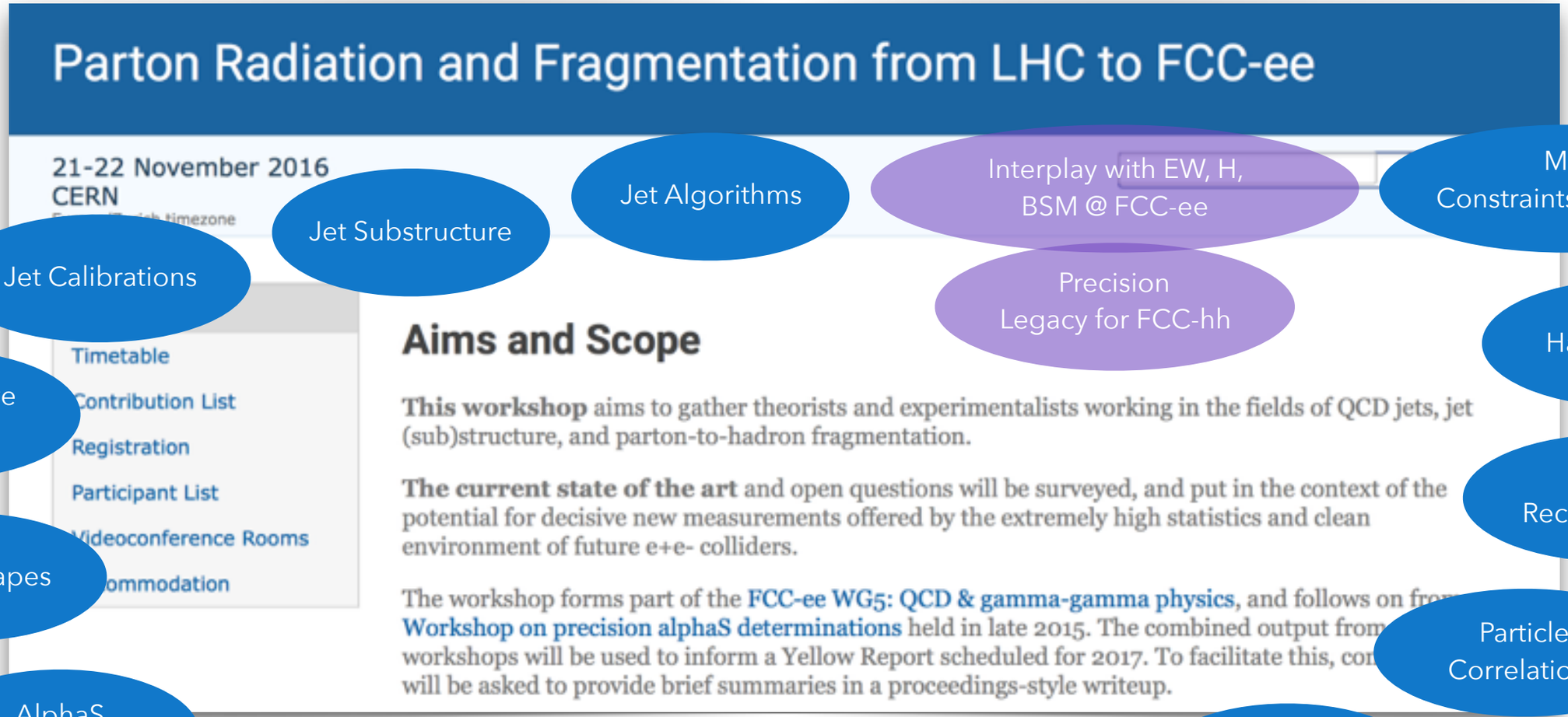
Workshop on Parton Radiation & Fragmentation: Summary of Detector Requirements



Jet Algorithms
Jet Substructure
Jet Calibrations
Interplay with EW, H, BSM @ FCC-ee
MC Constraints & Tuning
Precision Legacy for FCC-hh
Hadronisation
Perturbative QCD
Colour Reconnections
Event Shapes
Particle Correlations
AlphaS Extractions
Particle Spectra
QCD Resummation
Fragmentation Functions
Heavy Quarks

