

Online, September 8, 2021



Results on exclusive  $\rho(770)$  photoproduction  
and  
on collectivity in small systems obtained in ep collisions at HERA

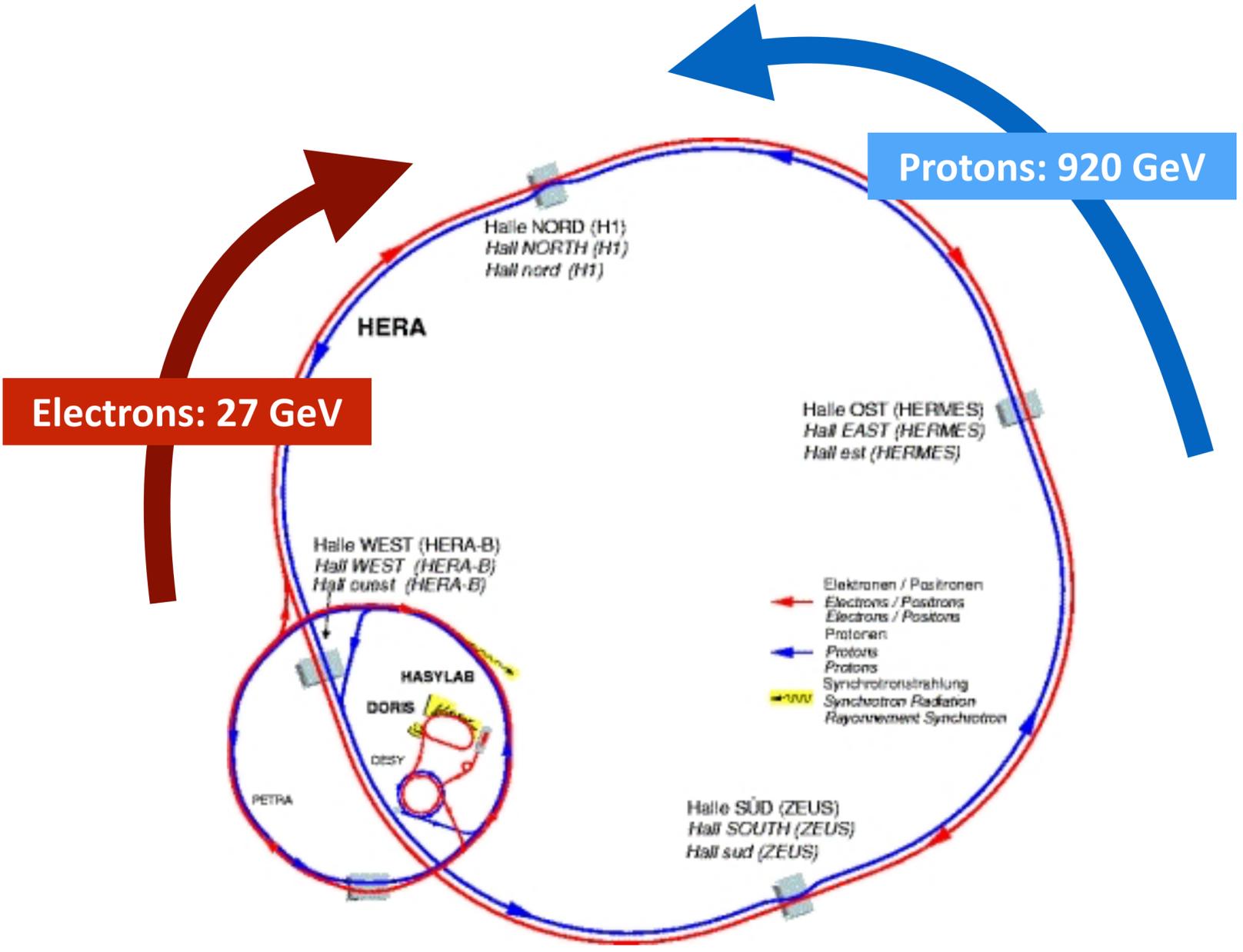


Guillermo Contreras  
Czech Technical University in Prague

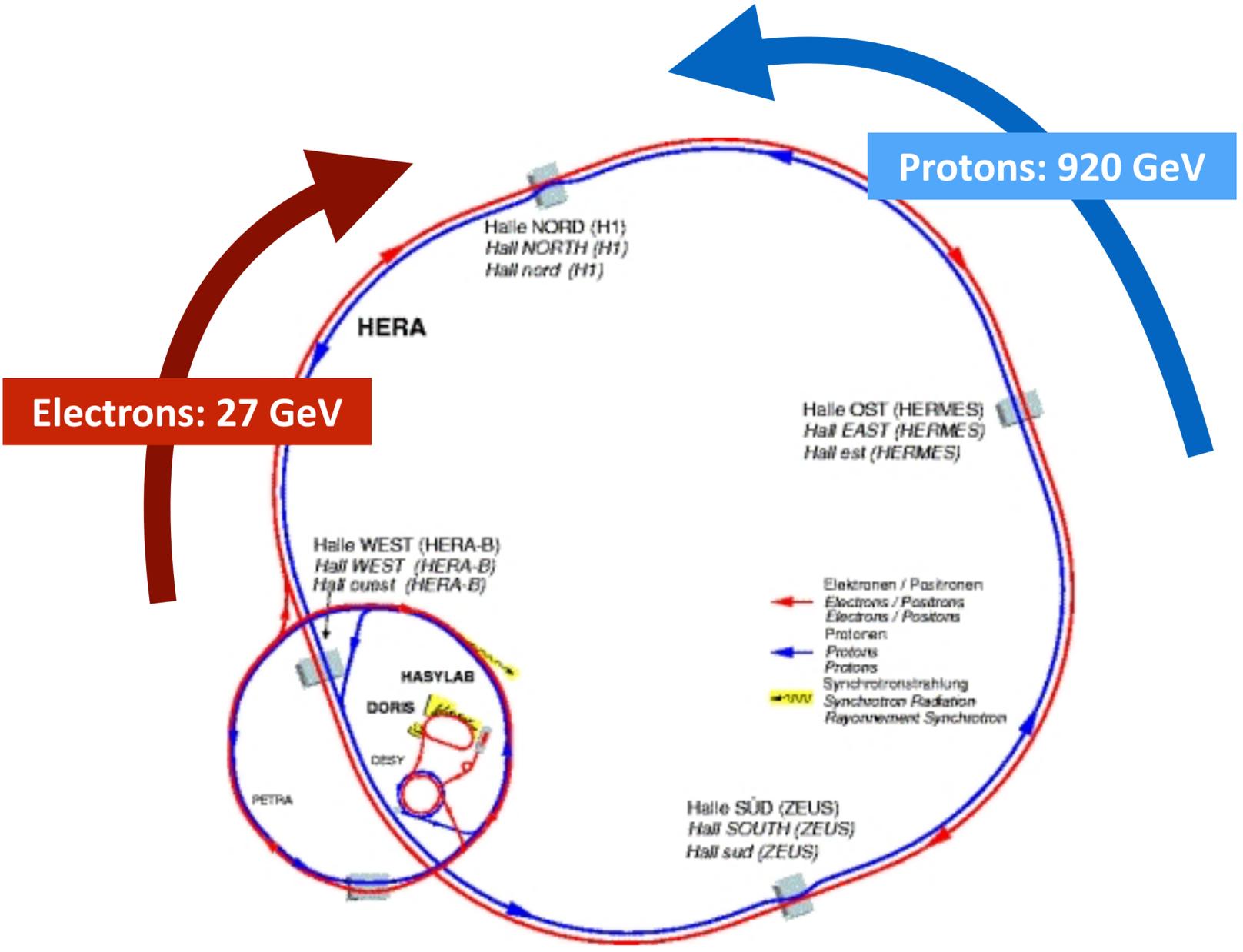
On behalf of the H1 Collaboration



# HERA and H1

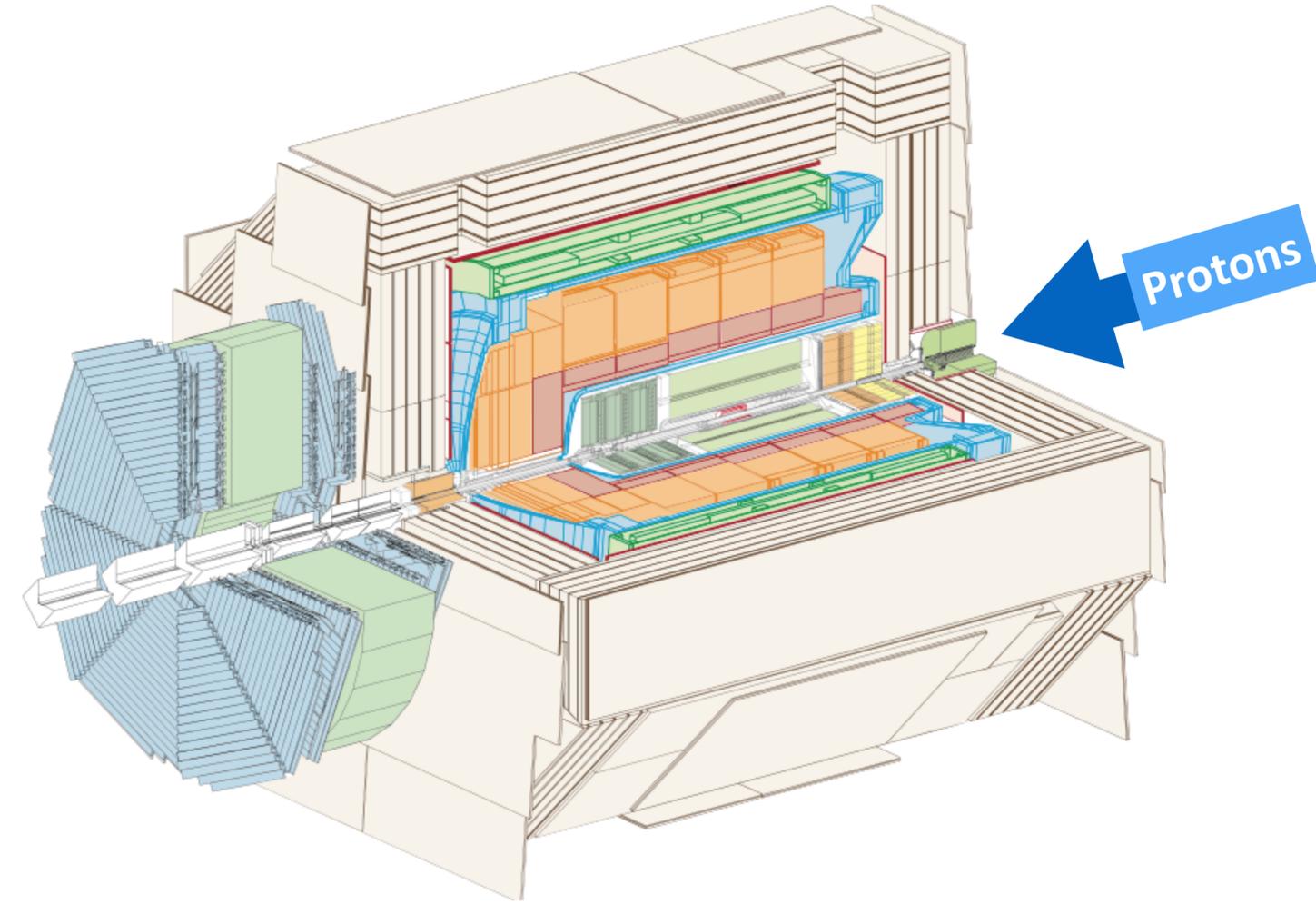
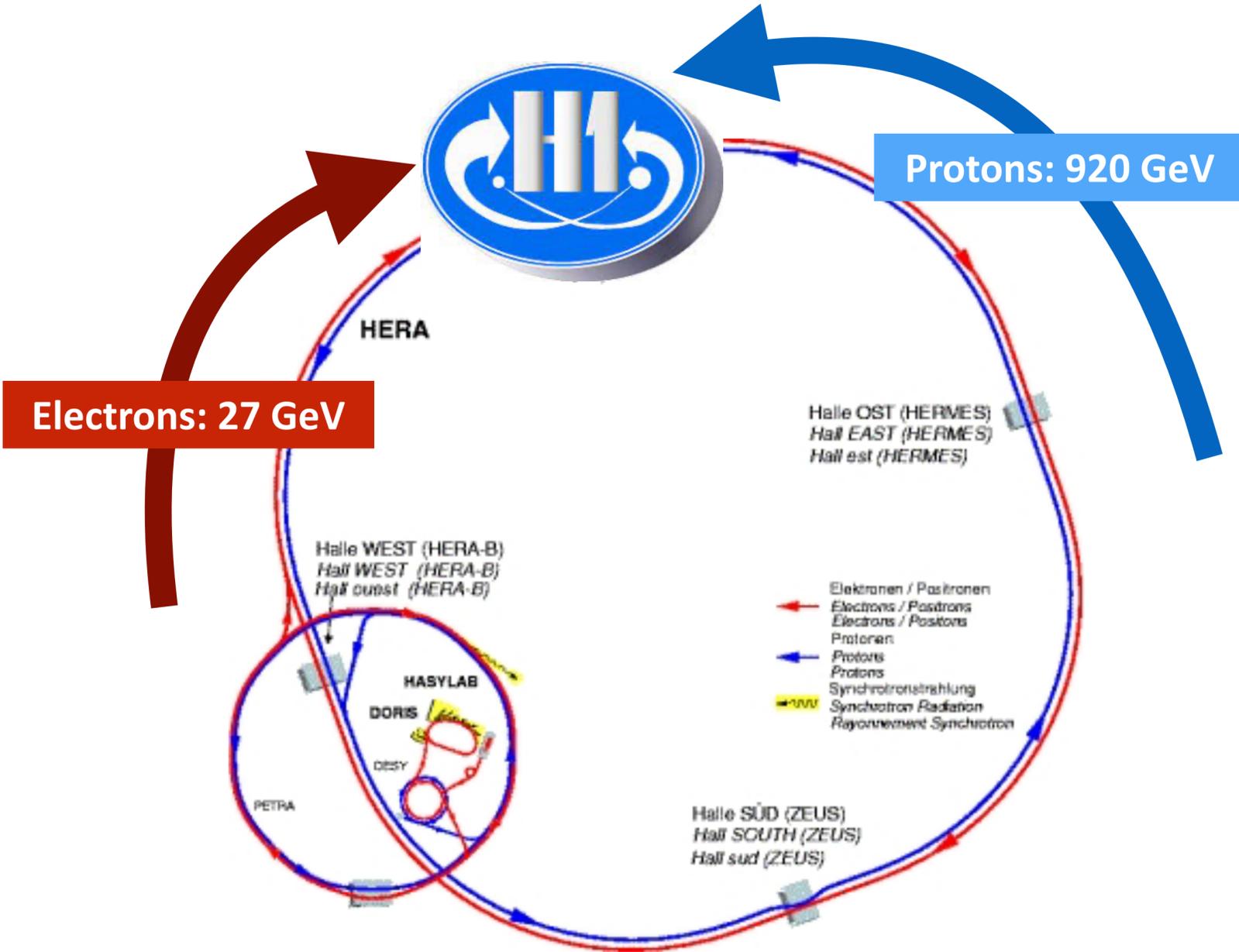


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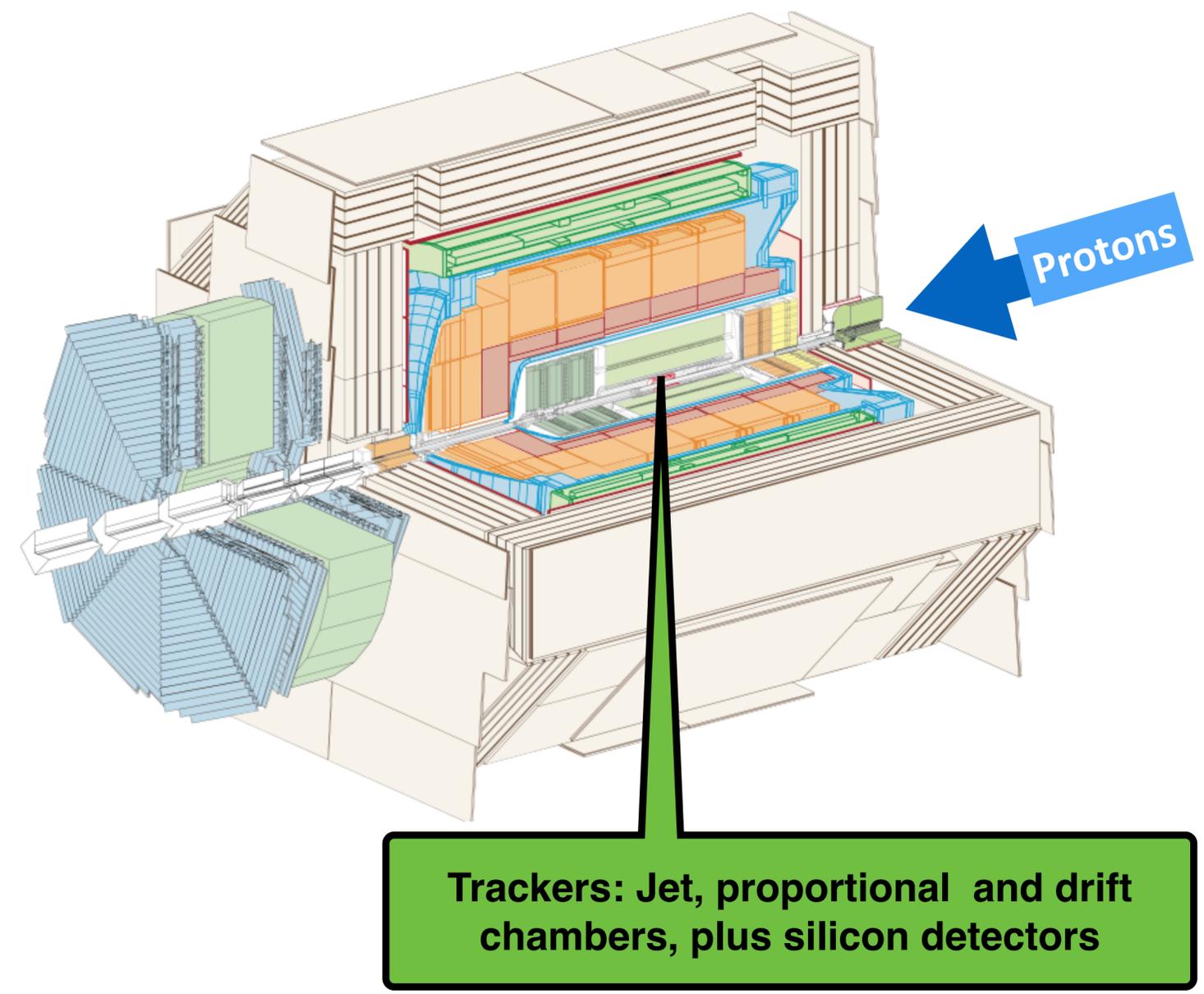
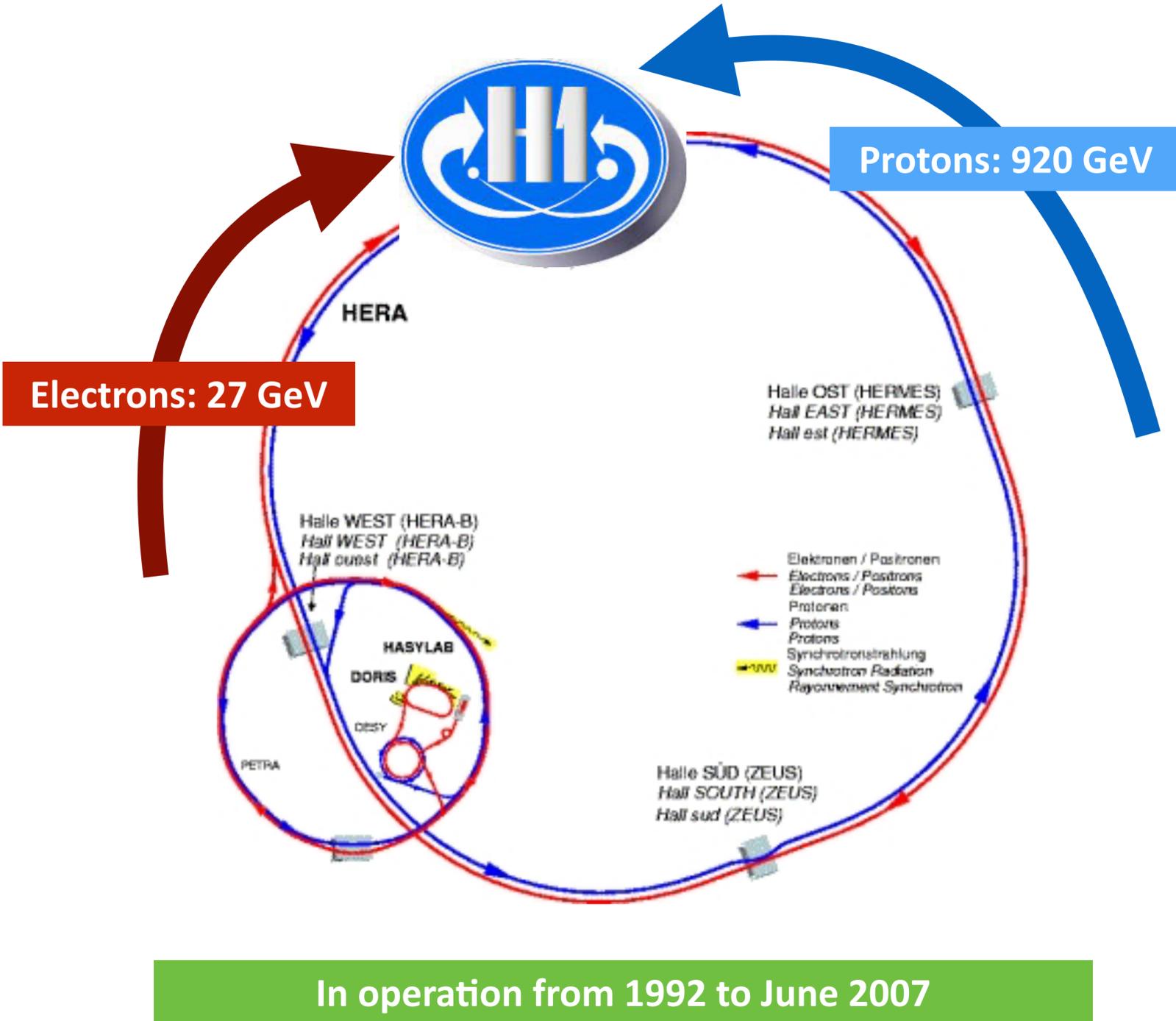
In operation from 1992 to June 2007

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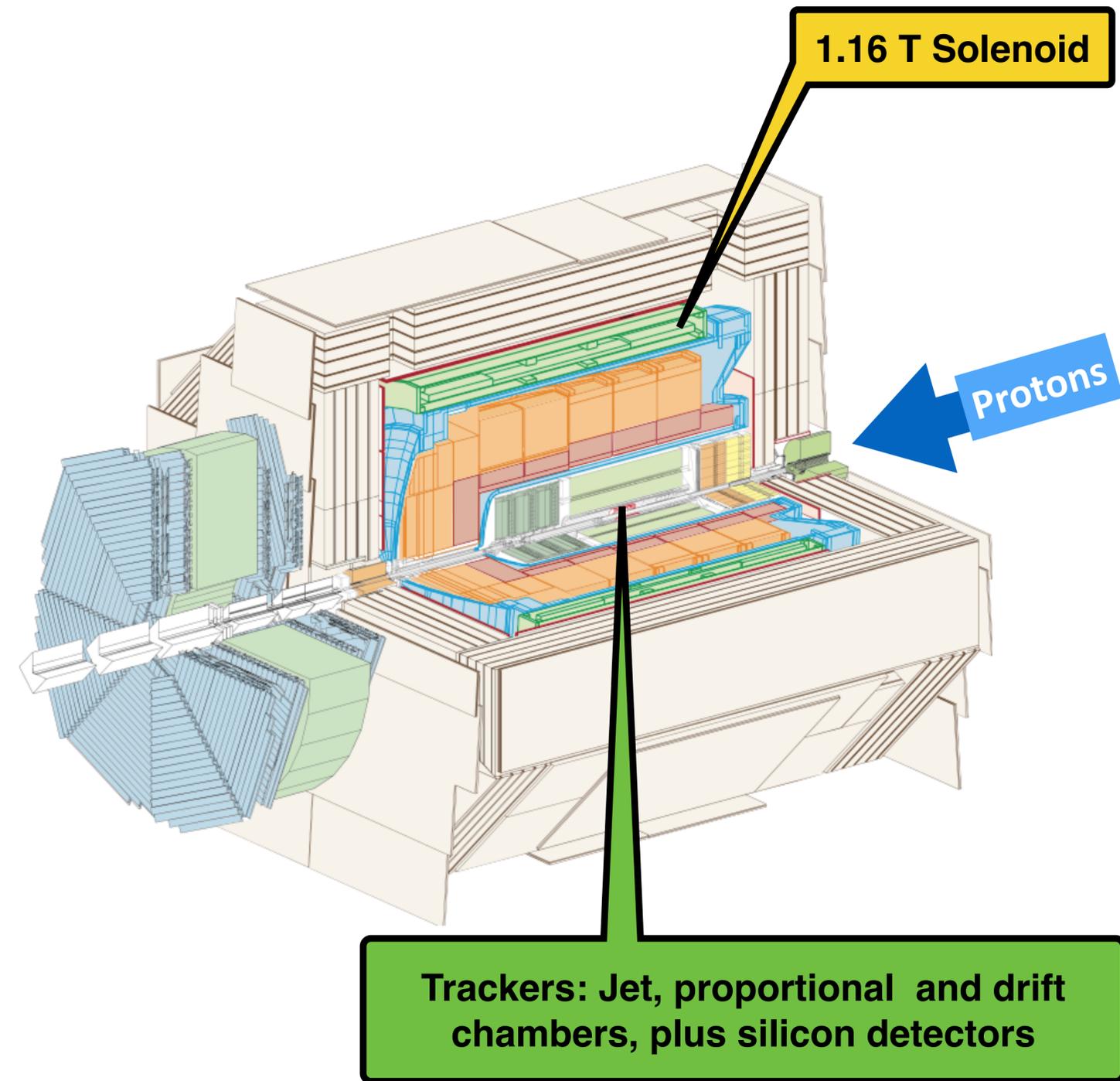
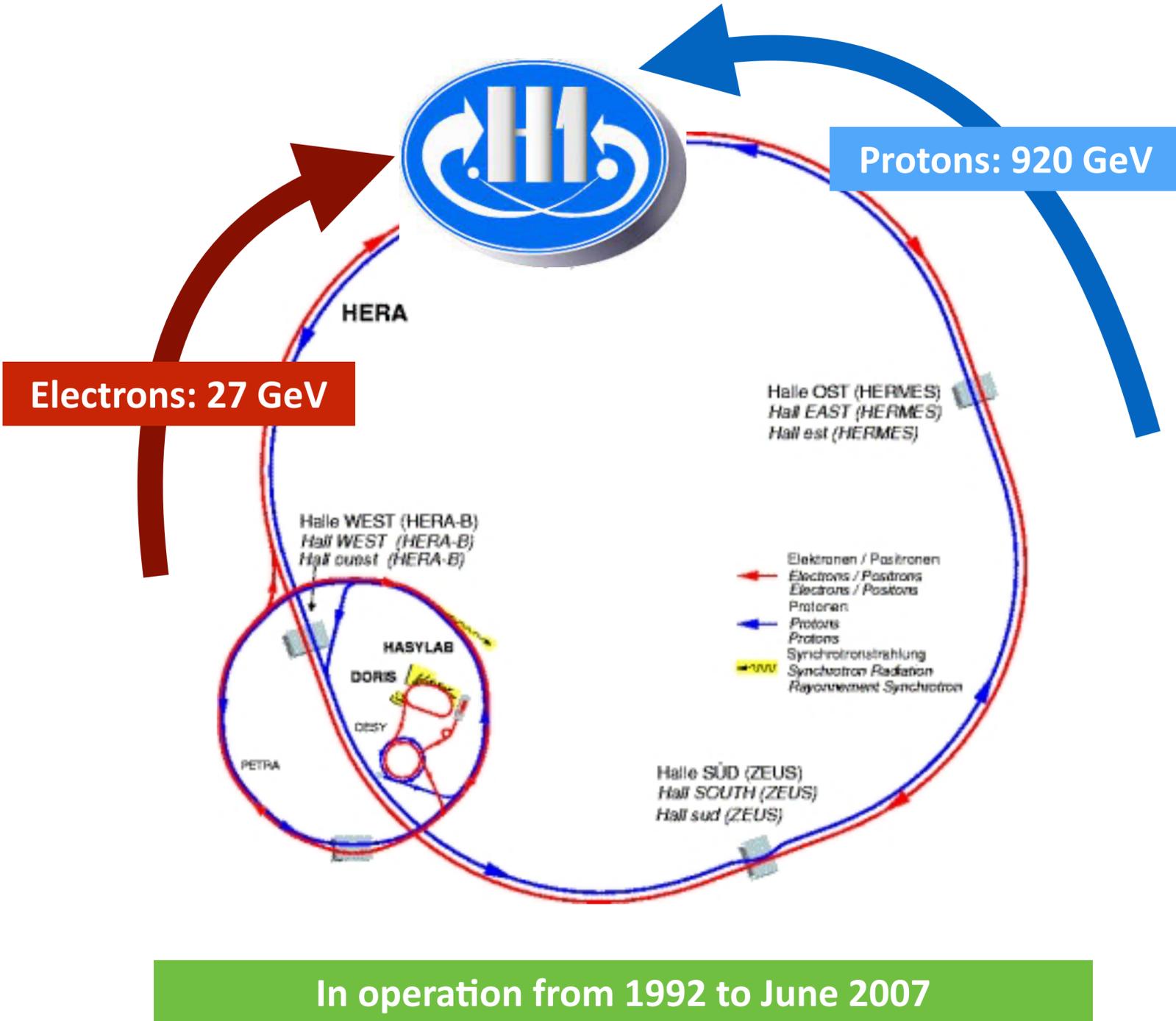


