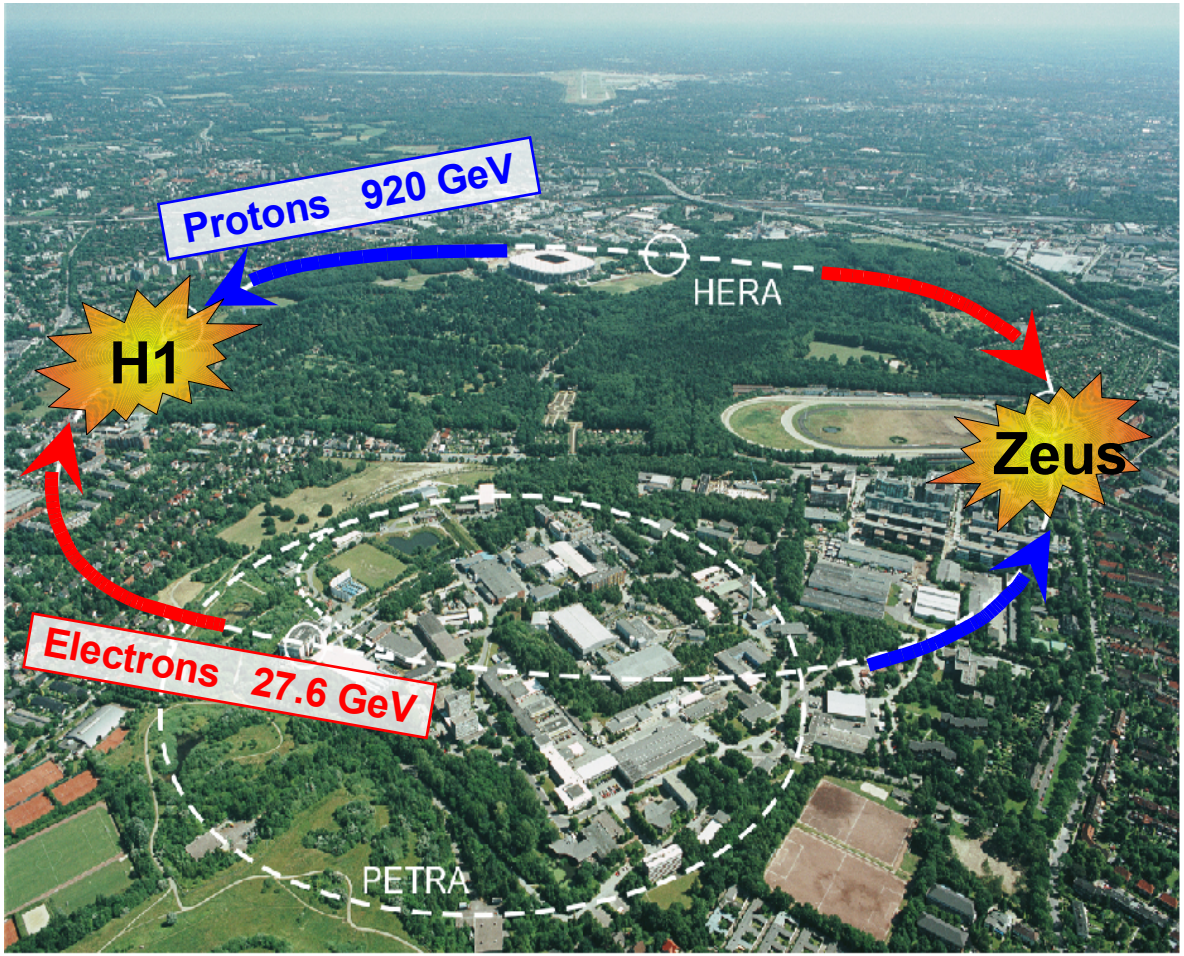
The Fast Track Trigger & Measurement of the D* cross section – summary from Ph.D.

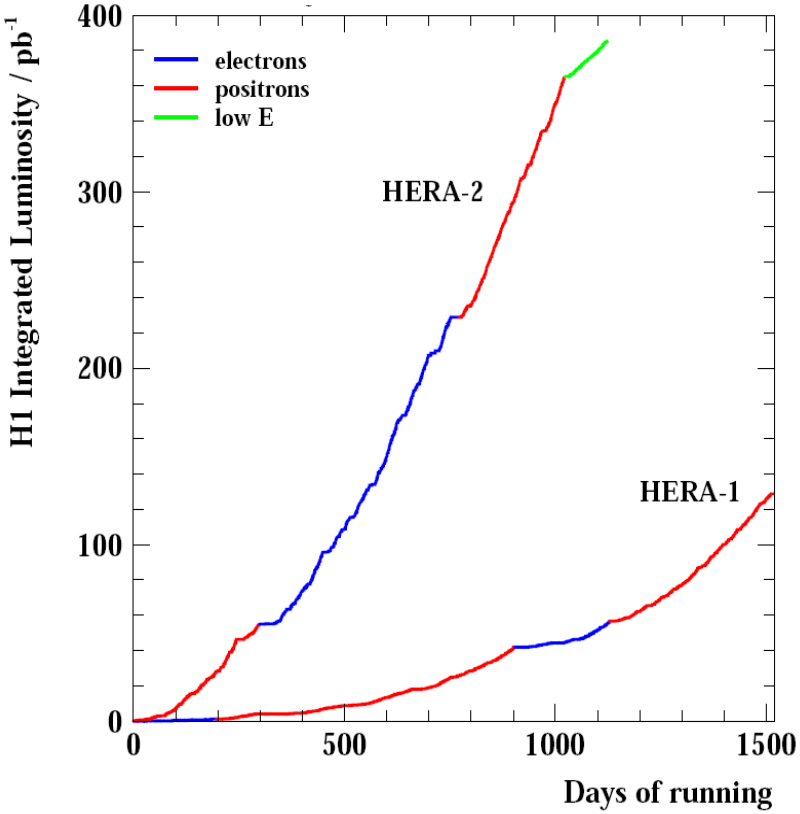
- Introduction
- H1 & The Fast Track Trigger:
  - Introduction
  - The third trigger level
- D* production:
  - Theoretical aspects
  - Results: D* Cross section & $F_2^c(x,Q^2)$
  - Current field of work
- Conclusions

The HERA Collider (1992-2007)

Unique ep collisions at $\sqrt{s} \approx 320\ \mathrm{GeV}$:

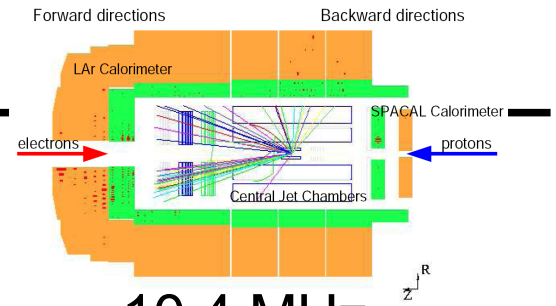


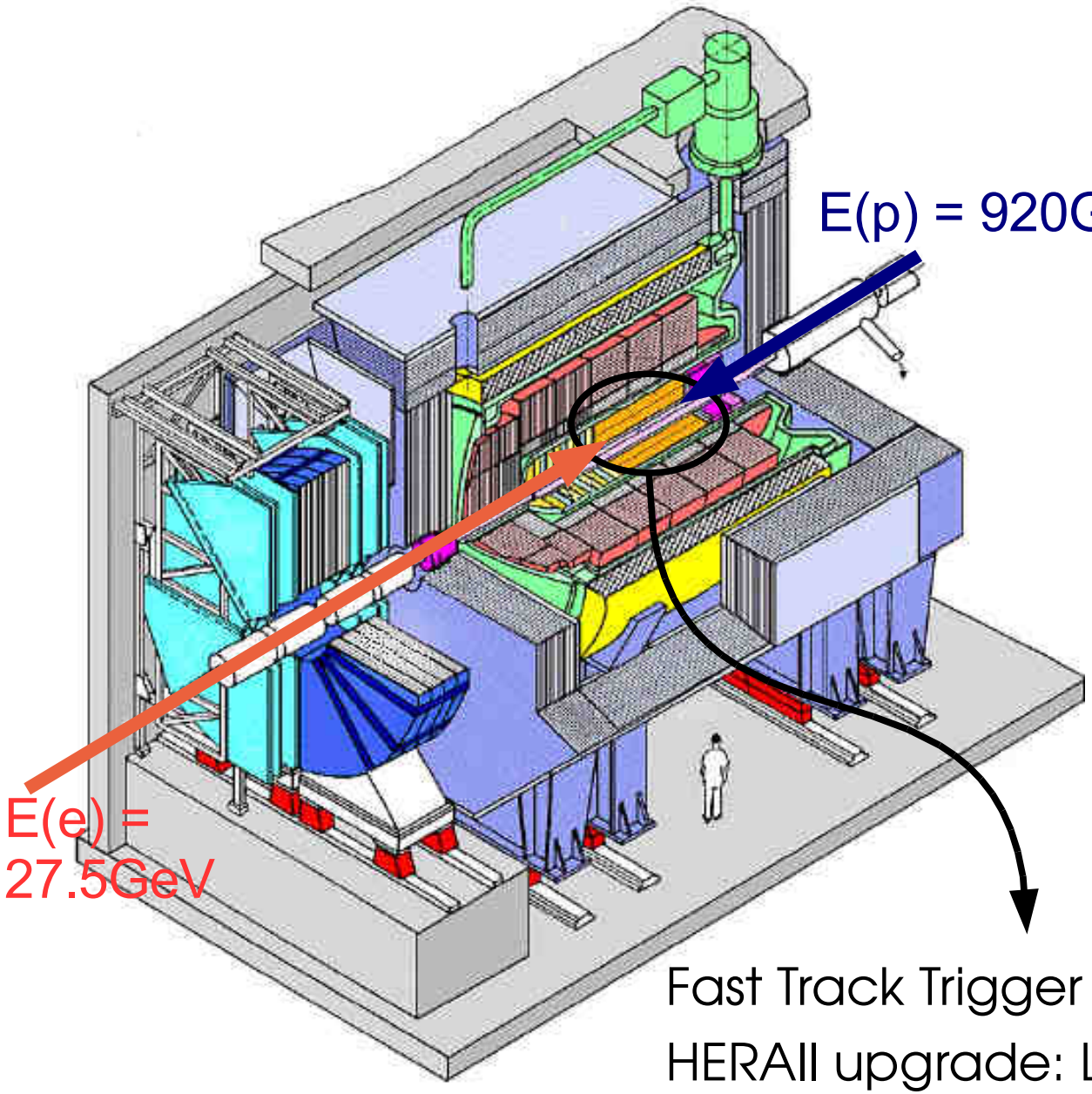
Collected Data samples:



- The ideal machine for DIS physics: The QCD laboratory HERA
- Two multi-purpose detectors: H1 & Zeus
- Collected Luminosity HERAI + HERAII: ~ 0.5 fb^{-1} per experiment

H1 Detector & Trigger





10.4 MHz

L1 2.3 μs (Pipeline)
Calo,Muon,**FTT**,...

<1kHz

L2 22 μs (Readout?)
FTT,NN,...

< 200Hz

L3 100 μs (Abort RO?)
FTT

Dead time

max. 50Hz

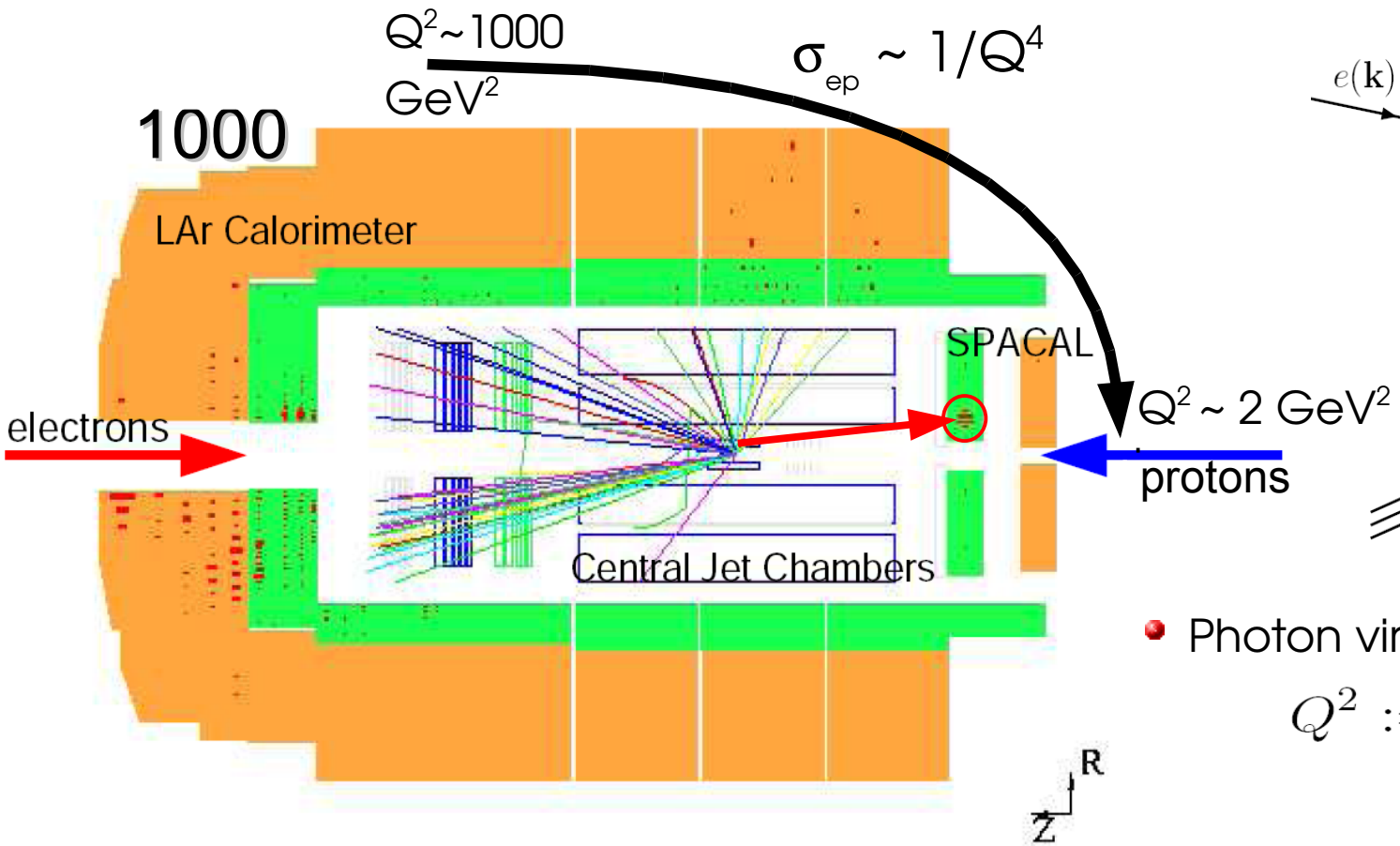
L4 asynchr. On-line reconstruction

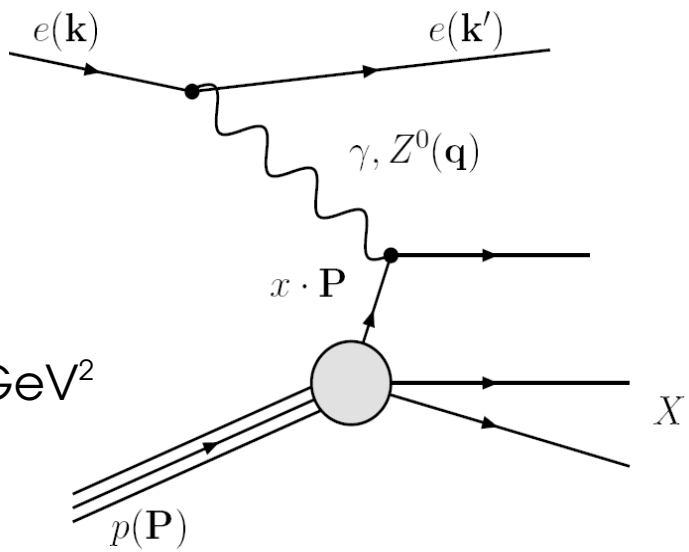
~15Hz

Fast Track Trigger (FTT):

HERAII upgrade: Lumi x5

H1 Detector & Trigger





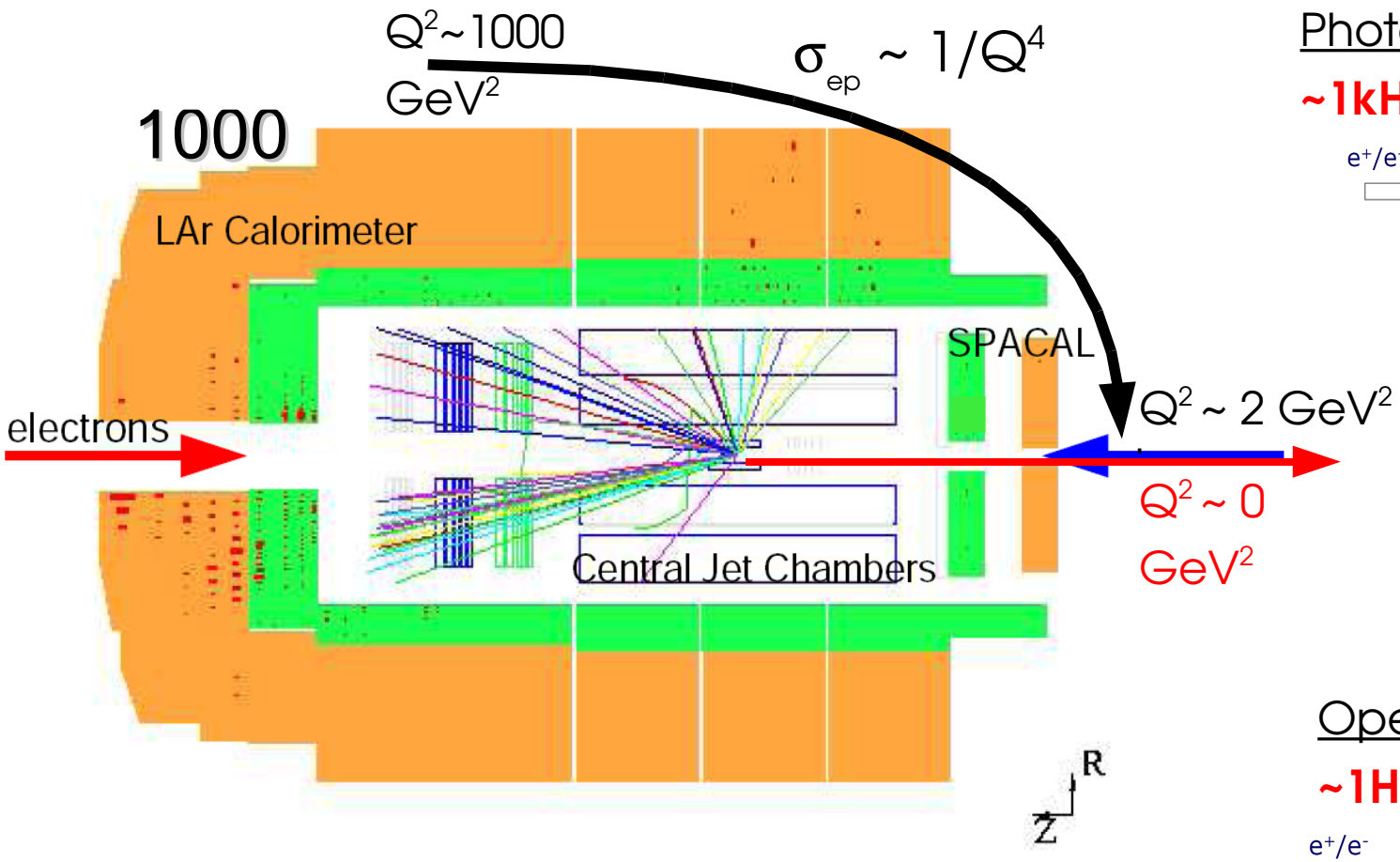
- Photon virtuality / Resolving power:

$$Q^2 := -q^2 = -(\mathbf{k} - \mathbf{k}')^2$$

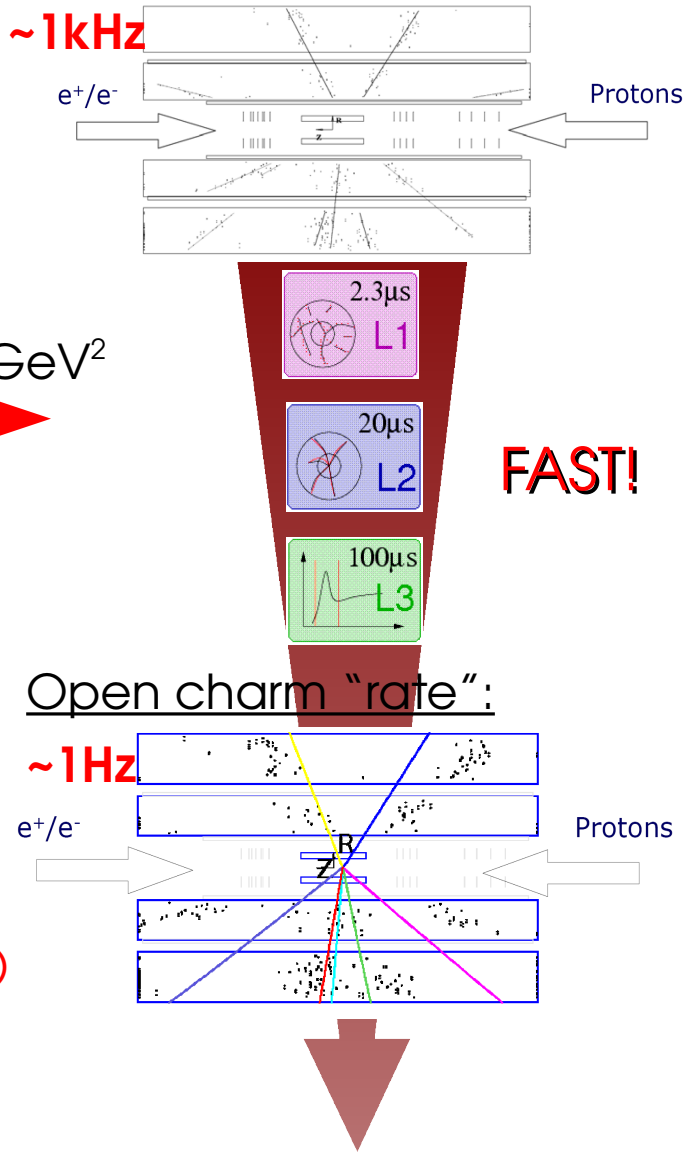
<u>Trigger: DIS case</u>

- scattered electron
  in Calorimeters
- tracks

H1 Detector & Trigger



Photoproduction "rate":



Trigger: DIS case

- scattered electron in Calorimeters
- tracks

Trigger: Photoproduction case:

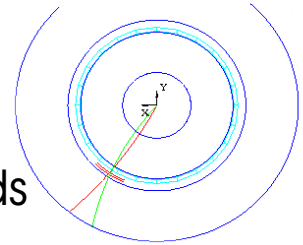
- no scattered electron (untagged)
- Track based final states:

H1 Fast Track Trigger!

