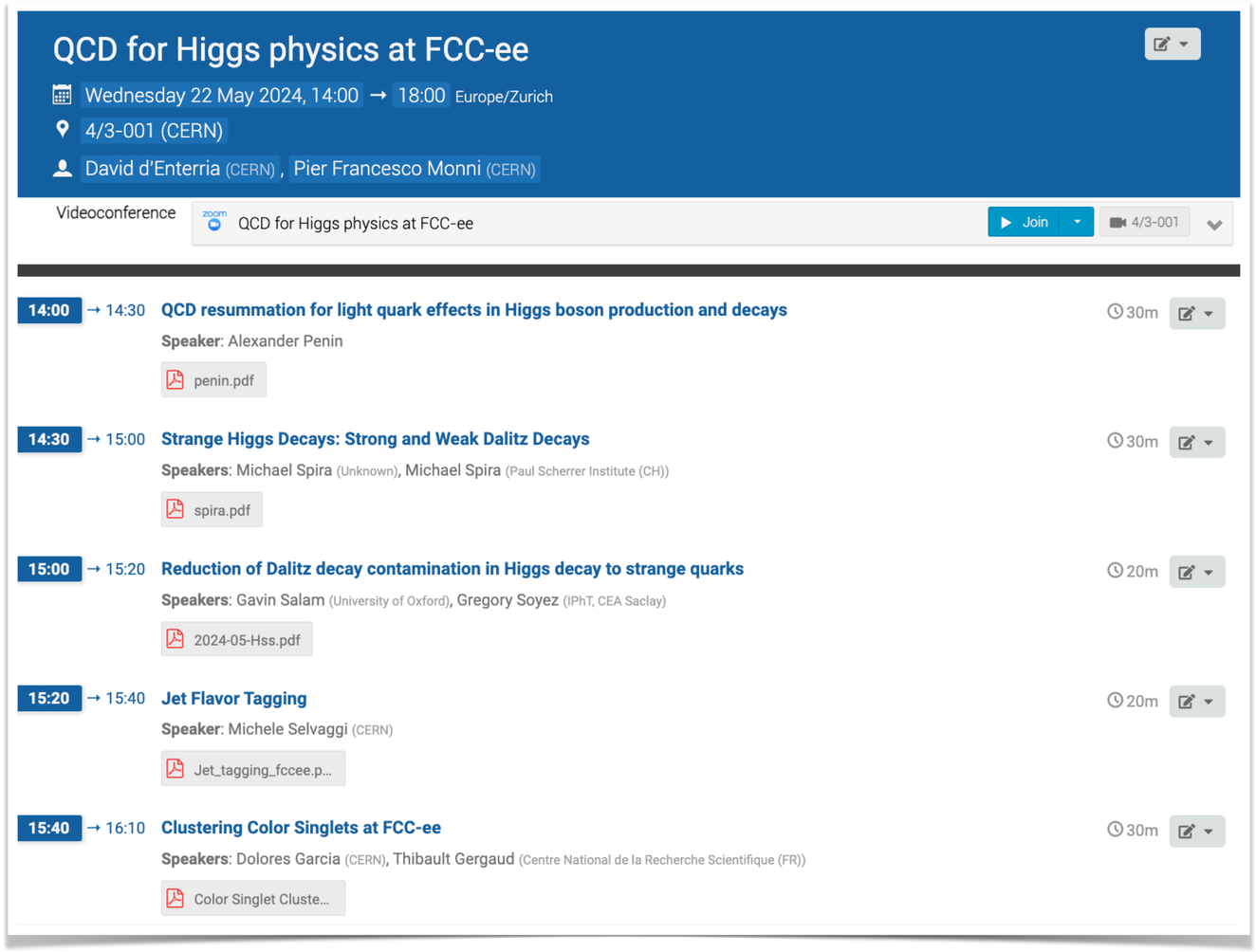
Summary of
“QCD for Higgs physics at FCC-ee”

Physics Performance Meeting - May 2024

Goal: extraction of Y_s at FCC-ee



QCD for Higgs physics at FCC-ee

Wednesday 22 May 2024, 14:00 → 18:00 Europe/Zurich

4/3-001 (CERN)

David d'Enterria (CERN), Pier Francesco Monni (CERN)

Videoconference — QCD for Higgs physics at FCC-ee — Join — 4/3-001

14:00 → 14:30 **QCD resummation for light quark effects in Higgs boson production and decays** — 30m

Speaker: Alexander Penin

penin.pdf

14:30 → 15:00 **Strange Higgs Decays: Strong and Weak Dalitz Decays** — 30m

Speakers: Michael Spira (Unknown), Michael Spira (Paul Scherrer Institute (CH))

spira.pdf

15:00 → 15:20 **Reduction of Dalitz decay contamination in Higgs decay to strange quarks** — 20m

Speakers: Gavin Salam (University of Oxford), Gregory Soyez (IPhT, CEA Saclay)

2024-05-Hss.pdf

15:20 → 15:40 **Jet Flavor Tagging** — 20m

Speaker: Michele Selvaggi (CERN)

Jet_tagging_fccee.p...

