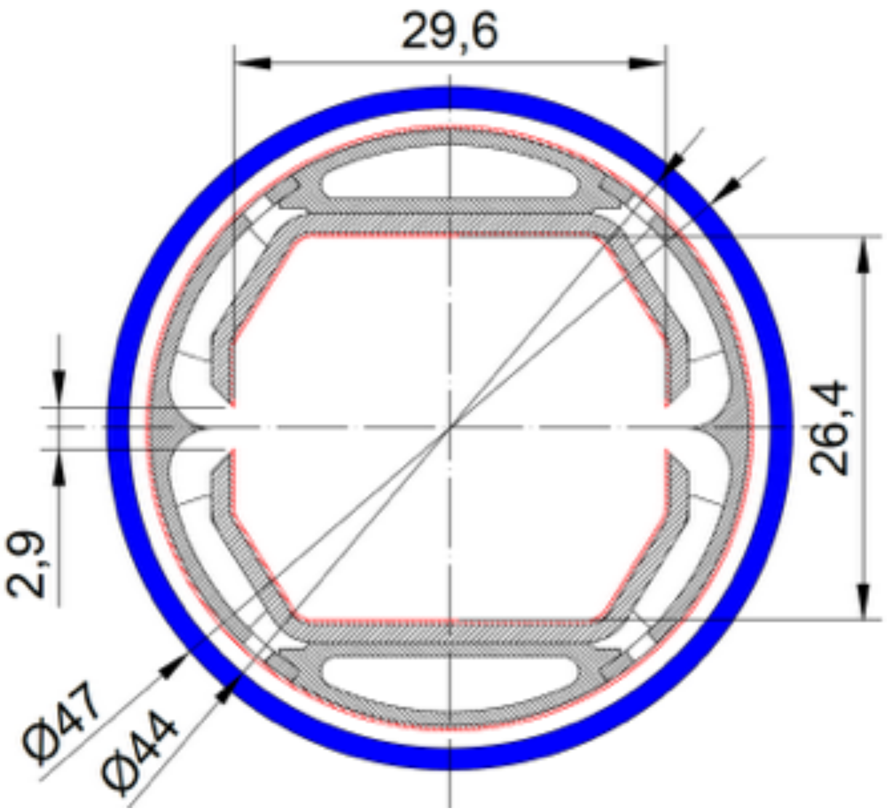

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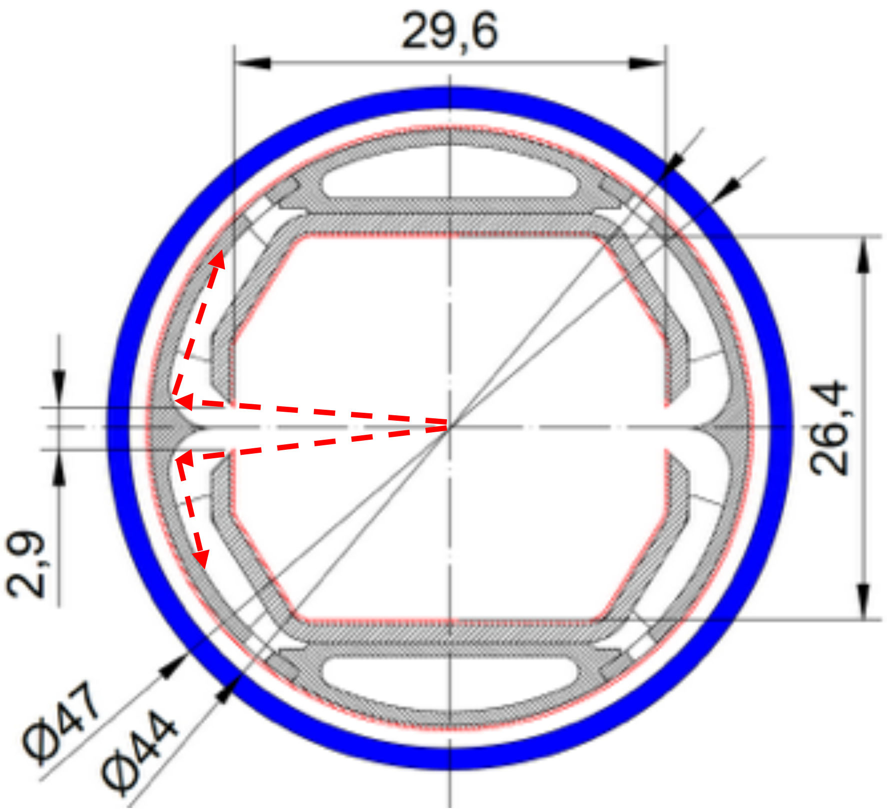

