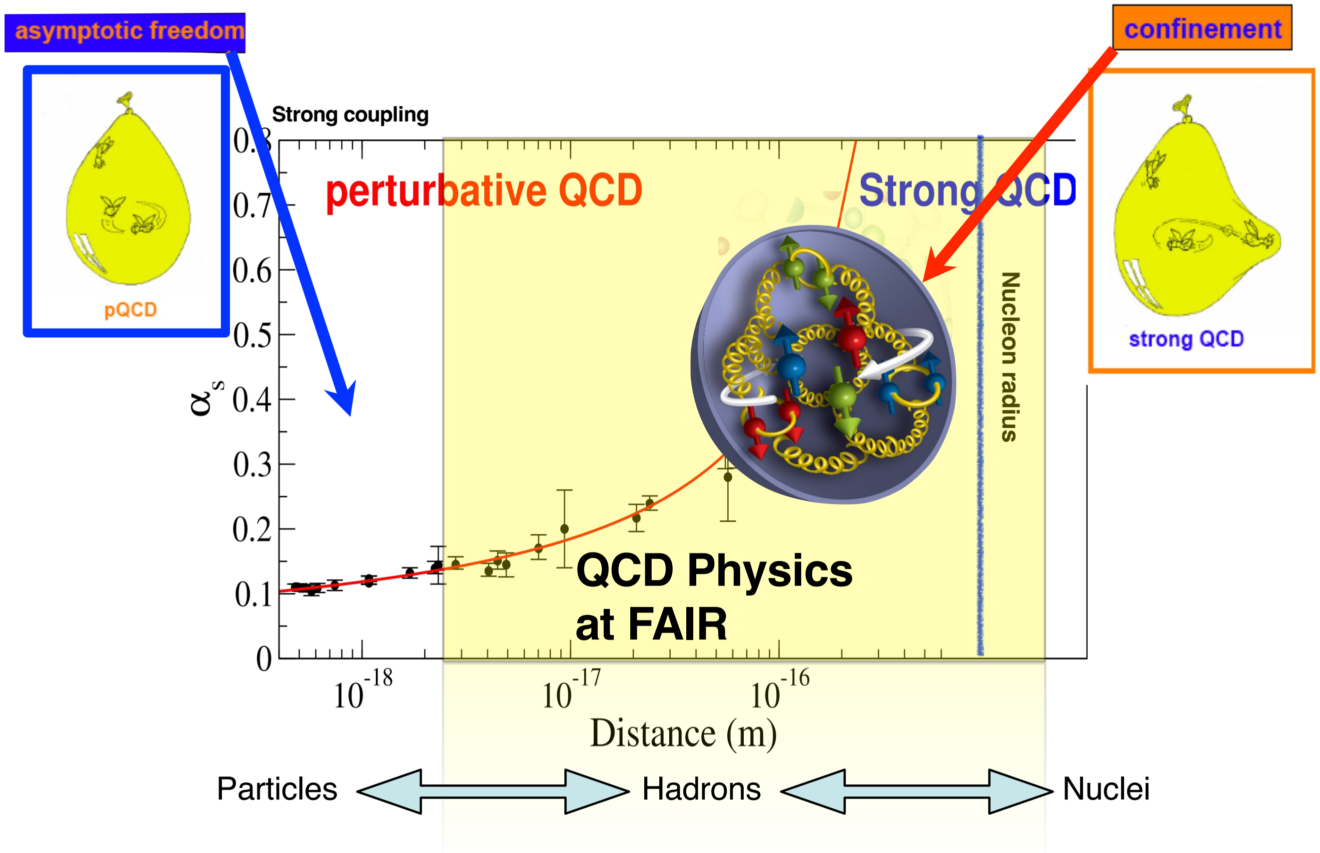
Exclusive Reactions with Proton Beam from SIS100

Overarching Physics Objectives

…from hadron to heavy-ion physics

- Properties of strongly interacting matter?
- Formation of hadronic matter?
- Underlying symmetries
- Degrees of freedom: from quarks/gluons to baryons/mesons?
- Origin of mass?



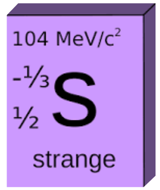
Physics with 30 GeV/c Proton Beams at FAIR

There are two main foci for proton beam from SIS100

(N.B. not really separate topics)

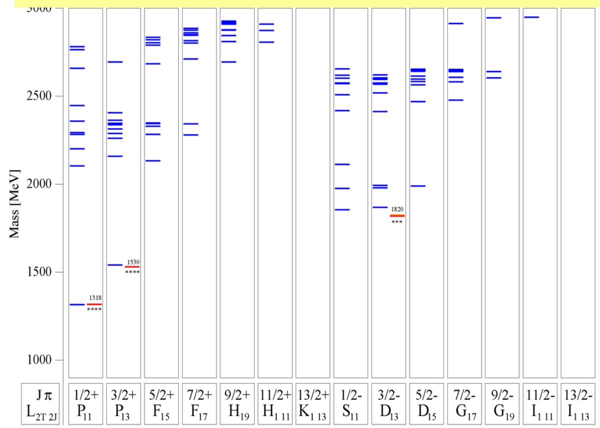
- pp (pn) and pA as input for AA reaction studies
- Hadron physics studies outright
  - (Multi-)strange baryon production and properties
  - Open/hidden charm hadrons

Strangeness Physics with Proton Beam at SIS100



- <u>Hyperon (Y) Spectroscopy</u> in |S|=1,2,3 systems, *e.g.* Ξ^*, Ω^*, spin-parity determination

Quark models: U. Löring *et al.*, EPJA 10 (2001) 447



|S| = 2

Q.N. known for only 2 excited Ξ states

PDG: „nothing of significance on Ξ had been added since 1988"

Many states predicted below 3 GeV. Dynamical origin baryon-meson interactions? (see *e.g.* baryogenesis of Lutz/Kolomeitsev)

Production mechanism (string fragmentation, decays of heavy resonances)?

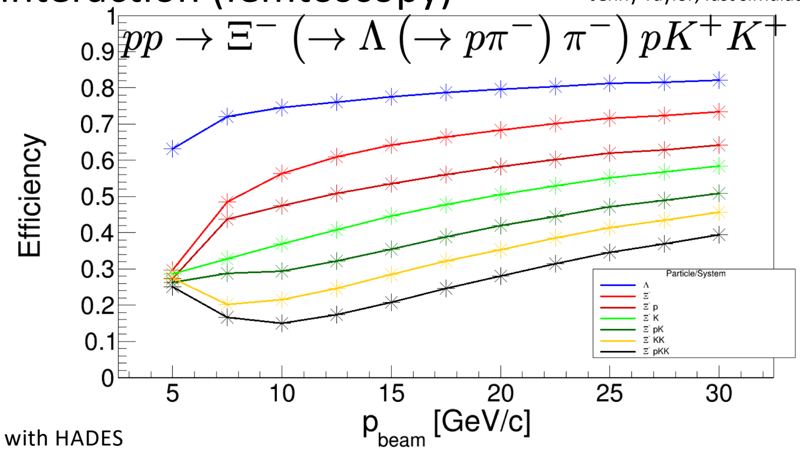
Compare $1/2^+$ and $1/2^-$ excitation (chiral partners?)

