# Possible QCD Studies @ FCCee
# ( *selected appetizers* )

Bogdan MALAESCU

LPNHE, CNRS

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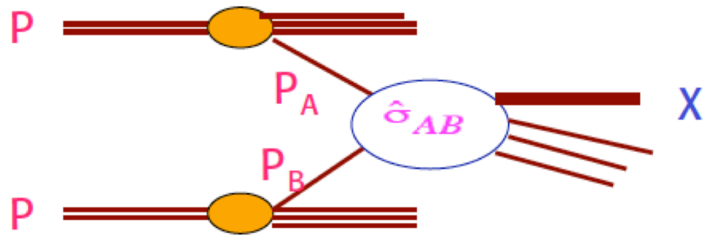
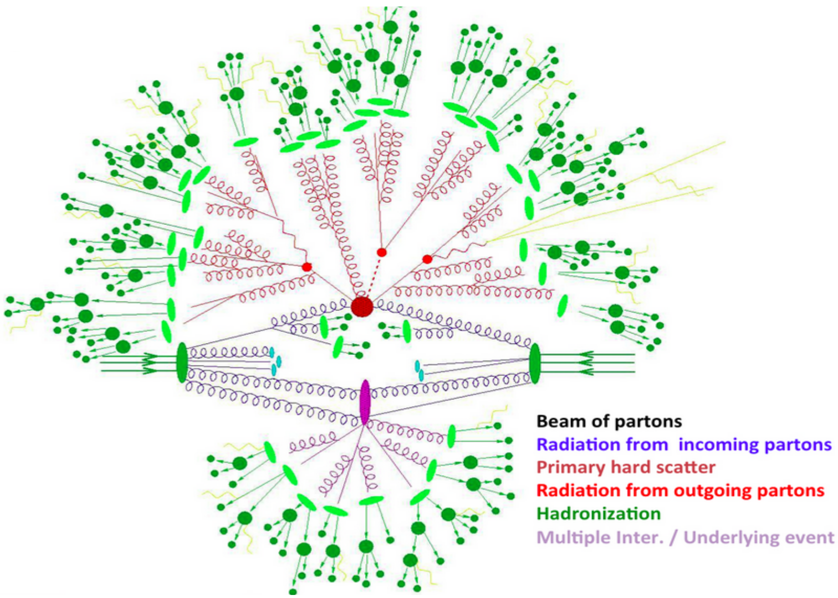
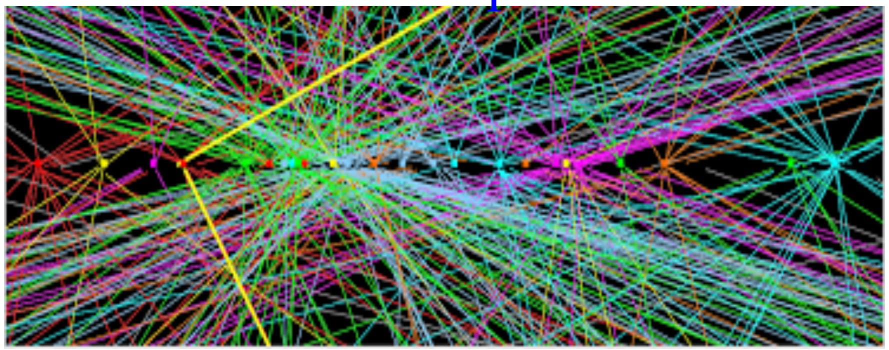
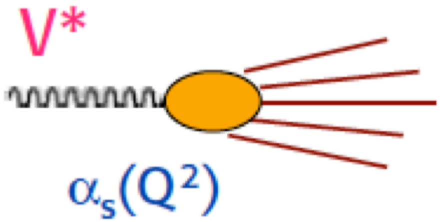
# Comparison of LHC / FCCee "environments"




Pile-up






@ FCCee:

→ Short distance interaction of virtual bosons with quarks

→ No PDFs

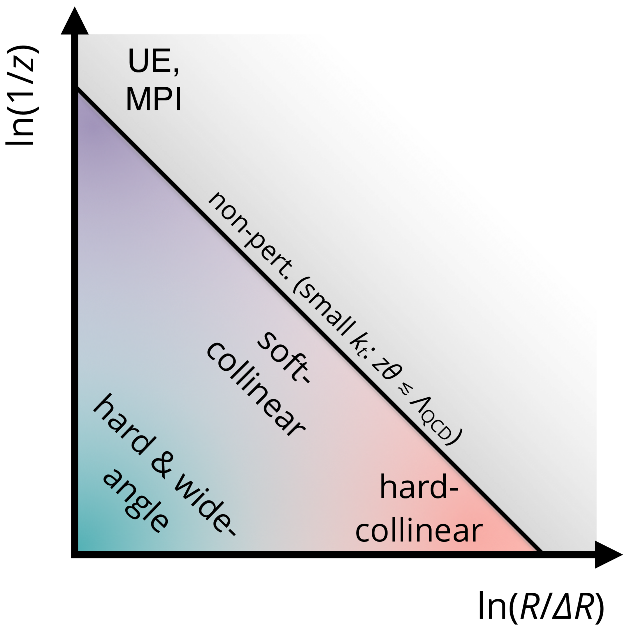
→ No underlying event & MPI

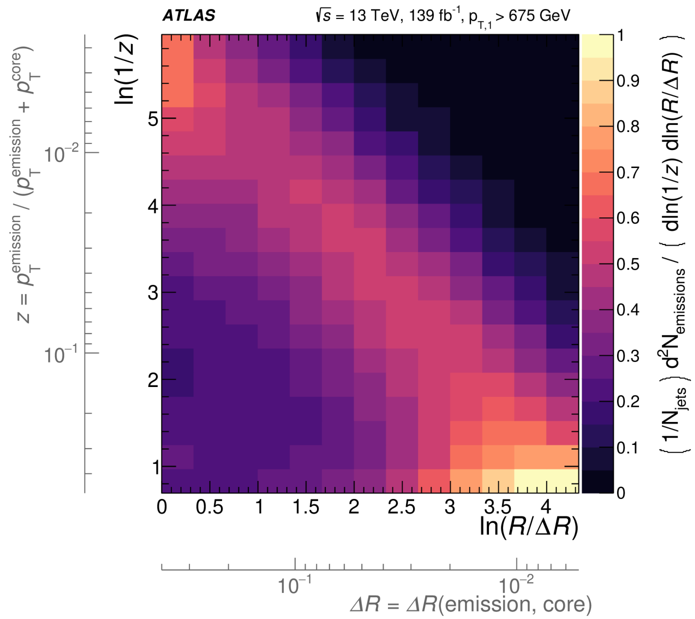
→ No pile-up

# 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

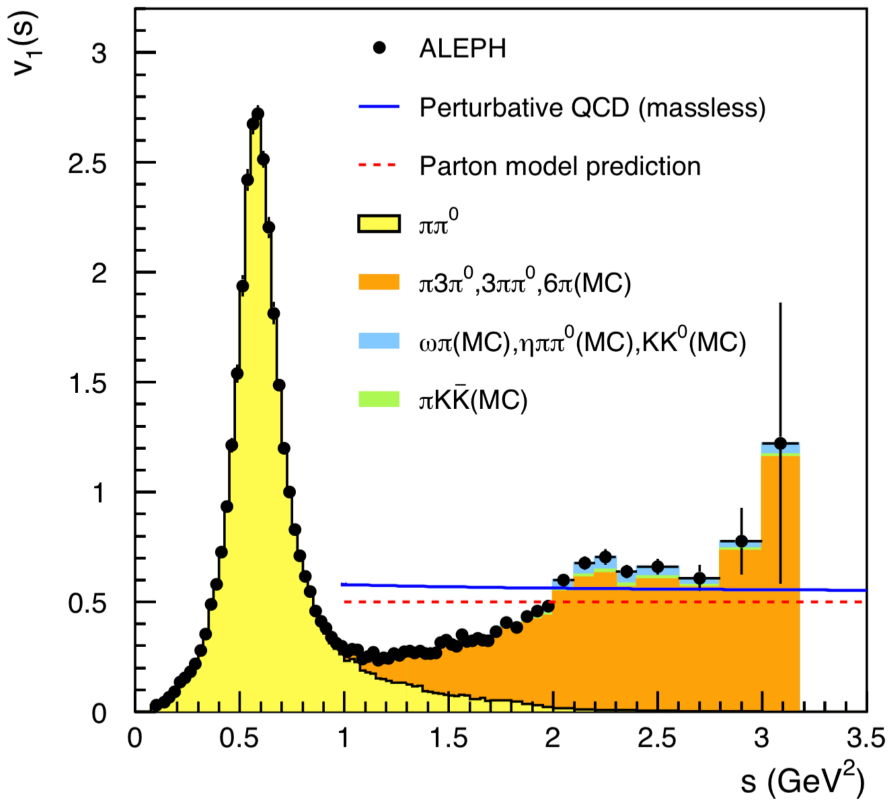