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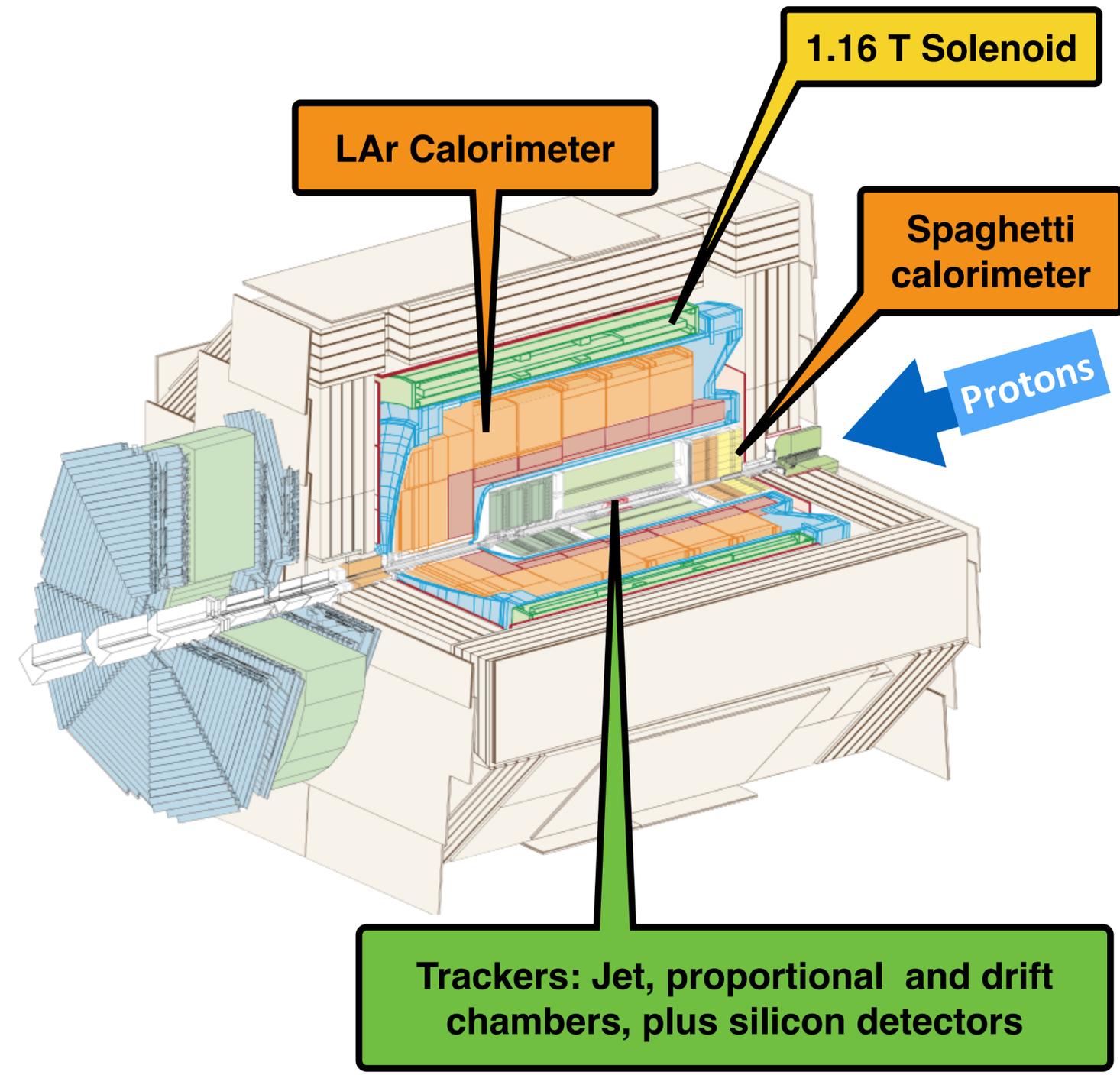
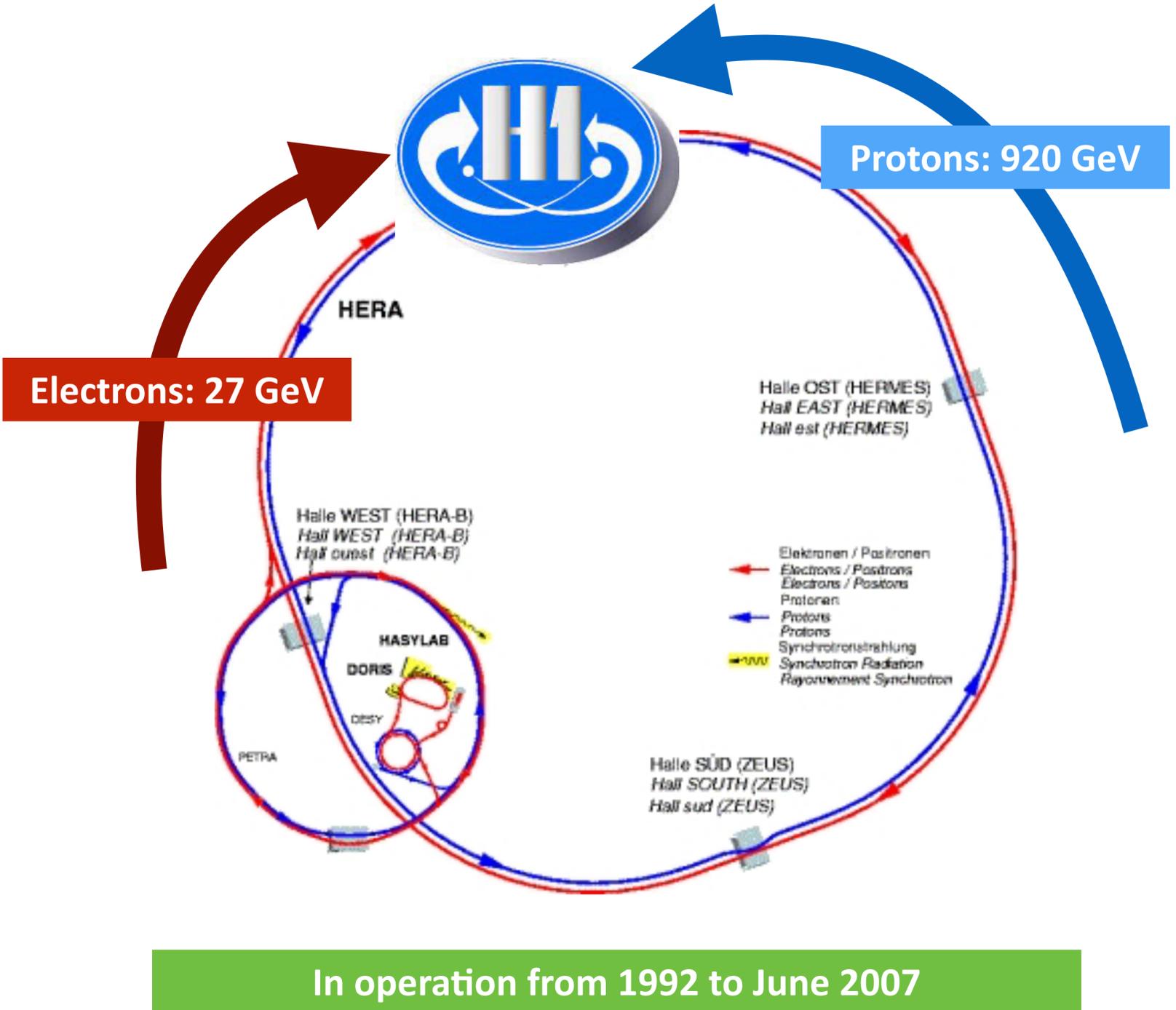
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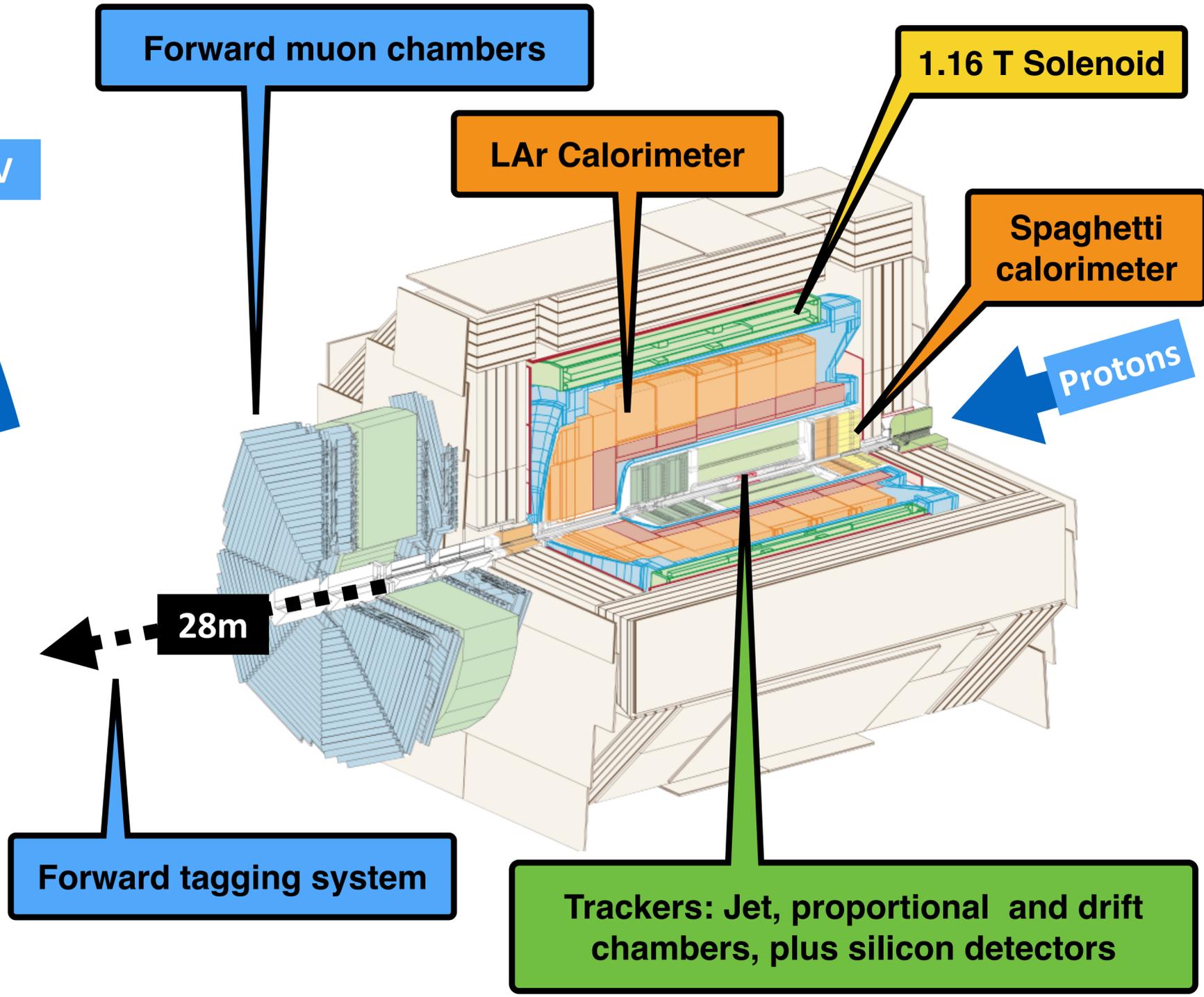
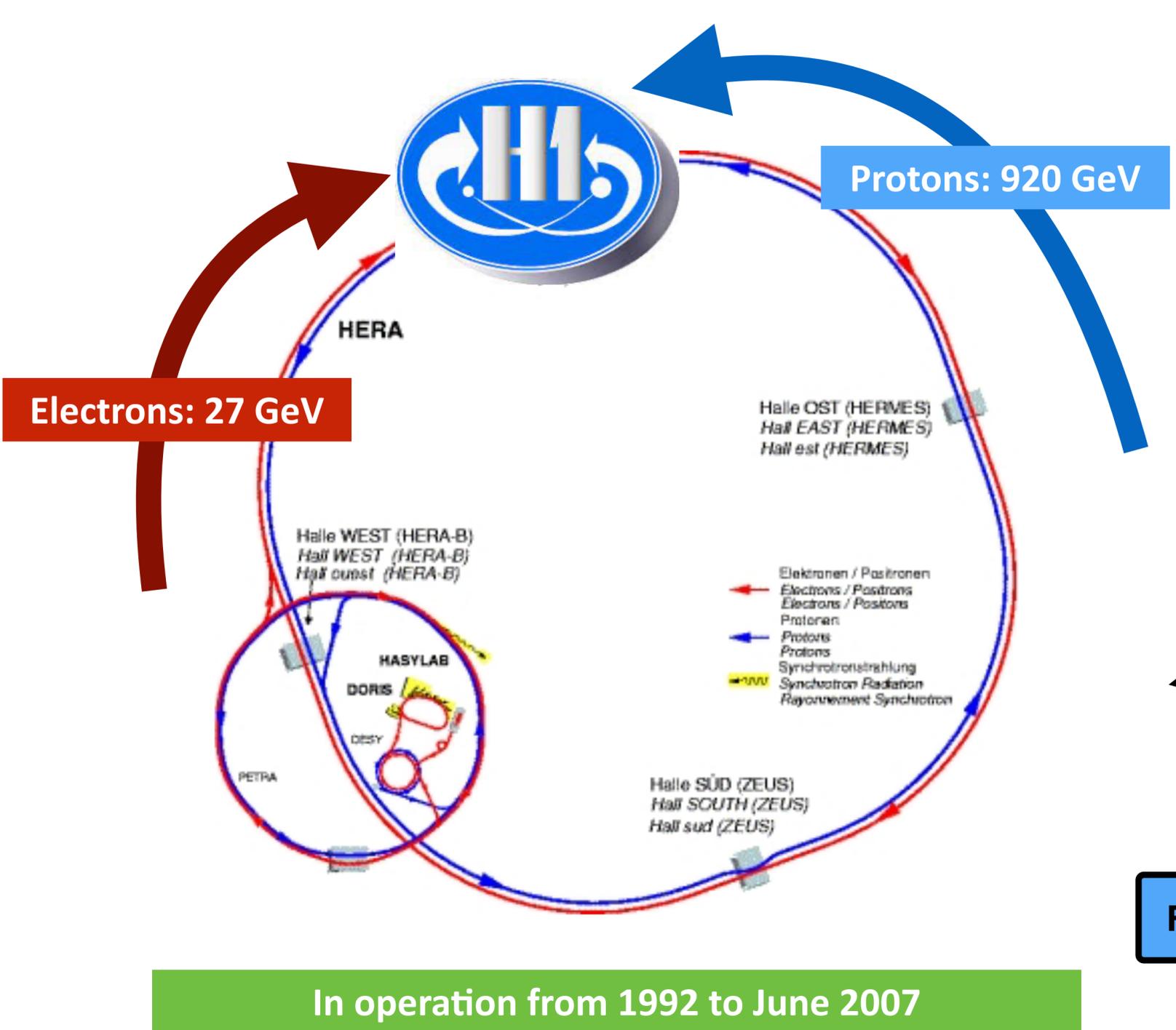
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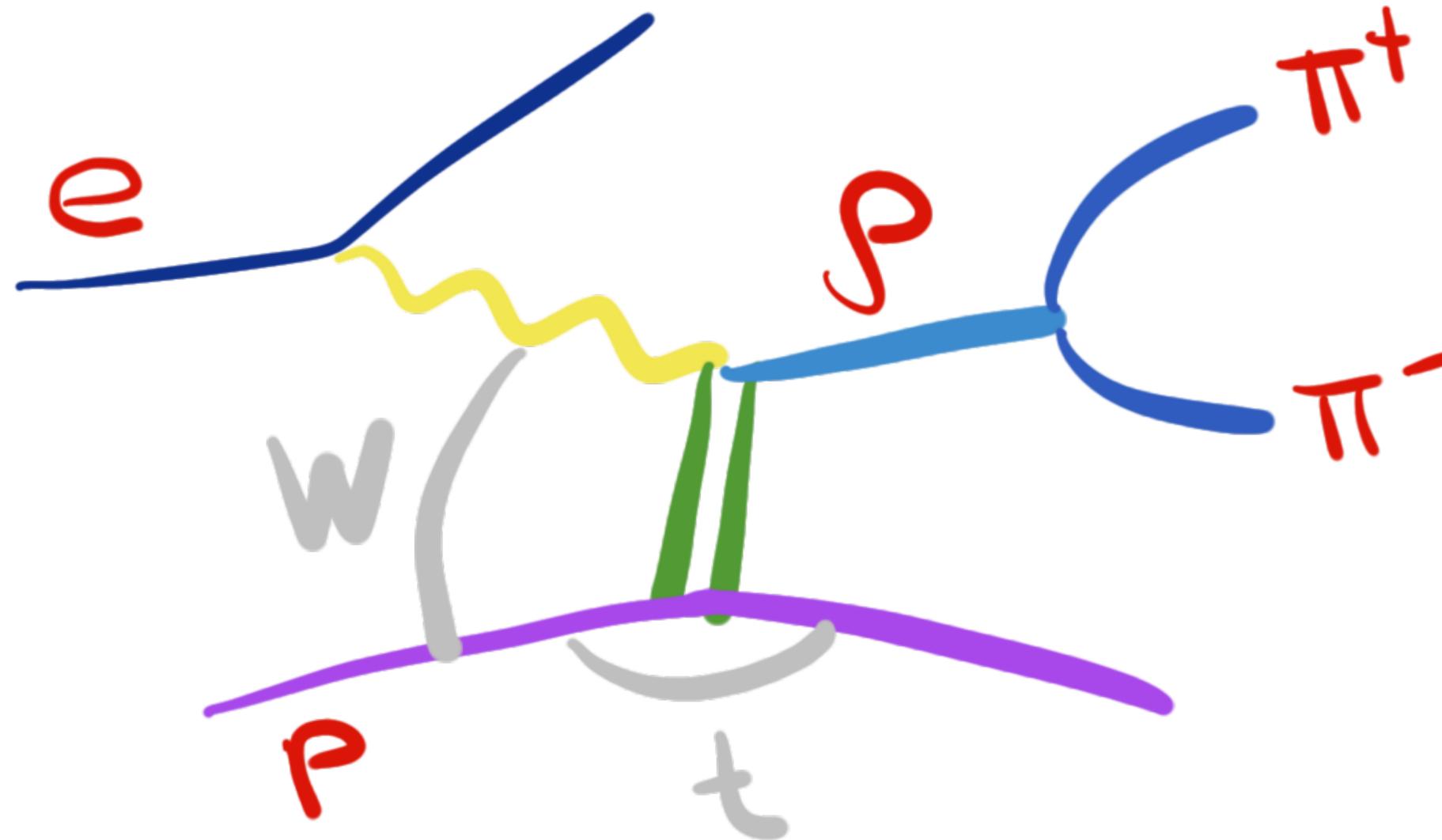
# HERA and H1



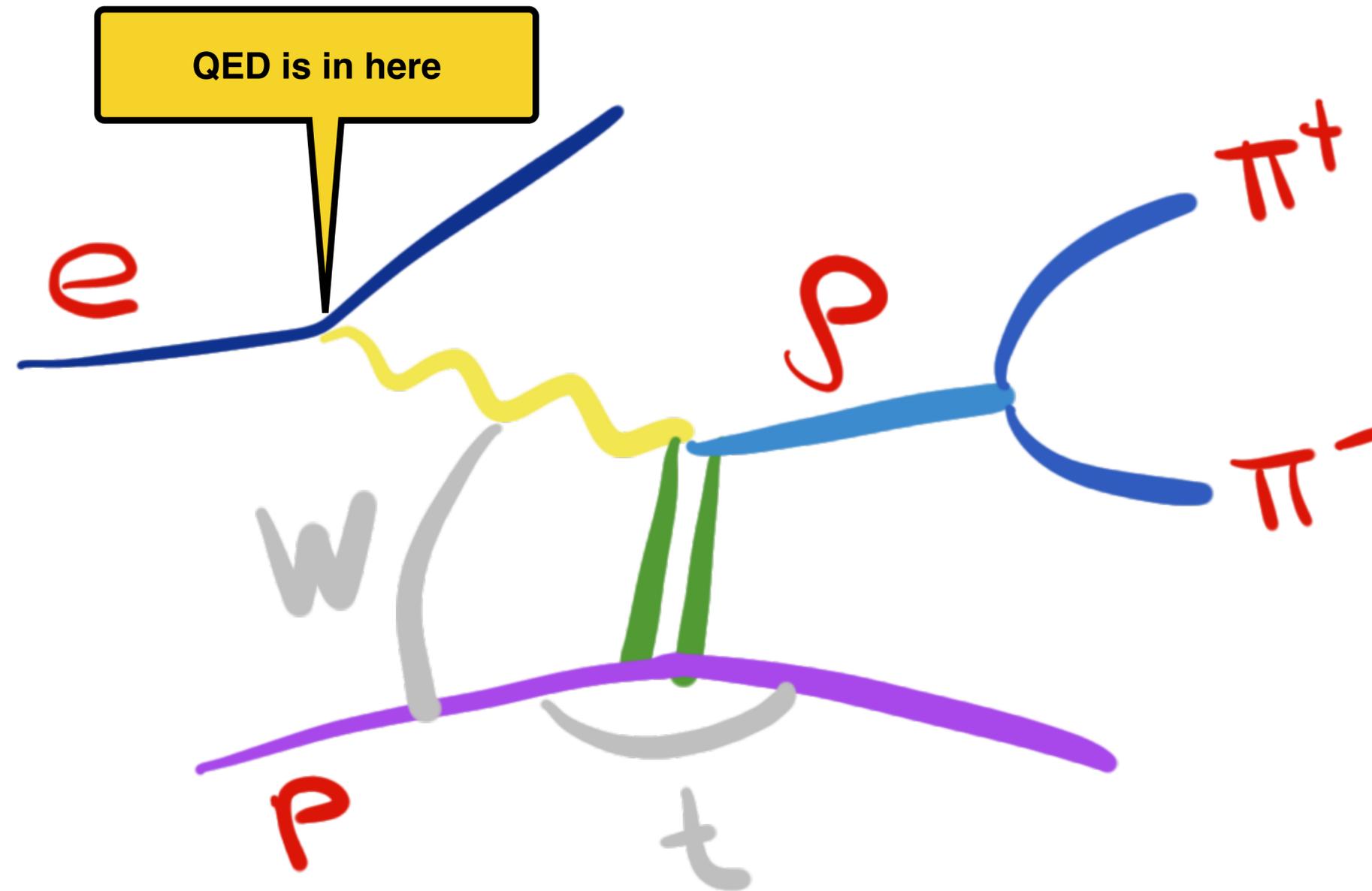
## Exclusive $\rho(770)$ photoproduction

H1 Collaboration, EPJC 80 (2020) 12, 1189  
<https://doi.org/10.1140/epjc/s10052-020-08587-3>

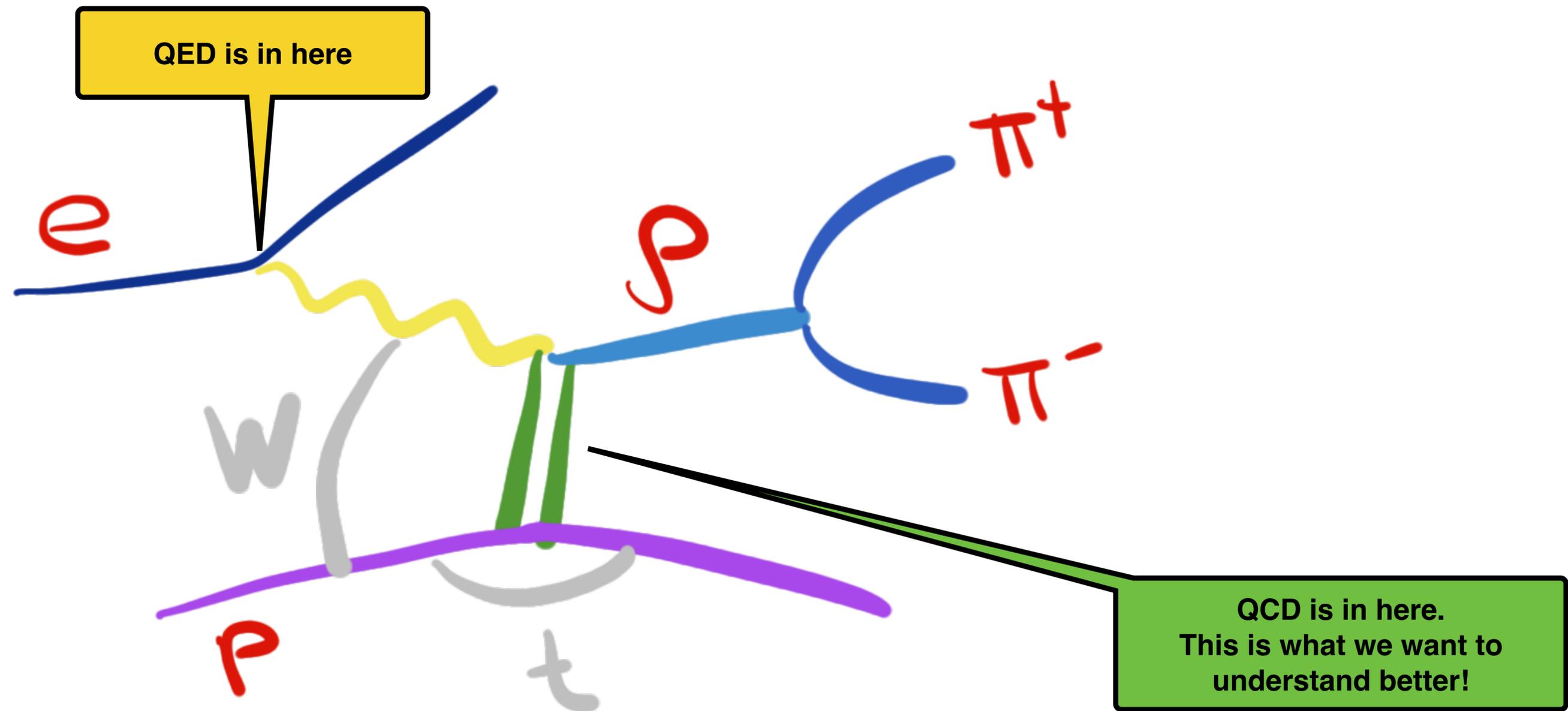
# The processes we are interested in: exclusive production



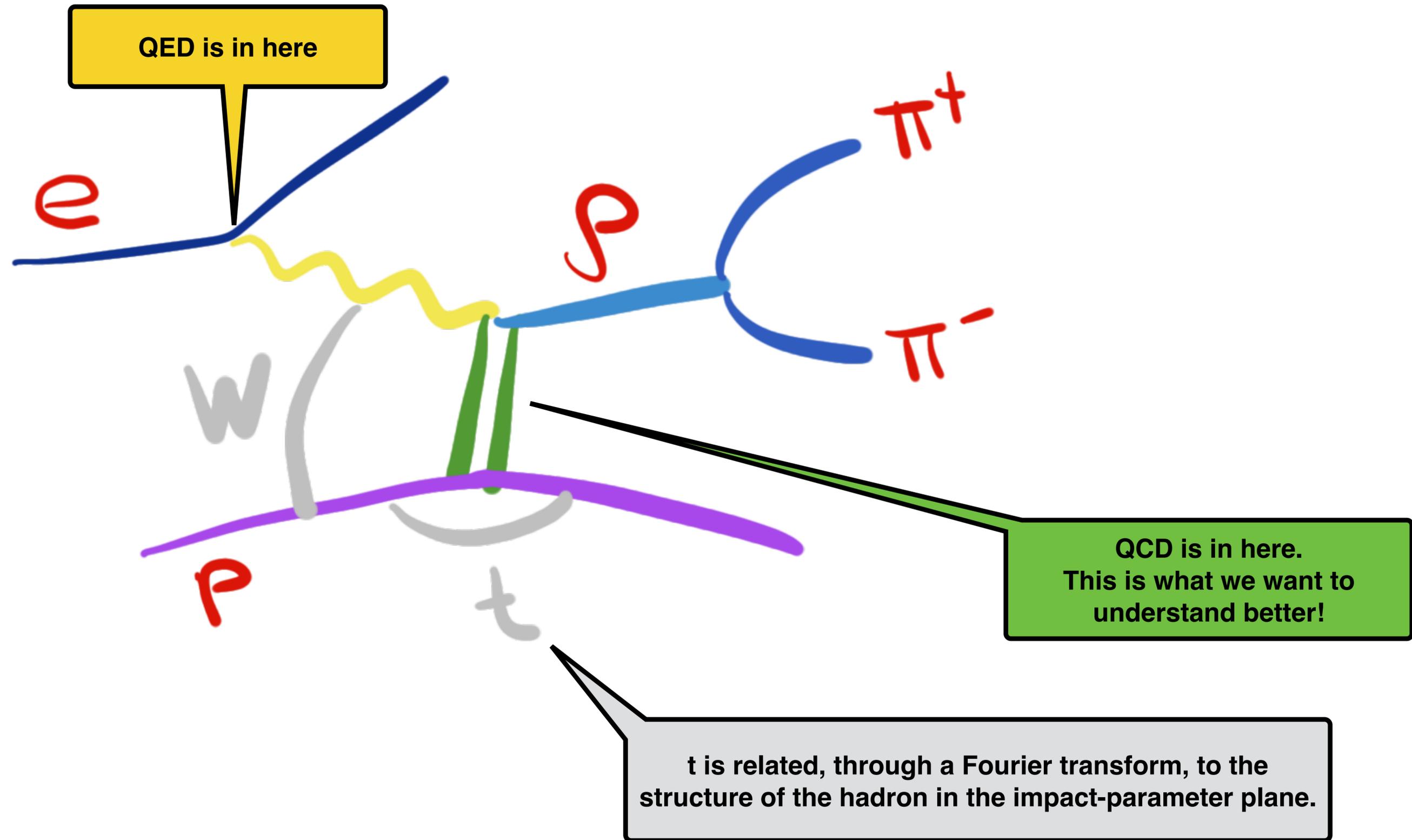
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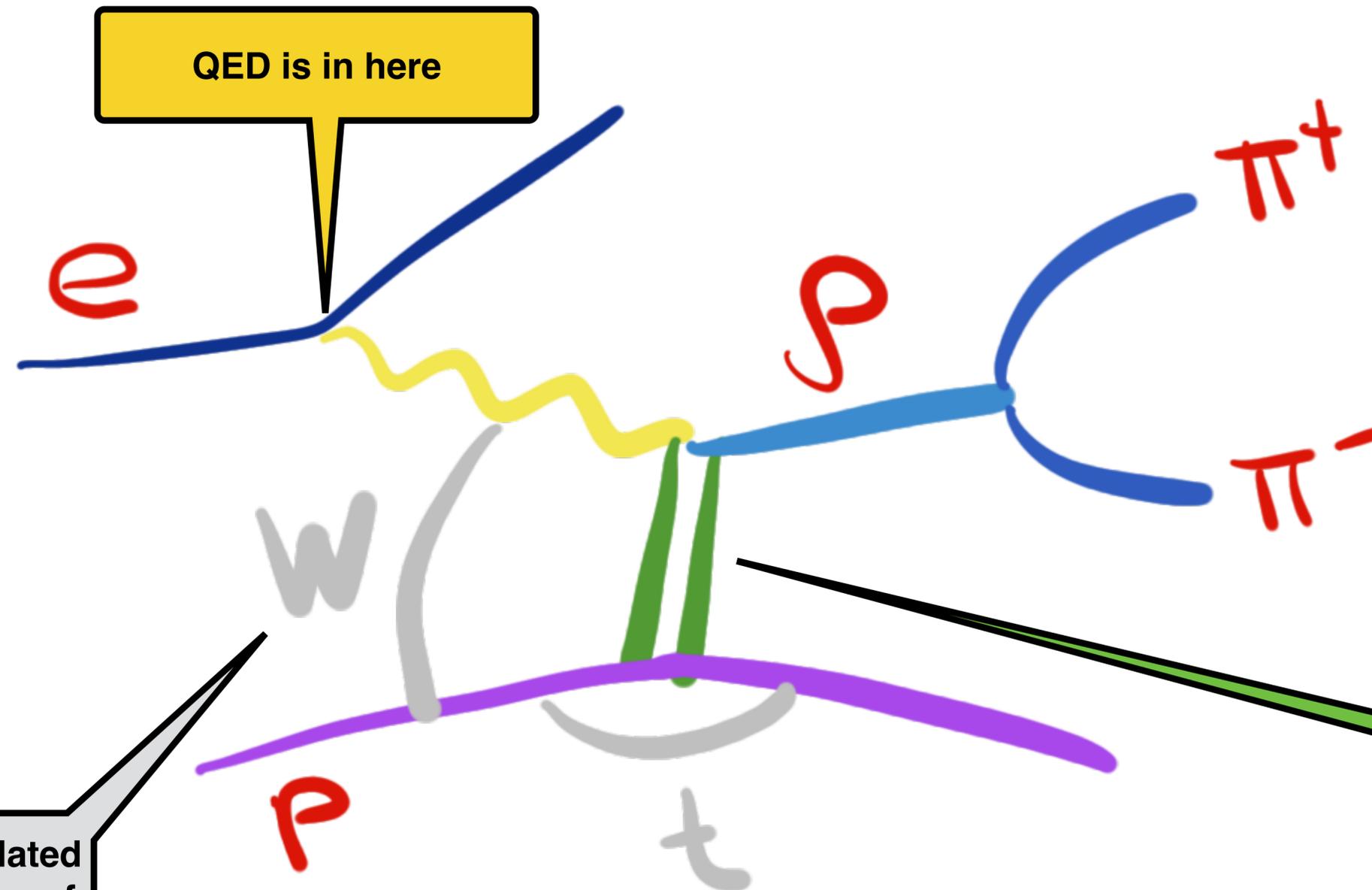
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QED is in here

$e$

$p$

$\pi^+$

$\pi^-$

$W$

$p$

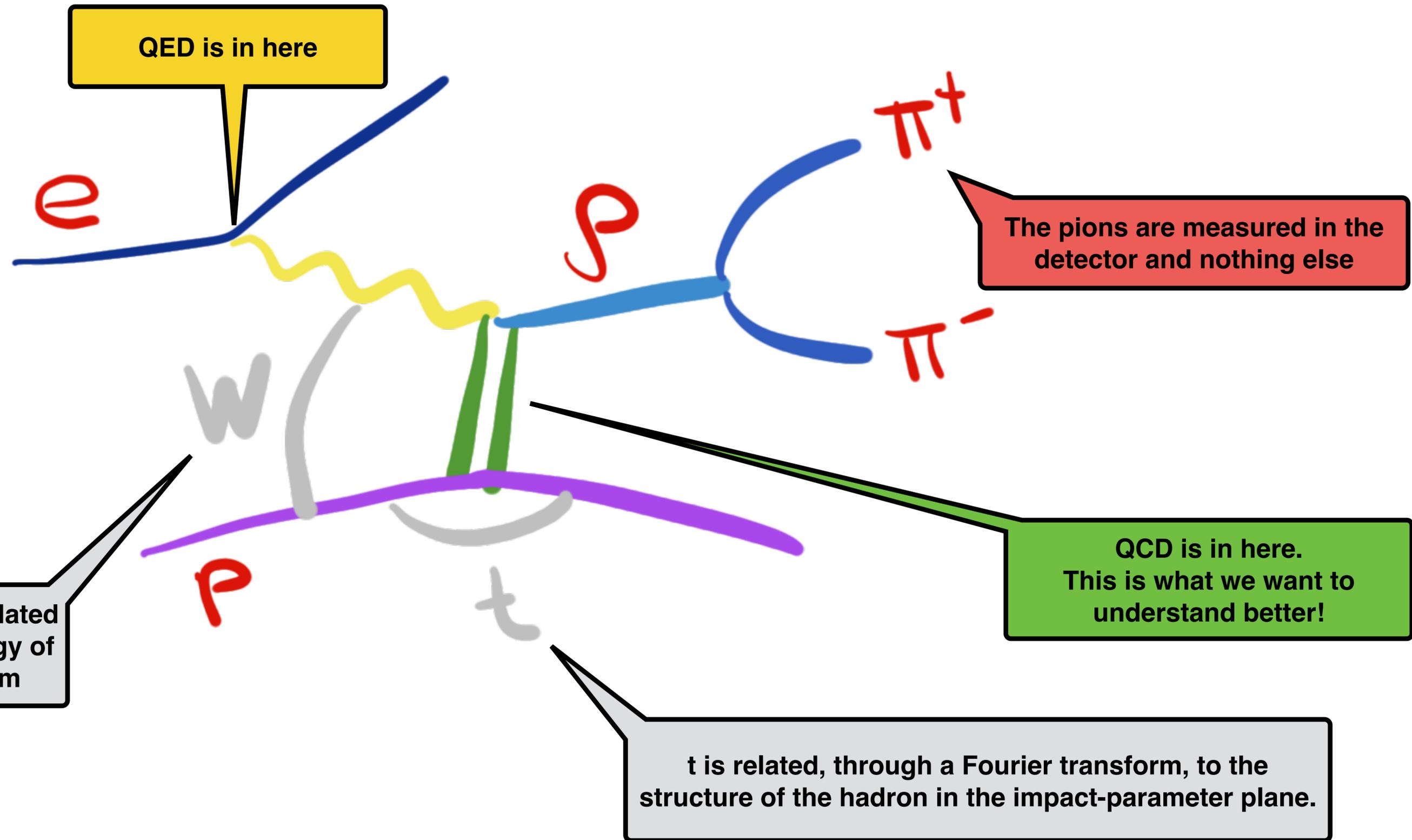
$t$

QCD is in here.  
This is what we want to  
understand better!