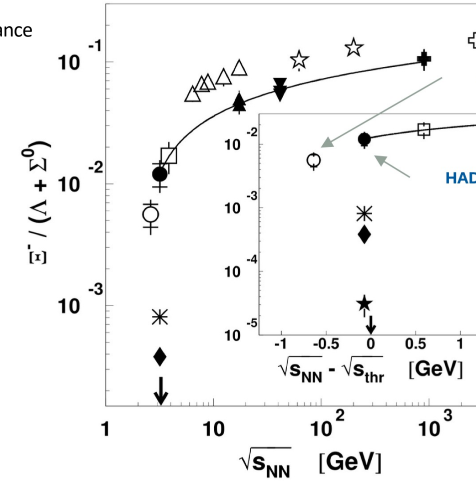
AA aspects: feed-down from higher states important for SHM and hyperon-nucleon interaction (femtoscopy)

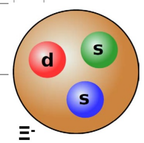
Jenny Taylor

Also pilot studies Ξ with HADES

Jenny Taylor, fast simulation, CBM acceptance







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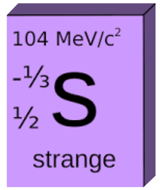

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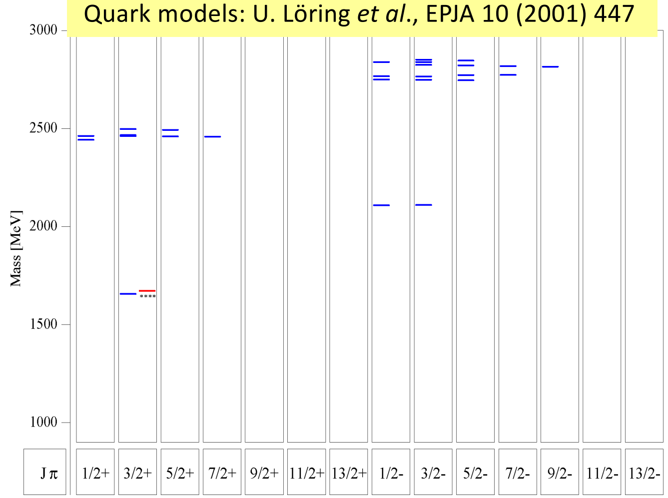

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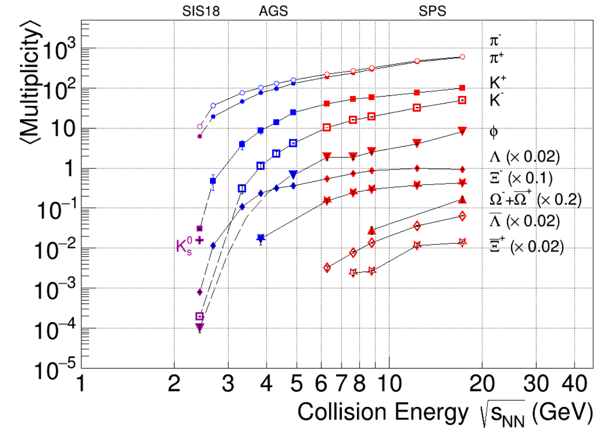


|S| = 3

Q.N. only for ground state, only 2 other states seen

Compare $3/2^+$ and $3/2^-$ excitation (chiral partners)

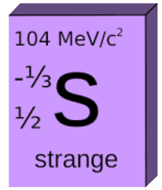
No u,d valence quarks, easier to interpret?

Energy scan is needed.

PWA as working horse for hyperon spectroscopy under development

Ahmed Foda
PWA dev.

Strangeness Physics with Proton Beam at SIS100



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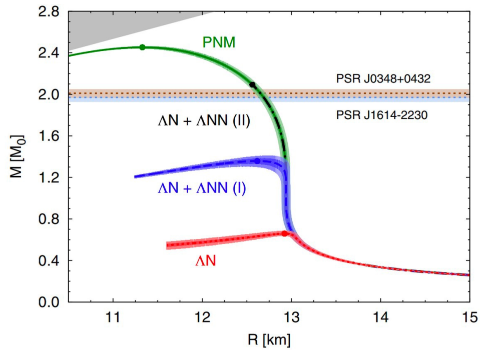
- N* Spectroscopy and coupling to strangeness, *e.g.* $pp \rightarrow p\, N^* \rightarrow p\ (\Xi K K)$
- Low-Energy Constants in chiral SU(3) via axial-vector transition form factors, *e.g.* $\Xi^* \rightarrow \Xi\pi\gamma$
- YN, YY Interactions in exclusive pp reactions and via femtoscopy

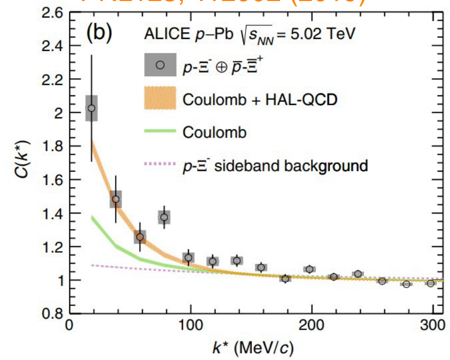
PRL114, 092301 (2015)



Interest related to EOS and neutron star
Lots of progress in femtoscopy at LHC
Advantage of pp@CBM: less feed-down from higher Y*

Access via FSI in exclusive reactions

PRL123, 112002 (2019)



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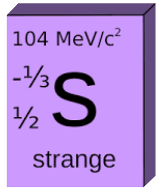