→Huge potential for doing precision studies of jet substructure in the clean FCCee environment

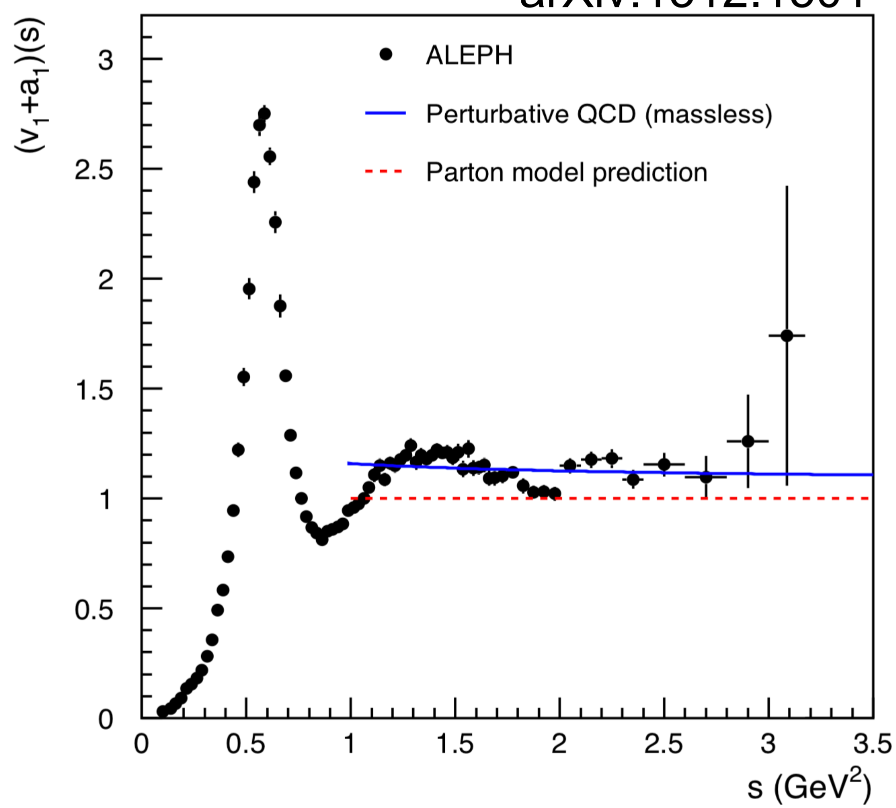
→ Need to perform detector optimization in terms of granularity, energy resolution, (tracking/calorimeter) acceptance