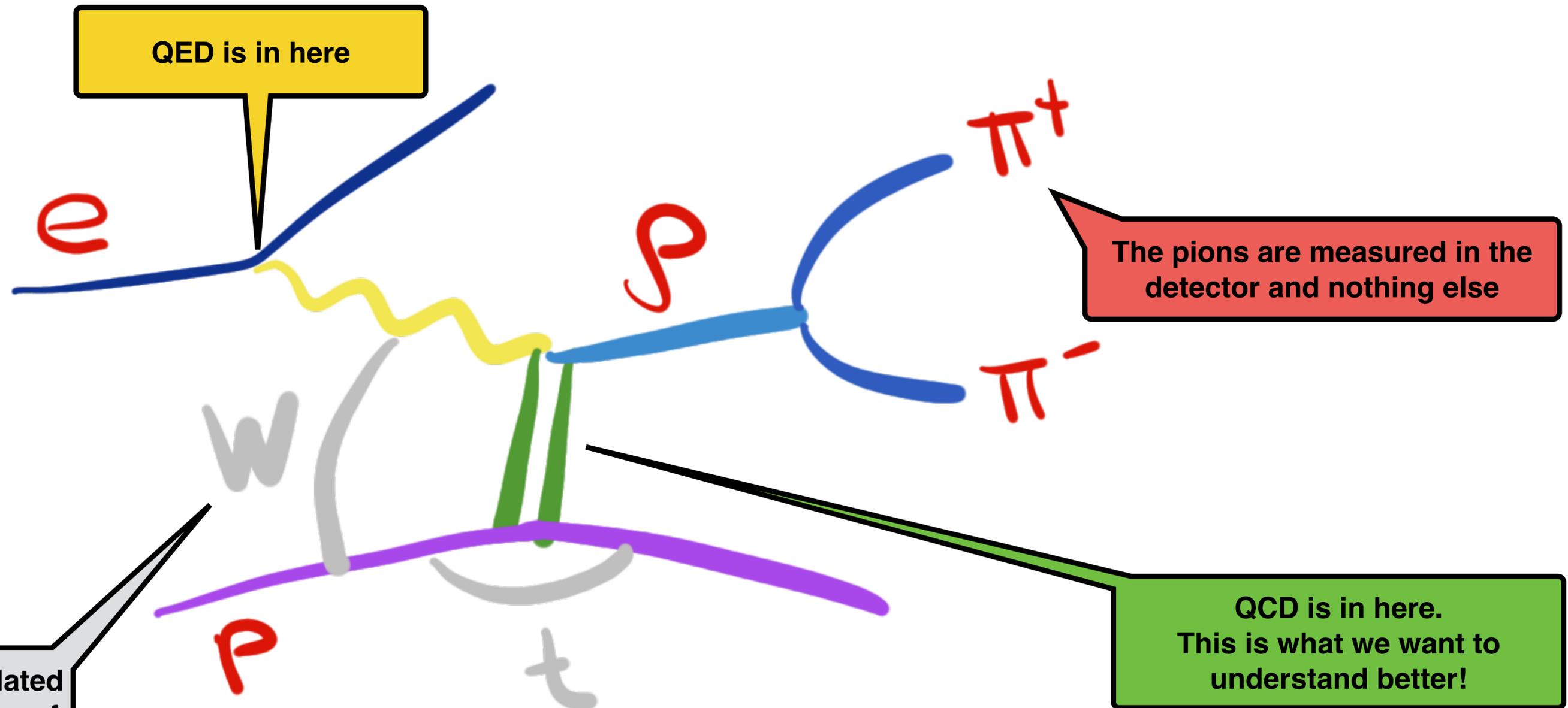
The  $p$  scattering angle is related  
to the centre-of-mass energy of  
the photon-proton system

$t$  is related, through a Fourier transform, to the  
structure of the hadron in the impact-parameter plane.

# The processes we are interested in: exclusive production



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The  $\theta$  scattering angle is related to the centre-of-mass energy of the photon-proton system

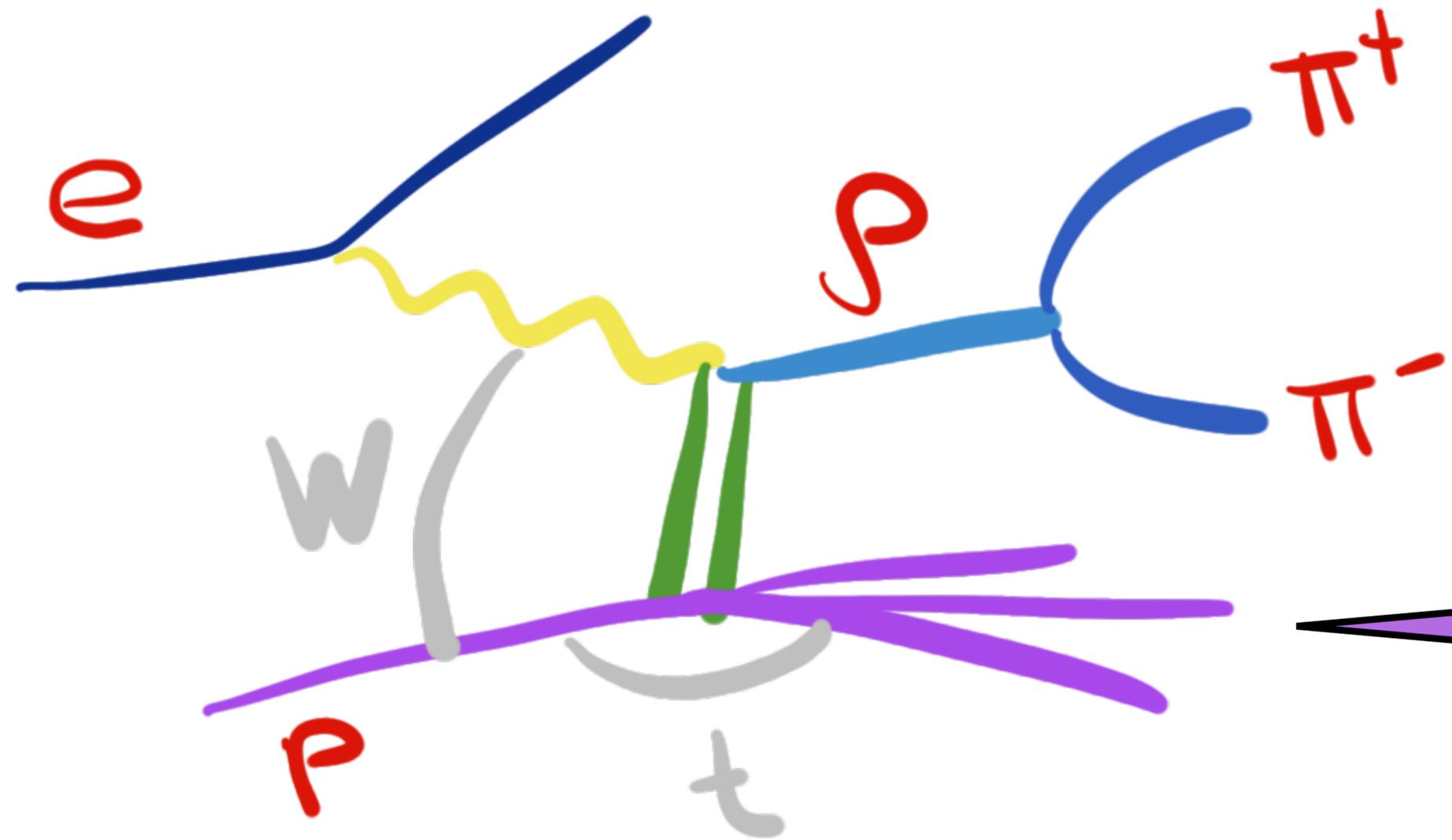
The pions are measured in the detector and nothing else

QCD is in here. This is what we want to understand better!

This process allow us to study the approach to the black-disc limit in QCD

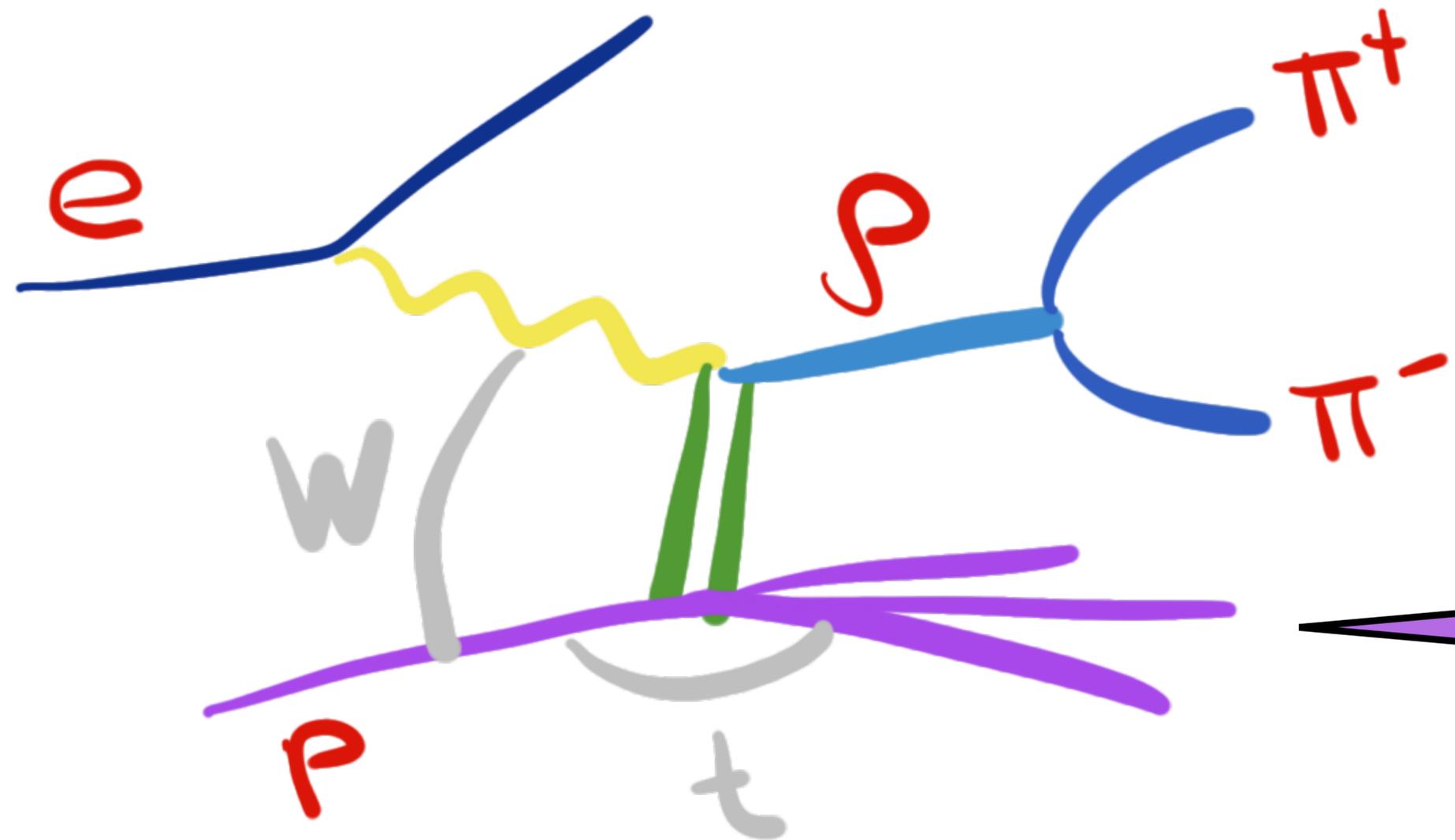
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A few particles are produced near the proton-beam rapidity

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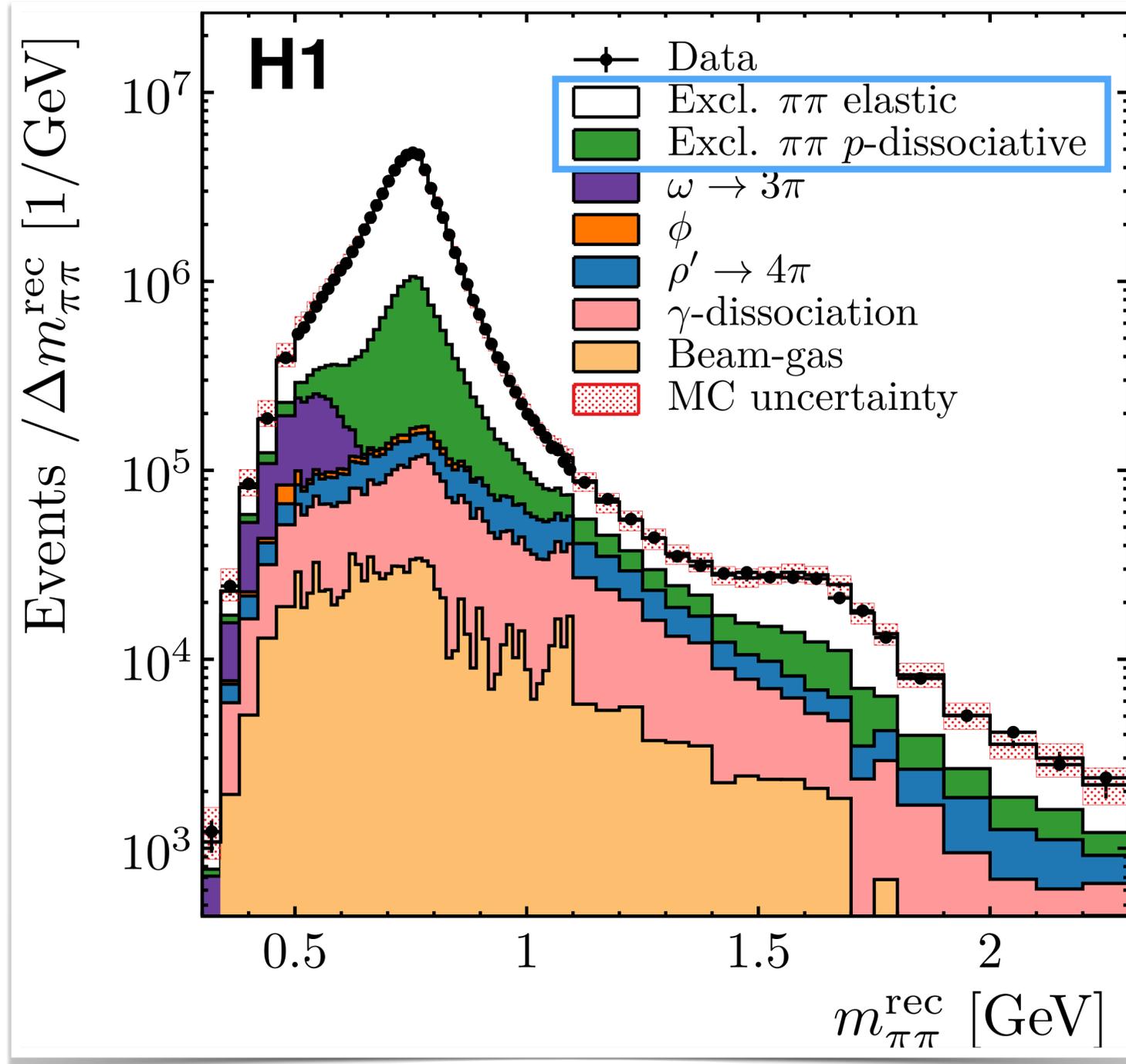


A few particles are produced near the proton-beam rapidity

In a Good-Walker picture, this process is sensitive to the fluctuations in the hadronic structure of the proton

# Invariant mass distribution of pion pairs

H1 Collaboration, EPJC 80 (2020) 12, 1189

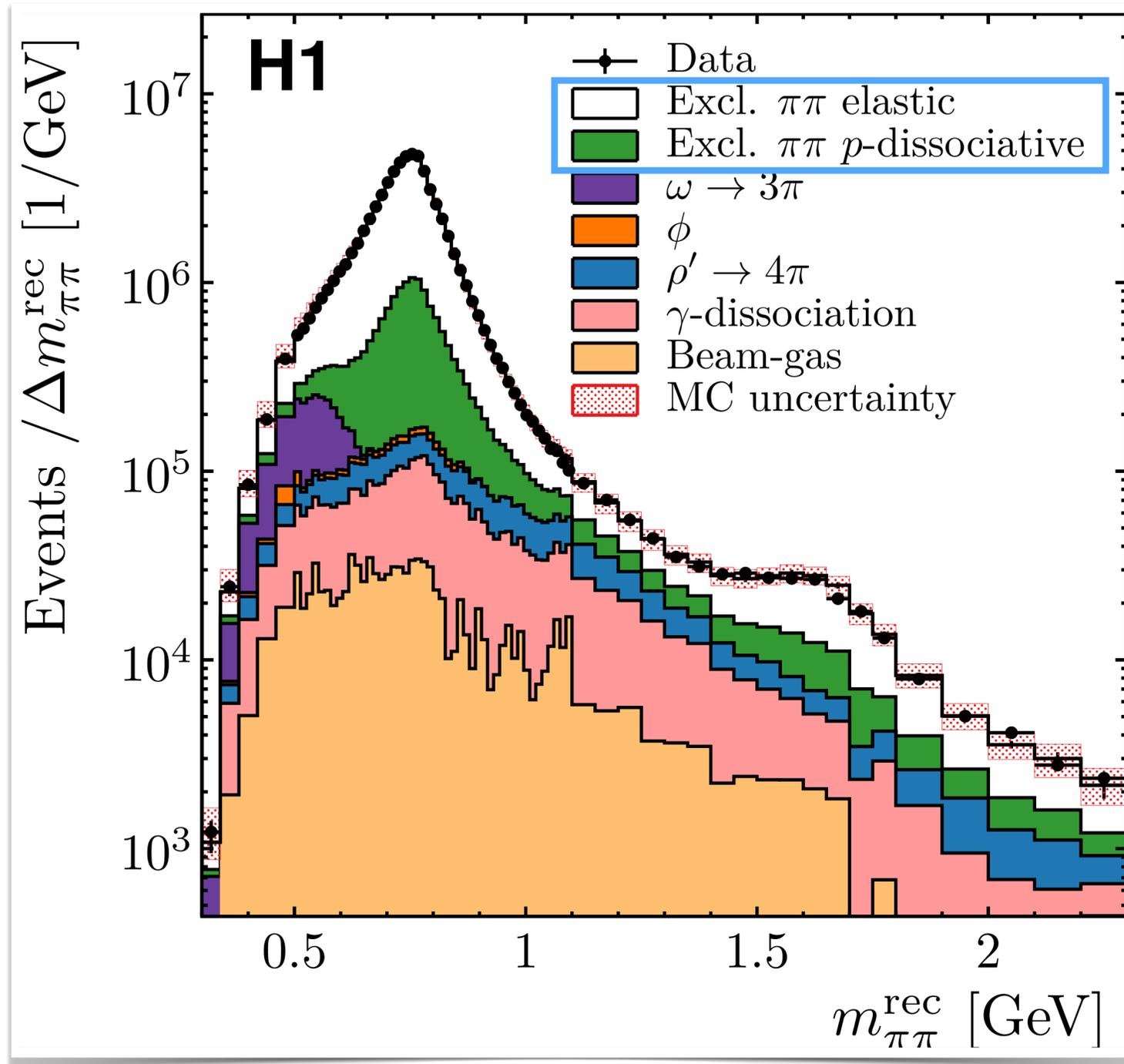


## Signal:

- ✓ resonant and continuum production of pion pairs
- ✓ interference between both of them to be taken into account in the model fitted to data
- ✓ Detector effects corrected via unfolding

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H1 Collaboration, EPJC 80 (2020) 12, 1189



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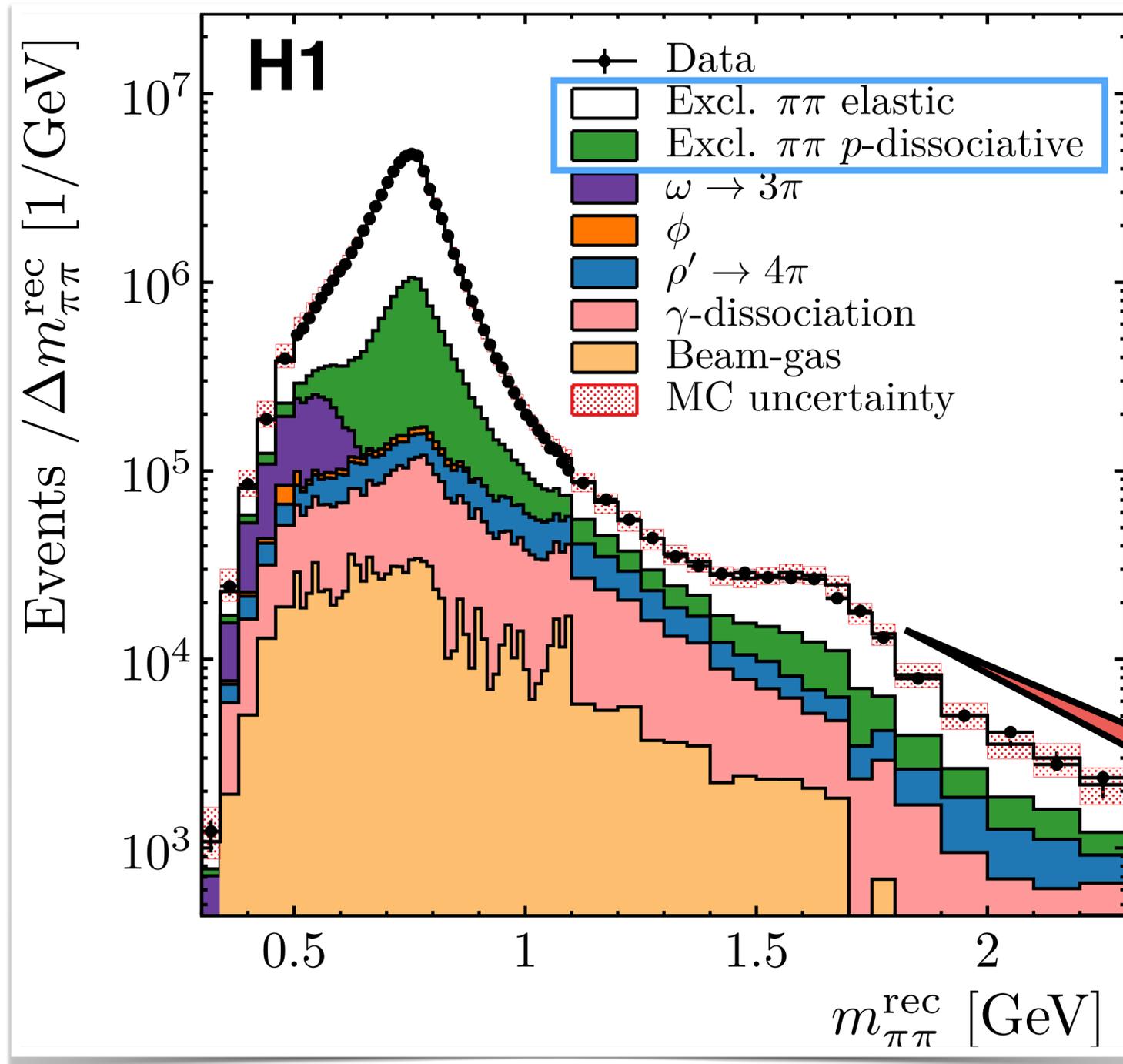
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## Main systematic uncertainties from:

- ✓ trigger and normalisation (exclusive)
- ✓ calorimetry and tagging (dissociation)

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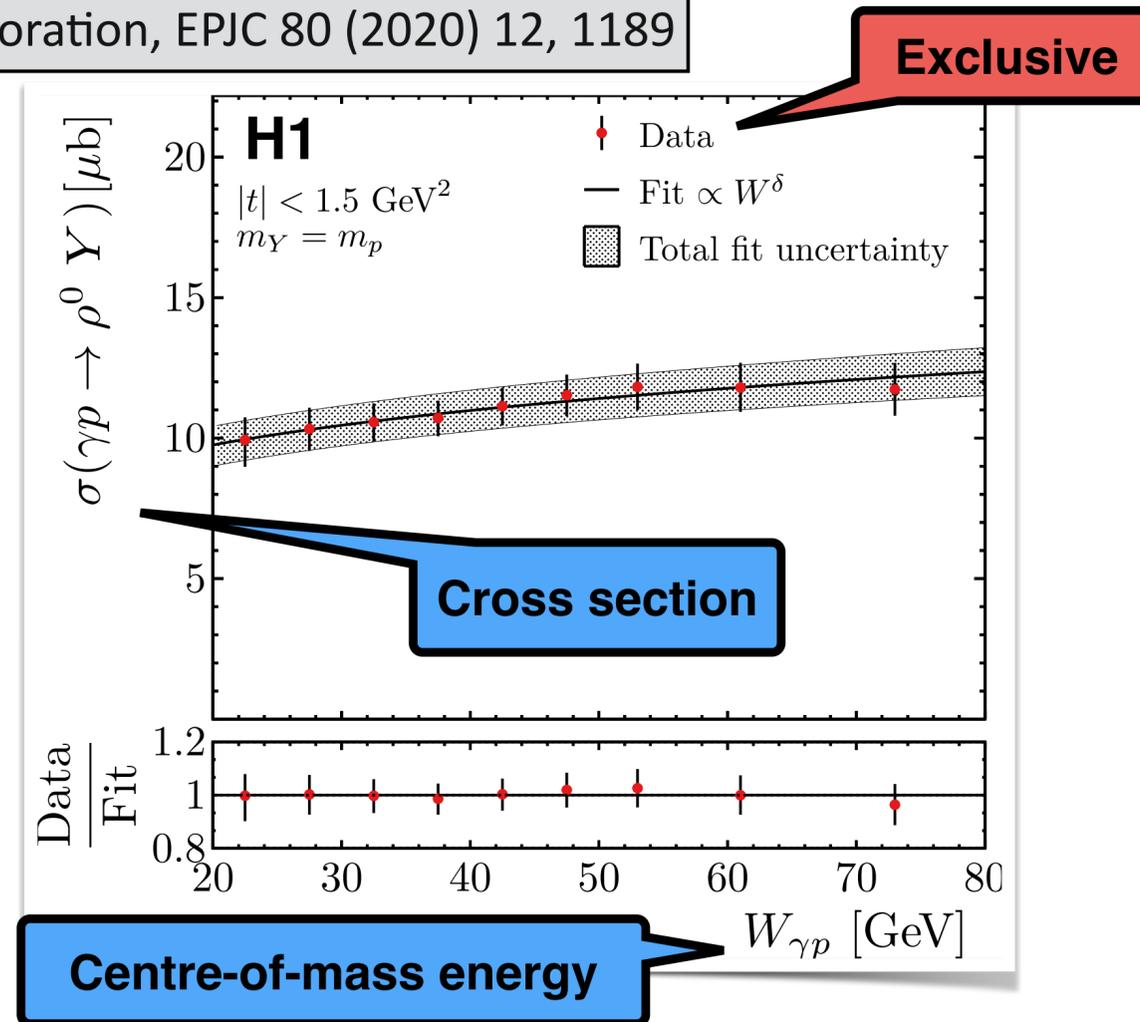
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Interesting bump. Similar structures observed by the STAR and ALICE Collaborations in photoproduction off nuclear targets

# Results: energy dependence

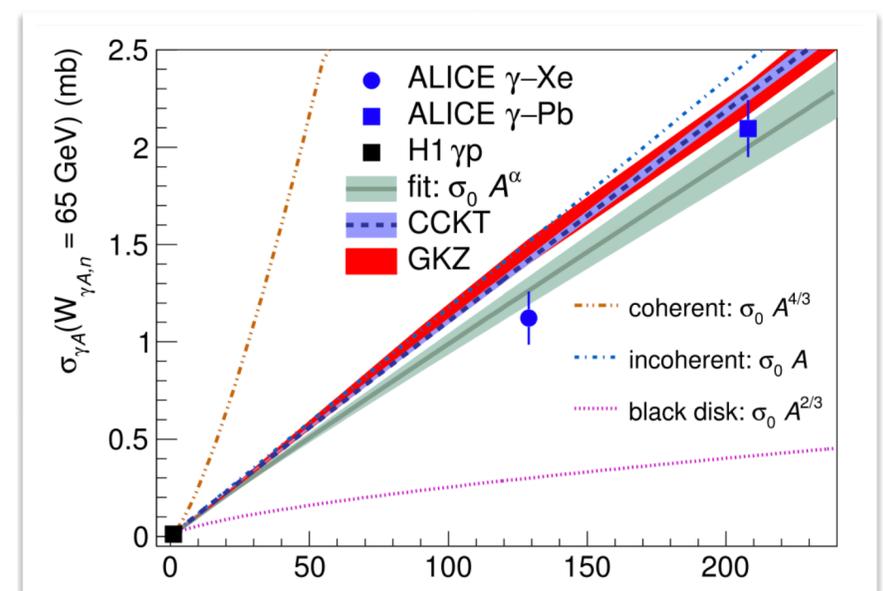
H1 Collaboration, EPJC 80 (2020) 12, 1189