P. Skands (Monash U.) **& D. d'Enterria** (CERN)

2nd mini-workshop on FCC-ee detector requirements, Nov 23 2016

Disclaimer

For many, this was their "first take" on FCC-ee

Fresh set of people thinking about the possibilities, but few came with prepared studies → Few explicitly quantitative statements about detector requirements

Several themes emphasised repeatedly

Particle Identification (particle spectra, correlations)

Fragmentation Functions, Hadronisation Models (Jet composition ⟷ particle flow)

Genuine non-perturbative effects revealed at scales ~ Λ_{QCD} ~ few hundred MeV

Important to resolve soft tracks down to |p| ~ 70 MeV = $m_\pi/2$

Gigi says 3 hits down to 30-40 MeV

Good π/K down to |p| ~ 100 MeV? (LEP had x_K measurements down to $|p_K|$ ~ 250 MeV)

Leading-Particle (x→1) studies: hard protons, Kaons, pions? (→fake rates

Probably not realistic for protons. Use tracks, K0S, Lambda, …

+ MC constraints & tuning, Colour Reconnections, Baryon and Strangeness Correlations, Bose-Einstein (π,K) and Fermi-Dirac (p,Λ) correlations, …

Note: **Fermi-Dirac radius puzzle**. Fermi-Dirac correlations at LEP across multiple experiments & for both protons and Lambda → 0.1 fm << r_p W. Metzger

Calo resolutions (& thresholds)

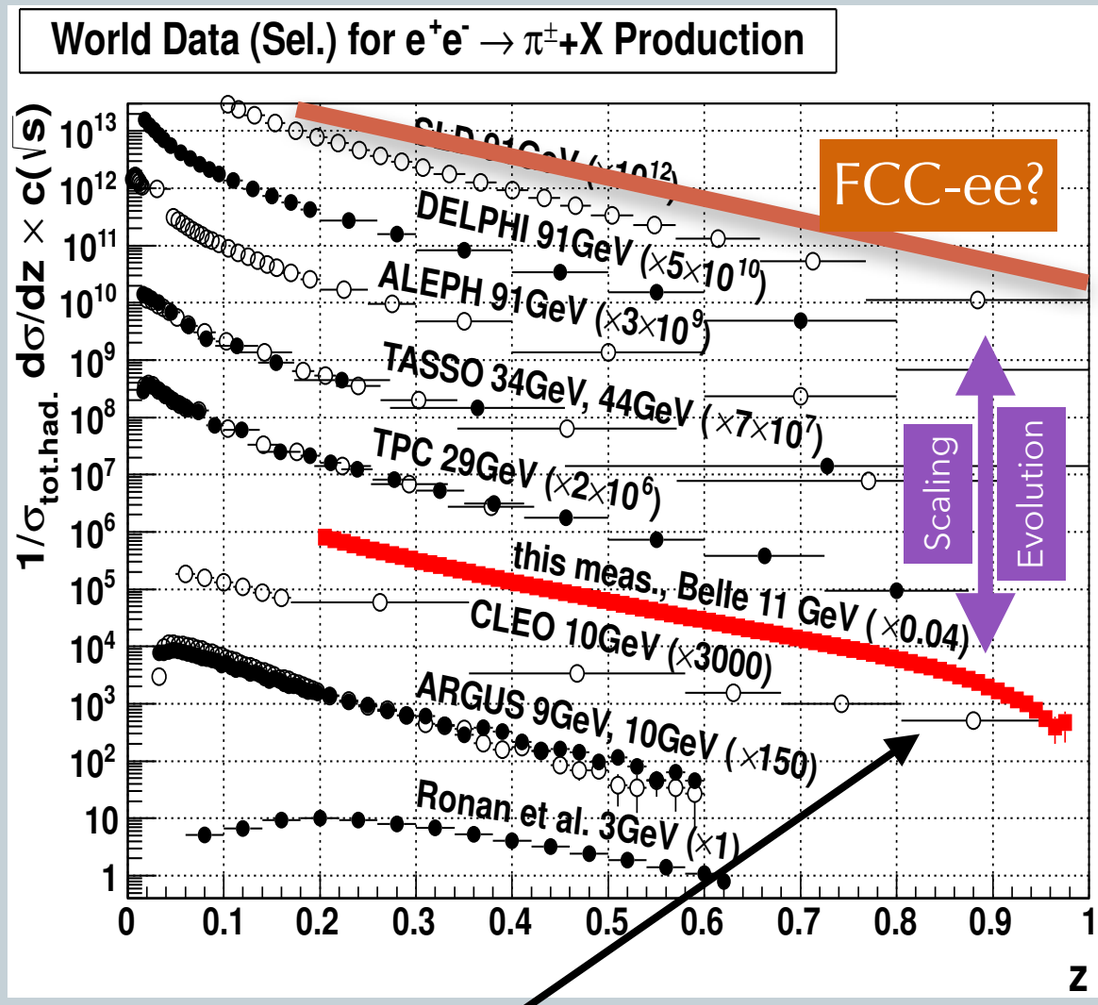
Neutrals: Jet charge (colour reconnection constraints), gluon (vs q) jet discrimination