# $\alpha_S$ evaluation from *hadronic $\tau$ decays* (1/3)

→ $\tau$ hadronic spectral functions from ALEPH, unfolded of detector effects

arXiv:1312.1501



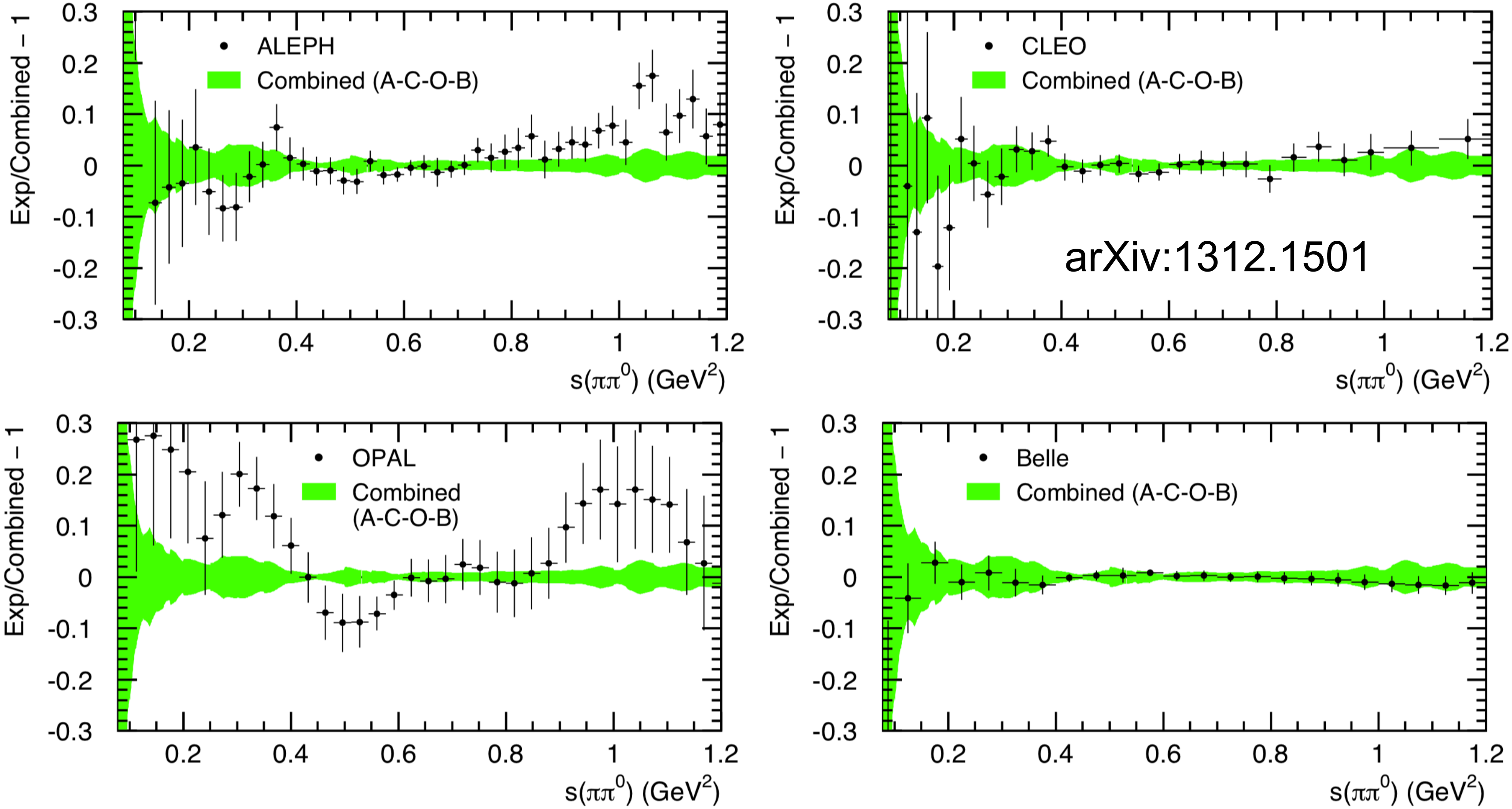




$$\upsilon_1 / a_1\left[\tau^- \to V^- / A^- \nu_\tau\right] \propto \frac{\mathrm{BR}\left[\tau^- \to V^- / A^- \nu_\tau\right]}{\mathrm{BR}\left[\tau^- \to e^- \bar{\nu}_e \nu_\tau\right]} \frac{1}{N_{V/A}} \frac{dN_{V/A}}{ds} \frac{m_\tau^2}{\left(1 - s/m_\tau^2\right)^2 \left(1 + s/m_\tau^2\right)}$$