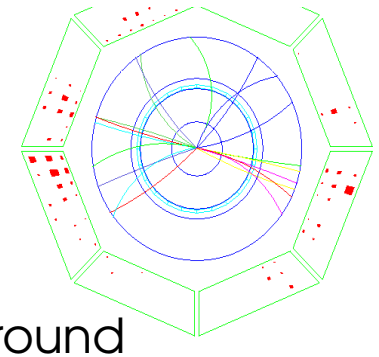
Concept of the FTT:

Requirements:

$\phi \rightarrow K^+K^-$



$D^* \rightarrow D^0\pi_{slow} \rightarrow K\pi\pi_{slow}$



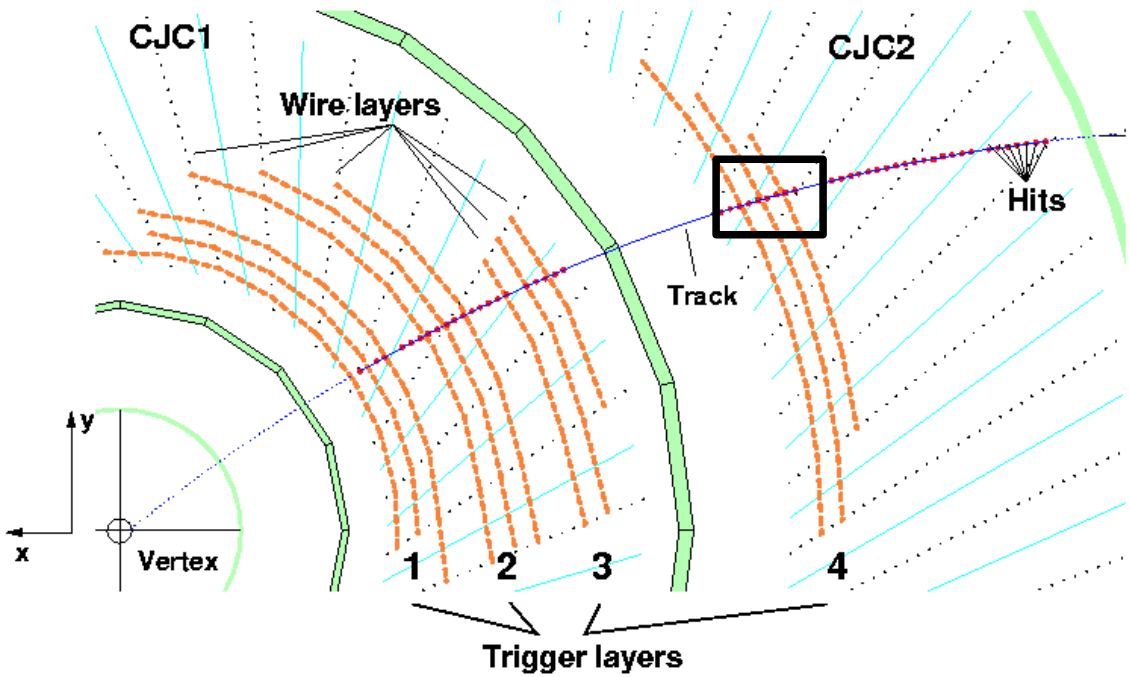
- lowest p_T-thresholds
- precise track reconstruction
- high selectivity in huge ep background

12 Wire layers grouped in four trigger layers

Hit digitization and coarse 2D tracks with

FTT – L1 in 2.3μs

The Fast Track Trigger:



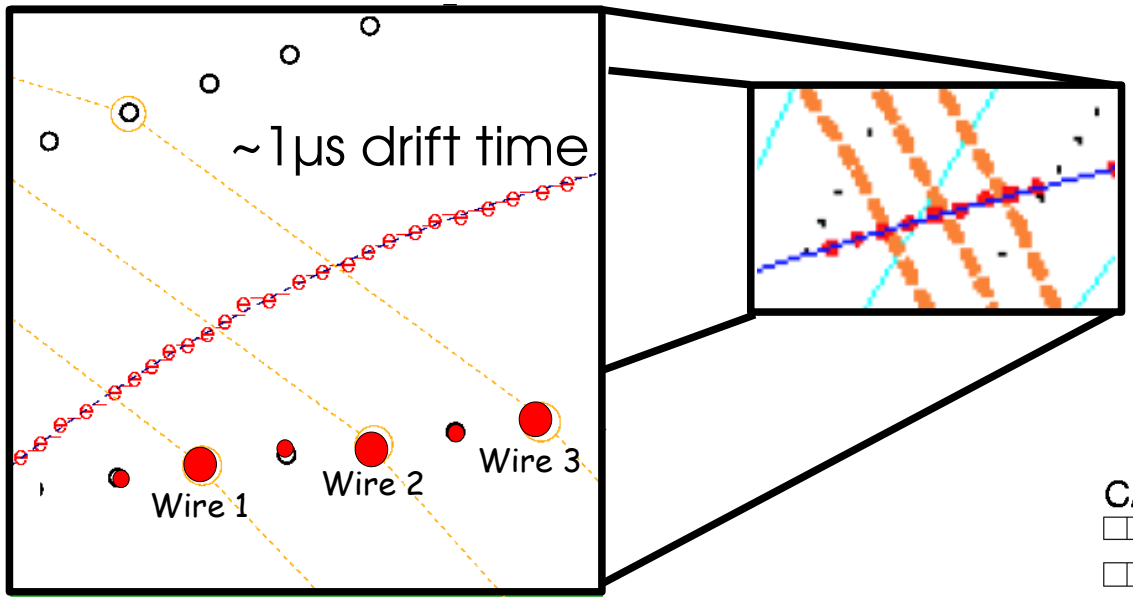
- Track fit for up to 48 high precise 3D tracks with

FTT – L2 in 22μs

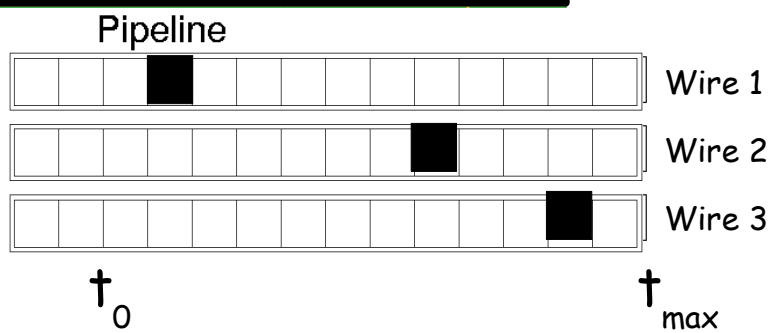
- Exclusive final states & Particle identification with

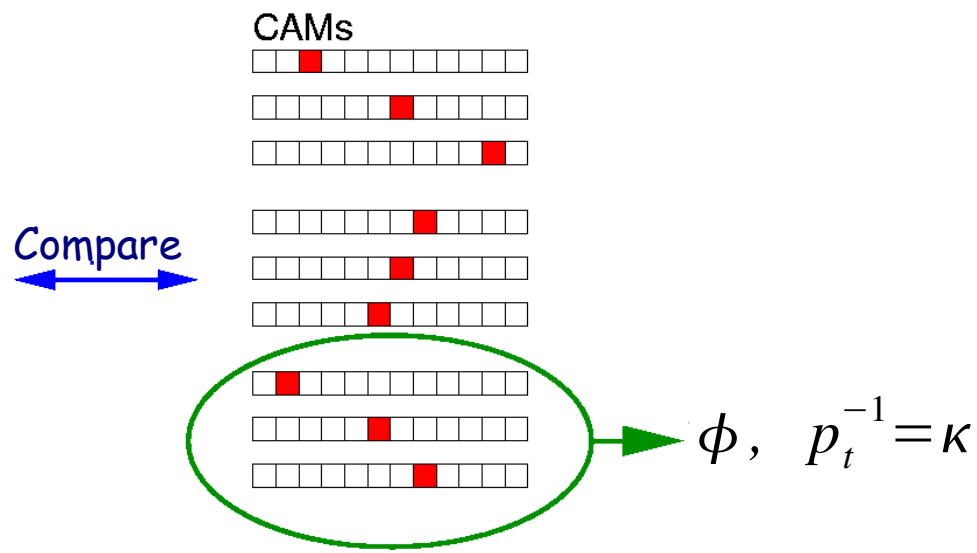
FTT – L3 in 100μs

FTT-L1: Track segments



Compare track segments with precalculated masks:





Reduced data volume – effective sampling rate reduced:

20 MHz (Comparison with ~ 3000 Masks for Level 1)

80 MHz (Comparison with ~ 100000 Masks for Level 2)

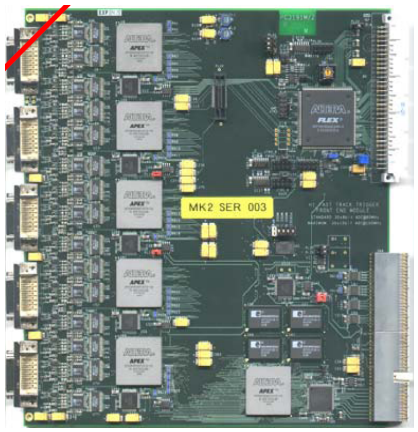
FTT-L1: Track linking

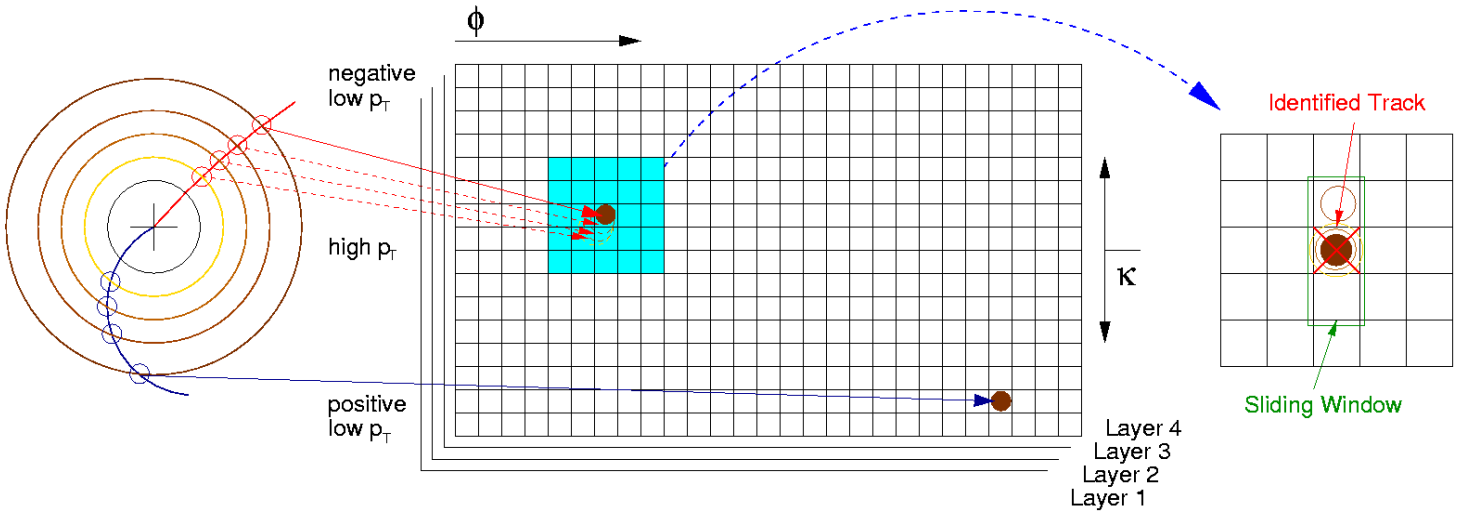
2.3µs L1

Level 1: - coarse histogram with 16x 60 (κφ)–bins (40 x 640 bins at L2)

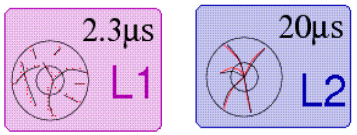
Track linking in 4 trigger groups: at least 2 out of 4 segments

FTT-L1 FEM board:





FTT: Track linking & fitting



Level 1: - coarse histogram with 16x 60 ($\kappa\varphi$)–bins (40 x 640 bins at L2)

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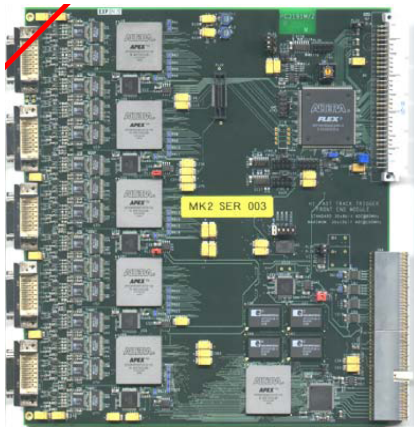
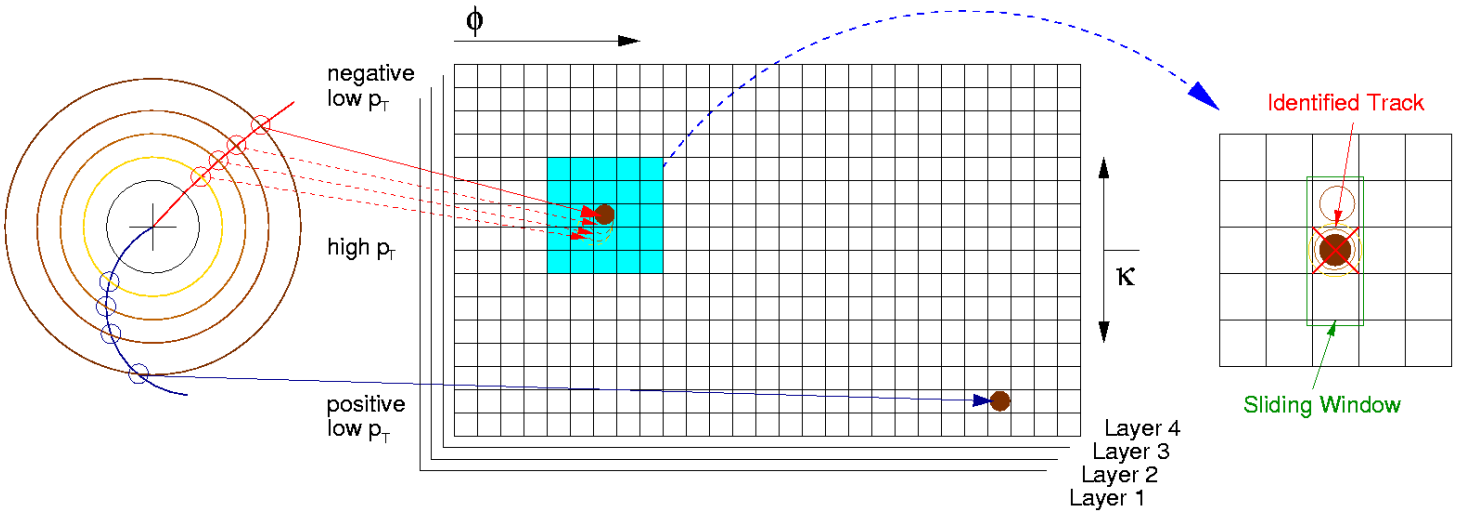
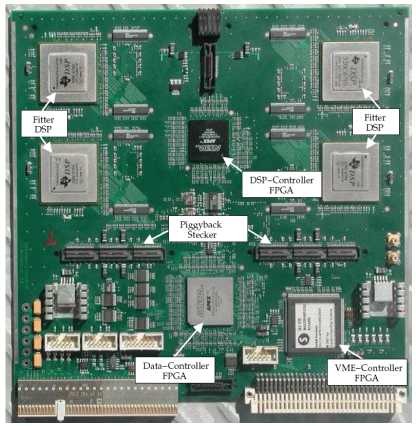
FTT-L1 FEM board:





Further increase in precision only via track fit at FTT-L2 possible:

FTT-L2 Fitter board:



> 10^6 3dim-Spurfits/s

Non-iterative Karimaeki Algorithm:

- x,y values of linked track segments
- beam position (constant)

Linear Fit:

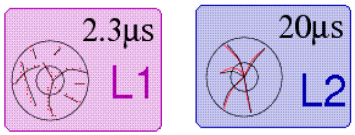
- z-values of track segments
- z-Vertex position (calculated by FTT!)

Result: 48 precise 3D tracks

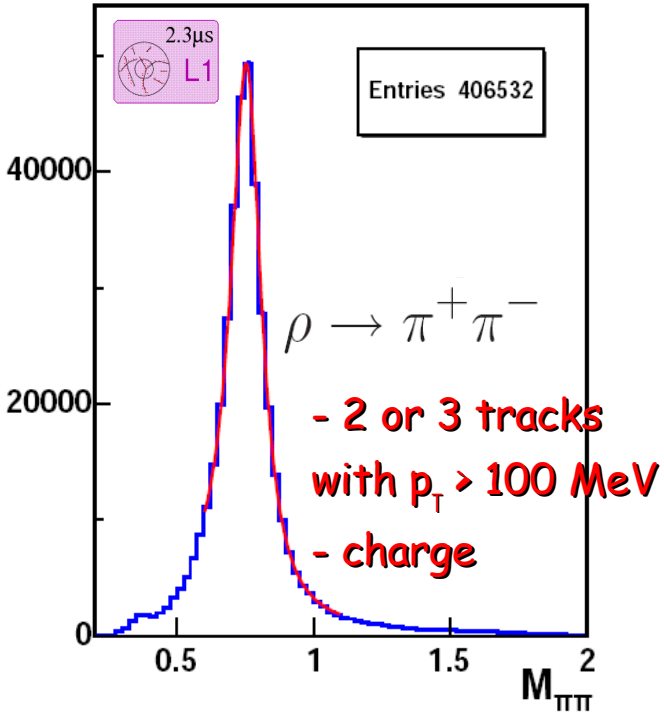
- Curvature $\sim p_t^{-1}$
- Azimuthal angle ϕ
- Polar angle ϑ

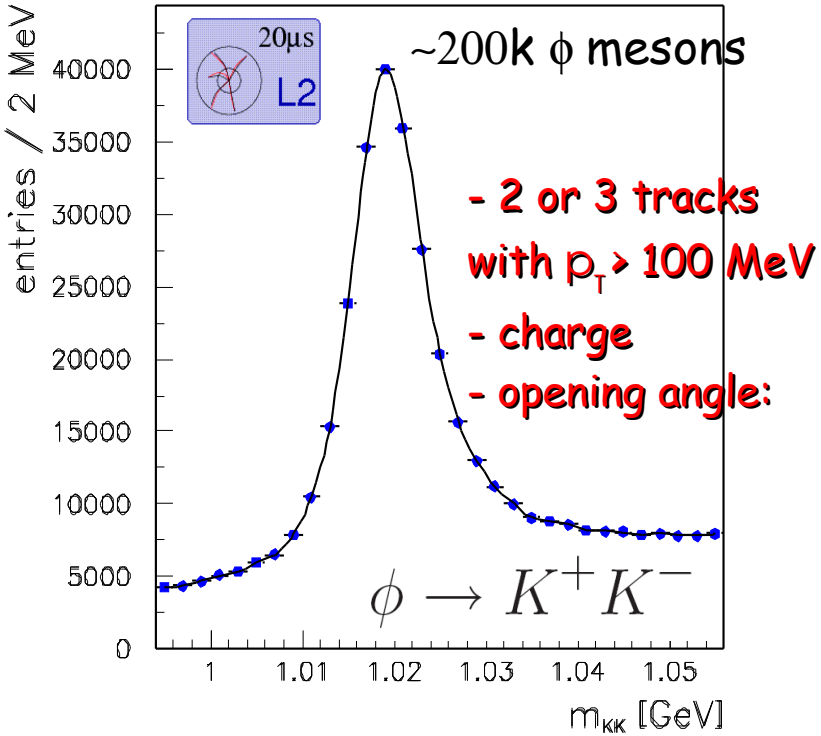
→ **Input for FTT-L3 !**

FTT-L1 & L2: Physics samples

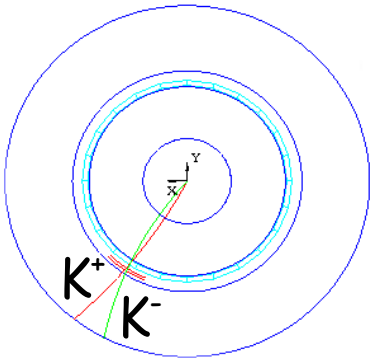


Collected large light meson samples:





M(ϕ)–M(KK) ~ 40MeV !



- Tracks with p_T > 100 MeV at **L1**
- High precision tracks: Opening angle at **L2**
- Huge statistics provides new insights into cross section measurements in photoproduction cross section (diffractive processes)

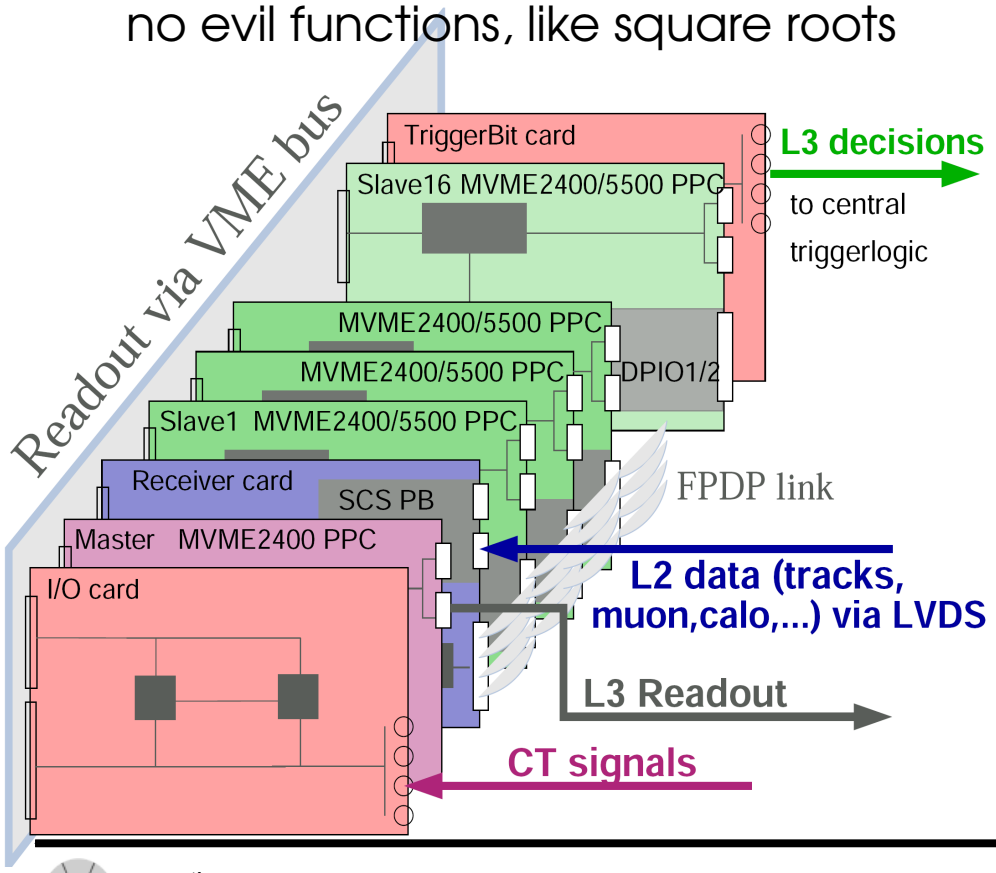
FTT-L3: Realization

L3 Hard- & Software:

- 5 PowerPCs (VME G3 – processor cards)
- Real time OS "vxWorks"
- **F**ront **P**anel **D**ata **P**ort (FPDP):

  simultaneous data transfer
- Time optimised C – code:

  no evil functions, like square roots



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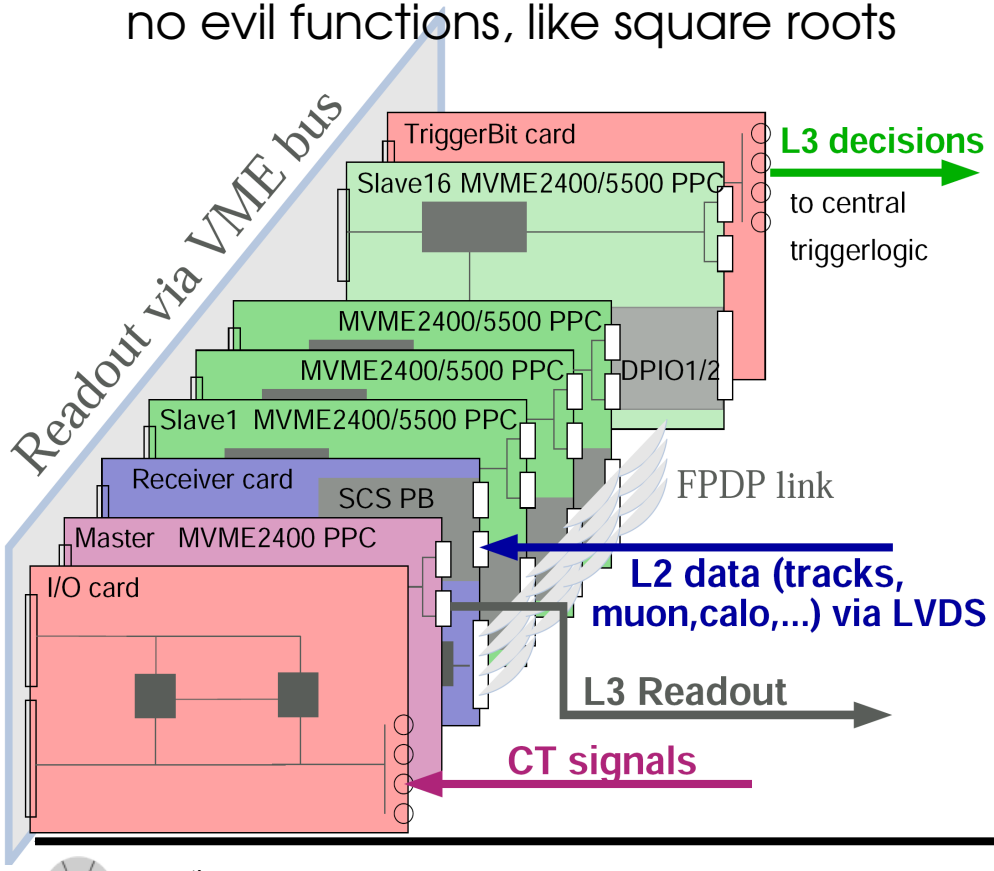
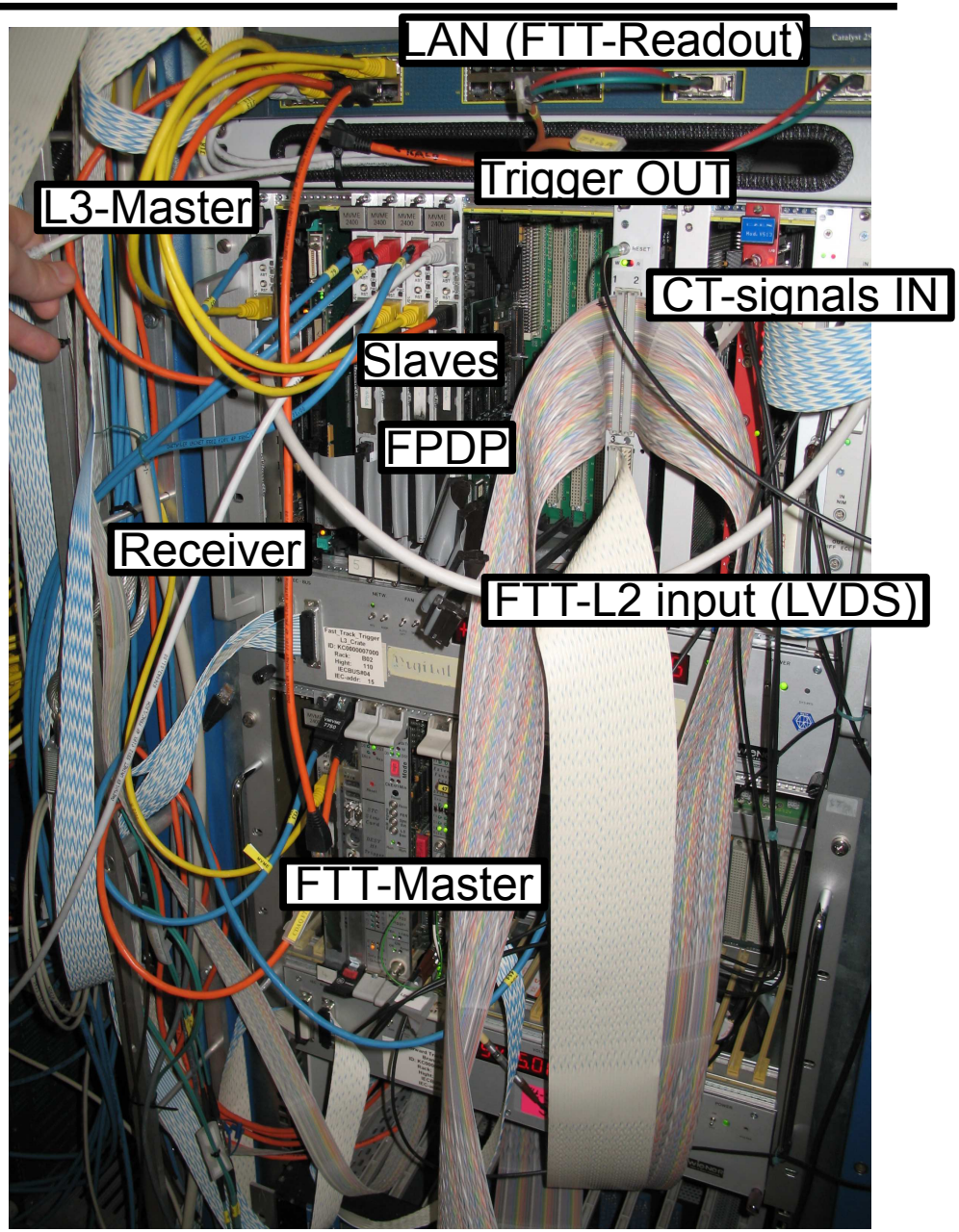
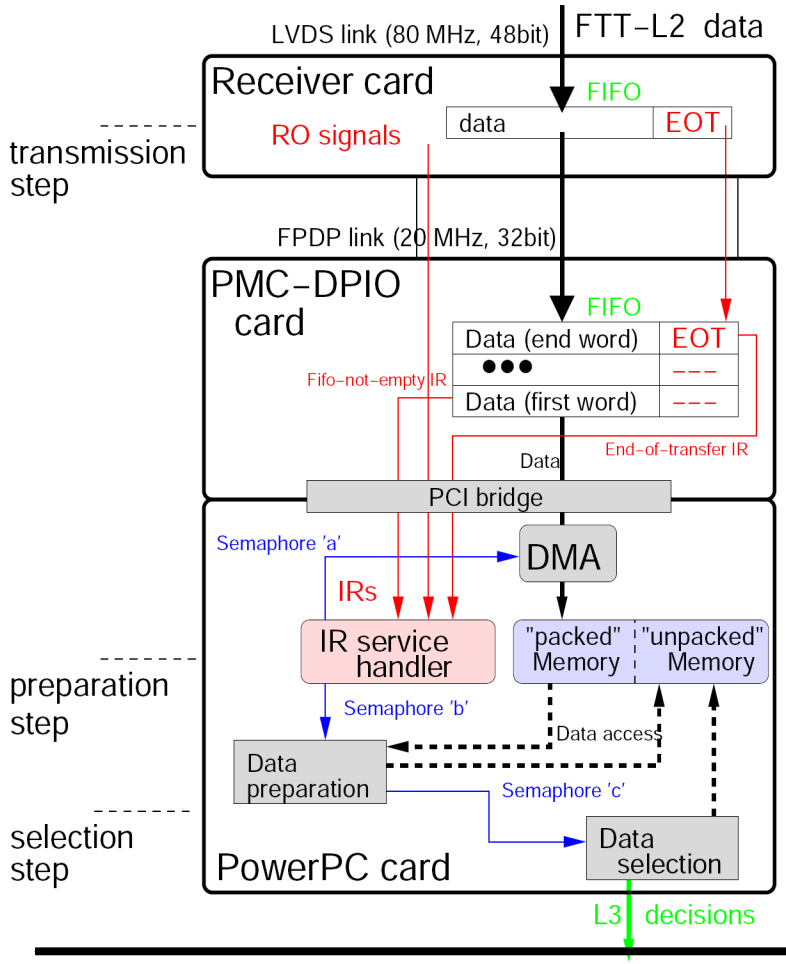




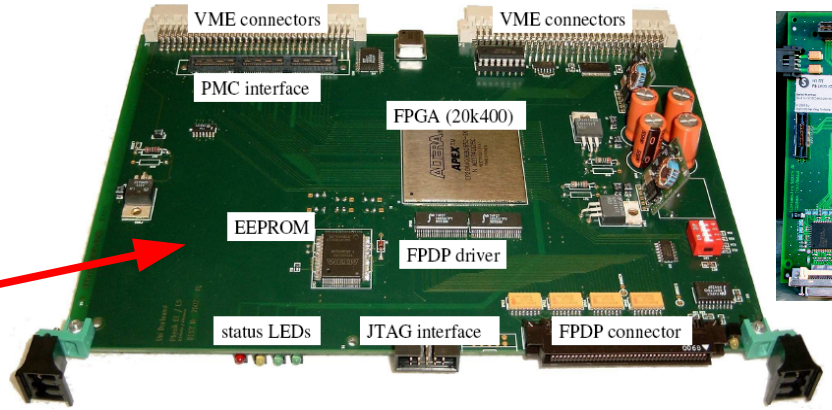
FTT-L3: Data processing

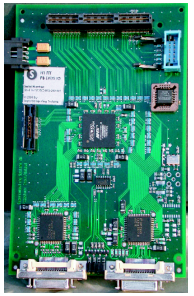
Data processing:

- Input via hardware protocols (LVDS, FPDP)
- Data preparation via software protocols:
  - "vxWorks" provides task management
  - task communication via semaphores

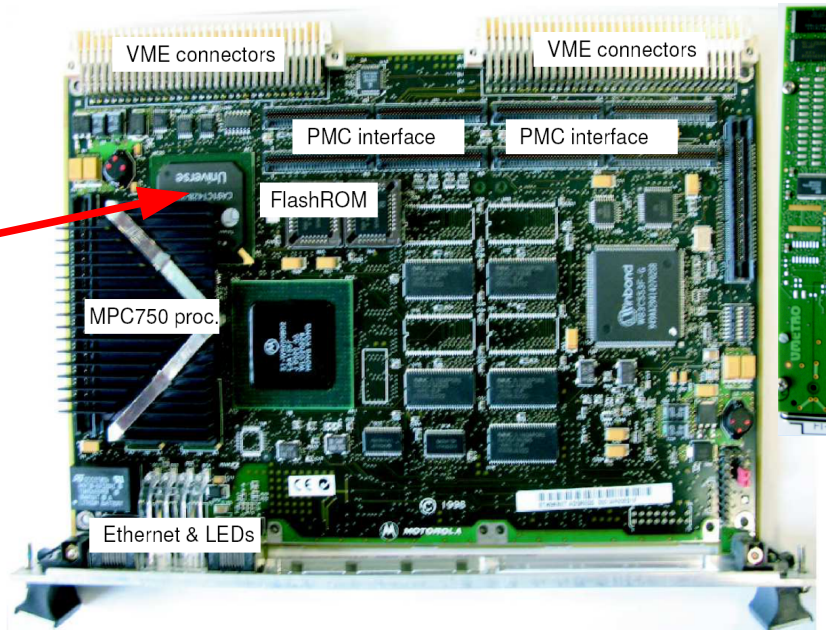


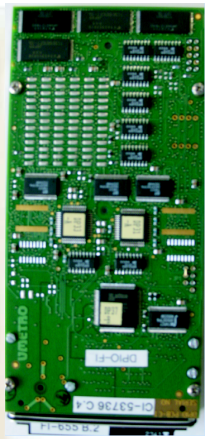
Receiver card & "SCS" piggy back card:





PowerPC & "Vmetro" PMC-DPIO card:





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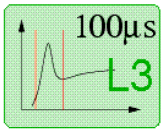

Data processing:

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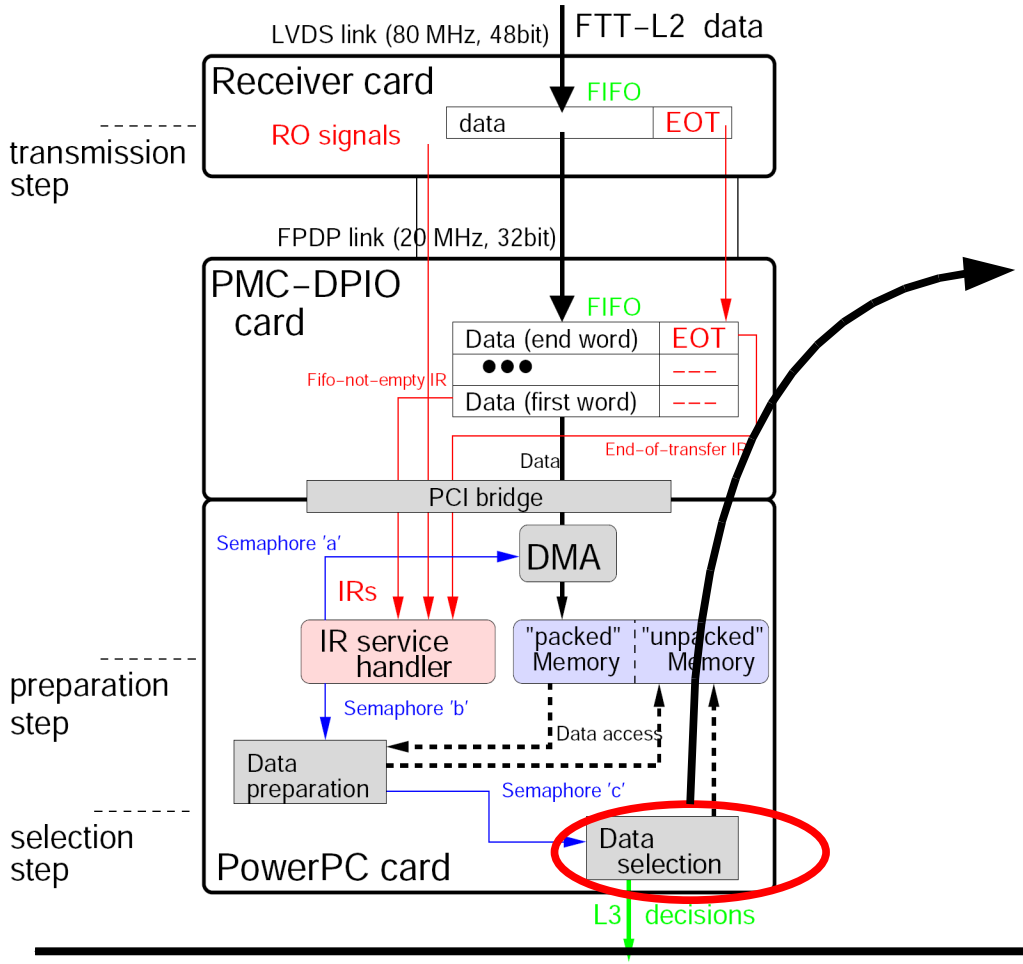
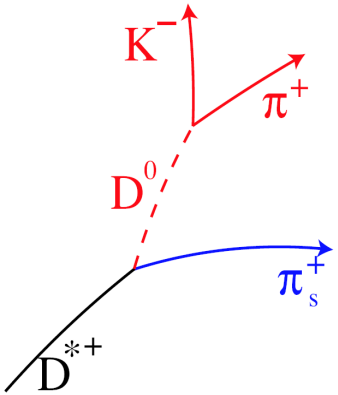
L3 selection algorithms:

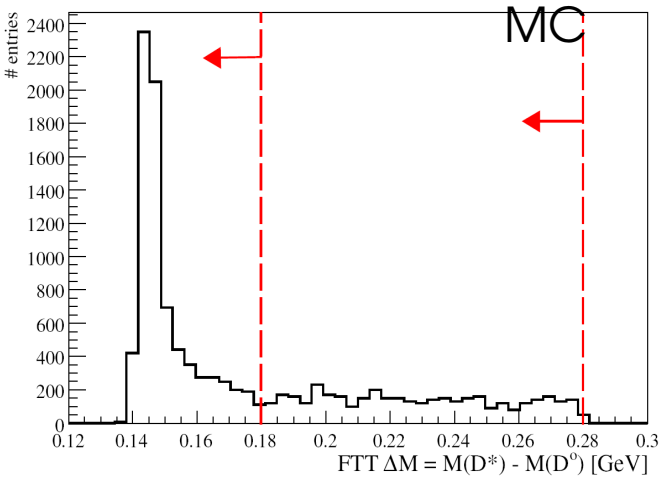
- J/ψ, **D***, b-mesons (electrons), muons, etc.
- Uses FTT, Calorimeter & Muon information



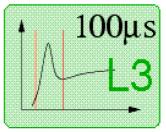


Trigger D* mesons:

- p_T, Charge, ...
- Inv. mass for: $D^* \; D^0$
- $\Delta M = M(D^*) - M(D^0)$



FTT-L3: Data processing



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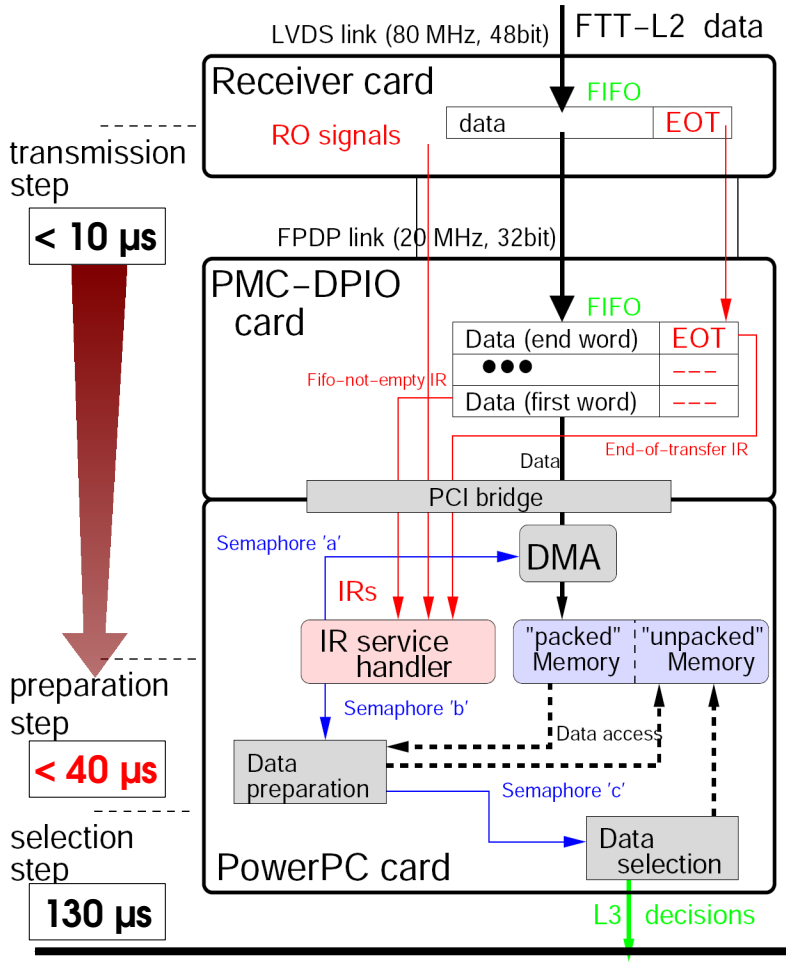
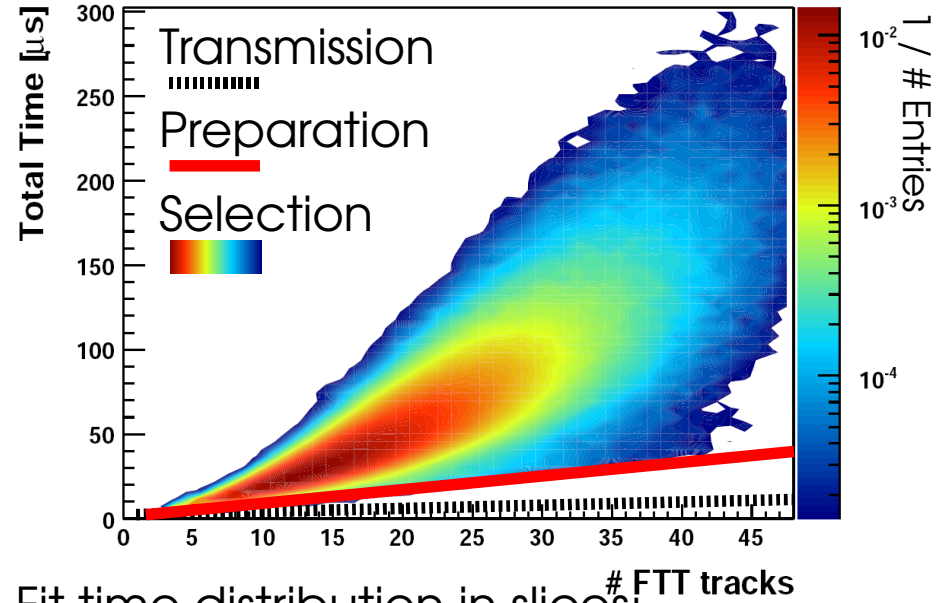
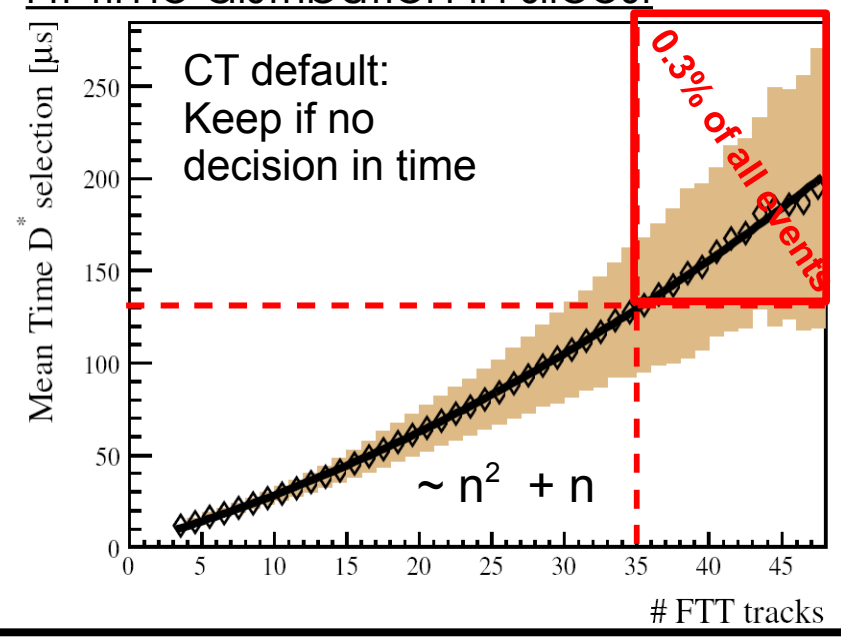


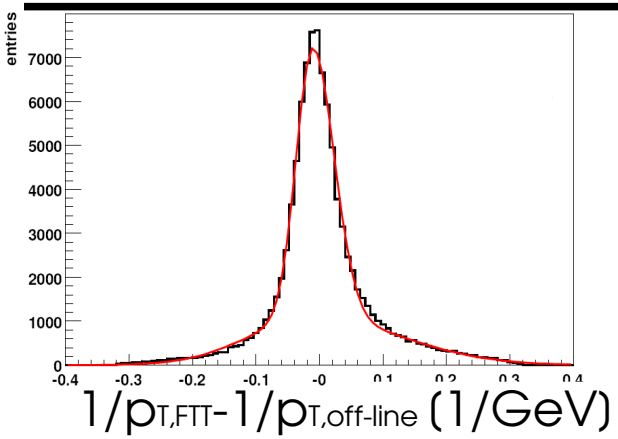
Time distribution of D* selection (data):

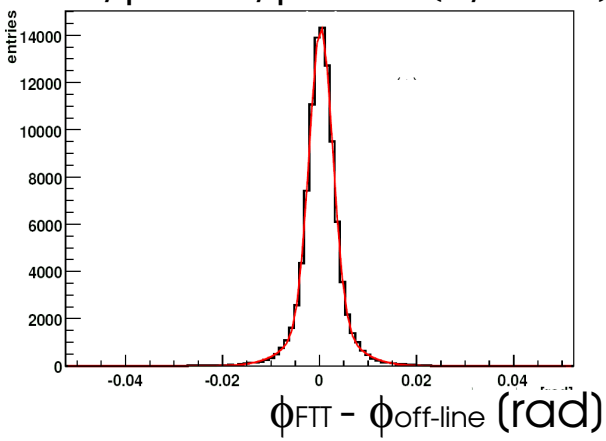


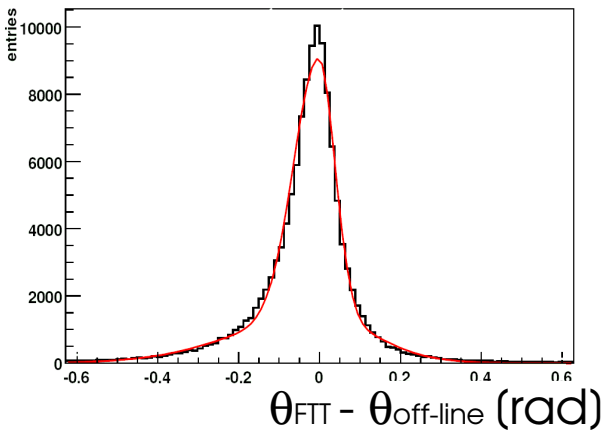
Fit time distribution in slices:



FTT-L3: Performance





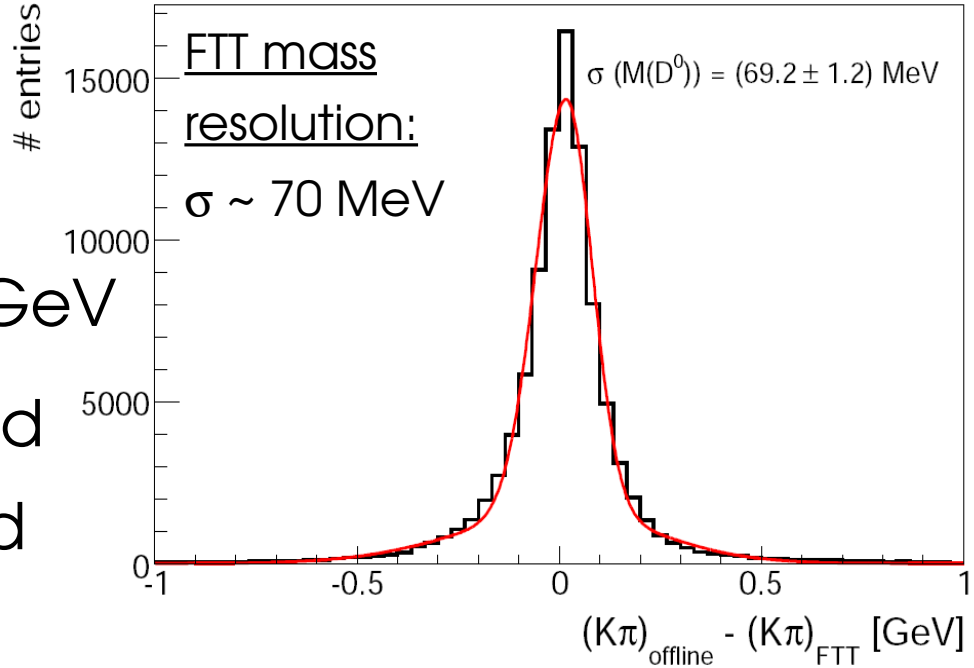


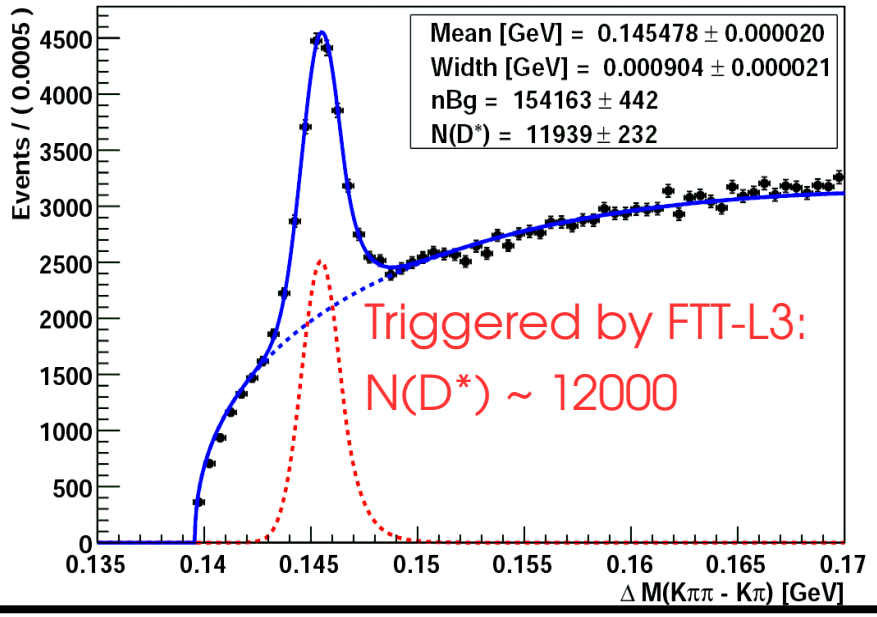
FTT track resolutions:

$\sigma(1/p_T) = 2\%/\text{GeV}$

$\sigma(\phi) = 2.4$ mrad

$\sigma(\theta) = 50$ mrad

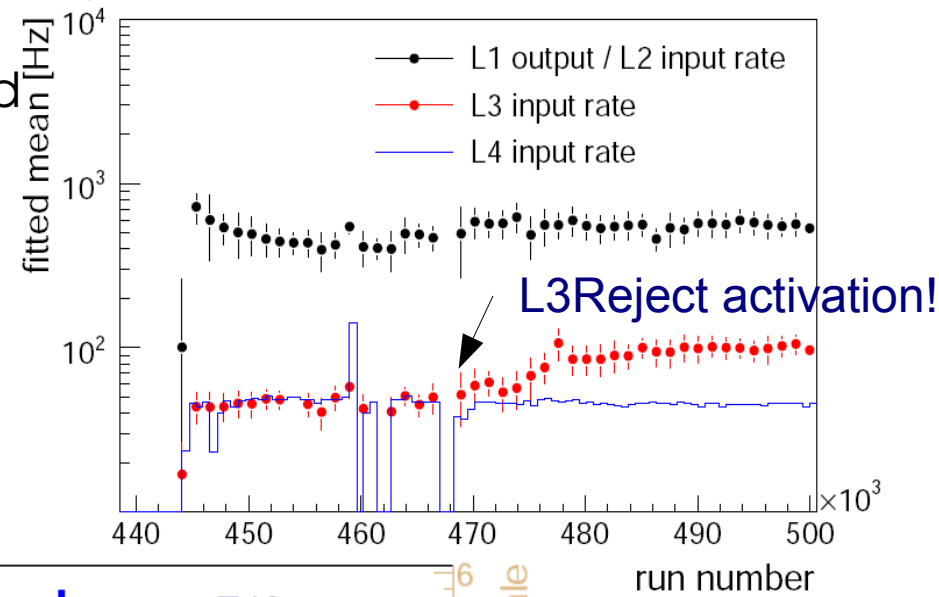


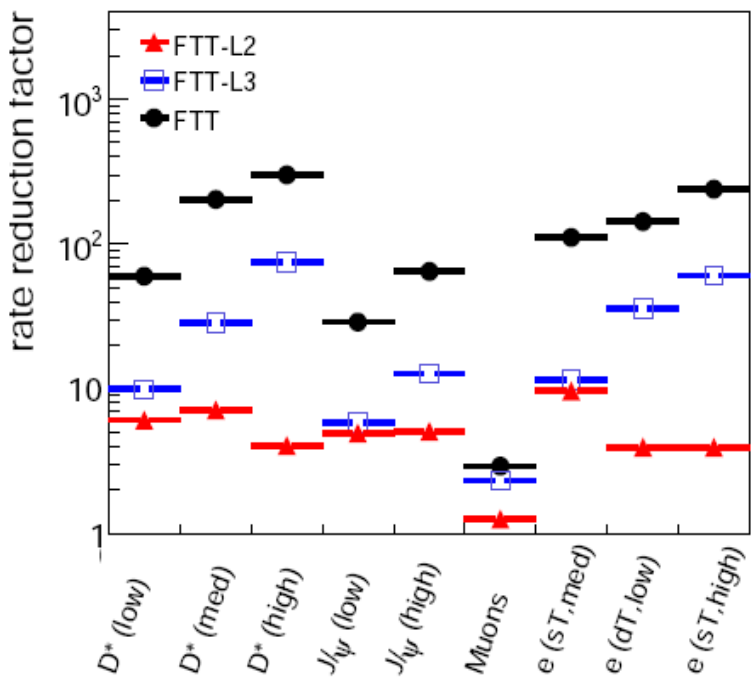


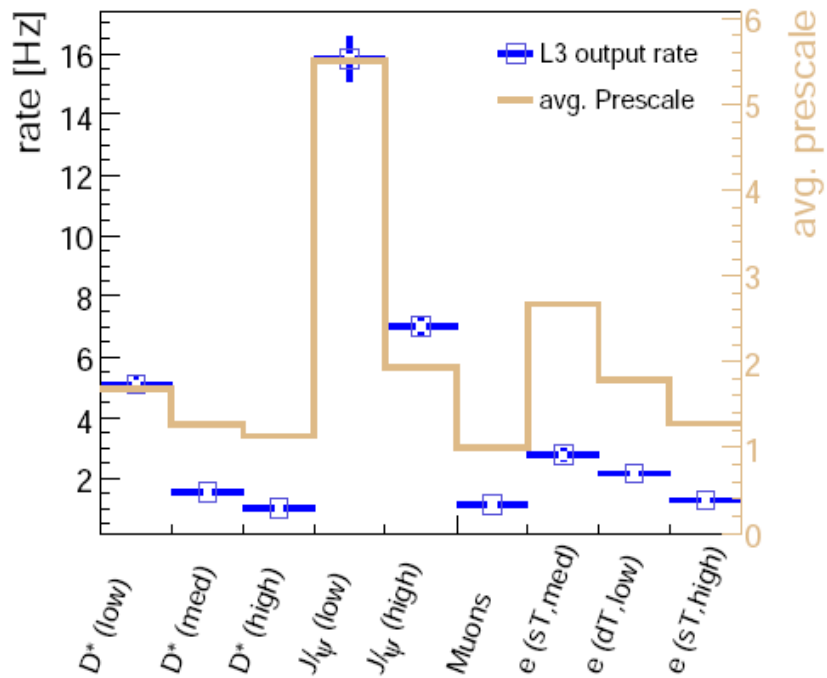
The FTT "one-slide" summary:

- FTT was the main H1 Track Trigger
- Complete H1 Readout used the L3Reject derived from FTT-L3 after mid 2006
- Increased trigger capabilities & selectivity for H1
- Rate reduction factors of about 100
- Achieved high performance
- For more details see 2nd part of thesis:
  https://www-h1.desy.de/psfiles/theses/h1th-504.pdf

Major effort of the H1 collaboration:



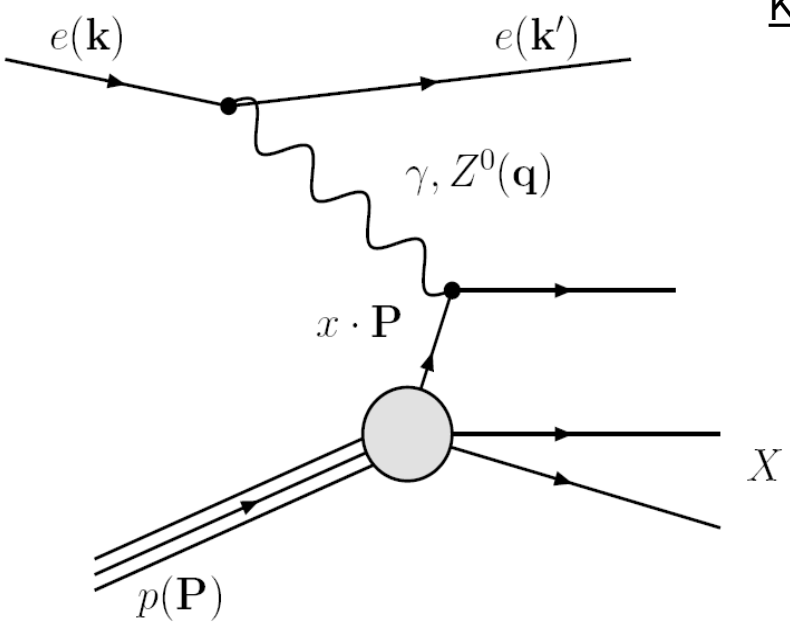




The Fast Track Trigger & D* production at medium Q^2 – summary from Ph.D.

- Introduction
- H1 & The Fast Track Trigger:
  - Introduction
  - The third trigger level
- D* production:
  - Theoretical aspects
  - Results: D* Cross section & $F_2^c(x,Q^2)$
  - Current field of work
- Conclusions

Deep Inelastic Scattering (DIS)



Kinematics of DIS given by Lorentz invariant quantities:

- Photon virtuality / Resolving power:

$$Q^2 := -q^2 = -(\mathbf{k} - \mathbf{k}')^2$$

- Inelasticity:

$$y := \frac{(\mathbf{p} \cdot \mathbf{q})}{(\mathbf{p} \cdot \mathbf{k})}$$

Bjørken x:

$$x := \frac{Q^2}{2(\mathbf{p} \cdot \mathbf{q})}$$

(momentum fraction of scattered parton)

- Related by: $Q^2 = sxy$

Neutral Current cross section at $Q^2 << M^2_Z$:

$$\frac{d^2\sigma^{\mathrm{NC}}_{\mathrm{Born}}}{dx dQ^2} = \frac{2\pi\alpha^2_{\mathrm{em}}}{xQ^4} \cdot \left\{ \left(1 + (1-y)^2\right) \cdot F_2(x, Q^2) - y^2 \cdot F_L(x, Q^2) \right\}$$

→ DIS is a unique tool to:

- Test perturbative QCD dynamics & measure substructure of proton:

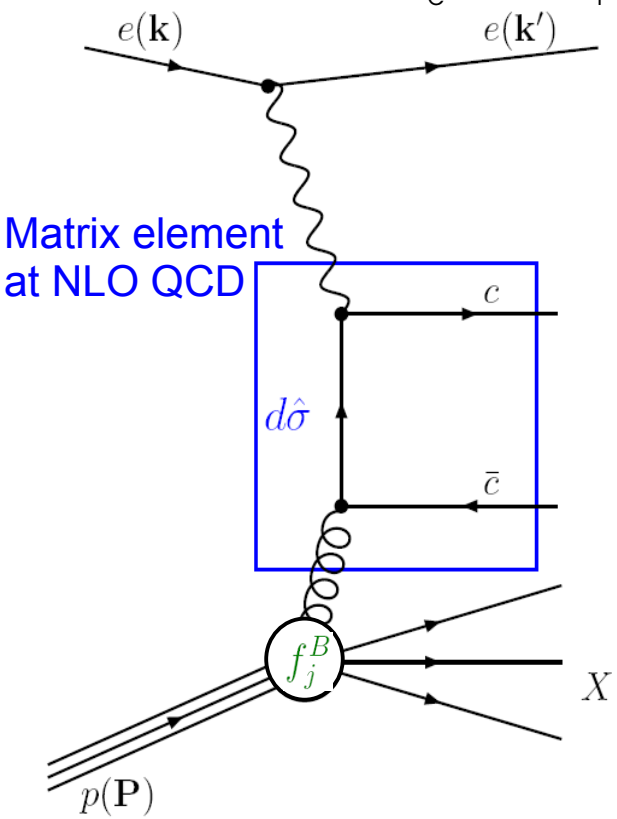
  parton **d**istribution **f**unctions (PDFs)

- Precise knowledge of the PDFs is vital for measurements at hadron colliders

Heavy Quarks in DIS

Leading order: boson-gluon fusion

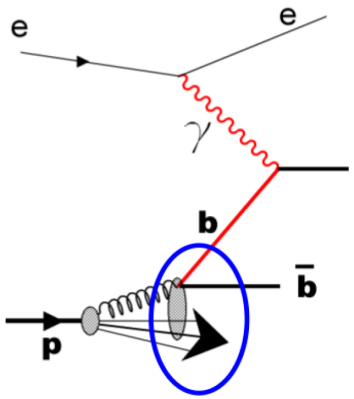
- NLO provided by HVQDIS (Harris et al.)
- But: multiple scales (m_c^2, Q^2, p_T^2)



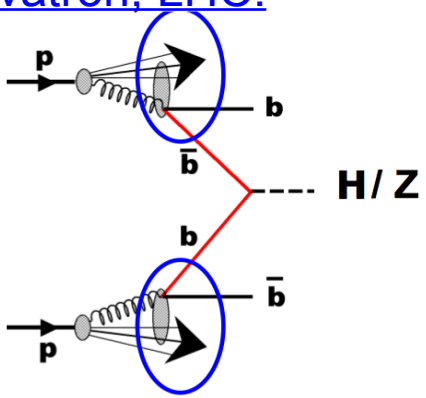
Constraint on parton density functions (PDF):

- Direct access to g(x), Consistency with g(x) from scaling violations (inclusive DIS)
- At $Q^2 \gg m_c^2$ heavy quark "is" a parton: c, b PDFs
- Different theoretical HQ schemes, so called variable flavor number schemes (VFNS)
- At $x \ll 1$, $Q^2 \gg m_c^2$: c(x), b(x) same size as u(x), d(x), s(x)
- HQ data & treatment in global fits affects cross section predictions at hadron-hadron machines:

HERA:



Tevatron, LHC:

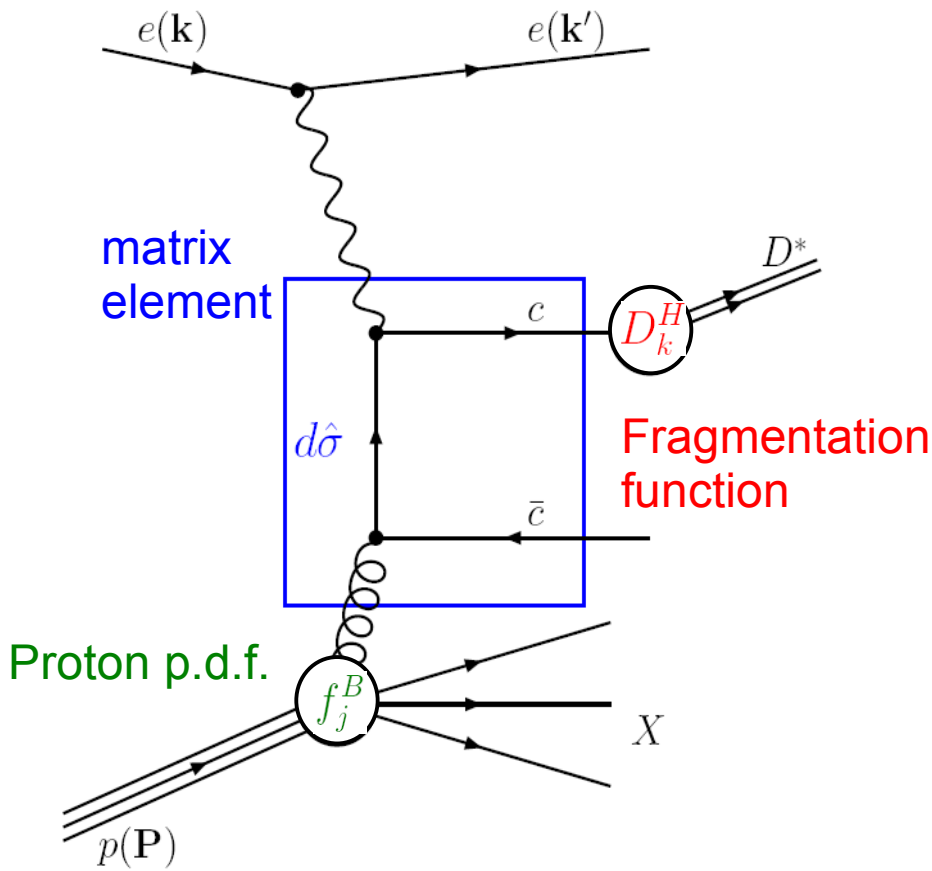


→ Heavy Quarks (c,b) vital for:

- Test perturbative QCD dynamics & measure substructure of proton
- Cross section predictions at hadron colliders

D* Production: Boson-Gluon Fusion

Dominant process: boson-gluon fusion:



Kinematic quantities: Q^2 , y and Bjørken x

- Inclusive cross section

$$\frac{d^2\sigma^{c\bar{c}}(x,Q^2)}{dxdQ^2} = \frac{2\pi\alpha_{em}^2}{xQ^4}\cdot\left(\left[1+(1-y)^2\right]\cdot F_2^{c\bar{c}}(x,Q^2) - y^2\cdot F_L^{c\bar{c}}(x,Q^2)\right)$$

D* via Fragmentation:

- Pseudo-rapidity: $\eta = -\ln\left(\tan\left(\frac{\theta}{2}\right)\right)$
- Transverse momentum: p_T

Perturbative QCD:

- For inclusive DIS this is a NLO correction!
- Q^2, m_c^2 or p_T^2 provides a hard scale
- Test of heavy flavor treatment in pQCD
- Parton densities ("gluon structure")

Factorisation ansatz:

$$d\sigma = \sum_{i,j,k} f_j^B(x_2,\mu_f) \otimes d\hat{\sigma}_{ij\to kX}(\mu_f) \otimes D_k^H(z,\mu_f)$$

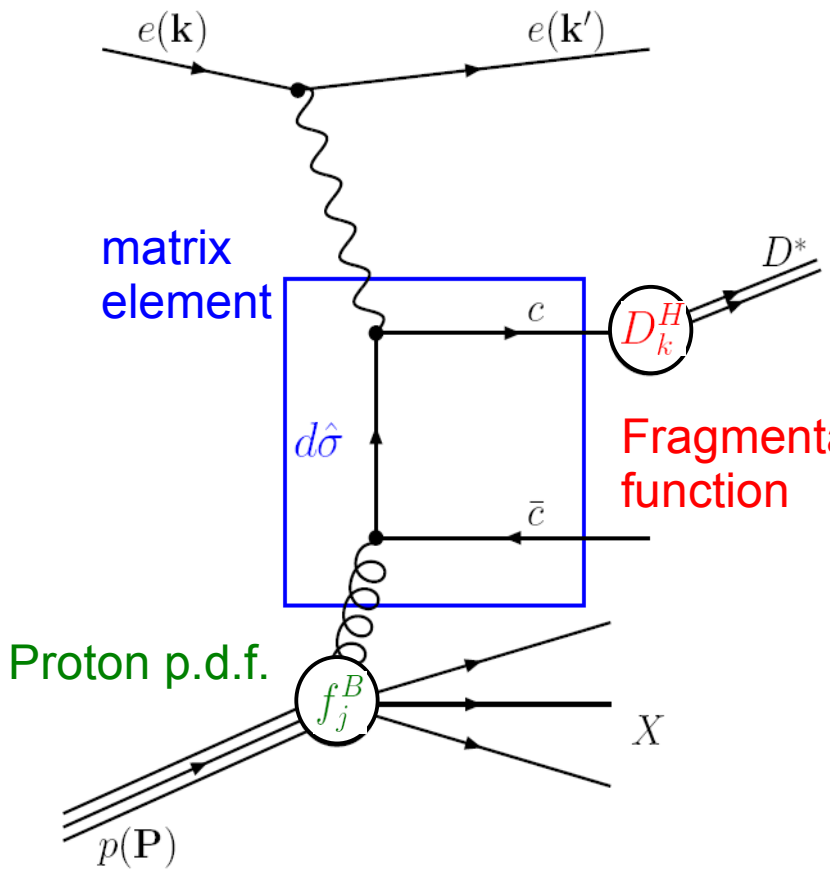
Parton density functions (PDFs): from global fits to data

Matrix element: calculable in different heavy flavor schemes

Fragmentation function: from data

D* Production: Boson-Gluon Fusion

Dominant process: boson-gluon fusion:



RAPGAP	vs.	CASCADE	vs.	HVQDIS:
LO(α_s) + PS	↔	LO(α_s) + PS	↔	NLO(α_s^2)
massive BGF	↔	massive BGF	↔	massive BGF (FFNS)
DGLAP	↔	CCFM	↔	DGLAP
all partons	↔	only gluons	↔	all partons
Lund frag.	↔	Lund frag.	↔	Independent frag.