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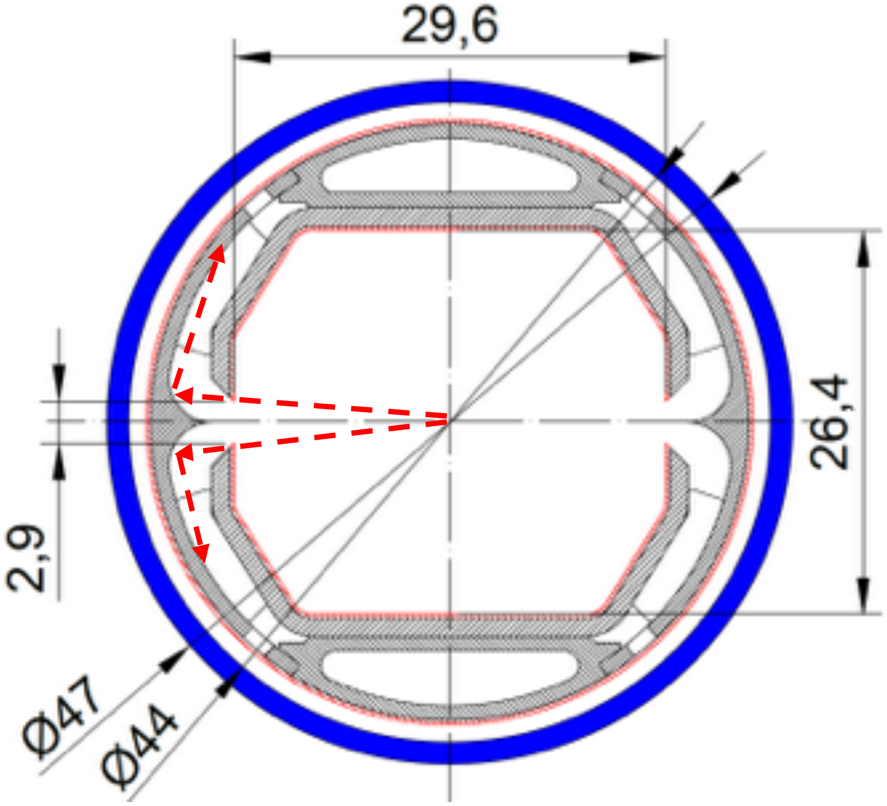
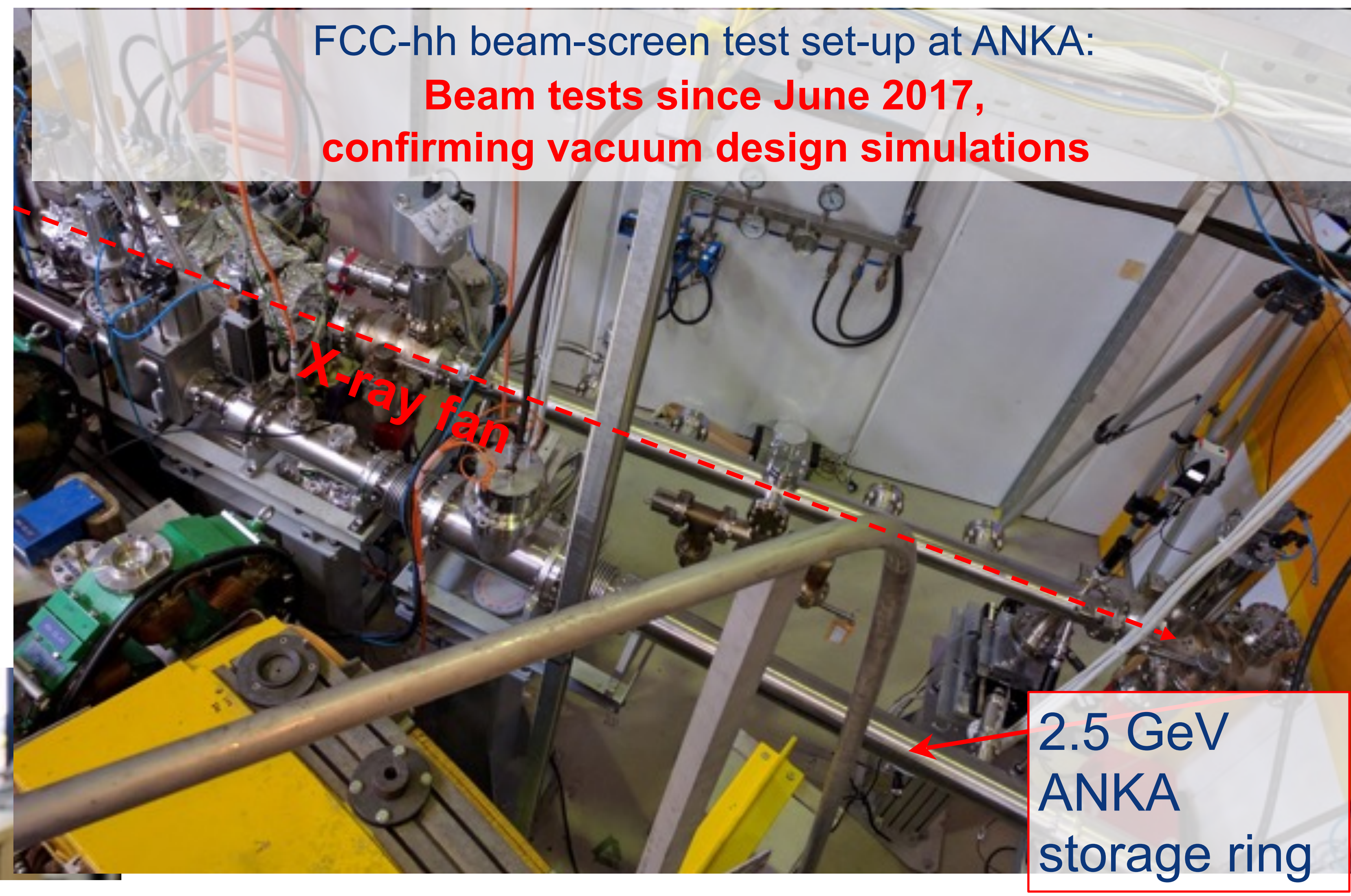
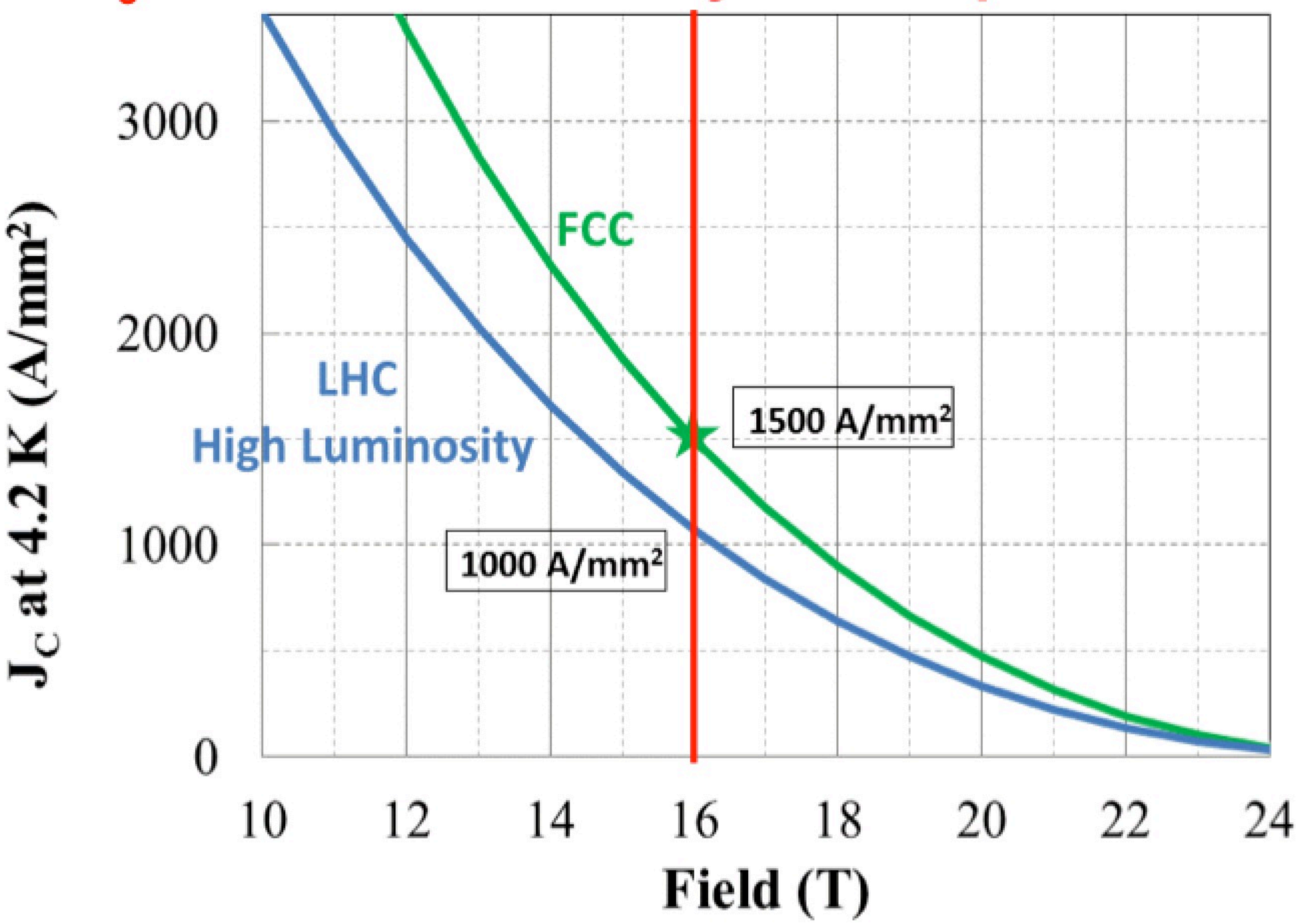