15:40 → 16:10 **Clustering Color Singlets at FCC-ee** — 30m

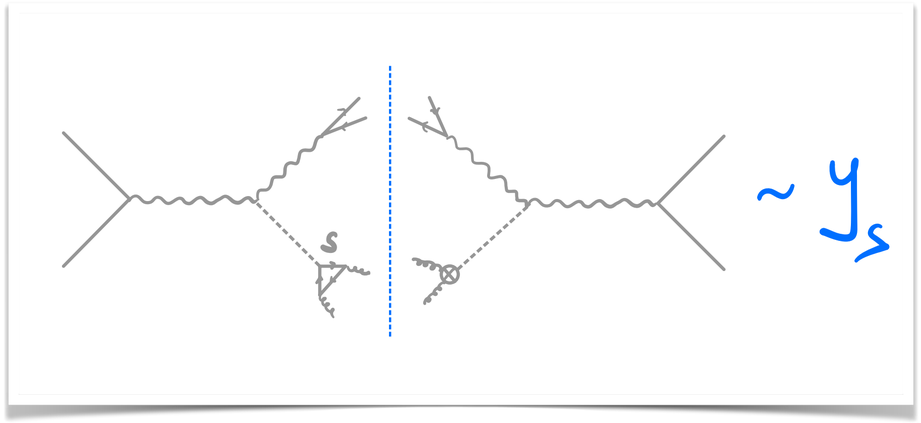
Speakers: Dolores Garcia (CERN), Thibault Gergaud (Centre National de la Recherche Scientifique (FR))

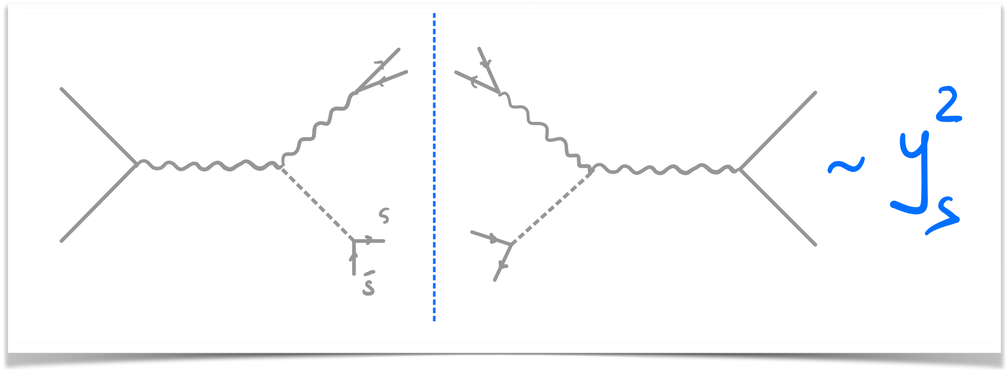
Color Singlet Cluste...

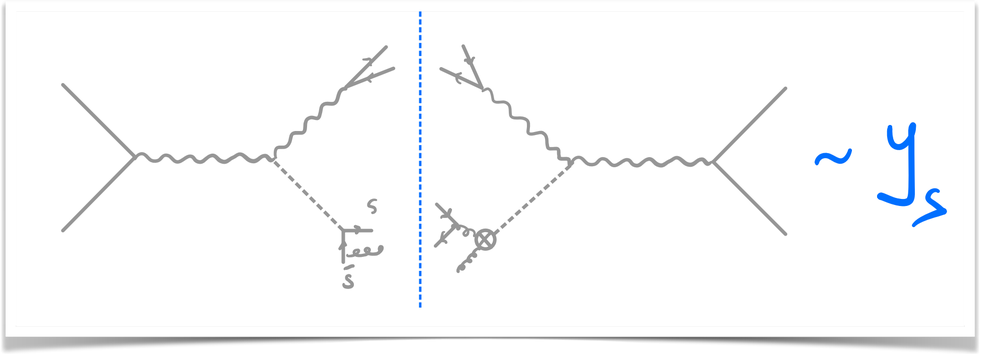
- **GOAL of this workshop**: Explore feasibility and reach of strange Yukawa (Y_S) constraints at FCC-ee
  - First brainstorming with discussions on the main theoretical and experimental obstacles
  - Follow-up work necessary to address these problems before a precise conclusion is reached

Many thanks to all the speakers for the efforts!

