Perspective for High Precision QCD Studies @ FCCee
(*selected appetizers*)

Bogdan MALAESCU

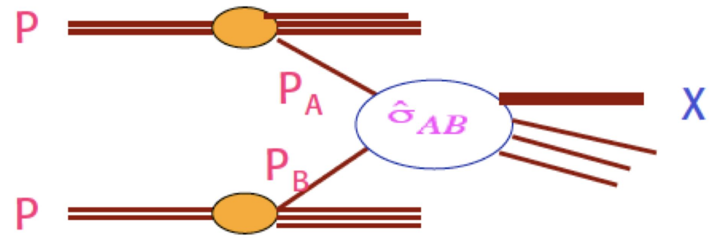
LPNHE, CNRS

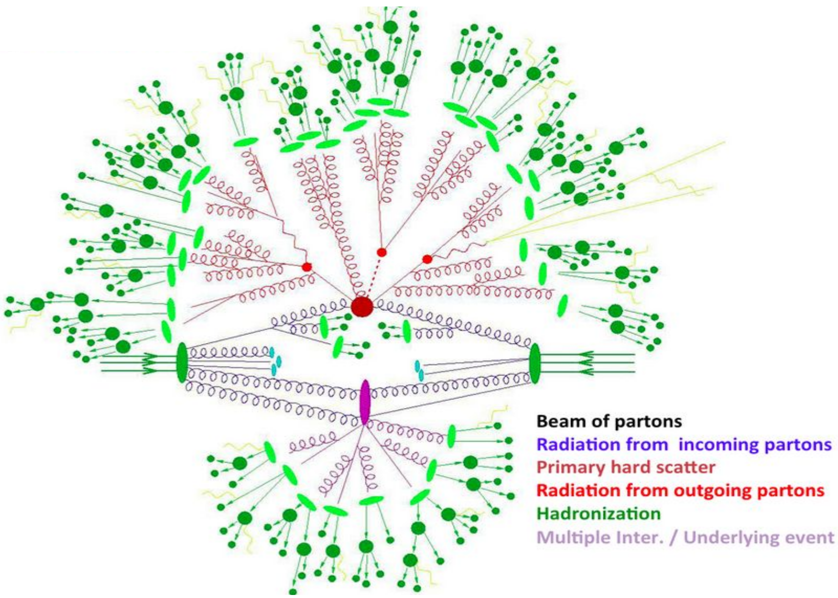
See also talk by David d'Enterria "α_S @ FCC-ee" @ FCC France 2020
→ α_S extractions from hadronic decays of τ, Z, W; event shapes; jet rates etc.

Snowmass studies (LoIs):
"Perspectives for high-precision $\alpha_S(m_Z^2)$ determinations at FCC-ee"
"High-precision $\alpha_S(m_Z^2)$ determinations from e +e− → hadrons below Z peak"

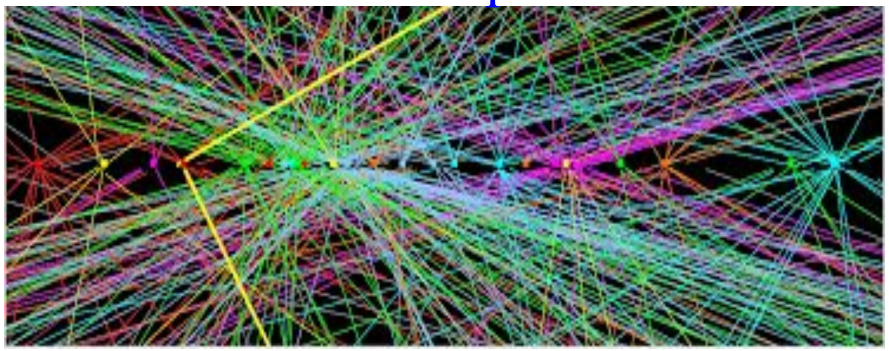
20/01/2021

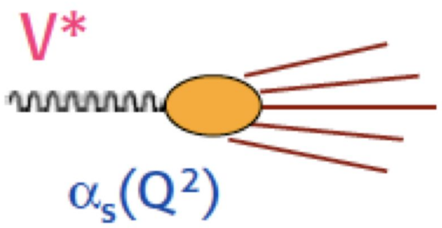
Comparison of LHC / FCCee “environments”





Pile-up





@ FCCee:

→ Short distance interaction of virtual bosons with quarks

→ No PDFs

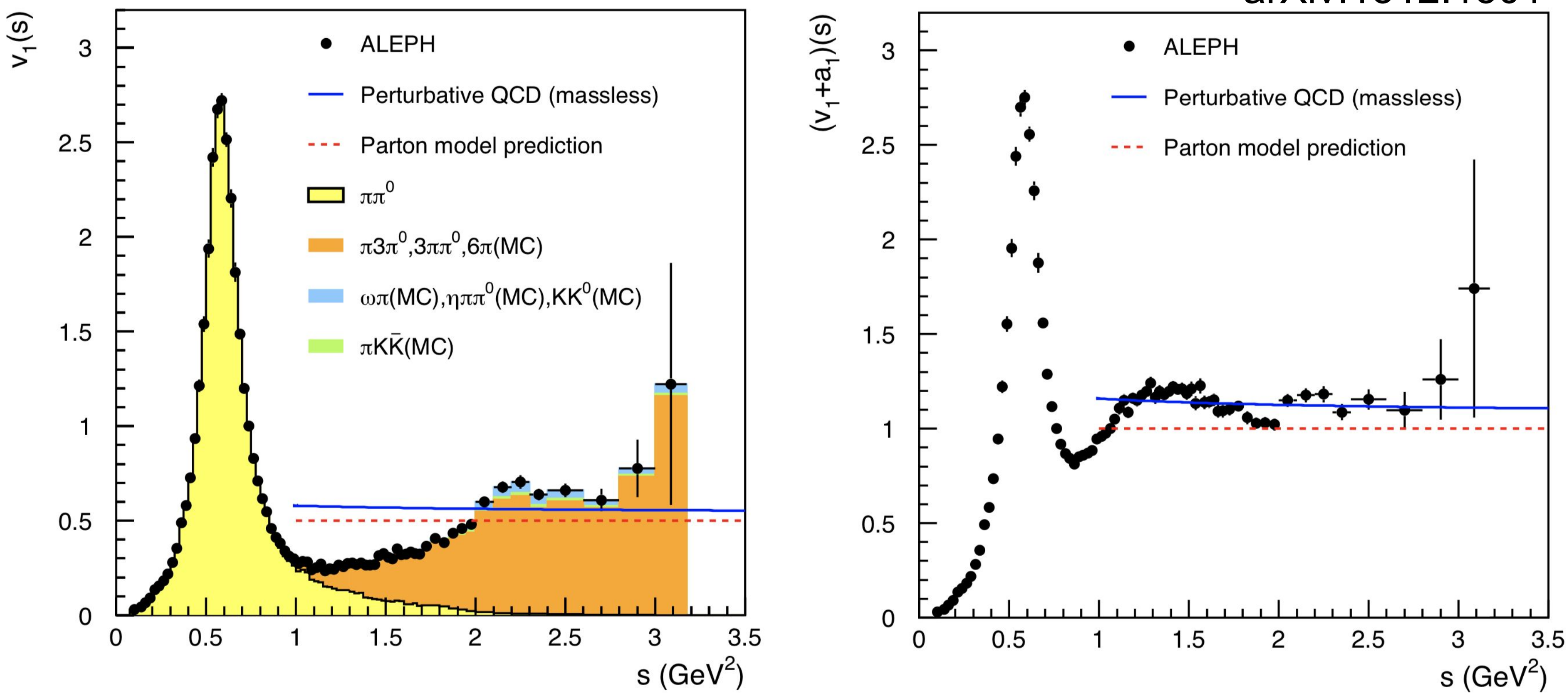
→ No underlying event & MPI

→ No pile-up

α_S evaluation from *hadronic τ decays* (1/3)