Nb_3Sn conductor development program

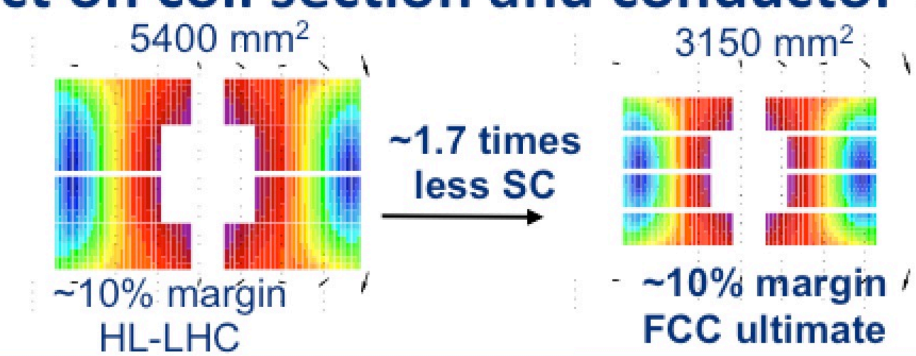
Nb_3Sn is one of the key cost & performance factors for FCC-hh / HE-LHC



Main development goals:

- J_c increase (16T, 4.2K) > 1500 A/mm² i.e. 50% increase wrt HL-LHC wire
- Reference wire diameter 1 mm
- Potentials for large-scale production and cost reduction