branching fractions — mass spectrum — kinematic factor

# $\alpha_S$ 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 (due to the large boost)

→ Shape of the distribution best determined by Belle (high statistics)

→ What precision can one achieve at FCCee?

# $\alpha_S$ evaluation from *hadronic τ decays* (3/3)

$$R_\tau = \frac{\Gamma\left(\tau^- \to \text{hadrons}\ \nu_\tau\right)}{\Gamma\left(\tau^- \to e^- \nu_e \nu_\tau\right)}$$

EW correction:

$\simeq 0.0010$ (neglected)

Perturbative quark-mass terms:

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

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

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

Adler function to avoid unphysical subtractions:

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

Nonperturbative contribution

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

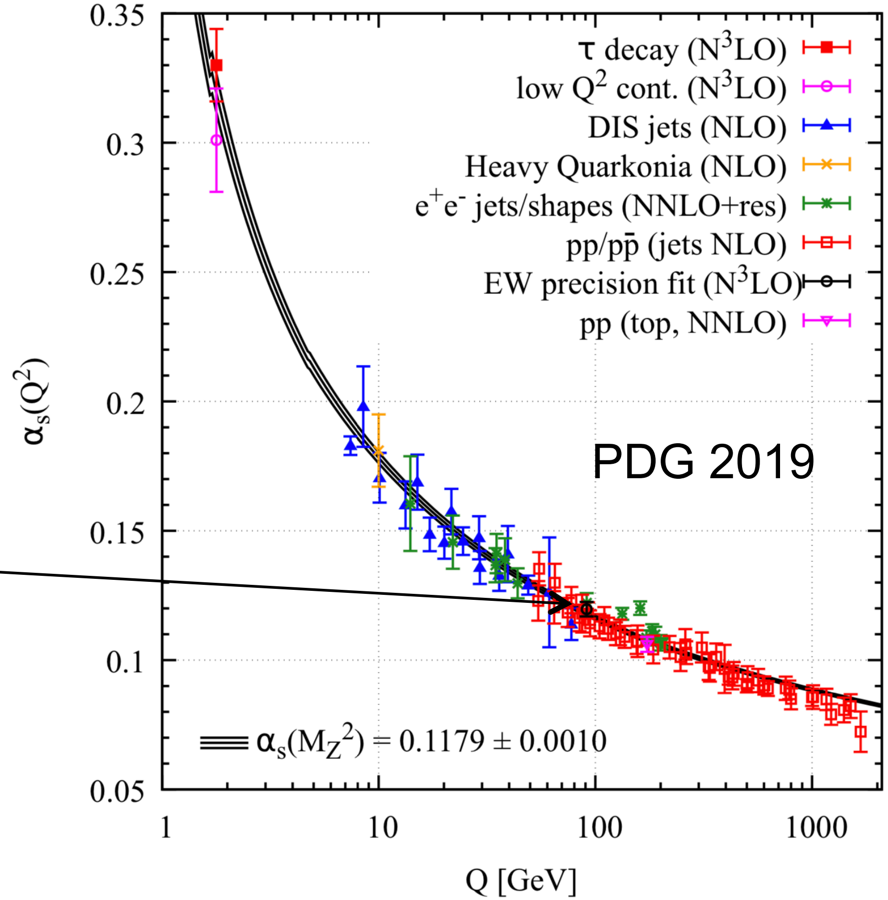
→ Theoretical prediction available at $N^3LO$: can hope for even higher precision at the time of FCCee