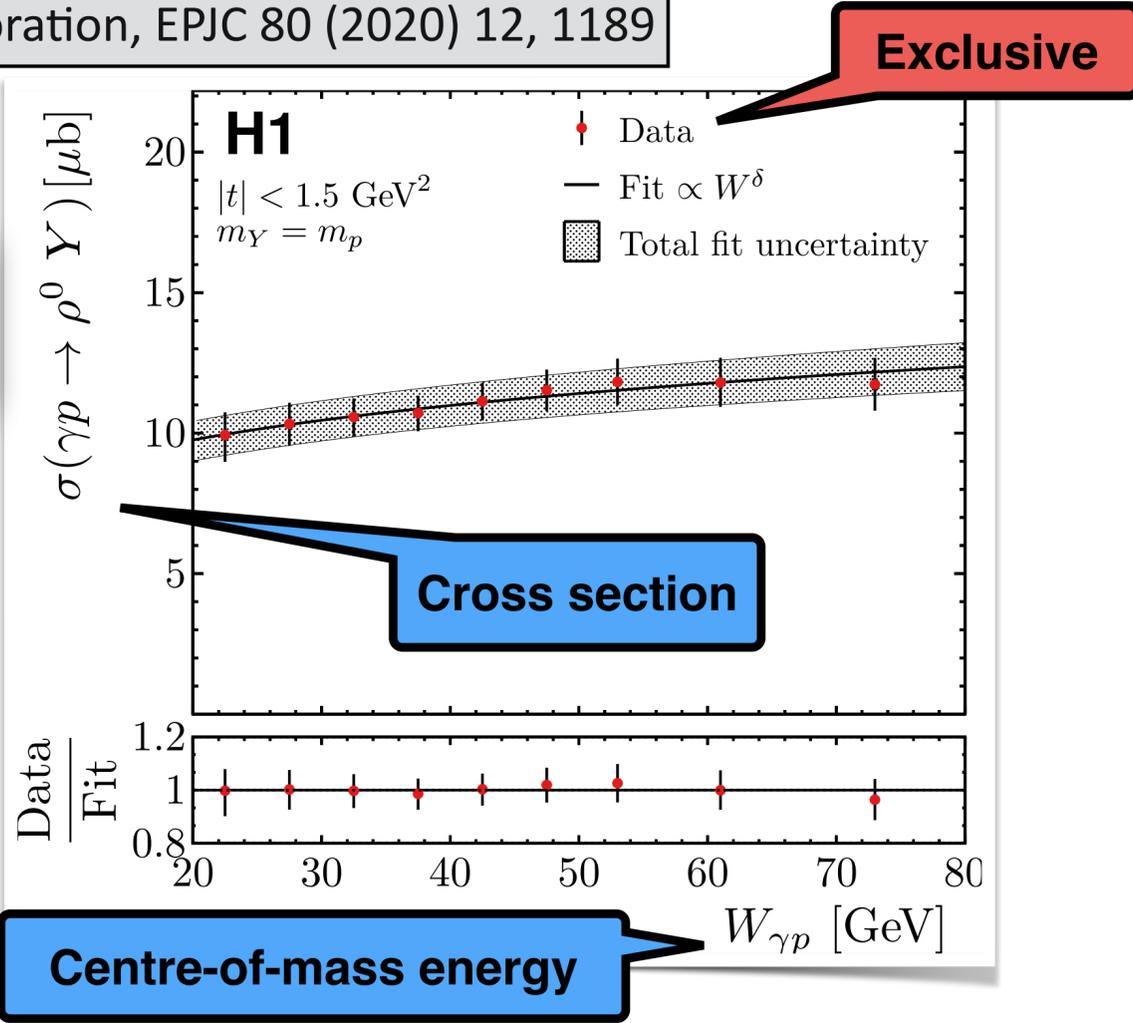
# Results: energy dependence

H1 Collaboration, EPJC 80 (2020) 12, 1189

H1 results have been used by ALICE to study A dependence



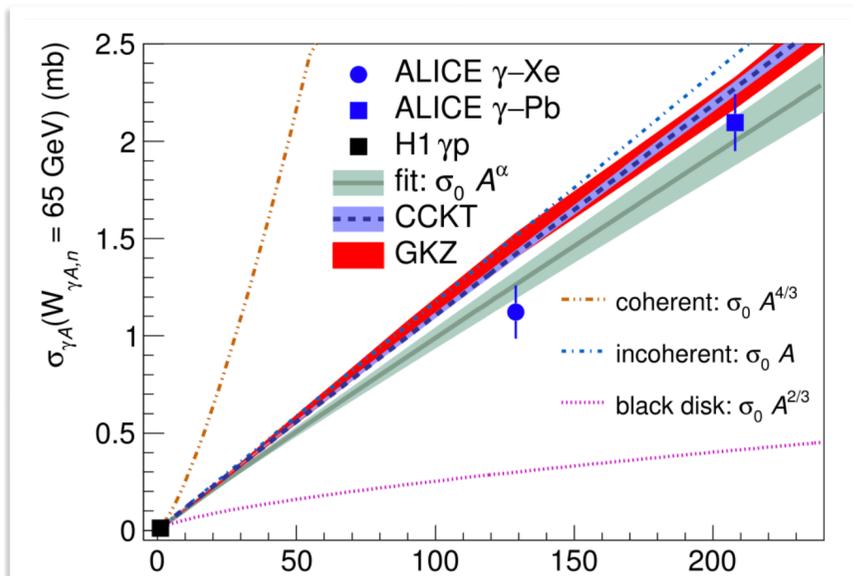
ALICE, PLB 820 (2021) 136481



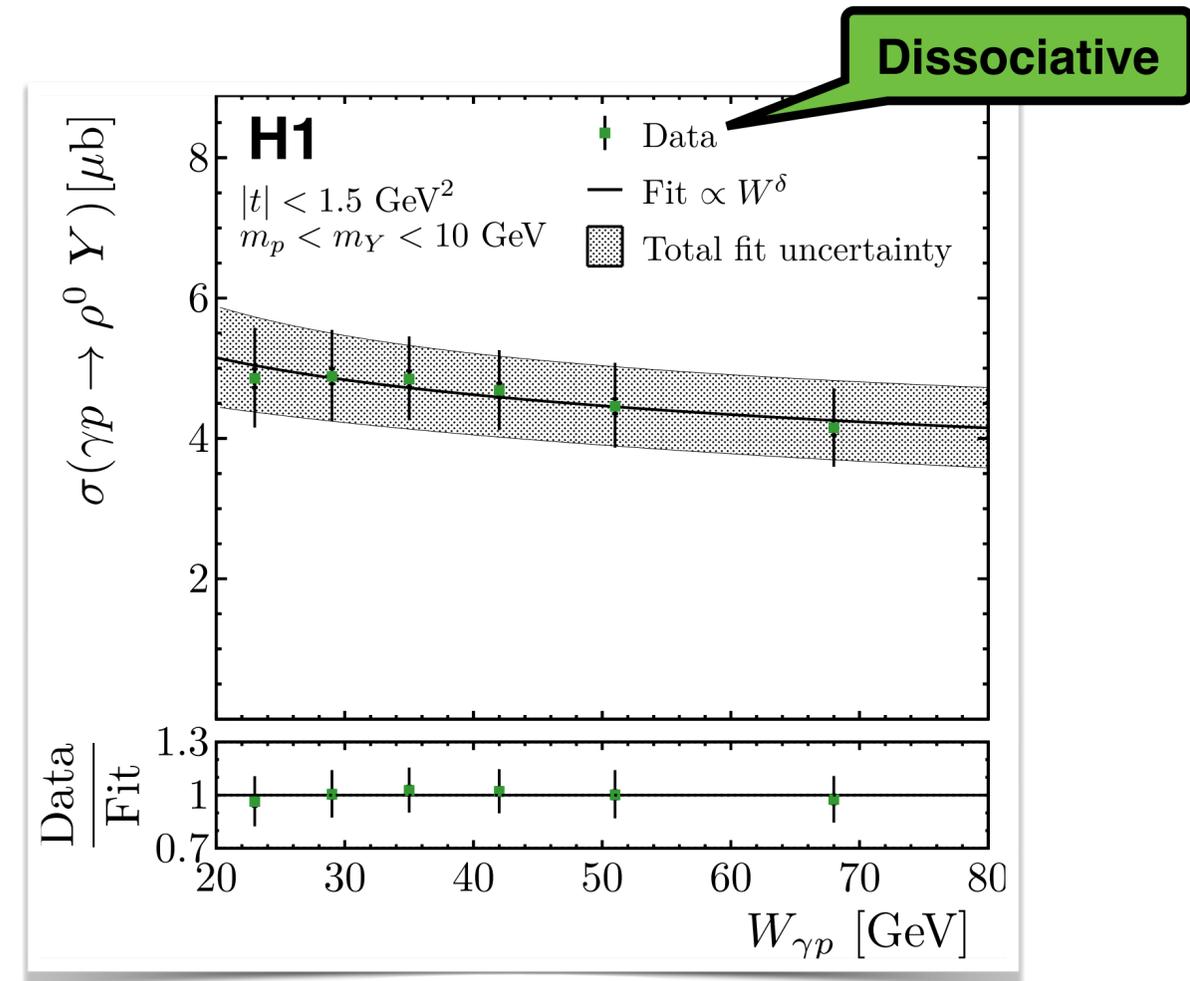
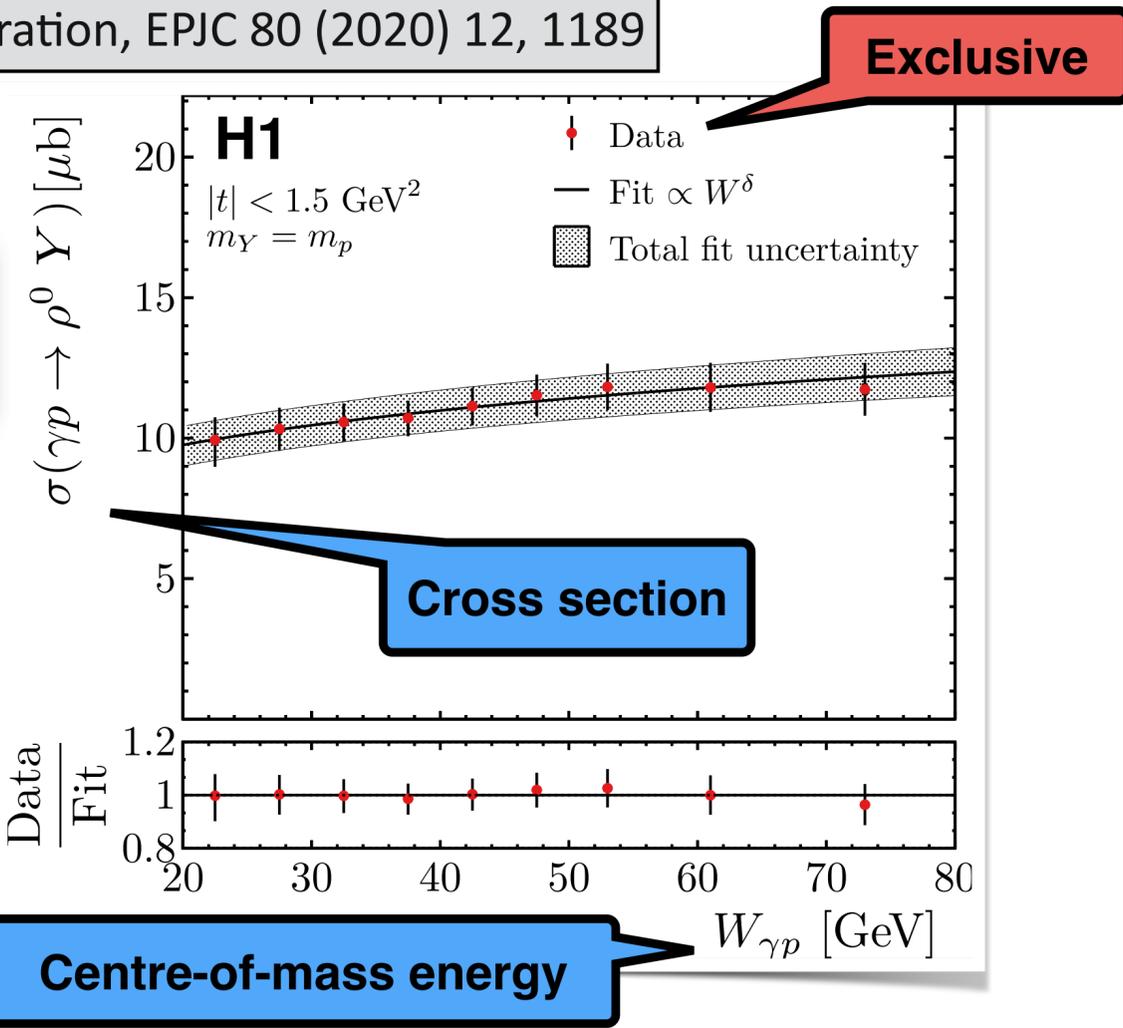
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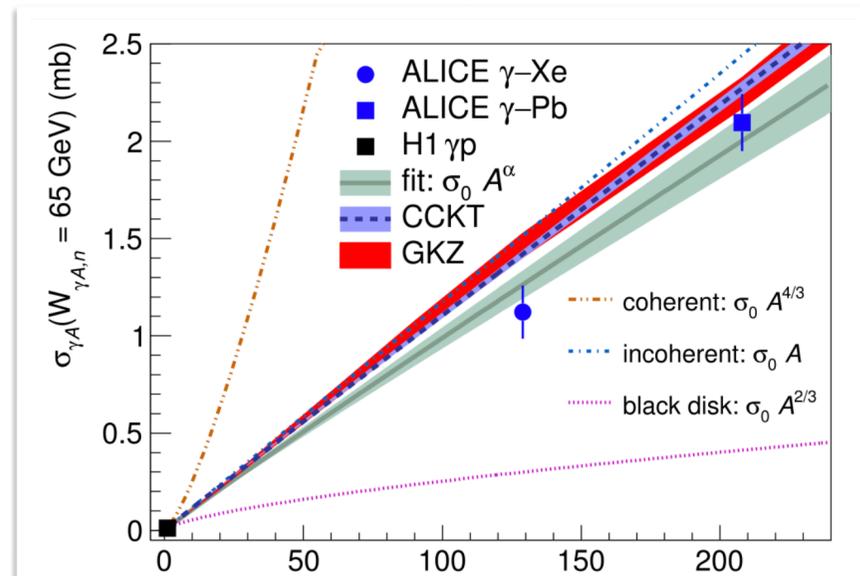
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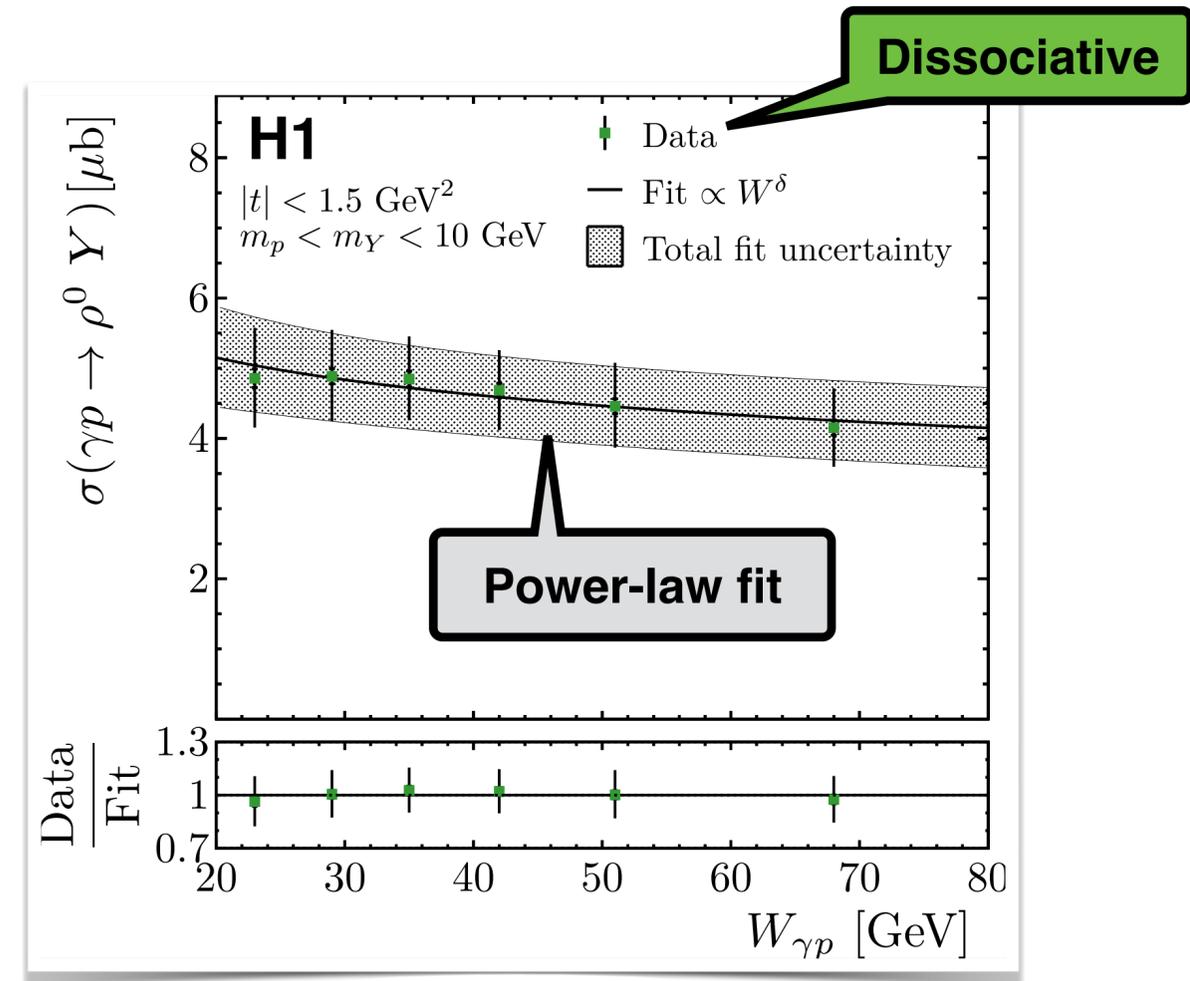
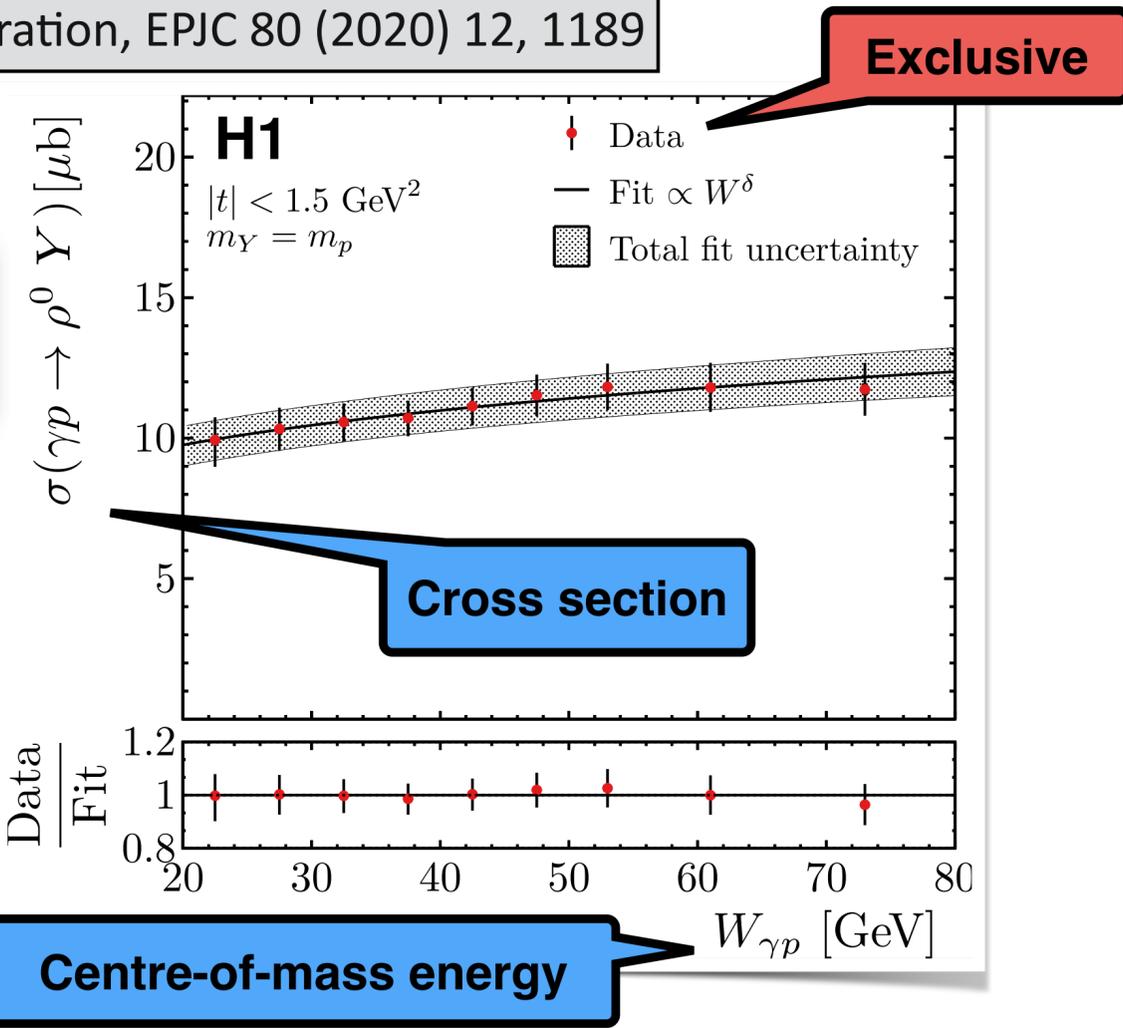
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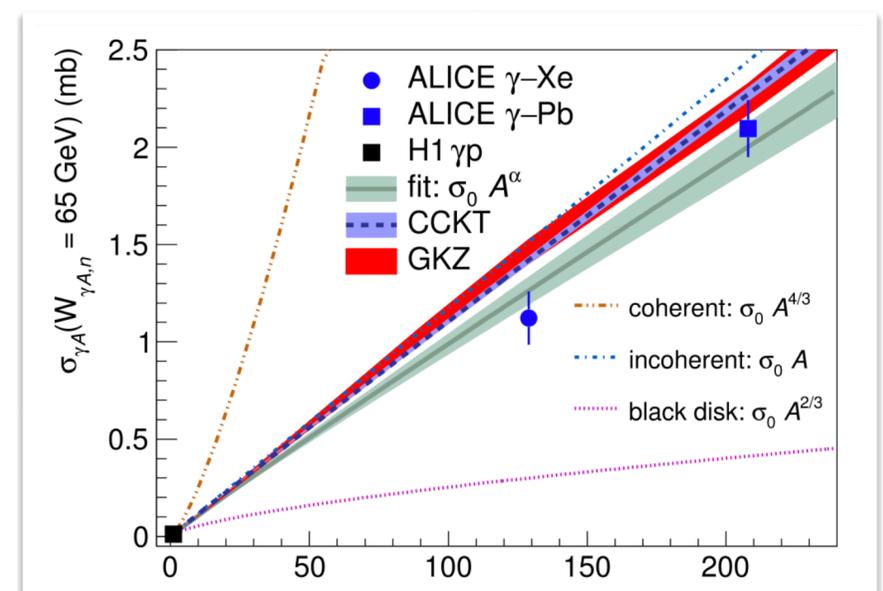


Parameter	$m_Y = m_p$			$m_p < m_Y < 10 \text{ GeV}$		
	Value	$\Delta_{\text{stat.}}$	$\Delta_{\text{syst.}}$	Value	$\Delta_{\text{stat.}}$	$\Delta_{\text{syst.}}$
$\sigma_\rho(W_0=40 \text{ GeV}) (\mu\text{b})$	10.98	0.07	+0.72 -0.74	4.62	0.06	+0.59 -0.57
$\delta$	0.171	0.009	+0.039 -0.026	-0.156	0.026	+0.081 -0.079

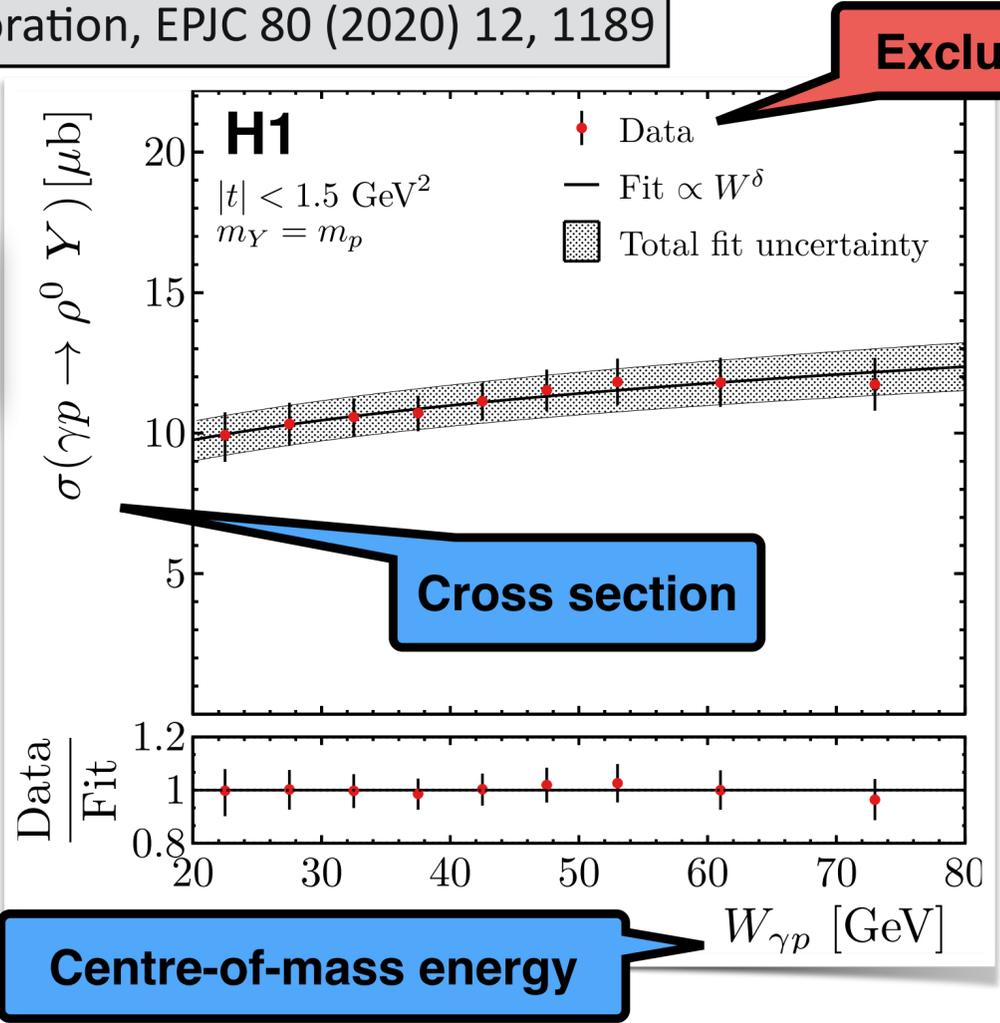
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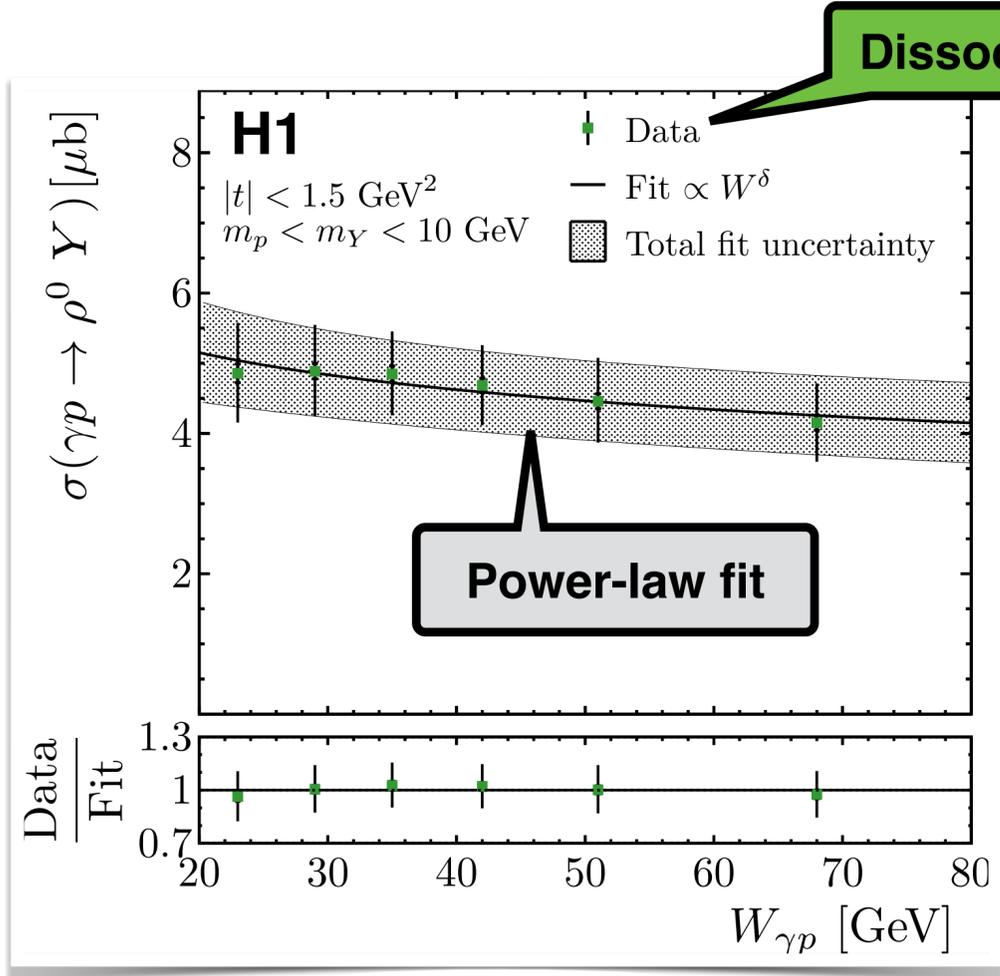
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ALICE, PLB 820 (2021) 136481



Exclusive



Centre-of-mass energy

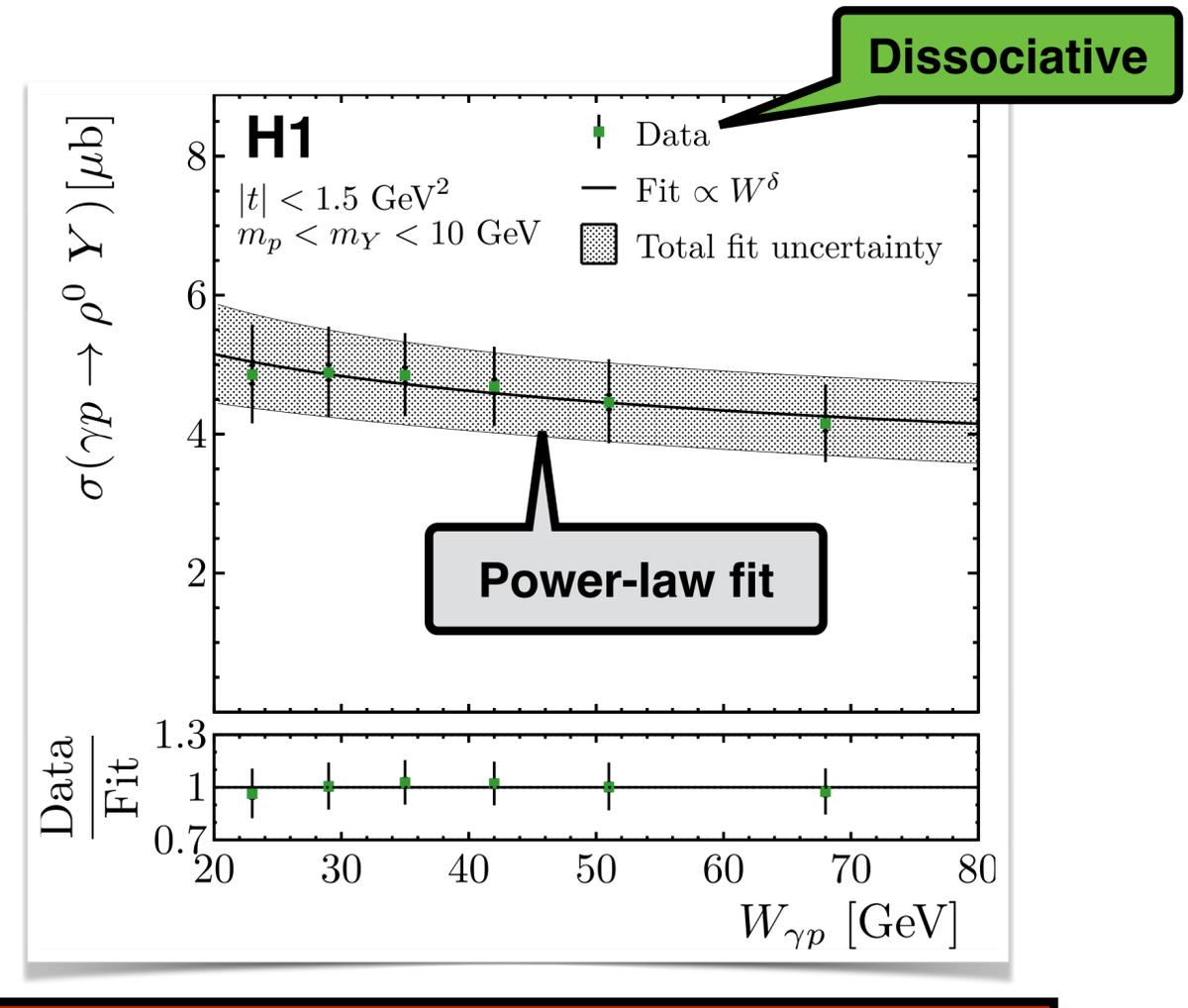
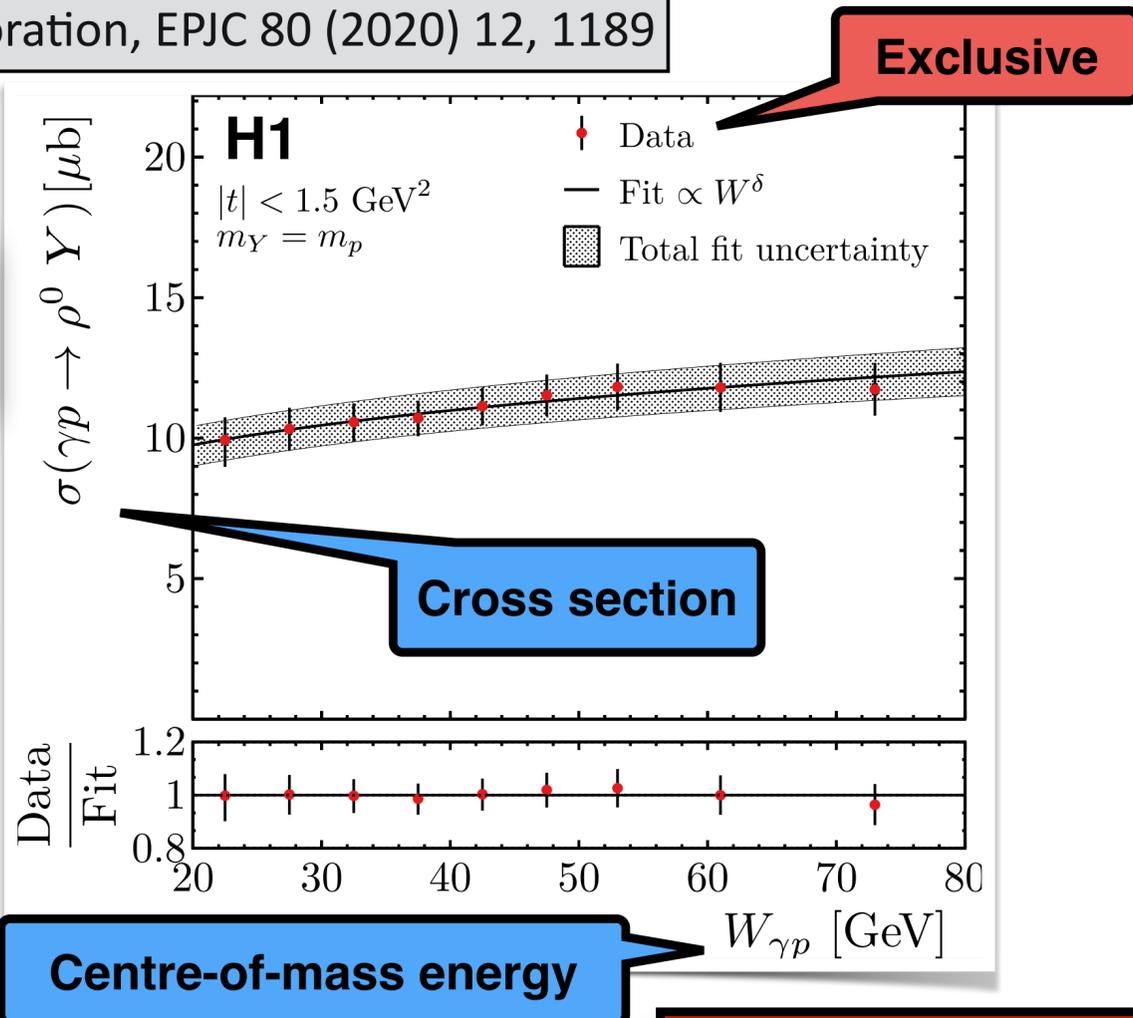
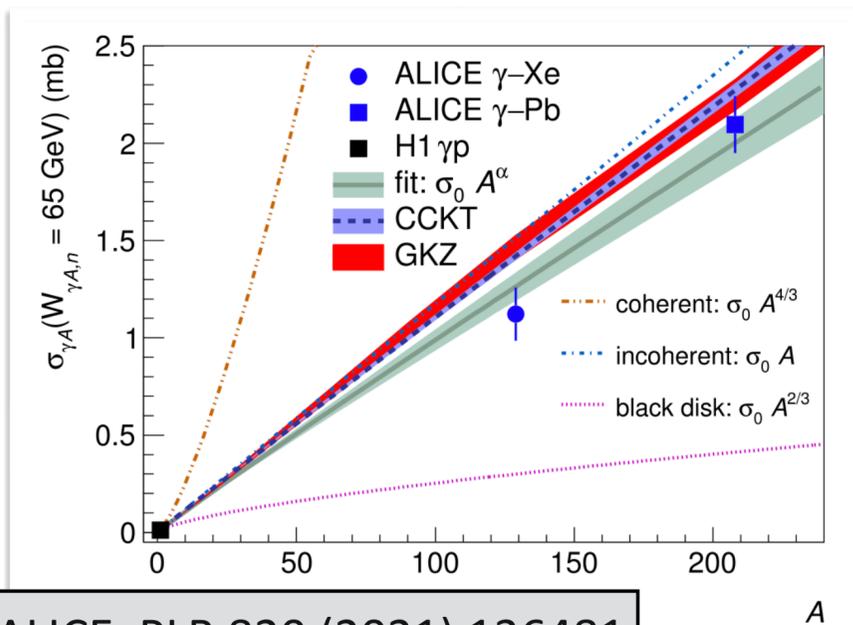
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Negative!