Heavy-quark dead-cone effect: θ ~ m/E ~ 0.1 for b quarks, 0.03 for c quarks (at m_Z)

Fragmentation Functions

A. Vossen (FF overview)

- Precision of theory and experiment big advantage → Complementary to *pp* SIDIS
  - Evolution
  - Transverse momentum dependence in h+Jet Fragmentation
  - Gluon FFs
  - Smaller mass effects at low z
  - Flavor separation (polarization?)
- Flavor structure for FFs of Hyperons and other hadrons that are difficult to reconstruct in *pp* and SIDIS
- Heavy Quark FFs – Also from H decay?
- Larger multiplicities: Parity violating FF $\widetilde{H}_1$: Local strong parity violating effects (next…)



Repeatedly emphasised gluon FF poorly constrained: Z→bbg , ZH(→gg): **good b-tagging**

High-N_{ch} performance

Particle ID

Higher ee energy (than Belle) → reach in z determined by reach in **low-|p| track reco**

Belle has FCC-ee like statistics at 10 GeV
High-z binning determined by **high-|p| track reco**

Gigi says 1% all the way up to x=1

S. Moch (& others): field now moving towards NNLO accuracy: **per-cent level errors** (or better)

Parton Showers

P. Richardson (overview talk)

- In general good agreement for event shapes, jet rates etc.
- The description of meson spectra was generally good.
- However in all simulations baryon production has issues.
- At LEP II interest in colour reconnection between the W decay products and Bose-Einstein correlations.

Multi-jet events: kicked off matrix-element matching & merging

→ State of the art at LHC: multi-jet NLO merging

- For the first time in many years more work on the accuracy of the parton-shower algorithms.
- Needed as we go to higher accuracy for the matrix elements.
- $1/N_c$ (Plätzer, Sjödahl JHEP 1207 (2012) 042), (Nagy, Soper, JHEP 1507 (2015) 119)
- Subleading logs (Li, Skands, arXiv:1611.00013)
- This is the area where there is probably the greatest potential for improvement.
- If we can consistently improve the logarithmic accuracy.

(Precision) Jet Substructure → Resolution!

Quarks and Gluons

G. Soyez, K. Hamacher, G. Rauco, S. Tokar, Y. Sakaki

Handles to split degeneracies

H→gg vs Z→qq

Rely on good **H→gg vs H→bb** separation;
mandated by Higgs studies requirements anyway?

Z→bbg vs Z→qq(g)