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

# $\alpha_S$ evaluation from *hadronic Z decays*

→ Theoretical prediction available at $N^3LO$

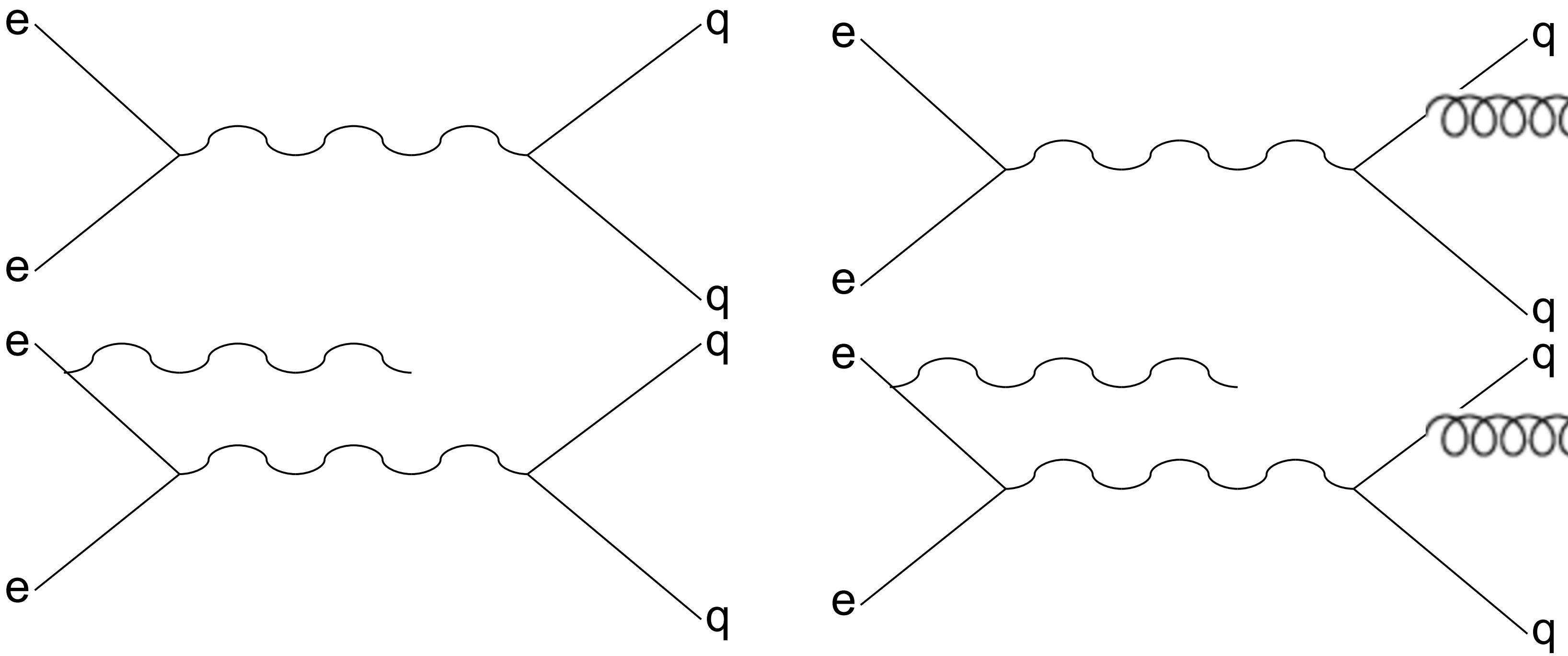
→ Better convergence of the perturbative series and less non-perturbative corrections compared to precise determinations at lower scales (e.g. from $\tau$ decays)