Direct vs. Indirect sensitivity





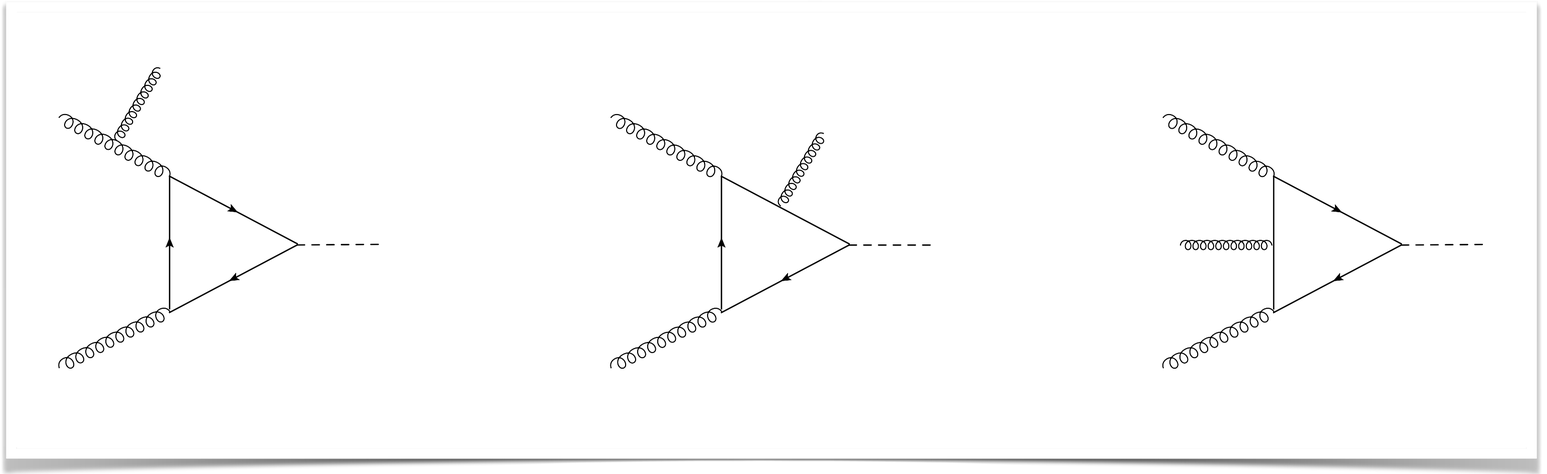


- Sensitivity to Y_S departure from the SM in Higgs hadronic decays:
  - **Direct**: tagging of strange jets and suppression of (irreducible/reducible) backgrounds
  - **Indirect**: distortions in kinematic distributions due to interplay of H->ss and strange mediated H->gg decay
- Precise control of signal and backgrounds poses TH problems + challenges in jet flavour tagging

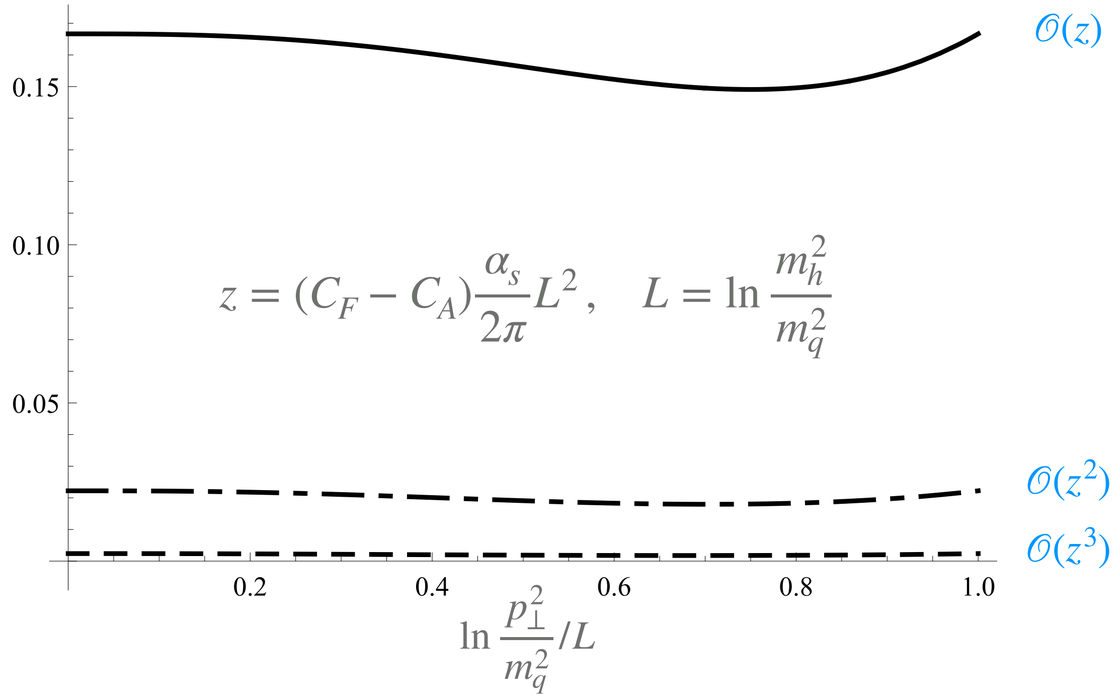
Theory challenge: light-quark mediated decay