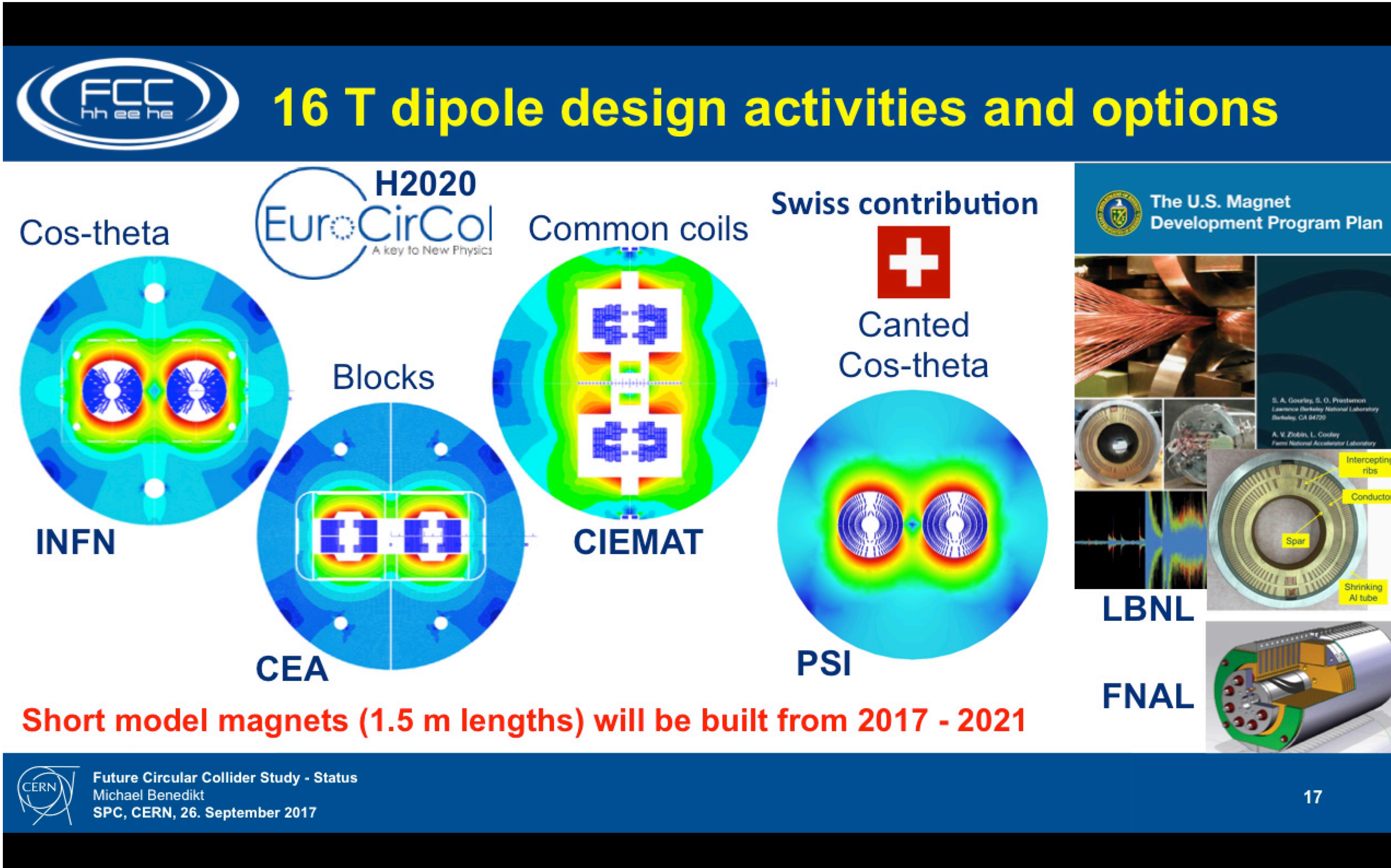
Impact on coil section and conductor mass