Note: RAPGAP + HERACLES used correction of data

Factorisation ansatz:

$$d\sigma = \sum_{i,j,k} f_j^B(x_2, \mu_f) \otimes d\hat{\sigma}_{ij\to kX}(\mu_f) \otimes D_k^H(z, \mu_f)$$

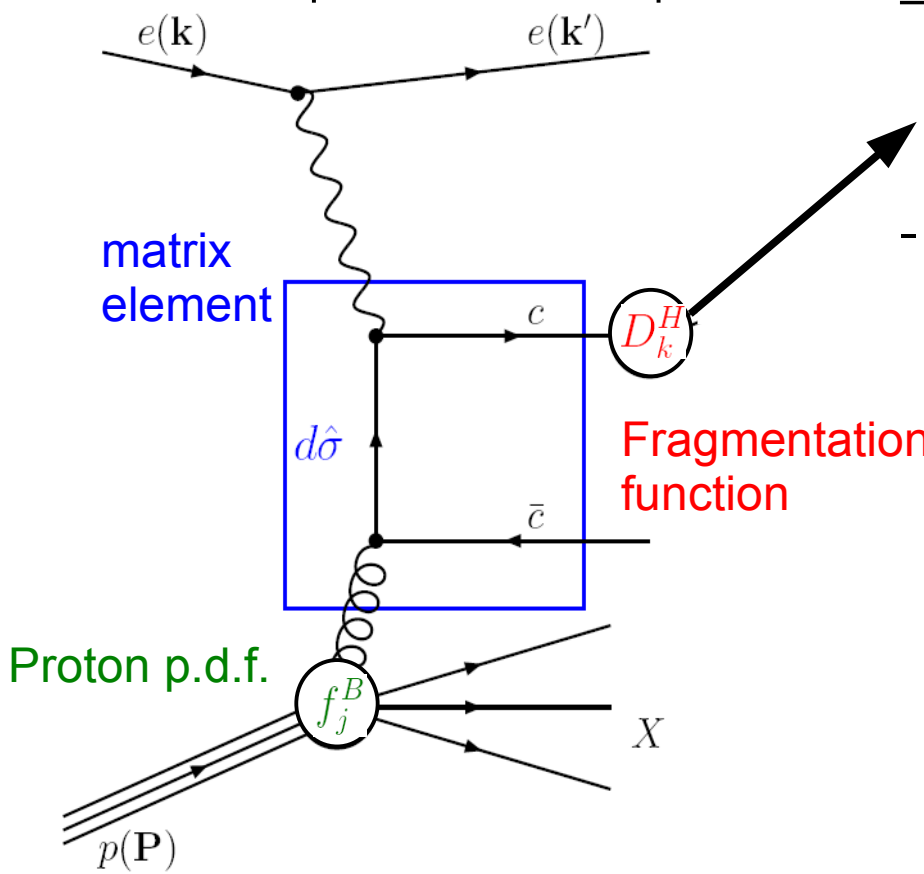
Parton density functions (PDFs): from global fits to data

Matrix element: calculable in different heavy flavor schemes

Fragmentation function: from data

D* Production: Boson-Gluon Fusion

Dominant process: BGF process

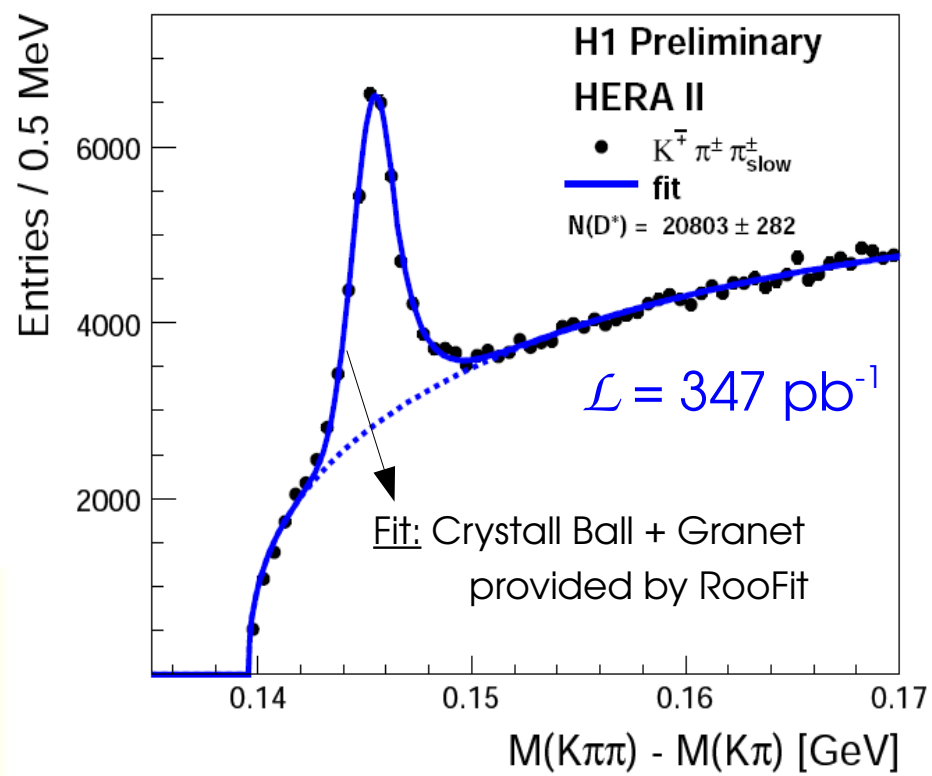


D* reconstruction in golden decay channel:

$$D^{*\pm} \to D^0 \pi^{\pm}_{slow} \to (K^{\mp}\pi^{\pm})\pi^{\pm}_{slow}$$

- Higher resolution in mass difference:

ΔM = M(Kππ)-M(Kπ)



Visible range for the D* cross section:

Q^2	: 5 - 100 Ge^{2}V	$p_T(D^*)$	: > 1.5 GeV
y	: 0.02 – 0.70	$\lvert\eta(D^*)\rvert$	: < 1.5

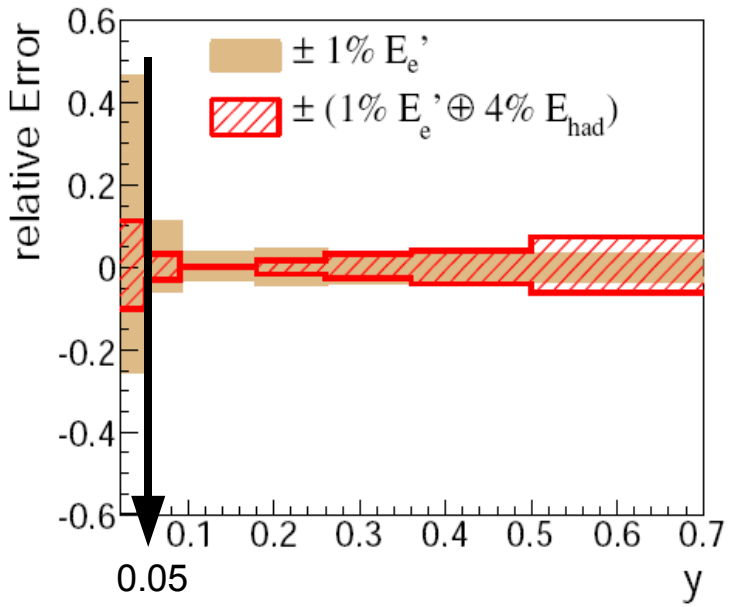
Note: Analysis is dominated by systematic error

Improved reconstruction method

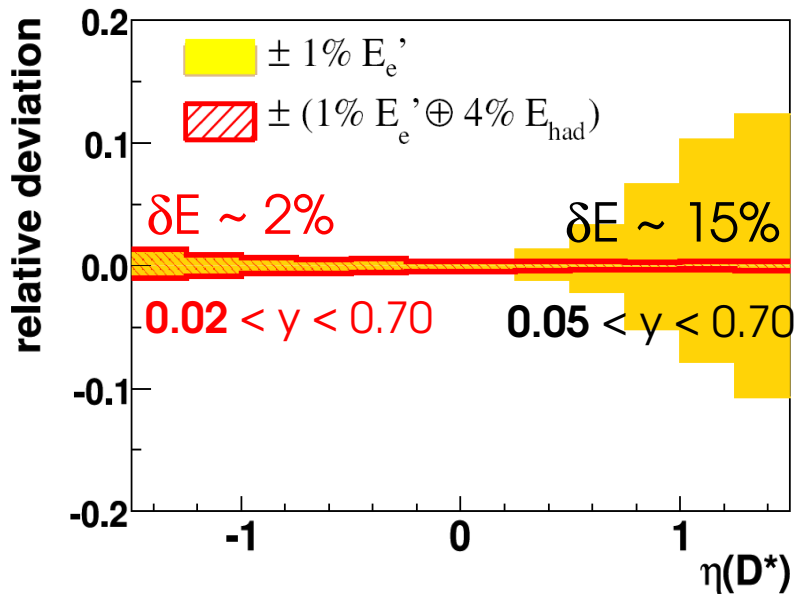
Different event reconstruction methods:

- Use measurement of the electron final state → **e-method**
- Combine measurements of electron & hadron final state → **eΣ-method**

Previous analysis vs. this analysis:



Also other quantities profit:



→ Systematic error (from energy scale unc.) reduced significantly with eΣ-method

Phase space extended to lower y of 0.02

Total experimental error: ~ 9.5% (dominant is tracking with 6%)

Cross section results

H1prel-08-072

Total BR of 2.57%

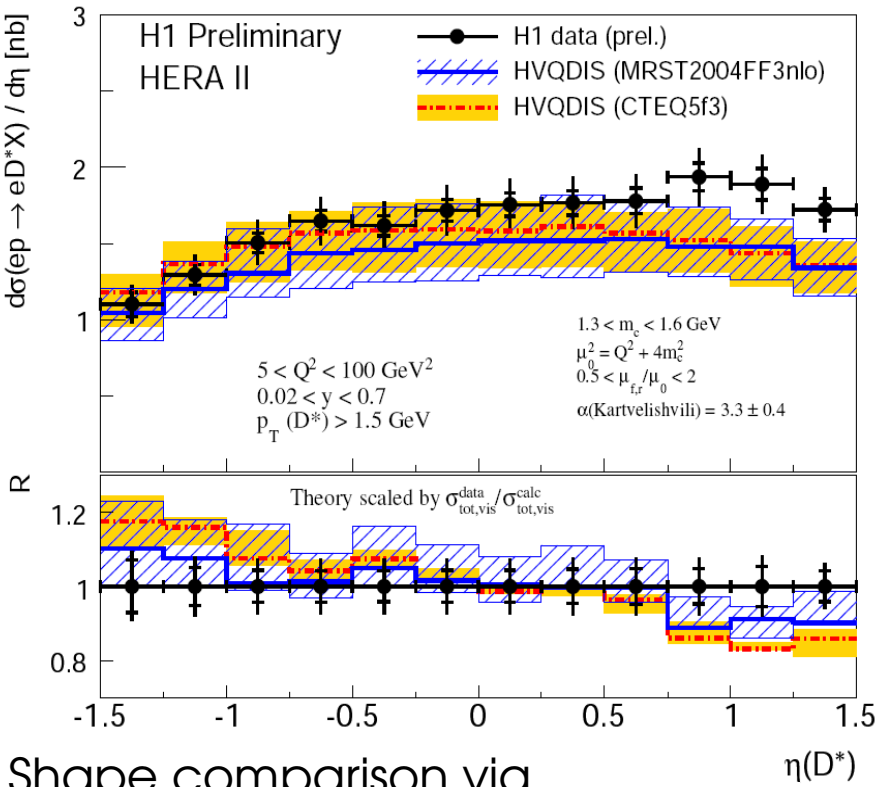
From fits

$$\sigma_{\mathrm{tot}}^{\mathrm{vis}}(ep \to eD^*X) = \frac{N(D^*)}{\mathcal{L} \cdot \mathcal{B}(D^* \to K\pi\pi_{\mathrm{slow}}) \cdot \epsilon}$$

Data corrected with RAPGAP ε ~ 60%

Other Corrections:

- Contribution due to b-quarks not subtracted → but < 2%
- QED NLO corrections → ~ 2%
- Correction D^0 decay → ~ 4%



Shape comparison via ratio:

$$R = \frac{1/\sigma_{tot,vis}^{calc} \cdot \frac{d\sigma^{calc}}{dY}}{1/\sigma_{tot,vis}^{data} \cdot \frac{d\sigma^{data}}{dY}}$$

https://www-h1.desy.de/psfiles/confpap/ICHEP08/H1prelim-08-072.ps

Cross section results

H1prel-08-072

Total BR of 2.57%

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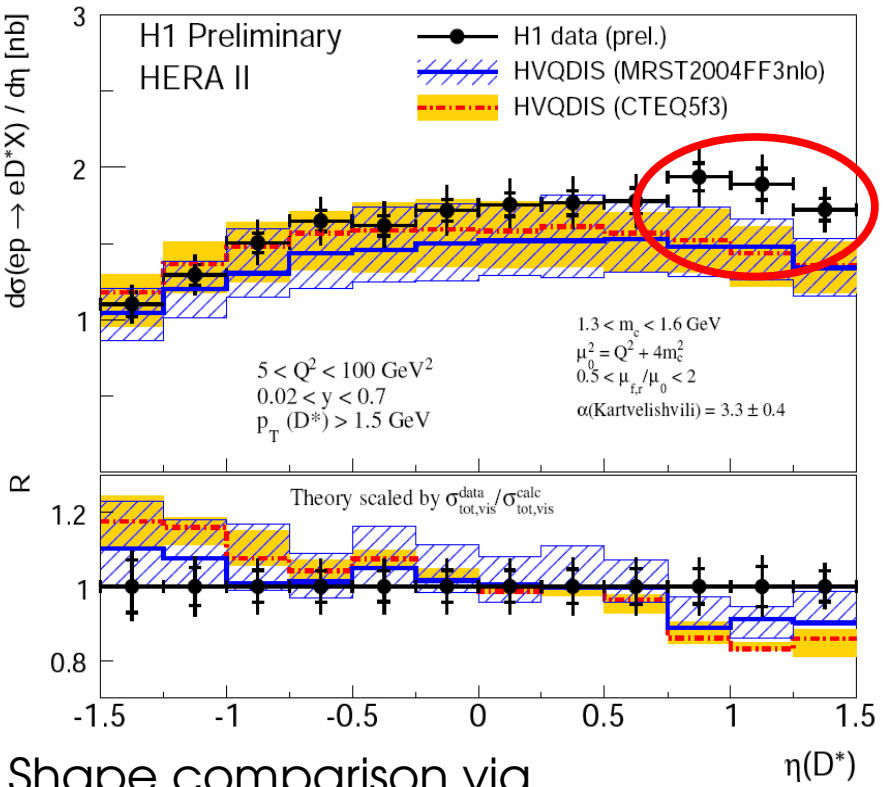
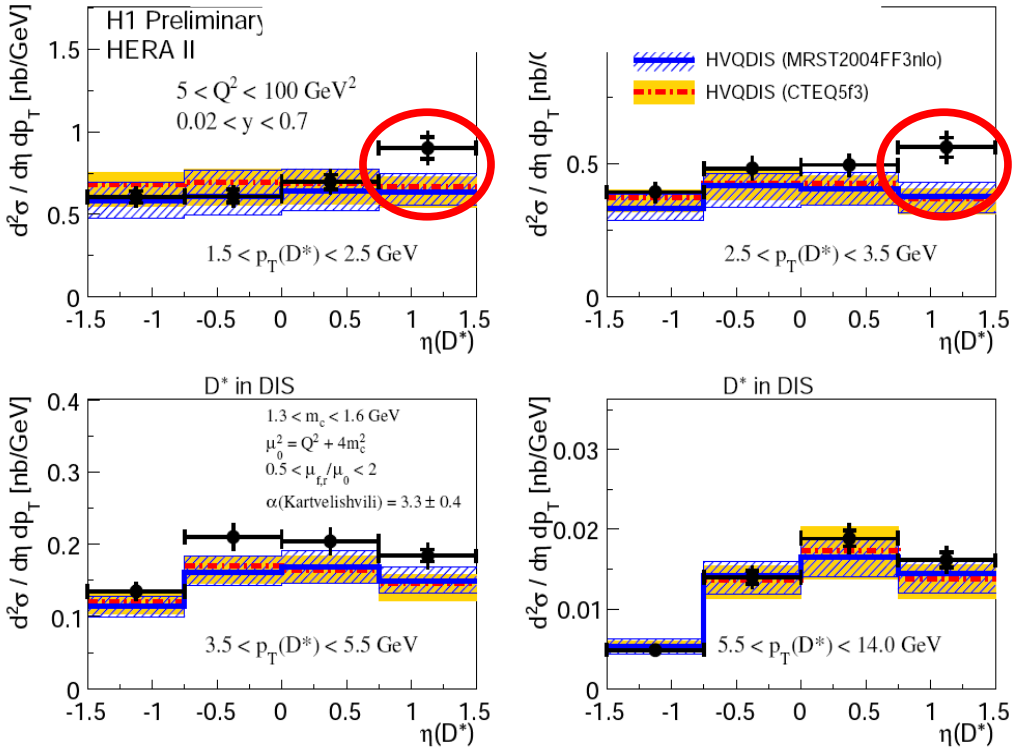




Shape comparison via ratio:

$$R = \frac{1/\sigma_{tot,vis}^{calc} \cdot \frac{d\sigma^{calc}}{dY}}{1/\sigma_{tot,vis}^{data} \cdot \frac{d\sigma^{data}}{dY}}$$

→ - NLO prediction describes data reasonable

- Small excess in forward directions at low p_T

Extraction of $F_2^c(x,Q^2)$

$$\frac{d^2\sigma^{c\bar{c}}(x,Q^2)}{dx dQ^2} = \frac{2\pi\alpha_{em}^2}{xQ^4}\cdot\left(\left[1+(1-y)^2\right]\cdot F_2^{c\bar{c}}(x,Q^2) - y^2\cdot F_L^{c\bar{c}}(x,Q^2)\right)$$

Only at high y: 2-3% for this measurement negligible

What is done to measure $F_2^c(x,Q^2)$:

Double differential cross section measurement in **visible phase space**

$$F_2^{c\ \mathrm{exp}}(x,Q^2) = \frac{\sigma_{\mathrm{vis}}^{\mathrm{exp}}(y,Q^2)}{\sigma_{\mathrm{vis}}^{\mathrm{theo}}(y,Q^2)}\cdot F_{2\ \mathrm{full}}^{c\ \mathrm{theo}}(x,Q^2)$$

Double differential prediction of cross section in **visible phase space** (DGLAP & CCFM)

Prediction of $F_2^c(x,Q^2)$ in **full phase space (η,p_T)** (DGLAP & CCFM)

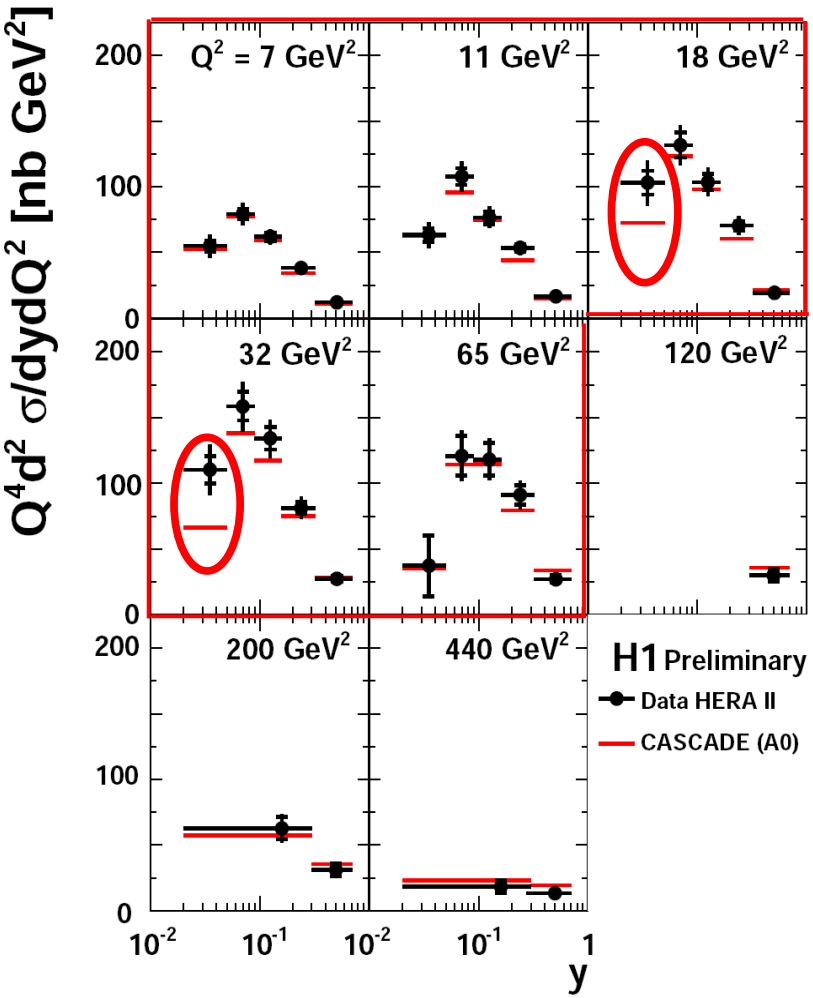
$p_T(D^*) \rightarrow 0$ GeV

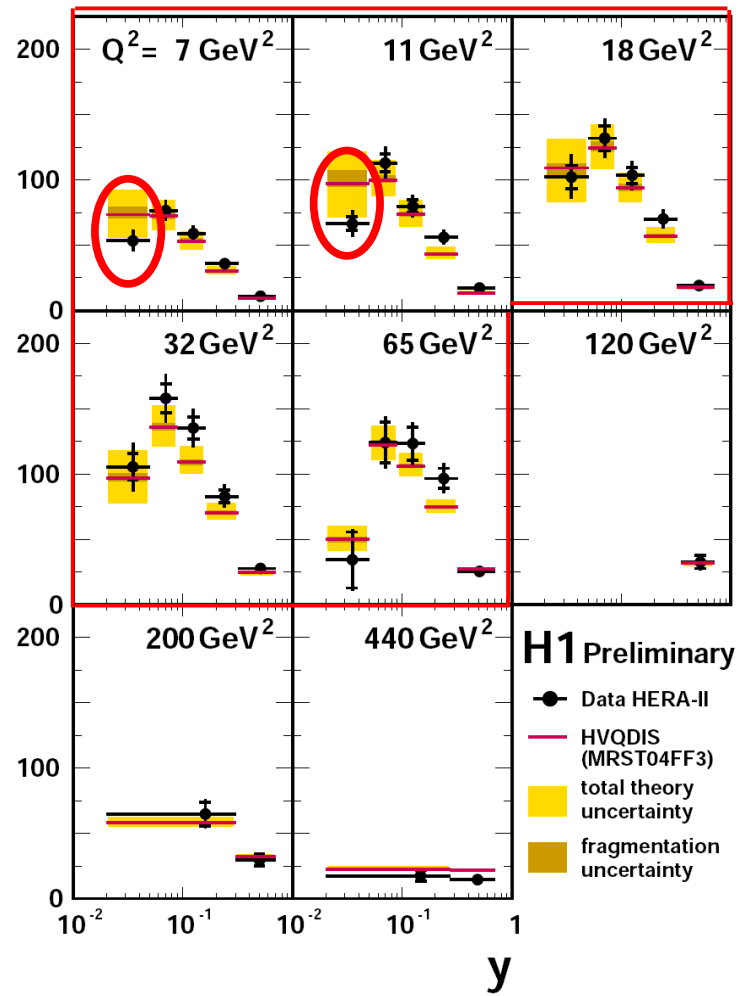
$|\eta(D^*)| \rightarrow 10$

- Extrapolation into not measured region:

Use different models and assign extrapolation uncertainty!

Cross section results





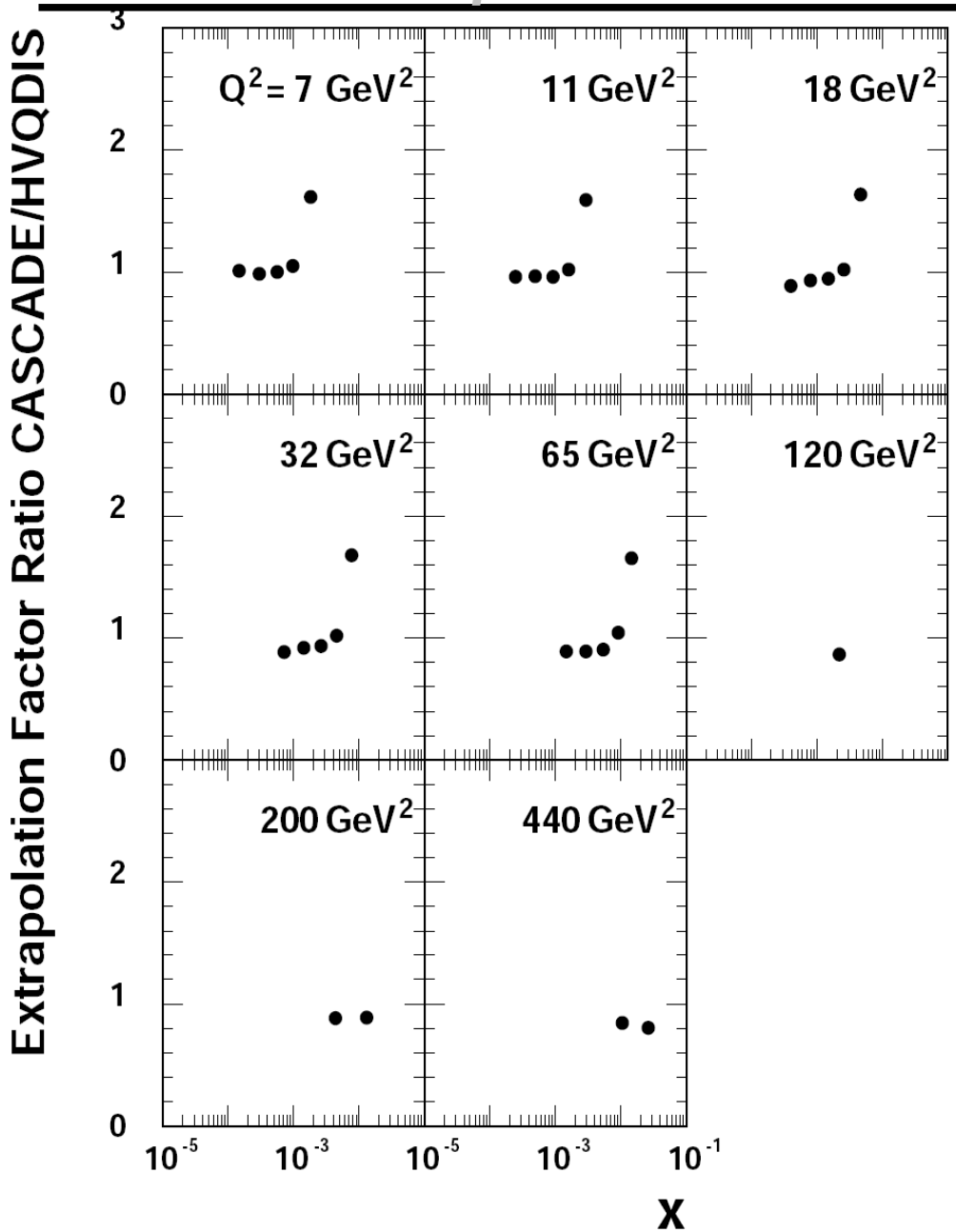
- Medium Q^2 points this analysis
- High Q^2 points from other analysis

→ - Equally good described by HVQDIS (NLO, DGLAP) and CASCADE (LO+PS, CCFM)

- Both have difficulties to describe the new (lowest) y-bin (→ highest x)

- Data don't prefer a specific model – **use both for the extraction of $F_2^c(x,Q^2)$**

Extrapolation factors



Extrapolation to full phase space:

$$f^{\text{extra}} = \frac{\frac{d^2}{dydQ^2} \cdot \sigma^{\text{theo}}_{\text{full}}}{\frac{d^2}{dydQ^2} \cdot \sigma^{\text{theo}}_{\text{vis}}}$$

$p_T(D^*) \rightarrow 0$ GeV

$|\eta(D^*)| \rightarrow 10$

- CASCADE & HVQDIS used, $\langle f^{\text{extra}} \rangle \sim 3$
- Ratio CASCADE/HVQDIS within 10%
- BUT at high x differences of up to 80%
- Reason is the restricted phase space

  → larger $\eta(D^*)$ range helps !