# Results: energy dependence

H1 Collaboration, EPJC 80 (2020) 12, 1189

H1 results have been used by ALICE to study A dependence



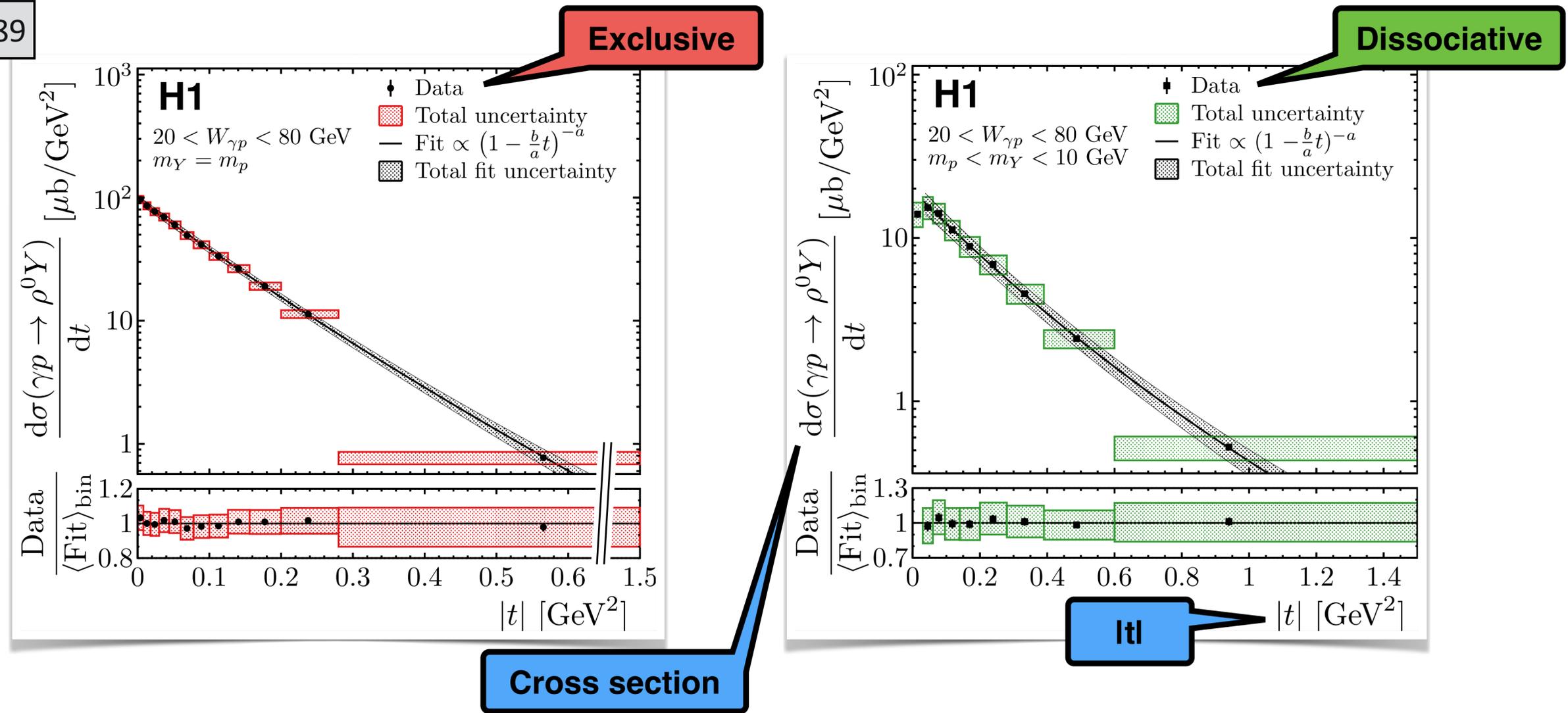
In a Good-Walker picture  $\rightarrow$  Variance of fluctuations decreases with energy: first glimps of the onset of the black-disc limit?

Parameter	$m_Y = m_p$			$m_p < m_Y < 10 \text{ GeV}$		
	Value	$\Delta_{\text{stat.}}$	$\Delta_{\text{sys.}}$	Value	$\Delta_{\text{stat.}}$	$\Delta_{\text{sys.}}$
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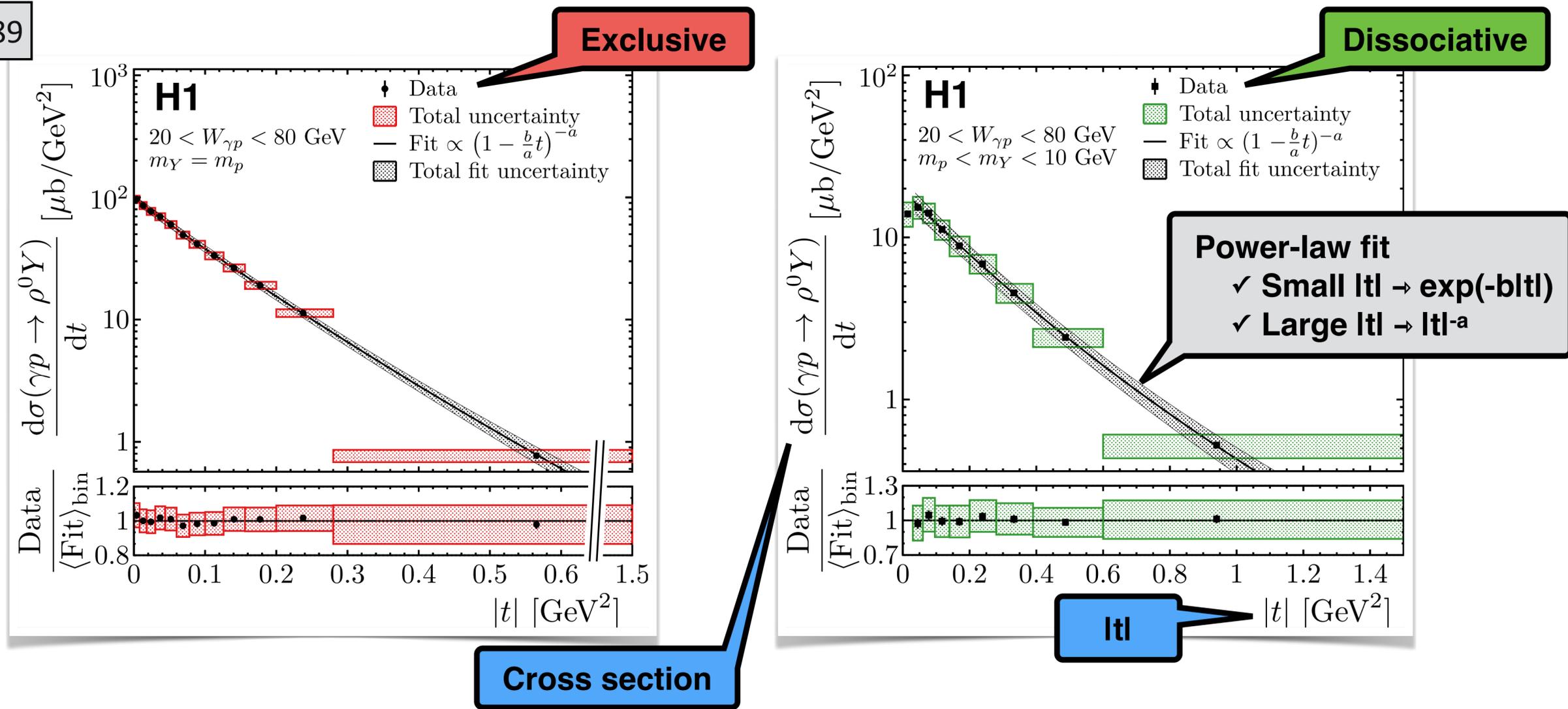
# Results: $|t|$ -dependence

H1 Collaboration, EPJC 80 (2020) 12, 1189



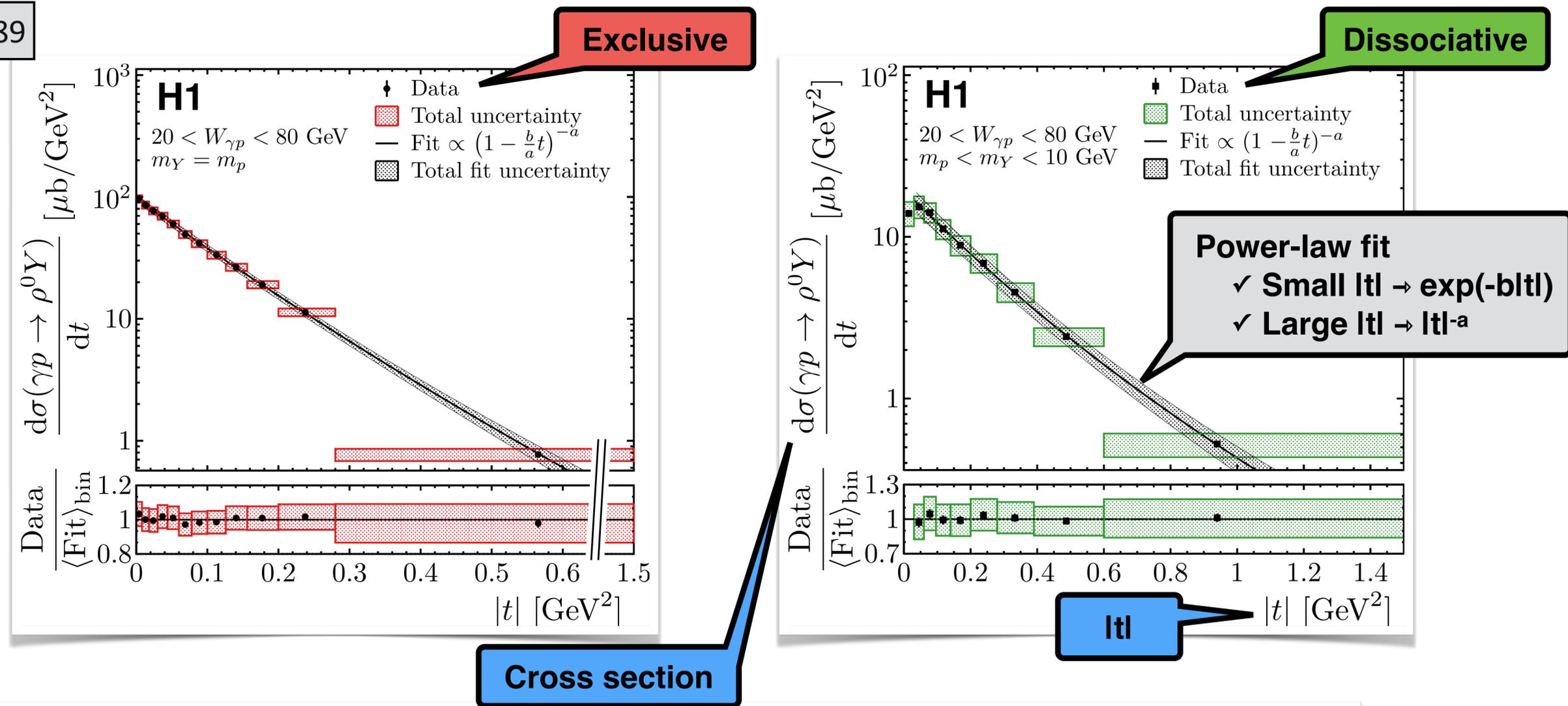
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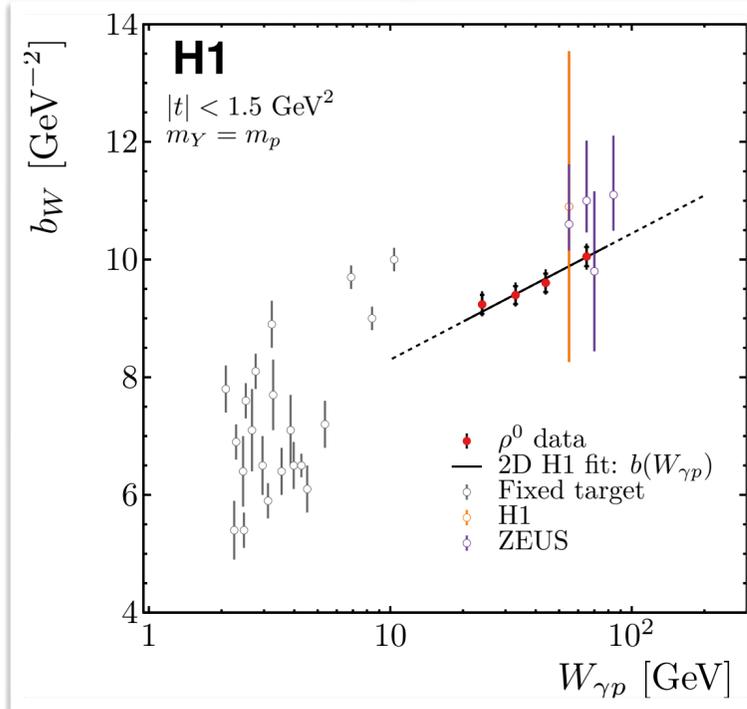
H1 Collaboration, EPJC 80 (2020) 12, 1189



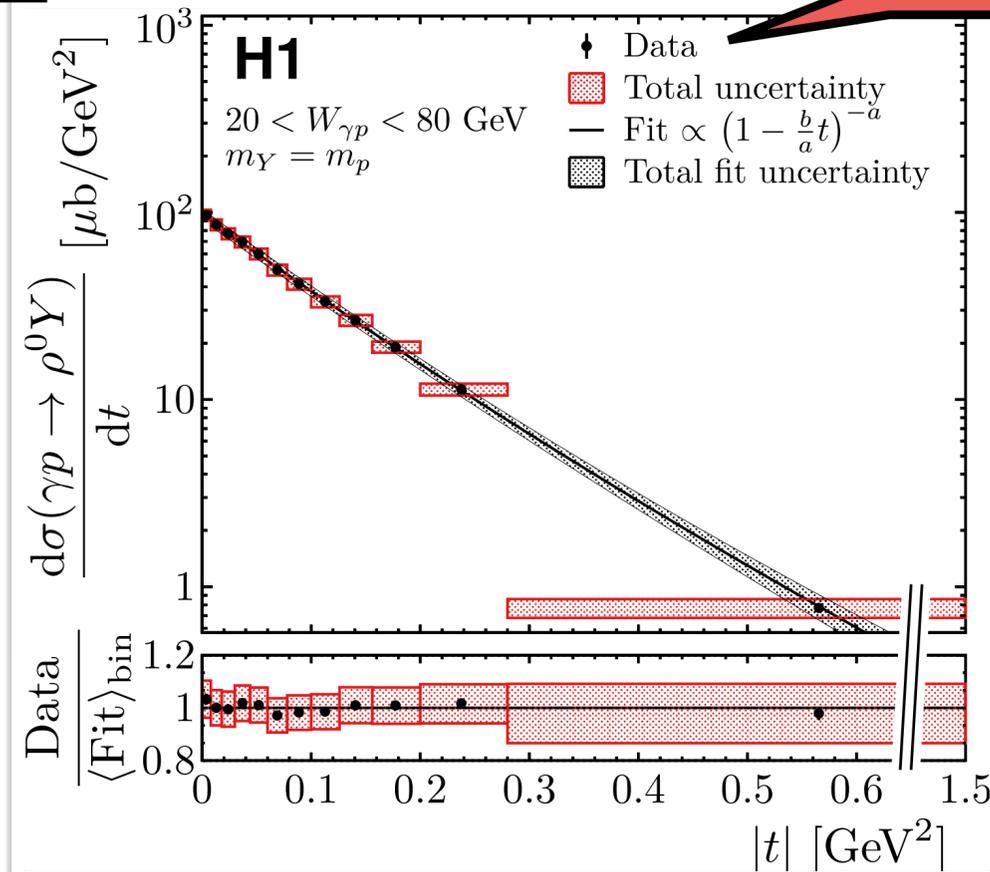
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$d\sigma_\rho/dt(t=0)$ ( $\mu\text{b}/\text{GeV}^2$ )	97.3	1.2	+6.3 -6.3	19.5	0.7	+3.0 -2.9
$b$ ( $\text{GeV}^{-2}$ )	9.61	0.15	+0.20 -0.15	4.81	0.24	+0.39 -0.37
$a$	20.4	3.7	+6.8 -5.1	8.5	1.7	+2.7 -2.1

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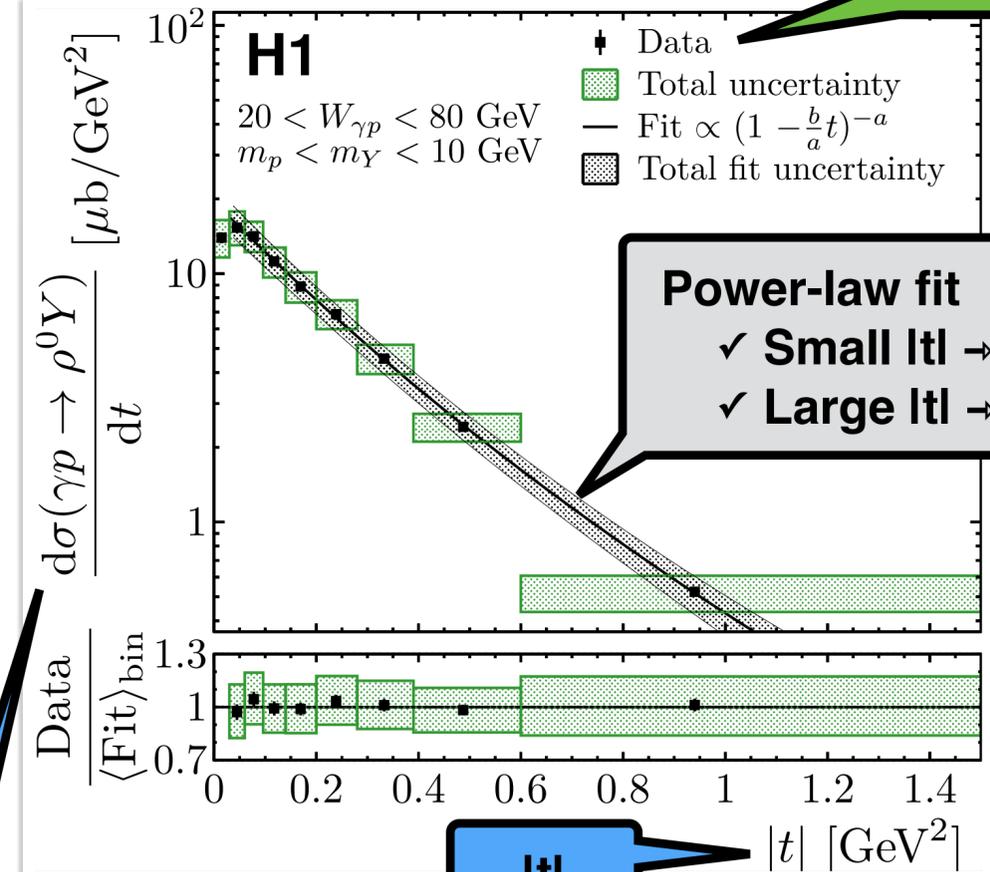
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**b grows with energy**



**Cross section**

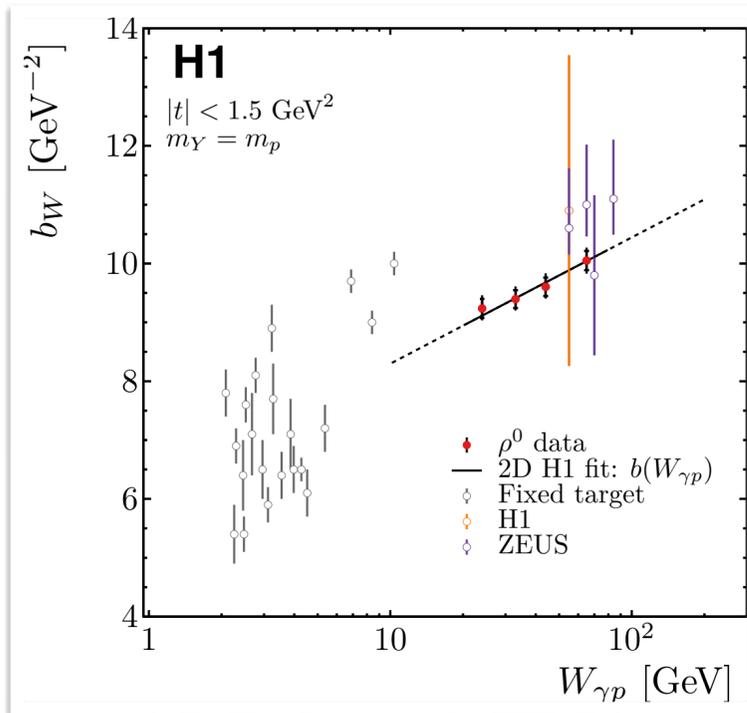


**Power-law fit**  
 ✓ Small  $|t| \rightarrow \exp(-b|t|)$   
 ✓ Large  $|t| \rightarrow |t|^{-a}$

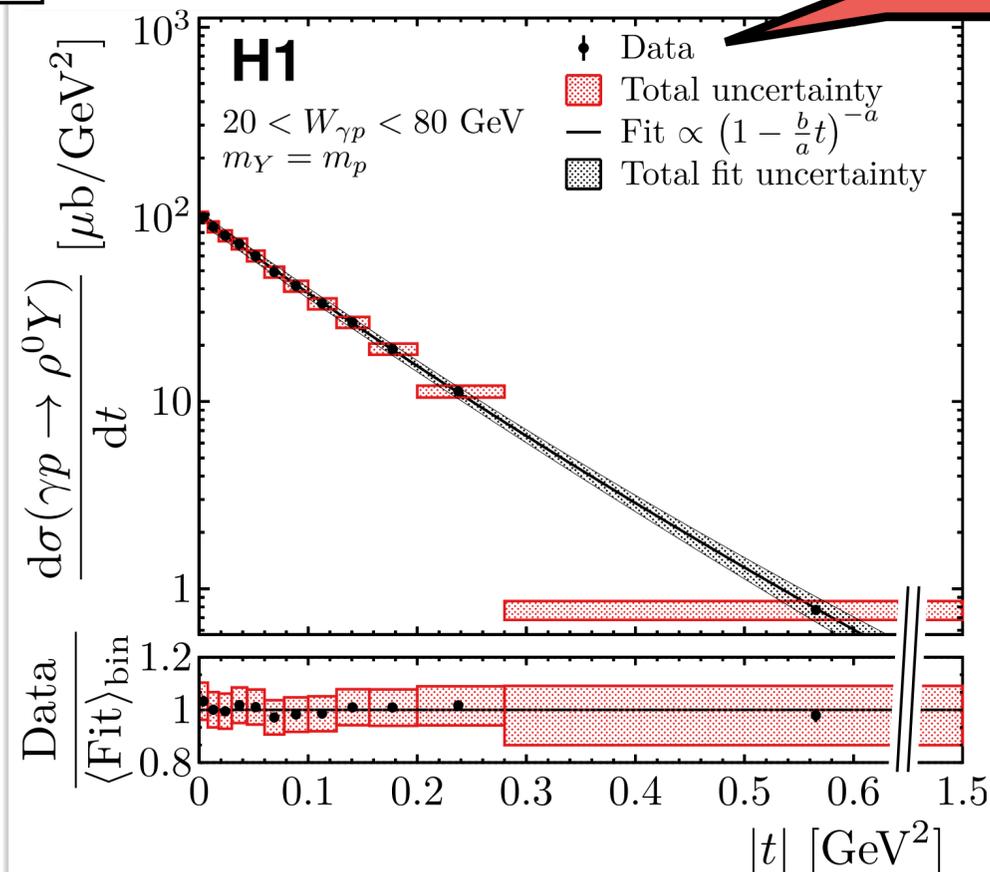
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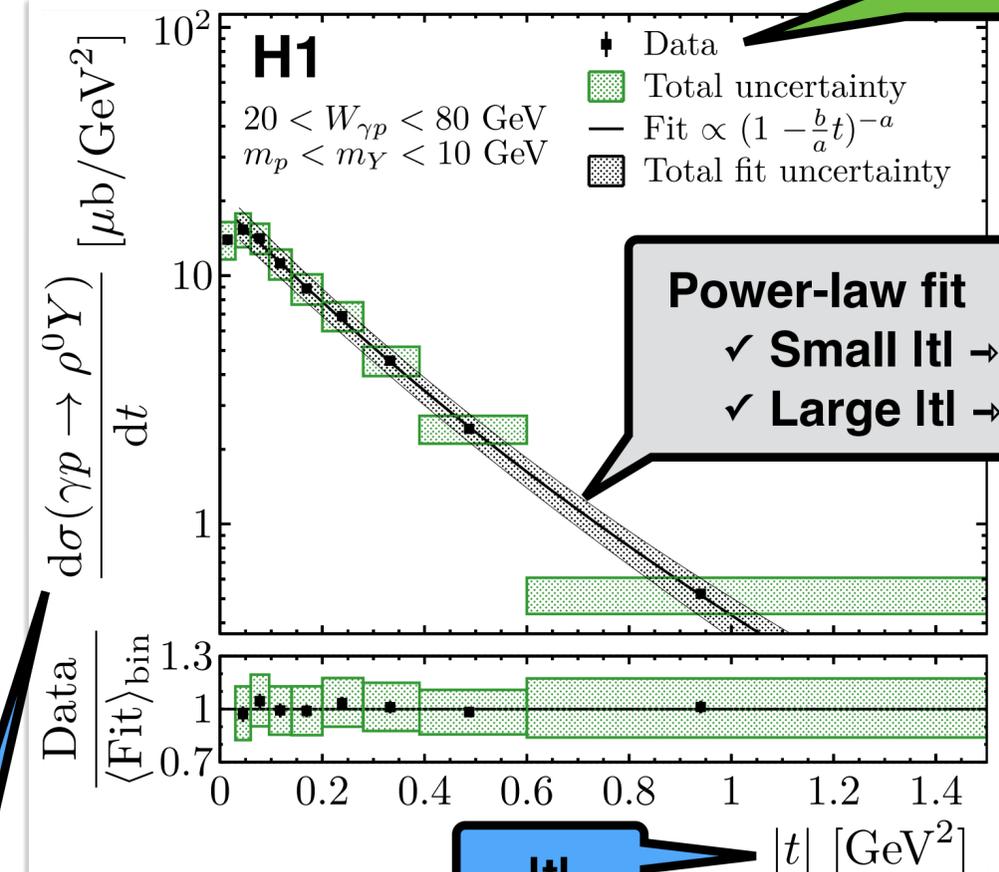
H1 Collaboration, EPJC 80 (2020) 12, 1189



**Exclusive**



**Dissociative**



**|t|**

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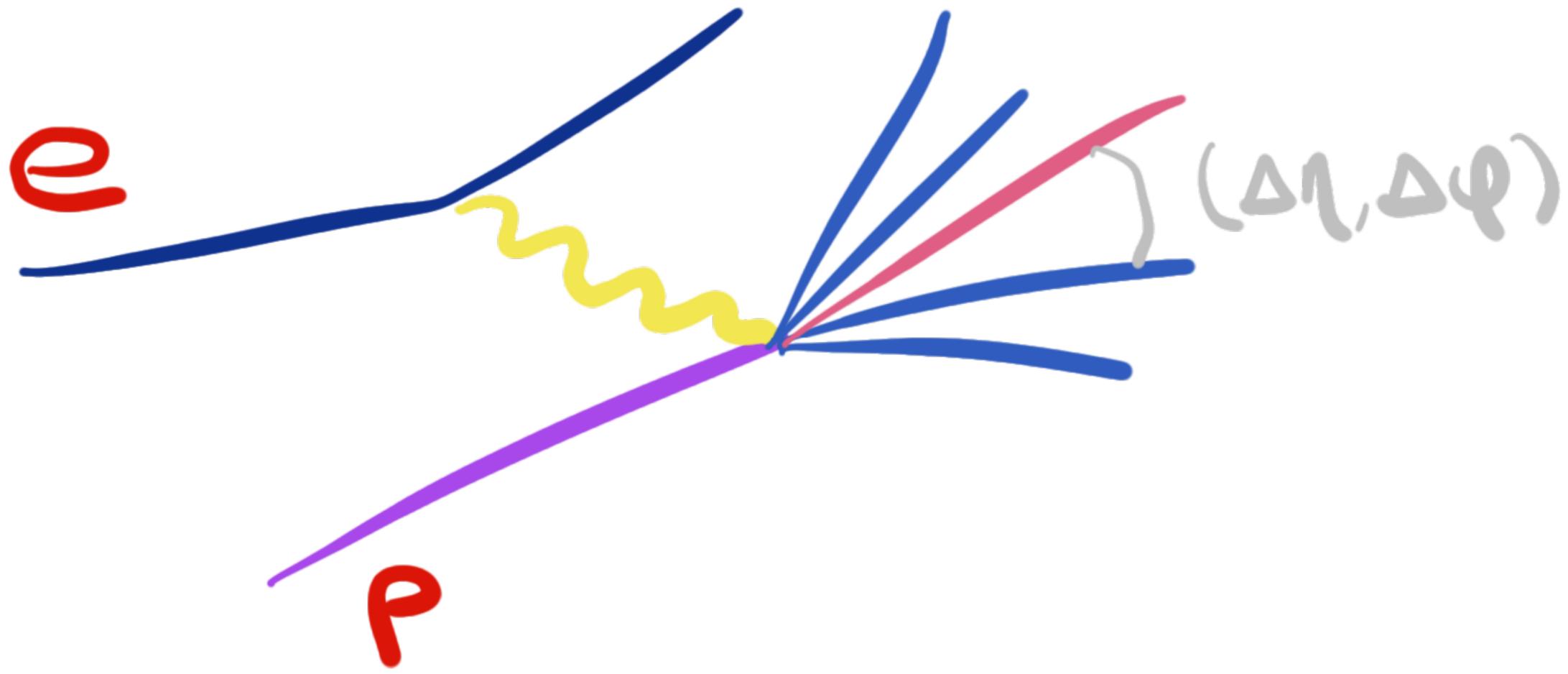
Many more results in the paper (eg Regge analysis)