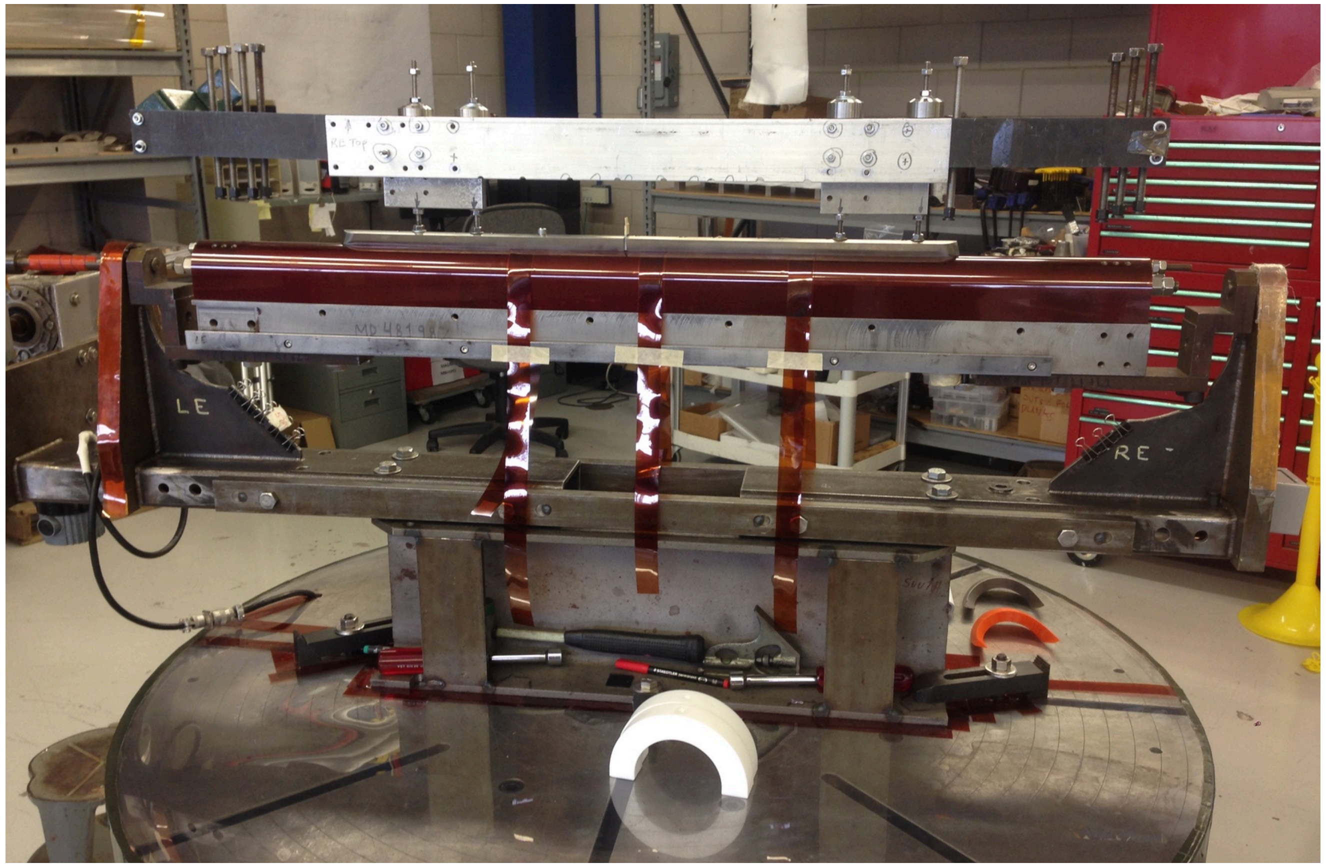
Collaborations FCC Nb_3Sn program

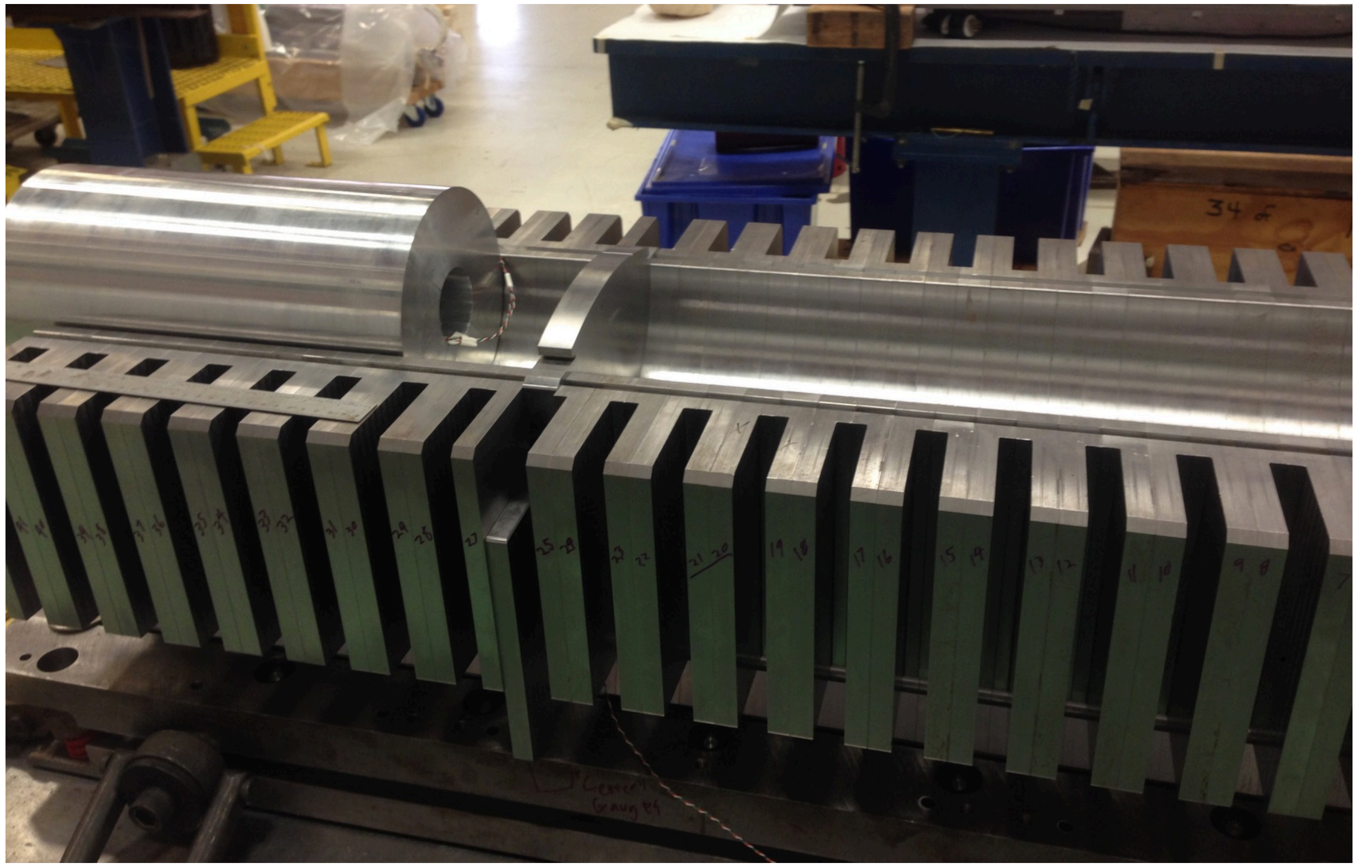
Established worldwide activities for Nb3Sn development:

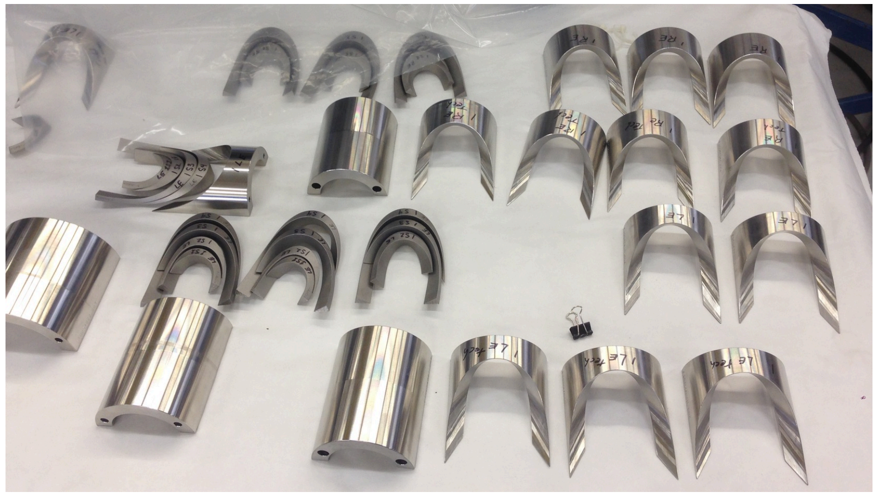
- **Procurement of state-of-the-art conductor for protoyping:**
  - **Bruker-OST**– **European/US**
- **Stimulation of conductor development with regional industry:**
  - **CERN/KEK** – **Japanese** contribution. Japanese **industry** (JASTEC, Furukawa, SH Copper) and laboratories (Tohoku Univ. and NIMS).
  - **CERN/Bochvar High-technology Research Inst.** – **Russian** contribution. Russian **industry** (TVEL) and laboratories
  - **CERN/KAT** – **Korean** **industrial** contribution
- **Characterization of conductor & research with universities:**
  - **Europe: Technical Univ. Vienna, Geneva University, University of Twente**
  - **Applied Superconductivity Centre** at Florida State University