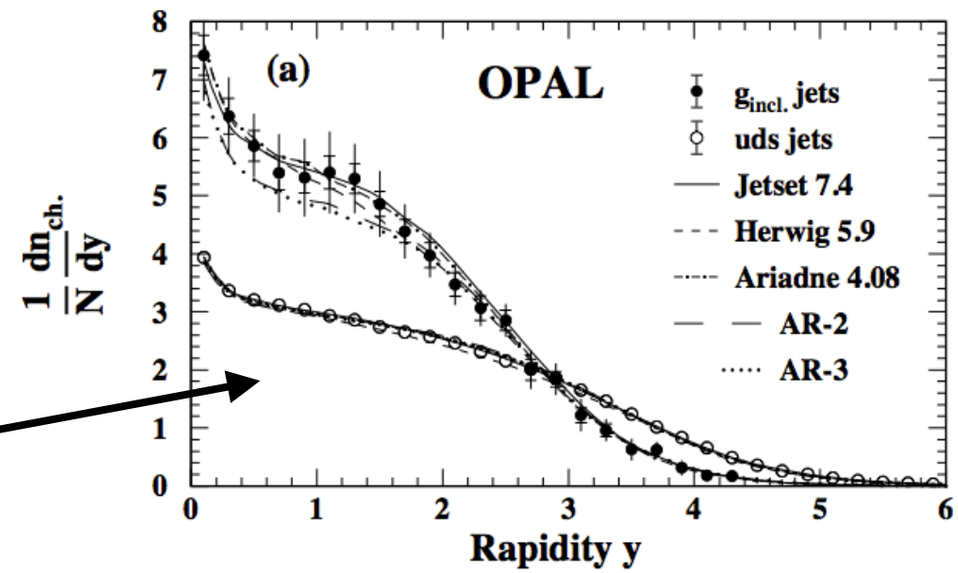
g in one hemisphere recoils against two b-jets in other hemisphere: **b tagging**

Vary jet radius: **small-R → calo resolution**

(R ~ 0.1 also useful for jet substructure)

Vary E_{CM} range : below m_Z : radiative events → **forward** boosted

(also useful for FFs & general scaling studies);
Scaling is **slow**, logarithmic → large lever arm



Octet neutralisation? (zero-charge gluon jet with rapidity gaps) → neutrals
Colour reconnections, glueballs, …

Leading baryons in g jets?
(discriminates between string/cluster models)
high-E baryons

Hamacher

- mitigate systematics/resolution by unfolding, control using E-dependence

- measurements mass-plots of resonances incl. (!) neutrals
- check baryons + resonances ($\Delta^{0,++}$, Λ, $\Lambda(1520)$, …)

Experimentally: need some particle id., high resolution e.m. calorimetry

Colour Reconnections & Correlations

T. Sjostrand, W. Metzger, S. Kluth, C. Bierlich

At LEP 2: hot topic (by QCD standards): 'string drag' effect on W mass

Sjostrand

Can turn around at FCC-ee; use semi-leptonic events to measure m_W → use m_W as constraint in fully hadronic WW to measure CR

Non-zero effect convincingly demonstrated at LEP, but without much detailed (differential) information

No-CR excluded at 99.5% CL.

Has become even hotter topic at LHC

Much more colour flowing around; expect larger effects

<pT> increases with N_{ch} (known since long)

ALICE @ ICHEP 2016: strangeness increases with N_{ch}

It appears jet universality is under heavy attack. Fundamental to our understanding (and modelling) of hadronisation

Many follow-up studies now underway at LHC.

High-stats EE needed to tell the other side of story

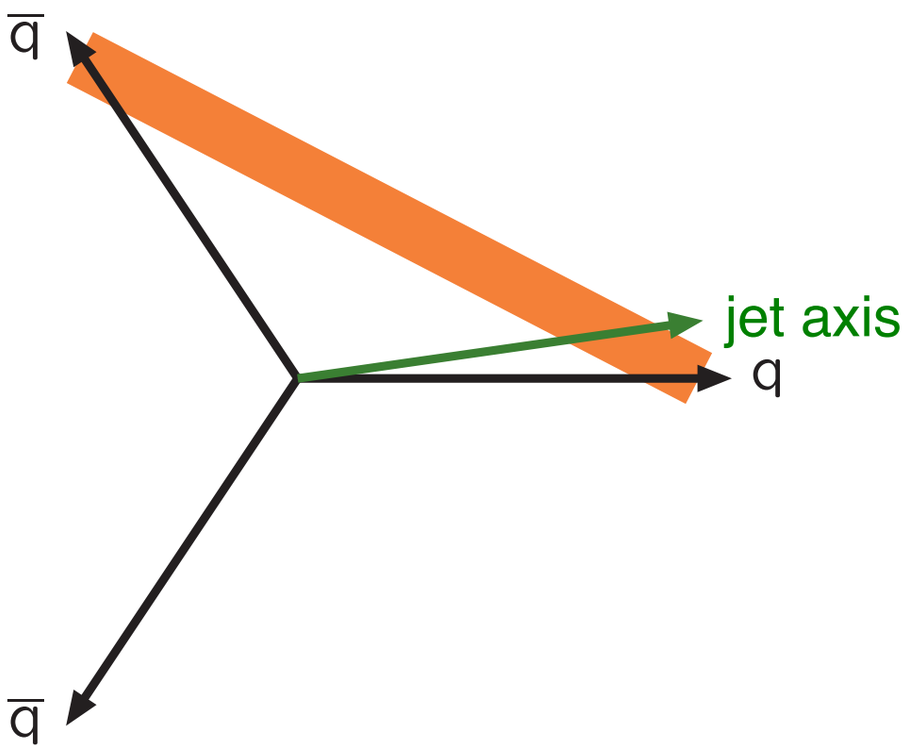
Low-momentum (identified) particles in high-multiplicity Z and WW events