$$M_{++\pm} \propto e^{\frac{\alpha_s}{2\pi} I} \sum_{q \in \text{quarks}} \underbrace{A^{(q)}_{++\pm}}$$

$$\sim \frac{m_q^2}{m_h^2} L^2 g(z) + \mathcal{O}(m_q^4)$$



Expansion up to 4 loops normalised to 1 loop result



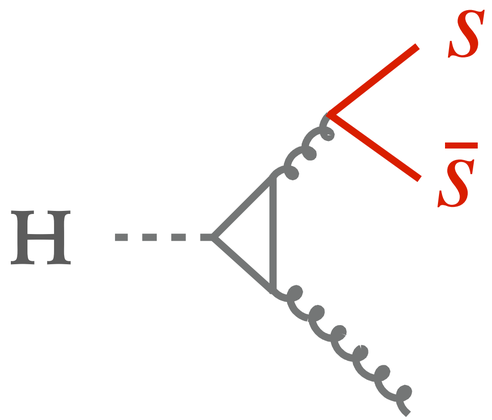
$$z = (C_F - C_A)\frac{\alpha_s}{2\pi} L^2, \quad L = \ln \frac{m_h^2}{m_q^2}$$

- Double logarithmic enhancement of the $h \to ggg$ amplitude (and mass^2 suppressed)
  - Possible distortions in decay distributions
  - Double logarithms cancel exactly at one loop, and cancellation found to persist at higher orders (form factor type effect - easy to include in MC generators)
  - Subleading logs known not to cancel at 1L, more studies on higher orders desirable

Theory challenge: contamination from Dalitz decay

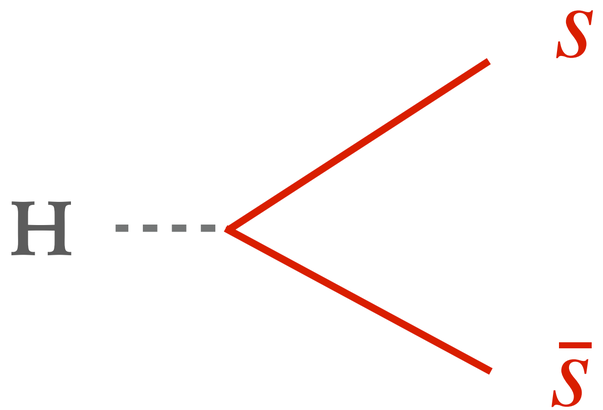
Talk by G. Salam

Dalitz v. Yukawa H → ss + X



Dalitz decay $(\alpha_s^3 y_t^2)$

$\sim \alpha_s$ suppressed
relative to $H \to gg$



Yukawa decay (y_s^2)