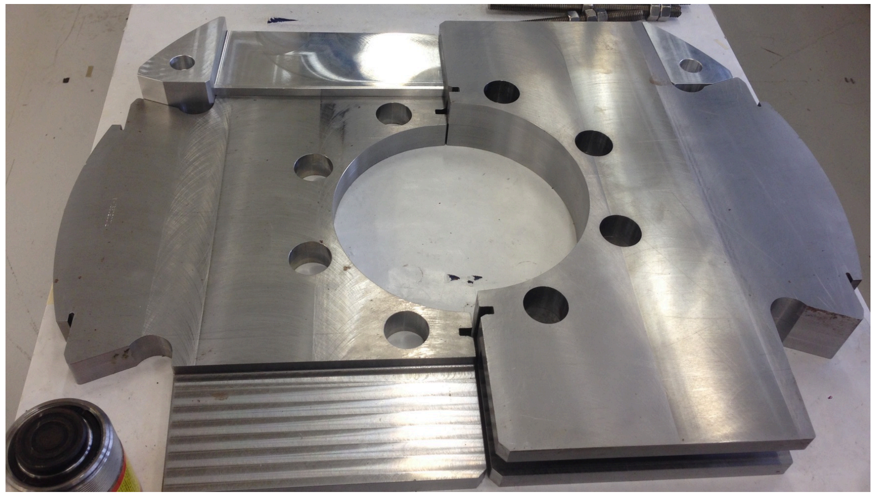

16 T dipole design activities and options
H2020
EuroCirCol
A key to New Physics
Cos-theta
Common coils
Swiss contribution
Canted
Cos-theta
Blocks
INFN
CIEMAT
CEA
PSI
The U.S. Magnet
Development Program Plan
S. A. Gourlay, S. O. Prestemon
Lawrence Berkeley National Laboratory
Berkeley, CA 94720
A. V. Zlobin, L. Cooley
Fermi National Accelerator Laboratory
Intercepting ribs
Conductor
Spar
Shrinking Al tube
LBNL
FNAL
Short model magnets (1.5 m lengths) will be built from 2017 - 2021
CERN
Future Circular Collider Study - Status
Michael Benedikt
SPC, CERN, 26. September 2017
17

15T dipole prototyping at FNAL (60mm aperture, L=1m)