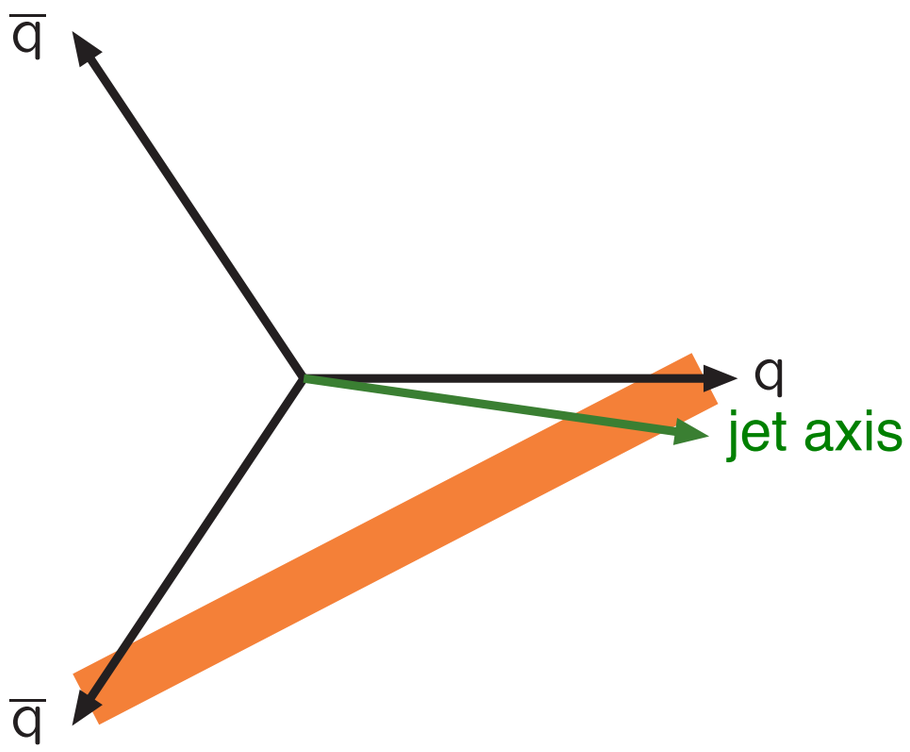
(Another reason to measure CR)

T. Sjostrand

Is the 125 GeV Higgs a pure *CP*-even state? Any odd admixture?

For LHC and future $\mathrm{e^+e^-}$ (& $\mu^+\mu^-$?) colliders to probe.
One possibility is $\mathrm{H^0} \to \mathrm{W^+W^-} \to \mathrm{q_1\overline{q}_2q_3\overline{q}_4}$.
Angular correlations put limits on odd admixture.





But: colour reconnection ⇒ shifted jet directions
⇒ shifted angular correlations.

Details of Hadronisation

E.g.: how "local" is it? Fundamental property of hadronisation models

Baryon number, Strangeness, Spin, correlations between successive-rank hadrons (is it "screwy"? S. Todorova)

Matevosyan: quark spin in hadronisation

Particle ID is crucial

- Particle production in MCs important for precision modelling
  - Should pay attention to LEP MC modeling tests
- Both OPAL measurements stat. limited
  - ~$4 \cdot 10^6$ hadronic Z decays
  - Would reach OPAL systematics at 10^8 Z decays
- LC detectors:
  - Particle ID, mom. resolution, displaced vertices :)
  - Low momentum particles? Run with scaled B-field on Z peak and WW threshold?

Kluth on baryon correlations