- Extrapolation uncertainty:

  charm mass: $1.3 < m_c < 1.6$ GeV

  renormalization & factorization scale:

  $0.5 < \mu_{f,r}/\mu_0 < 2$, $\mu_0^2 = Q^2 + 4m_c^2$

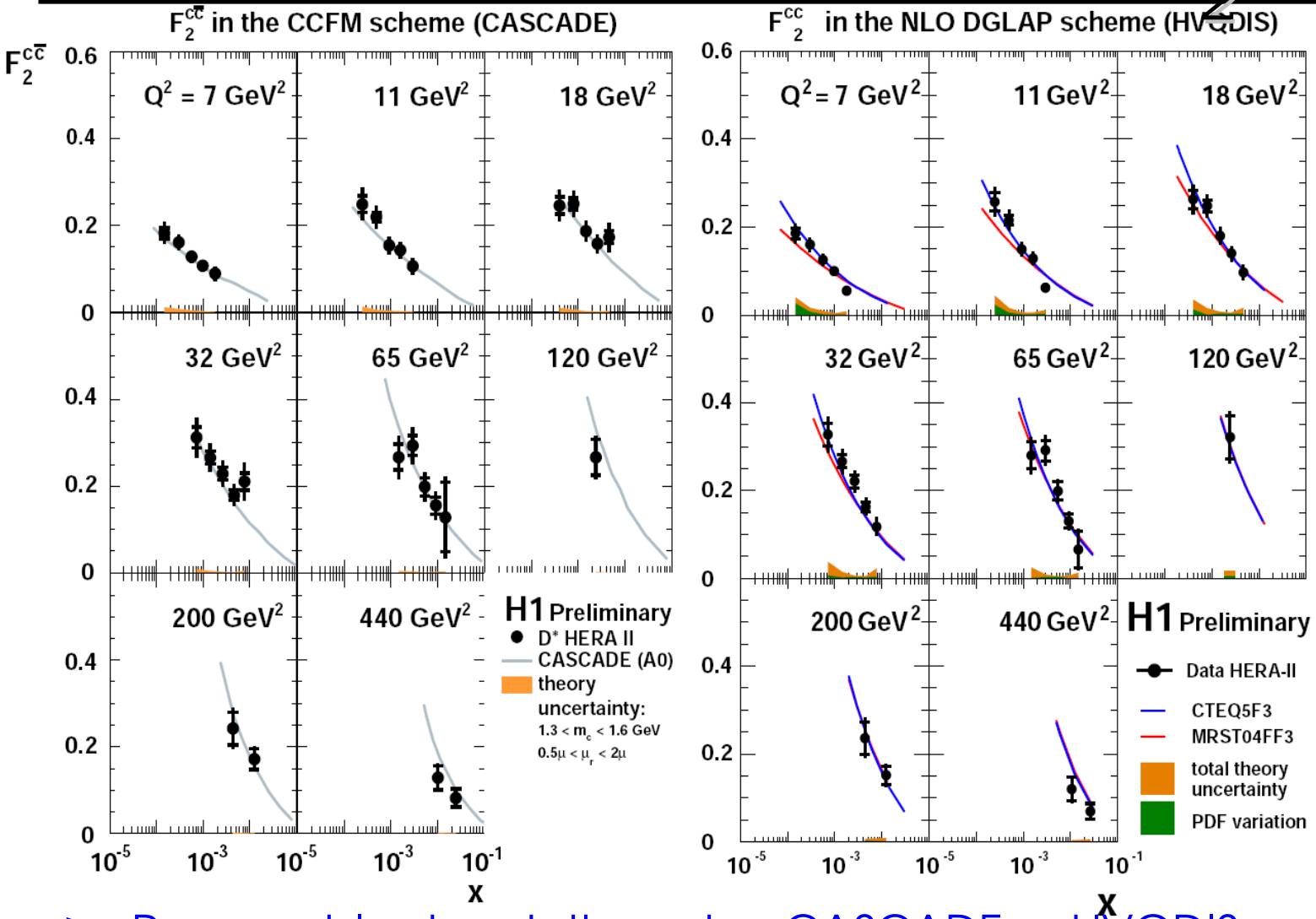
  PDF: MRST vs. CTEQ

  Fragmentation: from H1 measurement

- Partial cancellation of uncertainties

Charm contribution $F_2^c(x,Q^2)$

H1prel-08-172



- Medium Q^2 points this analysis
- High Q^2 points from other analysis
- Extrapolation Unc. from variation of:
  - charm mass
  - scale
  - fragmentation
  - PDF (HVQDIS)
- Single most precise measurement of $F_2^c(x,Q^2)$ at HERA

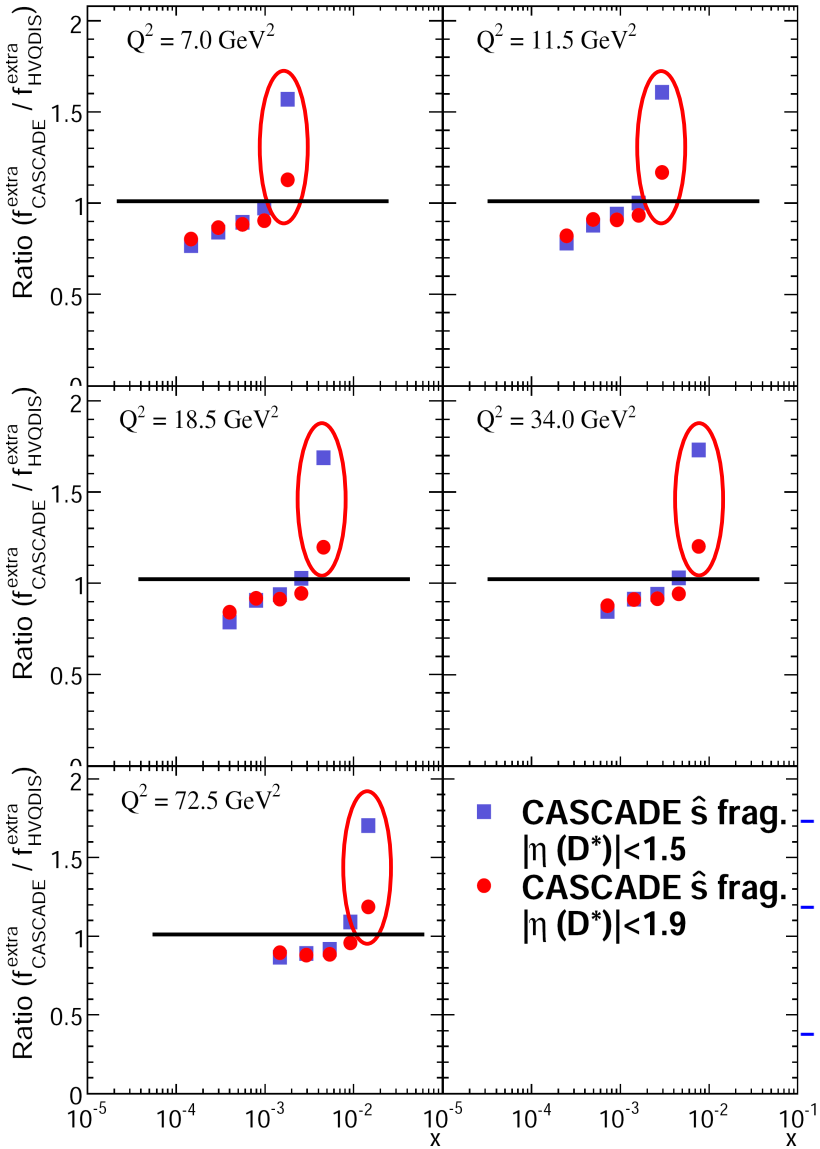
→ Reasonable description using CASCADE or HVQDIS

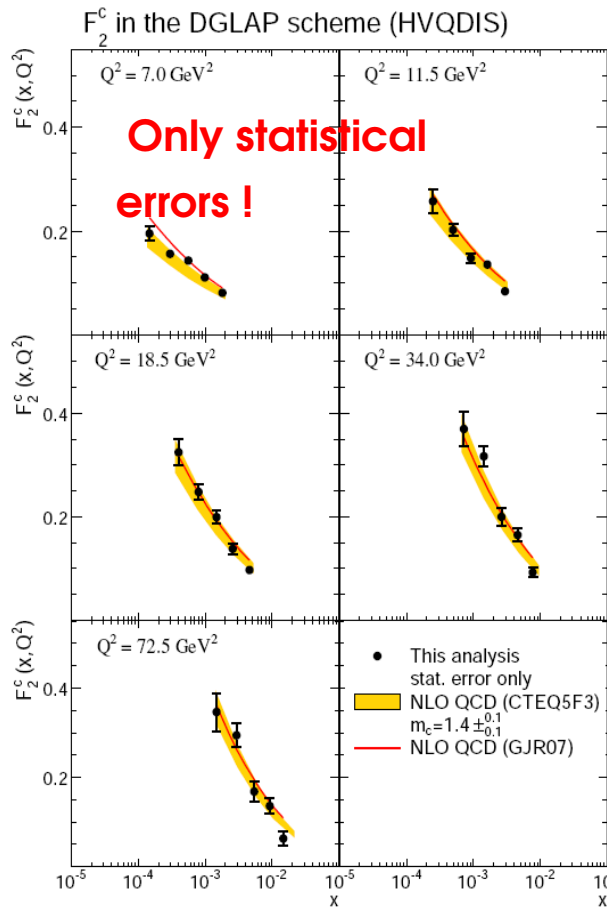
Steep rise with increasing Q^2: Scaling violations

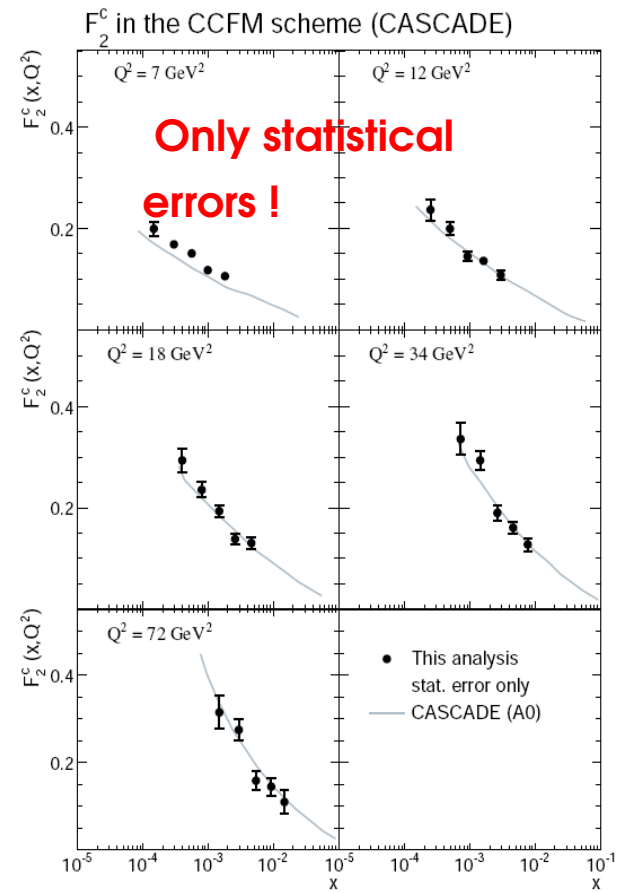
Differences of 20% - but large differences at highest x ~ 100%

Current field of work: Extension

Difference in extrapolation at highest x goes down to ~20%:







- Extend phase space: $p_T(D^*) > 1$ GeV and $|\eta(D^*)| < 1.8$
- Good description of data by CCFM & DGLAP scheme
  (For GJR07 thanks to P.J. Delgado)
- consistent with H1prel-08-172 & smaller differences between $F_2^c(x,Q^2)$ in different schemes!

Current field of work: Unfolding

- Bin-by-bin correction method common in HEP:
  - Possibly strong model dependencies
  - Errors in general too optimistic
- Unfolding introduces:
  - No bias with respect to a particular model of the physical process and MC simulation
  - No or small bias, with respect to general requirements of the solution (smoothness, ...)

"Correction factors – a disaster. ...The data will tend to follow the MC that gave you the correction factors..."
(R. Barlow, SLUO lecture 9 (2000) SLAC)

	Bin-by-Bin method	Unfolding with regularization, m > n
Measurement errors taken into account	no	yes
small bin-to-bin correlations	no	yes
unbiased w.r.t. Model	no	yes
simple	yes	no

- For a discrete measurement with n bins:

$$\boldsymbol{Ax = y} \;\rightarrow\; \boldsymbol{x = A^{-1}y} \qquad \boldsymbol{V}_x = \boldsymbol{A}^{-1}\boldsymbol{V}_y(\boldsymbol{A}^{-1})^T$$

x = n-histogram of true variable x
y = m-histogram of measured variable y
A = m × n response matrix

$\boldsymbol{V}_x$ = error propagation for true variable x
$\boldsymbol{V}_y$ = error of measured variable y

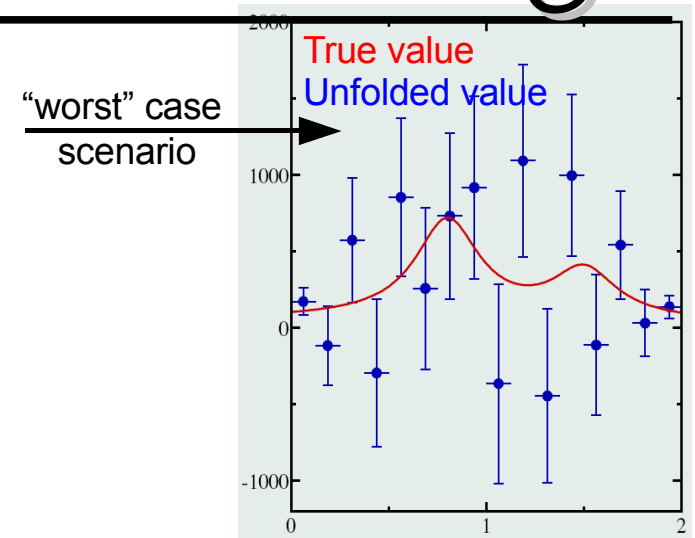
→ Use the best correction method with (almost) no bias: **Unfolding method**

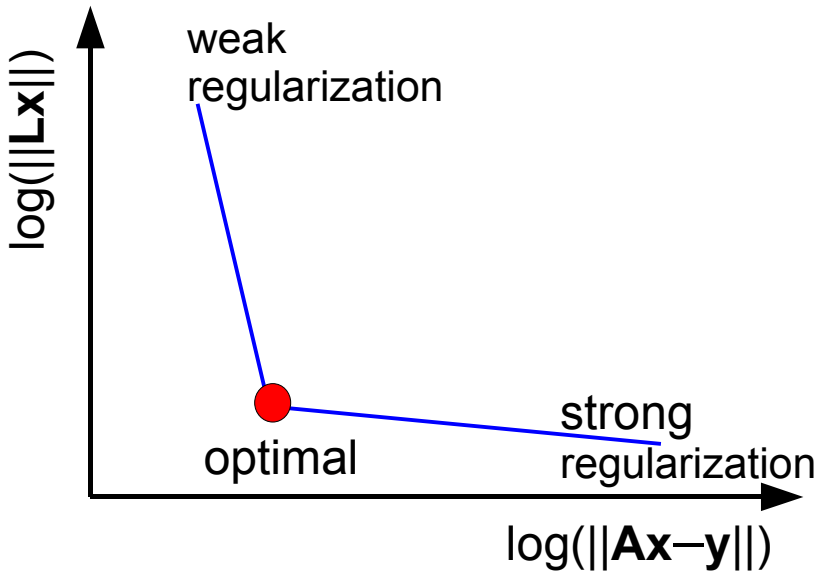
Current field of work: Unfolding

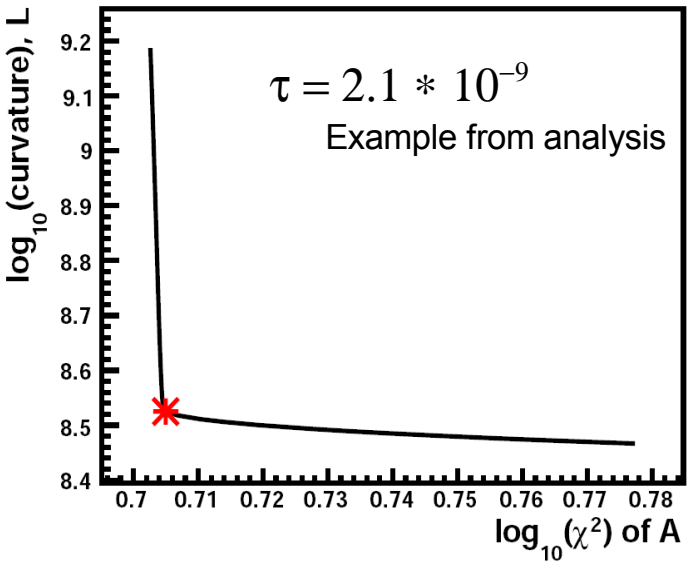
- Bin size = resolution → huge fluctuations originates from contributions of not significant bins
- Use regularization (or if possible: larger bins):

$$F(x) = \|\boldsymbol{Ax} - \boldsymbol{y}\|^2 + \tau \|\boldsymbol{Lx}\|^2 = min \qquad \tau > 0$$

- Optimal value of τ: L–curve method:



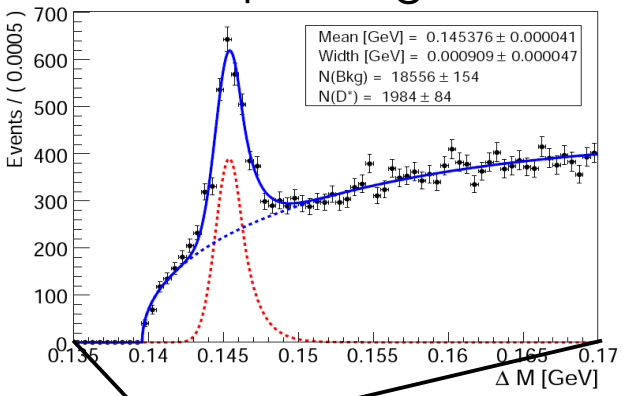


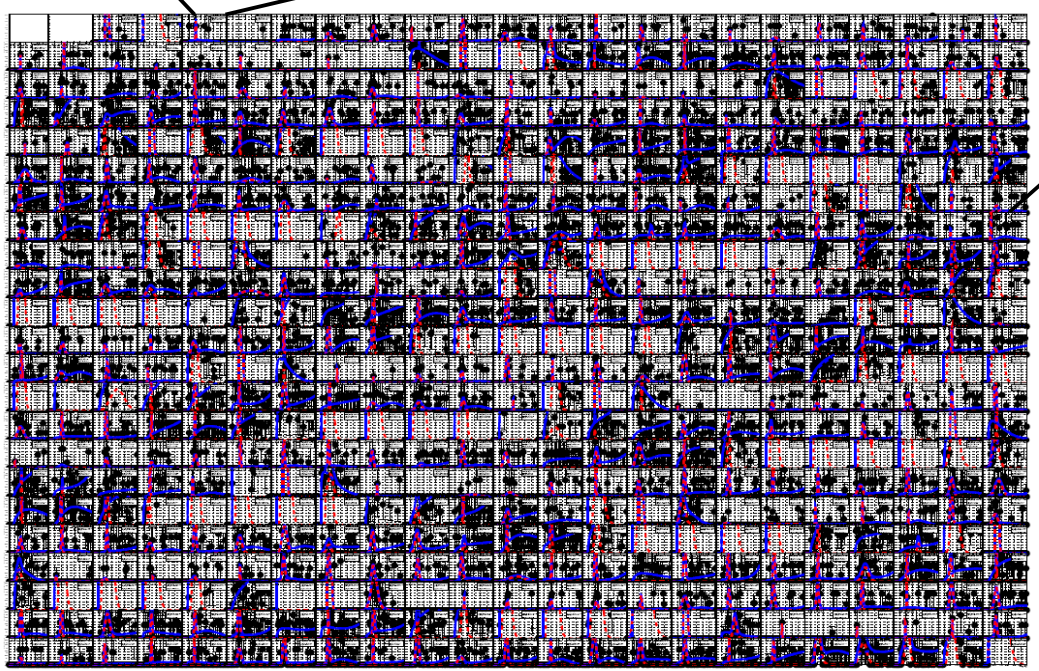


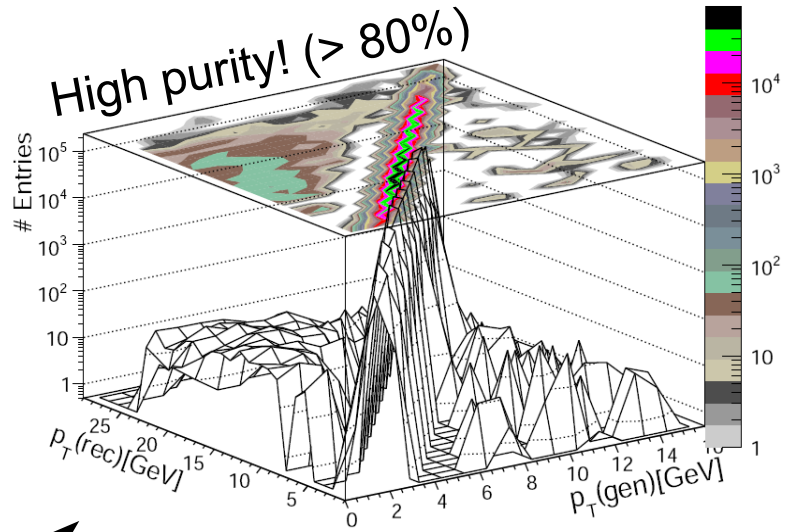
→ Several conditions for the regularization possible – choice is non-trivial & depends on the problem/analysis

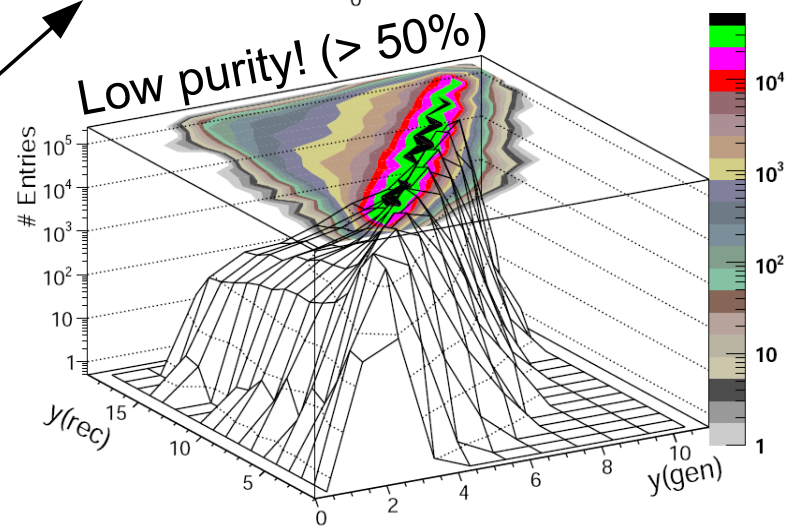
Current field of work: Unfolding

- Not a "counting" measurement, need fits in ΔM distributions to "get" the response matrix **A**
- O(500) fits per single differential distribution