→ τ hadronic spectral functions (SFs) from ALEPH, unfolded of detector effects

arXiv:1312.1501

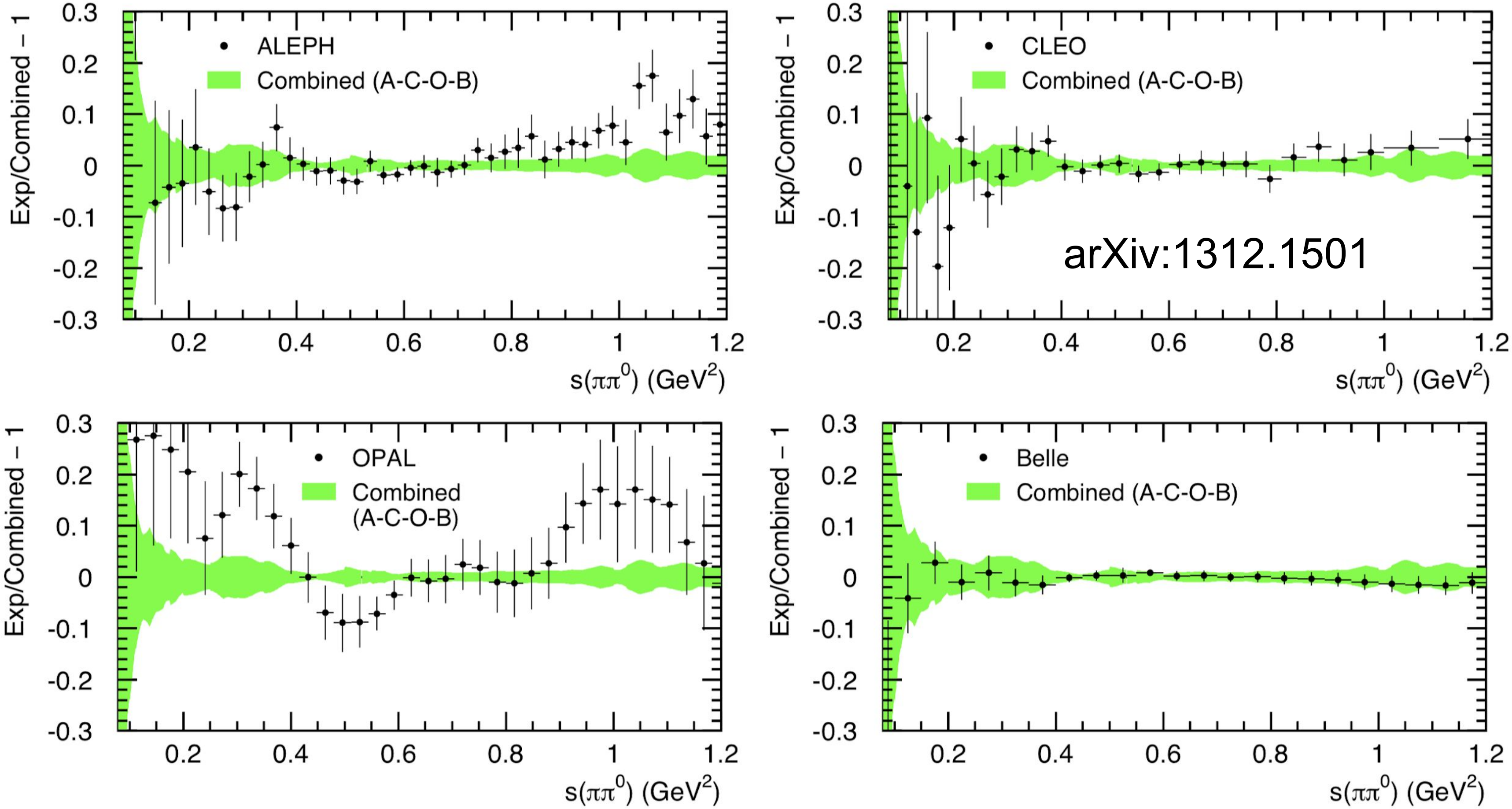


$$\upsilon_1 / a_1\left[\tau^- \to V^- / A^- \nu_\tau\right] \propto \frac{\mathrm{BR}\left[\tau^- \to V^- / A^- \nu_\tau\right]}{\mathrm{BR}\left[\tau^- \to e^- \bar{\nu}_e \nu_\tau\right]} \frac{1}{N_{V/A}} \frac{dN_{V/A}}{ds} \frac{m_\tau^2}{\left(1 - s/m_\tau^2\right)^2 \left(1 + s/m_\tau^2\right)}$$

branching fractions   mass spectrum   kinematic factor

α_S evaluation from *hadronic τ decays* (2/3)

→ τ hadronic spectral functions ($\pi\pi^0$ channel) from various experiments



→ Normalisation from branching fractions best determined by ALEPH (large boost)

→ Shape best determined by Belle (high statistics); improvements @ Belle II

→ What precision can one achieve at FCCee?