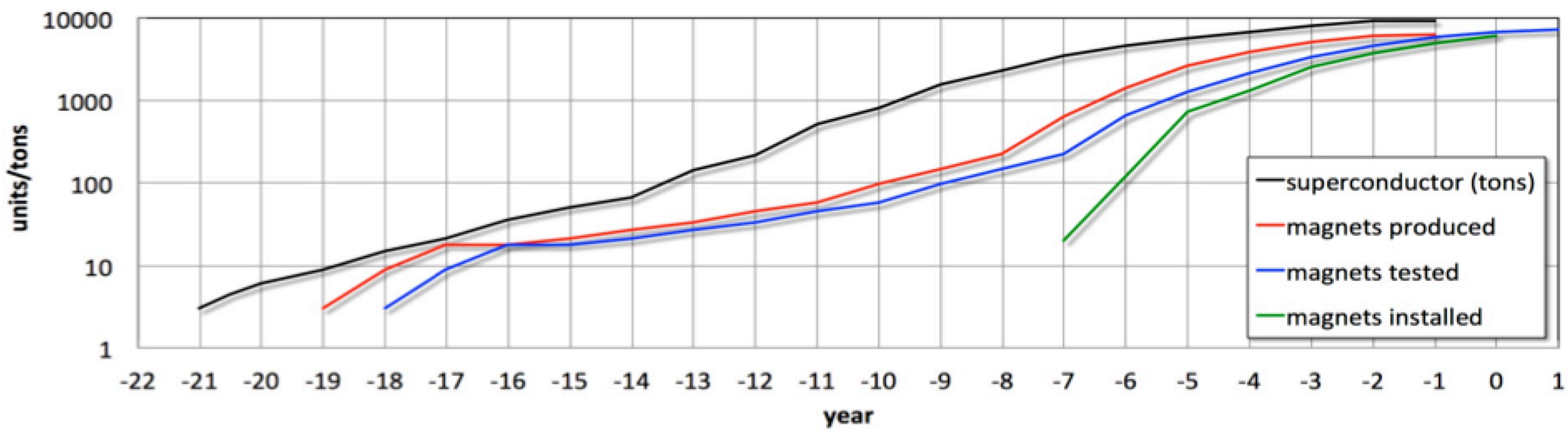






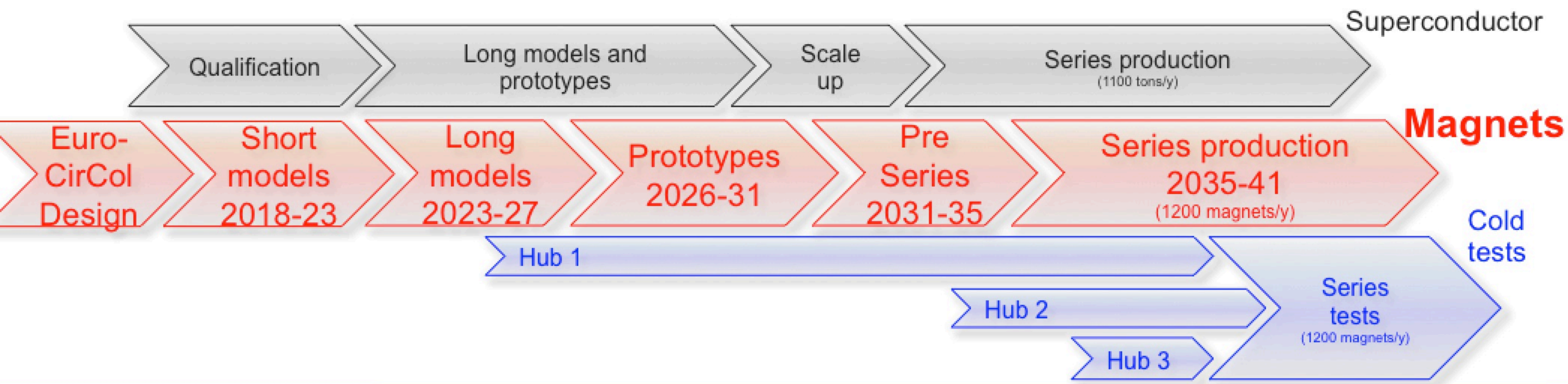


16 T magnet R&D schedule



Total duration of magnet program:

~20 years



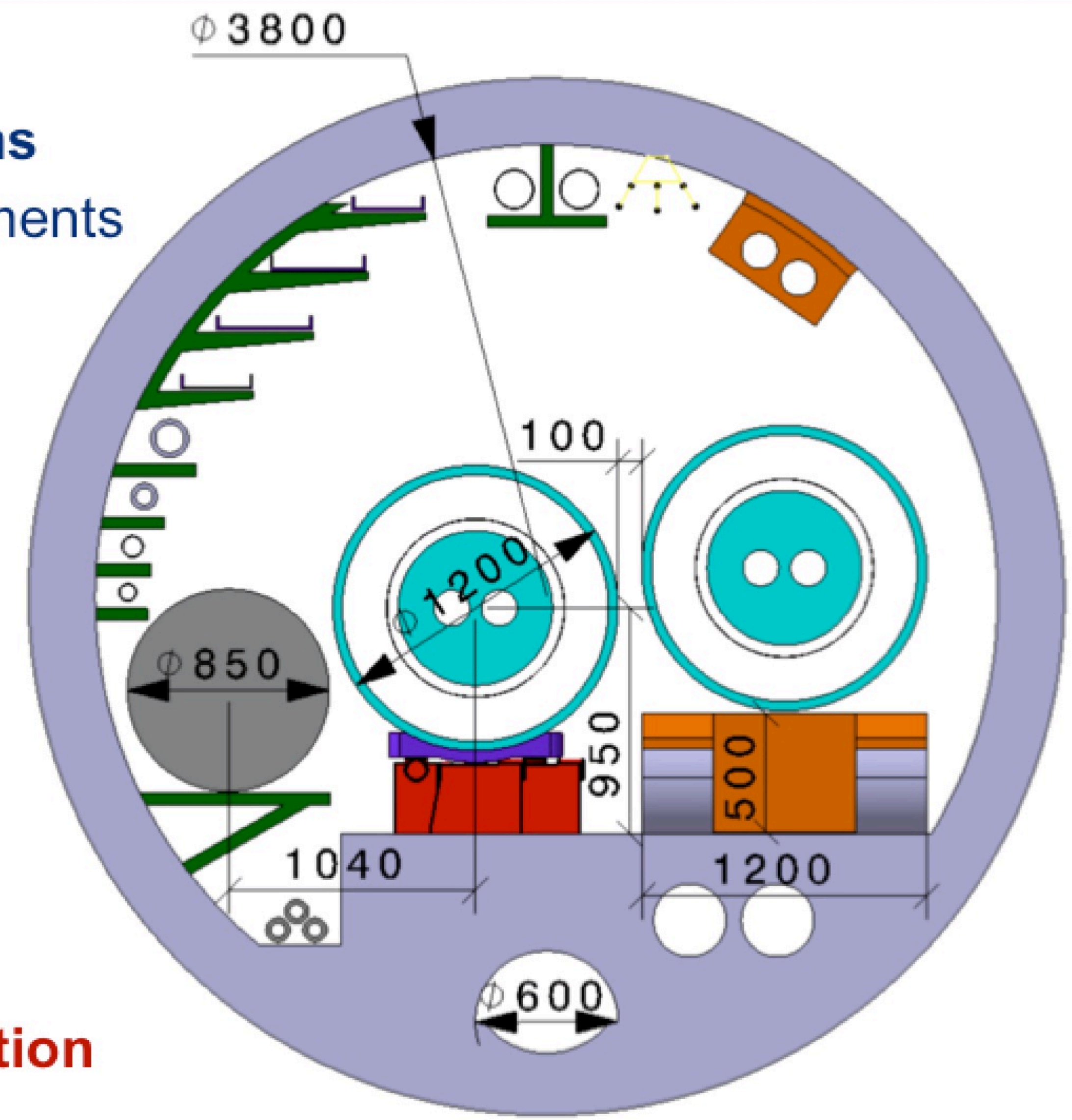
Would follow on HL-LHC Nb_3Sn program with long models with industry from 2023/24

HE-LHC integration aspects

Working hypothesis for HE LHC design:

No major CE modifications on machine tunnel and caverns

- Similar geometry and layout as LHC machine and experiments
- **Maximum magnet cryostat external diameter compatible with LHC tunnel ~1200 mm**
- **Classical 16 T cryostat design based on LHC approach gives ~1500 mm diameter!**



Strategy: develop a single 16 T magnet, compatible with both HE LHC and FCC-hh requirements:

- **Allow stray-field and/or cryostat as return-yoke**
- **Optimization of inter-beam distance (compactness)**