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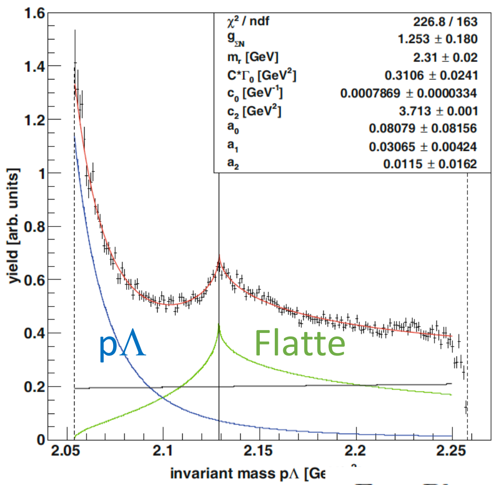
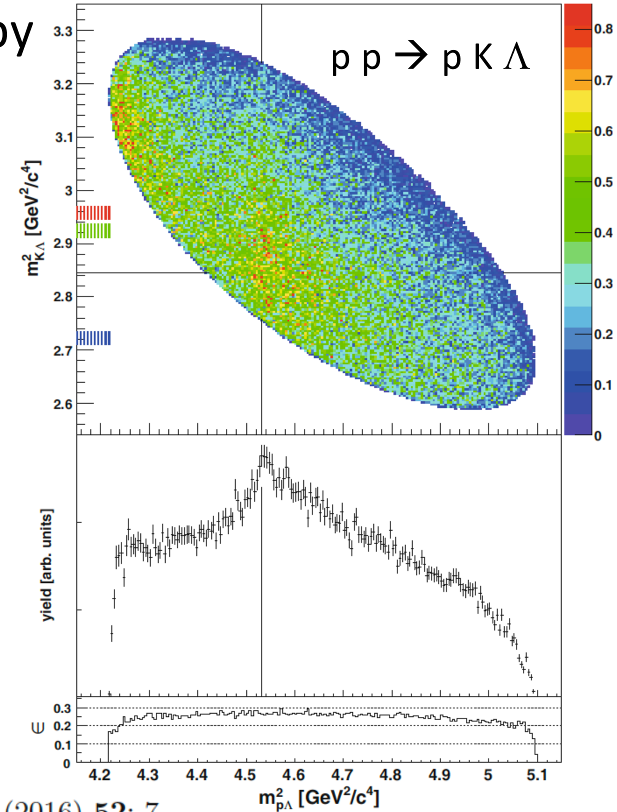
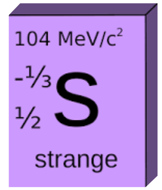




Eur. Phys. J. A (2016) **52**: 7

Strangeness Physics with Proton Beam at SIS100



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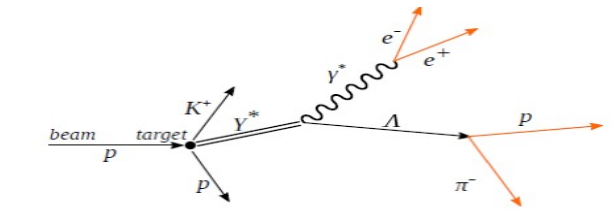
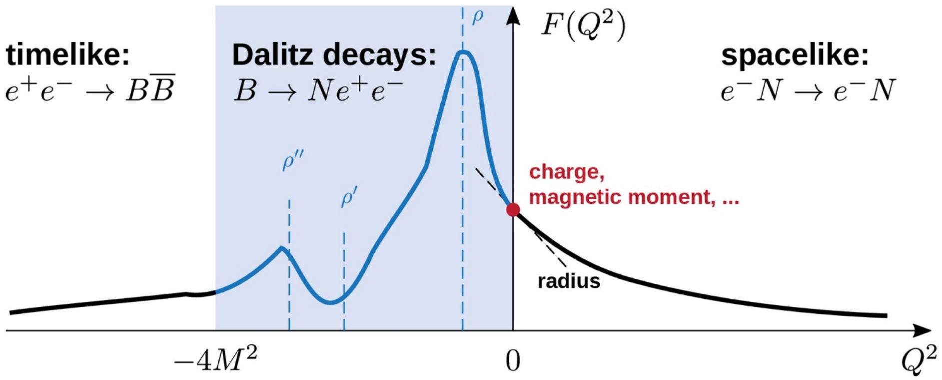
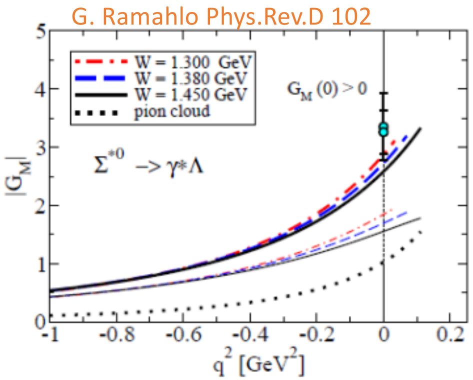
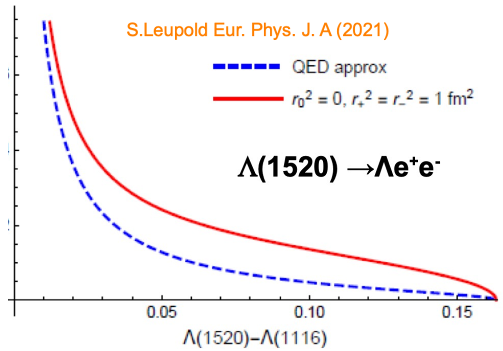
- YN, YY Interactions in exclusive pp reactions and via femtoscopy
- Hyperon Structure, e.g. $Y^* \to Y\ell^+\ell^-$, precision eTFF studies



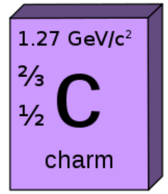
Information on hadron structure (*e.g.* size of hyperon)
Dalitz decays of *e.g.* Λ(1405), Σ(1385), Λ(1520),..(narrow states)
Radiative BR about 10^{-5}
Large rates needed (→ CBM and SIS100) (First attempt, HADES in pp@4.5 GeV)