## Collectivity in small systems: ep collisions

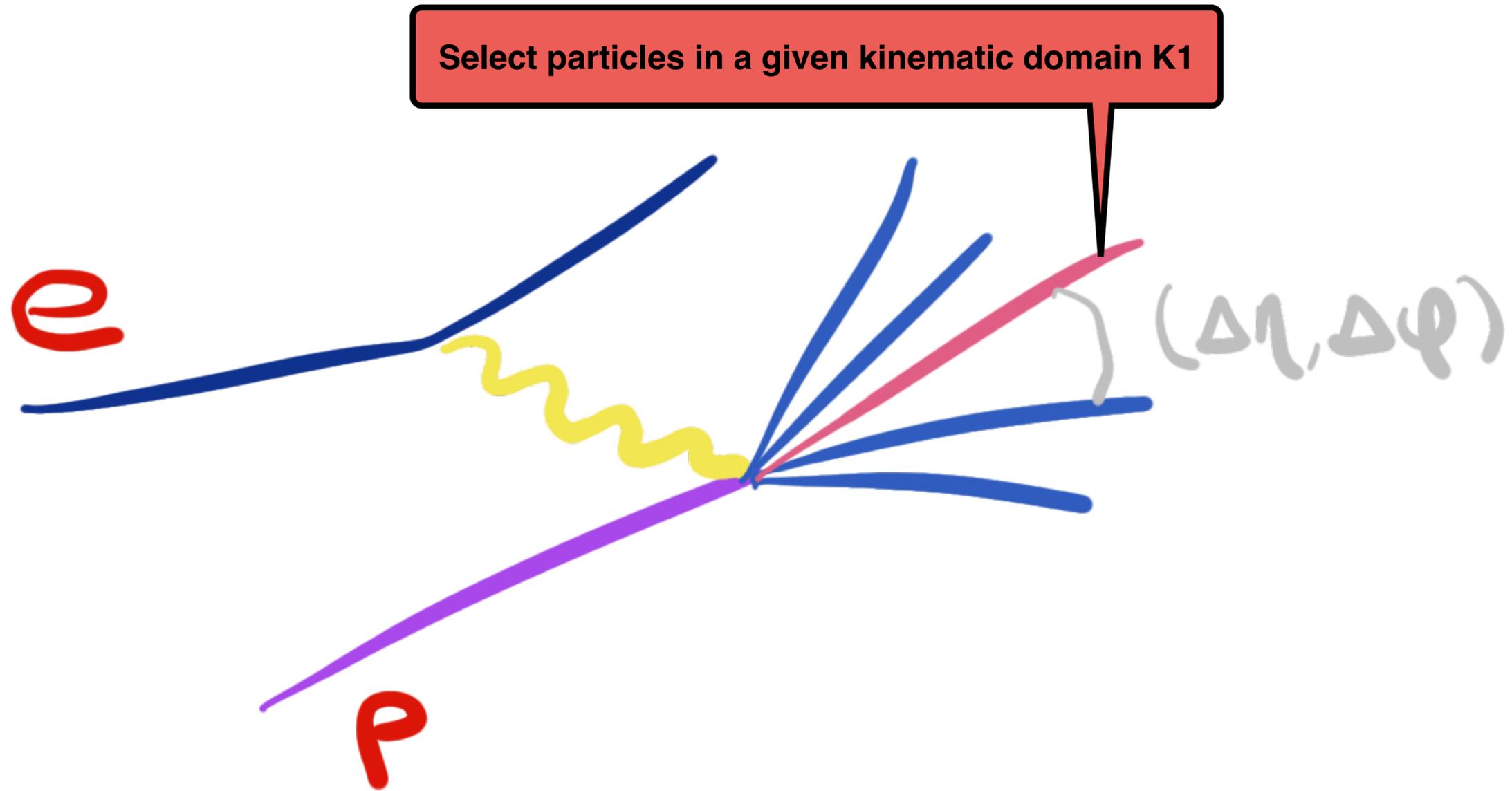
H1 Collaboration, H1prelim-20-033

<https://www-h1.desy.de/h1/www/publications/htmlsplit/H1prelim-20-033.long.html>

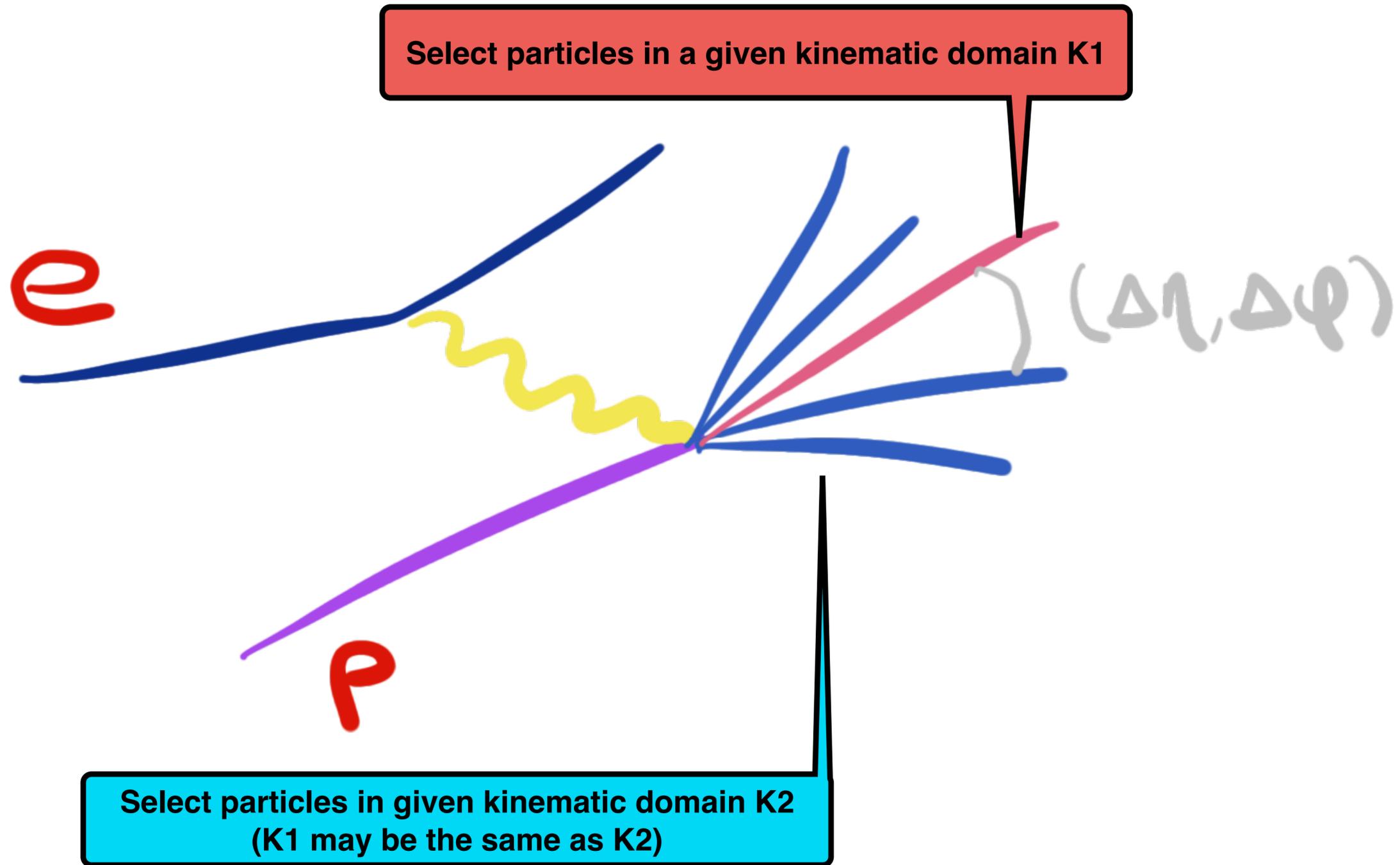
# Two-particle correlations (1/2)



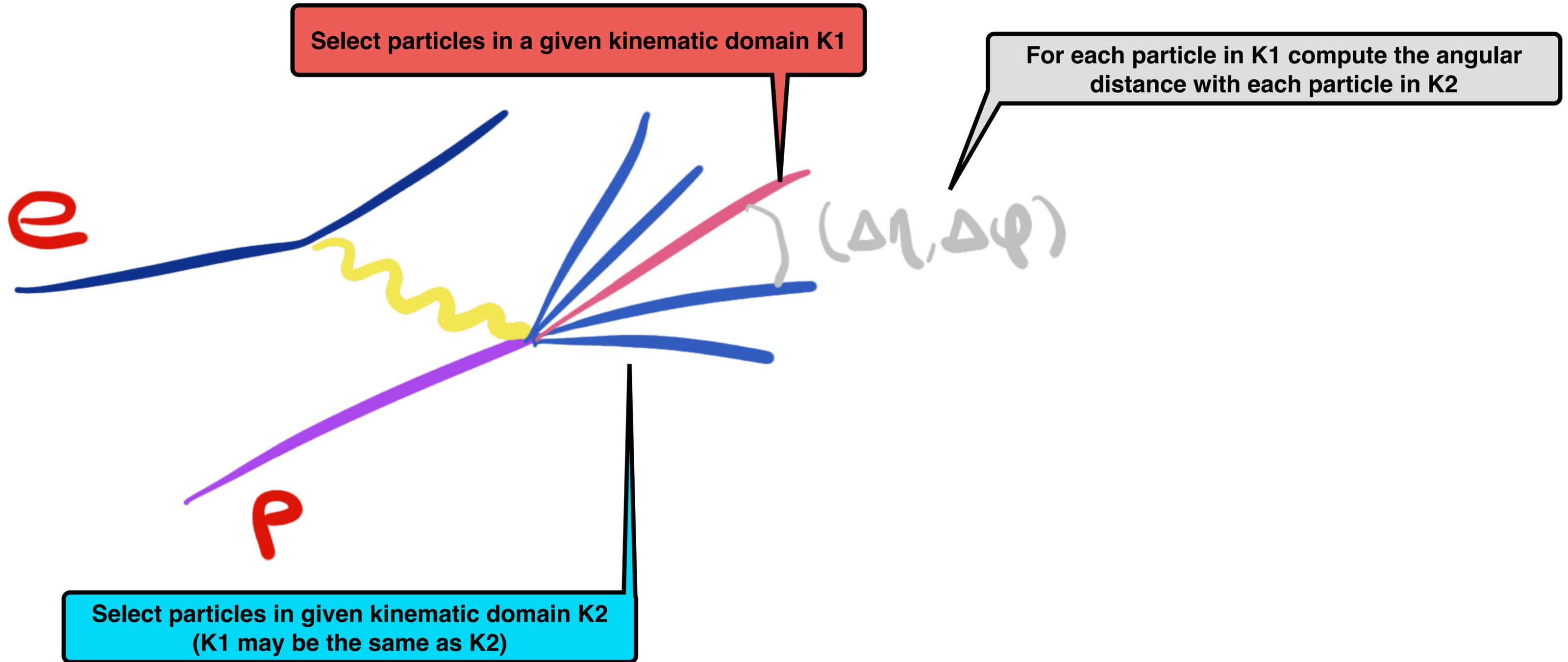
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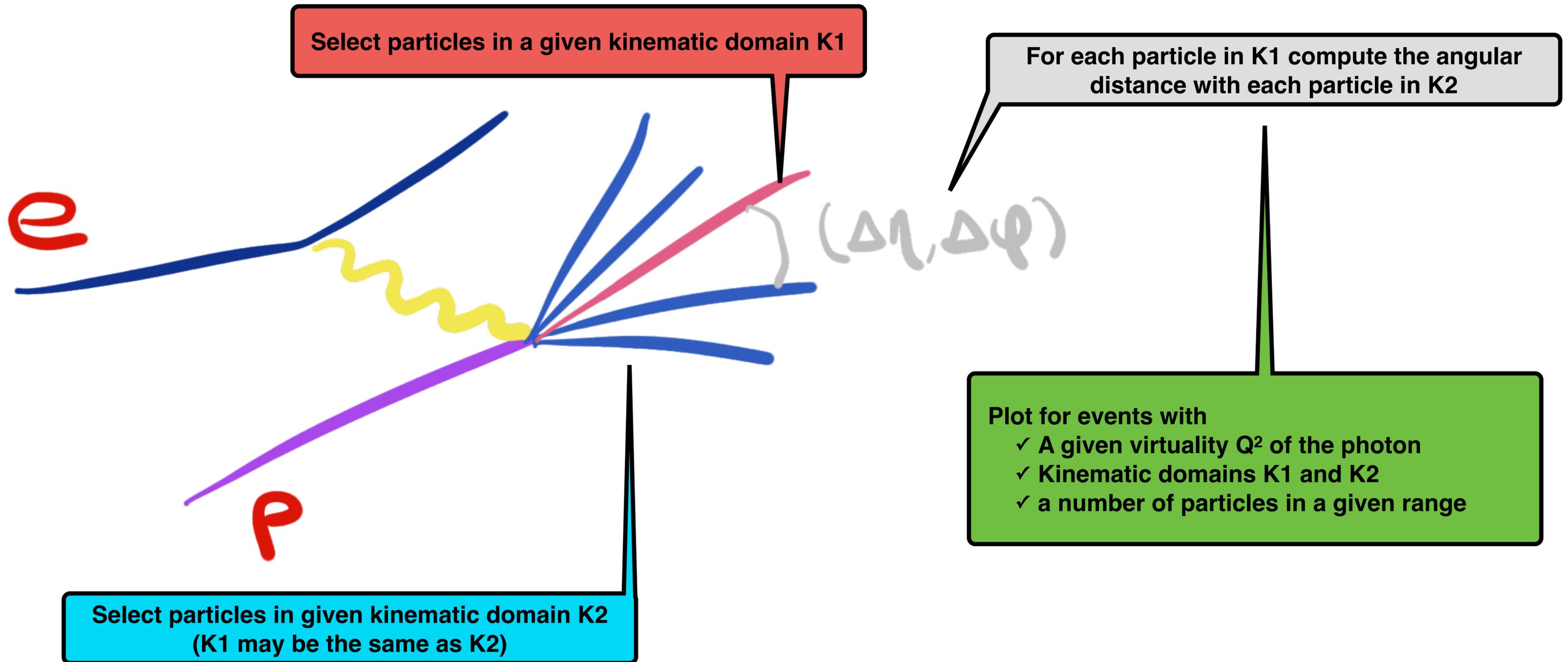
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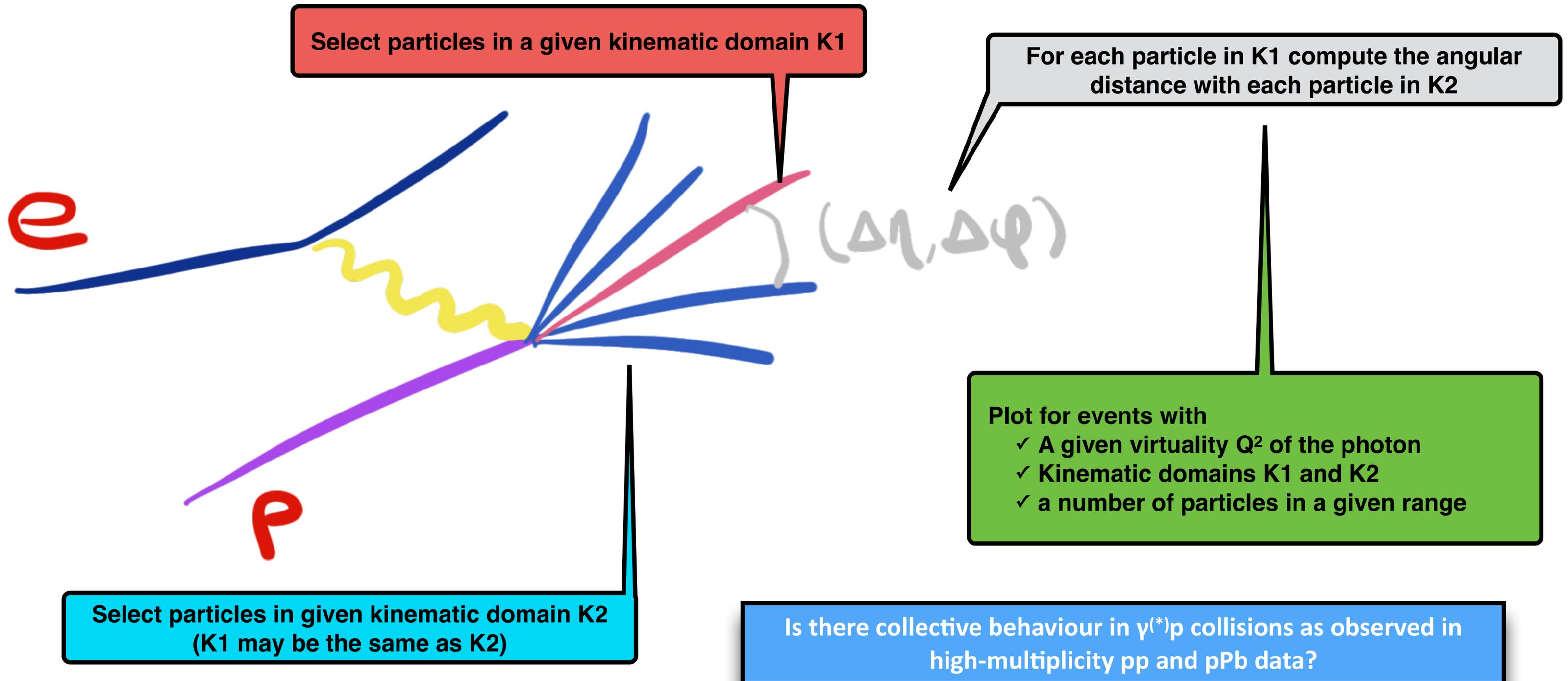
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**H1 Preliminary**

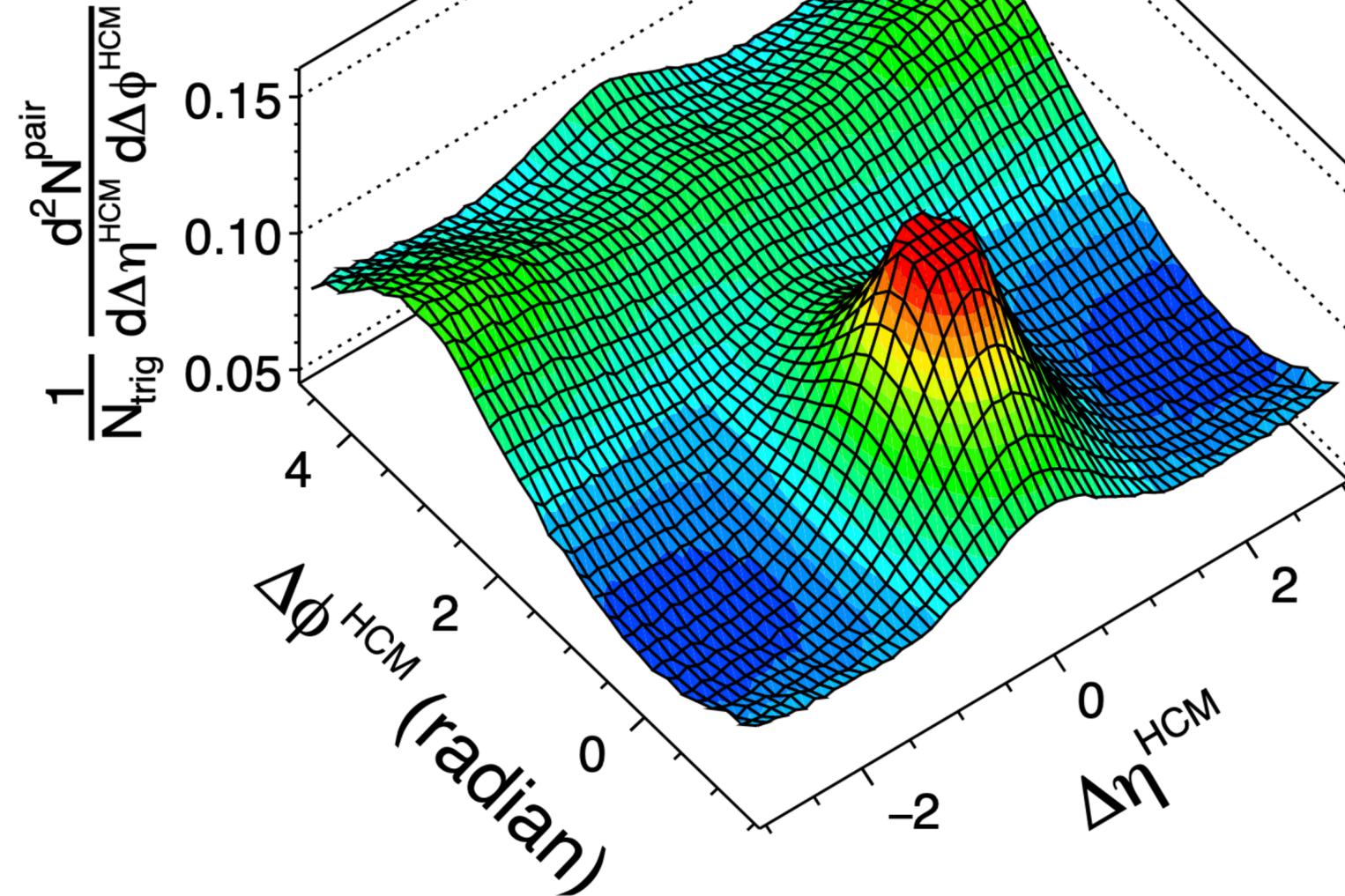
ep  $\sqrt{s} = 319$  GeV

$5 < Q^2 < 100$  GeV<sup>2</sup>

$2 \leq N_{\text{trk}}^{\text{obs}} < 4$

$0.3 < p_{\text{T}}^{\text{HCM}} < 3.0$  GeV

Selection



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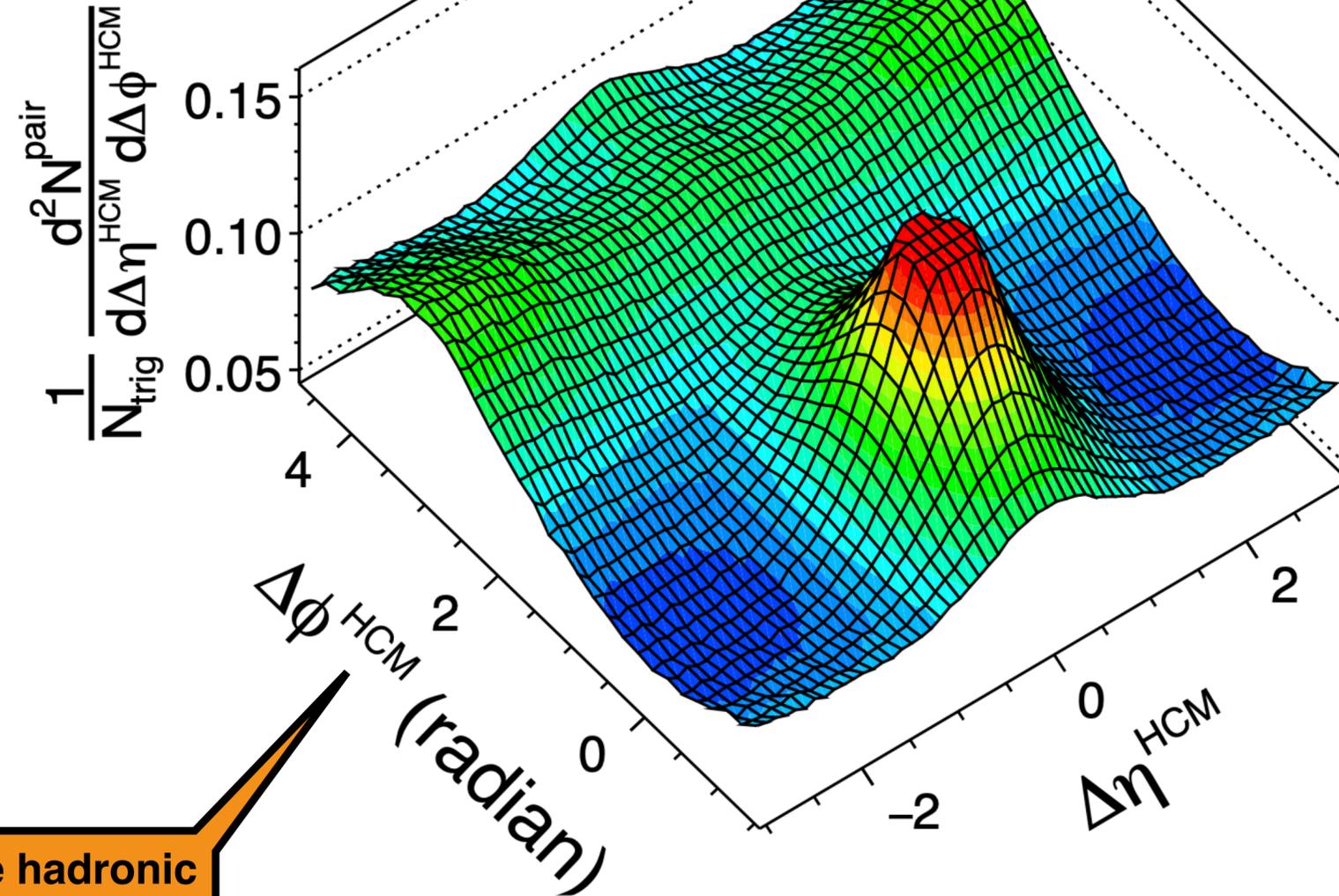
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Measurements in the hadronic  
centre-of-mass frame

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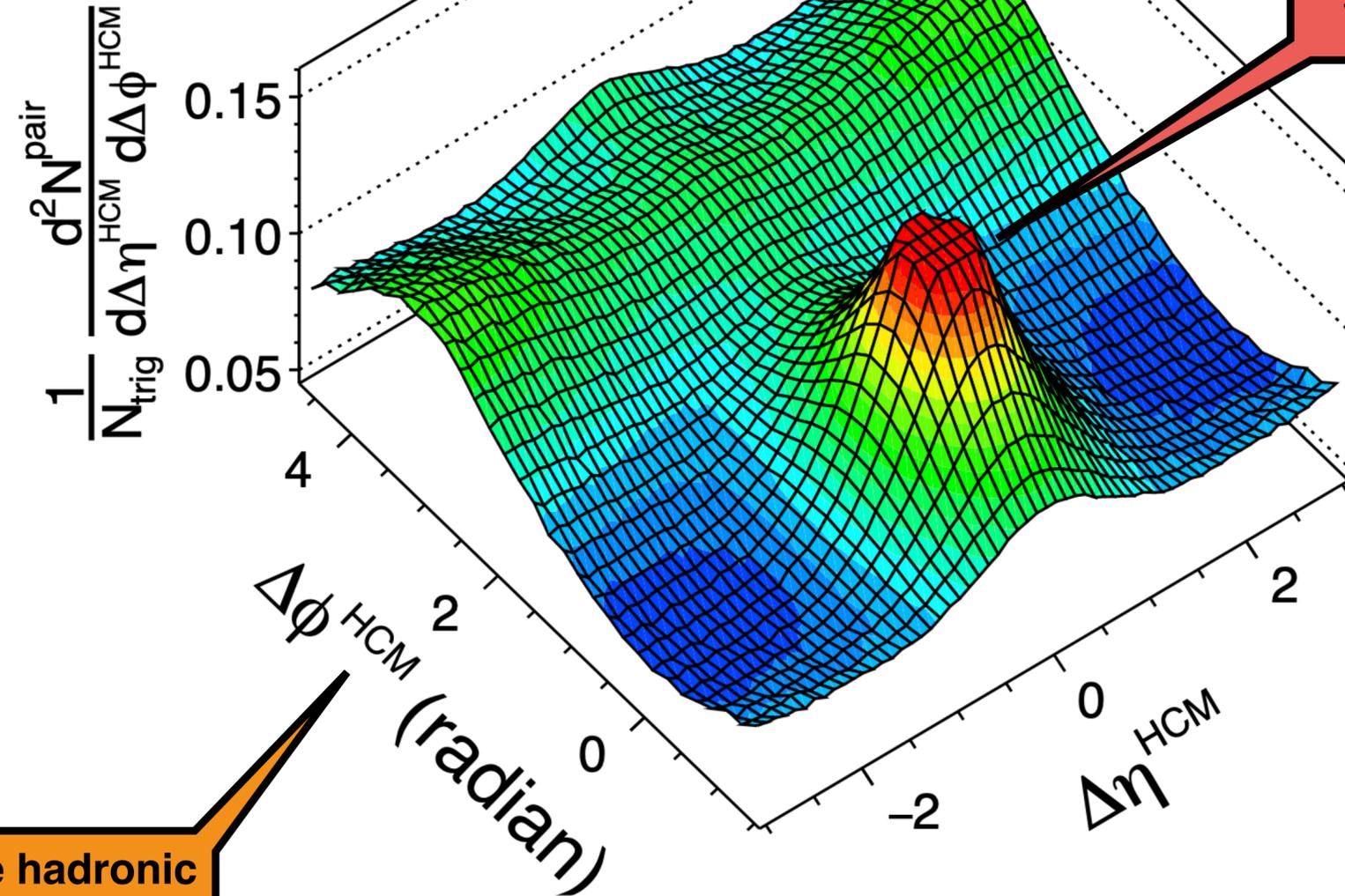
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Short range correlations: jets, resonances, ...

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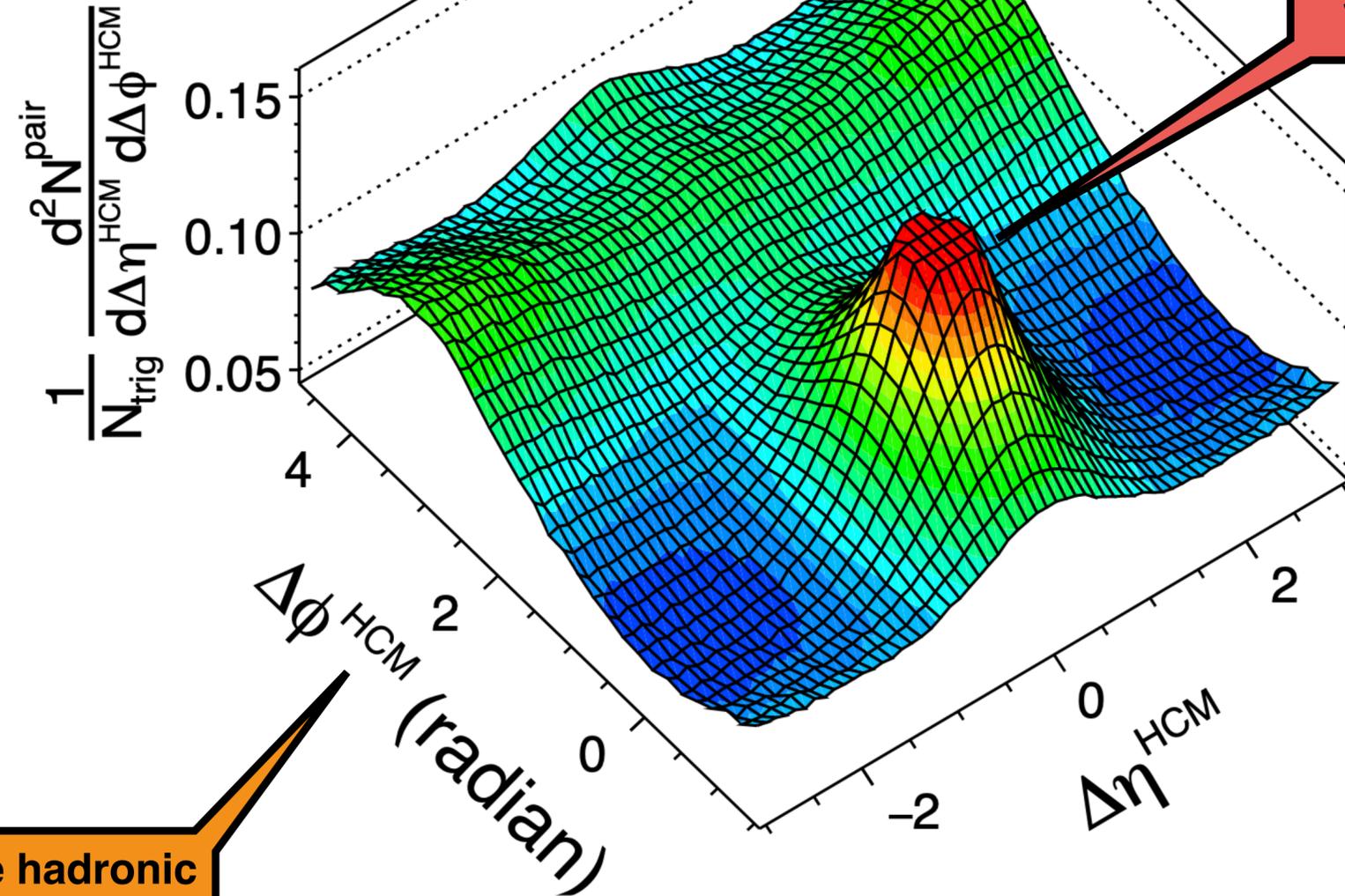
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Selection



Back-to-back jet

Short range correlations: jets, resonances, ...

Measurements in the hadronic  
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# Two-particle correlations (2/2)

**H1 Preliminary**

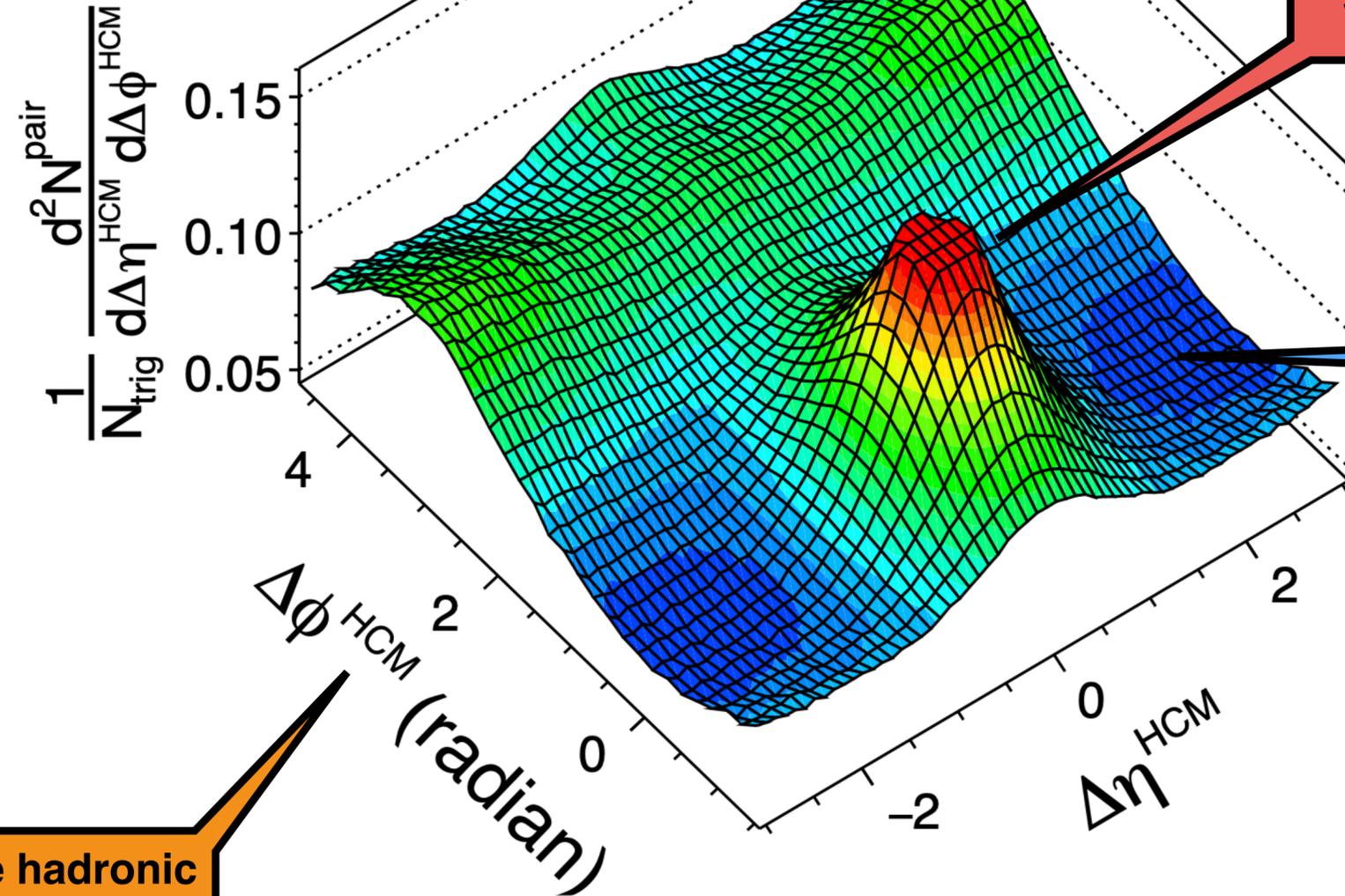
ep  $\sqrt{s} = 319$  GeV

$5 < Q^2 < 100$  GeV<sup>2</sup>

$2 \leq N_{\text{trk}}^{\text{obs}} < 4$

$0.3 < p_{\text{T}}^{\text{HCM}} < 3.0$  GeV

Selection



Back-to-back jet

Short range correlations: jets, resonances, ...