Need to study acceptance, reconstruction efficiency, resolution etc. in view of *optimizing the detector design* for SFs measurements

α_S evaluation from *hadronic τ decays* (3/3)

$$R_\tau = \frac{\Gamma(\tau^- \to \text{hadrons}\ \nu_\tau)}{\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}$$

EW correction:

$\simeq 0.0010$ (neglected)

Perturbative quark-mass terms:

$$\sum_{i,j=u,d,s} C_{U,ij}(s_0) \frac{m_i(s_0)\cdot m_j(s_0)}{s_0}$$

$$R_{\tau,U}(s_0) \propto |V_{\text{CKM}}|^2 S_{\text{EW}} \left(1 + \delta^{(0)} + \delta'_{\text{EW}} + \delta_U^{(2,m_q)} + \sum_{D=4,6,\ldots} \delta_U^{(D)}\right)$$

Perturbative contribution

$$-2\pi i \oint_{|s|=s_0} \frac{ds}{s_0}\left(1 - 2\frac{s}{s_0} + 2\left(\frac{s}{s_0}\right)^3 - \left(\frac{s}{s_0}\right)^4\right)\cdot D(s)$$

where: $D(s) = \frac{1}{4\pi^2}\sum_{n=0}^{\infty} \tilde{K}_n(\xi) a_s^n(-\xi s)$

Adler function to avoid unphysical subtractions:

$$D(s) \equiv -s\frac{d\Pi(s)}{ds}$$

Nonperturbative contribution

$$\delta_U^{(D)} = (-1)^D \sum_{\dim O = D} C_U(\mu) \frac{\langle O(\mu)\rangle_U}{s_0^{D/2}}$$

→ Theoretical prediction available at N^3LO: need for even higher precision at the time of FCCee to reduce dominant uncertainty from perturbative series (CIPT/FOPT), to benefit from the statistical precision ($\delta\alpha_S / \alpha_S << 1\%$)

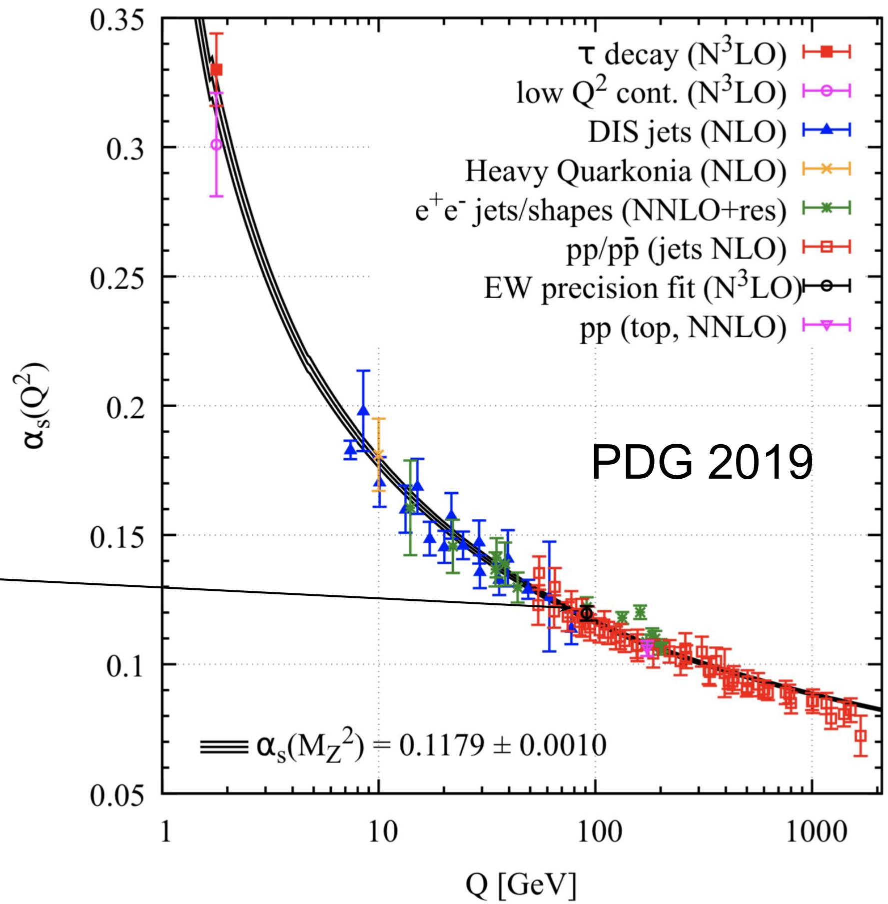
→ More precise SFs will allow to better pin down non-perturbative corrections and probe the structure of the QCD vacuum (condensates)