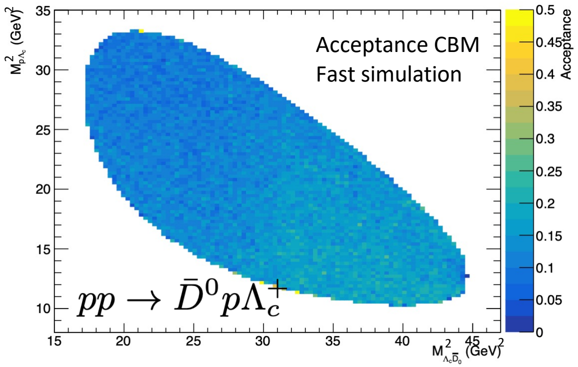




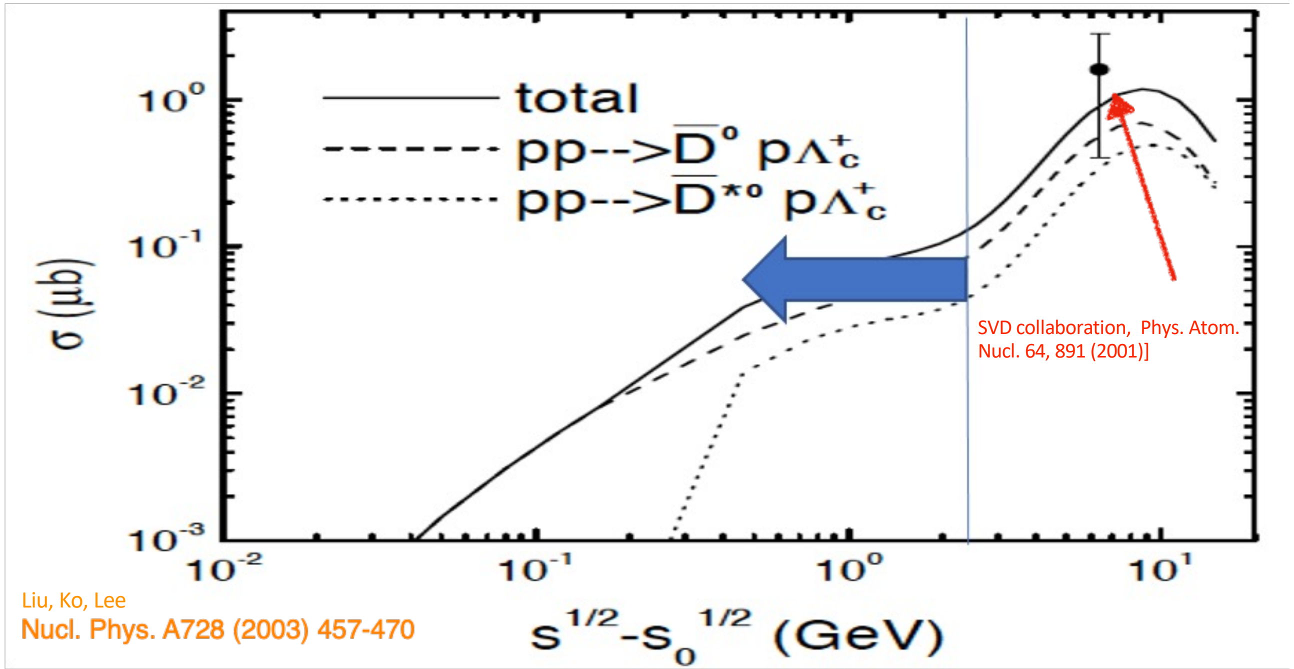
Charm Physics with Proton Beam at SIS100

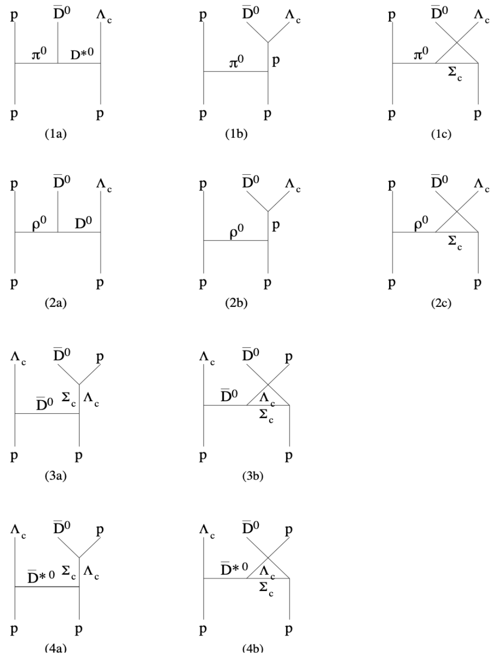


- Charm-N Interactions : SU(4) dynamics!

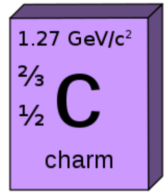


Hadronic model with interaction Lagrangian based on SU(4) flavor symmetry





Charm Physics with Proton Beam at SIS100



- Charm-N Interactions : SU(4) dynamics!
- Intrinsic Charm component of the nucleon

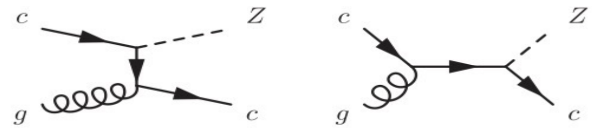
Long standing debate: "does the proton wave function contain an intrinsic charm (IC) component?”

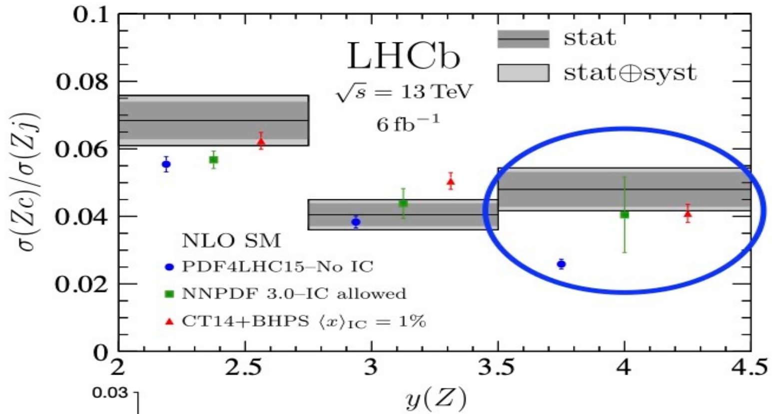
Brodsky *et al.:* IC manifest as valence-like charm content in PDFs

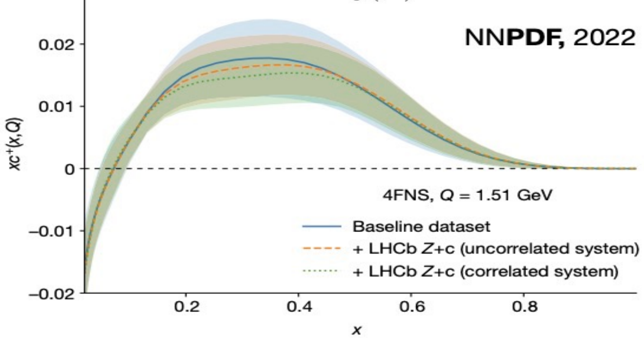
LHCb hints towards observation of IC via Z+charm jets
[PRL128, 082001, 2022]

Evidence claimed by NNPDF collaboration based on global analysis + ML methods
[Nature608, 483, 2022]

Can IC in proton increase charm production close to threshold?





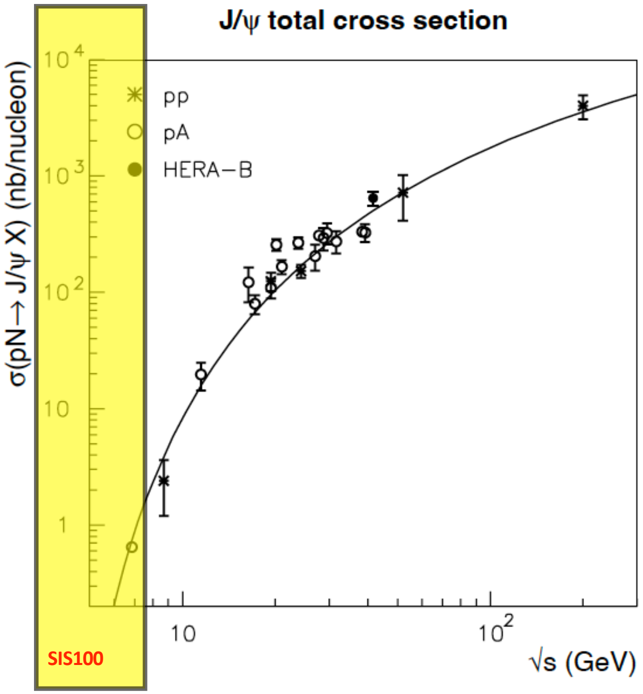


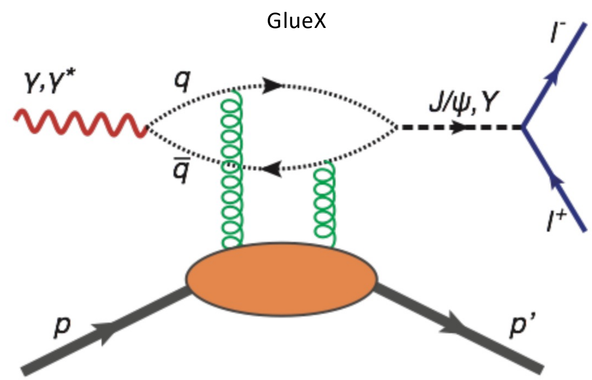
Charm Physics with Proton Beam at SIS100