	BR
H → gg	8.1×10^{-2}
H → ss	$\sim 2 \times 10^{-4}$

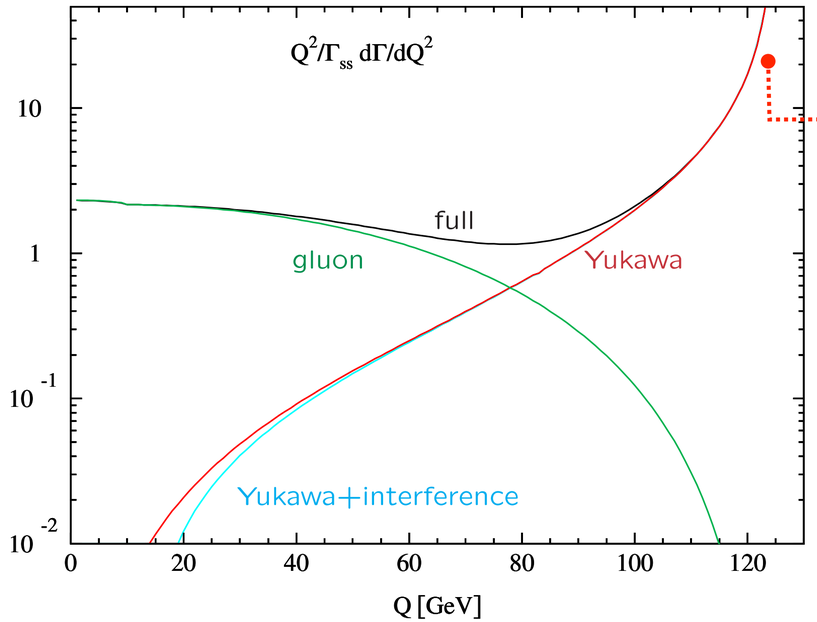
Ratio is ~ 400

Theory challenge: contamination from Dalitz decay

Talk by M. Spira

QCD Dalitz decay

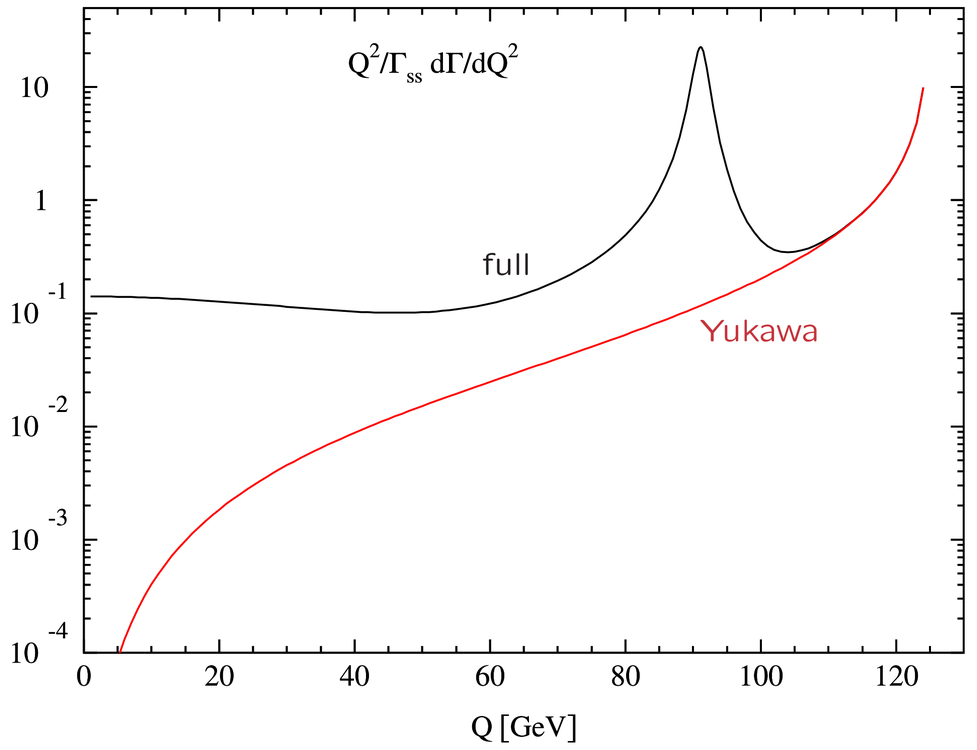
$H \to s\bar{s}g$



- using $\overline{m}_s(M_H)$ (neglecting regular mass effects)
- no resummation towards the end-point

Double logarithmic divergence (resummation?)

EW Dalitz decay

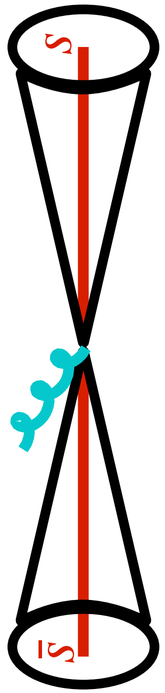


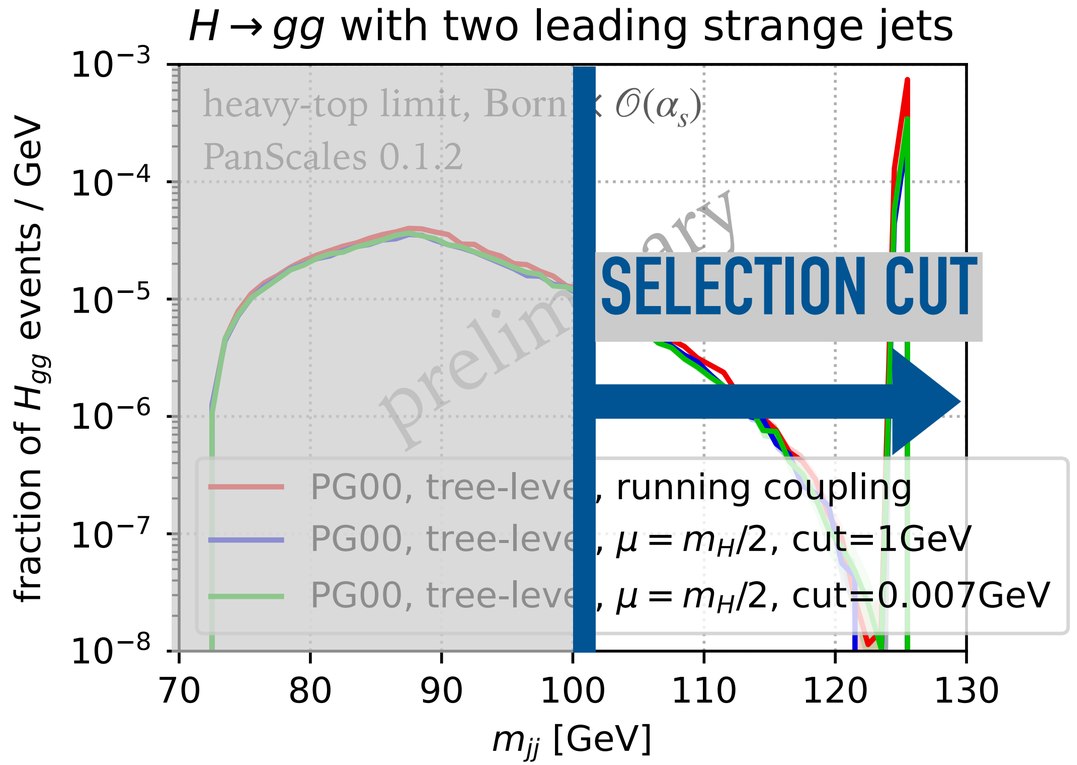
- **Conclusion**: Dalitz decays do not constitute a bottleneck to the determination of Y_S
- Important to find robust ways to suppress it