See also: arXiv:2012.07099 (A. Pich: "Challenges for tau physics at the TeraZ")

α_S evaluation from *hadronic Z decays*

→ Theoretical prediction available at N^3LO

→ Better convergence of the perturbative series and less non-perturbative corrections compared to precise determinations at lower scales (e.g. from τ decays)

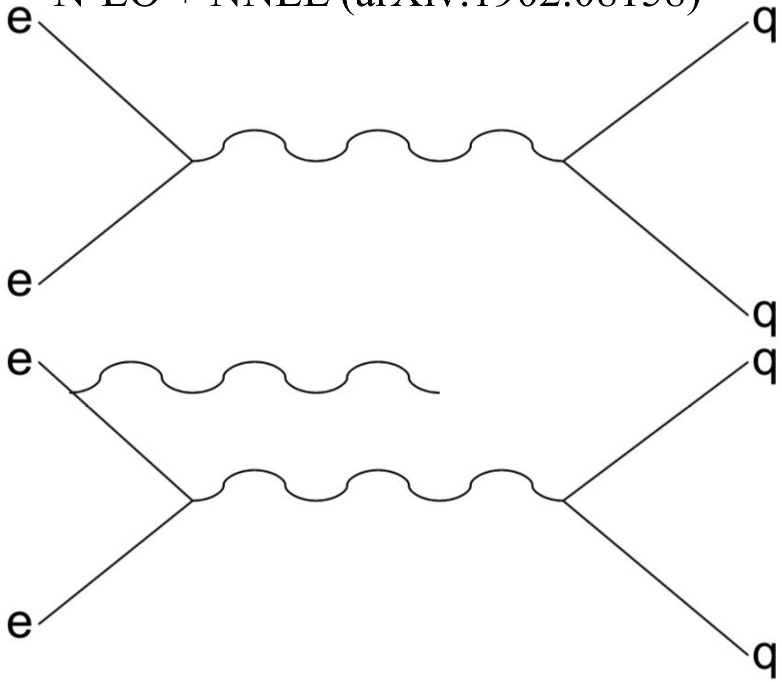


→ Used for "reference value": determinations at other energies evolved at the m_Z scale and then compared to *test the RGE from QCD*

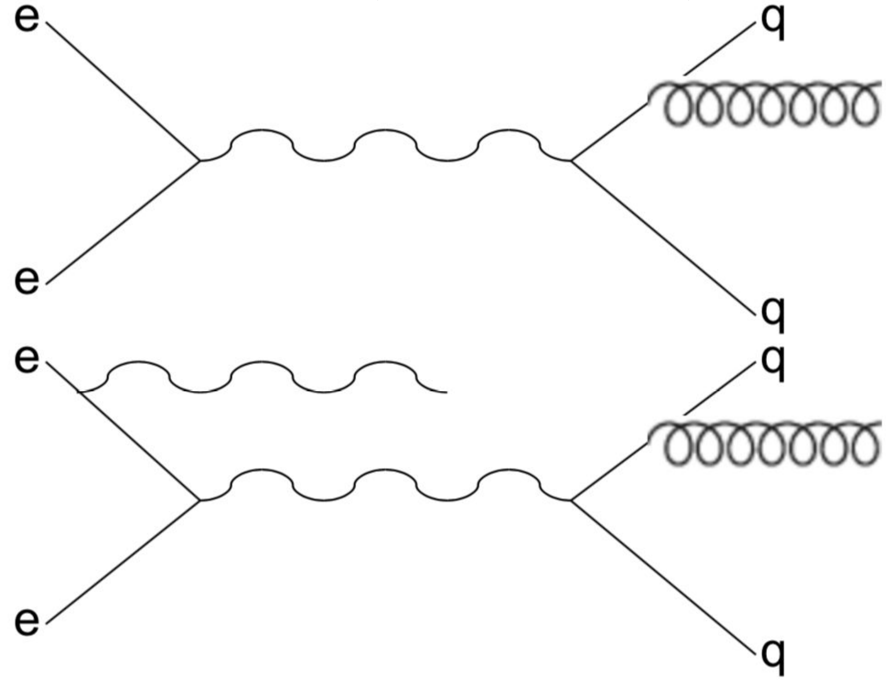
→ Need to study acceptance and reconstruction efficiency etc. in view of *optimizing the detector design*