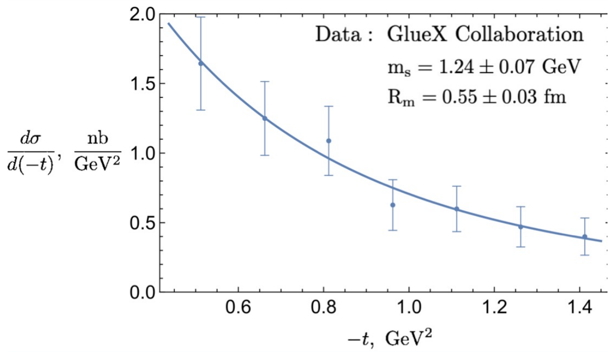
1.27 GeV/c²
⅔ c
½
charm

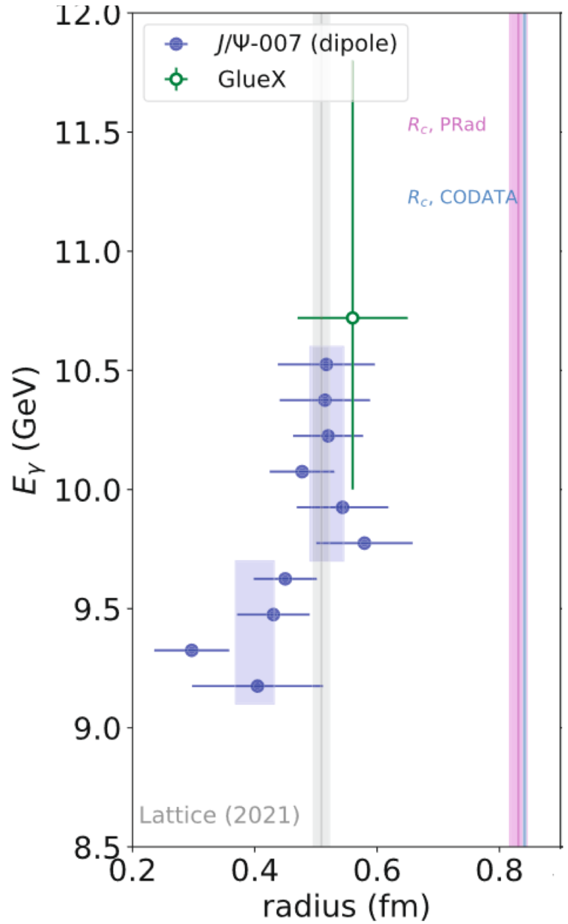
- Charm-N Interactions : SU(4) dynamics!
- Intrinsic Charm component of the nucleon
- Mass Structure of the proton

Duran et al., Nature 615, 813 (2023),
"Determining the gluon gravitational form factor of the proton"









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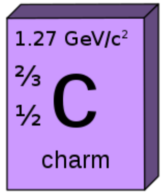
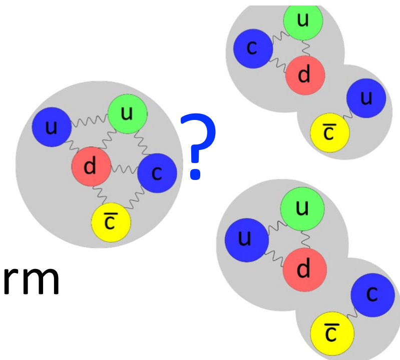
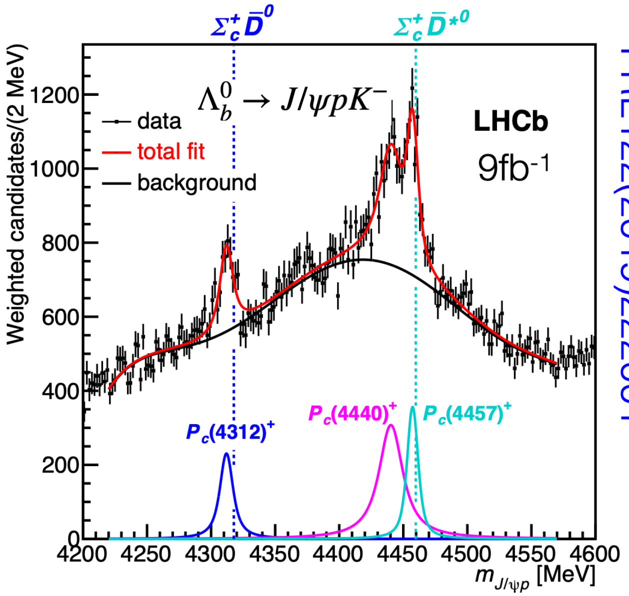


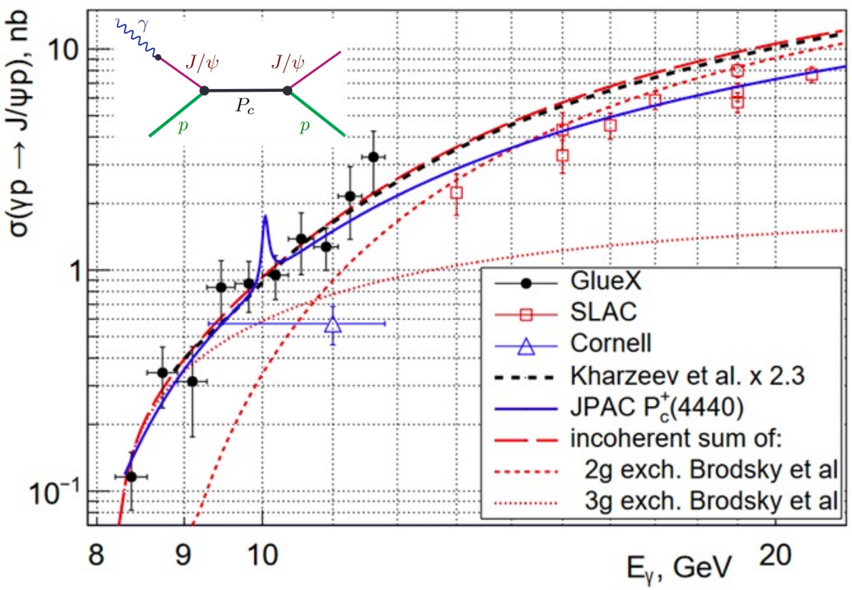
- Charm-N interactions : SU(4) dynamics!
- Intrinsic Charm component of the nucleon
- Mass Structure of the proton
- Exotic baryonic-like states with hidden charm