Long-range correlations in pseudorapidity at  $\Delta\phi \approx 0$  (aka the ridge) not observed

Measurements in the hadronic centre-of-mass frame

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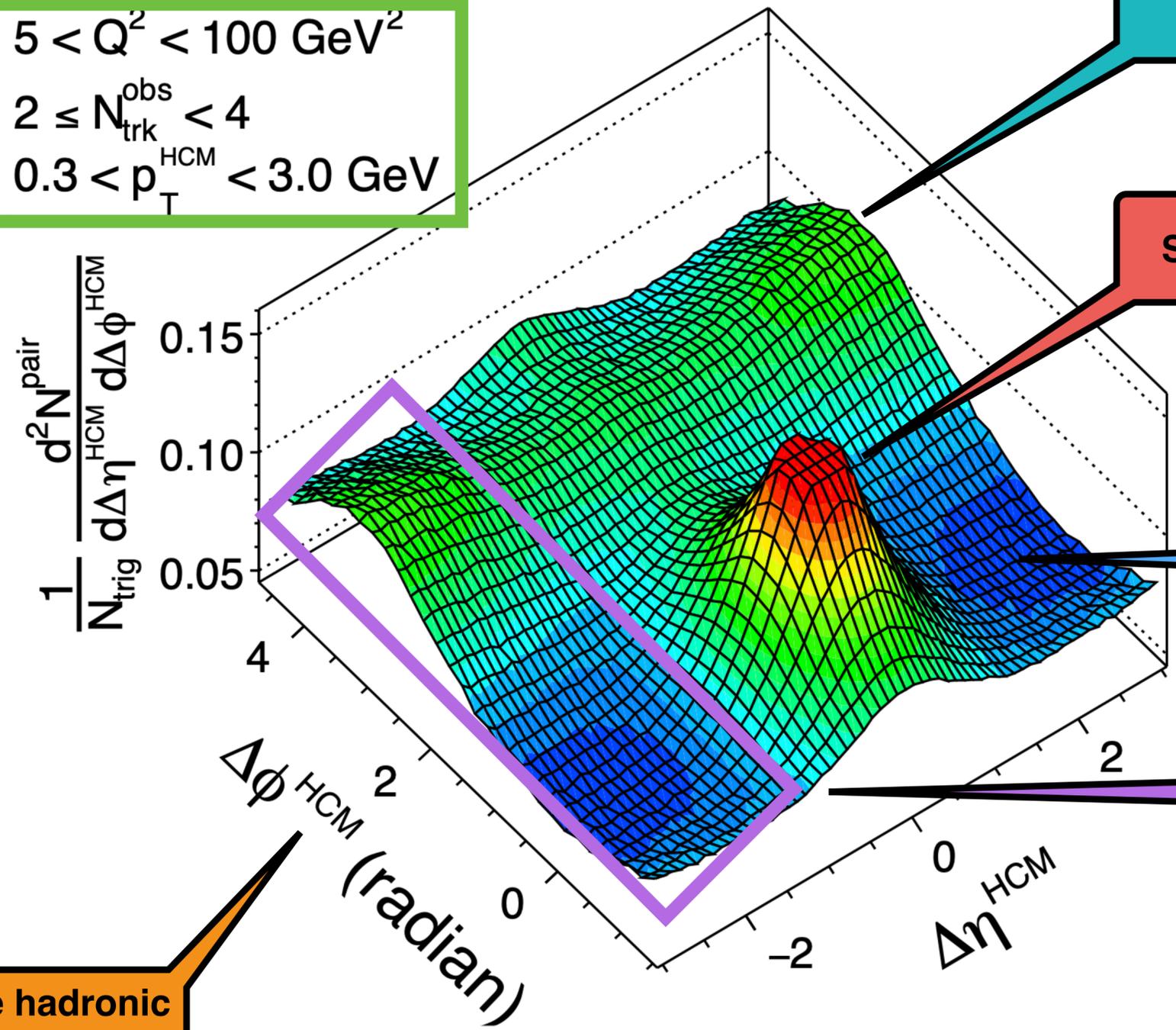
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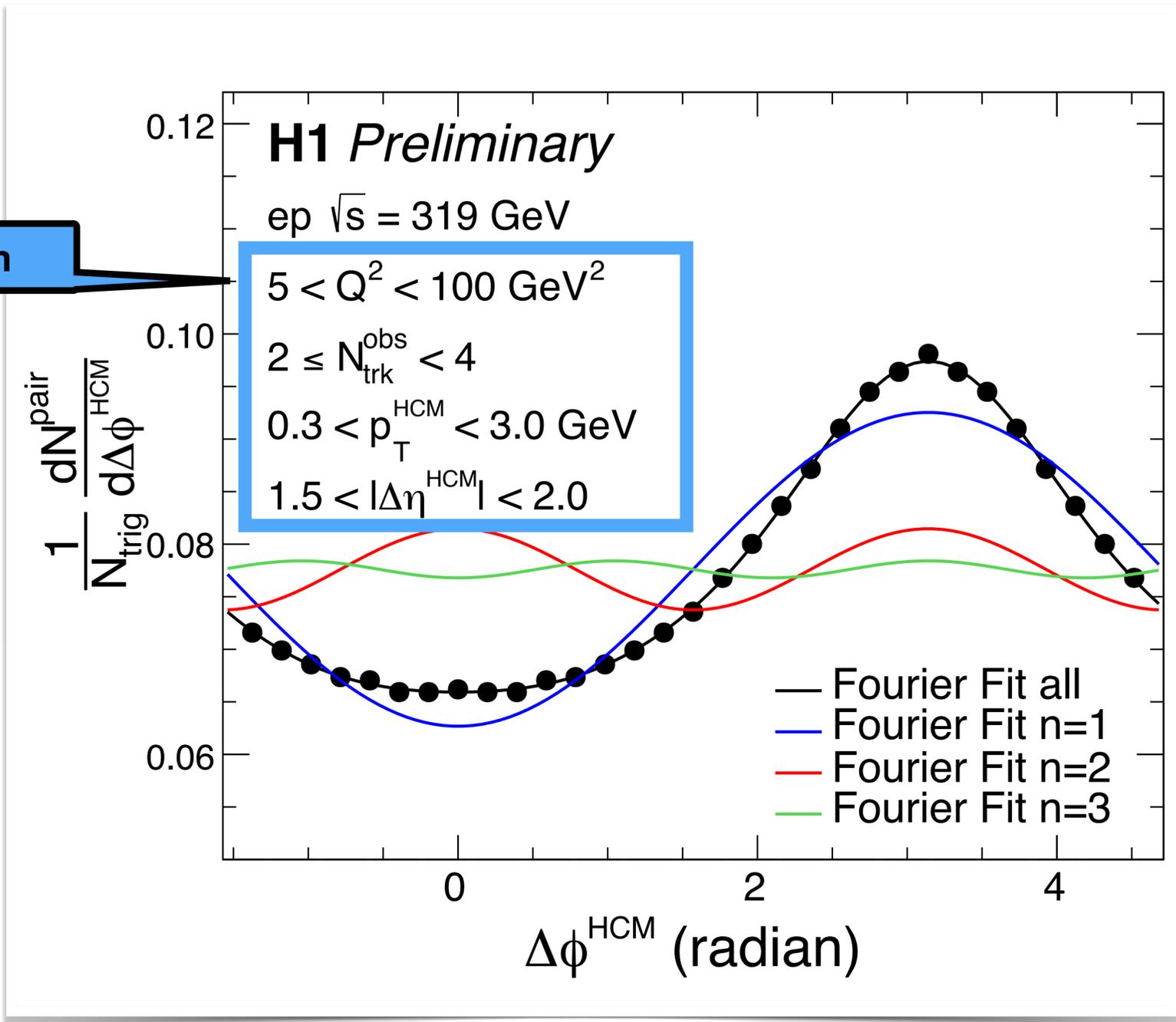
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Select this region and decompose the azimuth distribution in Fourier contributions

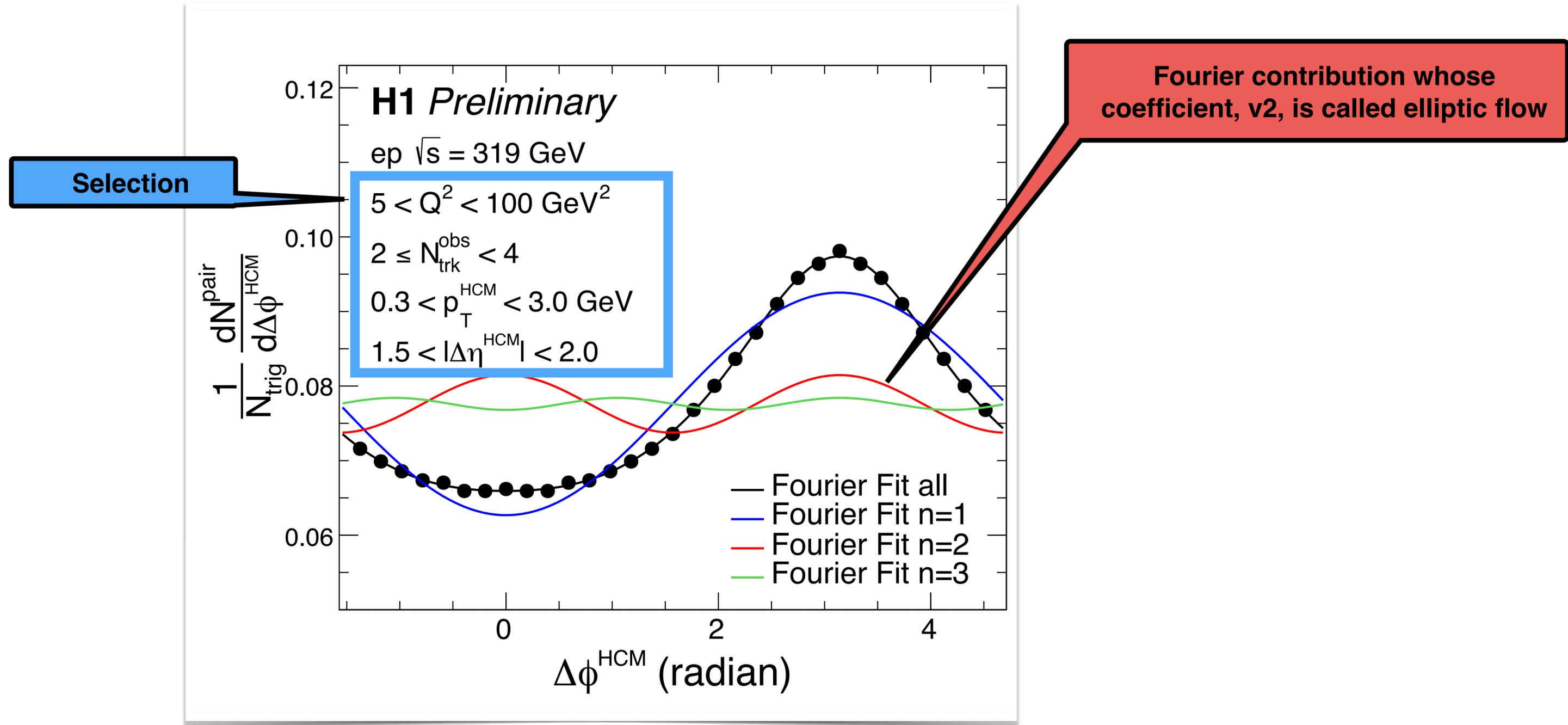
Measurements in the hadronic centre-of-mass frame

# Long-range pseudorapidity correlation

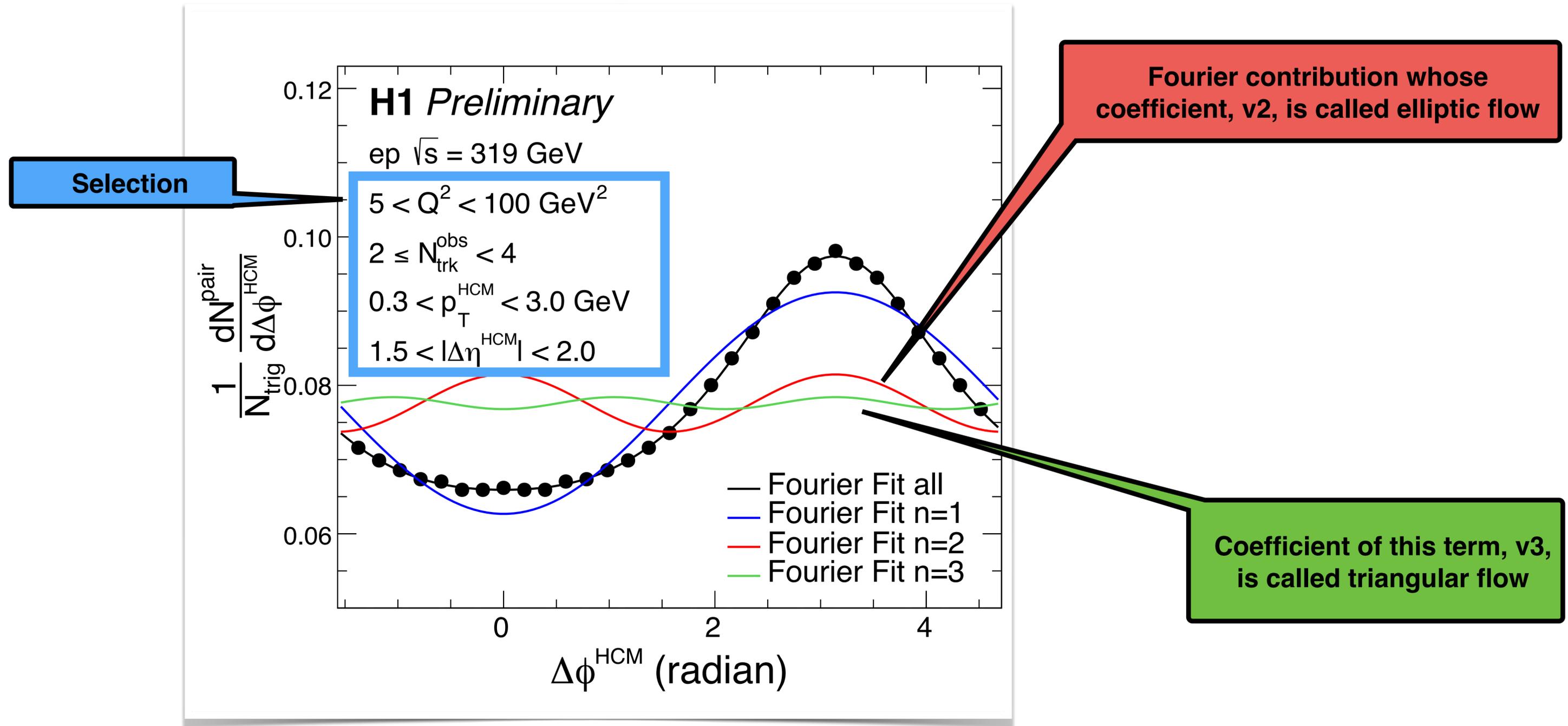
Selection



# Long-range pseudorapidity correlation

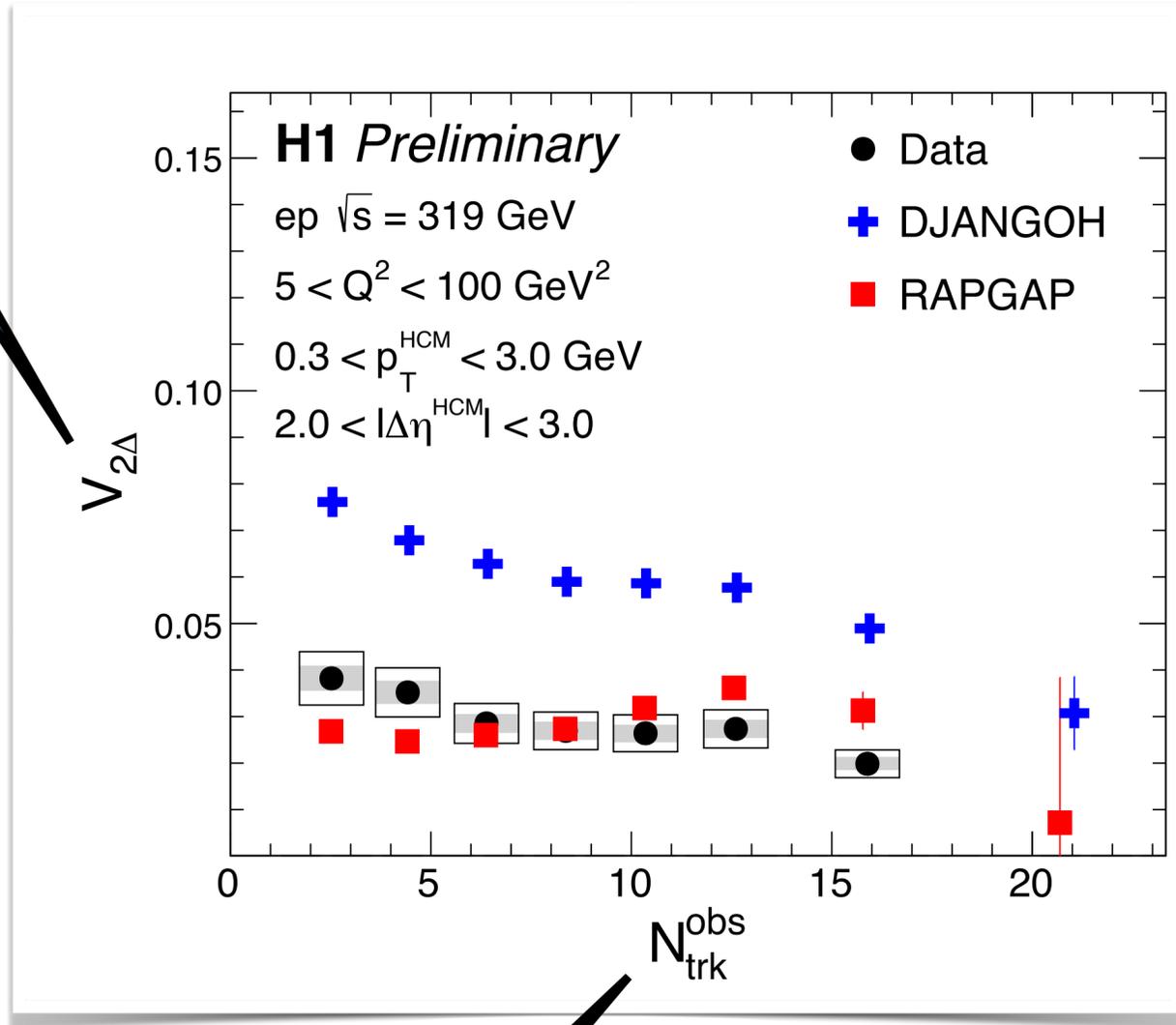


# Long-range pseudorapidity correlation



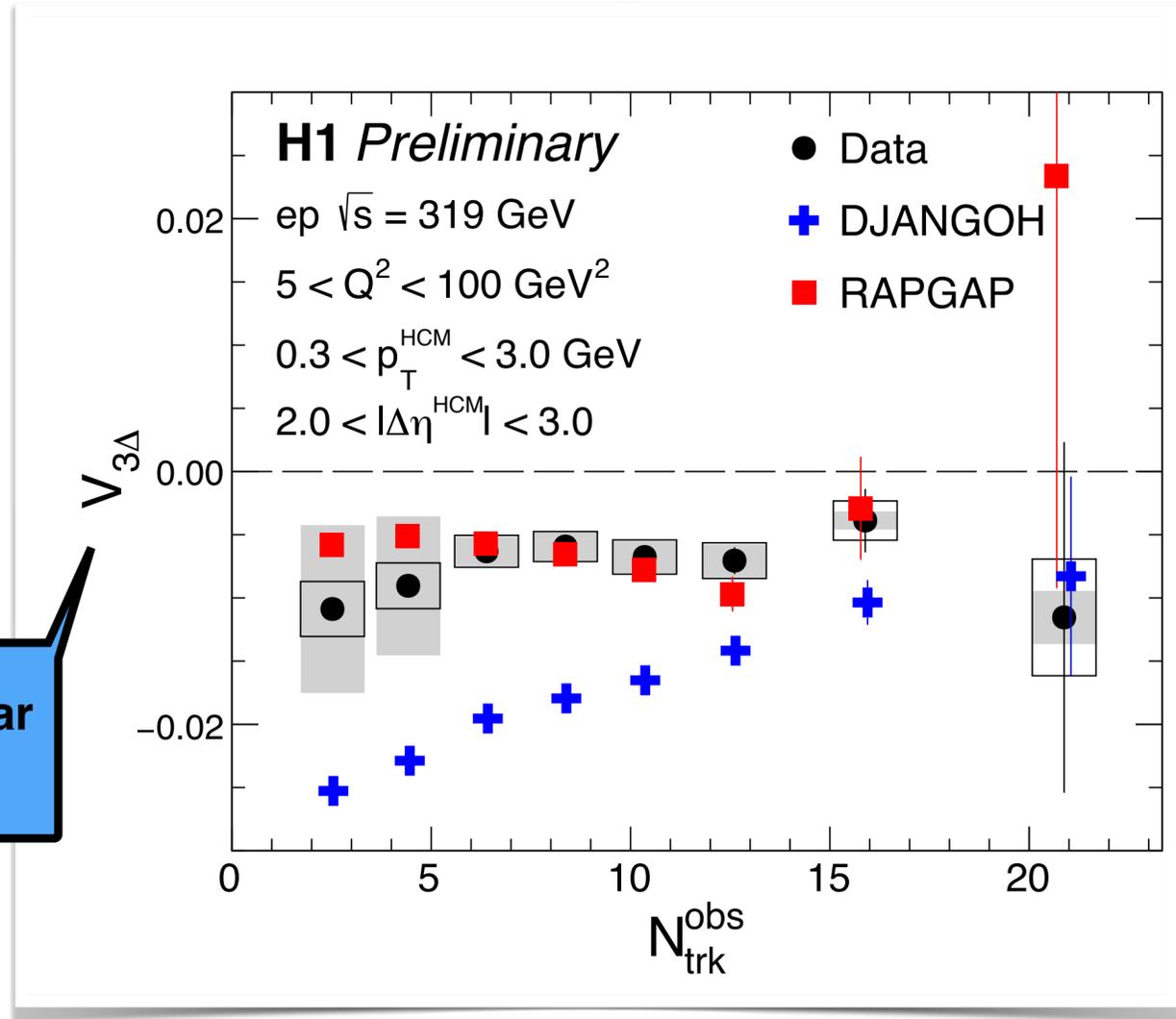
# Results: elliptic and triangular flow

Elliptic flow



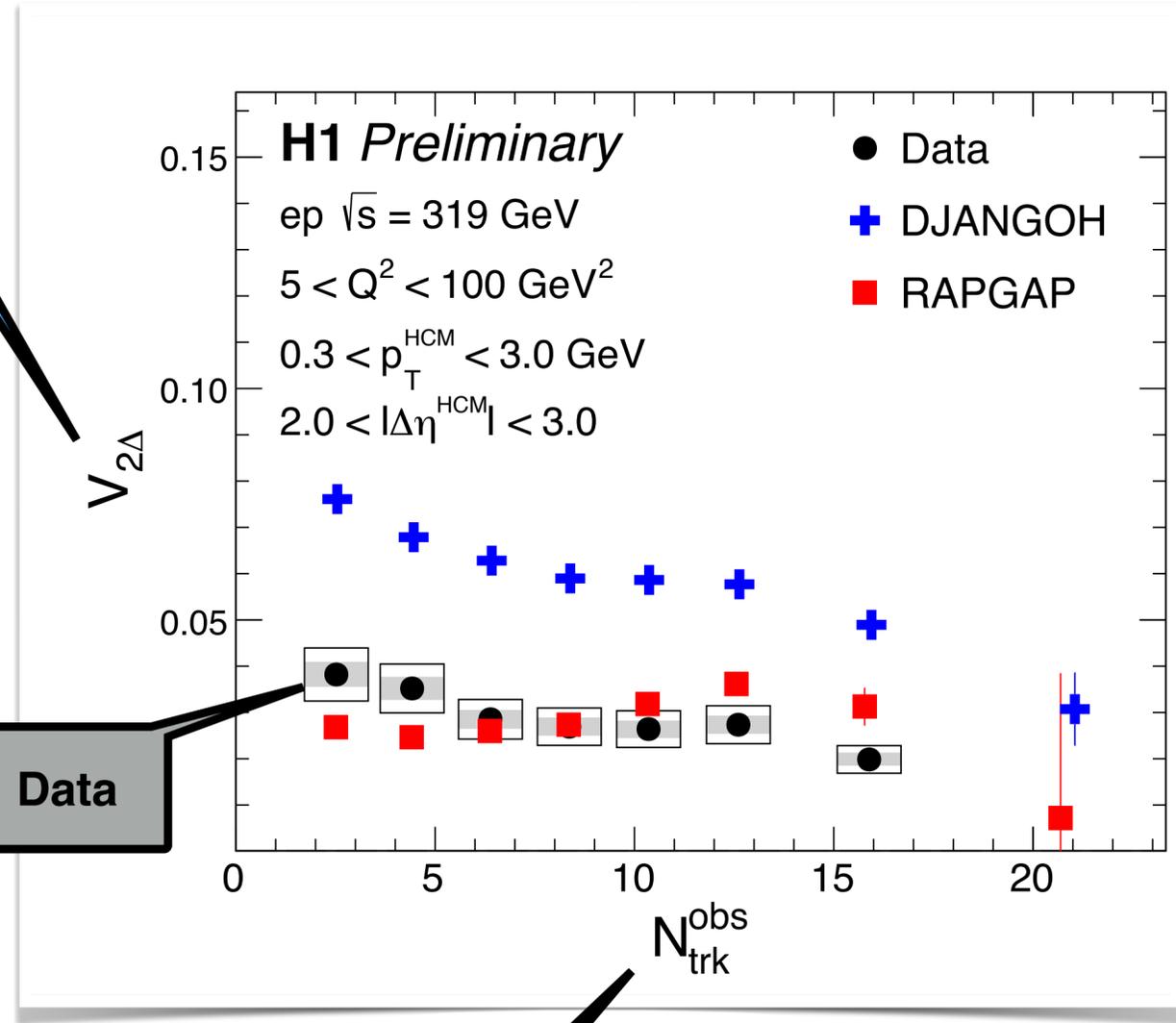
Multiplicity

Triangular flow

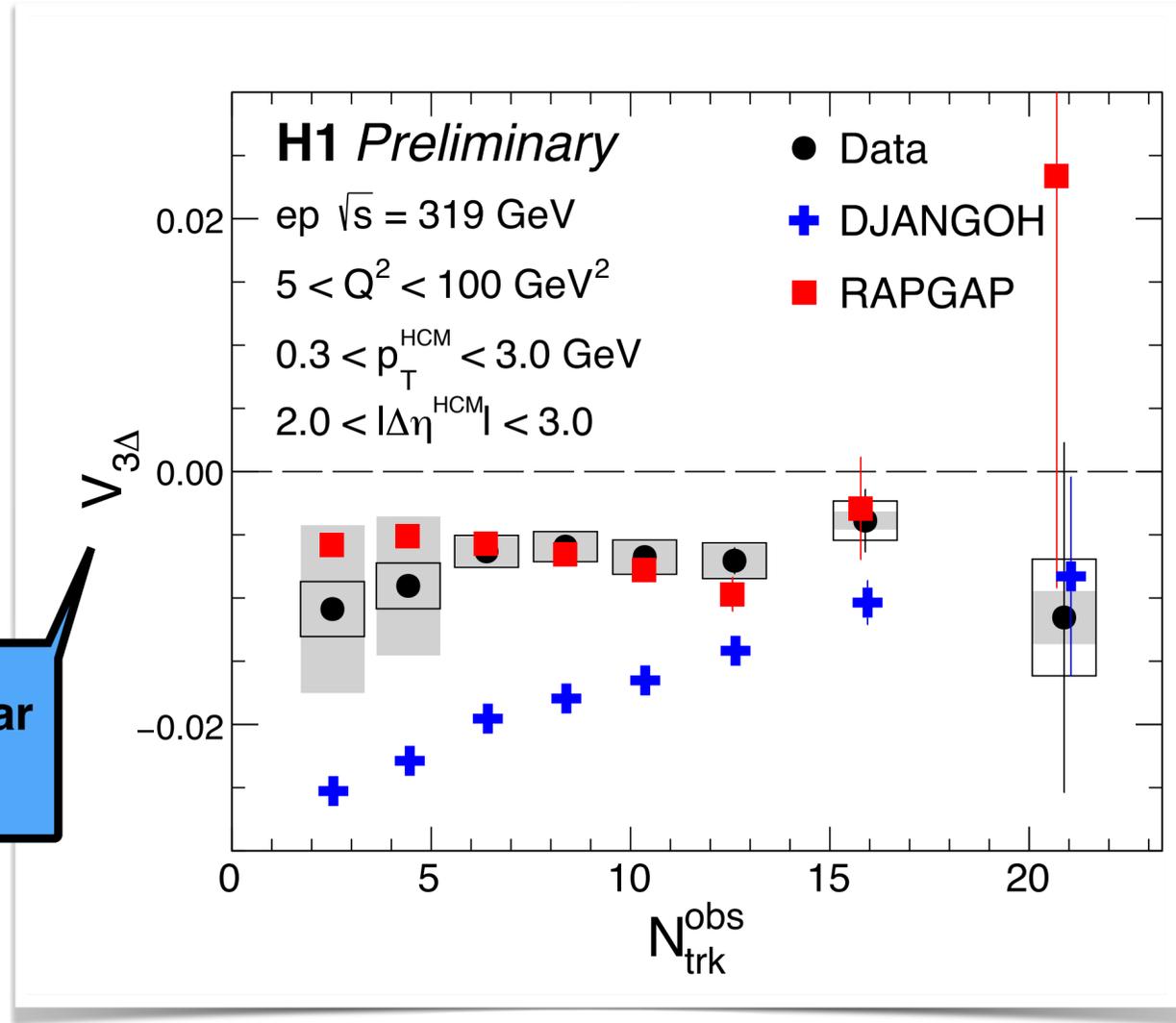


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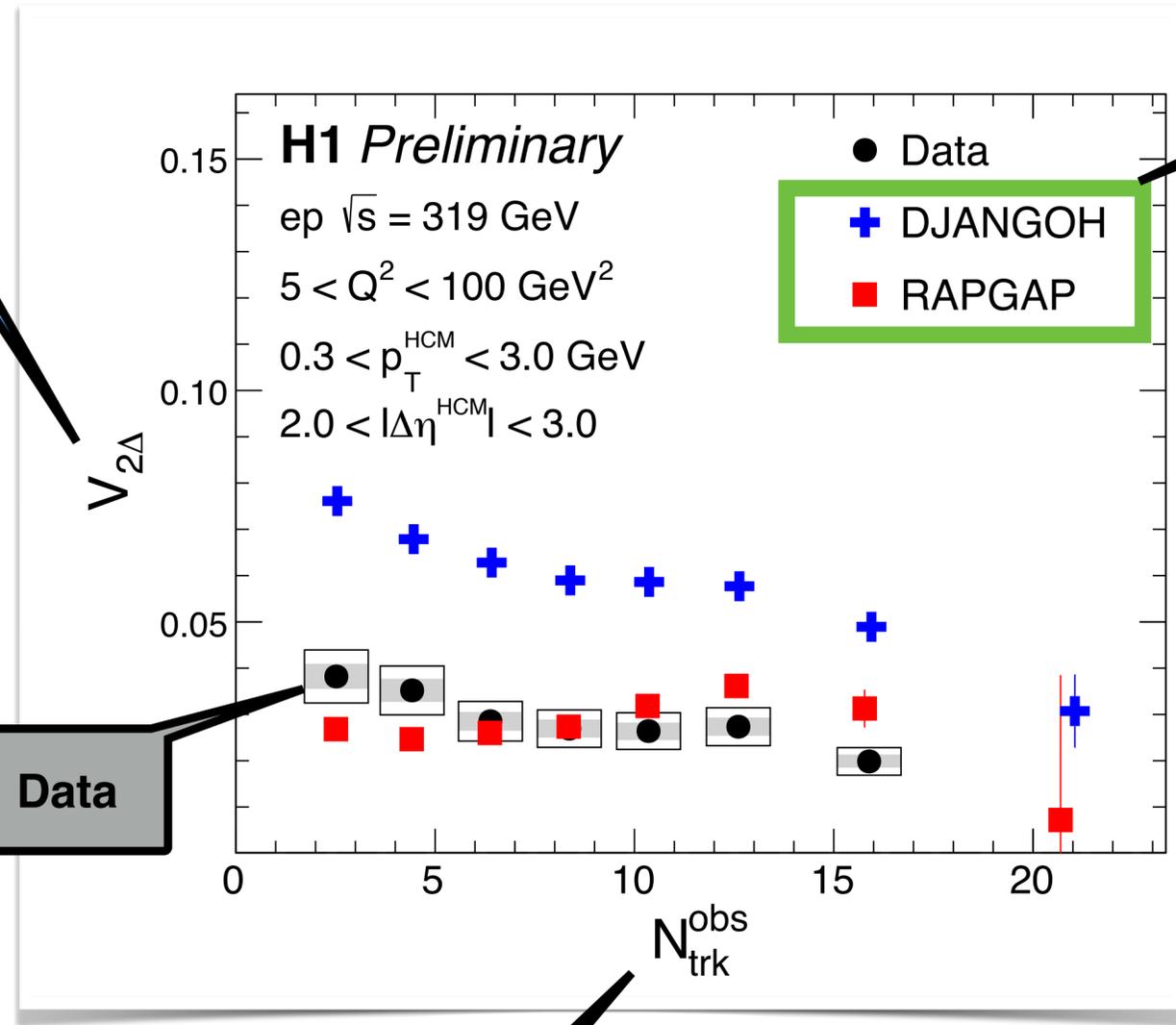