α_S evaluation from *(ISR) jet production*

N^3LO + NNLL (arXiv:1902.08158)



N^2LO + NLLA (arXiv:1205.3714)



→ Sensitivity to α_S e.g. from 3/2 jet ratios (OR jet rates w.r.t. total hadronic Xsec)

→ High luminosity allows to select large samples of events with collinear / large angle ISR photons: allows to scan √s' with the same detector and collider conditions – important for RGE test

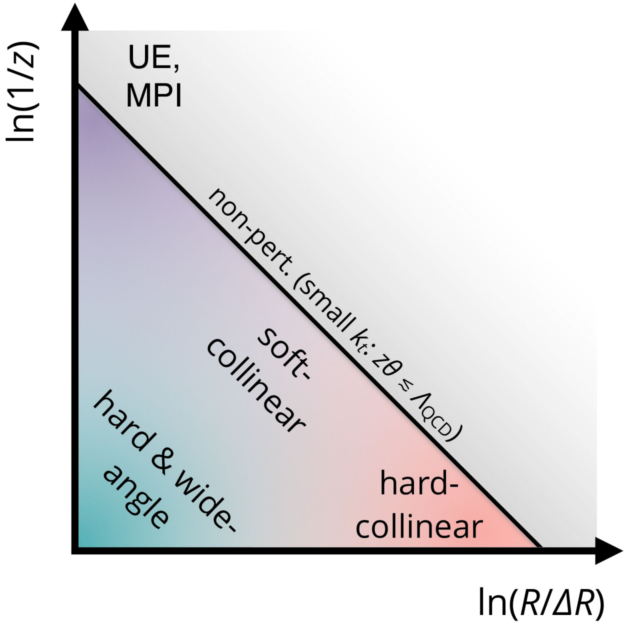
→ Need to study jet and photon energy calibration and resolution, acceptance and reconstruction efficiency etc. in view of *optimizing the detector design*

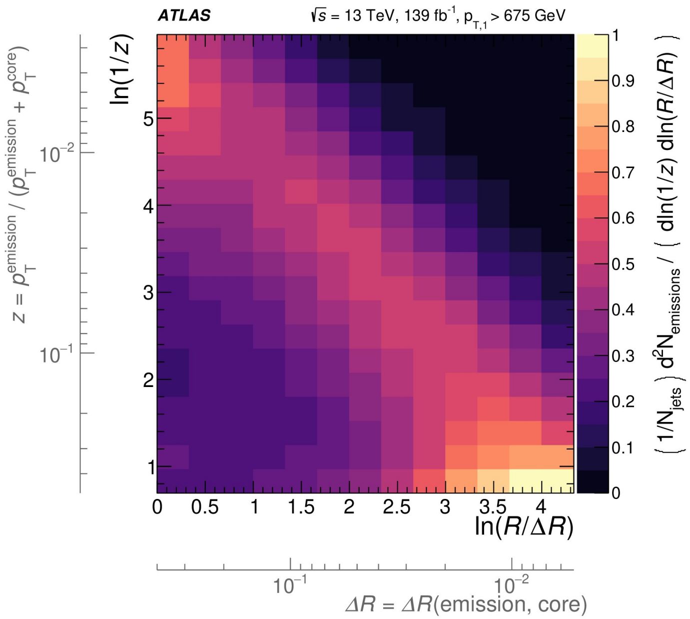
Should be able to target $\delta\alpha_S / \alpha_S$ < 1%

M2 internship (+ PhD) starting @ LPHNE (Supervisors: Luc Poggioli & BM)

Jet substructure opportunities

→ Numerous algorithms/methods developed for studying into detail the jet substructure in the LHC environment:
Important for understanding QCD effects inside jets, jet tagging (e.g. boosted top, H→bb), New Physics searches