- Reveal their nature!
- Hadronic production $pp \to pP_c(\to J/\psi\ \mathrm{p})$
- Line-shape study near $\Sigma_c\overline{D}^{(*)}$ thresholds
- Hunt for new states



PRL122(2019)222001



SIS100 scan up to 6.6 GeV
Gluon rich production
Measure pJ/Ψ and ΣD

Day-1 Physics with Proton Beam at SIS100

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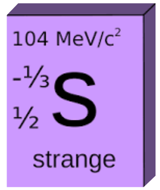


Internal degrees-of-freedom of hyperons

- Probing the hyperon excitation spectrum
- Missing mass scan using strangeness *tagging*
- Example:
- Identification of charged tracks from primary vertex with PID capabilities
- Without secondary vertex analysis, dilepton identification, photon detection, …

J^P	(D, L^P_N)	S	Octet members				Singlets
$1/2^+$	$(56,0^+_0)$	1/2	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	
$1/2^+$	$(56,0^+_2)$	1/2	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$	$\Xi(1690)^\dagger$	
$1/2^-$	$(70,1^-_1)$	1/2	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(?)$	$\Lambda(1405)$
					$\Sigma(1560)^\dagger$		
$3/2^-$	$(70,1^-_1)$	1/2	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
$1/2^-$	$(70,1^-_1)$	3/2	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$	$\Xi(?)$	
					$\Sigma(1620)^\dagger$		
$3/2^-$	$(70,1^-_1)$	3/2	$N(1700)$	$\Lambda(?)$	$\Sigma(1940)^\dagger$	$\Xi(?)$	
$5/2^-$	$(70,1^-_1)$	3/2	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$	$\Xi(1950)^\dagger$	
$1/2^+$	$(70,0^+_2)$	1/2	$N(1710)$	$\Lambda(1810)$	$\Sigma(1880)$	$\Xi(?)$	$\Lambda(1810)^\dagger$
$3/2^+$	$(56,2^+_2)$	1/2	$N(1720)$	$\Lambda(1890)$	$\Sigma(?)$	$\Xi(?)$	
$5/2^+$	$(56,2^+_2)$	1/2	$N(1680)$	$\Lambda(1820)$	$\Sigma(1915)$	$\Xi(2030)$	
$7/2^-$	$(70,3^-_3)$	1/2	$N(2190)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	$\Lambda(2100)$
$9/2^-$	$(70,3^-_3)$	3/2	$N(2250)$	$\Lambda(?)$	$\Sigma(?)$	$\Xi(?)$	
$9/2^+$	$(56,4^+_4)$	1/2	$N(2220)$	$\Lambda(2350)$	$\Sigma(?)$	$\Xi(?)$	

Experimental conditions

- 10 GeV protons (max M_X=2.6 GeV)
- ~ 10^8 protons/spill (duty cycle 50%)
- LH_2 target (5 cm)
- CBM Dipole magnet+TRD+TOF+FSD

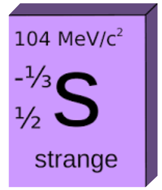
Estimates @M_X=1.32 GeV

- Objective ~ 4k counts/day
- Resolution ~ 30 MeV
- Eff. *x* accept. 75% x 60% = ~ 45%

—> Cross section sensitivity ~ 100 nb

Thank You !

Strangeness Physics with Proton Beam at SIS100



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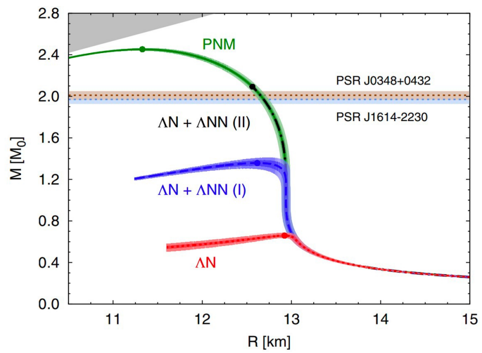

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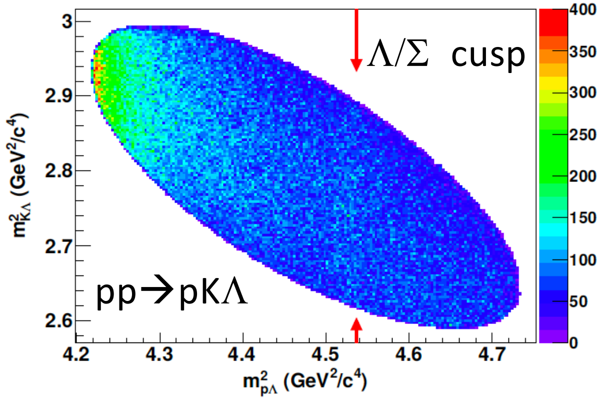
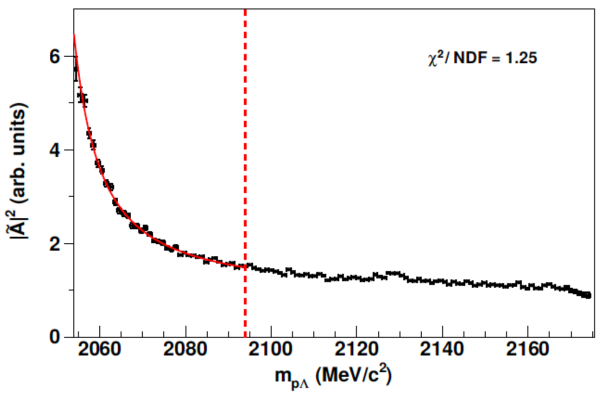


Phys. Rev. C 95, 034001 (2017)



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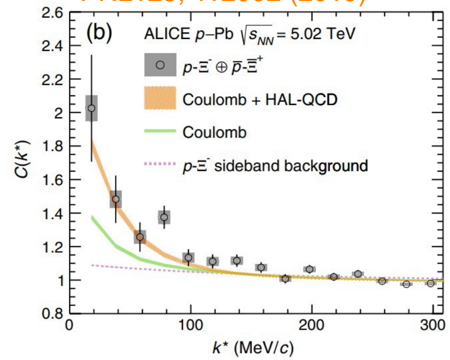
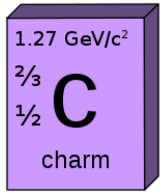


Charm Physics with Proton Beam at SIS100

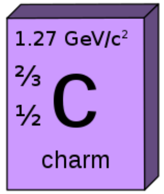


Fast Simulation

- STS ~ $\frac{\Delta p}{p} = 2\%$ and $\Delta\theta = \Delta\phi = 2$ mrad
- Acceptance ~ $\theta \in [2.5°, 25°]$, $\phi \in [0, 2\pi]$
- Efficiency ~ $98\ (< 2\ \text{GeV})..96\ \%(> 2\ \text{GeV})$
- MVD ~ $\Delta z = 4\ \mu\text{m}$, $\Delta x = \Delta y = 8 \times \Delta z$
- PID (TRD,TOF,PSD) ~ 99.x % (e, μ, π, K, p)