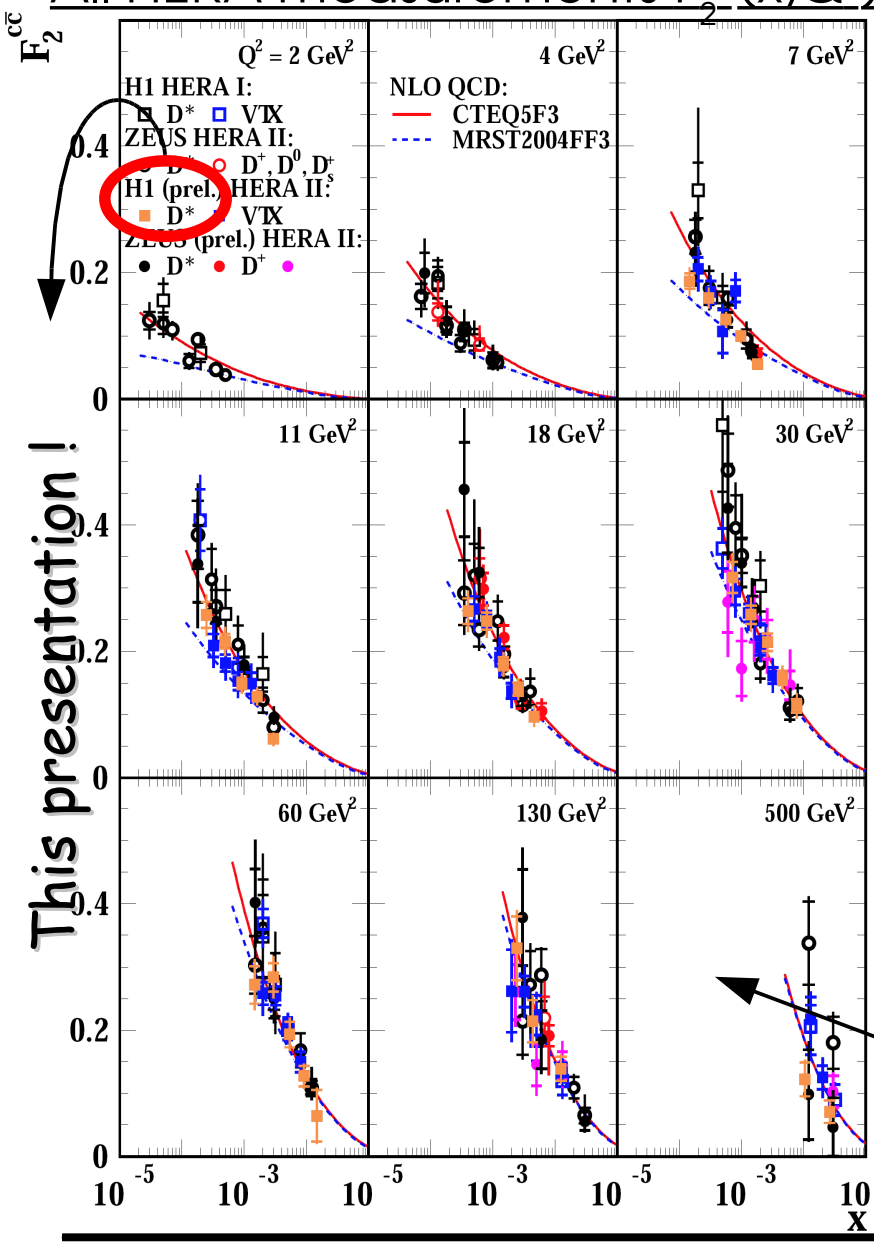




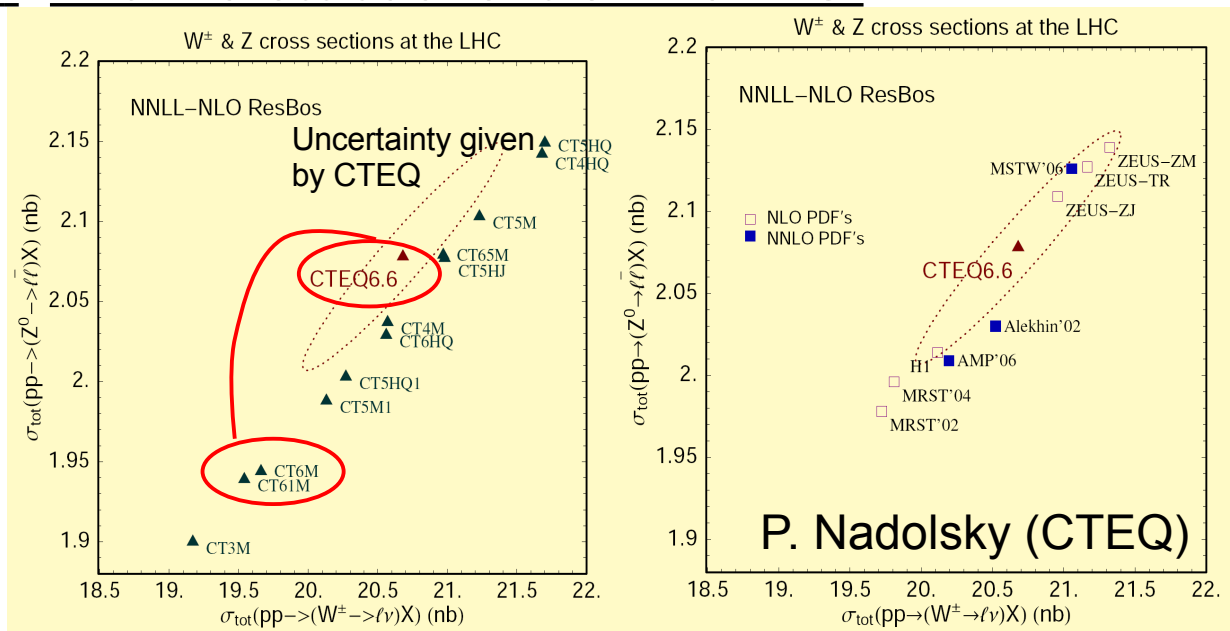
- Not limited in η(D*) or p_T(D*) but in y (especially at low y)

Impact of charm for global fits

All HERA measurements $F_2^c(x,Q^2)$: W & Z cross sections at the LHC:



This presentation !



→ Global analysis of structure function data:

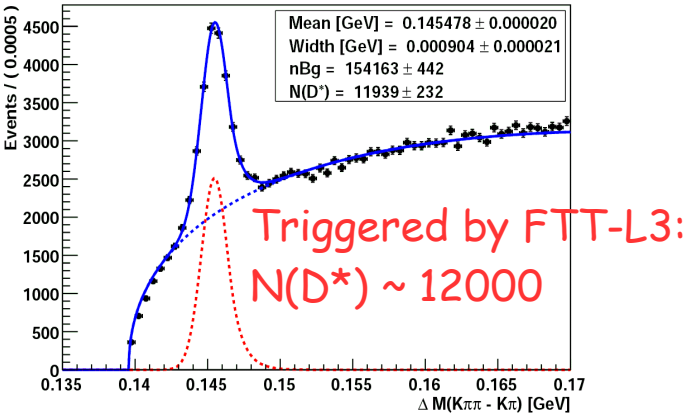
- CTEQ6.6: **massive** HF scheme
- CT6M & CT61M: massless HF scheme

Cross section prediction for LHC can change quite largely & outside cited CL

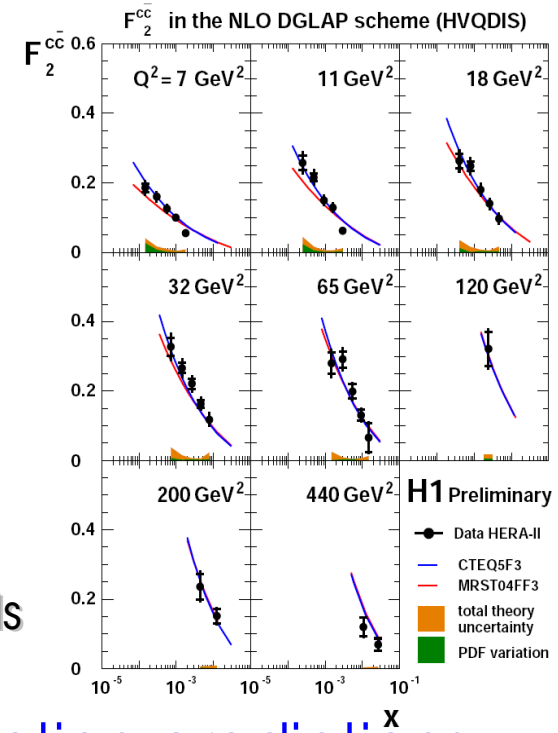
- Increase precision by combination of data (ongoing)
- Gain in systematic error by "cross-calibration" with ZEUS

Conclusions

- The Fast Track Trigger:
  - The "working horse" trigger at H1
  - Fully operational at all 3 layers
  - large data samples of exclusive final states like ρ, ϕ , J/ψ, D* and b mesons



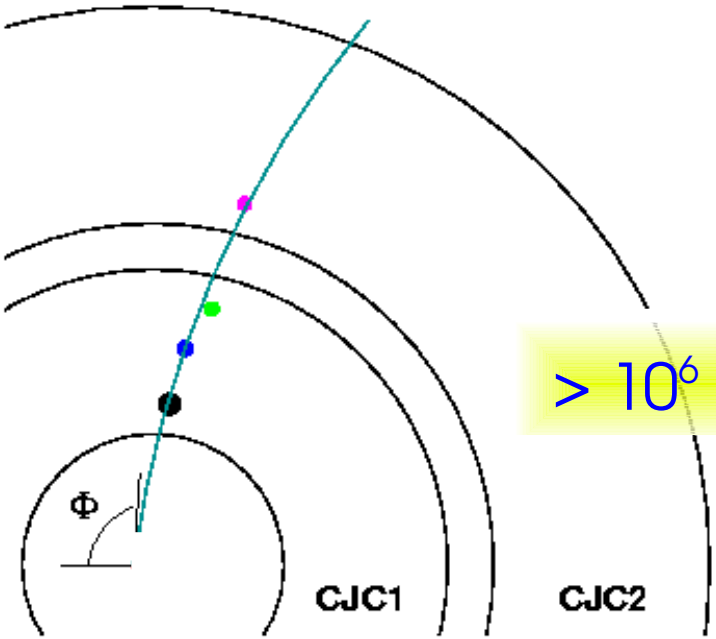
- D* cross section results:
  - Systematic Uncertainty decreased!
  - Good description of the data except forward region
  - Single most precise $F_2^c(x,Q^2)$ measurement at HERA
  - Forthcoming publication:
    - more insights into forward region
    - $F_2^c(x,Q^2)$: significantly smaller differences between models



→ Precise PDFs vital for LHC cross section predictions

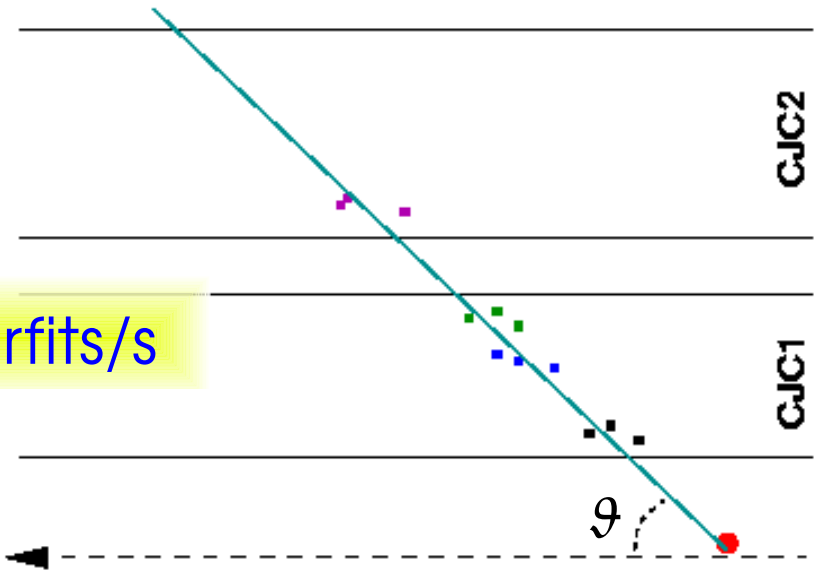
Backup

FTT-L2: Track fitting



Circle fit in transverse plane

> 10^6 3dim-Spurfits/s



Linear fit in longitudinal plane

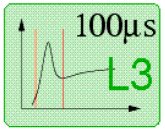
non iterative Karimäki Algorithm:

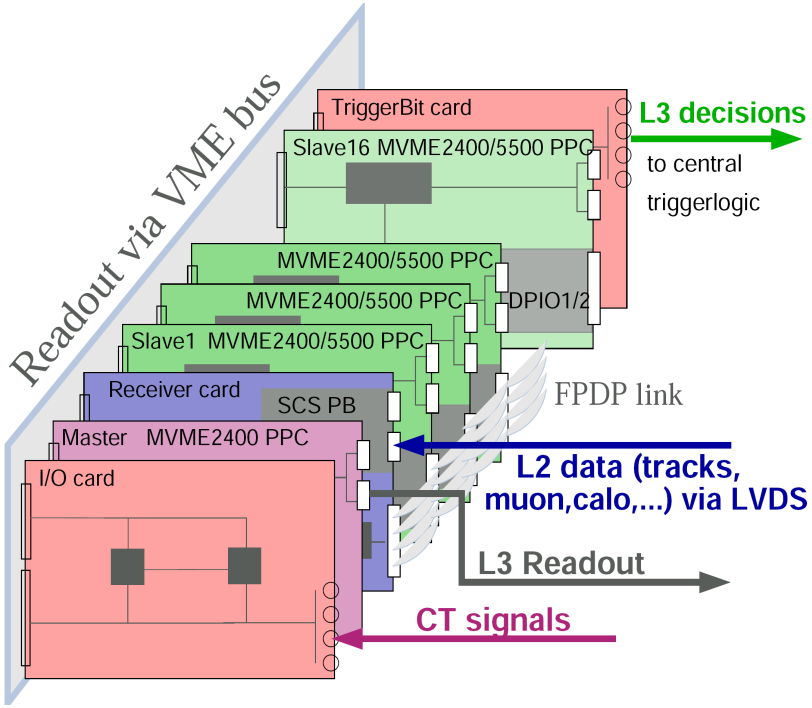
- Input:
  - x,y values of linked track segments
  - beam position (constant)
- Result:
  - Curvature ~ p_t^{-1}
  - Azimuthal angle ϕ

Linear fit:

- Input:
  - z-values of track segments (measured with charge division)
  - z-Vertex position (calculated by FTT!)
- Results:
  - Polar angle ϑ

FTT-L3: Read out





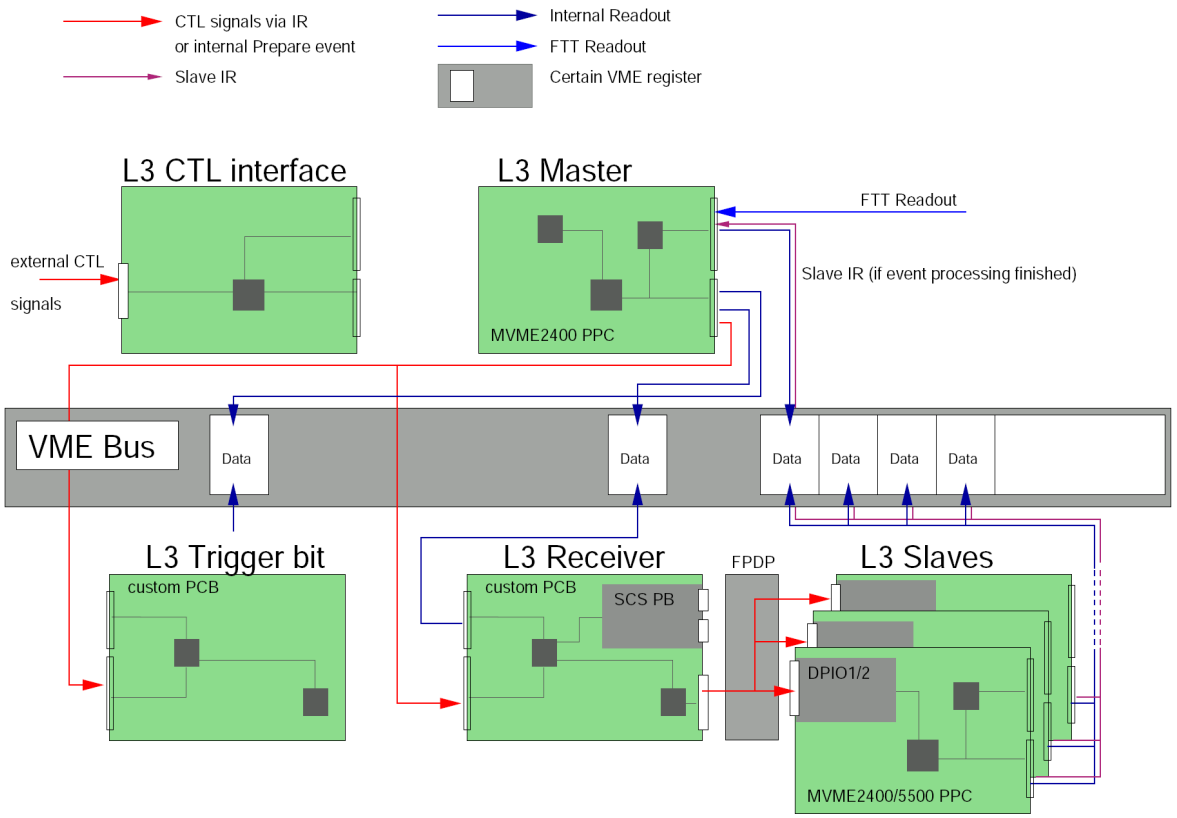
Readout information:

- Internal bank structure
- Input & all derived quantities
- Trigger decisions
- Typically 1kB/event of trigger data

The readout concept:

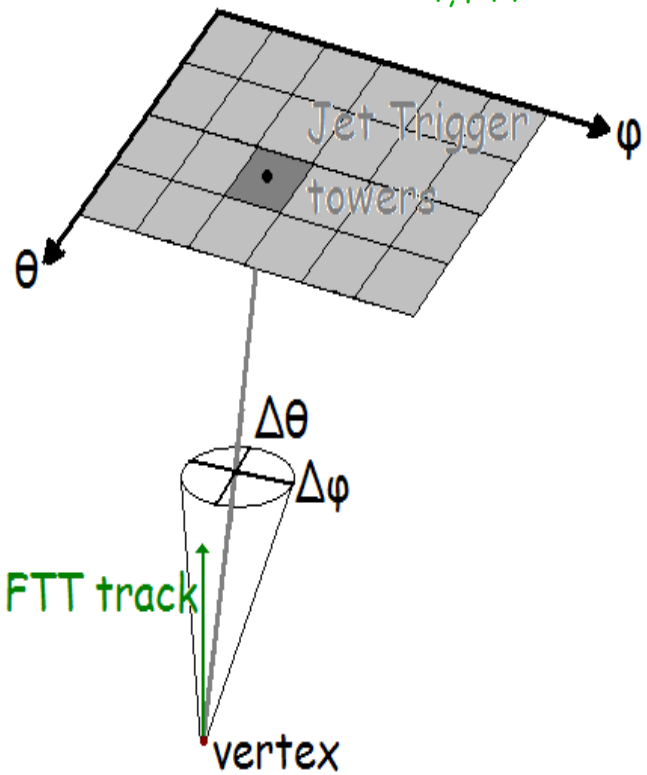
- Readout based on interrupts: Slave signals Master with IR that it is ready
- Afterwards all other cards readout

L3 Readout concept:



FTT-L3: Particle ID for electrons

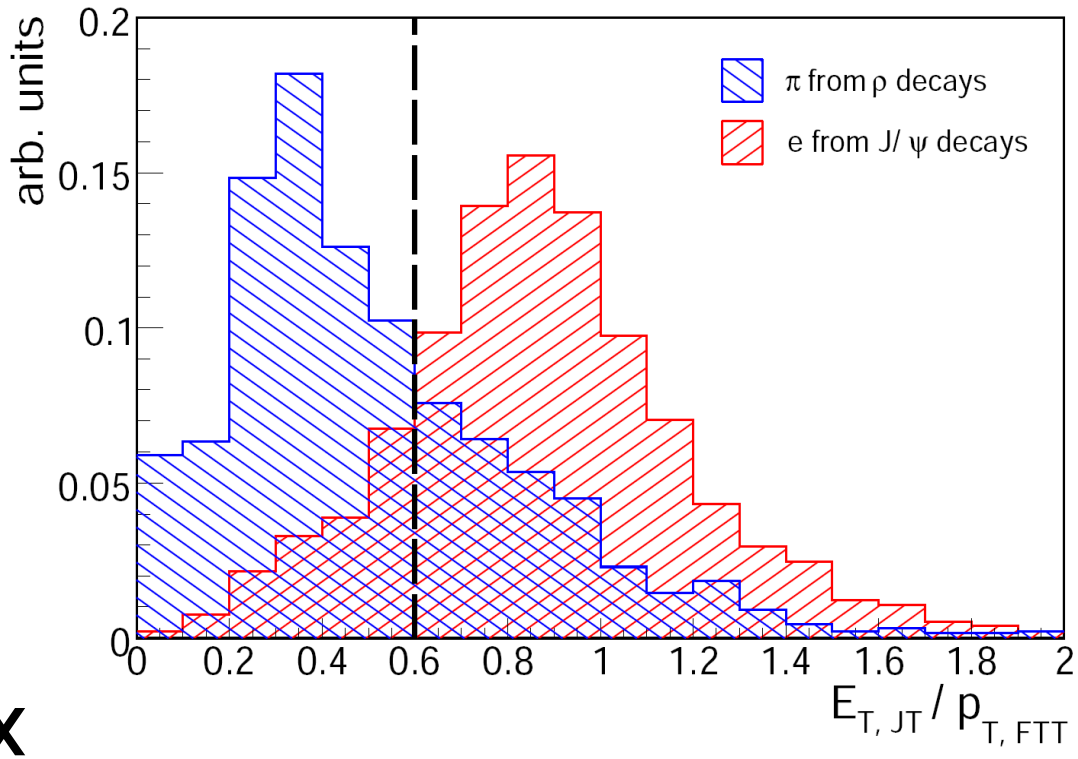
Combination of Calorimeter energy depositions ($E_{T,Kalo}$, θ, φ) and track information ($p_{T,FTT}$) in L3:



Allows to cut on:

- $p_{T,FTT}$ and opening angle: Δφ, Δθ
- $E_{T,Kalo}/p_{T,FTT}$ (Peak at ~1 for Electrons)

- **Separation between Pions & Electrons:**



Focus: **electron ID at low p_T**

b-tagging for b -> eX

Fits of asymmetric shapes:

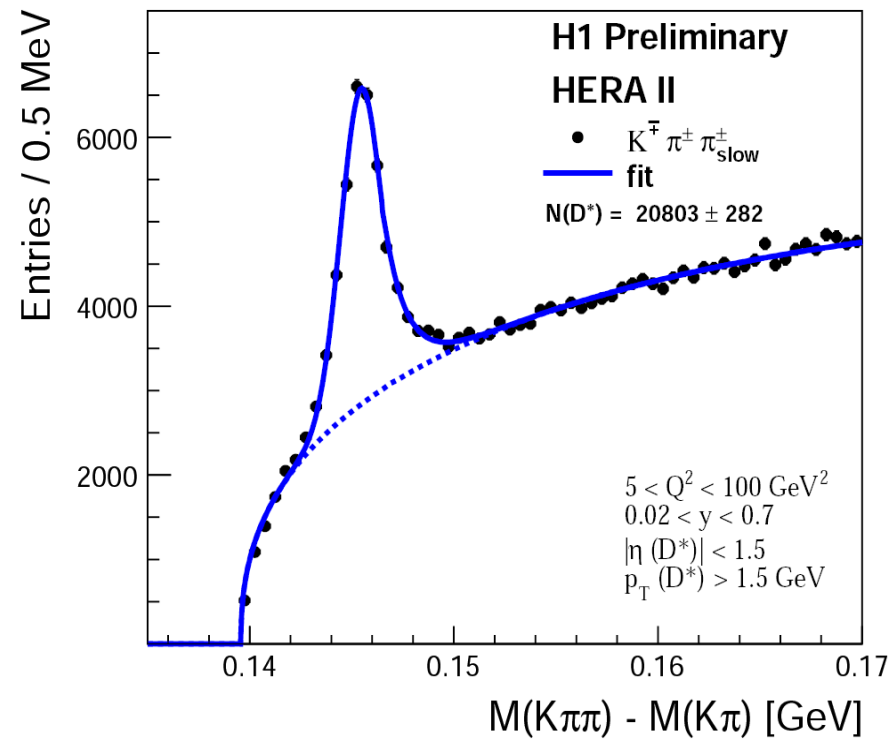
asymmetric Peak:

Crystal-Ball:

$$f(x) = \begin{cases} \frac{\left(\frac{n}{|\alpha|}\right)^n \exp\left(-\frac{1}{2}\alpha^2\right)}{\left(\frac{n}{|\alpha|} - |\alpha| - \frac{x-m}{\sigma}\right)^n} & \text{if } \frac{x-m}{\sigma} < -\alpha, \quad \text{exponential decay} \\ \exp\left(-\frac{1}{2}\left(\frac{x-m}{\sigma}\right)\right)^2 & \text{if } \frac{x-m}{\sigma} \geq -\alpha \quad \text{Gauss distribution} \end{cases}$$

Background (Granet Parametrisation:)

$$f(x) = p_0 \cdot (x - m_{\text{Cutoff}})^{p_1} \cdot e^{-p_2 \cdot x \, (-p_3 \cdot x^2)}$$



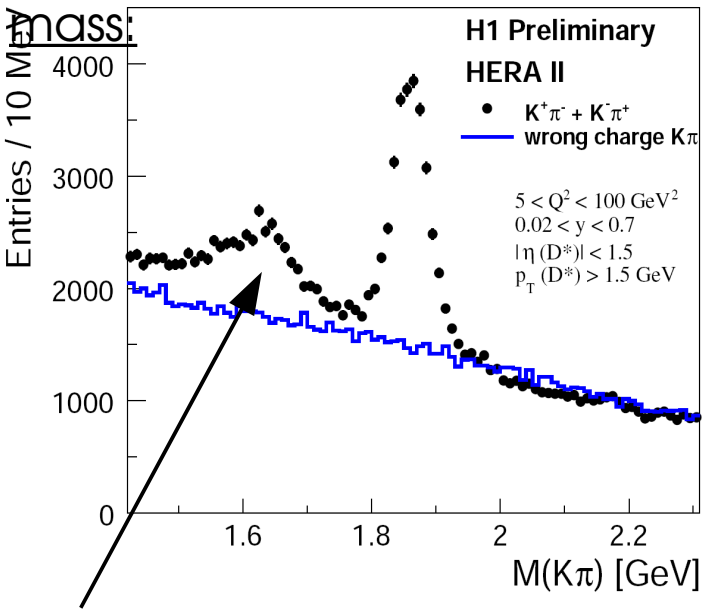
- Signal function: Gauss with exp. tail
- α determines where they are fit together in units of σ
- Un-binned likelihood fit of signal & background function
- Describes MC and data well