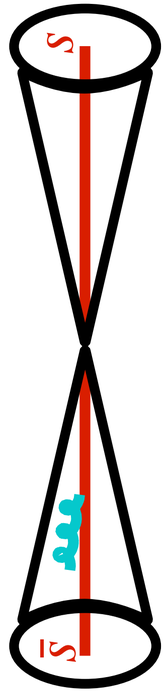
Theory challenge: suppressing the Dalitz contribution

Talk by G. Salam

- **Preliminary study**:
  - two IFN anti-kt strange jets (R=0.4) in the Higgs c.o.m frame
  - cut on the di-jet invariant mass
  - m_{jj}>100 GeV leads to sufficient suppression of Dalitz decays

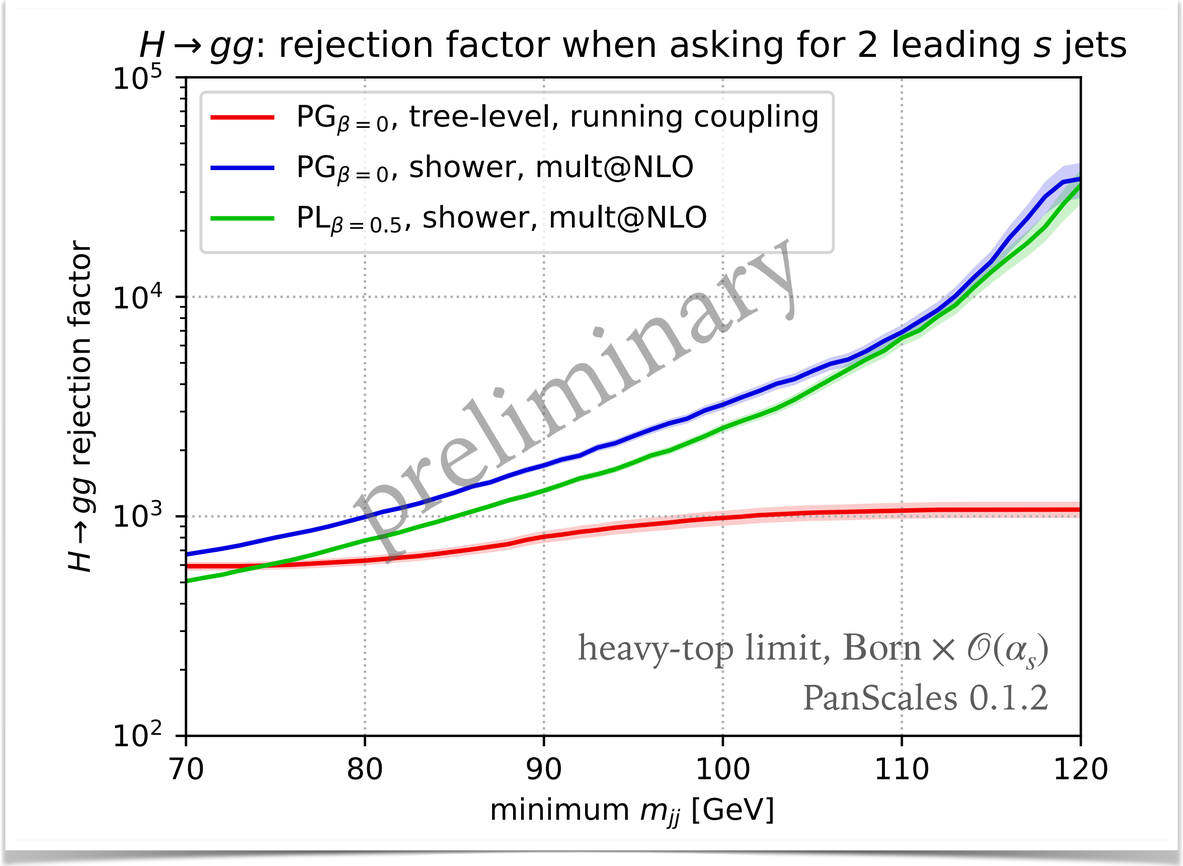


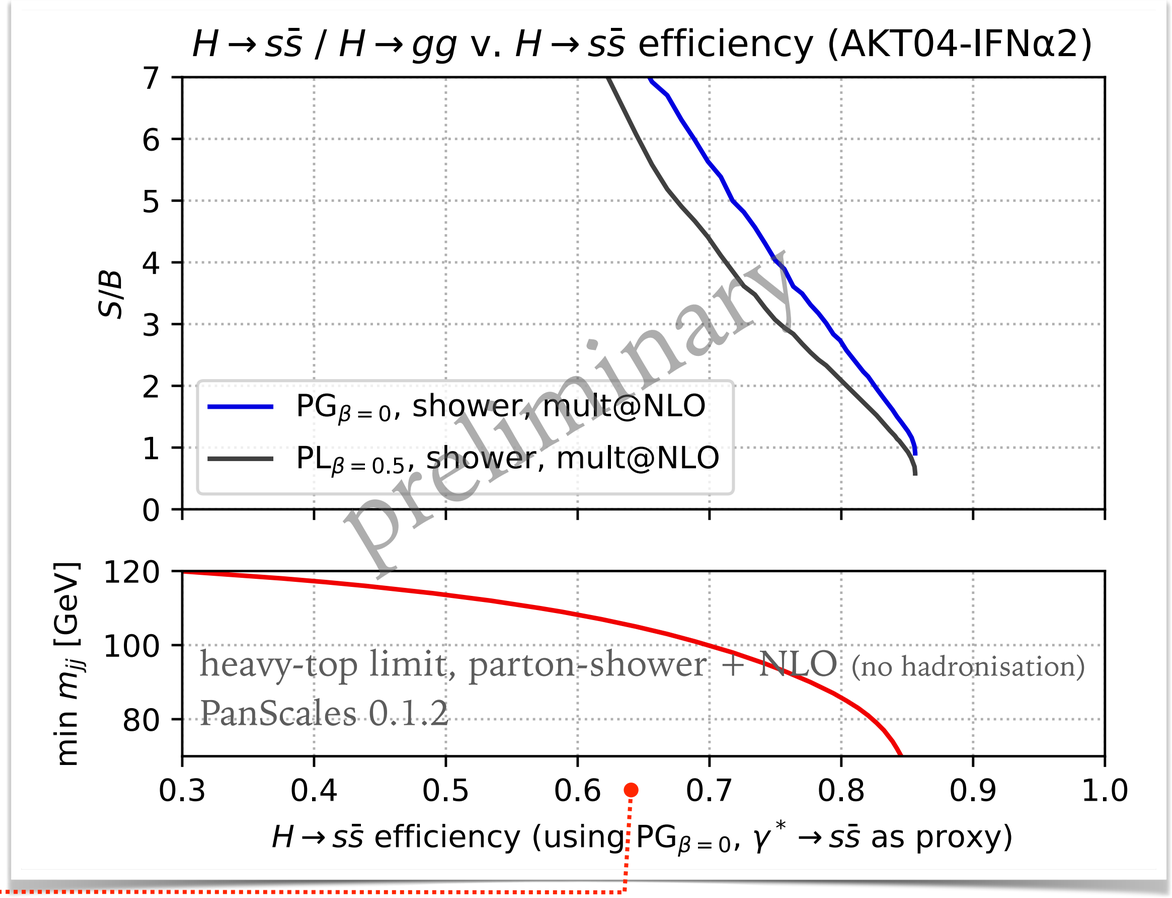




Theory challenge: suppressing the Dalitz contribution

Talk by G. Salam

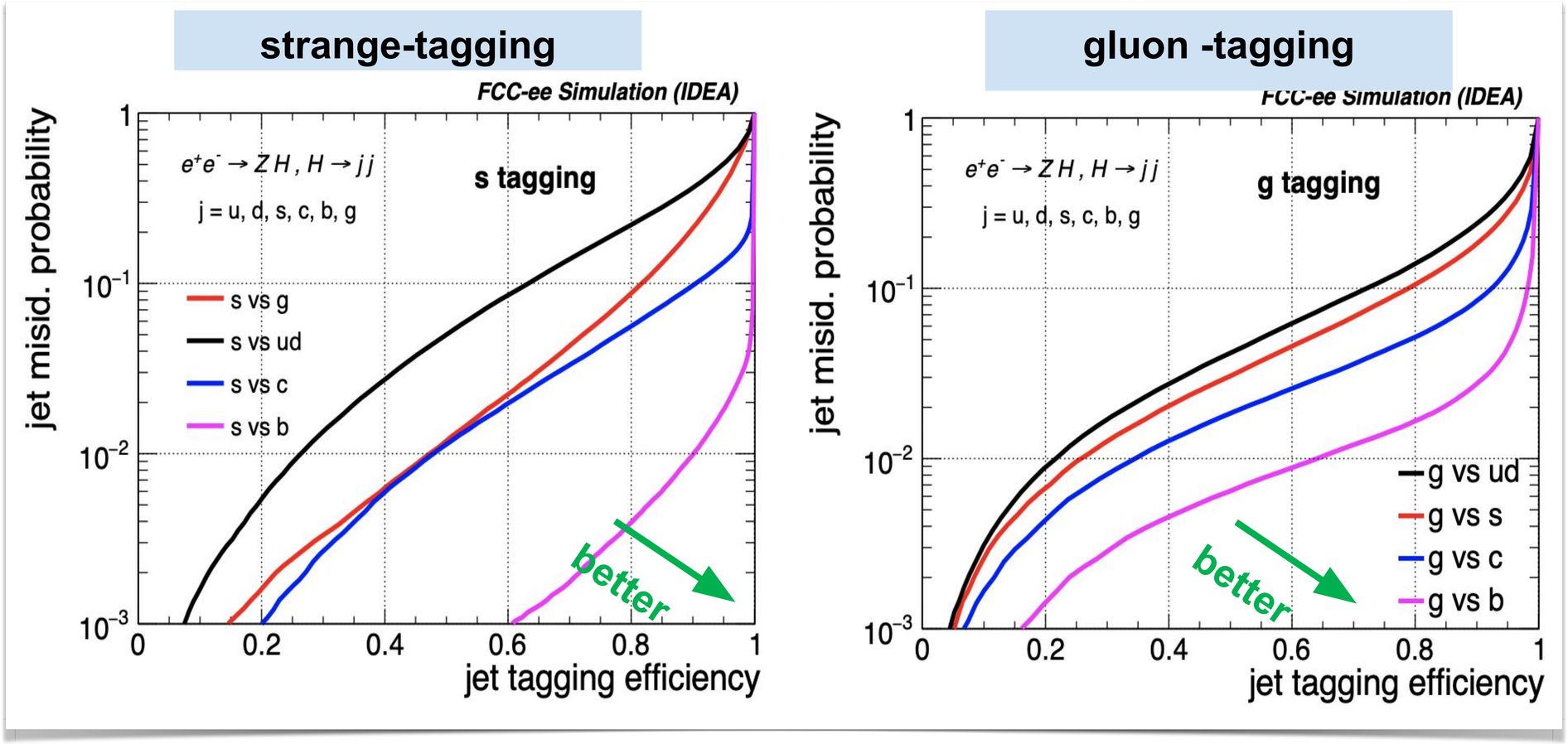




- **Outlook**:
  - Large parton shower corrections: we need higher orders and resummation