→ Inputs for our Simulation

Charm Physics with Proton Beam at SIS100



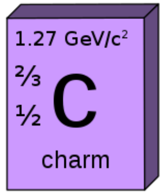
Fast Simulation

- Signal: $pp \to ppJ/\psi(\to ee)$ $10^{-3}\mu$b x 0.06 (branching ratio)
- Background: $pp \to pp\pi^{+}\pi^{-}$ ($pp\pi^{+}\pi^{-}\pi^{0}$) $10^{3}\mu b$ x 10^{-6}(misID π^{+} & π^{-})
- 10^{10} protons per spill (= 10 seconds)

Signal	Cross Section [μb]
$pp \to ppJ/\psi(\to ee)$	10^{-3} (×0.06 BR)

Background	Cross Section [μb]
$pp \to pp\pi^{+}\pi^{-}$ ($\pi^{+}\pi^{-}$mis-ID as $e^{+}e^{-}$)	1000 (×10^{-6}, suppression factor)

Charm Physics with Proton Beam at SIS100



Ömer Pennek

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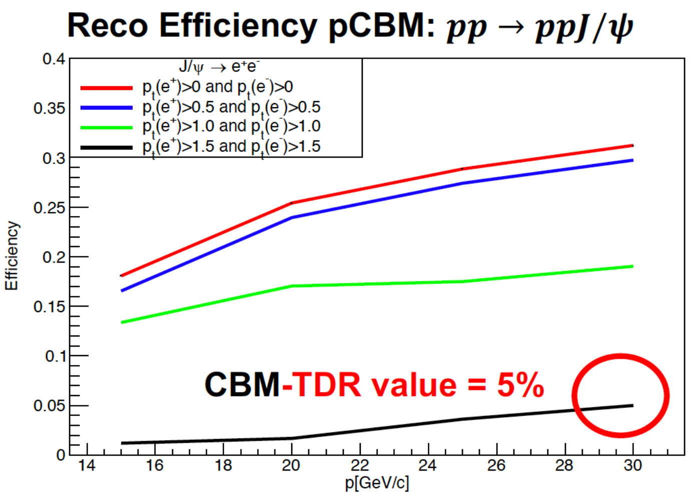
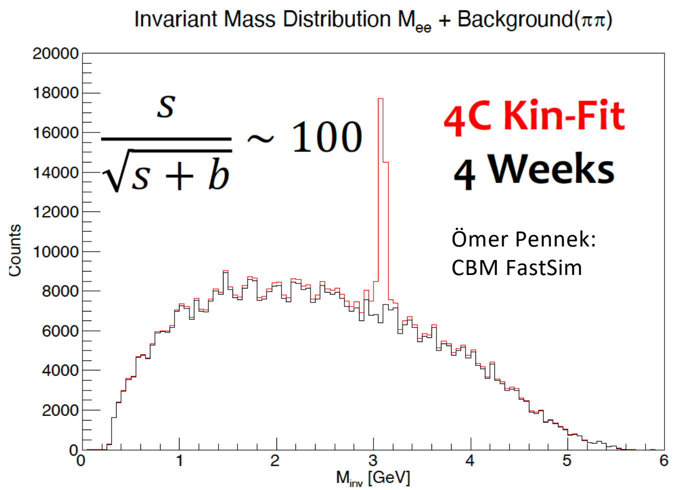
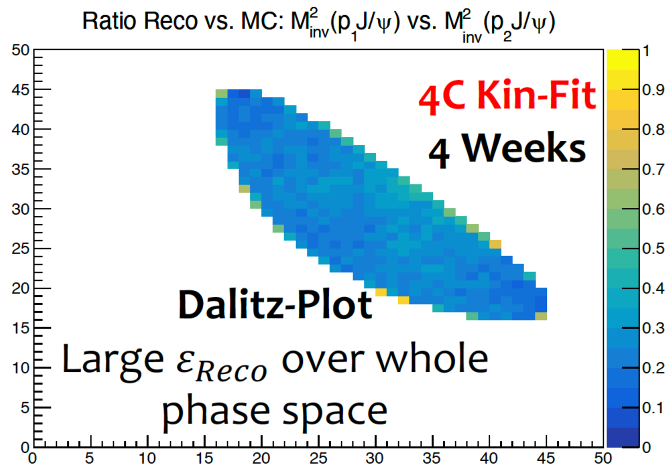
- Signal: $pp \rightarrow ppJ/\psi(\rightarrow ee)$ — $10^{-3}\mu$b x 0.06 (branching ratio)
- Background: $pp \rightarrow pp\pi^{+}\pi^{-}$ ($pp\pi^{+}\pi^{-}\pi^{0}$) — $10^{3}\mu b$ x 10^{-6}(misID π^{+} & π^{-})
- 10^{10} protons per spill (= 10 seconds) → 1100 reco events per day

Signal	Cross Section [μb]
$pp \rightarrow ppJ/\psi(\rightarrow ee)$	10^{-3} (×0.06 BR)

Background	Cross Section [μb]
$pp \rightarrow pp\pi^{+}\pi^{-}$ ($\pi^{+}\pi^{-}$mis-ID as $e^{+}e^{-}$)	1000 (×10^{-6}, suppression factor)