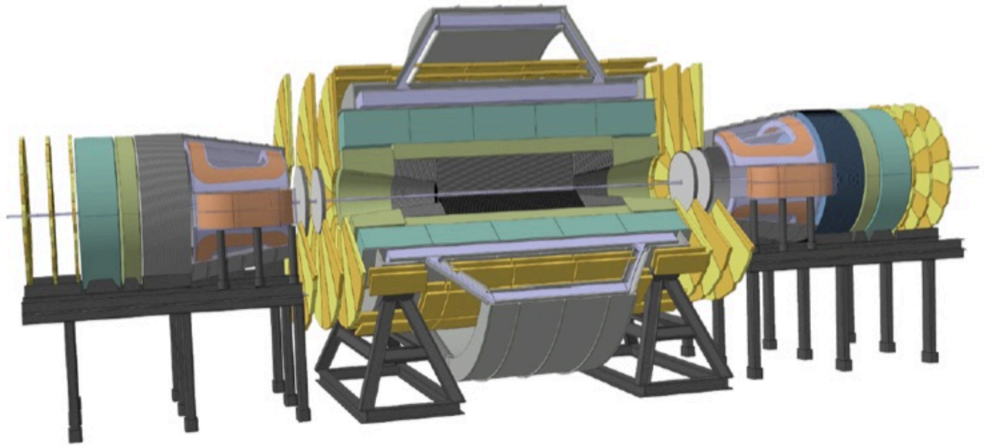
→ Smaller diam. also relevant for FCC-hh cost optimization

Reference detector

earlier design

6 T, 12 m bore solenoid, 10 Tm dipoles, shielding coil

- 65 GJ stored energy
- 28 m diameter
- >30 m shaft
- multi billion project

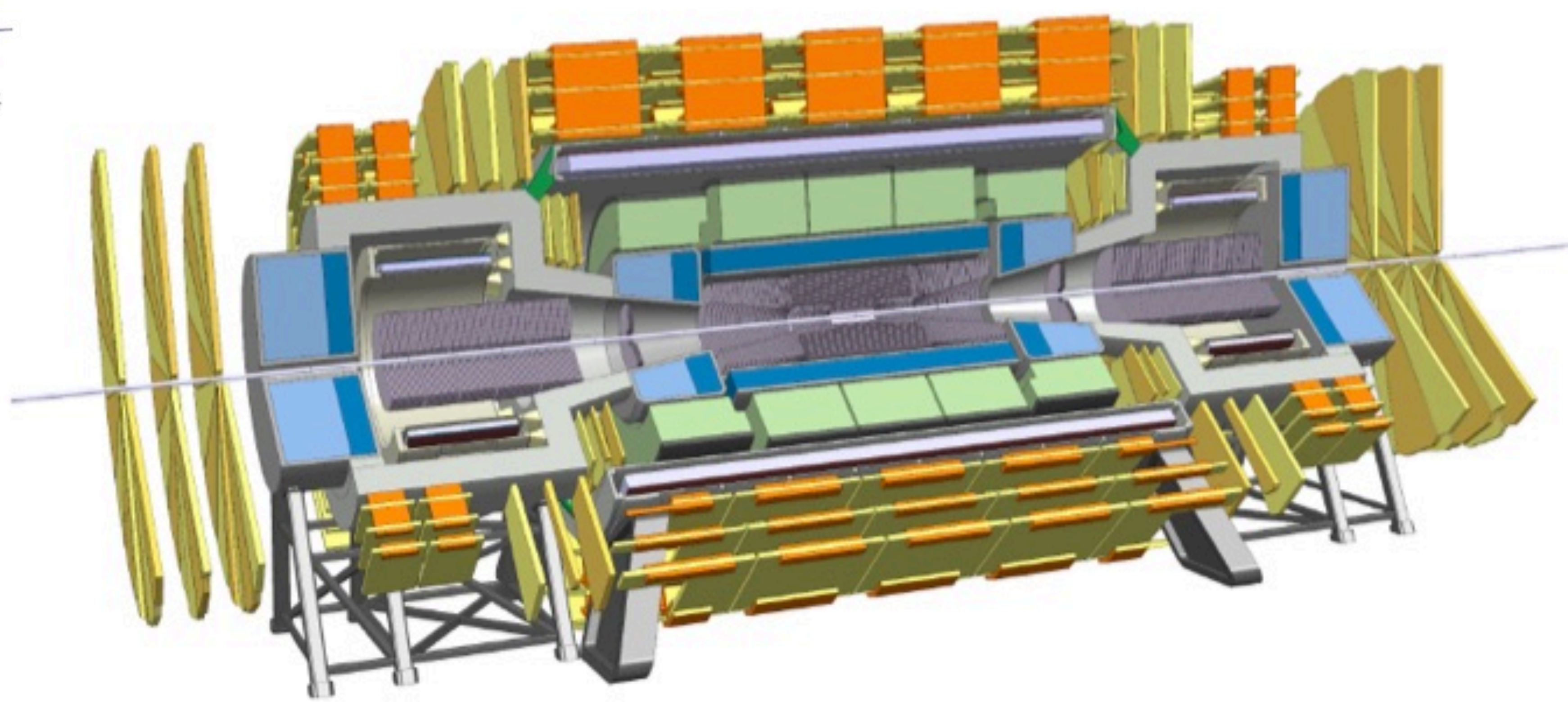


→

current design

4 T, 10 m bore solenoid, 4 T forward solenoids, no shielding coil

- 14 GJ stored energy
- rotational symmetry for tracking!
- 20 m diameter (~ ATLAS)
- 15 m shaft
- ~1 billion project



latest l^* = 40 m

W. Riegler et al.

- **Detector design** group leader: Werner Riegler
  - Indico site of mtgs: http://indico.cern.ch/category/8920/
  - join the mailing list
- **Physics Simulation** subgroup leaders: Heather Gray & Filip Moortgat
  - Indico site of mtgs: http://indico.cern.ch/category/6067/
  - join the mailing list
- Monthly mtgs of each group, if interested register to the mailing lists