Triangular flow



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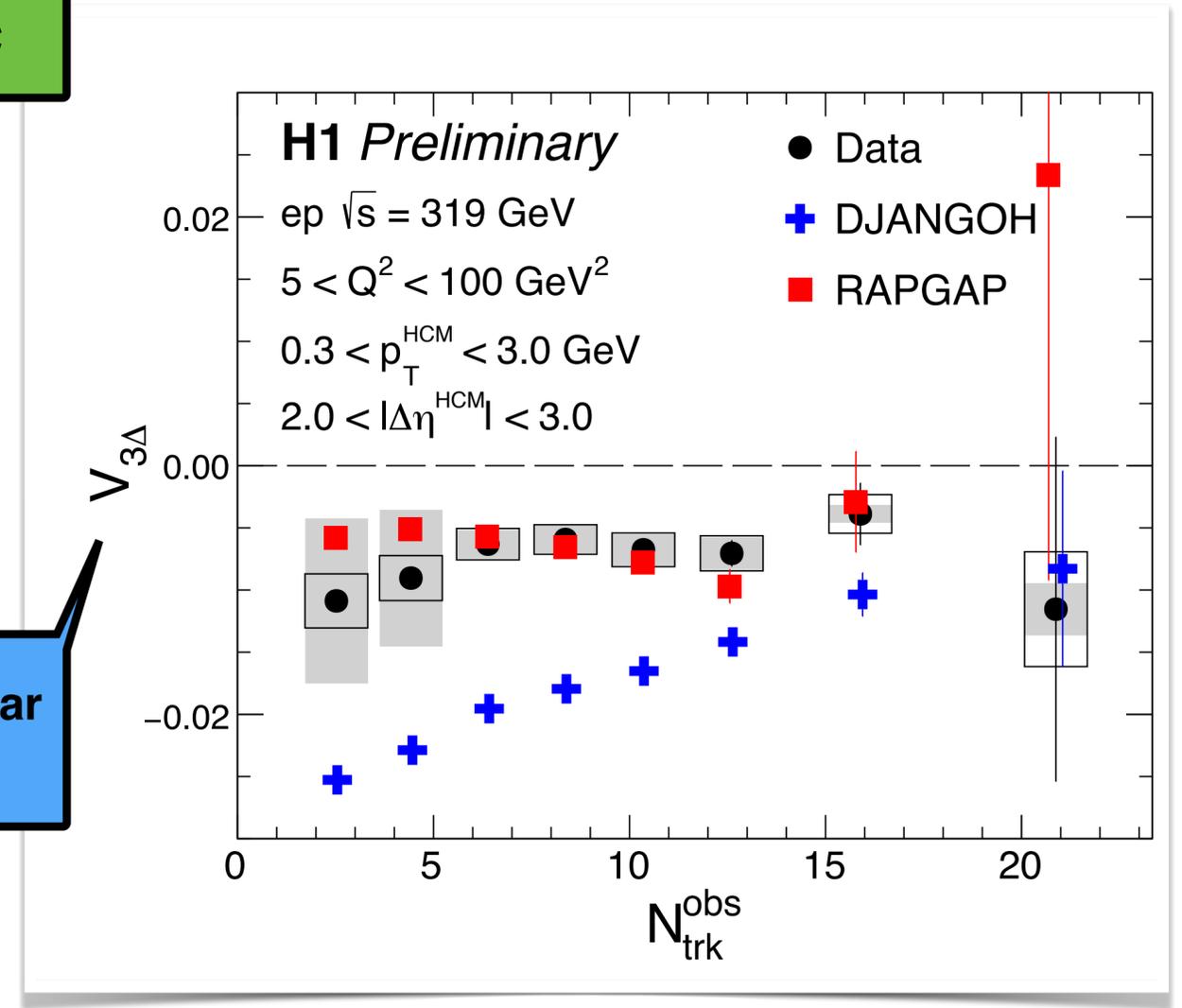


Data

Multiplicity

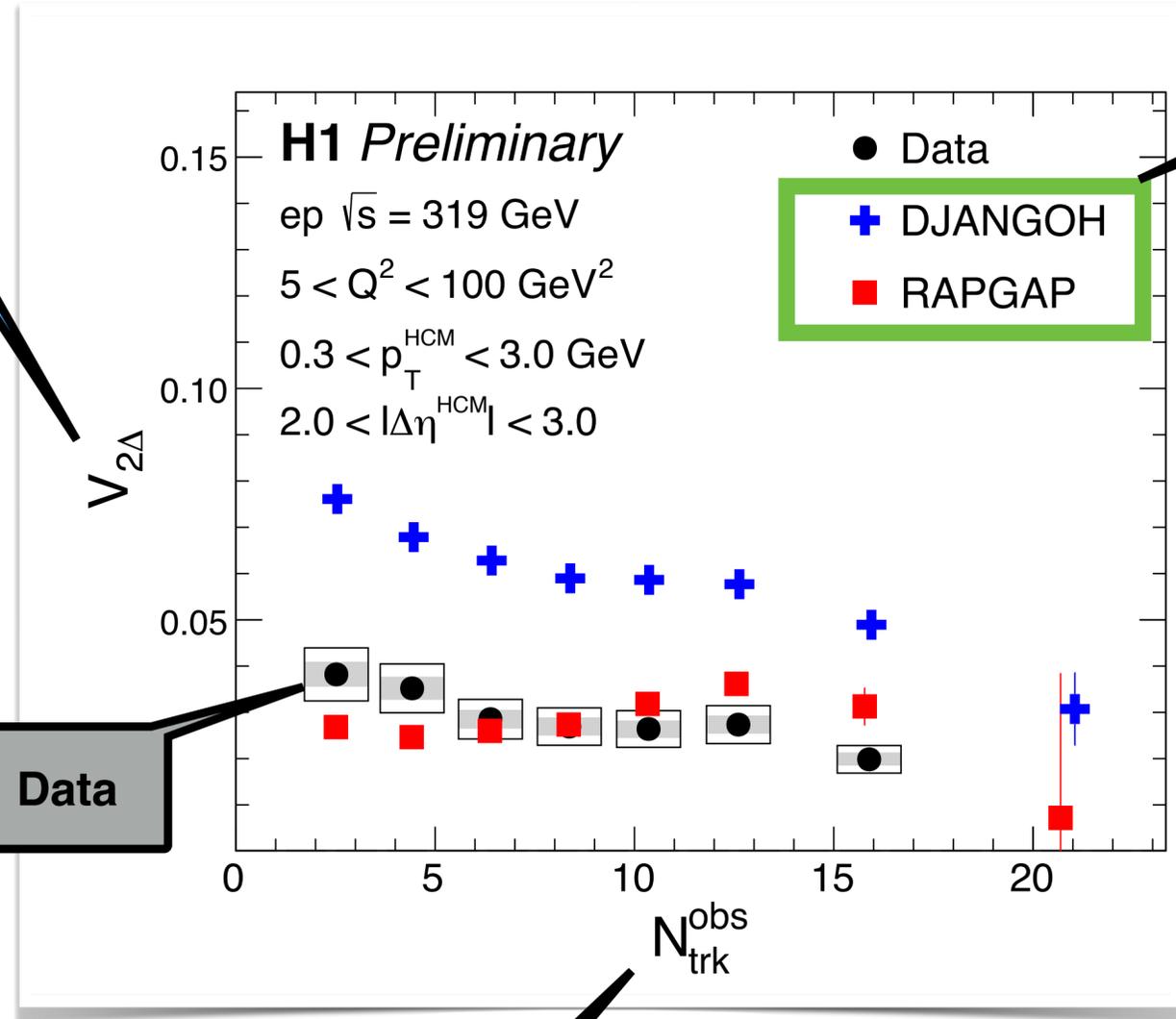
MC

Triangular flow



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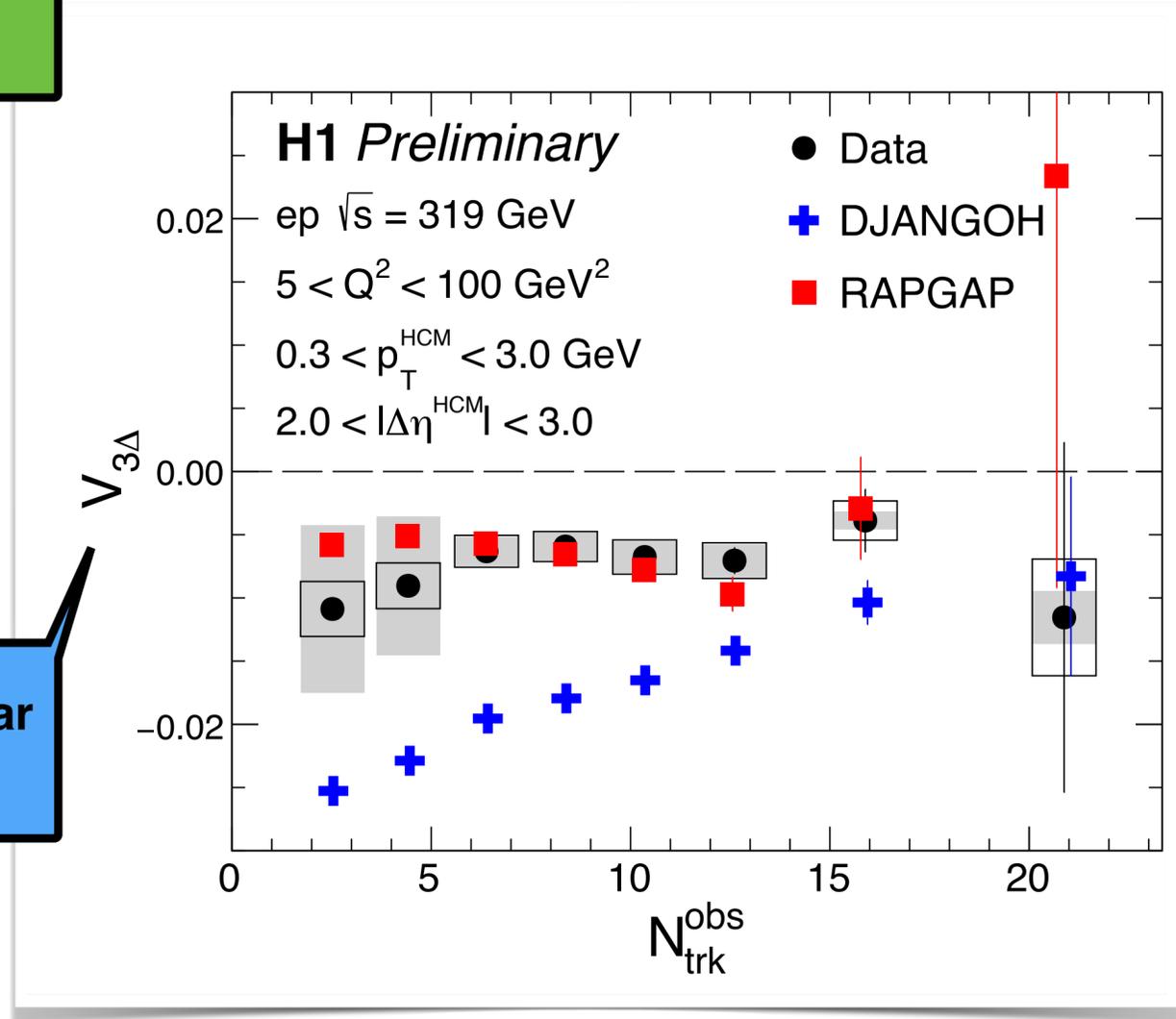


Data

Multiplicity

MC

Triangular flow



Rapgap, w/o collective behaviour, describes data

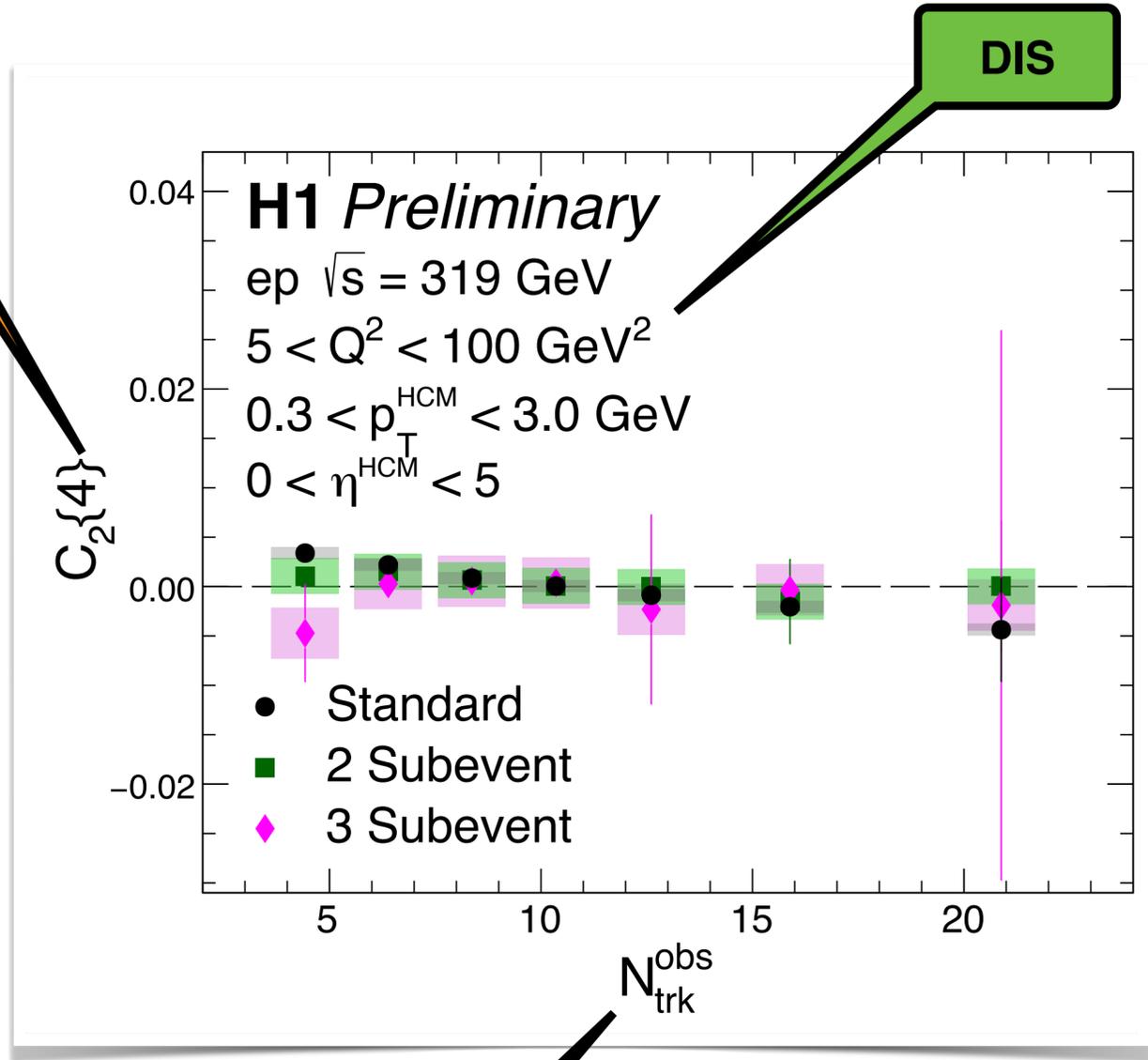
## Results: cumulants

Use 4-particle cumulants: a negative  $C_2\{4\}$  is considered to be a signature of collectivity

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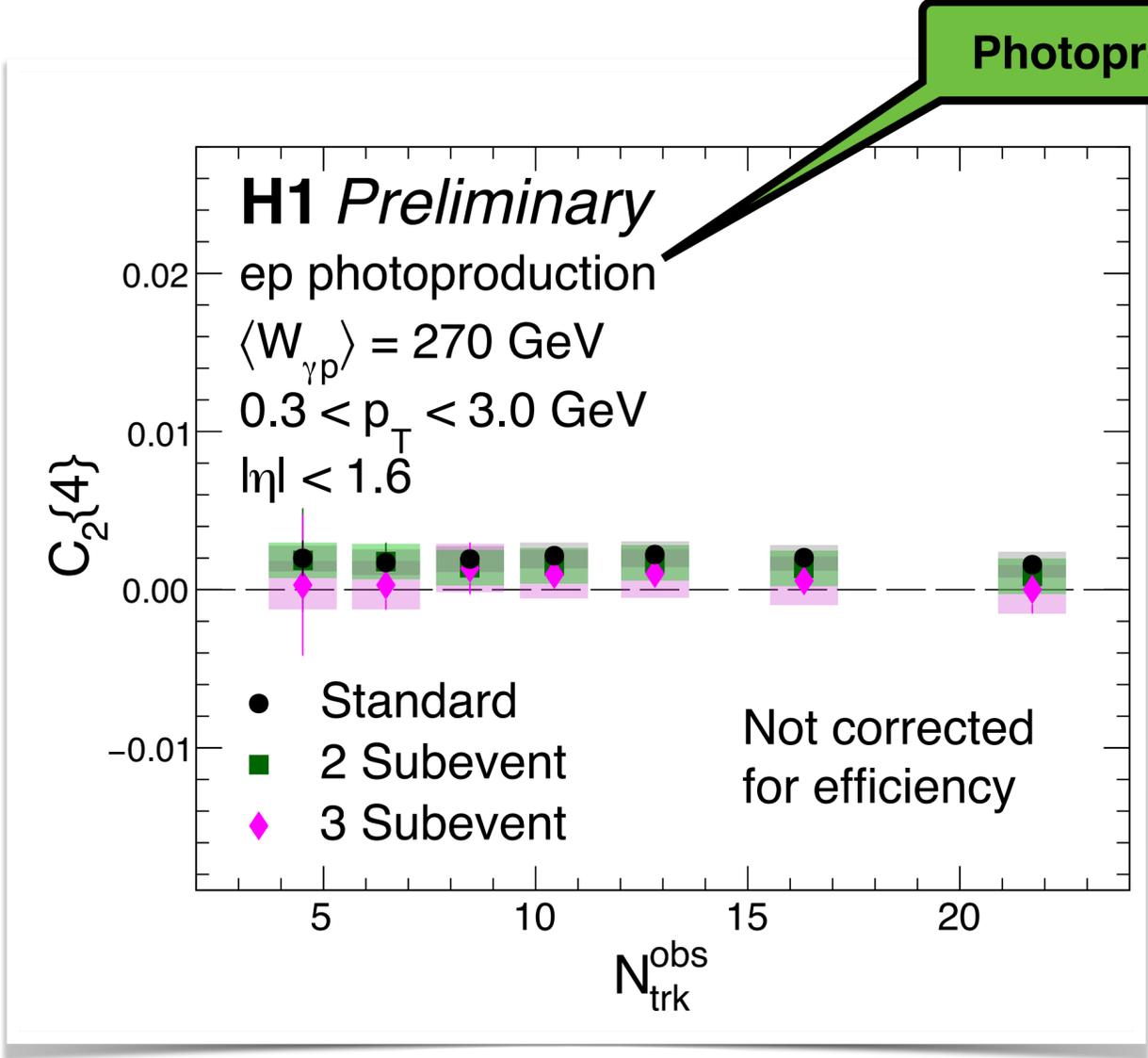
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Cumulant



Multiplicity

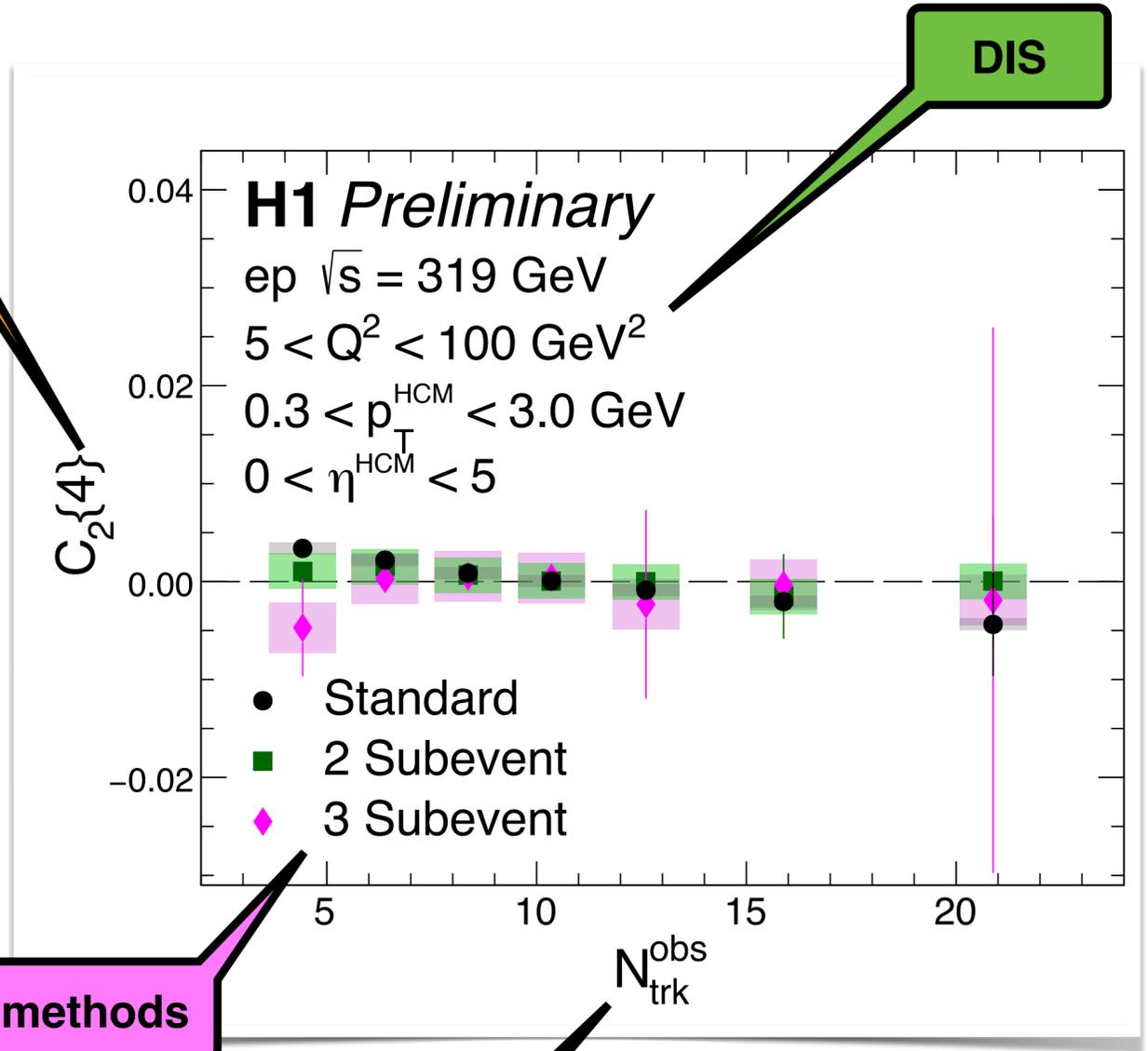
Photoproduction



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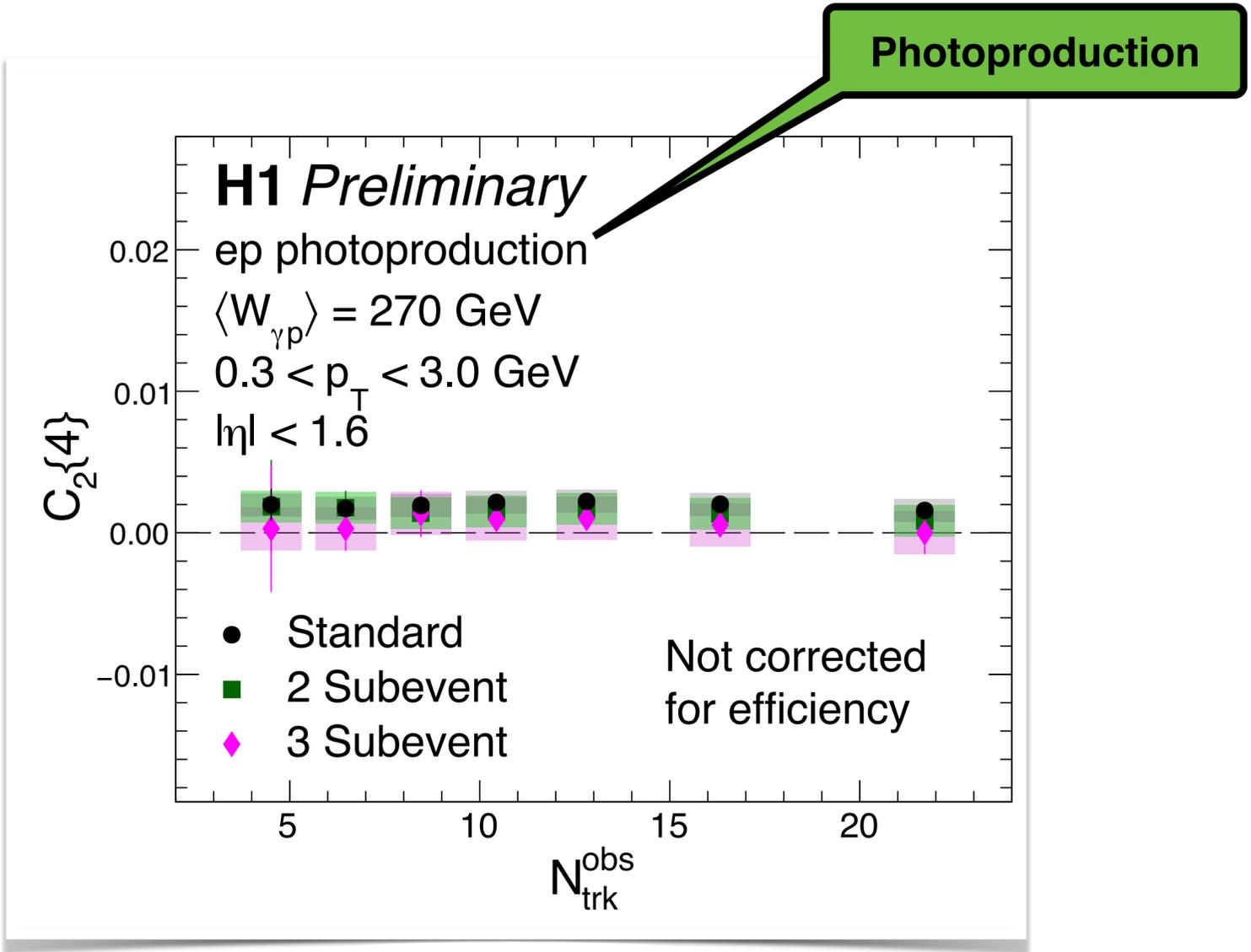
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Cumulant



Subevent methods

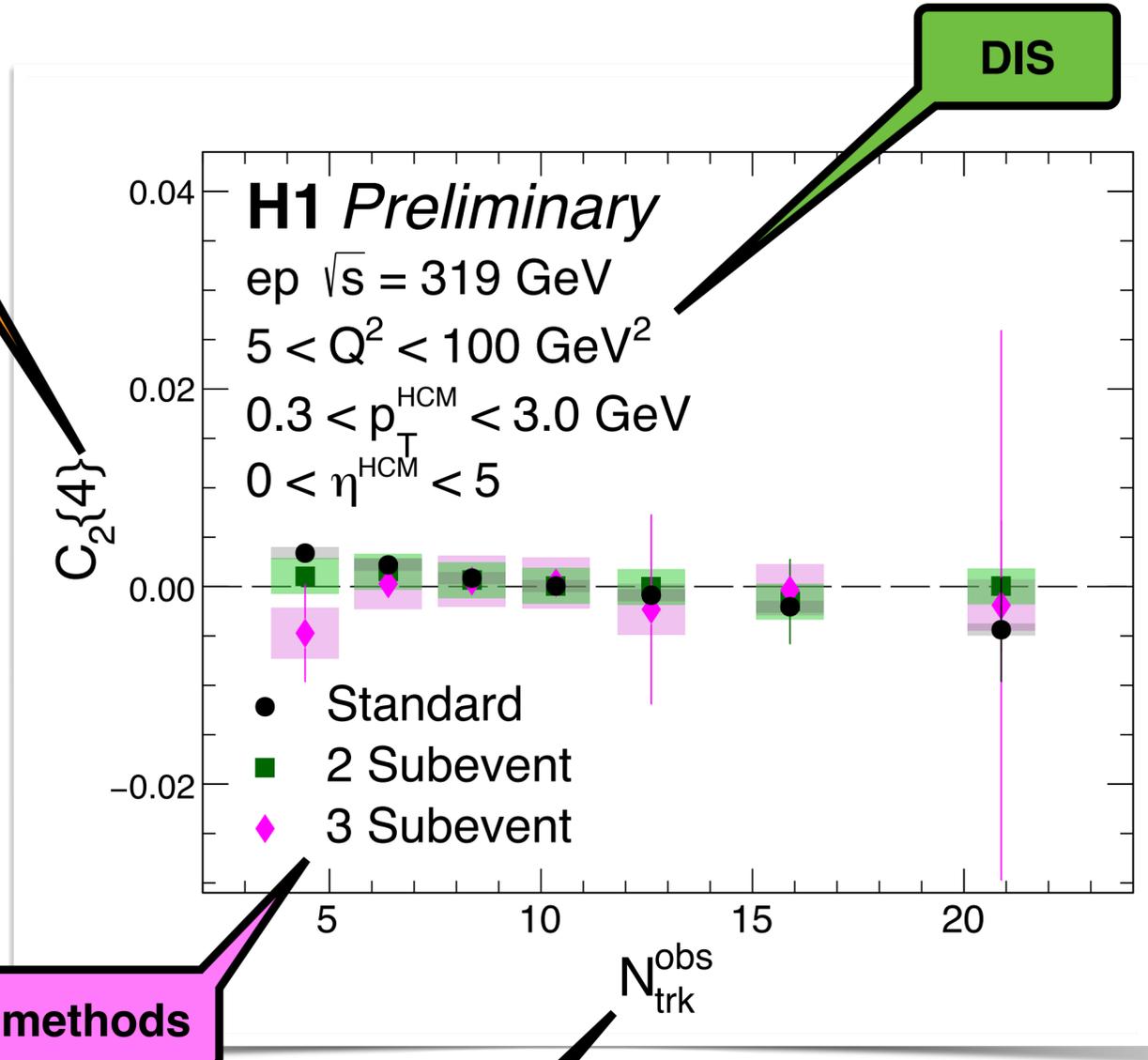
Multiplicity



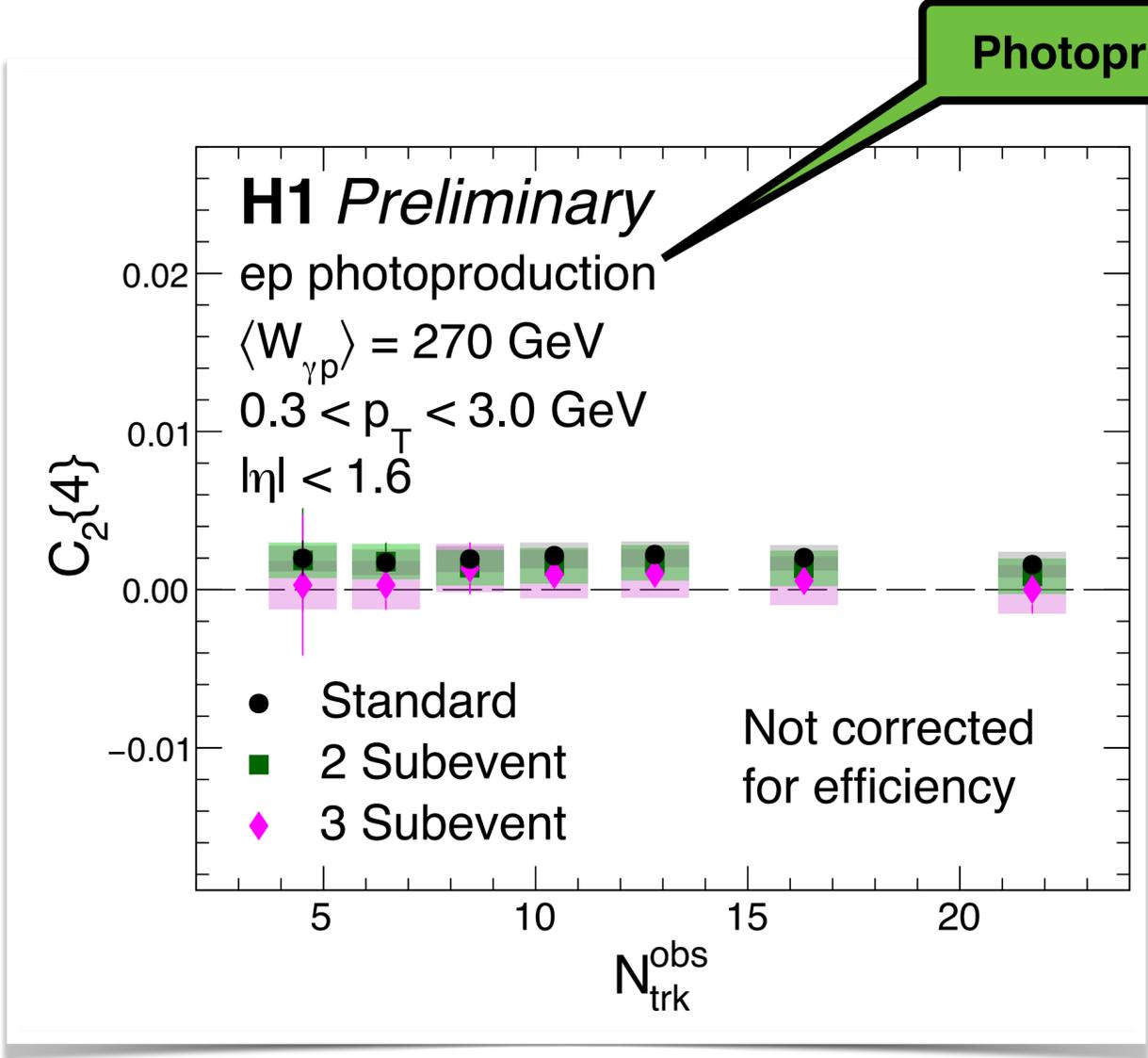
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Photoproduction



Subevent methods

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$C_2\{4\}$  is compatible with zero → no sign of collectivity

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Even though HERA stopped in 2007, H1 data is still being explored and yielding new physics results