  - S/B ~ 3-4 seems reachable

Experimental challenges: jet flavour tagging

- Very promising performance from GNN (ParticleNet)
- Performance fairly robust w.r.t. model used in training, more studies and assessment of theory uncertainty desirable (e.g. considerations in the previous slides)



New ideas: colour singlet clustering

Talk by D. Garcia, T. Gergaud

- Interesting idea to consider fully hadronic final states (e.g. exclusive kt jets) and flavour tag jets to identify H and Z

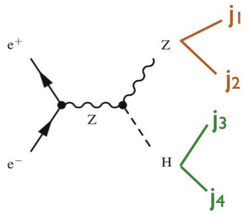
- Substantial gains in terms of mass resolution, several technical problems to investigate

  - jet algo: mis-clustering / mis-pairing
  - explore alternative GNN architectures (e.g. graph transformer model)
  - Possible issues in modelling/training? e.g. colour reconnection vs. H/Z lifetime

HZ decay mode

Z decay m(Z) = 91Gev :
- Z(ll) ~ 10%
- Z(vv) ~ 20%
- Z(jj) ~ 70%

H decay m(H) = 125Gev :
- H(bb) ~ 58 %
- H(gg) ~ 8%
- H(tautau) ~ 6%
- H(cc) ~ 2%
- H(ss) ~ 0.02%



- Z(vv/ll) final states:
  - “easy”: 2 jets
    - from the Higgs decay
- Z(jj):
  - “hard”: 4 jets
    - can originate from H or Z

Fully hadronic, HZ → jjjj ~ 51%:
- Hardest
- Largest BR

Thank you