→ 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

# $\alpha_S$ evaluation from *(ISR) jet production*

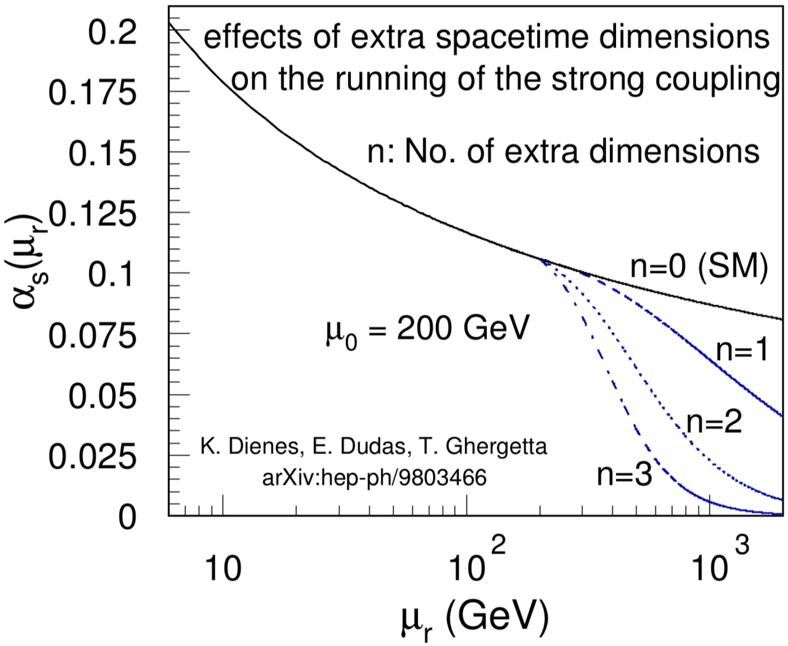


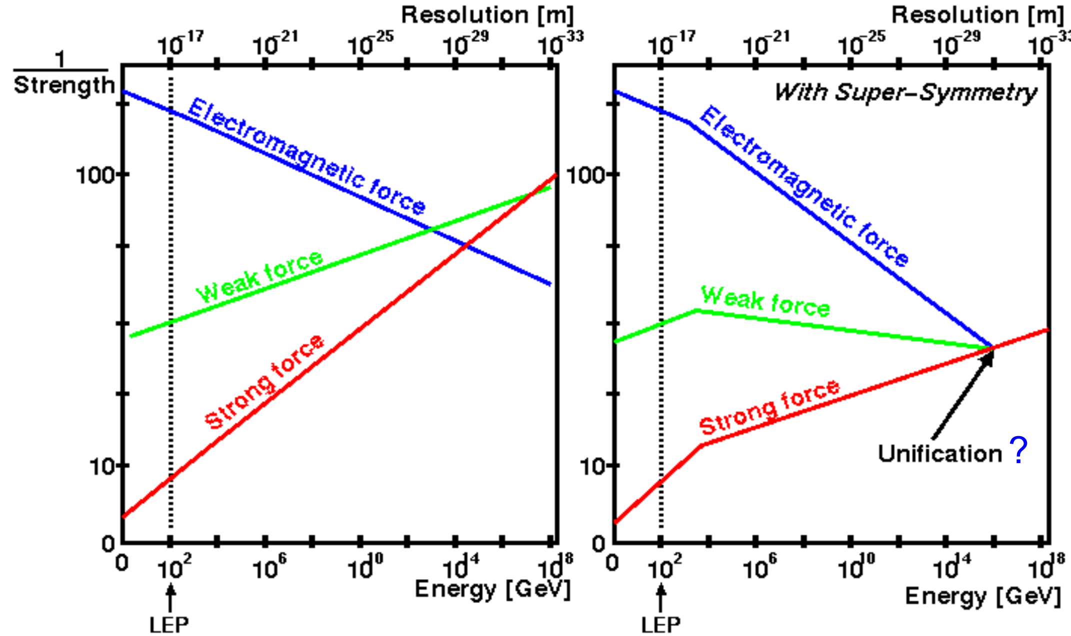

→ Sensitivity to $\alpha_S$ e.g. from 3/2 jet ratios

→ 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

# 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*