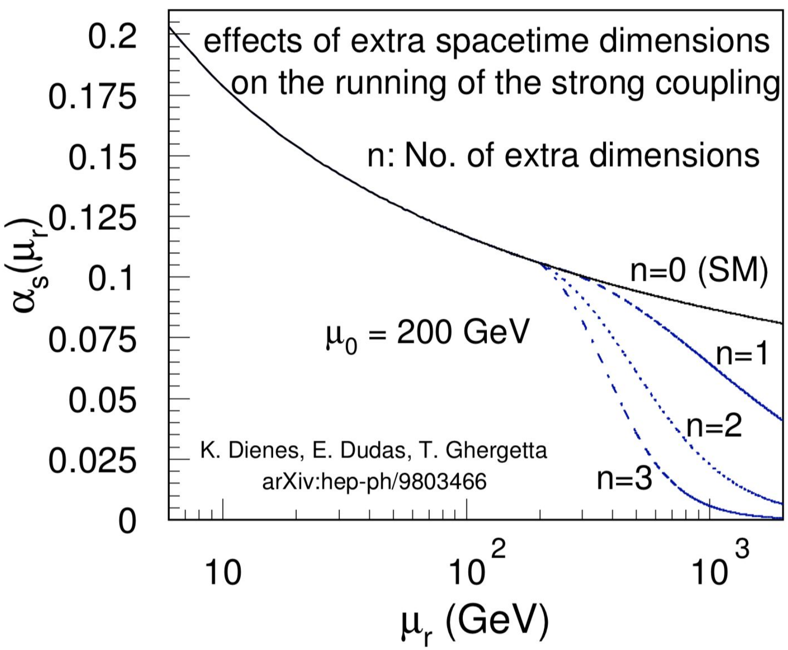


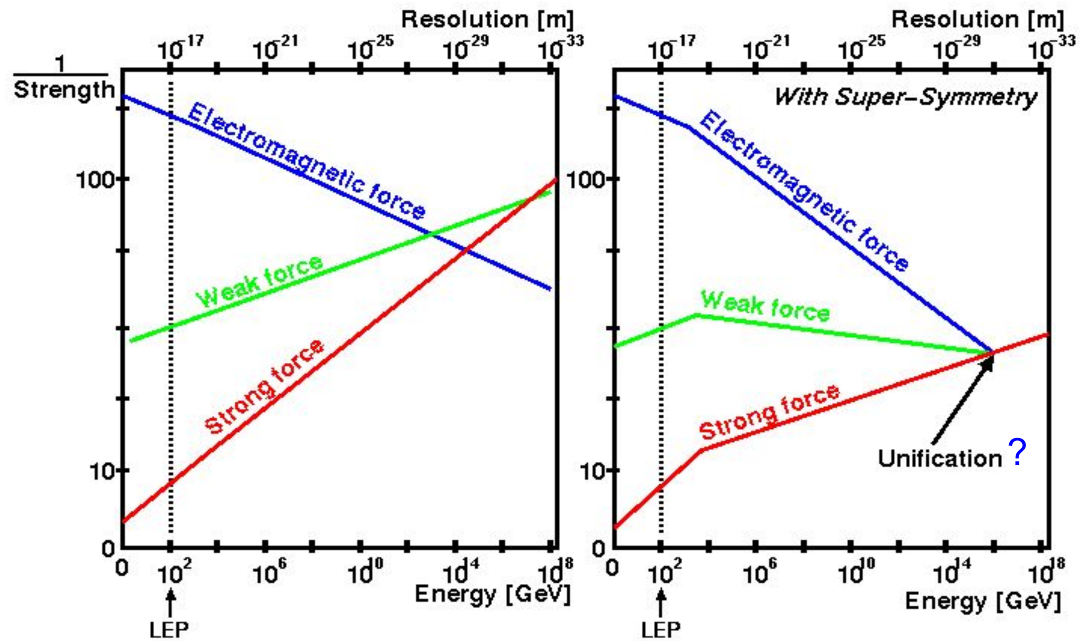


Recent example:
ATLAS Lund jet plane measurement
arXiv:2004.03540

→ Huge potential for doing precision studies of jet substructure in the clean FCCee environment
→ Need to *perform detector optimization* in terms of granularity, energy resolution, (tracking/calorimeter) acceptance

Ultimate goal: *test RGE & unification of couplings*





→ A deviation from the SM prediction for the RGE can be an indication of New Physics

→ Are the coupling constants unified at the Plank scale?

→ *Need to evaluate the strong coupling at multiple scales, with high precision*

→ *Lots of possibilities to collaborate*