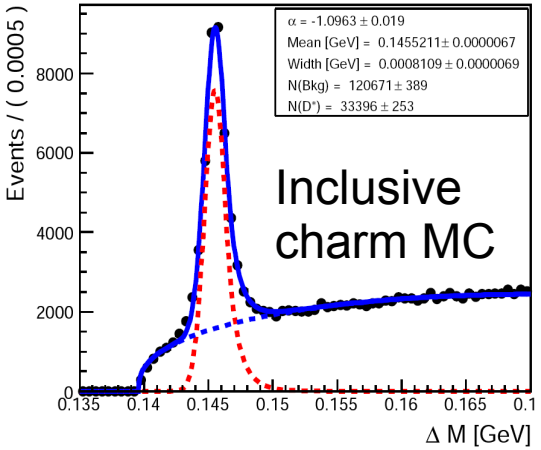
RooFit comes from the BaBar collaboration:

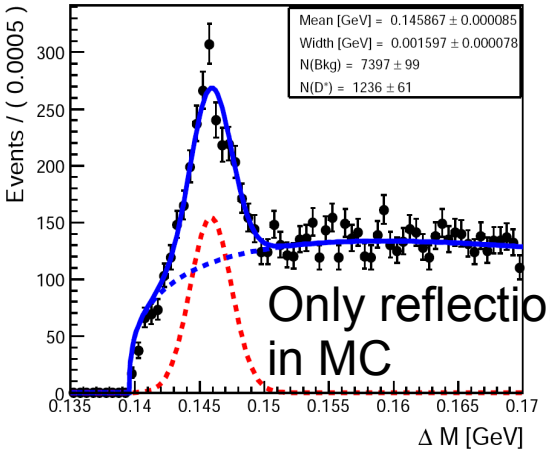
- Developed by W. Verkerke and D. Kirkby
- basically everything is a C++ object: Data, Integrals, Fits, p.d.f.'s
- Relies on ROOT, but extends the ROOT functionalities for fitting, minimization, etc.
- Nice Framework with single line commands

Reflections

D* selected by window in D^0 mass:







Other decay channels (reflections):

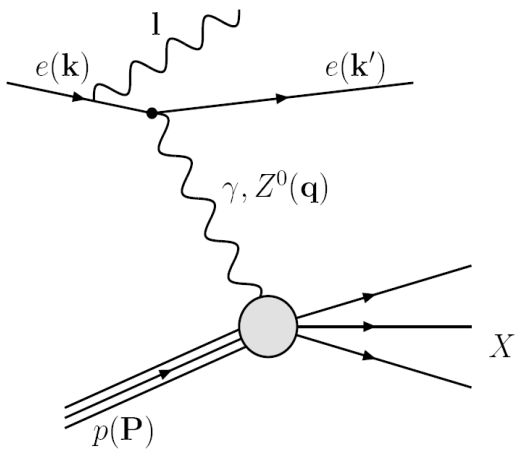
	decay	Branching fractions
golden channel:	$D^{*\pm} \to D^0 \pi^{\pm}_{\text{slow}}$	$(67.7 \pm 0.5)\%$
	$D^0 \to K^{\mp}\pi^{\pm}$	$(3.8 \pm 0.07)\%$
other channels:	$D^0 \to K^{\pm}K^{\mp}$	$(3.84 \pm 0.10) \times 10^{-3}$
	$D^0 \to K^{\mp}\pi^{\pm}\pi^0$	$(14.1 \pm 0.5)\%$
	$D^0 \to \pi^{\mp}\pi^{\pm}$	$(1.36 \pm 0.03) \times 10^{-3}$
	$D^0 \to \pi^{\mp}\pi^{\pm}\pi^{\mp}\pi^{\pm}$	$(7.31 \pm 0.27) \times 10^{-3}$
	$D^0 \to \pi^{\mp}\pi^{\pm}\pi^0$	$(1.31 \pm 0.06)\%$
	$D^0 \to K^{\mp}e^{\pm}\overset{(-)}{\nu_e}$	$(3.51 \pm 0.11)\%$
	$D^0 \to K^{\mp}\mu^{\pm}\overset{(-)}{\nu_\mu}$	$(3.19 \pm 0.16)\%$
	$D^0 \to \pi^{\mp}e^{\pm}\overset{(-)}{\nu_e}$	$(2.81 \pm 0.19) \times 10^{-3}$
	$D^0 \to \pi^{\mp}\mu^{\pm}\overset{(-)}{\nu_\mu}$	$(2.4 \pm 0.4) \times 10^{-3}$

$$r = \frac{N^{\text{only refl.}}(D^*)}{N^{\text{all}}(D^*)} = 0.04$$

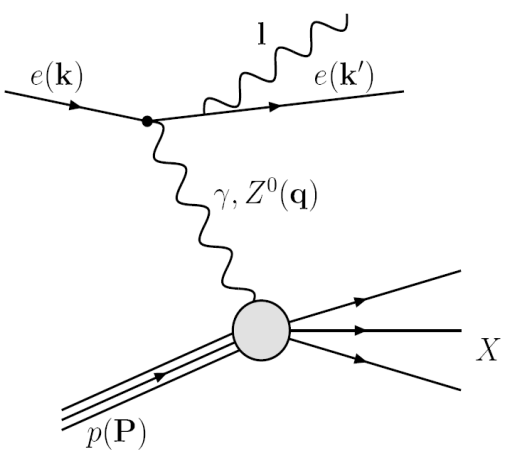
Radiative Corrections

Advantages of the eΣ-method:

Initial State Radiation:



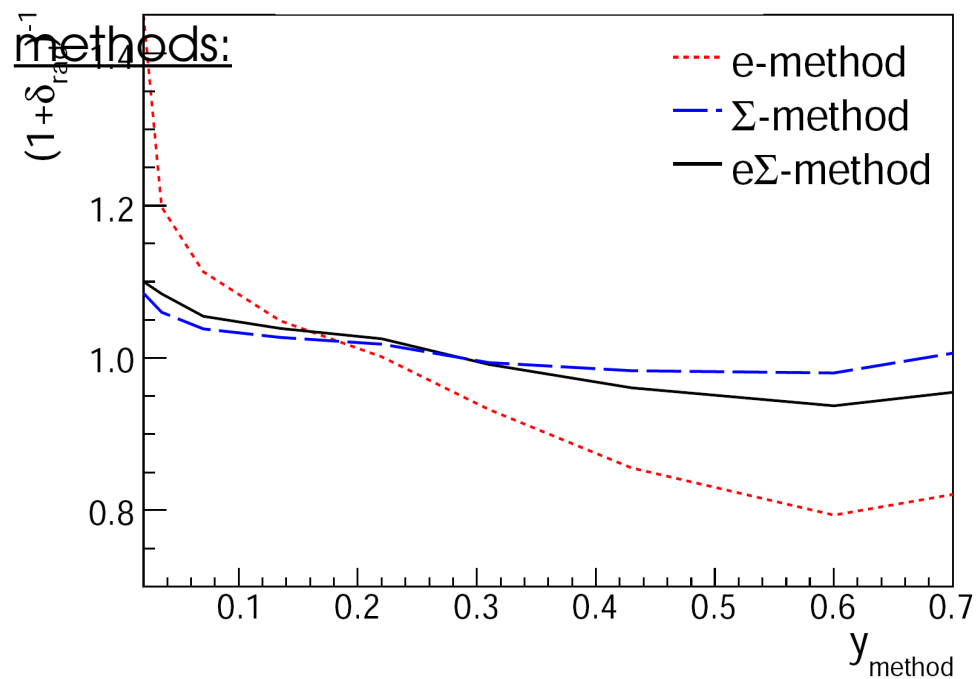
Final State Radiation:



Correction of NLO QED effects

$$\sigma_{\mathrm{Born+NLO}} = (1 + \delta_{\mathrm{rad}})$$

Size of correction with different methods:



→ - Compromise between resolution & size of corrections

- eΣ-method provides best resolution & small corrections

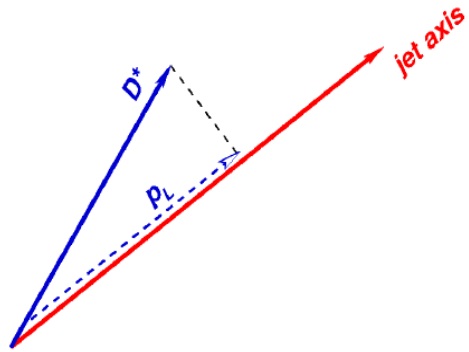
Fragmentation functions (FF):

Jet method:

- ▷ momentum of c-quark approximated by momentum of rec. D^*-jet

$$z_{\rm jet} = \frac{(E+p_{\rm L})_{D^*}}{(E+p)_{\rm jet}}$$

- ▷ $k_\perp$-clus jet algorithm applied in γp-frame ($E_t(D^* jet) > 3$ GeV)

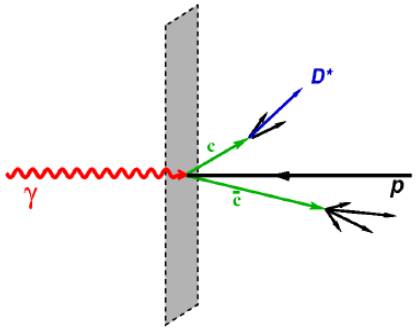


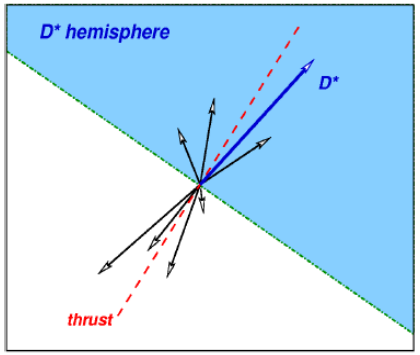
Hemisphere method:

- ▷ momentum of c-quark approximated by momentum of rec. D^*-hemisphere

$$z_{\rm hem} = \frac{(E+p_{\rm L})_{D^*}}{\sum_{\rm hem}(E+p)_i}$$

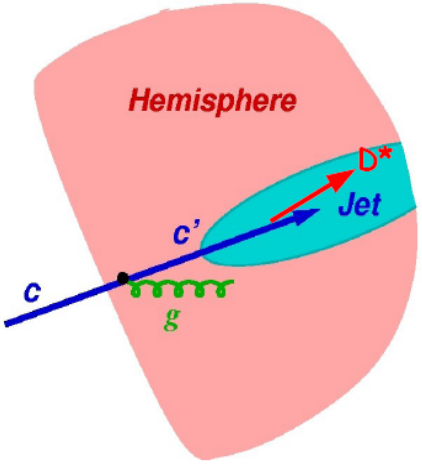
- ▷ $\eta(\text{part}) > 0$ for p-remnant suppression
- ▷ thrust axis in plane perpendicular to γ used for hemisphere division





Differences of the methods:

- Jet method & hemisphere method:

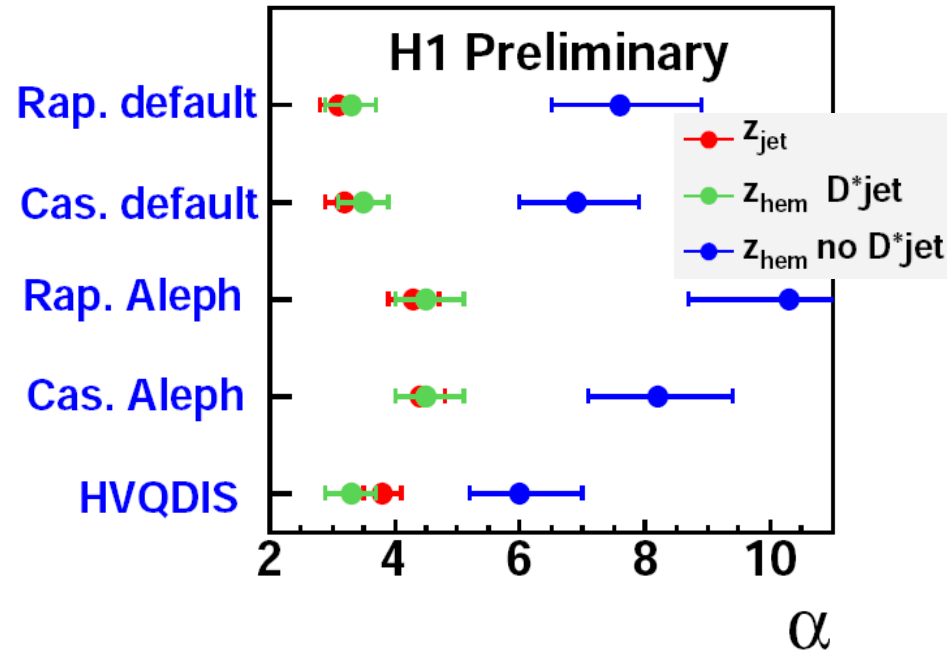


- Methods are different, i.e. hemisphere method sums more gluon radiation and does not need a hard scale (jet E_T-cut)
- Hem. method is sensitive to threshold region !

Fragmentation functions (FF):

- If **a hard scale** is involved:
  - jet- & hemisphere method agree well
  - FF also agrees with ZEUS and LEP data
- If **no hard scale** is involved:
  - discrepancy at charm production threshold in QCD models
  - much harder fragmentation

More information:
http://arxiv.org/abs/0808.1003v2



- Fragmentation uncertainty from FF values for charm production:

	HVQDIS:	CASCADE:
at-threshold:	$\alpha = 6.0^{+1.0}_{-0.8}$	$\alpha = 8.2 \pm 1.1$
above-threshold:	$\alpha = 3.3 \pm 0.4$	$\alpha = 4.6 \pm 0.6$

- Threshold position from $\hat{s}$ (cms energy of hard subprocess): $70 \pm 20\ \mathrm{GeV}^2$ $70 \pm 20\ \mathrm{GeV}^2$

Systematic errors

Uncorrelated errors:

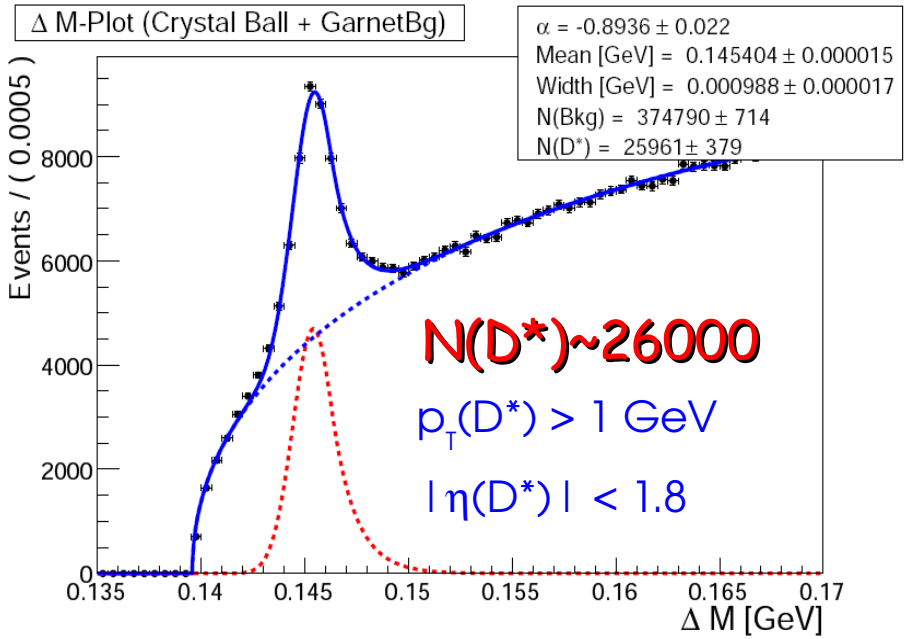
Track efficiency	2% per track	6%
Luminosity		3.2%
Radiative correction		2.5%
Branching ratio		2.3%
Primary-vertex fit efficiency		2.5%
Signal extraction		2%
Trigger efficiency		1.4 %
D^0 meson mass cut		1.0%
PDF uncertainty	Cteq6ll vs. Cteq65m	1%
Reflections		$< 1.0\%$
Photoproduction background		$\sim 0.15\%$

Correlated errors:

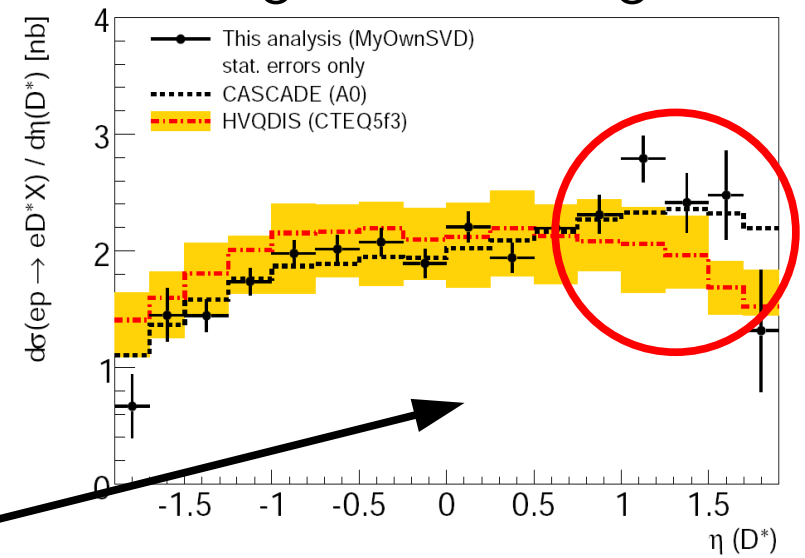
Model uncertainty	CCFM vs. DGLAP	$< 3\%$
Electromagnetic energy scale	$\pm 1\%$	1-2.5 % (6% at high y)
Scattering angle θ	± 1 mrad	$\sim 2\%$
Hadronic energy scale	$\pm 4\%$	1.0 % (10% at low y)

Error breakdown for the cross section measurement available in thesis:
https://www-h1.desy.de/psfiles/theses/h1th-504.pdf

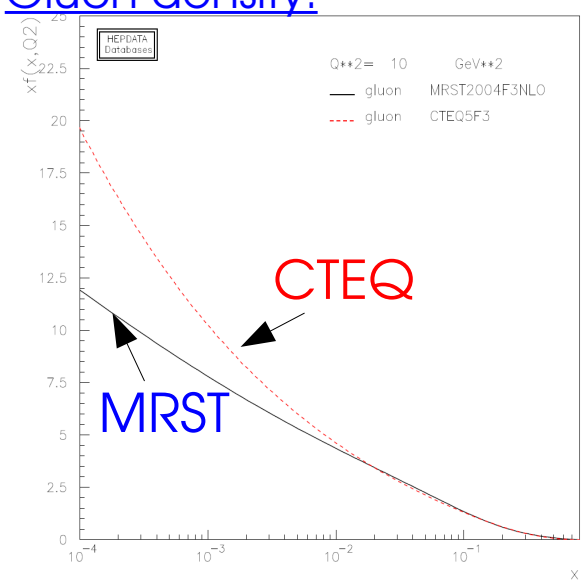
The extended region: not final!



Forward region interesting:



Gluon density:

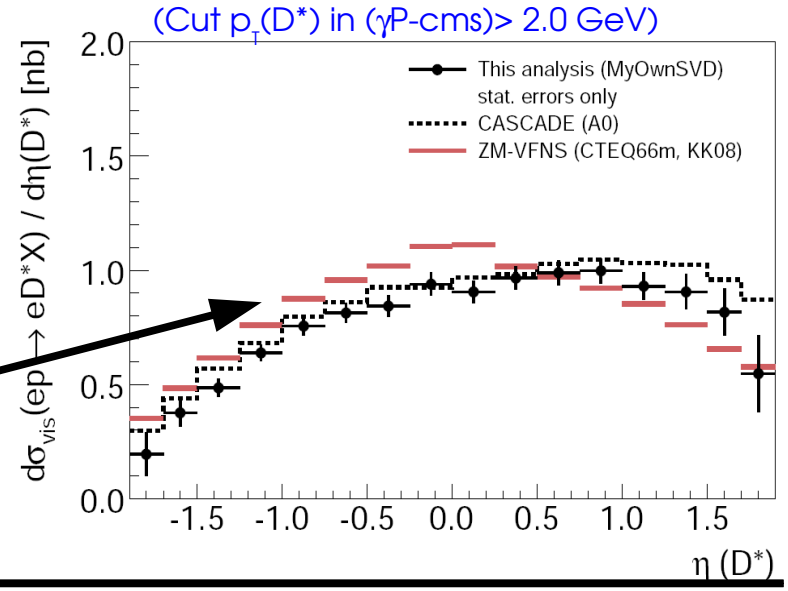
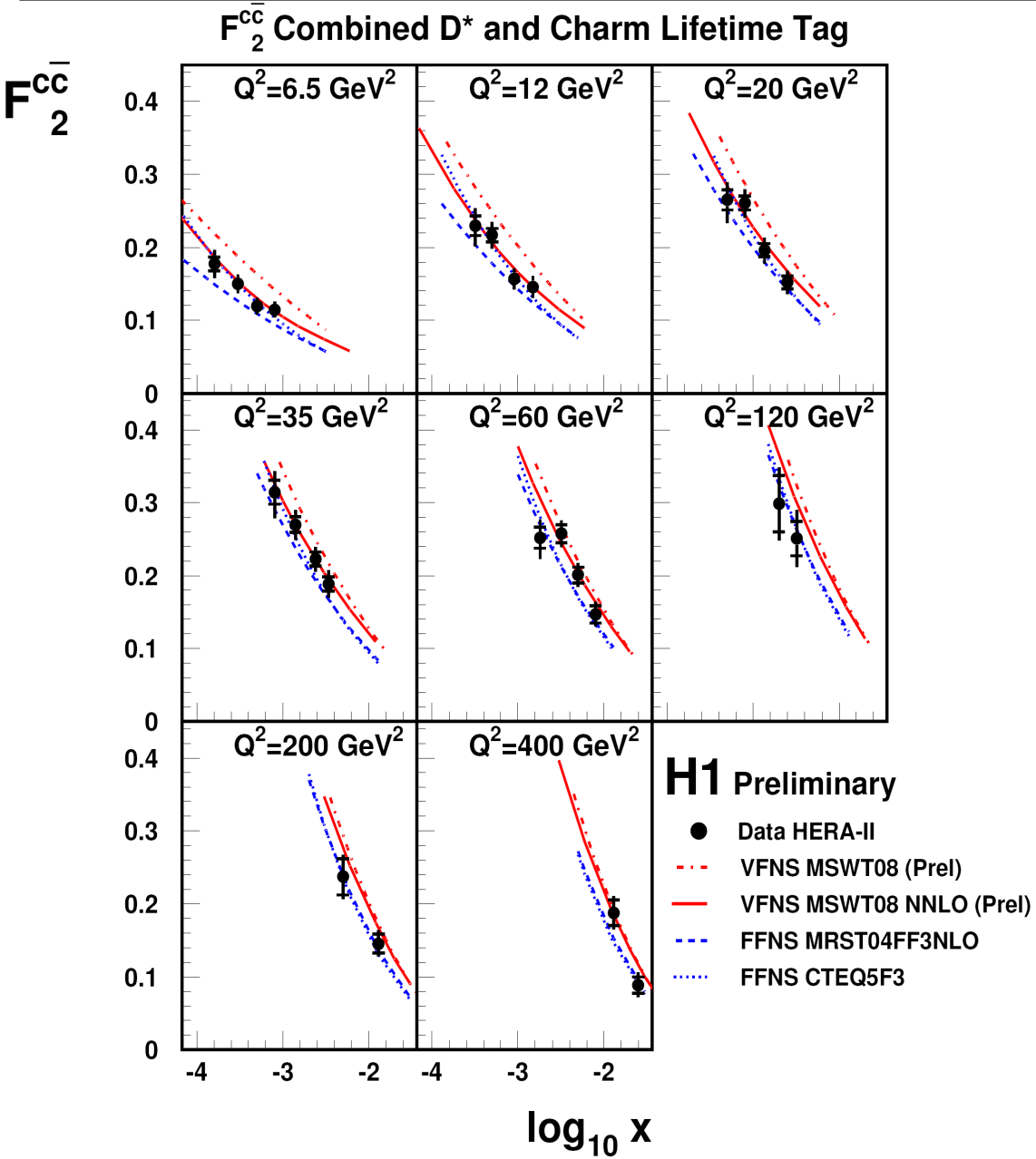


CASCADE vs. RAPGAP vs. HVQDIS: Fragmentation, parton shower, etc.

Massive vs. Massless HF schemes

(ZM-VFNS: G.Kramer & C.Sandoval)

(Cut $p_T(D^*)$ in (γP-cms)> 2.0 GeV)



Combination of charm data