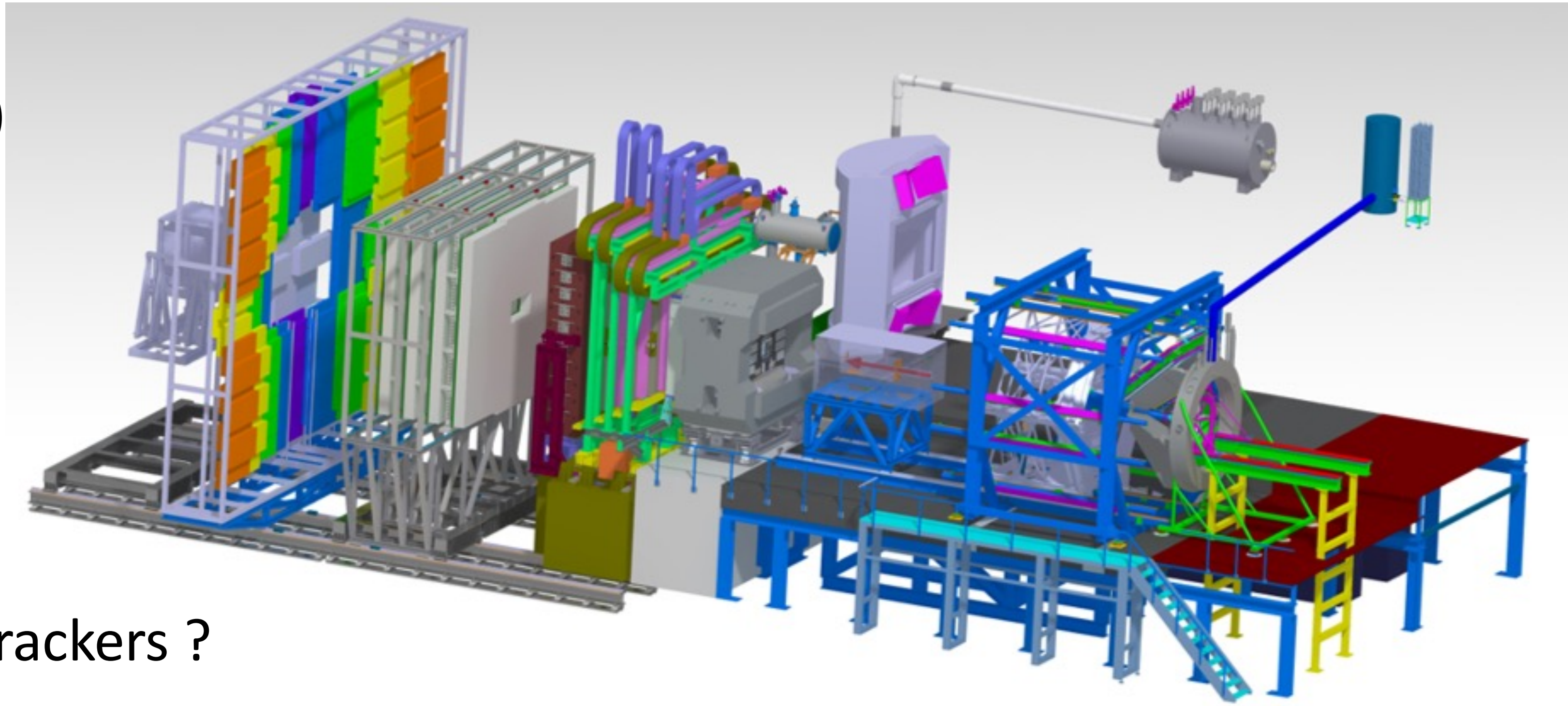


Physics Interest:
Exclusive Channels with Proton Beams

→ We need to measure high energy electrons → TRD
→ We need to measure particles with low momentum transfer → FSD
→ Basic /fast simulations ongoing, CBMROOT-simu started

Detector Configuration Assumed

- LH2 Target at entrance of Dipole (Uni Münster contacted)
- Dipole
- STS (MVD…)
- RICH
- TRD
- TOF
- FSD
- Beamline…
- Additional trackers ?



Contributions of FFN to CBM

Gas system for the TRD Detector
- ongoing communication with Uni-MS, Uni-F

Light Readout and Calorimeter for the FSD
- ongoing communication with Prague groups

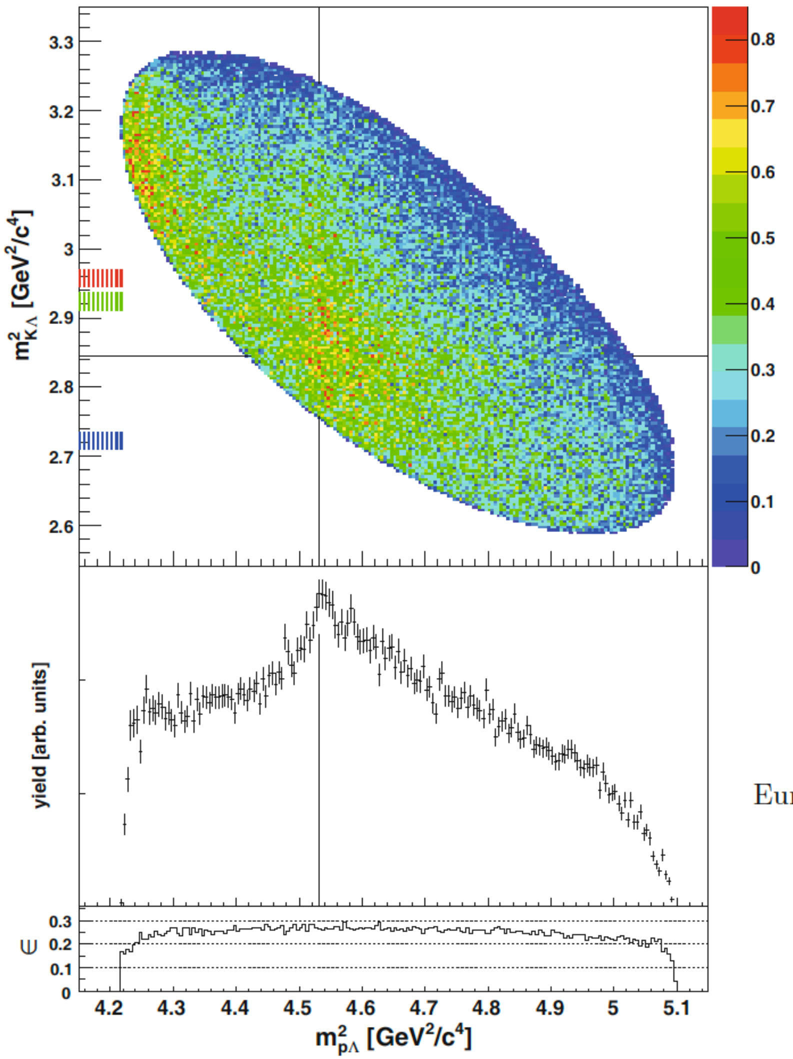
Simulation/Analysis Software Framework

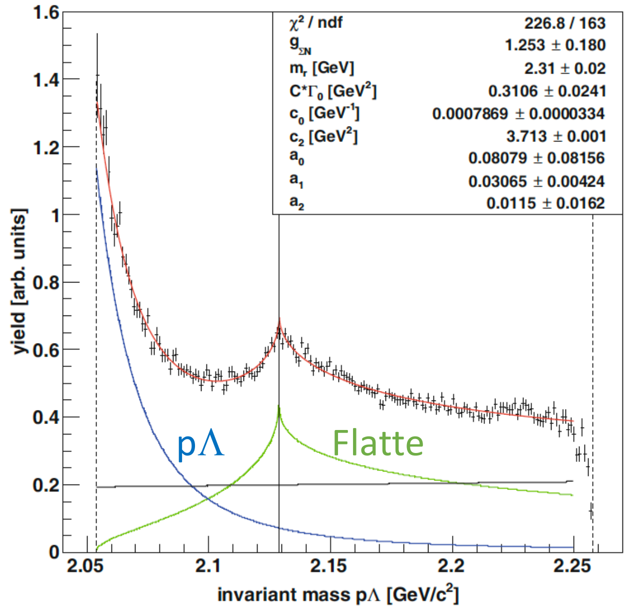
Peter Wintz
+(Nikolay P.)

Dieter Grzonka
+Dachi Okropiridze

Tobias Stockmanns
+ many

Σ/Λ CUSP





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